Tests of a proximity focusing RICH with aerogel as radiator

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We have studied a proximity focusing ring imaging Cherenkov counter with aerogel radiator, as a possible upgrade option of particle identification system in future e^+e^- B factory experiments. In this paper, we introduce concept of the detector, report results of the first beam test and discuss future prospect.

1. INTRODUCTION

Silica aerogel is a unique material that has refractive index (n) in the region between compressed gas and liquid materials. This material has been used in many high energy and nuclear physics experiments as radiator of threshold Cherenkov counters to separate charged π and K mesons in GeV/c region. In the Belle experiment [1] at the KEK B-factory [2], a large scale array of threshold Cherenkov counters (Belle-ACC) has been operated, and it has been proven to provide kaon identification of more than 90% with pion misidentification probability of less than 10% up to 3.5 GeV/c [1][3]. For the construction of Belle-ACC, a new production method has been developed to provide aerogel tiles of $n = 1.01 \sim 1.03$ with improved optical transparency and also with hydrophobic surface [4].

Such improvement in aerogel quality at KEK and also at Novosibirsk [5] has brought us possibility of using aerogels as radiators in ring imaging Cherenkov counters (aerogel RICH). Ypsilantis and Seguinot proposed a RICH counter with a dual radiator of aerogel and gas for the LHC-B experiment at CERN [6]. A similar detector has been operated in the HERMES experiment at DESY [7]. These detectors utilize reflective mirrors to focus Cherenkov photons emitted from the radiator onto a photodetection plane. However, in general, this mirror-focusing geometry is hard to apply in collider experiments, where allocated space for each subdetector is limited In the present paper, we report our investigation of a proximity focusing aerogel RICH, that do not require mirrors. Such a detector is being considered in connection with a possible upgrade of the particle identification (PID) system at Belle, especially in the endcap region, where the present system does not function for K/π separation in the high momentum region around 4 GeV/c [8].

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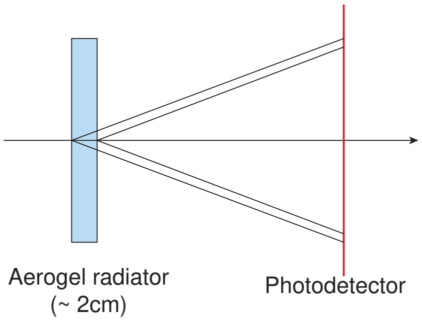

Figure 1. Concept of the proximity focusing aerogel RICH.

2. DETECTOR CONCEPT

Fig.1 shows the concept of the proximity focusing aerogel RICH under investigation. Cherenkov photons, which are produced in aerogel radiator and do not suffer from absorption or scattering inside the radiator, are directly projected onto a photodetection plane. We mainly consider aerogel radiator with $n = 1.03$ or 1.05, giving Cherenkov angle difference between pions and kaons ($\Delta\theta_c$) of 31 or 23 mrad, respectively, at 4 GeV/c. Photons are detected by an array of pixelized vacuum-based photodetectors, sensitive to a single photon in visible light region, such as multi-anode photomultiplier tubes (PMT) and hybrid photodetectors (HPD). In this geometry, the Cherenkov angular resolution per single photon (σ_θ) is determined mainly by the ambiguity in the photon emission point along the incident particle trajectory and the position resolution of the photodetector. With the radiator thickness of 20 mm, the photodetector pixel size of 5 mm $\times$ 5 mm, and the distance between the radiator and the photodetector surface of 20 cm, σ_θ is calculated to be about 10 mrad. The light yield (N_{pe}) per single track must be reasonably high to statistically improve the angular resolution and to retain high enough identification efficiency. This is the primary concern in the proposed geometry, as relatively thin radiator has to be used to minimize the ambiguity in the photon emission point. Our Monte Carlo simulation indicates that the average light yield $\langle N_{pe}\rangle$ for $\beta = 1$ particles is about 10 (12) for 20 mm thick $n = 1.03(1.05)$ radiator, based on the measured transmission length of aerogel tiles produced with the previously mentioned method at KEK [9], and assuming photodetection is made by bialkari photocathode with the peak quantum efficiency of 20% and with no geometrical loss. The detector in this geometry easily fit in the Belle detector, where the allocated space for PID is about 28 cm.

3. BEAM TEST

In order to test feasibility of the proximity focusing aerogel RICH experimentally, we have carried out a beam test at the $\pi 2$ beam line of KEK-PS, following a cosmic ray test, already reported in [10]. Fig.2 shows the experimental setup of the beam test. The π^- beam momentum ranges from 0.5 to 4.0 GeV/c, and their trajectories are measured with two MWPC's. Measurements have been carried out mainly with approximately 20 mm thick aerogel tiles with $n = 1.029$, 1.050 and 1.070, each having transmission length at 400 nm wavelength (λ_T) of 38, 15 and 7.2 mm, respectively [9]. These tiles are produced at KEK with the same method as described in [4]. For comparison, we have tested also a 28 mm thick $n = 1.050$ sample from Novosibirsk, having $\lambda_T = 48$ mm [5]. The photodetector is a 6×6 array of 16-channel multi-anode PMT (Hamamatsu R5900-M16 [11]) at 30 mm pitch, to cover the total detector area of 36cm $\times$ 36 cm. The sensitive bialkari photocathode area in each PMT is 18mm $\times$ 18mm, and is divided into $= 4 \times 4$ channels, each covering 4.5mm $\times$ 4.5mm. Therefore, only 36% of the detector area is effective to detect photons. The photodetector is situated 17, 21 and 29 cm downstream the aerogel tile of $n = 1.029$, 1.050 and 1.070, respectively. As only 196 read-out channels are available for the 576 PMT anode outputs, signals are read out with two compromised ways; 1) coarse read-out scheme, shown in Fig.2-b), where the entire system are read out with 9mm pixel size by connecting 4 anodes to one channel, 2) fine read-out scheme, shown in Fig.2-c), where

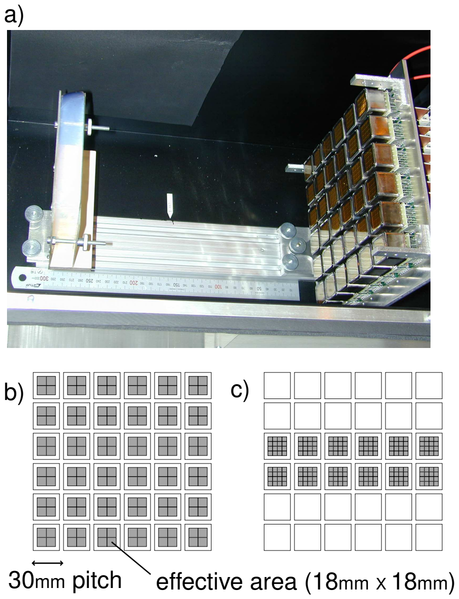

Figure 2. a) Experimental setup of the beam test. Schematic drawings to show the b) coarse and c) fine read-out scheme (see text).

only one third of the system are read out with the 4.5 mm pixel size. Both the aerogel tile and the PMT array can be rotated around an axis perpendicular to the beam direction, so that incident angle dependence of the performance can be tested.

Fig.3-a) shows the observed Cherenkov ring images for normal incidence of 3 GeV/c π^- beams on the $n = 1.029$ aerogel tile. The figure demonstrates that a Cherenkov ring image is clearly observed with a low background level. The background hits, spread over the detector area, are due to photons scattered when they traverse the radiator. Hits around the center are due to Cherenkov light emission by beams penetrating the glass surface of a PMT.

The Cherenkov angle (θ_c) is calculated from the hit position of a photon and the measured incident track direction. For each measurement, θ_c distribution, as shown in Fig.3-b), is fitted with a Gaussian peak and a linear background. The Gaussian peak width (σ) represents the Cherenkov angle resolution per photon σ_θ. The average light yield for a single track $\langle N_{pe} \rangle$ is calculated by dividing the Gaussian peak yield within $\pm 3\sigma_\theta$ region with number of events accumulated for each measurement. Hits in adjacent pixels are clusterized, if their timing agree, and teated as a single hit.

Fig.4 presents the measured σ_θ and $\langle N_{pe} \rangle$ for normal incidence of 3 GeV/c π^- beams on each refractive index of aerogels. Results are shown for different conditions of the aerogel radiator and the read-out scheme; a) with a 20mm thick radiator and the coarse read-out scheme, b) with a 20mm thick radiator and the fine read-out scheme, c) with two aerogel tiles stacked to make a 40mm thick radiator and the coarse read-out scheme and d) with the 28mm thick aerogel radiator from Novosibirsk and the fine read-out scheme.

For instance, the Cherenkov angular resolution σ_θ, measured with the condition b), is 7.0 and 9.8 mrad for $n = 1.029$ and 1.050, respectively. Note that the linear increase of σ_θ with n, noticed in Fig.4-a), is the consequence that the distance between the radiator and the photodetector surface (d) is varied, depending on n. The resolution evaluated at the same distance $d_0 = 20$cm, by scaling the measured σ_θ by d_0/d, is about 10mrad for both $n = 1.029$ and 1.050 cases.

As for the light yield, Fig. 4 shows results with event-by-event correction of the measured $\langle N_{pe} \rangle$ by the fraction of the ring circumference inside the 36 cm $\times$ 36 cm detector area, that is estimated from the tracking information. With this correction, two results with conditions a) and b) are consistent, and the obtained $\langle N_{pe} \rangle$ is 2.6, 2.7 for $n = 1.029$, 1.050, respectively. It is seen that $\langle N_{pe} \rangle$ does not increase with n. This is because the transmission length decreases with n for the used aerogel tiles, while the number of produced Cherenkov photons increases with n. Because of the same reason, $\langle N_{pe} \rangle$ does not scale to the radiator thickness, and this behavior is pronounced more for $n = 1.050$ than 1.029 radiator.

Fig.5 presents the incident angle dependence. Almost no dependence is observed up to 30° for

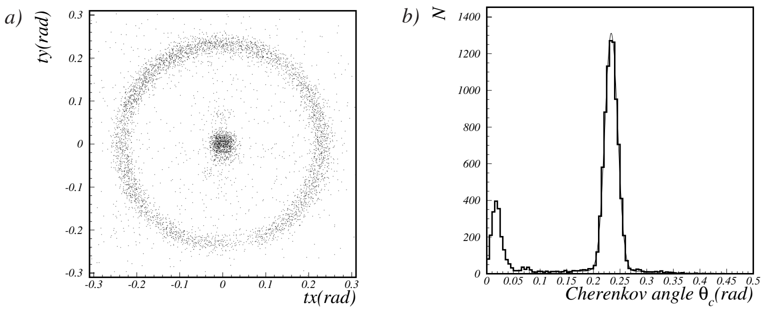

Figure 3. a) Cherenkov ring image and b) σ_θ distribution observed with 20mm thick $n = 1.029$ aerogel radiator for the normal incidence of 3 GeV/c π^- beams (coarse read-out scheme.

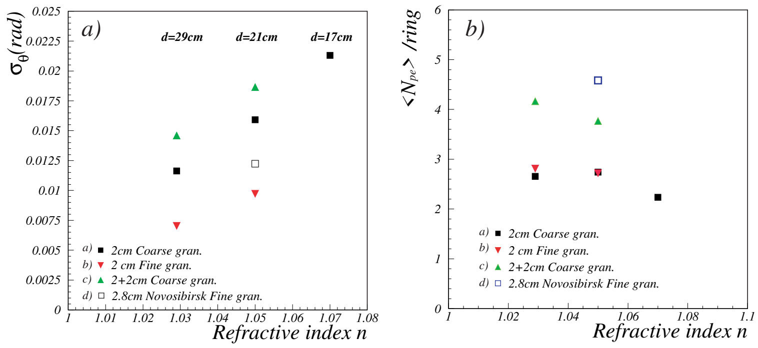

Figure 4. the measured σ_θ and $\langle N_{pe}\rangle$ for normal incidence of 3 GeV/c π^- beams.

both σ_θ and $\langle N_{pe}\rangle$.

4. DISCUSSIONS

The presented beam test results are almost consistent with expectation. For instance, for $n = 1.029(1.050)$ radiator, the obtained $\sigma_\theta = 7.0(9.8)$ mrad is in agreement to the expected value of 6.7(9.7) mrad. The measured light yield $\langle N_{pe}\rangle = 2.6(2.7)$ for $n = 1.029(1.050)$ is again in agreement to the expected value of 2.7 (2.9), based on the Monte Carlo simulation, mentioned in Section 2, if we take into account of the 36% effective area ratio and the dynode correction efficiency of 70%.

In the results shown in Fig.4-b), one notices that the $n = 1.050$ Novosibirsk sample (28mm thick) yields $\langle N_{pe}\rangle = 4.6$, about 70% higher than the result with the nominal sample (20mm thick). This increase is remarkable, even if we take their thickness difference into account. The former sample has excellent transmission length ($\lambda_T = 48$mm) despite its hydrophilic surface nature. With the production method, applied to the latter sample, the transmission length is highest at around $n = 1.03$ ($\lambda_T \sim 45$mm), but decreases as n becomes higher ($\lambda_T \sim 15$mm at n =1.05). We have started R&D works to optimize precursor and solvent materials in the aerogel production, aiming at increasing the light yield espe-

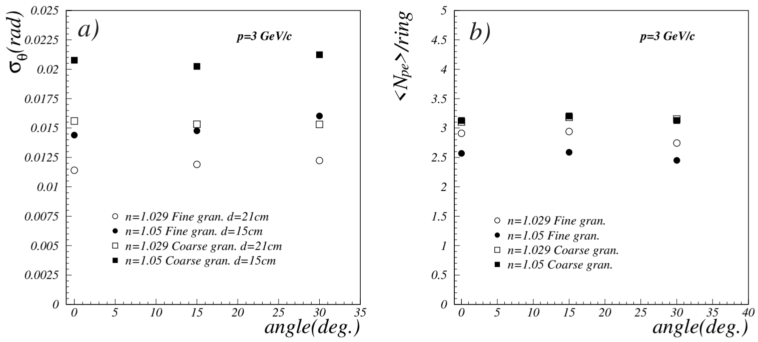

Figure 5. Incident angle dependence of σ_θ and $\langle N_{pe} \rangle$.

cially at around $n = 1.05$.

In order to improve the light yield, it is essential also to increase the geometrical acceptance of the photodetector. The recently developed H8500 multi-anode PMT, known as "flat panel PMT", has great advantage in this aspect because of its effective area ratio as high as 89% [11]. However, in the application in Belle, the photodetector must operate in the strong magnetic field of 1.5T. It is therefore desired to develop a photodetector with a good effective area ratio $\geq$ 70%, $\leq$ 5mm pixel size, and a good detection efficiency for single photoelectron in the magnetic field. A multi-anode hybrid photodetector (HPD) with a large effective area ratio seems to be the primary candidate to develop.

5. SUMMARY

We have introduced the proximity focusing aerogel RICH as a possible upgrade option of PID system in future e^+e^- B factory experiments. The first beam test demonstrates that the basic performance is almost consistent with expectation. In order to prove its feasibility, the primary concern is the light yield, and it is essential to improve the transmission of aerogels and also to develop a position sensitive photodetector with a large effective area ratio and with magnetic field immunity. We have commenced an R&D program in such direction.

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