Recent Progress in Silica Aerogel Cherenkov Radiator

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TIPP 2011 in Chicago

Overview

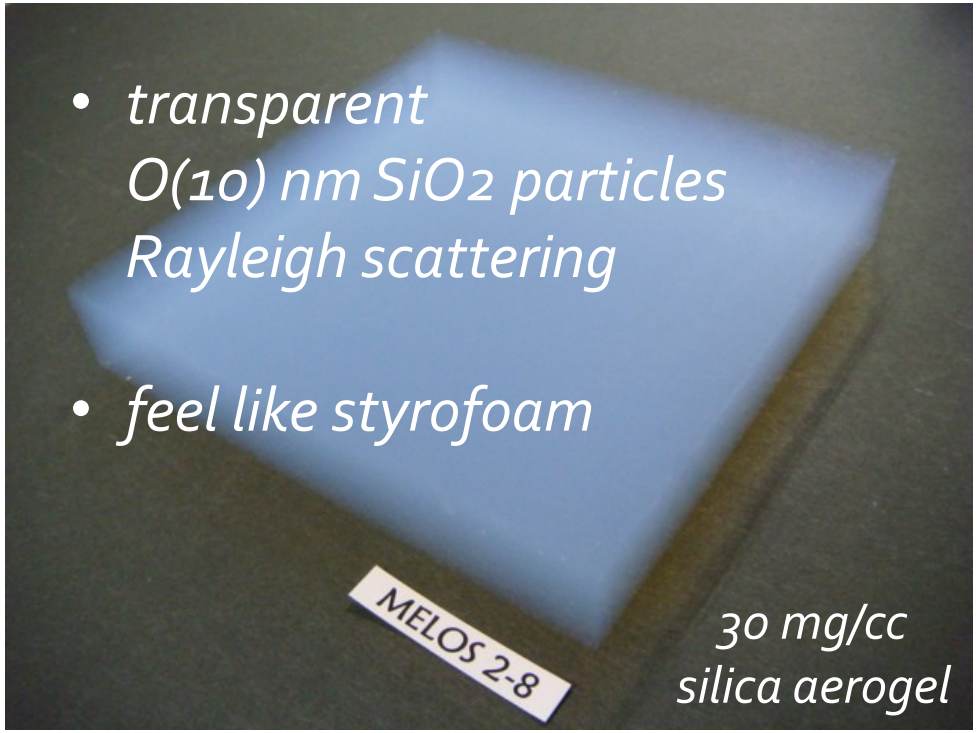
- *Introduction to Silica Aerogel*
- *Novel Pin-drying Production Method of Silica Aerogel*
- *Optical Performance of New Silica Aerogel*
- *Summary*

Introduction

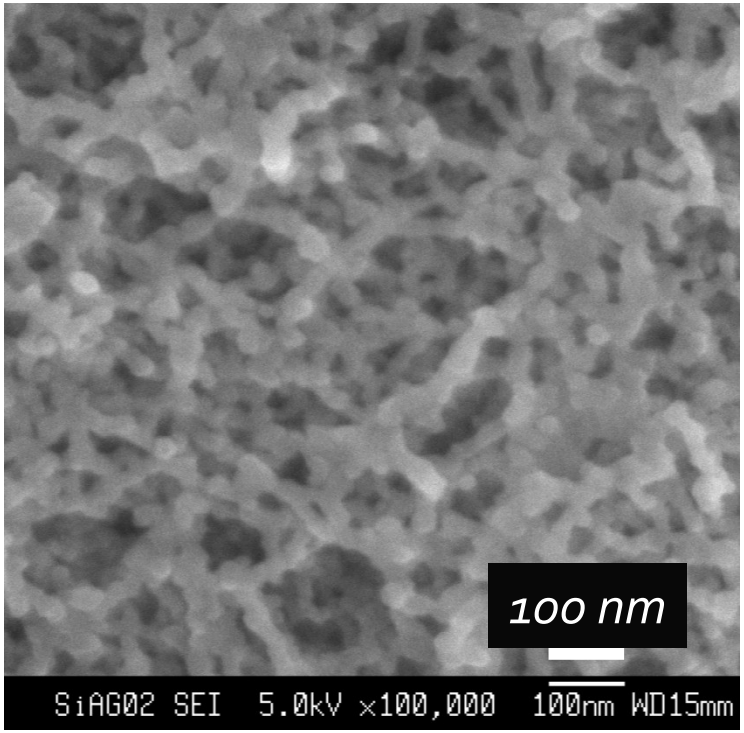
Silica Aerogel

Silica aerogel is a 3D structural solid of SiO2 particles.

- *porous (>99% air)*
  low bulk density
  thermal insulator



Scanning electron microscope image
10 mg/cc silica aerogel
(magnification: x 100,000)

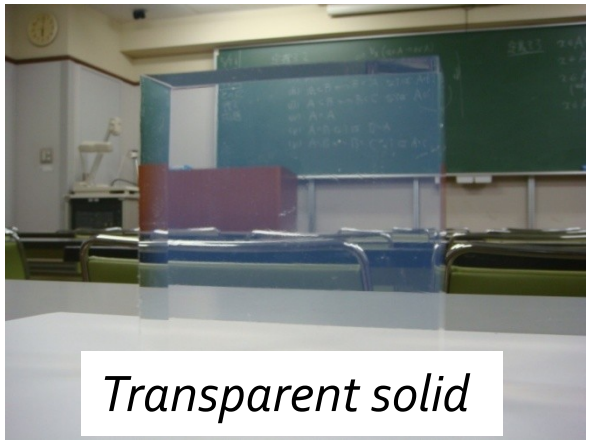


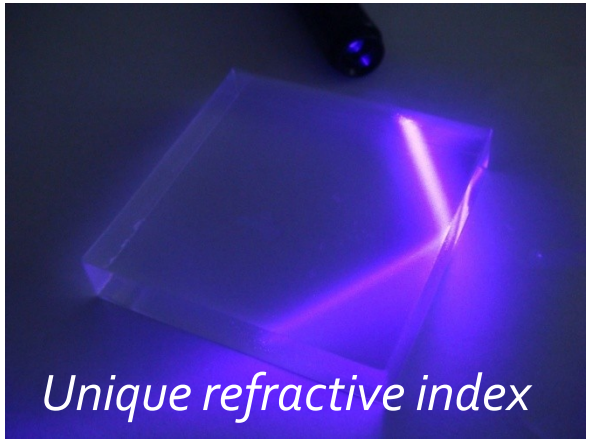
Applications

Silica aerogel is the most convenient material for Cherenkov radiator (typically n ~ 1.03).

ex) Aerogel Cherenkov counters

- *TASSO @DESY*
  n = 1.024 for π / K / p separation
  Discovery of gluon
- *Belle @KEK*
  n = 1.01-1.03 for π / K separation
  Discovery of CP violation in B system
- *LHCb @CERN*
  n = 1.03 for π / K / p separation
  Ring imaging Cherenkov counter



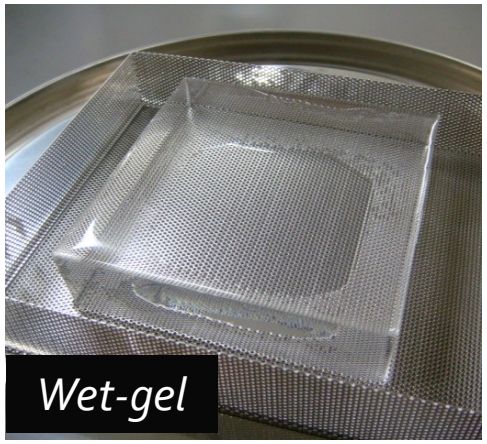


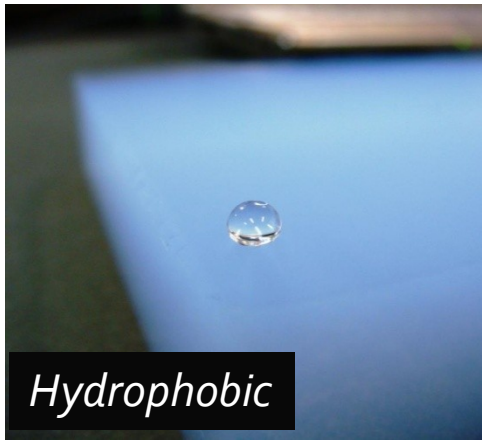
Conventional Production Method

Refractive index (density) can be controlled in the sol-gel step.

1st method: Single-step method
2nd method: Two-step method ← world standard
3rd method: KEK method ← our original

1. *Wet-gel synthesis (sol-gel step)*
   We have various preparation recipes for chemicals.
2. *Aging*
3. *Hydrophobic treatment ← our original*
4. *CO_2 supercritical drying* *1 month in total*

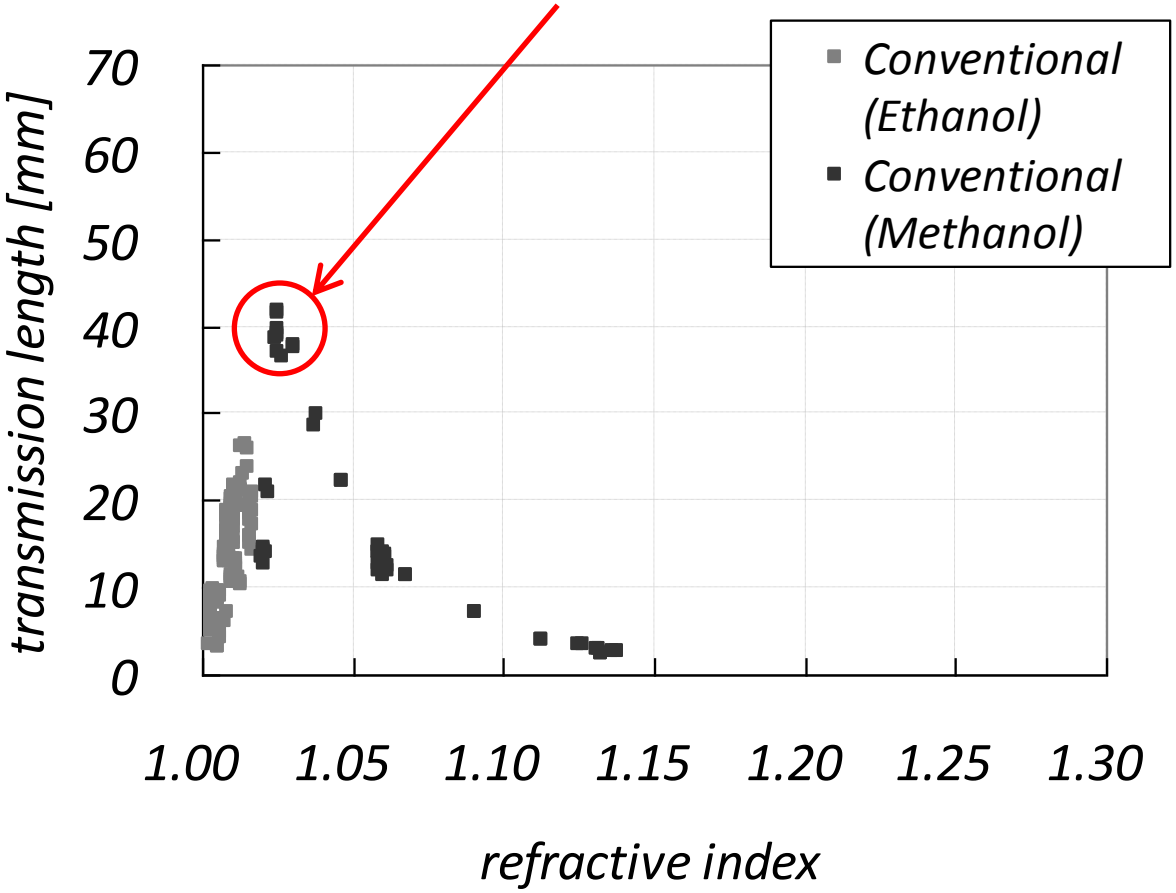




extract liquid component of wet-gel through supercritical drying

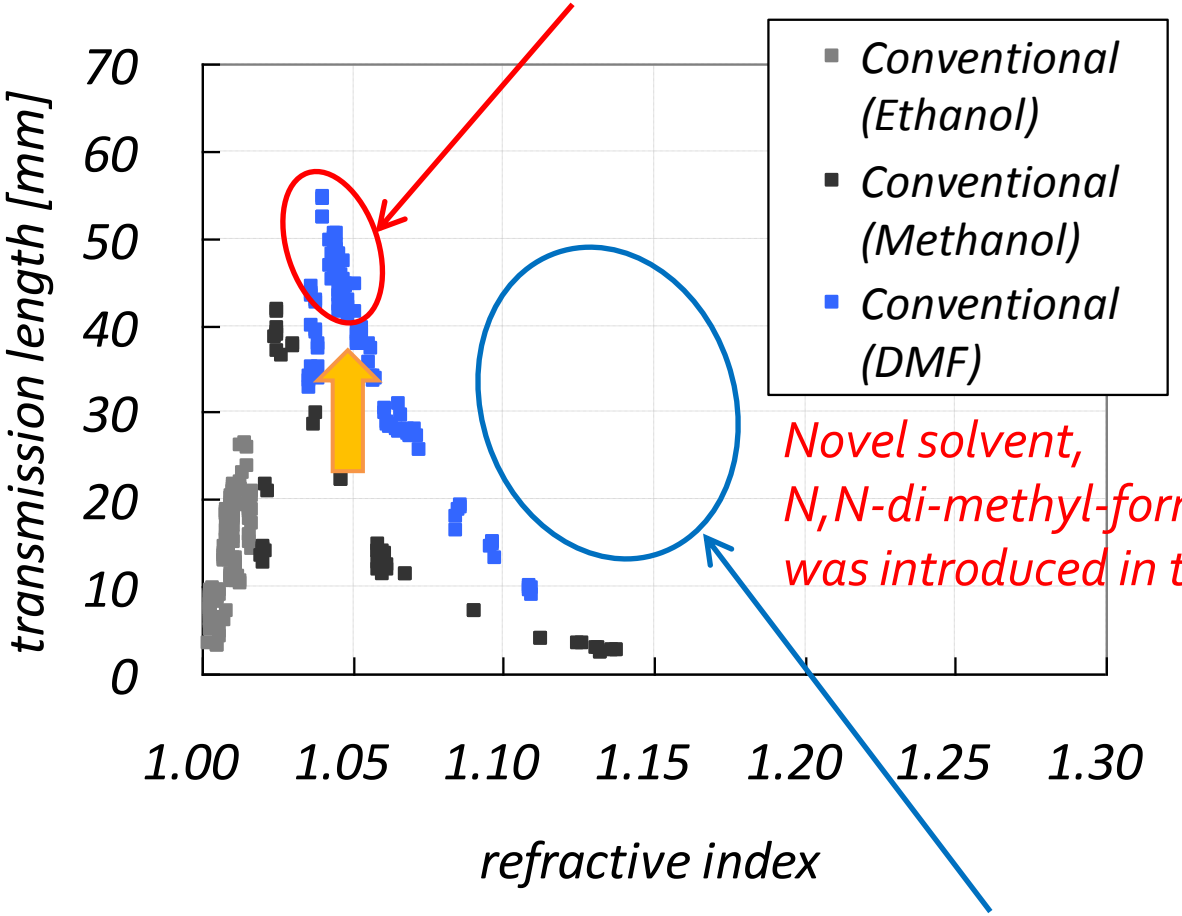
Our First Step in 1990s

Λ = 40 mm at n = 1.025 was obtained in the conventional method using alcohol solvent in 1990s.



Improvement of Transparency in 2004

The transmission length was improved in n ~ 1.04 in 2004.



Further efforts are needed in higher refractive index range.

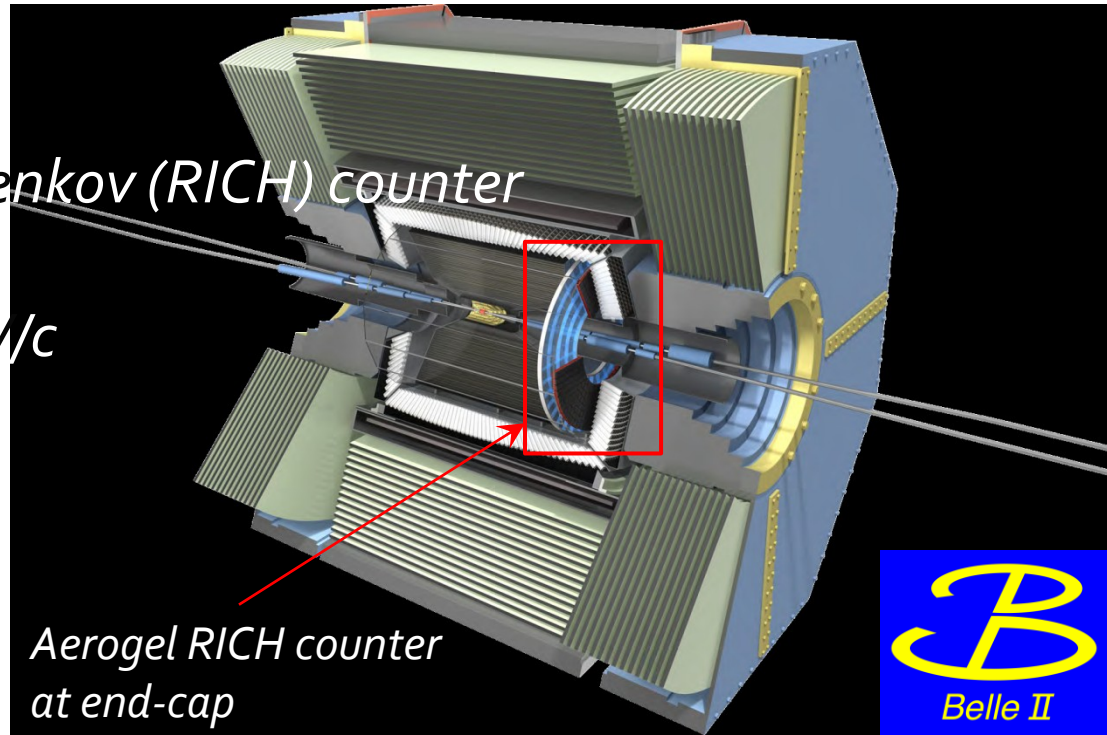
Further Requirements

"High refractive index with high transparency" is a trend of recent aerogel development.

- *Hadron experiments at J-PARC*
  Threshold Cherenkov counter with aerogel
  n = 1.12-1.25
  K / p separation at 1-2 GeV/c

- *Belle II at SuperKEKB*
  Aerogel Ring imaging Cherenkov (RICH) counter
  n = 1.05-1.06 (Λ > 40 mm)
  π / K separation up to 4 GeV/c

Our studies will open up further opportunities to employ aerogel in Cherenkov counters.



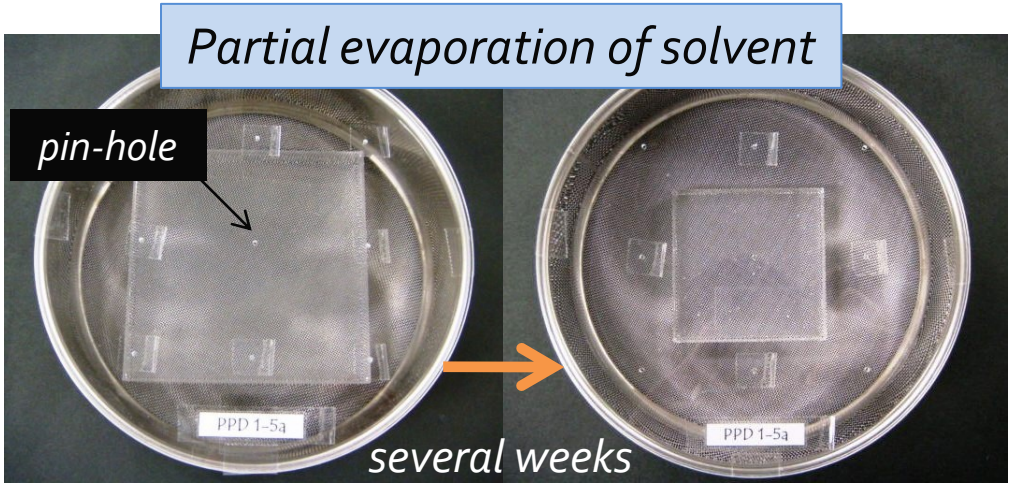
Novel Pin-drying Production Method

Pin-drying Production Method

Pin-drying (PD) method is 4th method to produce aerogel with high refractive index.

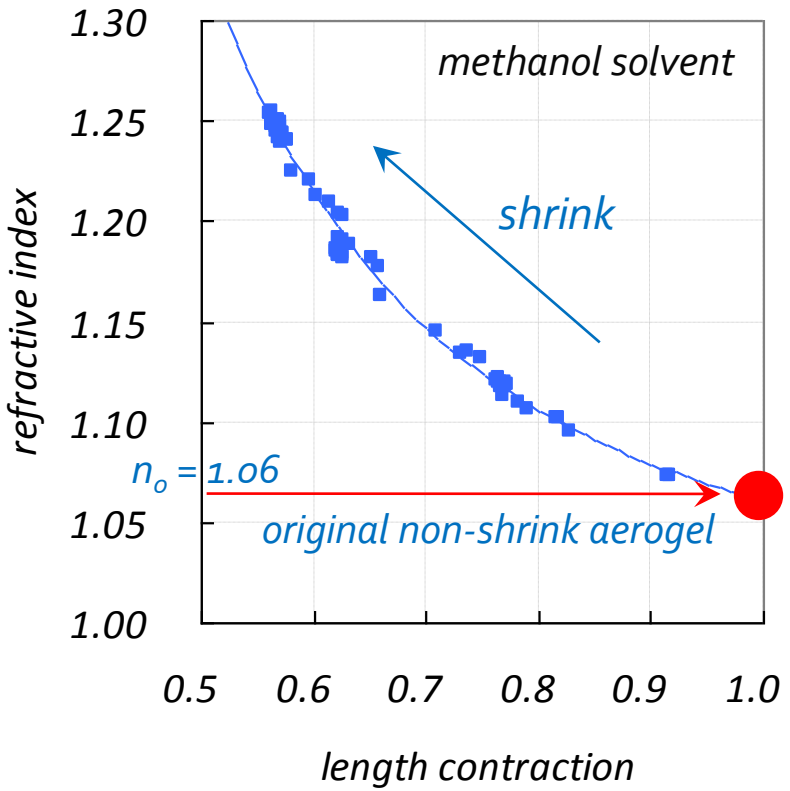
1. *Wet-gel synthesis (1st density control)*
2. *Aging*
3. *Pin-drying (2nd density control)*

need additional time for the pin-drying process



Semi-sealed container with some pin-holes

4. *Hydrophobic treatment*
5. *CO_2 supercritical drying*



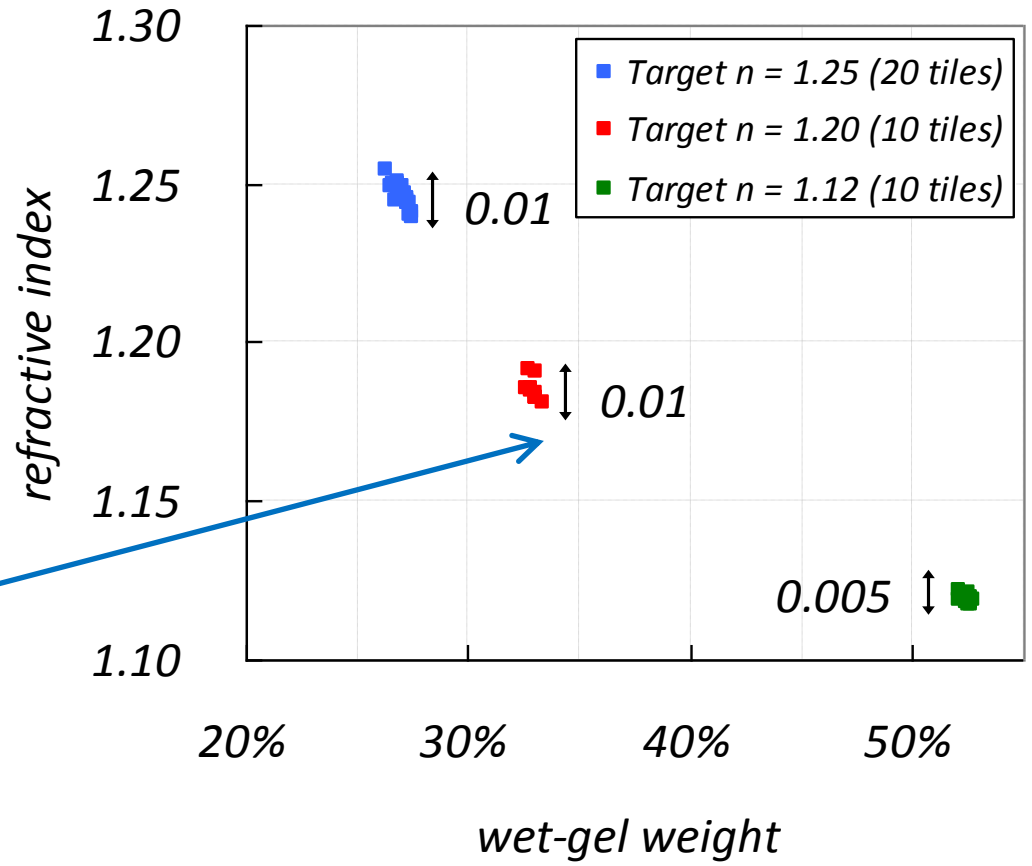
Reproducibility in PD Method

Target refractive index is well-controlled by monitoring wet-gel weight.

40 tiles were produced for n = 1.25, 1.20 and 1.12.

(Wet-gels were synthesized for n_o = 1.06 using methanol solvent.)

Refractive index fluctuations were evaluated at each target index.



Large Tile Production

Large tiles were produced w/o any cracks w/ keeping optical performance.

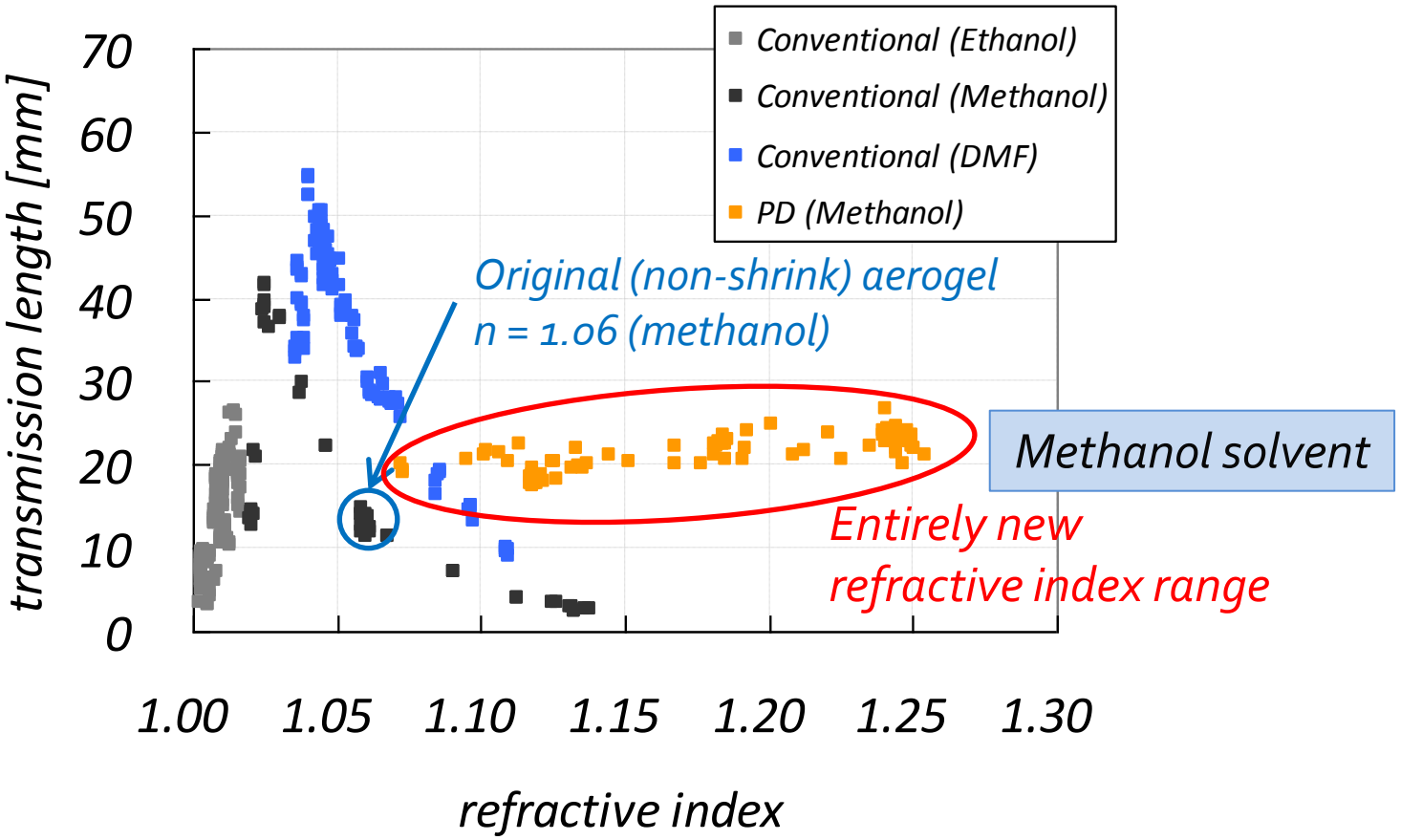
n ~ 1.05-1.06

- *Conventional method: 11 × 11 × 2 cm³ → 18 × 18 × 2 cm³*
- *PD method: 9 × 9 × 2 cm³ → 14 × 14 × 2 cm³*

Optical Performance

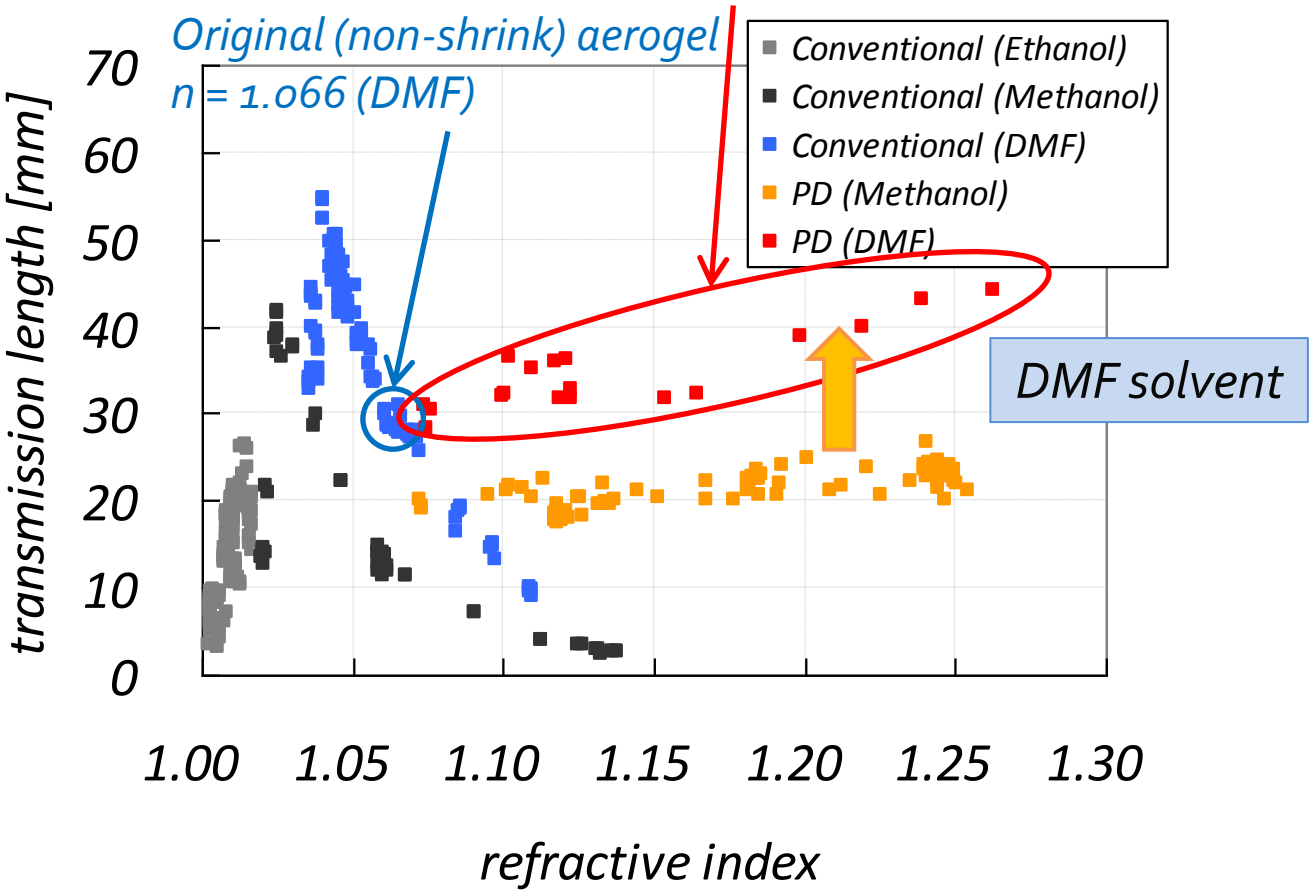
Expansion of High Index Range in 2005

Ultra-high refractive index (n > 1.10) aerogels with sufficient transparency (Λ > 20 mm) were developed.



Improvement of Transparency in 2008

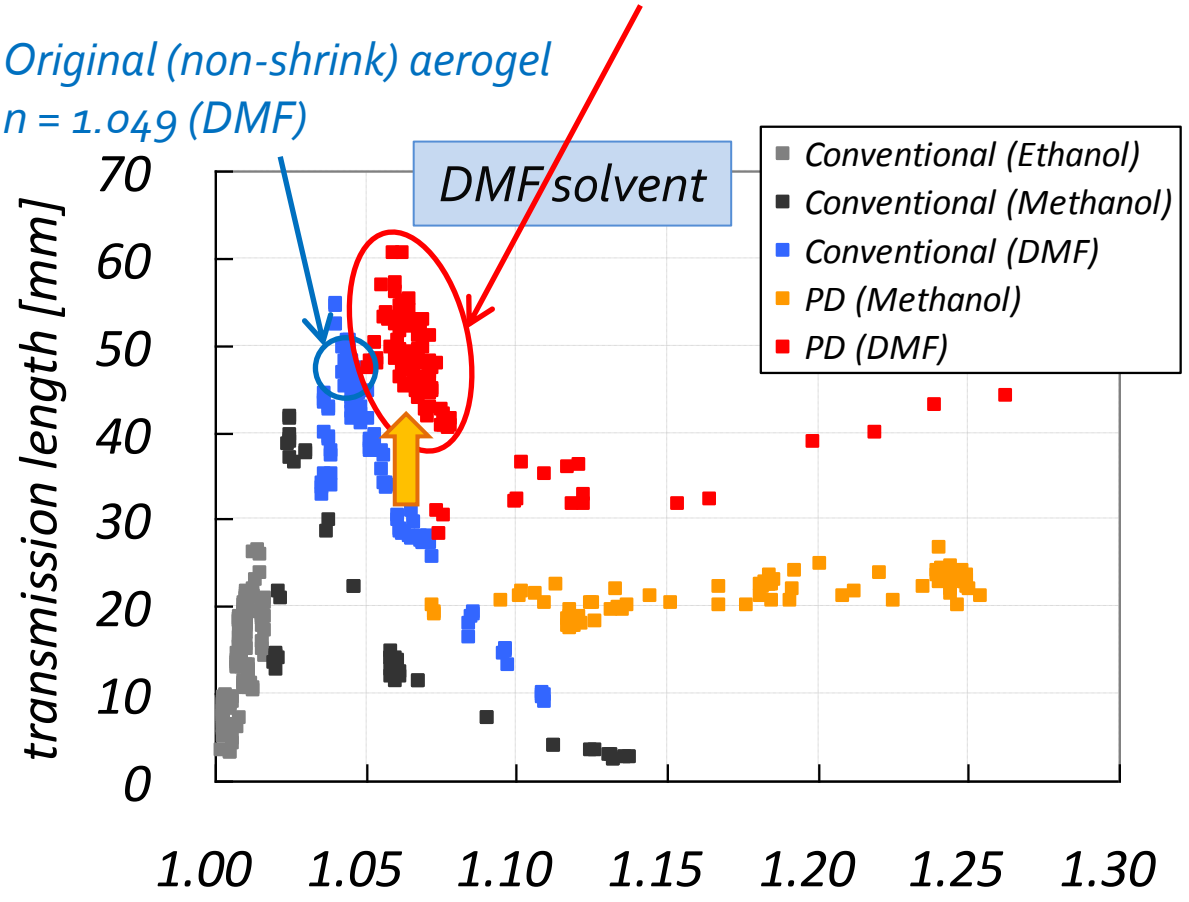
The transmission length was improved in n > 1.10.



It takes long pin-drying process because DMF is difficult to evaporate.

The Most Transparent Sample in 2008

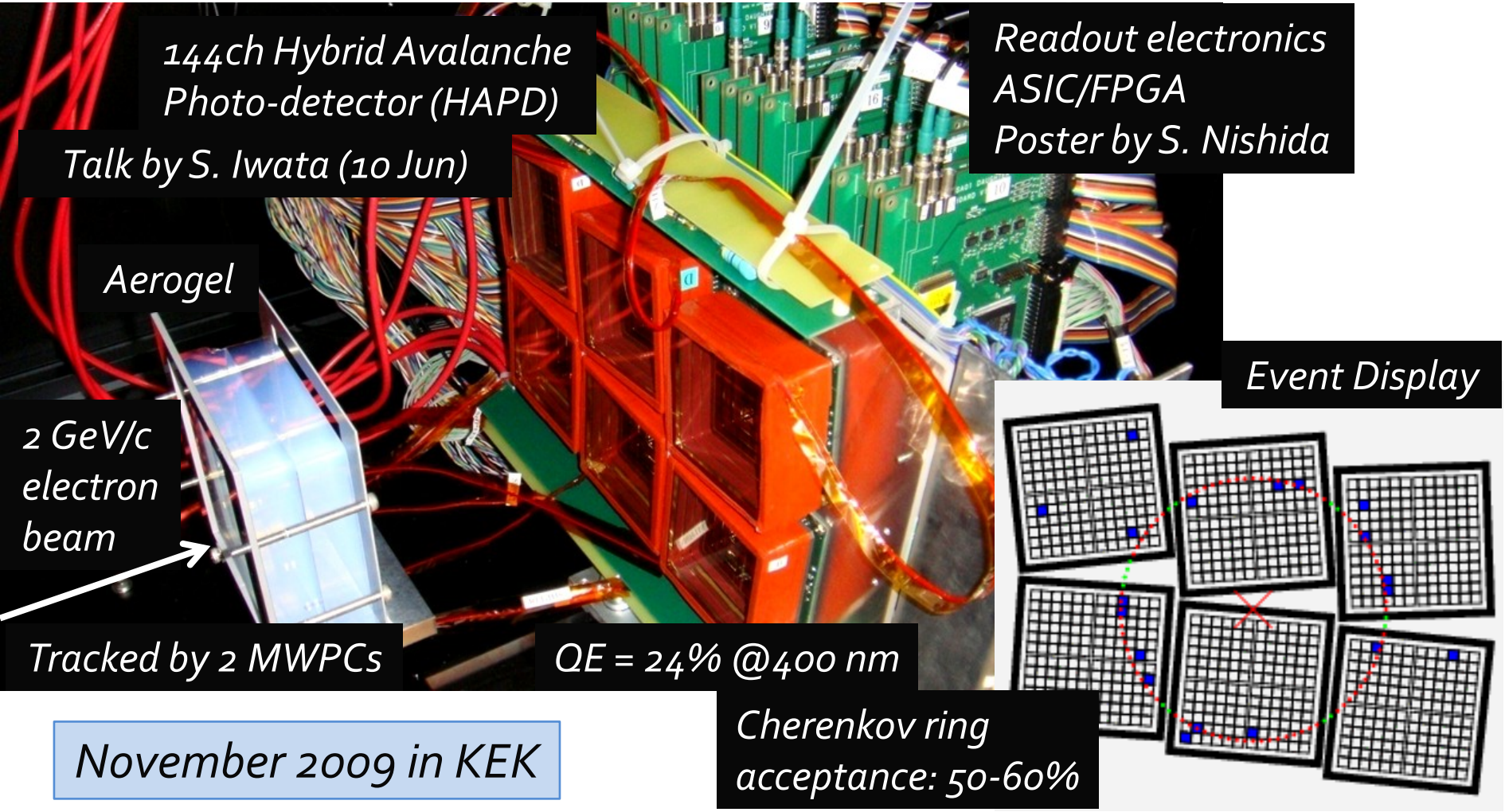
The highest transparency (Λ > 50 mm) was obtained in n ~ 1.06.



1.003 < n < 1.26 available

Beam Test Set Up

To evaluate aerogel, proximity RICH counter was used.



November 2009 in KEK

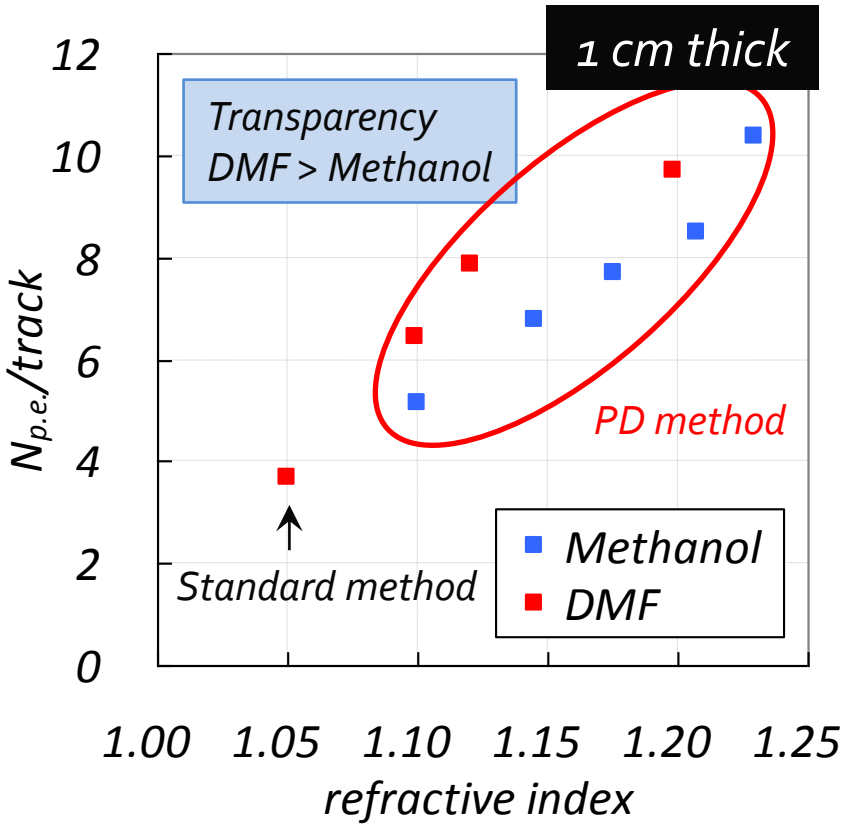
Photoelectron Yield

Sufficient photoelectrons were detected.

- $n = 1.05 + 1.06$, 2 cm thick each (total 4 cm thick)
  $N_{p.e.} = 10.6$ (conventional) → 13.6 (improved)
  60% ring acceptance

- $1.10 < n < 1.23$
  1 cm thick each
  $N_{p.e.} = 5\text{-}10$ (new data)
  50% ring acceptance

Clear Cherenkov rings were observed.



Summary

- *The novel pin-drying method was developed and studied in detail as the 4th technique to produce silica aerogel with high refractive index and high transparency.*
- *Large aerogel tiles with n ~ 1.05 and good transparency were successfully manufactured without any cracks.*
- *Sufficient photoelectrons were detected in the beam test. We confirmed our aerogel has excellent performance.*

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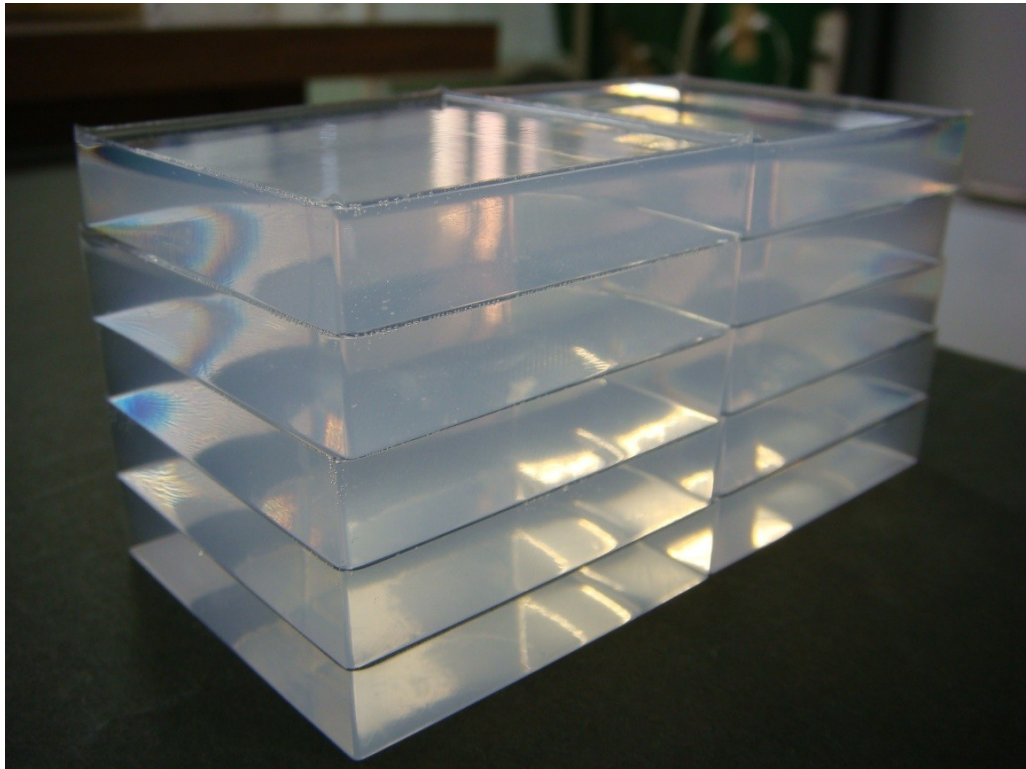
and Belle II ARICH Group



Appendix

Hydrophobic Treatment

Aged wet-gels are immersed in ethanol.
Hydrophobic reagent is added to ethanol.
The following reaction proceeds.

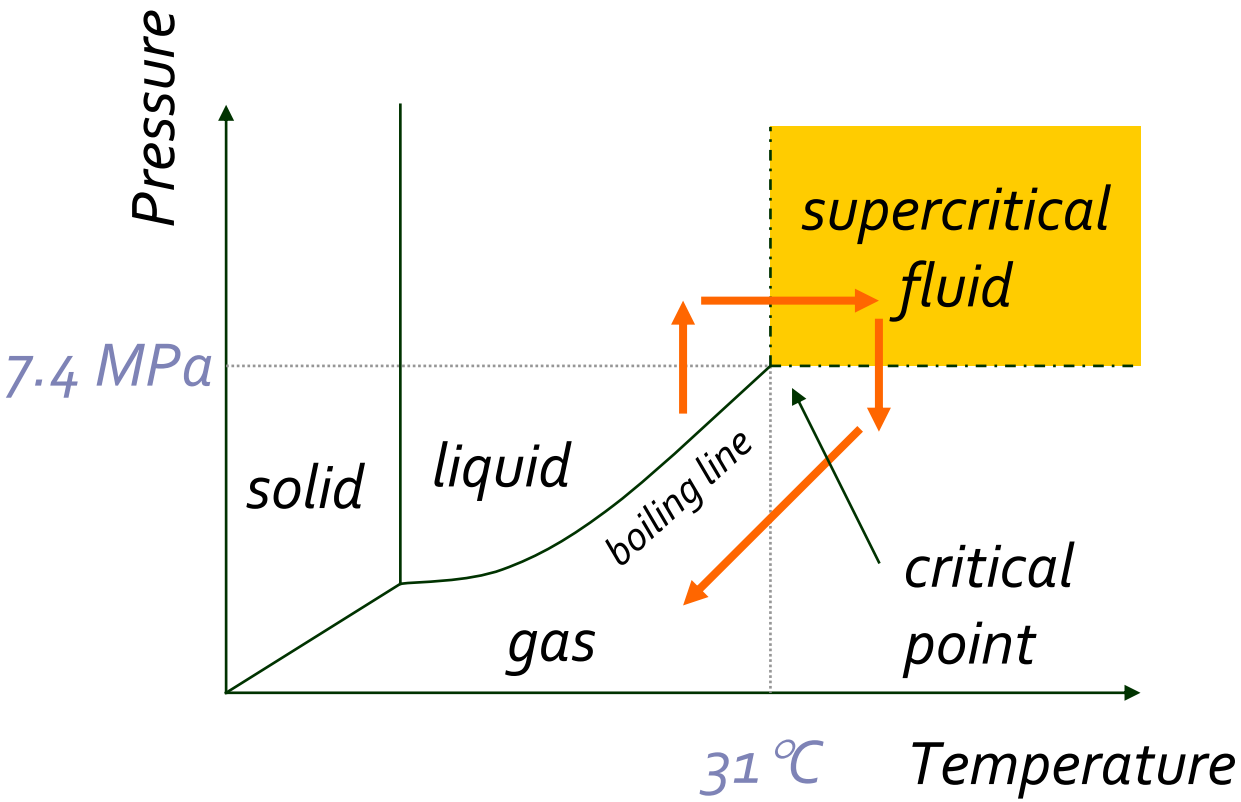
Hydrophobic reagent: hexamethyldisilazane $((CH_3)_3Si)_2NH$

$$2(-OH) + ((CH_3)_3Si)_2NH \rightarrow 2(-OSi(CH_3)_3) + NH_3$$

Hydroxyl group (hydrophilic)

Trimethylsiloxy group (hydrophobic)

CO_2 Supercritical Drying

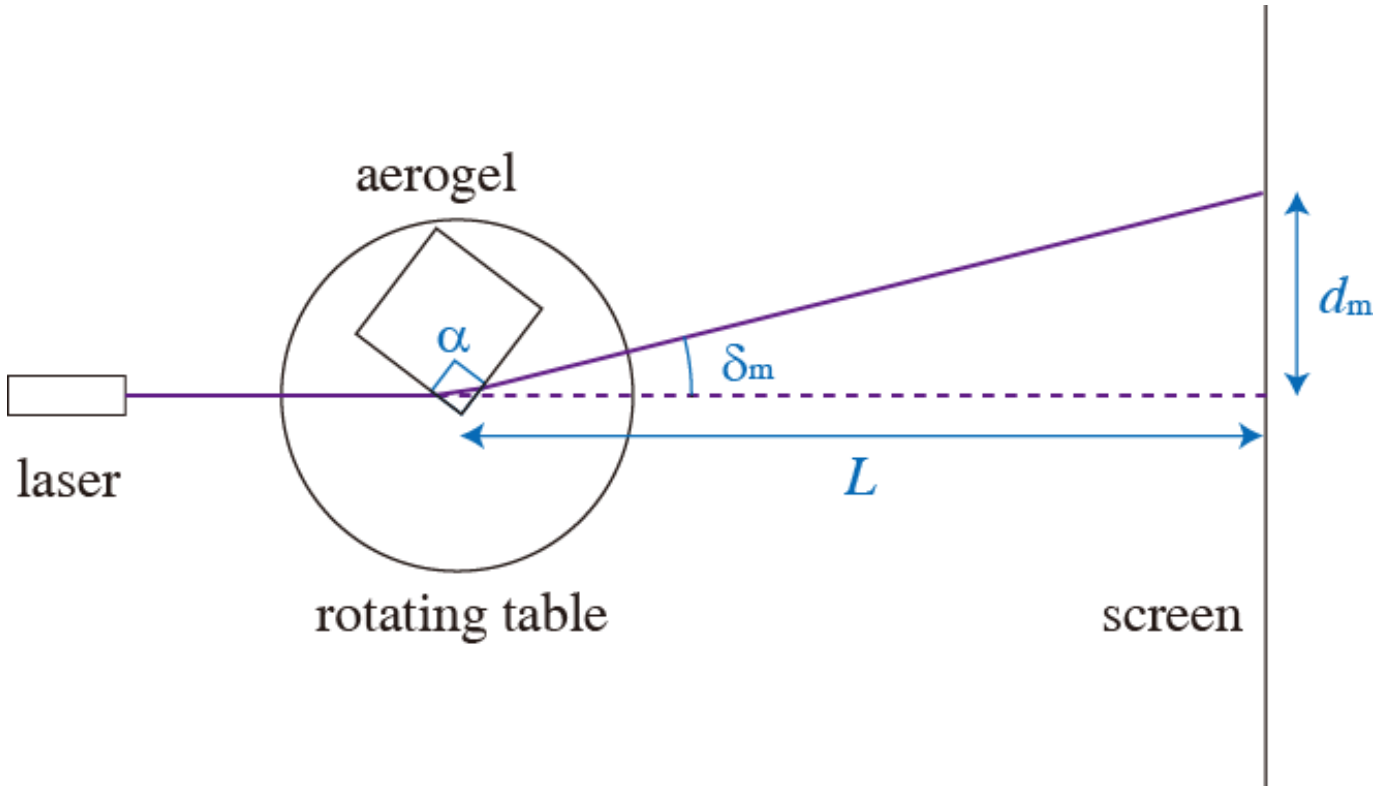


CO_2 phase diagram

Refractive Index Measurement

Refractive index is measured by Fraunhofer method using 405nm blue-violet semiconductor laser.

Prism formula: $n/n_{air} = \sin\{(\alpha+\delta_m)/2\}/\sin(\alpha/2)$, $\delta_m = \tan^{-1}(d_m/L)$



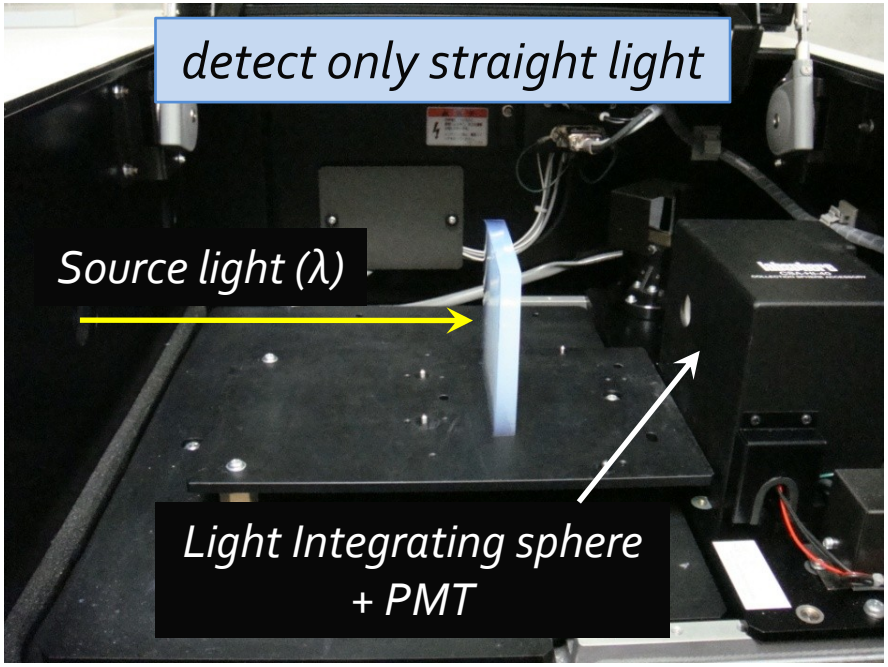
Transmittance Measurement

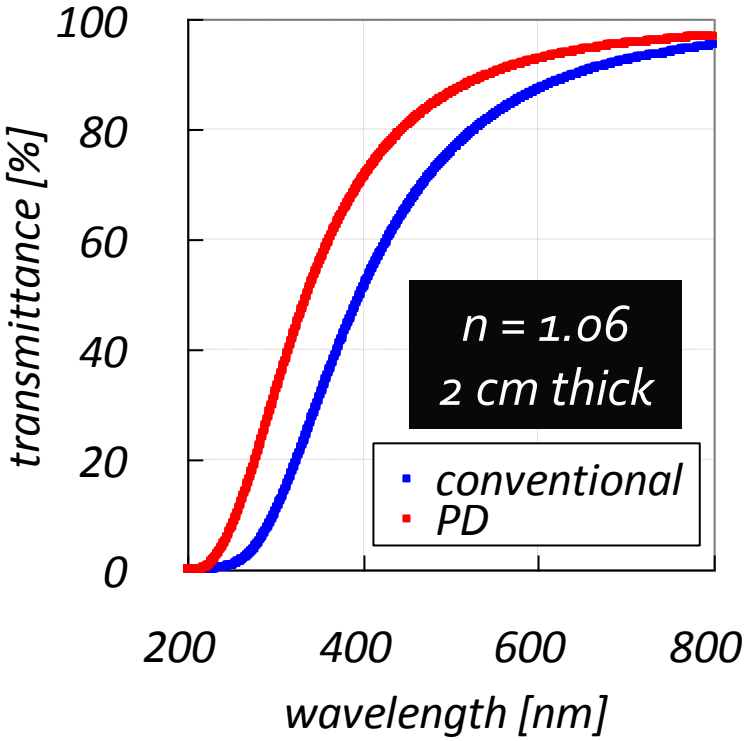
Transmittance (T) is measured by a spectrophotometer.

$T=Aexp(-Ct/\lambda^4)$ *A, C: clarity parameters, t: thickness of aerogel*

We evaluate the transmission length at λ = 400 nm:

$\Lambda = -t/\ln T.$



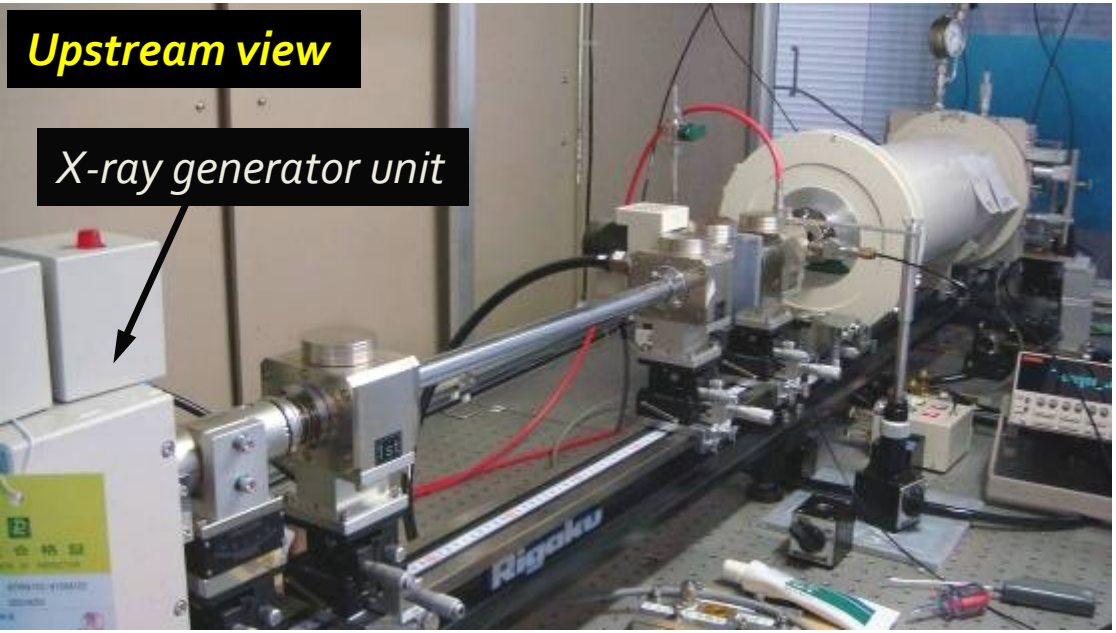


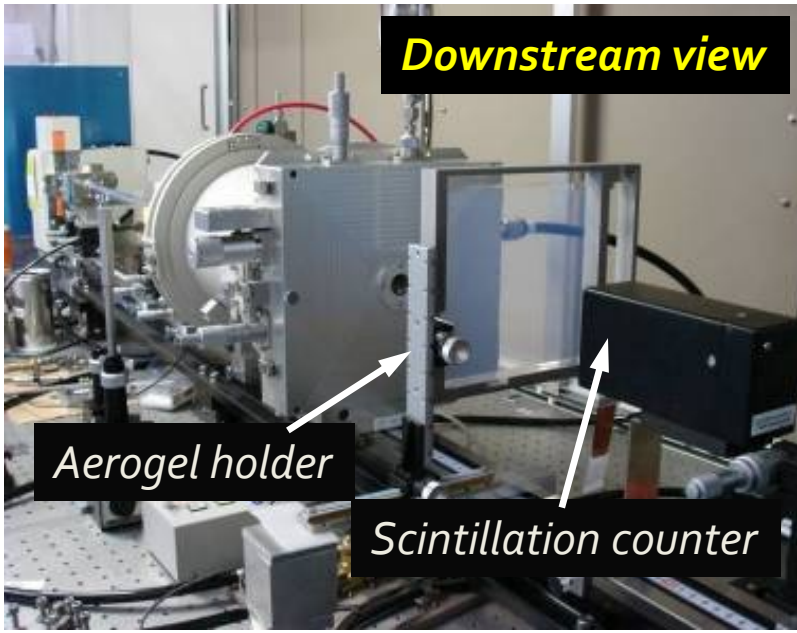
Refractive Index Uniformity Measurement

X-rays are the most promising probe to evaluate density (ρ) uniformity in a aerogel tile.

Density measurement means refractive index measurement:

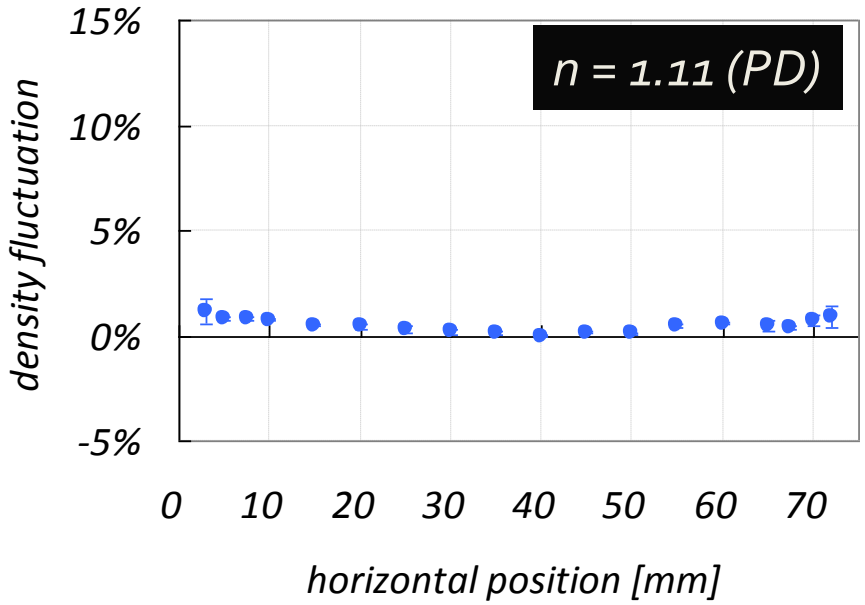
$$n = 1+\alpha\rho \qquad \alpha = const.$$

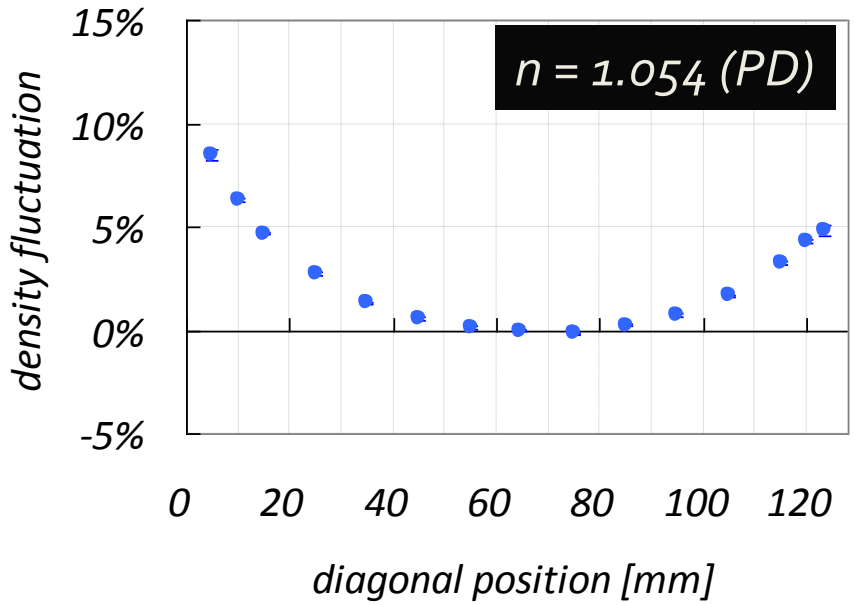




Refractive Index Uniformity Data

Tile scan data along diagonal (or horizontal) line of a tile.
X-ray beam size is ~1 mm in diameter.





length contraction = 78%

length contraction = 95%

Pin-drying Process

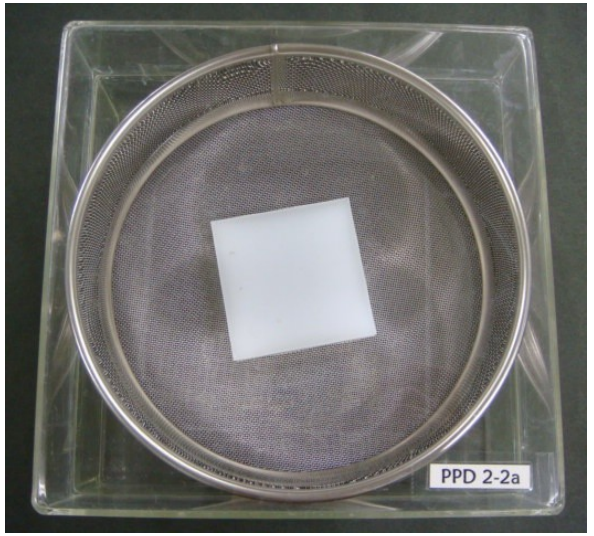
- *Standard 1 month + pin-drying process*
  The length of the pin-drying process depends on
  - *Initial and target refractive index*
  - *Solvent (methanol(fast) or DMF(slow))*
  - *Size*

- *Example*
  - *Original wet-gel size: 10 × 10 cm², final thick: 1 cm*
    n_o = 1.05 (DMF) → n = 1.065: 1 week
    n_o = 1.06 (methanol) → n = 1.12: 2 weeks
    n_o = 1.06 (methanol) → n = 1.25: 8 weeks

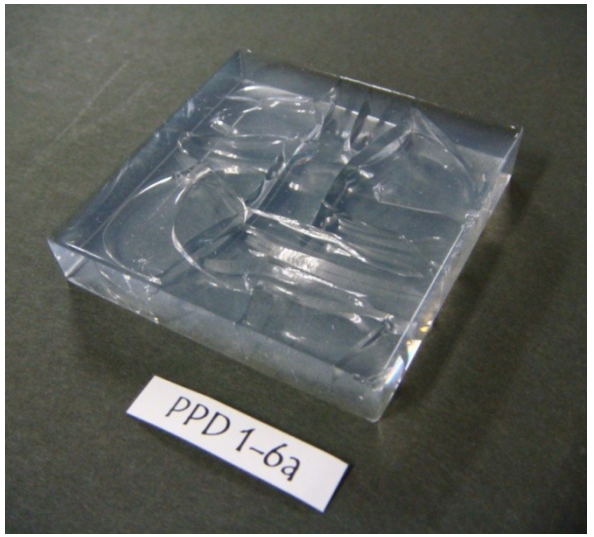
  - *Original wet-gel size: 16 × 16 cm², final thick: 2 cm*
    n_o = 1.05 (DMF) → n = 1.065: 2 weeks

Upper Limit of Pin-drying Method

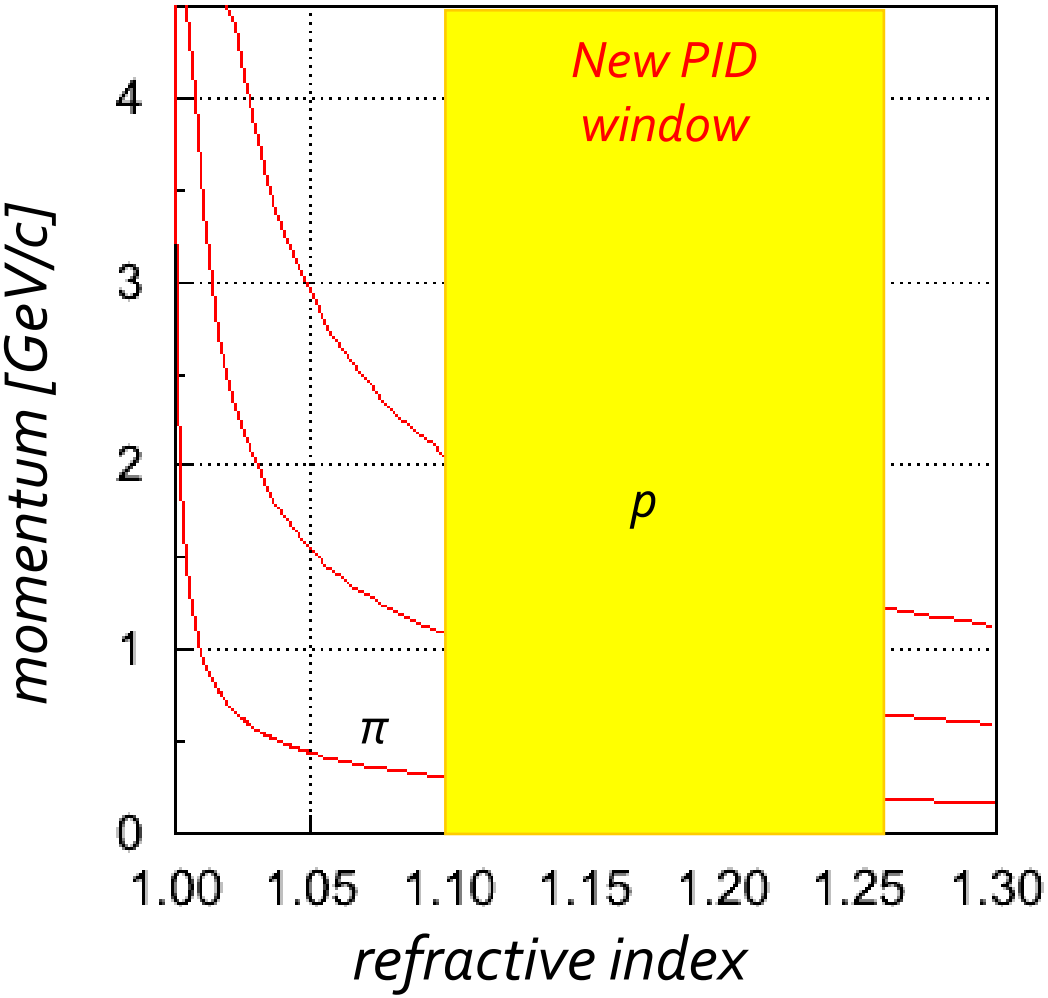
- *Methanol solvent*
  Wet-gels become milky and are broken at $n \sim 1.25$ *in the pin-drying process.*



- *DMF solvent*
  Wet-gels successfully shrink over n = 1.25. However, it is fragile in the hydrophobic treatment and supercritical drying process in $n > 1.20$.



Threshold Momentum



J-PARC Experiments

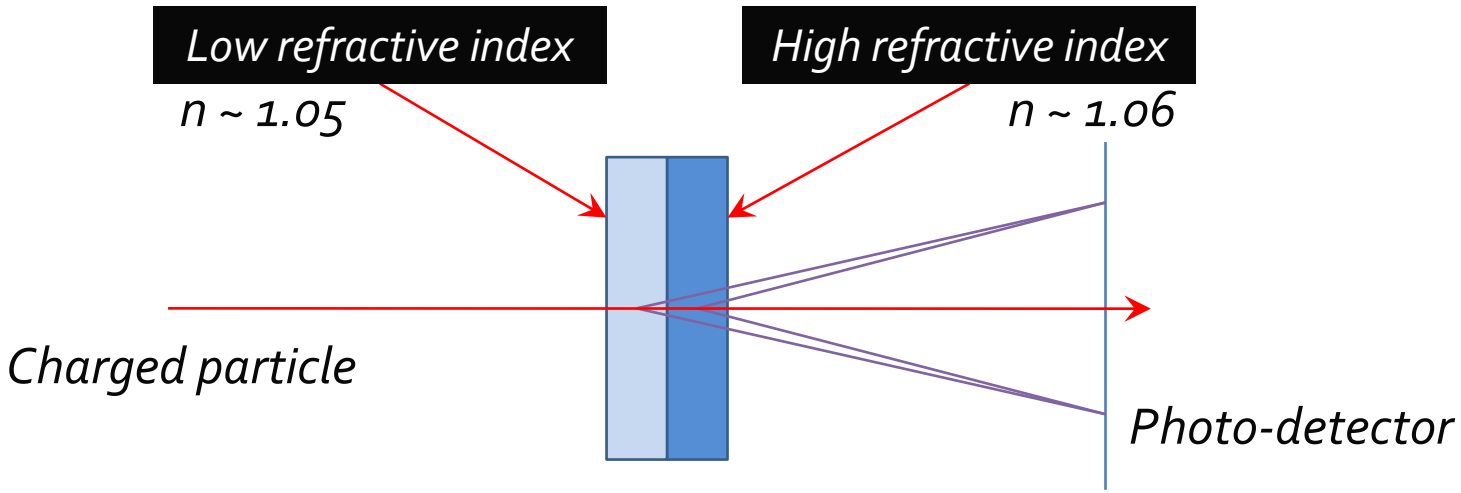
- *E27 (search for K^-pp state)*
  requires n = 1.25 to separate kaons from high momentum protons.

- *E03 (measurement of Xi^--atomic X rays)*
  requires n = 1.12 to trigger positive kaons from protons at 1-2 GeV/c.

  Report from XiX Collaboration
  (K^-, K^+), (K^-, p) first level trigger rate: 10^4/sec → DAQ issue
  prototype threshold Cherenkov counter using aerogel by PD method
  $N_{p.e.}$ = 12-15 as a result of a beam test
  K^+ detection efficiency: > 90%, p fake trigger: 1/10

Proximity Focusing Radiator

Belle II Aerogel RICH counter



Proximity focusing radiator scheme

Prototype performance
# of photoelectrons = 15.3
Cherenkov angle resolution = 13.5 mrad
6.6σ π / K separation at 4 GeV/c