Overview of LHCb-RICH upgrade

LHCb-RICH collaboration

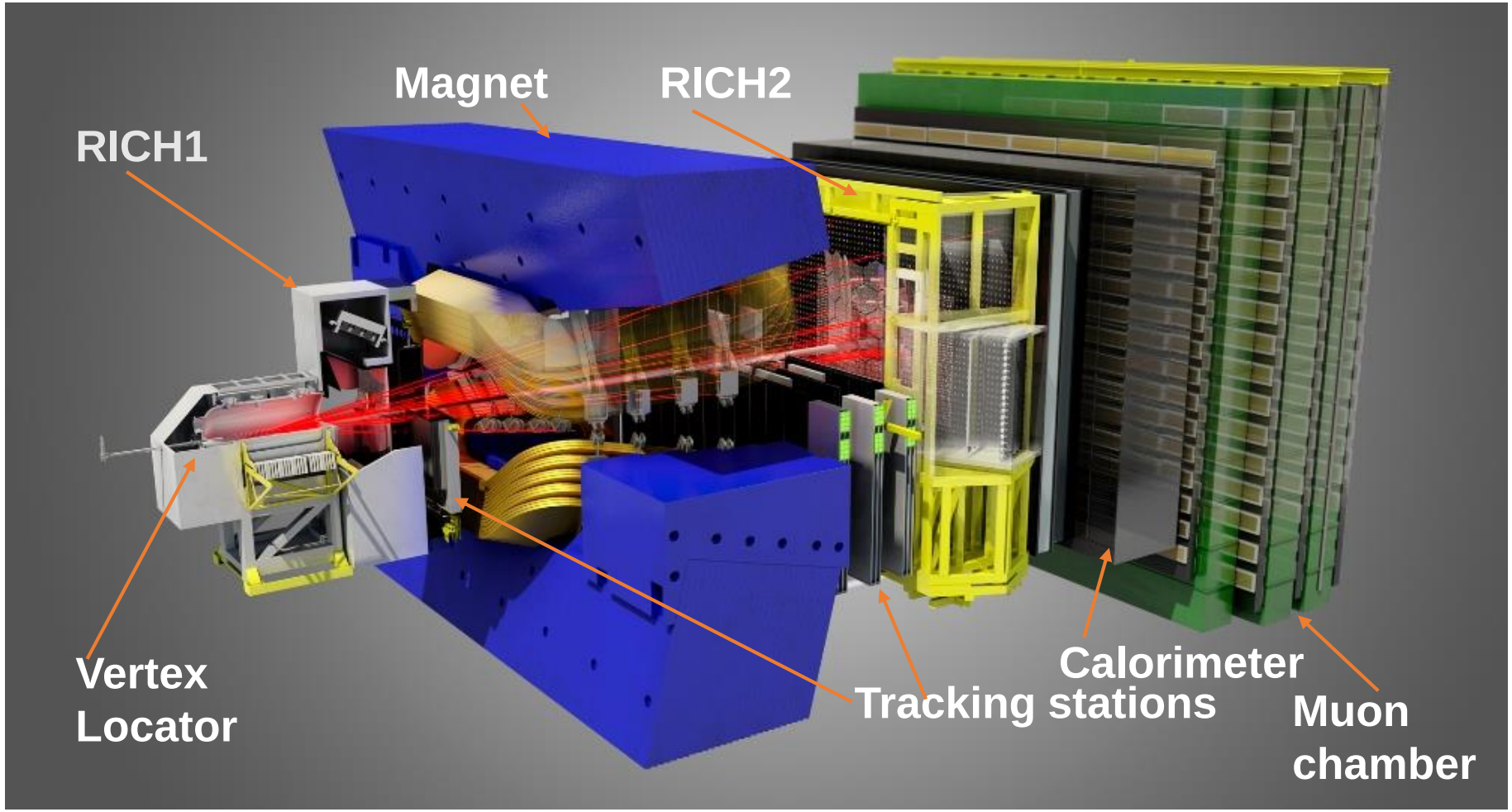
RICH-2016, Bled, Slovenia

Science & Technology Facilities Council

Sajan Easo

September 05, 2016

The LHCb Experiment



At present:

- pp : $\sqrt{s}$ = 13 TeV

- RICH1:
  C_4F_{10} < ~ 60 GeV/c
  Photodetectors:
  Top + Bottom

- RICH2:
  CF_4: > ~ 20 GeV/c
  Photodetectors:
  Left+ Right

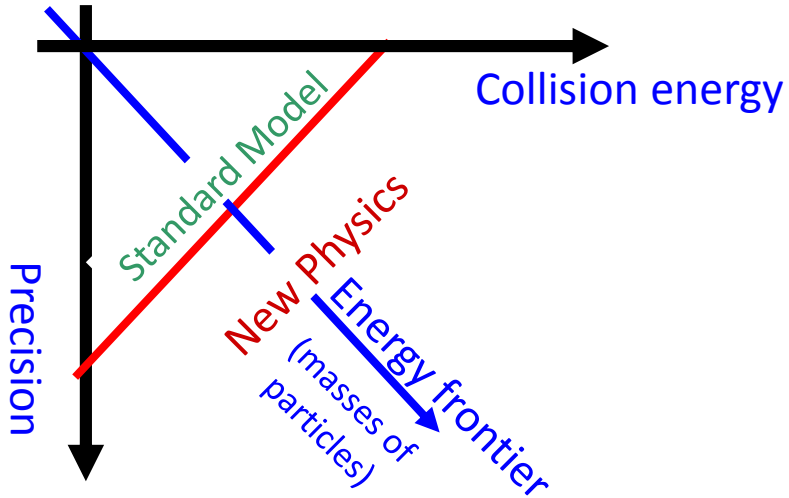
RICH detectors in current LHCb : Talk by A. Papanestis today

$2 < \eta < 5$

Overall acceptance ~ 10→300 mrad, Momentum range : 2-100 GeV/c

LHCb upgrade : concept

- Search for signals of new physics(NP) beyond the standard model (SM) in high energy physics
  - Indirect search from the decays of hadrons with b and c quarks
- Large sources of flavour symmetry breaking are excluded at TeV scale, from the current measurements
- Aim for a significant increase in the precision of LHCb measurements by increasing the readout rate in Run3



LHC era → HL-LHC era

Run (years)	Run 1 (2010-2012)	Run 2 (2015-2018)	Run 3 (2021-2023)	Run 4 (2027-2029)
Integrated luminosity	3 fb^{-1}	8 fb^{-1}	25 fb^{-1}	50 fb^{-1}
Instantaneous luminosity	4 x 10^{32} $cm^{-2}s^{-1}$		2 x 10^{33} $cm^{-2}s^{-1}$	

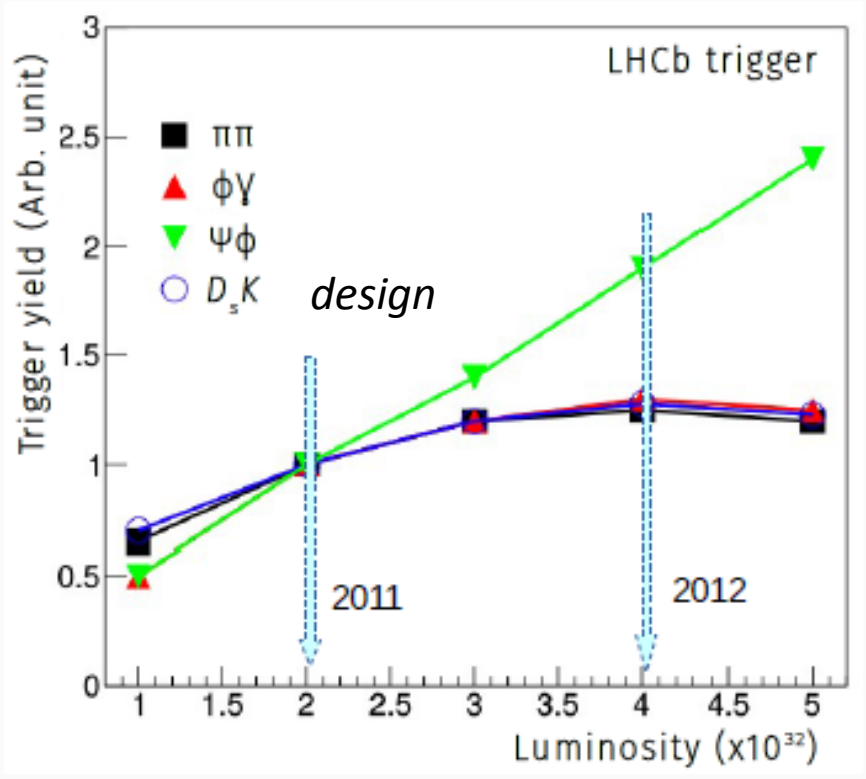
Current LHCb → Upgraded LHCb

LS2
LHCb Upgrade

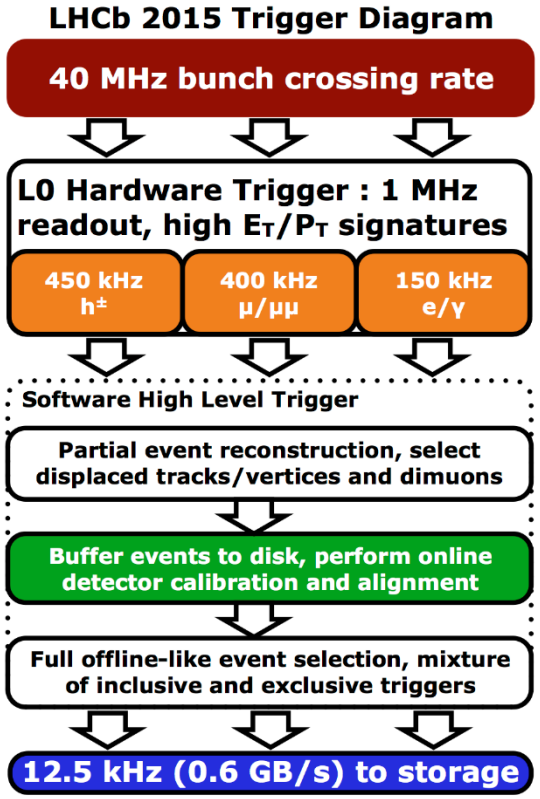
- Current upgrade to be installed during 2019-20
  - *Ideas for a future RICH upgrade to be installed during 2024-26 : Talk by C. D'Ambrosio tomorrow*

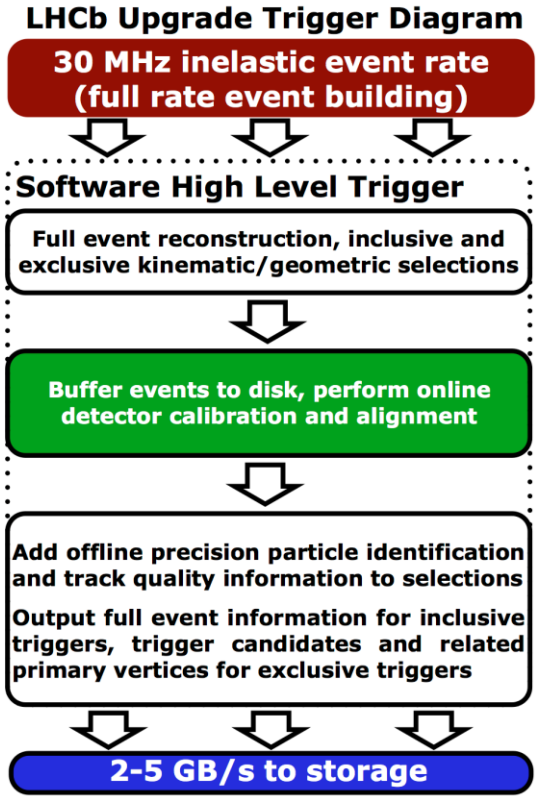
LHCb upgrade : concept

- Main bottlenecks for going to high readout rate:



- Current 'Front End' max readout rate = 1.1 MHz
- Level0 hardware trigger (E_T & P_T *in calorimeter & muon detectors*):
  Limited discrimination power → Yields saturate in hadronic channels



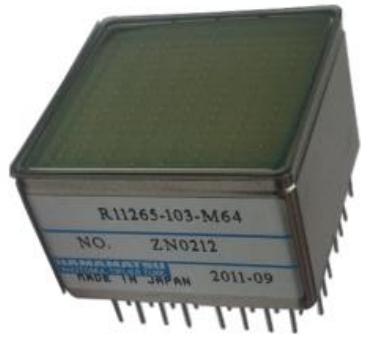


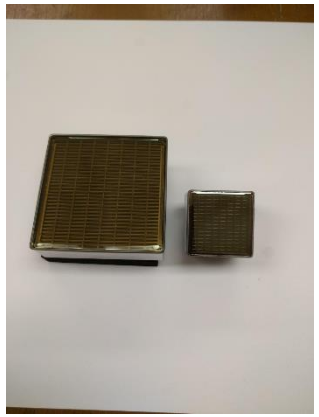
Optional low level hardware Trigger (LLT) with low thresholds

Year	2012	2015	2021
Data to storage in kHz	5	12.5	20 - 100

RICH in the LHCb upgrade

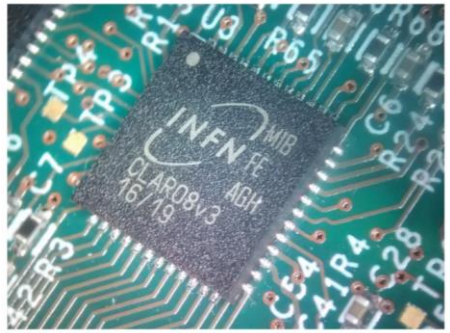
- Photodetectors:
  - Replace HPDs : Pixel chip encapsulated in each HPD has 1 MHz max. readout rate
  - Use new MaPMTs from Hamamatsu : each with 8 X 8 pixels
    - R13742 (*from R11265 series*) : Active area : 23 X 23 mm^2
    - R13743 (*from H12700 series*) : Active area : 48 X 48 mm^2





  - R13742 for RICH1 and inner region of RICH2
  - R13743 for outer regions of RICH2

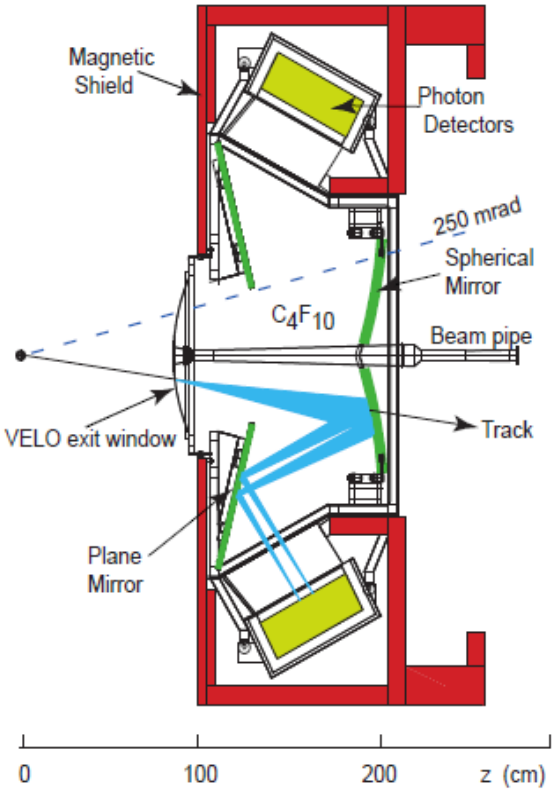
- Readout :
  - CLARO: custom made ASIC
  - New readout chain

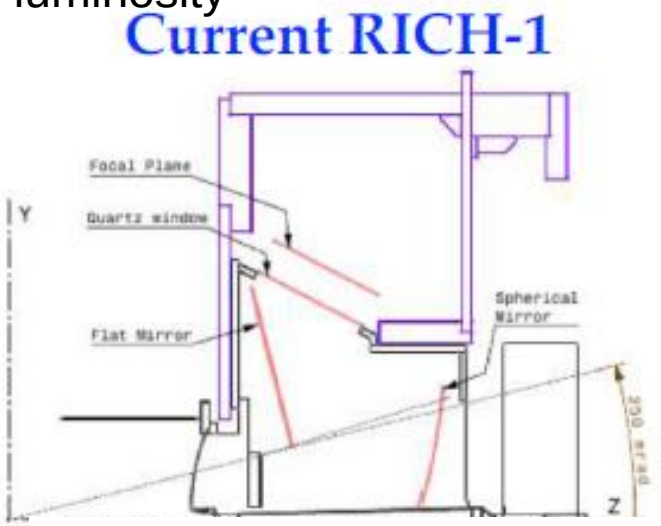


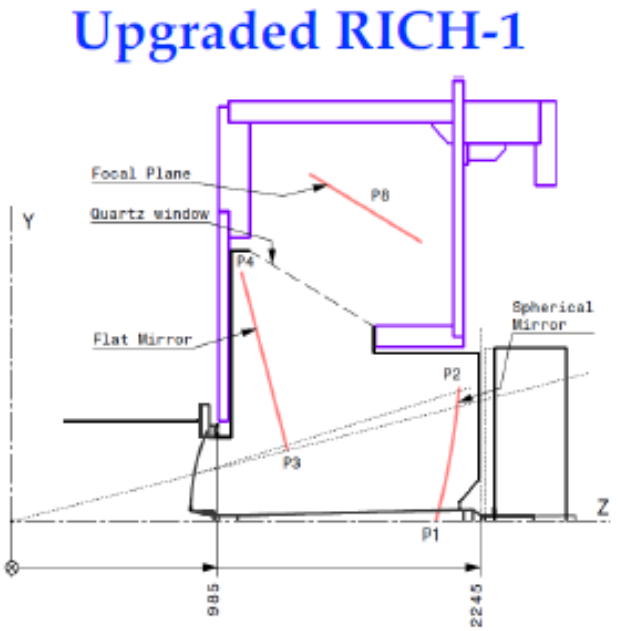
RICH1 in LHCb upgrade

- Improved optics in RICH1 to obtain optimal PID performance at the increased luminosity
- The upgraded RICH1 has similar structure to that of the current RICH1, but it is completely revamped

VW Golf GTI : Mk I vs Mk VII







- Spherical mirror ROC: 2710 → 3650 mm to reduce the occupancy at high luminosity
- New mechanical structure to the install the arrays of MaPMTs and their readout boards.
- New mirrors, new box which contains the mirrors and the radiator gas.

LHCb-RICH talks menu

Upgrade RICH

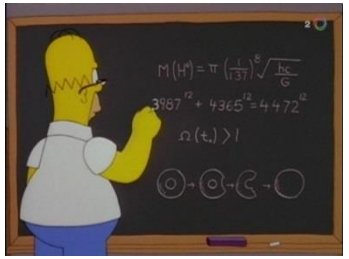
- ***CLARO + MaPMT : L. Cassina***
- ***Future upgrade : C. D'Ambrosio***
- ***Posters:***
  - ***MaPMT Shielding: F.Muheim***
  - ***MaPMT characterization: S.Gambetta***
  - ***MaPMT readout tests: M.Blago & F.Keizer***
  - ***Test beam results: P. Carniti***
  - ***Radiation hardness of CLARO: M.Fiorini***
- *This presentation: Amuse-bouche*

Current RICH

- ***Performance : A.Papanestis***
- ***Real time calibration & alignment : J.He***

- ***Performance from simulations***
- ***RICH1 and RICH2 mechanics development***
- ***MaPMTs, readout***
- ***Magnetic shielding***
- ***Prototype testing***

PID performance from simulations



- LHCb tracking detectors are also being upgraded.
- In the simulations, the upgraded tracking system is used along with upgraded RICH
  - *Simulations: PYTHIA v8 + EVTGEN + GEANT4*
- Reconstructed tracks and RICH hits are subjected to a log-likelihood algorithm for PID
  - *Results quoted in terms of the difference in the log-likelihood (DLL) between kaons and pions*

Configuration for simulation	Luminosity 10^{32} cm^{-2}s^{-1}	nominal # of Bunches	E TeV	ν
Current LHCb in Run 2	4.0	2300	13	1.6
Upgrade LHCb in Run 3	20	2400	14	7.6

ν = *Average number of pp interactions per bunch crossing*

Resolutions and yields

Yield = Number of detected hits per isolated track
Tracking resolution used: 0.4 mrad

Single photon resolutions from full simulations:

Resolution (in mrad)	RICH1-2015 current HPD	RICH1-upgrade MaPMT	RICH2-2015 current HPD	RICH2-upgrade MaPMT
Chromatic	0.84	0.58	0.48	0.31
Pixel	0.60, PSF=0.86	0.44	0.19 PSF=0.29	0.19
Emission point	0.76	0.37	0.27	0.27
Overall Overall+Track	1.60 1.65	0.78 0.88	0.65 0.76	0.45 0.60
Yield	**32**	**42**	**24**	**22**

Using RICH2 MaPMTs in central region

Resolutions improved for upgraded geometry

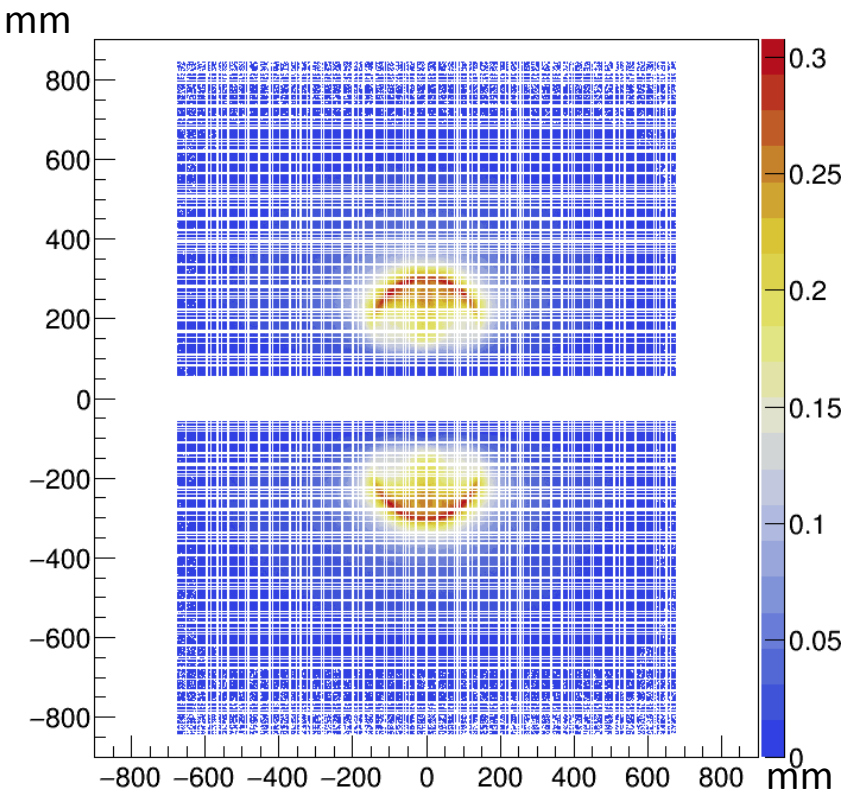
Improvements in

Chromatic error	*MaPMT QE peaked at higher wavelength than that of HPD*
RICH1: Emission point error	*Improved optics*
RICH1: Yield	*Increased radiator length*

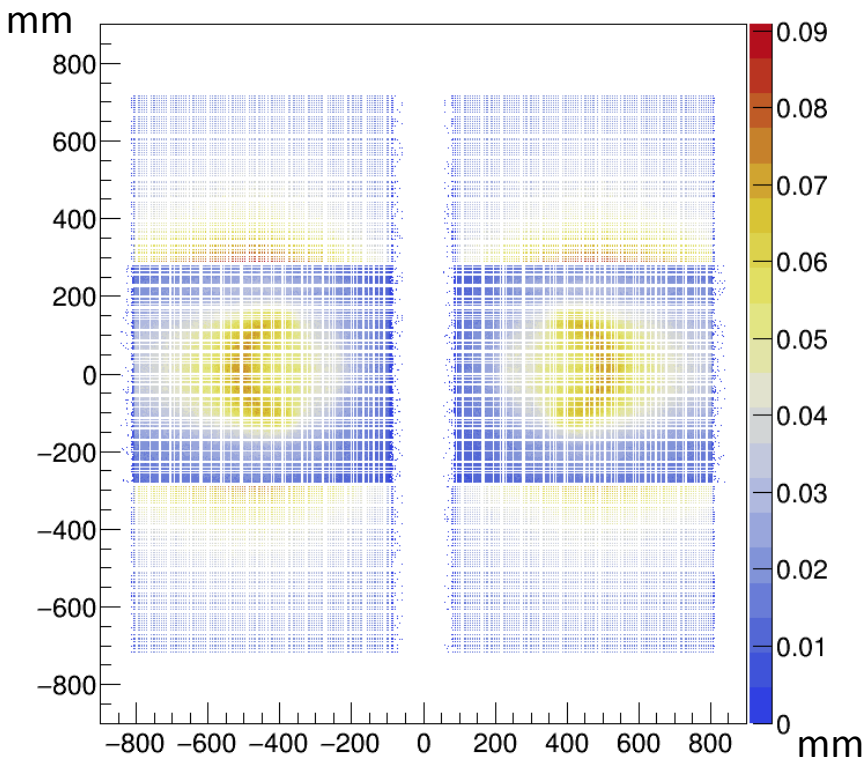
Occupancies in RICH1 and RICH2 for upgrade

XY coordinates of hits on detector plane

RICH1



RICH2



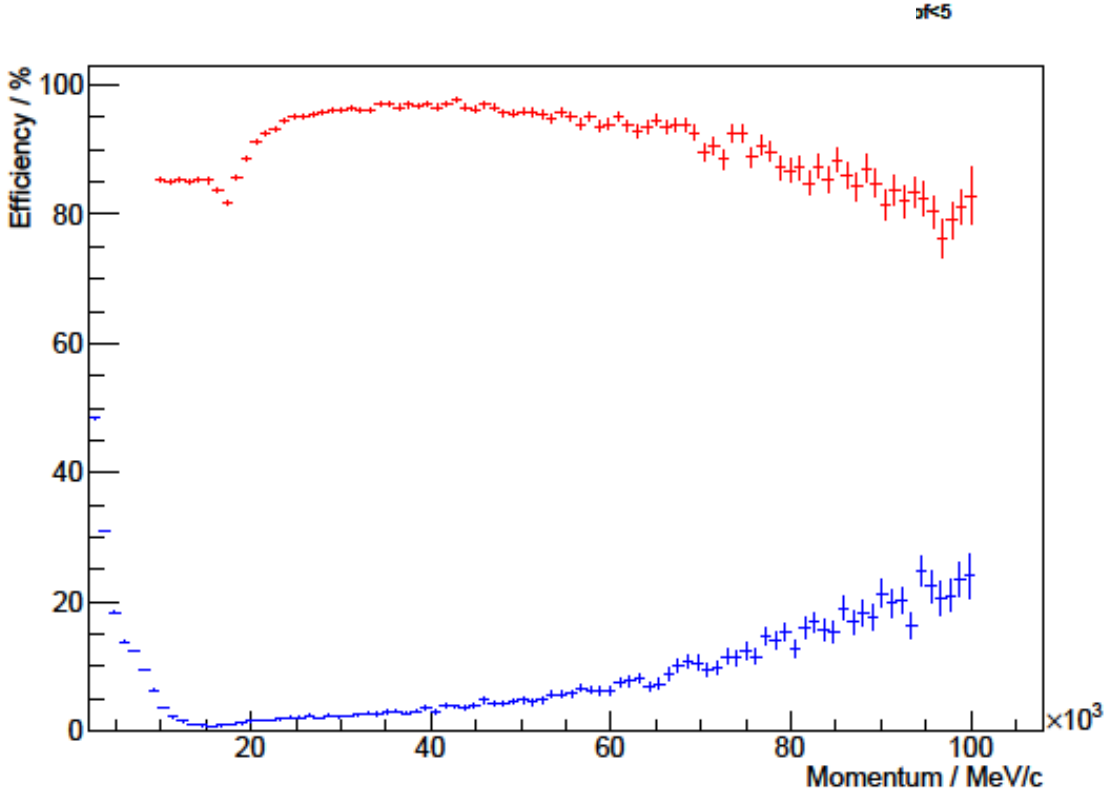
- Using upgrade geometry configuration with Run 3 luminosity
  - *Peak occupancy in RICH1: ~ 27 %*
- If 2015 geometry configuration were used:
  - *Peak occupancy in RICH1 would have been above 40%*

- *MaPMT R13742 : In RICH1 and inner region of RICH2*
- *MaPMT R13743 : In outer region of RICH2*

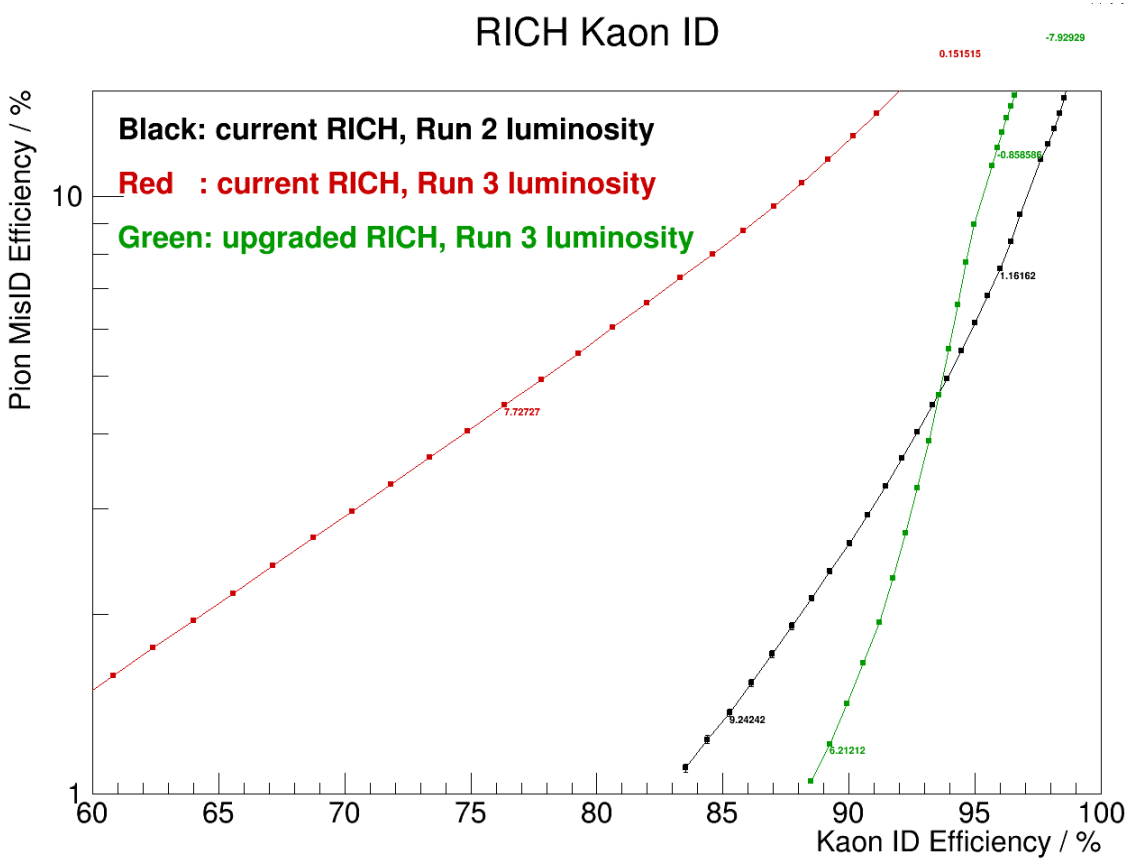
PID performance

Red: Kaon identification efficiency

Blue: Probability for pion to be misidentified as kaon



PID performance vs momentum at upgrade luminosity



Average PID in the momentum range 2-100 GeV/c for different DLL cuts

Improved performance obtained for upgrade configuration

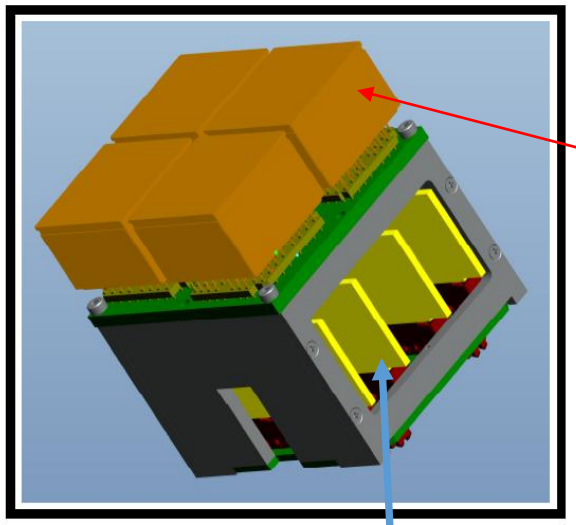
RICH components at LHCb upgrade

- Radiators:
  - Keep the same as those for the current system
    - C_4F_{10} for RICH1 and CF_4 for RICH2
  - At low momentum, use veto mode (as a threshold counter)
    - examples: below 9.3 GeV/c for π/K, below 17.7 GeV/c for K/p etc.
  - R&D to improve the low momentum PID in progress
    - *Talk on photonic crystals by I. Kaminer*
    - *Talk on TORCH (based on TOF method) by T.Gys Today*

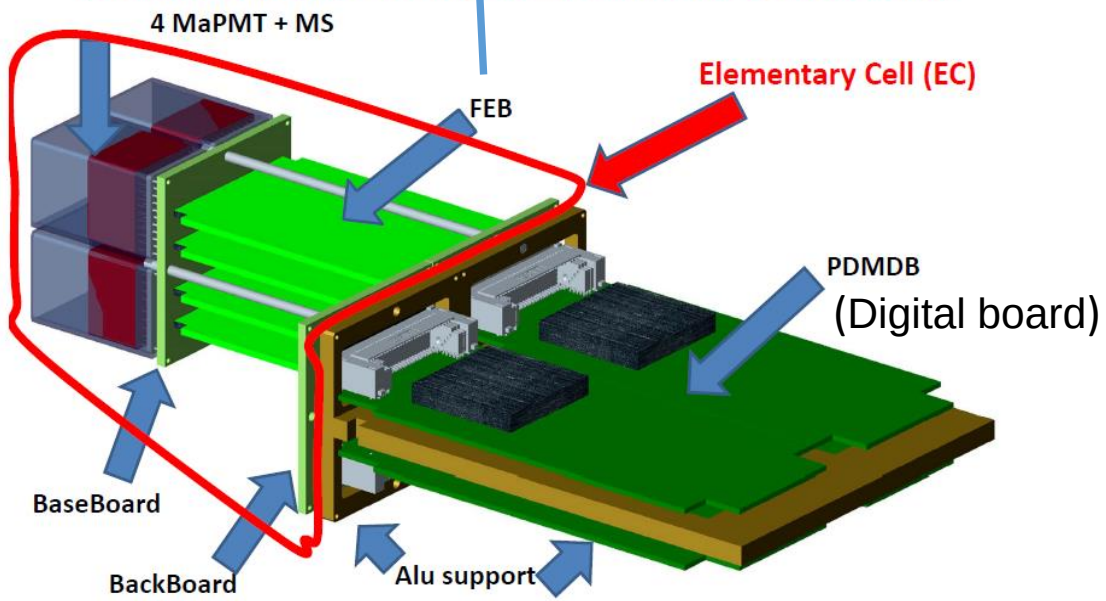
- RICH1 Mirrors:
  - New spherical mirrors to be made of carbon fibre, as in the current system.
  - New flat mirrors to be made of glass, as in the current system.
  - Prototypes being tested to verify reflectivity, ROC etc.

Mechanics: Photon detector module

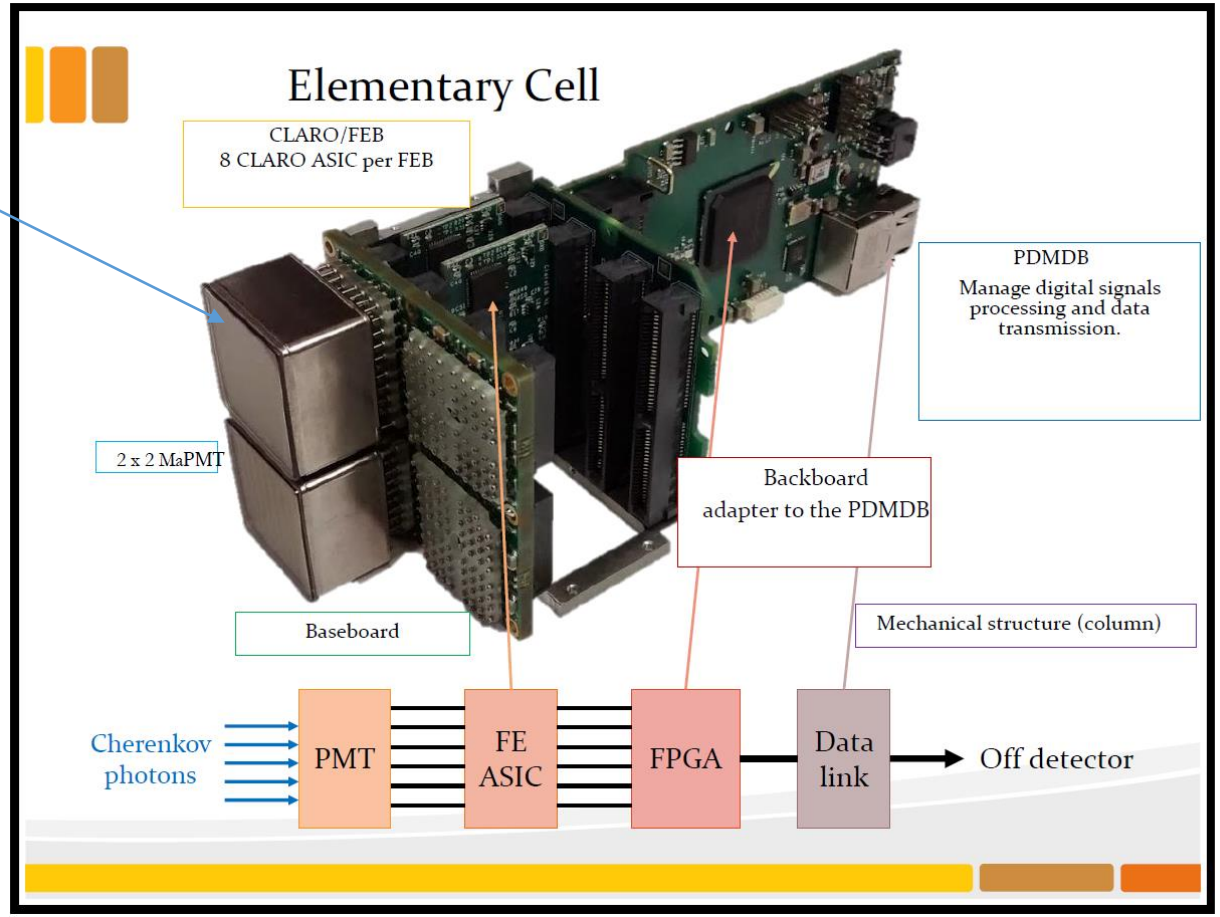
Elementary Cell (EC)



MaPMT

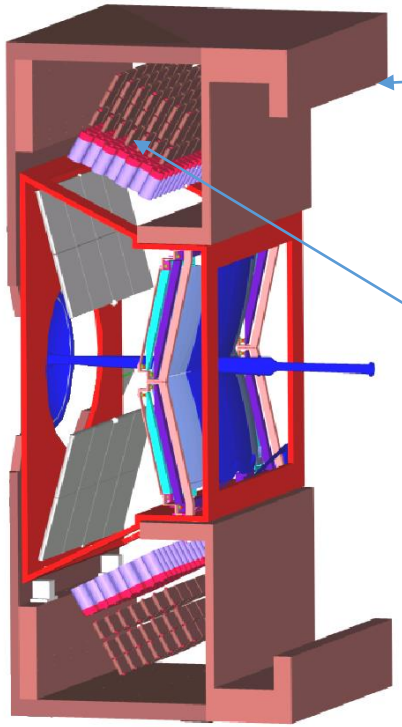


Partially assembled structure



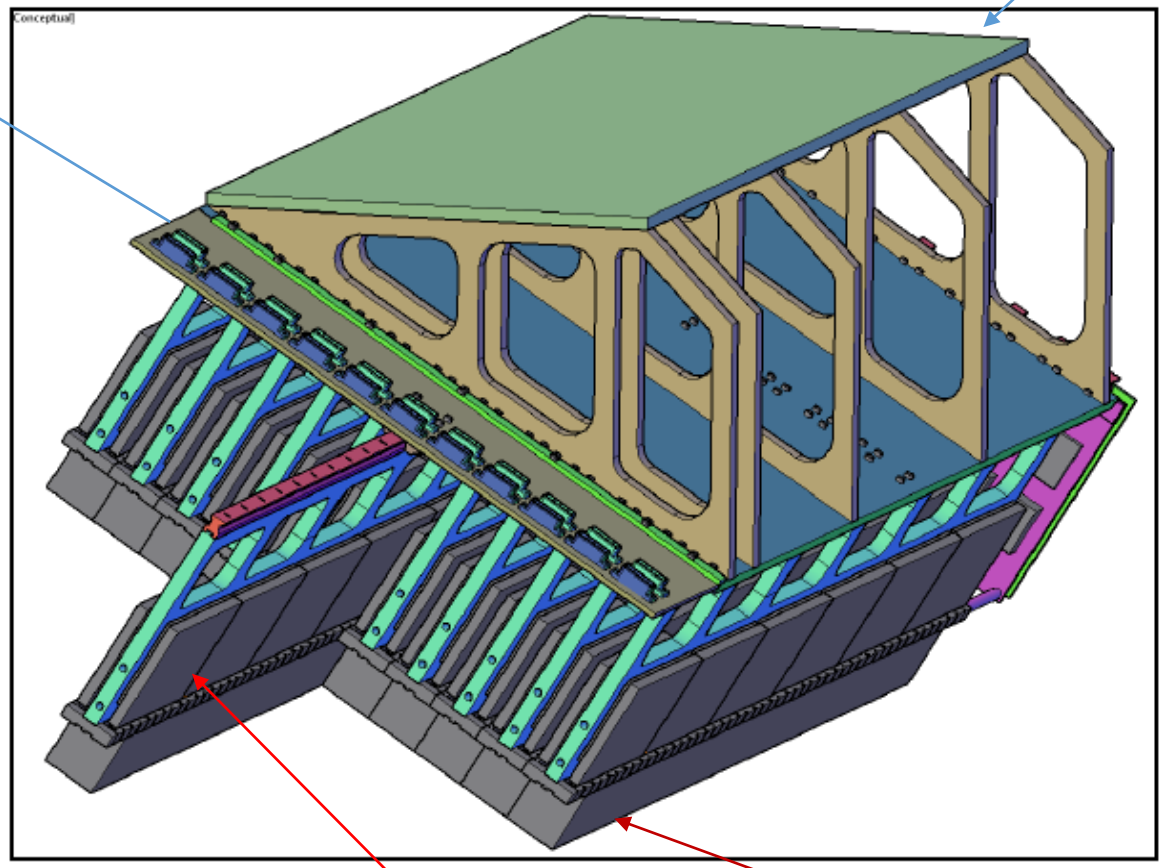
- 2 X 2 array of MaPMTs in an EC
- 4 X1 array of ECs in a Photodetector Module (PDM)
- Nominally, 6 X 1 PDMs assembled into a PDM column in RICH1
- Total of 2688 + 384 MaPMTs: 196608 pixels in RICH1+RICH2

RICH1 Mechanics

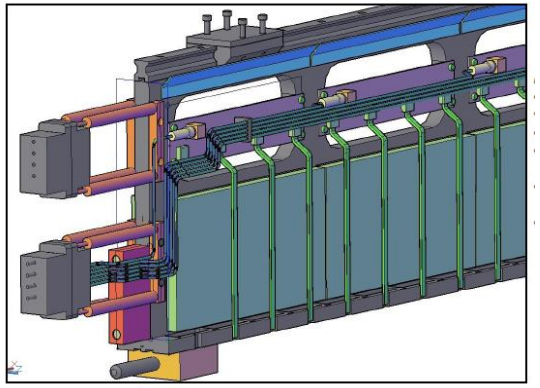


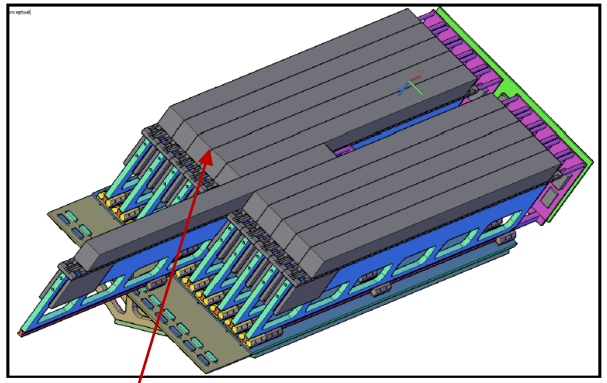
Magnetic shielding plates

Mechanical structure attached to the shielding plates



Column of PDM





Readout boards

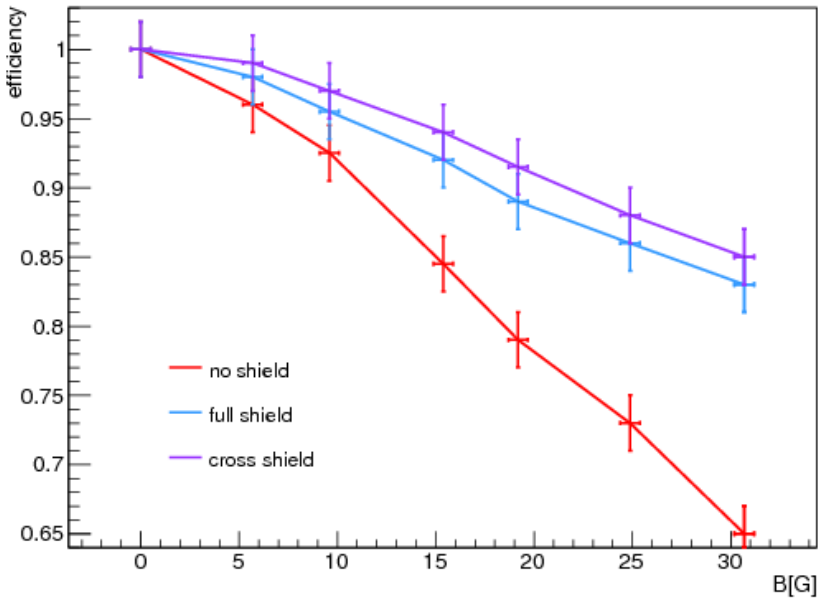
Arrays of MaPMT modules (PDM) in columns

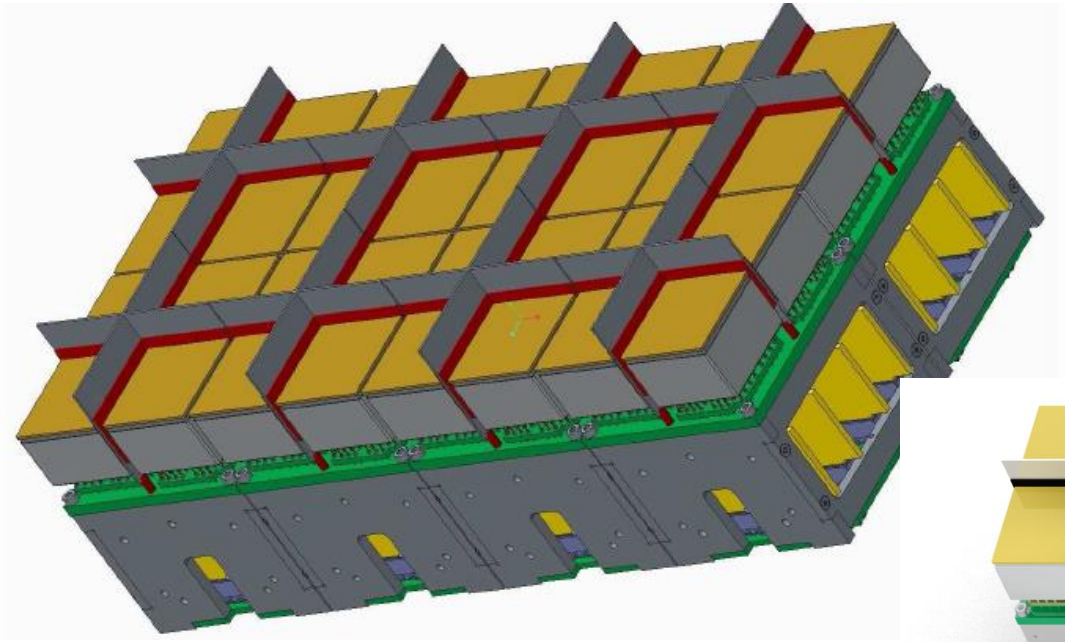
Easy to remove a column for maintenance operations

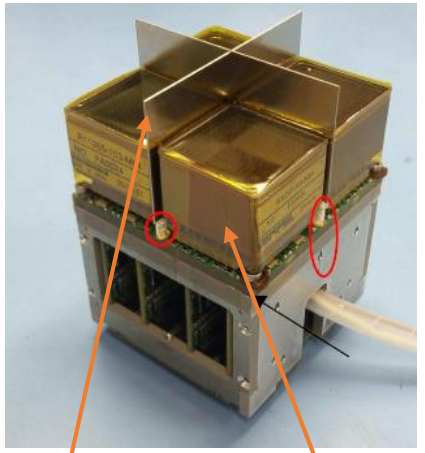
MaPMT Magnetic shielding

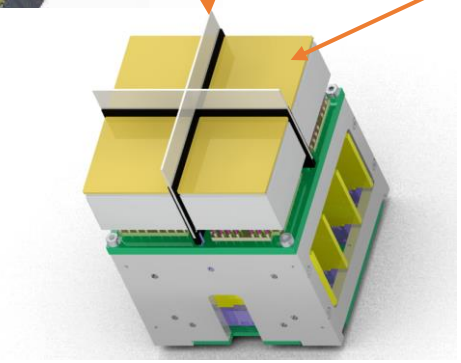
Poster from F.Muheim

- Maximum magnetic field expected in the detector region of RICH1: 25 Gauss , RICH2: 5 Gauss
- This can lead to reduction of detection efficiency.
- Lab tests performed to measure detection efficiency of MaPMT prototypes for different fields
- Local shielding to be applied using a ‘cross-shaped’ structure made of a material similar to ‘mu-metal’, on the EC

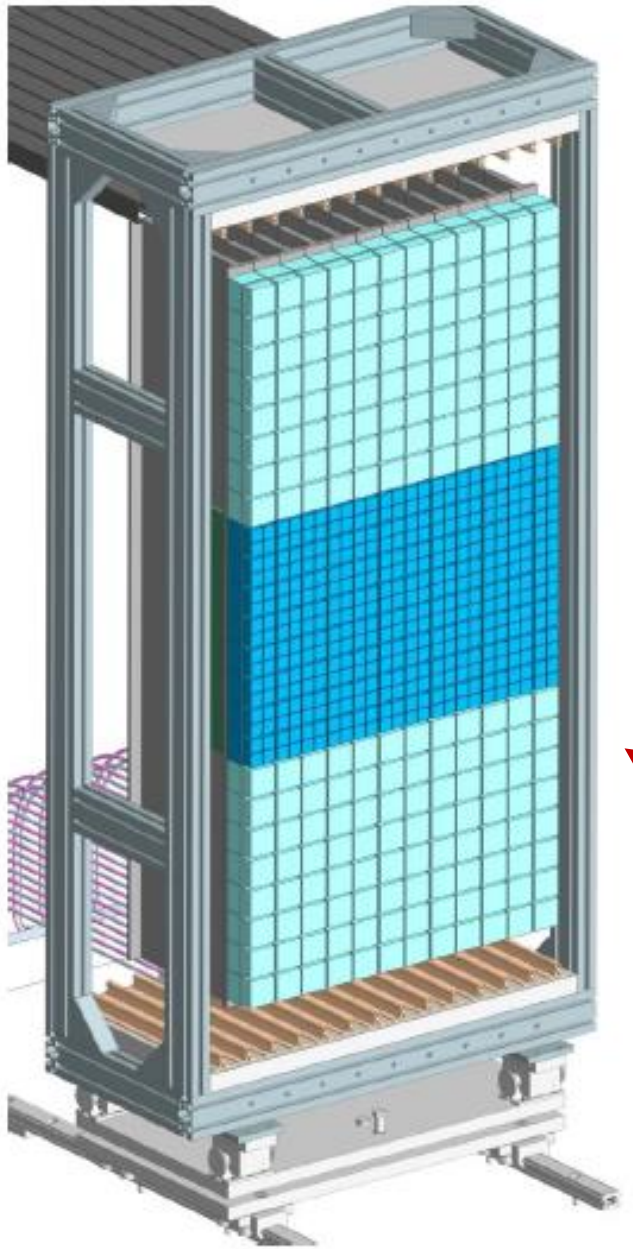




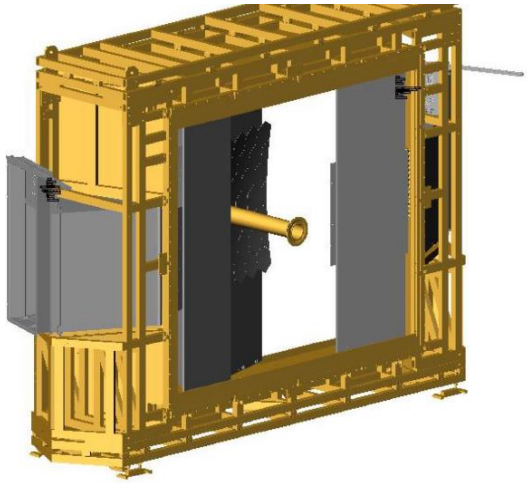


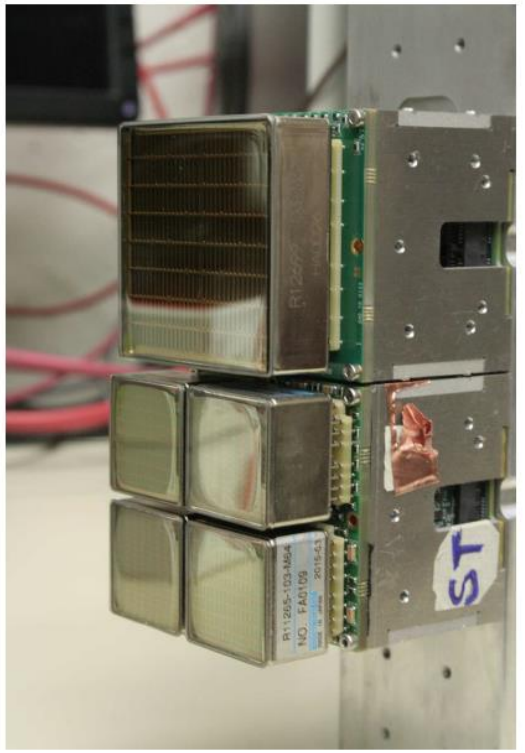


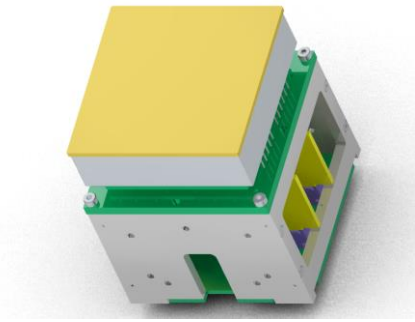
RICH2 Mechanics



- RICH2 optical layout same as that in the current detector
- Two types of MaPMTs :
  - Central region with R13742 , same as that for RICH1
  - Peripheral region R13743 with pixel size 6 mm X 6 mm
  - Versions of EC adapted for R13743 designed and prototypes tested

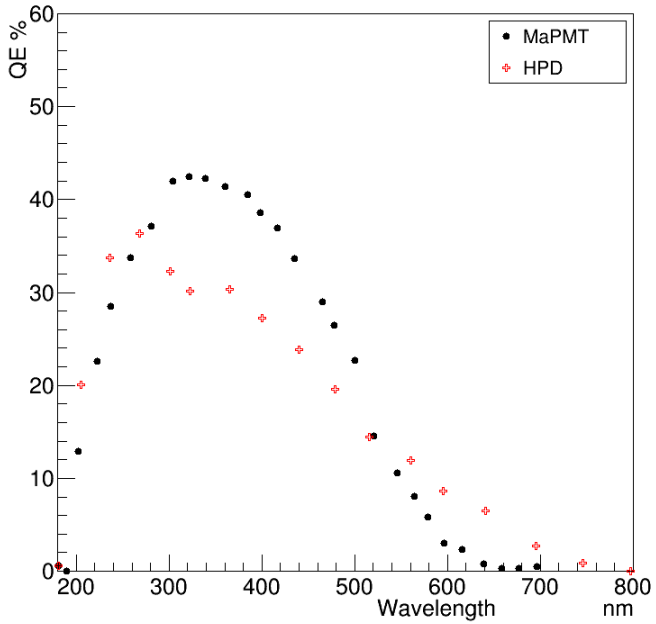






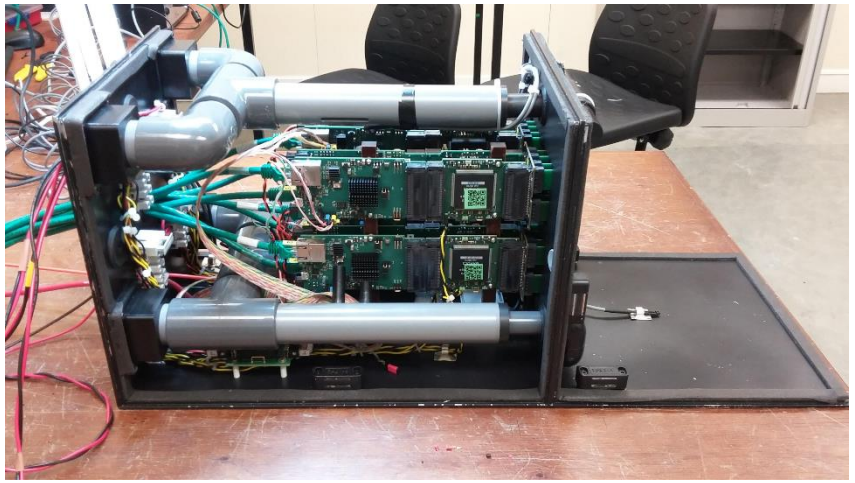
RICH Photodetectors

Typical QE



- Number of MaPMTS : 2700 (type R13742) + 400 (Type R13743)
  Pixels in each MaPMT : 8 X 8
- Active area fraction: R13742: 77 % (23mm/26.2 mm)
  R13743 : 87 % (48 mm/52 mm)
- gain 1.0 X 10^{6} with a variation less than 1: 4 and 1:3
- Average cross-talk : < 5 %
- Quality verification of each of these MaPMTs to be done in LHCb-RICH test centres

Poster from S.Gambetta



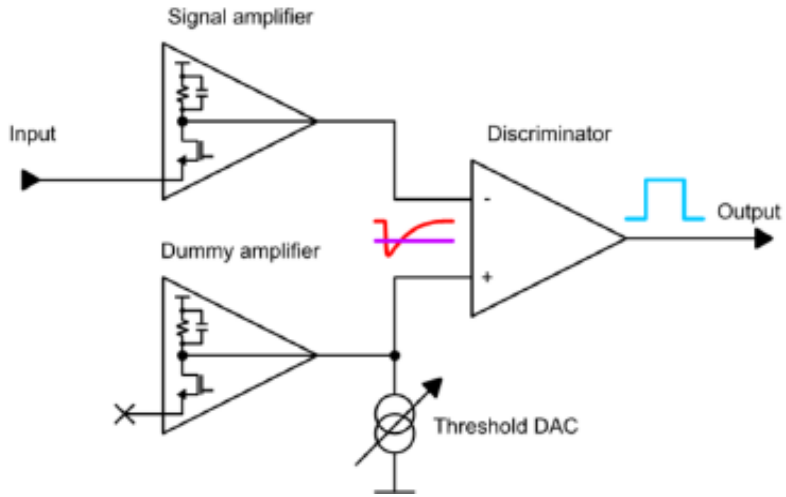
MaPMT at test centre setup

RICH Readout

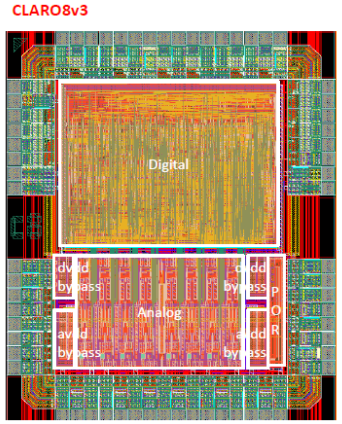
Talk by L. Cassina
Also JINST 8 C01029 (2013)

CLARO : 8 channel ASIC

- 64 possible threshold settings from 30 ke$^-$ to 2 M e$^-$
- 3 attenuation levels
- Power consumption only ~ 1 mW per channel
- Recovery time less than 25 ns.
- Radiation tolerant up to ~ 1 Mrad (10 k Gy) TID
  (*Even better results obtained from recent tests*)



- Performances of prototypes verified using lab tests and beam tests



- Production of the CLARO chips expected to start soon. LHCb-RICH needs about 28000 chips.
- Characterization will be done in the test centres

Poster from M.Blago & F.Keizer

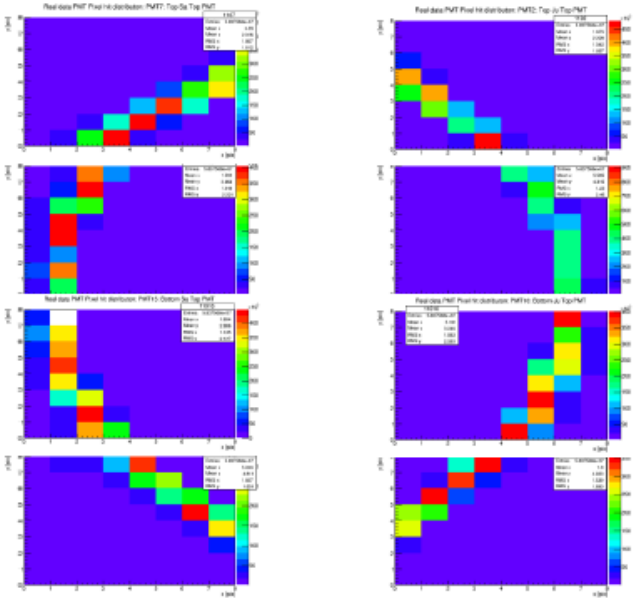
Prototype testing

Poster from P.Carniti

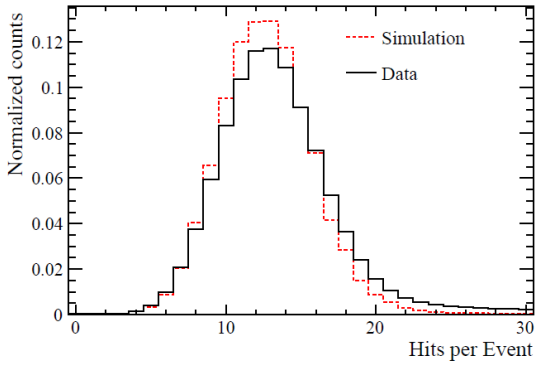
Test beam at CERN:

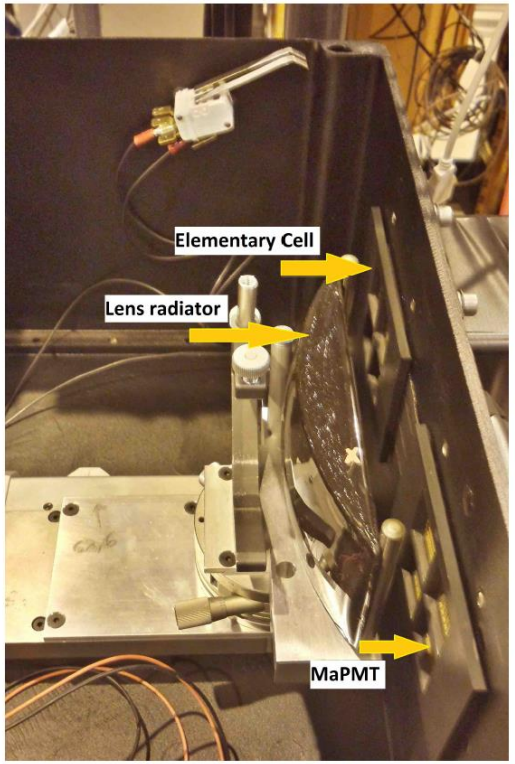
- 180 GeV/c pions incident on a spherical segment of quartz
- The detector plane equipped with arrays of prototypes of MaPMTs, CLARO, digital readout boards and EC.
- Several test beam runs in the last three years to test various versions of these.

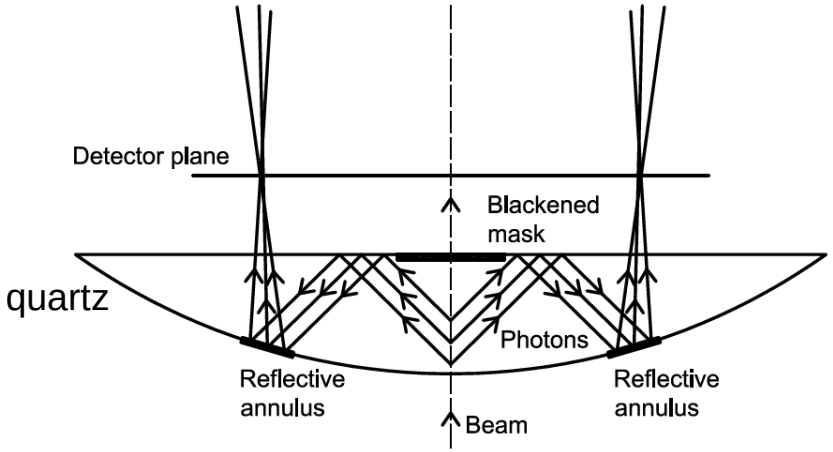
Cherenkov ring from RICH test beam in 2015



Number of hits per track in test beam





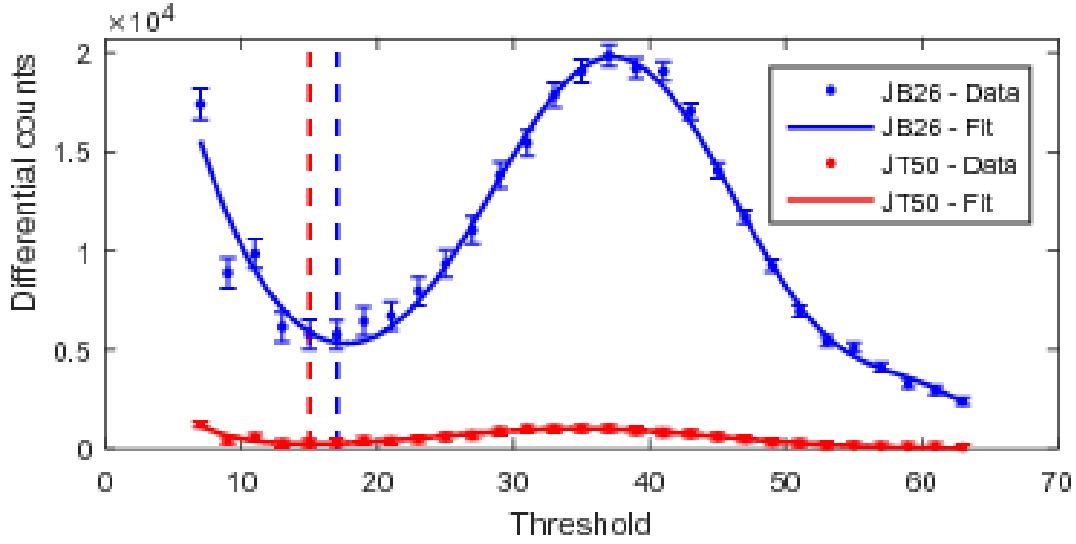


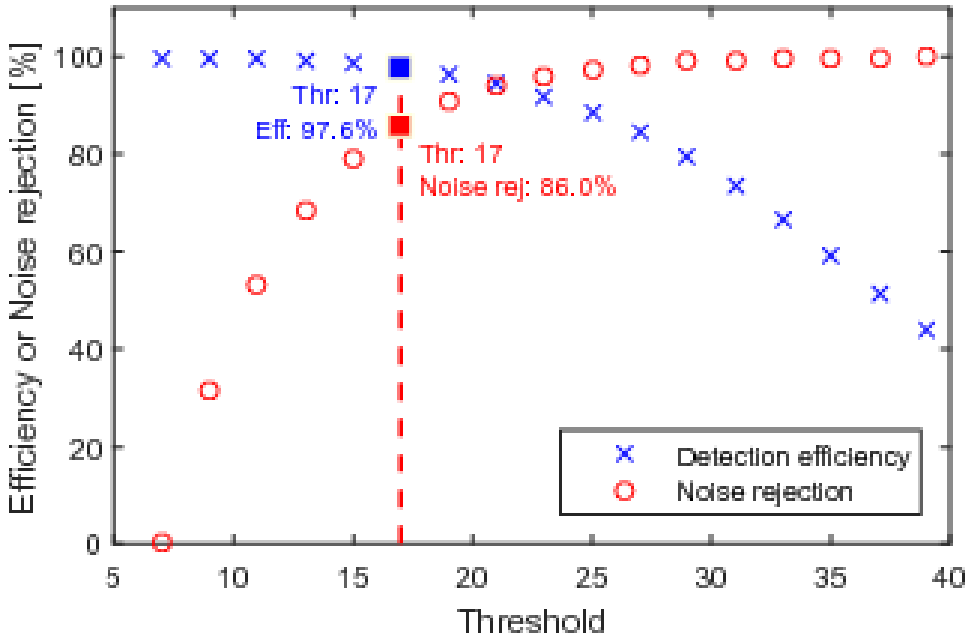
Overall resolution per photon

Simulation	**17.0 ± 1.3 mrad**
Real data	17.0 ± 0.8 mrad

Prototype testing

Typical pulse height spectra



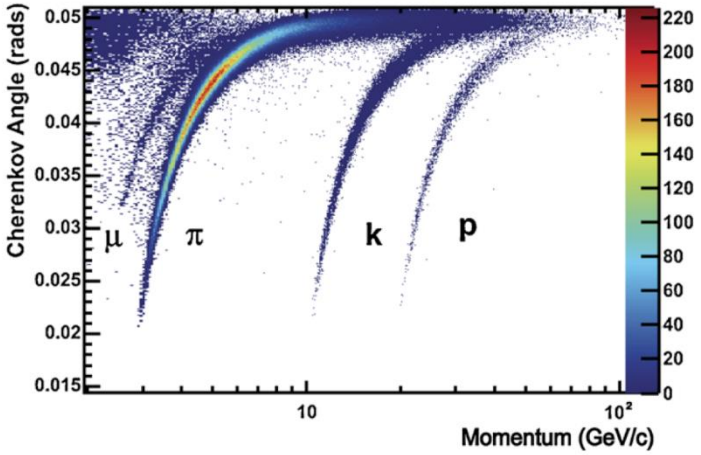


Efficiency and noise rejection

- Threshold scans: *Threshold unit = 35X10^3 e$^-$*
  - Collect data with different thresholds
  - Determine the pulse height spectra
- Dark count rate:
  - For 1000 Volt HV, the dark count rate was below 100 Hz per MaPMT.
  - This is negligible compared to the expected hit rate
- Mean cross-talk rate : below 5 %

SUMMARY

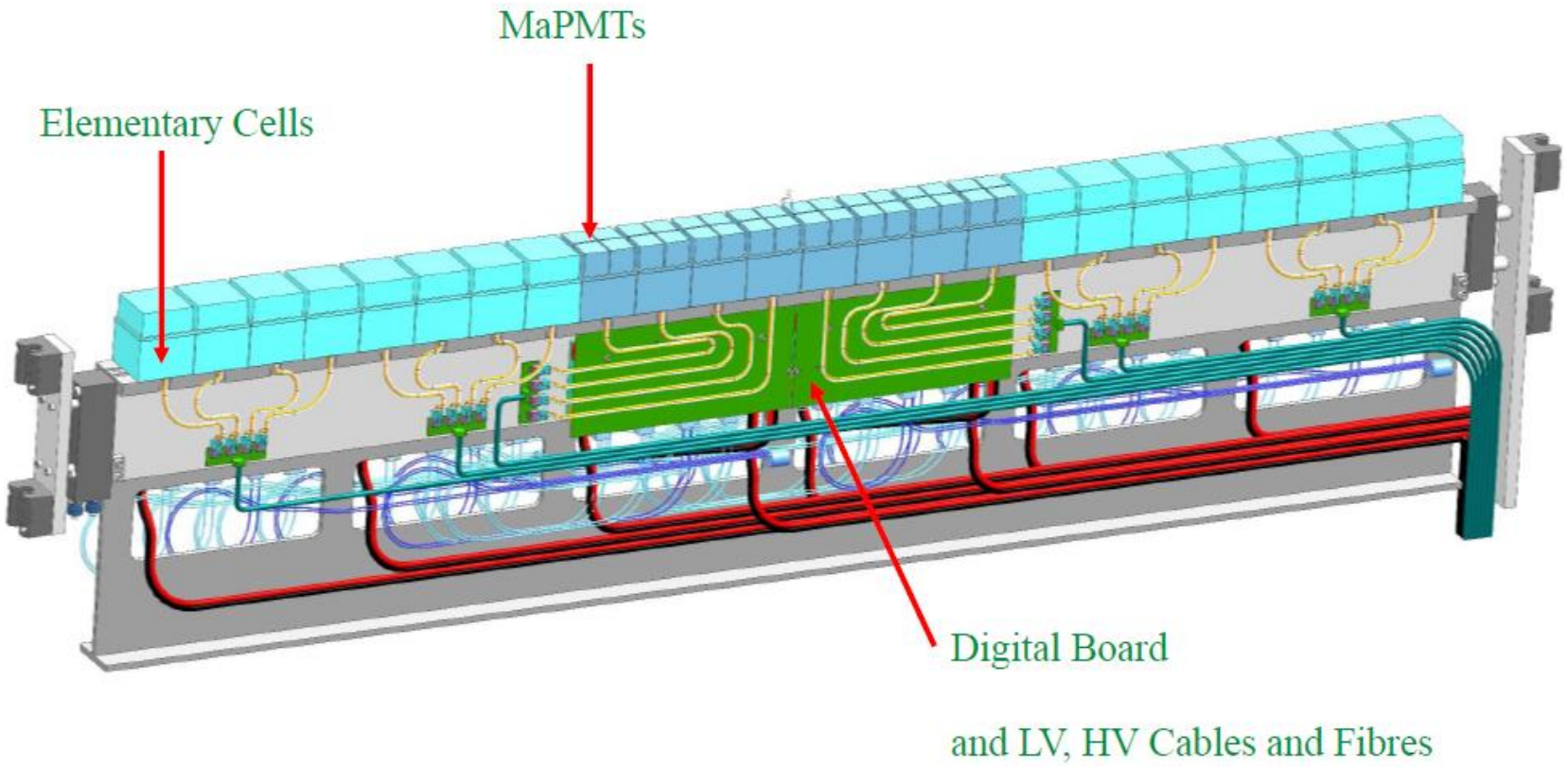
- The LHCb RICH upgrade programme is well underway.
- For the RICH upgrade, the technical design review(TDR) completed in 2013.
- The engineering design reviews of various parts of the RICH system are in progress in 2016.
- It is expected to install the new detector during 2019-20



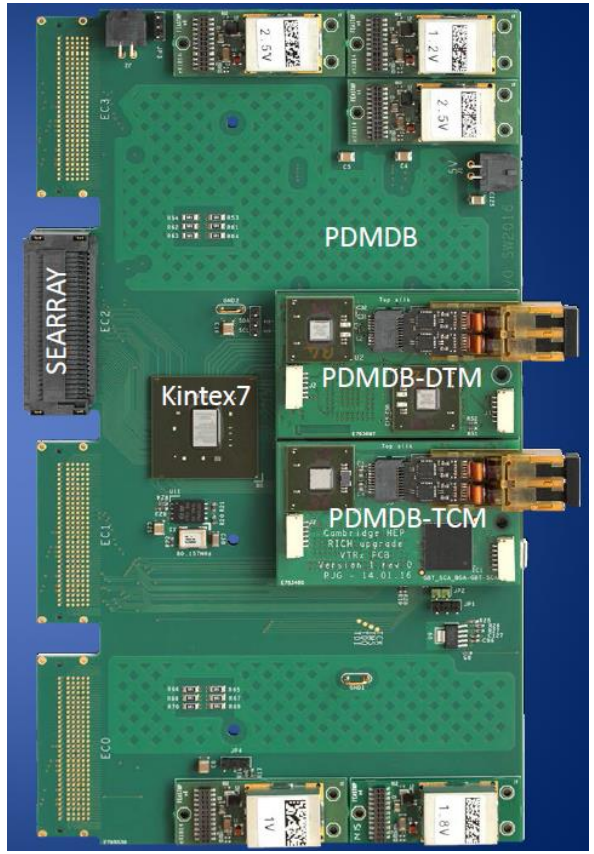
EPJC (2013) ,73:2431
From RICH1 gas radiator

BACKUP SLIDES

RICH2 Mechanics

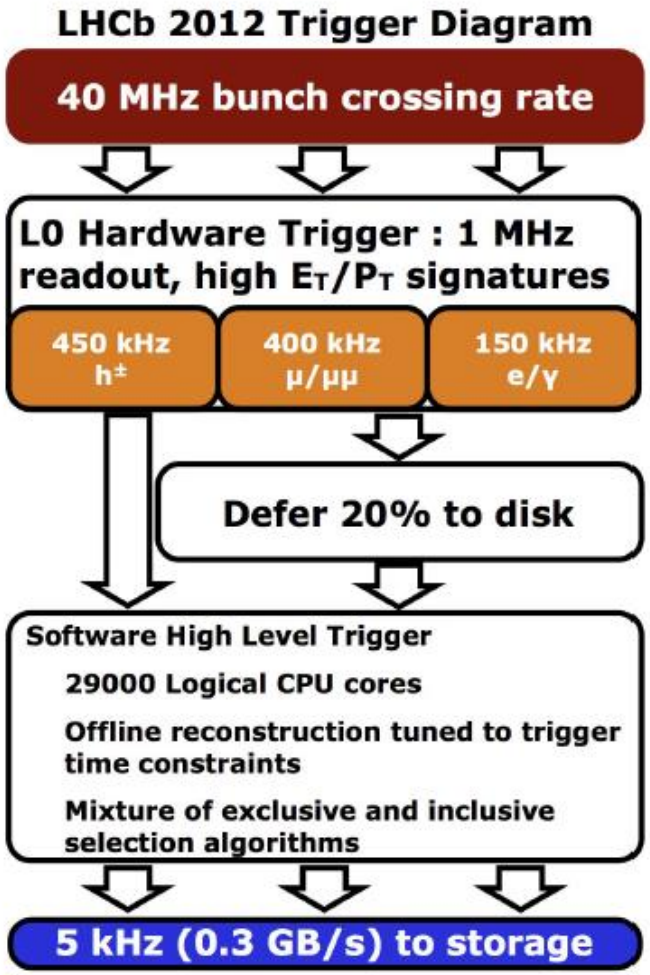


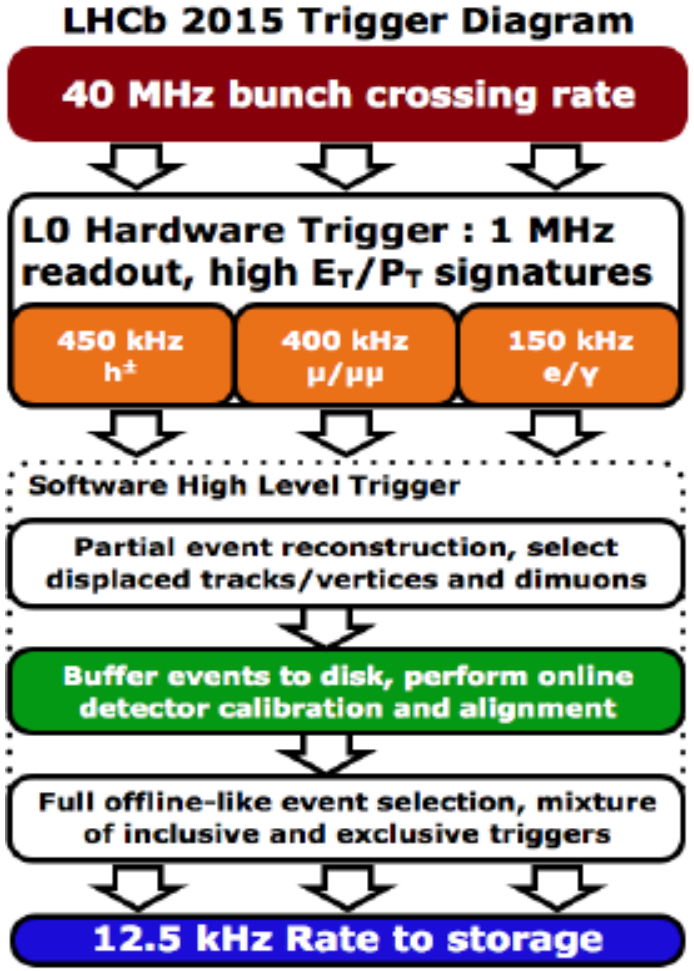
Photodetector Module (PDM) column in RICH2

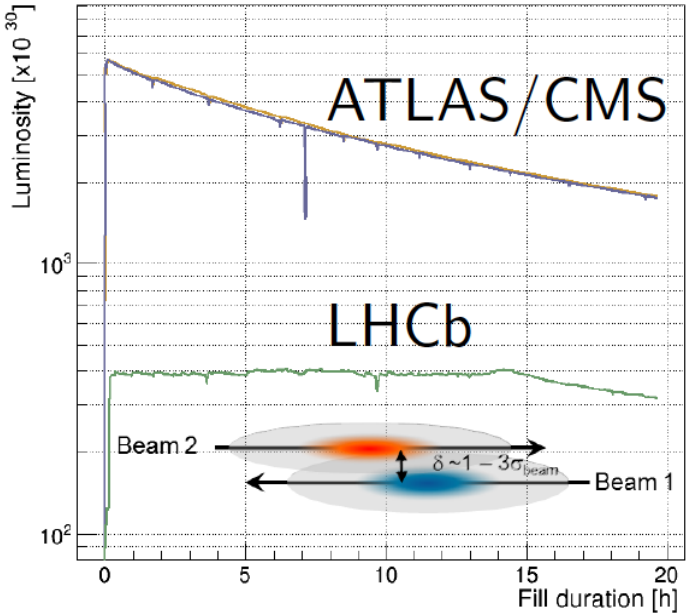


prototype of digital board

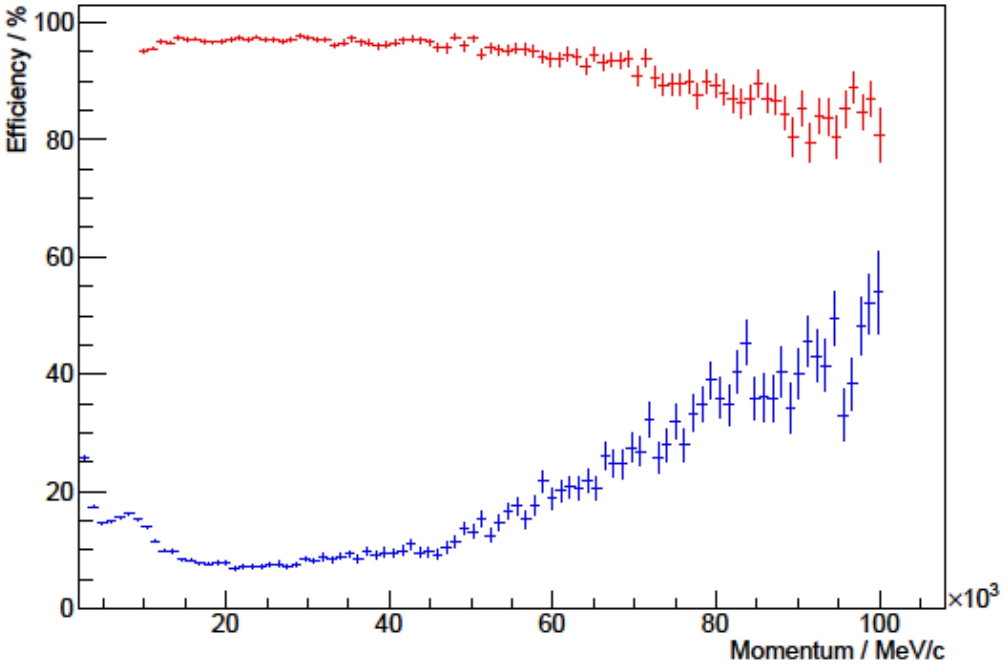
LHCb Trigger



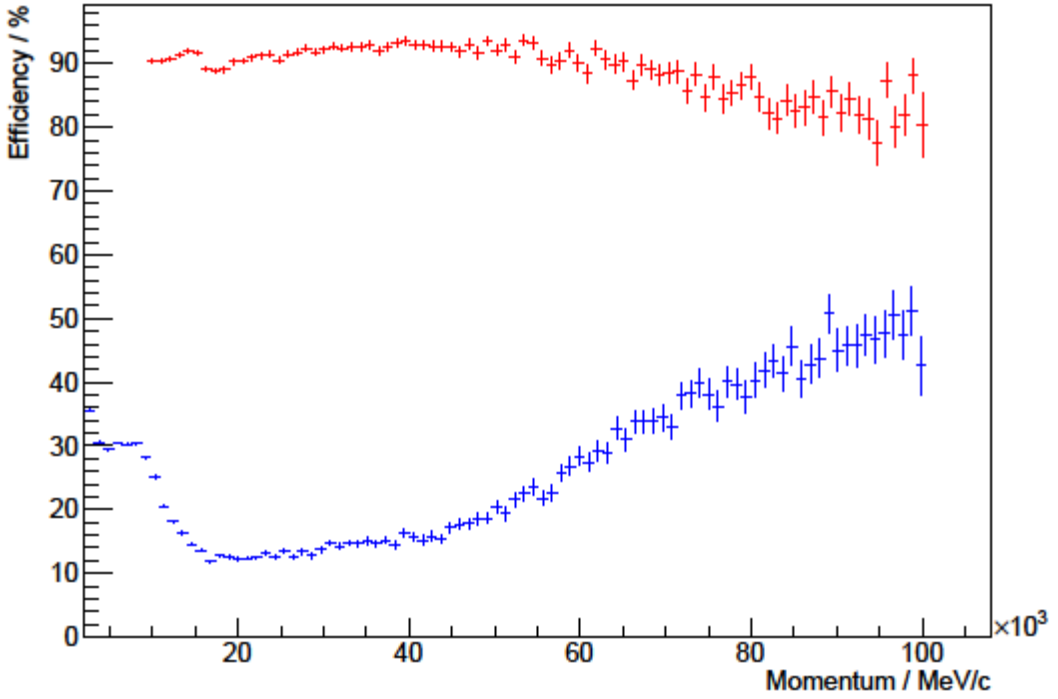




PID vs momentum

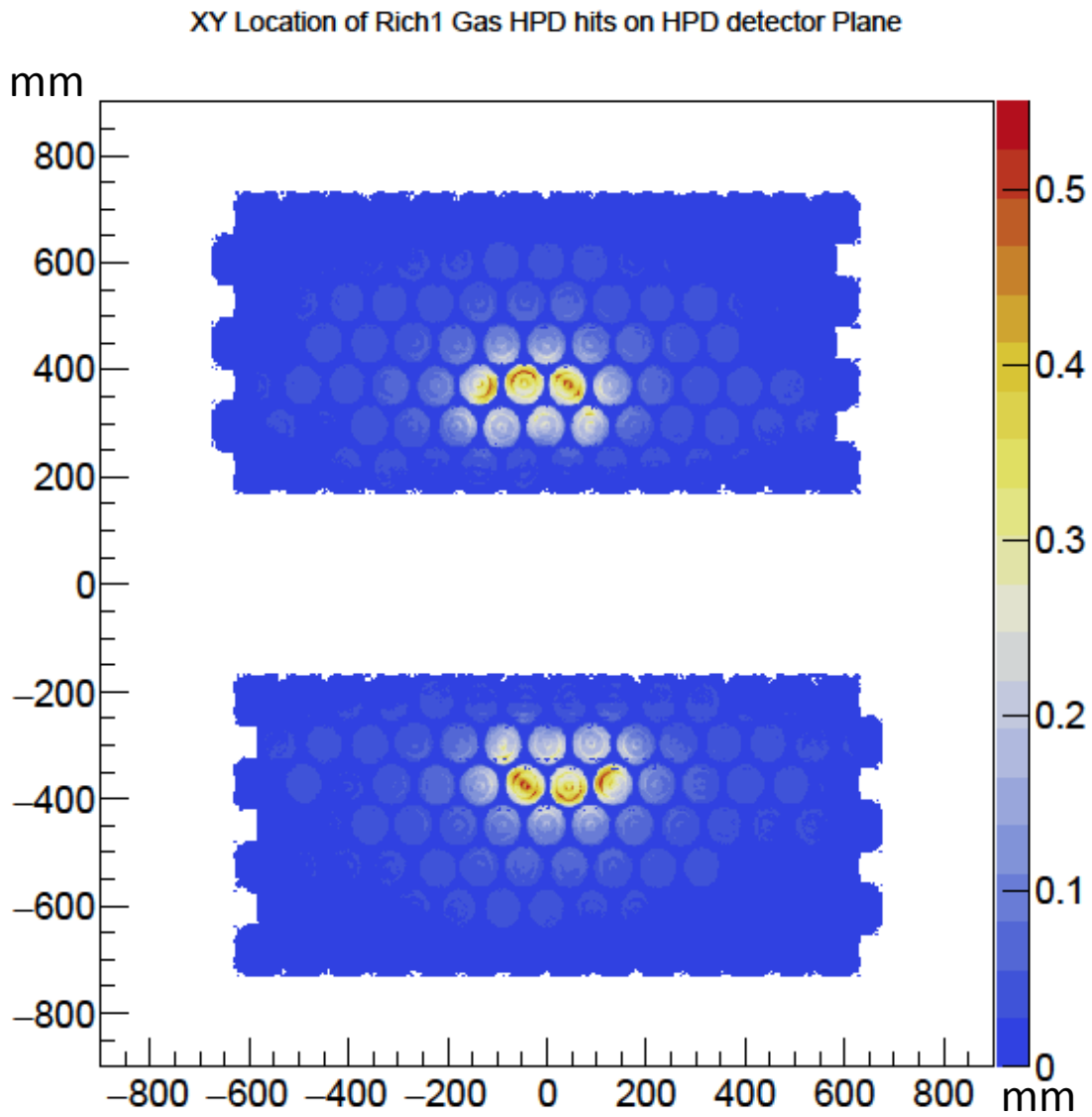


Current LHCb at Run 2 luminosity



Current LHCb at Run 3 luminosity

RICH1-2015 : Occupancy



Occupancy at Run 3 luminosity

Nominal refractive index of the radiators