The RICH system of LHCb

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on behalf of the LHCb collaboration

1. RICH detector layout
2. Photon detectors
3. Performance and first data
The LHCb experiment

- Dedicated B physics experiment at the LHC searching for new physics in complementary way to ATLAS & CMS through precision measurement of CP violation and rare decays
- B hadrons are predominantly produced in the forward direction → single-arm spectrometer (working in pp collider mode) including two RICH detectors for charged hadron identification
From design… to reality!

The experiment is fully installed and commissioned, ready for first collisions.
Requirements

- Momentum range $\sim 1 < p < 100$ GeV to match spectrum of B decay products
- Hadron identification is crucial for some modes (eg $B \rightarrow hh$)

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Radiators

- Correlation between polar angle of tracks and $p \rightarrow$ two RICH detectors used

- RICH1 for low and intermediate momenta (before spectrometer magnet) combines use of two radiators: $C_4F_{10}$ gas ($n = 1.0014$) and aerogel ($n = 1.03$)
- RICH2 for high momentum, using CF$_4$ gas as radiator ($n = 1.0005$)
RICH1 layout

Cross section (side view)

- Magnetic shielding
- Photon Detectors
- Aerogel
- Spherical Mirror
- Beam pipe
- VELO exit window
- Plane Mirror
- C$_4$F$_{10}$
- Track

3D model

- Vertex detector
- Vacuum tank
- Photon detectors

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RICH1 construction

- Challenge: to minimize material budget (since within tracking volume)
  - “No entrance window” — attached directly to vertex detector tank
  - Inner acceptance defined by conical beryllium beam pipe
  - Carbon-fibre composite construction of spherical mirror (~ 1% $X_0$)
**RICH2 layout**

- Much larger structure
- High precision required ~ 0.7 mrad
- Glass mirror substrate, segmented

![Diagram of RICH2 layout](image)

**Internal view**
RICH2 installation

- RICH2 constructed on surface, including alignment of optical elements
- Delicate transport (~ 1 kph) to the LHCb cavern, 100 m underground
Photon detectors

- Hybrid Photon Detectors (HPD) developed in collaboration with industry
  Principal partner: DEP-Photonis for encapsulation of pixel anode in tube

8192-channel pixel chip
8\times OR \rightarrow 1024 \text{ pixels (}500 \times 500 \mu\text{m square)}

→ Presentation by K. Wyllie

5\times \text{ demagnification from electron optics} \rightarrow 2.5 \text{ mm at photocathode, as required}
HPD production

- 484 HPDs required in LHCb (196 in RICH1, 288 in RICH2)
- 550 produced including spares over 18 months up to July 2007
- Multialkali (S20) photocathode, quantum efficiency improved during production, significantly better than the specification

Window cutoff  Sensitivity in visible range for aerogel

Average & running average/batch
HPD installation

- HPDs mounted in columns, to cover detector plane

Mumetal magnetic shield tube around each HPD
Services for HV, LV, and readout electronics mounted in frame
Fully equipped plane
Test pattern

- Regular array of light spots projected over HPD plane in situ in RICH2 (similar results achieved in RICH1 using motorized stage with LEDs)
- Nicely uniform response and very low noise for almost all the HPDs. A few show noisy behaviour, peaking around the central axis of the tube
- Due to degraded vacuum quality in those tubes
- Photoelectrons ionize residual gas. Ions then accelerated back to the photocathode producing further p.e. \( \rightarrow \text{ion feedback} \)
Ion feedback

- Ion feedback rate determined using fraction of large clusters (\(\geq 5\) hits)
  Rate measured regularly for all HPDs over the last 18 months
- Most show a linear increase of ion feedback with time, with low gradient
  The noisy tubes have a higher gradient
- The bad tubes eventually start to glow, but only after ion feedback rate > 5%

Glow light

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HPD repair

- 24 HPDs in the RICH detectors that started to glow have been replaced with spares
- Failure of tubes can be accurately predicted from the ion feedback measurements
  ~ 11 HPDs / year predicted to require replacement over the lifetime of the experiment (i.e. 2% / year)
- Removed tubes are successfully repaired by DEP-Photonis
  Opened, cleaned, photocathode reapplied: ion feedback gradient is low after repair
Beam test

- Before final installation in the RICH detectors, production HPDs used in a beam test with 25 ns bunch structure and \( C_4F_{10} \) radiator
- Clean reconstructed ring spread over a number of HPDs → exercised alignment procedure

Number of detected photoelectrons matches expectation from the GEANT-based full simulation
Magnetic distortions

- Minor distortions to HPD image expected from fringe field of magnet

- Calibration of distortion from LHCb spectrometer dipole made in situ, using light spot pattern

- Raw data superimposed from runs taken with \( B = 0, B^{+ve}, B^{-ve} \) displayed sequentially

- Distortion can be parameterized with a few constants per HPD
Alignment & calibration

- After all corrections, reconstructed light spot positions match precisely with regular ~ 10 mm grid pattern
- Residual contribution to resolution $\sigma \sim 0.6 \text{ mm} << \text{pixel size (2.5 mm)}$ → correction of magnetic distortion and misalignment is under control

Residuals in both dimensions
Pattern recognition

- Simulated event from 14 TeV collision: high multiplicity, overlapping rings

- Pattern recognition based on reconstructed tracks:
  \( \theta_C \) of each p.e. from each track calculated under (e, \( \mu \), \( \pi \), K, p) hypotheses
  Vary chosen hypotheses of tracks to maximize the global event likelihood
Expected performance

- Determined using $b\bar{b}$ events from PYTHIA passed through the full simulation
- Efficiency to identify kaons and misidentification rate of pions plotted vs momentum
- Performance fed into the physics studies recently undertaken for six of the key measurements of LHCb:
  - $B (B_s \rightarrow \mu\mu)$, $A_{FB} (B^0 \rightarrow K^*\mu\mu)$
  - $A_{CP} (B_s \rightarrow \phi\gamma)$, $A_{CP} (B_s \rightarrow J/\psi\phi)$
  - $A_{CP} (B \rightarrow DK)$, $A_{CP} (B \rightarrow hh)$
- Particle ID performance matches well the requirements from the physics
First LHC data

- No collisions yet, but data from injection tests last September:
  - Particle flux (plan view)
  - Unfortunately tracks passed through LHCb in “wrong” direction, high density $\sim 10/\text{cm}^2$ → Cherenkov light in the HPD windows
  - Sufficient to measure relative timing
  - Ready for collisions!

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Upgrade plans

- Upgrade of LHCb under discussion to follow first data-taking phase. Expected at ~ 2015, but need to consider now to launch any R&D required.

- Plan to increase B rate by running at higher luminosity (~ $10^{33}$ cm$^{-2}$s$^{-1}$) and read out full experiment at 40 MHz (instead of 1 MHz at present). → upgraded HPD or a different photon detector will be required.

- Detector concept also under study to use of time-of-flight for $p < 10$ GeV Quartz plate with focusing system (PANDA-style) to correct for photon time-of-propagation in plate:

  \[ \sigma(t) \sim 100 \text{ ps} / \text{photon required} \]
Conclusions

• The LHCb RICH system is fully installed and commissioned

• The HPD photon detectors have been thoroughly tested in beam tests and with the first LHC beams, and most perform excellently

  A few suffer from noise due to degraded vacuum quality and are being replaced as necessary (predict 2% of the HPDs / year)

• Alignment and calibration of magnetic distortions has been performed using light spot data, and will be refined with data from collisions

  Particle ID performance determined from simulation matches the requirements of the LHCb physics programme

• First ideas for an upgrade are being considered, to be ready in case the (new) physics from the first phase of LHC running demands it

• We are ready for the first LHC collisions expected later this year