Development and production of aerogel radiators for Cherenkov detectors

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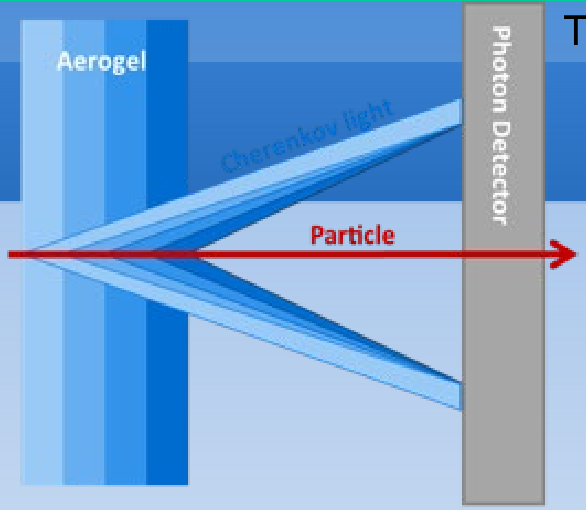
behalf of BINP Aerogel team

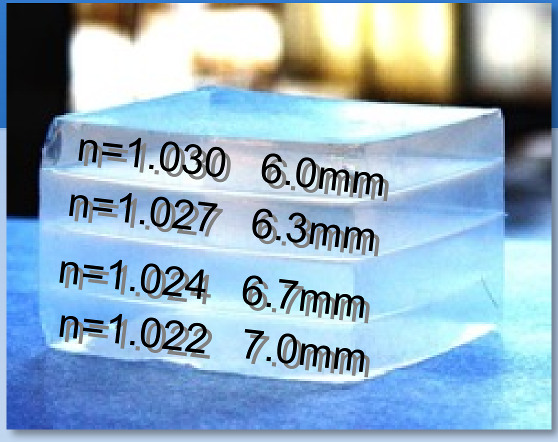
Outline

- PID option for CEPC detector endcap based on FARICH
- Aerogel production at BINP/IC, main parameters
- Comparison of “Novosibirsk” and “Chiba University” aerogels
- Beam tests of aerogel RICH with n=1.008 aerogel

FARICH technique milestones

The first 4-layer monolithic sample





Increase N_{pe} due thickness increase without $\sigma_{\Theta c}$ degradation 2004÷2005

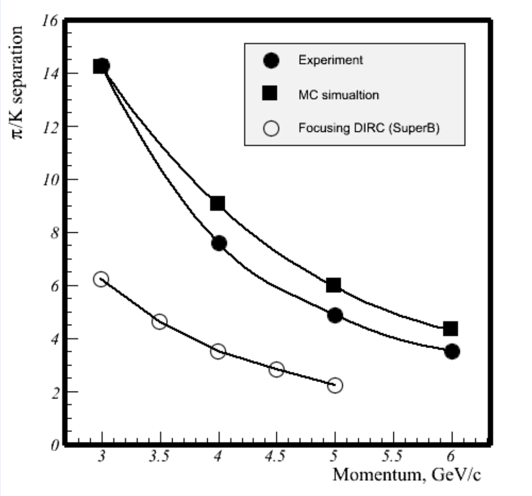
T.Iijima et al., NIM A548 (2005) 383 and A.Yu.Barnyakov et al., NIM A553 (2005) 70

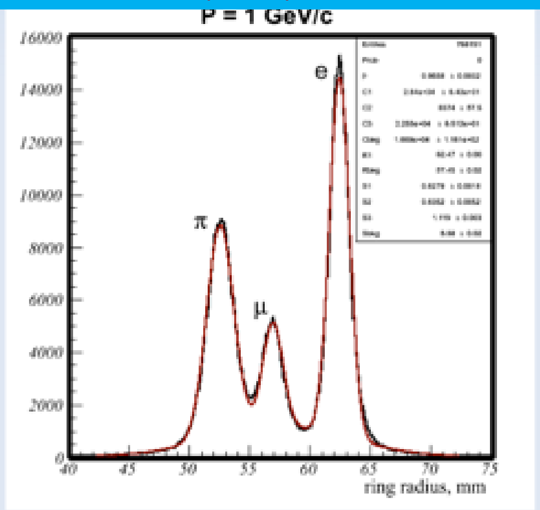
The Belle II (ARICH) is the first application of the me thod

2017

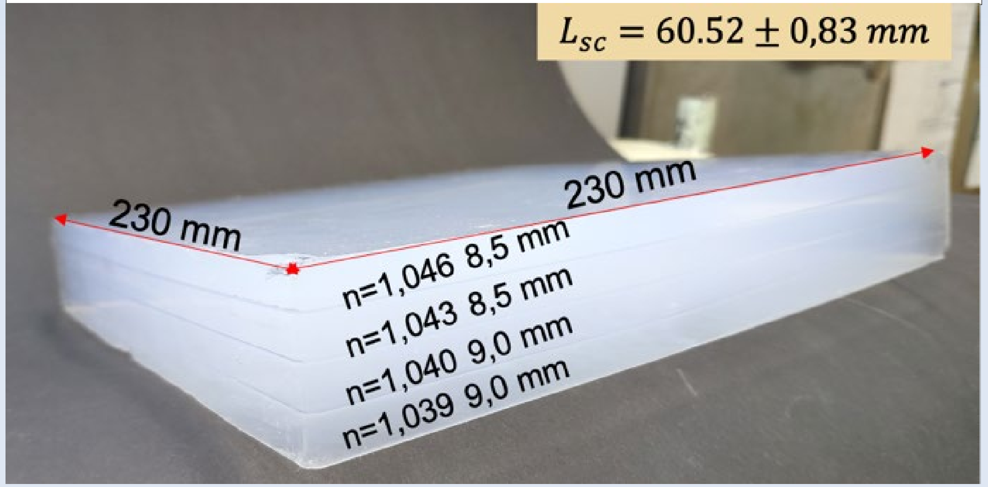
Excellent PID capability were shown at CERN beam test in 2012

A.Yu. Barnyakov, et al., NIM A 732 (2013) 352





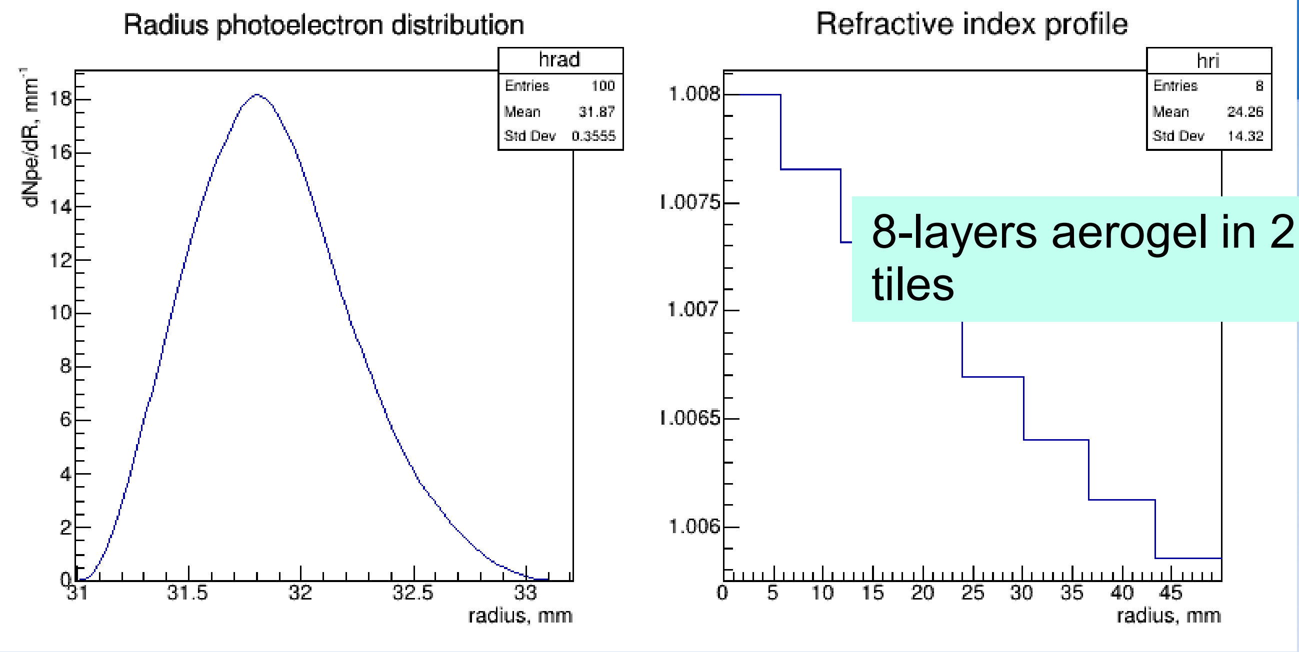
Two 4-layer focusing aerogel blocks 230x230x35 mm



2022÷2023

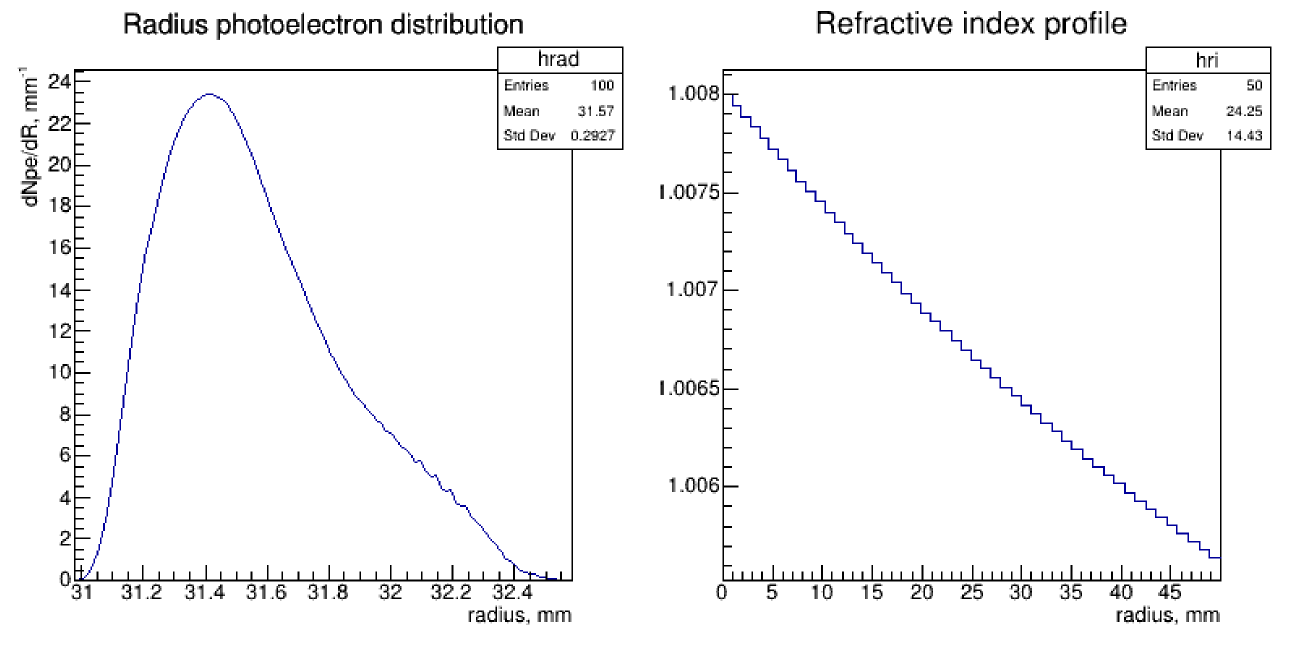
FARICH option for π/K–separation above 20 GeV/c

8-layer aerogel n_{max}=1.008; pixel≈0.2mm | **Gradient aerogel n_{max}=1.008; pixel≈0.7mm**



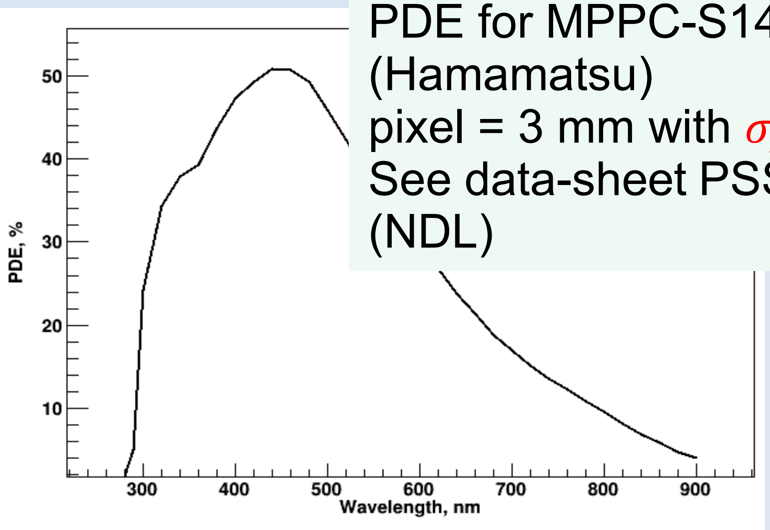
8-layers aerogel in 2 tiles

Focal distance is 300 mm



The possibility to produce of gradient aerogel was demonstrated in
NIM A766 (2014) 88-91 and NIM A766 (2014) 235-236

- N_{pe}≈16
σ_C^{tr}≈0.33 mrad!!!

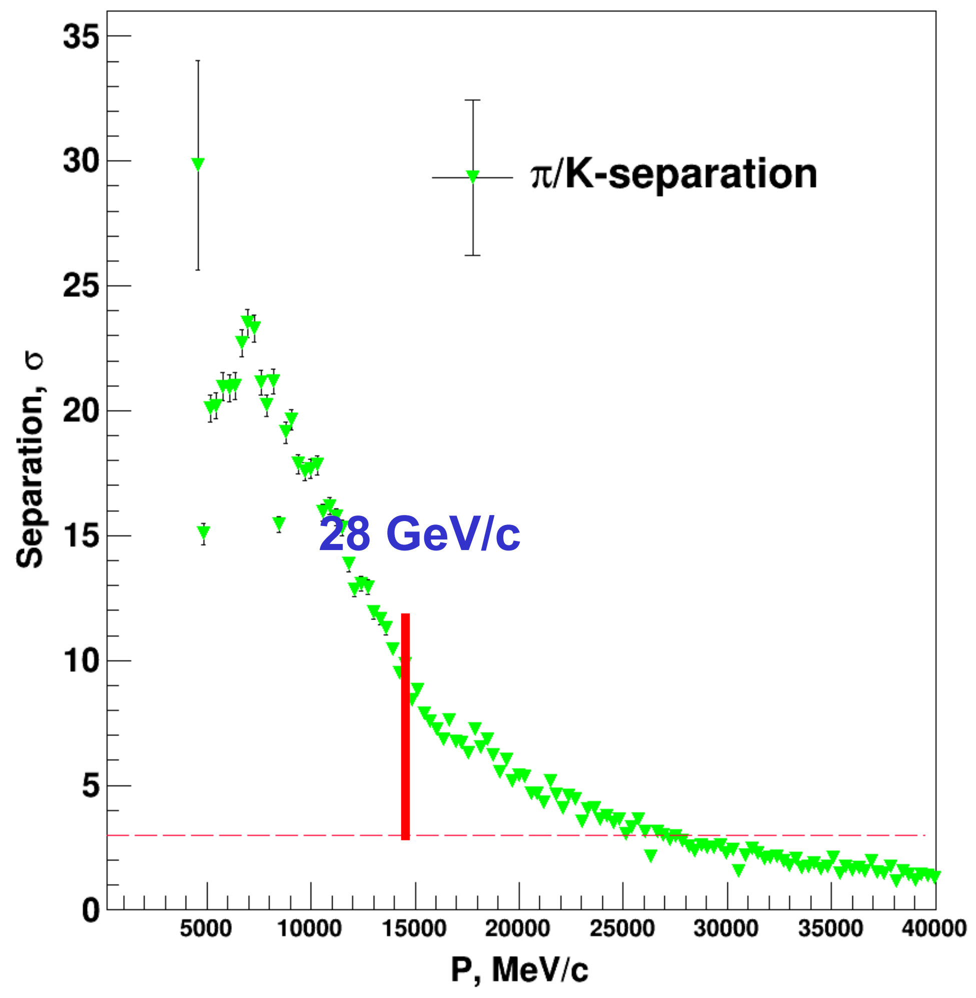


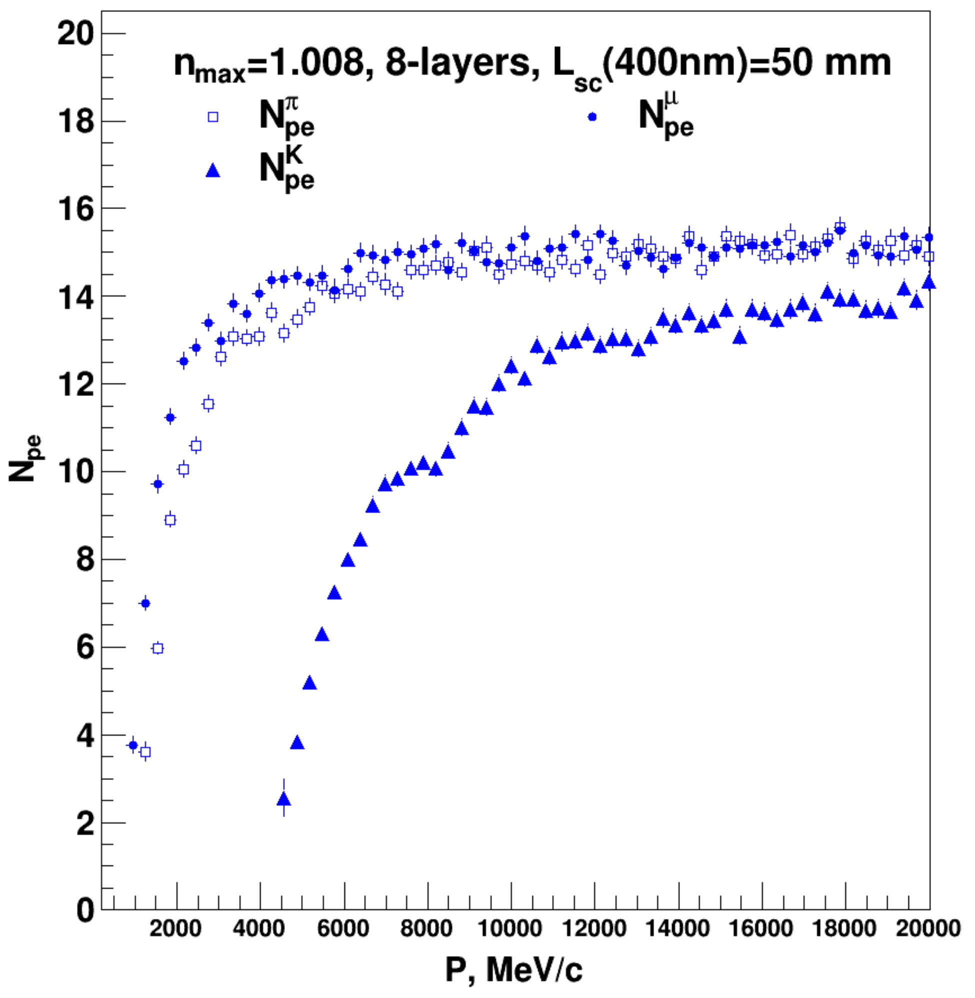
PDE for MPPC-S14160 (Hamamatsu)
pixel = 3 mm with $\sigma_x \approx 0.2mm$
See data-sheet PSS 11-3030-S (NDL)

- N_{pe}≈16
σ_C^{tr}≈0.33 mrad!!!

It looks good enough for reliable π/K–separation @ 30 GeV/c

FARICH for π/K–separation at 30 GeV/c: G4sim results

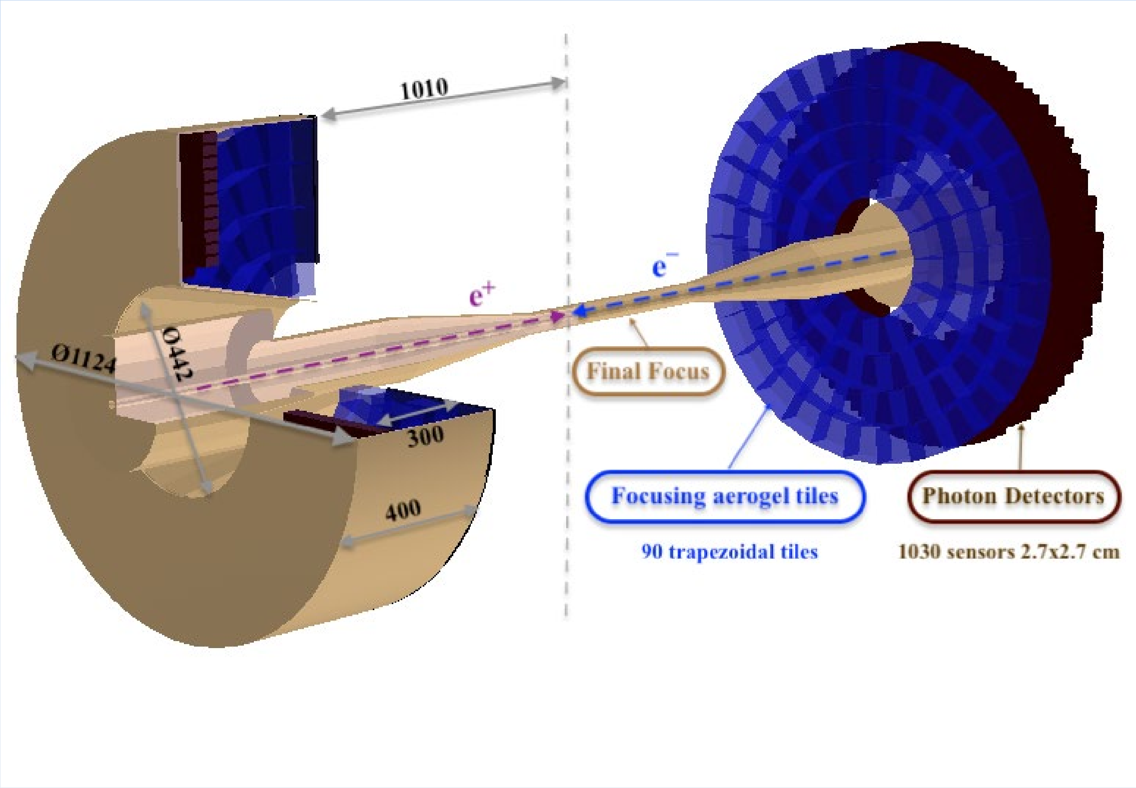


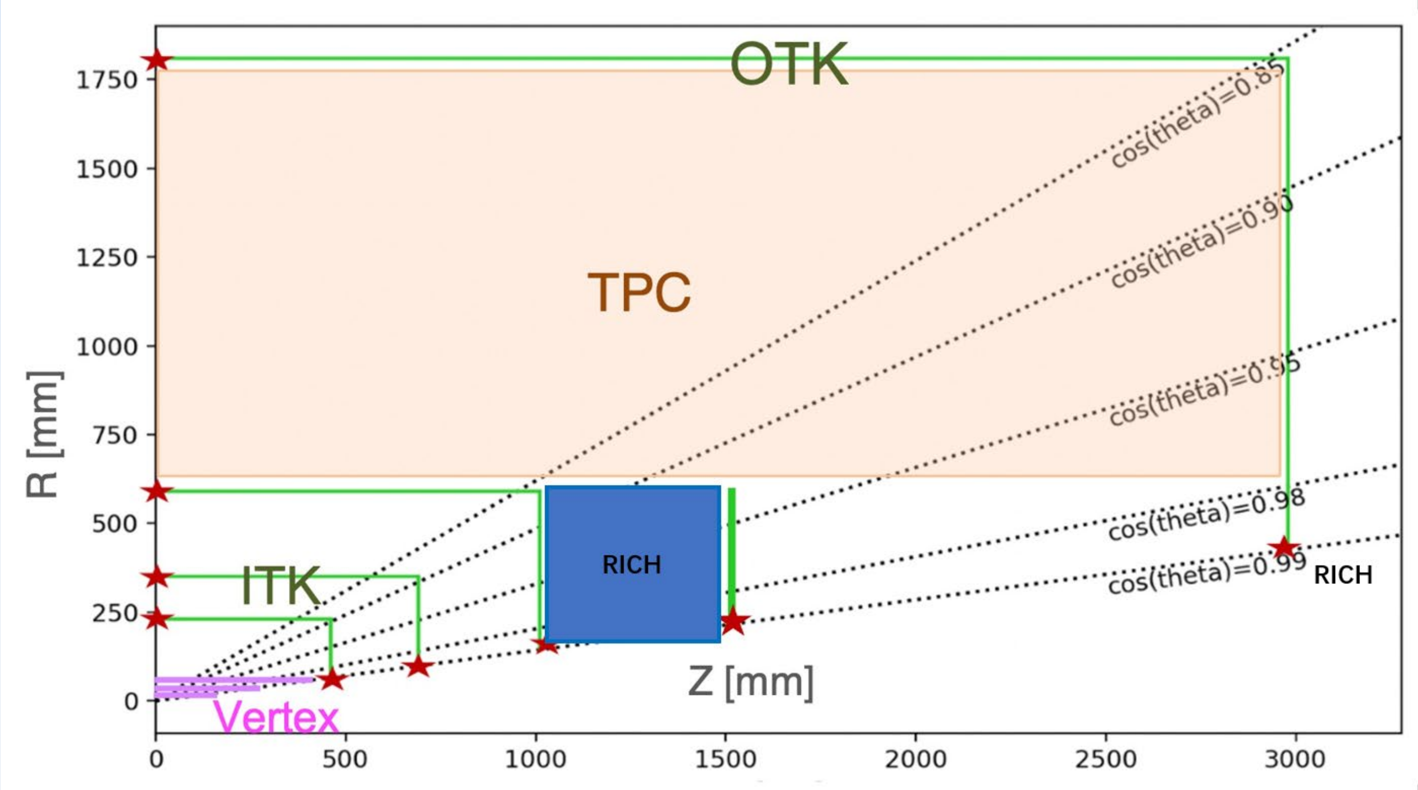


Focusing aerogel with n ≤ 1.008 and Lsc(400 nm) is needed!

FARICH configuration for the endcap

- Presented by Alexander Barnyakov earlier
- The aim is to increase PID working solid angle and to have high momentum PID in the endcaps





“Novosibirsk” aerogel radiators for Cherenkov detectors

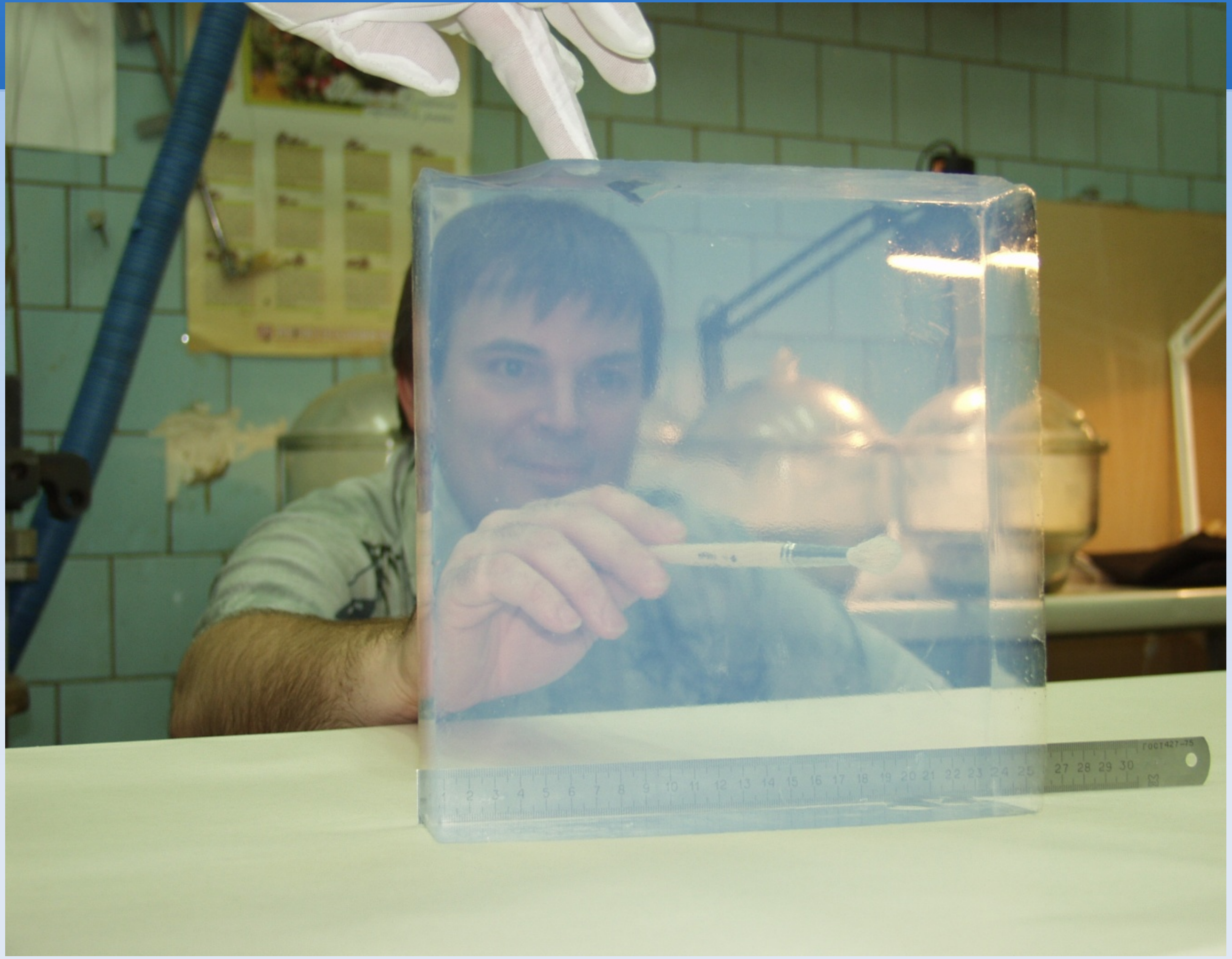
Aerogel development has started in 1986 (KEDR detector project)

More than 3000 liters have been produced for threshold Cherenkov detectors:

- 2000 liters – KEDR and SND ASHIPH counters (n = 1.05, n = 1.13)
- ~ 10 liters DIRAC (CERN) n = 1.008

RICH detectors:

- ~ 1 м^2 LHCb RICH, n = 1.03
- ~ 2 м^2 AMS02 RICH, n = 1.05
- ~ 5 м^2 CLAS12 RICH, n = 1.05

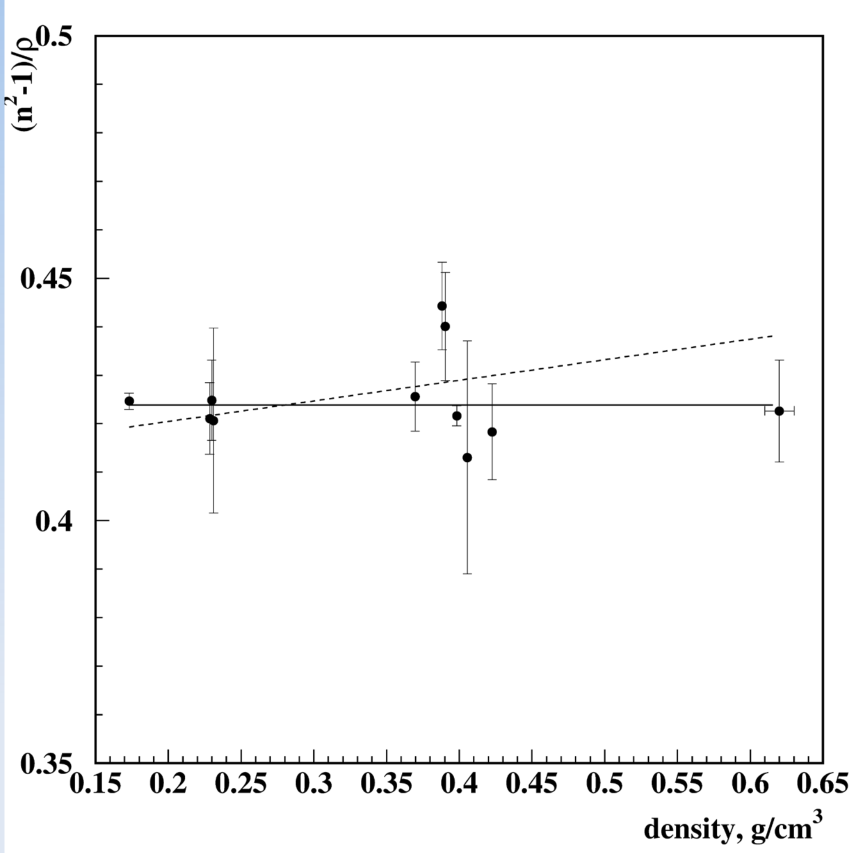


n = 1.004 – 1.06 (1.13)

Requirements on aerogel tiles for use in Cherenkov detectors (1)

Index of refraction of aerogel is selected considering physics tasks and working regions of other PID methods: KEDR – 1.05, SND – 1.13, DIRAC – 1.008

$$I_{Ch} \sim z^2 \left(1 - \frac{1}{n^2 \beta^2}\right)$$ if β→1, (n-1) << 1 ⇨ $$I_{Ch} \sim \rho$$



$$n^2 = 1 + 0.438 * \rho[g/cm^3]$$

Variation of index of refraction from tile to tile:

- n=1.050±0.002 ⇨ ρ=0.234±4% ⇨ 4% variation of Cherenkov light intensity from different tiles -- much less than light collection variation within the detector.

The density of all tiles is measured to determine index of refraction.

Requirements on aerogel tiles for use in Cherenkov detectors (2)

At λ=400 nm

- L_{sc}~ 40 mm, L_{abs}~ 4-5 m

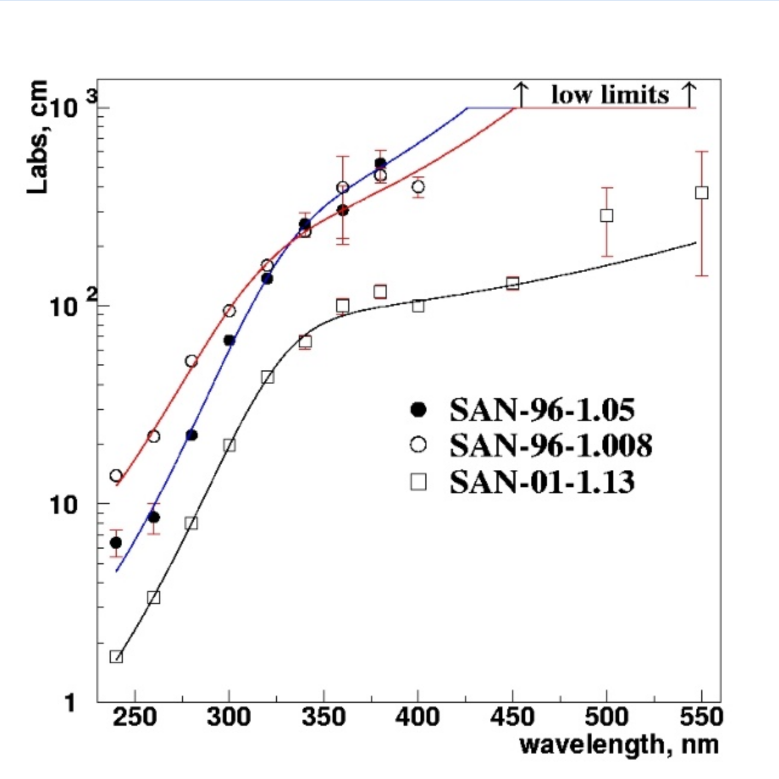
At λ=300 nm

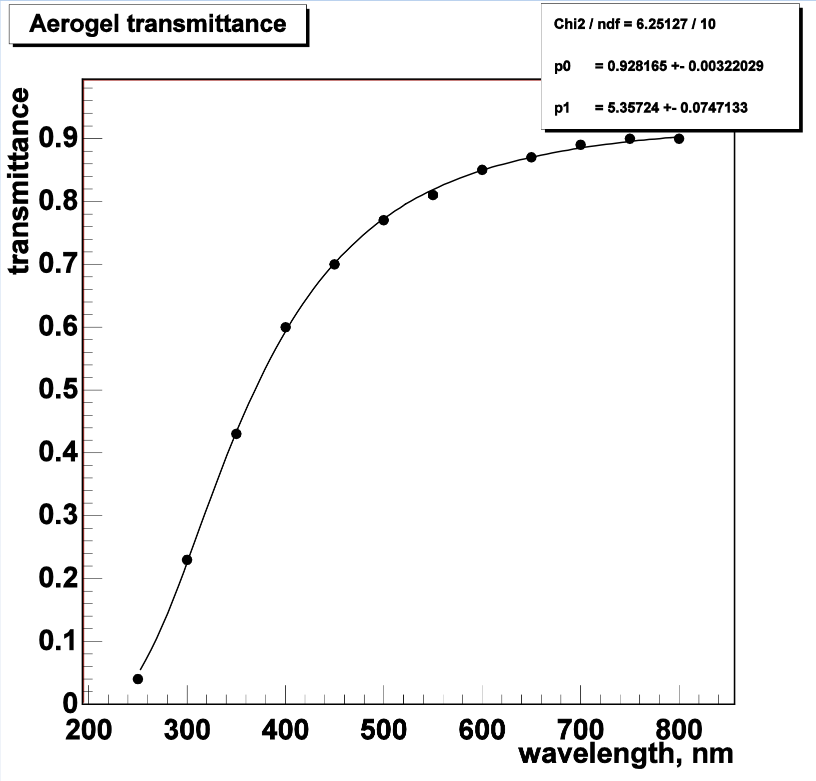
- L_{sc}~12 mm, L_{abs}~ 0.5-1 m

$dN/d\lambda \sim 1/\lambda^2$

In **threshold aerogel counters** with the diffusive light collection the **light absorption** in aerogel is the main effect defining the number of detected Cherenkov photons.

In **aerogel RICH detectors** the main process which effects signal is the **light scattering**.



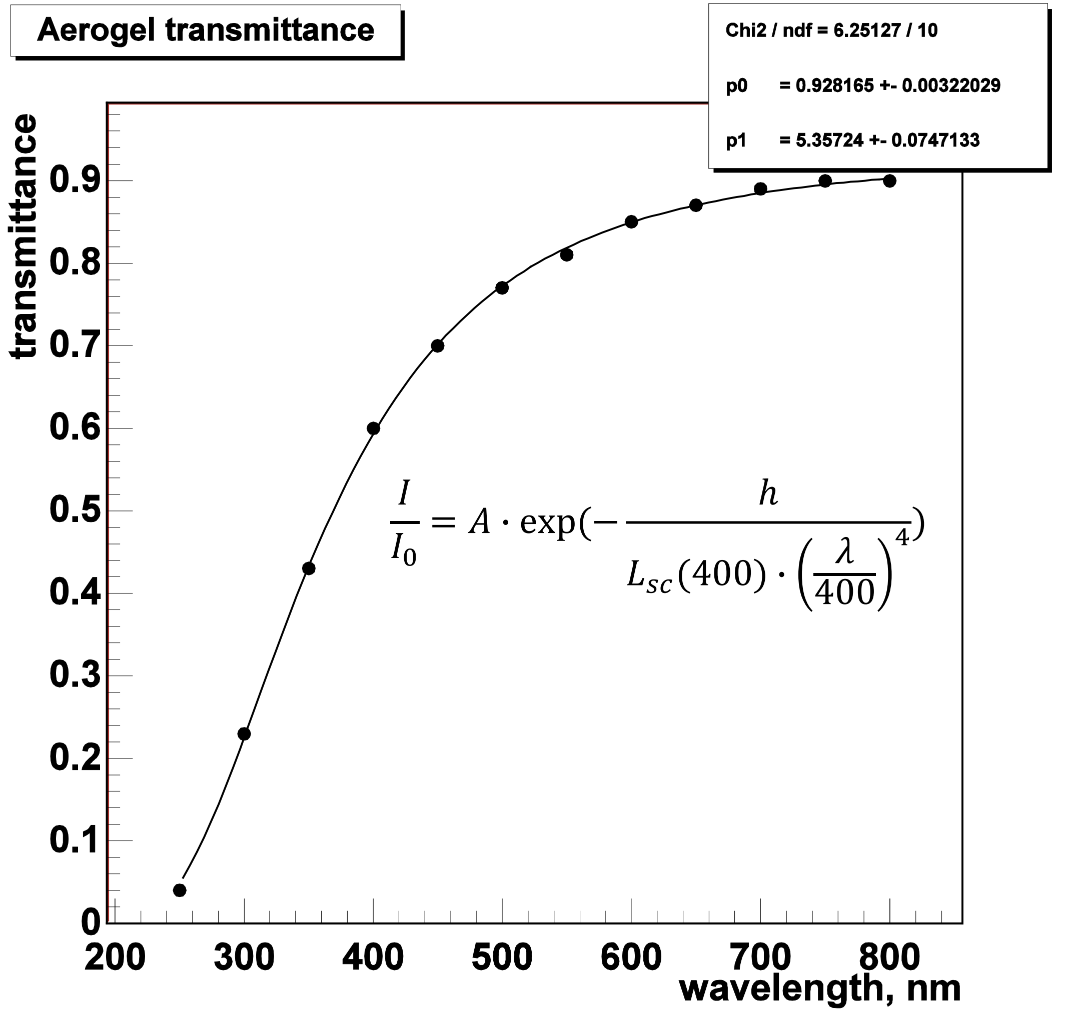


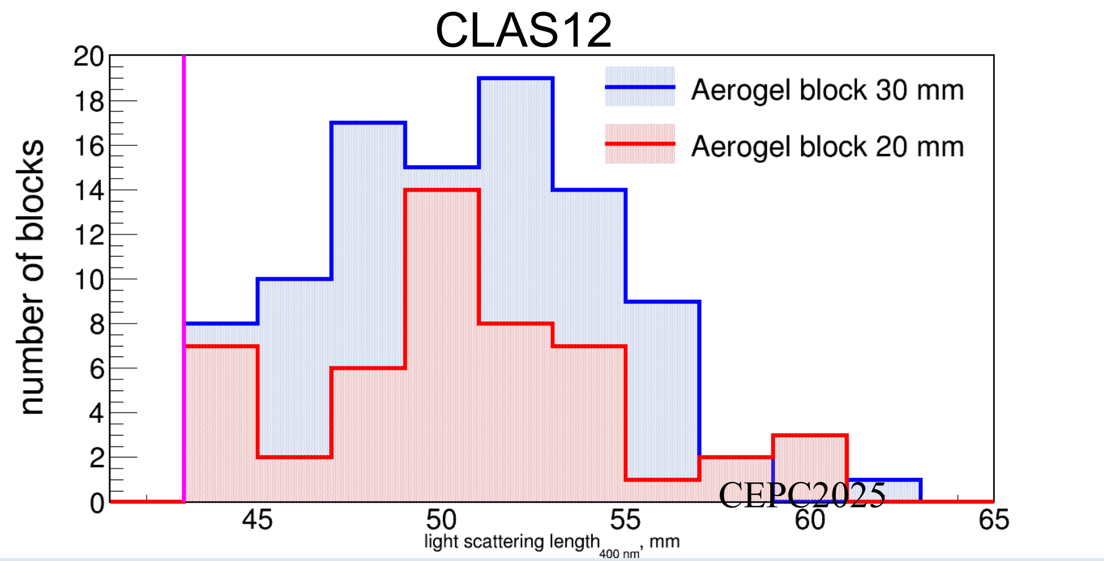
Requirements on aerogel tiles for use in Cherenkov detectors(3)

Transparency requirements:

$$N_{out} = N_0 \frac{L_{sc}}{h}\left(1 - e^{-\frac{h}{L_{sc}}}\right)$$

- L_{sc} at 400 nm (maximum of QE) for h ~ 5 cm must be about 4-5 cm.
- There are no requirements on L_{abs} for RICH detectors

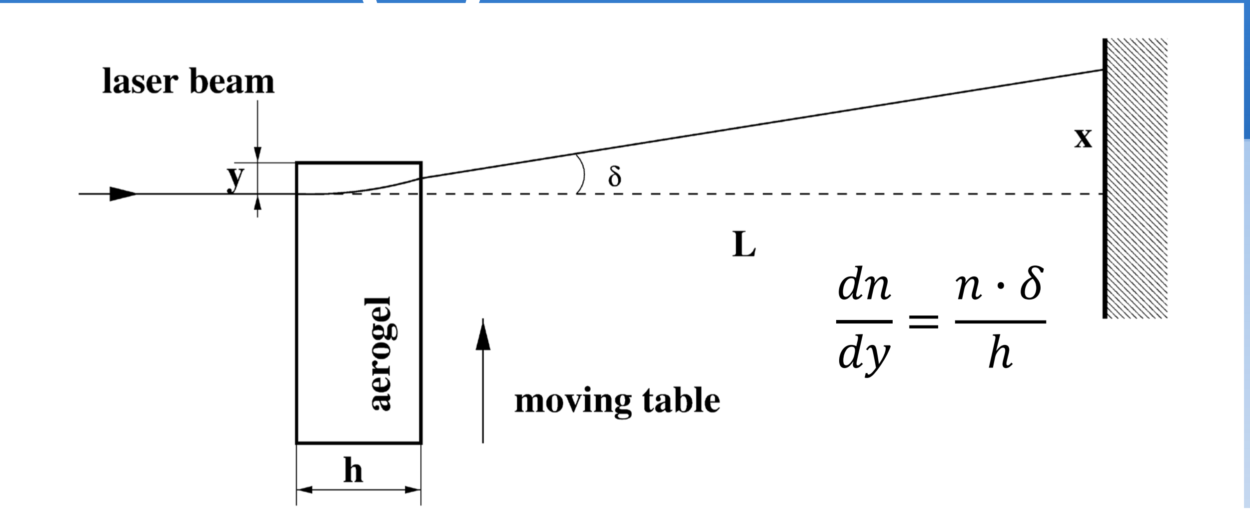


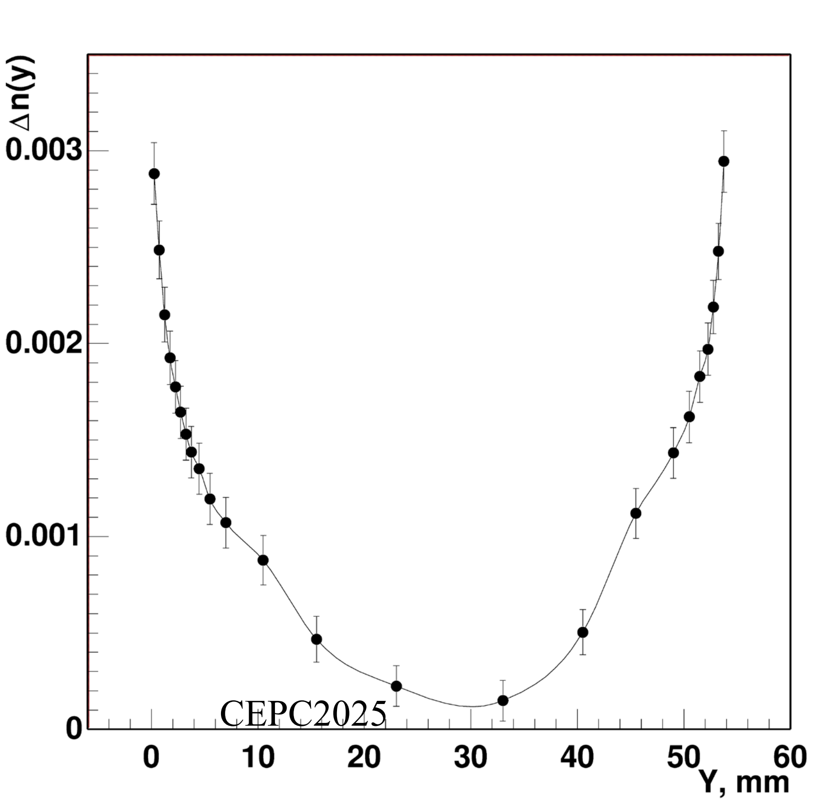


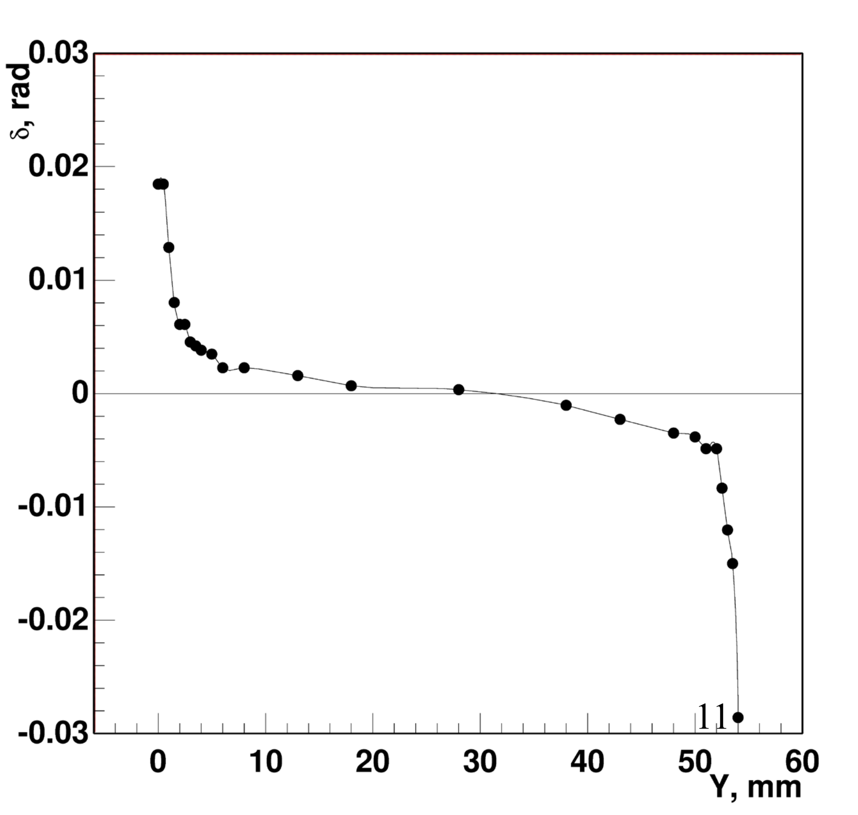
Requirements on aerogel tiles for use in Cherenkov counters(4)

The are refractive index (density) variations within aerogel block:

- they could be measured using optical methods,
- main variations are close to aerogel tile surfaces

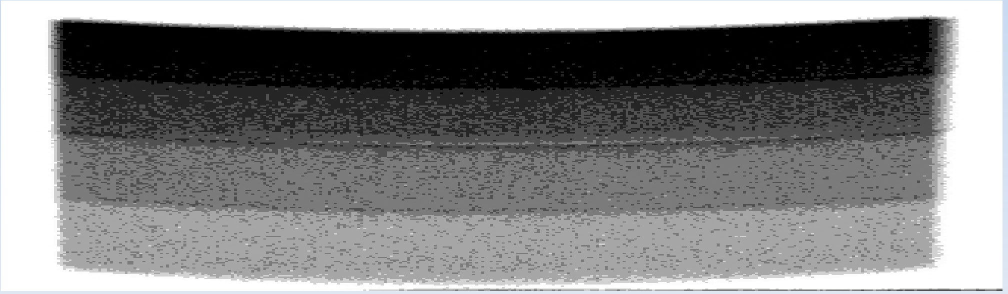






Requirements on aerogel tiles for use in Cherenkov counters(5)

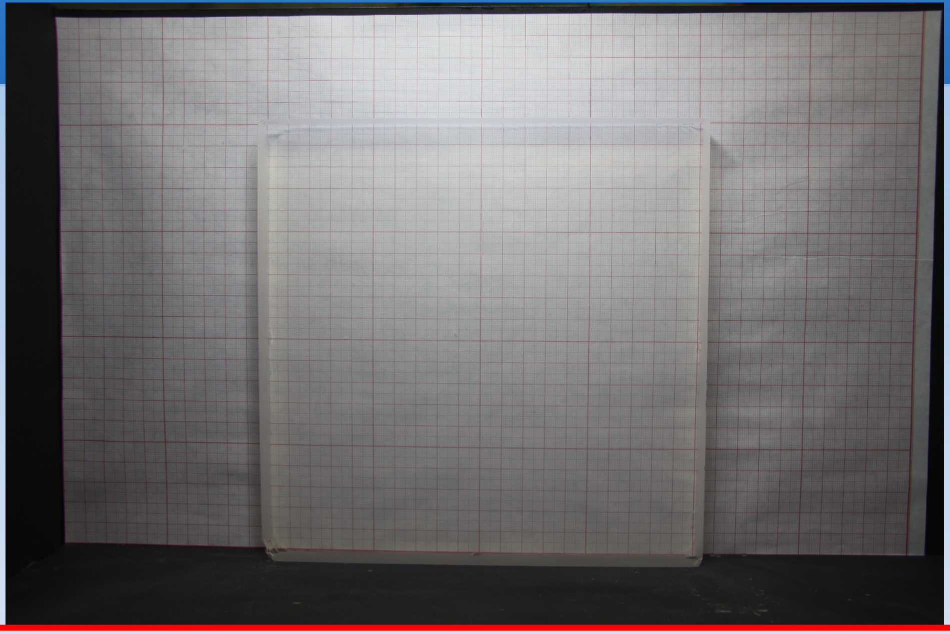
- Refractive index (density) variations can be measured with X-rays also.
- Density variations [$d\rho/\rho = dn/(n-1)$] can reach ~5%. This is comparable with refractive index dispersion over wavelength
- Variations could have constructive or destructive effect on RICH performance
- Regions with large variations close to aerogel tile edges can be cut away



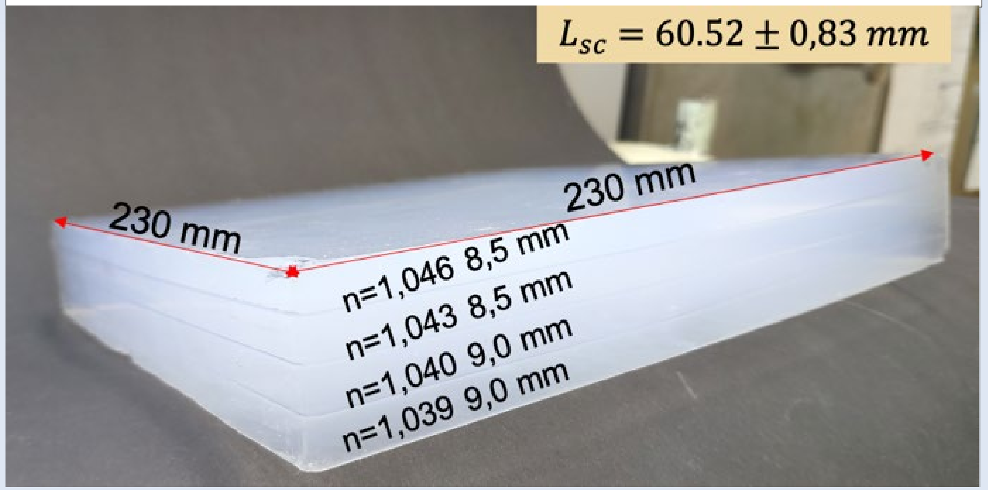
Requirements on aerogel tiles for use in Cherenkov counters(6)

Requirements on tile dimensions and form:

- The size of aerogel tile ought to be as large as possible. This minimizes edge regions where only part of Cherenkov light is coming out. Maximum size for Novosibirsk aerogel is 20x20 cm.
- Accuracy on tile dimensions are about 0.1-0.2 mm. This is required to fit the support frame

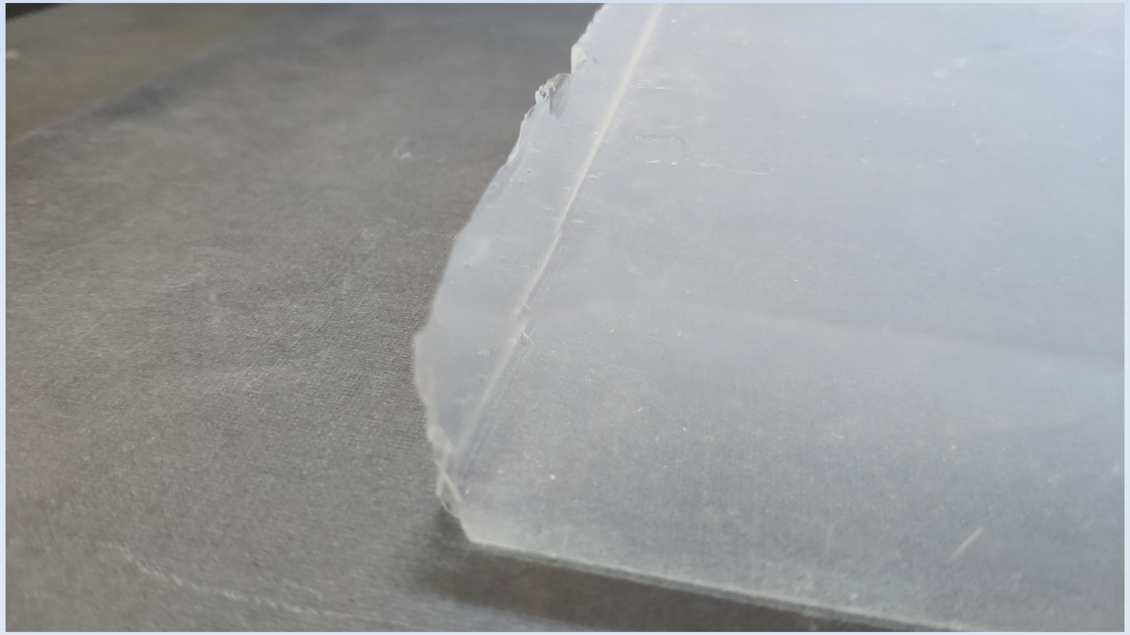


Two 4-layer focusing aerogel blocks 230x230x35 mm



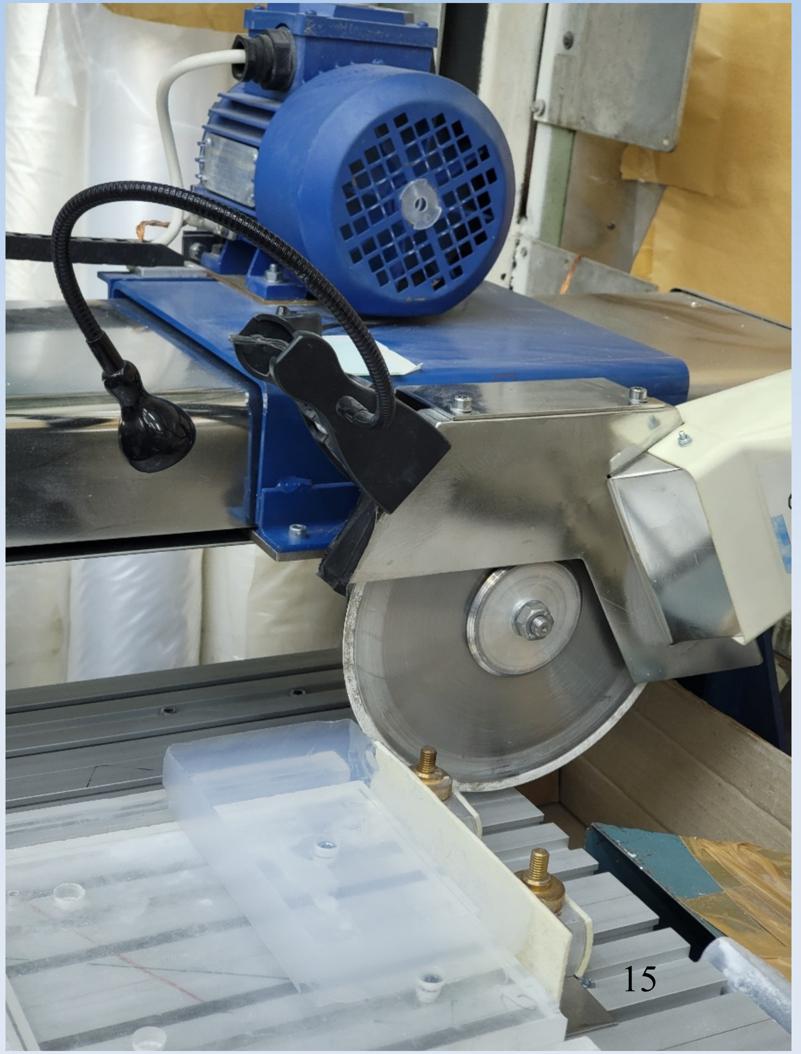
Methods of mechanical processing of the aerogel(1)

- Polishing is used mainly for production of tiles for threshold aerogel counters. Abrasive paper or abrasive wheel can be used.
- After polishing aerogel surface is cloudy. This does not play significant role for threshold counters.



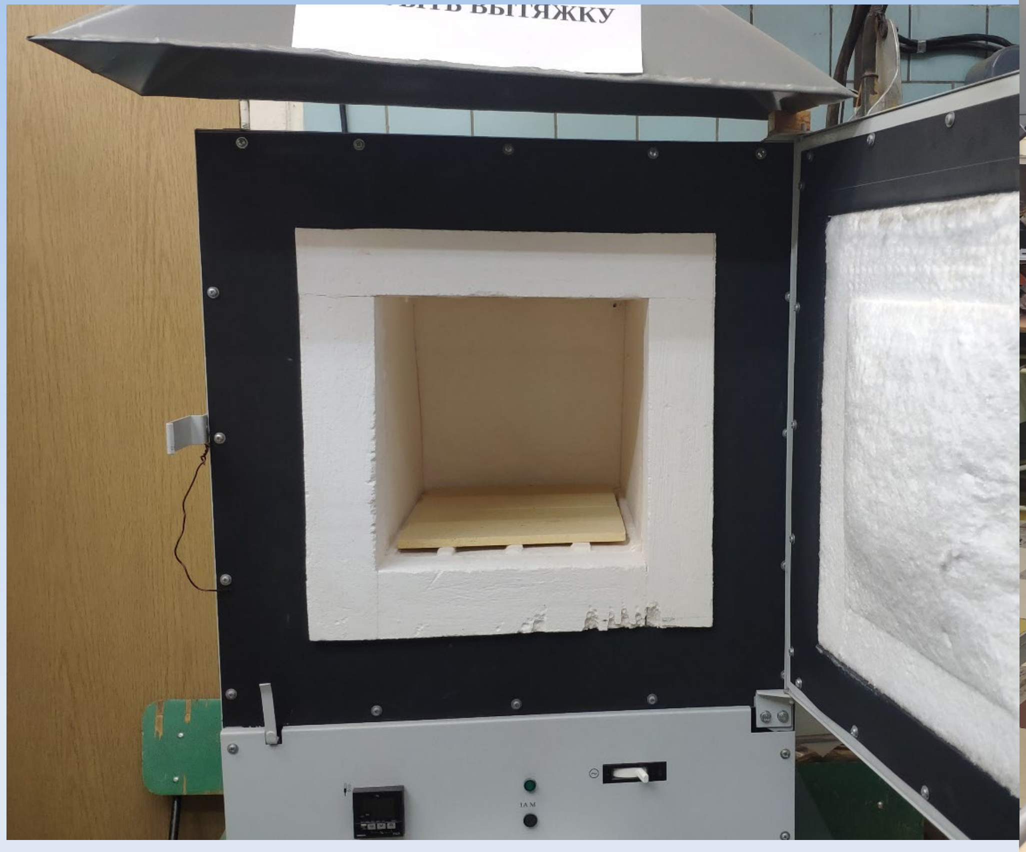
Methods of mechanical processing of the aerogel(2)

- Cutting of aerogel:
  - to give the required size,
  - To remove meniscus, chips and areas with large density variations,
- 2 dimond wheel mashines
  - bottom wheel position and moving table (by hand)
  - top wheel position and fixed table, 2d moving wheel with stepper motor and precise positioning



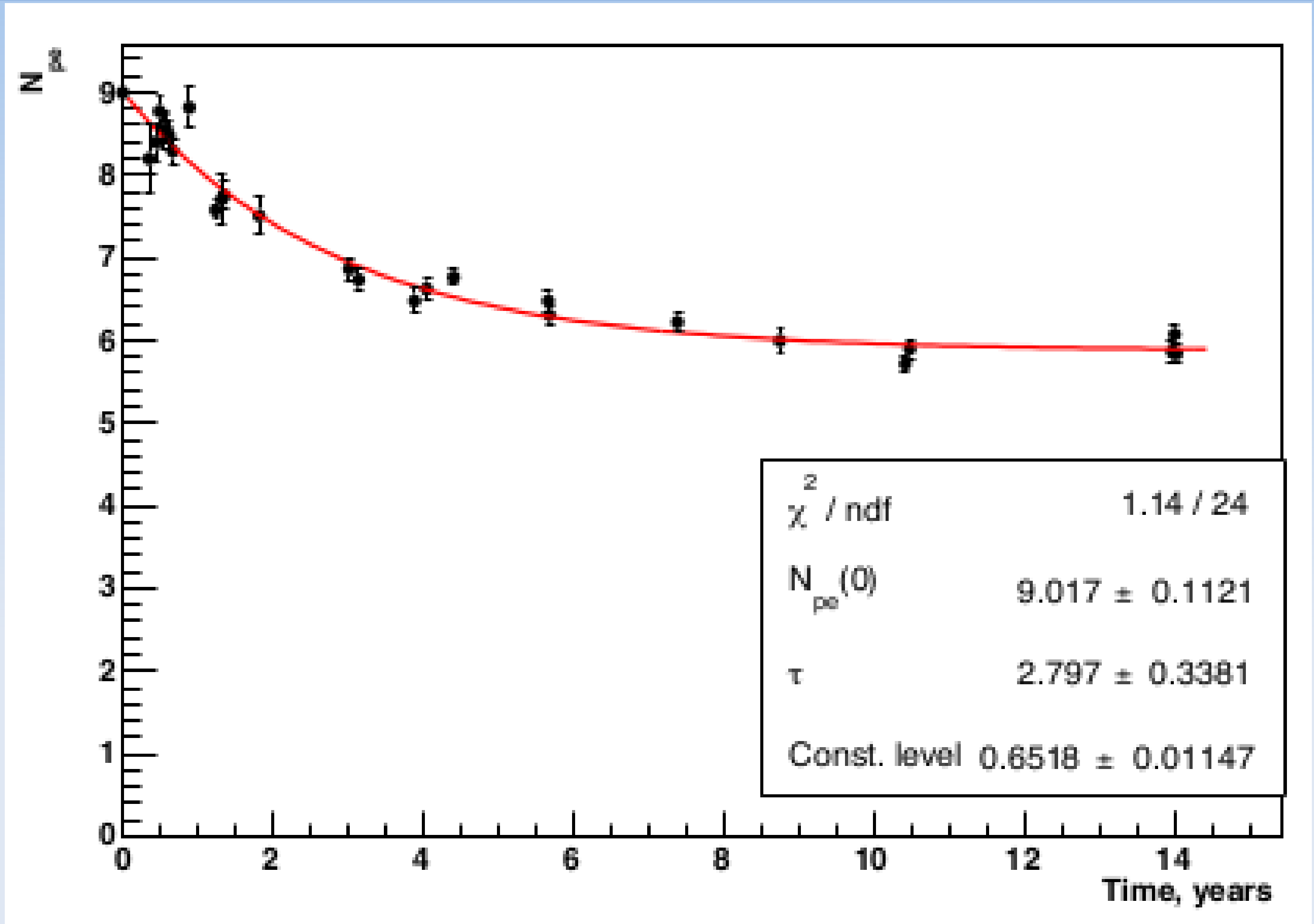
Aerogel storage

- Aerogel produced in Novosibirsk is hygroscopic:
  - To remove absorbed water baking can be used (several hours at 400-500 C). Optical transparency restores to 100%.
  - Aerogel need to be stored in dry conditions. We use dry cabinet (0-2% humidity level)



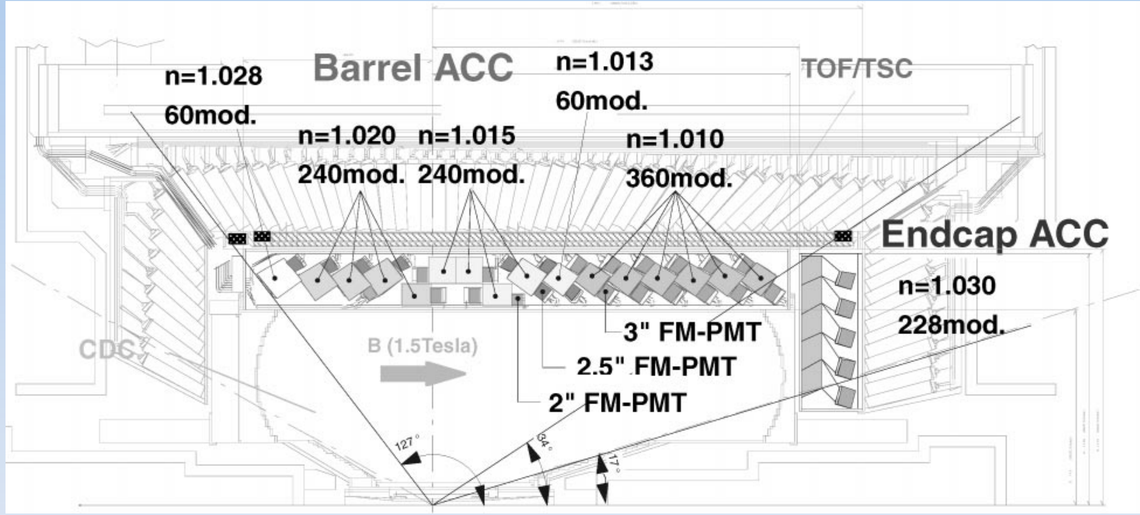
Comparison of “Novosibirsk” and “Chiba University” aerogels(1)

Threshold ASHIPH counters of the KEDR detector are under operation since 2000. From time to time it is tested in Cosmic Ray Telescope (CRT). Its signal degradation now has stabilized at the level of 60% from the initial value. 15% of the drop is due to deterioration in light collection, 15% of the drop is due to deterioration in the QE of the PMT



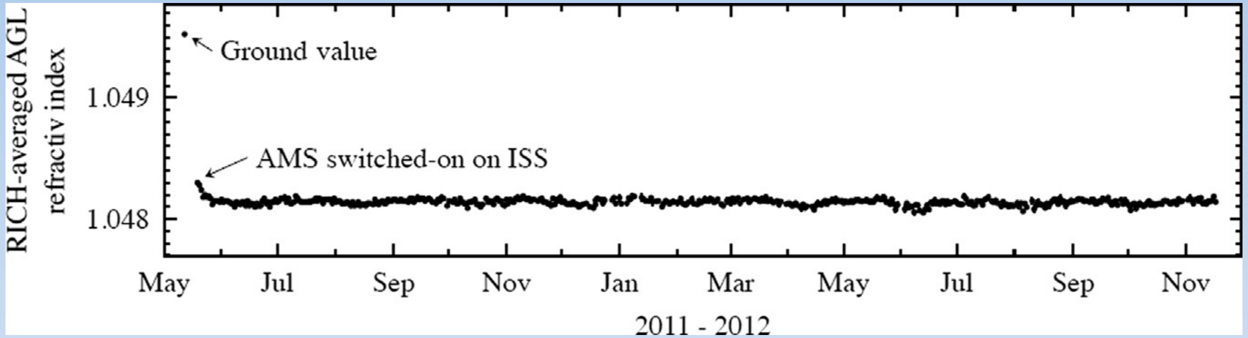
Comparison of “Novosibirsk” and “Chiba University” aerogels(2)

Hydrophobic aerogel



Belle ACC → **no degradation**

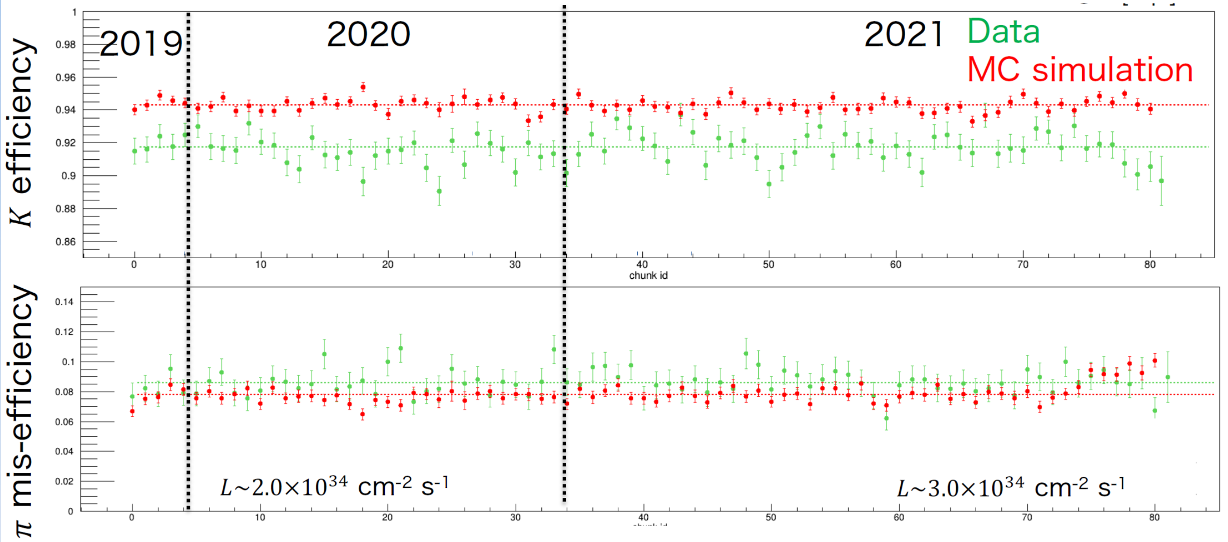
Hygroscopic aerogel



AMS-02 RICH → **no degradation**

Comparison of “Novosibirsk” and “Chiba University” aerogels(2)

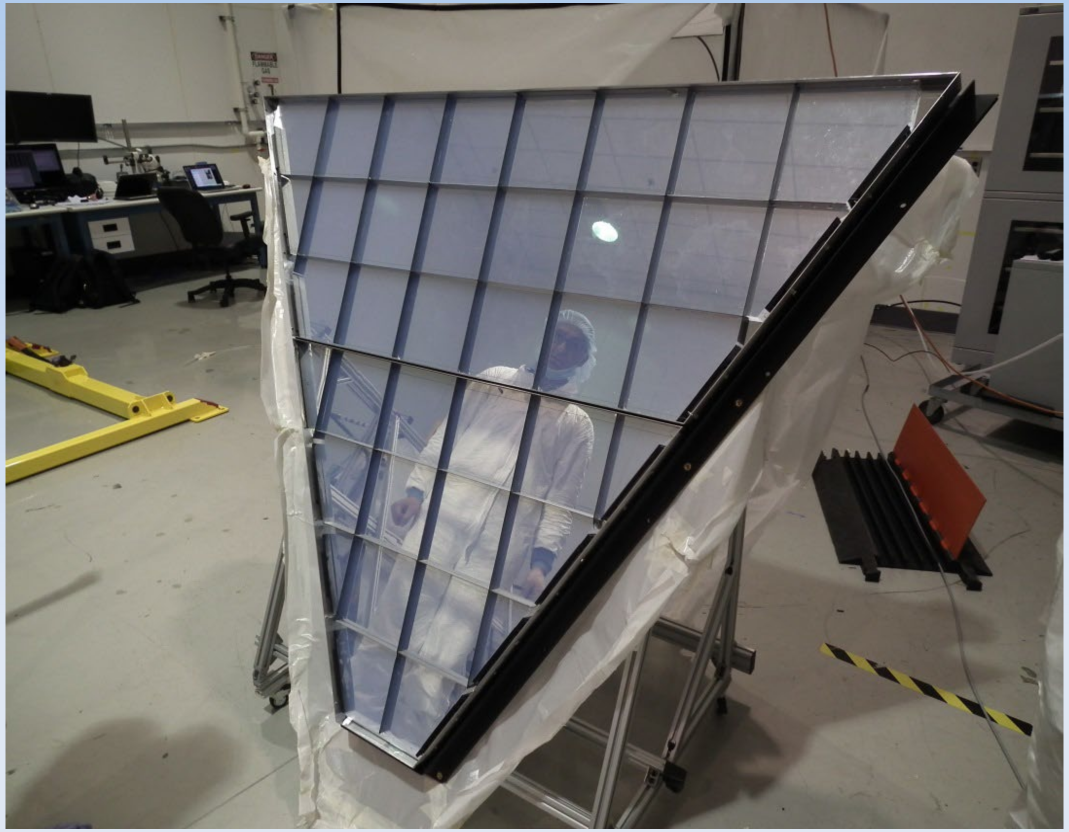
Hydrophobic aerogel



Belle II ARICH → **no degradation**

Lsc(400) = 40 mm

Hygroscopic aerogel

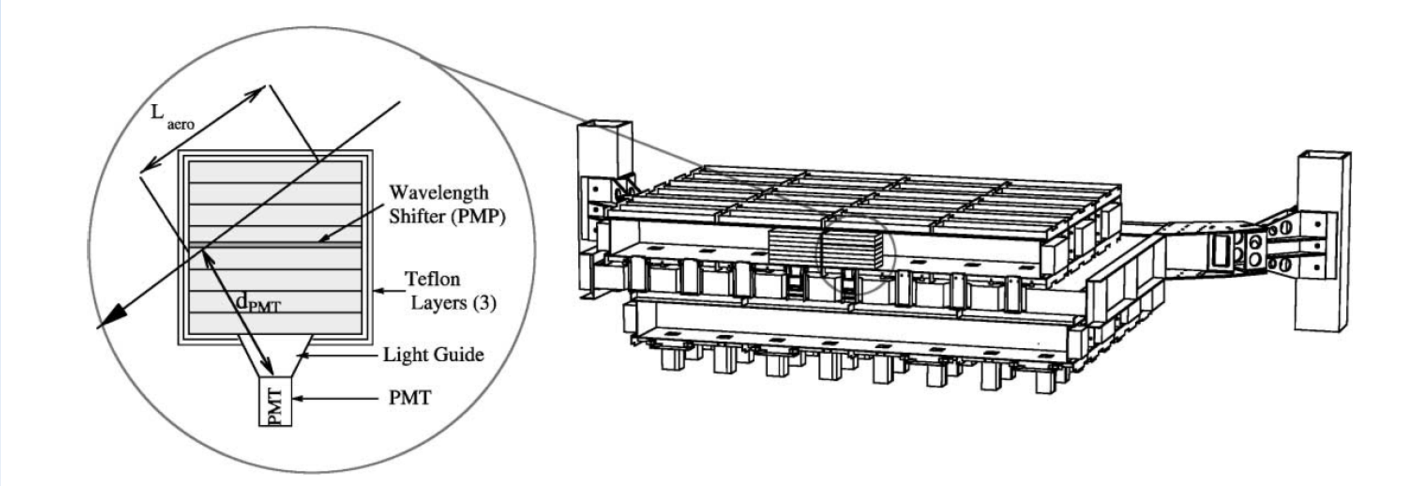


CLAS12 RICH → **4—9% drop after 4 years (aerogel+PMT)**

Lsc(400) = 50 mm

Comparison of “Novosibirsk” and “Chiba University” aerogels(2)

Hydrophobic aerogel



“irreversible optical losses and mechanical degradation are induced by pefluorocarbons and liquid alcanes.”
A.K. Gougas et.al., NIMA421(1999)249

The hygroscopic aerogel has survived after the strong absorbtion of C4F10 in LHCb RICH.

AMS-01 ATC → **70% drop from 5 pe to 1.5 pe after 1 year**

Comparison of "Novosibirsk" and "Chiba University" aerogels(3)

Hydrophobic aerogel

PROS

- Good stability

CONS

- Maximum thickness 20 mm
- Minimal refractive index n = 1.012 (?)

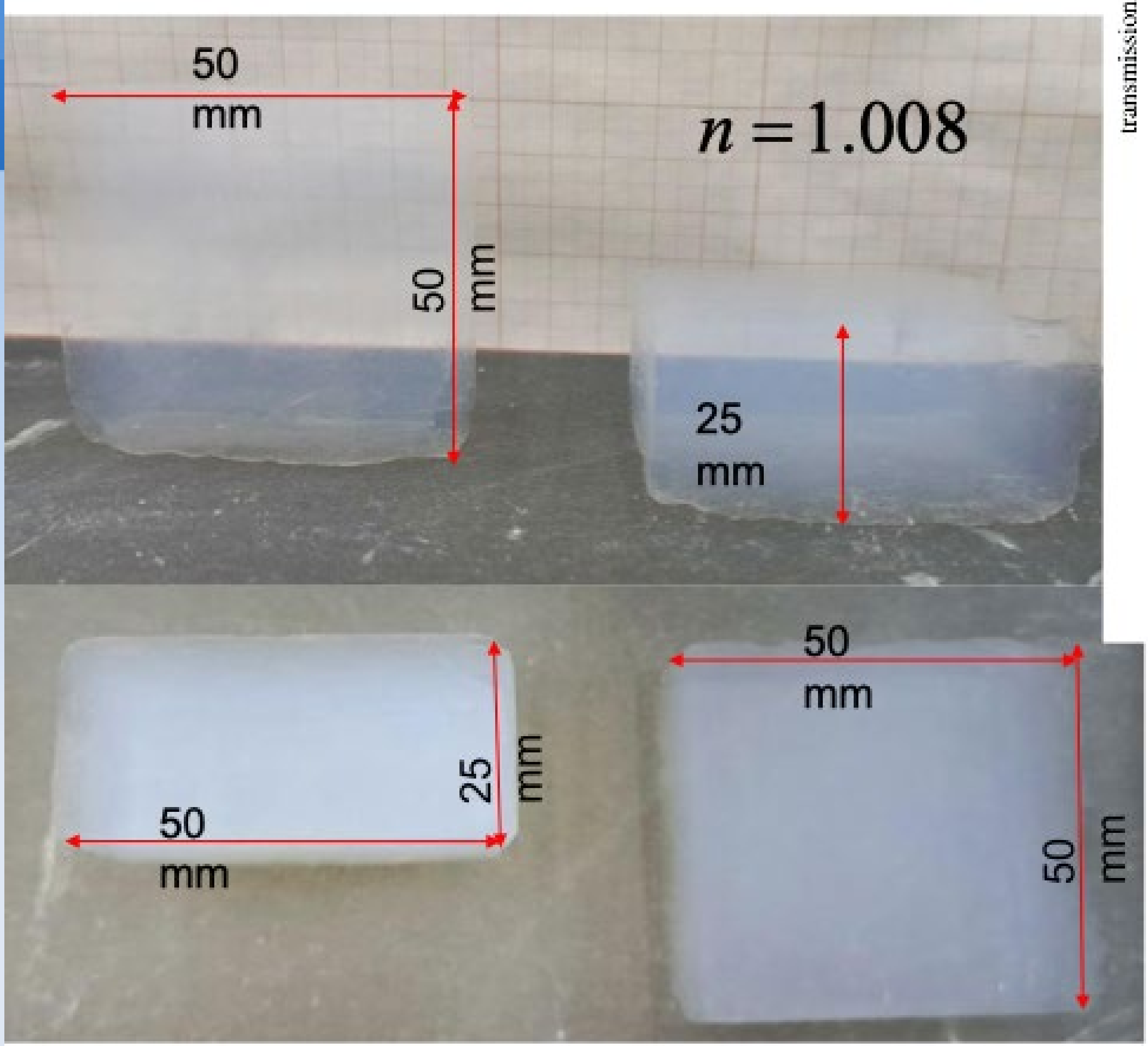
Hygroscopic aerogel

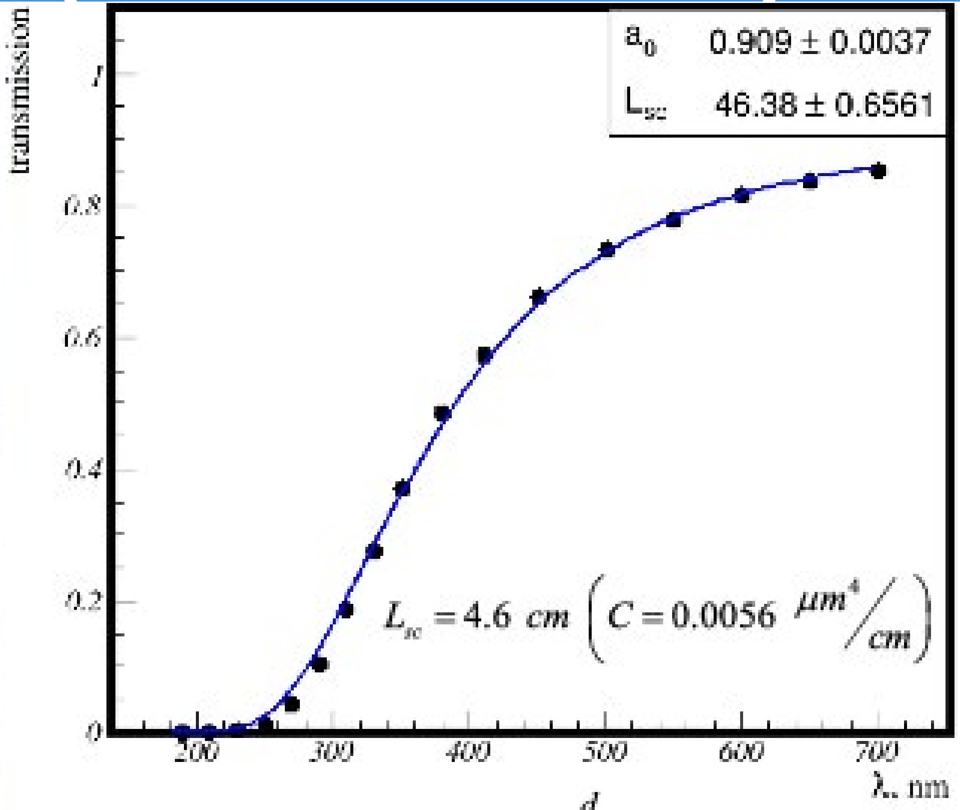
PROS

- Good transparency
- Maximum thickness 50 mm
- Low refractive index n < 1.008
- **CONS**
- Moderate stability

Beam tests of aerogel RICH with n=1.008 aerogel

Aerogel with n=1.008 (Novosibirsk)

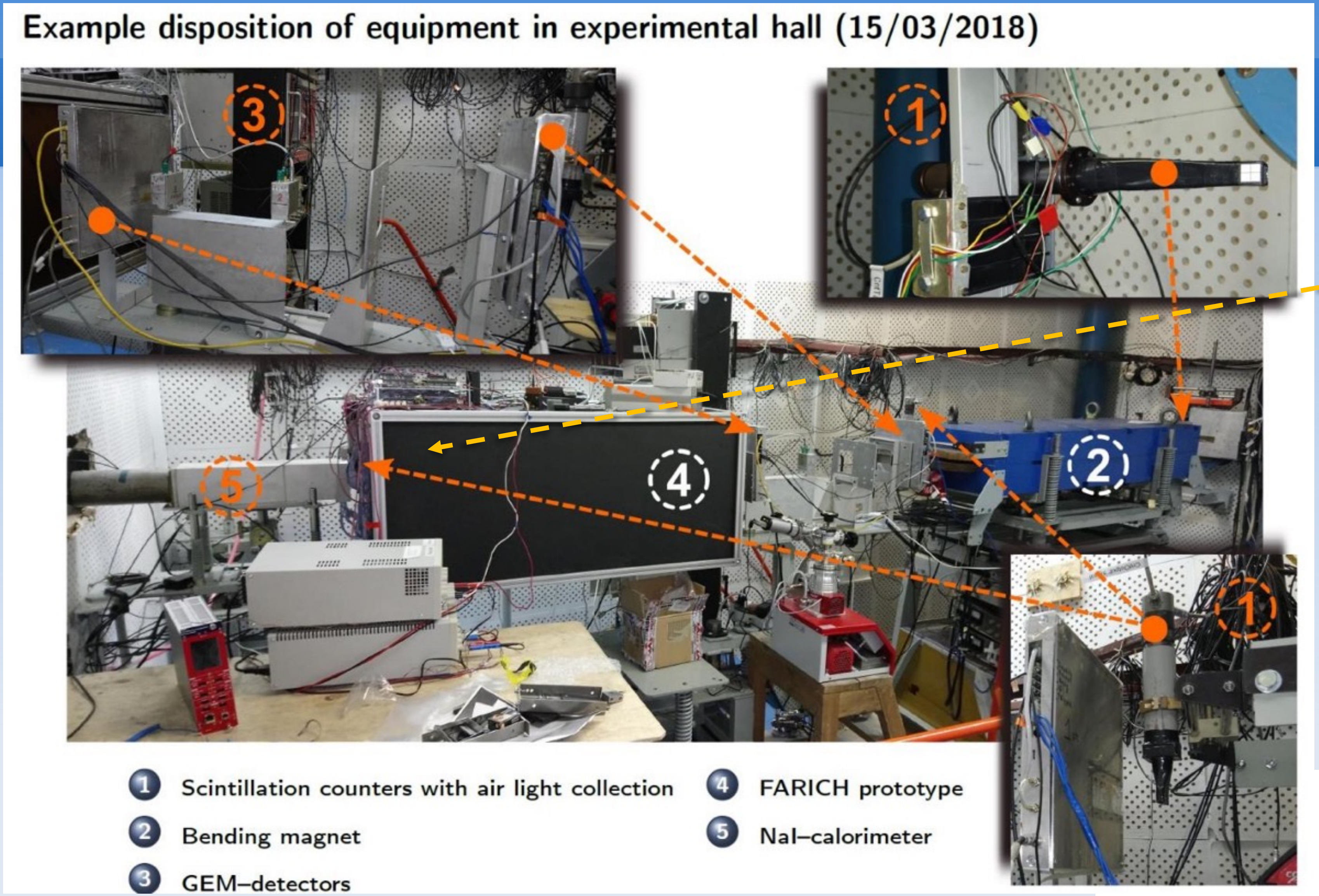


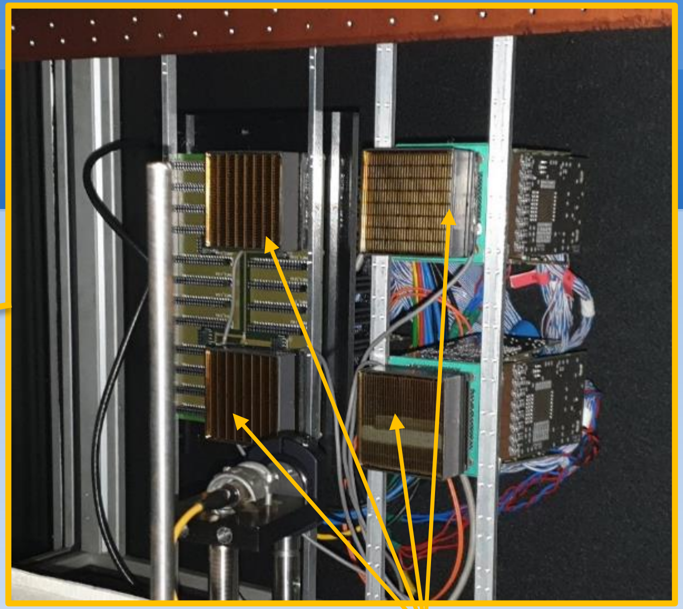


$$T = \frac{I}{I_0} = a_0 \cdot e^{-\frac{d}{L_{sc}\cdot\left(\lambda/400\right)^4}} = a_0 \cdot e^{-\frac{C\cdot d}{\lambda^4}}$$

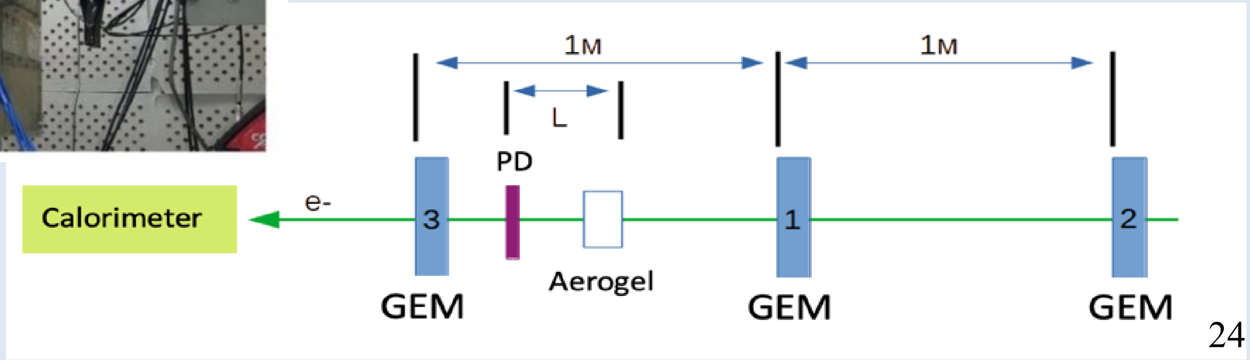
d – thickness of a sample,
λ – wavelength in nanometers,
Lsc – scattering length at 400 nm,
a_0 – surface scattering coefficient,
C – clarity coefficient

BINP beam test facility



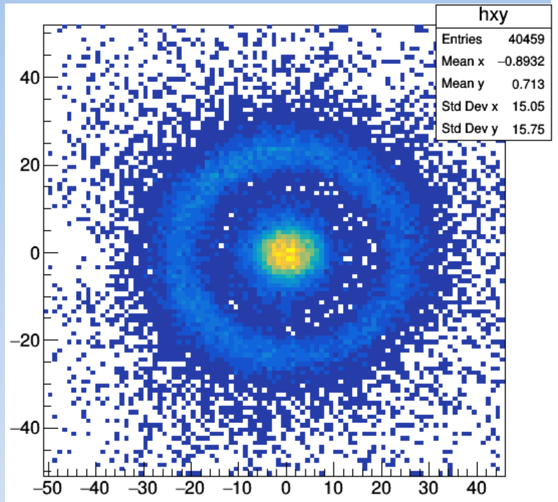


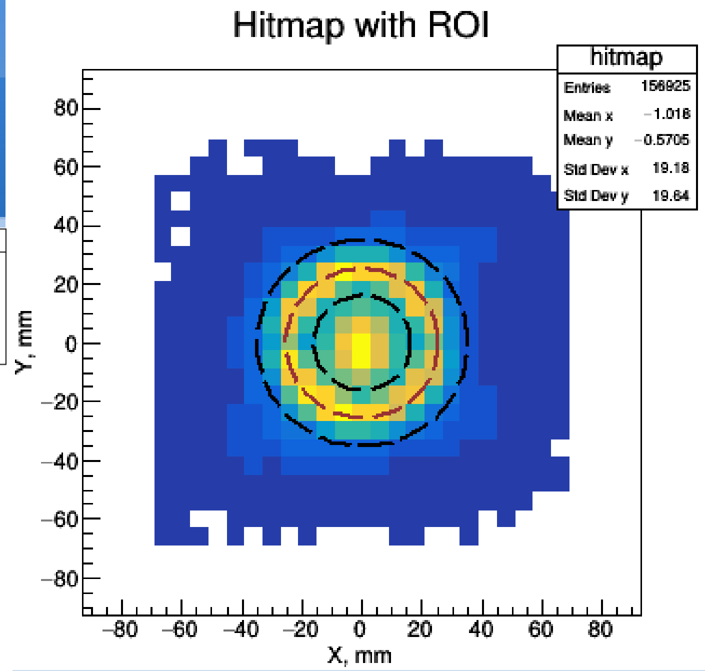
*G N Abramov et al 2014 JINST **9** C08022*

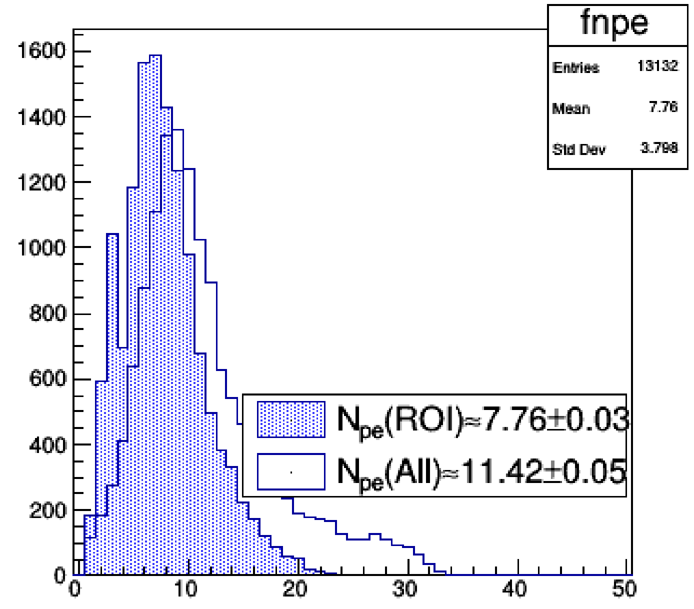


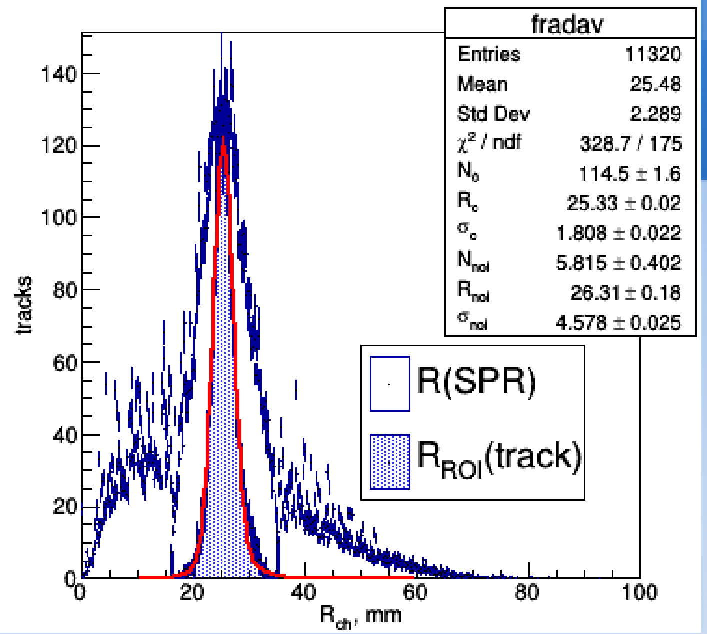
RICH based on aerogel n=1.008: some beam test results

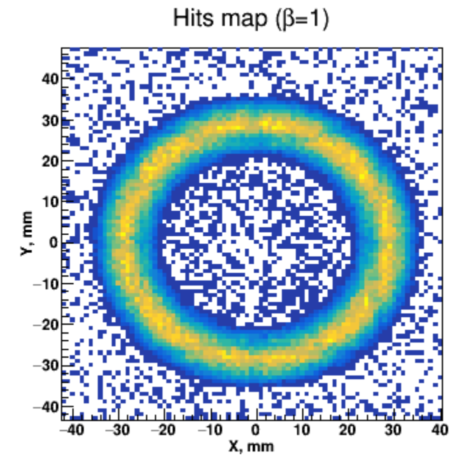
Tbeam e⁻@2.5GeV
- t_{aer}=25+25=50 mm
- L_F=200 mm









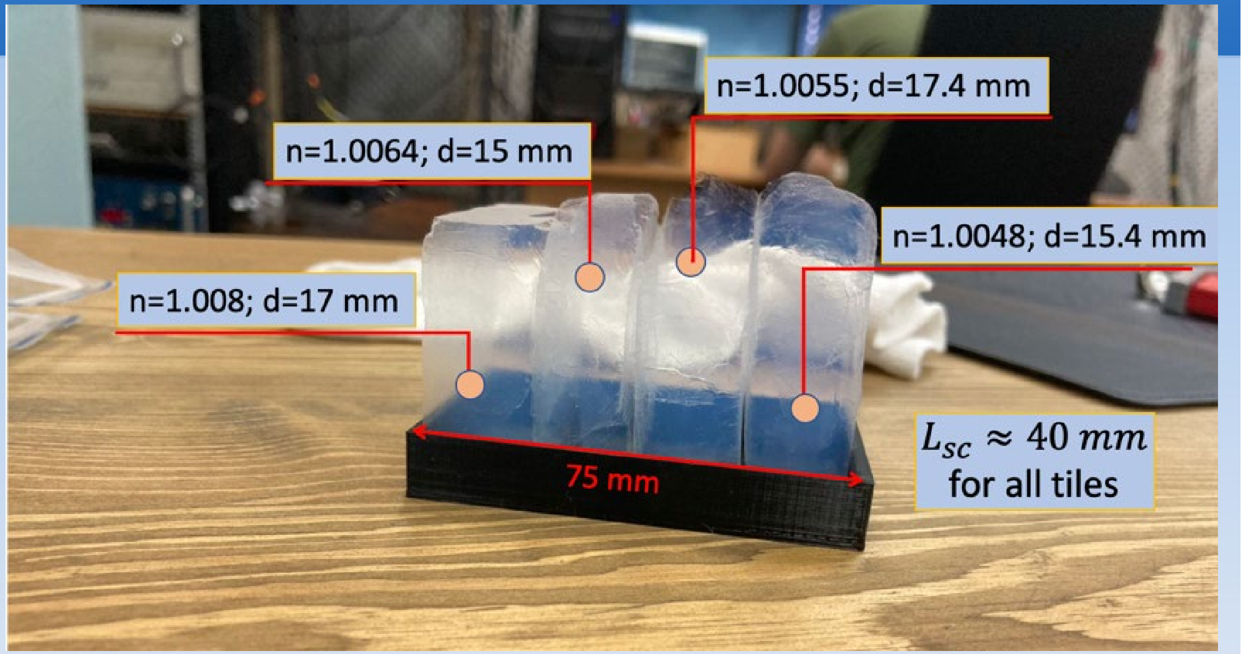


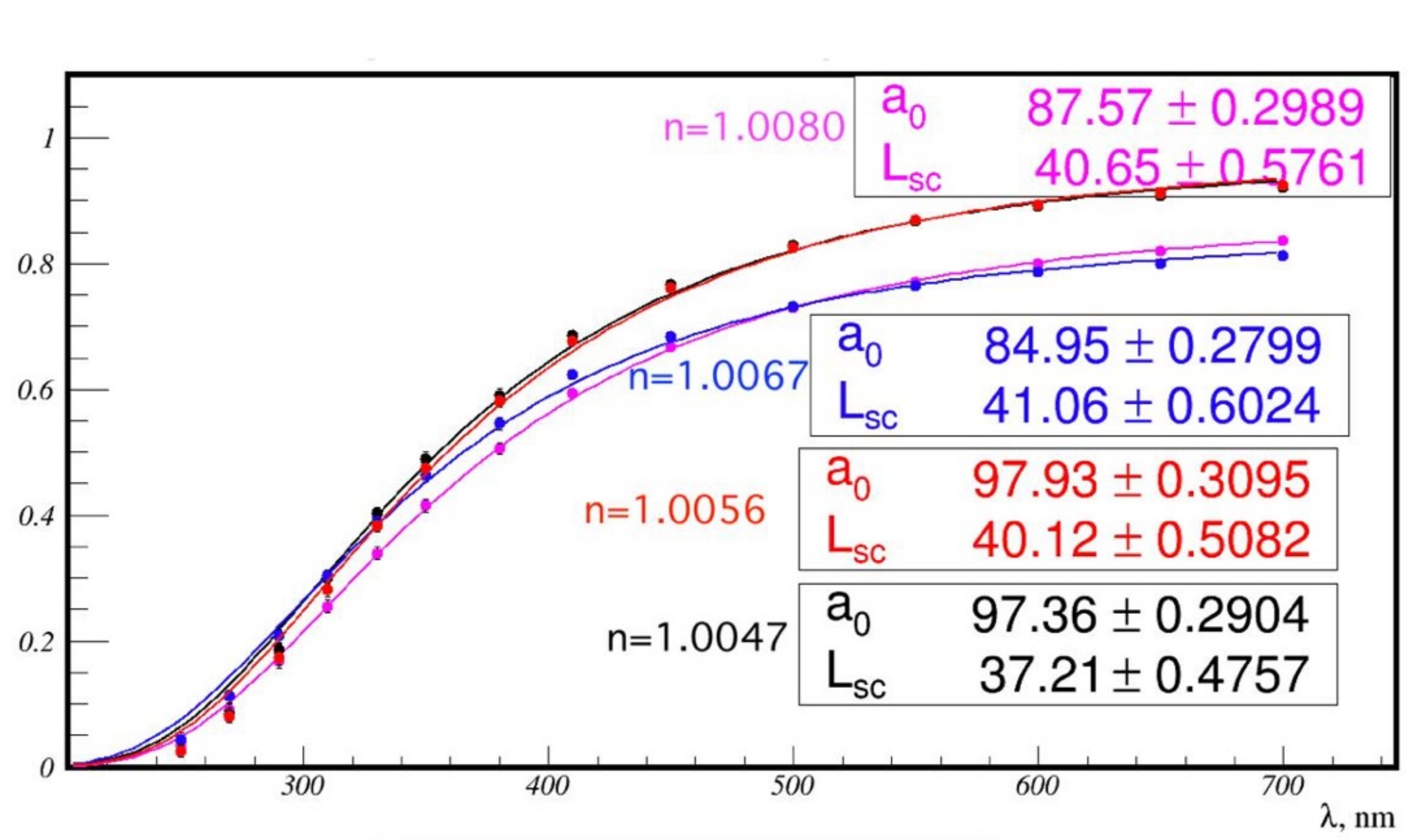
Geant4 sim.:
- t_{aer}=60 mm
- L_F=250 mm

TBeam results reconstructed w/o track information:
- MaPMT H12700 with QE(400nm) ≈ 20%
- Pixel 6x6 mm
- Aerogel:
  - stack of 3 tiles 25+25+25=75 mm
  - refractive index n≈1.008
- L_F=235 mm

OUTPUT:
- SiPM based photon detector with PDE(400nm)=45÷50% will alow us to detect 10÷20 ph.e. for relativistic tracks
- ***Proximity focusing system and PD with $\sigma_x \leq 1\,mm$ is required to reach π/K-separation above 20 GeV/c***

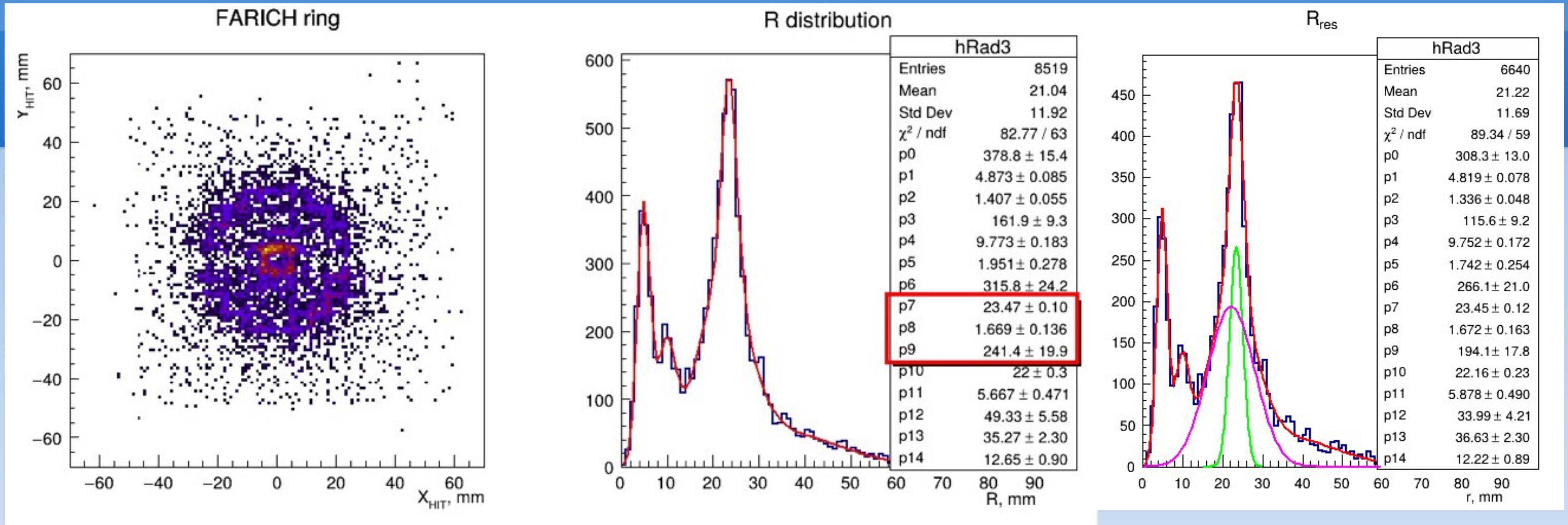
Some practical results of 2025

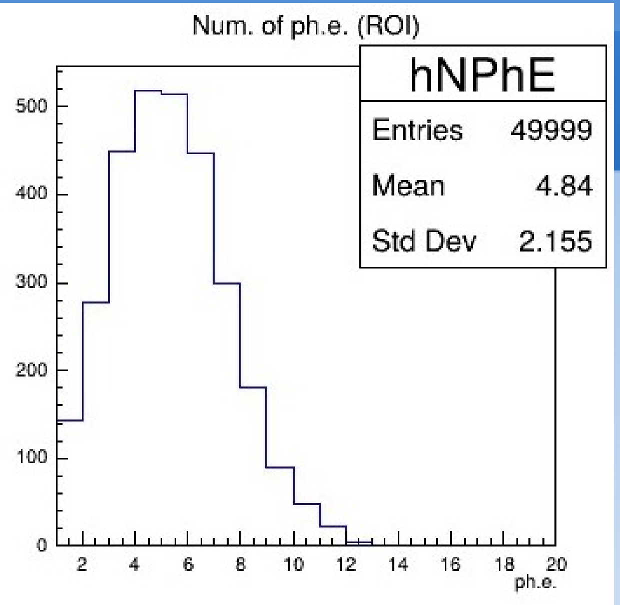


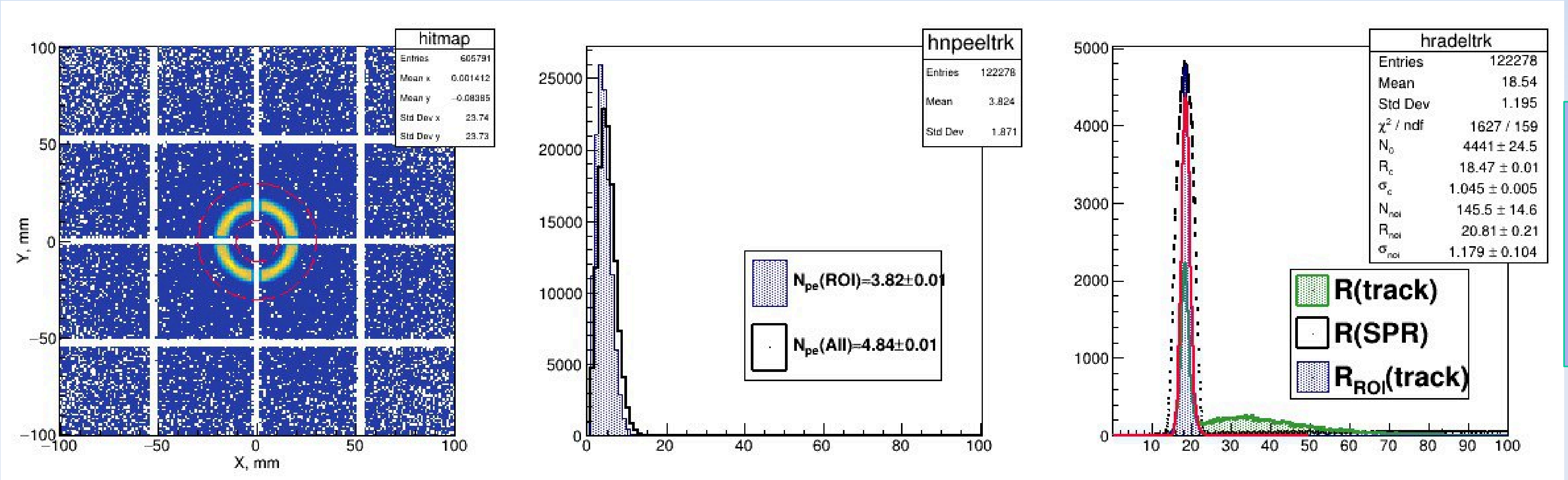


In 2025 for the first time ultra-light SiO_2 aerogels with high transperancy were produced in Novosibirsk!

Ultralight aerogel FARICH beam test results and G4sim.







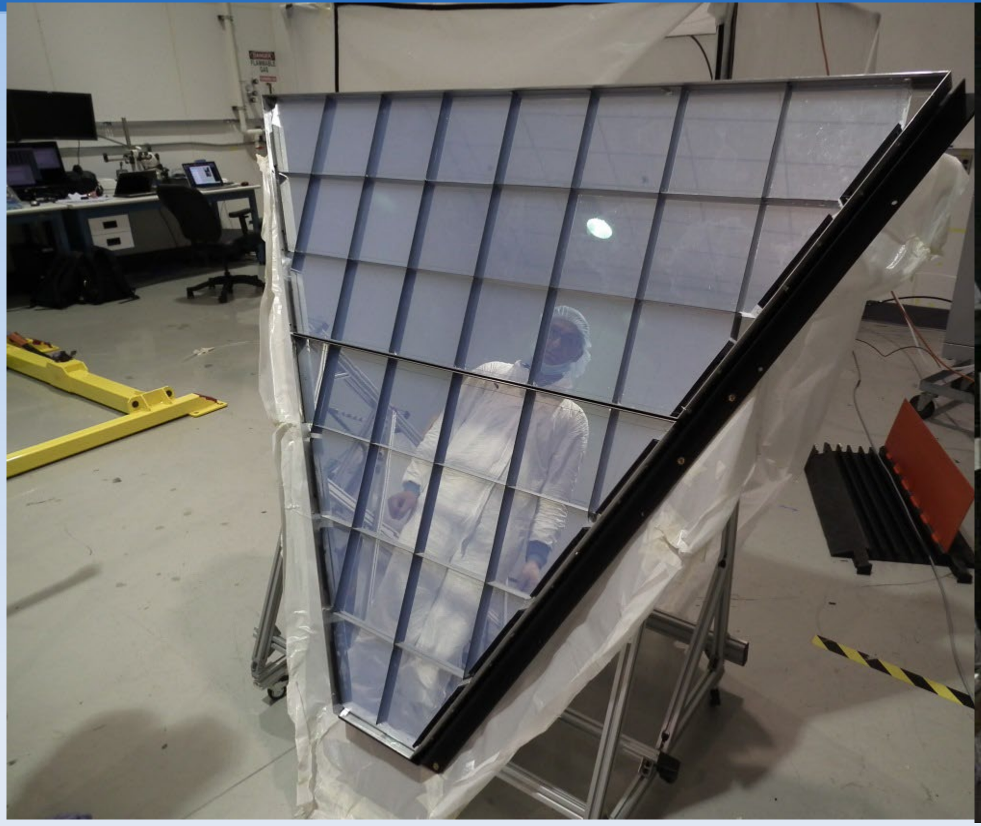
- More or less good agreement between G4sim and TBeam is observed.
- We need to use another type of PMT instead of flat-panel H12700 (Hamamatsu).

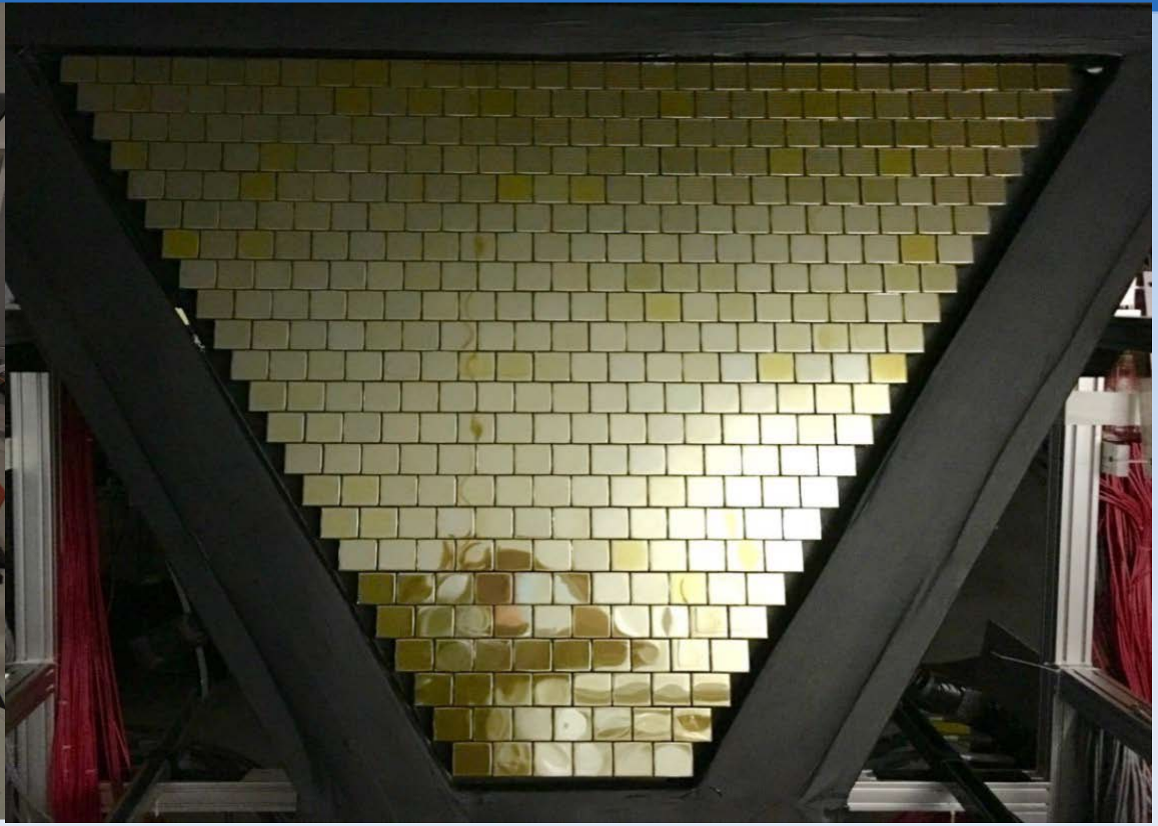
Summary

- The FARICH PID option based on light aerogel (n ≤ 1.008) could provide π/K identification upto 28 GeV/c momentum
- Advantages of “Novosibirsk” aerogel:
  - Better transparency Lsc (400nm) ≥ 40 mm
  - Thickness of a single tile up to 50 mm
  - Low refractive index n ≤ 1.008
- Advantages of “Chiba University” aerogel:
  - Hydrophobic (limited water absorption, easier storage and handling)
- Beam tests with RICH prototype approve that it is possible to get Npe ≥ 10 with light aerogels
- Single photon detection is needed with special resolution ~300 μm

Additional slides

Aerogel RICH for CLAS12



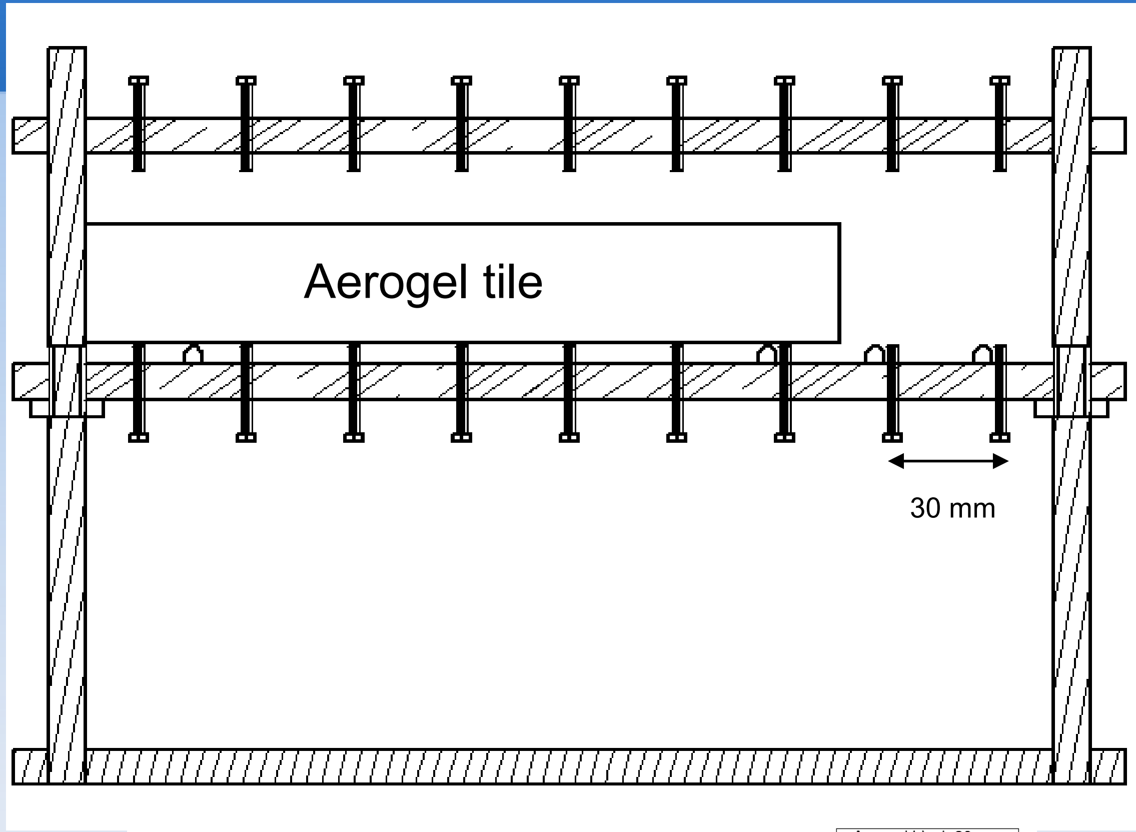


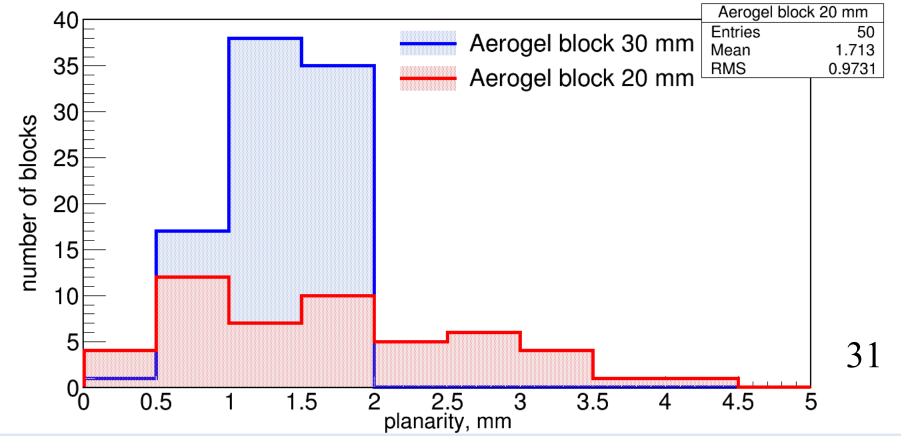
Requirements on aerogel tiles for use in Ring Imaging Cherenkov counters(4)

- RICH can also measure charge of the particle (AMS02). The variations of the thickness of the tile must be as law as possible (<0.2 mm for AMS02).

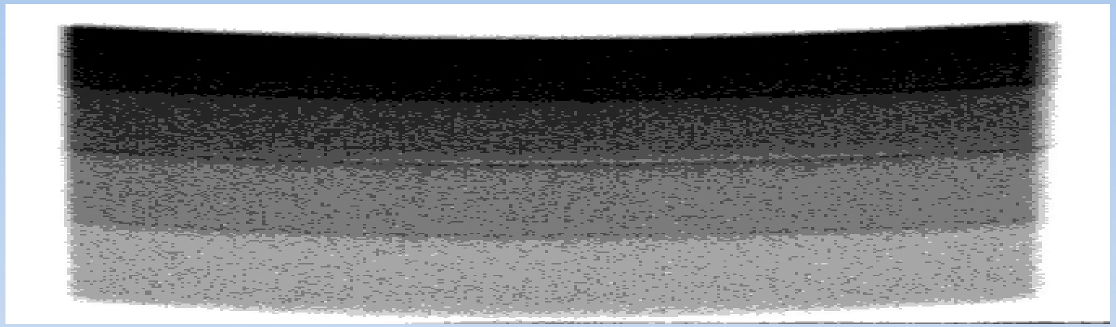
$$I_{Ch} \sim z^2 \cdot h$$

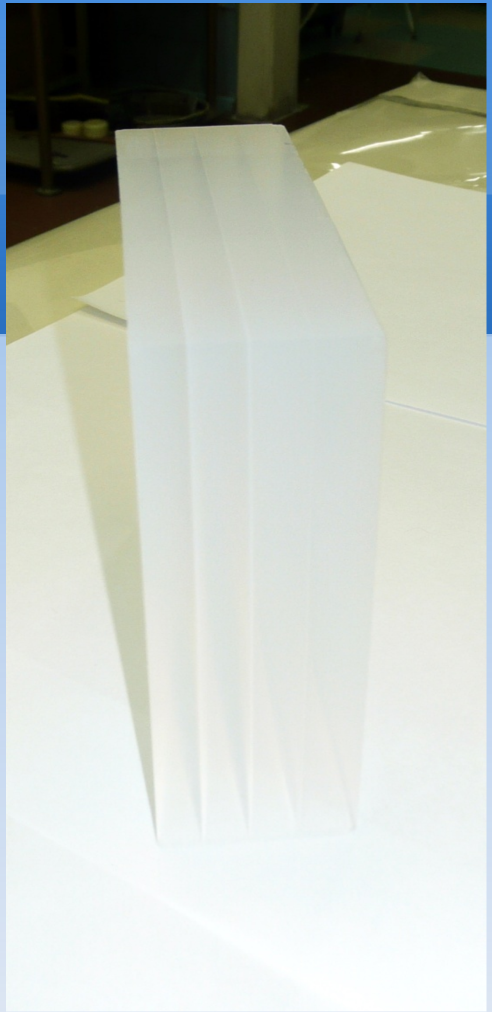
- The bottom surface of the tile can be cut with dimond wire to satisfy this requirement
- The unflatness (planarity) of aerogel surface can affect accuracy of Cherenkov angle measurement.
- Special touch stand was developed to measure thickness and planarity of the tile. For 30 mm thickness CLAS12 tiles height difference does not exceed 2 mm.





Aerogel sample





	n	h, mm
Layer 1	1.050	6.2
Layer 2	1.041	7.0
Layer 3	1.035	7.7
Layer 4	1.030	9.7

- $100x100x31\ mm^3$
- Lsc(400nm)=43 mm
- $n^2=1+0.438*\rho$

Aerogel degradation due to water adsorption(2)

- The refractive index (n-1) and light scattering length depends on amount of adsorbed water and are changed less than 10% after water adsorption of 2-4% of aerogel mass.
- The light absorption length (L_{abs}) in different aerogel samples after baking is the same, but after water impregnation could be very different
- It is possible to make aerogel selection after water impregnation
- One atom Fe is able to attract 6 molecules of water
- To achieve maximum degradation of L_{abs} it is enough to adsorb 1ppm of water.

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