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BELLE AEROGEL CHERENKOV COUNTER – A DETECTOR FOR PARTICLE IDENTIFICATION

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Abstract: 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. For the BELLE detector at the KEK B-Factory in Japan, a threshold aerogel Cherenkov counter (ACC) has been used to separate pions and kaons in the momentum range between 1.0 GeV/c and 3.5 GeV/c. This paper gives a brief description of the ACC design, construction, monitoring system and its performance of the beam test and Monte-Carlo simulation.

Key words: CP violation; B-factory experiment; Particle identification; Aerogel Cherenkov counter; Monte Carlo simulation

Introduction

One of the long standing puzzles of nature to the particle physicists is why the Universe is composed of matter in contradiction with cosmological theory, which suggests that an equal amount of particles and antiparticles have been created in the big bang. It is interesting to note that at the current level of theoretical knowledge, amount of matter-antimatter asymmetry (CP asymmetry) present in the Standard Model (SM) appears to be insufficient (Rubakov and Shaposhunikov, 1996). After all starting with an equal amount of matter and antimatter in the very beginning, one needs some degree of asymmetry which would let matter prevail and produce the baryon density of the universe we are observing now. In order to elucidate this long standing puzzles about the origin of the CP asymmetry, several B-Factories have been proposed and are being constructed around the world (Miller, 1994, BELLE collaboration, 1994, BABAR collaboration, 1995, Lohse, 1994 and LHC-B collaboration, 1995) where large numbers ($\sim 10^{7-8}$ /year) of B meson will be produced and their decays will be examined. At KEK (National Accelerator Research Organization) in Japan such an e^+e^- asymmetric collider referred to as "KEK B-Factory" is now under operation (data taking is going on) which will produce about 10^8 B mesons/year. In a B-Factory detector, an identification of the particle species is an important issue. The simplest way for such type of particle identification involves detection of Cherenkov light emitted by charged particles (pions, kaons etc.) passing through a transparent material. A transparent material having a refractive index in the range 1.010 ~ 1.015 is necessary in order to achieve a π/K separation capability in the

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momentum region of 1.0 ~ 2.5 GeV/c. Practically it is very difficult to attain such a very low refractive index with most materials. In a large number of experiments around the world silica aerogels have been used for thereshold type Cherenkov counters (Hasegawa, 1994).

The BELLE collaboration (the experimental group for the KEK B-Factory in Japan) has used an array of silica aerogel Cherenkov counters for such particle identification (Sumiyosh, 1999). In this paper the design, construction, production method of the aerogel and monitoring system of the ACC for the KEK B-Factory experiment have been discussed briefly. The performance of the ACC by beam test data and Monte Carlo simulations are also presented.

Cherenkov Radiation

Cherenkov radiation is emitted when a charged particle in a material medium of the refractive index *n* moves with a velocity *v* which is larger than the light velocity in the medium (Cherenkov, 1937). Excited atoms in the vicinity of the particle become polarized and coherently emit radiation at the characteristic angle θ_c, the Cherenkov angle.

The angle between the direction of the Cherenkov light emission and that of the particle motion is expressed as

$$\cos\theta = \frac{1}{n\beta} \quad (1)$$

where, β=v/c.

The number of Cherenkov photons per unit path length and per unit energy interval of the photons produced by the particle with charge *ze* is given by (Frank and Tamm, 1937) where α is the fine structure constant and λ is the wavelength of photon. The integrated

$$\frac{d^2N_\gamma}{dxd\lambda} = \frac{2\pi\alpha z^2}{\lambda^2}\left(1-\frac{1}{\beta^2 n^2}\right) \quad (2)$$

number of Cherenkov photons over the wavelength from λ_{min} to λ_{max} is given by

$$N_\gamma = 2\pi\alpha z^2\left(\frac{1}{\lambda_{\min}}-\frac{1}{\lambda_{\max}}\right)\left(1-\frac{1}{\beta^2 n^2}\right) \quad (3)$$

For the medium of refractive index *n*, the threshold velocity β_{th} of the particle and the corresponding threshold momentum p_{th} for the particle of mass *m* are
and

$$\beta_{th} = \frac{1}{n} \quad (4)$$

$$p_{th} = \frac{m}{\sqrt{n^2 - 1}} \qquad (5)$$

respectively. The refractive index of the aerogel is set so that Cherenkov photon is emitted for pions not for kaons.

Aerogel Cherenkov Counter for BELLE

The configuration of the ACC system in the BELLE detector is shown in Fig. 1. Aerogels with different refractive index are used at different polar angles in order to obtain good π/K separation for the whole kinematical range. As shown in the figure aerogels of a refractive index of 1.010, 1.013, 1.015, 1.012 and 1.028 are used for the barrel ACC modules depending on the polar angle to cover the momentum region upto 3.5 GeV/c. Aerogels of refractive index of 1.030 are used for the endcap ACC so that the device functions for the flavor tagging in the momentum region from 0.8 to 2.5 GeV/c. There are 960 modules for the barrel and 228 modules for the endcap one. The typical shape of a single counter module is shown in Fig. 2. Five aerogel tiles are stacked in a thin (0.2 mm) box of 12×12×12 cm^3 in dimensions. The inner walls of these boxes are covered with a white reflector Gortex (Japan Gortex Inc.). One or two fine mesh photomultiplier tubes (FM-PMTs) are used for readout of Cherenkov photons under a 1.5 Tesla magnetic field (Enomoto, Sumiyoshi, Hayashi, Adachi, Suzuki, 1993, Iijima *et al.*, 1997).

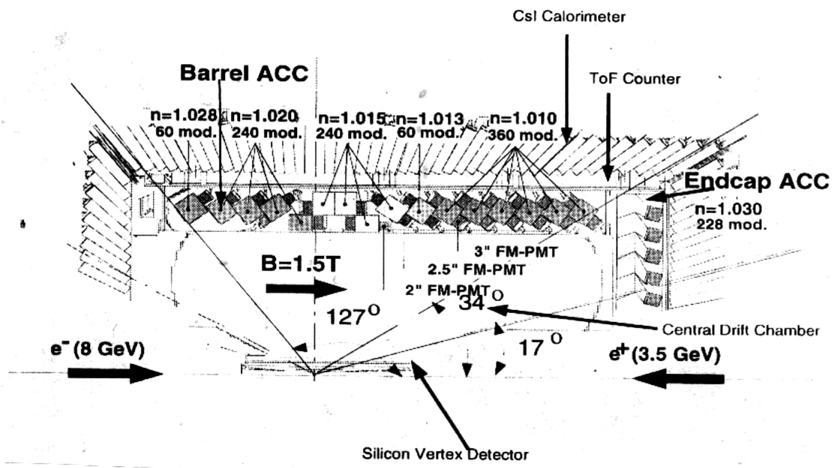

Fig. 1. The configuration of the ACC system in the BELLE detector.

***Production of Silica Aerogel*:** Silica aerogels are collidal form of glass, in which globules of silica are connected as three dimensional network with siloxan linkage. They are solid, very light, transparent and their refractive index can be controlled in the range between 1.006~1.06 at the production process. Fig. 3 shows the schematic view of the silica aerogel. The flow chart of the production method of the aerogel for the BELLE ACC is shown in Fig. 4.

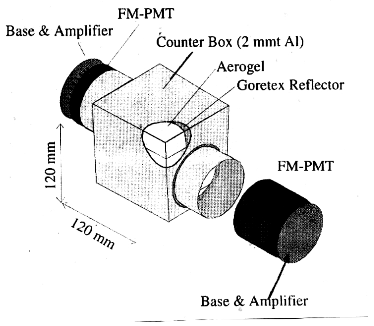

Fig. 2. The typical shape of a single ACC counter module.

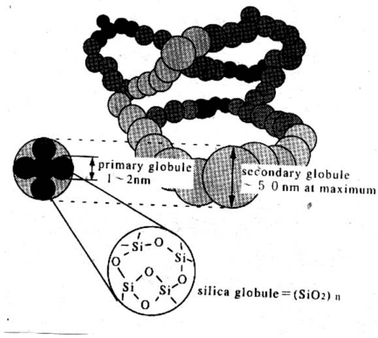

Fig. 3. Schematic view of the silica aerogel.

The details of the R&D of silica aerogel for the BELLE ACC can be obtained from (Suda, 1998, Adachi *et al.*, 1995, Sumiyoshi *et al.*, 1998). A test was carried out to ensure the radiation hardness of aerogels by placing them in high intensity gamma-rays from ^{60}Co source (Sahu *et al.*, 1996). Transparencies and refractive indices of aerogels were measured at several radiation levels. At about 10 Mrad, which corresponds to more than 10 years of running at the KEK B-Factory, no deterioration on the transparency and no change in the refractive indices were observed.

Ethyl Alcohol + Methyl Silicate : : **Solution A**

Ethyl Alcohol + Distilled Water + Ammonia : **Solution B**

A+B ⟶ **Alcogels**

↓ (several minutes)

put into ethyl-alcohol vapor

↓ (one week)

sink into ethyl-alcohol

↓ (3 days 30^0 C)

add hydrophobic agent (hexamethyldisilazane)

↓ (3 days)

sink into ethyl-alcohol

↓ (9 days)

supercritical drying

↓ (2 days 160 kg/sq.cm, 80^o C)

Aerogel

Fig. 4. Flow chart of the aerogel production.

Fine-mesh Photomultiplier Tube (FM-PMT): As discussed before the ACC is placed in 1.5 Tesla magnetic field in the BELLE detector. In such a strong magnetic field, electrons spiral along the field and hence the line-focus type PMT can not be used for detection of the Cherenkov photon from the aerogel. For detection of Cherenkov light down to a few photoelectron level, the photodetector must have enough gain and effective area. A special type of PMT called the fine-mesh PMT (FM-PMT) meets these requirements of high gain and large effective area. There are other candidates for such a photo-detector which may work in the magnetic field such as avalanche photo-diode (APD), hybrid avalanche photo-diode (HAPD), micro-channel plate PMT (MCP-PMT) etc.. However all of them have limited gain or effective area.

For BELLE ACC the FM-PMTs having diameters 2″, 2.5″ and 3″ are used (Suda, 1998). Each PMT has a borosilicate glass window, a bi-alkali photo-cathode, 19 fine-mesh dinodes and an anode. The average quantum efficiency (QE) of the photocathode is 25% at a wavelength of 400 nm (PMT catalogue of Hamamatsu photonoics, 1995).

***The ACC monitoring system*:** As described above, the ACC consists of 1188 modules and is equipped with a total of 1788 FM-PMTs to readout the Cherenkov photons. The gain of the FM-PMTs and the light yield of aerogel may change during the period of data taking. In order to achieve high quality particle identification it is necessary to monitor the gain of all of the PMTs and the light yield of aerogels of the ACC with a precision of a few percent level. A new monitoring system consists of blue LEDs, a diffuser box and optical distributors (which distribute the LED light to the ACC modules) has been designed and tested (Khan *et al*., 1998, Khan, 1999). The LED has been observed to have high reliability on the long term stability and the temperature dependence. The diffuser box is employed to reduce the intrinsic non-uniformity of the LED light intensity. The uniformity of the light intensity of the developed monitoring system has been measured to be 94.20±0.09 % over all the ACC modules. The present monitoring system can supply roughly 10-40 photoelectrons to each ACC module which is enough for monitoring. The performances of the present monitoring system me *et al*l the requirements for monitoring of all the ACC modules of the BELLE detector (Khan, 1999).

Performance of the ACC

***Beam test results*:** To design and to check the performance of the single ACC modules, the modules were tested by using beam test facilities at the π2 beam line of the KEK 12 GeV PS which provides charged particles, pion and proton in the momentum range 0.6~3.5 GeV/c. From the results of the beam test and optimizing all the effects (Suda, 1998) the final design was made which is shown in Fig.1. The number of photoelectrons obtained for 3.5 GeV/c pions are 18.2, 20.3 and 20.3 for n=1.01, 1.015 and 1.02 aerogels, respectively. Fig. 5 shows the pulse height distribution for a typical counter (n=1.010 with two 3.0″ FM-PMTs) for 3.5 GeV/c π^- and protons beam. Pions (above threshold) and protons (below threshold) are clearly separated by more than 3σ. This separation is maintained even in high magnetic field. It has been found that cracks in the aerogel make no difference in the light yield.

***Monte Carlo Simulations*:** In order to get a better understanding of the performance of the ACC a Monte Carlo program (Suda, 1998) has been developed to simulate the behavior of the Cherenkov photons in the aerogel as realistically as possible. Every important effects such as Rayleigh scattering, absorption by the aerogel , reflection by the Gortex walls, absorption by the wall and the response of the PMTs are taken into account as a function of wavelength.

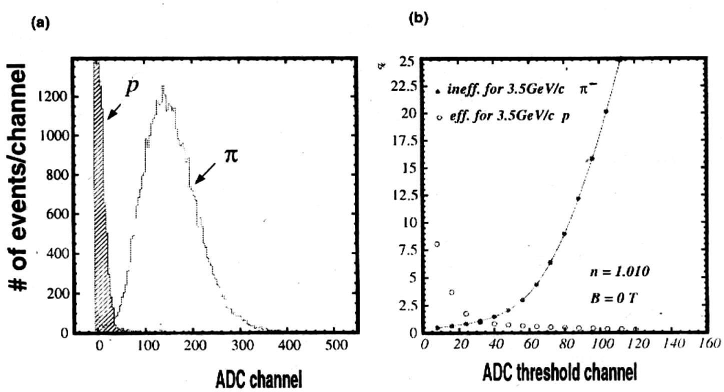

Fig. 5. (a) The signal distribution of 3.5 GeV/c π^- (the blank area) and 3.5 GeV/c p (the hatched area) as a function of the ADC channel, (b) shows inefficiency for π^- (the solid line) and efficiency for p (the dashed line) as a function of a threshold ADC channel.

This simulator is installed in the BELLE standard detector simulator based on the GEANT 3. The performance of the ACC for π/K separation is demonstrated in several selection processes e.g. $B\rightarrow\eta' K/\ \eta'\pi$, which are very important for the CP physics in the B-Factory.

Fig. 6 shows the energy imbalance ΔE, which is defined as $\Delta E = E_1 + E_2 - E_{beam}$, where E_1 and E_2 are the energies of η' and K(or π), respectively. Fig. 6(a) shows the ΔE distribution of the generated $B\rightarrow\eta' K/\ \eta'\pi$ events. $B\rightarrow\eta'\pi$ is considered to be the background for $B\rightarrow\eta' K$ decay mode. In this figure the hatched area shows the contribution from $B\rightarrow\eta' K$ and the solid line that from $B\rightarrow\eta'\pi$. The figures 6(a) and 6(b) also show the ΔE distributions before the ACC PID (Particle Identification Detector) cut and after the ACC PID cut, respectively. These figures clearly show the efficiency of the ACC in separation of π and K.

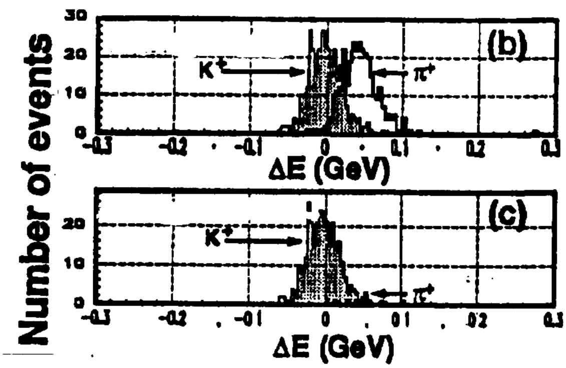

Fig. 6. (a) and (b) show the ΔE distributions before the ACC PID cut and after the ACC PID cut, respectively.

Summary

To explore the long standing puzzle about the origin of CP violation, the B-factory has been constructed at KEK by the BELLE collaboration. In the B-factory experiment, identification of particles, especially separation of pions from kaons aerogel Cherenkov counter system has been constructed and was tested using the beam test facilities at KEK π2 PS (Proton-Synchroton). The ACC is capable to separate π from K in the momentum range from 1.0 to 3.5 GeV/c. The FM-PMTs were found to show an excellent performance even in the strong magnetic field of 1.5 T for the detection of the Cherenkov light. A Monte-Carlo simulation study has been made for the rare B decay ($B \rightarrow \eta' K$) and the ACC has been found to work effectively in the separation of pions in kaons in this decay mode. Finally the ACC was successfully installed in the BELLE detector in November 1998 and now the data taking is going on.

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