

## Development of aerogel Cherenkov counters at Novosibirsk

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### Abstract

The work on aerogel Cherenkov counters was started in Novosibirsk in 1986. Production of aerogels with refractive indices of 1.006–1.13 and thicknesses of blocks up to 50 mm was developed. The light absorption length at 400 nm is 5–7 m, the scattering length is 4–5 cm. By these parameters, the Novosibirsk aerogel is one of the best in the world. The ASHIPH Cherenkov counters with light collection on wavelength shifters have been developed. The ASHIPH system of the KEDR detector contains 10001 of aerogel. The  $\pi/K$  separation is  $4.5\sigma$ . A project of ASHIPH counters for the SND detector has been developed. Aerogel RICH for LHCb gives a possibility to identify hadrons in the momentum range of 2–10 GeV/c. The Novosibirsk group is developing an aerogel RICH for the endcap for the SuperBaBar project. Calculations performed by a group of physicists from Novosibirsk and DESY-Zeuthen have shown that aerogel radiators enable to achieve time resolution up to 20 fs.

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### 1. Introduction

Cherenkov counters provide a powerful technique which is used successfully in particle physics. The development and use of Cherenkov counters in experi-

ments has a long history. The main Cherenkov detectors and results obtained by the Novosibirsk group, as well as results of joint works of the Novosibirsk group with the group from LHCb and the group from DESY-Zeuthen are presented below.

### 2. VEPP-2, MD-1 Cherenkov detectors

The first Cherenkov detectors in the world employed in an experiment at colliding beams were water

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Table 1  
Main parameters of Cherenkov counters build in BINP

Detector	VEPP-1970	MD-1	KEDR	SND
Year	1970	1980–1985	2003–present	Project
$E_{\text{cm}}$ (GeV)	1.18–1.34	7.2–10.5	3.0–10.5	0.4–2.0
Solid angle/ $4\pi$	13%	60%	95%	60%
Number of counters	2	8	160 (80 in 2003)	9
Dimensions (cm)	$40 \times 40 \times 7$	$160 \times 60 \times 17$	$52 \times 21 \times 7$	$25 \times 9 \times 2.5$
Radiator [ $n$ ]	$\text{H}_2\text{O}$ [1.33]	$\text{C}_2\text{H}_2$ (25 bar) [1.02]	Aerogel [1.05]	Aerogel [1.13]
$\pi^\pm$ Efficiency	99.3% at $E = 0.67$ GeV	95% at $P = 2$ GeV/ $c$	99.9% at $P = 1.2$ GeV/ $c$	
$K^\pm$ Misidentification	7% at $E = 0.67$ GeV	7% at $P = 2$ GeV/ $c$	10% at $P = 1.2$ GeV/ $c$	

threshold counters at the VEPP-2 collider in the Novosibirsk Institute of Nuclear Physics in 1970 (Onuchin and Serednyakov, 1972). The main parameters of these counters are presented in Table 1. Use of these counters was crucial for two important discoveries in this experiment:

- (i)  $e^+e^- \rightarrow$  hadrons (a hint to light quarks) (Kurdadze et al., 1972);
- (ii)  $e^+e^- \rightarrow \pi^+\pi^-, K^+K^-$ . Form factors of  $\pi$  and  $K$ , mesons exceeded theoretical predictions (later  $\rho', \omega', \phi'$  mesons were discovered) (Balakin et al., 1972).

These results, together with results from colliders at Stanford and Frascati, stimulated construction of the next generation colliders VEPP-2M, DORIS, SPEAR, CESR, VEPP-4.

The second experiment in Novosibirsk, in which Cherenkov counters were used, was one with the MD-1 detector at the collider VEPP-4 (Table 1). A specific feature of these counters was the use of pressurized ethylene with the refractive index  $n = 1.02$ . A series of experiments was performed with the MD-1 detector on  $\Upsilon$ -resonance and  $\gamma\gamma$  physics in 1980–1985. A review of obtained results was published in Physics Reports (Baru et al., 1996).

### 3. Aerogel

Silica aerogel has unique physical properties. It is the unique material with the refractive index under normal conditions covering the range between condensed states ( $n \simeq 1.3$ ) and gases ( $n < 1.001$ ).

The use of silica aerogel as a radiator in Cherenkov threshold counters was first suggested by Cantin et al. (1974). The first large-scale employment of aerogel Cherenkov counters in an experiment was in the TASSO detector at PETRA (Burkhardt et al., 1981).

Presently, several experiments are using aerogel in detectors of different types. A large system was built for

the Belle detector at KEK, Japan (Sumiyoshi et al., 1999). Several studies of physics of Cherenkov radiation in aerogel were performed by a group from JINR, Dubna (Ruzichka et al., 1997). A large system of aerogel Cherenkov counters is being built for the KEDR detector in Budker Institute of Nuclear Physics (BINP).

The work on aerogel production in Novosibirsk was started in 1986 by a collaboration of the Boreskov Institute of Catalysis and BINP as part of the KEDR detector project for the collider VEPP-4M. The first samples of aerogel were produced in 1988 (Aksenov et al., 1988). Presently, aerogels are produced by the two-step technology, the refractive index of produced aerogel is in the range from 1.006 to 1.13, dimensions of blocks are up to  $200 \times 200 \times 50$  mm<sup>3</sup> (Buzykaev et al., 1996b; Danilyuk et al., 1999, 2002).

The light absorption length in aerogel at  $\lambda = 400$  nm is 5–7 m, the scattering length is 4–5 cm. By these parameters the Novosibirsk aerogel is one of the best in the world (Danilyuk et al., 2002).

Methods of measurement of the refractive index, the light scattering length, and the light absorption length in aerogel has been developed (Danilyuk et al., 2002; Buzykaev et al., 1999).

In order to optimize a design of a counter and a whole system, a special Monte Carlo program simulating the process of Cherenkov light collection in the aerogel counter was developed (Shamov and Buzykaev, 1997).

The first project of aerogel Cherenkov counters for KEDR was presented in Dubna (Aksenov et al., 1988). That was an option with the direct collection of Cherenkov light from aerogel on fine-mesh PMTs. In 1990, a prototype was successfully tested (Onuchin et al., 1990).

### 4. ASHIPH method

The ASHIPH method of Cherenkov light collection (Aerogel, wavelength SHifter, and PHotomultipliers) was suggested by Novosibirsk group in 1992 (Onuchin et al., 1992). The idea of the method is to collect

Cherenkov light on wavelength shifting bars and then to transport the captured reemitted light to the phototube. In this case one can make long counters and use PMTs with smaller photocathode area.

Two options for the ASHIPH method were investigated. The first one (Buzykaev et al., 1996a) was based on ‘blue’ shifters doped with POPOP dye and fine-mesh phototubes from Hamamatsu. The present ASHIPH counter (Fig. 1) is based on ‘green’ wavelength shifters doped with BBQ dye and micro-channel plate photomultipliers (Buzykaev et al., 1998; Barnyakov et al., 1998, 2000). The use of the ASHIPH method permitted to reduce the total surface of photocathodes of PMTs in the KEDR system by a factor of 10.

#### 4.1. KEDR ASHIPH system

The ASHIPH system of the KEDR detector consists of 160 counters in two layers (Fig. 2). The counters are arranged in such a way that a particle from the interaction point with a momentum above 0.6 GeV/c does not cross the shifters of both layers at once. The system works in high magnetic field of the KEDR detector (up to 1.5 T). Total volume of aerogel is 10001.

The highly transparent SAN-96 aerogel (Buzykaev et al., 1996b; Danilyuk et al., 1999; Buzykaev et al., 1999) with the refractive index 1.05 was chosen as a

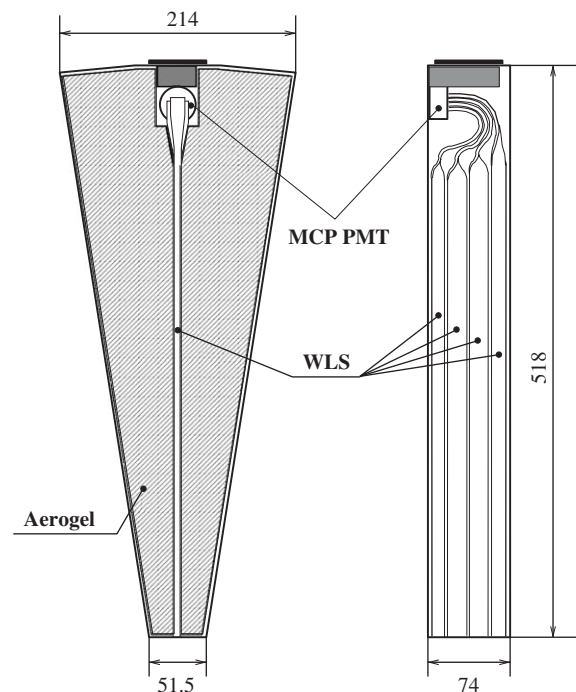


Fig. 1. The ASHIPH endcap counter of the KEDR detector. The sizes are in mm.

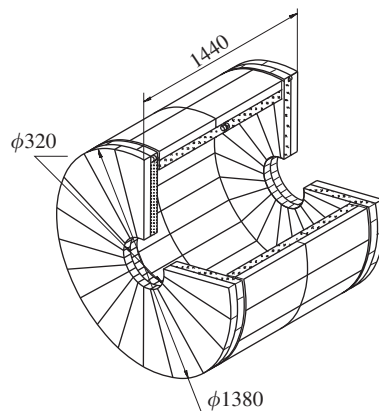


Fig. 2. The KEDR ASHIPH system.

radiator, giving the possibility to separate  $\pi$  and  $K$  mesons with momenta from 0.6 to 1.5 GeV/c.

The test beam results were described in our previous publications (Barnyakov et al., 2002a,b, 2004). The main results are the following:

- At  $p = 0.86$  GeV/c, the number of photoelectrons for pions is 7.7, the pion suppression coefficient is 900 at 94% kaon detection efficiency (separation is  $4.7\sigma$ ). At 1.2 GeV/c, the number of photoelectrons for pions is 9.2, the pion suppression coefficient is 1300 at 90% kaon detection efficiency ( $4.5\sigma$ ).
- The time resolution of ASHIPH counter measured with pions at 0.86 GeV/c is  $\sigma_\tau = 2$  ns.

The first layer (80 counters) of the ASHIPH system of the KEDR detector has been produced, installed in the detector, and works in the experiment.

#### 4.2. Project of ASHIPH system for the SND detector

The SND detector is being upgraded now for operation at VEPP-2000  $e^+e^-$  collider (Abramov et al., 2001). The ASHIPH system (Fig. 3) is intended to identify  $\pi$  and  $K$  mesons in the momentum range of 300–900 MeV/c (Table 1) (Beloborodov et al., 2002). The refractive index of aerogel is 1.13. Such aerogel is produced by thermal sintering of aerogel with lower density (Danilyuk et al., 2002). The experimental study of a prototype counter is in progress now.

#### 5. Aerogel for the LHCb RICH detector

The LHCb detector is a single arm spectrometer dedicated to the  $B$  meson study. It will operate on the LHC collider. The main feature of the LHCb is a

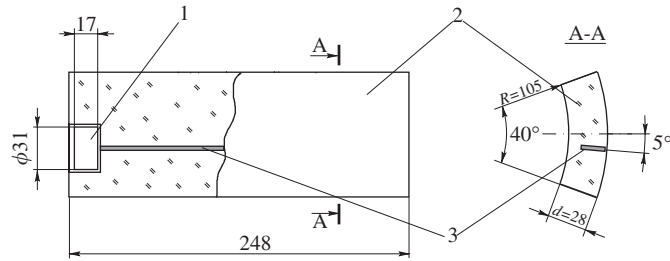


Fig. 3. The SND ASHIPH counter: (1) MCP PMT; (2) Aerogel; (3) WLS bar.

powerful particle identification system (Matteuzzi, 2002). The momentum range to be covered is 2–150 GeV/c. The RICH1 detector will use aerogel with  $n = 1.03$  for the hadron identification between 2 and 10 GeV/c.

The beam tests with a prototype were performed (Bellunato et al., 2004). The main results of the tests are presented in Table 2.

Recently, the Novosibirsk collaboration has succeeded to produce aerogel blocks with dimensions of  $200 \times 200 \times 50 \text{ mm}^3$  and high transparency. The light scattering length in these blocks is 45 mm at  $\lambda = 400 \text{ nm}$  (Clarity =  $0.0057 \mu\text{m}^4/\text{cm}$ ).

## 6. Aerogel Endcap RICH project for SuperBaBar

Two  $B$ -factories are working now in the world. Scientific results obtained with BaBar (SLAC, USA) and Belle (KEK, Japan) detectors on physics of CP-violation in  $B$ -meson decays are of great importance. The success of these experiments initiated suggestions to build Super  $B$ -factory with the luminosity of  $10^{35}\text{--}10^{36} \text{ cm}^{-2} \text{ s}^{-1}$ . In the project of the SuperBaBar detector, it is suggested to use for particle identification a DIRC system in the barrel and aerogel RICH in the endcap of the detector.

The Novosibirsk group has performed calculations of parameters of proximity focusing RICH (Fig. 4). Aerogel with  $n = 1.07$  has thickness of 20 mm. With the existing multianode MCP PMTs from Burle Co. (bialkali photocathode, maximum quantum efficiency 24%,  $8 \times 8$  pads of  $6 \times 6 \text{ mm}^2$ ) the number of detected photoelectrons from relativistic particle is about 15. The  $\pi/K$  separation at  $P = 4.5 \text{ GeV}/c$  is  $4.5\sigma$ ; it is  $3\sigma$  at  $P = 5 \text{ GeV}/c$ .

## 7. Aerogel for bunch length measurements

Successful optimization of the photo injector test facility at DESY-Zeuthen (PITZ) requires high-resolution beam diagnostics. To measure the temporal properties of the electron bunch, a radiation process is needed

Table 2

Cherenkov angle resolution at the LHCb aerogel RICH prototype for protons and pions and corresponding  $p/\pi$  separation in numbers of  $\sigma$

$P$ (GeV/c)	$\sigma_p$ (mrad)	$\sigma_\pi$ (mrad)	$N_\sigma$ ( $p/\pi$ )
6	7.8	2.9	17.1
8	4.1	2.8	9.9
10	3.0	2.3	7.8

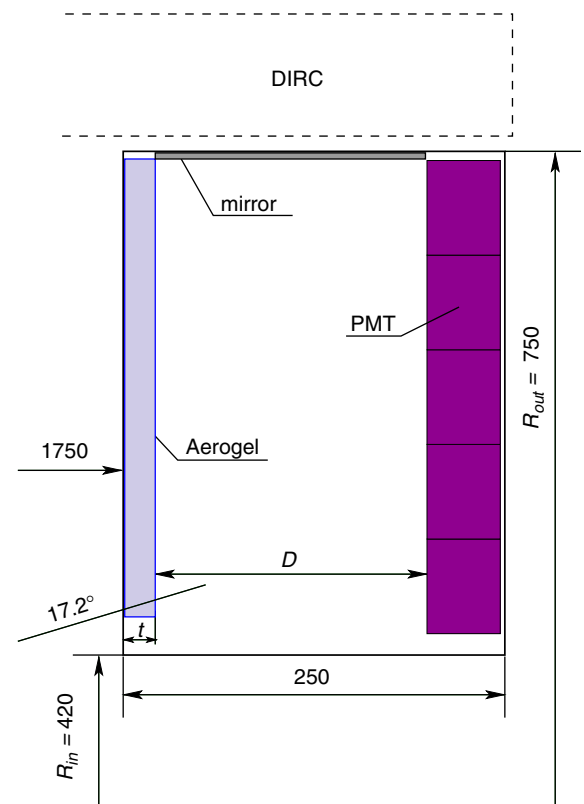


Fig. 4. Proximity focusing aerogel RICH for SuperBaBar.

that produces a photon bunch with the same time properties as the electron bunch. Cherenkov radiation is better than widely used optical transition radiation for

the electrons produced at PITZ with energies between 4 and 5 MeV because of much larger number of photons and better directivity.

The time resolution determined by aerogel was calculated both analytically and by Monte Carlo simulation (Table 3). It was shown that, for aerogel with the refractive index of 1.05, 1 mm thickness and an aluminium window of 20  $\mu\text{m}$  thickness, the system response has a rectangular shape with the RMS resolution of  $\sim 0.1$  ps (Fig. 5). In addition, it was shown that a time resolution of 20 fs could be reached with aerogel of  $n = 1.01$  and 2 mm thickness (Bähr et al., 2005).

Table 3  
RMS time resolution in ps for different refractive indices of aerogel samples for 4.5 MeV/c electrons

$l$ (mm)	$n = 1.01$	$n = 1.03$	$n = 1.05$	$n = 1.01$
	20	2	1	1
Cherenkov	0.14	0.092	0.086	0.014
+ Rayleigh	0.60	0.104	0.090	0.014
+ MS	0.80	0.094	0.084	0.012
+ Al	0.58	0.110	0.091	0.017

From top to bottom the processes are added one by one (MS is multiple scattering in aerogel, Al is multiple scattering in aluminium window).

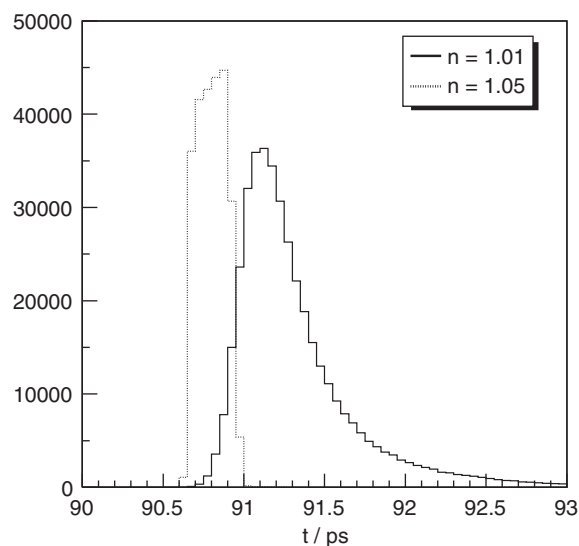


Fig. 5. Time distribution of Cherenkov photons produced by electron bunch with zero length. Rayleigh and multiple scattering as well as a 20  $\mu\text{m}$  thick aluminium window are considered. The thickness of the aerogel samples is 20 mm for  $n = 1.01$  and 1 mm for  $n = 1.05$ . The distribution for 20 mm thickness is smeared due to multiple scattering of electrons. This effect to the time resolution is negligible for thin aerogel.

## 8. Conclusions

The first in the world Cherenkov counters at colliding beams were threshold counters at the VEPP-2 collider in Novosibirsk in 1970.

The work on aerogel Cherenkov counters began in Novosibirsk in 1986. The production of aerogel with refractive index of 1.006–1.13 and thickness of blocks up to 50 mm was developed. The light absorption length at 400 nm is 5–7 m, the scattering length is 4–5 cm. By these parameters Novosibirsk aerogel is one of the best in the world.

Methods of measurement of optical parameters of aerogel have been developed. The Monte Carlo program simulating the process of the light collection in aerogel counter has been developed.

The ASHIPH Cherenkov counters with the light collection on wavelength shifters was developed. Comparing with the direct light collection on PMT, the use of the ASHIPH method in the KEDR detector permitted us to reduce the total area of photocathodes of PMTs in the system by an order of magnitude. The ASHIPH system of the KEDR detector contains 160 counters, the total volume of aerogel is 1000 l.  $\pi/K$  separation is  $4.5\sigma$ . In 2003, 80 counters of the system were installed in the KEDR.

The project of ASHIPH counters for the SND detector was suggested, the prototype counter was constructed and is being tested now.

The LHCb RICH detector will use aerogel with  $n = 1.03$  for the hadron identification between 2 and 10 GeV/c. For this project, aerogel blocks with dimensions of  $200 \times 200 \times 50 \text{ mm}^3$  were produced in Novosibirsk.

Novosibirsk group is developing project of an aerogel RICH for endcap for the SuperBaBar project.

Calculations performed by a group of physicists from Novosibirsk and DESY-Zeuthen have shown that it is possible to achieve the time resolution of 20 fs using aerogel radiators.

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