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Cherenkov rings from aerogel detected by four large-area hybrid photodiodes

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Abstract

We report on the results obtained using thick samples of silica aerogel as radiators for a Ring Imaging Cherenkov counter. Four large-diameter hybrid photodiodes with 2048 channels have been used as photon detectors. Pions and protons with momenta ranging from 6 to 10 GeV/c were separated and identified. The number of photoelectrons and the radius of the Cherenkov rings together with the Cherenkov angle resolution were measured. A comparison with a simulation program based on GEANT4 is discussed.

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Keywords: RICH; Hybrid photodiode; Particle identification; Aerogel; LHCb

1. Introduction

The use of silica aerogel with refractive index around $n = 1.03$ inside the Ring Imaging Cherenkov detector will provide the LHCb experiment [1,2] the identification of particles with momenta of a few GeV/c.

We present here the results obtained by exposing samples of aerogel of different thicknessess and optical properties to pion and proton beams with momenta between 6 and 10 GeV/c in the PS testbeam facility at CERN.

We report on tests of two tiles, $7\times 8\times 4\,\mathrm{cm}^3$ and $10\times 10\times 4\,\mathrm{cm}^3$, of hygroscopic aerogel.[1] They were tested separately and together to form

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[1] Produced by the Boriskov Institute for Catalysis, Novosibirsk, Russia.

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to total thickness of 8 cm. The refractive indices of the two tiles were slightly different, 1.0306 and 1.0298, respectively. We also tested one big tile, $20 \times 30 \times 2\,\mathrm{cm}^3$, of hydrophobic aerogel.[2] It was cut prior to the exposure to the beam into four blocks in order to compose stacks of 6 and 8 cm thickness.

The tested aerogel samples had undergone optical measurement before exposure to the beam. The parameters which define the transparency of the aerogel were extracted by fitting spectrophotometric analysis data according to the Hunt formula:

$$T(\lambda) = A\mathrm{e}^{-CL/\lambda^4} \qquad (1)$$

which assumes a wavelength independent absorption factor and light diffusion due to Rayleigh scattering. In Eq. (1) L is the aerogel thickness, λ is the wavelength of the impinging light, A is the absorption coefficient and C is the clarity factor.

The two hygroscopic tiles had a clarity factor $C = 4.5 \times 10^{-3}\ \mu\mathrm{m}^4/\mathrm{cm}$ and $C = 6.5 \times 10^{-3}\ \mu\mathrm{m}^4/\mathrm{cm}$, respectively, while the hydrophobic tile had $C = 9.6 \times 10^{-3}\ \mu\mathrm{m}^4/\mathrm{cm}$.

Rayleigh scattering of the Cherenkov photons inside the aerogel affects the resolution of the emission angle measurement. Data were taken with and without filters, D263 glass, mylar film and Pyrex, interposed downstream of the aerogel in order to absorb UV photons, which, due to the λ^{-4} dependence of the Rayleigh cross-section are the most likely to be scattered.

2. Experimental setup

The experimental setup consisted of a light tight and reflection-free aluminium vessel, housing the aerogel radiator and a spherical mirror with a focal length of 59.6 cm. Nitrogen was fluxed inside the vessel to maintain the water content lower than 20 ppm and prevent a degradation of the quality of the hygroscopic aerogel tiles. In order to determine the trajectory of the incoming particles, three silicon planes were located upstream and downstream the vessel, allowing for a spatial resolution of about 1 mm.

The Cherenkov photons produced in the aerogel were detected by four position-sensitive hybrid photodiodes, developed at CERN, called Pad HPD [3]. They were positioned in the focal plane of the mirror, providing a geometrical coverage of about $\frac{2}{5}$ of the total ring. The Pad HPD is a fast, large area, highly sensitive hybrid photodiode. It consists of a vacuum tube with a diameter of 127 mm (114 active), capped with a transparent cathode window. A bialkali photocathode is evaporated on the window. The quantum efficiency of the K_2CsSb photocathodes ranged between 20% and 30% at 330 nm, as shown in Fig. 1.

Photoelectrons emitted from the photocathode are accelerated by a focusing electric field onto the silicon sensor, which consists of 2048 $1 \times 1\,\mathrm{mm}^2$ pixels. The demagnification factor is about 2.3.

The analogue readout was based on Viking VA3 chips [4] encapsulated within the vacuum envelope of the tube which provide also the multiplexing of the data. Background data were taken in runs without beam and with random trigger to study the noise of the HPDs, and the probability to have a photoelectron signal in these conditions was measured to be 10^{-4} per pixel.

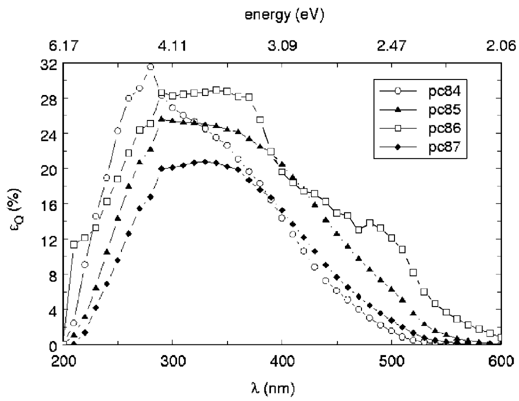

Fig. 1. Quantum efficiency of the photocathodes of the four HPDs used for the testbeam.

[2] Produced by Matsushita Electric Works LTD, Japan.

Table 1
Single photoelectron resolution in mrad for several 9 GeV/$c\pi^-$ runs. When available, the expectation from the simulation is also shown

Aerogel	No filter	D263	Glass	
Hygroscopic 4 cm	250.0 ± 5.4	247.1 ± 5.0	243.6 ± 5.3	Data simulation
	248.7 ± 4.0	246.8 ± 3.1	243.2 ± 3.8	
Hygroscopic 8 cm	246.8 ± 5.8	245.4 ± 4.8	246.0 ± 5.3	Data simulation
	245.0 ± 3.9	243.7 ± 3.0	—	
Hydrophobic 6 cm	250.2 ± 8.7	250.9 ± 5.8	251.3 ± 5.4	Data
Hydrophobic 8 cm	249.5 ± 9.8	250.3 ± 6.2	—	Data

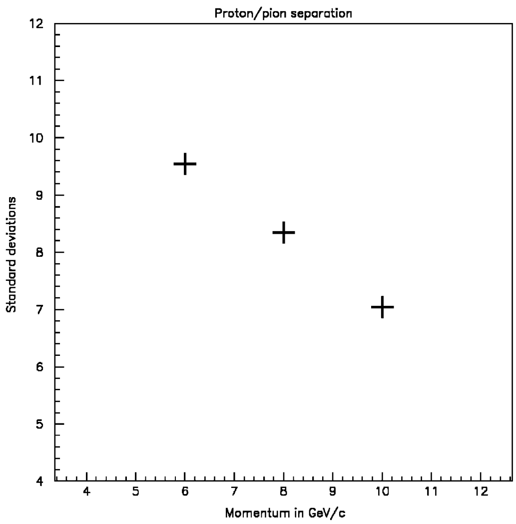

Fig. 2. Proton/pion separation as a function of the beam momentum.

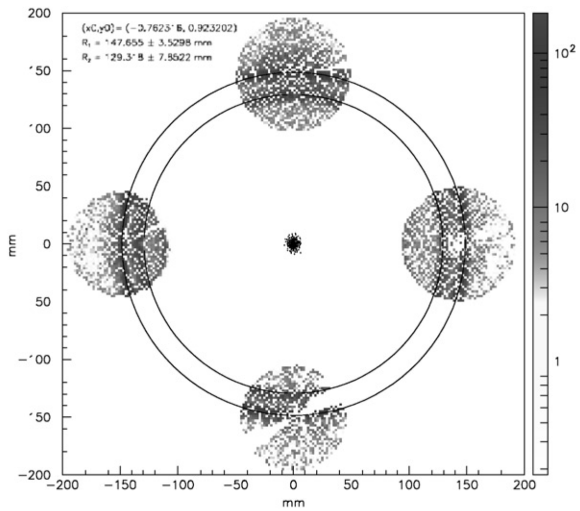

Fig. 3. Cherenkov rings from 30 000 events in 8 GeV/c positive pions and protons run.

3. Results and conclusions

Table 1 gives the results obtained on single photoelectron resolution, together with the expectation from the simulation.

Fig. 3 shows the recorded data for 30 000 π^+/p events with 8 GeV/c momentum. The two ring regions are clearly visible on the four HPDs.

Proton/pion resolving power is shown in Fig. 2 as a function of the beam momentum.

The photoelectron yield per track was high as 10.7 photoelectrons on the ring and $10^{-2}\,\text{cm}^{-2}$ scattered for 8 cm thick hygroscopic aerogel. The result for the number of photoelectrons in the ring region is normalised to 2π geometrical acceptance.

The test we performed validates that silica aerogel is a suitable radiator for a Ring Imaging Cheronkov detector designed to provide positive particle identification in the few GeV/c momentum range. The separation between protons and pions has been shown to be effective for particle momenta up to 10 GeV/c .The results we obtained are in agreement with the expectations from a detailed simulation program.

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