Study on the performance of the Particle Identification Detectors at LHCb after the LHC First Long Shutdown

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ICHEP conference 2016
Chicago, Illinois, 3 - 10 August 2016
The LHCb experiment

- Single arm forward spectrometer
- Optimized for $b$- and $c$-physics
- Good vertex resolution and tracking
- Excellent particle identification (RICH, CALO, MUON)
- Fast, efficient and flexible high bandwidth trigger system

[See E. Michielin poster]
The PID detectors: RICH

- Need to identify heavy flavour decays from huge hadronic background
- Good $\pi/K/p$ separation on a wide momentum range

- Usage of 2 separate detectors and 2 different radiators:
  - RICH1 covering low $p$ (2-60 GeV/c) region, using $C_4F_{10}$ radiator
  - During LS1 the aerogel has been removed from RICH1
  - RICH2 covers higher momenta (15-100 GeV/c) with $CF_4$ radiator

- The light rings are produced on an array of HPD located outside the LHCb acceptance (usage of spherical and flat mirrors)
- Combine photon rings and track momentum information
- Log likelihood recomputed for the mass hypothesis of all charged particles
The LHCb detector

The PID detectors: MUON

- 5 tracking stations interspersed with hadron absorbers ($\sim 23\lambda$)
  - M1 before the calorimeter
- Technology
  - MWPC
  - 3-GEM in M1 (inner region)
- Identification based on
  - Track extrapolation to the $\mu$-system
  - Look for hits in the $\mu$ stations around the extrapolated track
  - Calculate probability from hit distribution in $\mu$-stations
The PID detectors: CALO

- Calorimeter system identifies electrons/photons/$\pi^0$ and hadrons
- It combines information from:
  - SPD
  - Preshower
  - ECAL
  - HCAL

- Photon PID based on 2D PDF $\to \Delta LL$ method
  - Energy: total cluster energy in the ECAL and reconstructed energy deposit in the PS
  - Direction: from the interaction point and the energy-weighted position of the photon candidate
The PID strategy

- The majority of analyses in LHCb rely on particle identification
- The performance are measured with a data-driven method, since PID variables are poorly reproduced in MC

The information obtained from sub-detectors is combined to provide a single set of more powerful variables:

1. $\Delta LL$: the likelihood information produced by each sub-system is added linearly, to form a set of combined likelihoods
2. ProbNN: they are built using multivariate techniques by combining tracking and PID information from each sub-system into a single probability value for each particle hypothesis

In Run 1 the calibration samples were produced with offline selections $\rightarrow$ lack of statistics in some phase-space regions

In Run 2 the strategy has been completely renewed:
- Select the calibration samples directly in the high level trigger  
- Larger statistics to have smaller statistical uncertainty
- Systematic studies possible, including those with detector low-level information

[See B. Sciascia talk]
Calibration samples

- Pure samples of known-ID particles have to be collected
- There is a main line (red) 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>$J/\psi \rightarrow e^+e^-$</td>
<td>$e^\pm$</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>$\Lambda^0 \rightarrow p\pi^-$, $\Lambda_c^+ \rightarrow pK^-\pi^+$</td>
</tr>
</tbody>
</table>

- New selections designed to improve the kinematic coverage

- The final samples are background subtracted
The PID calibration samples

- **$J/\psi \rightarrow \mu^+\mu^-$**
  - $m(\mu^+\mu^-)$ distribution
  - Candidates / 0.22 MeV/$c^2$

- **$K_s^0 \rightarrow \pi^+\pi^-$**
  - $m(\pi^+\pi^-)$ distribution
  - Candidates / 0.06 MeV/$c^2$

- **$B^+ \rightarrow J/\psi K^+$**
  - $m(J/\psi)$ distribution
  - Candidates / 5.50 MeV/$c^2$

- **$\Lambda_0 \rightarrow p\pi^-$**
  - $m(p\pi^-)$ distribution
  - Candidates / 0.03 MeV/$c^2$

- **$D^{*+} \rightarrow D^0\pi^+$**
  - $m(D^0\pi^+)$ distribution
  - Candidates / 0.28 MeV/$c^2$
The RICH performance

- PID performance better than Run 1
- Better background rejection at low momentum, due to RICH1 changes in LS1
The MUON performance

- Integrated efficiency over the full spectrum $\varepsilon(\mu) \sim 95%$
- Mis-id hadron rates: $\varepsilon(p, \pi, K \to \mu) < 1%$ over most of the kinematic range
The CALO performance

- Capability to work with neutral objects: expected $\pi^0$ resolution: $< 9 \text{ MeV}/c^2$

![Graph showing mass distribution of $\pi^0\pi^+\pi^-$ events with LHCb Preliminary data from 2015, $\sqrt{s} = 13\text{ TeV}$, luminosity $= 140\text{ pb}^{-1}$.

Example of $\pi^0\pi\pi$ decay, where $\pi^0 \rightarrow \gamma\gamma$, selected in CEP lines.

- Expected electron ID not different from Run 1:
  5.5% misID rate for 90% efficiency

![Graph showing electron efficiency vs. misID rate with LHCb data from 2015.]

The ProbNN performance

- In Run 2 the MVA PID algos are used at trigger level
- In MC MVA algos perform by far better than DLL
- Both ProbNN and DLL remain useful in data

Performance on top of IsMuon
• Only slight modifications on PID detectors during LS1 in LHCb
• For Run 2 a new procedure has been introduced to select the PID calibration samples directly at trigger level
• The selection of the samples have improved the purity, leading to lower statistical uncertainties and better performance
• Better tunings of the global PID algorithms have been implemented
• The improvements open the door to a large number of PID-related studies, which will result in a better understanding of the systematic effects related to the detector
• All these features pave also the way for an improved PID performance for the LHCb upgrade
Backup