Technological and physical aspects of the production of aerogel radiators for Cherenkov detectors of various types.

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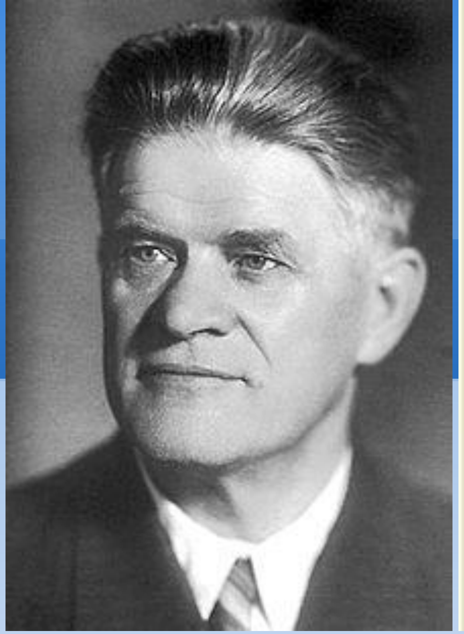
Outline

- Introduction: Cherenkov radiation and aerogel
- Requirements on aerogel tiles for use in threshold Cherenkov counters
- Requirements on aerogel tiles for use in Ring Imaging Cherenkov counters
- Examples of used machining methods
- Conclusions

Cherenkov radiation and aerogel



Pavel Alekseevich Cherenkov

Samuel Stephens Kistler

$$\cos\theta = \frac{1}{n\beta}, \qquad \beta = \frac{v}{c} \qquad\qquad \frac{d^2N}{dx d\lambda} = \frac{2\pi\alpha z^2}{\lambda^2}\left(1 - \frac{1}{\beta^2 n^2(\lambda)}\right)$$

⇒ $P_{thr} = \frac{mc}{\sqrt{n^2 - 1}}$

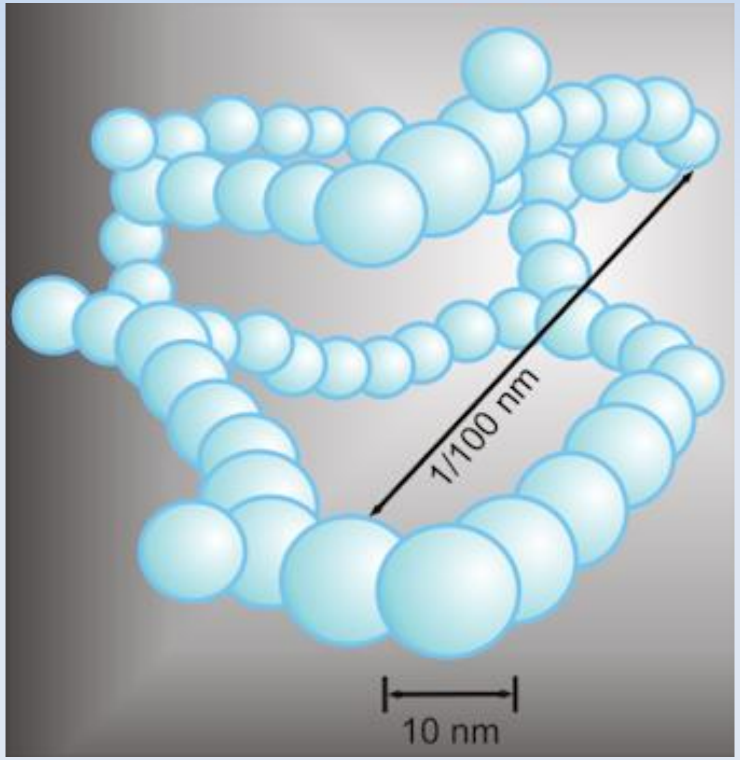
⇒ $n \sim 1.1 - 1.01$ (for $P_{thr}(\pi, K, p)$ in the 1-10 GeV/c region)

Silica Aerogel

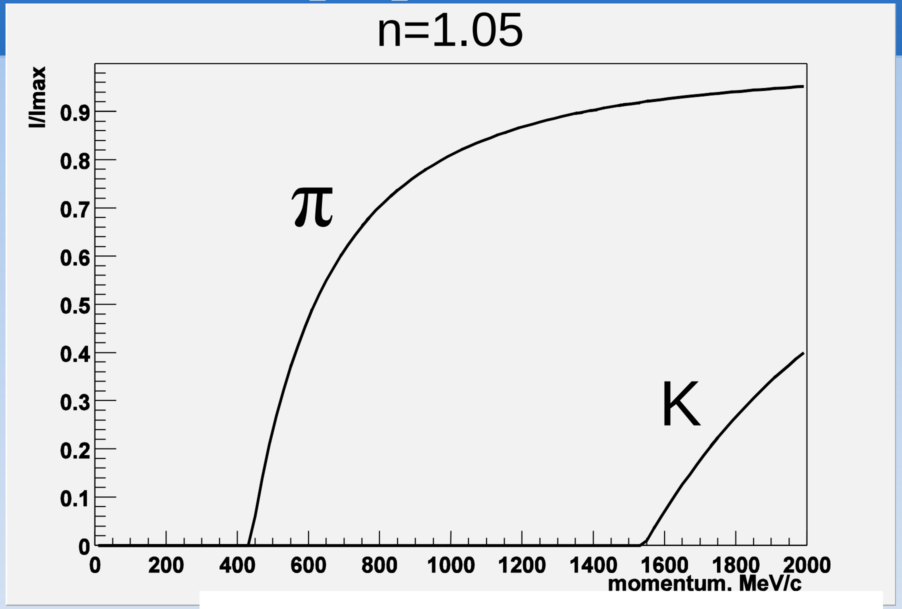
- porous material with pore dimension less than visible light wavelength.

⇒ $n \approx 1 + 0.2 * \rho[g/cm^3]$ ⇒ $\rho \approx 0.05 - 0.5\ [g/cm^3]$

⇒ Aerogel is a **light fragile** material with **strong Rayleigh scattering** of light which **easily absorb gases and vapors**.



Requirements on aerogel tiles for use in threshold Cherenkov counters (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

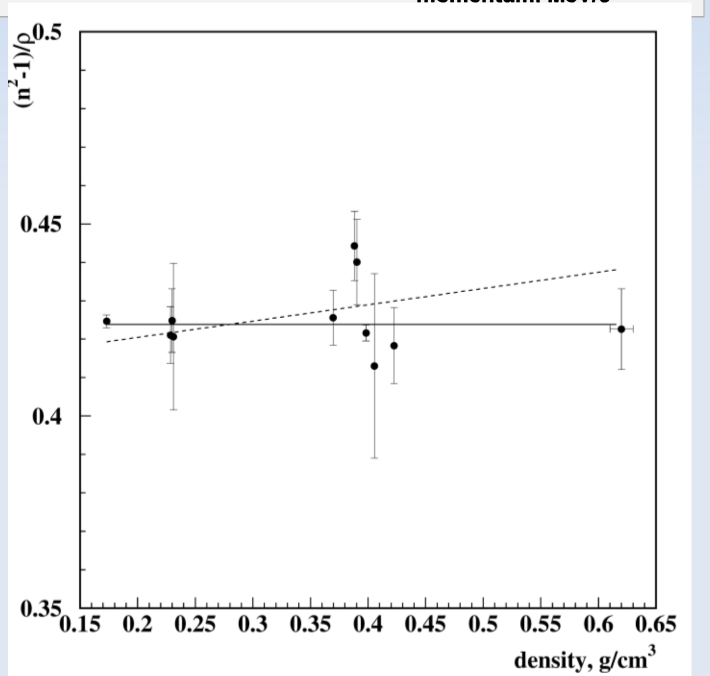
$$I_{Ch} \sim z^2 \left(1 - \frac{1}{n^2\beta^2}\right) \text{ if } \beta\to 1,\ (n-1) \ll 1 \implies I_{Ch} \sim \rho$$

Variation of index of refraction from tile to tile:

- in one counter 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 counter.
- The momentum of the Cherenkov threshold is also vary – this does not matter because it is out of working region

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

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



Requirements on aerogel tiles for use in threshold Cherenkov counters (2)

At λ=400 nm

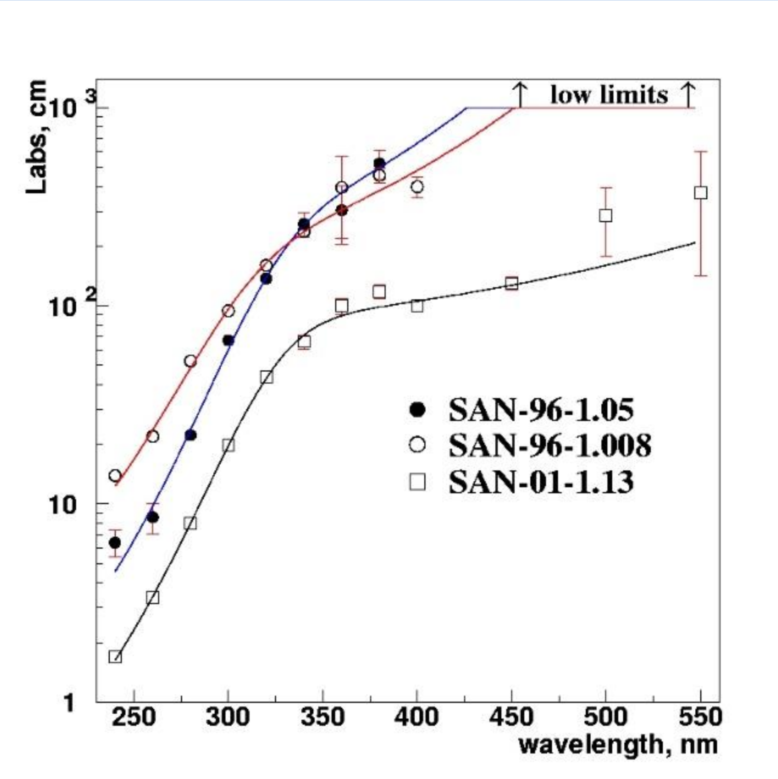
- L_{sc}~ 40 mm, L_{abs}~ 4-5 m

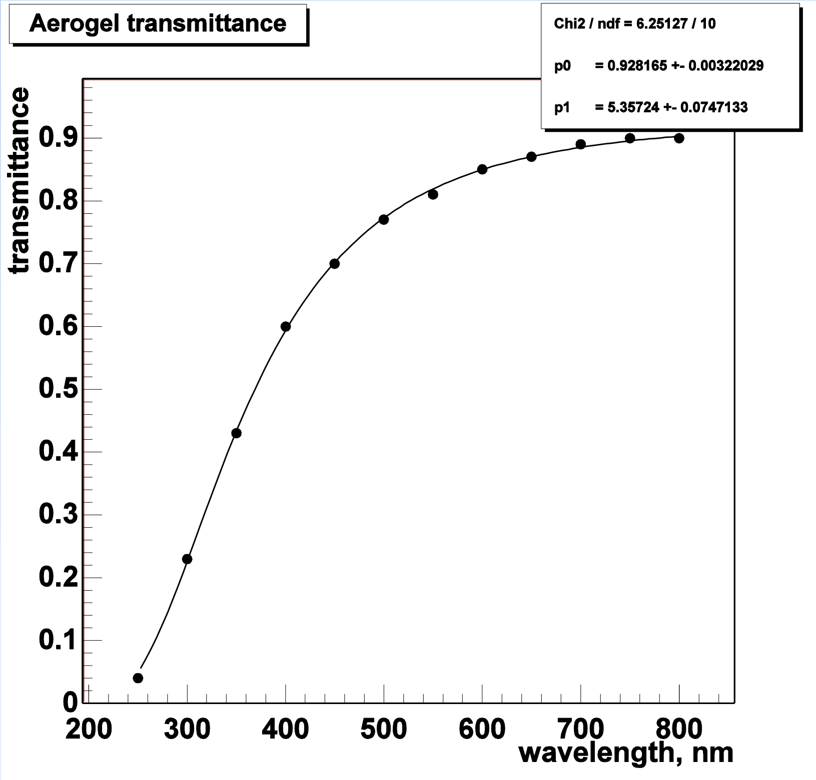
At λ=300 nm

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

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

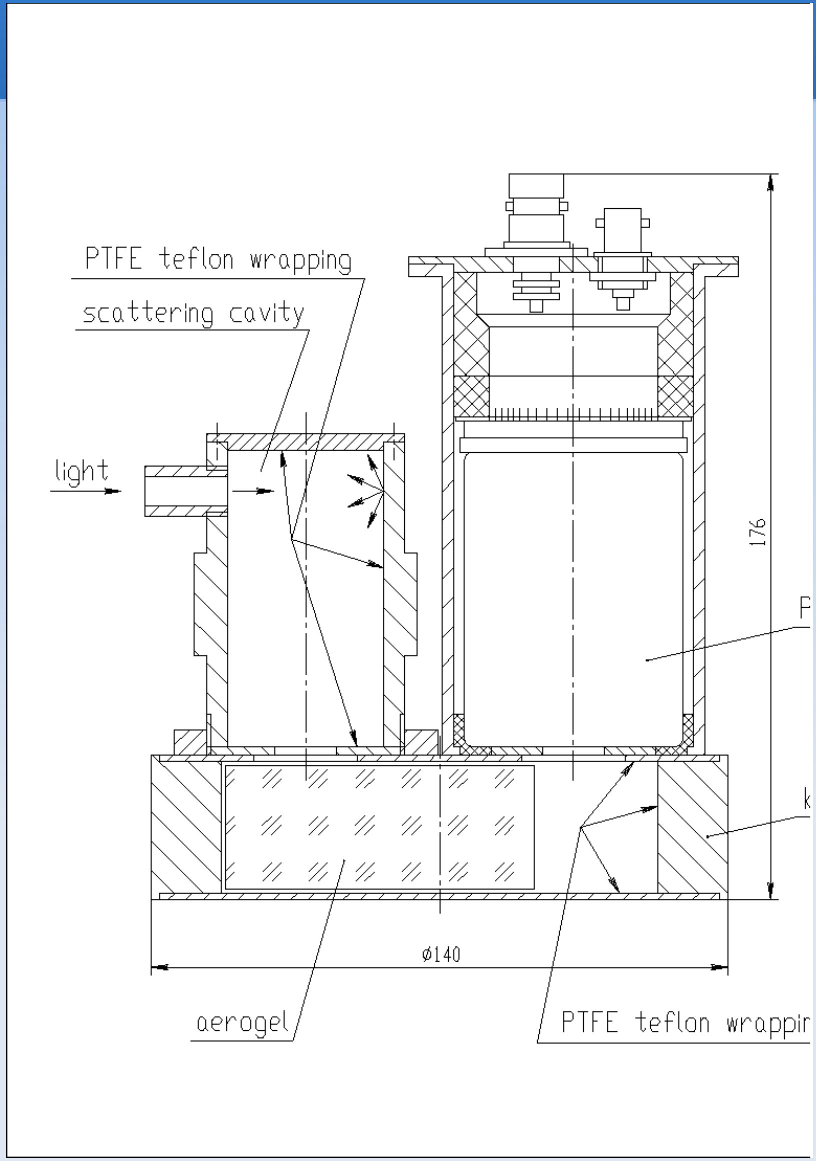
In aerogel counters with the diffusive light collection the light absorption in aerogel is the main effect defining the number of detected Cherenkov photons.

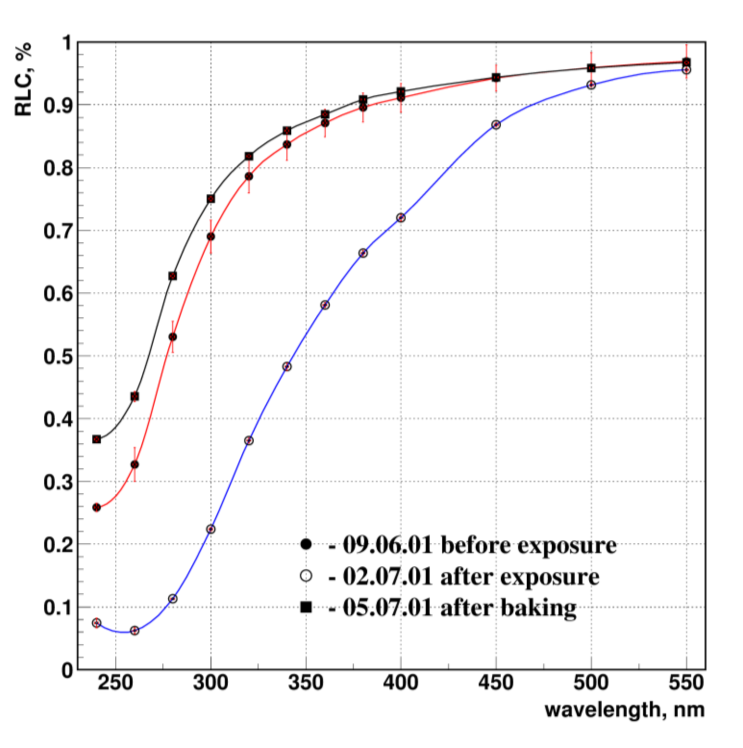




Requirements on aerogel tiles for use in threshold Cherenkov counters (3)

- The method was developed for the measurement of the light absorption length in aerogel.
- The simplified stand for relative control of the light absorption in each tile was used for entrance quality control. More than 15000 tiles were tested for KEDR ATC system.



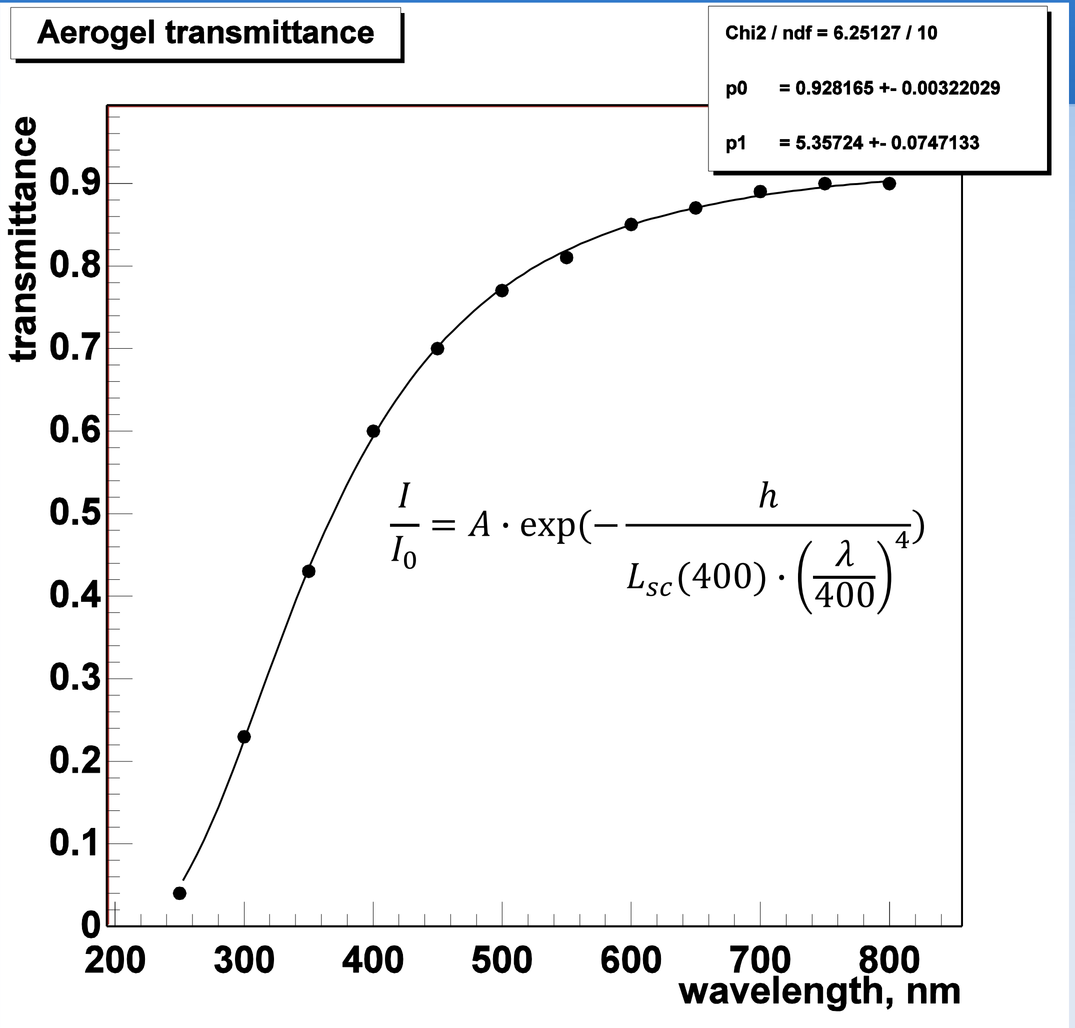


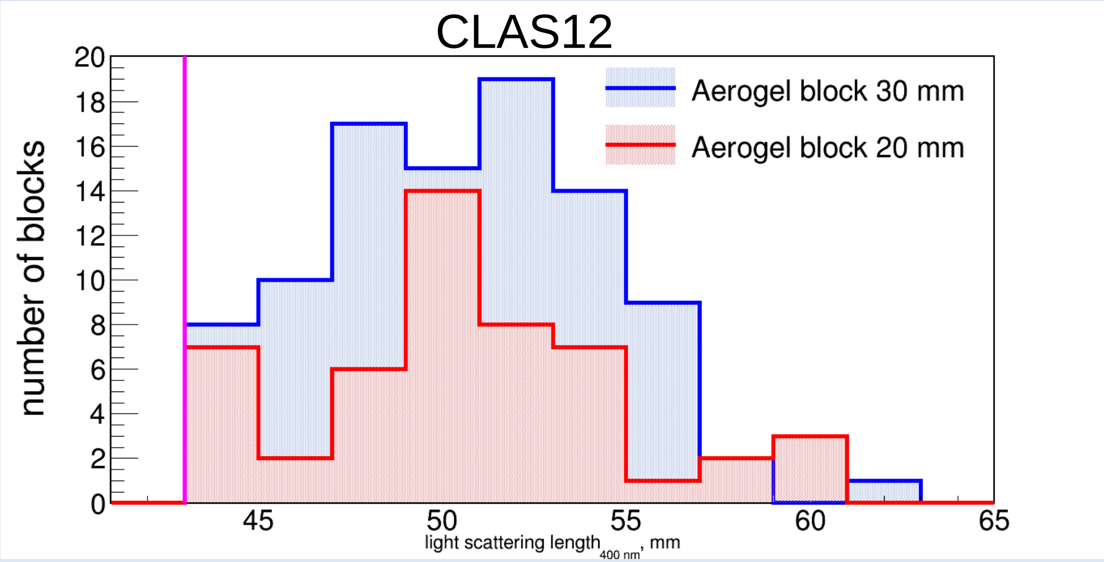
Requirements on aerogel tiles for use in Ring Imaging Cherenkov counters(0)

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 ~ 4 cm must be about 3-4 cm.
- There are no requirements on L_{abs} for RICH detectors

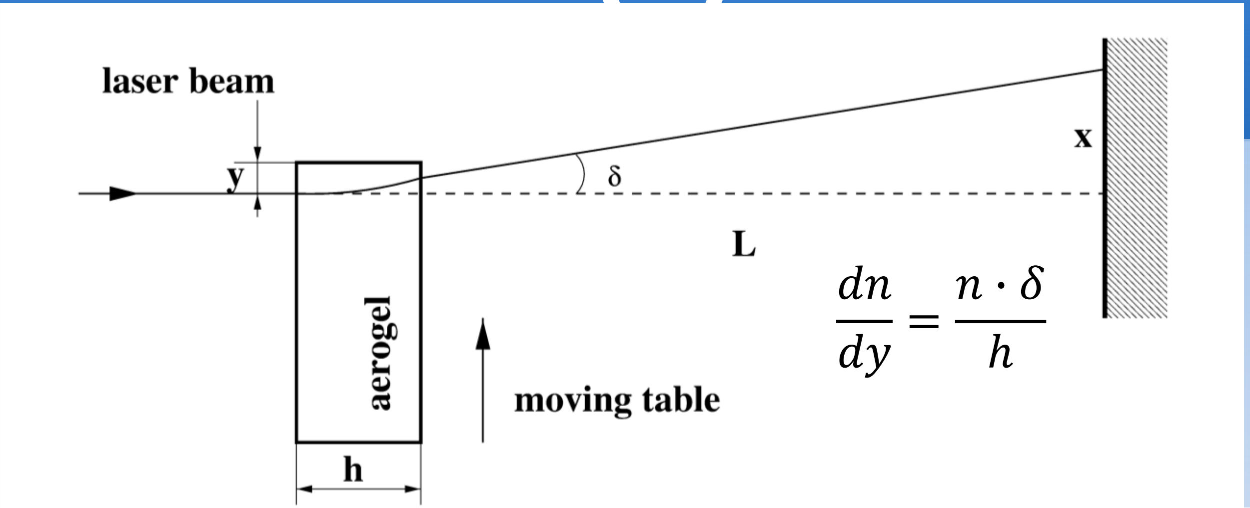


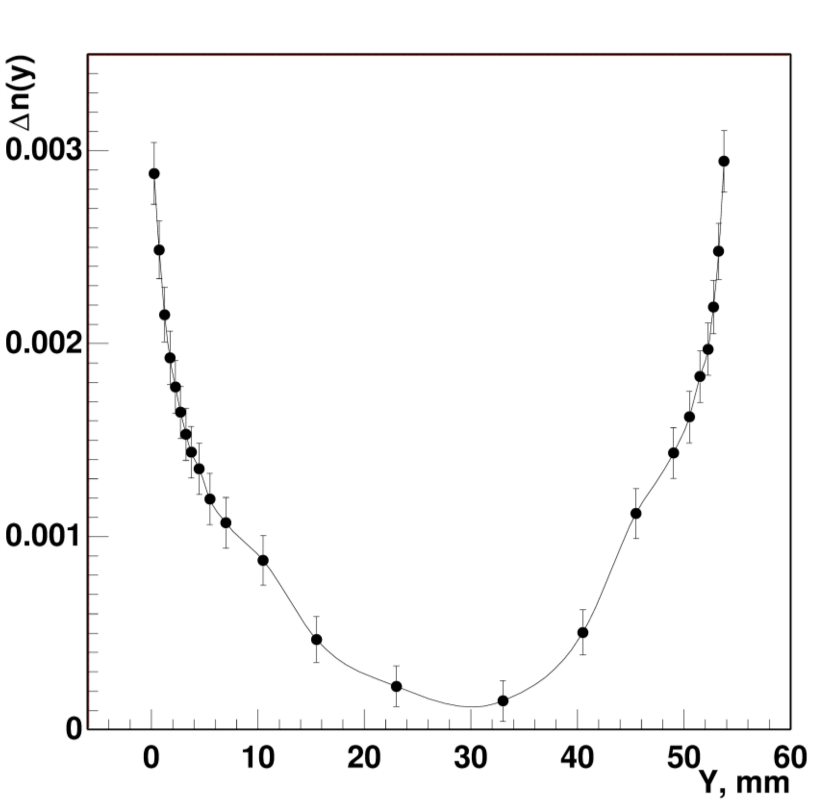


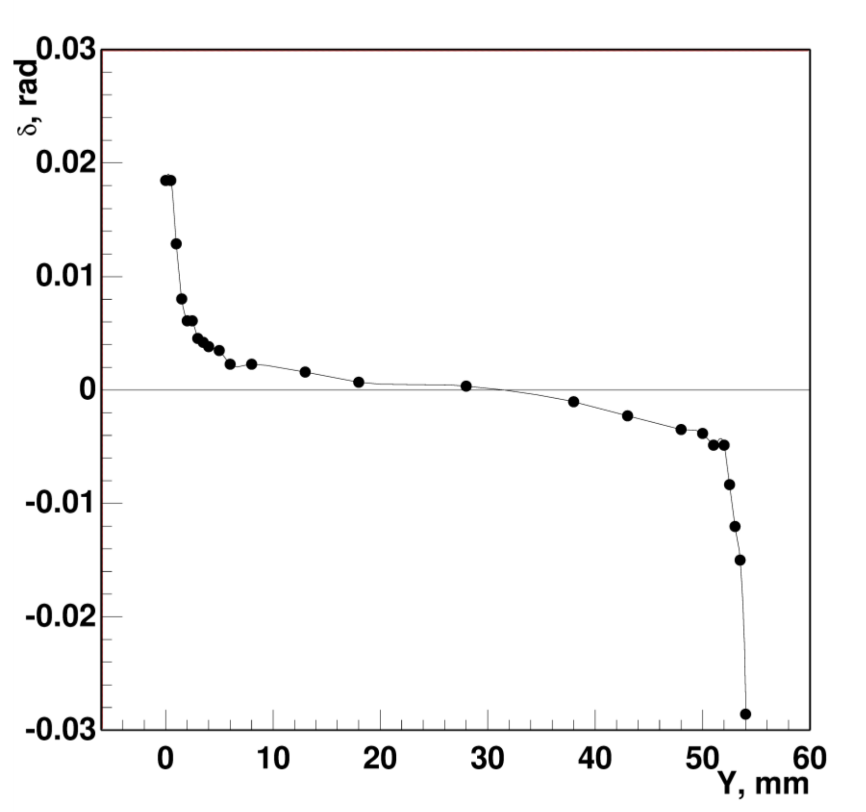
Requirements on aerogel tiles for use in Ring Imaging Cherenkov counters(1)

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

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







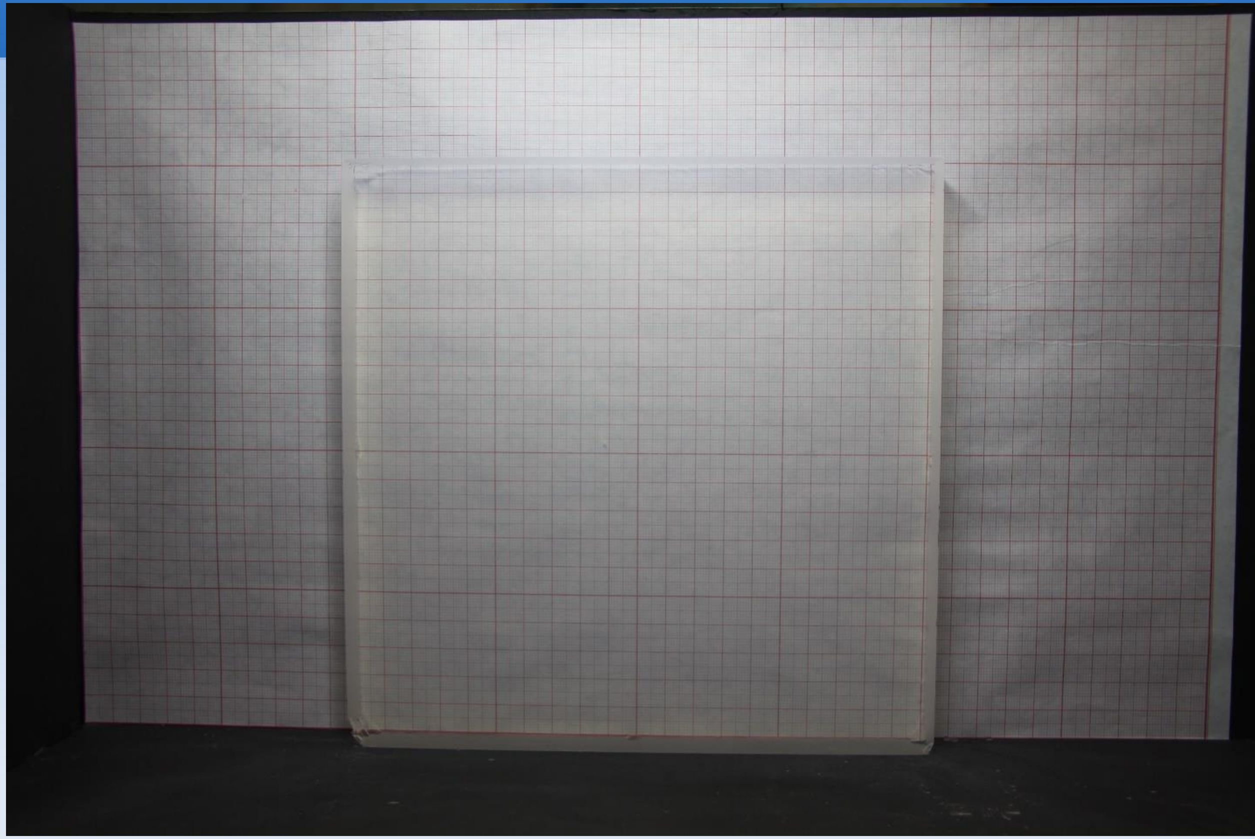
Requirements on aerogel tiles for use in Ring Imaging Cherenkov counters(2)

- 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 Ring Imaging Cherenkov counters(3)

Requirements on tile dimensions and form:

- The size of aerogel tile ought to be as large as possible. This minimize 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

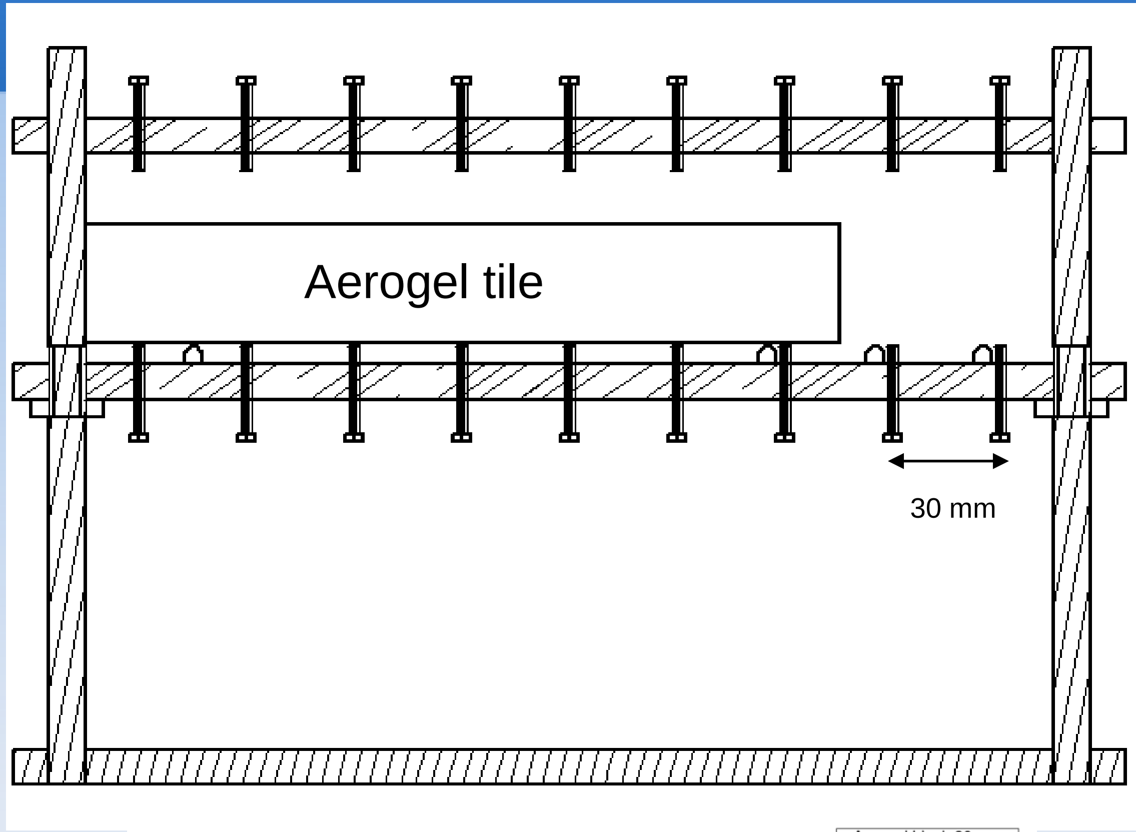


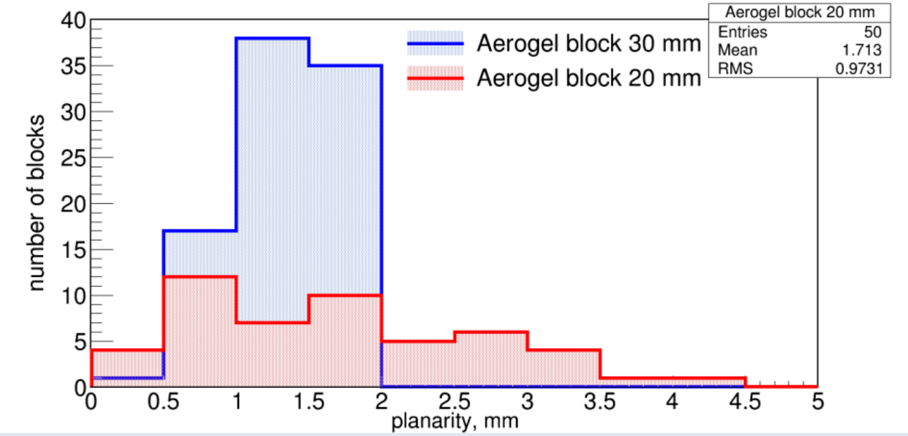
Requirements on aerogel tiles for use in Ring Imaging Cherenkov counters(4)

- 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).

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

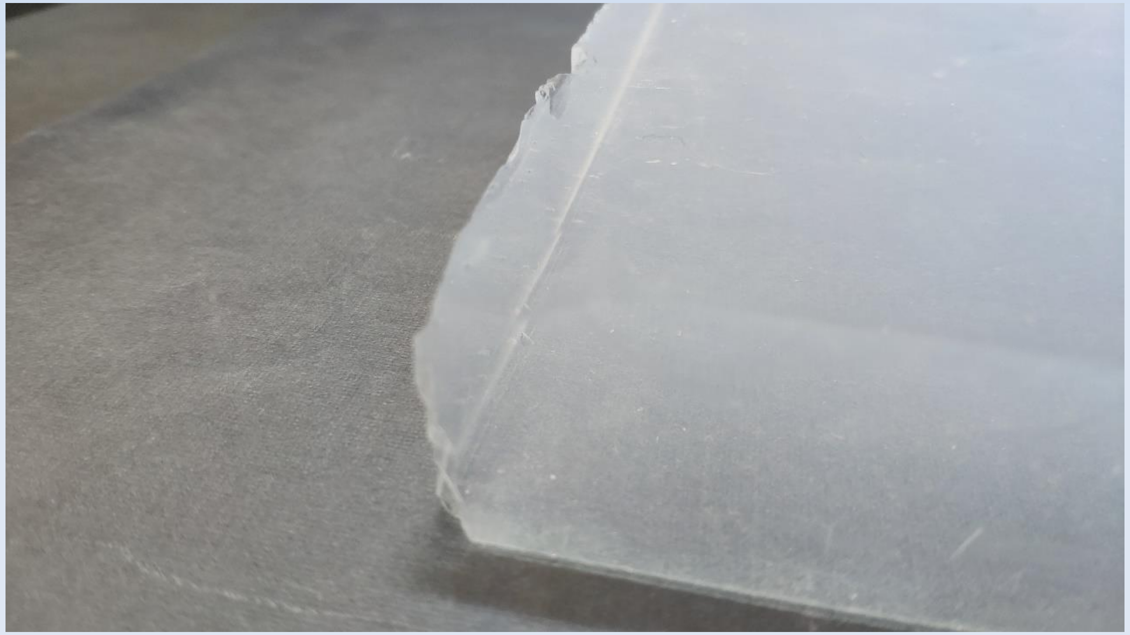
- The bottom surface of the tile can be cut with dimond wire to satisfy this requirement
- The unflatness (planarity) of aerogel surface can affect accuracy of Cherenkov angle measurement.
- Special touch stand was developed to measure thickness and planarity of the tile. For 30 mm thickness CLAS12 tiles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





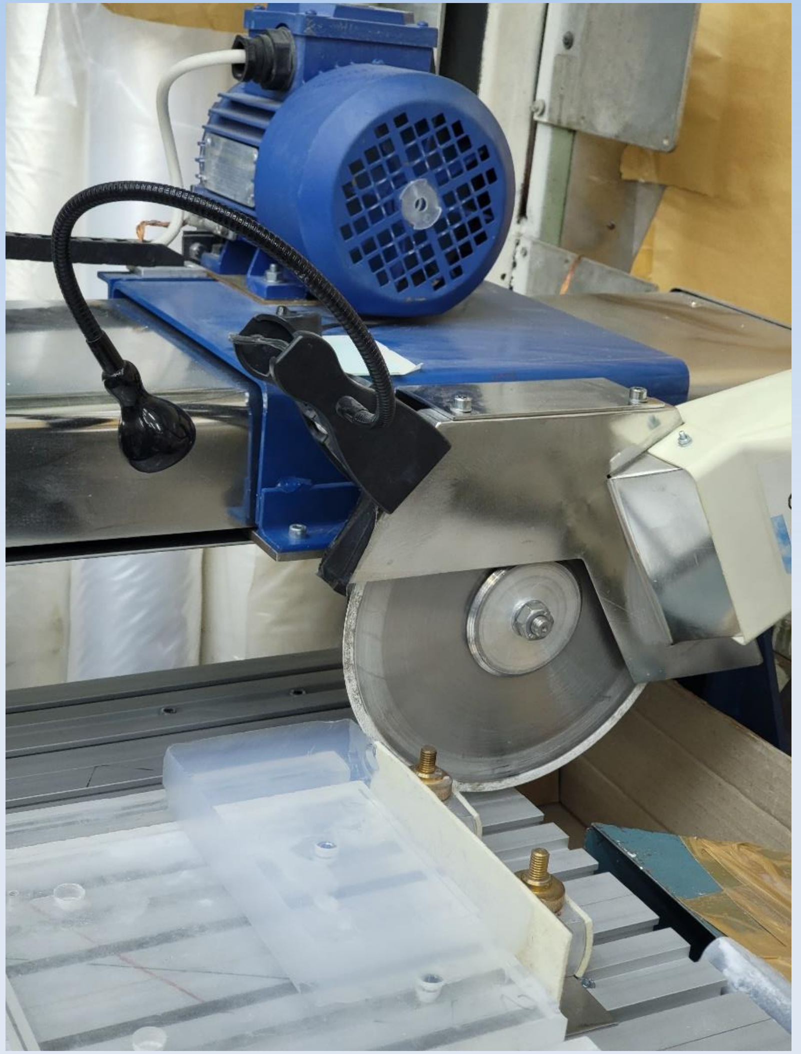
Methods of mechanical processing of the aerogel(1)

- 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.



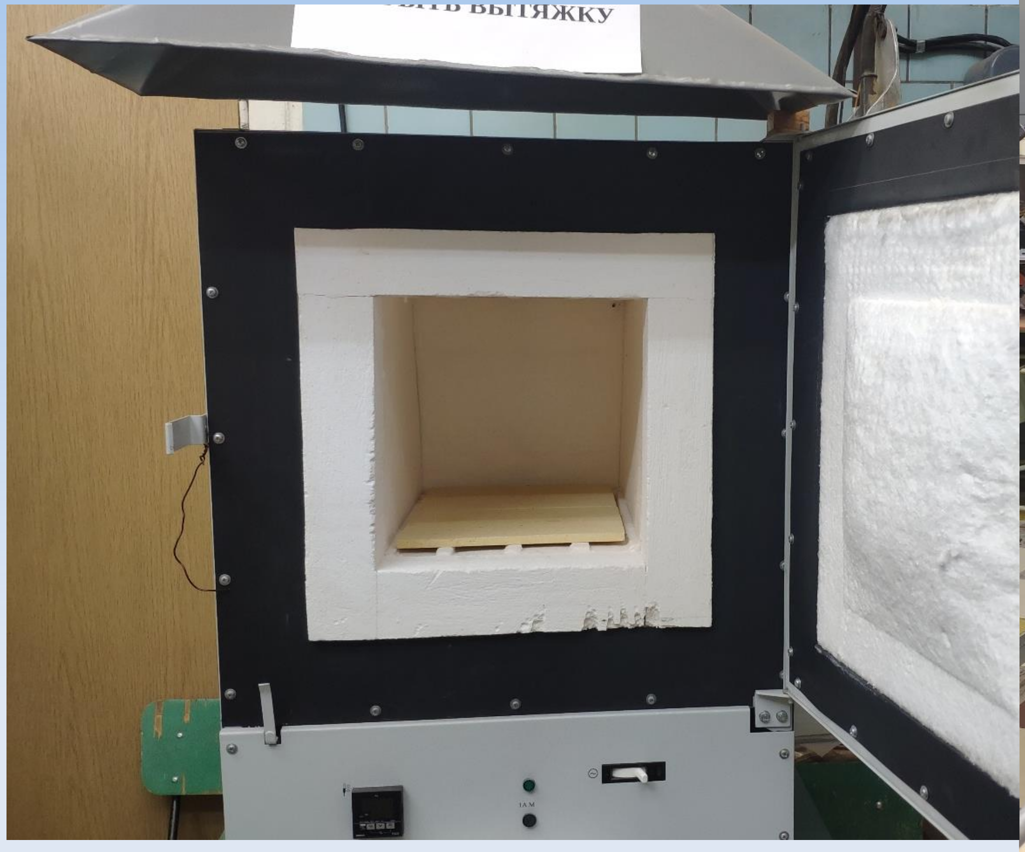
Methods of mechanical processing of the aerogel(2)

- 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



Aerogel storage

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



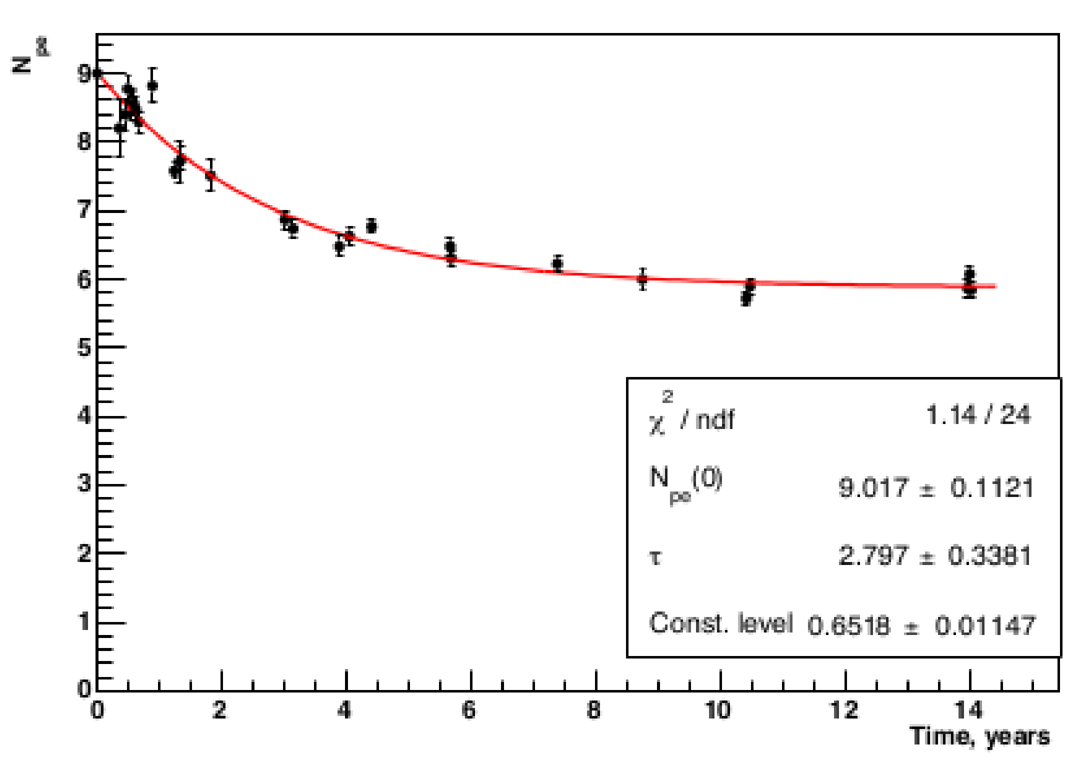
Conclusions

- The specialized area for the production of aerogel radiators for Cherenkov detectors of different type was developed at BINP (Novosibirsk)
- Aerogel radiators for several experiments have been produced (KEDR, SND, LHCb, AMS02, DIRAC, CLAS12)
- We are ready for new ones (Super CHarmTau focusing aerogel RICH and others)

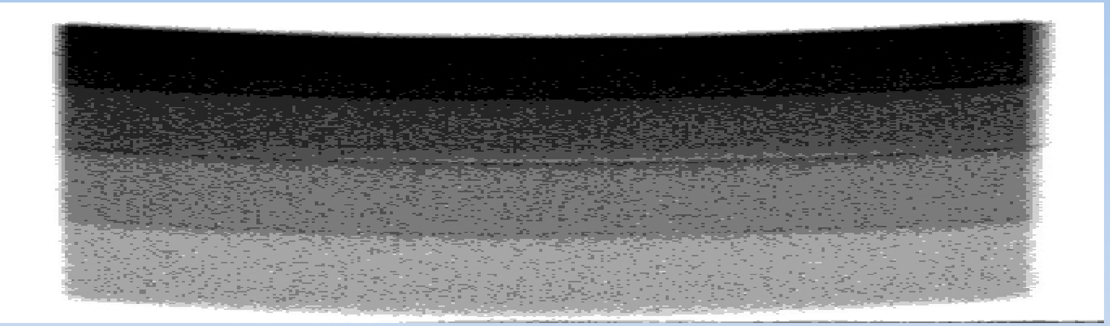
Additional slides

ASHIPH long term stability

A prototype of the endcap ASHIPH counter 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 initial value.



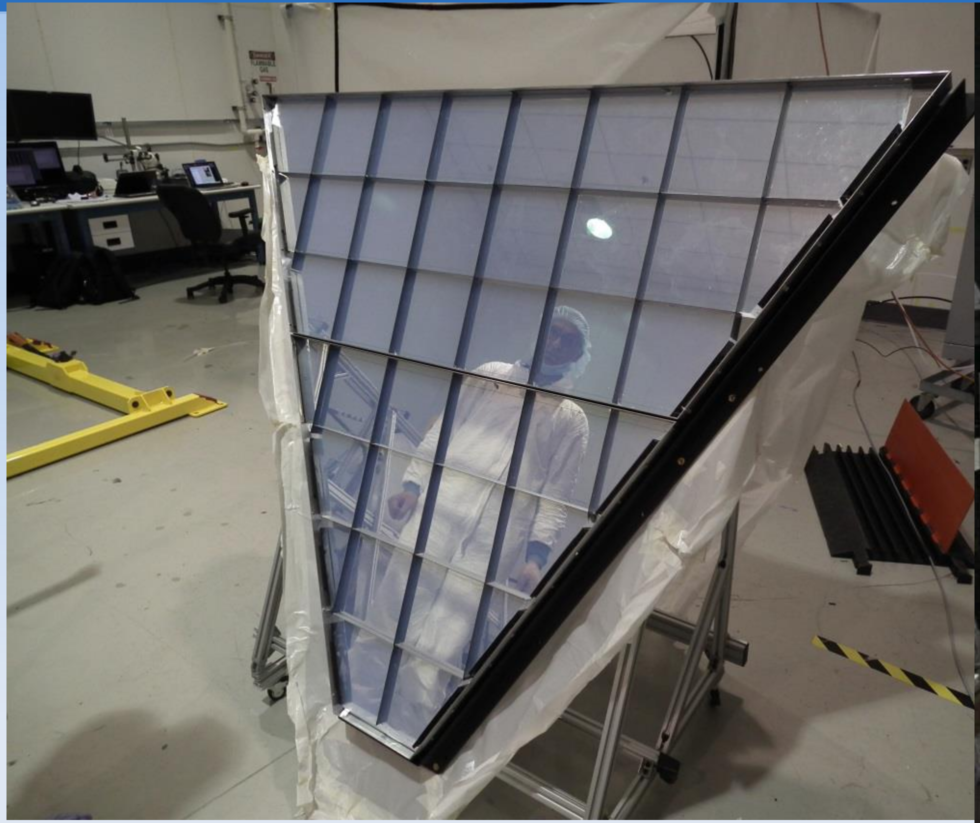
Aerogel sample

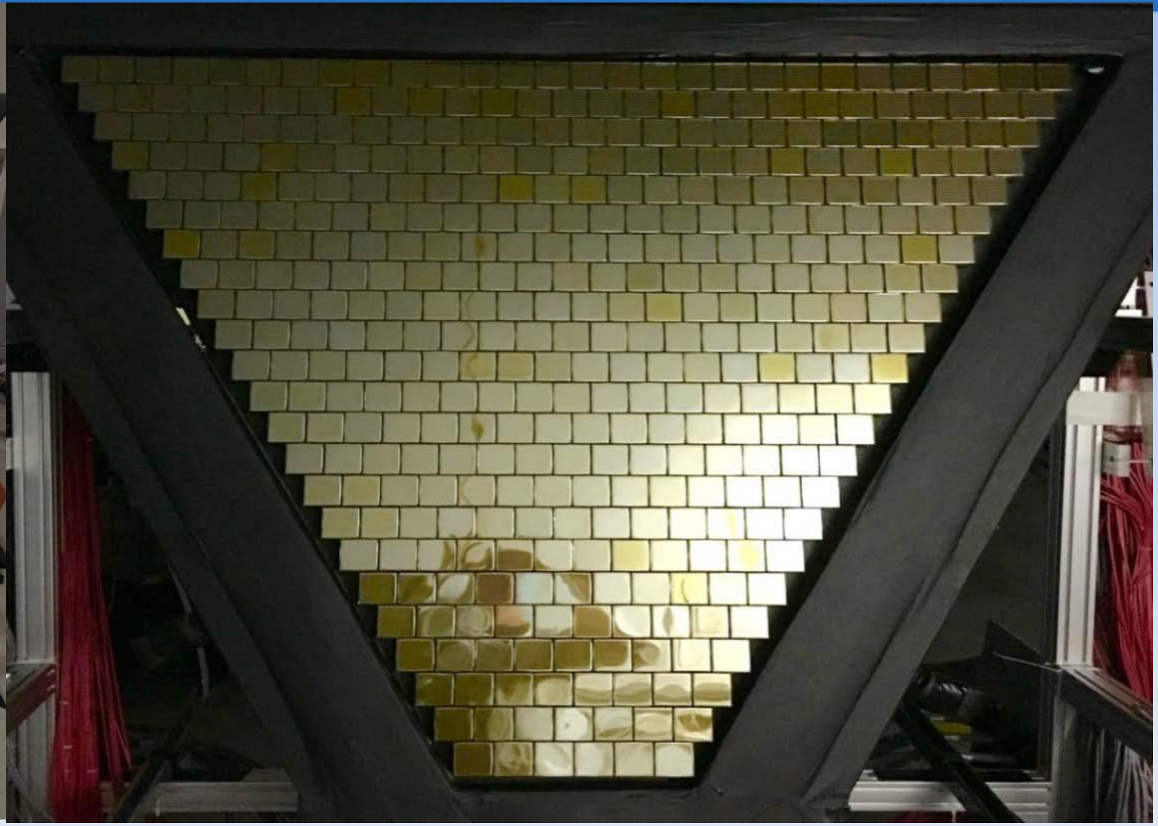


	n	h, mm
Layer 1	1.050	6.2
Layer 2	1.041	7.0
Layer 3	1.035	7.7
Layer 4	1.030	9.7

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

Aerogel RICH for CLAS12

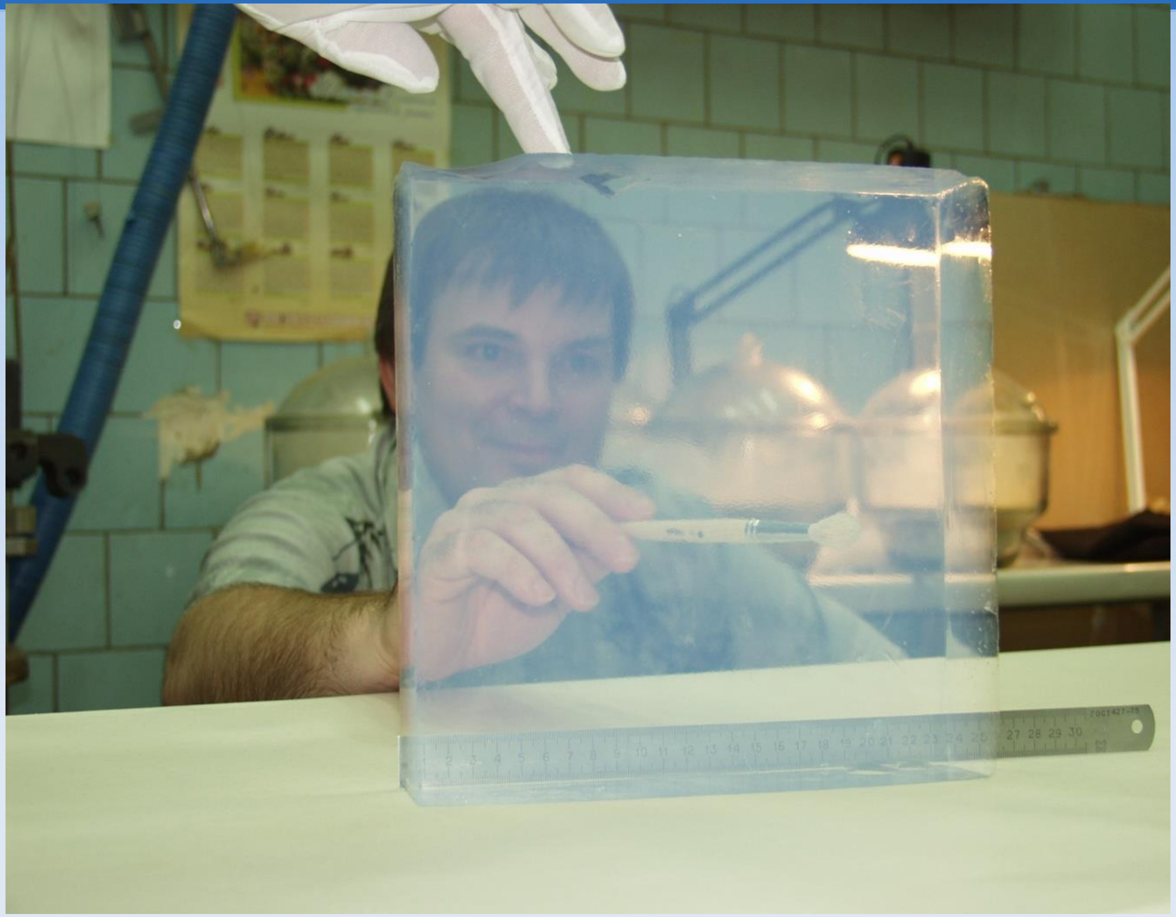




Aerogel development has started in 1986 (KEDR detector project)

More than 3000 liters have been produced:

- 2000 liters – KEDR and SND ASHIPH counters
- ~ 1 м^2 LHCb RICH,
- ~ 2 м^2 AMS02 RICH
- ~ 5 м^2 CLAS12 RICH



n = 1.006 – 1.06 (1.13)

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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