ELSEVIER

Nuclear Instruments and Methods in Physics Research A 478 (2002) 348–352

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A

www.elsevier.com/locate/nima

Testbeam results on particle identification with aerogel used as RICH radiator

M. Alemi[a], T. Bellunato[a], A. Braem[b], M. Calvi[a], E. Chesi[b], A. Duane[c], C. Joram[b], D. Liko[b], C. Matteuzzi[a], P. Negri[a], N. Neufeld[b], M. Paganoni[a,*], J. Seguinot[d], D. Voillat[b], S. Wotton[e], T. Ypsilantis[f,✠]

[a] University of Milano Bicocca and INFN, Piazza della Scienza 3, 20100 Milano, Italy
[b] CERN, Geneva, Switzerland
[c] Imperial College, London, UK
[d] College de France, Paris, France
[e] University of Cambridge, Cambridge, UK
[f] University of Bologna and INFN, Milano, Italy

Abstract

We present the results obtained by testing in a beam sample of silica aerogel which is foreseen as one of the radiators for the Ring Imaging Cherenkov counter of LHCb. Pion and proton beams with momenta ranging from 6 to 10 GeV/*c* traversed different thickness of aerogel. Two large diameter (12 cm) Hybrid Photodiodes with 2048 channels, produced at CERN, were used as photodetectors. The number of photoelectrons and the radius of the Cherenkov rings allowed pion–proton separation over the whole considered momentum range.

Keywords: RICH; Particle identification; Hybrid photodiode; Large hadron collider

1. Introduction

Particle identification is essential for the LHCb experiment [1], in order to perform measurements of CP violation in B decays at the LHC collider. The momentum range where hadron identification is required extends from 1 to 150 GeV/*c*. The upper limit comes from the requirement of discriminating between various two-body B decay channels ($B^0_d \to \pi^+\pi^-$, $B^0_d \to K^+\pi^-$, $B^0_s \to K^-\pi^-$, $B^0_s \to K^-K^+$). The lower limit is set by the identification of kaons from the $b \to c \to s$ decay chain, which provides a valuable b-flavour tag in high multiplicity events. The particle identification has to cover the full angular acceptance of the LHCb spectrometer, from 10 to 300 mrad in the horizontal plane and to 250 mrad in the vertical plane. A strong correlation between the polar angle and the momentum of the tracks makes the spectrum softer at wide angles.

The LHCb experiment has based its particle identification on a RICH system divided into two detectors. An upstream detector (RICH1) contains both the aerogel and C_4F_{10} radiators, respectively, for identification of low and intermediate momentum tracks in the full outer acceptance. A

*Corresponding author.
✠ Deceased
E-mail address: Marco.Paganoni@cern.ch (M. Paganoni)

0168-9002/02/$ - see front matter
PII: S 0 1 6 8 - 9 0 0 2 (0 1) 0 1 8 2 6 - 5

down-stream detector (RICH2) has a CF_4 radiator, suitable to analyze high momentum tracks in the inner acceptance. Tilted spherical mirrors bring the Cherenkov light towards the photodetector planes, outside the spectrometer acceptance. A schematic layout of RICH1 is shown in Fig. 1.

2. The aerogel radiator

Silica aerogel is a low density ($\rho \simeq 0.15\,g/cm^3$) solid with a netlike structure of small-scale length ($\leqslant 50\,nm$). Its refractive index is in the useful range ($n \simeq$ 1.01–1.10) for identification of low-momentum hadrons. The light transmission of aerogel is determined by Rayleigh scattering, and can be expressed by the relation

$$T = A\exp(-Cd/\lambda^4) \quad (1)$$

where d is the aerogel thickness, A is the transmittance at long wavelengths and C is the clarity coefficient, whose value is related to the amount of unscattered light. Small values of clarity are crucial to use the aerogel as radiator in a RICH, because only the unscattered light keeps the direction of the Cherenkov cone. Great care has to be taken when handling aerogel, because it is very fragile and may degrade due to water absorption. Furthermore, detailed optical measurements have to be made on each aerogel sample in order to avoid non-uniformities in the thickness and in the refractive index.

Two samples of aerogel have been tested. The first sample consists of $55 \times 55 \times 10\,mm^3$ tiles of hydrophobic aerogel produced by Matsushita Electric works Ltd. (Japan). The second sample is made of $100 \times 100 \times 20\,mm^3$ tiles of hydrofilic aerogel produced by the Boreskov Institute of Catalysis in Novosibirsk (Russian Federation) [2].

The results of the measurements of light transmission for both samples are shown in Fig. 2. The clarity coefficients obtained are $C = 96 \times 10^{-4}\,\mu m^4/cm$ for the Matsushita aerogel and $C = 56 \times 10^{-4}\,\mu m^4/cm$ for the Novosibirsk aerogel.

3. The testbeam set-up

Both aerogel samples were exposed to the T7 secondary beam, extracted from the PS accelerator at CERN. This beam can provide pions and protons up to 10 GeV/c with a momentum bite of 1%. By choosing the polarity of the beam, we could select either a pure π^- beam, or a mixture of π^+ and protons.

As photodetector, we used the pad-HPD, a large area Hybrid Photodiode with pixelized readout,

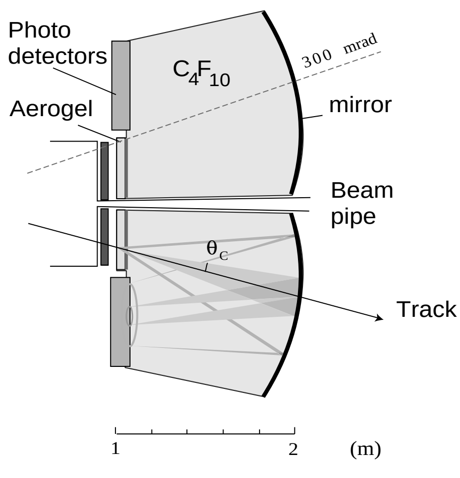

Fig. 1. Layout of the RICH1 detector.

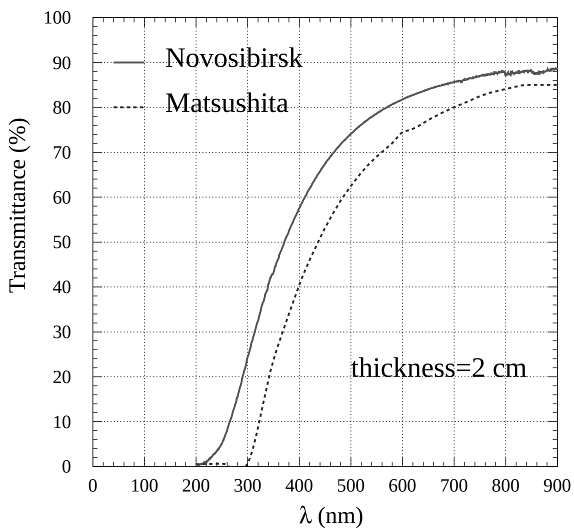

Fig. 2. Transmittance of a 2 cm thick tile of both Matsushita and Novosibirsk aerogel versus light wavelength.

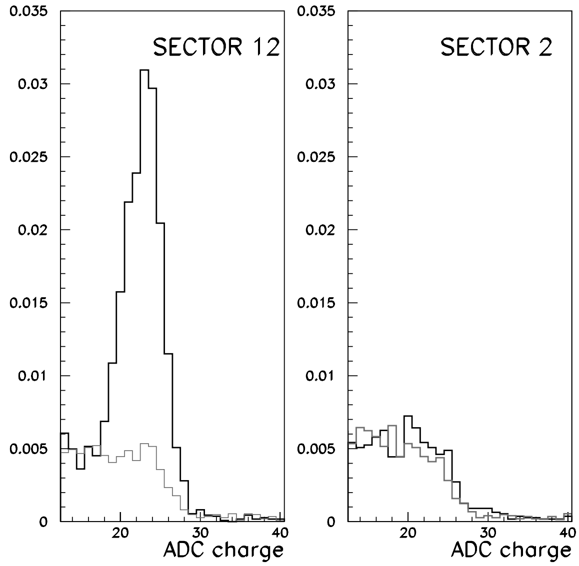

Fig. 3. Sum over the 128 pixels in the same sector of the ADC values: sector containing the ring (left) and sector far away from the ring (right) in runs with 6 cm aerogel (dark line) and without aerogel (light line).

entirely developed and produced at CERN [3]. In the pad-HPD, a fountain shaped electric field accelerates the photoelectrons and focuses them towards the silicon sensors, providing an image demagnified by a factor 2.5. The 2048 $1 \times 1\,\mathrm{mm}^2$ silicon pixels are read out using a low noise analog chain based on the Viking VA3 chip.

Various thicknesses of the two aerogel samples were placed in the beam inside a light-tight aluminium vessel. A flux of nitrogen was protecting the aerogel from humidity. A spherical mirror at the downstream end of the vessel reflected the Cherenkov light back to the photodetector plane, where two pad-HPDs covered about 1/5 of the Cherenkov ring. The high voltages of the pad-HPDs were set to 14 and 15 kV. The average noise per pixel was below 10^{-3} per trigger. Some noisy pixels were masked for the data analysis.

4. Results

The sum of the ADC counts of the 128 pixels belonging to the same sector is shown in Fig. 3 both for a sector containing the Cherenkov ring (sector 12) and for a sector far away from the ring (sector 2). The distribution produced by 9 GeV/c pions in 6 cm of aerogel is compared in both plots with the background estimated in runs without the aerogel.

In Fig. 4, the radial distribution of hits around the fitted center of the Cherenkov ring is shown for 9 GeV/c pions in 6 cm of aerogel. Here, again, the background estimated in runs without the aerogel is superimposed.

The photon yield of the aerogel was measured using a region of 9 mm around the fitted Cherenkov ring, after correcting for signal losses and for the reduced geometrical acceptance due to the presence of only two pad HPDs. In Fig. 5, the results of the measurement of the photon yield for various aerogel thickness are compared with a Monte-Carlo simulation. Also, the number of photons outside the ring, due mainly to Rayleigh scattering, is shown.

As can be seen in Figs. 6 and 7 the rings originating from protons and pions with the same momentum are clearly separated.

As an alternative to the direct ring reconstruction, the Cherenkov angle was determined by

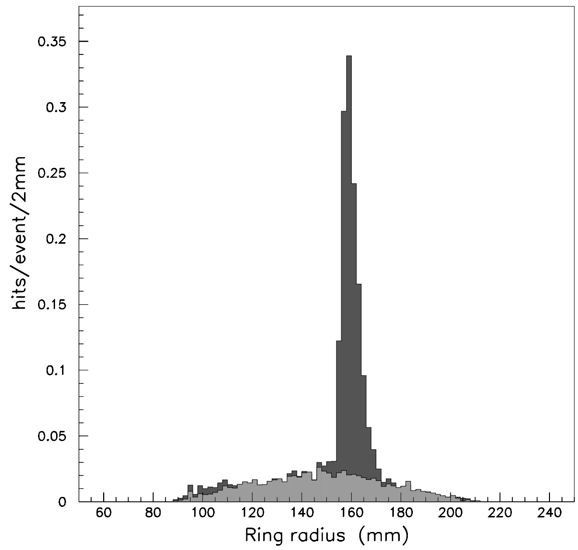

Fig. 4. Number of pads with signal as a function of the Cherenkov ring radius: run with 9 GeV/c π and 6 cm aerogel (dark histogram) superimposed on a run without aerogel (light).

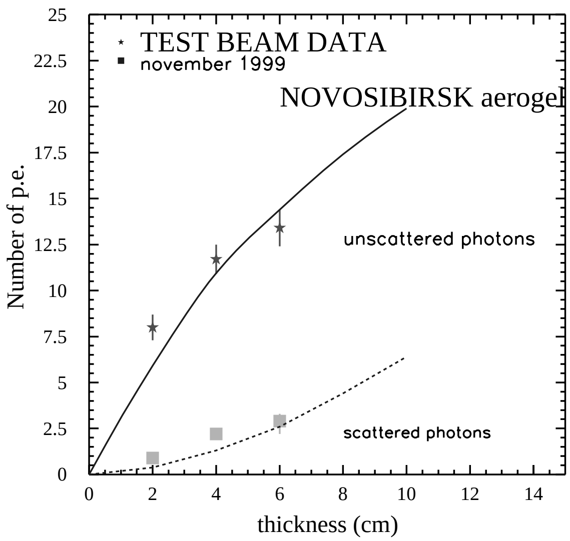

Fig. 5. Comparison of testbeam data and simulation for the photon yield as a function of the aerogel thickness.

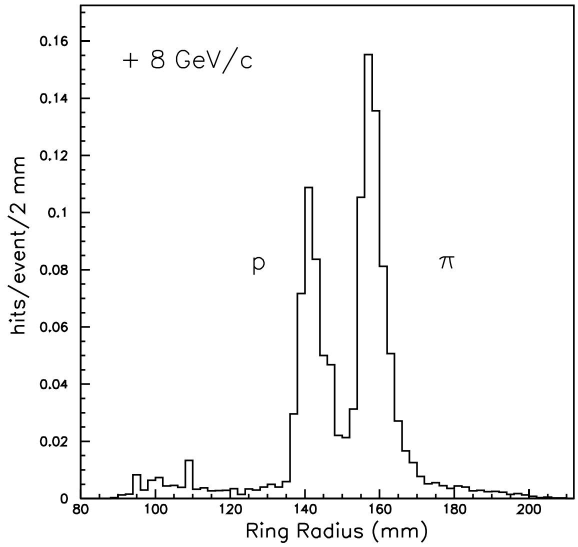

Fig. 7. Number of pads with signal as a function of the Cherenkov ring radius for a beam of 8 GeV/c containing protons and pions.

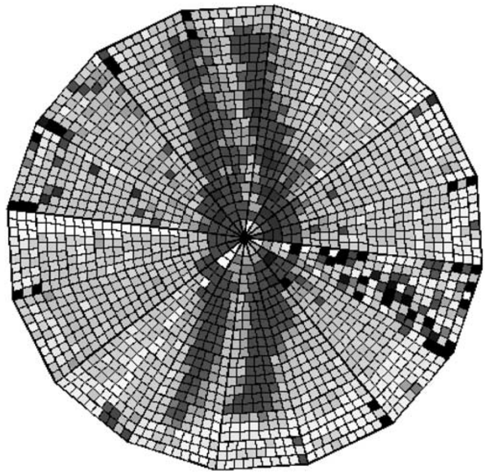

Fig. 6. Display of the two Cherenkov rings produced by 8 GeV/c pions and protons in a pad-HPD.

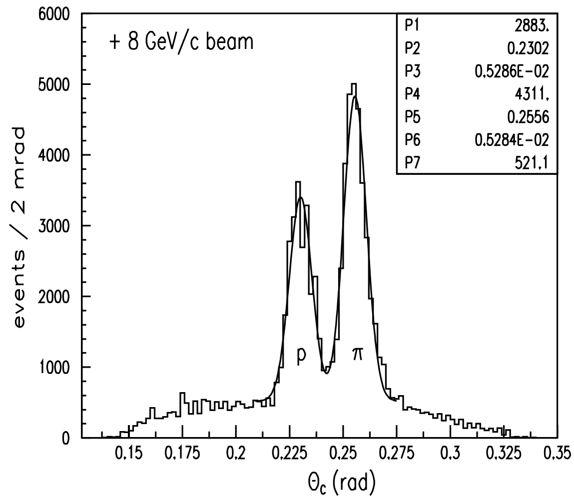

Fig. 8. Reconstructed Cherenkov ring for 8 GeV/c pions and protons.

using a retracking procedure applied to each photon, after fixing the charged particle direction. The resulting Cherenkov angles are in agreement with the expectations. A nice separation between pions and protons is also reached in this case, as can be seen in Fig. 8.

5. Conclusions

We exposed different thickness of silica aerogel to pions and protons with momenta between 6 and 10 GeV/c. The number of photoelectrons was found to be in agreement with the Monte Carlo expectations. Pion–proton separation was achieved over the whole momentum range.

Acknowledgements

We would like to thank A. Buzykaev, E. Kravchenko and A. Onuchin from the Budker Institute of Nuclear Physics of Novosibirsk and A. Danilyuk from the Boreskov Institute of Catalysis of Novosibirsk who provided us with the aerogel samples. We would like to acknowledge the excellent technical work of R. Mazza for the mechanical installation.

References

[1] LHCb RICH Technical Design Report, CERN/LHCC/2000-0037.
[2] A. Buzykaev, et al., Nucl. Instr. and Meth. A 401 (1997) 187.
[3] A. Braem, et al., Nucl. Phys. B (Proc. Suppl.) 78 (1999) 381.