Heavy Gas Čerenkov Detector
January 2011 Update

Garth Huber,
Wenliang Li & Lee Sichello

Outline

- Brief Overview.
- Tests of sample mirror from Sinclair Glass.
- Our plans for next ~6 months.
- New FEA calculations of Pressure Vessel entrance window from University of Alberta.
  - Aluminum alloy used is now 2024-T3, in conformance with JLab Safety Requirements.
  - Two hydroformed depths and window curvature radii considered.
Cylindrical aluminum vessel similar to HMS Gas Čerenkov (rated to 1 atm underpressure).

170cm inner diameter.

Hardest to collect all light at 7 GeV/c.

Dr. Garth Huber, Dept. of Physics, Univ. of Regina, Regina, SK S4S0A2, Canada.
Test Mirror from Sinclair Glass

- Sinclair Glass recently purchased Europtec’s mirror works (the previous vendor who supplied quotes).
- Because we require mirrors with square corners, instead of their usual 2” corner radius, Sinclair made a test mirror for us, which arrived in early-December.
- Sinclair used a mold made for a different client, similar to our requirements with 40” mirror radius of curvature.

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How the Mirrors are Made

It will be helpful to understand how the mirrors are made:

Stage 1
- Spread release agent onto the mold.
- Place flat glass onto the mold.

Stage 2
- Place mold into the oven.
- Glass slumps toward the mold.

Stage 3 (Important)
- **Sinclair Glass usually does not let the glass slump all the way to the mold.**
- To assure the test mirror is exactly spherical, they allowed the glass to slump all the way into the mold.
Test Mirror Corner & Edge

- The test mirror was a simple square blank (1→2).
- We are happy with the quality of the test mirror corner and edges.

- For the actual mirrors, Sinclair will precut the glass to shape 3→4, to give even more square corners.

Dr. Garth Huber, Dept. of Physics, Univ. of Regina, Regina, SK S4S0A2, Canada.
Test Mirror Surface Imperfections

- Black arrows indicate large imperfections on back surface.
- These are caused by release agent, because glass was slumped all the way into the mold (not their normal procedure).

Reverse video of photo at left.
More Detail on Surface Imperfections

- **Double Reflection of line provides useful check of top vs. bottom surface quality.**
- **Circled dips in bottom line confirm Sinclair’s claim that imperfections are primarily on the bottom surface.**
- **Top reflected line is also not smooth, so some imperfections have made their way through to the top surface.**

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Our suggestion to reduce surface imperfections

- Sinclair Glass typically leaves a small gap between the glass and mold when slumping.
- We can tolerate (in fact prefer) a slightly non-spherical mirror.
- A parabolic mirror of the same focal f=55.0cm length will provide better focusing for our application.
- The bottom of the parabolic mirror is 2.58mm shallower than the spherical mirror at the center.
- Sinclair agrees a gap makes things easier from their viewpoint, but there will be a ~1/16” gap variation from mirror to mirror.

Dr. Garth Huber, Dept. of Physics, Univ. of Regina, Regina, SK S4S0A2, Canada.
We measured the mirror height at 7 locations along each edge, and compared with Sinclair’s specified 40” radius of curvature.
Our measurements confirm the glass curvature is close to a 40” sphere along the 4 outer edges.

Curvature measurements on interior of mirror are planned but not yet completed.

Dr. Garth Huber, Dept. of Physics, Univ. of Regina, Regina, SK S4S0A2, Canada.
Summary of Sinclair Glass Test Mirror

- **Good**
  - Edges and Corners are very good.
  - Radius of curvature seems close to Sinclair’s stated 40”.

- **Bad**
  - Surface imperfections (caused by release agent and mold surface).

- **Possible Solution**
  - Glass does not have to be slumped all the way into the mold.

- Mirror order will be placed shortly.
- Need to prepay Sinclair’s tooling charges, with balance due upon delivery.
- Expect mirrors to be delivered ~8 weeks after order.

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Geant4 studies planned for next ~6 mo.

- Ongoing bug checking and documenting of Geant4 code.
- Implement Donal Day’s PMT position sensitivity measurements in SensitiveDetector analysis to produce more accurate simulated photoelectron distributions.
- Continue double-checks of optimized PMT-mirror locations and angles before finalizing vessel design later this summer:
  - Determine sensitivity to misalignments.
  - Once mirrors arrive, can refine MC to more closely approximate actual mirror geometry.
  - Need to be sure all engineering constraints in mirror mounts, beam envelope, etc. have been taken into account.

Dr. Garth Huber, Dept. of Physics, Univ. of Regina, Regina, SK S4S0A2, Canada.
Project Timeline Plans  *(updated Aug 11/10)*

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<th>Name</th>
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<td>Prototype Mirror stiffening brackets</td>
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<td>3</td>
<td>Mirror Procurement</td>
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<tr>
<td>4</td>
<td>Finalize PMT and Mirror Placement via Geant4 Simul.</td>
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<td>5</td>
<td>Mirror Optical Testing</td>
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<td>6</td>
<td>Mirror Mount Assemblies</td>
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<tr>
<td>7</td>
<td>PMTs, mu-Shields, Bases Procure</td>
</tr>
<tr>
<td>8</td>
<td>PMT Mount Assemblies</td>
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<tr>
<td>9</td>
<td>Mirror stiffening brackets</td>
</tr>
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<td>10</td>
<td>Ship Mirrors from Regina to CERN</td>
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<td>Mirror Aluminization at CERN</td>
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<td>12</td>
<td>Ship Mirrors from CERN to JLab</td>
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<td>PMT Adapters and Spectroscopy Windows Procure</td>
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<td>16</td>
<td>Pressure Vessel Vendor Bids</td>
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<td>Pressure Vessel Vacuum Test</td>
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<td>20</td>
<td>Ship Vessel &amp; Parts from Regina to JLab</td>
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<td>Assembly of Detector in Test Lab @ JLab.</td>
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<td>Cosmic Tests at JLab</td>
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<td>23</td>
<td>Install on SHMS</td>
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<td>24</td>
<td>Completion of Project</td>
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Dr. Garth Huber, Dept. of Physics, Univ. of Regina, Regina, SK S4S0A2, Canada.
- 2024-T3 aluminum alloy material analysed.
- Window hydro-formed to be initially spherical with studies made for a center depth of 53.4 mm and 146.9 mm respectively.
- Window thicknesses analysed were 1 mm for the 53.4 mm center depth and 1 mm and 2 mm for the 146.9 mm center depth.
- Bonded joint was assumed between the sheet and the window flange up to the R 12.5 mm lip.
- Contact modeling was applied between the sheet and the rounded lip of the flange.
- The complexity of the analysis model was reduced by studying a quarter-symmetry segment.
# Selected Properties of 2024-T3 Aluminum Alloy

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<th>Property</th>
<th>Value 1</th>
<th>Value 2</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>2.78 g/cc</td>
<td>0.1 lb/in³</td>
<td>AA; Typical</td>
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<tr>
<td><strong>Mechanical Properties</strong></td>
<td></td>
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<tr>
<td>Hardness, Brinell</td>
<td>120</td>
<td>120</td>
<td>AA; Typical; 500 g load; 10 mm ball</td>
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<tr>
<td>Hardness, Knoop</td>
<td>150</td>
<td>150</td>
<td>Converted from Brinell Hardness Value</td>
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<tr>
<td>Hardness, Rockwell A</td>
<td>46.8</td>
<td>46.8</td>
<td>Converted from Brinell Hardness Value</td>
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<tr>
<td>Hardness, Rockwell B</td>
<td>75</td>
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<td>Converted from Brinell Hardness Value</td>
</tr>
<tr>
<td>Hardness, Vickers</td>
<td>137</td>
<td>137</td>
<td>Converted from Brinell Hardness Value</td>
</tr>
<tr>
<td>Ultimate Tensile Strength</td>
<td>483 MPa</td>
<td>7000 psi</td>
<td>AA; Typical</td>
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<tr>
<td>Tensile Yield Strength</td>
<td>345 MPa</td>
<td>5000 psi</td>
<td>AA; Typical</td>
</tr>
<tr>
<td>Elongation at Break</td>
<td>18 %</td>
<td>18 %</td>
<td>AA; Typical; 1/16 in. (1.6 mm) Thickness</td>
</tr>
<tr>
<td>Modulus of Elasticity</td>
<td>73.1 GPa</td>
<td>10600 ksi</td>
<td>AA; Typical; Average of tension and compression. Compression modulus is about 2% greater than tensile modulus.</td>
</tr>
<tr>
<td>Poisson's Ratio</td>
<td>0.33</td>
<td>0.33</td>
<td></td>
</tr>
<tr>
<td>Fatigue Strength</td>
<td>138 MPa</td>
<td>20000 psi</td>
<td>AA; 500,000,000 cycles completely reversed stress; RR Moore machine/specimen</td>
</tr>
<tr>
<td>Machinability</td>
<td>70 %</td>
<td>70 %</td>
<td>0-100 Scale of Aluminum Alloys</td>
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<tr>
<td>Shear Modulus</td>
<td>28 GPa</td>
<td>4060 ksi</td>
<td></td>
</tr>
<tr>
<td>Shear Strength</td>
<td>283 MPa</td>
<td>41000 psi</td>
<td>AA; Typical</td>
</tr>
</tbody>
</table>

STUDY #1: HYDROFORMED 2024-T3 1mm THICK ALUMINUM SHEET WINDOW

With a pre-hydro-formed dish radius of $R = 6043.22$ mm, dish depth of 53.3 mm.
FEA STUDY OF A HYDROFORMED 2024-T3 ALUMINUM SHEET WINDOW

\[ t = 1\text{mm}, \quad R = 6043.22\text{mm}, \quad d = 53.3\text{mm} \]

Polynomial order (P-Level) of the model mesh.

FEA MESH AND THE ELEMENT POLYNOMIAL ORDER

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FEA STUDY OF A HYDROFORMED 2024-T3 1mm THICK ALUMINUM SHEET WINDOW
With a pre-hydro-formed depth of 53.4mm.

Displacement Mag (WCS) (mm)
Deformed
Max Disp  +1.9907E+01
Scale  2.1757E+00
Loadsets:LoadSet1: LO_DEF_2024_FOIL_ASSY

Maximum additional window deflection = 1.99mm

Dr. Garth Huber, Dept. of Physics, Univ. of Regina, Regina, SK S4S0A2, Canada.
FEA STUDY OF A HYDROFORMED 2024-T3 ALUMINUM SHEET WINDOW
(Detail)

$t = 1\text{mm}, \ R = 6043.22 \text{mm}, \ d = 53.3\text{mm}$

Maximum tensile stress (on top of rim) = 691 MPa.

NOTE: This exceeds the ultimate tensile strength of the material (483 MPa).

MAXIMUM PRINCIPLE STRESS (MAXIMUM TENSILE STRESS)
FEA STUDY OF A HYDROFORMED 2024-T3 ALUMINUM SHEET WINDOW
(detail)

Stress Min Prin (WCS)
(N / mm²)
Loadset: LoadSet1: LO_DEF_2024_FOIL_ASSY

Minimum Principal Stress in Low Profile Al 2024-T3 x 1mm foil window

MINIMUM PRINCIPLE STRESS (MAXIMUM COMPRESSIVE STRESS)

Max compression stress (on underside of rim) = 102.7 MPa

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FEA STUDY OF A HYDROFORMED 2024-T3 ALUMINUM SHEET WINDOW

\[ t = 1 \text{mm}, \quad R = 6043.22 \text{ mm}, \quad d = 53.3 \text{mm} \]

Maximum shear stress (on the rim) = 363 MPa

NOTE: This exceeds the shear strength of the material (283 MPa)
FEA STUDY OF A HYDROFORMED 2024-T3 ALUMINUM SHEET WINDOW

\[ t = 1 \text{mm}, \quad R = 6043.22 \text{ mm}, \quad d = 53.3 \text{mm} \]

Stress von Mises (WCS)
\[ \text{IN / mm}^2 \]
Loadset:LoadSet1 :  LO_DEF_2024_FOIL_ASSY

View Max: 6.035E+02

Von Mise’s Stress in Low Profile Al 2024-T3 x 1mm foil window

Maximum Von Mise’s stress = 573 MPa

VON MISE’S STRESS (detail)

Dr. Garth Huber, Dept. of Physics, Univ. of Regina, Regina, SK S4S0A2, Canada.
STUDY #2: HYDROFORMED 2024-T3 1mm THICK ALUMINUM SHEET WINDOW

With a pre-hydro-formed dish radius of $R = 2254.25$ mm,
Dish depth of 146.9 mm.

Dr. Garth Huber, Dept. of Physics, Univ. of Regina, Regina, SK S4S0A2, Canada.
FEA STUDY OF A HYDROFORMED 2024-T3 1mm THICK ALUMINUM SHEET WINDOW
With a pre-hydro-formed dish radius of $R = 4508.5$ mm.

Maximum additional window deflection = 2.65mm

Dr. Garth Huber, Dept. of Physics, Univ. of Regina, Regina, SK S4S0A2, Canada.
FEA STUDY OF A HYDROFORMED 2024-T3 ALUMINUM SHEET WINDOW
(Detail)

Stress Max Prin (WCS)
(N / mm²)
Loadset:LoadSet1 : NEW_Q_IMM_FOIL ASSY

\[ t = 1\text{mm}, \ R = 2254.25\text{mm}, \ d = 146.9\text{mm} \]

Maximum tensile stress (on top of rim) = 271 MPa.

NOTE: This is ~1/2 of the ultimate tensile strength of the material (483 MPa).

MAXIMUM PRINCIPLE STRESS (MAXIMUM TENSILE STRESS)

Dr. Garth Huber, Dept. of Physics, Univ. of Regina, Regina, SK S4S0A2, Canada.
FEA STUDY OF A HYDROFORMED 2024-T3 ALUMINUM SHEET WINDOW (detail)

Stress Min Prin (WCS) (N / mm^2)
Loadset: LoadSet1 : NEW_Q_IMM FOIL ASSY

t = 1mm, \ R = 2254.25 \text{ mm}, \ d = 146.9 \text{ mm}

Minimum Principal Stress (Maximum Compressive Stress)

Dr. Garth Huber, Dept. of Physics, Univ. of Regina, Regina, SK S4S0A2, Canada.
FEA STUDY OF A HYDROFORMED 2024-T3 ALUMINUM SHEET WINDOW

Stress Max Shear (WCS)
(N / mm²)
Loadset:LoadSet1 : NEW_Q_IMM_FOIL_ASSY

\[ t = 1\text{mm}, \quad R = 2254.25 \text{ mm}, \quad d = 146.9 \text{ mm} \]

Maximum shear stress (on the rim) = 186 MPa

NOTE: This is \sim 1/2 the shear strength of the material (283 MPa)

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FEA STUDY OF A HYDROFORMED 2024-T3 ALUMINUM SHEET WINDOW

Stress von Mises (WCS) (N / mm^2)
Loadset: LoadSet1 : NEW_Q_IMM_FOIL_ASSY

Von Mises Stress in Quarter_2024_T3_Imm_foil_flig

VON MISE'S STRESS (detail)

Maximum Von Mise's stress = 324 MPa

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Window FEA Summary

- Study #1 results with 53.4mm hydroform depth (suggested by Steve Lassiter) seem to indicate that (prior to possible yielding and stretching) the tensile stress on the window exceeds the posted strength of 2024-T3 aluminum.

- Study #2 results with 146.9mm hydroform depth seem to conform to the material strength.

- Further studies with intermediate hydroform depths planned.

- Comments & suggestions from Hall C engineering staff are needed.