10th International Workshop on Ring Imaging Cherenkov Detectors
Russian Academy of Sciences, 29 July – 4 August 2018

The LHCb RICH

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on behalf of the LHCb RICH collaboration

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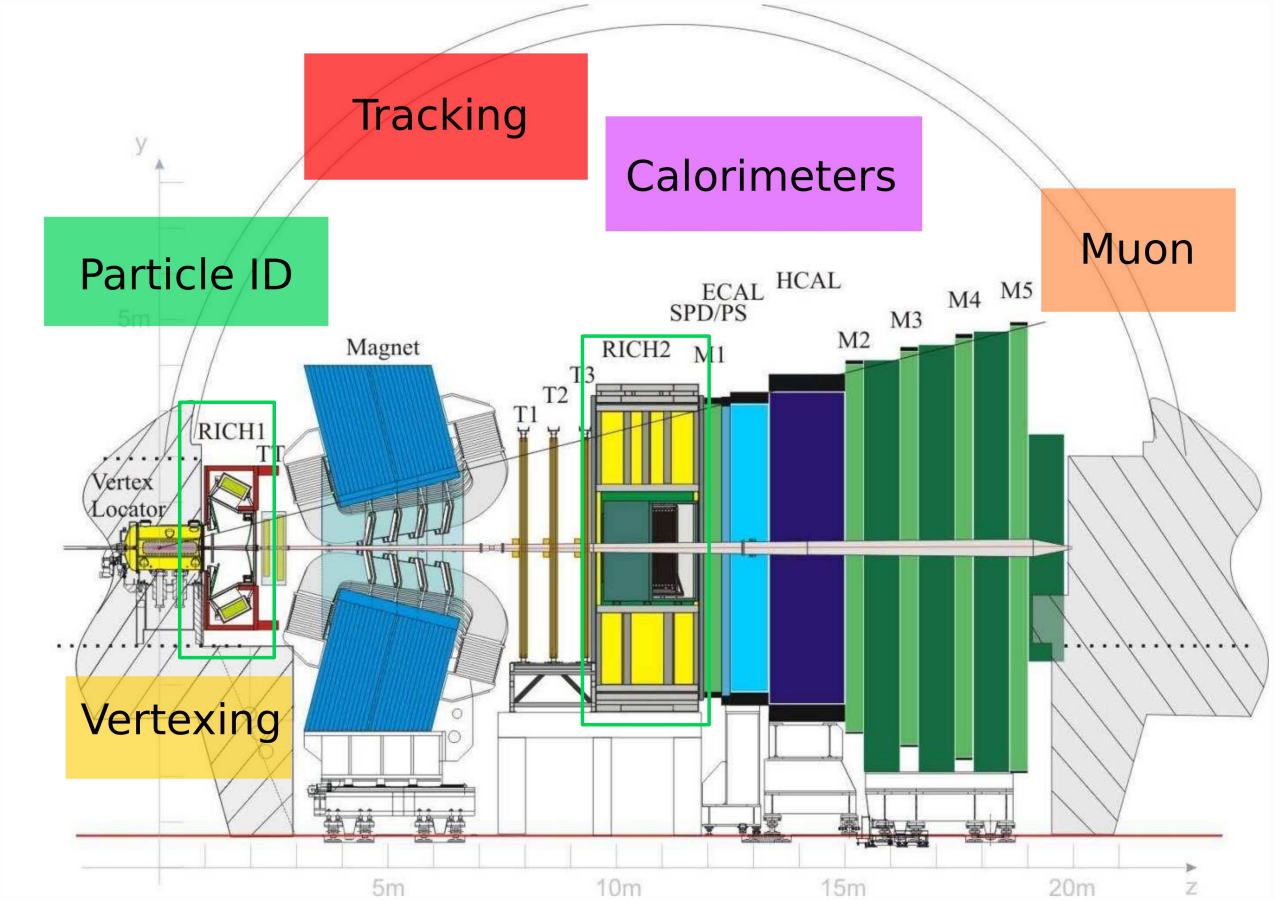
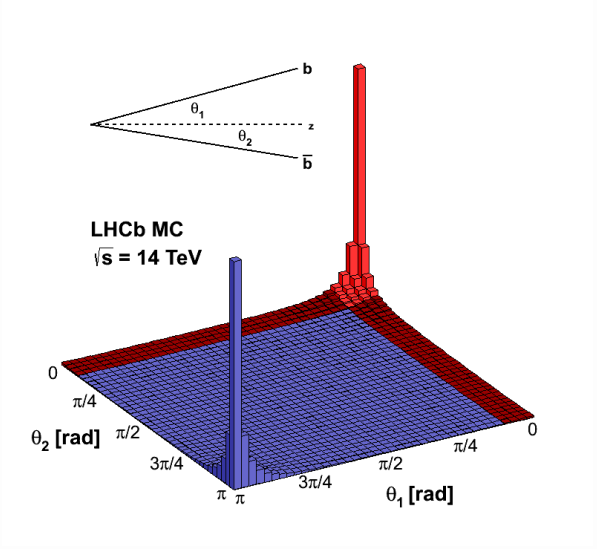
Introduction

The LHCb experiment

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

[J. Instrum. 3 (2008) S08005]





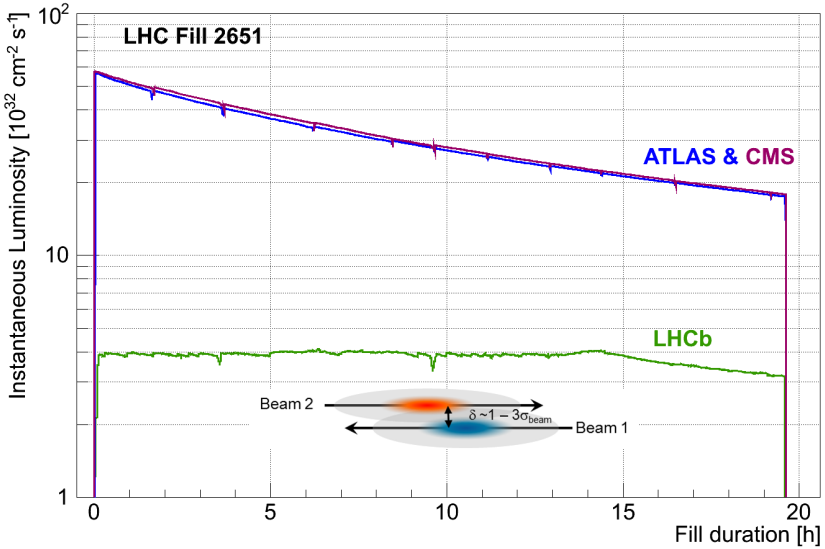
LHCb physics:

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

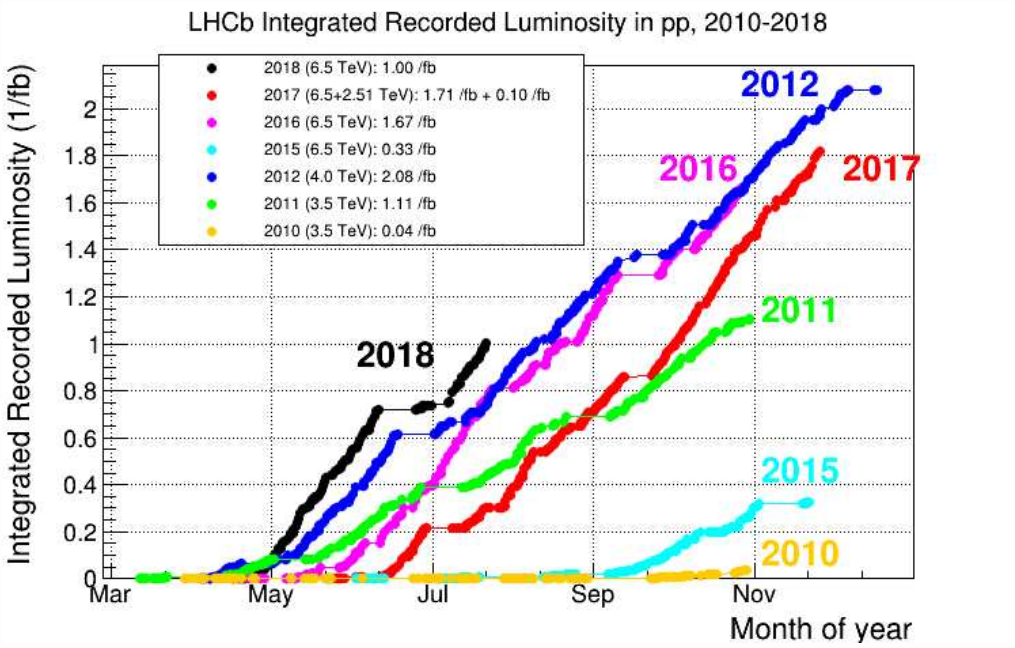
Unprecedented collection of bottom and charm hadrons
Very successful physics programme

The LHCb performance

- LHCb designed to 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 luminosity design value



Excellent performance in 2017!

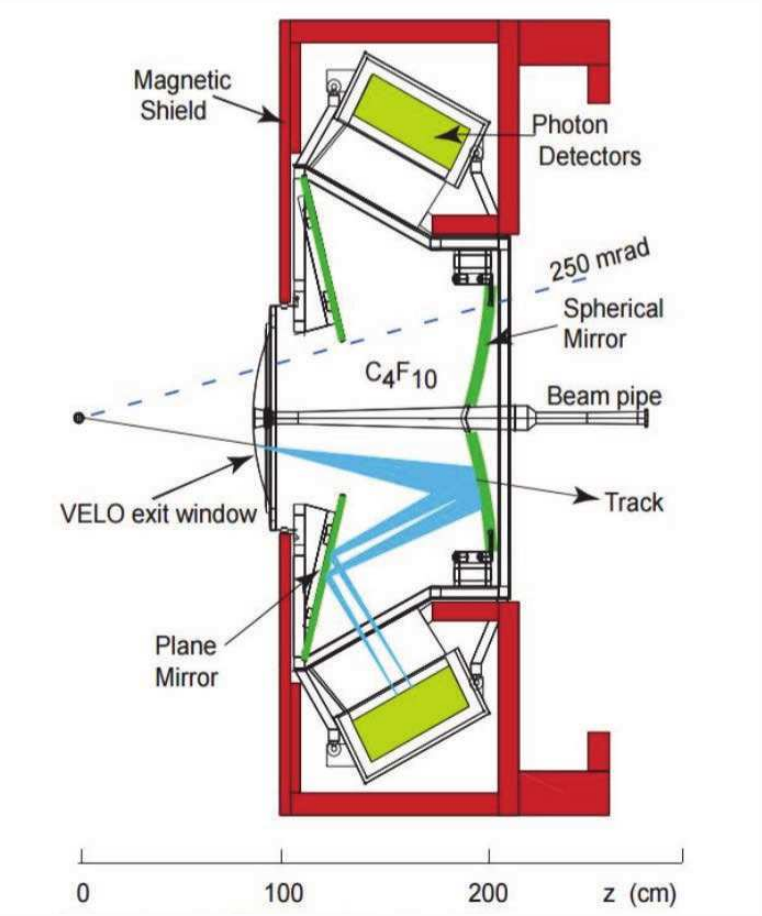


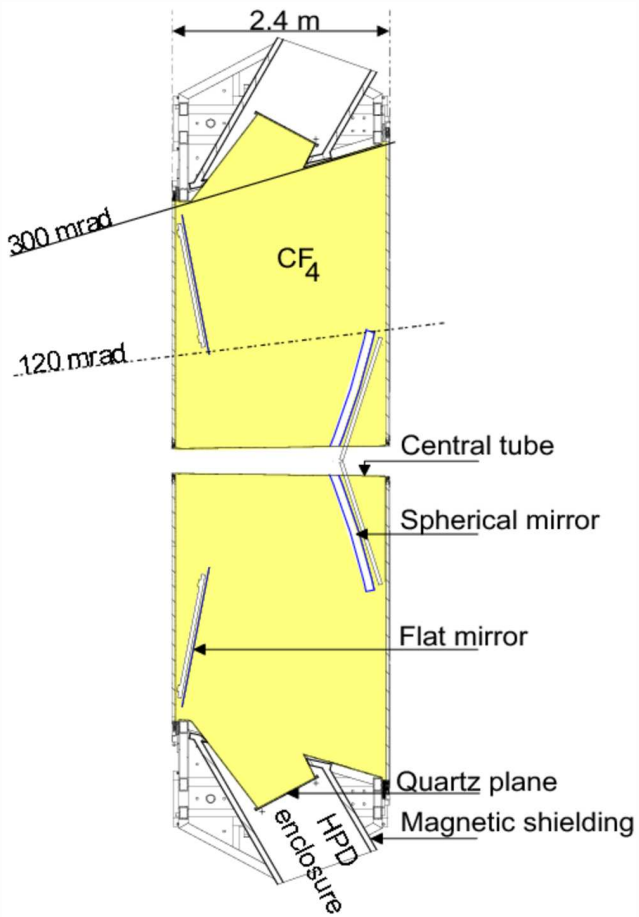
- ~ 3 fb^{-1} of pp collisions at 7-8 TeV in Run 1
- ~ 5 fb^{-1} of pp collisions at 13 TeV in Run 2
- expect to reach $\sim$9 fb^{-1} at the end of Run 2

The LHCb RICH detectors

Two RICH detectors

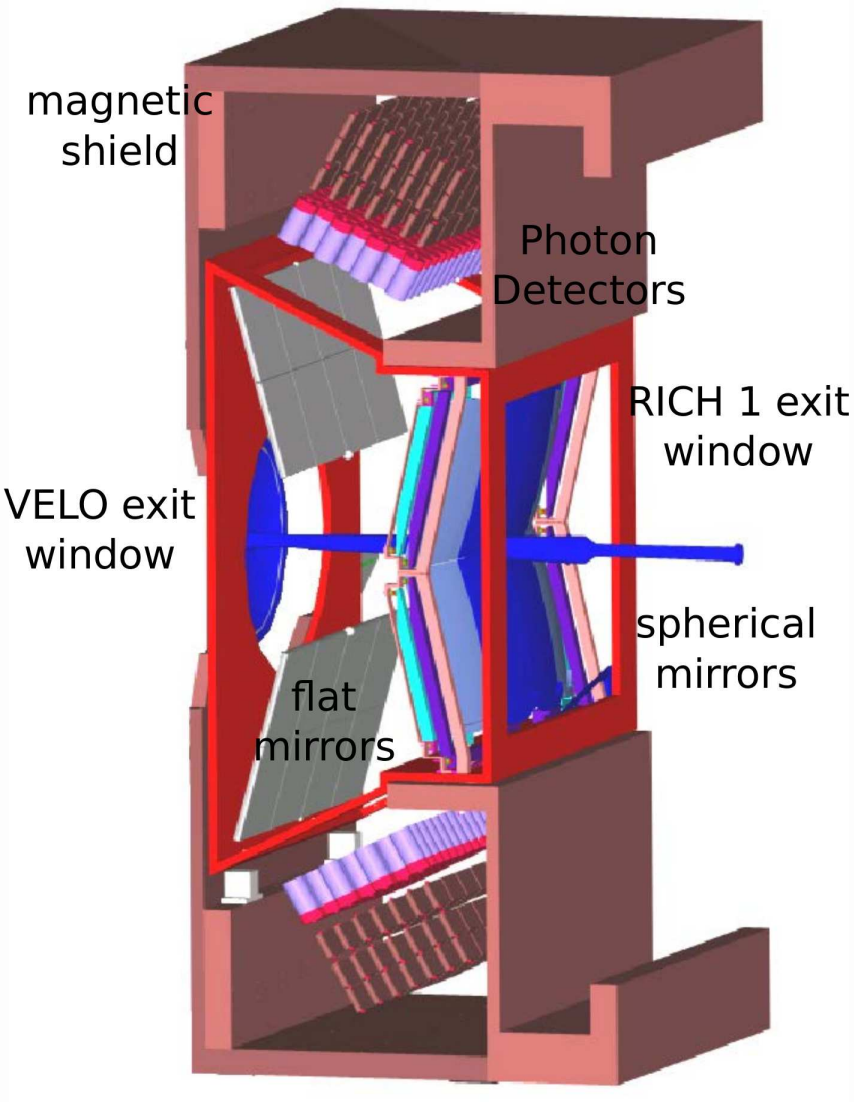
- RICH 1 (C_4F_{10}): upstream, 2 GeV/c - 60 GeV/c over 25 mrad - 300 mrad
- RICH 2 (CF_4): downstream, 30 GeV/c - 100 GeV/c over 15 mrad - 120 mrad





- Charged particles produce Cherenkov radiation then focused on Hybrid Photon Detectors (HPD) plane
- Responsible for charged hadrons particle identification (PID)

RICH 1



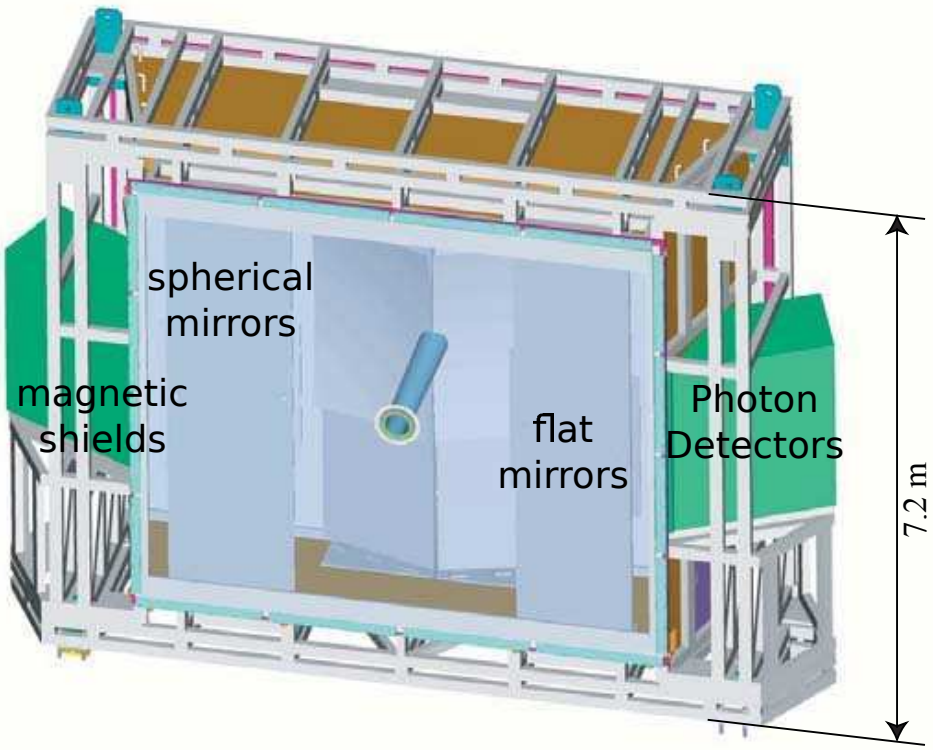
- covers the low and intermediate momentum region over the full angular acceptance
- detector close to the interaction point to limit its volume
- two halves above and below the beam pipe
- gas enclosure sealed directly on VELO exit window to limit material budget
- tilted spherical focusing primary mirrors (4 segments)
- secondary flat mirrors to limit detector length (16 segments)
- The total material budget for RICH 1 is only about 5% X_0 within the experimental acceptance
- gas radiator: C_4F_{10}

RICH 1


Composite
Mirror
Applications


Composite
Mirror
Applications

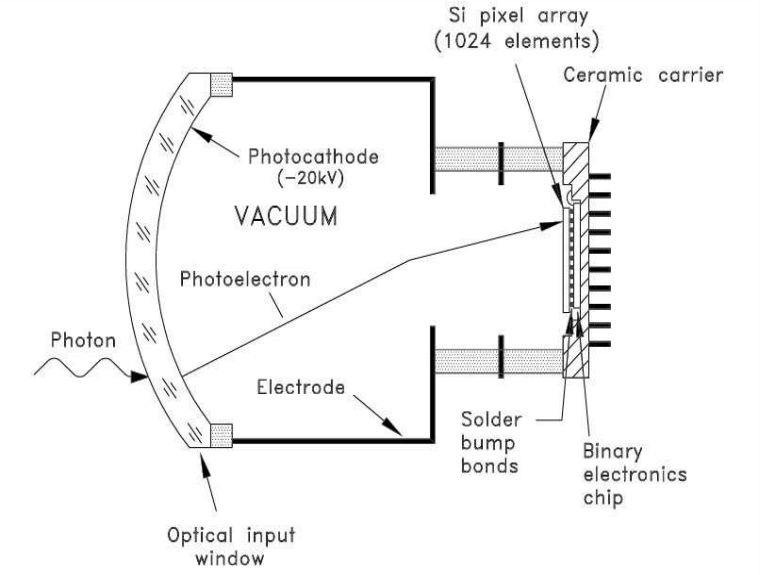
RICH 2



- covers the high momentum region over the the angular range 15-120 mrad
- downstream detector since high momentum particles are less affected my magnetic field
- two halves on the sides of the beam pipe
- tilted spherical focusing primary mirrors (56 segments)
- secondary flat mirrors to limit detector length (40 segments)
- The total material budget for RICH 2 is about 15% X_0 within the experimental acceptance
- gas radiator: CF_4

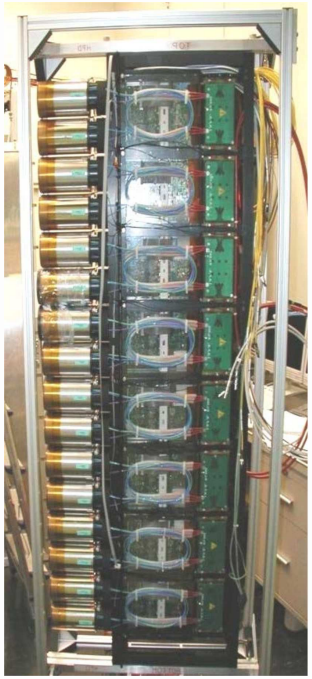
RICH 2

The Hybrid Photon Detectors



photon detectors developed in collaboration with industry for application in the LHCb RICH system:

- quartz window with thin multialkali photocathode
- cross focusing optics ⇒ photons focused on silicon pixel array (granularity $2.5 \times 2.5\text{mm}^2$)
- front-end chip encapsulated in the vacuum tube
- magnetic shield installed around each HPD
- active diameter 75 mm:
  - 196 tubes in RICH 1
  - 288 tubes in RICH 2



HPDs arranged in columns with ancillary front-end electronics

LV and HV boards to power the column

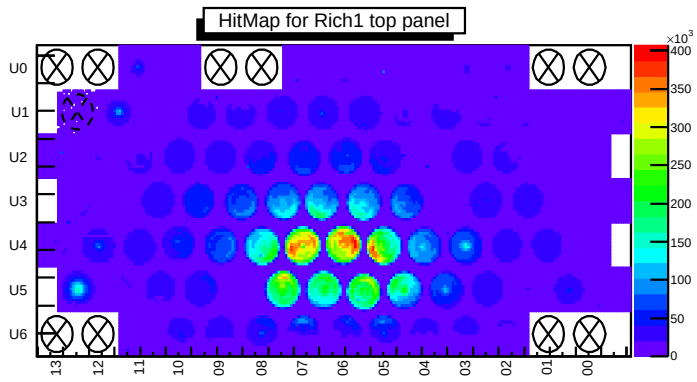
Level-0 boards transmit data to Level-1 boards (off detector) via optical links

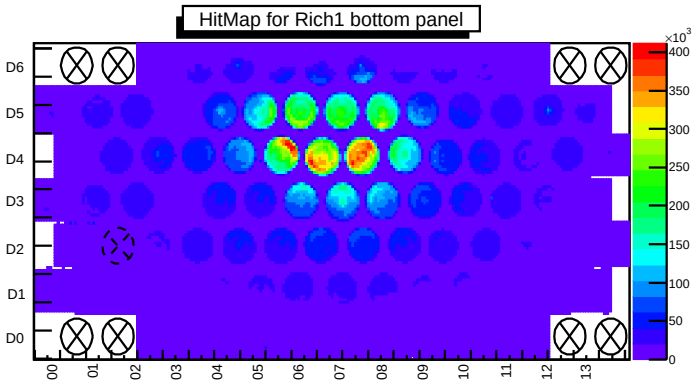
Level-1 boards zero suppress and transmit data to the DAQ

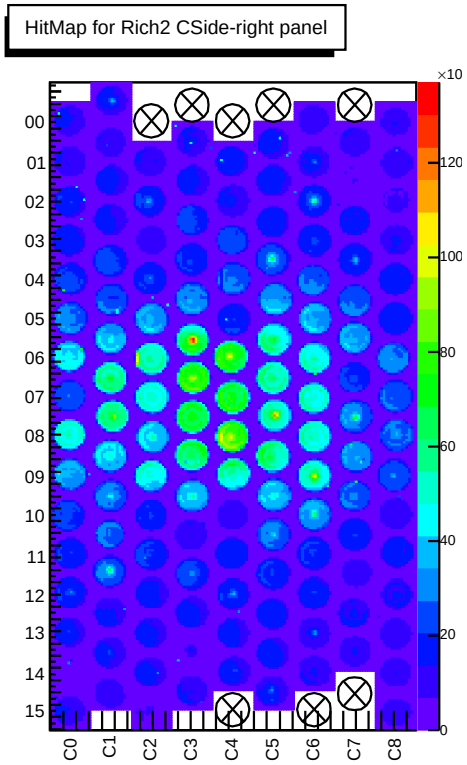
RICH hitmaps

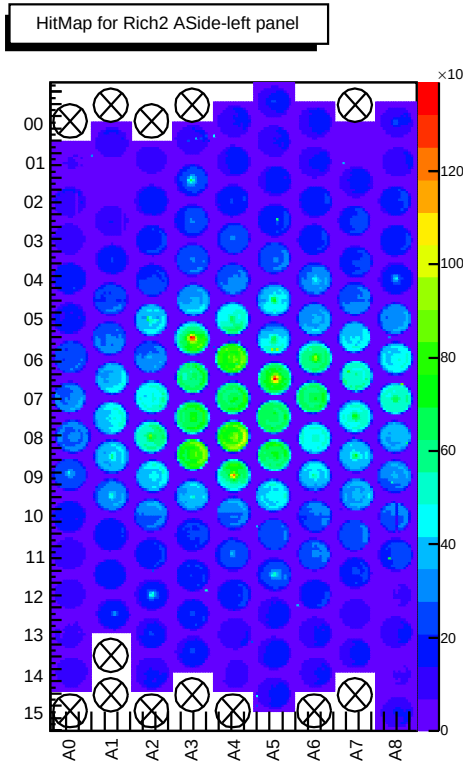
/RICH/Default

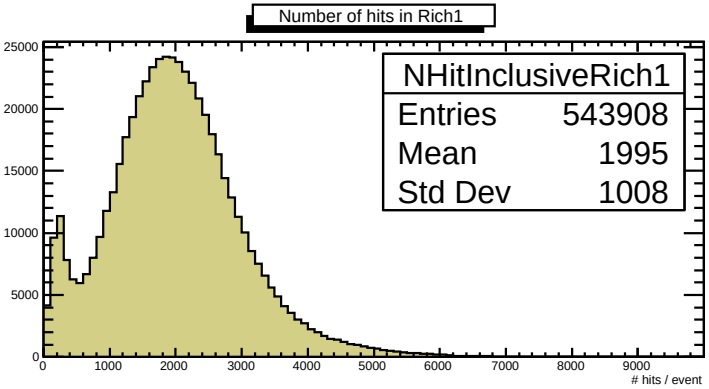
Run 212325, started 2018-07-23 05:41:42, duration: 00:27:54

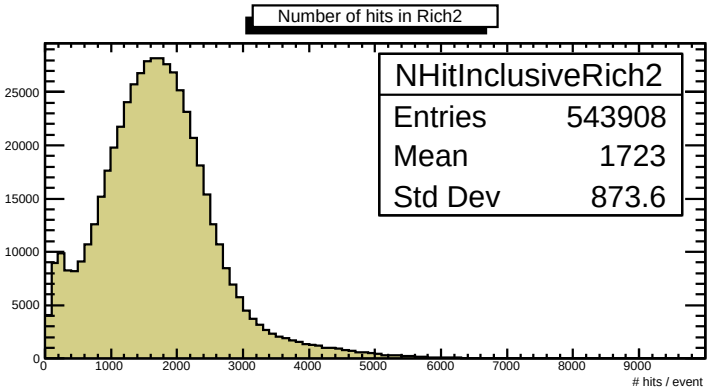












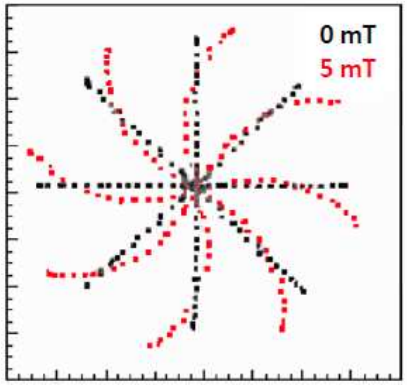
Alignment and Calibration

Intervention on RICH 1 Down box

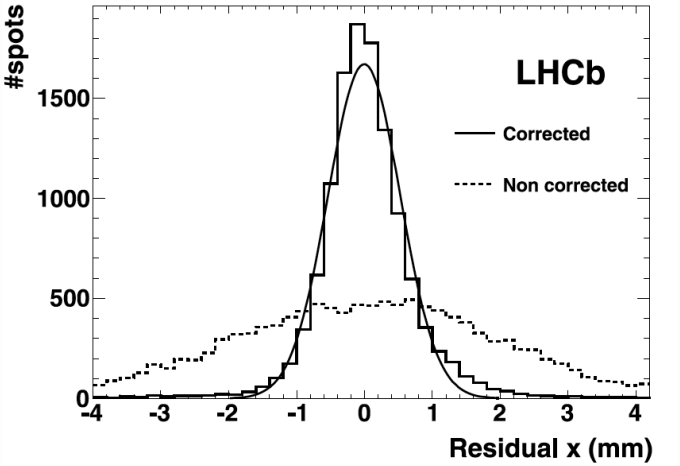
Intervention performed during 2016-2017 winter shutdown: replacement of some HPDs, L0 and LV boards

Magnetic field correction (once per year)

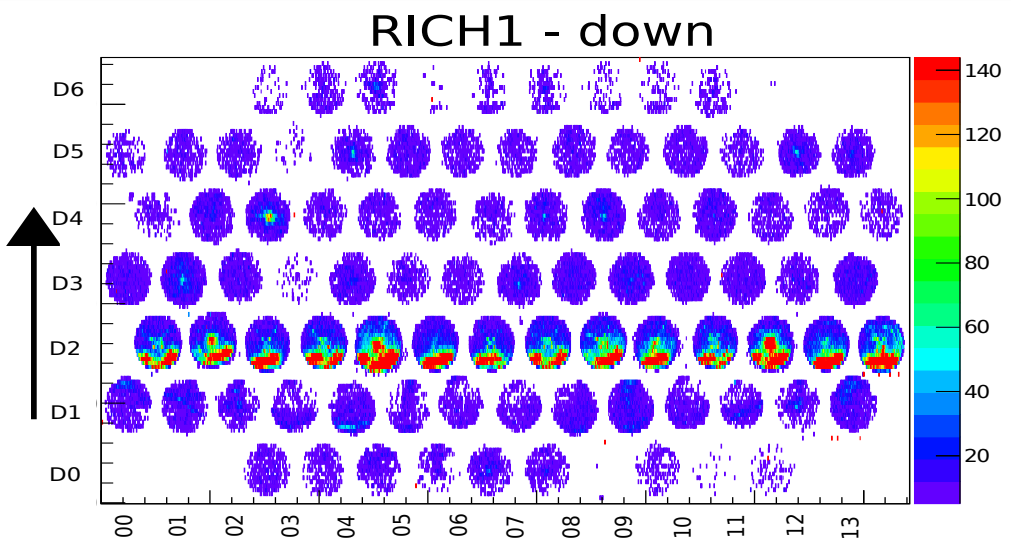
HPD image distortion due to the magnetic field

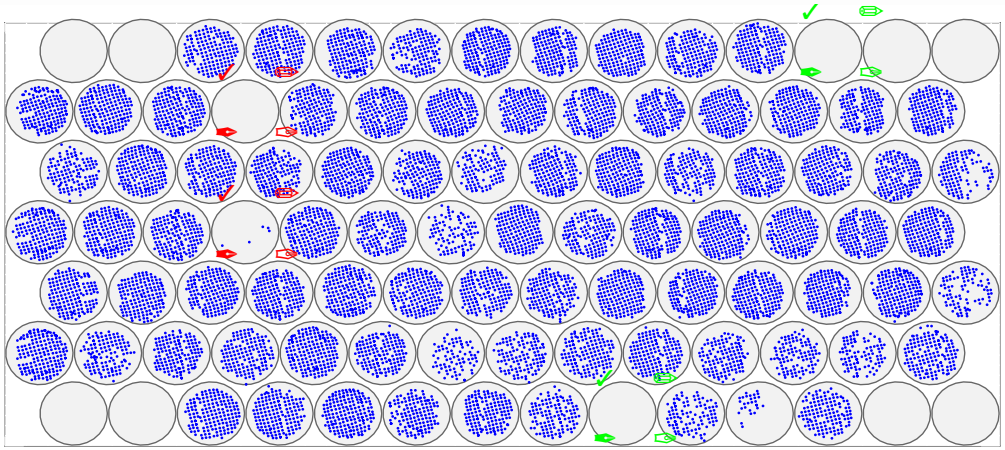


distance from the measured light spot to the test point before and after correction



Dedicated setup illuminating the HPDs in RICH 1 with pattern of light spots with magnet on

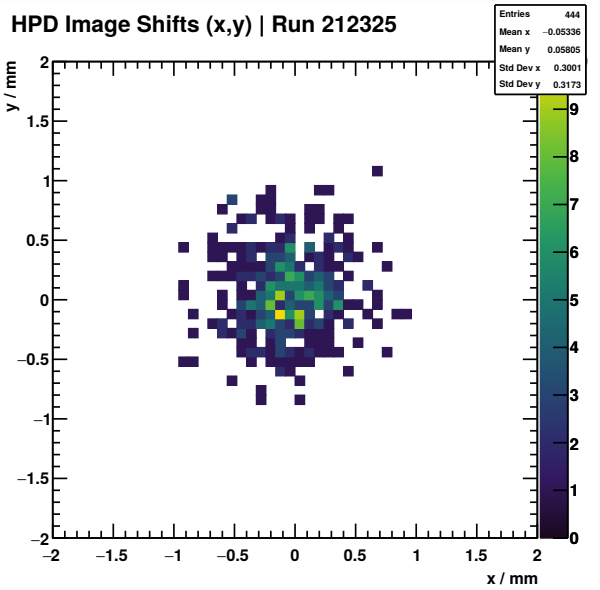


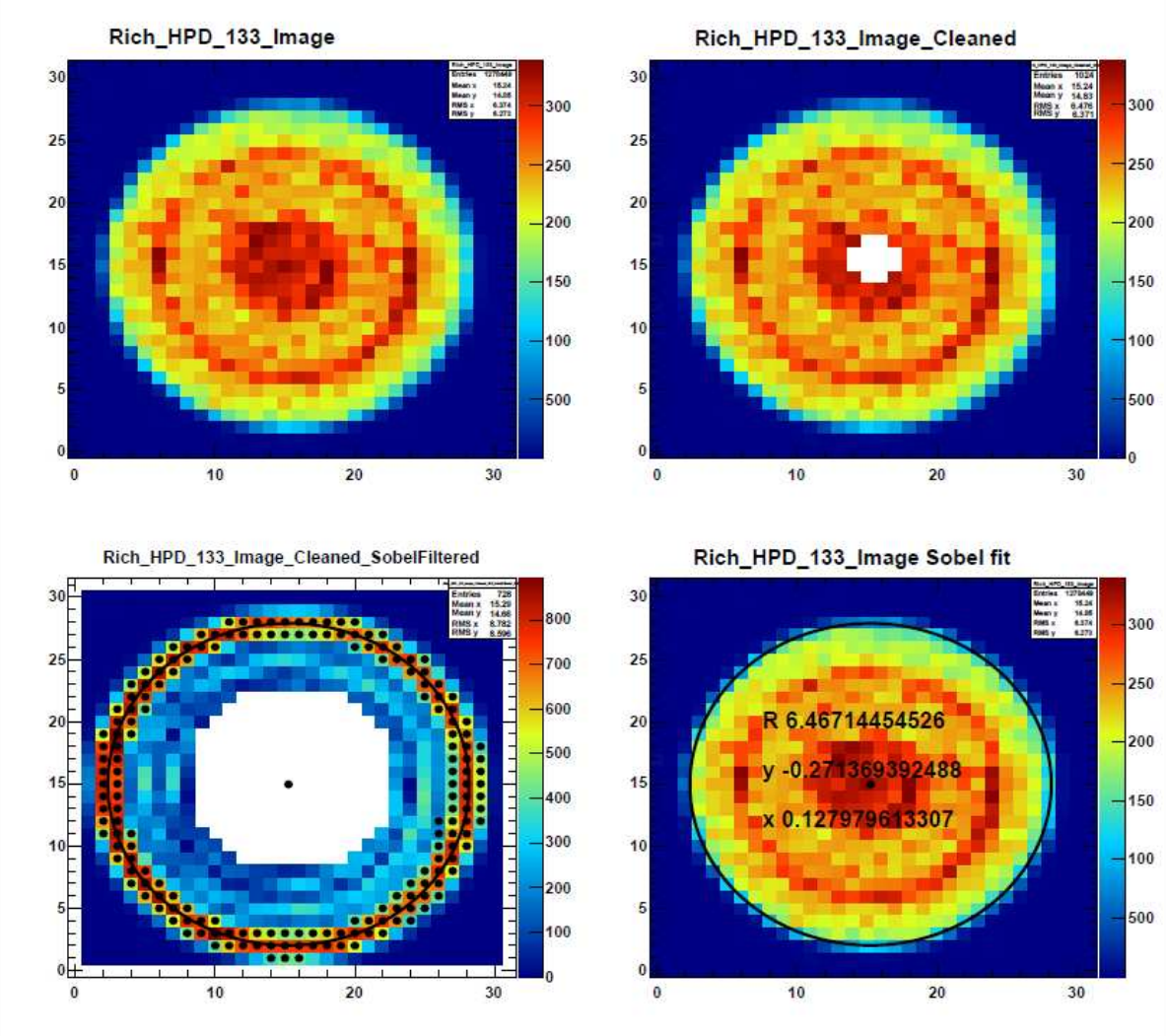


HPD image calibration (once per run ≃1h)

The position of the Photocathode image on the anode can change due to thermal and charging effects degrading the reconstruction of the Cherenkov angle and affect the PID performance

- image cleared from ion feedback
- edges detected applying Sobel filter
- fit to determine the radius and the centre position used then by reconstruction

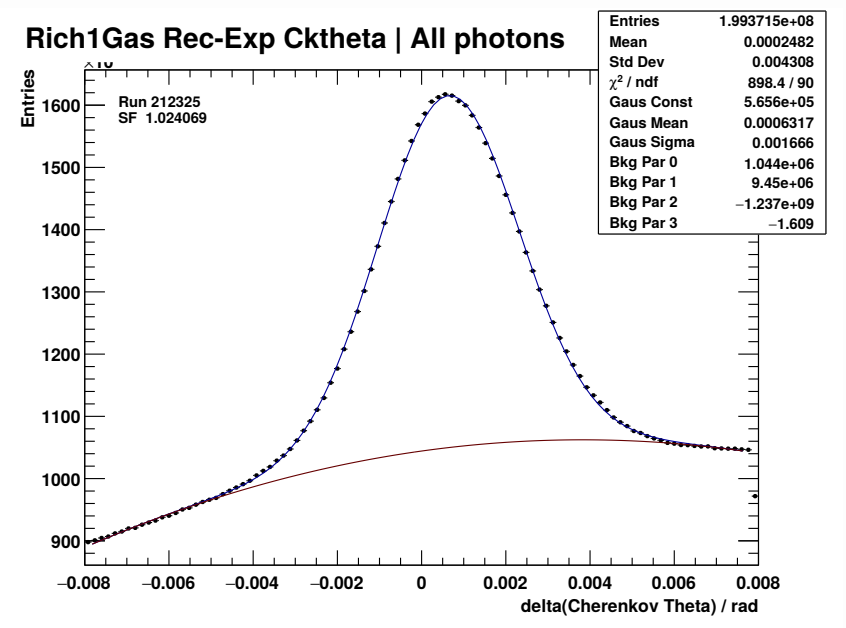


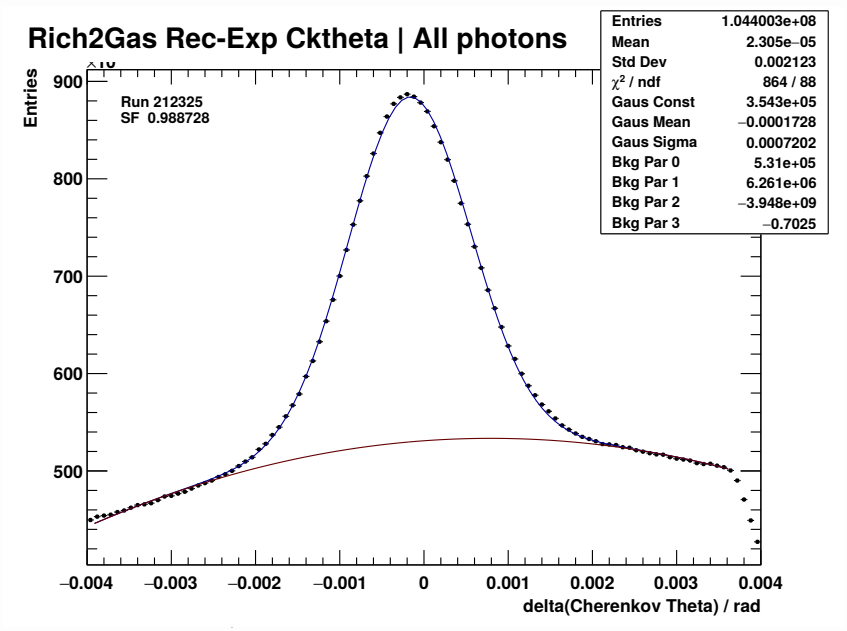


Refractive index calibration (once per run $\simeq$1h)

The refractive index of the radiators can vary due to temperature, pressure and variation in the gas mixture. Monitoring of these quantities not precise enough for physics analysis $\Rightarrow$ further correction needed

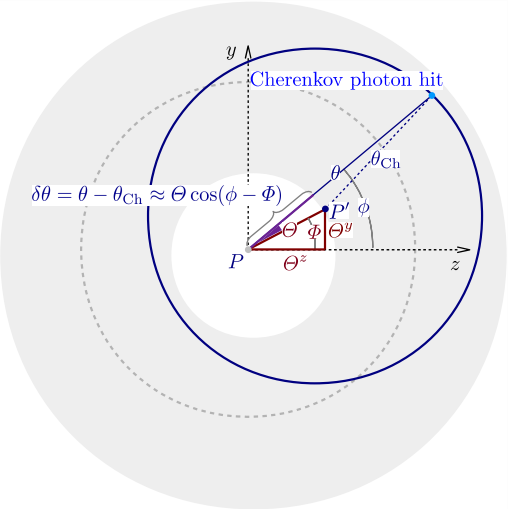
Very high momentum tracks, with well defined Cherenkov angle, are used to evaluate the difference between the measured and the expected Cherenkov angles



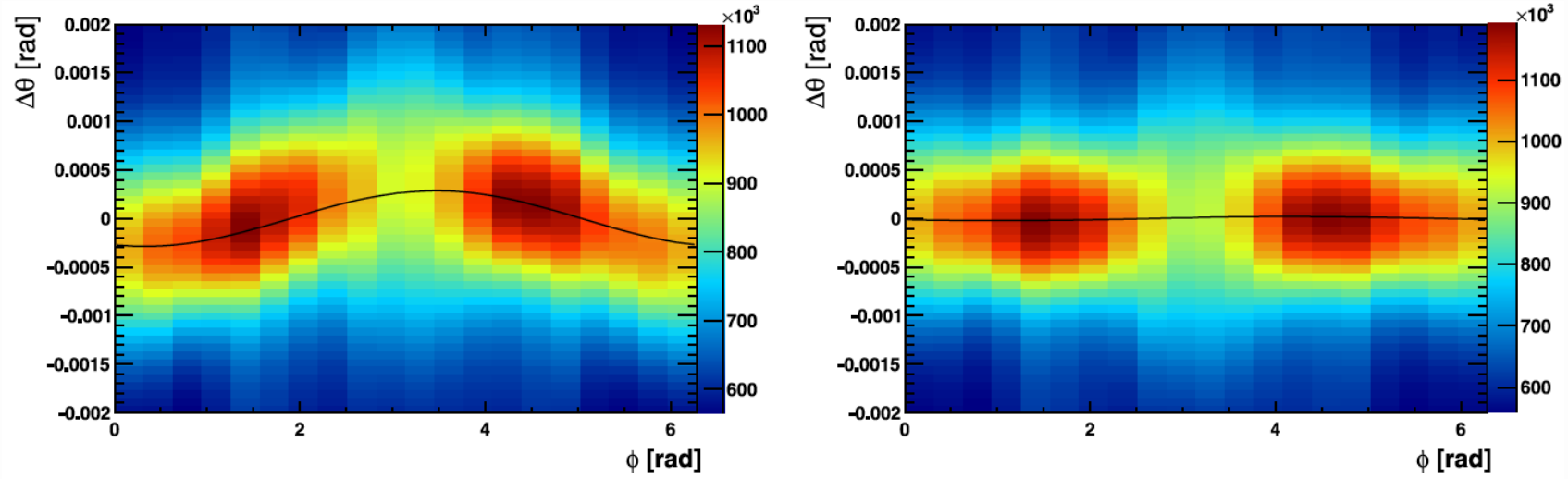


Correction factor extracted and used to compute the refractive index

Mirror alignment (once per fill $\simeq$12h)



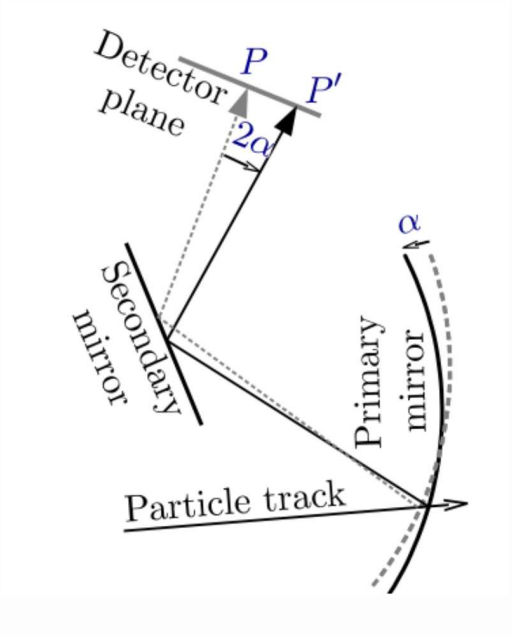
- mirror misalignment can cause a displacement of the centre of the ring with respect to the track
- a dependence of the variation of the Cherenkov angle on the azimuthal angle is observed $\Rightarrow$ sinusoidal distributions
- distribution fitted and misalignment corrected in reconstruction

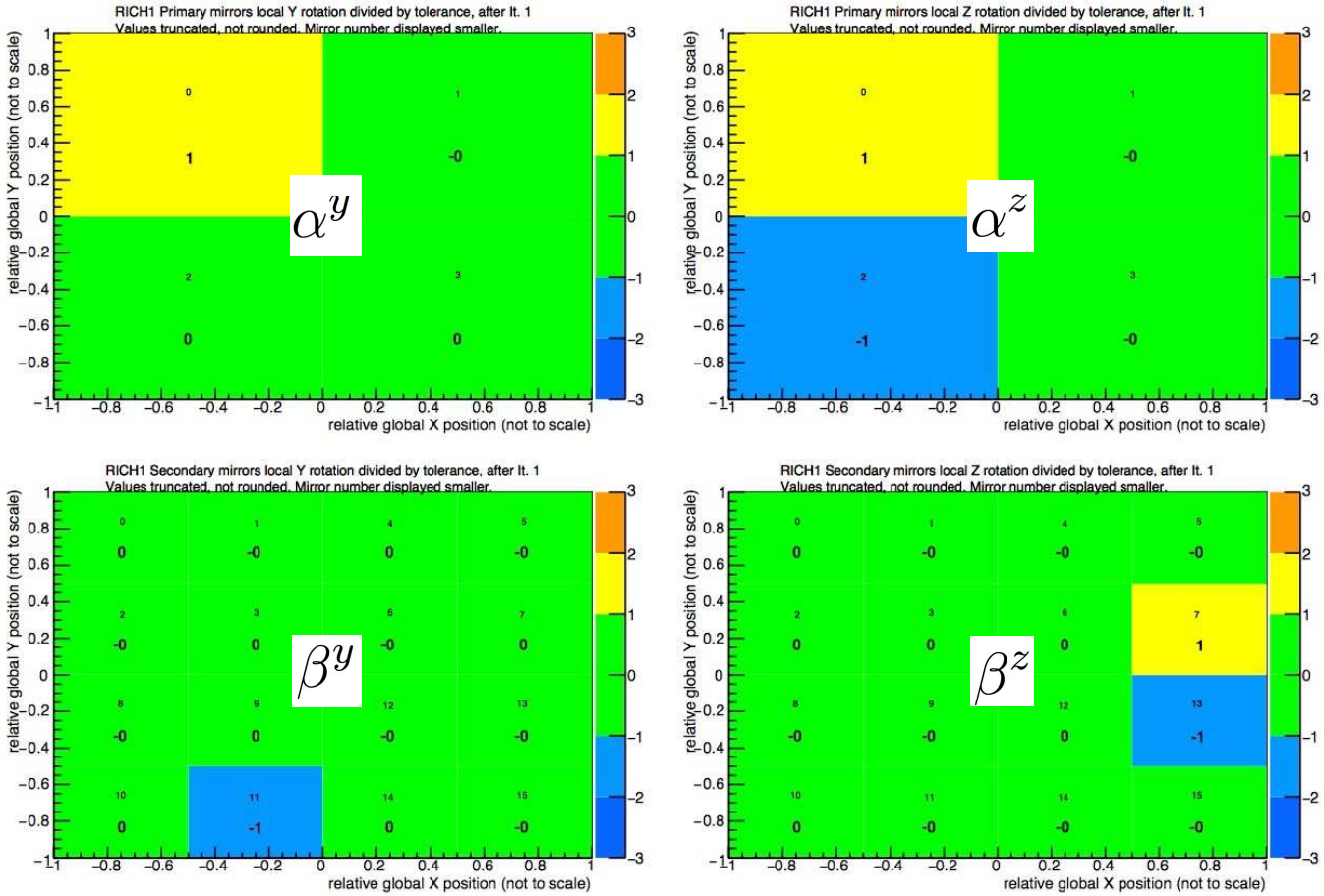


Mirror alignment monitored during 2015 and 2016 $\Rightarrow$ alignment tolerances determined

$\Rightarrow$ full automation implemented in 2017

Mirror tilts

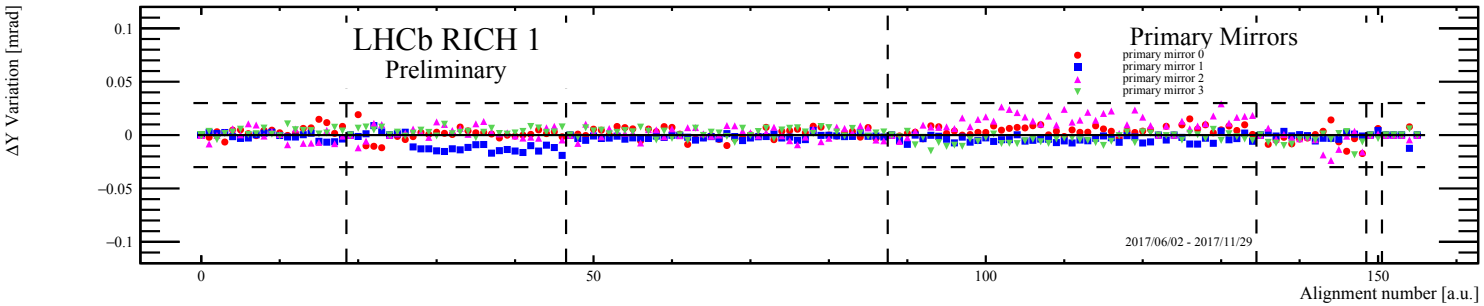




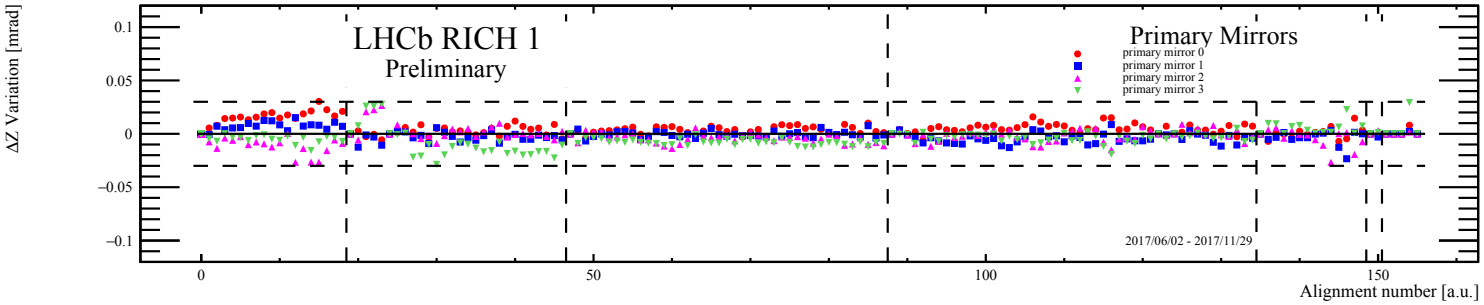
- alignment constants determined for each mirror
- correlation of different mirror pairs taken into account
- iterative procedure on a dedicated farm allows to extract mirror alignment to be applied by the reconstruction for each fill

Mirror alignment stability in 2017 (RICH 1)

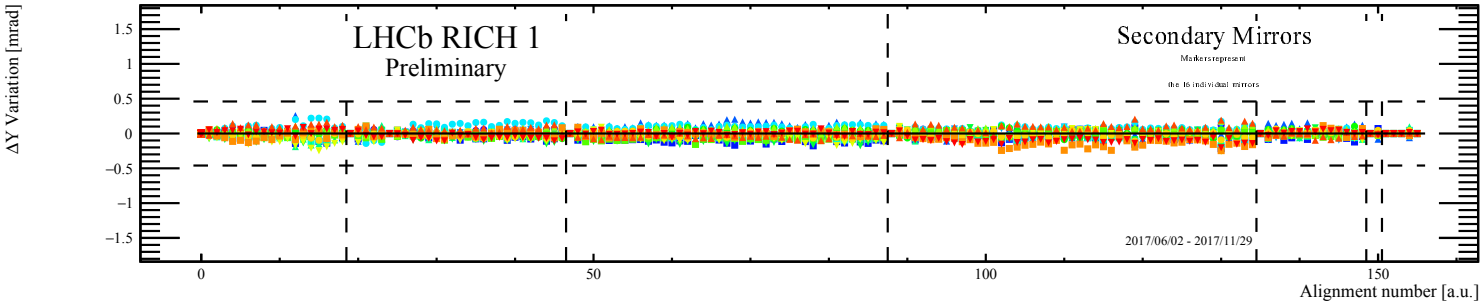
α^y



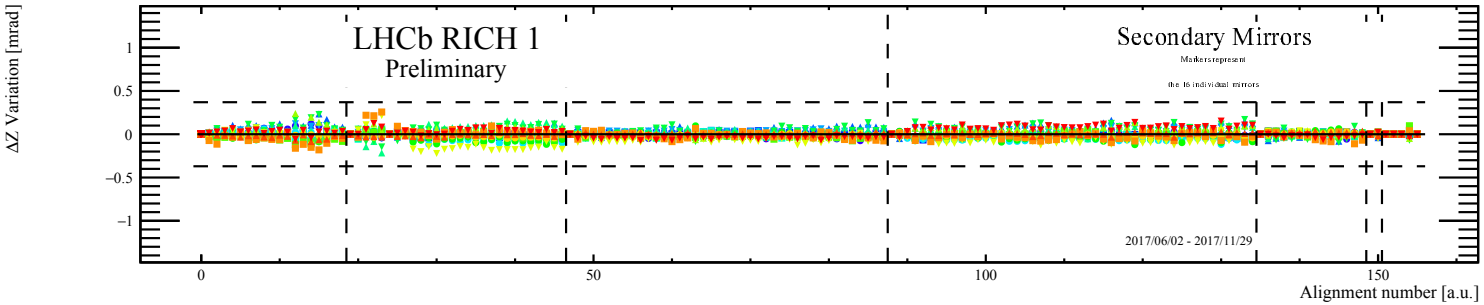
α^z



β^y

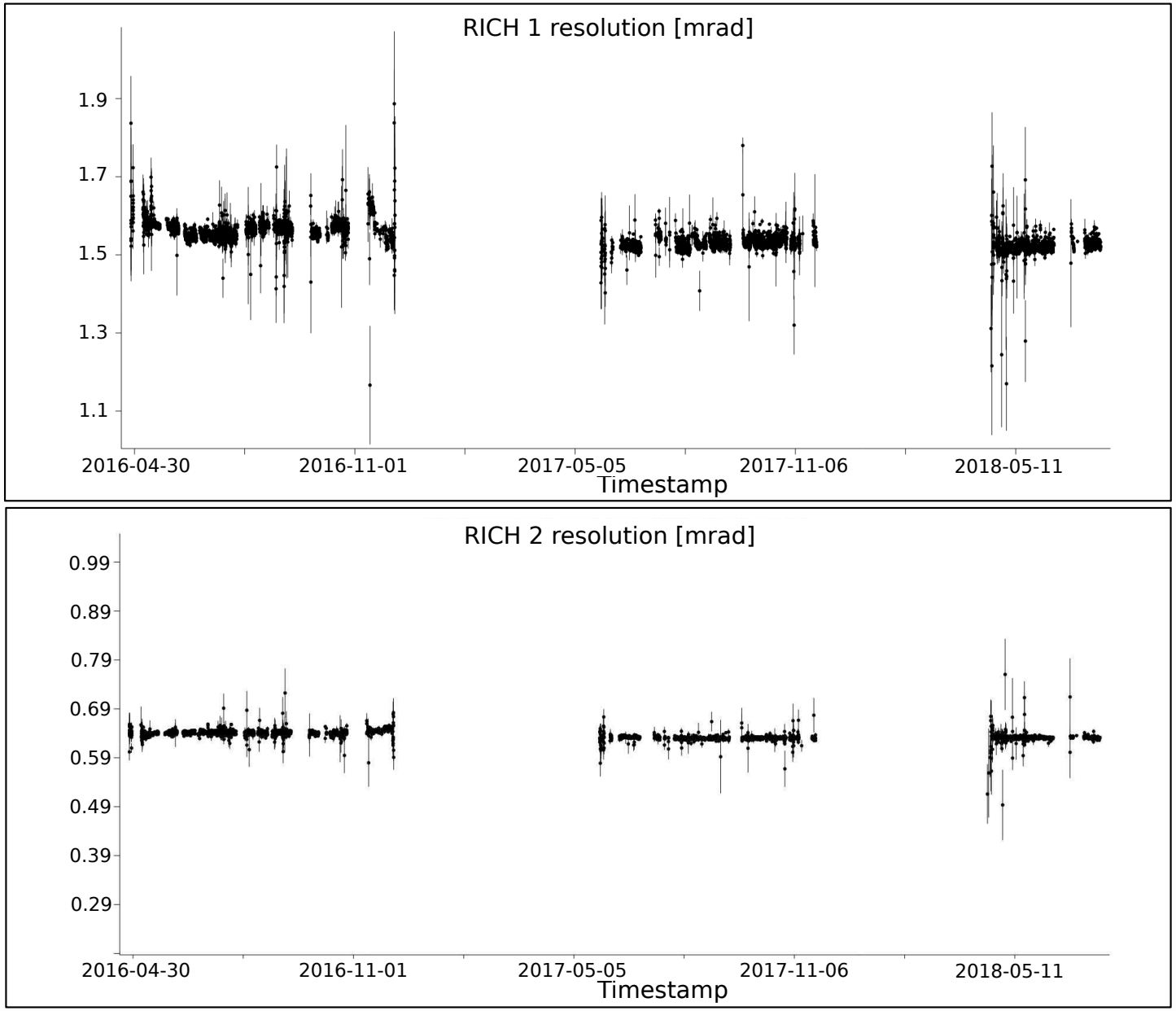


β^z



Performance

Cherenkov resolution stability over time

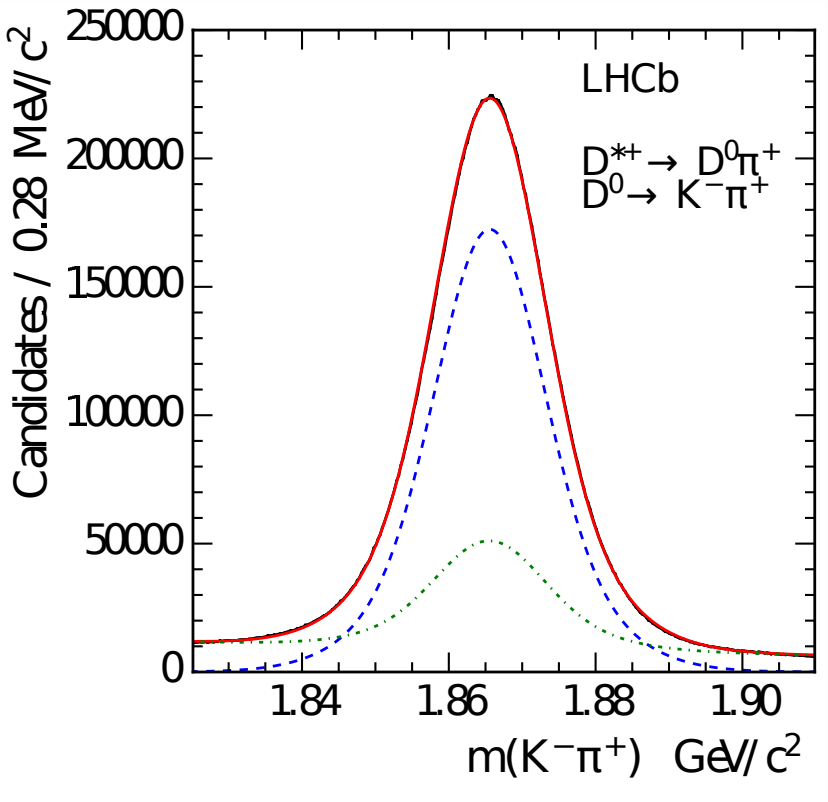


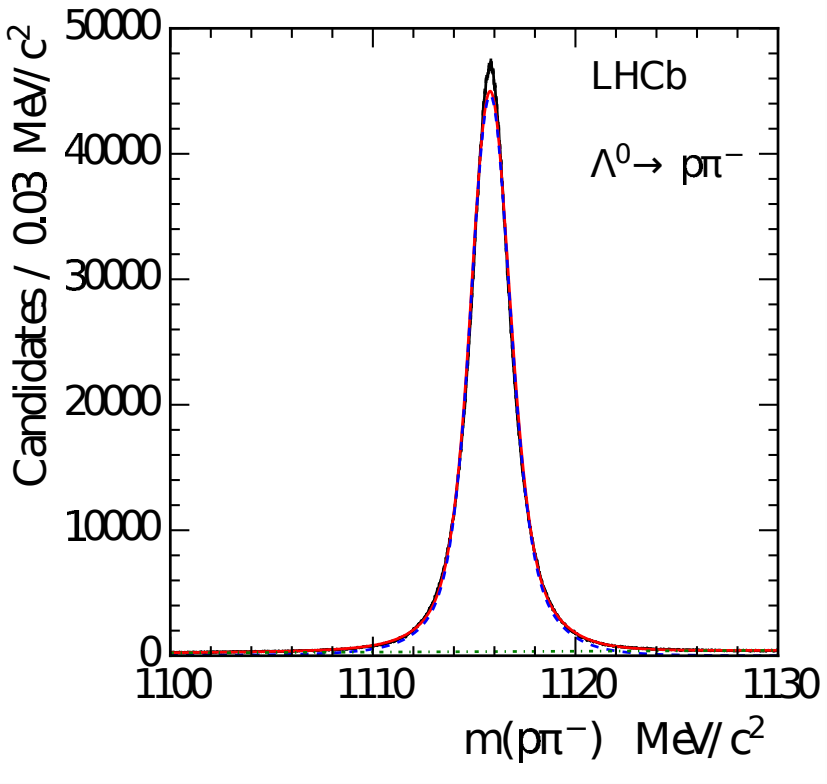
Excellent stability!!!

PID calibration sample

PID performance studied with pure samples: each particle species is selected with kinematical information only

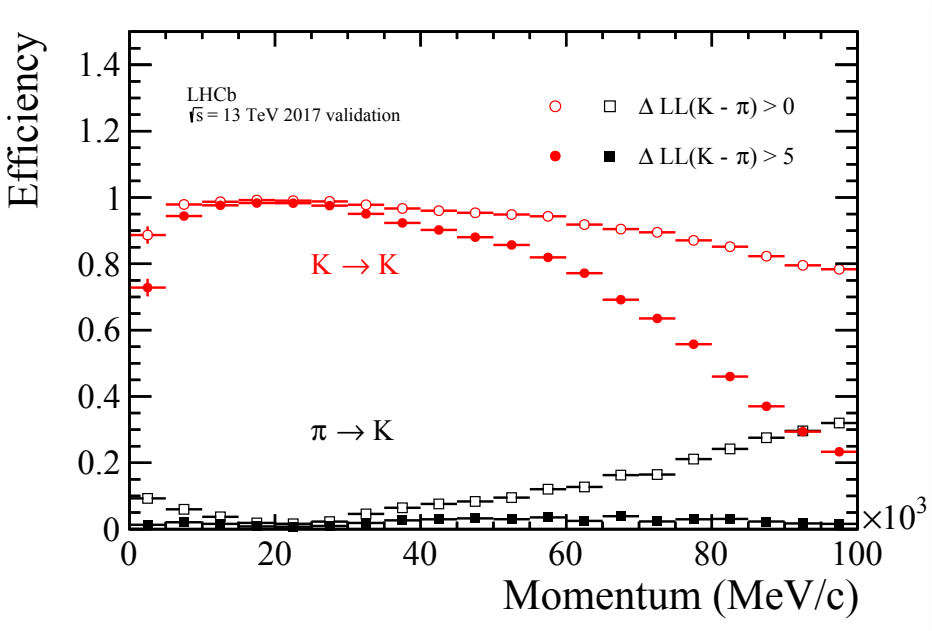
- pions performance studied using $K_S^0 \to \pi^+\pi^-$
- kaons performance studied using $D^* \to D^0\left(K^-\pi^+\right)\pi^+$
- protons performance studied using $\Lambda^0 \to p\pi^-$

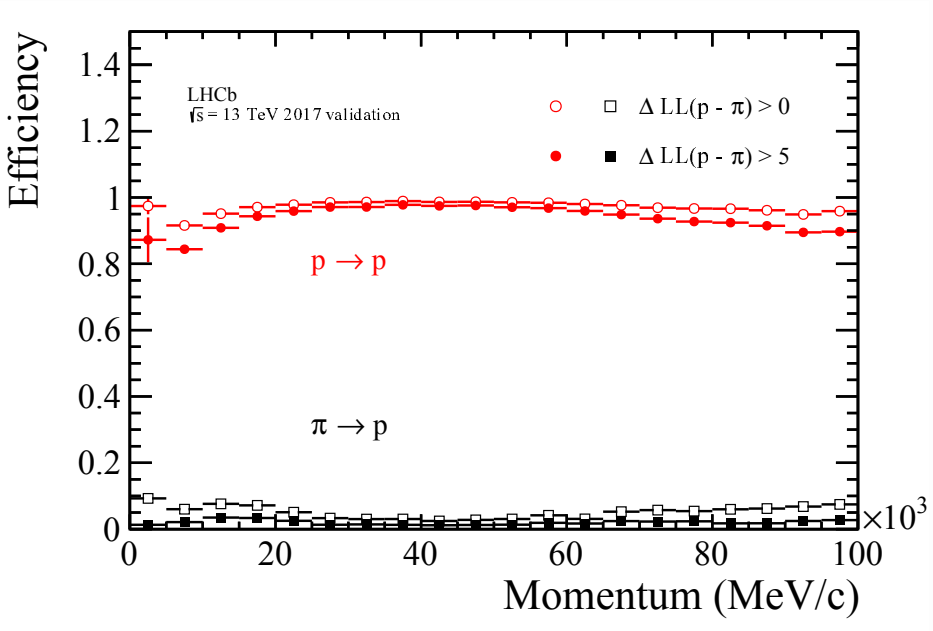


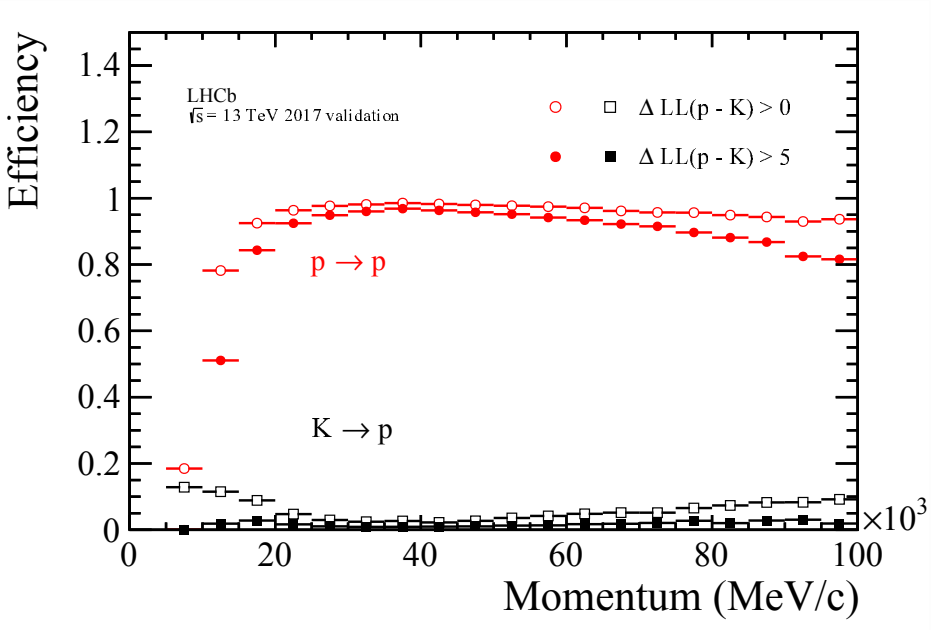


example of mass distribution for PID samples [PoS (ICHEP2016) 295]

RICH PID performance (2017)

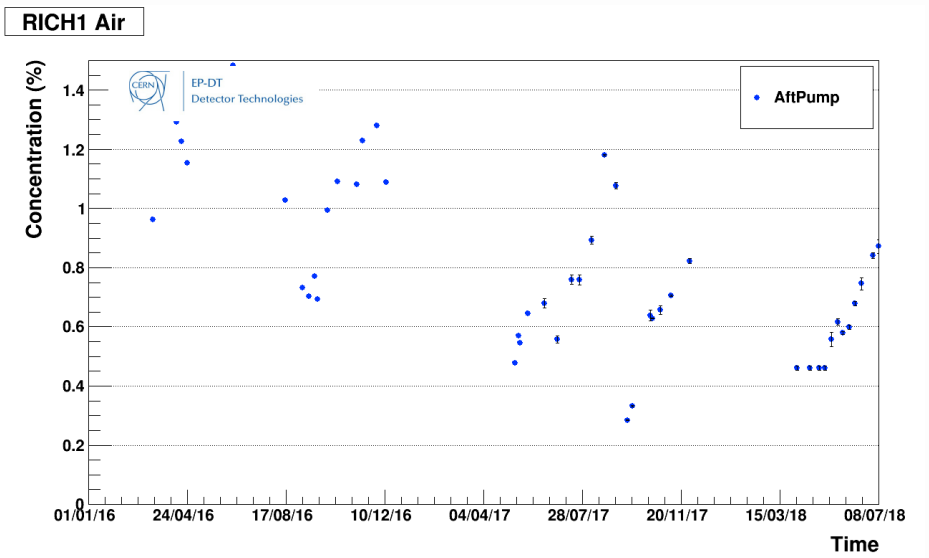


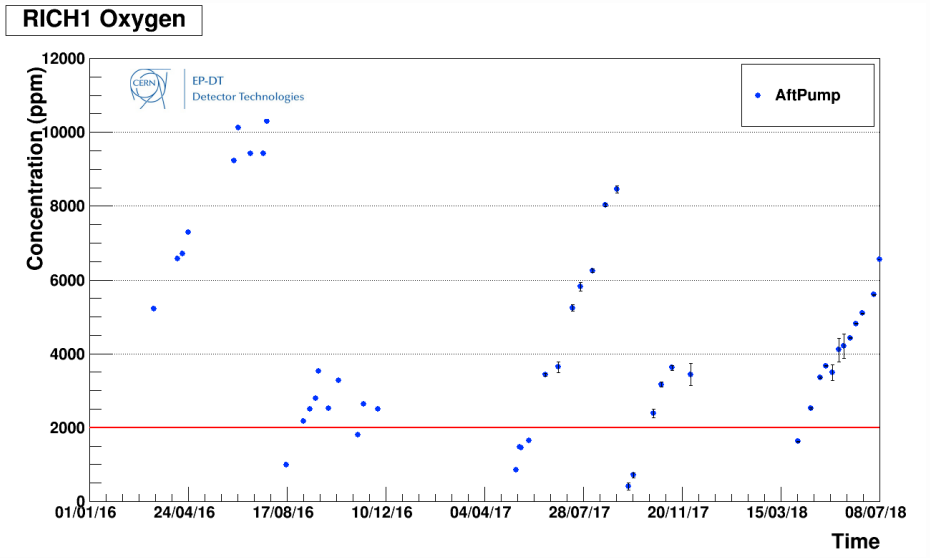


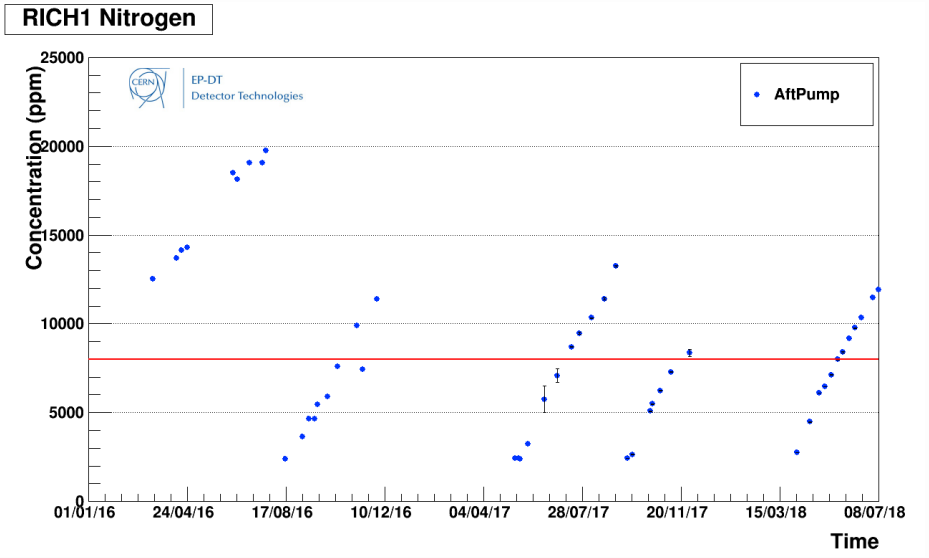


Gas purity RICH 1

- gas purity monitored during the year
- RICH 1 filled with CO_2 during winter shutdown and back with C_4F_{10} before the beginning of the run
- air contamination increases during the year due to small leak
- gas cleaning performed during technical stops to ensure the stability of the performance



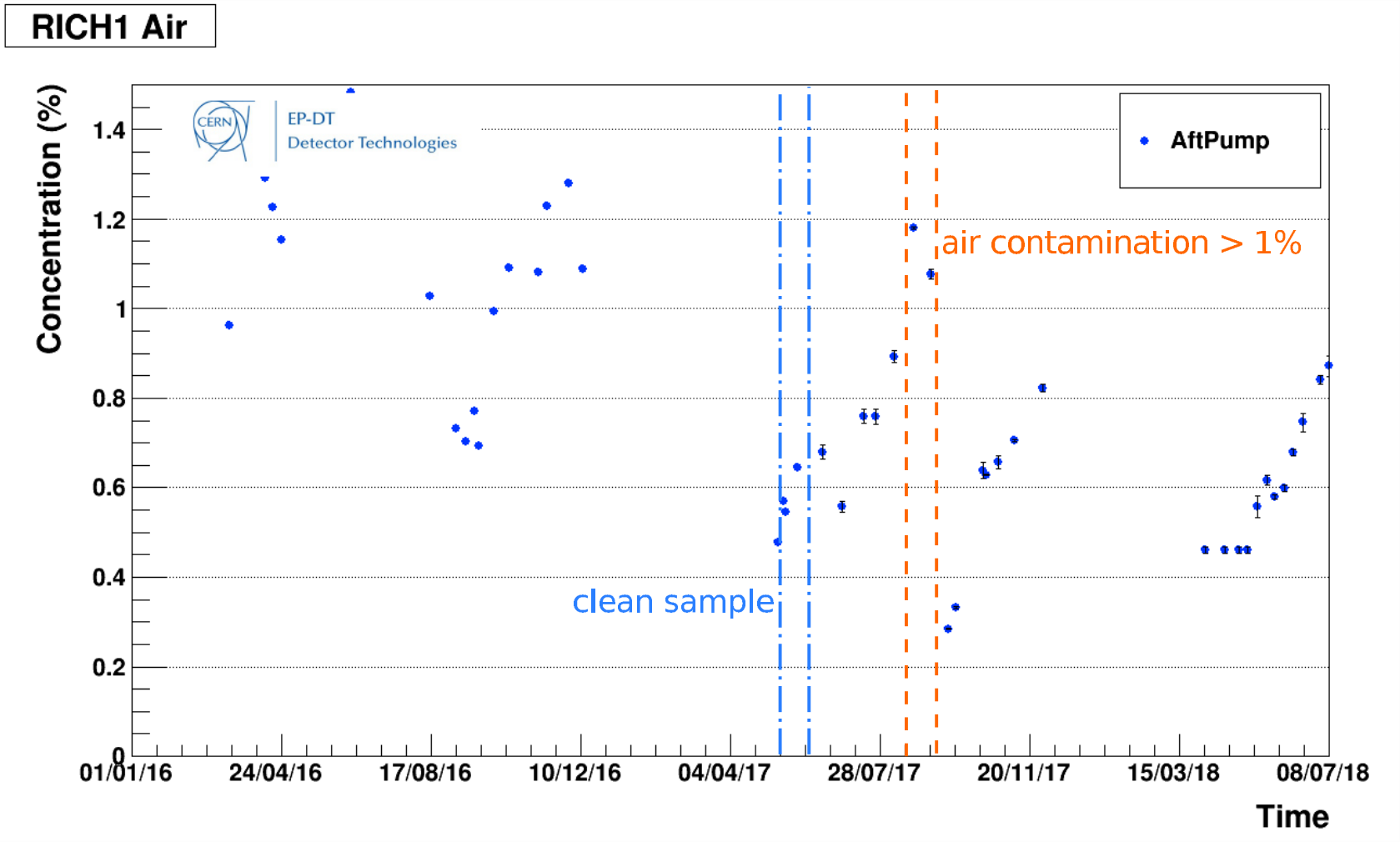




Gas contamination affects refractive index, dispersion, photon yield....

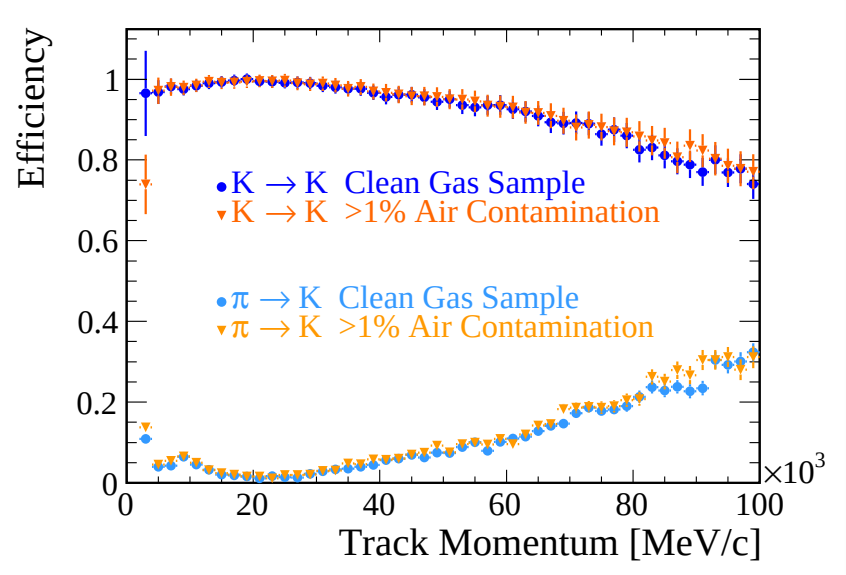
Impact of gas purity

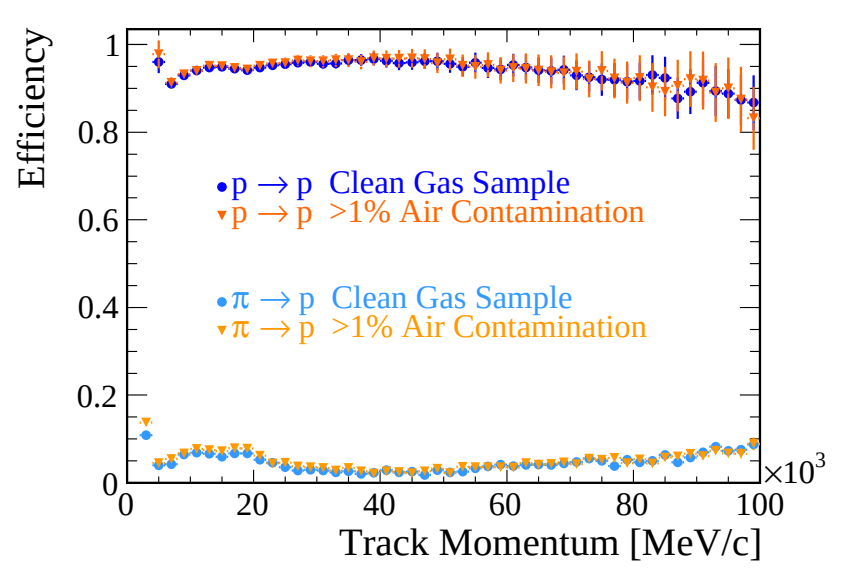
- two periods in 2017 selected: gas clean and contamination above the limit for cleaning
- both periods with the same magnet polarity (UP)

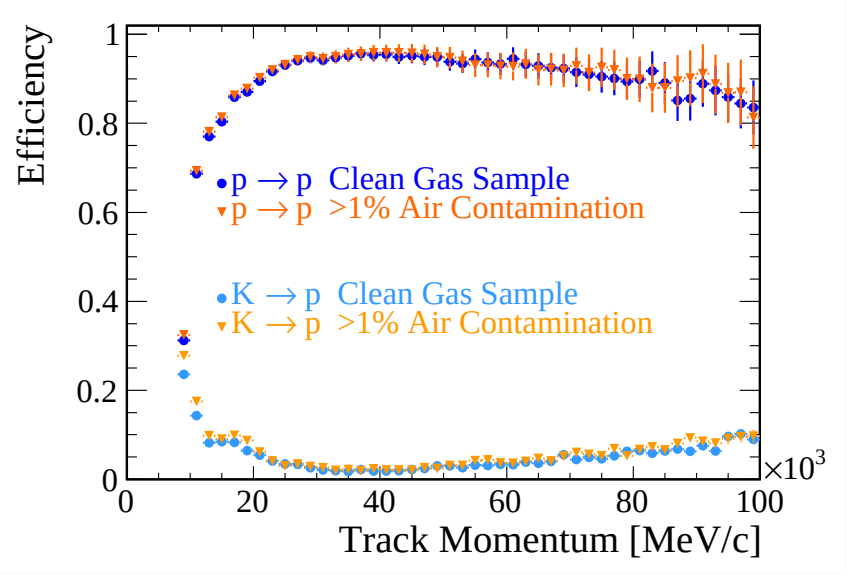


- use calibration samples to compare PID performance in two time periods

PID dependence on gas purity





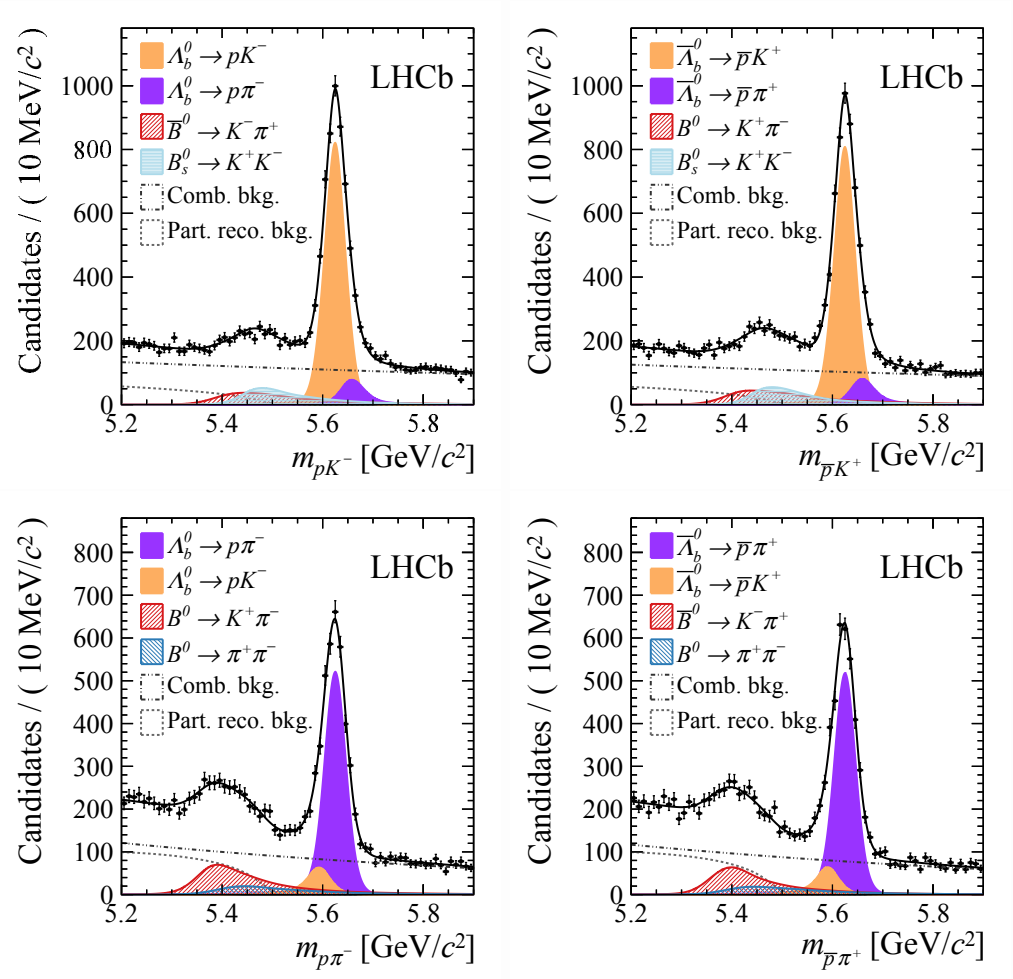


PID performance stable in time

Conclusions

LHCb RICH detectors successfully and stably operating since 2010

Key ingredient to the successful physics program delivered by LHCb



"Search for CP violation in $\Lambda_b^0 \to pK^-$ and $\Lambda_b^0 \to p\pi^-$ decays"
[LHCb-PAPER-2018-025]

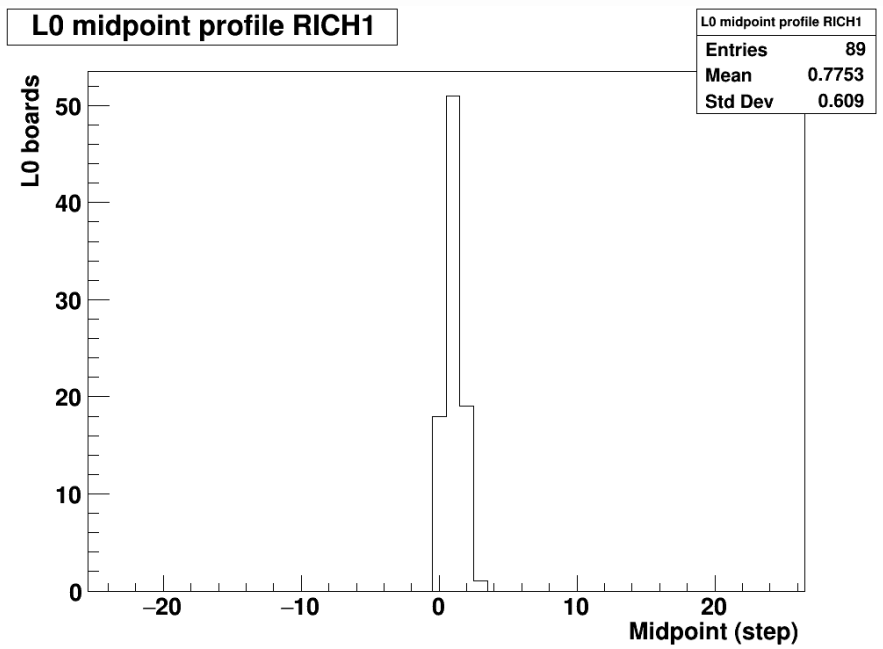
Thank you for your attention!

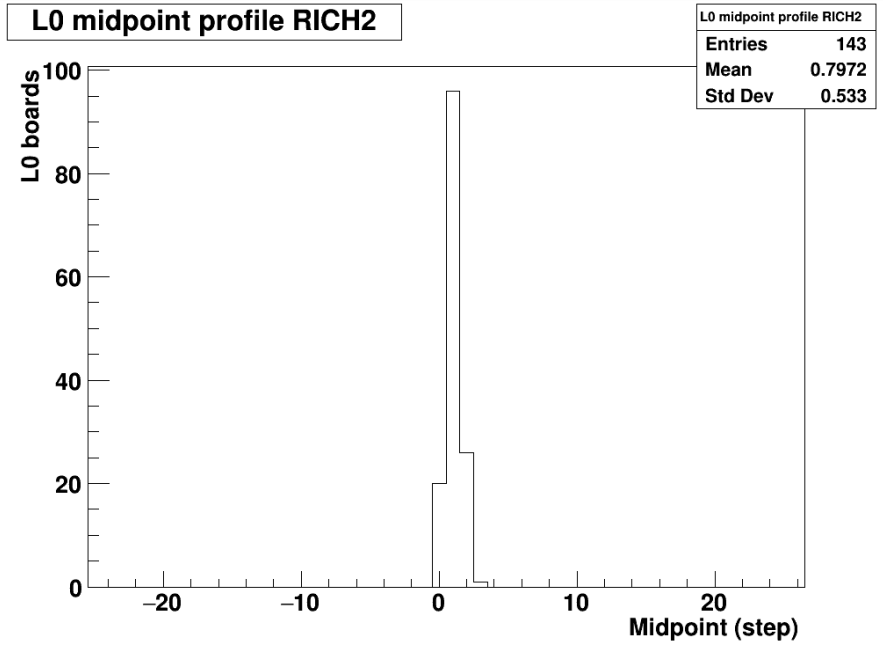
Extra slides

Timing scan

- 3 timing scans acquired during 3 bunch fill
- RICH1 already well timed
- corrections of timing applied for RICH2
- further scan acquired to confirm timing

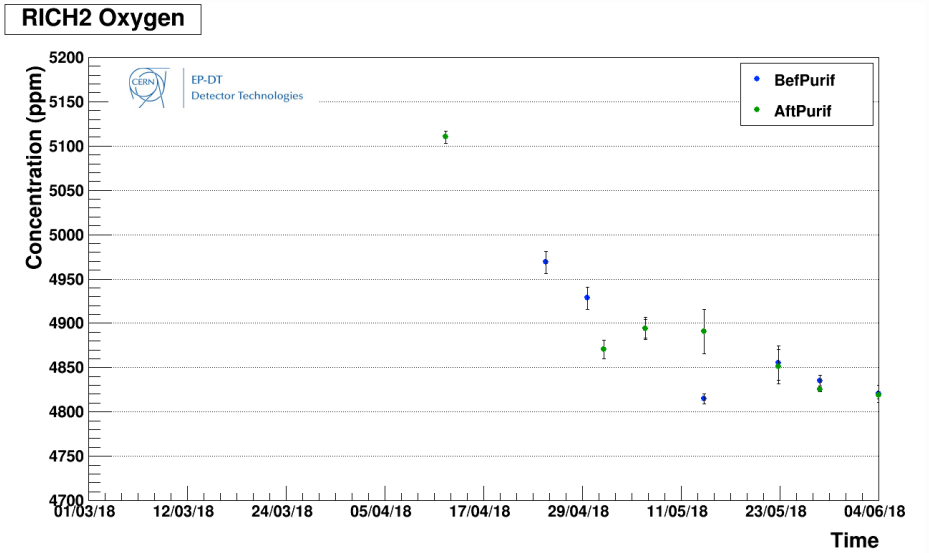
Run 205938, after timing correction

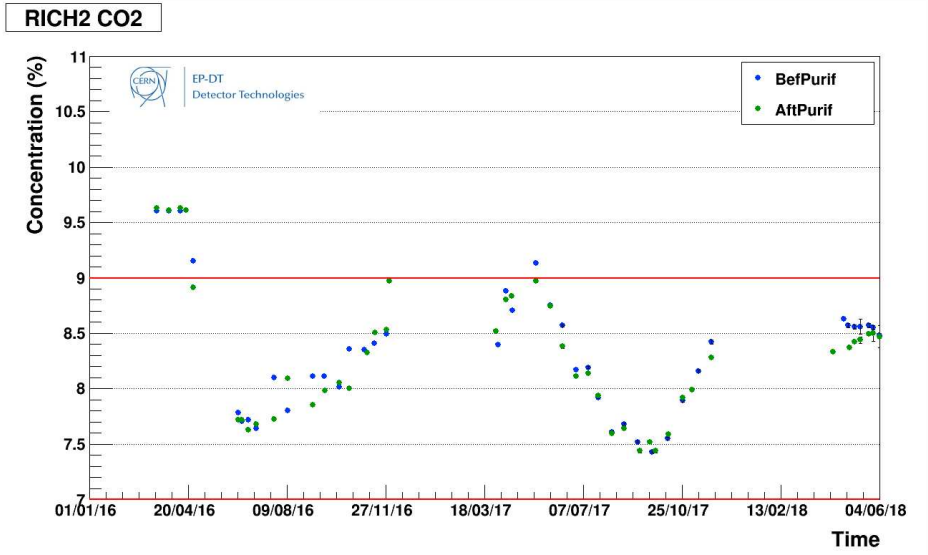


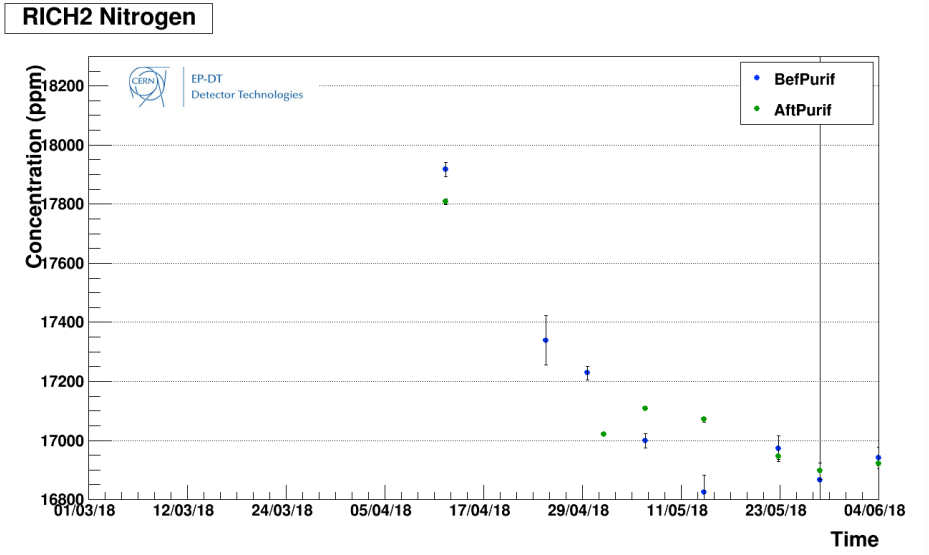


RICH2 gas

- RICH2 gas status monitored by gas group and plot available online
- CO_2 well contempt well controlled by gas group (very stable)
- small air contamination observed this year
- contamination is decreasing while new gas is pushed in

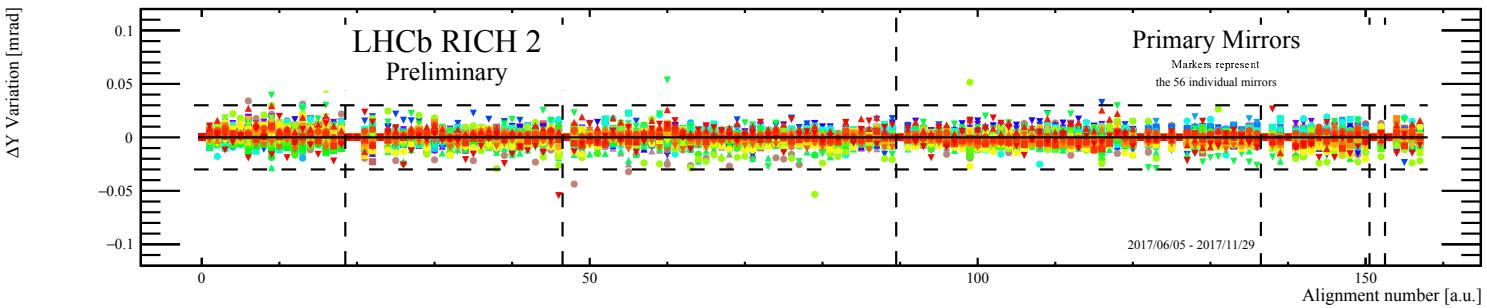




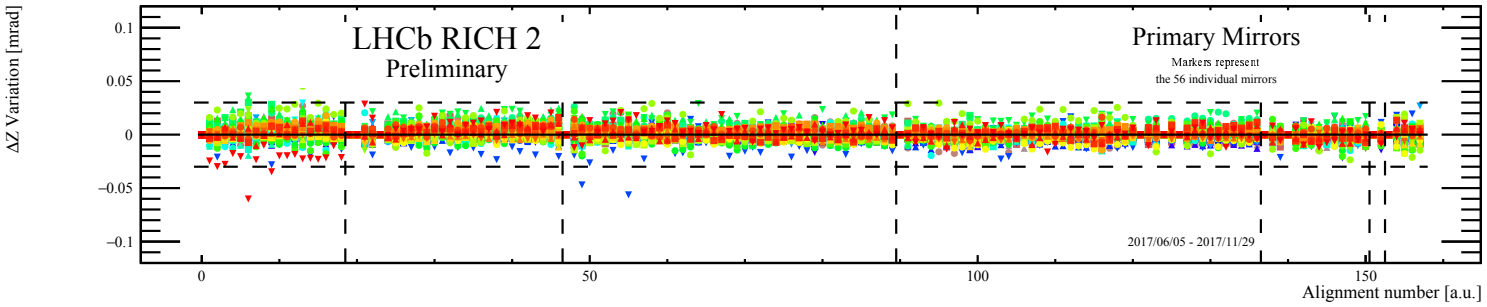


Mirror alignment stability in 2017 (RICH 2)

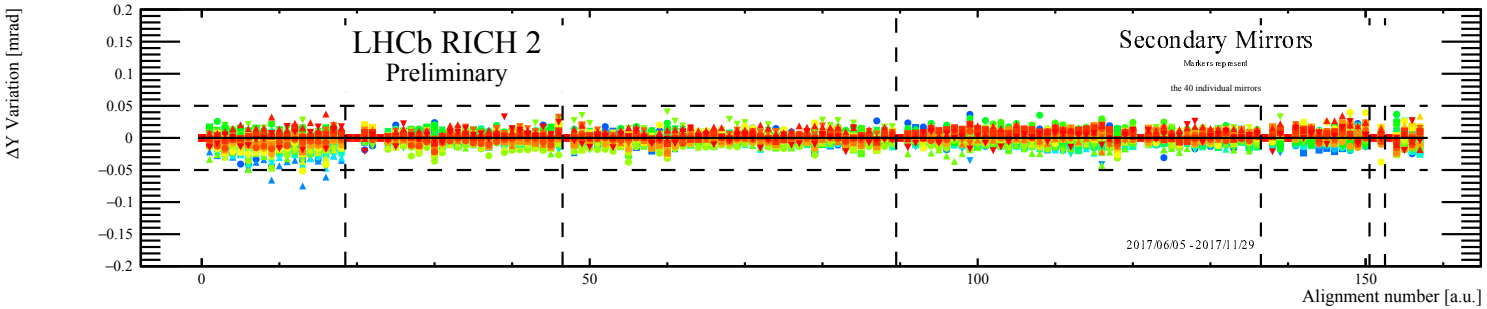
α^y



α^z



β^y



β^z