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Development of aerogel Cherenkov detectors at Novosibirsk

A.Yu. Barnyakov[a], M.Yu. Barnyakov[a], J. Bähr[b], T. Bellunato[c], K.I. Beloborodov[a], V.S. Bobrovnikov[a], A.R. Buzykaev[a], M. Calvi[c], A.F. Danilyuk[d], V. Djordjadze[b], V.B. Golubev[a], S.A. Kononov[a], E.A. Kravchenko[a,*], D. Lipka[b], C. Matteuzzi[c], M. Musy[c], A.P. Onuchin[a], D. Perego[c], V.A. Rodiakin[a], G.A. Savinov[a], S.I. Serednyakov[a], A.G. Shamov[a], F. Stephan[b], V.A. Tayursky[a], A.I. Vorobiov[a]

[a]*Budker Institute of Nuclear Physics, Novosibirsk, Russia*
[b]*DESY Zeuthen, Zeuthen, Germany*
[c]*Università di Milano-Bicocca and INFN, Milano, Italy*
[d]*Boreskov Institute of Catalysis, Novosibirsk, Russia*

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Abstract

The development of aerogel Cherenkov counters with the light collection using a wavelength shifter is described. 80 counters of this type are working in the KEDR detector. A project of similar counters for the SND detector based on "heavy" aerogel with $n = 1.13$ has been developed. Aerogel with a refractive index of 1.006–1.13 and dimensions of blocks up to $200 \times 200 \times 50\,\text{mm}^3$ is produced by the Novosibirsk group for use in Cherenkov counters of different types. The Novosibirsk group is participating in the development of LHCb RICH as well as a beam diagnostics for a photo-injector test facility at DESY–Zeuthen. Recently we started development of RICH based on focusing aerogel (FARICH) for the endcap of the SuperBaBar. For the first time in the world the focusing aerogel with layers of different refractive indices has been produced.

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1. Introduction

Silica aerogel is a unique material with a refractive index covering the range between condensed phases ($n \simeq 1.3$) and gases ($n < 1.001$). The

*Corresponding author. Tel.: +7 3832 394933; fax: +7 3832 342163.
E-mail address: kravchenko@inp.nsk.su (E.A. Kravchenko).

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use of silica aerogel as a radiator in Cherenkov threshold counters was suggested by M. Cantin in 1974 [1]. Aerogel was used and is used now in Cherenkov detectors of different types [2–7]. The Cherenkov detectors developed by the Novosibirsk group, as well as results of joint work with the groups from LHCb and DESY-Zeuthen are presented below.

2. Aerogel production

The work on aerogel production in Novosibirsk was started in 1986 by a collaboration of the Boreskov Institute of Catalysis and Budker Institute of Nuclear Physics as a part of the KEDR detector project. The first samples of aerogel were produced in 1988 [8]. At that time we have used single step production technology, the variant of that described in [9]. The optical parameters of produced aerogel were ordinary for that time: the light scattering length (L_{sc}) at 400 nm was about 2 cm, the light absorption length (L_{abs}) was about 1 m in the range of $\lambda = 300$–600 nm. The interaction length L is defined by the formula $L = d/\ln(I_0/I)$, d—a path length of light in the media, I_0—an initial intensity of light, I—an intensity of unabsorbed or unscattered light. The dimensions of produced blocks were $60 \times 60 \times 25\,\mathrm{mm}^3$ [10].

A variant of the two-step method is used now for aerogel production [11–13]. Presently we produce aerogel with the refractive index of 1.006–1.13, the dimensions of blocks are up to $200 \times 200 \times 50\,\mathrm{mm}^3$. L_{abs} at $\lambda = 400$ nm is 5–7 meters, L_{sc} is 4–5 cm [12,13]. Recently, the aerogel blocks with $n = 1.03$ and increased L_{sc} were produced: hygroscopic aerogel with $L_{sc} = 7.4$ cm, hydrophobic aerogel with $L_{sc} = 5.2$ cm.

3. Threshold aerogel counters

The first project of aerogel counters for KEDR used the direct collection of Cherenkov light at fine-mesh PMTs [8]. In 1990 the prototype was successfully tested [10]. The whole system needed 400 fine-mesh Hamamatsu PMTs. The high cost of the project inspired our further investigations.

The ASHIPH method of Cherenkov light collection (Aerogel, wavelength SHIfter, and PHotomultipliers) was suggested for the KEDR detector in 1992 [14]. The idea is to collect Cherenkov light on wavelength shifting (WLS) bars and then transport the reemitted light to a phototube. In this case one can make long counters and use PMTs with a small photocathode area.

Two options for the ASHIPH method were investigated. The first one was based on a wavelength shifter doped with POPOP dye (1,4-Di-2-(5-phenyloxazolyl)benzene, $C_{24}H_{16}N_2O_2$) and fine-mesh Hamamatsu PMT with bialkali photocathode. This WLS absorbs Cherenkov photons in the range of 280–390 nm, the maximum of the emission spectra is at 420 nm. The prototype was tested, the number of photoelectrons from the relativistic particle was 6.8. It was planned that the KEDR particle identification (PID) system based on this design would consist of 72 counters with 72 2-in. PMTs [15].

The present ASHIPH counter is based on wavelength shifters doped with BBQ dye (4,4-Bis-(2-butyloctyloxy)-p-quaterphenyl, $C_{48}H_{66}O_2$) and micro-channel plate photomultipliers [16–18]. The BBQ has the wide absorption spectrum (260–420 nm), its emission spectrum (maximum at 500 nm) is well matched with the multialkali photocathode of MCP PMT. The whole system will consist of 160 counters. The system will work in the magnetic field up to 1.5 T. The total volume of aerogel is 1000 l. The highly transparent SAN-96 aerogel with the refractive index of 1.05 was chosen, giving the possibility to separate π and K mesons with momenta 0.6–1.5 GeV/c [11,12,19]. The test beam results were described in our previous publications [20–22]. The use of the ASHIPH method permitted to reduce the total surface of photocathodes of PMTs in the KEDR PID system by a factor of 10. The first layer (80 counters) of the system has been installed in the detector in 2003 and is working in the experiment in the ψ-meson mass region.

Methods of measurement of the refractive index, the light scattering and absorption lengths were developed [13,19]. A special program simulating the process of Cherenkov light collection in the aerogel counter was developed and widely used for the optimization of the counter design in our projects [23]. This code simulates the following processes: Rayleigh scattering in the aerogel, Lambert angular distribution of the reflected light, Fresnel refraction on the boundary of two media, light absorption inside the aerogel and on the walls. Calculations based on the measured data are in agreement with the experiment for several counter designs [15,18,24].

To investigate stability of ASHIPH counters we used 20 test counters produced in 1999–2000, installed into the KEDR detector in May 2000. Counters were sealed during production. In 2002 these counters were removed from the detector. Then they were stored in room conditions. Thirteen counters were disassembled and parameters of aerogel, MCP PMT, WLS, PTFE (polytetrafluoroethylene) reflector were measured separately. The mean decrease of the number of photoelectrons from the counters after ~3 years is 38%. It is caused mainly by degradation of aerogel (18%) and quantum efficiency of PMT (17%). The time dependence of the number of photoelectrons on one typical counter is presented in Fig. 1. There is a plateau at the level of 64%, the N_{pe} does not change during last 2 years.

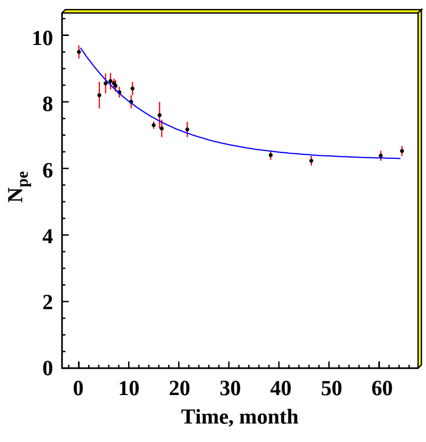

Fig. 1. N_{pe} vs time.

Table 1
Main parameters of the SND ASHIPH system

E_{cm}, GeV	0.4÷2.0
$\Omega/4\pi$, %	60
Number of counters	9
Dimensions, cm	25 × 9 × 2.5
Amount of material, $\%X_0$	8

3.1. Project of ASHIPH system for the SND detector

The SND detector is being upgraded now for operation at the VEPP-2000 e^+e^- collider [25]. The ASHIPH system based on aerogel with $n = 1.13$, BBQ doped WLS and MCP PMT is intended to identify π and K mesons between 300 and 900 MeV/c (Table 1) [26]. Such a aerogel is produced by thermal sintering of aerogel with lower density [13]. The first counter was tested with cosmic muons ($\beta > 0.99$) $N_{pe} > 8$.

4. Aerogel for the LHCb RICH

The LHCb detector is a single-arm spectrometer dedicated to the study of B mesons. The LHCb will have a powerful particle identification system [27]. The LHCb RICH1 detector will use aerogel for hadron identification between 2 and 10 GeV/c [28]. Recently, the Novosibirsk collaboration has succeeded to produce for LHCb RICH highly transparent aerogel blocks ($n = 1.03$, $L_{sc} = 45$ mm at $\lambda = 400$ nm) with dimensions of $200 \times 200 \times 50\,\text{mm}^3$.

5. Focusing aerogel RICH

In a proximity focusing RICH one of the main factors determining the precision of ring radius measurement is a finite thickness of radiator. Recently groups from the BELLE detector [29] and from Novosibirsk have started studies on multi layer aerogel radiators aimed to reduce this effect. The BELLE group results are presented in [30]. Novosibirsk group results are presented [31]. We succeeded in producing a 4-layer aerogel

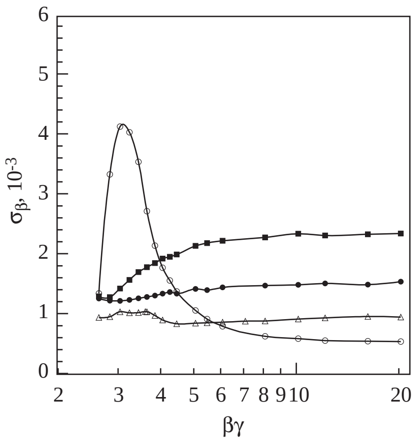

Fig. 2. Resolution of β for different types of aerogel radiators. ■ — 24 mm single layer, • — 12 mm single layer, △ — 3-layer, ○ — focusing 6-layer.

block. Measured refraction indices in each layer have matched designed values with a good precision. The Monte Carlo simulation of Focusing Aerogel RICH (FARICH) has been performed. Several options were considered: single-layer radiator, 3-layer radiator and 6-layer focusing aerogel radiator. The particle velocity resolution is presented in Fig. 2. The use of 6-layer focusing aerogel gives the possibility to separate π/K up to momentum 8.0 GeV/c and to separate π/μ up to 1.6 GeV/c. The FARICH is the option for particle identification in the endcap of the Super BaBar detector suggested for the experiment at the super B-factory with luminosity of 10^{35}–10^{36} cm^{-2}s^{-1}.

6. Aerogel for bunch length measurements

Optimization of the photoinjector test facility at DESY–Zeuthen (PITZ) requires high resolution beam diagnostics. To measure the time profile of the electron bunch a radiation process is needed which produces a photon bunch with the same time properties as the electron bunch.

The time resolution determined by aerogel was calculated both analytically and by Monte Carlo simulation. The time resolution of photon detector was not considered in this work. It was shown that for aerogel with a refractive index of 1.05, 1 mm thickness, the system response has a rectangular shape with the RMS resolution of ~0.1 ps. In addition, it was shown that with aerogel of $n = 1.01$ and 2 mm thickness a time resolution of 20 fs could be reached [32].

7. Conclusions

The ASHIPH Cherenkov counters were developed. The test beam experiment with the prototype was performed. In 2003, 80 counters of the system were installed in the KEDR detector and are working in experiment. The project of ASHIPH counters for the SND detector was proposed, the counter has eight photoelectrons from cosmic muons.

The Novosibirsk collaboration has succeeded to produce for the LHCb RICH highly transparent aerogel blocks with dimensions of $200 \times 200 \times 50\,\text{mm}^3$.

The Novosibirsk group is developing RICH for the endcap for the Super BaBar project. The novel option of focusing aerogel (FARICH) is considered. It gives the possibility to measure particle velocity with the accuracy of 5×10^{-4}, to separate π/K up to momentum of 8.0 GeV/c and μ/π up to momentum 1.6 GeV/c.

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

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