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Timing and Detection Efficiency Properties of Multi-Anode PMTs for a Focusing DIRC[*]

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Abstract

For the present *BaBar*-DIRC, the Cherenkov angular resolution is dominated by three contributions - the chromatic error, bar thickness and pixel size. This paper discusses a prototype for a Focusing DIRC, which uses a smaller pixel size, a focusing mirror to reduce the effect of the bar thickness and precise timing in the range of 50-100ps per photon to reduce the size of the chromatic error. This paper describes two novel photon detectors which are candidates for this type of concept: Hamamatsu 64-channel multi-anode Flat Panel H-8500 PMTs and Burle 64-channel micro-channel plate 85011-501 MCP-PMTs. The detectors were tested with a PiLas laser diode providing light pulses with 35ps FWHM timing resolution. A single-photon timing resolution of (1) $\sigma \approx \mathbf{120 - 140}$ps was achieved with the Hamamatsu PMTs, and (2) $\sigma \approx \mathbf{55}$ps with the Burle MCP-PMTs. To achieve the good timing resolution results, we have developed a new fast amplifier and a constant-fraction discriminator. We have also developed a computer-controlled two-dimensional scanning setup, which allows a detailed study of the uniformity of the PMT and of the efficiency response to single photons relative to a reference PMT.

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1 Introduction

The Dirc is a Cherenkov Ring Imaging Detector operating at *BaBar* [1]. It has proven to be a successful detector, which has contributed substantially to the success of the *BaBar* physics performance in the past 4 years [2]. The present Dirc reconstructs the Cherenkov angle using the known track intersection with a bar, and the x, y position of the detected photon known from the PMT position. The Cherenkov angle of a single photon is measured with a total error of ~9.6mrad [2]. The individual contributions are ~1mrad for track error, ~2-3mrad for error due bar imperfections that affect the photon transport along the bar, ~4.1mrad for bar thickness effect, ~5.5mrad due to a PMT pixel size, and ~5.4mrad due to the chromatic error. This error is the result of the dependence of the refractive index of the radiator bar on the wavelength of the Cherenkov photon and has so far been considered to be an irreducible contribution to the Cherenkov angle resolution. Since one typically measures 20-60 photons per track, the overall Cherenkov angle error is ~2.4mrad per track on average. The time of photon arrival is measured with a resolution of about 1.6ns, which is important for background suppression, but not adequate for correcting the chromatic effect, which requires timing resolution at a level of 50-100ps [3,4]. To demonstrate the capability to measure the chromatic error contribution, we are building a Focusing Dirc prototype, which will measure both the x, y coordinates of the Cherenkov photons, and their timing to 50-100ps. By using another chromatic effect, the wavelength dependence of the photon arrival time due to the dispersion of the group velocity of the photon in the radiator [5], it is possible to use the precise time measurement to correct for the wavelength dependence of the refractive index. The prototype will also use smaller PMT pixels and essentially eliminate the error due to a bar thickness by using a focusing mirror. The expected resulting total angular error is 4-5mrad per single photon, which makes it possible to achieve an angular resolution of ~1.5mrad per track in principle. The present *BaBar*-Dirc achieves ~2.7σ π/K separation at 4GeV/c. The equivalent performance of the Focusing Dirc prototype would be ~4.3σ at 4GeV/c for photons traveling a full bar length of 3-4m. This paper focuses on a portion of the entire effort, namely the initial experience with two different photon detectors: Hamamatsu Flat Panel 64-channel multi-anode PMT and Burle 64-channel micro-channel MCP-PMT, both equipped with a bialkali photocathode. There are other possible photon detector candidates [6]. However, the two candidates discussed in this paper represent the most practical application at present. This R&D effort is directed towards the next generation of B-factories (~10^{36}cm^{-2}sec^{-1}).

2 Experimental setup

There are two setups to study the new photon detector candidates. The first is used to tune the timing resolution methodology for a single channel, as well as develop the electronics. The second setup is used to study the uniformity of the response of the detector across its face in a two-dimensional scan. Both setups use a PiLas laser diode [7]. The wavelength used for most measurements is 632nm, which is still within the wavelength acceptance of the bialkali photocathode. Only for one series of scans of the Burle MCP-PMT a PiLas laser diode with a wavelength of 430nm, closer to the maximum efficiency of bialkali photocathodes, is used. The PiLas laser contributes to the overall timing resolution with 35ps FWHM (manufacturers data). The laser beam enters a 5-meter long 62.5μm multi-mode fiber via a lens and collimator. At the detector end, it exits the fiber again by a similar lens/collimator package. The laser diode power is adjusted so that the photodetector operates predominantly in the single photon counting mode, which is defined by requiring that the probability to get a single photoelectron is less than 10%. The upstream end of the fiber is mounted on a precision x-y stage to optimize the coupling efficiency to the laser diode. This is especially important for smaller diameter single-mode fibers. However, we find that switching to a single-mode 4μm diameter fiber does not improve the overall timing resolution.

In the timing setup, the fiber end was fixed and pointing to a certain anode. For the scanning setup, the fiber downstream end is mounted on a precision computer-controlled x-y stage, allowing small step sizes (100μm typically) with repeatability of better than 7μm. The scanning setup measures the uniformity of the photon detector as well as the response relative to two reference PMTs in single photon mode using a <1mm spot size. The two reference PMTs, one Photonis XP2262B and one ETL 9125FLB17 (the same type of PMT is used in the present DIRC), are also used to monitor the laser intensity. The relative response combines many contributions to the efficiency, such as the photocathode quantum efficiency, photoelectron transmission losses, detection efficiency, etc.

In order to achieve timing resolution in the range of 50-100ps, it was necessary to develop a fast amplifier based on Elantek 2075, and a new constant fraction discriminator (CFD) to remove the time slewing due to pulse height variation. The time was measured using a TDC with a resolution of 25ps per count. The scanning setup, which reads out all 64 anodes, does not yet use the final electronics; at present, we use a simple leading edge LeCroy 4413 discriminator, and a LeCroy 3377 TDC with a resolution of only 0.5ns per count. As a result we are not yet able to perform a two-dimensional scan of the time resolution. Instead, we use the timing information only to reject random noise by selecting a signal time window of typically 10ns width. With future improvements of the electronics of the scanning setup we do expect to see a complicated timing structure across the photodetector face due to gain variation, cross-talk, and charge sharing between pads.

3 Hamamatsu H-8500 Flat panel PMT

This tube has 64 pads and multi-anode design. Figure 1 shows the typical timing resolution obtained with the Elantek amplifier with a voltage gain of ∼130, and a CFD threshold of 30mV. Numerous measurements have been performed, but typical timing resolution results were not better than 120-140ps for the narrow component of the double Gaussian fit. The time resolution of this PMT is at the upper limit of the resolution required to correct for the chormatic error.

Figure 2 shows the relative response measurement with the Hamamatsu PMT. The scanning step size was 0.1mm (1mm) in the x (y) directions, respectively. The intensity of the PiLas laser at 632nm was monitored by two reference PMTs. The response of the Hamamatsu PMT was normalized to the point with the highest efficiency. One can see that the

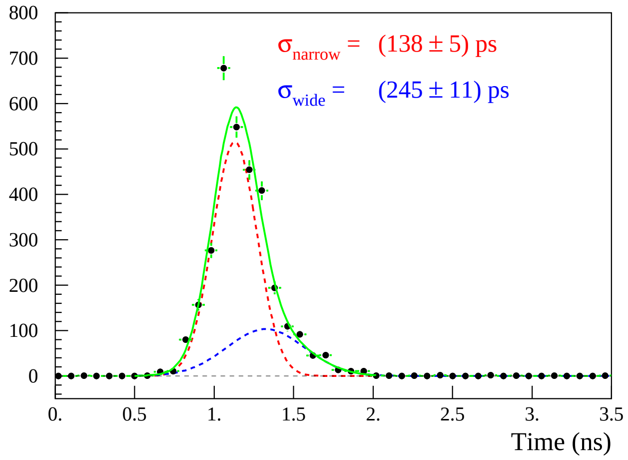

Figure 1: Single photoelectron timing resolution with Hamamatsu H-8500 64-pad multi-anode PMT, using the PiLas laser diode at 632nm. The graph shows the result of a fit of a double-Gaussian function to the data.

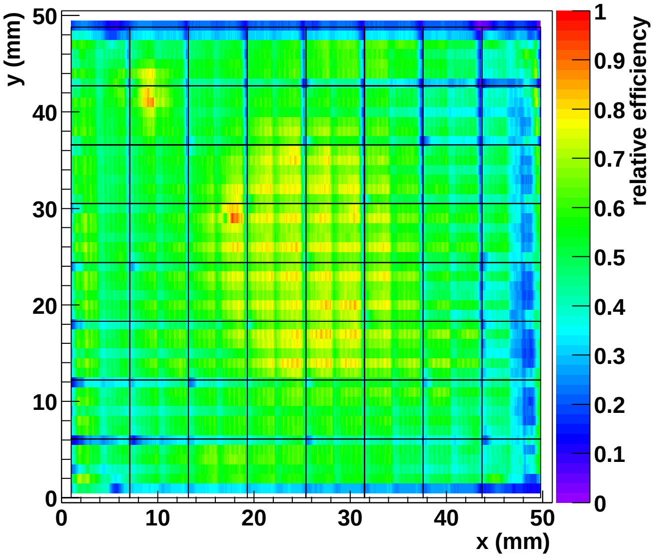

Figure 2: Relative response in the single photon mode of the Hamamatsu H-8500 64-pad multi-anode PMT, using the PiLas laser diode at 632nm. The solid lines indicate the approximate borders between pads.

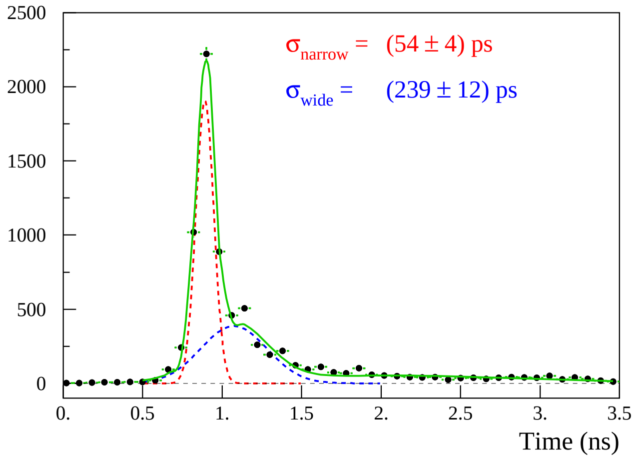

Figure 3: Single photoelectron timing resolution with Burle 64- pad MCP-PMT, using the PiLas laser diode at 632nm. The graph shows the result of a fit of function consisting of a double-Gaussian plus a constant background to the data.

response is not uniform, with one wide maximum in the center and one sharp maximum on the upper left quadrant, both range from 80-100%. The response drops off to below 40% close to the edges. These non-uniformities are partially caused by charge sharing between neighboring pads, photoelectron transmission losses, gain and quantum efficiency variations. In this measurement, we have not disentangled these contributions. The charge sharing, for example, causes dips in the efficiency between pads. If we add all neighbors of a given pad, the efficiency uniformity in the pad region improves considerably. Detailed studies of this effect are in progress.

4 Burle 85011-501 MCP-PMT

This tube has also 64 pads coupled to a double micro-channel plate (MCP) design. Figure 3 shows the typical timing resolution with a single pad, amplifier voltage gain of 130, and CFD threshold of 30mV. The distribution, as expected, has a long tail due to recoil photoelectrons from the front MCP surface. We fit the data with a double-Gaussian plus a flat background and obtain ∼54ps for the major component and ∼240ps for smaller one. A number of measurements were conducted using various timing strategies. The typical result was in the range of 55-60ps. The worst result was about 90ps for the major component, due to a RF higher noise in the area. We can even achieve such a good resolution using a lower amplifier bandwidth of ∼300MHz. The time resolution of this PMT is a very good match to the resolution required to correct for the chormatic error.

In order to understand the ultimate timing resolution capability of this tube, we will also need to determine the contribution from the PiLas laser diode itself.

Figure 4 shows the relative response measurement with the Burle 64-anode MCP-PMT. The scanning step size was 0.1mm and 1mm in x and y directions, respectively. The intensity

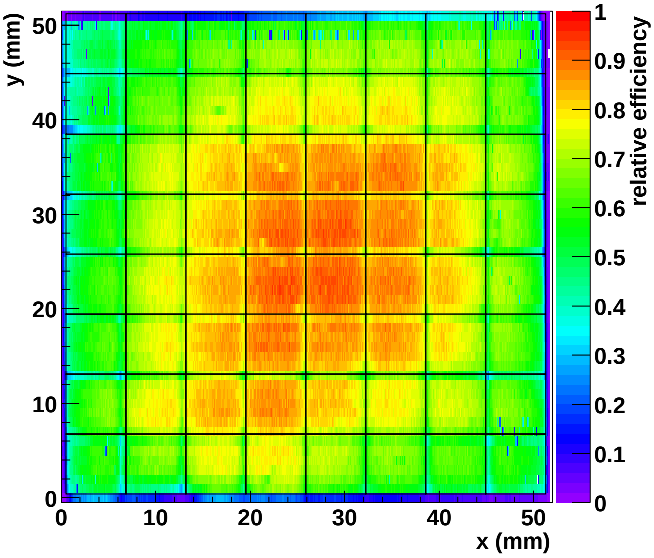

Figure 4: Relative response in the single photon mode of the Burle 64-pad MCP-PMT, using the PiLas laser diode at 632nm. The solid lines indicate the approximate borders between pads.

of the PiLas laser at 632nm was monitored by two reference PMTs. The response of the Burle MCP-PMT was normalized to the point with the highest efficiency. Again, the response is not uniform, especially along the edges, due to similar reasons we presented for the Hamamatsu tube. There is a plateau of high relative efficiency (more than 80%) that extends over some 60% of the PMT surface. The response drops to about 60% close to the edges, making the response of this Burle PMT more uniform than the Hamamatsu PMT described above.

Figure 5 shows the measurement of the response of the Burle 64-anode MCP-PMT relative to the PMT used in the present Dirc. The scanning step size was 0.5mm and 1mm in x and y directions, respectively, the wavelength of the laser diode is 430nm. The laser intensity was monitored by two reference PMTs. The efficiency of the Burle MCP-PMT at this wavelength is between 50 and 60% of the efficiency of the Dirc PMT. One of the reasons for the lower efficiency is the collection efficiency of the MCP that is estimated to be 60-65% for the current pore size of 25μm. R&D efforts are underway to increase the collection efficiency to 80%.

5 Focusing Dirc Prototype

An R&D prototype of the focusing Dirc is currently under construction at SLAC. While the final design of the prototype is still to be completed, several key components have been designed and built. The prototype will consist of one fused silica radiator bar, a focusing mirror, a stand-off region to allow the Cherenkov rings to expand, and an array of multi-anode PMTs.

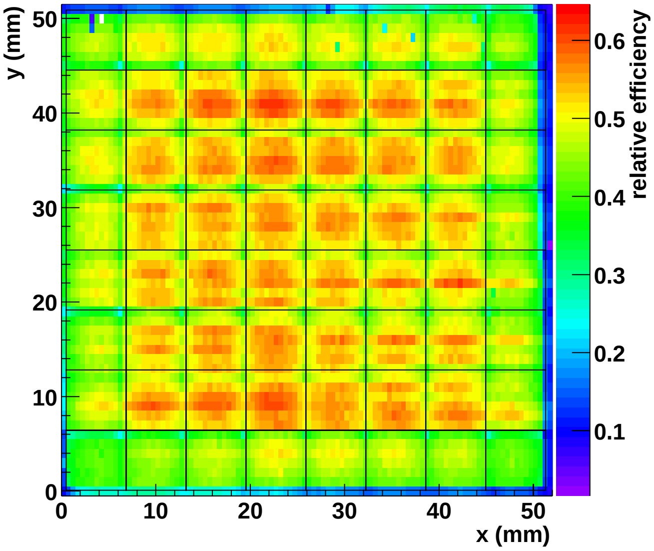

Figure 5: Relative response in the single photon mode of the Burle 64-pad MCP-PMT, using the PiLas laser diode at 430nm. The solid lines indicate the approximate borders between pads.

The radiator bar is 3.66m long, 35mm wide and 17mm thick, made from high-quality bar pieces produced during Dirc construction. The bar is equipped with a mirror on one (backward) end and coupled to the stand-off region in the other (forward) end. The size of the stand-off region is approximately 40cm deep, 90cm wide, and 35cm high. Ulta-pure mineral oil (dodecane and isoparaffin oils) is used to fill the stand-off region instead of the ultra-pure water used in the present Dirc. This type of oil has recently been used by the KamLAND experiment. It is a very good match to the refractive index of the synthetic fused silica and avoids the potential corrosive effects that ultra-pure water may have on the focusing mirror that is placed in the stand-off region. The focal length of the mirror is 48.5cm and an array of ten Burle 85011-501 MCP-PMTs will be placed in the focal plane, coupled to the stand-off region with a large window made from synthetic fused silica.

Construction of the prototype is expected to be completed in December 2003. Initial tests of the hardware and readout electronics will be performed in a hardened cosmic ray setup before the prototype will be moved into a beamline at SLAC in the spring of 2004.

6 Conclusion

Initial performance results of the multi-anode PMTs, are quite encouraging. In particular, the timing resolution of the Burle 85011-501 MCP-PMT is an excellent match to an application in a focusing Dirc. Furthermore, we expect the performance of the multi-anode PMTs to continue to improve as the manufacturers improve upon their product, and as we gain more experience with the new timing techniques.

There is a long road towards a final RICH implementing the chromatic correction. This requires the development of more sophisticated electronics with 20-30k channels each capable of reaching 50-100ps timing resolution. Nevertheless, our present results are a small but important step towards this goal.

It is important to stress that DIRC is ideal for chromatic error correction, as it is inherently a very fast device. Presently, to our knowledge, there is no other RICH technique where this idea would work.

A final arbitrator of the performance of these new photodetectors, of course, will be the Cherenkov rings. This is our next step.

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