Performance of the particle identification system at LHCb

on behalf of the LHCb Collaboration

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**Introduction**

- LHCb’s main purpose is the search for New Physics in heavy-flavour and CP violating decays
- Excellent Particle Identification (PID) performance is fundamental:
  - *e.g.* distinguish final states with identical topologies

![Graph showing data and various decay channels](LHCb-PAPER-2023-029)
The LHCb Upgrade I detector

Single-arm forward spectrometer with excellent performance in:
- PID
- vertex, tracking and momentum resolution

LHCb recently had a major upgrade:
- higher luminosity and avg number of $p$-$p$ collisions ($\mu$)
- upgrade of all sub-systems
- full-software trigger

[2024 JINST 19 P05065]
The Ring Imaging Cherenkov detectors

- Excellent PID for charge hadrons
- Fully new RICH1 detector
- New photon detectors (MaPMTs) and readout in RICH2

The Calorimeters

- Sampling calorimeters with scintillator tiles alternated to Pb/Fe spacers
- Measurement of energies and position of the e.m. and hadronic showers
- PID for photons, electrons and hadrons (neutral and charged)
The Muon system

- Four stations with Multi-Wire Proportional Chambers (MWPC) interleaved by thick iron "filters"
- Hits around the track extrapolation provide performant muon ID criteria (IsMuon)
PID variables

The information obtained from the subsystems can be gathered in a set of charged and neutral PID variables:

$\Delta LL(x-\pi)$ or PIDx

- difference in log-likelihood for a track to be $K$, $p$, $e$, $\mu$ or $\pi$
- $\mathcal{L} = \mathcal{L}_{\text{RICH}} \cdot \mathcal{L}_{\text{CALO}} \cdot \mathcal{L}_{\text{MUON}}$

IsNotH and IsPhoton

- Dedicated Neural Networks for $\gamma/h$ and $\gamma/\pi^0$ separation
- Challenges: cluster pile-up and $\gamma/e$ separation
PID strategy in LHCb

- PID performance to sub-permille level to keep systematics sub-dominant
- Collect data samples of high rate, pure modes for each species
  - \( \sim 10 \text{ kHz} \) of trigger lines handled centrally (TURCAL) dedicated to calibration
  - Online alignment and calibration, offline reconstruction quality
- PID performance obtained using the tag-and-probe method, e.g. \( J/\psi \rightarrow \mu^+ \mu^- \)
Charged PID calibration samples

- Mass fits to extract PID performance
- Discussed today →
- e.g $K, \pi$ samples before and during Upgrade I

Species | Primary channels
---|---
e | $B^+ \rightarrow K^+ J/\psi (\rightarrow e^+ e^-)$
$\mu$ | Detached $J/\psi \rightarrow \mu^+ \mu^-$
$\pi$ | $D^{*+} \rightarrow D^0 (\rightarrow K^- \pi^+) \pi^+$
$K$ | $D^{*+} \rightarrow D^0 (\rightarrow K^- \pi^+) \pi^+$
$p$ | $\Lambda \rightarrow p \pi^-$

[EPJ Tech. Instrum. 6 (2019) 1]

![Graph 1](LHCb-FIGURE-2023-019)

- $D^+ \rightarrow (D^0 \rightarrow K^- \pi^+) \pi^+$

![Graph 2](LHCb-FIGURE-2023-019)

- $D^0 \rightarrow K^+ \pi^+$
- Signal
- Background
- Random $\pi$
- Fit model

$L = 23 \text{ pb}^{-1}$
$N_{\text{sig}} = 662083 \pm 926$
Charged hadron PID performance

- Expected performance as a function of $N_{PV}$
- Current $h$PID outperforms results obtained before Upgrade I (even at higher $\mu$!) as detector design point
Electron PID performance

- Bremsstrahlung clusters compatible with an electron track provide additional PID
- Similar ePID performance for 2015(all) and 2024(with brem only)
- No significant dependence on $\mu$

![PIDe Efficiency for 2brem etag PIDe>5](LHCb-FIGURE-2024-010)
Muon PID performance

- Removal of hardware trigger allows for low $p_T$ muons
- $\mu$PID comparable to 2017 performance
- Stable performance at different $\langle \mu \rangle$
Conclusions

- Excellent PID is fundamental for LHCb’s physics goals during Upgrade I
- Key sub-detectors for PID: RICH, Calorimeters and Muon stations
- Features of the sub-detector response are combined in powerful charged and neutral PID variables
- Precise data-driven calibrations ensure a performant PID
- Preliminary results show that LHCb’s charged PID:
  - Performs similarly to Run 1-2, but in busier conditions
  - Small sensitivity to $\mu$ variations
  - Increased coverage in kinematics with software trigger
- Studies on neutral PID ongoing - more updates soon!
Backup
Neutral PID

- Dedicated NN aiming to provide:
  - $\gamma/h$ separation: IsNotH
  - $\gamma/\pi^0$ separation for $E_T^\gamma > 2\text{GeV}/c^2$: IsPhoton
  - Challenges: cluster pile-up and $\gamma/e$ separation

- PID calibration as before Upgrade I:
  - $\gamma$: $B^0 \rightarrow K^*0\gamma$, $D_s^+ \rightarrow \eta'(\rightarrow \rho\gamma)\pi^+$, $D_s^{*-} \rightarrow D_s^+\gamma$
  - $\pi^0$: $D^0 \rightarrow K^+\pi^-\pi^0$

- Neutral PID performance is WIP, needs good understanding of ECAL
  - ECAL calibration: getting closer to performance before Upgrade I
Charged hadron PID performance

LHCb Preliminary
2023

LL(K) > 0
LL(K) > 5

LL(p K) > 0
LL(p K) > 5

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Mis-ID in muon PID performance

\[ \Lambda \rightarrow p\pi^- \quad 0.2 < p_T(\mu) < 0.8 \text{ GeV/c} \]

\[ \langle \mu \rangle = 2.9 \]

\[ \Lambda \rightarrow p\pi^- \quad p_T(\mu) > 0.8 \text{ GeV/c} \]

\[ \langle \mu \rangle = 2.9 \]