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RICH Alignment at LHCb with Collision Data

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on behalf of the LHCb RICH Group

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- Introduction to LHCb & its RICH detectors
- Magnetic field effects & corrections
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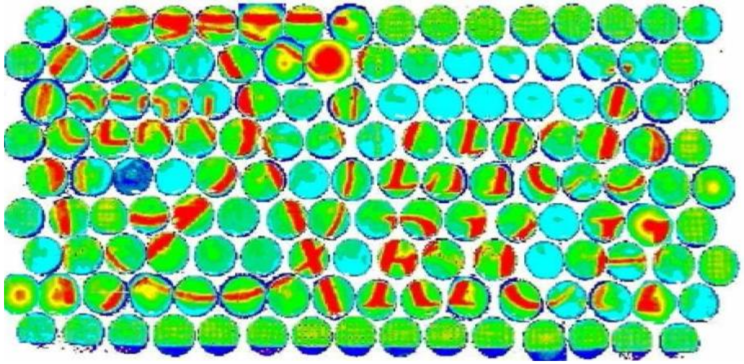
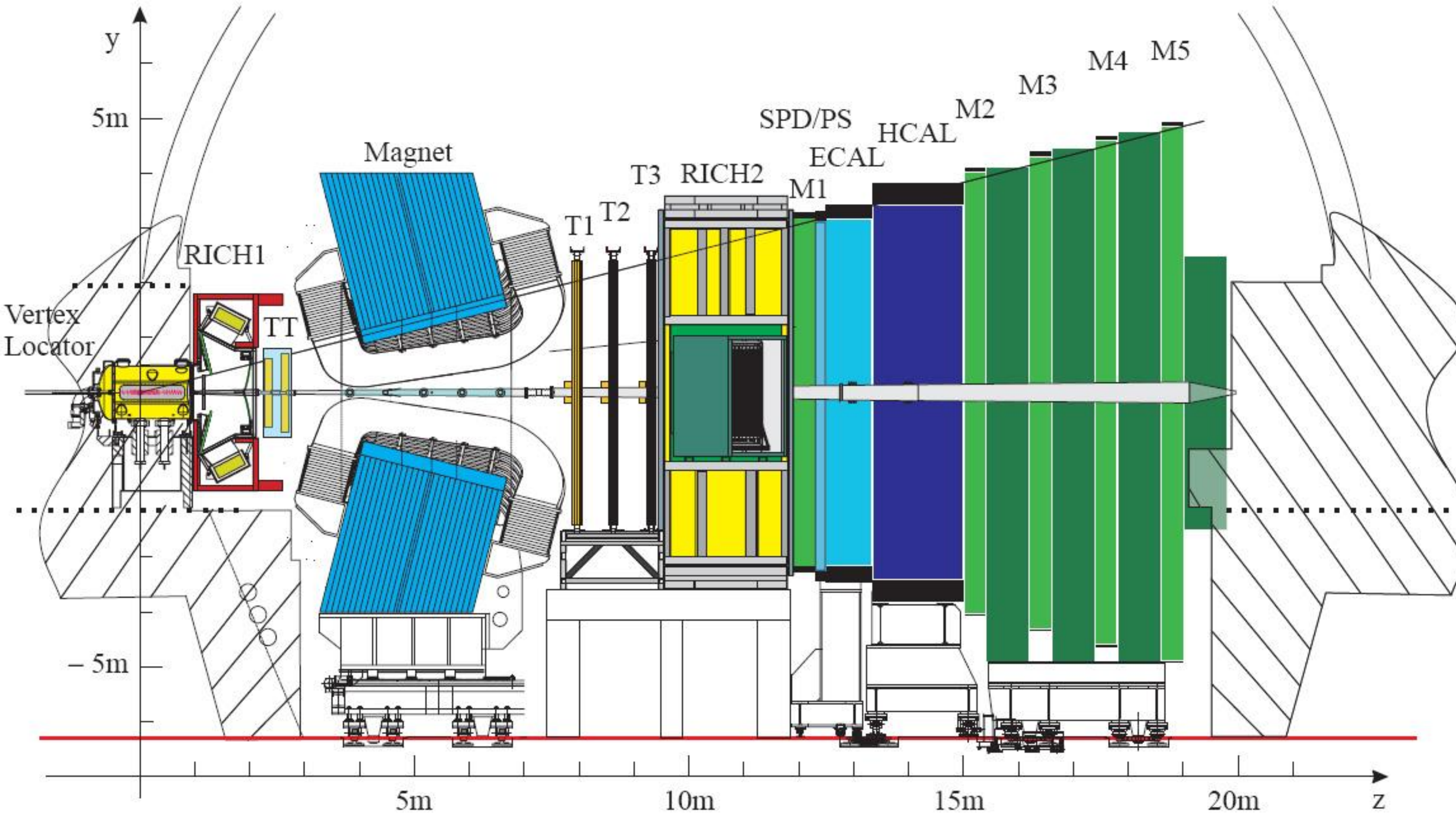
- Particle identification (PID) performance
- Summary



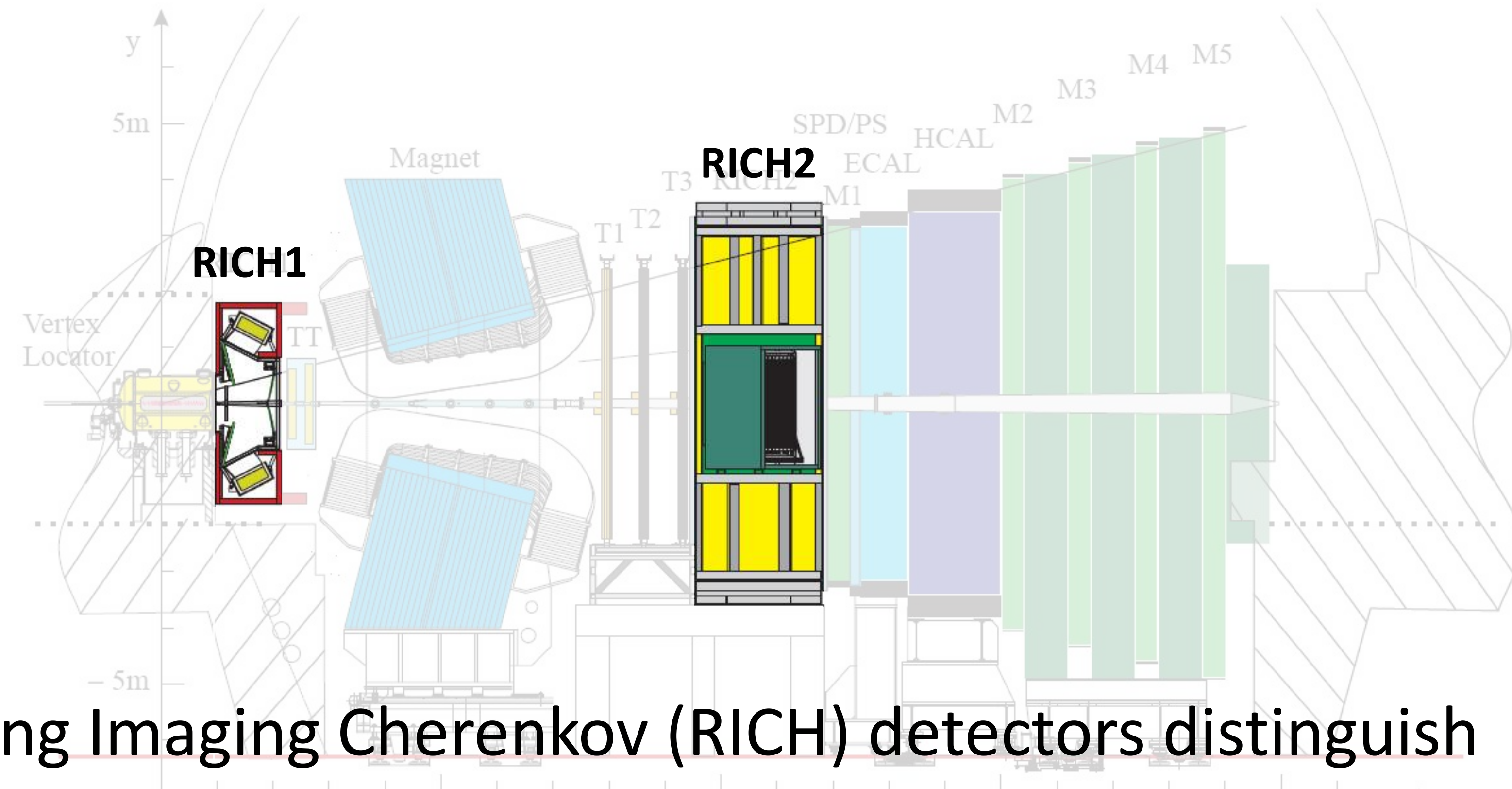
The LHCb Experiment

A forward detector (2<η<5) for precision measurement of CP violation and rare B-decays:



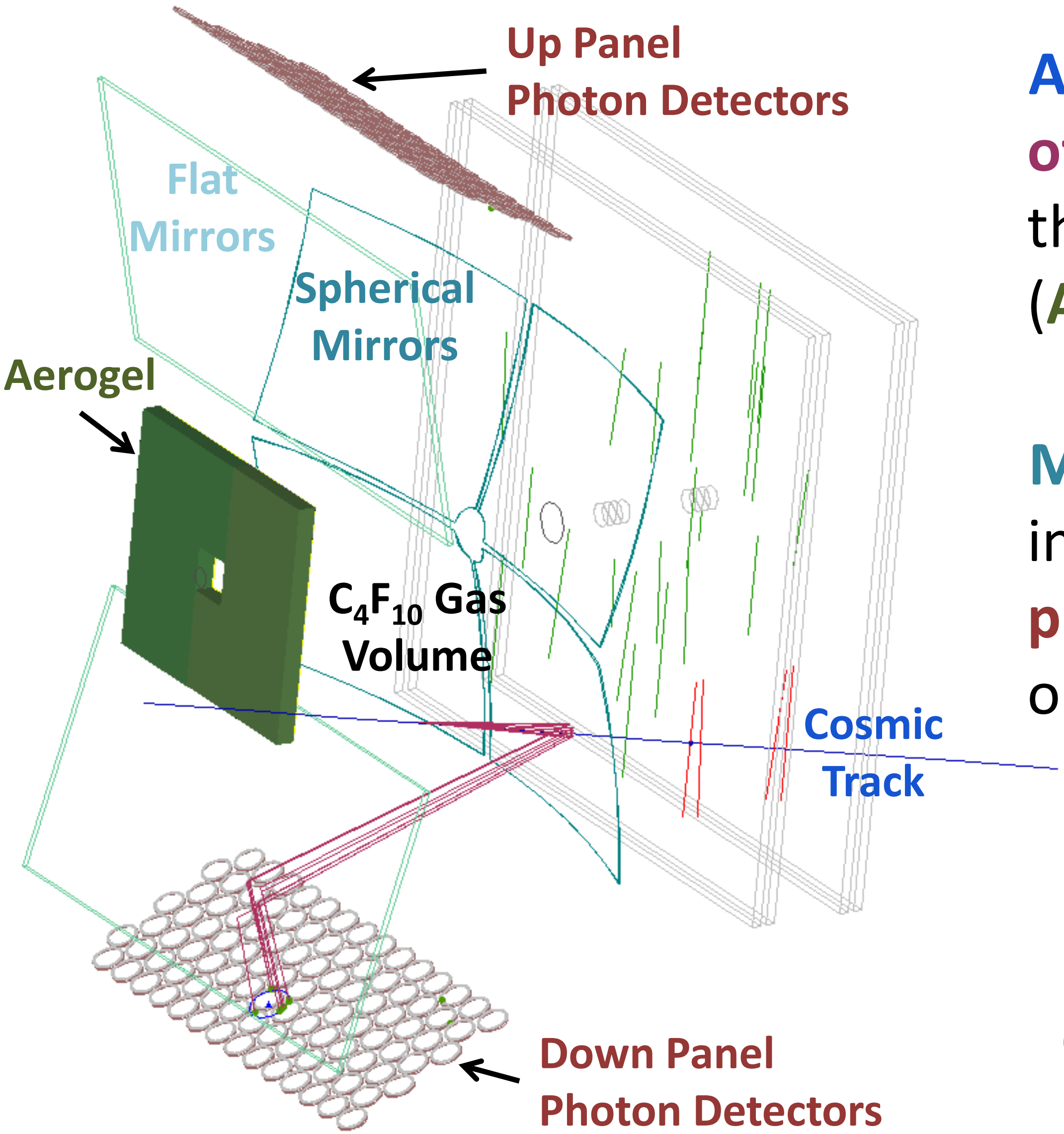
The LHCb RICH Detectors

A forward detector (2<η<5) for precision measurement of CP violation and rare B-decays:



2 Ring Imaging Cherenkov (RICH) detectors distinguish charged particles by mass over a momentum range of 2 to ~100 GeV/c.

RICH1 in Action



A charged track emits a **cone of Cherenkov light** on passing through the radiators (**Aerogel** & **C_4F_{10} Gas**),

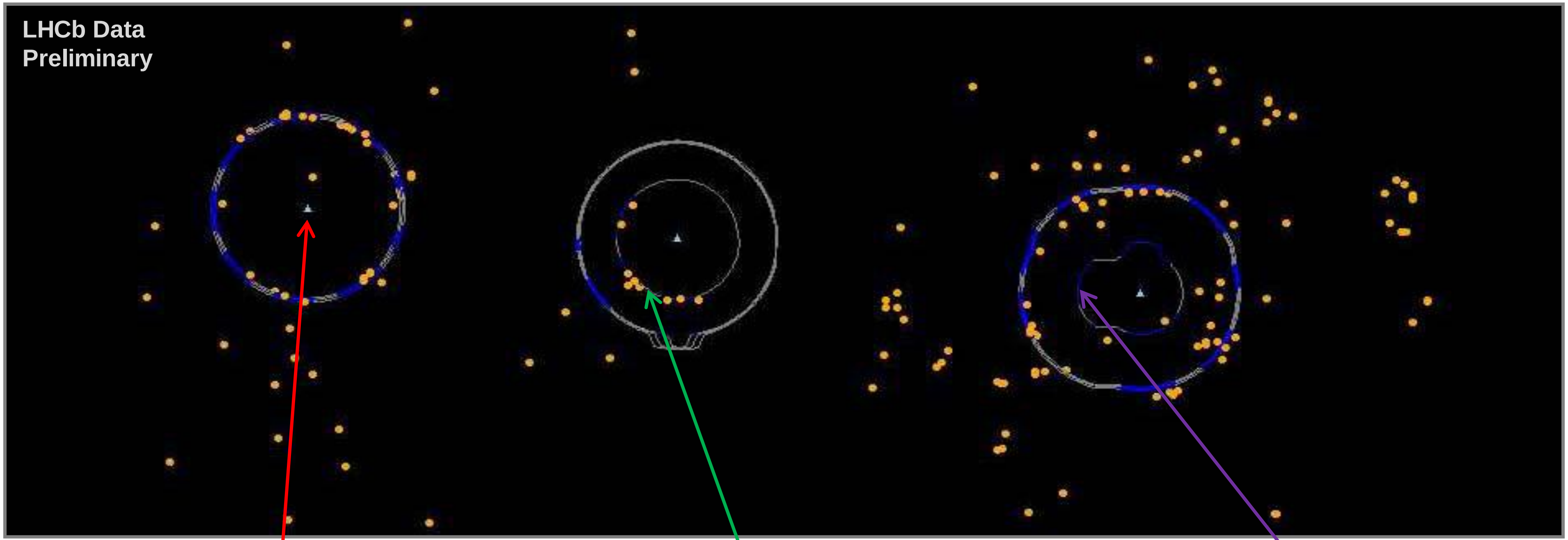
Mirrors focus these cones into rings on 2 **banks of photon detectors** positioned out of LHCb acceptance.

Cosmic event display

Particle Identification

An event display from real data show "rings" projected on to RICH2's photon detector plane:

Detector acceptance



Saturated track: particle hypotheses indistinguishable

Photons clearly favour the Kaon ring hypothesis

Ring distortions due to detector geometry

RICH1&2 in Detail

	RICH1	RICH2
Detector Planes	2 (*Horizontal*)	2 (*Vertical*)
Photon Detectors	2×7×14 = 196	2×9×16 = 288
Flat Mirrors	16	40
Spherical Mirrors	4	56

Each of these components must be aligned.

Installation of RICH2 spherical mirrors segments.

The upper RICH1 photon detector plane.

Design Limits on θ_C Precision

Emission Point: Spherical mirror tilts introduce a dependence of photon impact point on the detector plane with emission along the particle track.

Pixel Size: The photon detector pixel size limits precision.

$\Delta\theta_C$ [mrad]	Aerogel	C_4F_{10}	CF_4
Emission	0.4	0.8	0.2
Chromatic	2.1	0.9	0.5
Pixel	0.5	0.6	0.2
Tracking	0.4	0.4	0.4

[2008-JINST-3-S08005]

Chromatic Dispersion: Cherenkov photons are emitted with a distribution of wavelengths. Since refractive index varies with wavelength, θ_C is also spread.

Tracking: θ_C calculated after photon-track association, so includes track precision.

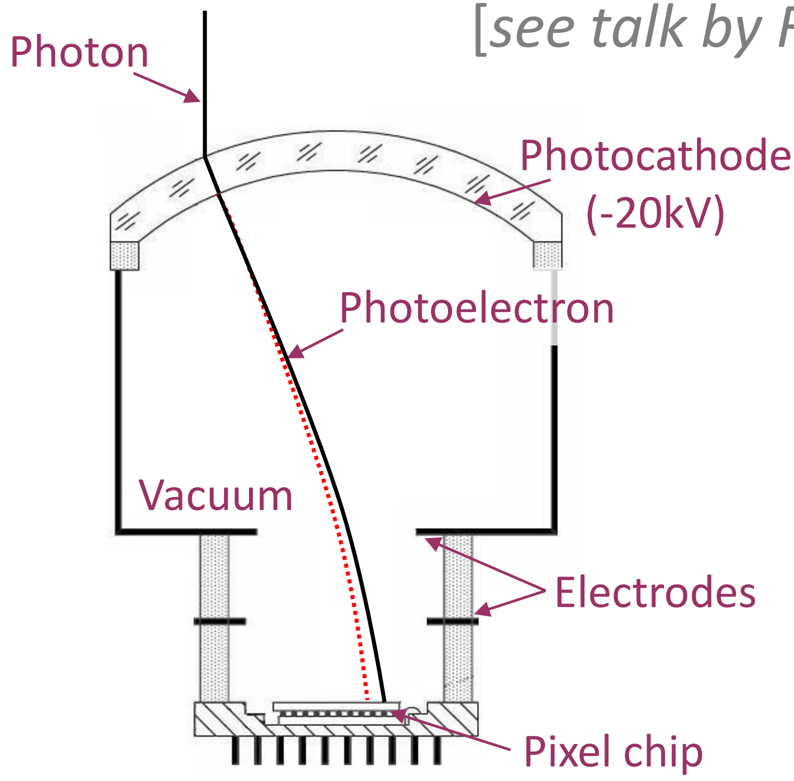
[*see talk by C. Matteuzzi*]

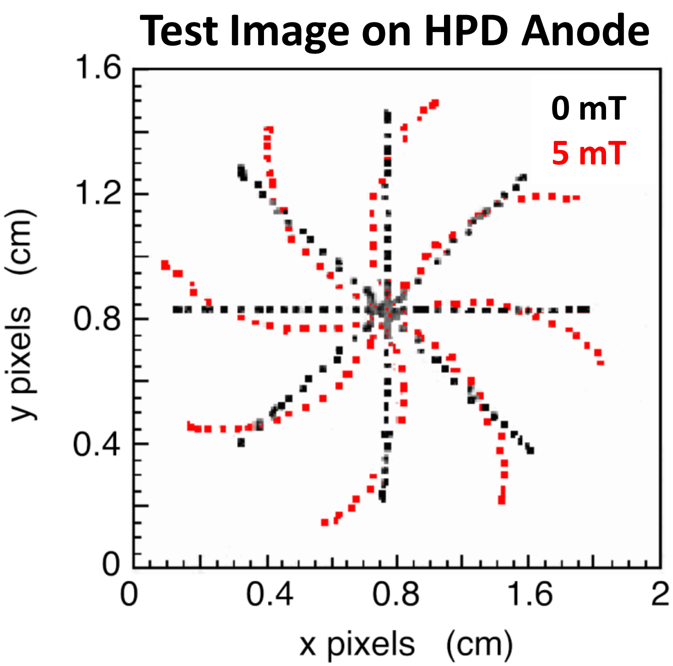
Additional contributions due to misalignment must be controlled to ~0.1 mrad.

Complications with a Magnetic Field

LHCb RICH uses Hybrid Photon Detectors (HPDs), combining digital readout with 5× demagnification using a vacuum tube.

[*see talk by R. Young*]





[2008-JINST-3-S08005]

Photoelectron trajectories are deformed by LHCb's magnetic field.

Field strength (*after shielding*) at detector plane:
1.4 mT (R1) & **0.4 mT** (R2)

Calibration Methods

[*see poster by F. Xing*]

1. Magnetic Field Corrections

Two independent procedures exist to calibrate LHCb's RICH:

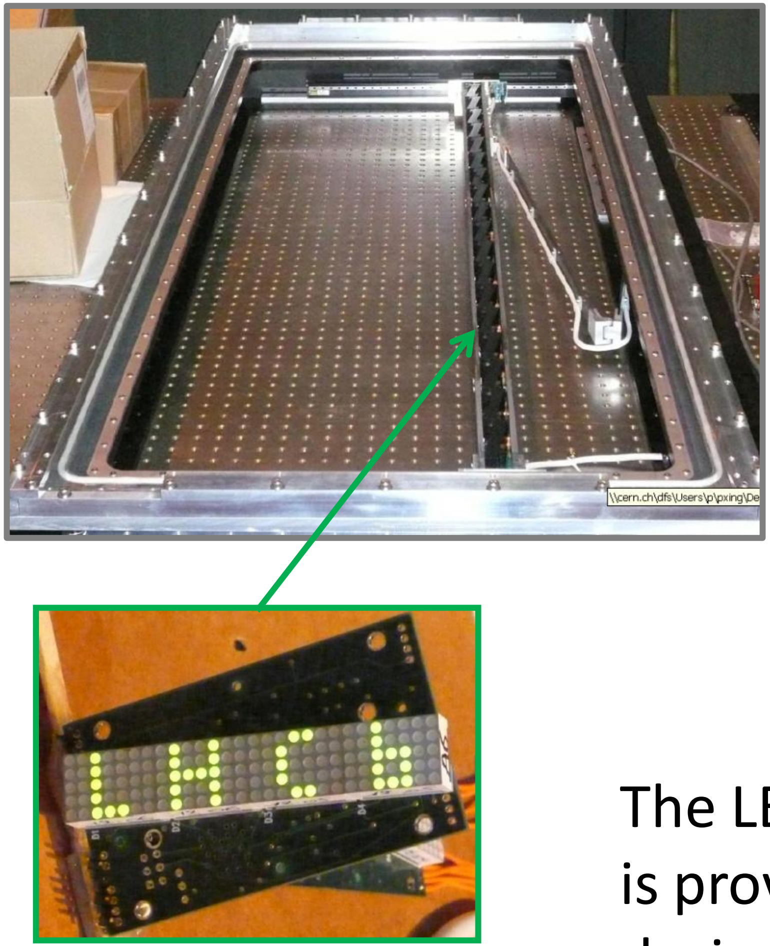
a. RICH1 Magnetic Distortion Calibration System (MDCS),
b. RICH2 "Beamer",

Both employ a similar approach:

a. Shine a reproducible light-spot pattern on to the photon detector plane,
b. Measure the light-spot positions with field ON and OFF,
c. Calculate correction factors.

2. Geometric Alignment

RICH1 MDCS Setup



The Magnetic Distortion Calibration System is built in to RICH1, with 1 unit permanently mounted in front of each photon detector plane,

Each unit contains:

LED bar: 19 LED boards,

LED boards: 4 arrays 7 × 5 LEDs,

Driven by 2 synchronised motors.

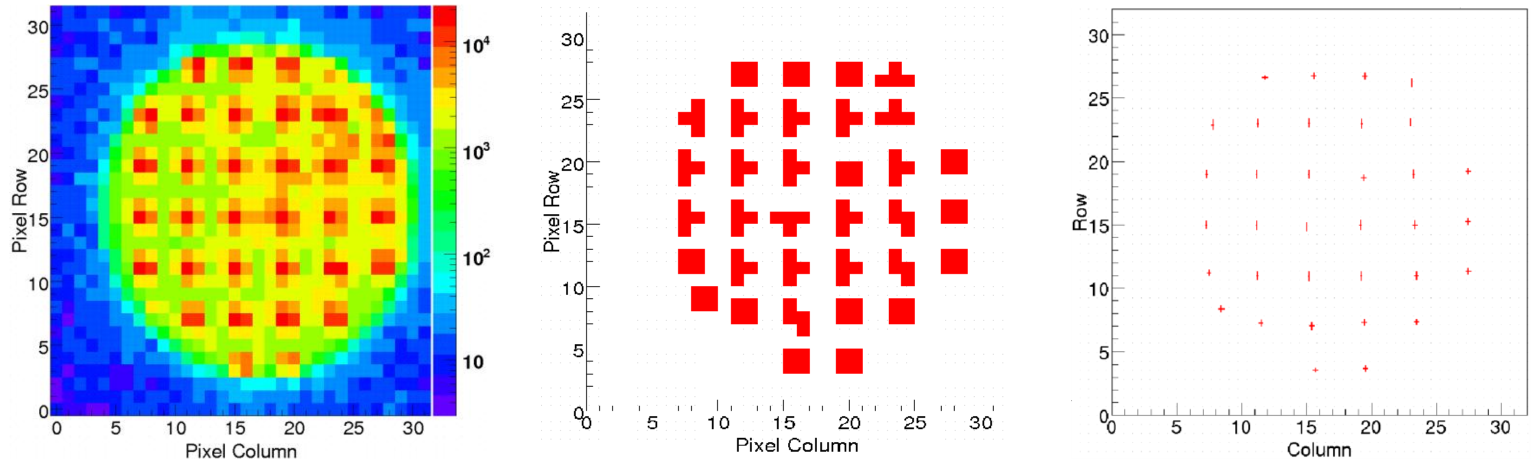
The LED bar is retracted whenever the LHC is providing collisions but can be moved out during quiet periods for regular scans across the detectors.

RICH2 "Beamer" Setup

A temporary setup, using commercial projector (*the "Beamer"*) was used in 2008 to project a static, reproducible grid of light spots onto the photon detector plane,

The raw spot images were analysed to calculate the centre of gravity for precision comparison between measurements:

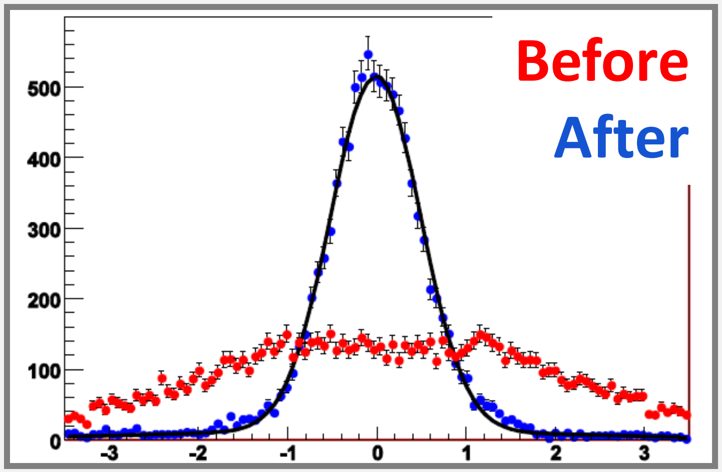
1. Accumulated HPD Image **2. Applied Thresholds** **3. Centre of Gravity**



Magnetic Correction Results

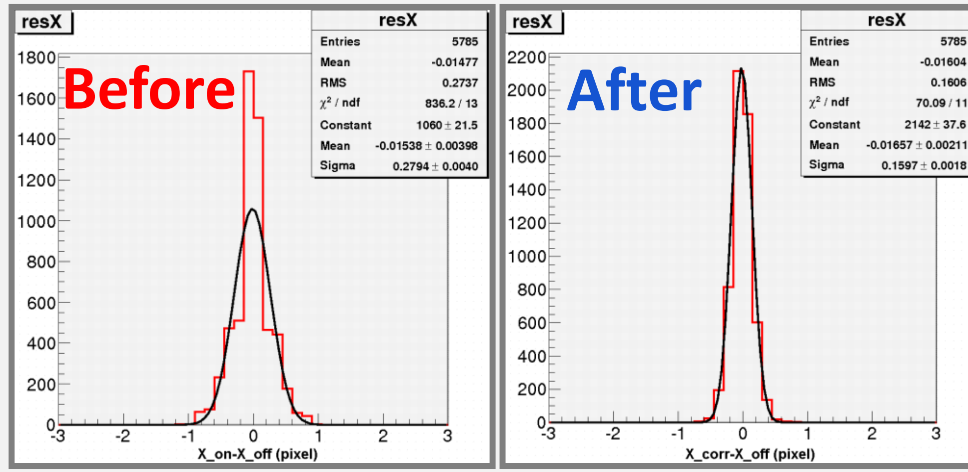
Distributions of spot centre Δx and Δy (*field ON-OFF*) show a significant improvement after corrections are applied:

RICH1 : Δx



Δx = 0.51 mm

RICH2 : Δx



Δx = 0.47 mm

Both RICH1 and RICH2 have been corrected to better than the photon detectors' intrinsic pixel resolution: 0.72 mm.

Calibration Methods

1. Magnetic Field Corrections

2. Geometric Alignment

Studies with a simulated detector have allowed us to understand how misalignments can effect measurement of collision data,

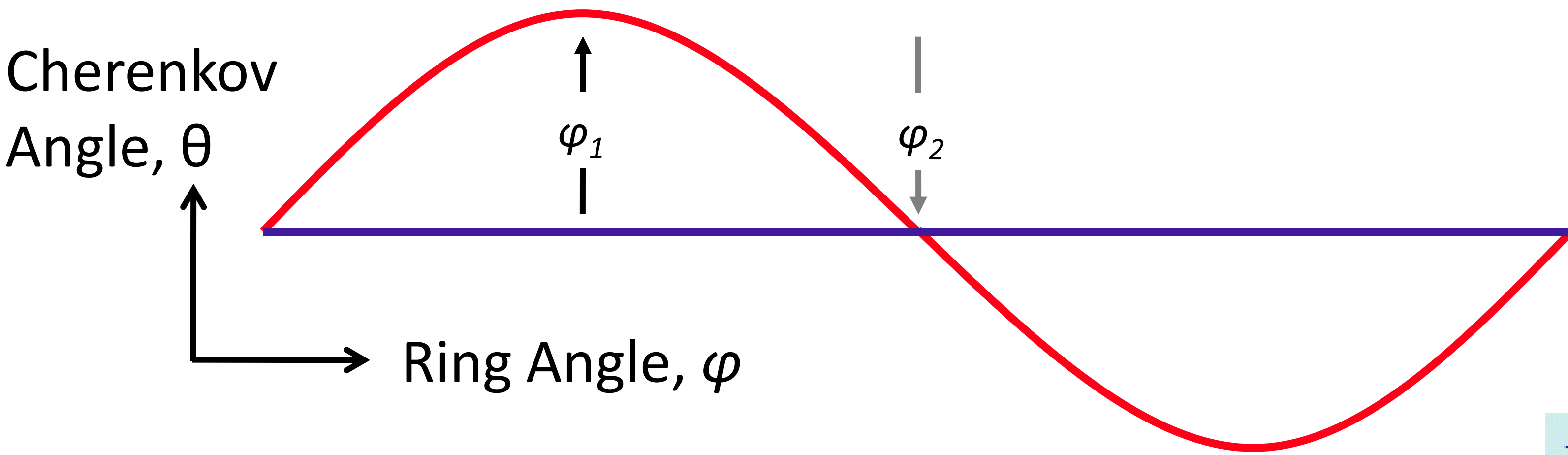
By analysis of collision data to find these effects, we can choose which components to align and by what magnitudes,

Alignment began with the first data taken at the end of 2009 and work is ongoing to fully understand the system.

RICH Misalignments

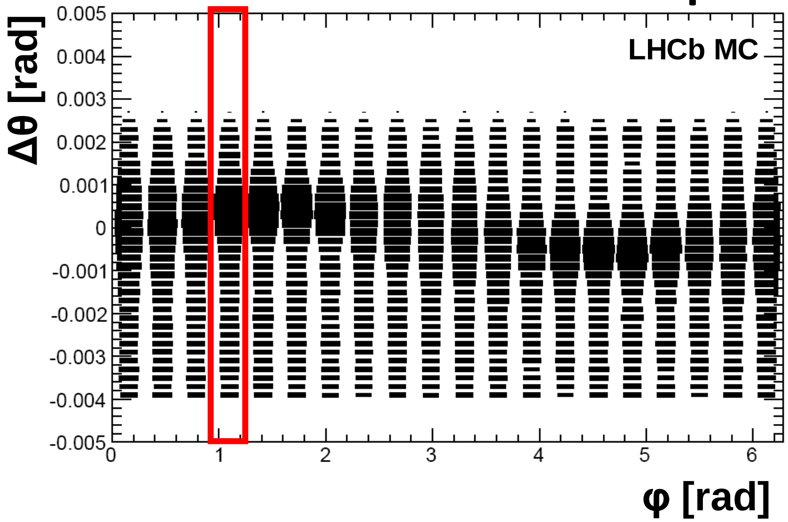
Misalignment is observed relative to tracking:

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



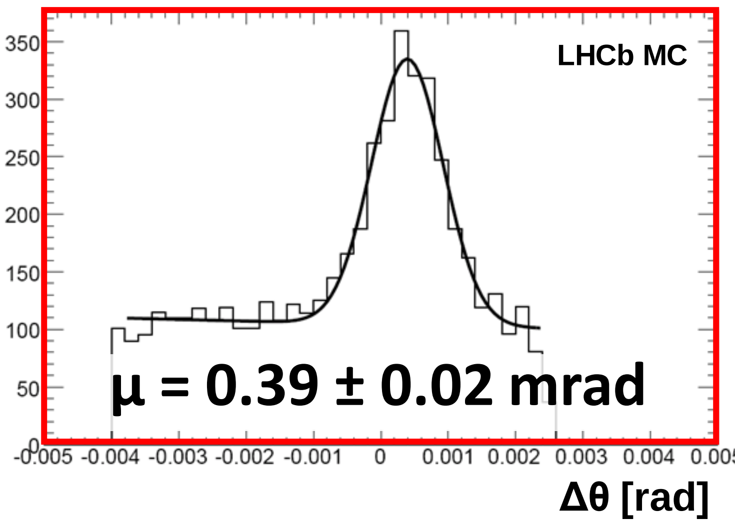
Fitting Procedure

Reconstructed RICH2 Output

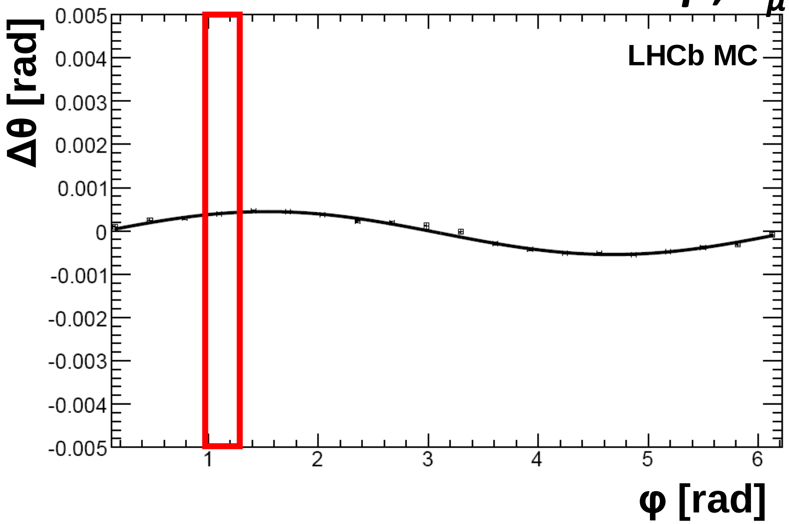


RICH output is split into bins of φ then fitted with Gaussian peak on a straight-line background,

Fit: P1 + Gaussian



Reduced Curve: Gaussian μ, σ_μ

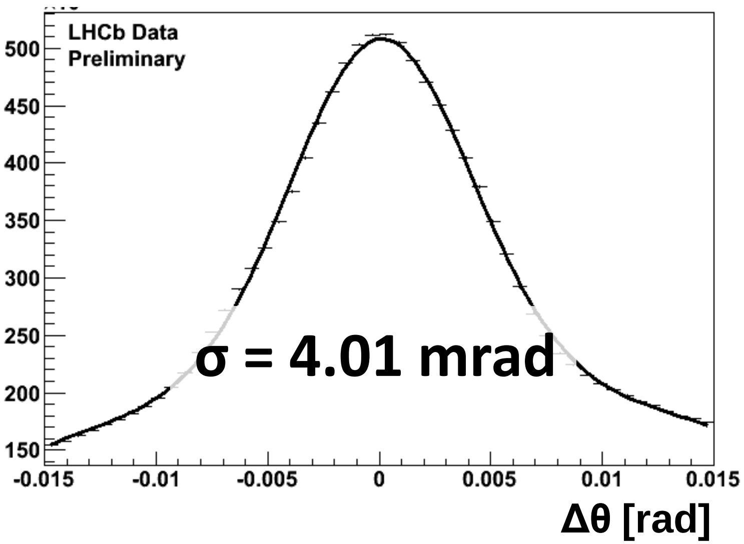


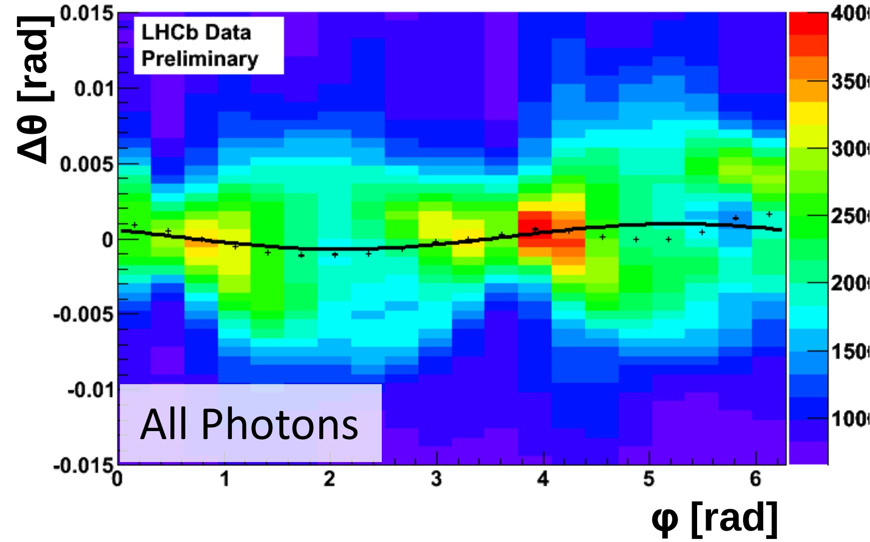
LHCb output re-plotted using Gaussian μ and fitted with:

$$\Delta\theta = A\sin\varphi + B\cos\varphi$$

Real Data from RICH1

Total Resolution





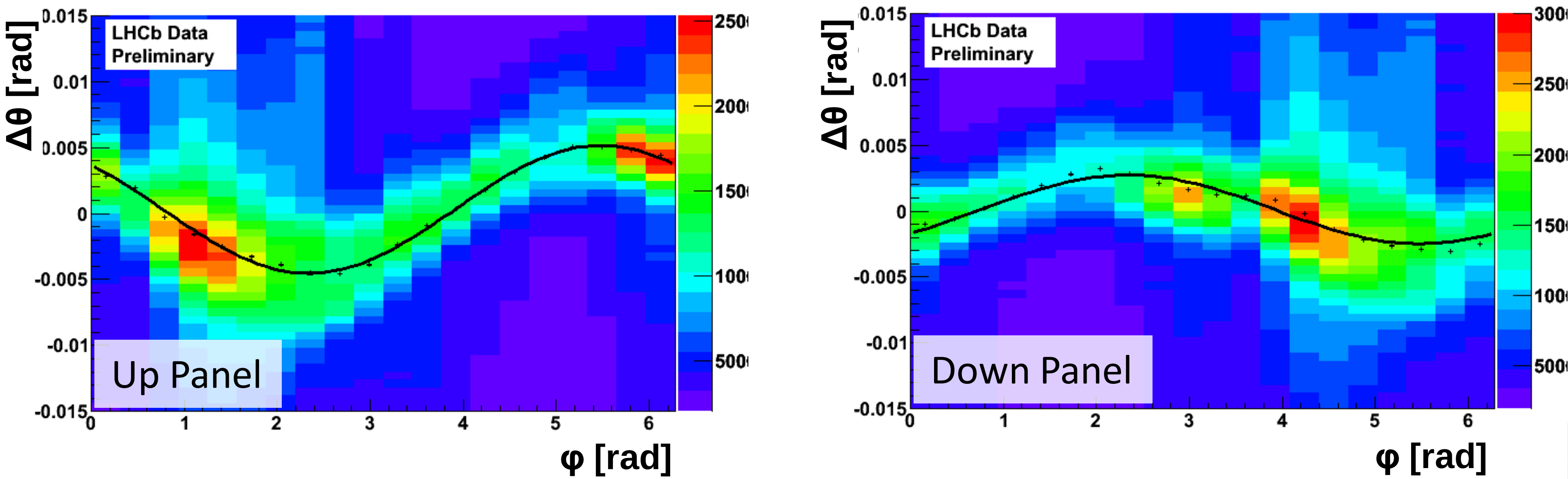
Without alignment, real data shows less than optimal resolution in RICH1 – we expected σ = 1.6 mrad!

The Δθ vs. *φ* alignment plot didn't look promising. Where is the large sinusoidal deviation?

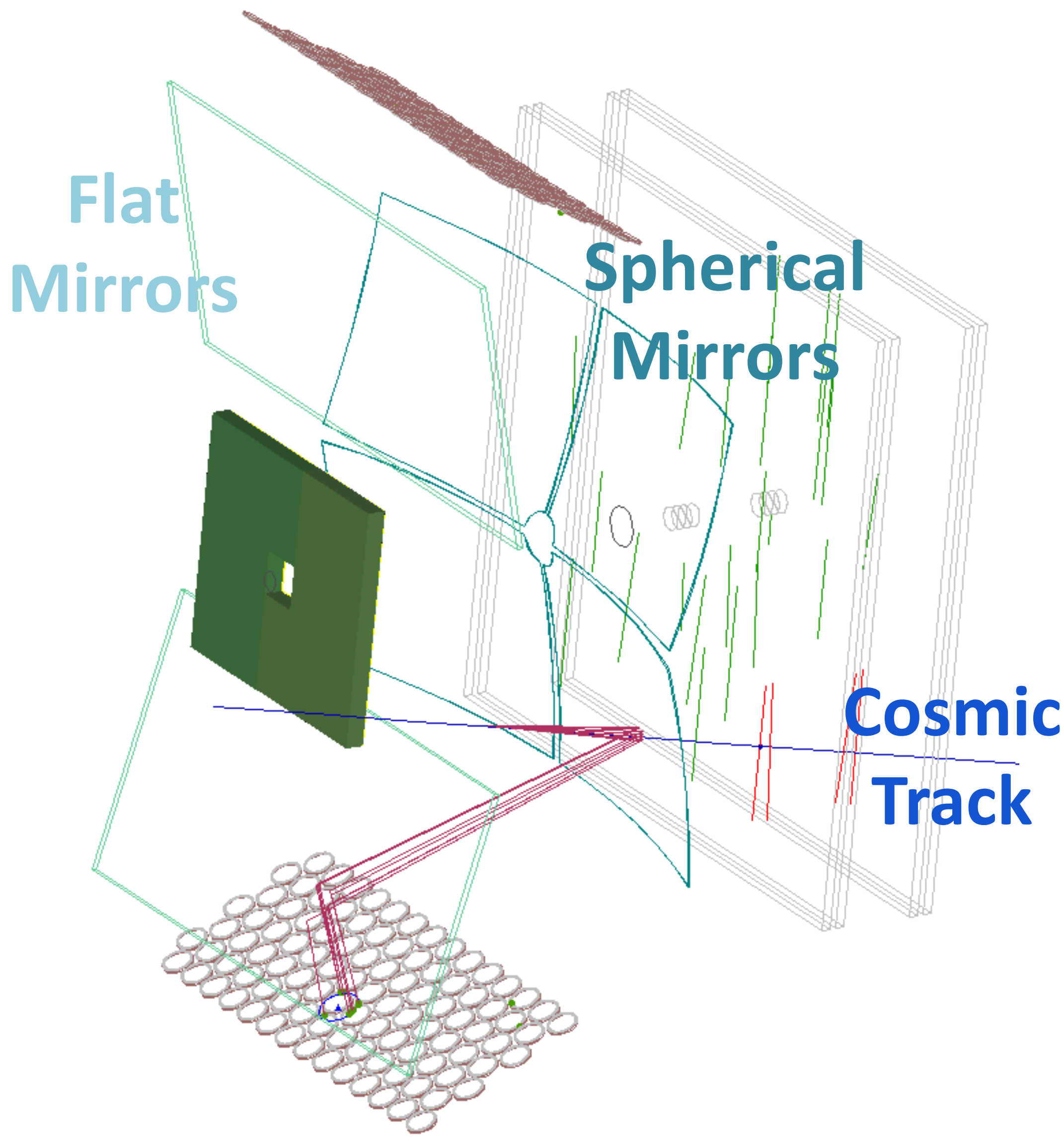
Real Data from RICH1

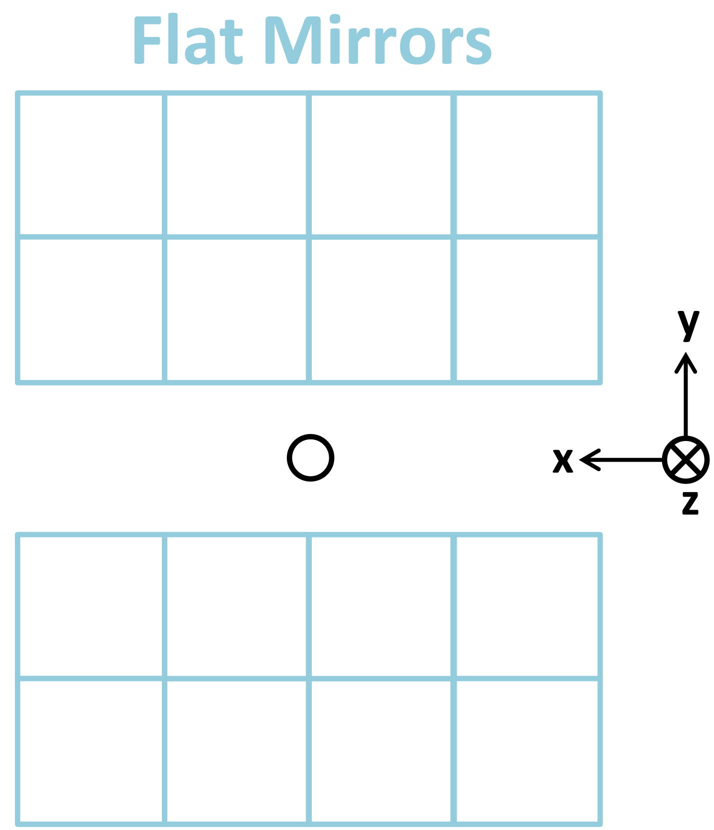
Seen separately, Up & Down panels show the expected Δθ distributions,

By splitting up the data further we can focus on aligning any combination of components.

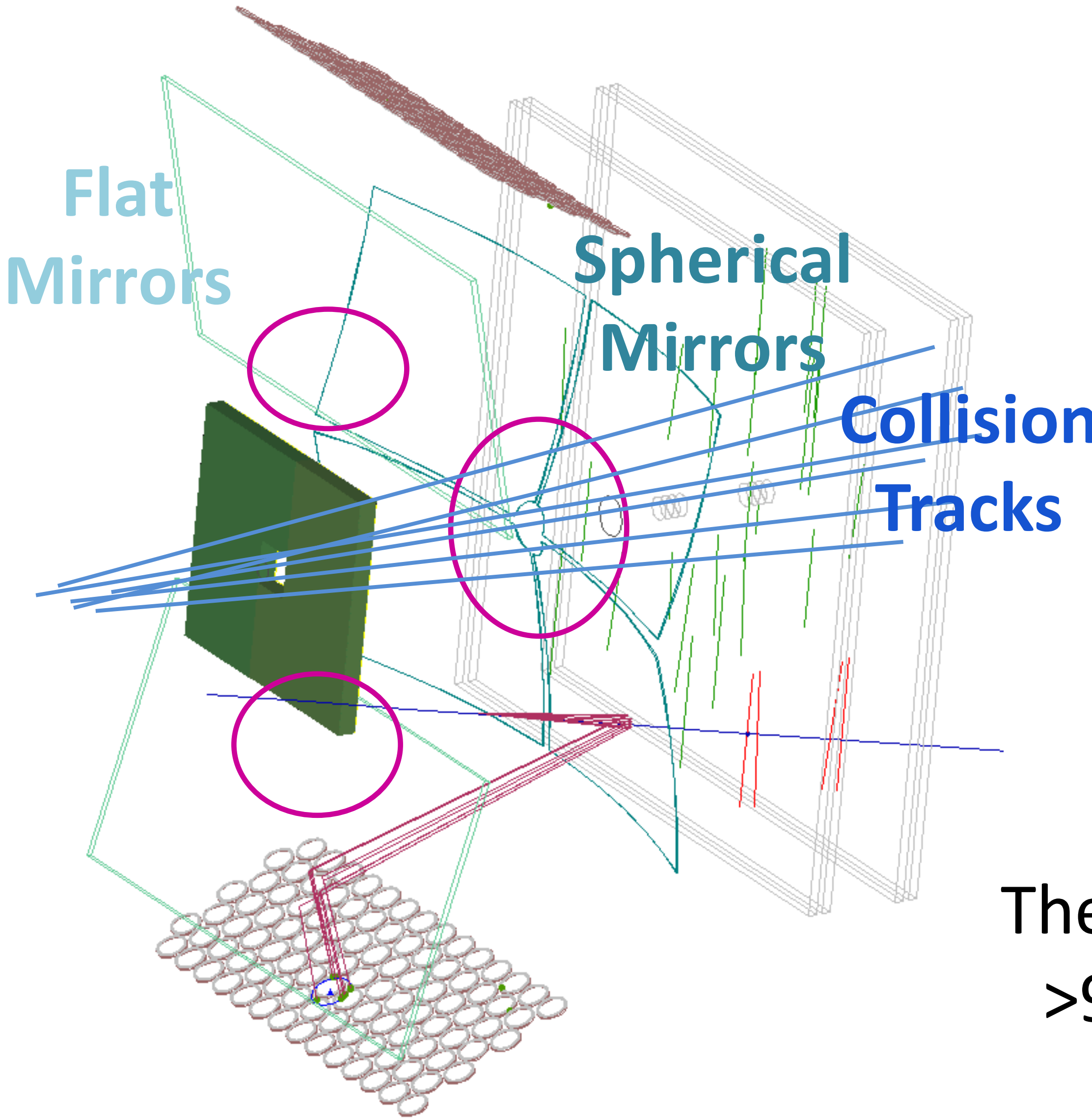


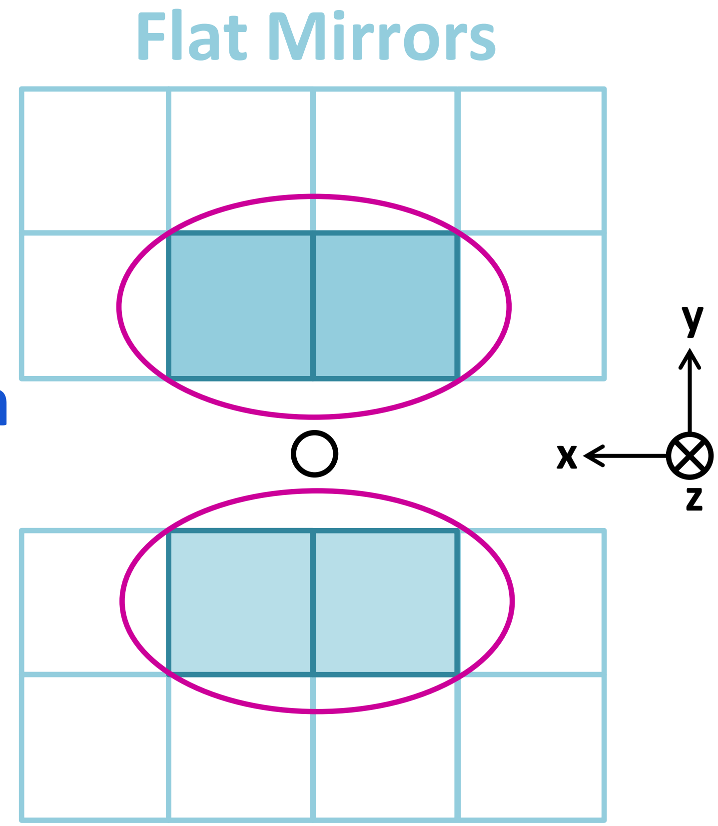
RICH1 Mirror Configuration





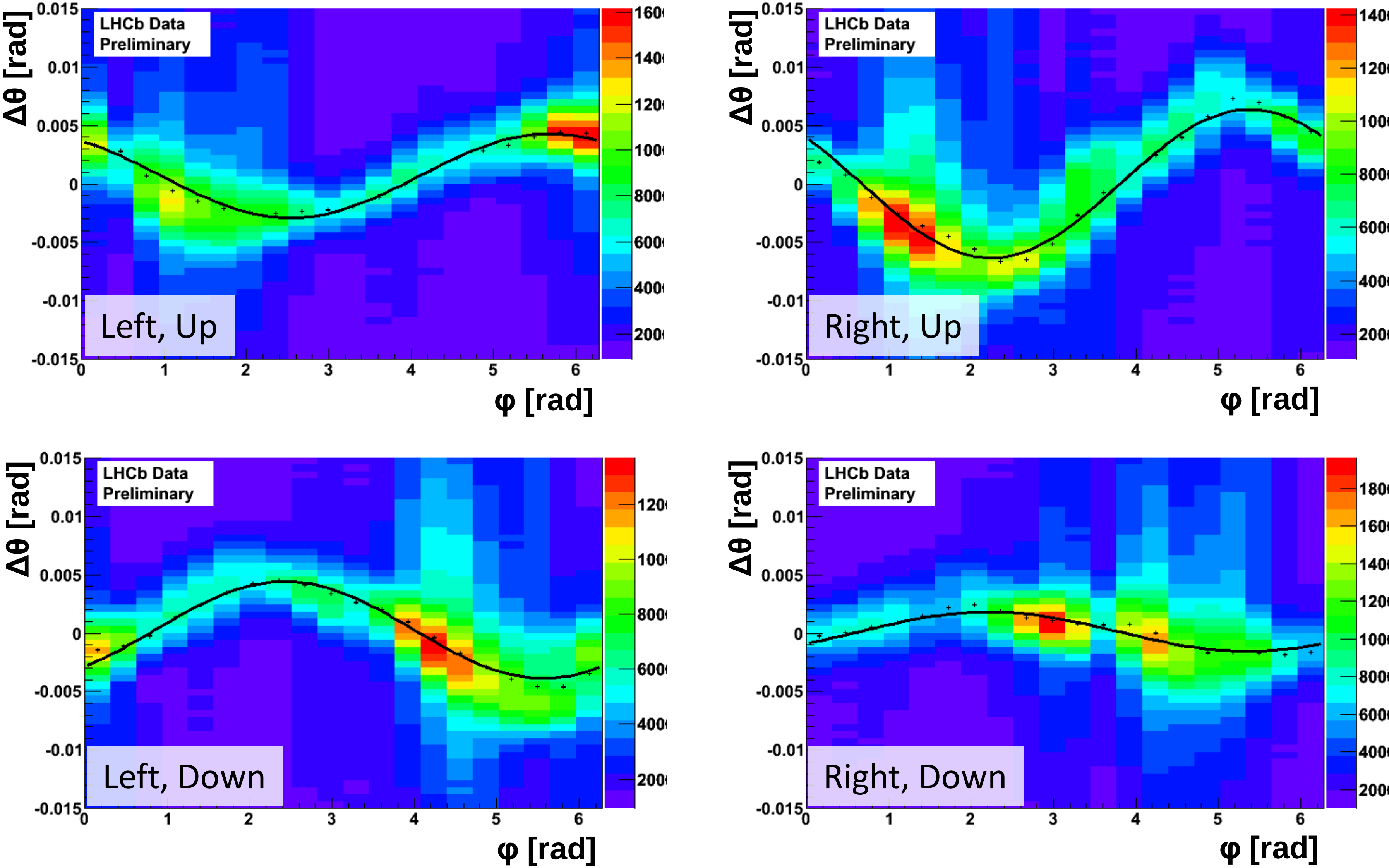
RICH1 Mirror Configuration





The **central** flat mirrors see >99% of all gas photons.

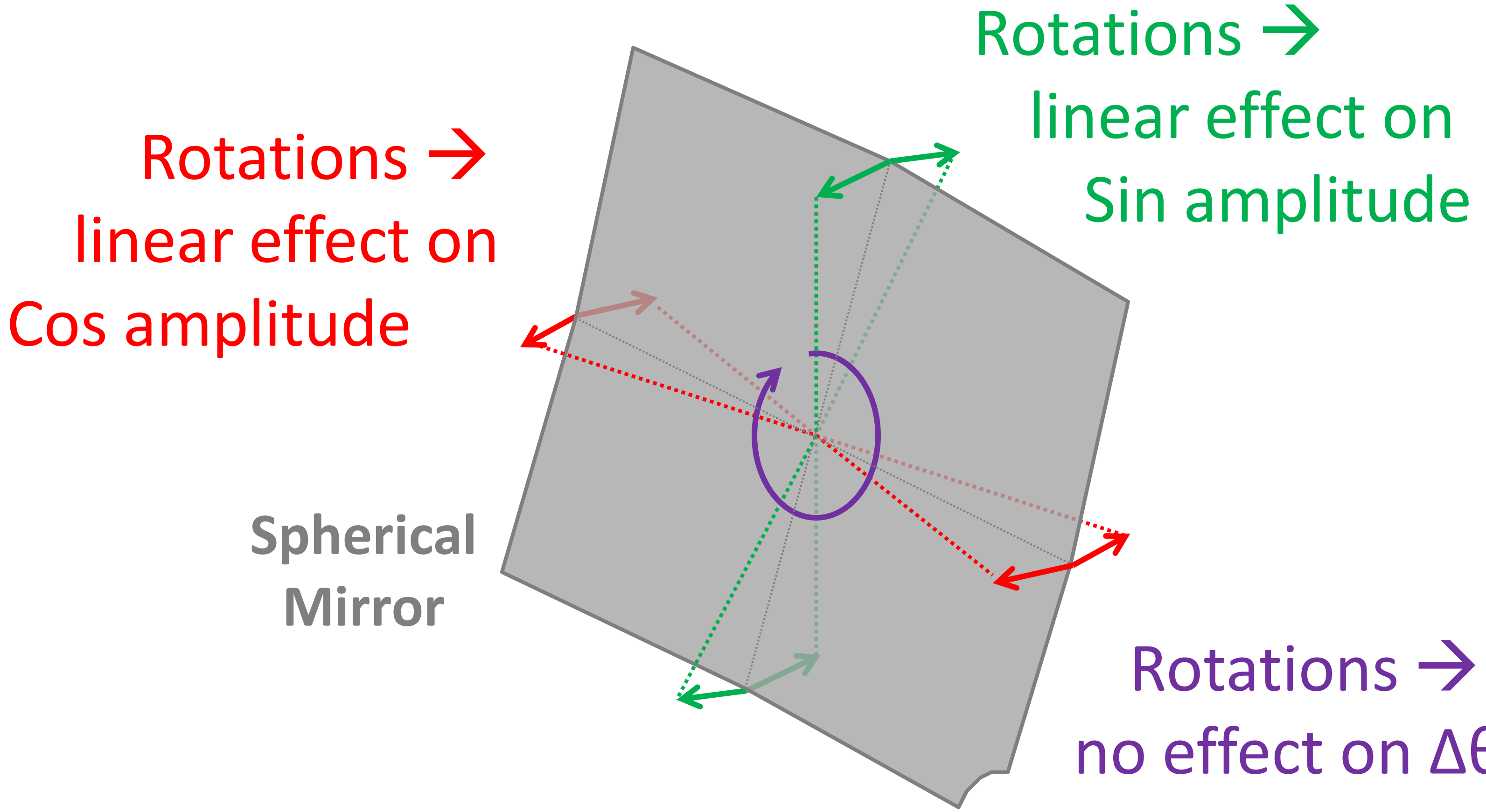
RICH1 Misalignments by Quadrant



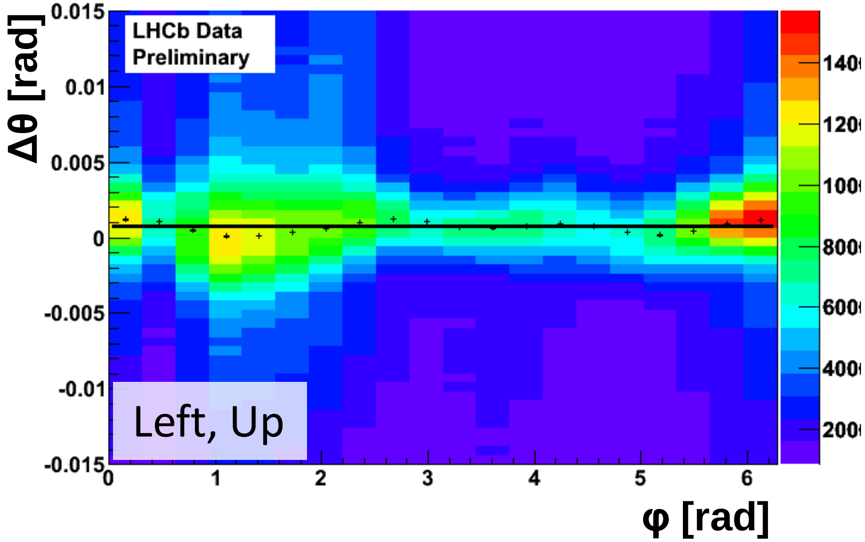
Aligning RICH1 Spherical Mirrors

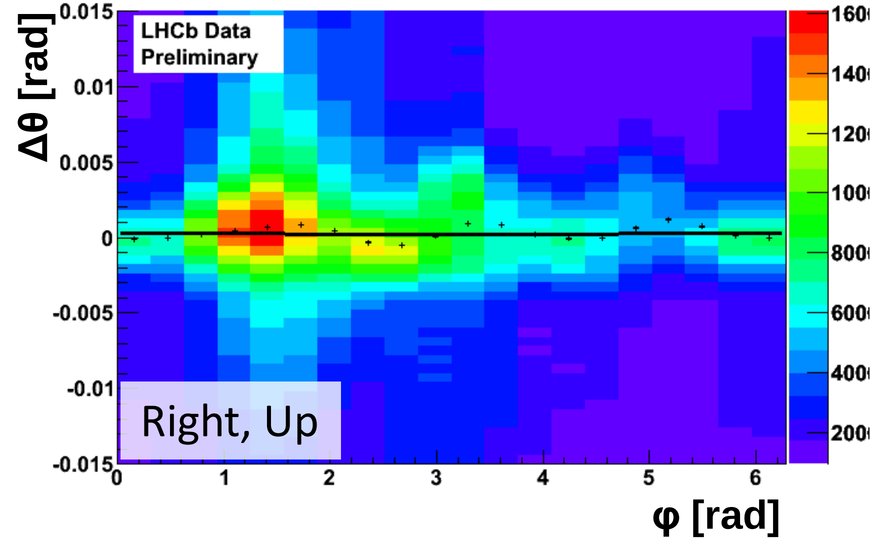
How do we compare mirror misalignment to our function:

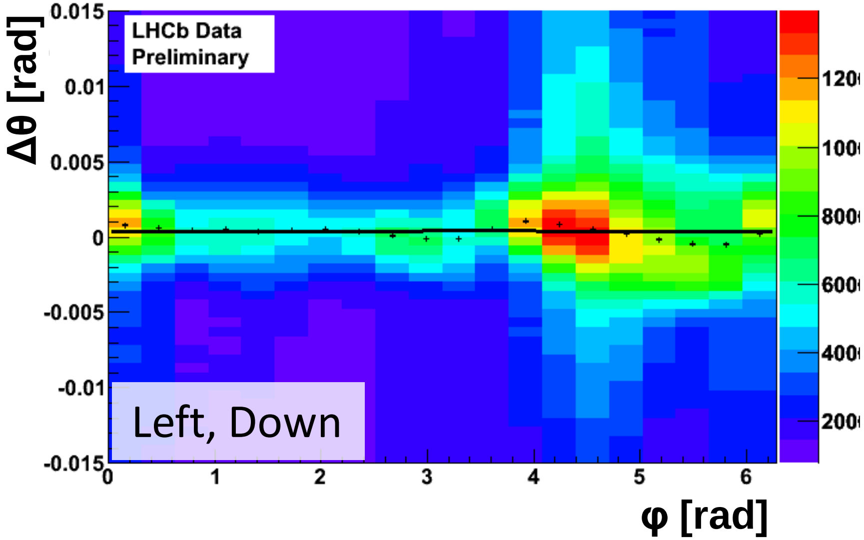
$\boldsymbol{\Delta\theta = A\sin\varphi + B\cos\varphi}$?

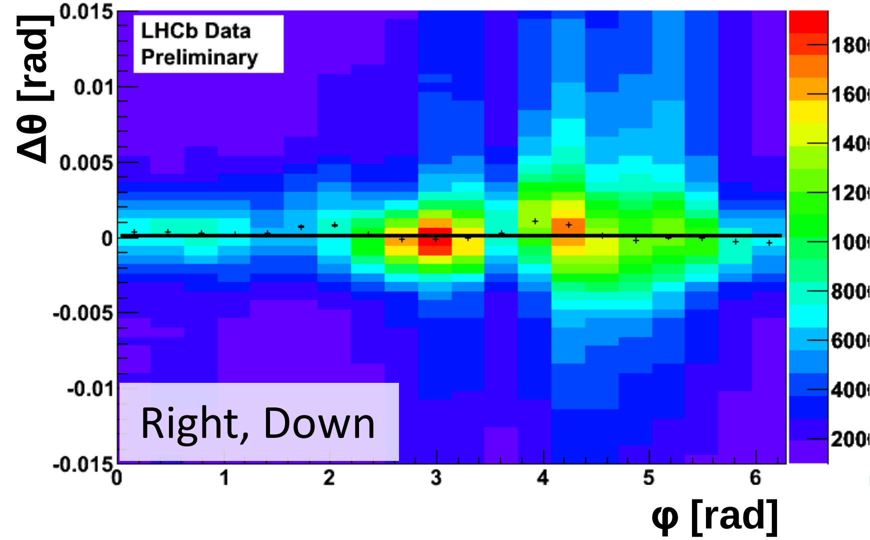


RICH1 Spherical Mirrors Aligned

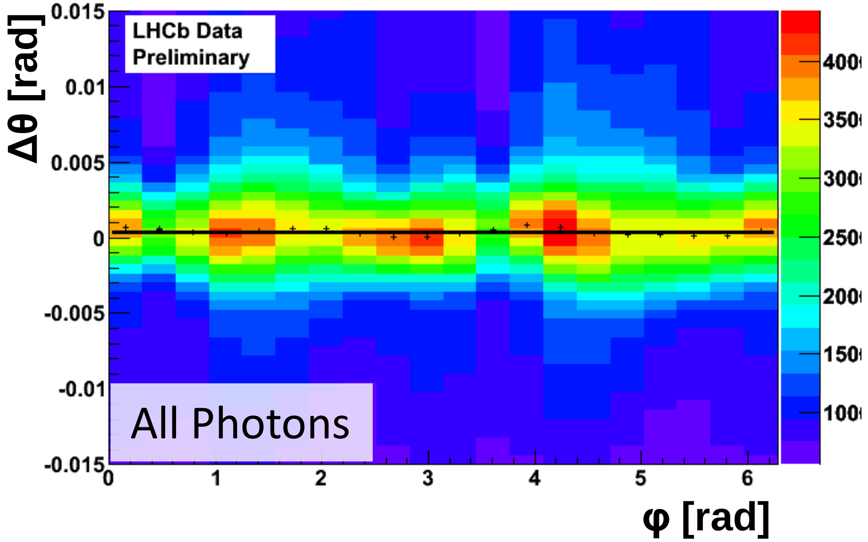




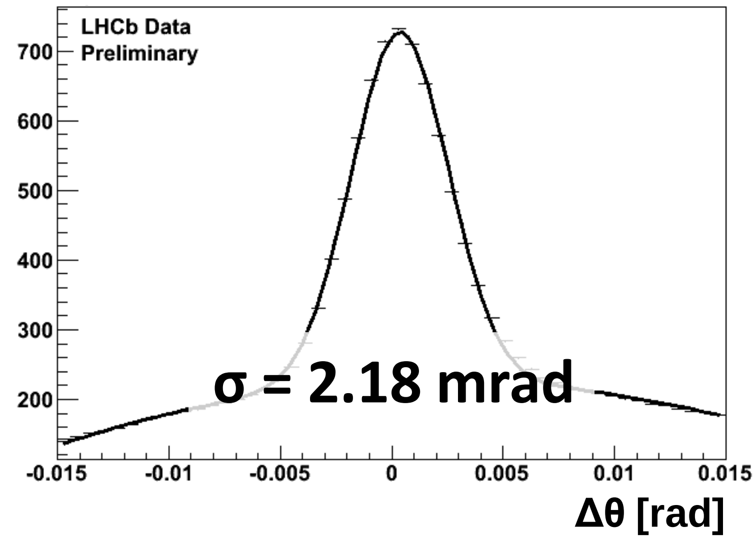




Aligned Resolution RICH1



Total Resolution



A great improvement from our starting point: **σ = 4.0 mrad**

Not yet reached MC prediction of: **σ = 1.6 mrad**

Correction	A, Up	C, Up	A, Down	C, Down
Local Ry	-1.42 mrad	-1.67 mrad	+1.44 mrad	+0.43 mrad
Local Rz	+1.20 mrad	+2.92 mrad	-1.68 mrad	-0.75 mrad

Corrections expected from survey: < 2 mrad

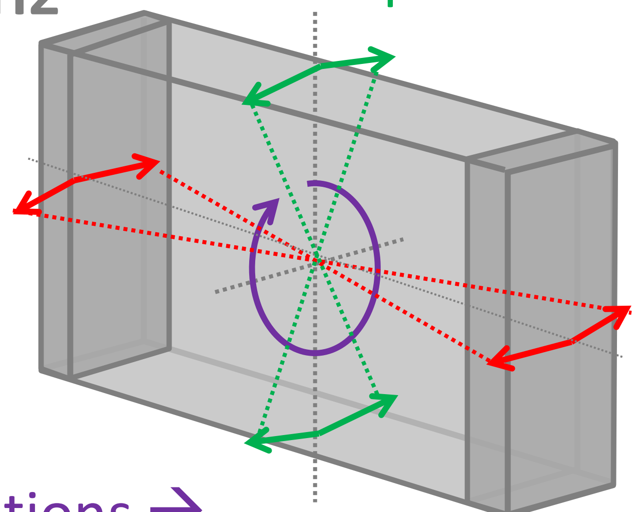
Aligning RICH2

How do we compare mirror misalignment to our function:

$\Delta\theta$ = Asinφ + Bcosφ ?

Rotations → linear effect on Sin amplitude

RICH2



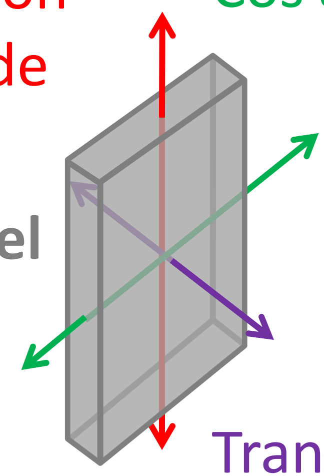
Rotations → no effect on $\Delta\theta$ vs. φ

Rotations → linear effect on Cos amplitude

Translations → linear effect on Cos amplitude

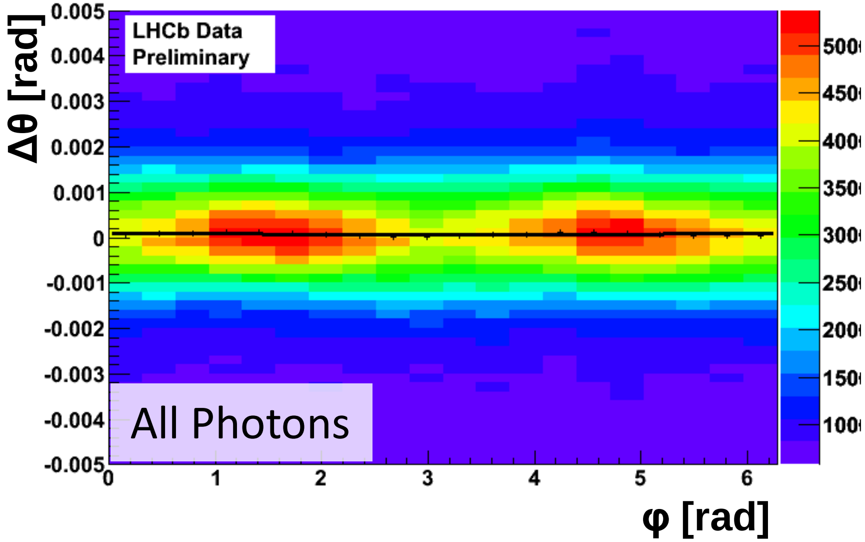
Translations → linear effect on Cos amplitude

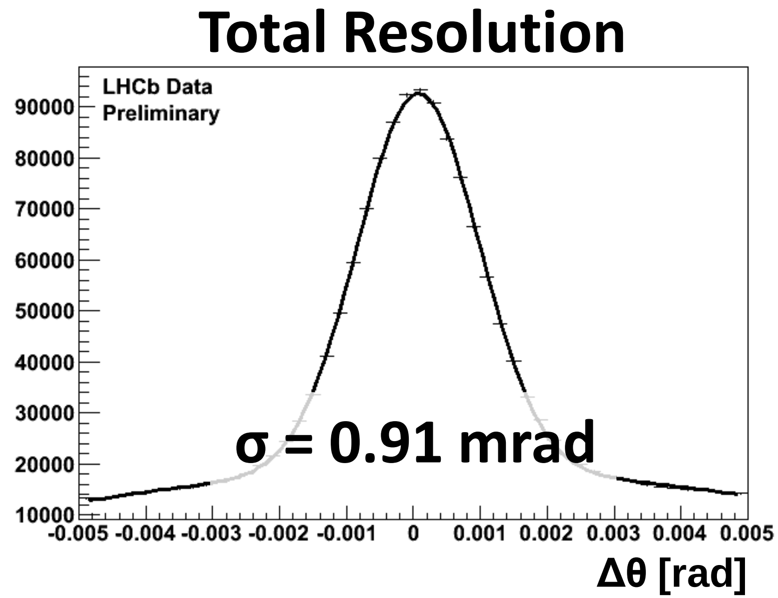
HPD Panel



Translations → no effect on $\Delta\theta$ vs. φ

Aligned Resolution RICH2





A great improvement from our starting point: **σ = 1.5 mrad**

Not yet reached MC prediction of: **σ = 0.7 mrad**

Correction	RICH2
Local Rx	-0.69 mrad
Local Ry	1.27 mrad

Correction	HPD Panel L	HPD Panel R
Local Tx	-3.18 mm	4.04 mm
Local Ty	-0.93 mm	-0.72 mm

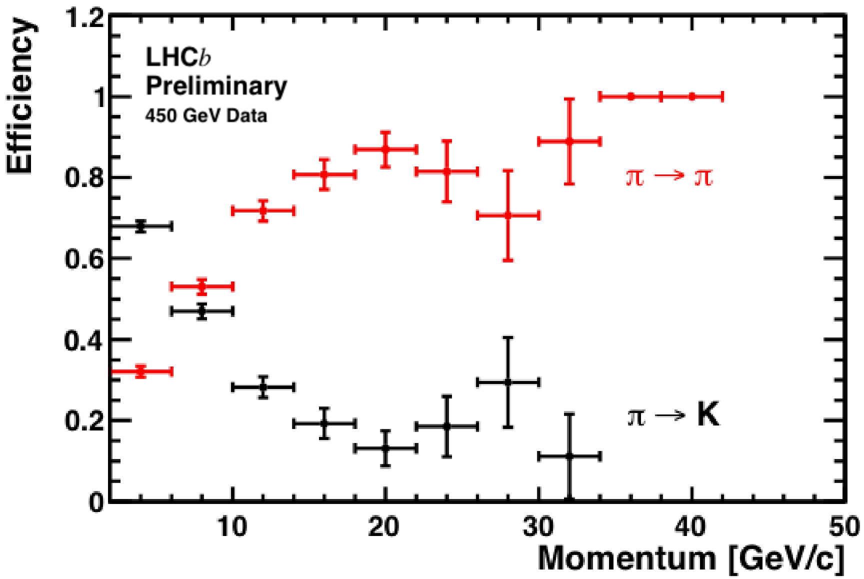
Corrections expected from survey: < 2 mrad or < 3 mm

RICH Performance Improvement

The performance of the RICH system is measured by its efficiency at separating between charged particle species, e.g. π vs. K:

[*see talk by A. Powell*]

Before Calibration



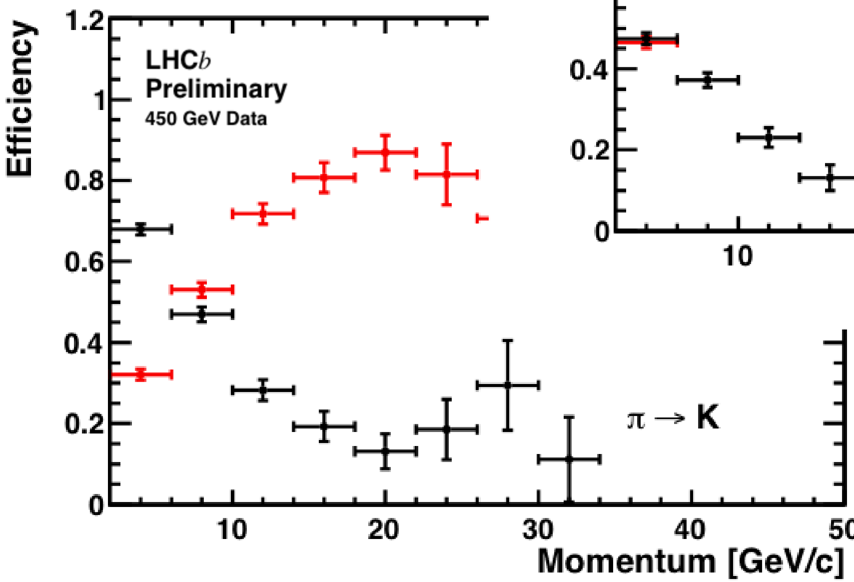
Using *known* π from selected K_S -> ππ decays, this example plot shows the efficiency of:

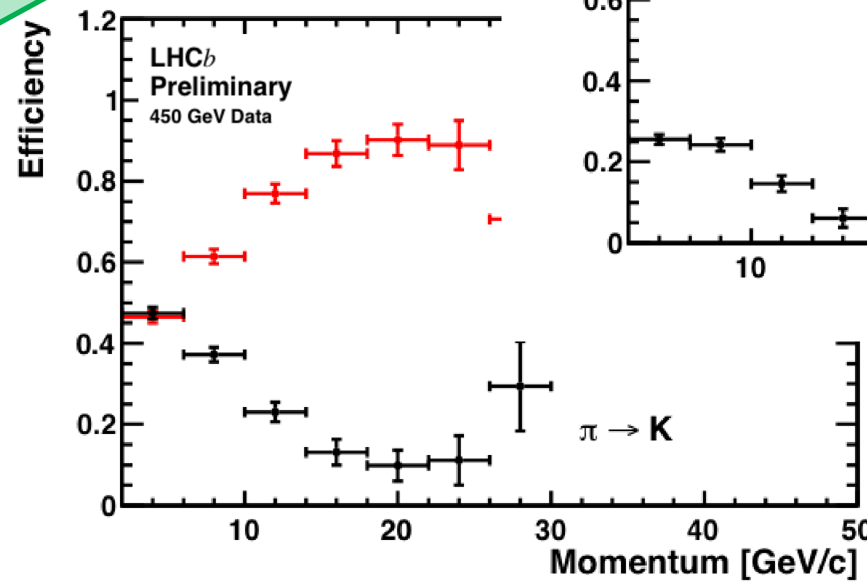
- **π identification**,
- **misidentification as a K**

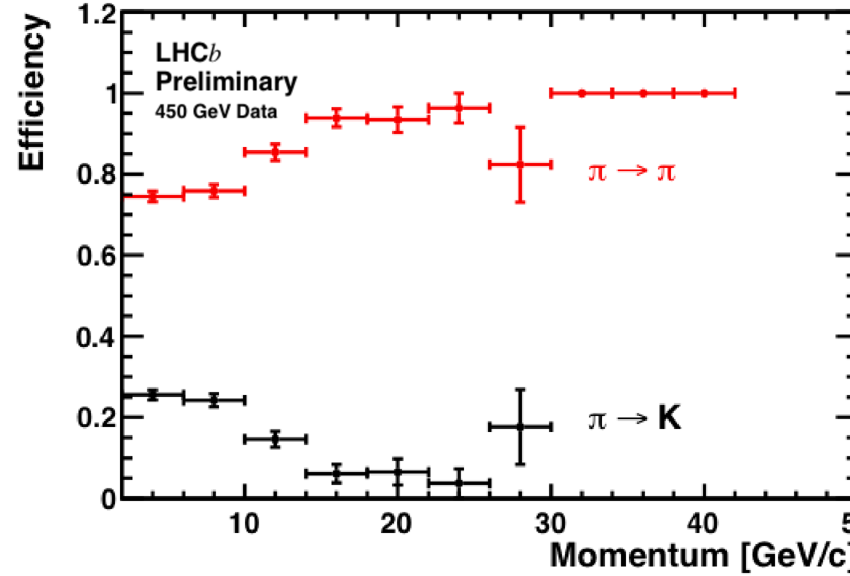
(*only considering these two possible hypotheses*).

RICH Performance Improvement

Improving Calibration







Better Tracking alignment, Magnetic field corrections & RICH alignment.

So far, so good…

RICH1 : 4.0 mrad	✓	2.2	…	1.6
RICH2 : 1.5 mrad		0.9		0.7

With more data we are starting to align more components:

- RICH1's (16) flat mirrors,
- RICH2's (40) flat and (56) spherical mirrors,
- (484) Photon detector chip centres.

Data can now be selected to target outer mirrors and we have preliminary results for automated systems for simultaneous alignment.

So far, so good...

RICH1 : 4.0 mrad ✓ 2.2 … 1.6

RICH2 : 1.5 mrad 0.9 0.7

Wit… …ents:

- R…
- R…
- (4…

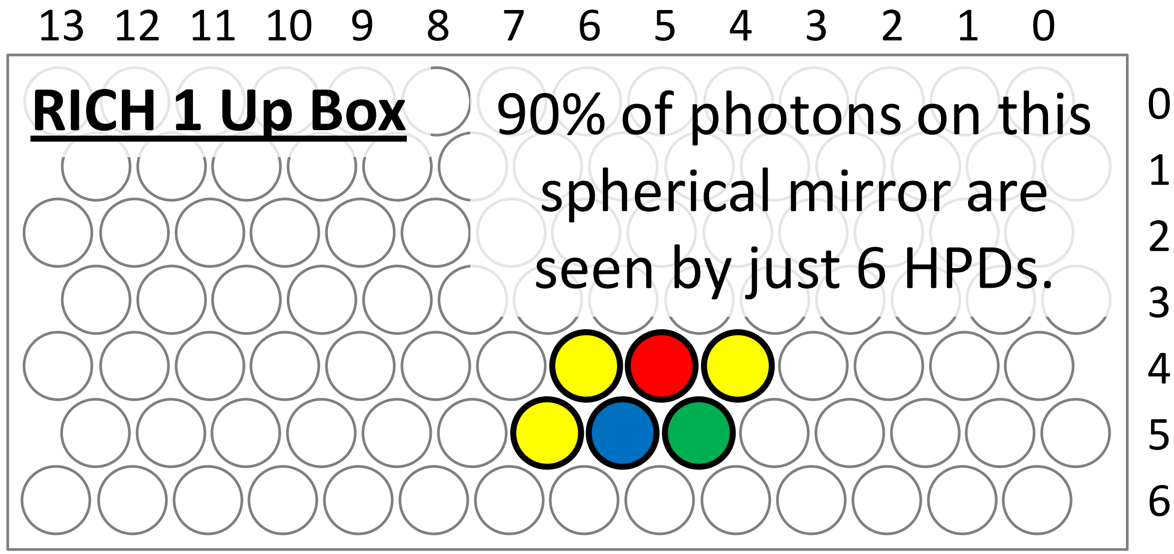
LATEST NEWS :

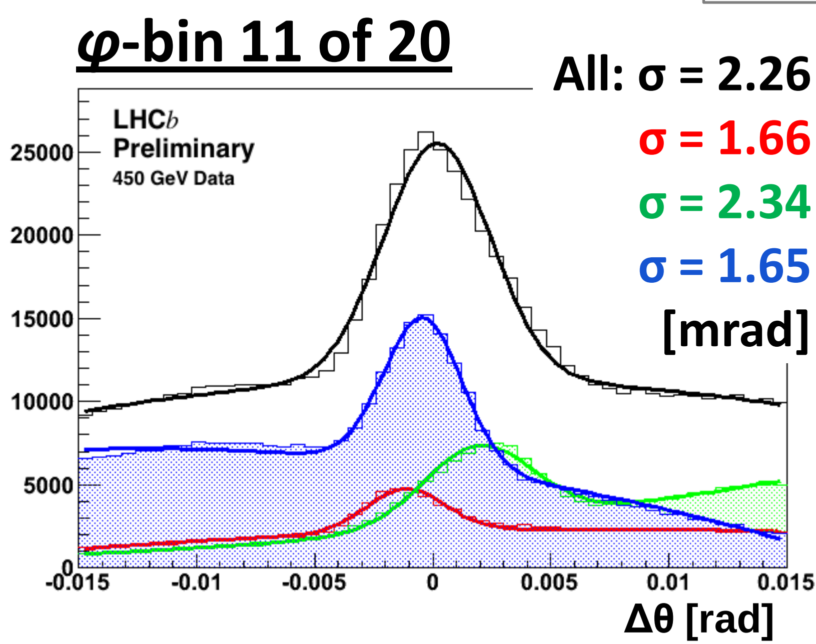
Preliminary results from a new demagnification factor for the photon detectors show RICH1 single-photon Δθ resolution -> **1.9 mrad**

Data can now be selected to target outer mirrors and we have preliminary results for automated systems for simultaneous alignment.

Photon Detector Misalignments

RICH data is dominated by a few central photon detectors, so their alignment is critical.





Red & Blue are close to MC target resolution in this φ-bin and just need to be aligned.

Green also requires some internal calibration.

Summary

- LHCb finally took collision data last year
- Calibration of magnetic field distortions achieved
- Alignment strategies successfully applied to real data
- PID performance is improving and we can do more

Great improvements throughout the LHCb collaboration

New Physics could be just around the corner!

Back up

Multiple Peaks in φ-bins