ICHEP 2020 | PRAGUE
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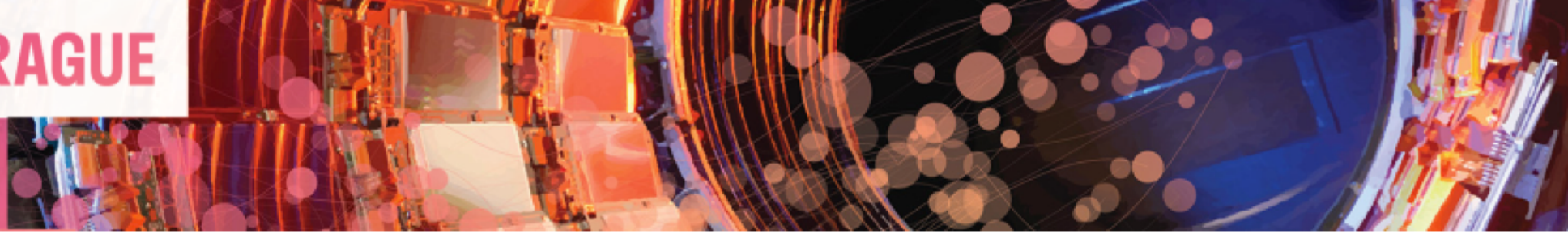

The Upgrade of the LHCb RICH Detectors

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ON BEHALF OF THE LHCb COLLABORATION

INFN

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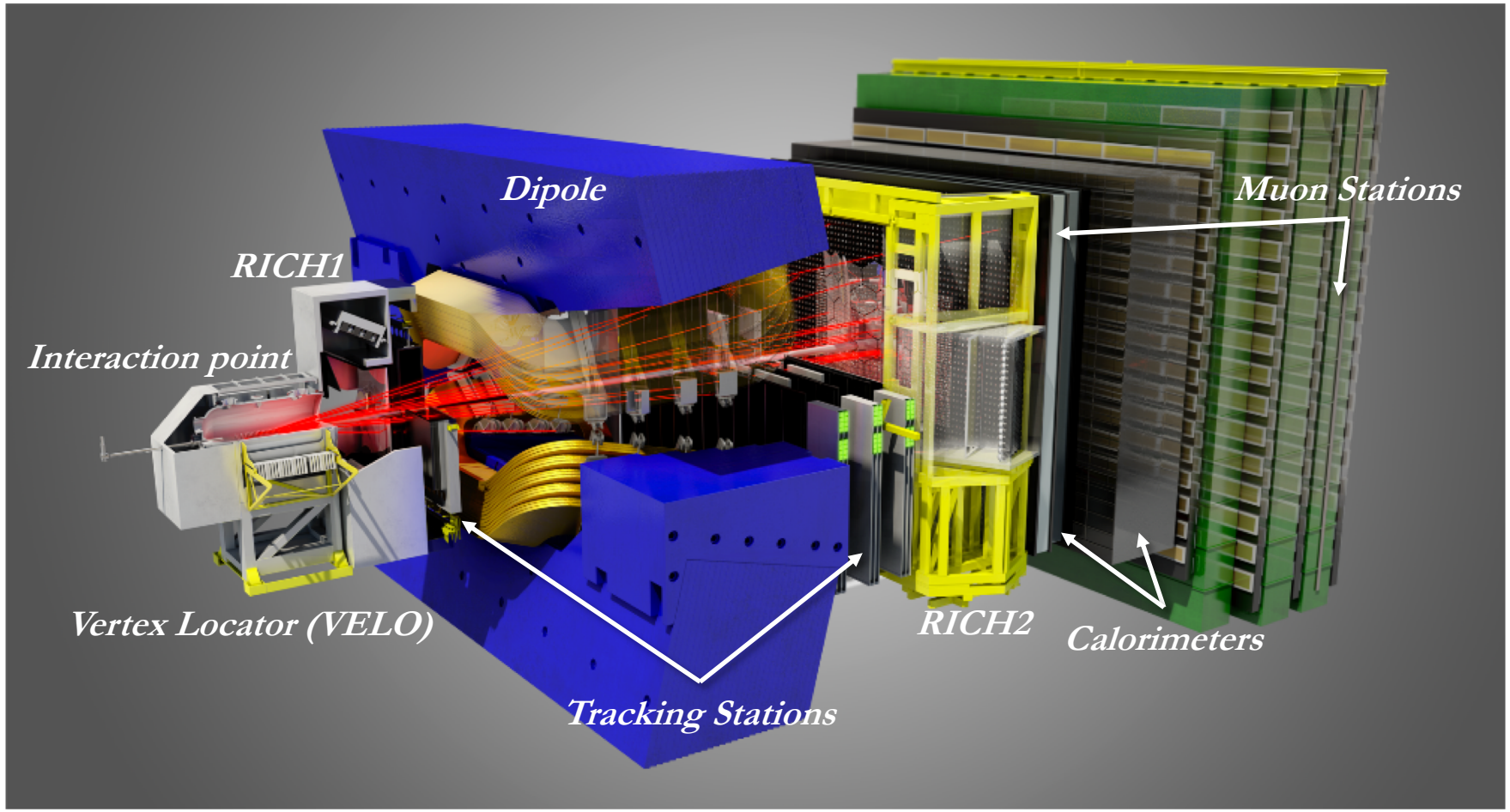
The LHCb Detector



The LHCb RICH Detectors

RICH1 (25-300 mrad)

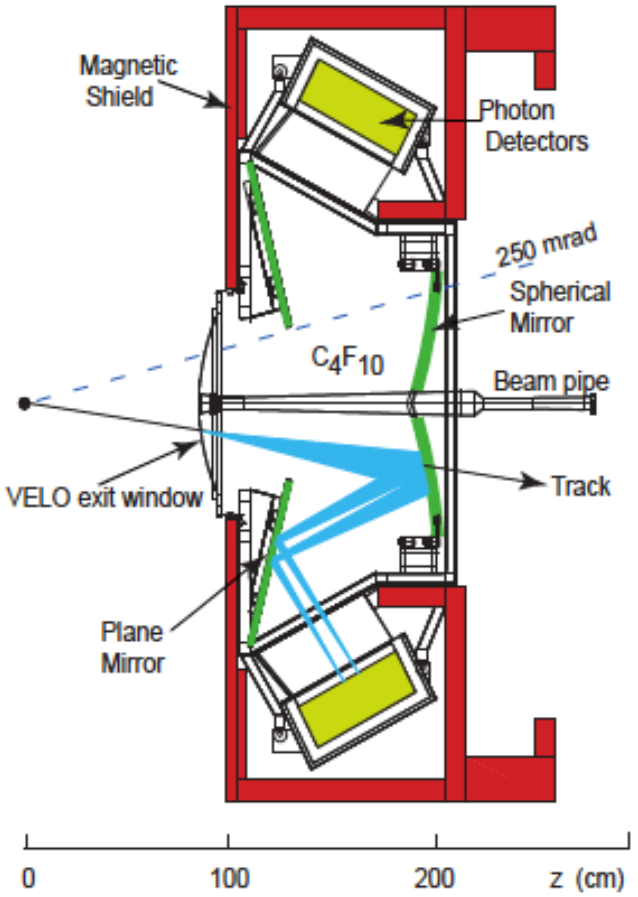
C_4F_{10}
- n = 1.0014 at 0°, 101.325 kPa, λ = 400 nm
- V = 4 m^3
- Up to 60 GeV/c

RICH2 (15-120 mrad)

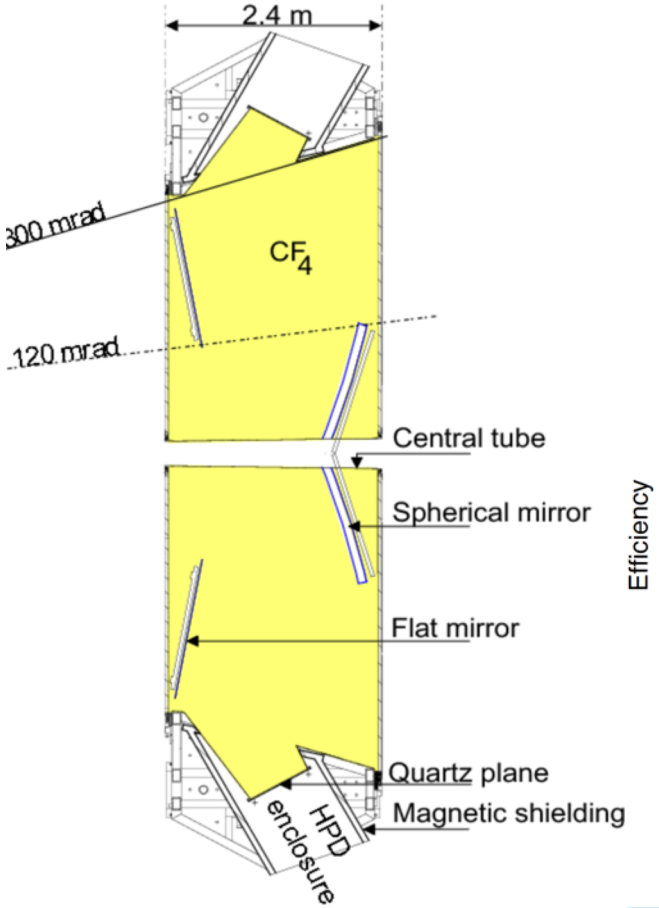
CF_4
- n = 1.0005 at 0°, 101.325 kPa, λ = 400 nm
- V = 100 m^3
- Up to 100 GeV/c

Hybrid Photon Detectors (HPDs) in both RICH1 and RICH2
- Solid state detectors
- Embedded 1 MHz electronics

RICH1

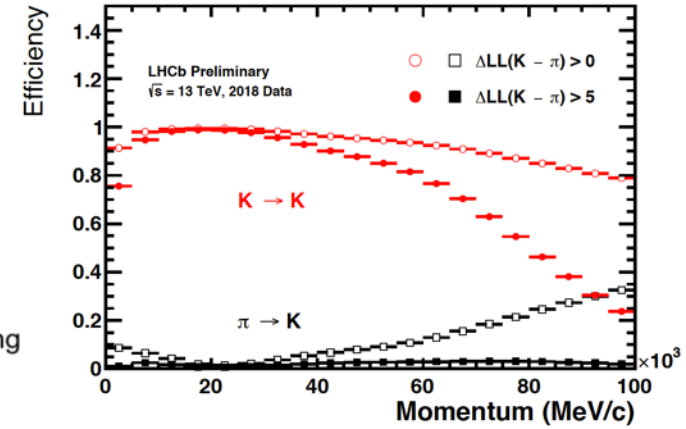


RICH2



Excellent PID performances (LHCb-FIGURE-2020-012)

Talk by Martina Pili "Performance of the LHCb detector in the Run 2" for more performance plots



LHCb Phase 1 Upgrade and RICH Upgrade

LHCb Upgrade (2019-2021)

- LHCb luminosity from 4×10^{32} cm^{-2} s^{-1} to 2×10^{33} cm^{-2} s^{-1}
- Readout frequency from 1 MHz to 40 MHz (bunch-crossing rate)

LHCb RICH Upgrade

- Mechanical and Optical system
  - Optical system redesigned to reduce occupancy at higher luminosity
  - New cooling system and support mechanics
- Front-End (FE) Electronics and DAQ system
  - HPDs replaced with 64-channels Multi-Anode PhotoMultiplier Tubes (MaPMTs)
  - FE Electronics to read-out at 40 MHz
    - CLARO8 ASIC
    - FPGA-based Digital Board
    - Data transmitted via GigaBit Transceiver (GBT) chip

LHC Era | HL-LHC Era

	Run 1 (2010-2012)	Run 2 (2015-2018)	Run 3 (2021-2023)	Run 4 (2027-2029)
Integrated Luminosity	3 fb^{-1}	9 fb^{-1}	25 fb^{-1}	50 fb^{-1}
Instantaneous Luminosity	4×10^{32} cm^{-2} s^{-1} (Current LHCb)		2×10^{33} cm^{-2} s^{-1} (Upgraded LHCb)	

LS2

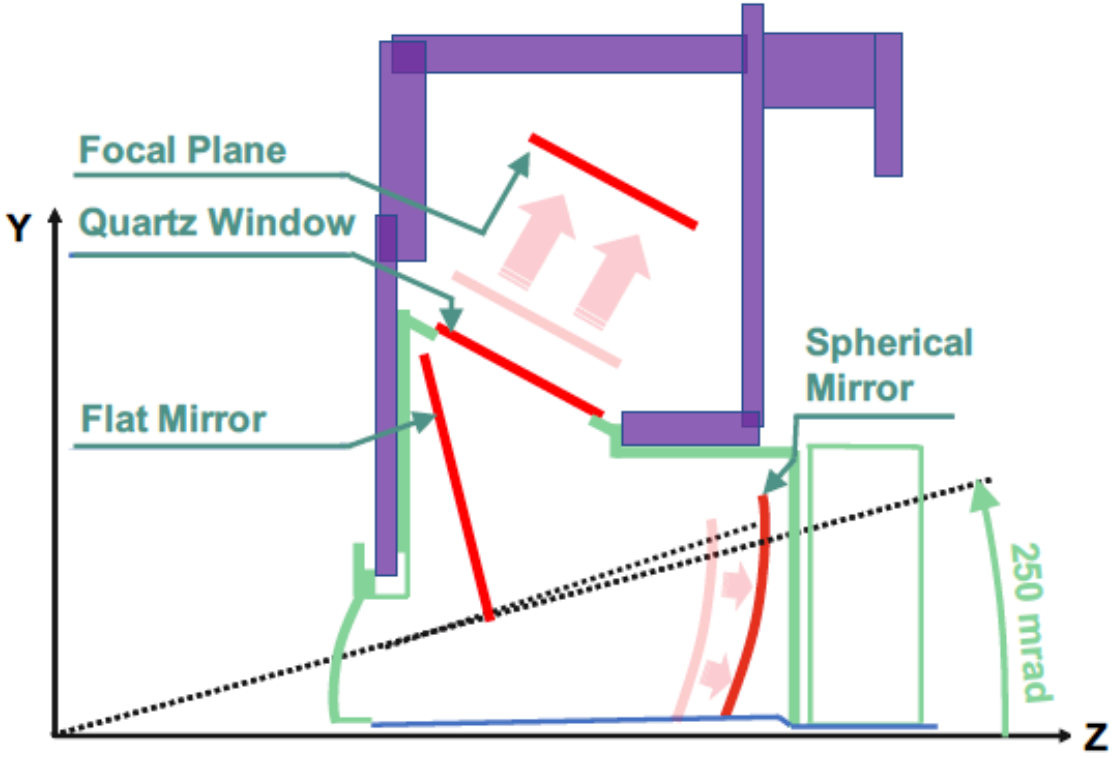
LHCb RICH1 Upgrade Optical System

Peak occupancy < 30 % to maintain actual PID performance

- Focal plane and spherical mirror warded from flat mirror to increase ring size
- New spherical mirrors with larger radius of curvature

Larger gas enclosure

Compact photo-detection system required



RICH1 Optical System Upgrade

LHCb RICH MaPMT

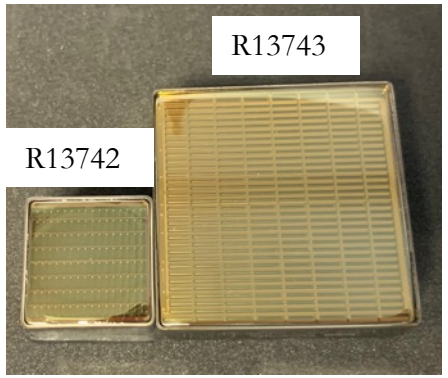
Hamamatsu MaPMT
- 3100 R13742 (from R11265 series) and 450 R13743 (from R12699 series), spares included

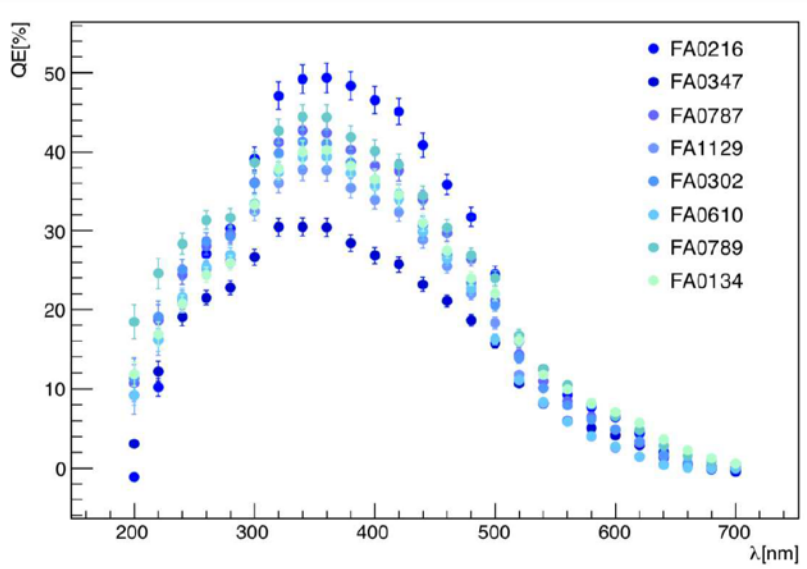
Ultra-bialkali photocathode and UV glass window
- Chromatic error reduction

Minimum gain of 1×10^6 @ 1 kV

Maximum pixel-to-pixel gain spread
- R13742 1:4
- R13743 1:3

Dark Count Rate (DCR)
- < 1 kHz per pixel
- < 16 kHz per R-type MaPMT
- < 70 kHz per H-type MaPMT





LHCb RICH Upgrade Elementary Cell

MaPMTs housed in custom sockets on Baseboard (Bb)

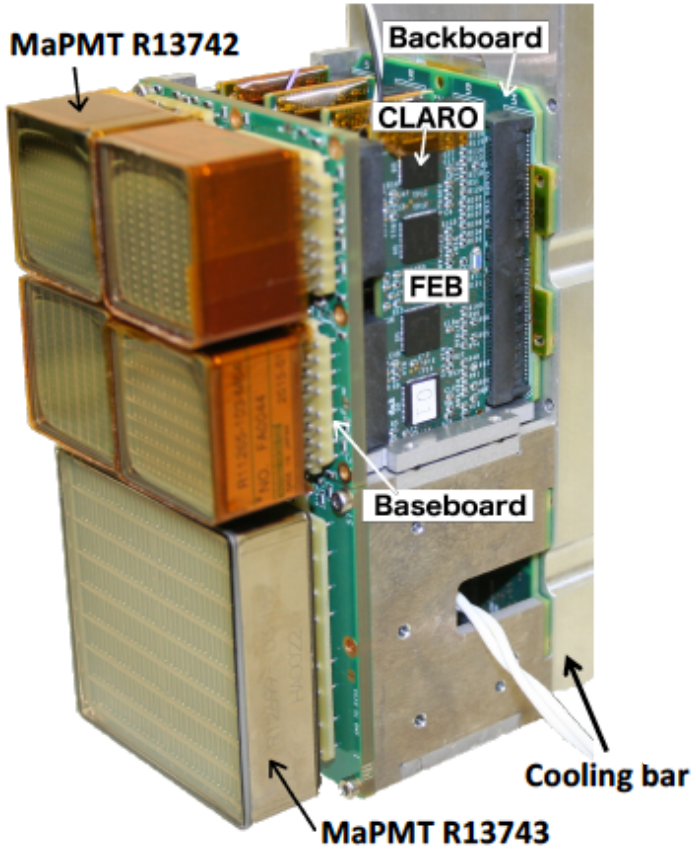
- Hamamatsu MaPMTs, 8×8 pixel matrix
  - 1"×1" R13742
  - 2"×2" R13743
- Validated with dedicated Quality Assurance (QA) procedure
- EC-H type
  - One R13743 MaPMT per EC
  - Only outer regions of RICH2
- EC-R type
  - 2×2 matrix of R13742 MaPMT per EC
  - All RICH1 and central regions of RICH2

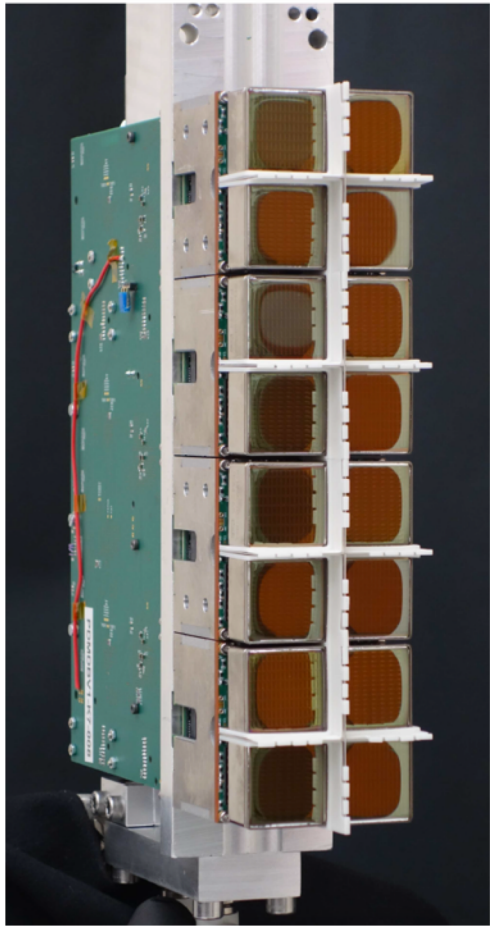
CLARO ASIC mounted on Front-End Boards (FEBs)

Interface between FEB and FPGA based Digital Board with Backboard (Bkb)

Photon Detector Module (PDM)

- 4 ECs (R or H type)
- 2 Digital Boards

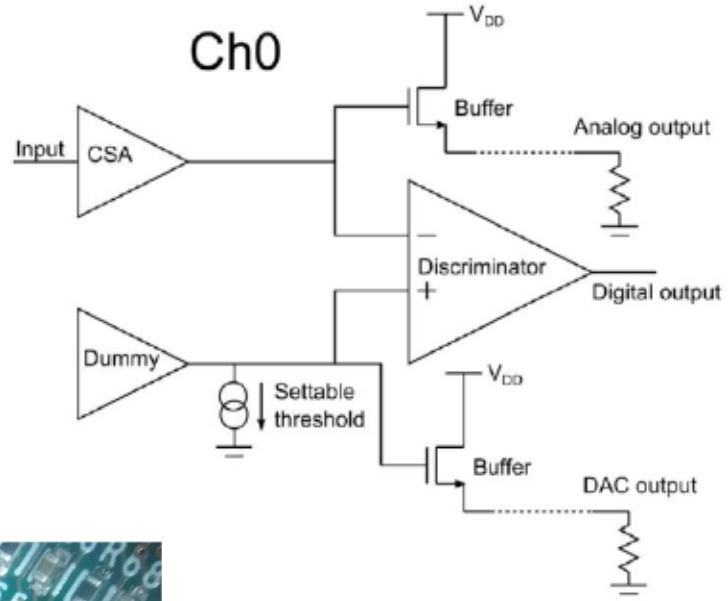


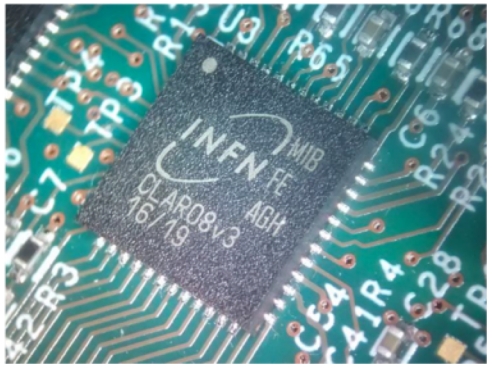


LHCb RICH Upgrade CLARO ASIC

8-channel amplifier/discriminator ASIC

- 0.35 μm AMS CMOS technology
- **Recovery time < 25 ns**
- Power consumption ~1 mW/channel
- Adjustable threshold and gain (6+2 bits) to compensate for PMT gain variation
- Binary read-out
- **128-bit register protected by triple modular redundancy**
- Radiation-hard by design cells
  - IMSE-CNM Sevilla





LHCb RICH Upgrade Prototype Beam Test

Beam test at CERN North Area

- 180 GeV/c positively charged hadrons: 67% protons, 30% pions, 3% kaons

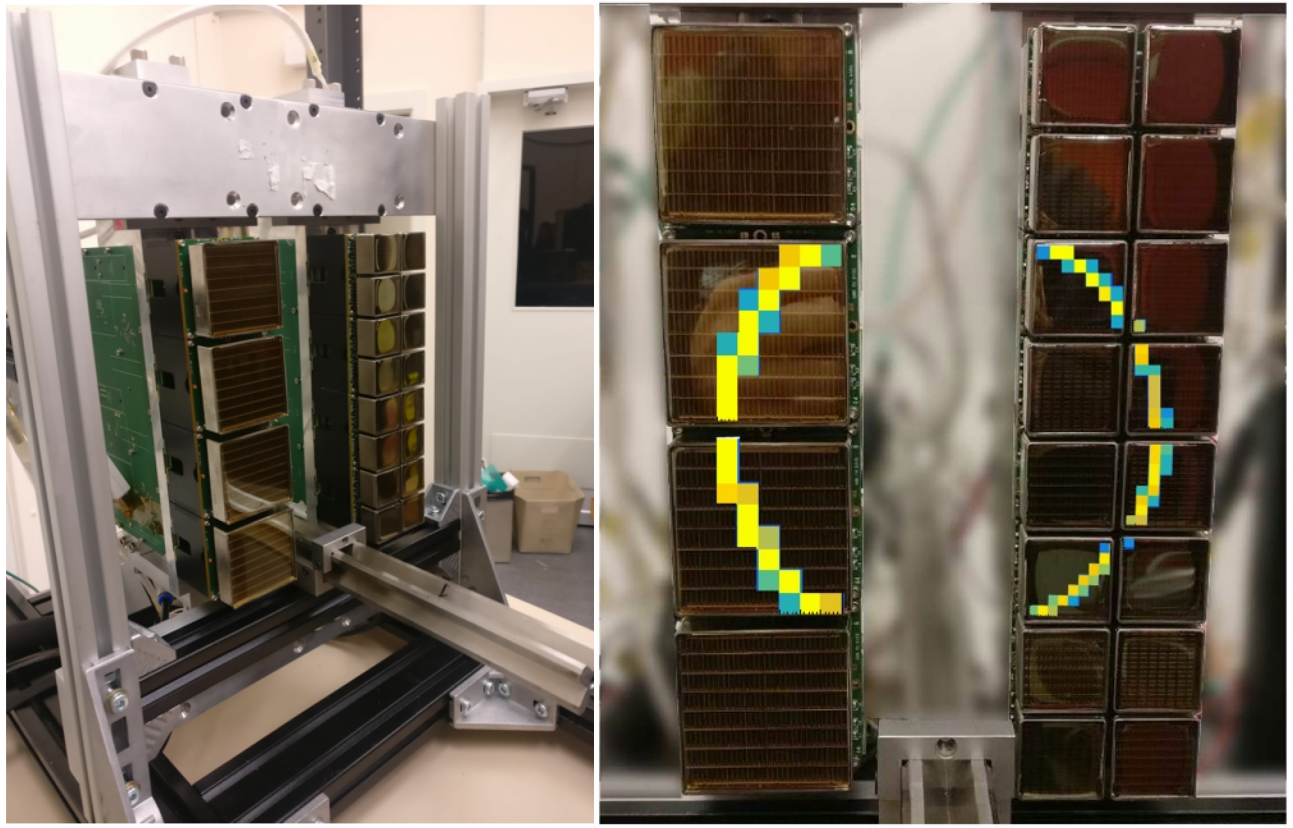
PDMs on movable stage

Cherenkov radiator: plano-convex borosilicate lens (N-BK7)

Light-tight polypropylene box

- Thermally insulated
- N2 flow for humidity control
- Liquid cooling

Real time Cherenkov ring monitoring



LHCb RICH Upgrade Nanosecond Time Gate

RICH Detectors time resolution < 10 ps, prompt Cherenkov radiation

Signal peak (S) in photon hit time distribution

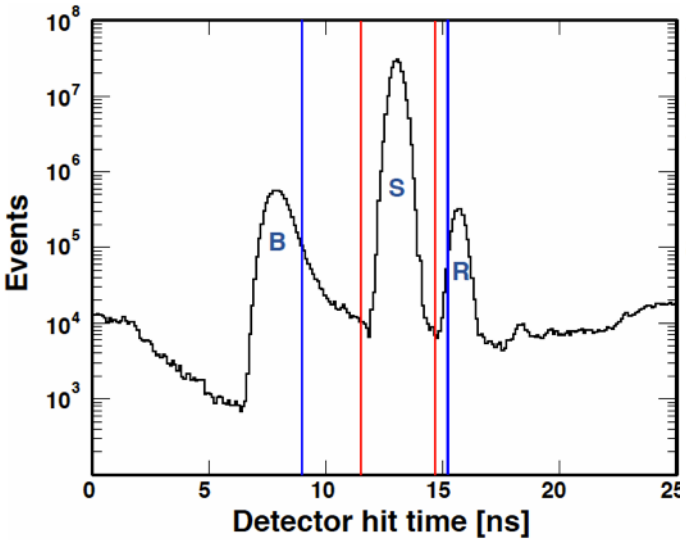
- FWHM ~ 0.5 ns

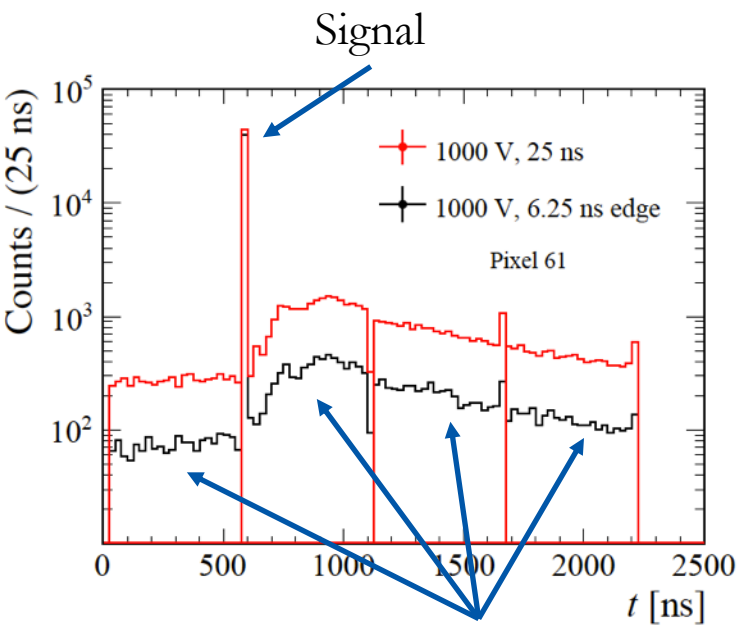
Nanosecond time gate around signal peak

- Red: 3.125 ns
- Blue: 6.250 ns
- Eliminate background photons (B and R) and sensor noise
- Hit occupancy reduction beneficial to PID

Time gate studies on RICH Upgrade Beam Test

- Reduction of uncorrelated background, signal peak unaffected





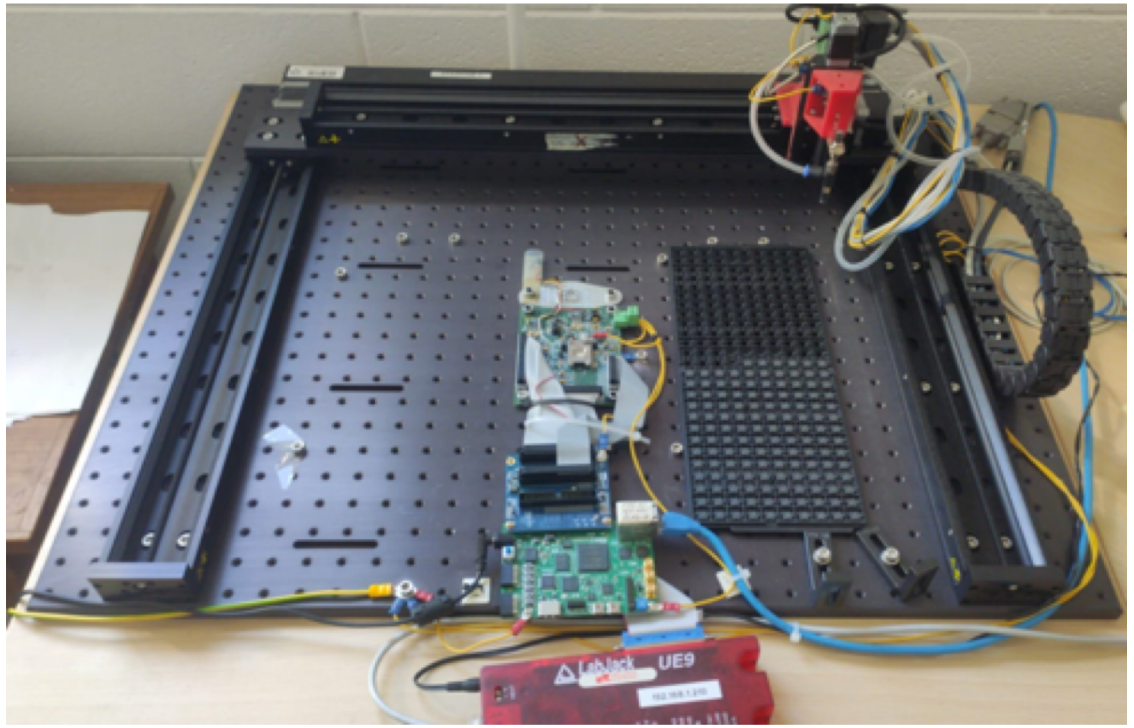
Quality Assurance Tests on the LHCb RICH Upgrade Components (1)

Components validation

- MaPMT
- CLARO, FEB, Backboard, Baseboard
- Digital Board
- Mechanics and support

CLARO QA tests

- ASICs validation and characterization
- Automatized pick-and-place station
- NI LabVIEW based control software
- Test protocol for acceptance/rejection



Quality Assurance Tests on the LHCb RICH Upgrade Components (2)

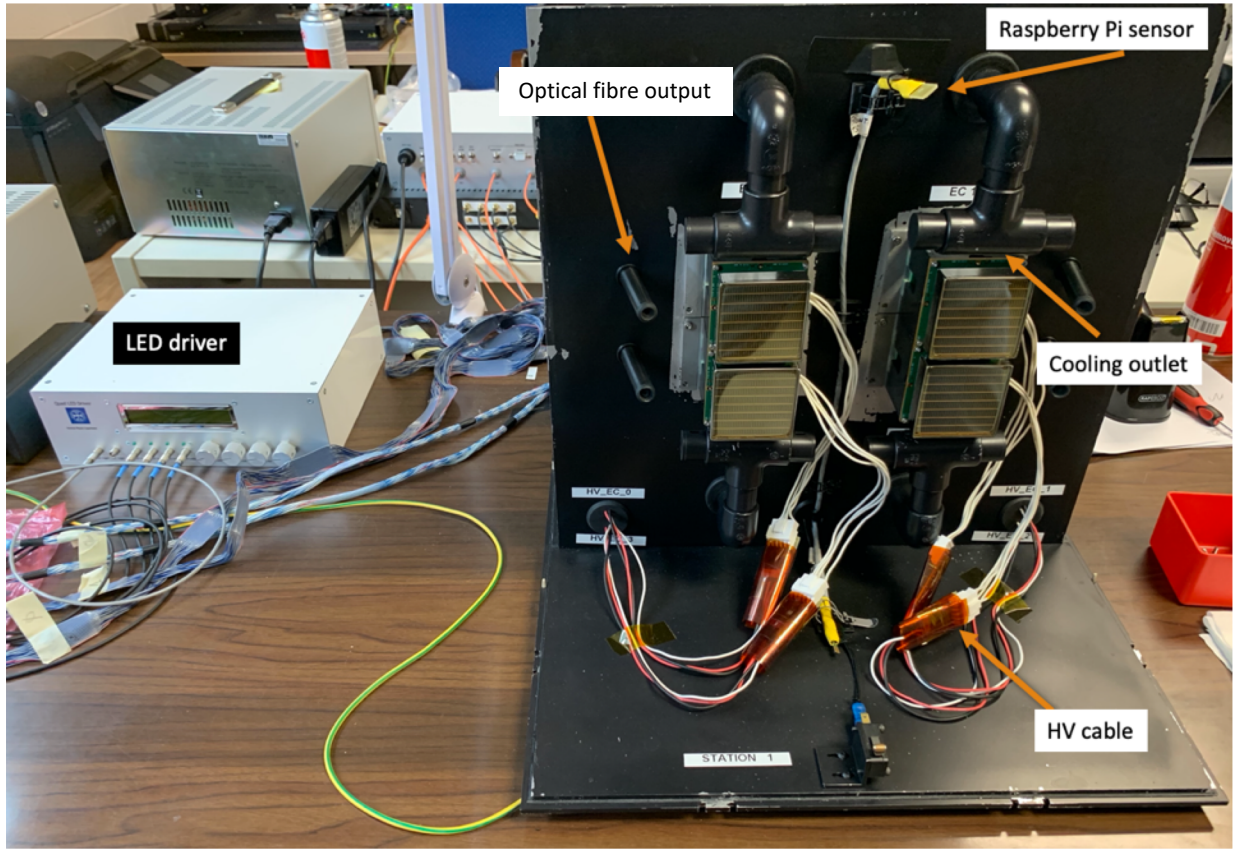
ECQA tests
- EC validation
- Parameters comparison with CLAROs QA tests

ECQA test station
- Light-tight box
- Air cooling system
- Temperature and humidity control
- Controlled light injection for characterization tests
- Up to 4 ECs tested simultaneously
  - Digital Boards for data readout

NI LabVIEW control software
- Finite-state machine

Test protocol for acceptance/rejection

Great number of channels
- ECH ~400 modules
- ECR ~700 modules



RICH2 Columns Commissioning

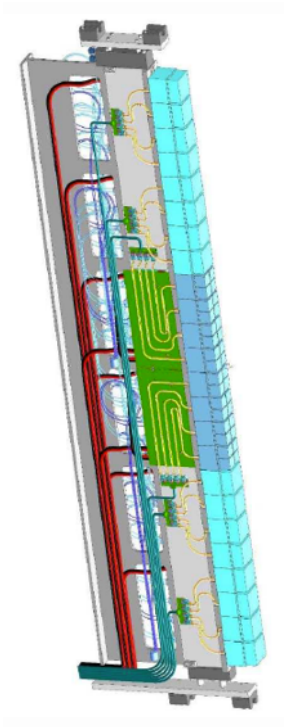
ECs, PDMDBs and mechanics assambled at CERN for commissioning

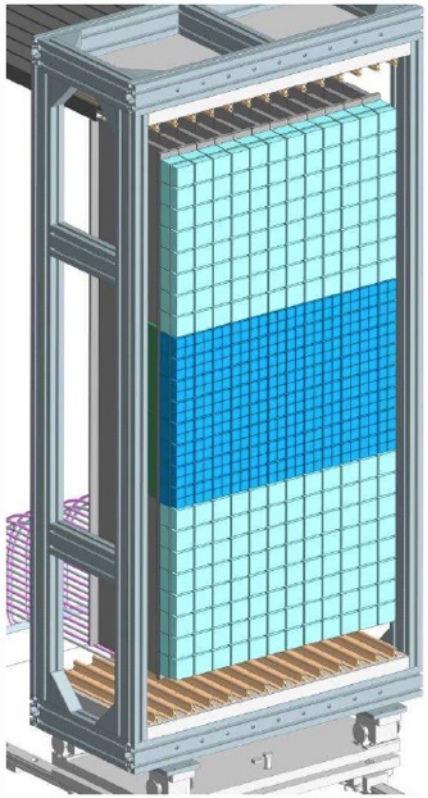
PDM columns modularity

Columns into PD planes

RICH2 mechanics, readout and services assembled

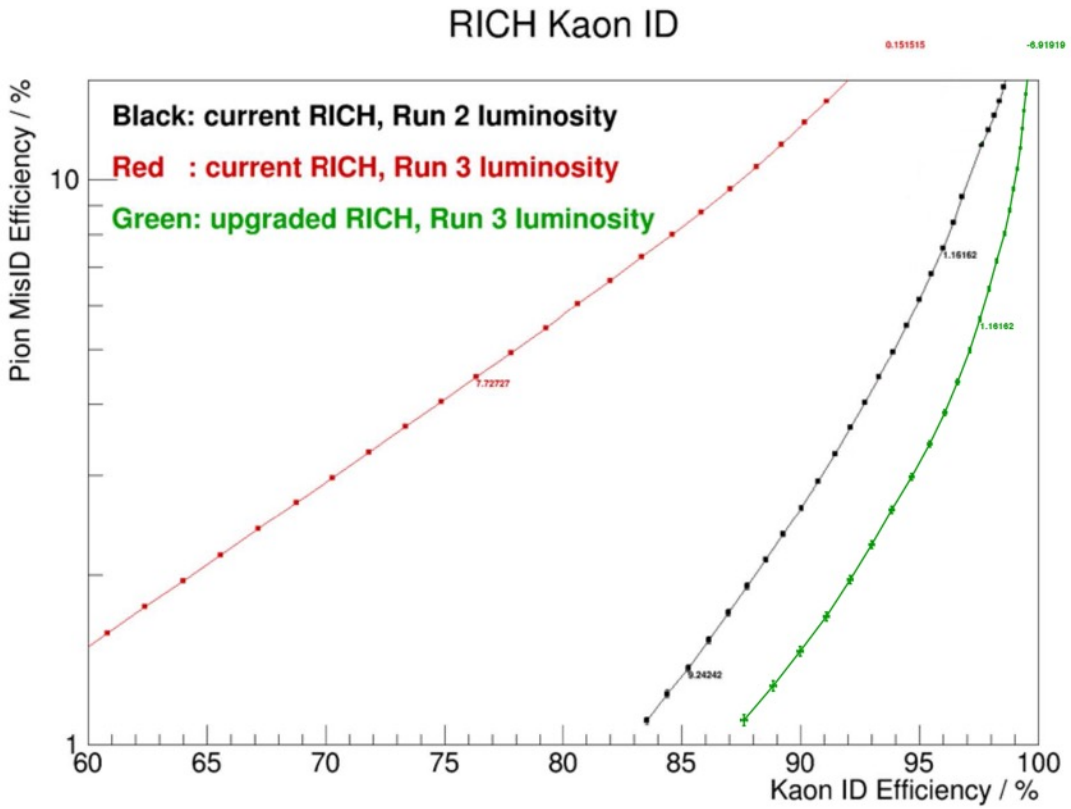
On 23/07/2020 RICH2 full A-side test installation performed





LHCb RICH Upgrade Performance

	Chromatic Error [mrad]	Emission Point Error [mrad]	Pixel Error [mrad]	Total Error (resolution) [mrad]	Photon Yield
Current RICH1	0.84	0.76	0.60 PSF = 0.86	1.60	34
Upgraded RICH1	0.58	0.37	0.44	0.78	40
Current RICH2	0.48	0.27	0.19 PSF = 0.29	0.65	24
Upgraded RICH2	0.31	0.27	0.19	0.45	24



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Conclusions

LHCb will increase luminosity to 2×10^{33} cm^{-2} s^{-1} and read-out rate to 40 MHz

Mechanical structure of RICH1 modified to decrease photon occupancy in post-upgrade running conditions

RICH detectors opto-electronic chain is being replaced

- Compact modular structures: ECs
- MaPMTs and CLARO custom ASIC for single-photon detection and fast read-out
- FPGA based Digital Board for DAQ

PDM and mechanical components tested in beam experiments and in laboratory setups

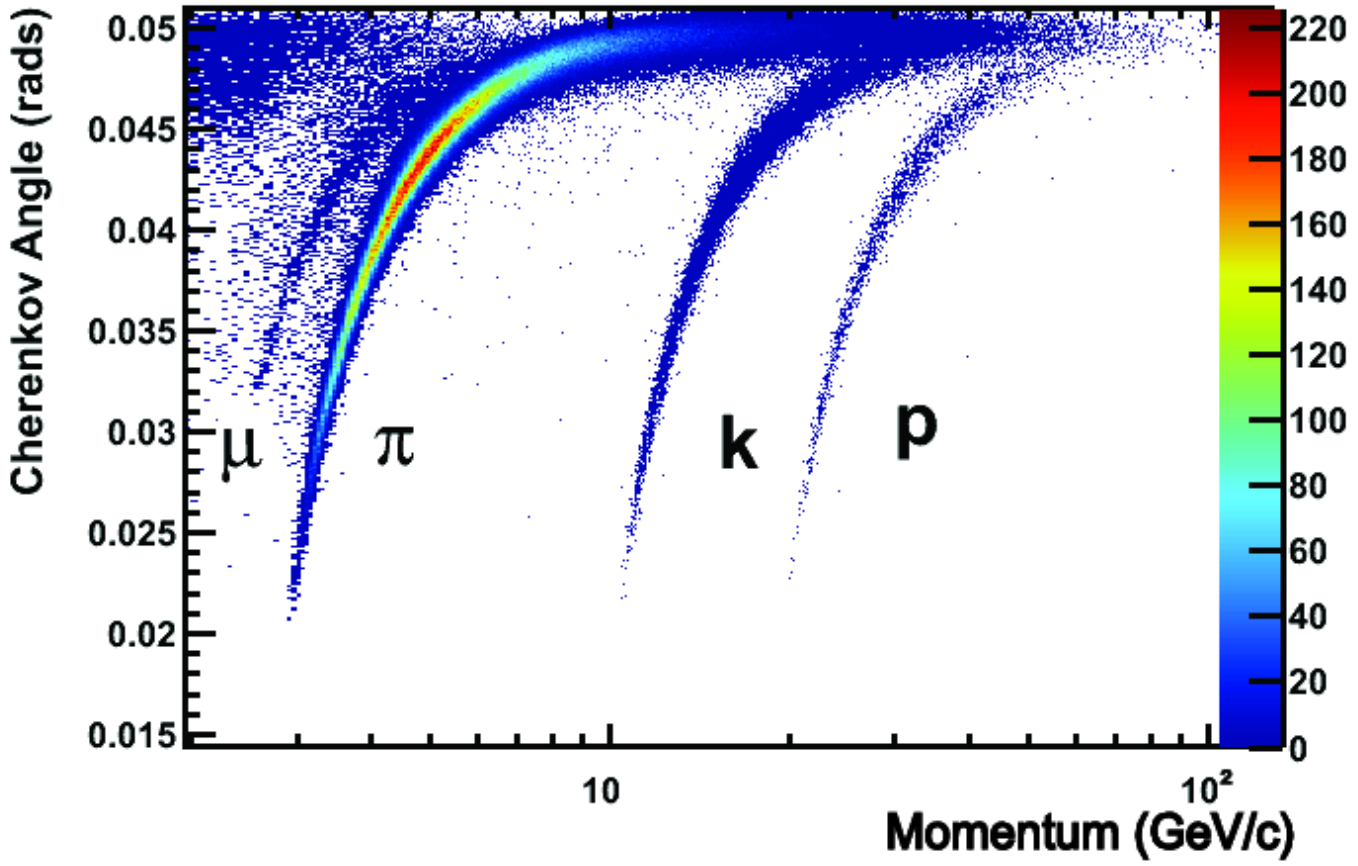
QA procedures to validate all components installed during the Upgrade

- Almost all the ECs have been delivered at CERN from QA test locations
- RICH2 ready to be installed in the cavern

Backup Slides

Cherenkov Angle θ_c VS Particle Momentum

Eur. Phys. J. C 73:2431 (2013)



LHCb RICH
Hybrid Photon Detectors

Pixel HPD developed in collaboration with industry

- Vacuum technology, silicon pixel read-out
- 32×32=1024 pixels, 0.5×0.5 mm^2

484 HPDs, total area 3.3 m^2

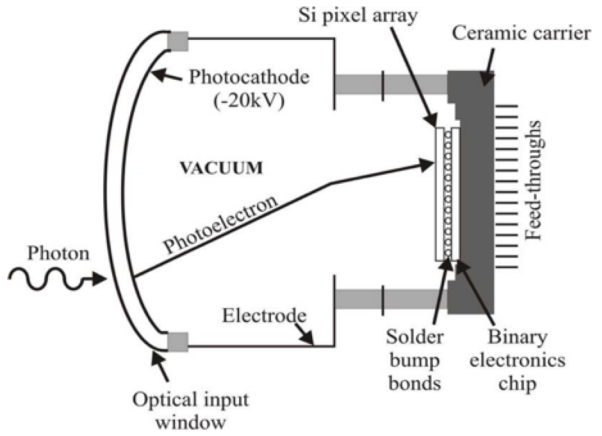
Quantum Efficiency

- ~27% @270nm

Silicon sensor bump-bonded to binary read-out chip (1.1 MHz)

Noise level: 145 e$^-$

- Signal 5000 e$^-$ typ.



LHCb RICH Prototype Beam Test Setup