# Real-time alignment and calibration: the RICH systems

**22/06/2016**     **Claire Prouve - University of Bristol**          **LHCb Week**

presenting work by Anatoly, Antonis, Chris, <u>Claire</u>, Jibo, Paras and many more
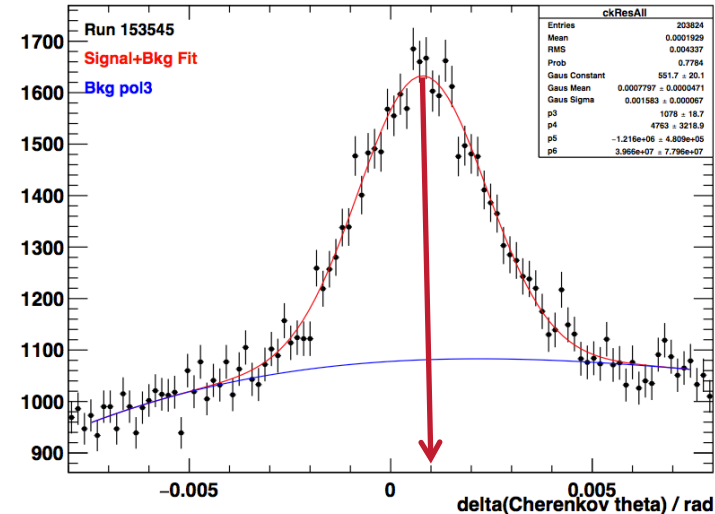
# Overview

- **RICH calibrations**

- **RICH mirror alignment**

  - **Procedure**

  - **Improvements during Run II**

- **Results**

# RICH calibrations

**Refractive index calibration:**

- Hardware sensors monitor pressure and temperature.
- Limited precision and does not account for gas mixture changes.
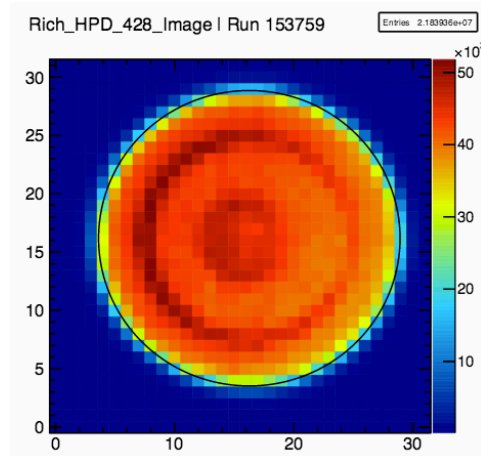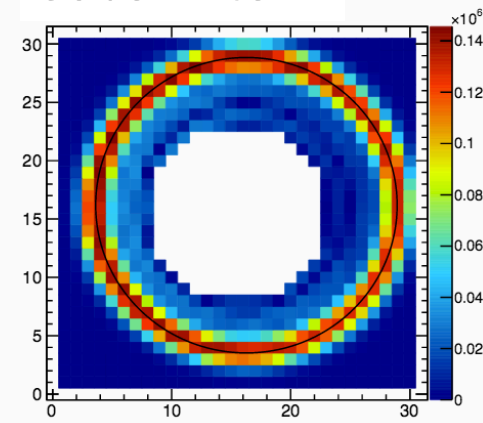- Simple fit to reconstructed-expected Cherenkov angle yields (n-1) scale factor.

**HPD image calibration:**

- Image fit performed for each HPD and used to provide calibration for the anode element.

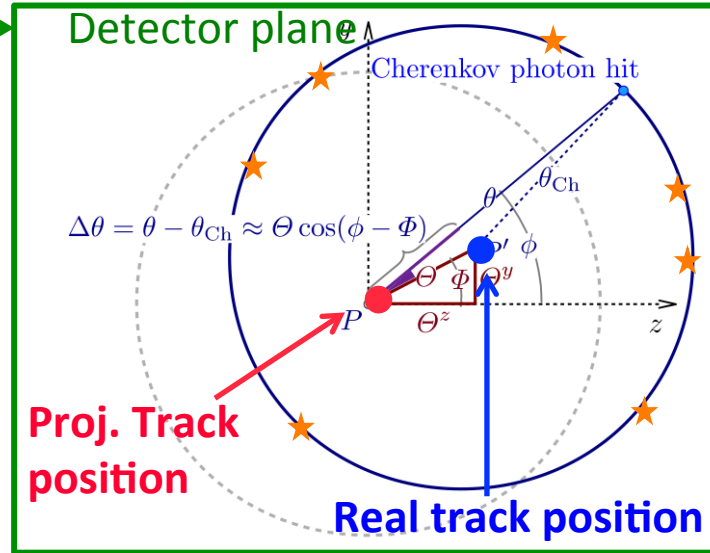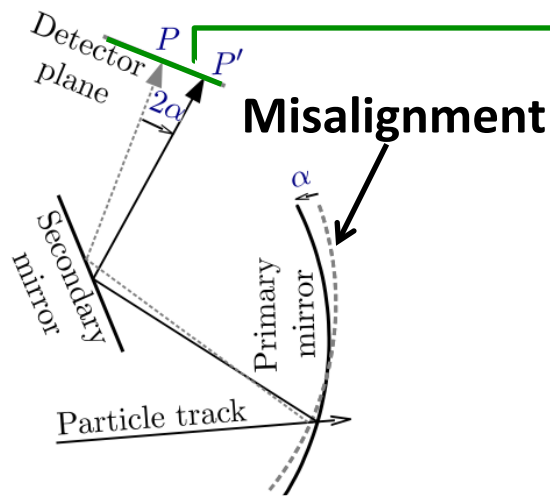**Fully automatically for every run since beginning of Run II.**



Rich1Gas Rec-Exp Cktheta | All photons



Rich_HPD_428_Image | Run 153759

**Sobel Filter**

# RICH mirror alignment



Detector plane

**Misalignment**

Secondary mirror

Primary mirror

Particle track

Detector plane

Cherenkov photon hit

$\Delta\theta = \theta - \theta_{Ch} \approx \Theta\cos(\phi - \Phi)$

$\theta_{Ch}$

$\theta$

$\Theta$ $\phi$ $\Phi$ $\Theta^y$

$\Theta^z$

$z$

**Proj. Track position**

**Real track position**

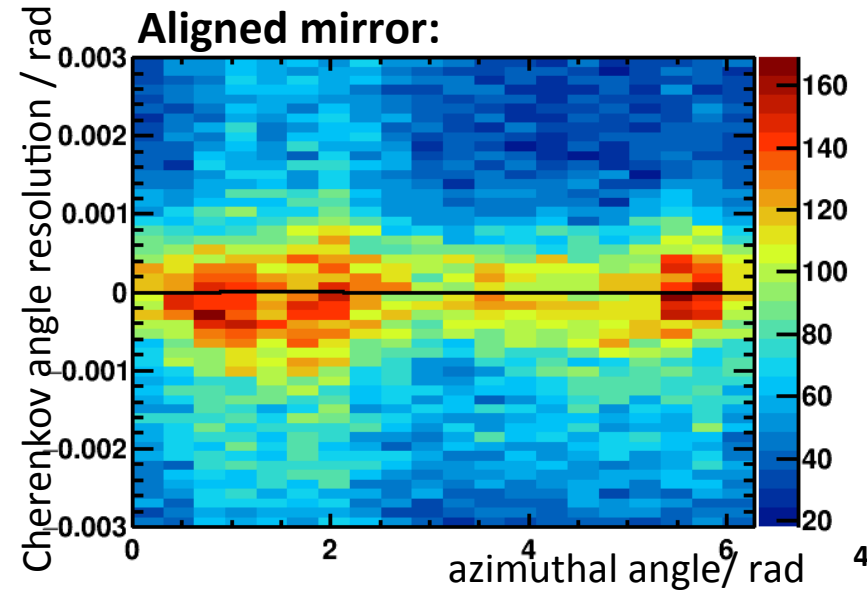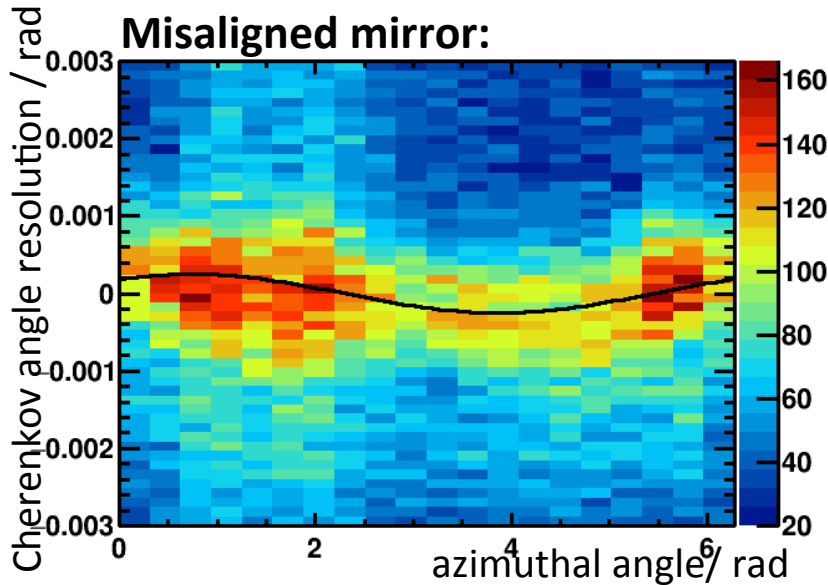**Identify misalignment:**

$$\Delta\theta_C(\Phi) = \theta_{meas.} - \theta_{exp.}$$

$$\Delta\theta_C(\Phi) = \Theta^y_{p,s}\cos(\Phi) + \Theta^z_{p,s}\sin(\Phi)$$

Misalignments on detector plane



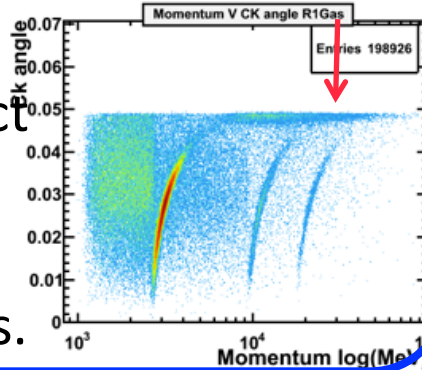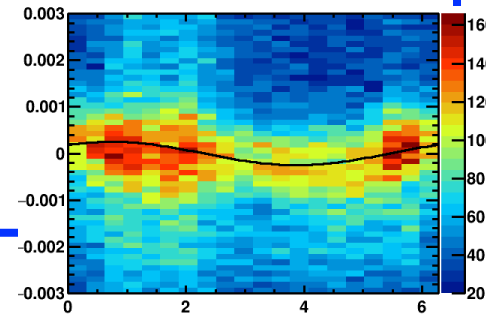**Misaligned mirror:**

Cherenkov angle resolution / rad

azimuthal angle/ rad



**Aligned mirror:**

Cherenkov angle resolution / rad

azimuthal angle/ rad

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# Mirror alignment procedure

**Events** → **Select high momentum tracks + reconstruct under pion-hypothesis.**



**database** →

→ **Fill histograms with (Δθ vs. Φ) of unambiguous photons for each mirror com-bination.**



**Replace database and perform another iteration.**

**Alignment converged!**

NO

YES

**Produce new database and verify if the convergence criteria was met.**

← **Fit misalignment on the detector plane and determine individual mirror misalignments.**

# Development during Run II

| | Reco. | Mode | Improvements | Time per alignment |
|---|---|---|---|---|
| Run I | Ganga | manually | | Several days |
| Run II | HLT farm | manually | • **Migrated to online**<br>• **Dedicated HLT1 lines** | ~4 hours |
| Run II end of 2015 | HLT farm | manually | • Using **pre-calculated magnification coefficients**<br>• Improved method for fitting 2D histograms | ~**20 minutes** |
| Run II beginning of 2016 | HLT farm | **automatic for every fill** | • **L2 regularization method** for finding individual mirror tilts<br>• **New CondDB** | ~**10 minutes after mag. flip:**<br>~**30 minutes for RICH1** |
| Run II end of June 2016 | HLT farm | automatic for every fill | • **Different convergence criteria** for primary/ secondary mirrors in y/z<br>• Calculation of **difference between final alignment and alignment in CondDB** | ~**10 minutes for each RICH detector** |

RICH1 2016 primary mirror tilts in Y

RICH1 2016 primary mirror tilts in Z
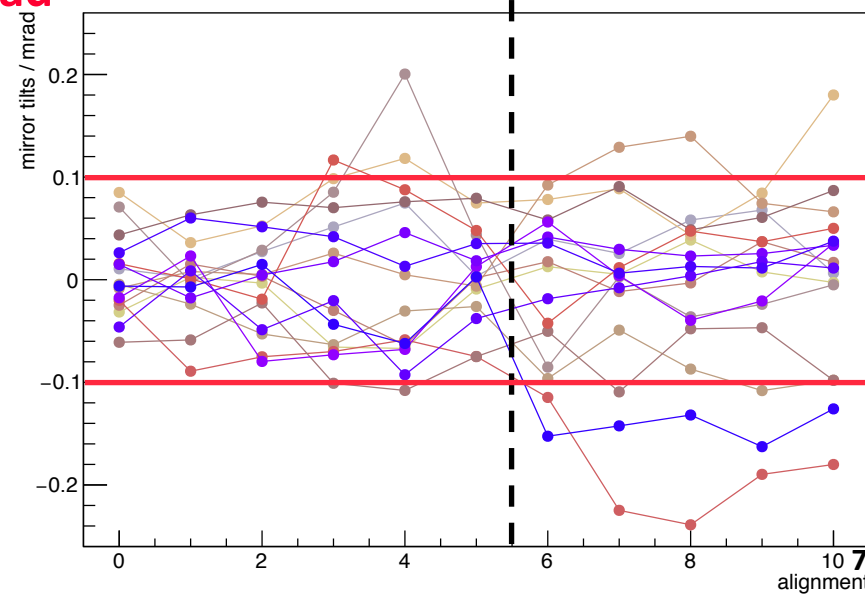
Mag Down ← – – – → Mag Up
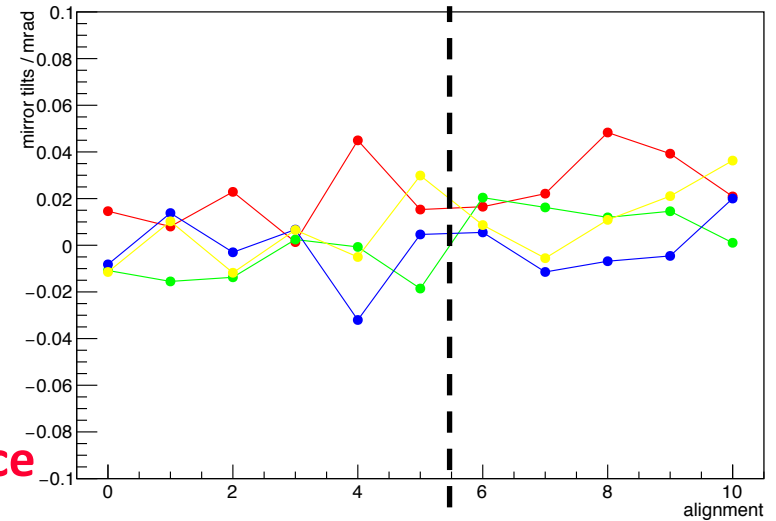
**Convergence criteria 0.1 mrad**
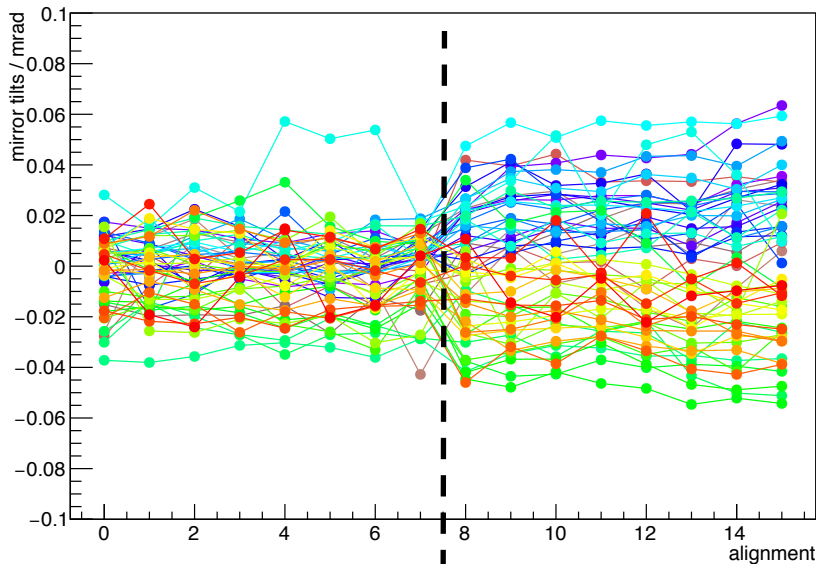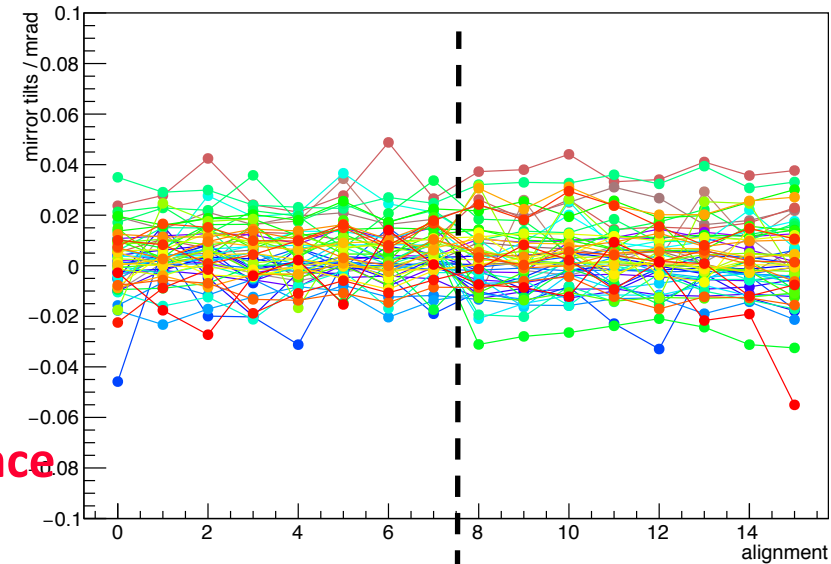
RICH1 2016 secondary mirror tilts in Y
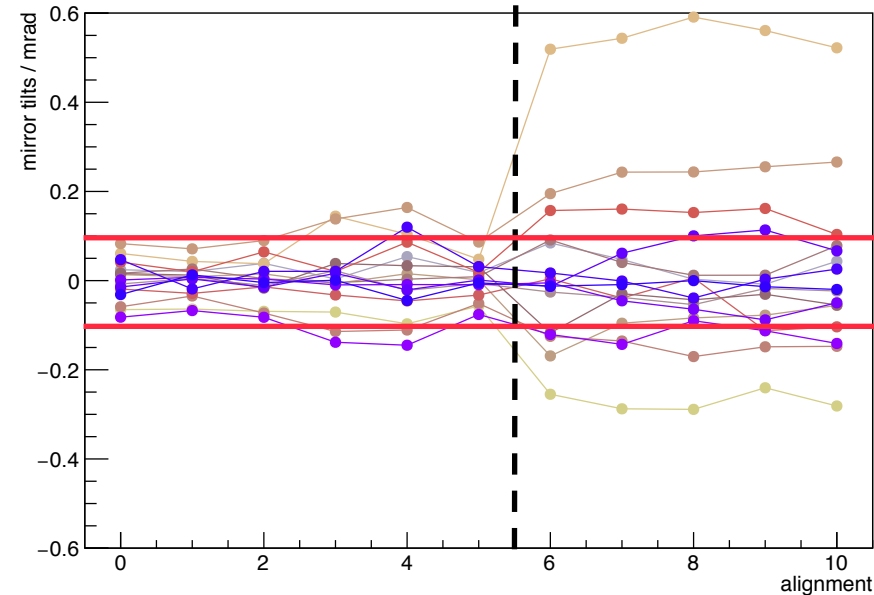
RICH1 2016 secondary mirror tilts in Z

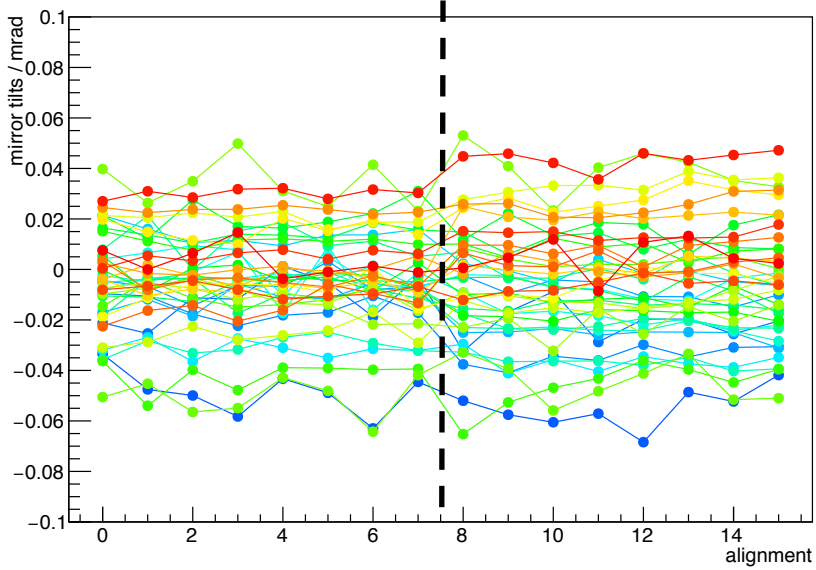# Stability of tilts – RICH2

RICH2 2016 primary mirror tilts in Y

RICH2 2016 primary mirror tilts in Z

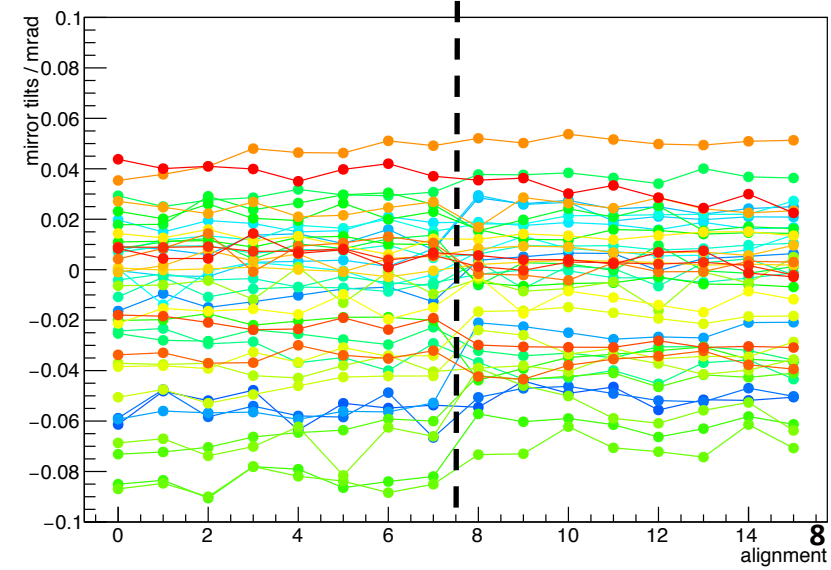

RICH2 2016 secondary mirror tilts in Y

RICH2 2016 secondary mirror tilts in Z
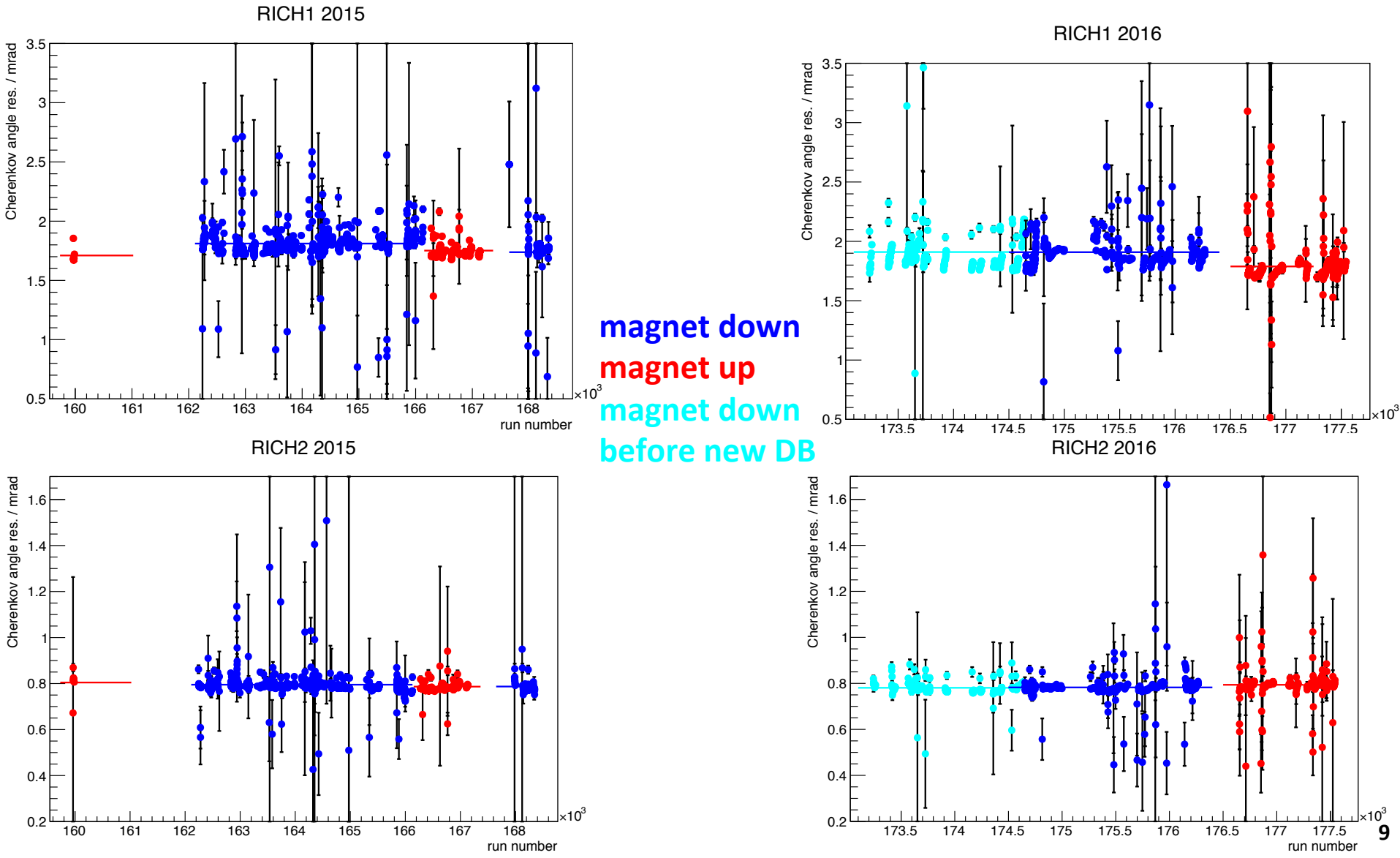
**Convergence criteria 0.1 mrad**

# Stability of Resolution

**Resolutions from refractive index calibration (without HPD image correction).**



RICH1 2015

RICH1 2016

RICH2 2015

RICH2 2016

**magnet down**
**magnet up**
**magnet down**
**before new DB**

# Current monitoring

https://lbgroups.cern.ch/rich/calibview.php
https://lbgroups.cern.ch/rich/alignmentview.php

# Summary

- RICH calibrations run online for every run

- RICH mirror alignment runs online for every fill

- Several improvements in stability and speed

- Information from frequently run alignments to understand and make improvements

-  Monitoring plots for the RICH piquet

# Backup

# Cherenkov angle resolution

Limiting factors to Cherenkov angle resolution:

| | $\sigma$ [mrad] | | |
| --- | --- | --- | --- |
| | RICH1 | | RICH2 |
| | Aerogel | $C_4F_{10}$ | $CF_4$ |
| Emission point | 0.4 | 0.8 | 0.2 |
| Chromatic dispersion | 2.1 | 0.9 | 0.5 |
| Pixel size | 0.5 | 0.6 | 0.2 |
| Tracking | 0.4 | 0.4 | 0.4 |
| Total | 2.6 | 1.5 | 0.7 |

# Fit to 2D histograms

**Misaligned mirrors:**



**Aligned mirrors:**





**Signal:**
**Gaussian**

**BKG:**
**2nd order polynomial**
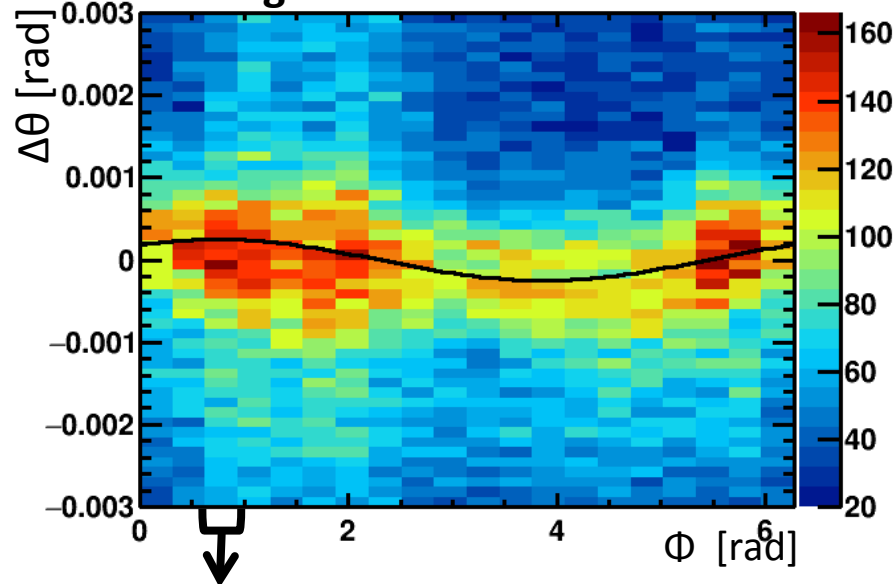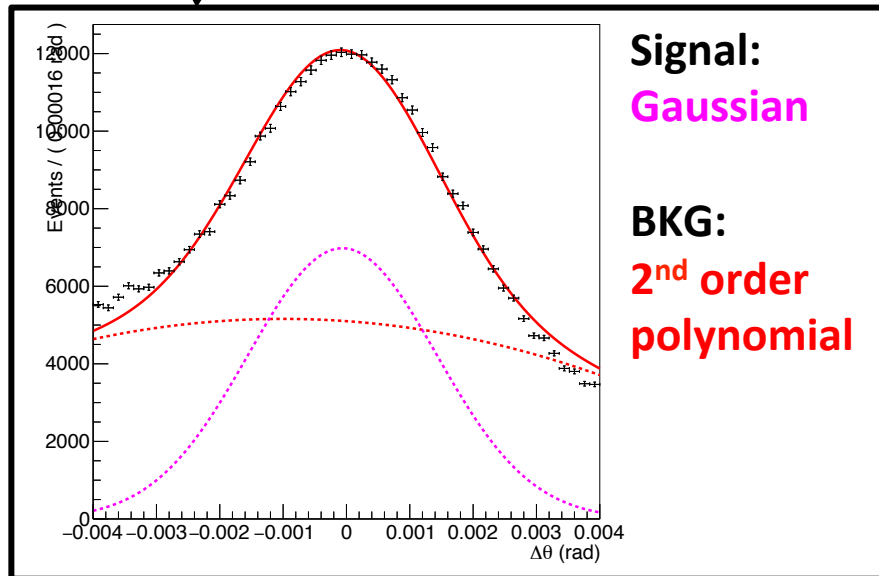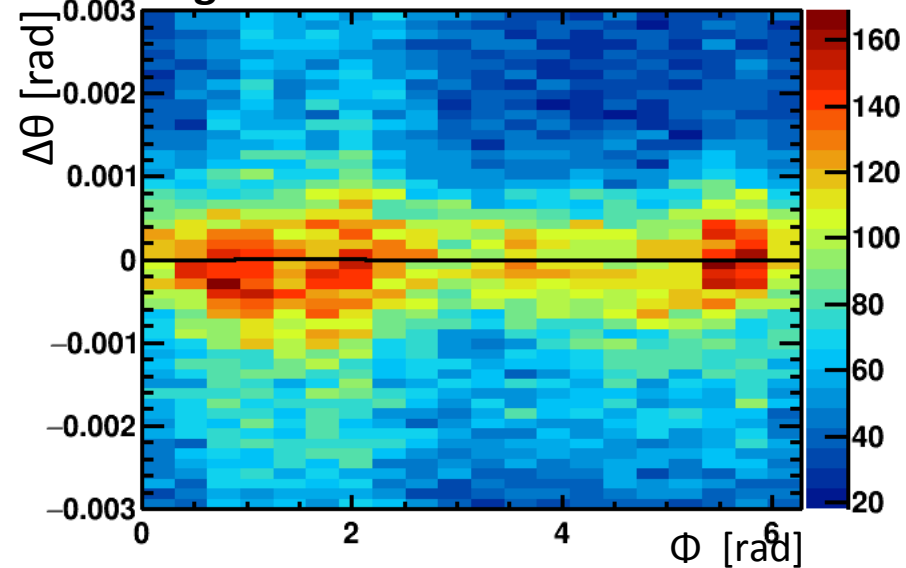
Means of Gaussians connected by:

$$\Delta\theta_C(\Phi) = \Theta^y_{p,s} \cos(\Phi) + \Theta^z_{p,s} \sin(\Phi)$$

# Magnification coefficients

Magnification coefficients: Translate the tilt on the detector plane into actual mirror tilts

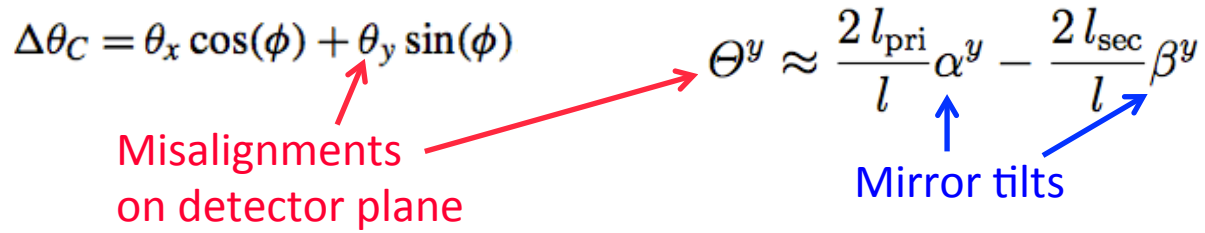$$\Delta\theta_C = \theta_x \cos(\phi) + \theta_y \sin(\phi)$$

$$\Theta^y \approx \frac{2\,l_{\text{pri}}}{l}\alpha^y - \frac{2\,l_{\text{sec}}}{l}\beta^y$$

Misalignments
on detector plane

Mirror tilts

Magnification coefficients are calculated new for each iteration:

- Introduce 8 rotations: primary and secondary mirrors rotated around ±y and ±z axis respectively

- Rotate about 0.3 mrad ( half the resolution of RICH2)

- Reconstruct events for each rotation and evaluate the tilts on the detector plane

**Need to reconstruct all events 9 times!**

$$\Theta^y \approx 2.0\,\alpha^y - 0.9\,\beta^y \quad \text{and} \quad \Theta^z \approx 1.8\,\alpha^z + 0.6\,\beta^z.$$
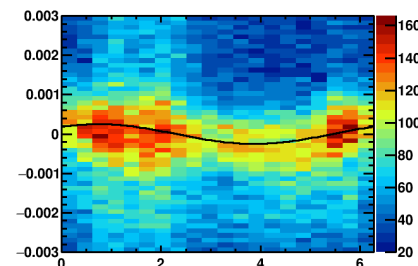
# Disentangling mirror-pairs

Each pair of **primary mirror $p$** and **secondary mirror $s$** has 2 equations:

$$A^y_{p,s}\alpha^y_p + B^y_{p,s}\beta^y_s + a^y_{p,s}\alpha^z_p + b^y_{p,s}\beta^z_s = \Theta^y_{p,s}$$
$$A^z_{p,s}\alpha^z_p + B^z_{p,s}\beta^z_s + a^z_{p,s}\alpha^y_p + b^z_{p,s}\beta^y_s = \Theta^z_{p,s}$$

<span style="color:blue">Magnification factors</span>   <span style="color:red">individual mirror tilts</span>
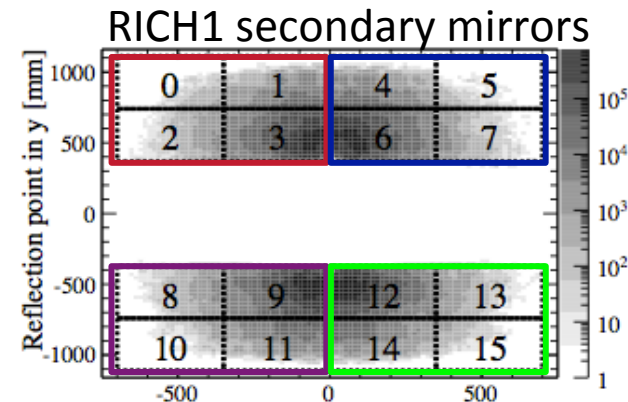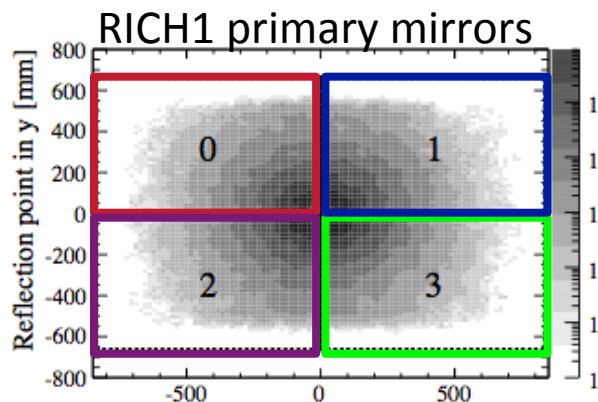
$$\Delta\theta_C(\Phi) = \Theta^y_{p,s}\cos(\Phi) + \Theta^z_{p,s}\sin(\Phi)$$



**Challenge:** not enough information to fully constrain the solution

RICH1: 8 equations for 10 unknowns

Rotation of primary mirrors followed by according rotation of secondary mirrors yields same results
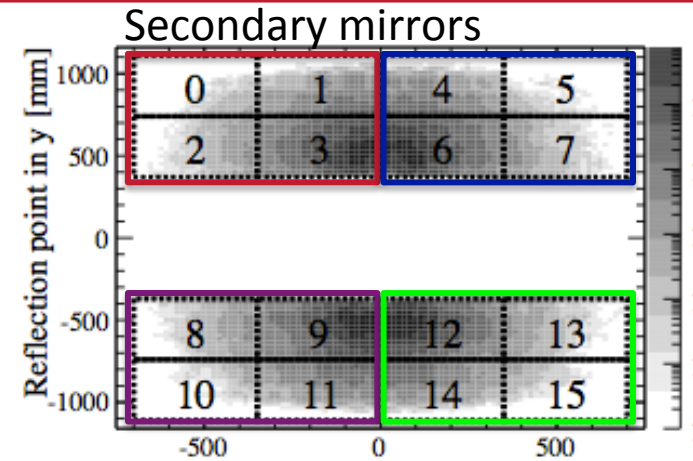


RICH1 primary mirrors



RICH1 secondary mirrors

➔ **Need additional constraint**

**RICH1:**
- fix primary mirrors, align secondary mirrors
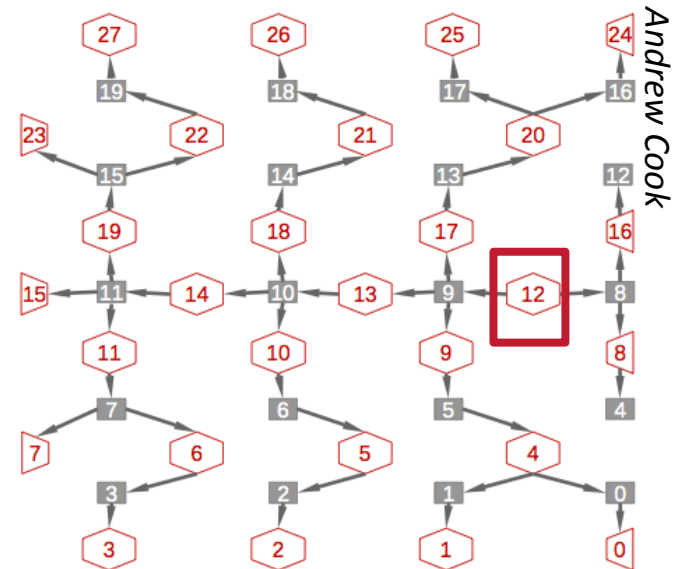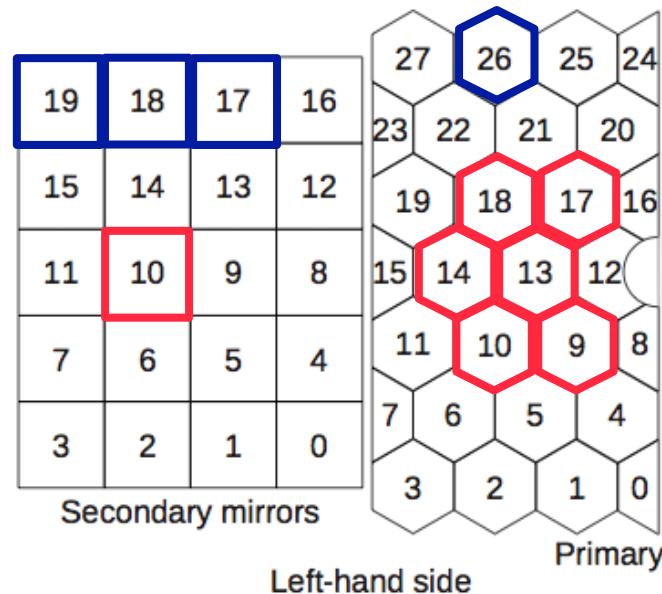
Primary mirrors

Secondary mirrors

**RICH2:**
- Left half: system of equations linking all mirrors starting from primary mirror 12.

Secondary mirrors

Left-hand side

Primary

*Andrew Cook*

27 primary mirrors,  18 secondary mirrors **17**

# Disentangling – from 2016

**L2 regularization** (ridge regression):

- rewrite problem as $A\mathbf{x} = \mathbf{b}$

  Matrix of
  magnification factors

  Vector of individual
  mirror tilts

  Vector of results
  of fit to histograms

- Minimize: $\underbrace{\|A\mathbf{x} - \mathbf{b}\|^2}_{\text{least square method}} + \underbrace{\|\Gamma\mathbf{x}\|^2}_{\text{L2 regularization term}}$

## Advantages:

- more stable than the previous method

- Stable w.r.t. small statistical fluctuations (unlike L1 regularization)
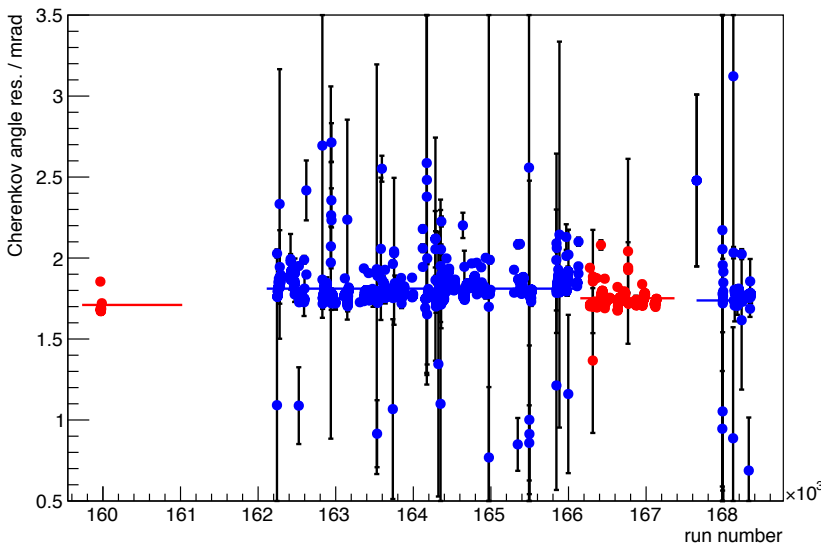
➡ **Fewer iterations needed to converge**

# Resolution



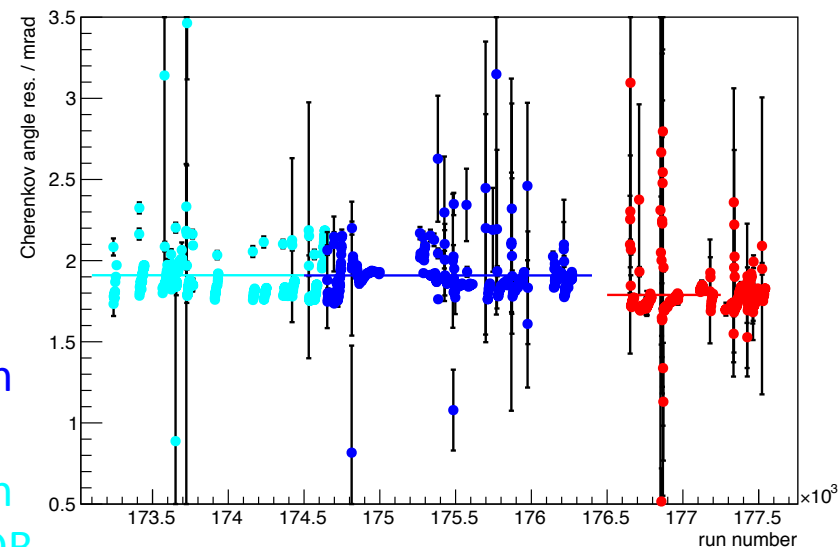RICH1 Online Brunel Cherenkov Resolution (Excluding HPD Image Corrections)
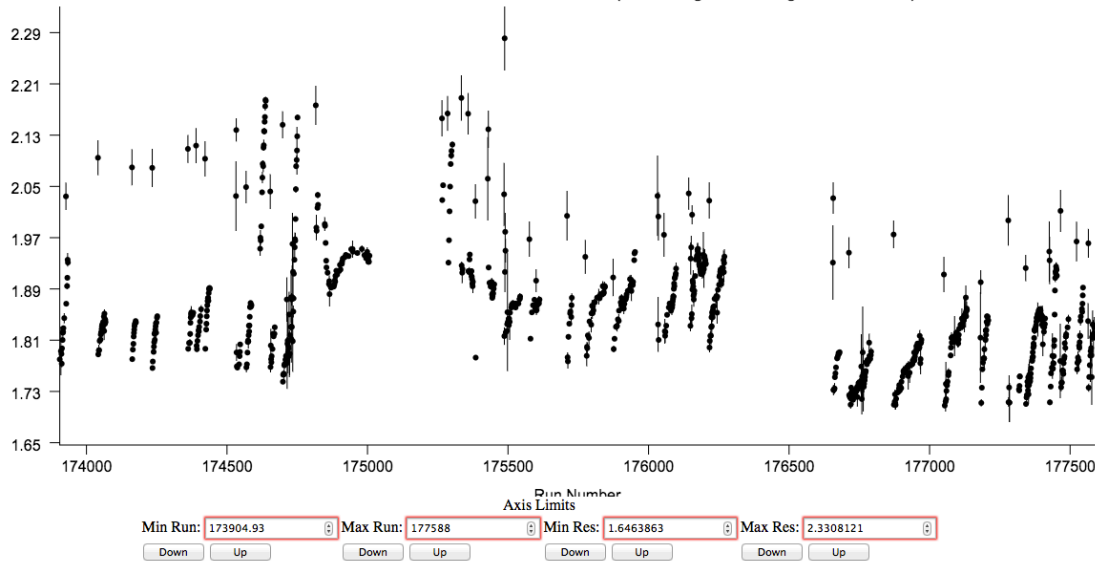
Without HPD image correction:
Degradation of resolution over fill.
➔ Longer fills in 2016

RICH1 2015

RICH1 2016

magnet down
magnet up
magnet down before new DB

# New HLT Lines

- Trigger on tracks that will populate the hardest-to-populate mirror-pairs

➔ usually the very outer mirrors

- Other tracks in the events will populate the rest

**RICH2 line**:
p > 40 GeV  **&&**  $\chi^2 < 2$  **&&**  $2.65 < \eta < 2.80$
$(-2.59 < \Phi < -2.49)$ **||** $(-0.65 < \Phi < -0.55)$ **||**
$(0.45 < \Phi < 0.65)$ **||** $(2.49 < \Phi < 2.59)$

**RICH1 line**:
p > 10 GeV  **&&**  $\chi^2 < 2$  **&&**  $1.6 < \eta < 2.04$
$(-2.65 < \Phi < -2.3)$ **||** $(-0.8 < \Phi < -0.5)$ **||**
$(0.5 < \Phi < 0.8)$ **||** $(2.3 < \Phi < 2.65)$

**Need to reconstruct ~10 times less events!**



RICH2

Track azimuthal angle / rad

Track pseudorapidity



RICH1

Track pseudorapidity