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THE DIRC DETECTOR AT BABAR*

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Abstract

A dedicated particle identification system based on the Detection of Internally Reflected Cherenkov (DIRC) light will be used in the BaBar detector. We provide an overview of the DIRC concept, design, and expected performance of the production device and a

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status report on its construction and commissioning. The DIRC is expected to be operating in the BaBar detector on beam line at the PEP-II B Factory in late spring 1999.

I. Introduction

The primary purpose of the BaBar detector [1] is to study CP violation in the decays of B^0 mesons from Υ (4S) production, at the SLAC PEP-II B factory [2]. PEP-II is an asymmetric e^+e^- collider with beam energies of 9 GeV electrons on 3.1 GeV positrons, corresponding to a center-of-mass energy equal to the Υ (4S) mass with $\beta\gamma$ (lab) = 0.56. The initial luminosity is expected to be about 3×10^{33} $cm^{-2}s^{-1}$, increasing ultimately to 10^{34}, with a B-$\overline{B}$ production rate of 10 Hz.

An essential requirement for CP-violation studies is to have high quality particle identification of kaons and pions over a large range of solid angle and momentum, to provide flavor-tagging of the B mesons and to reconstruct exclusive final states. A stringent performance "figure of merit" is the π-K separation in the rare two-body decays, $B^o \rightarrow \pi^+ \pi^-$ ($K^+ \pi^-$). Kaons for flavor-tagging have momenta less than about 2 GeV/c, with most below 1 GeV/c, whereas those from the two-body decays ($B \rightarrow K\pi$) have momenta between about 1.5 and 4 GeV/c. Since the BaBar inner drift chamber tracker can provide π-K separation up to about 700 MeV/c, the dedicated Particle Identification (PID) system must perform well over the range 700 MeV/c to about 4 GeV/c.

Another important requirement is dictated by the fact that the PID system is surrounded by a high-performance CsI electromagnetic calorimeter. Thus, the PID system inside the calorimeter volume should be thin and uniform in radiation lengths (to minimize degradation of the fine calorimeter energy resolution) and thin in radial dimension to reduce the volume, and hence, CsI material and cost of the calorimeter. Finally, for high luminosity running conditions, the PID system must have fast signal response and be able to tolerate high backgrounds if necessary.

II. The DIRC Concept

The DIRC [3] is a novel type of ring-imaging Cherenkov detector based on the Detection of Internally Reflected Cherenkov light (hence, the acronym, DIRC) produced by the passage of charged particles through long, thin, rectangular fused silica radiator bars, with expanded readout at the end of the bar. Figure 1 shows a schematic of the DIRC geometry which illustrates the imaging principle. A charged particle with velocity v traversing the fused silica bar with index of refraction n (~1.474), generates a cone of Cherenkov photons with half-angle ϑ_c with respect to the particle direction, where $\cos\vartheta_c = 1/\beta n$ ($\beta = v/c$, c = velocity of light). The photons are transported through successive internal reflections to the end of the bar. Depending on the particle incident angle, the Cherenkov light trapped in the bar will be reflected to either one or both ends of the bar. To avoid having to instrument both bar ends with photon detectors, a mirror is placed at one end, perpendicular to the bar axis. This mirror reflects most of the incident photons to the other (instrumented) bar end.

Since the bar has a rectangular cross section and is made to optical precision, reflections at the surfaces of the bar preserve the magnitude of the Cherenkov angle at which the photons were produced but add up-down and left-right ambiguities. The double image from the up-down ambiguity is eliminated by gluing a fused silica wedge to the instrumented end of the bar [Fig. 1(a)], so that rays having experienced even and odd number of reflections in the bar are then directed to the same point in the photon detector plane. The bottom of the wedge has a slight (~0.6 mrad) upward slope to minimize the displacement of the reflected image due to the finite bar thickness. Fused silica is a good choice for bar radiator material because of its large index of refraction, low chromatic dispersion, long radiation length, long absorption length, and allows for excellent optical surface finishes of the bars.

Most of the photons exit the bar when they reach the instrumented end. There the Cherenkov image is allowed to expand through a standoff region (called a "Standoff Box") filled with purified water which has an index of refraction (n ~1.34) close to that of fused silica, thus minimizing the total internal reflection at their interface. The photons are detected by an array of densely packed photomultiplier tubes (PMTs) [4] surrounded by collars of reflecting "light catcher" cones to capture light which would otherwise miss the PMT active area. This increases the light collection by about 20%. The PMT surface is about 1.2 m from the bar end. The expected Cherenkov light pattern at this surface is essentially a conic section [Fig. (1b)], whose cone opening angle is the Cherenkov production angle modified by refraction as it emerges from the fused silica. There is only one conic section image, instead of two, because of the fused silica wedges mentioned earlier.

III. The DIRC Detector at BaBar

The BaBar detector is shown schematically in an elevation view in Fig. 2. It is built around a solenoidal magnet, and thus, has a cylindrical central barrel region. The DIRC bars are arranged in a 12-sided polygonal barrel between the drift chamber and the CsI calorimeter. Because of the beam momentum asymmetry, particles are produced preferentially forward in the laboratory. To minimize interference with other detector subsystems in the crowded forward region, the DIRC instrumented end is in the backward direction.

The principal components of the DIRC are shown schematically in Fig. 3. The bars are grouped together into 12 hermetically sealed units, called bar boxes, made of very thin aluminum. Each bar box [Fig. 3(b)] in turn contains 12 long bars placed very close together (~75 μm gap) side by side, for a total of 144 long bars. The bars are 1.72 cm thick, 3.5 cm wide, and 4.9 m long. The length is achieved by gluing four 1.225 m "short" bars end-to-end, that size being the longest high quality bar currently feasible to obtain from industry. The bars are supported at 60 cm intervals by small nylon buttons

(two per short bar) for optical isolation. Each long bar has a fused silica wedge glued to it at the readout end. The wedge is made of the same material as the bar, 9 cm long with very nearly the same width as the bars (3.5 cm) and a trapezoidal profile (2.8 cm high at bar end and 8 cm at the light exit end). The wedges are glued to a 1-cm thick fused silica window, which provides the interface and seal to the water. For reasons of radiation hardness, the raw material used for the bar radiator is synthetic fused silica, Spectrosil [5], rather than "natural" fused quartz. Further specifications on the bars may be found in Ref. 6. The bars are being manufactured by Boeing [7].

The mechanical support of the DIRC [Fig. 3(a)] is cantilevered from the iron endcap region of the instrumented flux return (IFR). The Strong Support Tube (SST) is a steel cylinder located inside the end doors of the IFR and provides the basic support for the entire DIRC. It, in turn, is supported by an iron gusset plate and "horsecollar" which fix the SST to the Barrel magnet iron. It also minimizes the magnetic flux gap caused by the DIRC bars extending through the IFR and takes the axial load of the inner magnetic plug surrounding the beam in this region.

The fused silica radiator bar boxes are supported in the active region by an aluminum tube, the Central Support Tube (CST), attached to the SST via an aluminum transition flange. The CST is a thin, double-walled, cylindrical shell, using aircraft-type construction with aluminum skins and riveted or glued joints. The CST also provides the support for the inner drift chamber.

The Standoff Box (SOB) is made of stainless steel, consisting of a cone, cylinder, and 12 sectors at the rear end containing the PMTs, and holds about 6000 liters of pure water. It is supported by the horsecollar. The PMTs at the rear of the SOB lie on a surface that is approximately toroidal. Each sector contains 896 29-mm PMTs (ETL model 9125 [4]), closely packed, inside the water volume. Each PMT is mounted from the inside of the SOB and is connected via a feedthrough to a base mounted outside. Each PMT has an associated "light catcher" [Fig. 1(a)], which results in an effective active surface area light collection fraction of about 90%. The distance from the bar end to the PMTs is

1.17 m, which together with the size of the bars and PMTs, gives a geometric contribution to the single photon Cherenkov angle resolution of 7 mrad. This is approximately equal to the resolution contribution from production and transmission dispersions.

This configuration of the DIRC occupies 8 cm of radial space including supports and construction tolerances, with a total radiation length thickness of about 19% at normal incidence. The radiator bars subtend about 94% of the azimuthal angle and 87% of the center-of-mass polar angle cosine.

IV. DIRC Performance Characteristics

The DIRC performance has been extensively studied with a variety of prototypes, culminating with a full-size prototype in a series of test beam runs at CERN [8]. The results are very well described by the Monte Carlo simulations of the detector. With the actual DIRC detector now installed in BaBar, a long cosmic ray run was taken very recently with one radiator bar box in place. A typical cosmic ray event is shown in Fig. 4(a), where only the top half of the PMT sectors is displayed. Figure 4(b) shows the number of detected photons per track as a function of dip angle, for this configuration. Two salient features are the large number of photons everywhere and the close agreement of the Monte Carlo predictions with the data.

As described earlier, perhaps the most stringent test of the PID system, or "figure of merit" is the π-K separation for the rare two-body decay modes, B —> $\pi\pi$, $K\pi$. The predicted "figure of merit" for the DIRC, from the Monte Carlo simulations, is shown in Fig. 5. Figure 5(a) shows the angular resolution per track as a function of momentum and the corresponding π-K Cherenkov angle difference. Thus, the π-K separation in standard deviations is simply the latter divided by the former. This is shown in Fig. 5(b), plotted as a function of dip angle. (Because this is a two-body decay there is a one-to-one correlation between dip angle and momentum). Thus, the DIRC provides a π-K

separation well above four standard deviations over most of the acceptance, with a minimum of about 3.7 standard deviations near the most forward direction.

V. Installation Status and Run Schedule

At present, the entire DIRC is installed in the BaBar detector, but with only one out of twelve radiator bar boxes in place, and has been operated successfully on cosmic ray triggers for several months. The bar delivery from the grinding and polishing vendor [7] had been slowed significantly because of production problems, but these problems appear to be resolved and the recent bar delivery rate has increased considerably. By the time the BaBar detector is rolled onto the beam line in April 1999, the DIRC should have four or five bar boxes in place. The first beam run is scheduled for approximately four months. The remainder of the bar boxes will be installed after the first run ends in late summer 1999.

VI. Conclusions

The DIRC is a novel ring-imaging Cherenkov detector, which is well-matched to the particle identification requirements of BaBar. It is simple in concept and consists only of conventional components, such as PMTs, fused silica radiators, and water, making it thin, fast and tolerant of background. The performance is promisingly robust, with a signal of many photoelectrons leading to excellent π-K separation in the kinematic region of the B factory. All the detector components are in place in the BaBar detector, but including only a partial complement of radiator bar boxes for the first beam run starting in May 1999, the remainder to be installed before the next run.

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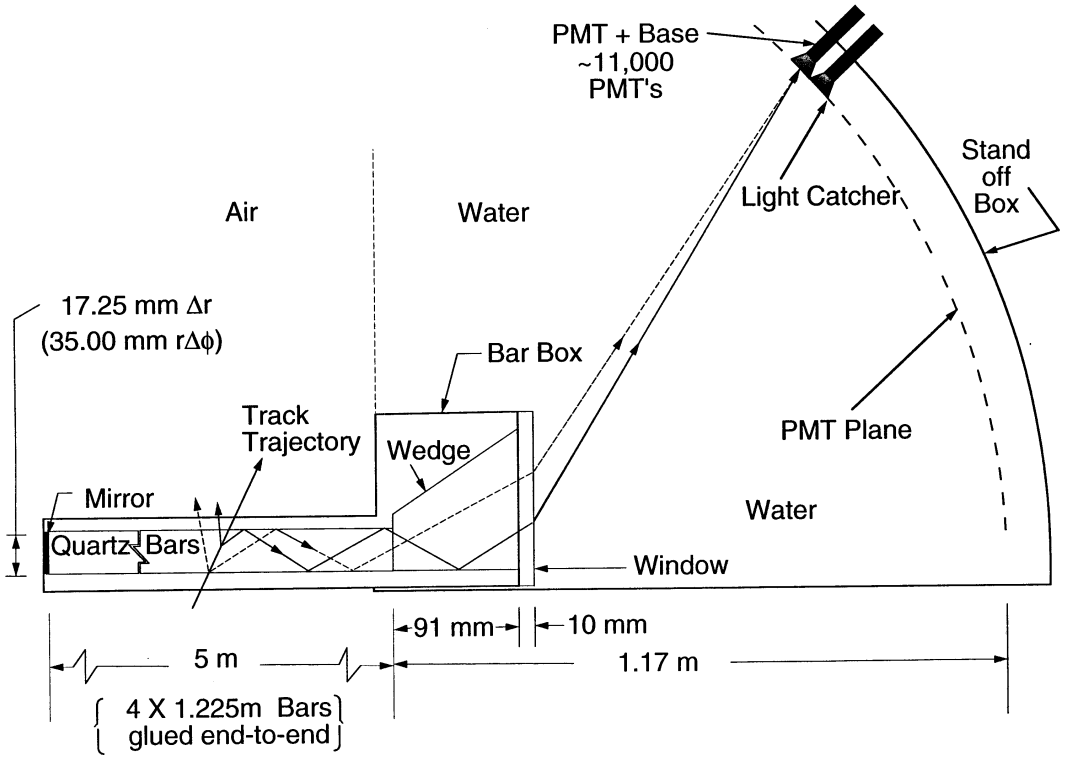
Figure Captions

1. Schematic of a DIRC fused silica ("quartz") radiator bar and optics; (a) side view, and (b) isometric view showing PMT plane image.
2. Schematic midplane section of the top half of the DIRC within the BaBar detector. The high momentum beam is incident from the left.
3. (a) Schematic of DIRC mechanical components; (b) Schematic of the DIRC fused silica ("quartz") radiator bar box assembly.
4. (a) Typical cosmic ray event, showing upper half of PMT sectors; (b) DIRC signal from cosmic ray tracks: number of detected photons versus dip angle.
5. "Figure of Merit" particle ID performance for the DIRC: predicted π-K separation from two-body decays B —> $\pi\pi$, $K\pi$; (a) angular resolution and angle difference; (b) number of standard deviations. For such two-body decays, there is a one-to-one correspondence between momentum and dip angle.

Figure 1

(a)


PMT + Base
~11,000
PMT's
Stand
off
Box
Light Catcher
Air
Water
17.25 mm Δr
(35.00 mm rΔϕ)
Bar Box
Track
Trajectory
Wedge
PMT Plane
Mirror
Water
Quartz Bars
Window
91 mm
10 mm
5 m
1.17 m
4 X 1.225m Bars
glued end-to-end

(b)

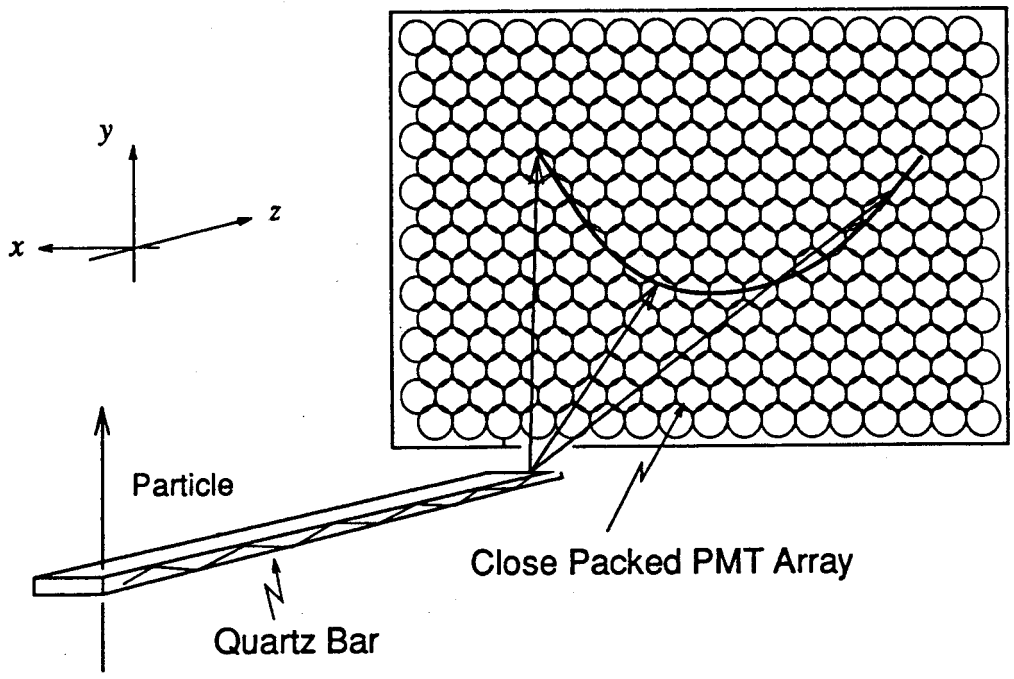
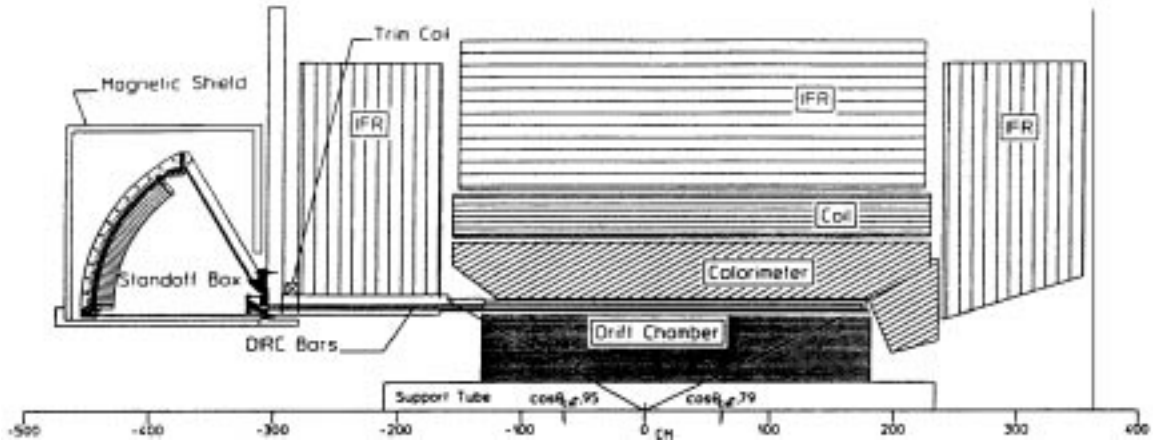

y
z
x
Particle
Close Packed PMT Array
Quartz Bar

Figure 2


Trim Coil
Magnetic Shield
IFR
IFR
IFR
Coil
Standoff Box
Calorimeter
DIRC Bars
Drift Chamber
Support Tube
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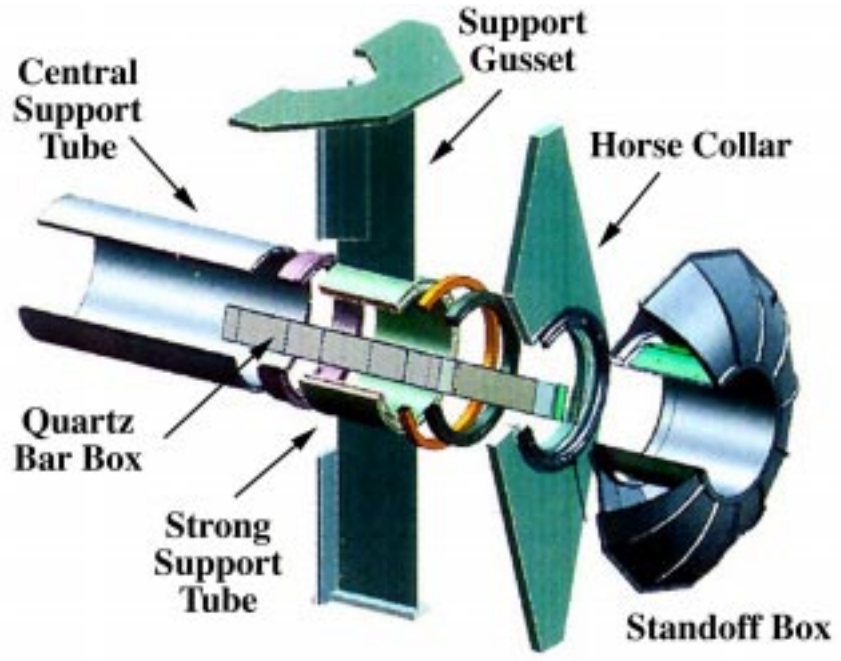
-300
-200
-100
0 CM
100
200
300
400

Figure 3

(a)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Gusset
Central
Support
Tube
Horse Collar
Quartz
Bar Box
Strong
Support
Tube
Standoff Box

(b)

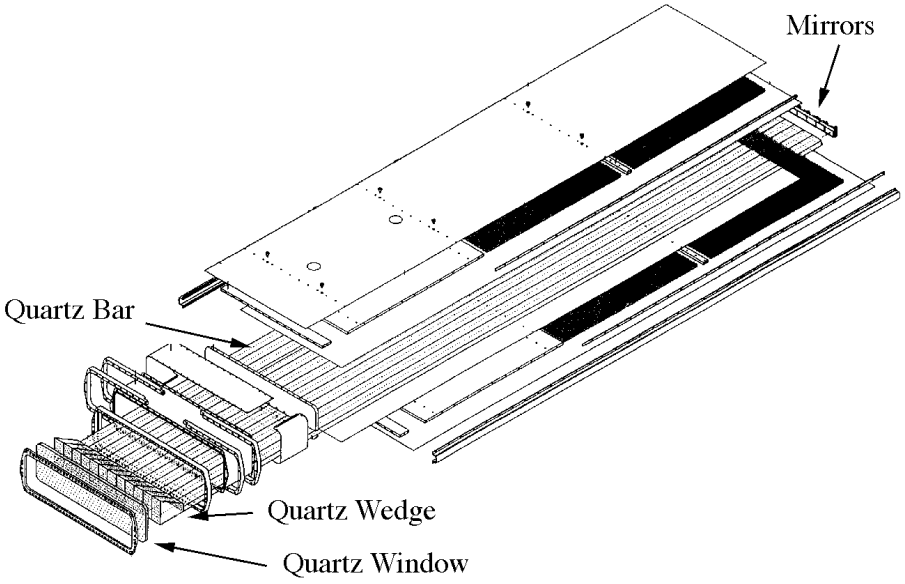
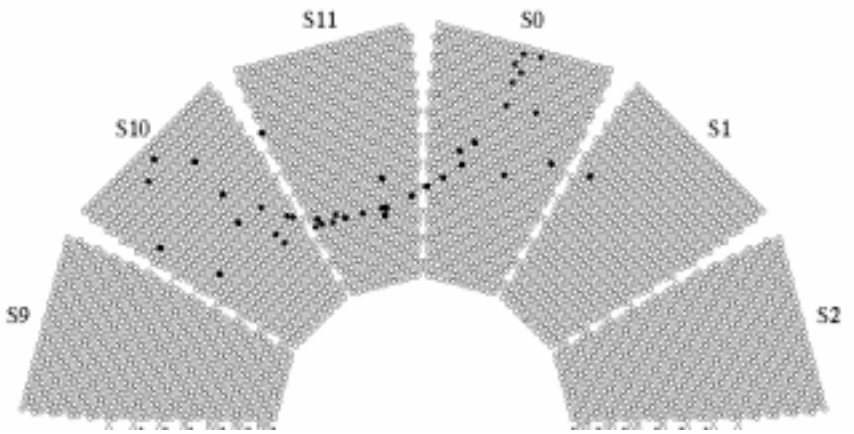

Mirrors
Quartz Bar
Quartz Wedge
Quartz Window

Figure 4

(a)


S11
S0
S10
S1
S9
S2

(b)

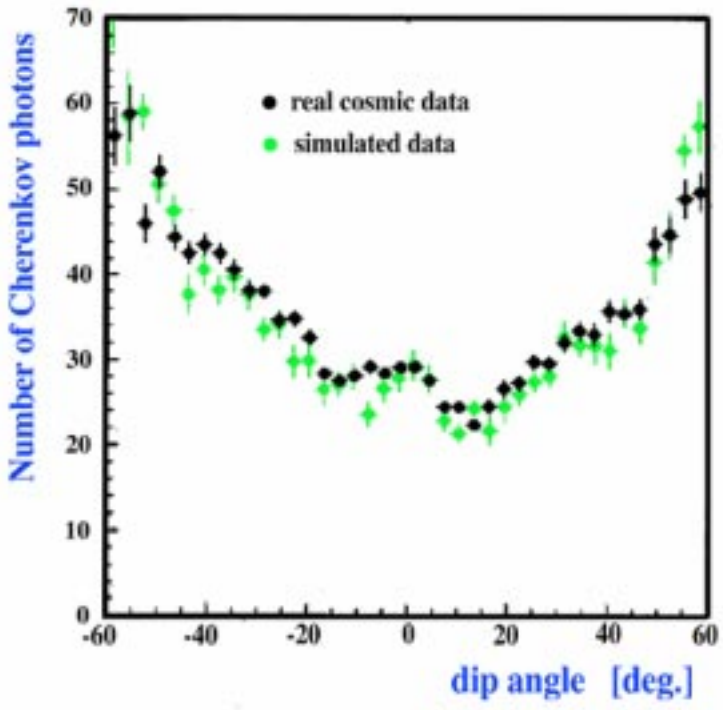
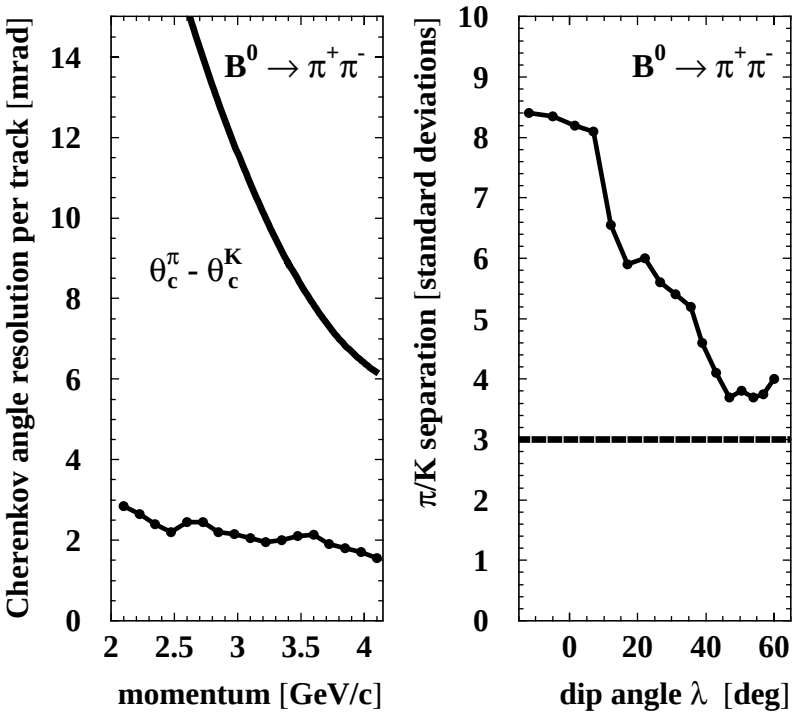

Number of Cherenkov photons
real cosmic data
simulated data
dip angle [deg.]
70
60
50
40
30
20
10
0
-60
-40
-20
0
20
40
60

Figure 5


Cherenkov angle resolution per track [mrad]
momentum [GeV/c]
$B^0 \to \pi^+\pi^-$
$\theta_c^\pi - \theta_c^K$
π/K separation [standard deviations]
dip angle λ [deg]
$B^0 \to \pi^+\pi^-$