PROCEEDINGS OF SCIENCE

Particle Identification at LHCb

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Particle identification (PID) is a fundamental requirement for LHCb and is provided by CALO, Muon and RICH sub-detectors. The Calorimeters provide identification of electrons, photons and hadrons in addition to the measurement of their energies and positions. As well as being part of the LHCb trigger, the Muon system provides identification of muons to a very high level of purity, essential for many CP-sensitive measurements that have J/ψ's in their final states. Hadron identification, in particular the ability to distinguish kaons and pions, is crucial to many LHCb analyses, particularly where the final states of interest are purely hadronic. The LHCb RICH system provides this, covering a momentum range between approximately 1 and 100 GeV/c. To maintain the integrity of the LHCb physics performance, it is essential to measure and monitor the particle identification efficiency and misidentification fraction over time. This can be done by using specific decays, such as of the K^0_S, ϕ, Λ and J/ψ, for which pure samples can be isolated using only kinematic quantities, due to their unique decay topologies. This allows for clean samples of known particle types to be selected, which can then be used to calibrate and monitor the PID performance from data. The procedures for performing this will be presented, together with preliminary results from the 2010 LHC run.

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1. Introduction

The LHCb experiment [1] is designed to exploit the unprecedented production of heavy flavour at the LHC in order to perform precision measurements of CP violation and rare decays. This involves studying all species of beauty and charm mesons, as well as baryons, reconstructed in many exclusive final states, be they hadronic, (semi-)leptonic or radiative. Achieving such a goal at a hadron collider is an ambitious challenge, and something only possible through:

1. a highly adaptable trigger;
2. a precision tracking detector;
3. an extensive Particle Identification (PID) system.

In order to identify exclusive final states in each of the above listed decay groups, the LHCb experiment employs a PID system composed of three sub-systems: Calorimetry, Muon and Ring Imaging Cherenkov (RICH) systems. A description of each PID sub-detector will now given, proceeded by a comment on their performance following the first $\sqrt{s}$ = 7 TeV collisions at the LHC earlier this year. Details of LHCb's implementation of 1. and 2. above may be found elsewhere in these proceedings [2][3].

2. Overview of LHCb's PID Sub-dectectors

2.1 The Ring Imaging Cherenkov System

Of the LHC experiments, LHCb is unique in that its charged hadronic PID information comes solely from a RICH[1]. This design choice, necessarily, imposes highly demanding requirements on the LHCb RICH system. In particular, it is required to provide charged particle identification over the extensive momentum range of $\sim$ 1 to 100 GeV$/c$. To achieve this, two separate RICH detectors are employed, utilising three separate radiators: aerogel, C_4F_{10} and CF_4. The aerogel radiator of RICH-1, located upstream of the LHCb dipole magnet, is composed of 5 cm thick tiles arranged around the LHC beam pipe. Located directly behind the aerogel is $\sim$ 1 m of C_4F_{10}. Together, the radiators of RICH-1 provide PID for tracks from 1 to approximately 60 GeV$/c$. RICH-2, located downstream of the magnet, contains the CF_4 gas radiator and provides PID over the momentum range of approximately 50 to 100 GeV$/c$. The arrangement of optics is similar in both sub-detectors; spherical focusing mirrors project the Cherenkov photons onto a series of flat mirrors which then reflect them onto a series of photon detector arrays, located outside the detector acceptance. The photon detector used is the Hybrid Photon Detector (HPD) [4].

2.2 The Calorimetry System

The LHCb Calorimetry system (CALO) takes the classical form of an electromagnetic calorimeter (ECAL) followed by a hadron calorimeter (HCAL) and is located downstream of RICH-2. The ECAL is a shasklik type sampling calorimeter of thinkness 25 X_0, composed of 66 alternating layers

[1]The ALICE experiment also employ a RICH system, but this is complemented by dE/dx and Time-of-Flight (TOF) information from the tracking system.

of lead absorber and scintillator. The HCAL, also a sampling type detector, is composed of alternating layers of iron and scintillator. To help distinguish $e^{\pm}$ from the overwhelming background of π^0 and $\pi^{\pm}$ mesons, longitudinal separation of the EM showers is needed. This is achieved by using two additional detectors in front of the ECAL: a Scintillator Pad (SPD) and Pre-Shower (PS) detector.

2.3 The Muon System

The LHCb Muon system is composed of five stations of Multi-Wire Proportional Chambers (MWPCs), labelled M1-M5, positioned around the beam axis. Stations M2 to M5 are located downstream of the calorimeters, with separate 80 cm thick iron plates interspersed between each. These iron plates act as absorbers to reduce any hadronic background that survives past the calorimeters. The first station, M1, sits immediately in front of the calorimeters. Due to the high particle fluxes experienced around the inner region of this up-stream station, a technology with extended longevity is used: triple-GEM (Gas Electron Multiplier) detectors.

3. Monitoring PID Performance at $\sqrt{s} = 7$ TeV

In order to maintain the integrity of the data being recorded to disk, it is essential to monitor the performance of each sub-detector. In the case of the CALO, Muon and RICH sub-dectectors one is ultimately concerned with monitoring their respective PID performance. To achieved this, it is necessary to gather from data high statistics samples of known particle types and assess the PID decision returned by the relevant sub-detector in each case. To comprehensively test the performance of all three sub-detectors, pure samples of the following particles need to be isolated: $e^{\pm}$, $\mu^{\pm}$, $K^{\pm}$, $\pi^{\pm}$, p and anti$-p$. The strategy employed is to reconstruct, through purely kinematic selections[2], exclusive decays of particles copiously produced at the LHC, such as $\gamma \to e^+e^-$, $J/\psi \to \mu^+\mu^-$, $K^0_S \to \pi^+\pi^-$, $\Lambda \to p\pi^-$ and $\phi \to K^+K^-$. To demonstrate the statistics and purities obtainable, the K^0_S and ϕ invariant mass distributions obtained from the first 65 μb^{-1} of $\sqrt{s} = 7$ TeV data are shown in Fig. 1.

3.1 RICH Performance

The off-line performance of the RICH system will now be presented by considering the rates for genuine p, K and π, as selected through Λ, ϕ and K^0_S decays, to be identified as either protons or kaons by the RICH reconstruction. In order to account for the residual background present within each track sample, an sWeight unfolding technique [5][6] is employed. Fig. 2(a) shows the proton ID and pion mis-ID in data as a function of momentum when a PID requirement of $\Delta\log\mathscr{L}(p-\pi) > 5$ has been imposed on all tracks, i.e. the likelihood returned by the RICH reconstruction algorithm under the proton mass hypothesis is five times that when under the pion hypothesis. As can be seen, after only a short time of running, the performance is excellent with nominal ID and mis-ID rates of $> 90\%$ and $< 10\%$, respectively. Fig. 2(b) shows the equivalent situation for discriminating kaons from pions with a PID requirement of $\Delta\log\mathscr{L}(K-\pi) > 5$. The performance

[2]This is not strictly the case for the $J/\psi \to \mu^+\mu^-$ and $\phi \to K^+K^-$ selections which utilises PID on one of the two daughter tracks through a tag-and-probe technique.

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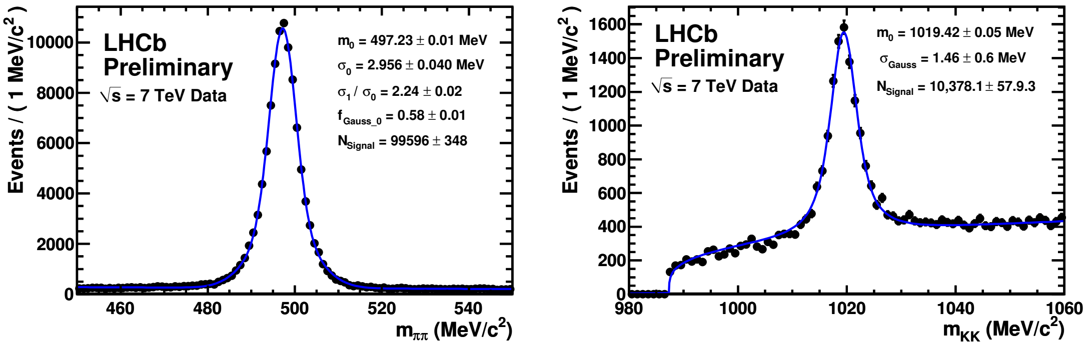
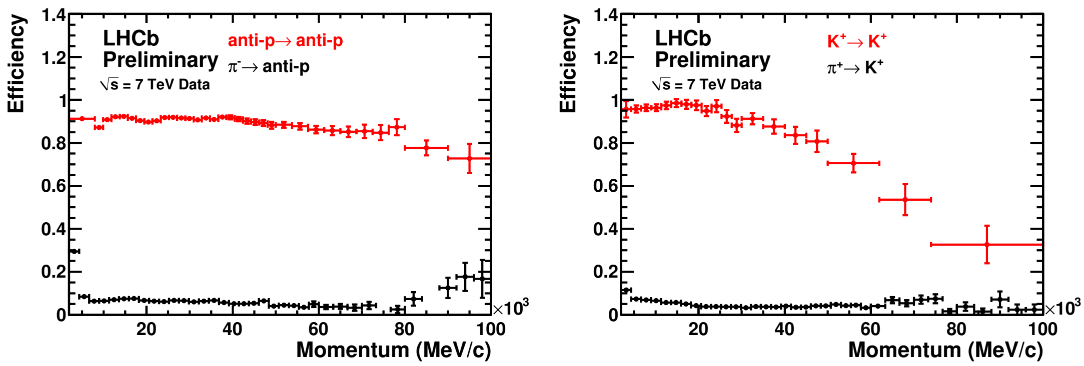


(a) (b)

Figure 1: The K_S^0 (a) and ϕ (b) invariant mass distributions extracted from the first 65 $\mu\mathrm{b}^{-1}$ of $\sqrt{s} = 7$ TeV data. While no PID has been applied in the K_S^0 selection, a tag-and-probe technique has been used to isolate the ϕ resoance.

at low track momenta ($< 40\mathrm{GeV}/c$) is again excellent, although at higher momenta the kaon ID performance is seen to degrade. At the time these results were presented, a complete calibration of the gaseous radiator's refractive indices had not yet been conducted and, as a result, the PID performance at high momenta was affected. Calibration of the refractive indices post ICHEP 2010 has seen a marked improvement in kaon performance at high momenta.



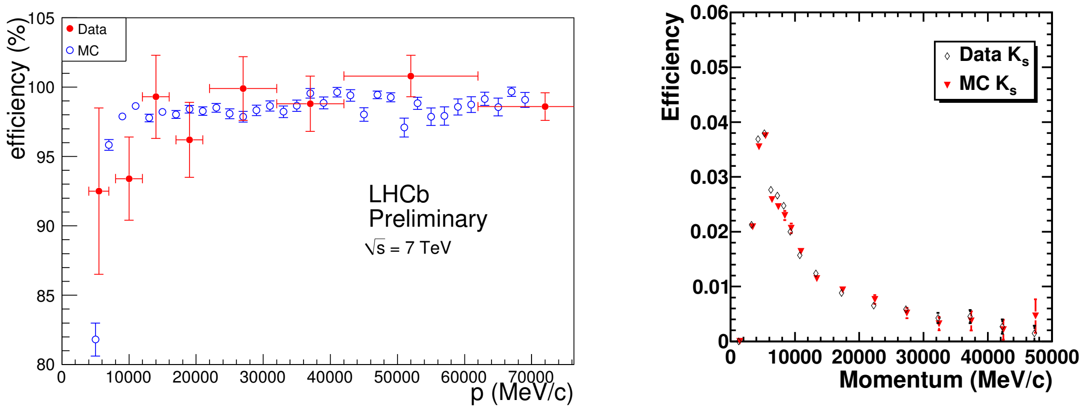
(a) (b)

Figure 2: RICH PID performance measured on data as a function of track momentum. In (a), proton identification (red) and pion mis-identification (black) following a PID requirement of $\Delta\log\mathcal{L}(p-\pi) > 5$. In (b), kaon identification (red) and pion mis-identification (black) for a PID requirement of $\Delta\log\mathcal{L}(K-\pi) > 5$.

3.2 Muon Performance

The PID performance of the Muon system will now be presented. To determine the muon identification efficiency, genuine muons from J/ψ decays are used. Fig. 3(a) shows this efficiency as a function of the tracks momenta, when a loose muon ID requirement is applied to J/ψ muons in both data and Monte Carlo. As can be seen, while the calibration muon statistics are limited, there is reasonable agreement between the distribution from these events and those from the Monte Carlo simulation. The integrated efficiency over the full momentum spectrum is found to be $(97.3\pm$

1.2)%. To determine the mis-ID coming from both pion and kaon tracks escaping out of the HCAL, the same K_S^0 and ϕ samples as used to study the RICH performance are exploited. Fig. 3(b) shows a comparison of the mis-ID rates from pions, as a function of momentum, in both data and Monte Carlo. With the plentiful K_S^0 statistics in the first data, the resulting error bars on each data point are seen to be almost negligible, and the overall agreement with the Monte Carlo distribution is excellent. The integrated mis-ID rates for pions and kaons is found to be $(2.35 \pm 0.04)\%$ and $(1.67 \pm 0.06)\%$, respectively.



(a) (b)

Figure 3: Muon PID performance as a function of track momentum. In (a), a comparison of the muon identification between data (red) and Monte Carlo (blue) following a loose ID requirement. Note the offset on the y-axis. In (b), a comparison of the pion mis-identification between data (back) and Monte Carlo (red).

4. Summary

Particle identification at LHCb is essential in order for it to perform precision measurements of CP violation and rare decays. From day one of LHC collisions, the PID systems of the RICH, CALO and Muon sub-detectors have been fully operation. Each detectors performance is found to be reliable with efficiencies, as determined on $\sqrt{s} = 7$ TeV data, approaching design specifications.

References

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