

The LHCb RICH Upgrade II

Silvia Gambetta

The 2026 International Workshop on the High Energy Circular Electron Positron Collider

THE UNIVERSITY of EDINBURGH

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The LHCb Upgrade II - When and Why

LHCb experiment [2010-2018], collected 9 fb^{-1} [JINST 3 S08005]

LHCb Upgrade I [2022-2033], collected so far 28 fb^{-1}, expect to collect 50 fb^{-1} [JINST 19 P05065]

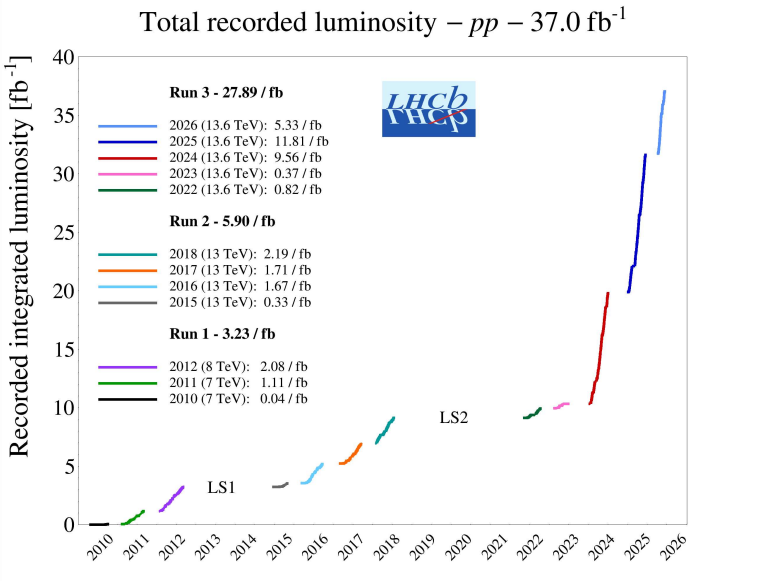
LHCb Upgrade II [2035-], expected to collect 300 fb^{-1}

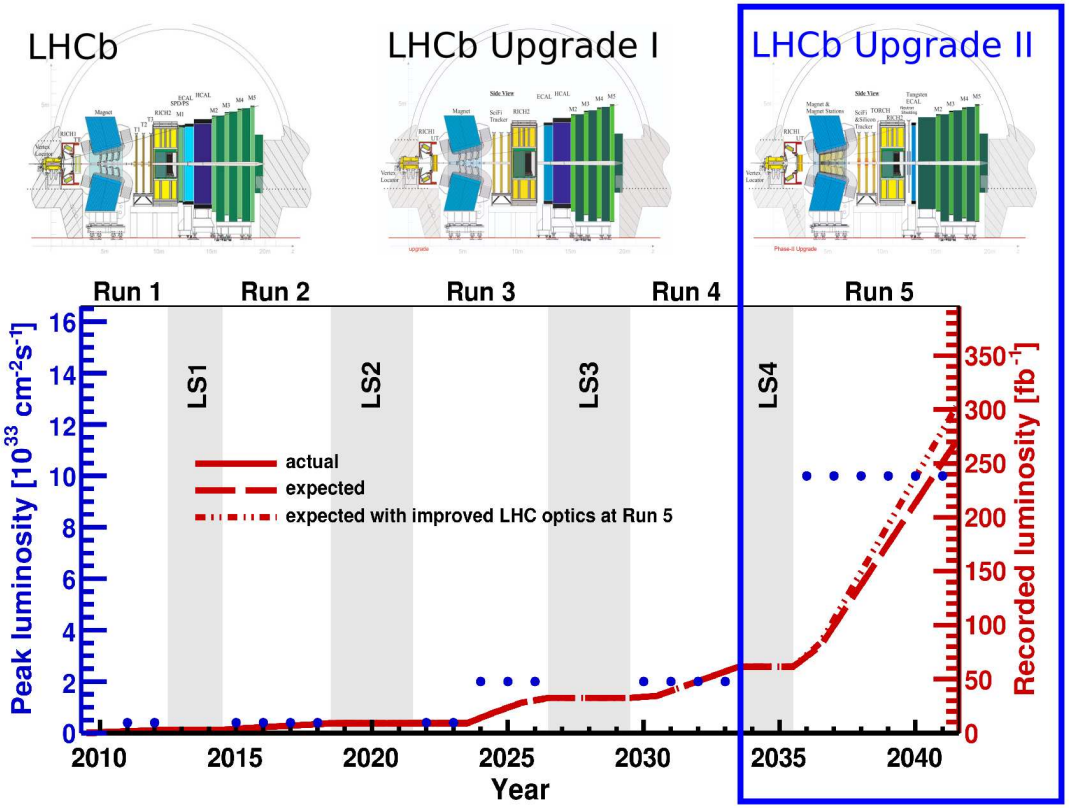
[CERN-LHCC-2017-003]

[CERN-LHCC-2018-027]

[CERN-LHCC-2021-012]

[CERN-LHCC-2024-010]





Full redesign of the LHCb experiment (same footprint): five-fold increase of Upgrade I instantaneous luminosity to fully exploit High-Lumi LHC

More in this workshop:

Vinicius' talk on Velo

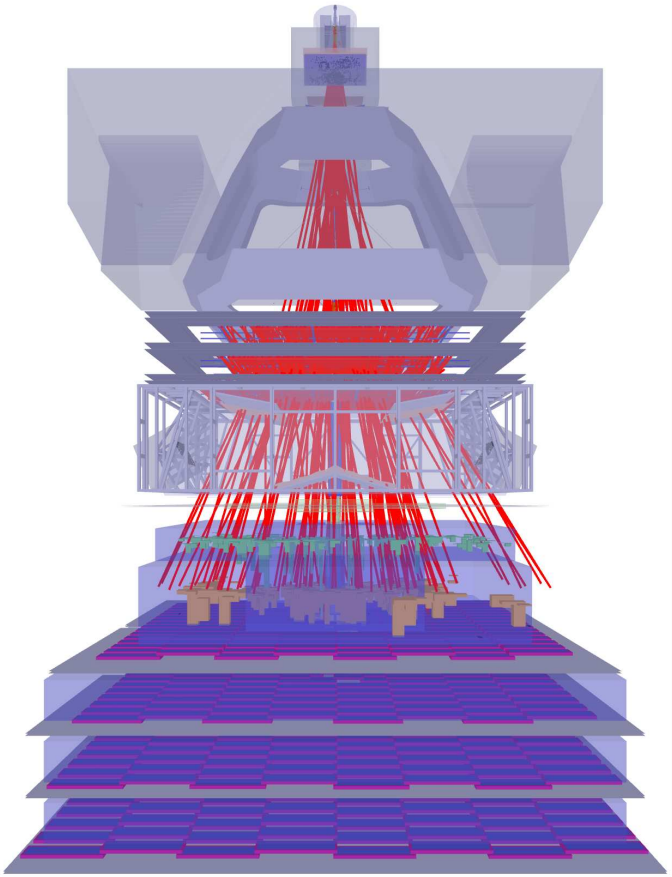
Yanyan's talk on HV-CMOS

Zehua's talk on LHCb highlights

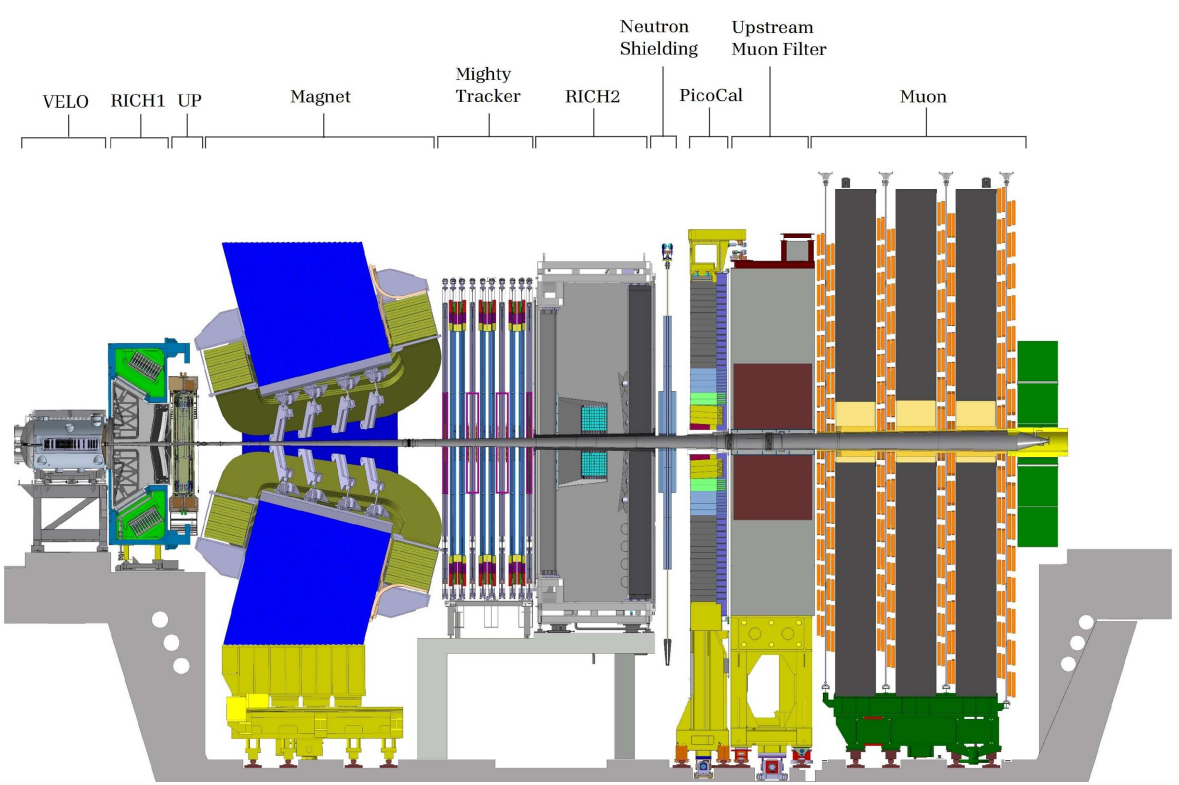
Vincenzo's overview of Flavour Physics

LHCb Upgrade II - How

LHCb forward geometry characterised by high track density



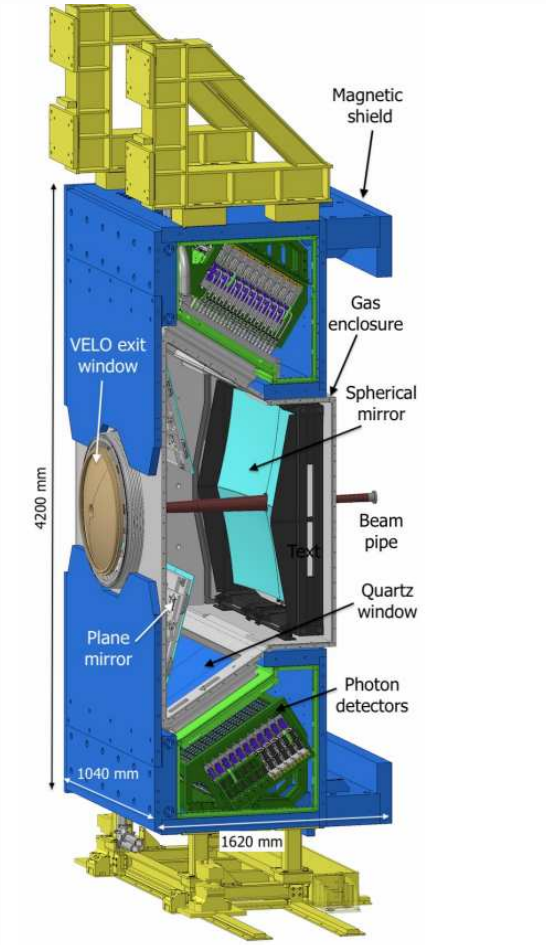
Run3 event display

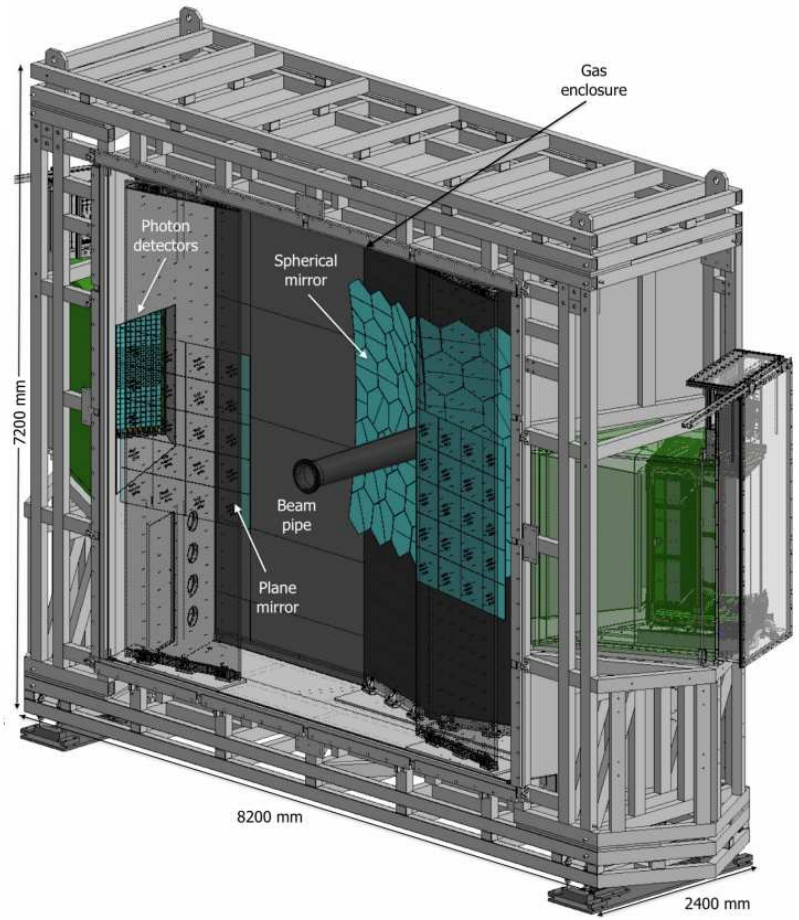


Five-fold increase in lumi $\Rightarrow$ almost totality of sensitive material will be rebuilt, 100% readout channel will be replaced, new DAQ and data distribution chain

- New tracking system: new Vertex Locator, new Upstream Tracker, new Mighty Tracker (downstream tracker)
- New PID system: new Ring Imaging Cherenkov detectors, new PicoCal (electromagnetic calo), enhanced Muon system

The RICH system - the enabler of the LHCb physics





- RICH 1 (C_4F_{10}): upstream, 2 GeV/c - 40 GeV/c over 25 mrad - 300 mrad
- RICH 2 (CF_4): downstream, 15 GeV/c - 100 GeV/c over 15 mrad - 120 mrad
- system installed and operated in Run1&2, Upgraded in Run3

[Eur. Phys. J. C 73 (2013) 2431]

[JINST 17 P07013 (2022)]

A quick crash course in RICH detectors

Charged hadrons (pions, kaons and protons) identification in a wide range of momenta
$\Rightarrow$ dedicated particle identification system based on detection of Cherenkov radiation, in crowded environment

Separation power: $n_\sigma = |m_1^2 - m_2^2|/2p\Delta\theta_C \tan\theta_C$

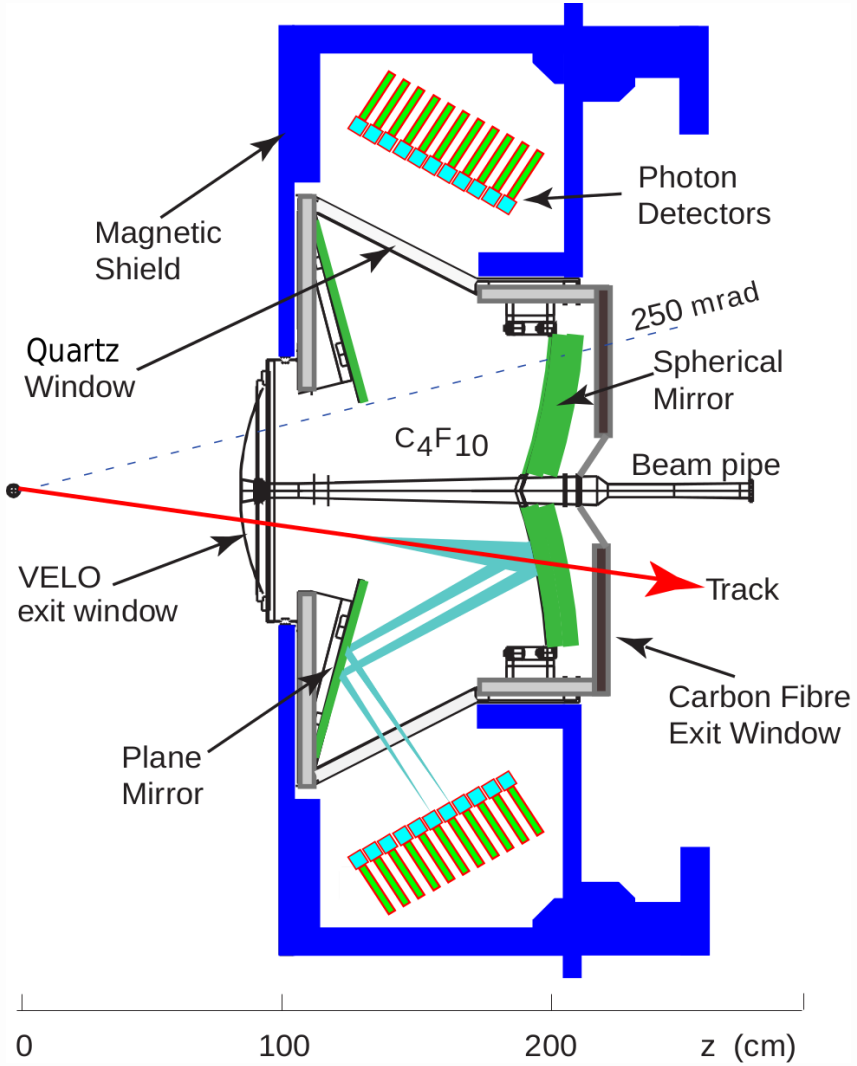
Where:
$\Delta\theta_C = \sigma_C/\sqrt{N_{ph}} \oplus C_{trk}$

Single photon resolution key parameter to discriminate particles

- Chromatic matching between refractive index dispersion and Photon Detector Efficiency (PDE)
- Emission Point due to tilting of mirrors
- Pixel Error due to finite size of photon detector pixel

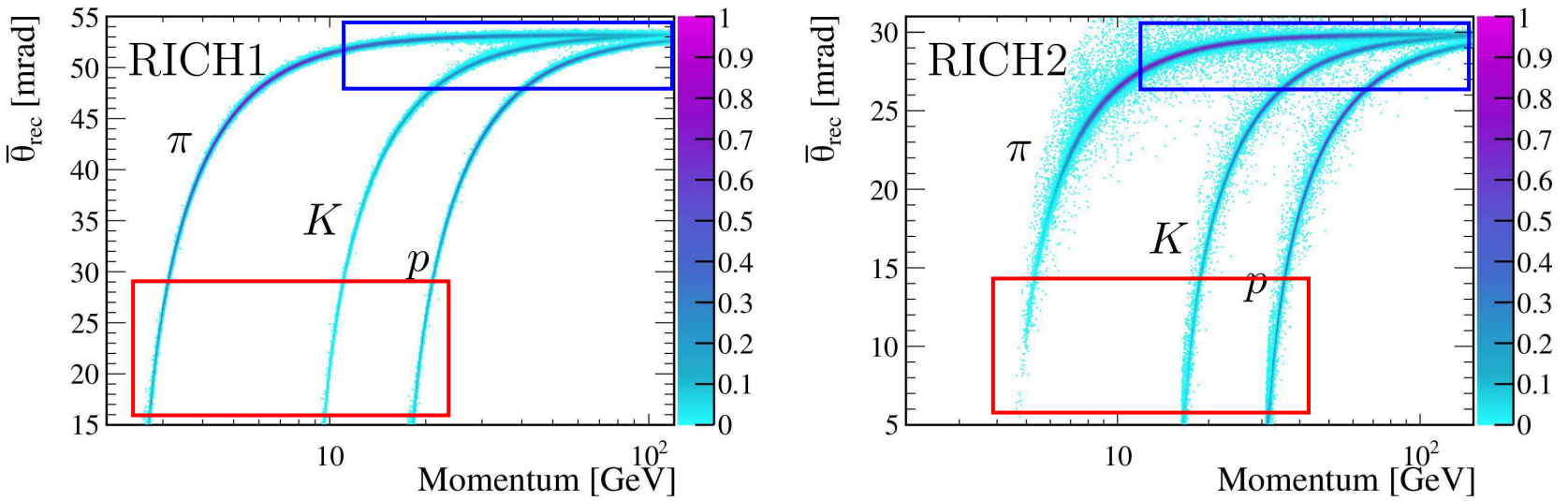
Number of photons guarantees better performance and robust reconstruction

Tracking information important for trajectory/curvature, intrinsic tracking resolution and momentum information

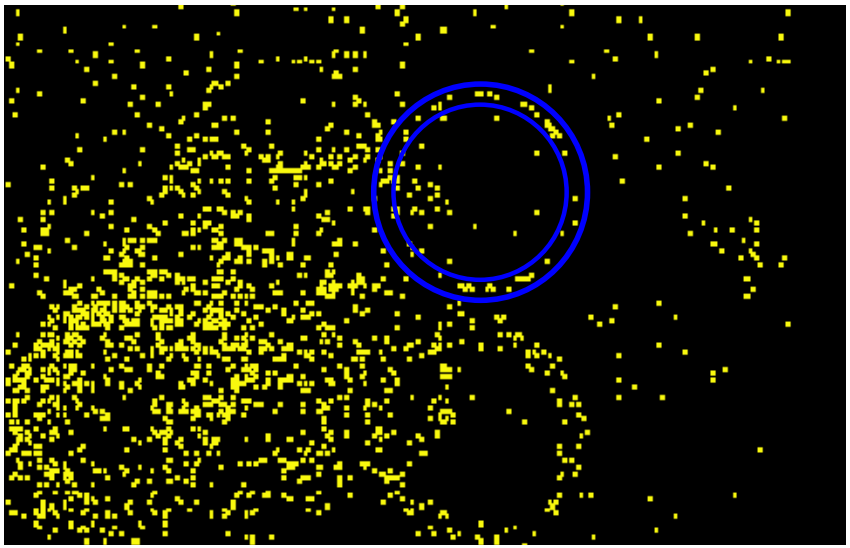


Recipe: resolution and number of photons

- ■ - saturation region: at high momentum particles are more challenging to distinguish
- ■ - threshold region: momentum threshold for a particle to emit Cherenkov radiation

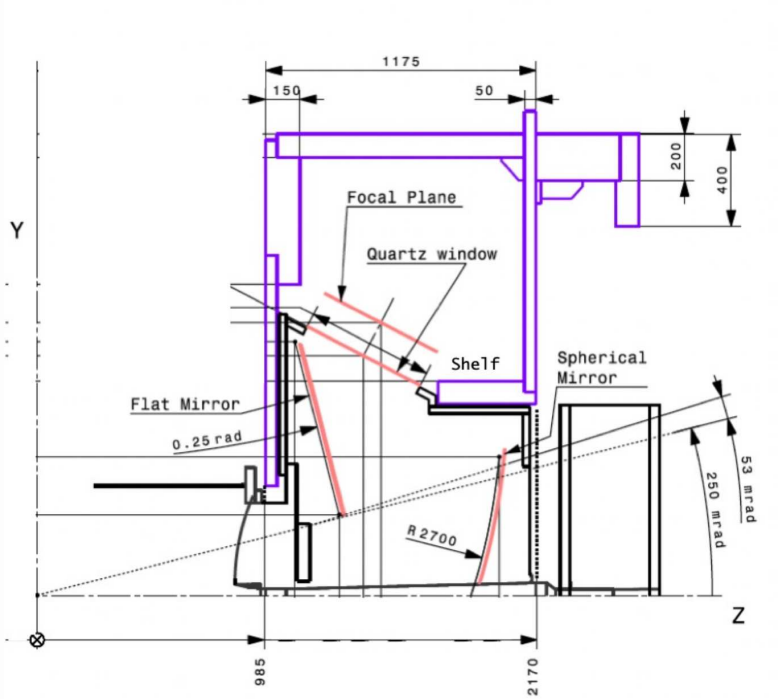


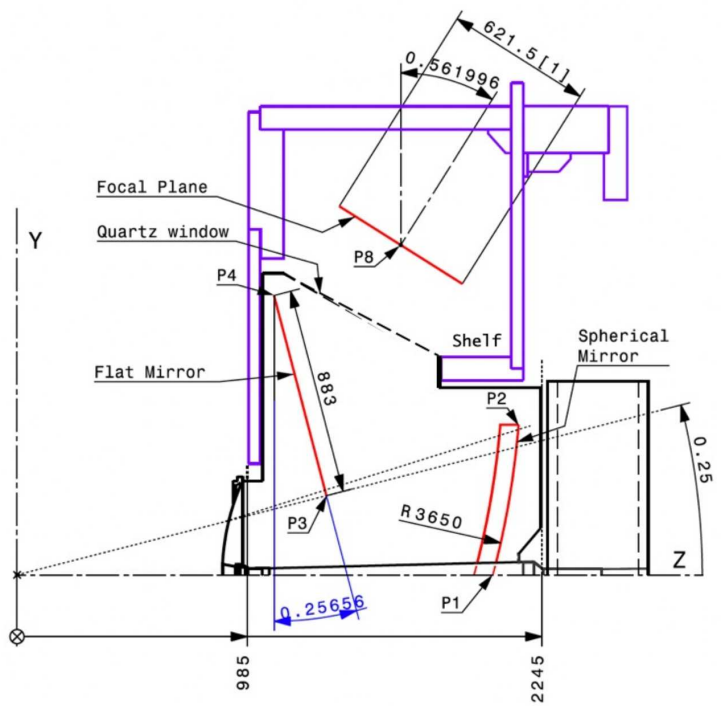
- Improve the single photon resolution to ensure robustness in very crowded environment (∼100 tracks per hard scattering *pp* event in Run 3)
- single photons are the signal detected by the RICH photon detectors: larger photon yield improves track association and PID performance
- cope with peak occupancy expected in Upgrade II: tune granularity and introduce timing

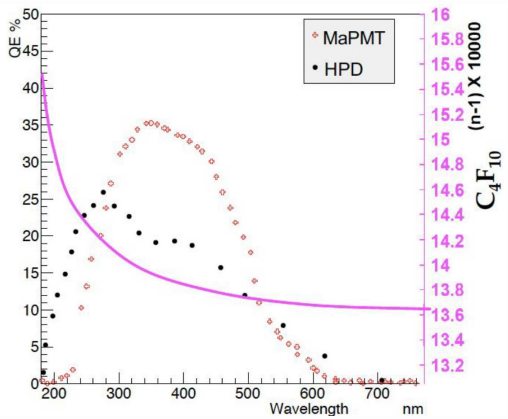


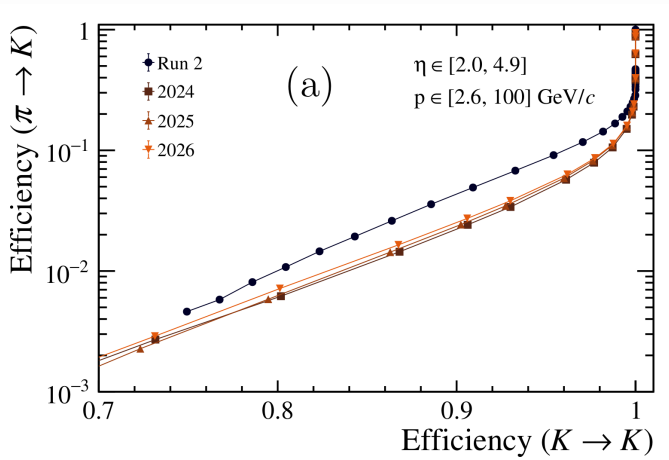
The Upgrade I benchmark: the recipe for success

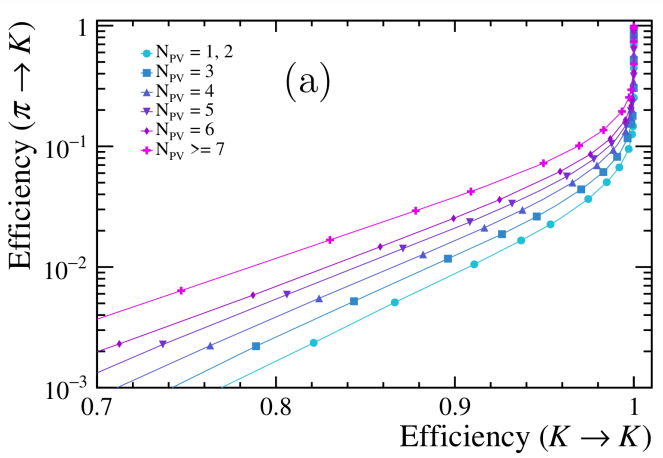
Modified optics, lower chromatic dispersion, more photons ⇒ better resolution, PID exceeding design performance





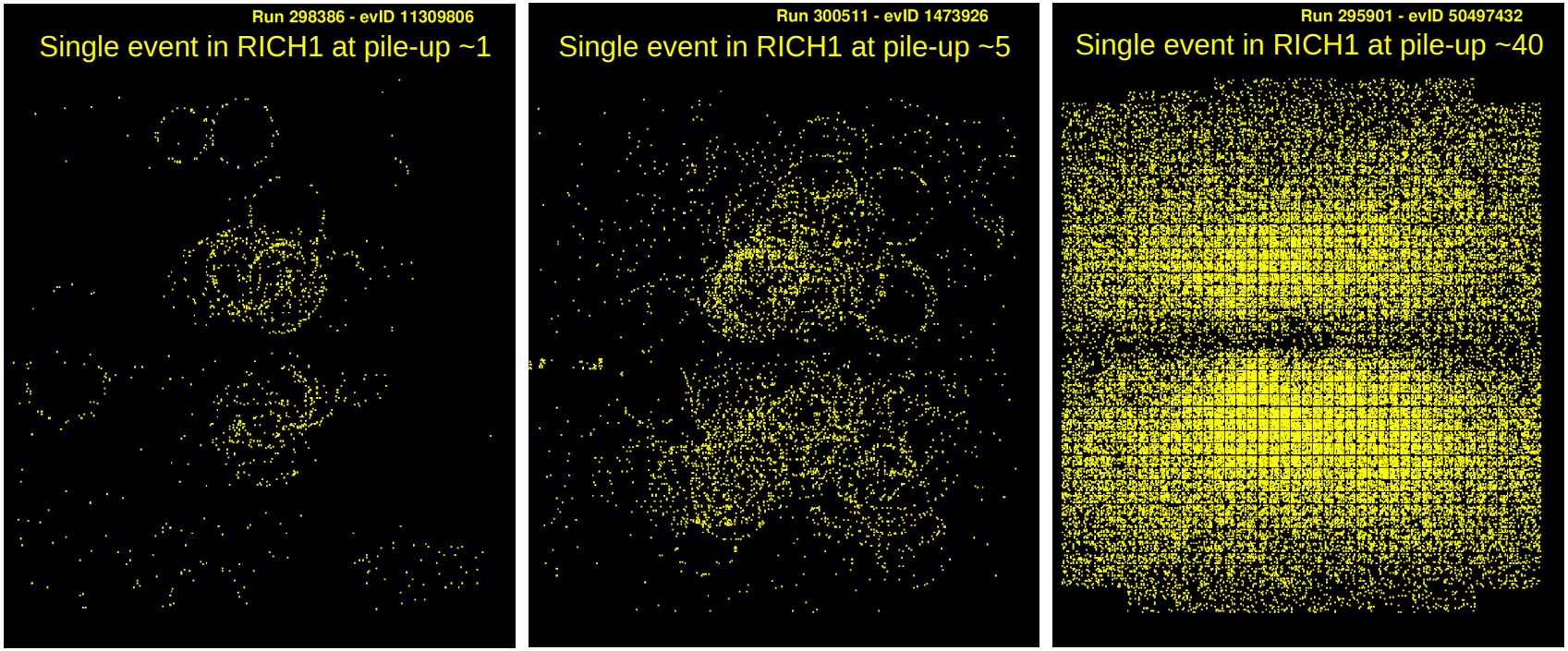






The Upgrade II challenge

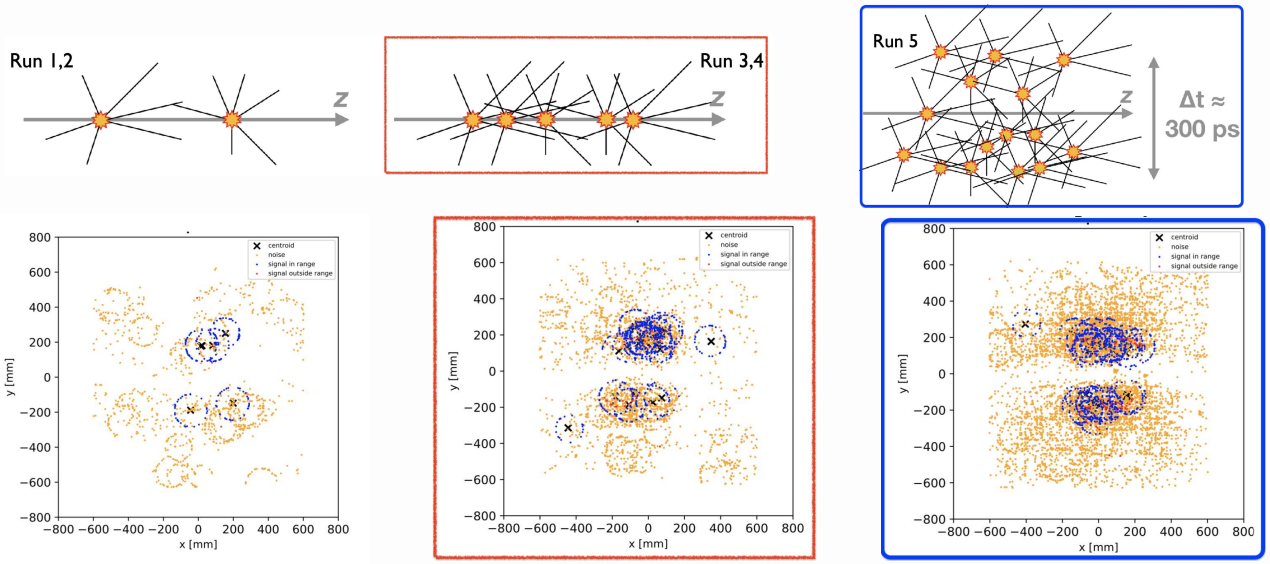
Evolution of typical single events in RICH1 in Run 2 - Run 3 and expected Run 5



- New photon detectors to cope with increased luminosity (RICH1 and RICH2)
- New mechanical structure with challenges imposed by photon detector choice and existing cavern footprint (RICH1)
- New optics to improve resolution (RICH1)

Requirements for photon detectors in Upgrade II

Increase in pile-up to ∼30 implies major technological challenges



RICH1 rings with 1 PV

RICH1 rings with 5 PVs

RICH1 rings with 10 PVs

- higher granularity
- introduction of timing helps reducing background and having a better photon association to tracks from the same Primary Vertex (⇒ timing information from PVs is critical ingredient, interplay with other detectors choices)
- **very high fluence**, especially in RICH1

(rings in blue matching search window for the input tracks)

Photon Detectors

SiPM

- versatile → can easily accommodate finer granularity
- good timing
- resilient to magnetic field → RICH 1 shield could be removed with gain of space
- high DCR after irradiation → challenging operations

MCP

- can accommodate finer granularity → study of charge sharing
- limited rate capability → limited areas in the RICH where they could be operated
- excellent timing
- resilient to magnetic field

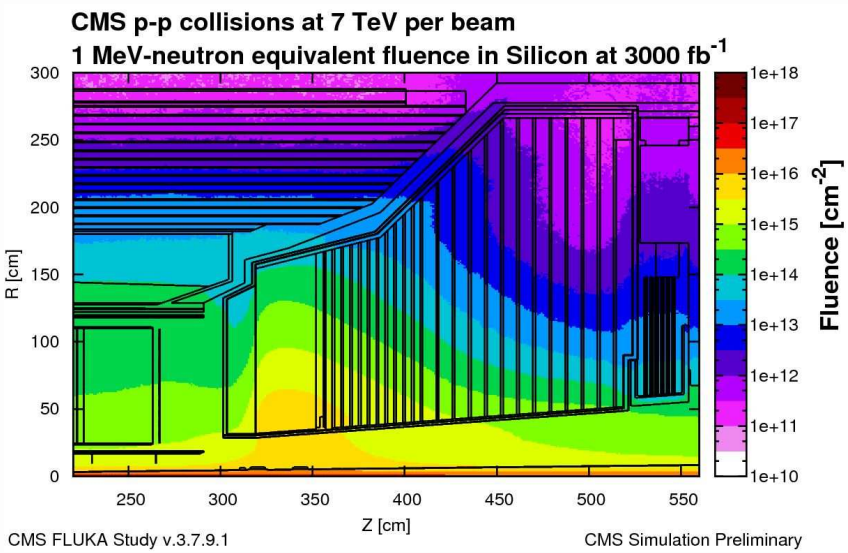
MaPMTs

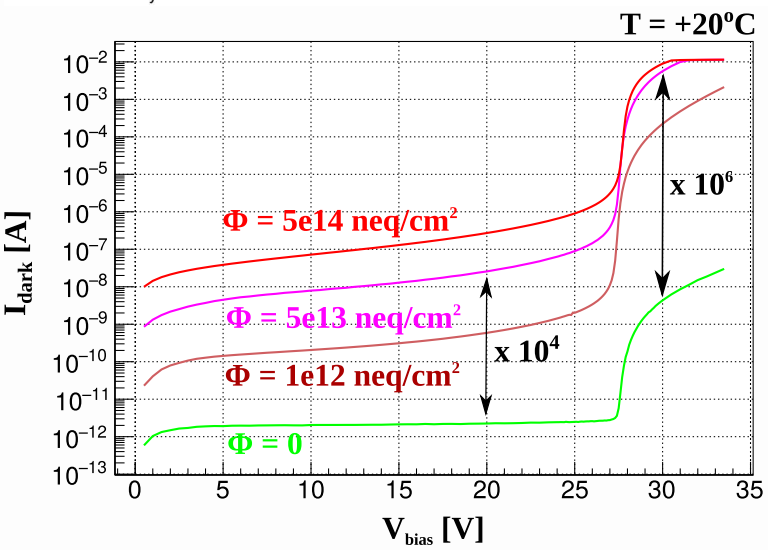
- robust and reliable technology (currently operated in LHCb)
- granularity limited for high occupancy regions
- limited timing
- not resilient to magnetic field

⇒ R&D carried out on different technologies

SiPMs trend in HEP

Trends in SiPMs (not a review)
SiPMs employed in calorimetry, tracking and now increasing trend in PID (both ALICE3 and LHCb Upgrade II)





https://doi.org/10.1016/j.nima.2017.11.003

From E. Garutti's summary of radiation effects in SiPMs at PD2025

Some requirements examples:

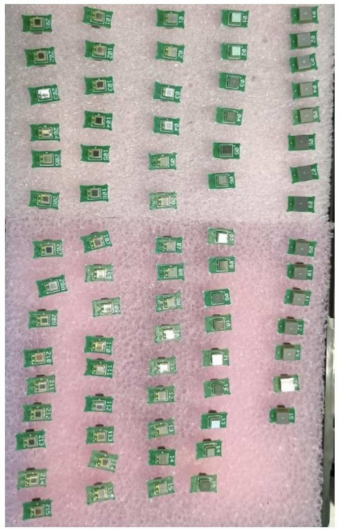
- Imaging calorimeters for collider experiments: Hadronic calorimeter for lepton collider (CALICE) $\rightarrow \phi_{eq} \sim 10^{10}, cm^{-2}$ after $500\,fb^{-1}$
- Upgrade of CMS hadronic calorimeter (HGCAL) $\rightarrow \phi_{eq} \sim 5 \times 10^{13}\,cm^{-2}$ after $3000\,fb^{-1}$
- New CMS MIP timing detector $\rightarrow \phi_{eq} \sim 2 \times 10^{14}\,cm^{-2}$ after $3000\,fb^{-1}$
- RICH detectors at EIC: Single photon detection up to $\rightarrow \phi_{eq} \sim 2 \times 10^{10}\,cm^{-2}$
- Space experiments: High radiation expected for detectors in space $\rightarrow \phi_{eq} \sim 5 \times 10^{10}\,cm^{-2}$, AG ILE gamma ray detector

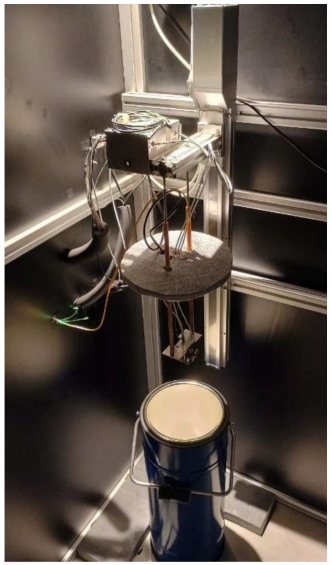
$\Rightarrow$ Operating temperature is a key ingredient to cope with increased DCR for **single photon detection** in RICH

Photon detectors: SiPM

SiPM are considered the baseline for Upgrade II: S13360 series thoroughly tested

- Expected delivered fluence to RICH1 with 300/fb recorded in 5 data-taking years is $6 \cdot 10^{13}$ 1MeV n_{eq}/cm^2
- $6 \cdot 10^{11}$ 1MeV n_{eq}/cm^2 accumulated in just 1 week in RICH1

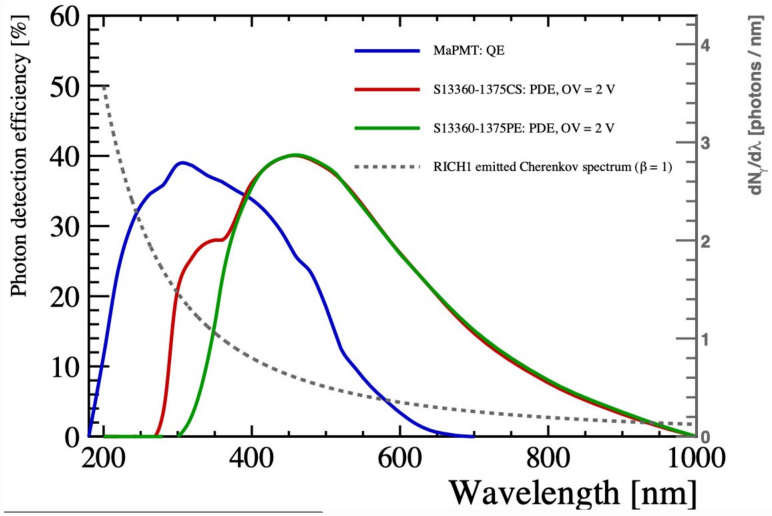


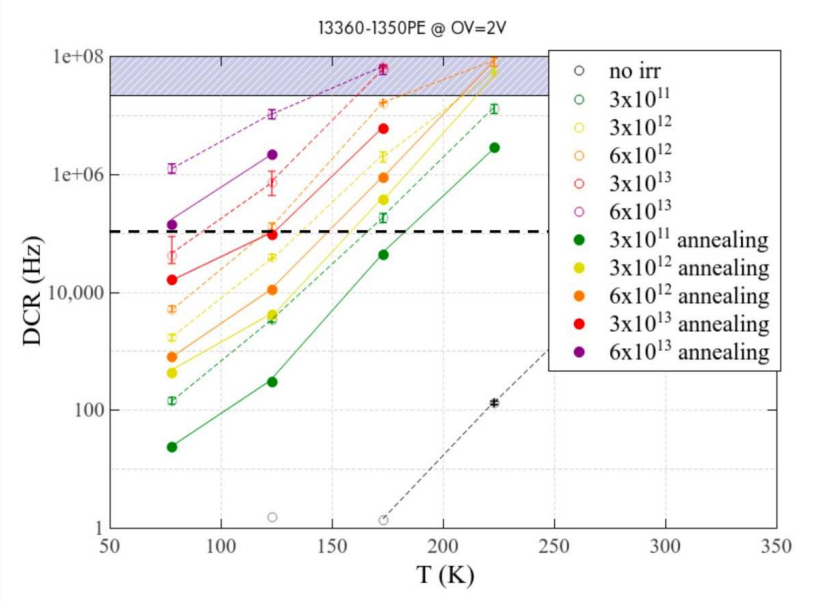


R&D campaign conducted by RICH INFN institutes irradiating and testing over 45 devices

- qualify candidate for operations in the RICH (granularity 1-3 mm2)
- determine operating parameters (temperature $T \sim 120$ K and over-voltage $OV \sim 2$ V)

$\Rightarrow$ Complexity in mechanical design of photon detector enclosure



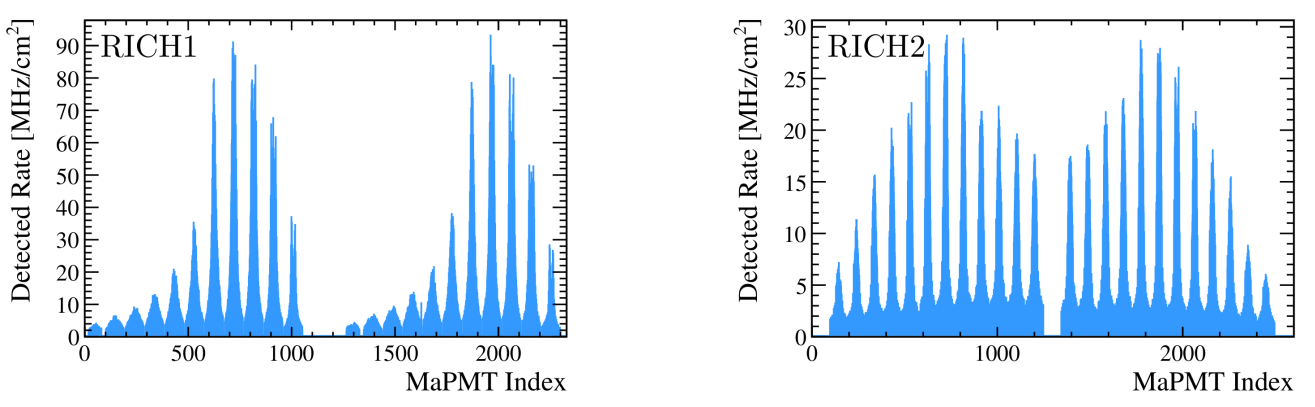


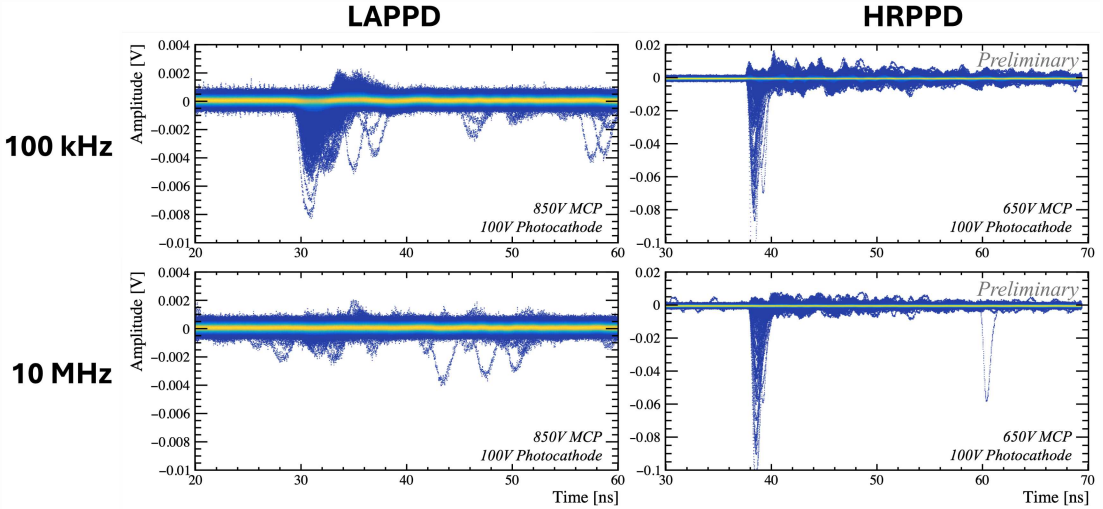
"Characterization of SiPMs for the LHCb Upgrade-II RICH detectors"

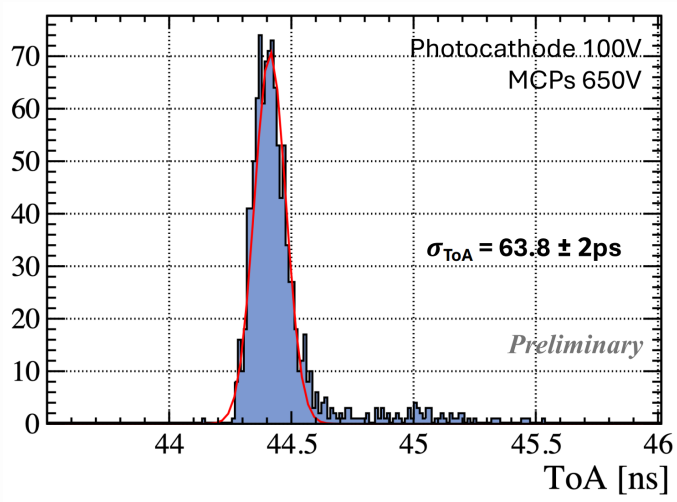
MCP-PMTs: large area devices

R&D driven by UK with intense campaign of tests in the laboratory and on beam: option particularly attractive for intrinsically good timing

Detected photon rate in Run3







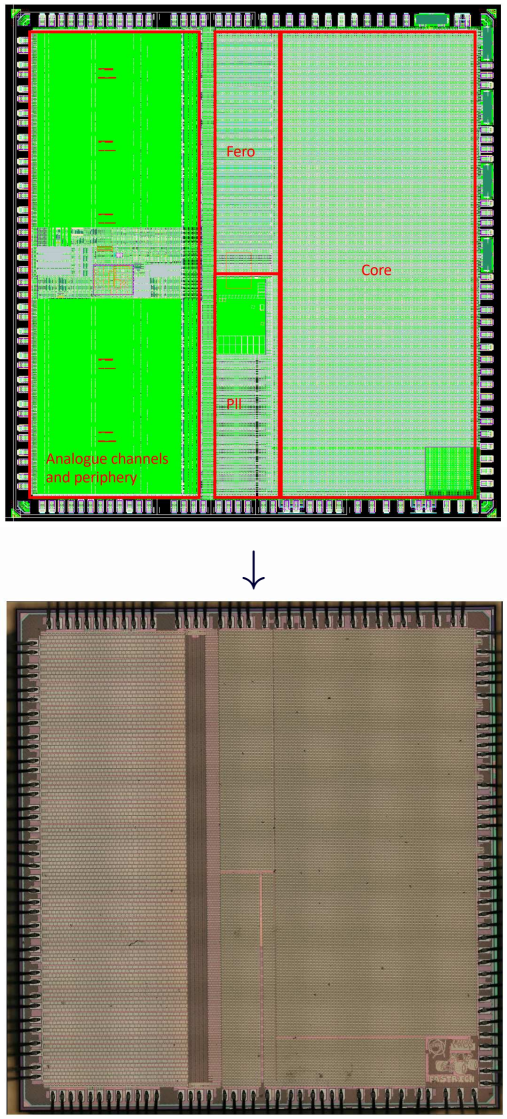
Detailed study of rate capability needed to evaluate in what areas of the RICH MCPs could operate

"Large area picosecond photodetector for the Upgrade II of the LHCb RICH"

Electronics: FastRICH ASIC

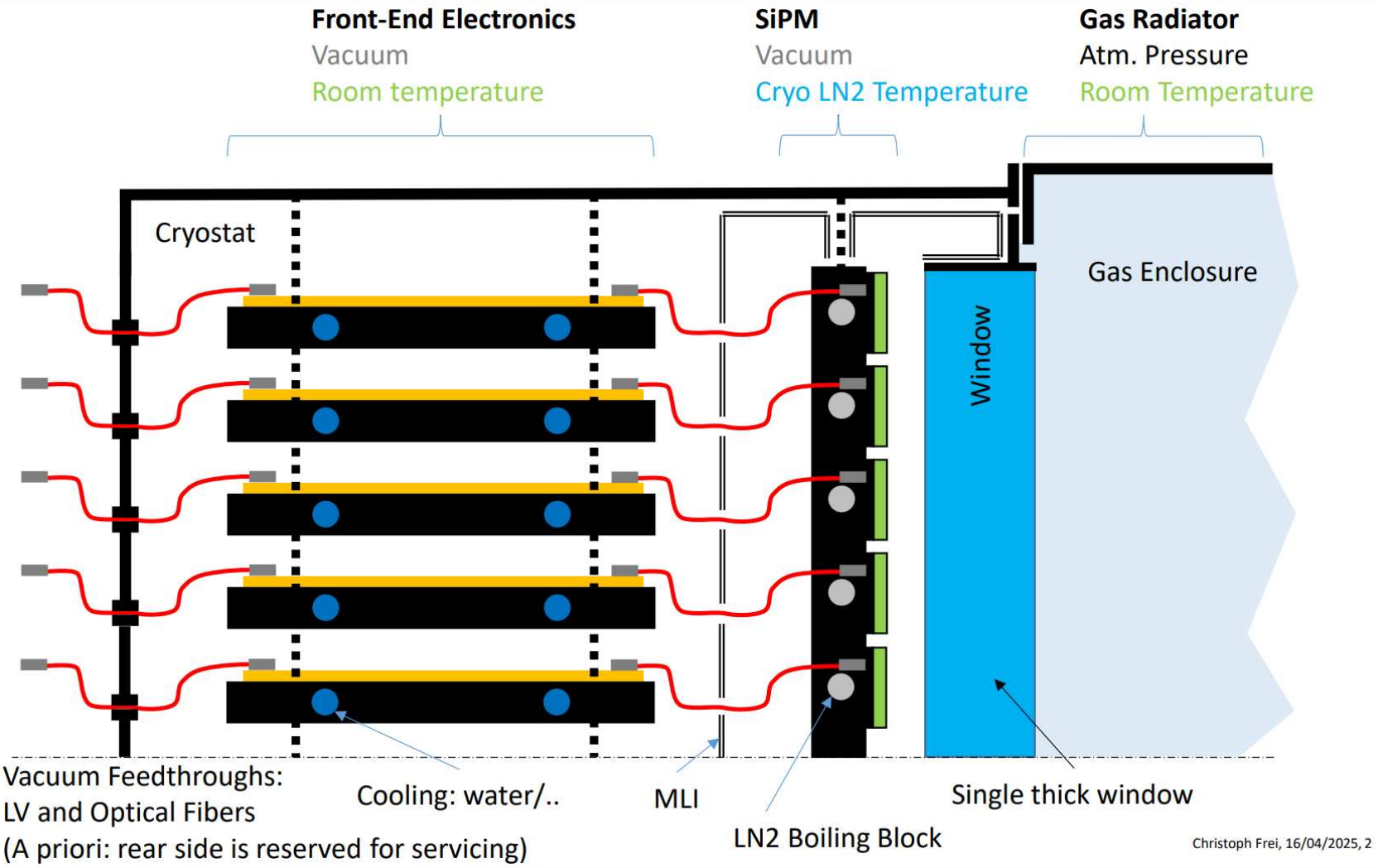
"The FastRICH ASIC for next-generation RICH detectors"

- 65 nm radiation-hard CMOS technology
- 16-channels with digital-on-top design
- die size of 5 mm x 5 mm and packaged in QFN88 package
- embedded time-to-digital converter (TDC) with 24.41 ps time bins
- versatile front-end with possibility to choose between Leading-Edge Discrimination (LED) and Constant Fraction Discrimination (CFD)
- channel input polarity can be configurable to use either negative or positive polarity
- wide dynamic input range of 50 μA to 5 mA and compatible with MaPMT/MCP-based/SiPM sensors
- output data-compressed format based on the aurora 64b/66b protocol for serial links
- configurable data throughput between 0.32 Mbps and 5.12 Gbps
- power consumption of about 13mW/channel at 1.2 V nominal power supply



ASIC produced in 2025, under test for early installation coupled with MaPMTs as part of the LS3 Enhancement [CERN-LHCC-2023-005]

The photon detector enclosure concept



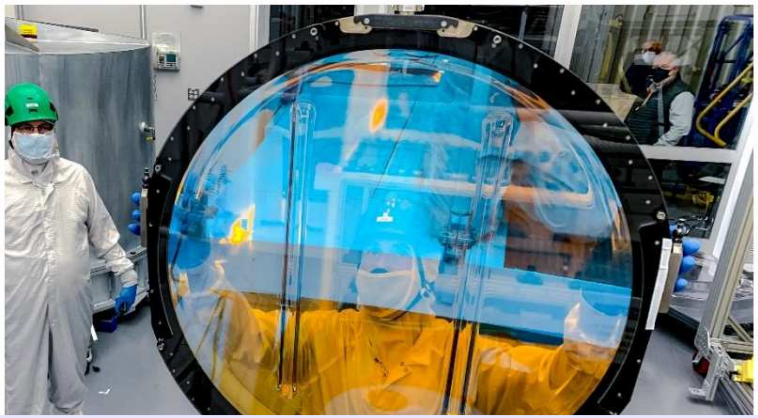
Concept of enclosure developed by CERN RICH group:

- thick quartz window separating gas volume and vacuum vessel ⇒ thermal insulation
- local LN2 cooling on SiPMs
- "warm" electronics in vacuum vessel

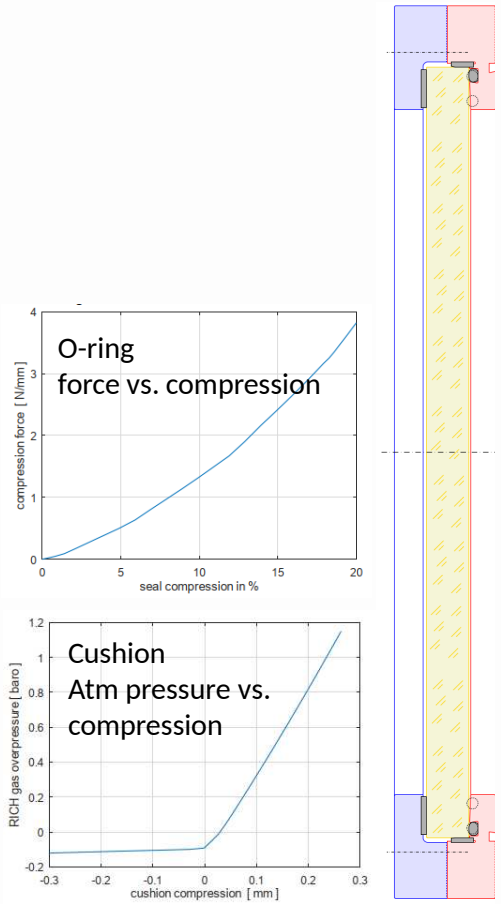
Studies on the window

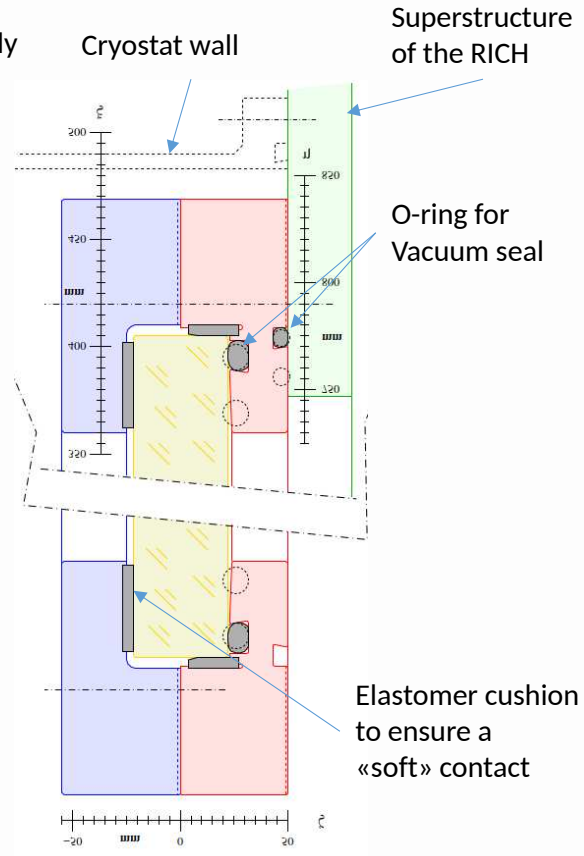
- Market survey to identify potential manufacturer: from ISS benchmark to LHCb cavern
- Polishing quality: survey synergic with studies on pressurised RICH of EIC
- Low emissivity coating under investigation





- Mechanical studies conducted at CERN to identify window parameters

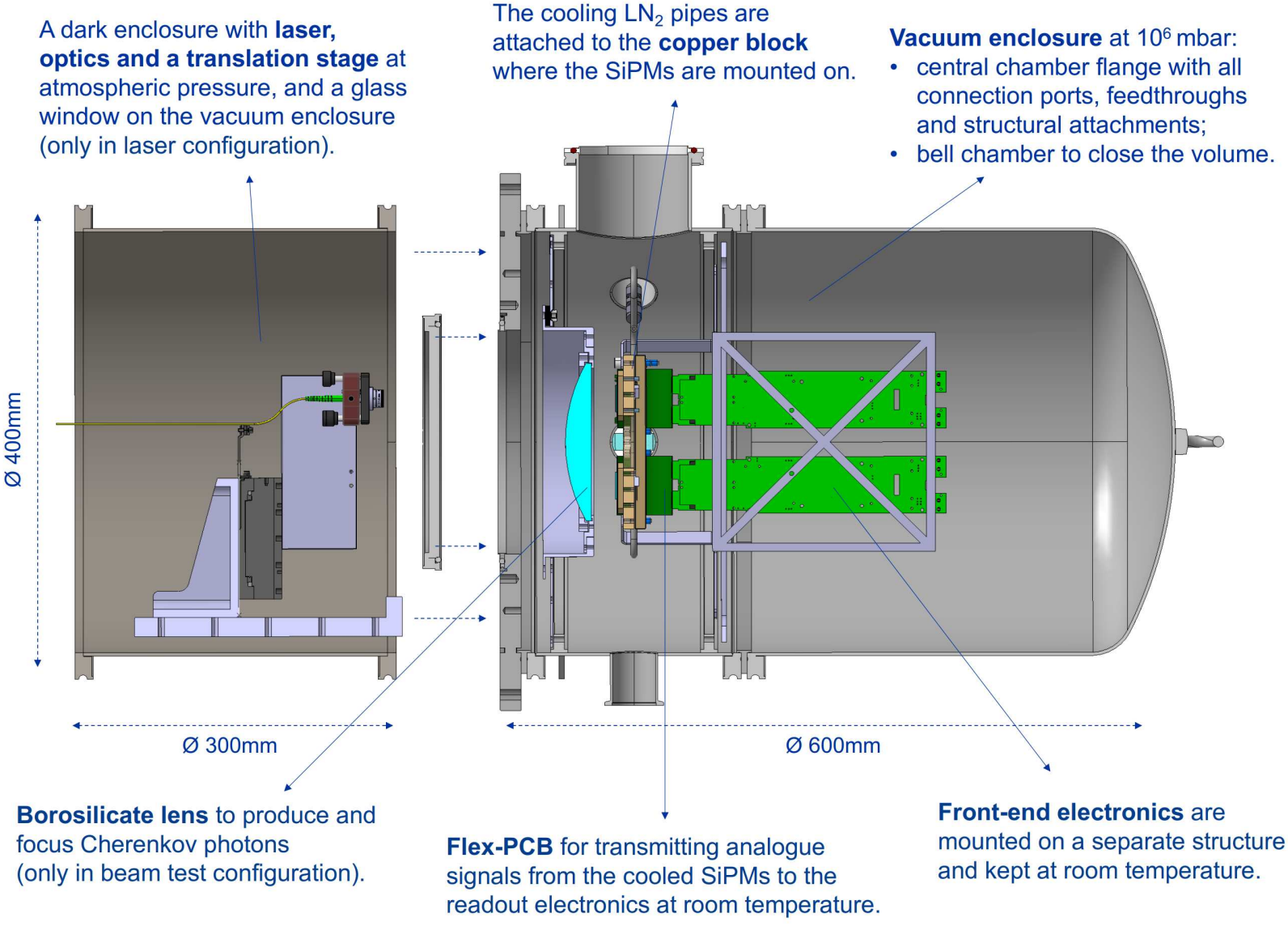




[Credit to Piet Wertelaers]

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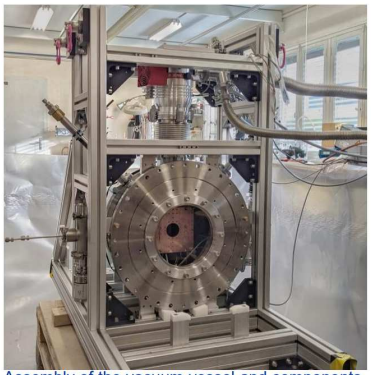
From concept to demonstrator

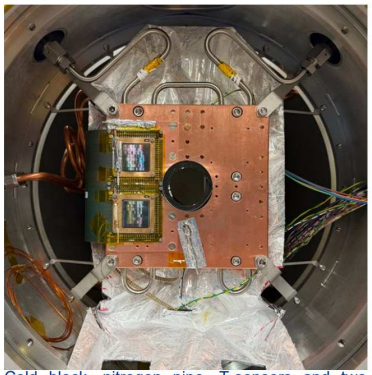


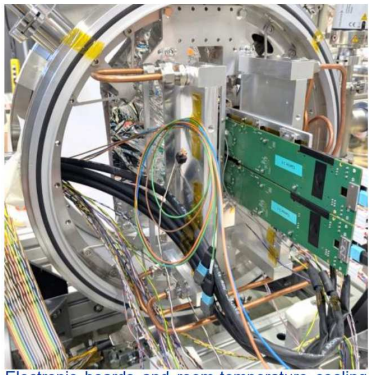
Demonstrator designed and built at CERN as work package of the EP R&D programme: vacuum vessel to host cryo-cooled SiPMs, warm electronics → validate thermal concept and build setup for tests in laboratory (laser) and on beam (borosilicate radiator)

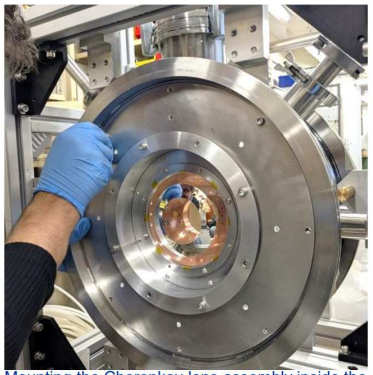
From concept to demonstrator

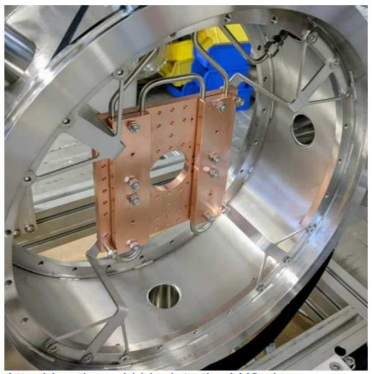
Few highlights of manufacturing and assembly:

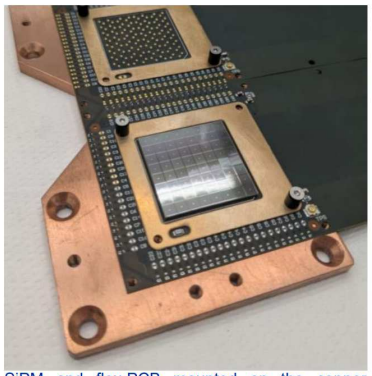

Assembly of the vacuum vessel and components, mounted on the supporting frame, with the cold block inside.

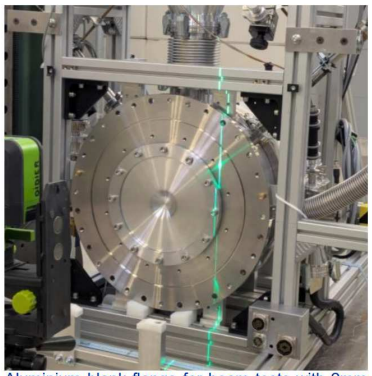

Cold block, nitrogen pipe, T-sensors and two SiPM and flex-PCB mounted inside the cryostat. MLI in place before sealing.

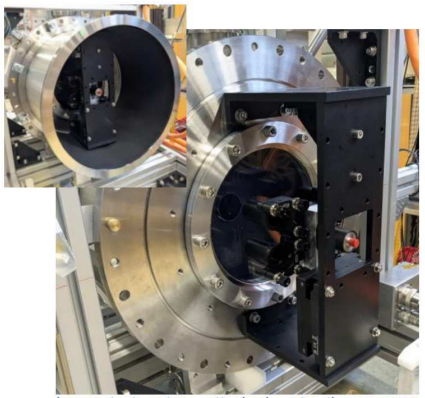

Electronic boards and room-temperature cooling inside the vacuum chamber.


Mounting the Cherenkov lens assembly inside the cryostat.


Attaching the cold block to the LN2 pipe.


SiPM and flex-PCB mounted on the copper plates, with the clamping frame on top.

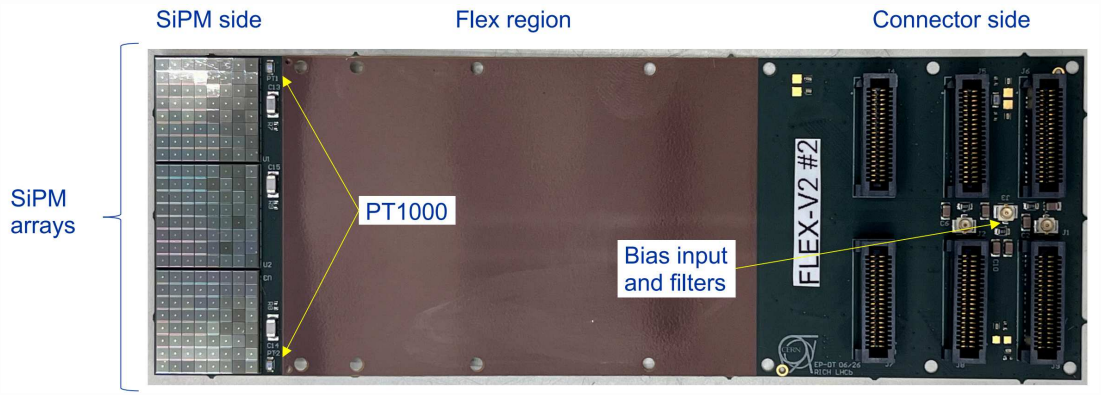

Aluminium blank flange for beam tests with 2mm central thickness


Laser test setup, attached onto the vacuum chamber. Dark enclosure installed to prevent external light through the viewport.

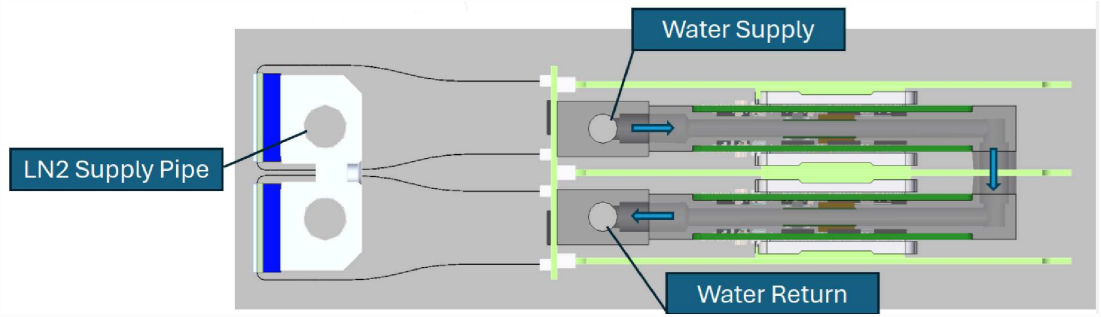
"A cryogenic RICH detector demonstrator for SiPM operation with flex-PCB readout"

Photon detector module

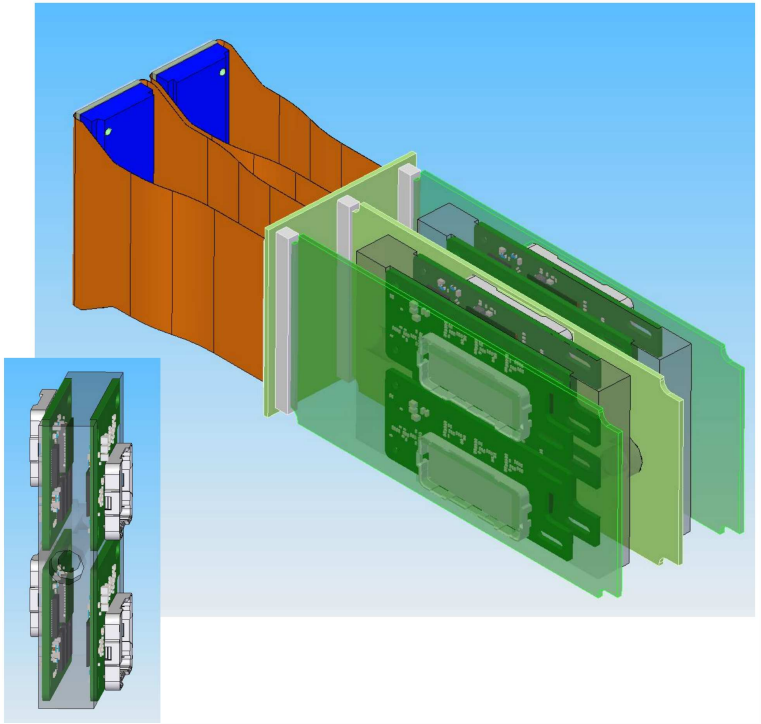
Flex v1 designed for SiPMs $3 \times 3\,\mathrm{mm}^2$, v2 for $2 \times 2\,\mathrm{mm}^2$ (EP-LCB)



Cooling distribution (LN2 to SiPMs and water cooling to electronics) in vacuum chamber tested and validated in cryo demonstrator



Photon Detector Module (PDM): integration of photon detector, ASIC, digital readout and local cooling



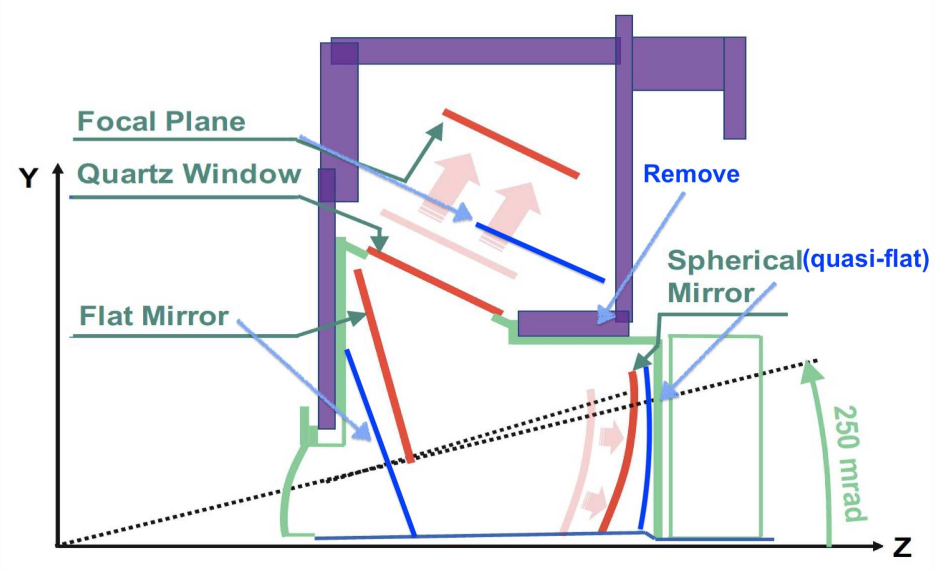
Opto-electronics chain concept design and integration in photon detector plane under validation

The RICH1 Upgrade II concept layout

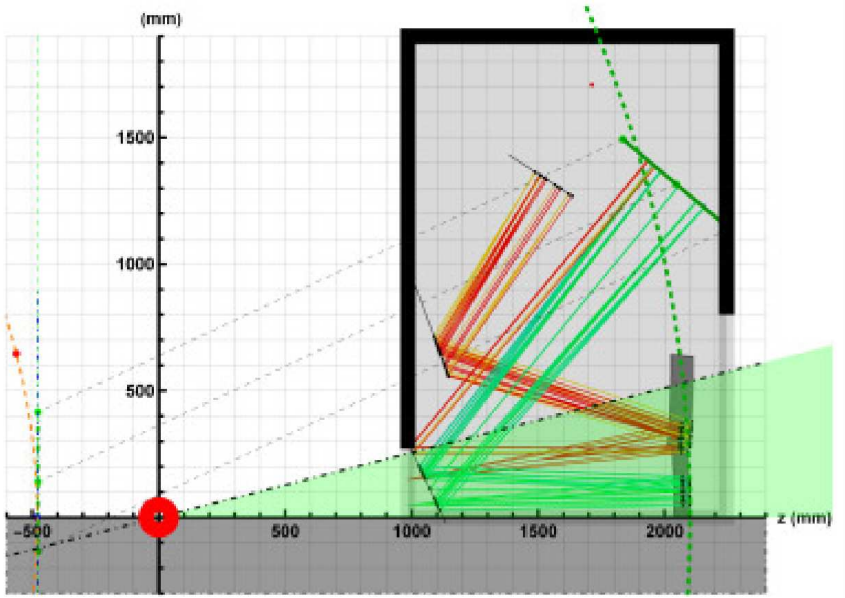
Road to the optimisation of the optics design:

- move flat mirrors in the acceptance ⇒ requires R&D on carbon fibre flat mirrors, light-weight supports and with good resistance to radiation ⇒ improve emission point error
- further increase in spherical mirror curvature radius ⇒ reduced occupancy and decreased pixel error

FTDR design for RICH1

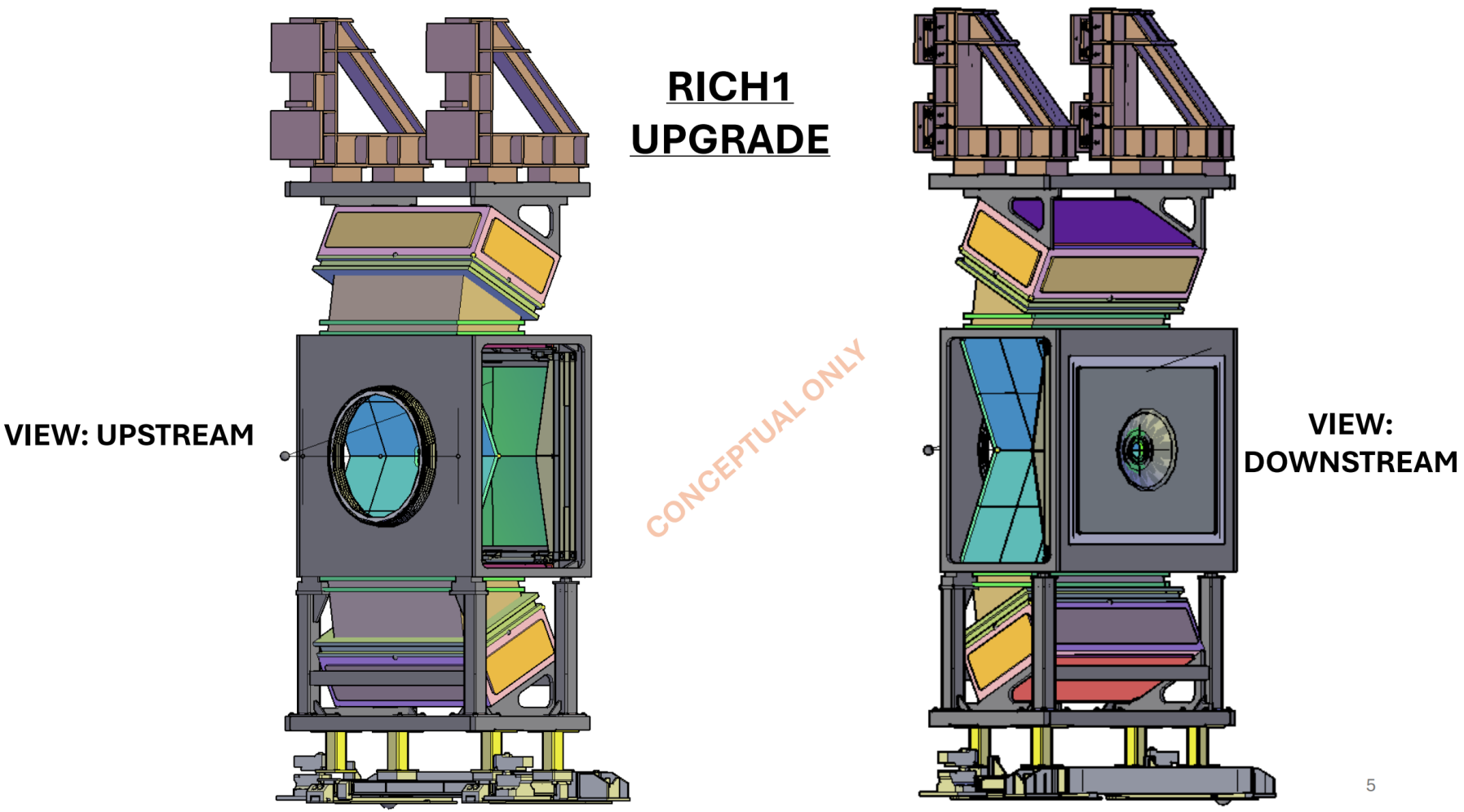


Split optics design for RICH1



Aim to reduce the emission point error: 0.38 mrad (Run3) → ∼ 0.13 mrad (Run5)

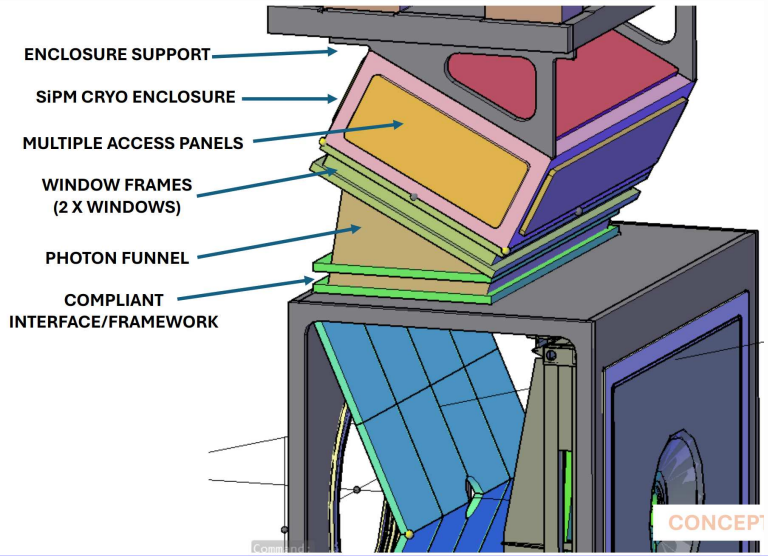
The RICH1 Upgrade II concept layout



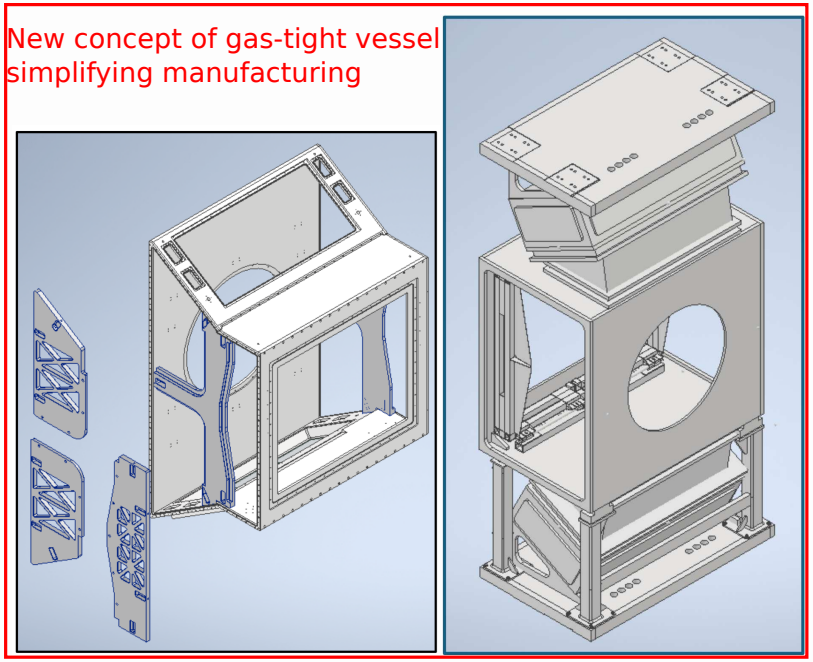
Concept design of the new RICH1 detector in preparation for the TDR

Few highlights on mechanics design

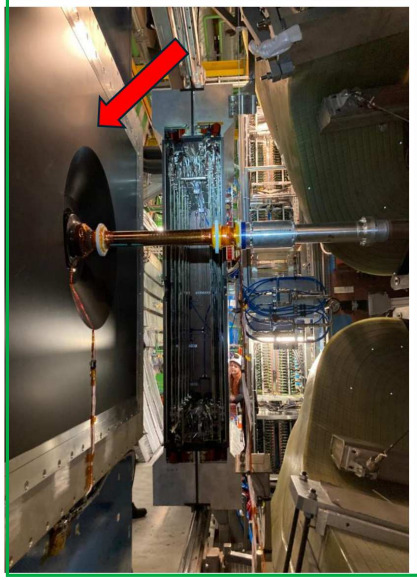
New support structure replacing current magnetic shielding

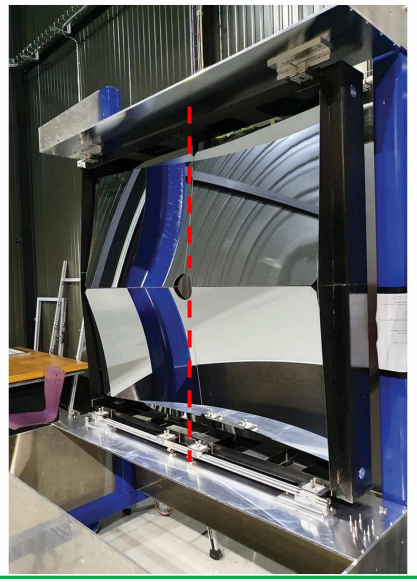


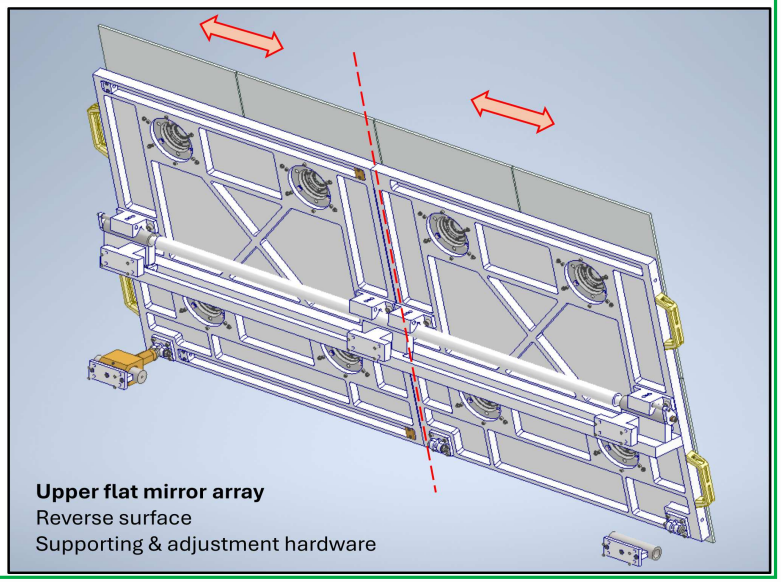
New concept of gas-tight vessel simplifying manufacturing



Light-weight structures in acceptance: sandwich exit window, spherical and flat mirrors with respective supports

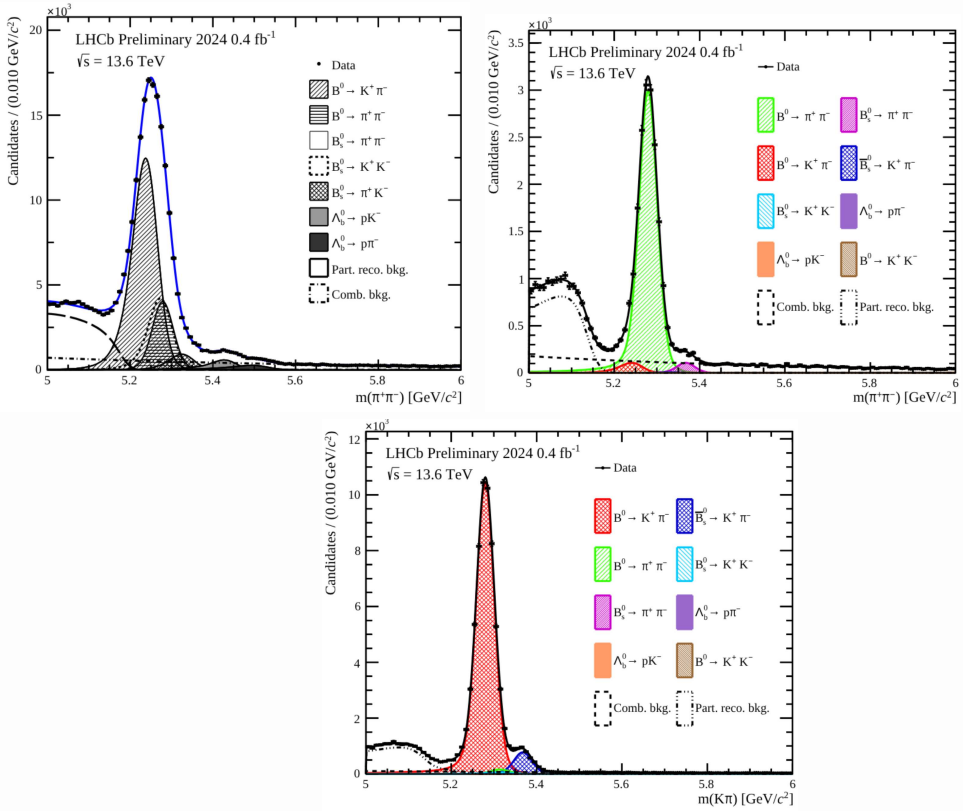






Conclusions

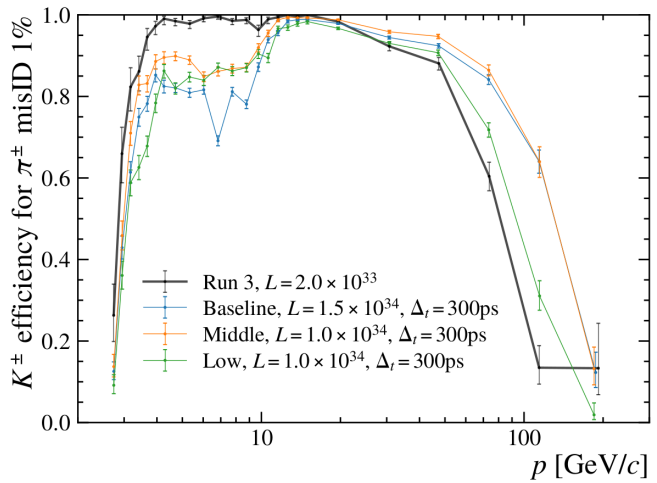
- The RICH for the LHCb Upgrade II represents an unprecedented challenge for RICH detectors concerning track density, expected fluence and overall PID requirement
- Concept design for various elements well on target for TDR schedule



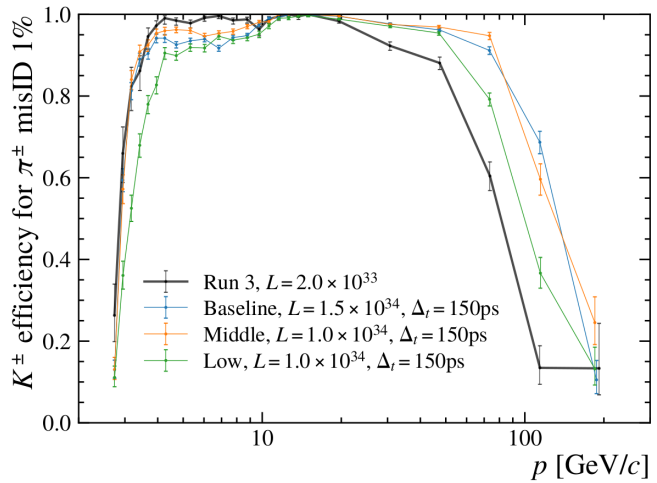
$B \to hh'$ mass distributions in 2024 data, LHCb-FIGURE-2025-016

Expected RICH Upgrade II performance for time window of:

300 ps



150 ps



Prepare to deliver excellent PID in Upgrade II following the footsteps of the excellent performance of the LHCb Upgrade I