The performance of the LHCb RICH detectors during the runs 1 and 2 of the LHC

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on behalf of the LHCb RICH Collaboration

Overview

- The LHCb RICH detectors
- Cherenkov angle resolution and alignment
- Number of photons
- Real-time Online calibration
- PID performance
- Physics impact

Performance of the LHCb RICH detectors during LHC Run 2
R. Calabrese et al 2022 *JINST 17 P07013*

Performance of the LHCb RICH detector at the LHC
Adinolfi, M. et al. Eur. Phys. J. C 73, 2431 (2013).

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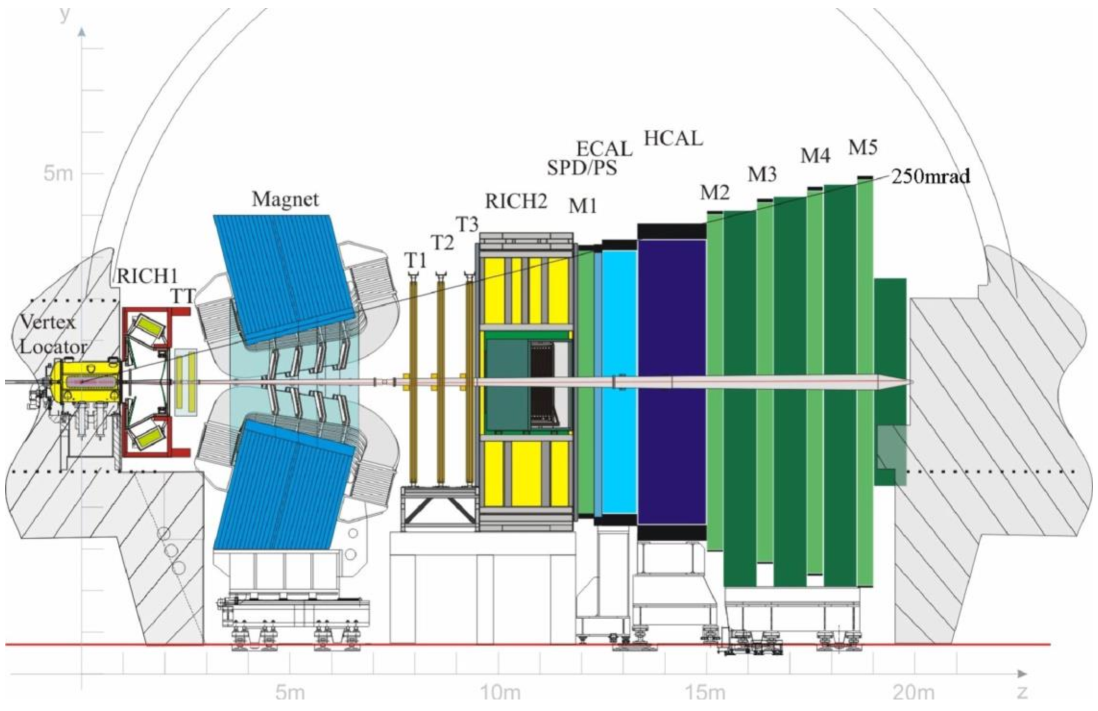
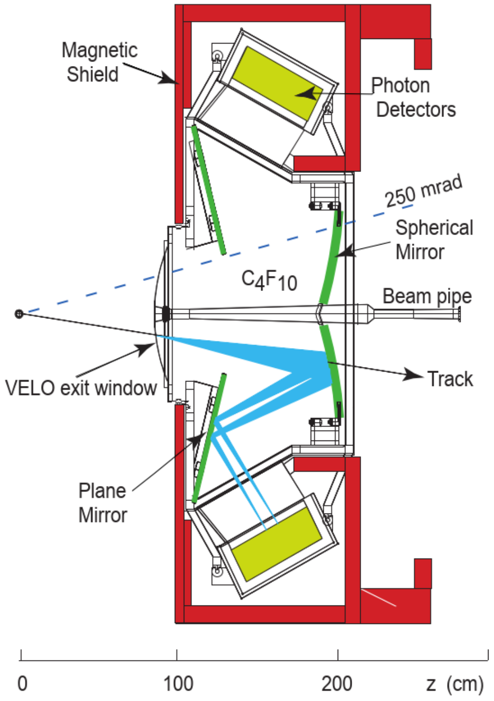
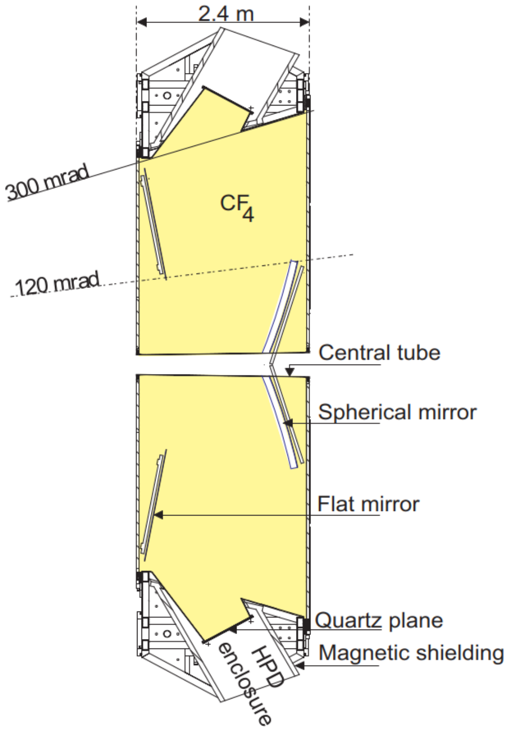
The LHCb experiment





RICH 1



RICH 2

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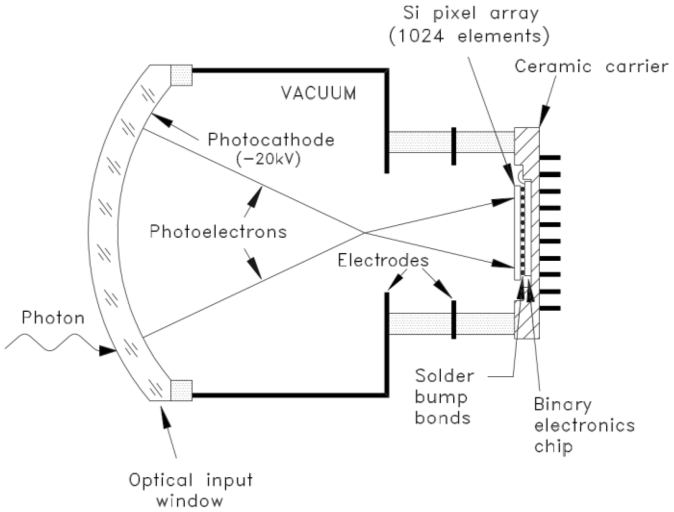
The Pixel Hybrid Photon Detectors



The encapsulated electronics operate at a maximum read-out rate of 1 MHz; not compatible with 40 MHz readout

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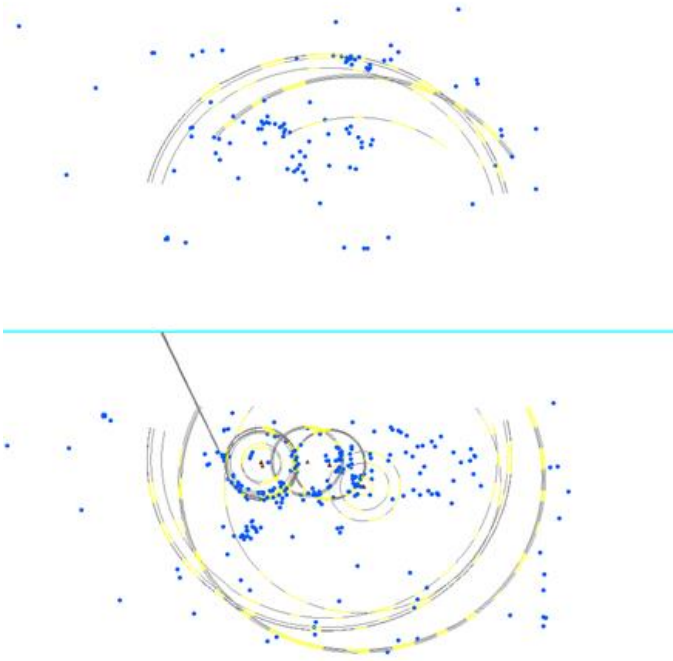
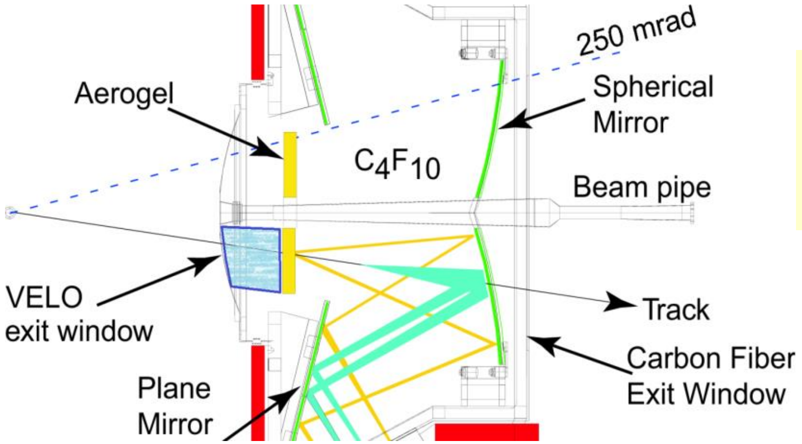
RICH 1: From 2 radiators to 1

- Original design of RICH 1 was to accommodate 2 radiators to cover a wider momentum range:
  - C_4F_{10}
  - Aerogel
- However:
  - Increased luminosity compared to original design and increased background (and underestimate of track multiplicity) made aerogel photons difficult to identify
  - The requirement for offline quality results from High-Level Trigger output put strict conditions for processing time
    - Online alignment and calibration before HLT
- Removal of aerogel extended the length of the gas radiator



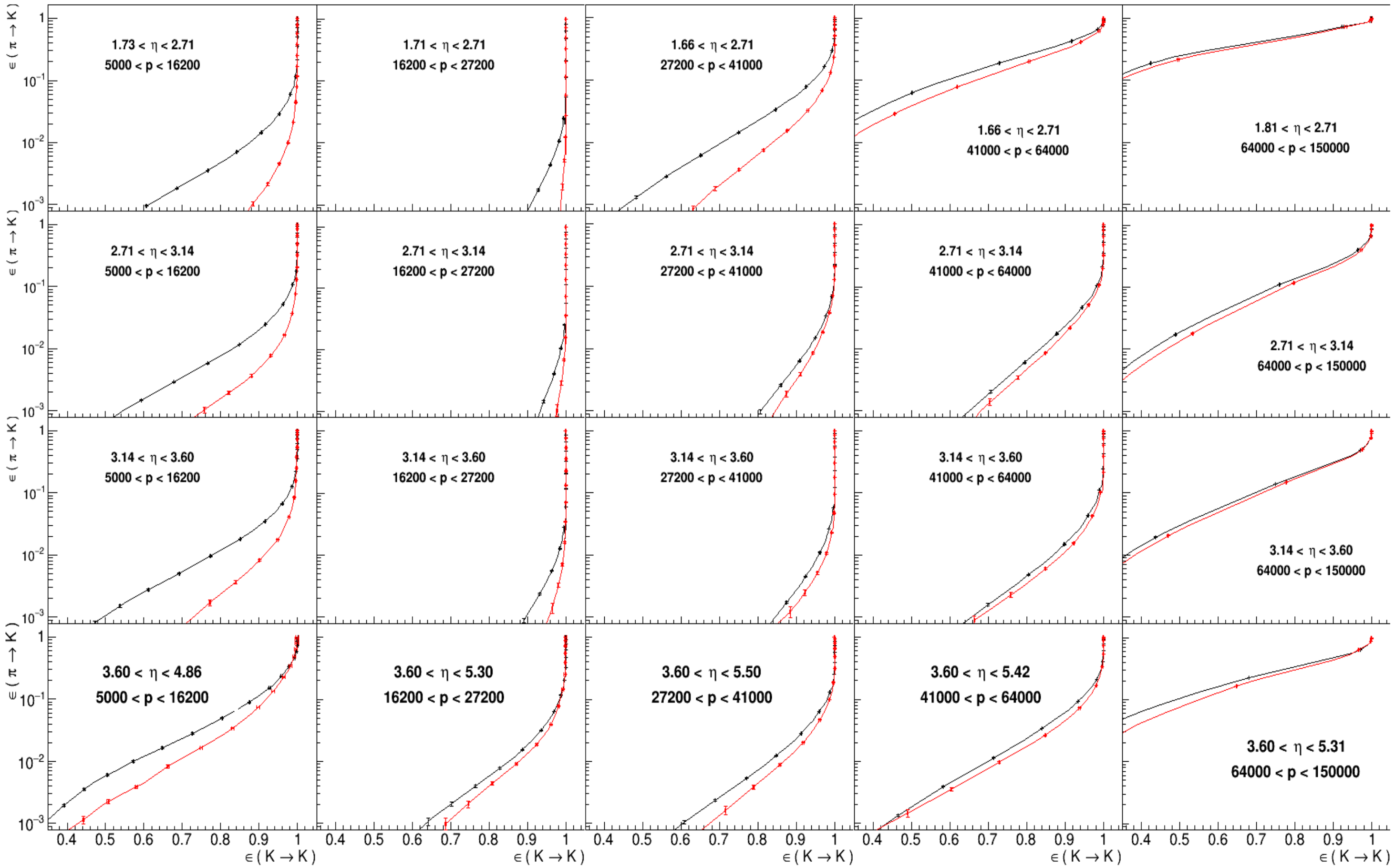
Aerogel removal

π/K PID 2012/2015



Mis-ID π⟶K

← η



Momentum →

Efficiency K⟶K

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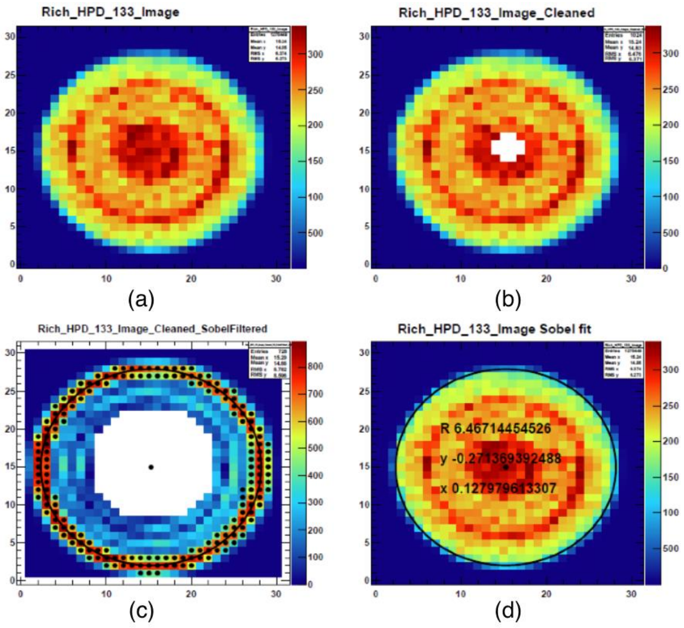
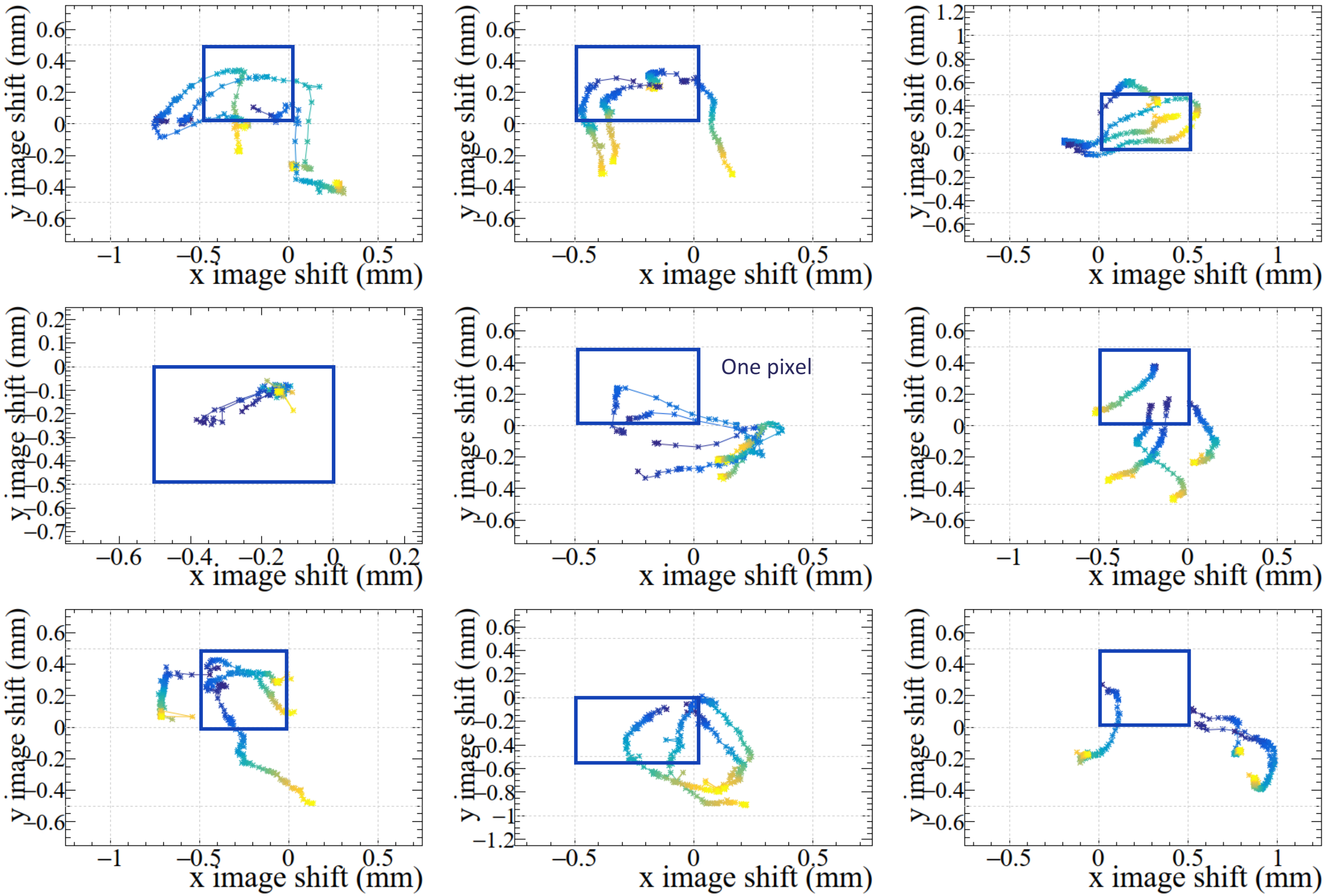
Cherenkov angle reconstruction

HPD photocathode position





Automatic Online calibration for every run (max 1 hour)

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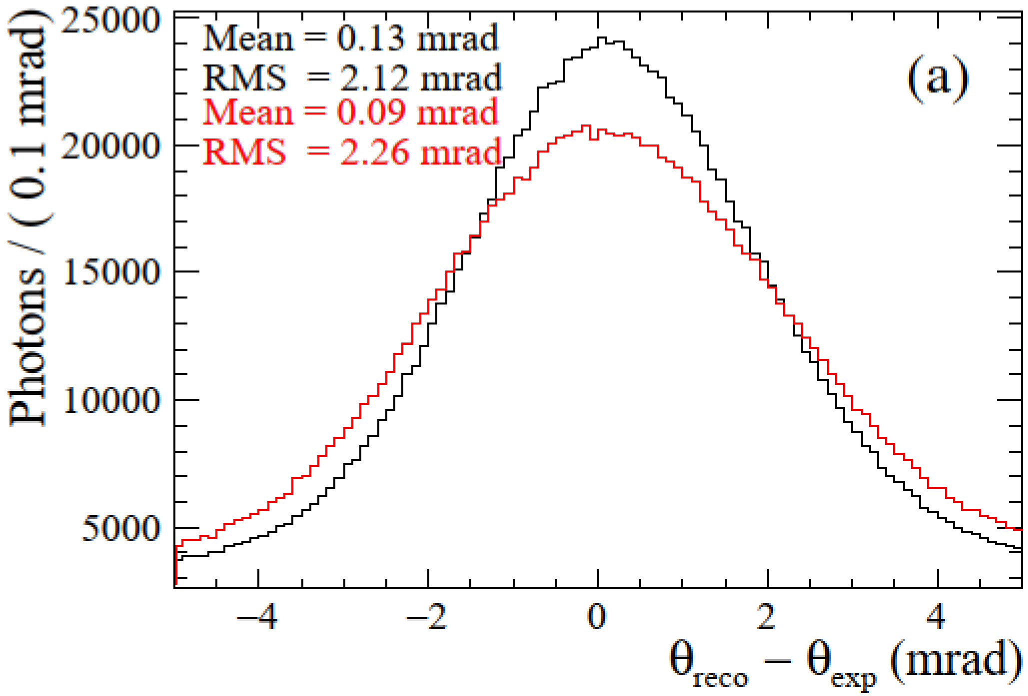
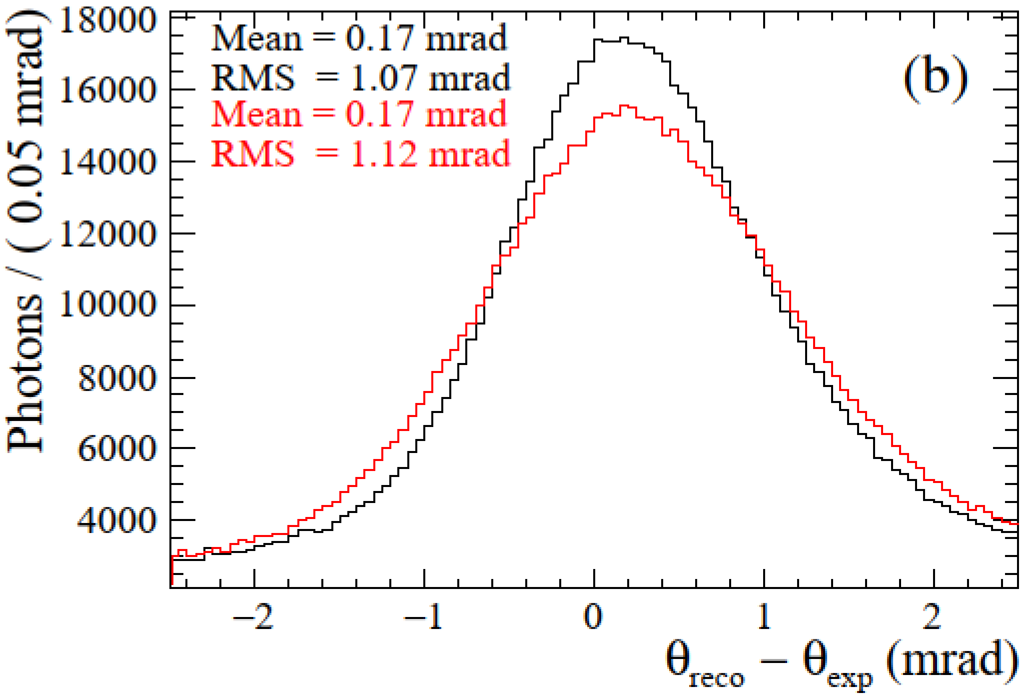
HPD Image centre effect





RICH 1

Before corrections

After corrections

RICH 2

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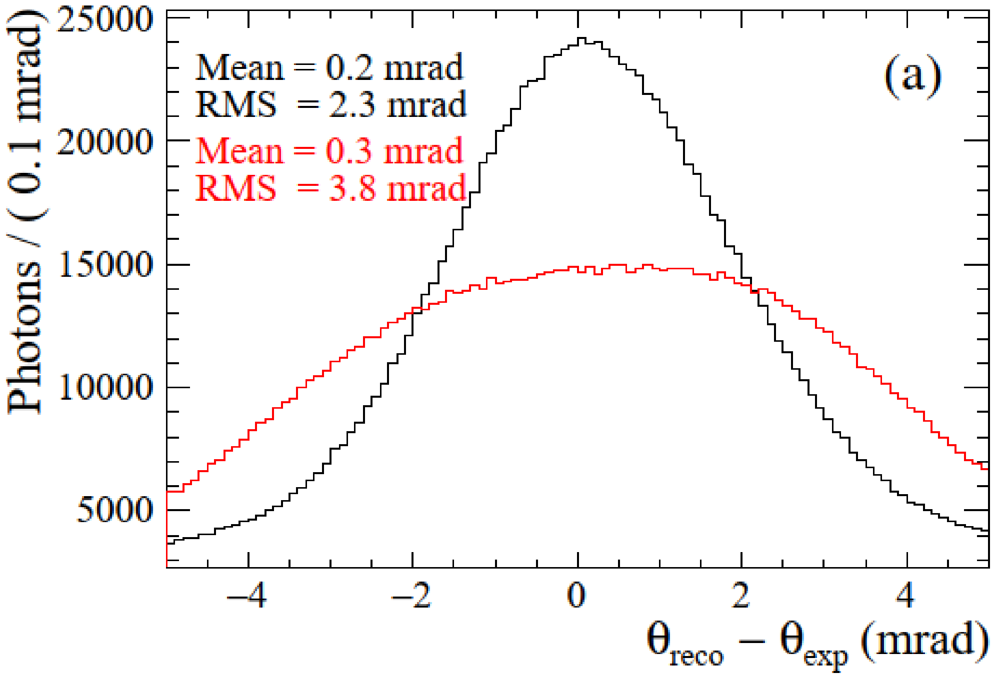
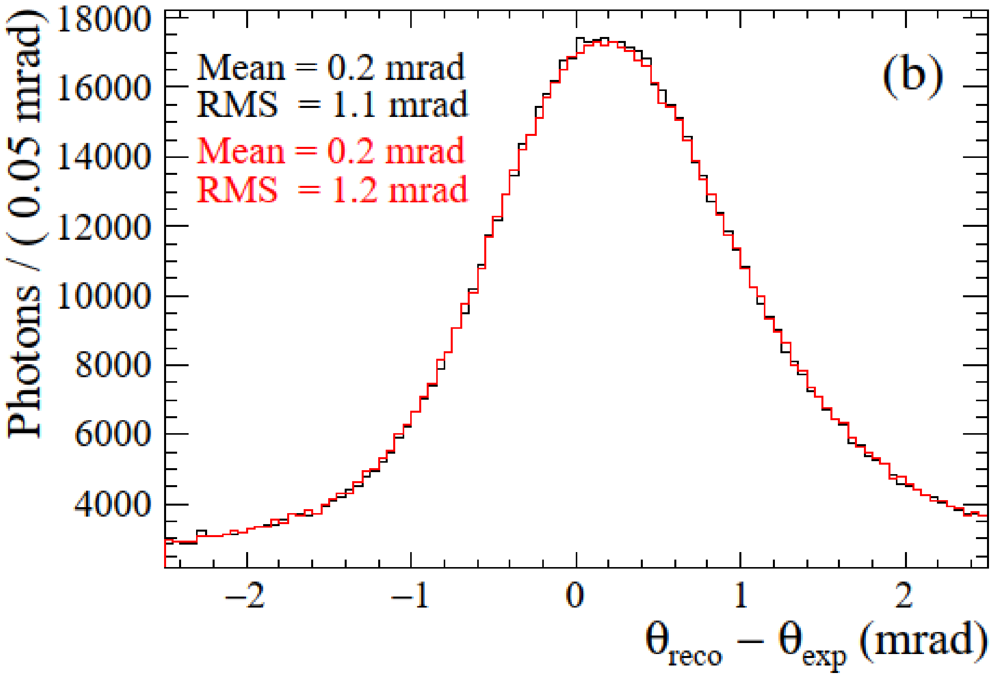
Magnetic field distortions





A Borgia *et al*, NIM A 735 (2014) 44-52

R Cardinale *et al,* 2011 *JINST* **6** P06010

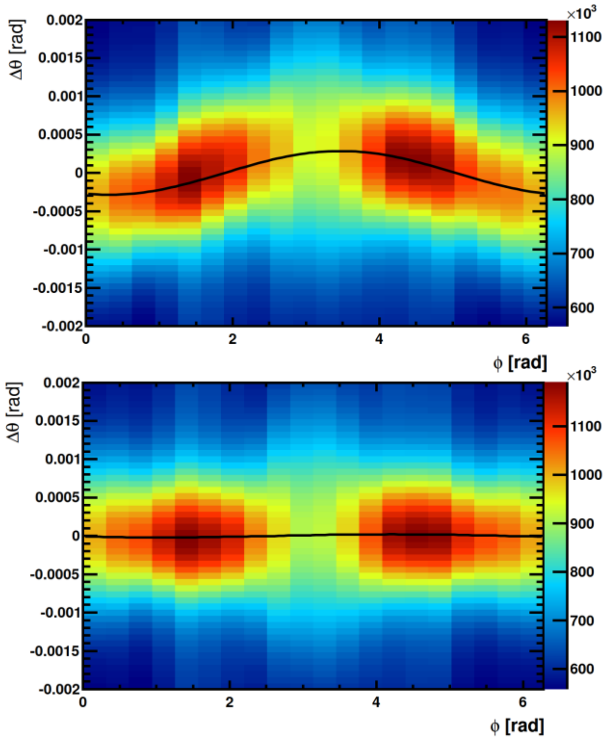
RICH 1

Before corrections

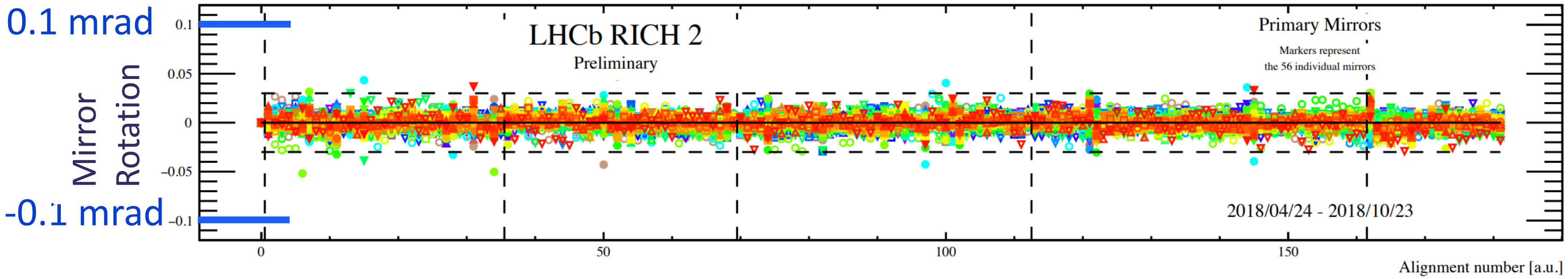
After corrections

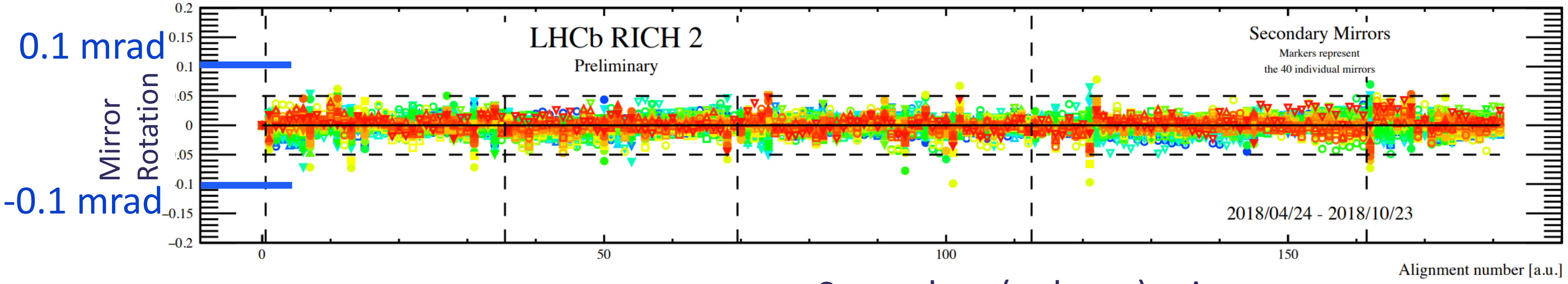
RICH 2

Mirror alignment



Primary (spherical) mirrors





Secondary (~planar) mirrors

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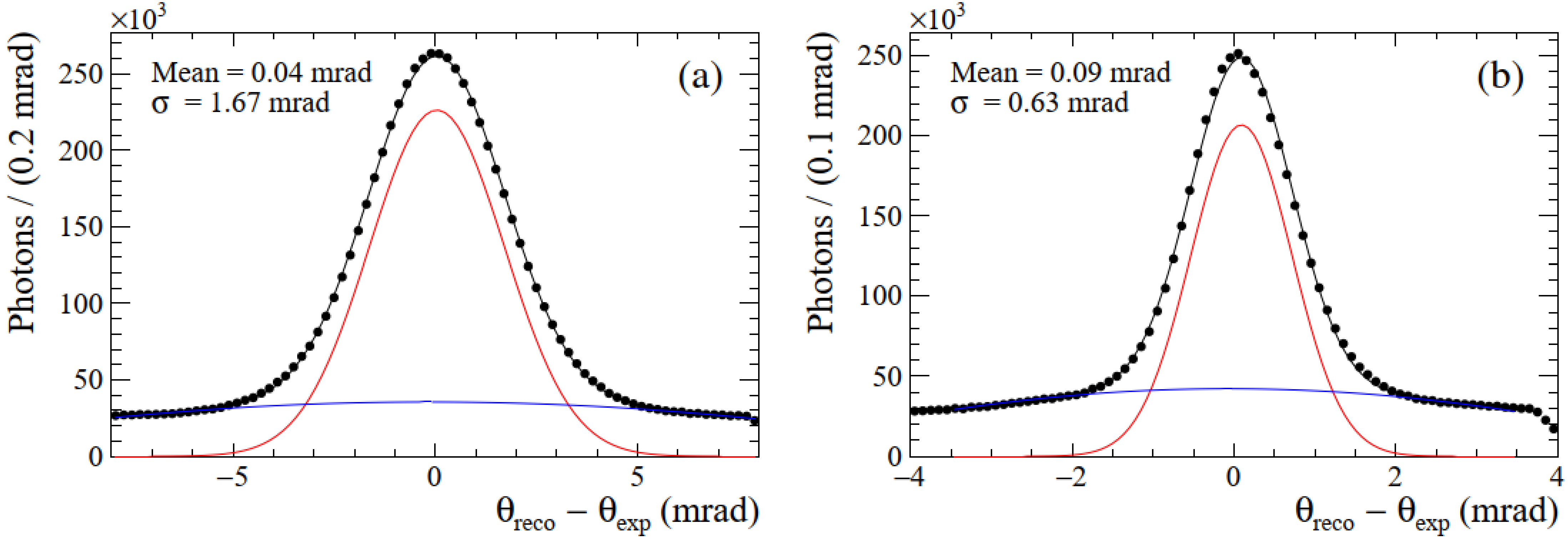
Cherenkov angle resolution

From low track multiplicity events



RICH 1 **RICH 2**

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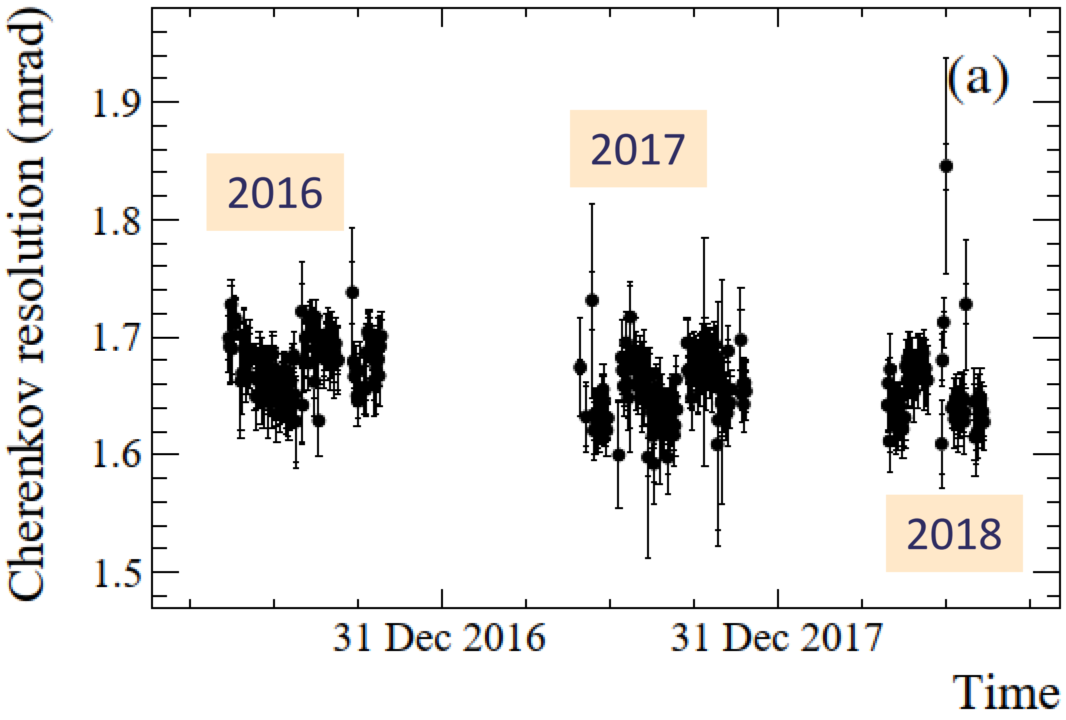
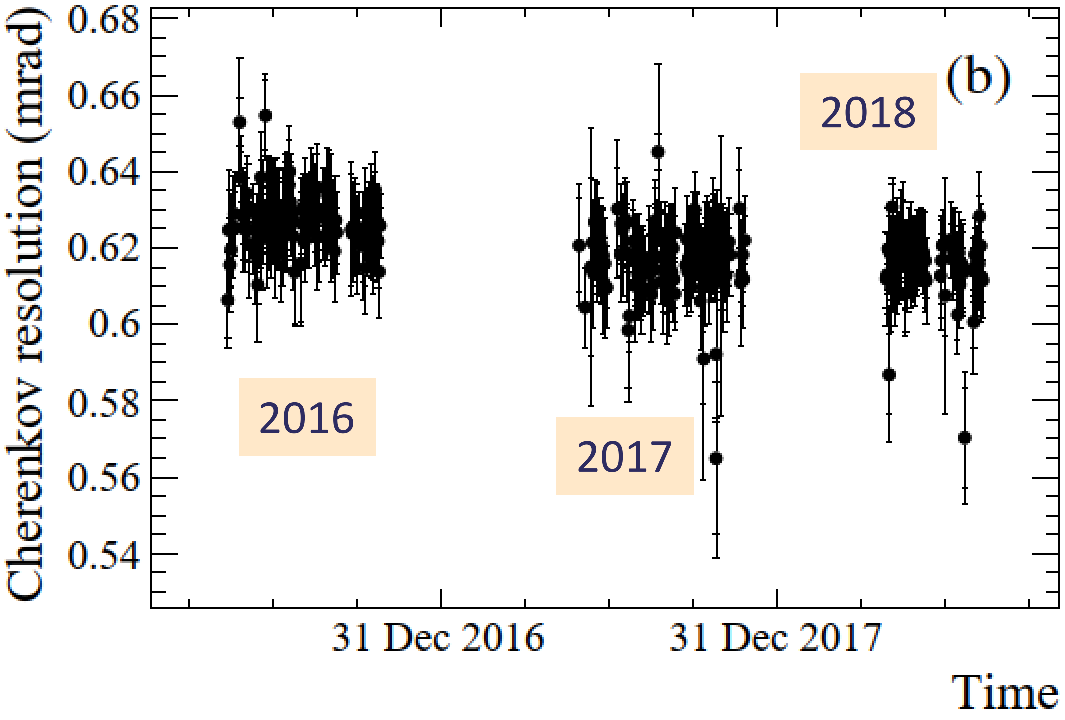
Cherenkov angle resolution stability



RICH 1



RICH 2

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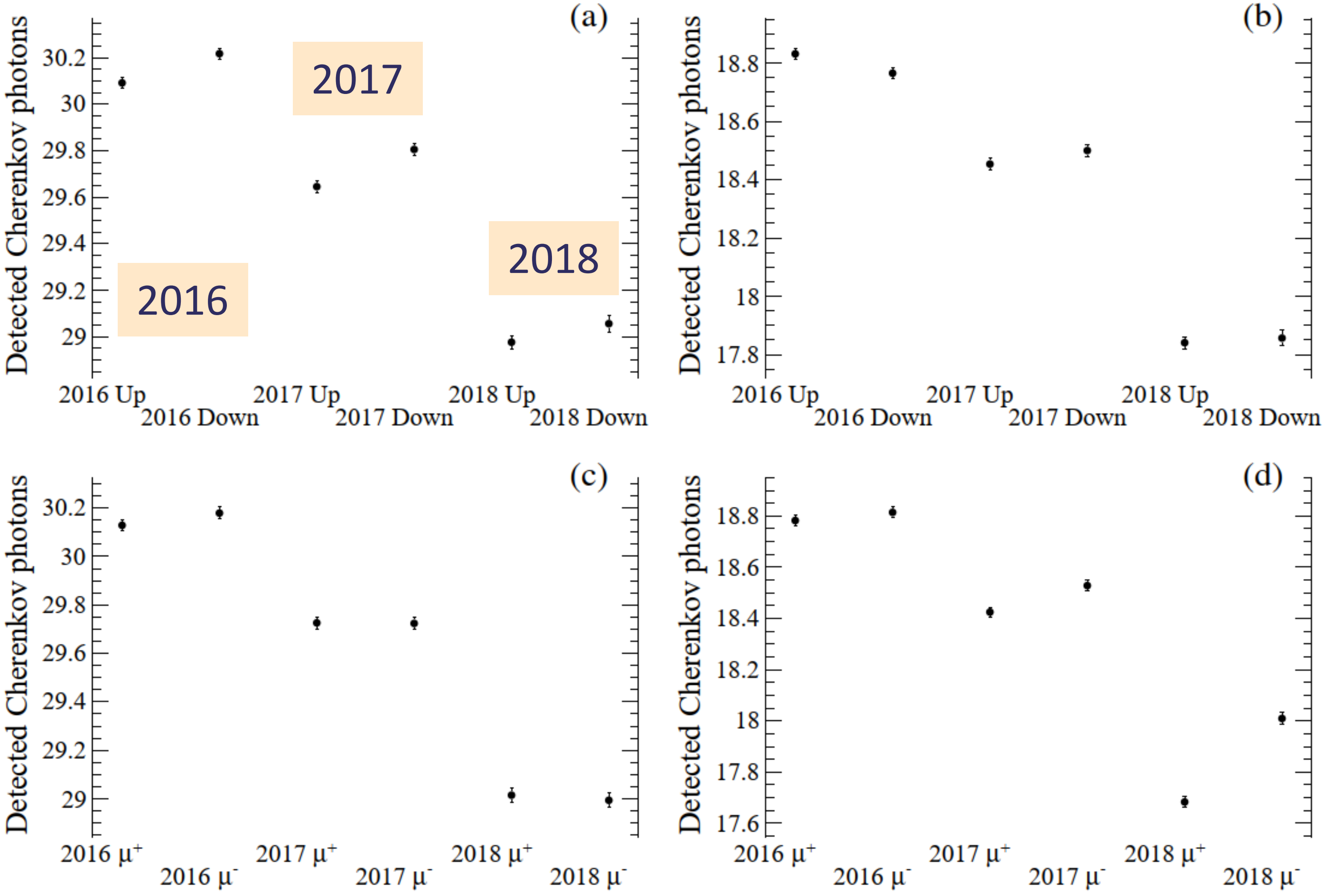
Number of detected photons

Using low multiplicity events, identified as muons by the muon system

The number of photons is estimated per track from the resolution plot with the background subtracted



RICH 1

RICH 2

LHCb operates with two magnetic field polarities to avoid systematic errors:
Field UP
Filed DOWN

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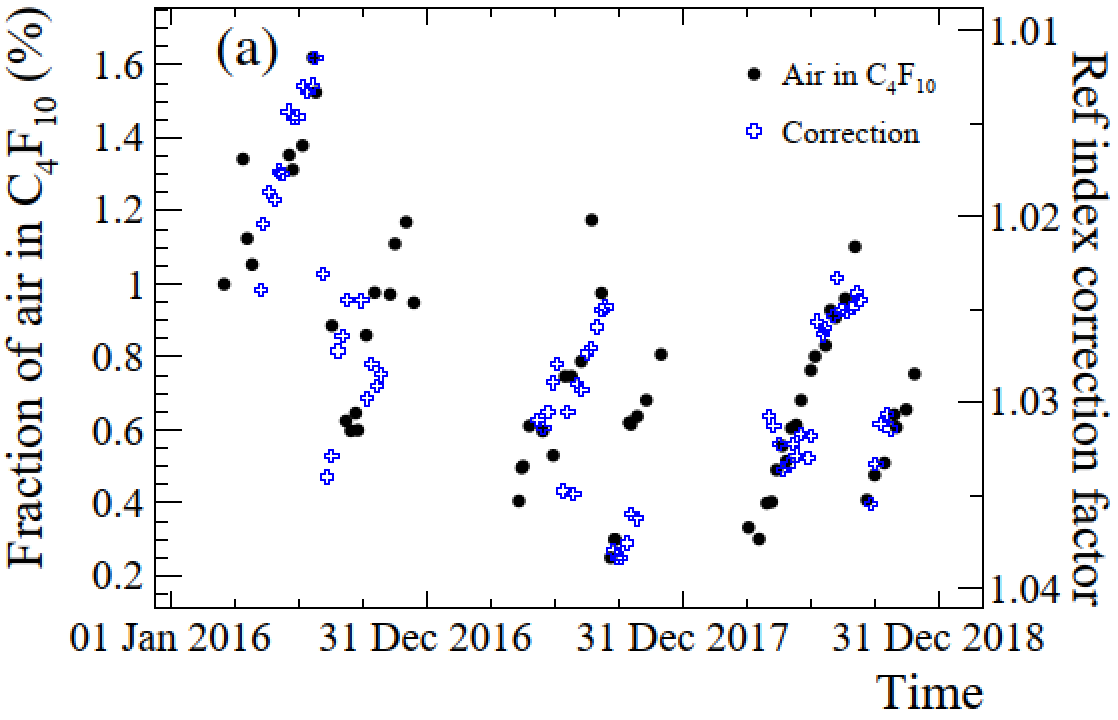
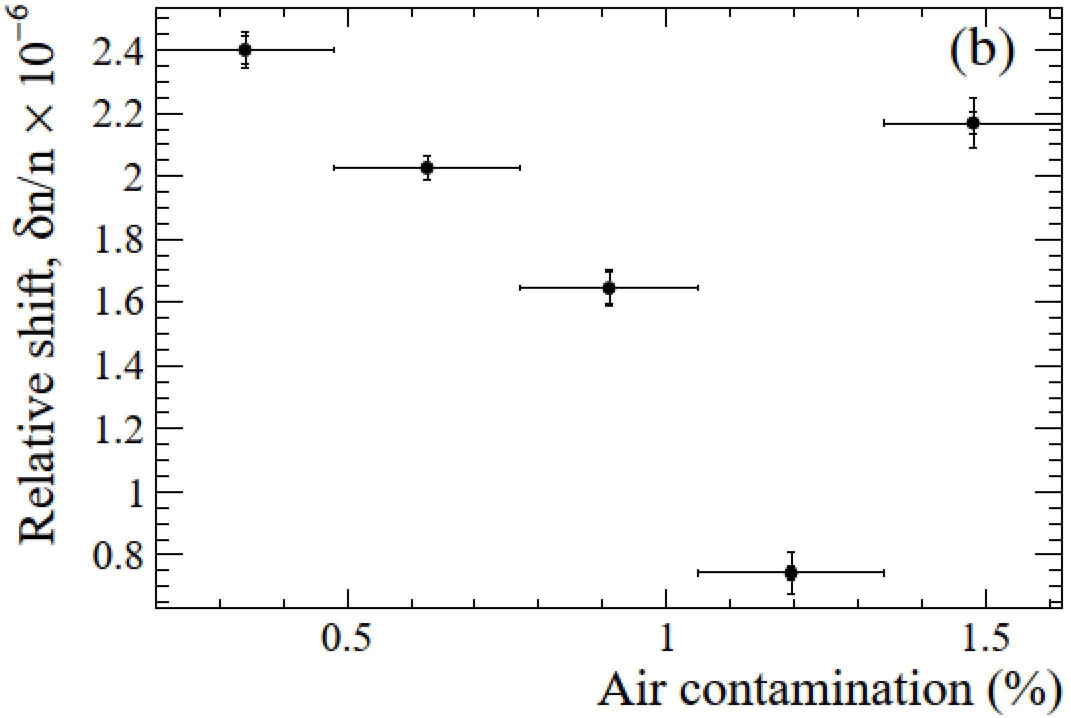
Calibration

Refractive index calibration



Correction factor and air contamination



Residual refractive index bias after correction

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Decays for PID calibration

Identified without RICH information

Species	Low momentum	High momentum
$e^{\pm}$	$B^+ \to J/\psi K^+$ with $J/\psi \to e^+e^-$	
$\mu^{\pm}$	$B^+ \to J/\psi K^+$ with $J/\psi \to \mu^+\mu^-$	$J/\psi \to \mu^+\mu^-$
$\pi^{\pm}$	$K^0_S \to \pi^+\pi^-$	$D^{*+} \to D^0\pi^+$ with $D^0 \to K^-\pi^+$
$K^{\pm}$	$D^+_s \to \phi\pi^+$ with $\phi \to K^+K^-$	$D^{*+} \to D^0\pi^+$ with $D^0 \to K^-\pi^+$
p, $\overline{p}$	$\Lambda^0 \to p\pi^-$	$\Lambda^0 \to p\pi^-$; $\Lambda^+_c \to pK^-\pi^+$

EPJ Techn Instrum 6, 1 (2019). https://doi.org/10.1140/epjti/s40485-019-0050-z

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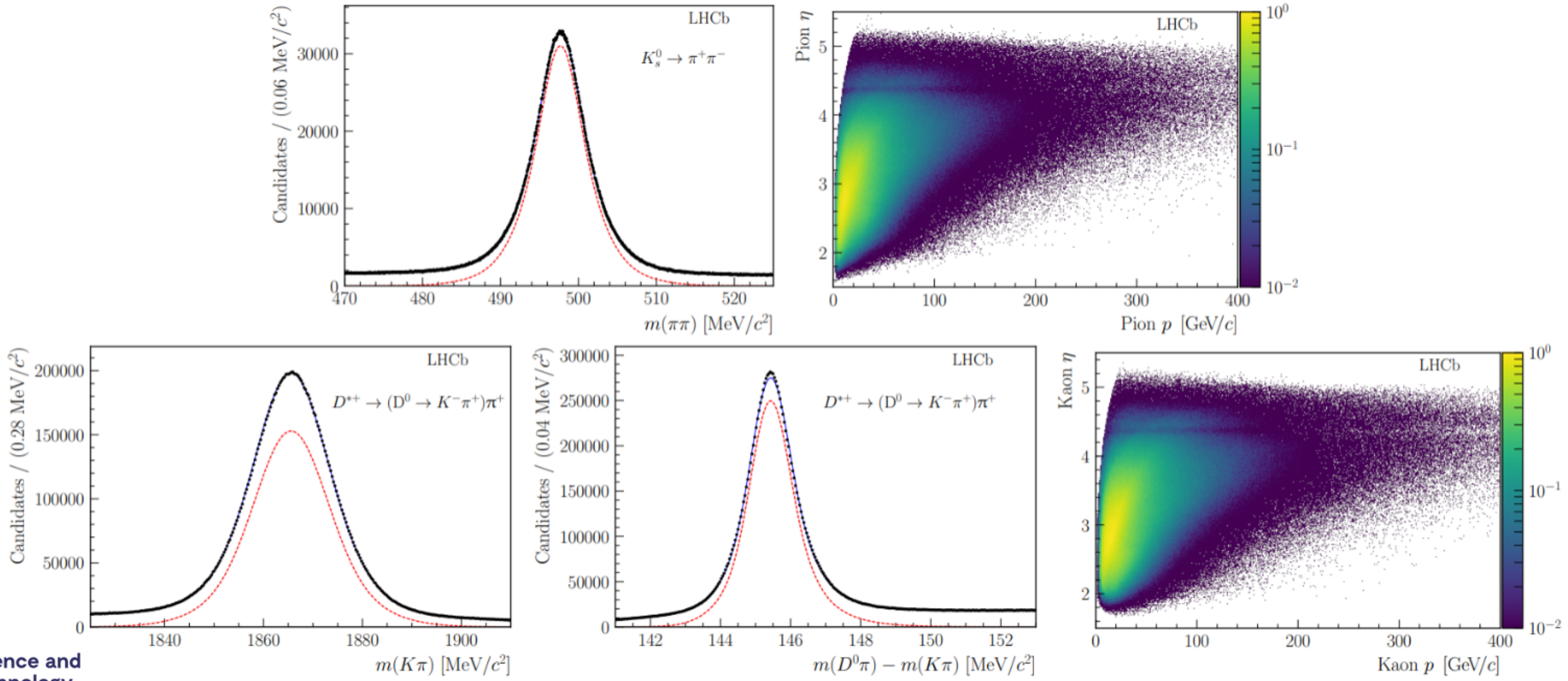
Kinematic range (K, π)



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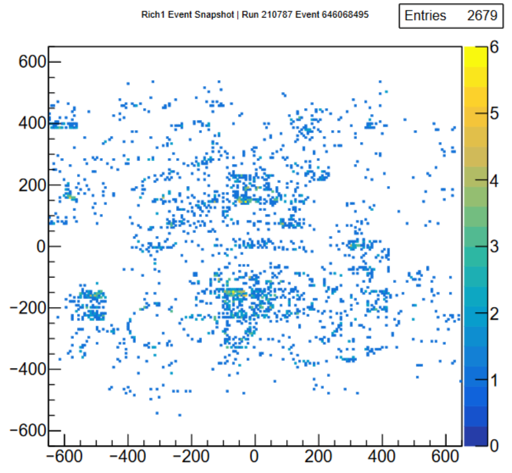
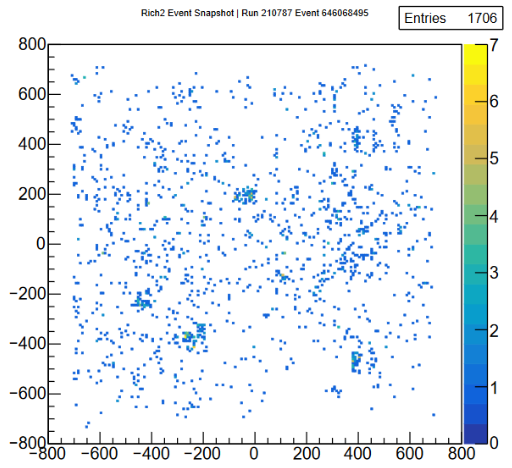
PID performance

Global likelihood PID method

- In the busy LHC environment, most of the “background” to the identification of a given track comes from signals of other tracks in the event
  - → make a global optimisation of the mass hypotheses
- For each track in the event, for a given mass hypothesis, determine the expected distribution of Cherenkov photons on the detector plane using the knowledge of the geometry of the detector and its optical properties
- Repeat for all the tracks in the event
- From the photon distribution on the detector plane calculate the probability that a signal would be seen in each pixel of the detector from all tracks
- Compare this with the observed set of photoelectron signal on the pixels and calculate a likelihood
- Repeat the above, changing the set of mass hypothesis of the tracks to find the set of mass hypotheses which maximize the likelihood





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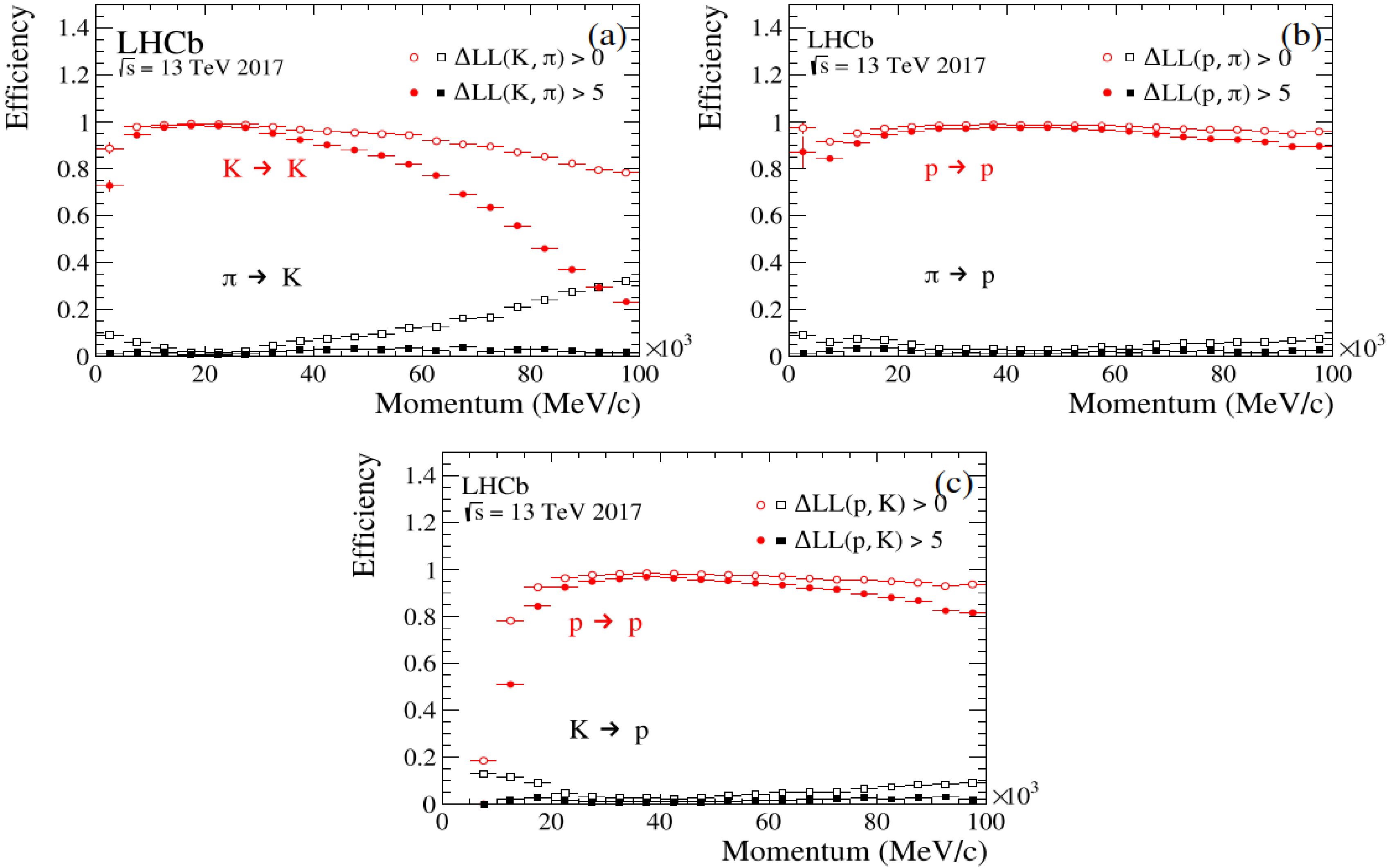
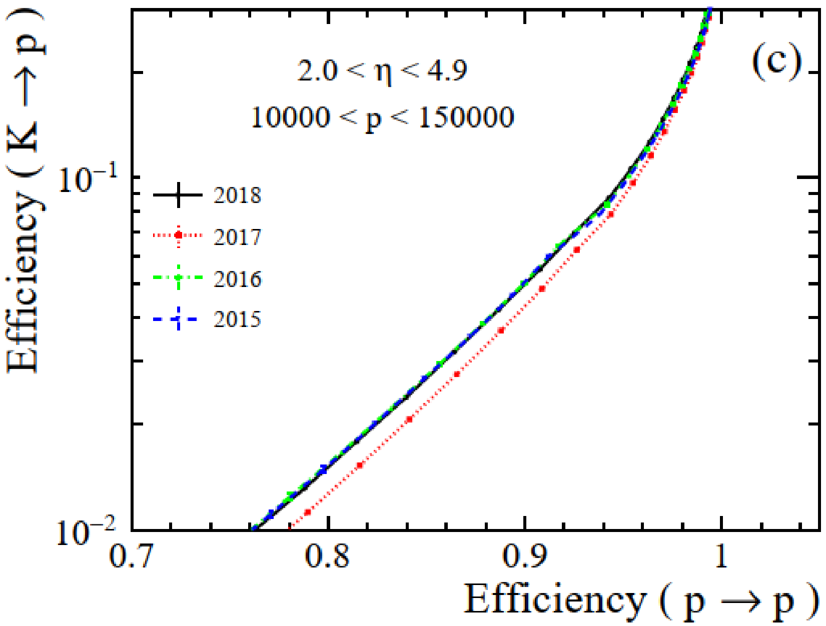
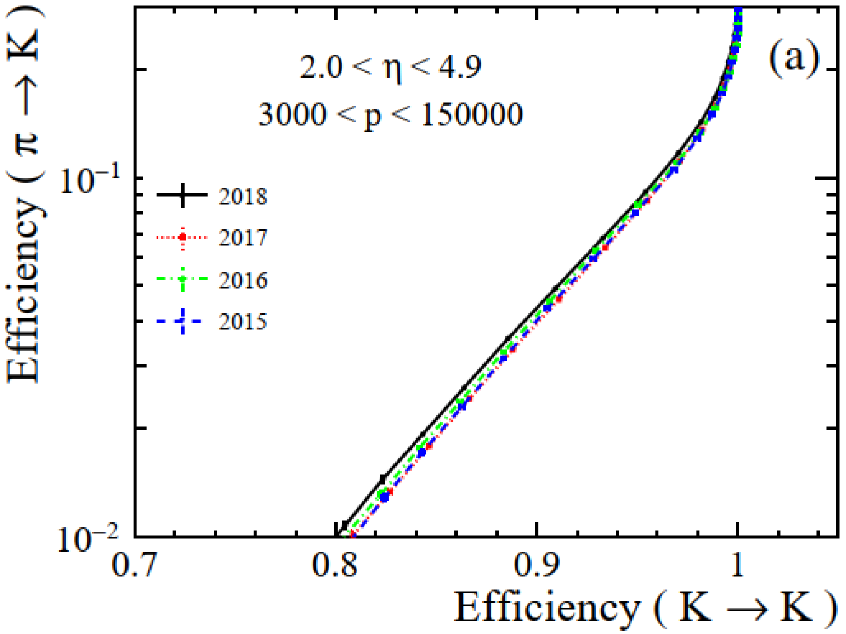
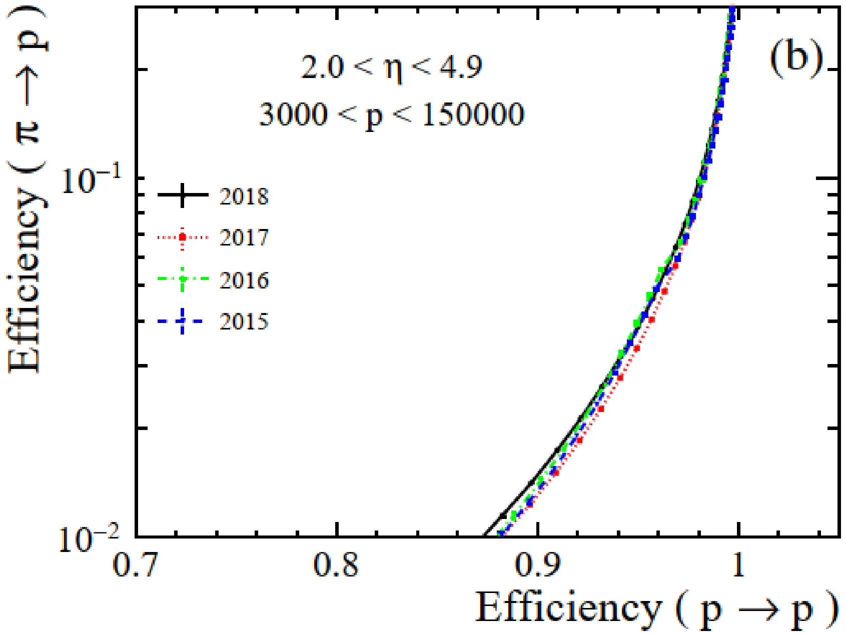
PID performance (2017)



PID stability







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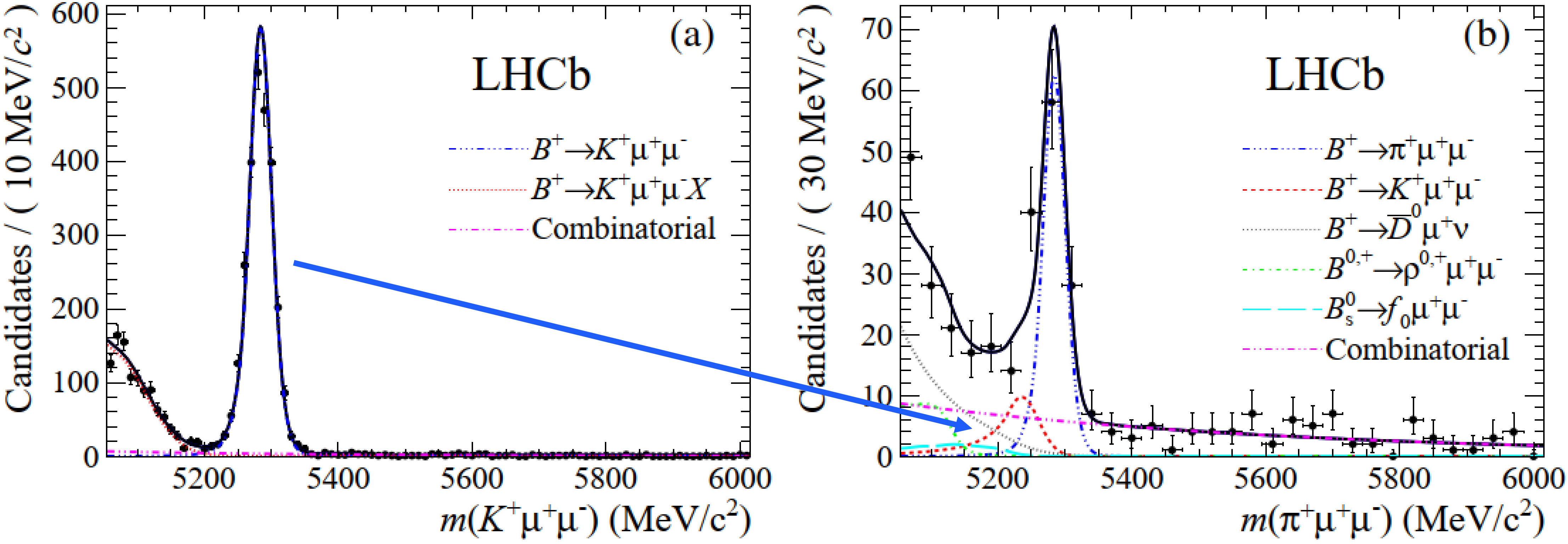
Physics impact of hadron PID



First measurement of the differential branching fraction and CP asymmetry of the $B\pm \to \pi\pm\ \mu+\ \mu-$ decay, JHEP 10 (2015) 034 [arXiv:1509.00414]

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Summary

- The data from years 2016 to 2018 have been analysed leading to a better understanding of the detectors and knowledge towards future designs
- The original LHCb RICH detectors have been replaced with the new upgraded versions
  - Brand new RICH 1, new photon detectors and new electronics everywhere
- This is an opportunity to celebrate the success of the original design showing the exceptional performance and stability in a difficult hadron environment

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Thank you

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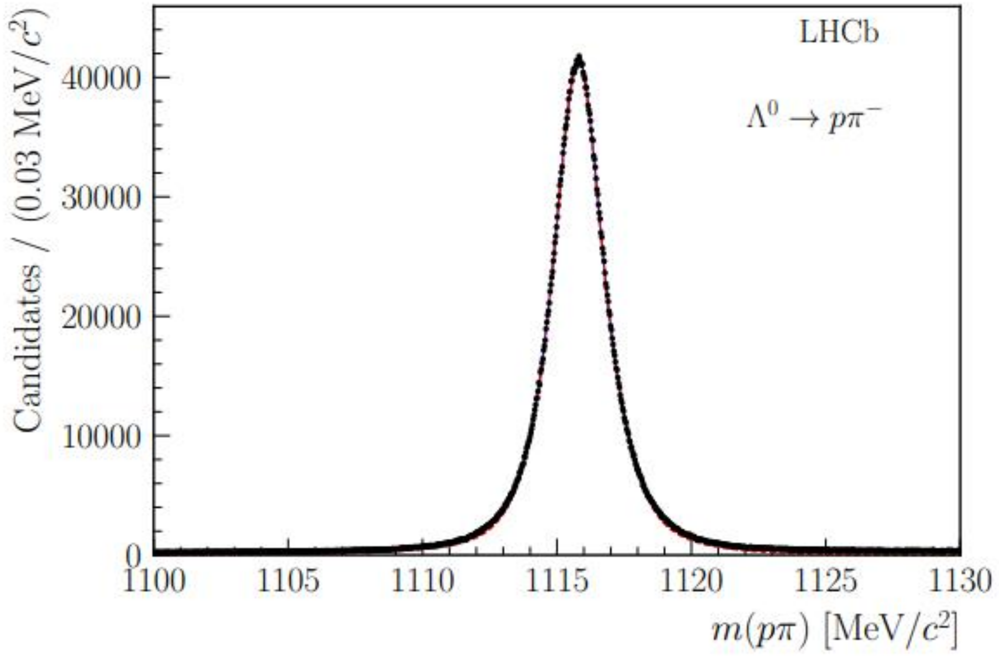
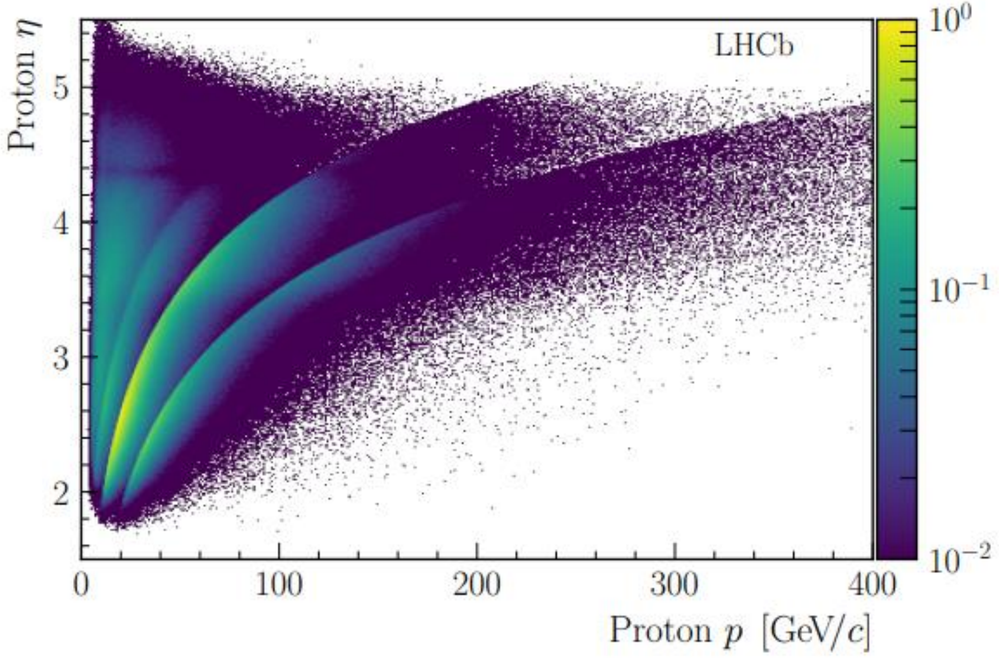
Kinematic range (p)





N_{pe} from Run 1 and simulation

	N_{pe} from data		N_{pe} from simulation	
Radiator	tagged $D^0 \to K^-\pi^+$	pp→ pp $\mu^+\mu^-$	Calculated N_{pe}	true N_{pe}
Aerogel	5.0 ± 3.0	4.3 ± 0.9	8.0 ± 0.6	6.8 ± 0.3
C_4F_{10}	20.4 ± 0.1	24.5 ± 0.3	28.3 ± 0.6	29.5 ± 0.5
CF_4	15.8 ± 0.1	17.6 ± 0.2	22.7 ± 0.6	23.3 ± 0.5

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