Study of a Silica Aerogel for a Cherenkov Radiator

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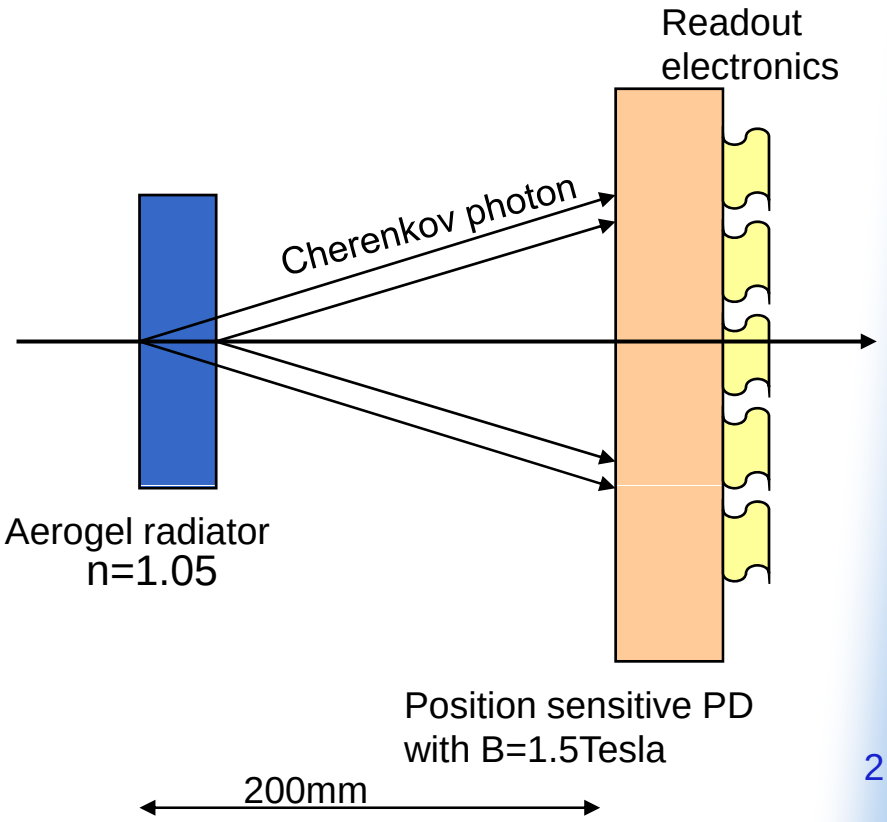
Outline

- Introduction
- Silica Aerogel Production
- Optical Quality Improvements & Studies
  - Transparancy
  - Refractive Index Uniformity
- Machining Possibility
- Further Developments
- Conclusions

Introduction

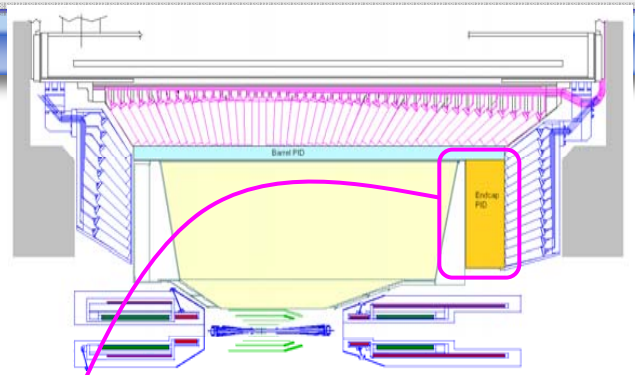
- Proximity focusing RICH with silica aerogel as Cherenkov radiator for new Belle forward PID
  - upgrade program going on to replace the present threshold-type aerogel Cherenkov counter

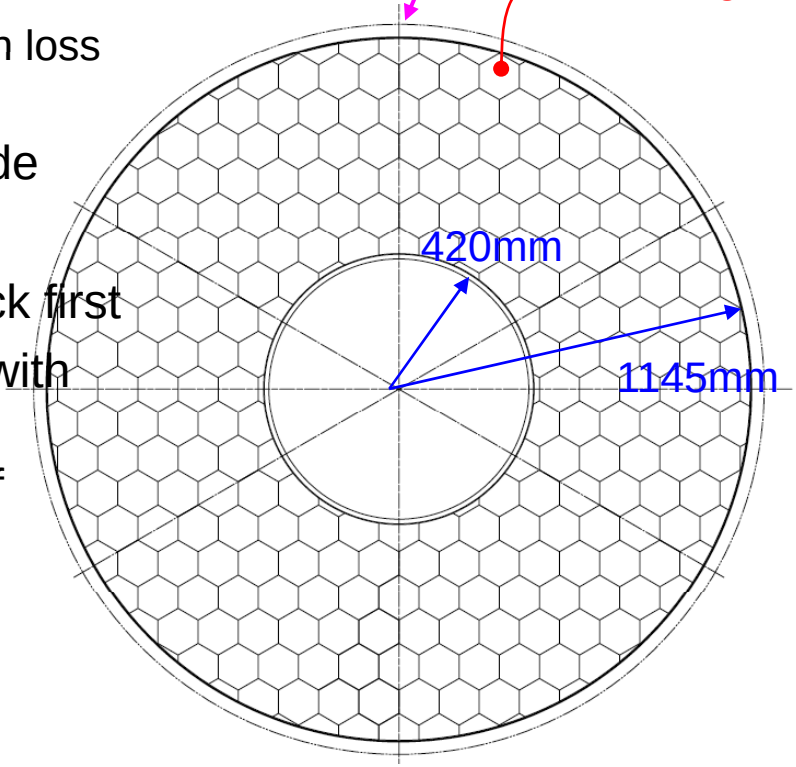
- Requirements for radiator
  - Refractive index ~ 1.05
  - High transparency
  - Hydrophobic
    - for long term stability
  - Reasonable block size

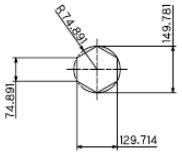


Radiator Tiling Layout

- Baseline aerogel tiling configuration
  - Cover ~3.6m^2 area
  - Use hexagonal-shape aerogel block
    - Reduce possible photon loss at corner
  - Hexagon with 75-mm side
  - ~220 tiles in total
  - Make square shape block first
  - Then, make it hexagon with water-jet cutting device, making full advantage of hydrophobic nature





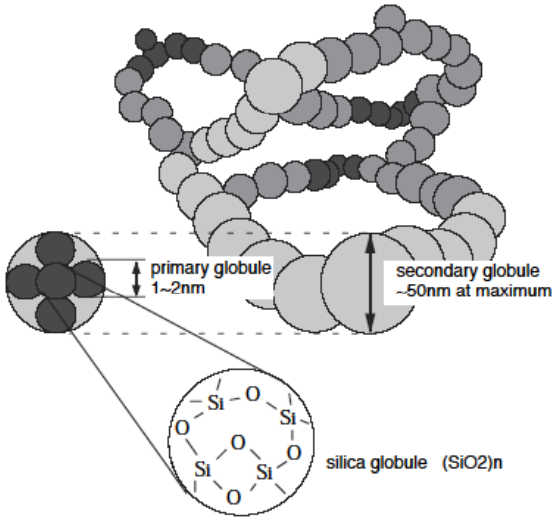


Silica Aerogel Production

- Production Method
  - Sol-gel process

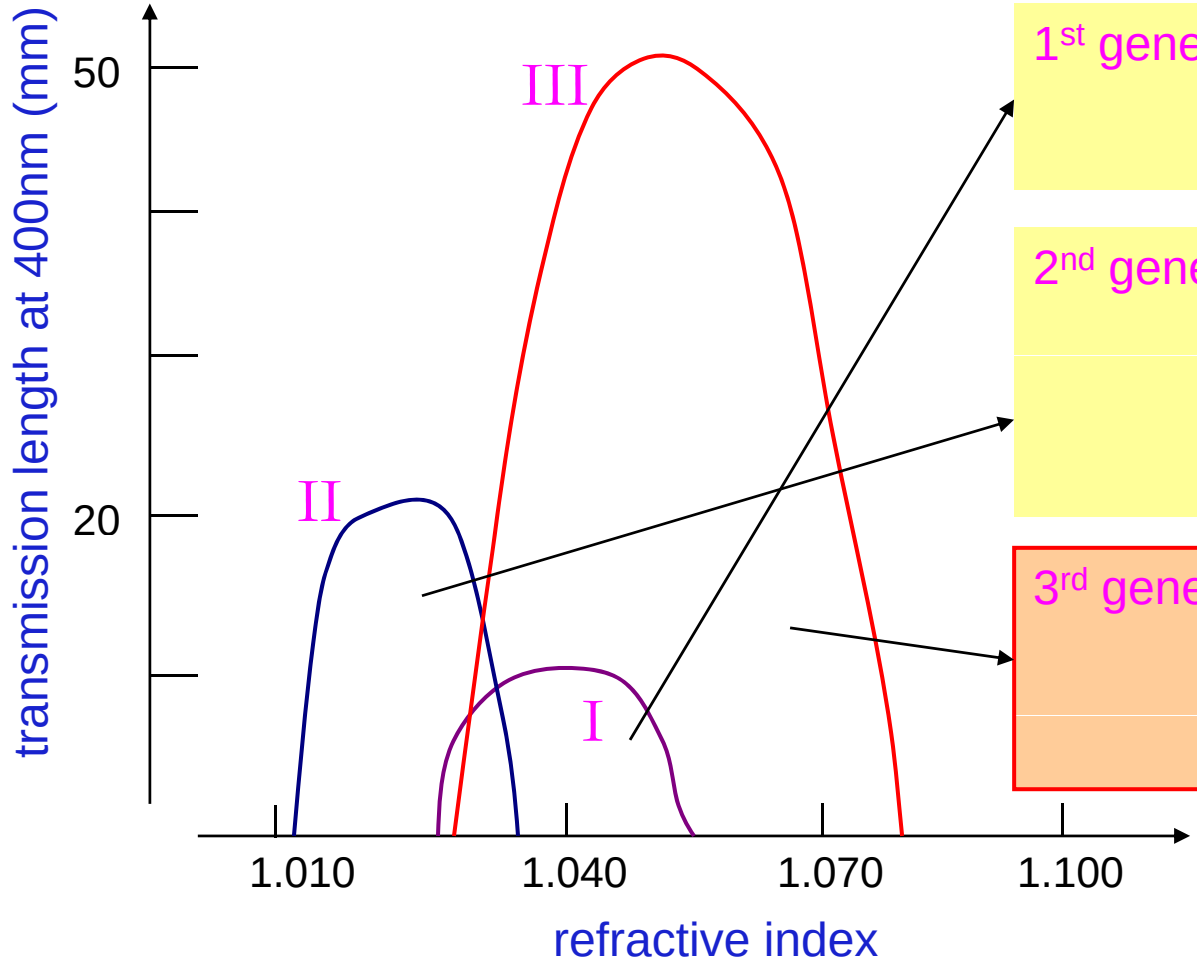
$$n\mathrm{Si(OR)_4} + 4n\mathrm{H_2O} \rightarrow n\mathrm{Si(OH)_4} + 4n\mathrm{H_2O} \quad \text{hydrolysis}$$
$$n\mathrm{Si(OH)_4} \rightarrow (\mathrm{SiO_2})_n + 2n\mathrm{H_2O} \quad \text{condensation}$$

→ 3 dimensional network



  - Chemical treatment to make hydrophobic
  - Supercritical drying
    - CO_2 extraction method
    - 31 degree Celsius and 7.5 MPa
- Optical Quality
  - Transparency
    - $T = T_0 * \exp(-d/\Lambda)$ where T is light intensity and d sample thickness
  - Refractive index measured with Fraunhofer method
  - These properties are strongly related to:
    - Chemical solvent
    - Mixing ratio between them

History of Aerogel Production



1st generation:1970's-1980's
TASSO/PETRA
1.025 ~ 1.055

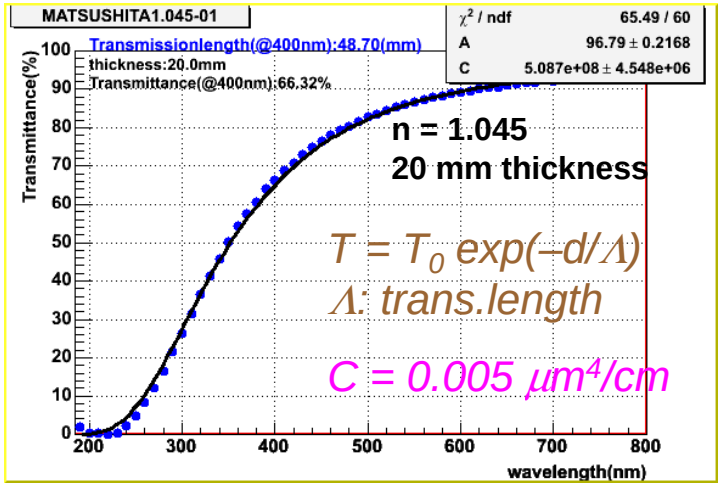
2nd generation:1992-2002
Belle Aerogel counter/KEKB
1.010 ~ 1.030
new production method
hydrophobic

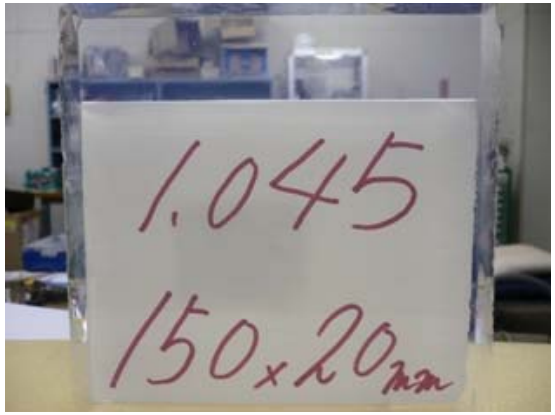
3rd generation:2002-
A-RICH for Belle upgrade
1.030 ~ 1.080
new solvent

Optical Transparency

transmission measurement for 20 mm thickness samples

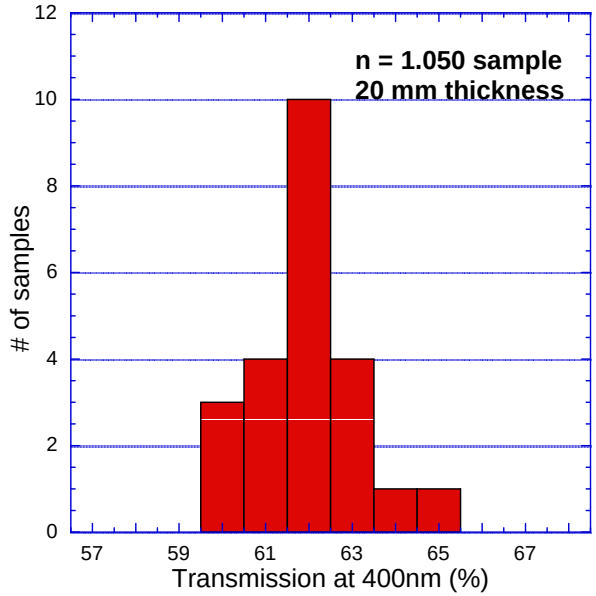
Target index	Averaged transmission length at 400nm
1.045	46.6 ± 1.4
1.050	40.4 ± 1.1
1.055	32.8 ± 1.1
1.060	28.9 ± 0.7





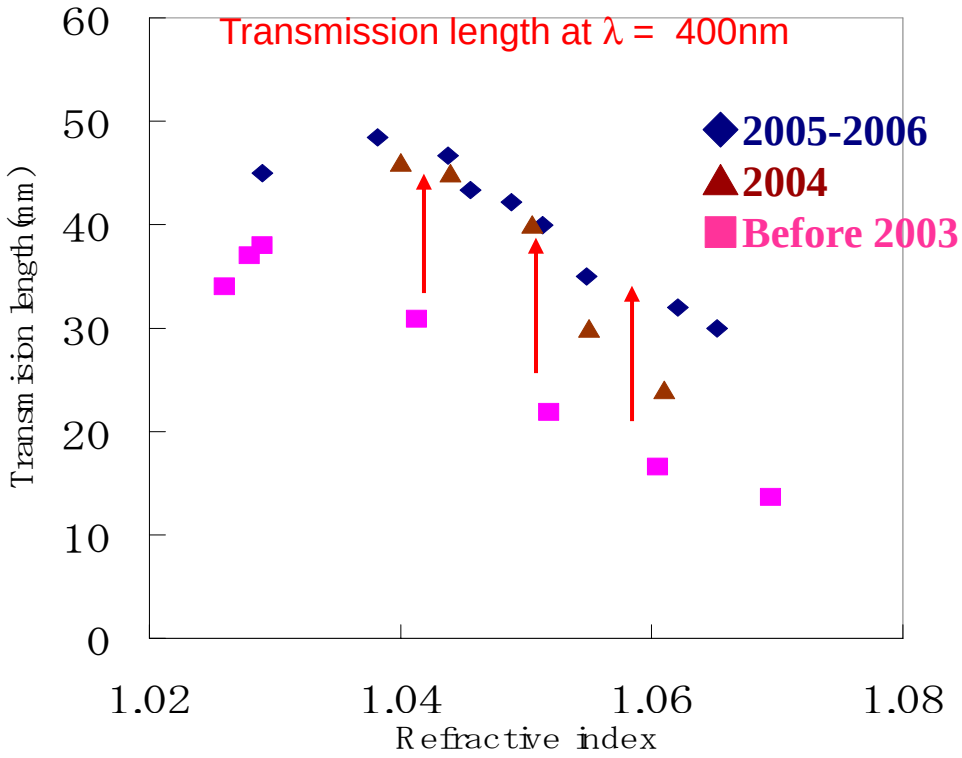
2 times higher than previous samples

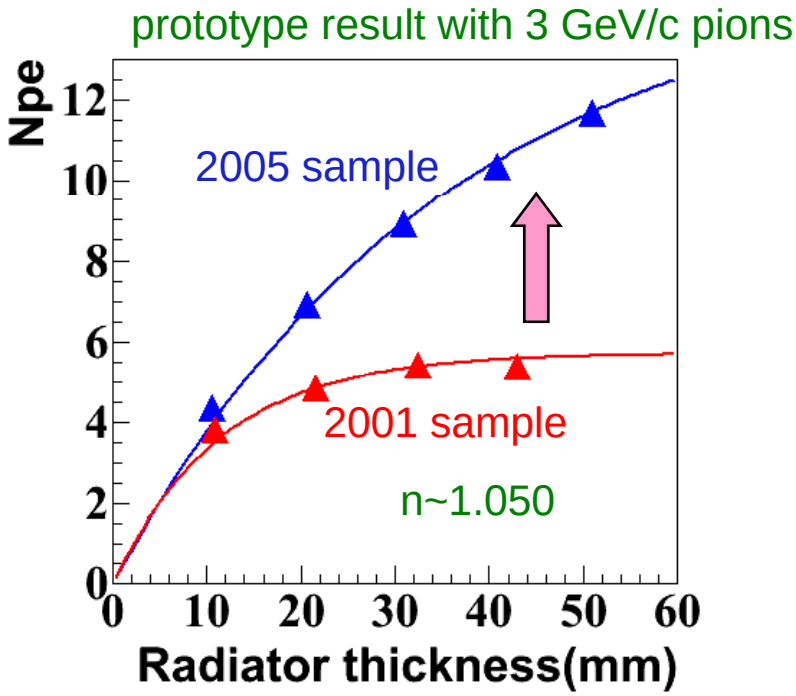
C ~ 0.005-6 μm⁴/cm



Transmission Length

- Transparency for index ~ 1.04-1.06 samples almost doubled
- Confirmed in a series of test beam experiments

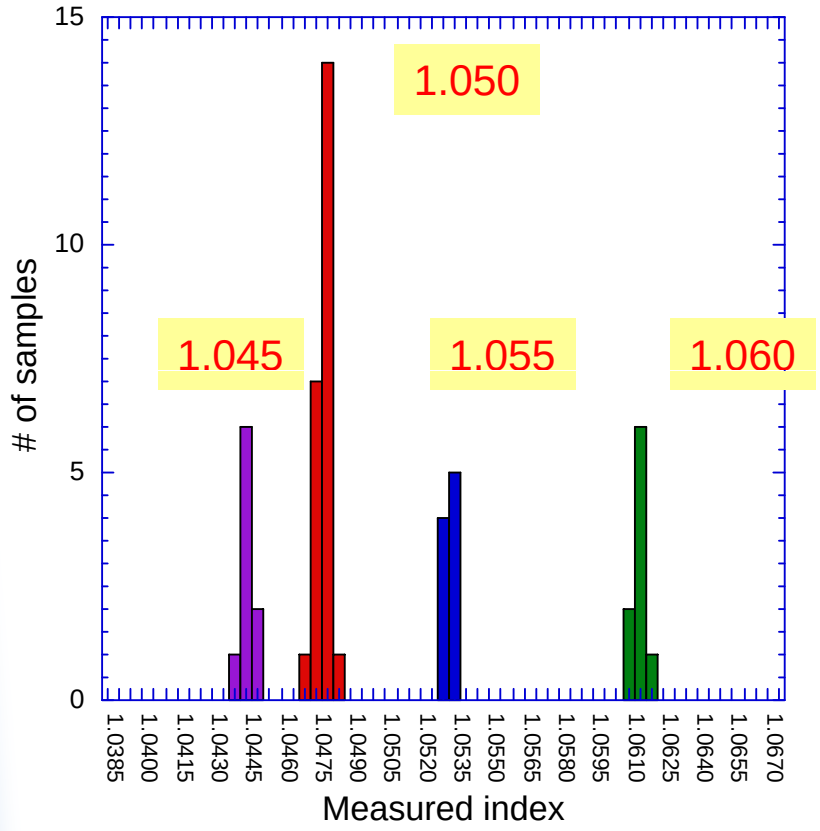


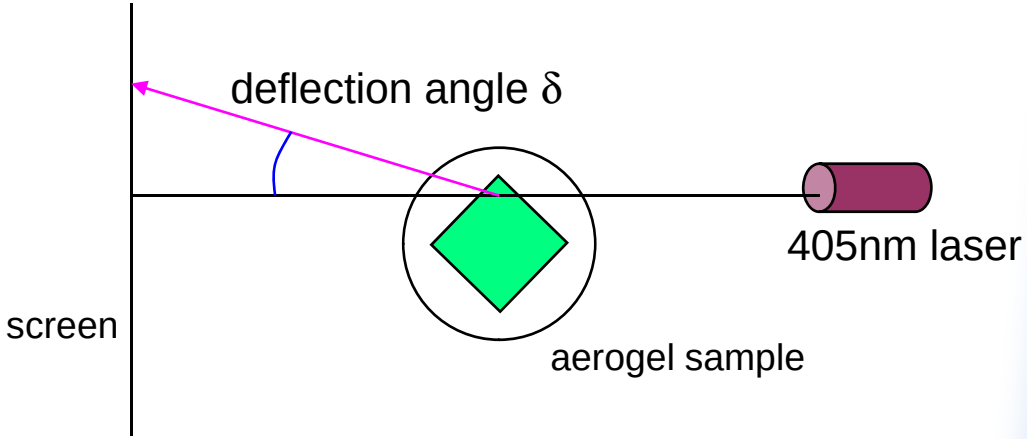


photon yield is not limited by radiator transparency up to ~50mm

Index Measurement

- Refractive index
  - Measured with Fraunhofer method using 405nm laser



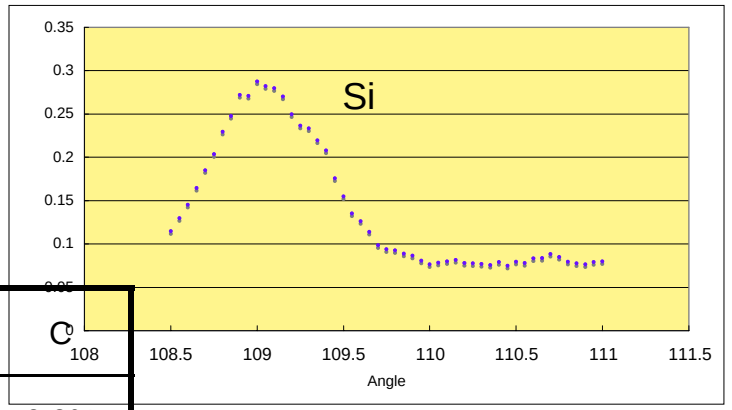


Target index	Measured
1.045	1.0446 ± 0.0002
1.050	1.0488 ± 0.0001
1.055	1.0533 ± 0.0003
1.060	1.0614 ± 0.0002

only edge of aerogel block is used
Check other area with an independent way

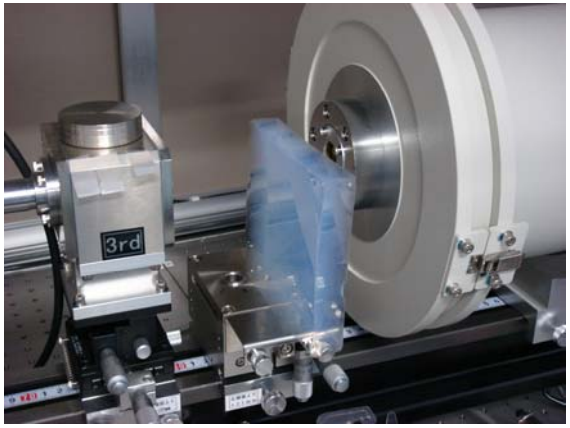
Index Scan Study (1)

- Relative weight for each composition in an aerogel was examined with XRF (X-ray fluorescence) analysis



element	Si	O	C
weight(%)	43.4%	50.6%	6.0%

- X-ray tomography device was used to scan relative aerogel density difference



X-ray λ=0.156nm

$\phi_{\text{beam spot}} < 1\text{mm}$

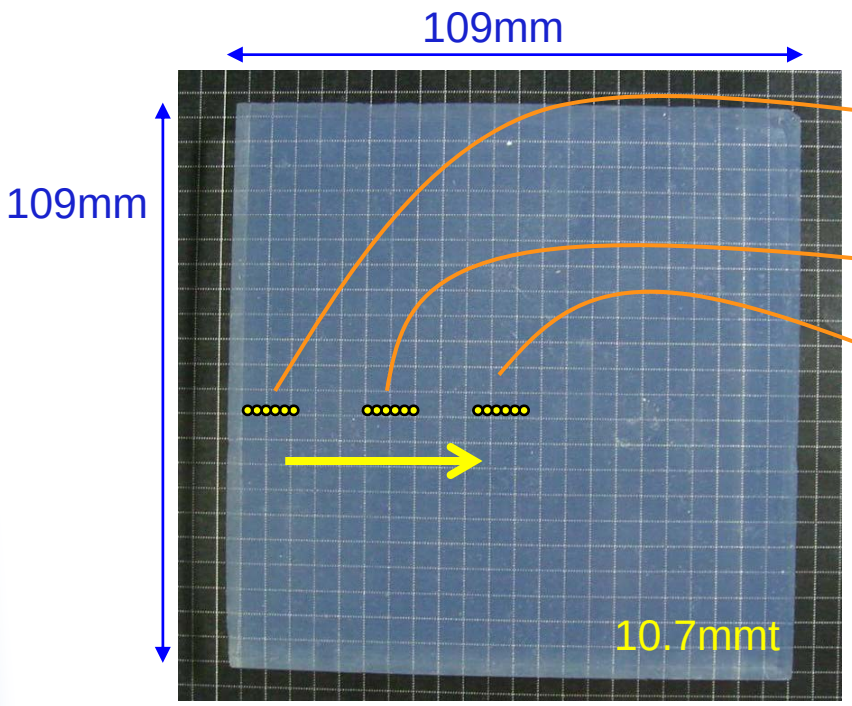
Index Scan Study (2)

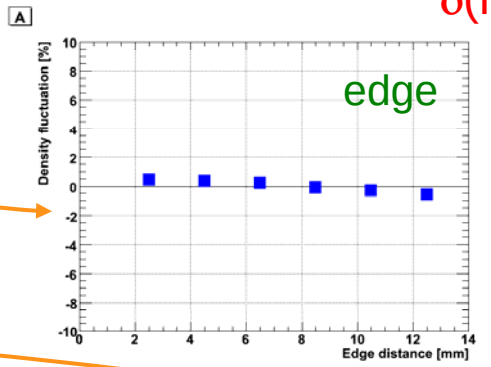
- density relative uniformity

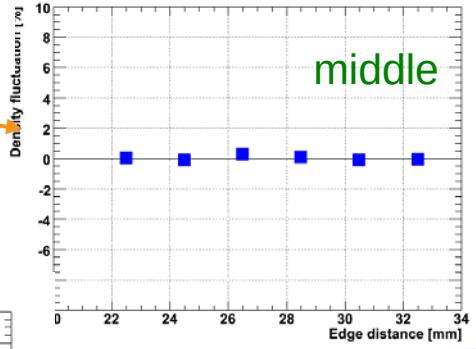
preliminary value:

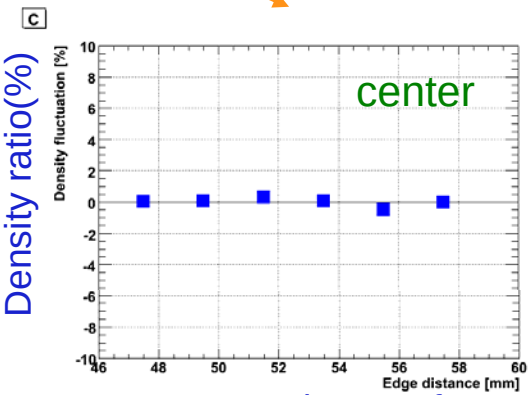
$\delta(n-1)/(n-1) \sim +/-0.02$

need further studies





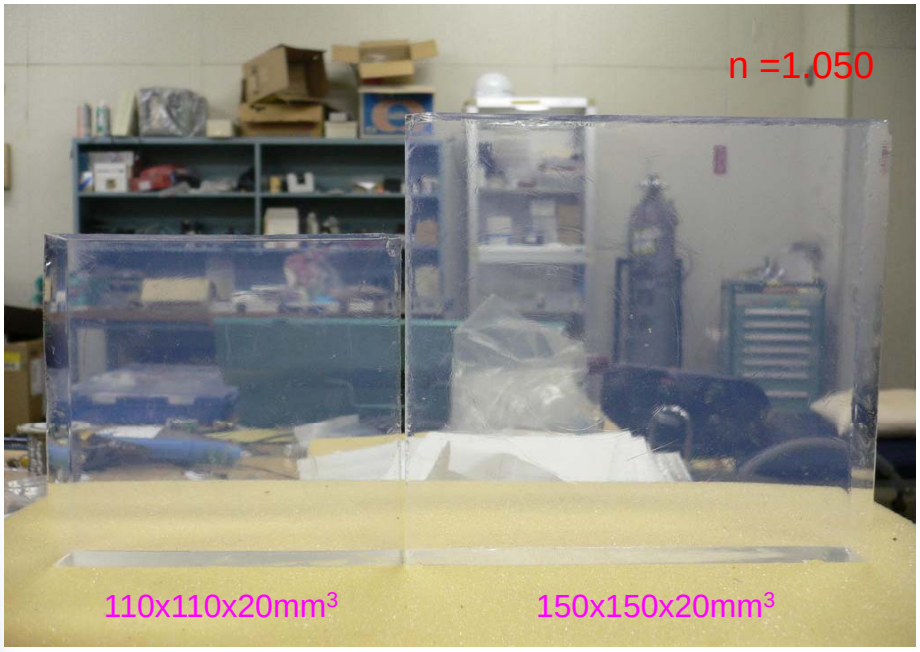




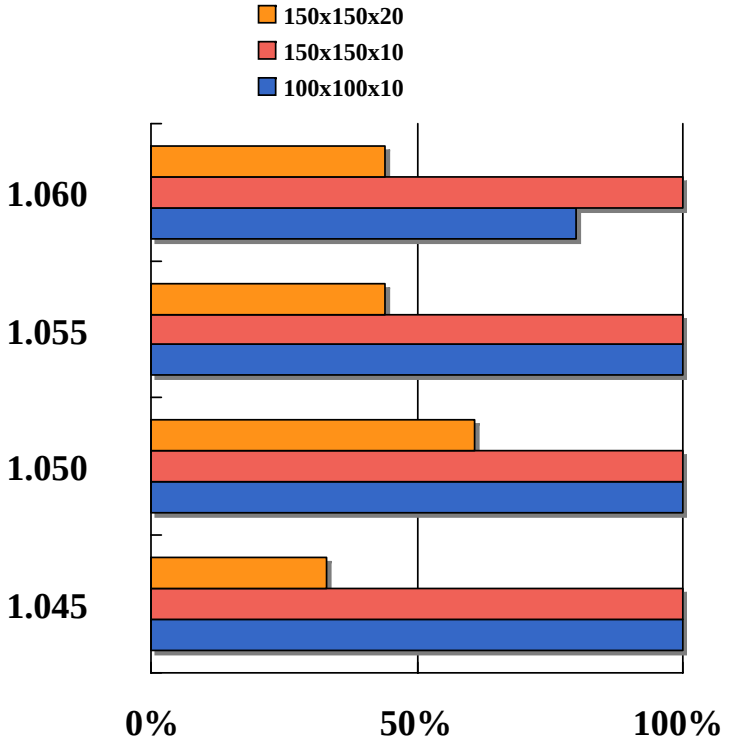
Index (Fraunhofer method at 405nm)
= 1.0577 +/- 0.0006

Block Size

- Large sample produced
  - Can be used for real detector
  - 150 x 150 mm^2 cross section
  - Thickness: 10 mm and 20 mm

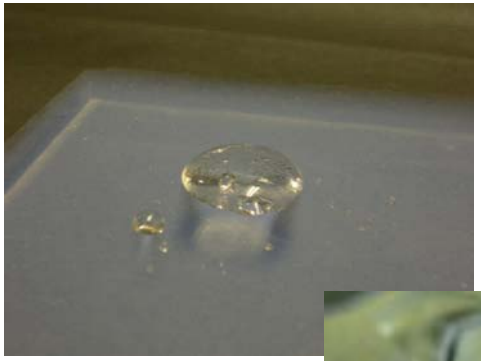


"crack-free" rate by visual scan



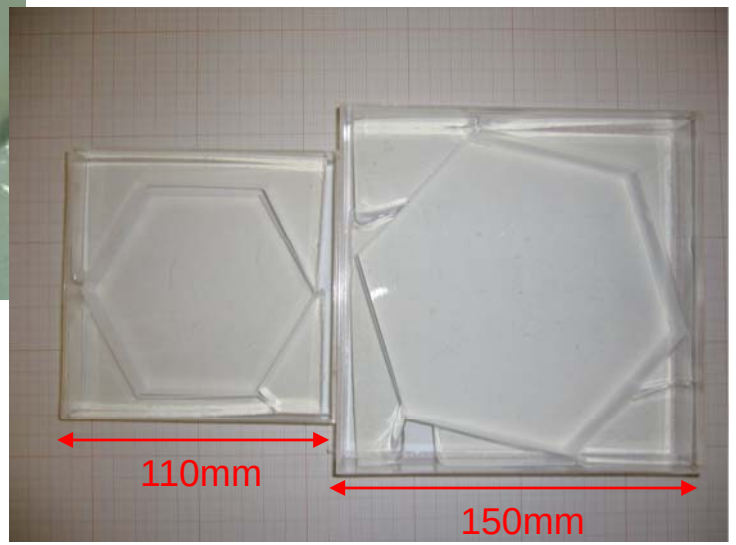
Machining Possibility

- Hydrophobic feature allows us to use “water-jet” cutter for machining

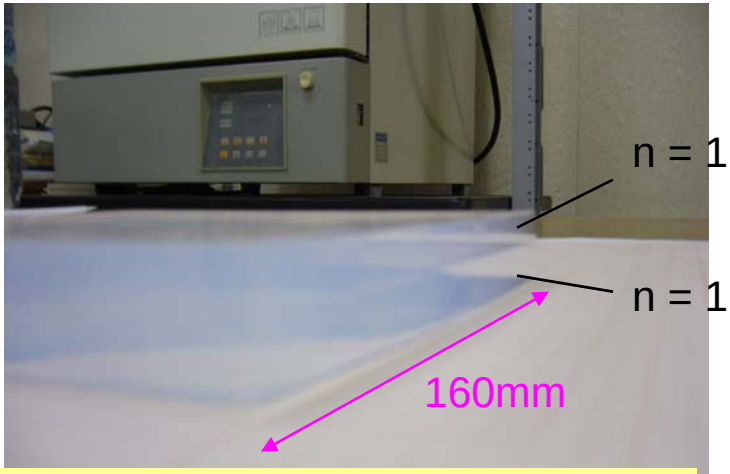


highly pressurized water injected via very small hole to a sample

hexagonal shape for two samples



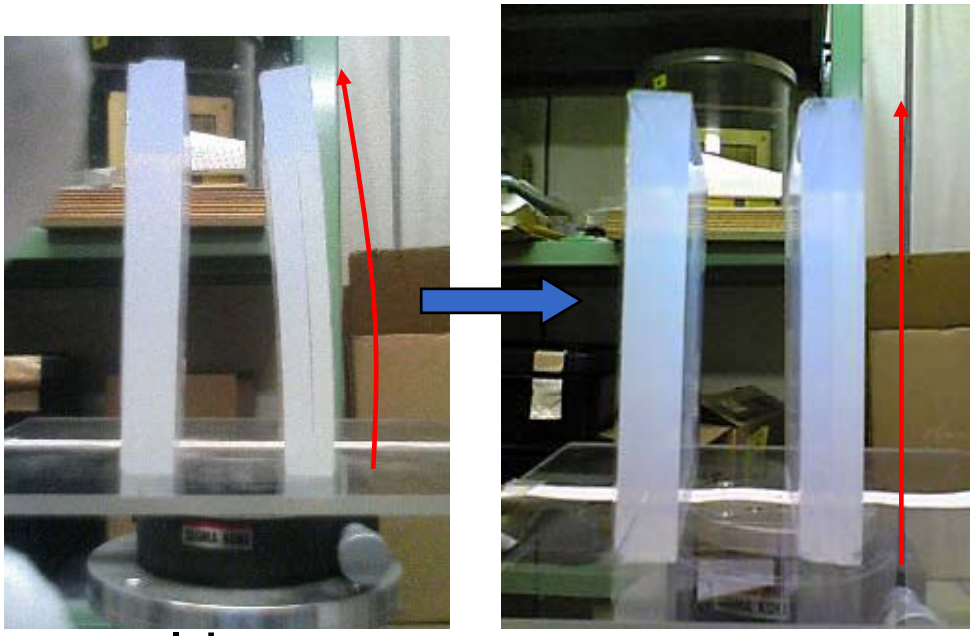
Multiple-Layer Sample



transmission length(400nm): 46mm

two-layer sample with 160x160x20 mm^3
has been successfully produced
one can use two aerogel layers as one unit

stress inside a tile well controlled

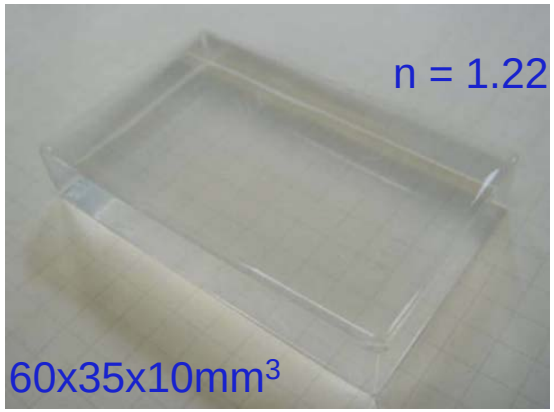


old

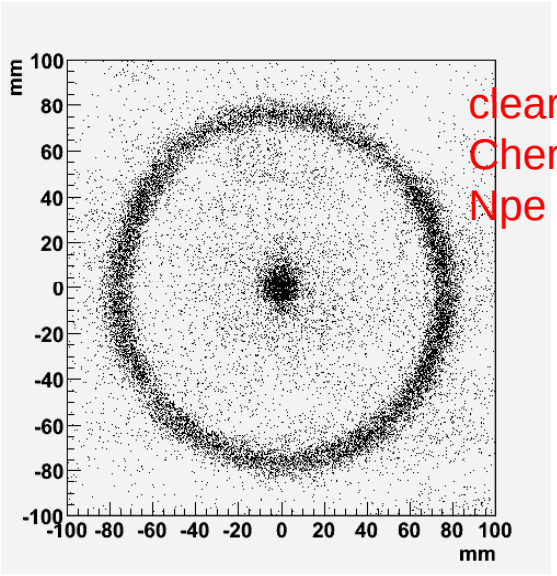
new

High Density Aerogel

- Challenge to produce transparent aerogel with high density
  - index ~ 1.10-1.20 (ρ~ 0.4-0.8g/cc). Fill a “gap” between gas and liquid.
  - Very difficult to make high density aerogel. Aerogel gets milky and it can not be used due to low transparency in a normal way.
  - new method invented



transmission length: 18mm at 400nm



clear enough to detect Cherenkov photons
Npe ~ 9 for 3 GeV/c pions

Conclusions

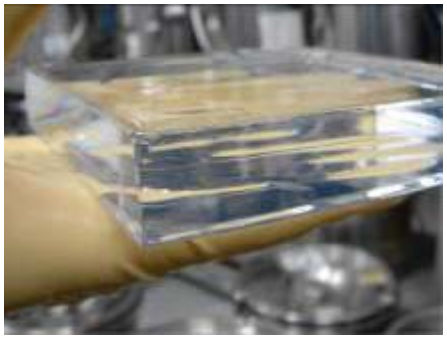
- Aerogel in the 3rd generation has been produced.
  - index : 1.03 - 1.08
  - transmission length at 400 nm ~ 40 mm
  - clarity factor ~ 0.005-6 $\mu m^4/cm$
  - transparent sufficiently to employ Cherenkov radiator
  - uniformity of index examined with X-ray tomography device
- Various aspects in aerogel production as well as handling possibility have been investigated
  - machining
  - two layer samples with big size of 160x160x20 cm^3
- Further attempt for the 4th generation
  - high density aerogels

KEK - J. Stefan Institute - Univ. Ljubljana - Nagoya - Chiba - Tokyo Metro. Univ. - Toho

Acknowledgements to Matstushita Electric Works

Backup Slide

Aerogel Production Procedure



Preparation

Aging ~2 weeks

Rinse 1 3 days

Hydrophobic treatment 3 days

Rinse 2-1 2 days

Rinse 2-2 2 days

Rinse 2-3 2 days

(Rinse 2-4) (2 days)

Supercritical drying 3 days

total 1 month