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Results from R&D of Cherenkov detectors at Novosibirsk

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Abstract

Our group produces silica aerogels with refractive indices of 1.006–1.13 with good optical transparency. The particle identification systems for the KEDR and the SND detectors based on threshold aerogel counters are described. Cosmic test results for the SND counters are presented. The possibility of employing a RICH with a sodium fluoride crystal radiator for π/K separation up to $5\,\mathrm{GeV}/c$ momentum is explored. The combined NaF-aerogel radiator is proposed to decrease the minimum working momentum of the RICH below the Cherenkov threshold in aerogel.

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Keywords: Aerogel; Sodium fluoride; Particle identification; Ring imaging; Cherenkov counter

1. Introduction

Cherenkov counters provide a powerful technique for particle identification in the high momentum region where ionization and time-of-flight measurements often cease to work. Silica aerogel has a uniquely low refractive index among solids (less than 1.13). Its use in threshold Cherenkov counters was suggested by Cantin et al. [1] in 1974. The aerogel was used and is used now in a number of Cherenkov detectors of different types [2–7]. The work on aerogel Cherenkov detectors developed by the Novosibirsk group is presented below. Also we studied the use of a sodium fluoride radiator in a Ring Imaging Cherenkov (RICH) detector to possibly cover momenta below the Cherenkov threshold in aerogel.

2. Aerogel production

The work on the silica aerogel production in Novosibirsk was started in 1986 by a collaboration of the Boreskov Institute of Catalysis and the Budker Institute of Nuclear Physics as a part of the KEDR detector project. The first samples of aerogel were produced in 1988 [8]. Since that time significant progress has been made in improving the optical quality of aerogel [9–11]. The following typical values were achieved for hygroscopic aerogel: the light absorption length is 5–7 m at 400 nm wavelength, the Rayleigh scattering length is 4–5 cm at 400 nm (Clarity $= 0.0051$–$0.0064\,\mu\mathrm{m}^4/\mathrm{cm}$). Presently, we can synthesize aerogel with a refractive index in the range of 1.006–1.07. Aerogel with $n > 1.07$ can be produced by a sintering technique. The maximum block dimensions achieved for $n = 1.03$ are $200 \times 200 \times 50\,\mathrm{mm}^3$.

3. Threshold aerogel counters

The ASHIPH method (Aerogel, SHIfter, PHototubes) of Cherenkov light collection was suggested to be used in Cherenkov counters of the KEDR detector in 1992 [12]. The idea is to collect the Cherenkov light on a wavelength shifting bar and transport the re-emitted light to a phototube. This allows one to make longer counters and to use phototubes with smaller photocathodes. Having

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done R&D for the KEDR aerogel counters, we chose the combination of PMMA (Polymethylmethacrylat) with BBQ dye (Benzimidazo-Benzisochinolin-7-on) as wavelength shifter and micro-channel plate photomultipliers (MCP PMTs) with multialkali photocathodes [13–16]. The use of the ASHIPH method allowed us to reduce the total area of the PMT photocathodes in the KEDR aerogel system by a factor of 10.

3.1. KEDR ASHIPH counters

The ASHIPH system of the KEDR detector [19] consists of 160 counters [16]. They are arranged in two layers to reduce losses in geometric acceptance resulting from hits in the shifters. This allows us also to increase essentially the separation power for 80% of the full acceptance, where particles cross both aerogel layers without hitting a shifter. The highly transparent SAN-96 aerogel [9] with a refractive index of 1.05 was chosen to enable π/K separation from 0.6 to 1.5 GeV/c momentum. About 1000 l of aerogel are used in the system. The test beam results were described in Refs. [17,18]. The π/K separation level obtained in the test for a momentum of 1.2 GeV/c amounts to 4.5σ. The first layer comprising 80 counters was built and installed in the detector in 2003. The installation of the remaining counters is planned for 2008.

3.2. Project of ASHIPH counters for SND

For the upgrade of the SND detector for experiments at the VEPP-2000 e^+e^- collider, a particle identification system based on ASHIPH Cherenkov counters will be installed [20,24]. The system must provide π/K separation in the momentum range 300–870 MeV/c. The aerogel refractive index of 1.13 was chosen for this objective. This aerogel is produced by sintering aerogel of a lower refractive index. The absorption length of sintered aerogel amounts to 1 m at 400 nm. The design of the counters is similar to that of the KEDR counters. The whole system consists of 9 counters surrounding the drift chamber. The general layout of a counter is shown in Fig. 1.

A number of tests using cosmic muons with a momentum above 1 GeV/c were carried out with one full-size counter. The measured signal magnitude ranges from 8.2 to 10.7 photoelectrons for different points of the counter.

4. Focusing aerogel RICH

In a proximity focusing RICH one of the main contributions to the Cherenkov angle resolution comes from the uncertainty in the emission point, which is proportional to the radiator thickness. Recently groups from KEK [21] and from Novosibirsk [22] started studies of multi-layer aerogel radiators aimed at the reduction of this effect. We have considered two options:

Single ring: Cherenkov rings from different layers are focused to a single ring in the detection plane.

Multi-ring: There are a few separate Cherenkov rings from different layers.

We succeeded in producing a 4-layer aerogel block whose layers had refraction indices matching the projected ones with a good precision [22]. A Monte Carlo simulation program based on Geant4 has been developed to describe these Focusing Aerogel RICH detectors (FARICH) [22,23].

The following aerogel radiators were simulated [23]: single layer with a thickness of 12 mm and $n = 1.07$ (SLA), 6-layer single ring (FASR-6) and 3-layer 3 rings (FAMR-3). A photomultiplier tube with bialkali photocathode and borosilicate window was chosen ($QE_{max} = 24\%$). The photoelectron collection efficiency and the packing density of the phototubes were taken into account by an overall efficiency of 50%. The distance between the radiator input face and the photodetector plane was set to 100 mm. The 6-layer focusing aerogel option was demonstrated to identify π and K mesons up to 8 GeV/c momentum [23].

5. Proximity focusing RICH with NaF radiator

The possibility of employing a sodium fluoride radiator in a RICH with a gaseous photon detector was discussed [25] and tested [26] many years ago. These studies reported

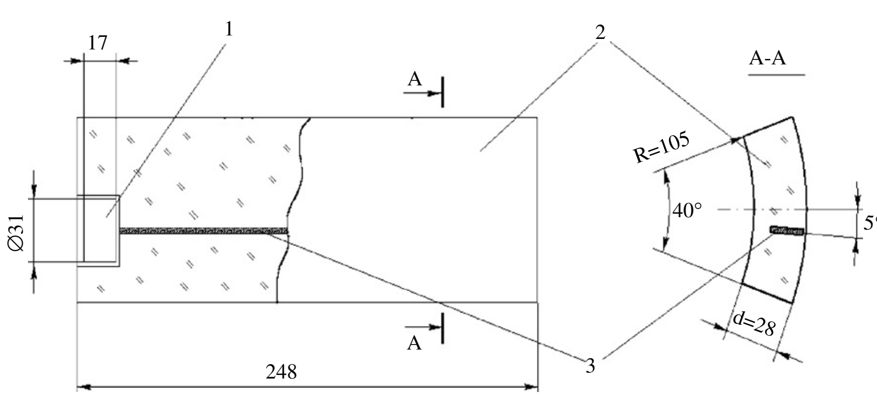

Fig. 1. The SND ASHIPH counter: (1) Micro-Channel Plate PMT, (2) Aerogel, (3) WLS bar.

a π/K separation with a 10 mm NaF radiator up to 2.5–3 GeV/c. A NaF–RICH was used in the CAPRICE balloon-borne experiment in 1994 [27]. NaF is also considered for the AMS space-borne experiment as a part of the dual radiator RICH [28].

NaF has the lowest refractive index ($n = 1.33$ at 400 nm) among solids (except aerogels). It allows the Cherenkov light (down to 170 nm wavelength) to refract out for $\beta \approx 1$ particles of normal incidence. It is commercially available as monocrystals of 10–20 cm transverse size with superb transparency for visible and near-UV light.

We have studied the feasibility of using the combination of a NaF radiator and photomultiplier tubes with bialkali photocathodes in the same conditions as the aerogel radiators studied earlier. To optimize the thickness of the radiator we plotted the Cherenkov angle uncertainty per track as a function of thickness, obtained for 3.5 GeV/c kaons (Fig. 2). Though the minimum is located around 15 mm, we chose the 10 mm thickness to keep the amount of material below 10% of radiation length.

Fig. 3 shows the particle velocity resolution at normal incidence for the NaF–RICH and the aerogel options as a function of $\beta\gamma$. The NaF–RICH has a somewhat better resolution for high $\beta\gamma$ than the single layer aerogel option and about 2.5 times worse than the FASR-6 option. The corresponding $\beta\gamma$-dependences of the number of photoelectrons are shown in Fig. 4. One can see that the NaF–RICH gives twice as many photoelectrons than the FASR-6 RICH. For a 30° angle of incidence the velocity resolution for NaF deteriorates (Fig. 5), what can be partially attributed to the decrease in the number of photoelectrons (Fig. 6) when a part of Cherenkov photons is trapped by total internal reflection in the radiator.

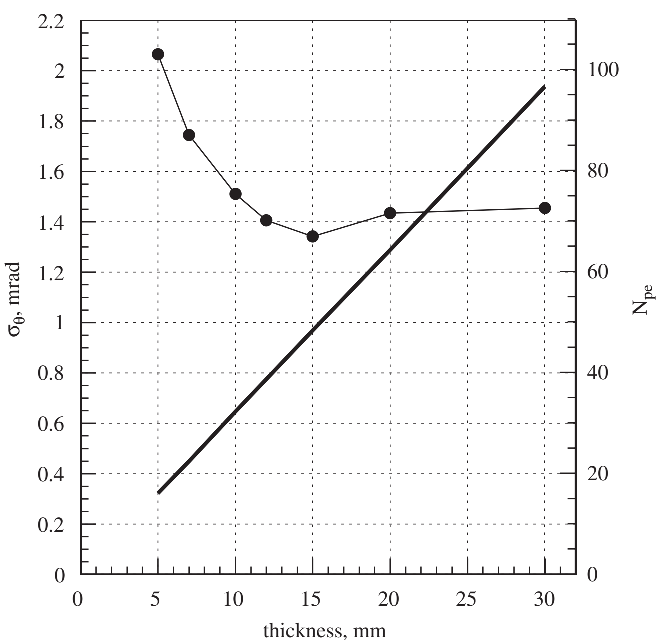

Fig. 2. NaF–RICH: Cherenkov angle resolution (points) and mean number of photoelectrons (line) versus NaF thickness.

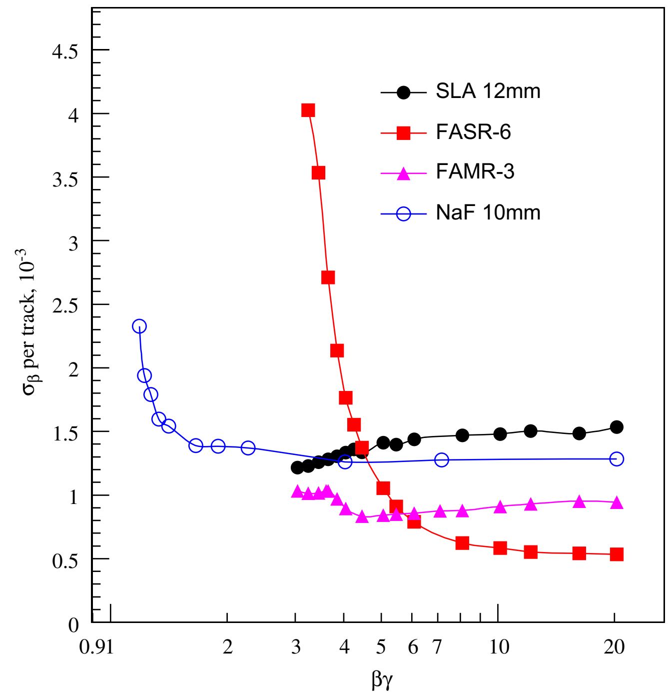

Fig. 3. Particle velocity resolution at normal incidence.

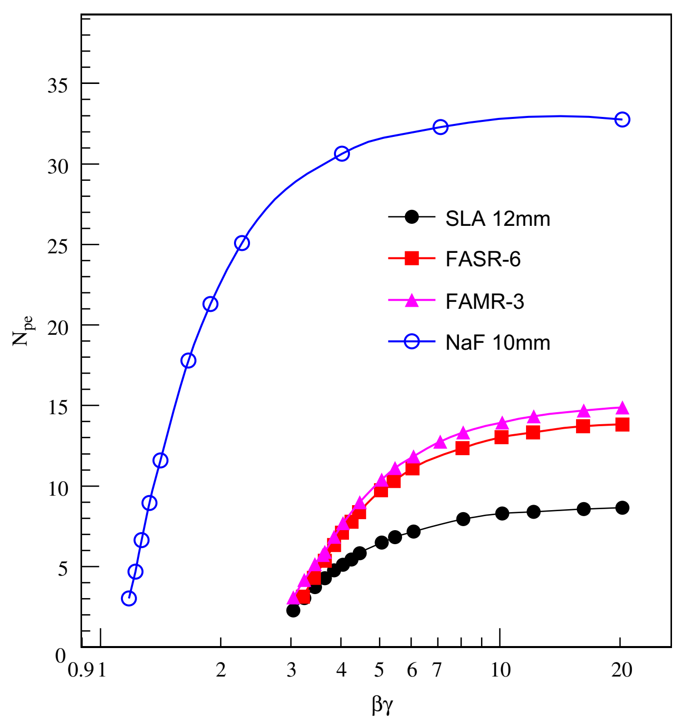

Fig. 4. Number of photoelectrons at normal incidence.

The momentum dependence of the π/K separation is shown for normal particle incidence in Fig. 7, and for a 30° incidence angle in Fig. 8. Normally incident π- and K-mesons can be separated at the level of better than 3σ up to 5 GeV/c. At 30° incidence angle this limit drops to 3.5 GeV/c. The minimum working momentum is estimated to be about 0.6 GeV/c.

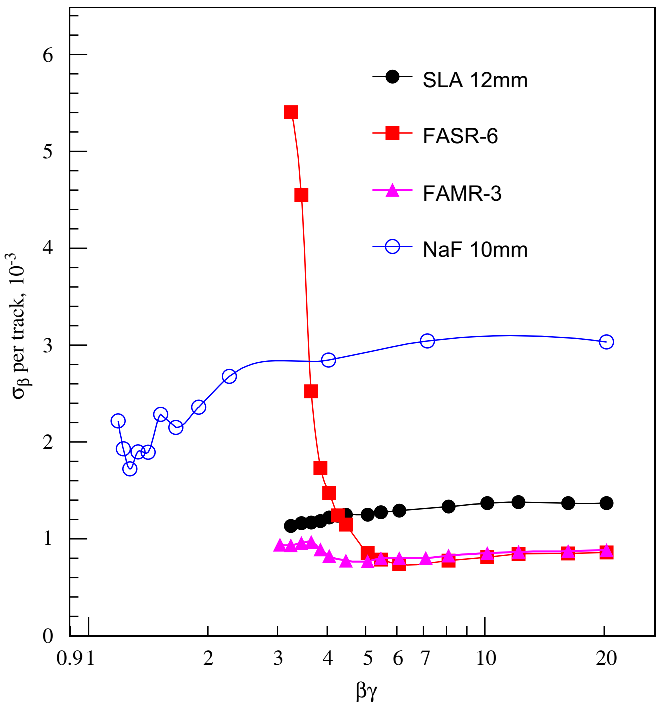

Fig. 5. Particle velocity resolution at 30° angle of incidence.

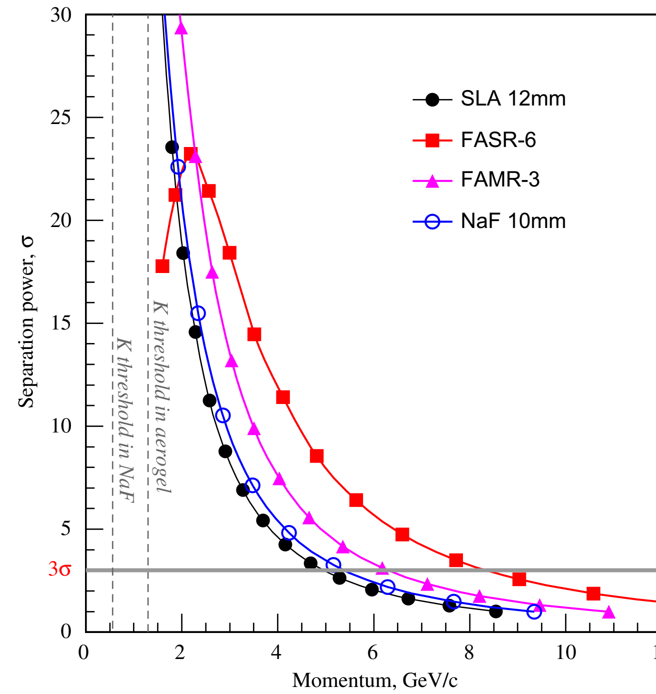

Fig. 7. π/K separation versus momentum, normal incidence.

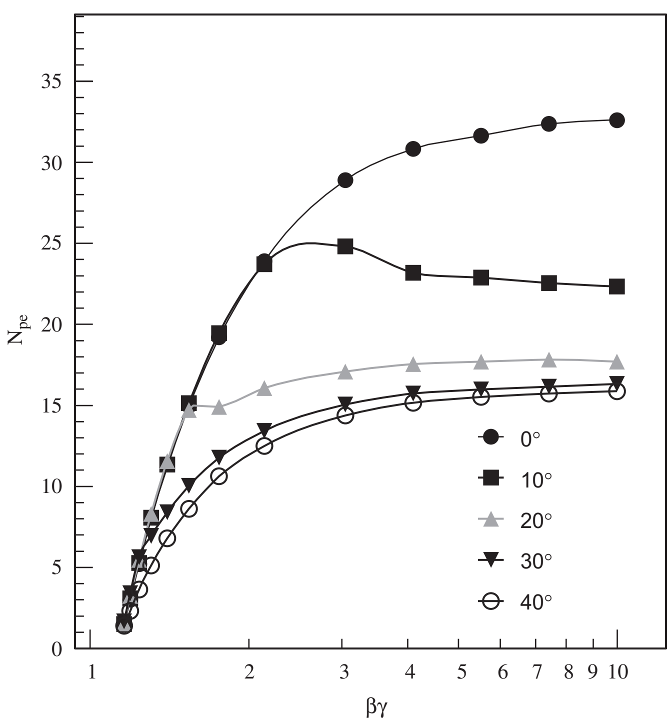

Fig. 6. NaF (10 mm): Number of photoelectrons for different angles of incidence.

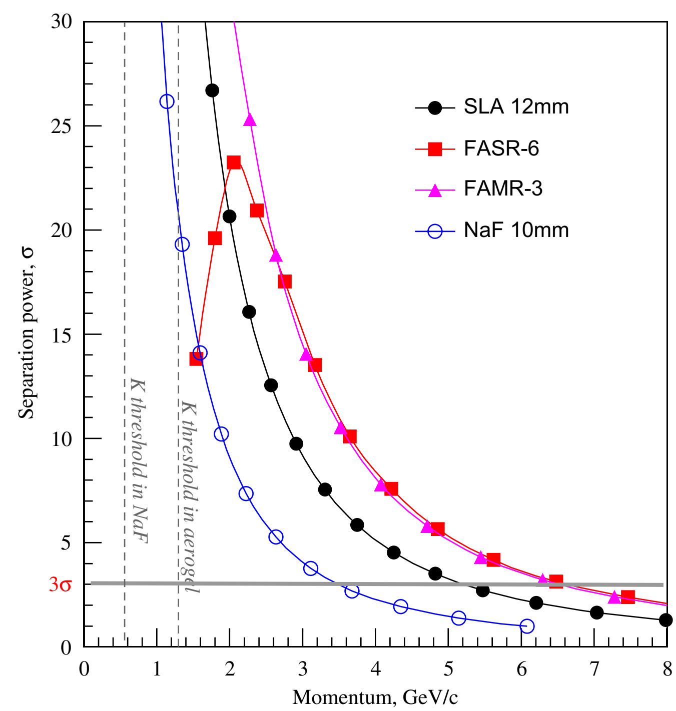

Fig. 8. π/K separation versus momentum, 30° angle of incidence.

The photodetector's spatial resolution is considered to be of secondary importance for these studies. Though, to choose the proper pixelization one should compare the pixel size with the width of the Cherenkov ring in the detector plane. The single photon radius error at $\beta \approx 1$ is presented in Table 1. It shows that the pixel size for the NaF option can be several times larger than for the aerogel options. This greatly reduces the required number of readout channels.

We consider NaF to be a good alternative material as compared to aerogels for the π/K separation up to 3.5 GeV/c. To get particle identification over the largest

Table 1
Ring radius error for a single photon

Radiator	$\sigma_r(1\gamma)$ (mm)
SLA 12 mm	1.3
FASR-6	0.6
FAMR-3 (2-nd ring)	1.1
NaF 10 mm	7.4

possible momentum range we propose a multiple layer aerogel being combined with NaF. Though further investigations are needed for such a combined radiator.

6. Conclusion

Our group developed the technique to produce highly transparent aerogel. The system of Cherenkov ASHIPH counters for the KEDR detector, employing wavelength shifters for light collection, was developed. The first layer of the system was installed in the detector. The project of ASHIPH counters for the SND detector has been presented, the first counter was produced and tested with cosmic muons. The mean number of photoelectrons ranges from 8.2 to 10.7 for different points of the counter.

The use of a sodium fluoride radiator in a proximity focusing RICH with bialkali photocathode PMTs has been investigated. The NaF–RICH with a radiator thickness of 10 mm and an expansion gap of 100 mm has been shown to provide π/K separation of better than 3σ up to $5\,\mathrm{GeV}/c$ for normal particle incidence and $3.5\,\mathrm{GeV}/c$ for a 30° angle of incidence. It has been concluded that this choice of radiator is preferable to aerogel below this momentum limit. The use of a combined NaF-aerogel radiator has been proposed to extend the particle identification capabilities to the momentum region below the Cherenkov threshold in aerogel.

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