University of Glasgow | Experimental Particle Physics

GLAS-PPE/2008-38
26th November 2008

Department of Physics and Astronomy
Experimental Particle Physics Group
Kelvin Building, University of Glasgow,
Glasgow, G12 8QQ, Scotland
Telephone: +44 (0)141 330 2000 Fax: +44 (0)141 330 5881

The RICH system of the LHCb experiment: status and performance

A. Pickford[1], (for the LHCb RICH Collaboration)

[1] University of Glasgow, Glasgow, G12 8QQ, Scotland

Abstract

The LHCb experiment is a single forward arm spectrometer at the LHC at CERN. Particle identification (pion, kaon and proton discrimination) is a crucial requirement to meet the physics goals of the experiment. This is provided by two Ring Imaging Cherenkov (RICH) detectors providing particle identification coverage between 1 and 100 GeV/c.

After a brief description of the LHCb experiment and RICH detectors, the results from the latest beam test using the final detector components and readout system will be given and the anticipated particle identification performance of the RICH detectors from Monte Carlo simulations will be presented. Finally a technique to calibrate the particle identification performance of the RICH system with data using D^* decays will be described.

8th International Conference on Position Sensitive Detectors
Univerisity of Glasgow

1 Introduction

The Large Hadron Collider beauty (LHCb[1]) experiment, shown in Figure 1, is one of the four main experiments at the LHC[2]. LHCb is a single forward arm spectrometer which will make precision measurements of CP violation as well as search for rare decays and physics beyond the Standard Model. This requires excellent particle identification, in particular distinguishing between pions and kaons over a wide momentum range (1-100 GeV/c). This is achieved using two Ring Imaging Cherenkov (RICH) detectors.

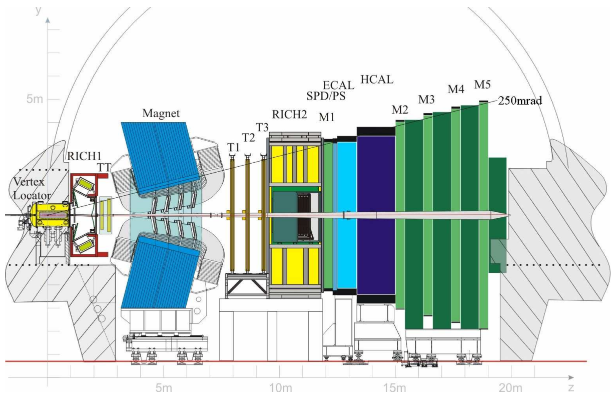
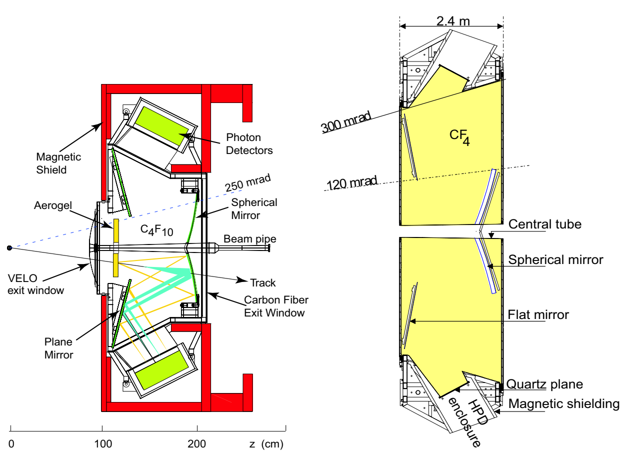


Figure 1: The LHCb Detector. Far left is the proton-proton interaction point surrounded by the Vertex Locator (VELO) subdetector. The two RICH detectors are located either side of the bending magnet.

2 The RICH Detectors

The two RICH detectors are shown schematically in Figure 2. RICH1, located ∼1 m from the interaction region, has C_4F_{10} gas and aerogel radiators to distinguish low momenta particles up to ∼65 GeV/c. RICH2, located downstream of the LHCb spectrometer magnet, covers higher momenta particles up to ∼100 GeV/c using CF_4 gas as a radiating medium. To minimise material inside the LHCb acceptance, both RICHes use a combination of low density spherical mirrors inside the spectrometer acceptance and flat mirrors outside the acceptance to image the Cherenkov photons on the photon detector planes, which are also located outside the spectrometer acceptance. The RICHes use a total of 484 pixel Hybrid Photon Detectors (HPDs)[3] for position-sensitive photon detection. Each HPD has an active diameter of 75 mm; the photons are imaged onto a silicon anode which is segmented into 1024 pixels, giving a granularity at the HPD photocathode of 2.5 mm x 2.5 mm.



(a) (b)

Figure 2: Schematic views of (a) RICH1 (side on) and (b) RICH2 (from above).

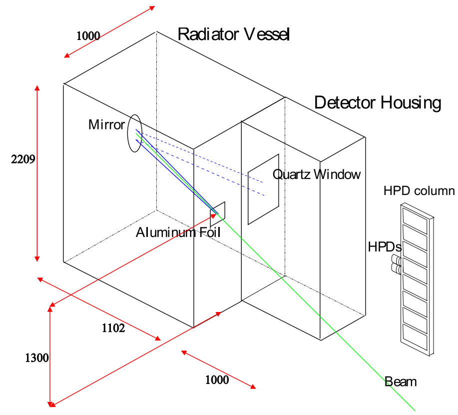


Figure 3: Schematic of the RICH test-beam setup showing beam entry from the bottom right and Cherenkov radiation path from the particle trajectory, reflection off the mirror and onto the HPDs.

3 Test-beam Results

Beam tests[4],[5] at the CERN SPS have verified the final RICH components including the production HPDs and electronics readout. Figure 3 shows the experimental setup used in the test-beam. The 80 GeV/c particle beam of mostly pions with a small admixture of kaons, protons and electrons enters the radiator volume through a thin aluminium foil. The beam has a 25 ns bunch structure to emulate that of the LHC.

Figure 4 shows the distribution of the mean Cherenkov angle per photoelectron for both measured and simulated data using N_2 as the radiating medium. Figure 5 shows the superimposed images of multiple rings on the photon detector plane for a C_4F_{10} radiator.

A near final version of the LHCb RICH software code is used to reconstruct Cherenkov photons in the test-beam. The results of the photon yield and Cherenkov angle resolution measurements for both N_2 and C_4F_{10} radiators are shown in Table 1. The Cherenkov angle resolution is extracted by fitting a double Gaussian to the distribution and using the width of the central distribution. The photon yield and Cherenkov angle resolution are important as both directly impact the particle identification performance of the RICHes and both parameters show good agreement between measurement and simulation.

4 Commissioning

Both RICH detectors are installed in the experimental cavern ready for the first LHC beam. The various RICH subsystems: high and low voltage, cooling, data acquisition, control and monitoring, are all operational. Commissioning data are being taken with a laser light source (see Figure 6) and cosmic rays.

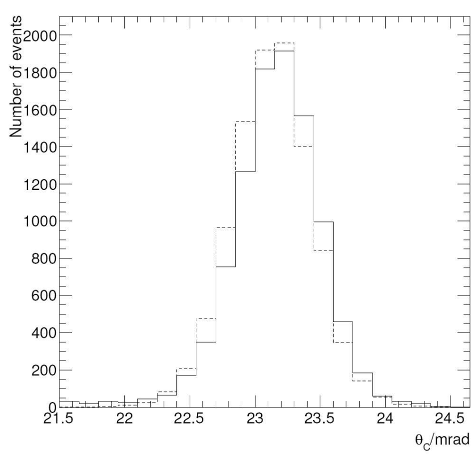


Figure 4: Single photon Cherenkov angle distribution for measured (solid) and simulated (dotted) data, using an N_2 radiator.

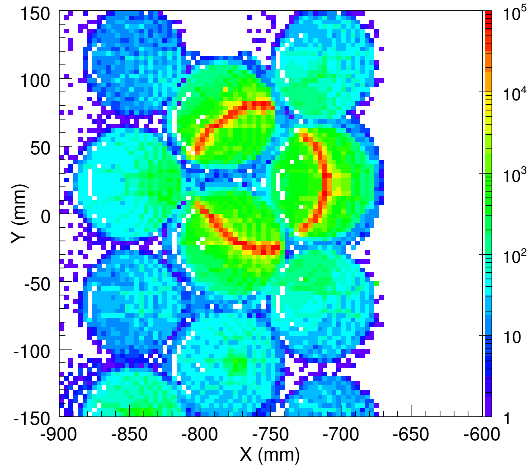


Figure 5: Cherenkov rings imaged on the HPD plane from multiple tracks through the RICH test-beam setup using a C_4F_{10} gas radiator.

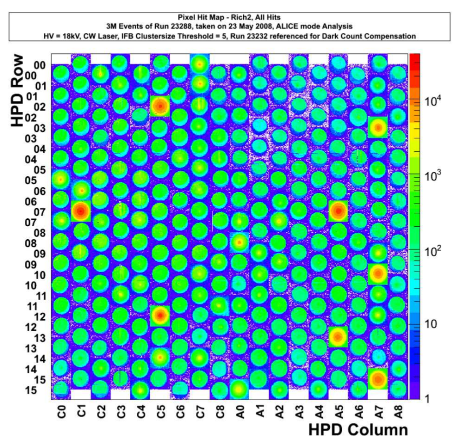
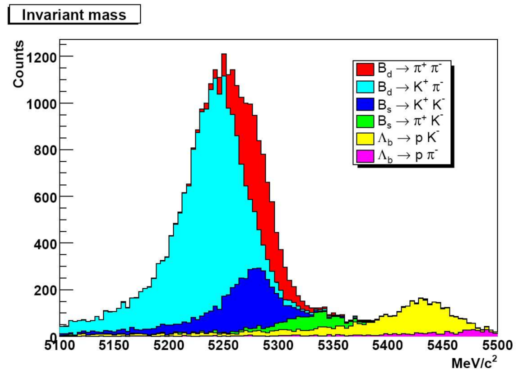
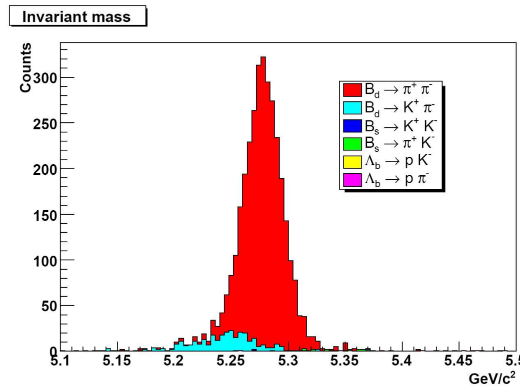


Figure 6: RICH2 commissioning data, showing the illumination of all photon detectors from a laser light source.



(a)



(b)

Figure 7: Simulation of reconstructed $B_d \to \pi\pi$ mass spectrum: (a) without particle identification, (b) with particle identification.

5 Particle Identification

Particle identification, in particular separation of pions and kaons, is key to the LHCb physics programme. An example is shown for the decay $B_d \to \pi\pi$ in Figure 7; to separate the signal from background processes particle identification is essential[6]. The baseline method used is a global pattern-recognition approach in which the hits in the RICH photon detectors are compared to the expected hit distributions from reconstructed tracks, assuming various particle identification hypotheses (electron, muon, pion, kaon, proton) for these tracks. A likelihood function is calculated from the comparison of all tracks in all three RICH radiators simultaneously and the particle identification hypotheses varied to maximise the likelihood. The performance of the LHCb detector has been extensively studied via simulation[7]. Figure 8 shows the simulated kaon/pion separation from 1 to 100 GeV/c.

The decay $D^* \to D^0(\pi K)\pi$ will be used to monitor the particle identification performance of the LHCb detector, which has a 300 Hz output trigger stream for $D^* \to D^0(hh)\pi$ decays. The $D^* \to D^0(\pi K)\pi$ mode can be specifically selected without using any RICH information; the D^0 mass combinations $K\pi$, KK and $\pi\pi$ can be made for each of the candidate decay products in turn and then combined with a third track as a candidate for

	Cherenkov Angle Resolution (mrad)		Photon Yield	
	Data	Simulation	Data	Simulation
N_2	0.296 ± 0.003	0.28 ± 0.01	12.8 ± 0.15	12.7 ± 0.6
C_4F_{10}	0.166 ± 0.002	0.158 ± 0.001	8.9 ± 0.5 rad^{-1}	9.3 ± 0.5 rad^{-1}

Table 1: Comparison of Cherenkov angle resolution and photon yield measurements with simulation. For both radiators used, N_2 and C_4F_{10}, there is excellent agreement between measurement and simulation. Since the Cherenkov ring for C_4F_{10} spans multiple HPDs with dead area between them, the yield in this case is quoted per radian of Cherenkov ring.

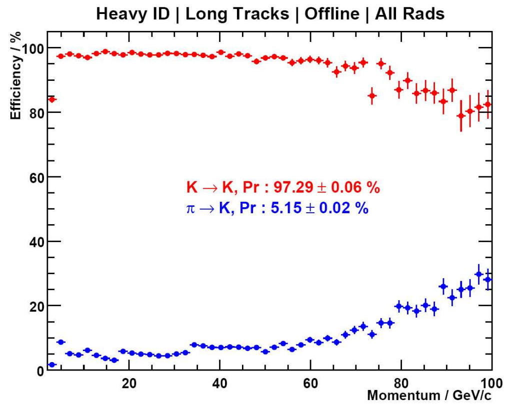


Figure 8: Simulated $K\pi$ separation performance over the momentum range 1 - 100 GeV/c. The efficiency for kaons to be identified as kaons or protons and the pion misidentification probabilities are shown.

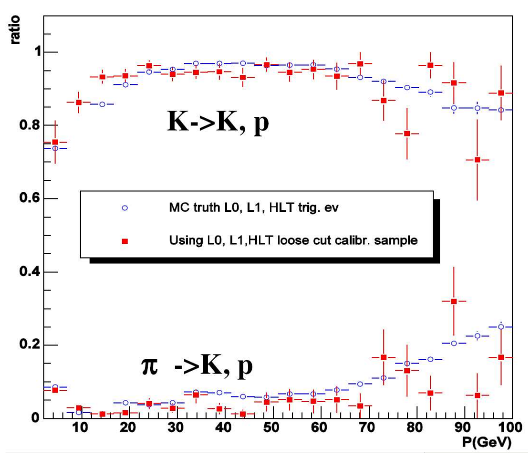


Figure 9: Comparison of the RICH particle identification performance showing (i) the Monte Carlo truth information (circles) and (ii) simulated measurements from reconstructed D^* decay to assign the particle ID hypothesis to determine the RICH performance from data (squares).

the slow pion from the D^* decay. With loose cuts on transverse momentum and impact parameter significance an estimated 50×10^6 usable $D^* \to D^0(\pi K)\pi$ events per year of running are expected from the $D^* \to D^0(hh)\pi$ trigger. This provides an ample number of events for monitoring the RICH particle identification performance, as demonstrated in Figure 9.

6 Summary

In summary, the RICH detectors of the LHCb experiment are ready for data taking. The detectors show excellent particle identification performance and will be crucial for the physics programme of LHCb.

References

[1] The LHCb Collaboration, A Augusto Alves Jr et al, The LHCb Detector at the LHC, 2008 JINST 3 S08005

[2] L. Evans and P. Bryant eds., LHC Machine, 2008 JINST 3 S08001

[3] L. Carson, Hybrid Photon Detectors for the LHCb RICH: performance and operational experience, these proceedings

[4] M. Adinolfi et al, Performance of the LHCb RICH photodetectors in a charged particle beam, Nucl. Instrum. Meth. A 574 (2007) 39.

[5] M. Adinolfi et al, Performance of the LHCb RICH photodetectors and readout in a system test using charged particles from a 25ns-Structured beam, in preparation.

[6] A. Carbone et al, Charmless charged two-body B decays at LHCb, LHCb Public Note 2007-059.

[7] N. Harnew, An overview of the status of the LHCb RICH detectors, Nuclear Inst. and Methods in Physics Research, A, 595 (1), p.31-35, Sep 2008

[8] R. Muresan, Charm Physics at LHCb, Nucl. Phys. Proc. Suppl. 170:237-242, 2007