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RICH counters for b-experiments

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Abstract. The paper reviews the motivation and status of ring imaging Čerenkov (RICH) counters for Belle and BaBar, experiments at e^+e^- B-factories, as well as their upgrades.

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1 Introduction

One of the main driving forces of the research and development for the RICH counters was in the last decade the need to have excellent hadron identification for precision B physics measurements. For a statistically significant measurement of CP violation in the B system, tagging of B meson flavour with kaon charge was an indispensable method. In addition, in order to study the rare few body hadronic decays of B mesons it is essential to separate pions from kaons up to the kinematic limits of the experiment.

2 Present Čerenkov counters for B-factories

2.1 DIRC at BaBar

The DIRC counter of the BaBar spectrometer is a novel type of a ring-imaging Čerenkov counter [1], based on the detection of internally reflected Čerenkov light (Fig. 1). The patterns on the photon detector are quite complicated, but result in well resolved peaks in the Čerenkov angle distribution. The time of arrival of photons is used to eliminate background from conversions in the water tank, 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 per saturated ring depends on the polar angle of the charged track, but always stays above 20. The efficiency for kaon identification exceeds 90% in the momentum range 0.5 GeV/c - 3 GeV/c, while the probability that a pion is identified as a kaon stays at a few percent level (Fig. 2).

2.2 ACC at Belle

In the present Belle spectrometer the separation of kaons from pions is performed with an Aerogel Cherenkov Counter (ACC), a threshold Čerenkov counter (Fig. 3) with aerogel as radiator [5]. The refractive index of the radiator is chosen such that pions emit Čerenkov light, while kaons stay below threshold. Since the momentum spectrum of particles becomes harder in the forward direction, the refractive index of the modules gradually decreases from $n = 1.028$ to $n = 1.01$. Note that while in

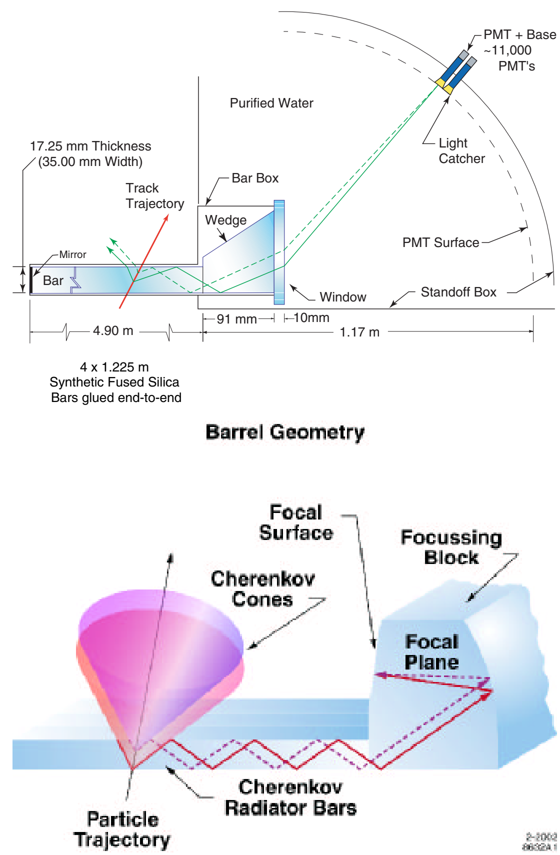

Fig. 1. Principle of the DIRC counter (*top*) and its upgrade (*bottom*)

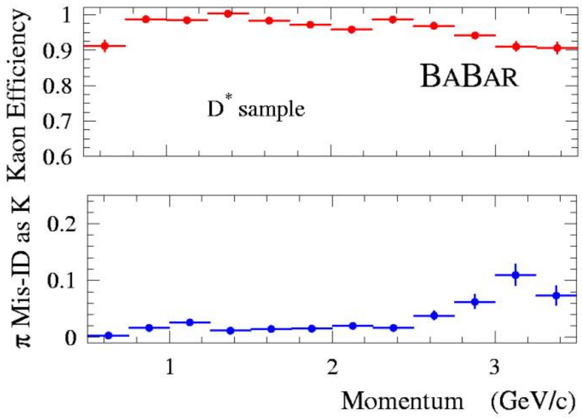

Fig. 2. Particle identification with DIRC: K efficiency and $\pi \to K$ missidentification probability

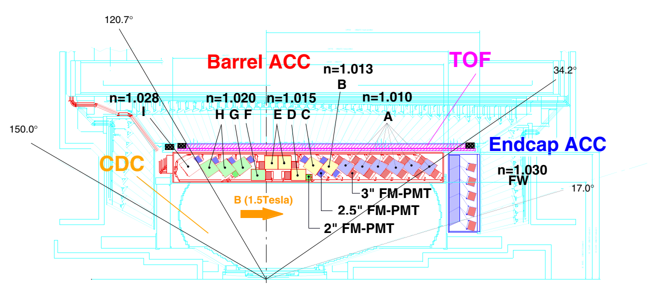

Fig. 3. Aerogel Čerenkov Counter (ACC) of the Belle spectrometer

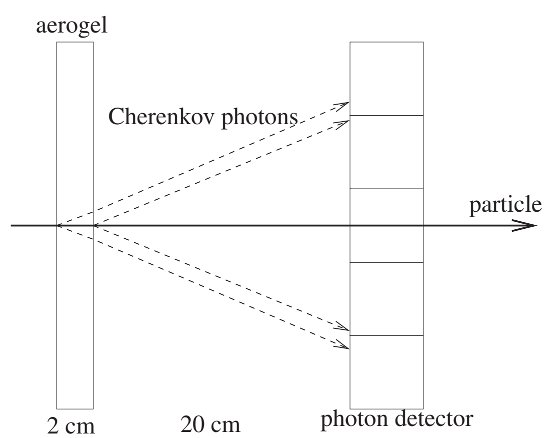

Fig. 4. Proximity focusing RICH for the Belle upgrade in the endcap region

the central (barrel) part it is possible to cover both the tagging kaons and $B \to \pi\pi, K\pi$ decay products, in the forward (endcap) direction only the former can be identified. The kaon identification efficiency amounts to 90% with the pion fake probability equal to 6% [6].

3 Upgrades for B-factories

For the next round of B physics experiments at upgraded e^+e^- machines ('Super B factories') with luminosities exceeding 10^{35} cm^{-2}s^{-1}s considerable upgrades of particle identification devices are envisaged to cope with higher rates and with more stringent requirements on separation capabilities for rare decay channels.

3.1 Upgrades at Belle

Two systems are being considered for the upgrade of the Belle spectrometer. For the barrel region a time-of-propagation counter (TOP) is being studied, a kind of 'inverted DIRC' in which the Čerenkov angle is deduced from the time of arrival of Čerenkov photons [7]. For the endcap region, a proximity focusing RICH with aerogel as radiator is being tested (Fig. 4). The counter should have a low threshold for pions, and enable a good separation of pions and kaons up to 4 GeV/c. Another benefit of such a counter would also be a reasonable $e/\mu/\pi$ separation at low momenta, of importance for the studies of rare $B \to K\ell\ell$ decays.

In a series of beam tests the feasibility of such a counter was studied [8,9]. The recently developed flat panel PMTs (Hamamatsu H8500) were used as the photon detector. As can be seen from Fig. 5a, the Čerenkov peak is well pronounced above a small background, mainly coming from Čerenkov photons which were Rayleigh scattered in the radiator. The resolution in the Čerenkov angle measurement (14 mrad) and the number of detected photons (around 6, Fig. 5b) agree well with expectations. The resulting resolution per track is about 5.7 mrad. Since the difference in Čerenkov angle of pions and kaons is 22 mrad at 4 GeV/c, such a counter would allow a good (about 4σ) separation up to the kinematic limit of the experiment.

The present R&D efforts are oriented mainly towards the development of a photon detector which can stand the high magnetic field (1.5 T) in the Belle spectrometer. In a joint effort with Hamamatsu a new type of hybrid photon detector (HPD) of the proximity focusing type is being studied.

3.2 Upgrade at BaBar

At BaBar an upgrade of the DIRC counter with a considerably smaller stand-off box is being considered [2,3] as shown in Fig. 1. Such a change would significantly reduce the beam related background. However, in order not to degrade the angular resolution, single channel PMTs would have to be replaced by multichannel devices among which Hamamatsu flat panel 64 channel PMTs and Burle 64 channel micro-channel plate (MCP) PMTs are being studied. Two further changes are considered which should considerably improve the angular resolution. The uncertainty in the emission point along the track will be eliminated by focusing optics of the expansion volume made of quartz. The chromatic error will be reduced by measuring

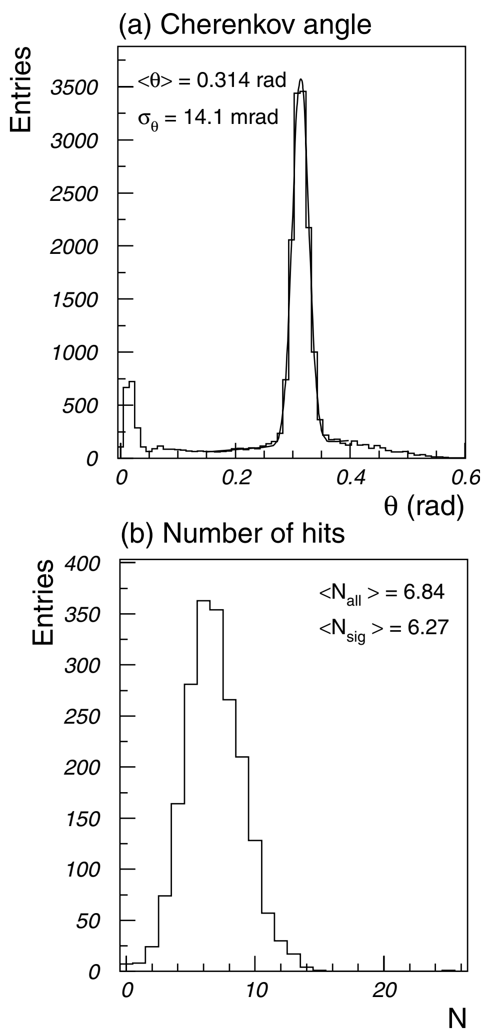

Fig. 5. Single photon resolution (**a**) and the number of detected photons (**b**) for a 2 cm thick aerogel tile

the time of arrival of Čerenkov photons with a resolution of 50-100 ps, from which the wavelength of each photon can be estimated. The expected resulting total angular error is 4-5mrad per single photon, which makes it possible to achieve an angular resolution of 1.5 mrad per track in principle. While the present BaBar DIRC achieves 2.7σ separation at 4 GeV/c, the equivalent performance of the upgraded DIRC would be 4.3σ at 4 GeV/c for photons traveling a full bar length of 3-4 m.

To demonstrate the capability of measuring and thus eliminating the chromatic error contribution, tests of candidate photon detectors were carried out where their timing resolution and homogeneity of response were evaluated [4]. By using a pulsed (35ps FWHM) laser diode and dedicated read-out electronics developed for this application, the time resolution of the tubes was measured. As can be seen from Fig. 6, the results are quite promising.

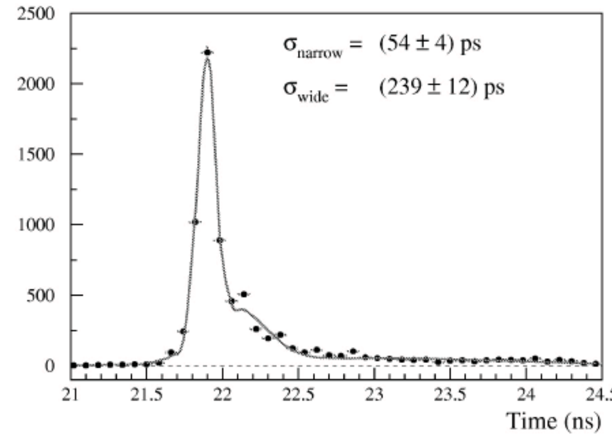

Fig. 6. Time of arrival for single photons as detected by the Burle 85011 MCP PMT

4 Summary

Čerenkov counters of the BaBar and Belle spectrometers have contributed significantly to the rich B physics harvest of the last three years. Upgrades are planned to further improve their performance and to allow them to work at even higher event and background rates. It is expected that they will again play a decisive role in the next generation of precision experiments in B physics.

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