Performance of Clear Fiber TOP Detector

D. Kumogoshi, S. Han, S. Iijima, H. Ito, H. Kawai, S. Kodama and K. Mase

***Abstract*– Usual TOP (time of propagation) detectors have several disadvantages. We propose a new TOP detector which overcomes those by using clear fibers (these have high transparency than general optical fibers). We performed Monte Carlo simulations with Geant4 and tested a prototype with e^+ of 0.7 to 1.0 GeV at SPring8 BR33LEP beam line. We propose this detector to E-36 experiment at J-PARC.**

I. Introduction

When photon runs in a matter of refractive index n, its velocity is c/n. If charged particles run faster than photon in the matter, light is emitted. The light is called Cerenkov light and this phenomenon is called Cerenkov radiation. Cherenkov photon is emitted at an angle in accordance with the formula.

$$\cos\theta_c = 1/n\beta$$

TOP detector totally reflects the light emitted, transmits in radiator and measures the arrival time and arrival x coordinate with photo multiplier tube (PMT). If the momentum of particles are equal, the Cherenkov angle θc is different because of various β of each particle. As a result, the difference of propagation time and arrival position are appeared. TOP detector identifies particles by using this method.

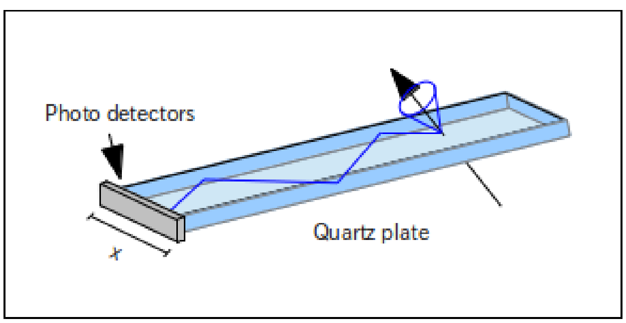

Fig.1. Usual TOP detector

Usual TOP detector have several disadvantages. First, this is very expensive. This detector is consist of a quartz plate. The typical size is about 2 m length, 40 cm width and 2 cm thickness. The surface of detector has to be polished to transmit photon to PMT. Secondly, this must use many PMTs which have high time resolution and can be used in magnetic field. Because this propagation length is 2 m, the short length make small time difference. It have to set many small PMTs to obtain high position resolution. It is assumed that this detector is used in magnetic field. Thirdly, this data taking system is complicated. This detector identifies particles by reconstructing a ring image with arrival time and arrival position.

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II. TOP detector under development

Our detector uses the optical fibers as a radiator. We have 2 candidate fibers. One is single cladding fiber ESKA made by Mitsubishi Rayon Co. Ltd. The other is double cladding fiber made by Kuraray Co. Ltd. The core is made of polymethylmethacrylate with the refractive index of 1.49 and the cladding is made of fluorinated polymer with the refractive index of 1.42. The price is 33,000 yen/km. The other is double cladding fiber Kuraray Co. LTD. The core is made of polystyrene with the refractive index of 1.59 and the outer cladding is made of fluorinated polymer. The price is 540,000 yen/km. These attenuation length is 50 m.

This detector is constructed from several fiber sheets. The fiber sheet is composed of 2 layers of the fibers. Thickness of detector is modifiable by a condition.

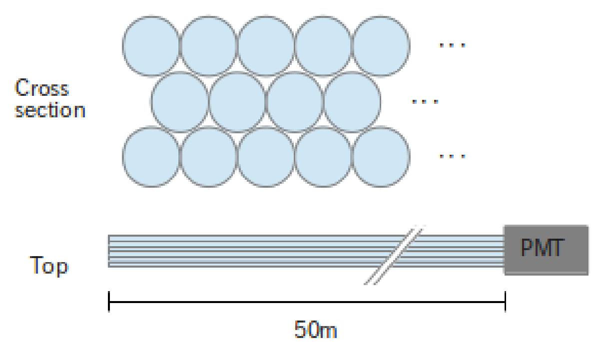

Fig.2. TOP detector under development. Diameter of fibers is 1mm. We bundle up fibers of 50 m and make it.

Cherenkov light generated propagates in fibers. If a radiator is a long fiber, our detector can identify particles by only it and it is able to use standard PMTs at out of magnetic field. Thus, our detector is more economical and easy to treat and this data taking system becomes simple.

III. Simulation

A. Calculation

Because the difference between refractive index of core and clad of an optical fiber is small, range of angles satisfying the total reflection condition is limited.

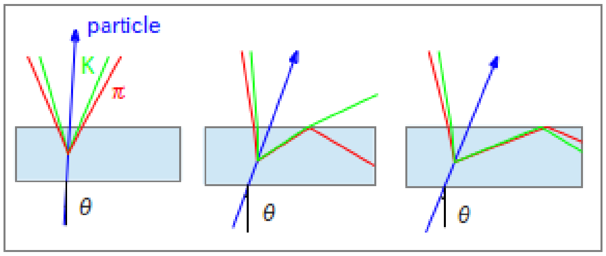

Fig.3. These are patterns of cherenkov light propagation by incident angle of particle. If the incident angle is small, a fiber does not reflect the light at all.

It is conceivable that both Cherenkov light of π and K is not reflected or the light generated either π or K is reflected. Therefore we calculated range of incident angles of particles that Cherenkov light generated in the optical fiber is totally reflected. We also calculated the angle when the difference of time is the longest. Momentum of particles is 1 GeV/c.

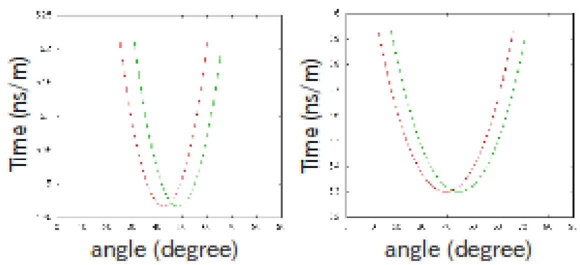

Fig.4. We calculated and found left graph with a fiber made by Mitsubishi Rayon and right graph with a fiber made by Kuraray. Because difference between refractive index of core and clad of a Kuraray fiber is bigger, range of available angle is also bigger.

The maximum time difference of a Mitsubishi Rayon fiber is 0.13 ns/m. The difference of a Kuraray fiber is 0.23 ns/m. Thus, it is likely that we obtain pleasing results to identify particles by making detector with long fibers.

B. Simulation

We performed a Monte Carlo simulation with Geant4. In this simulation, π/K separation and e^+/μ separation is a purpose. e^+/μ separation is required from E-36 experiment(see chapter 5). These figures show the propagation time distribution in case that the propagation length of 50 m. Particles passed into a target that is five layers of the fiber sheet at the angle of the maximum difference of propagation time. Fibers made by Mitsubishi Rayon Co. Ltd

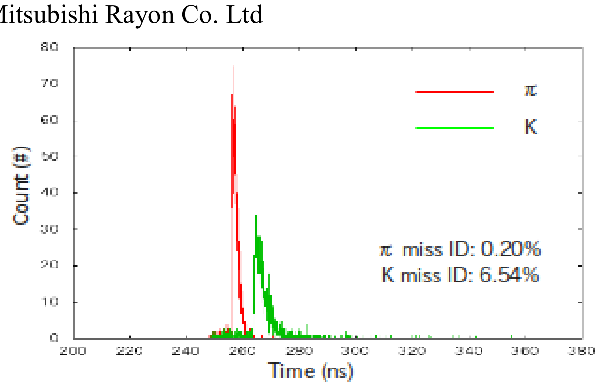

Fig.5. This is π/K of 1.0 GeV/c separate simulation. A group before a peek of green is Cherenkov photons emitted by knock on electron.

In Fig.5., a detector detected Cherenkov light from all fiber sheets. It outputs the shortest propagation time when the light is detected. The light emitted by knock on electrons also were detected. Because of that, miss-identification of K increased but miss-identification of π decreased.

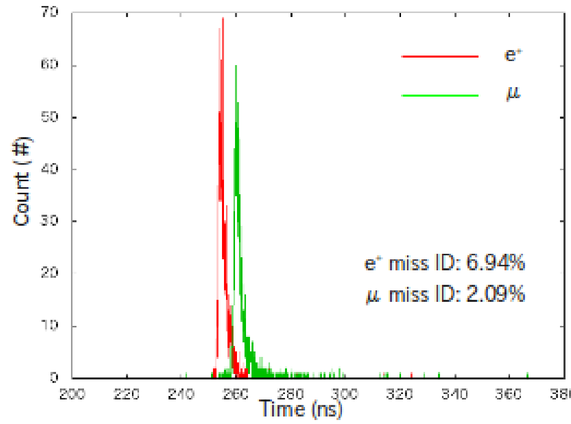

Fig.6. This is e^+/μ separate simulation. The momentum of e^+ is 247 MeV/c. The momentum of μ is 235.7 GeV/c. In this simulation, we used 5 photo detectors to reduce effects of knock on electron.

In the simulation of e/μ separation, we prepared a detector for each sheet. We collected the shortest propagation time of each detector and calculated average of propagation time without the shortest and longest propagation time of five propagation times. In doing it in this way, we could reduce effects of knock on electron. Miss-identification of e increased but miss-identification of μ decreased. This shows a possibility that our detector can use in various experiment by changing detection method each experiment.

IV. EXPERIMENT

We made a prototype that is consist of a fiber sheet with Mitsubishi Rayon fibers and tested the detector whether Cherenkov light arrived to a PMT. This test use e+ of 0.7 to 1 GeV at Spring-8 BR33LEP beam line. As a result, The fiber transmitted Cherenkov light without a critical problem. In this experience, $N_{p.e.}$ is approximately 0.80 because efficiency is 55.2 %. If our detector is made with ten fiber sheets and fiber length is 50m, efficiency is 94.7 %.

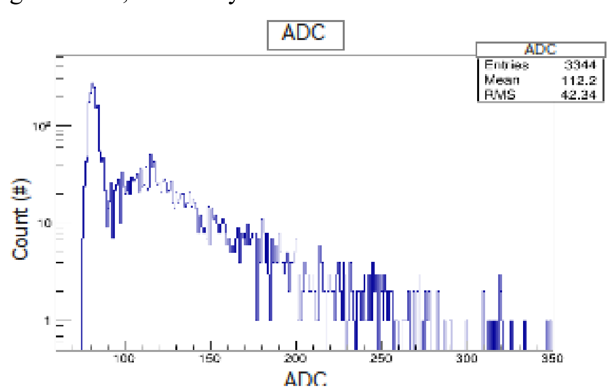

Fig.7. TOP detector ADC. Because a prototype was consist of a fiber sheet in this experiment, count of pedestal is much. Since our real size detector is consist of 5 – 10 fiber sheets, it is assume that the count decrease.

Time resolution of this detector is 400 ps. This value is consist of Time resolution of PMT. (Rise time of PMT used in this experiment is 570 ps.)

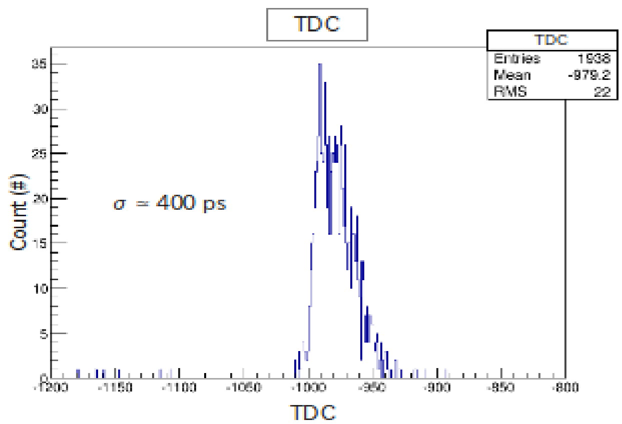

Fig.8. TOP detector TDC. Time resolution of this prototype depends on rise time of PMT used in this experiment.

V. Conclusion and Discussion

In Monte Carlo simulation of π/K and e/μ separation, we obtained results that π miss-identification is 0.20 % and μ miss-identification is 2.09 %. We have produced a prototype using a fiber sheet which is made with optical fibers. In the beam test with e of 0.7 to 1.0 GeV, the prototype showed that efficiency is 55.2 %. So it is conceivable that efficiency is more than 94.7 % by making our detector with ten fiber sheets.

VI. Plan for the Future

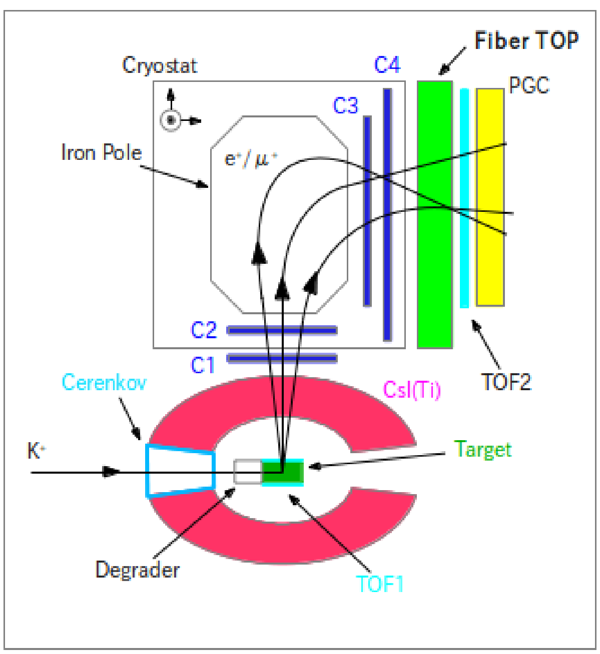

Fig.9. Rough design of E-36 detectors at J-PARK

Fig.9. shows the rough design of E-36 detectors at J-PARC. This experience's purpose is to measure a ratio of 2 body leptonic decay width of K. Now,

$$\Gamma(e^+\nu_e)/\Gamma(\mu^+\nu_\mu) = 2.493 \pm 0.025.$$

This experiment want to measure this ratio with ± 0.01. Therefore, more accurate e^+/μ separation is necessary. Particle identification system is not decided. We propose the clear fiber TOP detector.