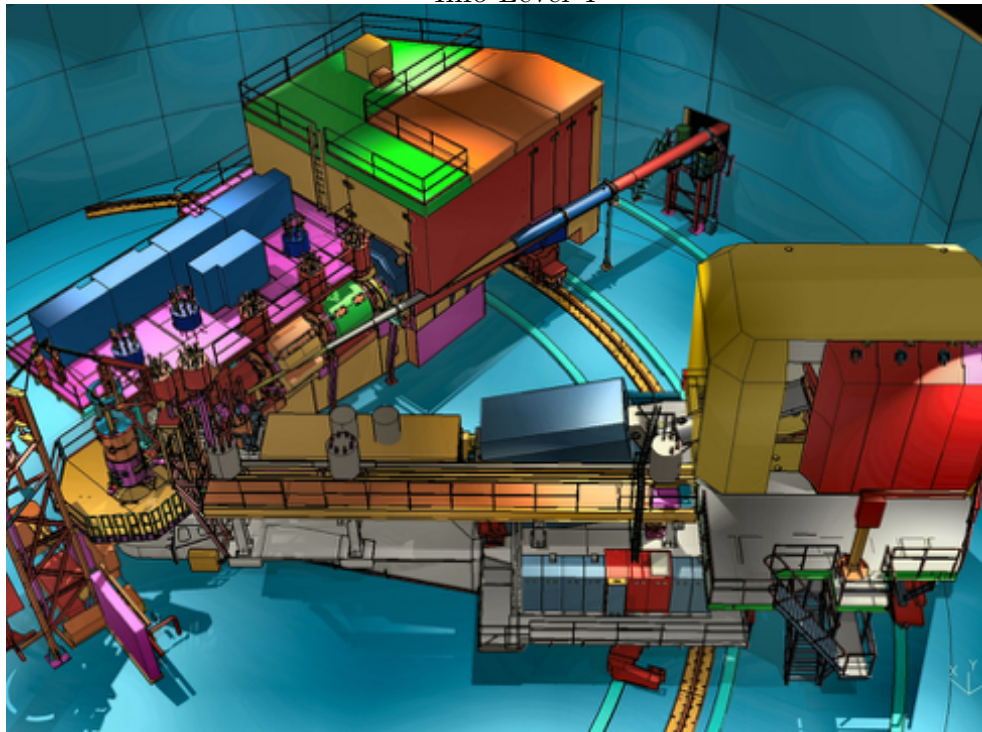


2019 Version: Jefferson Lab Hall C Standard Equipment Manual

Info Level 4



Hall C Staff and Users

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Chapter 1

Introduction

1.1 Technical Information About this Document

*This is a PDF document with hyper-references. Browsing is helped by the “bookmark” menu at the left side of the **acroread** or **xpdf** window. The objects like citations, figures, tables etc. are hyper-marked. One can “click” on a reference to an object and jump to the page with this object. Jumping back can be done using the right mouse button (**acroread**) or the left arrow button at the bottom of the window (**xpdf**). External references to the Web are also “clickable”. In order to use them, make sure that your PDF browser is configured to work with a Web browser (use the button “Preferences” in **acroread**, or provide and edit the file `~/xpdfrc` for **xpdf**). One should open a Web browser window and afterward one may use the WWW-links from the PDF browser. Finally, the PDF browsers allow to search for a given pattern in the whole document.*

The areas of text, dedicated to safety issues, are marked by red color throughout this document. Sometimes only the titles of the appropriate sections are marked. Also, red margin bars mark the beginnings of these areas.

*LaTeX (more specifically, **pdflatex**) is used to produce this document. The document source was originally kept in CVS format but has now moved to the Jefferson Lab github repository [1].*

This document can be printed, but it is best used on-line.

1.2 The Purpose of this Document

This document contains the following information concerning the Hall C “base equipment”:

- general overview;
- safety assessment;
- technical overview;
- operating procedures;
- performance information.

Although reading of this document is not explicitly required, the other documents refer to it, as far as safe operations of the base Hall C equipment are concerned.

The operating procedures are intended to provide shift personnel with the information they need to understand, at least at a rudimentary level, the function of the various subsystems in the end-station. It should also aid in determining if the equipment is performing properly and provide instructions for what to do in the case of malfunctions. This document does not necessarily give a complete comprehensive reference to each subsystem, but at least provides a guide for the shift personnel. When appropriate, other references are indicated for the user who requires more information.

This document includes some information on this matter in order to help the shift workers to check up the equipment.

1.3 Hall C Overview

The design purpose of Hall C is to study electron scattering on nuclei and nucleons at high luminosity of up to $5 \cdot 10^{38} \text{ cm}^{-2}\text{s}^{-1}$ with good momentum resolution. Reactions such as $(e, e'p)$ and $(e, e'\pi^\pm)$ are often utilized.

The basic lay-out of Hall C is shown in Fig. 1.1, demonstrating the Hall dimensions. A CAD-drawn 3-dimensional view of the Hall is given on the scalable picture on the [cover](#) page.

The beam line transports the CEBAF electron beam, in the energy and current ranges of 0.4 - 11.0 GeV and 0.1 - 120 μA to the target at the Hall center. Various types of targets have been used, including liquid hydrogen, liquid deuterium, other gas targets, solid targets polarized targets. Secondary particles are detected with the High Momentum Spectrometer (HMS) and Super High Momentum Spectrometer (SHMS). Both of these devices provide a momentum resolution of $\sim 1 \times 10^{-3}$ and a horizontal angular resolution of better than 2 mrad at a design maximum central momenta of 7.4 GeV/c and 11 GeV/c. Unscattered beam is transported to the high power water cooled beam dump.

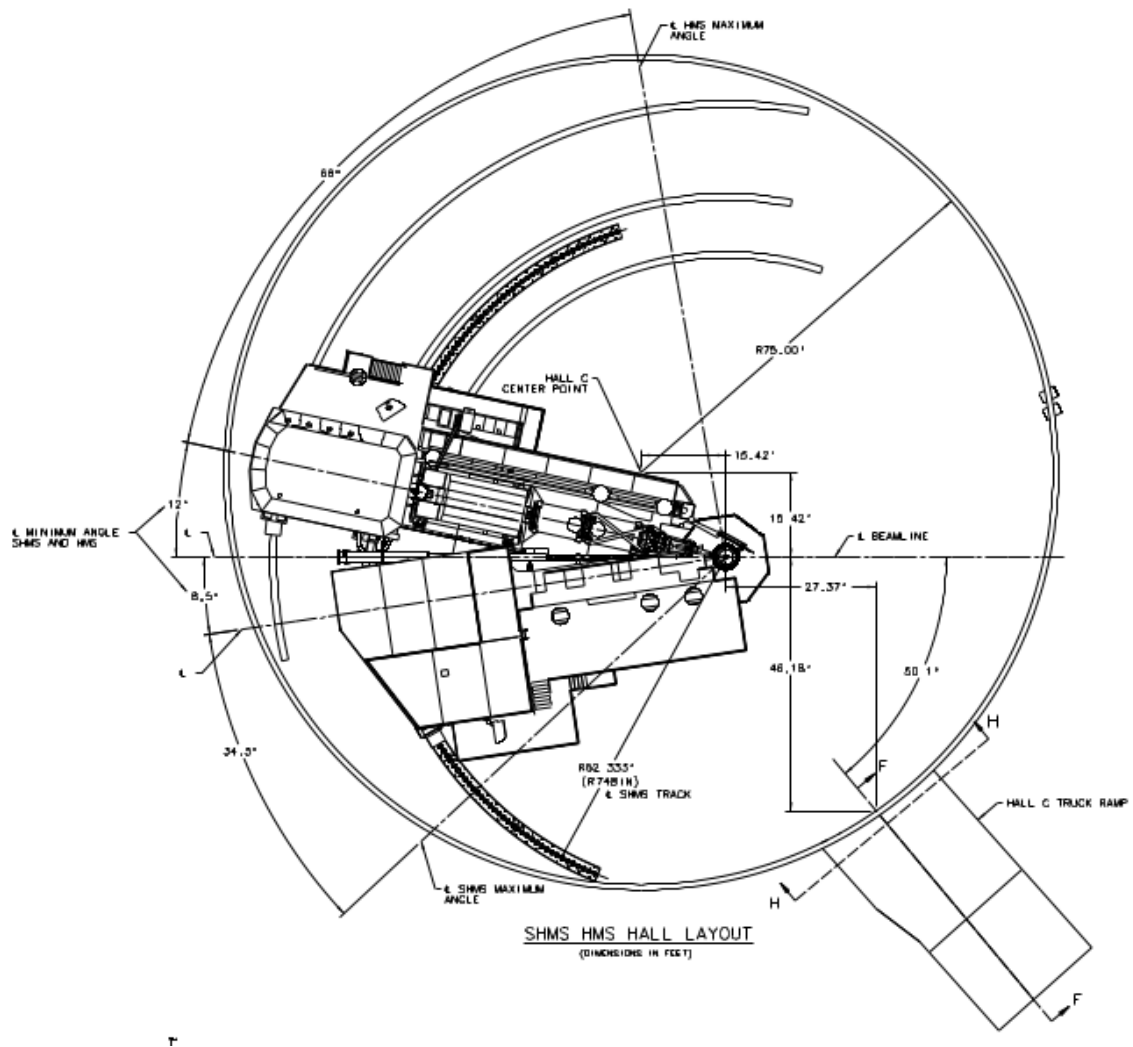


Figure 1.1: Schematic of Hall C showing the HMS (beam right) set at a scattering angle of 12° and the SHMS (beam left) at a scattering angle of 5.5° .

Chapter 2

Beamline

2.1 Introduction

The control and measurement equipment along the Hall C beamline consists of various elements necessary to transport beam with the required specifications onto the reaction target and the dump and to simultaneously measure the properties of the beam relevant to the successful implementation of the physics program in Hall C.

The resolution and accuracy requirements in Hall C are such that special attention is paid to the following:

1. Determination of the incident beam energy;
2. Control of the beam position, direction, emittance and stability;
3. Determination of the beam current;
4. Determination of the beam polarization.

Drawings of the Hall C line from the shield wall to the target are shown in Figs. 2.1, 2.2, 2.3, and 2.4.

The multiple elements in the beamline have a variety of “owners” and a variety of organizations with operational and fiscal responsibilities. These ownerships and responsibilities are detailed in Fig. 2.5 and on the web [2].

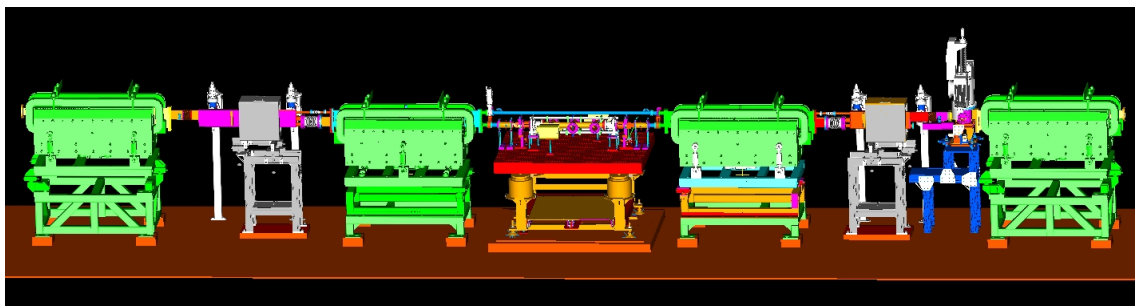


Figure 2.1: Compton Polarimeter, located in the alcove.

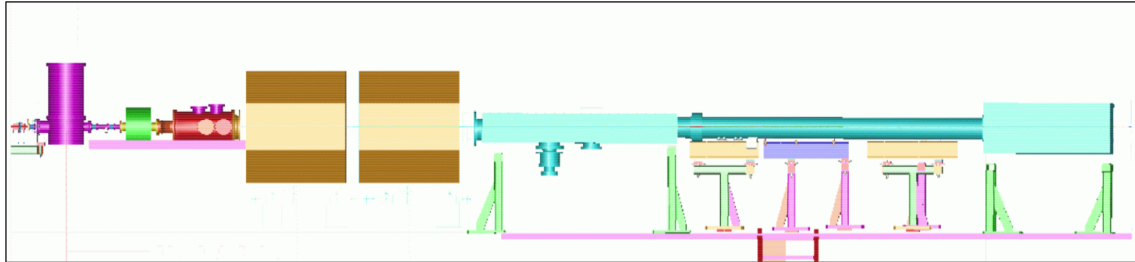


Figure 2.2: Schematic of the Hall C Moller Polarimeter, consisting of a superconducting magnet that polarizes the Moller target, 3 quadrupole magnets that function as a spectrometer to analyze Moller scattered electrons, and detectors. The 3 quadrupoles also serve as beam optics elements during normal operations.

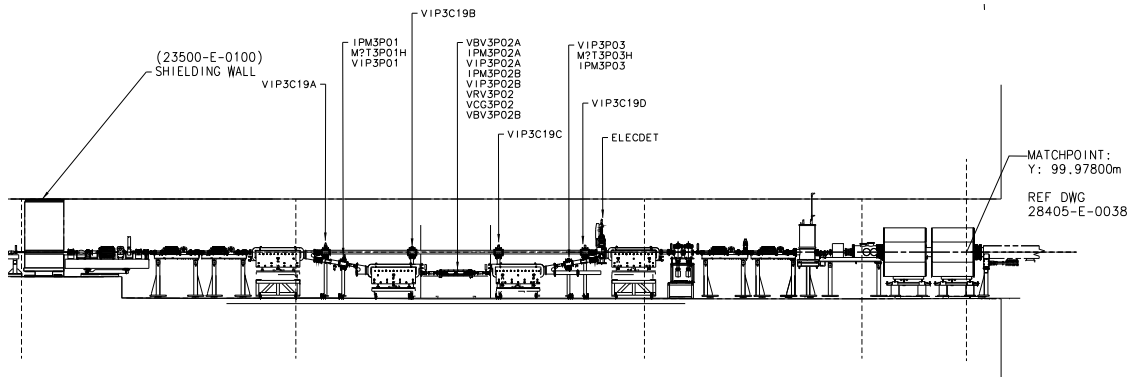


Figure 2.3: Hall C beamline from green shield wall to hall entrance.

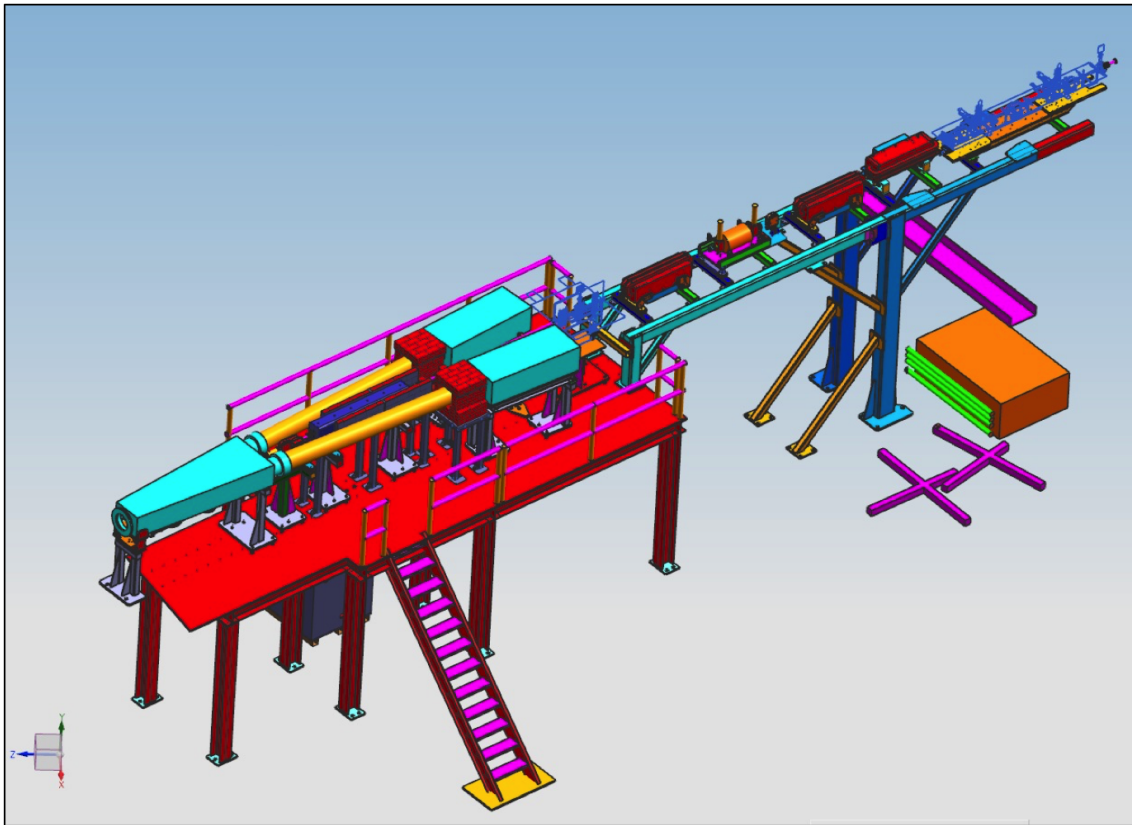


Figure 2.4: View of the beamline from entrance to the hall to the target scattering chamber.

System	Operational Responsibility/Ownership <i>Responsible contact for operations, group responsibilities</i>	Group	Fiscal responsibility <i>Account for maintenance, replacements</i>	System Integrator <i>Single point of contact to ensure system operational</i>
General beamline and corrector magnets (including Hall C vertical and horizontal chicanes)	Magnet Hardware - Joe Meyer Power Supplies - Sarin Philip Control Software - Pam Kjeldsen	MagTest DC Power Controls	Accelerator	Hall C - Jay Benesch Hall A - Yves Roblin
Harps	Hardware - Nate Rider Software - Pam Kjeldsen	I&C Controls	Accelerator	Hall A - Ciprian Gal Hall C - Dave Gaskell
BCMs (old + new)	Hardware - Nate Rider Software - Pam Kjeldsen	I&C Controls	Accelerator/Halls	Dave Mack
BPMs and cavity monitors	Hardware - Nate Rider Software - Pam Kjeldsen	I&C Controls	Accelerator/Halls	Ciprian Gal
Hall C downstream "big BPM"s	Hardware - Nate Rider Software - Pam Kjeldsen	I&C Controls	Hall C	John Musson
Compton Power Supplies and Magnets Hall C MBE Dipoles (3H05.7 H/V)	Magnet Hardware - Joe Meyer Power Supplies - Sarin Philip Beam Optics, A - Yves Roblin Beam Optics, C - Jay Benesch Vacuum systems - Greg Marble Control software - Pam Kjeldsen	MagTest DC Power HA APEL HC APEL Vacuum Controls	Halls	Dave Gaskell
Compton Laser and Detector(s)	Dave Gaskell		Halls	Dave Gaskell
Moller Power Supplies and Magnets	In-Hall Magnet Hardware - Ellen Becker Power Supplies - Sarin Philip Control software - Pam Kjeldsen	Hall A/C DC Power Controls	Halls	Don Jones
Moller Target and Detectors	Hall A - Don Jones Hall C - Dave Gaskell	Hall A Hall C	Halls	Hall A - Don Jones Hall C - Dave Gaskell
Parity Beam Modulation Systems	Magnet Hardware - Sarin Philip RF Hardware - Dave Gelhaar Cabling / Controls - Nate Rider Hall DAQ Interface - Ciprian Gal	DC Power EESRF I&C Hall A/C	Halls	Ciprian Gal
Arc Dipoles and Power Supplies (9th Dipole included)	Magnet Hardware - Joe Meyer Power Supplies - Sarin Philip Control Software - Pam Kjeldsen	MagTest DC Power Controls	Accelerator	Ciprian Gal
Arc Beam Energy Measurements (NMR, current)	NMR Hardware - Ellen Becker Control Software - Pam Kjeldsen Analysis Software - Theo Larrieu	Hall A/C Controls HLA	Accelerator	Ciprian Gal
Hall A OTR	Hardware - Nate Rider Software - Pam Kjeldsen	I&C Controls	Accelerator	Yves Roblin
Hall C YAG crystal	Hardware - Nate Rider Software - Pam Kjeldsen	I&C Controls	Accelerator	Jay Benesch
Raster Systems	Hardware and Electronics - Chris Cuevas Control Software - Pam Kjeldsen	Fast Electronics Controls	Halls	Bill Henry
Unserts	Hardware - Dave Mack Electronics - Chris Cuevas Cabling - Nate Rider Software - Pam Kjeldsen	Fast Electronics I&C Controls	Halls	Dave Mack
Halo Monitor (Hall A)	Hardware - Nate Rider Software - Pam Kjeldsen	I&C Controls	Hall A	Ciprian Gal
Beam Dump	Radiation - Dave Hamlette Helium / Nitrogen - Neil Wilson Diffuser - Nate Rider	RADCON Install I&C	Accelerator	Keith Welch
Vacuum Systems	Pivot to the Wall - Remele / Kellner Beam line up to pivot - Greg Marble Beamline controls - Rider / Kjeldsen	Hall A/C Vacuum I&C / Controls	Halls Accelerator Accelerator	Zach Remele / Walter Kellner
Target system FSD Interface Target system DAQ	Ties from FSD cards - Jerry Kowal Custom Cards, firmware - Nate Rider Software (experiment specific) - Pam/C. Keith	SSG I&C Hall A/C	Accelerator Accelerator Halls	Chris Keith
BLMs and Ion Chambers	Hardware - Jerry Kowal Software - Pam Kjeldsen	SSG Controls	Accelerator	Kowal / APEL
Ion Chambers	Hardware - Jerry Kowal Software - Pam Kjeldsen	SSG Controls	Accelerator	Mark Jones
Beamline Documentation (PS Specs, field maps, trip levels, etc.)	Decks / CED - CASA, Physics DIMAD - Chris Curtis songsheets - Chase Dubbe	Hall A/C Alignment ME	Accelerator	APELs
Utility Infrastructure (LCW, power, gases changes that will affect beamline components)	all (except dump) - Remele / Kellner	Hall A/C	Halls	Zach Remele / Walter Kellner
Cryo Systems	Distribution Can to load - Remele / Kellner ESR to Distribution Can - Jonathan Creel	Hall A/C Cryo	Halls ENG	Jonathan Creel
Ozone Monitors	Hardware - Jen Williams Software - Bill Henry	ESSH Controls	ESSH	Jen Williams

Updated 8/9/23

Figure 2.5: Beamline elements with operational and fiscal responsibilities. The most up to date version is maintained on the accelerator website [2].

2.1.1 The Beam Entrance Channel

The beam entrance channel consists of 63.5 mm inner diameter stainless steel tubing connected with conflat flanges. Through magnets the inner diameter of the tubing is restricted to 25.4 mm. Each section has a roughing port and is pumped with an ion pump. The pressure is about 10^{-6} Torr or better.

2.1.2 The Beam Optics Channel

These consist of dipoles, quadrupoles, sextupoles (generally not used), and beam correctors with their standard girders and stands. Starting from the beam switch yard, there are eight dipoles in the arc section which (along with five other smaller beam deflectors) bend the beam 37.5 degrees into the hall. After the shield wall at the entrance to the tunnel into the hall the beam is essentially undeflected onto the target and into the dump. However a small vertical displacement of the beam (≈ 2 cm up) is implemented to adjust the beam height to the optical axis of the Hall C spectrometers.

The beamline optics elements are designed to deliver various optical tunes of the beam on to the physics target as well as simultaneously deliver various optical tunes at other locations along the beamline. During normal operations, it is possible to deliver beam with a focus at the physics target in the hall and at the interaction point of the Compton polarimeter. It is not possible to simultaneously achieve a focused beam at the Møller polarimeter target.

During normal operations, the beam is delivered with an achromatic tune. For measurement of the beam energy, a dispersive tune is used. The nominal Hall C beam properties (achromatic tune) are listed in Table 2.1.

Emittance (nm-rad)	Energy Spread σ (%)	spot size σ (μm)	Halo (%)
$\epsilon_x < 10$	< 0.05	$\sigma_x < 400$	< 0.01
$\epsilon_y < 5$	< 0.03	$\sigma_y < 200$	

Table 2.1: Hall C Beam nominal properties at target

2.1.3 Beam Diagnostic Elements

The key beam diagnostic elements consist of beam position monitors (BPMs), beam current monitors (BCMs), and wire scanners (harps). Hall C uses harps similar to those used throughout the CEBAF accelerator - there are several harps placed in the Hall C beamline which provide both absolute position and beam size information. The harps at 3C07 and 3C17 are used as part of the beam energy measurement procedure. The harp at 3C20 provides information relevant for the Compton and Møller polarimeters. Finally the harps on the “Hall C” girder just before the target (3CH07A and 3H07B)

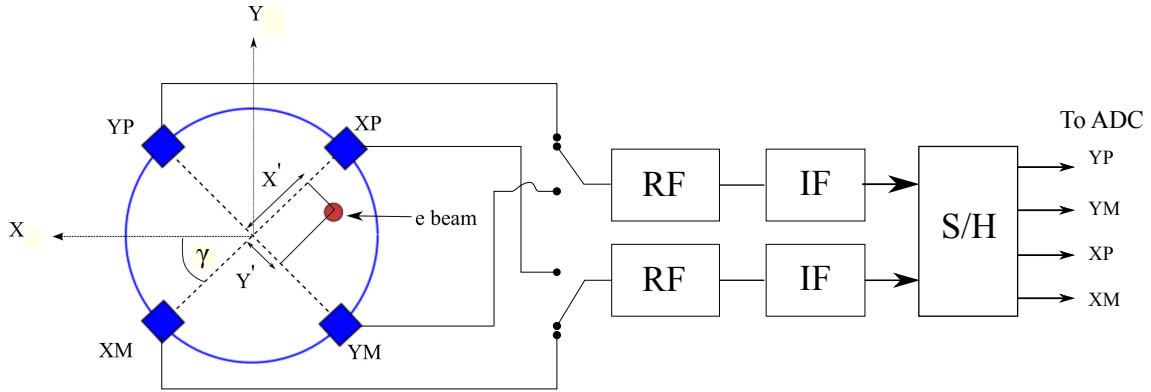


Figure 2.6: Readout chain for the beam position monitors in Hall C.

provide position information for calibration of the BPMs and beam size information. All the harps in the Hall C beamline are controlled by accelerator. When harp scans are required for the experiment in the hall, shift workers should contact MCC, request a scan of the relevant harp, and request that they post the result in the electronic logbook.

To determine the position and the direction of the beam on the experimental target point, three Beam Position Monitors (BPMs) are located at distances 3.71 m (IPM3H07A), 2.25 m (IPM3H07B) and 1.23 m (IPM3H07C) upstream of the target position. The BPMs consist of a 4-wire antenna array of open ended thin wire striplines tuned to the fundamental RF frequency of 1.497 GHz of the beam [3]. The standard difference-over-sum technique is then used [4] to determine the relative position of the beam to within 100 microns for currents above $1 \mu\text{A}$. The absolute position of the BPMs can be calibrated with respect to the superharps which are located adjacent to each of the BPMs (IHA3H07A at 3.46 m and IHA1H07B at 1.55 m upstream of the target).

The BPMs are typically read out in two ways.

1. The averaged position over 0.3 seconds is logged into the EPICS [5] database (1 Hz updating frequency) and injected into the datastream every few seconds, unsynchronized but with an reference timestamp. From these values we can consider that we know the average position of the beam calculated in the EPICS coordinate system which is left handed.

2. Event-by-event information from the BPMs are recorded in the CODA datastream from each of the 8 BPM antennas (2x4) from which the position of the beam can be reconstructed. However, these raw values belong to a parallel electronics chain whose constants have to be retrieved by calibrations to the EPICS or scanner data.

Figure 2.6 shows a schematic of how the BPMs are read out for use in the Hall C data acquisition.

In addition to measuring the beam trajectory before the target, it is also desirable to measure the position and trajectory of the beam downstream because of the scattering chamber because of potential steering effects from the fringe fields of the SHMS magnets under certain operating conditions when the spectrometer is configured for small

forward laboratory angles. To accomplish this two large diameter BPMs (a.k.a. Big BPMs) are installed in the beam line as shown in Fig. 2.8. These are mounted inside dedicated 1.5m long removable sections of the 24 diameter downstream beam pipe. Their mechanical structures, insulation materials and electrical connections to the outside are constructed of extremely radiation hard materials (metals and ceramics). These devices are designed to work with standard JLab BPM electronics. Exact fit but hollow 24 beam pipe replacement sections are available should removal or repair of these Big BPMs be desired/required. A cross-section sketch of a Big BPM is shown in Fig. 2.7.

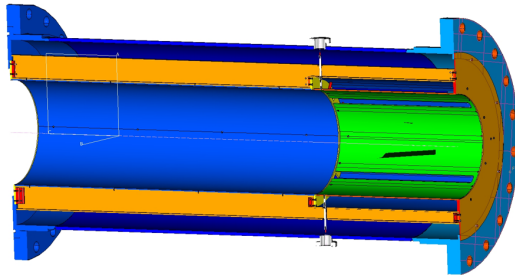


Figure 2.7: Cross-section of “Big BPM” to be installed in the beamline downstream of the Hall C scattering chamber.

2.1.4 Beam Exit Channel

After the target vacuum chamber, there is an exit beam pipe which transfers the scattered beam onto the dump tunnel under vacuum. The exit beam pipe will have more than one configuration due to the need to accommodate the use of the smallest SHMS angle in some cases as well as the potential need to incorporate magnetic shielding to prevent the beam from being deflected due to stray fields from the SHMS.

The downstream beam pipe has an overall length of about 90 feet from the exit of the scattering chamber to the dump entrance. The portion of the pipe closest to the dump entrance is made of several sections of 24-inch diameter aluminum tube. As described earlier, some sections of this 24-inch pipe can be replaced with sections to be used as beam position monitors (BPMs). Closer to the target, the beam pipe steps down to an 18-inch diameter tube. The combined length of the 18 and 24 inch diameter sections is about 44 feet.

Moving upstream the next section of pipe has a 6 inch diameter and is about 23 feet long. The 16-foot long section between the scattering chamber exit and the 6-inch diameter pipe is the region that undergo the most potential configuration changes. Depending on the minimum angles required for the SHMS and HMS, the beam pipe diameter can vary from 1.5 to 4 inches. As noted earlier, special magnetic shielding will be required when the SHMS is at small angles (typically less than 10 degrees), depending on the momentum.

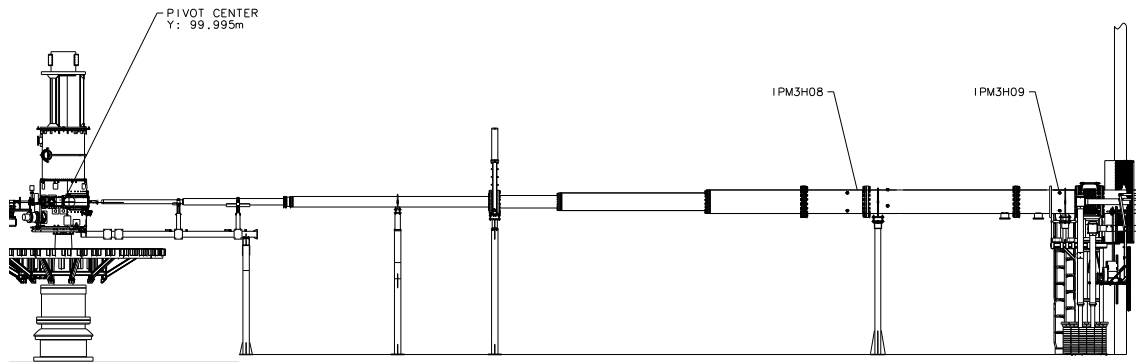


Figure 2.8: Schematic of the beam pipe that runs between the Hall C scattering chamber and the beam dump entrance.

An overview of the downstream Hall C beamline is shown in Fig. 2.8.

2.1.5 Machine/Beamline protection system

The MPS [6] system is composed of the Fast Shutdown System (FSD), Beam Loss Monitor (BLM), and gun control system.

The FSD system is a network of permissive signals which terminate at the electron gun and chopper 1. The permissive to the gun and chopper 1 may be inhibited by any device connected to an FSD mode. Devices connected to the FSD system include vacuum valves, RF systems, Beam loss systems, beam current monitors, beam dumps, and particular to Hall C, the target motion mechanism and the raster.

The gun control system includes software program which monitors beam operating conditions and the state of the FSD and BLM systems. the program will warn the operators if a potential for beam damage exists. Potential for damage exists when running high average current beam, when FSD nodes are masked and when the beam power approaches the operating envelope limits for a specific beam dump.

2.1.6 Safety Information

The beamline in the Hall provides the interface between the CEBAF accelerator and the experimental hall. All work on the beamline must be coordinated with both physics division and accelerator division; in order to ensure safe and reliable transport of the electron beam to the dump.

2.1.6.1 Hazards

Various hazards can be found along the beamline. These include radiation areas, vacuum windows, electrical hazards, magnetic fields and conventional hazards.

2.1.6.2 Mitigations

All magnets (dipoles, quadrupoles, sextupoles, beam correctors) and beam diagnostic devices (BPMs, scanners, Beam Loss Monitor, viewers) necessary for the transport of the beam are controlled by Machine Control Center (MCC) through EPICS [5], except for special elements which are addressed in the subsequent sections. The detailed safety operational procedures for the Hall C beamline should be essentially the same as the one for the CEBAF machine and beamline.

Personnel who need to work near or around the beamline should keep in mind the potential hazards:

- Radiation “Hot Spots” - marked by ARM or RadCon personnel,
- Vacuum in the beam line tubes and other vessels,
- Thin windowed vacuum enclosures (e.g. the scattering chamber),
- Electric power hazards in vicinity of the magnets,
- Magnetic field hazards in vicinity of the magnets, and
- Conventional hazards (fall hazard, crane hazard etc.).

These hazards are noted by signs and the most hazardous areas along the beamline are roped off to restrict access when operational. In particular, the scattering chamber, with its large volume and thin windows requires hearing protection once it has been evacuated. Signs are posted by RadCon for any hot spots along the beamline and RadCon must be notified before work is done in a posted area.

Where appropriate (such as for the Møller polarimeter magnets), magnet leads are covered with plastic guards for electrical safety.

Additional safety information is available in the following documents:

- EH&S Manual [7];
- Personnel Safety System procedures [8–10];
- Accelerator Operations Directive [11];

2.1.6.3 Responsible Personnel

Since the beamline requires both accelerator and physics personnel to maintain and operate and it is very important that both groups stay in contact that any work on the Hall C beamline is coordinated.

Name (first,last)	Dept.	Call [12]		e-mail	Comment
		Office	Cell		
<i>Hall C Physicists</i>					
Dave Gaskell	Hall-A/C	6092	757-719-5482	gaskelld@jlab.org	<i>1st Contact</i>
Mark Jones	Hall-A/C	7733	Web [13]	jones@jlab.org	<i>2nd Contact</i>
<i>Liaisons from Accelerator Division</i>					
Jay Benesch	Accel.	6505	757-289-3983	benesch@jlab.org	..to Hall-C

Table 2.2: Beamline physics division and accelerator division points-of-contact.

2.2 Beam Current Measurement

The Beam Current Monitor (BCM) is designed for stable, low noise, non-intercepting beam current measurements. The primary system consists of an Unser monitor and two rf cavities (bcm1 and bcm2), with associated electronics and a data acquisition system. An additional three RF cavities are also available for use for most experiments, although must be removed for certain configurations of the beamline (e.g. during polarized target experiments that require a slow raster system). There is also a bcm (bcm17) placed upstream of the Hall C Compton polarimeter on the 3C17 girder. This bcm is used primarily for current measurements for the Hall C polarimeters. The Unser monitor, bcm1, and bcm2 are wrapped in thermal blankets for temperature stabilization and are located 7.7 meters upstream of the target. The additional rf cavity triplet is enclosed in a thermally stabilized box and is located at the end of the blue platform that extends from the Hall C beam way, about 13 meters upstream of the target. In the standard configuration, an additional bcm is placed immediately upstream of the target; this bcm is controlled/read out for purposes of machine protection (to monitor beam loss) and is not considered part of the Hall C current measurement system for experiments.

All electronics for reading out the Hall C bcms, as well as the temperature controllers, are located in the Counting House.

2.2.1 System Layout

The schematic diagram of the BCM system is presented in Fig. 2.9.

The Unser monitor is a Parametric Current Transformer designed for non-destructive beam current measurement and providing an absolute reference. The monitor is calibrated by passing a known current through a wire inside the beam pipe and has a nominal output of 4 mV/ μ A. It requires extensive magnetic shielding and temperature stabilization to reduce noise and zero drift. As the Unser monitor's output signal drifts significantly on a time scale of several minutes, it cannot be used to continuously monitor the beam current. However, this drift is measured during the calibration runs (by taking a zero current reading) and removed in calibrating the cavities. The more stable cavities are then used to determine the beam current and charge for each run.

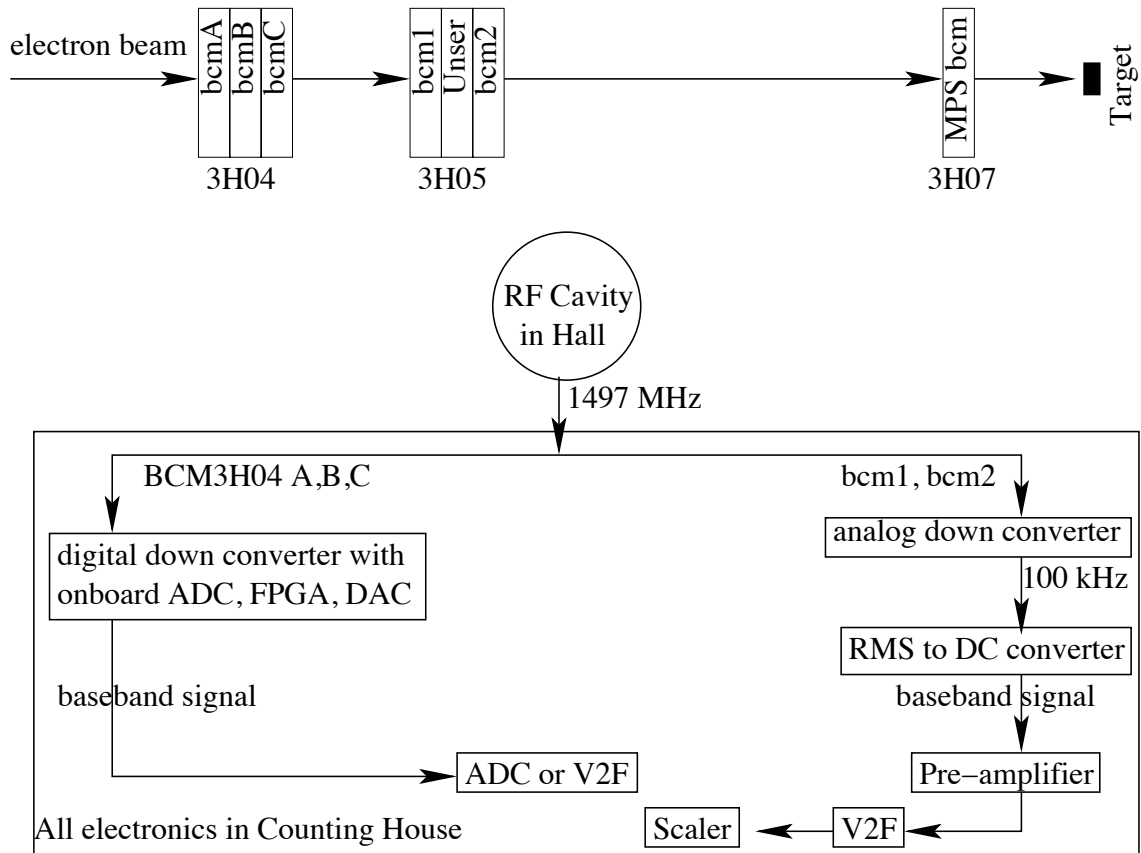


Figure 2.9: Schematic of the Hall C beam current measurement system.

The two resonant rf cavity monitors on either side of the Unser Monitor (bcm1 and bcm2) are stainless steel cylindrical high Q (~ 500) waveguides which are tuned to the frequency of the beam (1.497 GHz) resulting in voltage levels at their outputs which are proportional to the beam current. Each of the rf output signals from the two cavities are sent upstairs to the counting house where the rf output is converted to 100 kHz signals (by the “downconverters”) and fed into an RMS-to-DC converter board consisting of a 20 kHz bandpass filter to eliminate noise, amplified and sent to a V2F (via a pre-amplifier which adds a 2.5 V offset). The amplification of the RMS-to-DC converter is manually adjustable to provide optimal linearity for the relevant beam current range. The output of the V2F modules is sent to the data acquisition for fast readout in scalers. A copy of the V2F output is also sent to a nearby slow-controls VME crate for processing and integration into the slow EPICS data stream.

The bcm triplet further upstream of the Unser/bcm1/bcm2 girder (bcma, bcmb, and bcmc), as well as bcm17, make use of rf cavities of the same geometry and properties as bcm1 and bcm2. In this case, however, the readout scheme is a bit different. the rf signals from bcma, bcmb, and bcmc are sent to the counting house where they are processed using a digital down converter with onboard ADC, FPGA, and DAC. This

module provides an analog signal which can be sent to an ADC or V2F for integration in the data acquisition. The readout electronics are controlled via EPICS (in particular the gain settings), and can also provide direct EPICS readout.

Absolute calibration of the rf cavities with uncertainties of 100-200 nA is possible depending on how much time is devoted to calibration with respect to the Unser monitor.

2.2.2 Safety Information

In coordination with the Hall C run coordinator, all Hall C members are authorized to take BCM calibration data using the Standard Non-Invasive Hall C BCM Calibration Procedure which is maintained in the accelerator document database and it is executed by operates.

2.2.2.1 Hazards and Mitigations

As operators perform the calibration procedures there is no hazard to Hall C personnel in performing a beam current measurement.

2.2.2.2 Responsible Personnel

System responsible personnel are shown in Table 2.3.

Name (first,last)	Dept.	Call [12]		e-mail	Comment
		Office	Cell		
Dave Mack	Hall-A/C	7442	Web [13]	mack@jlab.org	<i>Contact</i>
John Musson	EESICS	7441	Web [13]	musson@jlab.org	Accel. expert

Table 2.3: Beam Current Monitor: authorized personnel

2.3 Raster Systems

2.3.1 Safety Information

The Hall C beamline includes two raster systems permanently installed. These systems, the Møller Raster (MR) and the Fast Raster (FR), rapidly move the beam position on the Møller Polarimeter target and the Hall C target, respectively, in order to prevent possible damage to the target by overheating. A third raster system (the slow raster) can be installed for use with polarized targets and is not part of the “standard” beamline. The Møller raster is only used in special circumstances and operated under the auspices of a test plan or TOSP. The FR serves to reduce boiling and uncertainties in target thickness for cryogenic targets. The beam rastering is done with vertical and horizontal air-core magnets that are driven by AC currents from a 250 W audio amplifier. The fast raster coils are shielded with a Plexiglas cage and a “Magnet On” sign indicates

the presence of current in the raster coils. No DC fields exist when these magnets are operated and no remnant field remains when the current is switched off.

The Møller raster magnets are located on the accelerator side of the beamline shield wall (on the 3C07 girder) so are not normally accessible from Hall C.

The following conditions lead to a fast shutdown of the raster devices:

- Crate power failure
- Magnets power failure
- Overcurrent detection (short occurs inside the magnets)
- Over temperature
- Detection of missing cycles or improper frequency
- VME system reset
- Phase-lock network is broken

The FR power drivers have an automatic fault display and shutdown. The signals are also sent to FSD.

The following Reference Documents exist:

- Requirement for beam raster monitor for the beam dump and target, R. C. Cuevas, C. Yan, 12 July, 1995
- Technical requirement for Hall C beam dump raster, C. Yan, June 24, 1995, JLab-R-94-02
- Møller Raster Manual [14]

2.3.2 Hazards

The primary hazards associated with the updated fast raster system are electrical and are addressed in the accompanying OSP.

2.3.3 Mitigations

The electrical hazards are mitigated by enclosing the raster coils in Plexiglas covers while the raster power supplies are stored in a protective enclosure nearby. Only qualified personnel should access the power supplies or coils. The mitigations of this updated system are addressed in the accompanying OSP.

2.3.4 Responsible Personnel

Points of contact for the fast raster system are listed in the Tab. 2.4.

Name (first,last)	Dept.	Call [12]		e-mail	Comment
		Office	Cell		
Mark Jones	Hall-A/C	7733	Web [13]	jones@jlab.org	Primary Contact
William Gunning	Fast Electronics	5017		gunning@jlab.org	Secondary Contact

Table 2.4: Fast Raster responsible personnel

2.4 Compton Polarimeter

The Compton Polarimeter provides a continuous, non-destructive measurement of the electron beam polarization. The system was installed and commissioned in 2010 and has been updated for use at 11 GeV. The Compton polarimeter is located in the Hall C alcove, just upstream of the Møller Polarimeter (between the 3C19 and 3C20 girders). Accelerator Operations sets up beam through the Hall C Compton chicane as part of the Hall C Beam Delivery Procedure:

opsntrsrv.acc.jlab.org/ops_docs/MCC_web_interface/interface_pages/operating_procedures.asp

An overview of the Compton Polarimeter is shown in Fig. 2.10. The main components of the Compton Polarimeter are:

1. A 4-dipole chicane that deflects the beam vertically (down) by 13 cm where it interacts with a laser system and is then steered back to the nominal beam height.
2. A laser system in which a 10 W CW laser is coupled to a moderate gain Fabry-Pérot cavity which results in up to 2 kW of stored laser power.
3. A compact photon detector consisting of a 4 crystal lead-tungstate array read out by a single photomultiplier tube.
4. A highly segmented, diamond strip electron detector for detecting the Compton scattered electrons.

2.4.1 Polarimeter Description

The Hall C Compton polarimeter is used to make continuous, non-destructive measurements of the beam polarization using the well-understood electron-photon (Compton) scattering process. Due to the relatively low luminosity of the Compton scattering process, the Compton polarimeter can be used without impacting the data-taking of the main experiment.

The Compton polarimeter works as follows. The electron beam is steered from its nominal height to a laser system which sits 13 cm below beam height. The electron beam collides with 2.3 eV photons provided by a high power laser system. The high power laser system consists of a resonating Fabry-Pérot cavity, locked to a CW, 10 W laser. After

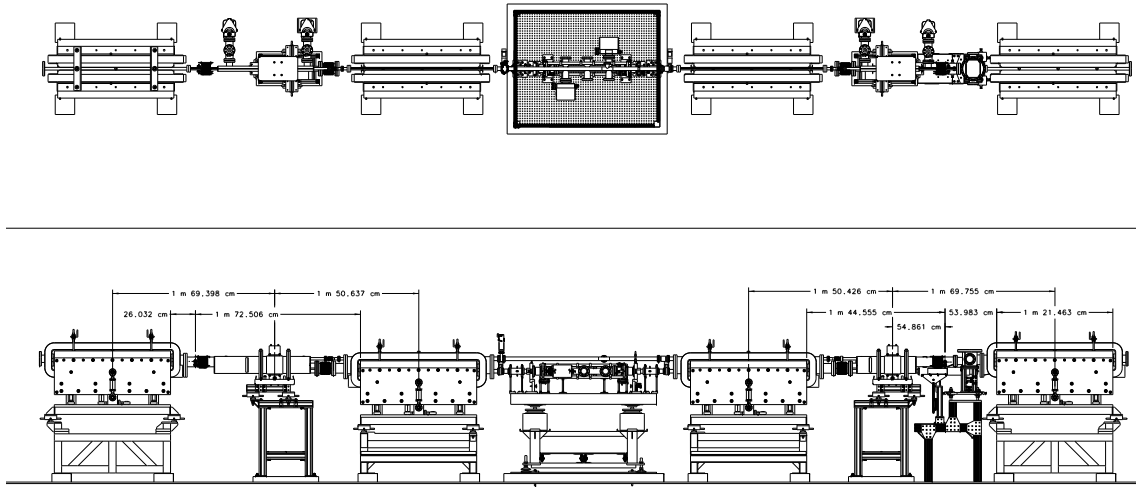


Figure 2.10: Overview of the Compton polarimeter in Hall C.

collision, the laser-photon is boosted backwards and has maximum energies ranging from 45 MeV (for 1 GeV beam energy) to 3 GeV (for 11 GeV beam energy). The backscattered photons are detected in a compact, lead-tungstate detector. This detector operates in “energy-integrating” mode, measuring the asymmetry in the total energy deposited for each electron beam helicity state. The beam electrons also lose energy in the Compton scattering process. These electrons will be deflected away from the unscattered electrons as they pass through a dipole downstream of the interaction region. The scattered electrons are detected in the segmented, diamond-strip electron detector. The electron detector must be movable, since the scattered electrons’ separation from the beam will change with beam energy. In principle, the electron detector can function at distances as close as 5 mm from the beam.

The photon and electron detectors provide quasi-independent measurements of the electron beam polarization; while the detector systematics are very different, they do share common systematic uncertainties from the laser system.

2.4.1.1 Dipole chicane

The Compton polarimeter chicane allows the electron beam to be deflected 13 cm from its nominal beam height to interact with the laser system between dipoles 2 and 3, allow detection of the backscattered photon, and provide momentum analysis of the scattered electron. The overall length of the chicane is about 11.1 meters (entrance of dipole 1 to exit of dipole 4). The distance between dipoles 1-2 and 3-4 is 1.95 m, with 2.2 m allocated for the interaction region between dipoles 2 and 3.

The key components of the chicane are four identical dipoles of length 1.25 m. The dipoles were designed by MIT-Bates and manufactured by Buckley Systems. Nominal properties of the dipoles are listed in Table 2.5 and a photograph is shown in Fig. 2.11.

The four dipoles are connected in series and powered from a single power supply. A few turns in the coils of the dipoles are controlled separately by low power supplies (trim cards) to allow $\approx 2\%$ independent variation of the strength of each dipole.

Bend angle	2.3°
Field at 11 GeV	12.5 kG
Effective length	1.246 m
Max. current	250 A
Turns/coil	64
Resistance @ 25° C	75 m-Ohms
Coil voltage	20 V x 2
Weight	275 lbs./coil Steel=5000 lbs.

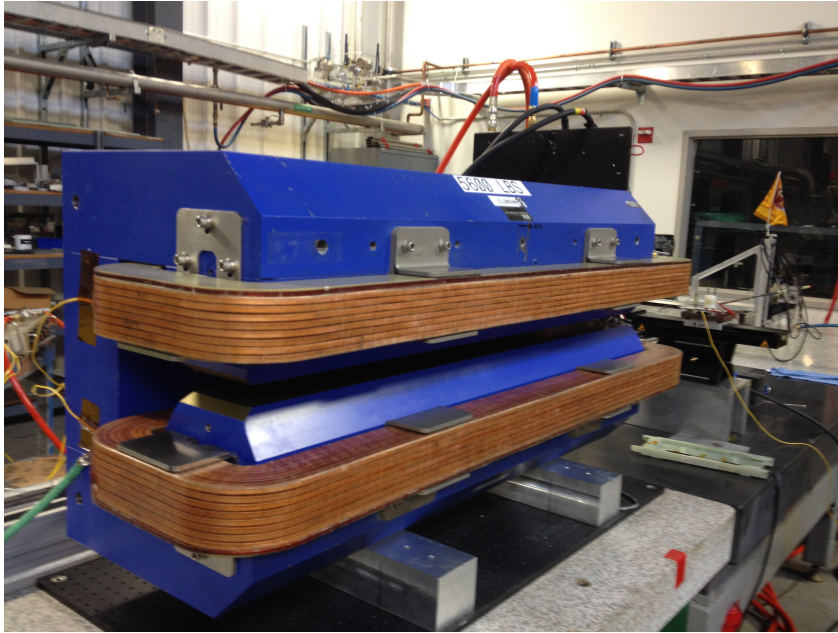
Table 2.5: Compton dipole properties.

While the trim coils allow vertical correction of the orbit through the chicane, correctors between dipoles 1-2 and 3-4 allow horizontal beam adjustment. Because of the large vacuum chambers required between the Compton dipoles, the horizontal correctors encompass both the “straight-through” and “chicane” beam paths. The large size of the correctors also lead to larger than usual stray fields - these are mitigated using a magnetic shield mounted over the corrector coils. A photograph of the horizontal corrector is shown in Fig. 2.11.

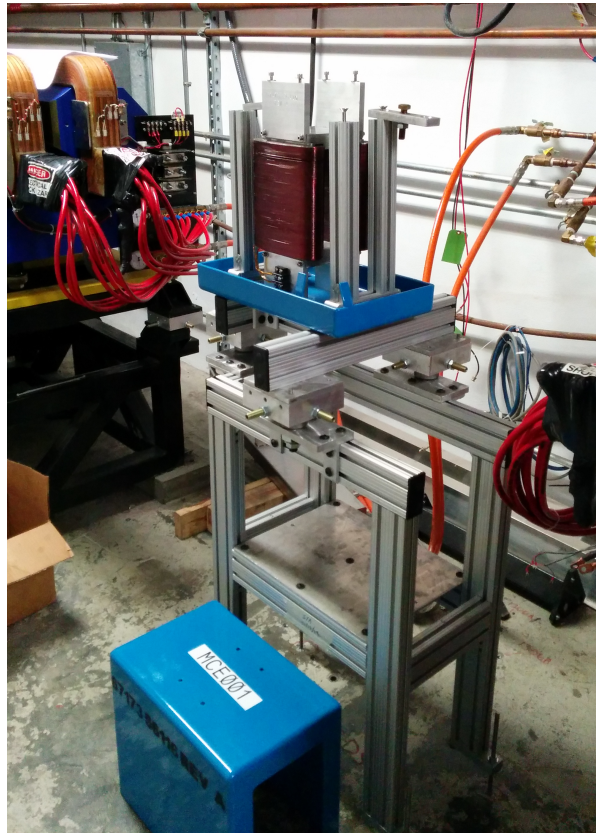
In addition to the magnetic components of the Compton chicane, beam diagnostics are used to ensure the correct orbit of the beam through the chicane and to minimize the chances of damage to detector components. Two standard beam position monitors are located on the upstream and downstream ends of the laser table. These are used to provide knowledge of the beam trajectory where it collides with the laser and are used as part of a slow position lock. In addition, BPMs are used between dipoles 1-2 and 3-4 to provide knowledge of the beam position as it exits dipole 1 and enters dipole 4. Because of the limited space available, these BPMs are not standard stripline BPMs, but rather are so-called “button” style BPMs, mounted directly in the vacuum chamber. Typically, an ion chamber is also placed near the electron detector to minimize the chance of beam excursions damaging the diamond strip detector. Two small scintillators are also placed on the laser table, right next to the beam pipe to help monitor beam-related backgrounds near the laser. These detector are provided and maintained by Hall C, but the EPICS signals showing the rates from these detectors are provided to the accelerator operators.

2.4.1.2 Laser system

The Compton laser system consists of a moderate gain (≈ 200) Fabry-Pérot cavity, pumped by a 10 W CW green laser (Coherent Verdi V10). In order to store power in the cavity, the length of the cavity must equal an integer number of laser wavelengths



(a) Compton polarimeter dipole



(b) Compton horizontal corrector

Figure 2.11: Photographs of magnets used in the Compton chicane. The top picture shows one of the Compton dipoles (mounted for field measurement). The bottom picture shows one of the new, large horizontal correctors mounted on its stand. The magnetic shield (not yet installed in this picture) can be seen on the floor next to the corrector stand.

($L_{\text{cavity}} = n\lambda$). This is achieved by feeding back on the laser wavelength via the so-called Pound-Drever-Hall (PDH) technique. The wavelength modulation of the Verdi laser is achieved via PZT stacks that adjust the lasing cavity length inside the laser head.

The laser system sits on a small optical table (with pneumatic vibration-isolating legs) between dipoles 2 and 3. During normal operation, an interlocked cover prevents any laser light from leaving the optical table. In addition, laser safety curtains surround the laser table. During alignment of the laser and optical elements, additional laser safety curtains are dropped creating a mini-laser room. While the alignment is ongoing and the laser table cover is removed, pressure sensitive floor mats prevent accidental “walk-through” of the laser area. The safety interlock system and its features are fully described in the Hall C Compton Laser Safety Operating Procedure (LSOP).

The main components of the laser system are:

1. The 10 W, Coherent Verdi V10 laser. This laser has been modified to include two PZT stacks for slow and fast wavelength adjustment of the laser.
2. Optics for laser beam steering, shaping, and polarization control.
3. Optical detectors for monitoring incident and transmitted laser power, laser beam position, and for use with the PDH feedback system.
4. Moderate gain Fabry-Pérot cavity. The low-loss cavity mirrors live inside the beam-line vacuum and have a nominal reflectivity of 99.5% with losses better than 50 ppm.
5. Feedback electronics for matching the laser wavelength to the Fabry-Pérot cavity length. The Hall C Compton polarimeter uses a commercial FPGA-based module manufactured by Toptica Photonics called the Digilock-110.
6. Slow controls system. We use remotely controllable (closed-loop) mirror mounts and rotation stages manufactured by New Focus for controlling the laser beam steering and polarization on the table. The control system is written in LabView and runs on a PC that is located just inside the labyrinth that leads to Hall C. The slow control system allows remote control of the Verdi laser, the New Focus optics stages, and interfaces with the Digilock locking electronics to allow automated locking and unlocking of the cavity.

A detailed schematic of the layout of optical components on the laser table is shown in Fig. 2.12. To summarize briefly: The laser is positioned on the downstream, beam left corner of the table. The polarization controlling optics are on the other side of the table. The laser is brought from 2 inches above table height up to beam height via a periscope. The laser enters the vacuum pipe from the beam right side and is steered into the cavity from downstream. The transmitted laser beam (upstream of the cavity) exits from bottom of the vacuum pipe and is steered to power monitoring detectors as well as a CCD camera.

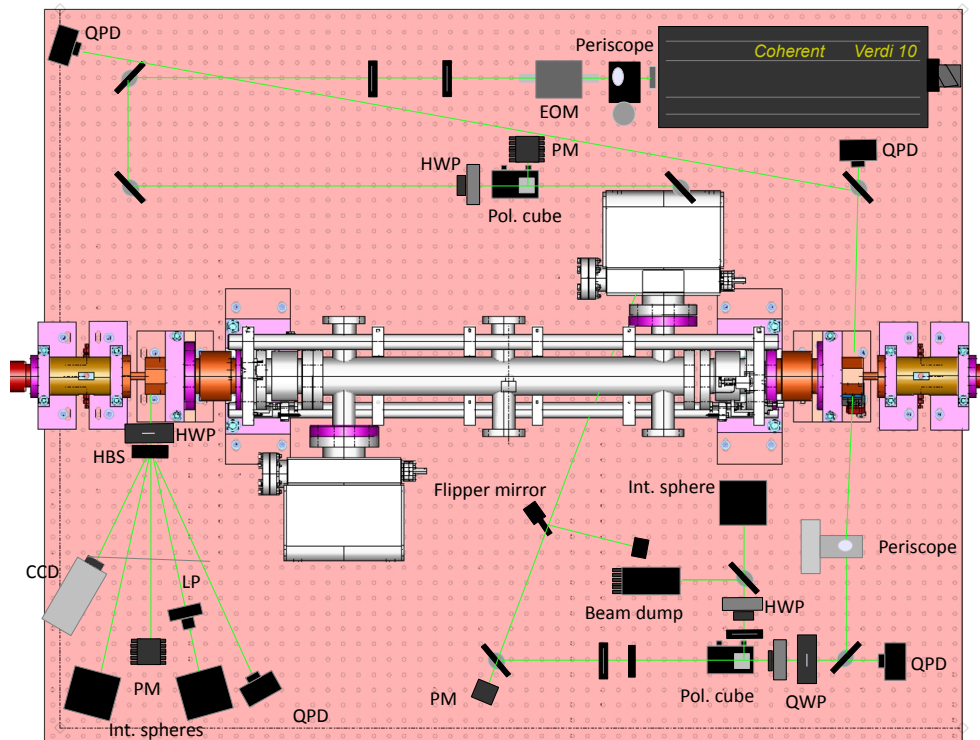


Figure 2.12: Laser table layout for Hall C Compton polarimeter. The output of the Verdi goes through a variety of optics used for intensity control, frequency modulation, and mode-matching before entering the low gain Fabry-Pérot cavity. Upon exiting the cavity, the power and polarization of the laser is monitored on the analysis station. Key: EOM = electro-optic modulator, HWP=half-wave plate, QWP=quarter-wave plate, PM=power meter, QPD=quad-photodiode, HBS=harmonic beam sampler.

As noted earlier, the laser is controlled via a LabView program running on a PC in Hall C. The controls can be accessed by a Compton laser expert using a VNC session from the Counting House. The laser slow controls are never accessed by a non-expert: only Compton laser experts are authorized to manipulate the system. The LabView control program does interface with EPICS, but only for the purpose of providing readback and archiving of laser-related quantities. No features of the laser system can be modified from EPICS.

The LabView control program incorporates several “tabs” to manipulate various aspects of the system. These tabs include:

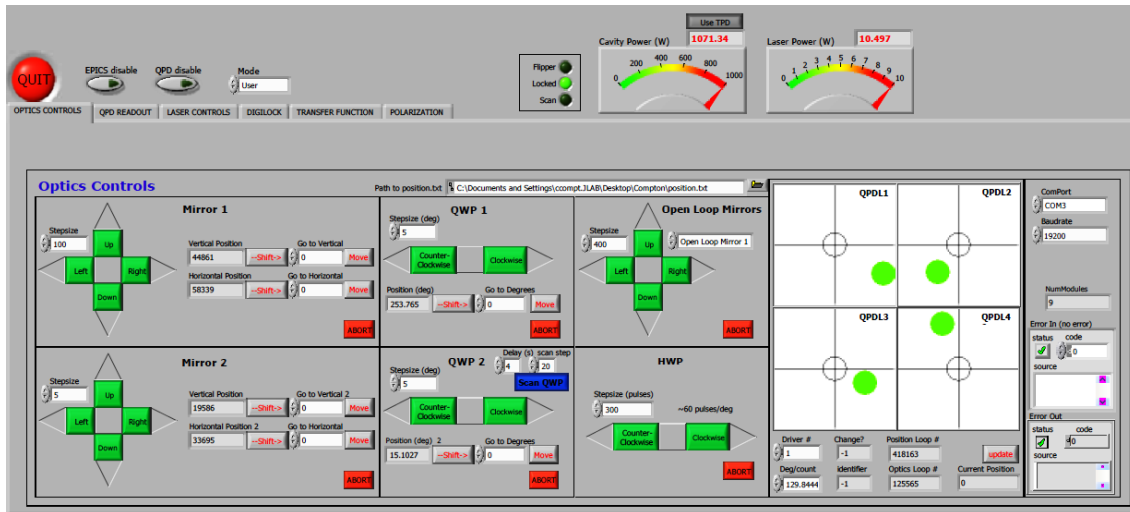
1. Optics control: steering of the laser into the cavity and visualization of the laser position via position sensitive detectors (QPDs).
2. QPD readout: manipulation and diagnostics of the QPD readout loops.
3. Laser controls: control of the Coherent Verdi V10 laser.
4. Digilock: readback of the parameters used in the cavity feedback electronics as well as control of the lock and unlocking intervals. This tab is not typically used to control the Digilock directly. Rather that is done using a control program provided by the manufacturer of the Digilock module.
5. Transfer function: used for measurements required for constraining the degree of polarization inside the cavity. These measurements are not typically done during “production” running.
6. Polarization: setup of the laser polarization via manipulation of the rotation stages that hold half and quarter wave plates.

Fig. 2.13 shows the LabView laser system controls, with the top plot showing the “Optics Control” tab and the bottom plot showing the “Feedback Controls” tab.

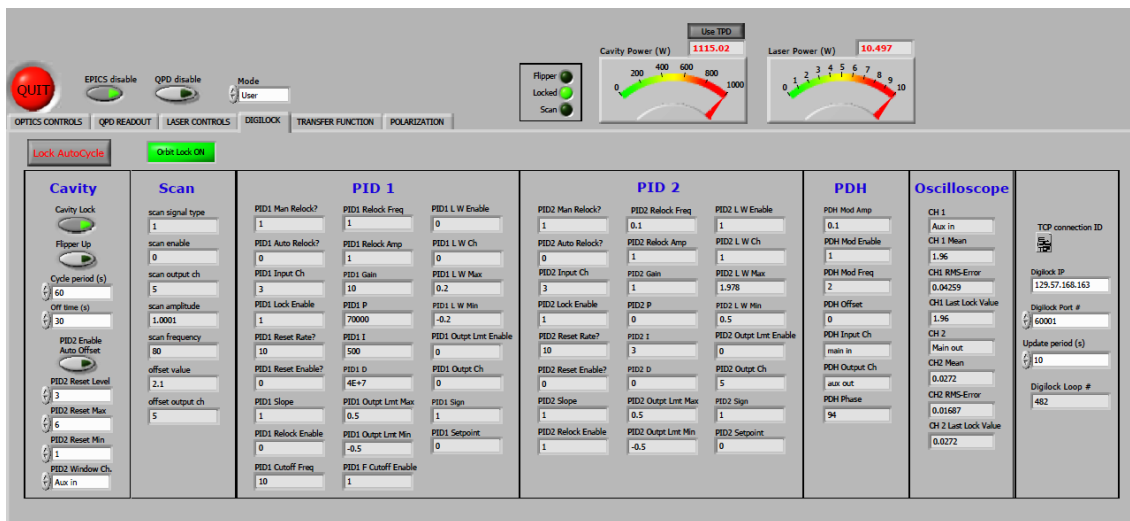
2.4.1.3 Electron Detector

The electron detector in use is a 21mm x 21mm CVD diamond microstrip. Four planes are used in coincidence with each of the 4 planes separated by 1cm with the strips of each plane aligned to $\approx 20 \mu\text{m}$. Each plane contains 96 horizontal diamond strips (polycrystalline CVD diamond). Each strip is $180 \mu\text{m}$ wide with a $20 \mu\text{m}$ gap separating each strip. Metalization was done on each plane with Titanium-Platinum-Gold (TiPtAu). The carrier boards are Ceramic (alumina). A single plane of the electron detector is shown in Fig. 2.14 with a detailed schematic in Fig. 2.15.

The strips are connected to custom, low-noise amplifier discriminator boards (Q-Weak Amplifier Discriminators, QWADs) via 55 cm long, Kapton flexible circuit boards with capacitance 60-90 pF. Each QWAD has 48 channels, thus requiring 2 QWAD boards per plane. One QWAD processes the signal from all odd strips of the detector, while another processes the signals from all even strips.



(a) Mirror/steering controls



(b) Feedback controls

Figure 2.13: Slow controls for the Compton laser system. The top panel shows the controls for the two steering mirrors located just before the laser enters the beamline vacuum. The bottom panel shows the readback of variables set in the commercial locking module and allows control of the time scales for locking and unlocking the cavity.

The QWAD can accept signals of both positive and negative polarity with a jumper on the board setting the appropriate configuration (the electron detector operates at negative polarity). The QWAD utilizes 3 different power supplies. For the main power input, we use two Acopian 5 V supplies to provide positive and negative 5 V. These supplies are behind the green wall near the entrance to Hall C in rack HC01Z02.

Agilent 3633A power supplies (also located in Hall C, neat the Acopian supplies) are used for setting the external threshold of the QWAD. In the usual operating mode it can deliver a maximum output of 8.0 V. The Agilent power supply used for external threshold can be remotely accessed via port 11 on hall C terminal server 5. One can access this by the command from any cdaq machine:

- Type `telnet hctsv5 2011`
- Next, access the telnet prompt by pressing `Ctrl +]`
- At the telnet prompt explicitly set the line mode on the terminal: `telnet> mode line`

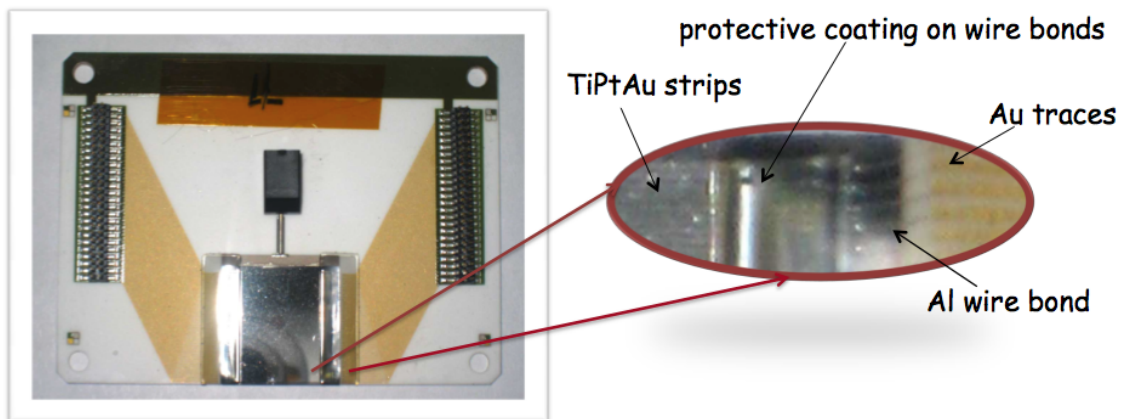


Figure 2.14: Picture of one of the diamond strip detector planes.

We use an NHQ 202L HV power supply to give HV to the diamond micro strip detectors. The detectors are typically operated at -400 V. The module is set to deliver negative voltage through a turn-switch on its side (not visible on the front panel). The actual value of the voltage can be set by the front panel knob or remotely. If the module is intended to be operated remotely, the DAC flip-switch should be flipped away from the knob. The high voltage module is located in a NIM bin in the Compton racks in the Hall C Counting House. A standard SHV cable runs from the module to a feed-through located at the top the electron detector vacuum can. The HV module is connected to port server hctsv4 at port 3. In order to connect to the device once has to execute from any cdaq terminal, `telnet hctsv4 2003`.

The Compton electron detector can be moved vertically to allow the detector to be placed totally out of beam, or moved into position for a Compton measurement. The

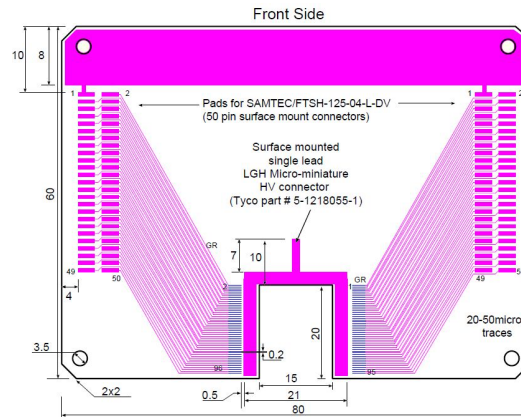


Figure 2.15: Detailed schematic of diamond detector plane.

detector motion is accomplished using an MDC 665529 linear motion stage (with an 8 inch full range of motion) with stepper motor, controlled by an IDC S6961 motion controller. The motion control program is hosted on iochc10 (located in Hall C, also used for Møller polarimeter slow controls) and the control interface is via EDM.

It is important to note that the Hall C Compton electron detector is interfaced with the accelerator fast-shutdown (FSD) system. If the Compton dipole chicane is not energized (i.e. dipole power supply is off), the electron detector must be in its fully retracted position (indicated via a limit switch) to allow beam delivery. Only if the chicane is energized, can the detector be moved away from its fully out position. In addition, if the detector moves while beam is on, an FSD will be triggered.

The Compton electron detector motion program can be started as follows:

1. Log in to any cdaqIX as `cvxwrks`.
2. `cd MEDM/compton`
3. `edm -x HLC_E_CompED.ed1`

The electron control GUI is shown in Fig. 2.16.

Before any motion on the e-detector is attempted, call MCC beam to request beam OFF and mask the Compton electron detector motion FSD. There is no visual verification of this FSD on the motion GUI, so please confirm the masking before moving the detector.

The electron detector motion GUI has several pre-defined positions selectable from the drop-down menu. “Garage” removes the detector from beam. “Pos 1” and “Pos 2” are two positions manually programmed into the controller to be close to the nominal electron detector running position. One can also “jog” the detector using a set of pre-defined, small increments (0.1 to 0.5 cm steps).

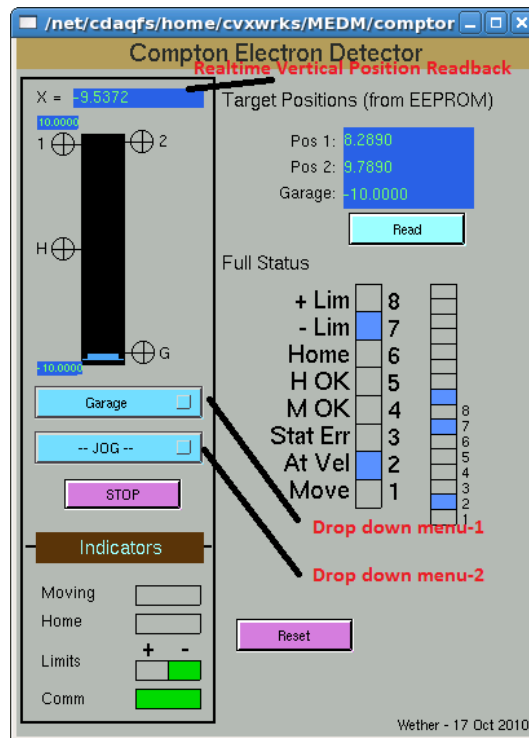


Figure 2.16: Compton electron detector motion GUI. In this picture, the detector is fully out of beam, indicated by the activation of the “-” limit switch.

2.4.1.4 Photon Detector

The Compton polarimeter photon detector is used to detect the backscattered photons from the Compton scattering process. The photon detector is located at the same height as the laser–electron beam interaction (i.e., centered at 13 cm below nominal beam height). The detector sits downstream of the third dipole, just upstream of the electron detector. The backscattered photons travel through the vacuum chamber of dipole 3, into the vacuum chamber between dipoles 3-4 and exits through a 0.5 mm thick window (radius 1.74 cm).

The detector itself consists of 4 lead-tungstate crystals; each crystal is 3 x 3 cm wide, 20 cm long. The inner surfaces of the crystals are in optical contact (not individually wrapped) and the light from the crystals is detected in a single 3–inch PMT (Hamamatsu H6526 PMT+base assembly). The detector typically runs at ≈ -1700 V, provided from a HV supply in the Hall C Counting House. The PMT signal is also sent to the Counting House where it is read out in a flash ADC.

In addition to the detector itself, an LED system is used for gain monitoring. This system consists of 2 LEDs flashing at different rates and strengths to provide relative monitoring of the system gain and stability. The LEDs sit in small boxes below the detector and are connected via optical fiber to the detector itself. No hazards are associated

with these LEDs due to the low voltages used to drive them and the diffuse, low-power of the light emitted.

2.4.2 Safety Information

The Compton Polarimeter integrates beamline elements (magnets and vacuum systems) with particle detector systems. Typical hazards for both types of systems are present.

2.4.2.1 Hazards

There are several specific hazards (potentially beyond those found in the accelerator beamline) associated with the Compton Polarimeter. These include:

1. Laser hazards: A high power laser system is contained between the 2nd and 3rd dipoles in the polarimeter chicane.
2. Electrical hazards: These exist in the vicinity of the magnet leads, as well as the detector high voltage.
3. Magnetic fields from the dipole magnets and new horizontal corrector magnets.

2.4.2.2 Mitigations

The special hazards associated with the Hall C Compton are mitigated as described below.

1. Laser hazards for the non-expert are mitigated by signage, flashing beacons to indicate the laser is on, and the containment of the laser system in on a fully-enclosed and interlocked laser table. Any attempt to access the laser area will result in automated shut-down of the laser. The Hall C Compton laser system safety procedures are fully described in the Laser Safety Operating Procedure (LSOP).
2. Electrical hazards due to magnet leads are mitigated using shields or covers over magnet leads where appropriate. The Compton detectors (outside the beamline vacuum) use standard SHV connectors. The electron detector planes use a mini-HV connector mounted to the plane - however, these are not accessible during normal operation.
3. “Magnet on” signs or blinking lights alert users to the presence of magnetic fields. The new horizontal corrector magnets between dipoles 1-2 and 3-4 also have additional magnetic shielding to mitigate the presence of any stray field.

Additional safety information is available in the following documents:

- EH&S Manual [7];
- PSS Description Document [?]
- Accelerator Operations Directive [11];

2.4.2.3 Responsible Personnel

Points of contact for the Hall C Compton Polarimeter are listed in the Tab. 2.6.

Name (first,last)	Dept.	Call [12]		e-mail	Comment
		Office	Cell		
Dave Gaskell	Hall-A/C	6092	757-719-5482	gaskell@jlab.org	<i>1st Contact</i>

Table 2.6: Compton Polarimeter points of contact.

2.5 Møller Polarimeter

The Møller Polarimeter is used to measure the electron beam polarization. Instructions for carrying out such a measurement are documented in the Møller Step-By-Step Guide [15]. MCC follows a complementary [procedure](#). The polarimeter is located at the end of the Hall C alcove downstream of the Compton polarimeter. All magnetic elements of the polarimeter are located between the BPMs 3C21 and 3H02: there are a solenoid and three quadrupoles. The Møller target is located in the center of the solenoid. The detectors are positioned 11 meters downstream of the target and 0.49 meters horizontally away from the beam line in a lead house.

The Hall C Møller polarimeter consists of: the target and target solenoid, the quadrupole magnets, a collimator box, and the detectors. These are described in turn in the paragraphs below:

Target Solenoid This is a ≈ 4 T super conducting solenoid used to “brute force” polarize the valence electrons in a thin, $\approx 4 \mu\text{m}$, iron foil perpendicular to the plane of the foil. This magnet has a liquid nitrogen cooled radiation shield and requires liquid helium for operation.

Quadrupole Magnets In order to keep the locations of the Møller target and detectors fixed regardless of the incident beam energy a “two” quadrupole optics was chosen. The first quadrupole (the “Los Alamos” or small Møller quad) has a 4 inch bore and a physical length of about 1 ft. The second focusing element is actually a pair of identical quadrupoles (10Q36, large Møller quads) each with a 10 inch bore and physical length of 123 cm. The quadrupoles are wired in series and operated as one magnet for use at high energies.

Collimator Box There are seven movable blocks of densimet (densimet is a machinable alloy of tungsten) for the collimator. These blocks form two horizontal jaw pairs and one vertical jaw pair. The seventh block has a hole in it through which the unscattered electron beam travels.

Detectors The Hall C polarimeter was built to operate in coincidence mode with both the scattered and recoiling electrons being detected in coincidence. There are thus two identical detector stacks placed symmetrically about the beamline. Each stack consists of a sixteen element hodoscope followed by a lead glass block.

Polarimeter Description The layout of the polarimeter is shown in fig. 2.17. The incoming electron beam hits an iron target foil. The target thickness is on the order of 1 to 10 μm . The electrons in the iron foil are polarized by the 3-4 T magnetic field of the super conducting solenoid. The beam electrons scatter off the target electrons (Møller Scattering) with the scattering angle of interest at about 1° or below in the laboratory system. Since the electrons are very close to the beam line they need to be deflected away from it in order to be detected in coincidence. This is achieved by the quadrupoles. The first smaller quadrupole is focusing in the horizontal plane while the second and third large quadrupoles defocusing in the same plane. The use of two (three) quadrupoles allows us to keep the cone of the 90° CM scattered electrons at fixed dimensions after a 11 meter drift distance. In the 6 GeV era, only one large quadrupole was used, the size of the 90 degree cone was 49 cm horizontal and 16 cm vertical from the beam line. This tune can still be used (if only one large quad is used) up to a beam energy of about 5 GeV. In the new configuration (with two large quads), the cone of the CM scattered electrons is 49 cm and 9 cm vertical from the beamline. This option can be used over the full range of available beam energies, up to 11 GeV.

The first quadrupole (the Los Alamos quad) has a 4 inch bore and a physical length of 12 inches. The second pair of quadrupoles (10Q36) has a 10 inch bore and a physical length of 123 cm. The two electrons are detected in coincidence using two lead glass

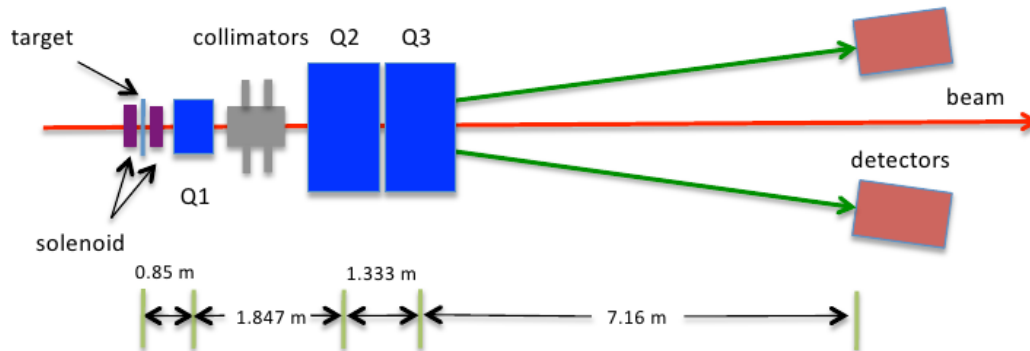


Figure 2.17: Sketch of the Møller polarimeter in Hall C.

shower counters as shown in Figure 2.18. In front of each counter is a collimator that defines the acceptance. The right collimator is intentionally larger than the left. This reduces the sensitivity of the coincidence acceptance to beam and detector positions. In front of the collimator is a hodoscope with 16 channels. Each channel is a scintillator of 1cm width.

Since the cross section for Mott scattering (electron - nucleus scattering) is much larger than Møller scattering it is necessary to use collimators to reduce this background that leads to accidental coincidences. This is achieved with a set of movable collimators located between the small and large quadrupoles (see fig. 2.17 and 2.19). Mott electrons

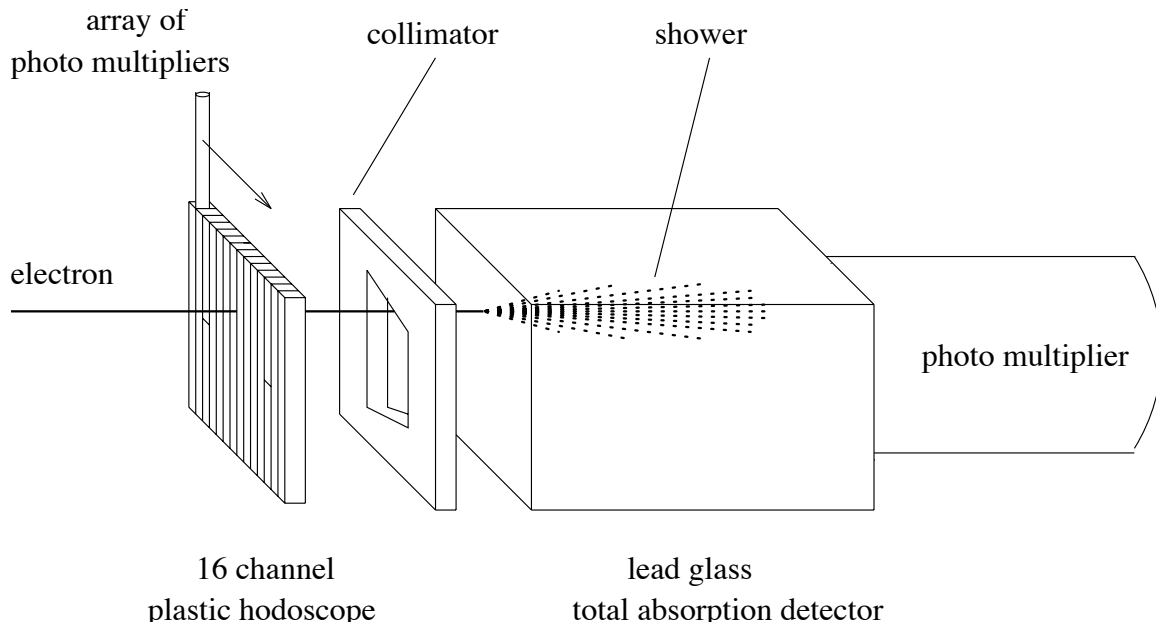


Figure 2.18: Detector arrangement

with the right momentum and scattering angle that make it through the quadrupoles into the detectors do not follow the same path in configuration space as the Møller electrons do. The collimators are used to shield the space that is not traversed by the Møller electrons. The space of the Møller stripes is given by the collimators in front of the lead glass detectors that define the coincidence acceptance.

Møller Control Software and Hardware There are three main control packages for the Møller Polarimeter. Two of them are GUIs run from the Hall C Counting Room. They control 1) the solenoid cryogenics, and 2) the solenoid field, the target, and the collimators. Control of the Møller quadrupoles is possible only from MCC, although the second counting room GUI does allow experimenters to monitor the quadrupole settings.

Polarimeter GUI To run the GUI using medm do the following steps

- Log onto to any cdaqIX machine from the account `cvxwrks`.
- Set directory: `cd ~/MEDM/moller`
- Start the GUI: `medm moller.adl`

Quadrupole Settings Although the quadrupoles are controlled only by MCC, it is the responsibility of the experimenter to make certain that they are set to the correct currents. The correct currents are a function of the incident beam energy . The initial

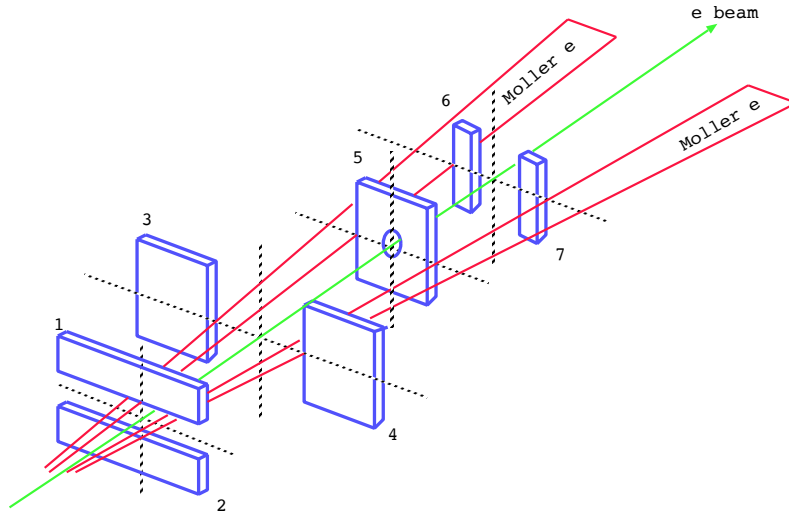


Figure 2.19: Collimator with Møller trajectories

settings are determined by a simple optics model of the Møller polarimeter and the final values are determined empirically by tuning the system using beam. The final currents are determined experimentally by optimizing the Møller hodoscope left-right correlation. This guarantees that the polarimeter acceptance is centered around 90 degrees in the center of mass. Predicted quadrupole currents for several beam energies are shown in Tab. 2.7.

Beam Energy (GeV)	Q1 (A)	Q2/Q3 (A)
1.0	102.14	60.85
5.0	159.73	423.18
9.0	114.13	937.85
11.0	100.10	1352.24

Table 2.7: Møller Quadrupole Current Settings from optics model predictions.

Currently the Degauss procedure for Q2 and Q3 is to ramp the magnet up to 800 Amps then ramp down to zero, reverse polarity, ramp to -240 Amp and finally back to zero. This procedure is almost never used and is not known to be important.

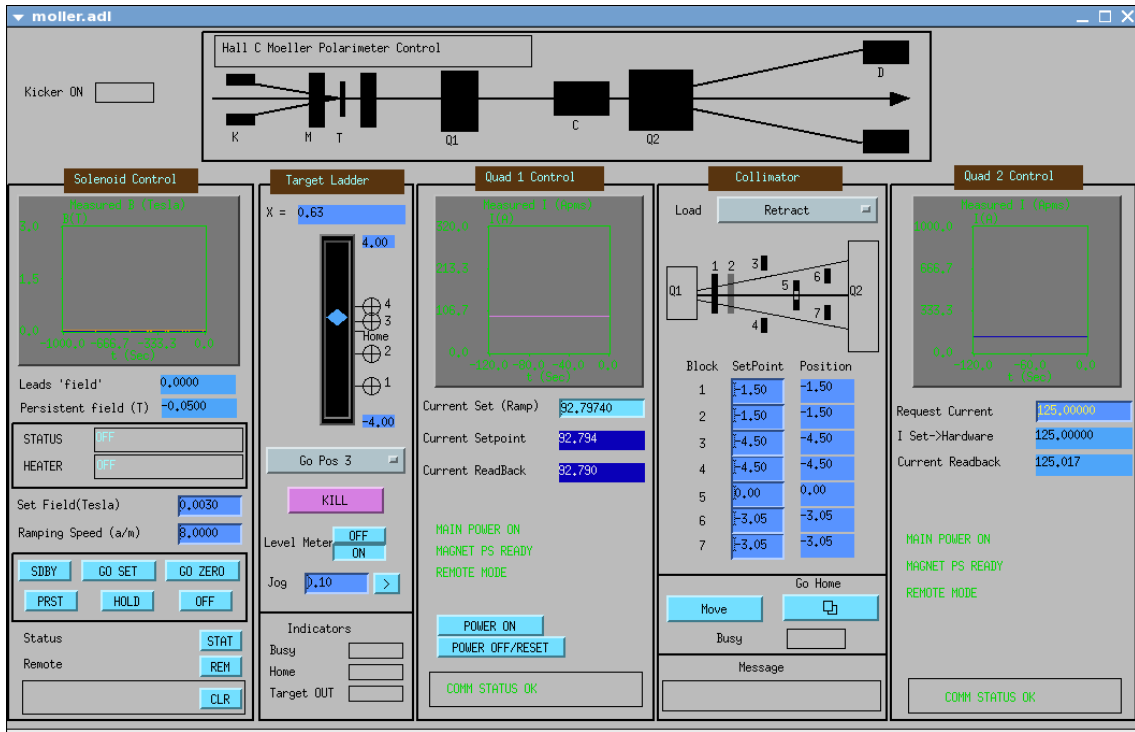


Figure 2.20: Møller Polarimeter Control GUI

Target Motion There are four possible target positions, shown in Table 2.8. They can be selected using the GUI with the frame title ‘‘Target Ladder’’ . In the menu indicated by the term ‘‘Cancel’’ the four individual target positions can be selected. Once chosen with the mouse pointer the target ladder will move! **ALWAYS (BEAM OFF) WHEN TARGET IS BEING MOVED.** Since the target positions are hard-wired in the code, any corrections to these values need to be done manually using the ‘‘Jog’’ option of the GUI. The camera button ‘‘ON OFF’’ turns the target camera and light on and off respectively.

After a power cycle the target first needs to find HOME. This can be done selecting the ‘‘HOME’’ in the menu. To move the target ladder fully out of the beam select ‘‘RETRACT’’ from the menu. At position -3.86 the target is fully out of the beam.

Target	Material	Thick μm	Position
1	Fe	1	-2.03
2	Fe	4	-0.56
3	Fe	1	+0.93
4	Empty	-	N/A

Table 2.8: Møller Targets

Collimator Positions Never move collimator 5 while beam is present!!!
Never issue the Go Home while beam is present!!!

The collimator positions also depend on beam energy. However this dependency is only small since the collimators do not need to be located very tight to the Møller stripes. The singles rates do not increase significantly if the collimators are even 5 mm away from the Møller stripes. The starting values for the Møller collimators can be determined using the Møller Monte Carlo.

Each collimator can be moved individually by typing a value in the column ‘‘SetPoint’’ at the appropriate window, see fig. 2.20. Use the ‘‘RETURN’’ key to set the value and the ‘‘Move’’ button to move the collimator to this value. For the collimators 1,2,3,4,6 the values can not be larger than zero because that would move the collimators into the beam (software cut). The collimator 5 is a special case since the beam goes through a central hole in the collimator. After a power cycle all the collimators need to find the HOME position first. This is done by using the ‘‘Go Home’’ menu that pops up a window to ask if one really want to search the home position.

Target Solenoid Since the target solenoid is superconducting and therefore cooled with liquid helium the controls are somewhat more complicated. Currently we run the magnet at a field of 3.5 Tesla. Before ramping up the magnet, check the helium and nitrogen levels (see Fig. 2.21). The magnet has to be put into standby mode first, this turns the heater on. Use button ‘‘SDBY’’. After 20 seconds one can ramp up the magnet using the ‘‘GO SET’’ button. This ramps up the magnet to the field value set in the frame ‘‘Set Field(Tesla)’’. After reaching the desired field the magnet can be put into persistent mode (i.e. turns off the heater) by hitting the button ‘‘PRST’’. If the solenoid will not be left at full field for a significant period of time (more than several hours), it is not necessary to put the magnet in persistent mode. The maximum ramp up speed is 12 Amps per minute. The power supply has an internal ramp up parameter that will limit ramping to 4 Amps per minute at higher fields. The ramp up process can be stopped at any time by hitting the ‘‘HOLD’’ button.

After a power cycle the remote button ‘‘REM’’ has to be activated first in order to establish communication to the power supply. The power supply is an IPS120-10 from OXFORD. Since it is a polarity reversible device the sign of the field value chosen by the ‘‘Set Field(Tesla)’’ is important. To reverse polarity the magnet needs to be ramped down to zero first.

Møller Cryogenics GUI The liquid nitrogen and helium supplies are monitored and controlled by a GUI with the drivers running on the IOC vmec10 (aka *iohc10*). A screen snapshot is shown in Figure 2.21. To run the GUI using medm, perform the following steps:

- Log onto to any cdaqLX machine from the account `cvxwrks`.
- Set directory: `cd MEDM/Møller/CRYO`

- Start the GUI: `medme hmcryocryo.adl`

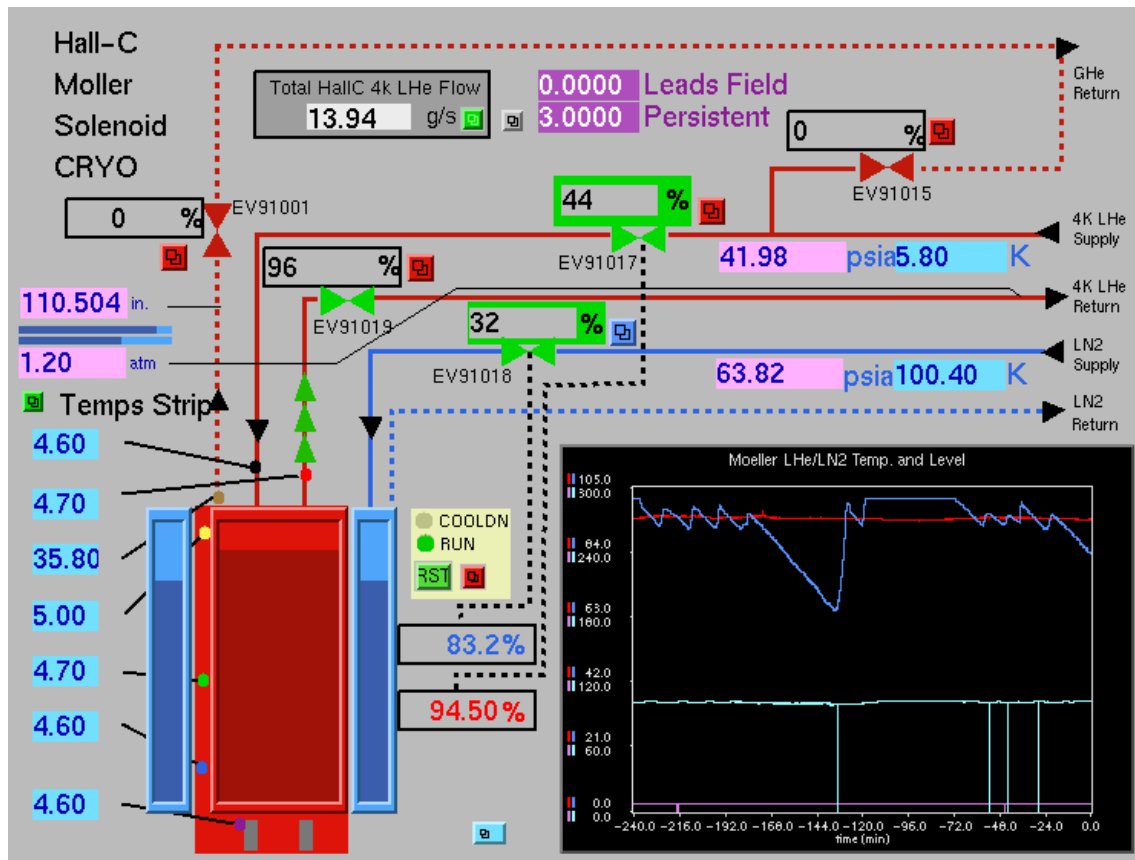


Figure 2.21: Møller Cryo GUI

Normally, the cryogen levels in the solenoid cryostat should be automatically maintained at or above 60% by the controls software. If mandated, you may turn off the supply of helium or nitrogen by closing JT-valves EV91017 or EV91018, respectively.

Note that if VMEC10 (iohc10) gets rebooted, it is necessary to RESTORE the cryo valve parameters for the Møller. You do this by clicking on the small blue box on the bottom of the cryo overview screen (hmcryocryo.adl), selecting "SAVE/RESTORE", then selecting "iohc10:NORMAL RESTORE" from the "!" box in the resulting screen. It will prompt you to hit ENTER several times. Do so until the dialog window goes away.

Cooling down the magnet from room temperature should only be done by a Møller cryo expert in coordination with the JLab Cryo group. In general, the steps are:

1. Make sure all all supply valves and the helium cold return valve are closed and the warm return is open.
2. Open the LN2 supply valve (EV91017) and allow the transfer line and cryostat to cool down. When the nitrogen reservoir is full, turn on the supply valve PID loop.

3. Pre-cool the Møller cold return line by flowing cold helium backwards through the cold return to the warm return (EV91001) by opening the cold return valve (EV91019).
4. Close the cold return and start cooling the helium transfer line helium reservoir by opening EV91017
5. Once the helium reservoir is full, gradually open the cold return - once it is fully open, start closing the warm return.
6. Once the warm return valve is closed, the helium valve control PID loops should be engaged (Figs. 2.22, 2.23, and 2.24).

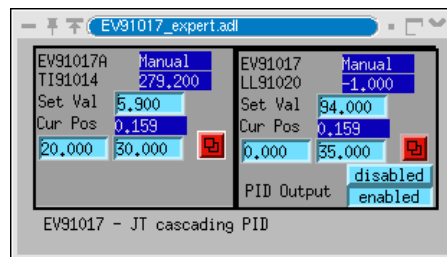


Figure 2.22: PID MEDM Screen - EV91017 Cascade Loop

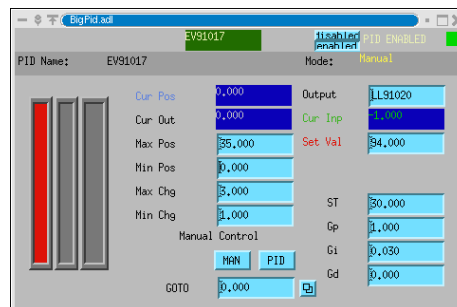


Figure 2.23: PID MEDM Screen - EV91017 Liquid Level Control

Detector HV The HV of all detectors is controlled from the SOS HV GUI. Nominal settings for the PMT's are given in Table 2.9. If necessary, the Møller High Voltages can be controlled from the front panel of the CAEN mainframe from which they are powered. This mainframe is the only one in relay rack CHC15. **Note: The lead-glass voltages are beam energy dependent.*

Table 2.9: Nominal Møller Detector High Voltages and CAEN Power Supply Assignments

Detector	Left HV	Left CAEN#	Right HV	Right CAEN#
Pb Glass	1220*	38	1310*	39
Hodo 01	1200	00	1220	05
Hodo 02	1220	01	1190	06
Hodo 03	1150	02	1120	07
Hodo 04	1190	03	1100	08
Hodo 05	1100	04	1120	09
Hodo 06	1120	10	1200	15
Hodo 07	1150	11	1100	16
Hodo 08	1080	12	1270	17
Hodo 09	1230	13	1100	18
Hodo 10	1100	14	1180	19
Hodo 11	1250	20	1150	25
Hodo 12	1230	21	1200	26
Hodo 13	1160	22	1150	27
Hodo 14	1200	23	1180	28
Hodo 15	1220	24	1170	29
Hodo 16	1200	30	1150	35

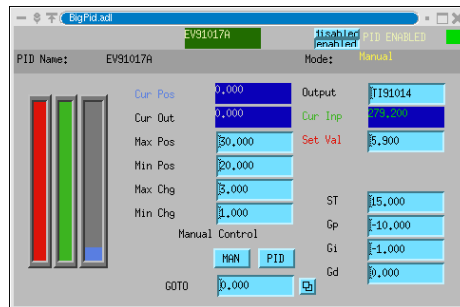


Figure 2.24: PID MEDM Screen - EV91017 Helium Supply Temperature Control

Møller IOCs Reference There is one IOC which support the Møller polarimeter device, (*iochc10* or *vmec10*). This IOC is on the accelerator network and is managed by the accelerator group. It manages the superconducting solenoid power supply and cryogenics system as well as the Møller target and collimators.

The Møller target, collimators, solenoid power supply, and solenoid cryogenics controls are all handled by *vmec10* (also known as *iochc10*). This IOC resides in the left hand side of a split-plane VME crate in Hall C (behind the green wall, in the racks immediately to the right as one enters the hall). Its boot ROM looks like:

```
boot device : ei
processor number : 0
host name : opsrv
file name : /cs/op/iocs/iochc10/vx/vxWorks
inet on ethernet (e) : 129.57.168.110:fffffc00
inet on backplane (b):
host inet (h) : 129.57.236.50
gateway inet (g) : 129.57.168.1
user (u) : vxwrks
ftp password (pw) (blank = use rsh):
flags (f) : 0x0
target name (tn) : iochc10
startup script (s) : /cs/op/iocs/iochc10/startup
other (o) :
```

Data acquisition The data acquisition reads out three Struck scaler modules at each (possible) helicity transition. Scalers '1' and '2' are gated for '+' and '-' helicity intervals as defined by the signal coming from MCC. (For experiments using delayed helicity reporting the active scaler will still be determined by the MCC signal, but this signal does not necessarily indicate the instantaneous helicity state. The actual state must be

determined at analysis time.) Scaler '3' is gated 'on' during all helicity intervals, and should normally count the sum of scalers '1' and '2'.

The CAMAC Crate is read out on an prescaled event by event basis reading one ADC and one TDC module and two dual port memories. The ADC and TDC provide diagnostic information about the lead glass shower counters and the Møller coincidence timing. The memories provide horizontal positioning information about the two Møller electrons in front of the shower counters. This information is used to optimize the quadrupole settings in order to center the 90° CM Møller electrons on the lead glass.

Data is taken using CODA2.5 running on cdaq15. The DAQ can be started from the "moller" directory (in the cdaq home directory) by invoking "codamaster-moller."

Møller Beam line tuning A thorough step-by-step procedure for tuning the beam through the polarimeter has been worked out with the MCC operations group. Only MCC operators may modify the settings of the Møller quadrupoles. The procedure is available for your reference at opsntsrv.acc.jlab.org/ops_docs/MCC_web_interface/interface_pages/operation. In addition, there is a companion document, the Møller Step-By-Step Guide [15] for Hall-C operators to follow.

The following is simply a coarse outline of the steps to be followed. For actually tuning up the beamline and turning on the polarimeter, you **must** refer to the separate documents mentioned above. The tuneup procedure should take no more than about 20 minutes if the beam is already tuned to Hall C. The time required to ramp up the superconducting solenoid is about 10 minutes.

1. With all Møller magnets off MCC will center the beam through the BPMs at 3C20 and 3C21 in both horizontal and vertical directions.
2. MCC will then turn on Q1, re-center the beam, then turn on Q2 and re-center the beam again. The required quad currents must be supplied by Hall C. (The Møller expert should have posted them in the logbook.)
3. MCC will request that the Hall shift crew ramp up the Møller solenoid. We normally run it at 3 Tesla.
4. With the solenoid and the two quadrupoles Q1, Q2, and Q3 on at nominal current, MCC will once again center the beam through the polarimeter and into the hall.
5. If it is desired to take Møller measurements at beam currents higher than $\approx 2 \mu$ A it will be necessary to energize the Møller raster system. See the Moeller Raster Manual [14] and the Moeller Raster Setup howto [16].

2.5.1 Safety Information

The Møller Polarimeter integrates beamline elements (magnets and vacuum systems) with particle detector systems. Typical hazards for both types of systems are present.

2.5.1.1 Hazards

There are several specific hazards (potentially beyond those found in the accelerator beamline) associated with the Møller Polarimeter. These include:

1. Radiation areas: These are potentially caused by use of the Møller using thick targets, at higher than normal currents, or at low energies.
2. Vacuum windows: There are thin vacuum windows at the ends of the Møller detector legs.
3. Electrical hazards: These exist in the vicinity of the magnet leads, as well as the detector high voltage.
4. Magnetic fields from the quadrupole and solenoid magnets.
5. Lead: The detectors are shielded using painted lead bricks.

2.5.1.2 Mitigations

The special hazards associated with the Hall C Møller are mitigated as described below.

1. Potential radiation areas are surveyed and posted before access to the hall is permitted after beam operations.
2. The thin vacuum windows at the end of the Møller legs are mitigated by shields that prevent inadvertent punctures of the window. If work near the exit windows (this includes the downstream half of the blue platform on which the Møller detectors sit) is required, hearing and eye protection is required.
3. Electrical hazards due to magnet leads are mitigated using Plexiglas shields where appropriate. The Møller detectors use standard SHV connectors.
4. Red blinking lights alert users to the presence of magnetic fields.
5. Before removing lead bricks to access detectors, contact the JLab Industrial Hygiene group to mitigate any possible lead exposure.

Additional safety information is available in the following documents:

- EH&S Manual [7];
- Accelerator Operations Directive [11];

2.5.1.3 Responsible Personnel

Points of contact for the Hall C Møller Polarimeter are listed in the Tab. 2.10.

Name (first,last)	Dept.	Call [12]		e-mail	Comment
		Office	Cell		
<i>Hall C Physicists</i>					
Dave Gaskell	Hall-A/C	6092	757-719-5482	gaskell@jlab.org	<i>1st Contact</i>
William Henry	Hall-C	6989	Web [13]	wmhenry@jlab.org	<i>2nd Contact</i>

Table 2.10: Møller Polarimeter points of contact.

2.6 Target Chamber

The cryotargets and the associated solid targets (see Sec. 3.1) are contained in a special target chamber consisting of a large evacuated cylinder in two stacked sections.

The chamber was designed (in 2006) to isolate the beam line vacuum from each spectrometer so that each could rotate around the target without vacuum coupling and without jeopardizing the kinematics and acceptance specified for approved experiments at that time. It was also designed to simultaneously contain a liquid or gas target and an array of conductively cooled solid targets hung below the cryo-targets. A single axis (vertical) motion system is employed to select the desired target. The desired kinematic specifications that were considered included momentum and energy resolution in both arms, angular range of spectrometers, angular acceptance, and luminosity. The relevant JLab drawing numbers are 67153-E-56001 to 67153-E-56020, although as described below, the window design has changed dramatically. Note that the portal to JLab drawings is <https://misportal.jlab.org/jlabDocs/search.seam>.

The chamber vacuum is isolated from the atmosphere by a thin aluminum window. The nominal vacuum is typically a few times 10^{-6} Torr warm, and about a decade less with a cold cryotarget. Operation with the scattering chamber vacuum in or even near the 10^{-4} Torr range is not recommended.

2.6.1 Vacuum Window

The scattering chamber can be configured differently (in principle) for different experiments by having different window configurations and rotations of the scattering chamber about its central vertical axis. The nominally 2 inch thick aluminum chamber has an inner diameter of 41 inches, and an outer diameter of 45 inches, not including the semi-cylindrical window flanges or extruding ports. In the standard configuration (see Fig. 2.25), both spectrometers share a single “smile” (cut-out) on the scattering chamber. The exit beam pipe connects via a threaded compression flange (no o-ring) to this scattering chamber window. A conflat-style seal is employed using an Iconel 718 seal. An aluminum nut on the evacuated side of the window seals the window to the aluminum compression flange, as detailed in drawing 67153-56029. The 2024-T3 aluminum hydro-formed window is 0.020 *in* thick. The window surface is relatively smooth, with mild wrinkles from the hydro-formed design. The window design (see Fig. 2.26) supports the exit beam pipe flange in a novel way in order to keep o-rings far (>7.5 *in*) from

the beamline, which should mitigate problems with radiation damage and subsequent vacuum leaks which plagued the old design.

The new design also greatly reduces the mass next to the beam axis at the scattering chamber exit. The mass associated with the 2 *in* thick chamber wall and window frames near the beam axis is essentially replaced as a source of background by the thinner compression flange/nut on the window, which furthermore subtends a much smaller solid angle from the target than the old arrangement did. The minimum scattering angle from the target center which does not interfere with the exit beam pipe flange is 3.2° .

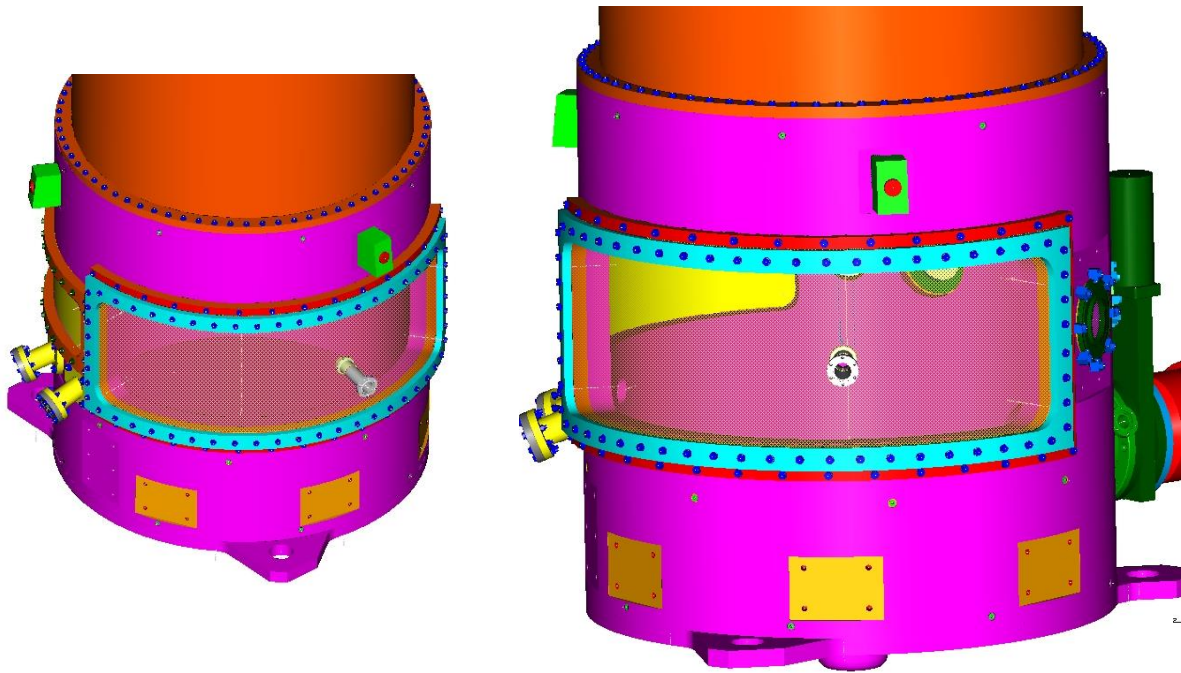


Figure 2.25: A couple CAD drawings showing some details of the new scattering chamber window design. The exit beam pipe is shown protruding from the window. The SHMS opening is on the right side of the picture; the HMS opening is on the left side. The turbopump and its gate valve are visible on the extreme right.

2.6.2 Angle Ranges

On the HMS side, the horizontal angular range is from 3.2 to 77.0 degrees, and $\pm 17.3^\circ$ vertically. On the SHMS side, the horizontal angular range is 3.2° to 47.0° degrees, and $\pm 17.3^\circ$ vertically. The angular limits presented by the scattering chamber are less restrictive than the limits associated with the spectrometers themselves. The SHMS can be moved over the angular range from 5.5 to 40 degrees, and the HMS can be rotated from 10.5° out to about 80° . The minimum opening angle between the two spectrometers is 17.5° , or greater depending on the exit beam pipe in use.



Figure 2.26: Photograph of the scattering chamber window with the short exit beam pipe attached. The inset shows the nut on the opposite side (the vacuum side) attaching this beam pipe to the window.

2.6.3 Penetrations

There are also openings in the scattering chamber through which the beam can enter, two pumping ports, several viewports, and some spare ports. A remotely controlled TV camera and light are used in conjunction with the viewports to observe target motion and position in the counting room. Beam position on the target can be viewed even at low beam currents with a scintillating BeO target, or on the cryotarget cell window via transition radiation which produces a visible spot above 5 or 10 μA .

Top and bottom plates complete the shell of the scattering chamber. The bottom plate is mounted to an adjustment plate on the solid shaft which forms the pivot axis for the two spectrometers. The scattering chamber's bottom plate has the shape of an

inverted top hat. The “hat” penetrates into an opening in the center of the pivot, allowing more vertical motion and more solid targets to be hung off the bottom of the cryotarget assembly. The hat extends 5.25 inches below the bottom surface of the 1.5 inch thick bottom plate, and has an i.d. of 5 inches.

The top plate has a number of penetrations. The largest of these allows the cryotarget coolant plumbing, wiring, and lifting mechanisms into the vacuum and is sealed by a large diameter bellows.

2.6.4 Vacuum Pumping System

Although the usual fast-acting gate valve on the instrumentation girder just upstream of the scattering chamber will close in the event of a loss of vacuum in the chamber, there is no longer a gate valve just downstream of the chamber. Instead there is a gate valve about halfway between the scattering chamber and the dump tunnel entrance. This means that whenever the beampipe just downstream of the scattering chamber has to be changed into or out of the small-angle configuration, the target will have to be warmed up and cooled down again (typically a 2 day operation).

The vacuum in the target chamber is maintained by a Leybold 1000 l/s turbomolecular vacuum pump. The pump is connected through a gate valve to an 8.386 *in* id port in the lower of the two cylinders which compose the scattering chamber. An optional, similarly sized turbopump and gate valve can be used with a port on the top half of the chamber to improve the vacuum in the chamber. Still further improvement in vacuum has been achieved using an Alcatel turbomolecular drag pump as a backing pump in addition to the induction-motor-driven mechanical pump normally on the turbopump exhaust. The gate valves isolate the turbopumps if the pressure in the scattering chamber rises above a threshold value. The chamber vacuum is read by a cold cathode gauge. This gauge is turned off in the event of poor vacuum in the chamber because it can arc above about 10^{-2} Torr. In addition, the chamber is equipped with a thermocouple vacuum gauge, a Convectron gauge, and a Barksdale DX1-A3SS vacuum switch.

Note that it is usual that the turbopumps will trip off if the cryotarget temperature rises from its operating temperature of 20 K to above 80 K, at which point air frozen out on the cold cryotarget surfaces can turn to vapor. In fact when warming up the target, resetting the turbopumps at this temperature should be part of the planning process. The gate valves on both sides of the scattering chamber should also be closed during warmup or cooldown of the cryotarget. Alternatively, the vacuum in the target chamber should be brought to atmospheric pressure using a dry gas by the cryotarget group so that the target can warm to room temperature before the chamber or the beamline it is connected to is opened. If the target is still cold when air is let into the chamber, water will condense on the cold surfaces and subsequent pump-down will take much longer.

2.6.5 Safety Assessment

The scattering chamber is typically a low maintenance item but it is a vacuum system and hence problems may occur. The day-to-day operations of the cryogenic targets are managed by the Hall A/C target experts, while major maintenance operations are handled by the Cryogenic Target Group (Physics Division).

The target chamber may pose several hazards:

1. **Rupture of vacuum windows.** This hazard is mitigated by lexan covers on the vacuum windows, installed by the hall technicians when access to the target chamber area is needed or at the start of a long down period. Installation and removal of the window covers is included in the technician's checklists. When the chamber is under vacuum, it is mandatory to use ear protection in the chamber vicinity. The appropriate signs must be installed by the technicians.
2. **Induced radioactivity.** The ARM measures the activity near the scattering chamber as a part of the general survey and may declare the target area as a "High Radiation Area", and rope it off [17]. Targets may not be removed from the target chamber or transported from the Hall without concurrence by the RCG. An SRWP specifies the requirements for target removal and/or transport. Targets which have been surveyed and released by the RCG are stored either in RCG storage areas or the target group's RCA storage cabinets in the EEL building.
3. **Pivot Access** The pivot area where the scattering chamber is located is located about 10 feet off the floor and is at the same level as and is directly accessible from the first level of the SHMS carriage. This area is restricted to authorized personell when the scattering chamber is under vacuum (with or without a full target) or when full railing coverage (passive fall protection) is not in place. A control document [18] and authorized personell access list are posted at the entrance to the pivot area. A rope and sign strung across the SHMS carriage near the pivot mark this entrance to remind people of the restrictions. Hearing protection is required in pivot area when the scattering chamber is under vacuum. Active fall protection and appropriate training when in the pivot area. Railings are installed on the pivot between run periods, at which point active fall protection is not required.

Some other safety issues are discussed in the cryo-target chapter 3.3.

2.6.6 Authorized Personnel

The contact person for issues with the scattering chamber or its vacuum is the Hall C technician on call. The contact person for issues specifically with the target is the target expert on call, who should also be contacted in the event of vacuum problems. On call personnel for both of these systems rotate, and should be identified on the white board in the counting room along with their contact information. If there are issues with the target coolant, the target expert on call should be contacted first, and will either recommend a solution to the problem or else that the cryo expert on call be contacted

through the MCC. The vacuum system is considered to be part of the target system and shall be operated by the JLab target group.

Chapter 3

Targets

3.1 Overview ¹

Several types of mutually exclusive target systems are used in Hall C, including:

1. a system of cryo-targets and solid targets;
2. a target of polarized gaseous ^3He .
3. a target of polarized NH_3 or ND_3 .

The set of cryogenic targets currently operates with liquid hydrogen, liquid deuterium and gaseous helium 3 or helium 4 as target materials. A variety of solid targets are also provided; BeO, Carbon and Aluminum are typical but other self supporting materials are available if need arises. Carbon targets with holes typically 2 mm in diameter are used to center the beam. The combination of cryogenic targets and a few solid targets is the standard configuration.

In addition, there are programs based on polarized ^3He and polarized NH_3/ND_3 . These are special installations and hence are not available at the same time as the cryogenic target system.

The target(s) presently in use are discussed in the following sections.

3.2 Procedure for Normal Running of the Hall C Cryogenic Targets

This procedure provides guidelines for the everyday running of the Hall C cryogenic targets.

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3.2.1 Introduction

The Hall C cryotarget system allows for multiple configurations depending on the requirements of the experiment(s). In the standard configuration, the system has three separate target loops. One of these loops is used as a spare, and contains ^4He gas usually pressurized up to ~ 30 psia. The other two loops are usually used for liquid hydrogen and deuterium targets. Each loop can have one or two target cells, which is again dependent on experiment requirements. Below the loops, solid targets such as carbon foils can be added. A typical configuration of cryogenic and solid targets is shown in Fig. 3.1.

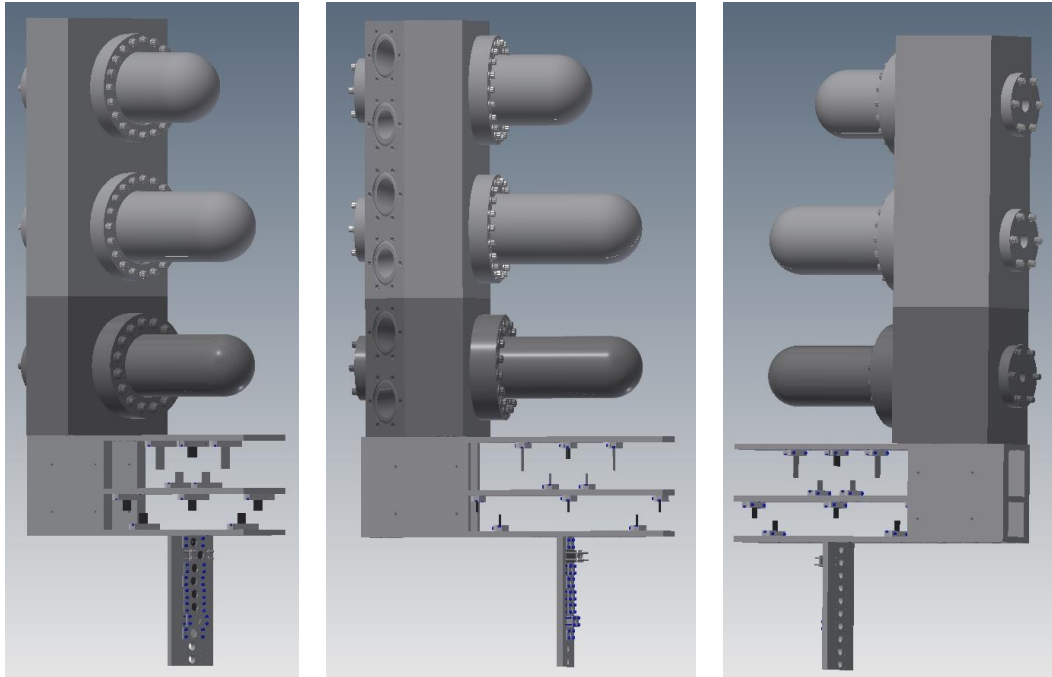


Figure 3.1: CAD views of the cryogenic and solid target ladders. In this example, there are three cryogenic loops, with one cell per loop. The cryo targets are assembled above the solid target ladder. Beam enters from the left in the leftmost picture, and from the right in the rightmost picture. The middle picture shows the hydrogen inlet and outlet manifolds.

A wealth of information about the Hall C cryotarget system is available at <https://userweb.jlab.org/~smithg/target/Qweak/>. At that location links to the target training talk can be found, as well as contact numbers for the target experts, a guide to the control system (GUIs), a FAQ, descriptions of the essential responsibilities and how-tos for the target, the operational restrictions (current and raster limits) for each target, the slow controls archiver, and much more.

During normal operation, the hydrogen and/or deuterium targets shall have already been liquefied by the target group and are in a stable state of about 3 degrees sub-cooled liquid (19.0 K for hydrogen and 22.0 K for deuterium) at pressures of ~ 24 psia. The

Target	Temperature (°K)	Pressure (PSIA)	Freezing T (°K)	Boiling T (°K)
H ₂	19 ± 0.1	24 ± 2	13.86	22.24
D ₂	22 ± 0.1	24 ± 2	18.73	25.13

Table 3.1: Normal operating conditions of the cryo-target cells.

normal operating conditions of the targets are given in Table 3.1. Also listed in Table 3.1 are the freezing and boiling temperatures. These parameters should be reasonably stable (temperature to ± 0.1 K, pressure to ± 2 psi) provided that the End Station Refrigerator (ESR) is stable. The temperature is controlled by a software PID (Proportional-Integral-Differential feedback) loop with a high power heater (up to 1500 Watts). The PID loop reads the output of one of the temperature sensors and adjusts the power in the high power heater to keep the temperature constant. The control loop functions extremely well and the temperature fluctuations with steady beam are typically measured in hundredths of degrees. The PID control loop also monitors the electron beam current to keep the target temperature stable by compensating for this heat load during unstable beam situations.

Graphical User Interface

The principal interface with the target is through the Graphical User Interface (GUI) of the control system. Every target operator must be familiar with the use of the primary and secondary target GUIs. A screenshot of the main target GUI is shown in Fig. 3.2. In this example, hydrogen is condensed in Loop 3. The status (current values) of the temperatures and pressures associated with the target loops as well as the coolant is displayed. In addition the target heater power, recirculation fan frequency, and JT (coolant) valve opening are provided, along with information about the selected target and the lifter.

3.2.2 Alarm Handler

It is *mandatory* to have an audible alarm handler, ALH, running at all times when the target gas has been condensed. Further, it is *mandatory* that the alarm handler be visible in all work spaces on the target control computer and “on top” of other GUIs. It is further mandatory that all alarms be “serviced” in the sense that each alarm must be investigated. No alarm may ever be ignored. While engineered controls ensure personnel and equipment safety, the alarm handler can save the experimenter lots of time, grief and potentially prevent problems with data. The ALH will alarm if any of its parameters go out of normal range. Servicing the alarm is the responsibility of the target operator. At high beam currents, the ALH may alarm when the beam goes from on to off or from off to on, if the high power heater does not respond quickly enough to the change in the

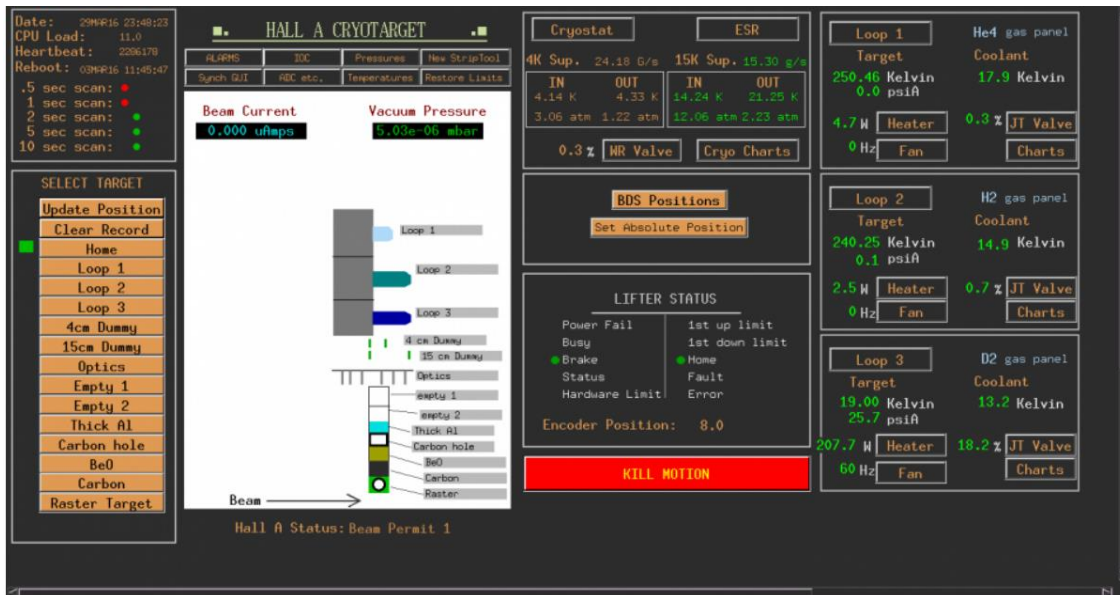


Figure 3.2: Screenshot of the main target GUI. Loop 3 contains LH2, the other loops are unused. Secondary GUIs can be launched from the buttons on this main GUI. The values of various temperature and pressure parameters are green when they are inside the alarm limits, and change color when they fall outside the limits defined in the alarm handler.

beam heat load, or if there is insufficient reserve heater power available. The ALH can also repeatedly alarm if there are noisy analog channels. If the AH alarms repeatedly or the cause of the alarm is not clear, the target operator should contact the on-call target expert. The ALH GUI and its secondary GUIs are shown in Fig. 3.3.

3.2.3 Target Motion and Fast Raster

Target motion is interlocked with the machine Fast Shut Down (FSD) system. Therefore, it is *mandatory* that operators call MCC so that they can remove beam from the Hall and mask our target-motion FSD node *before* moving the target. During target motion, the target operator must watch the target GUI carefully to insure the motion is going as expected. In case it is not, target motion crash switches are provided on the GUI and in the counting room. When target motion has completed, the MCC must be called again to restore beam and remove (unmask) the target motion FSD. The target operator must insure that the requested beam current and raster size are consistent with the operational restrictions (http://opweb.acc.jlab.org/internal/ops/ops_webpage/restrictions/ops_restrictions.html) for the new target. MCC should also perform this check, but the target operator is the first line of defense. Finally, the target operator must also

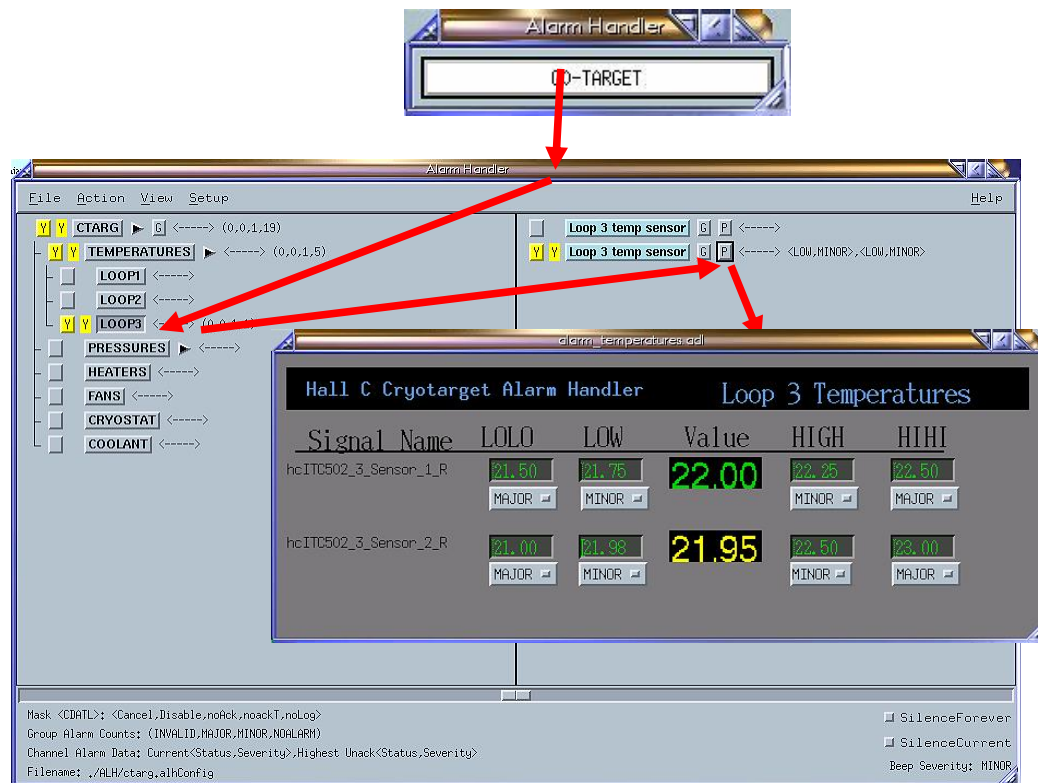


Figure 3.3: Screenshot of the ALH GUIs. In an alarm state, this GUI blinks and beeps. The arrows indicate the steps to service the alarm. Pressing the upper GUI brings up the large secondary GUI. Pressing the highlighted “LOOP3” button on the left brings up the LOOP3 branches of the alarm tree on the right. Pressing the “P” button there brings up a third GUI with the current values and alarm limits associated with that particular branch.

insure that adjustments to the cooling power are made, if necessary, in response to the new target and/or beam current.

The intrinsic diameter of the electron beam is typically only $100 \mu\text{m}$. When beam of such a small size hits the cryotarget, there is a danger that it can melt the aluminum target cell, and/or significantly reduce the density of the cryogenic target along the path of the beam through the cell. The former is catastrophic. The latter has a negative impact on most experiments, but can be characterized with sufficient precision for many experiments by making additional measurements as a function of beam current.

The fast raster is used to mitigate these effects by dithering the beam at the face of the target. At regular intervals, and every time the target is moved to a new position, the target operator *must check to make sure that the fast raster is on* and that it has a size consistent with that specified in the operational restrictions for that target. It’s best to check the raster setpoints as well as the raster magnet current readback. In addition,

a scope in the counting room provides an image of the raster pattern as a quick visual check. Because the raster magnet current is a function of the beam momentum and desired raster size, it's difficult to set alarm limits on. As a result we rely on the target operator to check that the raster is on and working as desired. Unlike the situation found in Hall A, in Hall C there are no quadrupoles between the raster magnets and the target. As a result there is a much more robust relationship between the raster magnet currents and the rastered beam size at the target.

3.2.4 Cryogenic Consumption

The ESR is not a bottomless reservoir of helium coolant. Typically not more than 25 g/s of 15 K coolant can be delivered from the ESR, which must be split between Halls A & C. Every effort should be made to keep our consumption within reasonable bounds. This means that heater overheads should be tens and not hundreds of Watts and that loops which will be dormant for extended periods should be powered down as much as possible. If the target operator thinks that the cryogenic consumption is too high (or has received complaints from another ESR user) and is uncertain about the appropriate action, he/she should contact the on-call target expert first.

Typical values for the temperature and pressure associated with the “15 K” helium coolant supply when running a LH2 target are 14 K and 12 atm. Typical return values are 20 or 21 K, and 2.2 atm. The mass flow of the coolant is typically 15 g/s, but varies depending on the beam current and target thickness. The condition of the insulating vacuum in the transfer lines also impacts the mass flow needed to cool the target. Unusually large mass flow and/or supply temperature may indicate that this vacuum space must be pumped out again. A minimum mass flow of 6 or 7 g/s is needed to keep the transfer lines cold.

3.2.5 Checklist

The Hall C target experts and the JLab target group tracks the state of the target. To facilitate this task the charts and the main target page screen must be captured to the HCLog at least once per shift.

3.2.6 Target Operators

One individual on each shift is responsible for target operations whenever liquid hydrogen or liquid deuterium has been condensed, even if the experiment is in a “standby” mode. This individual is the dedicated target operator (TO) and shall have the appropriate training to keep the target safe and ready to use in the experiment.

Personnel with no previous training must complete the following three steps to be certified as a TO:

1. The first step is the “theoretical part”, which consists of a target expert going through the target training talk with you. This talk explains the basics, including

GUI operation, as well as recommended responses to off-normal events. Ideally the prospective TO has arranged for this with a target expert well in advance so that the talk may be given to a group, instead of individually on a case-by-case basis.

2. The second part is a practical, also given by a target expert, which usually takes place in the Hall C counting house and consists of a hands-on walk through of the control system and some of the procedures for handling off normal events. This practical requires that the target be condensed. It also should be arranged with a target expert in advance so that it can be coordinated with other prospective TOs.
3. Finally, the last step requires the new TO to shadow a trained TO for (typically) half a shift in order to get more comfortable with normal operation. This last step can be accomplished while on shift as a shift leader or 3rd, or just by coming to the counting room at a convenient time.

All TOs have to renew their training for the 12 GeV era, because of the long hiatus in operation during 12 GeV construction. Training taken for Hall A (12 GeV training) is good for Hall C, and vice versa. If a TO was already trained for the 6 GeV era but wants to renew their training for the 12 GeV era, the requirements are simpler.

1. It is recommended but not required that the training talk be attended. In lieu of attending this talk, the training slides can be reviewed online at https://userweb.jlab.org/~smithg/target/Qweak/HallACTgt_Training.pdf.
2. A brief practical training is required with a cold target, in the counting room, with a target expert, in order to refresh the skills of the TO.

After the target operator's training has been completed, he/she should email one of the target experts so that the TOs name can be added to the list of trained target operators maintained by the experts.

All of the documentation that must be read and signed by any person on shift (the COO, RSAD, ESAD, RWP, and any other documents required of regular shift-takes) must also be read and signed by target operators. Radiation worker I training must be current, and the TO must have a valid TLD (radiation dosimeter) in case a target-related entry to the hall must be made. The target operator shall be familiar with the GUI system and be able to handle the normal target loop operation, the cryostat operation and the target motion. He/she shall also be able to deal with GUI crashes, IOC crashes and the usual alarms.

The following table contains the names of the currently recognized target experts (who have worked on the Hall C cryotarget system and have extensive knowledge of the system) and their pager numbers.

One cryotarget expert will be on-call 24/7 whenever hydrogen or deuterium has been condensed. The currently on-call target expert will be identified on the white board in the counting house. A list of other cryotarget-experts will be posted in the Hall C Counting House as well, in case the expert on call cannot be reached.

Group	Name	Contact info
Hall C	Silviu Covrig	tgt pager: (757) 584-5411
Hall A	JianPing Chen	cell: 218-0722
Cryo-Target Group	Dave Meekins	cell: 968-9076
Cryo-Target Group	Christopher Keith	cell: 746-9277

Table 3.2: Cryotarget experts and authorized personnel, with their phone numbers.

3.3 Safety Assessment

The Hall C target safety assessment document resides on the target group’s web page at <https://polweb.jlab.org/hallc/Cryotarget/Target%20Safety%20Assessment%20Document1.5.doc>. This is the document which contains the safety analyses, detailed calculations, and mitigations of the hazards identified for the cryotarget. It dates from Feb. 25, 2004. More recent and applicable information e.g. calculations, design and fabrication documents, testing documentation, etc. are stored in the pressure system database and are beyond the scope of this document.

Cryotarget installation, maintenance, and repair is performed exclusively by the JLab target group (not by users). The task hazard analysis worksheet covering such work in the scattering chamber is <https://polweb.jlab.org/hallc/Cryotarget/In%20chamber%20work.doc>, and that for disconnecting the target is found here: <https://polweb.jlab.org/hallc/Cryotarget/Disconnect%20Target.doc>. A guide and checklist used by the target group and occasionally the target experts which describes the procedures for determining what state the target is in, pumping and purging operations, and warmup and cooldown of the targets is at <https://polweb.jlab.org/hallc/Cryotarget/Target-operation-manual.pdf>.

Target operation is the responsibility of the system owner but, for practical purposes is the domain of the staff and users on a given experiment. The users’ guide to general operation of the Hall C cryotarget, prepared by the target group but somewhat dated (March, 2003), is available at https://polweb.jlab.org/guides/ctarg/CTARG_MAN.html. The resource <https://userweb.jlab.org/~smithg/target/Qweak/> is a more recent guide (Feb., 2014) for the general user.

3.3.1 Hazards

The cryogenic hydrogen and deuterium targets present a number of potential hazards, such as fire/explosion hazard of the flammable gas as well as the hazards connected with the vacuum vessel and cryogenic liquids (ODH and high pressure). The target system benefits from many years of experience using it at Jefferson Lab. Hazards, mitigation measures, and causes and corrective measures associated with past failures are described in the “Hydrogen Target Safety Assessment Document” at <https://polweb.jlab.org/hallc/Cryotarget/Target%20Safety%20Assessment%20Document1.5.doc>.

3.3.2 Mitigations

Flammable Gas Hydrogen and deuterium are colorless, odorless gases and hence not easily detected by human senses. Hydrogen air mixtures are flammable over a large range of relative concentrations from 4% to 75% H₂ by volume. Detonation can occur with very low energy input, less than 10% of that required by mixtures of air and gasoline. At temperatures above 23 K hydrogen gas is lighter than (STP) air and hence will rise. At atmospheric pressure, the ignition temperature is approximately 811 K but air-H₂ mixtures at pressures of 0.2 to 0.5 Atm can be ignited at temperatures as low as 610 K. Hydrogen mixtures burn with a colorless flame [19].

The total volume of hydrogen in the target is approximately 7 *l*. The volume changes between the liquid state and gas at STP by a factor of about 850. Thus filling the target would require about 6000 STP *l* of hydrogen. The hydrogen target is connected to a 1,000 Gallon (about 3,800 *l*) recovery tank. The normal running pressure for hydrogen is about 25 psia. Thus, the total amount of hydrogen in the system is about 14000 STP *l*. A similar volume of deuterium is required. In addition to this volume, two hydrogen bottles (in any combination of H₂ and D₂ may be kept in the Hall in order to fill and pump/purge the targets. These bottles will be placed in a gas rack behind the gas panels. The large storage tanks are located outside the Hall at the rear of the counting house.

The basic idea behind safe handling of any flammable or explosive gas is to eliminate oxygen (required for burning) and to prevent exposure to any energy source that could cause ignition. In the Hall C environment, the most likely source of oxygen is of course the atmosphere and the most likely ignition sources are from electrical equipment. Oxygen is removed from the internal volumes of the system by pumping and purging the system. Extensive procedures reviewed by an independent expert are used to perform this task. This task shall only be performed by system experts.

Electrical Installation Hall C contains a significant amount of electrical equipment and almost all of it could serve as an ignition source in the presence of an explosive oxygen and hydrogen mixture. Extensive efforts have been made to minimize the dangers from the equipment that is most likely to come into contact with hydrogen gas. Electrical equipment considered to be in close contact with hydrogen meets the requirements of NFPA 2 Hydrogen Technologies Code and/or NFPA 55 Compressed Gases and Cryogenic Fluids Code as well as NFPA 497. Equipment not meeting these Code requirements is isolated during off-normal events by either valve isolation (vacuum turbopumps) or by electrical power trip.

A combination of pressure switches, installed on the scattering chamber, will trip when the vacuum in the scattering chamber is greater than 0.1 and 1 Torr (i.e. during a loss of insulating vacuum event). These switches de-energize the following systems: vacuum gauge power, fan motor power, and heater power supplies. The switch also forces pneumatically actuated gate valves to close, isolating the turbo pumps. A Machine FSD is issued from the cold cathode gauge controller when the vacuum pressure exceeds 50 micro Torr.

There are a number of electrically powered devices associated with the target gas handling system. All the pressure transducers in the system are approved for use in a hydrogen atmosphere. The readouts for the pressure transducers are mounted in the target control equipment racks many meters from the gas panels. All the pressure transducers have 4–20 mA outputs.

In addition to the electrical devices in the gas handling system, there are a number of devices inside of or mounted on the scattering chamber.

All the devices which are in the scattering chamber must have their power delivered to them by wires in vacuum. The insulation of these wires must be radiation resistant, so Kapton and glass fiber tubing insulation has been used where applicable.

The following electrical items are in close proximity to or are actually in the hydrogen system.

Axial Circulation Fan The fans which circulate the hydrogen in the target are AC induction motors and therefore contain no brushes and are practically immune to sparking. The three phase (480 V) power for these fans is delivered to them by 18 gauge stranded copper wire with Kapton insulation. The maximum current that the fans draw is 5 A for a maximum power consumption of 200 W when pumping liquid hydrogen/deuterium. The current and voltage drawn by the fans is monitored by the control system.

Fan Motor Tachometer The fans have a tachometer which consists of a coil that views the flux change caused by a permanent magnet attached to the motor rotor. The tachometer signals are carried on 22 gauge stranded wire with Kapton insulation. This is a low power signal. The control system monitors the frequency of the fans.

High Power Heater There is a high-power heater in the pipe of the loop. The maximum power available is 1500 W (150 V, 10 A). The current and voltage supplied to this heater are monitored by the control system and there is a software power maximum enforced on the power setting of this heater. Internal vacuum connections to the heaters are made with 18 gauge stranded wire with Kapton insulation.

Resistive temperature sensors There are six resistive temperature sensors immersed in each target loop. These resistors provide temperature measurements of the target fluid. The temperature controllers that read them use a current of less than 30 μ A to excite them (they are excited with a constant voltage which for our resistors is on the order of 30 mV). The resistors are connected to the outside world with quad strand 36 gauge phosphor bronze wire with Formvar insulation.

Target Lifter An AC servo motor provides the power to lift the target ladder. This motor is powered by three phase 90 V power and is equipped with fail safe brakes (the brakes are **released** by a loss of 24 V DC control voltage) and 50 to 1 gear reducers. On power up, there is a delay relay that ensures that the motors are always energized before the brakes are released. The motor controller is powered by three phase 208 V and is located roughly 10 m from the target.

Vacuum Pumps The scattering chamber is evacuated by two Leybold 1000 *l/s* turbo pumps that are backed by a Leybold 65 *cfm* mechanical pump. The turbo pumps are powered by 120 *V* AC power while the backing pump requires three phase 208 *V* AC power. The turbo pumps are isolated during an insulating vacuum failure event by the use of automatic gate valves. The motors on the backing pumps are induction motors and approved for use in this environment. (The JLab fire protection engineer has reviewed this issue). An identical mechanical pump is used in the pump and purge system of the gas panels. Both the scattering chamber backing pump and the pump and purge system's mechanical pump exhaust to the vent line.

Vacuum Gauges The chamber vacuum is monitored by an HP cold cathode gauge. This gauge is not rated for hydrogen service and is therefore isolated from the scattering chamber vacuum during an insulating vacuum loss event by automatic gate valve. This gauge has a maximum operating voltage of 4000 *V* and a maximum current of 133 μ A. The pressure at the entrance to the roughing pump is measured by a convectron gauge.

Gas Handling System The most important aspect of hydrogen safety is to minimize the possibility of explosive mixtures of hydrogen and oxygen occurring. Therefore the gas handling system has been made of stainless steel components (wherever possible) and as many junctions as possible have been welded. Flanged connections are made with metal seals where possible. Reasonable measures have been implemented to ensure that the system pressure does not fall near or below atmospheric pressure.

The pressure in the gas handling system is monitored in numerous places. Most importantly, the absolute pressure of the target is viewed by two pressure transducers, one on the fill line, PT127 for H₂ and PT136 for D₂, and one on the return line, PT131 for H₂ and PT140 for D₂. These pressures are also measured by manual gauges. The fill line gauges are PI126 for H₂ and PI135 for D₂. The return line gauges are designated PI130, H₂ and PI139, D₂. The gas tanks are viewed with both pressure transducers (PT133 for hydrogen and PT142 for deuterium) and pressure gauges (PI123 for hydrogen and PI112 for deuterium).

If the pressures significantly deviate either from one another or from the normal operating pressure, the target operator shall call the target-expert-on-call. When they differ from one another, it often is due to a failure of one (or more) of the pressure transducers. If more than one deviates significantly from the normal operating pressure, it could be due to temperature change or could be a more serious situation (i.e. a leak in the system).

The target system is considered by JLab to be a pressure system which must be in compliance with the requirements of ESH&Q Manual Chapter 6151. This is a legacy system where the original design and construction was not in full compliance with the applicable ASME pressure Codes. A JLab Design Authority shall be responsible for all alterations and repairs to this system which shall meet the requirements given in Chapter

6151. All currently used cells and cell blocks also meet the requirements of ASME B31.3. Overpressure protection of all piping components is also in full compliance with ASME B31.3. The large volume storage tanks located outside the Hall also meet the requirements of the ASME Boiler and Pressure Code Section VIII Division 1 and bear a valid ASME nameplate. These tanks are inspected on a regular basis and currently meet the National Board NB-23 Code requirements. Overpressure protection of these vessels is in full compliance with the appropriate division and edition of the ASME BPVC VIII.

Target Cells The target cells themselves represent the most likely failure point in the hydrogen system. The outer wall is made of 0.006 *in* thick aluminum. The entrance and exit windows are thinner, but no less than 0.004 *in*. There is typically one 15 *cm* long cell bolted on to each cell block. The cell has an outer diameter of (typically) 3 inches. The upstream windows are connected to 0.8 *in* diameter tubes with flanges which are also bolted on to the cell block. A vertical flow diverter plays a role to make the coolant flow in the vertical direction to help remove the beam heating more effectively. The cell and cell block are piping components and have been designed, fabricated, examined, and tested in compliance with ASME B31.3 (2014). The design pressure of the current cell is 100 psi. Overpressure protection is in compliance with ASME B31.3 322.6.3 which allows for an accumulated overpressure of 120% of the design pressure.

Pressure Relief The gas handling and control systems have been designed to prevent excessive pressure build up in the system in order to protect the target cells from overpressure and rupture. It has been determined that the worst case pressure load will arise from an insulating vacuum loss. The calculation of this load was reviewed by a JLab Design Authority not associated with the target group. Under normal conditions, i.e. vacuum loss with unobstructed return path to storage vessel, the target safely relieves to the storage vessel. Overpressure protection, in the form of a reclosing ASME relief valve, for the target loops (including cells) in compliance with ASME B31.3 322.6.3 is provided on both the supply and return of each loop. These reliefs exhaust to a dedicated hydrogen exhaust system. The estimated relief load is 350 scfm of hydrogen. The capacity of each relief is 1100 scfm for hydrogen. The hydrogen exhaust line is 2 inch Sch 10s IPS stainless steel pipe by an end of line vent. This line is maintained at a positive pressure of 1.5 psig using the 4 atm He system. The scattering chamber and pump/purge vacuum pumps are also exhausted to this line. Thus any vented target gas is placed in an inert environment until it is released outside of Hall C.

The scattering chamber provides secondary containment in the event of a cell rupture. Therefore, the scattering chamber itself has a 1 psig relief (check valve), VRV01 and a 4 psig rupture disk. Thus, the scattering chamber internal pressure will not exceed 5 psig. This relief path is also exhausted to the hydrogen vent line. A series of valves and controls allow for the safe removal and exhaust of hydrogen from the scattering chamber should a cell burst.

Scattering Chamber Vacuum The scattering chamber will be leak checked before service, but the possibility of vacuum loss cannot be eliminated. A conservative calculation estimating the relief load on the relief system of each loop has been performed. This calculation was performed as part of Code and JLab policy requirements and was reviewed by an independent JLab Design Authority. This calculation (TGT-CALC-301-010) has been filed in the Hall C Cryotarget pressure system directory PS-TGT-XX-026. In summary, this calculation conservatively indicates that the relief path and safety devices limit the maximum developed pressure in the cell to less than the 120 psi for all credible overpressure conditions as required by ASME B31.3 322.6.3.

Temperature Regulation This is really more an issue of target stability than one of safety. However, a target with a carefully regulated temperature will presumably not undergo worrisome pressure changes.

Each target contains six quality temperature measurements with resistive (Cernox) temperature sensors. The temperature regulation is performed by a software PID control of a high power heater using one of the quality temperature measurements as input to the loop. This is a three parameter control loop (Proportional, Integral and Differential Control or PID). The PID loop also compensates for the beam heat load during beam trip and recovery incidents. This latter functionality is not a true regulation but rather a one-step replacement of the beam load should the beam disappear for whatever reason. The beam load is calculated from the target length, the beam current as read from a current monitor and the target material.

Excursions of the target temperature outside acceptable limits will cause alarms, and the target operator to take action. Finally the redundancy of temperature measurements can be used to pick up the failure of a sensor or its readout channel. A more complete discussion of target temperature regulation is available in Reference [20].

Target Freezing Solid hydrogen is more dense than the liquid phase, so freezing does not endanger the mechanical integrity of a closed system. The chief hazard is that relief routes out of the system will become clogged with hydrogen ice, making the behavior of the system during a warm-up unpredictable. For this reason, the relief route bypasses the heat exchanger and should not freeze during any credible scenario.

The coolant flow through the three target heat exchangers is connected in parallel for the three target loops. The entire target system will be operated so that it represents a stable heat load on the ESR. For instance, the ESR will deliver a constant mass flow of helium cryogen at a constant temperature of about 15 K (but more typically 14 K), and the coolant will be returned at an approximately constant but higher temperature, usually about 20 K. The targets are temperature regulated by IOC heater PID loop.

In the unlikely event that the target temperature drops too low, an alarm will sound and the target operator shall turn down the corresponding J-T valve(s) or apply auxiliary heater power. Target temperature can fall after target IOC reboot. After the reboot the high power heater will be reset to zero before going back to PID control. Although the time the high power heater is zero is short (for about 1 minute), the temperature will

drop. To prevent this from happening, an auxiliary heater is used in parallel to the regular heater. During an IOC reboot, the auxiliary heater supply will replace the main supply to keep the temperature from dropping unacceptably. Since 2008, the IOC has been relocated to the entry labyrinth where the radiation exposure has been minimized. As a result the frequency of IOC reboots has dramatically decreased.

ODH The total volume of the targets is relatively small, with the entire scattering chamber containing only 12000 STP l of target gas when all three targets are full. As the scattering chamber is located in the middle of Hall C (i.e. not in a confined area) and the total Hall C volume is 26,000 m³ (40,000 m³ for Hall A), the ODH hazard is minimal. In the event that all the H₂ was released into the hall, the oxygen content would drop from 21.0% to 20.99%.

Controls The target controls have been implemented with the EPICS [5] control system and with hardware very similar to that employed by the accelerator. The basic control functions reside on a VME based single board computer or IOC. The graphical interfaces to the control system use a PC, and also require a computer for control (HAC) to be present as well. Power failures will result in a loss of computer control. As a result of such a failure the target heat exchanger may freeze and the remainder of the target may vent through the relief path. The beam will also be tripped during such a failure. There is thus, little chance of damage or danger from the system. When a power failure occurs, the target operator shall call the target-on-call immediately.

The principal functions that the control system performs are:

Pressure/Temperature Monitoring The pressure and temperature are monitored at various places in the system and alarm states are generated if a sensor returns a value that is outside defined limits.

Target Lifter The target lifting mechanism is controlled by the computer. This allows one to place the desired target in the beam. Limit switches and hard stops are installed to ensure the target cannot move outside the allowable range.

Although strip charts are running on the target operator's work station, it can be useful to look further back in time when diagnosing potential problems, or simply answering the question "Is this normal?". To this end a simple-to-use archiver interface is provided to interrogate and plot target EPICS variables as a function of time at <https://hallcweb.jlab.org/targetlog/>.

3.3.3 Checklist

Checklist for pre-hall-closing:

- Target has completed cool-down, at least one loop has liquid hydrogen with temperature stable at 19K, pressure stable at around 25 psi.

- High power heater in PID control for the hydrogen loop.
- Loop fan (pump) has been set to non zero value (20-75 Hz) for the hydrogen loop.
- Coolant (ESR) flow and inlet temperature are stable.
- All unused loops are filled with over 1 atm gauge of helium gas.
- The target vent line is inerted.
- Scattering chamber vacuum is normal (below 10^{-5}).
- target in “Empty/HOME” position for beam tuning.
- Alarm handler is on and all alarm limits are set.
- No constant alarms caused by abnormal conditions.
- Target-on-call name is written on the whiteboard.
- Target EPICS variables are being archived.

3.3.4 Responsible Personnel

The principle contacts for the cryogenic targets were listed in table 3.2. Every shift must have a trained target operator whenever the cryogenic targets contain liquid. These operators are trained by one of the “experts” listed in the table and certified by J.P. Chen or Silviu Covrig. If the target operator suspects issues with the ESR are impacting the target, the target expert on call should be called first. The target expert may then recommend that the cryo expert on call be contacted through the MCC.

3.4 Target Chamber

The target scattering chamber, which is coupled to the beamline, is described section 2.6 in the Beamline chapter.

3.5 The Solid Target Ladder

The solid target ladder is hung directly below the cryotarget ladder, forming a single vertical column of cryogenic and solid targets. The solid targets are typically conductively cooled and rely on a good thermal connection to the cryotarget ladder which provides a 20 K thermal reservoir. A single vertical motion system with a 24 inch stroke is used to select which target is placed on the beam axis.

Like for the LH2 target, target motion is performed by the target operator using the main target control GUI in the Hall C counting room. He/she must coordinate this target

motion through the MCC, to insure the target motion is masked during the motion, and unmasked after the target has moved. The target operator should always make sure that the beam current and raster size for the target on the beam axis is within safe limits, as determined in advance and posted in the operational restrictions (see below). A couple different views of the solid target ladder are shown in 3.4.

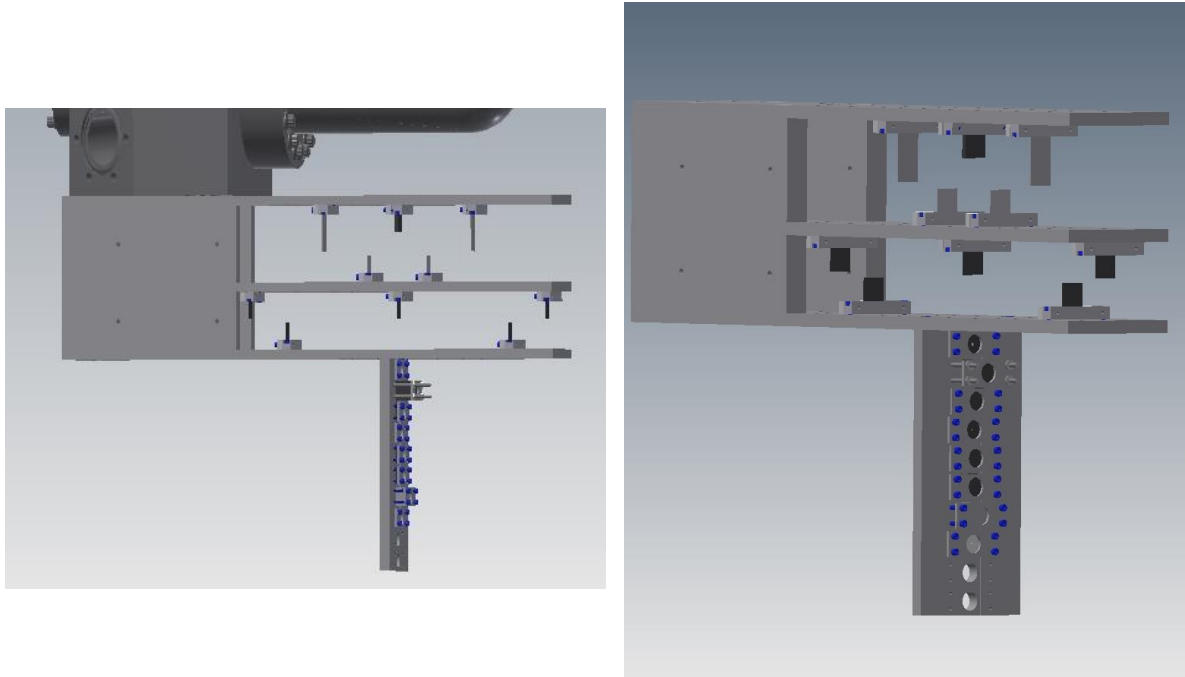


Figure 3.4: CAD views of the solid target ladder.

3.5.1 Default Targets

There are several different solid targets currently in use in the Hall C Scattering Chamber.

- **Optics Target:** This target is an array of carbon foils arranged at different Z locations along the beam axis. Since the cryotarget system generally includes a short (typically 4 cm long) and a long (typically 15 cm long) cryotarget cell, the usual configuration includes foils at ± 2 cm and ± 7.5 cm about $Z=0$ (the spectrometer pivot axis), as well as a target foil at $Z=0$. The resulting picket fence along Z (the beam axis) is useful for spectrometer optics calibration.
- **Dummies:** Dummy targets are also provided for subtraction of the aluminum cell window background associated with the cryotarget windows. The dummy targets are typically sized to provide the same radiation length as a full hydrogen cell of the same length. The target cell windows are typically each 0.005 *in* thick, and the dummy targets are typically about 1 mm thick. In terms of radiation length,

15 cm of LH2 is 1.7%. Add 2 aluminum cell windows each 0.1 mm thick (each 0.11%) for a total of 1.9%. Two 1 mm thick aluminum dummy targets amount to 2.2%, a reasonably good match in radiation length to the 15 cm target plus its cell windows.

A pair of aluminum dummy targets is provided at a single vertical target position for each target cell length included in the cryoloops. For example there will be a dummy target position with aluminum dummy targets at ± 7.5 cm about $Z=0$ (the spectrometer pivot axis and target center) to facilitate subtraction of the aluminum window background associated with the 15 cm long cryotarget.

- **Hole Target:** A carbon hole target is also usually provided on the solid target ladder at $Z=0$ to locate the beam. This target has a central hole usually 2 mm in diameter. By rastering the beam in a pattern at least 2×2 mm², and using the spectrometer as a trigger to detect electrons that miss the hole, an image can be constructed from the X & Y raster magnet currents showing the relative location and width of the rastered beam pattern with respect to the hole.
- **Viewer:** A BeO target at $Z=0$ is also a useful diagnostic to check the beam location. The BeO scintillates even at low beam current. By viewing the target with a TV camera in the counting room, it's easy to see where the beam is.
- **Carbon:** A general purpose C target capable of handling high beam current is also usually on the ladder at $Z=0$ for other assorted diagnostics.
- **Empty:** An empty target position at $Z=0$ consists of the same frame used to hold the other targets, but without these other targets. It's used to see how much beam halo is intercepted by the frame.
- **Home, aka Target Out:** In the "Home" target position the target motion system is fully retracted to the upper limit switch. In this position the beam scoots well underneath the lowest target on the solid target ladder. This position is chosen for Moller runs and for beam tuning, when the beam position and/or width is not well determined.
- **Other:** Different experiments may require other nuclear targets. In the past targets of Li, Be, BeO, C, Al, Ca, Fe, Cu, W, Au, Pb, and others have been employed, but not all at once. The vertical motion of the target motion system has a limited (24 in) range, and solid target choices have to be traded off against the number of cryotarget loops (1-3, typically 3), and the number of cells per loop (1-2, typically 2).

3.5.2 Safety Considerations

Operational restrictions on the maximum beam current and minimum raster size have to be set in advance for each target by a target expert on the Hall C staff. The target operator and the staff at MCC are supposed to look at this page (<http://opweb.acc.jlab>).

org/internal/ops/ops_webpage/restrictions/ops_restrictions.html) to insure the targets don't receive more beam current or power density than they can safely handle.

The main safety issue concerning the non-special targets is that they will be radioactive ("hot") after they have been exposed to the JLab beam for an experiment. Targets may not be removed from the target chamber or transported from the Hall without concurrence by the RCG. An SRWP specifies the requirements for target removal and/or transport. Targets which have been surveyed and released by the RCG will be stored in the Radiologically Controlled Area (RCA) of the Target Group in the EEL building.

3.5.3 Special Targets

Some solid targets require special attention. One category will oxidize when exposed to air, resulting in a large oxygen content in the target. Calcium should always be stored in an argon-filled or evacuated container, or in an oil solution. Calcium can be handled in air for a limited amount of time (a few hours) if handled with a layer of oil. The same considerations apply to Lithium.

Other special targets may pose a safety concern, namely ceramic Beryllium-Oxide (BeO) and Beryllium (Be). In solid form, BeO is completely safe under normal conditions of use. The product can be safely handled with bare hands. However, in powder form all Beryllia is **toxic** when airborne. Overexposure to airborne Beryllium particulate may cause a serious and sometimes fatal lung disease called Chronic Berylliosis. Beryllium has also been listed as a potential cancer hazard. Furthermore exposure to Beryllium may aggravate medical conditions related to airway systems (such as asthma, chronic bronchitis, etc.). Since beryllia are mainly dangerous in powdered form, do not machine, break, or scratch these products. Machining of the Beryllia can only be performed after consulting the EH&S staff. It is good practice to wash your hands after handling the ceramic BeO. If handling the pure Beryllium target or the Beryllium windows, wear gloves and an air filter mask. Beryllium targets and windows are stored in approved storage locations (either in Hall C or in the Target RCA) with labels identifying the contents as Beryllium.

In the past water or helium cooled copper radiators have been used to generate photons upstream of the physics target. This is not part of the standard target configuration and therefore not part of this COO.

3.5.4 Storage

The targets are stored in the target group's RCA in the EEL building. Targets may not be removed from the target chamber or transported from the hall without concurrence by the RCG.

Chapter 4

Hall C Spectrometers

The two magnetic spectrometers in Hall C are designed to perform high resolution and high accuracy nuclear physics experiments. These spectrometers transport and detect charged particles that are scattered or produced in beam-target interactions. In this chapter we discuss the features and safe operation of these spectrometers, the High Momentum Spectrometer, or HMS, and Super High Momentum Spectrometer, or SHMS. These spectrometers share many common features. After this introduction and overviews of the individual spectrometers, the spectrometers are discussed together as a series of subsystems. This chapter covers the “mechanical” subsystems of the spectrometers. This chapter covers the “mechanical” subsystems of the spectrometers. The detector packages and shield houses are discussed in Chapter 5.

Both the HMS and the SHMS are designed around a series of superconducting magnets, including quadrupoles and dipoles, followed by a set of particle detectors. The first magnet on the SHMS is a horizontal-bending (HB) dipole that bends particles away from the beam-line. The HMS does not have a horizontal bender. The primary purpose of the quadrupole magnets is to increase the flux of charged particles entering the main dipole magnets and to focus the orbits of the charged particles into the detector huts. The dipole magnets deflect charged particles vertically as they enter the detector huts. Some of the detectors measure the amount of deflection so that we may determine the momentum of each particle. Other detectors provide accurate timing to trigger the readout of all detector data, or they measure a particle’s speed or total energy so that we can determine its mass.

Each spectrometer is built on a rotatable support structure or “carriage”. These ride on steel wheels and rails and rotate around the pivot. Experiments using the HMS or SHMS place their experimental targets along the beamline above the pivot. The support structures carry the weight of the magnets and detectors, and keep them aligned to one-another and pointed at the target. On the SHMS, the shield house and all of the other spectrometer equipment are also carried by the support structure. The HMS has a separate carriage that supports the weight of the shield house.

During beam operations a many particles are scattered and produced in the target. A few of these enter one of the spectrometers. Most of them go forward at small angles

and are stopped in the beam dump. The remainder, scattered over a wide range of angles, interact with the beam pipe, the air, nearby structures, etc., and constitute background radiation that would overwhelm the detectors. The shield houses have thick walls that are designed to reduce the amount of radiation that gets inside. Both spectrometers use concrete and lead lining on the walls as shielding. On the SHMS, two custom types of concrete improve the neutron stopping power of the walls by adding boron (in the form of boron-carbide) or extra hydrogen (recycled plastic chips). Each shield house has a room that surrounds the detectors. The SHMS has a second room, shielded from the first, that protects the electronics of the DAQ system and the magnet control systems.

4.1 High Momentum Spectrometer (HMS)

The HMS, which operates on the beam-right side of the beamline, includes three superconducting quadrupole magnets and one superconducting dipole magnet. The quadrupoles were manufactured for JLab by *OXFORD* while the dipole was built for JLab by *ELIN*. The quadrupole magnets are referred to as Q1, Q2, and Q3, where a particle first traverses Q1, then Q2 and Q3, and finally traverses the dipole magnet. The dipole of the HMS deflects central-momentum particle trajectories upwards by 25° .

The magnet system is followed by a large concrete detector hut, in which all detector elements reside. The main fraction of the detector elements have been built by universities involved in the Hall C physics program. These detectors are described in chapter 5.

The HMS spectrometer can be moved to scattering angles between 10.5° and 90° . This range is usually constrained by administrative, software and hardware limits depending on what downstream beam pipe is installed and what obstructions are currently in the hall. The maximum momentum accessible to the HMS magnet system is presently $6 \text{ GeV}/c$. This limit is expected to increase once the HMS dipole has been certified for use at higher momenta during the 12 GeV era.

4.2 The Super High Momentum Spectrometer (SHMS)

The Super High Momentum Spectrometer (SHMS) operates on the beam-left side of the beamline, and can be rotated around the pivot for scattering angles from 5.5 to 40 degrees. It was built between 2009 and 2016 as the major Hall-C component of the 12-GeV Upgrade Project. The five superconducting magnets on the SHMS can be set for a central-ray momentum of up to $11 \text{ GeV}/c$. The minimum design momentum is $2 \text{ GeV}/c$. A CAD model of the SHMS is shown in Fig. 4.1, and Table 4.1 lists the performance specifications.

The primary magnetic elements on the SHMS, the Q1, Q2, Q3, and Dipole magnets, provide point-to-point focusing and momentum dispersion just like the four magnets with the same names on the HMS. The dipole of the SHMS bends central-momentum particles trajectories up by 18.2° . The SHMS Q1 was manufactured by Scientific Magnetics, Inc.

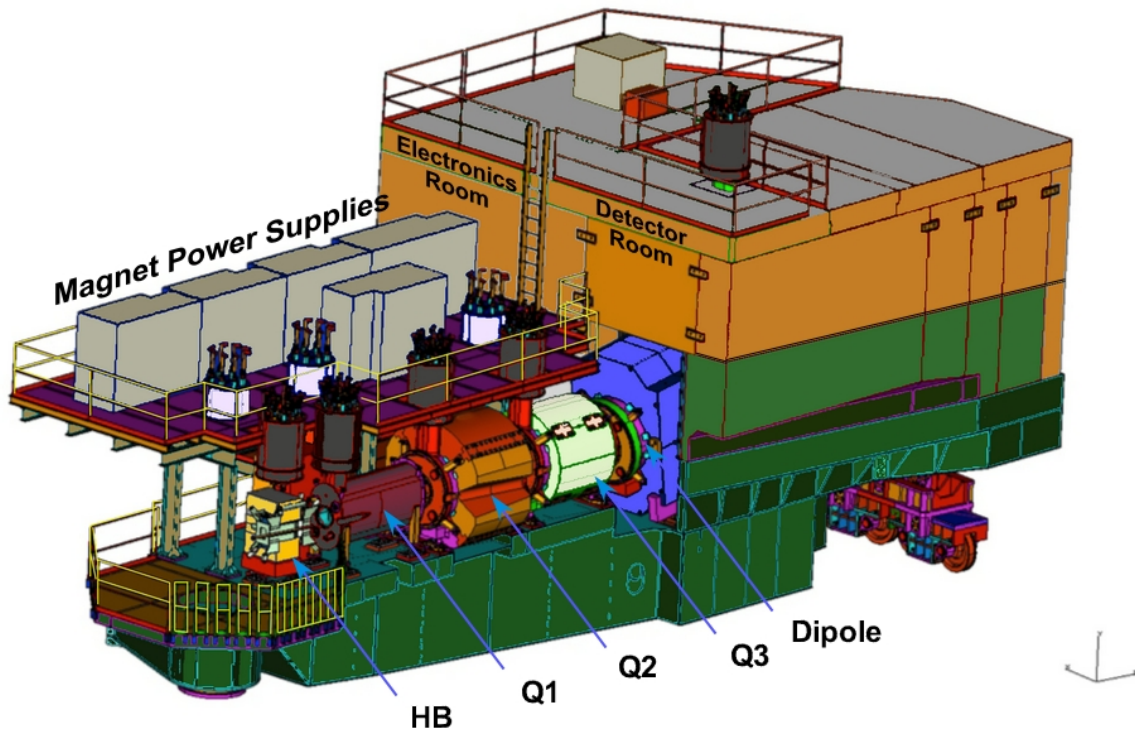


Figure 4.1: CAD Rendering of the Super-High-Momentum Spectrometer.

Table 4.1: SHMS Design Parameters

Parameter	SHMS Design
Range of Central Momentum	2 to 11 GeV/c for all angles
Momentum Acceptance δ	-10% to +22%
Scattering Angle Range	5.5 to 40 degrees
Solid Angle Acceptance	> 4.0 millisterradians
Horizontal Angle Resolution	0.5 - 1.2 mrad
Vertical Angle Resolution	0.3 - 1.1 mrad
Vertex Length Resolution	0.1 - 0.3 cm
Tracking Rate Capability	5 MHz
Beam Capability	Up to 90 μ A

in Abingdon, England. Q2, Q3, and the Dipole were constructed by Sigmaphi in Vannes, France.

In order to reach the smallest scattering angles, the SHMS has a horizontally-bending dipole magnet as its first magnetic element. Referred to as “HB”, it was built by FRIB, the Department of Energy facility at Michigan State University. This small, high-field magnet bends central-momentum particles to the left by 3 degrees so that the remainder of the spectrometer parts will be further away from the primary electron beam. The HB magnet is an asymmetric “C”-dipole which has a flux-return iron yoke only on the side away from the primary beam. When the SHMS is set for small scattering angles, the electron beam passes very close to the spectrometer and to the HB magnet’s superconducting coils. In this configuration the coils see a high radiation dose [21] which may cause them to have a limited lifetime. Experiments must be planned in such a way that this exposure is minimized.

A further consequence of making the SHMS operate at small scattering angles is that the iron yokes of the HB and Q2 magnets had to be designed with notches that just clear the beamline vacuum pipe. The fringe fields from these magnets can deflect the primary electron beam away from the middle of the beam dump. The effects of this field must be mitigated by a combination of good experiment planning, magnetic shielding, and automatic safety systems.

The SHMS shield house has two rooms. The dipole magnet penetrates the front wall of the room containing the detectors. Inside this are the two sets of 6-plane drift chambers, the Heavy-Gas Cherenkov (HGC), the two pairs of trigger hodoscopes (S1X/S1Y and S2X/Q2Y), and the Preshower and Shower Counters (calorimeters). The SHMS focal plane forms an angle of about 5 degrees with respect to the central trajectory, and intersects that trajectory at a point midway between the two drift chamber boxes. Additional particle-identification detectors (Noble-Gas Cherenkov (NGC), and/or Aerogel Cherenkov) may also be installed if needed by the current experiment. When the NGC is not in use it may be replaced by a tank that extends the vacuum system up to a window just in front of the first drift chamber. In this configuration, a mechanical safety shutter must be closed over this large vacuum window before personnel may enter the room.

The second room in the SHMS shield house houses the electronics controlling the magnet power supplies, the data-acquisition electronics (DAQ) and power supplies for the detectors, and the VESDA smoke and flammable gas sensor systems. When personnel enter the shield house they first pass into this ”Electronics Room”.

4.3 Safety Information

4.3.1 Hazards

The spectrometers have associated vacuum, electrical, cryogenic and magnet systems all of which can be extremely dangerous due to the size and stored energy in the systems. Parts of the spectrometers are at elevated levels which would present fall hazards if the installed safety equipment were not present. Hazards of rotating the spectrometers as

well as the particle detectors that get placed inside the detector hut of the spectrometer are covered in detail in following sections.

Signage and alerts are placed to remind workers of some of the potential hazards in Hall C, but each individual is ultimately responsible for his or her own safety. Always read and respect warning signs, and never attempt to circumvent barriers or other equipment that has been installed for your protection. If you discover what appears to be a new or unidentified hazard, protect your coworkers by warning them and alert the Hall-C management and Safety Warden.

4.3.2 Mitigations

Both of the spectrometers have elevated work platforms that are secured by gates and handrails. Never attempt to bypass these protections. During experiment running periods, in order to allow spectrometer rotation, it may be necessary to remove the handrails around the target platform. In this condition access to the target platform is restricted to trained individuals who have been specifically authorized to work near there. Fall-protection equipment is required.

The vacuum systems associated with the spectrometers are essentially pressure vessels and care should be exercised so as not to damage or puncture the vacuum windows. The large vacuum windows inside the two shield houses are protected by shutters which must be lowered into place before the access door to the detector rooms will open. (When the Noble-Gas Cherenkov (NGC) is installed in the SHMS, the NGC itself protects the vacuum window and the shutter is not present.) During hall maintenance, covers are placed over the spectrometer vacuum windows near the pivot to help prevent anything from accidentally hitting a window. Hearing protection may be required when you work near a vulnerable vacuum window. As conditions may change, please take note of currently posted warning signs and instructions.

The magnets themselves are installed inside cryostats. These vessels are exposed to high pressures and are therefore equipped with safety relief valves and burst discs.

The cryogenic system operates at an elevated pressure and at temperatures about 4 Kelvin (helium system) and about 90 Kelvin (nitrogen system). One must guard against cold burns and take the normal precautions with pressure vessels when operating or working near this system. Manipulation of any cryogenic system component such as a U-Tube or manual valve may only be performed by a trained cryogenic-system expert.

When they are powered, the magnets have a great deal of stored energy as they are large inductors. (See Table 4.5.) Always make sure people are clear of the magnets and their dump resistors.

4.3.3 Responsible Personnel

In the event that problems arise during operation of the spectrometers, qualified personnel should be notified (see Table 4.2). This includes any prolonged or serious problem with the source of magnet cryogenics (the ESR). (See also “Checking Cryogenics” in Section

4.5.4, below.) On weekends and after hours there will be a designated individual on call for magnet services. Any member of the Hall C technical staff is qualified to deal with unusual magnet situations but in the event of serious problems the person on call should be contacted.

Name (first,last)	Dept.	Call [12]		e-mail	Comment
		Office	Cell		
Tech-on-Call	Hall-C	W.B.			<i>Contact</i>
Steve Lassiter	Hall-C	7129	252-340-1845	lassiter@jlab.org	
Joe Beaufait	Hall-A/C	7131	757-256-2776	beaufait@jlab.org	
Heidi Fansler	Hall-A	6915	Web [13]	fansler@jlab.org	

Table 4.2: List of spectrometer responsible personnel where “W.B.” stands for the white board in the counting house.

4.4 Features Common to Both Spectrometers

4.4.1 Vacuum Windows

Because multiple scattering degrades the performance of a spectrometer, it is important that the spectrometer volume be evacuated and that the vacuum entrance and exit windows be as low mass as possible. However, catastrophic window failure would generate a significant shock wave as air rushed to fill the vacuum volume. It would also cause a loud noise which could cause hearing damage to anyone in the immediate vicinity. The material chosen for the vacuum windows, then, must be both light enough to have a minimum effect on the beam and strong enough to operate reliably and safely.

One of the responsible personnel must be present for any work directly affecting any Hall C vacuum window. Refer to Table 4.3.

Thin metal windows have an indefinite lifetime and cause multiple scattering which is small compared to the intrinsic resolution of the Hall-C spectrometers. Both the HMS and the SHMS are now equipped with metal windows, as detailed in Table 4.4.

Name (first,last)	Dept.	Call [12]		e-mail	Comment
		Office	Cell		
Tech-on-Call	Hall-C	W.B.			<i>Contact</i>
Walter Kellner	Hall-C	5512	757-592-1527	kellner@jlab.org	

Table 4.3: List of Spectrometer Vacuum responsible personnel where “W.B.” stands for the white board in the counting house.

Table 4.4: Vacuum Windows in Hall C

Window Location	Dimensions (mm)	Material	Thickness (mm)
Scattering Chamber Exit	Very Wide	Al	0.406
HMS Entrance on Snout	254 (dia)	Al	0.508
HMS Exit	1016 (dia)	Al	0.508
SHMS Entrance on HB Magnet	180(<i>w</i>) × 220(<i>h</i>)	Al	0.508
SHMS Dipole Exit	692 (dia)	Al	0.508
SHMS Exit from Vacuum Extension	692 (dia)	Al	0.508

4.4.1.1 HMS Windows

The entrance window to the HMS vacuum channel is on the end of the snout which extends from the HMS Q1 magnet towards the target. The vacuum channel has a volume of approximately 6 m^3 , representing a stored energy of 6×10^5 Joules. A drawing of the flange to which the exit vacuum window is attached is shown in Figure 4.2. The window is a circle that covers the 38 inch diameter opening and has bolt holes for clamping it in place along a 40 inch center-to-center diameter. This is the largest vacuum window in Hall C. Under vacuum, it must support 16,785 lbs (74,425 N). It is located in the HMS detector hut as shown in Fig. 4.3.

To protect this window from damage, and for the safety of people working in the HMS shield house, an aluminum shutter plate must be lowered to cover the HMS exit window whenever it is under vacuum and the door to the detector hut is open. A system of interlocks assures that these conditions are met. The shutter control panel is just outside the shielding house door, and an indicator light signals whether the shutter is in or out. The shutter must be closed before the shield house door may be opened. *Note that the shutter needs to be open when data is being taken by the HMS, and the shutter may be opened only after the shield door is closed.*

4.4.1.2 SHMS Windows

The SHMS entrance window is on the front of the HB magnet. It has a rectangular shape. The SHMS exit window is inside the Shield House detector room. It is mounted on the downstream end of the SHMS dipole when the Noble Gas Cherenkov (NGC) is in use. Otherwise, it is mounted on the vacuum extension tank. These two locations are indicated in Fig. 4.4. Drawings of the window and its flanges are shown in Fig. 4.5. When in use the NGC provides protection for the vacuum window. When the window is placed on the end of the vacuum extension tank, however, it must be protected by a roll-down shutter that is interlocked with the detector-room door: if the door is open the shutter must be down, protecting the window. Just like the HMS, *the shutter needs to be open when data is being taken by the SHMS, and the shutter may be opened only after the shield door is closed.* The SHMS shutter controls are to be located near the “barn door” separating the SHMS detector shield house from the SHMS electronics shield house and

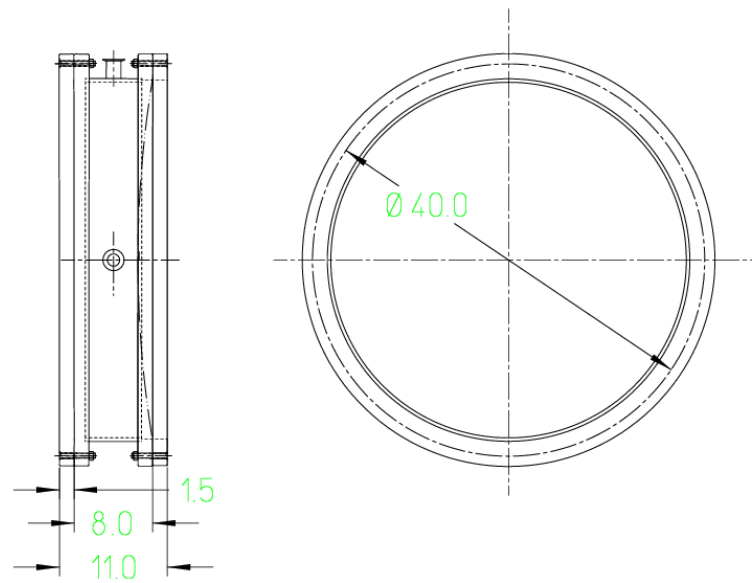


Figure 4.2: The HMS Exit Window Flange and Vacuum Spool Piece. The opening covered by the window is 38 inches in diameter.

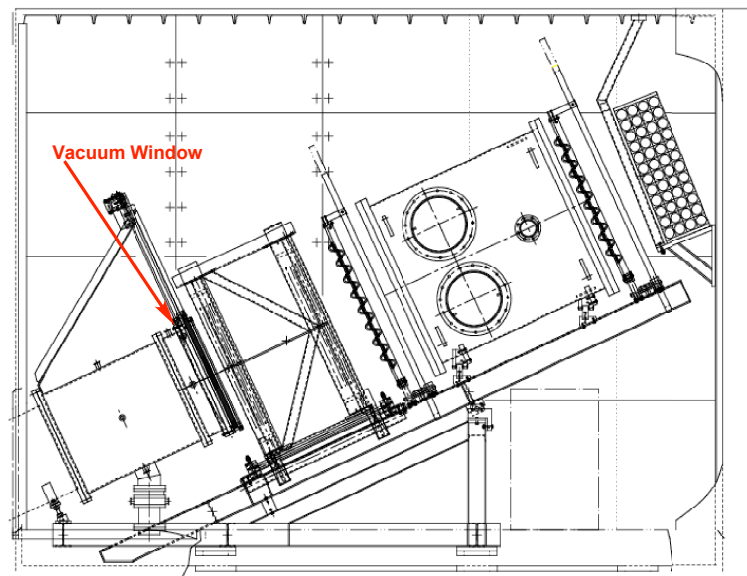


Figure 4.3: The HMS vacuum window in the HMS spectrometer hut.

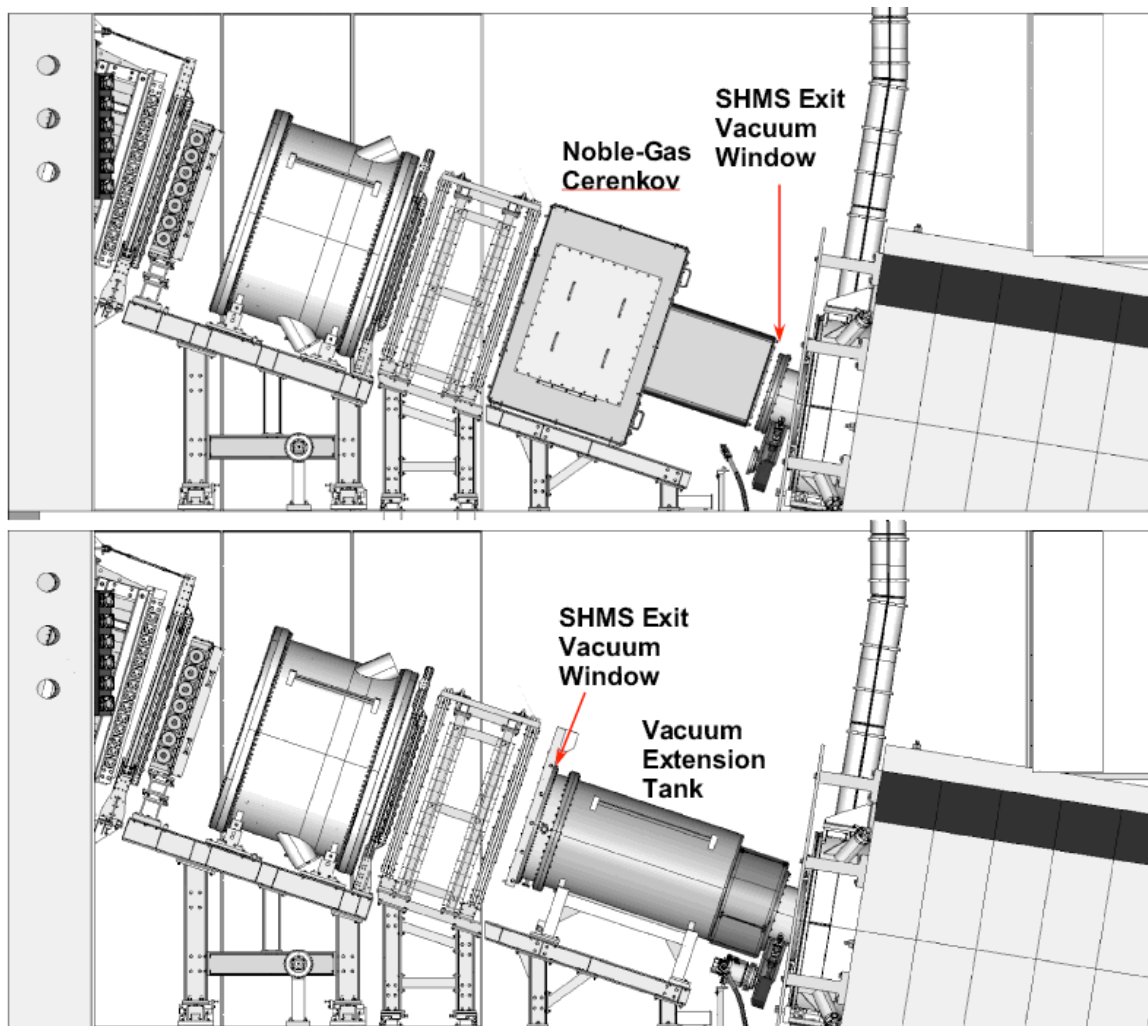


Figure 4.4: The two possible locations of the SHMS Exit Vacuum Window

are described in section 4.4.1.2.

4.5 Hall C Spectrometer Magnets

The basic parameters describing the magnets of the HMS and SHMS are provided in Table 4.5.

The quadrupoles determine the focusing properties of the spectrometers and to a large extent their acceptance. To achieve the lowest possible scattering-angle settings for each spectrometer, both Q1's are made asymmetric: narrow horizontally and elongated in the vertical direction. For the same reason a notch is present in the outer mantles of both Q1 vacuum cans so that the incident electron beam passes through this notch when the spectrometer is at its smallest angle (12.5° for HMS and 5.5° on the SHMS).

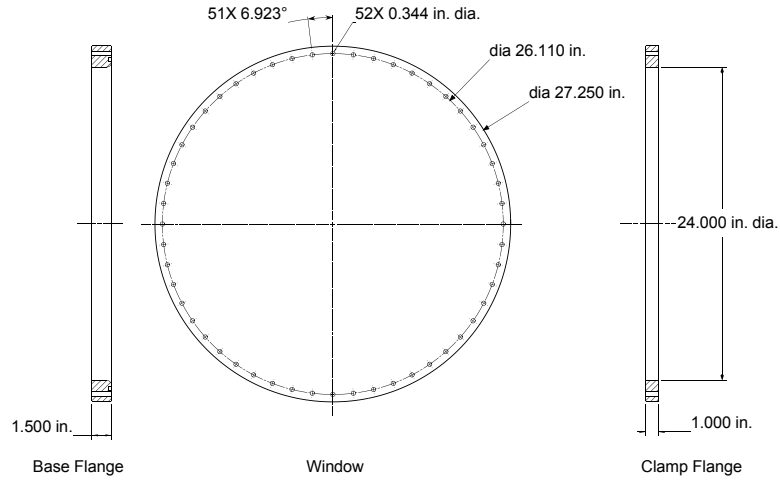


Figure 4.5: The SHMS Exit Vacuum Window and Flange.

Table 4.5: Characteristics of the SHMS Magnets

		Eff. Len. (m)	Aperture (cm)	Values at Maximum Momentum			
				Mom. (GeV/c).	Current (A)	Field or Gradient	Energy (MJ)
HMS Q1	Cold Iron	1.89	ϕ 40	7.4	980		0.23
HMS Q2	Cold Iron	2.10	ϕ 60	7.4	830		0.81
HMS Q3	Cold Iron	2.10	ϕ 60	7.4	370		0.16
HMS D	Wam Iron	5.26	42(<i>w</i>)	7.4	3000	2.03 T	9.9
SHMS HB	“C” Septum	0.752	14.5 × 18	11	3930	2.56 T	0.2
SHMS Q1	Cold Fe	1.86	ϕ 40	11	2455	7.9 T/m	0.39
SHMS Q2	$\cos(2\theta)$	1.64	ϕ 60	11	3630	11.8 T/m	7.6
SHMS Q3	$\cos(2\theta)$	1.64	ϕ 60	11	2480	7.9 T/m	3.4
SHMS D	$\cos(\theta)$	2.85	ϕ 60	11	3270	3.9 T	13.7

In order to reach such a small scattering angle, the SHMS is equipped with the HB (horizontal bend) dipole magnet. It bends the central-ray tracks 3° away from the beamline so that the remainder of the spectrometer components are aligned 8.5° from the beam when the spectrometer is rotated to center on a 5.5° scattering angle. When used at scattering angles below about 12° , the stray magnetic fields from the SHMS HB, Q1, and Q2 magnets can deflect the primary electron beam, possibly causing it to miss the beam dump, unless the schemes designed to prevent this are followed.

The main dipole is the dispersive element in each spectrometer system. It determines the central momentum of the spectrometer.

4.5.1 Magnet Cryogenics

The HMS and SHMS magnets are all superconducting and hence their coils must be maintained at cryogenic temperatures during operations. The LHe required by the magnets is supplied by the End Station Refrigerator, ESR. All of the spectrometer cryogenic services are supplied through the overhead cryogenic lines. The distribution network begins at the distribution box over the pivot. This box is connected to the HMS and SHMS networks via the flexible transfer lines over the pivot. The network is adjacent to the upstairs catwalk on the HMS and, on the SHMS, is along the small-angle side of the upper platform.

Cryogenic information about each magnet is available on the control screens located in the Hall C counting house.

All of the magnets were originally designed to be cryostable, meaning that they cannot quench unless the level of liquid helium drops below the coils. Testing of the HMS magnets up to 4 GeV/c settings has shown that this design goal was achieved. Nevertheless, the energy stored in the field of each magnet is sufficient to cause an unrecoverable quench if all of it were dumped into the magnet. Therefore, every superconducting spectrometer magnet in Hall C, even though cryostable, is protected by a quench protection circuit. This circuit safely dissipates much of the magnetic-field energy in a high-power dump resistor. The SHMS magnets have not received extensive cryostability testing yet.

4.5.2 Magnet Power Supplies

The power supplies for the magnets are located on the carriage adjacent to the magnets. The supplies are all water cooled and the water flow rate to the supplies can be seen on the water flow meter located near the electronics boxes on the floor near the pivot. This meter views the flow for all the HMS power supplies (dipole and quads) and a reading of 33 % corresponds to approximately 20 gallons per minute through the combination of supplies (they are supplied in parallel). As of writing, the total flow rate for the SHMS power supplies has not been measured. When it is measured, the nominal value will be available in the Hall-C electronic log book and the manual you are reading will be updated.

The front panels of the power supplies are interlocked. Under no circumstances should the front panel of any supply be opened by anyone other than authorized personnel.

When the supplies are energized there are flashing red lights and illuminated "Magnet On" signs placed at several locations on the HMS and SHMS carriages to alert personnel to the magnet status. There are also signs posted listing the dangers of high magnetic fields.

The control interfaces for the power supplies are available in the Hall C counting house on the HMS and SHMS control screens. Experimenters use these screens to control the magnet power supplies. The magnet experts will sometimes use controls that are local to the power supplies.

4.5.3 Magnet Personnel

In the event that any problems arise during operations of the magnets of either the HMS or the SHMS, one of the qualified responsible personnel listed in Table 4.2 should be consulted. This includes any prolonged or serious problem with the source of magnet cryogenics (the ESR). On the weekend and after hours there will be a designated individual on call for magnet services. This person should be contacted first.

4.5.4 Operation of the Spectrometer Magnets

HMS and SHMS magnet controls have been extensively revised. See section 4.9 for instructions. The controls and monitoring screens are accessed through a GUI/HMI that magnet system experts will have initialized in the Counting Room.

The information immediately following is being temporarily retained and is likely covered in more detail elsewhere.

4.5.4.1 Setting Magnet Currents

The polarities of the currents in the HMS and SHMS magnets are such that HB, Q2 and DIPOLE have the same sign as the charge of the particles to be transmitted. Q1 and Q3 have the other sign. If you use the “standard tune” setting on the controls GUI this will be handled for you automatically.

While in the past users of Hall C had to run a program called “field” to obtain the predicted current or field settings for a given spectrometer momentum, these parameters are now determined for you by the controls program. You need only to enter the desired momentum in the GUI.

One thing has not changed:

- Wait at least 7 minutes for the HMS dipole magnet to settle.

Up to this moment we have not witnessed any clear signature of hysteresis effects for the HMS dipole magnet. For the HMS quadrupole magnets a small effect on the field has been witnessed, but only for low currents (typically smaller than 100 A). A procedure for setting the quadrupoles was developed and shown to achieve a high degree of reproducibility in setting the quads at low current.

The HMS Quadrupole Cycling Procedure:

1. On every change of polarity, take the magnet up to 950 Amps (in the new polarity!), then down to zero before setting the current.
2. To set the current the first time after a polarity change go up to 200 Amps higher than the desired current, then down to the desired current.

This means: to change the polarity and set the current go to 950 Amps, down to zero, back up to 950 Amps, and down to the desired setting.

3. Subsequently:

- Changes to lower currents can be made directly. That is, just set the magnet for the lower current.
- For changes to higher current, first overshoot by 200 Amps, then come back down to the desired current.

This procedure is called **CYCLING THE MAGNET**, and needs to be followed for all three HMS quadrupoles.

Commissioning of the SHMS magnets with beam has not occurred as this is written, although it is expected that only SHMS Q1 might need to be cycled. The other SHMS magnets have current-dominated fields (rather than iron-dominated) and are not expected to exhibit significant hysteresis effects. Cycling procedures, if needed, will be established by the Physics Division Liaison in consultation with the engineering group and collaborators.

4.5.4.2 Checking Cryogenics

1 Routine checking

The HMS and SHMS magnets all operate with liquid-level controlled reservoirs. It is therefore sufficient to verify that the liquid level is near the set point to be assured of cryogenic happiness.

The setpoints are all 70%. The liquid level is normally within a few percent of this value. If the helium level is significantly above this the helium reservoirs are overfilling. This is not harmful and the levels will return to normal in several hours. If the level is significantly below the set points (5% or more) there is usually something wrong. Selecting a time graph of liquid level is helpful in determining if the situation is a temporary fluctuation or if the situation is serious.

2 Helium Problem Resolution

If helium liquid level is observed falling, check the cryogen status of all nine magnet systems. If multiple systems are losing liquid helium, call CHL x7405 as the likely cause is a site wide problem. CHL will advise if recovery is short (1-2 hours) or much longer. If the recovery is short do nothing! If the recovery is long then it can be beneficial to make some adjustments in Hall C. This requires an access and a knowledgeable individual: the on-call Hall C magnet responsible person should be summoned. Refer to Table 4.6.

3 Single System Failures

3.1 Single System Loss of LN₂

If a single system is observed losing LN₂ you can wait until the next day to call someone in as the LN₂ usage of all the magnets is extremely low. They can go for 24 hours without a refill. Remember that the HB magnet on the SHMS uses no LN₂, so do not let that confuse you.

3.2 Single System Loss of LHE Level

This is usually caused by a single computer failure or components failure. Call the on-call magnet responsible person (Table 4.6) and plan an access to Hall C. The dipole reservoir will go empty in 1 hour so a quick reaction is necessary. The quads take much longer, 4 hours or more to empty allowing more time to react. All of the magnets have low level interlocks that will automatically safely discharge the magnets so that you can safely operate until they are “dry.”

4 Temporary Loss of LN₂ To All Systems

Occasionally during site LN₂ delivery, the supply to Hall C is temporarily stopped. This can be checked by calling ESR Cryo Coordinator (see Table 4.6). There can be local Hall C problems that result in loss of LN₂ to the magnets. The “call in” can be deferred to a convenient time for this kind of problem.

Name (first,last)	Dept.	Call [12]		e-mail	Comment
		Office	Cell		
Engineer-on-Call	Hall-C	W.B.			
Steve Lassiter	Hall-C	7129	252-340-1845	lassiter@jlab.org	Cryo Expert via Guard Shack
Cryo-on-Call		5822			
David Schleeper	JLab		757-771-4491	davids@jlab.org	ESR Cryo Co- ordinator
Joe Wilson	JLab	7722	757-329-7576	jwilson@jlab.org	Cryo Opera- tions

Table 4.6: In case magnet cryogenic issues, contact the Hall C engineer on call and the cryogenic group if necessary. To contact the cryogenic group during working hours, try David Schleeper, Joe Wilson, or the guard shack. Outside of working hours, contact the guard shack at x5822 and ask for a call back from the on call cryo engineer.

4.6 Spectrometer Vacuum Systems

Each spectrometer contains several separate vacuum volumes. These are the isolation vacuums of each of the superconducting magnets and the main spectrometer volumes through which the particles to be detected travel.

The isolation vacuums are normally cryo-pumped by the cold mass when the magnets are cold and hence have no mechanical pumps associated with their maintenance. They also have no thin windows or other hazards and will not be discussed further in this document.

The main spectrometer vacuum of the HMS is maintained by the two mechanical pumps. One pump is located between Q3 and the Dipole on the small angle side of the carriage while the second pump is the backing pump of the turbo. It pumps the spectrometer volume through the turbo. This mechanical pump is located at the back of the carriage and the turbo is located in the shield house underneath the end of the vacuum can that protrudes into the detector hut. The vacuum in the HMS channel may be read out on a gauge that is sitting on the carriage beneath Q3. There is a TV camera that views this gauge readout and it is displayed on one of the TV monitors in the Hall C counting house.

A similar installation creates the vacuum in the SHMS channel. The mechanical pump sits on the beamline-side of the SHMS carriage below the upstream end of the dipole magnet. It is connected to the vacuum channel through a port on the bottom of the plenum on the downstream end of the dipole, inside the shield house. The vacuum level is monitored by the readout included on the SHMS controls GUI.

If either spectrometer vacuum starts to deteriorate rapidly an expert should be notified. Vacuum system responsible personnel are listed in Table 4.3.

4.7 Spectrometer Slit Systems

4.7.1 HMS

The HMS slit system is installed on the gate valve housing mounted to the front face of Q1. It consists of a vacuum box with a slit ladder mounted into it. The slit ladder has space for three separate slits, which will typically be one sieve slit and two solid angle defining collimators. The slits are rectangular blocks of densimet (90% W and 10% Cu/Ni) with a density of 17 g/cm³. The collimators have an octagonal shaped opening machined into them; the sieve slit has many holes drilled into it.

The outer size of the collimators is 11.75" vertical by 8.25" horizontal. The outer size of the sieve slit is 10.00" vertical by 8.25" horizontal. Its vertical size is reduced w.r.t. 11.75" due to space constraints. The sieve slit always has to be installed at the bottom position of the ladder, so that we can use the shielding of the collimator above it to clearly distinguish the top row of holes. The central hole of the sieve slit has a smaller aperture, and two blocked holes exist to easily distinguish center and directions. The collimator thicknesses are 2.5", while the sieve slit thickness is 1.25". The dimensions and shape of the inner aperture of the present HMS collimators is denoted in Table 4.7.

The total depth of the slit box is close to 3.75", which leaves enough space to later mount scintillators behind the collimators as an active veto counter (to prevent punch-through of hadrons) and/or to increase the collimator thickness. Two circular quick-connect flanges are added for feed-through of possible light guides.

Table 4.7: Apertures of Collimators

HMS	$d\Omega$ (msr)	Horizontal (mr)	Vertical (mr)	Shape
Large Collimator “Pion” Collimator	6.74	± 27.5 \pm	± 70.0 \pm	Octagonal, Flared Octagonal, Flared
SHMS Collimator	$d\Omega$ (msr)	Horizontal (mr)	Vertical (mr)	Shape
	4	± 24	± 40	Octagonal, Flared

4.7.2 SHMS

A similar remotely-operated collimator box is installed on the SHMS between the HB and Q1 magnets. The collimator ladder assembly within this box may be positioned at three settings. The top position (accessed when the assembly is at its lowest position) is a stretched octagon with opening height 9.843” and width 6.693” on the upstream side. It is 2.5” thick. The lower two positions both present sieve holes in rectangular pattern with holes separated by 0.6457” horizontally and 0.9843” vertically. The sieve pattern at the middle ladder position has 11 columns of holes with the sixth column centered horizontally. The holes on the bottom sieve are in ten columns and are offset by one-half a column gap from those in the middle sieve. The sieve collimators are 1.25” thick. The geometry is illustrated in Fig. 4.6. Both sieves and octagonal collimator are made of Mi-Tech™ Tungsten HD-17 (Density 17 g/cc. 90% W, 6% Ni, 4% Cu).

Because the SHMS has both a horizontal bend (HB magnet) and a vertical bend (main Dipole magnet), a second sieve collimator is helpful for optics calibration and understanding the magnets. It is placed immediately upstream of the HB magnet entrance. Two options are provided: a conventional passive sieve collimator and the so-called *active sieve* which is a detector based on Gas Electron Multipliers (GEMs). A photo of the passive sieve options is shown in Fig. 4.7 and the dimensions and hole pattern are shown in Fig. 4.8.

4.7.3 Operation of the Slit System

The HMS and SHMS slit systems are controlled by a remote control system consisting of motor/actuators that slide the slits in place. Resolvers specify the exact position of the slits. The resolver position of the slits is relative number of counts from the home position. The home position is set by a homing procedure that is programmed into the controller that sets the zero position by moving the slit to a position that activates the physical home switch. Once this homing procedure is complete, then the slits can be moved to surveyed positions that have been programmed. The home position for HMS

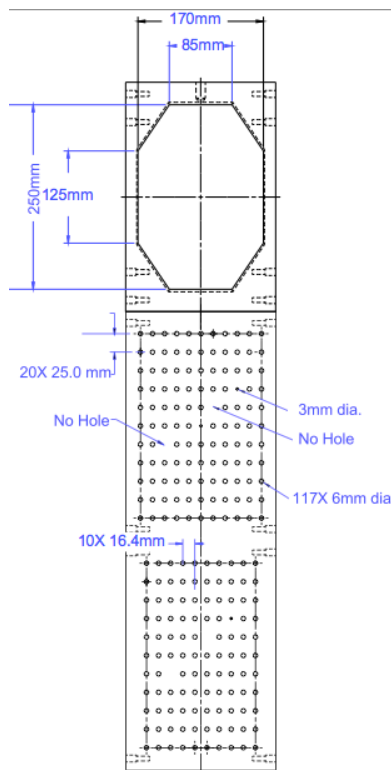


Figure 4.6: Geometry of the Main Collimator and the Sieve Slits in the SHMS

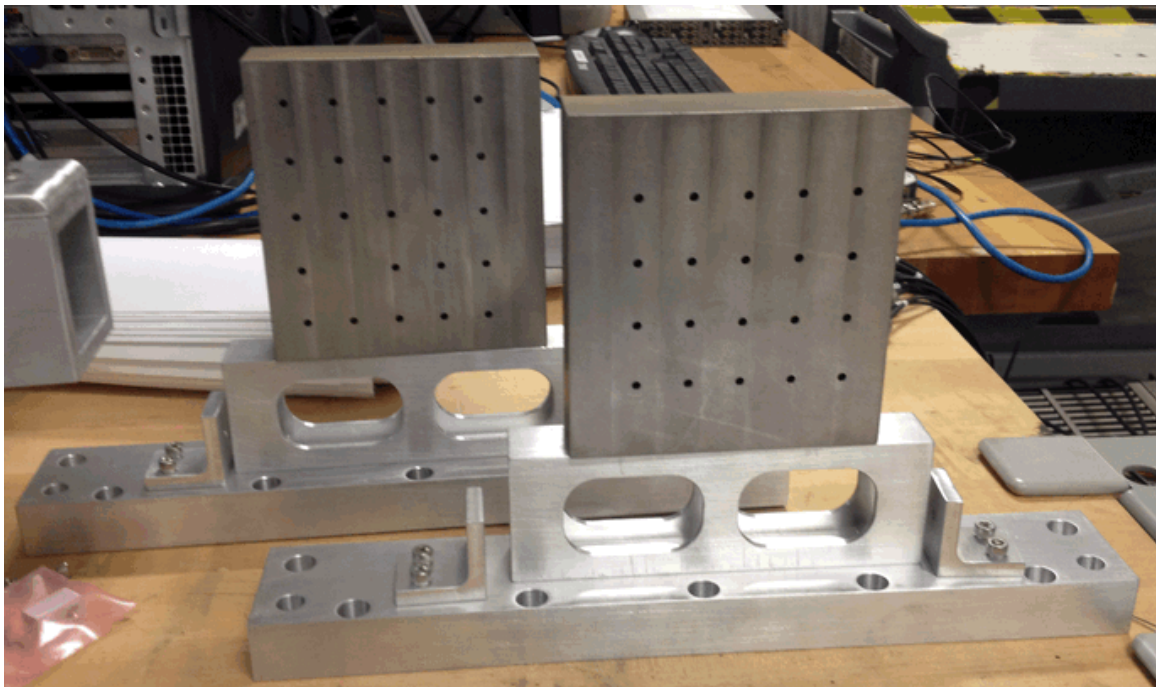


Figure 4.7: Upstream Sieve Slits that go on the front of the HB magnet of the SHMS

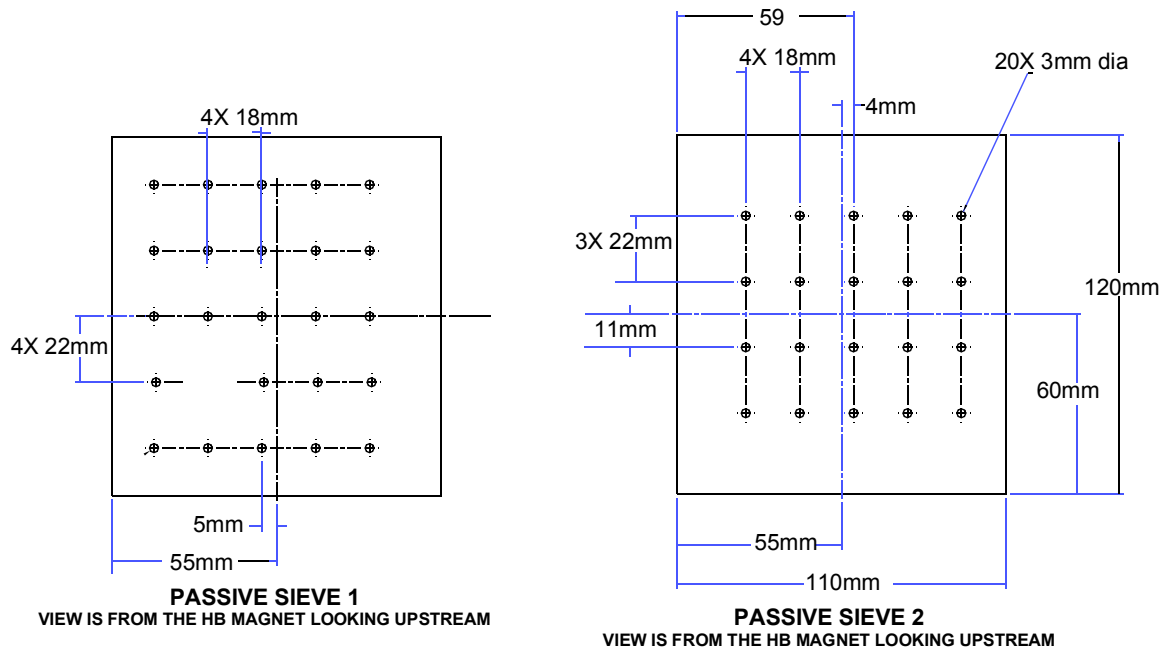


Figure 4.8: Upstream Sieve Slits that go on the front of the HB magnet of the SHMS

and SHMS slit system does not mean that the slits are moved out of the way. For the HMS it is possible to move the slits so that they are out of the way (*All Out*), but for the SHMS there is no such position for the slits. EPICS drivers have been written for normal operation of the slits by users and non-experts and operation of the slits through the EPICS screens is described below. Upper and lower limit switches are on the slit system drive shaft to keep the slits from being moved too far in either direction. There are also software limits. The control box is located downstairs in Hall C. In the control box, there is a driver for the HMS and one for the SHMS. If power is lost to the control box, then the brake engages on the motor that drives the slits. On the front of the control box is a red emergency power shutoff button. The control box should only be opened by trained experts.

EPICS drivers have been written for normal operation of the slits by users and non-experts. The EPICS screens are accessed through the accelerator **jmenu**. Instructions for access the **jmenu** will be given in the Hall C How-tos. From the **jmenu**, the HMS and SHMS slit system EPICS controls can be accessed on The Hall C Operations Menu which is open from **jmenu** → **Standalone Menus** → **HallC**. On the Hall C Operations Menu under *Experiment Specific* are *HMS Coll. Motion Control* and *SHMS Coll. Motion Control*. Clicking the respective title will bring up the EPICS screens shown in Fig. 4.9. Fig. 4.9 shows the HMS and SHMS slit controls in normal operation. In normal operation, the homing procedure has been completed as indicated by the orange rectangles next to *Home position found/reference point point set* and *Home routine finished*. With the homing procedure completed, the user can moved to the other slit positions by clicking on the labeled button. For the HMS slit system, the slits can be moved so that they are



Figure 4.9: HMS and SHMS slit system screens in normal operation.

out of the acceptance by clicking on the *All Out* button. It is not possible to move the SHMS slit out of the acceptance. In Fig. 4.10, the EPICS screens are shown when the slits are moving. The velocity should be around 1000 rpm and the current less than 2 amps (typically the reading fluctuates between 0 and 1). If the current is above 2 amps, then click the *Stop Motion* button and contact the expert. The option of experts moving the slits to an arbitrary position is available for the EPICS screen. The conversion is 327680 counts is one mm. The mostly likely use for this option is during the taking of optics data when one wants data with the sieve slit moved by half the distance between holes to get more vertical angles.

The EPICS controls are done through a soft IOC called *iocsofthmsco* and *iocsoftshmsco*. If EPICS screens are white then the IOC needs to be rebooted. Another reason that soft IOC would need to be reboot would be if the soft IOC has lost communication with the driver. In the case, the user could not move the slit and the text on the Warnings and Faults windows is in light grey color. Only the MCC operator can reset the soft IOCs by accessing **jmenu** → **Operations** → **Control Systems** → **Reboot** → **HallC**. The user can call MCC to reset the soft IOCs.

If there is a power outage, the brakes are engaged in the motor that drives the slits. Once power is restored then the user needs to do the following steps to get the slit system back in normal operation mode.

1. Ask MCC to reboot the soft IOC for the HMS and SHMS, *iocsofthmsco* and *iocsoftshmsco*.
2. Access the HMS and SHMS EPICS screens.
3. On the EPICS screens, click on the *Reset* button. this runs an initialization program which loads parameters into the driver. The EPICS screen should look like Fig. 4.11. The red warning is to remind the user to execute the homing procedure.



Figure 4.10: HMS and SHMS slit system screens when the slits are moving.

4. On the EPICS screens, click on the *Homing* button. This executes the homing program which defines the home position and is needed before moving to other position.
5. When the homing procedure is successful then the rectangles next to *Home position found/reference point set* and *Home routine finished* will be orange.
6. Click on button to move slit to desired position.

4.7.4 Hazard Identification

The principal hazards are:

Magnetic: There is a significant fringe field at the entrance and exits of the magnets. This represents a hazard to people working on the slit system if they are handling magnetic objects (tools) or to people with pacemakers. In addition the field could erase magnetic information storage media such as the strips on credit cards.

Mechanical: At the front of Q1 the housing for a spring loaded gate valve is mounted. In its normal operation mode a metal gate will be closed with severe pressure when the electrical power drops. This can cause serious damage to interfering body parts. But currently the shutter and actuator have been removed so this hazard does not exist. A similar mechanical problem involves the slit ladder itself. The total weight of the three slits amounts to approximately 350 Lbs (160 Kg) and can easily cause serious damage to body parts.

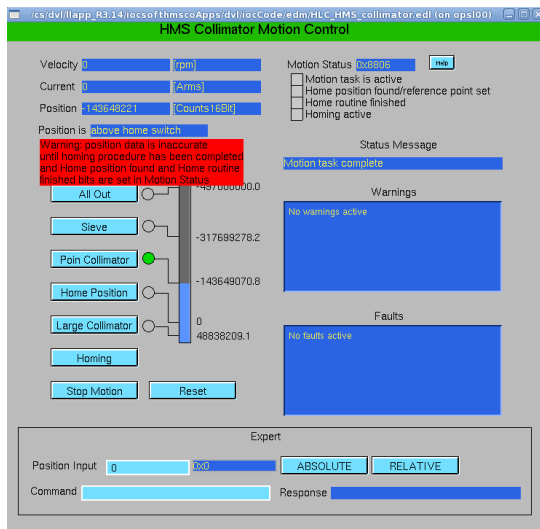


Figure 4.11: HMS EPICS screen when power restore but before the homing procedure as been executed.

4.7.5 Hazard Mitigation

Magnetic A sign will be posted which indicates the presence of a high magnetic field (this is standard JLab safety signage). The exact wording is “ High Magnetic Field - No Pacemakers or Credit Cards.” There are also flashing red lights located on the HMS and SHMS carriage indicating that the magnet power supplies are energized. Be careful with tools (are they magnetic?) when you work on the slit boxes with the red lights in a flashing state.

Mechanical If the gate valve is ever re-installed, the following safety procedures should be observed. Without power, the gate valve assumes its default closed position due to pressured air. When installing the slit boxes, or working with your hands in the vicinity of the inside of the gate valve, disconnect first the power plug of the gate valve, such that the gate valve closes. In case you need the gate valve to assume a default open position without power, first relieve the air pressure with power on, and verify that the default position of the gate valve has changed to “open” by removing the power.

When installing the slit ladder, be careful when you work with your hands under the slit ladder (like when you are bolting the slit box to the gate valve). Remove the slit ladder, or **install a support under the slit ladder to prevent it from falling all the way down.**

A brake system has been included in the control to prevent the slit ladder from sliding down in case of a power failure. However, this must not be relied upon for personnel safety.

4.8 Spectrometer Carriage and Rotation Systems

The Carriage is the support structure of the spectrometer.

Each entire spectrometer can be rotated. Rotation is driven by motors mounted near one of the sets of wheels. These motors are controlled by synchronous pulse width modulated drives which are mounted near the bottom of the shield house steps on the HMS, and under the rear of the SHMS structure.

The spectrometer angles are found using a reference plumb bob and/or TV camera attached at a known location under the rear of each spectrometer. This camera is focused on survey marks scribed into plates which are attached to the rail on the floor. Using the scribe plates and a vernier scale, the angles of the spectrometers may be determined with a resolution of approximately 0.01° .

Since the Hall C spectrometers each weigh hundreds of tons, it is very important that all safety precautions are carefully adhered to. During operations, the spectrometers are certified to allow remote rotation by shift crews within prescribed limits. In the absence of this certification, the spectrometers may only be rotated by trained technical staff.

4.8.1 Hazards

Hazards include:

- Knocking items over during spectrometer movement.
- The wheels crushing things (including fingers and toes) on the floor in the path of the spectrometer
- Damaging the beamline or other equipment on the floor if one goes to too small or too large an angle. There is only a small gap between the rear of the SHMS shield house and the shielding wall behind it.
- Tearing out of cables etc. physically attached to the superstructure
- Elevated platforms on the spectrometer carriages.
- Magnetic fields. Spectrometer magnets may be energized under either local or remote control.

4.8.2 Mitigations

Hazard mitigations:

- Stop-blocks attached to the rails to prevent spectrometer rotation beyond the needed angular range for each experiment.
- During experiments, the spectrometers are certified for rotation by shift crews within specified angle ranges. Spectrometer movement at other times may only be performed by authorized personnel.

- Hand rails are installed to prevent falls. Access is only allowed to areas on the carriage protected by hand rails.
- Hard hats may be required under certain conditions when working on or near the spectrometer carriages.
- Magnetic fields hazards are indicated by either red flashing lights and/or illuminated **Magnet on** signs.

4.8.3 Remote Rotation

Prior to the start of experiment operations, Hall-C staff will certify that the spectrometers are configured for safe remote rotation by verifying all required clearances and implementing interlocks, mechanical stops, or administrative controls, as appropriate. Refer to the section of this manual on *Controls* to find instructions for rotating the spectrometers. The cameras enable remote readout of the HMS/SHMS spectrometer angles using the survey marks on the floor. The wide-lens and zoom cameras located at the entrance and the exit of Hall C should be used to visually search for obstructions before and during remote rotation.

Limit switches are installed at forward and backward angles which prevent HMS (SHMS) from rotating to angles more forward than 10.6 (5.5) degrees and wider than 85 (40) degrees. To obtain more forward or wider angles an access is needed, and rotation has to occur manually downstairs with spotters. Hard limit switches will be installed to prevent the spectrometer from rotating out of maximum allowed range.

In case the spectrometers are rotated to more forward angles, pay special attention to possible interferences of HMS and SHMS, and interference between either spectrometer and the beam pipes or their stands.

4.8.3.1 Responsible Personnel

Following the experimental run plan, as posted in the counting house by the run coordinator, shift workers are allowed to rotate the Hall C Spectrometers following guidelines of the standard equipment manual. In the event of a problem getting the spectrometers to rotate the run coordinator should be notified. If the run coordinator is unable to solve the problem, and with the run coordinators concurrence, qualified personnel should be notified to repair the problem (see Table 4.8).

4.8.4 Personnel Trained for Manual Spectrometer Rotation

The spectrometer motors may only be manually controlled by trained personnel. If it is necessary to rotate the spectrometer manually, contact one of the trained personnel listed in Table 4.8. At least two people are required for manual spectrometer rotation: one to run the motors and at least one spotter. Prior to rotating the spectrometer a visual inspection of the area must be made to insure that there is nothing in the spectrometer's

Name (first,last)	Dept.	Call [12]		e-mail	Comment
		Office	Cell		
Tech-on-Call	Hall-C	W.B.			<i>Contact</i>
Steve Lassiter	Hall-C	7129	252-340-1845	lassiter@jlab.org	
Walter Kellner	Hall-C	5512	757-592-1527	kellner@jlab.org	
Joe Beaufait	Hall-A/C	7131	757-256-2776	beaufait@jlab.org	

Table 4.8: List of Spectrometer Rotation responsible personnel where “W.B.” stands for the white board in the counting house.

path or on the rails. During rotation the spotter should pay special attention to the cables which run from the spectrometer to the target motor controller to make sure that nothing is hung up or stretching.

4.9 Superconducting Magnet Controls

The Hall C superconducting magnets, power supplies, and cryogenics are controlled using two redundant pair Programmable Logic Controllers (PLC). The PLC’s are located on the second floor of the Counting House. They are connected to the the magnets through hot swap analog and digital IO modules. The IO modules for the High Momentum Spectrometer (HMS) are also located on the second floor of the Counting House while the IO modules for the Super High Momentum Spectrometer (SHMS) are located in the electronics hut on the SHMS structure in Hall C.

The operator interacts with the controls using the Human Machine Interface (HMI) console located in the Hall C control room. The HMI graphically displays the magnet status and allows the operator monitor the magnet status, adjust the power supply, cryogenics, and remotely rotate the spectrometers. Example screens are shown in Figs. 4.12, 4.13, 4.14, 4.15 4.16, 4.17, 4.18, 4.19, 4.20, 4.21 and 4.22,

Follow these instructions to operate the Hall C magnets.

- Type the command `go.cmagnets` from from one of the Hall C counting house console computers.
- Click on the “Magnet Controls” icon.
- Click on the “Status” button to bring up an overview screen for the magnets for both spectrometers. The spectrometers may be set “by momentum” from this screen.
- For individual magnet control, select the desired magnet and click the “PSU” button. Most power supply functions including setting current, changing polarity, and resetting interlocks can be done from these screens.
- To remotely change spectrometer angles, click the “Rotation” button.

Other screens are available to show the status of cryogenics, and forces and voltages within the magnets. Control of cryogenic valves may only be done under the direction of the engineer on call or other member of the Hall C engineering group.

4.9.1 Responsible Personnel

The PLCs are programmed by and maintained by the Hall C engineering staff. In case of problems with spectrometer magnet and spectrometer rotation controls, qualified personnel should be notified (See Table 4.9).

Name (first,last)	Dept.	Call [12]		e-mail	Comment
		Office	Cell		
Steve Lassiter	Hall-C	7129	252-340-1845	lassiter@jlab.org	

Table 4.9: List of spectrometer responsible personnel where “W.B.” stands for the white board in the counting house.

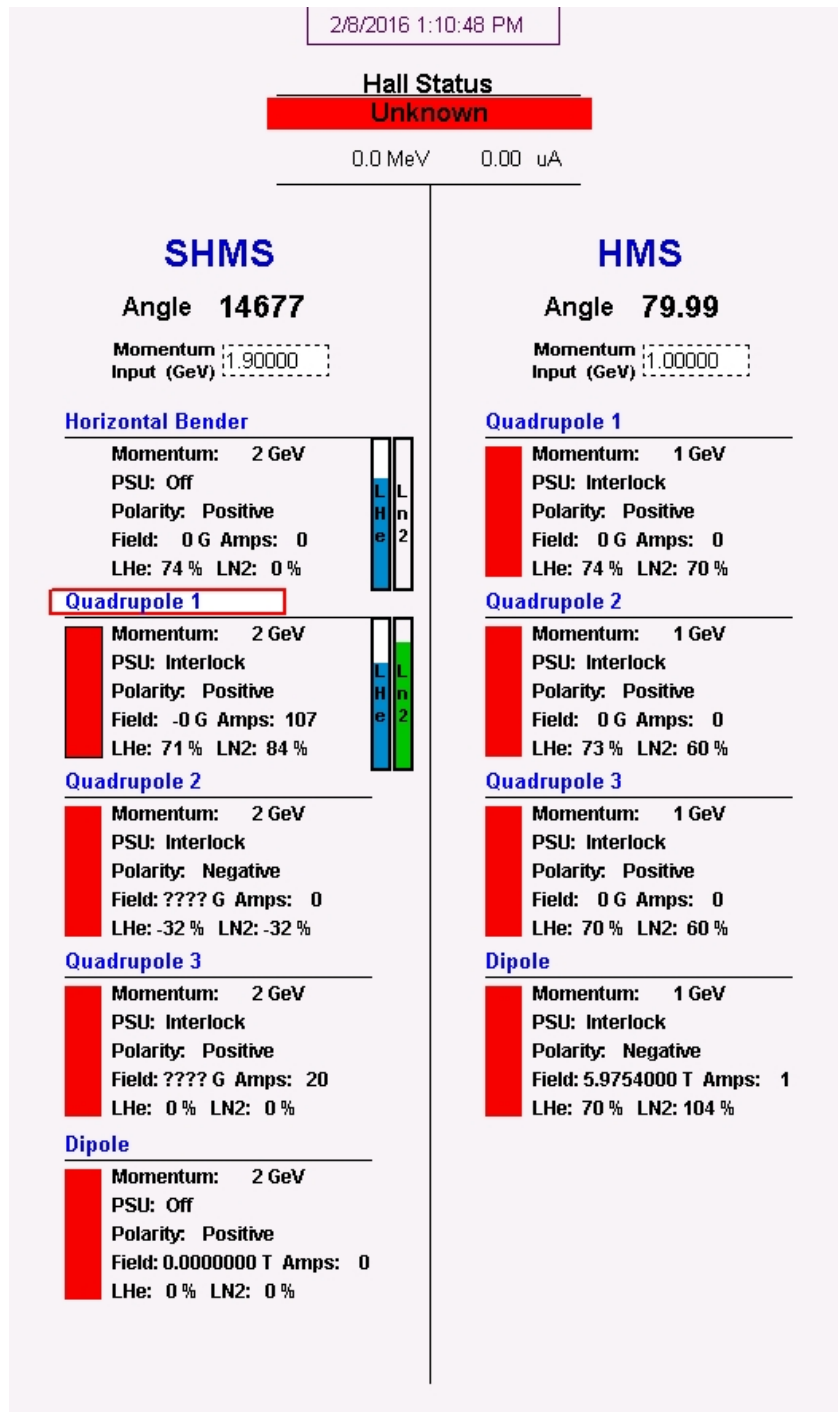


Figure 4.12: Overview of HMS and SHMS magnet status

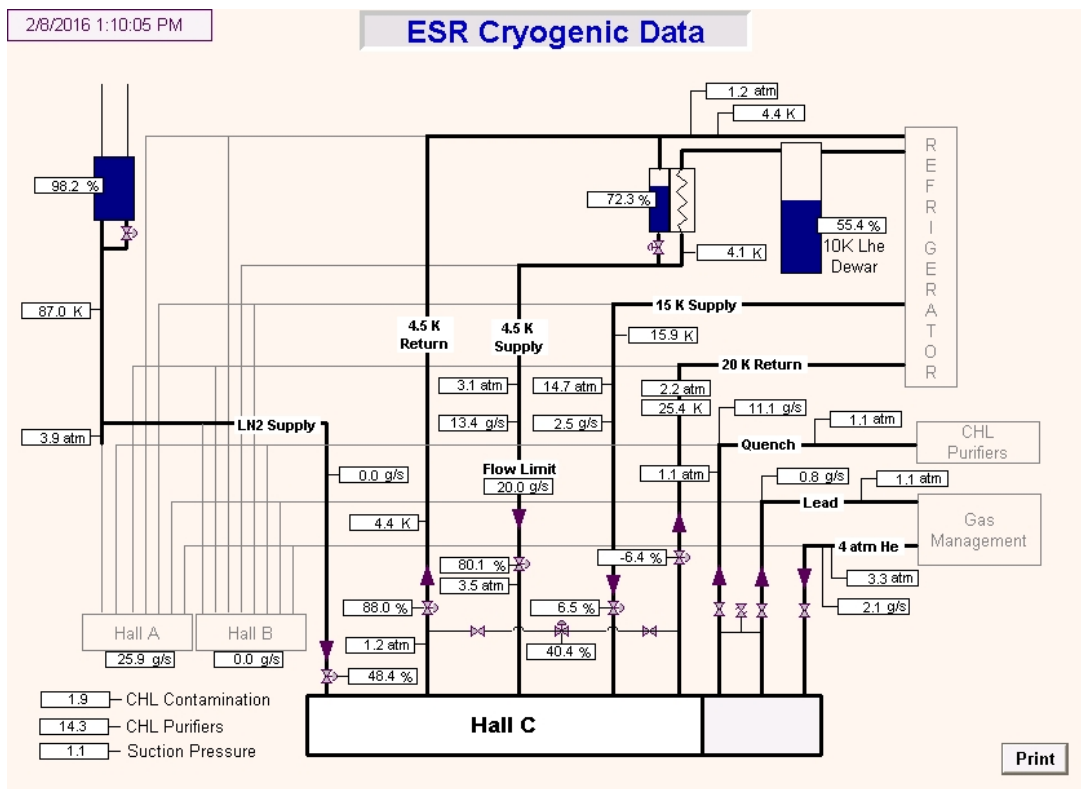


Figure 4.13: Status of ESR Cryogenic System

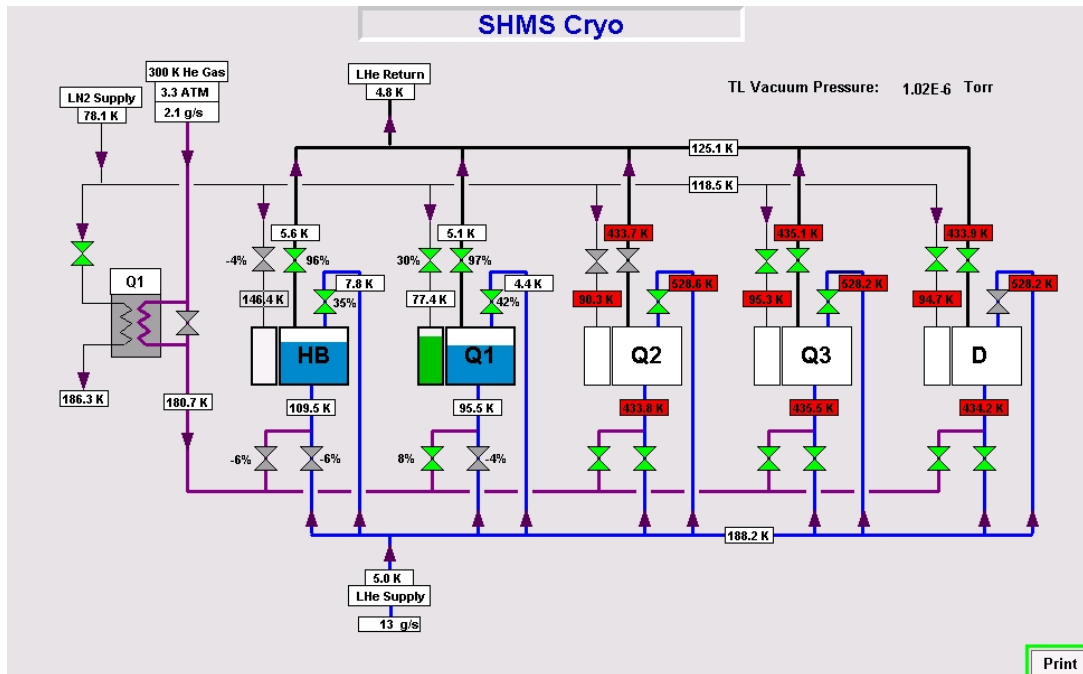


Figure 4.14: SHMS Transfer Line

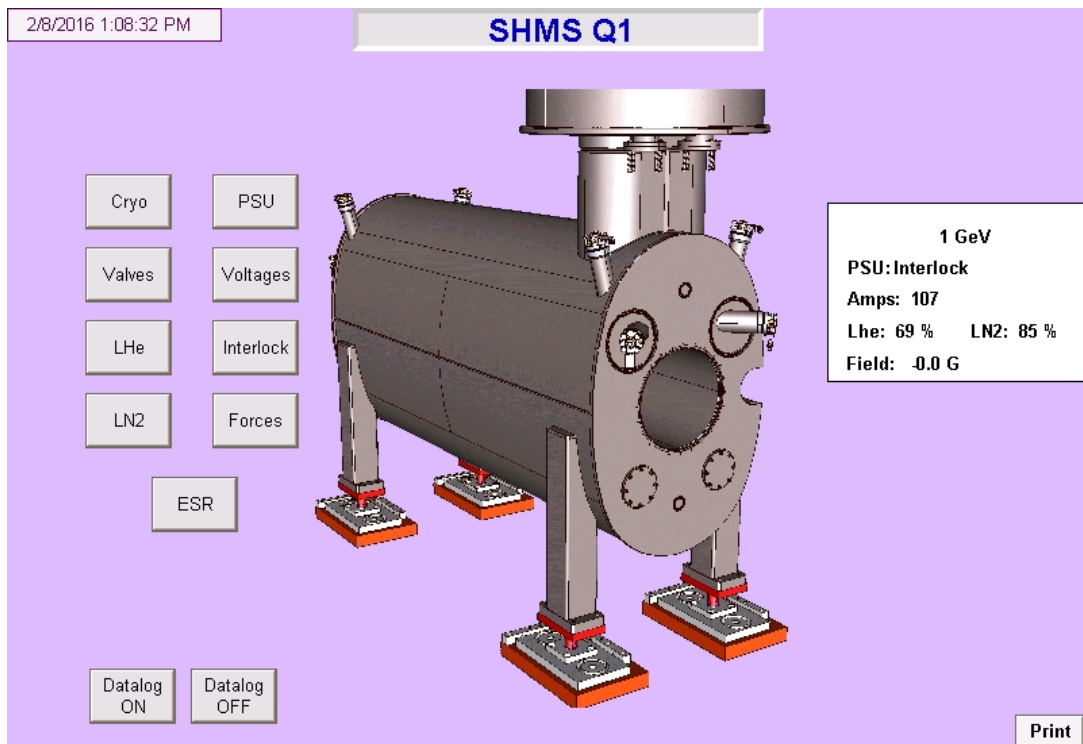


Figure 4.15: SHMS Q1 menu screen

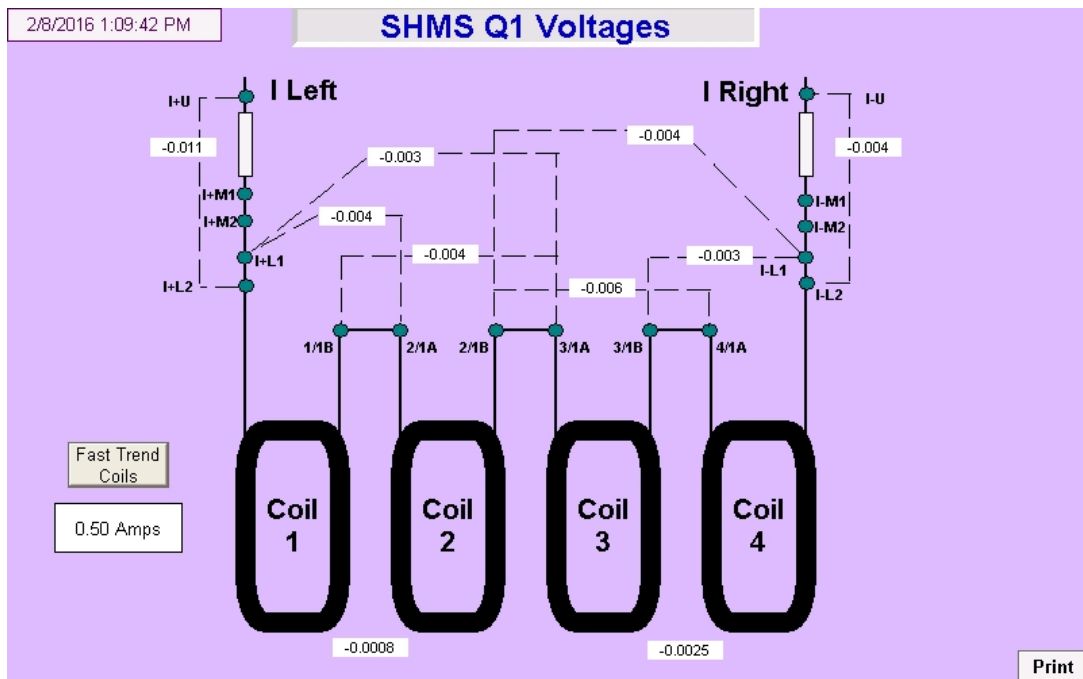


Figure 4.16: SHMS Q1 voltage taps.

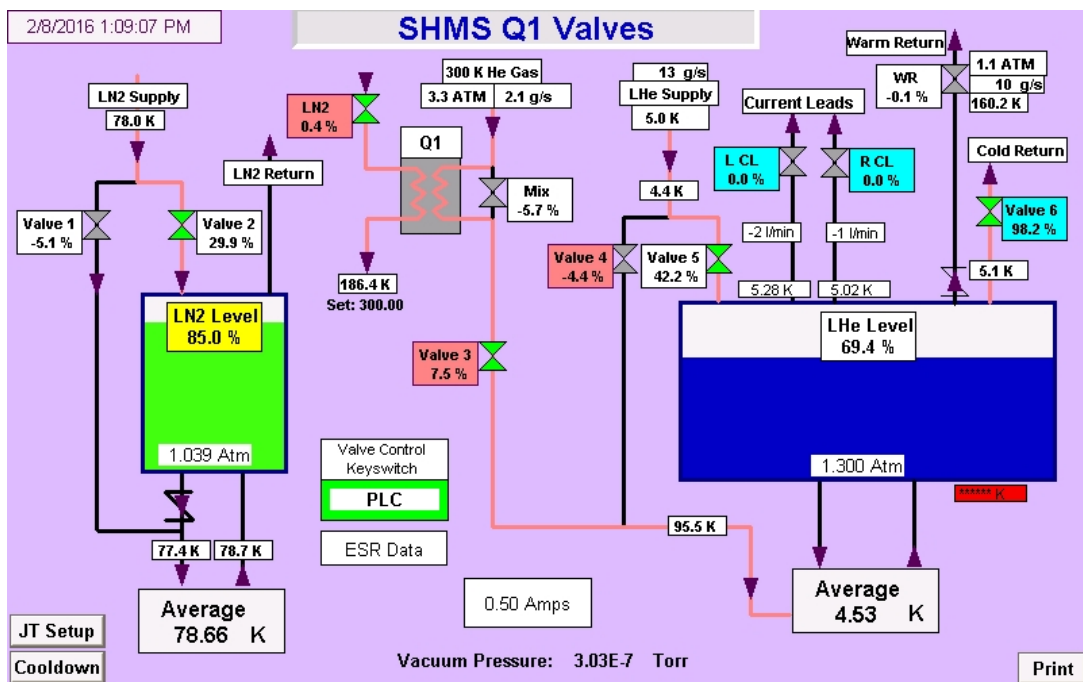


Figure 4.17: SHMS Q1 Valves

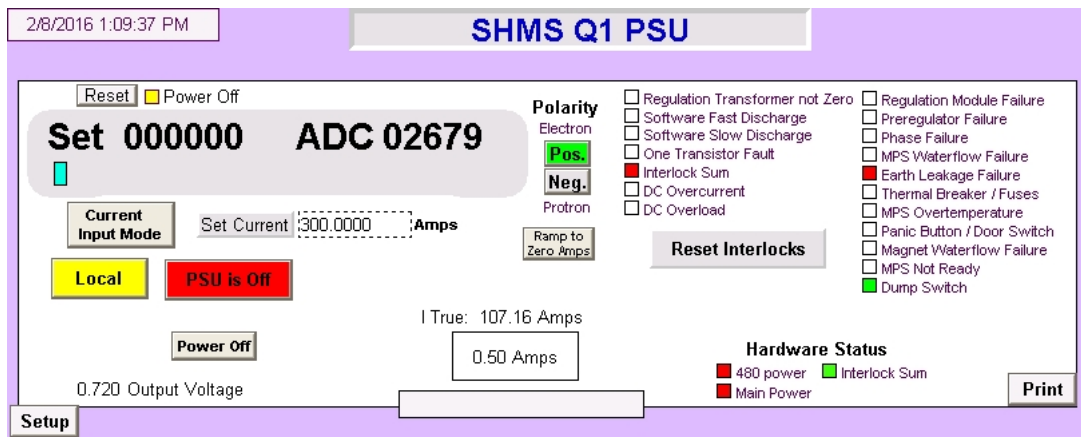


Figure 4.18

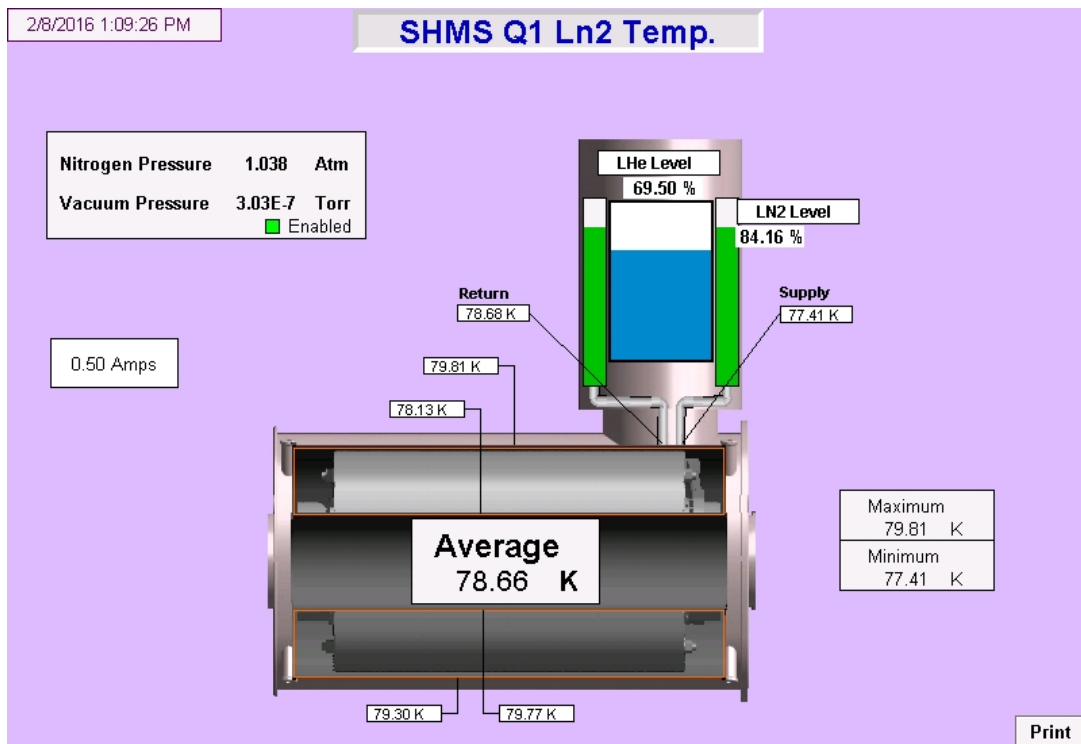


Figure 4.19: SHMS Q1 nitrogen temperature and levels

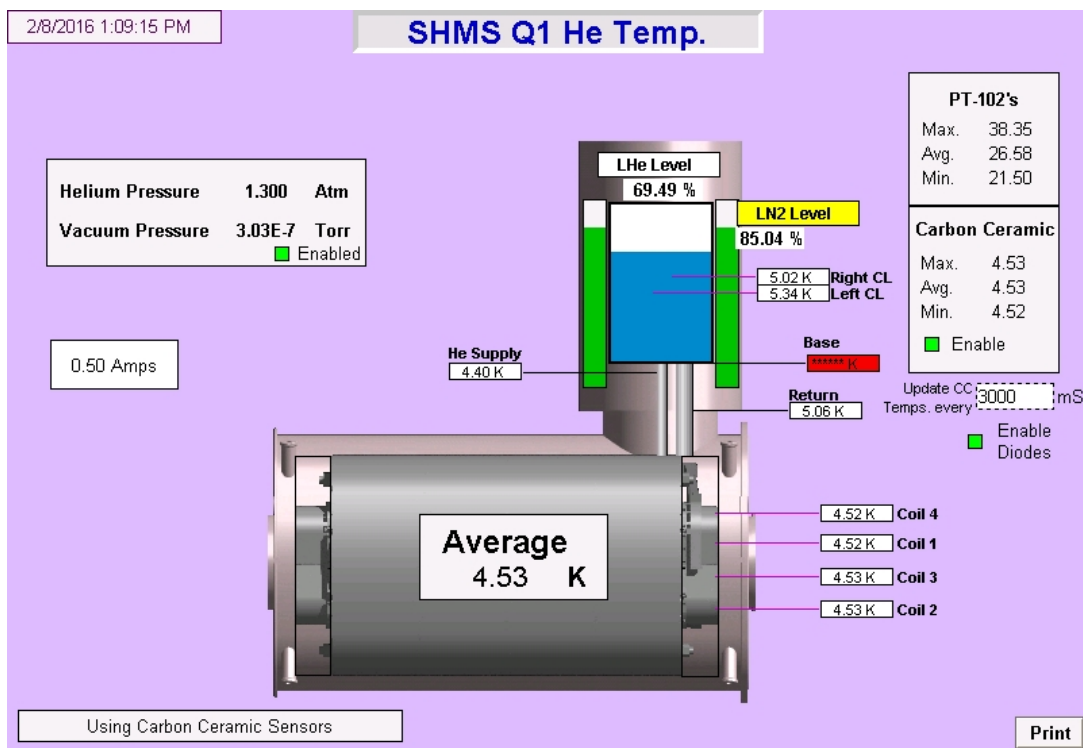


Figure 4.20: SHMS Q1 helium temperatures and levels

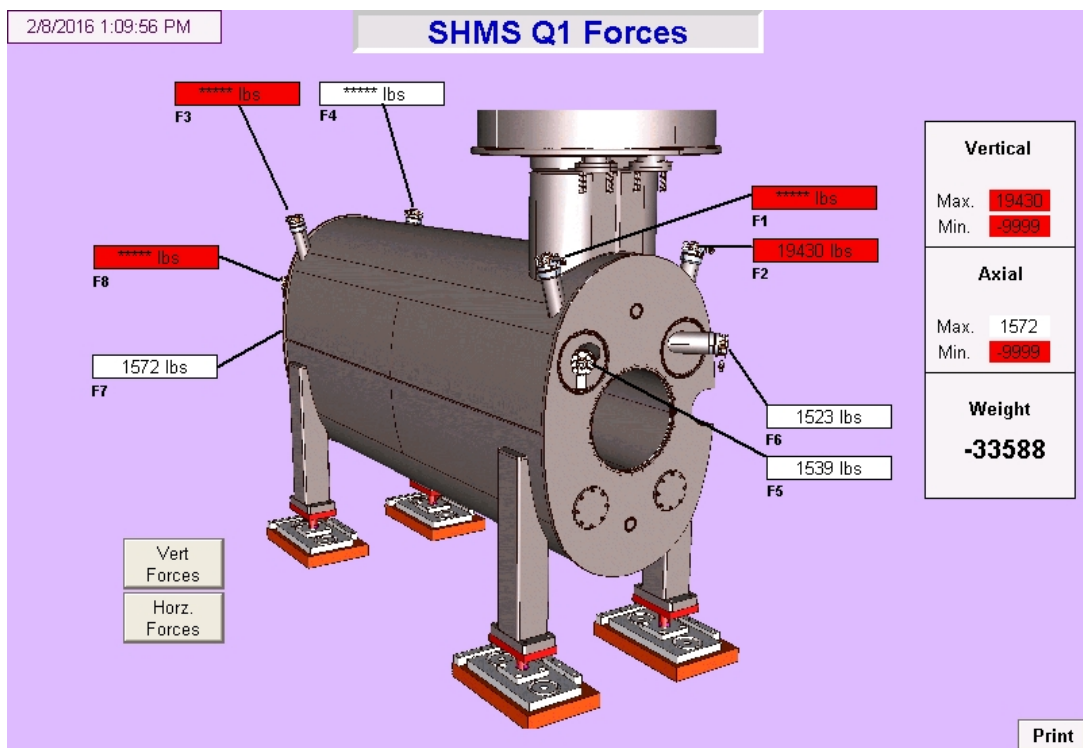


Figure 4.21: Forces on SHMS Q1 coil packs

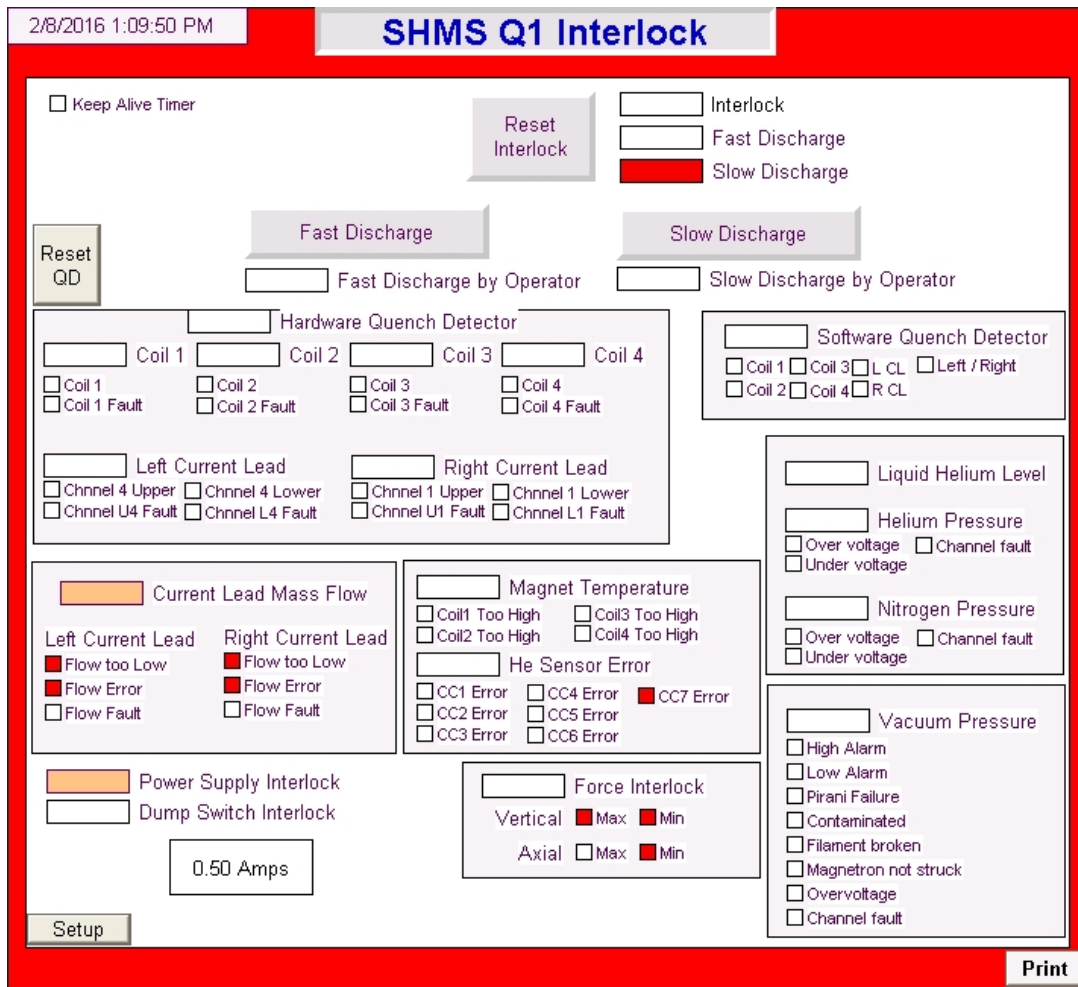


Figure 4.22: SHMS Q1 power supply interlock status

Chapter 5

Detectors

The SHMS and HMS spectrometers each contain a set of detectors that trigger event readout and perform tracking and particle identification (PID). The detector package in each spectrometer is similar with differences in part due to the different momentum ranges of the spectrometers. These detectors are located in shielded detector huts to minimize background from the hall. The detector huts include the following types of detectors, not all of which may be installed, depending on the needs of a particular experiment:

Drift Chambers Two drift chambers, each with 6 wire planes, separated by about a meter. These detectors provide tracking of particles exiting the spectrometer vacuum chamber. The tracks from these chambers are traced, with software, back to the target to provide particle momentum, scattering angles, and target position. They are usually the first detectors in the path of the detectors. (The SHMS Noble Gas Cherenkov will sometimes be installed in front of the SHMS drift chambers.)

Hodoscopes A set of 4 hodoscope planes. A hodoscope plane consists of a set of long thin elements/bars, each several centimeters wide, that covers the acceptance of particles passing through the detector package. A pair of planes, one with horizontal bars, one with vertical bars (S1X, S1Y) are located after the drift chambers. A second pair, S2X and S2Y, are located some distance past the pair. The sensitive elements of these planes are scintillator material, with the exception of S2Y in the SHMS which uses quartz. The light from particles passing through the bars is detected by photomultiplier tubes (PMTs) at the ends of each bar. The hodoscopes, possibly in coincidence with other detectors, provide the trigger to the data acquisition system and a time reference for the drift chambers. They also contribute to PID by measuring the time of flight between the two pairs of planes and from pulse amplitude.

Gas Cherenkov detectors Depending on momentum and index of refraction of the gas used, provide either discrimination between electrons and pions, or between pions and kaons

Aerogel Cherenkov Contain an Aerogel radiator and a diffusion box with PMTs to collect Cherenkov light. These detectors aid in the detection of kaons by discrimination between kaons and protons (or at low momentum discrimination between pions and protons.)

Shower Counter A large array of lead glass. This detector is last in each detector stack. Most of the energy of electrons or positrons is collected in the shower counter aiding in the discrimination between electrons/positrons and other particles.

The detector packages are key to successful measurements. Their proper operation should therefore be constantly monitored during shifts. There are normally a number of diagnostic spectra available to aid in this process. Typically each collaboration customizes it's own set of diagnostic spectra.

5.1 Common Systems

This section describes systems that are common to the detectors in both spectrometers.

5.1.1 High Voltage Supplies and Control

Overview All of the detector systems in Hall C use high voltages, from hundreds to several thousand volts, to either power photomultiplier tubes or maintain electric fields around sense wires in drift chambers. These include scintillators, drift chambers, scintillators, shower detectors, and aerogel Cherenkovs.

5.1.1.1 Hazards

The personnel hazard with these devices is the high voltage. This qualifies as a Class I electrical hazard due to the supplies providing voltage >50 VDC with current limited to ≤ 5 mA.¹ This same hazard can damage phototubes if voltage is left on when tubes are exposed to room lighting.

5.1.1.2 Mitigations

- All user configurable high voltage cabling/patching is made with coaxial cables rated for high voltage with SHV connectors.
- High voltage shall be turned off before disconnecting (or connecting) high voltage cables from (or to) phototubes, power supplies or patch panels.
- High voltage shall be turned off and high voltage cables shall be removed from phototubes before handling phototubes or the detector elements they are used with.

¹JLab ES&H Manual, Chapter 6230 - Appendix T1 - "Determining Equipment Class and Work Modes"

- Current limits are set on power supplies to trip high voltage in case of shorts or shocks.
- External metal parts of detectors such as mu-metal shields are wrapped with electrical tape. Exposed metal parts are grounded through both the HV cable and signal cable grounds.

5.1.1.3 Responsible Personnel

The individuals responsible for the operation of the high voltage system are shown in Table 5.1.

Name (first,last)	Dept.	Call [12]		e-mail	Comment
		Office	Cell		
William Henry	Hall-C	6989	Web [13]	wmhenry@jlab.org	

Table 5.1: Detector high voltage responsible personnel.

All the detector elements in the SHMS and HMS require the use of High Voltage. The high voltage supplies for the detectors are located in the electronics room and second floor of the counting house. They are connected to the detector shield houses through multiconductor high voltage patch systems, and to the detectors through coaxial cables with SHV connectors. During experiments the control of the high voltage supplies is done remotely via any of the computers at the console the Hall C counting house.

As a general rule no work should be done on detectors which are under High Voltage and High Voltage cables should never be removed or installed while the supply is on.

5.1.1.4 High Voltage Configuration and Operation

The CAEN Distributed High Voltage System is responsible for providing high voltage power to all HMS and SHMS detector systems. This system is a networked system made up of individual crates (Controllers) each of which can hold several independent high voltage modules (Cards). The crates are a mix of SY403 mainframes which hold four cards with 16 SHV outputs and newer SY4527 mainframes holding up to 8 cards with 24 SHV outputs each. (Other cards with different numbers of channels and different high voltage connector form factors are available, but only the described types are currently used in Hall C.) There are several flavors of cards in use with the Hall C detector systems which are listed in Tables 5.2 and 5.3. A given crate may have a mix of card types, although cards can not be exchanged between SY403 and SY4527 crates.

The system is typically controlled through EPICS. Various methods of direct/local control are available for the two different crate types.

HV channel assignments currently in effect are indicated in two files (“group_map” and “channel_map”) in the directories \$EPICSHL/HV/hms_all (for HMS) and \$EPICSHL/HV/shms_all (for SHMS) when logged in as cvxwrks to one of the cdaq machines.

Table 5.2: Specifications of SY403 High-Voltage Cards used in Hall C Detector Systems.

Card type	Max Voltage	Max Current	Detector System
A403 (or A503)	-3000V	3.0mA	Hodo/Shower
A503P	+3000V	3.0mA	Cherenkov/Aerogel
A505	-3000V	200 μ A	Drift Chambers

Table 5.3: Specifications of SY4527 High-Voltage Cards used in Hall C Detector Systems.

Card type	Max Voltage	Max Current	Detector System
A1535SN	-3500V	3.0mA	Hodo/Shower/Heavy Gas
A1535SP	+3500V	3.0mA	Noble Gas/Aerogel

General Operation

Normal Operation: In general the high voltage system will be controlled or monitored from the counting house using the EPICS slow control system. Operation of the EPICS graphical interfaces is described in the CAEN HV Operation Howto [22].

In case of a dead high voltage channel, the high voltage cable for a given detector element can be moved to a spare high voltage channel, if available. (The channel_map file, described above shows which channels are in use.) Care must be taken to always use the correct type of HV (positive vs. negative, vs. drift chamber supply). The procedure to make these changes is described in the CAEN HV Operation Howto [22]. Any changes in HV configuration shall be documented in the logbook.

For more complicated changes to the HV configuration, such as changing or adding HV cards or mainframes, consult and expert and the Caen High Voltage System EPICS Controls Expert Howto [23].

Important Features: The user can program several important features for individual cards and/or channels. The most common are:

- HV limits – 2 types including a hardware maximum (common to a card) set with a pot on the front panel of each card and a software maximum for each channel.
- Current Trip Value – The current over which the system will indicate an alarm status and initiate a trip off of that channel.
- Current Trip Time – The amount of time the system will allow the alarm condition before actually switching off that channel.

- Ramp-up Value – The number of volts/sec the voltage will ramp to its set point upon switching on the channel.
- Other Features – See the CAEN Technical Information Manual.

Direct/Local Operation The SY403 mainframes may be controlled through the front panel or an RS232 interface, while the SY4527 The high voltage main frames can be controlled through a web interface. These methods of control are described in the CAEN HV Operation Howto [22] and the vendor manuals for the SY403 [24] and SY4527 [25]. These modes of control are meant for diagnostics and testing of a detector system prior to running.

Safety Concerns/Caveats There are a number of cautions one should observe when operating the CAEN HV equipment to avoid damage and insure proper functioning:

- Use only proper SHV connectors and approved cables when connecting equipment to the supply.
- **DO NOT** attach/remove HV cables when loads are present on the channel (a red LED above each channel indicates the presence of a load).
- Insure adequate ventilation around crates to avoid overheating of the electronics.
- Wait 2-3 minutes after switching off a crate before removal of a HV card.
- Insure proper static precautions when handling HV cards.

For proper EPICS control operation (SY403):

- Inter-crate connections must be unbroken and terminated at the last crate at 50 Ohms. All crates must be powered on.
- Crate numbers for each crate in the chain must be distinct and different from 0 (i.e. 1-99)
- The HV Enable switch (on the front panel of each crate) must be on.
- One should refrain from any local operation of crates when the EPICS system is active.

5.1.1.5 High Voltage System Checkout

Before starting an experiment, or before using the high voltage system to test detectors, proper functioning of the HV supplies and EPICS controls should be verified with this checklist.

- Check EPICS: Using the EPICS Control system as described in the CAEN HV Operation Howto [22], verify that voltage set points and current/voltage limits are read by the control system.
- Verify Operation: For the detector(s) of interest, individually turn on each channel. Verify that the channel reaches the desired set voltage. If the readback voltage exceeds the set voltage by more than a few volts (Overvoltage), or fails to reach full voltage (Undervoltage), immediately turn off the channel, report the observation in the logbook and consult an expert.
- Verify Limits: Make a backup of HV settings. For each channel in the detector, set a current limit below the current being drawn by the detector channel. Verify that each channel trips. Similarly, set a maximum voltage for each channel below the set point and verify that the voltage limit is enforced. (This may change voltage set points, so they may need to be restored from backup.) Consult an expert if any channels fail to trip on overcurrent or if maximum voltage is not enforced.
- Interlocks: If any high voltage systems are interlocked with other systems, verify that assertion of the interlock signal turns off high voltage.

5.1.2 The Wire Chamber Gas Mixing System

The Hall C wire chamber gas mixing system is located in the gas shed located to the left of the counting house (when facing the counting house) in the parking lot between the counting house and the accelerator service building (building 96C). The SHMS gas system for the SHMS Noble Gas Cherenkov is also located in this shed. The gas cylinders in use are along the outside of the Gas Shed in a fenced area. There are racks next to the Gas Shed for storage of full gas cylinders. Hall C currently uses ethane, argon, ethanol, carbon dioxide, nitrogen and neon.

The main component of the system is a single MKS 647 menu driven 4-channel controller that maintains the mix proportions and pressure regulation of the gas supplied to the wire chambers. Gas flow is controlled by 2259c proportional mass flow control valves. The 647 allows the Gas Calibration factor to be altered in software, allowing the user to change to a different gas without recalibration of the mass flow control valves.

A temperature controlled alcohol bubbler is provided for the gas stream. The alcohol level in the stream is maintained by a float valve fed from a reservoir outside the bubbler chiller. This allows the alcohol system to be refilled without opening the system to air. A sight glass on the side of the reservoir allows the level to be monitored. A bypass loop around the alcohol system is provided should alcohol-free gas be desired, or if the alcohol system requires maintenance. Remote monitoring and limited controls are provided through an EPICS display screen accessible via **JMenu/Monticello → Hall C → Hall C Gas Shed**, or equivalent².

²Path to EDM file is /cs/opshome/edm/hlc/HLC_gas_shed.edl

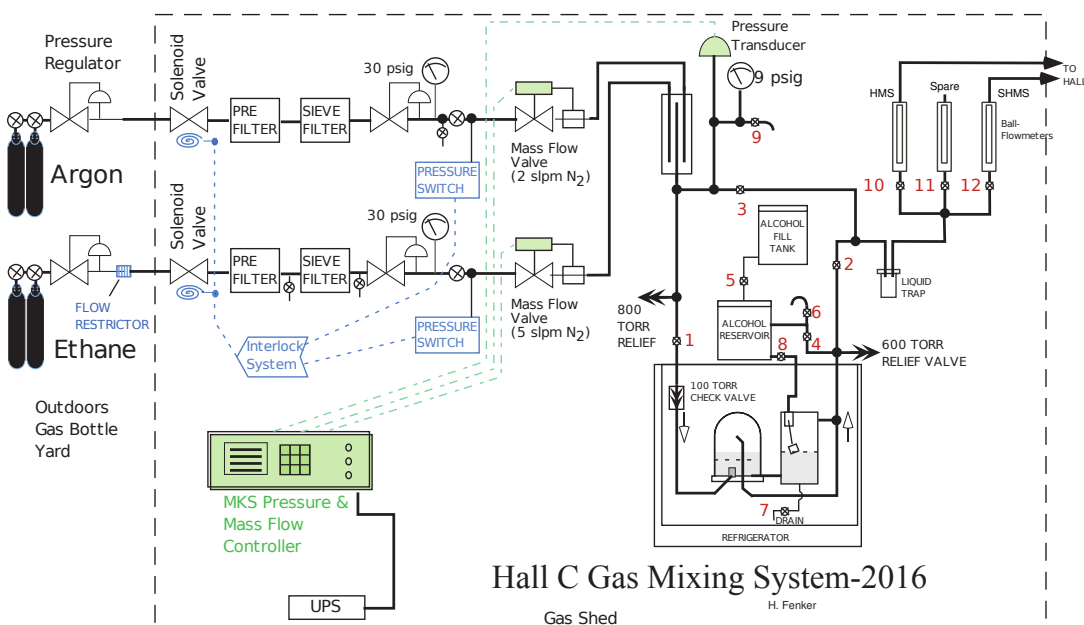


Figure 5.1: Diagram of the Hall C Gas Mixing System

This system operates by measuring and controlling pressure, not flow rate. This system will work to maintain a pressure, regardless of the flow rate. This allows the (pressure dependent) Rotameter-style flow meters to provide a constant flow rate to detector systems. Nevertheless, it should not be used without appropriate pressure relief device such as relief bubblers and relief valves.

The manual valves used in this system are numbered on their handles. Those numbers are referenced in this document and in Figure 5.1.

Settings for Normal Operation A summary of all of the settings required to make the controller function properly is given in Table 5.4. The table also shows which screen contains each parameter. Instructions for setting parameters are given below. Detailed instructions for configuring and operating the MKS 647 can be found in the manufacturer’s instruction manual [26].

General Operation of the Mass Flow Controller If the controller screen is dark, press **ESC** to awaken the display. Many screens merely provide a menu of other screens you may access: simply press the item number you desire. To go up one level in the menu hierarchy, press **ESC**. The *Menu Tree* for the 647C controller is shown in Fig. 5.2.

In general, to change a parameter displayed on the controller screen use the **left/right** arrow keys to move the cursor to the item you wish to change. Then either use the number keys to enter the value desired for that item (numeric parameter) or use the **ENTER** or **up/down** keys to cycle a parameter through its available settings (configuration parameter). Numeric parameters may be incrementally modified by using

Parameter	Set To	Controller Screen/Comments
Manual Valves		Valves are labeled
Valves 1, 2, 4, 8	OPEN	
Valves 3, 5, 6, 7	CLOSED	
Pressure PID Loop Settings		<i>Pressure Control</i> (Fig. 5.6)
Pressure	500 Torr	
PID Mode	AUTO	
PID GAIN	4.0	
PID INTEG	10.0	
PID LEAD	0.000	
Mixture	1	<i>User</i> (Fig. 5.4)/ Lower-right corner
Gas Composition for Mixture 1		<i>Gas Composition</i> (Fig. 5.7)
Channel 1	1.000	
Channel 2	1.000	
Channel 3	0.000	
Channel 4	0.000	
MFC Valve Size / Gas		<i>Range Selection</i> (Fig. 5.8) <i>Gas Selection</i> (Fig. 5.9) provides 2.78 SLM Argon provides 2.50 SLM Ethane
Channel 1	2.0 SLM / Ar	
Channel 2	5.0 SLM / C ₂ H ₆	
Channel 3	<i>unused</i>	
Channel 4	<i>unused</i>	
Channels ON/OFF Settings		<i>Extended Display</i> (Fig. 5.5) Press “ON 1” (<i>Argon</i>) Press “ON 2” (<i>Ethane</i>) Press “OFF 3” (<i>not in use</i>) Press “OFF 4” (<i>not in use</i>)
Channel 1	ON	
Channel 2	ON	
Channel 3	OFF	
Channel 4	OFF	
Pressure Transducer		<i>Pressure Setup</i>
Controller	STD	
Range F.S.	1000 Torr	
MFC Valve Controls		<i>Mode Selection</i> (Fig. 5.10)
Channel 1	PID	
Channel 2	SLAVE / 1	
Channel 3	INDEP	
Channel 4	INDEP	
Alcohol Temp.	2° C	Electronic Temperature Control Box

Table 5.4: Normal Valve and Parameter Settings for the Gas Mixing System.

the **up/down** arrow keys. To make certain that a new parameter becomes active, move the cursor off of the parameter after you have entered the new value.

The initial menu upon startup is the **Main Menu** (Fig. 5.3). For normal operation use the **User Display** menu (Fig. 5.4). It shows the amount of each gas currently flowing, the total gas flow, and the current delivery pressure. This display also shows which of several possible pre-defined gas mixtures is selected. These mixtures are configured on the **Gas Composition** screen, Fig. 5.7. For normal operation, we use only mixture #1, (number shown on the lower-right of the display). **Only on this screen can this parameter be changed.** Mixture #2 is usually configured to provide 100% argon for purging flammable gas out of the chambers.

The **Extended Display** menu (Fig. 5.5) shows actual flow, flow set point, units, valve full-scale range, gas calibration factor, whether that channel is enabled, and whether each channel is operating in master, slave, PID, or independent mode. This display is most useful to a system expert wishing to verify the system parameter settings. Most parameters cannot be modified from this screen, however.

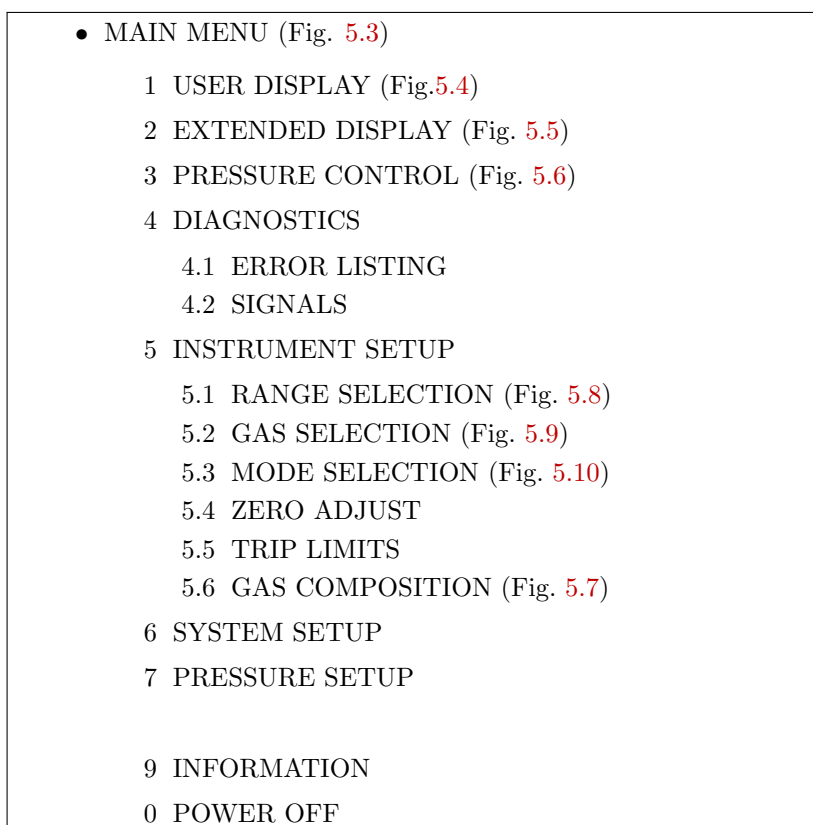


Figure 5.2: Command Tree for the MKS-647C Control Panel

Delivery pressure set-point and pressure *PID-loop* control parameters may be configured from the **Pressure Control** screen (Fig. 5.6).

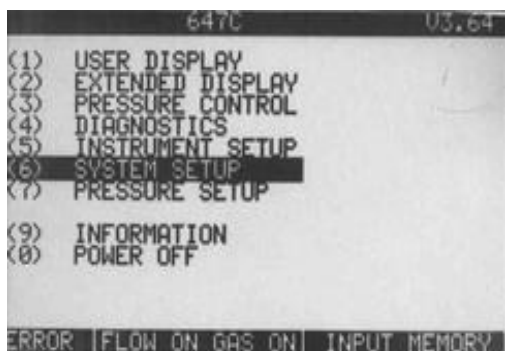


Figure 5.3: MKS 647 Main Menu



Figure 5.4: MKS 647 User Display

	CH1	CH2	CH3	CH4
ACT. FLOW	0.397	0.145	-0.000	0.000
SETPOINT	1.370	0.500	0.000	0.000
UNIT	SLM	SLM	SCCM	SCCM
RANGE FS.	2.740	2.500	1.000	1.000
GAS	Ar	C ₂ H ₆	USER	USER
MODE	PID	SLAVE	INDEP.	INDEP.
STATUS	ON	ON	OFF	OFF
PRESSURE	0500.0 Torr			

	CH1	CH2	CH3	CH4
	0.327	0.324	0.000	0.000
GAIN	04.00			
INTEG	10.00			
LEAD	00.00			
PRESSURE		0502.7		
SETPOINT		0500.0		
PCS	-0.00			
UNIT		Torr		
MODE		AUTO		

Figure 5.5: Extended Display Screen Figure 5.6: Pressure Control Screen

Gas Flow Rates The flow rates are adjusted automatically by the controller in order to maintain a constant delivery pressure at the output. Only the flow *ratios* should be set by the operator. We use a 1:1 ratio, set on the **Gas Composition** screen (Fig. 5.7), as indicated in Table 5.4.

The average total flow should equal the sum of the flows to all of the detectors in the shield house. (Note that the ball-type flowmeters in the shield house are calibrated for nitrogen. The approximate multiplier to convert these readings for 50/50 Argon-Ethane is 0.9 .)

System configuration parameters specifying the full-scale flow capacity (for nitrogen) of each valve, the types of gases actually flowing through each valve, and the mode of control for the valves are set in the screens pictured in Figs. 5.8, 5.9, and 5.10. These figures show the nominal settings for the Hall-C system.

	CH1	CH2	CH3	CH4
SET 1	1.000	1.000	0.000	0.000
SET 2	0.000	0.000	0.000	0.000
SET 3	0.000	0.000	0.000	0.000
SET 4	0.000	0.000	0.000	0.000
SET 5	0.000	0.000	0.000	0.000
UNIT	SLM	SLM	SCCM	SCCM
STATUS	ON	ON	OFF	OFF

	CH1	CH2	CH3	CH4
ACT. FLOW	0.138	0.288	0.000	0.000
UNIT	SLM	SLM	SCCM	SCCM
RANGE FS.	2.000	5.000	1.000	1.000
STATUS	ON	ON	OFF	OFF

Figure 5.7: Gas Composition Screen Figure 5.8: Range Selection Screen

To set the Delivery Pressure: Navigate to the **Pressure Control** menu. The pressure set-point (in Torr) is indicated at the bottom-center of the screen. This value should be set to 500.0. Note that the system can not respond instantly to a change in requested gas pressure: it has no way to release excess pressure and must wait for the

	CH1	CH2	CH3	CH4
ACT.FLOW	0.402	0.143	0.000	0.000
UNIT	SLM	SLM	SCCM	SCCM
GAS	Ar	C ₂ H ₆	USER	USER
FACTOR	01.37	00.50	01.00	01.00
STATUS	ON	ON	OFF	OFF

Figure 5.9: Gas Selection Screen

	CH1	CH2	CH3	CH4
ACT.FLOW	0.277	0.274	-0.000	0.000
UNIT	SLM	SLM	SCCM	SCCM
MODE	PID	SLAVE	INDEP.	INDEP.
INDEX		1		
STATUS	ON	ON	OFF	OFF

Figure 5.10: Mode Selection Screen

detector systems to consume it ³; it cannot build up pressure any faster than the flow-control valves can supply it. It may take thirty minutes or so for the pressure regulation system to stabilize at a new set-point or stabilize in response to a change in total gas consumption. However, you should be able to observe a change in the gas flow within a few seconds (possibly up to a minute) after a set-point change.

To turn gas flow on or off: The gas flow can be turned on or off while in any menu. In the Extended Display menu the bottom line displays “ON” or “OFF”, by channel, to show which mass flow valves are enabled. “ON” must be displayed in the bottom row of the Extended Display menu for gas to be flowing in a particular channel.

For gas to flow, two conditions must be met:

1. Each channel (1 and 2) must be enabled by pressing “ON” and then the desired channel number.
2. The entire system must be enabled by pressing “ON” and then “ALL” from the keypad.

Thus, each valve can be controlled individually using “ON/OFF - *Channel Number*”, or all flow can be controlled using “ON/OFF - ALL”. If the system is enabled, the status line at the bottom of every screen will indicate “FLOW ON GAS ON”. **Note:** because Valve-2 (ethane) is normally slaved to Valve-1 (argon), when Valve-1 is disabled there will be no flow through Valve-2.

To Change a Gas Bottle Only authorized personnel are permitted to change gas bottles.

The argon and ethane supply bottles should be replaced by new (full) bottles when the bottle content drops below about 10% of its capacity. For argon, the bottle content is directly indicated by the bottle pressure: a new bottle usually contains 2000 to 3000 psig.

³An *over-pressure relief valve* releases gas through a small oil bubbler in the gas shed if the pressure exceeds about 600 Torr.

Argon bottles should be changed whenever the bottle pressure is found to be below about 200 psig.

Ethane bottles, on the other hand, contain liquefied ethane. Thus the bottle pressure is just the vapor pressure of ethane at whatever the current temperature happens to be. At 70° F this is about 544 psig. The pressure gauge will not tell you how much ethane is left in the bottle until it reads zero! Instead, we measure the ethane content by observing the weight of the bottle and comparing it to the weight when the bottle was full. A standard B-size cylinder contains about 32 pounds of ethane. The ethane cylinders on the manifold sit on scales which have been pre-set to indicate the net weight of ethane in the bottle. Numbers in the green portion of the dial indicate ethane remaining. If the indicator points to the red portion of the dial, the bottle is empty.

Handling and connecting bottles of compressed gas require special knowledge. The high pressure gas stored in the cylinders (bottles) constitutes significant stored energy. Mishandling of a gas bottle can pose a lethal hazard! Refer to the JLab ESH&Q Manual for safe handling practices. If you do not already know how to safely manipulate compressed gas hardware, have a knowledgeable person train you.

After attaching a new gas bottle to the supply manifold, check the connection for leaks using *Snoop* or a similar leak detector.

The Alcohol Bubbler To reduce the rate of aging of the wire chambers, the operating gas contains a small quantity of alcohol vapor. The vapor is added by bubbling the argon/ethane mixture through liquid alcohol. The temperature of the alcohol controls the alcohol vapor pressure, which determines the amount of vapor added to the gas. The alcohol content also affects the electron drift velocity in the wire chambers, so it must be held approximately constant.

Gas is bubbled through the liquid alcohol inside the glass dome vessel in the refrigerator. The dome is covered by a perforated steel cylinder as a precaution against breakage. The alcohol level is controlled by a float valve inside the metal cold reservoir, which is also inside the refrigerator. As long as there is alcohol in the warm reservoir (sitting on top of the refrigerator), the liquid levels inside the refrigerator will remain constant. A drain valve (#7) inside the refrigerator is available for emptying all liquid from the system. It is for use by experts only and should remain closed during normal operation.

Alcohol Temperature Control To keep the alcohol temperature (and thus the vapor pressure) constant, the alcohol bubbler is housed in a refrigerator which is controlled by an electronic temperature regulator having 1°C sensitivity. The controller is located on a shelf in the right-hand rack of the gas mixing system. Normally, the actual temperature in the refrigerator is indicated on the front panel of the controller. The controller should be set to maintain a temperature of 2° C.

5.1.2.1 Safety Information

Hazards Some of the gases that are used are flammable. Also, the gas bottles are under high pressure and can become missiles.

Mitigations The bottles are located in a fenced area next to the gas shed with the bottles secured so that they can not fall.

In the Hall C counting house, alarms for the gas system are integrated into the VESDA system located on the left side of the control console. The VESDA system will go into alarm if elevated levels of flammable gas are present in either of the two spectrometer detector huts or the gas shed. Response to an alarm should be to contact the personnel listed below.

Responsible Personnel Maintenance of the gas systems is routinely performed by the Hall c technical staff. Shift personnel are not expected to be responsible for maintaining the detector gas systems (see Table 5.5 for the names of persons to be contacted in case of problems).

Name (first,last)	Dept.	Call [12]		e-mail	Comment
		Office	Cell		
Lars Gustavson	SSG	757-269-7415		larsg@jlab.org	
William Henry	Hall-C	6989	Web [13]	wmhenry@jlab.org	

Table 5.5: Responsible personnel for detector gas system.

5.2 The SHMS Detector Package and Shield House

The Super High Mometum Spectrometer contains two separate shielded rooms. The first room, referred to as the electronics hut, contains electronics associated with the trigger and data acquisition system as well as magnet power supply controls. (Figure 5.11) This room is entered through a concrete door on the second stairway landing of the spectrometer structure. The second shielded room, known as the detector hut, is accessed by passing through the electronics hut. These rooms are separated a sliding concrete door. Both doors must be closed during beam operations. The electronics and detector huts have removable ceiling and wall sections in case detectors or electronics racks need to be removed or installed. Walter Kellner, the Hall C work coordinator, must be contacted if the hut walls or ceilings need to be removed.

5.2.1 SHMS Electronics and Detector Shield Hut Doors

The SHMS electronics shield hut is accessed through concrete door held closed by a magnetic lock. To open this door, press and hold the button marked OPEN. (Figure 5.12)

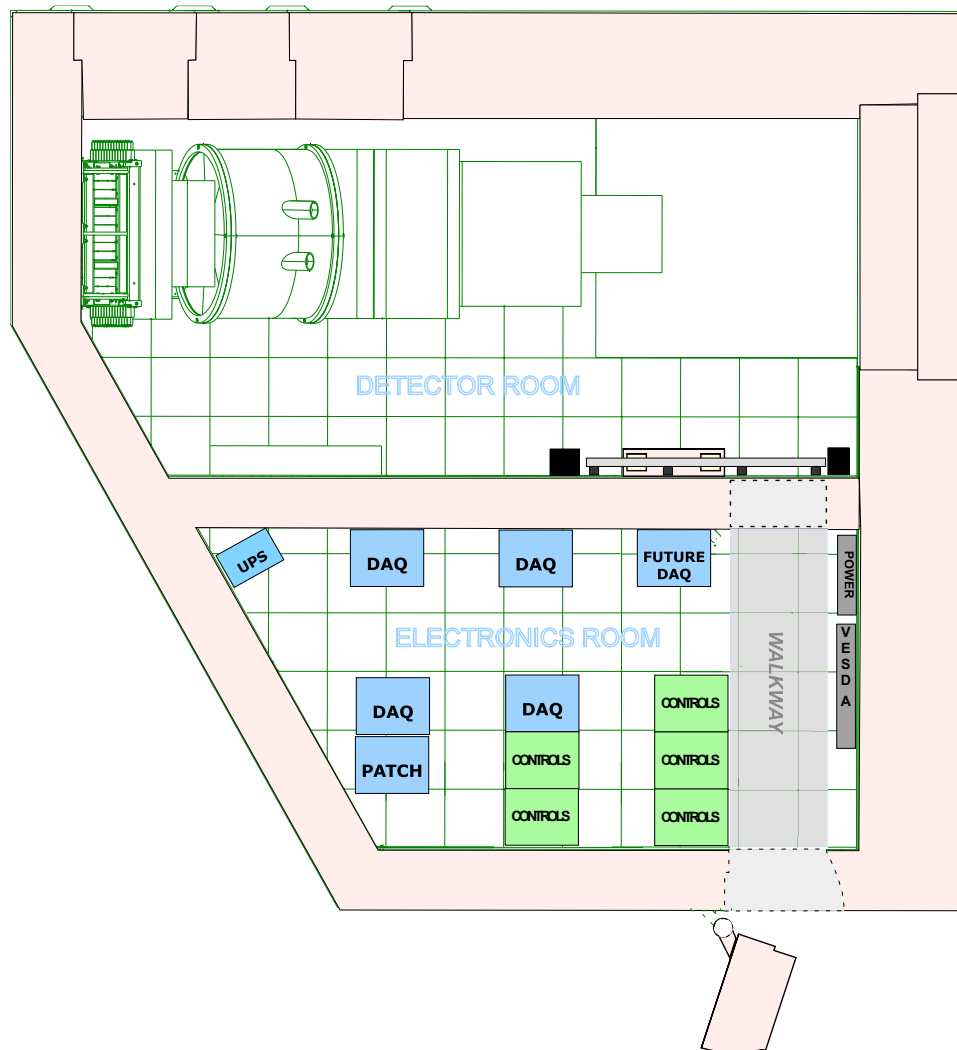


Figure 5.11: SHMS Detector and Electronics huts, accessible from the second level of the SHMS structure. The detectors are accessible by passing through the electronics room.

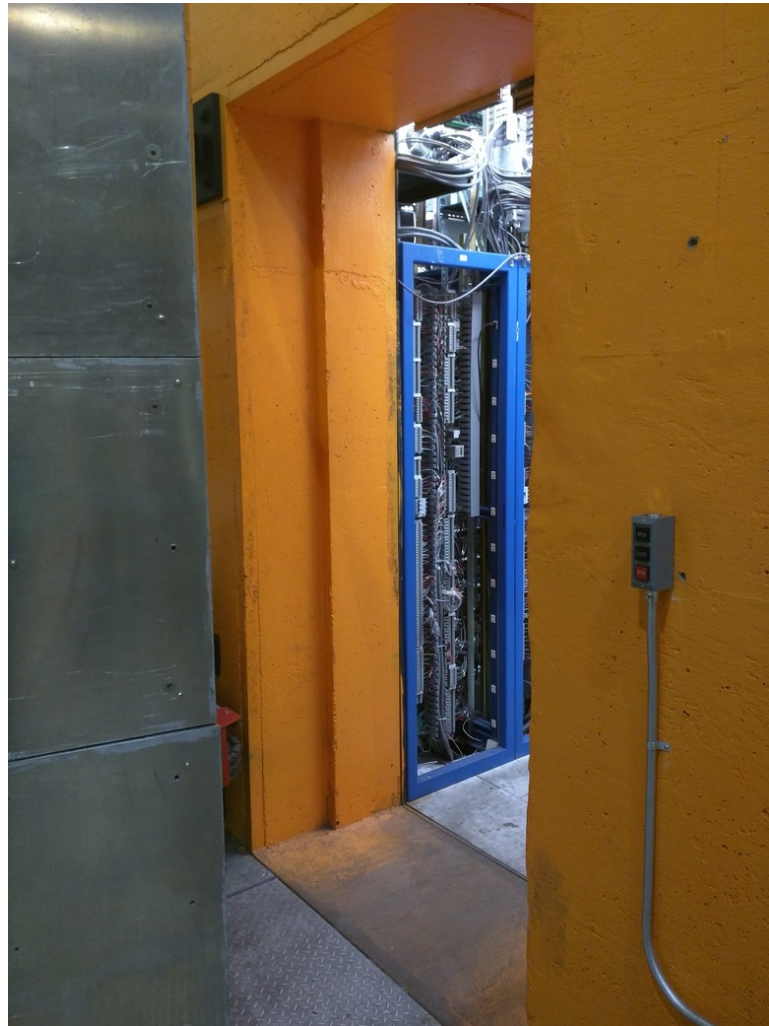


Figure 5.12: SHMS hut outside door control buttons.

This will deenergize the magnetic lock and rotate the door. When the door is open sufficient for access, release the button. To close the door, make sure the door is clear of obstructions and hold the CLOSE button until the door closes and the magnetic lock activates. A duplicate set of controls is located on the inside of this door. When the door motor is energized, audible and visual alarms will be activated.

The detector shield hut is accessed by passing through the electronics hut and passing through a second door. This door is a sliding door (“barn door”) and is operated by the lower set of buttons to the right of that door (Figure 5.13). This door is activated in the same manner as the outer electronics hut door: The door slides open while the OPEN button is depressed, slides closed when the CLOSE button is depressed and movement stops when the button is released. Audible and visual alarms are also installed for the sliding door. If the spectrometer vacuum window has a shutter installed, then this door may only be opened if that shutter is closed. This shutter is described in the next section.

An emergency bypass is available allowing override of the shutter interlock on the door. Hearing protection must be worn if detector hut is accessed while the shutter is open and the spectrometer is under vacuum.

5.2.2 SHMS Vacuum Window Shutter

As described in section 4.4.1.2, there is a large thin vacuum window at the end of the vacuum pipe in the SHMS detector hut. Because of the considerable stored energy in such a large vacuum volume, it is necessary to protect the window from accidental puncture by tools and equipment. If the Noble Gas Cherenkov detector is installed, protection is provided by that detector. If the Noble Gas Cherenkov is not installed, a vacuum extension pipe, with a window further into the detector hut will be used. In this case, the window will be covered by a shutter to protect the window from being punctured by tools. This shutter must be in place whenever the spectrometer is under vacuum and the “barn door” is open. The shutter is operated by using the top set of buttons shown in Fig. 5.13. To open or close the shutter, momentarily press the OPEN or CLOSE button. The shutter will move until it reaches the open or closed state. (Unlike the door controls, the button does not need to be held down.) Indicator lights near the shutter and door controls show whether the shutter is open or closed.

5.2.3 Super HMS Noble Gas Cherenkov Detector

Analyzing momenta up to 11 GeV/c at scattering angles from 5.5 to 40.0 degrees, the SHMS will reach kinematic regions in which the pion background rate dominates the scattered electron rate by more than 1000:1. The suppression of these anticipated pion backgrounds while maintaining efficient identification of electrons is therefore one of the main duties of the SHMS detector elements and the SHMS Noble Gas Cherenkov Detector shoulders a large portion of this particle identification burden. The design of the noble gas threshold Cherenkov detector is such that it will meet these twin goals of suppression and identification. The main goal of the detector is to distinguish between electrons and



Figure 5.13: SHMS barn door controls. The left picture shows the controls located in electronics hut. The bottom buttons control the barn door. The top buttons control the SHMS vacuum extension shutter. Below the shutter controls are lights indicating if the shutter is opened or closed. The right picture shows the barn door controls located inside the detector hut.

pions with momenta between 6 GeV and 11 GeV/c.

The basic equation governing Cherenkov radiation emitted by a particle of velocity β traveling through a medium with index of refraction n is

$$\cos \theta = \frac{1}{\beta n}, \quad (5.1)$$

where θ is the angle of the Cherenkov light cone. From this it is easy to see that for there to be any radiation

$$n > 1/\beta.$$

What we need is that

$$n < 1/\beta_{\pi,max} \quad (5.2)$$

to guarantee that the pions produce no radiation directly, and that

$$n > 1/\beta_{e^-,min} \quad (5.3)$$

to guarantee that all the electrons produce Cherenkov light. Since $1/\beta_{e^-,min} < 1/\beta_{\pi,max}$, we need to use only one value of n over the planned momentum range. Figure 5.14 emphasizes this point with a plot of the hadron velocity (given as $(1 - \beta)$) as a function of momentum along with the lines indicating the index of refraction of various gases at 1 atm, as $(n - 1)$. For a threshold Cherenkov counter only those particles with $(1 - \beta) < (n - 1)$ will produce light. For example no π 's with momenta less than 6 GeV/c will produce Cherenkov radiation in 1 ATM of Argon. If the π 's momenta exceed 6 GeV/c then it will cross the 'threshold' and Cherenkov radiation will be emitted. A first glance at Fig. 5.14 indicates that Neon would be a good choice for the SHMS Cherenkov detector. Operation at 1 ATM allow the windows on the detector tank to be very thin.

It is also possible to use a mixture of gases to fine tune the index of refraction and improve the detector performance. In this case the weighting of the index of refraction of the different gases is by the number of molecules per unit volume for each gas and the index is linear in the number per unit volume for each species. It should be possible to obtain pre-mixed gases from a vendor or mix them using techniques already in use at the laboratory. Hence the device has been designed to use Argon and Neon at the limits of 6 GeV/c and 11 GeV/c and a mixture in between.

The SHMS NGC design was restricted by the available space and the need to have good discrimination at the highest momenta. The number of photoelectrons is maximized in this design by the use of quartz window PMTs and mirrors with excellent reflectivity well into the UV. See Fig. 5.15. It was also desired to have a minimum of material in the path of the charged particles on order to keep multiple scattering small and preserve the SHMS design resolutions. The materials crossed by charged particles can be found in Fig. 5.16.

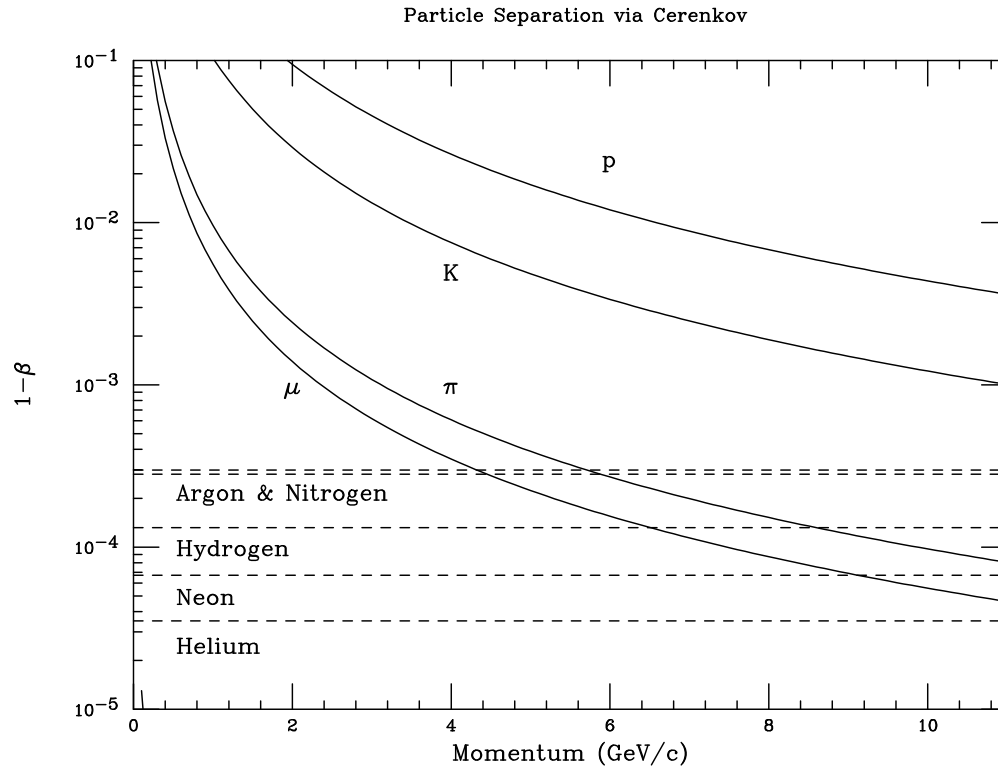


Figure 5.14: Particle identification with a threshold Cherenkov detector. Plotted is the hadron velocity as $(1 - \beta)$ against the hadron momenta. The horizontal lines indicate, for different gases at 1 ATM, the index of refraction as $(n - 1)$. Only when $(1 - \beta)$ is less than $(n - 1)$ does the particle produce light.

Description of the Cherenkov

The NGC consists of the following elements:

1. 2m long tank fabricated with an internal rigid frame and thin aluminum walls welded together. See Fig. 5.17.

The tank has an active volume of 2m along the beam direction and approximately 90 cm tank perpendicular to the beam direction. The tank was designed to position the PMTs outside the active area. The main access is provided through a large 'door' and four small panels provide modest access to the PMTS. There are large entrance and exit windows. The detector will operate at 1 ATM of either Argon or Neon or a mixture of the two. The tank has feedthroughs for gas management as well as for HV and signal cables. A black flat paint has been applied to the interior of the tank to prevent the reflection of light from cosmic rays or hall background.

2. Four spherical thin glass mirrors of radius 135 cm, square in shape with edges of

43 cm.

The mirrors overlap in the center to provide full coverage of the active area and each focus the reflected Cherenkov light on a separate PMT. The mirrors are tilted by 15° to allow the PMTs to be outside the active area. The mirrors are positioned in a monolithic frame that is installed as single unit. The mirrors are installed, the overlap set and rotated with the frame on a table outside the tank. See Fig.5.18.

3. Four 14 stage 5 inch quartz window PMTs manufactured by Electron Tubes Enterprises.

The PMTs are model 9823QKB04 and tubes with serial numbers 16747, 16777, 16787 and 16785 are installed to accept light from the mirrors in position Top Right, Top Left, Bottom Right and Bottom Left respectively while looking along increasing z . The tubes are surrounded by a mu-metal shield and the HV is distributed to the stages by a positive base.

4. Thin entrance and exit window made of two layers of 2 mils of the Dupont product, Tedlar - $(\text{CH}_2\text{CHCl})_n$.

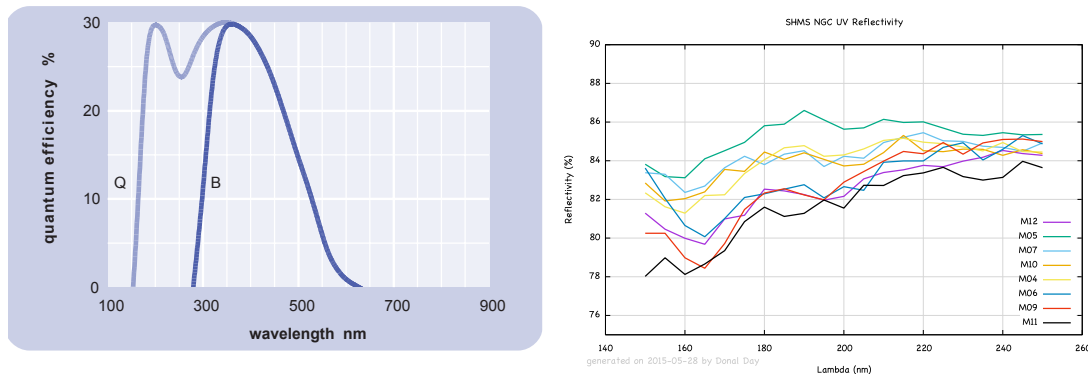


Figure 5.15: LHS: Quantum efficiency of Electron Tubes Enterprises model 9823QKB04 - light blue curve, labeled “Q”. RHS: The UV measured reflectivity of the mirrors coated at CERN. Between 250 nm and 600 nm the reflectivity rises to almost 90%.

The tank contains four 5 inch PMTs which use **positive** HV. They operate at between +1900 and +2400 Volts. The Anode is at HV and its signal is viewed through a decoupling capacitor in the base. The HV is supplied via the Hall C High Voltage system (see section 5.1.1).

The mirrors in the tank may require adjustment for optimal focusing on the PMT faces. This is only possible when the tank is out of the SHMS and on a horizontal surface (the hall floor) and the access door removed allowing entry into the tank. The tank is a confined space and hence this activity represents an ODH hazard. Stickers indicating this have been placed on the PMT ports and on the door. Before an entry into the tank the

Materials in path of electron in NGC Cerenkov										
Item	Material	Z	Atomic mass	density (g/cm ³)	RL (g/cm ²)	RL (cm)	Thickness(in)	Thickness (cm)	# RL	Source
Entrance Window ^{A*}	Tedlar ((CH ₂ CHCl) _n)	Z/A =	0.51201	1.3	25.51	19.63	0.002	0.00508	0.000259	PDG
Gas	Ar	18	39.948	1.66E-03	19.55	1.17E+04		200	0.017036	PDG
	Ne	10	20.18	8.39E-04	28.93	3.45E+04		200	0.005797	PDG
Glass	SiO ₂			2.2	27.05	12.29		0.3	0.024410	PDG
Exit Window	Tedlar ((CH ₂ CHCl) _n)	Z/A =	0.51201	1.3	25.51	19.63	0.002	0.00508	0.000259	PDG
									Total RL (with argon)	0.042
									Percent from mirror	58.2

*See http://pdg.lbl.gov/2014/AtomicNuclearProperties/HTML/polyvinylchloride_PVC.html

Figure 5.16: Materials in the path of charged particles passing through the NGC.

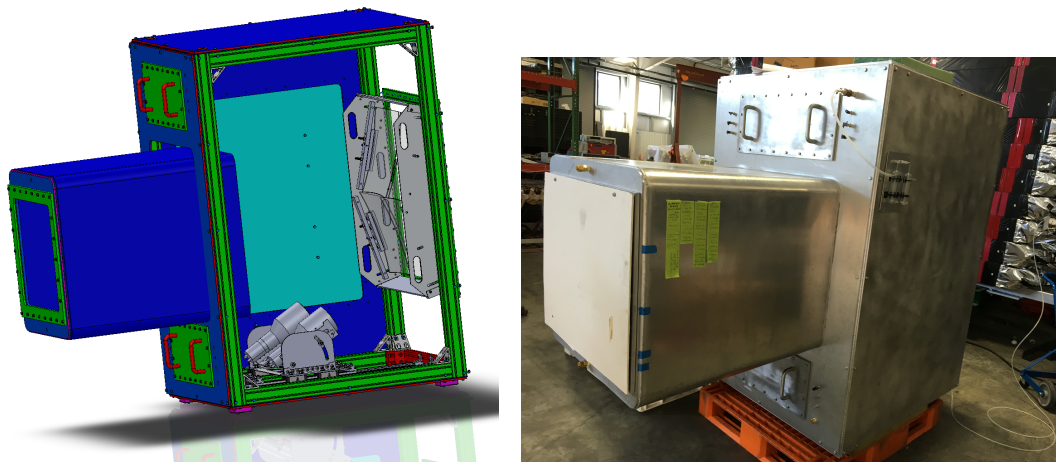


Figure 5.17: LHS: Sketch of the NGC tank. This view is possible as one panel is removed. Note the PMT mounting system is different than shown here. RHS: Buttoned up tank waiting installation.

atmosphere in the interior must be surveyed by a member of the physics division EH&S staff. This adjustment should only be done by personnel with experience. A document, “NGC Mirror Installation and Tuning”, has been written describing the optical tuning and it can be found at <https://hallcweb.jlab.org/doc-private/ShowDocument?docid=794>

Gas Filling Procedure

NOTE: All Fill procedures *MUST* be done by an approved NGC system expert.

1. At the Hall C Gas Shed.
 - (a) Configure the Mass Flow Controller (MFC) to deliver the desired mix of Argon and Neon.
2. At the SHMS gas panel in the SHMS detector hut:

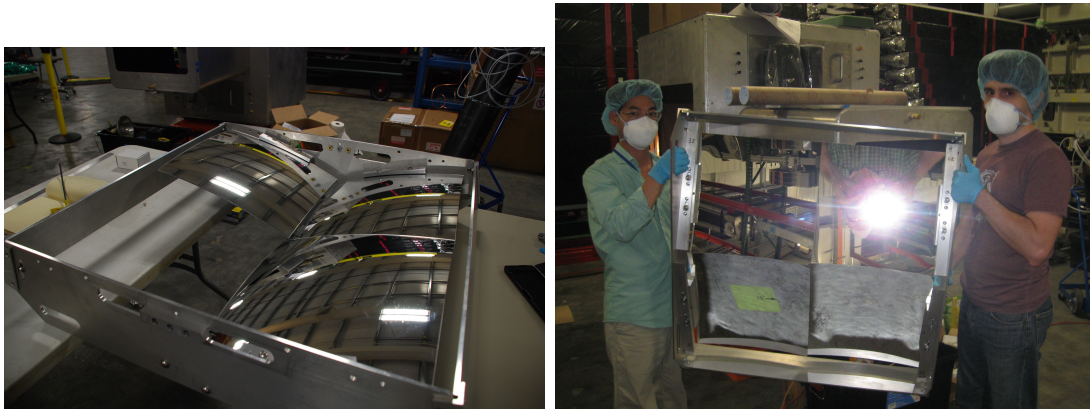


Figure 5.18: LHS: Three of four mirrors installed in frame. RHS: Frame about to be moved into tank.

- (a) Valve OFF the Ar/Ne supply upstream of the flowmeters (valve MV97902).
 - (b) Switch the 3-way OUTFLOW BUBBLER valve to the ‘High-Flow’ bypass.
 - (c) Switch the 3-way INPUT valve to the ‘High-Flow’ circuit.
 - (d) SLOWLY valve ON the Ar/Ne supply (valve MV97902) and monitor the flow on the ‘High-Flow’ flowmeter to ensure it does not exceed 100 scfh.
 - (e) Monitor the High-Flow over-pressure bubbler visible just under the NGC tank. **If there are bubbles, IMMEDIATELY close the Ar/Ne supply valve (MV97902), STOP the procedure and reassess the situation.**
 - (f) Allow the system to flow ≈ 100 scfh for a nominal 4 hours to ensure the gas concentration in the tank is composed of >98 – 99% of the desired mix.
 - (g) Valve OFF the Ar/Ne supply upstream of the flowmeters (valve MV97902).
 - (h) Switch the 3-way INPUT valve to the ‘Low-Flow’ circuit.
 - (i) Switch the 3-way OUTFLOW BUBBLER valve to the ‘Low-Flow’ bypass.
 - (j) SLOWLY valve ON the Ar/Ne supply (valve MV97902) and monitor the flow on the ‘Low-Flow’ flowmeter to ensure it does *not* go off-scale. (Typical flow ≈ 0.1 scfh.)
 - (k) Monitor the Low-Flow over-pressure bubbler visible on the gas panel itself **If there are bubbles, IMMEDIATELY close the Ar/Ne supply valve (MV97902), STOP the procedure and reassess the situation.**
 - (l) Wait until you observe 1–2 bubbles per second on the Low-Flow EXHAUST bubbler on the gas panel to ensure gas is flowing through the system.
3. The procedure is complete.

Additional Documentation Additional documentation may be found [27].

5.2.4 Hodoscope

The SHMS hodoscope consists of 4 planes, the first three made of bars of scintillating plastic, and the fourth of synthetic quartz. The purposes of the hodoscope planes include, providing a trigger that is approximately 100% efficient for minimum ionizing particles, to reject accidental coincidences in multi-arm experiments and to measure the efficiency of the tracking system.

The first two planes of the hodoscope, S1X, and S1Y, are located downstream of the second drift chamber. The second two planes, S2X and S2Y, are located about 2.2 meters downstream of the first pair. The Heavy Gas Cherenkov and Aerogel Counter are located between the hodoscope pairs.

5.2.4.1 Scintillator Hodoscope Planes

The SHMS scintillator planes are comprised of 13 paddles in S1X, 13 paddles in S1Y and 14 paddles in S2X. Further information about the scintillator hodoscope planes can be found in the “SHMS Hodoscope Scintillator Detectors” reference [28]. The scintillator material is RP-408 from REXON Corporation [29]. Each paddle has a photomultiplier tube on each end. A mix of XP2262 and ET9214B tubes are used. The scintillator plane PMTs use negative high voltage. Data sheets and testing information about these tubes and their bases can be found in the Hall C document database [30, 31].

5.2.4.2 Quartz Bar Hodoscope Plane

The fourth plane of the SHMS hodoscope, S2Y, (Figure 5.19) is comprised of 21 bars of Corning HPFS 7980 Fused Silica [32] (quartz), each with a length of 125 cm, width of 5.5 cm and thickness of 2.5 cm. As the quartz only emits light from Cherenkov radiation, it is relatively insensitive to low energy room backgrounds. Each quartz bar is read out by a photomultiplier at each end of the bar. A mix of Electron Tubes 9814Q, 9814W, and Photonis XP2020 tubes are used. All the tubes are powered by positive high voltage through RB1102 (for the 9814 tubes) and RB1106 (for the XP2020 tubes) resistive bases. Data sheets, testing and simulation information about these tubes and their bases can be found in the Hall C document database [33].

5.2.4.3 Responsible Personnel

The individuals responsible for the operation of the hodoscopes are shown in Table 5.6.

5.2.5 Drift Chambers

The drift chambers provide accurate measurements of particles position and angles in the detector hut. This information can be combined with a knowledge of the spectrometer optics to infer particle momenta and the angles and positions particles at the target.

The drift chamber package consists of two identical chambers, with 6 planes of wires each. (Figure 5.20) Each wire plane consists of a set of alternating 20 μm gold tungsten



Figure 5.19: The SHMS quartz bar hodoscope plane, S2Y, before mounting into the detector stack between S2X and the pre-shower plane.

Name (first,last)	Dept.	Call [12]		e-mail	Comment
		Office	Cell		
Dave Mack Gabriel Niculescu	Hall-A/C JMU	7442	Web [13]	mack@jlab.org gabriel@jlab.org	Scintillator Planes
Ioana Niculescu	JMU			ioana@jlab.org	Scintillator Planes
Abdellah Ahmidouch	NCA&T			abdellah@ncat.edu	Quartz Plane

Table 5.6: Hodoscope responsible personnel.

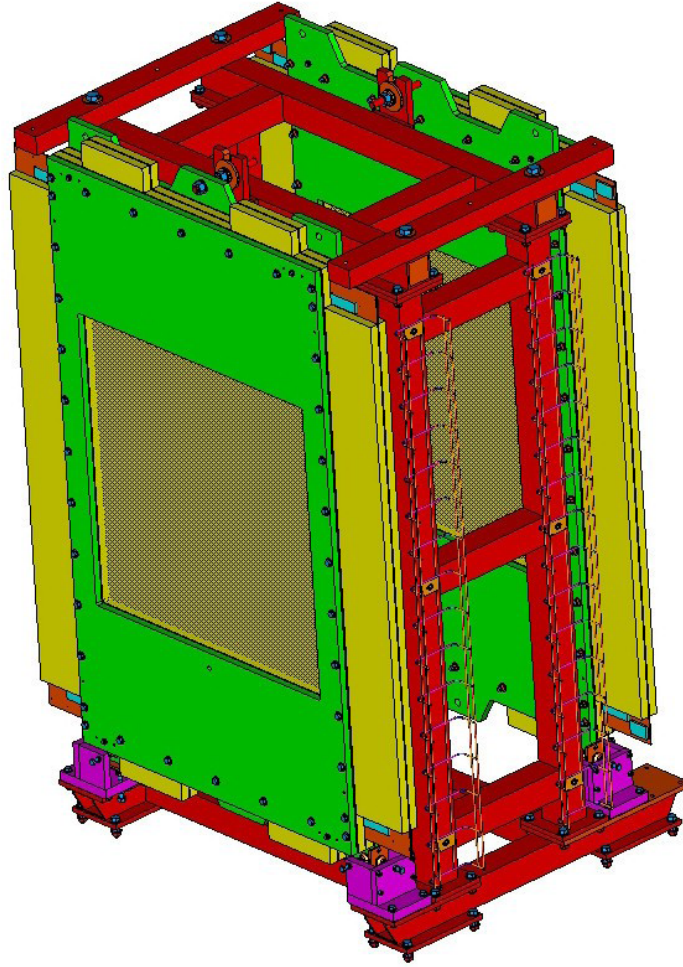


Figure 5.20: Technical drawing of the SHMS drift chambers mounted in the detector hut frame.

sense (anode) wires and $80 \mu\text{m}$ field wires, separated by 0.5cm . A cathode plane of copper coated mylar is located between each wire plane, before the first wire plane and after the last wire plane. In planes labeled X and X' , the wires are horizontal. In the U and U' planes the wires are rotated 60° relative to the X planes while in the V and V' planes the wires are rotated by -60° . The V' , X' , and U' planes are offset from the unprimed planes by 0.5 cm . The first chamber consists of planes ordered as (U, U', X, X', V', V) . The second chamber, while of identical design to the first chamber is rotated by 180° about the vertical axis, so the plane ordering is (V, V', X', X, U', U) . Note however, this rotation results in the U (V) planes in first chamber being parallel to the V (U) planes in the second chamber. The active area of each chamber is $80 \text{ cm} \times 80 \text{ cm}$ which has been set to match the active area for particles in the SHMS focal plane. Further details about the design and construction of the drift chambers are in the SHMS Drift

Chambers reference [34].

The drift chambers 50/50 mixture (by weight) of Ethane/Argon as a drift gas which flows across all of the wire planes. The system that delivers this gas is described in section 5.1.2.

The high voltage for the SHMS drift chambers is supplied by CAEN high voltage, low current, power supplies in the electronics room of the counting house and can be controlled through a GUI on the console computers. The operating voltages for the chambers are a nominal -1800V (foil) and -1800V (potential wires). Control of the high voltage system is described in section 5.1.1.

Each anode/sense wire has its own electronic readout through Nanometrics preamplifier/discriminator cards or LeCroy Corporation LRS 2735DC cards which are interchangeable with the Nanometrics cards. The discriminator outputs from the cards, each of which instruments 16 sense wires are connected to CAEN V1190 multi-hit TDCs located in the SHMS electronics hut. The discriminator cards are powered by +5V and -5V Acopian power supplies that are located in the SHMS electronics hut. The supply currents are several 10s of amps for the positive and negative supplies. The discriminator thresholds for these cards are controlled by a power supplies in rack CH03B10 in the Hall C counting house. Nominal threshold settings will be posted by on the supply.

Start-of-Run Procedure The procedure for turning the chambers on at the start of an experiment is the following:

1. Make sure gas is flowing through both chambers.
2. Turn on the low voltage Acopian power supplies in the SHMS detector hut.
3. Turn on the VME crate with the TDCs if it is not already on.
4. Turn on the threshold power supply to the appropriate setting (nominally 4V).
5. Turn on the high voltage.

End-of-Run Procedure At the end of an experiment or before an extended down, the high voltage supplies and the Acopian low-voltage supplies should be turned off. The ethane gas flow may be shut off, but the argon gas flow should be left on to keep the chambers clean and dry.

5.2.6 Heavy Gas Cherenkov Detector

A charged particle traveling faster than the speed of light in the medium will create an electromagnetic disturbance in the medium. The radiation emitted by this process is called Cherenkov radiation after its discoverer.

Cherenkov radiation is conically distributed about the trajectory of the particle, with an angle given by

$$\cos \theta = \frac{1}{\beta n}$$

where the index of refraction $n = c/u$ and $\beta = v/c$, with c the speed of light in vacuum, u the speed of light in the medium, and v the speed of the particle.

The index of refraction allows one to control the threshold particle velocity $v_T = u = c/n$ below which there is no Cherenkov light produced, and above which there is Cherenkov light produced. For a gas, the quantity $n - 1$ is proportional to the pressure, so adjusting the pressure of the gas allows one to select the threshold velocity. Adjusting the threshold velocity then allows one to select particles of different mass. Given the same momentum, two particles of different mass will have different velocity. Therefore, a Cherenkov detector can be tuned, for instance, to distinguish electrons from pions.

The SHMS Heavy Gas Cherenkov detector consists of a large cylindrical tank, with outer flange diameter of 1.88 m or 74 inch, and bolt to bolt length of 1.3 m or 51.1 inch. The detector contains four mirrors which focus light onto four 5 inch Hamamatsu R1584 photo multiplier tubes (PMTs), as shown in Fig 5.21.

The main detector cylinder is made of a 0.5 inch thick T6061-T6 Aluminum sheet with radius of 1.725 m or 67.9 inch. Both circular ends have been covered with 0.04 inch thick 2024-T4 Aluminum windows. These windows were hydrostatically formed (and hence tested) at a pressure of 45 PSI. In addition, the windows were hydrostatically tested at a pressure of 60 PSI. The tank itself was helium leak checked and is leak free on a scale of 10^{-8} Atm-cm³/s. HGC detector configuration only allows sub atmospheric pressure operation, thus under no circumstance the detector pressure shall exceed 1 Atm. Each of the aluminum windows are sandwiched between the detector vessel and a thick aluminum flange. All three components are clamped with stainless steel bolts with washers and silicon bronze nuts. Installation torque for each bolt is specified to be 26 lb-ft.

The HGC tank is mounted on the detector rails using a three point alignment scheme. The rails are easily capable of supporting the weight of the tank without deformation. The gas handling system for the tank is designed to enable the tank to be filled with gas suitable for the experiment. Typically this would be C₄F₈O (C₄F₁₀), or CO₂, at the desired operating pressure which is 0.2-1 Atm. Detector operating pressure must not exceed 1 Atm.

The system consists of a dual-bottle gas manifold for the production gas and a third single-bottle manifold for a purge gas (nitrogen or CO₂). The bottle rack is at floor height welded to the SHMS detector carriage under the stairs on the large angle side.

A diagram of the gas circuit is reproduced in Fig. 5.22. Each gas bottle has its own regulator, and all should be set to a nominal 40 psig. The ultimate gas pressure delivered to the gas panel in the SHMS hut is limited to less than 14 psig by a pressure regulator at the manifold output set to 12–13 psi and protected by a 14 psi popoff valve.

The gas flows through a 14X molecular sieve located on the SHMS detector gas panel in the detector hut to hedge against contamination and is delivered to the tank through a fill valve. A digital flow-meter monitors and logs the gas being delivered, and a digital pressure gauge records the pressure in the tank. Communication between the digital pressure gauge and digital fill valve limits the final pressure in the tank. A 1 psig popoff valve protects the tank from unintended overpressure due to misconfiguration or

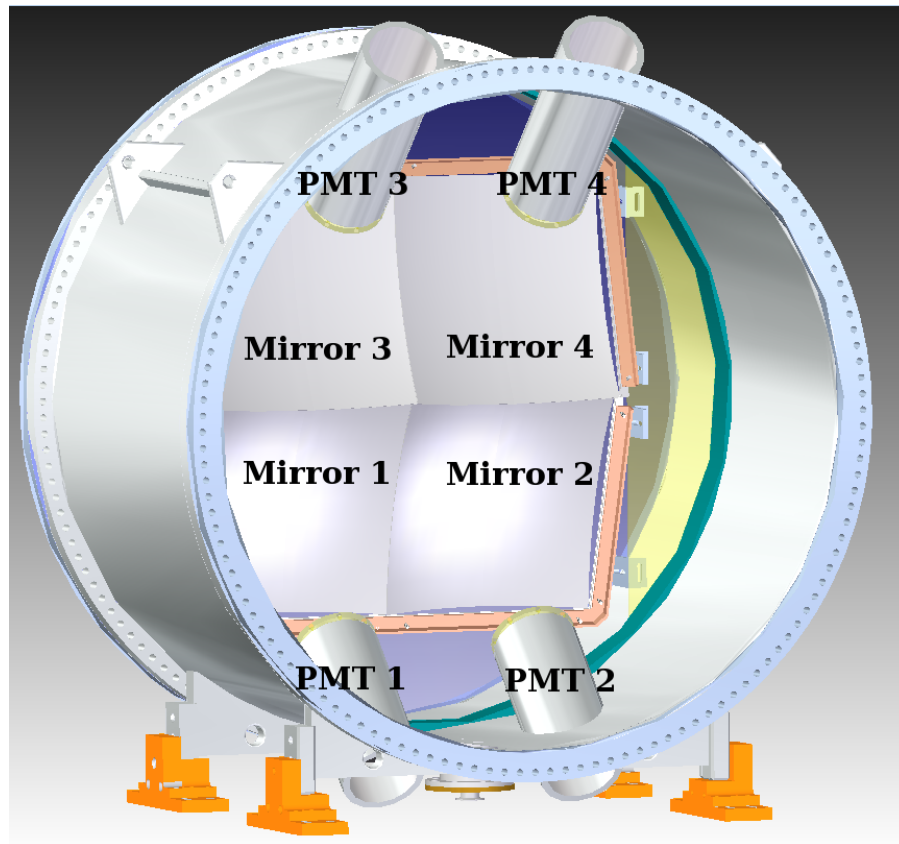


Figure 5.21: CAD Drawing of SHMS HGC detector.

equipment failure.

Before filling, the tank is first cleaned by executing several pump and purge cycles. The oil-free pump that used to evacuate the tank is located on a platform welded directly beneath the HGC tank and can be controlled both locally or remotely. The fill valve is verified to be closed (it's normal state), the pump engaged, and the pump-out valve opened. Pressure in the tank can be monitored both locally and remotely via the digital pressure gauge.

The mirrors in the HGC may require adjustment for optimal focusing on the PMT faces. Small adjustment to the mirror position cannot be done while the detector is mounted. The adjustment to mirror position can only be performed when the detector vessel is in the horizontal position with both aluminum windows completely removed. While the HGC is mounted, up to 1 cm adjustment to PMT position can be made by repositioning the plastic eccentric PMT holders. This adjustment should only be done by personnel who completely understand the design of the PMT mounting assembly.

PMTs From Fig 5.21, there are four aluminum sleeves welded onto the detector cylinder, where each sleeve hosts one PMT assembly. Note that the PMT assembly is outside of the vessel enclosure, viewing the Cherenkov radiation through a quartz viewport. The

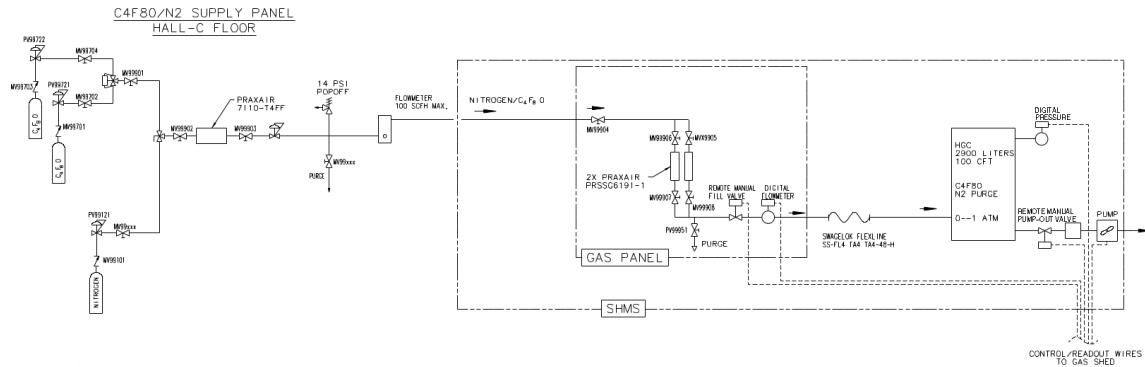


Figure 5.22: CAD Drawing of SHMS HGC gas system (excerpt from JLab Drawing 67165-00100).

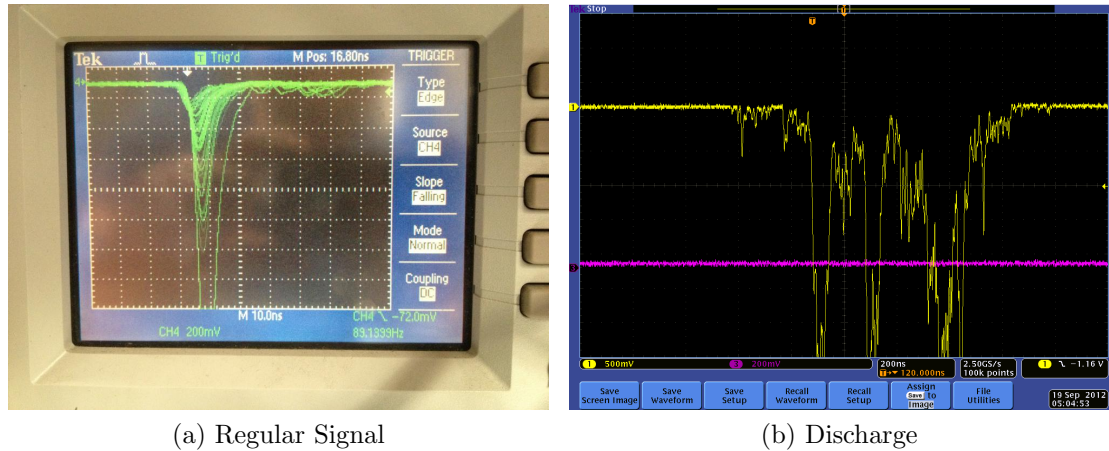
PMT #	Serial #	Voltage
1	LA0274	2132
2	LA0272	1967
3	LA0273	1926
4	LA0271	2013

Table 5.7: Serial number and initial recommended operating voltage for each PMT.

inner end of each sleeve is installed with a quartz window that provides vacuum seal. The rounded face of each Hamamatsu R1584 PMT is glued to a custom flat-head quartz adapter. The PMT and quartz adapter is pressed against the viewport, held in position via spring pressure. The contacting optical surfaces are coupled with a thin layer of UV-transparent silicon grease. A spring lock-in mechanism (open end of the sleeve) is used to provide mechanical pressure to ensure good contact between optical surfaces and a customized rubber cone is used to provide a seal against light leaks.

The SHMS HGC 5 inch PMTs use **negative** HV. The PMT photo-cathode is powered using high negative voltage and the mu-metal shield is grounded, so there is a 2000 V potential difference between the PMT and the shield. Note that the Aerogel and Noble Gas Cherenkov detectors use PMT bases that are designed for positive HV, therefore one must only use labeled HV cables for HGC. The HV is supplied by one pod of the *CAEN* power supply. The safe PMTs operating voltages are between 1500 and 2400 V. For the initial commissioning stage, the operation voltages should not exceed 2200 V. The serial number and initial recommended operating voltages for each PMT are listed in Table 5.7. At the recommended voltage, the expected average pulse height for a PMT signal should be ~ 400 mV and rates ~ 100 Hz.

Fig 5.23a shows an example of regular signal from a R1584 PMT; Fig 5.23b shows an example of discharging signal indicating a breach of electrical insulation between the photo-cathode and mu-metal shield. The discharging signals have very distinctive characteristics since they are relatively large pulses (>5 Volts) that are >100 ns long.



(a) Regular Signal

(b) Discharge

Figure 5.23: (a) shows example of regular PMT signal; (b) shows a discharged signal.

At the time of installation, extensive tests were performed for all four PMTs and confirmed no discharge at 2000 Volts. Once discharging signal is observed, one should carefully monitor the rate as well as report the incidence immediately. The primary suspect for causing discharge pulse is a possible electric insulation breach between the photo tube and mu-metal shield. Further diagnose would require complete removal of the PMT assembly from the aluminum sleeve while all four PMTs are switched off. Electric insulation that covers the inner edge of mu-metal shield cylinder must be carefully inspected. Once the location of discharge is identified, it is recommended to seal the suspect area with few layers kapton tape.

Operation Procedures The SHMS Heavy Gas Cherenkov Detector operates either as an π/κ or e/π discriminator. Figures 5.24 and 5.25 indicates suggested gas pressure vs. Cherenkov threshold for various particles and SHMS momentum settings. C_4F_8O and C_4F_{10} are functionally equivalent gases in this role. See references [35] and [36] for more detailed studies.

The nomenclature used in the description of these operation procedures refers to the gas system diagram in Figure 5.22.

π/κ Procedures This mode of operation typically requires the tank to be filled with C_4F_8O (C_4F_{10}) at pressures varying from 0.2 to 1 Atm (absolute). The detector is pumped down to 1 millitorr, then refilled with C_4F_8O (C_4F_{10}) gas.

Because the operating pressure is slightly subatmospheric, a pump and fill procedure is employed.

1. Initial Prep

- (a) Ensure that the HGC Remote Fill Valve is CLOSED.

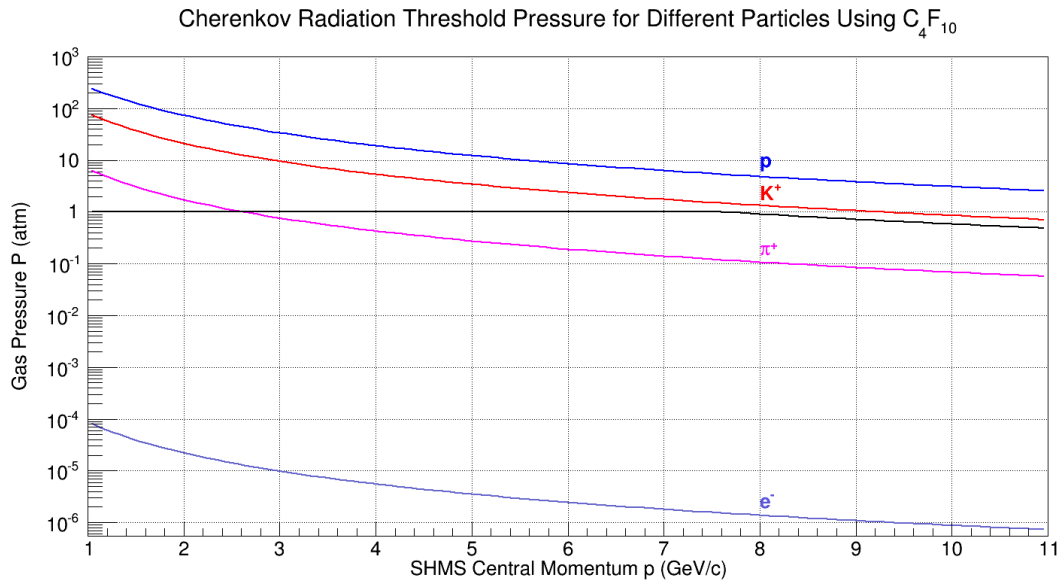


Figure 5.24: Gas Pressure vs. Particle Momentum. The black curve represents the suggested gas pressure of the HGC detector for good π/κ separation. The colored curves represent the Cherenkov threshold pressure for different particles. C_4F_8O performs equivalently to C_4F_{10} in this context.

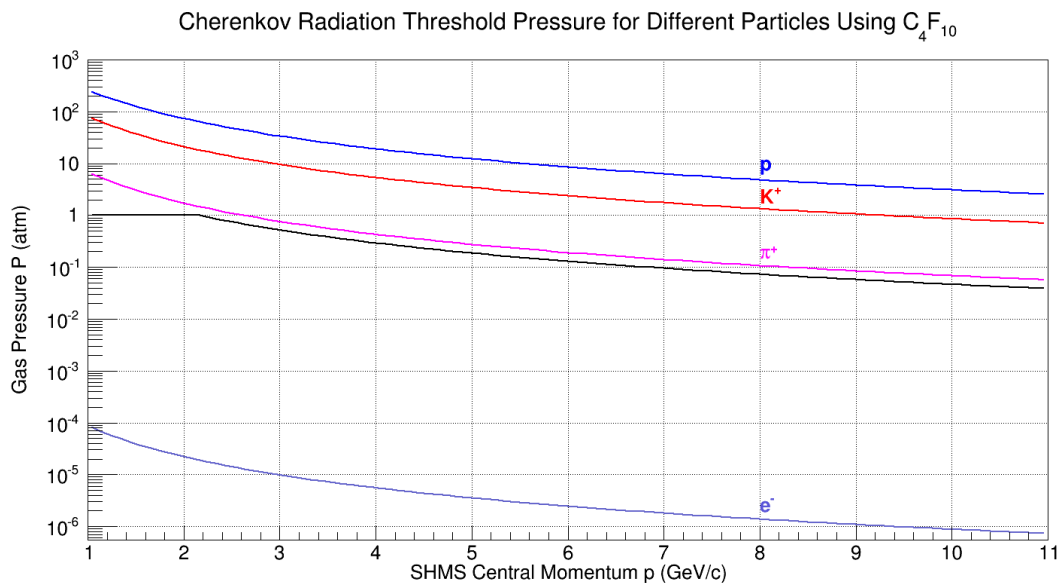


Figure 5.25: Gas Pressure vs. Particle Momentum. The black curve represents the suggested gas pressure of the HGC detector for good e/π separation. The colored curves represent the Cherenkov threshold pressure for different particles. C_4F_8O performs equivalently to C_4F_{10} in this context.

- (b) If you will be changing the radiator gas, then ensure Valve **MV9902** is also CLOSED. This is the main cut-off valve downstream of the 3-way valve on the supply gas panel under the stairs on the SHMS carriage.
 - (c) Rotate the 3-way valve to connect the radiator gas you require to the downstream system.
 - (d) Leave the cut-off valve closed for now.
2. The tank is now ready to be evacuated.
- (a) Turn ON the pump. (This pump is oil-free and does not require a trap.)
 - (b) Very *slowly* open the HGC Remote Pump-out Valve. Since this valve connects the pump line to the detector volume, the pump will work hard. Meter this valve so that the pump is never under extreme stress. It will take approximately 20 minutes to pump down the tank.
 - (c) Monitor the HGC Digital Pressure readback and close the HGC Remote Pump-out Valve when you have reached $\approx 110^{-3}$ Torr.
 - (d) CLOSE the HGC Remote Pump-out Valve.
 - (e) Turn OFF the pump.
 - (f) Monitor the HGC Digital Pressure readback for a few moments and ensure it is stable!
3. The tank can now be filled.
- (a) If required due to Step 1b, *slowly* open the cut-off valve on the gas supply manifold under the SHMS stairs. Monitor the flow-meter on the same panel and ensure that you do **NOT** see any flow beyond that needed to pressurize the lines to the distribution panel in the SHMS detector hut.
 - (b) Slowly open the HGC Remote Fill Valve and monitor the Digital Flowmeter *and* Digital pressure readbacks. A reasonable flow is 20 cfm.
 - (c) Monitor the HGC Digital Pressure readback and close the HGC Remote Fill Valve when you have reached the desired operating pressure.
 - (d) CLOSE the HGC Remote Fill Valve.
 - (e) If the tank will remain at this pressure for an extended period (*i.e.* over a week, then CLOSE the main cutoff valve at the supply panel under the SHMS carriage stairs (**MV9902**).

The fill should take approximately 30 minutes. The detector should NEVER be left unattended during a fill. Frequently check the pressure in the tank and be aware when the pressure is near to one atmosphere. **DO NOT let the pressure exceed one atmosphere under any circumstances; doing so risks damage to all of the equipment and personnel in the detector hut.**

Table 5.8: Momentum threshold above which pions, kaons and protons will produce Cherenkov light in Aerogels with various indices of refraction.

n	$\pi_{\text{thr}}(\text{GeV}/c)$	$K_{\text{thr}}(\text{GeV}/c)$	$p_{\text{thr}}(\text{GeV}/c)$
1.030	0.57	2.00	3.80
1.020	0.67	2.46	4.67
1.015	0.81	2.84	5.40
1.011	0.94	3.32	6.31

Table 5.9: List of materials in the path of particles traversing the SHMS aerogel detector

Component	Material	Thickness (cm)	Density (g/cm ³)	Radiation Length (g/cm ²)
Entrance Window	Al	0.13	2.7	24.01
Aerogel	SiO ₂	9	0.2	44.054
Air gap in detector	Air	17.1	0.00121	36.66
Exit window	Al	0.16	2.7	24.01

5.2.7 SHMS Aerogel Detector

The SHMS Aerogel detector [37] is located after the Heavy Gas Cherenkov detector and before the S2 hodoscope planes. It provides kaon/proton discrimination up to 7.2 GeV/c. The detector is mounted on a sliding rail system so that it may easily be placed into or removed from the path of particles in the detector hut. Several Aerogel indices of refraction, shown in Table 5.8, are available for use with the detector. The material in the path of particles passing through the detector stack is summarized in Table 5.9.

5.2.7.1 Design Overview

The detector consists of two main components: a tray which holds the aerogel material, and a light diffusion box with photomultiplier tubes (PMTs) for light readout. To cover the required kaon identification momentum range of up to 7.2 GeV/c, four identical trays for aerogel of nominal refractive indices of 1.030, 1.020, 1.015, and 1.011 were constructed. Using 5-inch diameter PMTs mounted on the vertical sides of the diffusion box and up to 9 cm aerogel thickness in the trays, the total depth of the detector is 29.0 cm along the optical axis of the SHMS. The design allows for replacement of the aerogel trays.

The main components and features of the detector assembly are:

- **Diffusion box** made mostly of aluminum alloy 6061-T6. The sides and top panel are constructed of 2.5 cm (1-inch) aluminum plates, while the bottom plate is

made of a 1 inch stainless steel plate. The back cover is 1.6 mm (1/16 inch) thick aluminium. The inner dimensions of the box are $113 \times 103 \times 17.3$ cm³ ($44.5 \times 40.5 \times 6.75$ inch³).

- **Four (4) exchangeable aerogel trays**, of the same transverse size as the diffusion box but 11.3 cm (4.45 inch) deep. The front cover of the trays is made of a 5 mm thick honeycomb sandwich panel with effective aluminum thickness of 1.3 mm (0.050 inch).
- **Fourteen (14) 5-inch diameter photo-multiplier tubes** (Photonis XP4572B) mounted upon waterjet cut circular openings on the left and right sides of the diffusion box. The mechanical design includes six openings on the top of the diffusion box, presently covered with blanks. PMTs are placed in aluminum cylinders for mechanical protection, with a 1mm thick mu-metal cylinder (also inside the aluminum cylinder) for magnetic shielding.
- **Fourteen (14) positive HV active bases** These bases include built-in amplifiers powered by the voltage divider [38, 39].
- **Approximately 700 tiles of aerogel (~10 kg) installed in each tray** in a running break bond pattern. Total thickness of the aerogel radiator along the optical axis is ~9 cm, or 8 tiles. Each tile has approximate dimensions of 11 cm by 11 cm by 1.1 cm.
- **GORE reflector material** (DRP-1.0-12x30-PSA) with reflectivity of about 99% covering the inner surface of the diffusion box with 3 mm (~60% of the surface) and 1 mm (~40% of the surface) thickness.
- **Millipore paper Membrane GSWP-0010** of reflectivity of ~96% covering the inner surface of the SP-30 and SP-20 aerogel trays with 1 layer of 0.45 μ m thickness.
 - 1 mm thick Gore diffusive reflector material is used instead of Millipore in the two lower refractive index trays (SP-15 and SP-11) to optimize light collection.
- **Aluminum mounting hardware.**

The aerogel trays attach to the diffusion box by means of bolting (stainless steel #10-24UNC \times 0.63 inch length hex tap bolts) through flanges surrounding the boxes. A round O-ring (1/8 inch EDPM of ~175 inch length cut to size) runs in the flange groove around the diffusion box and ensures light tight connection. Additionally, Scotch 130C tape is added on the top of the O-ring for light tightness of the detector. The entire detector is designed such that it can be slid out of the SHMS detector stack for aerogel tray exchange. Note, however, that no experiment can run with detector in this position since the right-side PMTs will extend into the SHMS acceptance.

5.2.7.2 Installation Location and General Operating Procedures

The SHMS aerogel detector is installed in the detector hut of the SHMS between the heavy gas Cherenkov and the second hodoscope plane. The installation and/or removal of the SHMS Aerogel Detector must be handled by Hall C technical staff, with experts assistance (see list of experts at the end). In general, the detector is designed for removal from the sliding detector stand.

Prior to any work that involves exchange of the aerogel trays or installation/removal of the diffusion box, the plastic safety cover on the Heavy Gas Cherenkov must be installed. This cover must be removed before resuming regular operation.

Before moving the diffusion box it should be checked that all high voltage and signal cables are long enough for the move or are disconnected from the HV bases. After any move of the detector it should be verified that the center of the aerogel detector is aligned with the SHMS optics axis. This should follow automatically when the detector is mounted on its stand and slides in its nominal position. Nevertheless, a survey should be performed after any major move of the detector. The drawings of the detector and its stand are available from the Hall C engineering group.

The photomultiplier tubes and bases are operated at positive high voltages up to ~ 2000 V (see Table 5.10). No directly accessible components carry high voltage. Standard safety precautions for handling high voltage on photo tubes must be observed, including, but not limited to disabling the HV at the power supply and disconnecting the HV cables from the bases (except in limited test cases) whenever the base covers are removed (to avoid electrical shock), or whenever there is possibility of room light entering the aerogel box (to avoid damaging photo-cathodes of the tubes). The personnel shall be careful when removing a tube-base assembly, shall avoid mechanical shocks of the tubes and of the whole assembly in order not to break the glass tubes and to preserve the properties of the inner mu-metal shielding.

The composition of the aerogel material is $(2n(\text{SiO}_2) + 2n(\text{H}_2\text{O}) + \text{air})$. This type of aerogel is not hygroscopic and will not lose its detector capabilities if contaminated with vapors from air. But, the box should be kept sealed whenever possible, clean and dry, and the material should not be touched directly. The aerogel is rather fragile, and a tile (especially of the lowest index of refraction $n = 1.011$) will usually not support its weight when grasped with one hand.

None of the materials and components used are known to pose any health or environmental hazards beyond cutting skin from broken glass or sharp edges. Any debris (dust) from a damaged aerogel material can be wiped off with a damp cloth or washed off. Extreme care should be taken to avoid getting aerogel dust or fragments in the eyes. Seek medical attention if this occurs.

The aerogel box, including aerogel material and tube/base assemblies but excluding SHMS mounting hardware, weighs about 100 kg and can be handled by 4 persons during (de-) installation.

5.2.7.3 Aerogel Tray Exchange

Installation and/or removal of the SHMS Aerogel Cherenkov must be handled by Hall C technical staff, with experts assistance (see list of experts at the end). Following is the standard procedure for change of aerogel tray:

Preparations

- turn off HV voltage on the aerogel Cherenkov detector, and on all nearby detectors (in special the Heavy Gas Cherenkov and the hodoscope);
- be sure that you and detectors are protected from any accidental HV connections;
- watch the HV and signal cables on the diffusion box during any movement of the detector. Removal may not be necessary
- install the plastic cover on the window of Heavy Gas Cherenkov on the aerogel tray side, i.e., downstream of the aerogel detector;
- mark current position of the aerogel detector in the detector stand (detector and components must be placed back at exact same position);
- keep all tools ready: mechanical supports and necessary materials which you will need for this operation (wrenches of different sizes, alignment pins, a spare O-ring, support structure, black tape, plastic cover for the Heavy Gas Cherenkov, cover for empty box while tray is being exchanged);
- taking out an aerogel tray from detector hut or replacing an aerogel tray requires a specially designed support structure (look in the physics storage building or ask the Hall C coordinator).

NEVER APPLY FORCE TO A PMT OR DETECTOR FRONT WINDOW! AVOID MECHANICAL SHOCKS OF THE DETECTOR DURING TRANSPORTATION & INSTALLATION! KEEP AEROGEL TRAY AT OPERATING ANGLE ~ 18 DEGREES!

Removal of an aerogel tray

- remove part of the roof of the SHMS hut (if that is in place), making enough room for lifting the aerogel tray in the horizontal position
- place a pallet on the floor of the SHMS hut for lifting the aerogel tray out of the hut
- loosen the clamps that are fixing detector position (one on the top of the detector and two on the slide stand);
- move the detector out from its position by sliding (along two slide stands);

- move support structure into the SHMS detector hut and adjust its position to hold aerogel radiator when it will be disconnected from the diffusion box;
- loosen all bolts that connect tray with diffusion box; when all detectors are installed, this operation may require the use of a step ladder to loosen bolts on the detector side closest to the SHMS wall.
- fit the support stand and fix it to the aerogel tray position at the same angle ~ 18 degrees (the SHMS normal operational position), using straps to tight the support to the tray's handles;
- remove all bolts that connect tray with diffusion box;
- gradually slide support structure with aerogel tray backward in order to disconnect it from diffusion box;
- put temporary shielding (black plastic or Tedlar cover) on the open window of diffusion box to keep its volume clean and dark, and put cover on the aerogel tray to keep its volume clean;
- carefully lower the aerogel tray assembly (aerogel tray with support structure) horizontally on the SHMS hut floor onto the pallet aerogel facing up. If the overhead crane is used, the tray must be guided by hand to minimize shifting of the aerogel tiles, in particular for the lowest aerogel indices.
- secure the aerogel tray assembly to the pallet
- cover the aerogel tray with an aluminum plate
- take out aerogel tray assembly from the detector hut using the crane and always keeping the pallet in horizontal position;
- disconnect aerogel tray from support stand and put it on the floor (assuming you already have some flat soft material laid down on the floor);
- put all bolts and fix position of the cover on tray, put tape along the tray-cover contact line. (this should be before, still inside the hut, to avoid dirty material from the crane to contaminate the aerogel)

Installation of an aerogel tray (assume the new tray is already in the SHMS balcony)

- place the aerogel support structure onto a pallet that can be picked up by the crane
- place the aerogel tray horizontally with aerogel facing up onto the support structure on the pallet (see Fig. 5.26)



Figure 5.26: Aerogel tray on the pallet picked up by the crane.



Figure 5.27: Illustration of lifting the aerogel tray to 18 degrees by hand and lifting it into position.

- loosen bolts on cover and mount aerogel tray at the correct position on the support structure (use marks which indicate best position for joining aerogel tray with diffusion box). Secure the tray with a strap onto the support structure and pallet;
- move the aerogel tray with support structure and pallet into the detector hut by use of the Hall C crane (keep the assembly horizontally);
- place the assembly on the SHMS hut floor. Unstrap the support and aerogel tray from the pallet.
- loosen bolts and, if installed, take away temporary covers from the aerogel tray and from the diffusion box;
- Attach the support and aerogel assembly to the crane, but do not lift yet. First carefully lift the assembly by hand to the required 18 degree angle. Once that is done, carefully lift the tray (keep the assembly at 18 degrees angle) towards the diffusion box this requires at least 2 people steadying the assembly during the lifting (see Fig. 5.27)



Figure 5.28: Illustration of the alignment of the aerogel tray with the diffusion box.

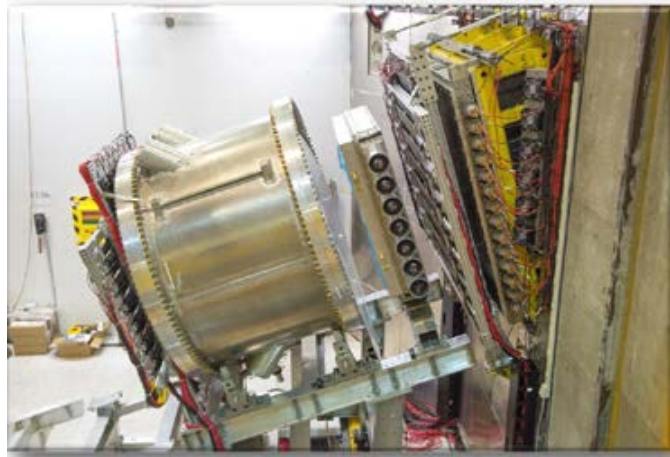


Figure 5.29: Kaon Aerogel detector in place at the SHMS detector hut.

- align position of the tray with the diffusion box. Make sure the flange O-ring is in place, make sure Scotch tape (C-130) is placed on top of O-ring, both in good conditions (otherwise replace them) (see Fig. 5.28)
- insert 4-6 guide pins in the corners of diffusion box (to keep diffusion box and tray aligned);
- if all looks OK, move the aerogel tray gradually closer the diffusion box and try slide it into the inner border of the box;
- put all bolts and tighten them by hand; take out the guide pins and put remaining bolts; when tightening the bolts make sure to gradually tighten them from a variety of positions in order to distribute the force evenly and create a uniform seal.
- Remove the support structure
- once you're sure that everything is OK, tighten all the bolts gradually;
- put a black scotch tape around connection line between the aerogel tray and diffusion box as an additional layer of protection against possible light leaks;
- slide detector to its nominal position centered relative to the SHMS axis;
- verify that the aerogel detector is in the correct position and fix it with clamps (one on the top of the detector and two on the slide stand);
- make sure all HV and signal cables are properly connected;
- switch HV "ON" for only one PMT and check for light leaks; start with a low HV of $\sim 400 - 700$ V (lower than nominal operational HVs), check the PMT signals on oscilloscope;

- switch HV “ON” for all PMTs and verify that no any light leak problem. Start again with an HV of $\sim 400 - 700$ V (lower than the nominal operational HVs) and check the PMT signals on oscilloscope;
- Once you are sure there is no light leak, ramp up all PMT HVs to their nominal values;
- Remove the plastic cover from the window of Heavy Gas Cherenkov on the aerogel detector side;

5.2.7.4 PMT Removal and Replacement

The detector employs fourteen Photonis XP4572B PMTs. These are large 5” diameter, 10 stage, bialkali photo-cathode tubes (flat glass window). They are housed in cylinder shields.

PMT Removal

- Make sure all HVs are OFF!
- Remember never touch or apply force to the photo-tube. The PMT window is very fragile!
- Be sure that you and detector are protected from any accidental HV connections.
- Disconnect signal and HV cables and remove the base.
- Loosen 4 bolts that connect the housing cylinder with diffusion box.
- Remove the entire photo-tube assembly
- Install temporary shielding (plastic or Tedlar cover) on the open window to keep the detector volume clean.

PMT Replacement

- Remember never touch or apply force to the photo-tube face. The PMT window is very fragile! Place the flange on top of an “office” wastebasket with the aluminum cylinder pointing down.
- Insert the O-ring into the back of the wide part of the shield, slide the photo-tube in, and place the plastic ring around the face of the tube.
- Wiggle the magnetic shield into the aluminum cylinder/flange.
- Once you’re sure that everything is secure, take away temporary cover, pick up the whole assembly and place it into the detector tank. Making sure the flange O-ring is in place, tighten the four bolts slowly.

Table 5.10: SHMS Aerogel High Voltages as of November 2015. PMTs with the label “P” are located on the beam left side of the detector when facing towards the pack of the spectrometer. PMTs with the label “N” are located on the beam right side.

PMT Number	PMT Serial	High Voltage (V)	PMT Number	PMT Serial	High Voltage (V)
1P	60135	1780	1N	60232	1550
2P	60127	1700	2N	60223	1600
3P	60129	1670	3N	60221	1620
4P	60023	1630	4N	60202	1600
5P	60240	1730	5N	60105	1450
6P	60228	1580	6N	60185	1730
7P	60197	1660	7N	60095	1570

5.2.7.5 Setting PMT High Voltage

- Nominal high voltage settings are 1.6-2.0 kV (but no more than 2200 Volts!) see Table 5.10.
- High voltages are POSITIVE (for the bases currently in use).
- These voltages may change but they shall NEVER EXCEED 2200 Volts without contacting someone from the responsible personnel!
- Normal high voltage operating procedures should be followed. If you need to change the high voltage by more than 50-100 Volts contact one of the responsible personnel.
- The positive high voltage supplies for the PMTs are in second floor electronic room and are under remote computer control. [22]
- Spare PMTs mounted in cylinder and HV bases can be found in the EEL 126 room ”Aerogel cabin”.

5.2.7.6 Safety Assessment

ADD A standard statement about high voltage, cable type used, warning to always turn off before and remove cable before handling. Turn of HV. Make sure in local, remove cables.

5.2.7.7 Authorized Personnel

At least one person from Table 5.11 should be present during a tray or PMT exchange.

Name (first,last)	Dept.	Call [12]		e-mail	Comment
		Office	Cell		
<i>Physicists</i>					
Arthur Mkrtchyan	CUA			mkrtchya@jlab.org	
Tanja Horn	CUA			hornt@jlab.org	
Vardan Tadevosyan	ANSL			tadevosn@jlab.org	
Hamlet Mkrtchyan	ANSL			hamlet@jlab.org	

Table 5.11: SHMS Aerogel: authorized personel

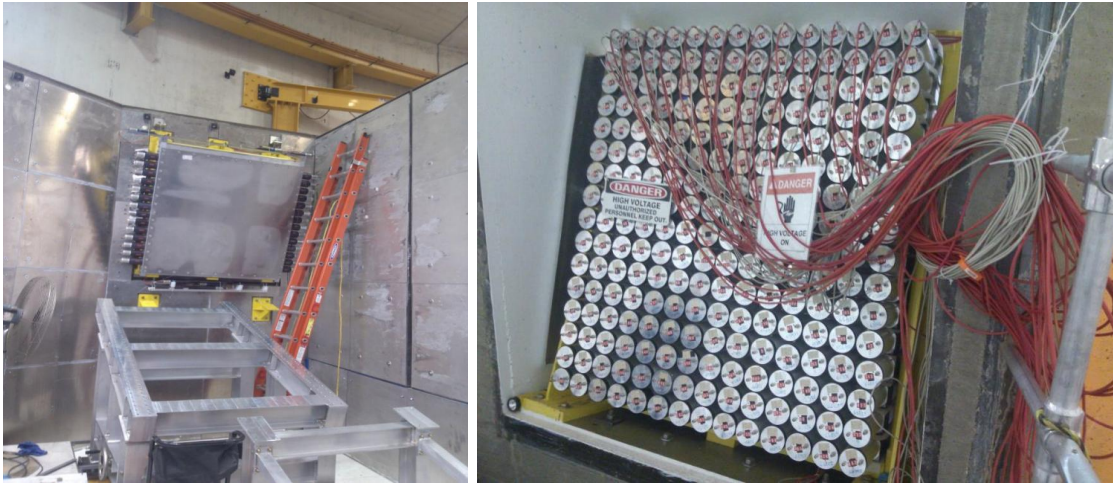


Figure 5.30: Preshower (front view) and Shower (back view) parts of the SHMS calorimeter.

5.2.8 SHMS Lead Glass Shower Calorimeter

The SHMS lead glass shower calorimeter, located behind the S2Y hodoscope plane, is the last detector in the SHMS detector stack. It consists of two sections, a pre-shower layer of 28 TF-1 lead glass 10 cm thick followed by a fly's eye array of 224 F-101 blocks with a depth of 50 cm. (Figure 5.30)

5.2.8.1 Design Overview

The SHMS lead glass calorimeter is designed for electron/hadron identification, by means of detection of Čerenkov light from electromagnetic (EM) showers and hadronic cascades developed in a dense optical radiator. It consists of 2 parts, dubbed the Shower and Preshower respectively. The main unit is Shower, which is 18 radiation lengths deep and ensures total capture of EM showers in the GeV range. The Preshower is just 3.6 radiation length thick and is positioned before the Shower. It is to augment PID by detecting the early (relative to hadronic cascades) onset of EM showers.

TF-1 and F-101 type lead glasses are used as an optical radiator in the Preshower

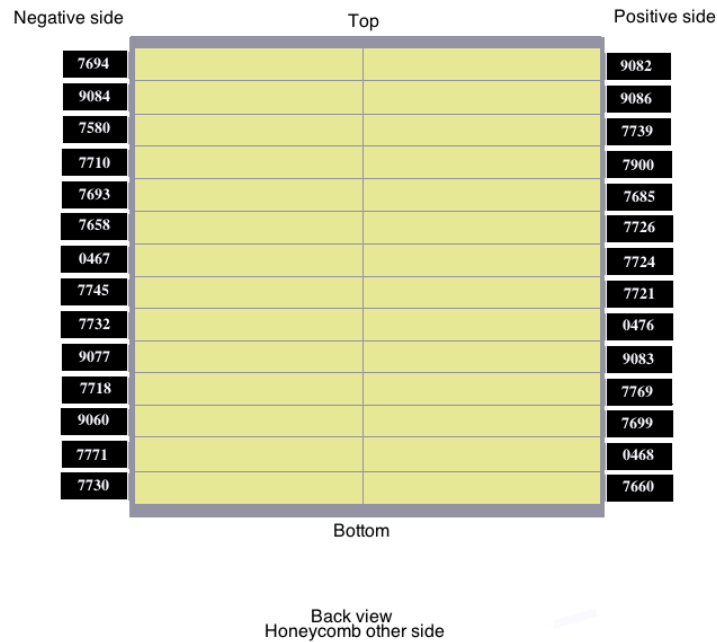


Figure 5.31: Schematic of SHMS Preshower as viewed from the rear showing PMT serial numbers.

and Shower respectively (refractive index 1.65, density 3.86 g/cm³). The light output is detected by means of 3 inch Photonis XP3462B and XP3461 PMTs in the Preshower and Shower respectively (8 stages, flat lime-glass window, bialkali photocathode with peak quantum efficiency of 29% at 400 nm).

The Preshower radiator consists of a layer of 28 TF-1 type 10 × 10 × 70 cm³ lead glass blocks from the calorimeter of the retired SOS spectrometer. (Figure 5.31 The blocks are stacked in two columns in an aluminum enclosure. They are optically insulated by a wrapping of 50 μm thick aluminized Mylar and 10 cm wide strips of 50 μm thick black Tedlar film running between them. On both sides of the enclosure there are 90 mm circular openings, one per block, into which the PMT cylindrical housings are screwed. Inside the housings, the PMTs are wrapped in thin Teflon tape and placed in heat shrink tubing for electric insulation, then are shielded from the fringe fields of the spectrometer magnets by 6 turns of 10 μm thick μ-metal foil The PMTs are optically coupled to the lead glass blocks by means of thin layer of Bicon ND-703 optical grease (refractive index 1.46). The PMT sockets protrude from the rear side of the housings, such that PMT bases are coupled to the sockets outside of the housings.

The Shower part consists of 224 modules from the retired HERMES calorimeter [40, 41], stacked in a “flys eye” configuration of 14 columns and 16 rows. (Figure 5.32) Each module is comprised of a 9 × 9 × 50 cm³ F-101 type lead glass block and a PMT assembly. Each block is wrapped in 50 μm aluminize Mylar film and 125 μm Tedlar paper for optical insulation. The PMT is surrounded by a 1.5 mm thick μ-metal sheet

62	566	657	708	256	711	831	827	698	52	835	401	197	71
1494	1518	1283	1480	1371	1481	1637	1446	1515	1536	1485	1391	1421	1460
817	110	547	213	261	344	214	106	257	405	135	435	371	388
1363	1403	1457	1486	1395	1457	1378	1357	1405	1479	1504	1374	1409	1324
821	4	64	297	100	58	294	615	22	530	13	216	568	563
1432	1394	1506	1414	1465	1390	1420	1512	1418	1412	1591	1419	1516	1481
458	429	525	183	897	498	74	21	879	408	483	412	174	101
1353	1433	1482	1526	1500?	1485	1331	1480	1405	1432	1353	1495	1446	1389
728	856	233	12	112	260	171	559	104	326	532	768	210	346
1452	1599	1372	1533	1322	1583	1477	1410	1517	1574	1328	1328	1449	1508
407	637	306	284	585	681	66	877	712	481	151	836	196	527
1576	1398	1435	1318	1519	1574	1539	1416	1408	1625	1341	1581	1409	1493
519	887	383	245	849	56	801	69	251	380	732	269	115	341
1388	1400?	1503	1490	1494	1442	1463	1475	1393	1451	1460	1456	1425	1519
63	20	55	358	750	665	399	647	240	219	840	695	147	140
1437	1339	1565	1486	1494	1410	1404	1525	1421	1421	1396	1330	1405	1511
78	741	46	236	446	875	878	701	814	593	238	434	539	659
1417	1383	1446	1523	1388	1380	1479	1449	1376	1409	1549	1549	1508	1379
567	167	302	786	424	812	120	427	125	347	489	145	775	421
1343	1453	1508	1437	1429	1476	1500?	1403	1424	1529	1329	1346	1331	1545
760	51	7	25	226	94	880	459	267	430	680	454	185	61
1472	1559	1502	1471	1525	1323	1524	1515	1550	1392	1390	1412	1447	1340
805	16	648	658	672	396	116	206	784	819	67	662	102	42
1345	1543	1579	1624	1403	1346	1465	1447	1302	1404	1452	1549	1431	1480
30	98	211	280	632	288	460	620	572	5	501	353	676	313
1419	1447	1313	1385	1440	1609	1418	1382	1368	1498	1508	1505	1333	1394
323	374	175	439	844	379	510	244	169	603	511	748	200	475
1546	1501	1491	1354	1400	1375	1444	1451	1464	1499	1415	1456	1398	1438
384	533	180	314	461	818	360	503	599	848	505	90	254	373
1357	1407	1415	1451	1425	1369	1382	1308	1481	1355	1490	1590	1357	1534
441	471	349	163	796	57	222	792	345	755	661	305	628	842
1385	1474	1428	1525	1420	1440	1444	1494	1428	1441	1350	1461	1322	1444

Figure 5.32: Schematic of SHMS Shower array as viewed from the rear showing block numbers and nominal high voltages taken from the HERMES database.

and wrapped in 2 layers of Teflon foil for magnetic shielding and electric insulation correspondingly. The cylindrical aluminum container of the PMT assembly is fixed to a titanium flange which is glued to the block. Silgard-184 optical glue with a refractive index of 1.41 is used for optical coupling of the PMTs to the blocks. Surface mounted HV divider is pin-to-pin soldered to the PMT.

As a full absorption detector, the calorimeter is positioned at the very end of the SHMS detector stack. The support stand for the Preshower is mounted on the back wall of the detector hut. The Shower is assembled directly behind the Preshower, in a rectangular opening within the wall. Both sub-detectors are aligned with the central ray of the spectrometer and are tilted by the SHMS bend angle of 18° relative to gravity. Both sides of Preshower are easily accessible from the detector hut, albeit a ladder is needed to access top PMTs. The back side of the Shower can be accessed only when SHMS is rotated to 40° and aligned with the SHMS service platform.

The drawings of the SHMS calorimeter are available from the Hall C engineering group. Expected performance, from simulations, is discussed in [42].

5.2.8.2 General Operating Procedures

The design of the SHMS Preshower permits changing of PMTs and bases during experimental operations, if needed. In contrast, the construction of the Shower modules does not assume an easy modification; experts must be consulted in case of a potential change in the Shower (see list of responsible personnel below). Spare Shower modules are in Physics Storage (ask Hall C technicians for assistance).

The photomultiplier tubes and bases are operated at negative high voltages up to ~ 2000 V. No directly accessible components carry high voltage. Standard safety precautions for handling high voltage on photo tubes must be observed, including, but not limited to disabling the HV at the power supply and disconnecting the HV cables from the bases (except in limited test cases) whenever the base covers are removed (to avoid electrical shock), or whenever optical hermeticity of the detectors is compromised (to avoid damaging photo-cathodes of the tubes). Personnel shall be careful when removing a Preshower tube-base assembly, shall avoid mechanical shocks of the tubes and of the whole assembly in order not to break the glass tubes and to preserve the properties of the inner μ -metal shielding.

None of the materials and components used are known to pose any health or environmental hazards beyond cutting skin from broken glass or sharp edges.

5.2.8.3 Preshower PMT Removal and Replacement

PMT Removal

- Make sure all HVs are OFF!
- Remember never touch or apply force to the photo-tube. The PMT window is very fragile!

- Be sure that you and detector are protected from any accidental HV connections.
- Disconnect signal and HV cables and remove the base.
- Remove wide aluminum washer from rear of the housing tube, by turning it anti-clockwise several times. (Use special wrench for this!).
- Remove μ -metal shielding which surrounds PMT from the housing tube.
- Detach PMT from lead glass block by rotating the PMT bulb around its axis and applying gentle pulling force to overcome viscosity of the optical grease between PMT window and the block.

PMT Replacement

- Remember never touch or apply force to the photo-tube face. The PMT window is very fragile!
- Remove old optical grease from the face of PMT using a soft tissue.
- Remove old optical grease from the surface of the lead glass block inside the PMT housing using a soft tissue.
- Put $\sim 1 \text{ cm}^3$ of fresh ND-703 optical grease at the center of PMT window.
- Insert PMT bulb into the housing tube, until it touches lead glass block. Center the bulb inside the tube.
- Rotate the PMT bulb around its axis 2-3 times, by gently pressing it against the block to have thin layer of optical grease evenly distributed between PMT window and the blocks surface.
- Insert μ -metal shielding into the tube, around the PMT bulb.
- Place back the washer into the threads at the rear of housing tube, by rotating it clockwise several times. Be sure the PMT socket is centered in the washer and firmly sits in the hole.
- Connect PMT base to the PMT socket, restore cable connections.

Setting PMT HVs

- Nominal high voltage settings are 1.3-1.7 kV (but no more than 1750 Volts!) and are available in Hall C wiki.
- High voltages are NEGATIVE.
- These voltages may change but they shall NEVER EXCEED 1800 Volts without contacting someone from the responsible personnel!

- The voltages are controlled remotely using the standard EPICS high voltage controls.
- Normal high voltage operating procedures should be followed. If you need to change the high voltage by more than 50-100 Volts contact one of the responsible personnel.
- The negative high voltage supplies for the PMTs are in electronic room and are under remote computer control.
- Spare PMT assemblies and HV bases for the Preshower can be found in EEL 126 room “Calorimeter cabin.”

5.2.8.4 Authorized Personnel

At least one person from Table 5.12 should be present during PMT removal or replacement.

Name (first,last)	Dept.	Call [12]		e-mail	Comment
		Office	Cell		
<i>Physicists</i>					
Vardan Tadevosyan	ANSL			tadevosn@jlab.org	
Hamlet Mkrtchyan	ANSL			hamlet@jlab.org	
Arthur Mkrtchyan	CUA			mkrtchya@jlab.org	

Table 5.12: SHMS Shower: authorized personel

5.3 The HMS Detector Package and Shield House

All the detectors are in the shield house (also referred to as the detector hut, located at the top of the rear set of stairs). The shield house has one wall which is removable in order to gain completely free access to the detectors. The removal of this wall is rarely needed as there is a door that provides access to the hut and there is adequate room inside the hut for most activities. Essentially, the only activities that require the removal of the hut wall are the installation or removal of an entire detector. The hut wall may only be removed by Hall C approved, and trained crane operators and requires several people. Walter Kellner, the Hall C work coordinator, must be contacted if the hut wall needs to be removed.

5.3.1 HMS Shield House Door

The HMS shield house and detectors are accessed through a 15 ton door. This door is moved by energizing the motor attached to it. Once you have it open as wide as you need, it is suggested that you use the rubber block provided to chock the door in the open position. It does tend to drift closed if not restrained. If you find yourself inside

the shield house with the door closed, there are pushbutton controls inside which you can use to open it (see below).

An interlock prevents access to the HMS detector hut unless the safety shutter inside the hut has been moved to its ‘down’ position, such that it covers the vacuum window. This is to prevent people from accidentally touching the large vacuum window. The door cannot be opened unless the shutter is already inserted. To prevent the door from drifting open on its own, a magnetic lock holds it in the closed position. This lock is de-energized when the OPEN control button is pressed.

The door is opened or closed by activating the motor attached to its hinges. The control panel for the door is mounted on the yellow post (Fig. 5.33) behind and to your right as you stand in front of the door. A duplicate set of controls is inside the shield house, to the right of the door. Press and hold the button marked OPEN and the door will be slowly opened. Press CLOSE to move the door towards the closed position. Remember that while the door motor will stop when the button is released, the door will continue to move because of its inertia. It takes about two minutes to fully open the door or to close it from the fully opened position. When closing the door, make certain to keep CLOSE pressed until the magnetic lock near the top of the door engages.

5.3.2 HMS Vacuum Window Shutter

The HMS vacuum volume extends from near the scattering chamber, through the three quadrupoles and the dipole, up to the thin aluminum vacuum window just upstream of the first HMS drift chamber. Because of the considerable stored energy in such a large vacuum volume, it is necessary to protect personnel working in the HMS shield house from the possibility of a catastrophic failure of this vacuum. See Fig. 5.34.

Protection is provided by a 1 inch thick aluminum plate which covers the large vacuum window in the HMS shield house. This plate slides up and down in an assembly which is attached to the end of the vacuum vessel. Movement of the shutter is managed by a motor which is controlled from a control box on the outside of the shield house, on the left side of the door.

An interlock prevents access to the HMS detector hut unless the safety shutter has been moved to its ‘down’ position, such that it covers the vacuum window. This is to prevent people from accidentally touching the large vacuum window, or suffering hearing loss should there be a catastrophic failure of the window. The shutter cannot be retracted unless the door is closed. The door cannot be opened unless the shutter is already inserted.

5.3.2.1 Shutter Operation

To close the shutter, press (and hold for a few seconds) the button labeled “DOWN” on the shutter control box. This will start insertion of the shutter. After a few seconds the light indicating “OUT” will turn off. It takes about two minutes for the shutter to move into place. When it does, the light labeled “IN” will glow. This indicates that the shutter is inserted and the door may be opened. To open (i.e. raise the shutter, after the HMS



Figure 5.33: HMS door control buttons.

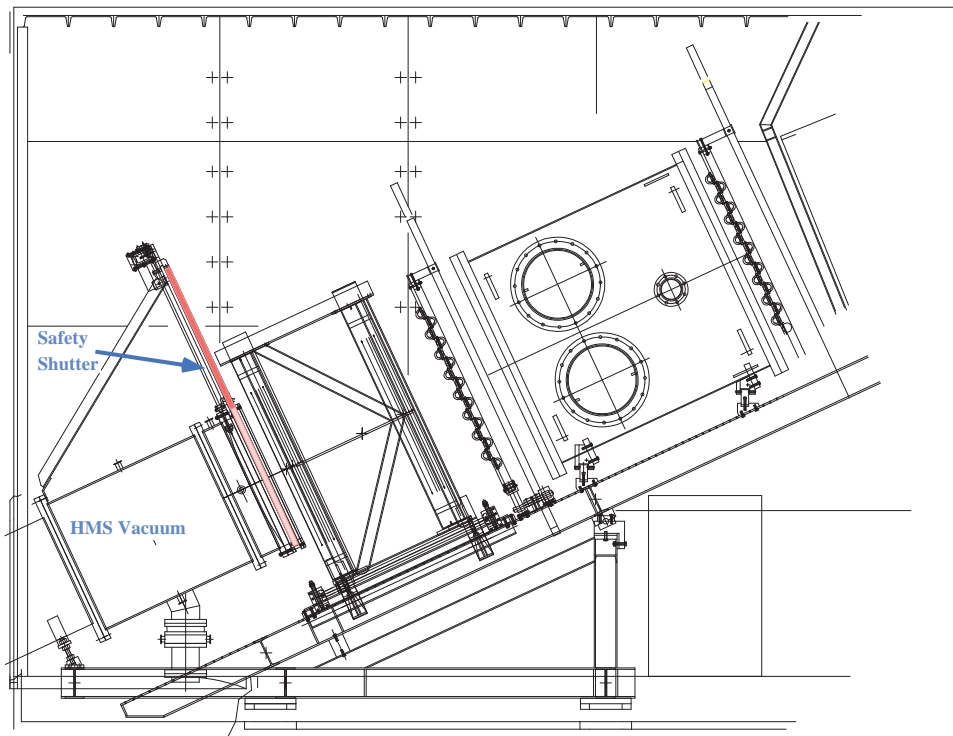


Figure 5.34: The HMS vacuum window in the HMS spectrometer hut.

shield house door has been fully closed, press the button labeled “UP” and hold it for a few seconds. The “IN” light will dim as the shutter moves away from the fully inserted position. Full retraction takes about two minutes. When the shutter is fully retracted, the “OUT” light will glow.

Usually the shutter is retracted by MCC operators after they have swept the interior of the HMS shield house and closed the door. Experimenters should watch the operators, using the hall survey TV cameras, to make certain that they complete this step during any sweep of the hall. If the operators complete the sweep of the hall without opening the shutter, you will have to make a controlled access and open the shutter yourself.

If you enter the HMS shield house during Controlled Access, you are responsible for closing the door and raising the shutter yourself.

“IN” and “OUT” shutter status lights are located both on the shutter control box and on the top left panel of the Counting House main console. You can check the status of the shutter from the Counting House via these lights.

5.3.3 Drift Chambers

The first detectors encountered by particles passing through the HMS are a pair of drift chambers. These chambers provide accurate measurements of the particles position and angles in the detector hut. This information can be combined with a knowledge of the spectrometer optics to infer the trajectory of the particles at the target.

The HMS wire chambers, installed in 2017, are of a design very similar to the drift chambers in the SHMS. The original chambers (Section 5.3.3.2), are in storage and serve as spares.

Independent of type of chamber, the old and new style chambers are instrumented in a similar fashion.

The chambers have field shaping wires (and in the case of the new drift chambers, foils on each side of each sense wire plane) that are operated at negative high voltage supplied by CAEN high voltage, low current, power supplies located in the electronics room of the counting house. The high voltage can be controlled through a GUI on the console computers as described in section 5.1.1.

Each anode/sense wire has its own electronic readout through Nanometrics preamplifier/discriminator cards or LeCroy Corporation LRS 2735DC cards which are interchangeable with the Nanometrics cards. The discriminator outputs from the cards, each of which instruments 16 sense wires are connected to CAEN V1190 multi-hit TDCs located in the SHMS electronics hut. The discriminator cards are powered by +5V and -5V Acopian power supplies that are located in the HMS hut. In total, several 10s of amps of both positive and negative voltage current are supplied. The supplies are not computer controlled.

The thresholds of the discriminators are held by a third set of supplies which are located upstairs in the counting house. This control is in the left side of the far left hand set of blue racks (near the disk drives) in the electronics bay of the Hall C counting house.

The amplified and discriminated signals from the chambers are fed to the CAEN Model V1190 VME pipeline TDC's. These TDC's are located in the detector hut in an electronics rack on the far side (from the door) of the detector mounting stand.

5.3.3.1 New HMS Drift Chambers

The new HMS drift chambers, built in 2016 and installed in 2017, are of a similar design to the SHMS drift chambers, described in section 5.2.5. The differences between the HMS and SHMS drift chambers are described in the HMS Drift Chambers references [43]. These chambers cover an active area of approximately 100 cm in the dispersion (vertical) direction and 50 cm in the horizontal dimension. As with the SHMS drift chambers, the planes in the first chamber are ordered (U, U', X, X', V', V). The second chamber, but rotated about the vertical axis. Thus the ordering of the planes is (V, V', X', X, U', U). Because of this rotation though, the wires in the U lanes of the first chamber are parallel to the V planes of the second chamber.

5.3.3.2 Legacy Drift Chambers

Overview The planes are designated X,Y,U,V,Y', and X'. X and X' wires measure position along the dispersive direction. Y and Y' wires measure in the transverse direction while the U and V planes are inclined at fifteen degrees with respect to the X planes.

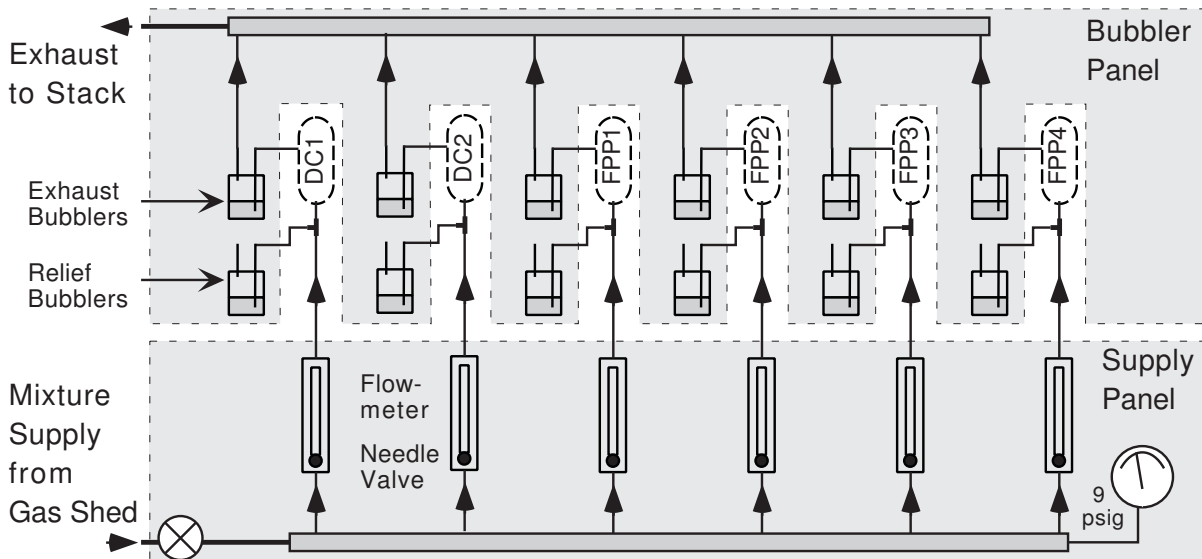


Figure 5.35: Flow and Valve Diagram for the HMS Shield House. An equivalent installation will service two drift chambers in the SHMS Shield House.

Gas System Operating Procedures The HMS drift chambers use a 50:50 mixture (by weight) of argon and ethane gas. Each chamber has a volume of about 120 liters. Each is operated slightly above atmospheric pressure. The gas flow through the two chambers can be varied and is typically set at 1000 cc/min when flushing (full purge in about 2.5 hours) and 400 cc/min when operating at low to moderate charged particle rates. The chambers are connected in parallel for gas flow as shown in Figure 5.35. There are flow meters connected to the exit line of each chamber.

The gas flow control electronics and gas handling system are located in the gas shed just outside of the Hall C counting house. See section 5.1.2 for details.

Electronics Operating Procedures The readout electronics associated with the HMS drift chambers are all commercial products from LeCroy Research Systems, Nanometrics, CAEN and Wiener. There are 544 electronics channels per chamber for a total of 1088 readout channels. (588 per chamber, 1176 total for the new chambers).

These anodes are read out using LRS 2735DC and Nanometrics N-277 preamplifier/discriminator cards mounted directly on the chambers. Each chamber has both types of cards, however each plane (of six total planes per chamber) has only one type of card. The digitized signals are sent to VME CAEN 1190 TDCs inside of the detector hut via twisted pair cable. The low voltage (preamplifier) power supplies (the Acopian supplies) are in the 13 inch blue rack at the rear of the detector hut. The threshold voltage power supplies are on the frame under the Cherenkov counter. The remote threshold power supplies are located in the electronics room of the counting house.

Procedure (in the detector hut)

1. Turn on low voltage power supplies (the Acopian Supplies).
2. Turn on threshold voltage power supply to appropriate setting.
3. Turn on the VME Crate power supply if it is not already on.

The threshold voltage can be controlled locally in the detector hut or remotely in the counting house. There is approximately a one volt drop in the threshold voltage line in going from upstairs in the counting house to downstairs in the detector hut. Hence the supplies in the counting house should be set to 5.5 volts. The local/remote switch is on the controller in the detector hut. It should be switched to remote before exiting the hut. The LeCroy preamp/disc cards have LEDs (a green and a red light) which indicate that the power is delivered properly to the chamber electronics.

High Voltage Operating Procedures Only formally authorized person may alter drift chamber high voltage. There are four different voltages per chamber which must be turned on at the proper time and monitored throughout the experiment. **MAKE SURE THAT GAS IS FLOWING THROUGH THE CHAMBERS AND THAT THERE ARE EDGE CARDS MOUNTED ON ALL READOUT CHANNELS BEFORE TURNING ON HIGH VOLTAGE.** The high voltage power supplies are the CAEN supplies located in relay rack CH03B17 in the counting house electronics room. The voltages are set remotely using the GUI in the counting house. See section 5.1.1 for information on the high voltage controls. The four different voltages are (nominally): triangle wires (corner field wires) (-2500 V), square wires (-2250 V), circle wires (-1800 V), and guard wires (-1500 V). Note that each HMS drift chamber *plane* has its own triangle, circle, and square voltage source, while there is only one guard wire voltage source per *chamber*.

Procedure (in the detector hut)

1. Make sure an amplifier/discriminator card or a grounding plate is on each instrumented connector on the chamber.
2. Make sure that there is gas flow, particularly Ar gas.
3. Make sure high voltage cables are properly connected to chamber.
4. Turn on high voltage, using the EPICS GUI in the counting house, to proper settings.

In general all of the voltages and gas flow should be left on, even when no data is being collected. The gas supply should be checked periodically, approximately once every shift. The gas bottles' supply is depleted after about 2 weeks at the nominal (400 cc/min) flow rate. In the case of a HV trip, try cycling the CAEN power supplies. If this fails, call one of the responsible persons listed in the Responsible Personnel listed in the Drift Chamber Section of the ⁴.

⁴<https://hallweb.jlab.org/safety-docs/current/ESAD.pdf>

Table 5.13: Dimensions (at 70 F.) of the scintillators for the HMS TOF system.

	Thickness	Width	Length	Number
X(HMS)	1cm	8.0cm	75.5cm	32 units
Y(HMS)	1cm	8.0cm	120.5cm	20 units

5.3.4 Scintillator Hodoscopes

The purpose of the scintillator hodoscopes is to provide a clean trigger as well as particle identification by time of flight (TOF). These detectors consist of two pairs of spatially separated scintillator layers: a pair comprised of S1X and S1Y, and approximately 2 meters away a pair comprised of S2X and S2Y. General characteristics of the BC404 scintillator material are as follows:

- Polyvinyltoluene (PVT) is the base material.
- Light output is 68% that of Anthracene.
- Wavelength of maximum emission is 408 nm.
- Decay constant of the main fluorescence component is 1.8 ns.
- Bulk attenuation length is 160 cm.

The specific dimensions for the scintillator elements in the HMS are found in Table 5.13. Each scintillator is read out by two Philips XP2282B photomultiplier tubes (PMT's). These PMT's are 8-stage tubes with nominal operation at 2500 volts. The bases have two anode outputs, one of which is terminated with a short clip line and 40 Ohms. Because of pmt to pmt variations in gain and the 5% precision zener diodes in the bases, the spread in gains can be a factor of 2-3. Individual high voltages must therefore be adjusted to balance the gains. The gains have been carefully matched with a source, and HV save files exist, so the gains will not normally need to be readjusted. If gain adjustment is necessary, inform one of the hodoscope contact persons as soon as possible. Mysterious gain shifts are probably due to transient problems like bad solder contacts or broken glue joints. They require repair. A rough rule of thumb is that an increase of 50 volts will increase the gain by 30%.

With our base, the HV channel will trip on overcurrent (3 mA) at 2900 V (this base is essentially divider C in the Philips catalog). If a channel needs more than 2800 volts, and the base and glue joints are okay, then our policy is to replace the pmt. We have several spare modules in the counting room. In desperation, "spares" can be taken from the edges of the acceptance. In the HMS, S1X16 or S2X16 contain little or no useful data, and similarly for S1Y01 or S1Y10.

The light guide material is UVT lucite. Wrapping material for the SOS scintillator elements was one layer of aluminized mylar (aluminum side facing inward), followed by two layers of tedlar for light tightness. The HMS elements were wrapped in aluminum foil, followed by one layer of tedlar.

The HMS elements are supported at the lightguides. In case of repair use BC-600 glue. Each element has a 1 mm plastic fiber glued into the light guide. These fibers are also very delicate and care must be taken when moving a scintillator element to avoid snagging and breaking the fibers.

What to check: Before starting to operate the detectors, one has to check the trip setting (current limit) of the HV power supply for each channel and the set HV value of each channel. During operation, the current of each channel and its HV should be periodically checked. The HV should be on for at least half an hour before taking data. During runs one should check the histogram of the plane hit distribution. This should be rather flat reflecting the normal trigger requirement of 3 out of 4 planes. Also the element hit distributions for the individual planes should be checked regularly. These distributions are defined for both ends of the elements using both ADC and TDC information.

Nomenclature: The coordinate system (right handed, following TRANSPORT convention) is defined as z downstream, x pointing down, and when looking downstream, y to the left. In this convention the X-tubes at positive Y are called X+ and the Y tubes at the bottom (pos x) are called Y+. Numbering of the elements is done as one would read a book in English: left to right in the case of the Y and top to bottom in X.

There are one ADC and one high resolution (25 ps/channel) TDC per PMT. For the SOS, S1X and S1Y and S2Y each have 18 channels, while S2X has 32 making it 86 channels in total. Each “X” plane in the HMS has 32 and each “Y” has 20, making it 104 channels in total.

The signals are carried on an RG-8 size cable which is a Belden 213 equivalent. The nominal specifications are 50 Ohm impedance and the signal velocity is $0.82c$. The signals are passively split in the counting house with one going to the ADC and one going to leading edge discriminators. The performance is typically 150 psec mean time resolution (sigma) per element.

5.3.5 Gas Cherenkov Detector

A charged particle travelling faster than the speed of light in the medium will create an electromagnetic disturbance in the medium. The radiation emitted by this process is called Cherenkov radiation after its discoverer.

Cherenkov radiation is conically distributed about the trajectory of the particle, with an angle given by

$$\cos \theta = \frac{1}{\beta n}$$

where the index of refraction $n = c/u$ and $\beta = v/c$, with c the speed of light in vacuum, u the speed of light in the medium, and v the speed of the particle.

The index of refraction allows one to control the threshold particle velocity $v_T = u = c/n$ below which there is no Cherenkov light produced, and above which there is Cherenkov light produced. For a gas, the quantity $n - 1$ is proportional to the pressure, so adjusting the pressure of the gas allows one to select the threshold velocity. Adjusting the threshold velocity actually allows one to select particles of different mass. Given the same momentum, two particles of different mass will have different velocity. Therefore, a Cherenkov detector can be tuned, for instance, to distinguish electrons from pions.

The HMS Cherenkov detector consists of a large cylindrical tank, $\phi_{in} = 59''$, $L = 60''$, containing two mirrors which focus light onto two 5 inch Burle 8854 multiplier photo tubes (PMT's). The tank has been installed with 0.04 inch thick 2024-T3 Aluminum windows covering the circular ends of the cylindrical tank. These windows were hydrostatically formed (and hence tested) at a pressure of 28 PSI. The tank itself was helium leak checked and is leak free on a scale of 10^{-8} Atm-cm³/s. In addition, the tank was hydrostatically tested at a pressure of 35 PSI. Detailed information on this testing program can be found in [44], [45].

The tank is mounted on the detector rails using a three point alignment scheme. The rails are easily capable of supporting the weight of the tank without deformation. The gas handling system for the tank is designed to enable the tank to be filled with pure gas, CO₂ or N₂, at the desired operating pressure which is, ≈ 1 Atm (11.5 PSI) for the near future.

The system consists of the fill gas bottle and primary pressure regulator which are in a bottle rack that's welded to the bottom of the HMS detector hut on the small angle side at a height of about six inches from the hall floor. The primary regulator is a Matheson model 2596 with a maximum outlet pressure of 400 PSI. During fills this regulator should be set to 150 PSI. The outlet of this pressure regulator is connected to the main gas control panel which is mounted on the first floor balcony of the detector hut behind the dipole control racks. All connecting tubes in the system are 0.25 inch diameter stainless steel tubing with the exception of the nitrogen purge line which is thick wall tygon. At the entrance to the gas panel there is a 0-300 PSI gauge so that the pressure in the inlet line can be viewed by the operator. The line is then relieved by a Circle Seal relief valve set at 200 PSI. After this, the gas passes through a second regulator (Matheson 3420) which has an outlet pressure range of 0-60 PSI. This regulator can be set at up to 40 PSI for high flow during the early stages of fills (the line is relieved further downstream by a second Circle Seal relief valve set at 45 PSI) and then reduced as the desired operating pressure is approached. Following the second regulator and its relief valve the gas passes through oil and oxygen filters. A 120 Volt AC solenoid valve (ASCO) switched with a solid state relay is used to isolate the gas flow from the tank. The state of the relay and hence the valve is indicated by a LED on the panel. The gas line is routed through an opening in the floor of the detector hut to the tank inlet. A gauge on the panel allows the operator to view the pressure in the inlet line (the same as the tank pressure when the subsequent manual valve is open, see following). At the inlet there is a pair of manual valves (NUPRO) which allow the fill line to be purged. During operation the valve which vents the line to atmosphere is closed and the valve to

the tank inlet is open. The tank is relieved by a 1 inch diameter, 1 PSI pop off (NUPRO) which was sized to take the maximum flow of the second regulator even if that regulator has failed wide open. There is a pressure gauge on the tank so that its condition can be determined by workers in the shield house. In addition, there is a Omega pressure transducer (PX-305-05A) and a temperature transducer attached to the tank. These are read out and powered by units (Omega) which are located below the gas panel. Outputs of these are currently viewed with a video camera attached to a monitor in the counting house.

Before filling, the tank is first cleaned by executing several pump and purge cycles. The pump that is used to evacuate the tank is located on a platform welded to the small angle side of the shield house balcony which can be accessed from the small angle side of the HMS carriage. Eventually, it will be possible to switch the power for this pump from the gas control panel with a relay but currently it is necessary to turn the pump on and off with a switch located on the pump. The low pressure side of this pump is equipped with a liquid nitrogen cold trap to prevent any contamination of the tank (or mirrors !) with pump oil. This trap will remain filled for approximately 12 hours and should always be checked before use. There is currently a manual valve located at the Cherenkov tank that isolates the tank from the pump. This valve will later be replaced by a pneumatically actuated solenoid valve that will be controlled from the gas panel. There is a manual valve on the tank which is equipped with a hose barb through which clean nitrogen purge gas can be admitted to the tank. The nitrogen gas comes from a spigot on the HMS cryogenic handling system located along the upper catwalk of the HMS. The nitrogen system delivers gas at a line pressure of ≈ 40 PSI (this pressure can be read on a gauge at the pivot end of the catwalk). The flow rate is readable from a flow meter attached to the spigot. A flow of about 150 - 200 cfm is reasonable. The tank should not be filled to more than -5 in Hg during purge cycles.

The tank contains two 5 inch PMT's which use **positive** HV. (Note: only this detector and the Aerogel counter use positive HV, all the other PMT bases in the HMS are designed for use with negative HV.) They operate at between 2000 and 2700 Volts. The Anode is at HV and its signal is viewed through a decoupling capacitor in the base. The HV is supplied by one pod of the same *CAEN* power supply used for the drift chambers.

The mirrors in the tank may require adjustment for optimal focusing on the PMT faces. The ports which hold the PMT's are sized big enough to allow a person inside the tank to make these adjustments. The tank is a confined space and hence this activity represents an ODH hazard. Stickers indicating this have been placed on the PMT ports. Before an entry into the tank the atmosphere in the interior must be surveyed by a member of the physics division EH&S staff. This adjustment should only be done by personnel who understand the fiducial markings of the PMT mounting system. The interior of the tank has foot braces and hand holds welded to allow this work at the angle of the detector rails.

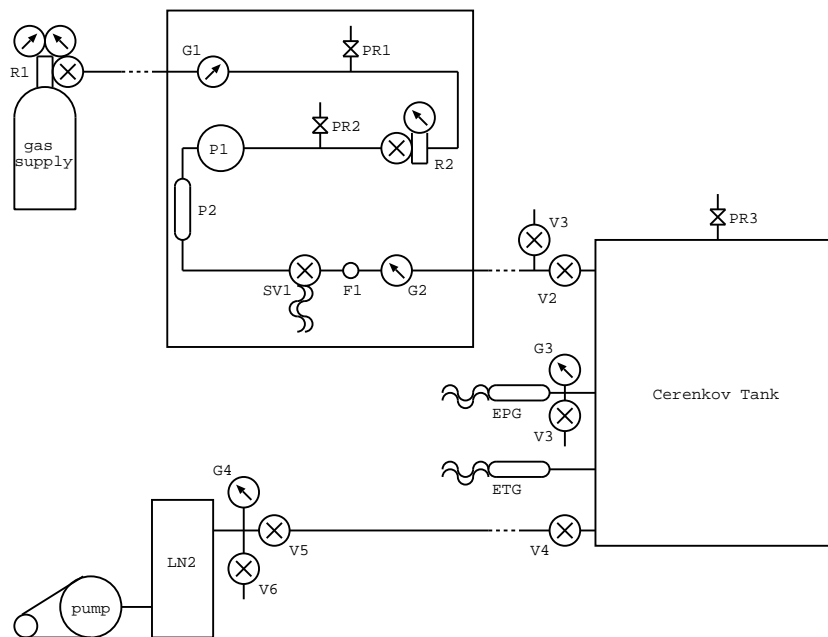


Figure 5.36: The Gas Handling System for the HMS Cherenkov Detector.

Operation Procedures The HMS Cherenkov Detector operates either as an e/π or π/p discriminator. Each mode has a unique set of procedures to prepare the tank for operation. The nomenclature used in the description of these operation procedures refers to Figure 5.36, showing the gas handling system. Components shown inside the dashed box of Figure 5.36, are all located on the Gas Control Panel.

e/π Procedures For both e/π and p/π separation, the procedure has been to run with 0.4 to 0.9 (?) atmospheres of C_4F_{10} . This is just a small modification to the current p/π procedures write-up described in the next section, with the HMS running sub-atmospheric instead of supra-atmospheric.

e/π running can also be accomplished using a nitrogen fill. This mode of operation requires the tank to be filled with approximately 13.5 psia of N_2 . The boiloff from the spectrometer magnets is a perfect source of clean, dry Nitrogen, and is normally used to fill the Cherenkov tank.

Because the operating pressure is slightly subatmospheric, a pump and fill procedure is employed. First make sure that:

- The 40 mil windows are installed and oriented such that they curve towards the interior of the tank.
- Valves **V1-V6** are closed.

- The LN2 trap is filled.
- There is enough oil in the pump.

The tank is now ready to be evacuated.

- Turn on the pump.
- Slowly open **V5**. This evacuates the pump line.
- Very slowly open **V4**. Since this valve connects the pump line to the detector volume, the pump will work very hard. Meter this valve so that the pump is never under extreme stress. It will take approximately 20 minutes to pump down the tank.

The tank can now be filled.

- Locate the boiloff manifold on the walkway on the top level of the spectrometer, at the gap between Q3 and the dipole.
- Turn the valve on this manifold open slightly so that the flow meter barely registers a flow.
- Connect the remaining end of the Tygon tubing to the vent of valve **V3** with a hose clamp.
- Open valve **V3**.
- Increase the flow on the flow meter. Do not exceed 100 cfm.
- When **G3** or **EPG** reach the operating pressure, close the manifold valve.
- Close **V3**.

The fill should take approximately 30 minutes. The detector should NEVER be left unattended during a fill. Frequently check the pressure in the tank and be aware when the pressure nears one atmosphere. DO NOT let the pressure exceed one atmosphere under any circumstances; doing so risks damage to all of the equipment and personnel in the detector hut. This pump/fill procedure is usually repeated at least once to insure the purity of the gas.

π/p Procedures This mode of operation typically requires the tank to be filled with Freon-12 at pressures varying from 2 to 3 atm. Because these operating pressures are greater than 1 atm, the detector must be filled by dilution. Contamination from air, however, is not a major problem as the optical absorption properties of air are actually more favorable than those of Freon-12 itself; the only difficulty is the increase in pressure needed for a mixture of air and Freon to achieve the same pion momentum threshold as for a pure sample of Freon.

First prepare the gas handling system:

- Make sure that the 60 mil windows are installed and oriented such that they bulge outwards from interior of the tank.
- Close the valves **V2-V4**, and the valve on regulator **R1**. **V1**, **SV1**, and the valve on regulator **R2** should be open.
- Open the valve on the gas supply bottle.
- Adjust **R1** to approximately 60 psig.
- Open the valve on **R1**.
- Check to make sure gauge **G1** agrees with the pressure setting on **R1**.
- Adjust **R2** so that a small flow is detected out the vent of **V1**.
- Close **V1**.
- Adjust **R2** to regulate at the required operating pressure.

The tank is now ready for the dilution process. These steps should be repeated as few times as possible to minimize the quantity of Freon-12 emitted to the atmosphere.

- Record the tank pressure.
- Open valve **V2**.
- Monitor the gas pressure until it reaches the required operating pressure. NEVER let the pressure in the detector exceed 3 atmospheres.
- Record the final pressure.
- Open **V3** to vent the tank.

From the recorded pressure readings, the threshold momentum of the mixture of air and Freon-12 can be calculated (assuming the volume of the tank is fixed).

5.3.6 Lead Glass Shower Calorimeter

The HMS lead glass shower calorimeter [42] consists of four stacks of TF1 leaded glass (similar to SF1). Each stack contains thirteen blocks for a total of 52 blocks. The blocks are 10 cm by 10 cm by 70 cm. The first two layers are readout with PMTs at both ends and the last two layers with a PMT at one end.

High energy particles emit Cherenkov radiation when passing through the glass and a signal is collected that is proportional to the sum of the path lengths travelled by all the particles which are above the threshold for Cherenkov emission. High energy electrons will produce a large signal as they have a large bremsstrahlung cross section and the photons which are produced in the bremsstrahlung process have a large cross section

Table 5.14: Momentum threshold above which pions, kaons and protons will produce Cherenkov light in Aerogel's with various indices of refraction.

n	$\pi_{\text{thr}}(\text{GeV}/c)$	$K_{\text{thr}}(\text{GeV}/c)$	$p_{\text{thr}}(\text{GeV}/c)$
1.030	0.57	2.00	3.80
1.015	0.81	2.84	5.40

to produce electron positron pairs (all of which will be above the Cherenkov threshold). This process of bremsstrahlung followed by pair production is called an electromagnetic shower.

The histograms associated with the calorimeter should be inspected regularly to assure that it is functioning properly.

5.4 Aerogel Detector

The HMS Aerogel detector [46] is located between the second wire chamber and the first plane of the hodoscopes. It provides improved $\pi/K/p$ particle ID for momenta above 3 GeV/ c . The detector is mounted on a sliding rail system so that it may easily be placed into or removed from the path of particles in the detector hut depending on the needs of a given experiment.

The Aerogel detector, which has an area of $120 \times 70 \text{ cm}^2$ consists of a 9 cm thickness of Aerogel followed by a diffusion box for a total thickness of 25 cm. The diffusion box is lined with Millipore paper “Membrane GSWP-0010” which has a reflectivity of $\sim 96\%$ [47]. The “long” sides of the diffusion box each have 8 Photonis XP4572 PMTs. These bases for these tubes are powered with positive HV. (Note: only this detector and the gas Cherenkov detector use positive HV, all the other PMT bases in the HMS are designed for use with negative HV.)

Two Aerogel indices of refraction, $n = 1.015$ and $n = 1.030$, are available for use with the detector. The Aerogel is in radiator trays which may be swapped (by experts) to change the refraction indexed installed in the detector.

Chapter 6

Controls

A distributed computer system based on the Experimental Physics and Industrial Control System (EPICS) [5] architecture monitors and commands various Hall C systems and the accelerator. The basic components of the system are:

- Input/Output Controllers (IOCs) - Systems containing single board computers (SBCs) and I/O modules (i.e analog-to-digital converters (ADCs), digital I/O and RS-232C interfaces). Each SBC executes the real-time operating system VxWorks and the corresponding EPICS application (signal database and sequencers). IOCs are typically VME SBCs and crates, but may also be other platforms such as standard Linux servers or small form factor systems such as Raspberry PIs.
- Operator Interfaces (OPI) - Computers capable of executing EPICS tools to interact with the IOCs. The four most used tools in Hall C are (a) the Extensible Display Manager (EDM) [48], (b) StripTool, (c) a signal archiver, and (d) an alarm handler. EDM is the main interface used for monitoring and controlling both the hall and accelerator equipment. StripTool allows to monitor the behavior of one or more signals as a function of time. The signal archiver keeps a record of a selected set of signals. The alarm handler alerts operators to situations requiring attention.
- Boot Servers - IOCs load the various software components needed to perform their functions from these machines (i.e. operating system, signal database and controls algorithms).

In addition to equipment controlled with EPICS, Hall C uses an industrial control system, composed of Allen Bradley PLCs (Programmable Logic Controllers) and commercial OPI software. This system is used to control the cryogenics, magnets and motion of the HMS and SHMS spectrometers. This system is described in section 4.9. The system includes an interface to EPICS making spectrometer information available to standard EPICS tools and to give the PLC based control systems access to cryogenic plant information available in EPICS.

Chapter 7

Data Acquisition and Trigger

The Hall C data acquisition uses CODA [49] (CEBAF Online Data Acquisition), a toolkit developed at Jefferson Lab by the Data Acquisition Group.

The signals from the photomultipliers and drift chambers are digitized with high speed analog-to-digital converters (ADCs) and time-to-digital converters (TDCs). The digitizers currently in use are:

1. CAEN V1190A TDCs [50]. These modules, with 128 channels each, digitize discriminated signals with a resolution of 100 ps. They are used both for drift chambers and hodoscopes.
2. FADC250 [51]. These 16 channel ADC modules digitize the inputs with a 4 ns period. When triggered they can provide either a digitized waveform, or an integrated amplitude. Signals from the lead glass calorimeters, Cherenkov detectors and the hodoscopes are recorded with the FADC250s.

These modules are located in 5 VXS and VME64X crates located both in the counting house electronics room and the detector/electronic bunkers of the spectrometers.

- HMS Detector Hut: VXS crate with CAEN1190 TDCs for the HMS drift chambers
- SHMS Electronics Hut:
 - VME64X crate with CAEN1190 TDCs for the SHMS drift chambers
 - VXS crate with FADC250 modules for the SHMS Pre-shower and shower detectors.
- Counting House Electronics Room:
 - VXS crate with FADC250 and CAEN1190 modules for the HMS Hodoscopes, HMS Shower Counter and HMS Cherenkov detectors and a Trigger Supervisor.
 - VXS crate with FADC250 and CAEN1190 modules for the SHMS Hodoscopes, and Cherenkov detectors and a Trigger Supervisor.

In addition to these crates, standard VME crates are for scalars.

This system of crates can be run as a single DAQ system for coincidence experiments using both the HMS and SHMS. Alternatively, the system can be split into separate DAQ setups if one or both spectrometers are being used for single arm measurements.

The trigger supervisor is a custom-made module built by the data acquisition group. Its functions are to synchronize the readout crates, to administer the deadtime logic of the entire system, and to prescale various trigger inputs. We have two trigger supervisors, one in each spectrometer. This allows us to run the spectrometers independently if needed.

The public account `cdaq` is normally used for running DAQ. It is also used for online analysis with the C++ analyzer `hcana` and online analysis software.

7.1 Trigger Logic

Each photomultiplier and drift chamber wire in the HMS and SHMS detectors is digitized with a flash ADC, a TDC or both. Many of these detectors are used to make HMS, SHMS, or coincidence triggers, causing readout of these digitized signals. An block diagram overview of this DAQ/Trigger system is show in Fig. 7.1. Schematics for the electronics for the various detectors are show in Figs. 7.2, 7.3, 7.4 and 7.5.

7.2 Authorized Personnel

The authorized personnel is shown in table 7.1.

Name (first,last)	Dept.	Call [12]		e-mail	Comment
		Office	Cell		
Robert Michaels	Hall-A	7410	Web [13]	rom@jlab.org	
Ole Hansen	Hall-A	7627	Web [13]	ole@jlab.org	Computers

Table 7.1: DAQ: authorized personnel.

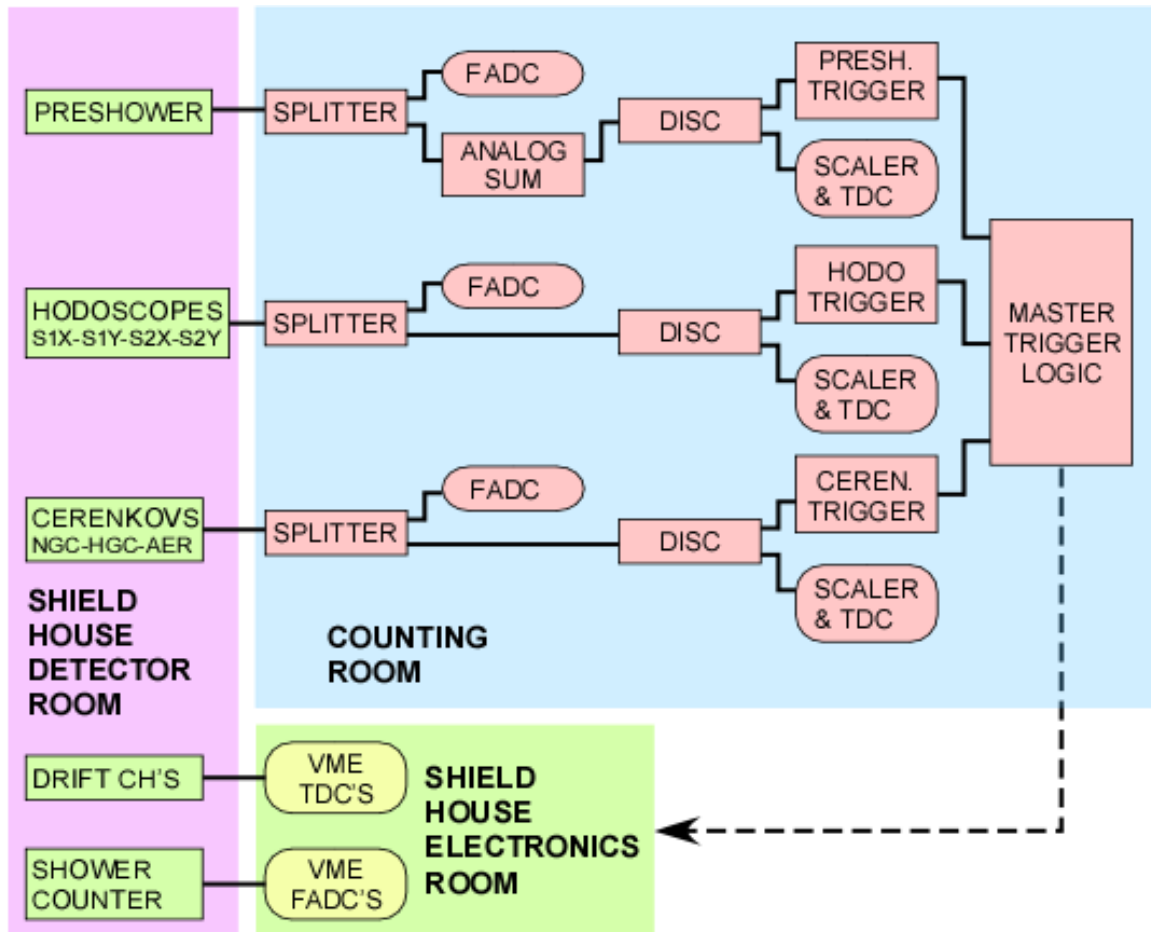


Figure 7.1: Overview of the SHMS trigger and DAQ. The HMS trigger is similar. The HMS drift chamber TDC's are in the detector hut, while the Flash ADC's for the HMS shower counter are located in the counting room.

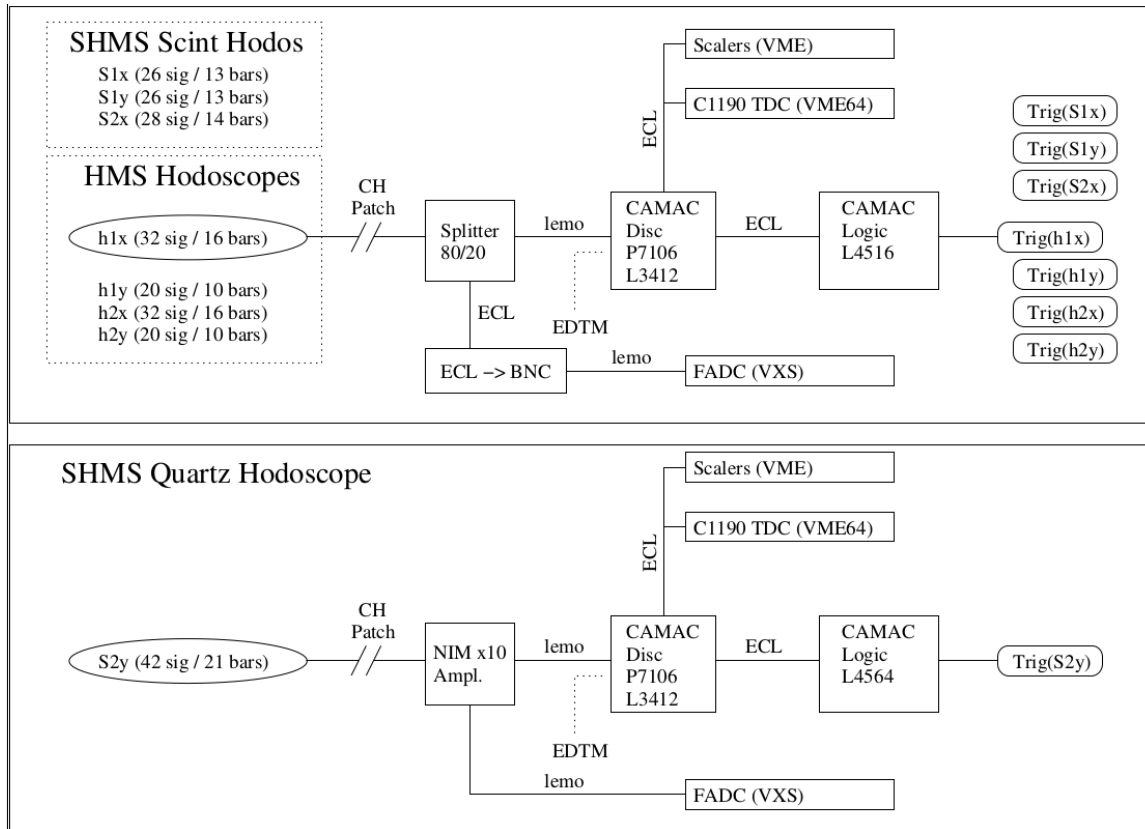


Figure 7.2: Schematic of trigger and DAQ for the HMS and SHMS hodoscopes. The CAMAC L4564 modules are used to make logical ORs of each plane. These OR'd signals are then used, with other detectors, to make a user configurable event trigger.

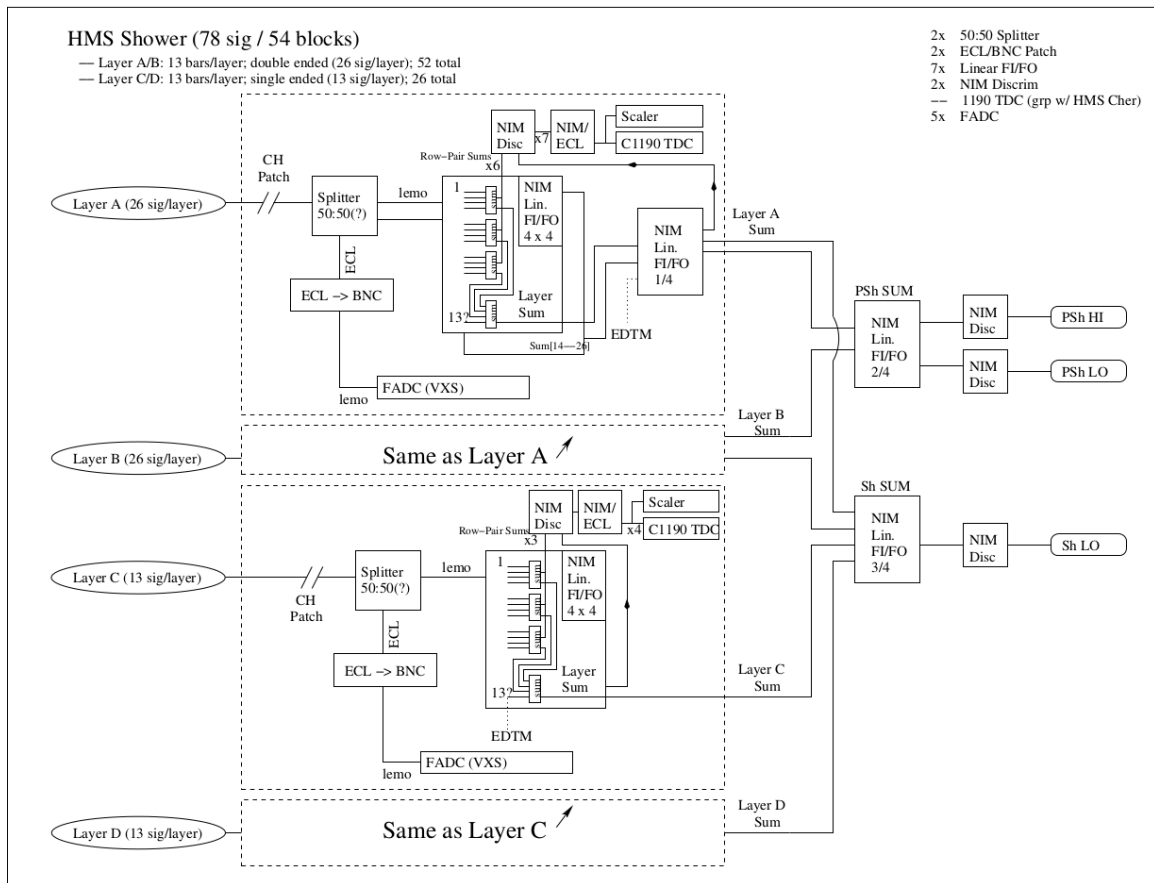


Figure 7.3: Schematic of the HMS Shower counter DAQ and trigger. The PSh HI, PSh LO, and Sh LO signals are used, with other detectors, to make a user configurable event trigger.

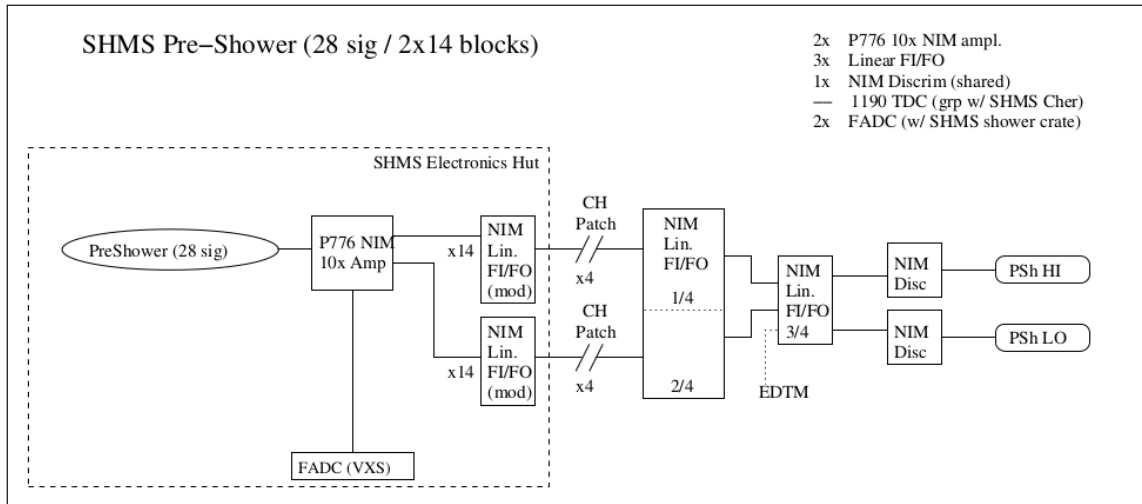


Figure 7.4: Schematic of the DAQ and trigger for the SHMS Pre-Shower layer of the SHMS shower detector. The PSh HI and PSh LO signals are used, with other detectors, to make a user configurable event trigger. The flash ADCs for the the 224 shower counter blocks behind the pre-shower are also located in the SHMS Electronics Hut. These blocks are not used in the trigger.

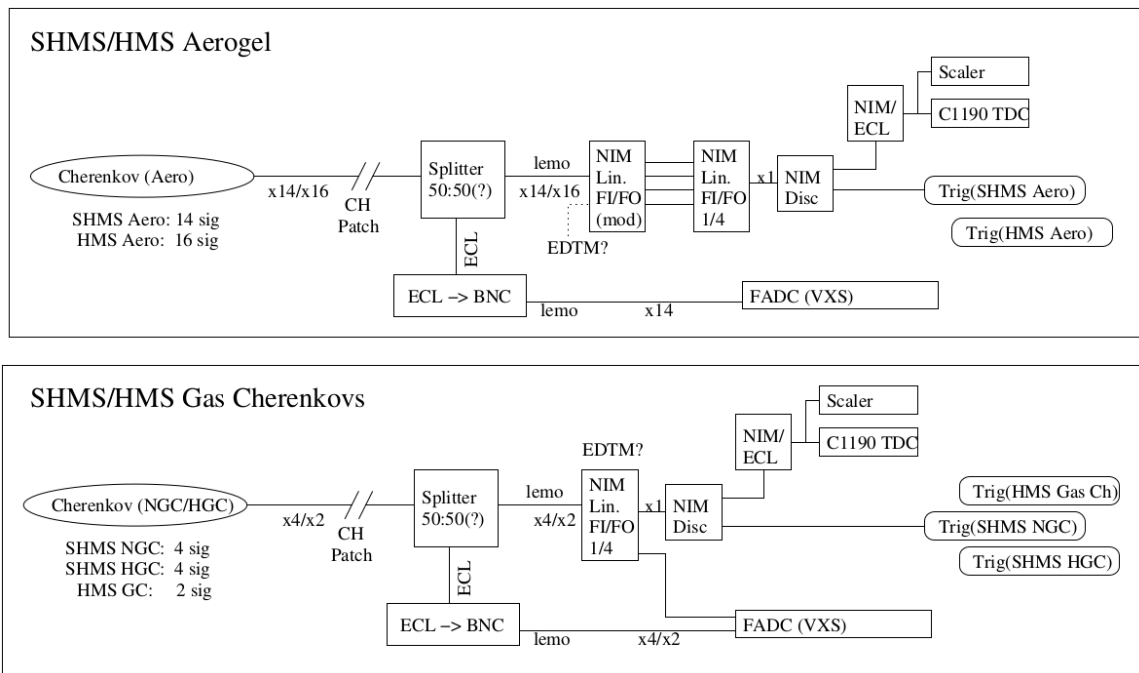


Figure 7.5: Schematic of the DAQ and trigger for the Aerogel and Gas Cherenkov detectors in the HMS and SHMS. The Trig signals (SHMS Aero, HMS Aero, HMS Gas CH, SHMS NGC, and SHMS HGC) are used, with other detectors, to make a user configurable event trigger.

Chapter 8

Analysis

The standard offline analysis software for Hall C data is “hcana” (a.k.a. the “Hall C Analyzer”), an object-oriented C++ class package developed by Hall C users and staff. hcana is built on top of the Hall A analysis software “podd” and uses the ROOT [52] programming framework, developed at CERN. All of ROOT’s analysis and visualization tools are available from within hcana, plus specialized classes for Hall C detectors and physics analysis. More information about the software (downloads, documentation, etc.) can be found at

https://hallcweb.jlab.org/wiki/index.php/ROOT_Analyzer.

hcana is newly developed for the 12 GeV era and supercedes the Fortran based ENGINE used in the 6 GeV era for analysis of HMS and SOS data. This new analysis software currently replicates the algorithms of the ENGINE, so in principle hcana could be used to analyze 6 GeV era data and reproduce the results of the Fortran analyzer.

Individual analysis components are designed as plug-in modules that can be loaded dynamically from an analysis script or otherwise as needed. As a result, the scope of the data analysis is largely user-configurable. Only data from the configured spectrometers and detectors are analyzed, and only the user specified physics calculations are carried out. Configuration can occur at run time without any need for recompilation of the program.

Currently supported are the analysis of the Hall C HMS, SHMS (and SOS) spectrometers, scaler and EPICS [5] slow control data. The event decoder is compatible with the CODA [49] event data format described in the section on Data Acquisition. The following detectors can be used in the spectrometers:

- Horizontal Drift Chambers (DCs)
- Hodoscopes (one or more planes of scintillator or quartz bars)
- Gas Cherenkov counters
- Aerogel counter
- Shower counters (one or more planes of side readout bars and optionally a fly’s eye array.)shower, preshower, pion rejectors with

The Drift Chamber code performs tracking in the focal plane and is able to identify multiple tracks. The THcHallCSpecrometer apparatus class projects these tracks back to the target, determining momentum, target position, and scattering angles for each track. This class also selects a best or “golden” track using various criteria including track fit χ^2 and information from hodoscopes.

The scintillator, Cherenkov, and shower counter classes perform basic decoding, calibration (offset/pedestal subtraction, gain multiplication), and summing (for Cherenkovs) or cluster-finding (for showers) of hits.

Several beamline apparatuses are available: a dummy beam (always at zero position and angle), an “unrastered” beam, and a “rastered” beam. BPM and raster detectors are implemented and can be analyzed to obtain the beam position on an event-by-event basis. The BPM code currently only supports standard ADCs (e.g. LeCroy), not the older Struck readout.

To carry out standard post-reconstruction calculations, the following so-called physics modules are available:

- Single-arm electron kinematics (Q^2 , ω etc.)
- Coincidence kinematics (missing energy etc.)
- Deuteron photodisintegration kinematics
- Single-arm elastic scattering kinematics from detected recoil particle
- Coincidence time
- Reaction point (vertex position) reconstruction
- Energy loss corrections

There is no limit (other than machine resources) to the number of physics modules that can be configured for an analysis run. Identical modules can be added multiple times with different parameters. For example, one can calculate “electron kinematics” using both uncorrected and energy-loss corrected tracks in one analysis pass without modifying or recompiling any code. For experiments requiring specialized calculations of kinematics or any other quantities, writing a new physics module is the preferred approach.

The results of calculations performed by the various analysis modules (spectrometers, detectors, physics modules) are made available via so-called global variables. Global variables provide access to data via names (text strings). Scalars as well as fixed and variable-size arrays are supported. The global variable names are used in the definition of the analysis output and of logicals.

Tests and cuts (“logicals”) can be defined dynamically at run time. They can be used for controlling the analysis flow, keeping statistics, pre-computing logical values to be included in the output, or applying cuts to histograms written to the output. If certain tests fail for a given event, further analysis of that event can be skipped, and the event is not written out. Such tests can be put at the end of all the major stages of the analysis. This allows making decisions about an event early in the analysis, improving performance. A summary of all test results is written to a file at the end of the analysis.

Data of interest that is save in global variables can be histogrammed and/or written to a ROOT Tree in the output file. The contents of the output is defined dynamically at the beginning of the analysis. Both 1- and 2-dimensional histograms are supported. Histograms can be filled selectively using logical expressions (cuts).

Text summaries of run and analysis information can be made with the PrintReport method of the THcAnalyzer class. Using text based templates, similar to templates used in the old ENGINE analyzer, hardware scalers, parameters, statistics of cut success, and other information such as EPICS values can be written to “reports.”

Table 8.1 lists the analysis modules available in version 1.5.24 of Podd.

8.1 Program Design Overview

Spectrometers (and similar major installations) are abstracted in an Apparatus class hierarchy, while individual detectors belong to a Detector class hierarchy. Apparatuses are collections of detectors that are analyzed in a particular way. Specialized physics analysis, such as kinematics calculations, vertex determination, and energy loss corrections, can be done in Physics Modules. All three types of objects, Apparatuses, Detectors, and Physics Modules, are kept in lists that are processed during replay. In setting up the replay, it is up to the user which objects to place in the lists.

Both the Apparatus and the Detector class hierarchies, as well as the Physics Modules, inherit from a common base class, `THaAnalysisObject`. Physics Modules currently do not use a particular class hierarchy; all physics modules inherit from `THaPhysicsModule`, which in turn inherits from `THaAnalysisObject`.

The behavior of existing analysis modules can be modified or extended easily by using class inheritance. In such a case, the only code that needs to be written is the implementation of the new feature. For example, the standard Cherenkov detector class currently only calculates the total sum of ADC amplitudes. For a new type of Cherenkov counter, or to do a more sophisticated analysis of the standard Cherenkov detectors, one might want to calculate separate ADC sums for certain groups of PMTs. To do so, one would write a new class inheriting from the standard Cherenkov class, which could contain as little as one function, performing the additional calculations, and the corresponding data members. New types of detectors and even entire spectrometers, as well as new types of physics calculations, can be added similarly easily, again using class inheritance. No change to and no rebuilding of the core program is necessary to support such new modules.

8.1.1 Responsible Personnel

The responsible personnel are shown in table 8.2.

Class name	Description
Support	
THcAnalyzer THcParmList THcFormula Apparatuses	Hall C customized analyzer event loop Read and store detector and physics parameters Extends ThaFormula to allow access to parameters and cut statistics
THcHallCSpectrometer THaIdealBeam THcRasteredBeam THaUnrasteredBeam THaDecData	Hall C spectrometer (SHMS, HMS or SOS) Dummy beam with zero position and angle. Beam with raster Beam without raster (for calibration) Miscellaneous decoder raw data
Detectors	
THcDC THcHodoscope THcCherenkov THcAerogel THcShower THcRaster	Drift Chamber Package Set of Scintillator (or quartz) planes Gas Cherenkov Aerogel Cherenkov combination of preshower and shower beam raster system
Physics Modules	
THaReactionPoint THaTwoarmVertex THaAvgVertex THaElectronKine THaPrimaryKine THaSecondaryKine THaPhotoReaction THaSAProtonEP THaExtTarCor THaCoincTime THaS2CoincTime THaGoldenTrack THaDebugModule	vertex position (intersection of spectrometer track with beam) vertex position (intersection of two spectrometer tracks) vertex position (average of reaction points from two spectrometers) single-arm electron kinematics single-arm kinematics for particle with arbitrary mass coincidence kinematics deuteron photodisintegration kinematics elastic $A(e, A)e'$ kinematics from detected A extended target corrections coincidence time calculation coincidence time using S2 scintillator in HRS selects Golden Track from multiple reconstructed tracks prints values of global variables for each event and waits

Table 8.1: Analysis modules available in Podd. Not tested with hcana.

Name (first,last)	Dept.	Call [12]		e-mail	Comment
		Office	Cell		
Mark Jones	Hall-A/C	7733	Web [13]	jones@jlab.org	<i>Contact</i>
Ole Hansen	Hall-A	7627	Web [13]	ole@jlab.org	

Table 8.2: Offline analysis: authorized personnel.

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