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Recent progress in particle identification methods

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ABSTRACT

The paper reviews recent progress in particle identification methods based on detection of Cherenkov radiation. We survey the present experience in Cherenkov counters employed for particle identification in various experimental environments, discuss upgrades of existing devices, a novel focusing radiator concept, and recent progress in photon detectors. Finally, the possibility to perform a precise measurement of the time of arrival of Cherenkov photons is evaluated, either in combination with a ring imaging counter or in a dedicated time-of-flight device.

1. Introduction

Reliable particle identification methods have by now become an indispensable part of spectrometers, in particular in heavy flavour physics and nuclear physics experiment. To list a few examples: tagging of B meson flavour with the kaon charge in the CP violation measurements in the B system, study of rare B and D meson decays, hadron identification in the search for quark–gluon plasma and in studies of the nucleon structure. Hadrons are identified by their mass, which is, in turn, determined by combining the measurements of momentum and velocity. Assuming that momentum is inferred from the measured radius of curvature in a magnetic field, the remaining issue is to measure the velocity with sufficient precision. This is either achieved by measuring the time-of-flight (TOF), ionization losses or Cherenkov angle of the particle. In the present contribution recent progress in Cherenkov counters and TOF measurements are discussed.

The structure of the paper is as follows. We first review the Cherenkov counters in some of the running or recently completed experiments. A number of new methods is presented, from upgrades of existing devices to a novel focusing radiator concept and new photon detectors. We then discuss the benefits of including a precise measurement of the time of arrival of Cherenkov photons either in order to reduce the dispersion error, or in a combined RICH and TOF, a time-of-propagation (TOP) counter, or even in a dedicated TOF counter.

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2. Cherenkov counters

2.1. DIRC at BaBar

The DIRC (Detector of Internally Reflected Cherenkov light) of the BaBar spectrometer is a special type of a ring-imaging Cherenkov counter [1], based on the detection of Cherenkov photons trapped in the quartz radiator bar (Fig. 1). The patterns on the photon detector are quite complicated, but result in well resolved peaks in the Cherenkov angle distribution. The time of arrival of photons is used to eliminate background from conversions in the large water tank, to assign photons to proper tracks, and to eliminate most of the ambiguities in the photon-track reconstruction.

The basic performance parameters of the counter are in excellent agreement with expectations [1]. The single photon resolution amounts to 9.6 mrad. The number of photons depends on the polar angle of the charged track, but always stays above 20 for $\beta = 1$ particles. The efficiency for kaon identification exceeds 90% in the momentum range $0.5\,\mathrm{GeV}/c{-}3\,\mathrm{GeV}/c$, while the probability that a pion is identified as a kaon stays at the few percent level.

2.2. ACC at Belle

In the Belle spectrometer the separation of kaons from pions is performed with the Aerogel Cherenkov Counter (ACC) (Fig. 2), a threshold Cherenkov detector with aerogel as radiator, and fine mesh PMTs as photon detectors [2]. The refractive index of the radiator is chosen so that pions emit Cherenkov light, while kaons

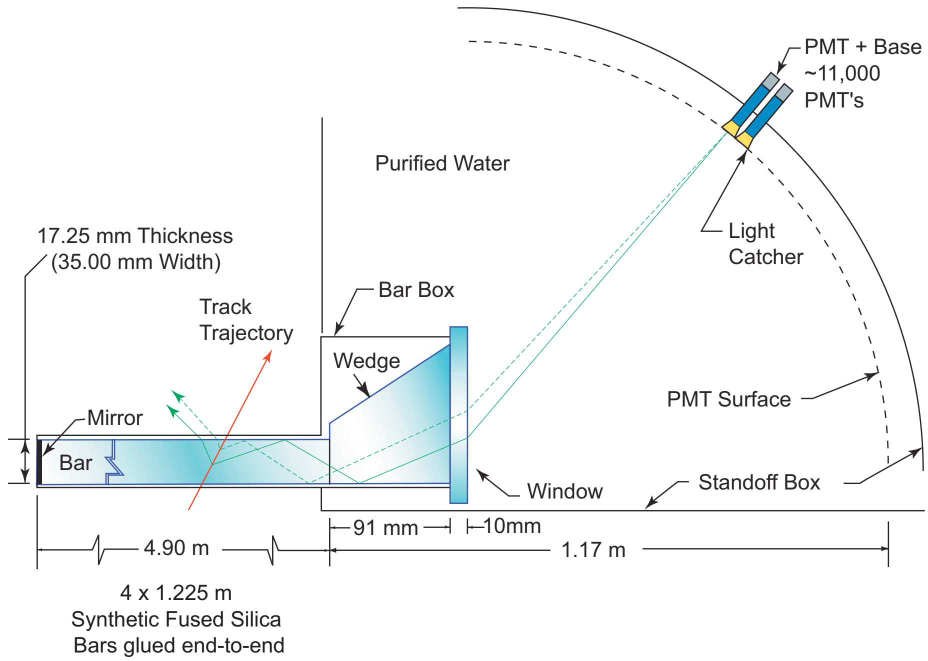

Fig. 1. Principle of the DIRC counter.

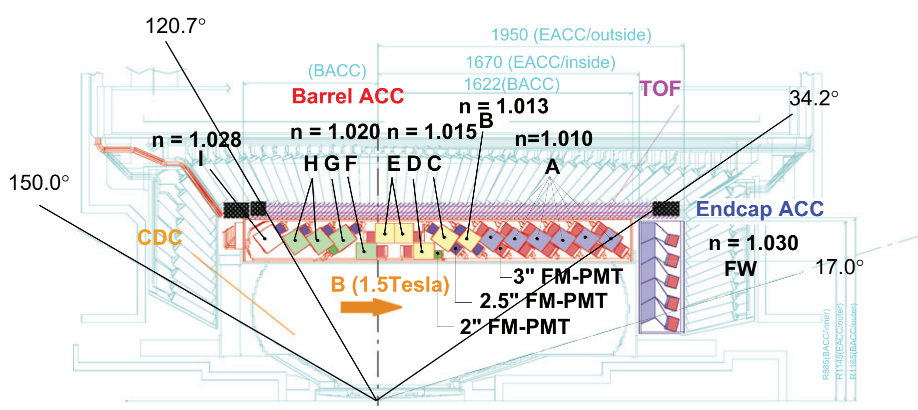

Fig. 2. Schematic drawing of the BELLE ACC system.

stay below threshold. Since the colliding electron and positron beams have different energies, the momentum spectrum of particles produced in collisions becomes harder in the direction of the more energetic beam ('forward direction'). To match this, the Cherenkov threshold has to vary as a function of the production angle, and the refractive index of the modules gradually changes from $n = 1.028$ to 1.01 in the central (barrel) part of the spectrometer. Note that while in the barrel part it is possible to measure both the low momentum tagging kaons and the $B \to \pi\pi, K\pi$ decay products with higher momenta, only the former can be identified in the forward (endcap) direction. The kaon identification efficiency amounts to 90% with the pion fake probability equal to 6% [3].

2.3. HERA-B RICH

The HERA-B collaboration was the first to employ multianode photomultiplier tubes in a RICH counter (Fig. 3) [4], after having shown that the Hamamatsu R5900 PMTs (versions M16 and M4 with 16 and 4 square shaped channels, respectively) have a capability to detect single photons with high efficiency, and little cross-talk [5]. The photon detector performed very well, showing clear rings with only a few noisy channels (<0.5%) even in the hostile environment of a hadron machine [4].

A common drawback of vacuum based photon detectors is a rather large fraction of dead area. While for single channel PMTs reflective cones can be used, multichannel PMTs need an imaging system. In the HERA-B RICH, a system of two lenses, shown in Fig. 3, was used to demagnify the image on the focal surface by a factor of 2 [6]. The system of lenses is used both to reduce the dead area as well as to adapt the required granularity of the photon detector to the granularity of the multianode PMT. The transparency of the system is high in the region of high quantum efficiency of the tube. It also has a flat acceptance for photons with incidence angles below 140 mrad as required by the detector geometry.

The experience of the HERA-B collaboration shows that a RICH counter can safely be operated even at high track densities with counting rates exceeding 1 MHz per channel in the hottest part of