The RICH detectors of the LHCb experiment

D. L. Perego \(^a\), \(^b\)

\(^a\)On behalf of the LHCb RICH Group,
Università degli Studi di Milano–Bicocca and INFN, Piazza della Scienza 3, I–20126 Milano, Italy

\(^b\)CERN, CH–1211 Genève 23, Switzerland
E-mail: Davide.Perego@mib.infn.it

The status of the Ring Imaging Cherenkov (RICH) system of the LHCb experiment is presented. The commissioning of both RICH detectors is in an advanced phase and they are ready to take data at the start–up of the Large Hadron Collider. The detectors provide essential contributions to the LHCb physics program. The expected performance of the RICH system, the pattern recognition and the particle identification is discussed.

1. Introduction

The LHCb physics programme will focus on high precision studies of CP violation and rare phenomena in heavy flavour decays at the LHC collider. The design of the detector is based on the forward–backward distribution of \( b \bar{b} \) pairs [1].

Powerful particle identification is essential to distinguish particles for trigger and flavour tagging purposes and to select high purity final states relevant for CP violation studies. Two Ring Imaging CHerenkov (RICH) detectors provide \( \pi – K \) separation in the 1–100 GeV/c momentum range, using three radiators suitably chosen for different momentum ranges of interest [2]. Their properties are summarized in Table 1.

The Cherenkov photons are detected by pixel Hybrid Photon Detectors (HPDs) located outside the spectrometer acceptance. In both RICH detectors, the photon detector housing is separated from the radiator gas enclosure by quartz windows. A total of 484 HPDs cover the 3.3 m\(^2\) total photon detection area. Fig. 1 shows the plane of HPDs of the upstream RICH 1 detector. Details and results from the commissioning of HPDs can be found elsewhere [3].

![Figure 1. Photograph of the RICH 1 upper matrix of the pixel Hybrid Photon Detectors.](image-url)

2. The RICH 1 detector

The RICH 1 detector, located at \(~ 1\) m from the interaction region, has solid silica aerogel and

<table>
<thead>
<tr>
<th>Properties of the LHCb RICH radiators.</th>
<th>Aerogel</th>
<th>( C_4 F_{10} )</th>
<th>CF(_4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length (mm)</td>
<td>50</td>
<td>950</td>
<td>1800</td>
</tr>
<tr>
<td>Refractive index</td>
<td>1.03</td>
<td>1.0014</td>
<td>1.0005</td>
</tr>
<tr>
<td>(N_{pe}/\text{track})</td>
<td>5.3</td>
<td>24</td>
<td>18</td>
</tr>
<tr>
<td>Momenta (GeV/c)</td>
<td>1–10</td>
<td>&lt;65</td>
<td>&lt;100</td>
</tr>
</tbody>
</table>
gaseous C\textsubscript{4}F\textsubscript{10} radiators, providing particle identification in the range 1–65 GeV/c for charged particles within the acceptance of ±300 mrad (horizontal) and ±250 mrad (vertical).

The radiators, the beryllium beam pipe and the optical system are located inside a gas, light tight aluminum vessel. To limit the material budget, the upstream side of RICH 1 is sealed directly to the Vertex Locator (VELO) vacuum tank downstream face and the LHC beam–pipe. The exit window of RICH 1 is manufactured from a sandwich of two 0.5 mm thick Carbon Fiber Reinforced Polymer skins separated by 16 mm thick polymethacrylimid foam. All other components of the optical system, the spherical mirror support, the glass flat mirrors and their support are located outside the spectrometer acceptance. The total radiation length is \( \sim 8\% X_0 \).

The Cherenkov identification of particles up to 10 GeV/c is provided by silica aerogel. The LHCb aerogel is hygroscopic, manufactured by the Boreskov Institute for Catalysis (Novosibirsk). Over the last decade a successful R&D program has been carried out culminating in the production of samples with excellent optical properties, large thickness and transverse dimensions up to 20.0 \times 20.0 \times 5.1 \text{ cm}^3 [4]. The refractive index is 1.030 at \( \lambda = 400 \) nm, with a uniformity within a block better than \( \sigma_{(n-1)}/(n - 1) \sim 1\% \) [5]. Several tests with particle beams have confirmed the particle identification potential [6].

Photon scattering within the aerogel block limits its performance as a Cherenkov radiator. The dominant contribution comes from the Rayleigh scattering mechanism with a cross section proportional to \( \lambda^{-4} \), where \( \lambda \) is the wavelength of the photon. The effect of scattering in the aerogel dominates at high energy, so a 0.30 mm thick window of glass is placed after the aerogel to absorb the UV photons. This also results in reduced chromatic aberration.

Tests have shown [7] that the aerogel optical properties will not degrade significantly over the timescale of the experiment. The aerogel is stable against intense irradiation (neutrons, protons and gammas). It is sensitive to water vapour absorption, but its transparency can be restored after a bakeout of the tiles. The aerogel sits in the C\textsubscript{4}F\textsubscript{10} gas radiator. Tests have shown that C\textsubscript{4}F\textsubscript{10} does not significantly degrade the aerogel performance.

3. The RICH 2 detector

The RICH 2 detector is located between the last tracking station and the first muon station. It contains 100 m\textsuperscript{3} of CF\textsubscript{4} gas radiator, providing particle identification from approximately 15 to 100 GeV/c for particles within the reduced polar angle acceptance of ±120 mrad (horizontal) and ±100 mrad (vertical). The optical and photon detector system geometry is symmetric either side of the beam axis.

The stainless steel mechanical superstructure of RICH 2 provides gas and light tightness and a stable support for the optical system. The superstructure also supports the thick iron magnetic shielding box surrounding each HPD plane.

Cherenkov photons are focused by spherical mirrors and reflected onto HPD planes by flat mirrors. The spherical mirror surface consists of 56 hexagonal (half–hexagonal at the edges) segments, 28 on each side, with a radius of curvature 8600 mm. The flat mirror surfaces are composed of 20 rectangular mirror segments in each plane. The greatest challenge for the manufacturers was the stability of the thin flat mirror substrates, leading to highly astigmatic or edge deformations. Therefore substrates with a finite but large radius of curvature (about 80 m) have been chosen. The mirror substrates are made of 6 mm thick Simax glass.

The installation and the alignment of the mirrors was also a challenging step in the integration of the RICH 2 detector. Both procedures were done in a laboratory prior to installation in the LHCb cavern. The mirrors were aligned to a precision of 100 \( \mu \)rad before the move. Even though the fully equipped RICH 2 detector was transported from the laboratory to the experimental area, no change in the alignment larger than 300 \( \mu \)rad of the mirrors was observed. A laser based alignment system is installed inside the gas enclosure, and periodical checks of the mirror positions relative to the HPDs are foreseen.
Figure 2. (Left) Cherenkov rings imaged on the photon detector plane. (Right) Photoelectron yield distribution with data (full histogram) and fitting functions (lines). Both plots refer to the same $C_4F_{10}$ run.

4. RICH performance

The RICH system has undergone extensive testing prior to installation in the LHCb experiment. Final production photon detectors and the full readout chain, coupled to the LHCb data handling system, have been tested in a 25 ns bunch-structured particle beam, with the same time structure as at the LHC. A total of 48 HPDs mounted on three RICH 2 columns have been installed inside a customized RICH detector using either $N_2$ or $C_4F_{10}$ gas radiators and exposed to the CERN SPS 80 GeV/c pion beam.

Beam particles entered the vessel through a thin aluminium foil and passed through one metre length of either $N_2$ or $C_4F_{10}$ gas radiator. Cherenkov photons were focused by a parabolic mirror onto the photon detector plane. Ring images, integrated over $\sim$50k events, are shown in Fig. 2 for a $C_4F_{10}$ run. Very few hits are visible outside the Cherenkov rings, indicating a very low level of noise. The photoelectron yield distribution was fitted with a Poisson distribution, modified for multiple pixel hits and charge-sharing. The data and the fit functions are displayed for a typical run in Fig. 2, showing excellent agreement.

These tests demonstrate that the HPD is a reliable photon detector that meets the stringent requirements of LHCb on photon detection efficiency and Cherenkov angle resolution.

A detailed simulation of the LHCb RICH detectors has been prepared and their performance has been extensively studied. A global pattern recognition and ring-fitting approach has been implemented and tested, making use of the assignment of rings to tracks in RICH 1 and RICH 2 simultaneously.

The expected identification performance from simulation and global reconstruction, including all known background sources, is shown in Fig. 3. The average efficiency is 97%; the average prob-
5. Conclusions

The RICH detectors of the LHCb experiment have been tested, installed and commissioned, and are ready to take data at the LHC. They will provide a powerful particle identification capability over a wide momentum range, contributing to the challenging physics program of LHCb.

REFERENCES

1. The LHCb Coll., The LHCb Detector at the LHC, 2008 JINST 3 S08005
3. F. Fontanelli, “The Pixel Hybrid Photon Detector of the LHCb RICH”, these proceedings