PID strategy and performance at LHCb in Run 2

Carla Marin Benito

on behalf of the LHCb collaboration
Outline

- Particle Identification at LHCb
- Computing strategy
- Calibration samples
- Performance
Particle Identification (PID) at LHCb

- LHCb is a heavy flavour physics experiment
- PID is crucial to study exclusive final states
- Recent example in JHEP02(2018)098:
The LHCb detector

**Collisions @ 40 MHz**

**Vertex Detector**
- Reconstruct vertices
- Decay time resolution: 46 fs
- IP reconstruction: 20 μm

**Tracking System**
- Momentum resolution \( \Delta p/p = 0.4\% - 0.6\% \)

**Dipole Magnet**
- 4 Tm
- Normal conducting regular polarity switches

**RICH Detectors**
- \( K/\pi/p \) separation

**Calorimeters**
- Energy measurement
- Particle identification

**Two-level Trigger**
- L0 hardware (12 → 1 MHz)
- HLT software (1 → 0.005 MHz)

Very good \( \varepsilon(\mu) \)
Good \( \varepsilon(h) \)

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PID at LHCb in Run 2
RICH detectors

- Two Ring Image Cherenkov Detectors (RICH)
  - RICH 1 based on $C_4F_{10}$ separates particles with $p$ in $[2, 60]$ GeV/c
  - RICH 2 based on $CF_4$ separates particles with $p$ in $[15, 100]$ GeV/c
- Combine light rings and momentum to build log(Likelihood) distributions
- Crucial for $\pi$, $K$, $p$ separation
Muon chambers

- Five tracking stations alternated with hadron absorbers at the end of the detector (M1 before calorimeters)
  - based on MWPC technology
  - 3-GEM in inner region of M1
- Track extrapolation and matching to hits in muon chambers
- Crucial for $\mu$ identification, also at trigger level

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Calorimeters

- Scintillating Pad Detector (SPD), Preshower (PS), Electromagnetic (ECAL) and Hadronic (HCAL) calorimeters
- Combine information into Multi-variate tools
- Provide energy and position for neutral objects and triggers for $e/\gamma$
- Crucial for $e$, $\gamma$ and $\pi^0$ separation
PID strategy [LHCb-DP-2018-001]

- Two types of variables from combination of charged PID information
  - $\text{DLL}_{X\pi}$: log likelihood difference between $X$ and $\pi$ hypothesis
  - $\text{ProbNNX}$: output of neural networks (NN) trained to identify $X$ including also tracking information

- Dedicated tools for neutral objects based on NN: $\text{isNotE}$, $\text{isNotH}$

- Exploitation of state-of-the-art classifiers under development

- Calibration from data-driven techniques since PID not perfectly reproduced in simulation

See A. Poluektov’s talk for details on latest techniques
Computing strategy: TurboCalib

- In Run 2, offline quality reconstruction is achieved in the Trigger
  - Details in M. Whitehead’s talk

- Calibration samples in the Turbo Calibration (TurboCalib) stream
  - Large statistic samples → required precision for analysis
  - Computation of both offline and online PID variables
  - Raw event information available → exploit offline re-calibrations and new tunnings
Computing strategy: Working Group productions

- TurboCalib samples processed centrally and provided to analysts as ROOT files:
  - Large resource optimisation wrt do-it-yourself approach
  - Gain control on systematic uncertainties

- Several steps to provide information needed by analyses:
  - Matching of online and offline candidates
  - Invariant mass fits
  - Background subtraction using sWeights

- Raw event information also available for particular studies (e.g. Upgrade, new PID variables)
## Calibration samples: charged species

<table>
<thead>
<tr>
<th>Species</th>
<th>Soft</th>
<th>Hard</th>
</tr>
</thead>
<tbody>
<tr>
<td>$e$</td>
<td>$B^+ \rightarrow K^+ [e^+ e^-] J/\psi$</td>
<td>$J/\psi \rightarrow \mu^+ \mu^-$</td>
</tr>
<tr>
<td>$\mu$</td>
<td>$B^+ \rightarrow K^+ [\mu^+ \mu^-] J/\psi$</td>
<td>$D^{**} \rightarrow [K^- \pi^+] D_0 \pi^+$</td>
</tr>
<tr>
<td>$\pi$</td>
<td>$K_S^0 \rightarrow \pi^+ \pi^-$</td>
<td>$D^{**} \rightarrow [K^- \pi^+] D_0 \pi^+$</td>
</tr>
<tr>
<td>$K$</td>
<td>$D_s^+ \rightarrow [K^+ K^-] \phi \pi^+$</td>
<td>$D^{**} \rightarrow [K^- \pi^+] D_0 \pi^+$</td>
</tr>
<tr>
<td>$p$</td>
<td>$\Lambda \rightarrow p \pi^-$</td>
<td>$\Lambda \rightarrow p \pi^-, \Lambda_c^+ \rightarrow p K^- \pi^+$</td>
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<td>( \mu )</td>
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Calibration samples: charged species

- Long-lived particles ($\Lambda$, $K^0_S$) decay mostly outside the VELO
- Downstream tracks might not have information from RICH 1
- Dedicated calibration samples included in TurboCalib since 2017 data-taking
Calibration samples: neutral objects

- Calibration samples for neutral objects also included in TurboCalib stream since 2017 data-taking

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<td>$\gamma$</td>
<td>$D^+ \rightarrow [\rho^0 \gamma] \eta' \pi^+$, $D_s^{*+} \rightarrow D_s^+ \gamma$, $\eta \rightarrow \mu^+ \mu^- \gamma$</td>
<td>$B^0 \rightarrow K^{*0} \gamma$</td>
</tr>
<tr>
<td>$\pi^0$</td>
<td>$D^0 \rightarrow K^+ \pi^- \pi^0$ (resolved)</td>
<td>$D^0 \rightarrow K^+ \pi^- \pi^0$ (merged)</td>
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Performance: charged species

- Excellent separation in wide momentum range
Good results also for downstream tracks and neutral objects
Excellent PID performance is key for outstanding flavour physics results at LHCb.

PID from combined information of dedicated sub-detectors:
- RICH 1 and RICH 2
- Muon chambers
- Calorimeters

New computing strategy developed for Run 2 exploiting the Turbo model for calibration (TurboCalib).

Calibration samples covering full analysis phase-space provided:
- Samples for downstream tracks and neutral objects recently included

Excellent performance achieved in Run 2, laying the foundations for the LHCb upgrade.
Summary

- Excellent PID performance is key for outstanding flavour physics results at LHCb
- PID from combined information of dedicated sub-detectors:
  - RICH 1 and RICH 2
  - Muon chambers
  - Calorimeters
- New computing strategy developed for Run 2 exploiting the Turbo model for calibration (TurboCalib)
- Calibration samples covering full analysis phase-space provided
  - Samples for downstream tracks and neutral objects recently included
- Excellent performance achieved in Run 2, laying the foundations for the LHCb upgrade

THANK YOU!
BACK-UP
Performance: charged species

- Excellent separation in wide momentum range