Quality Assurance for the LHCb RICH Upgrade Photon-Detection chain

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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 RUN3.

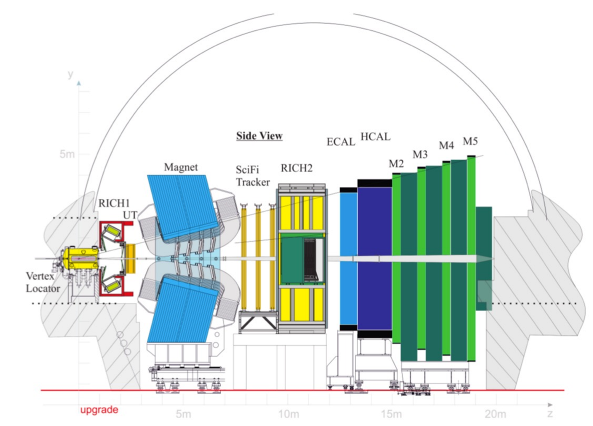

Figure 1: Side view of the Run 3 LHCb experiment.

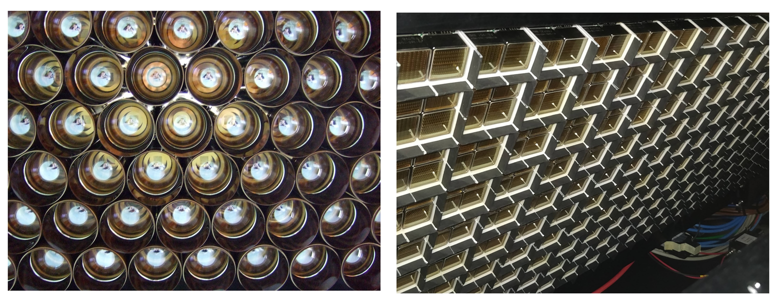

Figure 2: Left: HPD plane of the LHCb RICH 1 detector during RUN1 and RUN2. Right: MaPMT plane of the LHCb RICH 1 detector for Run 3.

In particular, the main change for the RICH was the replacement of the Hybrid Photon Detectors (HPDs) with Multi Anode Photomultiplier Tubes (MaPMTs), manufactured by Hamamatsu, with external read-out electronics [1, 2].

Photon-Detection chain

- **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 300nm) super-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

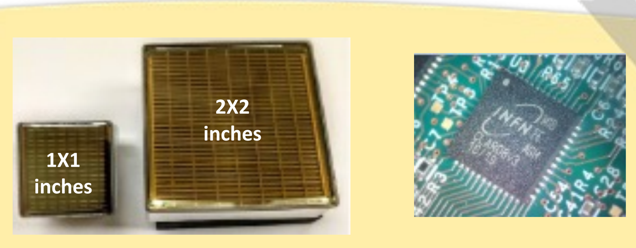

Figure 3: Left: Hamamatsu MaPMTs the R13742 (R-Type) on the left and R13743 (H-Type) on the right. Right: CLARO ASICS.

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)

- 4 ECs constitute the Photon Detector Modules (PDM) which interface with the new LHCb readout through Photon Detector Module Digital Boards (PDMDB)
- PDMs are the fundamental modules of the RICH columns which form the photodetector planes

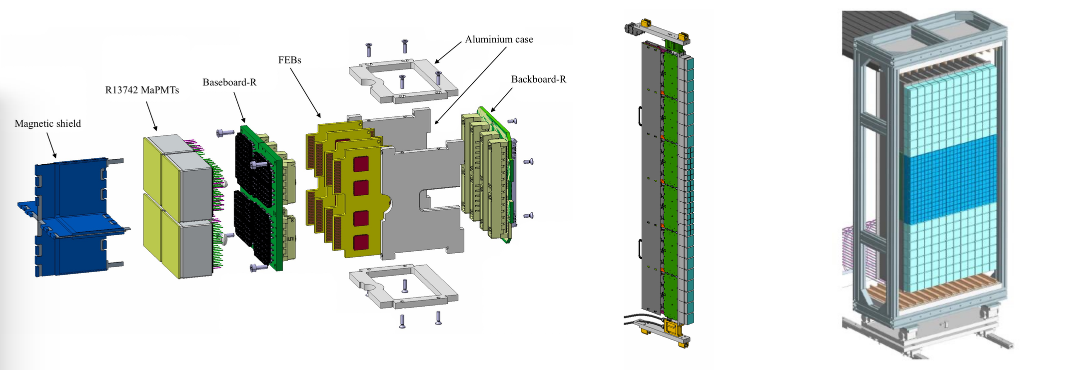

Figure 4: Left: R-type EC. Center: Column with 6 PDMs. Right: RICH2 Photodetector plane.

Quality Assurance and Commissioning

- Required more than 6 years
- Ensure minimum specifications
- Characterise the photon detectors and electronics
- Select components with similar characteristics to be installed in functionally related areas of the detector
- Calculate calibration parameters

Modular design to facilitate:
-maintenance
-operations
-**quality assurance campaigns**

Four major campaigns :

- Photodetector QA (PDQA) in Padova and Edinburgh
- 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
- Column commissioning at CERN

PDQA

verify the specifications of the MaPMTs provided by Hamamatsu

System deployed on four stations

TEST STATION:
- Test box
- LED driver
- Slow control
- Power supplies
- Workstation computer

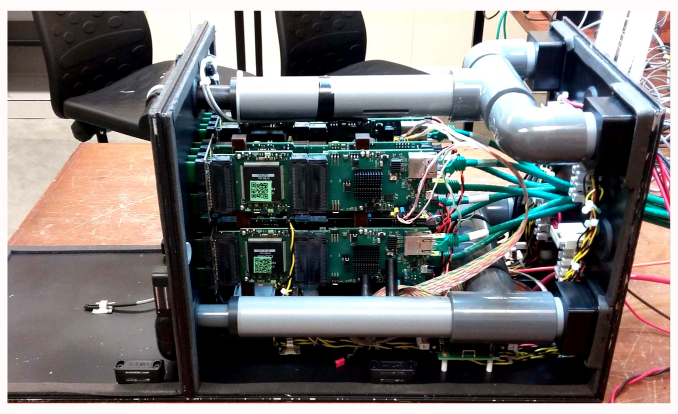

Figure 5: Test box with fully integrated Front-End readout, data acquisition, cooling and, environment monitoring.

The HV, light intensity, and the temperature and humidity sensors are controlled and monitored by a custom slow control based on the Arria-G25 FPGA

Automated procedure

The software implemented is a Finite State Machine (FSM) with C++ low-level language and graphical user interface in LabVIEW

The time required to test 16 R-Type or 4 H-type MaPMTs was one 1 day

Tested 3100 MaPMT R and 450 MaPMT H

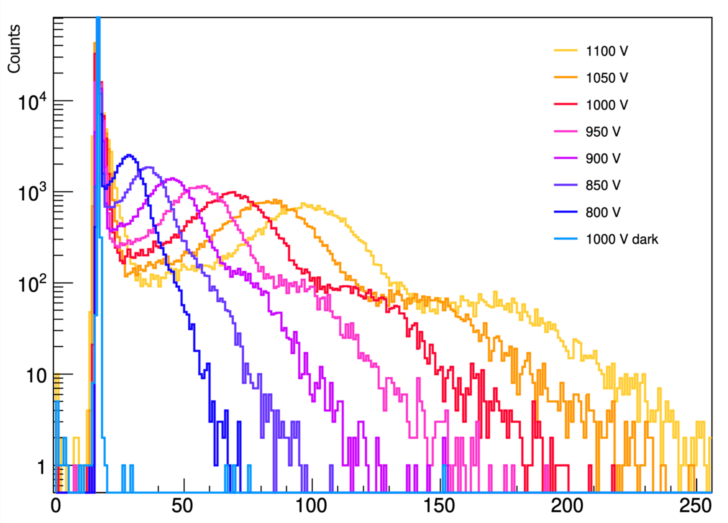

Figure 6: Typical signal amplitude spectra for a pixel as a function of the HV value.

QA of CLARO, FEBs, BkBs, and BBs

configure the CLARO chip register and read it back

verify the performances and the conformity of the BBs, FEBs and of the BKBs

System deployed on one station

The setup for the CLARO quality control:
- Pick&Place station
- interface board equipped with an Intel-ALTERA MAX10 FPGA
- computer running LabVIEW

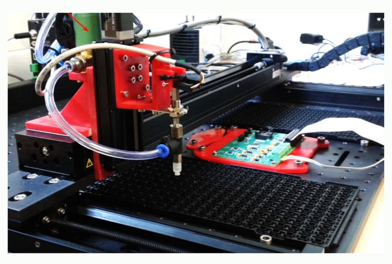

Figure 7: Pick&Place station used for the CLARO QA.

The time needed to perform the full test sequence was 160 seconds when no errors occur.

Tested more than 33000 CLARO then used in the upgraded RICH

The CLAROs passing the QA procedure have been assembled on the FEBs.

The test setup for the FEBs and BkBs:
- Test box
- custom boards based on Intel-ALTERA MAX10 FPGA
- system controller
- Workstation computer

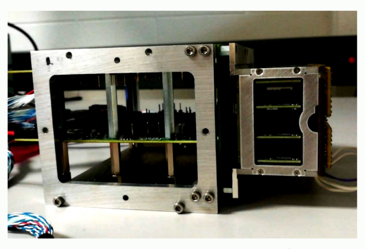

Figure 8: Test box used for the FEBs and BkBs QA.

The time required to test 4 BkBs was 15 mins.

A total of about 4200 FEBs were tested, together with 810 BkB-R and 460 BkB-H

The test setup for the BBs:
- Test station
- HV system controlled via WinCC-OA
- high precision multimeter for resistance measurement

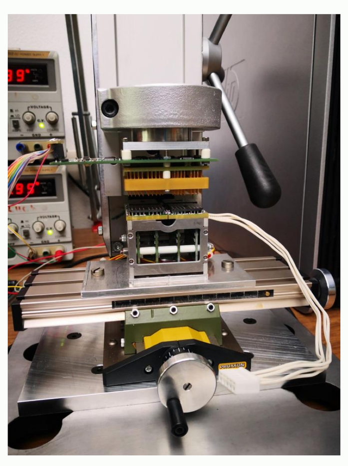

Figure 9: Test station used for the BBs QA .

Tested more than 1200 BBs

After the QA campaigns to validate all the components the ECs were assembled and the ECQA procedure started [3].

ECQA

verify the conformity of CLARO chips and MaPMTs

calibrate the CLARO channels and the MaPMTs anodes to optimise the single-photon detection efficiency

System deployed on four stations

TEST STATION:
- Dark box
- System controller
- LV power supply
- LED driver
- HV crate
- Raspberry Pi
- Workstation computer

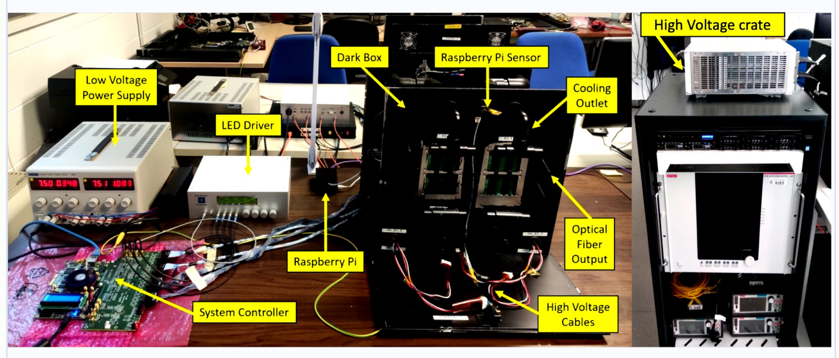

Figure 10: Test station used for the ECQA.

The core of the DAQ control software is given by low-level python functions while the upper hierarchy level is handled by the LabVIEW program.

Manual operation in case of critical errors and during the mounting procedures

ECs which successfully passed the QA tests were encapsulated in custom-designed jars to prevent any damage and then shipped to CERN to be assembled on columns.

The time needed to test 4 ECs was 18 hours

More than 1200 ECs have been characterised

Column Commissioning

characterise and calibrate the columns

All the components accepted by the QA procedure were assembled in the RICH columns during the commissioning performed at CERN. System deployed on one station

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

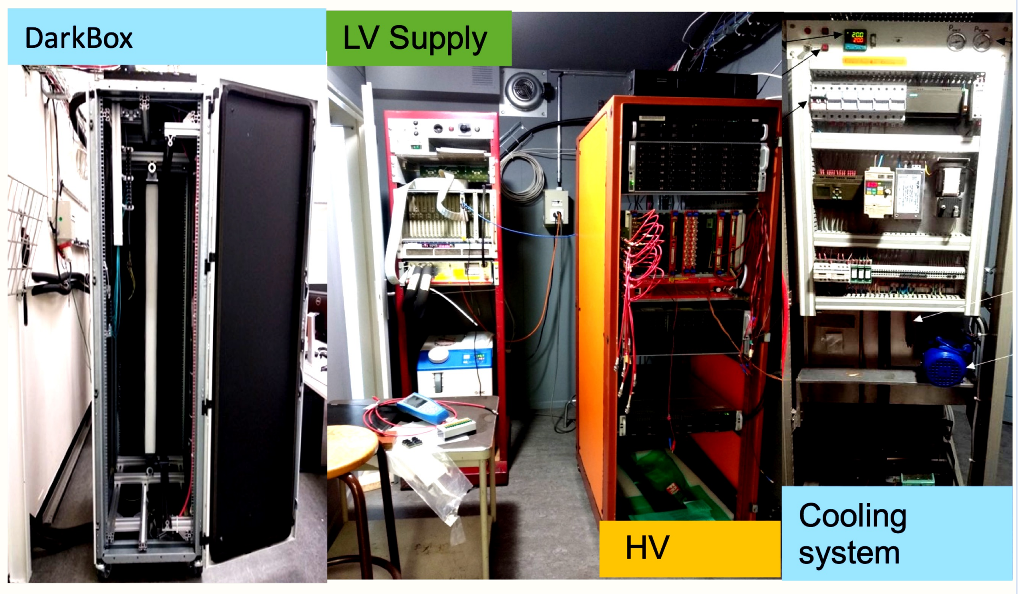

Figure 11: Test station used for the Column Commissioning.

Experiment Control System integrated in a FSM developed in WinCC-OA

Fully automated procedure

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

The time needed to test 1 column was 18 hours

22 columns for RICH1 and 24 for RICH2 have been commissioned

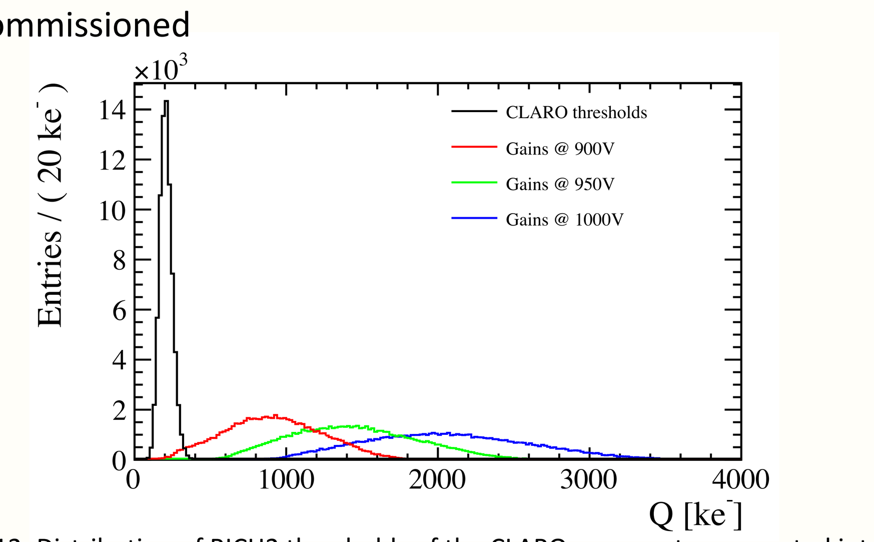

Figure 12: Distribution of RICH2 thresholds of the CLARO comparator converted into absolute charge (black). The threshold settings can be compared to the pixel gains at 900 V (red), 950 V (green) and 1000 V (blue) as determined from PDQA.

Conclusions

The extensive programme of QA, developed by the LHCb RICH group, tested and verified thousands of components enabling the installation of the photon detection subsystem in the LHCb cavern in a timely fashion, leading to the detection of Cherenkov rings in RICH2 during the pilot test beam of the LHC in October 2021.
The installation of both RICH detectors was completed successfully in March 2022 and are currently in full operation for the LHC Run 3.

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