Performance of the particle identification system at LHCb

on behalf of the LHCb Collaboration

12th Edition of the Large Hadron Collider Physics Conference

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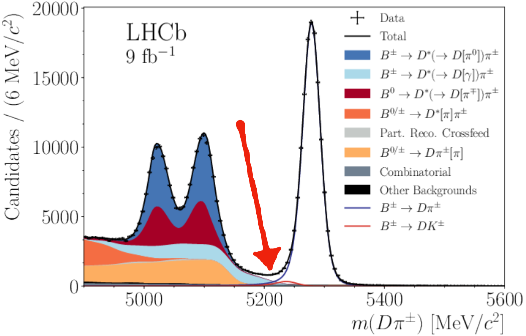
Introduction

- 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

[LHCb-PAPER-2023-029]

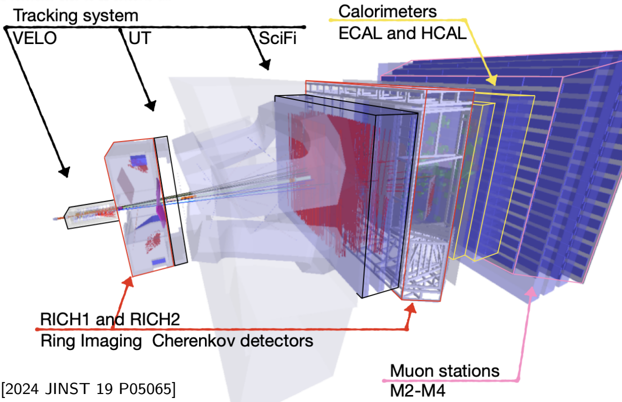


The LHCb Upgrade I detector

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

LHCb recently had a major upgrade:

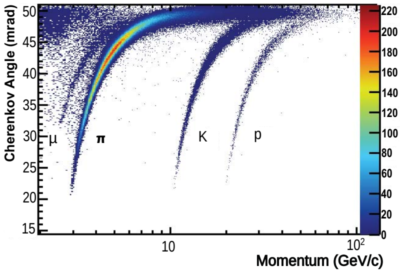
- higher luminosity and avg number of p-p collisions (μ)
- upgrade of all sub-systems
- full-software trigger



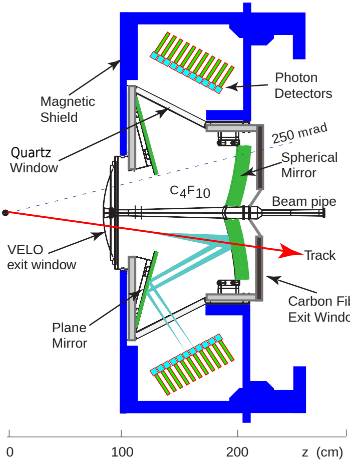
[2024 JINST 19 P05065]

The Ring Imaging Cherenkov detectors

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

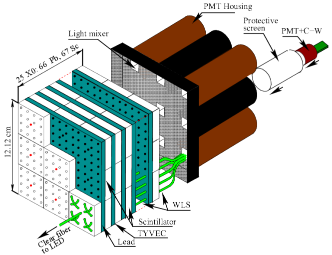


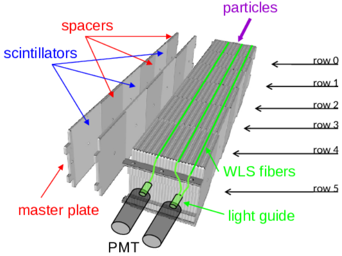
[Int. J. Mod. Phys. A 30 (2015) 15300223]



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)

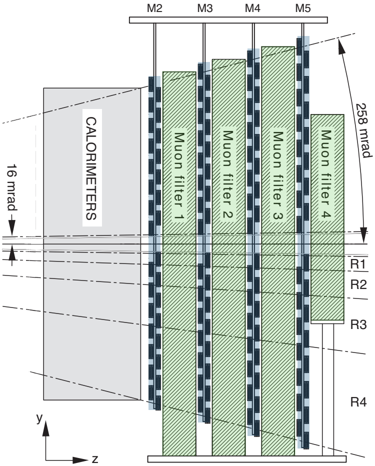




[LHCb-DP-2020-001]

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)



[JINST 3 (2008) S08005]

PID variables

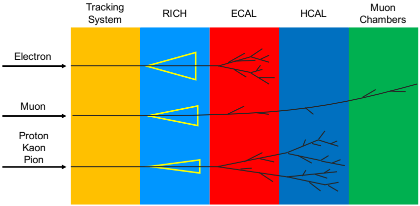
The information obtained from the subsystems can be gathered in a set of charged and neutral PID variables:

ΔLL(x-π) or **PIDx**

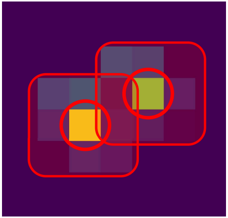
- difference in log-likelihood for a track to be K, p, e, μ or π
- $\mathcal{L} = \mathcal{L}_{\text{RICH}} \cdot \mathcal{L}_{\text{CALO}} \cdot \mathcal{L}_{\text{MUON}}$

`IsNotH` and `IsPhoton`

- Dedicated Neural Networks for γ/h and γ/π^0 separation
- Challenges: cluster pile-up and γ/e separation

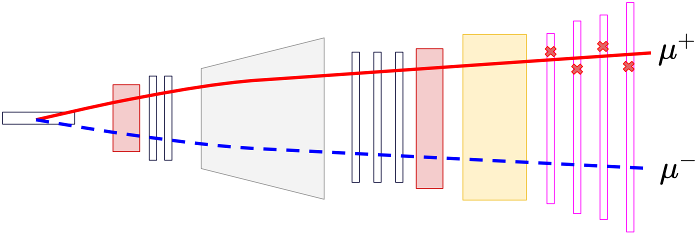


[EPJ Web Conf. 214 (2019) 06011]



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 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.* $J/\psi \to \mu^+\mu^-$

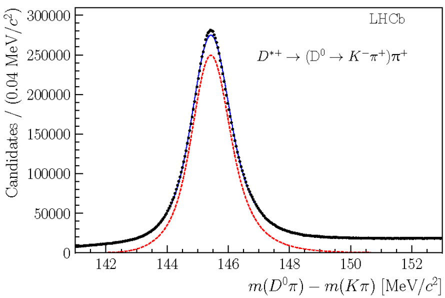


Charged PID calibration samples

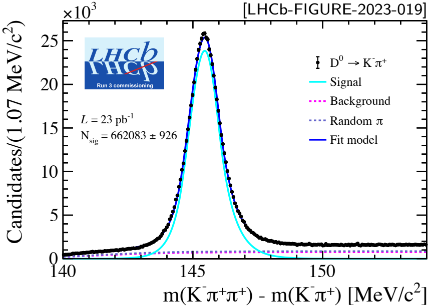
- Mass fits to extract PID performance
- Discussed today →
- *e.g* K,π samples before and during Upgrade I

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

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



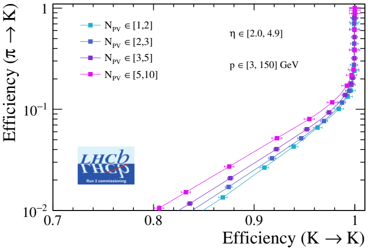
[LHCb-FIGURE-2023-019]

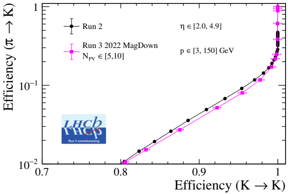


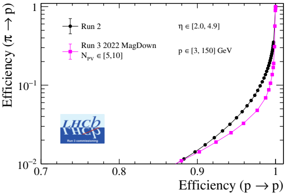
Charged hadron PID performance

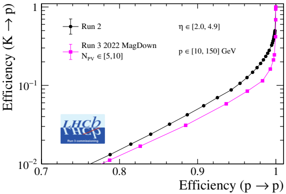
- Expected performance as a function of N_{PV}
- Current *h*PID outperforms results obtained before Upgrade I (even at higher μ!) as detector design point

[LHCb-FIGURE-2023-019]



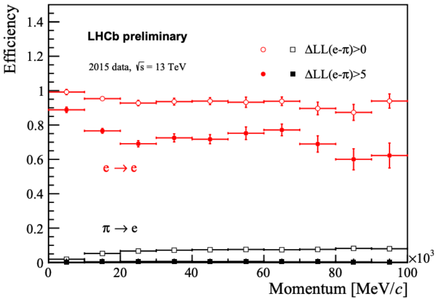




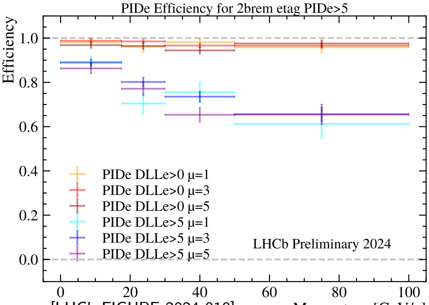


Electron PID performance

- Bremsstrahlung clusters compatible with an electron track provide additional PID
- Similar *e*PID performance for 2015(all) and 2024(with brem only)
- No significant dependence on μ



[LHCB-FIGURE-2020-012]

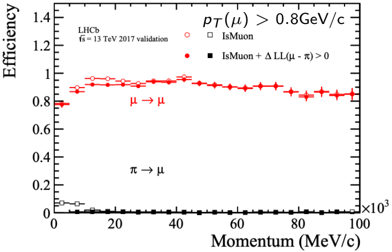


[LHCb-FIGURE-2024-010]

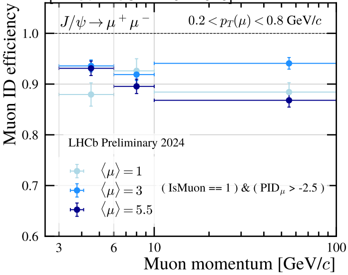
Muon PID performance

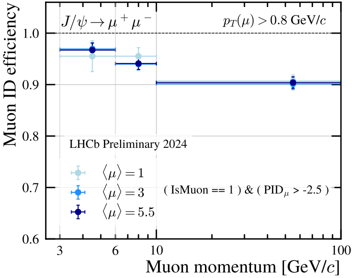
- Removal of hardware trigger allows for low p_T muons
- μPID comparable to 2017 performance
- Stable performance at different $\langle\mu\rangle$

[LHCB-FIGURE-2020-012]



[LHCb-FIGURE-2024-010]

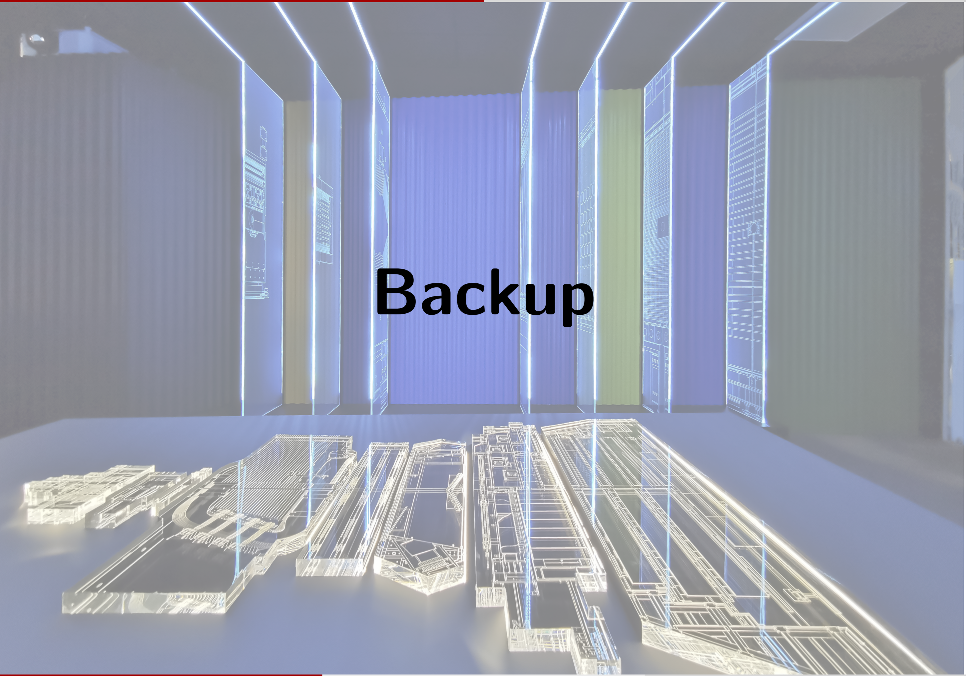




Conclusions

- 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 μ variations
  - Increased coverage in kinematics with software trigger
- Studies on neutral PID ongoing - more updates soon!

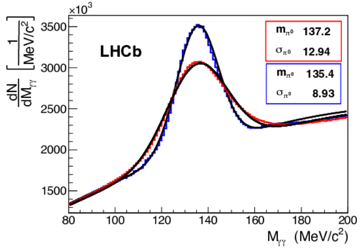
Backup



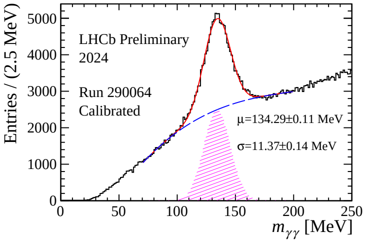
Neutral PID

- Dedicated NN aiming to provide:
  - γ/h separation: `IsNotH`
  - γ/π^0 separation for $E_T^\gamma > 2\mathrm{GeV/c^2}$: `IsPhoton`
  - Challenges: cluster pile-up and γ/e separation
- PID calibration as before Upgrade I:
  - γ: $B^0 \to K^{*0}\gamma$, $D_s^+ \to \eta'(\to \rho\gamma)\pi^+$, $D_s^{*+} \to D_s^+\gamma$
  - π^0: $D^0 \to K^+\pi^-\pi^0$
- Neutral PID performance is WIP, needs good understanding of ECAL
  - ECAL calibration: getting closer to performance before Upgrade I

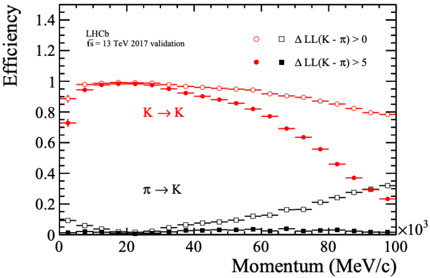
[CERN-LHCb-DP-2020-001]

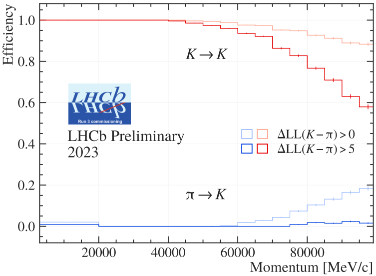


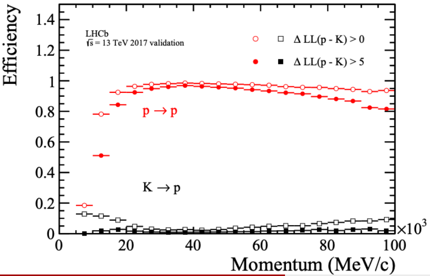
[LHCb-FIGURE-2024-009]

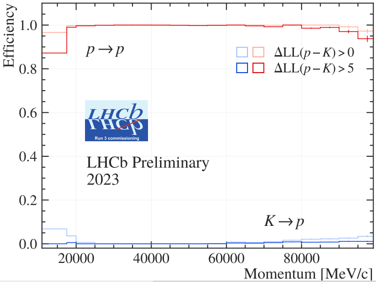


Charged hadron PID performance









Mis-ID in muon PID performance