Performance evaluation of a threshold-type Cherenkov detector using low index aerogel

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This article describes a performance evaluation of a threshold-type Cherencov dector designed for an experiment on charmed baryons (Y_c^{*+}) via the $p(\pi^-, D^{*-})Y_c^{*+}$ reaction at J-PARC (E50)[1]. The present work was based on Tasumi's master thesis [2] which received the HUA Master Thesis Award in FY2021.

One of the main goals of hadron physics is to understand how quarks build hadrons. Due to non-perturbative behavior of the Quantum Chromodynamics (QCD) at a low energy, the chiral symmetry of QCD is spontaneously broken. As a result, quarks are confined in a hadron and constituent quarks emerge as effective degrees of freedom to describe hadrons. Since the QCD Lagrangean is not analytically solved, the dynamics of the quarks in a hadron has yet to be clarified. In paricular, a diquark correlation, which is a two-quark correlation in a hadron and considered to play an important role to charactorize hadron properties, has not experimentally been established. The diquark correlation is expected due to a strong attraction of a spin-spin interaction between two quarks. Its attraction is a source of the diquark condensate which is thought to be realized in very high-density quark matter. Therefore, it is of importance to investigate the nature of the diquark correlation. As a first step, we will establish the diquark correlation developed in a baryon through studies of charmed baryons.

In the E50 experiment, a high-momentum π^- beam of 20 GeV/c is irradiated to a liquid hydrogen target to produce charmed baryons associated with D^{*-} mesons. The decay particles of D^{*-}, two π^- and K^+, are detected to reconstruct the invariant mass of D^{*-}. Then, the mass of Y_c^{*+} is reconstructed as a missing mass from measured beam-π^- and D^{*-} momenta. Since the cross section of the $p(\pi^-, D^{*-})Y_c^{*+}$ reaction is expected to be as small as $\sim$1 nb, a particle identification (PID) of kaons from pions is of vital importance in order to identify the Y_c^{*+} production with good sensitivity.

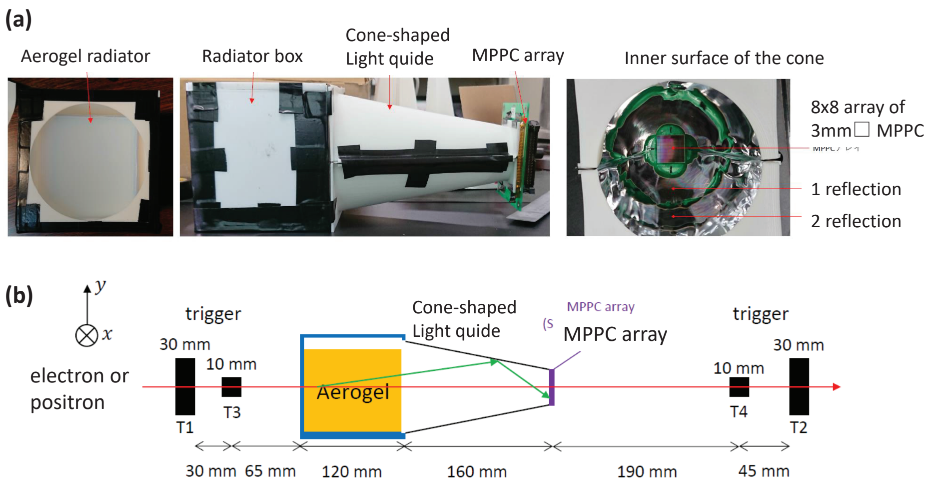

Figure 1: (a) Prototype of the threshold-type Cherenkov PID detector. (b) Setup of the test experiment by using an electron or a position beam at LEPS2.

We are preparing several kinds of PID detectors as a momentum range of scattered particles is as wide as up to 16 GeV/c. Time of Flight counters such as X-shaped acryl cherenkov counters [3], scintillator hodoscopes [4] and multi-gap resistive plate chambers [5] will be employed to separate kaons from pions in a momentum range below 2 GeV/c. A ring imanging cherenkov detector will be used to identify charged particle greater than 4 GeV/c [6]. As for PID in a momentum range of 2 to 4 GeV/c, we have developed a threshold-type Cherenkov PID detector using aerogel radiators with a low refractive index of 1.007 [7]. Cherenkov light emission from a low refractive index aerogel radiator is expected to be small so that it is necessary to collect the emitted light efficiently. We designed a PID detector with light sensors placed at the forward direction to directly detect the emitted Cherenkov lights. We finally employed an 8$\times$8 array of 3 mm$\times$3 mm Multi-Pixel Photon Counter (MPPC) as it has a good photon detection efficiency and can be operated freely under a magnetic field from the spectrometer magnet. A cone-shaped light guide is attached to the radiator box to accumulate Cherenkov lights to the effective area of MPPC. The inner surface of the light guide is covered by an Aluminum-coated Mylar sheet. A prototype PID detector was produced as shown in Fig. 1-(a). Its performances were evaluated by using an electron or a positron beam at LEPS2 in the SPring-8 facility (Fig. 1-(b). We determined the trasparency of the aerogel radiators, the defuse reflectivity of the radiator box, and the reflectance of the light guide so as to reproduce the number of photo-electrons and the multiplicity of hit sensors in the MPPC array observed in the test experiment. Taking into account those optimized optical properties in the simulation code, we re-designed a PID counter. Here, we assumed that the transparency of the aerogel radiators is 17.5 mm as Tabata has demonstrated successfully to fabricate aerogels with the transparency of 17∼18 mm at the refractive index of 1.007[8]. First, we determined the length of the light guide to be 120 mm to maximize the multiplicity of the hit sensors by the simulation. Sencond, we found that the misidentification probability of a kaon as a pion is reduced to be less than 1% when we select the events with the hit multiplicity greater or equal to 3, while the pion-detection efficiency of greater than 95% will be kept, as shown in Fig. 2.

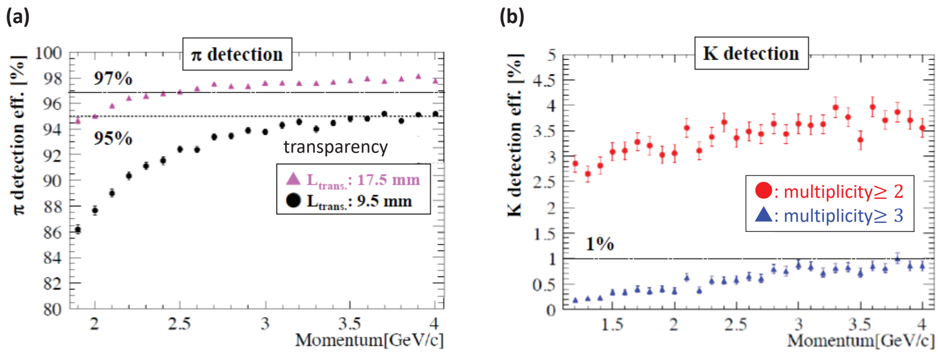

Figure 2: (a) pion-detection efficiency as a function of the pion momentum. (b) kaon-detection efficiency (mis-identification probality of a kaon as a pion) as a function of the kaon momentum.

References

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