The LHCb RICH upgrade

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PPE Christmas meeting

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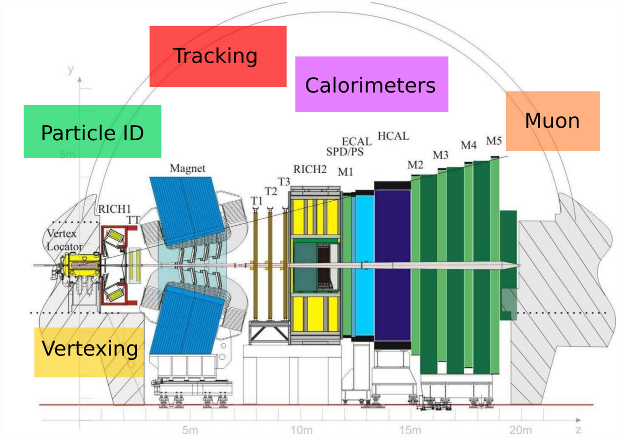
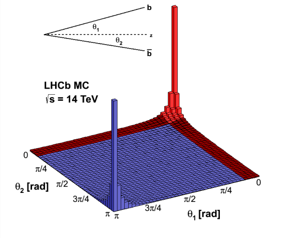
The LHCb experiment

General purpose single arm forward spectrometer
($2 < \eta < 5$, 4% of solid angle)

[J. Instrum. 3 (2008) S08005]





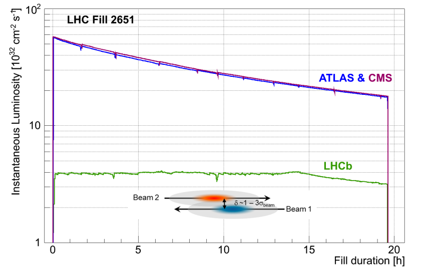
LHCb physics:

- rare b and c hadron decays
- CP-violation in b sector
- CKM parameters
- indirect search for NP
- spectroscopy
- electroweak physics

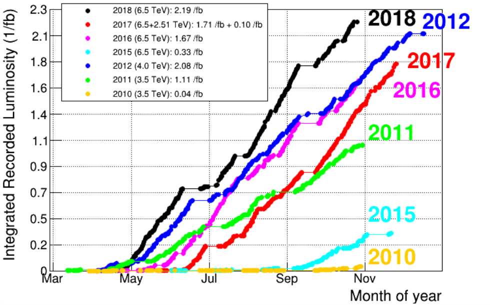
Unprecedented collection of bottom and charm hadrons
Very successful physics programme!!!

The LHCb performance

- LHCb designed to to run at lower luminosity than ATLAS and CMS
- mean number of interactions per bunch crossing ~ 1
- pp beams displaced to reduce the instantaneous luminosity: $\mathcal{L} \sim 4 \times 10^{32}\mathrm{cm}^{-2}\mathrm{s}^{-1}$
- twice the design value



Record performance in 2018!



- $\sim$ 3 fb^{-1} of pp collisions at 7-8 TeV in Run 1
- $\sim$ 6 fb^{-1} of pp collisions at 13 TeV in Run 2

- 9 fb^{-1} exceeded at the end of Run 2!

Why upgrade?

Type	Observable	Current precision	LHCb 2018	**Upgrade** (50 fb^{-1})	Theory uncertainty
B_s^0 mixing	$2\beta_s(B_s^0 \to J/\psi\phi)$	0.10 [139]	0.025	0.008	$\sim$0.003
	$2\beta_s(B_s^0 \to J/\psi f_0(980))$	0.17 [219]	0.045	0.014	$\sim$0.01
	$a_{\rm sl}^s$	6.4×10^{-3} [44]	0.6×10^{-3}	0.2×10^{-3}	0.03×10^{-3}
Gluonic penguins	$2\beta_s^{\rm eff}(B_s^0 \to \phi\phi)$	–	0.17	0.03	0.02
	$2\beta_s^{\rm eff}(B_s^0 \to K^{*0}\overline{K}^{*0})$	–	0.13	0.02	< 0.02
	$2\beta^{\rm eff}(B^0 \to \phi K_S^0)$	0.17 [44]	0.30	0.05	0.02
Right-handed currents	$2\beta_s^{\rm eff}(B_s^0 \to \phi\gamma)$	–	0.09	0.02	$<$0.01
	$\tau^{\rm eff}(B_s^0 \to \phi\gamma)/\tau_{B_s^0}$	–	5 %	1 %	0.2 %
Electroweak penguins	$S_3(B^0 \to K^{*0}\mu^+\mu^-; 1 < q^2 < 6\,{\rm GeV}^2/c^4)$	0.08 [68]	0.025	0.008	0.02
	$s_0 A_{\rm FB}(B^0 \to K^{*0}\mu^+\mu^-)$	25 % [68]	6 %	2 %	7 %
	$A_{\rm I}(K\mu^+\mu^-; 1 < q^2 < 6\,{\rm GeV}^2/c^4)$	0.25 [77]	0.08	0.025	$\sim$0.02
	$\mathcal{B}(B^+ \to \pi^+\mu^+\mu^-)/\mathcal{B}(B^+ \to K^+\mu^+\mu^-)$	25 % [86]	8 %	2.5 %	$\sim$10 %
Higgs penguins	$\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	1.5×10^{-9} [13]	0.5×10^{-9}	0.15×10^{-9}	0.3×10^{-9}
	$\mathcal{B}(B^0 \to \mu^+\mu^-)/\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	–	$\sim$100 %	$\sim$35 %	$\sim$5 %
Unitarity triangle angles	$\gamma(B \to D^{(*)}K^{(*)})$	$\sim$10–12° [252, 266]	4°	0.9°	negligible
	$\gamma(B_s^0 \to D_s K)$	–	11°	2.0°	negligible
	$\beta(B^0 \to J/\psi K_S^0)$	0.8° [44]	0.6°	0.2°	negligible
Charm *CP* violation	A_Γ	2.3×10^{-3} [44]	0.40×10^{-3}	0.07×10^{-3}	–
	$\Delta\mathcal{A}_{CP}$	2.1×10^{-3} [18]	0.65×10^{-3}	0.12×10^{-3}	–

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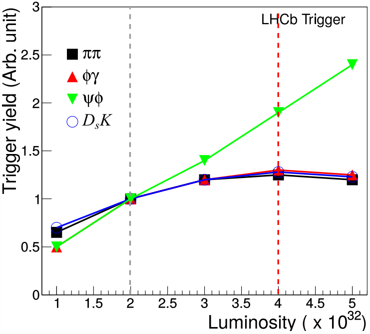
Need to increase the precision to reach theoretical uncertainty ⇒ search for NP
[LHCB-TDR-12]

Upgrade strategy



- LHC will increase luminosity
- Level-0 hardware trigger very efficient for dimuon events
- for hadronic channels trigger yield saturates with increasing luminosity
- detectors will start to degrade because of radiation
- physics programme limited by the detector

Strategy:

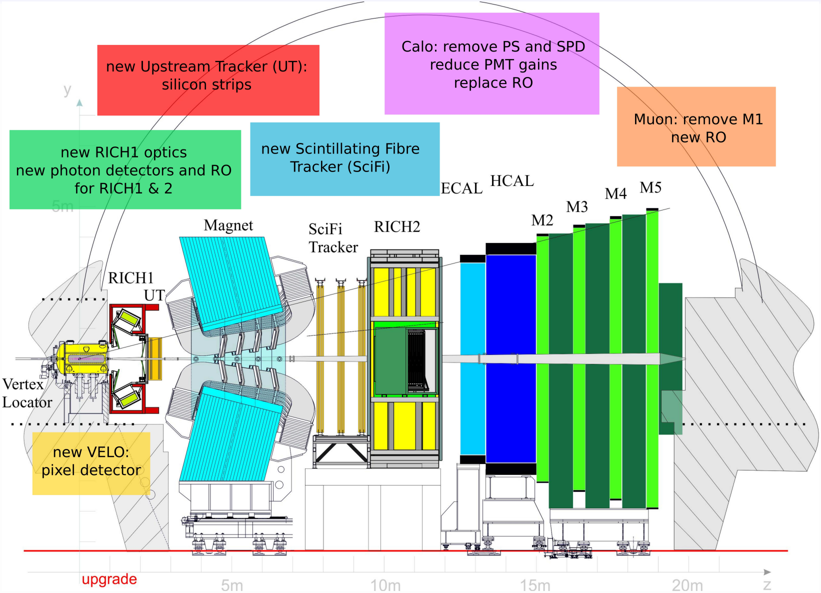
- remove 1MHz L0 bottleneck
- increase readout rate to 40MHz
- fully software trigger
- run at $\mathcal{L} \sim 2 \times 10^{33} \mathrm{cm}^{-2}\mathrm{s}^{-1}$

- need to cope with pile up
- need to cope with high occupancy and higher radiation
- new detector front-end electronics

$\Rightarrow$ upgrade detector during LS2

	LHC era		HL-LHC era		
Run # (year)	Run 1 (2010-12)	Run 2 (2015-18)	Run 3 (2021-23)	Run 4 (2025-28)	Run 5+ (2030+)
Integrated luminosity	3 fb^{-1}	8 fb^{-1}	23 fb^{-1}	46 fb^{-1}	100 fb^{-1}
	LHCb up to LS2		after LHCb upgrade		

The LHCb Upgrade



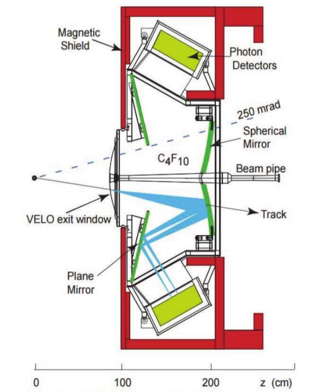
a brand new experiment!

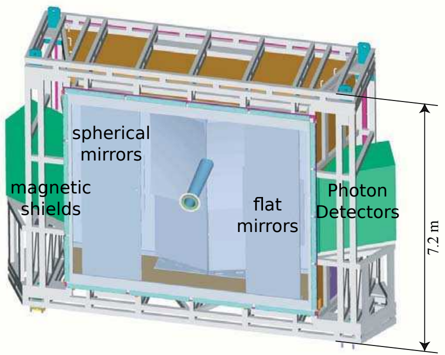
aim to reach 50 fb^{-1} [LHCB-TDR-12]

RICH

Two RICH detectors

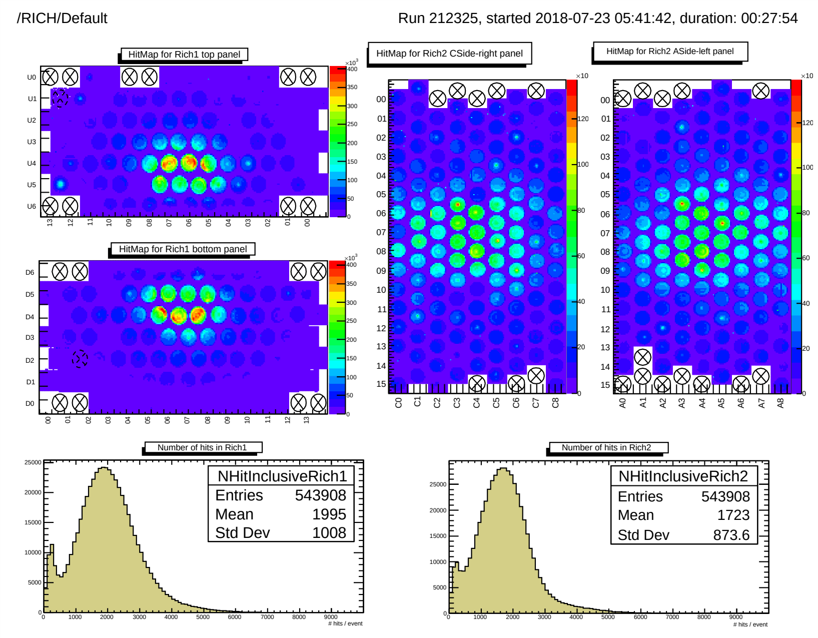
- RICH1 (C_4F_{10}): upstream, 2GeV/c - 40GeV/c over 25mrad - 300mrad
- RICH2 (CF_4): downstream, 30GeV/c - 100GeV/c over 15mrad - 120mrad





- Charged particles produce Cherenkov radiation focused on Hybrid Photon Detectors (HPD) plane
- HPDs equipped with embedded FE electronics, 1MHz readout

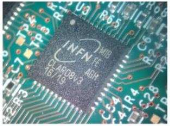
RICH hitmaps



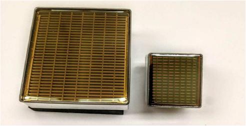
RICH upgrade challenges

- New readout electronics
  - fast electronics (dead time $< 25\,\mathrm{ns}$)
  - low power consumption
  - radiation tolerance
- New photon detectors
  - sensitive to single photons in the wavelength range between 200 and 600 nm
  - good spatial resolution
  - negligible cross talk between neighbouring pixels
  - negligible dark current rate
  - not affected by magnetic field
- significant modifications to RICH1 to reduce peak occupancy
  - optics to be optimised (focal distance, mirrors tile, radius of curvature)
  - mechanics to be redesigned (magnetic shield, columns, gas enclosure, mirror mounts...)

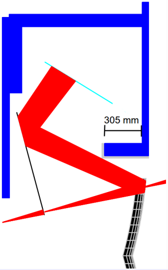
CLARO chip



MaPMTs



New design of RICH1



What Edinburgh does for the RICH upgrade

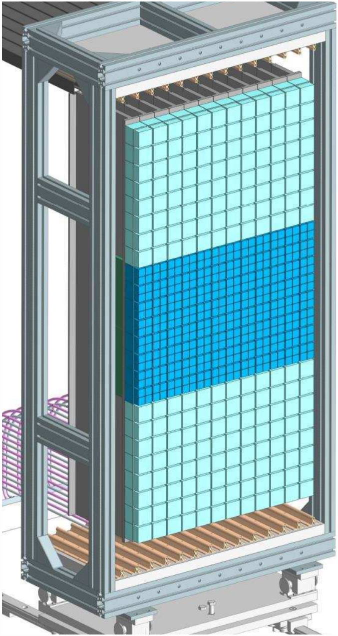
- Photon Detector Quality Assurance (PDQA) $\rightarrow$ 2016-2018, finished
- Elementary Cell Quality Assurance (ECQA) $\rightarrow$ starting now
- Testbeams $\rightarrow$ 2014-2018, finished
- Column commissioning $\rightarrow$ starting next year
- RICH commissioning $\rightarrow$ late 2019-2020

Photon Detectors: MaPMTs

Hamamatsu Multi-anode Photomultipliers: 64-ch (8 $\times$ 8 pixels), fast, sensitive to single photons, low dark counts, large active area, excellent granularity, radiation hard:

- R13742 1in (customisation of the R11265), to equip RICH1 and central region of RICH2
- R13743 2in (customisation of the R12699), to equip peripheral area of RICH2

a total of 3100 R13742 and 450 R13743, including spares, to be tested: production started in 2016



The Photon Detector Quality Assurance

High number of units to be tested over two years:

- 3100 R11265: 1"
- 450 H12699: 2"

Aim of the PDQA:

- verify minimum contractual specifications
- determine parameters for the selection of photon detectors
- gather initial calibration variables

Requirements for testing:

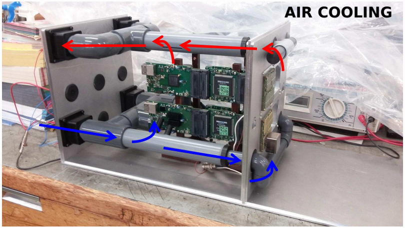
- reliability
- redundancy
- elevated automation

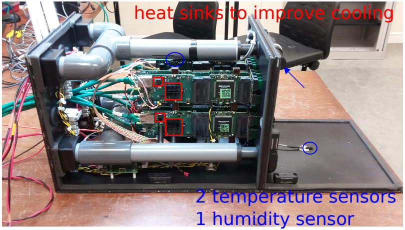
Two tests facilities:

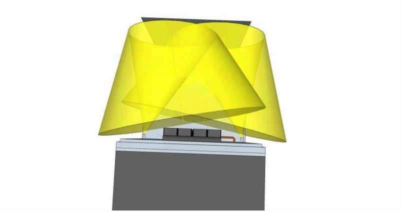
- Edinburgh
- Padova

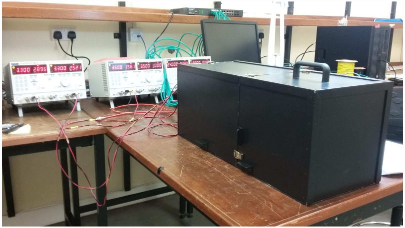
Test Stations

Compact setup 30 × 30 × 70cm: 16 1” tubes or 4 2” tubes





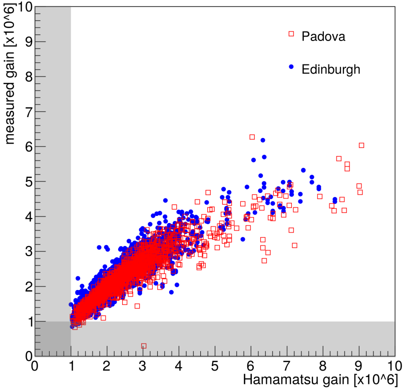


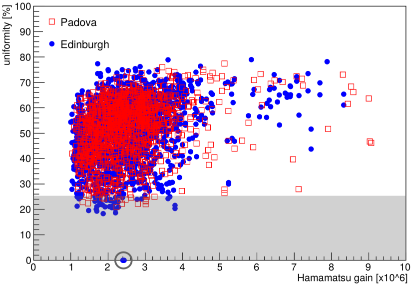


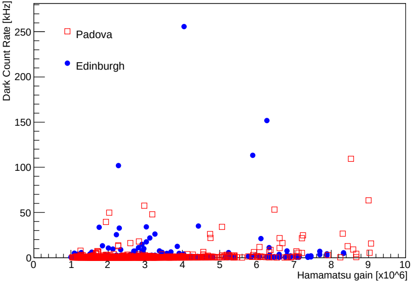
- temperature controlled with air cooling
- pulsed LED light (470nm): quasi-homogeneous illumination via two optical fibres and a mirror
- flexibility: front part can be exchanged (<1 hour) to convert from 1” to 2”
- custom slow control module based on Aria-G25 built to: control and monitor the HV and light intensity, monitor temperature and humidity sensors

Few results from the PDQA

- program completed successfully
- excellent coherence between the results obtained in the two test facilities
- very positive communication with Hamamatsu ⇒ low fraction of MaPMTs rejected (2.1% R13742 and 8.2% R13743)

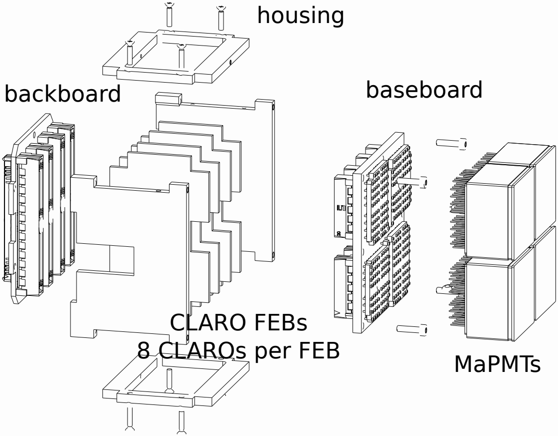


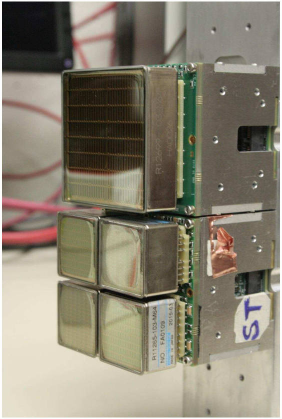




The Elementary Cell (EC)

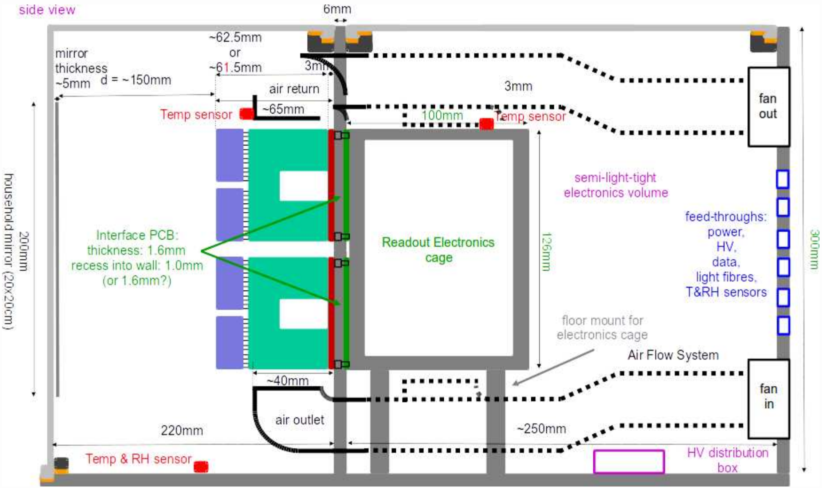
The smallest brick containing the front-end common to both RICH detectors





different components designed, produced and tested in different institutes, converging in Edinburgh and Ferrara where EC will be assembled, tested and then shipped to Cern

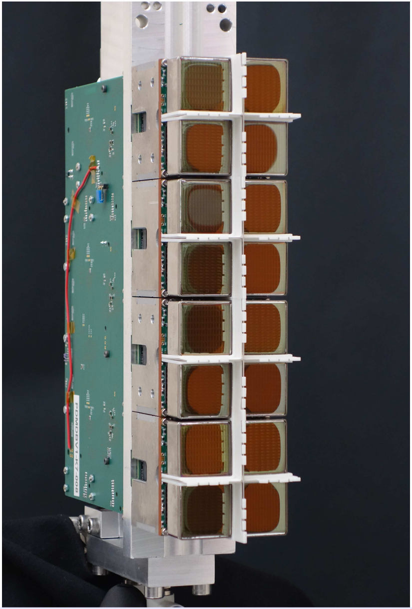
The ECQA test box

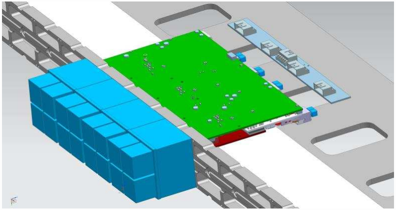


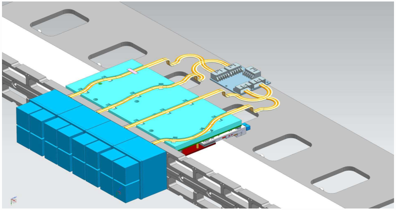
- combine experience of PDQA (strategy of the two compartment box) and new controller developed in Ferrara
- first integration tests performed in Edinburgh last summer
- first test station is being commissioned in Ferrara
- another intense test program starting at the beginning of 2019

The Photon Detector Module

PDM assembled at Cern: logical grouping of 4 ECs

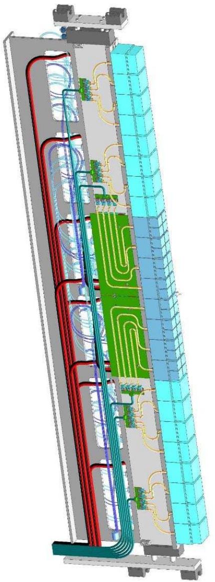


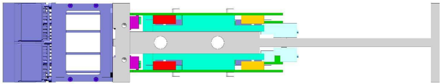




- 3 Kintex7 FPGA per digital board
- DC-DC converters
- optical links for data transmission

Upgrade mechanics: columns



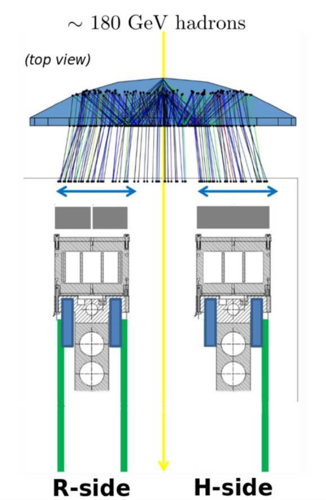


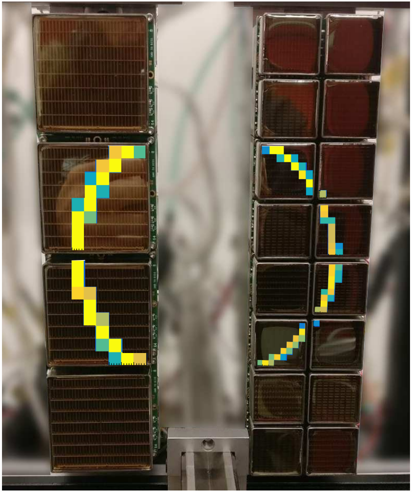
- same mechanical structure adopted for RICH1 & RICH2
- T-shaped coldbar: both mechanical support and cooling interface
- aluminium bar with cooling plate designed to improve coupling with PDMDB
- PDMs mounted on columns and commissioned in the lab at Cern with final cabling and services (HV, LV, cooling...)
- columns transported to LHCb, mounted in the detector and commissioned again

- preparation for the COM-lab is ongoing at Cern
- tests will start next year, once enough component to assemble a column will arrive at Cern

Validation of readout components

Intense campaign of testbeams (2014-2018) to validate optoelectronics chain with Cherenkov photons

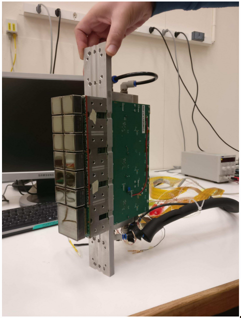




campaign concluded in October 2018 with 2 PDMs tested using with final LHCb DAQ

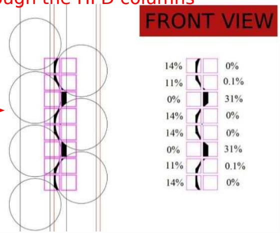
The PDM installed in RICH 2 in February

Installed during the winter shutdown

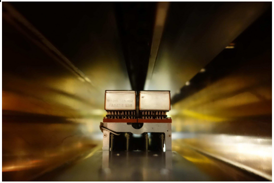


Cherenkov light
through the HPD columns

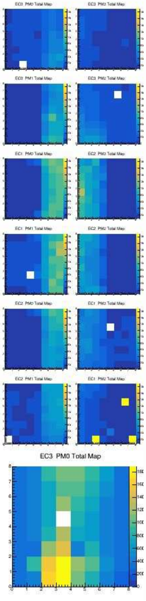
Idea



Installation



First
collisions

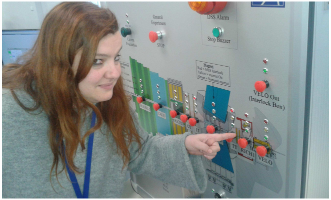


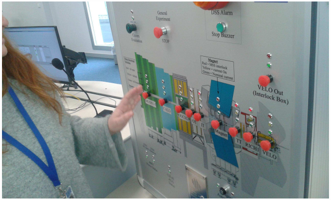
- Prototype adapted from test beams
- Pre-production components
- Ready for testing in real environment

setup operated in realistic conditions (p-p and Pb-Pb collisions)

Conclusions

- the RICH upgrade program is crucial to the success of the LHCb upgrade
- the Edinburgh group is strongly involved with several activities providing key contributions
- the program is tight and very challenging





- the RICH operations are over.... now the fun begins!

Extra slides