Pixel hybrid photon detectors for the LHCb-RICH system

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1 Introduction

The baseline option for the photon detectors of the LHCb Ring Imaging Cherenkov (RICH) subsystem is the pixel hybrid photon detector (HPD) [1]. Commercially available pixel HPDs do not fully meet the LHCb RICH requirements, namely wide area coverage over 2.6 m^2, single photon sensitivity in the wavelength range of 200-600 nm, channel size of 2.5 x 2.5 mm^2 and a speed compatible with the LHC bunch-crossing rate of 25 ns [2]. The current prototype is the latest to have been developed in collaboration with the company Delft Electronic Products (DEP) [3]. Previous prototypes were successfully tested during the 1998 and 1999 test beam periods at the CERN X7 facility [4, 5]. The performance of HPDs in magnetic fields was previously characterised using a phosphor screen anode tube [6].

2 The Hybrid Photon Detector Prototype

The latest HPD prototype is shown in Fig. 1. The quartz optical input window is 7 mm thick with a 72 mm active diameter. A S20 multi-alkali photocathode is deposited on the inside surface of the window and is biased at -20 kV. A photoelectron released by an incident photon is accelerated and electrostatically focussed onto the anode assembly at 0 kV. The anode assembly is a hybrid structure consisting of a pixel detector array, segmented in 256x32 reverse-biased p-n junctions, and bump-bonded to the ALICE1LHCb binary read-out chip [7]. This chip has been developed as a collaboration between the LHCb and ALICE experiments [8]. The anode assembly is mounted and wire-bonded onto a ceramic carrier before vacuum encapsulation within the tube structure.

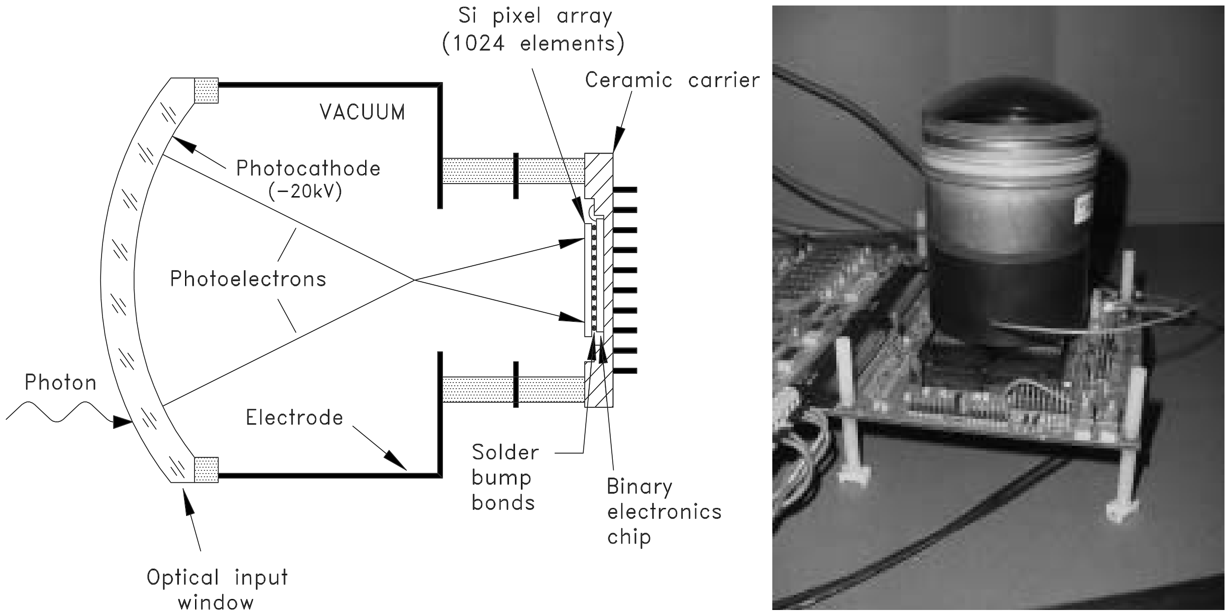

Figure 1: Schematic and photograph of the Pixel HPD. The schematic illustrates the photoelectron trajectories. The prototype is based on an electrostatic cross-focusing design with two intermediate electrodes demagnifying by a factor of ∼5 the photocathode image onto the anode.

3 Photoelectron Response

The prototype tube was tested using a procedure described in [9, 10]. Measurements were carried out in a light-tight box with a low intensity light-emitting diode (LED) operated in pulsed mode as a light source. The binary data from the HPD took the form of two scans, one at varying high voltage while at constant detector bias voltage, and the second at varying detector bias voltage while at maximum high voltage. At each point during these two scans, the fraction of events in which one or more pixels fired was calculated. From Poisson statistics, if $\mu^{'}$ is the average number of firing pixels per LED pulse, then this fraction is equal to 1-$e^{-\mu^{'}}$. Due to charge sharing effects at the pixel boundaries, one photoelectron can cause one or more pixels to fire. Consequently, it is more convenient to think in terms of the groups of pixels (clusters) which fire per LED pulse. This is shown in Fig. 2.

Fig. 3 shows the number of pixels which start firing at a given tube voltage and reflects the discriminator threshold distribution of the ALICE1LHCb chip. The Gaussian fit to this distribution yields a mean of 6.76 kV (∼ 1880 e^{-}) and a standard deviation of 0.82 kV (∼ 230 e^{-}).

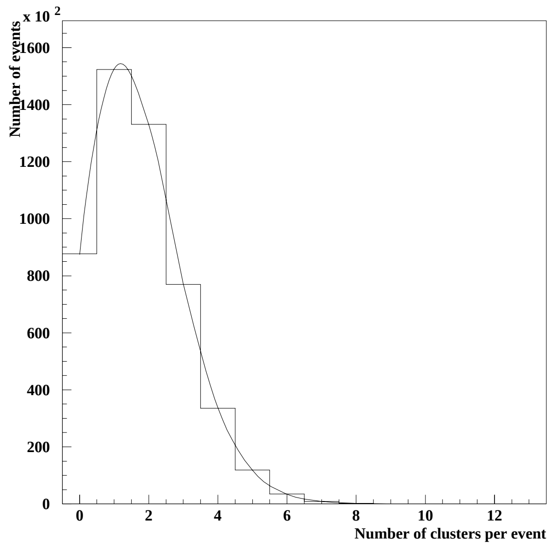

Figure 2: Discrete distribution obtained when counting the number of clusters per LED pulse at HPD high voltage 19 kV and detector bias voltage 80 V. The Poisson fit to this distribution yields a value of $\mu^{'} = 1.744$ compared to the measured value of 1.741.

The analogue signal from the back-plane of the silicon detector allows the measurement of the photoelectron spectrum as shown in Fig. 4. A fit [11] was made to the spectrum and the average number of photoelectrons μ, detected at the back-plane per LED pulse, extracted from the data. The ratio of the average number of firing pixels, $\mu^{'}$, to the average number of detected photoelectrons μ, is the efficiency of the HPD to single photoelectrons, since the probability of a pixel being hit by two or more photoelectrons is negligible. Before this efficiency can be calculated, corrections need to be made to the value of μ. A small fraction of the pixels were observed to fire due to their own noise and so were electrically masked prior to data taking. During the bake-out cycle (typically 300°C) of the encapsulation process, some bump bond detachment occurred, which also has to be corrected for. The bump bonding process has now been improved to take into account the high temperature steps during tube manufacturing. Additional corrections have to be applied for the effects of the LED intensity drift with time, charge sharing, and for backscattering at the silicon detector surface. The current estimate is around 80% efficiency, without corrections.

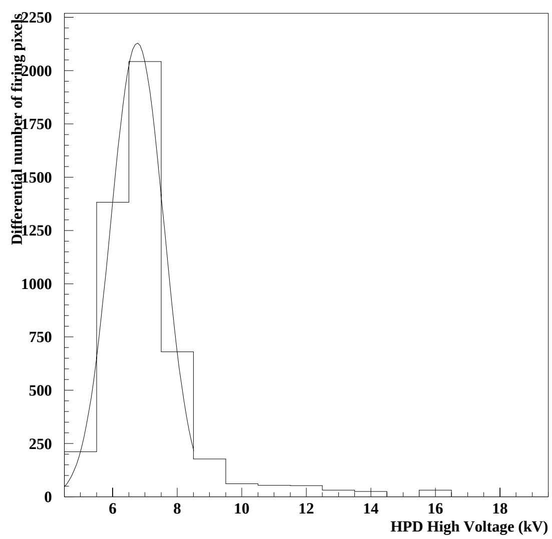

Figure 3: Differential number of firing pixels as a function of HPD high voltage. The detector bias voltage is 80 V.

4 Conclusions and perspectives

The HPD prototype behaves as expected but with two main improvements with respect to the performance of previous prototypes. These are a shorter peaking time (25 ns) of the front-end electronics and a lower detection threshold (< 7 kV). Current results indicate that the required detection efficiency will be reached. Two further prototypes are currently under manufacturing using the same chip but with the improved bump bonding process. A new pixel chip is currently undergoing testing at CERN, and indications are that it meets fully the LHCb specifications. Plans are in progress for future prototypes which will use this new read-out chip and an optimized bump-bonding procedure.

References

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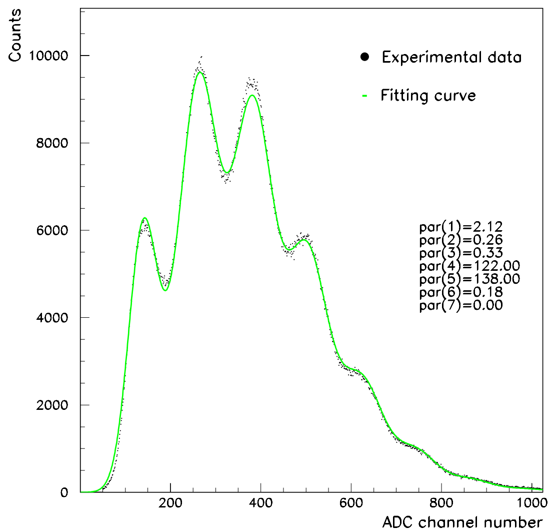

Figure 4: Photoelectron spectrum taken from the silicon detector back-plane, at 80V detector bias voltage and 19 kV HPD high voltage. The peaks for the pedestal, 1, 2, 3 ,4 and 5 photoelectrons are visible.

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