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To cite this article: U Kerzel 2008 *J. Phys.: Conf. Ser.* **110** 092014

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The LHCb RICH Detectors

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Abstract.

The LHCb experiment at the Large Hadron Collider has been optimised for high precision measurements of the charm and beauty quark sector. The different particle species produced in the high-energy reaction are identified using two Ring-Imaging Cherenkov detectors.

1. Introduction

The main objective of the LHCb [1] experiment is to precisely determine and over-constrain the parameters of the CKM matrix, and to search for further sources of CP violation and new physics beyond the Standard Model in rare B-decays. Efficient particle identification at high purities over a wide momentum range from around one to ≈ 100 GeV/c is vital to many LHCb analyses. Fig. 1 illustrates the essential contribution of the particle identification for the case of charmless B-meson decays: Using the particle identification information the signal mode $B_s^0 \rightarrow \pi^+\pi^-$ can be cleanly isolated against other decay modes.

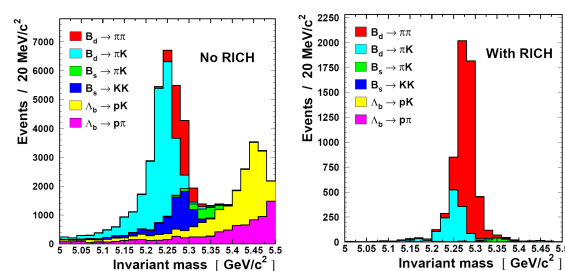


Figure 1. Left: reconstructed invariant mass spectrum of $B_s^0 \rightarrow \pi^+\pi^-$ candidates without particle identification. Right: same but with particle identification criteria. Simulated signal events are used in both figures.

2. RICH detectors

Central to the LHCb particle identification strategy are two Rich Imaging Cherenkov (RICH) detectors [2, 3]. A schematic overview over the RICH photo-detectors of the LHCb spectrometer is shown in Fig. 2.

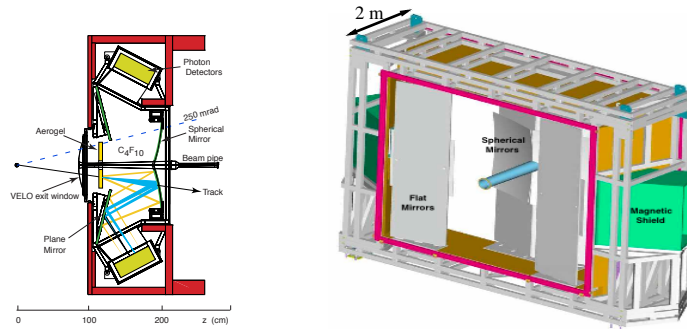


Figure 2. Schematic overview over the RICH photo-detectors of the LHCb spectrometer. Left: RICH 1 Right: RICH 2

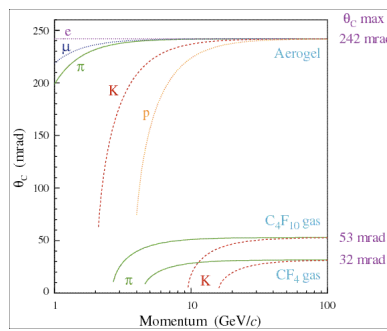


Figure 3. Detection thresholds for the different particle species in the three Cherenkov media.

In order to limit the degradation of the resolution of the tracking systems due to interaction with the detector material, the RICH photo-detectors are placed outside the acceptance of the LHCb spectrometer. Using a set of spherical, coupled with flat mirrors [4, 5], the Cherenkov light is projected onto the detector plane. The spherical mirrors are positioned inside the spectrometer acceptance and it is therefore of vital importance to minimise the fraction of radiation length X_0 while at the same time safeguarding the mechanical integrity of the optics. In the case of RICH1, industrial carbon fibre has been used for the support structure and the resulting contribution to the material budget is below 6kg/m^2 which corresponds to 1.5% X_0 .

Three different radiator materials are used in the two sub-detectors covering a large range of momentum. In RICH 1, Silica aerogel [6] is used to detect particles in the momentum range up to $\approx 10\text{ GeV}/c$ and C_4F_{10} is used for $10 \leq p \leq 60\text{ GeV}/c$. CF_4 is used as radiator material in RICH 2 and covers the range $16 \leq p \leq 100\text{ GeV}/c$. Fig. 3 illustrates the detection thresholds of the various particle species in each of the three Cherenkov radiators.

3. Photo-detectors

The need for a fast and efficient photon detector operating at the LHC frequency of 40 MHz and a large active surface area lead to the development of the custom-built pixel Hybrid Photon Detectors (HPDs) [7] to detect the Cherenkov light produced in the radiators. The HPDs are designed and built in collaboration with industry. Each HPD detects the converted photo-electrons using a silicon pixel-chip with 8192 active channels. Eight channels are actively OR-ed by the read-out electronics to form 1024 square super-pixels which results in an effective granularity of $2.5 \times 2.5\text{ mm}^2$ at the entrance window. In total, 0.5 M pixels are used to detect

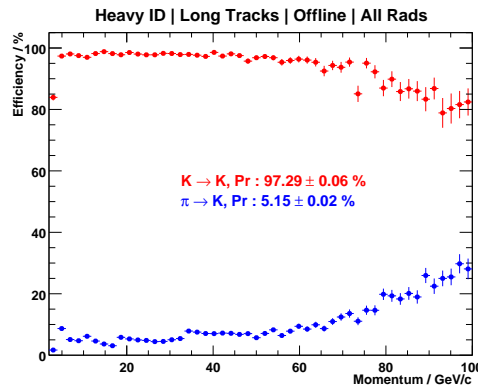


Figure 4. Estimated performance of the particle identification based on simulation studies including effects from the higher quantum-efficiency of the photo-detectors.

the Cherenkov light in an active area of $\approx 2.1 \text{ m}^2$ which corresponds to $\approx 64\%$ of the detection plane. The photo-detectors are sensitive to single photons in the wavelength range from 200 nm to 600 nm. The quantum-efficiency is one of the main parameters characterising the quality of the HPD. All HPDs produced exceed the typical quantum-efficiency of 23% at a wavelength of 270 nm. Due to significant quality progress at the manufacturer, an average quantum efficiency of $\approx 31\%$ could be achieved.

4. Estimated Performance and Current Status

Using information from the tracking system, a set of mass-hypotheses is assigned to each reconstructed track. This is then used to derive the probability distribution for finding photons in each pixel of the detector. A likelihood is calculated comparing the observed and anticipated hit distributions. By varying the mass hypotheses, the likelihood is maximised. Efficient $\pi - K$ separation is achieved at high purity as illustrated by Fig. 4 which includes effects from all known backgrounds.

The LHCb RICH project is in the final stages of preparations before the start of the LHC in 2008. The construction of the RICH2 detector is complete and the system is in place in the experimental zone. At the time of writing, the RICH2 sub-detector is being commissioned for data-taking. All elements of the RICH1 detector are already assembled and are being installed in accordance to the schedule of the experiment.

All individual components of both RICH sub-detectors meet or exceed the design specifications which has been verified in multiple beam-tests and excellent performance of the detector is expected.

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