Test of aerogel as Cherenkov radiator

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Abstract

Two different stacks of aerogel were tested on a pion/proton beam of momentum between 3 and 10 GeV/c. The optical characteristics of the tested aerogel samples were different: in particular one sample was hygroscopic while the other was hydrophobic. Two HPD tubes were used as photodetectors, and different thickness of the stacks were tried, in order to determine the photoelectron yield, the Cherenkov angle and its resolution. \( \pi/p \) separation has been proved up to momenta of 10 GeV/c.
1 Introduction

First test with aerogel used as Cherenkov radiator for RICH detectors was demonstrated to be successful few years ago [1]. Since then, even better quality of aerogel has been produced ([2], [3],) and one experiment has built RICH detectors with aerogel, HERMES [4], and others plan to build one like LHC-b [6] and AMS [5]. In this note, results are presented from a test made on a CERN-PS beam, with different qualities of aerogel with index of refraction $n \simeq 1.03$, in view of its application in the LHC-b experiment.

2 Experimental setup

2.1 Aerogel

The optical properties of the aerogel samples have been tested previously [7], by measuring the light transmission as a function of wavelength and of the aerogel thickness.

Both the $55 \times 55 \times 10 \ mm^3$ tiles, cut from the original $110 \times 110 \times 10 \ mm^3$ produced by Matsushita, with a clarity coefficient $C=0.0096 \ \mu m^4/cm$ and the $100 \times 100 \times 20 \ mm^3$ tiles produced in Novosibirsk with a clarity $C=0.0056 \ \mu m^4/cm$ were exposed to the beam. The transmittance curve for samples of 2 cm thickness is shown in Fig. 1.

![Transmittance Curve](Fig1.png)

Figure 1: The transmittance as a function of wavelength for two samples 2 cm thick, one of hygroscopic type produced in Novosibirsk (solid line), and one of hydrophobic type (dotted line) produced by Matsushita.
The nominal index of refraction was 1.030 and 1.034 respectively. The index of refraction was also determined from the data taken in the beam and remeasured in the laboratory.

### 2.2 PhotoDetectors

The readout of the Cherenkov photons produced inside the aerogel is performed by 2 pad HPDs positioned in the focal plane of the mirror, providing a geometrical coverage of about 1/5 of the total ring.

The pad HPD is a fast, large area, highly sensitive Hybrid Photodiode with pixelized readout.

The development of HPDs constitutes a major advance for the RICH technique because of their

- high granularity, i.e. very large number of pixels (2048), combined with a high spatial resolution;
- sensitivity to visible light, which simplifies the detector construction and results in better performances (merit factor $N_0$, chromatic aberrations) compared to UV gas detectors;
- excellent energy resolution compared to photomultiplier tubes;
- high rate capability.

The Pad HPD provides high sensitivity (visible and near UV range) single photon detection, with a granularity of about $2.5 \times 2.5$ mm$^2$.

The Pad HPD is a round photodetector of 127 mm (5 inch) diameter with a 114 mm diameter active area visible-light transparent bialkali photocathode. The spherical entrance window of the HPD is made of an UV extended borosilicate glass ($T = 50\%$ at $\lambda = 250$ nm). The window and the tube body are joined by a Kovar skirt in order to adapt to the slightly different thermal expansion coefficients of the glass types. A set of 4 stainless steel ring electrodes defines a fountain shape electrostatic configuration, which de-magnifies the photocathode image by a factor $\approx 2.5$ onto a silicon sensor of 50 mm diameter. The sensor comprises 2048 pads of size $1 \times 1$ mm$^2$ and is read out by multiplexed analogue electronics enclosed in the vacuum envelope. Both the sensor and the electronic chips are mounted on a ceramic carrier, which is wire bonded to the 40 vacuum feedthroughs of the stainless steel base plate.

The electrostatic configuration of the Pad HPD is defined in the following way: the electric field between the photocathode ($U_C = -20$ kV) and the silicon sensor plane ($U = 0$ V) is shaped by 4 concentric ring electrodes such that the photocathode image is linearly de-magnified onto the silicon sensor. The second electrode controls the demagnification, and the first electrode (the so-called bleeder electrode) corrects non-linearities and cross-focusing effects at the edge of the cathode.

The measurements presented in this paper have been obtained with the Viking VA3 electronics [8]. The VLSI chip comprises, for each of its 128 channels, a front-end charge amplifier, a shaper, and a sample-and-hold unit, which determines the maximum amplitude of the shaped signal. The power consumption is $\approx 300 \mu W$/channel. The VA3 has a shaping time of 1.3 $\mu$ s and is clearly too slow to be used at LHC.
The quantum efficiency of the K$_2$CsSb photocathode is measured online during the photocathode evaporation. Light from a tungsten halogen lamp is focused through a viewport in the vacuum tank onto the HPD entrance window. A set of interference filters (combined with appropriate broad band pass filters) provides a selection of wavelengths between 308 nm (4 eV) and 651 nm (1.9 eV). The intensity of each individual wavelength is determined by means of a calibrated photodiode. The light is chopped by an electronic shutter so that any background can be subtracted. The quantum efficiency is then measured in DC current mode by applying a voltage of typically 100 V between the photocathode and the focusing ring electrodes. Fig. 2 shows the quantum efficiency of one of the two HPDs used in the test.

It reaches a maximum of about 20% around 350 nm. All recently produced cathodes had peak quantum efficiencies between 15% and 20%. The further optimisation of the quantum efficiency is the subject of current studies. The light spot, which has a size of about 2 cm$^2$ can be scanned over the window surface. The uniformity of the efficiency is typically better than ±10%, and part of this may be due to a non-uniform and incomplete collection efficiency of the field configuration.

2.3 Beam

In the East Hall experimental area at CERN, a primary proton beam of 24 GeV/c is extracted from the PS synchrotron by means of a resonant extraction process. For each PS supercycle (14.4 s) the beam comes in 2 spills of 300 ms, providing $2 \times 10^{11}$ particles on the 2 downstream targets.

The secondary beams can be selected in momentum and polarity. For the test described in this note, the T7 secondary beamline was used, providing up to $10^6$ secondaries per spill, with a maximum momentum of 10 GeV/c and 1% momentum bite.

The negative polarity gives a pure $\pi^-$ beam, while the positive polarity yields a mixture of $\pi^+$ and $p$, the proton yield increasing from 50% at 6 GeV/c up to 70% at 10 GeV/c.

During the test, the beam was defocussed to reduce the pileup probability and the last dipole magnets were steered in order to have the beam centered on the silicon planes used to define the position and direction of the incoming particle impinging on the aerogel radiator.

2.4 Setup

The full setup is shown in Fig. 3 and consists in an aluminum vessel with a diameter of 50 cm and a length of 108 cm. Nitrogen was flushed through the vessel to protect hygroscopic aerogel from humidity. A mirror of radius of curvature R=119.25 cm was mounted at a distance of 60 cm from the end plate inside the vessel in such a way that the two photocathodes of the HPD’s mounted on this plane coincided with the focal plane. The distance between the two centers of the HPD photocathodes was 29.3 cm.

Charged particles having $\beta \simeq 1$ produce Cherenkov photons at an angle of 242 mrad with respect to the particle direction in the aerogel with refractive index n=1.030. During the test the HPD’s were operated between 14 and 15 KV.

The quantum efficiency of a photocathode is shown in fig. 2. From fig. 1, one can see that the match between the two quantities is quite bad. This will affect the final
Figure 2: The quantum efficiency of the photocathode of HPD2 as a function of the photon energy.
Figure 3: The experimental setup used for the test in T7.
photoelectrons yields obtained in the test.

The level of noise measured in the two HPD was extremely low, at the level of 1-2 per mille.

In order to determine the direction and position of the incoming particles, two silicon planes were located upstream the vessel, allowing for a spatial resolution of about 1 mm.

### 2.5 On-line Monitoring

For the online monitoring of the HPD data and the beam-telescope, a monitoring program has been developed. It reads the event data and fills histograms. A scripting language is used to provide a flexible graphic display of the event data.

The data is displayed by a graphical user interface written in Tk/Tcl, a scripting language [10]. This display shows in a flexible way event data and gives access to histograms. The detector is shown as a plan of the pads arranged in sectors. It is possible to inspect the relevant information of each pad by positioning the cursor on top of the pad. A suitable color code has been chosen to indicate the hit and the charge distribution for the pads and individual pads can be masked. The display can be rotated to allow for the different angular orientations of the device in the beam.

In addition histograms can be filled, and analyzed in the usual way, allowing rapid answers to technical questions during data-taking. In addition first results for the analysis can be provided online.

### 2.6 Simulation

A simple MonteCarlo was made to describe the experimental setup geometry.

The Cherenkov photons in the aerogel were allowed to be scattered in tiles of the correct length with transverse dimensions considered to be infinite.

### 2.7 Data samples

Several running conditions were tried: the thickness of the aerogel was varied between 2 and 6 cm, and in some runs a mylar filter (300 µm thick) was added at the exit of the stack, in order to absorb photons above 3 eV which are the most affected by the Rayleigh scattering, and degrade the resolution.

Data were taken with $\pi^-$ beam of 9 GeV/c, and with positive beams containing $\pi$’s and $p$’s of momenta ranging between 6 and 10 GeV/c.

### 3 Signal definition

The ADC charge spectra summed over one sector of pads (128 pads) are shown in figure 4 for data taken with 6 cm of aerogel compared with data taken without aerogel along the beam, which should give a good representation of noise. Two different sectors are shown: the first one (sector # 12) contained part of the ring, while the second (sector # 2) had only few pads hit by Cherenkov photons.

At the acquisition level, a cut at $4\sigma$ above the pedestal was applied, which correspond to about 8 ADC counts.
Figure 4: The ADC charge spectra summed over one sector of pads. Points: data taken with 6 cm of aerogel; histogram: data taken without aerogel. Upper plot: sector # 12, containing part of the ring; lower plot: sector # 2, having only few pads hit by Cherenkov photons.
In order to study the noise of the detector, data without aerogel were taken, in four runs, distributed along the whole data taking period, the first three with HPD 1 operated at 15 KV, the last one with HPD 1 and HPD 2, both operated at 14 KV. In these runs, the average number of counts per event on a single pad was 1 per mille, and 0.5 per mille in the region ADC > 15. Few scattered pads had hits in more than 1 per cent of the events. These pads were classified as noisy and masked in the analysis of all the aerogel runs. The masked pads are 50 in HPD 1 and 142 in HPD 2, also one full sector of HPD 1 was found noisy and masked.

The position of the signal peak was found to be around 21 ADC counts, with a global pad to pad variation of about 4 %, which reflects a variation inside the same sector of about 2.5 % and a maximum variation between different sectors of 10 %. To select the region with the Cherenkov signal, a fixed cut at charge > 15 ADC counts was applied.

In the case of photoelectron counting the amount of signal lost below this cut was calculated and corrected for (see section 4.1).

The number of counts per event, recorded in runs without aerogel was used in the following analysis to subtract, individually for each pad, the noise in Cherenkov data.

The three runs without aerogel, taken with HPD 1 at 15 KV, showed a variation of a factor about two in the number of counts per event, as shown in figure 5. This instability could be ascribed either to the electronics or to imperfect shielding from the external light.

![Figure 5: Number of hits per event (charge > 15 ADC counts) in HPD 1 as a function of the radial coordinate in four runs taken without aerogel.](image)

In order to reconstruct the Cherenkov angle, the position of the two HPDs on the end plate of the vessel was adjusted by software. The distance between the centers of the two HPDs was considered fixed to the nominal value of 293 mm, while the independent rotation of the two HPDs was determined by minimizing the spread in the ring reconstruction.
For this purpose the following expression defining a ring was used:

\[ \sum_i [(x_i - x_0)^2 + (y_i - y_0)^2 - R^2]^2 \]

where \( x_0, y_0 \) are the coordinates of the center of the ring, \( R \) is the radius and the sum is over all hits, after noise subtraction. The minimum of this expression can be found analytically, as described in [11], obtaining the radius and its error. The error on the radius was calculated as a function of the two HPDs angles and the minimum values were determined corresponding to 4.5 and 12.5 degrees for HPD1 and HPD2, respectively. The center of the ring results displaced of about (-2.5,-2.) mm with respect to the nominal center of the end plate of the vessel.

**Alternative Method**

An alternative method, referred hereby as method 2, was used to define the signal, and it is described in the following. The signal region was defined as a 4 cm wide band centered on the expected Cherenkov ring; the remaining of the HPD surface was then considered as the background region.

The region of the single photoelectron peak (which is centered at about 21 ADC counts), was defined as the range of ADC counting between 15 and 30 in each pad.

For each run, the noisy pads were excluded from the analysis; a pad was considered noisy if it happened to produce ADC counting higher than 50 in an event. The ADC distributions in both the signal and background regions were fitted with gaussians defined by the shape of the right part of the spectrum (that is, high number of ADC counts), as illustrated in fig. 6.

![Figure 6](image)

Figure 6: An example of gaussian fit to the single photoelectron peak used to determine the signal in method 2. The data shown are from a run with 2 cm of aerogel. a) is for the region on the ring, and b) for the region of “background”.

The area under the gaussian was then taken as the total numer of detected photoelectrons. An offset, extrapolated from the test runs without aerogel, was then subtracted as background. (see fig. 7). In fig. 8 a run with 6 cm of aerogel, but represented on the same scale, is shown for comparison.
4 Results

4.1 Photoelectron Counting

In order to estimate the photoelectrons yield, two different analyses have been performed on the test beam data. The two methods differ in the way the signal of the single photoelectron is defined in the pad-HPD. The center of the ring, as determined in section 4.2, was used to convert from cartesian to radial coordinates.

In figures 9 and 10 the number of hits per event are shown as a function of the radial coordinate are for runs with 6 cm aerogel compared with runs without aerogel. The cut at charge $> 15$ ADC counts has been applied. In order to subtract the noise and evaluate the number of hits due to photons, the counts per event recorded in runs without aerogel were subtracted individually for each pad.

As is visible in figure 11 the HPD efficiency in the crown close to the border was reduced.

In figure 12, where the number of hits as a function of the azimuthal coordinate is shown, the ring covers about 40 degrees only, w.r.t. about 42 degrees expected from the HPD dimensions. The holes visible at $\phi \simeq 0$ are related in HPD 1 to one dead pixel sector and in HPD 2 to 2 mm space between the Silicon half moons. In order to define a region of good acceptance, only pads in the azimuthal regions $-18^\circ < \phi < +21^\circ$ (HPD 1) and $-19^\circ < \phi < +19^\circ$ (HPD 2) were used. The corresponding correction factor to obtain the number of photons in the full ring is $360/39 = 9.23$ and $360/38 = 9.47$ for HPD 1 and HPD 2, respectively. A further correction of 4.2 % (HPD 1) and 5.3 % (HPD 2) was applied for losses inside that region due to masked or inefficient pads.

A fit to the charge spectra of the signal using an exponential to represent the tail of the pedestal and a gaussian function for the signal, shows that less than 1% of the gaussian signal is lost below the 15 ADC cut, therefore no correction was applied for this cut. From previous measurements (ref ??) it is known that, due to backscattering, about 18 % of the signal gets uniformly distributed in energy rather than concentrating in the signal peak. About 50 % of it is therefore falling below the cut, consequently a correction factor of 1.09 is applied.

The number of measured photoelectrons has been obtained in the region around the Cherenkov ring, defined as $(R - 3\sigma_R) < r < (R + 3\sigma_R)$ where $R$ and $\sigma_R$ are the values obtained from the ring reconstruction in sectio 4.2. Tables 1, 2 and 3 show the results for the two different qualities of aerogel. The first error quoted is statistical, the second is systematic.

The noise subtraction has been considered as a source of systematic uncertainty in the number of measured photoelectrons. As mentioned in section 3, different runs without aerogel were found to have a large variation in number of hits per event. For HPD 1 operated at HV = 15 KV the results of the three available runs without aerogel were averaged, and the spread assumed as systematic uncertainty due to noise subtraction. The same percentage error was assumed at HV = 14 KV, were only one run was taken without aerogel. Additional systematic uncertainties have been assumed on the correction factor used to extrapolate to full ring:

- 5% due to the acceptance correction ( $\pm 1$ degrees on the definition of the azimuthal angle ) ;
Figure 7: ADC counts in a run taken without aerogel. The ordinate gives the number of hits per event.
Figure 8: ADC counts in a run taken with 6 cm of aerogel. The ordinate gives the number of hits per event. Top figure shows the signal from photons on the ring, the bottom one shows the signal from photons not conserving the Cerenkov direction and being detected in the rest of the HPD area.
Figure 9: Number of hits per event as a function of the radial coordinate. Points: data taken with beam momentum -9 GeV/c, 6 cm of Novosibirsk aerogel. Histogram: data taken without aerogel.
Figure 10: Number of hits per event as a function of the radial coordinate. Points: data taken with beam momentum $-9$ GeV/c, 6 cm of Matsushita aerogel. Histogram: data taken without aerogel.

Figure 11: The 2048 pads in each HPD are shown with the signal in a run with $\pi$ and protons and 6 cm of Novosibirsk aerogel.
• 2% for the signal losses (signal below cut and backscattering correction);
• 3% for masked or inefficient pads.

In the region outside the ring (\( r < (R - 3\sigma_R) \) or \( r > (R + 3\sigma_R) \)) where photons that have undergone Rayleigh scattering are expected, the measured signal is small, and the number of hits in runs with and without aerogel are comparable. The uncertainty in the noise subtraction is dominant and makes it unfeasible to evaluate the number of produced photoelectrons with this method.

### Table 1: Number of photoelectrons produced in Matsushita aerogel, measured in HPD 1 in the ring region. The first error is statistical, the second is systematic.

<table>
<thead>
<tr>
<th>aerogel thickness</th>
<th>( N_{\text{phot}} ) measured in HPD 1</th>
<th>( N_{\text{phot}} ) extrapolated to full ring</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 cm</td>
<td>0.63 ±0.01±0.09</td>
<td>6.6 ±0.1±1.1</td>
</tr>
<tr>
<td>5 cm</td>
<td>0.60 ±0.01±0.09</td>
<td>6.3 ±0.1±1.1</td>
</tr>
<tr>
<td>6 cm</td>
<td>0.62 ±0.01±0.09</td>
<td>6.5 ±0.1±1.1</td>
</tr>
<tr>
<td>6 cm + Mylar</td>
<td>0.44 ±0.01±0.09</td>
<td>4.6 ±0.1±1.0</td>
</tr>
</tbody>
</table>

-Table 1-

### Table 2: Number of photoelectrons produced in Novosibirsk aerogel, measured in the ring region in HPD 1 operated at HV = 14 KV and HV = 15 KV. The first error is statistical, the second is systematic.

<table>
<thead>
<tr>
<th>aerogel thickness</th>
<th>( N_{\text{phot}} ) measured in HPD 2 (14 KV)</th>
<th>( N_{\text{phot}} ) extrapolated to full ring</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 cm</td>
<td>0.66 ±0.01±0.05</td>
<td>6.9 ±0.1±0.7</td>
</tr>
<tr>
<td>4 cm</td>
<td>0.94 ±0.01±0.05</td>
<td>9.9 ±0.1±0.8</td>
</tr>
<tr>
<td>6 cm</td>
<td>1.10 ±0.01±0.05</td>
<td>11.6 ±0.1±0.9</td>
</tr>
<tr>
<td>6 cm + Mylar</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>6 cm</td>
<td>0.90 ±0.01±0.06</td>
<td>9.4 ±0.1±0.9</td>
</tr>
</tbody>
</table>

-Table 2-

### Table 3: Number of photoelectrons produced in Novosibirsk aerogel, measured in the ring region in HPD 2 operated at HV = 14 KV. The first error is statistical, the second is systematic.

<table>
<thead>
<tr>
<th>aerogel thickness</th>
<th>( N_{\text{phot}} ) measured in HPD 2 (14 KV)</th>
<th>( N_{\text{phot}} ) extrapolated to full ring</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 cm</td>
<td>0.84 ±0.01±0.04</td>
<td>9.2 ±0.1±0.7</td>
</tr>
<tr>
<td>4 cm</td>
<td>1.16 ±0.01±0.04</td>
<td>12.7 ±0.1±0.9</td>
</tr>
<tr>
<td>6 cm</td>
<td>1.33 ±0.01±0.04</td>
<td>14.5 ±0.2±1.0</td>
</tr>
</tbody>
</table>

-Table 3-

-Alternative Method
Another measurement of photoelectron yield consists in splitting the surface of the HPD into two regions, the signal region and the background region, and counting the photoelectrons detected in each of them, according to the signal definition of method 2. The number of produced photoelectrons was then extrapolated taking into account the fraction of the Cherenkov ring which was lying on the HPD surface and the corrections made for the noisy pads.

The results for both methods are shown in Fig. 13. The measured photon yields compares quite well with the expected one.

4.2 Ring reconstruction

The Cherenkov ring was reconstructed on the sum of all events in each run fitting the bidimensional distribution of hits (ADC charge above 15), after noise subtraction. The following \( \chi^2 \) was minimized:

\[
\chi^2 = \sum_i [f(x, y)_i - N_i]^2 / f(x, y)_i
\]

where the index \( i \) runs over all the non-empty pads of the HPDs, in the geometrical acceptance defined as in section 4.1), and \( N_i \) is the number of hits in that pad, after noise subtraction. The expectation was taken as the sum of a flat function and one or two rings with gaussian spread:

\[
f(x, y)_i = A_j + B_j \exp\left(-\frac{(r - R)^2}{2\sigma^2}\right) + C_j \exp\left(-\frac{(r - R')^2}{2\sigma'^2}\right)
\]

with:

\[
r = \sqrt{(x_i - x_0)^2 + (y_i - y_0)^2}
\]

where \( x_i \) and \( y_i \) are the coordinate of the pads and the free parameters are: \( A_j, B_j \) and \( C_j \), representing the background and the signal level in HPD 1 (\( j = 1 \)) and HPD 2 (\( j = 2 \)), respectively; \( \sigma \) and \( \sigma' \) representing the spread of each ring; \( x_0, y_0 \) representing the coordinates of the common center of the two rings, \( R \) and \( R' \) representing the radii of the two rings. In runs with positive beam the two rings are produced by the pion and the proton component of the beam, while in runs with negative beam, where only pions were present, \( C_j \) was set to zero. In the other cases the constraint: \( C_2/B_2 = C_1/B_1 \) was assumed. As a consequence 11 (8) parameters were fitted in the two (one) rings case. Figure 14 shows the hits distribution in the photodetector plane and superimposed the two rings, for a +8 GeV/c run. Figures 15 and 16 show the projections of the rings in the radial coordinate, for two runs with beam at +8 GeV/c and +10 GeV/c, respectively. Table 4 shows the results for \( R \) and \( \sigma_R \) at different beam momenta. The statistical error on both \( R \) and \( \sigma_R \) is \( \pm 0.1 \) mm.

The largest contribution to the resolution is from the acromaticity of the emitted photons, enhanced by the Rayleigh scattering which affects the short wavelength more. In fig 17 and 18 the effect on the resolution made by a mylar layer at the end of the stack is shown. Also visible in the figures is the decrease in photon yield due to the mylar.

4.3 Cherenkov angle reconstruction

The Cherenkov angle was reconstructed event by event using a retracking procedure [12].
<table>
<thead>
<tr>
<th>beam energy</th>
<th>( R_\pi ) (mm)</th>
<th>( \sigma_{R_\pi} ) (mm)</th>
<th>( R_p ) (mm)</th>
<th>( \sigma_{R_p} ) (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>-9 GeV/c</td>
<td>153.6</td>
<td>3.6</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>+6 GeV/c</td>
<td>157.8</td>
<td>2.8</td>
<td>127.5</td>
<td>3.2</td>
</tr>
<tr>
<td>+8 GeV/c</td>
<td>157.9</td>
<td>3.0</td>
<td>142.2</td>
<td>3.0</td>
</tr>
<tr>
<td>+9 GeV/c</td>
<td>157.4</td>
<td>3.3</td>
<td>145.4</td>
<td>2.7</td>
</tr>
<tr>
<td>+10 GeV/c</td>
<td>156.9</td>
<td>3.3</td>
<td>147.4</td>
<td>2.3</td>
</tr>
</tbody>
</table>

Table 4: Radius and spread measured on the distribution of hits. 6 cm Matsushita (first line) and 6 cm Novosibirsk aerogel (lines 2 to 6).

The two HPDs were assumed to be in the focal plane of the 1192.5 mm radius of curvature spherical mirror. An inclination of the beam of 2.1 mrad with respect to the horizontal plane was assumed, as this was indicated by the beam telescope data (?). The Cherenkov angle has been corrected for the effect of refraction at the exit of the aerogel, assuming that the outer surface of the aerogel tiles was parallel to the detectors plane. Figures 19 and 20 shows the Cherenkov angle obtained with a -9 GeV/c beam with 6 cm of Novosibirsk aerogel and 3 cm of Matsushita aerogel, respectively. Figure 21 shows the Cherenkov angles produced by the proton and pion components of a +8 GeV/c beam. A fit with two gaussians and a constant factor gives for the mean Cherenkov angles 0.230 and 0.256 radians, respectively. In these cases no noise subtraction is performed.

Further studies are under way to understand the main contributions to the present resolution of 5 mrad.

The refraction indices of the aerogel can be calculated from the measured values of the Cherenkov angle, and gave the values: \( n_{\text{Novosibirsk}} = 1.0337 \) and \( n_{\text{Matsushita}} = 1.0316 \). The refraction indices of the aerogel tiles measured in laboratory, after the run, with the prism method, using a diode laser at \( \lambda = 635 \text{nm} \), are: \( n_{\text{Novosibirsk}} = 1.0336 \pm 0.0006 \) and \( n_{\text{Matsushita}} = 1.0297 \pm 0.0006 \).

5 Conclusion

Aerogel has been proven to be a good radiator to identify particles from a beam of momentum in the range 6-10 GeV/c. The separation between pions and protons has been shown to be possible, in the test beam conditions, up to 10 GeV/c.

5.1 Acknowledgments

We would like to thank A.R.Buzykaev, E.A.Kravchenko, A.P.Onuchin from the Budker Institute of Nuclear Physics, Novosibirsk and A.F.Danilyuk from Borekov Institute of Catalysis, Novosibirsk, who provided us the aerogel described in this paper. We would like to thank T. Duane, S. Wotton for efficient technical support with the installation of the DAQ, and R. Mazza.
References


Figure 12: Number of hits as a function of the azimuthal coordinate (6 cm of Novosibirsk aerogel, -9 GeV/c beam)
Figure 13: Comparison of expected and measured number of photoelectrons. The unscattered and scattered photons from the MonteCarlo are compared with number of photoelectrons measured on the ring and in the region outside the ring.
Figure 14: Distribution of hits in the photodetector plane and superimposed the line representing the pion and proton rings for a +8 GeV/c run.

Figure 15: Projection on the radial coordinate of the pion and proton rings. Histogram: data taken with beam momentum +8 GeV/c. Points: fit the function described in the text.
Figure 16: Projection on the radial coordinate of the pion and proton rings. Histogram: data taken with beam momentum $+10$ GeV/c. Points: fit the function described in the text.
Figure 17: Radius measured from data with and without a mylar foil. Superimposed dark histogram: data taken in a run without aerogel.

6 cm C=0.005

Figure 18: Radius expected from simulation with and without a mylar foil.
Figure 19: Cherenkov angle, 6 cm Novosibirsk aerogel, beam - 9 GeV/c.
Figure 20: Cherenkov angle, 3 cm Matsushita aerogel, beam - 9 GeV/c.

Figure 21: Cherenkov angle, 6 cm Novosibirsk aerogel, beam +8 GeV/c. The superimposed fit is with two gaussians and a constant factor.