THE HYBRID PHOTON DETECTORS FOR THE LHCB-RICH COUNTERS

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The LHCb RICH baseline photon detector is the pixel Hybrid Photon Detector (HPD). Its design is based on a cross-focused electron optics with a tetrode structure, de-magnifying by a factor of five the photo-cathode image onto a small, reverse-biased silicon pixel detector array, bump-bonded to a dedicated readout chip with matching pixel electronics. The status of the HPD prototype tube, encapsulating the new ALICE-LHCb pixel readout chip is presented, with emphasis on preliminary tests results on the first received anodes. The tube electron-optics sensitivity to stray magnetic fields is also assessed.

1 Introduction

The LHCb experiment will use two RICH detectors [1,2] for particle identification. RICH1 covers the 1-50 GeV/c momentum range with an angular acceptance of 25-300 mrad and contains two radiators: aerogel and C_4F_{10} gas. RICH2, which uses a CF_4 gas radiator, is optimised for high momentum particles up to 150 GeV/c, in the angular range from 10 to 120 mrad. Cherenkov rings are focused by mirrors onto photon detectors positioned outside the acceptance of the spectrometer. In total, the photon detectors must cover an area of about 2.6 m^2. They must provide single photon sensitivity over the wavelength range from 200 to 600 nm and a granularity of 2.5 mm x 2.5 mm at the photo-cathode. The time resolution has to be better than 25 ns to cope with the LHC bunch crossing rate. In addition a high occupancy, which in some regions of the RICH detector can be up to 8%, the high level-0 trigger rate of 1 MHz, and the level-0 latency of 4 µs place strong demands on the readout electronics. The development of prototypes designed to meet these requirements has been carried out in close collaboration with industry [3].

The HPDs use a silicon detector anode inside the envelope of a vacuum tube. A photo-cathode is deposited on an optical input window of the envelope. Each photo-electron, released from the conversion in the photo-cathode of an incident photon, is accelerated by an applied high voltage of ~20 kV onto a reverse-biased silicon detector. Its kinetic energy is then dissipated near the silicon surface, resulting in the creation of ~5000 electron-hole pairs.

The HPDs will have to operate in the stray magnetic field of the experiment's dipole magnet. In RICH1 the field amplitude is reduced to 30 Gauss by the presence of a shield plate and can be further decreased to the level of 10 Gauss by using additional Mu-metal shielding surrounding each tube. In RICH2 the field will be of the order of 150 Gauss. A dedicated shielding box has been designed to house the HPD planes and reduce the field to less than 10 Gauss. Results of studies of the HPD's performance in magnetic fields are discussed in section 2.2.

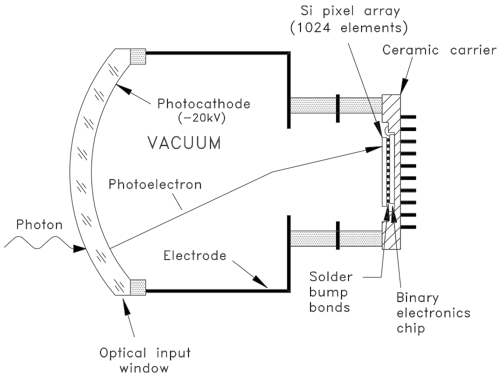

Figure 1.Schematic drawing of the pixel-HPD prototype tube.

2 The baseline pixel hybrid photon detector

2.1 Design principle and prototyping

The baseline pixel-HPD for the LHCb RICH counters is shown in Figure 1. It is based on an electrostatically focused tube design with a tetrode structure. The electrodes are shaped in such a way that the tube performance is unaffected by the proximity of other tubes or magnetic shielding. The baseline dimensions of the tube are 72 mm active diameter and a 18 mm output diameter. The photo-cathode image is de-magnified onto a small silicon detector array with 1024 pixels. To map the required cathode granularity of 2.5 mm x 2.5 mm, the pixels are 500 μm × 500 μm in size and are arranged as a matrix of 32 rows and 32 columns. The nominal operating voltage is 20 kV. The voltage difference between the photo-cathode and first electrode is adjustable and defines the precise value of the de-magnification factor.

The silicon pixel detector array is bump-bonded to a binary readout chip manufactured in the 0.25 µm CMOS technology, described in section 2.3. This assembly is mounted and wire-bonded onto a Pin Grid Array (PGA) ceramic carrier and is integrated inside the vacuum envelope of the tube. The feasibility of such a device has been already demonstrated by the successful realization of the imaging silicon pixel array tube [4].

A first full-scale prototype has been produced with a phosphor screen anode coupled to a CCD camera [5]. Detailed studies of the electron optics, reported in detail in [5], show that the tube active area is 81.7%. The de-magnification is 0.210 on-axis and 0.247 at the edge. The corresponding standard deviations of the point spread function at the anode are ~33 and ~54 µm, respectively.

Within the LHCb RICH R&D phase, four other 72:18 mm HPD prototypes have been manufactured. They are equipped with a commercial 61-pixel silicon detector anode and external analogue readout. Detailed studies of their performance in beam tests with the LHCb RICH1 prototype, discussed in Ref. [6], show that the photon-yield meets the LHCb requirements [7]. Typical quantum efficiencies at 270 nm are of the order of 23%.

2.2 *HPD performance in magnetic fields*

Extensive magnetic field tests have been carried out on the phosphor screen anode HPD, with and without shielding, using a Helmholtz coil that can provide fields up to 30 Gauss. Distortions to the optics are tolerable for fields up to 10 Gauss for a bare tube, and up to 30 Gauss with additional Mu-metal shielding. The distortions induced on a bare tube by an external 10 Gauss longitudinal and transverse magnetic field on a reference LED cross pattern anode image are shown in fig. 2.

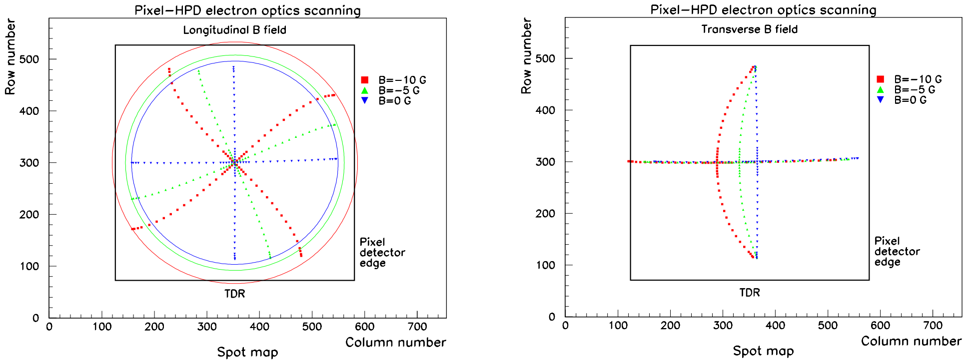

Figure 2 Image of a LED cross pattern seen on the phosphor anode. The images with and without an external longitudinal (left) and transverse (right) magnetic field up to 10 Gauss are superimposed.

In a longitudinal field the LED image is rotated and stretched; a transverse field induces an effect of non-uniform shift of the image in the direction perpendicular to the field orientation. Although the periphery of the image remains confined within the boundary of the detector active area for a 10 Gauss field applied on a bare tube, beyond this value, the mapping from anode to cathode is no longer unique, causing performance degradation of the Cherenkov rings pattern recognition.

In LHCb, the dipole field orientation will be regularly inverted. The HPD behaviour under magnetic field flipping cycles has also been checked: position residuals are of the order of a few μm on the anode, well within requirements.

2.3 Towards the final HPD prototype

In LHCb, the final pixel-HPD chip will have a 16 mm x 16 mm active area. It will be segmented into “super-pixels” of 500 μm^2, arranged as a matrix of 32 rows and 32 columns. Each super-pixel will be in turn sub-divided into 8 smaller pixel cells, each 62.5 μm × 500 μm. The silicon sensor will also consist of elements of the same size. The front-end chip must be optimised for single photo-electron detection and correctly discriminate hits and time-tag them with a specific bunch crossing. This requires that the front-end amplifier has a shaping time of ≤ 25 ns, and that the discriminator applies a threshold of < 2000 e^- with a pixel-to-pixel RMS spread of < 200 e^- to uniformly identify the low signals (≤ 5000 e^-) due to single photo-electrons. Each sensor pixel is connected via a solder bump-bond to a read-out chain, which includes a differential preamplifier and shaper, followed by a discriminator that compares its output with a threshold fixed globally across the chip. In addition, each pixel contains three logic bits, which can be used to adjust the thresholds on a pixel-to-pixel basis. With this electronics the effect of charge sharing between sub-pixels is minimized, and the photo-electron detection efficiency is dominated by the photoelectron backscattering (18 %) at the silicon detector surface. This efficiency is expected to reach 90 %.

The current pixel-HPD prototype encapsulates a pixel detector bump-bonded to the ALICE/LHCb pixel readout chip. This chip is a joint effort by two collaborations to produce a mixed mode integrated circuit to read out silicon pixel detectors for two different purposes: particle tracking in the ALICE Silicon Pixel Detector, and particle identification in the LHCb-RICH HPDs. Although the needs of these two detectors are different, the chip architecture has been designed with a selectable mode of operation to satisfy both. The sensitive area of the current chip is 12.8 mm x 13.6 mm, and is divided into 8192 pixel cells of 50 μm × 425 μm, arranged in 256 rows and 32 columns. It already satisfies the ALICE SPD requirements. The minimum average threshold at which the bare chip can be operated is around 700 e^-, with a RMS of about 150 e^-, without 3-bit adjust. The average noise is less than 100 e^-.

The first LHCb sensors, optimised for photoelectron detection, have been bump-bonded to ALICE/LHCb chips and tested in the laboratory. A bump-bonded assembly has a higher minimum threshold of about 1200 e^- and a slightly higher noise of 120 e^-. These values are well within the requirements of 2000 e^- and 250 e^- respectively.

Eight assemblies have been tested so far. I-V curve measurements show satisfactory leakage currents of about 100 nA with an applied detector bias of 80 V, on a surface of approximately 1.7 cm^2. The bump-bonding quality has been assessed by exposure to Fe^{55} and Cd^{109} sources, corresponding to a signal of 1600 and 6000 e^- respectively, close to the required sensitivity to single photo-electrons of 5000 e^-. About 95% of the pixels respond to these signals, as required.

3 Conclusions and perspectives

Pixel-HPD prototype tubes HPD for the RICH counters of the LHCb experiment are being developed in close collaboration with industry. A first full-scale prototype produced with a phosphor screen anode coupled to a CCD camera has been used to assess the performance of the tubes in presence of magnetic fields. The current development of the pixel-HPD involves encapsulation of a 13.6 mm x 12.8 mm silicon pixel detector, bump-bonded to the present ALICE/LHCb chip. The functionality of this chip has been assessed in laboratory tests and it has performed well within specifications. The first pixel-HPD prototype is currently being manufactured.

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References

1. LHCb RICH Technical Design Report, CERN/LHCC/2000-0037, LHCb TDR 3, September 2000.
2. S. Eisenhardt, this conference.
3. Delft Electronic Products (DEP) B.V., P.O. Box 60, Dwazziewegen 2, NL-9300 AB Roden, The Netherlands.

4. T. Gys et al., Nucl. Instr. and Methods A 355 (1995) 386.
5. M. Alemi et al., IEEE Trans. Nucl. Sc. 46 6 (1999) 1901.
6. E. Albrecht et al., Nucl. Instr. and Methods A 442 (2000) 164; T. Gys, Nucl. Instr. and Methods A 465 (2001) 240.
7. M. Adinolfi et al., A simulation of the LHCb RICH performance, LHCb 2000-066.