Tests of the Burle 85011 64-anode MCP PMT as a detector of Cherenkov photons

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An upgrade of the particle identification system of the Belle detector is envisaged. In the search for an optimal photon detector, the performance of the Burle 85011 64-anode, multichannel plate PMT has been tested. The Cherenkov angle resolution and photon yield have been measured with pion beams at KEK, while the position and incident angle dependence of surface sensitivity have been measured on the bench.

1. Introduction

Within the envisaged upgrade of the Belle particle identification system, a proximity focusing ring imaging Cherenkov detector, with aerogel as radiator is considered [1]. The small available space, the 1.5 T magnetic field and the requirement of a 4σ pion-kaon separation pose strong demands on the detector of Cherenkov photons. Tests of the Burle 85011 64-anode, multichannel plate PMT [2] are presented below. The 64 anodes, ≈ 6 mm$\times$ 6 mm each, with ≈ 0.5 mm gaps, cover an active area of ≈ 51 mm $\times$ 51 mm, which represents $\approx 52\%$ of the PMT front surface. Measurements of Cherenkov angle resolution and photon yield have been carried out with pion beams at KEK, while the position and angle dependence of PMT response have been performed on the bench.

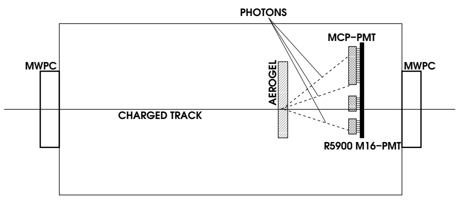

Figure 1. The experimental setup with a light-tight box and a set of MWPC's used for tracking of the incident particle.

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2. The experimental setups

The experimental setup is similar to the one used previously for testing the Hamamatsu H8500 PMT [3]. The apparatus is enclosed in a light tight box, with multiwire proportional chambers (MWPC's) at beam entrance and exit in order to record individual tracks (Fig. 1). The charged particles first pass through a multilayer aerogel radiator with varying refractive index, so as to achieve a focusing effect on the photon detector [4]. The photon detector, located 20 cm downstream of the aerogel radiator, consists of two parts. The upper detector is the Burle MCP PMT, while the lower detector is a 6×2 array of Hamamatsu R5900-00-M16 16-channel PMT's [5], which cover parts of the same Cherenkov ring and serve as a reference detector.

The photon detector inside the light tight box is connected to the readout system. In the first stage the PMT anode signals are amplified, shaped and discriminated in the ASD8 chips [6] used originally for the HERA-B RICH counter [7]. The digital outputs of the ASD8 are led out of the light tight box. They are adapted to the standard ECL logic signals which are then recorded by CAMAC multihit, multichannel TDC's, for which a common STOP signal is provided by the scintillation counter. The TDC information is stored for later analysis.

Again in a light tight box, the Burle 85011 MCP PMT was illuminated with a ≈ 50 μm diameter light beam, obtained from a LED, collimated and focused with a microscope condensor lens [8]. The surface scan was performed in steps of 12.5 μm with a computer controlled mechanism. The ECL logic signals were led into VME counters and the entire measuring procedure as automated.

3. Measurement and results

Figs. 2, 3 and 4 were obtained with 4 GeV/c pion beams. Fig. 2 shows the accumulated distribution of photon hits on the photon detector, with the individual positions corrected in order to correspond to a charged particle track along the axis of the apparatus. From the photon hit position and measured charged particle track, one

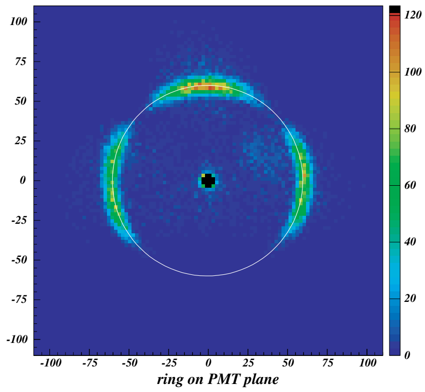

Figure 2. Accumulated hits corresponding to Cherenkov rings, as recorded by the two photon detectors (bottom).

calculates a Cherenkov angle for each individual photon. The accumulated distribution of the number of hits as a function of the corresponding Cherenkov angle is fitted with a Gaussian for the peak and a linear background. This yields the average Cherenkov angle, the standard deviation as well as the average number of hits per track. Fig. 3 represents such a distribution, except that instead of hits, the histogram represents the number of clusters and the Cherenkov angle corresponds to the center of gravity of each cluster. This improves the resolution.

Often two or more adjacent pads are hit and form clusters of hits. These can be random cases when real photons hit adjacent pads or the cluster could be a result of cross talk or charge sharing between the channels. The accumulated number of events depending on the number of hits in the event and on the number of clusters in the event is shown in Fig. 4. Also shown is the Poisson distribution, normalized to the number of events with no hit. The Poisson distribution lies between the two measured cases. The average number of hits per event is 2.6, the number of clusters is 1.2 and the Poisson mean is 1.8. For the reference counter, consisting of PMT's with 16 channels which are smaller than the channels of MCP PMT, the distribution in the number of hits follows the Poisson distribution very well.

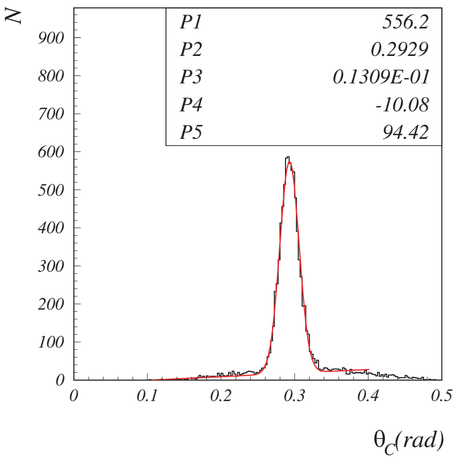

Figure 3. The distribution of Cherenkov angles corresponding to center of gravity of hits in clusters as recorded for 4 GeV/c pions. Two ≈20 mm thick aerogel layers with refractive indices 1.046 and 1.056 were used in a focusing configuration.

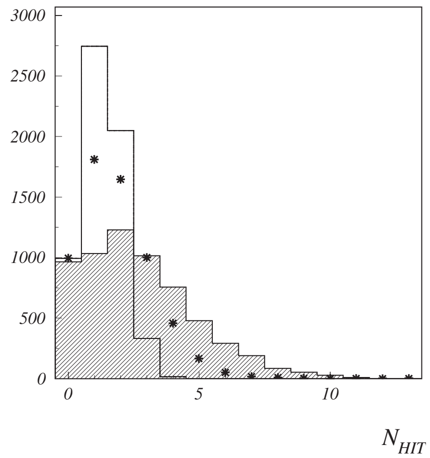

Figure 4. Distributions of events depending on: number of channels hit (hashed histogram), number of clusters (empty histogram) and the Poisson distribution matching N_{HIT}=0 bin entries (*).

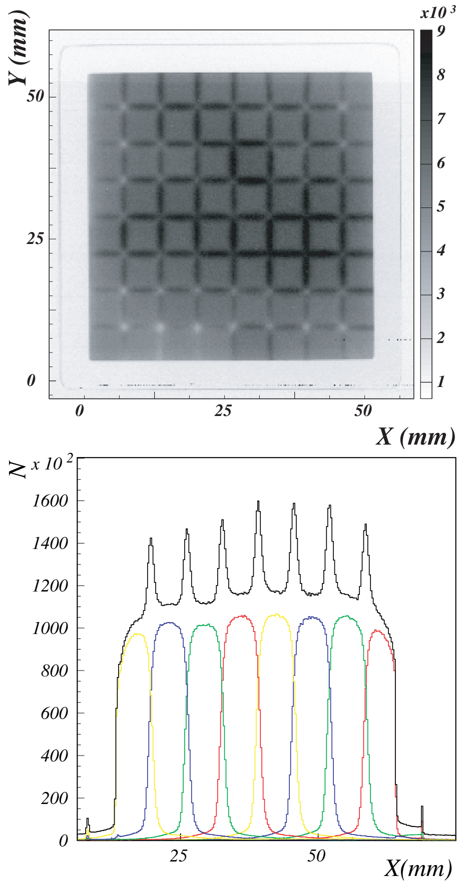

Figure 5. The count rates recorded by the Burle 85011 PMT, when scanning the LED photon beam across the PMT surface (top). A slice through the distribution, with individual channel count rates as well as their sum (bottom).

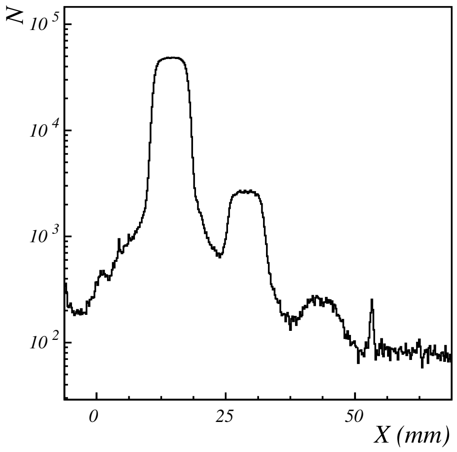

Figure 6. Count rate of one channel of the Burle 85011 PMT, depending on position of the incident photon beam, for 45^0 inclination of incident photons.

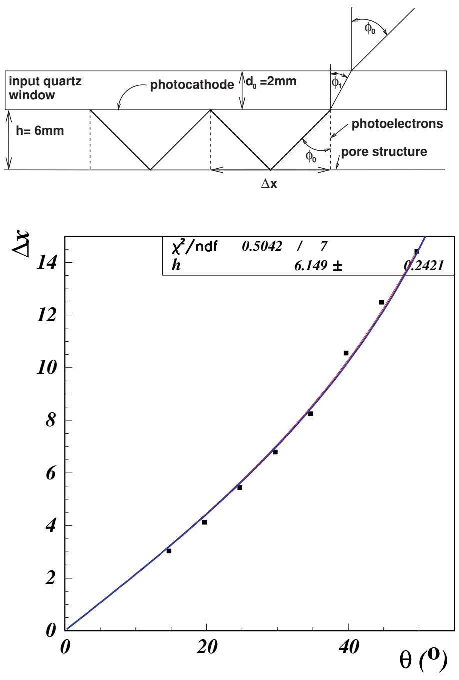

Figure 7. Diagram of photon path through the PMT window and reflection on the MCP structure (top). A fit to measured spacings between direct and "reflected" images of a pad as a function of photon beam incident angle (bottom).

For comparing the performance of the two detectors, the mean of the Poisson distribution was used. If $\langle N_{HIT} \rangle = 1.8$ is extrapolated to the full ring (and full active area is assumed), the number of detected photons would be 14. Taking into account the active area fraction of the MCP PMT, the number of detected photons per ring would amount to about 7 if the photon detector surface were covered by densely packed MCP PMT's. The reference Hamamatsu photon detector registered 1.95 photons; the corresponding extrapolated values are 17.5 (full active area) and 6.5 (densely packed PMT's). The ratio of the number of photons per full ring and full active area for the Burle MCP PMT and the Hamamatsu PMT is consistent with the ratio of their collection efficiencies, 60% and 75% respectively.

The resolution in Cherenkov angle for single clusters (determined from the fit in the Fig. 3) is σ_{θ_C}=13 mrad. The average number of clusters per track for the full ring is 4.5 in the case of a densely packed PMT's, which gives σ_{θ_C}=6 mrad for the Cherenkov angle resolution per track. This suffices for a 4σ separation of pions and kaons at 4 GeV/c, which is just acceptable.

The uniformity of response of the photon detector over its active surface as well as cross-talk between the individual detector pads was investigated in a separate study on the bench. The result of such a scan is shown in Fig. 5 along with a cross section through the 2D distribution. From the spikes, located at the borderlines between pads, it is evident that some of the photons have been registered by both adjacent channels. This charge sharing leads to clusters generated by a single photon, as already expected on the basis of the distribution in Fig. 4.

Another interesting effect has been observed with photons entering the PMT at an angle with respect to the normal incidence. Fig. 6 shows the count rate of a single pad depending on position at which the photon beam hits the PMT surface for 45^0 incident angle. For inclined incidence, one observes reflection images of the counting pad. These counts are due to single or double reflection of the photon on the structure of the microchannel plate and the entrance window (Fig. 7 top). The dependence of the distance between these pad images on the photon beam inclination angle confirms such an interpretation (Fig. 7 bottom). As the fraction of hits in these reflection images is about 7-8%, their impact on position resolution at 18^0 incident angle (typical for the present beam test) would produce a 10% increase of σ_{θ_C}, while their impact on timing resolution could be obtained from the estimated delay of 40 ps for such reflected photons.

4. Conclusion

The Burle MCP multianode PMT performed very well as a single photon detector both on the bench and in the test beam. The Cherenkov angle resolution and yield are in good agreement with expectations. The number of photons per track is still too small. There are two improvements which are possible according to the producer, namely the increase of active area up to 85%, and the increase of the photoelectron collection efficiency from 60% to 70%. This would provide 8.5 hits per ring on average and pion/kaon separation of more than 5σ at 4 GeV/c.

Another open question is the operation in high magnetic fields. The present Burle 85011 PMT with 25 μm pores works well in fields up to 0.8 T [9], whereas operation in 1.5 T is ultimately required. Hopefully this could be improved with 10 μm pore microchannel plates, which are under development.

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