Pixel Hybrid Photon Detector
Magnetic Distortions
Characterization and Compensation

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On behalf of the LHCb RICH collaboration

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The LHCb experiment

- b physics at the LHC p-p collider: CP violation, rare decays
- Single arm forward spectrometer (*W. Witzeling, IEEE NSS N21-8*)
- Hadrons identification -> Ring Imaging Cherenkov detectors RICH
LHCb RICH detectors

Particle ID by Cherenkov angle measurement from photon hits on detector planes

- **RICH1**
  - Aerogel (2 - ~10 GeV/c)
  - $C_4F_{10}$ (10 - ~60 GeV/c)

- **RICH2**
  - CF$_4$ (16 - ~100 GeV/c)

Magnet fringe field shielding boxes
Magnetic shielding and photon detector requirements

Photon detectors requirements:

• Single photon detection in the 200-600 nm wavelength range
• 2.5x2.5 mm² spatial resolution on entrance window equivalent to $\sigma_{\theta C} = 0.62$ mrad error contribution to Cherenkov angle
• Operational in magnetic field of $\sim 2.5$ mT in RICH1 and $\sim 1.0$ mT in RICH2
Hybrid Photon Detectors

- Vacuum tube
- Quartz window, S20 photo-cathode, 25% peak QE
- Cross-focusing electron optics
- Anode assembly:
  - hybrid pixel detector (16x16 mm²) fully encapsulated in the vacuum tube
  - 32x256 pixel silicon detector bump-bonded onto the LHCbPIX1 CMOS readout chip
  - Analog and digital chain readout on chip

- Electron trajectories distorted by magnetic field like in Image Intensifiers for fluoroscopy
- Rotation (S-distortion) due to axial component
- Translation due to transverse component
Magnetic distortions

- Individual magnetic shielding
- Smaller displacements for transverse component
- No losses due to magnetic effects unless image shifted out of anode (>> 5.0 mT)

- Reconstruct pixel hit – photon hit position correspondence for each HPD
- Magnetic field not uniform and varying tube-by-tube
Set-up description

- Projection of collimated light on known positions on the HPD entrance window
- Magnetic field generated by Helmholtz coils
  - B field value is the one in the region when HPD and shield are not there
- Cylindrical Mumetal® magnetic shield

- 160 points Double Cross pattern to position the LED
- Characterization for axial magnetic field $B_\parallel$
- Rotational symmetry
- Not too restrictive
  - Local shielding very effective on transverse component
  - Smaller displacement due to transverse field
Radial distance of hit on chip vs radial distance of LED source on entrance plane

\[ y = -0.0016x^2 + 0.2425x \]

\[ y = -0.001x^2 + 0.2043x \]

\[ y = -0.0004x^2 + 0.1772x \]

- Non uniform radial dilation
- Second order polynomial fit

\[ \rho = \rho_1(B) r + \rho_2(B) r^2 \]

\[ \rho_i(B) = \sum_j \rho_{i,j} B^j \]
Rotation law

- Non uniform rotation (S-distortion)
- Third order polynomial fit, first order coefficient zero

\[ \Delta \varphi = \Delta \varphi_0(B) + \Delta \varphi_2(B) r^2 + \Delta \varphi_3(B) r^3 \]

\[ \Delta \varphi_i(B) = \sum_j \Delta \varphi_{i,j} B^j \]
Photon hit reconstruction

Parameterization obtained is used to

- **Reconstruct** photon hit position from pixel hit position given the magnetic field
- Develop an estimator of $B_{//}$ with a test pattern

- **Distorted images** of double cross processed to calculate the photon hit position
- Reconstruction error at 2.5 mT larger than intrinsic resolution of the HPD ($2.5/\sqrt{12} = 0.72$ mm)
- First trial, on-going study

<table>
<thead>
<tr>
<th>Applied B field [mT]</th>
<th>Average reconstruction error [mm]</th>
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<tbody>
<tr>
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<tr>
<td>1.0</td>
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<td>2.0</td>
<td>1.40</td>
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<tr>
<td>3.0</td>
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Test Pattern

- **Test pattern features:**
  - Allows easy **automatic search** and identification of clusters (correspondence problem)
  - Spots averaged centers as coordinates for the analysis
  - Sample rotation of the image at various radii
  - **Estimate the B field** axial component by best fit of the model

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<td>5.0</td>
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Estimator average bias: 0.07 mT

- Projection of a **static pattern** on the detectors plane in the experiment
- **Automated calibration** procedure on the full set of HPDs determining field in each tube
Conclusion

- Innovative **Hybrid Photon Detectors** developed by the LHCb collaboration and industrial partners fulfil the LHCb RICH detectors requirements
- Shielded HPDs are **fully operational** in the residual magnetic field (2.5 mT) inside the shielding boxes
- **Characterization and parameterization** of **ExB distortions** of the image
- Strong S-distortion **correction** possible given $B_\parallel$ value, recovering spatial resolution
- $B_\parallel$ estimation with test pattern
- **Automated calibration procedure** for the LHCb RICH to estimate the axial field applied on each of the **484 HPDs installed** in the experiment has been proposed

**Acknowledgements**: The authors wish to thank **Asmund Skjaeveland** for the contribution given to this work in the framework of CERN Summer Students program
Spares
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