Production and Performance Measurement of Multipurpose Silica Aerogel Cherenkov Counter

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***Abstract*—We are developing a multi-purpose aerogel Cherenkov counter (M-ACC). M-ACC is a particle identification (PID) device which works in a narrow space and can cover large area with arbitrary shapes. It can also function in a magnetic field. M-ACC has a light guide comprising wavelength shifting fibers (WLSF), and its application is π/K identification in high-energy physics experiments, β-ray detection from radioisotope, and so on. We concretely propose a design of M-ACC for LEPS II project. We produced a prototype M-ACC, and measured the performance of it in the LEPS beam line.**

I. Introduction

A Photon travels at a velocity c/n in a matter of refractive index n. When charged particles travel faster than speed of photons in the matter, the electric field of the atom inside the matter is disturbed. A photon is emitted when the electric field returns to its original state. This phenomenon is called Cherenkov radiation. A condition of Cherenkov photons is given as

$$n\beta > 1,$$

where n is the refractive index, v is the velocity of the charged particle, c is velocity of photon and $\beta = v/c$. Particles have different velocities in the same momentum. A device to identfy particles using the velocity difference is called Cerenkov counter.

A particle identification device using a radiator of the silica aergel is called aerogel Cerenkov counter (ACC) . Silica aerogel has properties: transparent to visible light, low density, low refractive index and the ability to determine of the refractive index in the production stage. Recent results show, silica aerogel has a high transparency and can be produced in a broad range of refractive index [1].

In general, it is difficult to make for a Cherenkov counter of thinner and large area. Because Cherenkov light emitted from the aerogel is collected to a photomultiplier tube side.

II. Mechanism of M-ACC

M-ACC is a particle identification device which works in a narrow space and can cover large area with arbitrary shapes. It can also function in a magnetic field. M-ACC has a light guide comprising WLSF, and its application is π/K identification in high-energy physics experiments, β-ray detection from radioisotope, and so on.

A. Cladding and Transmission Mechanism of WLSF

Generally, an optical fiber has a long transmission length by a total reflection condition between the core and cladding. WLSF re-emits light with the wavelength shifted isotropically. Only light satisfying the total reflection condition is transmitted to the both ends. The condition depends on the refractive index and the parallelism of between core and cladding.

Others leak out of the fiber. As the result, a photomultiplier tube (PMT) observes less light. When we use WLS, it is important how wach lich can be collected. The collection efficiency of a single cladding WLSF is 3.1% (6.2% in both sides). On the other hand, a multi cladding fiber has 5.4% (10.8% in both sides) collection efficiency, which is 1.6 times light collection compared to the single cladding [2].

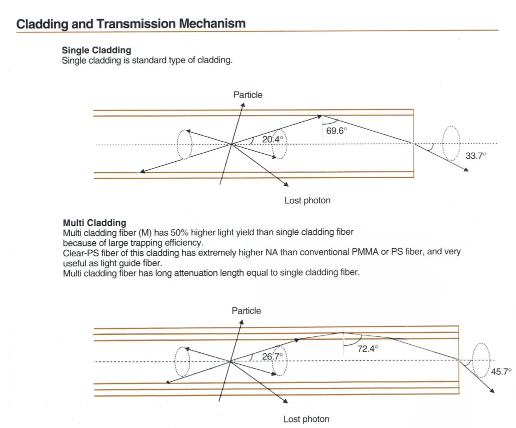

Fig. 1. WLSF's cladding and transmission Mechanism

B. Light guide system with four colors WLSF

Kuraray Co. Ltd. made four colors WLSF. Each fiber has different wavelength of absorption and emission (see TABLE I). Wavelength distribution of Cherenkov light is inversely proportional to the square of wavelength. Therefore, continuous wavelength is covered. A light guide is what sheet of fiber overlap in layers. The base has been laid a mirror. If the absorption wavelength of the fiber the emission wavelength range of the upper layer, light leaked from the fiber get a chance to be collected.

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It turned out that, those four colors was higher light collection efficiency compared with a color fiber by a beam test [3].

TABLE I
SPEC OF KURARAY'S FIBERS:ABSORPTION AND EMISSION PEAK WAVELENGTH

Type	absorption [nm]	emission [nm]
B-3	350	450
Y-11	440	470
O-2	540	550
R-3	570	610

C. Method of making equipment large area with arbitrary shape

A M-ACC has aerogel, air light guide which has inner reflector with aluminized mirror, fiber light guide made from four colors WLSF and small PMTs. The effective area increases in proportion to the length of the fiber. And it is possible to make arbitrary shapes by the fiber. The outlet of the fiber has small area, therefore a small PMT covers. If the particle hit to the fibers, define PID for the event loses reliable in a M-ACC. However, the second layer sensitive to the particle (Fig. 2).

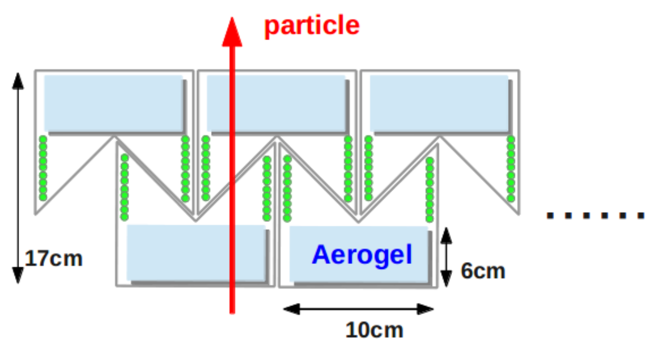

Fig. 2. Two layers of M-ACC have a thickness of 17 cm, nesting configuration and no dead region for PID. If a particle hits WLSF in M-ACC layer, Reliability of the information on the M-ACC is lost. However, the second layer sensitive to the particle.

D. Design for LEPS II ACC

One of the main motivations of the LEPS II experiment is to continue the existence of Θ^+ [4]. We are developing detectors to start the experiment in 2014. LEPS II was firstly scheduled to perform the particle identification by a time of propagation counter (TOP) and Time of Flight (TOF). There is a dead space if only TOF and TOP are installed. We are trying to compensate it putting the ACC between Drift Chamber and TPC. LEPS II ACC requires limited space, donut shape, working in Magnetic field and for K/π separation.

III. BEAM TEST FOR PROTOTYPE

We have produced a M-ACC prototype having 2 cm x 4 cm effective area using WLSF which has a diameter of 0.2 mm, multi cladding and four colors. We performed a measurement at the LEPS beam line in July 2013. The purpose was to verify whether the light guide using a fiber diameter of 0.2 mm could work properly.

A. LEPS beam line

Electrons of 8 GeV hit the laser at BL33LEP in SPring-8, γ-rays of 2.4-3.0 GeV are produced by inverse Compton scattering.LEPS the study of nuclei from the reaction with the target. e^+e^-pair production occur in the background. Beam test was used e^+. Positron is collimated by magnetic field (see Fig.3 Overview the beam line).

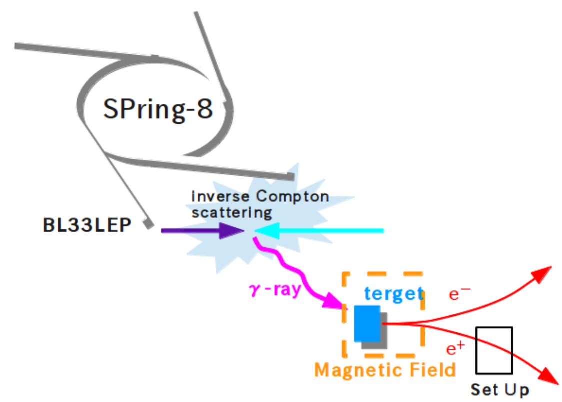

Fig. 3. Overview of LEPS beam line. Electrons of 8 GeV hit the laser at BL33LEP in SPring-8, γ-rays of 2.4-3.0 GeV are produced by inverse Compton scattering.LEPS the study of nuclei from the reaction with the target. e^+e^- pair production occur in the background. Beam test was performed by using e^+.

B. Configrations for the Beam Test

The beam test was carried out with a configuration shown in Fig. 4. We collected only events that the beam passes through the two scintillators. Aerogel that was used for the measurement has refractive index of 1.05, thickness 6 cm and the transmission length 4.1 cm. Cherenkov light is emitted when positron of 1-2 GeV passes the aerogel enter to fiber light guide on the forward side by the reflector that is set to 45 degrees.

Beam does not hit the fiber (Fig. 5). Each PMT is connected to four cables from the light guide. Two of the cable are bundled from the Y-11 and B-3, and is connected to the PMT 1, 4. Other bundled from R-3 and O-2, and is connected to PMT 2, 3. Model number of the PMT we used are as follows.

1. PMT 1ch, 4ch: R9880U-210
2. PMT 2ch, 3ch: R9880U-20
3. Photo cathode diameter 8 mm

C. Method of Analysis

As a trigger to obtain data, we required that a positron was detected by all of the scintillator in order to get the beam passing the aerogel properly. We analyzed the detection

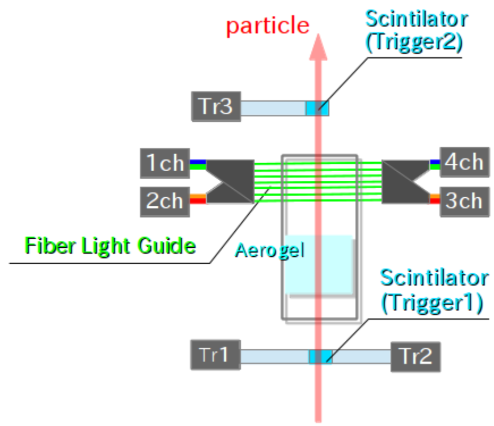

Fig. 4. Beam test set up: If the particles passed through the two scintillators, aerogel also must be traversed. Cross-section of the trigger is a 5 mm x 5 mm. Cherenkov light emitted from the aerogel enter the fiber light guide by being reflected. Four PMTs observe the light from the fiber.

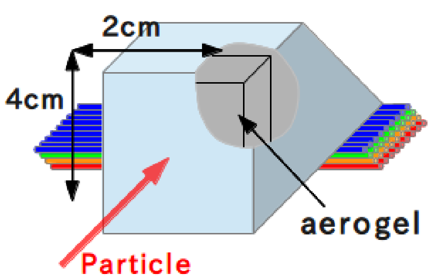

Fig. 5. Beam test set up: Cherenkov light emitted from the Aerogel enters the fiber light guide by being reflected. A fiber light guide is composed of of four colors WLSF (B-3, Y-11, O-2, R-3). Particles do not come into contact with fiber.

efficiency of M-ACC by all of the PMT connected the fiber light guide. It is a combination of the or logic:

$$1ch \cup 2ch \cup 3ch \cup 4ch,$$

of the detection event of each the PMT.

We calculated one of the PMT's detection efficiency (eff.) and the mean number of photoelectrons from the following equations:

$$eff. = \frac{DetectedEvent}{TotalEvent},$$

$$P_\lambda(k) = \frac{e^{-\lambda}\lambda^k}{k!},$$

where $P_\lambda(k)$ is the Poisson probability to calculate the number of detected photoelectrons with k, and λ is the expected number of photoelectrons (λ). If we substitute 0 for k, the equation represents a probability that PMT does not detect a Cherenkov light:

$$Inefficiency = 1 - eff. = e^{-\lambda}.$$

Therefore, the number of photoelectrons is expressed by the following equation:

$$\lambda = -In(1 - eff.).$$

Fig. 6 shows the distribution of the ADC for each PMT. We determined the detected event with statistical significance of 3σ from the mean of the pedestal.

D. Result

Mean number of photoelectrons and the detection efficiency in the PMT of each shows a TABLE II.From the analysis result of the or logic, measurements (61.1%) corresponded to the theoretical value (63.1%). We analyzed in the same way except of PMT 3 because it was out of order in this measurement. Measured value was 56.8% against 58% Expected value. If PMT 3 was running properly, detection efficiency can be calculated as 73.8% with a detection efficiency of PMT 2. It corresponds to Mean number of 1.34 photoelectrons.

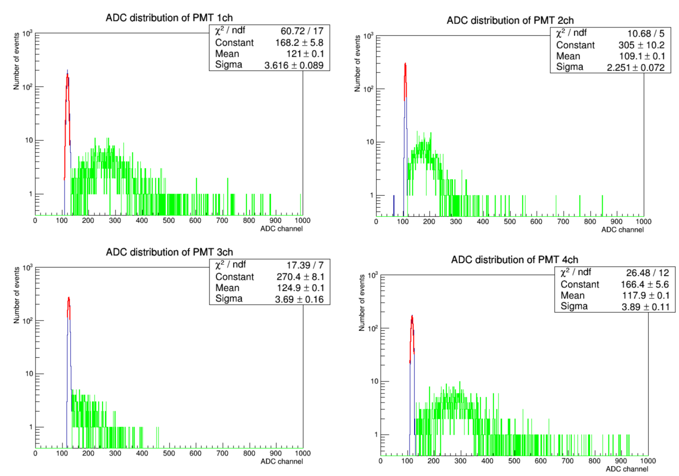

Fig. 6. Detection efficiency is derived from the ADC distribution of the PMT respectively. Gaussian fits to the pedestal (red line). Detection event is defined that is an event of statistical significance more than 3σ from the mean of pedestal (green).

TABLE II
RESULT ANALYSIS OF EACH PMT DETECTION EFFICIENCY AND THE MEAN NUMBER OF PHOTOELECTRONS.

ch	Total event	Detect. event	eff.	error	p.e.	error
1	2509	918	36.6%	±1.0%	0.46	±0.02
2	2509	845	33.7%	±1.0%	0.41	±0.01
3*	2509	263	10.5%	±06%	0.11	±0.01
4	2509	919	36.6%	±1.0%	0.46	±0.02

IV. CONCLUSION AND DISCUSSION

We have produced a prototype using WLSF which have diameter 0.2 mm, multi cladding and four colors. Results of the beam test, prototype I observed Cherenkov light of 58% detection efficiency. however, PMT 3 was out of order in this measurement. If PMT 3 was running properly, detection efficiency is expected 73.8% (1.34 photoelectrons).

Aerogel that was used for the measurement has a refractive index of 1.05, thickness 6 cm and the transmission length 4.1 cm. Amount of Cherenkov photons that generated by a positron of 1-2 GeV is about 50 photons per cm. WLSF have 88% probability of entering the core, about 50% efficiency to re-emission by absorbing light in the core, 10.8% light collection efficiency by total internal reflection. Mean quantum efficiency of the PMT is about 20% in the region of 300-600 nm wavelength sensitivity. Therefore theoretical value is 1.46 photoelectrons.

We measured using positron, but the measurement should be evaluated for pions in fact.From the velocity of pions of 1-2 GeV/c momentum, it is 1.07 photoelectron. PID efficiency can achieve 97% if four layers of M-ACC is used.

It is sufficient a thickness of 6 cm of the aerogel from the result. A layer has a thicness of 11 cm when the width of the light guide has a 10 cm. Two layers have a thickness of 17 cm because it is nested. Two or more layers have no dead region for PID. Total thickness of 34 cm is required in four layers. Future works are production of large size prototypes and test with atmospheric muons.

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