The Pixel Hybrid Photon Detectors of the LHCb Ring Imaging Cherenkov Counters

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Outline

- The LHCb detector
- The photon detectors of the LHCb RICH (HPDs)
- Results from the HPD test centres

The LHCb Detector

- Precision experiment designed to study CP violation and rare B decays.
 - Benefit from the large b-quark production cross-section at LHC $\rightarrow 10^{12}$ b-hadrons per year.
- Forward spectrometer covering 300 (250) mrad in the bending (non-bending) plane.

The LHCb RICH detectors

- 3 radiators to provide particle identification (π -K separation) in the range 2 – 100 GeV/c in 2 radiator volumes:
 - RICH 1: Silica aerogel and C_4F_{10} to cover 2 – 60 GeV/c.**
 - RICH 2: CF_4 to cover 17-100 GeV/c.**

The LHCb RICH detectors

484 HPDs covering a surface area of 3.3m^2 with an active-to-total area ratio of 65%.

Pixel Hybrid Photon Detectors

- The RICH photon detectors are Hybrid Photon Detectors (HPDs):
 - Combine a thin S20 photo-cathode (200-600nm) with a silicon pixel detector.
 - Accelerating and cross focusing electron optics .
 - **Tetrode structure**
 - **20kV cross-focusing field ($\rightarrow 5000e^-$ in Si)**
 - **De-magnification of image ~ 5**
 - 32x32 (256x32) silicon pixel sensor bump bonded to an encapsulated binary electronics readout chip.
 - 500 μm x 500 μm pixels $\rightarrow$ 2.5mm x 2.5mm spatial resolution in the photon detector plane.

These are a custom design, built in close collaboration with partners in industry (Photonis-DEP)

The Pixel Readout Chip

- Pixel chip is fabricated in $0.25\mu\text{m}$ (commercial) CMOS technology with:
 - Digital readout of pixels above threshold.
 - Typical threshold is $\sim 1050e^-$, c.f. signal of $5000e^-$ and noise $\sim 150e^-$.
 - $500\mu\text{m} \times 500\mu\text{m}$ super pixels are a logical OR of 8 $500\mu\text{m} \times 62.5\mu\text{m}$ sub pixels.
 - 40 MHz clock $\rightarrow$ LHC bunch crossing frequency.
 - 25ns shaping time $\rightarrow$ single bunch crossing.
 - 1 MHz trigger $\rightarrow$ LHCb Level 0 trigger rate.

HPD Production

Results from the Photon Detector Test Facilities

- 484 production HPDs + spares (550 in total) are completed and have been tested at the University of Edinburgh and the University of Glasgow.
- The HPDs are tested for:
 - Dark count rates (thermionic emission).
 - Vacuum quality (ion feedback).
 - Quantum efficiency.
 - Dead pixels (dead pixel rate typically below 1%).
 - Mechanical tolerance.
 - Leakage current (typically below $1\mu\text{A}$)

Yield has been excellent:

- 80% are rated as excellent
- 98% are suitable for use in LHCb

Dark Count rates and Ion Feedback

- Noise performance of the HPD is measured from dark count rates:
 - **Criteria for accepting a HPD is a dark count rate $< 5\text{kHz cm}^{-2}$.**
 - $5\text{kHz cm}^{-2} \sim 1\%$ per HPD per event (factor 1000 safety margin).
- Vacuum quality measured by looking for signs of ion feedback.
 - **Photo-electrons ionize residual gas. The ions drift to the photo-cathode releasing 10-40 photo-electrons which are detected $\sim 200\text{ns}$ after the initial signal.**
 - **Vacuum quality is excellent.**

Quantum Efficiency (QE)

- Single photon sensitivity between 200-600 nm.
 - Specification for QE is 20% at 270 nm → we do much better than this at ~ 31%.
- QE has been independently verified at the test facilities.

RICH Commissioning

- Beam test results, see talk by D. Perego:
 - “The Performance of the LHCb Pixel Hybrid Photon Detectors in a 25ns Structured Test-Beam”
- Currently commissioning the entirety of RICH 2, the downstream RICH detector.
 - 18 columns of 16 HPDs (288 HPDs) in a close packed arrangement.
 - Read out noise hits and time aligned test patterns.

Accumulated Cherenkov events from 80 GeV/c π^- beam test in a C_4F_{10} gas radiator.

Dark count noise from the commissioning system

Summary

- The LHCb RICH detectors use pixel hybrid photon detectors to detect Cherenkov photons.
- All 484 (550 including spares) production HPDs have now been completed.
 - Production yield is excellent, 98% are suitable for use in the RICH.
- RICH 2 is now commissioning, RICH1 will begin shortly.