The operation of the LHCb RICH photon detection system in a charged particle test beam

Presented by S.Brisbane on behalf of the LHCb collaboration
Goals

• In This Talk:
  – Validation of LHCb RICH* final hardware system
  – Synchronous data taking at LHC bunch crossing rate
  – Estimate the photoelectron yield for the upstream LHCb RICH

• Ongoing projects:
  – Determining the Cherenkov angular resolution in C_4F_{10}
  – Increase the realism of the LHCb Monte Carlo simulation to correctly model the environment of the test beam

• Check LHCb RICH alignment procedure (to be discussed by A.Papanestis, 19th October)

*For details of the full RICH detector in LHCb I refer you to talk on 16th October “An overview of the LHCb RICH detector status” by N.Harnew
• Bunches at 80 GeV/c with particle composition extracted from fit to data
  – 80% pions
  – 10% electrons
  – 7% kaons
  – 3% anti-protons
• Electrons, pions are saturated in the radiators used
• Average 1 particle per bunch train

First test beam with the LHC bunch spacing
Spherical mirror with adjustable focal point
Coefficient of reflectivity 0.9

~ 1 m Radiator, either $N_2$ or $C_4F_{10}$ gas

Scintillation triggers and 2 Pixelated anodes as trackers

Particle entry trajectory

HPD Plane

10 HPDs in acceptance
10 HPDs in test beam acceptance

- Vacuum tube of diameter 83 mm
- S20 multi-alkali cathode sensitive at 200-600 nm
- 30 % average quantum efficiency
- Cross focussing optics
- Binary readout of hits recorded by pixels on the anode
- Refer to previous 2 talks for more details on HPD
Radiators

$N_2$
- $n^{-1} \sim 3 \times 10^{-4}$ at NTP
- Ring image contained in single HPD
- Cherenkov angle resolution minimally affected by alignment
- Photon yield integrated over $2\pi$
- Simplest scenario
- 1 run taken for each HPD with mirror focus in HPD centre

$C_4F_{10}$
- $n^{-1} \sim 14 \times 10^{-4}$ at NTP
- Cherenkov ring is $\sim 55$ mrad
  - Spans multiple HPDs
  - HPD relative alignments important
- Photon yield statistics lower due to gaps
- Runs taken so that rings fall on 3 or 4 HPDs
Simulation

- Full LHCb Monte-Carlo framework based on GEANT 4
  - Full simulation of particle interactions with material
  - Specially modified geometry for test beam
  - Particles generated with measured beam composition

Simulation of test beam used to check $C_4F_{10}$ photoelectron expected yields
Every contribution to the photo electron yield should be understood and modelled
Test Beam to provide the tuning of the simulation ready for the LHC next year
Event selection for photoelectron yield

- Fit rings around the N$_2$ and C$_4$F$_{10}$ data on event-by-event basis
  - Require at least 5 hits in each event
  - Ring is fit with a circle
- Define signal region as a road around the average ring centre
  - Road is $<R> \pm 3$ pixels for N$_2$ and $<R> \pm 1.7$ for C$_4$F$_{10}$ data, where $<R>$ is average ring radius
  - Events with a large hit multiplicity outside this road are rejected
- Select events with 4 or more hits inside the road & less than 3 hits outside the road
- Histogram the number of hits in the road for each event
Modelling Photoelectron yield

- Extract yield from a fit to the number of hit pixels
- Series of terms in fit model
  - Sum of Poisson contributions modelling Cherenkov emission from $\pi$, $e$, $K$, $p$
  - Abundances of above particles left as free parameters
  - Terms in fit allowing for 1 and 2 beam particles per event
- Fixed term to allow for a single photoelectron to produce multiple adjacent hits
  - Due to sharing of charge between pixels
  - We measure this charge sharing for each HPD using a low intensity light source in vessel
- Fix probability that 2 photoelectrons strike the same pixel but only 1 hit recorded
Photoelectron yield in $N_2$

- $\chi^2$ of fit for HPD 117 31.5/21; suggests model is sufficient
- HPD 117 measured, repeated for 264, 265
- Dominant particles are saturated $\pi, e$
- Expected yield determined analytically
  - Error dominated by assumed 5% error on QRT (detector efficiency)
- Quantum efficiency measured by manufacturer

Results 12 p.e. / Rad, in good agreement with expected yields

<table>
<thead>
<tr>
<th>HPD</th>
<th>Measured Yield</th>
<th>Expected Yield</th>
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<tbody>
<tr>
<td>117</td>
<td>12.32 ± 0.12</td>
<td>12.20 ± 0.62</td>
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<tr>
<td>264</td>
<td>13.14 ± 0.13</td>
<td>14.09 ± 0.70</td>
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<tr>
<td>265</td>
<td>12.56 ± 0.12</td>
<td>12.81 ± 0.65</td>
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</tbody>
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Photoelectron yield in $C_4F_{10}$

- Allow for a 3 particle contribution, with only pions in the fit
- $\chi^2$ of fit for 117 19/21; suggests model is sufficient
- Multiple particle terms amount to 2% of total
- Yield is 9 photo-electron per particle per radian, consistent with simulated yields
  - 10% Spread in n.p.e, consistent with Q.E. variations between tubes
  - $d\mu/d\Delta\phi$ ratio checked and varies around ring following measured quantum efficiency
- Expected yield determined from full LHCb Monte Carlo simulation

<table>
<thead>
<tr>
<th>HPD</th>
<th>Data $\mu/\Delta\phi$</th>
<th>MC $\mu/\Delta\phi$</th>
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</thead>
<tbody>
<tr>
<td>36</td>
<td>10.7±0.2</td>
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<tr>
<td>88</td>
<td>8.3±0.5</td>
<td></td>
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<tr>
<td>116</td>
<td>8.6±0.3</td>
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<tr>
<td>117</td>
<td>8.5±0.4</td>
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<tr>
<td>222</td>
<td>9.0±0.5</td>
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<tr>
<td>223</td>
<td>8.9±0.3</td>
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<tr>
<td>265</td>
<td>8.8±0.3</td>
<td>9.6</td>
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<tr>
<td>282</td>
<td>9.4±0.6</td>
<td>11.3</td>
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<tr>
<td>283</td>
<td>9.2±0.6</td>
<td>9.2</td>
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<tr>
<td></td>
<td>9.1±0.7</td>
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- Evaluate systematics
  - Previously fixed values in the fit allowed to vary with Gaussian penalty term
- Systematics contribute at 5% level

RICH 2007: 15th-20th October, Trieste

Sean Brisbane
Summary

- Data acquisition at LHC clock frequency successful
- Photo-electron yields meet requirement for detector
- Simulation and reconstruction with the full LHCb framework successful
- First studies of Cherenkov angle resolution in progress with encouraging early results

- Photon detection system of LHCb working in realistic environment

LHCb RICH 2 under construction