Production of HPDs for the LHCb RICH Detectors

- LHCb RICH Detectors
- Hybrid Photon Detector
- Production
- Photo Detector Test Facilities
- Test Results
- Conclusions

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LHCb RICH Detectors

- **LHCb Experiment**
  - Precision measurements of CP violation in B meson decays, search for New Physics

- **Ring Imaging Cherenkov Detectors**
  - Charged particle identification
  - 2 RICH detectors - RICH1 and RICH2
  - 3 radiators - aerogel, C₄F₁₀, CF₄

- See talks in N25 - R Linder & C d’Ambrosio

- **RICH Photon Detector Requirements**
  - single photon sensitivity: 200 - 600 nm
  - quantum efficiency: >20%
  - photo detector area: 3.0 m²
  - active area fraction: 65%
  - spatial resolution /pixel size: 2.5 x 2.5 mm²
  - read-out at LHC int. rate: 40MHz
  - radiation tolerant: 3kRad/year

Simulated single event
**Hybrid Photon Detector - HPD**

- **HPD = Hybrid Device**
  - Visible light photon detector
  - Pixelised silicon sensor and readout electronics
  - Encapsulated in vacuum tube

- **Photon detector**
  - Multi alkali photo cathode (S20), quartz window
  - 20 kV photo cathode high voltage
  - Cross-focusing optics - de-magnification: ~5

- **Silicon anode**
  - Si-sensor array with 256×32 pixels
  - bump-bonded to binary readout chip
  - Single photo electron (p.e) at 20 kV
  - ~5000 e⁻ hole pairs in silicon
  - LHCb readout mode - 8-fold binary OR effective 32×32 pixel array
  - Pixel size - 500 µm × 500 µm

**LHCb RICH**
- 484 HPDs
- ~500k channels

- Photocathode
  - -20 kV

- Silicon anode
  - Ceramic carrier
  - Solder bump bonds

- Readout chip

- Quartz window
  - VACUUM

- Photocathode (~20kV)
- Photoelectrons
- Electrode
- Solder bump bonds

- 10 cm
HPD Production - Anode

Silicon sensor (Canberra - B)

Readout chip (IBM - F)

Ceramic carrier (Kyocera - JP)

Silicon sensor

High Temperature bump-bonding (VTT - FIN)

Brazing (DEP - NL) and gold-plating (CERN)

Assembly probing

Packaging (HCM - F)

Wafer probing

20 µm

Visual inspection and plating control

Anode testing

Hybrid photon detector production
(Photonis DEP - NL)

- Tube body assembly
- Photo-cathode deposition and vacuum sealing
- HPD cabling and potting
- Vacuum bake-out @ 300°C
- Anode incoming inspection and testing
- Anode testing
- QE measurement and anode testing
- HPD Q&A testing
HPD Quality Assurance

- **HPD Production**
  - Series production of ~500 HPDs started
  - 21 (+9 pre-series) HPDs delivered
  - Production rate - 30 HPDs/month over 18 months

- **Photo Detector Test Facilities (PDTF)**
  - Provide quality assurance (QA) and verify/measure HPD specifications/properties
  - Two PDTF sites: at Edinburgh and Glasgow Univ. with two fully equipped test stations/PDTF site
  - Automation wherever possible
  - Testing rate - one HPD / work day / site
  - Extended tests for subsample (~10%) of HPDs
PDTF Test Programme

- **Mandatory for all HPDs**
  - **Max. threshold:** \(<2000 \text{ e}^-\)
  - **Noise:** \(<250 \text{ e}^-\)
  - **Chip leakage current:** typ. \(1\mu\text{A} @ 80\text{V bias}\)
  - **HV operation:** stable @ 20kV
  - **Pixel response:** >95% for light
  - **Tube intrinsic coverage:** >80%
  - **Ion feedback rate:** \(<10^{-2} \text{ rel. to signal}\)
  - **Dark Count Rate:** \(<5\text{kHz/cm}^2\)

- **for 10% sub-sample of HPDs**
  - **Ph.e. detection eff.:** typ. 85%
  - **Quantum Efficiency:** at 270, 400, 520 nm

\{ threshold scans \}
\{ IV scan & Bias V scan \}
\{ High voltage scan \}
\{ long LED run \}
\{ time delay scan \}
\{ Dark count runs \}

**Measurements of 9 pre-series HPDs tested at CERN**
Results generally well within specification
Quantum Efficiency

- QE measurements
  - 9 pre-series HPDs at CERN

- QE specifications
  - based on HPD prototype results

Quantum efficiency vs wavelength [nm]

- Dark count rare correlated with QE
  - red response
- Measurements consistent between CERN and DEP
**Leakage Current**

- **Measurements**
  - 9 pre-series HPDs
  - 8 HPDs <1µA, typ. 1µA @ 80V
  - 1 HPD 4.3µA, OK

- **Measure “Chip” Temperature**
  - PT sensor at HPD read-out board

- **Photo detector test facilities**
  - Cross-calibration of 2 PDTF sites
  - Measure leakage current increases with “chip” temperature

- **Leakage Current**
  - Dependent on chip temperature
  - Not correlated with ambient temperature

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**Specifications**

![Graph showing Leakage current vs Si bias voltage](image-url)
**Bias & High Voltage Scans**

- **High Voltage Scans**
  - # of photo electrons vs high voltage
  
  ![Graph](image)

- **Bias Voltage Scans**
  - Strobe Timing is critical
  - drift velocity increases with $V_{Bias}$
  - depletion voltage and saturation yield depend on drift velocity

- **PDTF measurements**
  - Excellent agreement between PDTF sites
  - difference to CERN due to timing

- **PDTF Results**
  - HV curves are very similar
  - >90% relative efficiency > 10kV
  - large stable operating range
  - LED light yields vary between typ. 2 - 4 p.e./event
Long LED Run

High statistics LED run
(200k events, ~3 npe/event)

- HPD response
  - Full photo cathode area active
  - measure sensor positions
  - measure demagnification
  - cylindrical structures due to reflection on Al coating at edge
  - HPD edges will be shadowed mu-metal shielding

- 9 pre-series HPD results
  - uniform response over full active area (apart from reflections)
  - pixel response:
    - 8 HPDs >99%
    - 1 HPD > 94.8% (1 missing column)
    - Specifications: >95%
Ion Feedback

Ion Feedback signal

- Ion Feedback
  - photo electron ionises residual gas molecule
  - → travels back to the photo cathode
  - → releases cluster of photoelectrons
  - Delayed signal of clustered photo electrons
  - → peaks ~200ns after direct photon signal
  - indicator of vacuum quality

- 9 pre-series HPD results
  - ion feedback rate <10^{-3} x direct photon signal
  - consistent with specifications (<10^{-2})
Dark Counts

High statistics Dark Count run (5M events)

- Sources of dark counts
  - Thermionic electron emission (temperature)
  - Field emission (electric field)
  - Ion feedback (vacuum quality)

Ion Feedback clusters

9 pre-series HPD:
- dark count rate
- 0.03-3.0kHz/cm² (<5kHz/cm²)
  related to red response in QE
Long Term Performance - Ageing

- Aging Test Method
  - Illuminate HPD with intense LED light source
  - 40% occupancy at 50°C for 1 month
  - normal LHCb occupancy ~1%
  - equivalent to 10 years of LHCb running

- Measurements
  - Dark current - slight decrease with time
  - Ion feedback - increases from 1 to 3%
  - rate recovers
  - Light yield
  - Photocathode quantum efficiency unchanged

- Observe no degradation
  - Due to aging

Dark count rate
Ion feedback rate

Light yield
Quantum efficiency
Pixel Mask Measurement

- Prototype pin-hole mask
  - hole diameter: 1 mm
  - hole separation: ~11 mm

Response to LED light with pin-hole mask (200k events)

- Method
  - Mask placed at 3 cm distance to HPD
  - Illuminate mask & HPD with point-like light source (fibre)
  - Fit light spot positions

- Goals
  - Compare spots to hole positions
  - Test for image distortion
Conclusions

- Hybrid Photon Detectors meet requirements for LHCb RICH detectors
- Pre-series HPDs have been tested extensively and their performance is within specifications
- Production of ~500 HPDs has started
  21 HPDs have been delivered
- Photo detector test facilities built and commissioned
- Automated test procedures are in place
- Series testing of HPDs has started
# HPD Performance

*Results of 9 pre-series HPDs tested at CERN*

<table>
<thead>
<tr>
<th>Item</th>
<th>Specification</th>
<th>Results</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pixel response</td>
<td>&gt;95%</td>
<td>&gt;99%</td>
<td>missing column in 1 HPD</td>
</tr>
<tr>
<td>Min. threshold Noise</td>
<td>&lt;2000e-</td>
<td>Typ. 1200e-</td>
<td></td>
</tr>
<tr>
<td></td>
<td>&lt;250e-</td>
<td>Typ. 160e-</td>
<td></td>
</tr>
<tr>
<td>Leakage current</td>
<td>Typ. 1uA @ 80V bias</td>
<td>&lt; 1uA</td>
<td>4.3uA for 1 HPD see page 10</td>
</tr>
<tr>
<td>Dark count rate</td>
<td>Max. 5kHz/cm²</td>
<td>0.03–3kHz/cm²</td>
<td>Correlated to red response</td>
</tr>
<tr>
<td>Ion feedback rate</td>
<td>Max. 10⁻² rel. to signal</td>
<td>&lt;10⁻³</td>
<td></td>
</tr>
<tr>
<td>P.e. detection efficiency</td>
<td>Typ. 85%</td>
<td>79-89%</td>
<td>No dead channel correction</td>
</tr>
<tr>
<td>Quantum efficiency</td>
<td>see page 9</td>
<td>Generally well above specs</td>
<td>1 HPD below specs in UV</td>
</tr>
</tbody>
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