# Commissioning of the upgraded RICH system at the LHCb experiment

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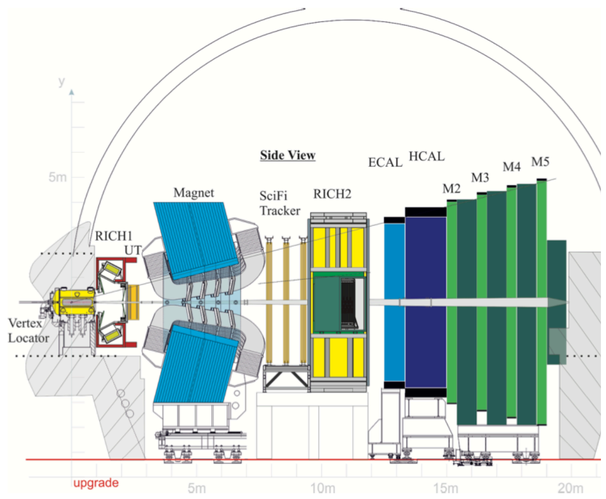
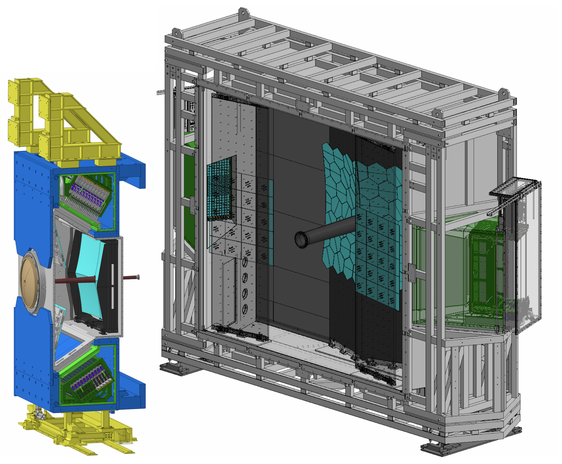
## LHCb RICH system upgrade

- LHCb is a general-purpose experiment optimized for the detection of c- and b-hadrons
- The RICH detectors are able to identify **charged hadrons** in the final state using Cherenkov radiation
- The emitted photons are focused by a system of **reflecting mirrors** into a **photo-detector plane** made of MaPMTs
- **PID** is performed using a **log-likelihood algorithm**. A 'photon object' is created for each combination of a track and photon within spatial constraints

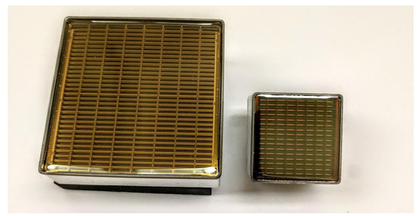


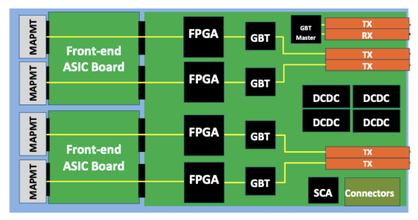



- **Upgrade phase**:
  - Five-fold increase in instantaneous luminosity up to $2 \times 10^{33}$ cm$^{-2}$ s$^{-1}$
  - Read out data at a rate of 40 MHz.
- **Challenges**:
  - Significant increase of the detector occupancy
  - Larger radiation dose
- RICH detectors have been upgraded with a **redesigned opto-electronic chain** and new photon detectors

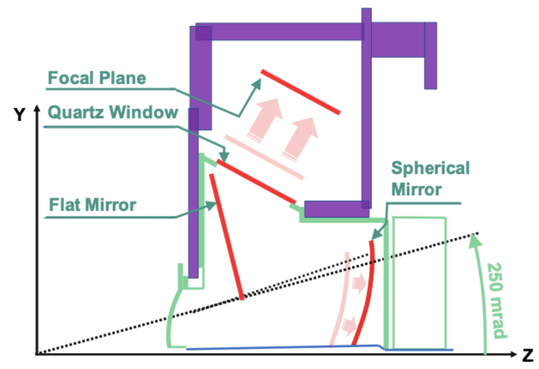
## The upgraded photon detection chain

- **MaPMT**: Hamamatsu Multi-anode PMT, 8x8 pixels featuring super-bialkali photocathode with high quantum efficiency (QE)
- **CLARO ASIC**: 8 channel amplifier-discriminator designed with 0.35 µm CMOS and radiation-hard technologies and recovery time better than 25 ns
- **Xilinx FPGA**: provides the interface between the CLARO ASIC and the optical links
- **GBT**: GigaBit Transreceiver for data transmission

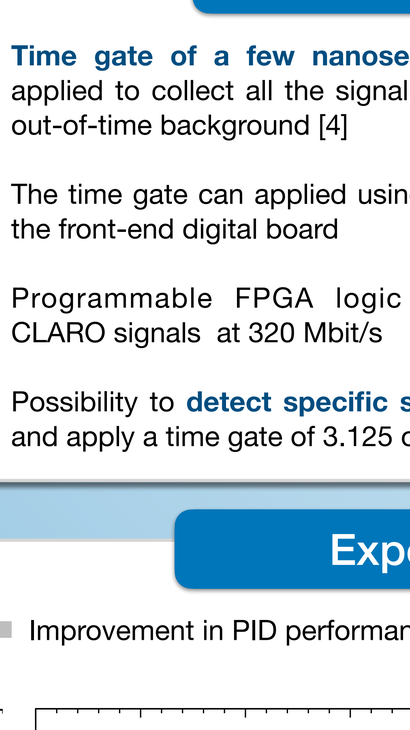




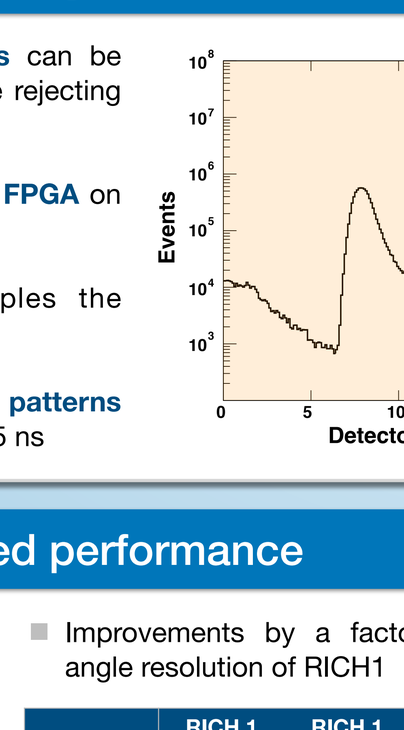

## RICH1 new mechanics and optics



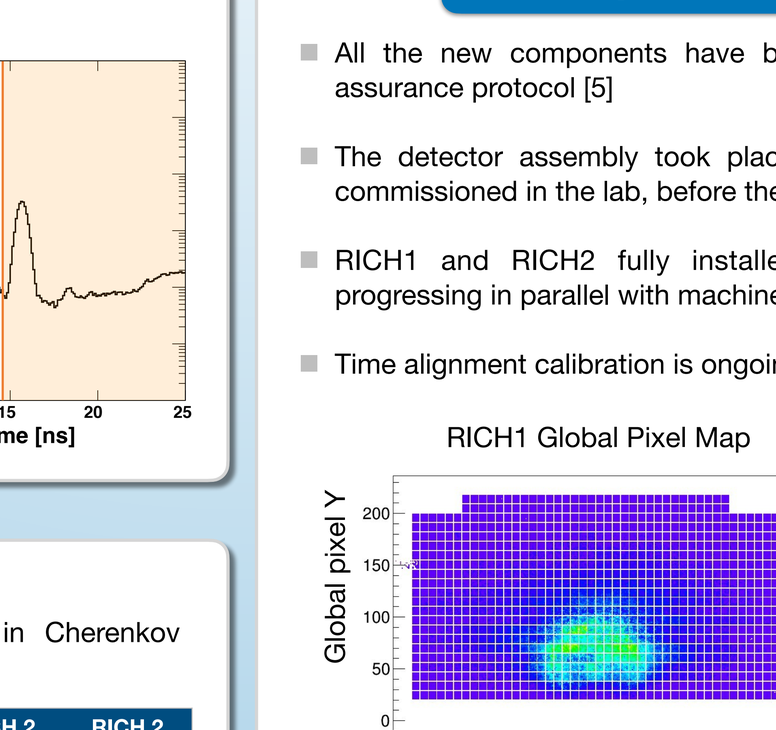

- Peak **occupancy** (fraction of detected photons over the total number of channels) should remain **< 30 %** to maintain PID performance [3]
- New spherical mirrors with larger radius of curvature to **increase ring size**
- Focal plane and spherical mirror moved back to accommodate **longer radius of curvature**
- Larger gas enclosure
- Compact photo-detection system



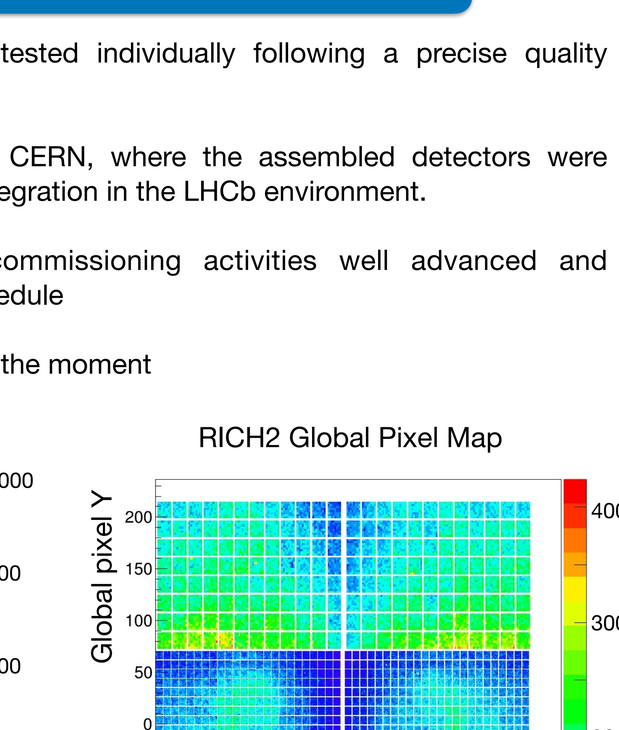
Gas Enclosure




Elementary Cells



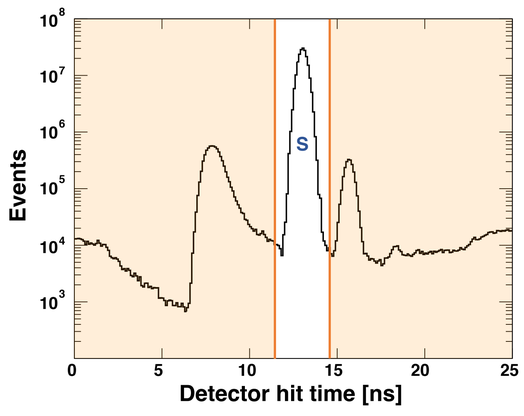
RICH1 Photodetector Plane




Cherenkov Rings

## Timing for background reduction

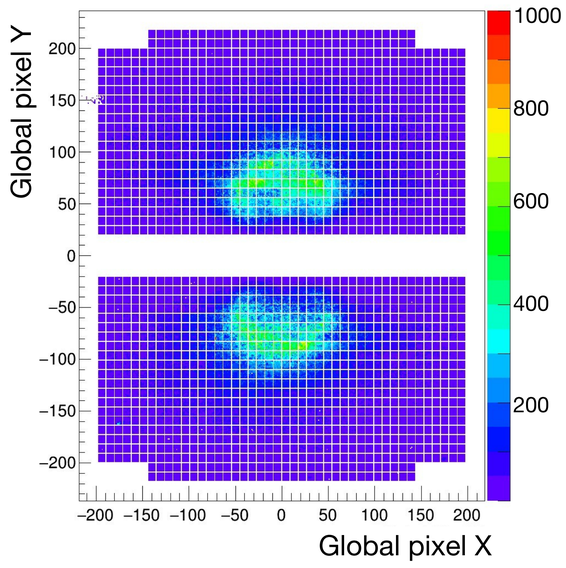
- **Time gate of a few nanoseconds** can be applied to collect all the signal while rejecting out-of-time background [4]
- The time gate can applied using the **FPGA** on the front-end digital board
- Programmable FPGA logic samples the CLARO signals at 320 Mbit/s
- Possibility to **detect specific signal patterns** and apply a time gate of 3.125 or 6.25 ns



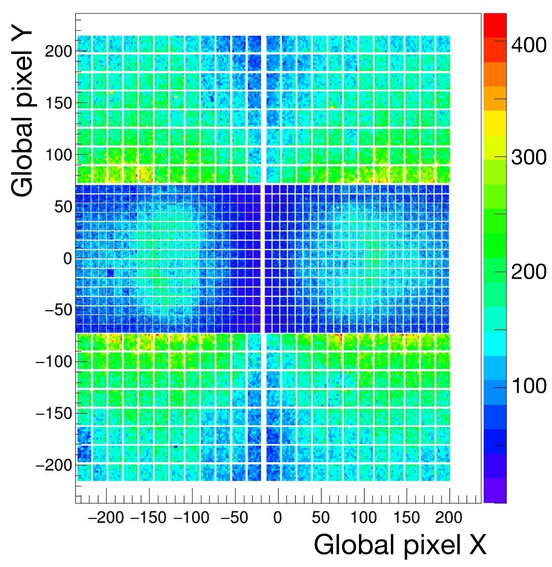

## Quality assurance and commissioning

- All the new components have been tested individually following a precise quality assurance protocol [5]
- The detector assembly took place at CERN, where the assembled detectors were commissioned in the lab, before their integration in the LHCb environment.
- RICH1 and RICH2 fully installed: commissioning activities well advanced and progressing in parallel with machine schedule
- Time alignment calibration is ongoing at the moment

RICH1 Global Pixel Map

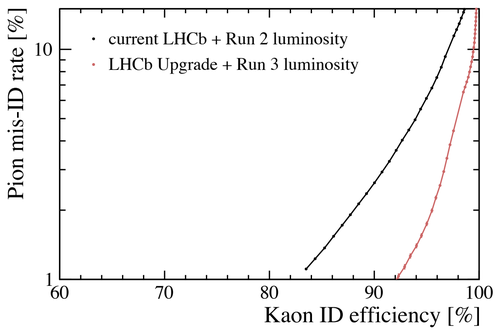



RICH2 Global Pixel Map




## Expected performance

- Improvement in PID performance




- Improvements by a factor 2 in Cherenkov angle resolution of RICH1

| Resolution | RICH 1 2015 | RICH 1 upgrade | RICH 2 2015 | RICH 2 upgrade |
|---|---|---|---|---|
| Chromatic | 0.84 | 0.58 | 0.48 | 0.31 |
| Pixel | 0.60 | 0.44 | 0.19 | 0.19 |
| Emission Point | 0.76 | 0.37 | 0.27 | 0.27 |
| Overall | 1.60 | 0.78 | 0.65 | 0.45 |

## References

[1] LHCb Collaboration, *LHCb PID Upgrade Technical Design Report*, CERN-LHCC- 2013-022, (2013)

[2] Papanestis A., et al, *The upgrade of the LHCb RICH system for the LHC Run 3*, J. Instrum., 15 (2020)

[3] D'Ambrosio C., et al, *The Future of RICH Detectors through the Light of LHCb RICH*, CERN-LHCb-PUB-2017-014, (2017)

[4] Keizer F., *Sub-nanosecond Cherenkov photon detection for LHCb particle identification in high-occupancy conditions and semiconductor tracking for muon scattering tomography*, PhD Thesis, (2020)

[5] Gizdov K., et al, *Strategy and automation of the quality assurance testing of MaPMTs for the LHCb RICH upgrade*, N. Instrum. 952 (2020)