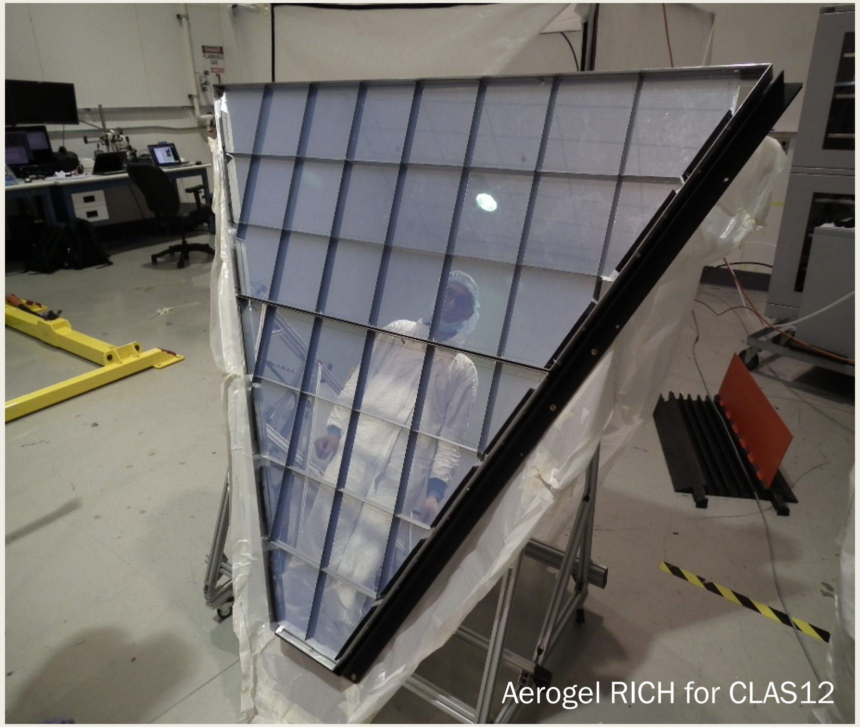
PROGRESS IN THE PRODUCTION OF AEROGEL RADIATORS FOR THE RICH DETECTORS IN NOVOSIBIRSK

Aleksandr A. Kattsin &
A.Yu. Barnyakov, E.A. Kravchenko, A.F. Danilyuk, A.S. Shalygin.
Budker Institute of Nuclear Physics of Siberian Branch
Russian Academy of Sciences

History of aerogel radiators in Novosibirsk

The history of the Novosibirsk aerogel begins in 1986.

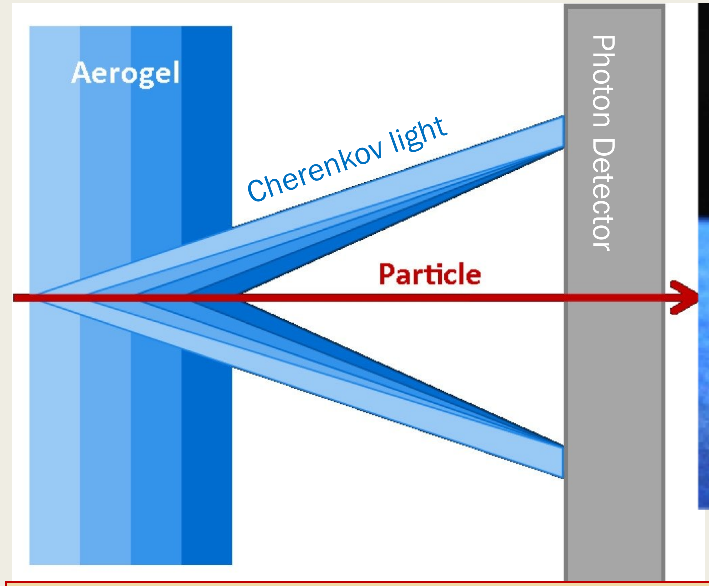
- KEDR ASHIPH system (VEPP-4M – BINP):
  - π/K-separation in the momentum range 0,6÷1,5 GeV/c.
  - Aerogel $n = 1{,}05$ (V~1000 L).
- SND ASHIPH system (VEPP-2000 – BINP):
  - π/K-separation in the momentum range 300÷870 MeV/c.
  - Aerogel $n = 1{,}13$ (V~9 L).
- DIRAC-II (PS – CERN):
  - π/K-separation 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.

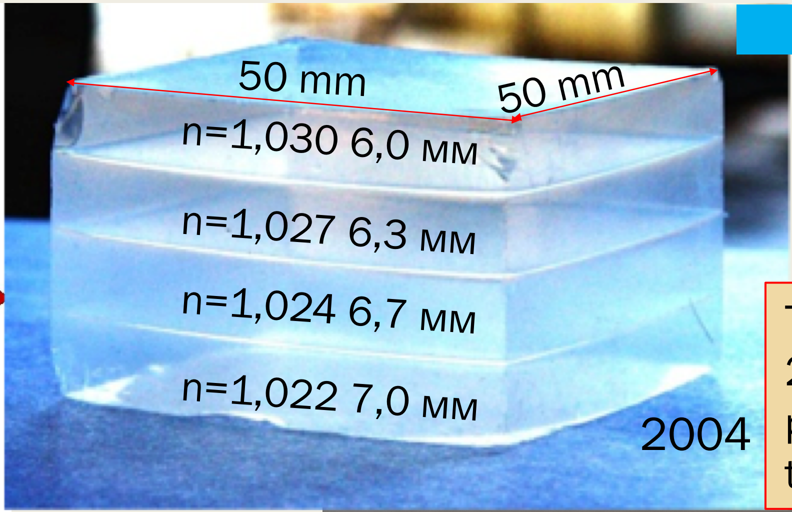

Aerogel RICH for CLAS12

Focusing Aerogel RICH - FARICH

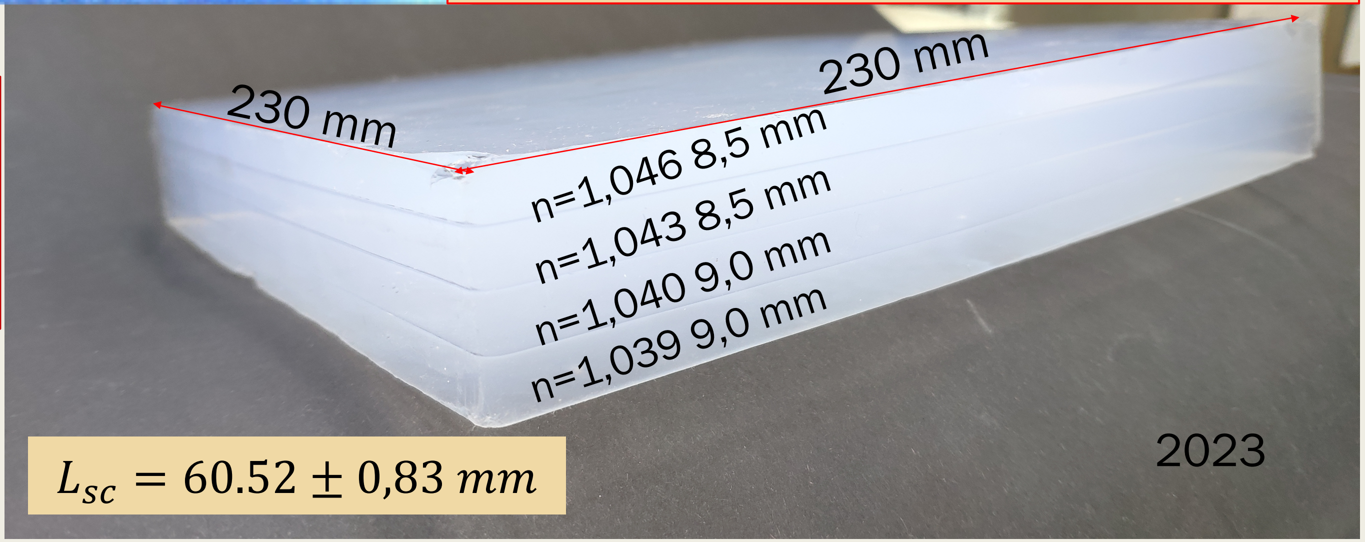
The first 4-layer monolithic sample

19 years of R&Ds





The 4-layer focusing aerogel sample with 230x230x35 mm size and with correct parameters for refractive index and transparency.



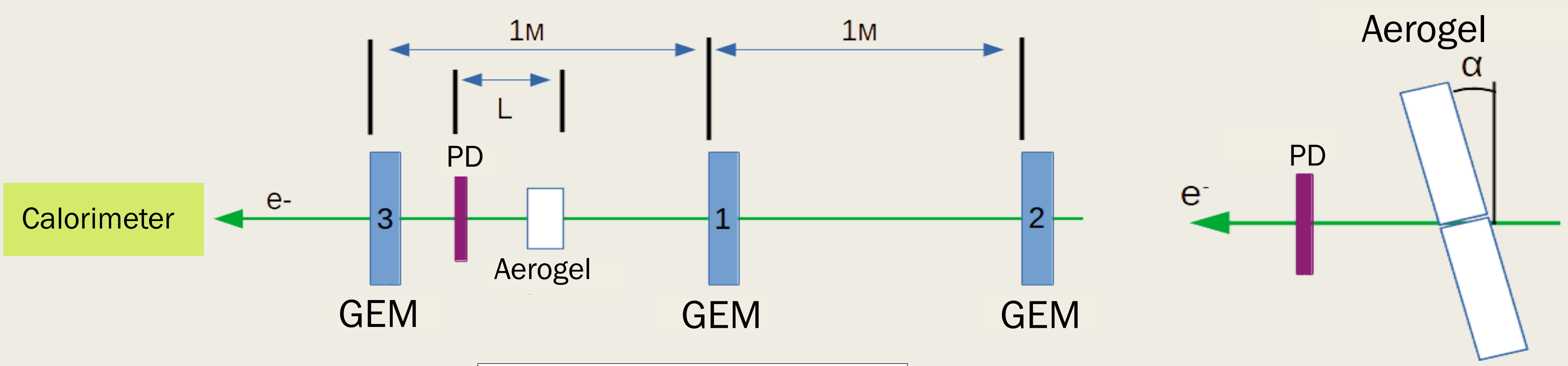
$L_{sc} = 60.52 \pm 0,83\ mm$

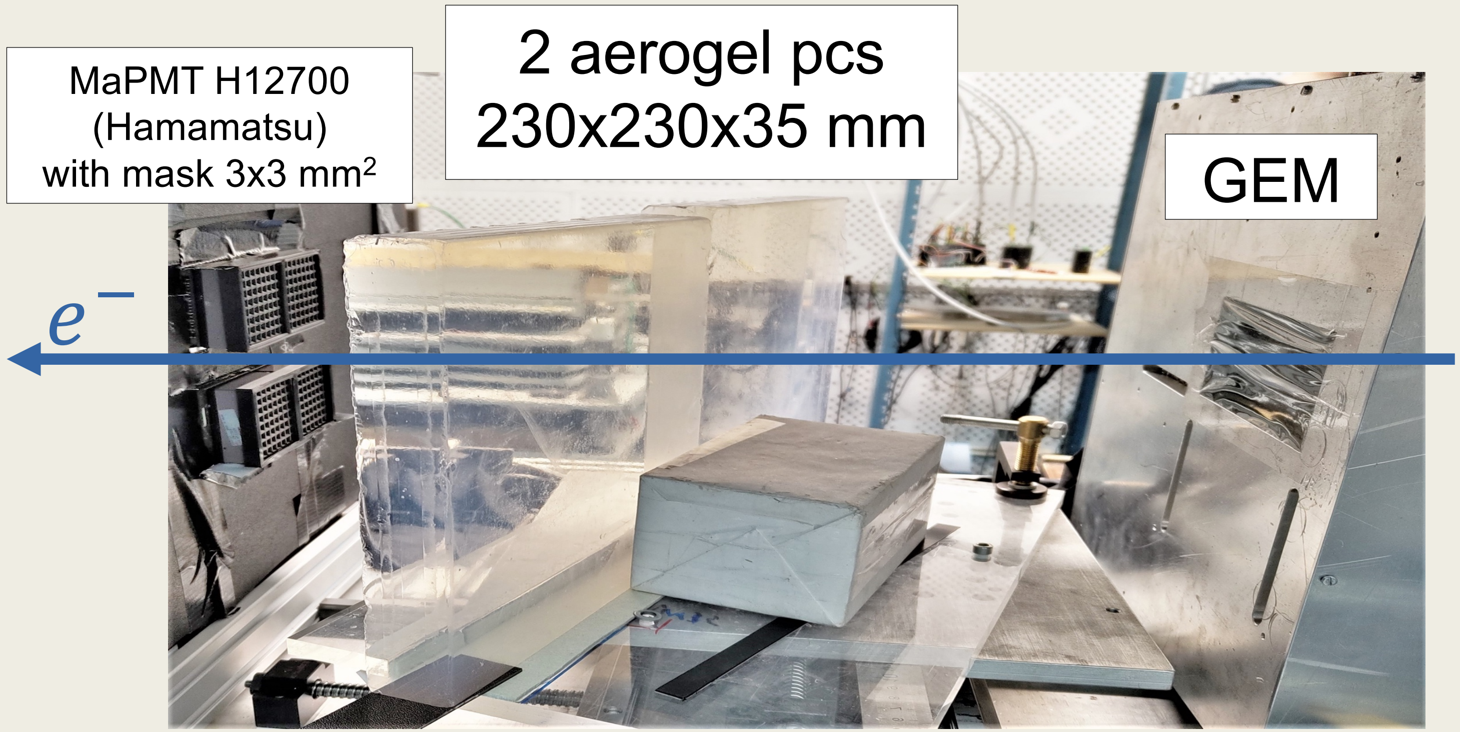
The refractive index and layer thicknesses are chosen so that the images of Cherenkov rings from different layers coincide in the detector plane.

Increase N_{pe} due thickness increase without σ_{Θ_c} degradation.

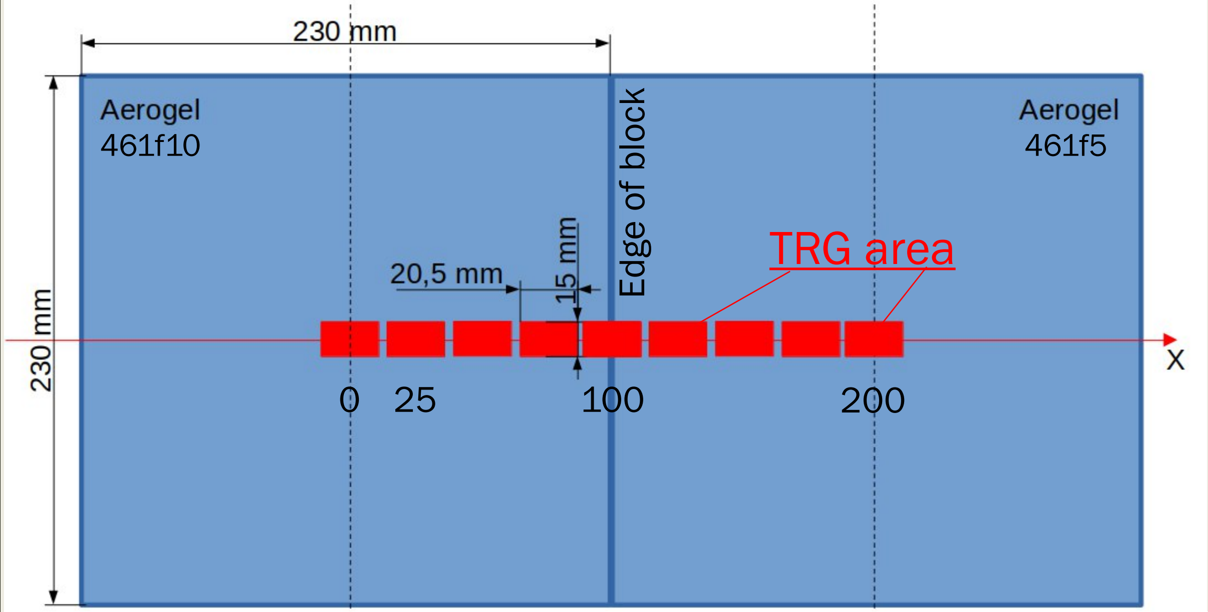
A.Yu.Barnyakov et al., NIM A553 (2005) 70

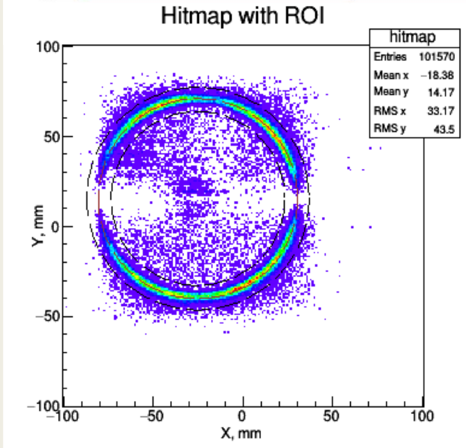
Focusing Aerogel RICH - FARICH

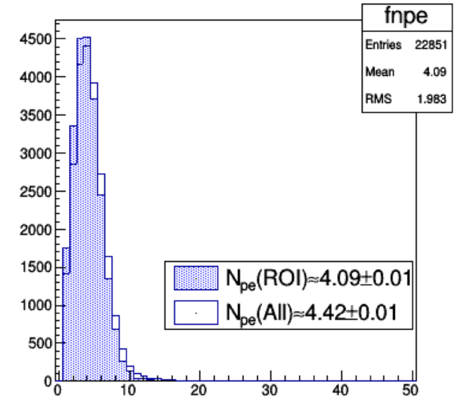


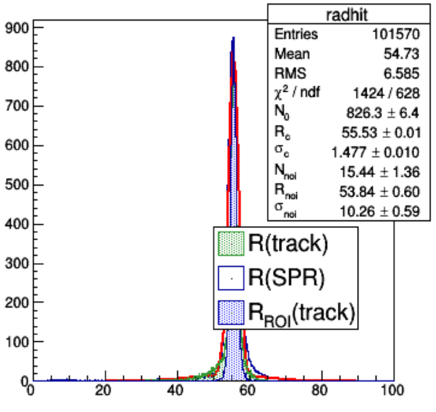


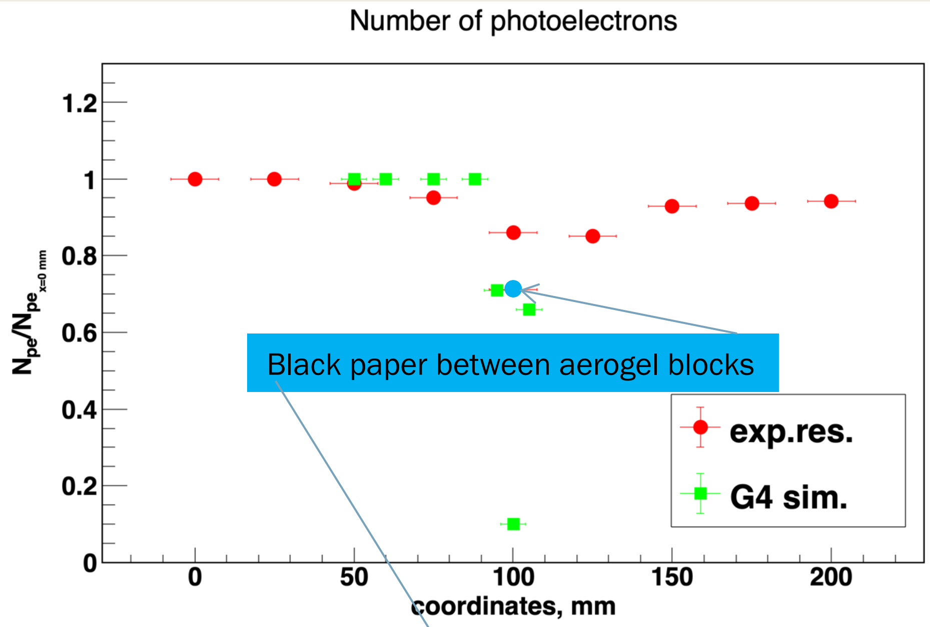
Focusing Aerogel RICH

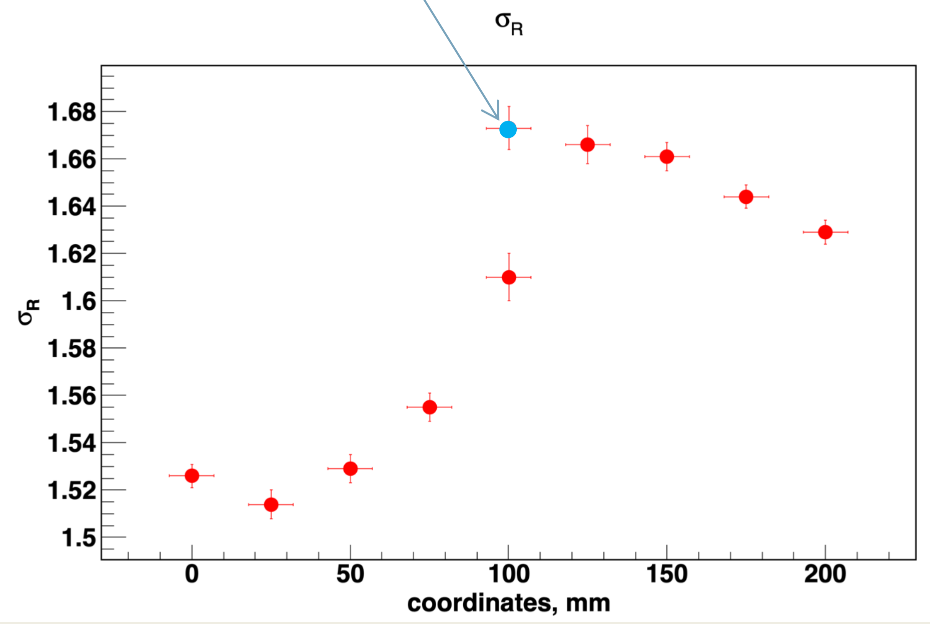










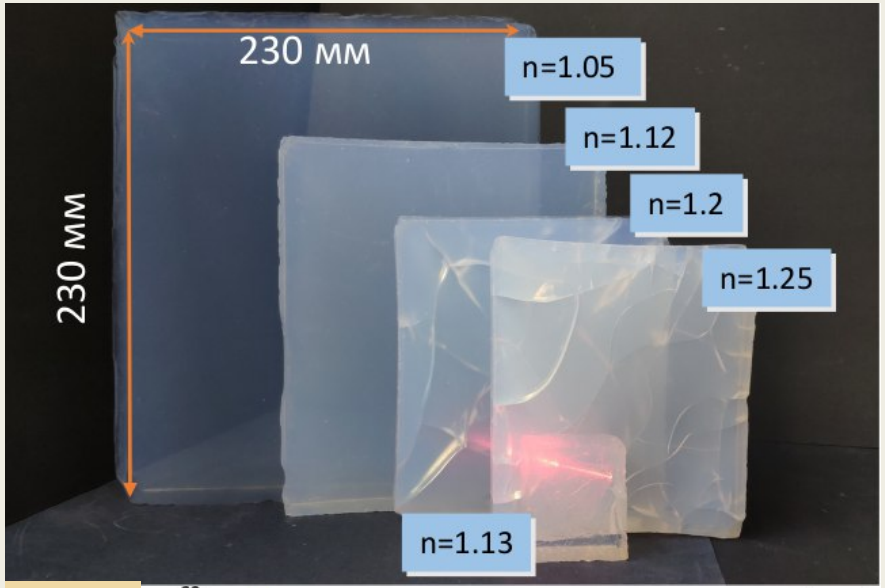


- σ_R increases towards the edge of the aerogel block;
- N_{pe} decreases towards the edge of the aerogel block.

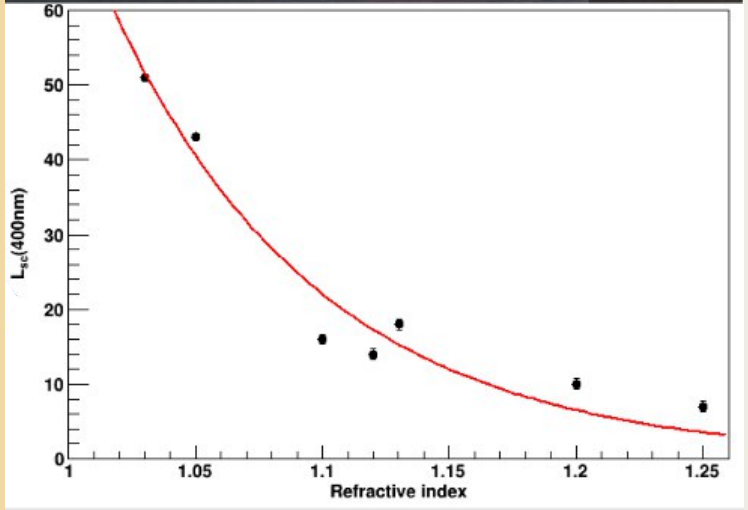
Black paper placed between aerogel tiles gives negligible effect.
Offset due to edge effects could be ≤10 mm.

Aerogels with high optical density

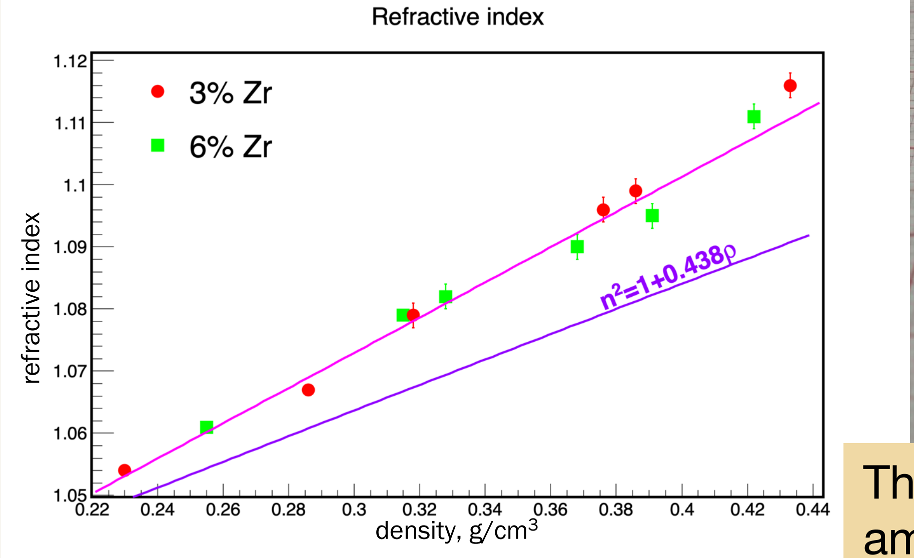
Sintering approach

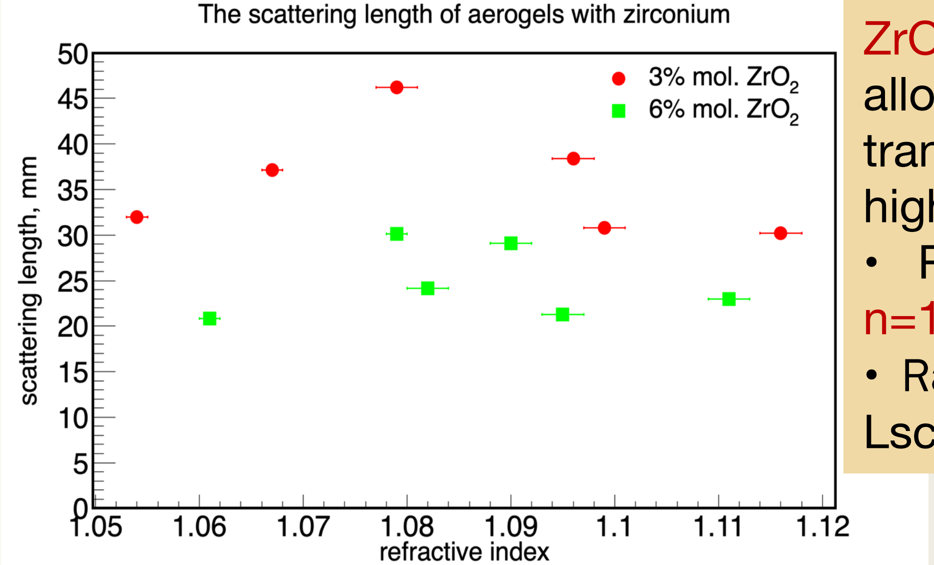


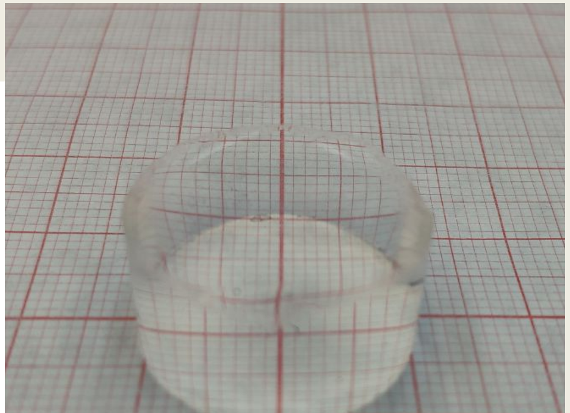
The sintering approach degrades the light scattering length in the aerogel



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 allow us to produce highly transparent aerogels with high optical density:

- Refractive index up to n=1.12
- Rayleigh scattering length Lsc(400nm) up to 30 mm

The thick aerogel

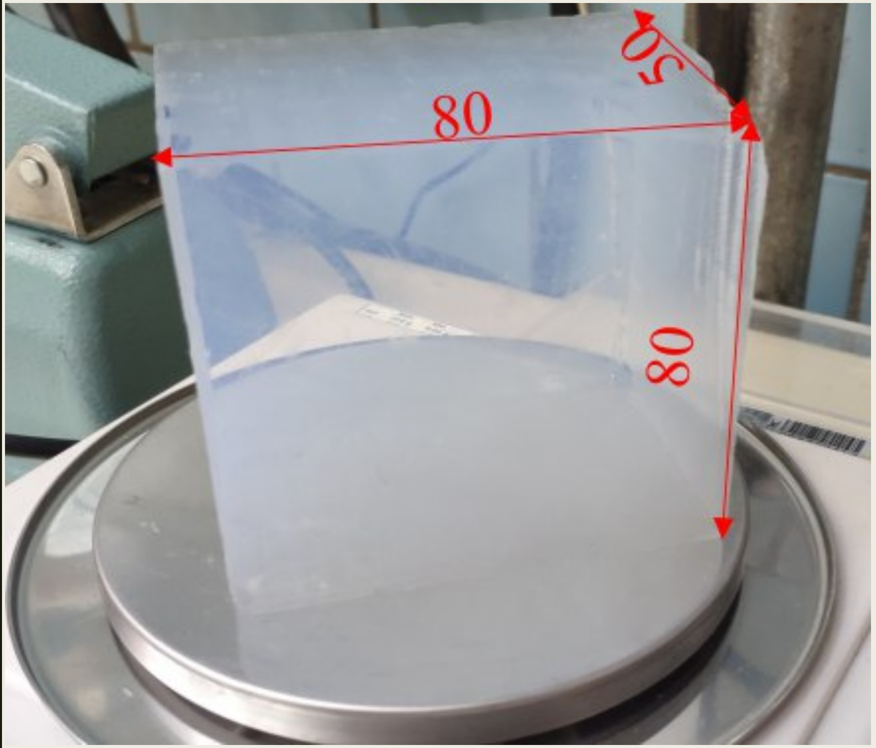
The new aerogel samples were produced in Novosibirsk in 2022 to be tested in prototype:

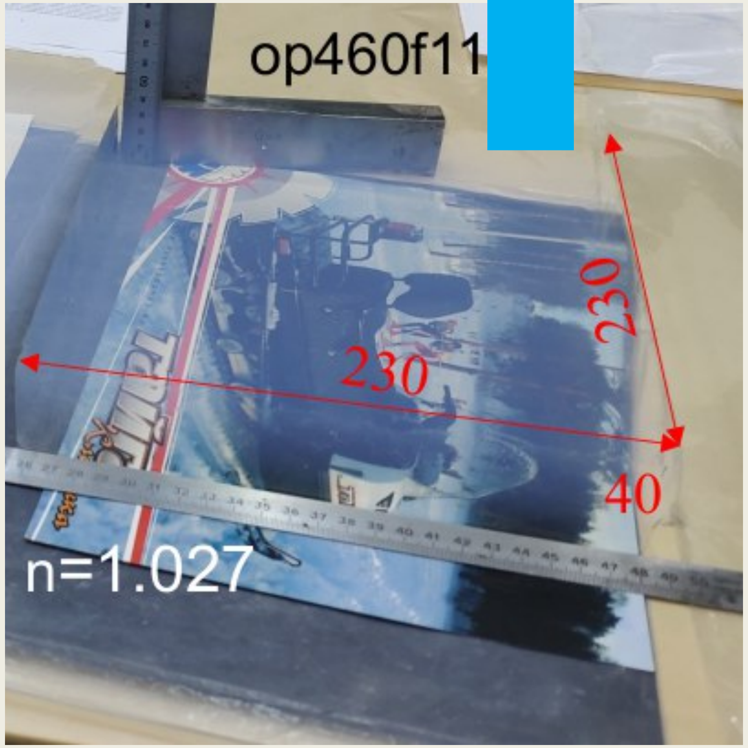
- 4 aerogel tiles 40 mm 100x100 mm
- 3 aerogel tiles 50 mm 80x80 mm

were made by cutting of the large block

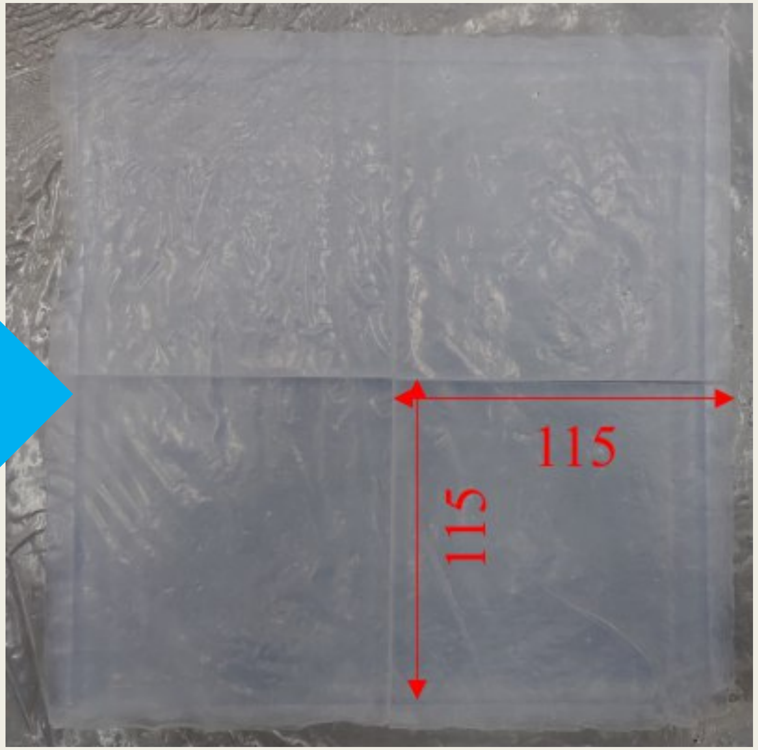
Refractive index of all tiles n = 1.028±0.001;

- L_{sc}(400 nm) for all blocks ≥43 mm;





Cutting of aerogel



40 mm

460f11_21
T(5 hours)=470˚C;
n=1.028;
L_{sc}(400nm)=48.2±0.7 mm.

460f11_22
T(5 hours)=600˚C;
n=1.029;
L_{sc}(400nm)=42.7±0.7 mm.

50 mm

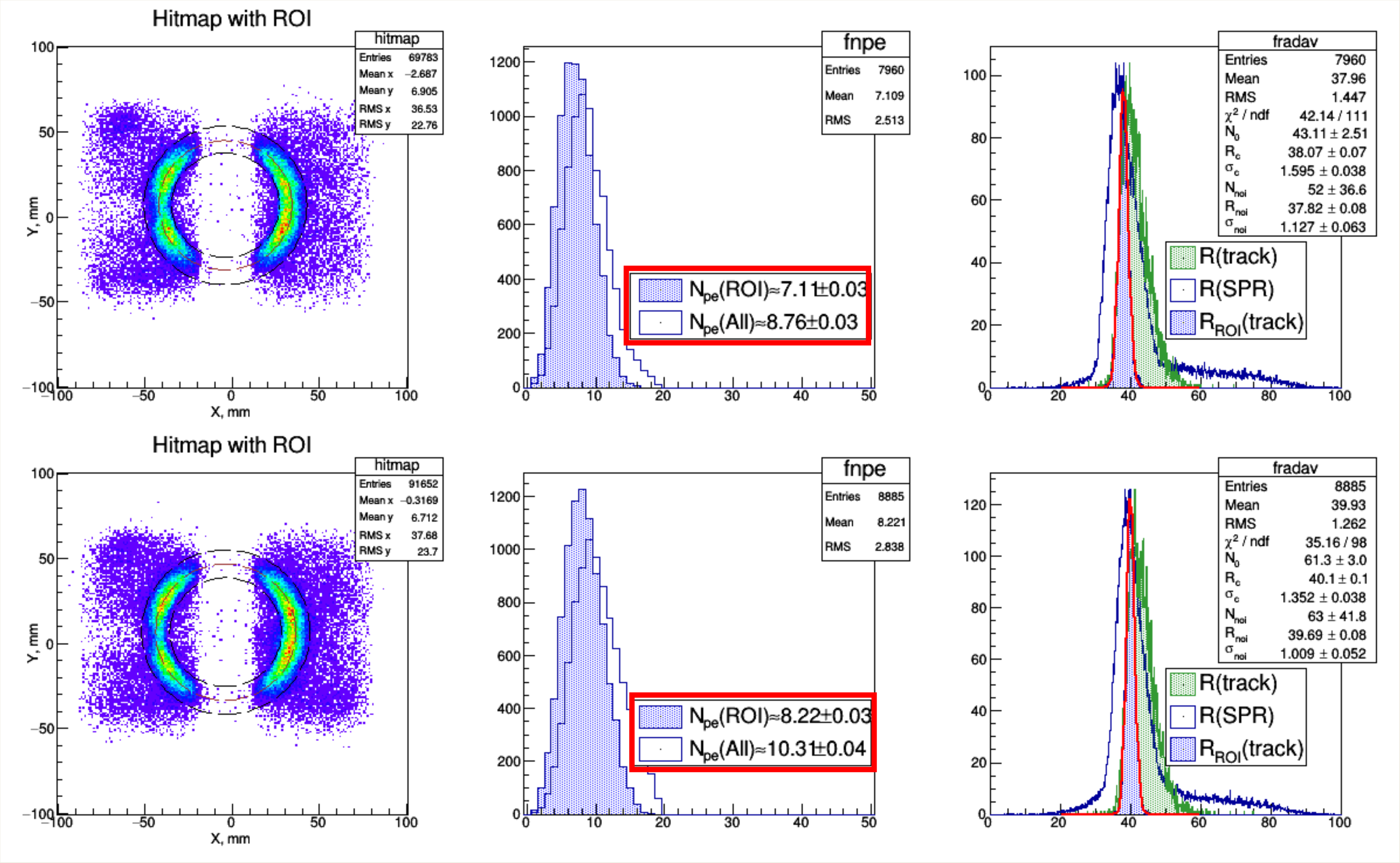
460f15_1
T(5 hours)=470˚C;
n=1.027;
L_{sc}(400nm)=43.7±0.6 mm.

460f15_3
T(5 hours)=600˚C;
n=1.029;
L_{sc}(400nm)=41.7±0.6 mm.

Beam test results with the thick aerogels, 40 mm

460f11_21
T(5 hours)=470˚C
n=1.028
L_{sc}(400nm)=48.2±0.7 mm

460f11_22
T(5 hours)=600˚C
n=1.029
L_{sc}(400nm)=42.7±0.7 mm



Number of photons

$$n\uparrow\Big|_{470^\circ C}^{600\,^\circ C} \qquad \frac{d^2N}{dxd\lambda} = 2\pi z^2 \sin^2\Theta\,(\lambda)\frac{1}{\lambda^2}$$

$$L_{sc}\downarrow\Big|_{470^\circ C}^{600\,^\circ C} \qquad N_{pe} = a_0\frac{L_{sc}(\lambda)}{d}\left(1 - e^{-\frac{d}{L_{sc}(\lambda)}}\right)$$

$$\frac{N_{pe}^{n=1.029}}{N_{pe}^{n=1.028}}\Bigg|^{d=40\,mm} = 1.04; \qquad \frac{N_{pe}^{L_{sc}=42}}{N_{pe}^{L_{sc}=48}}\Bigg|^{d=40\,mm} = 0.95;$$

$$\frac{N_{pe}^{600\,^\circ C}}{N_{pe}^{470^\circ C}}\Bigg|_{exp}^{40\,mm} = \frac{8.22}{7.11} \approx 1.15;$$

$$\frac{\frac{N_{pe}^{600\,^\circ C}}{N_{pe}^{470^\circ C}}\Big|_{exp}^{40\,mm}}{\frac{N_{pe}^{n=1.029}}{N_{pe}^{n=1.028}}\Big|^{d=40\,mm} \times \frac{N_{pe}^{L_{sc}=42}}{N_{pe}^{L_{sc}=48}}\Big|^{d=40\,mm}} = 1.16$$

$$\frac{N_{pe}^{n=1.029}}{N_{pe}^{n=1.027}}\Bigg|^{d=50\,mm} = 1.07; \qquad \frac{N_{pe}^{L_{sc}=41}}{N_{pe}^{L_{sc}=44}}\Bigg|^{d=50\,mm} = 0.97;$$

$$\frac{N_{pe}^{600\,^\circ C}}{N_{pe}^{470^\circ C}}\Bigg|_{exp}^{50\,mm} = \frac{8.05}{7.12} \approx 1.13;$$

$$\frac{\frac{N_{pe}^{600\,^\circ C}}{N_{pe}^{470^\circ C}}\Big|_{exp}^{50\,mm}}{\frac{N_{pe}^{n=1.029}}{N_{pe}^{n=1.027}}\Big|^{d=50\,mm} \times \frac{N_{pe}^{L_{sc}=41}}{N_{pe}^{L_{sc}=44}}\Big|^{d=50\,mm}} = 1.09$$

Some systematical increase of N_{pe} (~10÷15%) are observed in new thick aerogels after increase of backing temperature (470˚C -> 600˚C). This effect could not be quantitively explained by increase of refractive indexes (1.027 -> 1.029) and it is contra to N_{pe} decrease (~5÷6%) expected due to Rayleigh light scattering decrease ($L_{sc}(400nm, 1.027) \approx 47mm \rightarrow Lsc(400nm, 1.029) \approx 41mm$).

Higher temperature baking causes the length of light absorption (L_{abs}) to increase?

Various options are discussed on how to “remove” light-absorbing impurities without raising the temperature, that is, without sintering the aerogel, and thus without losing transparency due to Rayleigh scattering.

Summary

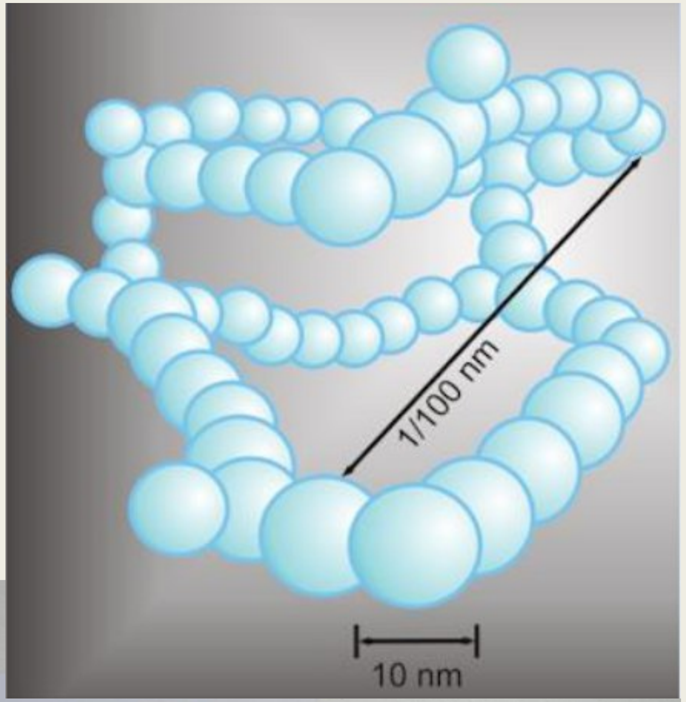
In 2022-2023 the essential progress in aerogel RICH development is achieved:

- Large and highly transparent aerogel blocks were produced and tested;
    - Aerogel tiles 230x230x40mm & 230x230x50 mm;
    - L_{sc}(400nm) for all blocks ≥43mm;
- The effect of light absorption at an insufficiently high annealing temperature was found (became noticeable in thick blocks);
- The 4-layer focusing aerogel sample with 200x200x35 mm size and with correct parameters for refractive index and transparency were produced for the first time in the world;
- Thus, the technical feasibility of creating full-scale systems (for example, 15 sq. m, as for SCTF) based on a focusing aerogel was demonstrated.

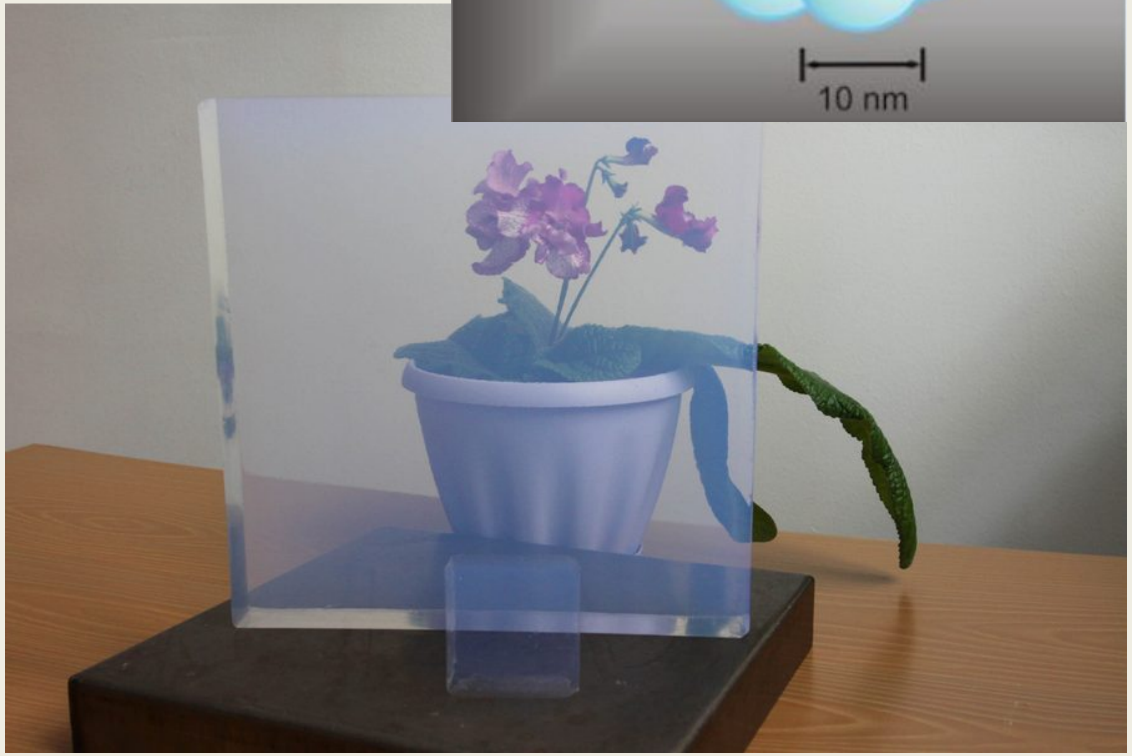
Conclusion

We know how to make large aerogel radiators for large and complex systems, although something new is discovered every time, so to be continued…

Silica aerogel



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



Aerogel is a light, fragile material with strong Rayleigh scattering of light which easily absorb gases and vapours.