The upgrade and performance of the LHCb RICH detector system

Edoardo Franzoso on behalf of the LHCb Collaboration
edoardo.franzoso@cern.ch

The LHCb RICH system Upgrade

LHCb [1] relies on the Ring Imaging Cherenkov (RICH) detector system for the charged hadrons identification in a wide momentum range (2 - 100 GeV/c). The Cherenkov light produced by the particles is redirected by an optical system towards the photodetector planes and outside the acceptance of the spectrometer

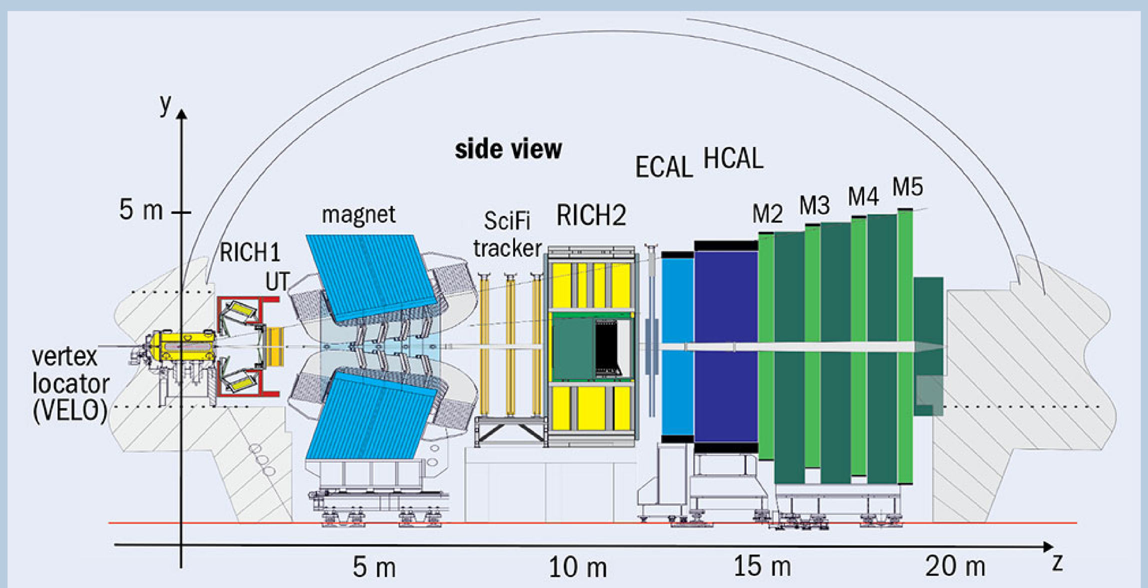

Figure 1: side view of the RUN3 LHCb configuration

The expected RUN 3 luminosity of $L = 2 \cdot 10^{33} cm^{-2} s^{-1}$ and the 40 MHz readout require a substantial upgrade [2] of the RICH system to maintain its excellent performance:

- replacement of the photon-detectors
- new Front-End (FE) readout electronics
- RICH1 optic modifications

Optics and Geometry

With the RUN 2 configuration and the luminosity expected in RUN 3, the photon occupancy at the detection plane will increase up to 50% resulting in degradation of particle identification performance. To reduce the occupancy, and improve pattern recognition, the radius of curvature of the spherical mirrors has been increased in order to spread out the photons into a larger area, and the photon detection plane has been pushed back as a result.

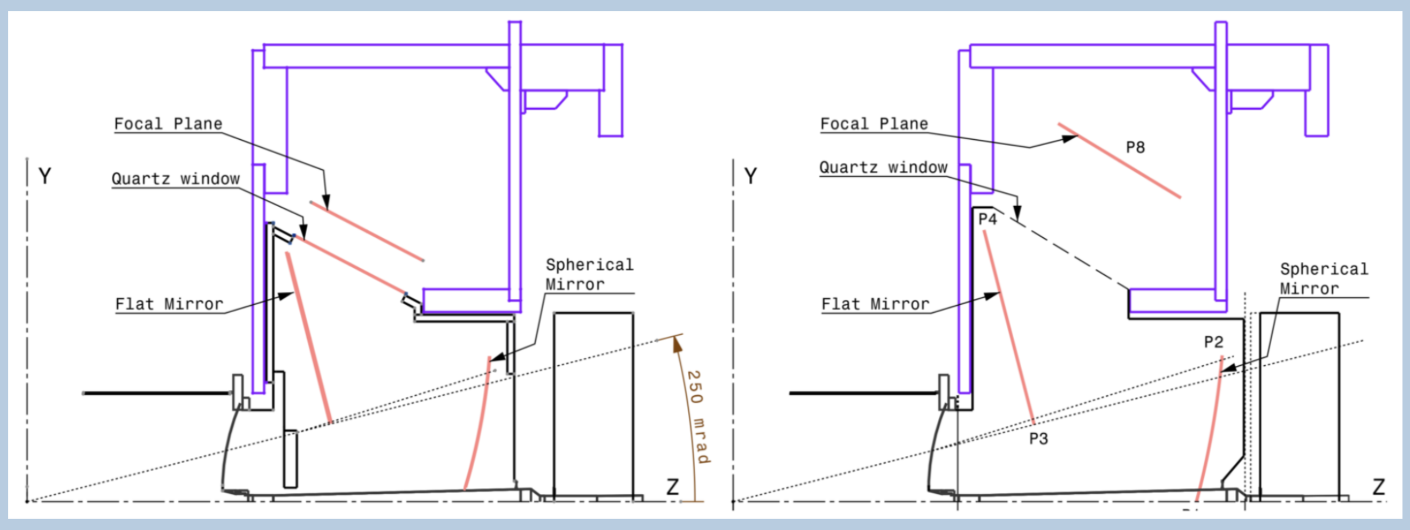

Figure 2: RICH 1 optical geometry in case of RUN2 (left) and RUN3 upgrade(right)

Time Gating and Performance

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 [3]. The programmable FPGA logic in PDMDB samples the CLARO signals at 320 MHz and detects specific input patterns. Given the time resolution of the detector chain, a 6.25 ns time gate might be required to achieve the best performance and to maximize the signal to noise ratio.

The excellent performance of the RICH is expected also in the RUN3 environment:

- improvement in the Cherenkov angle resolution (mrad) is expected
  - lower emission point error (new optics)
  - quantum efficiency of MaPMTs peaks at higher wavelength
  - improved pixel resolution
- improved particle identification (PID)

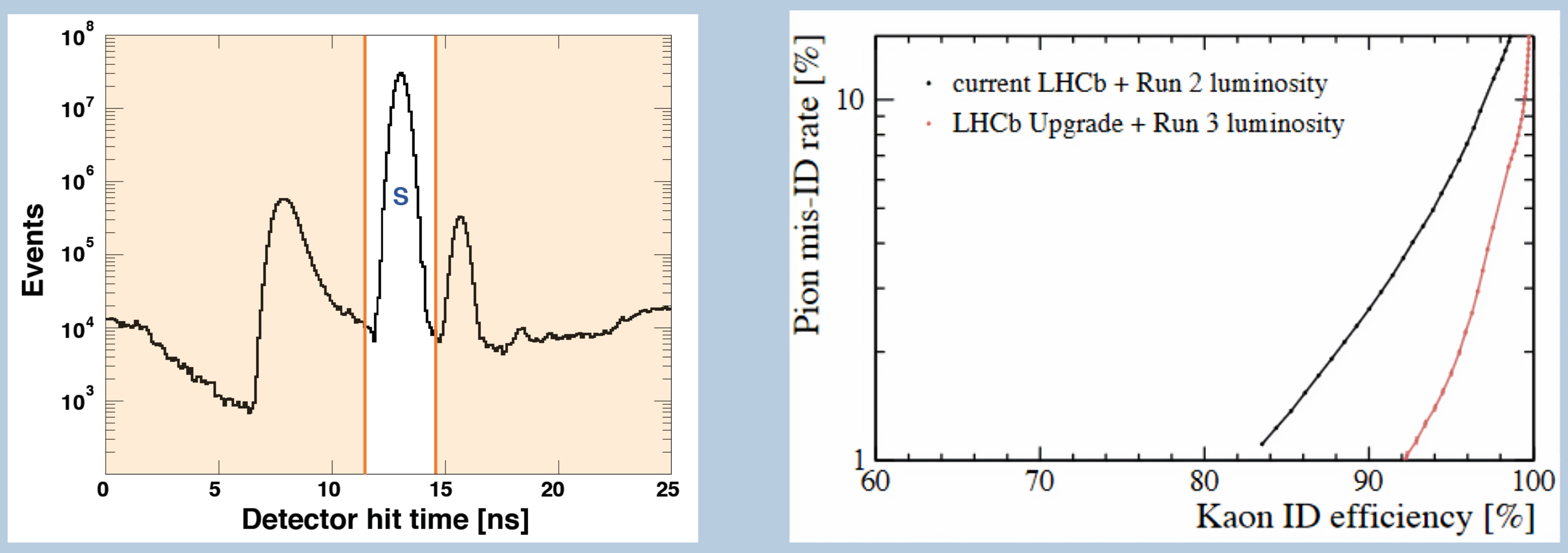

Figure 3: Left: Simulated photon hit time in RICH1, a time gate of 3.125 ns is highlighted. Right: PID performance comparing RUN2 and RUN3 conditions

References

[1] Alves Jr, A. Augusto, et al. "The LHCb detector at the LHC." Journal of instrumentation 3.08 (2008): S08005.
[2] LHCb Collaboration et al. LHCb PID upgrade technical design report. Tech. rep. 2013.
[3] 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.

Photon-Detection chain

- **MultiAnode Photomultipliers** (MaPMT)
  - 1×1 inches Hamamatsu MaPMTs for high occupancy region, 2×2 inches Hamamatsu MaPMTs for low occupancy region
  - 64 anodes with low dark count rate (< 1 kHz) and gain $\sim 2 \times 10^6$ at 1kV
  - high quantum efficiency (QE) super-bialkali photocathode

Figure 4: Left: front view the two types of MaPMTs. Right: the CLARO ASIC

- **CLARO chip**
  - 8-channel amplifier/discriminator ASIC
  - adjustable threshold and attenuation for each channel
  - radiation-hard by design and triple modular redundancy protection
- 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 2×2 inches MaPMT and four 1×1 inches MaPMTs, respectively)

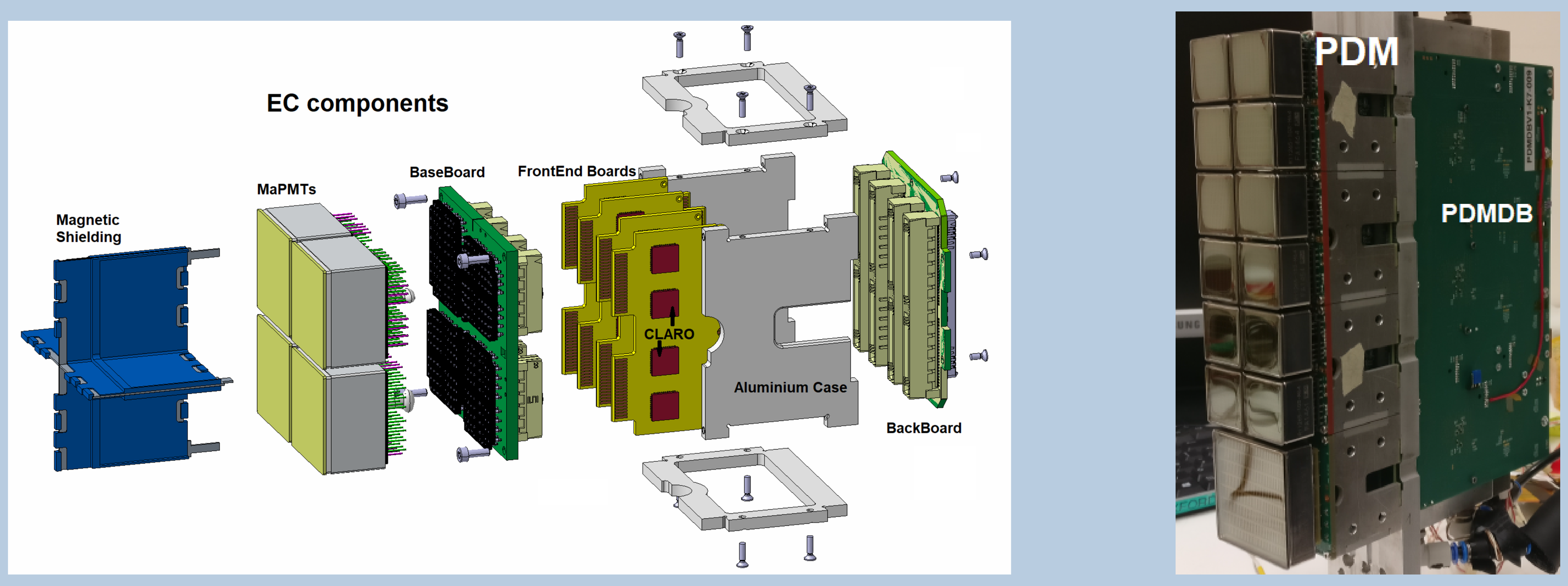

Figure 5: Left: R-type EC. Right: R-type PDM connected to PDMDB

- 4 ECs constitute the **Photo Detector Modules** (PDM) which will interface with the new LHCb readout through Photo Detector Module Digital Boards (PDMDB).
- PDMs are the fundamental modules of the **RICH columns** which will form the photodetector planes. This level of modularity of the detector facilitates maintenance and operations.

Quality Assurance and Commissioning

A quality assurance campaign validated the ECs and all the components therein. In total, more than 1200 ECs have been characterized to verify the conformity of CLARO chips and MaPMTs through dedicated measurements and the reliability of mounted EC. Every CLARO channel is then calibrated to optimize the single-photon detection efficiency.

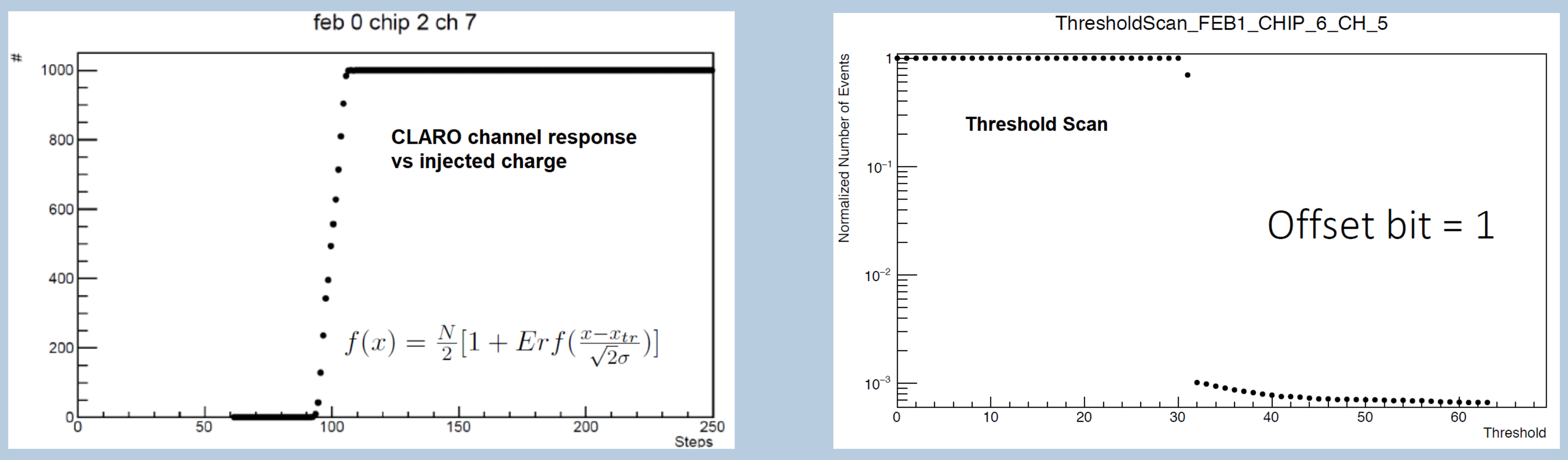

Figure 6: Examples of measurements for the single CLARO channel characterization

The commissioning of the columns at CERN is proceeding successfully in parallel with the development of the RICH experiment control system based on the JCOP Framework.

- RICH2 installed and commissioning to be finalized
- RICH1 commissioning ongoing and installation planned in few months

Figure 7: RICH2 A side commissioned. On the right, hitmap obtained with the front end electronics switched on and CLARO channels triggered by noise.