Tests of a proximity focusing RICH with aerogel as radiator

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***Abstract*— Using aerogel as radiator and multianode PMTs for photon detection, a proximity focusing Cherenkov ring imaging detector has been constructed and tested in the KEK $\pi 2$ beam. The aim is to experimentally study the basic parameters such as resolution of the single photon Cherenkov angle and number of detected photons per ring. The resolution obtained is well approximated by estimates of contributions from pixel size and emission point uncertainty. The number of detected photons per Cherenkov ring is in good agreement with estimates based on aerogell and detector characteristics. The values obtained turn out to be rather low, mainly due to Rayleigh scattering and to the relatively large dead space between the photocathodes. A light collection system and/or a higher active area fraction of the photomultiplier tubes, together with higher quality aerogels are expected to improve the situation. The reduction of Cherenkov yield, for charged particle impact in the vicinity of the aerogel tile side wall, has also been measured.**

***Index Terms*— Cherenkov counters, aerogel, multianode PMTs, Belle spectrometer.**

I. Introduction

Aerogels are materials with density and refractive index in the region between gases and liquids or solids. Already some time ago, Cantin et al. [1] proposed that Cherenkov radiation from silica aerogels could be used for detection of particles. Besides particle detectors like for example TASSO [2], such threshold counters found applications also in other fields [3]. With improved manufacturing techniques, aerogels of higher transparency i.e. less Rayleigh scattering became available, permitting their consideration as radiators in Ring Imaging Cherenkov (RICH) counters [4]. Ypsilantis and Seguinot [5] proposed a combined aerogel+gas, mirror-focused RICH counter for the LHC-B experiment at CERN. The HERMES team [6] constructed and operated such a ring imaging detector at DESY. The present paper reports on experimental investigation of an aerogel based RICH detector not requiring mirrors i.e. of the proximity focusing type. Such a detector is being considered in connection with a possible upgrade of the BELLE particle identification system at KEK [7], [8].

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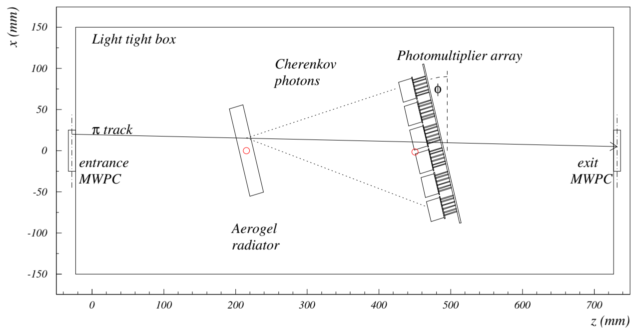

Fig. 1. The Experimental set-up

II. The experimental set-up

Initial tests of the apparatus with cosmic rays were reported recently [9]. The present paper describes measurements and results obtained with the π 2 beam at KEK. A beam particle - pion, muon or electron - traversing the apparatus is signaled by two 5×5 cm^2 scintillation counters which determine the time of arrival. Two CO_2 gas Cherenkov counters produce signals only upon the passage of electrons so these signals could be used either to select or to exclude electrons.

The aerogel radiator and the position sensitive, single photon detector are contained in a light tight box (Fig. 1), of which the entrance and exit sides each have a multiwire proportional chamber for measuring the track of the incident particle. These 5×5 cm^2 MWPC's, with 10 μm diameter, gold-plated tungsten anode wires at 2 mm pitch and with 90% Ar + 10% CH_4 gas flow, are read out by delay lines on the x and y cathode wires.

After passing through the entrance MWPC, the charged particle hits the aerogel radiator in which it emits Cherenkov photons. Measurements have been made mainly with 2 cm thick aerogel slabs of n=1.03, n=1.05 and n=1.07, produced by the method described in [10]. The position sensitive detector of Cherenkov photons is situated 17-29 cm downstream of the aerogel, depending on the refractive index value of the specific aerogel. The detector is a 6×6 array of 16 channel multianode photomultiplier tubes (Hamamatsu PMTs type R5900-M16 [11]) at 30 mm pitch. The sensitive surface of the M16 PMT is divided into 16 ($= 4 \times 4$) channels, each covering 4.5×4.5 mm^2.

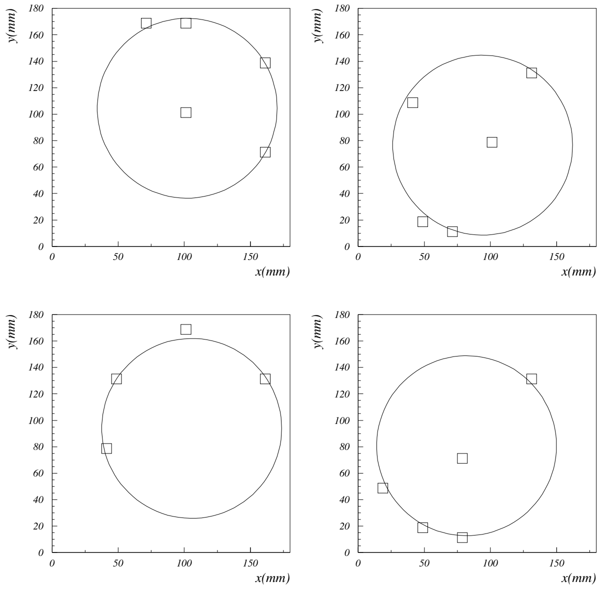

Fig. 2. Some examples of event hit patterns. The circle corresponds to the Cherenkov ring of 3 GeV/c pions given by the measured track position.

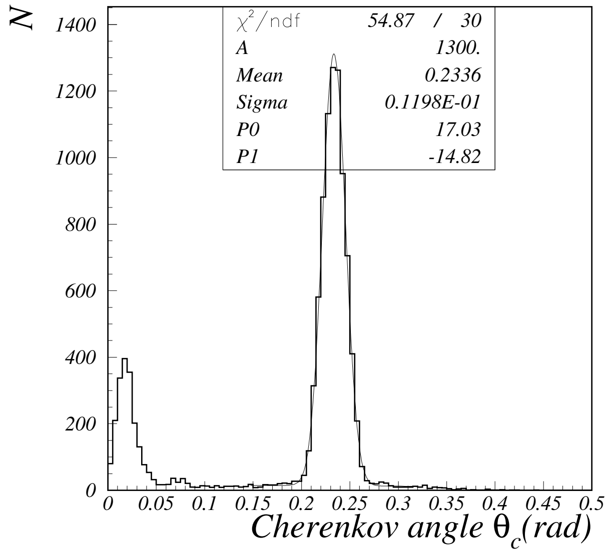

Fig. 3. Accumulated distributions of hits depending on their Cherenkov angle for 3 GeV/c pions, and $n = 1.03$ aerogel radiator.

It follows that only 36% of the detector area is occupied by the photosensitive channels, the rest being dead space. The photon detection system and the aerogel radiator tile may be rotated around an axis perpendicular to the beam direction, enabling measurements of angular acceptance i.e. measurements of the number of detected Cherenkov photons as a function of the charged particle incident angle.

The PMTs are plugged into voltage divider boards inside the light tight box with signals passing through connectors to the readout system located outside the box. The PMT anode signals are first discriminated and then recorded by CAMAC multihit, multichannel TDCs, for which the common STOP is provided by the scintillation counter signals. The TDC information is stored for later analysis in a personal computer.

As only 196 readout channels were available for the 576 PMT anode outputs, only part of the system could be read out with the 4.5 mm pixel size. However, by connecting 4 ($= 2 \times 2$) anodes to one readout channel, the entire system could be read out with 9 mm pixel size.

III. Measurement and Results

A few typical events are displayed in Fig. 2. From the photon hit position and the measured direction of the incident charged particle, the Cherenkov angle is calculated. Accumulated distributions of hits, depending on their Cherenkov angles, are plotted in Figs. 3 and 4. Peaks and rings, corresponding to pions, muons and electrons, are clearly visible. Signals from the gas Cherenkov counters may be used for either selecting or excluding electrons. Fitting these distributions with Gaussian peaks and linear backgrounds yields the average values and standard deviations of the measured Cherenkov angles.

The main contributions to the resolution in Cherenkov angle as determined from a single photon (standard deviations of the peaks in distributions of Figs. 3 and 4) come from pixel size and from uncertainty in the emission point. For normal incidence of tracks the first contribution could be estimated as $\sigma_{pix} = d{\cdot}\cos^2\theta_{ch}/X\sqrt{12}$, where d is the pixel size, θ_{ch} is the Cherenkov angle and X is the distance from aerogel to detector. The second contribution is $\sigma_{emp} = L{\cdot}\ \sin\theta_{ch}{\cdot}\cos\theta_{ch}/X\sqrt{12}$, where L is the aerogel thickness. The uncertainty in the track direction is expected to be negligible at 3 GeV/c, but should increase at lower momenta (0.5 GeV/c). While the error due to dispersion in the radiator (chromatic error) is expected to be negligible, additional contributions could arise due to possible non-uniformities of the aerogel (position variations in refractive index), non-flat aerogel surface, forward scattering of photons etc.

The measured Cherenkov angle resolution, i.e. the standard deviation of peaks in distributions of photon hits versus the value of aerogel refractive index, is shown in Fig. 5 for 3 GeV/c pions. Different data points in the figure refer to different values of parameters such as the radiator thickness, the radiator-to-photon-detector distance and the photon detector pixel size. The measured values are represented by full symbols, with different symbol shapes indicating different combinations of parameter values. Using the above expressions for the contributions of pixel size and emission point uncertainty and summing them in quadrature, one obtains estimates for the resolution, also shown in Fig. 5. These estimates are represented with empty symbols, their shape again corresponding to the same combination of parameter values as in the case of measurement. It may be seen

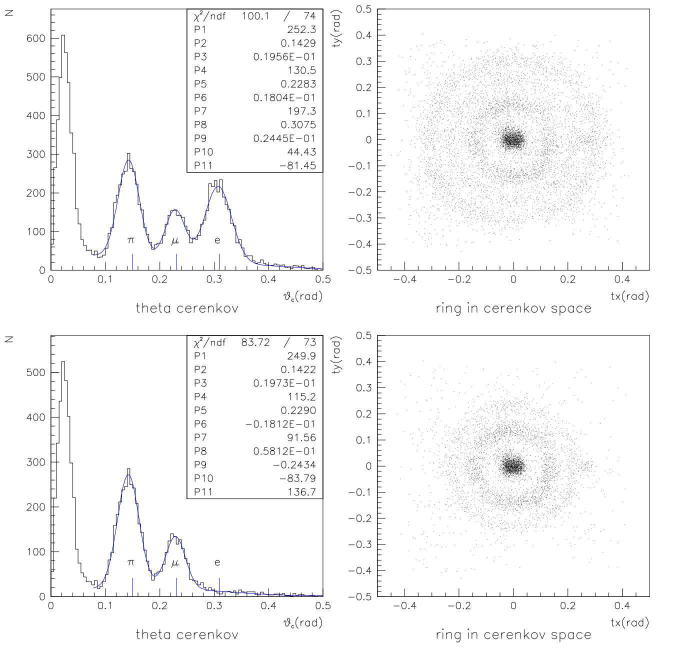

Fig. 4. Accumulated distributions of hits depending on their Cherenkov angle for all 0.5 GeV/c beam particles (top), and with gas Cherenkov signal vetoing the electrons (bottom). Aerogel with $n = 1.05$ was employed as the radiator.

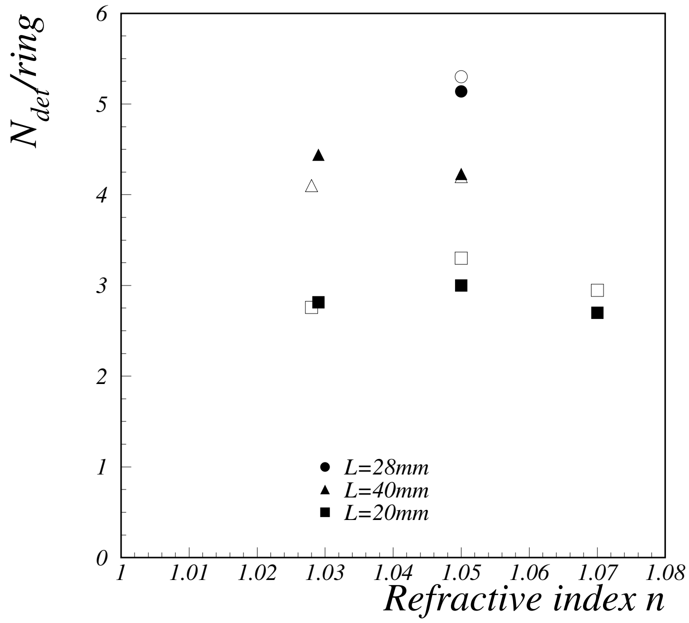

Fig. 6. Number of detected photons per Cherenkov ring for different aerogels, for a 3 GeV/c pion beam. L is the aerogel radiator thickness. Full symbols correspond to the measured values, empty ones to estimates.

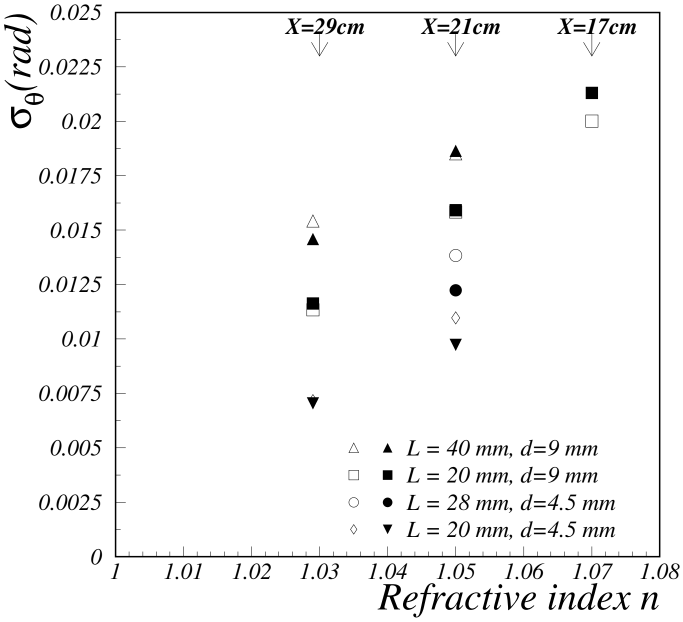

Fig. 5. The resolution i.e. the standard deviation of the single Cherenkov photon angular distribution for different values of the detector parameters, for a 3 GeV/c pion beam. Full symbols correspond to the measured values, empty ones to estimates of contributions from pixel size and emission point uncertainty only. X is the radiator-to-photon-detector distance, L is the radiator thickness and d is the photon detector pixel size.

from the figure that such estimates give a good approximation to the measured resolution.

The other important parameter of a RICH counter is the number of detected photons per incident charged particle. This is usually parametrised as $N_{det} = N_0 \cdot L \cdot sin^2\theta_{ch}$, where θ_{ch} is the Cherenkov angle, L is the radiator thickness and N_0 is a figure of merit depending on the radiator and system transparency, geometrical acceptance of photons (area and angle), quantum efficiency, photoelectron collection efficiency etc. Due to Rayleigh scattering, the aerogel transparency has a strong wavelength dependence in the region of R5900-M16 PMT quantum efficiency, so one may expect a sensitivity of the number of detected photons on the particular aerogel sample i.e. on the production procedure. The number of detected photons per Cherenkov ring is shown in Fig. 6 for 3 GeV/c pions. First one notices that the number of photons does not increase with refractive index as may be expected for $\beta = 1$ particles; $N_{det} \propto \sin^2\theta_{ch} = 1 - 1/n^2$. Then it is also obvious that the 4 cm thick aerogel radiator does not produce two times as many photons as does the 2 cm thick aerogel. And finally we see that the 2.8 cm thick aerogel tile [12], produced in a different process [13], yields more Cherenkov photons than the 4 cm thick aerogel [10]. That a higher refractive index of the aerogel sample does not necessarily produce more photons, is observed also in Fig. 7. Although the threshold for $n = 1.05$ is reached, as expected, at lower particle momenta than for $n = 1.03$, the saturated number of detected photons per Cherenkov ring is more or less the same for both radiators. The above discrepancies can be well understood, if in estimating

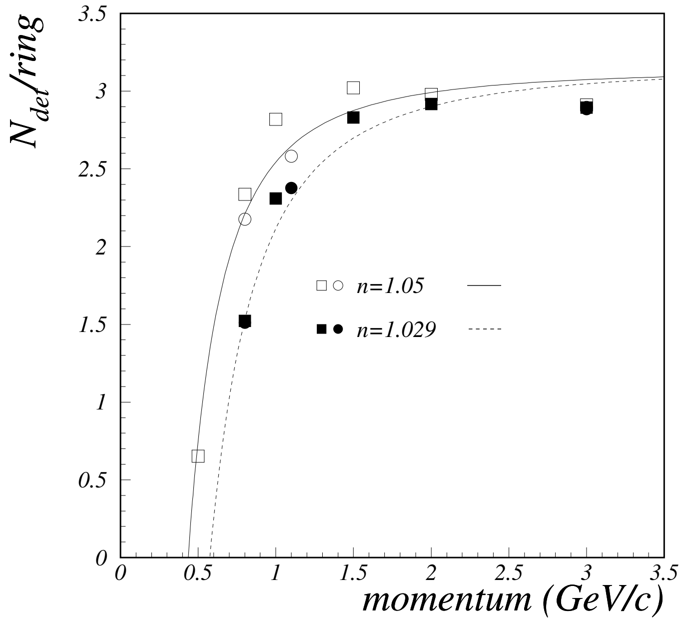

Fig. 7. Number of detected photons per Cherenkov ring depending on the charged particle momentum for different aerogel radiators.

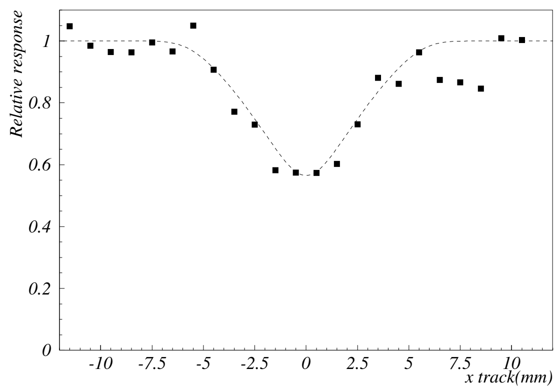

Fig. 8. The number of Cherenkov photons detected on the ring, as a function of the charged particle impact point distance from the side wall of the aerogel tile. The values shown are normalized to the measured values in case of a single tile covering the full range. Also shown is the estimate of a simple model.

the response of the counter, Rayleigh scattering is taken into account.

It has been already noted by the HERMES group [6], that a loss of Cherenkov photons occurs at the side wall boundaries between adjacent aerogel tiles. We have confirmed this finding by measuring the number of photons on the Cherenkov ring as a function of the distance of the charged particle impact point from the boundary between two tiles. The measurement is shown in Fig. 8, where a dip is seen at the tile boundary $x = 0$ mm. In order to eliminate other geometrical factors, like for example the acceptance of the photon detector, the measured yield was normalized to the yield obtained with one tile covering the entire range. The result clearly indicates the reduction of yield when the charged particle is closer than about 5 mm to the boundary of a 2 cm thick aerogel tile. It is worth noting that a simple model, where all photons hitting the boundary between the two tiles get lost, accounts for most of the observed dependence.

IV. Conclusions

We have constructed and tested a proximity focusing RICH detector module with aerogel as radiator and multianode PMTs as position sensitive detectors of individual Cherenkov photons. The measured values of the basic parameters i.e. the single photon Cherenkov angle resolution and the number of photons detected per Cherenkov ring, look promising. The resolution is in relatively good agreement with estimates based on pixel size and emission point uncertainty. The number of detected photons, however is sensitive to the particular aerogel used. It seems that these differences are due to Rayleigh scattering, which reduces the aerogel transparency mainly in the wavelength region of maximal photocathode sensitivity. Photomultipier tubes with a higher fraction of active area, possibly combined with a light collection system, consisting of lenses or light guides, are expected to increase the number of detected Cherenkov photons by reducing the dead space of the photon detector. The increase in photon yield, however, is in the latter case at the expense of an increase in the effective pixel size, so a compromise, optimizing the final resolution of the charged particle Cherenkov angle should be found.

The information obtained from the results of the present tests suggests that a proximity focusing aerogel RICH as required by the BELLE particle identification upgrade is feasible, so investigations of optimal detector parameters are being continued.

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