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# Long-term operational experience with the HERMES aerogel RICH detector

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ABSTRACT

For nearly 10 years, from 1998 until the closure of the HERA ring last July, a focused RICH has been used in the HERMES experiment at DESY to measure the semi-inclusive deep-inelastic scattering of polarized electrons on polarized gaseous targets. The RICH utilized two radiators, a heavy fluorocarbon gas, and a wall of silica aerogel tiles. It has identified pions, kaons, and protons in the momentum range from 2 to 15 GeV/$c$ with a K/$\pi$ separation of nearly $3\sigma$ at 4 GeV/$c$. The optical properties of the aerogel and the RICH performance related to this radiator are reviewed, and some parameters are sampled over the whole RICH operational period in order to test its long-term stability.



## 1. Introduction

For nearly 10 years the HERMES collaboration [1] has studied the nucleon spin structure by measuring the spin asymmetries of particles produced in the deep-inelastic scattering of 27 GeV longitudinally polarized electrons or positrons on polarized gaseous targets.

Most of the hadrons produced by HERMES lie between 2 and 10 GeV, a difficult region to unambiguously identify pions, kaons, and protons with standard particle identification (PID) techniques. In 1998 the HERMES collaboration solved this problem by installing [2] a RICH detector which utilized, for the first time in a data-taking experiment, the improvements brought at that time to the optical properties of hydrophobic aerogel by the Matsushita company [3]. The focused HERMES RICH [2,4,5] utilizes two spatially separated radiators, a clear aerogel wall and $C_4F_{10}$ gas. A schematic view is shown in Fig. 1 and its operating parameters are listed in Table 1.

In this paper the stability of the SP-30 Matsushita aerogel radiator is analyzed over the whole operational period of the detector. This aerogel is hydrophobic and for these 10 years has been maintained under a constant flow of dry nitrogen. The optical measurements [4] performed on aerogel before its installation in the RICH are briefly reviewed in Section 2 in order to calculate and to compare with experimental results the number of photoelectrons ($N_{\mathrm{pe}}$) detected in the aerogel rings and their precision in reconstructing the Cherenkov angle ($\theta_{\mathrm{C}}$). Although the HERMES RICH was planned to have an angular resolution ($\delta\theta$) dominated by geometrical contributions [2,5], rather than by the optical properties of aerogel, its characterization, described in more detail in Refs. [4,6], is necessary for providing a full interpretation of the RICH performance given in Section 2. Finally in Section 3 the $N_{\mathrm{pe}}$ number produced by $\beta{\sim}1$ particles and their precision in reconstructing $\theta_{\mathrm{C}}$ are monitored during the 10 years of operation of the detector, in order to test the long-term stability [7,8] of the aerogel radiator.

## 2. Aerogel optical properties

The aerogel optical quality is characterized by $\Lambda$, the light attenuation length at 400 nm. In the 1980s a typical value was $\Lambda = 1$ cm. In the early 1990s new production techniques raised this value to 2 cm, thus approaching the threshold for the use of aerogel as radiator of a focused RICH [9]. The $\Lambda$ value of the aerogel produced by Matsushita [3] and used in our RICH was 2.3 cm.

For a precise estimate of $N_{\mathrm{pe}}$ and $\delta\theta$, parameters affecting the RICH PID performance, the following optical measurements were performed on the SP-30 aerogel tiles ($10 \times 10 \times 1\,\mathrm{cm}^3$): the refractive index ($n$) of all tiles at fixed tile position and wavelength (633 nm), the density dispersion, the chromatic dispersion $n(\lambda)$, the transmittance ($T$), reflectance ($R$), diffuse transmittance ($T_{\mathrm{diff}}$), transflectance (TF), and forward scattering (FS).

The average $n$ value was obtained from all the tiles measured at 633 nm: $n \pm \delta n = 1.0304 \pm 0.0004$. The $\delta n$ fluctuation could be reduced by sorting tiles with similar $n$ into the same aerogel stack, formed from five tiles. Including the variation of $n$ within the individual tiles, a total $n$-dispersion contribution $(\delta\theta/\theta)_{n\text{-disp}} = 0.5\%$/p.e. was estimated. This contribution is for each detected Cherenkov photon (or photoelectron, p.e.).

The aerogel chromatic dispersion was obtained by measuring $n$ in one tile at 633, 514, 496, 458, 422 and 325 nm, as shown in Fig. 2.

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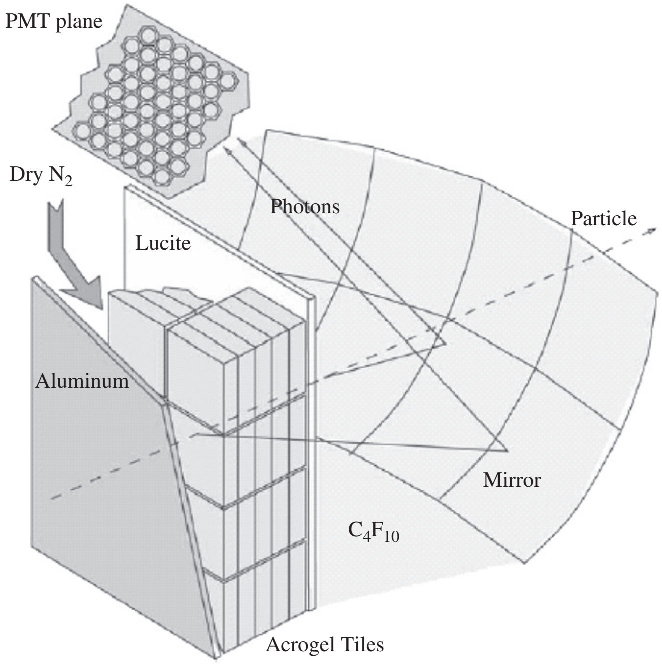


**Fig. 1.** Schematic view of one half of the focused HERMES RICH detector. The two radiators, the aerogel wall and the $C_4F_{10}$ gas, separated by a Lucite layer, are indicated together with the mirrors and the PMT plane. Dry $N_2$ gas has been kept continuously flushing the aerogel vessel.

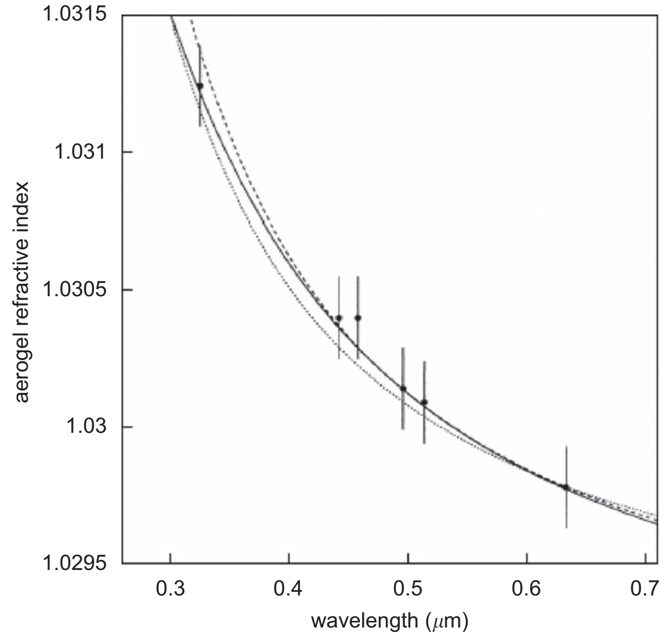


**Fig. 2.** The refractive index of one SP-30 Matsushita aerogel tile measured at six different wavelengths. The solid, dashed and dotted lines refer to different fits of the experimental data, all normalized to the value at 633 nm.

**Table 1**
Cherenkov light thresholds for pions, kaons and protons

| | Aerogel | $C_4F_{10}$ |
|---|---|---|
| $n$ | 1.0304 | 1.00137 |
| $\beta_{th}\gamma_{th}$ | 4.03 | 19.10 |
| π (GeV) | 0.6 | 2.7 |
| K (GeV) | 2.0 | 9.4 |
| p (GeV) | 3.8 | 17.9 |

The index of refraction $n$ is given at 633 nm, $\beta_{th} = 1/n$ is the threshold velocity and $\gamma_{th} = 1/(1-\beta_{th}^2)^{1/2}$.

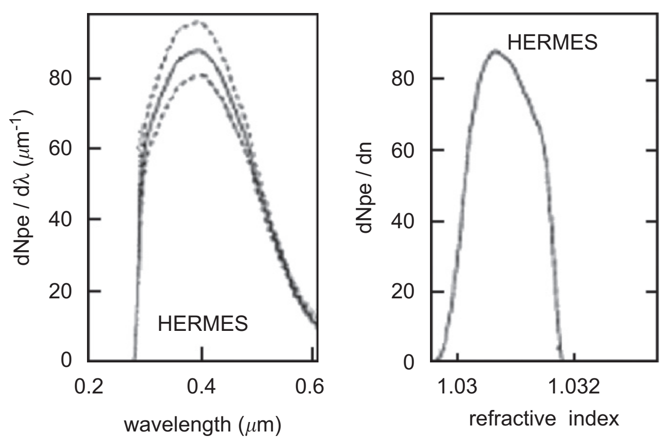


**Fig. 3.** Left: number of detected Cherenkov photons (solid line) with estimated uncertainties (dashed lines), as a function of wavelength. Right: number of detected Cherenkov photons as a function of the aerogel refractive index.

The $\lambda$-dependence of $N_{pe}$, shown in the left panel of Fig. 3 based on the measurements described below, is calculated for 5 cm-thick, $n = 1.0304$ aerogel, and for a 3 mm-thick Lucite exit window. The total efficiency and its separate contributions for transmission and detection of a Cherenkov photon from aerogel are shown in Fig. 4. In the right panel of Fig. 3 the $n$-dependence of the unscattered Cherenkov radiation ($dN_{pe}/dn$) is evaluated. From Fig. 3 the average $n$ value over all of the aerogel is derived: $n_{av} \pm \sigma_n = 1.0312 \pm 0.0008$. The chromatic contribution to the resolution is then: $(\delta\theta/\theta)_{chromatic} = 1/2[\sigma_n/(n-1)] = 1.3\%$/p.e.

For a RICH radiator the minimization of reflection, scattering, and absorption of the Cherenkov photons produced in the medium are crucial. The transmittance ($T$) accounts for the fraction of the residual light from a collimated light beam passing through an aerogel sample, the transflectance (TF) is the fraction of light emerging in all directions from the sample, linked to the absorbance ($A$) through the simple relation $TF = 1 - A$.

The TF curve, measured for small aerogel pieces placed in an integrating sphere, is shown in Fig. 5. The $T$ curve shown was obtained by averaging measurements of 200 tiles. $T$, linked to $\Lambda$ by $T = \exp(-t/\Lambda)$, is parameterized in aerogel by the Hunt formula $T = A\exp(-Ct/\lambda^4)$, assuming a $\lambda$-independent absorption, expressed by $A$. The parameter $Ct$ represents the Rayleigh diffused light fraction. Using the values of these parameters obtained from the fit of measurements in Fig. 5, $A = 0.964 \pm 0.002$ and $Ct = 0.0094 \pm 0.0008\ \mu m^4$, the p.e. distributions in Fig. 3 have been calculated [4]. The calculated undeflected p.e. number, obtained from the integral of the distribution in the right panel of Fig. 3, and including the mirror dispersion and coverage of the focal plane by the PMT-funnel system, is $N_{pe} = 12 \pm 2$.

In Ref. [6] it was found that $23 \pm 4\%$ of Cherenkov photons produced in 5 cm of the SP-30 aerogel are "forward scattered" at an average angle of $\theta_{FS} = 1.55$ mrad from their primary $\theta_C$ direction. The remaining 76% are not deflected. The p.e. angular distribution had a standard deviation ($\delta\theta_{FS}$) of 0.85 mrad, and a $(\delta\theta_{FS}/\theta_C) = 0.4\%$/p.e. term resulted.

The diffuse transmittance ($T_{diff}$), linked to the $T_{FS}$ through the relation: $T_{FS} = T_{diff} \times T$, is shown in the upper panel of Fig. 5. $T$, TF, and $T_{FS}$ are linked to the absorption $\Lambda_A$, Rayleigh scattering $\Lambda_S$, and forward scattering $\Lambda_{FS}$ lengths: $TF = \exp(-t/\Lambda_A)$, $T = \exp[-t/(\Lambda_A +$