PROCEEDINGS OF SCIENCE

Progress in the production of aerogel radiators for the RICH detectors in Novosibirsk

A.A. Katcin,[a,*] **A.Yu. Barnyakov,**[a,b] **A.F. Danilyuk,**[c] **E.A. Kravchenko**[d,a] **and A.S. Shalygin**[c]

[a] *Budker Institute of Nuclear Physics, Prospekt Lavrentieva 11, Novosibirsk, Russia*
[b] *Novosibirsk State Technical University, Prospekt Karla Marksa 20, Novosibirsk, Russia*
[c] *Boreskov Institute of Catalysis, Prospekt Lavrentieva 5, Novosibirsk, Russia*
[d] *Novosibirsk State University, St. Pirogova 2, Novosibirsk, Russia*

E-mail: a.a.kattsin@inp.nsk.su

Modern projects require large format aerogel radiators. In 2022-2023, several unique aerogel tiles were produced in Novosibirsk. Aerogel blocks larger than 200 by 200 *mm* in lateral size and 40, 50 *mm* thickness with a refractive index of 1.03 or 1.05 were fabricated. Also in 2023, for the first time in the world, samples of a multilayer focusing aerogel with overall dimensions of 230×230×35 *mm* were made.

6th International Conference on Technology and Instrumentation in Particle Physics (TIPP2023)
4 - 8 Sep 2023
Cape Town, Western Cape, South Africa

[*] Speaker

PoS(TIPP2023)012

1. Introduction

A collaboration of Boreskov Institute of Catalysis and Budker Institute of Nuclear Physics has been producing silica aerogel blocks for use in Cherenkov detectors since 1986. Novosibirsk aerogel is used in several detectors: among them are KEDR [1], SND [2] (BINP, Novosibirsk), LHCb [3] (CERN, Geneva), AMS02 [4] (for International Space Station mission) and CLAS12 RICH detector [5] (J-Lab, Newport) as well as others experiments.

In work some peculiarities of the development of the development of the production technology of large scale aerogel radiators for use in the Ring-imaging Cherenkov (RICH) detectors are described and discussed. In aerogel RICH detectors, important parameters are the refractive index and its uniformity, the light scattering length, quality, and the planarity of the output surface. Some procedures of control for these parameters are given in [6].

2. Thick aerogel

Aerogel is a nanomaterial that is a porous substance with a pore size smaller than the wavelength of light in the visible range. Aerogel consists of spheres of amorphous silica SiO_2 with a diameter of several nanometres with a size distribution peaked at 5–6 *nm*, connected in chains (such as "caterpillars"), they are separated by empty volumes, the size of which varies around 50 *nm*, forming a three-dimensional structure.

The refractive index of an aerogel produced in Novosibirsk is related its density:
$n = \sqrt{1 + 0.438 \cdot \rho}$ [7]. The boundaries of the distribution correspond to the boundaries of the refractive index. The homogeneity of the refractive index (density) is checked by x-ray [8]. Density variations $\left(\frac{d\rho}{\rho} = \frac{dn}{n-1}\right)$ can reach $\sim 5\%$. This is comparable with refractive index dispersion over wavelength.

We create aerogel tiles with a thickness of 20 and 30 *mm* and $n = 1.05$ [6] and aerogel tiles with a thickness of 50 *mm* and $n = 1.03$ [3]. The several new aerogel samples were produced in Novosibirsk in 2022-2023 (it shown in figure 1):

- An aerogel with a refractive index of $n = 1.028$ with a thickness of 40 and 50 *mm* was produced;

- An aerogel with a refractive index of $n = 1.050$ with a record thickness of 40 *mm* was manufactured.

Due to the inhomogeneous structure of the aerogel, scattering effects are present in it, the dominant of which is Rayleigh scattering. The light scattering length for a photon of wavelength λ is proportional to λ^4. The method used for light scattering length measurements is described in [9]. The characteristic scattering length of aerogels produced in Novosibirsk today exceeds 43 *mm* at 400 *nm*.

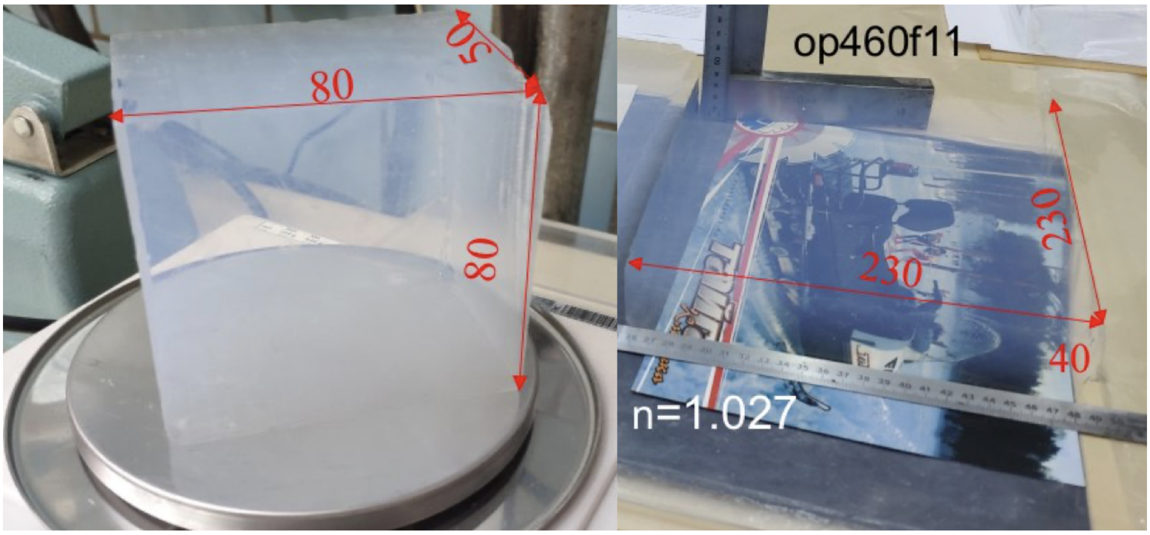

Figure 1: An example of thick aerogel samples $n = 1.028 \pm 0.001$ with thickness of 40 and 50 *mm* produced in 2022

3. Characteristics of thick aerogel

The planarity (unflatness) 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 experiment tiles height difference does not exceed 2 *mm* [6]. The average planarity of aerogel blocks with a thickness of 30 *mm* is 1.9 *mm*, and blocks with a thickness of 20 *mm* are 2.7 *mm*. The planarity of aerogel blocks with a thickness of 40 and 50 *mm* manufactured in Novosibirsk in 2022-2023 is also better than 2 *mm*.

The characteristics of some aerogel tiles made in Novosibirsk in 2022-2023 are given in Table 1.

Table 1: Parameters of some aerogels produced in Novosibirsk in 2022-2023.

aerogel	**thickness** d, *mm*	**refractive index** **n**	**light scattering length** L_{sc}, *mm*	**planarity** Δ, *mm*
460f9	40	1.050	44.75±0.62	1.90
460f11	40	1.027	47.90±0.68	-
461f14	40	1.028	50.09±0.69	-
461f4	40	1.046	44.34±0.37	1.99
460f15	50	1.027	46.13±0.67	-
461f13	50	1.028	49.43±0.68	1.02

The average light scattering length in the aerogel for the CLAS12 experiment, regardless of the thickness of the block (20 or 30 *mm*), was about 50 *mm* [6].

4. Multilayer aerogel

In a multilayer aerogel, the refractive index and layer thicknesses are chosen so that the images of Cherenkov rings from different layers coincide in the photon detector plane. Monolithic multilayer aerogels with a controlled refractive index are produced in Novosibirsk. The first four-layer monolithic sample was produced in 2004 [10]. In 2023, we produced several samples of four-layer focusing aerogel measuring 230×230×35 *mm* with the correct parameters for refractive index and transparency (see figure 2).

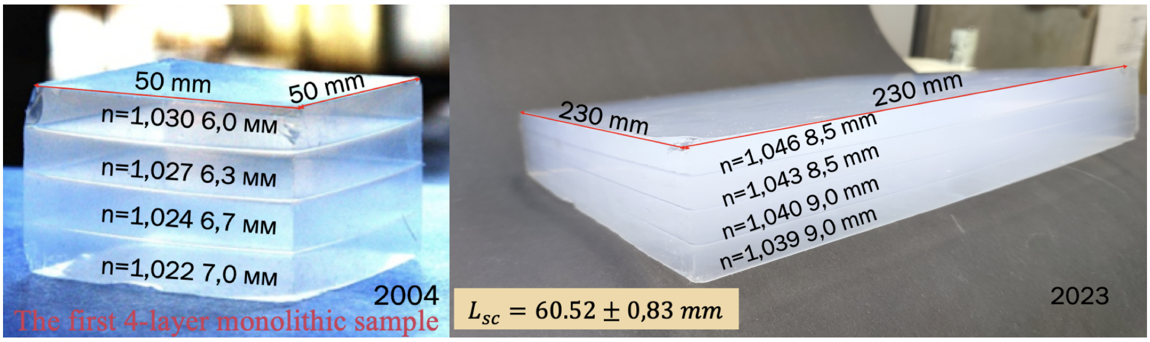

Figure 2: The first 4-layer monolithic sample (left) and a sample of 4-layer monolithic aerogel obtained in 2023 (on right)

The characteristics of four-layer monolithic aerogel tiles with a size of 230 by 230 *mm*, produced in Novosibirsk in 2023, are shown in the Table 2.

Table 2: Parameters of four-layer monolithic aerogel produced in Novosibirsk in 2023.

aerogel	**thickness** d_i, mm	**refractive index** n_i	**light scattering length** L_{sc}, mm	**planarity** Δ, mm
461f5	7.9	$n_1 = 1.039$	62.46±0.55	1.32
	8.5	$n_2 = 1.039$		
	9.0	$n_3 = 1.042$		
	9.0	$n_4 = 1.046$		
461f10	8.5	$n_1 = 1.039$	60.52±0.83	1.40
	8.5	$n_2 = 1.040$		
	9.0	$n_3 = 1.043$		
	9.0	$n_4 = 1.046$		

Samples of a large-format multilayer focusing aerogel (230×230×35 *mm*) obtained in 2023 were tested in a prototype FARICH [11] with a beam of relativistic electrons [12] and pixel 3 *mm*. Figure 3 shows the experimental distribution of Cherenkov photons averaged over several thousand electrons.

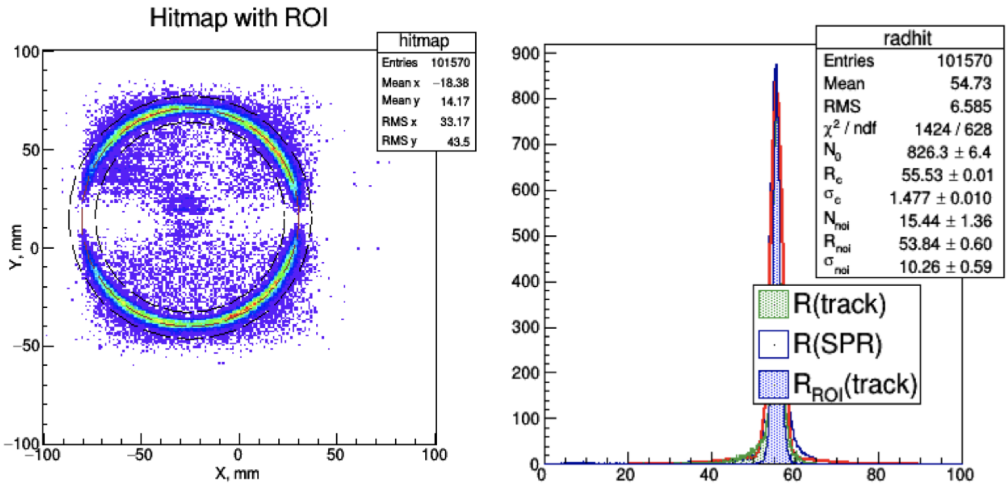

Figure 3: The distribution of Cherenkov photons in the FARICH prototype obtained in an experiment on relativistic electrons for several thousand registered electron tracks (left), the parameters of the Cherenkov ring for a focal length of 160 *mm* (right)

The resolution of the Cherenkov angle (single-photon resolution (SPR)) ($\sigma_C = 1.4\ mm$) was measured. It is approximately $\sigma_{\Theta_C} = 7\ mrad$. It was also investigated how the resolution of the Cherenkov angle σ_C changes in large samples of a four-layer focusing aerogel from the centre to the edge of the block. As expected, σ_C increases towards the edge of the aerogel block (see figure 4). At a distance of more than 10 *mm* from the edge of the aerogel sample, the Cherenkov radius resolution within one block can be considered homogeneous.

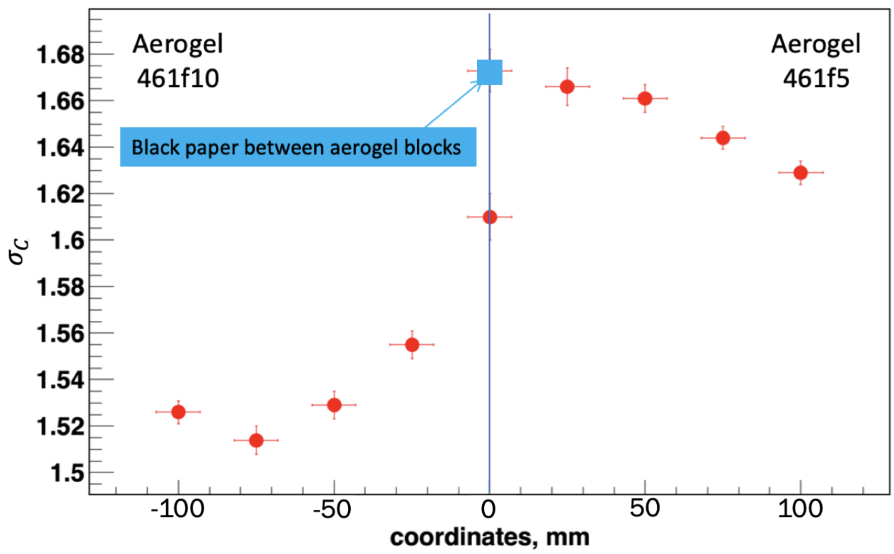

Figure 4: Changing the resolution of the Cherenkov angle. The coordinate 0 *mm* corresponds to the junction of the blocks, the coordinates −100 *mm* and 100 *mm* correspond to the centres of the aerogel samples 461f10 and 461f5, respectively. Also, black paper (blue square) was placed between the blocks so that photons from one sample would not fall into the other. Black paper placed between aerogel tiles gives a slight effect

The relative number of Cherenkov photons in samples 461f10 and 461f5 normalized by the number of photons in the center of the aerogel 461f10 is shown in figure 5. Also, black paper was placed between the blocks so that photos from one simple would not fall into the other. The number of photons decreases towards the edge of the aerogel block. Black paper placed between aerogel tiles gives a slight effect

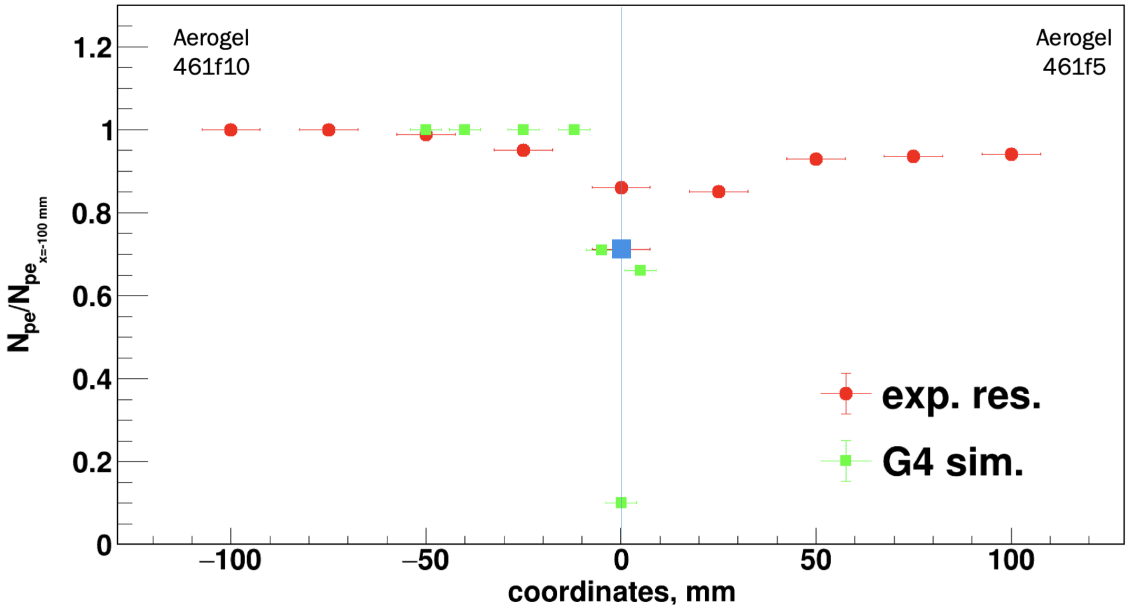

Figure 5: The relative number of Cherenkov photons in samples 461f10 and 461f5 normalized by sthe number of photons in the center of the aerogel 461f10 (coordinate −100 *mm*) The coordinate 0 *mm* corresponds to the junction of the blocks, the coordinates −100 *mm* and 100 *mm* correspond to the centres of the aerogel samples 461f10 and 461f5, respectively. The red dots are experimental data, the green squares are G4 simulations, and the blue large square is black paper between the aerogel blocks

5. Conclusion

In 2022-2023, significant progress was made in the development of aerogel RICH:

- Large and highly transparent aerogel blocks were produced and tested:
  - Thick aerogel tiles 230×230×40 *mm* and 230×230×50 *mm*;
  - For the first time in the world, an aerogel block with a refractive index of $n = 1.05$ was made with a thickness of 40 *mm* and linear dimensions of 230 by 230 *mm*;
  - All samples of thick aerogel have a light scattering length of more than 43 *mm*.
- The 4-layer focusing aerogel sample with 230×230×35 *mm* size and with correct values for refractive index and transparency were produced for the first time in the world.

References

[1] A.Yu. Barnyakov, et al., Nucl. Instr. and Meth. A 494 (2002) 424.

[2] A.Yu. Barnyakov, et al., Nucl. Instr. and Meth. A 598 (2009) 163.

[3] T. Bellunato, Nucl. Instr. and Meth. A 598 (2009) 147.

[4] M. Buenerd, Nucl. Instr. and Meth. A 553 (2005) 264.

[5] M. Contalbrigo, et al., Nucl.Instr.Meth. A 639 (2011) 302.

[6] A.Yu. Barnyakov, et al., Nucl. Instr. and Meth. A 592 (2020) 162035.

[7] A.F Danilyuk, et al., Nucl. Instr. Meth. A 494 (2002) 491.

[8] http://www.slac.stanford.edu/econf/C0604032/papers/0045.PDF.

[9] A.R. Buzykaev, et.al., Nucl. Instr. Meth. A 433 (1999) 396.

[10] A.Yu. Barnyakov, et al., Nucl. Instr. and Meth. A 553 (2005) 70.

[11] A.Yu. Barnyakov, et. al., 2020 JINST 15 C10014.

[12] G.N. Abramov., et al 2016 JINST 11 P03004.