PROCEEDINGS OF SCIENCE

The LHCb RICH Detector Upgrade

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LHCb is one of the four main experiments at the Large Hadron Collider (LHC) at CERN, focused on the study of CP violation and rare decays of b and c quarks. The Ring-Imaging Cherenkov (RICH) system is a crucial component of the LHCb experiment providing identification of charged particles over a large momentum range (2-100 GeV/c) and angular acceptance (15-300 mrad). The LHCb RICH performed well during Run 1 and the current Run 2. LHCb will upgrade many of its detector systems during the second LHC long shutdown (2019-2020) in order to sustain a five-fold increase in instantaneous luminosity up to 2×10^{33} cm^{-2}s^{-1}. In order to increase the readout rate of the entire detector from the current 1MHz to 40MHz, a substantial change in the LHCb trigger and readout schemes will be implemented. The RICH detectors will be upgraded by installing new photodetectors, electronics and modified optics and mechanics. The status of the RICH upgrade program will be reviewed, including tests of the complete photo-electronic chain in the lab and in charged-particle beams.

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1. LHCb experiment upgrade

LHCb is a precision experiment studying b and c quark decays at the CERN Large Hadron Collider (LHC) [1]. It is a single arm spectrometer covering the pseudo-rapidity region $2 < \eta < 5$, equipped with state of the art tracking and particle identification detectors. The Ring Imaging Cherenkov (RICH) system allows charged particle identification in a large momentum range and comprises two detectors: the first (RICH 1) is located close to the interaction point and covers the full acceptance of the experiment and the 2-50 GeV/c momentum region; the second (RICH 2) is placed downstream of the spectrometer magnet and tracking stations, and covers the 15-100 GeV/c momentum range and angles up to 120 mrad.

The RICH detector system has been operated since the start of LHC Run 1 (2009) with high efficiency and reliability [2]. During Run 1 LHCb operated at levelled luminosities up to about 4×10^{32} cm^{-2}s^{-1}, a factor of two higher than the design value, and accumulated 3 fb^{-1} of pp collision data. In the current Run 2 the experiment should collect an additional 5 fb^{-1} operating at the same instantaneous luminosity.

An upgrade program, approved by CERN, has been designed by the LHCb Collaboration to allow reading out all detectors at 40 MHz at instantaneous luminosities of 2×10^{33} cm^{-2}s^{-1} [3, 4]. The upgraded detector will be installed during the LHC long shutdown 2 (2019-20).

2. The RICH upgrade program

In order to allow operation of the RICH detector system at the upgrade luminosity the RICH 1 optical system is being redesigned: in particular the focal length of the spherical mirrors will be increased from 2.7 m to 3.7 m to reduce the hit occupancy on the photodetectors. The cooling system and the support mechanics will also be modified, with the goal of allowing stable operation and easier access to the detector during maintenance.

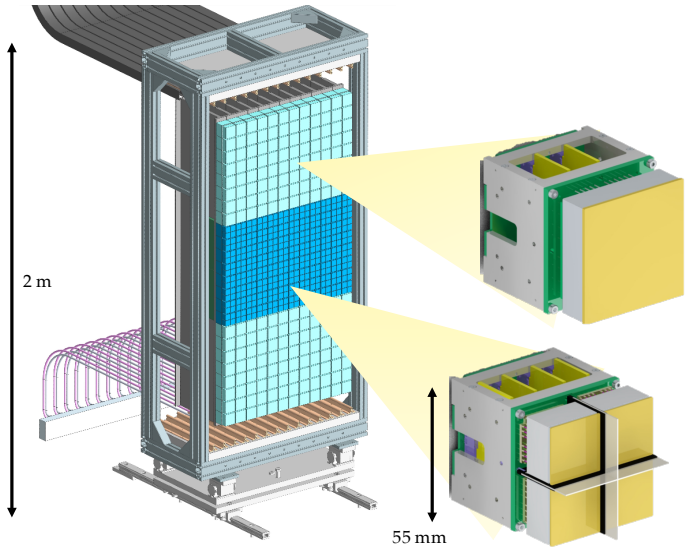

Figure 1: CAD model of the RICH 2 photodetector plane. The two types of elementary cell described in the text are shown.

The main limitation of the current detector is the 1 MHz read-out and L0 trigger rate. The requirements on the new RICH read-out system are single-photon counting capability at 40 MHz, compensation of the typical pixel gain variation (1:3) and radiation hardness (200 krad, 3×10^{12} 1 MeV n_{eq}/cm^2, 1.2×10^{12} HEH/cm^2).

The hybrid photodetectors used in the present RICH will be replaced by commercial Multi-Anode Photo-Multiplier Tubes (Ma-PMTs) and new front-end electronics, based on the CLARO chip [5, 6] plus FPGA-based digital board and GBT chip [7] for data transmission and front-end configuration. The CLARO8 is an 8-channel amplifier discriminator ASIC designed in 0.35 micron CMOS technology from AMS (formerly known as austriamicrosystems AG), featuring radiation-hard-by-design cells and triple modular redundancy, adjustable threshold and gain, binary read-out and a power consumption of about 1 mW per channel.

Two types of Ma-PMTs will be used in the RICH system, each with 8×8 pixels, arranged in the so-called Elementary Cells (EC): the 1" R13742 (a customisation of the Hamamatsu R11265 tube) and the 2" R13743 (from the R12699 series). As shown in Fig. 1, the outer (low occupancy) region of the RICH 2 photodetector plane will be equipped with about 400 EC, each equipped with one 2" Ma-PMT. The inner RICH 2 region and the whole RICH 1 will contain about 700 EC equipped with four 1" Ma-PMTs.

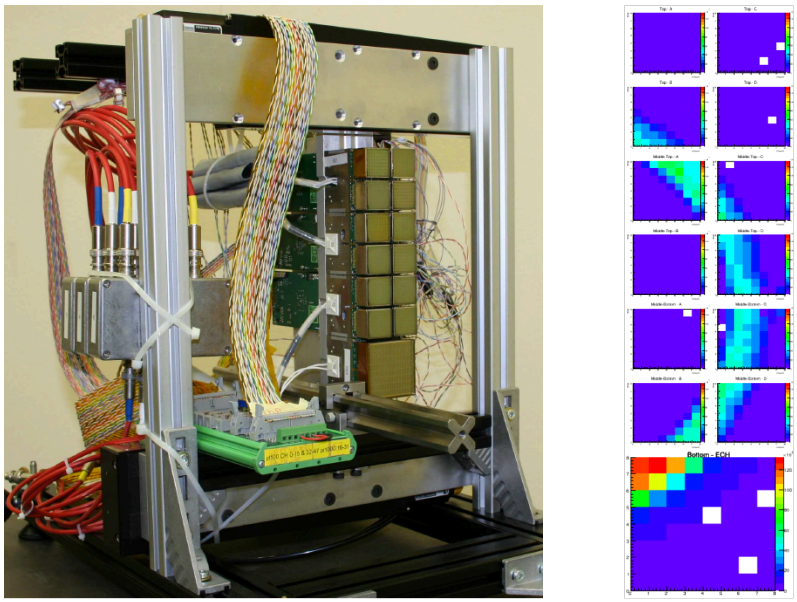

Figure 2: Picture of three Elementary Cells with 1" Ma-PMTs and one with 2" Ma-PMTs (left): this represents half of the photodetectors used in the test beam. The corresponding hit-map distribution is shown on the right.

2.1 Test beams

A custom Cherenkov system based on a solid radiator has been used to measure the performance of a close-to-final opto-electronics chain. A glass plano-convex lens was used both as radiator and to focus Cherenkov photons produced by 180 GeV/c charged hadrons onto an array of Ma-PMTs in a compact configuration installed in the North Area of the CERN SPS [8].

The beam tests allowed the operation of a complete setup with both EC types in a realistic environment. The Collaboration was able to study the CLARO chip calibration and noise, threshold scans, cross-talk, spatial resolution, photon yield and thermal behaviour. Fig. 2 shows part of the experimental setup and the corresponding cumulative Cherenkov "half-ring" hit map, recorded from several incident beam triggers.

Conclusions

The LHCb RICH upgrade program, proposed for operating at a luminosity of 2×10^{33} cm^{-2}s^{-1} luminosity in order to collect 50 fb^{-1} during Run 3 and 4, is well under way. New photodetectors and read-out electronics will allow full detector read-out at 40 MHz. A modified RICH optics and mechanics system will be used to maintain (and even improve) the current RICH performance at 40 MHz. Successful tests with charged-particle beams validated the close-to-final opto-electronics chain in realistic conditions. A technical design review was completed in 2013, and the production of several components has started. The whole upgrade program is on schedule for installation during the LHC long shutdown 2 (2019-2020).

References

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