Статус и перспективы развития методик и технологий производства аэрогелевых черенковских счетчиков в Новосибирске.

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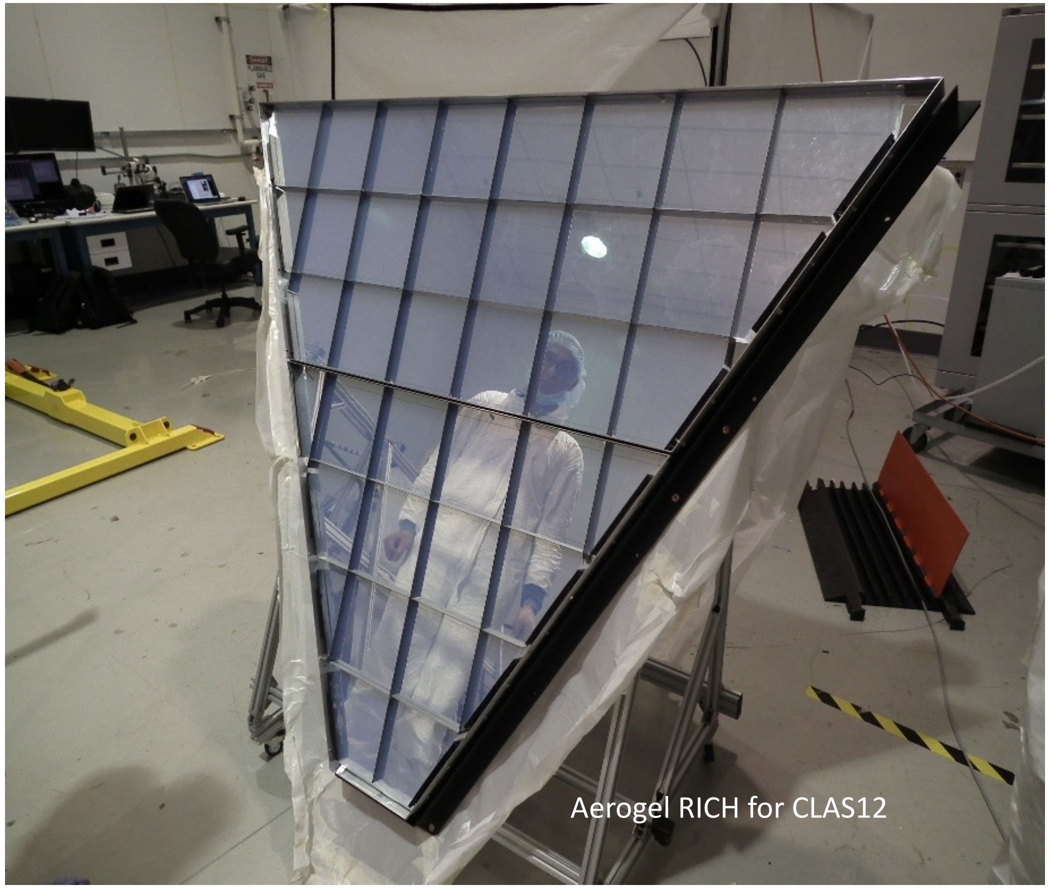
and other…

History of aerogel radiators in Novosibirsk

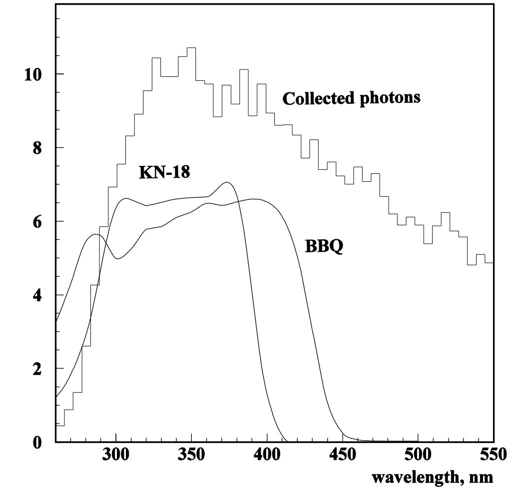
The history of the Novosibirsk aerogels began in 1986.

- KEDR ASHIPH system (VEPP-4M – BINP):
  - π/K-separation in the momentum range 0,6÷1,5 GeV/c.
  - Aerogel $n = 1{,}05$ (V~1000 L).
- SND ASHIPH system (VEPP-2000 – BINP):
  - π/K-separation in the momentum range 300÷870 MeV/c.
  - Aerogel $n = 1{,}13$ (V~9 L).
- DIRAC-II (PS – CERN):
  - π/K-separation in the momentum range 5,5÷8,0 GeV/c.
  - Aerogel $n = 1{,}008$ (V~9 L).
- AMS-02 aerogel RICH (ISS):
  - Search for antimatter, study of cosmic rays.
  - Aerogel $n = 1{,}05$ (S~1 m^2).
- LHCb aerogel RICH (LHC – CERN):
  - π/K-separation in the momentum range 5,5÷8,0 GeV/c.
  - Aerogel $n = 1{,}03$ (S~0,5 m^2), aerogel tile 20x20x5 $см^3$.
- CLAS-12 aerogel RICH (J-Lab):
  - π/K- & K/p-separation at level 4σ with several momentum GeV/c.
  - Aerogel $n = 1{,}05$ (S~6 m^2), aerogel tile 20x20x2-3 $см^3$.

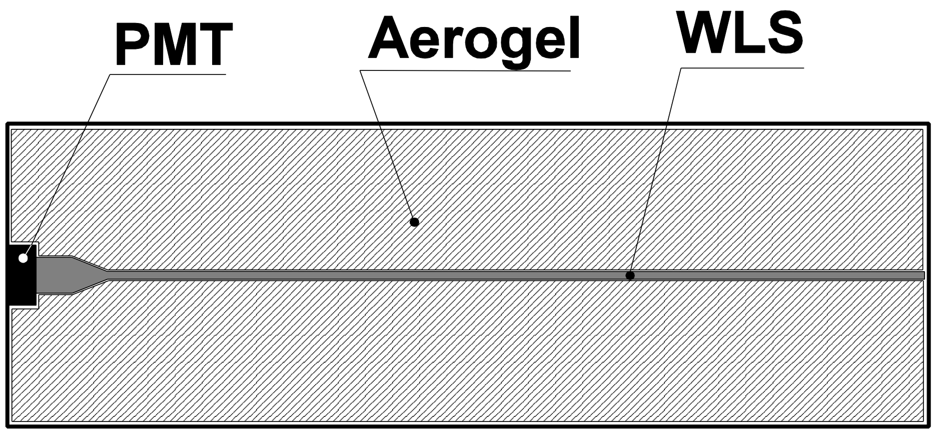

Aerogel RICH for CLAS12

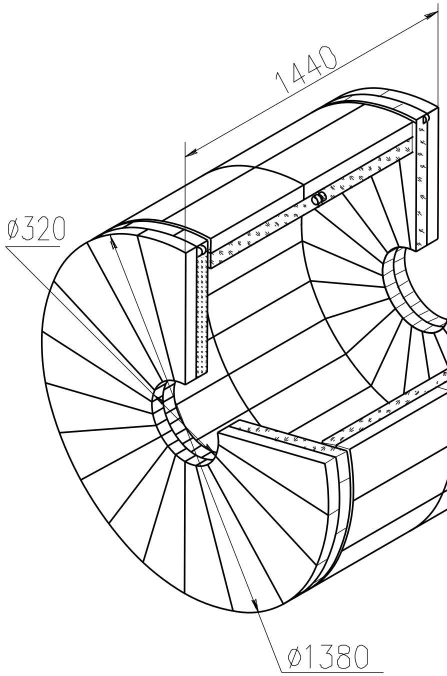
ASHIPH technique for π/K–separation up to 3GeV/c (STCF)

ASHIPH technique

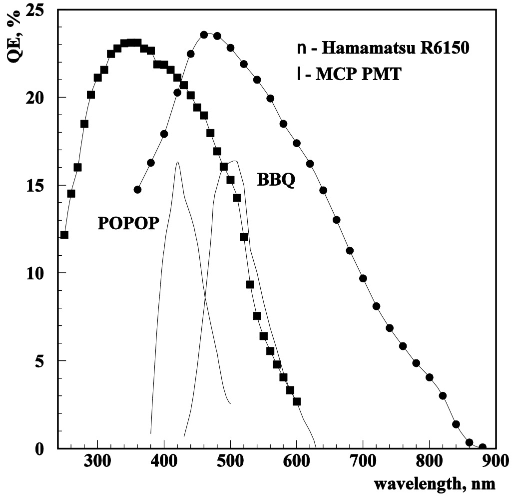


Aerogel SHIfter and PHotomultiplier



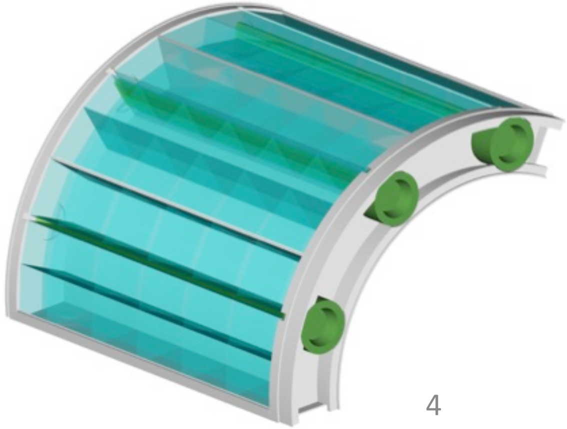


KEDR:
- 160 counters (2 layers)
- n=1.05 (1000l)
- WLS (BBQ)
- MCP PMT øPC=18 mm
- 0.97x4π
- 24% X_0



PMMA light guide doped with BBQ dye is used as wavelength shifter

SND:
- 9 counters (1 layer)
- n=1.13 (9l)
- WLS (BBQ)
- Thickness ~ 30 mm
- MCP PMT øPC=18 mm
- 0.6x4π

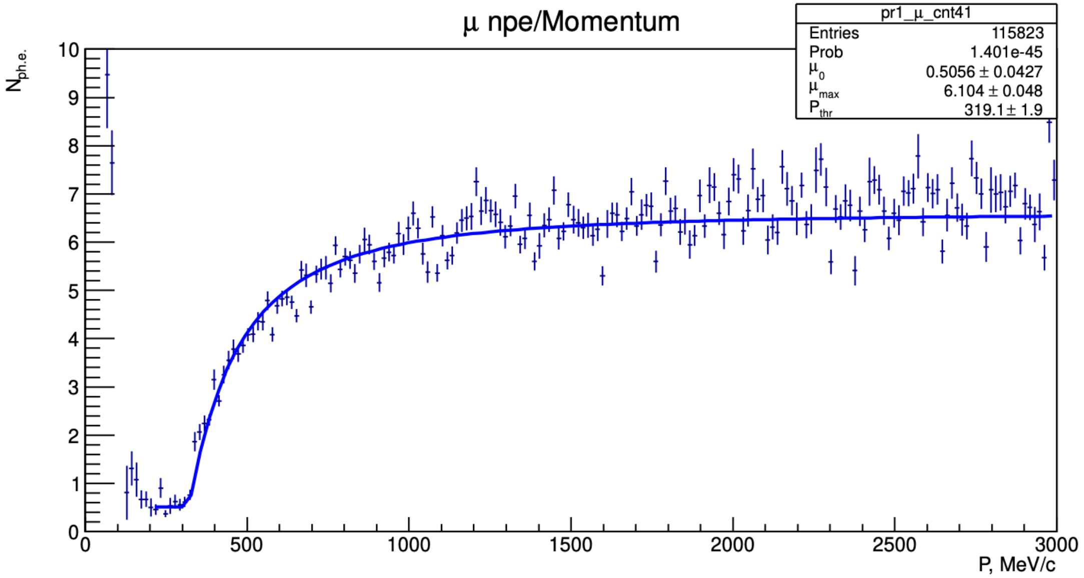


Suggested at BINP A.Onuchin et.al. NIM A315(1992)517

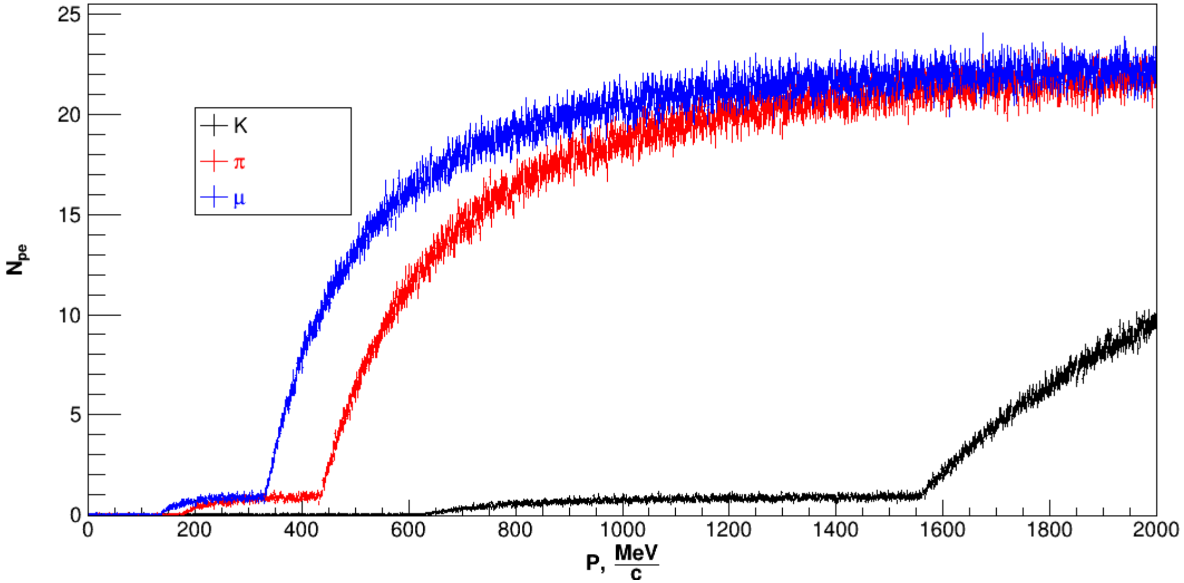
ASHIPH method upgrade: motivations and expectations

MCP PMT → SiPM
Gives increase of amp.
by 2÷2.5 times

KEDR experimental data



STCF proj. param. sim.

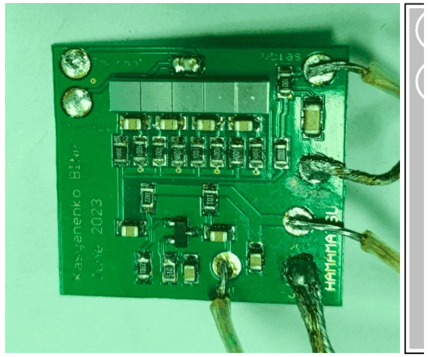


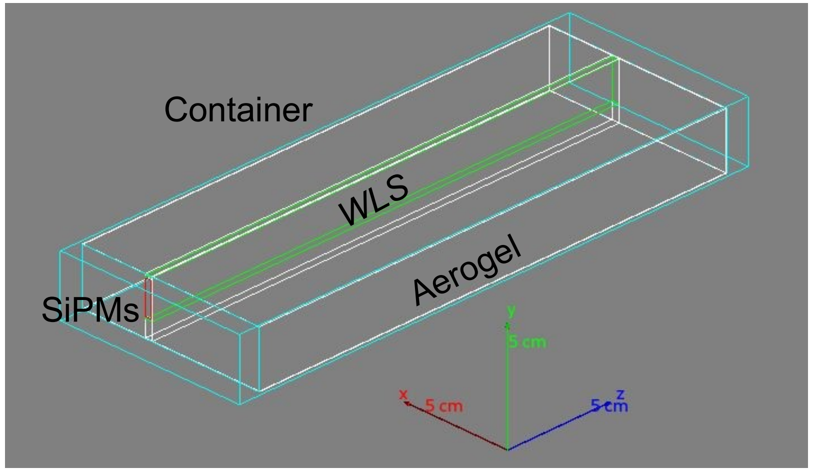
For future collidung beam experiments with high intesity interaction
high operational rate of the detector subsystems is required:
for future Super Charm-Tau factory time between two bunch-crossing about 6 ns is expected!!!

WLS(BBQ)→ WLS(NOL-1…13)

$\sigma_t(old) \approx 17ns \rightarrow \sigma_t(new) \approx 0.5 \div 1ns$ is expected!!!

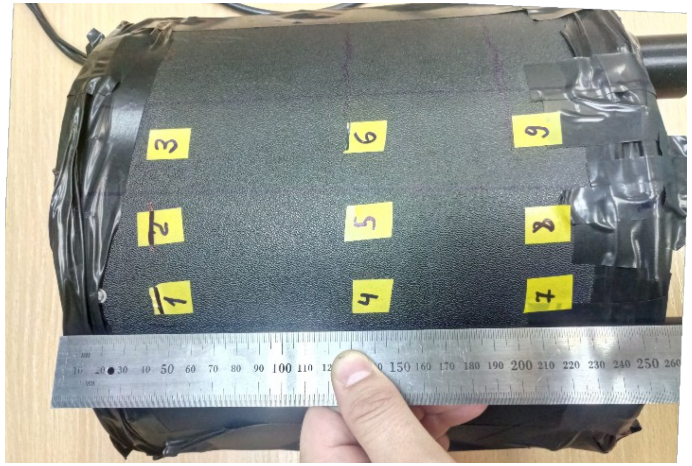
Some prototyping and beam test results



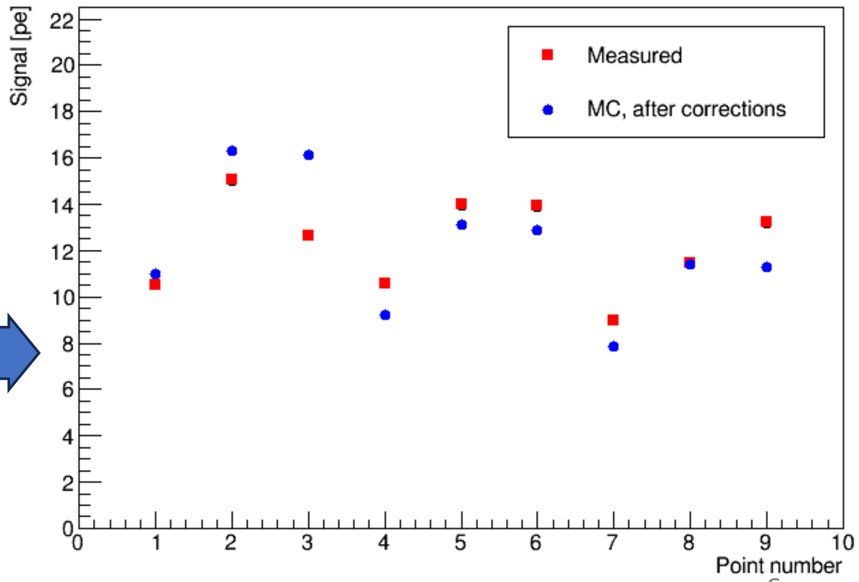


The simulated prototype:

SND ASHIPH counter was upgraded and tested with relativistic electrons (2.5 GeV) at the BINP beam test facilities.

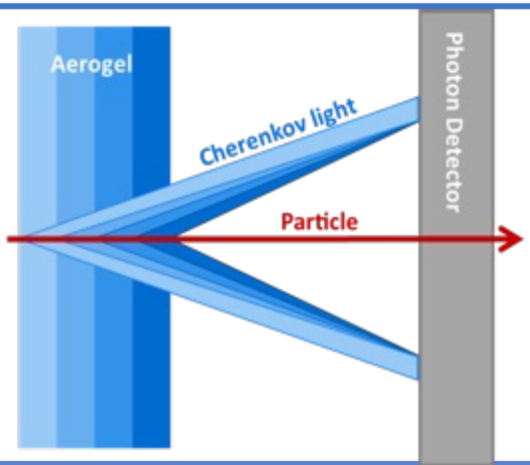


- Beam test results and GENT4 simulation are in good agreement
- Expected effect of Amp. increas is demonstrated!!!

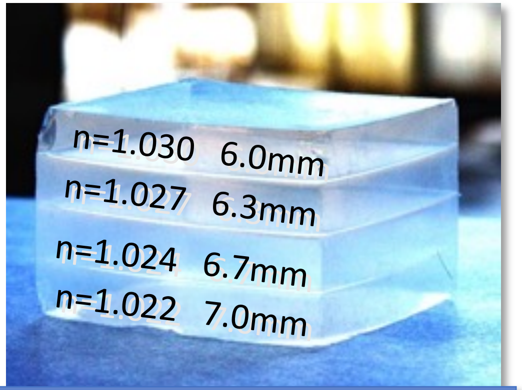


FARICH technique for π/K–separation up to 10GeV/c

FARICH technique



The first 4-layer monolithic sample

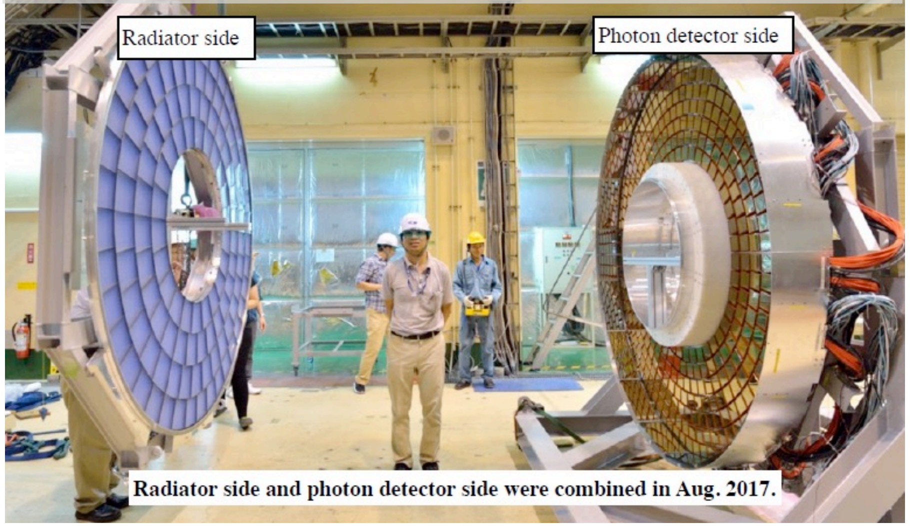


Increase N_{pe} due thickness increase without $\sigma_{\Theta c}$ degradation

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

2004÷2005

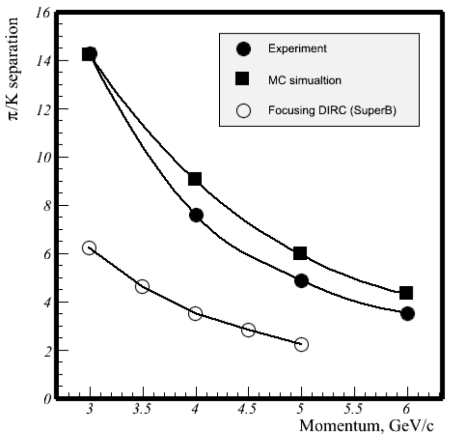
The Belle II (ARICH) is the first application of the method

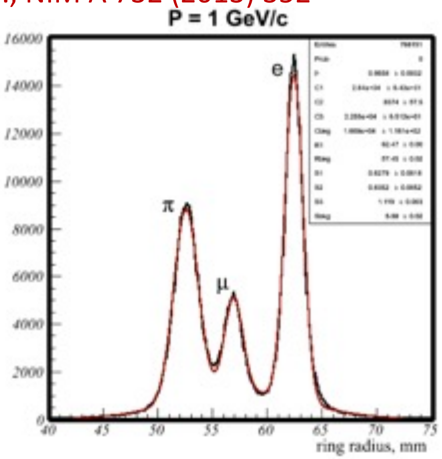


2017

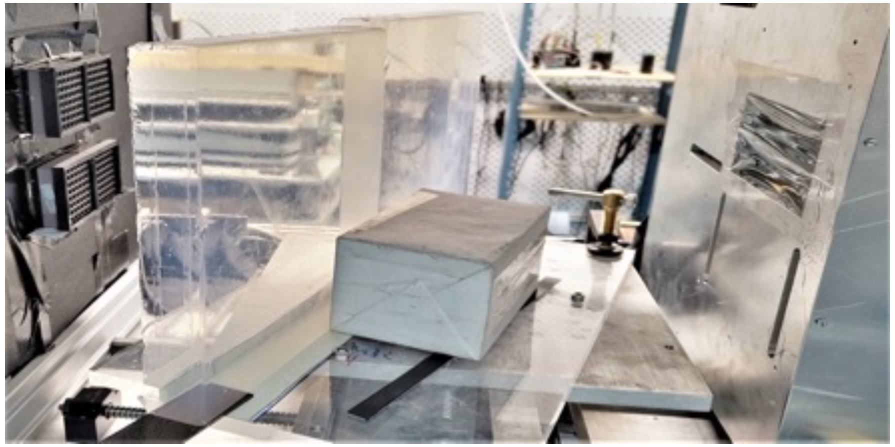
Excellent PID capability were shown at CERN beam test in 2012

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



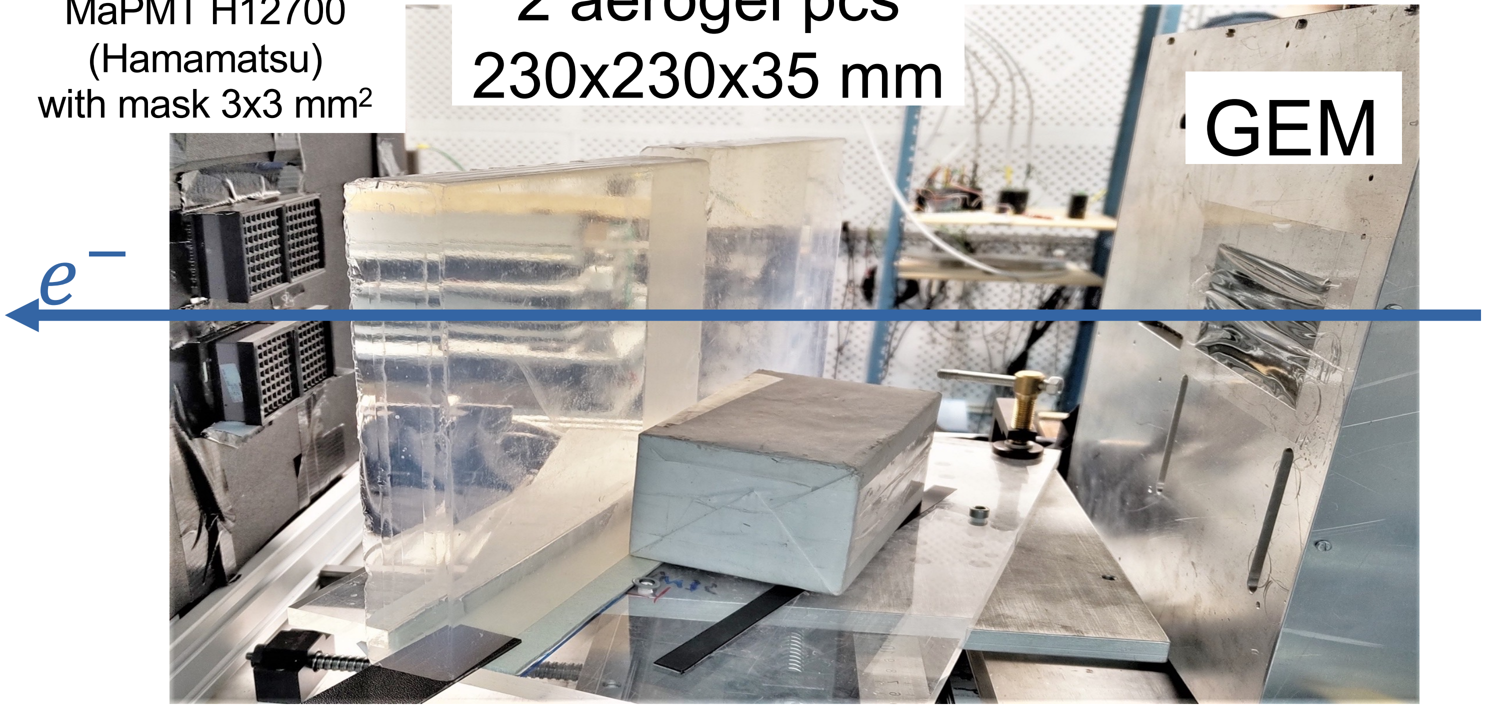


Two 4-layer focusing aerogel blocks
230x230x35 mm

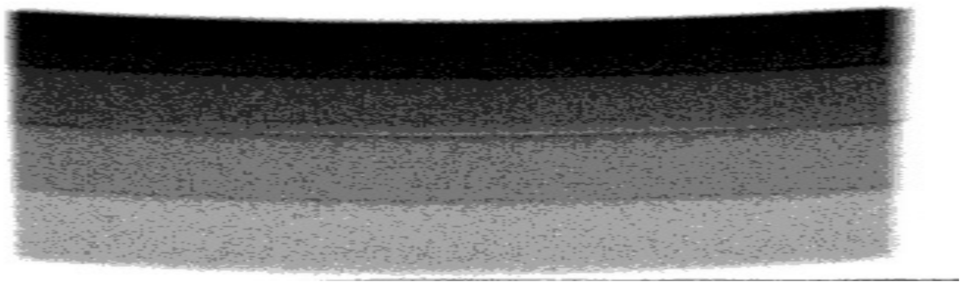


2022÷2023

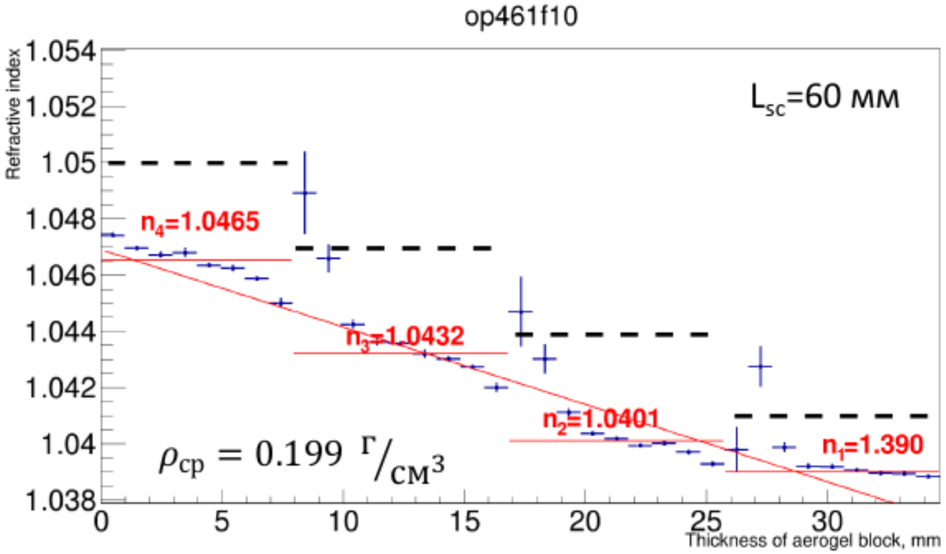
The largest 4-layer focusing aerogel samples were produced in Novosibirsk and tested at BINP in 2022-2023



Single photon Cherenkov angle resolution is investigated with relativistic electrons at BINP beam test facilities ”Extracted beams of VEPP-4M complex”.

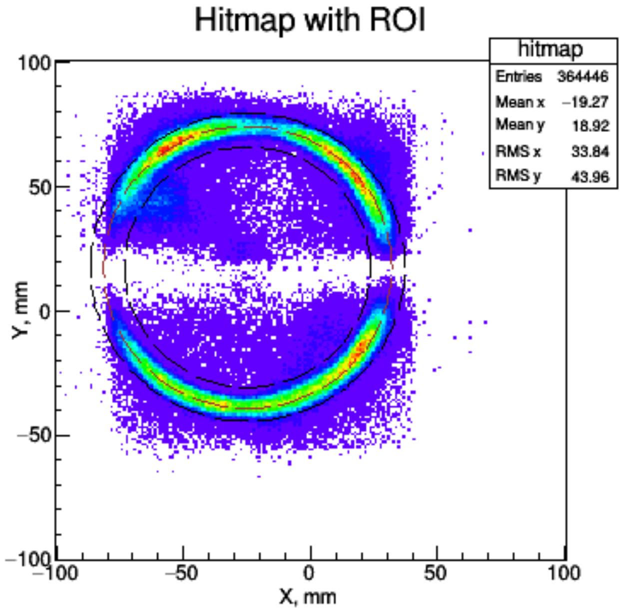


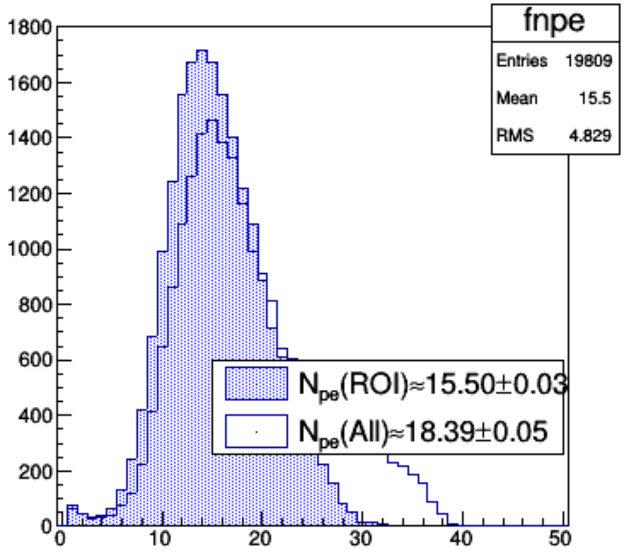
Refractive index profile is measured with help of didgital X-ray setup at the BINP.

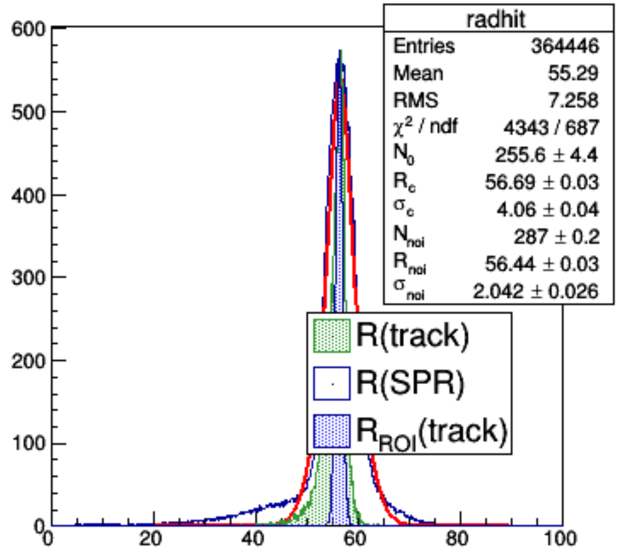


Beam test results

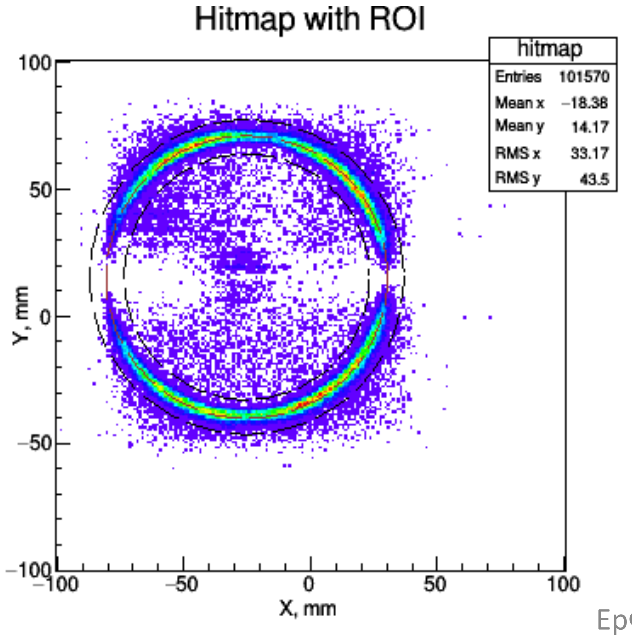
Pixel 6x6 mm
Geom.Eff. ~ 80%

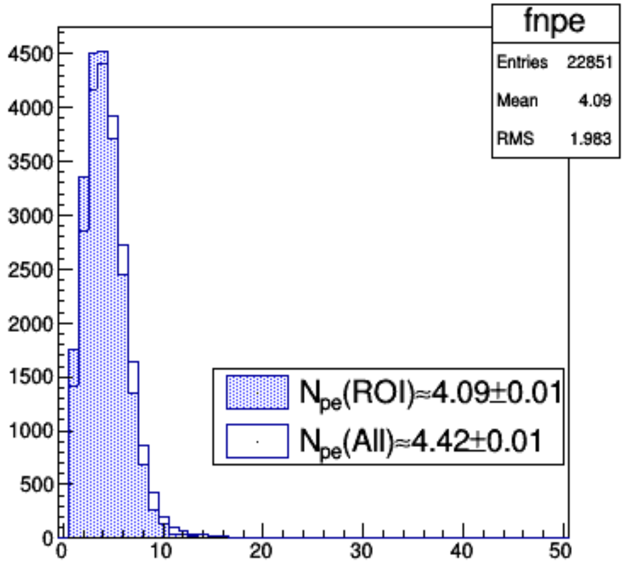


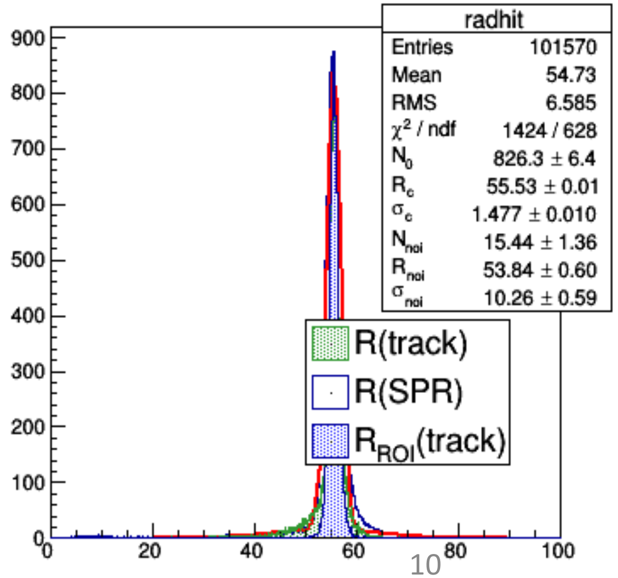




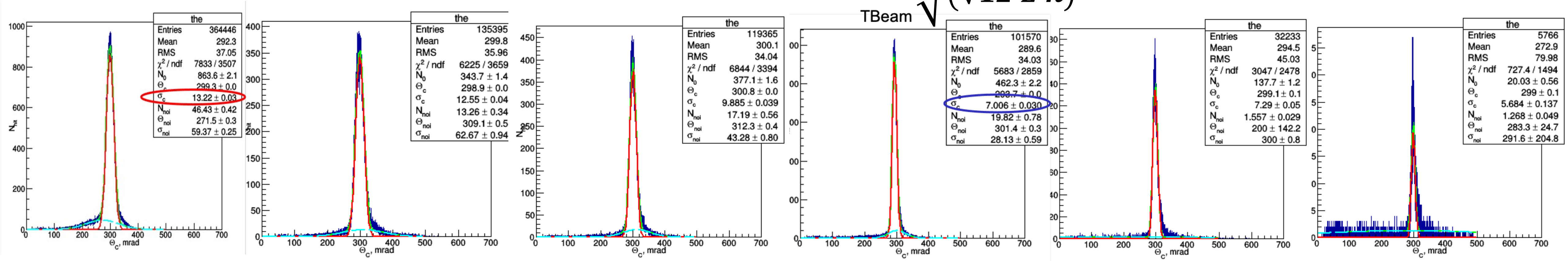
Pixel 3x3 mm
Geom.Eff. ~ 20%



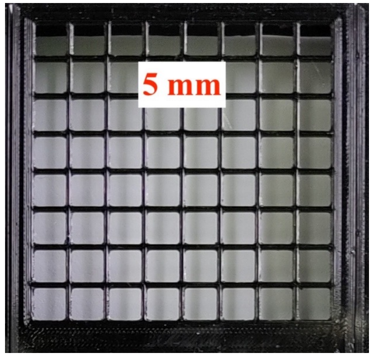


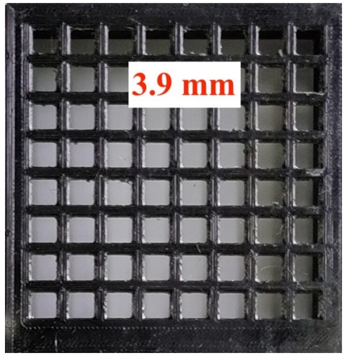


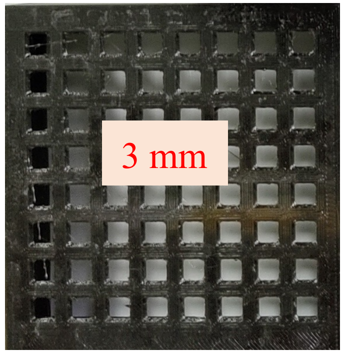
TBeam 2023 res.: $\sigma_{\theta_C}^{1pe} = \sqrt{\frac{\Delta_{pix}^2}{\left(\sqrt{12}\cdot L\cdot n\right)^2} + \sigma_{aer}^2 + \sigma_{trk}^2}$

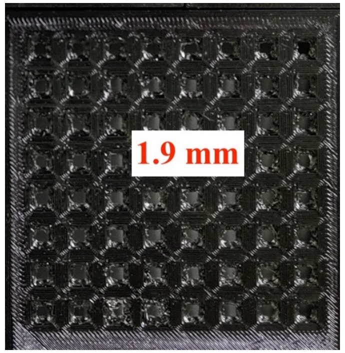


No mask: $6\times6\ mm$

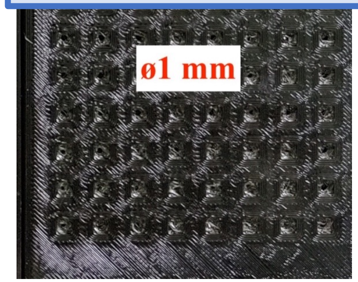








$\sigma_{aer} \approx 5.6$ mrad



No mask	5 mm	3.9 mm	3 mm	1.9 mm	ø1 mm
04/23: L≈200 mm	12/23: L≈180 mm	12/23: L≈180 mm	04/23: L≈200 mm	12/23: L≈180 mm	12/23: L≈180 mm
Geom.Eff. ~ 80%	Geom.Eff. ~ 56%	Geom.Eff. ~ 36%	Geom.Eff. ~ 20%	Geom.Eff. ~ 9%	Geom.Eff. ~ 2%
$N_{pe} \approx 16$	$N_{pe} \approx 12$	$N_{pe} \approx 8$	$N_{pe} \approx 4$	$N_{pe} \approx 2$	$N_{pe} \approx 1$

π/K: – 5.5 GeV/c — 6 GeV/c — 6.5 GeV/c — 8.0 GeV/c

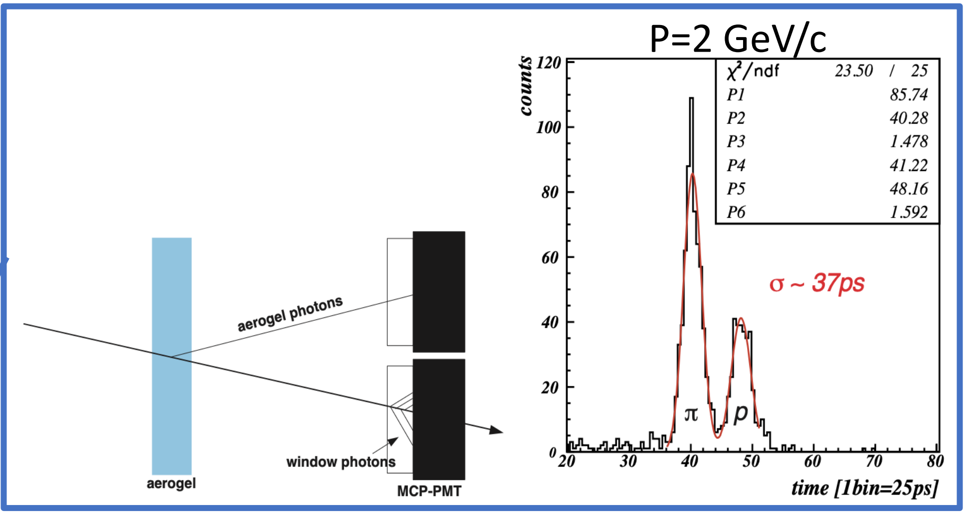
μ/π: – 1.2 GeV/c — 1.4 GeV/c — 1.5 GeV/c — 1.6 GeV/c

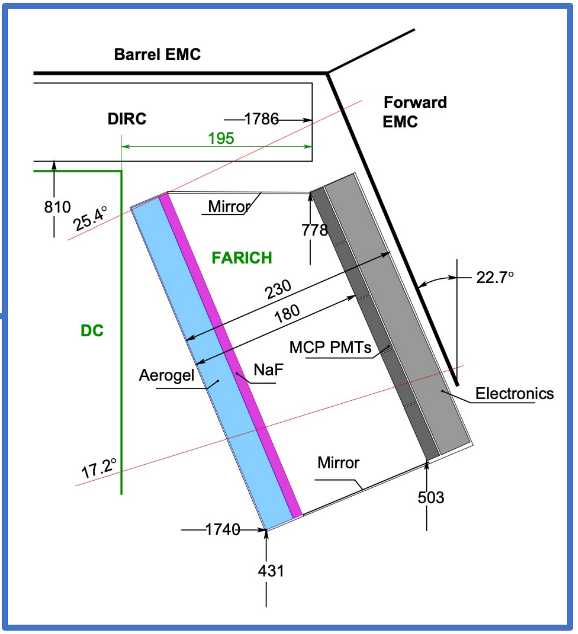
FARICH with dual aerogel radiator for μ/π–separation at P=0.2÷1.5 GeV/c (SCTF, Russia)

RICH with dual radiators is not very new idea!

- Liquid + Gas:
  - RICH – DELPHI
  - CRID – SLD
    - C_6F_{12}(n=1.278@190nm) + C_5F_{10}(n=1.00174@190nm)
- Aerogel + Gas:
  - HERMES
  - RICH1 – LHCb
    - Aer.(n=1.03@400nm) + C_4F_{10}(n=1.00137@400nm)
- Aerogel + Crystal:
  - RICH+ToF – SuperB:
    - Aer.(n=1.05@400nm) + Quartz (n=1.47@400nm)
  - FARICH – SuperB:
    - 3-layer aer. n_{max}=1.07@400nm + NaF (n=1.33@400nm)
- Aerogel + Aerogel:
  - FARICH – SCTF:
    - 4-layer aer. n_{max}=1.05@400nm + aer (n=1.12@400nm)

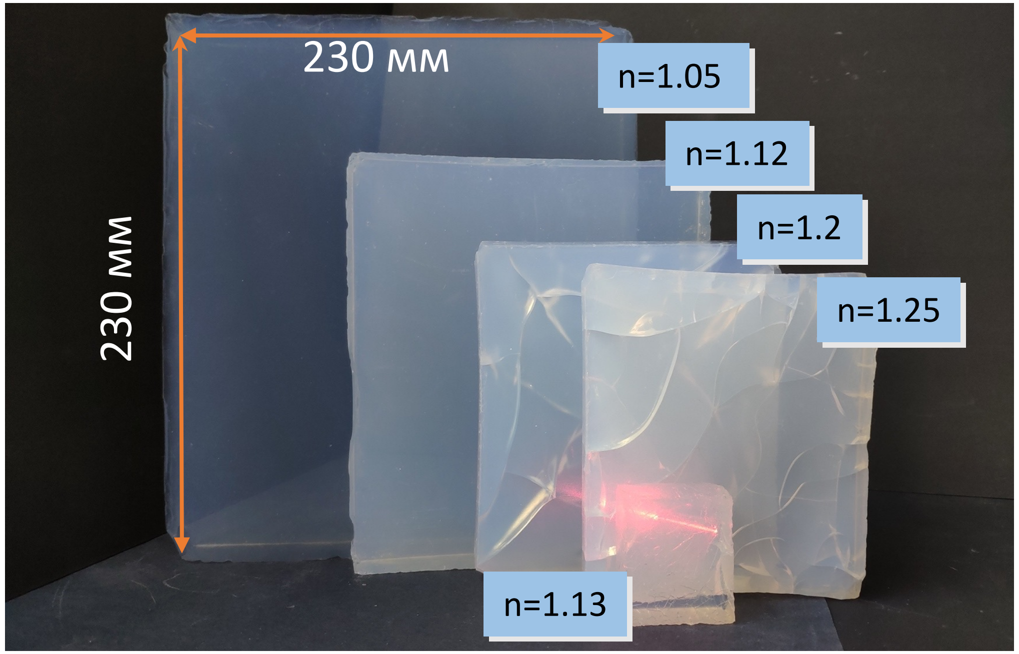
Aerogel is material with easy tunnable refractive index!



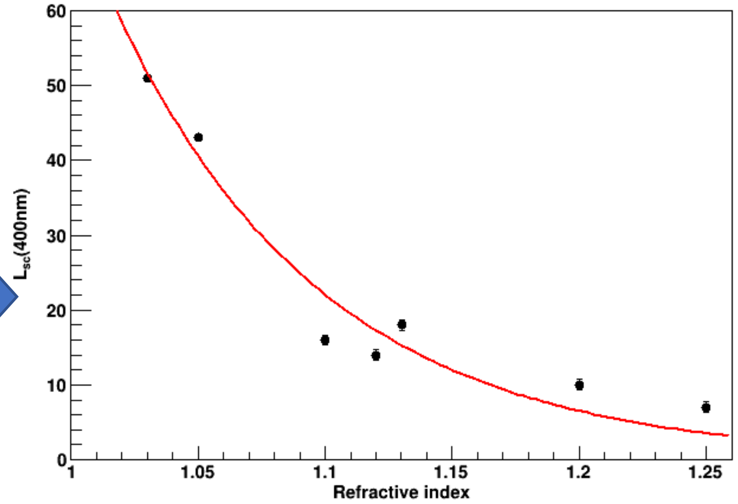


Aerogels with high optical density

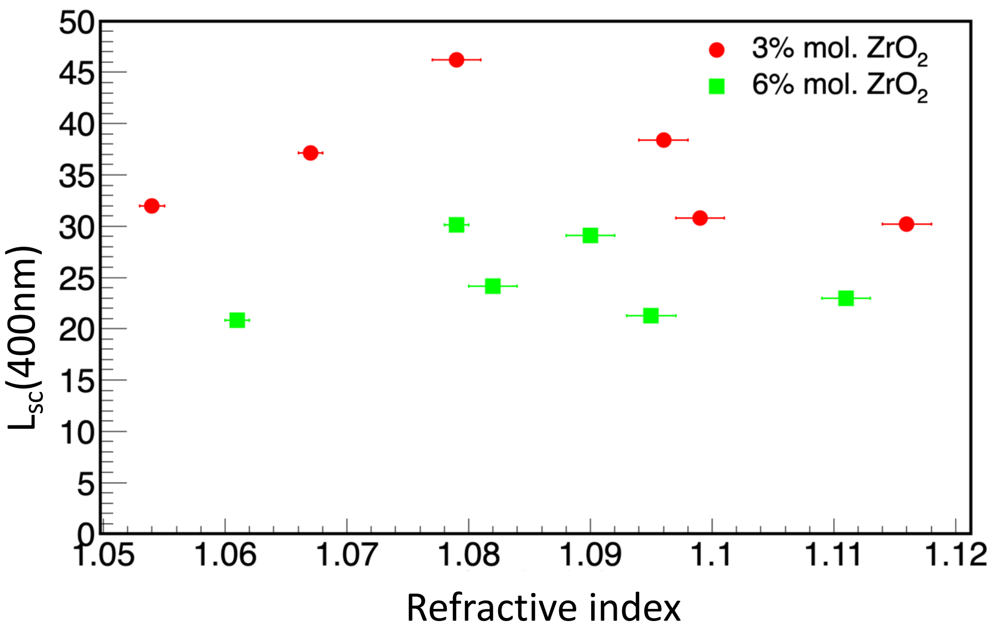
Sintering approach

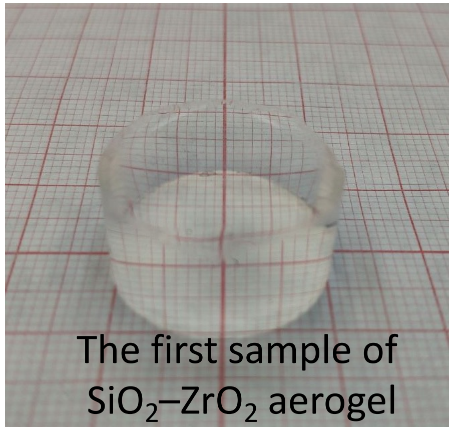


The main flaw of this approach



ZrO_2 addition approach



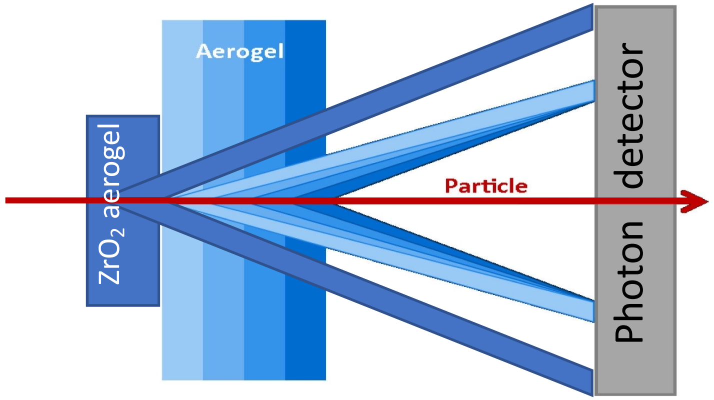


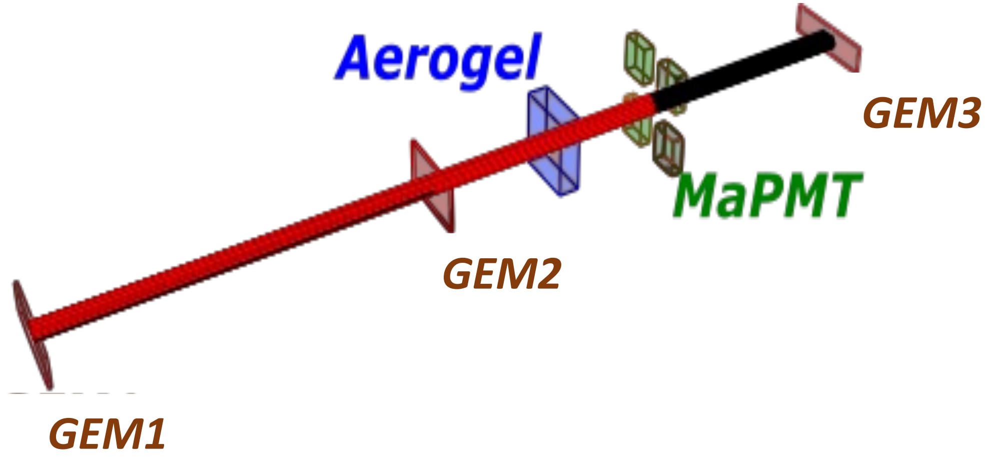
The first sample of SiO_2–ZrO_2 aerogel

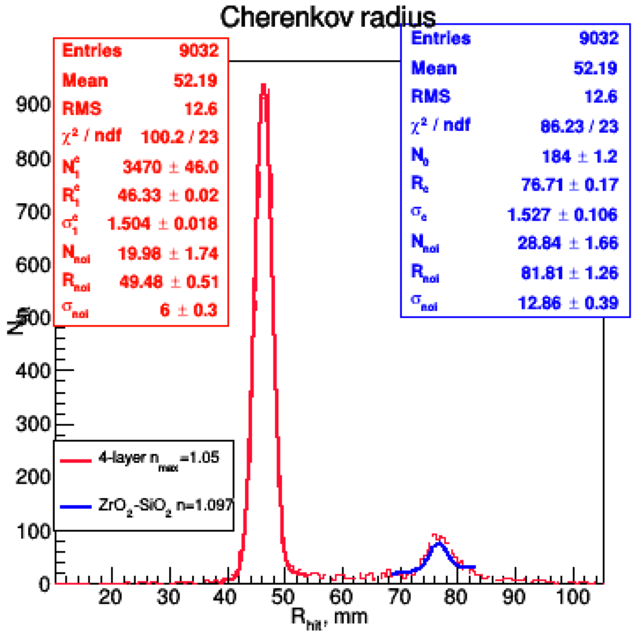
The addition of small amount (0.03÷0.06 mol) of ZrO_2 in SiO_2 based aerogel alow us to produce highly transperant aerogels with high optical density:

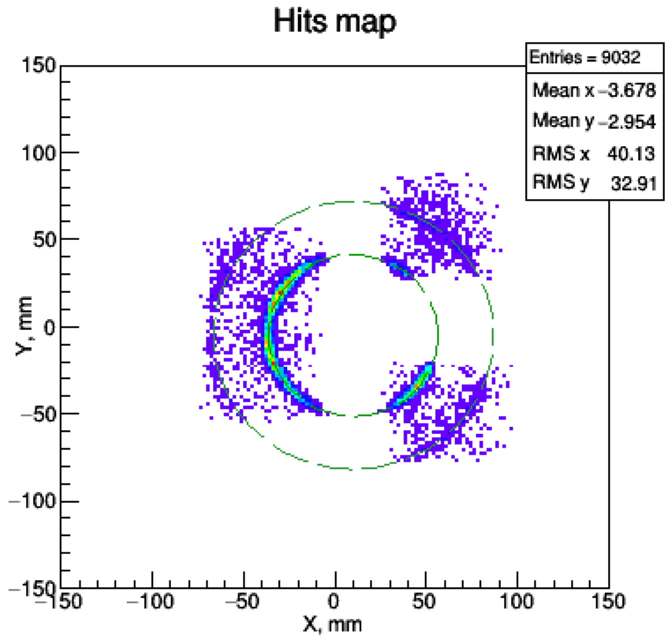
- Refractive index up to n=1.12
- Rayleigh light scattering length L_{sc}(400nm) up to 30 mm

Beam tests with FARICH in 2021 at BINP









ZrO_2–SiO_2 aerogel:

Thickness 12 mm/ ø20 mm;

L_{sc}(400nm)=21±0.5 mm;

4-layer SiO_2 aerogel:

100x100x35 mm;

L_{sc}(400nm)=37±0.3 mm;

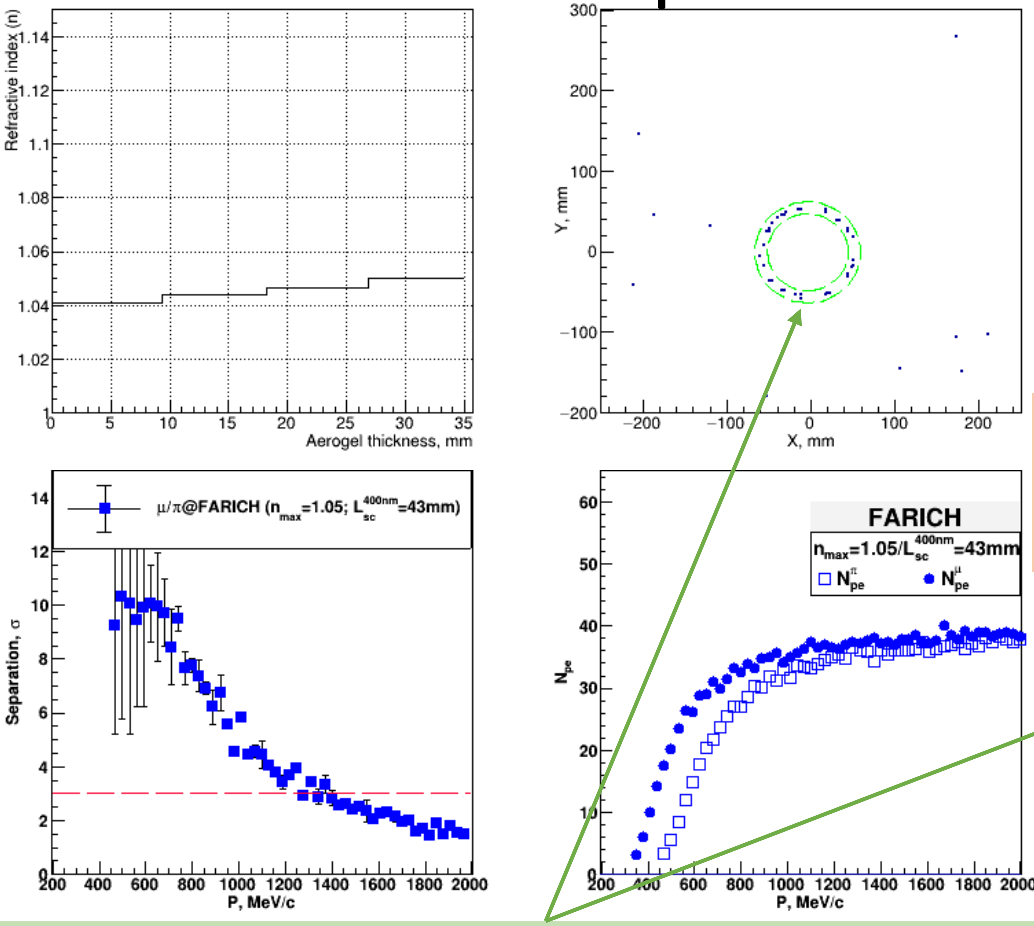
Photon detector

4 MaPMT H12700 (Hamamatsu);

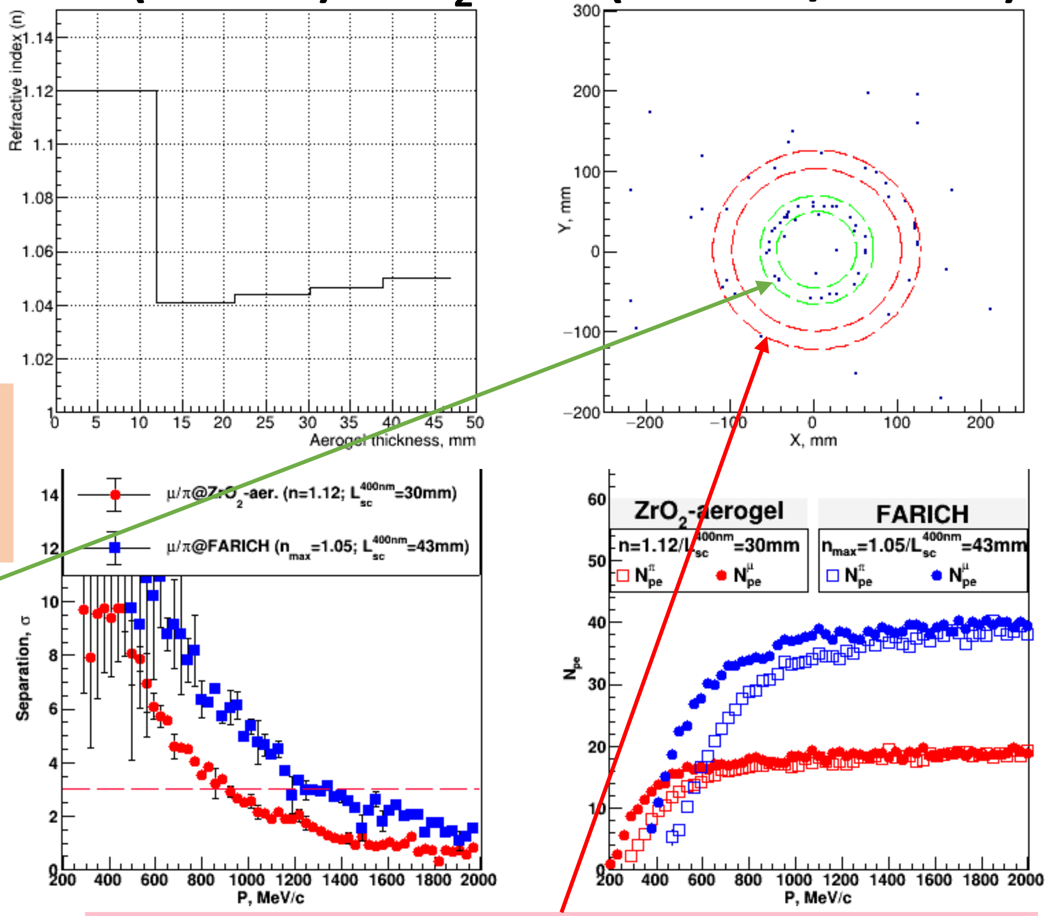
256 pixels with 3x3 mm size;

μ/π-separation via G4 simulation

FARICH: "ideal" n profile



FARICH ("ideal")+ZrO_2–aer. (n =1.12/12 mm)



$$N_\sigma = \frac{\bar{R}_C^{\mu} - \bar{R}_C^{\pi}}{\left(\sigma_R^{\pi} + \sigma_R^{\mu}\right)/2}$$

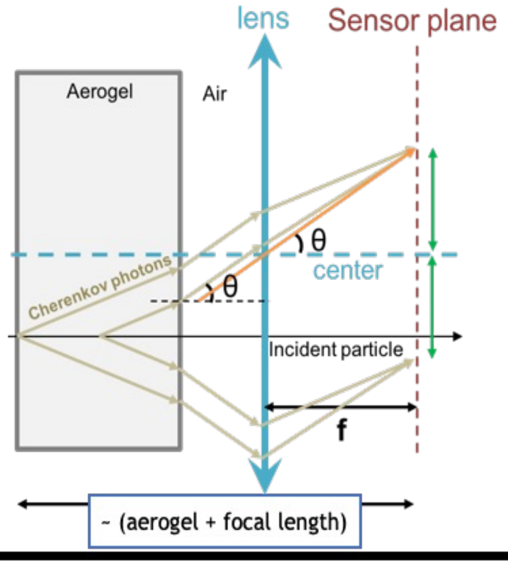
$$(\mathbf{L_f} - \mathbf{t_{Zr}} - \mathbf{t_{Fa}}) \cdot \frac{\sqrt{\left(\mathbf{n_{Fa}^{\mathit{min}\,2}} - 1\right) - \frac{\boldsymbol{m}^2}{\boldsymbol{p}^2}}}{\sqrt{\frac{\mathbf{m}^2}{\boldsymbol{p}^2} + 1}} \le \mathbf{R_{Fa}} \le (\mathbf{L_f} - \mathbf{t_{Zr}}) \cdot \frac{\sqrt{\left(\mathbf{n_{Fa}^{max\,2}} - 1\right) - \frac{\boldsymbol{m}^2}{\boldsymbol{p}^2}}}{\sqrt{\left(\mathbf{n_{Fa}^{max\,2}} - 2\right) + \frac{\mathbf{m}^2}{\mathbf{p}^2}}}$$

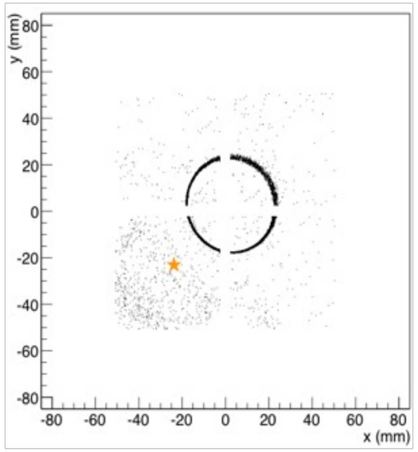
$$(\mathbf{L_f} - \mathbf{t_{Zr}}) \cdot \frac{\sqrt{\left(\boldsymbol{n_{Zr}}^2 - 1\right) - \frac{\boldsymbol{m}^2}{\boldsymbol{p}^2}}}{\sqrt{\frac{\mathbf{m}^2}{\mathbf{p}^2} + 1}} \le \mathbf{R_{Zr}} \le \mathbf{L_f} \cdot \frac{\sqrt{\left(\boldsymbol{n_{Zr}}^2 - 1\right) - \frac{\boldsymbol{m}^2}{\boldsymbol{p}^2}}}{\sqrt{\left(\boldsymbol{n_{Zr}}^2 - 2\right) + \frac{\mathbf{m}^2}{\mathbf{p}^2}}}$$

RICH with Fresnel lens for EIC (or EICC)

Aerogel RICH with Fresnel lens

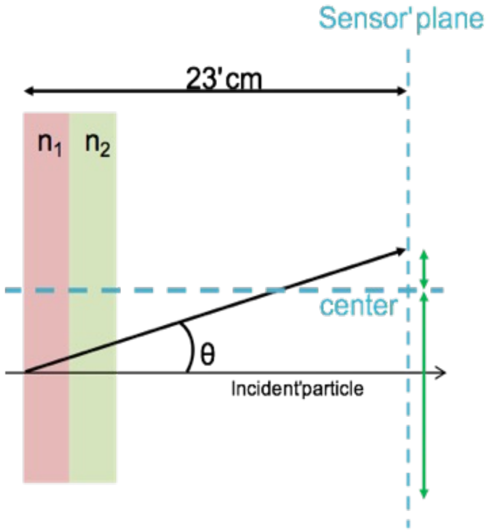
Lens-Based mRICH Design

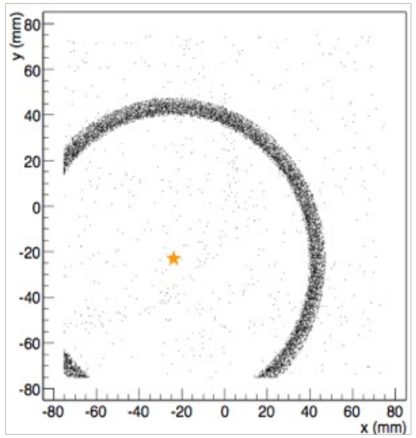




- 9 GeV/c pion beam incident at third quadrant (**star**) in simulation
- Ring image is **shifted toward the central region** on the sensor plane

Two-Layer Proximity Focusing Design (BELLE-2 ARICH)

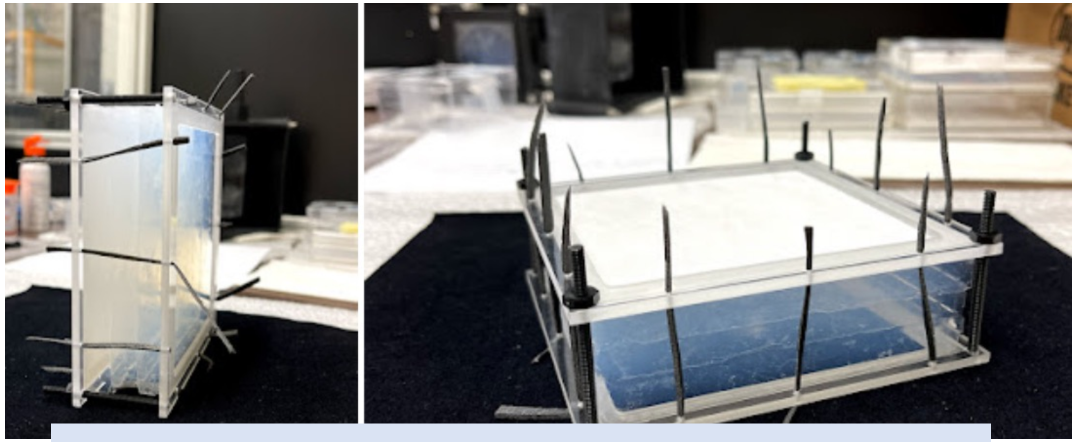




- 9 GeV/c pion beam incident at third quadrant (**star**) in simulation
- Ring is centered at point of incidence

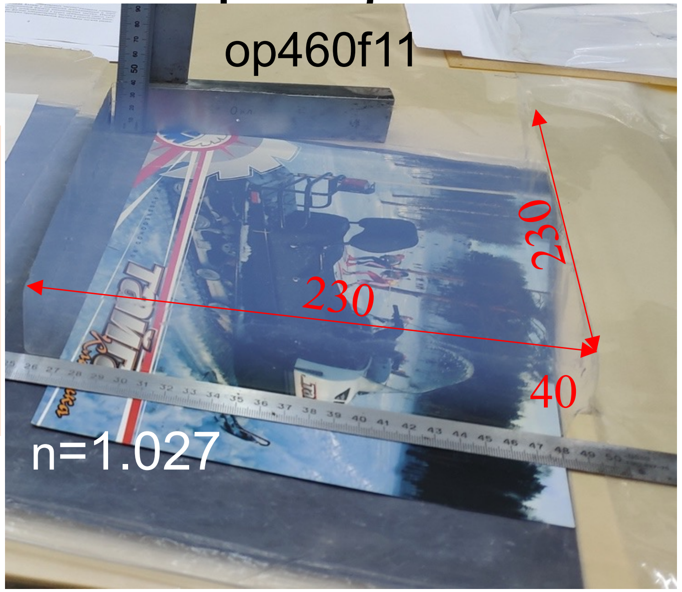
Such approach allows us to improve Cherenkov angle resolution and optimize photo detectors area!

The thick aerogel for mRICH – EIC or EICC projects



FermiLAB 2021: stack of three 1 cm thickness blocks with n=1.03 from Chiba University

BINP 2022: single block 23x23x4 cm with n=1.027 from BIC

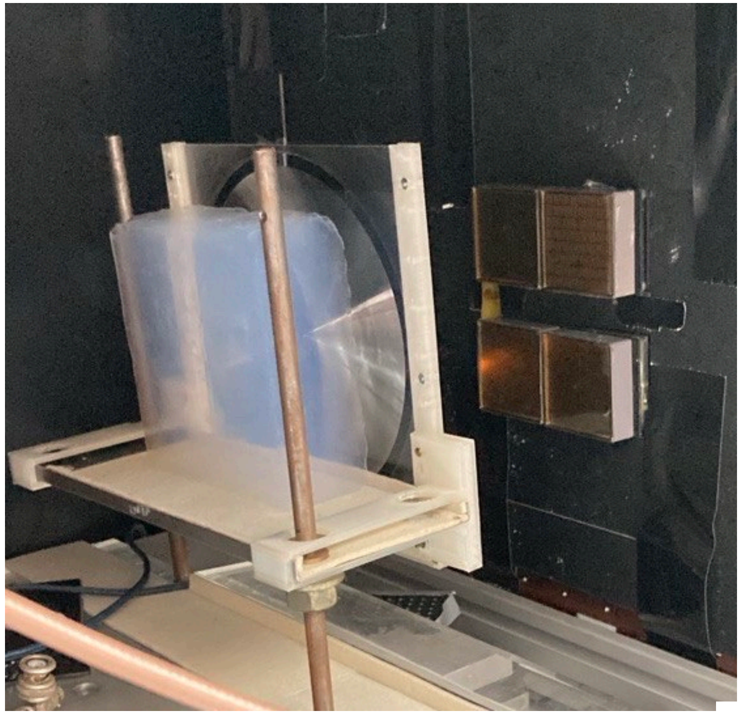


- In both cases there is no reason to make the aerogel thickness more than $(1 \div 2) \cdot L_{sc}$:

$$N_{out} = N_0 \frac{L_{sc}}{h}\left(1 - e^{-\frac{h}{L_{sc}}}\right), \qquad L_{sc} \sim \lambda^4$$

- In case of approach "stack" the additional Cherenkov photons loss is occurred due to reflectance and scattering on the additional surfaces
- There are two not cut off surfaces in aerogel
  - "Optical surface" – it contacts only with air during the production
  - "Bottom" – it contacts with metallic frame during the production processes
- Several configuration of the aerogel Cherenkov radiators were tested with relativistic electron beams at BINP beam test facilities in 2022.

Some results of beam tests at the BINP



Aerogel:

- n=1.028
- L_{sc}(400nm)=48.2±0.7 mm
- Thickness=40mm

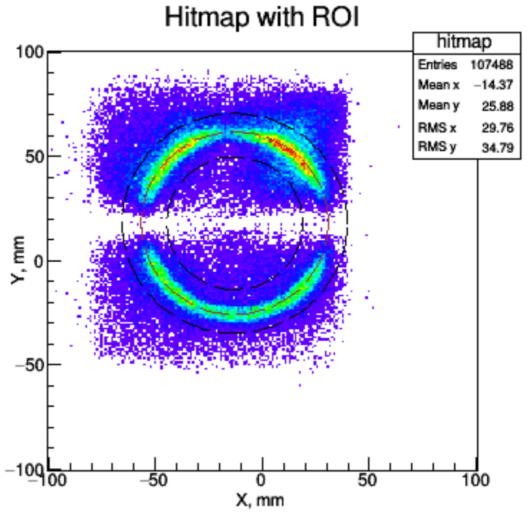
Fresnel lens:

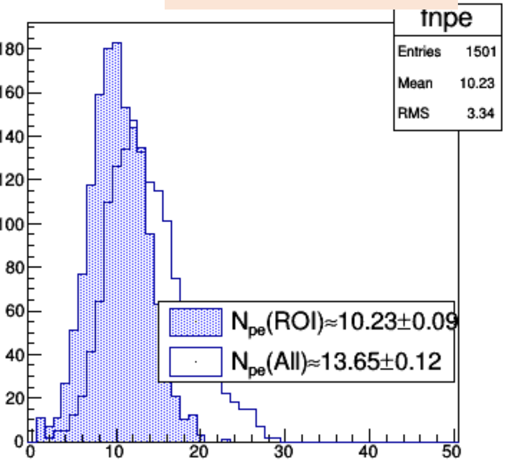
- Acrilic (PMMA)
- L_f=6’’
- Manufacturer: Edmund

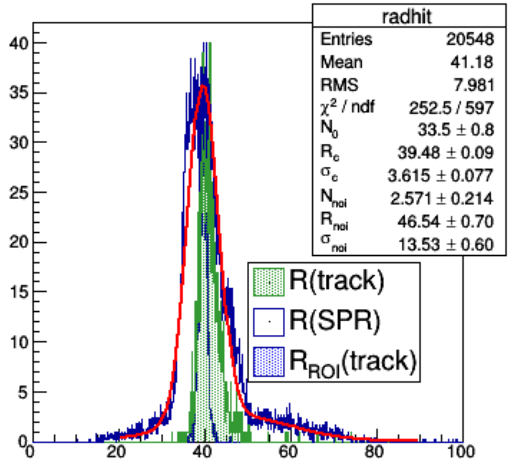
PMT:

- 4 Hamamatsu H12700
- pixel 6x6 mm

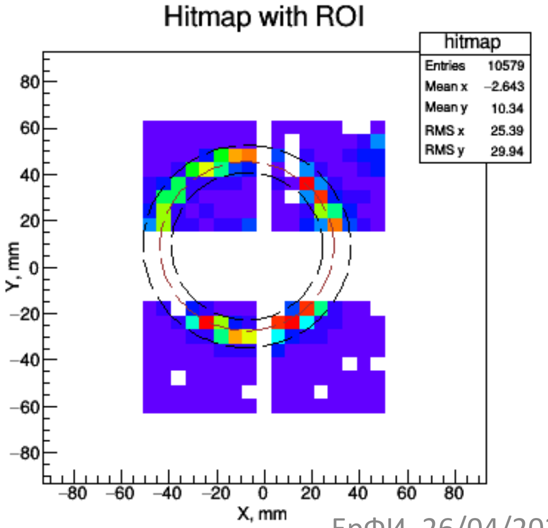
Without lens

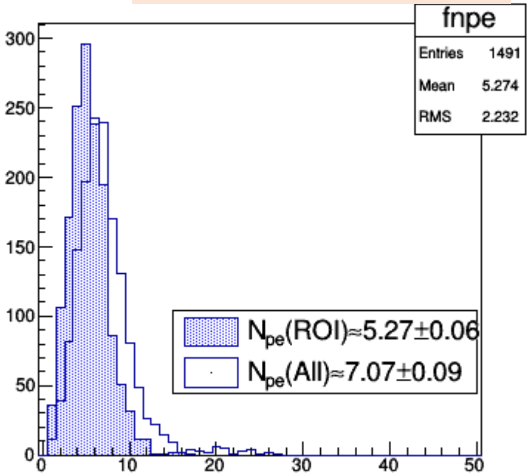


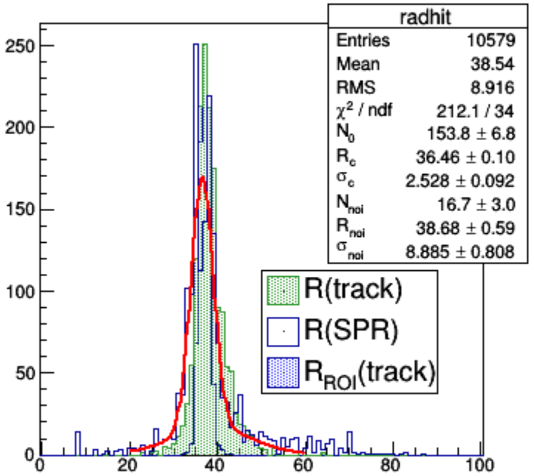




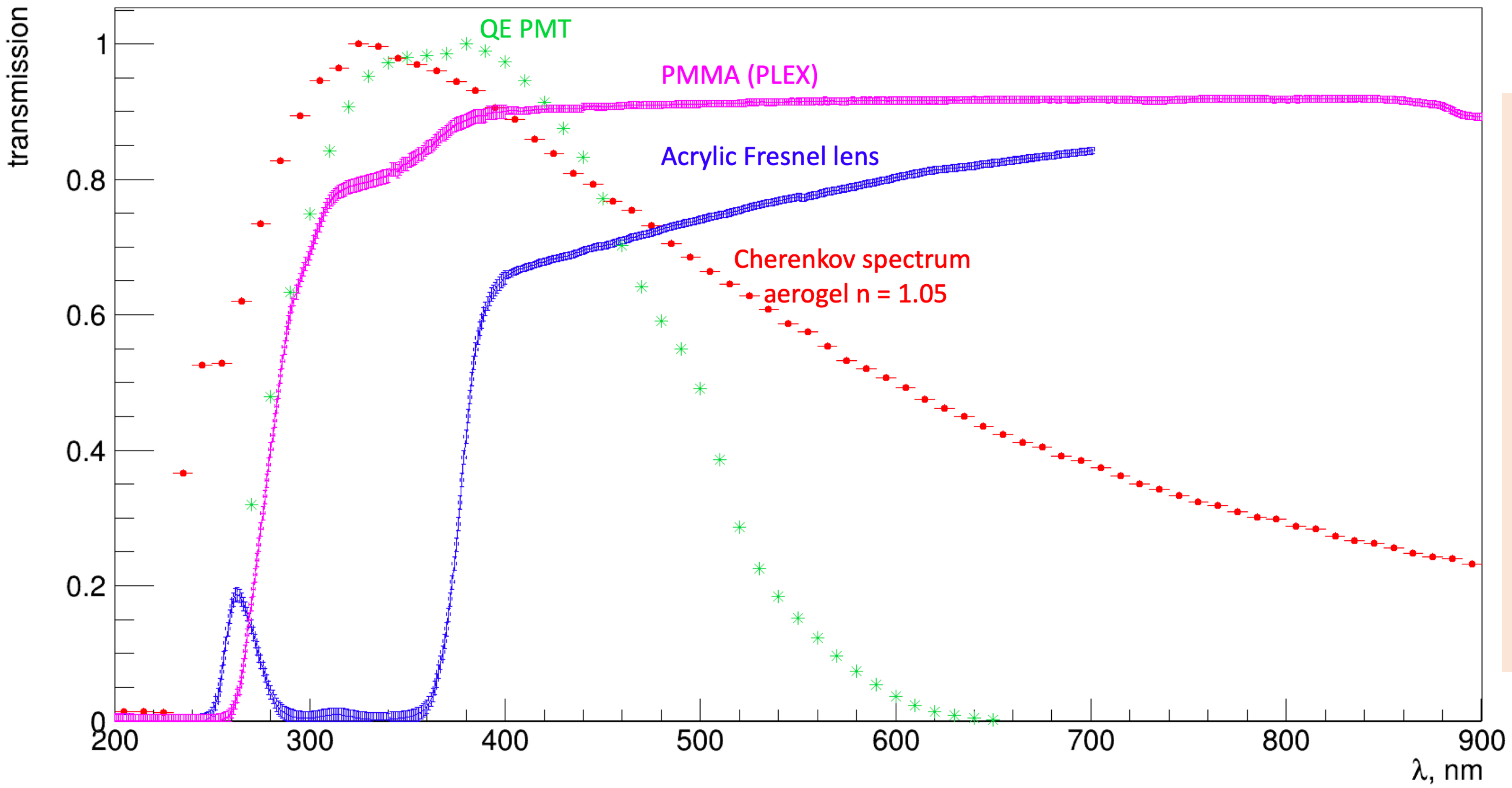
With Fresnel lens





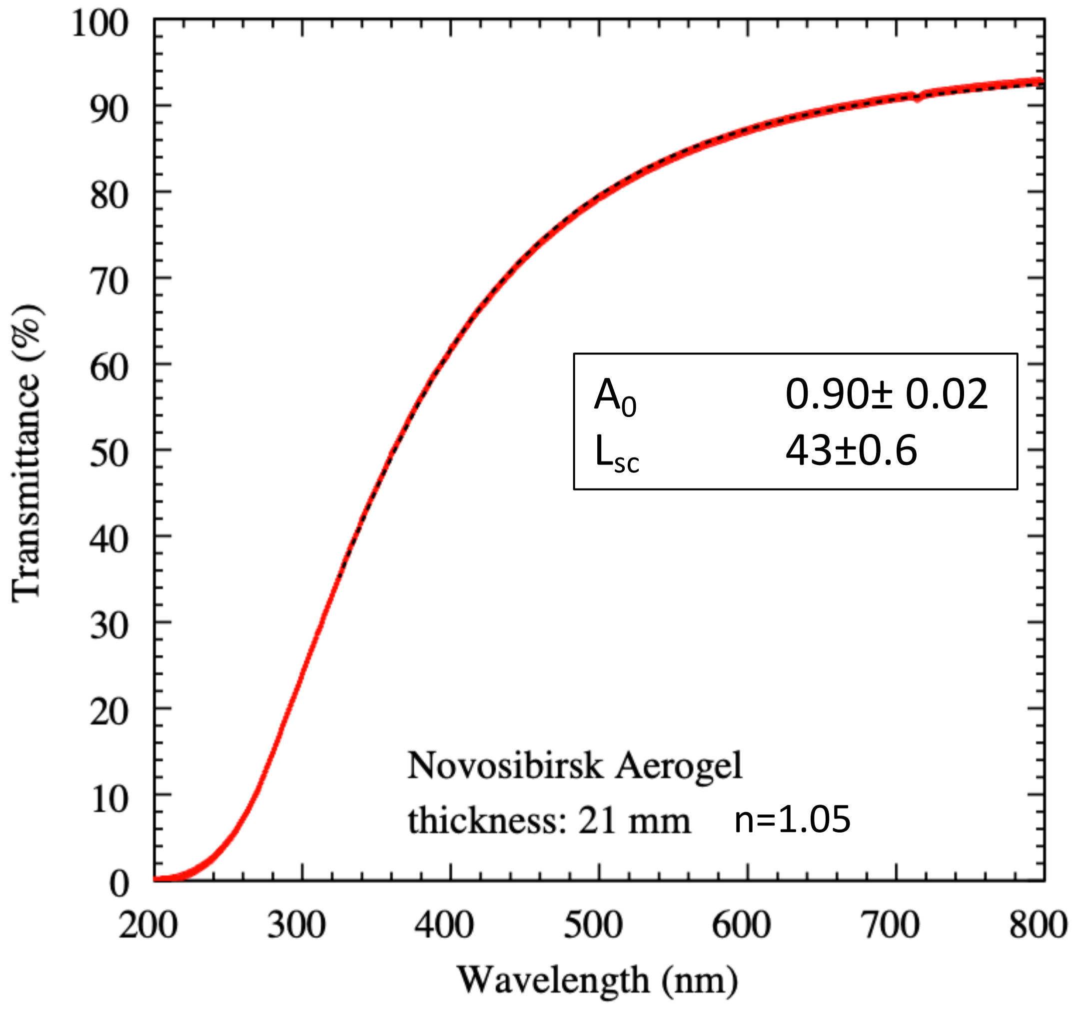


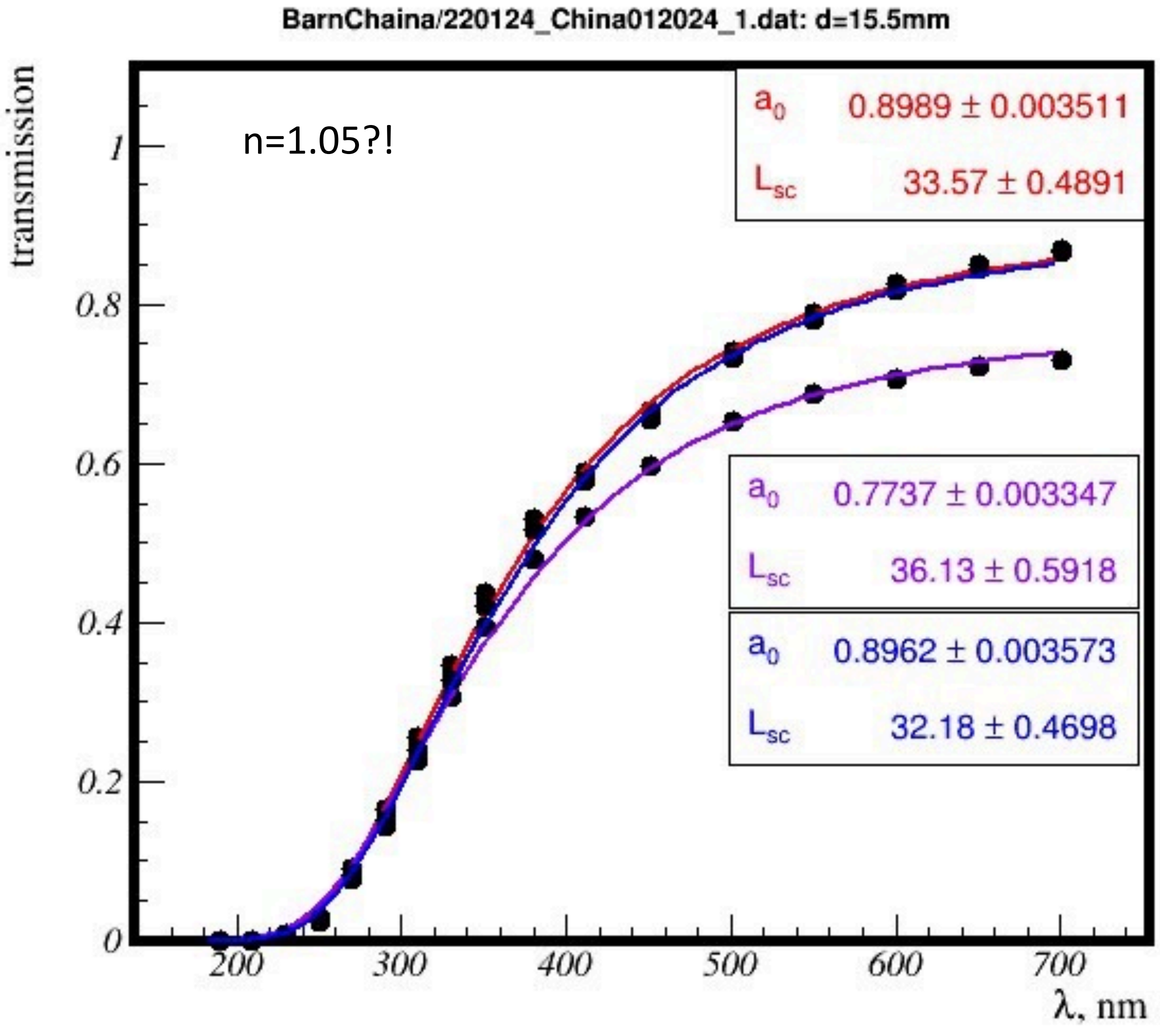
Fresnel lens transparency



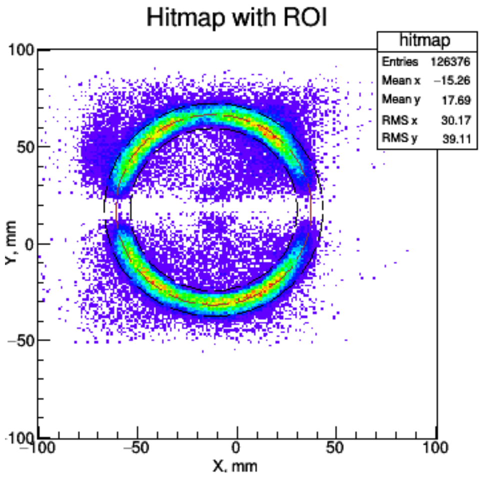
- About half of Cherenkov photons from aerogel is absorbed by lens material
- It is necessary to check possiblity to produce Fresnel lenses based on PMMA without UV absorbers and so on.

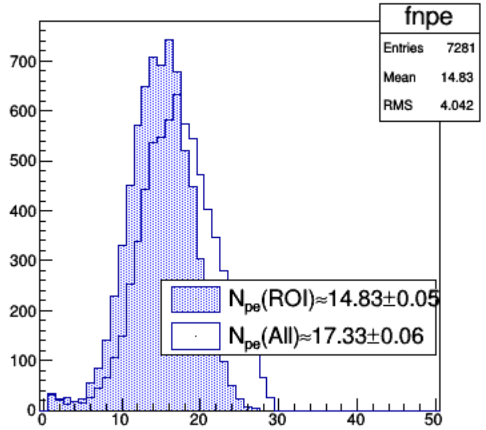
Very first expirience with aerogel produced in China: – Transperancy

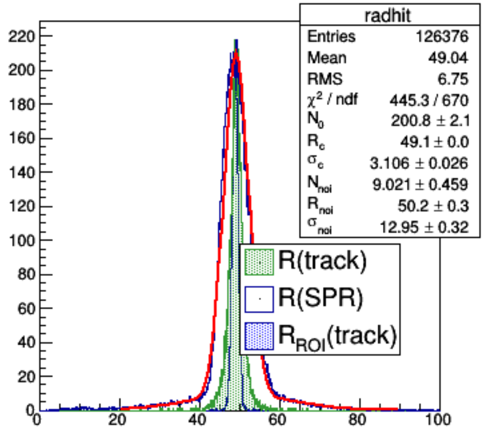




Very first expirience with aerogel produced in China:
– Beam test results





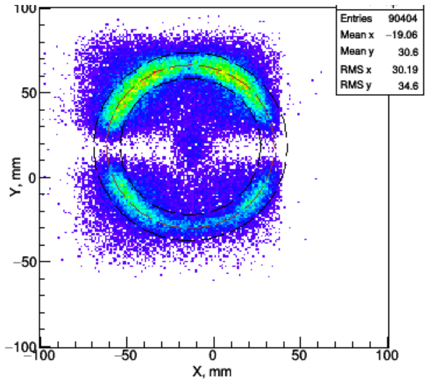


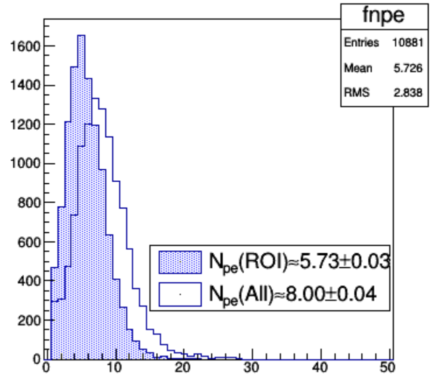
Novosibirsk aerogel:

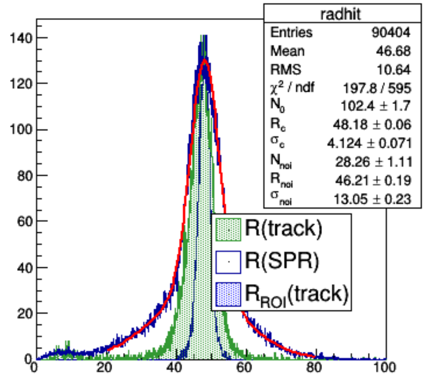
- n=1.05
- t=30mm
- L_{sc}(400nm)=43±0.7mm

Chinese aerogel:

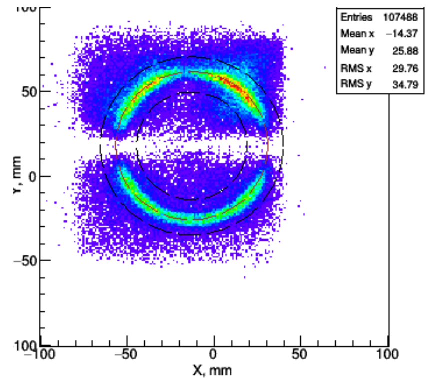
- n=1.055
- t=17mm + 17mm
- L_{sc}(400nm)=34±0.7mm

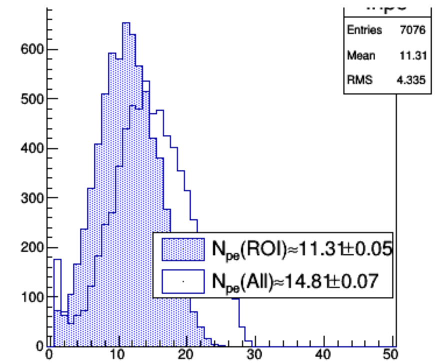


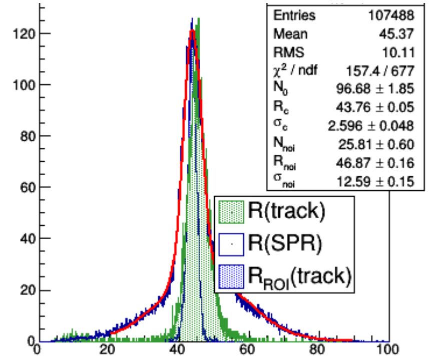




- t=17mm + 17mm + 17mm







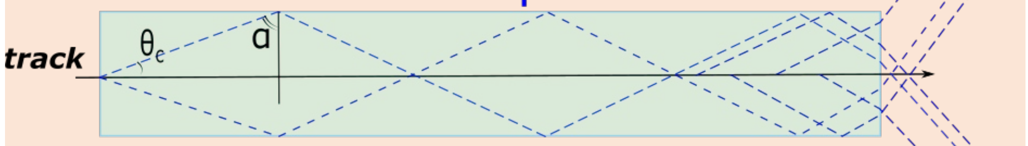
RICH based on aerogel fibers for π/K–separation above 10 GeV/c (CEPC?)

Fiber Aerogel RICH: idea & motivation

For π/K-separation above 10 GeV/c we need decrease n and N_{pe} decreases too. We consider approach how to compensate number of Cherenkov photons with help of aerogel fibers without segnificant angle resolution degradation.

- It was inspired by discussion at SINANO (Sughou) with prof. Xeutong Zhang and Co. in August 2023.
- The possibility of aerogel fiber production is decribed in article: *Adv. Sci.* **2023**, *10*, 2205762

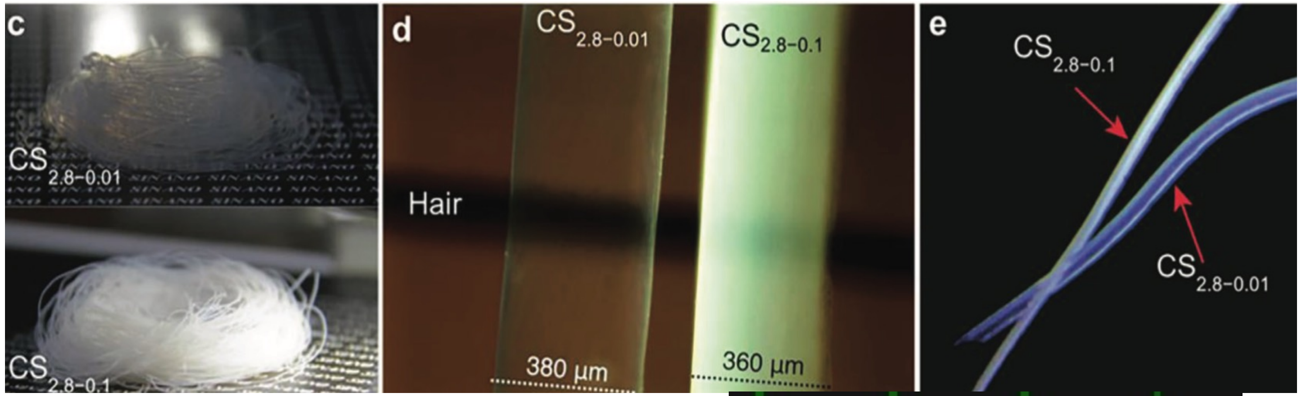
$$\cos(\theta_C)=\frac{1}{n\beta}=\sin(\alpha)$$

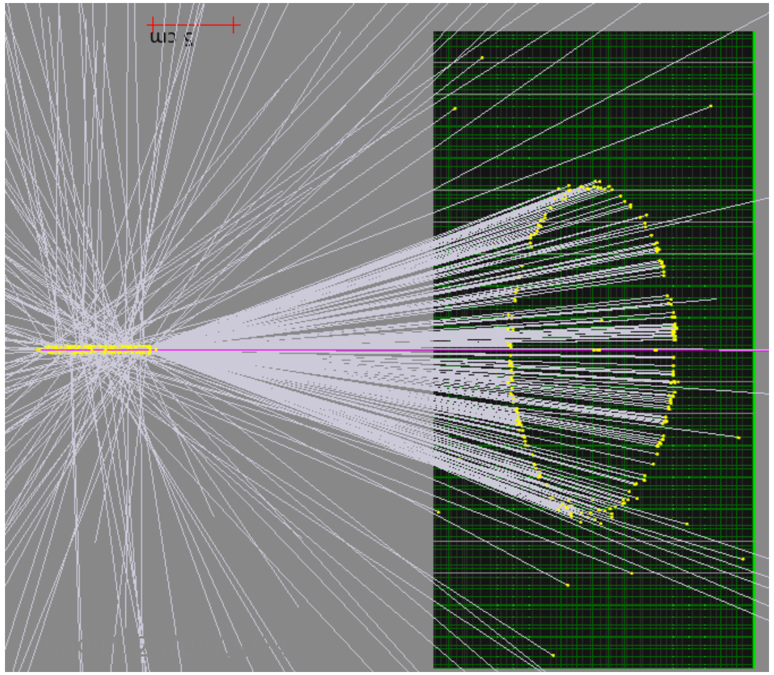


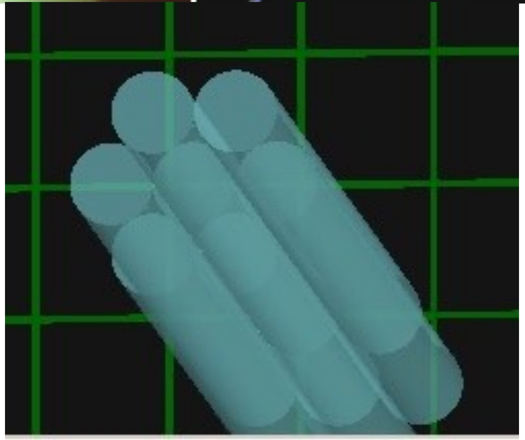
Cherenkov light ocurs in total internal reflection conditions if particle goes stright along bar or fiber axis!

Chernkov photon emmision point is determined by transverse size of fiber.

Chernkov photon number is determined by length, refractive index and transparency of fiber.



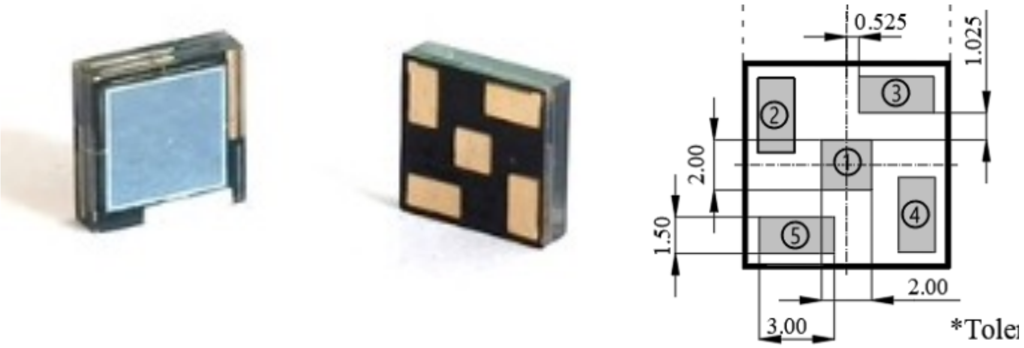


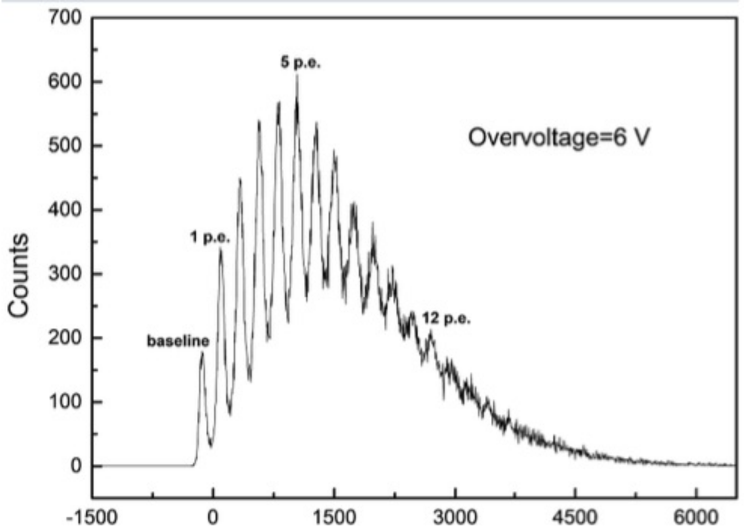


Single fiber params:
- n=1.03÷1.05
- Length = 35÷50 mm
- ø 0.4÷2 mm

Photon detector option for Fibra RICH

Position Sensetive SiPM or PSS 11-3030-S (from NDL, China) or LG-SiPM (from FBK, Italy) are able to provide spatial resolution $\sigma_x \approx 200\mu m$ per single photon detected.



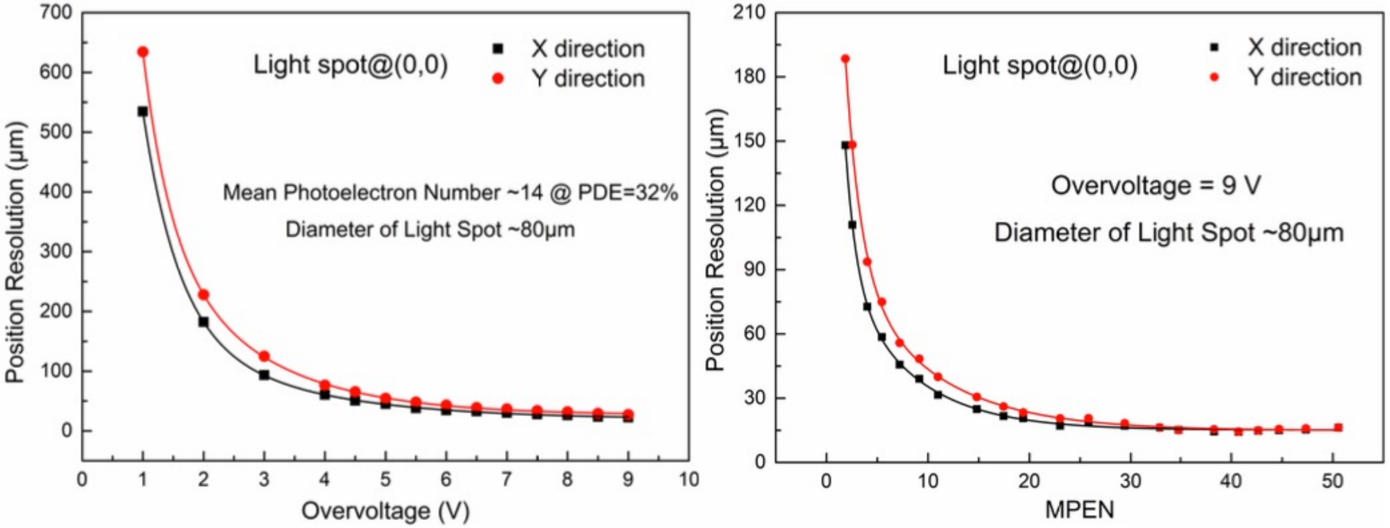


Position Algorithm

$$x_c = \frac{L}{2} \cdot k \cdot \frac{(Q_2 + Q_3) - (Q_1 + Q_4)}{(Q_1 + Q_2 + Q_3 + Q_4)}$$

$$y_c = \frac{L}{2} \cdot k \cdot \frac{(Q_3 + Q_4) - (Q_1 + Q_2)}{(Q_1 + Q_2 + Q_3 + Q_4)}$$

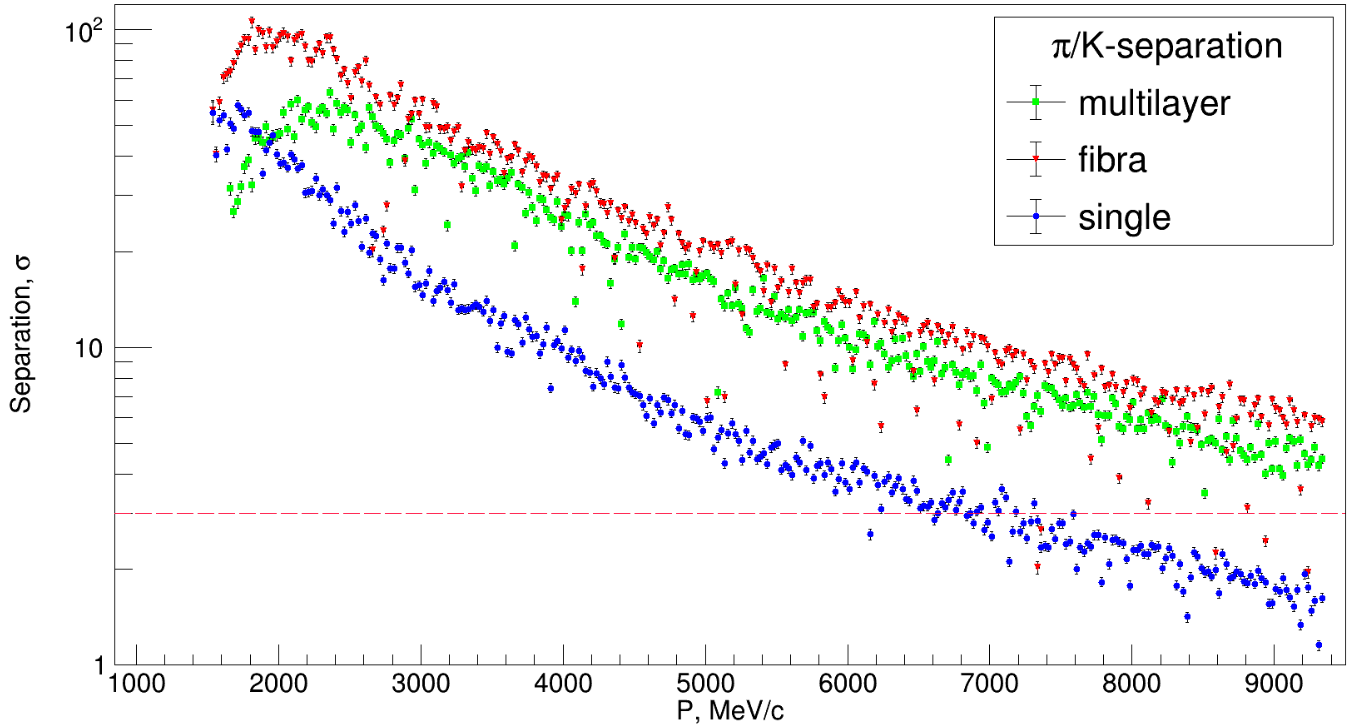
L is the length of the active area. Q_i (i = 1, 2, 3, 4) is the shared charge of the corresponding anode. k is the calibration factor.



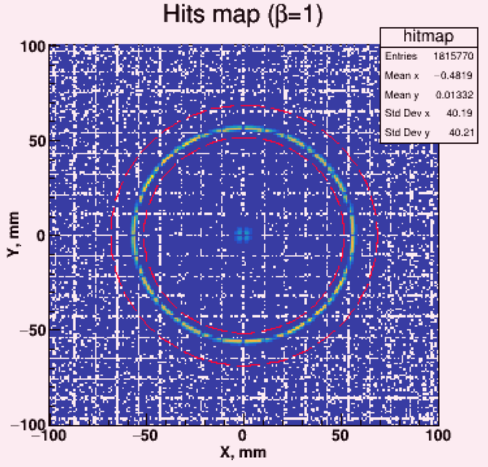
Test Conditions: OV=9 V if not specified, Temp.=20 °C, Load Impedance = 50 Ω.

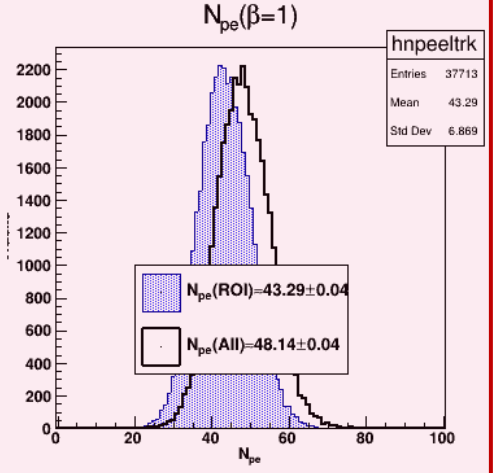
Particle separation power evaluated in GEANT-4

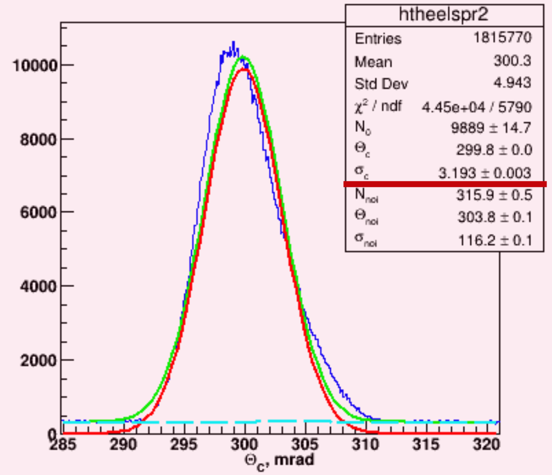
Phton Detector σ_x ≈200µm***;*** PDE(400nm)≈45% (Hamamtsu S14160)



Aerogel fiber (n=1.05, L=35 mm, L_{SC}(400nm)=43



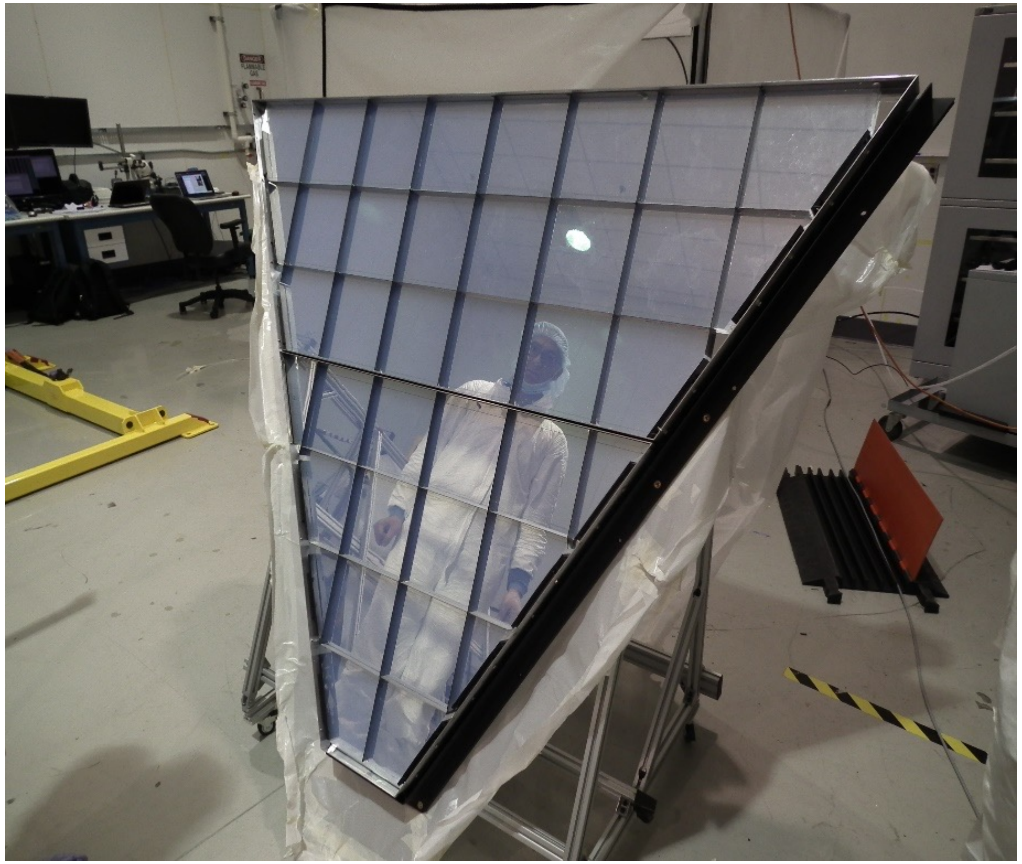




Main aerogel parameters & features

History of aerogel radiators in Novosibirsk

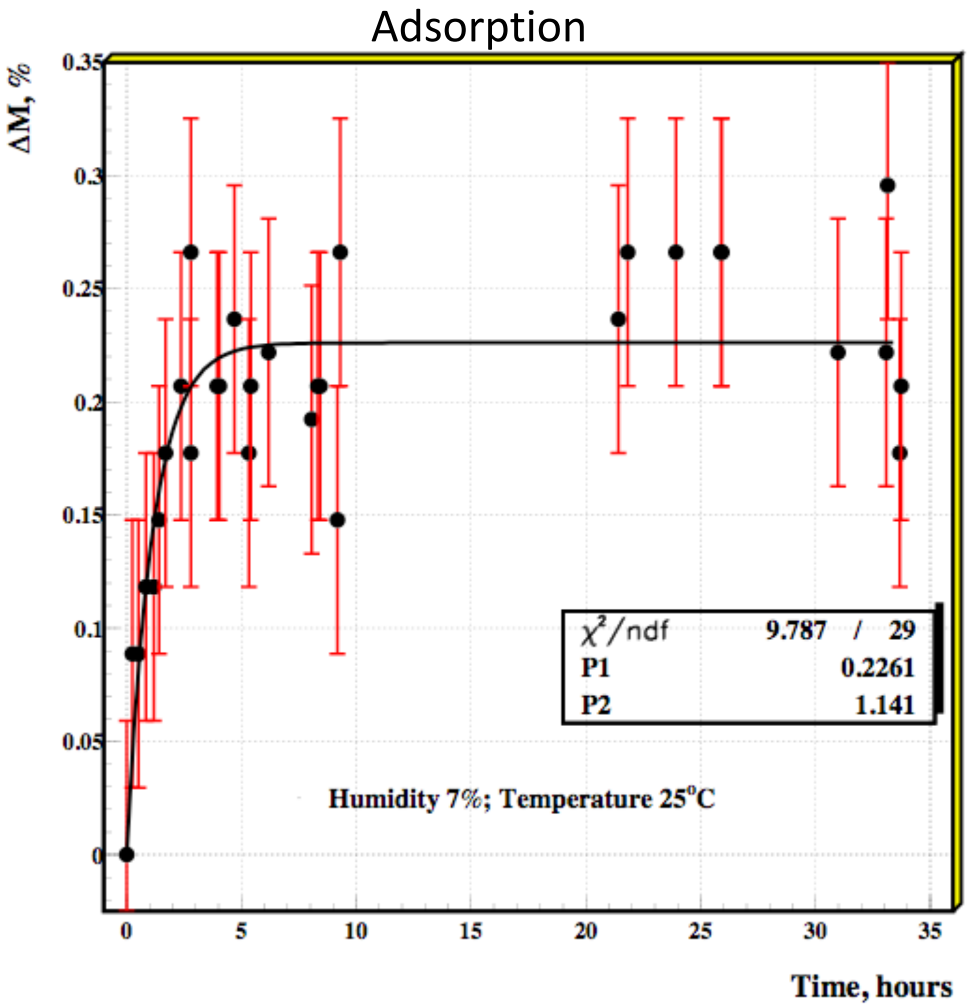
- **KEDR ASHIPH** system (VEPP-4M – BINP):
  - π/K-separation in the momentum range 0,6÷1,5 GeV/c.
  - Aerogel $n = 1{,}05$ (V~1000 L).
- **SND ASHIPH** system (VEPP-2000 – BINP):
  - π/K-separation in the momentum range 300÷870 MeV/c.
  - Aerogel $n = 1{,}13$ (V~9 L).
- **DIRAC-II** (PS – CERN):
  - π/K-separation in the momentum range 5,5÷8,0 GeV/c.
  - Aerogel $n = 1{,}008$ (V~9 L).
- **AMS-02** aerogel RICH (ISS):
  - Search for antimatter, study of cosmic rays.
  - Aerogel $n = 1{,}05$ (S~1 m^2).
- **LHCb** aerogel RICH (LHC – CERN):
  - π/K-separation in the momentum range 5,5÷8,0 GeV/c.
  - Aerogel $n = 1{,}03$ (S~0,5 m^2), aerogel tile 20x20x5 $см^3$.
- **CLAS-12** aerogel RICH (J-Lab):
  - π/K- & K/p-separation at level 4σ with several momentum GeV/c.
  - Aerogel $n = 1{,}05$ (S~6 m^2), aerogel tile 20x20x2-3 $см^3$.

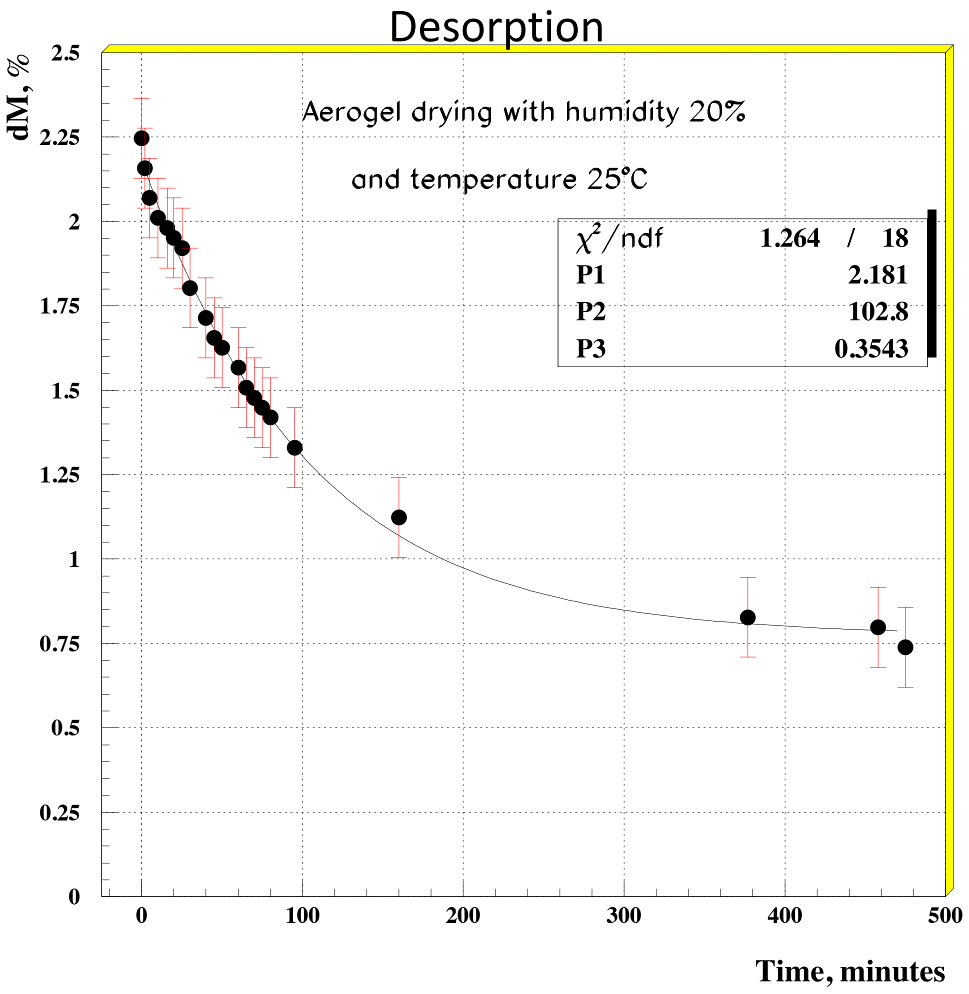


Novosibirsk aerogels is hydrophilic!N

- Aerogel with bulk density 0.24 g/cm^3 has internal surface area by 10^6 times larger than external.
- There are a lot of OH−groups at the aerogel SiO_2 surface. These groups are primary adsorption centres which are able to attract hundreds of the H_2O molecules per each.
- In the hydrophobic aerogels OH−groups are exchanged by hydrophobic radicals such like $Si(CH_3)_3$
- Influence of adsorbed water on optical parameters of hydrophilic aerogels produced in Novosibirsk are very well studied already.
- Heating of hydrophobic aerogel up to above 175℃ makes it hydrophilic. Also more active radicals are able to replace $Si(CH_3)_3$ – groups and change aerogel optical parameters.
- Before the finalization of any aerogel based counters design it is necessary to investigate influence of materials (such like WLS, hermetics or second gas/liquid Cherenkov radiators) which are going to be used in the construction on aerogel transparency.
- For (FA)RICH counters the major optical parameter is <u>Rayleigh Light scattering length</u>, while for threshold aerogel counters with diffusive light collection (like ASHIPH) it is <u>light absorption length</u>

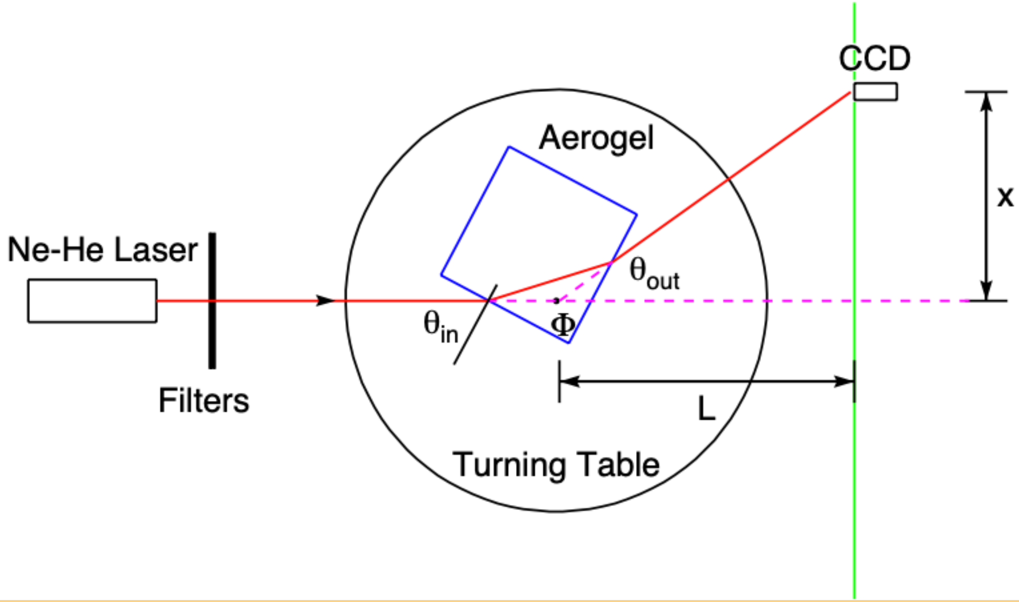
Water adsorption by aerogel





Water adsorption and desorption are the fast processes with time constant about 1 hour.
Amount of adsorbed water depends on relative humidity of invironment.

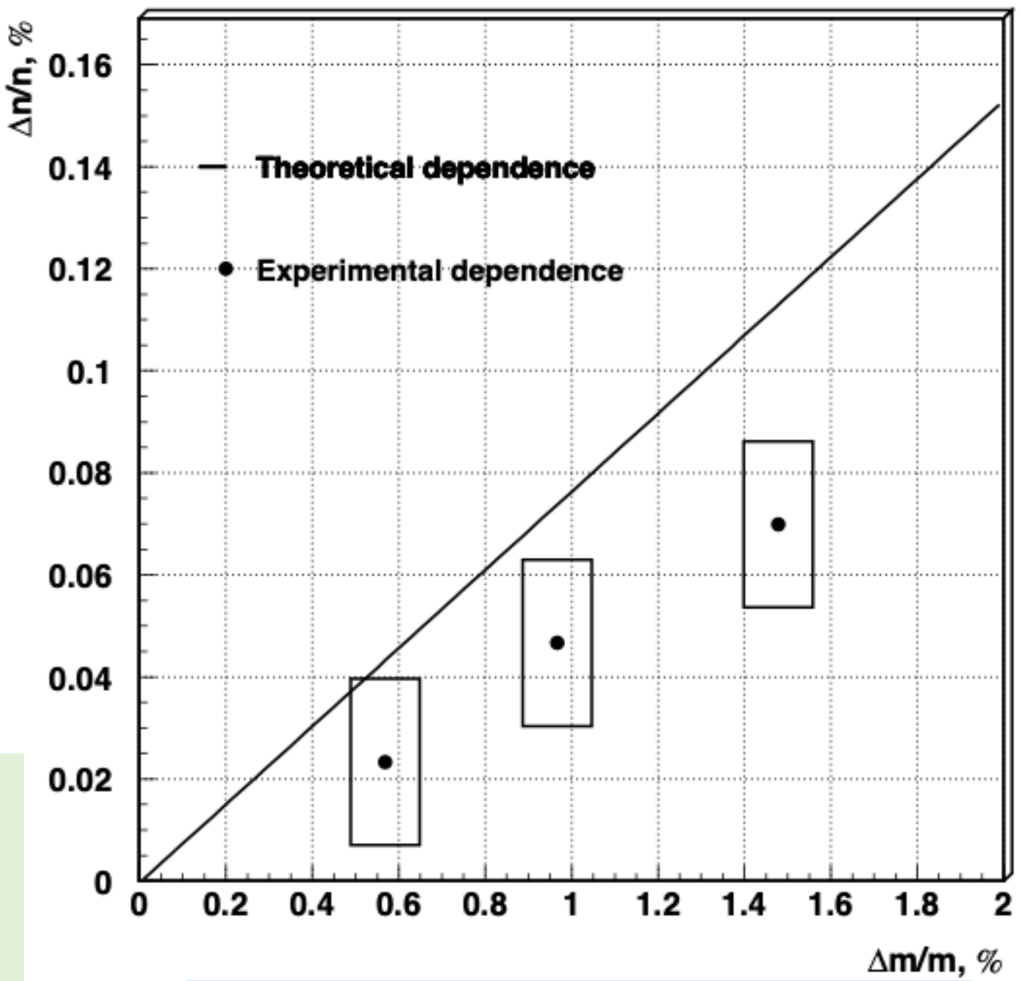
Refractive index



Impirical relation is used for fast determination of n:

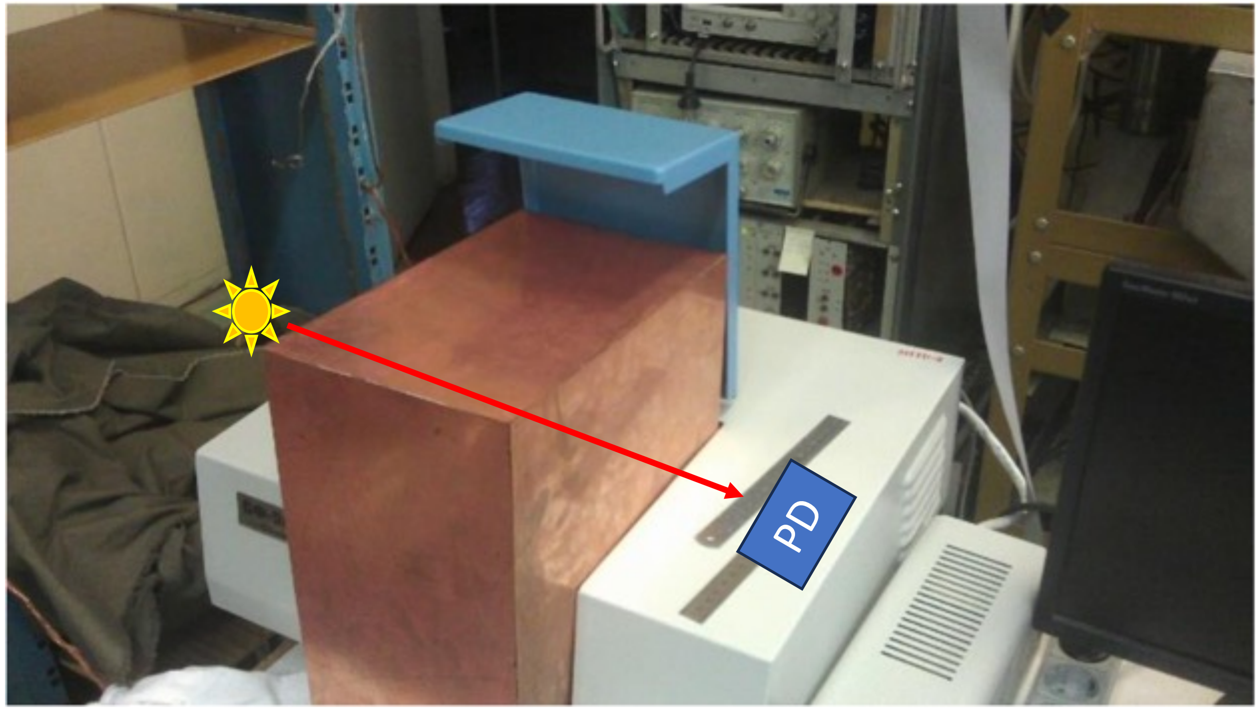
$$n^2 = 1 + 0.438 \cdot \rho \left[{}^{g}/_{cm^3}\right]$$

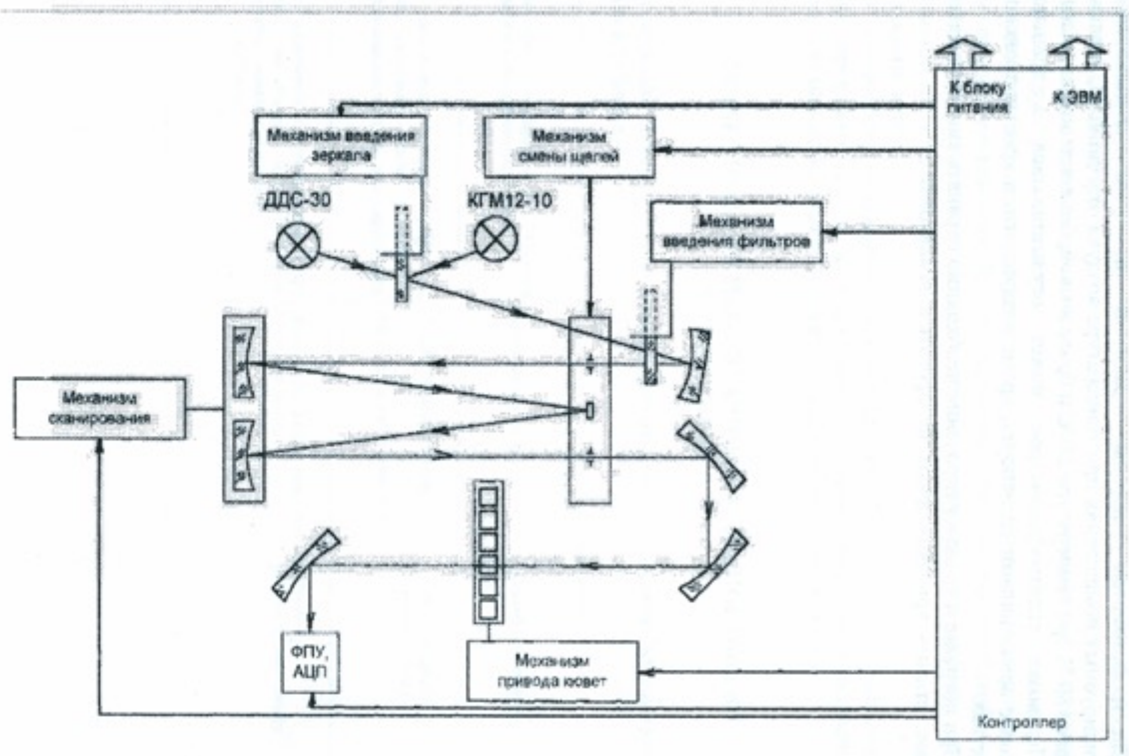
For theoretical dependence Lorentz-Lorentz formula was used, which was expressed to calculate refractive index of gases mixtures but it very often works for other mixtures.



n dependence on water adsorption

Aerogel transmittance measurement scheme



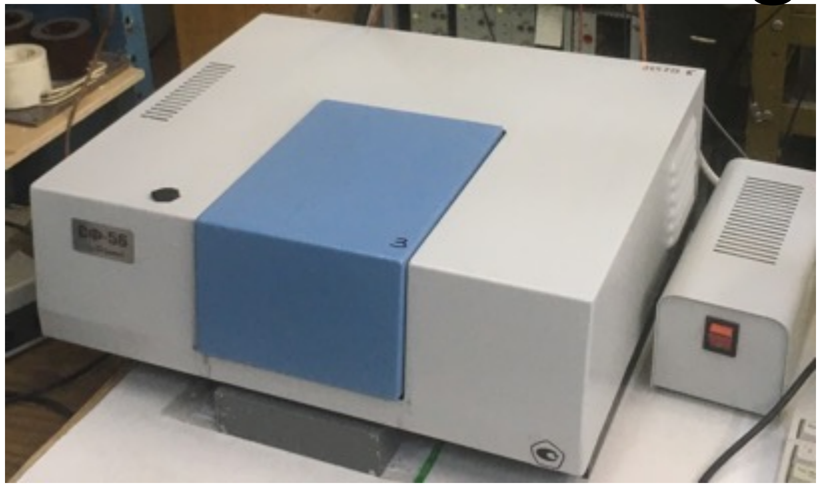


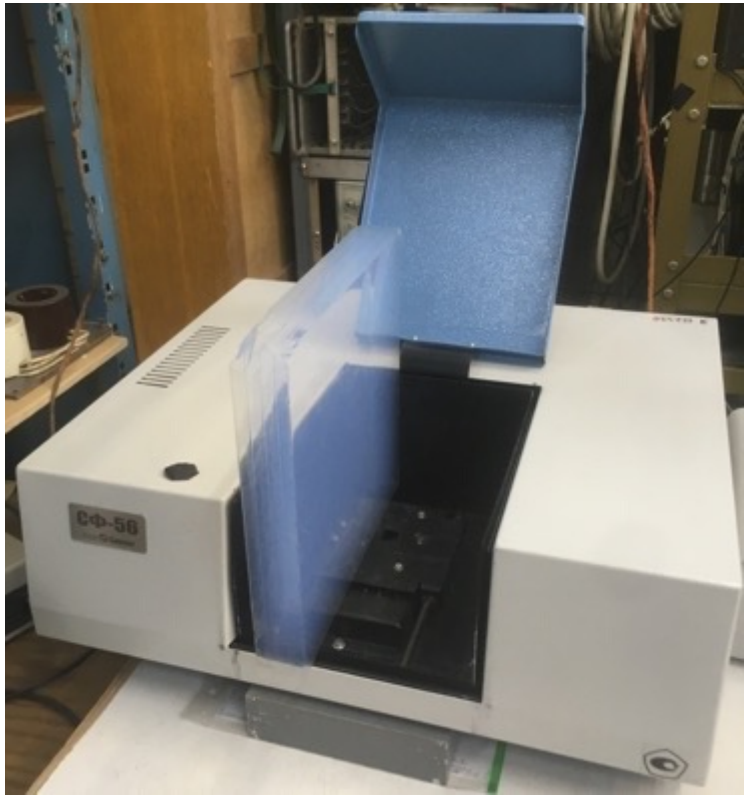
- Aerogel transmittance is measured with help of standard device SpectroPhtometer SPh-56 (OKB Spectra).

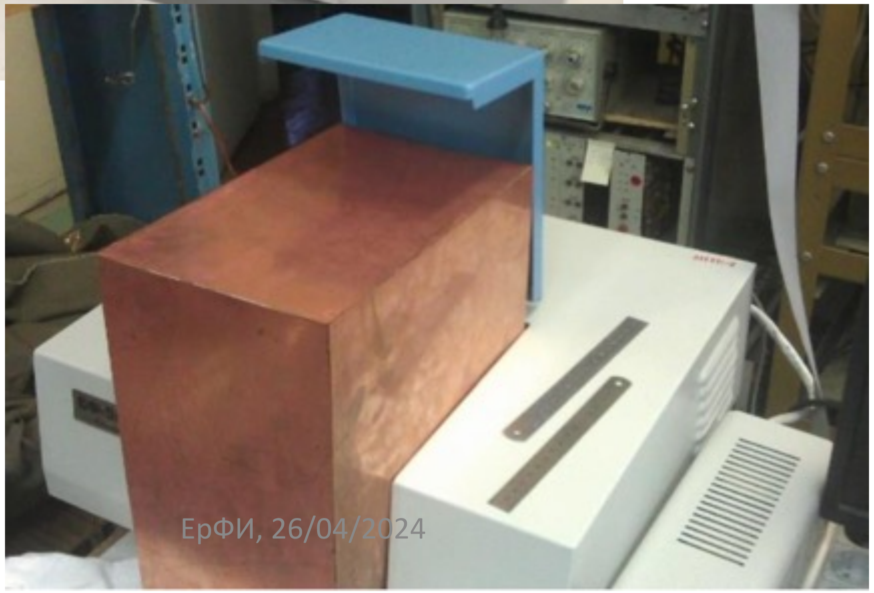
(https://okb-spectr.ru/products/spectrophotometers/sf56 ~0.5 million RUB or PerkinElmer Lambda 650 spectrometer for 30+k$)

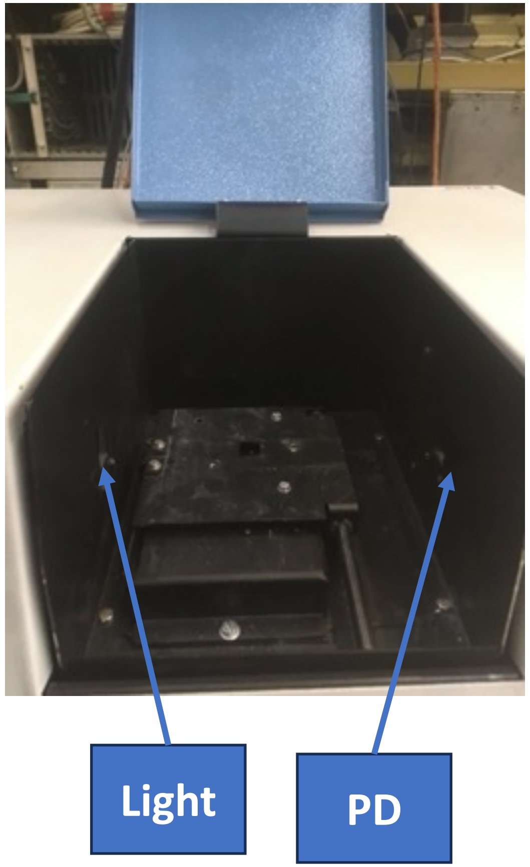
- Rayleigh's law parameters evaluated from dependence of realtion of light intensity with and without aerogel $^{I_{aer}}/_{I_0}$ on wavelength with help of approximation its by Hunt equation.
- For large aerogel blocks (≥100x100xXX mm) special light tightining box was constructed.
- Tuning of the wavelength and measurement of curent from Photon Detector (PD) performed automaticaly with help of PC and data with PD currents are stored in three ASCI files (i_0_begin.dat, i_aer.dat, i_0_end.dat). i_0_begin and i_0_end are measured to evaluate accuracy of the mesurement.
- The dependence of the aerogel transperancy on wavelength with consequently extracting of the Rayleigh's law parameters (fit the the measured data by Hunt relation) are performed with help of ROOT-script.

Aerogel transmission measurement scheme

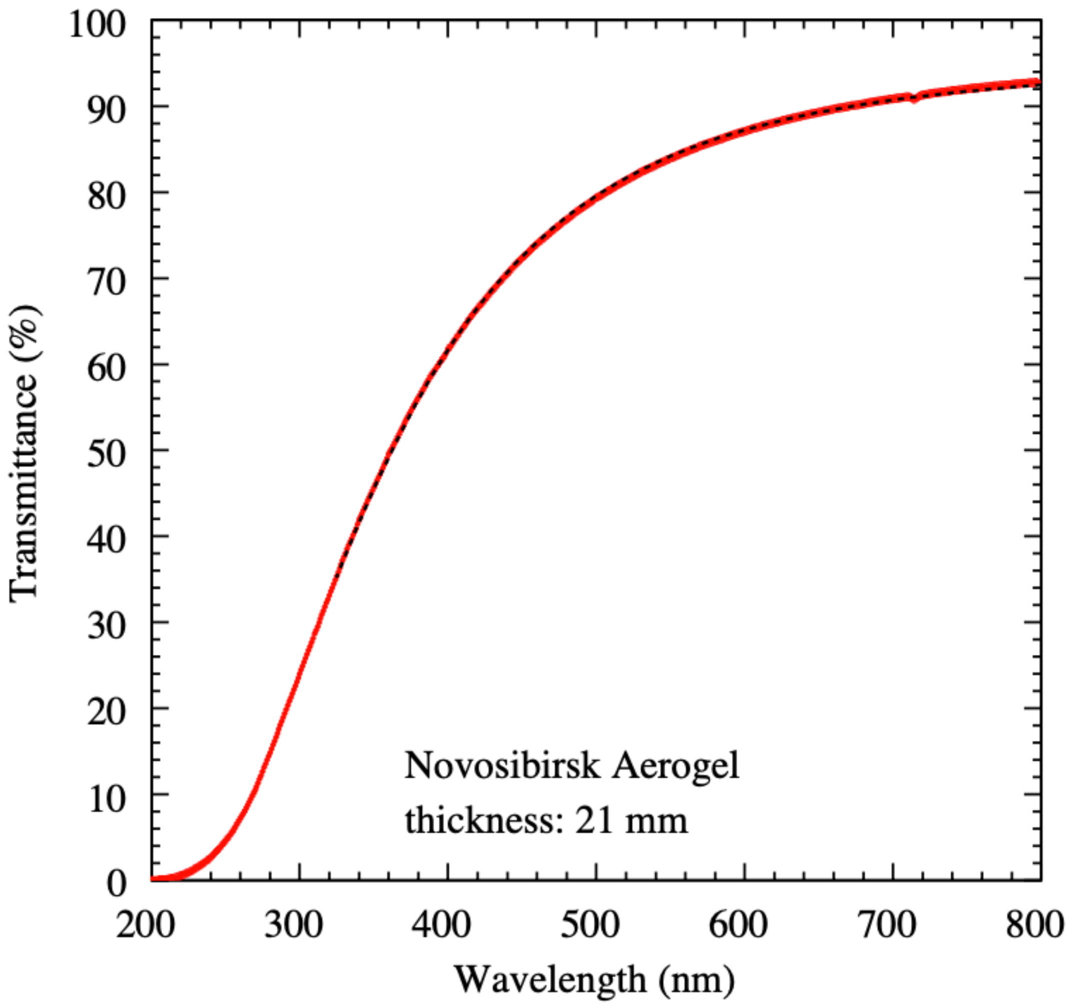






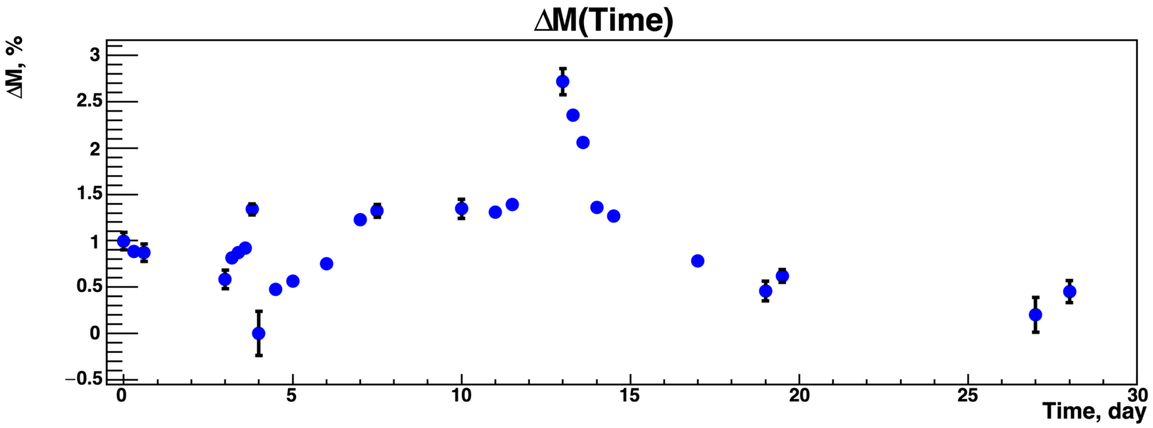


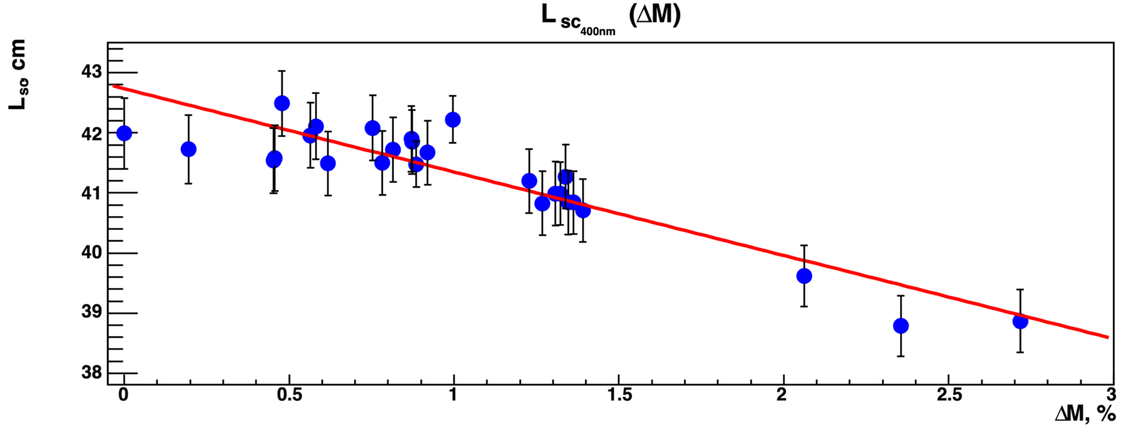
Aerogel transmittance and parameters of Rayleigh light scattering

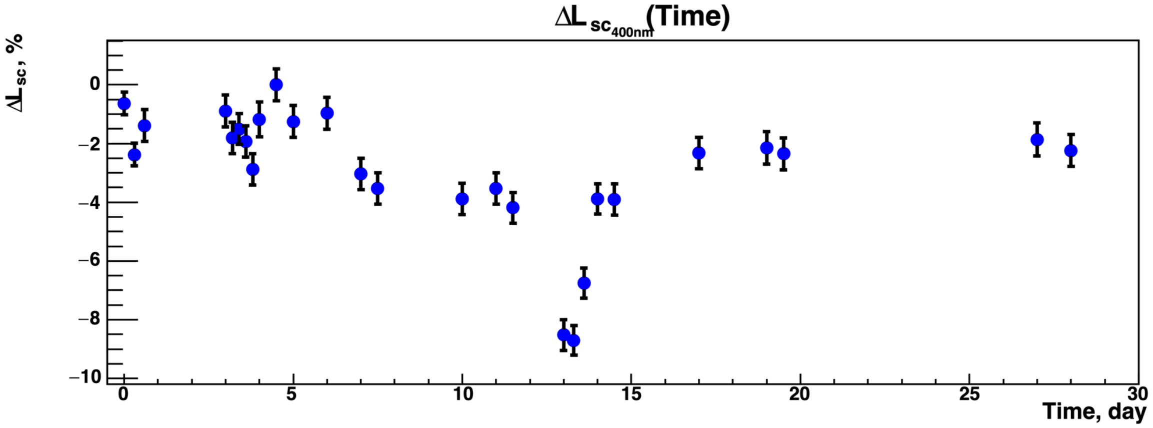


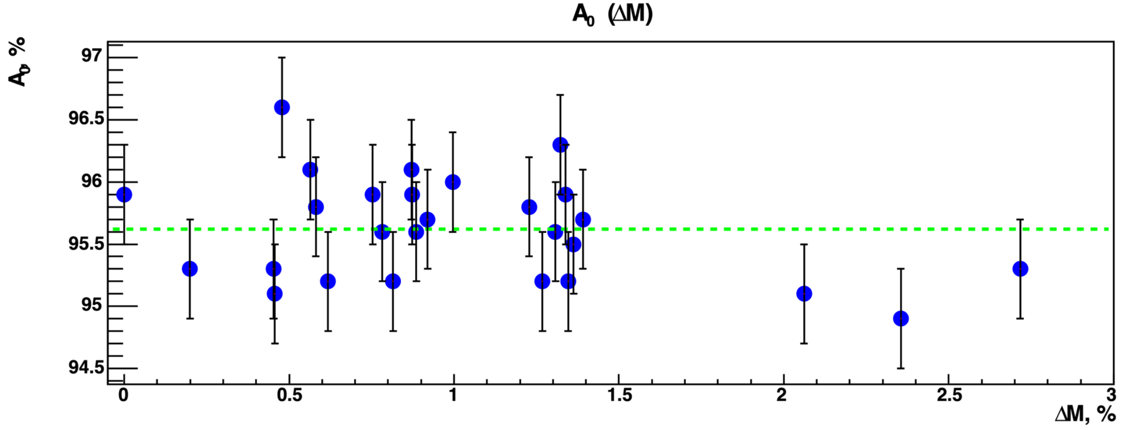
- Hunt formula to fit the transmittance (T) usually are used in two variations:
- $T(\lambda) = \frac{I}{I_0} = A_0 e^{-\left(\frac{d}{L_{sc}^{400} \times \left[\frac{\lambda}{400}\right]^4}\right)}$
- or
- $T(\lambda) = \frac{I}{I_0} = A_0 e^{-\left(C \cdot d / \lambda^4\right)}$
- where d – aerogel thickness, L_{sc}^{400}– light scattering length at 400 nm and C – so called clarity, A_0 – coefficient responsible for light absorption and scattering at the surface of aerogel samples.

Influence of adsorbed water on Raleigh light scattering in aerogel





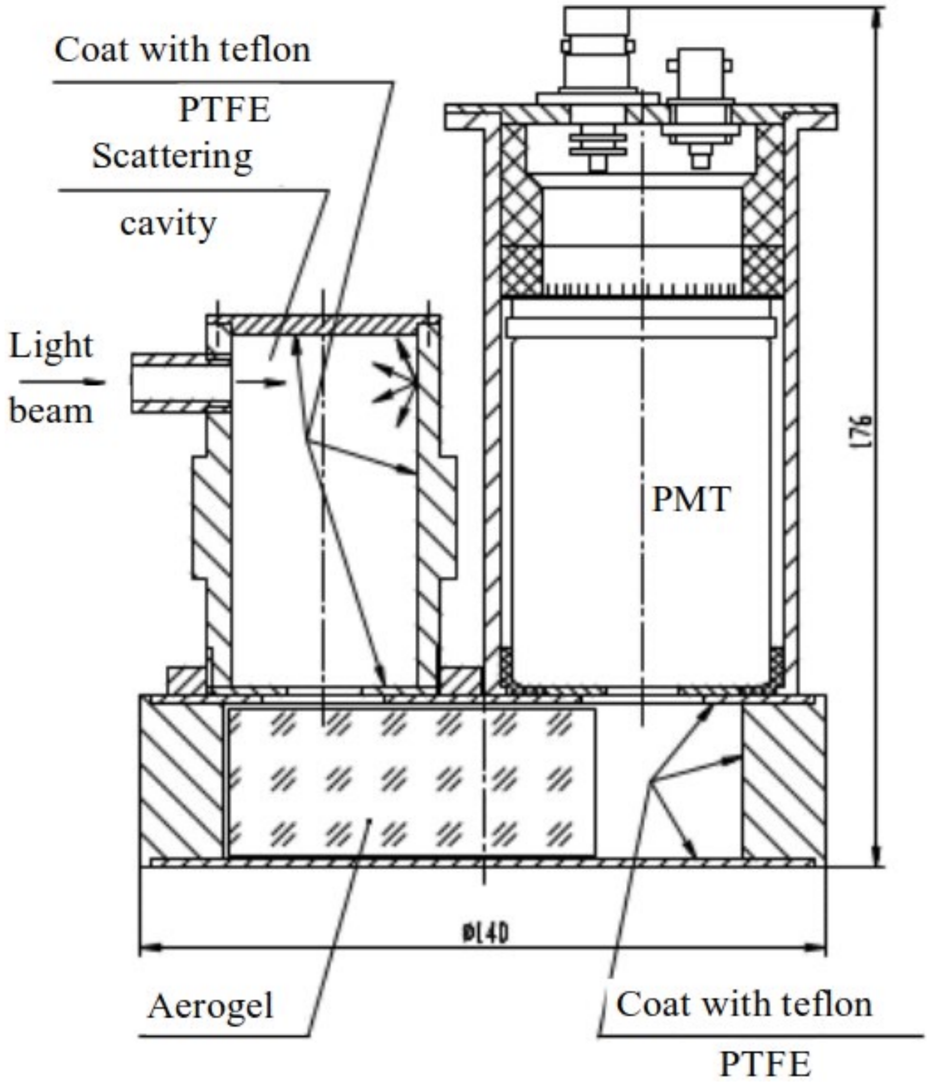




Raleigh light scattering in aerogel strongly dependce on amount of adsorbed water the effects of light scattering length decrease in normal conditions doesn't exceed 10% (L_{sc}(400 nm) drops from 43 to 38 mm).

T. Bellunato, et al., NIM A 527(3) (2004) 319

RLC & Light absorption length measurement



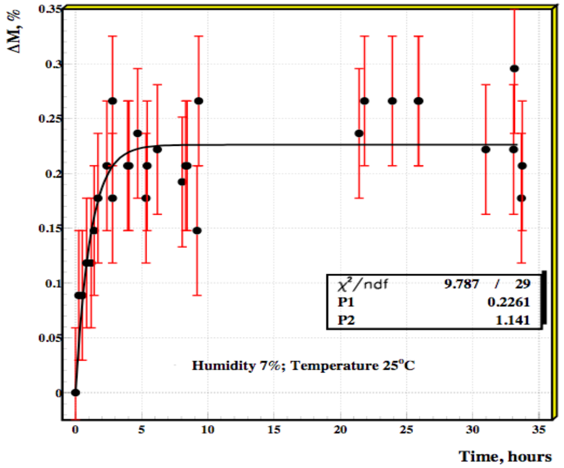
- Relative light collection (RLC):

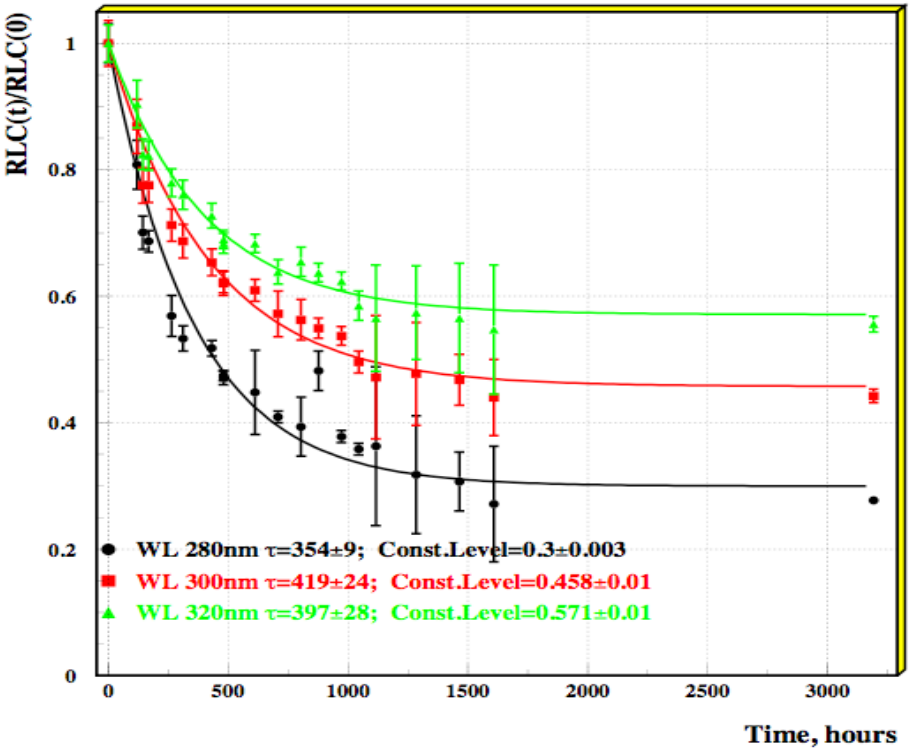
$$RLC(\lambda) = \frac{LC_{aer}(r(\lambda),\ L_{sc}(\lambda),\ L_{abs}(\lambda))}{LC_{box}(r(\lambda))} = \frac{I_{aer}(\lambda)}{I_{box}(\lambda)}$$

- Light scattering length $\left(L_{sc}(\lambda)\right)$ determined by Raleigh scattering in aerogel is measured from fit of aerogel transparency data.
- To determine reflective coefficient $\left(r(\lambda)\right)$ of PTFE a special data are took with ”Scattering cavity” coupled to PD
- Monte-Carlo simulation is used to evaluate light absorption length $\left(L_{abs}(\lambda)\right)$ from $RLC(\lambda)$ measured data

Light collection degradation due to water adsorption

- Aerogel internal surface is 10^6 times greater than external. Adsorption of water is very fast process (1-2 hours).
- Degradation of the light absorption length is very slow process (1-2 months) after water absorption.
- The time and the level of the degradation are depend on the impurities in aerogel from raw materials and production procedure (Fe, Mn, Cr, etc.).



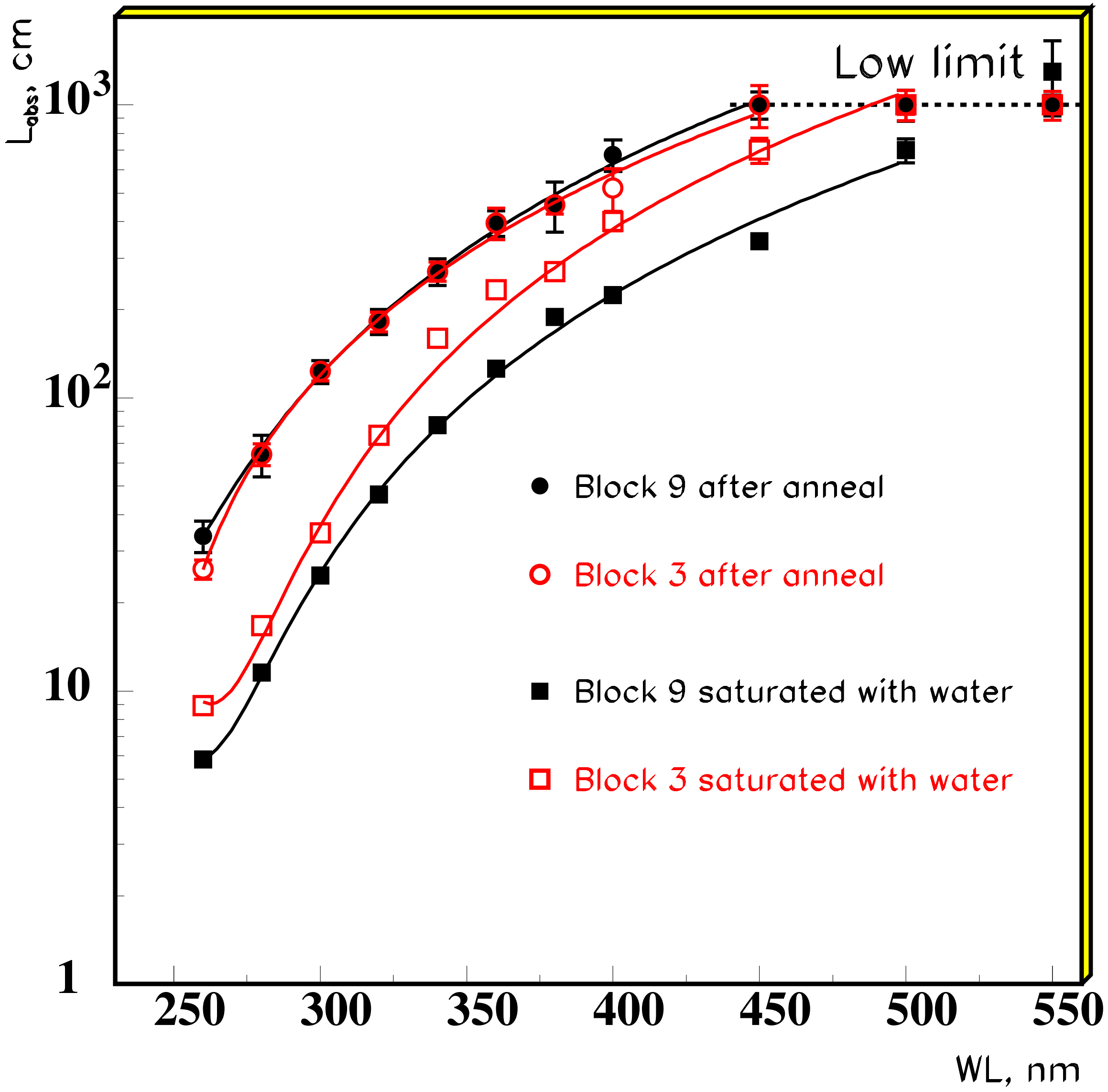


Concentration of metals in aerogel, ppb				
Fe	Cu	Mn	Cr	Ni
500	56	7	26	

Aerogel light absorption length degradation due to water adsorption

- 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.

•A.Yu.Barnyakov et al., NIM A598 (2009) 166-168



Mechanical tooling & storage

Equipment for other works with aerogels appart from the characterisation of optical parameters

1. **Aerogel cutting machine.**
   There is one picture of our CNC (Computer Numerical Control) cutting machine with diamond wheel in attached paper [NIM A952 (2020) 162035]. It was designed and produced in BINP but I think it is possible try to find some analog among the diamond wheel milling machines for tile or ceramic with feeding controlled by PC or by hand. The main parameters of our cutting machine are:
   - tuneable rotation frequency (default is 2800 rot/min);
   - feed velocity tuneable about 3 cm/min (it depends on aerogel density)
   - CNC is used to provide the position of cuts with high accuracy by stepping movers.

2. **Dry boxes or dry cabinet.**
   To store the aerogel samples during the production processes (between cutting or optical measurements). In BINP we use this one Totech Super Dry MSD-1106-02 (http://www.totech.com/products/superdry/02series/SD-1106-02.html).

3. **Oven to restore optical parameters of aerogel before assembling of counters.**
   Operational volume should be able to place several samples of aerogel radiators. The cycle of aerogel heating usually is about 17 hours: 5 hours to rise temperature to 500 Celsius degree, 5 hours plateau at this temperature and 7 hours to cool down to 100 Celsius. Internal surfaces of the oven should be chemically neutral and clean (I mean don’t provide any evaporation at high temperatures). The forced convection is not very necessary option for the oven (of course if the volume is not too large). By the way, I've just remember that we still not investigate properly the option of restoring opticla aerogl parameters with help of microwaves. This could be very useful option for mass production process.

4. **CCD sensor and Laser head** are needed for investigation and characterization of small angle forward scattering effects in aerogels [NIM A 876 (2017) 168–172]

Cutting maichine

Grinding & polishing


Backing & storage