2nd Workshop on Probing Strangeness in Hard Processes

RICH Technology and the LHCb experience

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The Ring Imaging Cherenkov technology

Ring Imaging CHerenkov detectors are the most adequate to satisfy a large spectrum of physics applications for Particle Identification. The technology choices are made by considering:

- Kind of physics measurements
- Momentum range to be covered
- Machine environments

    Particle density in the final state, operation frequency ,…..

⇩

geometry and technologies choices to achieve a given angular resolution $\sigma(\theta_C)$

⮡ keep all the contributions to the resolution under control during the whole lifetime of the experiment

A long list of applications of RICH detectors

Hadronic environment
- ALICE
- LHCb
- PANDA
- NA62
- COMPASS

e+e- environment
- BaBar, BELLE
- BELLE upgrade

Space experiments (on satellite and baloon)
- AMS (measures flux of charged particles and light nuclei)
- CREAM

Underground
- ANTARES, NESTOR, NEMO ,
- KM3net, AMANDA,ICECUBE

Nuclear physics
- ALICE
- JLAB

To measure the Čherenkov angle θ_C

Main contributions to angular resolution $\sigma(\theta_C)$ from :

Chromaticity N_γ multiplicity	**Radiator** (n (λ), thickness, transparency…)
$N_{p.e.}$ molteplicity Spatial localization	**Photon detection** (QE, photon collection efficiency,pixel size,…)
Emission point Photon path	**Geometry, optics** (Proximity focus, focussed geometry,…)
Tracking Multiple scattering Decays,interactions,..	**"External" error**

Čherenkov detectors performance

The angular resolution per photon:

$$\sigma(\theta_c) = \sqrt{\sigma(\theta_{rad})^2 + \sigma(\theta_{PD})^2 + \sigma(\theta_{geom})^2 + \sigma(\theta_{tr})^2}$$

$$\sigma_{ring}(\theta_C) = \frac{\sigma(\theta_C)}{\sqrt{N_{pe}}}$$

And the separating power:

$$N_\sigma \approx \frac{(m_1^2 - m_2^2)}{(2 p^2 \sqrt{n^2 - 1}\, \sigma(\theta_c))}$$

The number of photo-electrons N_{pe}:

$$N_{pe} = 370 L \int \varepsilon \sin^2 \theta_c dE = L N_0 \sin^2 \theta_c$$

Usually N_o between ~ 20 and 100

General rule: **minimize** $\sigma(\theta_c)$
maximize N_{pe}

RICH detectors by angular resolution

$\sigma(\theta_C) \approx$ O(10 mrad)

Ex: ALICE, BELLE, BELLE upgrade,JLAB,…..

BaBar and HERMES (closed)

differ by machine environment, particle density,
BUT momentum range similar

$\sigma(\theta_C) \approx$ O(1 mrad)

Ex.: COMPASS, LHCb, NA62

Examples of RICH detectors with $\sigma(\theta_c) \approx O(1\ \text{mrad})$

★ **LHCb** operate **at LHC** → more detailed description

★ **NA62** starting to operate end of 2014 **at SPS**

Physics aims: measure $BR(K^+ \to \pi^+ \nu\nu)$

Dominant Background : $K^+ \to \mu^+ \nu$ ($K_{\mu 2}$ largest BR: 63.4%)

3σ π-μ separation (15-35 GeV/c)

Need ~10^{-12} rejection factor of which from Particle ID: 10^{-2}

(Kinematics: 10^{-5} and Muon Veto: 10^{-5})

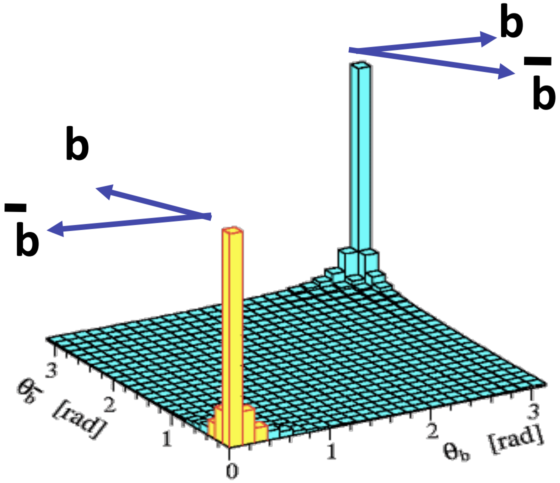
The LHCb experiment

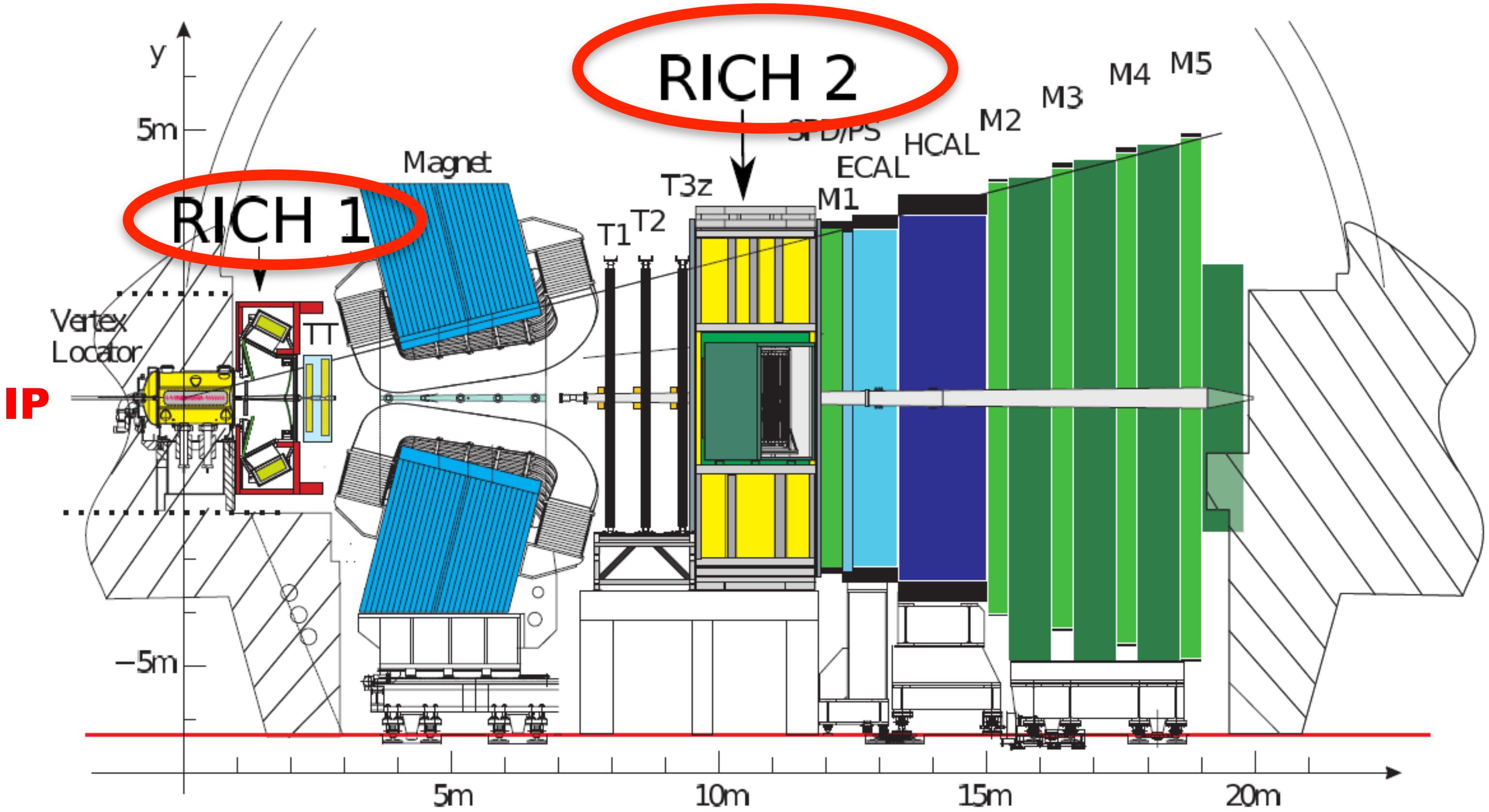
- Main physics measurements: *b* and *c* rare decays and CP asymmetries
- Momentum range of particles: B hadrons produced with <p> ≈ 70 GeV
  ⇨ decay products from 2 to 100 GeV
- Hadron machine environment (LHC)
  high particle density in the final state
  Run at 7 and 8 TeV , at 13 TeV in 2015

The LHCb experiment

The most important features:

- Efficient trigger for B decay topologies
- **Excellent particle identification**
- Precison vertexing (good decay time resolution)
- Good mass resolution





Acceptance:
300 mrad horiztl
250 mrad vertical

C. Matteuzzi

The RICH of LHCb

Physics aims:

separate K /π/p in the range 2-100 GeV/c to reconstruct rare (and less rare) B and D decays

(ex. $B \rightarrow \mu\mu$, $B \rightarrow KK$ and $K\pi$, $B \rightarrow D_s K$ and $D_s \pi$, …)

Environment:

At LHC , very high particle density, high background

Works at 1 MHz ➔ **upgrade in preparation for 2018/2019**

Must reject pion (the most abundant particle type) < the percent level

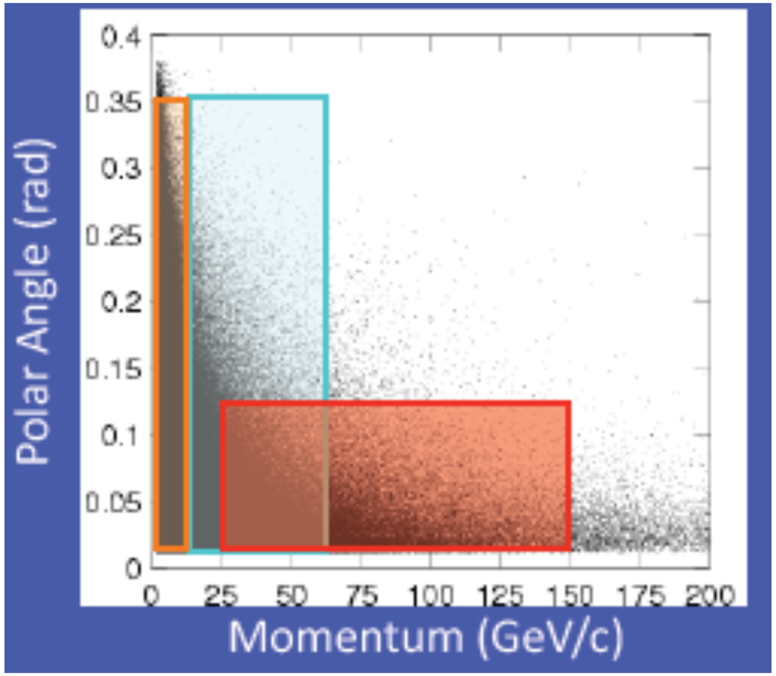
Geometry:

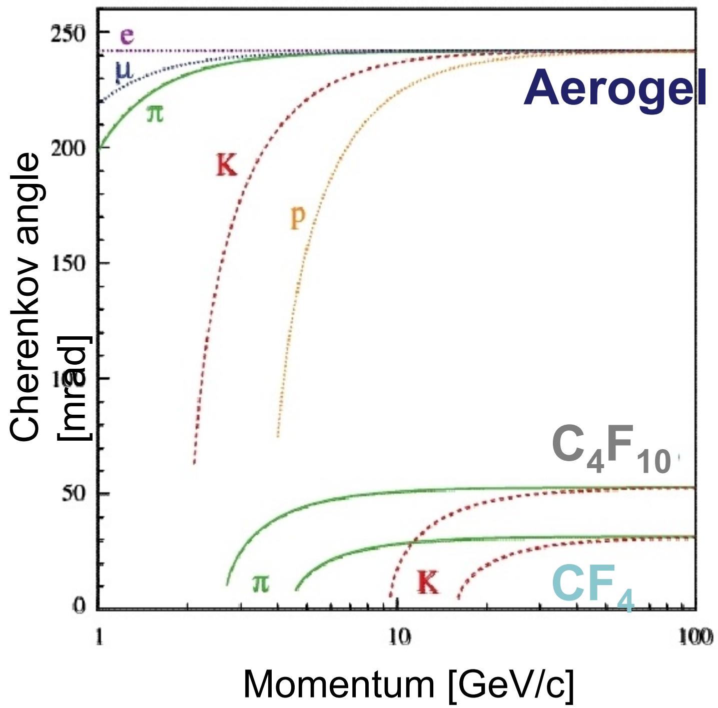
focussed, 2 RICHes with 3 different radiators

The RICH of LHCb: *the radiators*

Radiators: 5 cm aerogel n = 1.030 @ 400 nm
95 cm C_4F_{10} n=1.0014 @ 400 nm } **RICH-1**

180 cm CF_4 n=1.0005 @ 400 nm **RICH-2**





The RICH of LHCb : *the geometry*

Focussed geometry

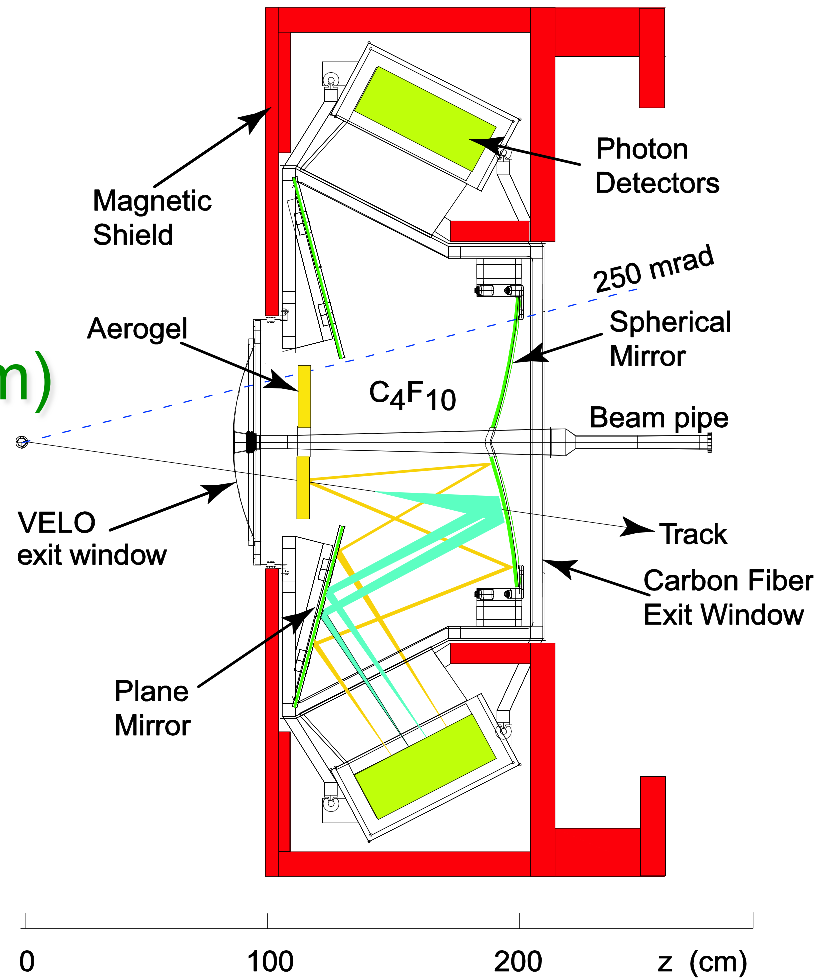
Mirrors :

4 spherical carbon fiber (f= 135 cm)
16 flat *(R>600m)* in RICH1

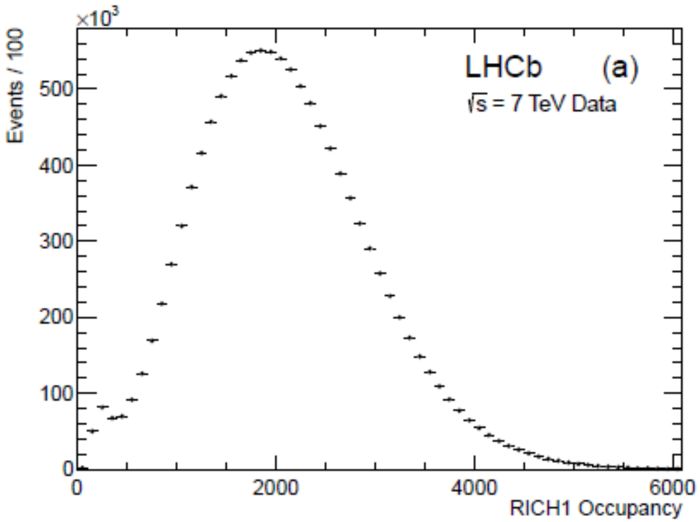
52 spherical (glass) (f= 430 cm)
40 flat *(R=80 m)* in RICH2

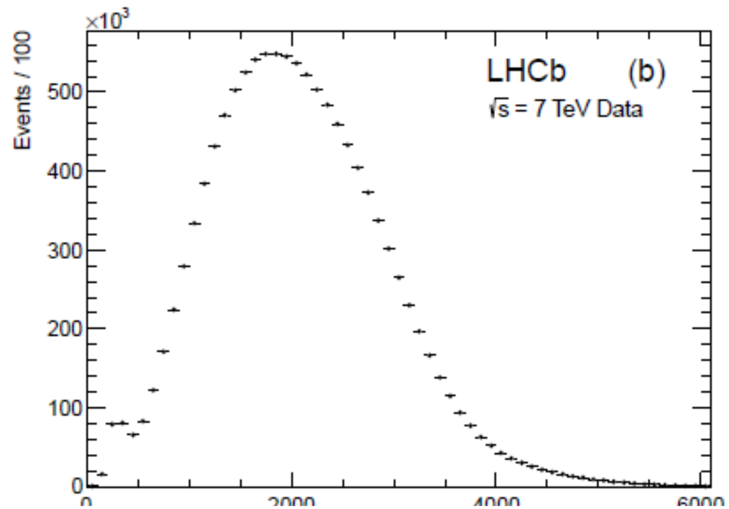
Photodetectors:

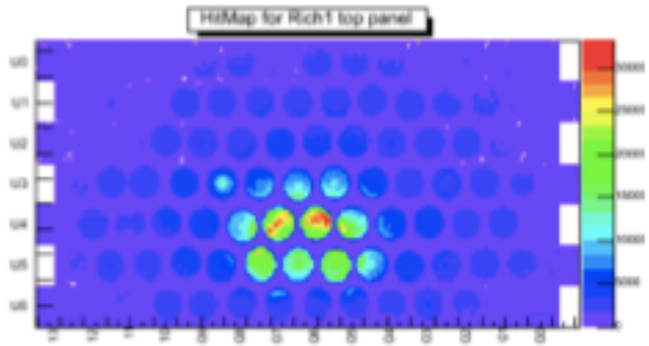
484 Hybrid Photon detectors (HPD) granularity 2.5 mm at the photocathode level (demagnification factor ≈ 5)

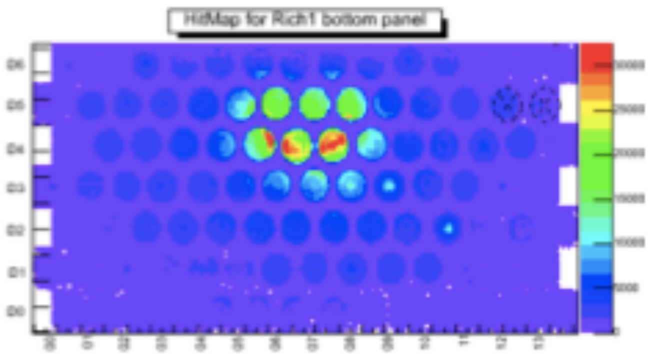


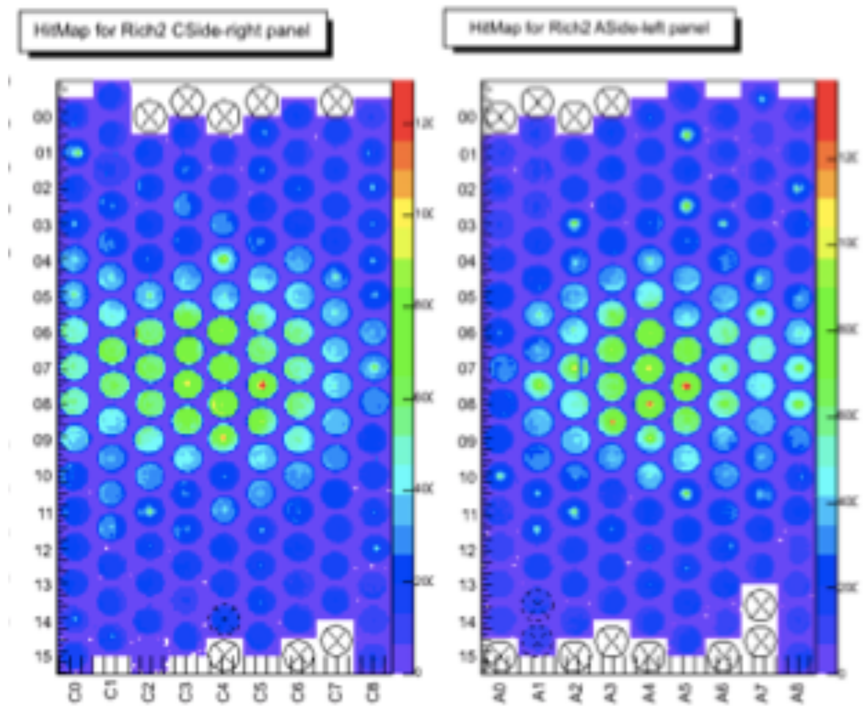
The RICH of LHCb: *the occupancy*











The RICH of LHCb: *the resolution*

To get the designed resolution $\sigma(\theta_C)$ needs to control:

Radiators:

Composition of gas radiators (some air, $N2$, $CO2$ contamination)
gas composition measured by chromotography to calibrate n-1
Control P and T continuously for correcting automatically the density ρ_{gas}

Geometry:

Mirror alignment with data. Down to 0.1 mrad

Spatial precision:

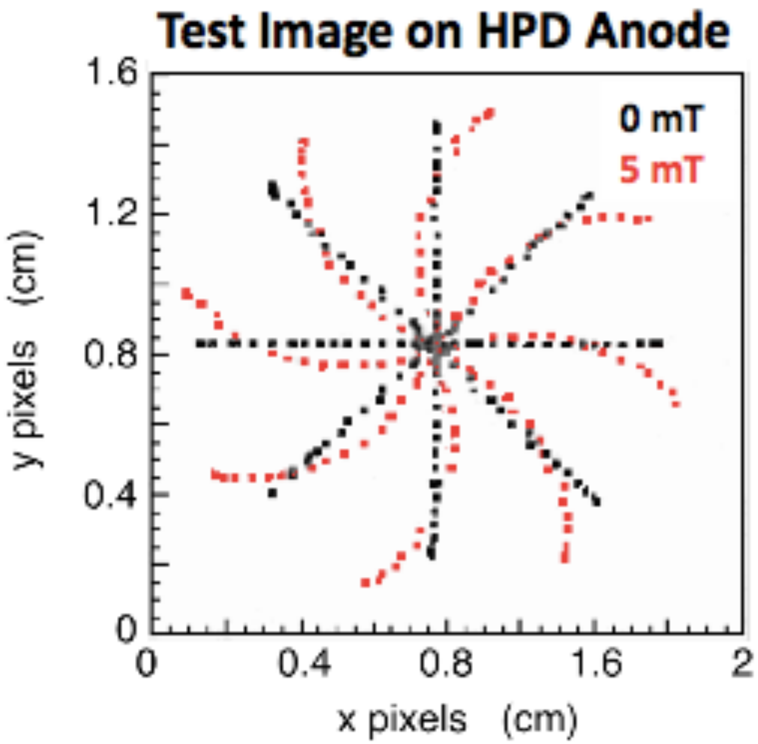
Monitor ageing of PD (HPD)
Corrections for magnetic distorsion
Alignment of HPDs

Tracking:

$\sigma(\theta_C)$ relies on track information also for alignment.

The magnetic field corrections

HPD are sensitive to the magnetic field fringes

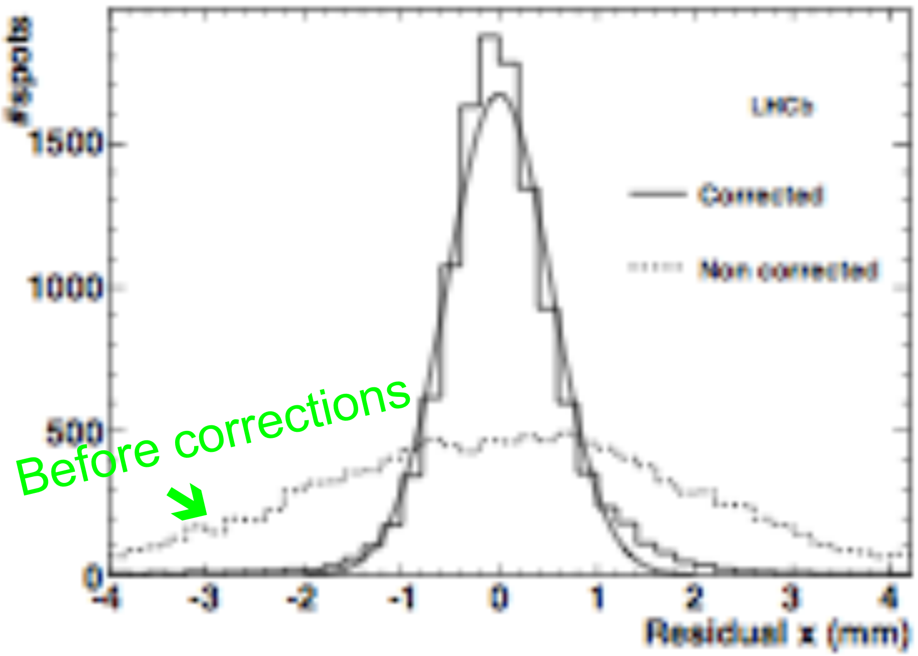


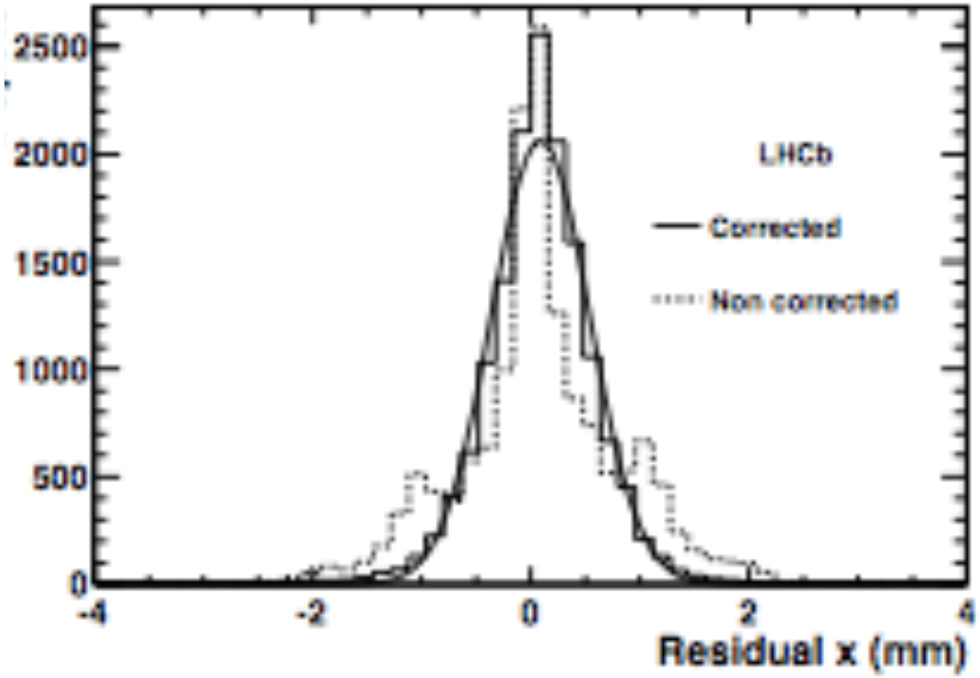
Projection of test pattern with and without magnetic field to extract correction parameters

The magnetic field corrections

Plot the distances from the measured light spot to the test point:

RICH-1 **RICH-2**





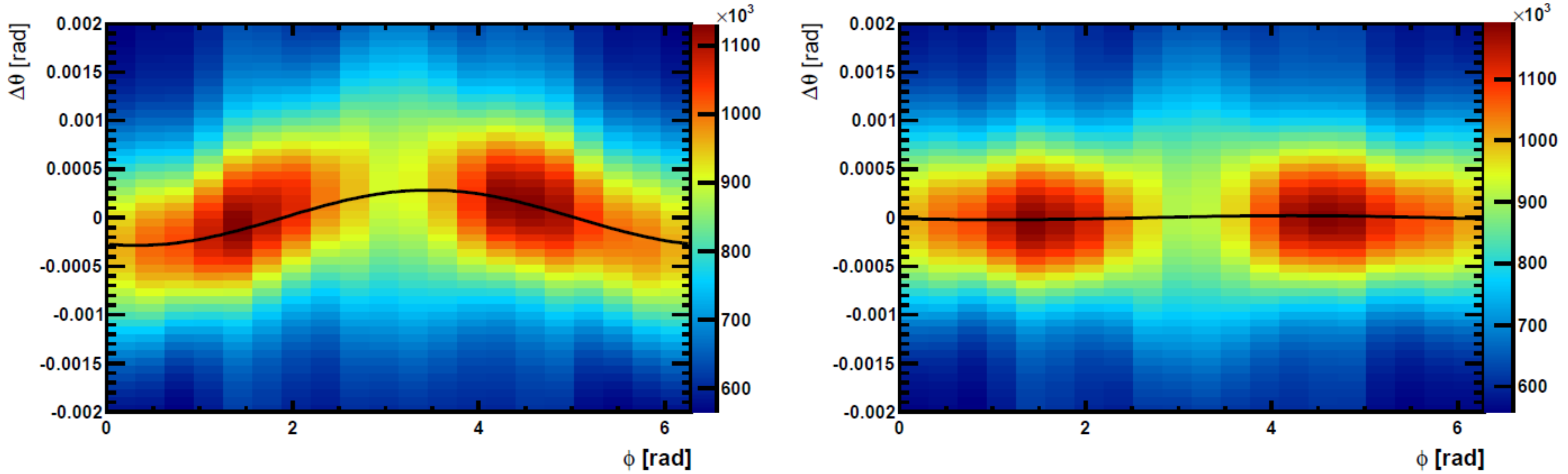
(*same behaviour along y coordinate)*

The alignment

Alignment of many components at different level:
whole detector, detector halves, mirror segments, HPD

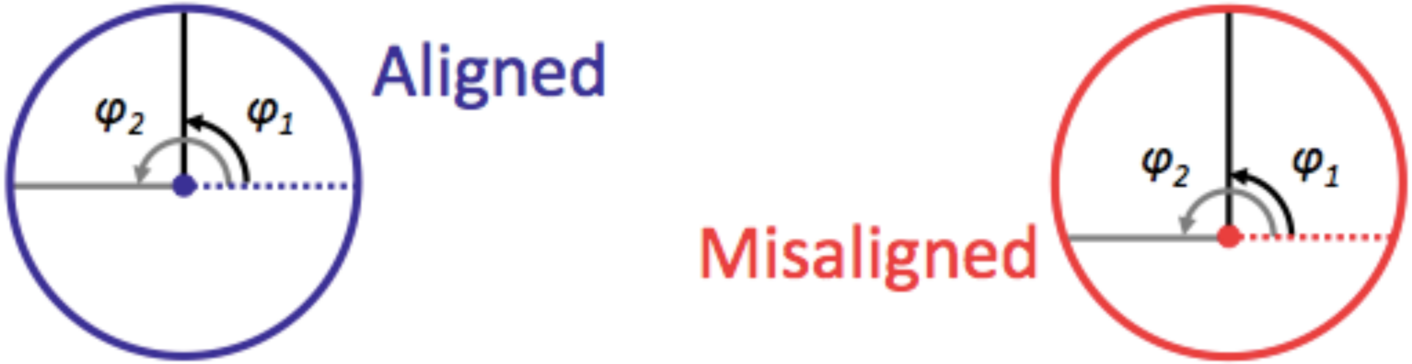
Use reconstructed Cherenkov angle of $\beta = 1$ tracks

Misalignment is observed as a shift of track projection point w.r.t the center of the corresponding Cherenkov ring

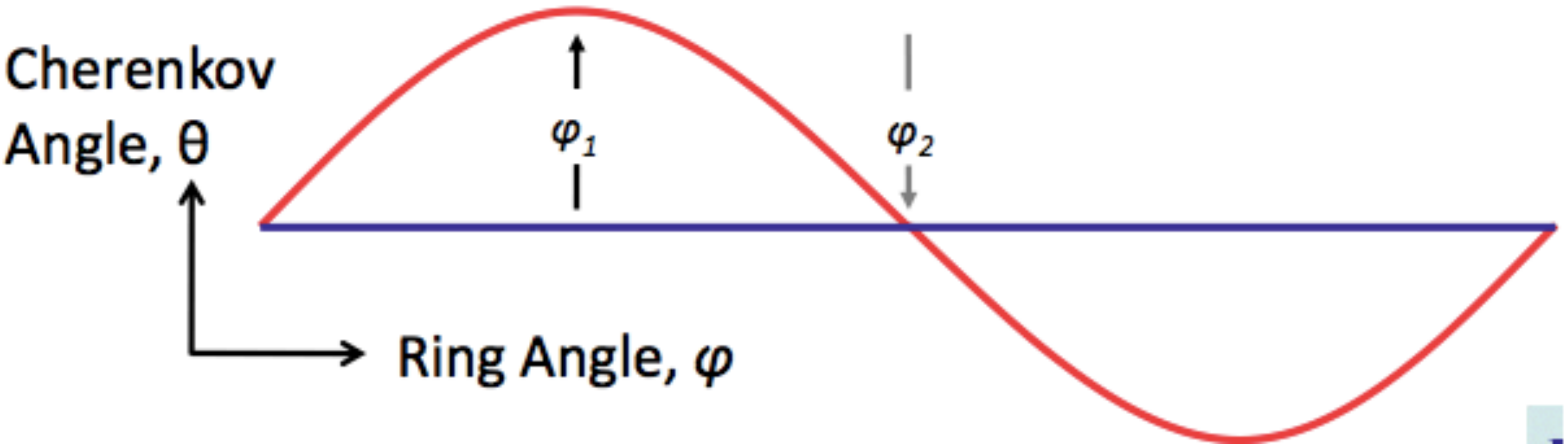


The alignment

Misalignment is observed relative to tracking:

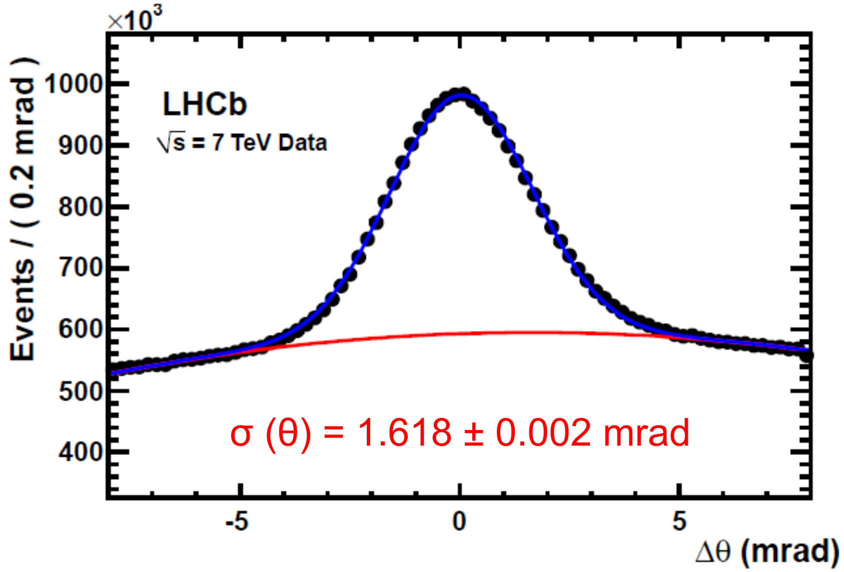


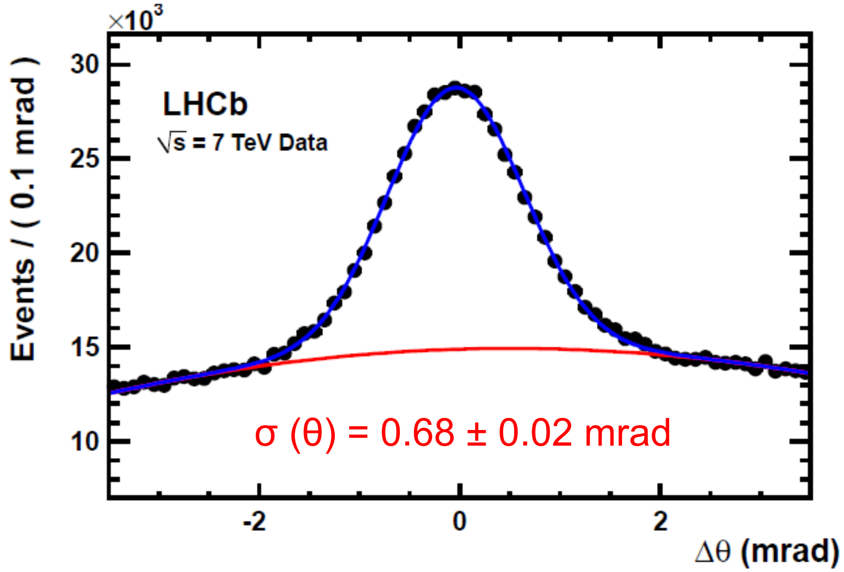
Seen as a distribution $\mathbf{\Delta\theta = A\sin\varphi + B\cos\varphi}$:

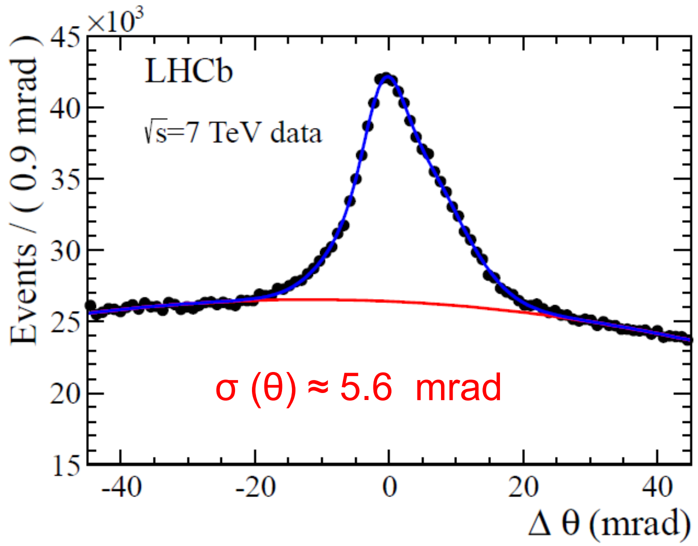


The RICH of LHCb: *the angular resolution*

After all corrections:



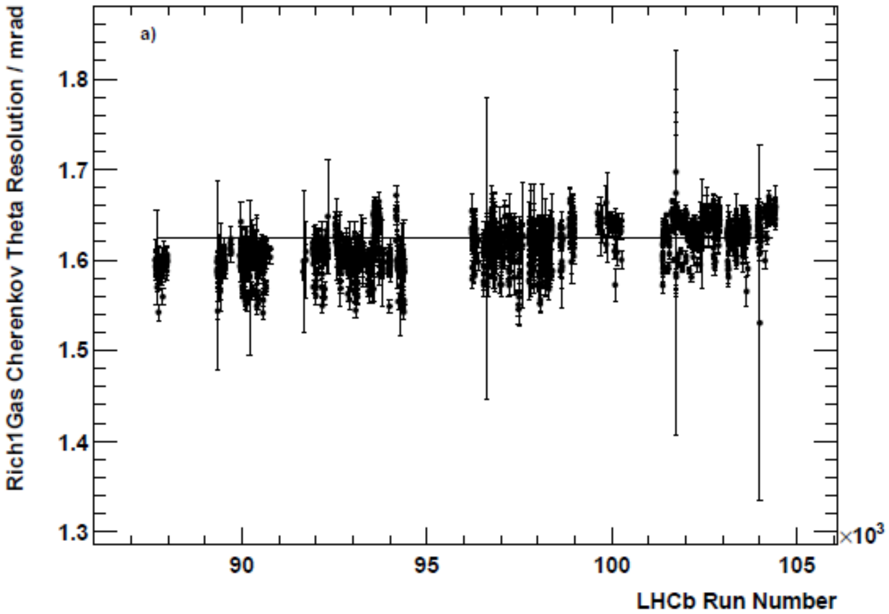




Expected :
2.6 mrad in aerogel
1.52 mrad in C_4F_{10}
0.68 mrad in CF_4

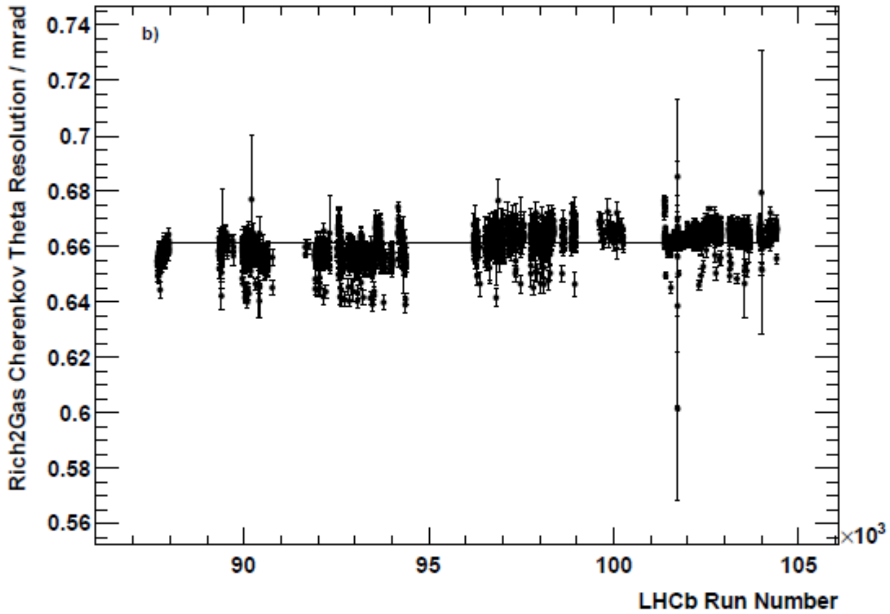
The RICH of LHCb: *the stability*

RICH-1



Time ➔

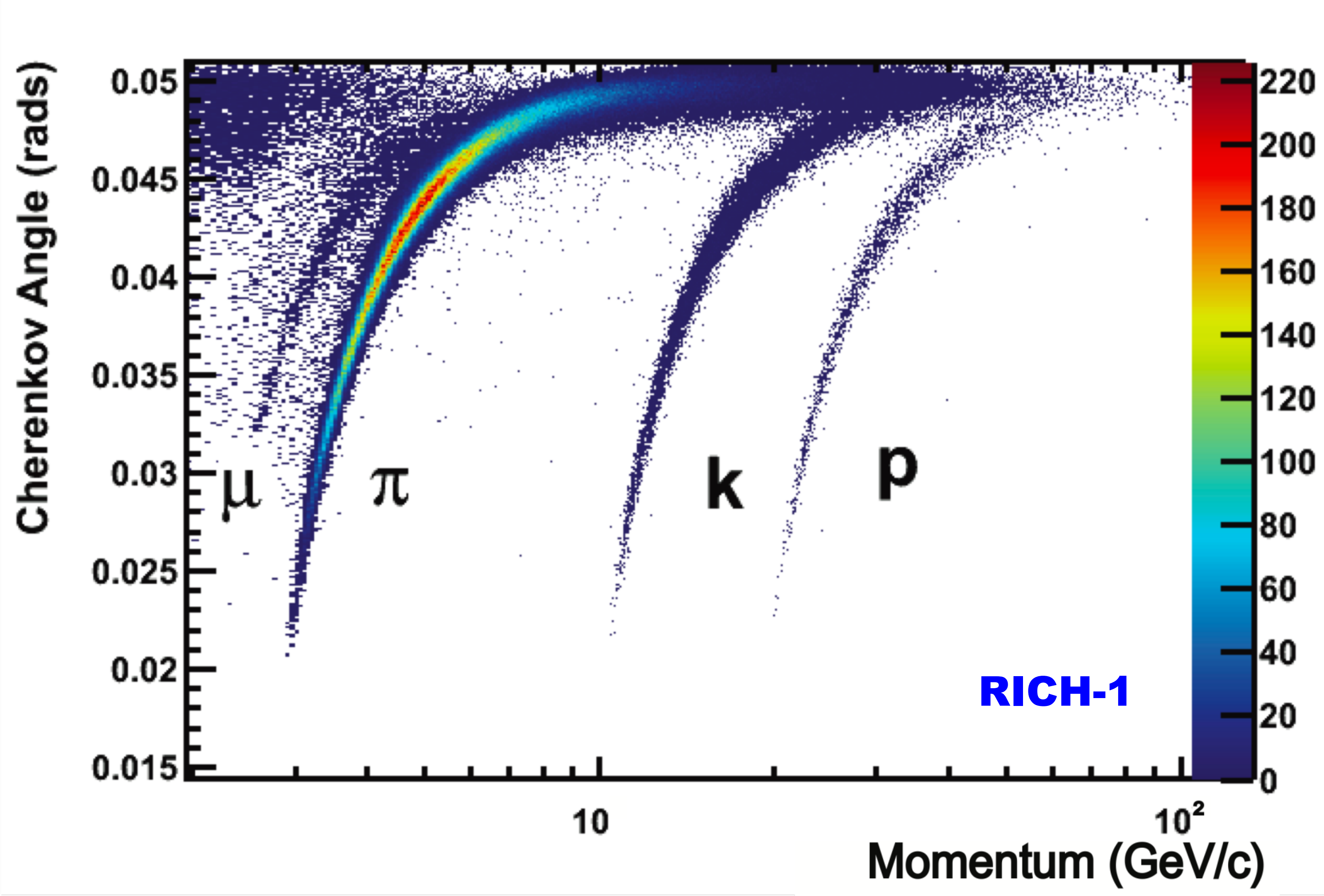
RICH-2



Time ➔

About 8 months period

The RICH of LHCb: *the PID performance*



Methodology

- Use 2 categories of events (in data):

  - ★ Tracks from $D^0 \rightarrow K^-\pi^+$ calibration sample (from the $D^{*+} \rightarrow D^0\pi^+$) with $\beta \approx 1$

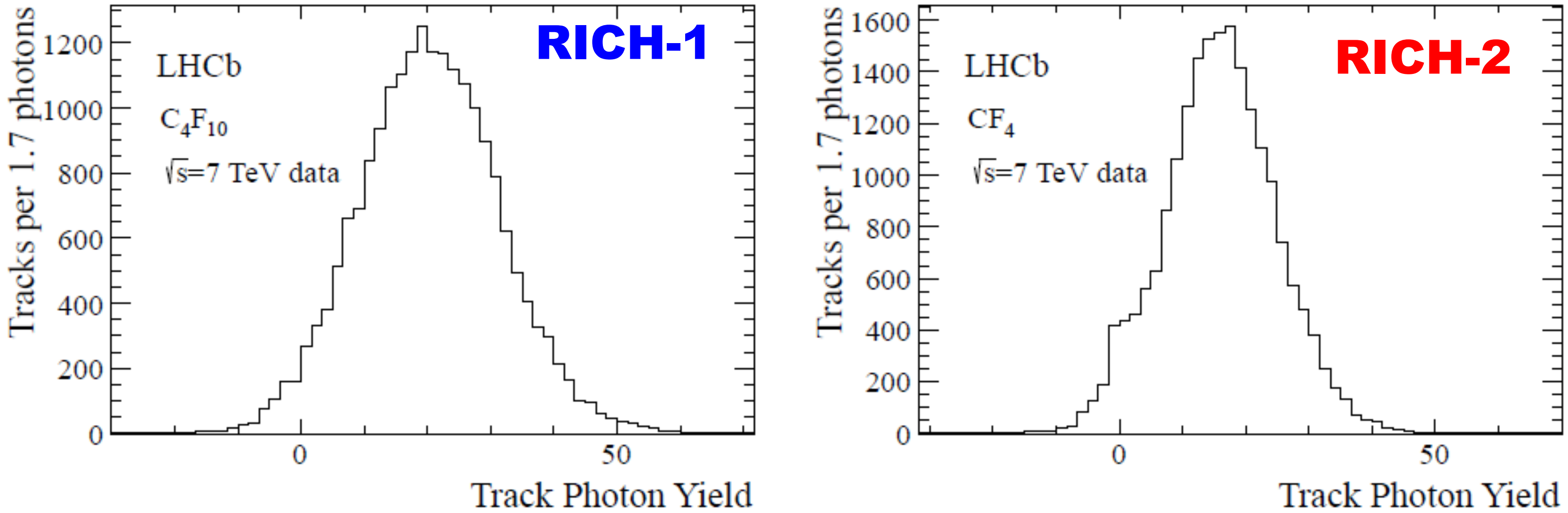
  - ★ Muons from events $pp \rightarrow pp\ \mu^+\mu^-$

- For each selected charged particle track, measure N_{pe} from the hits that lie within a range $\pm 5\sigma$

  → *see figure*

The RICH of LHCb : *photoelectrons counting*

N_{pe} counting based on the mean of the distributions:



	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

Methodology (I)

Construct a global log-likelihood algorithm considering ALL the photons, ALL the tracks and for ALL radiators:

- First step: consider all tracks as a pions
- Second step: change the hypothesis for each track in turn to electron, muon, kaon and proton and recalculate likelihood values for each hypothesis
- Third step: select the combination that gives the larger global likelihood value

Methodology (II)

- The final mass assignments are differences in the log-likelihood values $\Delta \log L$ which give for each track the change in the overall event log-likelihood when that track is changed from the pion hypothesis to each of the e, μ, K, p hypotheses.

The RICH of LHCb: *the PID performance*

To determine Identification probability and mis-identification rate, need PURE SAMPLES of each particle type selected via kinematics cuts alone

Exploit typical decays:

$K^0_S \rightarrow \pi^+\pi^-$

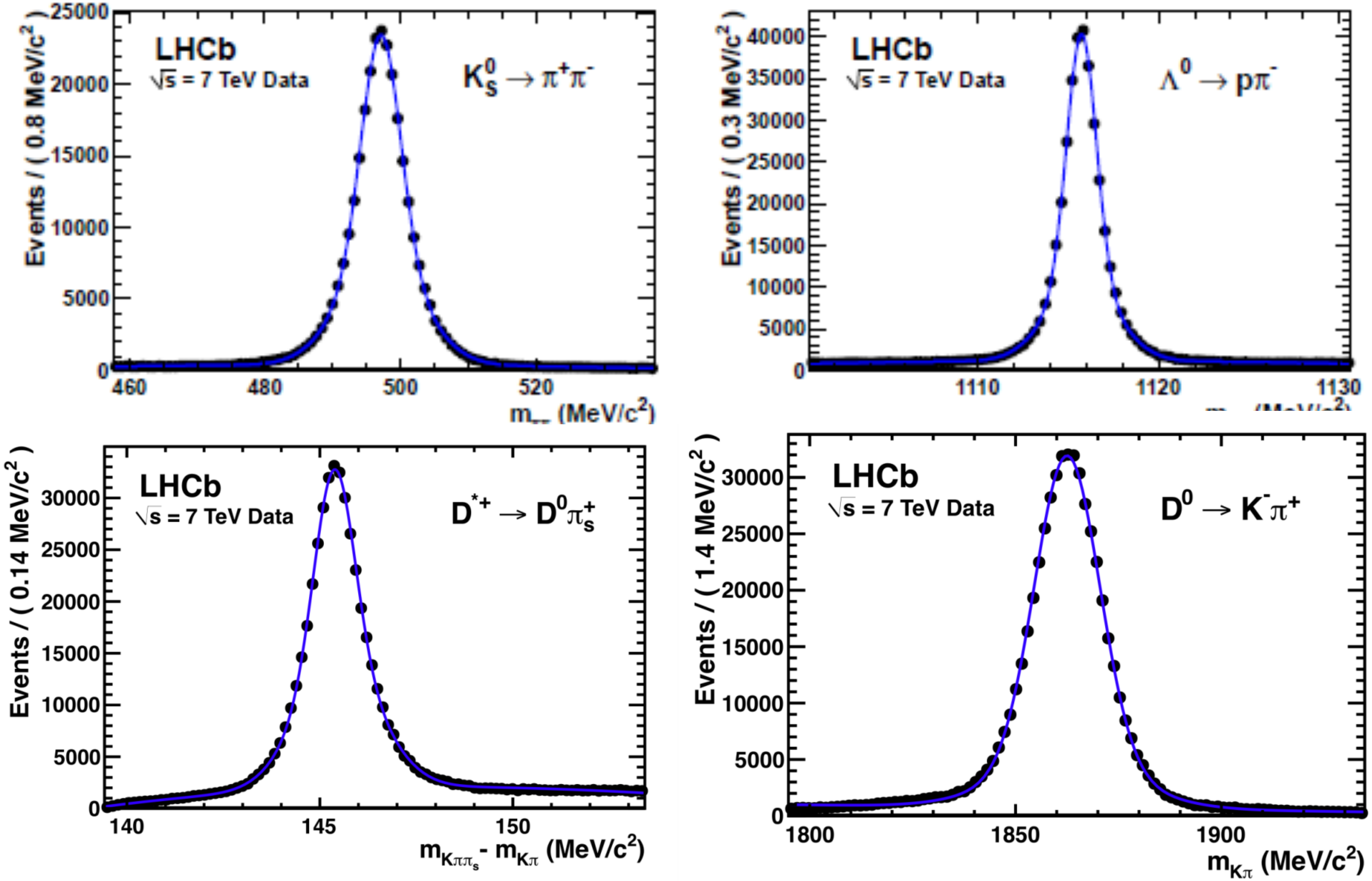
$\Lambda \rightarrow p\pi^-$

$D^{*+} \rightarrow D^0 (K^-\pi^+) \pi^+$

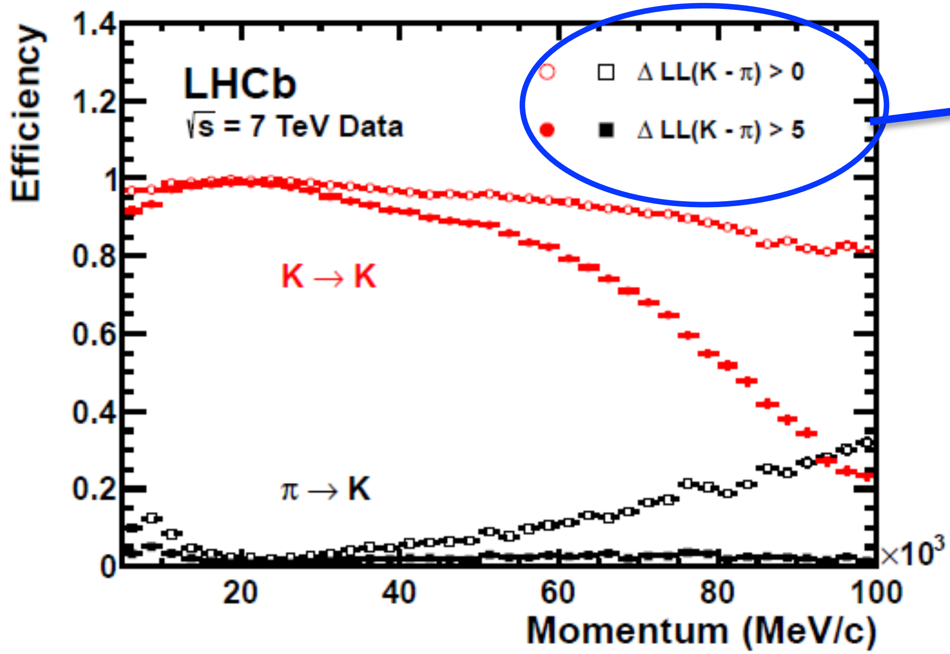
(and their charge conjugates)

Also $\Phi(1020)$ and photon conversion

The RICH of LHCb: *PID performance calibration*



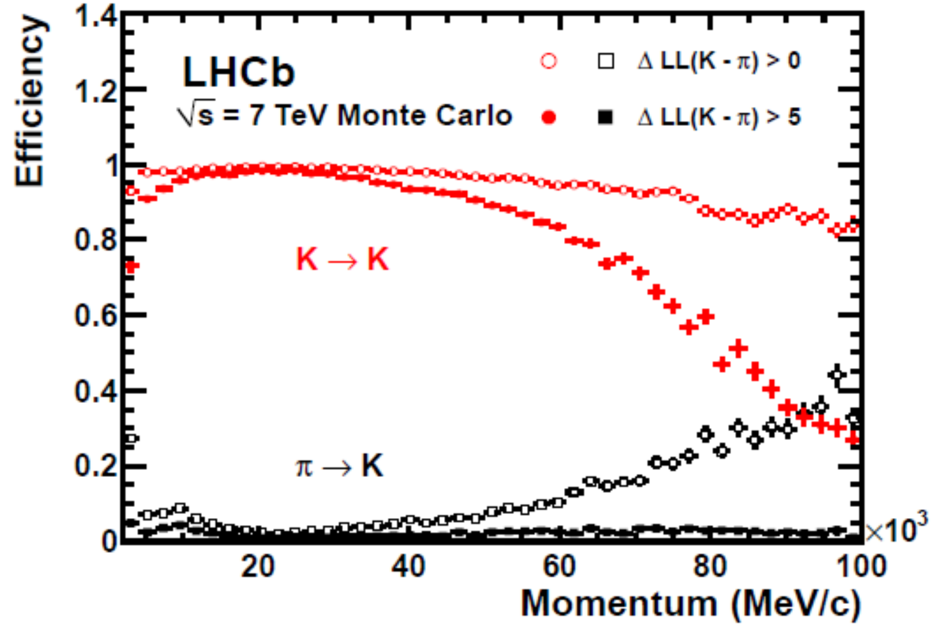
The RICH of LHCb: *PID performance*



Flexibility with ΔLL cut to optimize according to your specific analysis

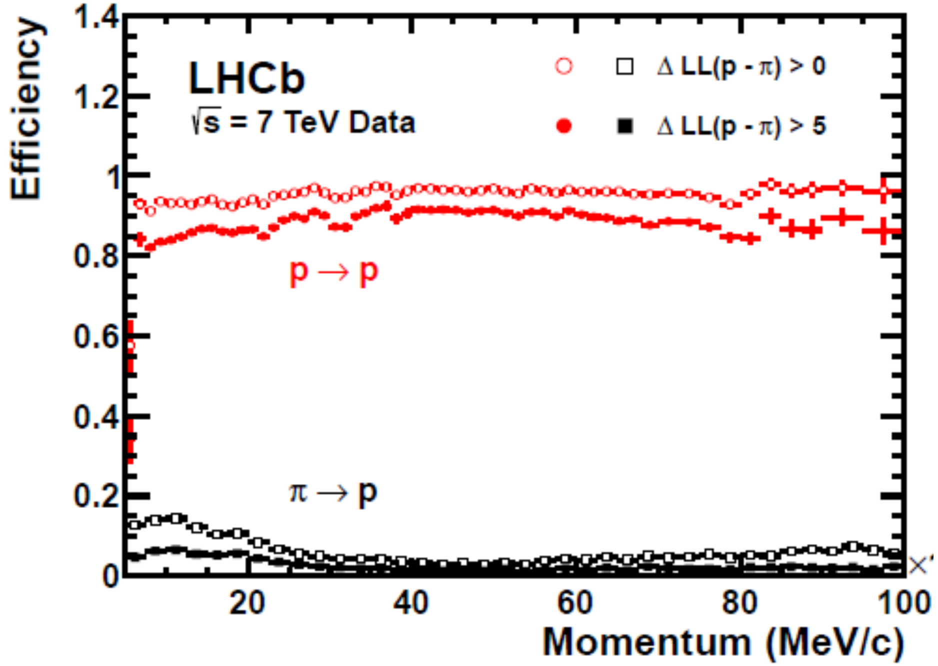
Kaon ID with DATA

and with simulation

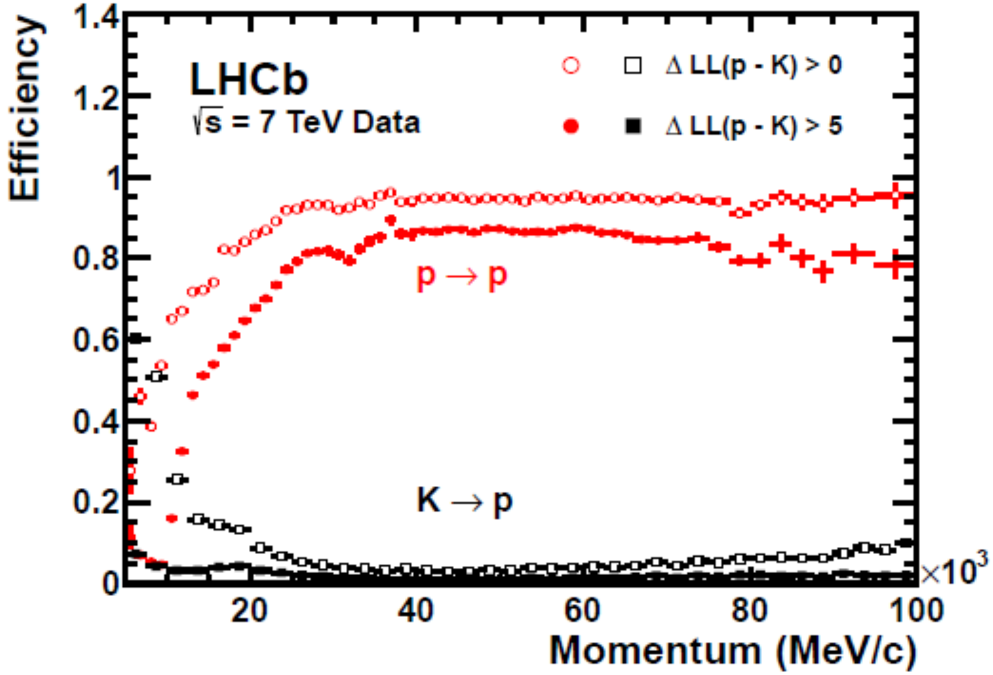


Identification probability and mis-ID for **protons**

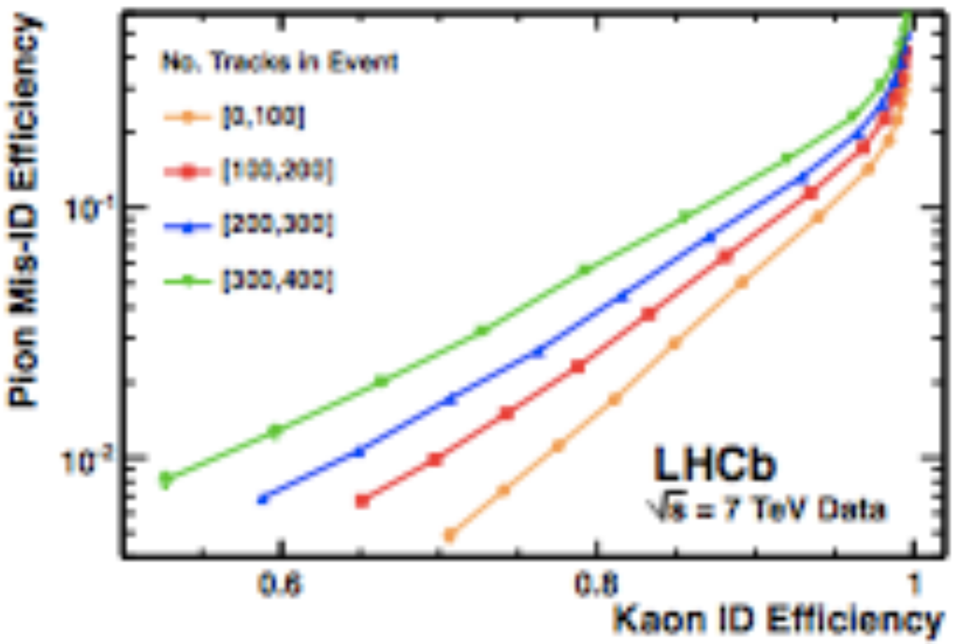
ΔLL(p-π)

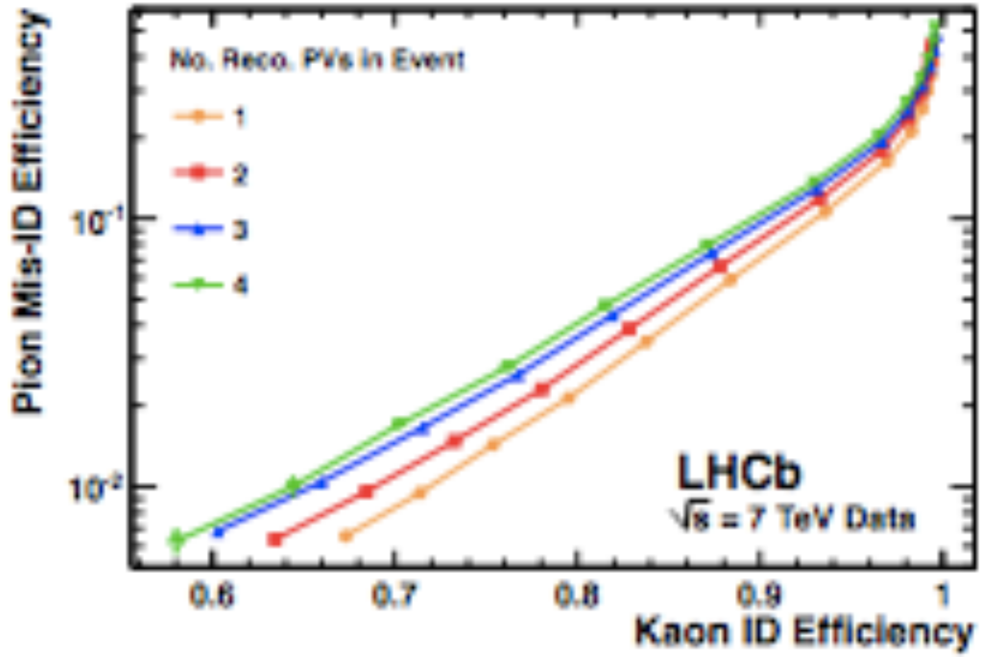


ΔLL(p-K)



Performance depends on track or primary vertices multiplicity

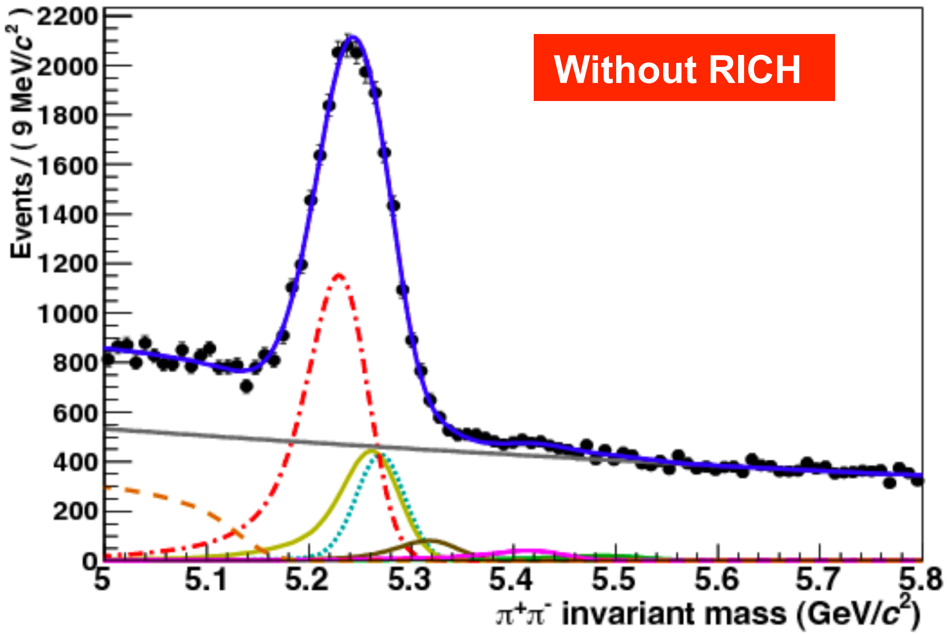


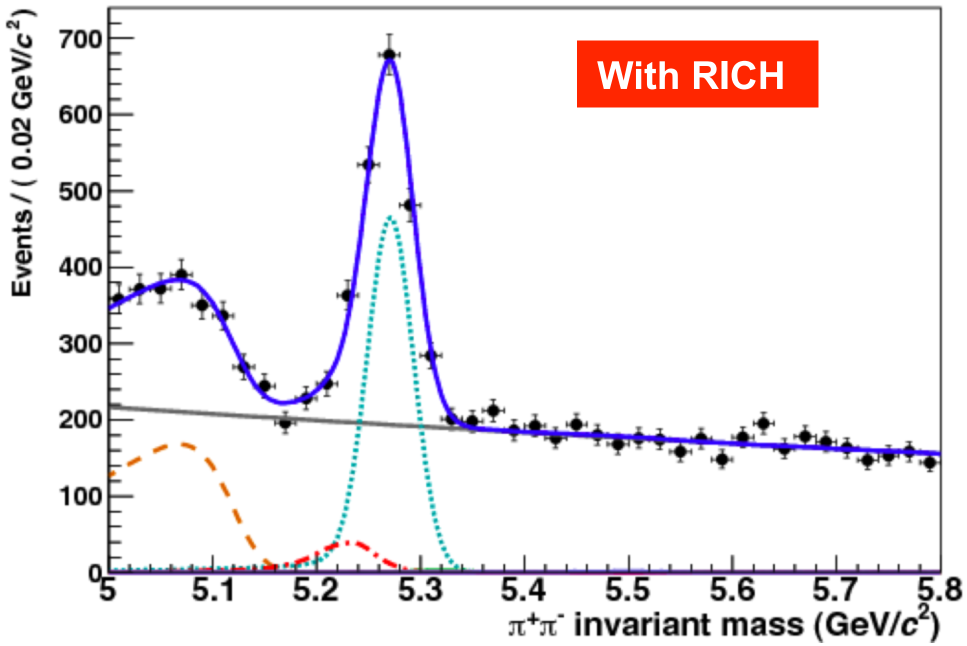


The RICH of LHCb: *the performance*

Most of LHCb analysis use extensively particle identification from RICH for decays and tagging.

An example: study of the decay B→ π+π- . Must separate all the components B→ h+h- where h = π , h= K if wants to measure CP asymmetry.





Signal: $B^0 \rightarrow \pi^+\pi^-$ (tourquoise dotted line)

Other contributions are eliminated ($B^0 \rightarrow K\pi$, $B^0 \rightarrow$ 3–body, $B_s \rightarrow KK$, $B_s \rightarrow K\pi$, $\Lambda_b \rightarrow pK$, $\Lambda_b \rightarrow p\pi$)

Concluding comments

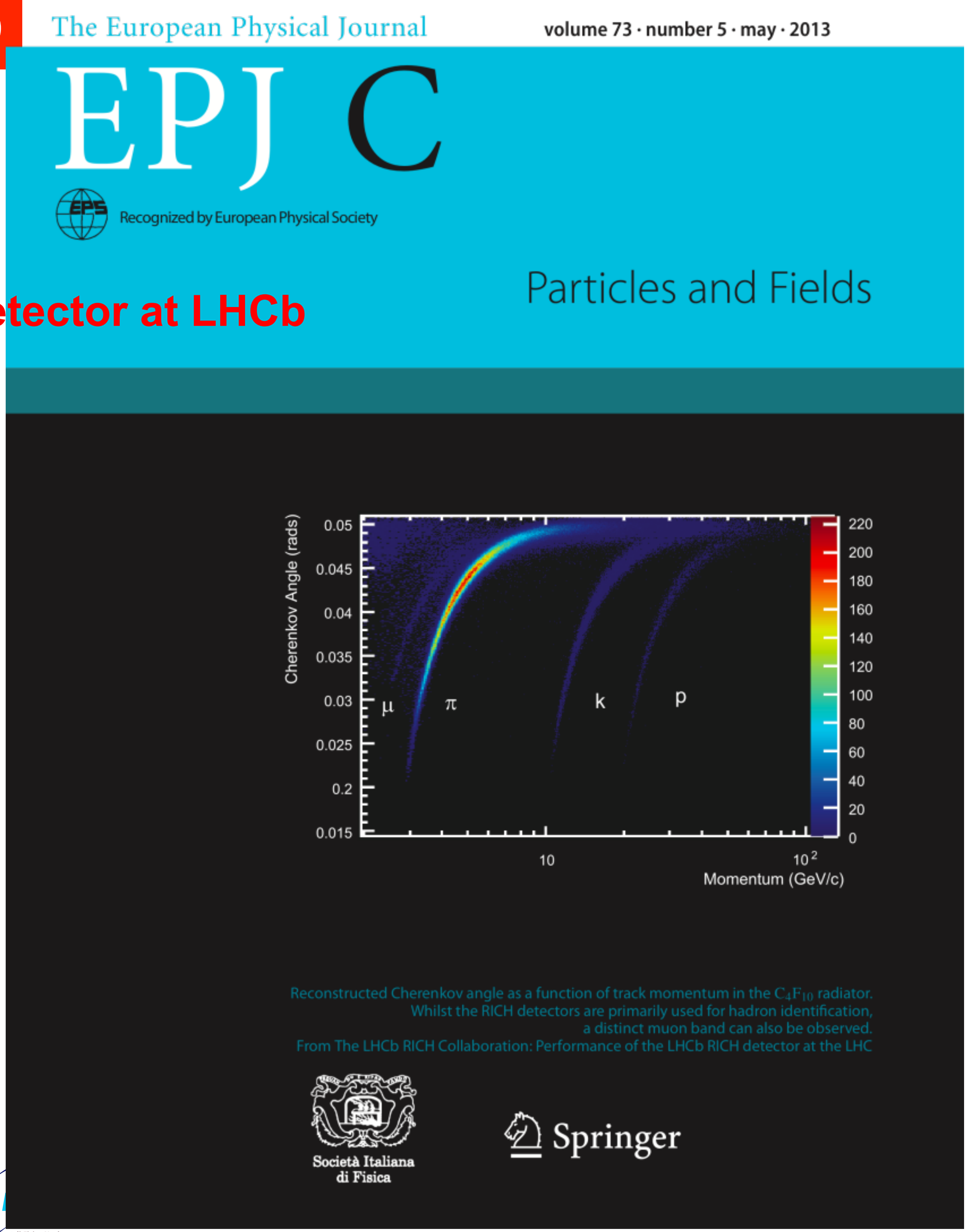
- RICH technique is extremely powerful and widely used for PID in different environments
- Choices of technologies make flexible RICH designs for different applications. Stability is often to be favoured.
- BUT: RICH detectors are in general sophisticated tools and need important effort to keep under control the different components of the Čherenkov angle resolution

The LHCb RICH is very successful detector and is one of the key ingredients for the many important and fundamental physics measurements performed by the LHCb experiment.

The RICH of LHCb

Performance of the LHCb RICH detector at LHCb

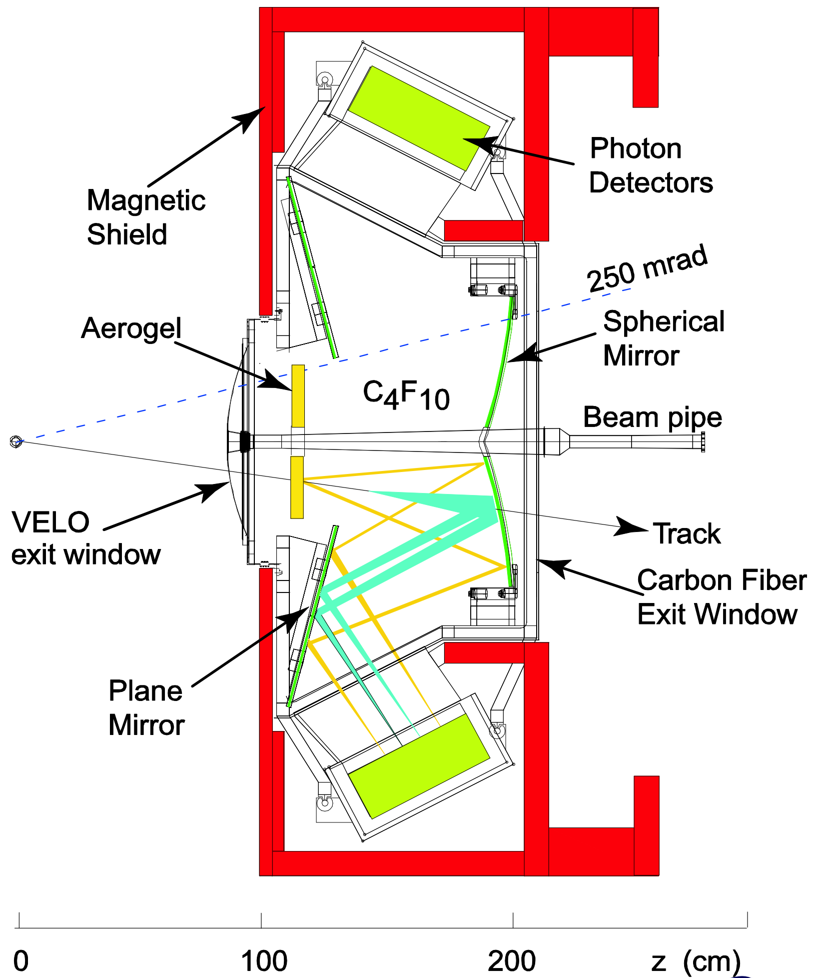
Eur. Phys. J. C (2013) 73:2431

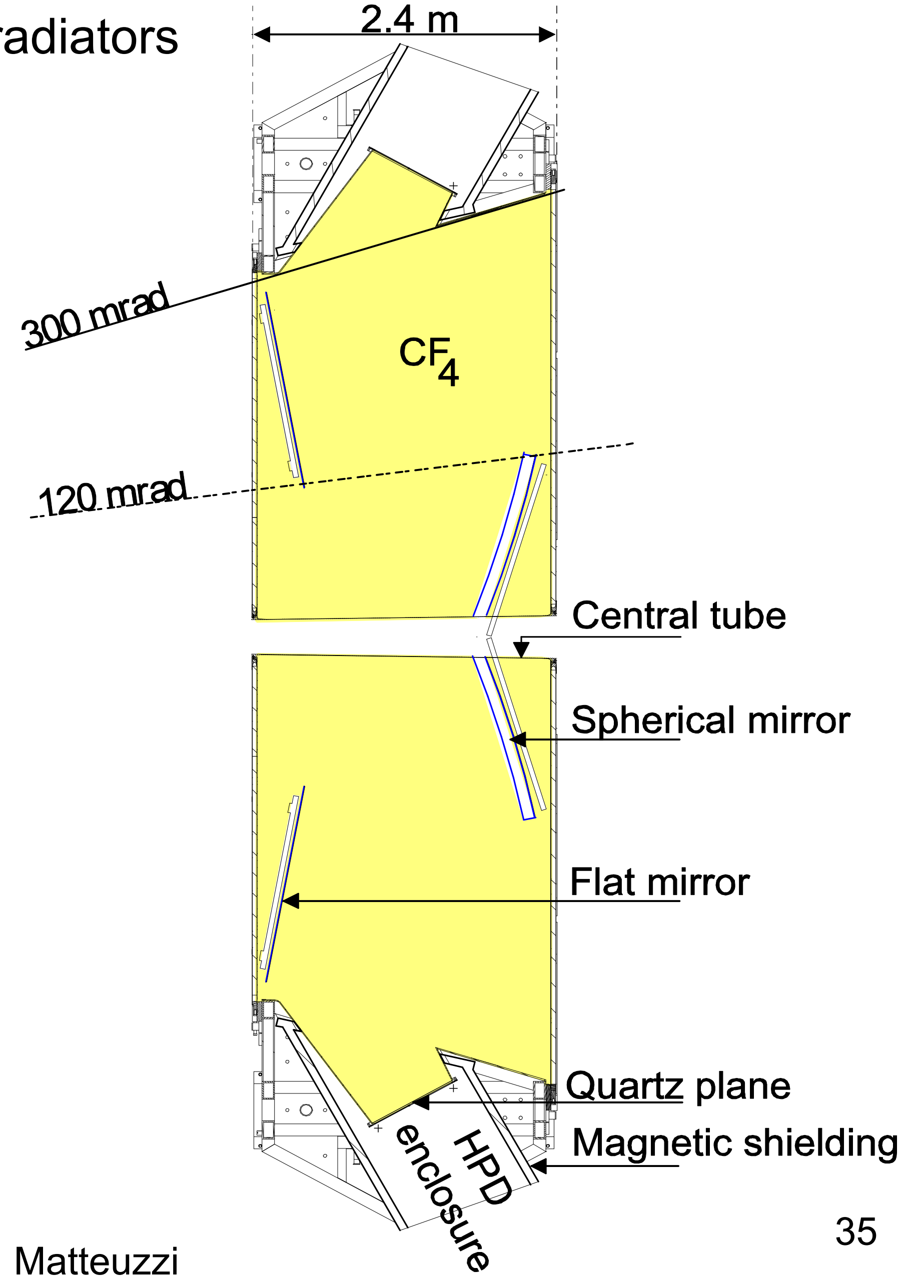


Spare slides

The RICH of LHCb

The solution of LHCb: 2 RICHes with 3 radiators





The RICH of LHCb: *the PID performance*