The focusing DIRC with waveform digitizing electronics

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Abstract

We have tested a novel Cherenkov imaging detector called the Focusing DIRC (FDIRC) with waveform digitizing electronics. The prototype's concept is based on the BaBar DIRC with several important improvements: (a) much faster, pixelated photon detectors, (b) a mirror that makes the photon detector smaller and less sensitive to background in future applications, (c) electronics capable of measuring single photon resolution to $\sigma \approx$ 150ps, which allows for correction due to chromatic error. In this test, the prototype has been instrumented with seven Hamamatsu H-8500 MaPMTs. Waveforms from ~450 pixels are digitized with waveform sampling electronics based on the BLAB2 ASIC, operating at a sampling speed of ~2.5 GSa/s. This version of the FDIRC prototype was tested in a large cosmic ray telescope providing muon tracks with ~1 mrad angular resolution and a muon momentum cutoff of ≥1.6 GeV/c.

Key words: Fast Focusing DIRC, Particle Identification, Waveform sampling electronics, Super B Factory
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1. Introduction

The DIRC detector at the BaBar experiment provided excellent particle identification performance [1, 2]. Based on this success, our group has been following an R&D program to develop an appropriate photon detector for future particle identification systems. One such idea, a focusing DIRC [3-7], would be capable not only of measuring an (x,y) coordinate for each photon with an angular resolution similar to the present BaBar DIRC, but, in addition, measuring the time-of-propagation (TOP[1]) of each photon along the Fused Silica bar with ~150 ps single-photoelectron timing resolution or better (the present BaBar DIRC has a timing resolution of only $\sigma \approx$ 1.6 ns). This precise timing allows a measurement of the Cherenkov angle, with a precision similar to that provided by the direct angular measurement. A small pixel size allows the design of a photon detector expansion volume up to a factor 10 smaller than the existing BaBar DIRC Stand-Off-Box. A smaller geometrical size together with better timing will allow the suppression of the background by more than one order of magnitude; in addition, better timing will allow a correction of the chromatic error and thus improve the angle measurement substantially. The focusing element also removes the bar thickness as a term that contributes to resolution smearing. Such a device could be important for a future Super B-factory. We have built the first prototype of a focusing DIRC and had two successful test beam runs with it. In these runs, we established that (a) the new photon detectors work as expected, based on our bench tests; (b) we can achieve Cherenkov angle resolution similar to the BaBar DIRC with much more compact and faster detectors; (c) we can achieve single-photon timing resolution at a level of 100-200 ps; (d) we can clearly observe the expected chromatic dispersion on a photon by photon basis; and finally, (e), we can correct the chromatic error through this timing measurement [5, 6, 7]. In addition we have developed software analysis packages and a Geant4 [8] Monte Carlo simulation of the prototype.

2. Description of the Focusing DIRC prototype

Figure 1 shows the concept and practical realization of the Focusing DIRC prototype. This prototype consists of a single DIRC bar of ~3.6 meters length (1.7 cm thick and 3.5 cm wide), a focusing element made of a 50 cm focal length spherical mirror placed in a small optical box filled with a mineral oil,[2] which is the coupling medium between the bar and seven 64-pixel Hamamatsu Flat-panel MaPMTs photon detectors. The detailed studies of these photon detectors are described in detail in our previous publications [3-7] these initial tests used Elantek 2075 amplifiers and home-made constant-fraction discriminators (CFD) coupled to Philips TDC 7186, which provided 25 ps/count timing resolution. Fig. 1 shows how the prototype's spherical mirror is designed to remove the effect of bar thickness on the resolution. One should add

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[1] Definition: TOP(Φ,θ_c,l) = [L/$v_g(\lambda)$] $q_z(\Phi,\theta_c)$, where θ_c is Cherenkov angle, L is light travel distance in bar, $v_g(\lambda)$ is light group velocity, λ is photon wavelength, and $q_z(\Phi,\theta_c)$ is the unit velocity vector z-component.

[2] KamLand experiment mineral oil: Bicron BC-599-14

that this prototype was designed to study the chromatic effects with a particle beam, and no effort was made to optimize it for any real application as a particle identification device. A laser calibration system based on the PiLas laser diode[3] is also shown schematically in Fig. 1.

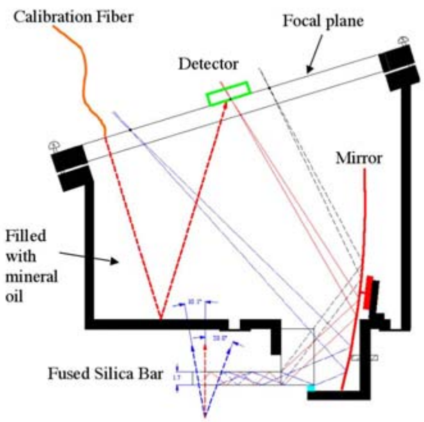

Figure 1: Principle of the Focusing DIRC prototype [3-7], where the angular error contribution due the finite bar thickness is removed by focusing parallel rays onto the same image plane location.

In the present work we switched to new waveform digitizing electronics [9, 10] based on a 2nd-generation Buffered LABRADOR [11, 12] (BLAB2) ASIC operating at ∼2.5 GSa/s. Tests of the earlier system have indicated sub-10ps timing resolutions are possible under bench test conditions. This next step is to instrument the FDIRC system with ∼450 channels of such electronics. As seen inset at the upper left of Fig. 2, these electronics have been designed to integrate directly into the footprint behind each of the H8500 PMTs. Control and readout are via Giga-bit fiber-optic transceivers connected to a compact-PCI readout crate with an embedded CPU running Linux.

We operate the photo-detectors at $\sim 5 \times 10^5$ gain. To detect single photons, direct integration of the electronics onto the back of the PMT requires the addition of amplification to the well-established waveform sampling [10] technique. A transimpedance gain of about $2k\Omega$ ($\sim \times 40$ voltage gain) was the design target. During testing it has been observed that while the added amplifier provides the necessary gain, due to the excess capacitance on its output and inductance on its input, the phase margin is tiny and under realistic loading from the PMT, a small amount of ∼300MHz oscillation is observed. This will be corrected in a future (BLAB3) design, however it can also be compensated by filtering in the frequency domain. Such noise can exist in the real application and waveform sampling provides a unique tool to minimize its effect.

[3]Manufactured by Advanced Laser Diode Systems, D-12489 Berlin, Germany

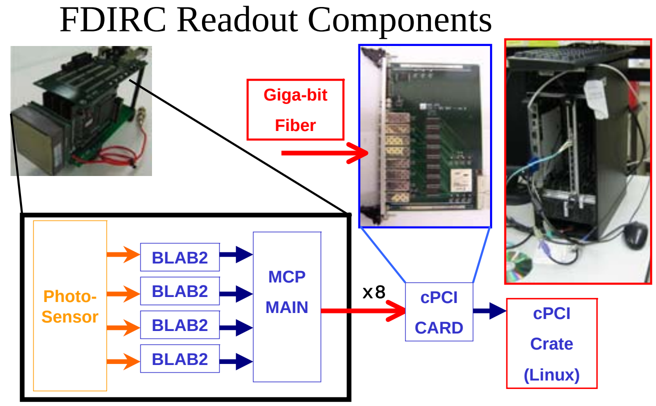

Figure 2: Components of the waveform sampling readout of the Focusing DIRC prototype. BLAB2 digitizer ASICs are placed immediately behind the 64-anode phototube and digitized events are carried over Giga-bit fiber links to a cPCI-based data acquisition system.

3. Description of the Cosmic Ray Test stand

We have constructed at SLAC a large cosmic ray telescope as shown in Fig. 3 to test the FDIRC prototype. The telescope consists of upper and lower orthogonal planes of scintillator-based hodoscope tracking, providing ∼1 mrad angular resolution, and a stack of 4 1ft-thick iron absorber plates, providing a muon momentum cutoff of ∼1.6 GeV/c.

A compact quartz radiator and MCP-PMT assembly is located just above the DIRC bar, near the center of the hodoscope array. This device uses muon-induced prompt Cherenkov photons and the good Transit-Time-Spread of the PMT to provide a precision start time. Measuring the muon range in the iron stack (min. momentum cut-off is ∼1.6 GeV/c) provides coarse momentum selection.

4. Experiment Results and Plans

Having demonstrated the expected performance of the FDIRC in test beam, within the cosmic test stand this prototype now serves as an excellent test-bed for developing the compact, high-performance electronics necessary for operation in a Super B detector environment.

Commissioning of the system commenced in January 2009. In order to ensure synchronization between the new waveform recording electronics and the existing CAMAC readout for the hodoscope, range stack, and start counter, merging of the data into a single cPCI data stream was adopted. Two USB-based Wiener Crate Controllers are connected through a USB hub to the embedded cPCI CPU. External NIM logic is used to provide a trigger decision and enforce a veto during readout. The prototype image plane consists of seven H8500 PMTs that are mounted into a custom machined G10 holder. The PMT hole pattern follows a configuration designed to match the calculated ring image. This holder is attached to rods on either side that allows the phototube array to be translated

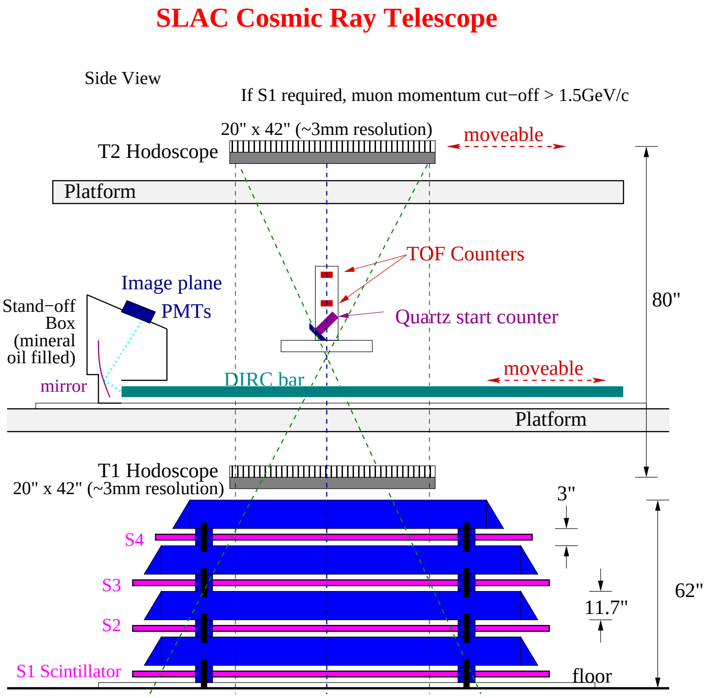

Figure 3: Schematic drawing of the FDIRC prototype located in a large cosmic ray telescope built at SLAC.

to match the optimal projected image position when the hodoscope array is moved to preferentially select inclined tracks. As seen in Fig. 4, BLAB-based readout modules have been installed onto the back of 6 of the PMTs and the rightmost slot in this photo has been left temporarily instrumented by an existing amplifier, to monitor the system trigger timing.

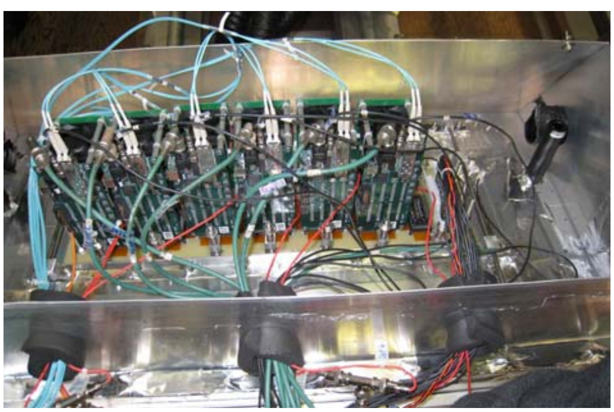

Figure 4: Integrated readout of six H8500 64-anode PMTs (384 channels). LC-Duplex fibers transport the data and are less bulky than the green RG-58 cables used for power.

A number of detailed comparison studies have been started and will be ongoing. Fig. 5 illustrates the type of comparison that can be performed in checking the ring image and photon yield in Geant4 versus recorded hits.

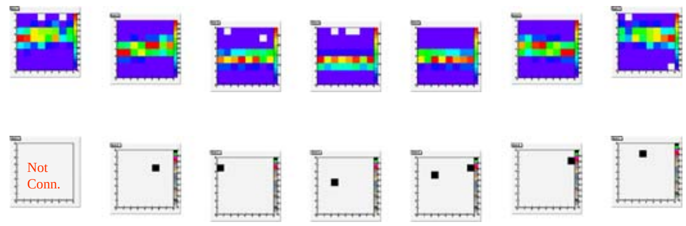

Figure 5: Comparison of results between Geant4 MC (top), where the color corresponds to the intensity of photons observed in each pad, and typical single cosmic data event (bottom), where each black square corresponds to a single recorded Cherenkov photon.

After initial timing and MC comparison studies, the next task will be to demonstrate at-speed time and charge extraction for single photon hits, a necessity for demonstrating viability in a Super B detector application.

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