LHCb PARTICLE IDENTIFICATION AND PERFORMANCE.

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The LHCb particle identification system is presented. It consists of two Ring-Imaging Cherenkov detectors which provide pion/kaon separation over the momentum range 1 to 100 GeV/c, the Calorimeter system with which it is possible to identify neutral particles and the Muon Detector.

1. Introduction

1.1. The LHCb Experiment

Figure 1. The LHCb detector.

The Large Hadron Collider Beauty¹ (LHCb) experiment (Fig. 1) is a forward one-arm spectrometer dedicated to the study of CP violation and other rare phenomena in the decay of hadrons containing b-quarks at the Large Hadron Collider (LHC). The physics goals are to check the consistency of the Standard Model through precision measurements of the sides and angles of the Cabibbo-Kobayashi-Maskawa (CKM) triangle, and to search for new physics in decays that are rare, or forbidden, in the Standard Model.

Many of the decay modes of interest for CP-violation studies at LHCb have topologically similar backgrounds. It is therefore necessary to efficiently identify particles in order to maximize our signal to background ratios. Particle Identification (PID) is also necessary in order to identify interesting events in the LHCb High Level Trigger (HLT) and the Level 0 trigger decision depends strongly on the identification of high p_T muons. PID in the LHCb environment is achieved using data from a number of subdetector systems, namely the two Ring Imaging Cherenkov (RICH) detectors, the Calorimeter systems and the Muon system.

2. LHCb Subdetectors

2.1. The LHCb RICH Detectors

Both LHCb RICH detectors follow the same basic design. Cherenkov radiation is emitted by charged particles passing through the radiating material in the detector. The radiation is focused onto the photon detector plane by a set of spherical mirrors which are tilted in order to remove the photon detectors from the LHCb acceptance. In addition to the spherical mirrors, a secondary set of plane mirrors is used to minimize the overall detector length. Both detectors use Hybrid Photon Detectors (HPDs) which are sensitive to single photons in the range $200\text{nm} < \lambda < 600\text{nm}$.

RICH 1 (Fig. 2) has an angular acceptance of 20 - 300 mrad and uses a combination of silicon aerogel ($n = 1.03$) and C_4F_{10} gas ($n = 1.0014$) radiators to identify low to intermediate momentum particles (up to $\sim 70\text{GeV}/c$). High momentum particles (up to $\sim 100\text{GeV}/c$) are detected by RICH 2 which has an acceptance of 15 - 120 mrad and uses CF_4 gas ($n = 1.0005$) as its radiator. Together, the RICH detectors cover the phase space of interesting events almost completely (Fig. 3).

Figure 2. Schematic diagram of the vertical RICH1 detector.

Figure 3. Track angle vs. momentum for all tracks from $B_0 \rightarrow \pi\pi$ events.

Particle identification using the RICH system is performed as follows. For each event, a set of mass hypotheses for each reconstructed track is calculated. Using this data, the probability distribution for finding photons in each pixel of the detector is determined and then compared to the observed hit distribution. A likelihood is determined from this comparison and then the track mass hypotheses are varied in order to maximise the likelihood. Efficient $\pi - K$ separation is achieved using this method, giving an average Kaon identification efficiency of $\sim 88\%$ and an average pion misidentification rate of $\sim 3\%$ (Fig. 4).

2.2. The LHCb Calorimeter systems

The LHCb Calorimeter System is composed of the Scintillator Pad/Preshower (SPD/PS), the Electromagnetic Calorimeter (ECAL) and the Hadronic Calorimeter (HCAL). The SPD/PS system is made from a lead converter plate sandwiched between two layers of scintillator pads. The ECAL is based on “shashlik” technology and uses a sampling structure of 2 mm lead sheets interspersed with 4 mm thick scintillator plates. The HCAL uses steel and scintillating tiles as absorber and active material respectively and is segmented into two sections with square readout cells of size 131.3 mm and 262.6 mm.

Figure 4. Kaon identification efficiency (top) and pion misidentification rate (bottom) using the RICH detectors.

Figure 5. π^0 identification efficiency for both resolved (solid line) and merged pions (dashed line) using the calorimeter systems.

Identification of neutral particles is possible using the Calorimeter system. For example, π^0 reconstruction from $\pi^0 \rightarrow \gamma\gamma$ decays is possible using information from the SPD/PS and ECAL. The pions may be separated into two categories; resolved (where the two photon candidates are distinct) and merged (where the two photon candidates overlap forming a “merged cluster”). In the merged case, an algorithm disentangles the photon pair using directional information from the merged cluster and in the resolved case, photon candidates are paired to reconstruct the resolved π^0 . Using this method, overall π^0 identification is achieved with $\sim 53\%$ efficiency (Fig. 5). In $B^0 \rightarrow \pi\pi\pi$ decays, π^0 identification produces a B^0 mass resolution of $\sim 60 \text{ MeV}/c^2$.

2.3. The LHCb Muon system

The purpose of the LHCb Muon System is to provide fast (L0) triggering and offline muon identification. Muon identification is important because they are present in the final states of many CP-sensitive B decays, in particular the two goldplated decays $B^0 \rightarrow J/\Psi(\mu\mu)K$ and $B_s^0 \rightarrow J/\Psi(\mu\mu)\phi$. The system is made of five Stations (M1-M5) of rectangular shape, covering an acceptance of $\pm 300 \text{ mrad}$ (horizontally) and $\pm 200 \text{ mrad}$ (vertically).

Figure 6. μ identification efficiency (left axis) and π misidentification rate (right axis).

Muons are selected by searching for muon station hits which are compatible with reconstructed track extrapolations from the tracking stations. In order to reduce the particle misidentification rate, information from other subdetectors may be used e.g. π identification using the RICH detectors. A muon identification efficiency of $97.6\% \pm 0.2\%$ with a pion misidentification rate of $2.50\% \pm 0.04\%$ is obtained (Fig. 6). Using muon identification, we expect to achieve a B^0 mass resolution of $\sim 9 \text{ MeV}/c^2$ in $B^0 \rightarrow J/\Psi(\mu\mu)K_S^0$ decays.

3. Conclusions

The particle identification provided by the RICH, CALO and MUON systems is crucial to the LHCb physics programme. The LHCb RICH design with two detectors and three radiators will provide significant kaon/pion separation over the required momentum range. The Calorimeter system will achieve π^0 identification with approximately $\sim 53\%$ efficiency and excellent muon identification ($\sim 96\%$ efficiency) will be achieved with the Muon system.

References

1. LHCb Collaboration. LHCb TDR 9 Reoptimised Detector-Design and Performance, September 2003. CERN-LHCC-2003-030.