Real-time calibration and alignment of the LHCb RICH detectors

Jibo HE (UCAS) on behalf of the LHCb-RICH collaboration
Importance of hadron PID for LHCb

- Goal: search for New Physics by studying CP violation & rare decays in $b/c$-hadrons
- Excellent PID is essential
The LHCb RICH system

- **RICH1** (25-300 mrad) $C_4F_{10}$, $n \sim 1.0014$, up to 60 GeV
- **RICH2** (15-120 mrad) $CF_4$, $n \sim 1.0005$, up to ~100 GeV

Hybrid Photon Detector (HPD)
RICH reconstruction in nutshell

- HPD hit $\rightarrow$ spatial position
  - Decode raw data
- Select tracks and reconstruct photon candidates, then calculate Cherenkov angle
- Determine PIDs with Global likelihood
  - Compare the observed Cherenkov angles with the expected under different PID hypothesis, and maximize the likelihood
Key points to have excellent PID

• Cherenkov angle
  – RICH mirrors / detector planes alignment
  – Tracking system alignment
  – HPD image calibration
  – Refractive index (Cherenkov angle)

• Number of photons
  – Refractive index

• These are time-dependent!
Why real-time calib./align.?

• Maximize physics output
  – From Run-I to Run-II, 7/8 TeV → 13 TeV
  – After upgrade, >4 times higher luminosity & hardware trigger removed

• Make trigger more selective & use trigger output for analysis directly
  – Need to have offline quality reconstruction
  – Alignment/calibration are time-dependent

⇒ real-time calibration and alignment
New dataflow
Refractive index calibration

- Gas components, temperature, pressure
- Monitored by hardware, not precise enough
Refractive index calibration (cont.)

- Difference between reconstructed and expected Cherenkov angle $\rightarrow$ scale factor

Before calibration

**Signal:** Gaussian

**Background:** polynomial
Refractive index calibration: how?

- Run-by-run
- Run reconstruction on ~50 Hz HLT1 outputs
- Fit and publish constants
- In case of problem, use constants of previous run
- Fast & automatically
Monitoring: trend

Pressure
Rich1 scale factor
Rich2 scale factor
Rich1 temperature
Pixel hybrid photon detector (HPD)

- Electrostatically focused tube
- Photon-cathode image *demagnified* by a factor of ~5 onto a small silicon detector
- Image affected by
  - Electric fields
  - Magnetic fields
HPD image calibration: how?

- Run-by-run, only need to decode raw data, process >500 Hz

- Procedure
  - Accumulate
  - Clean
  - Sobel filtered
  - Fit
PbPb collisions

HPD Image Shifts (x,y) | Run 169426

- Mean x: 0.1045
- Mean y: 0.0798
- Std Dev x: 0.3061
- Std Dev y: 0.304

Entries: 446

HPD Image Shifts (x,y) Errors (log10) | Run 169426

- Mean x: 4.397
- Mean y: 4.398
- Std Dev x: 0.1599
- Std Dev y: 0.1623

Entries: 446

HPD Image Radius | Run 169426

- Mean: 6.491
- Std Dev: 0.151

Entries: 446

HPD Occupancy Summary | Run 169426

- Mean: 27.53
- Std Dev: 8.085

Entries: 447
Mirror alignment

\[ \Delta \theta = \theta - \theta_{Ch} \approx \Theta \cos(\phi - \Phi) \]

Misaligned mirror:

Aligned mirror:
To speed up mirror alignment...

- 116 mirrors to align...
- Dedicated trigger (online selection) to populate mirror pairs at the edge...
- Dedicated framework to use HLT farm (~1800 nodes) to do alignment, as for Velo/tracker/…
Mirror alignment

- Monitored automatically fill-by-fill, following the Velo → Tracker → Rich1 → Rich2
Effects of magnetic field on HPD image

- Sensitive to longitudinal field
Correction with the MDCS

- MDCS (Magnetic Distortion Correction System)
Time alignment

• Each HPD has different response time
• Done with timing scan data taken during physics collisions
Time alignment: results

- RICH1 (ns)
- RICH2 (ns)

All HPDs are aligned to ns level!
Resolution stability: RICH2

LHCBb preliminary
$\langle \sigma_{\Delta \theta} \rangle = 0.666$ mrad

Calib. runs 50 ns 25 ns Physics Data
PID performance

- See more in A. Papanetis’s talk [Mon. 09h20]
- Analysis using trigger outputs directly

\[ D^+ \rightarrow K^- \pi^+ \pi^+ \]
\[ D_s^- \rightarrow K^+ K^+ \pi^- \]

[LHCb, JHEP 03 (2016) 159]
PID performance in PbPb collisions

- Works perfectly for less-busy events
- \( D^0 \to K\pi \) in PbPb:

![Graphs showing \( D^0 \to K\pi \) distributions for different event activity ranges and energy conditions.](image)
Summary

- Novel real-time calibration and alignment of the RICHes:
  - Refractive index, run-by-run
  - HPD image, run-by-run
  - Mirror alignments, monitored fill-by-fill
- Works well for pp & PbPb collisions
- Provide excellent PID for the trigger & offline analysis, essential to achieve LHCb physics goal