Track-based alignment of the ATLAS Inner Detector:

Run I performance & new extensions for the next physics data run

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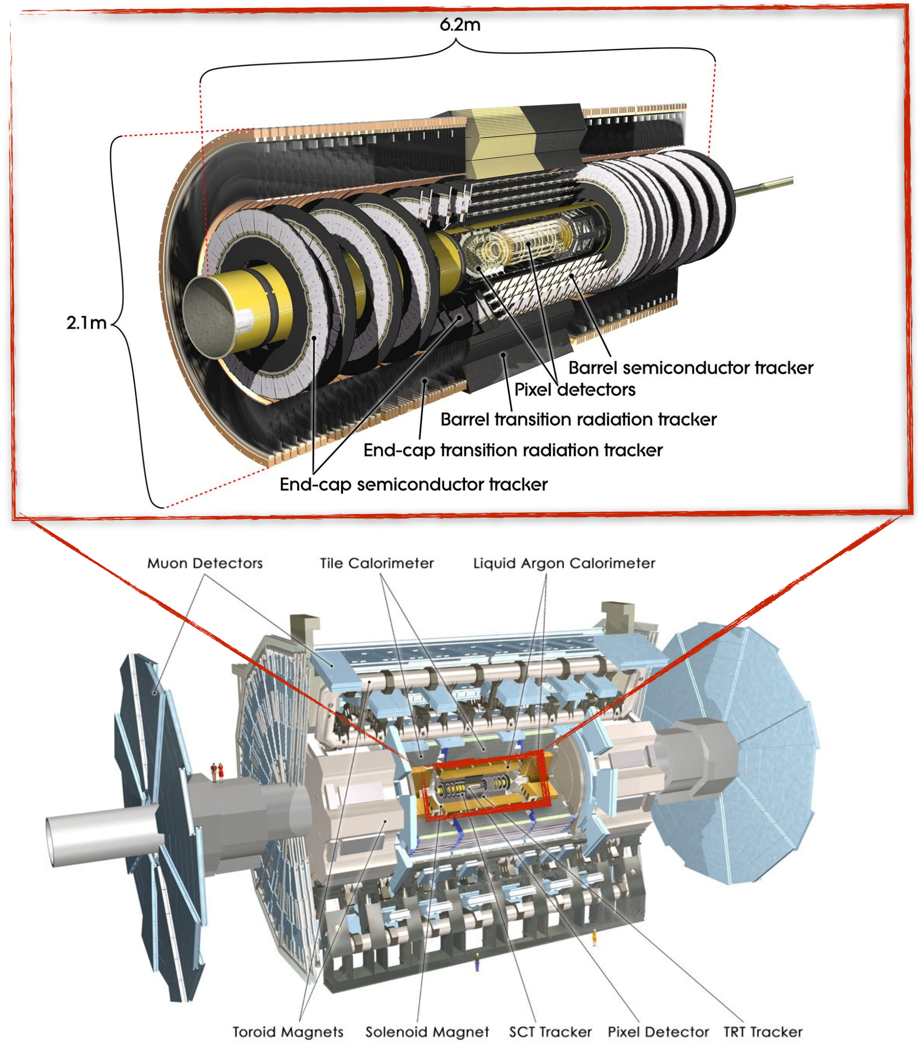
The ATLAS detector

Outline:

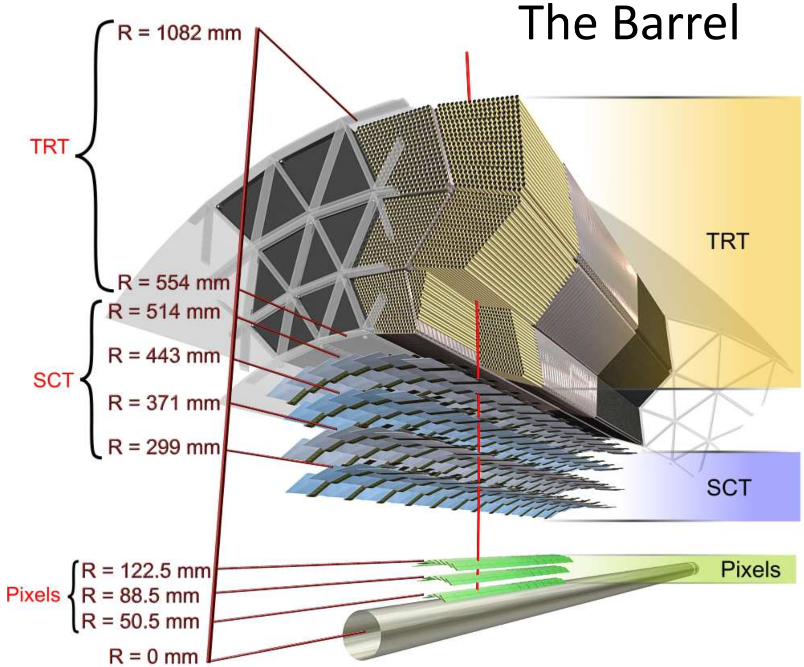
- Introduction
- Why is alignment a problem
- Methodology - track based alignment
- Run I results and performance
- Integration of IBL
- Looking ahead — Run II

Inner detector: Pixel/SCT/TRT

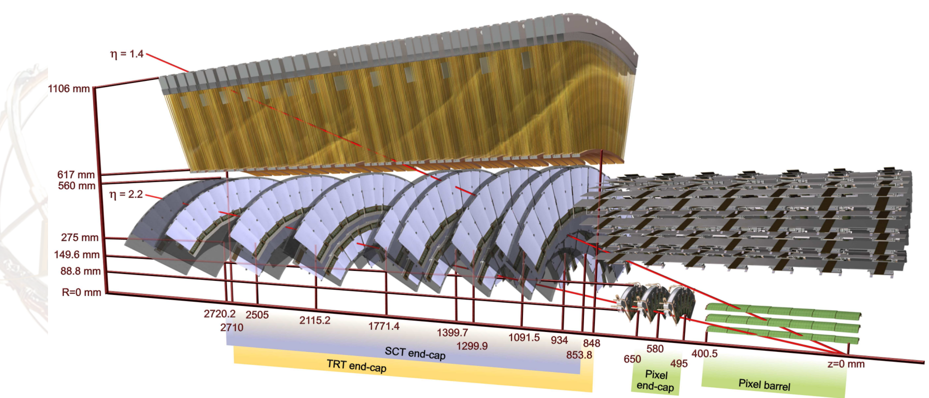


Introduction

The Barrel



The Endcaps



The Inner Detector:

Requirements:

- good p_T resolution
  (<30% at 500 GeV p_T)
- good impact parameter resolution
  —> b-tagging performance

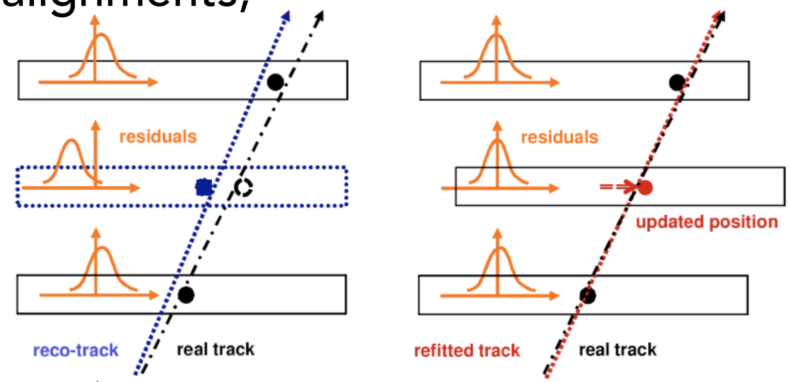
Alignment challenges:

- huge number of d.o.f.
  PIX: 1744 SCT: 4088 TRT: 350848
- Different scales of resolution
  PIX: O (10 μm)
  SCT: O (30 μm)
  TRT: O (140 μm)

Track based alignment algorithm

The χ^2 of the track fit is sensitive to detector misalignments, i.e. for a single hit:

$$\chi_i^2 = \left(\frac{|\mathbf{x}_i^{meas} - \mathbf{x}_i^{fit}|}{\sigma_i}\right)^2 = \left(\frac{r(\vec{\tau}, \mathbf{a})}{\sigma_i}\right)^2$$



The residual depends on:

- Track parameters τ
- Alignment parameters **a** (3 translations + 3 rotations)

Collect large number of events (tracks) —> sum over all hits:

- The χ^2 is minimized when detector elements are at true position $\frac{d\chi^2}{d\mathbf{a}} = 0$
- Approx. with Taylor expansion around $\mathbf{a_0}$ —> correction $\mathbf{\Delta a}$

Global χ^2: A simultaneous optimization (fit) of both track parameters and detector element positions is performed

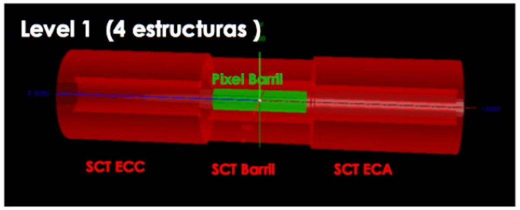
Local χ^2: After fitting tracks, attempt is made to match detector positions accordingly (inherently iterative)

Alignment Levels

Multistage alignment following the assembly structure:

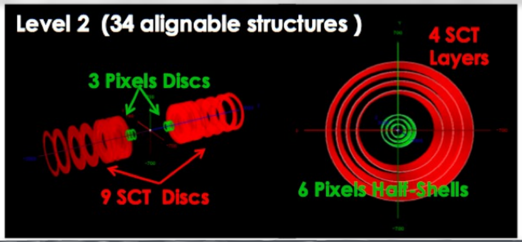
Level 1 — Rigid Body:

- run by run alignment to monitor environmental changes



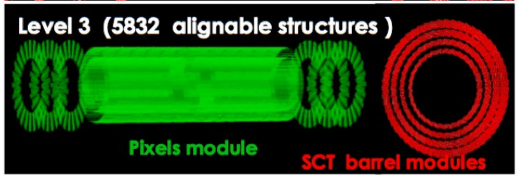
Level 2 — Disks/Staves:

- generally enough to achieve "good" precision -> residuals minimized



Level 3 — Si-Modules/TRT-straws:

- large statistics needed
  —> used to eliminate "weak modes"



	structures			Corr. Size
	pixel	SCT	TRT	µm
Level 1	1	3	3	**1000**
Level 2	12	22	96	**100**
Level 3	1744	4088	350848	**10**

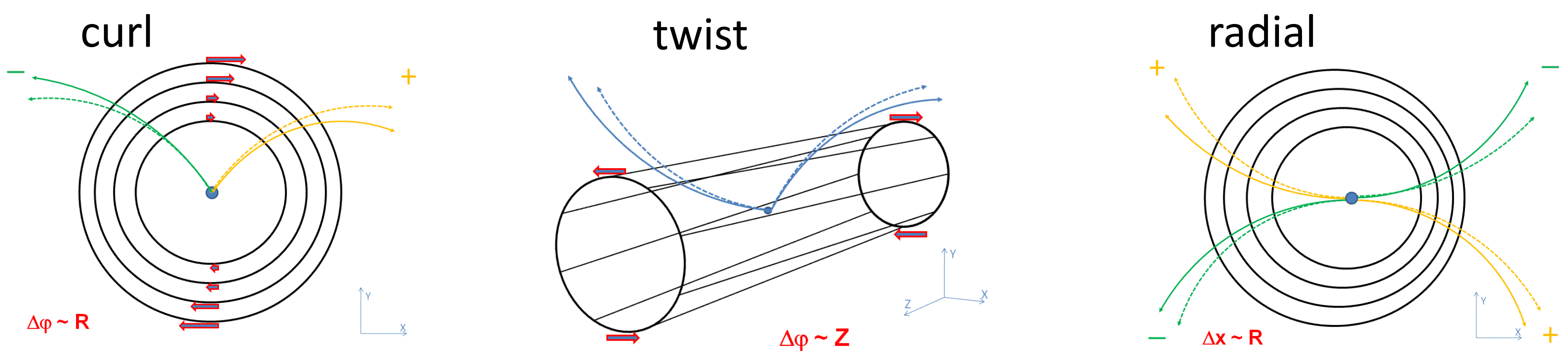
	strucures		DoFs
	pixel	SCT	#
Level 1	1	3	24
Level 2	12	22	204
Level 3	1744	4088	34992

	TRT		DoFs
	Barrel	End cap	#
Level 1	1	2	18
Level 2	96	80	1056
straw	105088	245760	701696

Weak Modes & constraints

Global distortions which preserve the helical trajectory of tracks and leave the χ^2 unchanged are known as "weak modes":

- The distortions are difficult to remove by the alignment algorithms

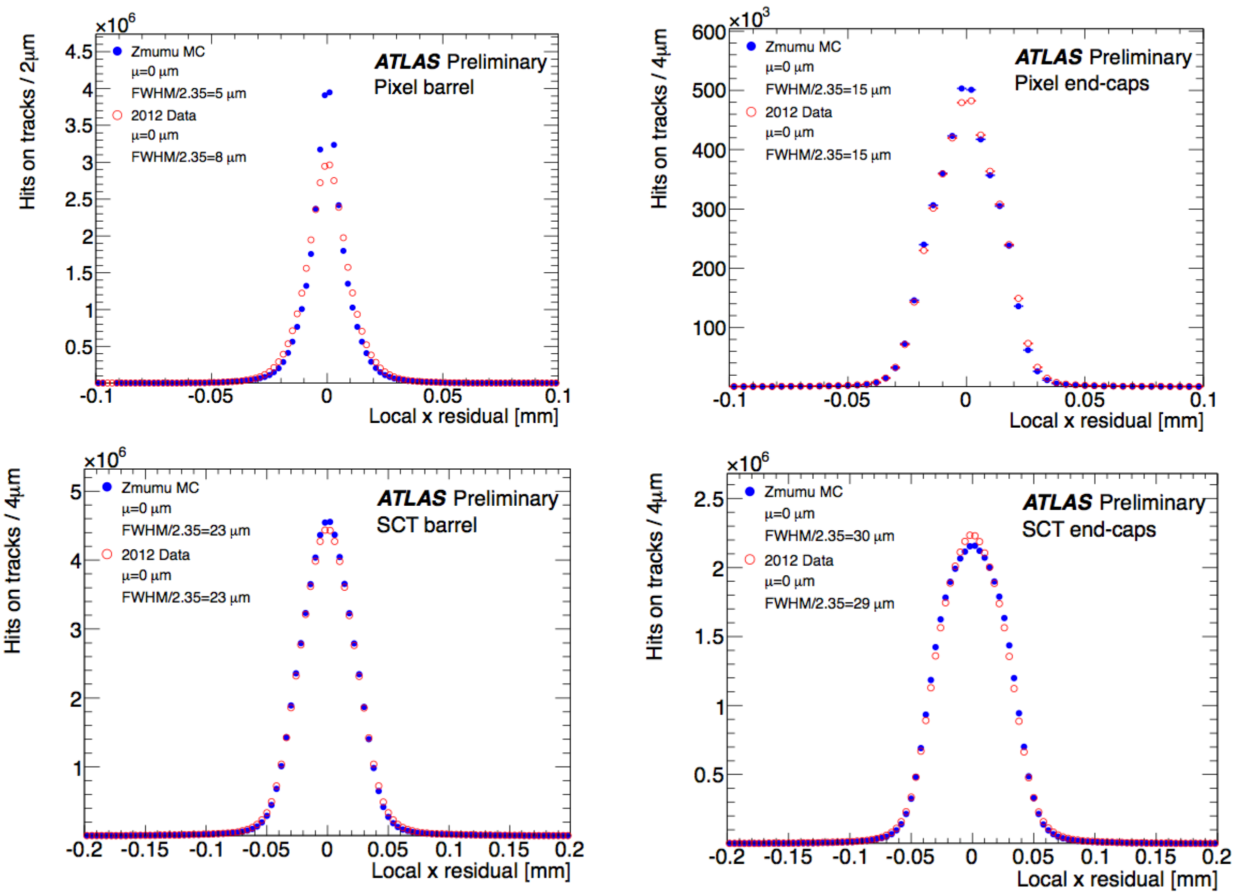


Extra data is necessary to constrain these modes:

- Beam spot constraint (used as additional track constraint)
- Mass of resonances (M_Z, K_S^0)
- Use of external detectors (E/P)
- Other event classes, i.e. Cosmic data (through-going tracks)

Alignment results: Residuals (Silicon)

- Residuals match well between data and MC
- Indicates the algorithms are working correctly
- Remaining difference most likely not due to misalignment alone (e.g. intrinsic detector resolution model)



Local x residual distributions:

The Pixel & SCT local x residual distribution for the Z —> $\mu\mu$ data sample reconstructed with 2012 alignment constants, compared to MC simulations. Distributions are integrated over all hits-on-tracks

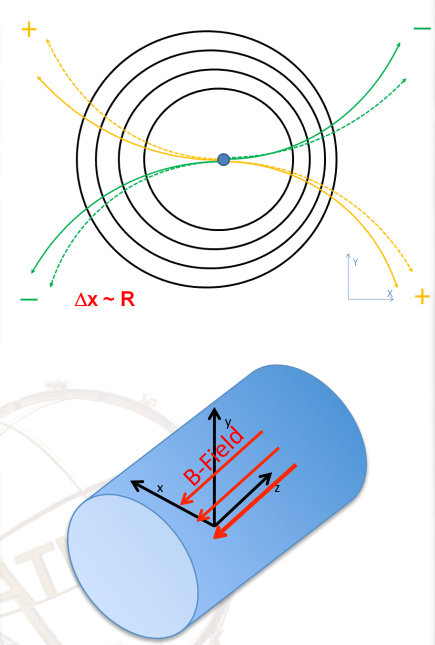
(Ref: ATL-COM-INDET-2014-011)

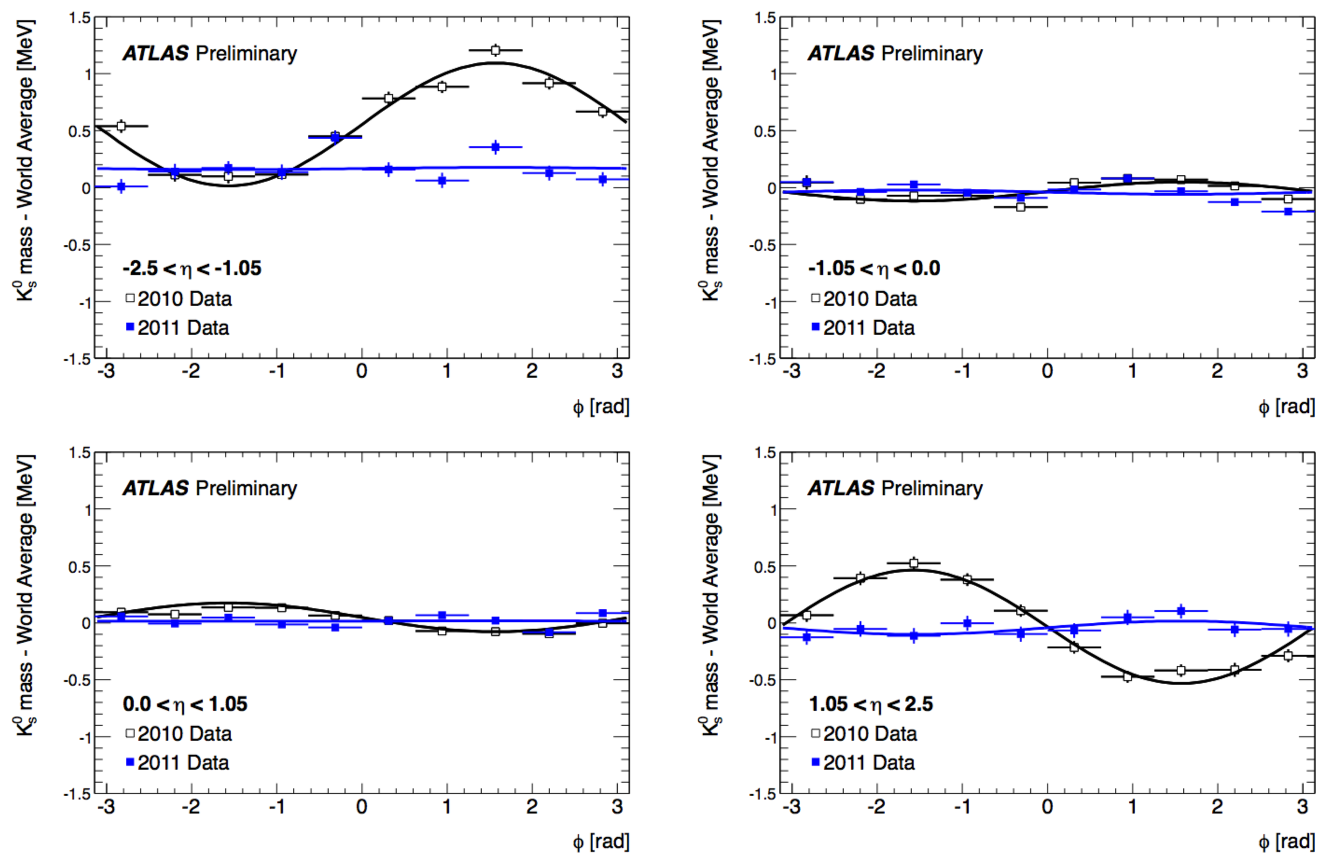
Alignment results: Radial distortions

Fit of the B-field direction from data:

- A tilt of the solenoid field was found as a bias in the Ks and J/ψ masses vs. φ
- Corrected by rotating the magnetic field in reconstruction by +0.55 mrad around the x-axis

lowest mode of radial distortion
—> charge symmetric





(Ref: ATLAS-CONF-2012-141)

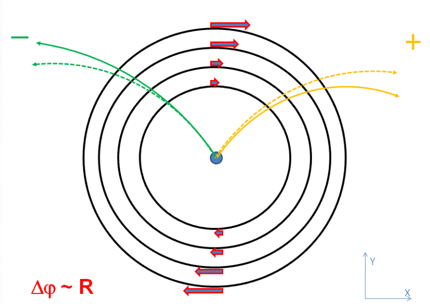
Alignment results: Sagitta bias

Momentum bias can be monitored:

- Cosmic data
- Mass resonances (Z —> $\mu\mu$) & E/p for opposite charge tracks

global sagitta — "curl": charge anti-symmetric

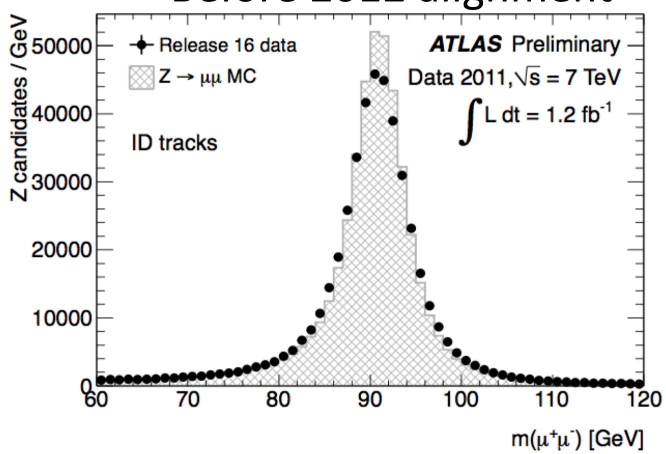
$$q/p_T^{reco} = q/p_T^{true} + \delta_{sagitta}$$



$$\langle E/p\rangle^{\pm} \longrightarrow \langle E/p\rangle^{\pm} \pm \langle E_T\rangle \delta_{\text{sagitta}}.$$

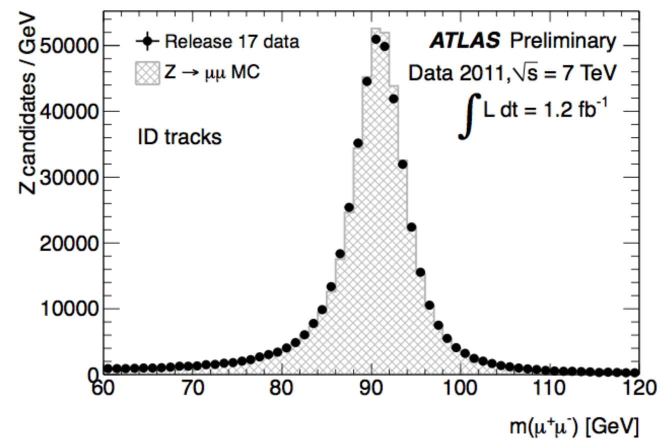
$$\langle E/p\rangle^{+}_{\text{true}} = \langle E/p\rangle^{-}_{\text{true}} \longrightarrow \delta_{\text{sagitta}} = \frac{\langle E/p\rangle^{+}_{\text{rec}} - \langle E/p\rangle^{-}_{\text{rec}}}{2\,\langle E_T\rangle}$$

Before 2012 alignment



(a) All η regions

After 2012 alignment



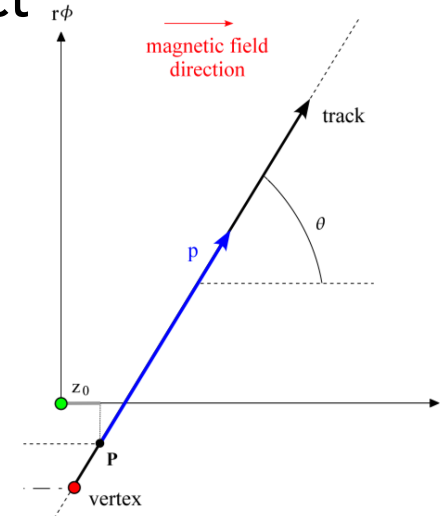
(a) All η regions

(Ref: ATLAS-CONF-2012-141)

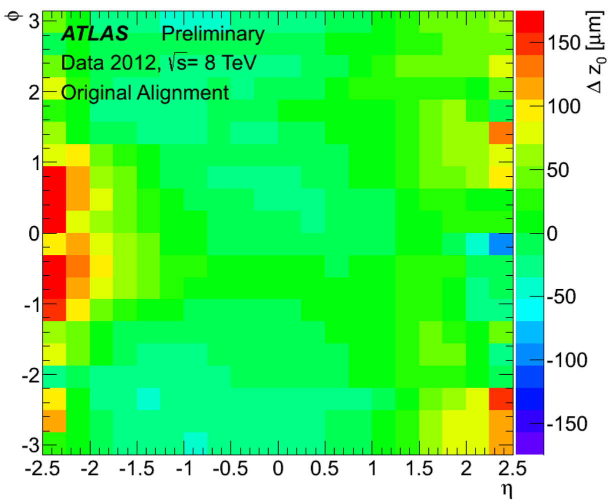
Alignment results: Impact parameter

Resolution of the transverse and longitudinal impact parameters (here: example of transverse):

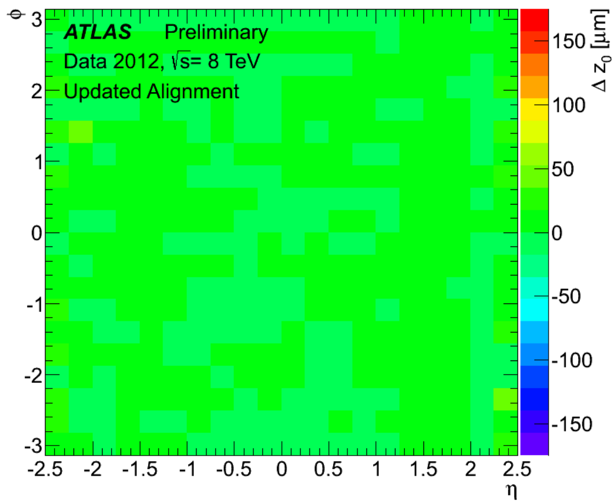
- Sagitta bias corrected with Z —> $\mu\mu$ & E/p methods

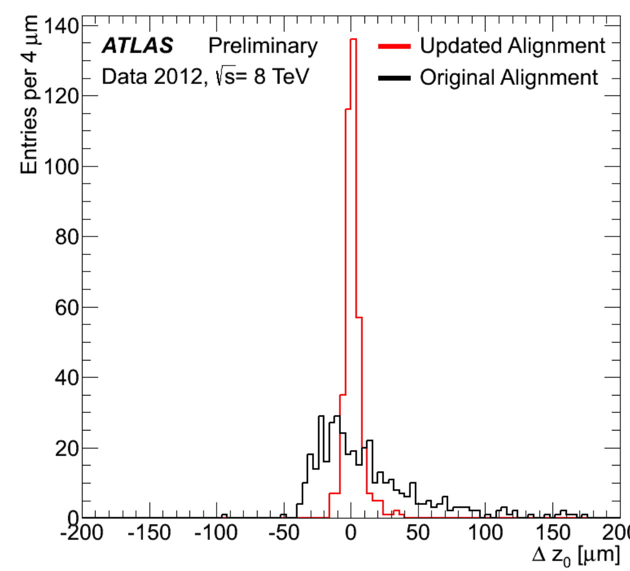


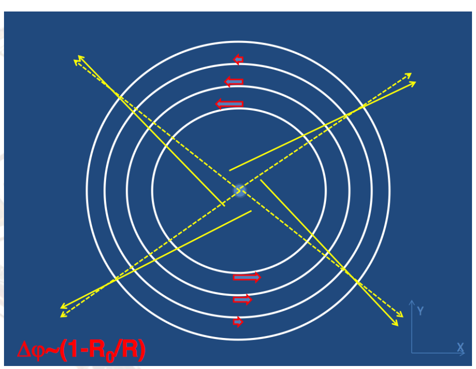
Before 2012 alignment

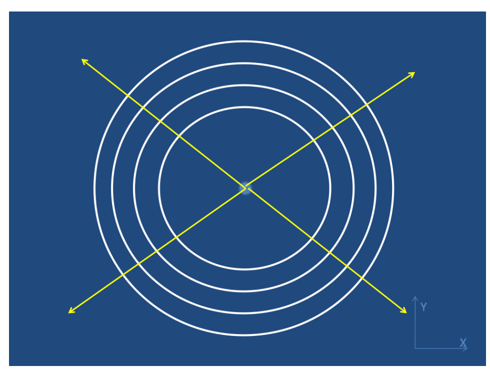


After 2012 alignment







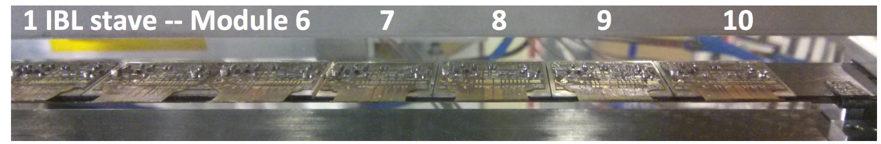


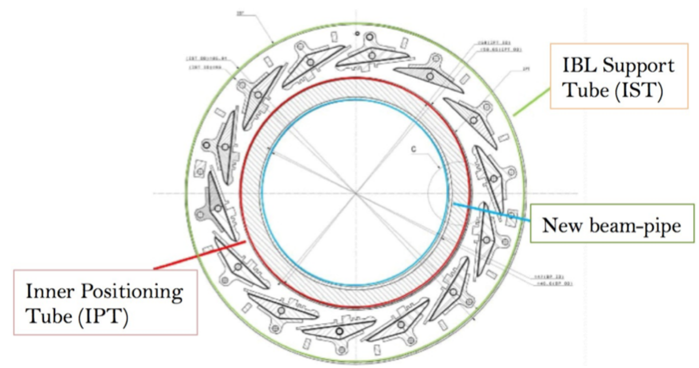
(Ref: ATL-COM-PHYS-2012-1520)

ID-upgrade for Run II — IBL

The new IBL poses a new challenge to the ID alignment

- New mechanically independent structure, integrated into Pixel detector
- 14 staves with average radius of 3.3 cm
- Pixel technology & novel 3D sensors
- Level 1 alignment has one additional independent structure
- Levels 2 & 3 more straight forward (additional layers & models)
- Software integration finished:
  - Monitoring
  - Data base structure



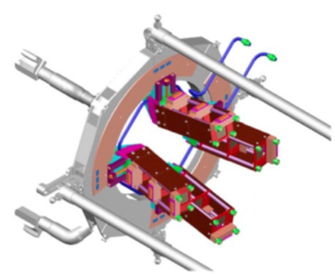


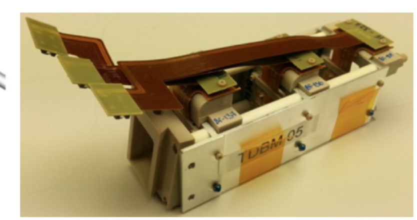
Run II alignment closure tests being performed:

- misalignment is introduced in MC
- Δa corrections recovered

Diamond Beam Monitor (DBM):

- Telescopes of diamond detectors in forward regions



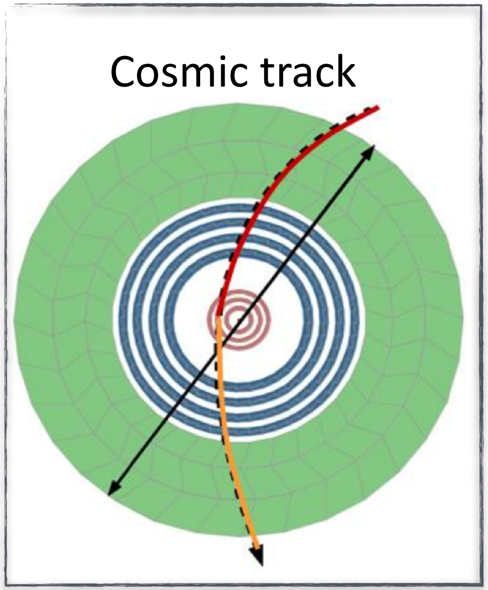


—> see next talk for more details

Conclusions & Looking ahead …

Run I performance:

- Final alignment constants show very good agreement between data & MC in physics observables
- Physical detector movements tracked down
- Many weak modes have been eliminated



Run II preparations:

- Alignment framework prepared
- IBL fully integrated
- Investigate possibility to run level 2 alignment in Calibration loop
- More detailed modelling & integration of individual module distortions

Pre Run II alignment:

- First rough alignment with Cosmic data (expected 100 mHz event rate in IBL)
  —> serves as input for first collision data alignment for Run II

Backup