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Aerogel Čerenkov Counter for the BELLE Experiment

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T.Iijima[a*], I.Adachi[a], M.Amami[b], R.Enomoto[a], R.S.Guo[c], K.Hayashi[a], H.C.Huang[d], R.Itoh[a], S.Kobayashi[b], Y.Kohashi[e], T.H.Liu[f], D.R.Marlow[f], S.Matsumoto[g], A.Murakami[b], S.Ogawa[e], S.K.Sahu[d], H.Shibuya[e], R.Suda[h], T.Sumiyoshi[a], K.Tsukada[a], T.Tsukamoto[b], C.H.Wang[i], M.Z.Wang[c], Y.R.Wang[d], M.Yamauchi[a], N.Yasuda[e], and Y.Yoshida[e]

a) National Laboratory for High Energy Physics (KEK), b) Saga University,
c) National Kaohsiung Normal University, d) National Taiwan University,
e) Toho University, f) Joseph Henry Laboratories, Princeton University,
g) Chuo University, h) Tokyo Metropolitan University,
i) National Lien-Ho College of Technology and Commerce

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*Corresponding author. E-mail:iijima@kekvax.kek.jp.

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Abstract

In the BELLE experiment at KEKB, a threshold Čerenkov counter system based on silica aerogels will be used to provide a π/K separation in the momentum region from 0.8 to 3.5 GeV/c. The detector design, recent progresses in R&D's and results of beam tests are reviewed in this talk.

1 Introduction

Particle identification, in particular the identification of charged pions and kaons, plays an important role for the studies of CP-violation in B-factory experiments. In the BELLE experiment at KEKB, a threshold aerogel Čerenkov counter (ACC) will be used to extend the momentum region beyond the reach of dE/dx and time-of-flight (TOF) measurements [1]. This paper gives a brief description of the detector design, recent progresses in R&D's and results of beam tests.

2 Detector design

Figure 1 shows the design of the BELLE ACC system, which consists of a barrel ACC and a forward endcap ACC. The barrel ACC is a 900-element array, segmented into 15 and 60 in z and ϕ directions, respectively. The typical dimension of each module is approximately $12 \times 12 \times 12\,\mathrm{cm}^3$. The refractive index ($n$) of aerogels ranges from 1.01 to 1.02, depending on polar angle to cover the momentum region up to 3.5 GeV/c, that is important for two-body B-decays such as $B^0 \to \pi^+\pi^-$.

As for the endcap ACC, the detector is a 224-element array, arranged in 5 layers of concentric rings. The front surface area of each module is about $11 \times 12\,\mathrm{cm}^2$ and the thickness of aerogels is 10 cm. Aerogels with $n = 1.030$ are used so that the device functions for the flavor tagging in the momentum region from 0.8 to 2.5 GeV/c.

For both the barrel and endcap ACC's, the inner surface of each counter box is coated with diffusive white sheets "Goretex" for better efficiency and uniformity of light collections. The whole system is located in a 1.5 Tesla magnetic field, and Čerenkov light signals are detected by finemesh PMT's [2] with diameters of 2, 2.5 or 3 inches, each equipped with a low-noise amplifier based on a JFET chip. Further optimization of the detector configuration is in progress.

3 Aerogel production at KEK

Using a KEK own facility, we have developed silica aerogels with low refractive indices. Details of the production method can be found in [3]. The unique feature of our aerogels is its hydrophobicity, by which long-term stability of the detector is ensured. Moreover, in our recent test, the radiation damage on aerogels has been found to be negligible up to 10 MRad equivalent dose [4].

In the past one year, the quality of aerogels have been significantly improved. Figure 2 compares ADC spectra for a prototype counter ($n = 1.015$) in four beam tests using 3.5 GeV/c π^-'s. The light yield has been improved by a factor of 2.4, as shown in the figure (from "January" to "October"). The improvement has been achieved by a success of producing crack-free aerogels in CO_2-based supercritical drying process, a success of removing impurity contamination in aerogels and further optimization of mixing ratios of raw chemicals, which have given improvement factors of 1.33, 1.43 and 1.24, respectively.

4 Performance of finemesh PMTs

A major issue in R&D's for readout components is the photon detection down to a single photoelectron level in a 1.5 Tesla magnetic field. We have carefully investigated about 75 samples of finemesh PMT's, with some modifications. The tested samples are Hamamatsu R5924(2"), R6505(2.5"), R5542 and R5543(3") with 19 dynode stages [5]. At 1.5 Tesla with 2100 Volt high voltage, recent modified PMT's have average gains of 1×10^5 and 9×10^5 for the angle between the PMT axis and the field direction (θ) of $0°$ and $30°$, respectively. The obtained gain is then, at least, an order of magnitude higher than the equivalent noise charge of the developed readout electronics, that is less than 10^4 electrons.

We have studied also deterioration of pulse height resolution, which result in a loss of effective photostatistics. In the case of $\theta = 30°$ with a fixed high voltage around 2000 Volt,

the loss of effective number of photoelectrons μ_{eff}, defined as $\mu_{eff} = (< mean > /\sigma)^2$ using a mean and a standard deviation of an ADC distribution, at 1.5 Tesla is about 35 and 23% for 2" and 3" PMT's, respectively. In the case of $\theta = 0°$, the loss is about 18% not depending much on the PMT size. It has been found, however, that μ_{eff} increases by $10 \sim 20\%$ by raising the high voltage up to $\sim$ 2700 Volt.

5 Beam test results and expected performance

A series of beam tests with prototype counter modules have been carried out at the $\pi 2$ beam line of KEK-PS for proving the device performance. For example, Figure 3-a) shows an ADC spectrum for an $n = 1.010$ counter, read out with two 3" finemesh PMT's, measured with 3.5 GeV/c π^-'s ($\beta = 0.9992$) and p's ($\beta = 0.966$, below the threshold velocity) in a 1.5 Tesla magnetic field. With improved aerogels mentioned above, the average number of photoelectron (N_{pe}) for 3.5 GeV/c π^-'s is 18.0, corresponding to 19.5 for light velocity particles. The light collection efficiency is estimated to be as high as 60% in this case. The light yield obtained for each type of counter can be found in Table 1.

In Figure 3-b) are shown the inefficiency for π^-'s and efficiency for p's as a function of the threshold on ADC counts. Emission of delta rays from aerogels is one of the reasons for finite efficiency for sub-threshold particles. The figure indicates that 98.3% efficiency for signals with 1.7% background contamination, corresponding to more than 4 σ separation between signals and backgrounds, can be obtained at 3.5 GeV/c. Taking account of these results, the momentum dependence of Čerenkov light yields and effective photostatistics with finemesh PMT's, we expect that more than 3 σ π/K separation can be achieved in the momentum region from 1.2 to 3.6 GeV/c for the barrel ACC and from 0.8 to 2.2 GeV/c for the endcap ACC.

6 Summary

The developed aerogel Čerenkov counter system has been proven to satisfy the required performance for the BELLE experiment. The barrel ACC enables us to extend the momentum region for π/K separation up to 3.6 GeV/c, by which 84% of $B \rightarrow \pi\pi$ events are covered. With the endcap ACC, combined with dE/dx information, the flavor tagging up to 2.2 GeV/c is possible. In near future, the design will be finalized, and construction of the detector, including the mass production of aerogels, will take place. The final system will be installed by Summer 1998.

References

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[5] Technical Data, Hamamatsu Photonics Inc.

Table 1: Photoelectron yields measured for each type of prototype counter.

Refractive index (n)	PMT (diam. × pcs.)	N_{pe} for light velocity particles
1.010	3" × 2	19.6
1.015	2.5" × 2	21.4
1.020	2" × 2	21.1
1.030	3" × 1	25.7

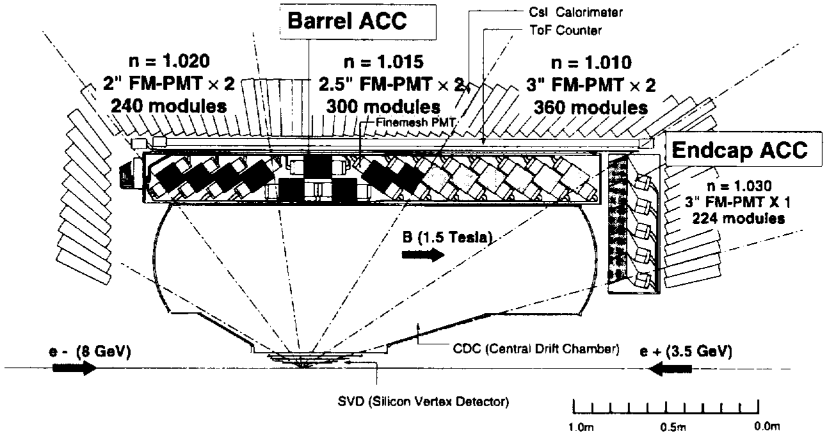

Figure 1: Design of the BELLE aerogel Čerenkov counter system (as of March, 1996).

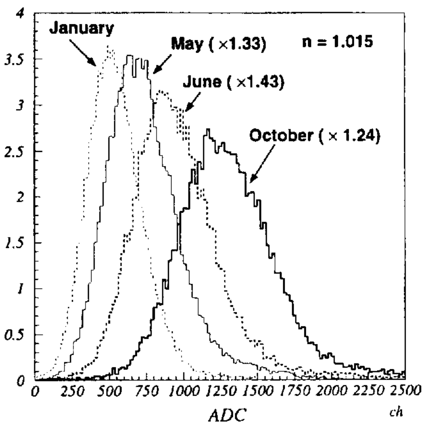

Figure 2: Pulse height spectra obtained with $n = 1.015$ aerogels in beam tests in the past one year. The counter configuration and PMT gains are the same for all measurements.

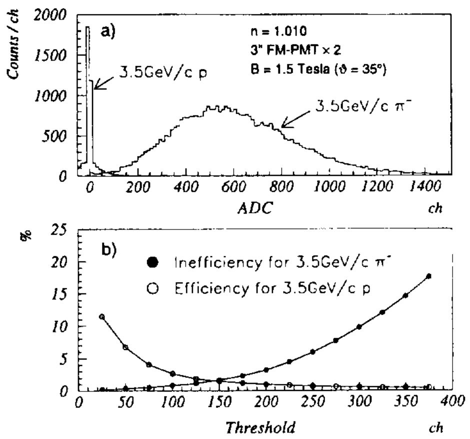

Figure 3: Pulse height distributions obtained for an $n = 1.010$ prototype counter with $3.5\,\mathrm{GeV}/c$ π^-'s and p's in a 1.5 Tesla magnetic field (top) and inefficiency for π^-'s and efficiency for p's as a function of the pulse-height threshold values (bottom).