Hybrid Photon Detectors for the LHCb RICH

Introduction – Requirements by LHCb
Hybrid Photon Detector
Photo Detector Tests
First Test Results
Conclusions

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On behalf of the LHCb RICH group

Pixel 2005, Bonn, 07.09.2005
- Single-arm spectrometer for precision measurements of CP violation in B-meson system
- Search for signals of ‘New Physics’ beyond Standard Model
- Charged particle identification over momentum range 2-100 GeV/c
  - using 2 Ring Imaging CHeerenvok (RICH) detectors
**LHCb RICH System**

- **RICH = Ring Imaging CHerenkov detector**
- **3 radiator media**
  - aerogel, $C_4F_{10}$, $CF_4$
  - spherical mirrors
  - focusing $\rightarrow$ ring image
  - tilt $\rightarrow$ outside acceptance
- **secondary flat mirrors**
  - $\rightarrow$ magnetic shielding
- **acceptance**
  - RICH1: 25-300mrad
  - RICH2: 15-120mrad

\[ \cos(\theta_c) = \frac{1}{n \cdot v/c} \]

- **RICH1** side view
- **RICH2**
  - Flat mirrors
  - Spherical Mirrors
  - Support Structure
  - 7.2 m
  - Central Tube
  - Photon Funnel + Shielding
single event in the full GEANT3 based simulation used in performance studies

- photodetector area: 2.6 m²
- single photon sensitivity: 200 - 600 nm
- quantum efficiency: >20%
- good granularity: 2.5 x 2.5 mm²
- active area fraction: 65%
- # of electronic channels: 500k
- LHCb DAQ rate: 40MHz
- rad. tolerant: 3kRad/year
Hybrid Photon Detector

- Photon detector:
  - Quartz window, S20 photocathode
    - Typical $\int \text{QE} \, dE > 0.7 \text{eV}$
  - Cross-focussing optics (tetrode structure):
    - De-magnification by $\sim 5$
    - Active diameter 75mm
      $\Rightarrow$ 484 tubes for overall RICH system
  - 20 kV operating voltage (~5000 e$^{-}$ [eq. Si])

- Anode:
  - 256x32 pixel Si-sensor array
    - small pixels $\rightarrow$ low noise
  - bump-bonded to binary readout chip
  - assembly encapsulated in vacuum tube
  - LHCb readout mode: 8-fold binary OR
    $\Rightarrow$ effective 32x32 pixel array
  - pixel size 500$\mu$m x 500$\mu$m sufficient
HPD Production: Anode

Detector chip (Canberra - B)

Readout chip (IBM - F)

Wafer probing

High T bump-bonding (VTT - FIN)

Assembly probing

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

Packaging (HCM - F)

Visual inspection and plating control

Anode testing

Ceramic carrier (Kyocera - JP)

20 μm
HPD Production: Tube

HPD tube production
(DEP - NL)

Vacuum bake-out
@ 300°C

Tube body assembly

Photo-cathode deposition
and vacuum sealing

HPD cabling and potting

Anode incoming inspection and testing

Anode testing

QE measurement and anode testing

Final HPD testing

PIXEL2005, Bonn, 07.09.2005
Stephan Eisenhardt
Basic HPD Properties

Typical and minimum QE specs based on HPD prototype results:

- dark counts 3.03 kHz / cm²
- dark counts 0.03 kHz / cm²

measurements consistent between CERN and DEP

threshold ➔ LHCb: binary readout
Aims of Photo Detector Test Facilities (PDTF)
- Provide quality assurance (QA) and verify specifications of 550 Hybrid Photo Detector (HPD) tubes
- Characterise the HPD properties
- Test programme will last 20 months, starting immediately
- Normal delivery and test rate: 30 HPDs/month

Strategy for Photo Detector Test Facilities
- Two PDTF sites: at Universities of Edinburgh and Glasgow
- Build four fully equipped test stations, i.e. two full chains per PDTF site
- Automation wherever possible
- Use one test station for mandatory tests at a rate of one HPD / work day / site
- Second test station is for extra characterisation of a subsample (~10%) of HPDs and for redundancy
### Test Programme

- **for all HPD:**
  - Max. threshold: $<2000$ e$^-$
  - Noise: $<250$ e$^-$
  - Pixel response: $>95\%$ for light
  - Tube intrinsic coverage: $>80\%$
  - Ion feedback rate: $<10^{-2}$ rel. to signal
  - Dark Count Rate: $<5$kHz/cm$^2$
  - HV operation: stable @ 20kV
  - Leakage current: typ. 1$\mu$A @ 80V bias, 50°C chip

- **for 10% of HPD:**
  - Ph.e. detection eff.: typ. 85%
  - Quantum Eff.: spec. at 270, 400, 520nm

- **Threshold scans**
  - HV settling & long dark count run
  - Time delay scan
  - HV settling & long dark count run
  - IV scan & Bias V scan
  - Backpulse meas.
  - QE measurement

All results from 9 pre-series HPD tested at CERN

Illustrative plots from test facilities which just started operation
Threshold Setting

average response to test pulse scan

- variable charge injection at input of readout chip
- response for each channel fitted for position and slope of 50% point

Mean ~ 970e-
RMS ~ 90e-

9 pre-series HPD:
- threshold 1100 - 1300e- (< 2000e-)
- noise 150 – 180e- (< 250e-)
  (cf 5000e- photoelectron signal)
- 1 noisy pixel → mask

2000 e-

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

- fit sensor position
- fit demagnification

Cylindrical reflection: reflection on Al coating ➔ will be shadowed!

- 9 pre-series HPD: uniform response apart from reflection
- Pixel response:
  - 8x >99% (>95%)
  - 1x >94.8% (one column missing)
Ion Feedback:
- photo electron ionises residual gas molecule
- travels back to the photo cathode
- releases cluster of photoelectrons
- delayed signal of clustered photoelectrons
  - peaks ~200ns after direct photon signal

- 9 pre-series HPD:
  - ion feedback rate:
    - $< 10^{-3}$ x direct photon signal ($< 10^{-2}$)
Dark Counts

- Main sources:
  - Thermionic electron emission (temperature)
  - Field emission (electric field)
  - Ion feedback (vacuum quality)

- High statistics Dark Count run (5M events)

- Ion Feedback clusters

- Dark Count profile

- 9 pre-series HPD:
  - dark count rate
  - 0.03-3.0kHz/cm² (<5kHz/cm²)
  - related to red response in QE
High voltage scan (20k events / run)

- pixel hits
- photoelectrons after clustering algorithm (spread due to charge sharing)
- photoelectron estimate from Poisson

- >90% relative efficiency from 10kV
- large operating range
- stable behaviour
Bias voltage scan (20k events / run)

- plateau >50V
- over-depletion at 80V

IV-curve

- 9 pre-series HPD:
  - leakage current
  - 8x <1μA (typ. 1μA @ 80V)
  - 1x 4.3μA (HPD still OK)
- prototype pin-hole mask:
  - hole diameter: 1.0mm
  - hole separation: ~11mm

- fit light spot positions
- compare to hole positions

3cm distance to HPD
point-like light source (light fibre)

- test for image distortion
- quantitative test of focusing field
## Performance Summary

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 (OK)</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 8</td>
<td>Generally well above specs</td>
<td>1 HPD below specs in UV</td>
</tr>
</tbody>
</table>
Conclusions

- HPDs meet requirements of LHCb RICH detectors
- HPD pre series performance very encouraging
- Robust testing procedures in place
- Production of ~550 HPDs has started
- Test stations currently in cross-calibration
- First shipment of tested HPDs to mount in RICH 2 in 01/06
backpulse response to LED light ($O(2M)$ events)

- measured: charge replenishing Si-sensor
- real number of photoelectrons ($N_{pes}$) is estimated from the spectrum of the analog backpulse signal.

efficiency =

$\frac{\text{# photoel. (binary data)}}{\text{true # photoel.}}$

possible signal loss in binary data:
- energy below threshold
- late discrimination time time-walk
  (charge sharing and back-scattered electron)

challenge!
- integrated charge over whole detector
- large capacitance $\rightarrow$ large noise

9 pre-series HPD:
- photo el. detection eff.
  79-89% (typ. 85%)
- dead channel correction missing