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Status of the LHCb silica aerogel Cherenkov radiator

D. L. Perego[a]

[a]On behalf of the LHCb RICH Group,
Università degli Studi di Milano–Bicocca and INFN,
Piazza della Scienza 3, I–20126 Milan, Italy
E-mail: Davide.Perego@mib.infn.it

A powerful particle identification capability is required for the LHCb physics programme. Two RICH detectors provide π/K separation between 1–100 GeV/c, using three radiators. Low–momentum particles, up to 10 GeV/c, are identified by Cherenkov light produced in silica aerogel. R&D results on the aerogel from test–beam and laboratory studies are presented.

1. Introduction

The LHCb physics programme will focus on high precision studies of CP violation and rare phenomena in B–meson decays. The design of the detector is based on the forward–backward distribution of $b\bar{b}$ pairs about the beam axis [1,2].

A powerful particle identification capability is required to distinguish particles for trigger and flavour tagging purposes and to select high purity final states relevant for CP violation studies. Two RICH detectors provide π/K separation between 1–100 GeV/c, using three radiators suitably chosen for different momentum ranges of interest. Slow particles up to 10 GeV/c are identified by Cherenkov light produced in silica aerogel, faster particles by two gaseous radiators [3].

Silica aerogel is a solid material made of SiO_2 with a very low density. Thanks to its transparency and its refractive index tunable within a wide range to match the physical requirements, silica aerogel is an appealing material for RICH detectors. It consists of a network of particles of $\simeq 5$ nm in diameter, and pores whose average radius is about 20 nm. The refractive index is tuned during production by calibrating the density. Depending on the manufacturing procedure, silica aerogel can be hygroscopic or hydrophobic.

Photon scattering within the aerogel block limits the performance of this material as a Cherenkov radiator. The dominant contribution is from the Rayleigh scattering mechanism with a cross section proportional to λ^{-4}, where λ is the wavelength of the photon. The transmittance $T(\lambda)$ is usually parameterized by:

$$T(\lambda) = A\ e^{-C\cdot t/\lambda^4} \qquad (1)$$

where t is the thickness of the aerogel and A is a constant for the material. The clarity factor C is used to specify the optical quality of the sample.

The RICH–1 detector is equipped with 50 mm thick hygroscopic aerogel. Its refractive index is around 1.03, with exceptionally good clarity, typically $C = 0.0050\ \mu m^4/cm$. The LHCb tiles have the largest transverse size ever produced.

2. Ageing effects and long–term stability

Due to its position inside the detector, the aerogel radiator will be exposed to a significant particle flux, up to 3.5×10^{12} particles/cm^2/year. Possible ageing of aerogel due to intense irradiation has been investigated [4].

Aerogel tiles have been exposed to very intense γ radiation from a ^{60}Co source and to proton and neutron high intensity beams. The transmittance has been monitored, studying the clarity factor C as a function of the increasing dose of irradiation. No detectable degradation of the optical parameters was observed for γ and proton doses equivalent to a few times the dose expected over the lifetime of the LHCb experiment. A small wors-

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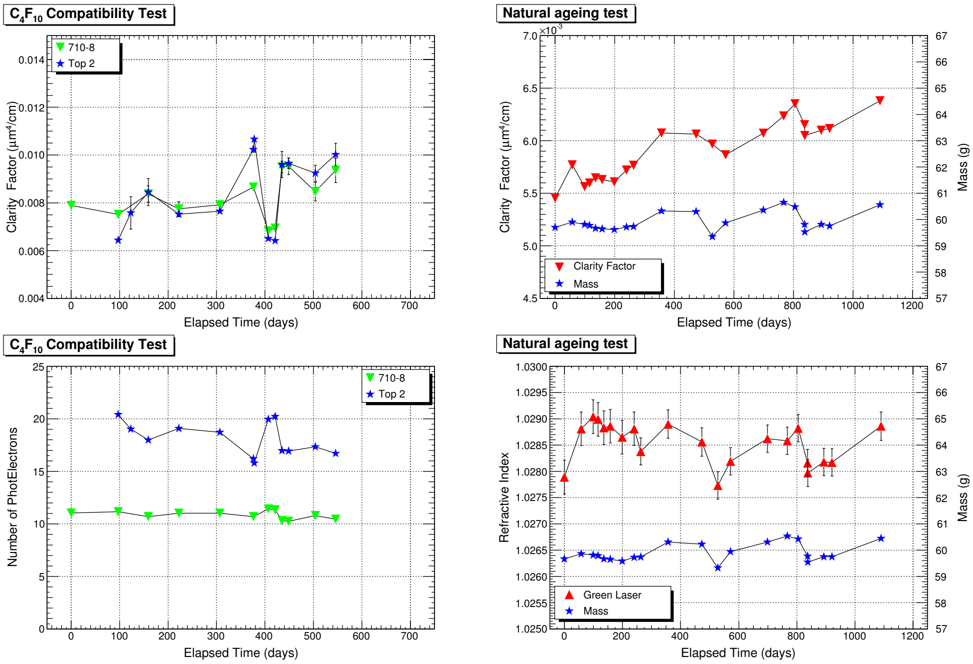

Figure 1. Clarity factor and photoelectron yield after exposure to C_4F_{10} gas for two hygroscopic aerogel tiles (*left*). In the computation of $\mathcal{N}_{pe}$, contributions from mirrors, quartz window and geometrical active area are not considered. Clarity factor and refractive index in the natural ageing tests (*right*).

ening of the clarity due to neutron irradiation has been observed. For a fluence corresponding to the LHCb lifetime, the clarity factor C increases by about 5%, which however is not a concern for the particle identification (PID) performance.

The behaviour of hygroscopic aerogel when exposed to humid air has been explored [4]. A modification of its optical properties is expected. The test revealed that a prolonged exposure to humid air changes the optical properties of the aerogel, but the clarity is completely restored by baking the exposed sample at high temperature. The assembly of the aerogel radiator inside the RICH–1 detector will be done with special care to prevent humidity absorption.

In RICH–1, the aerogel radiator will be in contact with the gaseous C_4F_{10} radiator. Generally, air fills the porous structure of this solid, and a replacement of air with C_4F_{10} is expected. Possible effects have been investigated. Aerogel tiles have been stored in a C_4F_{10}–filled box. The clarity factor is periodically monitored to evaluate possible effects due to the gas. The behaviour of C and the number of photoelectrons $\mathcal{N}_{pe}$ are shown in Fig. 1.

Referring to Fig. 1, after an initial rise, the degradation of the clarity slows down, but a second increase of C is then recorded. Following this rise, between day 378 and 407, the tile was kept in a N_2–filled box to check the possibility to reconstitute the aerogel to its initial status. The N_2 regeneration demonstrates that there is not a permanent degradation of the clarity. It can be seen in these studies that the maximum variation of C is $\simeq 66\%$, corresponding to a loss of the photoelectron yield around 23%.

Possible natural ageing effects can be studied by keeping a hygroscopic tile sealed from the at-

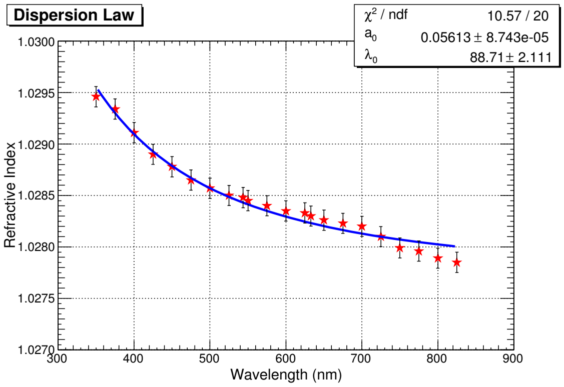

Figure 2. Measured and fitted chromatic dispersion of aerogel.

mosphere and periodically measuring its refractive index and clarity factor. Results are plotted in Fig. 1. After almost 3 years of monitoring, only a slight degradation has been observed; the visible steps in variation of n and C can be ascribed to uncontrolled absorption or rejection of humidity during measurements, as evidenced by a corresponding increase in the aerogel mass.

3. Refractive index uniformity

Local density inhomogeneities occurring during production lead to point–to–point variations of n and contribute to the Cherenkov angle θ_C uncertainty. In order for this contribution to the resolution on θ_C not to be dominant, the maximum allowed variation $\sigma(n-1)/(n-1)$ is 1%, corresponding to an uncertainty $\sigma(\theta_C) \simeq 1.17$ mrad for $n = 1.03$.

The homogeneity has been measured in the 500 MeV electron beam at the DAΦNE Beam Test Facility in Frascati [5]. Cherenkov photons were focused by a spherical mirror and collected by $8'' \times 10''$ photographic films. Runs taken with the electron beam entering the aerogel at different points of incidence allowed a check of the relative point–to–point variations of n inside a tile. The result of the first $200 \times 200 \times 50$ mm^3 tile produced is $\sigma(n-1)/(n-1) = 0.76\%$, well within specification.

4. Chromatic dispersion law

The wavelength dependence of the refractive index has been measured by means of a monochromator coupled to a Xe–UV lamp. The value of n at several wavelengths has been measured, and data were fitted to the one–pole Sellmeier formula [6]:

$$n^2 - 1 = a_0 \frac{\lambda^2}{\lambda^2 - \lambda_0^2} \tag{2}$$

In the wavelength range of interest, differences between one– and two– pole parameterizations of the chromatic law are negligible.

The measured and fitted chromatic dispersions are shown in Fig. 2. The position of the pole for the aerogel is $\lambda_0 = (88.7 \pm 2.0)$ nm, which is in good agreement with the one for pure fused silica, $\lambda_0 = (92.8 \pm 0.1)$ nm. The density calculated from the fitted a_0 parameter is 0.152 ± 0.0003 g/cm^3, compatible with the nominal value given by the manufacturer 0.149 ± 0.004 g/cm^3.

5. Conclusions

All the optical parameters of the LHCb aerogel have been verified. The production is complete and the tiles are now ready to be installed in the LHCb detector. We acknowledge the financial support by INTAS–5579 and by JRA9 of I3HP.

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