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Focusing aerogel RICH optimization

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ABSTRACT

The method of improvement of Cherenkov angle resolution in RICH detectors using 'focusing' aerogel radiators (FARICH) is under investigation. The 'focusing' three-layer aerogel radiator was investigated using a digital radiographic device. The Monte Carlo calculations of velocity resolution based on measured variations of the refractive index in aerogel tile are presented. With the observed variations, π- and K-mesons can be separated up to 8.4 GeV/c, π- and μ-mesons can be separated up to 1.6 GeV/c.

We studied the use of sodium fluoride radiator in a RICH detector. NaF radiator extends the working momentum region for the π/K identification down to 0.6 GeV/c. It has been shown that a RICH detector with NaF radiator can achieve a competitive velocity resolution up to 5 GeV/c as compared to single-layer aerogel RICH.

1. Introduction

The newly suggested method of improvement of Cherenkov angle resolution in the proximity focusing RICH detectors using multilayer aerogel radiators (FARICH) is under investigation [1,2]. The work on development of aerogel radiators for FARICH is presented below. Also we studied the use of sodium fluoride radiator in a RICH detector to possibly cover momenta below Cherenkov threshold in aerogel.

2. RICH with aerogel and NaF radiators

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 from the radiator for $\beta = 1$, normal incidence particles. The possibility of employing sodium fluoride radiator in a RICH with gaseous photon detector was discussed [3] and tested [4] many years ago. NaF-RICH was used in the CAPRICE balloon-borne experiment in 1994 [5]. NaF is also considered for the AMS space-borne experiment as a part of the dual radiator RICH [6].

We have studied the feasibility of using the combination of NaF radiator and photomultiplier tubes [7]. The MC simulation program based on Geant4 has been developed to describe RICH detectors [2,8]. For comparison with NaF the following aerogel radiators were simulated [8]: single layer with thickness of 12 mm and $n = 1.07$ (SLA), six-layer single ring (FASR-6) and three-layer three rings (FAMR-3). The thickness of NaF was chosen to be 10 mm, close to the optimal one. Optimum thickness depends on the pixel size and aerogel–photodetector distance. The photomultiplier tube with bialkali photocathode and borosilicate window was chosen ($QE_{max} = 24\%$). The photoelectron collection efficiency and packing density of phototubes were taken into account with overall efficiency of 50%. The distance between the radiator input face and the photodetector plane was 100 mm.

Fig. 1 shows normal incidence particle velocity resolution 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 is about 2.5 times worse than the FASR-6 option. The NaF-RICH gives twice as many photoelectrons (Npe = 32) than the FASR-6 RICH (Npe = 13).

The π/K separation dependence on momentum is shown for normal incidence particle in Fig. 2. π- and K-mesons can be separated at the level 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 0.6 GeV/c.

The single photon radius variance at $\beta = 1$ is presented in Table 1. It shows that pixel size for the NaF option can be much larger than for the aerogel options. This essentially reduces the required number of readout channels.

We consider NaF to be a good alternative material as compared to aerogels for π/K separation up to 3.5 GeV/c. To get PID in largest possible momentum region we propose a multiple layer aerogel being combined with NaF. Though a further investigation is needed for such a combined radiator.

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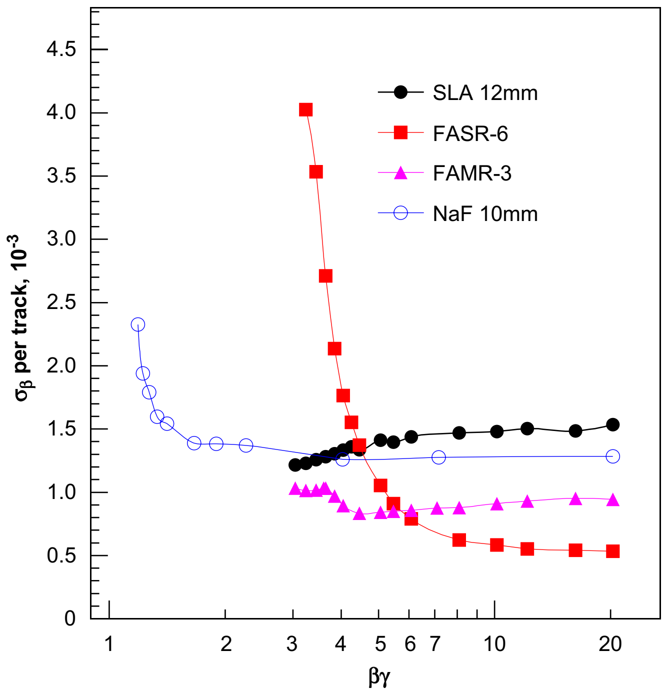

Fig. 1. Particle velocity resolution at normal incidence.

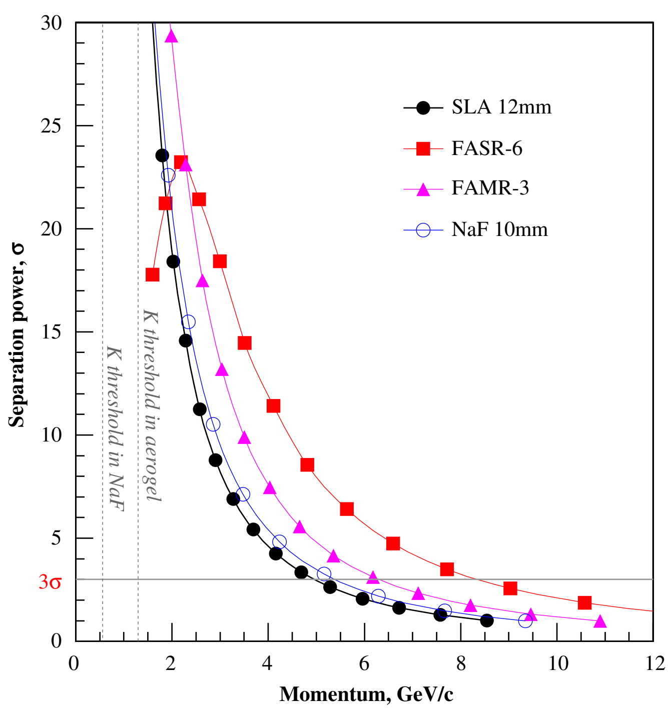

Fig. 2. π/K separation vs momentum. Normal incidence.

Table 1
Ring radius variance for single photon

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

3. Status of aerogel production in Novosibirsk

The work on 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. Since then a significant progress has been made in a pursuit of the improving of aerogel optical quality [9–12]. Further increase of the light scattering length in the aerogel allows to use thicker aerogel tiles thus increasing the number of Cherenkov photons. Recently, experimental series with the refractive index 1.05 and the light scattering length at 400 nm about 10 cm as well as series with the refractive index 1.08 and the light scattering length about 6 cm have been produced.

Variations of the refractive index inside an aerogel tile are a problem for aerogel RICH detectors as it results in a degradation of Cherenkov ring image. On the other hand, aerogel tiles with desired index variation allow to improve Cherenkov angle resolution. For the first time we have shown that modifying reaction conditions of solvogel synthesis it is possible to control refractive index variations inside an aerogel tile. Aerogel tiles of $5 \times 5 \times 3.2\,cm^3$ with average index of 1.047 were produced. We varied conditions of solvogel synthesis for different samples while keeping conditions of supercritical fluid extraction the same. A digital radiographic device was used to measure density variations in the depth of the tiles. Depending on the conditions, samples with minimal variations ($\Delta n \leqslant 0.001$) and noticeable monotonous variation from 1.041 to 1.053 were produced.

3.1. Aerogel radiator for FARICH

In a proximity focusing RICH one of the main contributions to the Cherenkov angle resolution comes from emission point uncertainty which is proportional to radiator thickness. Recently groups from KEK, Ljubljana, Nagoya [1] and from Novosibirsk [2] started studies of a multilayer aerogel radiator aimed at the reduction of this effect (FARICH).

In 2004 we succeeded in the production of a small ($5 \times 5 \times 3\,cm^3$) four-layer aerogel block [2]. In 2007 we have produced the large ($10 \times 10 \times 4\,cm^3$) three-layer aerogel block suitable for use in a real detector (Fig. 3).

To measure mean density and longitudinal density variations in the block we have used a digital radiographic device [2,8]. The X-ray image of aerogel block is shown in Fig. 4. The measured (mean) and designed values of the refractive index of the layers, measured and designed thickness of the layers are presented in Table 2. The thickness of the layers matched the designed one within 0.1 mm. The bottom layer 3 was made thicker than designed assuming that it could be precisely cut later.

The sharp increase of density is clearly seen at the borders between layers (Fig. 4). This means that we have a sharp increase in a refractive index in the depth of the block (Fig. 5).

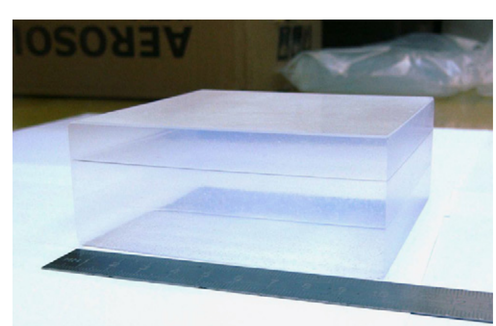

Fig. 3. The three-layer aerogel block.