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The LHCb RICH detector upgrade

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Summary. — LHCb, one of the four main experiments at CERN, is designed to study rare decays of *charm* and *beauty* hadrons to find evidence of New Physics. Charged hadron identification in LHCb is achieved by the Ring Imaging Cherenkov (RICH) detector, read out by Hybrid Photon Detectors (HPDs). The experiment will undergo an upgrade in 2019, after which it will be possible to reach luminosities up to $2 \cdot 10^{33}$ cm^{-2} s^{-1} and a data readout frequency of 40 MHz. As a consequence, the electronics of almost all the sub-detectors will be modified or replaced accordingly to the new required performances. The RICH HPDs will be replaced with Multi-anode Photomultiplier Tubes (MaPMTs) and will be read out using an 8-channels ASIC, the CLARO. MaPMTs and electronics will be arranged in basic units, the first prototypes of which have been tested in charged particle beams at CERN. The geometry of RICH 1 will be changed to operate at higher luminosities. An overview of the LHCb RICH upgrade is presented.

1. – Introduction

The LHCb experiment, designed to study New Physics (NP) effects in *CP*-violating processes involving rare decays of *beauty* and *charm* hadrons, operates at luminosities up to $4 \cdot 10^{32}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$ with a data readout frequency of 1 MHz [1]. After the upgrade, LHCb will be able to run at luminosities of $2 \cdot 10^{33}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$ with 14 TeV *pp* collisions and 25 ns bunch spacing. In order to operate at these performances the Level 0 trigger of the experiment, which limits the data readout frequency to 1 MHz, will be removed and substituted with a flexible software trigger. The LHCb Ring Image Cherenkov (RICH) system is composed of two detectors, RICH 1 and RICH 2, which provide particle identifications (PIDs) of charged hadrons in the range 2–100 GeV/c [2]. The actual RICH photodetection system is based on Hybrid Photon Detectors (HPDs). To be able to run the experiment at 40 MHz, they will be replaced with Multi-anode PhotoMultiplier Tubes (MaPMTs) with external readout electronics. The RICH upgrade readout system

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is based on the CLARO8 chip, an 8-channel ASIC designed to achieve single-photon detection coupled to the MaPMTs. The MaPMTs and the CLARO will be arranged in units called Elementary Cells (ECs). The details of the MaPMTs, the CLARO and the ECs will be given in sect. 2. A prototype for the RICH Upgrade detector has been tested at CERN using charged particle beam. During the tests two calibration procedures have been developed. The calibration procedures details will be given in sect. 3.

2. – The LHCb RICH upgrade

The actual RICH HPDs have the 1 MHz electronics embedded in the tubes, therefore they will be removed. The MaPMTs that will be used in the upgrade, produced by Hamamatsu Photonics®, are 12-dynode stage, 64-channels devices with an 8×8 silicon pixel matrix. The working tension is 1 kV with a gain factor $G = 10^6$. Two different models will be used: the R13742 (1″) in both RICH 1 e RICH 2, and the R13743 (2″) in the lower occupancy regions of RICH 2 [3]. The CLARO is an 8-channel amplifier/discriminator ASIC realized in 0.35 μm AMS CMOS technology [4]. The recovery time is shorter than 25 ns and the power consumption is 1 mW/channel, so that there is no need for additional cooling. Each channel is equipped with a 6-bit programmable threshold and a 2-bit programmable gain. To protect the chip from Single Events Effects (SEE) the 128-bit register is protected with Triple Modular Redundancy (TMR). The MaPMTs and the CLARO chip will be assembled in compact structures called Elementary Cells (ECs). In the RICH upgrade two types of EC will be installed: the R-type EC, composed of 4×4 R13742 (1″) MaPMTs, and the H-type EC, composed of a single R13743 (2″) MaPMT. As shown in the right-hand side of fig. 1, the MaPMTs are inserted in the Base Board, which connects the MaPMTs to the CLARO8 chips. The ASICs are mounted on Front End Boards (FEBs). The Back Board provides the connection between the FEBs and the FPGA-based Digital Board (DB), visible on the right. A magnetic shield of mu-metal is installed in the R-type ECs in RICH 1 to shield the MaPMTs from the residual magnetic field of the LHCb dipole. The ECs will be assembled in modules of 4×1 ECs called Photo-Detection Modules (PDMs). RICH 1 needs geometrical changes to operate in the high-luminosity post-upgrade conditions. To reduce the average occupancy on the RICH 1 MaPMTs, the spherical mirror focal length will be increased by increasing the radius of curvature. In addition, the photodetector planes will be moved away from the beam line to achieve a better Cherenkov angle resolution.

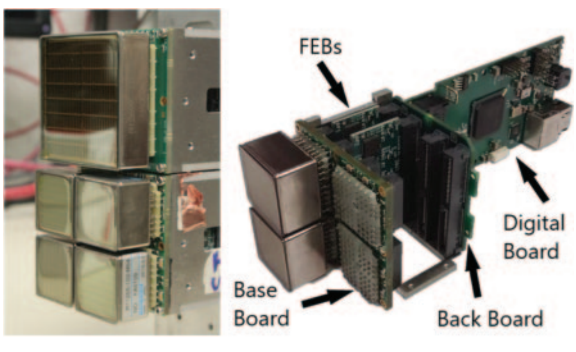

Fig. 1. – Left: front view of a H-type EC (top) and a R-type EC (bottom) MaPMTs. Right: a half-mounted R-type EC with digital board.

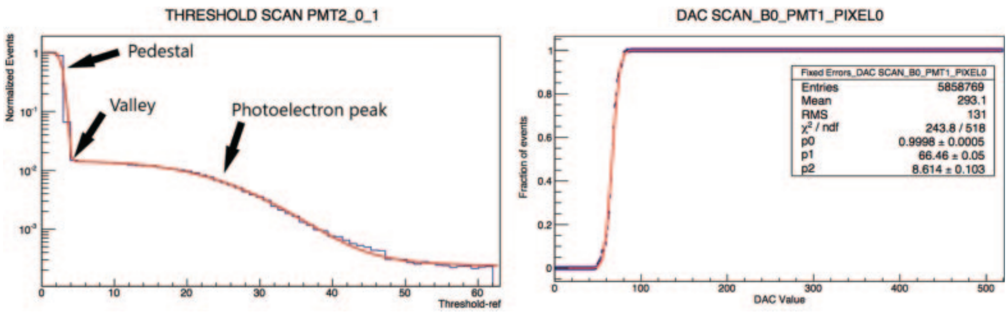

Fig. 2. – Left: typical threshold scan distribution. The pedestal is visible on the left-hand side. Right: S-curve distribution obtained from a DAC scan.

3. – The LHCb RICH upgrade prototype: CLARO and MaPMTs calibration

The RICH upgrade prototype has been tested using a charged particle beam at CERN, employing a plano-convex in optical glass (N-BK7) as radiator. The ECs are mounted on liquid-cooled mobile supports. The prototype is enclosed in a light-tight polypropylene box to achieve thermal insulation and humidity control using N2. A user graphic interface has been designed for real-time monitoring. Two calibration tests were developed during the beam tests. The threshold scan (fig. 2, left) is performed to find the optimal thresholds for each CLARO channel. A LED is placed in front of the MaPMTs. Starting from 63 and finishing at zero, the threshold is changed after a fixed number of events is collected. The number of times that a channel has switched on for a certain threshold is registered. The obtained distribution is the integral pulse-height spectrum distribution of the channel. There are three parameters of interest: the pedestal, created by electronic noise, the single photoelectron peak and the valley. The best CLARO channel threshold is then set to be in the valley between the pedestal and the first photoelectron peak, so that almost all the noise is eliminated. The DAC scan (fig. 2, right) is a test to check the CLARO channels linearity. The MaPMTs are switched off and the signal is injected in each channel from the DB. The channels have a fixed threshold. The DB injects the signals and, once the desired maximum number of signal has been sent, the signal amplitude is increased. The number of times that a channel has switched on for a signal amplitude is registered. The final distribution is an S-shaped distribution. There are two parameters of interest: the transition point, *i.e.*, the signal value at which the normalized distribution reaches 0.5, and the distribution spread. To check the linearity of the CLARO channels the transition point is plot as a function of the channel threshold. The LHCb RICH upgrade project is progressing on schedule and the installation will start in 2019–2020.

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