Silica Aerogel Radiator for the HELIX RICH System

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On behalf of the HELIX Collaboration
Outline

- **Topic 1:**
  HELIX RICH System Overview

- **Topic 2:**
  Recent Progress in Aerogel Mass Production

- **Topic 3:**
  Previous Aerogel Characterization Results
  (as a Guide of the Future Investigation)
HELIx RICH System Overview
HELIX Program

- HELIX (High Energy Light Isotope eXperiment)
- Balloon-borne cosmic-ray spectrometer designed to measure the mass of light cosmic-ray isotopes (in particular, those of Beryllium)
- Goal: Experimental investigation of cosmic-ray propagation models
- On schedule to fly during the 2019/2020 Antarctic Season.
HELIX Proximity-focusing RICH System

Design goal: $\Delta \beta/\beta < 0.1\%$

- Aerogel radiator
- Readout electronics: ASIC (CITIROC)
- Photodetectors: 64-ch SiPM modules (6-mm pixel)
**Refractive index** requirements:

- $n \sim 1.15$ for the 1st flight (covering 1–3 GeV/nec)
- $n \sim 1.03$ for the 2nd flight (covering up to 10 GeV/nec)

Silica aerogels cover these index range

- $n \sim 1.03$ can be fabricated by the conventional method
- $n \sim 1.15$ can be produced by introducing the pin-drying technology

- First validated in 2005
- Methodology established by 2010
- Now mass production possible (in-house manufacture at Chiba Univ.)
Optical Requirements

- **Transmission length @400 nm:**
  - > 30 mm (realistic; comparable to the Belle II ARICH)

  ➔ Tabata et al., Poster #24

- **Refractive index uniformity:**
  - ~ 1% across tile
  - 0.1% by mapping by an adequate method prior to flight and to be calibrated using in-flight data
    - e.g., Direct Cherenkov angle measurement by electron beams or tile scan by a laser, etc.

- **Thickness uniformity** (less strict requirement):
  - ~ 1% across tile
  - To be mapped prior to flight
Topic 2
Progress in Mass Production
Conventional production steps (Kept in solvent in ALL steps!)

- Wet-gel synthesis → Aging → Solvent exchange → Hydrophobic treatment
- Wash
- Supercritical drying (SCD)

Pin drying

Extract wet gel from solvent bath → Enclose it in pin container, immediately!

Solvent evaporation from silica skeleton

Pinholes

Wet-gel similar shrinkage with no cracking
Mass Production Schedule

- **Requirements**: 36 tiles (with no cracking)
  - Dimensions: 100 mm × 100 mm × 10 mm (after water-jet trim)

- **Nominal production**
  - 88 tiles × 0.9 × 0.5 × 0.9 = 36 tiles

- **Additional (backup) production**
  - 8 tiles

- **Total 96 tiles** (scheduled)
  - 32 tiles × 3 seasons
Mass Production Status

- Nominal production (begun in late March)
  - 32 tiles (Season 1) completed in the last week
    - Crack-free yield: 28/32 tiles (88%)
      → Close to expectation (90%)
  - 56 tiles (Season 2 + 3) in progress (pin drying)
    - 1st batch available in late September
    - Will finish by mid-October

- Additional production
  - 8 tiles (Season 3+) to be synthesized after this workshop
“Rayleigh” blue tile: Scattered light

Colorless tile: Transmitted light

\( n = 1.160 \)

Transmission length = 36 mm @400 nm

Dimensions

\[ = 112 \text{ mm} \times 112 \text{ mm} \times 10.5–10.7 \text{ mm} \]

One of the world’s heaviest aerogels
Transparency Check / Mean-Index Check

- **UV–vis spectrum** measured with a spectrophotometer
- **Refractive indices at 4 tile corners** measured with a laser

Transmittance ($T$)

$$T = A \exp(-C \cdot t / \lambda^4)$$

Rayleigh scattering

![Transmittance graph](image)

Transmission length @400 nm (from $T$ and $t$)

<table>
<thead>
<tr>
<th>Refractive index</th>
<th>Transmission length [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>-0.5%</td>
<td>Mean</td>
</tr>
<tr>
<td>1.1599</td>
<td>1.1607</td>
</tr>
</tbody>
</table>

![Transmission length graph](image)
Discussion on Refractive Index

- Results from the 1st mass production batch
  - Mean index: Not 1.15 but 1.16
- Index of 1.16 rather ideal for HELIX
  - Low energy threshold
  - Cross calibration with TOF possible much more

- Keep fabrication parameters for later production
Refractive Index (Uniformity Check)

- 8 tiles survive out of 16 tiles (50% > 45% expectation)

1st screening

Mean (16 tiles)
1.1607
±0.5% for each tile’s mean

OK

±0.5%
1.1615
+0.5%
Mean (16 tiles) 1.1607

OK

-0.5%
1.1599

OK

crack
Topic 3

Previous Aerogel Characterization — Supporting Information
Previous Study for 1st Generation Samples

- X-ray absorption technique for measuring density uniformity
  - Tabata et al., NIMA 697 (2013) 52.

\[ n - 1 = k \cdot \rho \]

\[ \frac{l}{l_0} = \exp(-\mu_m \cdot \rho \cdot t) \]

- X-ray absorption
- X-ray detector
- Aerogel
- X-ray source \( \varphi 1\)-mm beam
- Fluorescent X-ray (Elemental analysis)
- Measuring microscope (Thickness)

X-ray transmittance
Mass attenuation coefficient
Constant
Density
Thickness
Laser results consistent with X-ray results

X-ray absorption

Effective for 1st screening
Water-jetting Test

- First cut of $n = 1.15$ aerogel* → Successful! (last week...)
  - Aerogel powder generated during cutting still adhere on the surface.
  - Should be remove carefully with a blower, soft brush, and etc.

* Sample tile chosen from engineering production batches
Summary

- The HELIX RICH system employs aerogel tiles with the highest-refractive index ever used as Cherenkov radiator in the upcoming its first flight in Antarctica.

- For this application, we are now mass-producing 96 aerogel tiles with a refractive index of 1.16.

- We have just completed the first 16 tiles, and their basic optical properties were confirmed.
One More Child...

Princess Aerogel stopped over in Russia and Japan and flew on spacecraft from USA. Russian princess lives in AMS-02 RICH, and Japanese princess is now in Tanpopo cosmic dust collector aboard the International Space Station.

... And one more child will be born in Antarctica ...
The HELIX Collaboration

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Additional Information
Improving Pin Containers

- 3 generations of pin containers
  - Enhance index uniformity
  - Avoid excess shrinkage at tile edge

1st generation:
- Sieve + Upward/downward glass cases
- Pinholes (at 4 corners)

2nd generation:
- Sieve + Glass top plate + Aluminum bottom plate w/ edge sealing
- Pinholes (on top/bottom plates)

3rd generation:
- Sieve + PMMA top/bottom plates
- Pinholes (on top/bottom plates)

Tile uniformity improved
Thickness Measurements

- Ruler results consistent with microscope results

Measuring microscope

![Graph showing thickness measurements with markers for Tile center, Side AB, Side CD, and X-ray scan line.](image)

- Side AB: 9.75 mm
- Side CD: 10.0 mm
- 0.22 mm difference (3.1%)
- 0.30 mm difference (3.1%)
- 0.25 mm difference (2.6%)
Mass Production Scheme

- 3 types of grouping:
  - 4 tiles per lot: wet-gel synthesis at one time
  - 16 tiles per batch: supercritical drying at one time
  - 32 tiles per season: 8 lots (= 32 tiles) prepared for 8 straight days
- Total 3 seasons (=96 tiles) for mass production
  - Season 3 to Season 5 (Final mass production)
  - Season 1 (Pilot production)
  - Season 2 (Engineering production)
Pilot Production (Season 1)

- Oct. 2016 to Jul. 2017
- Feasibility test for $n = 1.12$ and $1.15$ by pin drying
- Starting index candidates: $n = 1.08$ and $1.10$
  - $1.10$ selected in view of the final degree of pin-shrinkage
- A total of 62 tiles investigated
  - HLX Season 1 (Lots: HLX1 to HLX12)
- Results
  - $n \sim 1.13$ and $1.15$ confirmed
  - Our final choice: $n = 1.15$
Engineering Production (Season 2)

- Nov. 2017 to Mar. 2018
- Final production test for \( n = 1.15 \)
  - Index control (Parameter adjustment in pin drying)
  - Thickness control
- A total of 23 tiles investigated
  - HLX Season 2 (Lots: HLX13 to HLX18)
- Results
  - \( n = 1.145–1.152 \) → Adjustment needed
  - Transmission length \( \sim 34 \text{ mm} \) → OK
  - Thickness (before water-jet cut) = 10.5 mm → OK