The LHCb RICH System Upgrade Commissioning

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The LHCb RICH system Upgrade

LHCb relies on the Ring Imaging Cherenkov (RICH) detector system for the charged hadron identification in a wide momentum range (2 - 100 GeV/c). The RICH systems have been upgraded to sustain an increase of the read-out rate from 1 MHz to 40 MHz and the expected luminosity of $L = 2 \cdot 10^{33}$ cm^{-2}s^{-1} foreseen during Run 3.

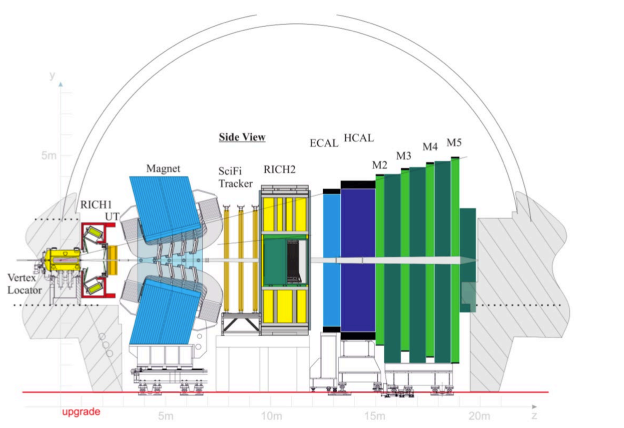

Figure 1: Side view of the Run 3 LHCb experiment.

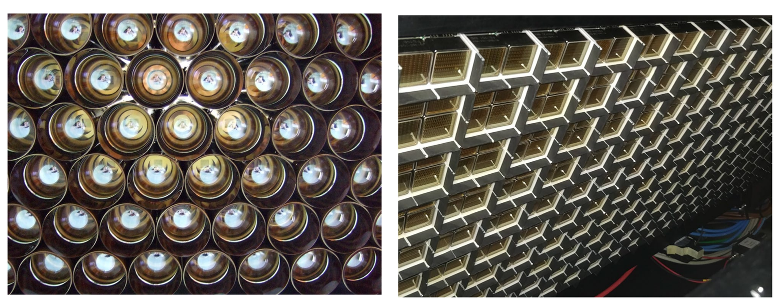

Figure 2: Left: HPD plane of the LHCb RICH 1 detector during Run 1 and Run 2. Right: MaPMT plane of the LHCb RICH 1 detector for Run 3.

Major upgrade [1] :

- replacement of the Hybrid Photon Detectors (HPDs) with Multi Anode Photomultiplier Tubes (MaPMTs), manufactured by Hamamatsu
- new Front-End (FE) readout electronics
- RICH1 optics modifications

Photon-Detection chain

Modular design to facilitate maintenance and operations

- **MaPMT**

–Hamamatsu R13742 MaPMTs for high occupancy region, Hamamatsu R13743 MaPMTs for low occupancy region
– 64 anodes with low dark count rate (< 1 kHz) and gain ~ 2 × 10^6 at 1kV
– high quantum efficiency (~ 40% at 300 nm) ultra-bialkali photocathode

- **CLARO chip**

– 8-channel amplifier/discriminator ASIC
– adjustable threshold and attenuation for each channel
– radiation-hard by design and triple modular redundancy protection

- **GigaBit Transceiver (GBT)** chip for data transmission
- **FPGA-based digital board**

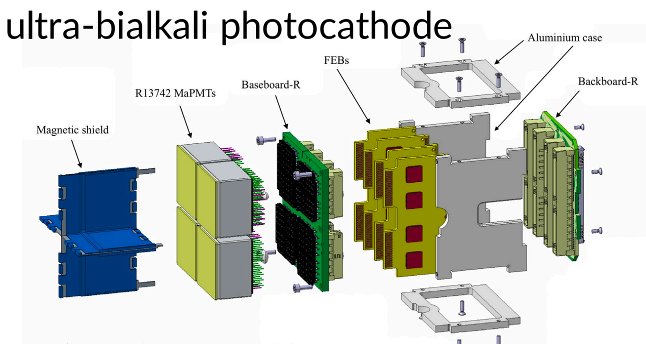

Figure 3: R-type EC.

Figure 4: Left: Hamamatsu MaPMTs the R11265 (R-Type) on the left and R12699 (H-Type) on the right. Right: CLARO ASICS.

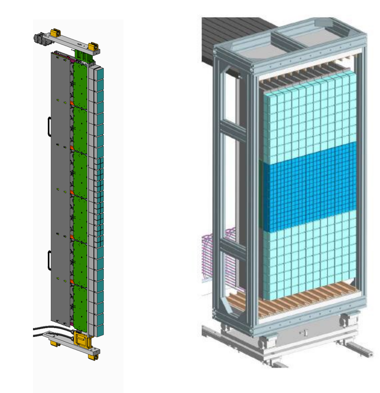

Figure 5: Left: Column with 6 PDMs. Right: RICH2 Photodetector plane.

MaPMTs are integrated with Front End Boards and the CLARO chips in a compact device called Elementary Cell (EC) of type H and R (hosting a single H-Type MaPMT and four R-Type MaPMTs, respectively)

Photon Detector Modules (PDM) are the fundamental modules of the RICH columns which form the photodetector planes, a PDM hosts 4 ECs and interfaces with the new LHCb readout through Photon Detector Module Digital Boards (PDMDB)

RICH System Commissioning

- Required more than 6 years
- Ensure minimum specifications
- Full characterisation of the photo-detection chain
- Extensive Quality Assurance campaign to extract relevant parameters

Major campaigns :

- Photodetector QA (PDQA) in Padova and Edinburgh [2]
- CLARO chips and control system of Front-End Boards (FEB) and Back Board (BkB) in Ferrara and of Base Boards (BBs) in Genova and by Studioemme
- Elementary Cell QA (ECQA) in Ferrara and Edinburgh [3]
- Column commissioning at CERN
- Commissioning at Point 8

Timeline RICH1

- **Installed end of 2021 – beginning of 2022**
- **Commissioned in the following months**

Timeline RICH2

- **Installed in early 2021**
- **Commissioned throughout 2021**
- **First light at the end of 2022**

Column Commissioning

All the components accepted by the QA procedure were assembled in the RICH columns during the commissioning performed at CERN.

TEST STATION

- Dark box
- Cooling system with Novec
- LV and HV power supplies
- Laser
- ELMB
- Server with LHCb Upgrade DAQ boards
- Workstation computer

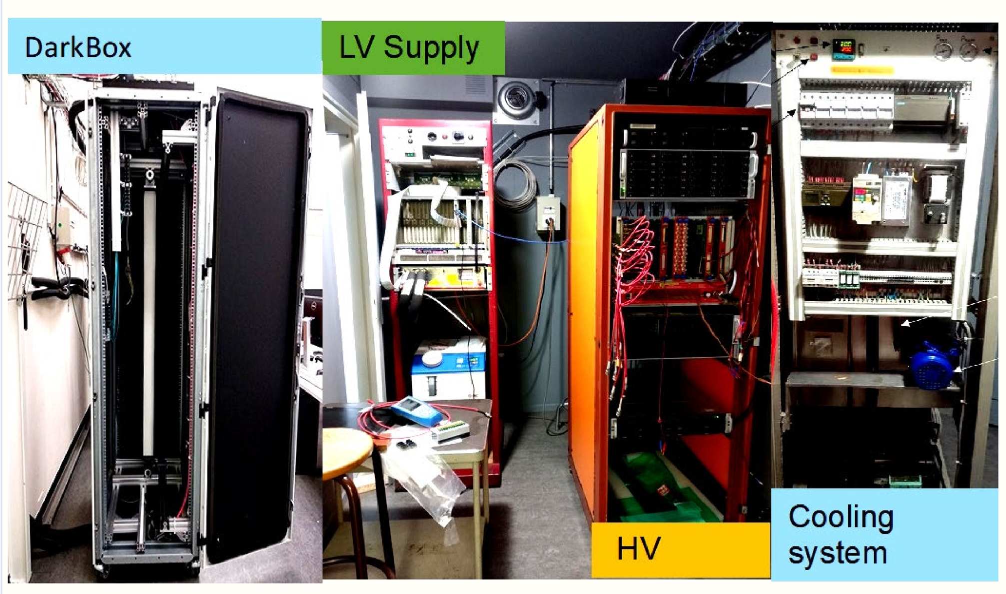

Figure 6: Test station used for the Column Commissioning.

Experiment Control System integrated in a FSM developed in WinCC-OA, similar to the FSM at Point 8

Fully automated procedure

Large number of temperature and humidity sensors to ensure the safety of the detector hardware

Time needed to test 1 column: 18 hours

In total, 22 columns for RICH1 and 24 for RICH2 have been commissioned

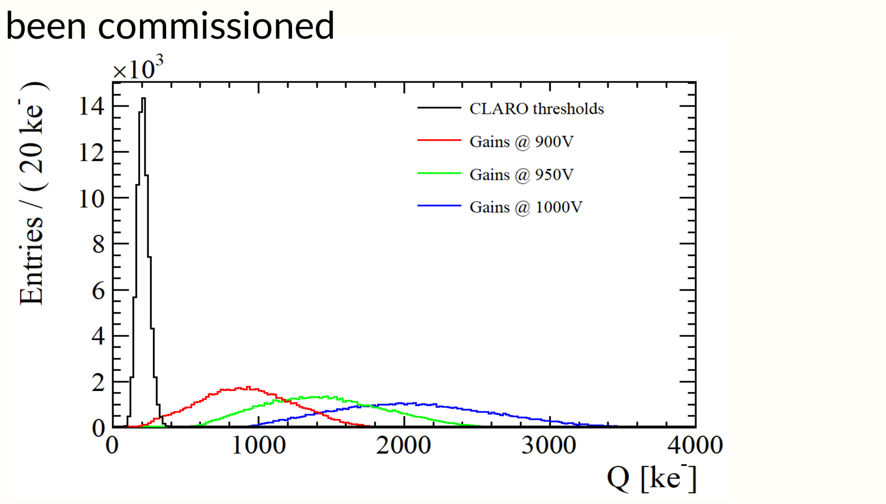

Figure 7: Distribution of RICH2 thresholds of the CLARO comparator converted into absolute charge (black). The threshold settings can be compared to the pixel gains at 900 V (red), 950 V (green) and 1000 V (blue) as determined from PDQA.

First Collisions

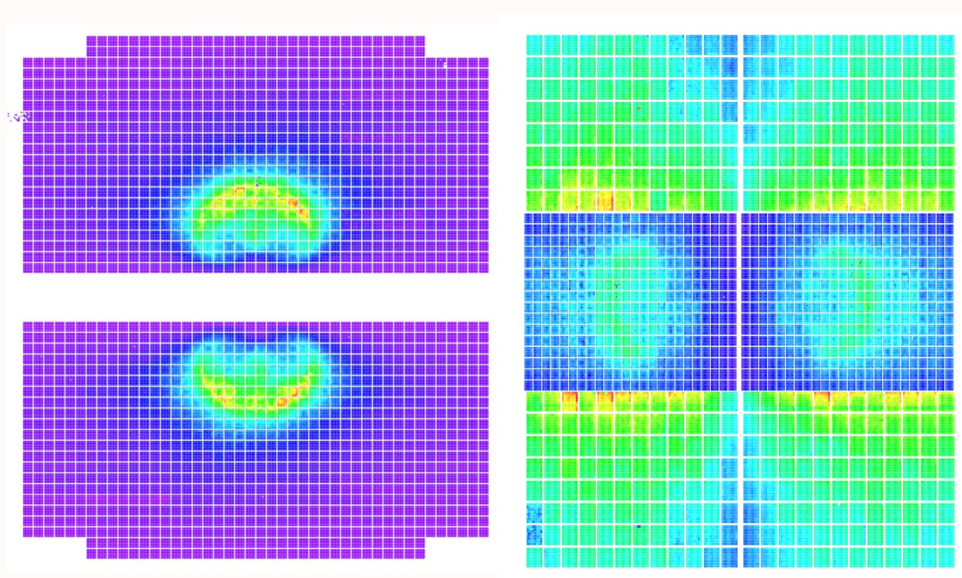

Figure 8: Left: RICH1 hirmap showning the typical occupancy during data taking with beam. Right: same plot for RICH2

The RICH collected successfully data during the first RUN3 collisions.

All control and data links operational:

- DAQ, HV, DCS properly working and integrated in run control
- Constant monitoring and alarms implemented
- Recipes for front-end configuration and HV setting implemented
- Online Monitoring tasks working

Synchronization with LHC orbit successful, repeatability verified.

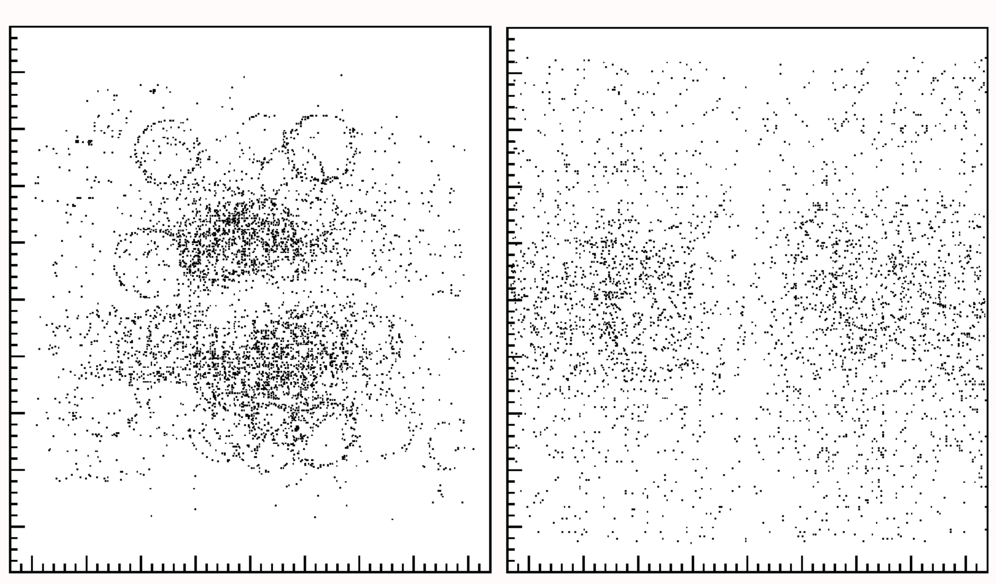

Figure 9: Single event display for a RUN taken with beam. Cherenkov rings are clearly visible in both RICH1 (left) and RICH2 (right).

Fine Time Alignment

The time spread of prompt Cherenkov photons hitting the RICH photon detectors is dominated by the time distribution of the proton collisions and the size of the bunches.

In RUN 3, a time gate of a few nanoseconds can be used to reduce background from beam interactions and MaPMT noise [4].

The programmable FPGA logic in PDMDB samples the CLARO signals at 320 MHz and detects specific input patterns.

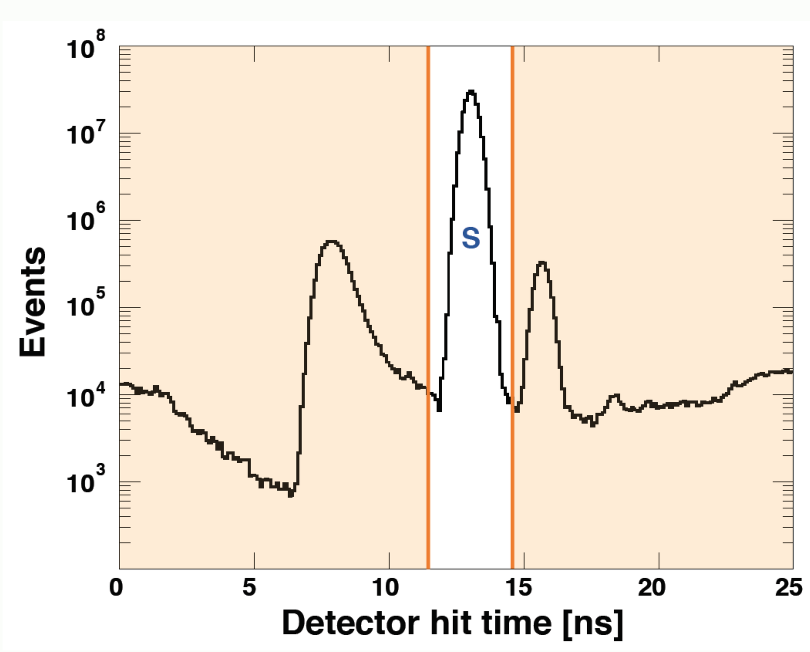

Figure 10: Left: Simulated photon hit time in RICH1, a time gate of 3.125 ns is highlighted

If the CLARO signal pattern matches one of the configured lookup table patterns, a hit is registered on the 40MHz system clock edge.

Two kind of patterns are currently under study

- level detection
- edge detection

Currently working on the optimization of time alignment down to 6ns, reducing the background by a factor of 4.

Luminosity

The RICH detectors variables can be used as a cross check with the PLUME detector for the luminosity estimation and can provide counters both from the control system and from reconstructed quantities at the HLT2 level to reduce the uncertainty on the luminosity estimate from LHCb.

Studies have been performed on simulated samples to validate the linearity of the Cherenkov photon hits in the detector planes with respect the number of primary vertices.

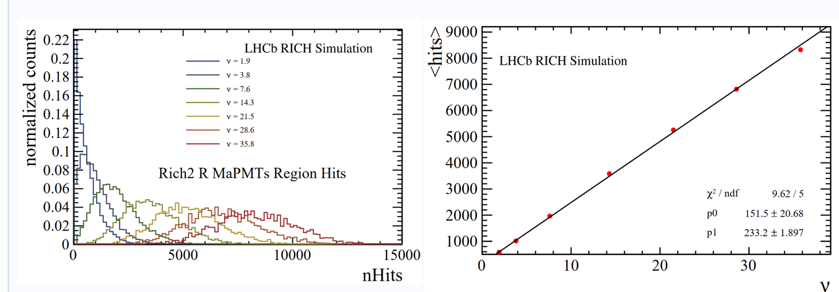

Figure 11: Linearity of the number of hits in the high occupancy region of RICH2 versus the number of inelastic pp collisions per bunch crossing in simulation. Overall, RICH2 hits are more stable (small dependence from PV position and magnetic field) and do not show a saturation effect.

RICH1 MaPMTs anode currents in the high occupancy region have been proven to scale linearly with the number of visible interactions as expected. Their behavior have been studied extensively in various mu scans.

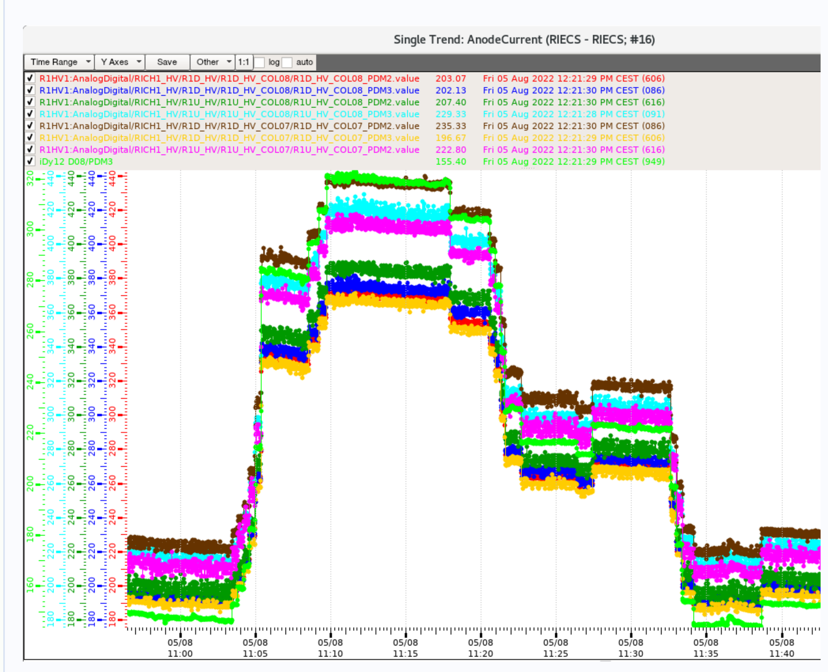

Figure 12: Values of the RICH1 anode currents in time during a mu scan. The plateau for different mu values set by LHC during the fill are clearly visible.

Conclusions

The LHCb RICH detector system is converging to the final part the commissioning at Point 8. The RICH system has already proved to be reliable and consistent during the fist collisions in 2022. The software reconstruction is expected soon, as well as the Cherenkov angle resolution to evaluate the detector performance.

References

[1] LHCb Collaboration, LHCb PID Upgrade Technical Design Report, CERN-LHCC-2013-022, LHCB-TDR-014

[2] S. Gambetta [LHCb RICH Collaboration], First results from quality assurance testing of MaPMTs for the LHCb RICH upgrade, Nucl. Instrum. Meth. A 876, 206 (2017). doi:10.1016/ j.nima.2017.02.079

[3] LHCb Collaboration, Experimental studies for the validation of the opto-electronic components for the LHCb RICH Upgrade,"2020", https://cds.cern.ch/record/2715879

[4] Keizer, Floris. Sub-nanosecond Cherenkov photon detection for LHCb particle identification in high-occupancy conditions and semiconductor tracking for muon scattering tomography. Diss. University of Cambridge, 2020.