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Development of photon detectors for a fast focusing DIRC ☆

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Abstract

We report progress in developing a focusing DIRC with very good timing resolution. This basic detector development has been motivated by a possible upgrade of the very successful BaBar DIRC particle identification detector for a future Super B-factory. We have built a single bar full size prototype, which aims to reduce the chromatic error by precise timing, and to remove the effect of bar thickness with a focusing mirror. This paper describes the design of the prototype, and systematic studies of the timing resolution and position response for single photons for two 64-pixel detectors: (a) Hamamatsu Flat Panel PMTs, and (b) Burle MCP–PMTs. To test the prototype, we have developed new electronics for ~300 pixels capable of measuring a single electron timing resolution to ~100 ps. We also report on a first measurement of aging with the MCP–PMT.

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1. Introduction

The DIRC detector at the BaBar experiment provided excellent particle identification performance [1,2]. Because of this success, our group is attempting to develop a next generation DIRC, which is capable of not only measuring an x and y coordinate of each photon with similar angular resolution to the present BaBar DIRC, but, in addition, each photon's time-of-propagation (TOP[2]) through the Fused Silica bar with ~100 ps timing resolution (the present BaBar DIRC has a timing resolution of only $\sigma \sim 1.6$ ns).

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[2]Definition: $\mathrm{TOP}(\Phi, \theta_c, \lambda) = [L/v_g(\lambda)]\ q_z(\Phi, \theta_c)$, θ_c—Cherenkov angle, L—distance of light travel in the bar, $v_g(\lambda)$—group velocity of light, λ—photon wavelength, and $q_z(\Phi, \theta_c)$—z-component of the unit velocity vector.

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This new capability will allow a correction of the chromatic error by timing. In addition, the precise timing will help to suppress the background, which would be probably necessary at any future Super B-factory. The focusing element will also remove the bar thickness from the resolution consideration. The smaller pixel size will reduce the overall size of the photon detector,[3] which will also help to reduce the background.

A DIRC-like detector equipped with the modern fast photon detectors appears to be the only PID system capable of correcting out the chromatic error, at least in principle. To do that one needs to achieve 100–200 ps timing resolution per single photon.[4]

The present efforts of our group is aimed to develop a reliable photon detector, learn how to achieve ~100 ps single photon timing resolution on a scale of ~300 channels, and decide how best to develop electronics on a much larger scale for the future. We have built a full length, single bar prototype that will be tested in the beam at SLAC soon. The prototype has a single DIRC bar of ~3.6 m length, and a focusing element made of a 50 cm focal length spherical mirror placed in a small optical box filled with mineral oil, which is the coupling medium between the bar and six 64-pixel photon detectors. The system is instrumented with ~300 channels of electronics.

2. Prototype description

Fig. 1 shows the concept and practical realization of the "fast focusing DIRC" prototype. This prototype is the first version of an fast focusing DIRC [3], however, it will not work in a magnetic field as yet, and the volume between the bar and the photon detectors is simply filled with mineral oil, instead of an expensive solid fused silica focusing piece, which would provide higher transparency near 300 nm. Fig. 1a shows how the prototype's spherical mirror is designed to remove the effect of bar thickness on the resolution. The optics defines a focal plane where the photon detectors are located. The prototype's photon detection is based on six 64-pixel photon detectors, four Burle MCP–PMTs, and two Hamamatsu flat-panel MaPMTs. One should add that the prototype was designed to study the chromatic effects in the beam, and no effort was made to optimize it for any real application as a particle identification device. Fig. 1a also shows schematically a calibration system for the detectors using a PiLas laser diode. The prototype is on the beam line at SLAC, being tested with PiLas laser diode light pulses. It should be ready to take beam data sometime during the spring of 2005.

Fig. 2a shows various efficiencies[5] for a perpendicular track entering the fast focusing DIRC prototype in the middle of its acceptance, if "it would be placed into BaBar" [4]. In this design, the detector optical box is filled with mineral oil from the KamLand experiment, which simplifies the construction and makes it affordable at this particular stage. This is not our first choice, as the mineral oil does not have as good transmission near 300 nm as, for example water.[6] On the other hand, its refraction index is a better match to fused silica, as one can see in Fig. 2b. Fig. 2c shows an estimate of the relative final detection efficiency of the fast focusing DIRC prototype and the present BaBar DIRC, assuming the KamLand mineral oil transmission, the Burle's recently quoted MCP–PMT QE, and the best present estimate of future MCP–PMT collection and boundary efficiencies by Burle Co. Ultimately, we would propose to construct a fast focusing DIRC similar to Fig. 3 [3]. Table 1 compares expected contributions to the Cherenkov angle resolution of the present BaBar, the fast focusing DIRC prototype, and the final fast focusing DIRC [3].

Timing dependence on the chromaticity in a 3.6-m-long DIRC bar is shown in Fig. 4a for a track

[3]In BaBar DIRC, this includes a standoff box (SOB) containing ~6000 l of water to provide optical coupling between the bars and ~11,000 PMTs [1].

[4]At this level of resolution the time coordinate does not usually provide a competitive angular measurement with that provided by the x and y coordinates.

[5]With a new MCP–PMT according to Table 2, we estimate $N_0 \sim 29\,\mathrm{cm}^{-1}$, and N_{pe}/track ~27 for $\Theta_{\mathrm{track}} = 90^\circ$ in the middle of the acceptance.

[6]One should point out, however, that no attempt was made to clean this oil in any special way, and further transmission improvements are likely.