The pixel hybrid photon detectors for the LHCb-RICH project

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Outline of the talk

Introduction
- The LHCb detector
- The RICH counters
- Overall RICH system requirements

The pixel hybrid photon detector
- Description
- Full-scale 61-pixel HPD prototypes
- Laboratory and beam test measurements
- Ceramic carrier designs
- Binary front end electronics
- Expected detection efficiency
- Back-scattering and charge sharing effects

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 1 counter

Mechanical design studies

Schematic view

http://lhcb.cern.ch/rich/images/rich1_schematic.gif
The RICH 2 counter

Schematic view

Photo detectors

Flat mirror

Spherical mirror

Gas CF$_4$

http://lhcb.cern.ch/rich/images/rich2_schematic.gif

CERN EP-TA2
P. Wicht et al.

INFN Genova
S. Cuneo et al.
Overall RICH system requirements

- **Photon detection**
  - ~2.9 m² total surface
  - Granularity: $2.5 \times 2.5$ mm²
  - Active area coverage $\geq 70\%$ (~325’000 channels)
  - Single-photon sensitivity ($\lambda = 200$-600 nm)

- **Environment**
  - Magnetic stray field: $\leq 30$ gauss (RICH1)
    $\leq 100$ gauss (RICH2)
  - Radiation dose: $\leq 3$ kRad/year

- **Read-out**
  - Maximum occupancy: $\leq 10\%$
  - BCO identification ($\tau_p \approx 25$ 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 (\(\int \text{QE} \cdot \text{d}E \approx 0.77 \text{eV}\))

Cross-focussing optics (tetrode structure):
  - De-magnification by \(\approx 5\)
  - 50 \(\mu\)m PSF (\(\approx 250 \mu\)m at window level)
  - Active diameter 75 mm (81.7 % tube coverage)
    \(\Rightarrow\) \(\approx 450\) tubes for overall RICH system
  - 20 kV operating voltage (\(\approx 5000 \ e^-\) [eq. Si])

32\(\times\)32 pixel sensor array (500 \(\mu\)m\(\times\)500 \(\mu\)m each)

Encapsulated binary electronics readout chip

http://www.cern.ch/~gys/LHCb/PixelHPDs.htm
Full-scale 61-pixel HPD prototypes

Manufactured by DEP B.V. (The Netherlands)

Preliminary tests at the factory were satisfactory:

20 kV high voltage operation
17% QE @ $\lambda = 400$ nm
Si detector leakage current: $\leq 1$ nA per pixel
Full-scale 61-pixel HPD prototypes (cont’d)

Laboratory measurements

**Single photoelectron response:**

Signal-to-noise ratio $\approx 11$ @ 20 kV

with external analogue VA2 readout ($\tau_p = 1.2 \mu s$)

(E. Albrecht et al., NIM A 411 (1998) 249)

**E- optics performance:**

Confirmed
Full-scale 61-pixel HPD prototypes (cont’d)

 Beam tests

Full-scale RICH1 prototype

Sketch of prototype layout for cluster test of Pixel HPDs

Cherenkov angle is 53 mrad with C4F10 radiator at 1000 mbar

E. Albrecht et al.
NIM A 442 (2000) 164

http://lhcb.cern.ch/rich/images/RICH_proto_layout_pixel_cluster.gif

61-pixel HPD cluster

http://www.cern.ch/~gys/LHCb/PixelHPDs.htm
Full-scale 61-pixel HPD prototypes (cont’d)

Accumulated Cherenkov rings

Tube figure of merit:

\[ N_0 \approx 225\text{–}250 \text{ cm}^{-1} \]
Ceramic carrier designs

1st HPD prototype:

Commercial 61-pixel anode
External VA2 readout
\( \tau_p = 1.2 \mu s \)
~65 feed-throughs

Final HPD prototype:

Custom 1024-pixel anode
Internal binary readout
\( \tau_p = 25\,\text{ns} \)
~100 feed-throughs

+ Bake-out compatibility
  (5h @ 350°C)
+ Power dissipation
  \( \leq 0.5\,\text{W} \) for binary electronics
Ceramic carrier designs (cont’d)

Manufactured by Kyocera (Japan)

Kyocera custom Pin Grid Array carrier

Custom Pin Grid Array carrier for the ALICE-LHCb chip

ALICE-LHCb chip within carrier cavity

~100 finger bond pads (out of 360) used
**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
- 10 sub-pixels ORed together

Digital FE electronics:
- 20 delay lines (4µs)
- 16-deep FIFO de-randomizing buffer
  ⇒ reduced occupancy seen by analogue FE and lower noise

**Sub-pixel**
- 50µm × 500µm area

Analogue FE electronics:
- Differential amplifier (250 e⁻ noise)
- Shaper (25 ns peaking time)
- Discriminator (2000 e⁻ aver., 30 e⁻ spread with 3-bit adjust)

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See also contribution of W. Snoeys (this workshop)
### Expected detection efficiency

<table>
<thead>
<tr>
<th>Pedestal</th>
<th>Cut</th>
<th>Signal</th>
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<tbody>
<tr>
<td>Pedestal: 250 e$^{-}$ RMS noise</td>
<td>Cut: 2000 e$^{-}$ aver., 30 e$^{-}$ RMS spread</td>
<td>Signal: 5000 e$^{-}$ @ full energy + 18 % back-scattering</td>
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⇒ ~90 % detection efficiency
Back-scattering and charge sharing effects

Charge sharing

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

Back-scattering

18% probability
$<E> = E_0/2$
Reduced effect if low cut
Conclusions and perspectives

- **Prototype tubes and electronics**
  - Close collaboration with industry:
    - reliability
    - easier transition to production
  - Binary electronics implies:
    - lower cost
    - simpler readout architecture, data transmission and processing

- **Successful R&D results**
  - Electron optics provide large tube active area
  - High quantum efficiency photo-cathodes
  - Cherenkov air and gas rings successfully detected in various LHCb RICH prototypes
  - Test pixel electronics provides optimized detection efficiency, same performance expected with full chip

- **Current and future R&D work**
  - HPD prototype with encapsulated ALICE-LHCb chip (milestone winter 2000)
  - Final LHCb chip and ceramic carrier design (submission spring 2001)
  - Final HPD prototype (completion winter 2001)