

Real-time alignment and calibration: the RICH systems

02/06/2016

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LHCb Week

presenting work by Anatoly, Antonis, Chris, Claire, Jibo, Paras and many more

Overview

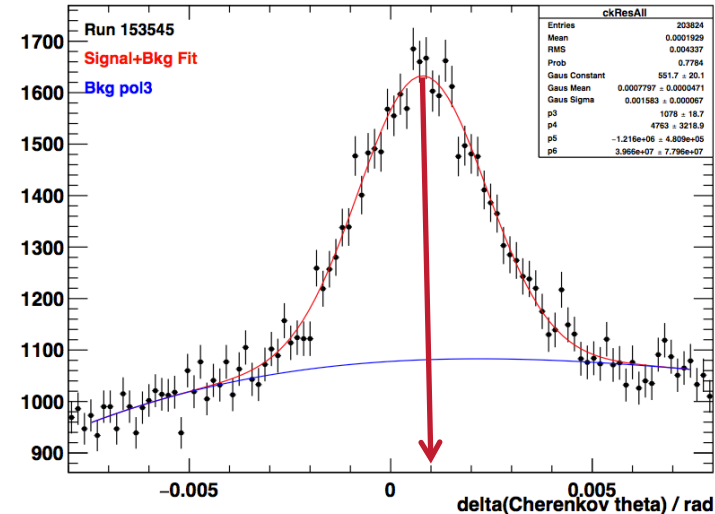
- **RICH calibrations**
- **RICH mirror alignment**
 - **Procedure**
 - **Improvements during Run II**
- **Results**

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.

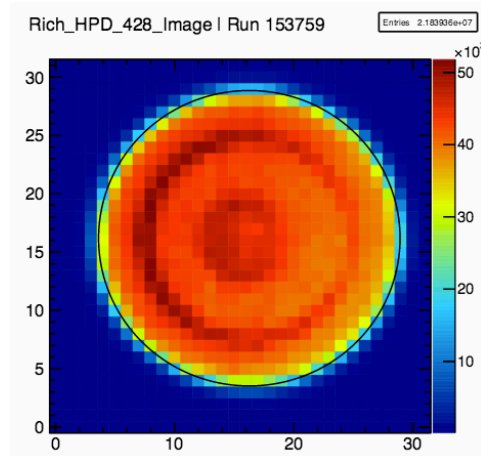
Rich1Gas Rec-Exp Cktheta | All photons



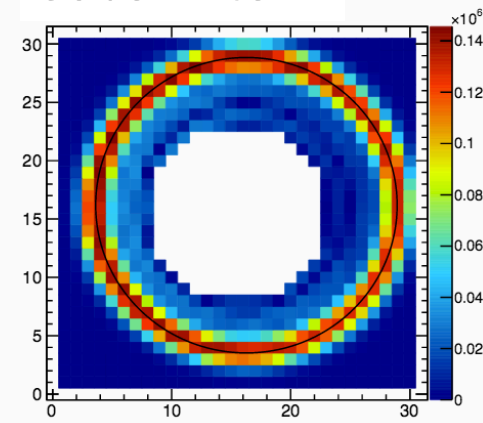
HPD image calibration:

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

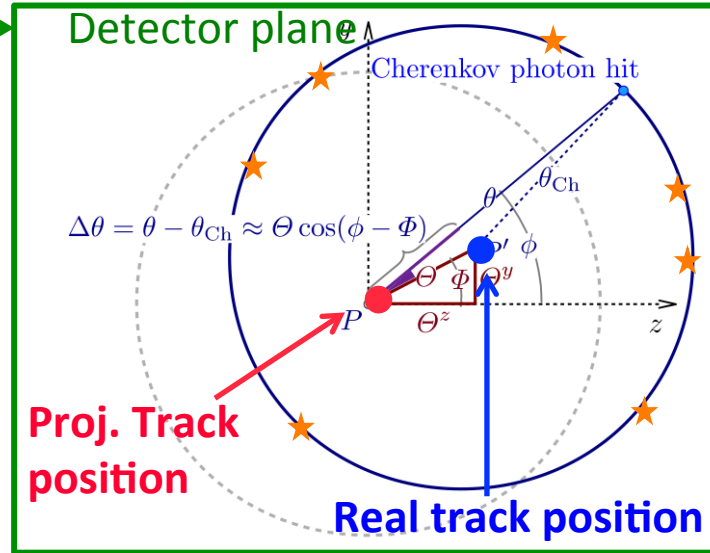
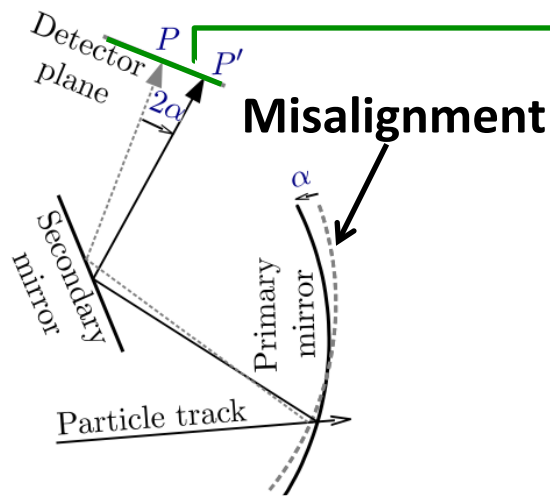
Fully automatically for every run since beginning of Run II.



Sobel Filter



RICH mirror alignment

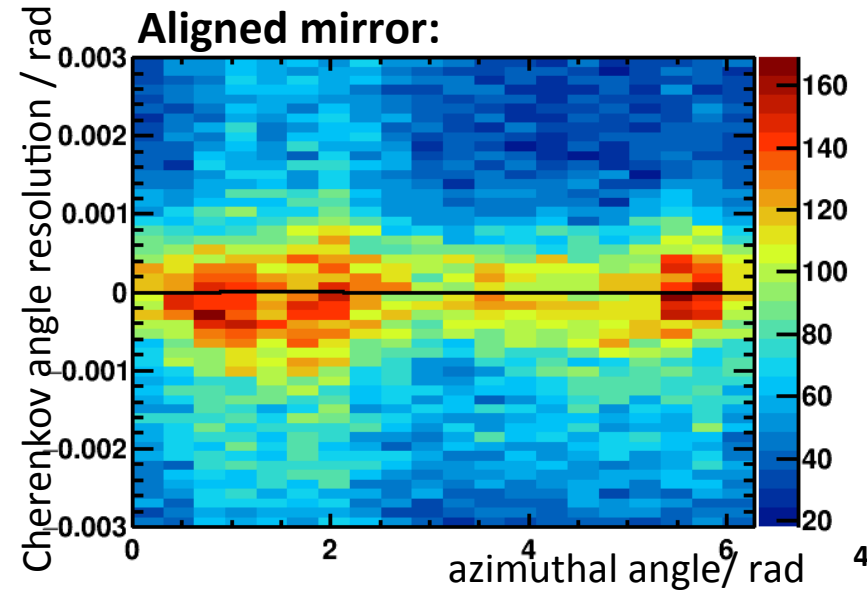
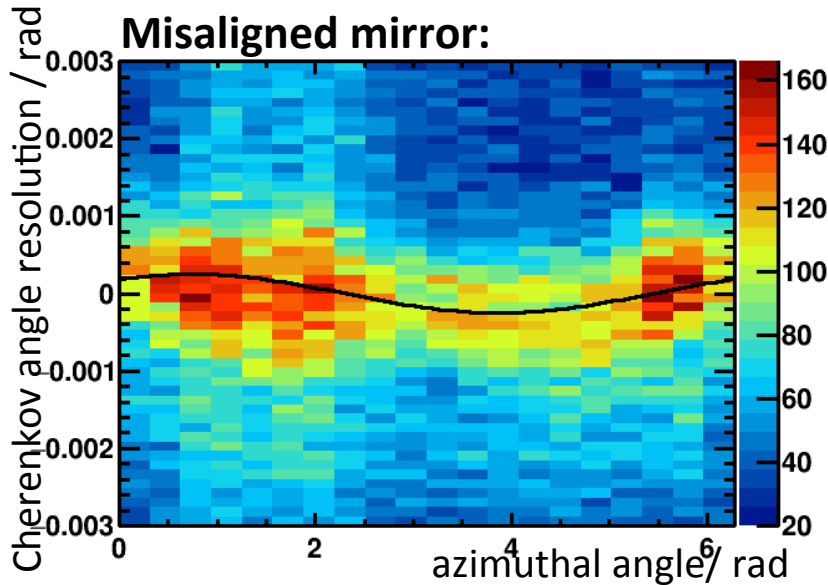


Identify misalignment:

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

$$\Delta\theta_c(\Phi) = \Theta_{p,s}^y \cos(\Phi) + \Theta_{p,s}^z \sin(\Phi)$$

Misalignments on detector plane

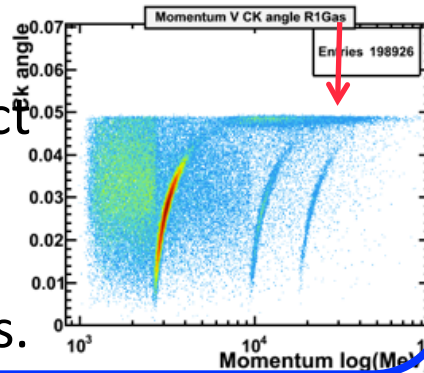


Mirror alignment procedure

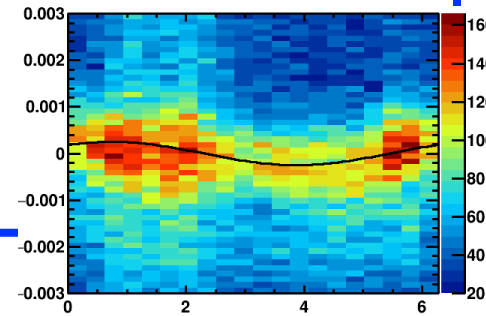
Events

database

Select high momentum tracks + reconstruct under pion-hypothesis.



Fill histograms with ($\Delta\theta$ vs. Φ) of unambiguous photons for each mirror combination.



Replace database and perform another iteration.

Alignment converged!

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

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

Y			
-.5	.9	.0	.7
-.2	.0	.1	.1
.0	.0	.2	.6
-.7	.8	-.9	.6

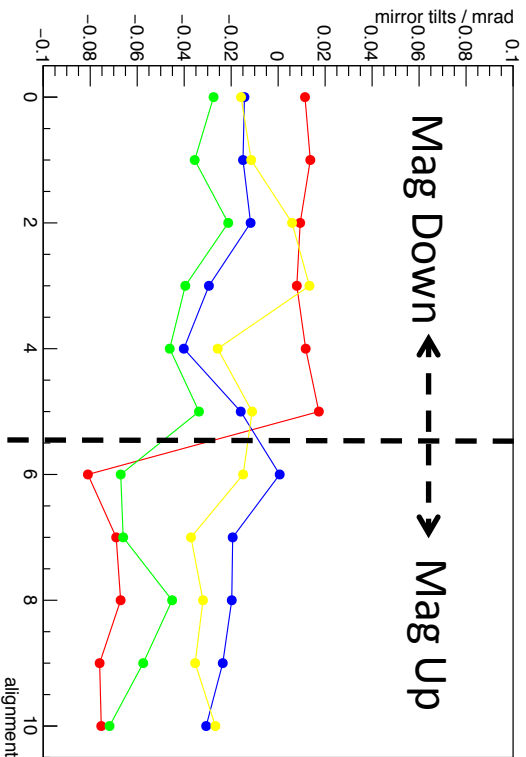
Z			
.2	.3	.3	.3
-.5	-.3	-.2	-.6
.6	.1	.1	.5
-.6	-.1	.6	-.3

Development during Run II

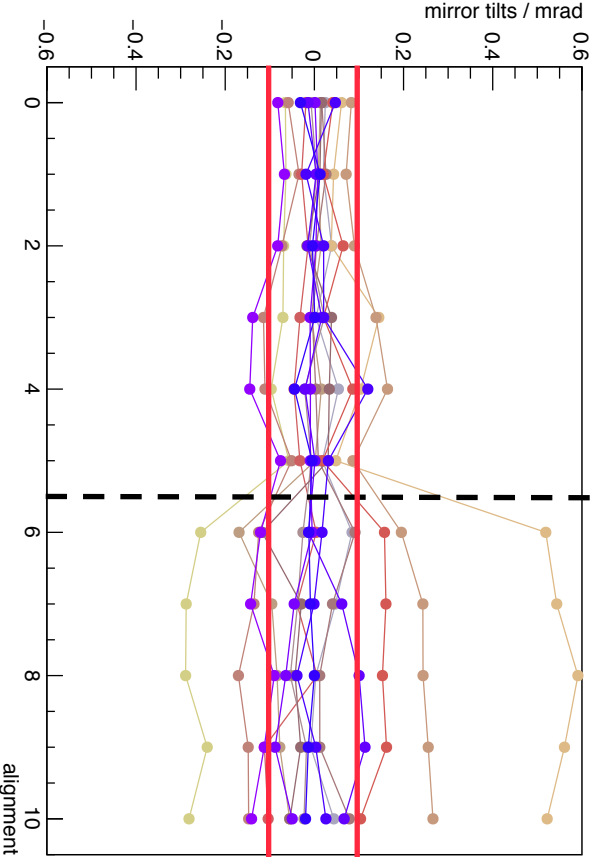
	Reco.	Mode	Improvements	Time per alignment
Run I	Ganga	manually		Several days
Run II	HLT farm	manually	Migrated to online	~4 hours
Run II end of 2015	HLT farm	manually	<ul style="list-style-type: none"> • Using pre-calculated magnification coefficients • Improved method for fitting 2D histograms 	~20 minutes
Run II beginning of 2016	HLT farm	automatic for every fill	<ul style="list-style-type: none"> • L2 regularization method for finding individual mirror tilts • New CondDB 	~10 minutes after mag. flip: ~30 minutes for RICH1
Run II end of June 2016	HLT farm	automatic for every fill	<ul style="list-style-type: none"> • Different convergence criteria for primary/secondary mirrors in y/z • Calculation of difference between final alignment and alignment in CondDB 	~10 minutes for each RICH detector

Stability of tilts – RICH1

RICH1 2016 primary mirror tilts in Y



RICH1 2016 secondary mirror tilts in Y

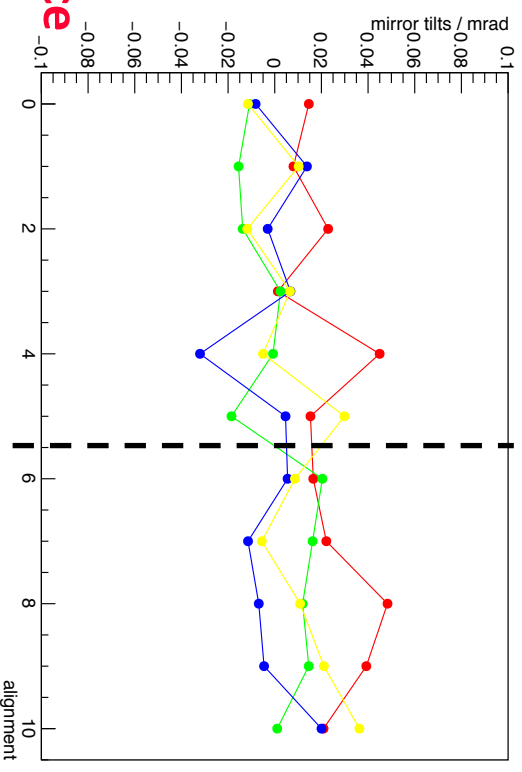


Convergence

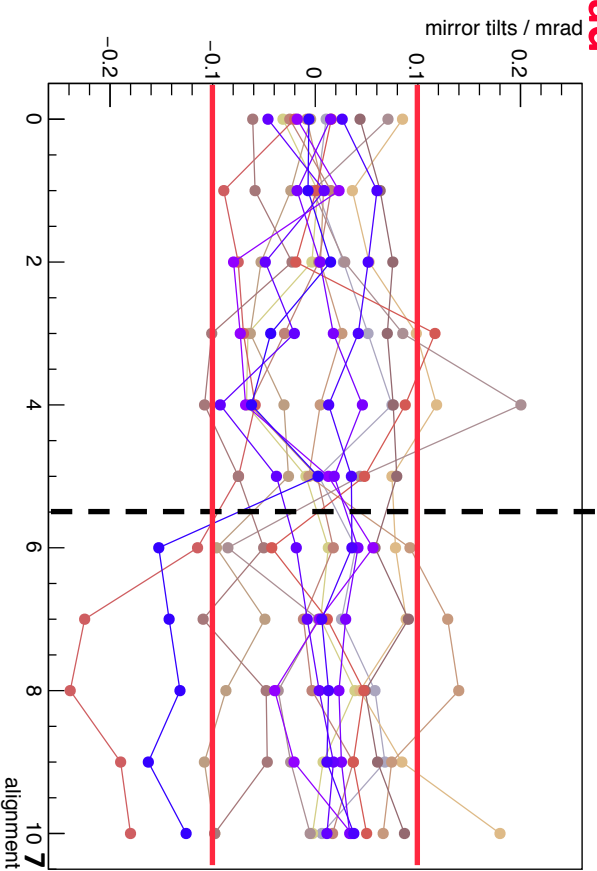
criteria

0.1 mrad

RICH1 2016 primary mirror tilts in Z

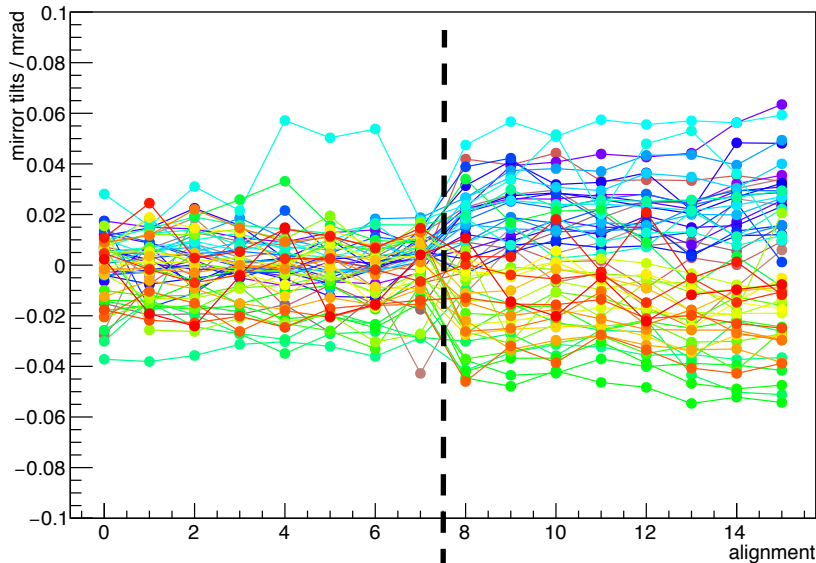


RICH1 2016 secondary mirror tilts in Z

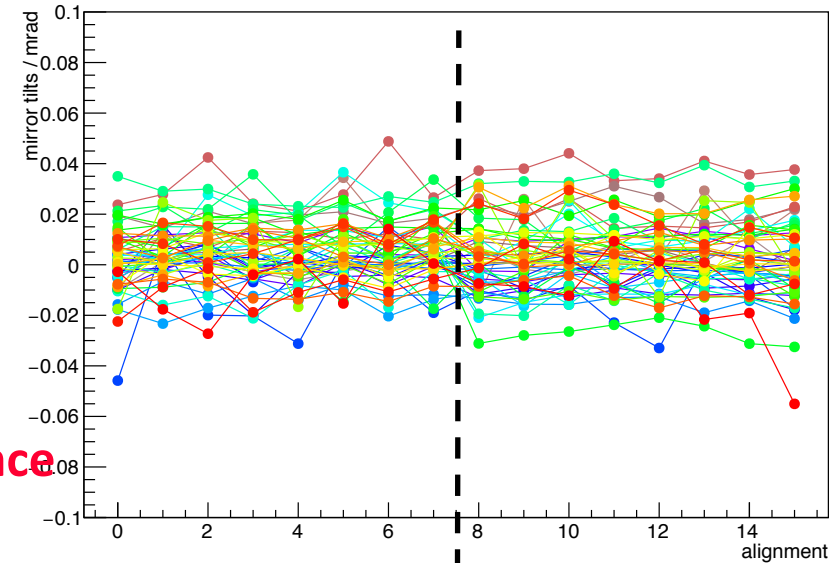


Stability of tilts – RICH2

RICH2 2016 primary mirror tilts in Y

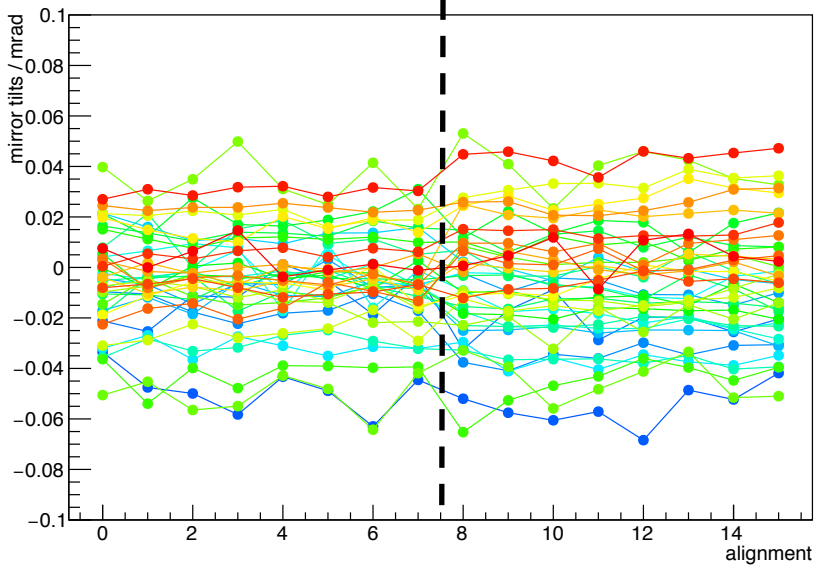


RICH2 2016 primary mirror tilts in Z

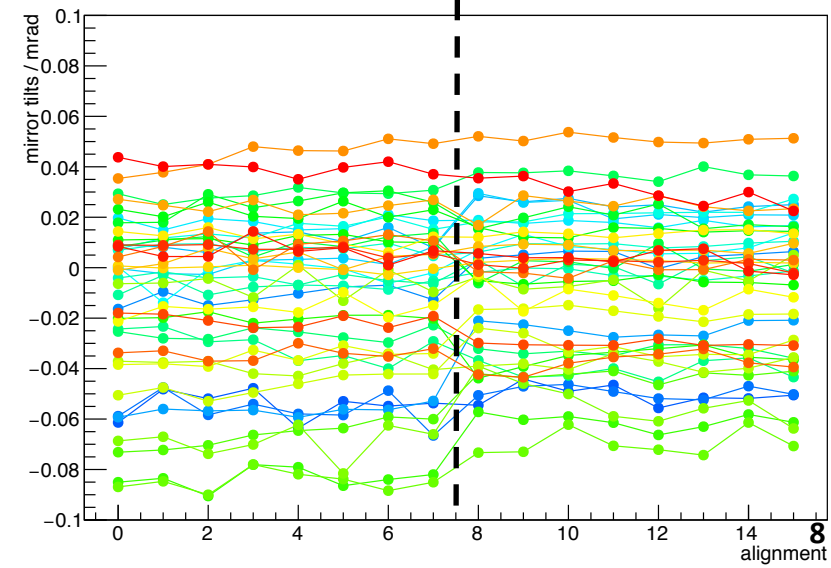


Convergence
criteria
0.1 mrad

RICH2 2016 secondary mirror tilts in Y

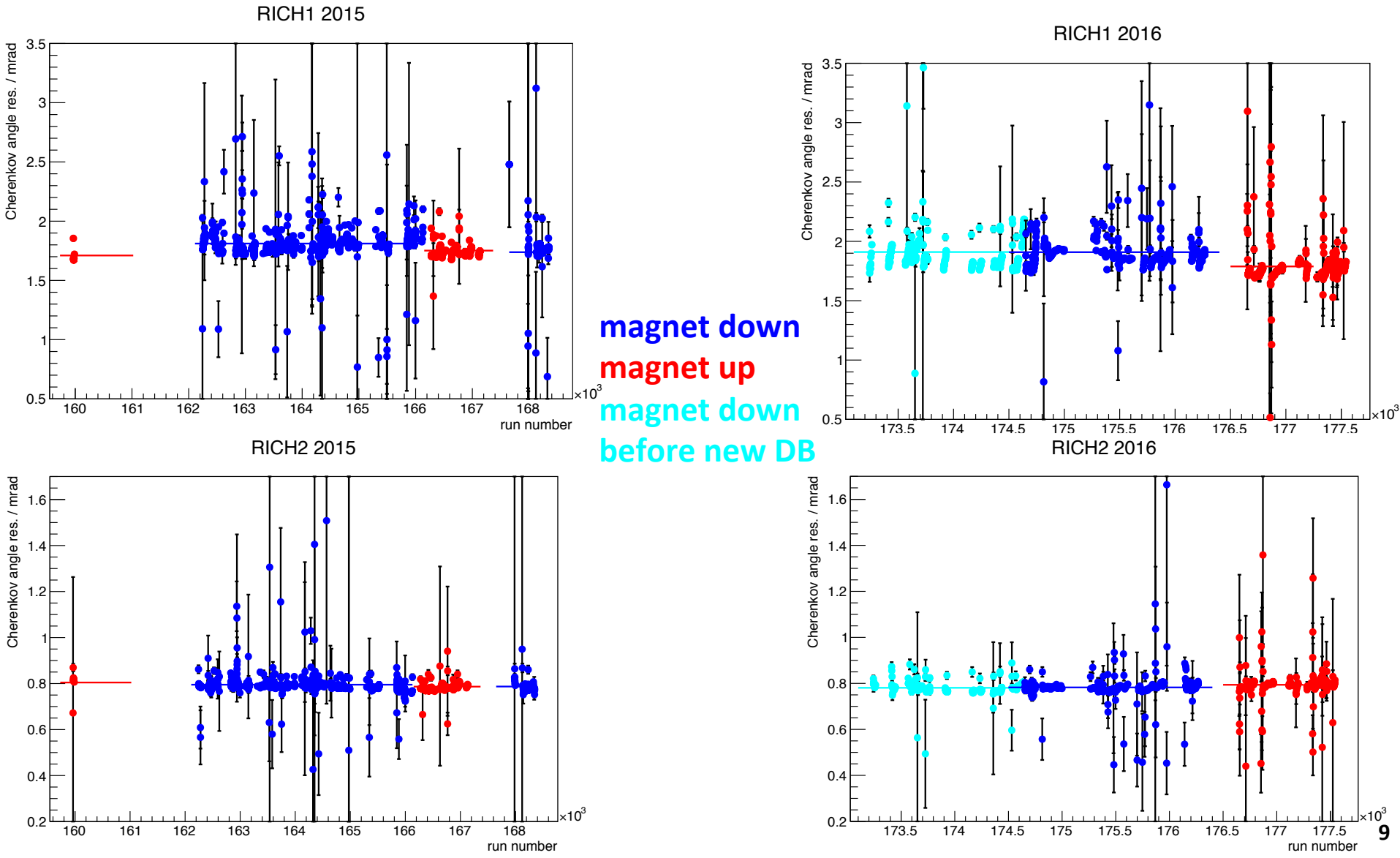


RICH2 2016 secondary mirror tilts in Z



Stability of Resolution

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



Current monitoring

<https://lbgroups.cern.ch/rich/calibview.php>

<https://lbgroups.cern.ch/rich/alignmentview.php>

RICH alignment summaries

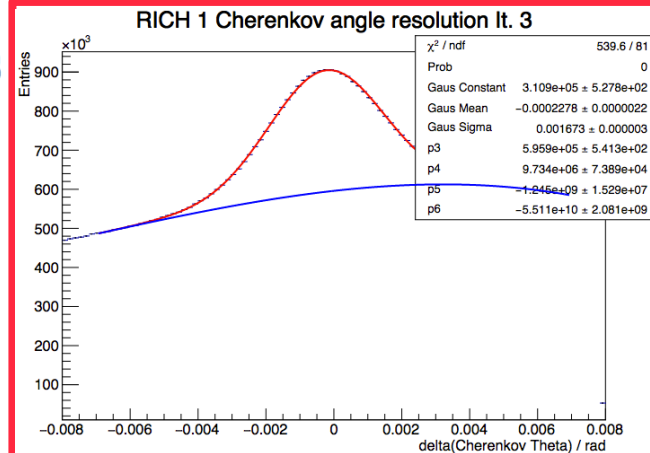
Date: 2016/06/16

End date: 2016/06/20

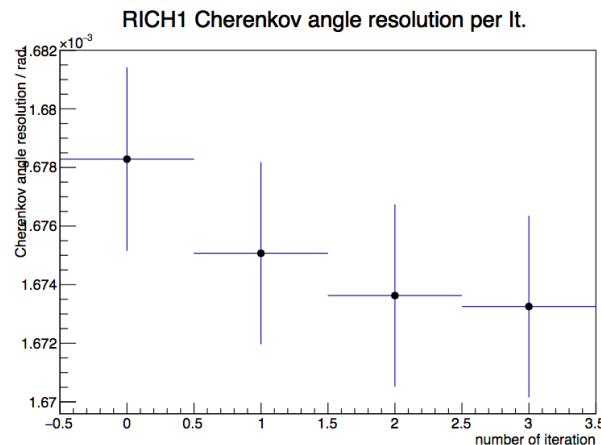
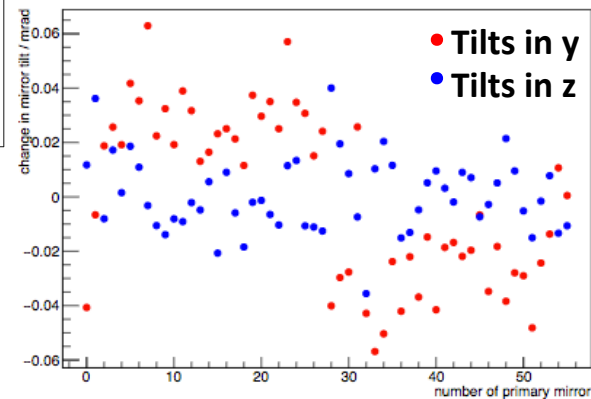
☒ Use end date?

Submit Query

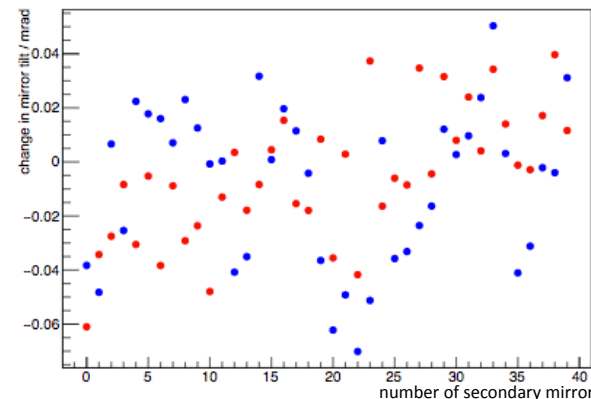
RICH 1 alignments	RICH 2 alignments
20160616_170644	
20160616_174432	
20160616_180427	
20160616_182620	
20160616_185541	
20160616_191413	
20160616_192744	
20160616_195828	
20160616_203146	
20160616_205455	
20160617_162358	
	20160617_163833
20160618_202237	
	20160618_203859
	20160619_103743
20160619_155907	
	20160619_161042
20160619_183331	
	20160619_185109



RICH2 primary mirror tilts w.r.t. CondDB



RICH2 secondary mirror tilts w.r.t. CondDB



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

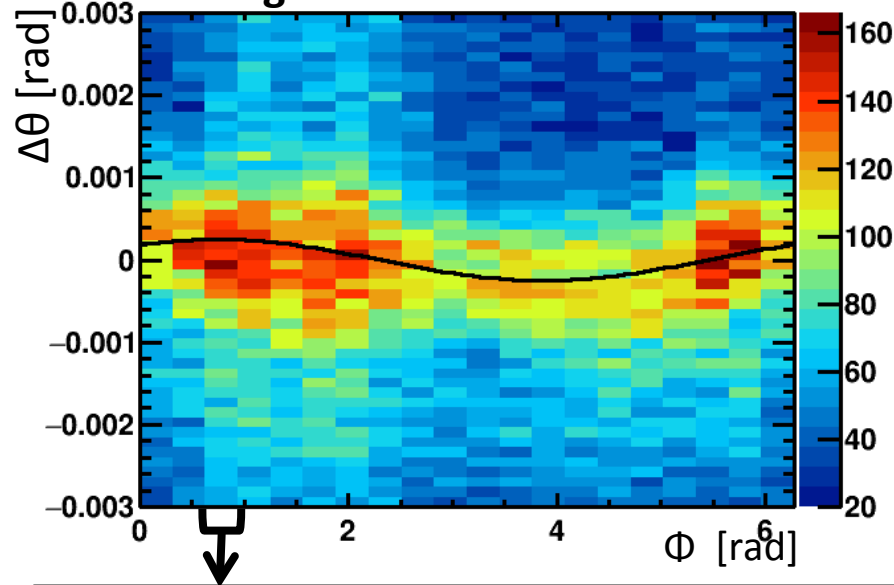
Cherenkov angle resolution

Limiting factors to Cherenkov angle resolution:

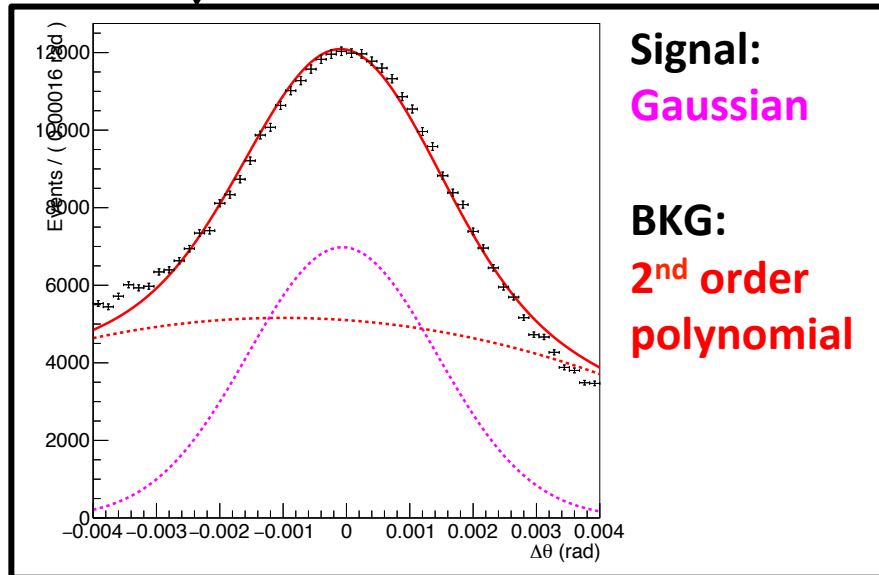
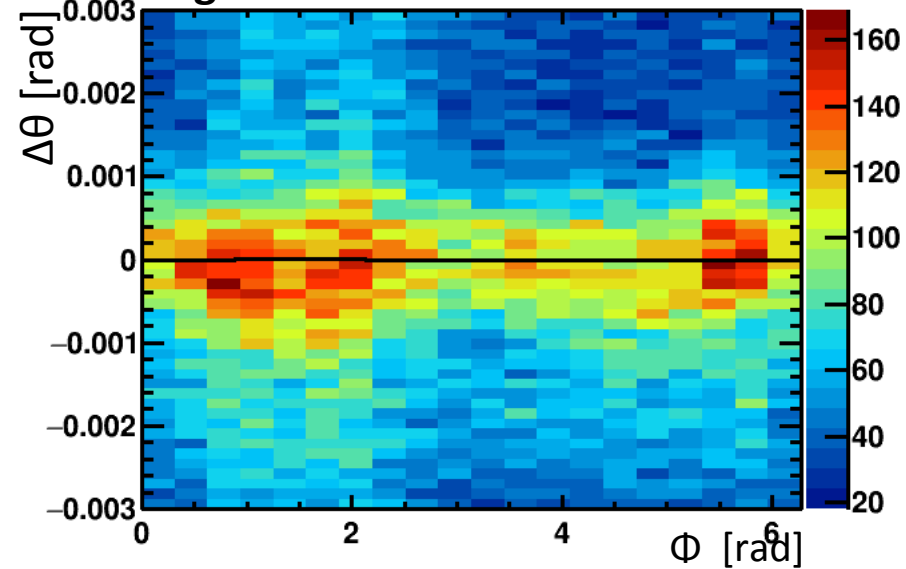
	σ [mrad]		
	RICH1		RICH2
	Aerogel	C ₄ F ₁₀	CF ₄
Emission point	0.4	0.8	0.2
Chromatic dispersion	2.1	0.9	0.5
Pixel size	0.5	0.6	0.2
Tracking	0.4	0.4	0.4
Total	2.6	1.5	0.7

Fit to 2D histograms

Misaligned mirrors:



Aligned mirrors:



Means of Gaussians
connected by:

$$\Delta\theta_c(\Phi) = \Theta_{p,s}^y \cos(\Phi) + \Theta_{p,s}^z \sin(\Phi)$$

Magnification coefficients

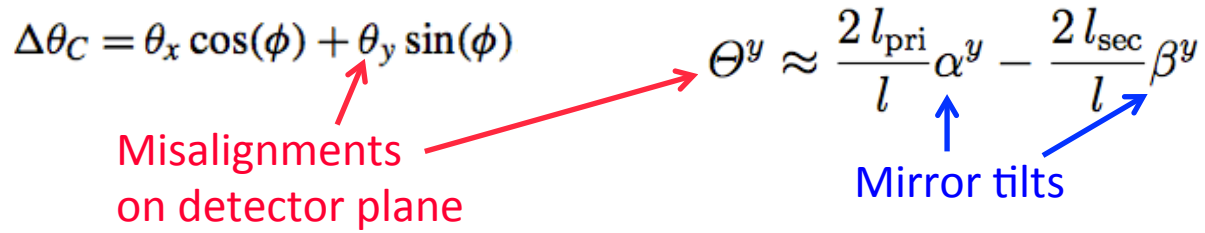
Magnification coefficients: Translate the tilt on the detector plane into actual mirror tilts

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

Misalignments
on detector plane

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

Mirror tilts



Magnification coefficients are calculated new for each iteration:

- Introduce 8 rotations: primary and secondary mirrors rotated around $\pm y$ and $\pm z$ 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

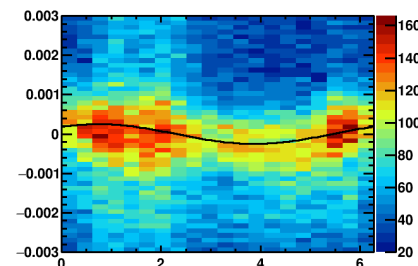
Each pair of **primary mirror** p and **secondary mirror** s has 2 equations:

$$\begin{aligned} & \boxed{A_{p,s}^y} \boxed{\alpha_p^y} + \boxed{B_{p,s}^y} \boxed{\beta_s^y} + \boxed{a_{p,s}^y} \boxed{\alpha_p^z} + \boxed{b_{p,s}^y} \boxed{\beta_s^z} = \boxed{\Theta_{p,s}^y} \\ & \boxed{A_{p,s}^z} \boxed{\alpha_p^z} + \boxed{B_{p,s}^z} \boxed{\beta_s^z} + \boxed{a_{p,s}^z} \boxed{\alpha_p^y} + \boxed{b_{p,s}^z} \boxed{\beta_s^y} = \boxed{\Theta_{p,s}^z} \end{aligned}$$

Magnification factors

individual mirror tilts

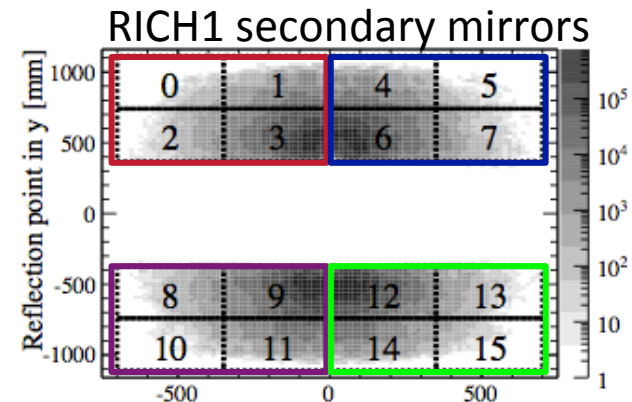
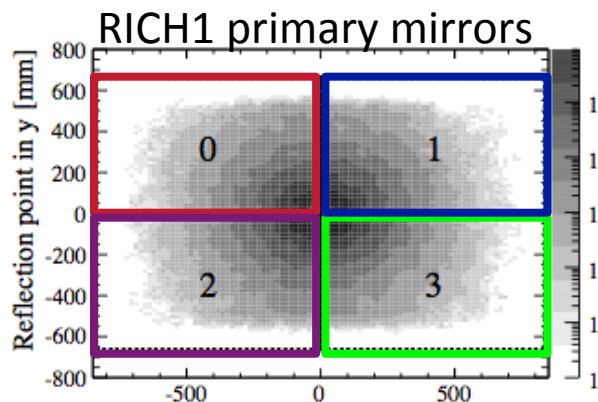
$$\Delta\theta_c(\Phi) = \Theta_{p,s}^y \cos(\Phi) + \Theta_{p,s}^z \sin(\Phi)$$



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

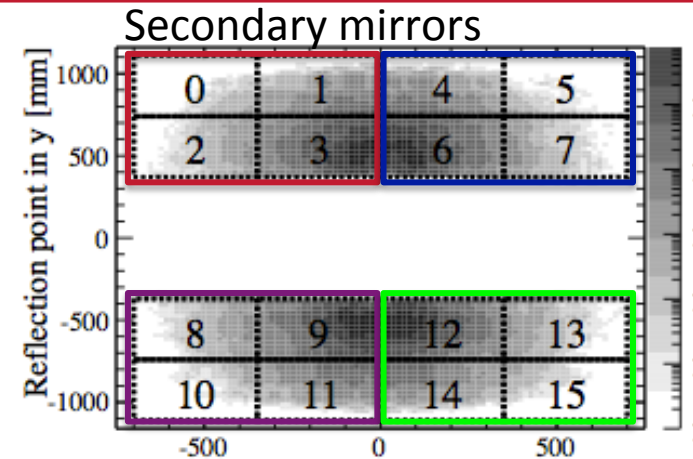
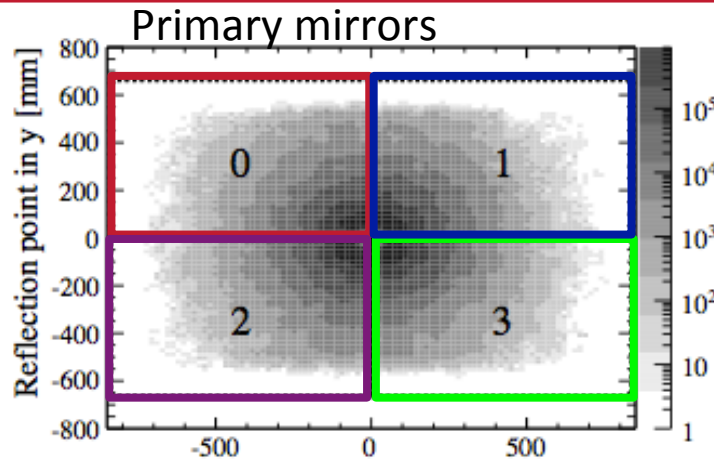


➔ Need additional constraint

Disentangling – until 2016

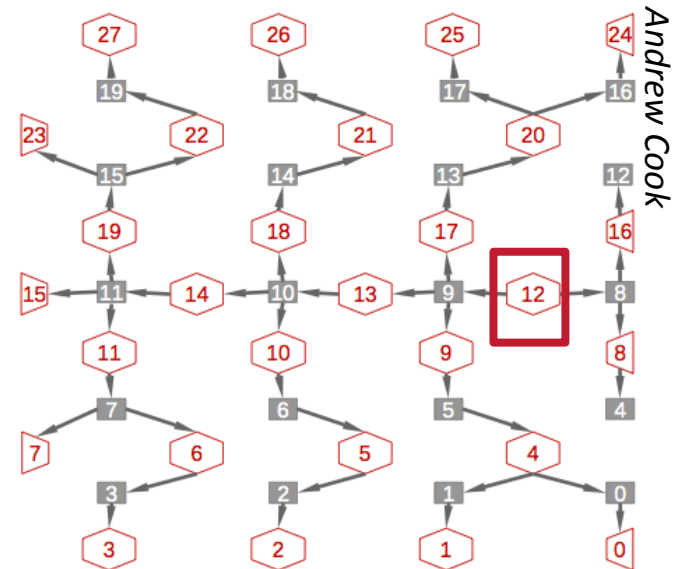
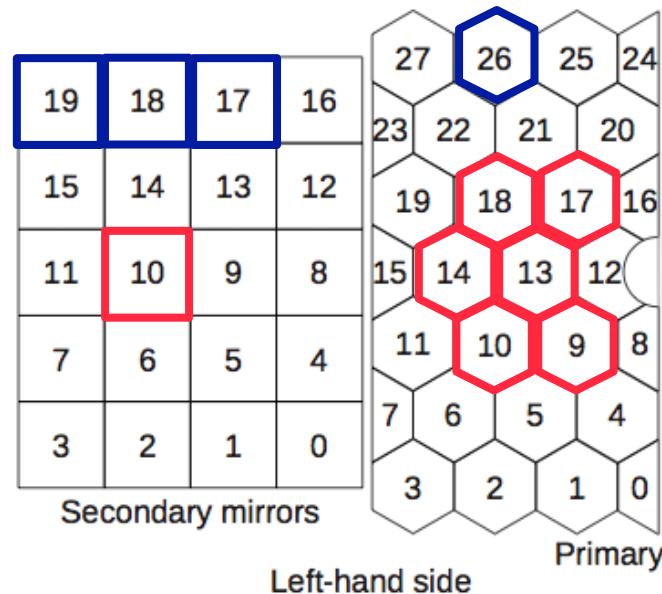
RICH1:

- fix primary mirrors, align secondary mirrors



RICH2:

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



Disentangling – from 2016

L2 regularization (ridge regression):

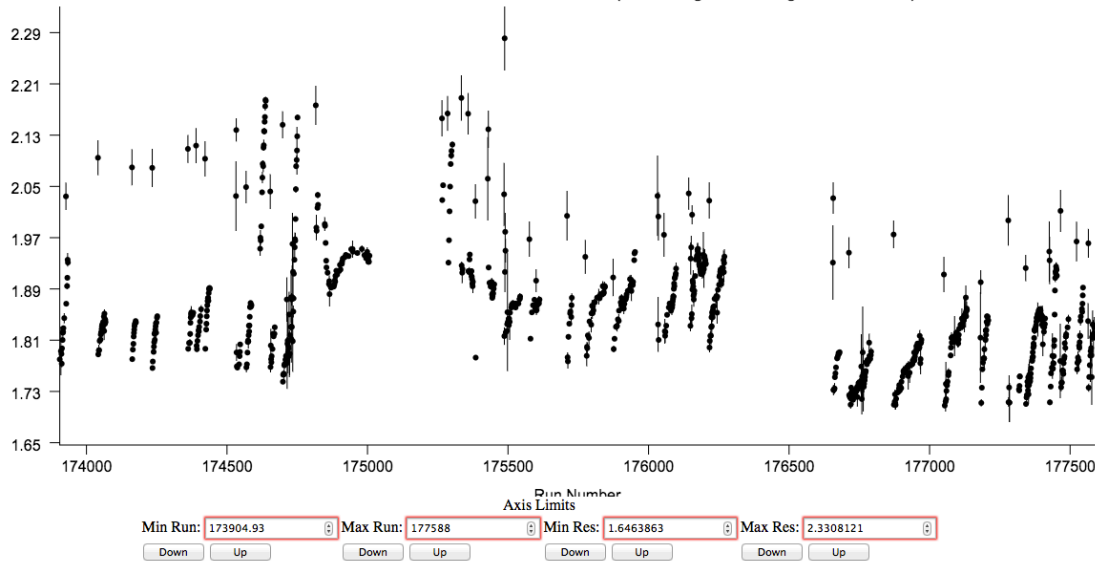
- rewrite problem as $\boxed{A}\boxed{x}=\boxed{b}$
 - Matrix of magnification factors
 - Vector of individual mirror tilts
 - Vector of results of fit to histograms
- Minimize: $\underbrace{\|Ax - b\|^2}_{\text{least square method}} + \underbrace{\|\Gamma x\|^2}_{\text{L2 regularization term}}$

Advantages:

- more stable than the previous method
 - Stable w.r.t. small statistical fluctuations (unlike L1 regularization)
- ➔ Fewer iterations needed to converge

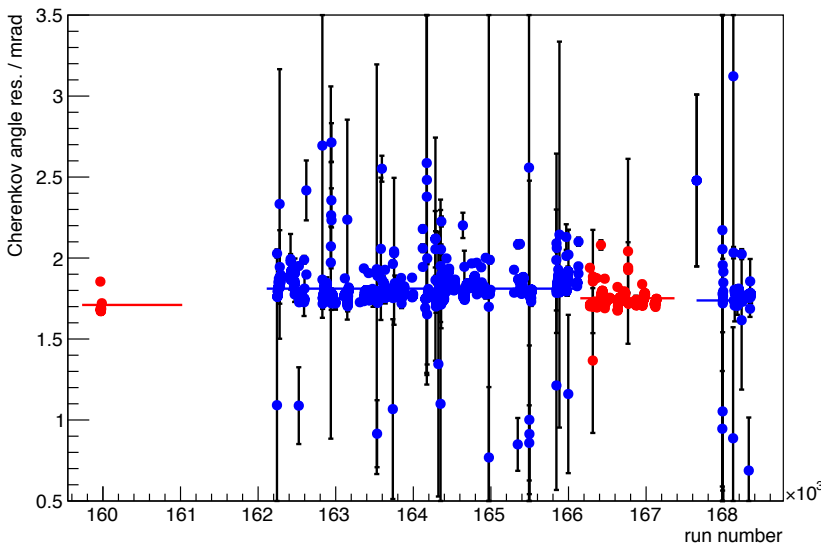
Resolution

RICH1 Online Brunel Cherenkov Resolution (Excluding HPD Image Corrections)



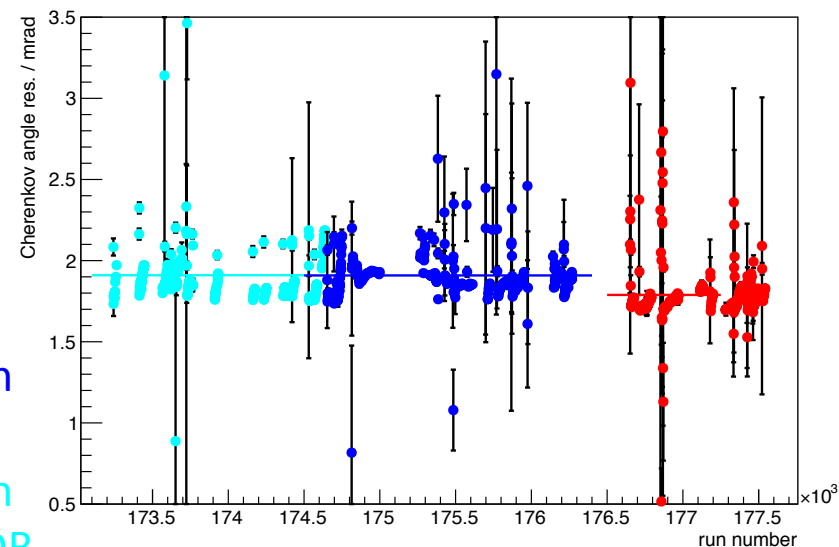
Without HPD image
correction:
Degradation of resolution
over fill.
➔ Longer fills in 2016

RICH1 2015



magnet down
magnet up
magnet down
before new DB

RICH1 2016



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:

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

RICH1 line:

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

Need to reconstruct ~10 times less events!

