Nuclear Instruments and Methods in Physics Research A 623 (2010) 48–56

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima

Recent topics of particle identification and photodetection

Toru Iijima *

Department of Physics, Nagoya University, Chikusa, Nagoya 464-8602, Japan

ARTICLE INFO

Available online 7 March 2010

Keywords:
Particle identification
Ring Imaging Cherenkov detector
Photodetectors
Quartz
Aerogel

ABSTRACT

The paper reviews recent progress in particle identification and photodetection. The main emphasis is on ring imaging Cherenkov detectors using aerogel and quartz radiators, and associated photodetectors in the visible light region, which have been developed in the past several years for the present and future B physics programs. It is shown that detection of a Cherenkov photon with precise time resolution at an order of 10 ps has become one of recent trends to improve particle identification performance.

1. Introduction

Particle identification (PID) is an important technique in particle, nuclear and astro-particle physics experiments. In many cases, it is essential to identify final-state particles to discriminate reactions or decays of interest against backgrounds. Especially, discrimination of pions and kaons plays essential roles in studies of heavy flavor particles. B decay experiments are the typical case. First, in *CP* violation measurements, identification of charged kaons and leptons are demanded to tag the B-meson flavor with their charge. Second, in reconstruction of rare decays, such as $B\to\pi\pi$ and $B\to\rho\gamma$, efficient PID is required to separate these decays from the $B\to K\pi$ and $B\to K\gamma$ decays, respectively. In the e^+e^- B-factory experiments, it is required to cover the momentum region up to $\sim 1.5\,\mathrm{GeV}/c$ for the first, and $\sim 4\,\mathrm{GeV}/c$ for the second categories. In the coming LHCb experiment, the momentum region of interest extends further to $\sim 100\,\mathrm{GeV}/c$, and K/p separation also becomes important. Clear identification of charged kaons are required also for reconstruction of charm mesons and baryons. Such heavy flavor reconstruction is important also in experiments to search for quark-gluon plasma and to study nucleon structures [1].

In this paper, we describe recent progress in PID and photodetection. In general, hadrons are identified by their mass, deduced from the measurements of momentum and velocity. In many experiments, the momentum is inferred from the measured radius of curvature in magnetic field. The role of PID detectors is to measure the velocity with sufficient precision. This is achieved either by measuring the time-of-flight (TOF), ionization loss (dE/dx) or Cherenkov angle of the particle. We place emphasis on Ring Imaging CHerenkov (RICH) detectors using aerogel and quartz radiators, and associated photodetectors in the visible light region, which have been developed in the past several years for the present and future B physics programs. It is shown that detection of a Cherenkov photon with precise time resolution at an order of 10 ps has become one of the recent trends to improve particle identification performance [1].

The structure of the paper is as follows. We first review the Cherenkov detectors with aerogel and quartz radiators. For both type of Cherenkov detectors, we present a number of new methods and idea in radiator design and photodetection, to overcome limitations of existing detectors. We then discuss some topics from recent R&D's; precision TOF counters with ~ 10 ps resolution, and utility of APD's operated in the limited Geiger mode as a RICH photodetector.

2. Cherenkov detectors with aerogel radiator

Silica aerogel, a colloidal form of SiO_2 with more than 95% porosity, is a unique material to fill the index gap between compressed gas and liquid materials. Available refractive index (n) ranges from ~ 1.006 to ~ 1.1, and the material is widely used as radiators of threshold Cherenkov counters for π/K separation in GeV/c region. In recent R&D's, optical transparency has been gradually improved to give the transmission length of more than 40 mm, which makes aerogel more promising as RICH radiators [2,3].

2.1. Aerogel Cherenkov counter for Belle

In the Belle experiment at the KEK B-factory, a threshold Aerogel Cherenkov Counter (ACC), is used to provide π/K separation in the momentum region from 0.8 to $3.5\,\mathrm{GeV}/c$ [4]. The system consists of a barrel ACC and a forward endcap ACC.

* Tel. +81 52 789 2893; fax: +81 52 782 5752.
E-mail address: iijima@hepl.phys.nagoya-u.ac.jp

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doi:10.1016/j.nima.2010.02.149

The barrel ACC is composed of 960 counter modules, segmented into 60 cells in the ϕ direction (see Fig. 1). The refractive index of aerogels ranges from 1.01 to 1.028, depending on the polar angle to cover the momentum region up to 3.5 GeV/c, which is important for two-body B decays such as $B^0 \to \pi^+\pi^-$. As for the endcap ACC, aerogels with $n = 1.030$ are used so that the detector functions for flavor tagging in the momentum region from 0.8 to 2.5 GeV/c. The whole system is located in a 1.5 T magnetic field, and Cherenkov light signals are detected by finemesh PMTs with diameter of 2, 2.5 and 3 in. The typical light yield for light velocity particles is about 15 for the barrel ACC and about 30 for the endcap ACC. Combined with time-of-flight measured by plastic scintillator array (TOF) and dE/dx measured by a central drift chamber (CDC), ACC provides the kaon identification efficiency of about 90% with the pion fake probability of 6%.

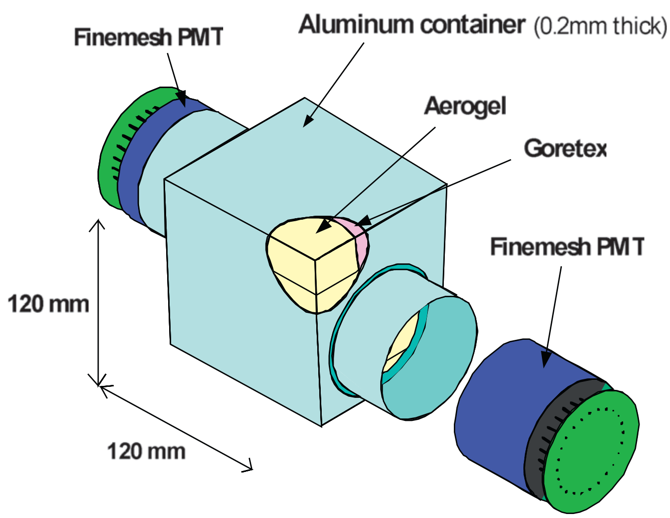

Fig. 1. Schematic drawing of a typical Belle ACC counter module.

2.2. RICH counters for LHCb

In the LHCb experiment, the RICH counters are designed to provide π/K separation between 1 and 150 GeV/c [5]. In general, the momentum region covered by a RICH counter, from p_{min} to p_{max}, depends on the threshold momentum for the lighter of the two particles to be separated, and on the Cherenkov angle resolution, ultimately given by the chromatic dispersion in the radiator medium. For most radiators, $p_{max}/p_{min} \approx 4-7$, according to Ref. [6]. In order to cover the wide momentum region, LHCb use three radiators arranged in two RICH counters, RICH1 and RICH2, as shown in Fig. 2. The RICH1 is equipped with aerogel radiator ($n = 1.03$) to cover 1–10 GeV/c and C_4F_{10} ($n = 1.0014$) to cover 10–60 GeV/c. The RICH2 uses CF_4 ($n = 1.0005$) to cover the higher momentum region.

The aerogel radiator for LHCb RICH1 has been developed by collaboration of Boreskov Institute of Catalysis and Budker Institute of Nuclear Physics [3]. Highly transparent aerogel with light scattering length of 4–5 cm at 400 nm wavelength and with thickness of 5 cm has been produced. Cherenkov lights from radiators are imaged onto the photodetection planes by a spherical mirror and a flat mirror for both RICH1 and RICH2.

Photodetection is carried out by using an array of hybrid photon detectors (HPD), developed in collaboration with the DEP company [7]. As shown in Fig. 3, photoelectrons are emitted from 80 mm ϕ S20 photocathode, accelerated by the electric field across a potential difference of about 20 kV with image demagnification factor of about 5, and bombarded into a silicon detector with pixel readout. In total, 550 HPD have been produced to construct the detectors. Both RICH1 and RICH2 detectors have been constructed, installed and wait for beams [8].

2.3. Proximity focusing RICH for Belle II

A proximity focusing RICH with aerogel as radiator has been proposed for the upgrade of the forward-endcap part of the Belle experiment. It is composed of a few cm thick aerogel radiator and

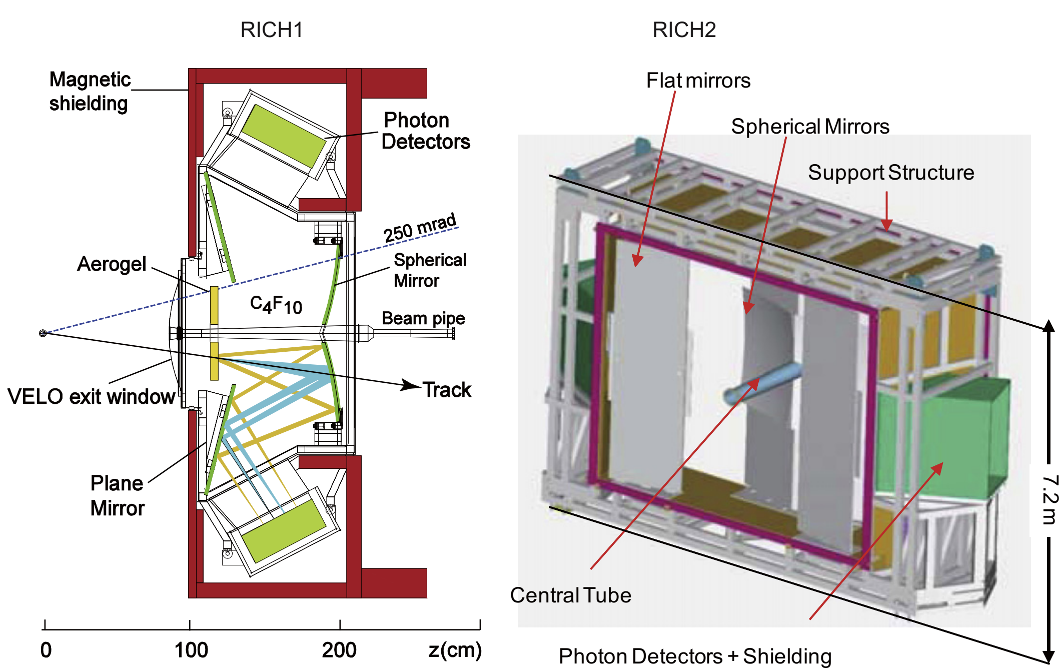

Fig. 2. RICH counters for the LHCb experiment.