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Apr. 24, 1996
BaBar TNDC-96-38

Effect of the Drift Chamber Outer Cylinder On the DIRC Resolution

Abstract

It has been proposed that the outer cylinder of the drift chamber be changed from 1.6 mm carbon fiber (0.6% X_0) to 2.5 mm aluminum (2.5% X_0). While such a change would have only a slight effect on the barrel CsI calorimeter performance, the question has been raised as to how it might affect the DIRC. Multiple scattering in the outer cylinder would cause as uncertainty in the entrance angle and position of the particle at a DIRC bar. However, the DIRC is remarkably robust against uncertainties of this type. A detailed Monte Carlo simulation indicates that even 1 X_0 of aluminum (10 cm) would cause only a 15% reduction in the significance of π/K separation at 4 GeV and $\cos\theta = 0.85$. In fact, if the drift chamber were solid aluminum the resolution of the DIRC would deteriorate only by a factor of two.

1 The DIRC

The concept of the DIRC is illustrated in Fig. 1. Particles pass through a quartz bar that is parallel to the beam axis. The resulting Čerenkov light propagates down the bar via internal reflection as the surfaces of the bar and emerges out the end of the bar. An extensive array of phototubes about 1 m from the end of the bar observes the Čerenkov photons, which lie along hyperboloid arcs.

In principle, the Čerenkov angle can be reconstructed with no knowledge of where the particle entered the DIRC bar. In practice, it is helpful to start the pattern recognition with a good hypothesis as to the trajectory of the particle through the DIRC so that candidate hyperboloids can be calculated and compared to the observed pattern of struck phototubes. But we can anticipate that the error is reconstructing the Čerenkov angle is smaller than the pointing error in the trajectory hypothesis.

We also note that the main sources of error in the reconstructed Čerenkov angle are chromatic dispersion in the quartz and the finite apertures of the phototubes, rather than multiple scattering in the quartz or external materials.

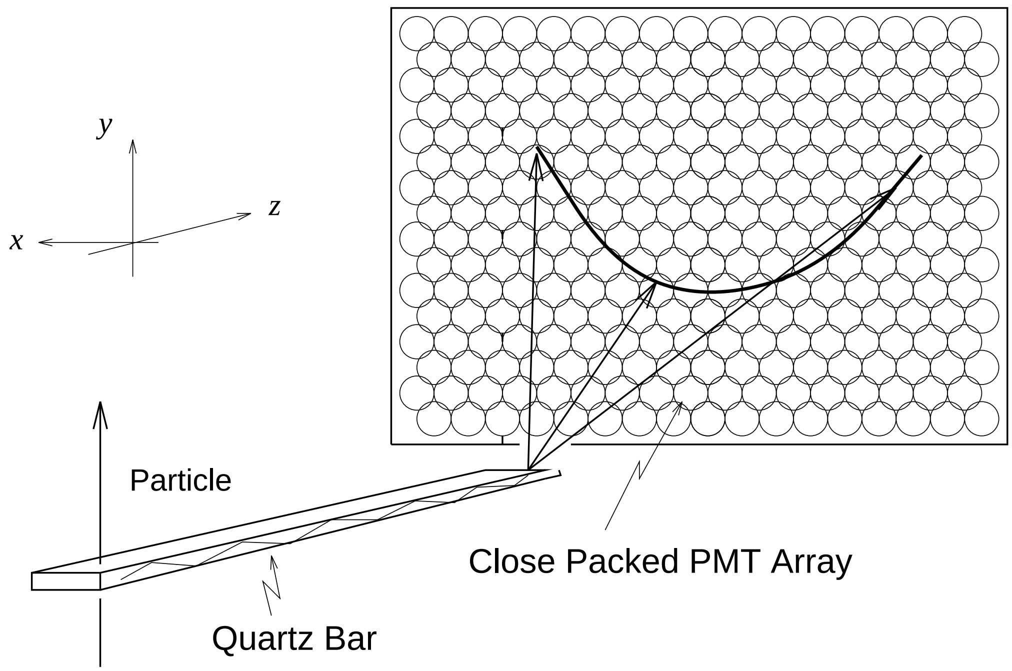

Figure 1: The principle of the DIRC.

2 Monte Carlo Simulation

We have studied the performance of the BaBar DIRC with a program developed for the Princeton/BELLE DIRC prototype, as described in BELLE Note #62 by C. Lu *et al.* (March 31, 1995). We use the nominal dimensions of the BaBar DIRC bars, $1.75 \times 3.5 \times 470$ cm^3 of quartz, with a 120-cm-thick water standoff between the end of the bar and a close-packed array of 2.96-cm-diameter phototubes with active diameter 2.5 cm each. In our simulation the phototubes are not arrayed on the surface of a torus, but on a cylinder whose axis is perpendicular to the quartz bar and passes through the end of the bar.

We only simulated 4 GeV π's and K's produced at a polar angle with $\cos\theta = 0.85$, as this is the most challenging case for $B \to \pi\pi$ or πK decays. The simulated particles enter the inside face of the DIRC bar randomly across this surface, and with an entrance angle that is randomly smeared from the nominal angle by an amount corresponding to a given thickness of material in front of the DIRC. The azimuthal entrance angle corresponds to that resulting from a 1.5-T magnetic field between PEP-II interaction point and the DIRC at radius 89 cm. As the particle traverses the quartz bar it multiple scatters and radiates Čerenkov photons. These photons are tracked through the bar and water standoff taking chromatic dispersion into account. The 4 GeV particles are produced in the forward direction, so the Čerenkov light bounces off the mirror at the forward end of the bar and then propagates to the backward end where the phototube array is located. Finally, phototube hits are generated based on the quantum efficiency and active area of the photocathode.

Figure 2 shows several simulated events with black circles indicating struck phototubes and smooth curves along the best-fit 'hyperboloids'. Figure 3 summarizes the calculated resolutions on the Čerenkov angle for various amounts of material.

The first plot in Fig. 3 shows the angular resolution of the DIRC to be $\sigma_\theta = 0.10°$ for 4-GeV π's and K's in the absence of multiple scattering. As noted above, this finite resolution is due chromatic dispersion in the quartz plus the granularity of the phototube array. If the analysis depended critically on knowledge of the angle of the particle in the DIRC we would expect a significant change in the resolution once the multiple scattering angle were $0.10°$. This corresponds to $0.2\ X_0$ of material along the track, and to a transverse thickness of about $0.1\ X_0$ at $\cos\theta = 0.85$.

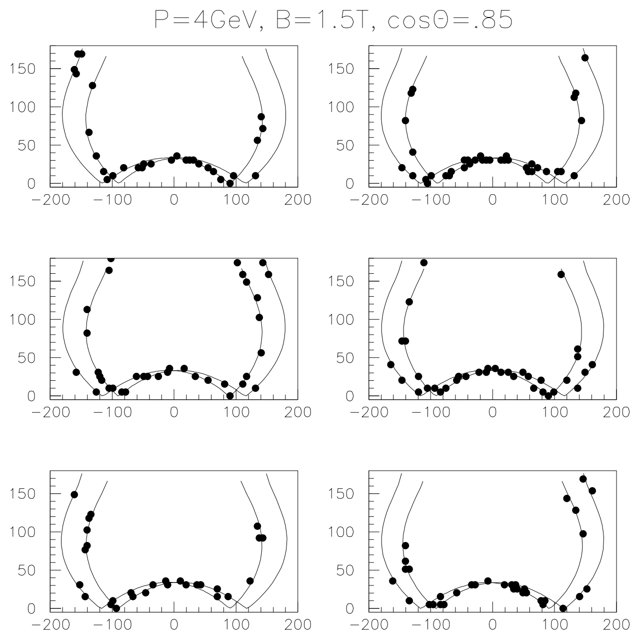

Figure 2: Simulated phototube hit patterns in the BaBar DIRC, along with best-fit 'hyperboloids'. The 'hyperboloids' are folded by reflections at the four walls of the DIRC bar and by the mirror in the water standoff box. They are also distorted by the curved surface of the PMT array.

The second plot in Figure 3 includes multiple scattering in the quartz of the DIRC but ignores the effect of any material in front of it. The resolution in the Čerenkov angle is again $\sigma_\theta = 0.105°$ and the difference in angles for π's and K's is $\Delta\theta = 0.37°$. Hence the statistical significance of the π/K separation is $\Delta\theta/\sigma_\theta = 3.5$ standard deviations, is close agreement with the value quoted in Table 6-3, p. 212 of the BaBar TDR.

Although the DIRC quartz is 1.75 cm thick, corresponding to $0.15\ X_0$, multiple scattering in the quartz appears to have little effect on the resolution. That is, the analysis accurately reconstructs the Čerenkov angle even when the track angle is not well known. Of course, we assume that the momentum of the track is known, so an analysis based on the hypotheses the particle is either a π or a K begins with a good knowledge of the Čerenkov angle. Then the code can find the pattern of phototube hits without a precise value for the track angle.

We immediately anticipate that adding additional material with thickness in radiation

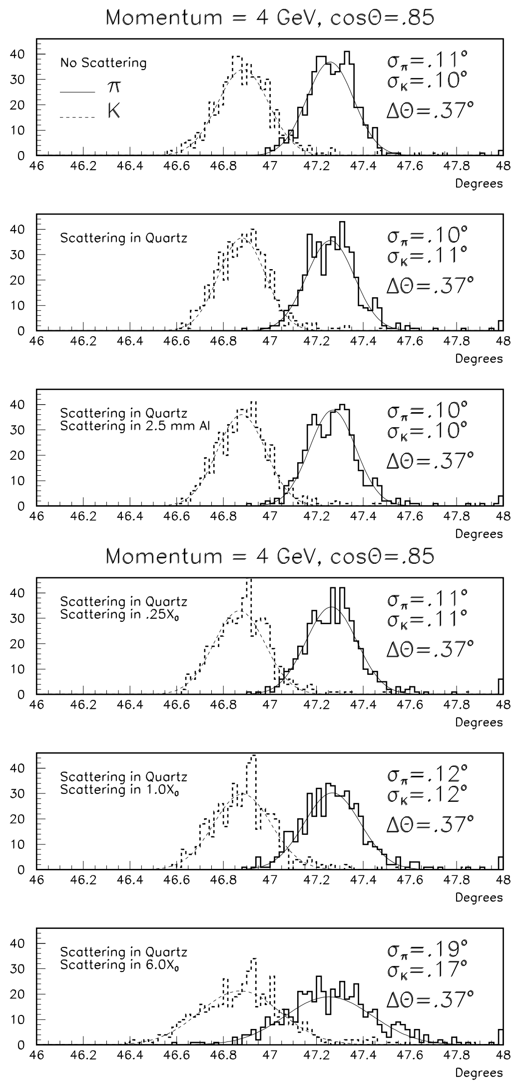

Figure 3: Simulated resolutions in the reconstructed Čerenkov angle for 4-GeV π's and K's entering the DIRC at polar angle $\cos\theta = 0.85$ for various amounts of multiple scattering in material just in front of the DIRC.

lengths smaller than $0.15 X_0$ will have little effect also.

The third plot of Fig. 3 shows the effect of adding a 2.5-mm-thick aluminum cylinder (0.028 X_0) just in front of the DIRC. Namely, there is no discernible effect, as is to be expected!

To have even a 5% reduction in the statistical significance of the π/K separation at 4 GeV we would have to put 25% of a radiation length of material in front of the DIRC, as shown in the fourth plot of Fig. 3. With 1 X_0 of material in front of the DIRC the resolution would deteriorate by 15%, and even with 6 X_0 of material in front of the DIRC we would still have 2-σ π/K separation at 4 GeV, as shown in the fifth and sixth plots of Fig. 3, respectively.