Performance of the LHCb RICH detectors during the LHC Run II

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Outline

- Brief description of the detectors
- Changes between Run I and Run II
  - LHCb changes
  - RICH changes
- Performance in Run II
  - Cherenkov angle resolutions
  - PID performance
  - Comparison with Run I
LHCb experiment

Ring Imaging Cherenkov

Calorimeters

Acceptance

250/300 mrad

10 mrad

Tracking detectors

Muon System

(side view)
LHCb RICH Detectors

RICH-1 (25-300 mrad)
4 m³ $C_4F_{10}$ $n = 1.0014$, up to 60 GeV

RICH-2 (15-120 mrad)
100 m³ $CF_4$ $n = 1.0005$, up to ~100 GeV
RICH Hitmap

Run 177581, started 2016-06-20 07:00:54, duration: 01:00:06

Mean 2179
Mean 2056

RICH 1 Up
RICH 2 Left
RICH 2 Right
RICH 1 Down

RICH 1
RICH 2
Single track event
**New LHCb Trigger**

### Run I

- **40 MHz bunch crossing rate**
  - L0 Hardware Trigger: 1 MHz readout, high $E_T/P_T$ signatures
  - $450 \text{ kHz} \quad h^\pm$
  - $400 \text{ kHz} \quad \mu/\mu\mu$
  - $150 \text{ kHz} \quad e/\gamma$

- **Defer 20% to disk**

- **Software High Level Trigger**
  - 29000 Logical CPU cores
  - Offline reconstruction tuned to trigger time constraints
  - Mixture of exclusive and inclusive selection algorithms

- **5 kHz Rate to storage**

### Run II

- **40 MHz bunch crossing rate**
  - L0 Hardware Trigger: 1 MHz readout, high $E_T/P_T$ signatures
  - $450 \text{ kHz} \quad h^\pm$
  - $400 \text{ kHz} \quad \mu/\mu\mu$
  - $150 \text{ kHz} \quad e/\gamma$

  - **Software High Level Trigger**
    - Partial event reconstruction, select displaced tracks/vertices and dimuons
    - Buffer events to disk, perform online detector calibration and alignment
    - Full offline-like event selection, mixture of inclusive and exclusive triggers

- **12.5 kHz (0.6 GB/s) to storage**
Consequences of the new trigger strategy

- RICH information in HLT2
  - Limited time for RICH decision
  - Needed to speed up the procedure
  - Aerogel rings very big
    - Many photons, many track/photon combinations
  - Need for 100% compatibility between online/offline on track by track basis, not average, likelihood values

- Aerogel geometry not well matched to new trigger requirements

- Aerogel performance impaired by running conditions:
  - Many tracks, high background

- Need to optimise performance/time

- Space behind the aerogel container for a longer gas radiator

Example rings in RICH1 from Run I

Real-time calibration and alignment of the LHCb RICH detectors
Jibo He, Tuesday 16:35
Changes in the RICH detectors

- Challenge: make an excellent RICH detector even better

- Removal of aerogel
- Better tuning of photon detectors, giving 2-3% better photon yield
- New vacuum treatment for HPDs
  - Better vacuum quality
  - No aging (so far)
- Liquefying stage in C₄F₁₀ recirculation
  - Allows to remove air periodically
  - Used mainly during LHC Technical Stops
- Better control of CO₂ in RICH2
  - For reduced CF₄ scintillation
RICH1 C$_4$F$_{10}$ purity

C4F10 mixture in RICH1 - 2015

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Cherenkov Angle Resolutions

Example resolution curve

Stability over time (2015)

Different scale

RICH1

RICH2
Calibration sample

- Collect pure samples of known-ID particles
- There is a main trigger line for each particle and possibly another one for cross-checks and systematic studies

<table>
<thead>
<tr>
<th>Species</th>
<th>Low $p - p_T$</th>
<th>High $p$ and $p_T$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$e^\pm$</td>
<td></td>
<td>$J/\psi \rightarrow e^+ e^-$</td>
</tr>
<tr>
<td>$\mu^\pm$</td>
<td>$D_s^+ \rightarrow \mu^+ \mu^- \pi^+$</td>
<td>$J/\psi \rightarrow \mu^+ \mu^-$</td>
</tr>
<tr>
<td>$\pi^\pm$</td>
<td>$K_S^0 \rightarrow \pi^+ \pi^-$</td>
<td>$D^* \rightarrow D^0 (K^- \pi^+) \pi^+$</td>
</tr>
<tr>
<td>$K^\pm$</td>
<td>$D_s^+ \rightarrow K^+ K^- \pi^+$</td>
<td>$D^* \rightarrow D^0 (K^- \pi^+) \pi^+$</td>
</tr>
<tr>
<td>$p^\pm$</td>
<td>$\Lambda^0 \rightarrow p \pi^-$</td>
<td>$\Lambda^0 \rightarrow p \pi^-$, $\Lambda_c^+ \rightarrow p K^- \pi^+$</td>
</tr>
</tbody>
</table>

New selections designed to improve the kinematic coverage
Mass distributions of PID samples

LHCb-PUB-2016-005
RICH PID performance

Comparison between:

Run I

Run II (2015)
Every line represents PID performance in a different period in 2015

- Periods follow big changes in data-taking
- There is a clear structure that coincides with changes in the trigger
- Detector studies show no change in detector performance
- Different mixture of events results in different PID performance
Equalising conditions for Run I/II

- Main factors affecting PID:
  - Momentum
  - $P_t$ or $\eta$
  - Number of tracks

- Differences Run I $\rightarrow$ II
  - Higher beam energy
  - Smaller number of primary interactions
  - Different thresholds for trigger

- A re-weighting method is used to equalise the track distribution
- PID is studied in terms of momentum and $\eta$
- RICH2 covers $\eta > 2.6$
Example PID comparison 2012/2015

$2.71 < \eta < 3.14$

$16200 < p < 27200$
p/π PID 2012/2015

Momentum →

π/π PID 2012/2015

Momentum →
p/K PID 2012/2015

Momentum →
The LHCb RICH detectors have been operational for 6 years, providing excellent hadron PID. The RICH is an essential part of the LHCb experiment.

- The entire charm physics programme relies on RICH PID

The LHC long shutdown gave us the opportunity to study their performance and find a new optimum within the new LHCb trigger strategy, and implement changes that improve PID

The experience gained in the process gives us great confidence that the design choices for the LHCb RICH Upgrade will bring the expected improvements in performance