Construction of Silica Aerogel Radiator System for Belle II RICH Counter

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KEK

2016.09.09

Belle II ARICH Group

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Contents of This Talk

Belle II RICH Counters

KL and muon detector:
Resistive Plate Counter (barrel)
Scintillator + WLSF + MPPC (end-caps)

EM Calorimeter:
CsI(Tl), waveform sampling (barrel)
Pure CsI + waveform sampling (end-caps)

Barrel : Time-of-Propagation (TOP) counter

End-cap : RICH based on silica aerogel radiator (ARICH)

Two Cherenkov detectors for Belle II PID

2cm diameter

Vertex Detector
2 layers DEPFET + 4 layers DSSD

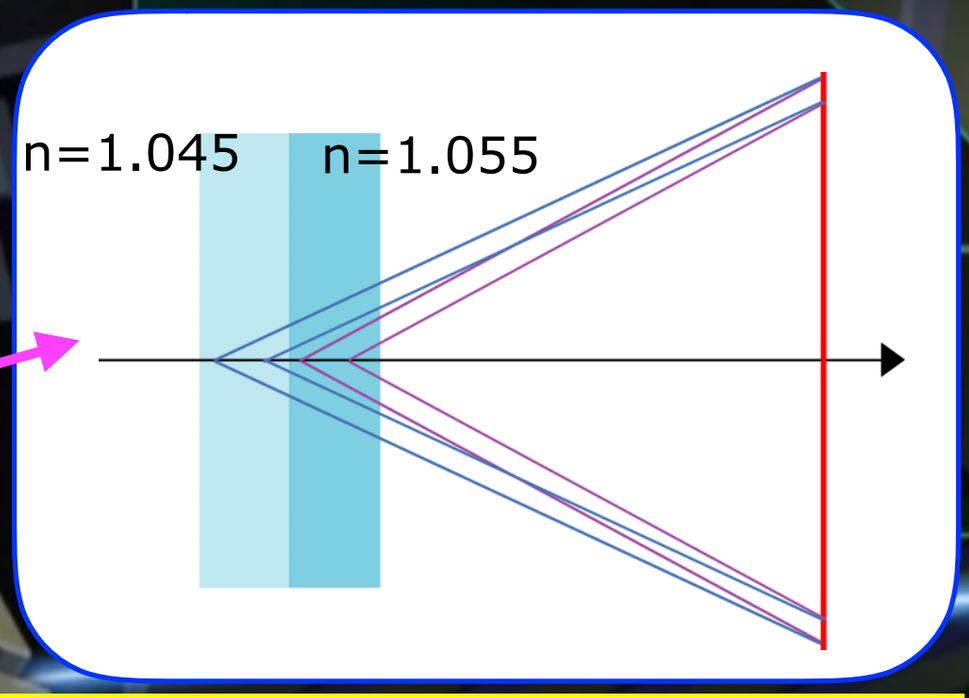
Central Drift Chamber
He(50%):C_2H_6(50%), Small ce
lever arm, fast electronics

ARICH general talk : R. Pestotnik
HAPD talk : Y. Yusa
Software talk : L. Šantelj
HAPD under B field poster : H. Kindo
Slow control poster : M. Yonenaga
Monitor poster : K. Hataya

ARICH Counter

Proximity focus RICH

20 cm expansion distance



Silica aerogels

Choose an **appropriate refractive index combination** to organize dual radiator layers so that **Cherenkov photons can be overlapped** onto the HAPD plane.

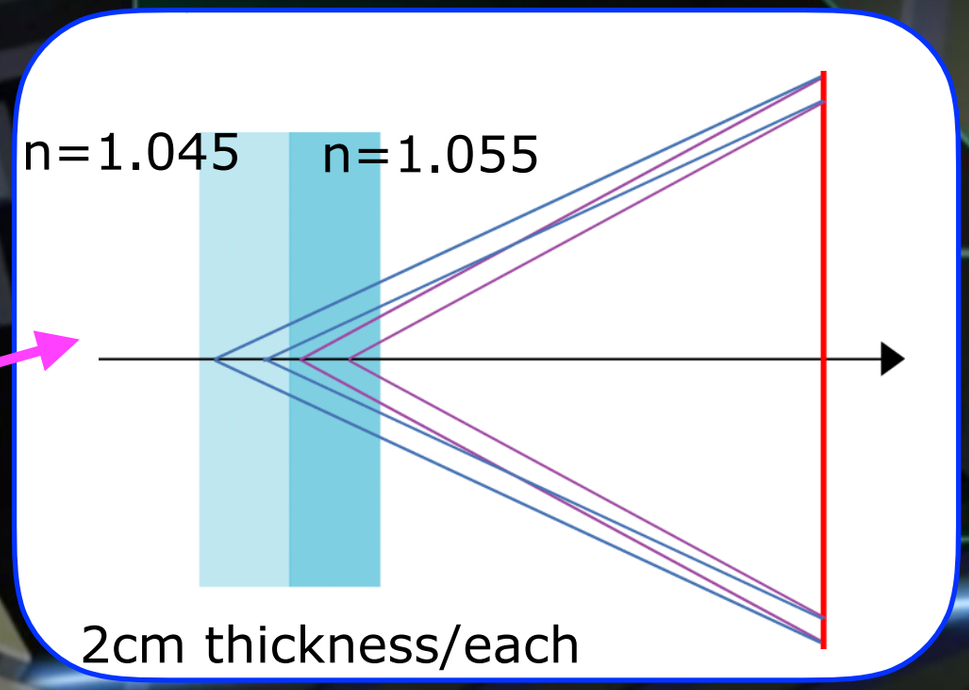
Hybrid Avalanche Photo-Detectors

Only possible with silica aerogel since refractive index (i.e.density) can be controllable.

ARICH Counter

Proximity focus RICH

20 cm expansion distance



Silica aerogels

Our requirements

(1) n=1.045/1.055 for upstream/downstream
(2) Big tile to reduce radiator boundaries
(But manageable for handling)
(3) High transparency for large photon yield
(More important for downstream tile)
(4) Crack-free for handling/transparency
(5) Hydrophobic for long-term stability

Only pos
index (i.

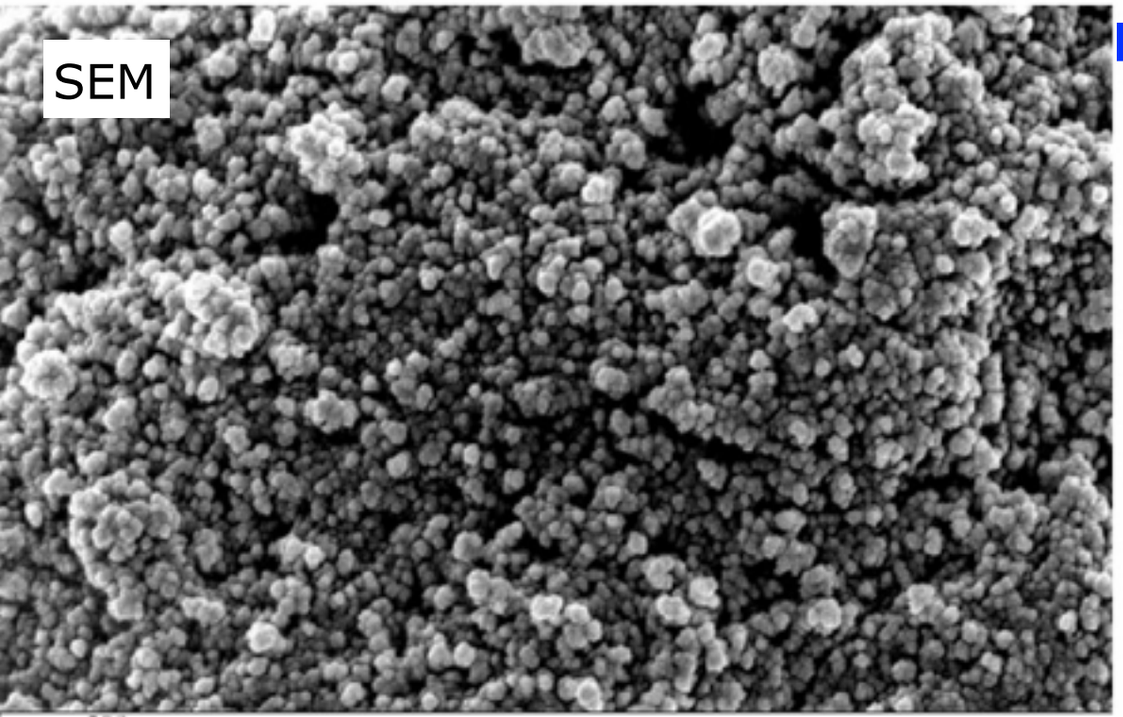
Silica Aerogel

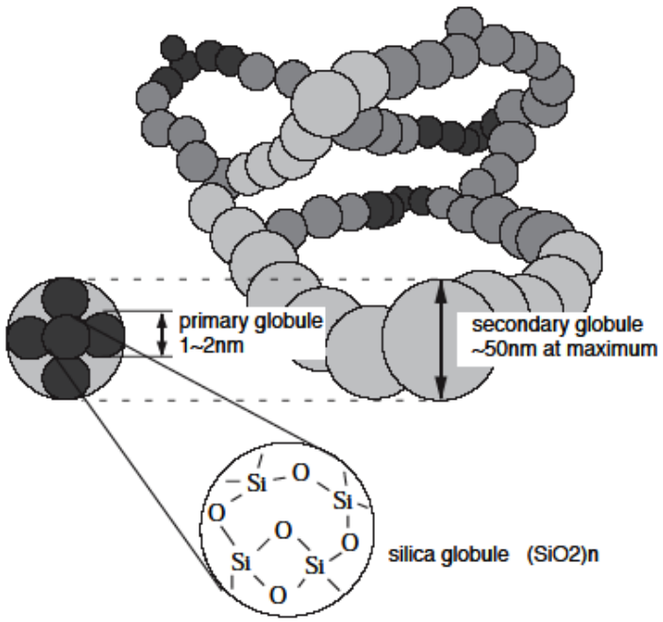
- Highly porous structure of silica clusters
  - 3 dimensional network of $(SiO_2)_n$
  - More than 90 % air inside the material

- Fraction of silica clusters defines its density, i.e. refractive index
- Uniformity and dimensions of silica clusters are related to transparency

Depends on the production technique

Managing the production steps is quite essential.





Production Method

- Alco-gel formation via sol-gel polymerization

$$n\mathrm{Si(OR)_4} + 4n\mathrm{H_2O} \longrightarrow n\mathrm{Si(OH)_4} + 4n\mathrm{ROH} \qquad \text{Hydrolysis}$$

$$n\mathrm{Si(OH)_4} \longrightarrow \underline{(\mathrm{SiO_2})_n} + 2n\mathrm{H_2O} \qquad \text{Condensation}$$

Alco-gel

This synthesis step determines refractive index (by our recipe)
Also critical for high transparency

- Hydrophobic treatment

Provide long-term stability in optical property

- Supercritical drying to obtain aerogel from alco-gel by avoiding a direct phase change.
  - CO_2 extractions (critical point: 31 degree Celsius with 7.4 MPa)

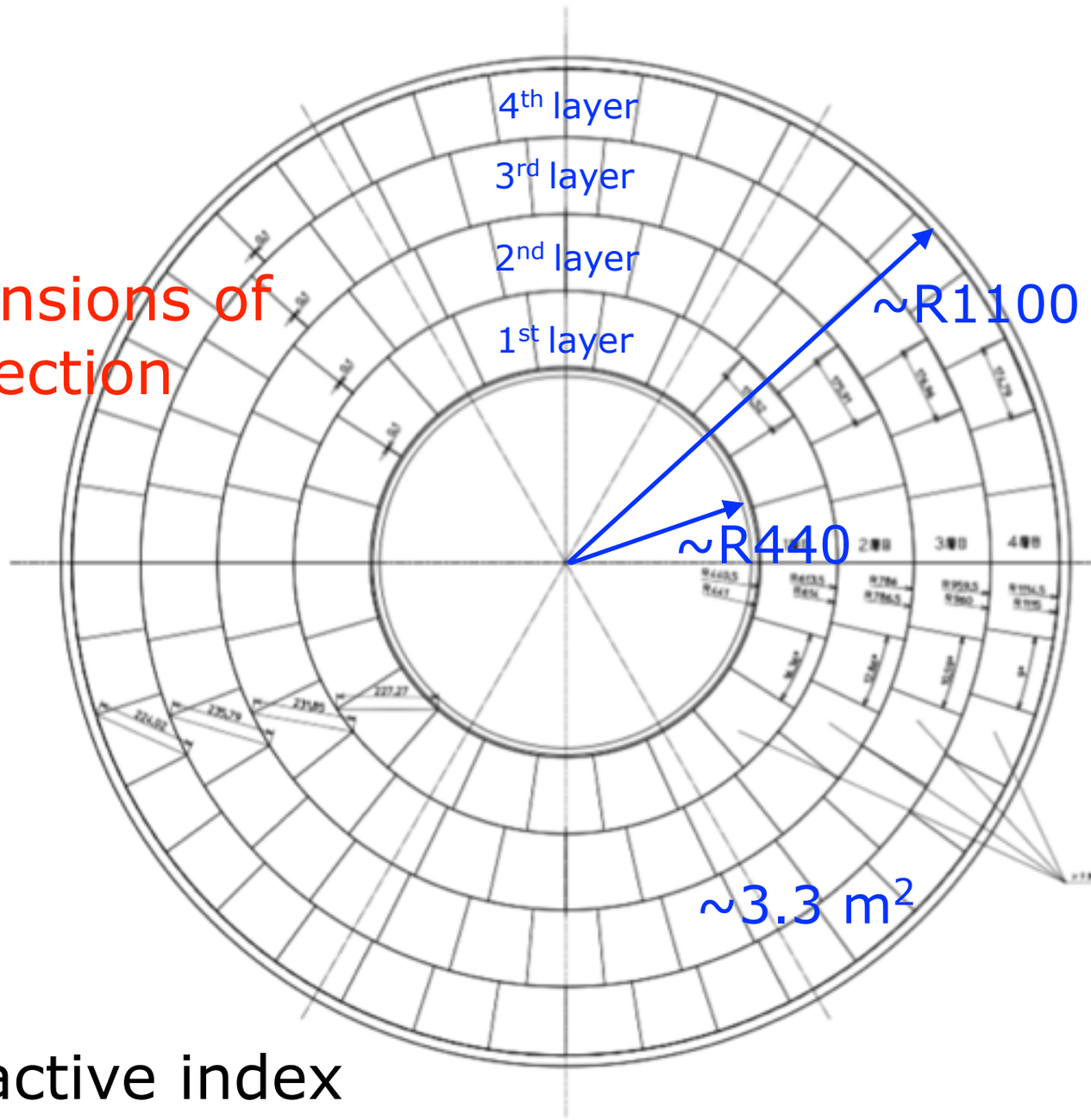
Managing operation conditions is essential to get crack-free samples in this recipe.

Radiator Tiling Design

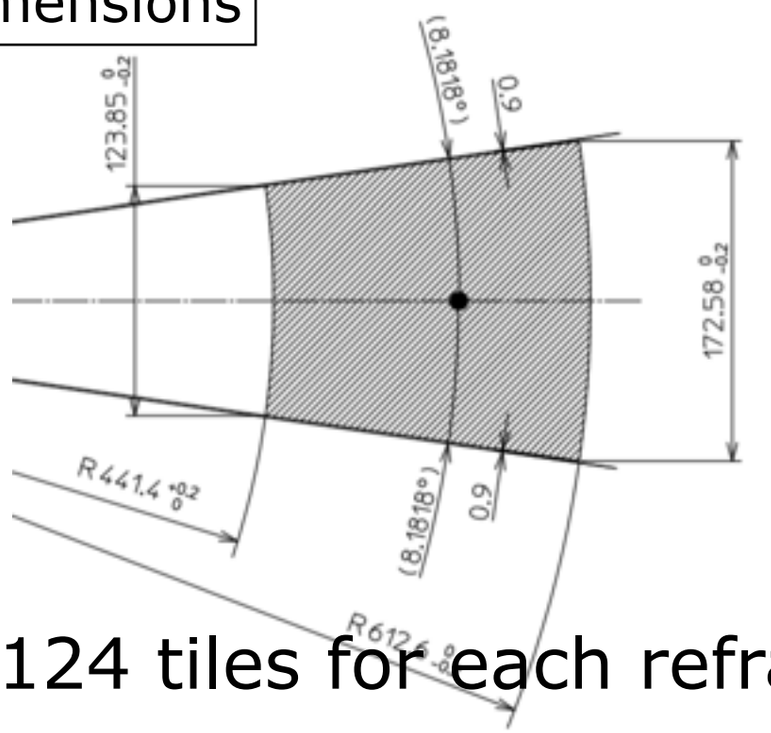
- Based on R&D done so far, aerogel tiling scheme was designed.

Wedge shape cutting from 180×180×20 mm^3 tile

4 layers (=4 different dimensions of wedge shaped tile) in R direction



typical dimensions



Total 124 tiles for each refractive index

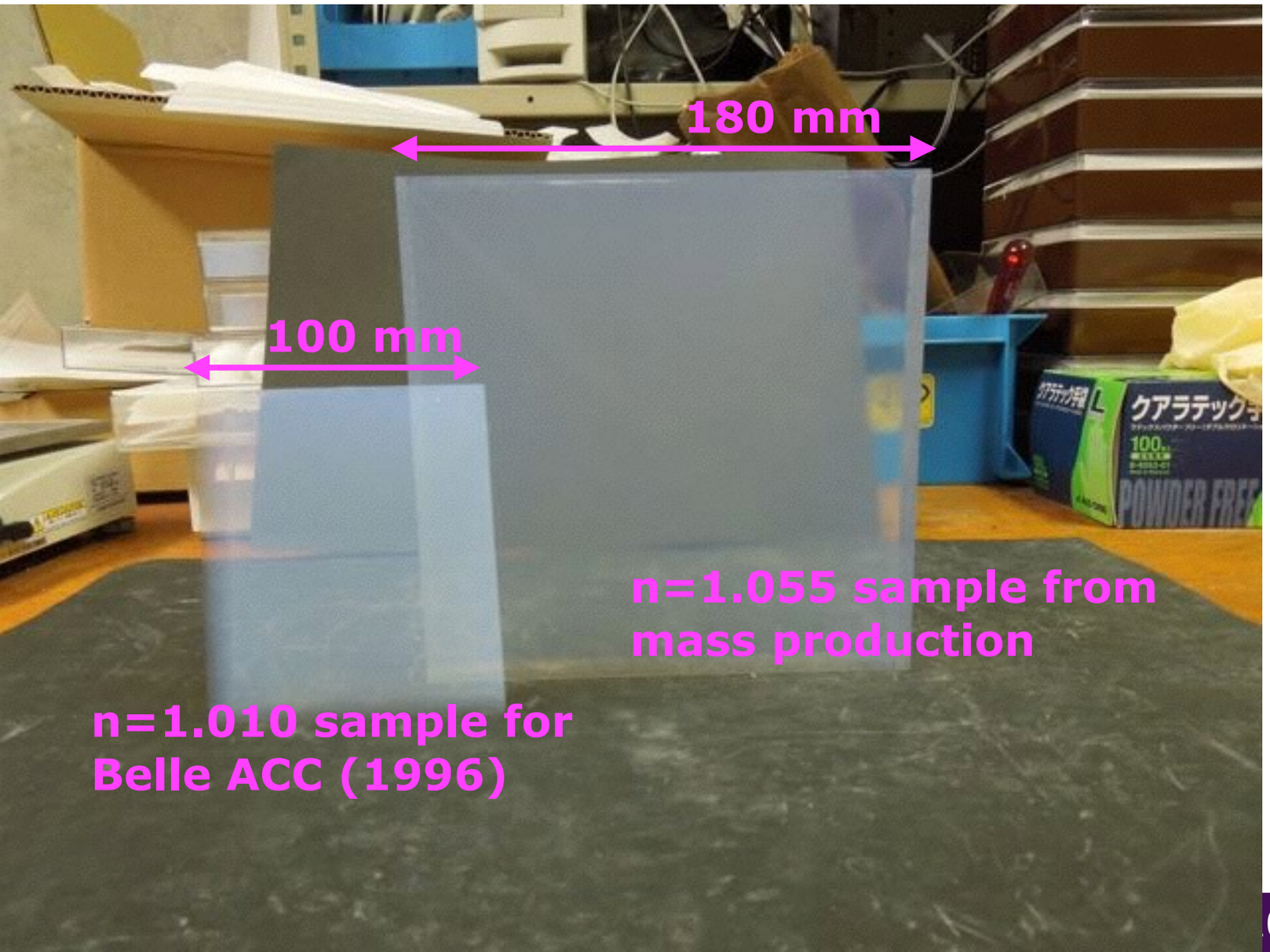
Mass Production

- **Japan Fine Ceramics Center (JFCC) for mass production.**
  - Panasonic no longer accepts new aerogel production.
  - Technology transfer by joint effort with us.
  - Recipe was provided from our side.

- **Started in September 2013. Completed in May 2014.**
  - 16 batches. 28 tiles in one batch.
  - This comes from capacity of the supercritical drying device.

New Aerogel Tile

- Large tile of 180×180×20 mm^3 with no cracks
  - Optimization of pressure control in supercritical drying process.
  - 3 times longer duration from operating point to atmospheric pressure introduced by Chiba university group.



Crack-free yield ~ 87%

Drawback is to need more time for tile production.

M.Tabata et al., The Journal of Supercritical Fluids, Vol.110, April 2016, Pages 183-192

Quality Check

- After delivery of aerogel tiles, quality checks have been carried out.
  - **Visual inspection**
    - **Crack/Chip/Milky area**
  - **Dimensions/weight measurement**
  - **Refractive index measurement**
    - **Fraunhofer technique**
  - **Transparency measurement**
    - **Using a spectro-photometer**
- After those measurements, the following # of tiles can be candidates to be installed.

182 tiles for n=1.045
151 tiles for n=1.055

(124 tiles required for each)

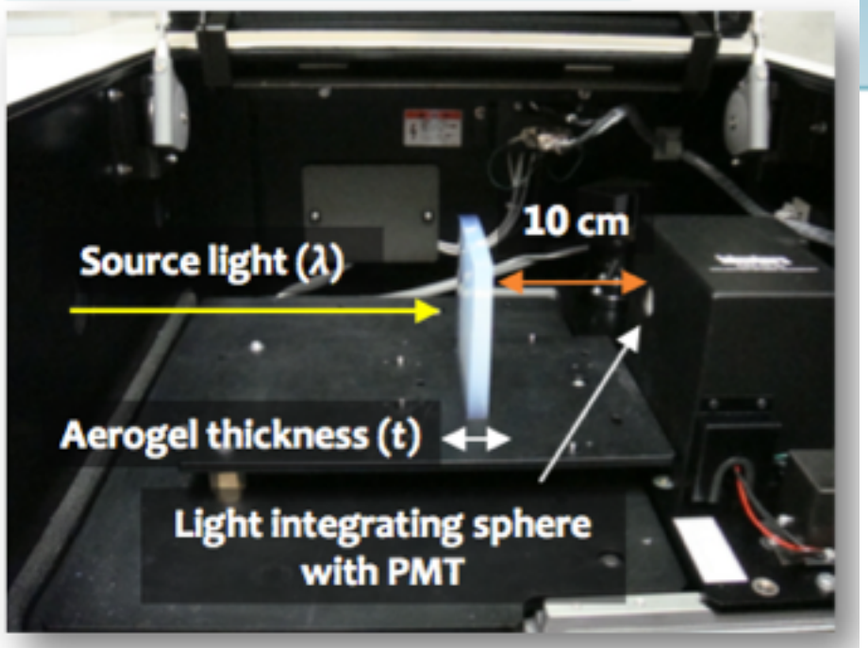
Yield ~74%

Transmittance Measurement

- Measuring aerogel transmittance (T) using a spectrophotometer
  - Detecting only light going straight
  - $T = A\exp(-C \cdot t/\lambda^4)$ A, C: clarity parameters
- Transmission length at 400 nm wavelength: $\Lambda_T = -t/\ln T$

Target
Λ_T>40 mm for n=1.045
Λ_T>30 mm for n=1.055

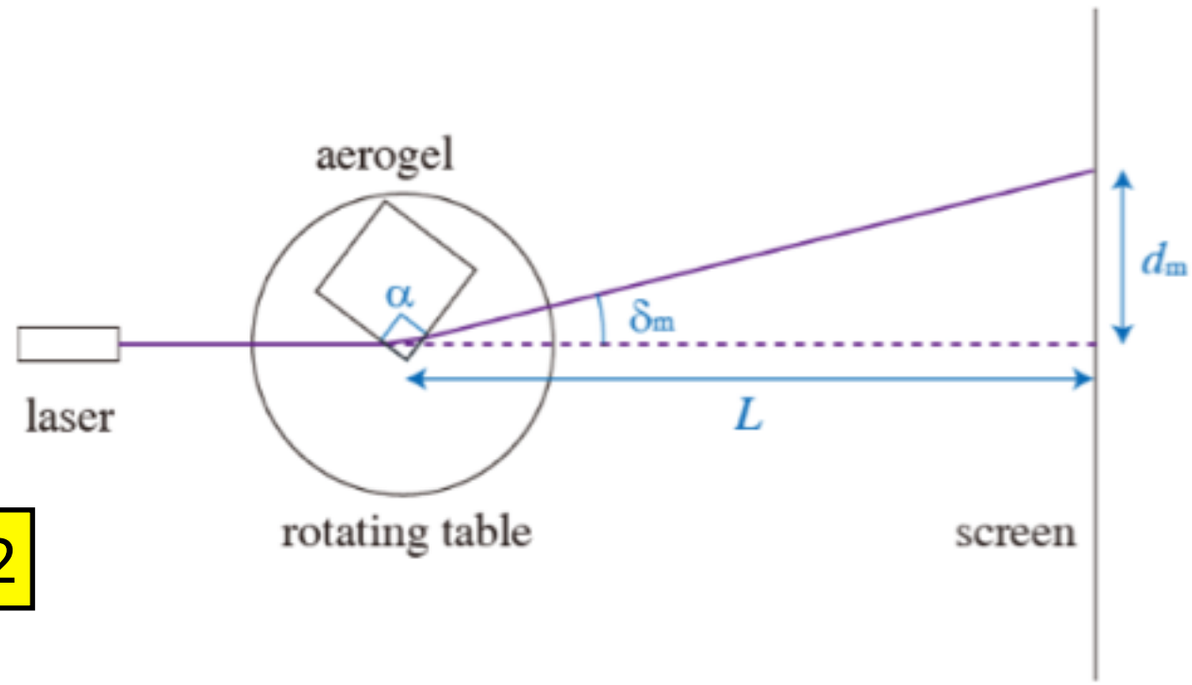
Setup in a spectrophotometer



Refractive Index Measurement

- Fraunhofer method using a 405-nm laser
- Prism formula: $\frac{n}{n_{air}} = \sin\left(\frac{\alpha+\delta_m}{2}\right)\left[\frac{1}{\sin(\alpha/2)}\right]$

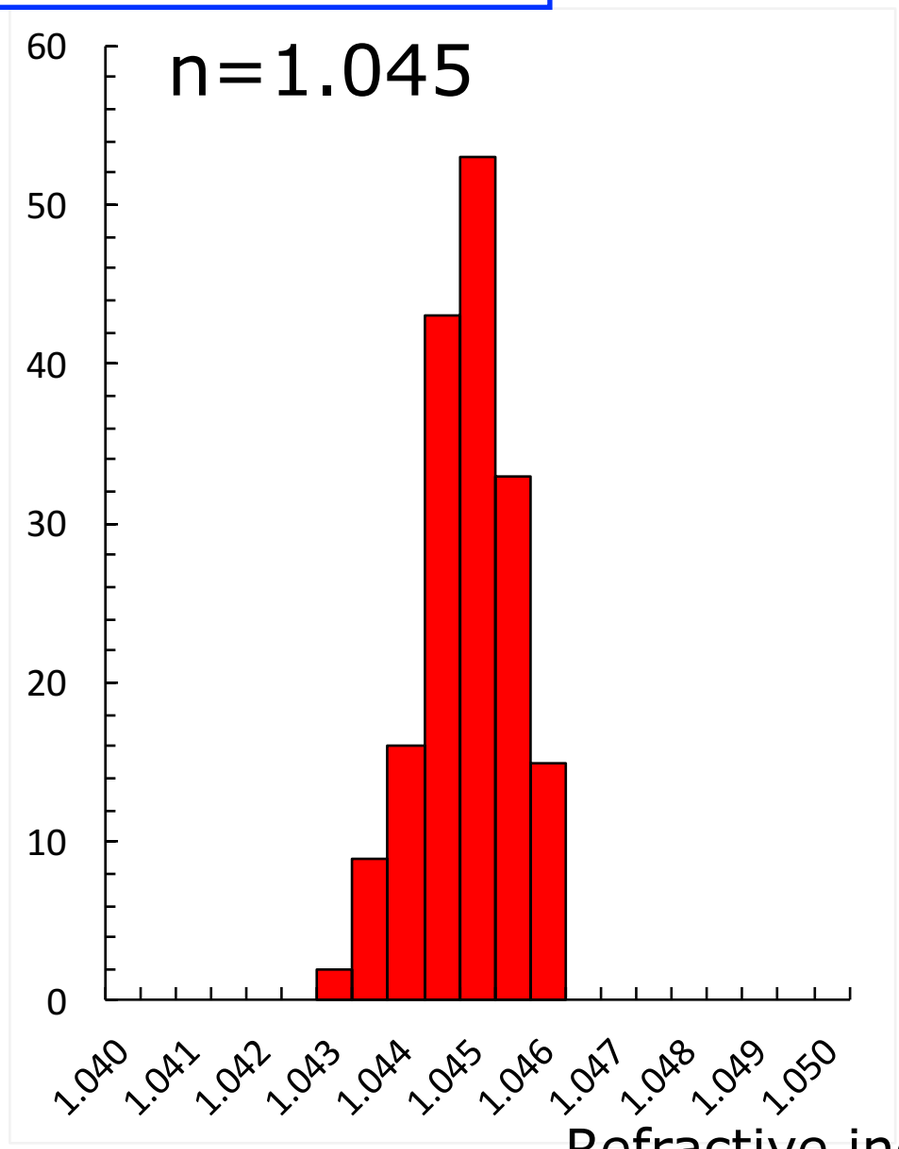
$$\delta_m = \tan^{-1}(d_m/L)$$



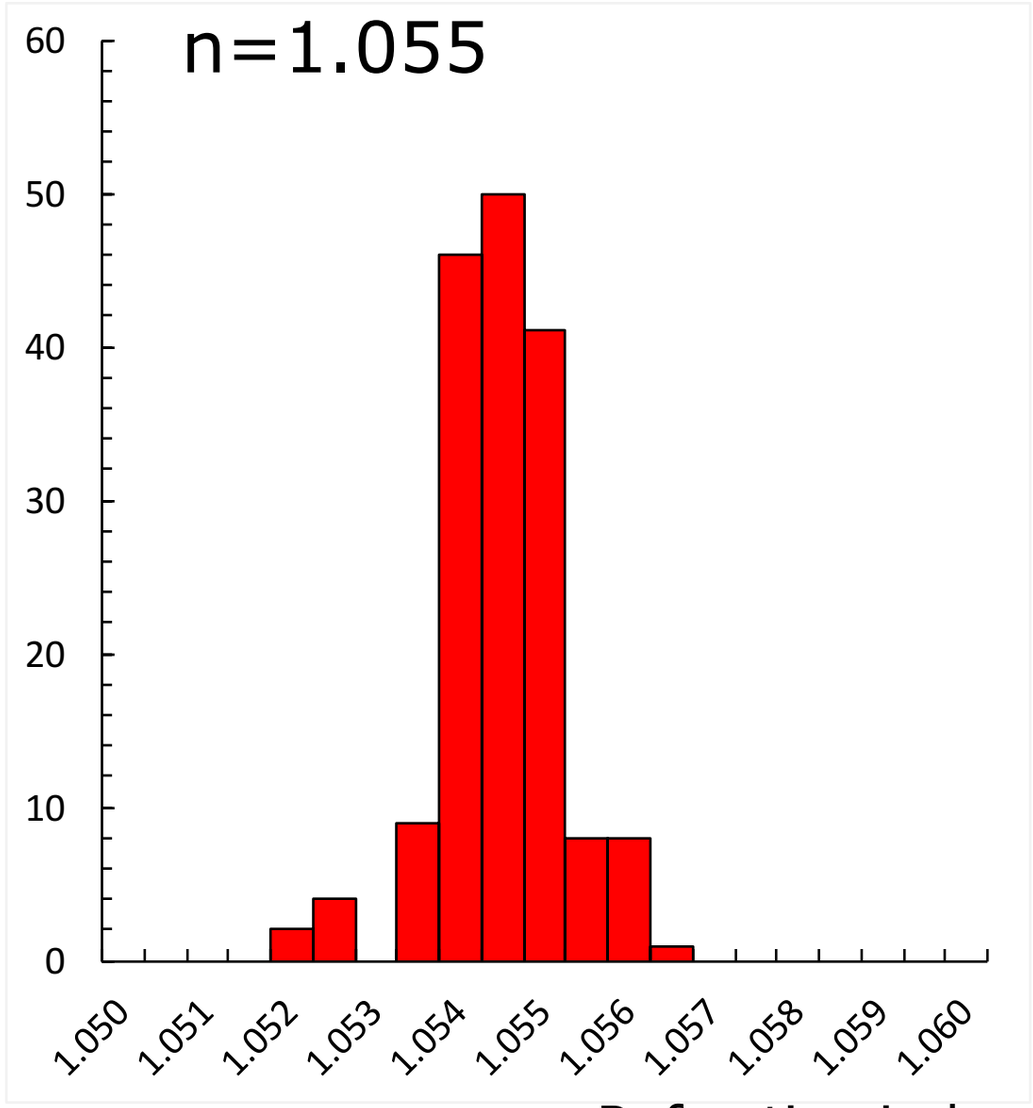
Target: |δn| < 0.002

Optical Properties (1)

Refractive index



average: 1.0451±0.0007

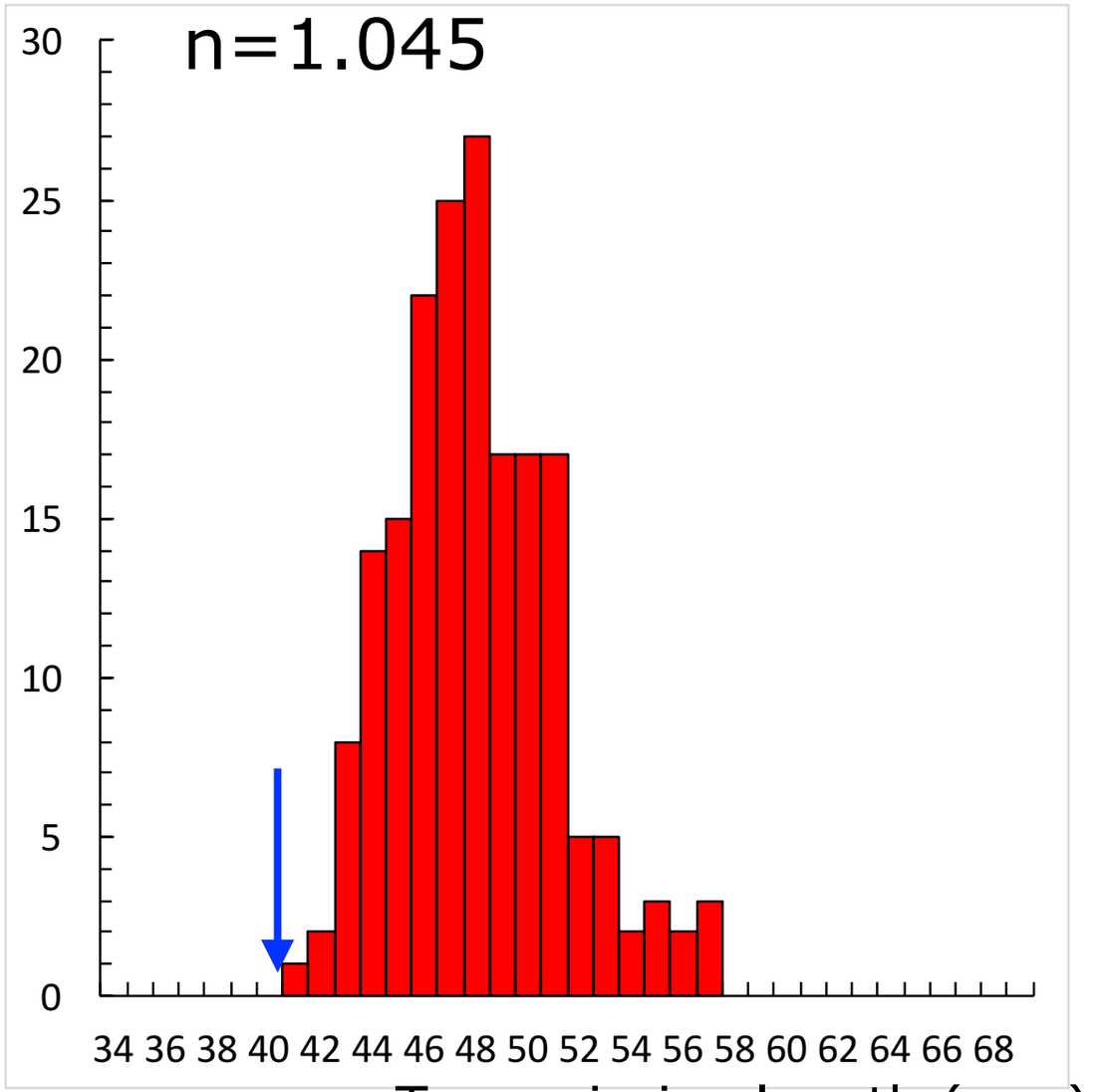


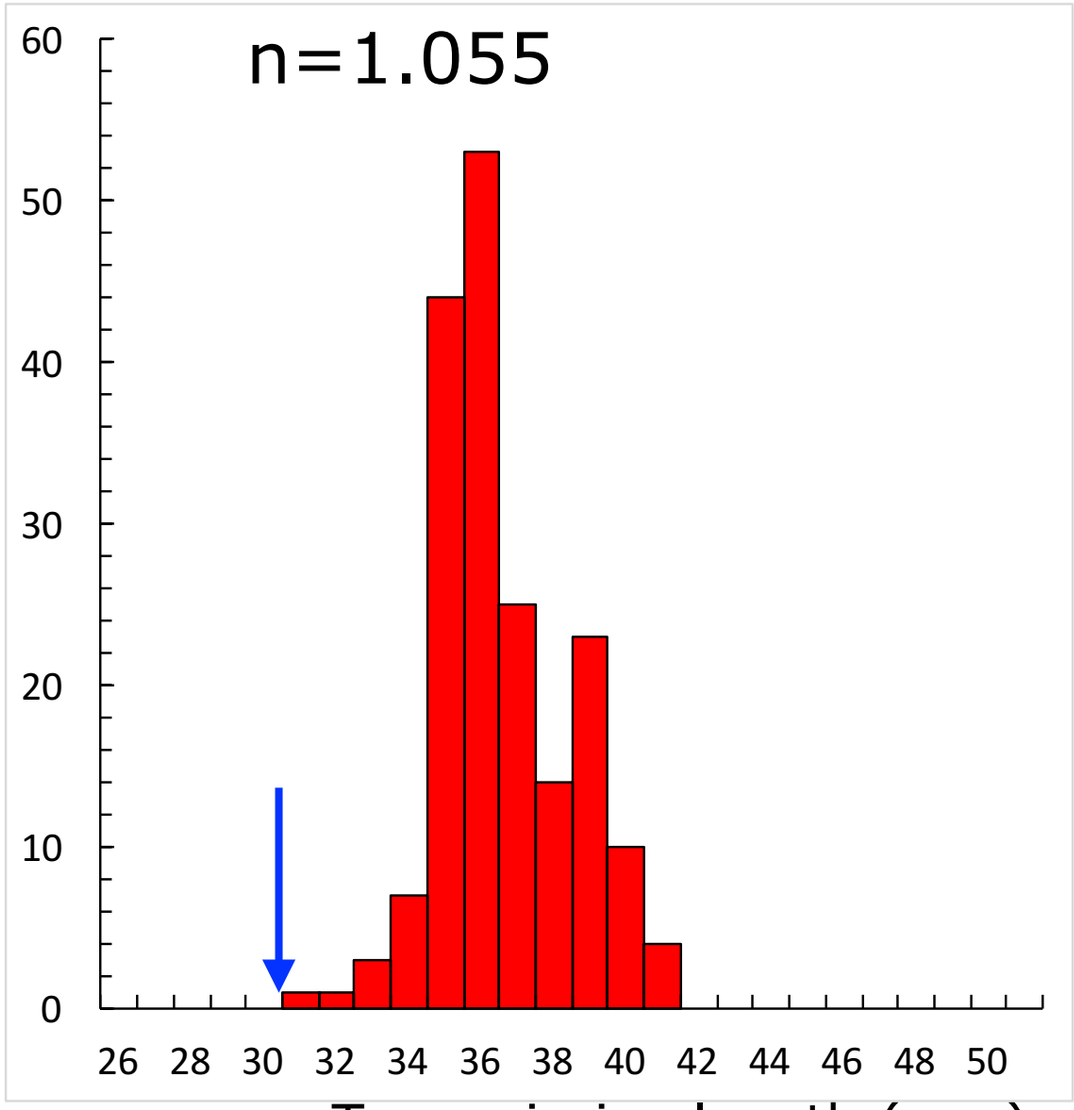
average: 1.0547±0.0007

Good agreement with our expectations

Optical Properties (2)

Transmission length(Λ_T) at λ=400nm





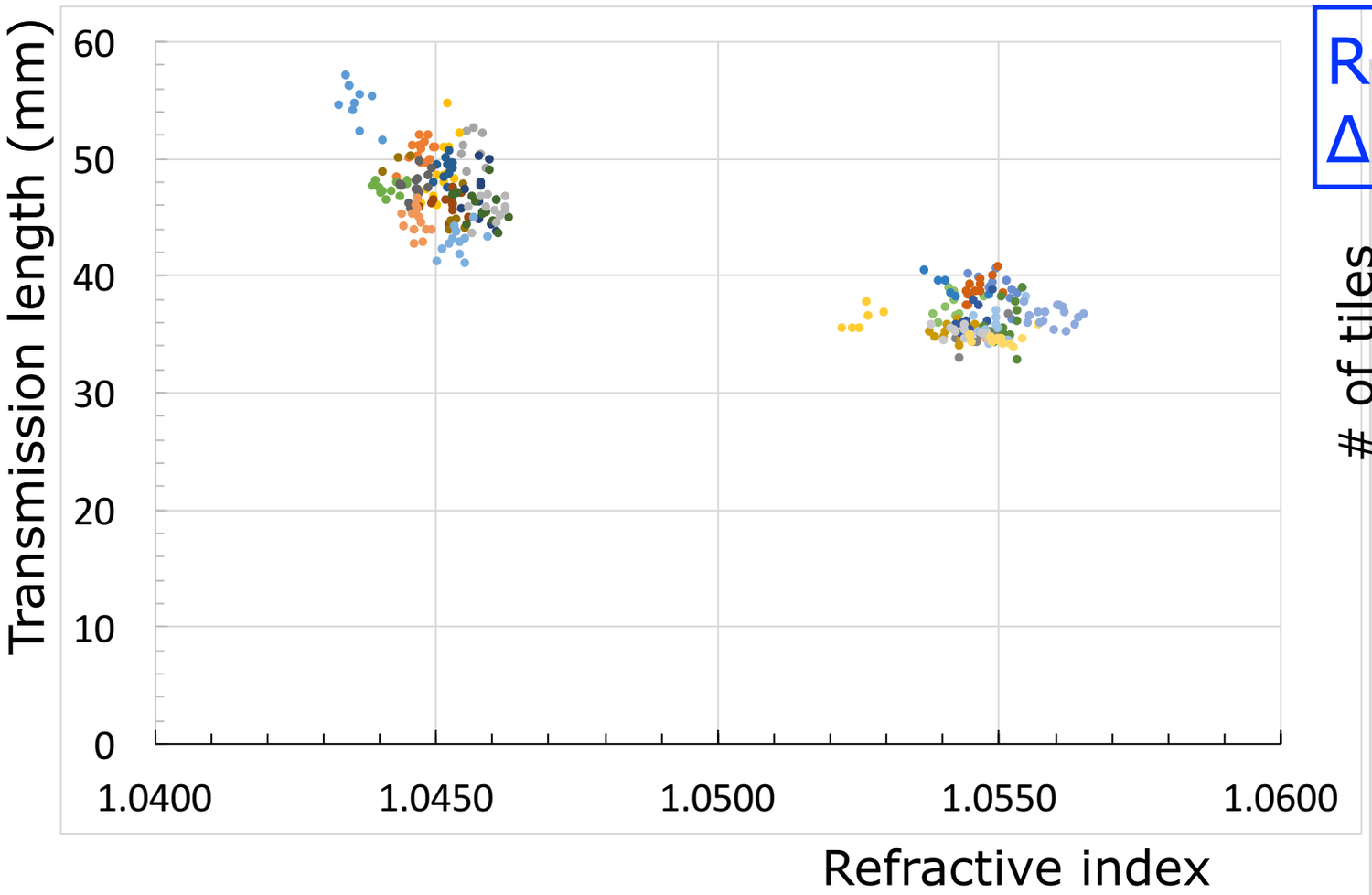
average: 47.3 ± 3.1 mm

average: 36.0 ± 2.7 mm

High transparencies for both indices

Optical Properties (3)

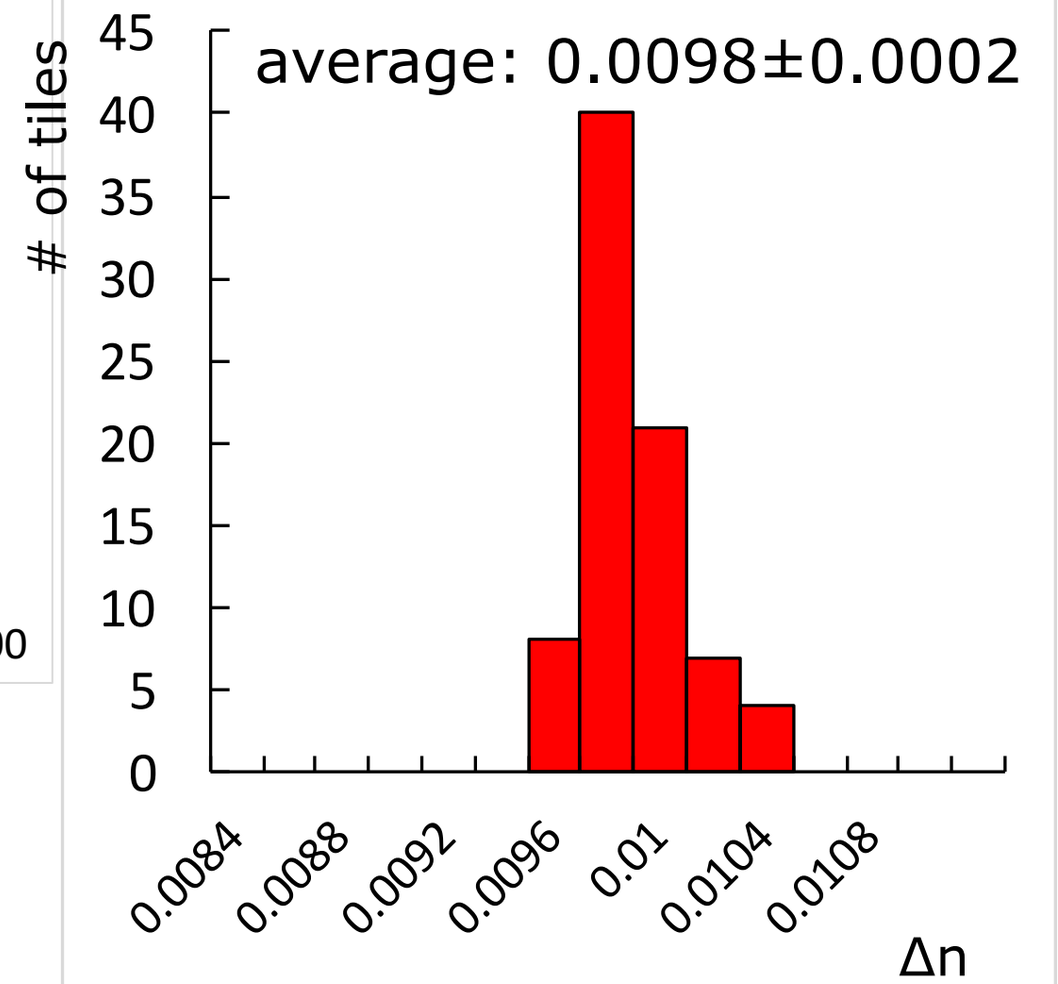
Refractive index vs transmission length at λ=400nm



Batch dependence can be seen, however, they are within tolerance.

Refractive index combinations

$\Delta n = n_{down} - n_{up}$

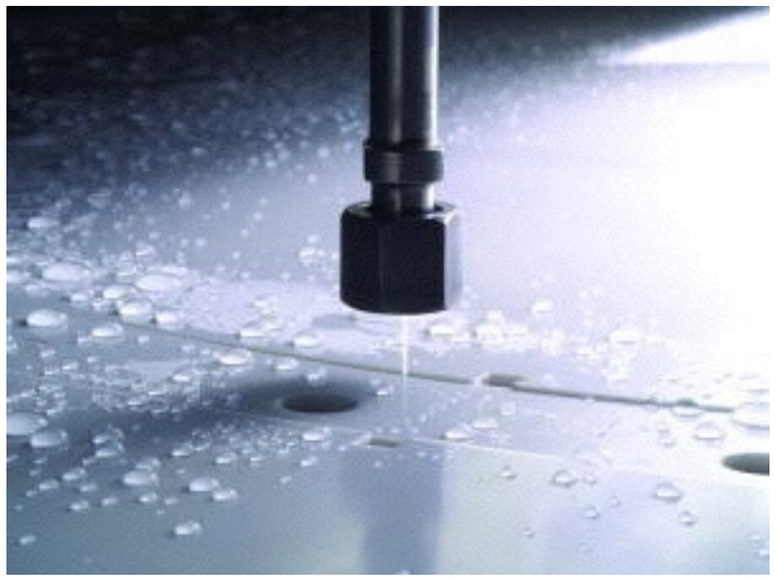


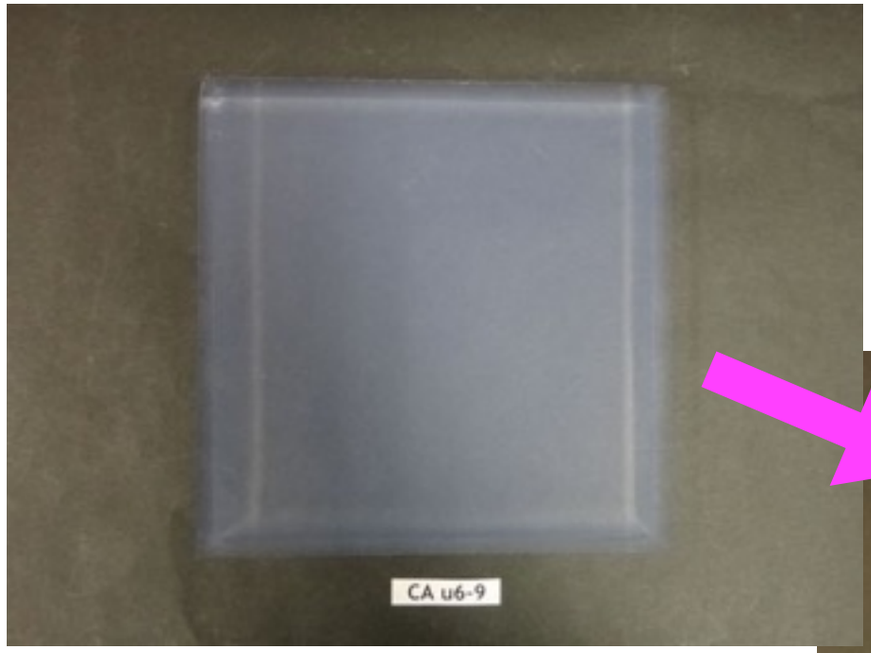
Our spec. $|\Delta n - 0.01| < 0.002$

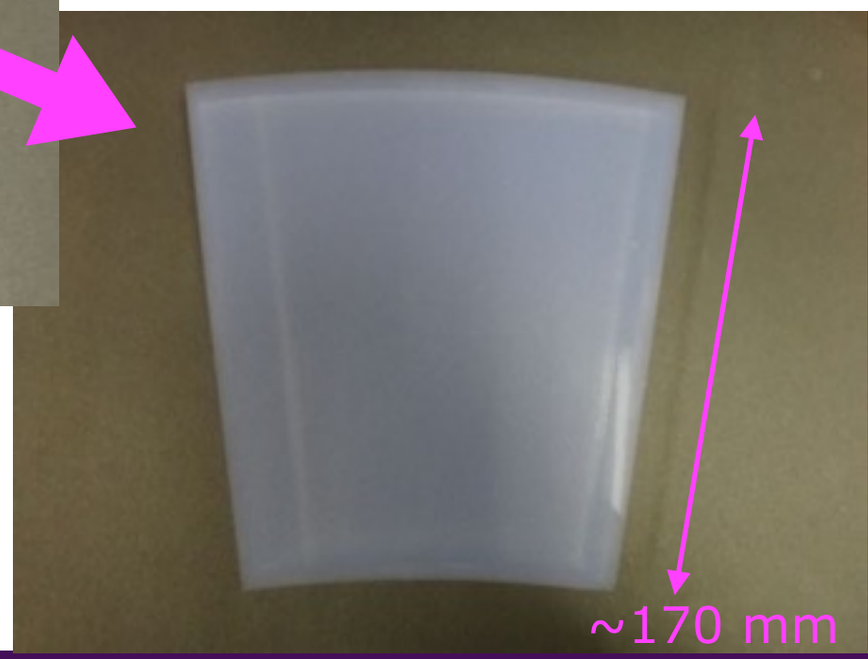
Good combinations arranged.

Tile Machining (1)

- Square tiles were cut into wedge shape using a water-jet cutting device at a company.
  - Highly pressurized water injected onto the tile through a small needle.
  - Needle moving speed and water pressure optimized.
  - Make full use of hydrophobic feature of aerogels.

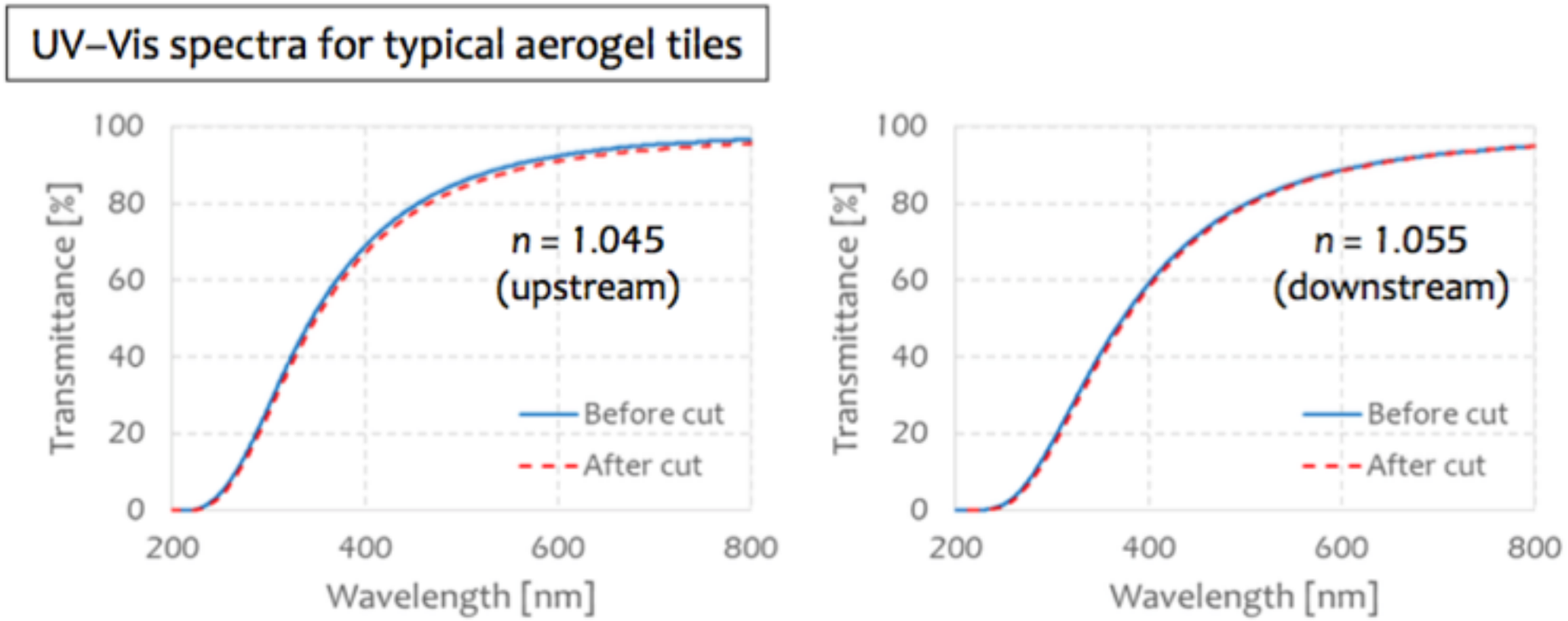






Tile Machining (2)

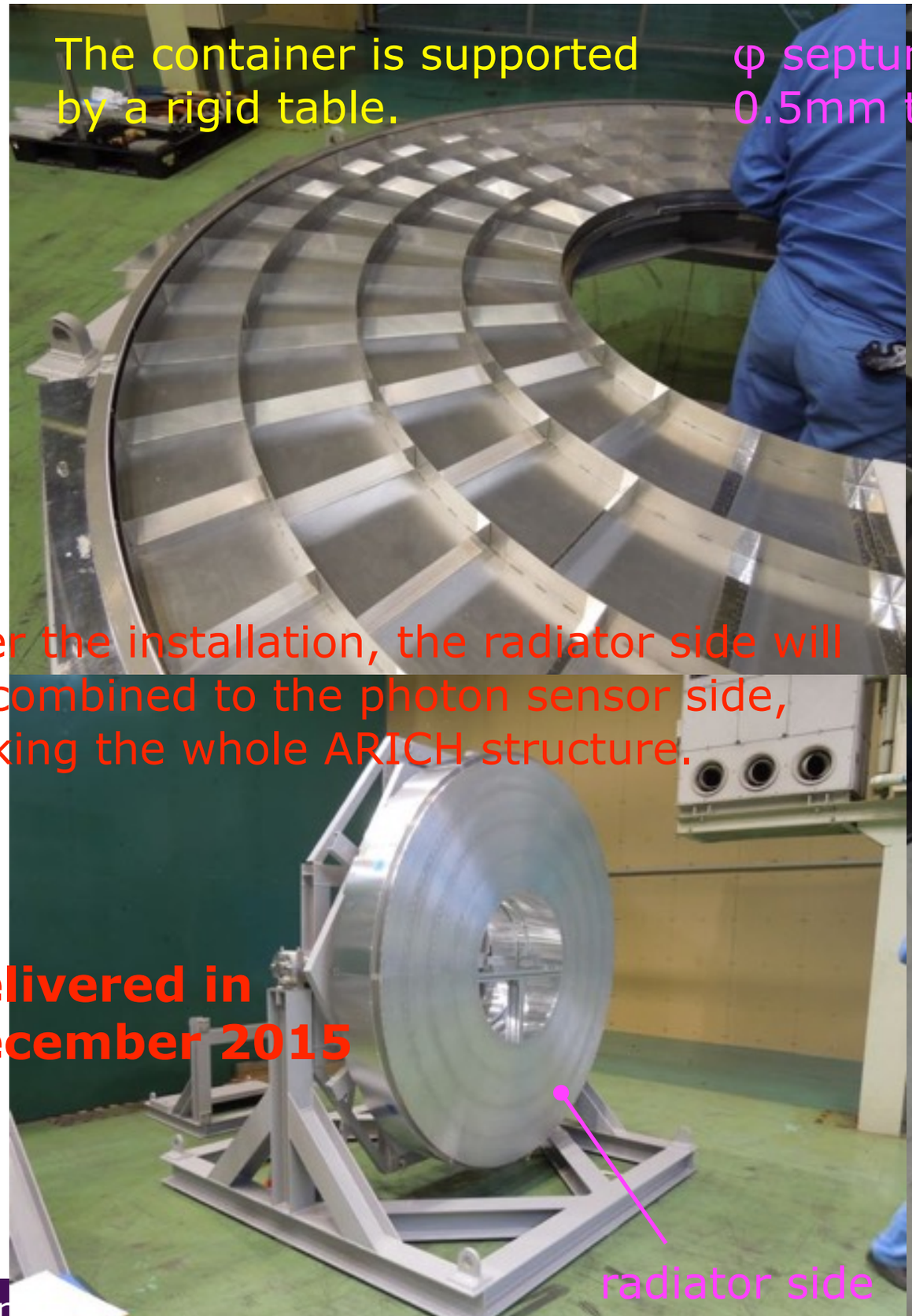
Very small degradations in transparency due to this machining

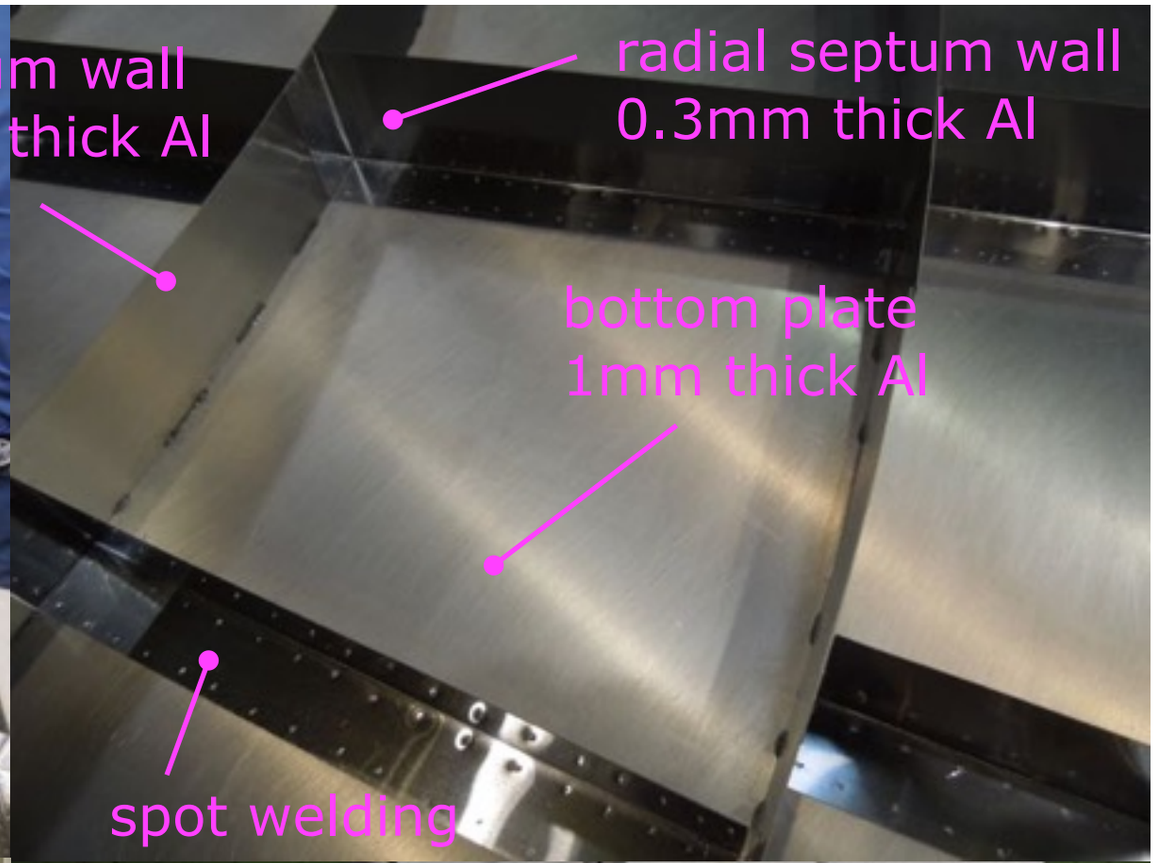


Small chips found in some tiles

If missing area > 0.4 % w.r.t. whole surface (~1.0 cm^2), the sample is removed from candidates.

Radiator Container

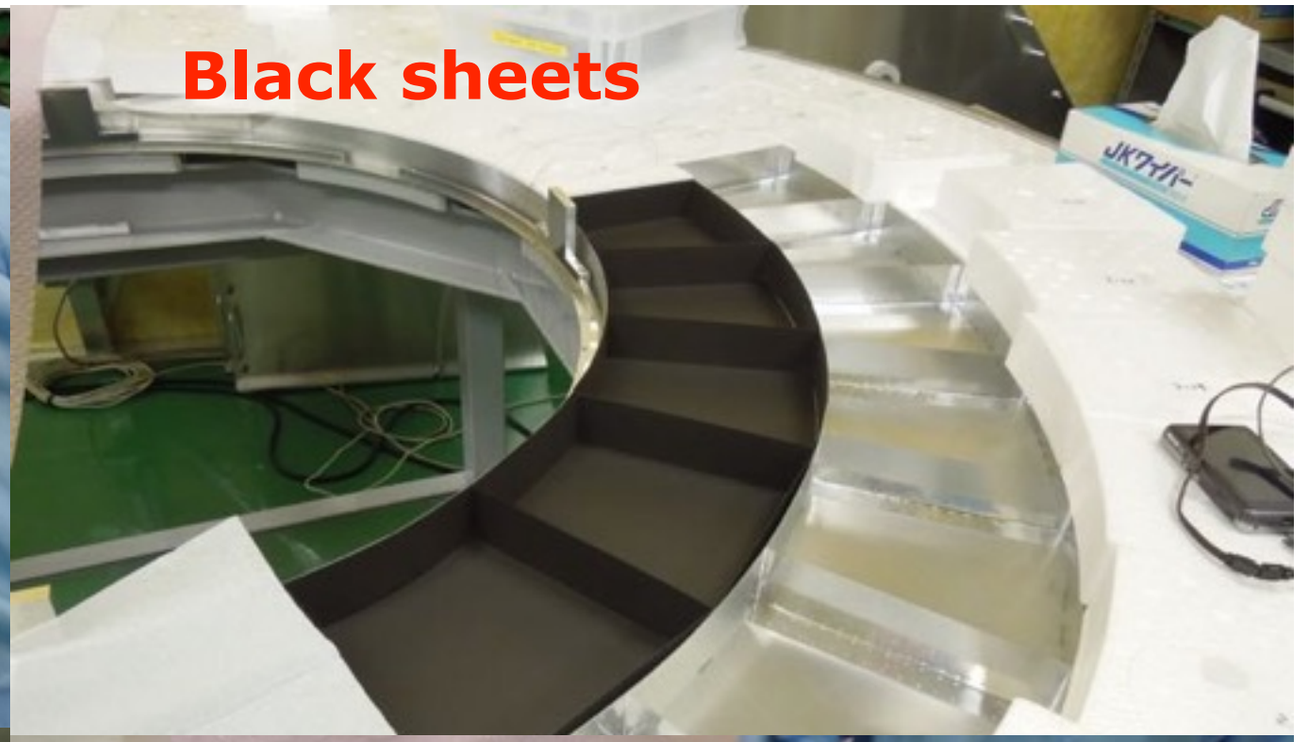


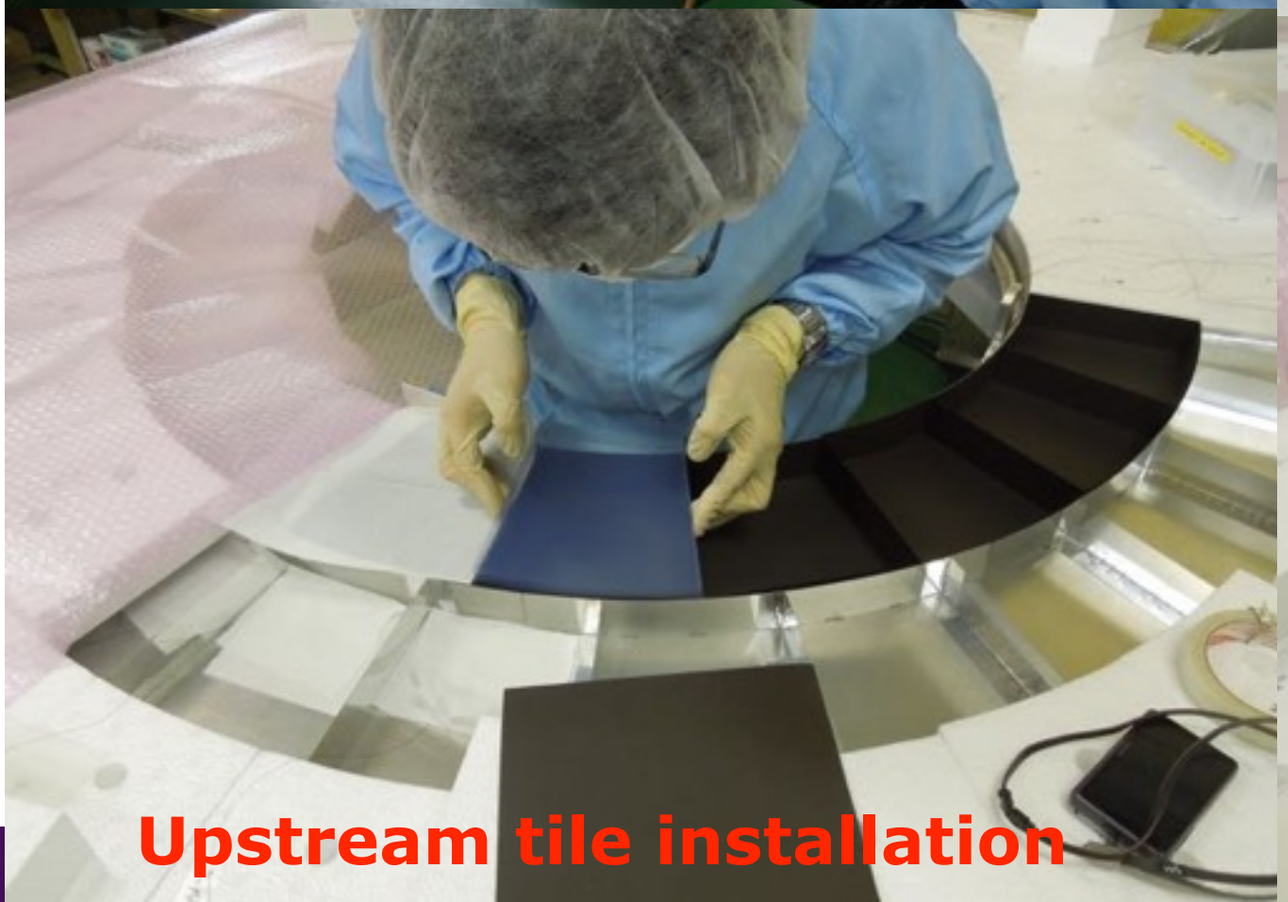


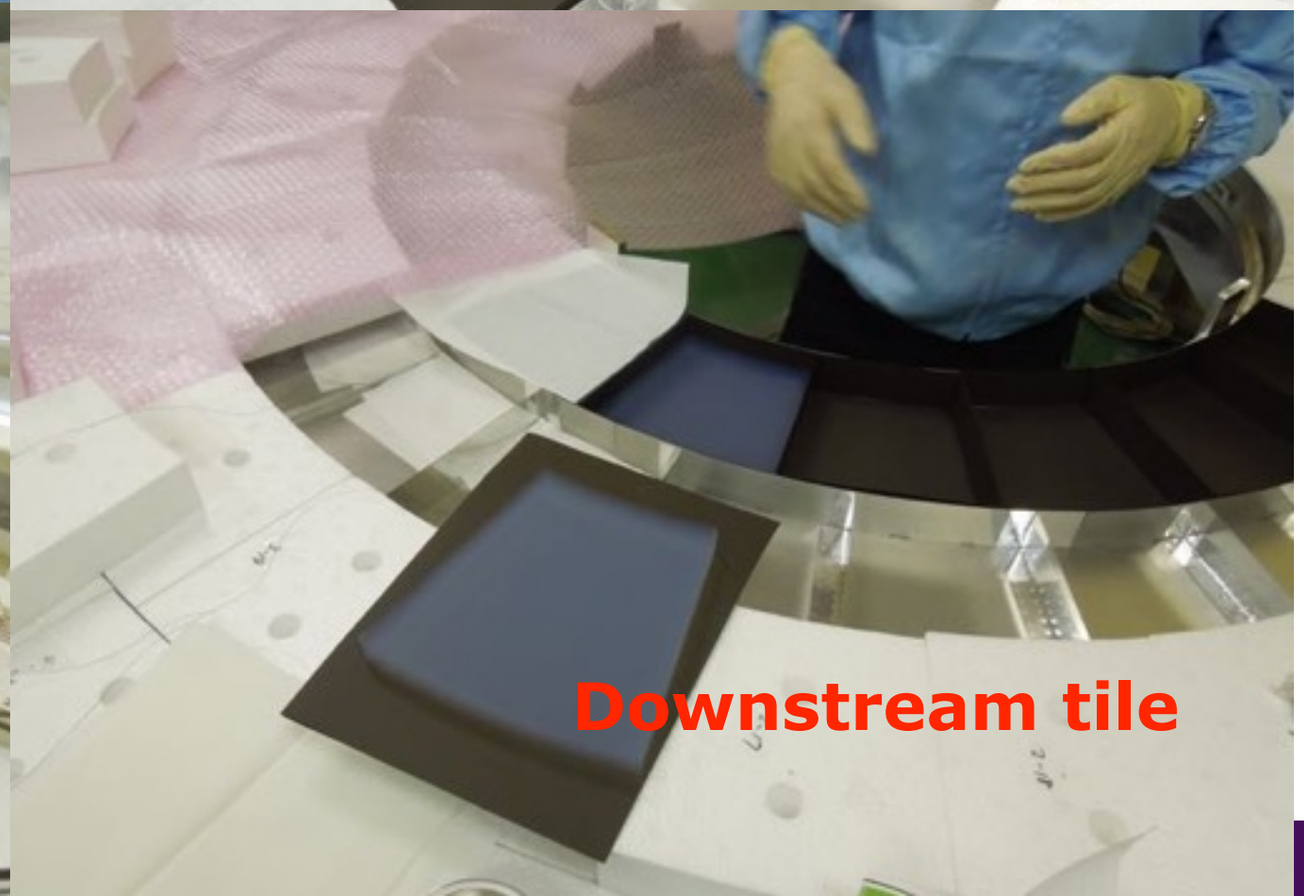
After the installation, the radiator side will be combined to the photon sensor side, making the whole ARICH structure.

Delivered in December 2015

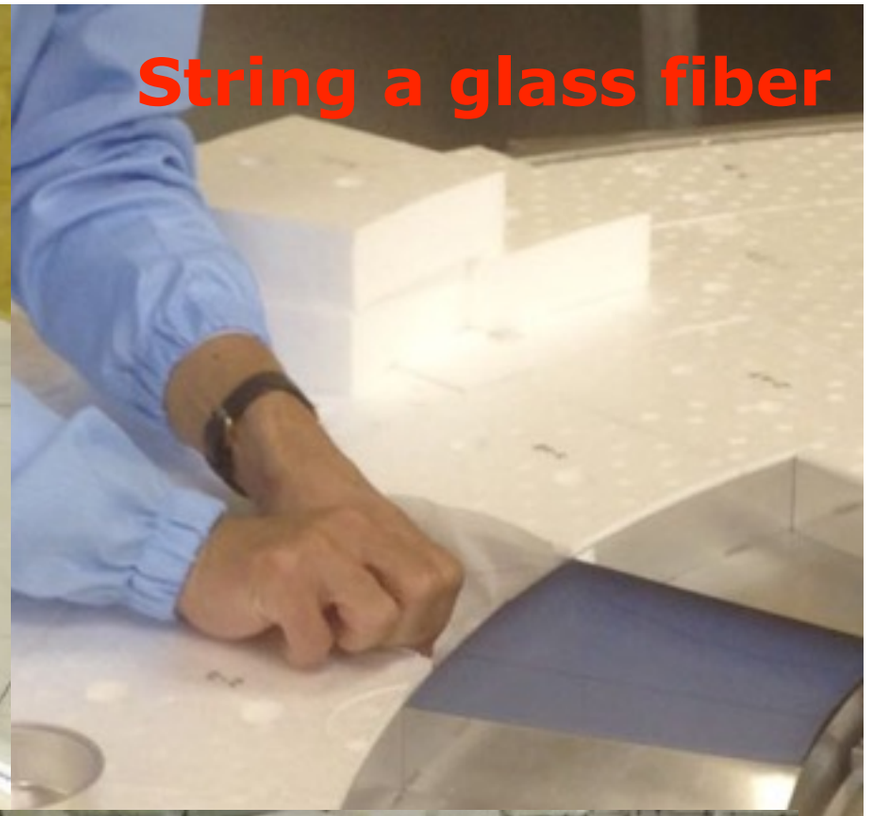
Tile Installation (1)

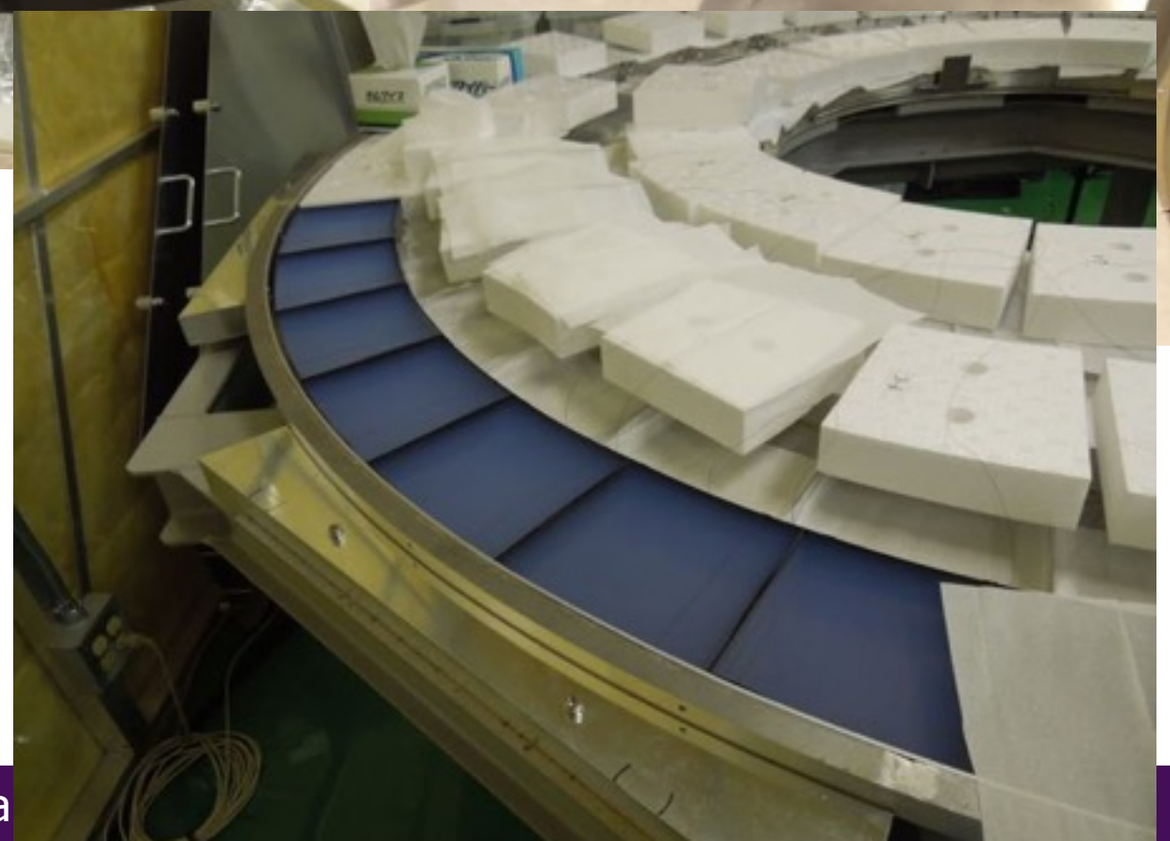






Tile Installation (2)





Installation is now underway.

Summary

- **Silica aerogel radiators for the Belle II ARICH** have been **successfully produced** in September 2013 - May 2014.

- **Optical properties** for aerogel tiles from mass production were examined, and we found **aerogel qualities are high enough** to be used as ARICH radiator.

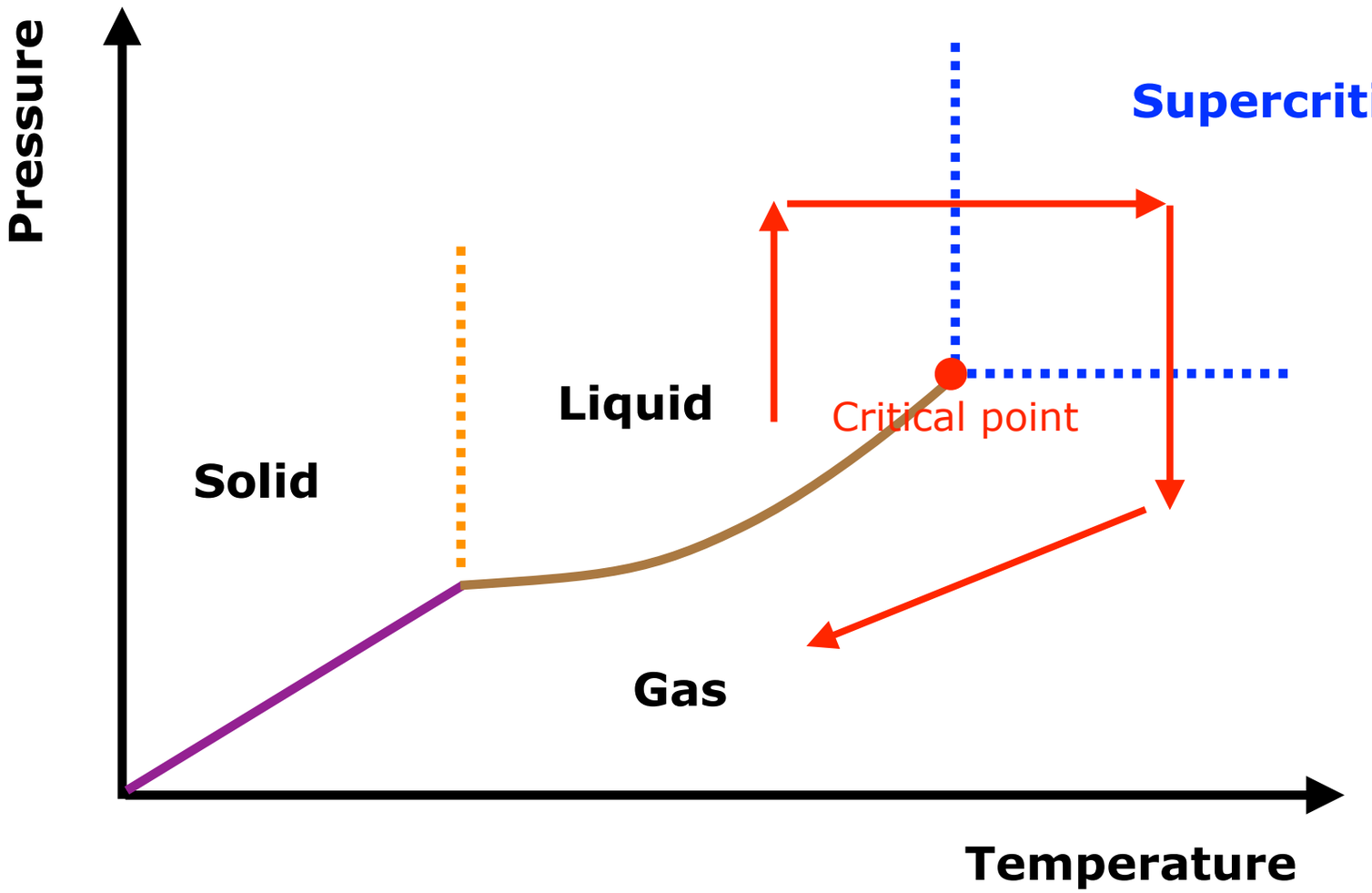
- Machining using a water-jet device has been done to make wedge shaped tiles **without degrading optical properties**.

- **Mechanical container for the radiator** has been **built and delivered** in 2015.

- Installation into the mechanical structure has started.
  - **65 % tiles have been already installed**.
  - It will be completed in a month or so.

Supercritical Drying

Phase diagram



Drying through supercritical region, instead of passing through liquid-gas boundary.