Pixel hybrid photon detectors
for the LHCb-RICH system

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Outline of the talk

- **Introduction**
  - The LHCb detector
  - The RICH 2 counter
  - Overall RICH system requirements

- **The pixel hybrid photon detector**
  - Description
  - Binary front-end electronics
  - Full-scale HPD prototypes
  - Systematic tests

- **Conclusions and perspectives**
LHCb is a single-arm spectrometer with a forward angular coverage from 10 to 300 mrad, dedicated to precision studies of CP asymmetries and of rare decays in the B-meson system.

Particle identification over the momentum range 1-150 GeV/c will be achieved by two Ring Imaging Cherenkov counters.
The RICH 2 counter

Schematic view

Photo detectors

Mechanical design studies

Flat mirror

Spherical mirror

Gas CF₄

300 mrad

120 mrad

SUPPORTING FRAME ASSEMBLY

COLUMN ASSEMBLY

RAILS

DETECTOR PLANE ASSEMBLY

http://lhcb.cern.ch/rich/images/
rich2_schematic.gif
Overall RICH system requirements

- **Photon detection**
  - ~2.9 m² total surface
  - Granularity: 2.5 × 2.5 mm²
  - Active area coverage ≥ 70 % (~325,000 channels)
  - Single-photon sensitivity (λ = 200-600 nm)

- **Environment**
  - Magnetic stray field: ≤ 300 gauss (RICH1)
    ≤ 100 gauss (RICH2)
  - Radiation dose: ≤ 3 kRad/year

- **Read-out**
  - Maximum occupancy: ≤ 10 %
  - BCO identification (τᵢₚ ≈ 25 ns)
  - High L0-trigger rate (1 MHz)

- **Photo-detectors**
  - Pixel-HPDs: baseline solution
    - cross-focussing geometry
    - binary pixel readout (this talk)
  - Multi-anode PMTs: backup solution
    - metal channel dynodes
    - analogue readout
**Main features:**

**Close collaboration with industry**

**Quartz window with thin S20 pK (\(\int QE \cdot dE \approx 0.77 eV\))**

**Cross-focussing optics (tetrode structure):**

- De-magnification by \(~5\)
- 50 µm PSF (~250 µm at window level)
- Active diameter 75 mm (81.7 % tube coverage) \(\Rightarrow ~450\) tubes for overall RICH system
- 20 kV operating voltage (~5000 \(e^- [\text{eq. Si}]\))
- 32×32 pixel sensor array (500 µm×500 µm each)

**Encapsulated binary electronics readout chip**

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**Binary front end electronics (baseline specifications)**

**Full readout chip**

32 × 32 super-pixel array  
16mm × 16mm active area  
40MHz readout clock  
⇒ ~800ns readout time  
complying with LHCb L0 trigger rate (1MHz)

**Super-pixel**

500µm × 500µm area  
8 sub-pixels ORed together  
Digital FE electronics:  
• 16 delay lines (4µs)  
• 16-deep FIFO de-randomizing buffer  
⇒ reduced occupancy seen by analogue FE and lower noise

**Sub-pixel**

62.5µm × 500µm area  
Analogue FE electronics:  
• Differential amplifier (250 e− noise)  
• Shaper (25 ns peaking time)  
• Discriminator (2000 e− aver.)

See also another contribution of K. Wyllie (this workshop)
Manufactured by **DEP B.V.** (The Netherlands)

**First prototype (completed in 1999)**
- Phosphor screen anode
- **CCD** readout

⇒ check of active area, electron-optics, photocathode uniformity, magnetic field sensitivity and shielding options.


**Second prototype (completed in 1999)**
- **61-pixels** anode
- External analogue **VA2** readout

⇒ check of response to Cherenkov light, installation of a cluster in the RICH prototype.

http://www.cern.ch/~gys/LHCb/PixelHPDs.htm
Full-scale pixel-HPD prototypes (2)

Laboratory measurements

Pulsed LED spectrum

Signal-to-noise ratio ≈ 11 @ 20kV with external analogue VA2 readout ($\tau_p=1.2 \, \mu s$)

Beam tests in LHCb RICH 1 prototype

HPD cluster

Tube figure of merit: $N_0 \approx 225-250 \, \text{cm}^{-1}$
Third prototype (to be completed in 2001)

- ALICE1LHCB single assembly anode on custom ceramic carrier

- ALICE DAQ (software+hardware) readout
  ⇒ check of response to pulsed LED light.
Systematic tests of pixel-HPD prototype (1)

- **Operating conditions**
  - HPD high voltage = 0 ⇒ 19kV
  - Silicon detector bias 0 ⇒ 80V
  - Back-pulse spectrum recorded at end of data taking
  - Temperature and HV remotely controlled and monitored
  - Noisy pixels masked
  - Missing bump-bonds in central part, due to HPD bake-out cycle
    ⇒ LED shining window edge

**Detector bias scan**

<table>
<thead>
<tr>
<th>Detector Bias (V)</th>
<th>Average number of firing pixels</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>0.2</td>
</tr>
<tr>
<td>40</td>
<td>0.4</td>
</tr>
<tr>
<td>50</td>
<td>0.6</td>
</tr>
<tr>
<td>60</td>
<td>0.8</td>
</tr>
<tr>
<td>70</td>
<td>1.0</td>
</tr>
<tr>
<td>80</td>
<td>1.2</td>
</tr>
</tbody>
</table>

\[ \mu' = 1.741 \]
\[ @ 19kV, 80V \]

**HV scan**

<table>
<thead>
<tr>
<th>Tube High Voltage (kV)</th>
<th>Average number of firing pixels</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>0.2</td>
</tr>
<tr>
<td>8</td>
<td>0.5</td>
</tr>
<tr>
<td>10</td>
<td>0.75</td>
</tr>
<tr>
<td>12</td>
<td>1.0</td>
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<tr>
<td>14</td>
<td>1.25</td>
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<tr>
<td>16</td>
<td>1.5</td>
</tr>
<tr>
<td>18</td>
<td>1.75</td>
</tr>
<tr>
<td>20</td>
<td>2.0</td>
</tr>
</tbody>
</table>

\[ \mu' = 1.90 \]
\[ @ 19kV, 80V \]

\[ \mu' = \text{average number of firing pixels} \]
\( \text{(Poisson statistics)} \)
Systematic tests of pixel-HPD prototype (2)

Firing pixels per LED pulse

Back-pulse spectrum

\[ \mu = 2.6 \] @ 19kV, 80V

\( \mu \) = average number of photoelectrons per LED pulse inferred from back-pulse fit

Differential number of firing pixels as a function of HPD HV (detector bias 80V)

Gaussian fit:
\[ m = 6.76\text{kV} \ (1880\text{e}-) \]
\[ s = 0.82\text{kV} \ (230\text{e}-) \]

This distribution reflects the comparator threshold distribution of the ALICE1LHCb chip (without threshold adjust)

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• 1 p.e can cause more than one pixel to fire
• 2-pixel cluster: two adjacent pixels respond to 1 p.e.:

  - Horizontal
  - Vertical
  - Diagonal

• Vertical 2-pixel clusters are most common due to larger probability of charge sharing along long pixel side
Photoelectron detection efficiency estimate

Efficiency estimate from baseline specifications:

- Pedestal: 250 e- RMS noise
- Signal: 5000 e- @ 20kV

18% back-scattering probability, $<E> = E_0/2$, reduced effect if low cut

Charge sharing, 7 µm RMS lateral spread (300 µm-thickness, 90 V bias) not significant if $E_{cut} < E_0/2$

$\Rightarrow \sim 90\%$ expected detection efficiency

Experimental procedure

LED shining smaller pixel area, where bump-bonds are generally good:
Experimental procedure (cont’d)

- Analyze event size, correct for double pixel clusters, infer $\mu'$:

- Record back-pulse spectrum, infer $\mu$ from fit

- Compare values of $\mu'$ and $\mu$; present estimates range from 81% to 83%; not corrected for LED drift with time, LED tail, missing bump-bonds, masked pixels, photoelectron pile-up

- Error estimates:
  - LED drift: 5-10%
  - Fit parameters: 5%
  - LED tail: a few %
Conclusions and perspectives

**Conclusions**

- Pixel-HPD with ALICE1LHCB chip operational
- General behaviour nominal:
  - Good QE: >23% @ 270nm
  - HV operation OK
  - Chip electrical response: same as before encapsulation
  - Detector leakage current: same as before encapsulation
  - Heat dissipation: 15 °C temperature increase for ~0.85W power consumption

- Photoelectron response: nominal (missing bump-bonds excluded)
  - Preliminary photoelectron efficiency estimates range from 81% to 83%; not corrected for LED drift with time, LED tail, missing bump-bonds, masked pixels, photoelectron pile-up

- Improved bump-bonding process survive bake-out cycle, new HPD prototypes under manufacturing
- New LHCBPIX1 chip fully operational at 40MHz

**Perspectives**

- New silicon pixel detector and ceramic carrier designed, expected for the end of 2002
- New bump-bonded assemblies to be manufactured early 2003