Hybrid Photon Detectors for the LHCb RICH Counters

Paul Soler
University of Glasgow and Rutherford Appleton Laboratory

On behalf of the LHCb RICH Group

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Contents

- RICH Detectors for the LHCb Experiment
- Hybrid Photon Detectors for RICH counters
- Pixel chip, bump bonding and assembly of HPDs
- Performance of HPD pre-series
  - Threshold, leakage current, dark count, Quantum Efficiency, ion feedback
- Magnetic field distortions of HPD image
- Test beam preliminary results
- Conclusions
LHCb detector

LHCb aims to make precision measurements of CP violation and rare decays from B mesons.
Particle Identification: Ring Imaging Cherenkov detectors

**RICH1**

- Acceptance: 25-300 mrad

Three radiators: aerogel, C₄F₁₀ and CF₄

\[
\cos(\theta_c) = \frac{1}{n \cdot \beta}
\]

π/K separation: 2-100 GeV/c

**RICH2**

- Acceptance: 15-120 mrad

Flat mirrors, spherical mirrors, central tube, photon funnel + shielding
<table>
<thead>
<tr>
<th>Detector</th>
<th>PE/track</th>
<th>$\sigma(\theta_c)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$C_4F_{10}$ (small)</td>
<td>31</td>
<td>1.6 mrad/PE</td>
</tr>
<tr>
<td>Aerogel (large)</td>
<td>6.8</td>
<td>2.6 mrad/PE</td>
</tr>
<tr>
<td>CF$_4$</td>
<td>23</td>
<td>0.7 mrad/PE</td>
</tr>
</tbody>
</table>

**Reconstructed rings**

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Photon Detector Planes

e.g. RICH2

Photon detector plane

Hybrid Photon Detectors

RICH1: 7 columns of 14 HPDs (2 planes)
RICH2: 9 columns of 16 HPDs (2 planes) \( \Rightarrow 484 \) HPDs (area =2.6 m\(^2\))
Hybrid Photon Detectors

- Quartz window (S20 photocathode)
  - $\int QE \, dE > 0.7 \text{ eV}$
- 20 kV accelerating potential
  - 5000 e⁻ signal
- Cross-focussing optics
- Active diameter: 75 mm

- Encapsulated readout chip
- 32x256 (8192) pixel array (Canberra)
  - 62.5 $\mu$m x 500 $\mu$m
- Digital OR: 32x32 (1024) super-pixels
  - 0.5 mm x 0.5 mm
- Demagnification factor of ~5:
  - 2.5 mm x 2.5 mm effective size
Hybrid Photon Detectors

- Simulation of Point Spread Function:
  - Shows that RMS in position of electron at the Si plane is 97 μm
  - Effectively, all points collected within one super-pixel

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Pixel chip (LHCBI IX1)

- Low noise (< 250 e⁻)
- Low threshold (< 2000 e⁻)
- 40 MHz (25 ns precision)
- Binary architecture
- 16 mm x 16 mm active area
- 62.5 μm x 500 μm pixel size
- Two modes of operation: 8192 pixels or 1024 pixels

- 0.25 μm CMOS process
- Radiation tolerant (3 kRad/year)

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Mass production of 484 HPDs has commenced at DEP (~30 /month)
Quality assurance to be provided by two test facilities
Pre-series of 9 tubes tested: More than 99.3% good pixels
Threshold: 1100-1200 e- (< 2000 e-)
Pixel-pixel variation ~ 90-100 e-
Noise: 160-170 e- (< 250 e-)

LED scan
Leakage current and dark count

Leakage current: < 1 μA @ 80 V
8 out of 9 HPDs satisfy requirement (but tube still operational)

Dark count rate (< 5 kHz/cm²):
Measured rates between 0.03 and 3.0 kHz/cm².
Stabilises after 90-100 mins.
Quantum eff. and ion feedback

- Ion feedback:
  - Photoelectron ionises residual gas molecule
  - Ion travels back to cathode ejecting PE 200 ns after first electron pulse

- Test of gas quality
- Requirement < 1% signal
- Results < 0.1% signal

8 out of 9 satisfy QE min. requirement

QE > 20% @ 270 nm
(smaller QE in UV but higher QE in red tube can also be used)
Magnetic field

- Max field in RICH1 25 G, in RICH2 8 G
- Mu-metal shielding for each of the HPDs
- Distortions due to axial and transverse fields:

Need to correct for B-field distortions by use of test patterns.

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**Radial distance of hit on chip vs radial distance of LED source on entrance plane**

- \( B_{\perp} = 0 \text{ G}, 30 \text{ G}, 50 \text{ G} \)

**Image rotation vs radial distance on entrance plane**

- \( B_{\parallel} = 10 \text{ G}, 30 \text{ G}, 50 \text{ G} \)

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Test beam at CERN PS:
10 GeV/c electrons and pions

Observation of aggregate Cherenkov rings in C$_4$F$_{10}$ gas.

Test beam

HPD housing

Radiator vessel

Beam Pipe

Six HPDs tested in beam test

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Test beam (II)

Cherenkov rings in N$_2$ radiator focussed on one HPD

Electron/pion separation at 10 GeV/c clearly observed

Expectation: 19.1 mrad  23.7 mrad
Conclusions

- Hybrid Photon Detectors (HPD) will be used for the RICH counters of LHCb
- HPDs performing as expected
- Production of ~500 HPDs underway
- Quality assurance of production (~ 30 /month) to be provided by two test facilities.
- Test beam validates test results obtained in the laboratory
Bump bonding and HPD assembly

- Bump-bonding: high melting point solder (Sn/Pb = 10/90) at VTT (Finland)

- HPD assembly at DEP:
  - Tube body assembly
  - Photo-cathode deposition and vacuum sealing
  - Vacuum bake-out @ 300°C
  - HPD cabling and potting