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The RICH with Aerogel for the LHCb Experiment

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We report on the status of the art of the aerogel project for LHCb, from the production, in terms of specifications and achieved quality, to the optical and beam tests performed to qualify the material as a Cherenkov radiator. A brief summary of the ageing and radiation tolerance tests performed on some aerogel tiles is also given.

1. Introduction

Silica aerogel is one of the three radiators chosen for the Ring Imaging Cherenkov system of the LHCb experiment, designed to provide a powerful particle identification tool. Aerogel, in the RICH detector [1], covers the momentum range $1-10$ GeV/c for π/K separation.

The material is a hygroscopic quality of silica aerogel produced by the Boreskov Institute for Catalysis in collaboration with the Budker Institute of Nuclear Physics in Novosibirsk. A big effort has been put during the last few years to obtain large size tiles with high transparency and good uniformity with respect to refractive index variations from point to point, to the level of 1% of $(n-1)$, with $n = 1.03$ at $\lambda = 543.5$ nm. At the end of this R&D period, large size silica aerogel tiles with unprecedented optical quality have been delivered to us for testing, making it realistic to achieve the requested resolution in the Cherenkov angle measurement.

2. Optical characterisation of aerogel

The structure of aerogel defines its optical properties. It essentially consists of a linked network of SiO_2 nanocrystals, with a size distribution peaked at 5–6 nm, separated by empty volumes whose size ranges from 1 to about 50 nm. Aerogel inherits the transparency of silica quartz, but it gets modulated by scattering effects, the dominant one being Rayleigh scattering, due to its extremely inhomogeneous structure. The scattering cross section for a photon of wavelength λ is proportional to λ^{-4}.

The absorption cross section is, within a wide range, wavelength independent and can be neglected when considering samples a few centimetres thick. The transmittance T of the aerogel can be parameterised by the Hunt formula [2]:

$$T(\lambda) = \frac{I}{I_0} = A\ e^{-C\cdot t/\lambda^4} \tag{1}$$

where I_0 and I are the incident and the transmitted intensities of the light beam through the sample. A is the surface scattering coefficient, t is the thickness of the aerogel block, and λ is the wavelength of the impinging light beam. C is the clarity factor and it is used to specify the optical quality of a sample together with A. The transmittance T of each tile is measured by means of a double beam spectrophotometer. A scan in the wavelength range between 200 nm and 800 nm is performed in steps of 1 nm, and the resulting curve is fitted to the Hunt formula to extract A and C. Typical values for our tiles are $C = 0.0050 - 0.0060\,\mu\text{m}^4/$ cm and $A \simeq 0.9$, but tiles with C as good as $C = (0.0045 \pm 0.0001)\,\mu\text{m}^4/\text{cm}$ have been delivered and tested.

The refractive index n of the aerogel was measured using green (λ=543.5 nm) and red (λ=632.8 nm) He-Ne laser sources. The measurements were performed using the prism method. Fig. 1 shows the block positioned in front of the laser beam on a rotating table. The sample is rotated until the deflection angle θ_{out} reaches its minimum. In that condition the index of refrac-

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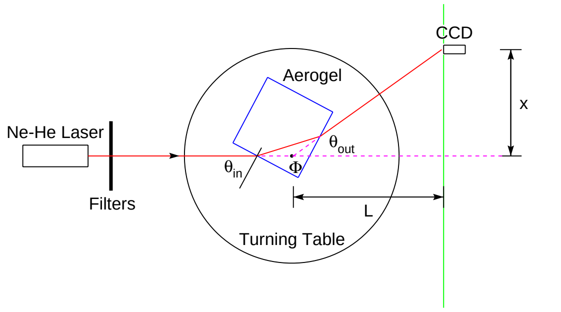

Figure 1. Experimental setup used for the measurement of the refractive index.

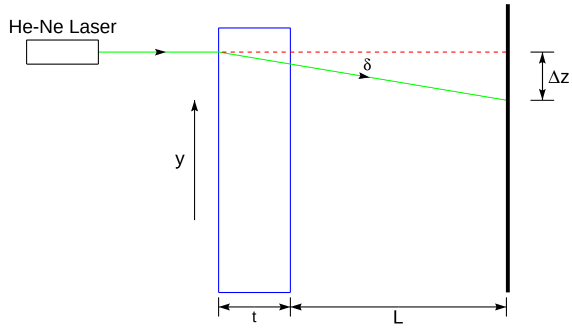

Figure 2. A sketch of the setup used to measure the refractive index uniformity with a laser beam normal to the aerogel surface.

tion is given by:

$$n = \sin\left(\frac{\Phi + \theta_{out}}{2}\right) \bigg/ \sin\left(\frac{\Phi}{2}\right) \qquad (2)$$

where Φ is the angle between the two adjacent sides of the block ($\Phi \simeq 90°$); θ_{out}, the deflection angle, is determined by measuring the displacement x with a CCD camera located at L=870 mm from the aerogel. The resolution we achieve is $\sigma(n) = 3 \cdot 10^{-4}$.

2.1. Refractive index uniformity

The relative spread of the refractive index for a given wavelength within each aerogel tile is measured (Fig. 2) by looking for deviations from the straight line of the optical path of a laser beam normal to the aerogel surface [3].

The deviation angle δ from the straight line is proportional to the gradient of the refractive index in the plane normal to the incident beam direction, according to:

$$\mathrm{d}n/\mathrm{d}y = n \cdot \delta/t \qquad (3)$$

where t stands for the aerogel thickness. Consequently, the variation of n along the y direction can be calculated from measurements of δ all over the surface following:

$$\Delta n(y) = \frac{n}{t}\int_{y_0}^{y} \delta(y)\mathrm{d}y. \qquad (4)$$

The resulting plot for one such measurement is shown in Fig. 3.

3. APACHE

We have built a setup to test the uniformity of the refractive index by means of a 500 MeV electron beam at the DaΦne Beam Test Facility [4,?] in Frascati. It consists of a dark room installed around a support for the aerogel tile to be tested facing a holding structure for a $8 \times 10''$ photographic film holder. We have called our apparatus, shown in Fig. 4, APACHE, for Aerogel Photographic Analysis by Cherenkov Emission.

The photons emitted by the electrons passing through the aerogel and the nitrogen are collected on the photographic film and the net result at the end of each run, once the film is developed, is a pair of concentric rings, the inner one from nitrogen and the outer one from aerogel. A simulation of the photon distribution on the film is shown in Fig. 5 for a tile with dimensions $100 \times 100 \times 41$ mm^3.

The image is then scanned and analysed. The analysis consists in finding the centre of gravity of the nitrogen ring, which coincide with the intersection point between the electron beam and the film. Starting from that point, the radial distribution of the light intensity deposited on the film is performed for progressively increasing ring radii. The radial distribution of light intensity is then fitted with a gaussian curve convoluted with the appropriate threshold response of the film to

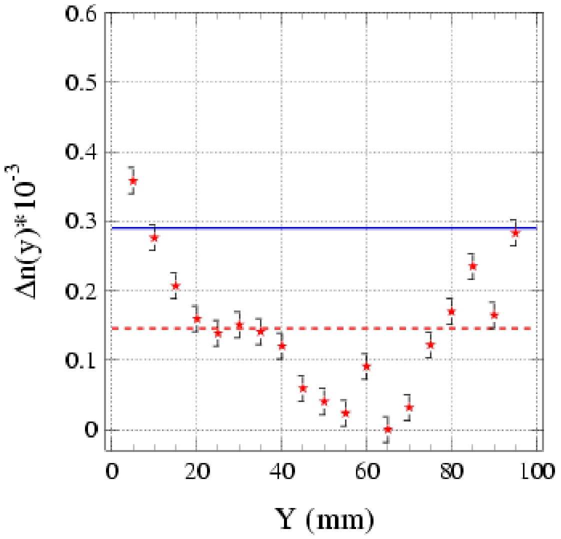

Figure 3. A sample plot for the refractive index uniformity scan for one tile. The solid line shows the requirement $\Delta(n-1)/(n-1) \leq 1\%$, the dotted line shows the mean value of $\Delta(n-1)$ for the measured tile.

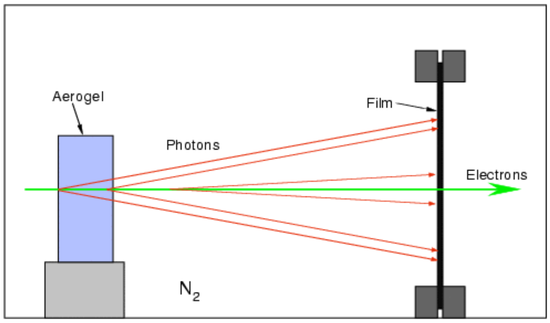

Figure 4. A sketch of the setup used to measure the refractive index uniformity with an electron beam and a photographic film.

multiple photon hits on the same grain. One sample plot resulting from such analysis is shown in Fig. 6.

Runs taken with the electron beam entering the aerogel in different points allow to check for relative point to point variations of the refractive index within a tile. The resolution needed for disentangling a $\Delta(n-1)/(n-1) = 1\%$ is 0.25 mm. With the simple setup just described we could achieve just about that precision, the biggest limitation being the thickness of the areogel. We tested the stability of our results by taking data in the same geometrical conditions, with and without an UV filter of the same grade of the one which will be installed in LHCb. The peak position is stable, but the distribution is significantly wider for runs without filter, since the UV photons have a much higher probability of being diffused by the Rayleigh scattering mechanism. To improve our measurement we have modified the existing setup introducing a tilted spherical mirror to focus the Cherenkov photons on the film eliminating the effects of the thickness of the aerogel. We will soon test the new configuration in the BTF beam line.

4. Particle identification

Several beam tests have been performed with aerogel and Hybrid PhotoDiodes (HPD) as photon detectors [6,7]. In those tests the particle identification potential of an aerogel based RICH detector has been demonstrated using a mixed pion/proton beam from the PS accelerator test beam line at CERN. Recently, the first beam test with the latest version of the Pixel HPD [8], which has been chosen as the photon detector for the RICH system of LHCb, have been successfully carried out. The photon yield has been found to be close to 10 photons per particle, in full agreement with the expectations. The analysis is being carried out as far the single photoelectron resolution is concerned.

5. Ageing tests

Ageing effects due to irradiation and absorption of humidity have been investigated [9]. Aerogel tiles have been exposed to γ radiation from a ^{60}Co source and to proton and neutron high intensity beams. The transmittance has been monitored in the wavelength range between 200 nm and 800 nm, determining the clarity factor C as a function of the increasing dose of irradiation. The index of refraction n was also measured be-

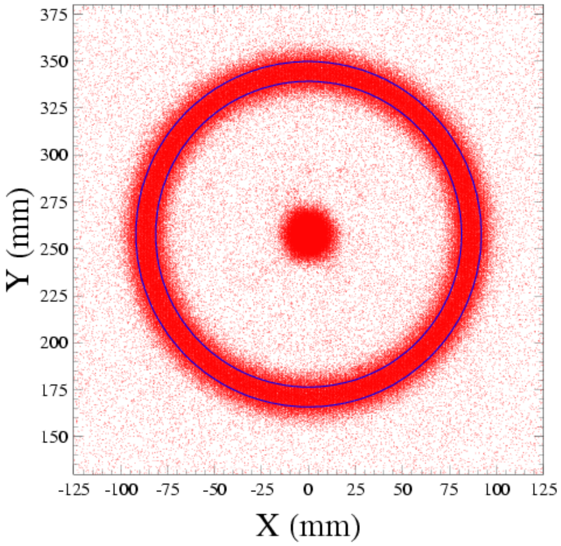

Figure 5. A GEANT4 simulation of the distribution of photon hits on a photographic film after an APACHE run. Superimposed to the photon hits, two circles show the edges of the distribution foreseen in the absence of scattering, the width being due to the aerogel thickness only.

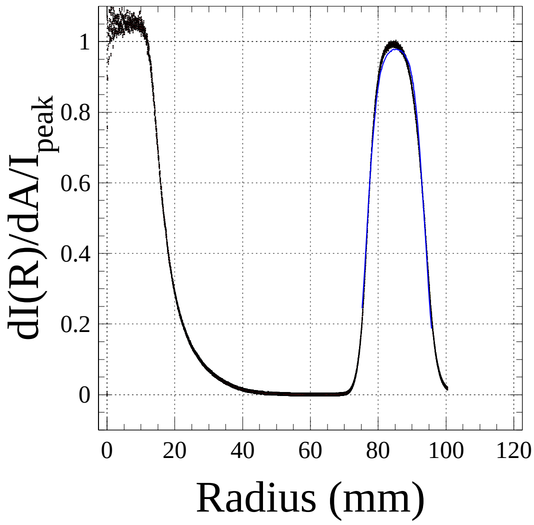

Figure 6. The plot shows the radial normalised intensity distribution of a film exposed in a run with a total fluence of about 10^{10} electrons. The fit to the expected shape with the refractive index n as the free parameter is superimposed on the peak.

fore and after the irradiation.

No significant degradation of the optical parameters were observed for doses equivalent to a few times the LHCb experiment lifetime in the case of γ and proton irradiation. We found indications of a worsening of the clarity due to neutron irradiation. However, for a fluence corresponding to the LHCb lifetime, the clarity factor C increase is about 5%, which is not a concern for the performance of the detector.

6. Conclusions

The aerogel project for the LHCb RICH detector is well on track. All the important parameters of the materials have been checked, and the final production, which fulfils the experiment requirement, has already started. We acknowledge the financial support by INTAS contract 679.

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