SINGLE PHOTOELECTRON DETECTION IN LHCB PIXEL HPDS

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To achieve the particle identification (PID) performance required by LHCb, the photodetectors in its Ring Imaging Čerenkov (RICH) detectors must be capable of identifying single-photon signals accurately. Such a requirement sets strict performance constraints on the components of candidate photodetectors. The constraints on the electrical performance of the detector chip of one such photodetector, the Pixel Hybrid Photon Detector (HPD), and some strategies for keeping to them are considered.

1. Introduction

LHCb is a single-arm forward spectrometer detector for the LHC, designed to take advantage of the high bunch-crossing rate and CoM energies of that collider to probe the phyics of b-hadrons in greater depth and detail than is possible with the current generation of experiments. To provide good particle identification (PID) performance it features two RICH detectors, which perform accurate measurements of particle velocity over a wide range of energies. Each RICH contains one or more radiator media, in which cones of Čerenkov light are induced by traversing particles. Spherical and flat mirrors then focus and guide the light onto plane arrays of photodetectors. The final choice of photodetector has not yet been made; one candidate is the Pixel Hybrid Photon Detector (HPD)[1].

Figure 1 shows the design of the HPD. Incoming photons pass through the glass entrance window and release an electron from the photocathode on its inner surface with a quantum efficiency of 27% at 270nm. The photoelectrons are accelerated to 20keV and cross-focussed by electric fields before striking the anode assembly at the rear of the tube, releasing ~5000 electrons within it[2]. The anode assembly is comprised of a silicon pixel

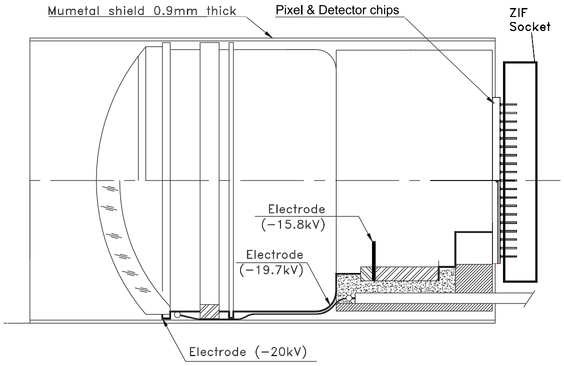

Figure 1. A schematic diagram of the Pixel HPD.

detector and the LHCBPIX1 binary readout chip, bump-bonded together. Both chips contain an array of 256x32 pixels; the detector chip pixels are simple reverse-biased p-n junctions, but those of the readout chip are rather more complicated, as can be seen in Fig. 2.

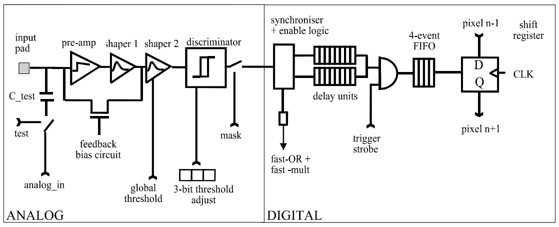

Figure 2. Block diagram of a single pixel of the LHCBPIX1 binary readout chip.

Each pixel has analogue and digital parts. In the analogue part, the incoming signal from the detector pixel is amplified, shaped and passed through a discriminator, the binary output of which is fed into the digital part of the chip, where it is clocked, buffered and read out (if triggered).

An important parameter to determine is the threshold voltage of the discriminator. This is set by a Digital to Analogue Converter (DAC) referred to as "Pre_VTH" to a value higher than the background noise but lower than the pulse height of an incoming photoelectron. An issue with pixel detectors is that of "charge sharing", in which a single photoelectron distributes its energy between two (or occasionally more) adjacent pixels. To ensure efficient single photoelectron detection despite this, it has been determined that the threshold should be less than ˜2000e^- and the electronic noise less than ˜250e^- for all pixels. These values translate to ˜20mV and ˜2.5mV respectively at the discriminator. Owing to the limited accuracy of the manufacturing process, each pixel responds slightly differently to the Pre_VTH signal. The result is a distribution of measured thresholds.

To ensure that the width of the threshold distribution does not prevent some pixels on the chip from meeting the standards set out above, the threshold of each pixel can be adjusted with its own three-bit DAC known as "TH012", which applies a correction to the threshold between 0mV and a value determined by the value of a second chip-wide DAC, "dis_biasth". It is these TH012 bits that are used to minimise the threshold distribution width.

2. Performing the Minimisation

The first minimisation step is to find the optimum value for dis_biasth. A value too large will decrease the resolution of the TH012 DACs: increasing the width of the minimised distribution by preventing the use of their full range. A value too small will mean that the threshold of some bits cannot be shifted far enough, again increasing the width. Since the thresholds follow a Gaussian distribution (Fig. 4), we expect the minimised distribution to be described by:

$$P(x') = \begin{cases} G(x' - 3.5a) & x' < -\frac{1}{2}a \\ \sum_{n=-4}^{3} G((n + \frac{1}{2})a + x') & -\frac{1}{2}a < x' < \frac{1}{2}a \\ G(x' + 3.5a) & x' > \frac{1}{2}a \end{cases} \tag{1}$$

$$G(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-(x-\mu)^2/(2\sigma^2)} \tag{2}$$

where $G(x)$ is the Gaussian probability distribution of mean μ and width σ (in mV) and a is the change in threshold in mV due to incrementing a TH012 DAC (ie $8a$ is the full range of TH012). Integrating this numerically over a range of values for a shows (Fig. 3) that, as expected, the curve displays a broad trough. The integration predicts a minimum at $8a \approx 5\sigma$. The results of an actual dis_biasth scan are also shown: while the two curves are similar qualitatively, they differ in their predictions of the optimal value of dis_biasth and of the achievable minimisation; this is interpreted as being due to the considerable non-linearity of the TH012 DACs.

Having chosen a value for dis_biasth, the second step in the optimisation is to select an algorithm to find values for the TH012 DACs. To simplify this

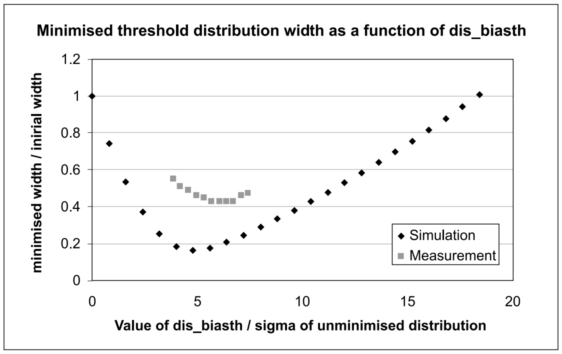

Figure 3. Simulated and measured threshold distribution widths as a function of dis_biasth.

process, we introduce two concepts: the "effective width" of the distribution and the "target threshold". The effective width $w \equiv 8a$ is the full range of each TH012 DAC as described above. The target value is the threshold to which we try and adjust each pixel using its TH012 DAC. Since the effect of these DACs is to reduce the threshold, this is the lower end of the distribution, at $\mu - w/2$.

The simplest possible minimisation algorithm is then, for each pixel, to divide the difference between its unminimised threshold and the target threshold by a: rounded to the nearest integer. This gives the new value for that pixel's TH012 DAC. The results of this algorithm are shown in Fig. 4: the unminimised distribution has a fitted deviation of 1.02mV; the algorithm reduces this to 0.43mV, a factor of ˜2.5 improvement.

The main assumption of the above algorithm is that the TH012 DACs are linear. Figure 5 shows the distribution of threshold changes due to incrementing a TH012 DAC. All seven possible increments from all 8,192 DACs are plotted. If the DACs were perfectly linear, the width of the distribution would be zero; as it is, they are (as postulated above) significantly non-linear: some increments even result in a threshold shift of the opposite sign. The mean incremental change in a DAC is 0.80±0.36mV.

Since the average difference between adjacent TH012 settings is already almost twice the standard deviation of the minimised threshold distribution, further reduction seems unlikely. However, to see if reconsidering the linearity assumption results in a further improvement in the minimisation, a second, "optimal" algorithm was tested. Eight measurements of the thresholds were performed, with a different chip-wide setting for TH012 each time.

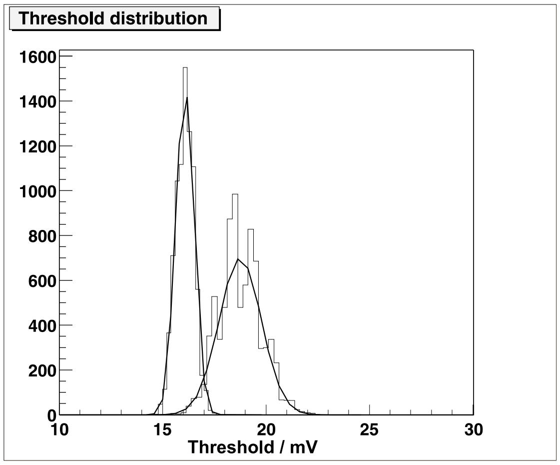

Figure 4. Simply-minimised (left) and unminimised (right) threshold distributions for LHCBPIX1 "chip 9".

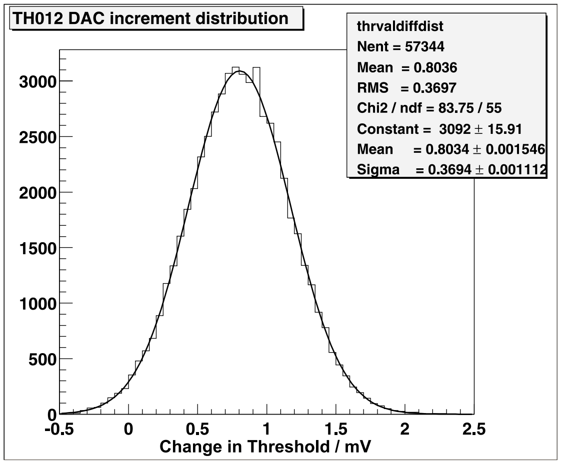

Figure 5. Threshold changes due to TH012 incrementation in "chip 9".

Then, for each pixel, the measured threshold closest to the target value was chosen and its corresponding value of TH012 chosen as the optimal value. The results of a scan taken following this procedure is shown in Fig. 6. The width of the distribution is ˜0.41mV - a negligible improvement over the simpler algorithm.

The minimisation techniques described above were tested on a second

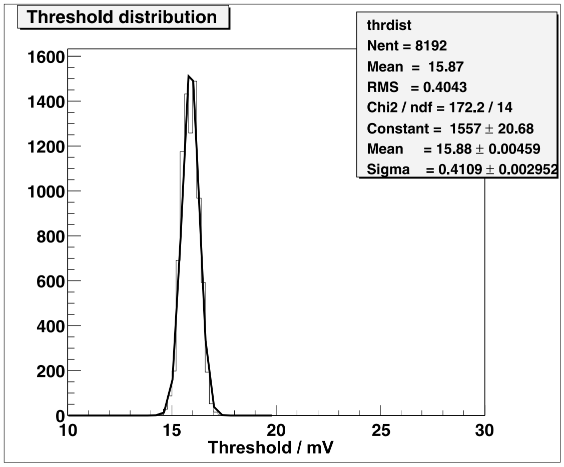

Figure 6. The optimally-minimised threshold distribution of "chip 9".

chip, with similar results.

3. Conclusion

Pixel HPDs remain a promising candidate photodetector for the RICH detectors of LHCb. The pixel chips already meet LHCb threshold and signal to noise ratio requirements. Should it become necessary, however, the chip's built-in features for minimising the width of the threshold distribution can be used to reduce it by a factor of ~2.5. The two algorithms tested gave similar results; the simpler, faster algorithm that assumes linear TH012 DACs is thus favoured.

Acknowledgements

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References

1. M. Girone, "The hybrid photon detectors for the LHCb-RICH counters", 7th International conference on advanced technology and particle physics, Como, Italy, 15-19 Oct 2001.
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