LHCb RICH Detectors

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Abstract. The LHCb experiment will perform high precision studies of CP violation and other rare phenomena in the B meson sector. Particle identification will be essential to enhance the signal to background ratio in the selection of B–decay channels and to provide an efficient kaon tag. LHCb will use two RICH detectors, one covering the charged particle momentum range $1 - 65 \text{ GeV}/c$ using solid silica aerogel and gaseous C$_4$F$_{10}$ radiators, and the other covering up to 100 GeV/$c$ using gaseous CF$_4$. Hybrid Photon Detectors (HPDs) have been developed to detect Cherenkov light in the wavelength range 200 – 600 nm. The engineering design of the upstream RICH–1 detector is very well advanced and the assembly of the downstream RICH–2 is almost complete.

1 LHCb RICH Detectors

LHCb is the dedicated experiment for precise measurements of CP violation and rare decays at the Large Hadron Collider, LHC. Based on the expected topology of $b\bar{b}$ pair production at the LHC, its design consists of a single–arm spectrometer with a forward coverage from 10 mrad to 300 (250) mrad in the bending (non–bending) plane [1].

Particle identification, essential to enhance the signal to background ratio in the selection of $B$–decay channels and to provide an efficient kaon tag, will be achieved using Ring Imaging CHerenkov (RICH) detectors. Due to the strong correlation between the polar angle and the momentum of the particles, shown in Fig. 1, two detectors are designed (RICH–1 and RICH–2). To cover the wide momentum range $1 - 100 \text{ GeV}/c$, three radiators are required. The first, solid silica aerogel ($n = 1.03$), is suitable for the lowest momentum particles up to $\sim 10 \text{ GeV}/c$. Gaseous C$_4$F$_{10}$ ($n = 1.0014$) and CF$_4$ ($n = 1.0005$) then provide particle identification of the intermediate and the highest momentum particles up to approximately $65 \text{ GeV}/c$ and $100 \text{ GeV}/c$, respectively. The Cherenkov angle for the three radiators as a function of momentum is shown in Fig. 1 for the $\pi$, $K$ and $p$ hypotheses [2,3].

2 Silica Aerogel

Silica aerogel is a solid material made of SiO$_2$ with a very low density. It consists of a linked network of particles of $2 - 5 \text{ nm}$ in diameter, and pores whose average radius is about 20 nm. The density is calibrated during production and it is typically between 0.003 and 0.35 g/cm$^3$. It is transparent and its refractive index can be tuned within the wide range of $1 - 1.48$. Depending on the manufacturing procedure, silica aerogel can be hygroscopic or hydrophobic.

Photons scattering within the aerogel is the factor limiting the performance of this material as a Cherenkov radiator. The dominant contribution is from the Rayleigh scattering mechanism with a cross section proportional to $\lambda^{-4}$, where $\lambda$ is the wavelength of the photon.

Fig. 1. Left: polar angle vs momentum for all the tracks in simulated $B^+_s \rightarrow D^+_s \pi^+$ events; the regions of interest for RICH–1 and RICH–2 are drawn. Right: Cherenkov angle vs momentum for different particle hypotheses for the three radiators.

Fig. 2. Left: photograph of the Cherenkov vessel used to study the resolution and performance of aerogel blocks and Hybrid Photon Detectors. Right: reconstructed Cherenkov angle $\theta_C$ for a mixed beam of $\pi^+$ and $p$. 
The LHCb RICH–1 detector will be equipped with 200 × 200 × 50 mm$^3$ tiles of hygroscopic silica aerogel produced by the Boreskov Institute of Catalysis in Novosibirsk (Russia). These tiles have the largest size ever fabricated. Several tests have been done to check the optical properties required by the experiment. Possible ageing effects due to intense irradiation and to humidity absorption have been studied: no evidence of permanent degradation of the optical properties has been detected [4]. The index of refraction homogeneity complies with the specifications $\sigma(n - 1)/(n - 1) < 1\%$. From a beam test an excellent $p/\pi^+$ separation has been achieved up to 10 GeV/$c$, as shown in Fig. 2.

3 Hybrid Photon Detectors

Cherenkov photons will be detected by a total of 484 Hybrid Photon Detectors (HPDs). The photon detector planes of both RICH detectors cover a total area of about 2.8 m$^2$, with an active over total ratio greater than 70\%.

Pixel HPDs consist of a cylindrical vacuum tube of diameter 83 mm. On the inner surface of the 7 mm thick quartz spherical entrance window, a multialkali photocathode is deposited. The base of the tube houses a silicon sensor equipped with 1024 pixels of size 0.5 × 0.5 mm$^2$ which, due to an electrostatic image demagnification factor of five, corresponds to a 2.5 × 2.5 mm$^2$ granularity at the HPD photocathode. The HPD is sensitive in the wavelength range between 200 nm and 600 nm.

Photoelectrons created at the photocathode are accelerated and cross-focused onto the silicon sensor by a 20 kV potential difference. An overall iron shield and individual Mumetal tubes allow the HPDs to operate safely in the residual magnetic field of up to 25 gauss.

Recently the full readout chain has been successfully tested in a 10 GeV/$c$ $\pi^-$ and $e^-$ beam test. Cherenkov photons produced in a C$_4$F$_{10}$ radiator have been detected by six pre–production HPDs integrated with Low Voltage (LV) and High Voltage (HV) boards. A photograph of the HPDs and a detected pion ring integrated over many events are shown in Fig. 3.

4 RICH Particle ID Performance

The task of particle identification (PID) is to assign a particle type to each reconstructed track [6]. Fig. 4 shows the mass spectrum of candidate $B_s^0 \rightarrow K^+K^-$ events before and after PID is applied. The powerful PID allows rejection of almost all the backgrounds during the offline analysis.

Two approaches have been developed for ring reconstruction: a “local” method which treats each track separately and a “global” one which optimizes the assignment of particle types for all the tracks in RICH–1 and RICH–2 simultaneously. In both methods a likelihood function is maximized varying the mass hypothesis. Typical values of PID performances are 95% for $K$ identification and 5–7% misidentification between 20–60 GeV/$c$. Varying the cut on the difference of log–likelihood functions used to separate kaons from pions, the misidentification rate of pions can be reduced (improving the purity of the selected sample) at the cost of reducing the kaon identification efficiency.

Pion–kaon separation is achieved at about 3$\sigma$ over most of the momentum range of interest 2–100 GeV/$c$.

5 Status RICH Detectors

The status of RICH detectors is on schedule for LHC turn–on [6]. The design of RICH–1 is very well advanced and the magnetic shielding boxes have been installed in the pit. The construction of RICH–2 is finished, and it is ready to be installed in its final position. The production of the silica aerogel and the HPDs is underway.

References

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