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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

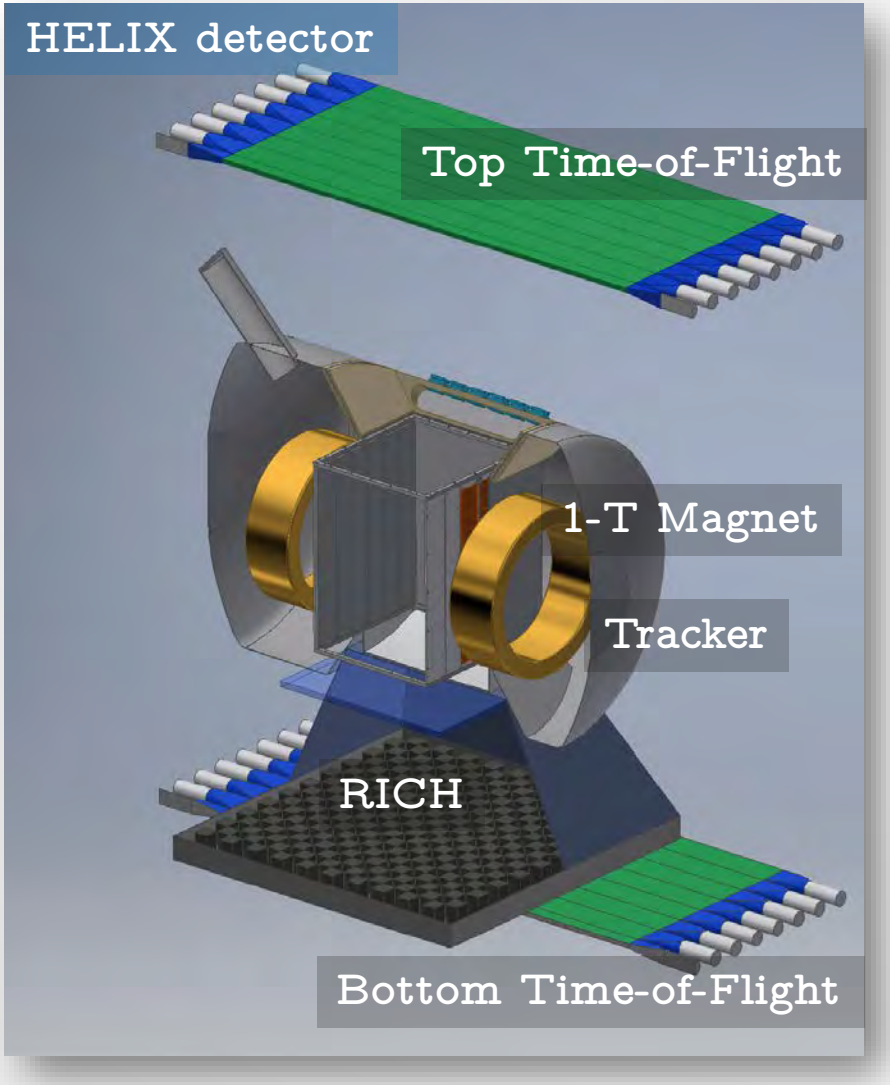
  (as a Guide of the Future Investigation)

Topic 1

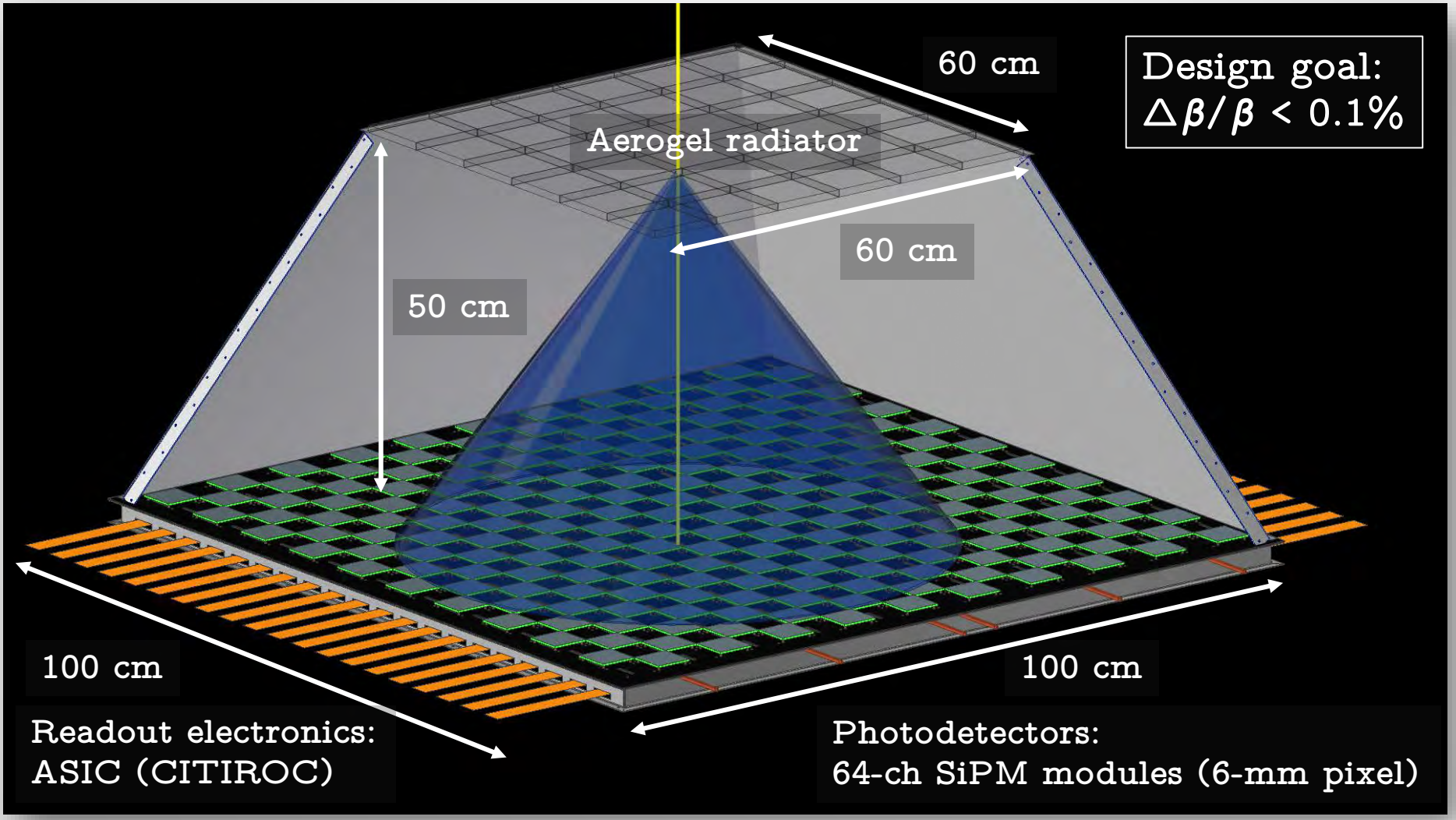
HELIX RICH System Overview

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.



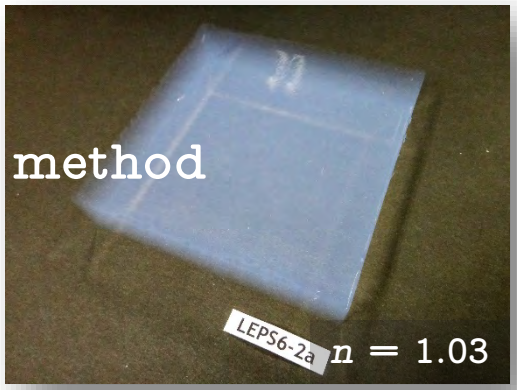
HELIX Proximity-focusing RICH System



HELIX RICH Radiator

- 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
      - Tabata *et al.*, Conf. Rec. on IEEE NSS/MIC (2005).
    - Methodology established by 2010
      - Tabata *et al.*, NIMA 623 (2010) 339.
    - 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 a 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

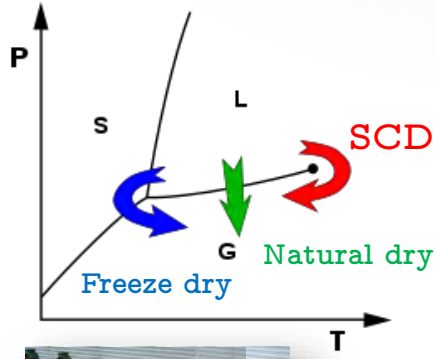
Production Technology

- Conventional production steps (Kept in solvent in ALL steps!)

Wet-gel synthesis → Aging → Solvent exchange → Hydrophobic treatment

→ Wash

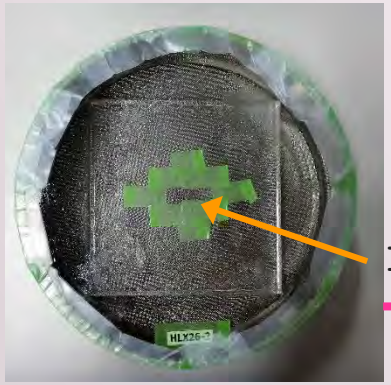
→ Supercritical drying (SCD)



Pin drying

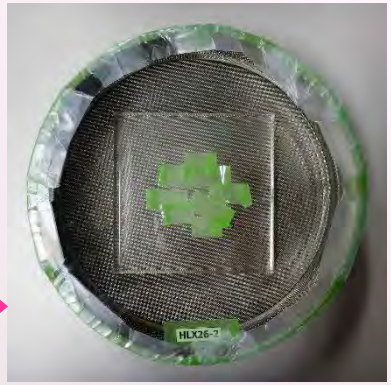
Extract wet gel from solvent bath

→ Enclose it in pin container, immediately!



Solvent evaporation from silica skeleton

Pinholes



Wet-gel similar shrinkage with no cracking

Mass Production Schedule

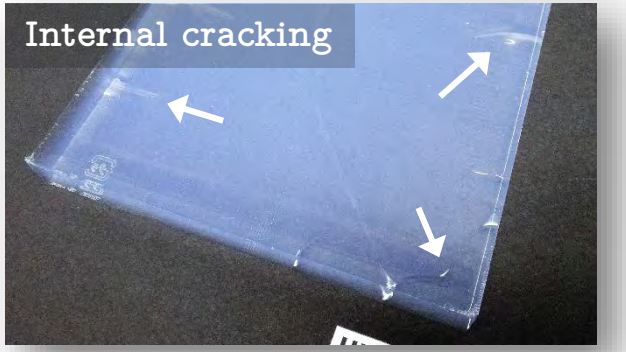
- Requirements: 36 tiles (with no cracking)
  - Dimensions: 100 mm × 100 mm × 10 mm (after water-jet trim)
- Nominal production
  - 88 tiles × 0.9 × 0.5 × 0.9 = 36 tiles

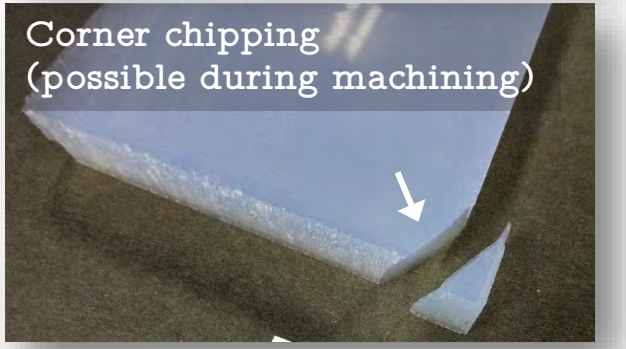
Crack-free yield

Index screening (mean, uniformity)

Water-jet cut yield

- Additional (backup) production
  - 8 tiles
- Total 96 tiles (scheduled)
  - 32 tiles × 3 seasons



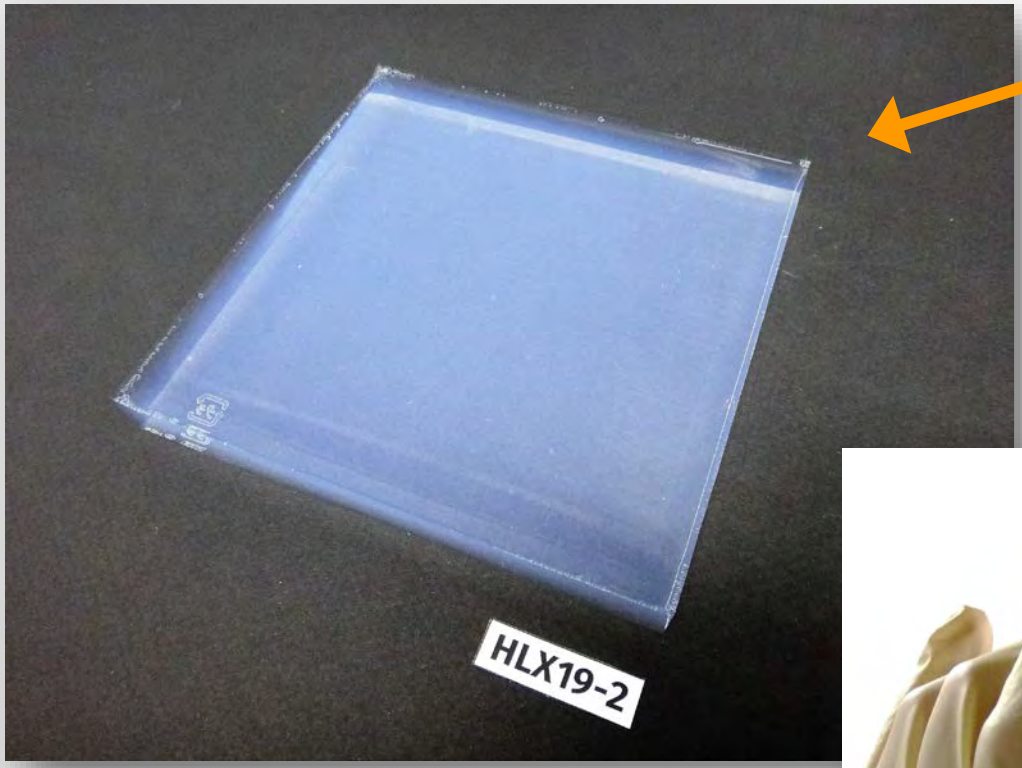


Mass Production Status

- 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

The First Tile

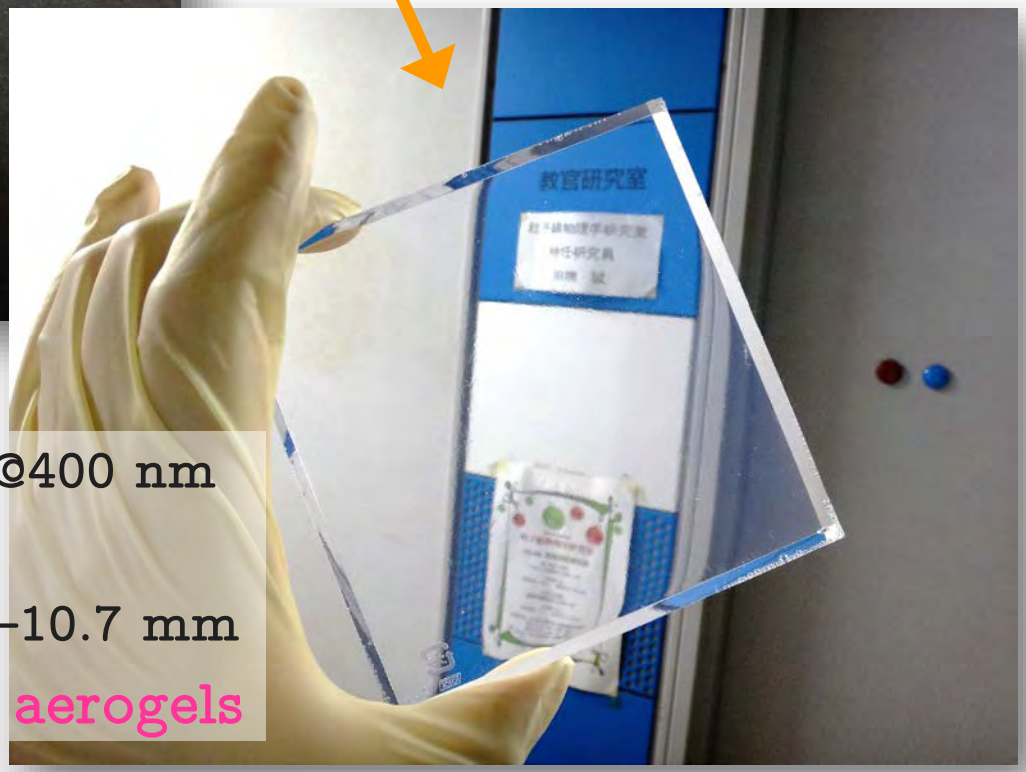


"Rayleigh" blue tile:

Scattered light

Colorless tile:

Transmitted light



n = 1.160

Transmission length = 36 mm @400 nm

Dimensions

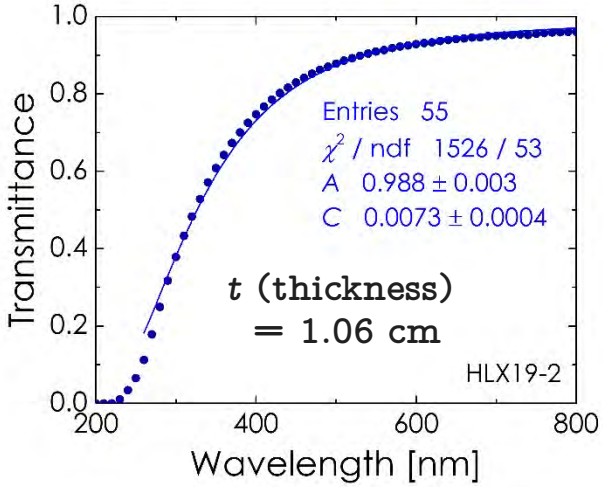
= 112 mm × 112 mm × 10.5–10.7 mm

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

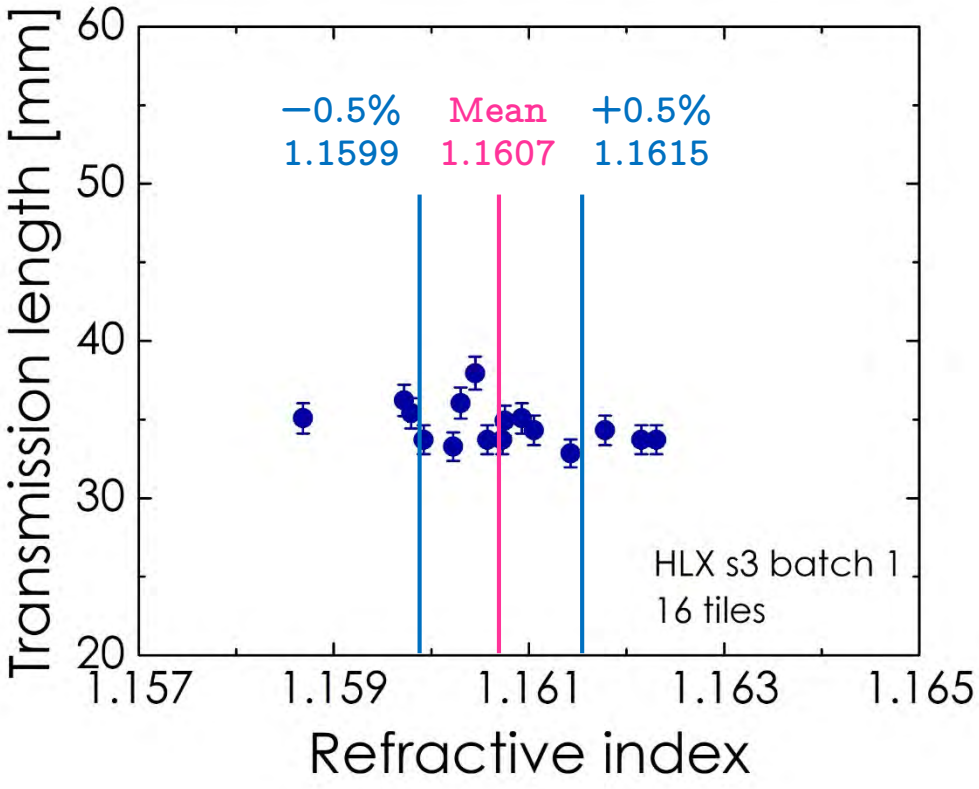
Transmittance (T)



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

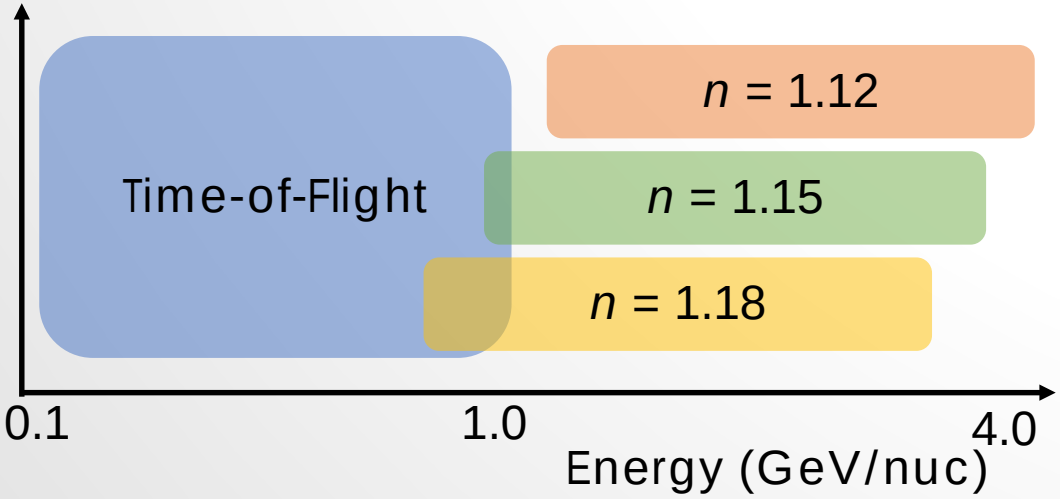
Rayleigh scattering

Transmission length @400 nm (from T and t)



Discussion on Refractive Index

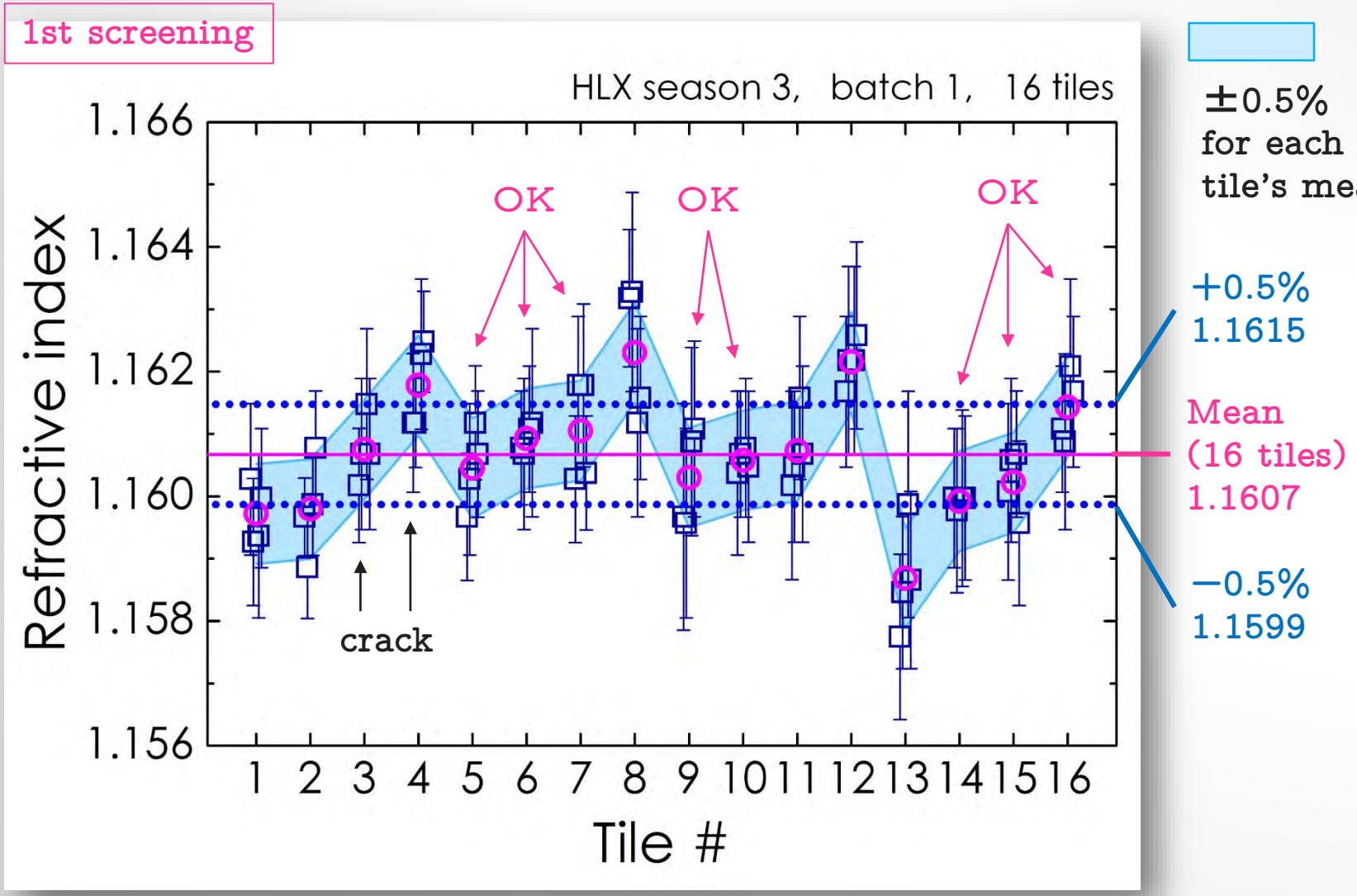
- Results from the 1st mass production batch
  - → Mean index: Not 1.15 but 1.16
- Index of 1.16 rather ideal for HELIX
  - → Low energy threshold
  - → Cross calibration with TOF possible much more



- Keep fabrication parameters for later production

Refractive Index (Uniformity Check)

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



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.

Constant

$n - 1 = k \cdot \rho$

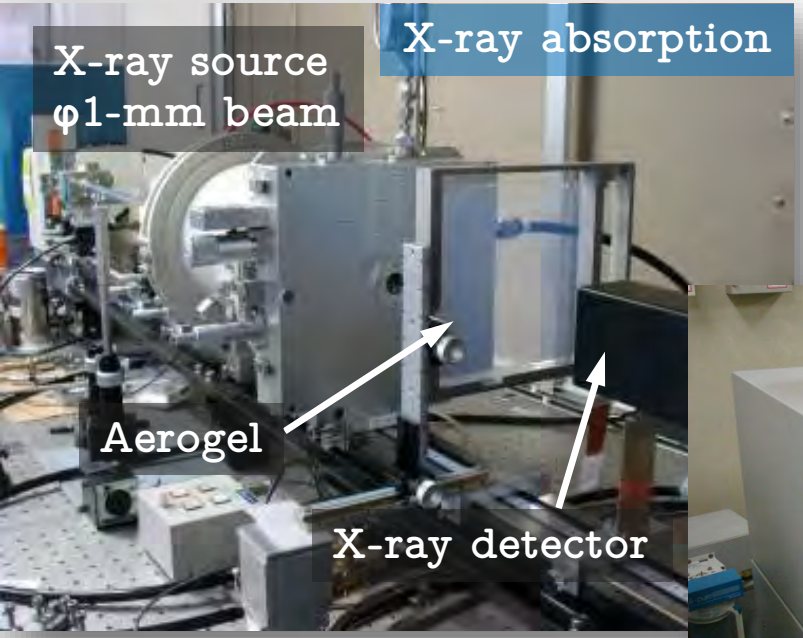
Density

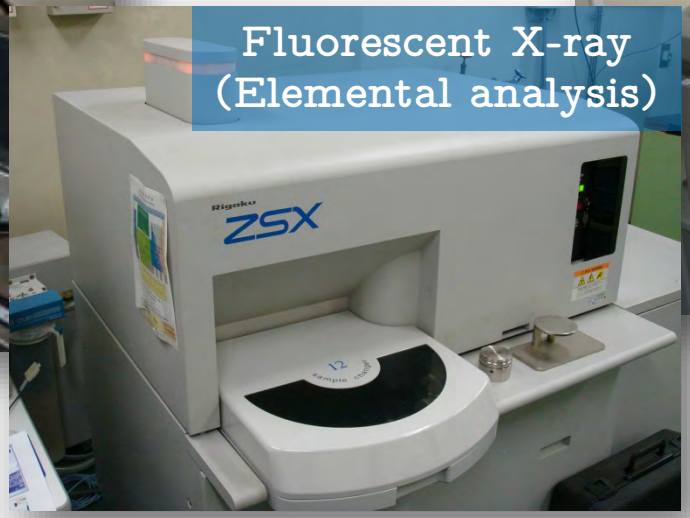
X-ray transmittance

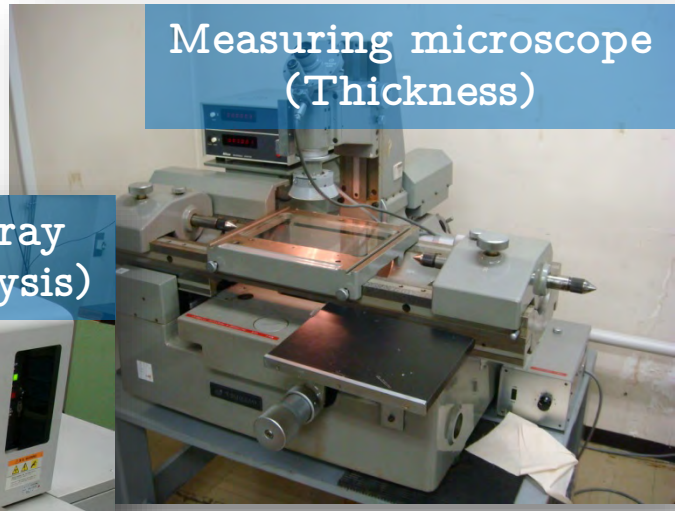
$I/I_0 = \exp(-\mu_m \cdot \rho \cdot t)$

Thickness

Mass attenuation coefficient





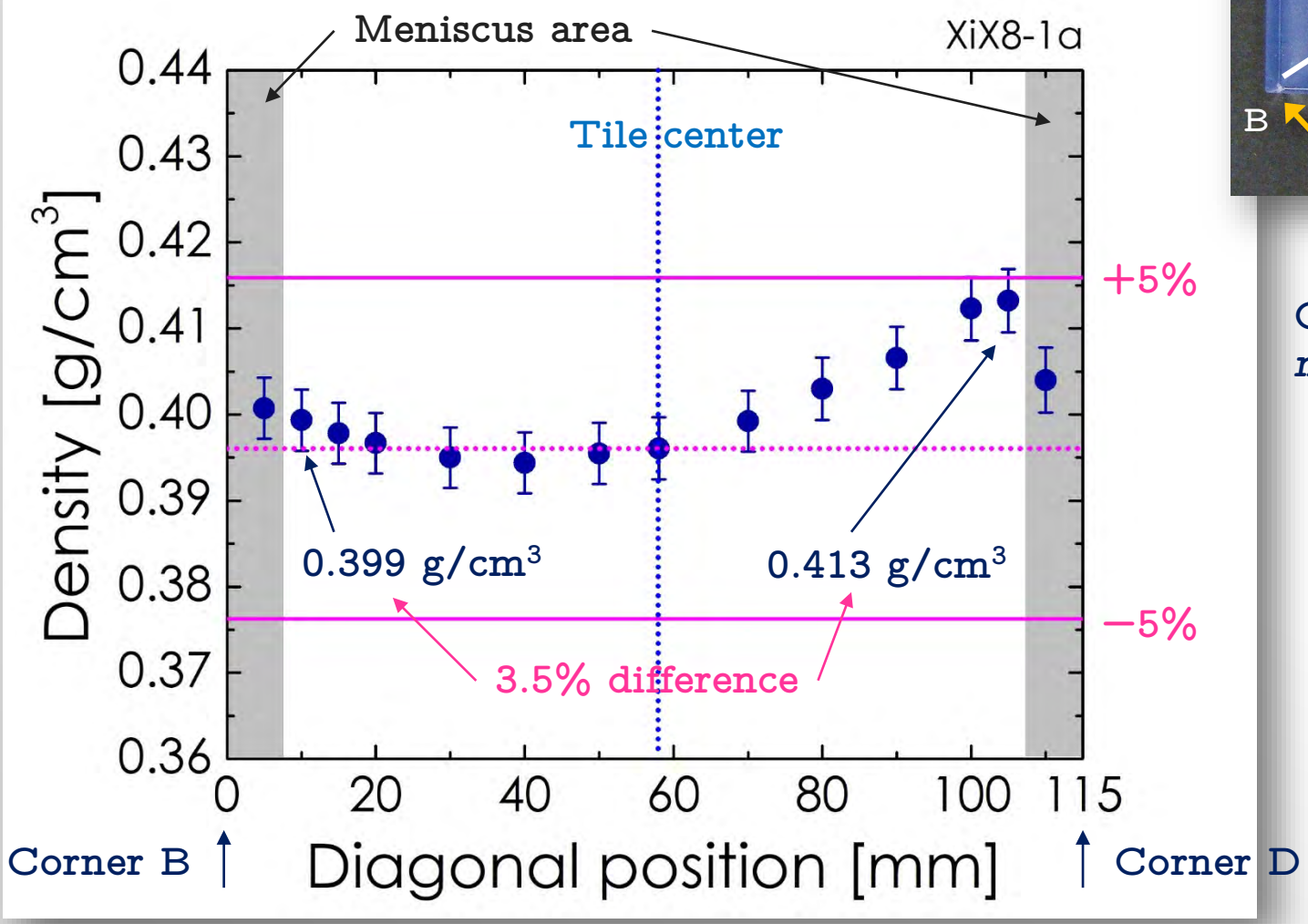


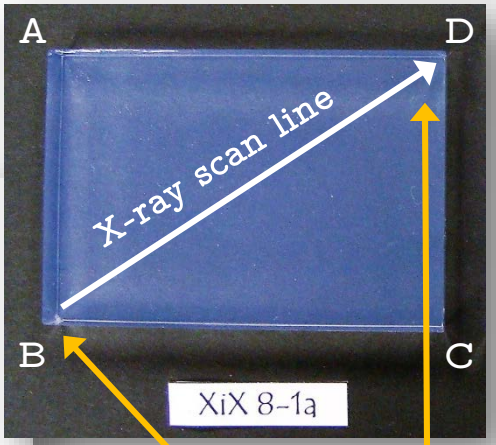
Comparison b/w X-ray and Laser Measurements

- Laser results consistent with X-ray results

X-ray absorption

Effective for 1st screening





Laser

Corner B
n = 1.1184

4.1% difference

Corner D
n = 1.1233

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

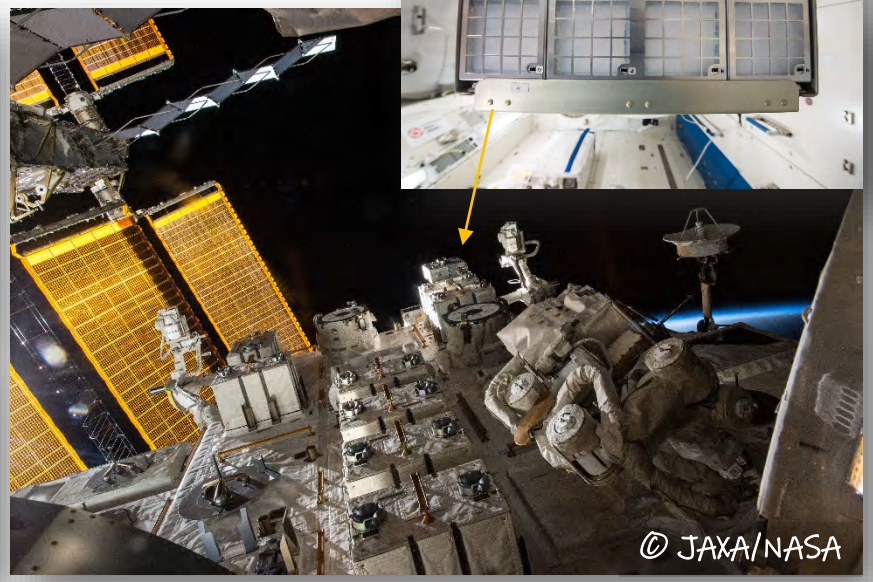
and flew on spacecraft from USA.

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

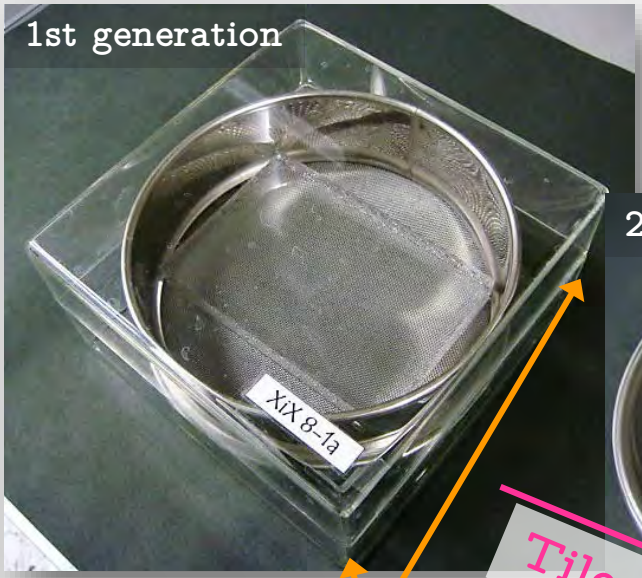
ALLISON, Patrick (Ohio State University); BEATTY, James J. (Ohio State University); COUTU, Stephane (Penn State University); GEBHARD, Mark (Indiana University); GREEN, Noah (University of Michigan); HANNA, David (McGill University); KUNKLER, Brandon (Indiana University); LANG, Mike (Indiana University); MOGNET, Isaac (Penn State University); MÜLLER, Dietrich (University of Chicago); MUSSER, James (Indiana University); NUTTER, Scott (Northern Kentucky University); PARK, Nahee (University of Chicago); SCHUBNELL, Michael (University of Michigan); TABATA, Makoto (Chiba University); TARLÉ, Gregory (University of Michigan); TOMASCH, Andrew (University of Michigan); VISSER, Gerard (Indiana University); WAKELY, Scott P. (University of Chicago); WISHER, Ian (University of Chicago)

Additional Information

Improving Pin Containers

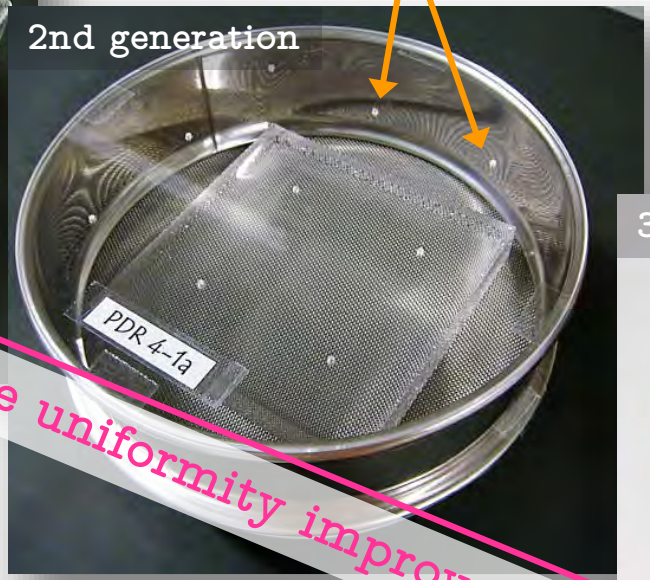
- 3 generations of pin containers

→ Enhance index uniformity → Avoid excess shrinkage at tile edge



Sieve +
Upward/downward glass cases

Pinholes (at 4 corners)



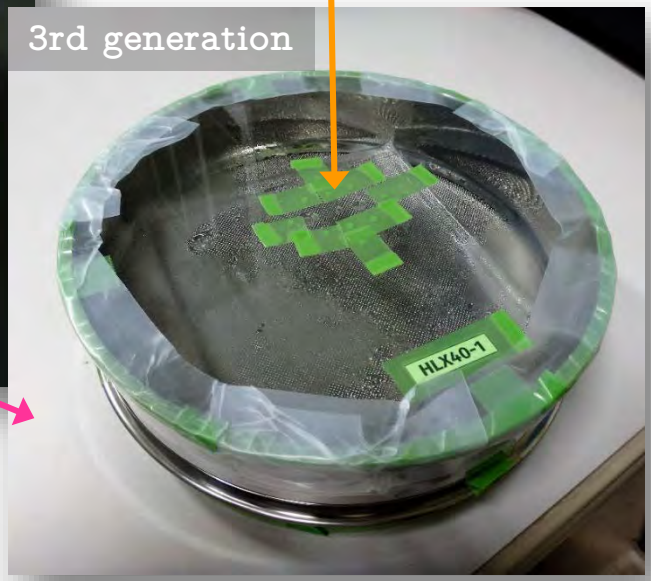
Pinholes
(on top/bottom plates)

Sieve +
PMMA top/bottom plates

Tile uniformity improved

Sieve +
Glass top plate +
Aluminum bottom plate
w/ edge sealing

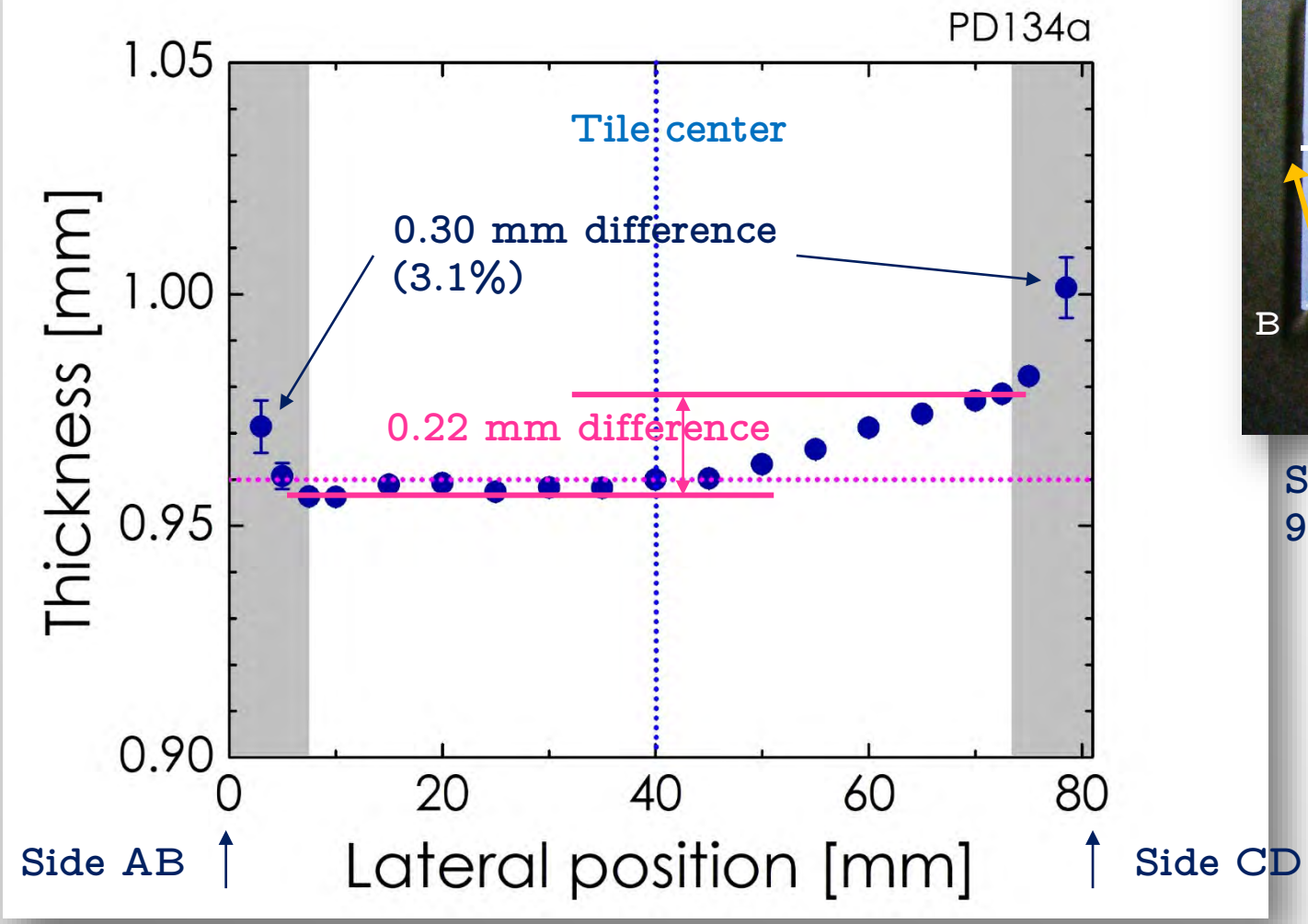
Pinholes
(on the center of
top/bottom plates)

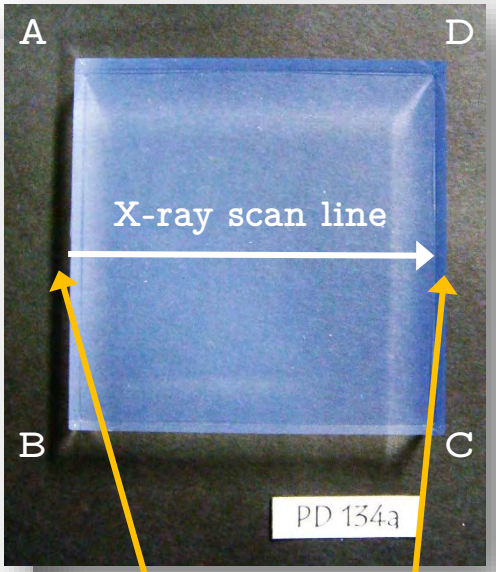


Thickness Measurements

- Ruler results consistent with microscope results

Measuring microscope





Ruler

Side AB
9.75 mm

0.25 mm difference
(2.6%)

Side CD
10.0 mm

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 ~ 34 mm → OK
  - → Thickness (before water-jet cut) = 10.5 mm → OK