UNIVERSITY
of
GLASGOW

Department of Physics & Astronomy
Experimental Particle Physics Group
Kelvin Building, University of Glasgow,
Glasgow, G12 8QQ, Scotland
Telephone: +44 (0)141 339 8855 Fax: +44 (0)141 330 5881

GLAS-PPE/2008-036
26th November 2008

Hybrid Photon Detectors for the LHCb RICH: Performance and Operational Experience

LAURENCE CARSON[1] on behalf of the LHCb RICH collaboration

[1]Department of Physics and Astronomy, University of Glasgow,
Glasgow, G12 8QQ

Abstract

Pion/kaon discrimination in the LHCb experiment will be provided by two Ring Imaging Cherenkov (RICH) counters. These use arrays of 484 Hybrid Photon Detectors (HPDs) to detect the Cherenkov photons emitted by charged particles traversing the RICH. The results from comprehensive quality assurance tests on the 550 HPDs manufactured for LHCb are described. Leakage currents, dead channel probabilities, dark count rates and ion feedback rates are reported. Furthermore, results from two specialised measurements carried out on a sample of HPDs to determine the efficiencies of the HPD pixel chip and photocathode respectively are described. Finally, an overview is given of the in-situ performance of the HPDs which are now installed in the RICH.

8th International Conference on Position Sensitive Detectors
University of Glasgow, Glasgow, United Kingdom

1 Introduction

The LHCb experiment [1] is an experiment that will run at the Large Hadron Collider (LHC) at CERN, Geneva. When data taking begins in 2008, LHCb will commence the study of rare processes in the B-hadron system with the aim of discovering New Physics. Accurate and reliable Particle Identification (PID) will be crucial to the success of the LHCb physics program. To this end the LHCb detector includes two Ring Imaging Cherenkov (RICH) detectors which will identify pions, kaons and protons over a wide momentum range of 1–100GeV/c.

Both RICH detectors make use of arrays of pixel Hybrid Photon Detectors (HPDs) [2] to detect the Cherenkov photons which are emitted by charged particles as they traverse the RICH. The RICHes use 484 HPDs between them, 196 being in RICH1 and 288 being in RICH2. The HPDs must meet stringent performance requirements if they are to provide PID capability over the lifetime of the LHC. This paper reports the results of comprehensive quality assurance tests on all 550 HPDs which were manufactured for LHCb, and also gives an overview of the in-situ performance of the HPDs which are now installed in the RICH.

2 The Pixel Hybrid Photon Detector

The pixel HPD combines the advantages of vacuum and silicon technology by encapsulating a silicon sensor inside a vacuum-sealed tube. Figure 1 shows a schematic diagram of an HPD.

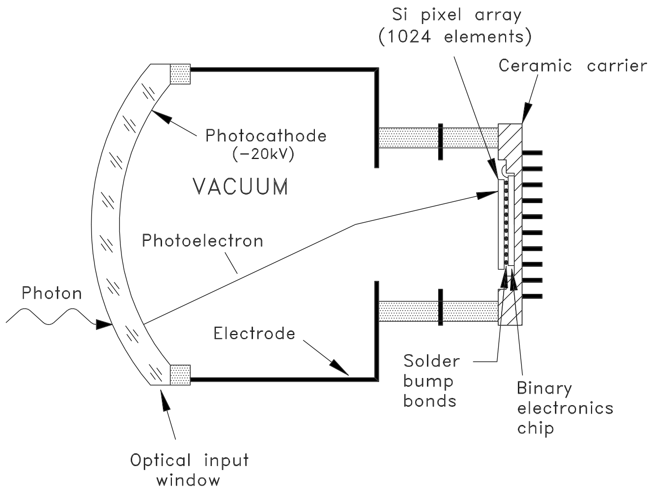

Figure 1: Schematic of the pixel hybrid photon detector.

The principle of operation of an HPD is as follows: an incoming Cherenkov photon reaches the quartz window of the HPD, and strikes the layer of S20-type multialkali photocathode material which is deposited on the vacuum side of the window. This liberates a photoelectron, which is then accelerated and focused onto the anode by a 20kV electric field. The anode consists of a pixellated silicon diode which is bump-bonded to a binary (pixel) readout chip. The binary readout chip has 8192 pixels. During LHCb running these are ORed in groups of 8 to make 1024 superpixels.

The HPD manufacturing process involved a number of different international companies, with the final stages carried out by Photonis-DEP[1)]. The quality assurance tests were carried out by LHCb between October 2005 and July 2007 using dedicated Photon Detector Test Facilities (PDTFs) at the University of Glasgow and the University of Edinburgh.

3 Quality Assurance Tests

All 550 HPDs which were manufactured for LHCb have now been tested at the PDTFs. Table 1 shows some of the specifications for the performance of the manufactured HPDs, compared to the actual average performance of the HPDs from tests carried out at the PDTFs. The collective performance of the HPDs in the areas most crucial for their physics performance is further illustrated in Figs. 2 and 3. Note that the whole sample of 550 HPDs contained only 12 HPDs (i.e. 2.2% of the sample) which had a performance issue serious enough to disqualify them from use in the RICH.

[1)] Photonis Netherlands B.V., Dwazziewegen 2, P.O. Box 60, NL-9300 AB Roden, Netherlands. Formerly Delft Electronic Products.

Table 1: Selected specifications and actual HPD performance.

Property	Specification	Average Performance
Working Pixels	95% min	99.8%
Photoelectron Detection Threshold	1500e$^-$ max	1064e$^-$
Photoelectron Detection Noise	100e$^-$ typical	145e$^-$
Photoelectron Detection Efficiency	85% typical	88%
Leakage Current at 80V reverse bias	1μA typical	1.49μA
Quantum Efficiency at 270nm	20% min	30.9%
Dark Count Rate	5kHz/cm^2 typical	2.54kHz/cm^2
Ion Feedback Probability	1% max	0.03%

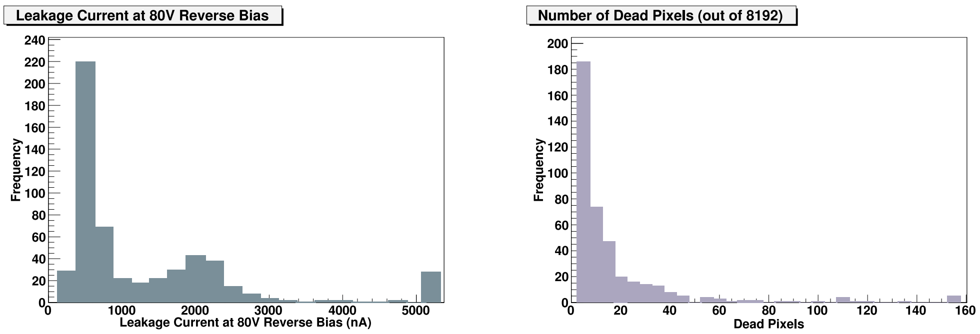

Figure 2: Left: Silicon sensor leakage current (nA) at 80V reverse bias. Right: Number of dead pixels (out of 8192).

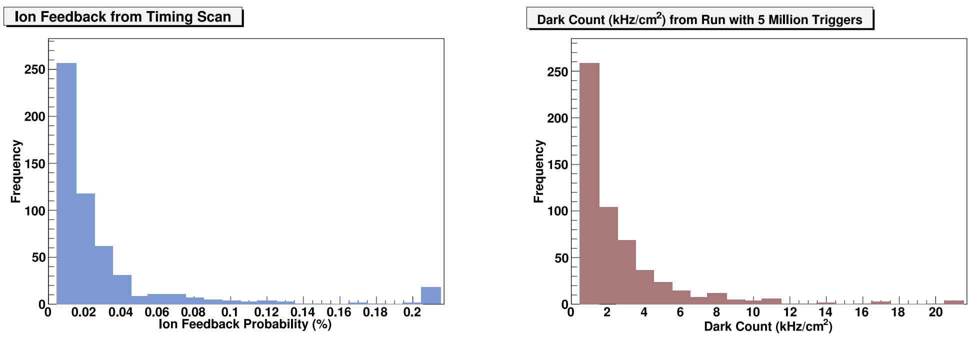

Figure 3: Left: Ion feedback probability (%). This measures the quality of the vacuum inside the HPD by measuring the number of ions created by photoelectrons as they pass through the vacuum. Right: Dark count levels (kHz/cm^2). This is the noise level seen when the high voltage is on but no light is incident on the HPD.

It can be seen that the leakage current is normally less than 1μA, which is the specified typical leakage current. A few HPDs exhibit high ($> 5\mu$A) leakage current, but this is not a problem as long as the amount of voltage lost is small enough such that the sensor is still fully depleted when 80V reverse bias is applied. Only one HPD failed to fully deplete due to high leakage current, and it was rejected. The dead pixel probability is always less than the specified maximum of 5%, which corresponds to 410 dead pixels. At the time of measurement, no HPD exceeds the specified maximum of 1% ion feedback probability. Some HPDs do exceed the specified maximum dark count level of 5kHz/cm^2, but these HPDs were not rejected as the dark count level is still 1,000 times lower than the level where it would adversely affect the physics performance of the RICH. In addition, the higher dark count rate is correlated with the improved quantum efficiency of the HPDs.

4 Specialised Tests

The tests described in Sec. 3 were carried out on all 550 HPDs. In addition there are two further tests which, due to their time consuming nature, were only carried out on a subset of HPDs. One of these tests measures the detection efficiency of the silicon sensor/binary readout chip ensemble, and the other measures the quantum efficiency of the photocathode.

4.1 Backpulse Measurements

The number of photoelectrons seen by the binary readout chip will be lower than the number arriving at the backplane of the silicon sensor because some photoelectrons do not deposit enough charge within the readout time of the binary readout chip to reach the detection threshold. This is due to charge-sharing and backscattering effects, and defines the photoelectron detection efficiency η_{Si} of the silicon sensor/binary readout chip ensemble. A specialised test to measure η_{Si} (the "backpulse measurement") was carried out on two HPDs. This measurement involves shining light from an LED onto the quartz window, and counting the number of photoelectrons this produces by two different methods. Firstly, the number of photoelectrons striking the backplane is estimated by measuring the amount of charge deposited there. This is done by tapping in to the backplane directly and then passing the signal through a preamplifier and a buffer amplifier. Over many events, a histogram of the charge can be built up, which should show peaks at multiples of the charge deposited by one photoelectron, which is around 5,000 electrons. The number of photoelectrons at the backplane is then measured by fitting a custom-defined function [3] to the charge spectrum. One of the parameters in the fit is the (Poisson mean) number of photoelectrons per event. A typical spectrum (black dots) and fit (green line) is shown in Fig. 4.

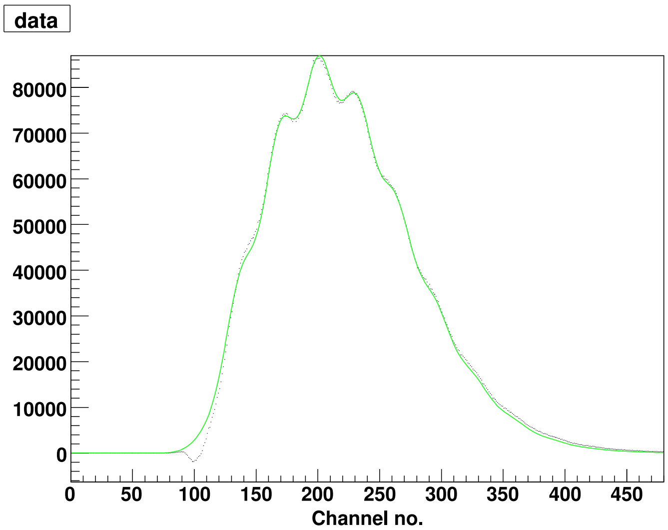

Figure 4: Fit to backpulse spectrum. The yaxis shows the number of counts per channel, accumulated over a period of around one hour. The 2nd, 3rd and 4th photoelectron peaks can be clearly seen, with the other peaks appearing as shoulders due to the high noise level.

Secondly, the standard PDTF Labview software is used to count the number of hits registered by the binary readout chip. This is then divided by the number of photoelectrons seen at the backplane to give η_{Si}. The measured value of η_{Si} depends on the amount of time (known as the binary readout time) allowed to the binary readout chip to integrate the signal from the silicon sensor. Figure 5 shows the η_{Si} values obtained for one of the two measured HPDs, tube H630005, using a binary readout time of 50ns. The average value across the two HPDs is $\eta_{\mathrm{Si}} = (94 \pm 2)\%$. The errors on each η_{Si} value are estimated by considering the change in the light

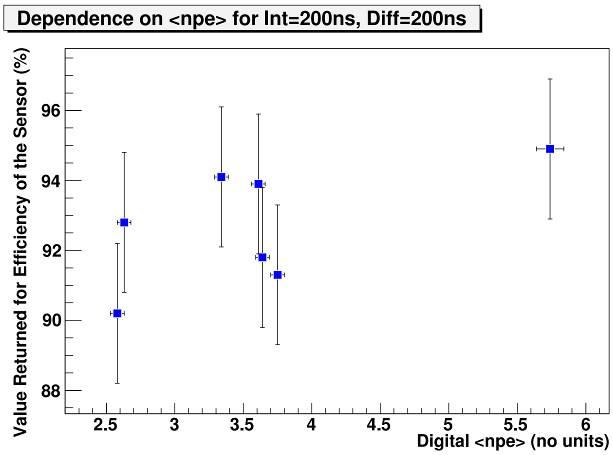

Figure 5: η_{Si} results for HPD H630005, using a binary readout time of 50ns. This HPD has $\eta_{\mathrm{Si}} = (92 \pm 2)\%$. Note that η_{Si} is independent of the amount of light input (x-axis).

output level of the LED during a single measurement, and by examining the stability of the fit to the backpulse spectra. Measurements were also carried out on tube H630005 using a binary readout time of 25ns, as this is what will be used during LHC running. These yield $\eta_{\mathrm{Si}} = (88 \pm 2)\%$, which as expected is lower than the 50ns value.

4.2 Quantum Efficiency Measurements

The quantum efficiency (QE) of the photocathode was measured in a standard way by biasing the photocathode relative to the anode then illuminating the photocathode with monochromatic light and comparing the current at the photocathode to the current across a photodiode of known QE. The QE measurement was carried out for every HPD by Photonis-DEP, and for a subset of HPDs by LHCb at the PDTFs. In general excellent agreement was found between Photonis-DEP measurements and LHCb measurements (see Fig. 6).

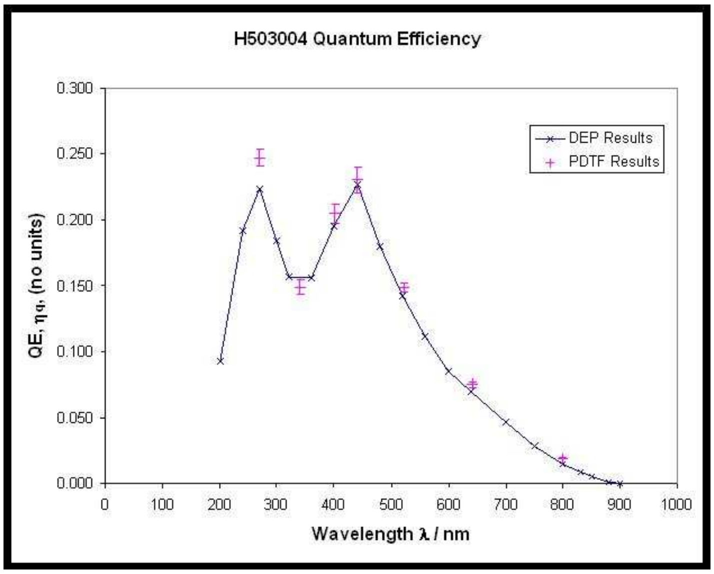

Figure 6: Comparison of QE measurements made by Photonis-DEP and PDTF on a single HPD.

During the production process, Photonis-DEP achieved consistent improvement in the QE of manufactured HPDs, with the QE value at 270nm rising from around 26% in early batches of HPDs to around 32% for later batches. The fact that the QE of all HPDs is higher than expected (see table 1) will directly improve the performance of the RICH.

5 Commissioning and Monitoring

All 484 HPDs have been mounted on columns and installed in the RICHes in the LHCb experimental area. A thorough programme of in-situ commissioning and monitoring is well underway. Figure 7 (left) shows the whole photodetector plane of RICH2 under illumination by continuous laser light.

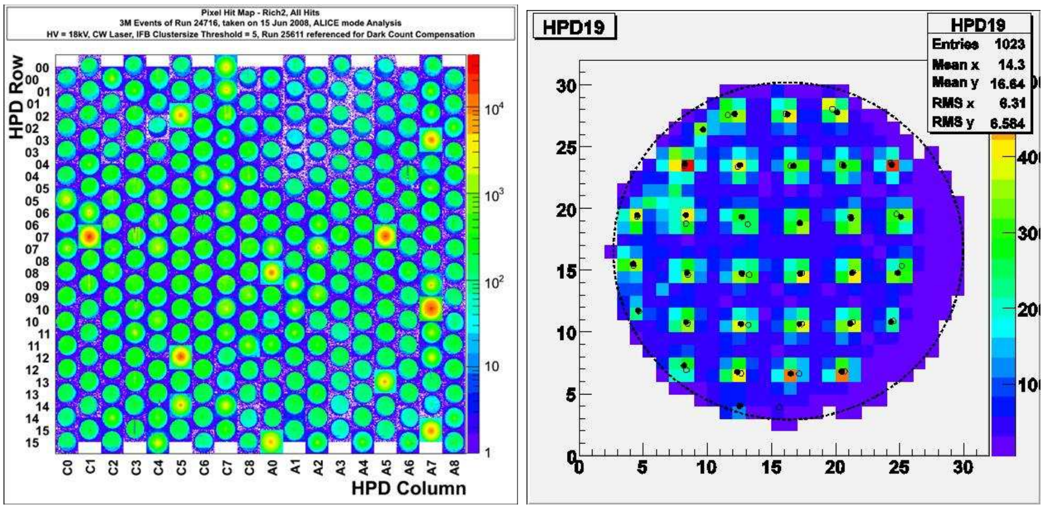

Figure 7: Left: Illumination of RICH2 HPD plane using continuous laser light. Right: Illumination of an HPD in RICH2 by the MDMS system.

One of the monitoring systems being used is the magnetic distortion monitoring system, or MDMS. This system measures the deflection of the path of the photoelectrons due to the residual field (maximum value of around 2.4mT) from the LHCb magnet. This deflection must be measured so that it can be corrected for when finding Cherenkov rings.

To measure the deflection the HPD plane is illuminated with a specific pattern of light, and the deformation of the pattern is monitored as the LHCb magnet is powered on and off. The pattern on one HPD in RICH2 is shown in Fig. 7 (right).

6 Conclusions

All HPDs required by the LHCb RICH detectors, including spares, have now been produced and thoroughly tested. Only 12 out of 550 HPDs fail to meet the performance requirements. The remaining HPDs meet all specifications and exceed them in certain key areas, for example number of working channels, dark count rate and quantum efficiency. The manufacture and testing of the whole sample of HPDs required for LHCb has proceeded according to plan. Commissioning of the HPDs in the RICH detector is well underway, and the LHCb RICH collaboration are awaiting the first LHCb data with optimism.

References

[1] The LHCb Collaboration, A Augusto Alves Jr et al., The LHCb Detector at the LHC, 2008 JINST 3 S08005.

[2] M. Moritz et al., IEEE Trans. Nucl. Sci. NS-51 (3) (2004) 1060.

[3] T. Tabarelli de Fatis, Nucl. Instr. and Meth. A **385** (1997) 366.