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RICH upgrade in LHCb experiment

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Summary. — The LHCb experiment is dedicated to precision measurements of CP violation and rare decays of B hadrons at the Large Hadron Collider (LHC) at CERN (Geneva). The second long shutdown of the LHC is currently scheduled to begin in 2019. During this period the LHCb experiment with all its sub-detectors will be upgraded in order to run at an instantaneous luminosity of $2 \times 10^{33}\,\text{cm}^{-2}\text{s}^{-1}$, about a factor 5 higher than the current luminosity, and to read out data at a rate of 40 MHz into a flexible software-based trigger. The Ring Imaging CHerenkov (RICH) system will require new photon detectors and modifications to the optics of the upstream detector. Tests of the prototype of the smallest constituent of the new RICH system have been performed during testbeam sessions at the North Area test beam facility at CERN in the last years.

1. – The LHCb experiment and its RICH detectors

The LHCb experiment is one of the four big experiments which is currently operating at the Large Hadron Collider (LHC) at CERN (Geneva) [1]. The physics studies at LHCb are dedicated to probe New Physics in CP violation and rare decays of b and c hadrons.

An excellent particle identification (PID) is fundamental in order to perform this kind of studies. The Ring Imaging Cherenkov (RICH) system of the LHCb experiment is able to identify charged hadrons over a momentum range of 1.5–100 GeV/c [2].

The RICH system is composed by two RICH detectors equipped with Hybrid Photon Detectors (HPD). The HPDs are photosensors custom-built in collaboration with industry. They combine vacuum tube technology with a silicon pixel detector bump-bonded to the readout electronics. The maximum event rate is limited at 1 MHz.

At the end of Run II of the LHC the integrated luminosity recorded by the LHCb experiment will be $\sim 8\,\text{fb}^{-1}$.

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2. – The LHCb and RICH upgrade

In order to expand the potential for discovery and study of new phenomena, an upgrade of the LHCb experiment is planned in 2019 during the second long shutdown of the LHC [3]. In order to collect $5\,\text{fb}^{-1}$ per year, the LHCb experiment plans to run at an instantaneous luminosity of $2 \times 10^{33}\,\text{cm}^{-2}\text{s}^{-1}$, removing trigger limitations and reading out the detectors at a rate of 40 MHz.

In order to cope with the high-luminosity environment and this maximum readout rate, the RICH detectors will require new photo-sensors [4]. The requirements for these new photo-sensors are high spatial resolution, single-photon detection, fast response, ability to operate in magnetic fields, negligible dark current and cross-talk rates. Due to its characteristics the baseline photon detector for the upgraded RICH is the Multi-Anode Photo-Multiplier Tube (MaPMT) combined with an external readout electronics, featuring low deadtime, low power consumption and radiation tolerance. Moreover significant modifications of the optics and mechanics of the upstream RICH detector are necessary in order to reduce the high peak occupancy and improve the PID performance of the experiment.

3. – RICH testbeam

A full characterization of the components of the readout chain has been performed in laboratory: single-photon gain and cross-talk rate, dark current per pixel rate, irradiation tests, thermal and aging measurements, magnetic field tolerance, test on the electronics.

After this campaign of tests, performed in many European institutes, the first tests of the full opto-electronics chain have been performed in testbeam sessions at the North Area test beam facility at CERN during 2014 and 2015. In order to test the system performance, a beam consisting mainly of 10^6–10^7 pions and protons per spill with momentum of $180\,\text{GeV}/c$ has been used. The beam has been directed through a light-tight and thermally insulated experimental box containing a borosilicate plano-convex lens and the MaPMTs, together with their DAQ chain, housed in an aluminium structure. The lens had a double role, acting as a solid radiator in order to produce Cherenkov light and as focusing element in order to focus the photons on the detector plane. The detector system was made by 4 prototypes of the future smallest constituent, called Elementay

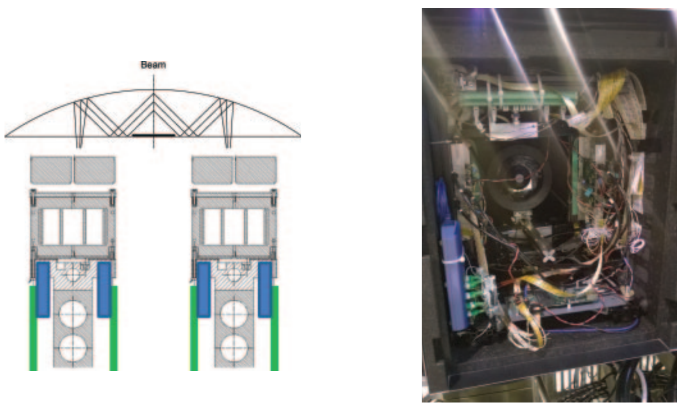

Fig. 1. – Left: scheme of the concept. Right: picture of the system used in 2015.

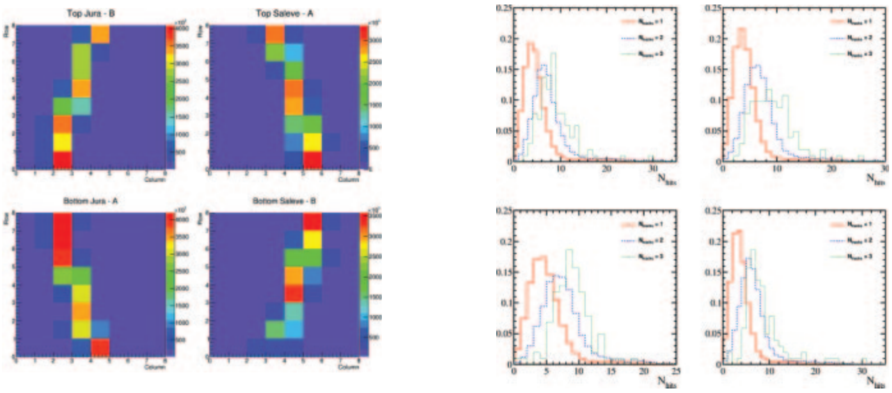

Fig. 2. – Left: image of the Cherenkov ring detected by four different ECs. Right: distributions of the number of photons for events with one, two and three tracks associated.

Cell (EC), of the new RICH detectors. The setup was equipped with a cooling system, position stages and several sensors, in order to completely monitor the system. Figure 1 shows the concept and a picture of the system used in 2015.

4. – Conclusions

The main purpose of 2014 and 2015 testbeam sessions was to test and qualify the full opto-electronic chain, in a particle beam.

Using the data collected, several analyses have been performed: on the one hand threshold scans and cross-talk studies along with measurements of dark counts in order to test the system performances and learn a lot on the MaPMTs and on the readout electronics; on the other hand, analyses such as fit of the Cherenkov ring, reconstruction of the Cherenkov angle, photo-electron yield measurement and check for a possible correlation between multiple tracks events and higher number of hits in order to understand if the simulations of the setup were good (fig. 2). Most of the data are in good agreement with the expected values from simulations and most of the test confirm that the MaPMTs, together with their DAQ chain, meet the LHCb upgrade requirements.

After the additional test performed in laboratory using the complete opto-electronics chain, new testbeam sessions are foreseen in Summer and Autumn 2016.

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