THE STATUS OF THE LHCb RICH SYSTEM

R. W. Plackett* on behalf of the LHCb RICH Group

Physics Department, Imperial College London
SW7 2AZ, United Kingdom
**E-mail: richard.plackett@imperial.ac.uk*
http://www.imperial.ac.uk/research/hep/

As the completion of the LHCb detector approaches we report on the status of the Ring Imaging Cherenkov (RICH) detectors that provide light hadron particle identification. The design and status of the two detectors RICH1 and RICH2 is explored and an overview is given of the photon detector technology the Hybrid Photon Detector. RICH1 is a more compact system working at lower particle momenta closer to the interaction point and is currently nearing completion. RICH2 is a larger detector operating at higher momenta and is complete and currently being commissioned.

Keywords: LHCb; Ring Imaging Cherenkov Detectors; Hybrid Photon Detectors.

1. LHCb

The LHCb experiment is designed to study the high yield of hadrons containing the b-quark at the CERN Large Hadron Collider (LHC). Its primary goals are to make precision measurements constraining the Standard Model description of CP violation and to study rare B-meson decay where the discovery potential of physics beyond the Standard Model is high. Most b-hadrons produced in LHC collisions are emitted at small angles with respect to the colliding beams. The LHCb detector is therefore designed as a single-arm spectrometer with a limited angular acceptance of about 300mrad. The ability to distinguish between pions and kaons in the final states of a variety of B-decay modes is essential and Ring Imaging Cherenkov[1,2] (RICH) detectors are used.

2. Ring Imaging Cherenkov Detectors

Charged particles traversing a transparent medium, faster than the speed of light in that medium, radiate Cherenkov light in a cone of half angle θ, given by $\cos\theta = \frac{1}{n\beta}$ where n is the refractive index and β is the particle speed as a fraction of c. By focusing this cone of light to a ring, using a spherical mirror, it is possible to measure the ring radius and hence the Cherenkov angle θ. This gives the particle velocity that, combined with a measurement of its momentum, allows the particle's mass to be calculated. The Cherenkov light is uniform in photon energy and the intensity is very low, requiring efficient detection of single photons over a wide energy spectrum.

3. The LHCb RICH System

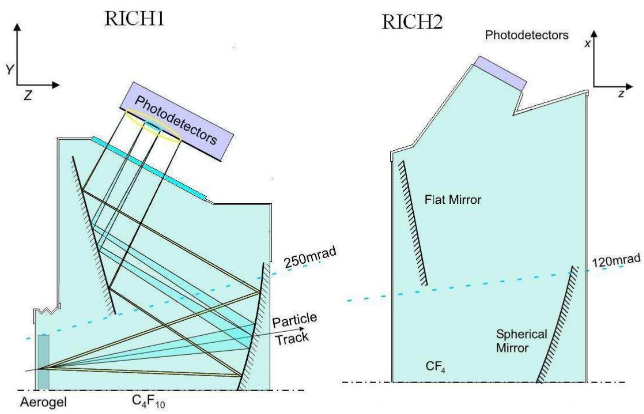

Fig. 1. The optical components of the (left) RICH1 and (right) RICH2 detectors. An example charged particle track is shown in the RICH1 detector to illustrate the way in which the two radiators operate in the same RICH detector.

LHCb requires separation of pions and kaons over a wide momentum range from 1GeV/c up to and beyond 100GeV/c. Owing to the performance limitations listed above there is a limited momentum range over which a radiator of a given refractive index can provide the required separation. LHCb uses three different radiators - silica aerogel (1-10GeV/c), C_4F_{10} gas (up to 60GeV/c) and CF_4 gas (up to and beyond 100GeV/c). The angular distribution of the particles of interest means it is not necessary for the CF_4 radiator to cover the entire LHCb acceptance. As a consequence the CF_4 radiator is contained in RICH2, downstream of the spectrometer magnet, covering a polar angle of about 100mrad, while aerogel and C_4F_{10} in RICH1 upstream of the magnet, cover the full acceptance.

The optical layout of both RICH detectors is similar and shown in Figure 1. In both detectors the Cherenkov cones produced in the radiators are focused using tilted spherical mirrors and reflected from plane mirrors onto photon detectors that are located outside the LHCb acceptance. In RICH1 the cones of light from the aerogel and C_4F_{10} gas radiators form concentric rings on the Hybrid Photon Detector (HPD) arrays. The two detectors share the pixel HPD[3] technology that was developed at CERN with partners in industry specifically for the LHCb RICH detectors.

4. RICH1

The design of RICH1[4] has been heavily shaped by the necessity to protect the HPDs from the fringe field of the LHCb spectrometer magnet, this has resulted in large iron shielding boxes above and below the RICH optics protecting the HPD planes. Between these shields the RICH optics shown in Figure 1 are held within an aluminium gas enclosure, this supports the flat and spherical mirrors, the aerogel radiator, the upstream and downstream particle windows and the quartz windows to the HPD planes. All of the components within the 250/300mrad (horizontal/vertical) LHCb acceptance are required to have a very low radiation length. This has led to the use of composite carbon fibre spherical mirrors that contribute only 1.5% of a radiation length and a carbon fibre and foam exit window.

RICH1 is currently being constructed. The magnetic shields, gas enclosure, mirrors, beryllium beampipe and acceptance windows have been installed, aligned and, where appropriate, leak tested. The outstanding tasks are to install the HPD planes above and below the gas enclosure and mount the quartz windows. The quartz windows and HPD electronics 'columns' are complete and ready to be installed and the mechanics required to support them is currently being prepared.

5. RICH2

Figure 1 demonstrates that the design of RICH2[5] is conceptually similar to that of RICH1, a gas radiator volume containing spherical focussing mirrors and flat mirrors taking the HPD planes beyond the LHCb acceptance. The major difference between the detectors is their scale. RICH2 is much larger, requiring a very stiff aluminium superstructure to rigidly hold the optical components in place. The downstream position of RICH2 reduces the effect of any scattering on the performance of LHCb allowing glass substrate mirrors to be used. The RICH2 spherical mirrors each comprise 21 hexagonal segments and the flat mirrors 20 rectangular ones. The upstream and downstream acceptance windows were technically challenging to produce due to their size and the low scattering requirement. They were manufactured as carbon fibre and aluminum skinned foam sandwiches respectively.

RICH2 has been completed and is undergoing commissioning. The HPD planes have been successfully read out and control systems are currently being developed. RICH2 is the first LHCb sub-detector ready to be integrated into the LHCb global data aquisition system.

6. Hybrid Photon Detectors

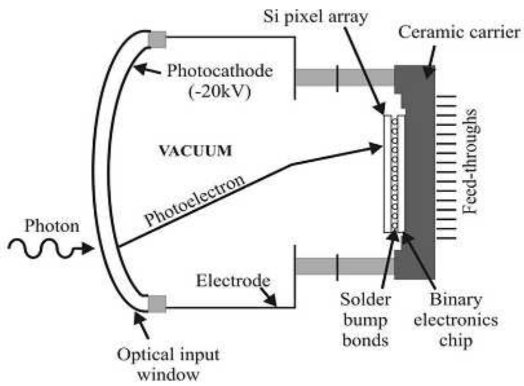

Fig. 2. A schematic cross-section of an HPD. Showing the path of a photon detected by the device and the design of the HPD itself.

Both RICH detectors use the Hybrid Photon Detector developed at CERN in partnership with Photonis-DEP. These photo-tubes provide a pixel size of 2.5×2.5mm with single photon sensitivity, operate at the LHC rate of 40MHz and have a signal to noise ration of 50:1. They operate, as shown in Figure 2, by accelerating a single photoelectron in a 20kV electrostatic field and detecting it with a pixelated silicon sensor. The sensor chip is bump-bonded[6] directly to a read out chip and both are encapsulated within the vacuum of the photo-tube itself. The tube has a quartz window to increase its UV sensitivity and an S20 multialkali photocathode. The production and initial testing of the 484 HPDs required for the RICH photon detector planes is now complete. The HPDs and the necessary power and readout electronics have been mounted on columns that allow them to be hexagonally close packed to form the photon detector planes. All RICH1 and RICH2 columns have been mounted and tested and the RICH2 columns have been installed.

7. Projected Performance

The performance and read-out chain of the HPDs has been verified in experiments in charged particle beams.[7] This information informs our Cherenkov ring reconstruction simulations that currently predict the particle identification performance for pion and kaon identification is adequate for the physics program of LHCb.

8. Conclusions

The RICH system plays a vital part in the physics program of LHCb, providing light hadron identification unavailable to the other LHC experiments. The wide momentum coverage requires three Cherenkov radiators housed in two detectors RICH1 and RICH2. RICH1 contains silica aerogel and C_4F_{10} gas radiators and is nearing completion. RICH2 contains a CF_4 gas radiator and is undergoing commissioning. Both detectors use HPDs to provide a large pixelated area of single photon sensitivity. The production of the HPDs is complete. Simulation based on tests of the systems indicate the performance of the RICH detectors will meet the needs of LHCb. We look forward to taking data in 2008.

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