

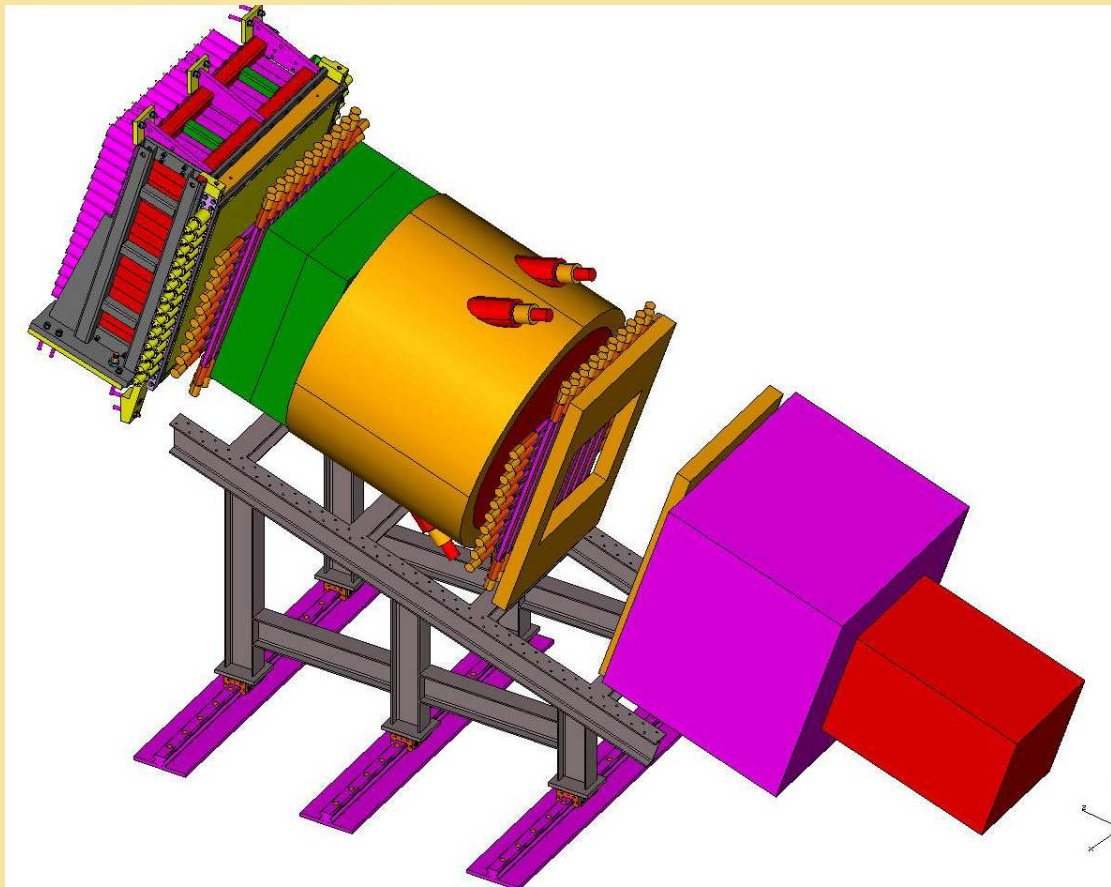
# SHMS Particle Identification

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Hamlet Mkrtchyan,  
Donal Day

# Particle Identification @ 3.5-11 GeV/c

- Efficient, high-confidence PID requires extensive use of non-TOF techniques such as Čerenkov detectors.
- Good PID can be obtained with a series of Čerenkov detectors:
  - $e^-/\pi^- \Rightarrow$  Noble Gas Čerenkov ( $n-1 < 10^{-4}$ )
  - $\pi^+/K^+ \Rightarrow$  Heavy Gas Čerenkov ( $n-1 \leq 10^{-3}$ )
  - $K^+/p \Rightarrow$  Aerogel Čerenkov ( $n-1 \leq 0.05$ )
- Lead Glass Calorimeter also plays a critical role in  $e^-/\pi^-$  separation.

# SHMS Detector Package



## **Noble Gas Čerenkov:**

**e/ $\pi$  separation at high momenta, where multiple-scattering is less of an issue.**

## **Trigger Hodoscopes:**

**Time-of-Flight at low momenta; insensitive to photon or low-energy background.**

## **Heavy Gas Čerenkov:**

**$\pi$ /K separation for  $P > 3.4$  GeV/c.**

## **Aerogel Čerenkov(s):**

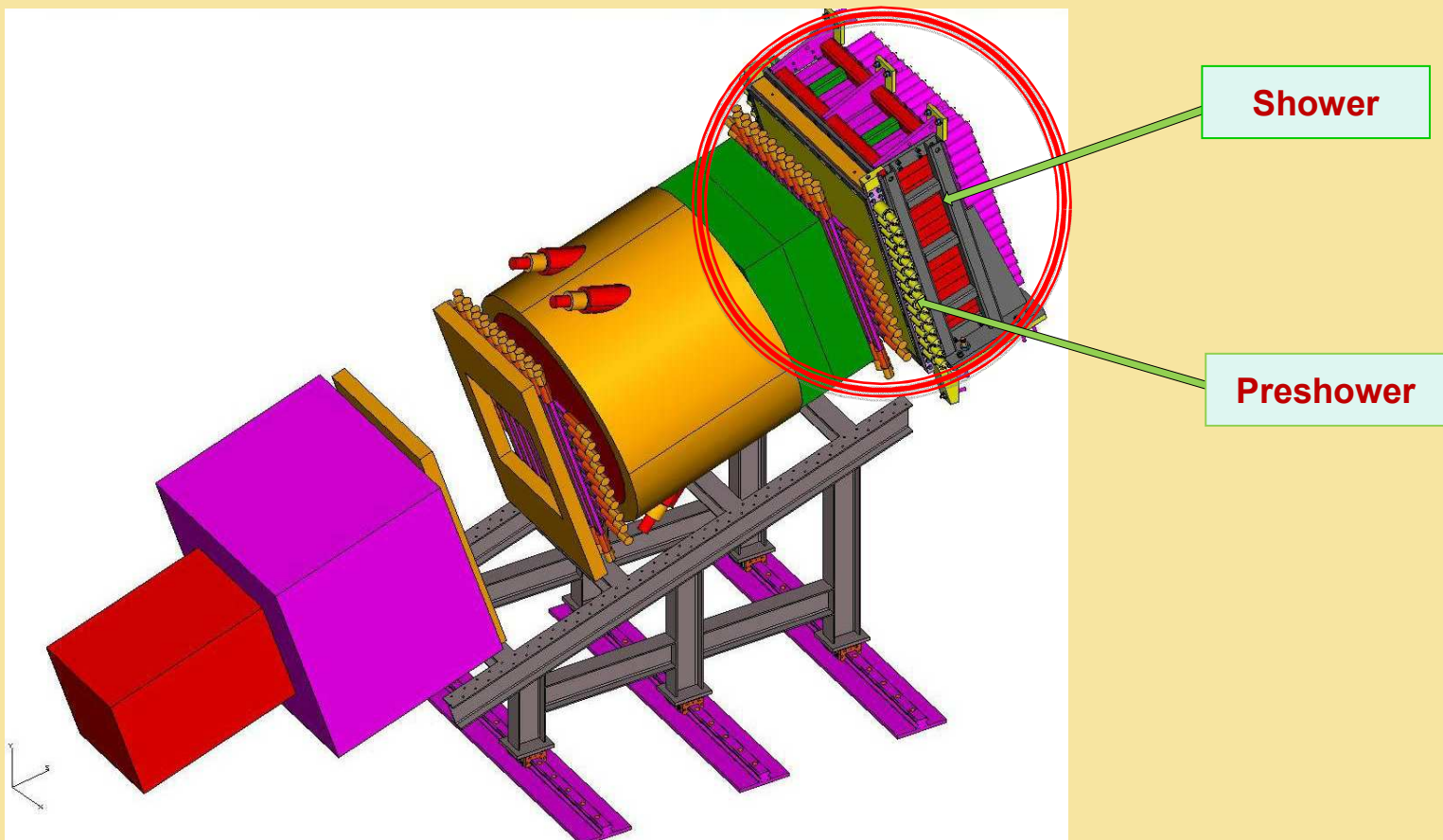
**Depending on the  $n$  used, K/p separation or  $\pi$ /K separation at low momenta.**

## **Lead Glass Calorimeter:**

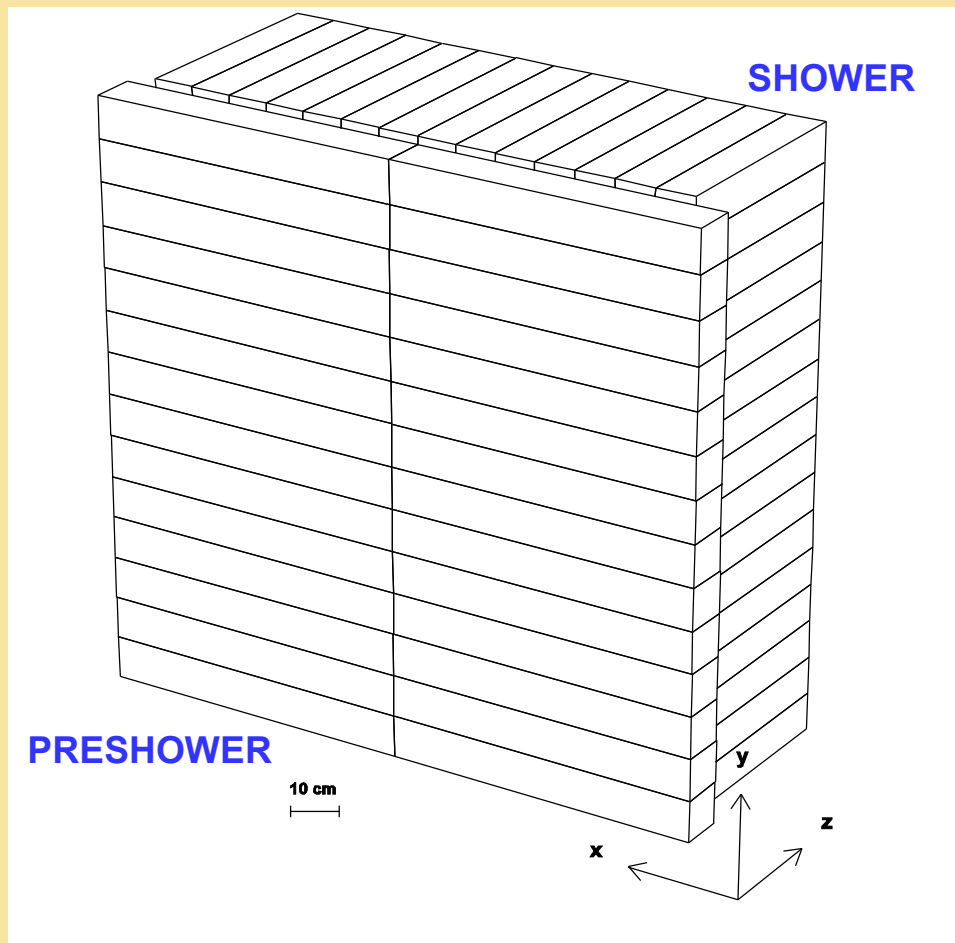
**e/ $\pi$  separation.**

# Calorimeter: $e/\pi$ separation

- Lead-Glass Block / PMT / Base Assemblies from SOS and HERMES Calorimeters.



# Lead Glass Block Arrangement



- **Separate stands for Preshower and Shower**
- **Final option for blocks arrangement in Shower**  
(Note, engineering work have been started on June 09 !)

## PRESHOWER:

# of SOS blocks	28
Block size (cm <sup>3</sup> )	10x10x70
Lead Glass type	TF-1
<b>Cross section (cm<sup>2</sup>)</b>	<b>140x140</b>
<b>Thickness (cm)</b>	<b>10.</b>
<b>Weight (T)</b>	<b>0.757</b>

## SHOWER:

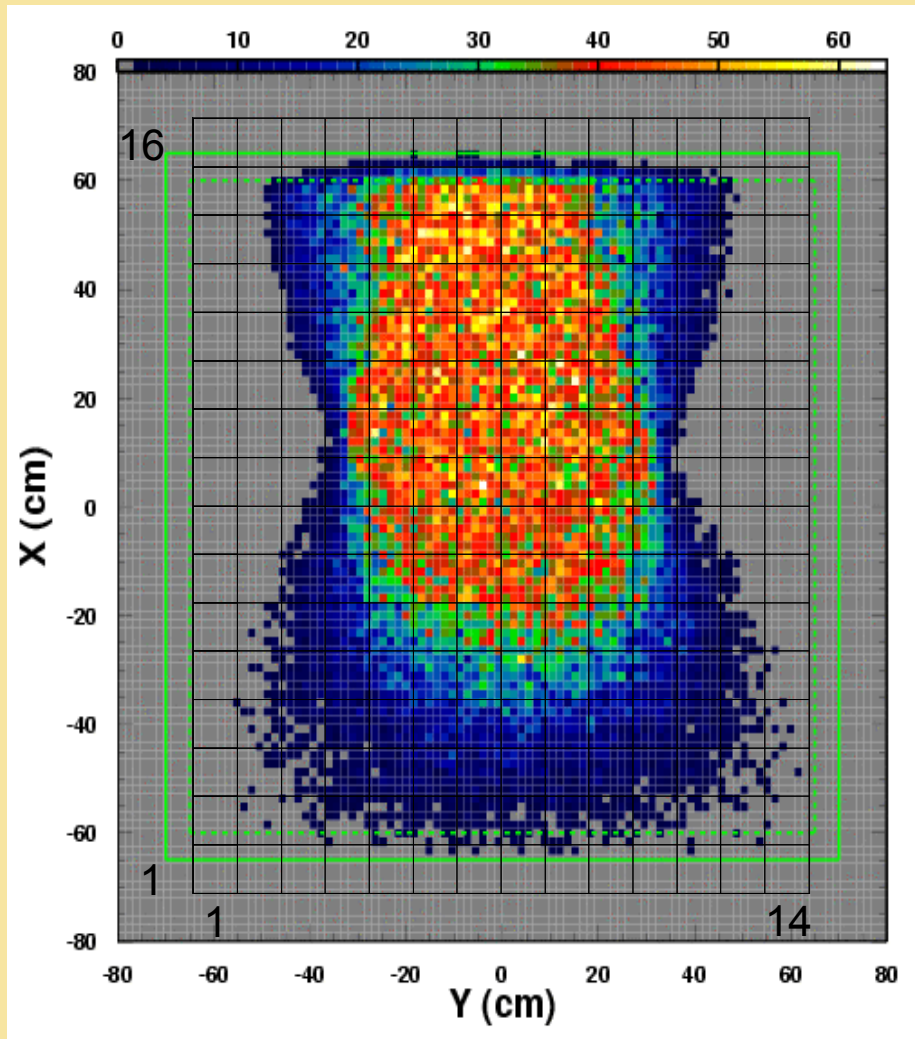
# of HERMES blocks	224
Block size (cm <sup>3</sup> )	9x9x50
Lead Glass type	F-101
<b>Cross section (cm<sup>2</sup>)</b>	<b>126x144</b>
<b>Thickness (cm)</b>	<b>50.</b>
<b>Weight (T)</b>	<b>3.502</b>

## CALORIMETER:

Number of channels	252
<b>Max. width (cm)</b>	<b>140</b>
<b>Max height (cm)</b>	<b>144.</b>
<b>Thickness (cm)</b>	<b>60.</b>
<b>Total weight (T)</b>	<b>4.259</b>

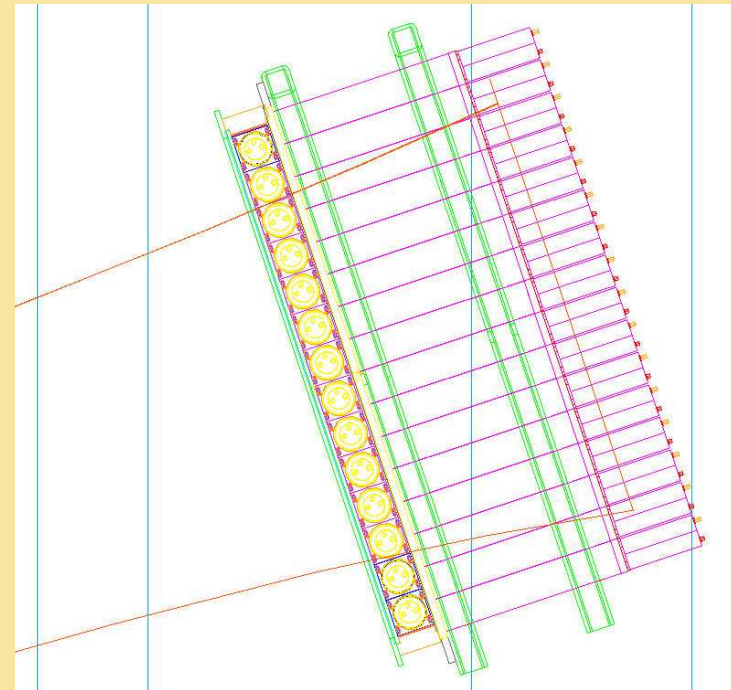
\*Numbers for Lead Glass ONLY!

# Calorimeter Position and Dimensions



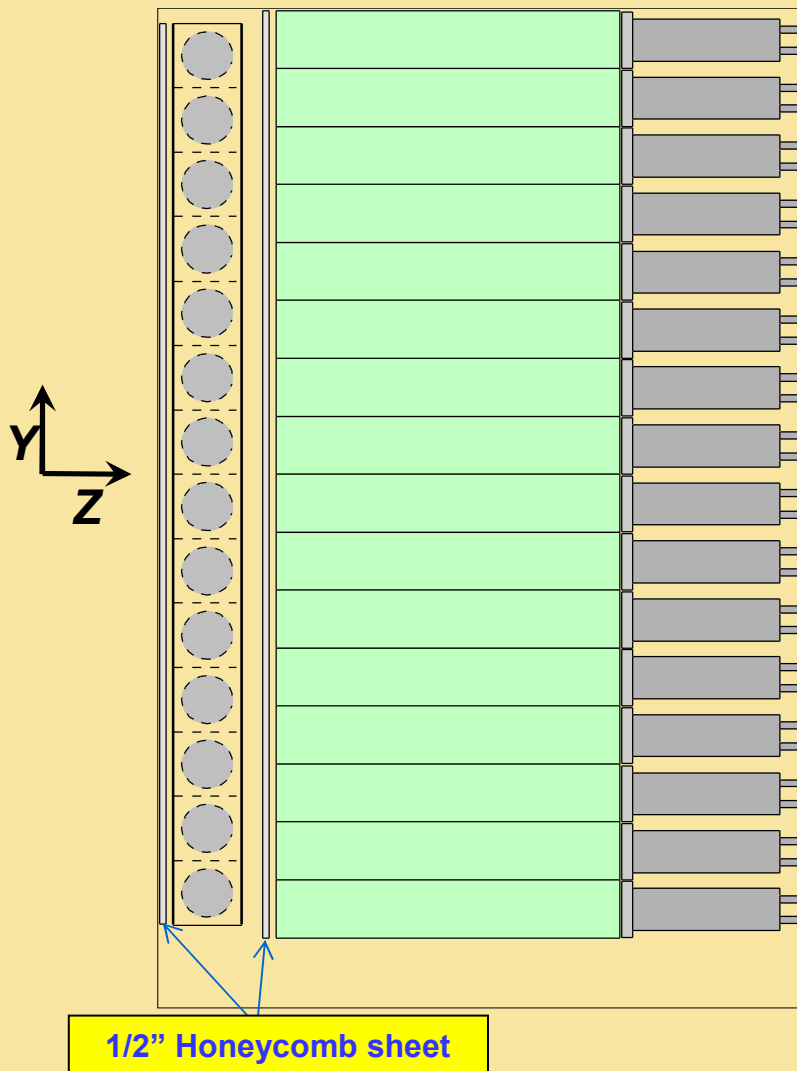
Beam envelope at back of calorimeter.

- Calorimeter will have enough effective area to be insensitive relative to SHMS optics or final location changes (to 4-5 “).
- Calorimeter will be installed at 2-3° relative to central optical axis to exclude particle pass through calorimeter without interaction.



# Side View

(Engineering coordinates !)



## In Z direction:

### PreShower :

1/2" Honeycomb sheet	1.3 cm
Lead Glass Block	10.0 cm
1" Gap	2.5 cm

### Shower:

1/2" Honeycomb sheet	1.3 cm
Module (lg.block+PMT)	74.0 cm
~5" space for cabling	12.5 cm

**Total in Z direction** **101.6cm\***

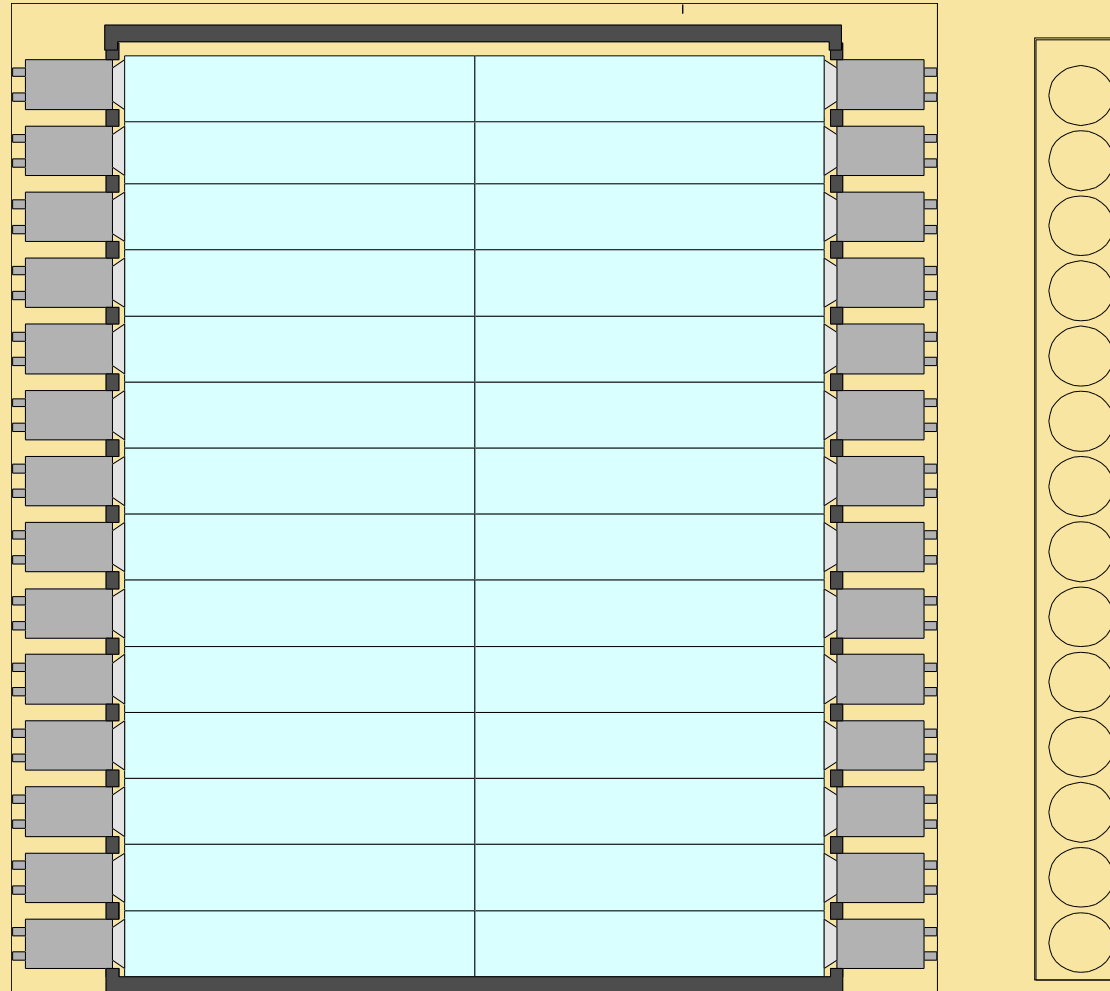
\* Other constructive elements not taken into account

## In Y direction:

Preshower, 14 blocksx10cm	140 cm
Shower, 16 blocks x 9cm	144 cm
<b>Max. in Y direction</b>	<b>144 cm</b>

# Front View: Preshower

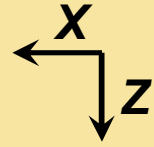
2 x 14



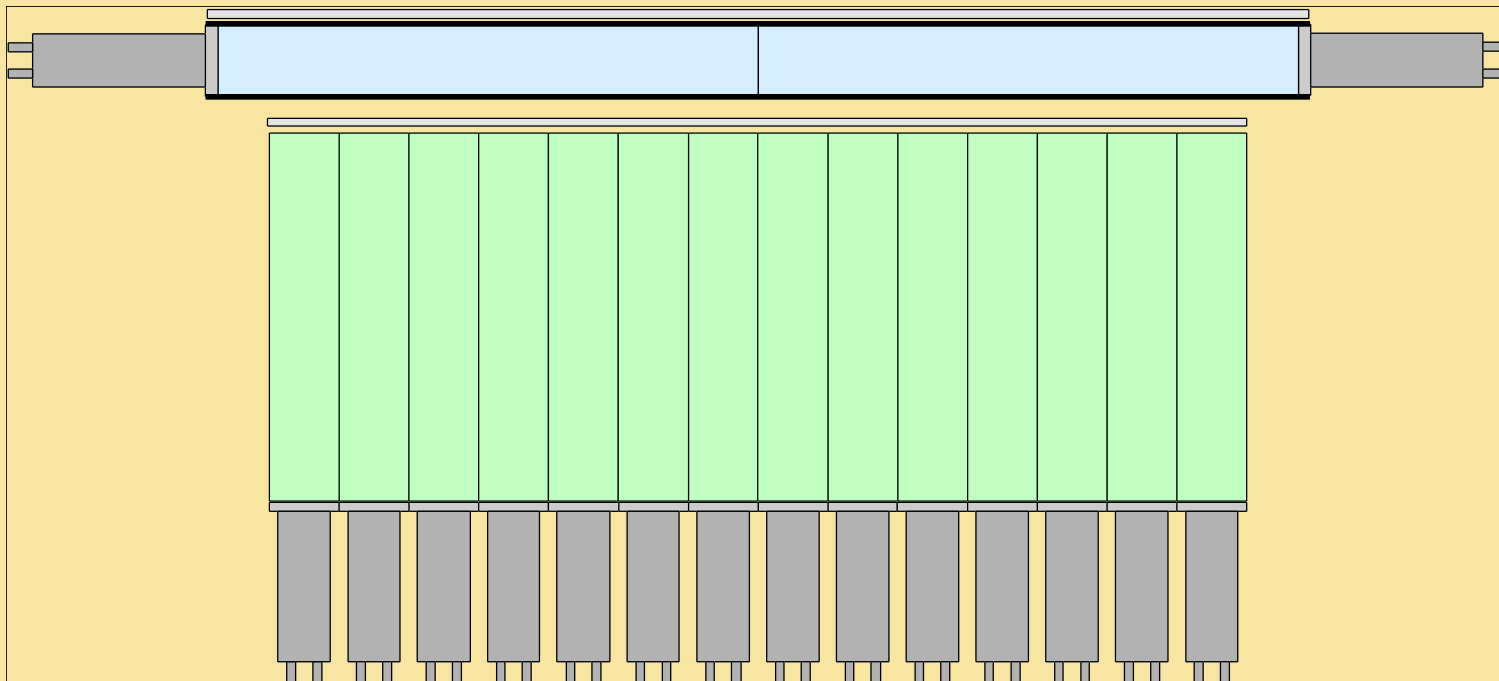
- Silicone grease for coupling.
- Preshower will be independent detector.
- Easy to change PMTs and HV bases.



# Top View

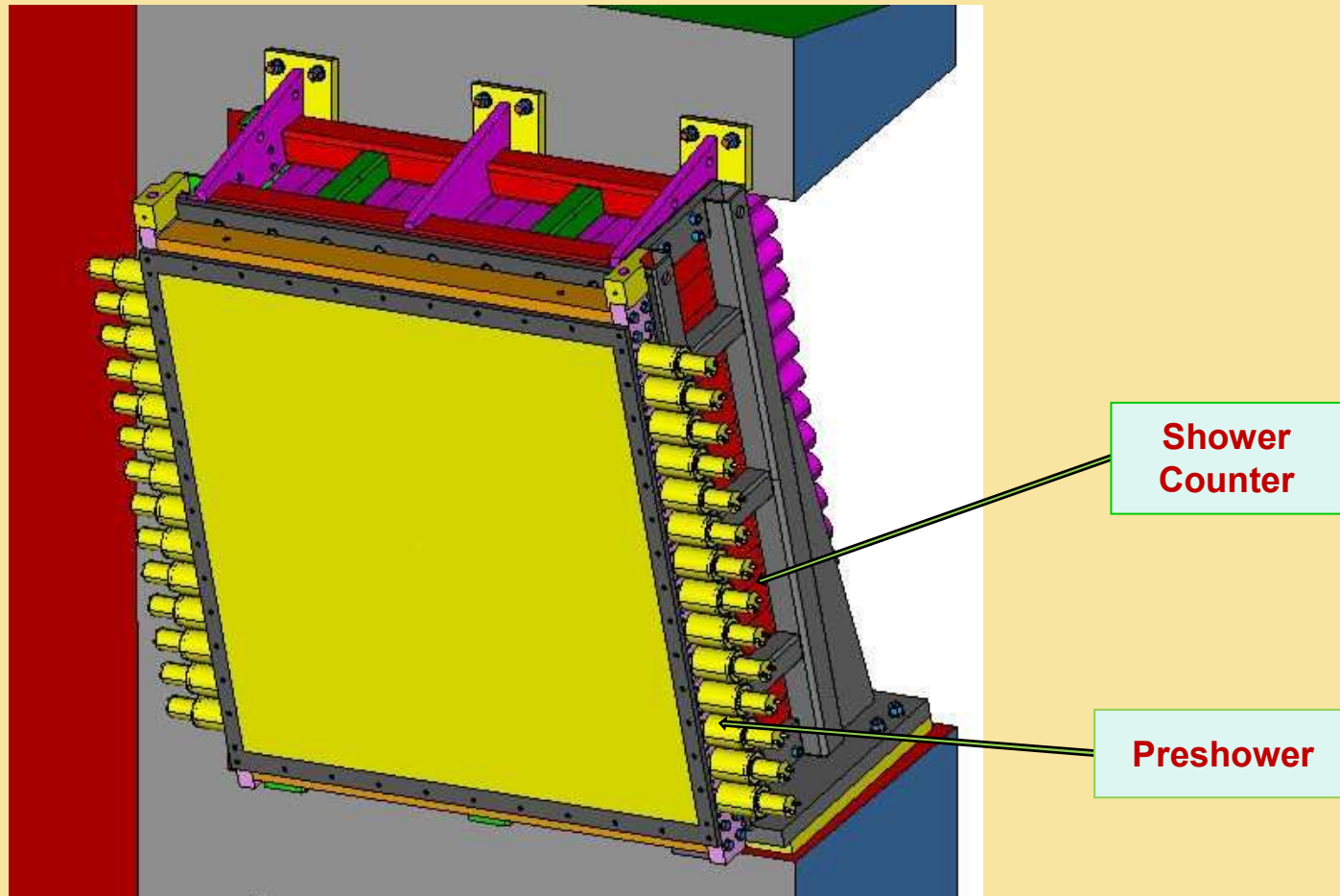


(Engineering coordinates !)



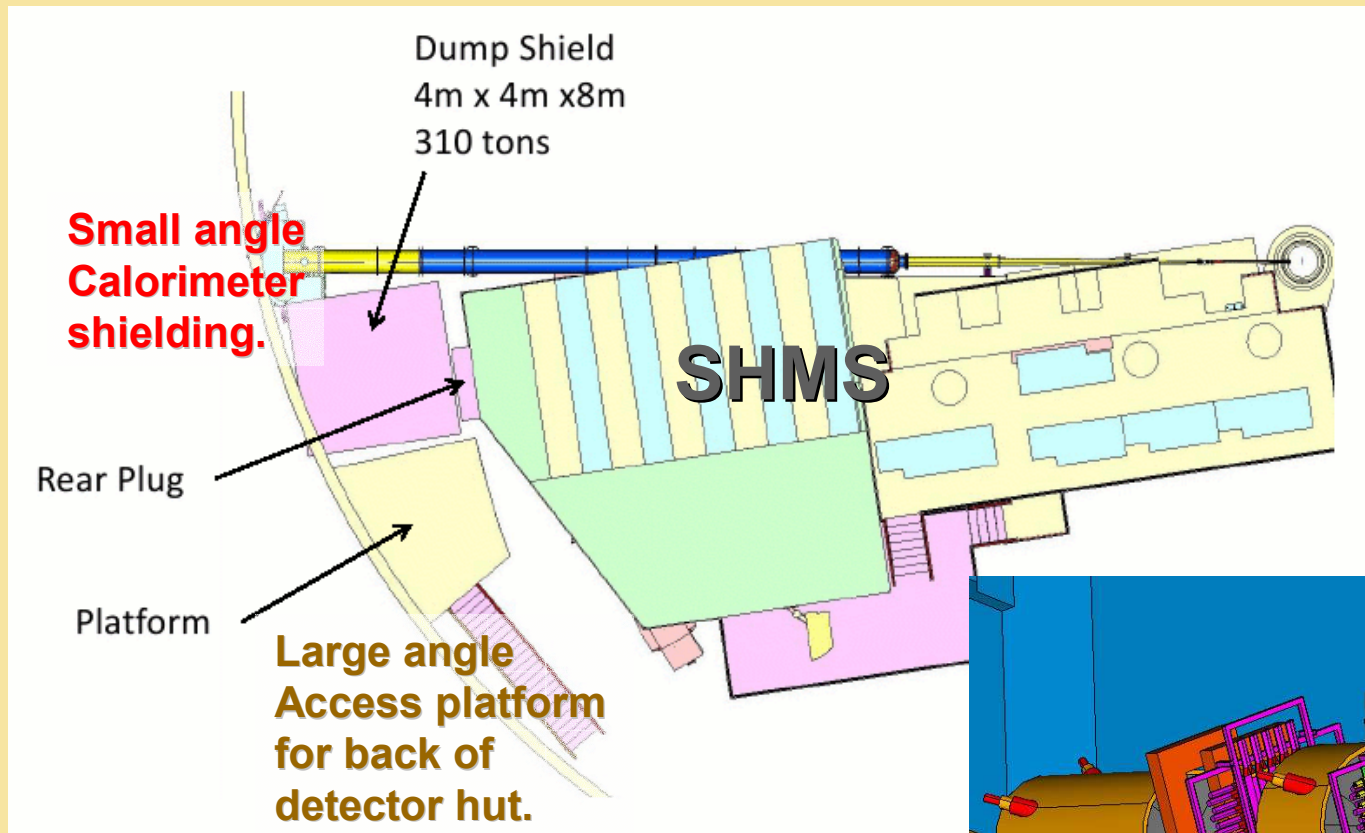
<u>Preshower width:</u>		<u>Shower width:</u>	
Module (lg.block+PMT)	97.0cm	14 Blocks	14x9 = 126 cm
Space for cables	10.0cm		
Total width	2 x 107 = 214 cm	<b>Max. width</b>	<b>214 cm</b>

# Calorimeter Mounting & Assembly

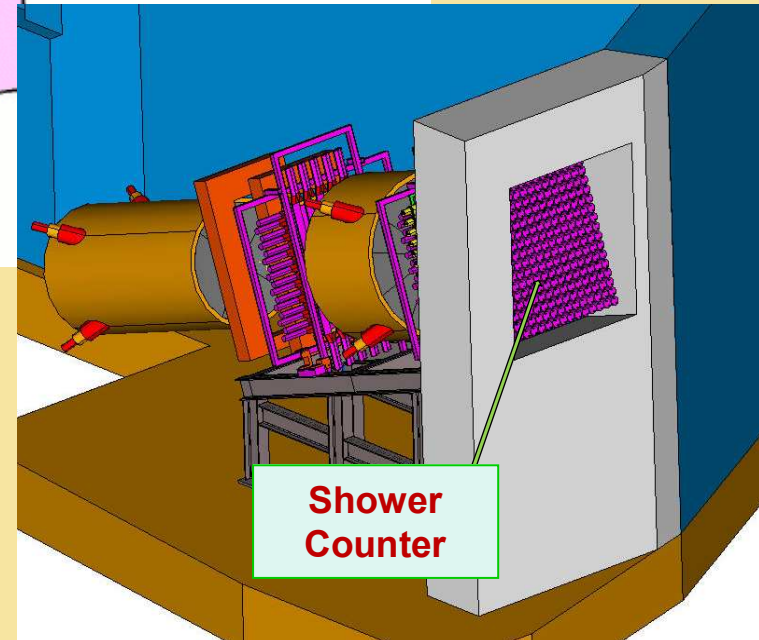
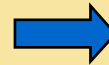


- At least two persons will be needed to stack shower blocks.
- Front window of shower counter (honeycomb) must be sufficiently strong to hold pressure of 224 blocks.
- Need at least ~1-1.5" gap between Shower and Preshower.

# Rear Access Considerations

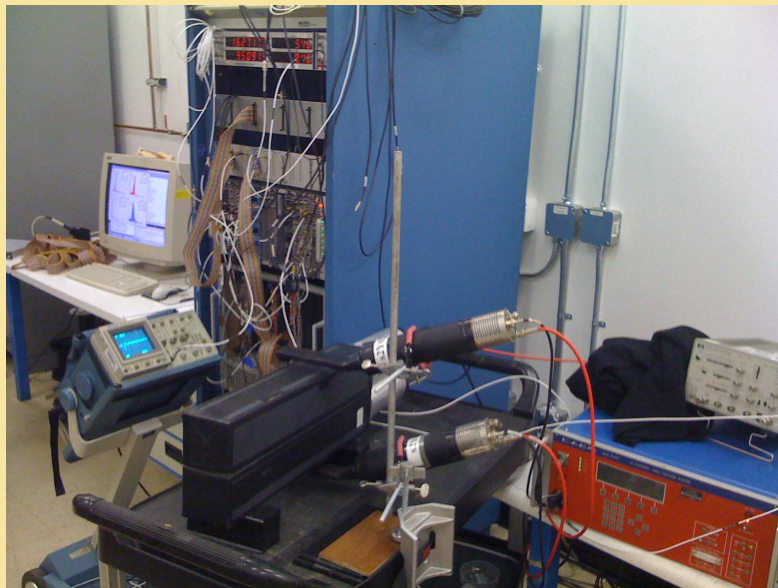
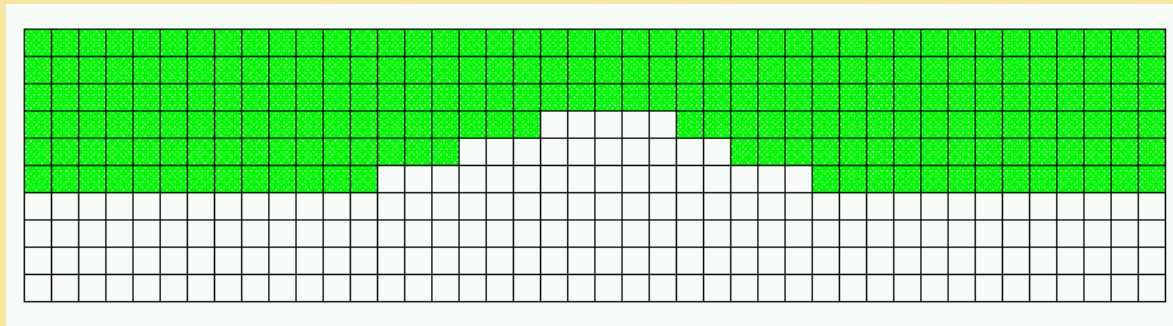


**Need to ensure sufficient air circulation for 224 PMT's when Rear Plug in position.**



# HERMES Blocks+PMTs are already at JLab and undergoing cosmic-ray tests

Elements from low-rate regions of HERMES Calorimeter selected for use in the SHMS.

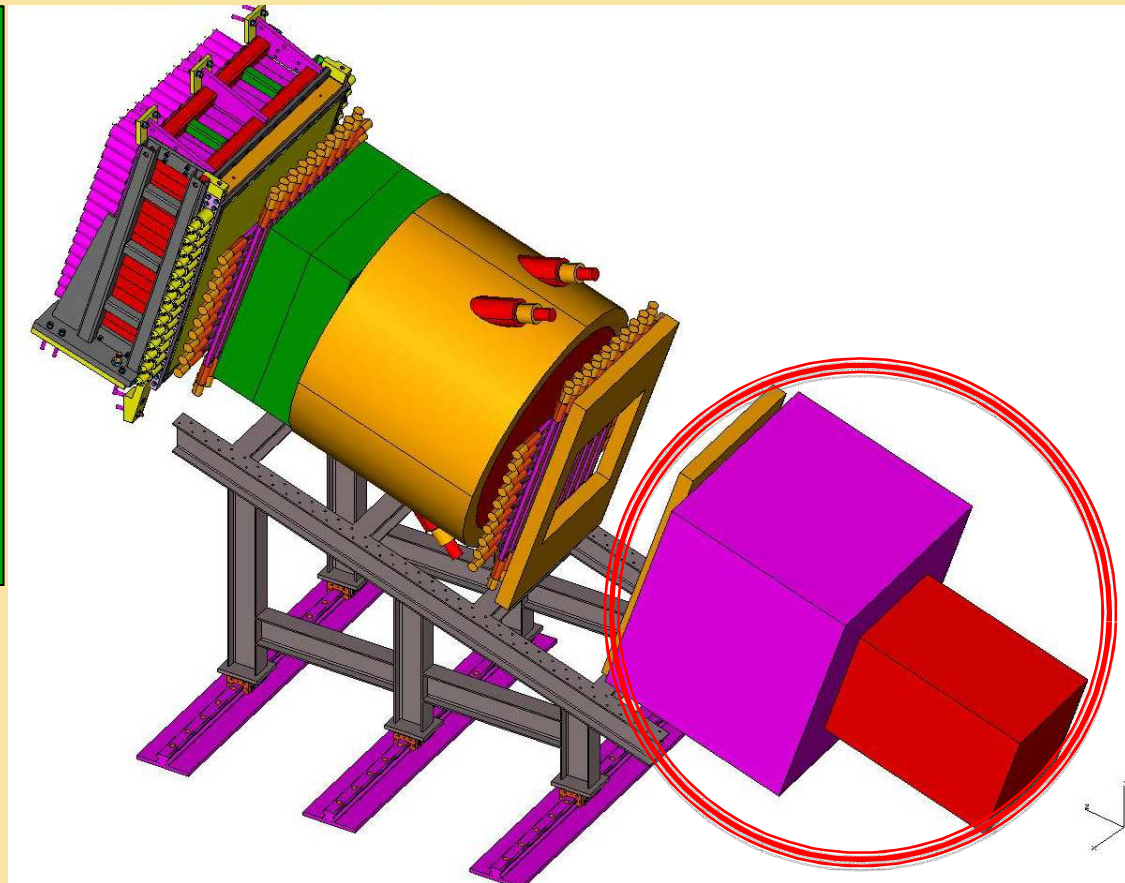


## COSMIC RAY TEST @ JLab:

- ~100 blocks performed to date.
- Problems in ~20 blocks found and fixed (Arthur Mkrтчhyan).
- Test of remaining blocks in progress.

# Noble Gas Čerenkov : e/ $\pi$ separation

- Supplements the Calorimeter to provide 10000:1 e/ $\pi$  separation where required.
- At low momenta: remove detector and insert tank coupled to vacuum system to reduce MCS.



# Radiator Gas Choices

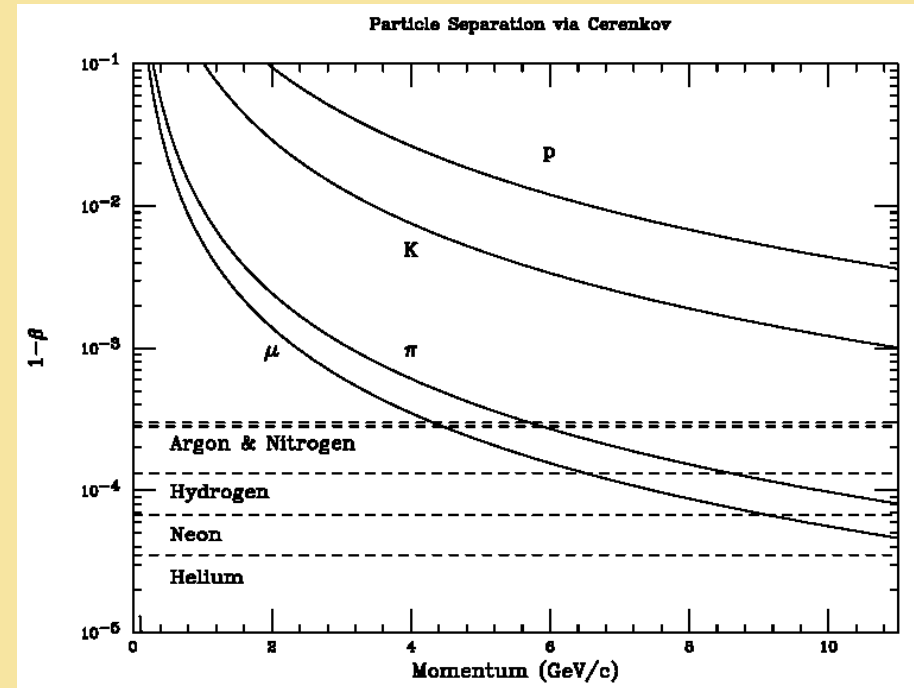
**$e^-/\pi^-$  separation requires**

$$1/\beta_{e,\min} < n < 1/\beta_{\pi,\max}$$

**$\pi$  threshold at 1 atm:**

- **Argon: ~5.5 GeV/c.**
- **Adding Neon: up to 11 GeV/c.**

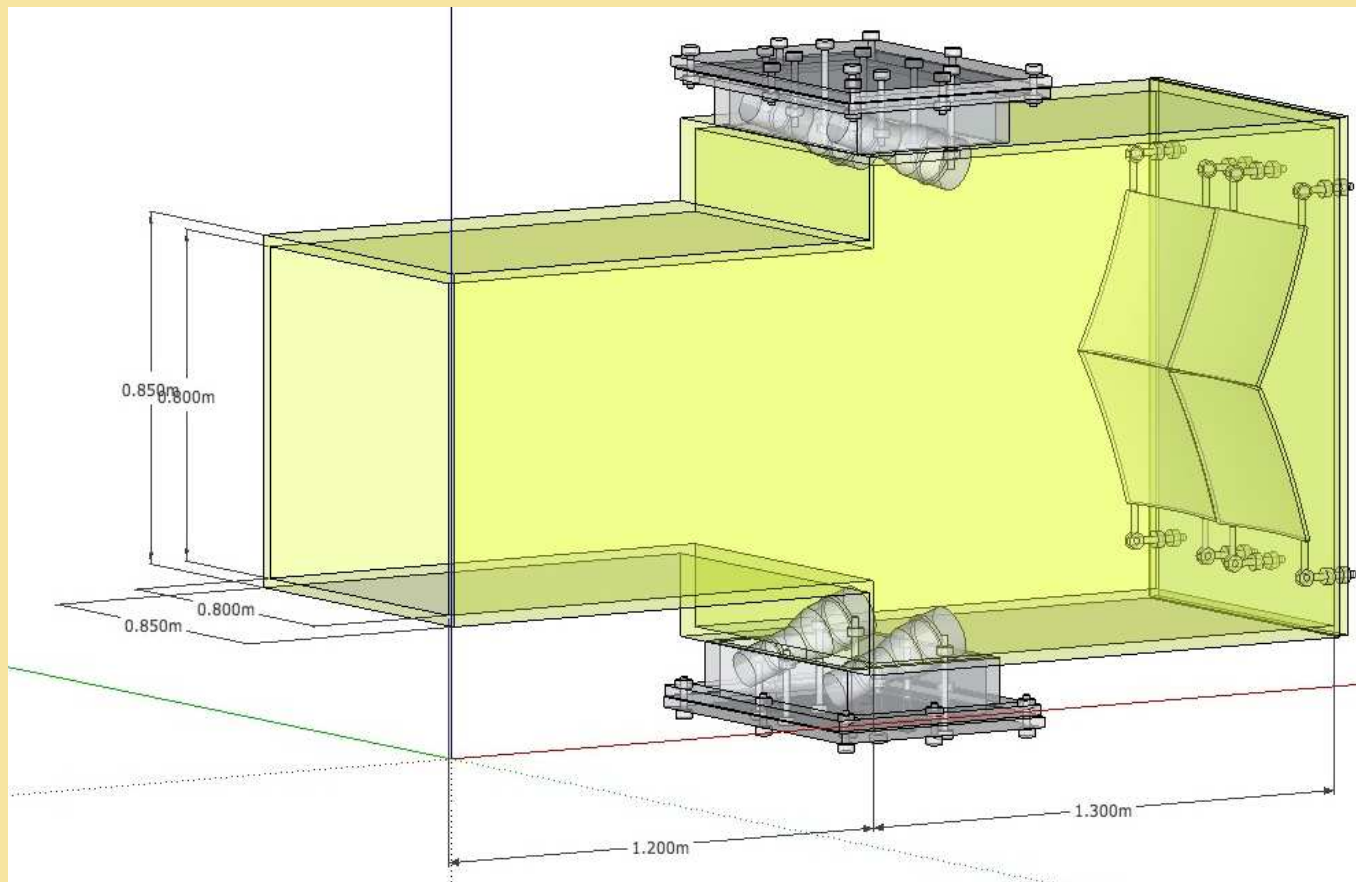
Gas	$P_{r\pi}^{\pi}$ Threshold 6 GeV/c	$P_{r\pi}^{\pi}$ Threshold 10 GeV/c	$e^- N_{p.e.}$ relative Neon
Argon	0.95 atm	0.28 atm	4.3x
Nitrogen	0.99	0.29	4.5
Neon	4.04	1.20	1.0
Helium	7.73	2.30	0.53



Neon can be used over the entire SHMS momentum range, but at the cost of fewer photoelectrons collected at lower momentum, in comparison to Argon.

# Noble Gas Čerenkov Plan View

- 2.5 m long gas radiator in simple enclosure at 1 atm.
- Four mirrors --- each 75/2cm tall x 80/2cm wide.
- Four 5" PMTs at top and bottom (Hamamatsu R1584).



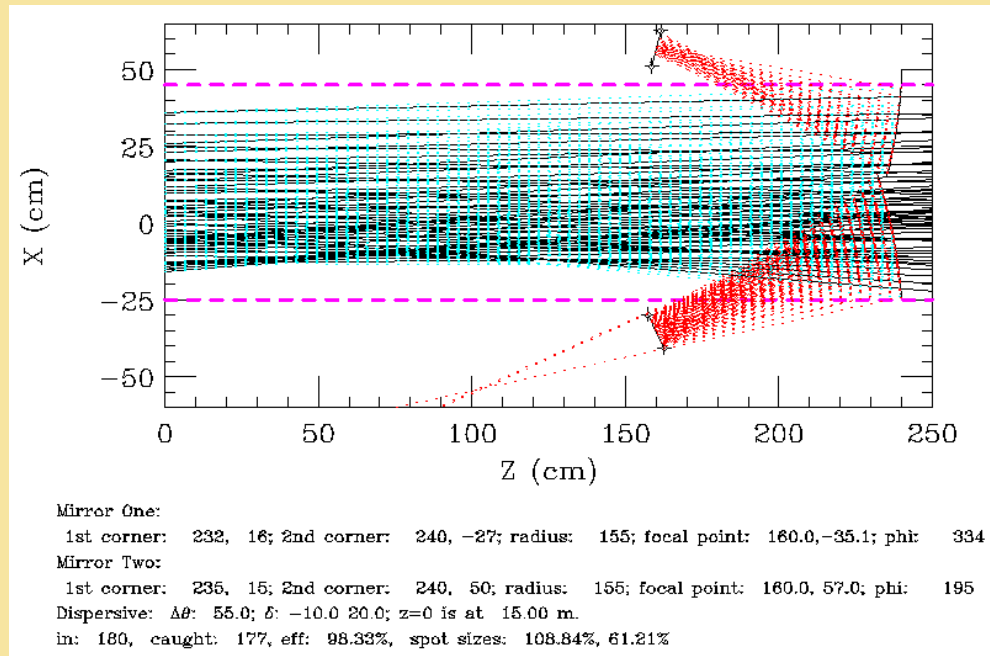
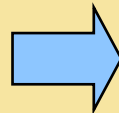
# Optics Simulations

- Both Čerenkovs are co-ordinating design efforts.
- Available tools:
  - 2D Raytrace program used in design of HMS Čerenkov.
  - 3D Geant4 studies making use of 50000 event SHMS white spectrum provided by Tanja Horn.

## 2D Raytrace Output:

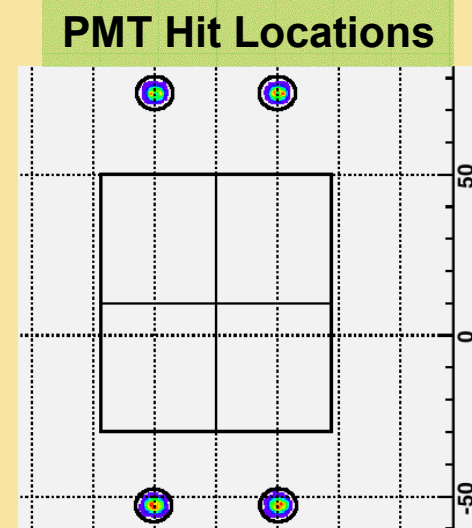
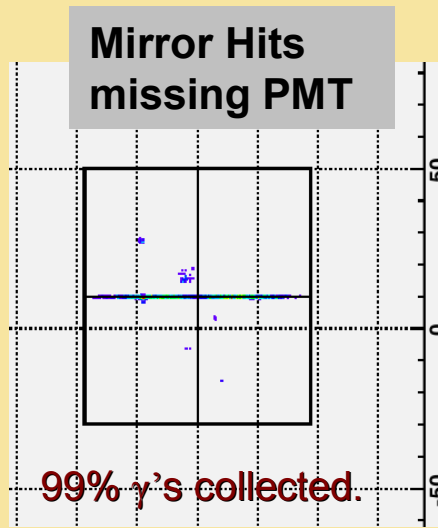
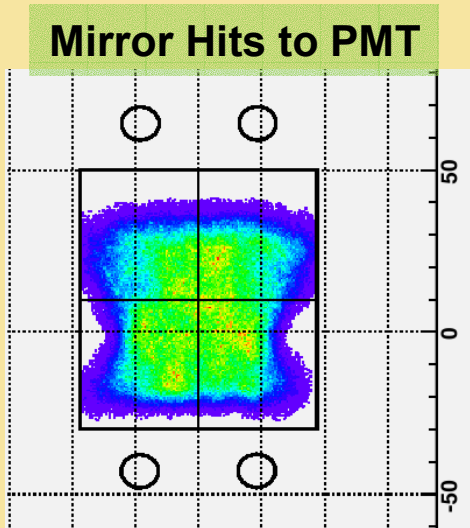
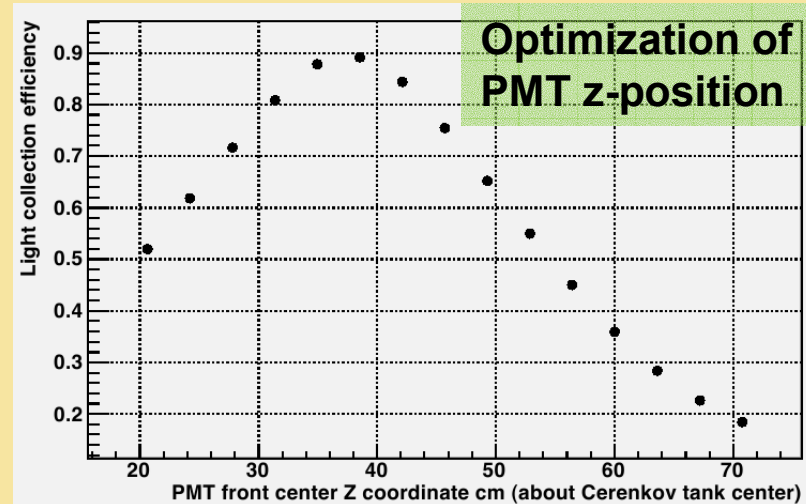
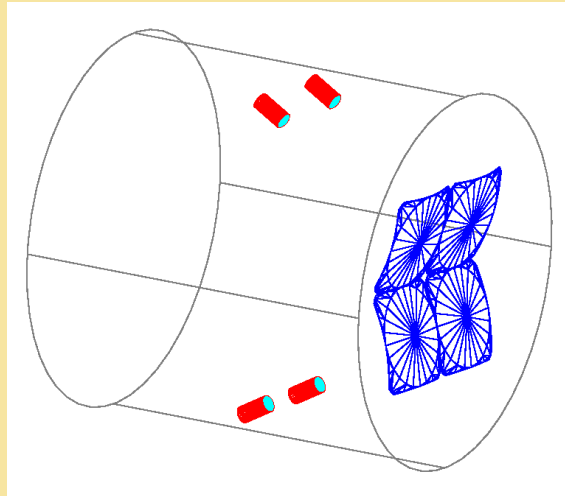
→ R=155cm Spherical Mirrors.

→ Asymmetric SHMS envelope dictates different mirror and PMT placements for  $\pm\delta$ .



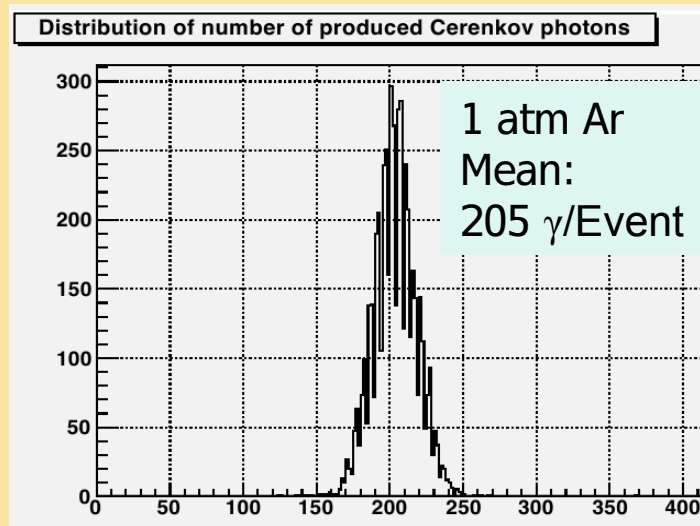
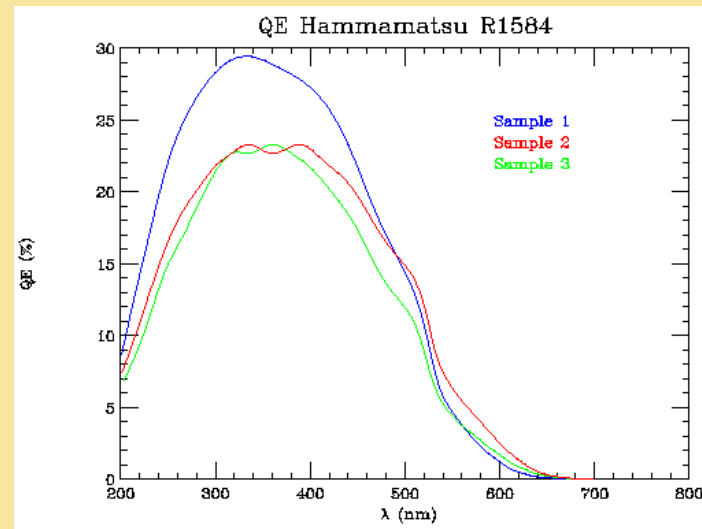
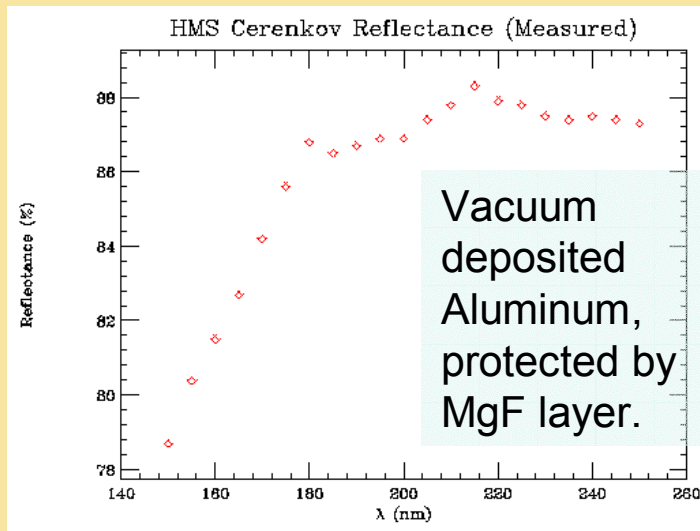


# Geant4 Simulations In Progress



# Design & Projected Performance

## Reference Design: HMS Čerenkov

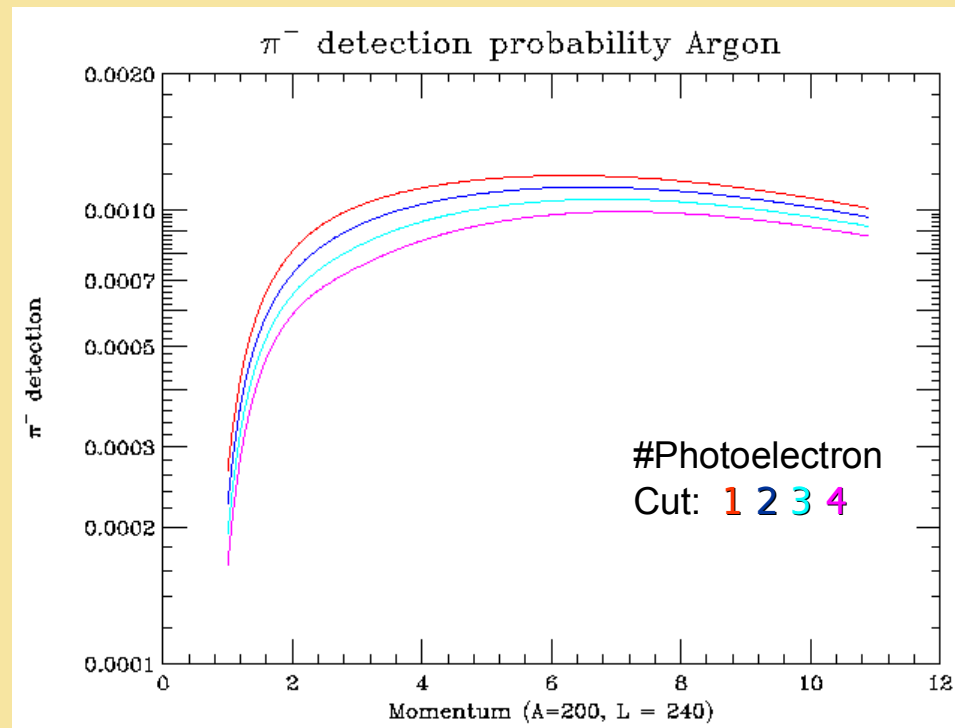


- Mirror reflectivity extends further into UV than R1584 PMT.
  - 79% @ 150nm.
- Coat PMT entrance window with wavelength shifter to match mirror. (24.3 kÅ para-Terphenyl covered w/ 250nm MgF).
- Expect 10 photoelectrons with Neon at 11 GeV/c (worst case).

# Background Estimate: Knock-on Electrons

Major source of background:

- Below-threshold particles knock atomic  $e^-$  with sufficient energy to produce Čerenkov radiation.
- Largest contribution from small-angle  $\pi^-$  scattering, where the Coulomb interaction cross-section is large.
- Expected to be larger effect at higher momenta.



Estimate performed for Argon, which is worst case gas (largest  $Z$ ).  
Expect pion rejection rate of  $\sim 1000:1$  over full momentum range.

# Electron-Pion Discrimination

## Director's Project Review (Dec/08):

### Comment:

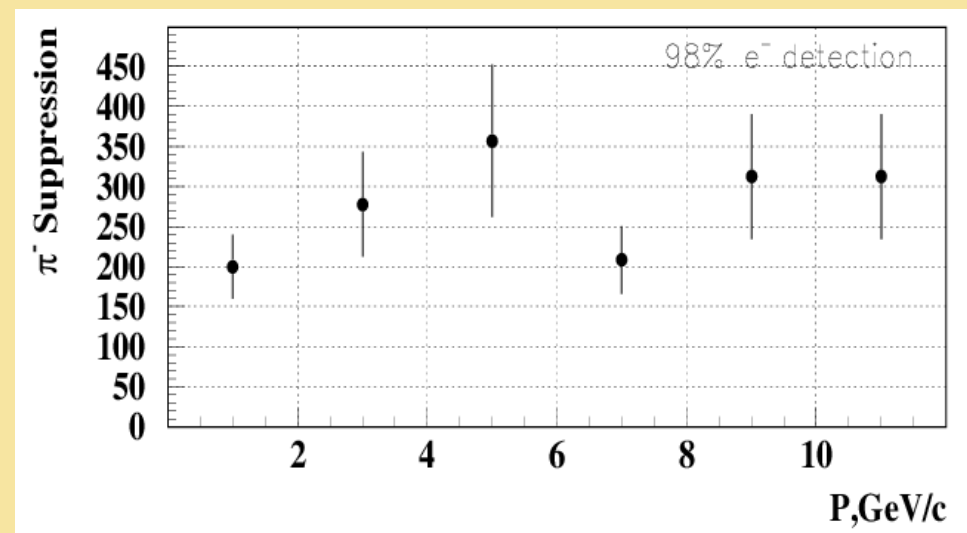
- Question if 1000:1  $\pi^-/e^-$  separation (above 6 GeV/c) can be reached by Shower+PreShower, given that reactions of the pions will give a tail that extends underneath the electron peak.

### Recommendations:

- Reinvestigate the pion rejection factor and the accompanying electron efficiency, also checking how well Geant3 (or preferably Geant4) describes measured pion spectra in the HMS.
- Re-evaluate whether the pion rejection requirements quoted by prospective experiments are really necessary.

# Geant3: Pion Rejection Factor

- Geant3 simulation of pion suppression for a version of SHMS calorimeter (50cm CAL depth).
- Particle separation is done by means of a Neural Network (NN).
  - NN (SVM\_light) is trained on positive and negative signals on events to be separated.
  - Cut is placed on output NN signal.
- ~250:1  $\pi^-:e^-$  suppression is obtained across entire SHMS momentum range.
- Work underway to repeat these estimates with Geant4.



Calculations by Vardan Tadevosyan.

# Electron-Pion Discrimination

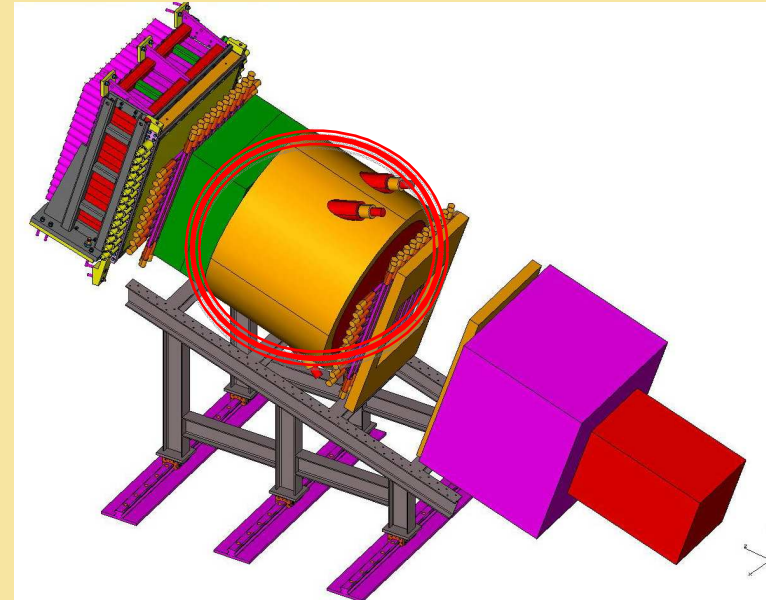
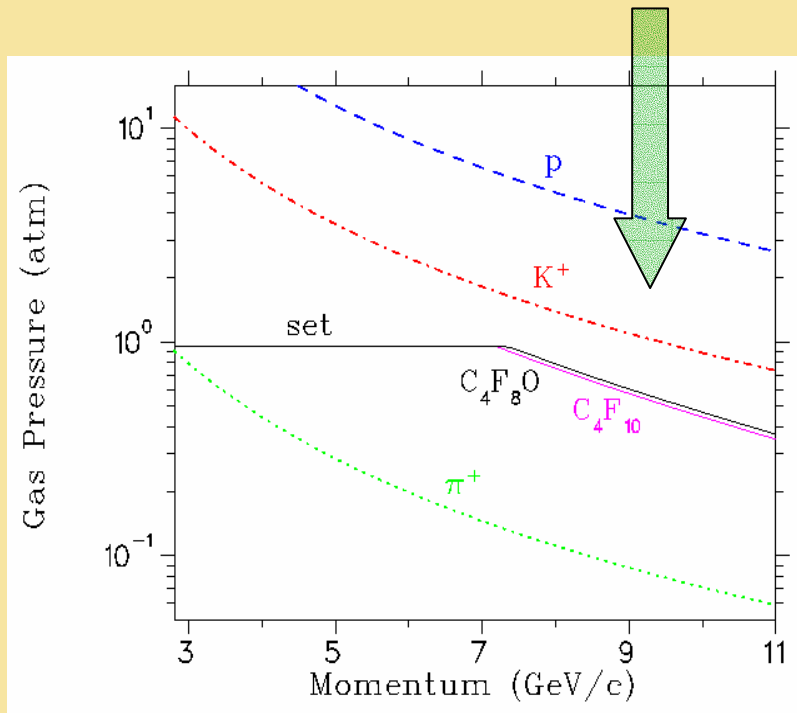
- The most stringent requirements arise when the SHMS is set to negative polarity.
- Both  $\pi^-/e^-$  and  $e^-/\pi^-$  separations are required:

Expt	$P_{SHMS}$ (GeV/c)	Worst Fore/Bkd Rate Ratio	Noble Gas Čerenkov	Pb-G Cal	Total $e:\pi$ Reject
$F_\pi$ (E12-06-101)	5.1,6.5	1( $\pi^-$ ):1000( $e^-$ )	1000:1	200:1	>10000:1
SIDIS $p_T$ (E12-09-017)	1.5-5.0	1( $\pi^-$ ):10 ( $e^-$ )	Not used for lowest P.	250:1	250:1
$x>1$ (E12-06-105)	4.8-10.6	1( $e^-$ ):50( $\pi^-$ )	1000:1	100:1	>10000:1
DIS-parity (E12-07-102)	4.9-6.7	3( $e^-$ ):1( $\pi^-$ )	1000:1	100:1	>10000:1

**Conclusion:** Most challenging electron-pion discrimination requirements can be met by Calorimeter in combination with Noble Gas Čerenkov.

# Heavy Gas Čerenkov: $\pi/K$ separation for $P > 3.4$ GeV/c

To maintain good  $\pi/K$  separation, it is necessary to reduce the gas pressure above 7 GeV/c.



Gap between the 'set' and 'K' curves takes into account the SHMS momentum bite and a possible 0.1 atm error in the setting of the gas pressure regulator.

# Radiator Gas Options

The traditional heavy gas choice is  $C_4F_{10}$ .

- 3M stopped production years ago, but still available from Europe (>\$300/kg).

**$C_4F_8O$  (OctaFluoroTetraHydroFuran) appears to be a good substitute.**

- Easily available from many commercial suppliers (~\$100/kg).

Used in semiconductor industry for plasma etching.

- **Never before used in an operating experiment, but extensively studied by BTeV for use in RICH detector, including prototype beam tests.**

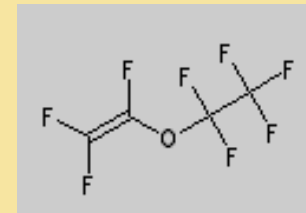
*T. Skwarnicki, NIM A 553 (2005) 339-344.*

*N. Artuso, et al., NIM A 558 (2006) 373-387.*

## $C_4F_8O$ Properties:

- Gas phase ~10 times heavier than air (9.19 g/L at 21°C).
- Boiling point: -5°C. Vapor pressure: 1.7 atm @ 21°C.
- Stable, non-toxic, non-explosive, non-reactive (except with alkali halide metals).
- Unlike  $C_4F_{10}$ , it does not destroy ozone.
- **(n-1) only ~4% smaller than  $C_4F_{10}$ .**
- **Optical transmission cuts off slightly earlier in UV: 95% @175nm, vs 160nm ( $C_4F_{10}$ ).**

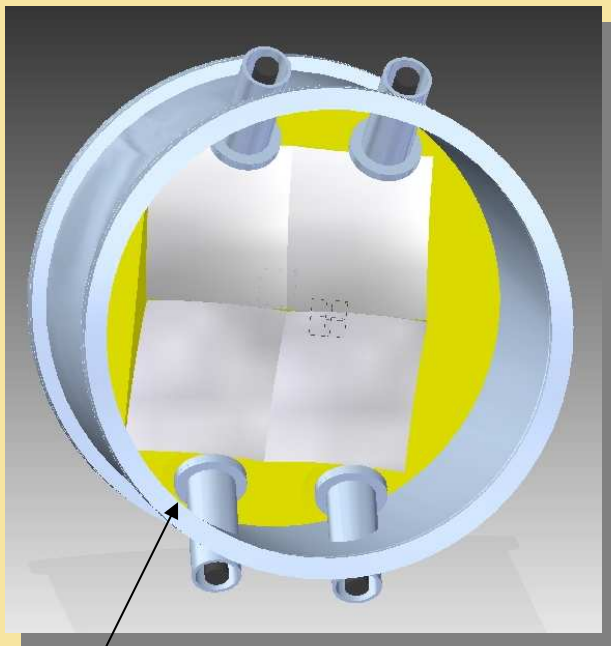
**Frank Wesselmann plans to study this gas in more detail.**



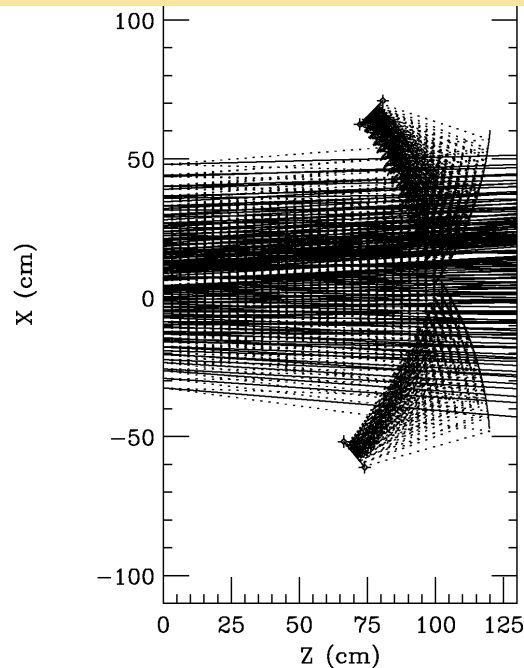


# Heavy Gas Čerenkov Overview

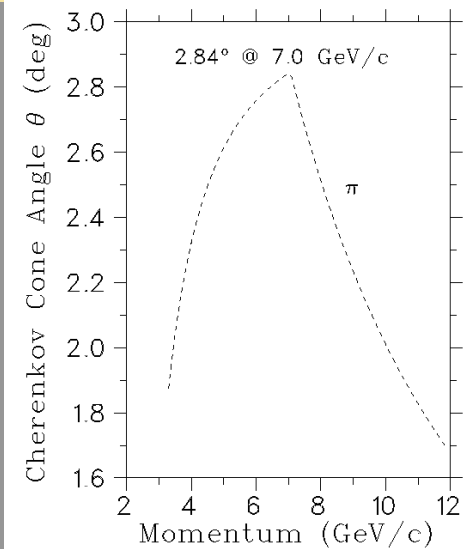
Cylindrical aluminum vessel similar to HMS Gas Čerenkov (rated to 1 atm underpressure).



170cm inner diameter.



Mirror One:  
 1st corner: 120, 60; 2nd corner: 100, 5; radius: 115; focal point: 76.4, 66.6; phi: 224  
 Mirror Two:  
 1st corner: 120, -50; 2nd corner: 102, 6; radius: 115; focal point: 70.1, -56.5; phi: 320  
 Dispersive:  $\Delta\theta$ : 70.0;  $\delta$ : -10.0 22.0; z=0 is at 18.80 m.  
 in: 429, caught: 429, eff: 100.00%, spot sizes: 90.26%, 84.76%



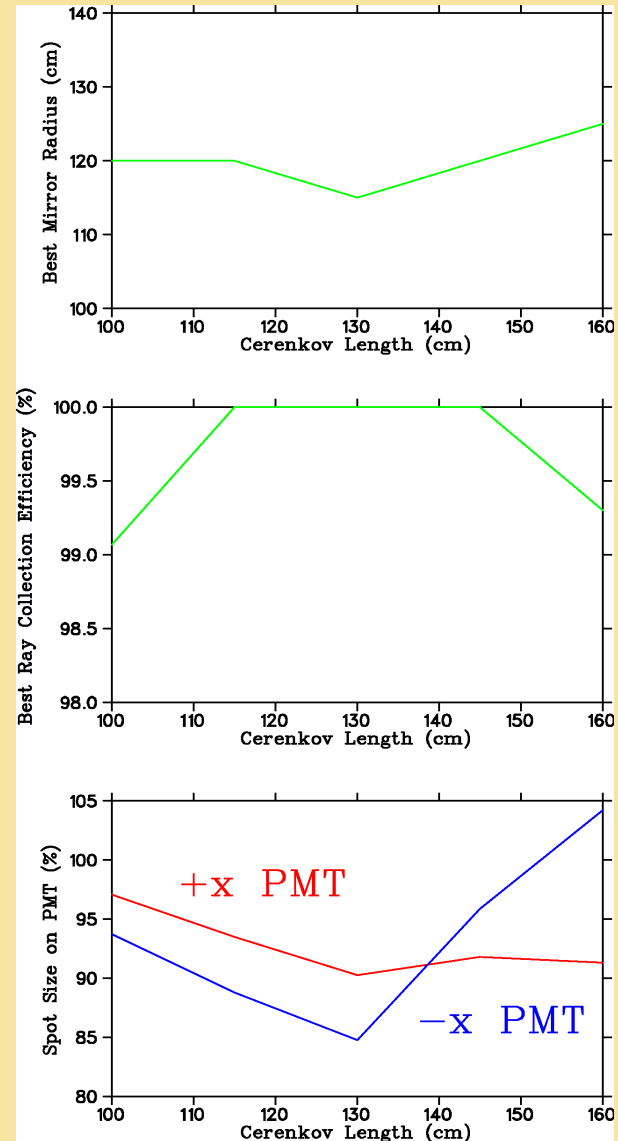
Hardest to collect all light at 7 GeV/c.

# Optimal Detector Length Study

- Original allocation in SHMS stack for this detector was only  $L=100\text{cm}$ .
- Optics studies indicated it was very difficult to efficiently collect and focus light onto PMTs within this length.
- 2D Raytrace program used to study optical properties versus length.
  - Fast execution time lended itself easily to iterative searches.
  - Performed on WestGrid CPU facility in Vancouver, BC.

## CONCLUSIONS:

- Good collection efficiency obtained for  $L=115\text{-}145\text{cm}$  detectors.
- **Best Overall Performance:  $L=130\text{cm}$  detector with  $r=115\text{cm}$  mirrors.**



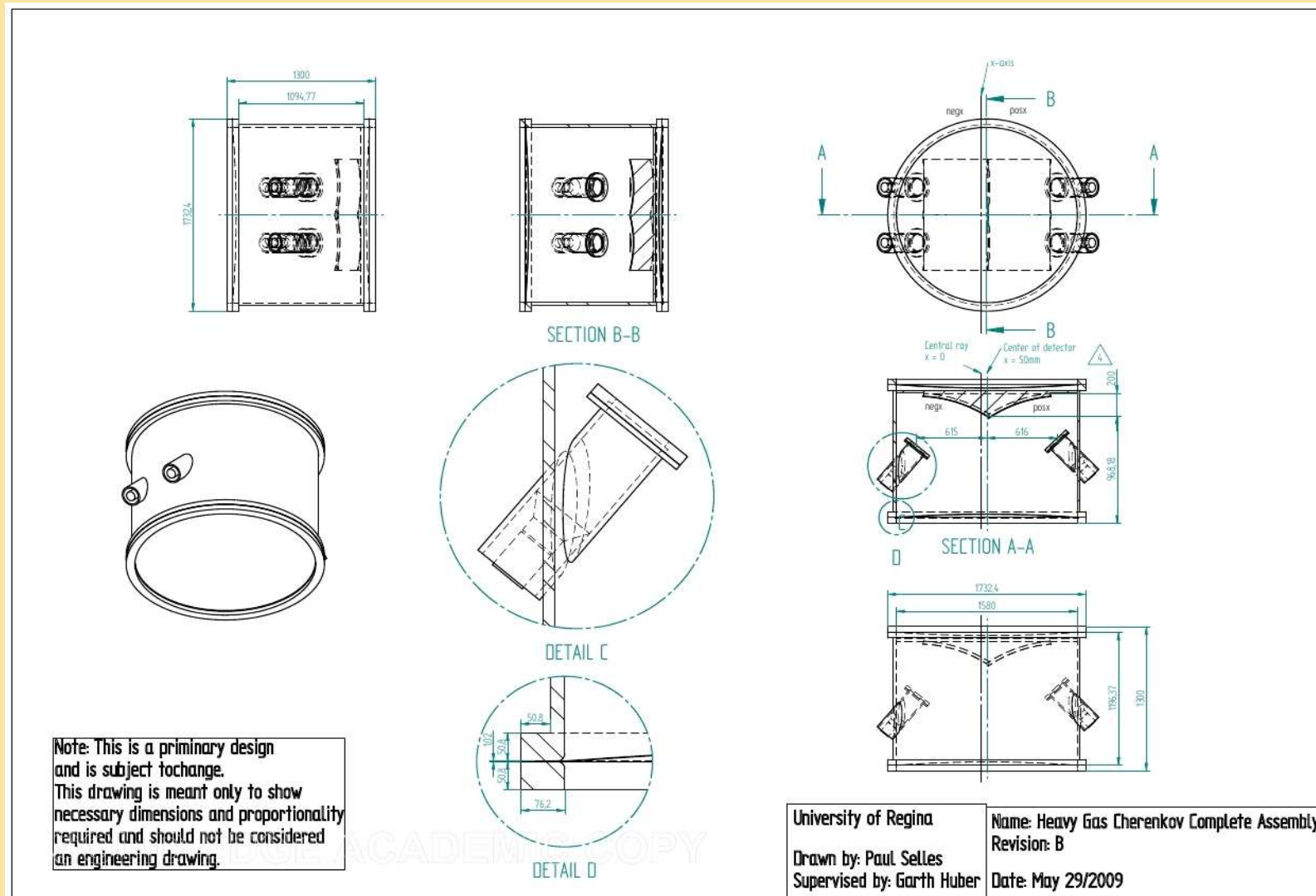
Larger # is better



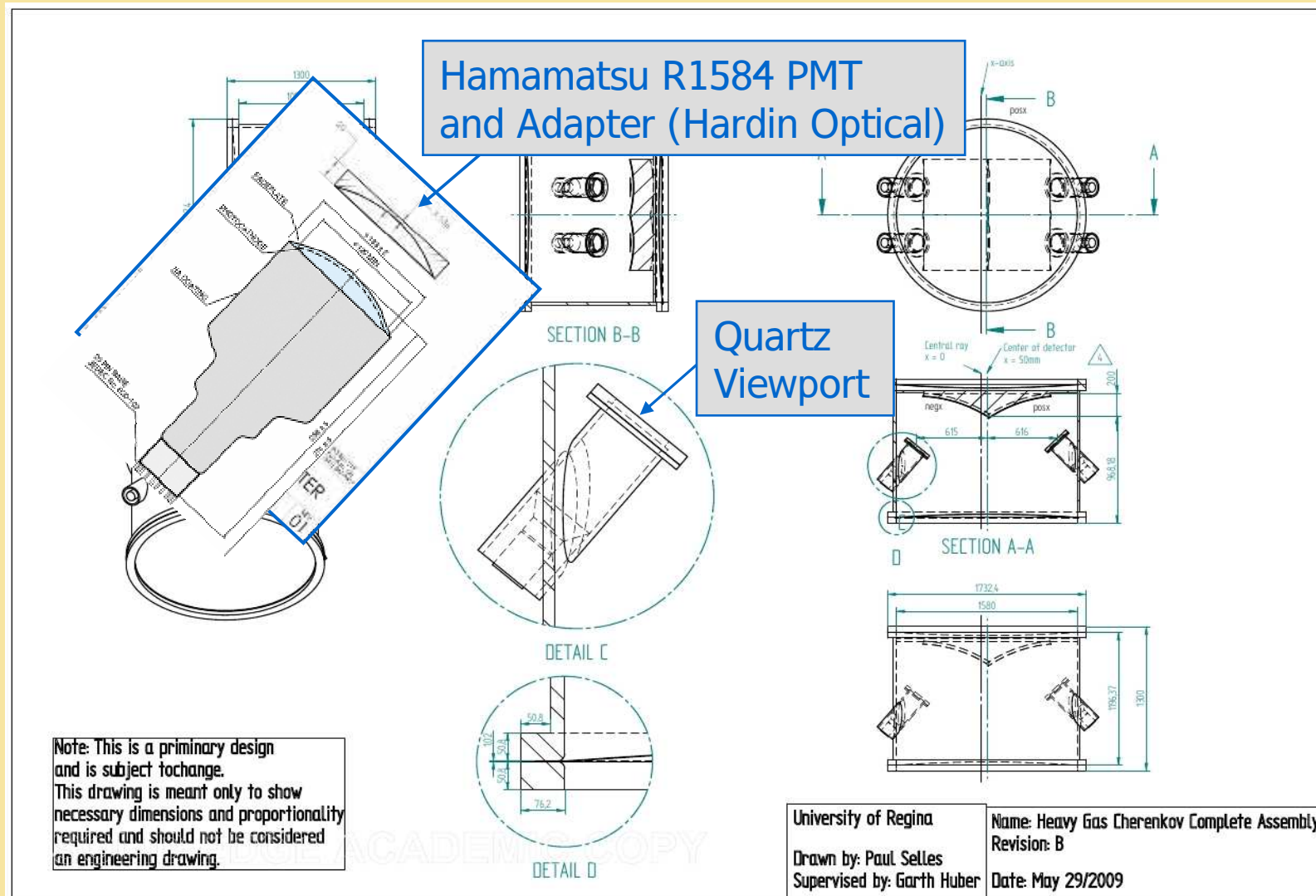
Smaller # is better



# Preliminary Design Drawings



# Preliminary Design Drawings

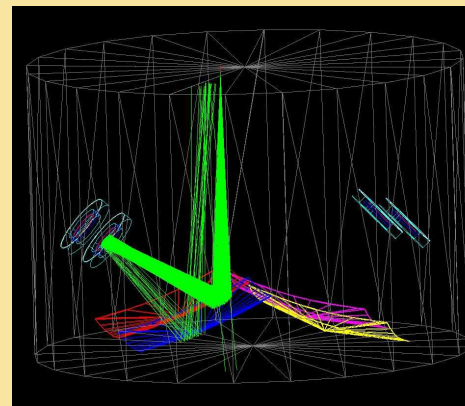


# Geant4: Spherical Mirrors, r=115cm

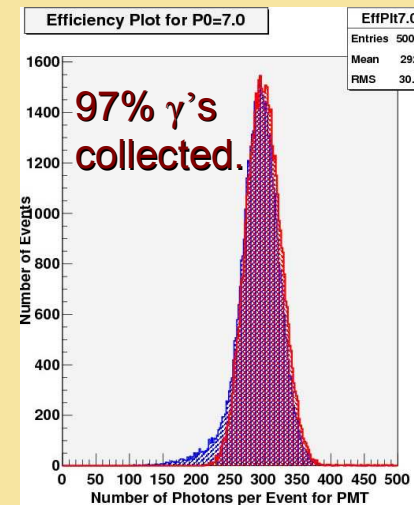
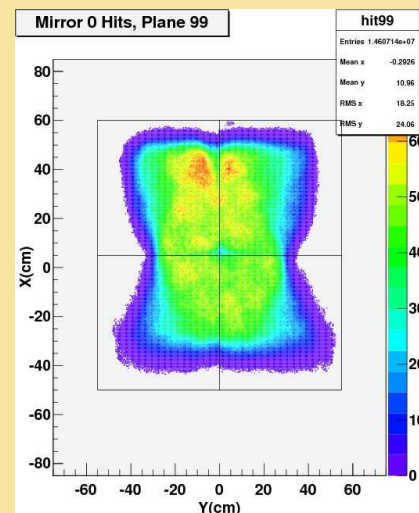
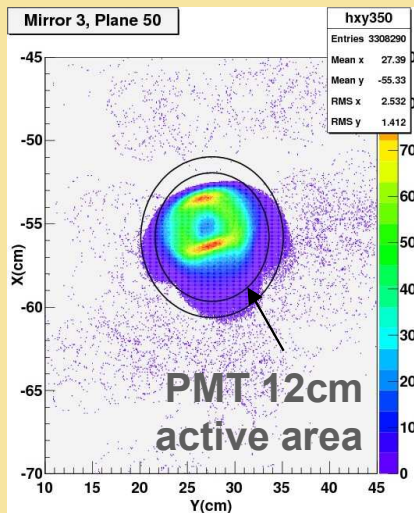
More  $\gamma$ 's generated than in Noble Gas Čerenkov.

**Challenges here:**

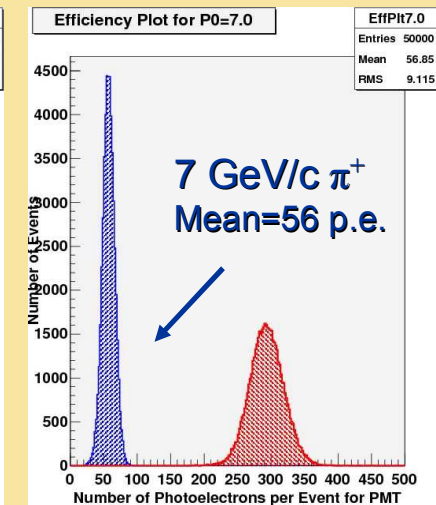
- Čerenkov cone angle larger.
- Incident rays more divergent, further downstream in stack.



About 10% of  $\gamma$ 's reflect off quartz viewports and are lost.

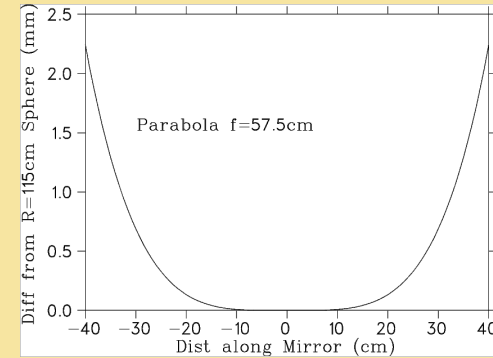


$\gamma$ 's generated.  
 $\gamma$ 's collected.

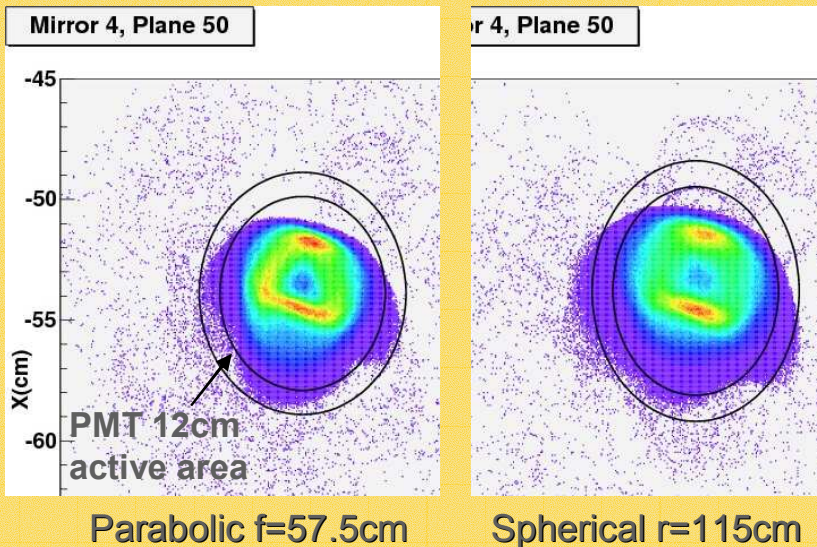


# Spherical vs. Parabolic Mirrors

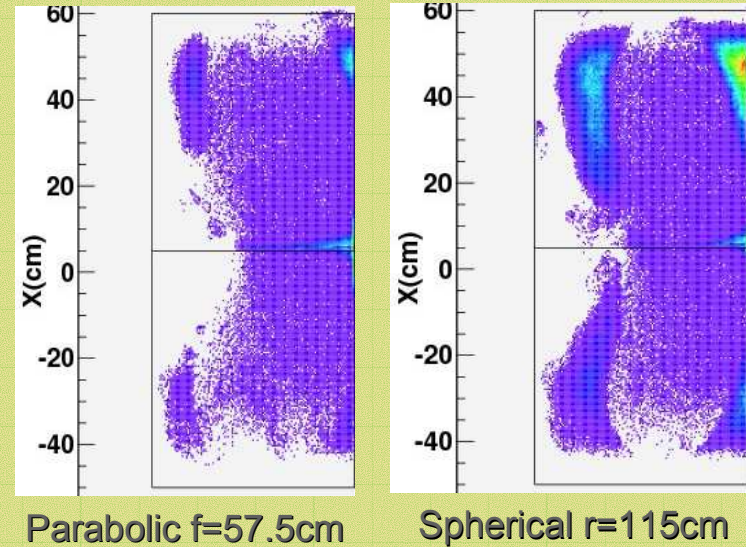
Director's Project Review asked if non-spherical mirrors would result in better light collection.  
→ **Very Preliminary 7 GeV/c results.**



## Focusing onto PMT



## Mirror Hits missing PMT

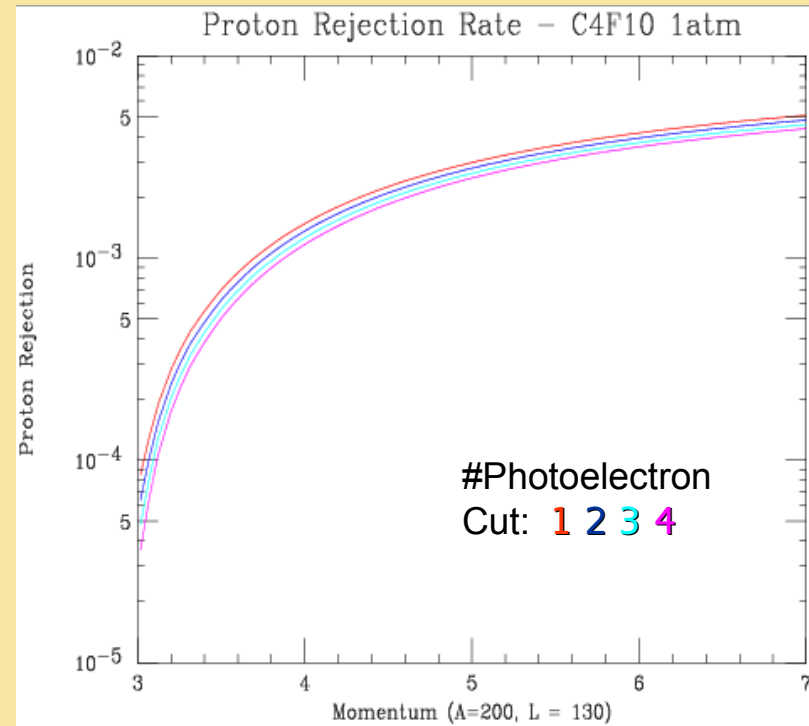
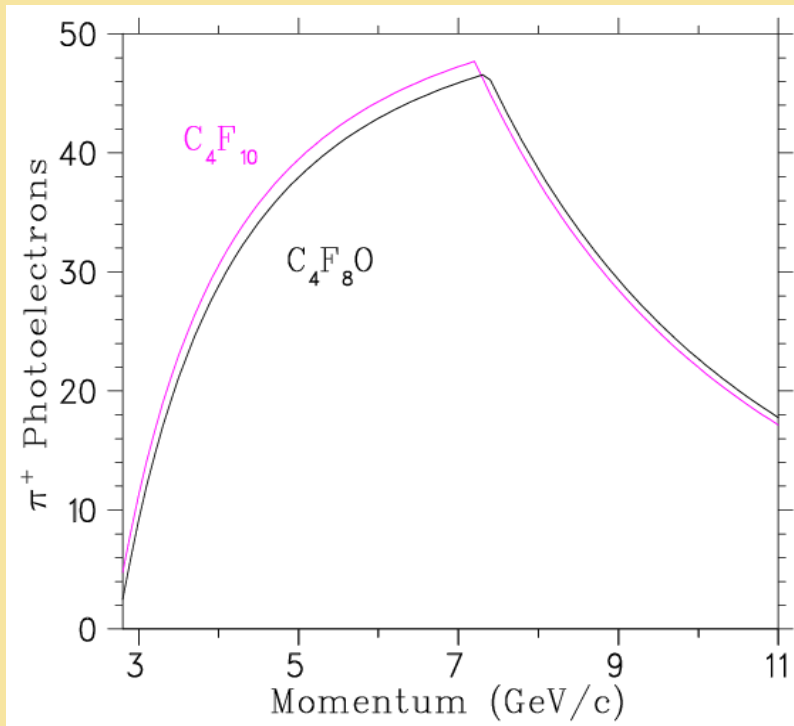


# Projected Performance

- $\pi/K$  separation best at 7 GeV/c.
- Useful lower momentum limit estimated to be 3.4 GeV/c.  
⇒ to be validated in Geant4 study.

Background due to knock-on  $e^-$  from protons,  $\sim 10000 \rightarrow 200:1$ .  
⇒  $K^+$  expected to be similar to slightly worse.

Calculation by Donal Day.



# Pion-Kaon Discrimination

- Both  $\pi/K$  and  $K/\pi$  separations are required.
- Supplemental Aerogel or TOF must supplement Heavy Gas Čerenkov at low momentum.

Expt	$P_{\text{SHMS}}$ (GeV/c)	Worst Fore/Bkd Rate Ratio	Heavy Gas Č $P > 3.4$ GeV/c	Aerogel Č $P < 3.4$ GeV/c ( $n=1.010$ )
$F_{\pi}$ (E12-06-101)	2.2-8.1	2( $\pi$ ):3(K+p)	1000-200:1	200:1
CT (E12-06-107)	5.1-9.6	1( $\pi$ ):1(K+p)	300-200:1	NA
$\pi$ Factorization (E12-07-102)	2.4-8.5	2( $\pi$ ):3(K+p)	1000-200:1	200:1
$K$ Factorization (E12-09-011)	2.6-7.1	1(K):30( $\pi$ )	1000-200:1	



# Gas System Options

## Noble Gas Čerenkov:

- Operating pressure: 1 atm.
- Present design allows only slight overpressure of detector.
- Fill by flushing
  - asymptotic dilution: est. 5 volume exchanges > 99% purity, 10 exchanges > 99.99% purity.
- Either obtain pre-mixed gases (Ar/Ne) from vendor or mix them using techniques already in use at JLab.

## Heavy Gas Čerenkov:

- **Sub-atmospheric pressure, will be changed at higher SHMS momenta.**
  - Approx 0.95 atm pressure below 7.3 GeV/c.
  - Above 7.3 GeV/c, reduce gas pressure (as low as 0.3 atm) to maintain good  $\pi/K$  separation.
- **Pump detector to vacuum, then introduce heavy gas to desired pressure.**
- **Infrequent pressure *decrease* can be achieved by pumping/venting inert  $C_4F_8O$ .**

Gas Systems for both Čerenkovs under study by Frank Wesselmann.

# Summary

- Particle identification requirements of approved SHMS experiments are expected to be met by the planned detectors.

## e/ $\pi$ Separation:

- Most demanding scenario is  $\pi$  runs of  $F_\pi$  Experiment  
→ 1000:1 background/foreground ratio.
- Can be achieved by reliable operation of:
  - Calorimeter: ~250:1 across full momentum range.
  - Noble Gas Čerenkov: 1000:1.
- SIDIS  $p_T$  Experiment will need to rely solely on Calorimeter for lowest momentum measurements,  
→ but only 10:1 background/foreground ratio is expected.

## $\pi/K$ Separation:

- Most demanding scenario is  $K$  Factorization Experiment  
→ 30:1 background/foreground ratio in worst case.
- Heavy Gas Čerenkov should be able to provide 1000:1 at 3.4 GeV/c, degrading to about 200:1 at 7 GeV/c.
- At least one Aerogel Čerenkov is likely needed to supplement the Heavy Gas Čerenkov for  $\pi^\pm$  identification at  $P < 3.4$  GeV/c and for  $K^\pm$  identification up to at least 5 GeV/c.