Particle Identification in LHCb

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Particle identification (PID) is a fundamental requirement for LHCb. It is provided by RICH, Muon and Calorimeter sub-detectors. To maintain the integrity of the LHCb physics performance, it is essential to measure and monitor the PID efficiencies and mis-ID fractions over time. This can be done by using specific decays of certain particles, such as $\mathrm{K_s^0}, \phi, \Lambda, \mathrm{J}/\psi$ and D^{*+}, for which pure samples can be isolated using only kinematic quantities. These samples can then be used to calibrate the PID performance from data. This report presents preliminary PID results from early 2010 LHC runs at $\sqrt{\mathrm{s}} = 7\mathrm{TeV}$.

1 Introduction

The LHCb experiment [1] is designed to make precision measurements of CP-violation and rare decays of B and D hadrons at the Large Hadron Collider (LHC). LHCb is a forward spectrometer (Fig. 1). Its design is optimised to accept the decay products of b and $\overline{b}$ hadrons, which are preferentially produced with a strong angular correlation in the forward−backward directions.

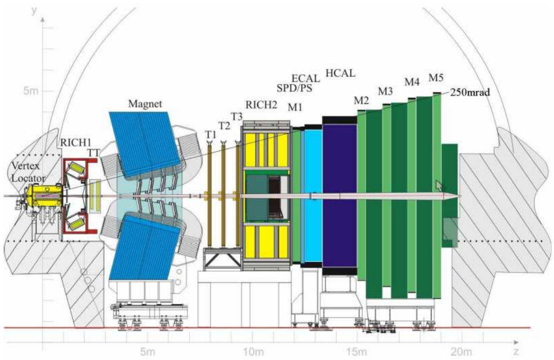

Figure 1: LHCb Detector. Of particular importance for this report are the RICH detectors (RICH 1 and RICH 2), the calorimeter system (SPD-PS, ECAL and HCAL) and the muon system (M1-M5). The tracking is provided by the vertex locator and the stations TT and T1-T3.

LHCb aims to search for evidence of new physics through precise measurements in the flavour sector. Measurements of particular importance are as follows [2]:

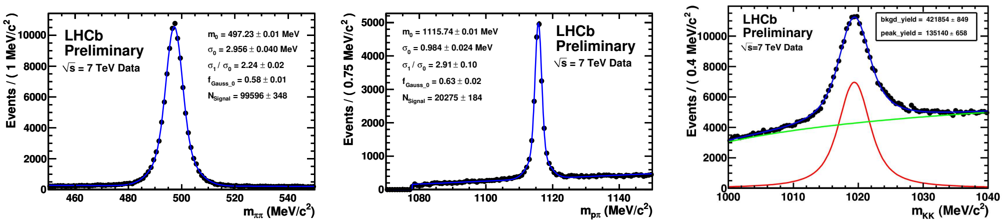

Figure 2: K^0_s(a), Λ^0(b) and ϕ(c) samples selected with kinematic properties alone for RICH calibration. In (c), the lower line indicates the signal component. RICH PID information is used to identify one daughter kaon.

1. Measuring CP-violation in B^0_s-mixing with $B^0_s \to J/\Psi\phi$;
2. Searching for the very rare decay $B^0_s \to \mu^+\mu^-$;
3. Measuring the angular distribution in the decay $B^0_d \to K^*\mu^+\mu^-$;
4. Precision measurement of γ angle in both tree and loop processes. This involves the reconstruction of channels such as $B^+ \to D^0K^+$ and $B^0_s \to hh'(h, h' = \pi, K)$ respectively;
5. Photon polarisation measurements in $B^0_s \to \phi\gamma$ and $B^0_s \to K^*\gamma$;
6. Mixing and CP-violation measurements in the D-meson systems.

It can be seen that all the above measurements require particle ID, whether it be of muons, neutrals in the final state, or discrimination between different hadron species. In LHCb, particle ID is provided by the Ring Imaging Cherenkov (RICH), muon and calorimeter sub-detectors.

2 RICH

LHCb possesses 2 RICH detectors, which utilise 3 radiators (silica aerogel, C_4F_10 and CF_4) to perform $\pi/K/p$ separation from 2 to 100 GeV/c. The polar angular acceptance of the upstream RICH 1 detector, in the spectrometer bending plane, is 25 $\to$ 300 mrad, while that for the downstream RICH 2 is 15 $\to$ 120 mrad. Pixel Hybrid Photon Detectors (HPDs) have been developed to detect and reconstruct the Cherenkov rings. A total of 484 HPDs cover the $3 \times 3\text{m}^2$ total photon detection area, consisting of 196 HPDs in RICH 1 and 288 in RICH 2.

To calibrate the PID performance of the RICH, pure samples of π, K, p have to be identified independent of RICH PID. Specific decays (Fig. 2) can be used due to their clean kinematic signatures. For example $K^0_s \to \pi^-\pi^+$ is used to select a π sample, $\Lambda^0 \to \pi^-p^+$ is used to provide both p and π samples. In $\phi \to K^-K^+$, RICH PID information is used to identify one kaon, which leaves the other kaon as an unbiased source for calibration. In using this sample it is important to subtract off the effects of the non-negligible background lying under the peak. At higher luminosity, $D^{*+} \to D^0(K^-\pi^+)\pi^+$ will be the main particle source for kaon calibration.

The RICH PID performance from 2010 data is illustrated in Fig. 3. These results are for a particular cut on the log likelihood information from the RICH pattern recognition. A tighter cut can be used to suppress the mis-ID rate to a lower level. These plots show that the RICH system already has excellent performance over the typical track momentum range of the B/D meson decays, from 2 to 100 GeV/c. Though the performance is very good, it is not yet at the level found in the Monte Carlo. Improvements are underway in terms of mirror alignment and calibration of the radiator refractive indices.

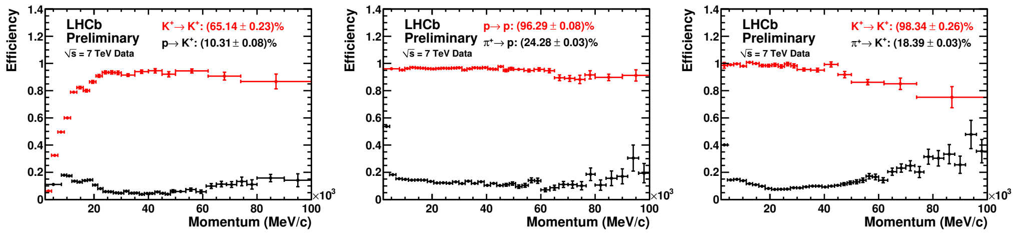

Figure 3: RICH PID performance from collisions data. The kaon identification efficiency versus $\mathrm{p} \to \mathrm{K}$ mis-ID rates is shown in (a). (b) shows the equivalent curve for proton identification and $\pi \to P$ mis-ID, and (c) for kaon identification and $\pi \to K$ mis-ID.

3 Muon System

The muon system is designed to identify muons with high efficiency and purity. It consists of 5 tracking stations, each subdivided into 4 regions with different granularities. It incorporates two types of tracking technologies: Multi Wire Proportional Chambers (MWPCs) and Gas Electron Multipliers (GEMs). The total thickness of the LHCb hadron absorber, which acts as shielding for the muon system, is 23λ.

Calibration of the muon ID efficiency can be performed using $\mathrm{J}/\psi \to \mu^-\mu^+$, where one μ is identified with the Muon system and the other μ with information from the calorimeters only. The results are shown in Fig. 4. The average efficiency is measured to be $\epsilon = 97.3 \pm 1.2\%$. This is in good agreement with Monte-Carlo simulations.

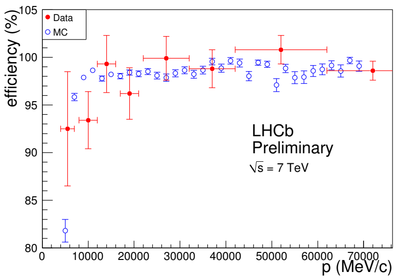

Figure 4: Muon ID efficiency using $\mathrm{J}/\psi \to \mu^-\mu^+$, over a momentum span of around 5-70 GeV/c. Data and MC are shown in filled and empty circles, respectively.

The μ mis-ID rates can be estimated using $\mathrm{K}^0_\mathrm{s} \to \pi^-\pi^+$ (for $\pi \to \mu$ mis-ID) and $\Lambda^0 \to \pi^-\mathrm{p}^+$ (for $\mathrm{p} \to \mu$ mis-ID). The results are shown in Fig. 5. As can be seen the mis-ID rates fall with momentum and there is good agreement seen between data and Monte-Carlo. Misidentification in the pion sample arises from decays in flight, whereas for the protons it comes about from misassociation of hits or punch-through. Additional variables, which quantitify the agreement of the position of the hits in the muon system with the expected trajectory, can be used to suppress the mis-ID rate further.

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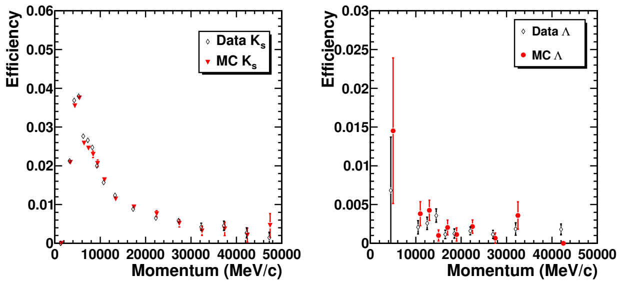

Figure 5: $\pi - \mu$ (a) and p - μ (b) mis-ID rate, with data in empty circles and MC in filled shapes.

4 Calorimeter System

The calorimeter system consists of scintillator pad detector (SPD), pre-shower detector (PSD), electromagnetic calorimeter (ECAL) and hadron calorimeter (HCAL). They provide identification of e, γ and neutral hadrons/resonances, as well as the measurement of their energies and positions. Figure 6 shows examples of the neutral resonances ($\pi^0 \to \gamma\gamma$ and $\rho, \omega \to \pi^-\pi^+\pi^0$) identified by the calorimeter system.

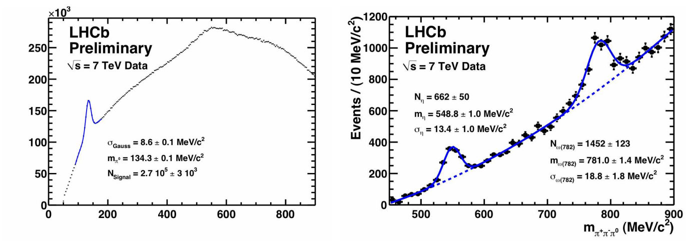

Figure 6: Neutral resonances $\pi^0 \to \gamma\gamma$ (a) and $\rho, \omega \to \pi^-\pi^+\pi^0$ (b) identified by calorimeter.

5 Conclusions

Particle identification is essential for achieving the physics goals of LHCb. The RICH, muon and calorimeter sub-system are all fully operational and have already provided useful PID information for physics analysis. The muon ID performance already is the same as for the Monte-Carlo. With ongoing work in the detector calibration and alignment, the RICH PID performances are approaching the Monte-Carlo expectations.

References

[1] [The LHCb Collaboration], "The LHCb Detector at the LHC," 2008 JINST 3 S08005, doi: 10.1088/1748-0221/3/08/S08005

[2] [The LHCb Collaboration], "Roadmap for selected key measurements of LHCb," arXiv:0912.4179.