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Multilayer aerogel for compact RICH detectors

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This paper covers some of the latest achievements in the testing of multi–index silica aerogel. Optical bench measurements and preliminary results from a recently performed charged particle beam test are presented. This work is part of an effort aimed at assessing the potential of multilayer aerogel as a radiator for compact, proximity focused ring imaging Cherenkov detectors.

1. Multilayer aerogel

Silica aerogel has gained over the last few decades an ever increasing popularity as Cherenkov radiator. One of the most appealing properties of aerogel is the possibility to fine tune its refractive index over a rather wide range ($n = 1.008$–1.13) to match the physical requirements of the experiments. This makes it particularly suitable for experiments aiming at particle identification in the few GeV/c range, where gas and liquid Cherenkov radiators are ineffective. As a figure of merit for the required performance, for $n = 1.05$, the difference in Cherenkov angle for pions and kaons with a momentum of 4 GeV/c is 23 mrad, so a 4.6 mrad resolution per track is needed in order to separate the particle species by more than 5σ. Where space constraints are important, such as in the very forward region of experiments at current or future Flavour Factories, the best compromise between angular resolution and detector size is the proximity focused Ring Imaging Cherenkov (RICH) detector. Such devices schematically consist of a radiator, an expansion volume and a photon detection plane. The main factor limiting the resolution of a proximity focused detector is the uncertainty in the photon emission point, which is proportional to the radiator thickness. Therefore, the radiator is usually thin, and as a consequence the photon yield can be rather poor, with obvious drawbacks on the detector performance. If, however, instead of a single thicker tile, one uses a stack of tiles, one can tune the index of refraction of each layer to obtain an overall focusing effect, as shown in Fig.1 [1]. In such a configuration, the number of detected photons is increased without spoiling the single photon angular resolution, thereby offering a potential for a substantial improvement of the resolution per track.

Each aerogel–air boundary contributes to efficiency losses via scattering or reflection of Cherenkov photons. To overcome this, a development program towards monolithic multi–index aerogel is being carried out. The manufacturing of multilayer tiles is challenging, and diffusion across the layer boundaries during the super–critical drying could spoil the focusing properties. It is therefore of paramount importance to assess

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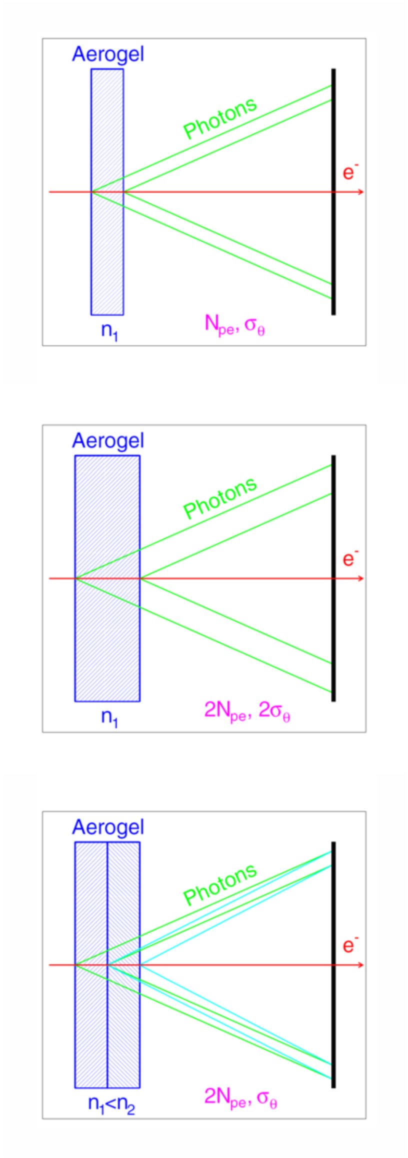

Figure 1. Comparison between a single aerogel tile with thickness t (*top*), a mono–index tile with thickness $2t$ (*centre*) and a two–index tile of total thickness $2t$ (*bottom*). With a multilayer block, the number of detected photons is enhanced without degrading the angular resolution.

the performance of multilayer monolithic aerogel. We have tested several such samples produced by the Boreskov Institute of Catalysis in Novosibirsk. We will concentrate on three aerogel configurations. The first one is a three–layer tile, hereby named MI3, with a design focal length of 200 mm. The second one is a smaller four–layer tile, hereby named NOVO4, with a focal length of 100 mm. This latter one has been produced together with four mono–layer tiles which are copies (same thickness, refractive index and overall focal length) of the layers composing NOVO4, and have been tested to verify the actual advantage of multilayer monolithic tiles.

2. Optical properties

Prior to the beam test, a detailed optical characterization of the three–layer tile MI3 has been performed. The transparency of silica aerogel is proportional to $A \cdot e^{-Ct/\lambda^4}$, where λ is the photon wavelength, t is the aerogel thickness and the clarity factor C is inversely proportional to the scattering length. The transmittance curve has been measured across the layer boundaries as well as in each layer independently by letting the spectrophotometer beam entering the aerogel from the front and side surfaces respectively. The clarity factors extracted from the transmittance measurements are very consistent, ranging from $C = 0.0055\ \mu\text{m}^4/\text{cm}$ (across the layers) to $C = 0.0061\ \mu\text{m}^4/\text{cm}$ along a single layer.

Right after the production an X–ray tomography has been performed on each sample, to measure its density profile. The average refractive index at $\lambda = 400$ nm is then estimated from its known functional dependence on the density. We also measure n directly with a green laser beam going through a corner of the tile and looking for the minimum deflection (prism method). The two methods yield similar values for n, once the laser results are scaled to $\lambda = 400$ nm) with a Sellmeier expansion in order to account for the chromatic dispersion. However, a systematically higher value is measured with the X–rays, which suggests that the aerogel density inhomogeneities become important close to the edge of the tile, where the prism measurement is performed. Ta-

Table 1
Optical parameters of the three–layer aerogel tile

thickness (mm)	n from X–rays	n measured (632 nm)	n scaled (400 nm)
12.6	1.046	1.045	1.046
13.2	1.041	1.038	1.039
15.2	1.037	1.033	1.034

Table 2
Refractive index uniformity of the three–layer tile

Layer	$\sigma(n-1)/(n-1)$
1	3.01%
2	0.84%
3	1.61%

ble 1 summarizes the results of both measurements.

The refractive index inhomogeneities have been measured directly. A laser beam was directed perpendicular to the aerogel surface in order to measure deviations from the straight optical path. The deviation angle is proportional to the refractive index gradient [2]. Table 2 lists the refractive index homogeneity for each layer. Even the maximum observed relative variation of 3.3% would still be acceptable.

3. Beam test

A prototype proximity focused Cherenkov detector was recently built and operated at the DAΦNE Beam Test Facility (INFN, Frascati) [3] in order to assess the performance of self focusing aerogel. The analysis of the photoelectron yield and the Cherenkov angle resolution is not complete yet, and all the results mentioned here are to be regarded as preliminary.

A photograph of the set–up is shown in Figure 2. A light tight anodized aluminium vessel provides the housing for the aerogel and the photon detectors. The aerogel support is mounted on a rail running along the beam axis. The distance between the aerogel and the photon detector is varied until the optimal position, defined by the smallest width of the Cherenkov rings, is found. The volume is flushed with dry nitrogen to avoid as much as possible a variation of the optical properties of the aerogel due to water absorption. The beam has a repetition rate of 50 Hz, and comes in 1 ns long bunches. Each bunch contains a few mono–energetic 500 MeV electrons which produce, upon traversing the aerogel, saturated Cherenkov cones. The beam multiplicity is distributed as a poissonian whose mean value is tunable down to 1 e^-/bunch to have the highest purity of single tracks. Cherenkov photons are detected by an array of eight Hamamatsu H9500 flat panel MAPMTs[1]. These photon detectors have 16×16 channels, each pixel is 2.8×2.8 mm^2 in size with a pitch of 3.04 mm; they have been chosen because of their excellent packing factor and their good quantum efficiency in the $300-500$ nm wavelength interval. The high voltage has been tuned for each photon detector to have all single photoelectron peaks in the same ADC channel, and it ranges from 800 to 950 V. The readout electronics consists of PCOS IV digital modules (from the HERMES RICH experiment [4]) adapted via interface boards to the photon detector layout. The output from the PCOS IV front–end boards is a 1–bit binary information without photon multiplicity information. The threshold used during most of the test was set at roughly 0.3 the distance between the pedestal and the single photoelectron peak.

The RICH is used as an essentially stand–alone detector, with very limited information on track direction and bunch multiplicity coming from four silicon strip planes placed in front of the vessel. The Cherenkov angle resolution analysis has been done on an event–by–event basis clustering the hits on the photon detector plane and fitting a ring using the centroids of the clusters. A cut on the reduced χ^2 is applied to exclude events with two or more well separated electrons. A cut on the tracking station cluster size helps rejecting events with two or more close electrons which

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[1] Unfortunately one out of eight photon detectors turned out to be broken.

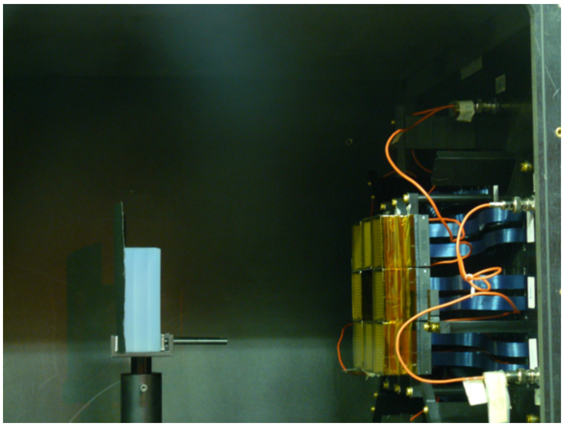

Figure 2. Photograph of the set–up used during the multilayer test beam.

Table 3
Cherenkov ring radius distribution and angular resolution for various focusing configurations. The four tile stack and the four–layer tile have the same design focal length.

Radiator	R (mm)	θ_C (mrad)
three–layer (MI3)	67.4 ± 1.1	273.9 ± 4.3
four tile stack	64.8 ± 1.3	306.0 ± 6.2
four–layer (NOVO4)	61.6 ± 1.1	291.7 ± 5.7

would give two overlapping rings.

Figure 3 shows the hits accumulated in a run with 40k triggers and the distribution of the fitted ring radii. Results are listed in Table 3. The error quoted is the gaussian standard deviation of the fitted distribution of the relevant variable. The breakdown of the systematic contributions is in progress. The three–layer tile MI3, even with the limitations due to the lack of tracking information, has a resolution per track comparable with the expected one. The comparison between the stack of four tiles and the single four–layer tile, hints that there is some improvement in the Cherenkov angle resolution using a monolithic tile.

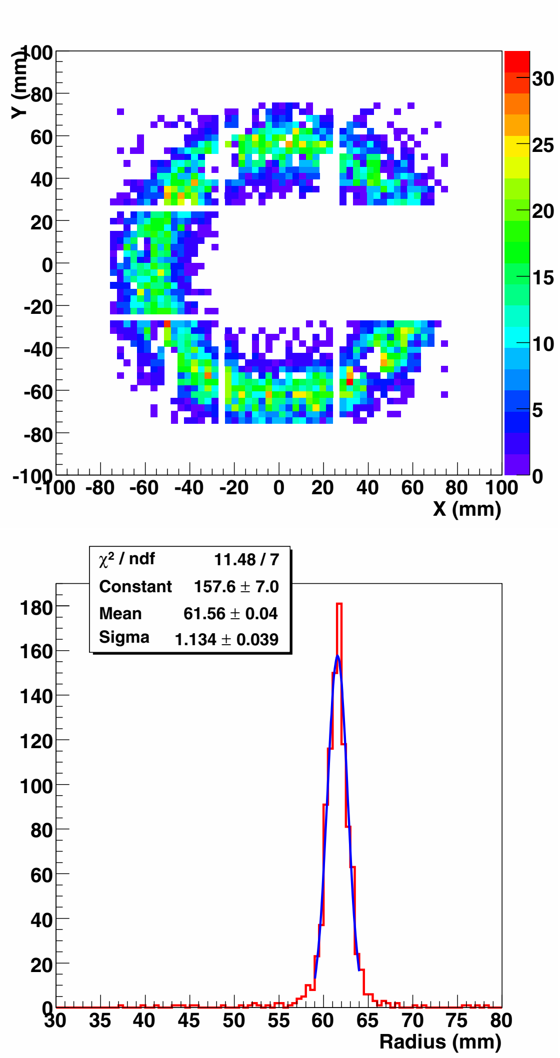

Figure 3. Accumulated Cherenkov photons from the NOVO4 sample (*top*) and reconstructed ring radii for the same run (*bottom*).

The photoelectron yield for each aerogel sample has been measured by fitting a Poisson distribution to the number of clusters per event, with the same cuts on data as for the resolution analysis. The results are in coarse agreement with expectations from simulation studies. An important contribution to the uncertainty in the photon yield comes from the photon detectors efficiency and cross–talk figures, which are being characterized in dedicated tests.

4. Conclusions

Samples of high quality multilayer aerogel have been produced and fully characterized. Preliminary results from a beam test show that the Cherenkov photon yield and angular resolution meet expectations. Also, data indicate that monolithic multilayer aerogel offers a better performance with respect to a stack of tiles with the same overall focusing characteristics.

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