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The LHCb RICH Upgrade

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on behalf of the LHCb RICH Collaboration

CERN

UNIVERSITY OF CAMBRIDGE

LHCb

The LHCb experiment

The current LHCb RICH detectors

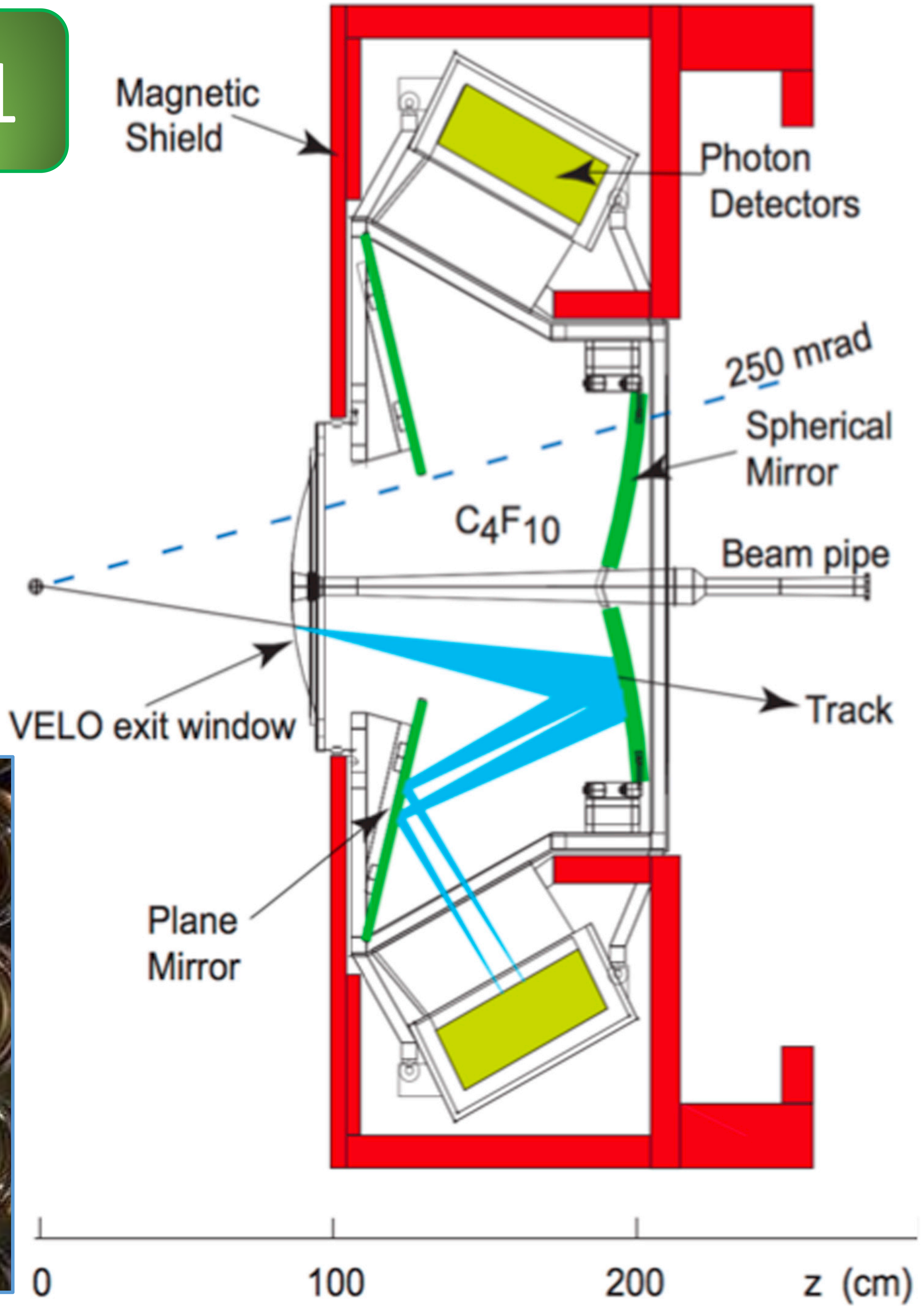
RICH: **Ri**ng Imaging **Ch**erenkov Detector.

Particle Identification up to 100 GeV/c by determining Cherenkov angle.

C_4F_{10} (RICH 1) and CF_4 (RICH 2) gas as **Cherenkov radiators**.

Photon detection using **Hybrid Photon Detectors** (HPDs): solid state detectors with readout electronics integrated inside vacuum tube.

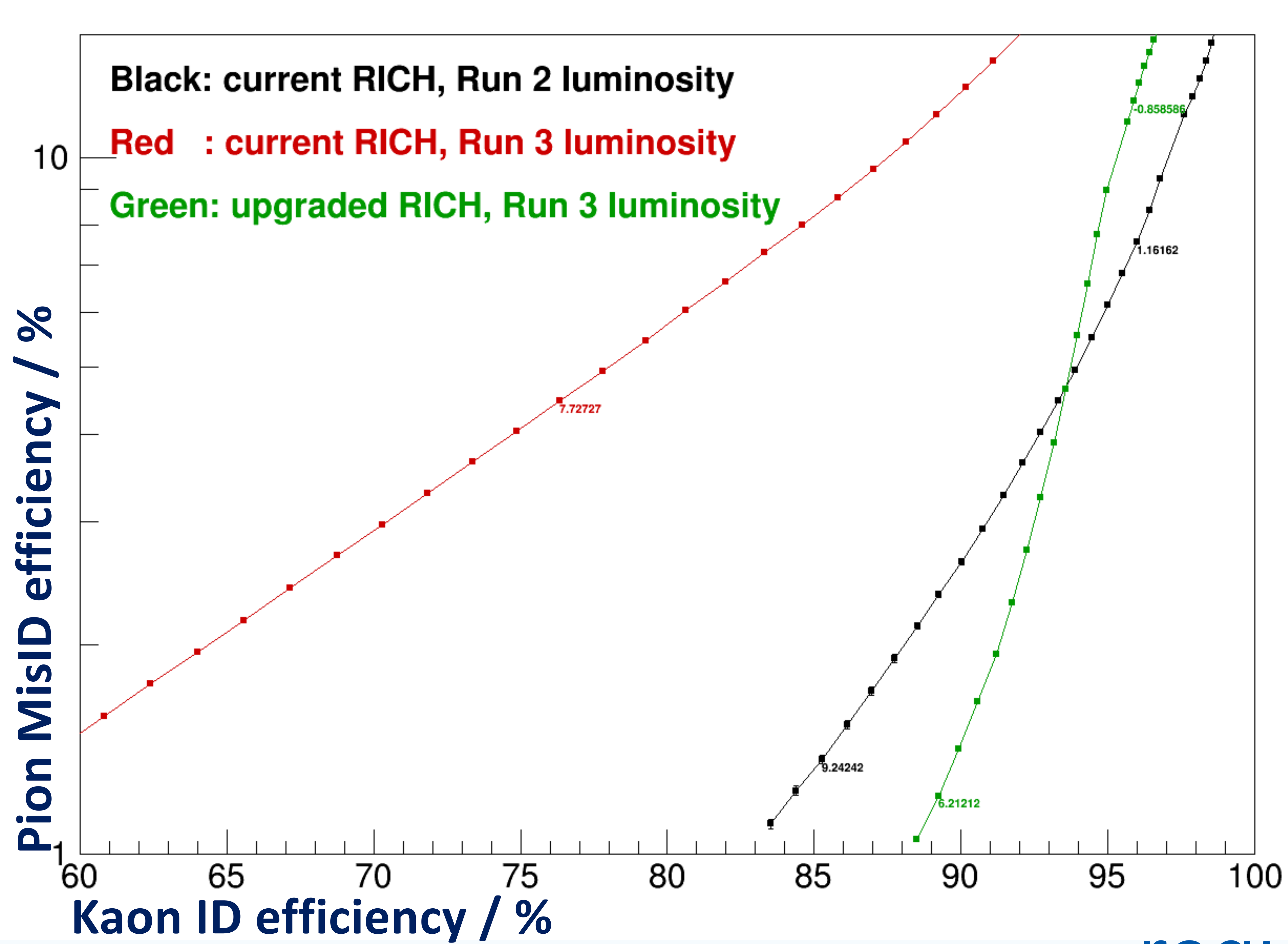
RICH 1



Upgrade challenges for RICH

L0-hardware trigger (1 MHz) replaced by **software trigger (40 MHz).**

Inst. luminosity increases from $4 \times 10^{32} cm^{-2} s^{-1}$ to $\mathbf{2 \times 10^{33} cm^{-2} s^{-1}}$.



Increased rate requires **upgrade of front-end electronics**.

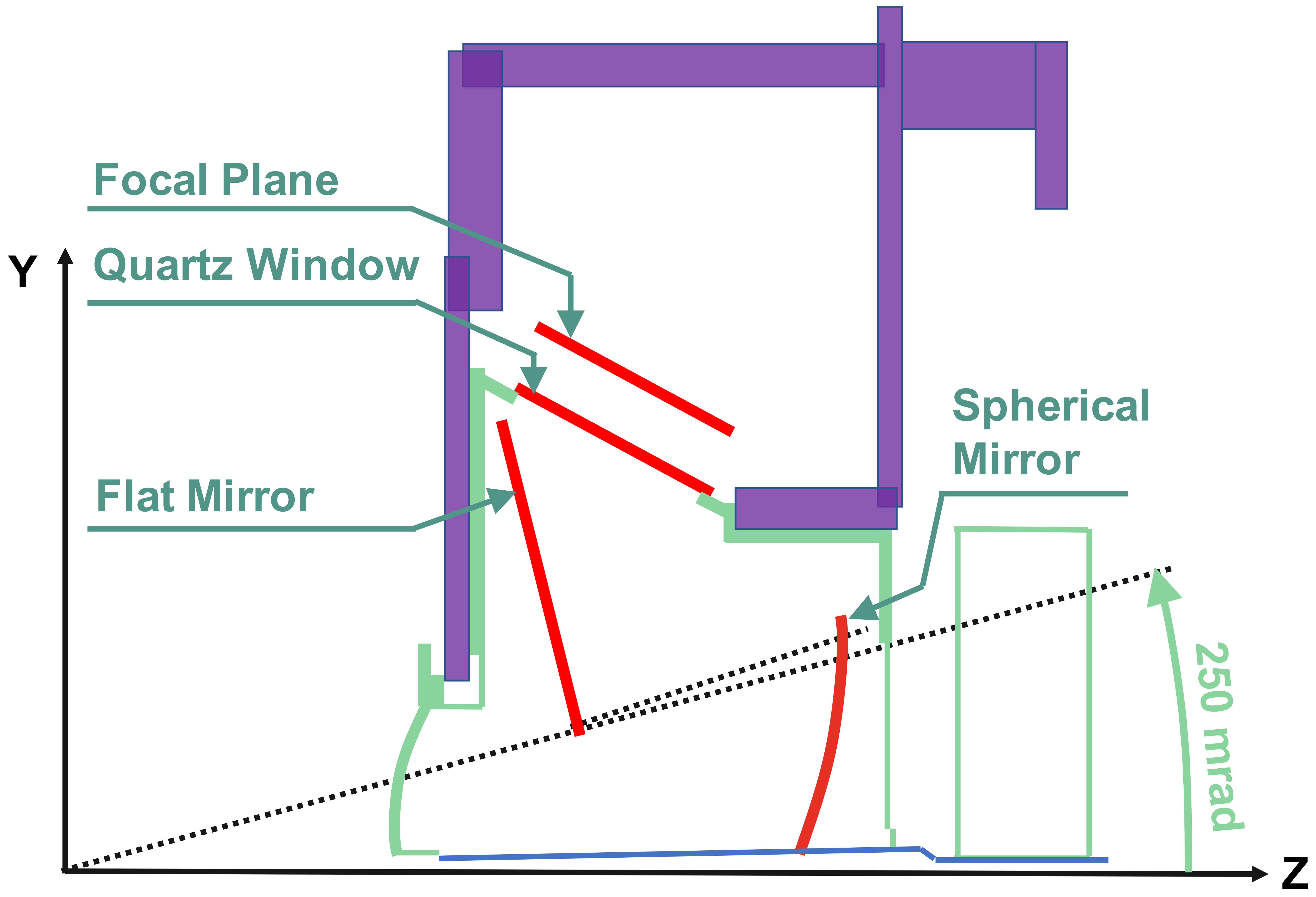
Particle multiplicity requires **upgrade of optical system for pattern recognition.**

Mechanical changes

Peak occupancy should remain < 30 % to maintain PID performance.

- Focal plane and mirror moved back to increase ring size.
- New spherical mirrors with larger radius of curvature.
- Larger gas enclosure.
- Compact photo-detection system required.

Current RICH 1



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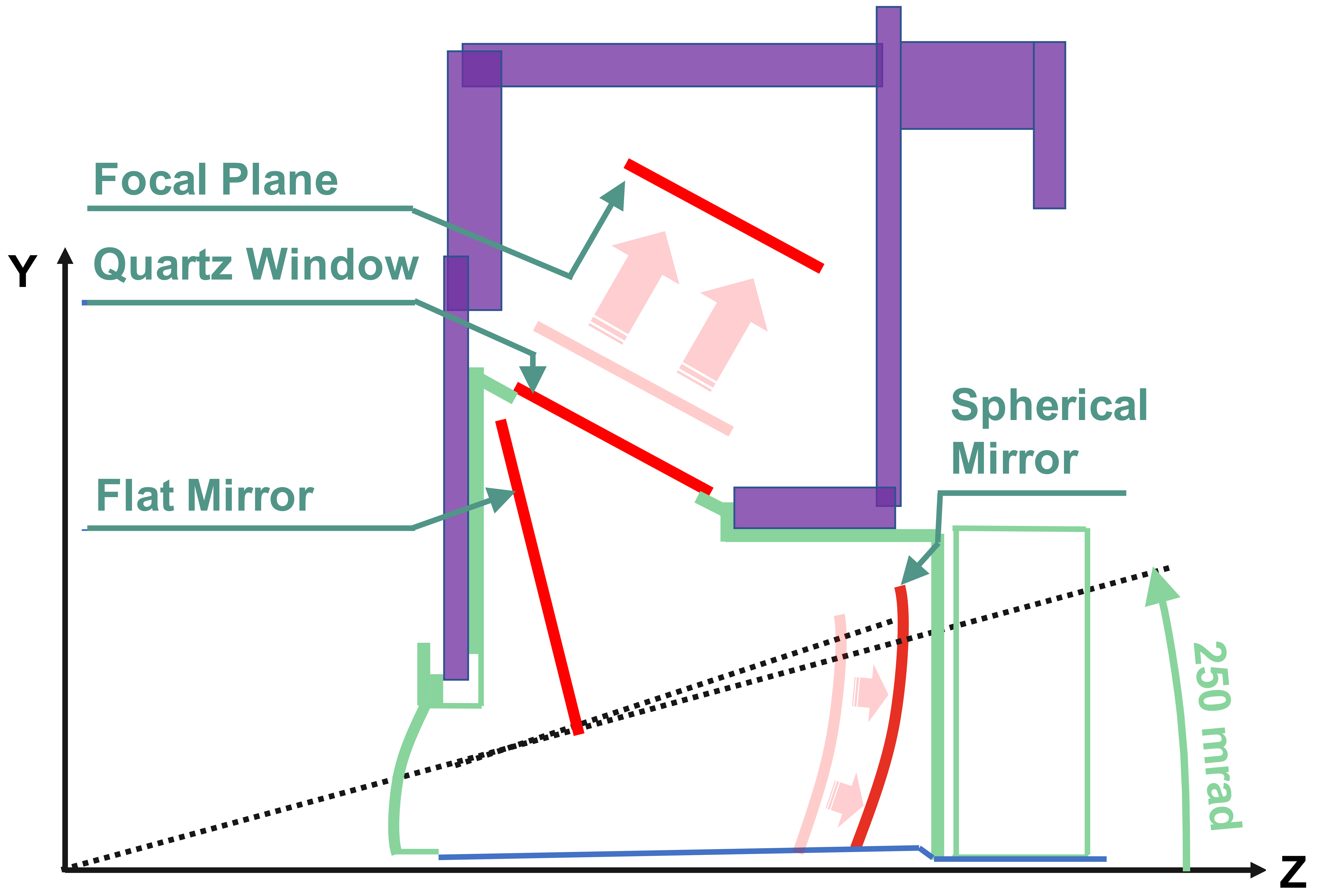
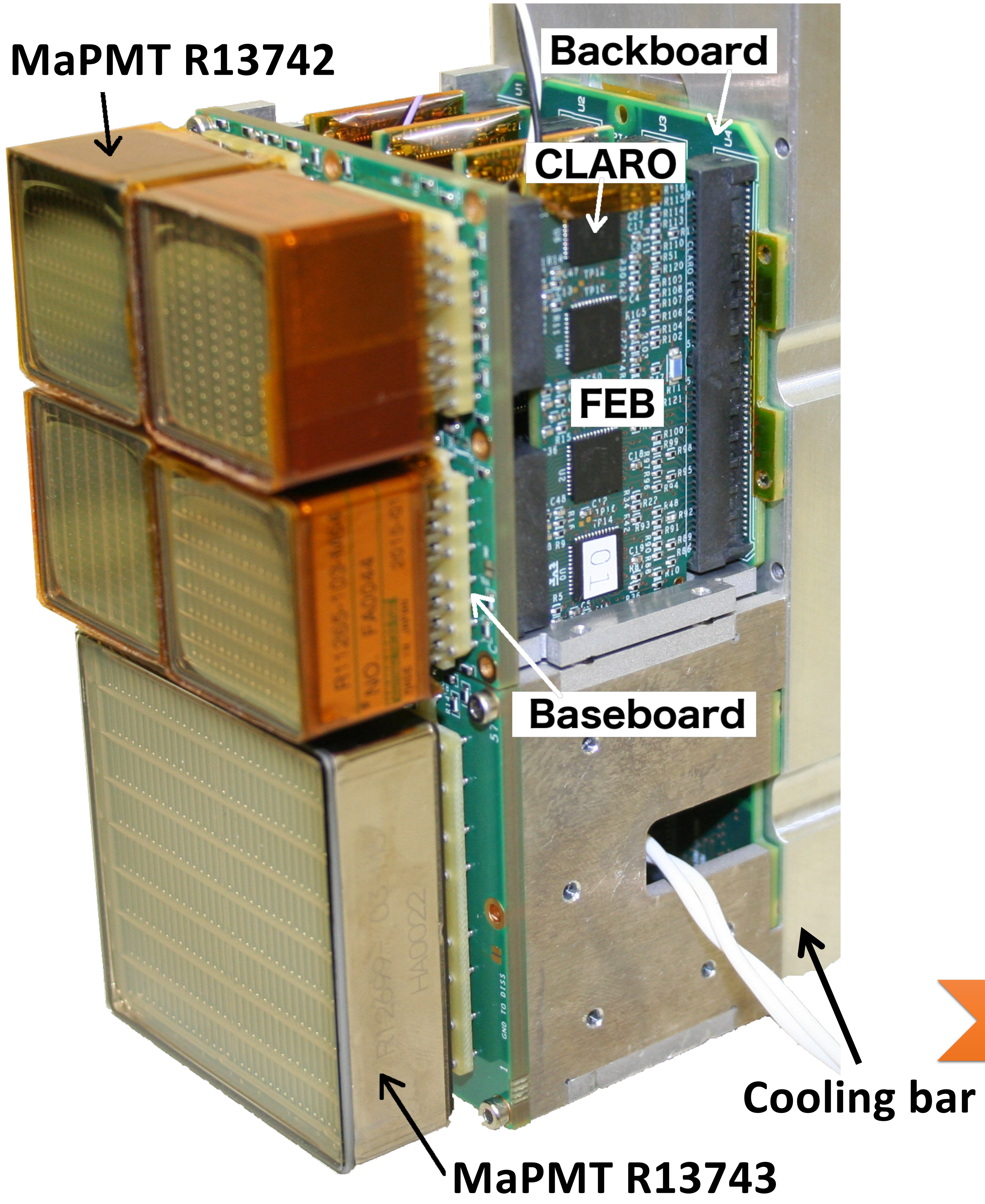
Upgraded RICH 1



The elementary cell & read-out



Hamamatsu multi-anode PMTs (MaPMTs):

64 channels, single photon sensitive, QE sensitive in green region, fast, radiation hard, low dark count rate.

1 x 1 in^2 MaPMTs (R13742) in RICH1 and high-occupancy regions of RICH 2.

2 x 2 in^2 (R13743) in low-occupancy regions of RICH 2.

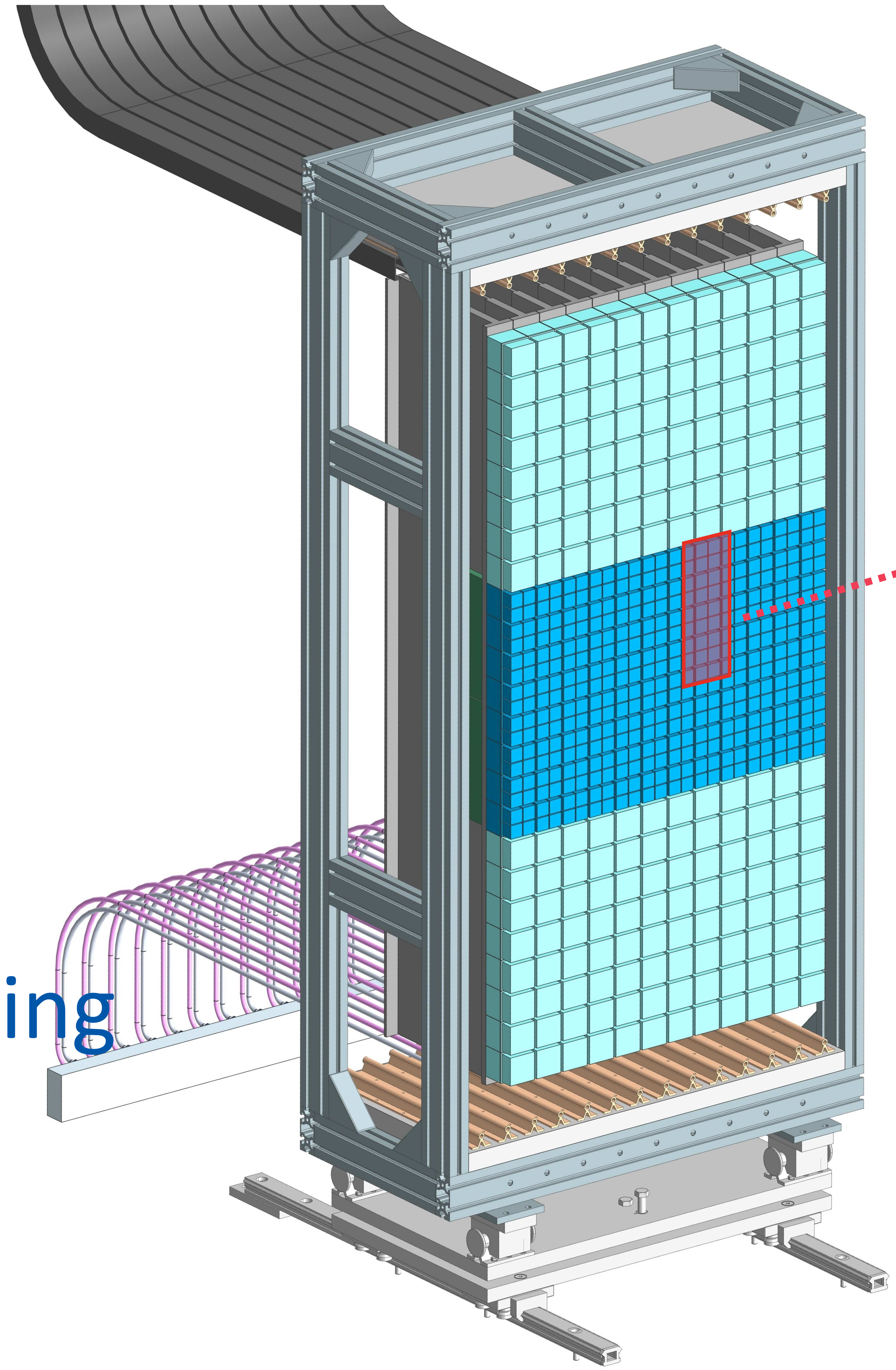
Custom ASIC (CLARO) designed for LHCb RICH.

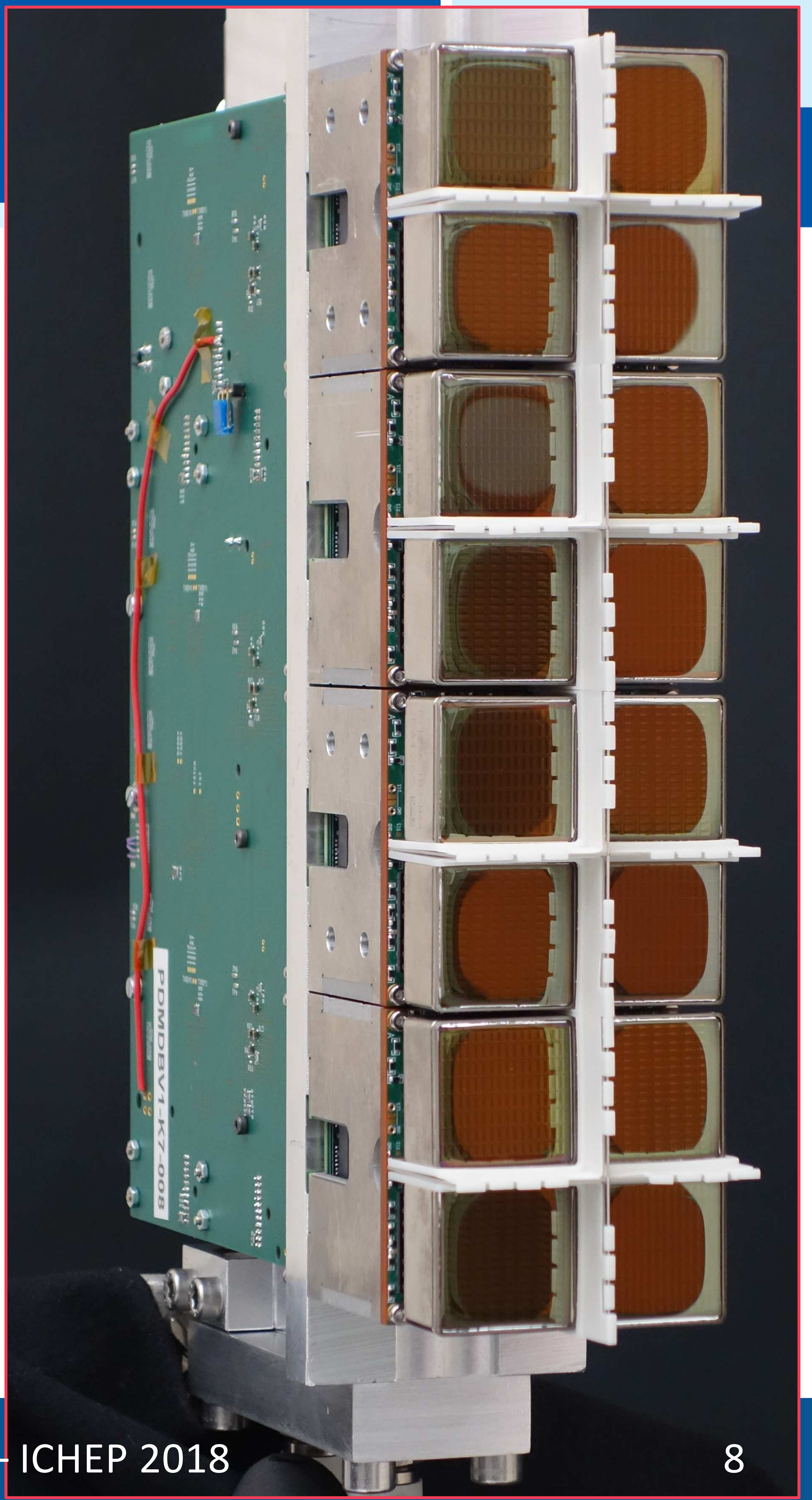
Signal propagation:

Light → MaPMT → CLARO → FPGA → Data link

Photon Detector Module (PDM)

- 2 digital boards.
- 4 elementary cells:
  - Hamamatsu MaPMTs
    (1x1 in^2 & 2x2 in^2).
  - CLARO read-out chips.
  - Magnetic & electric shielding for RICH 1 MaPMTs



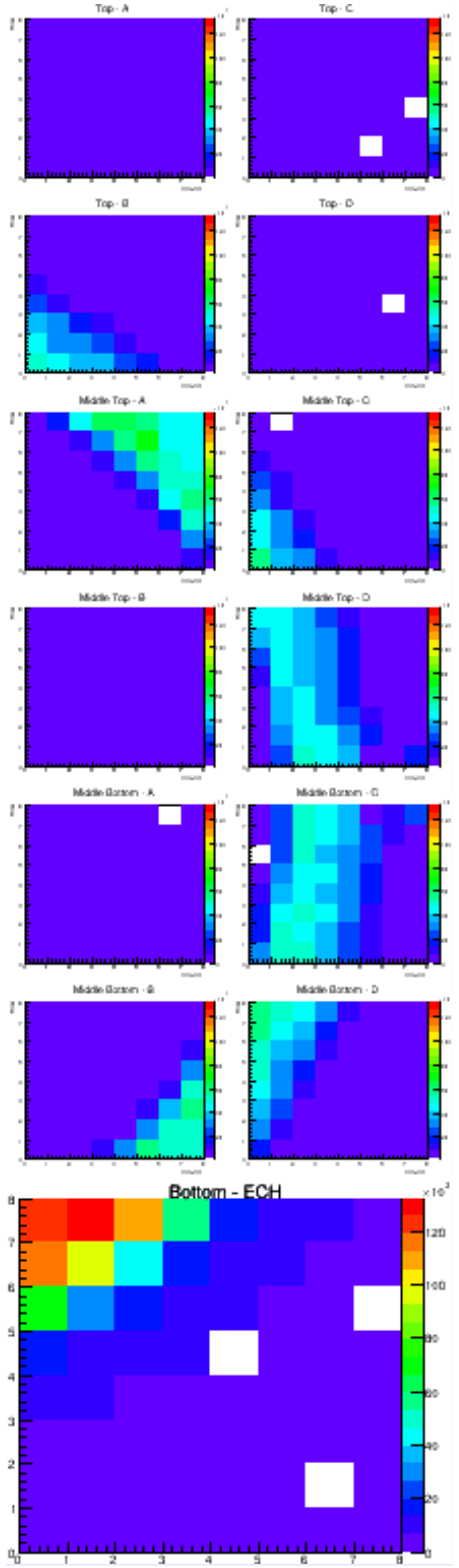


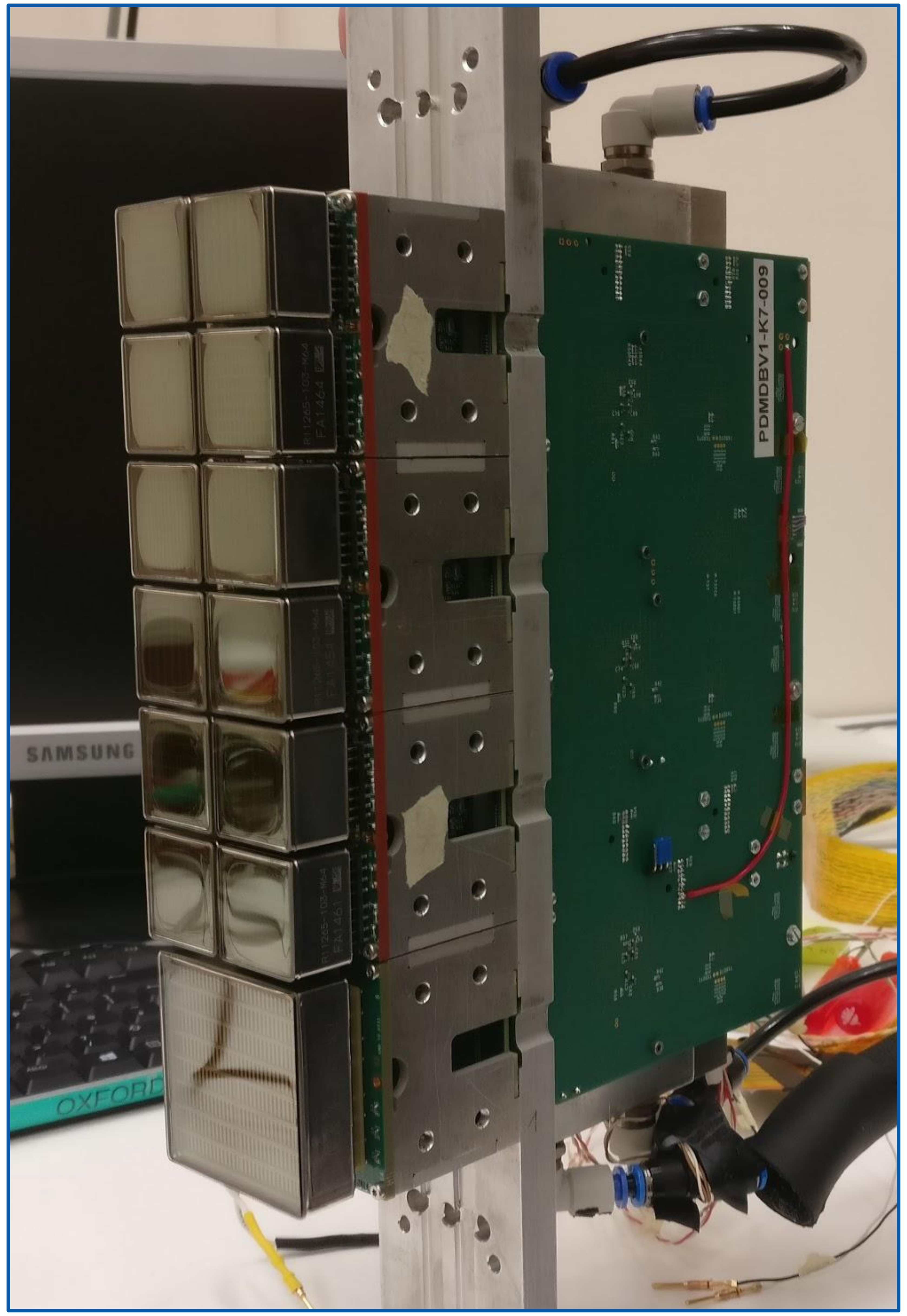
Beam test experiments

Various beam test experiments since 2014 to study opto-electronic chain.

Test set-up in thermally insulated light-tight box. Cherenkov photons generated and focussed in borosilicate radiator.

Cherenkov ring measured using PDM with prototype or pre-production components.





LHCb RICH upgrade in a nutshell

- Increase in **luminosity to** $\mathbf{2{\times}10^{33}}\boldsymbol{cm^{-2}s^{-1}}$ and read-out rate to **40 MHz**.
- Entire **opto-electronic chain needs to be replaced**. Modularisation in elementary cells and photon detector modules.
- Two types of **MaPMTs** used with **CLARO custom ASIC** for single-photon detection and fast read-out. Have been completely delivered and are in quality assurance phase.
- **Mechanical structure of RICH 1 needs to be modified** to decrease photon occupancy. Spherical mirrors and gas enclosure will be exchanged.
- **All components of PDM and mechanical structure successfully reviewed for production readiness** and tested in beam experiments, inside RICH 2, and in laboratory set-ups.

Backup slides

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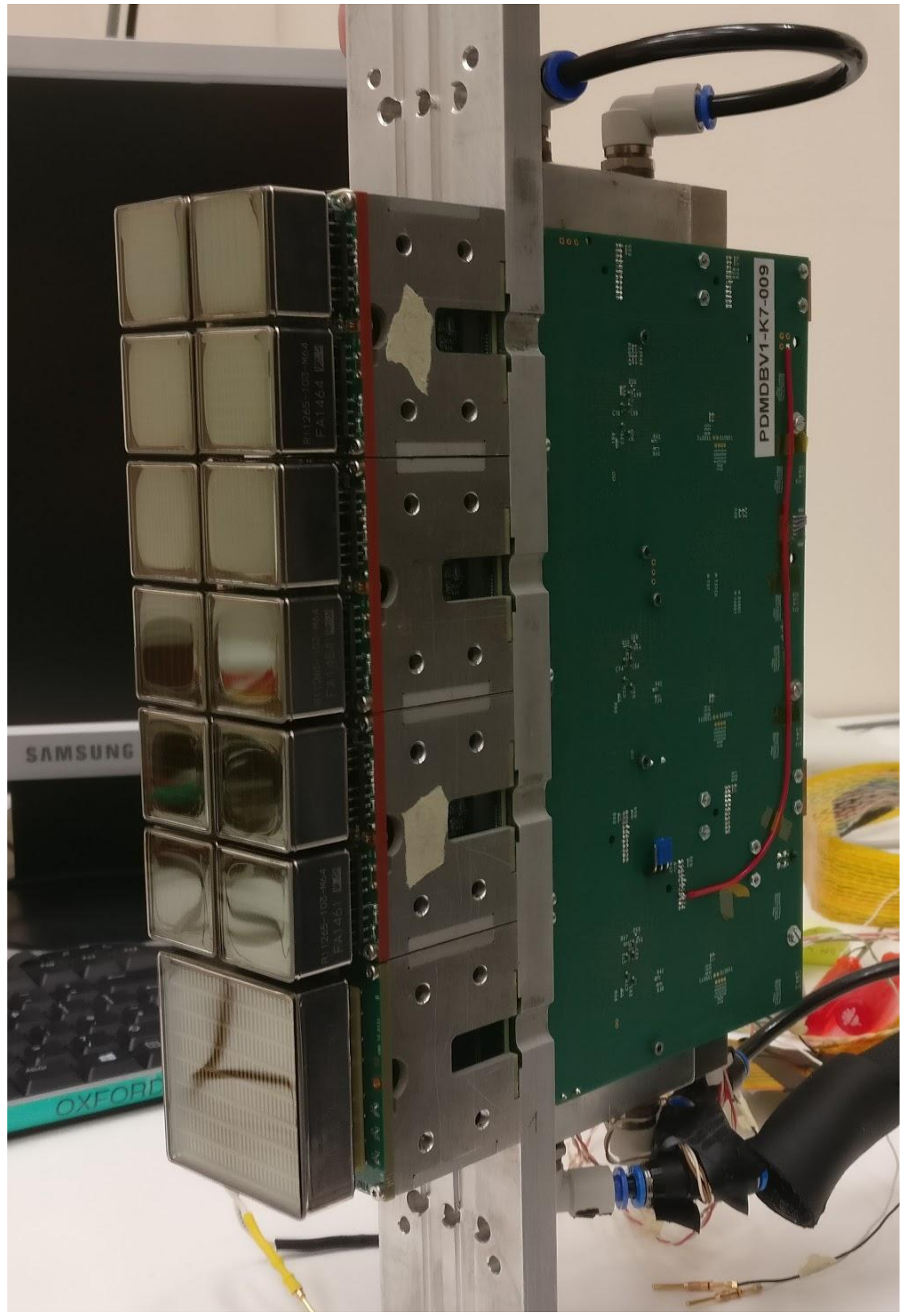
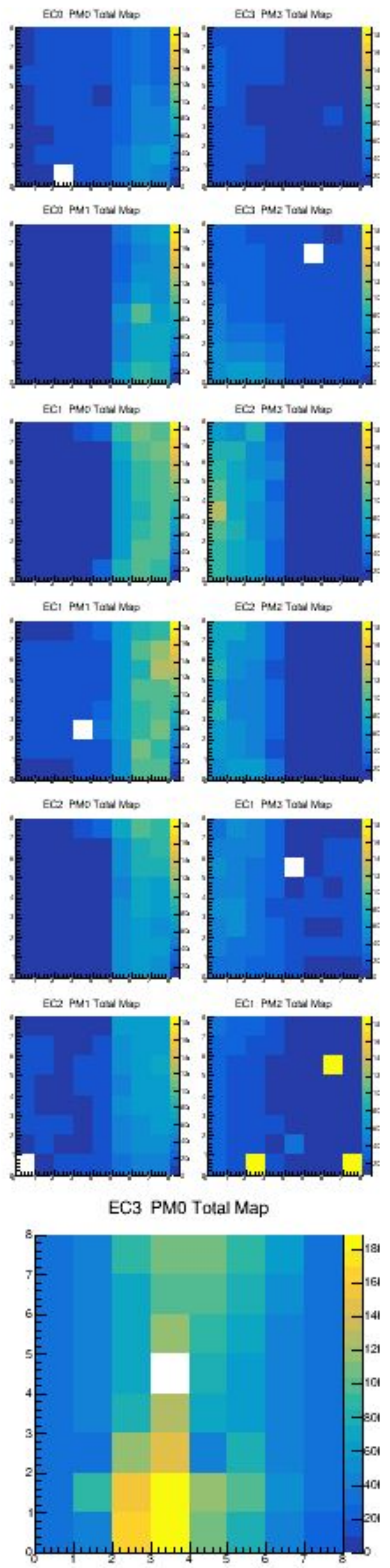
PDM integration in RICH 2



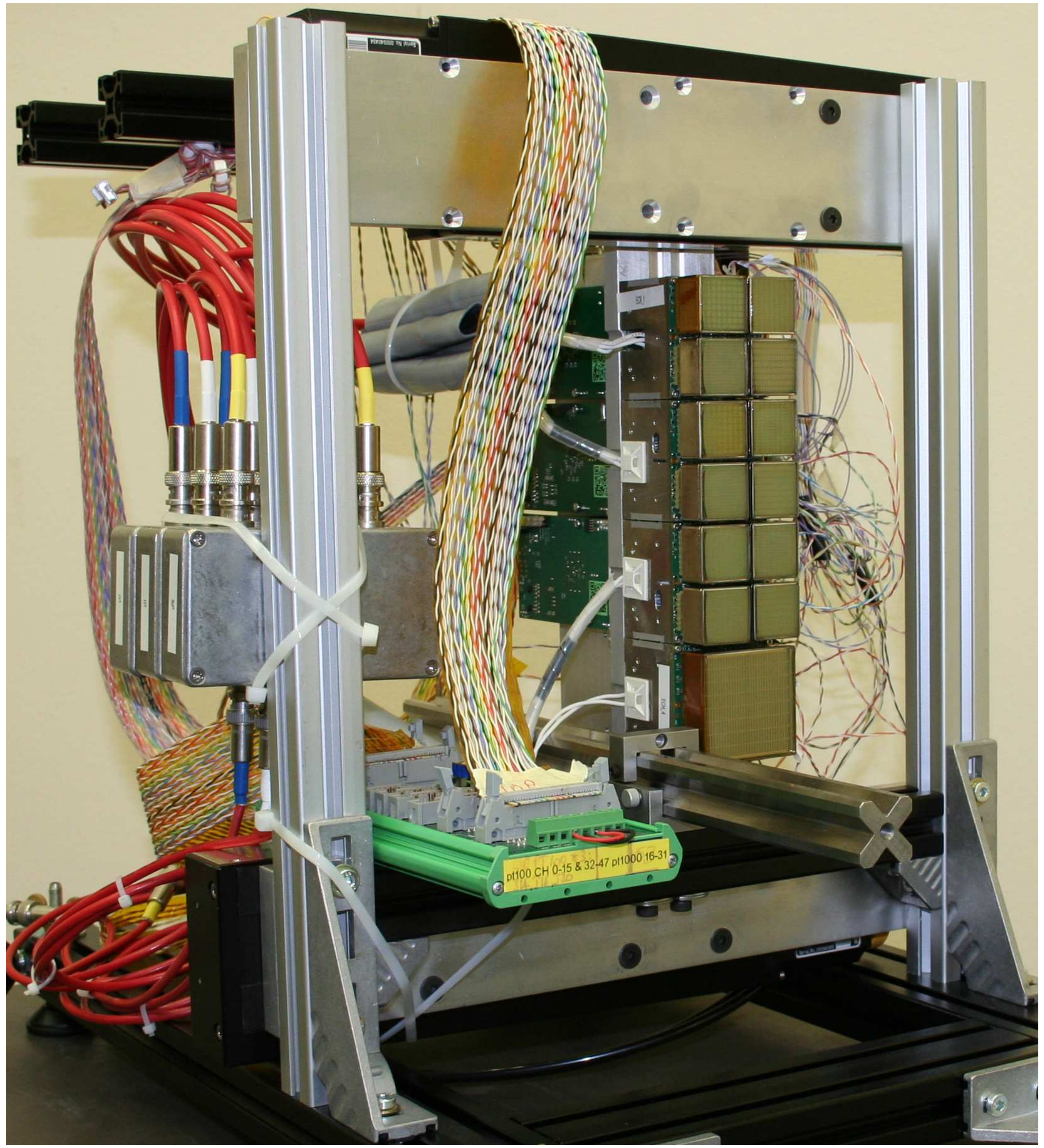
Photon Detector Module
(pre-production components)

Top view of PDM installed in RICH 2,
synchronised with LHCb clock and trigger.

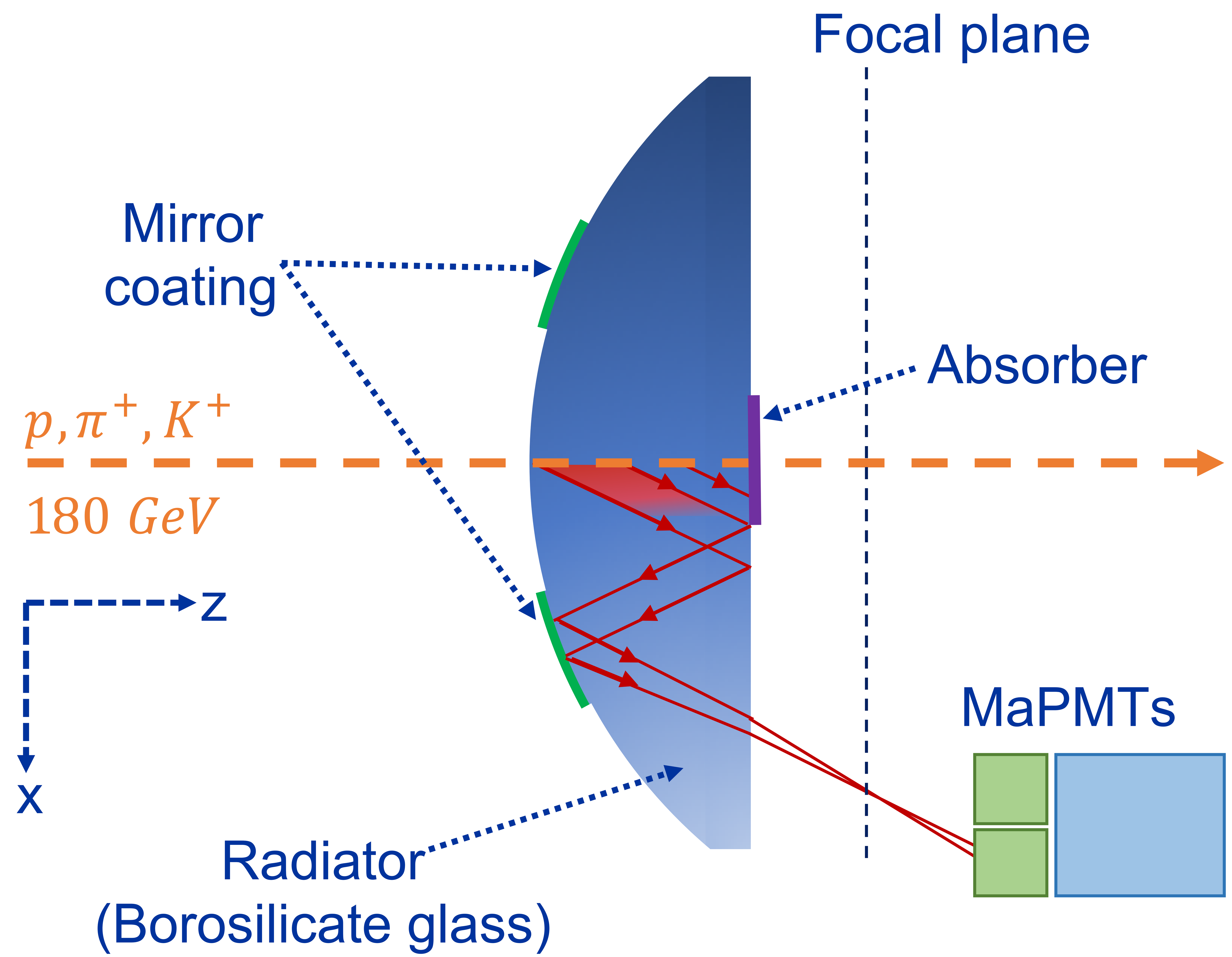


Cherenkov light from LHCb collisions

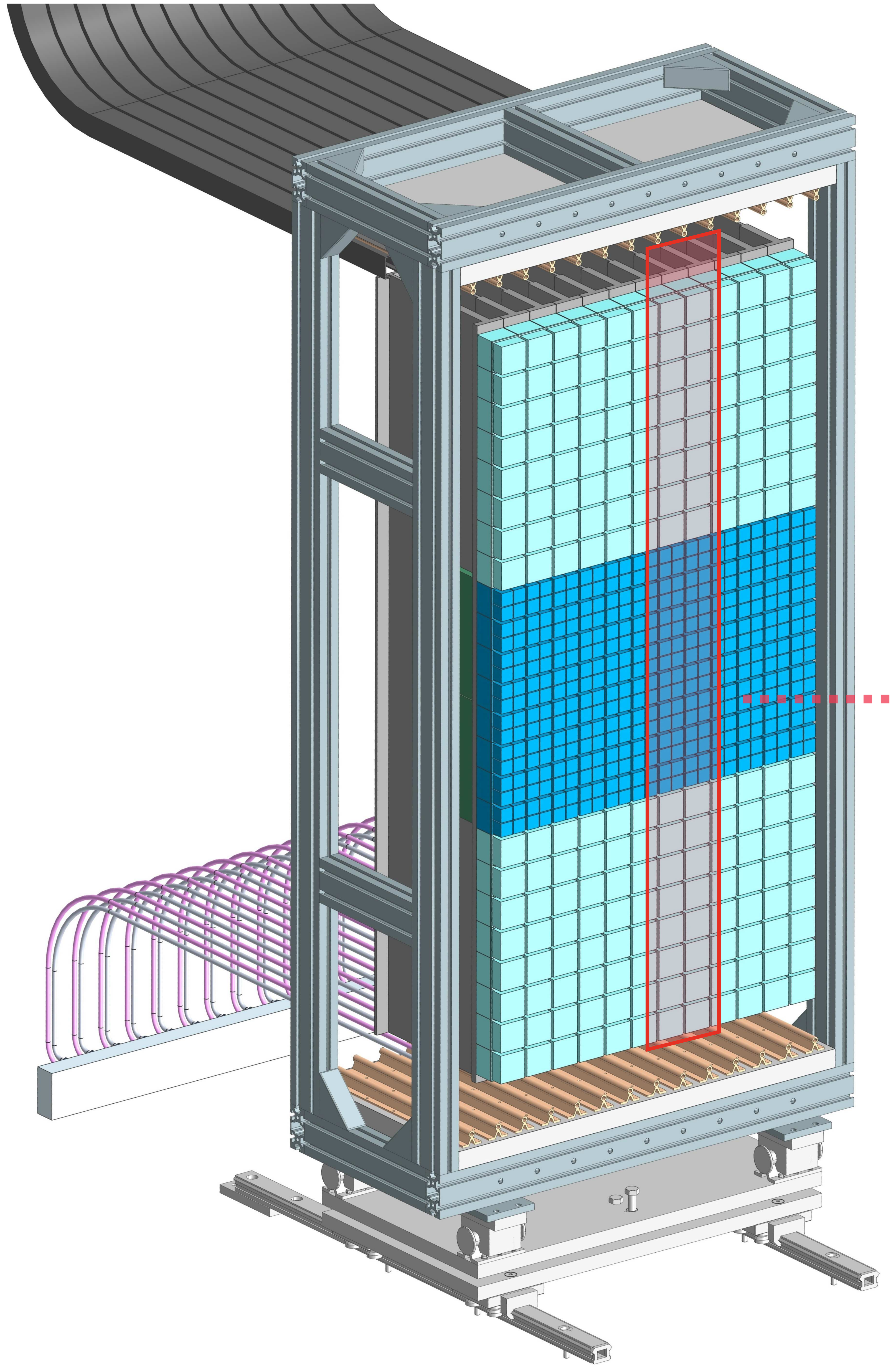
Beam test set-up

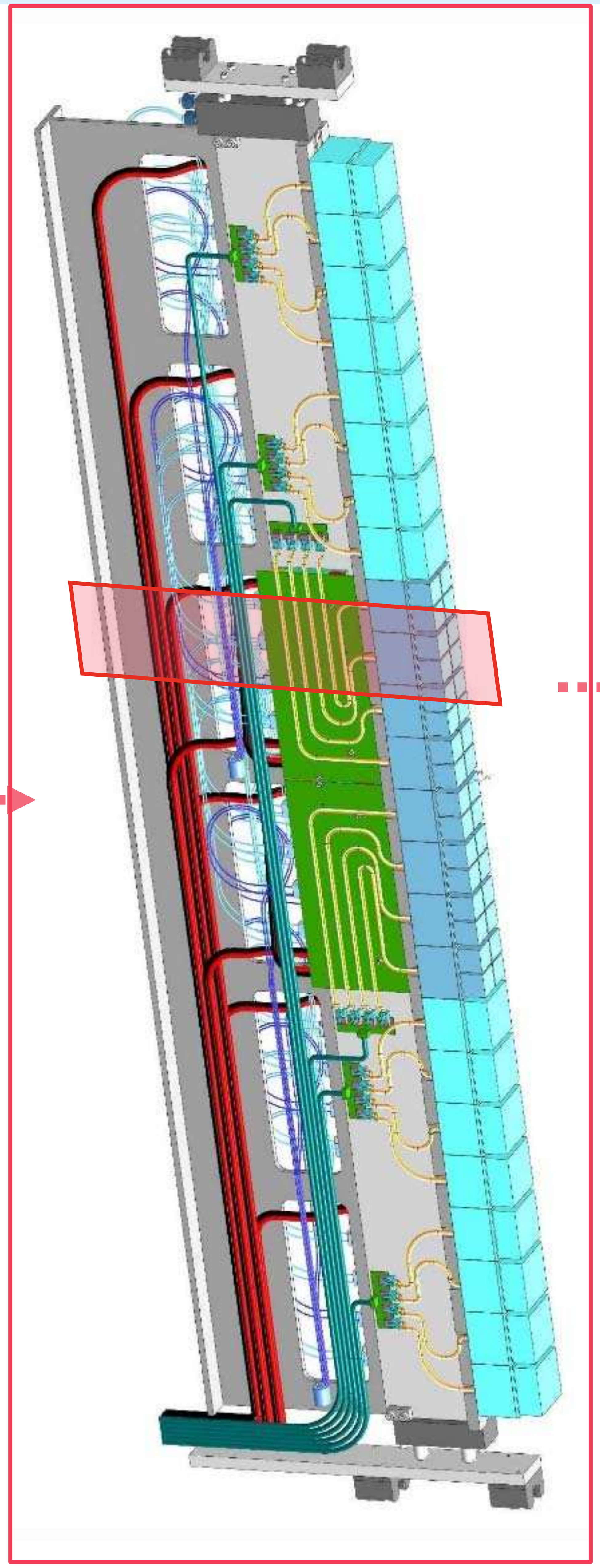


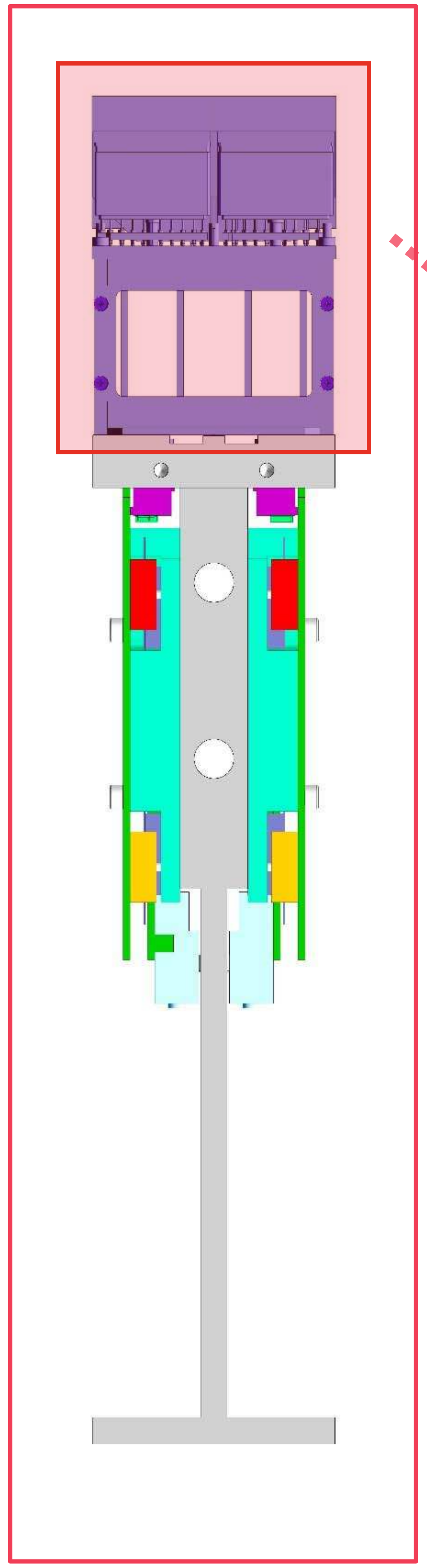
Schematic of photon path in set-up (top view)

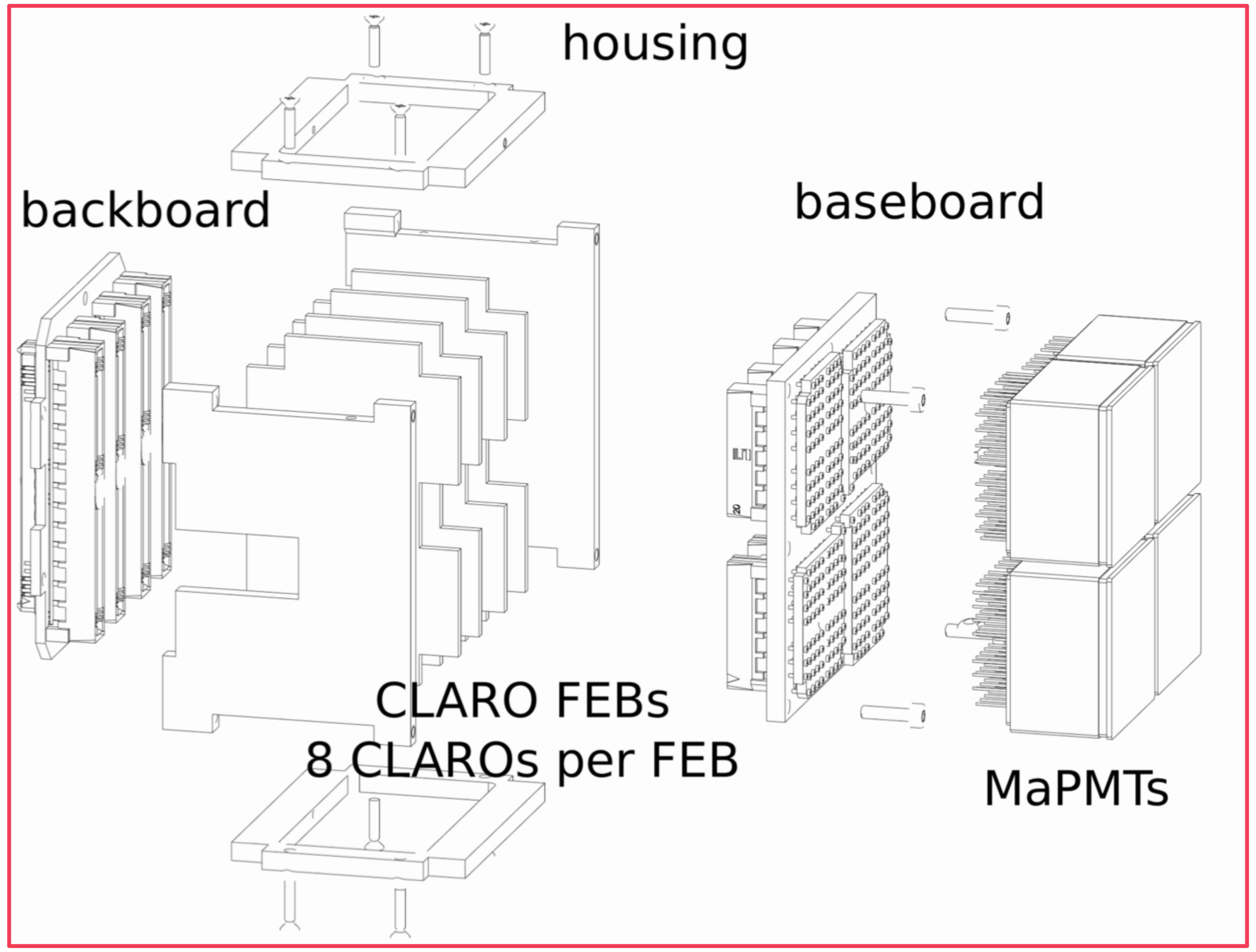


Photon detector assembly



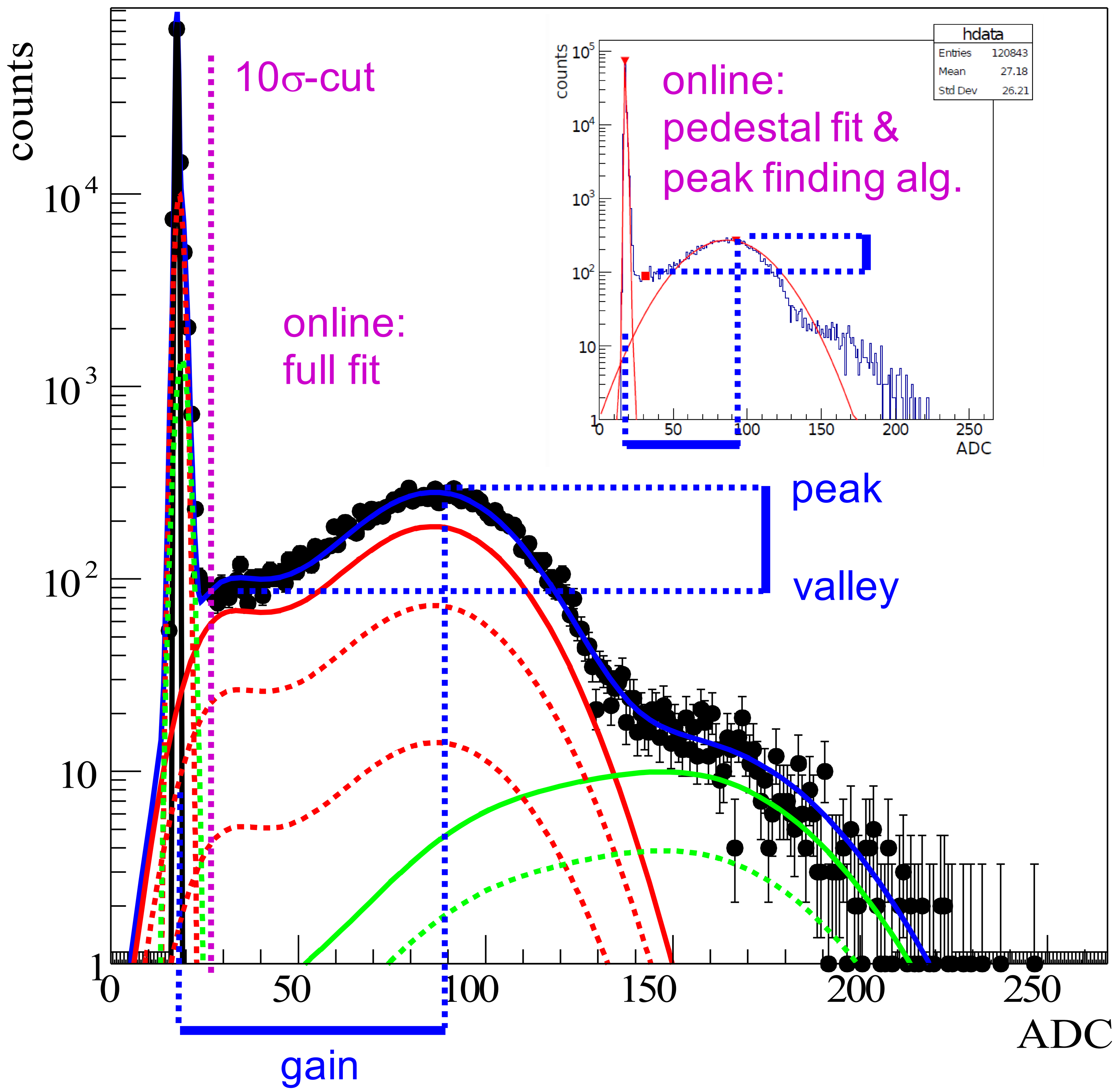






Hamamatsu MaPMTs

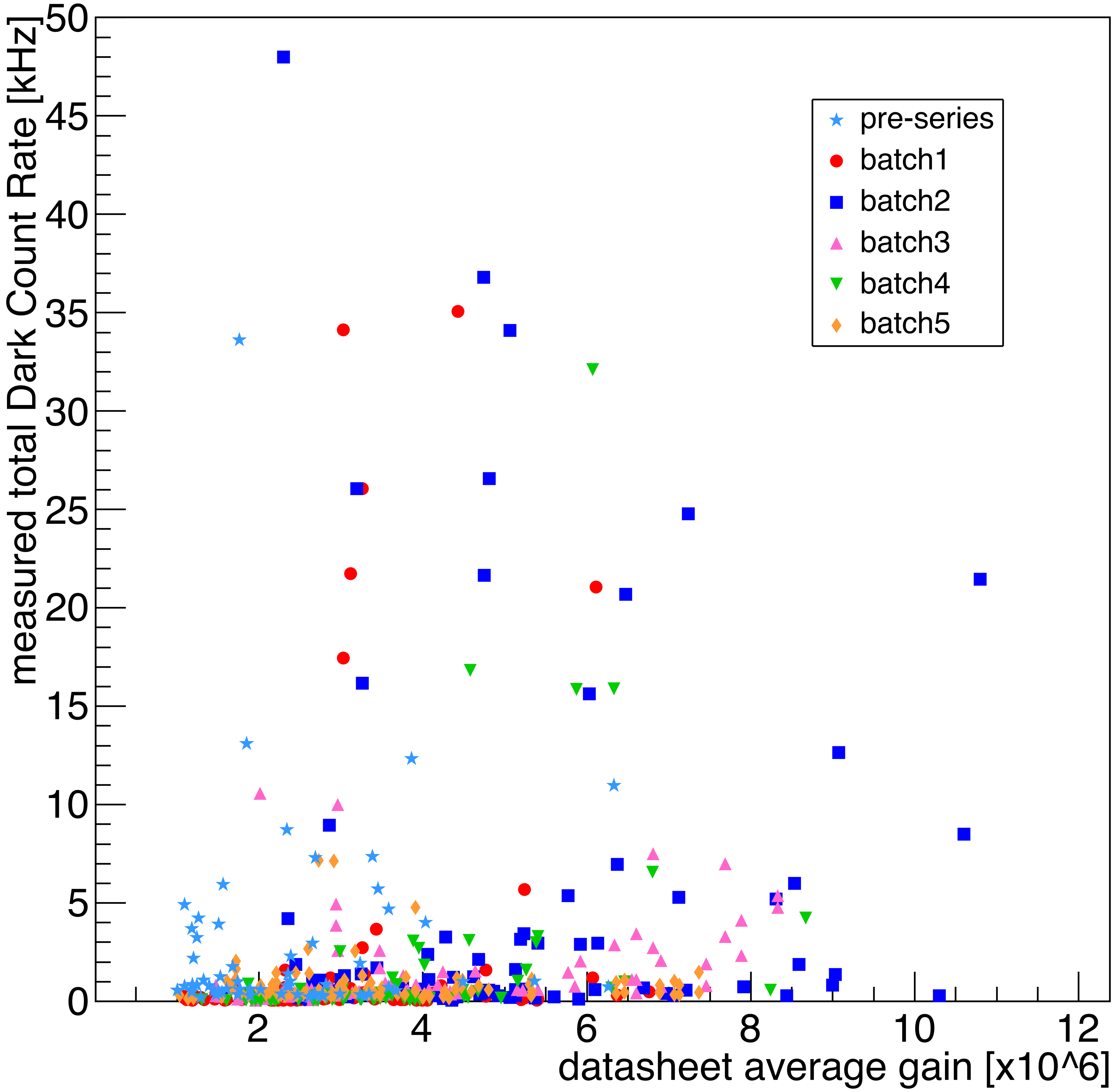
Negligible cross talk and dark count rate.
Single photon sensitivity for wavelengths between 200 nm and 600 nm.



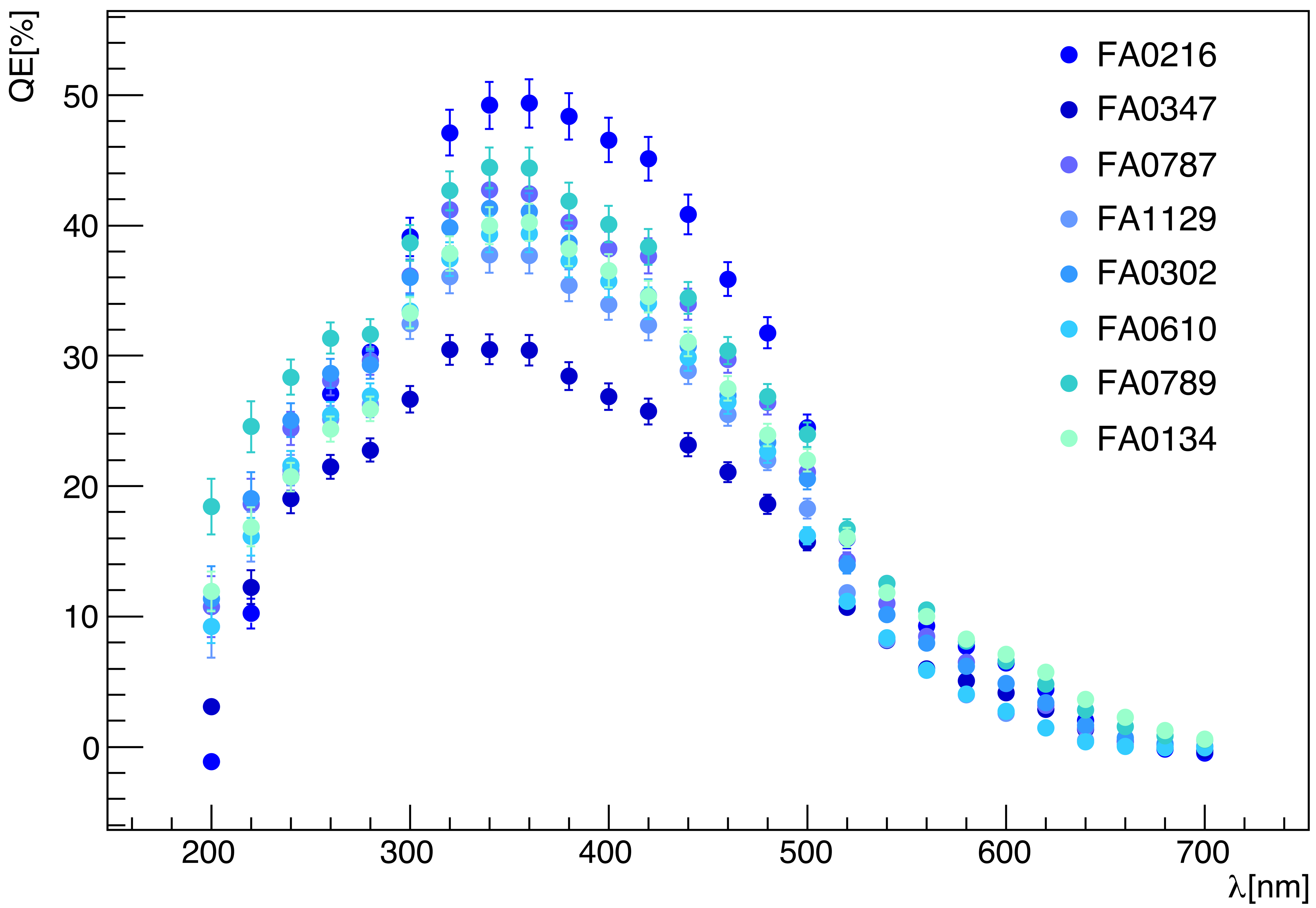
8 x 8 channel multi-anode photomultiplier tubes.
3100 (incl. spares) 1 x 1 in^2 version for RICH 1 and high-occupancy regions of RICH 2.
450 (incl. spares) 2 x 2 in^2 version for low-occupancy regions of RICH2.

MaPMT quality assurance

Dark count rate vs. gain

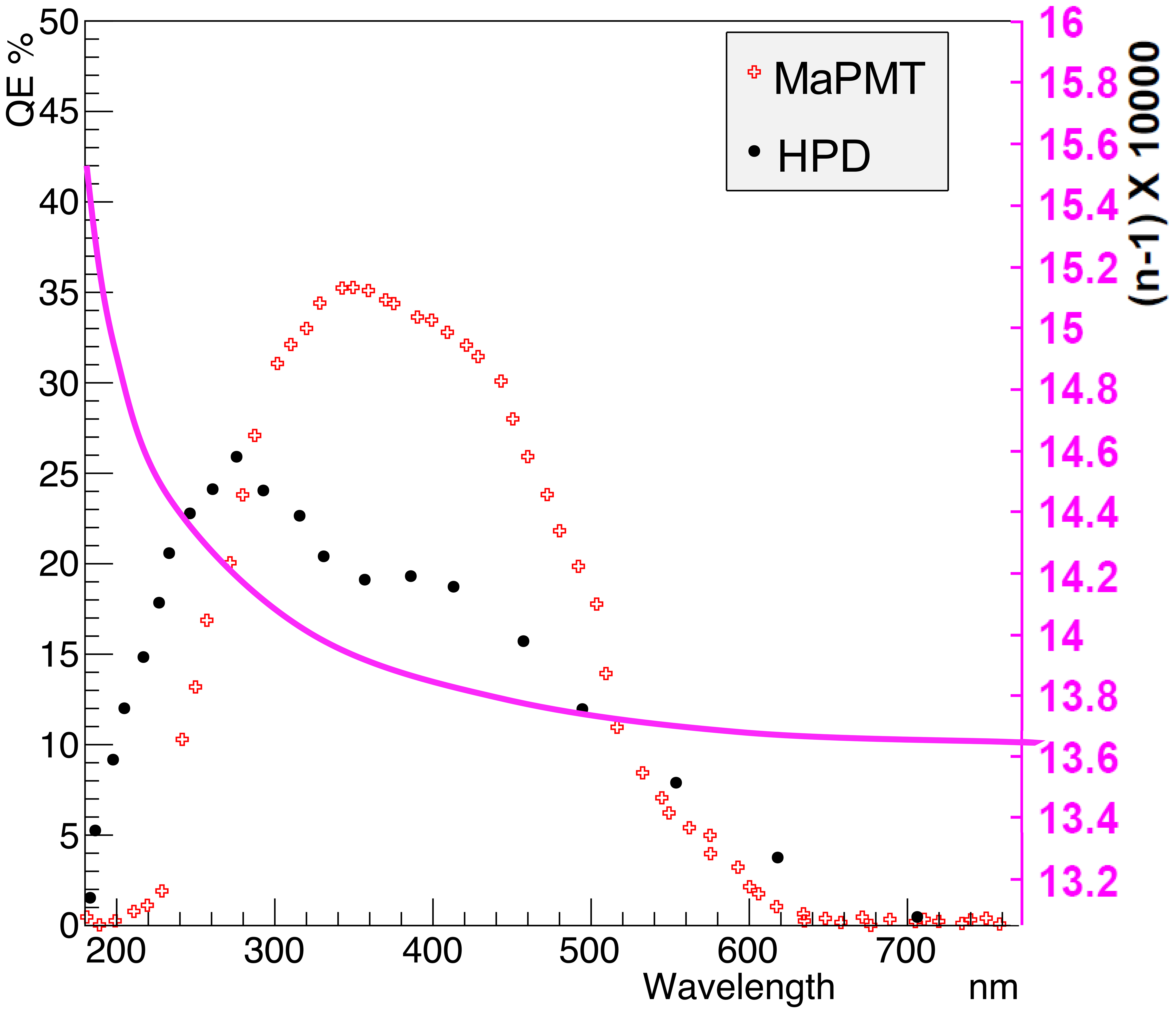


Quantum efficiency



Silvia Gambetta et al.

Quantum efficiency



Quantum efficiency of MaPMT (super-bialkali photocathode and borosilicate glass entrance) more sensitive in the green wavelength region where the refractive index of C_4F_{10} is more stable.

→ Reduces chromatic uncertainty.

Resolution & yield

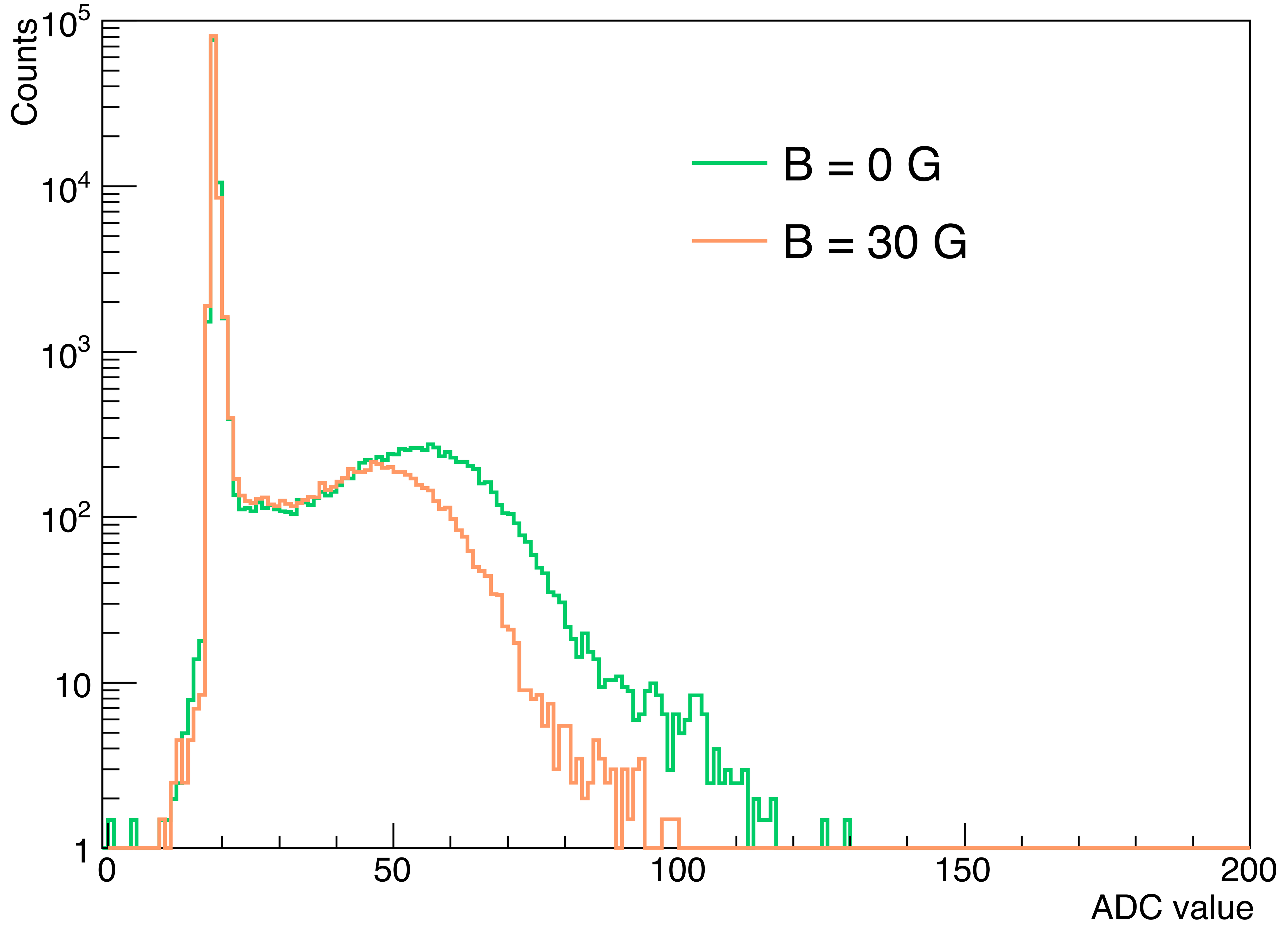
Expected improvements of Cherenkov angle uncertainties and photon yield

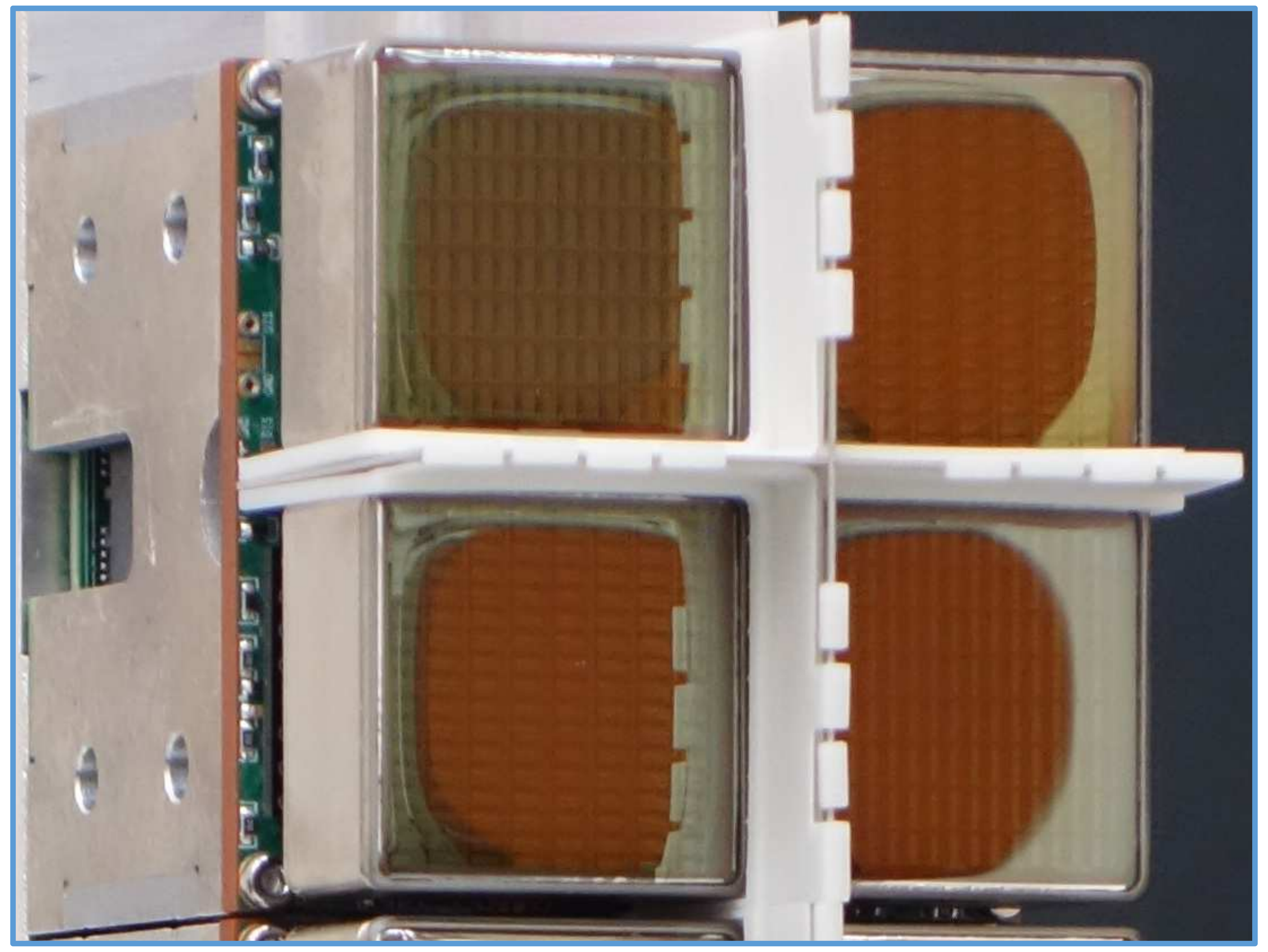
	Chromatic uncertainty [mrad]	Emission point uncertainty [mrad]	Pixel uncertainty [mrad]	Total uncertainty (resolution) [mrad]	Photon Yield
Current RICH 1	0.84	0.76	1.04	1.60	32
Upgraded RICH 1	0.57	0.36	0.45	0.78	41.2
Current RICH 2	0.48	0.27	0.35	0.65	24
Upgraded RICH 2	0.31	0.26	0.20	0.45	23

Elementary cell shielding

Stray magnetic field up to 25 G in RICH 1.

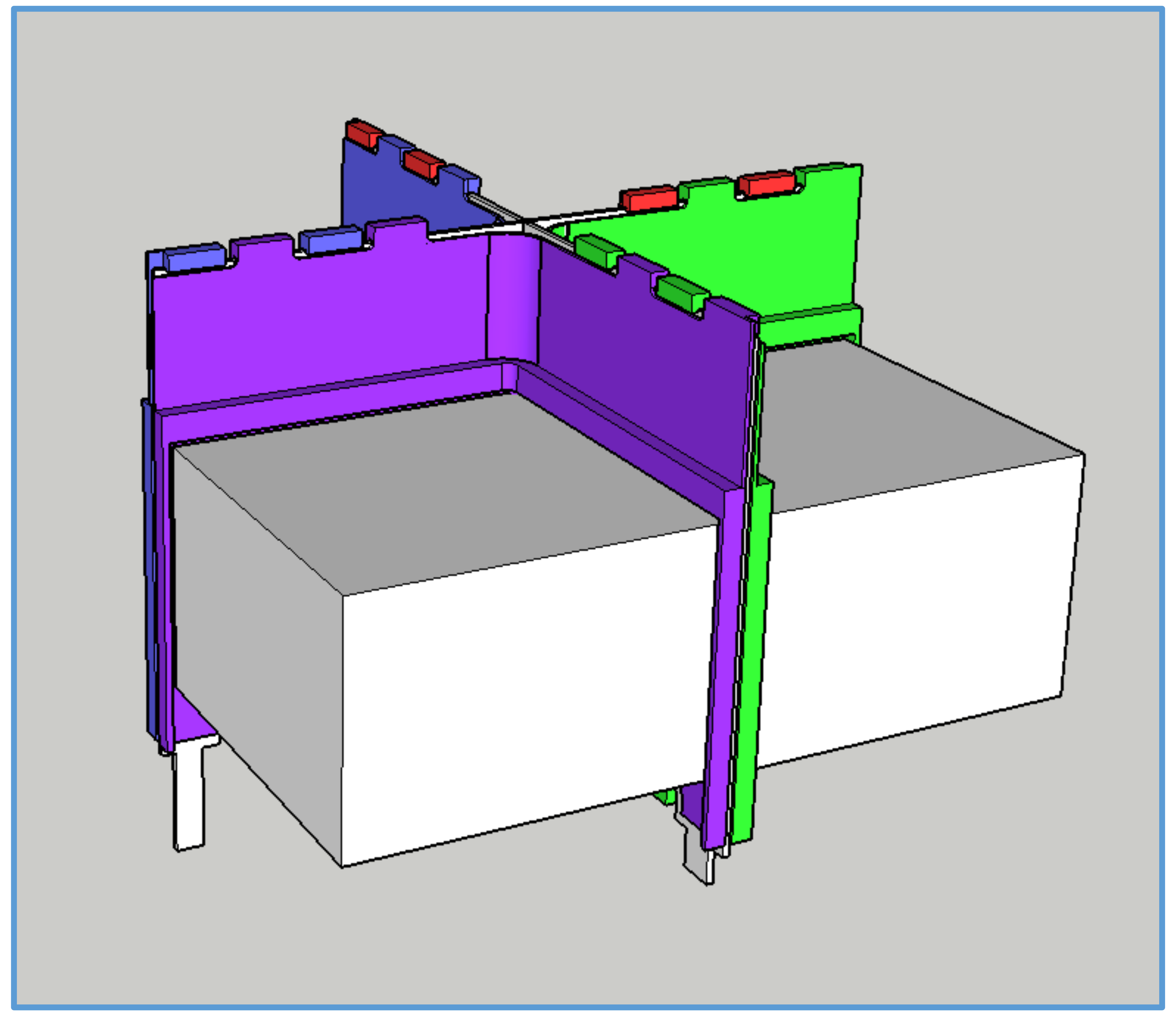
Longitudinal field degrades detection efficiency and gain.





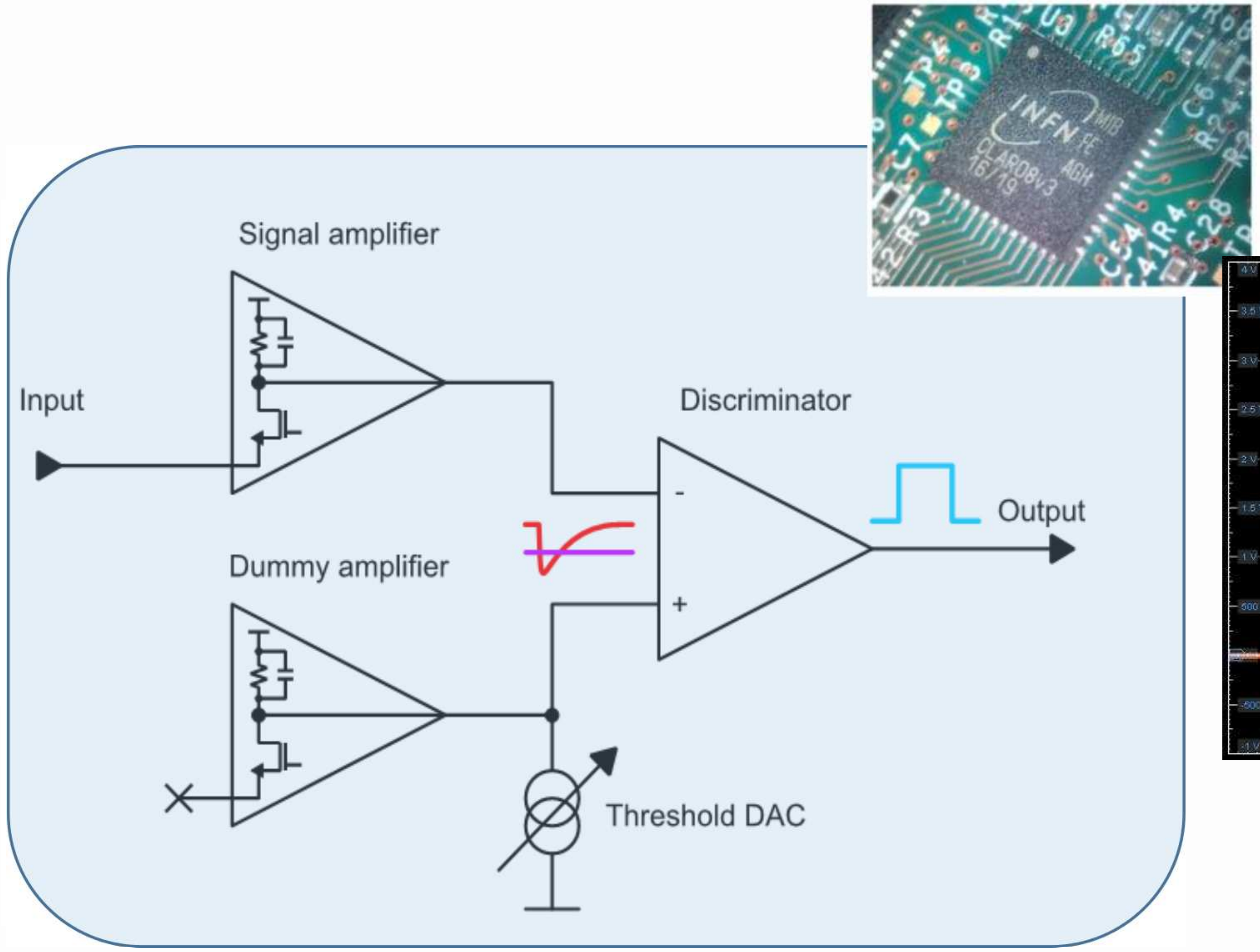
Recovered by mu-metal shielding.

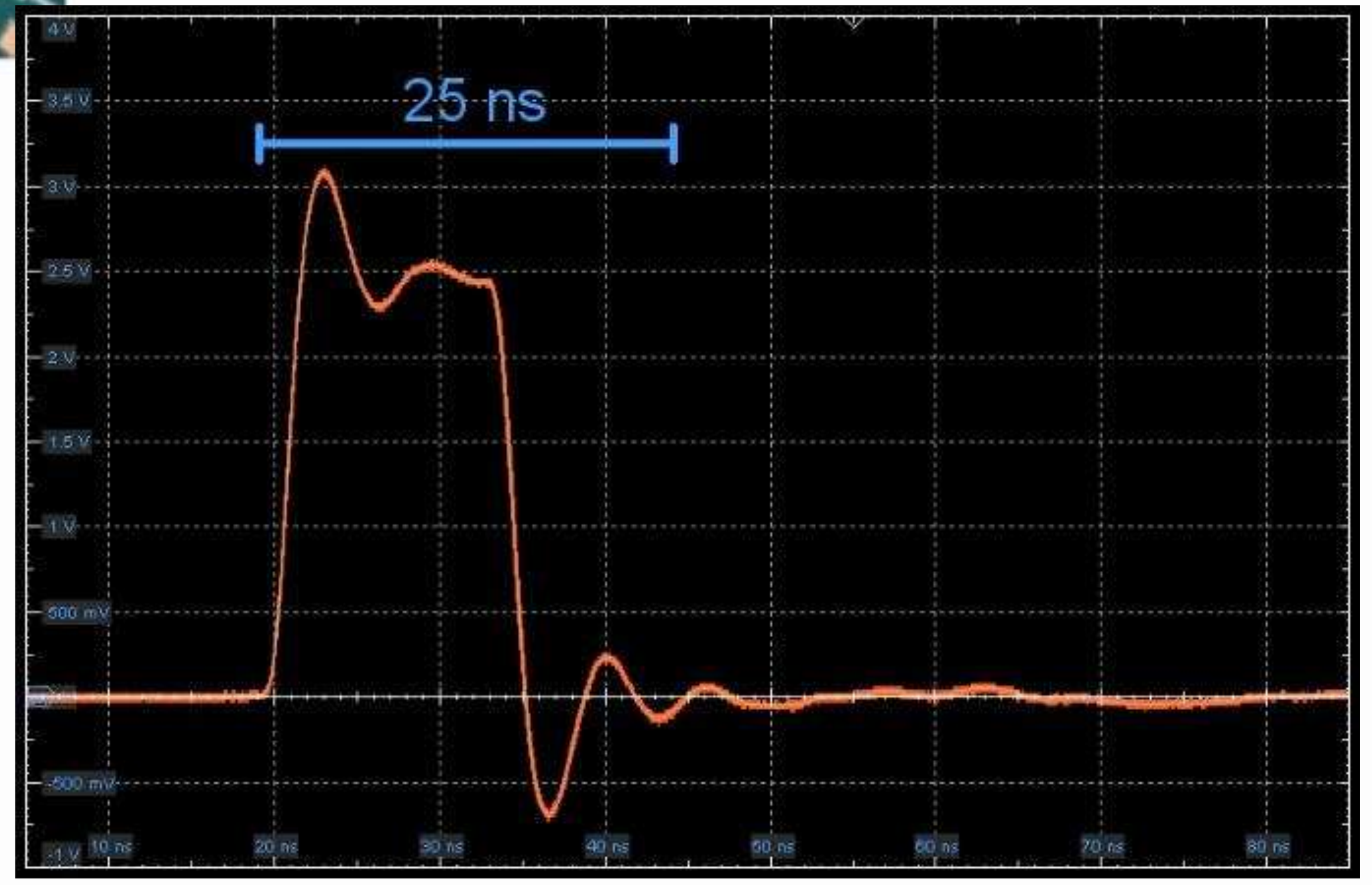
Shielding additionally provides 1kV HV–insulation.



Didier Piedigrossi et al.

CLARO read-out chip



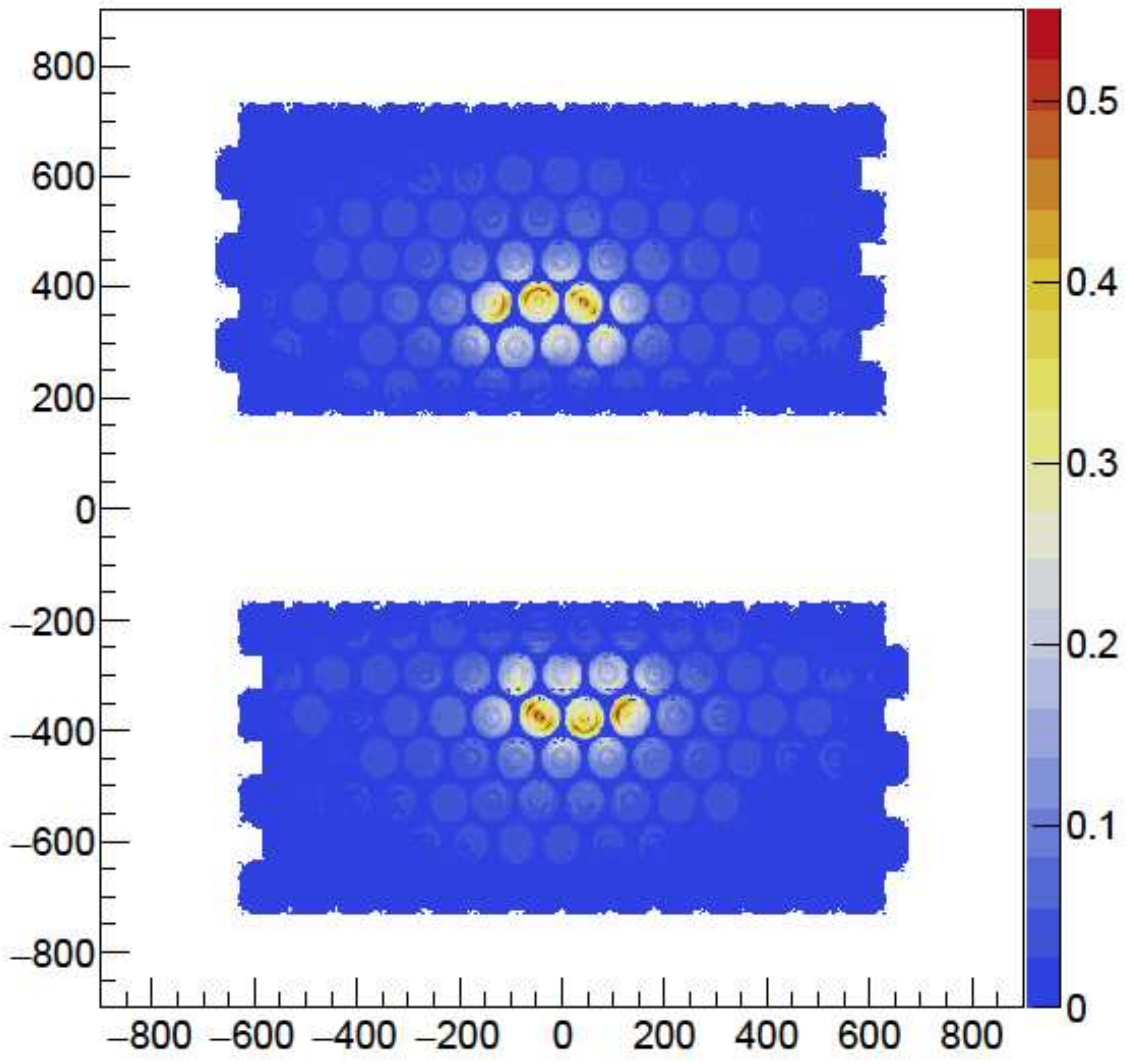


CLARO output signal

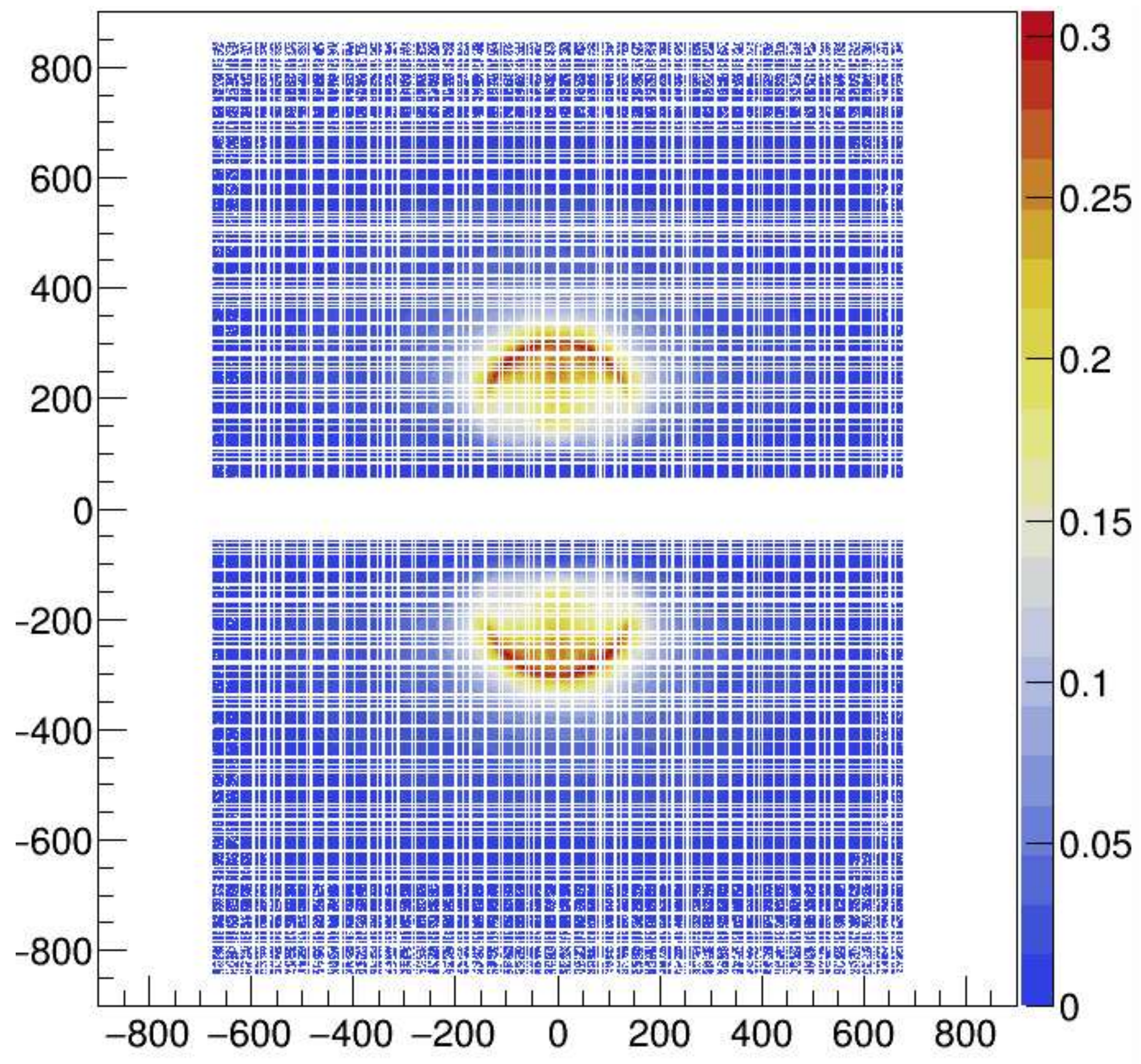
- 8 channel custom ASIC (CMOS)
- Single photon counting at 40 MHz
- Low power consumption
- Radiation tolerant
- Settable gain (4 options) and threshold (64 options)

Occupancy and PID performance

Occupancy for $L_{inst} = 2\times10^{33} cm^{-2} s^{-1}$

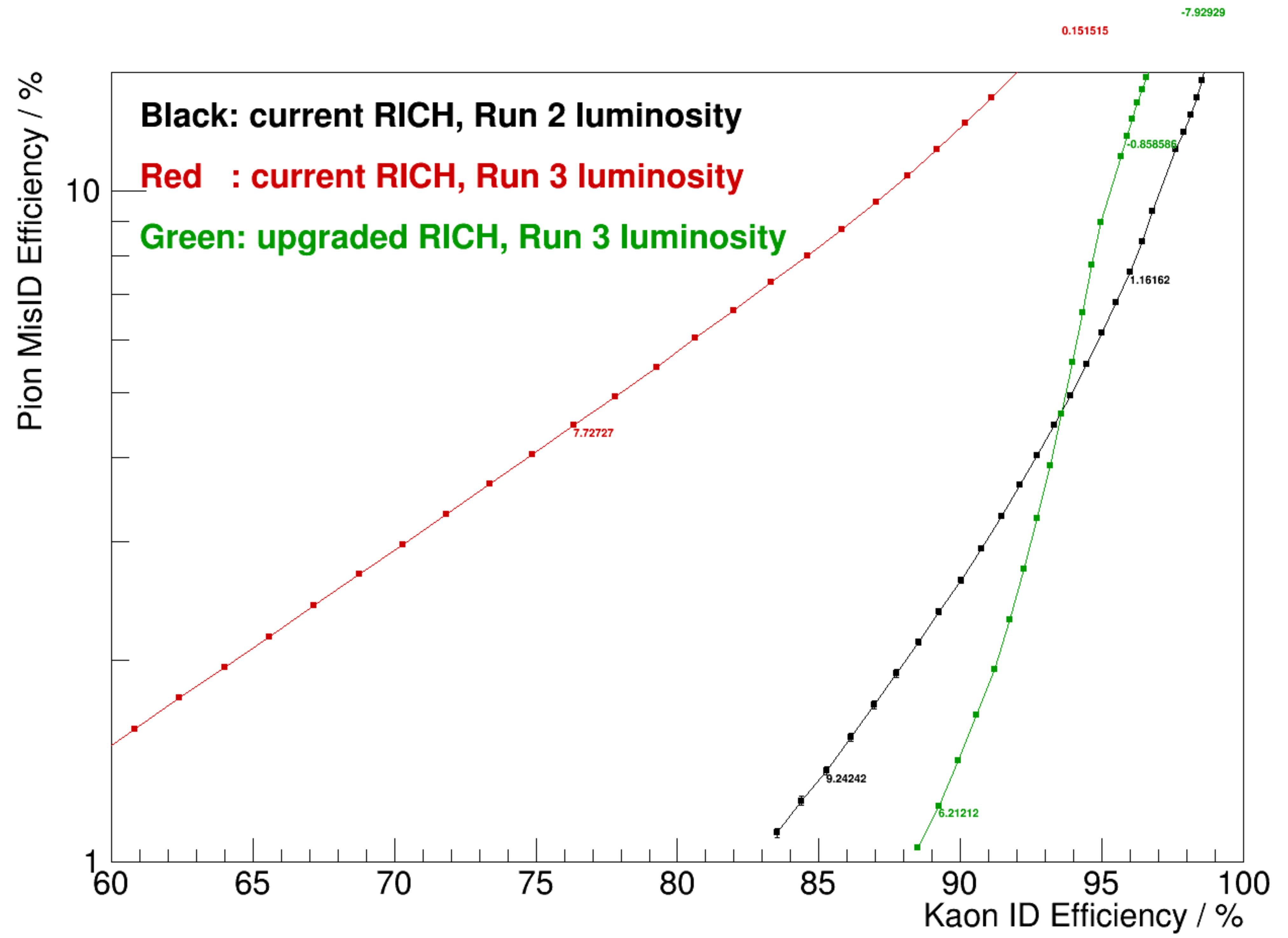


Current detection system



Upgraded detection system

Kaon ID



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