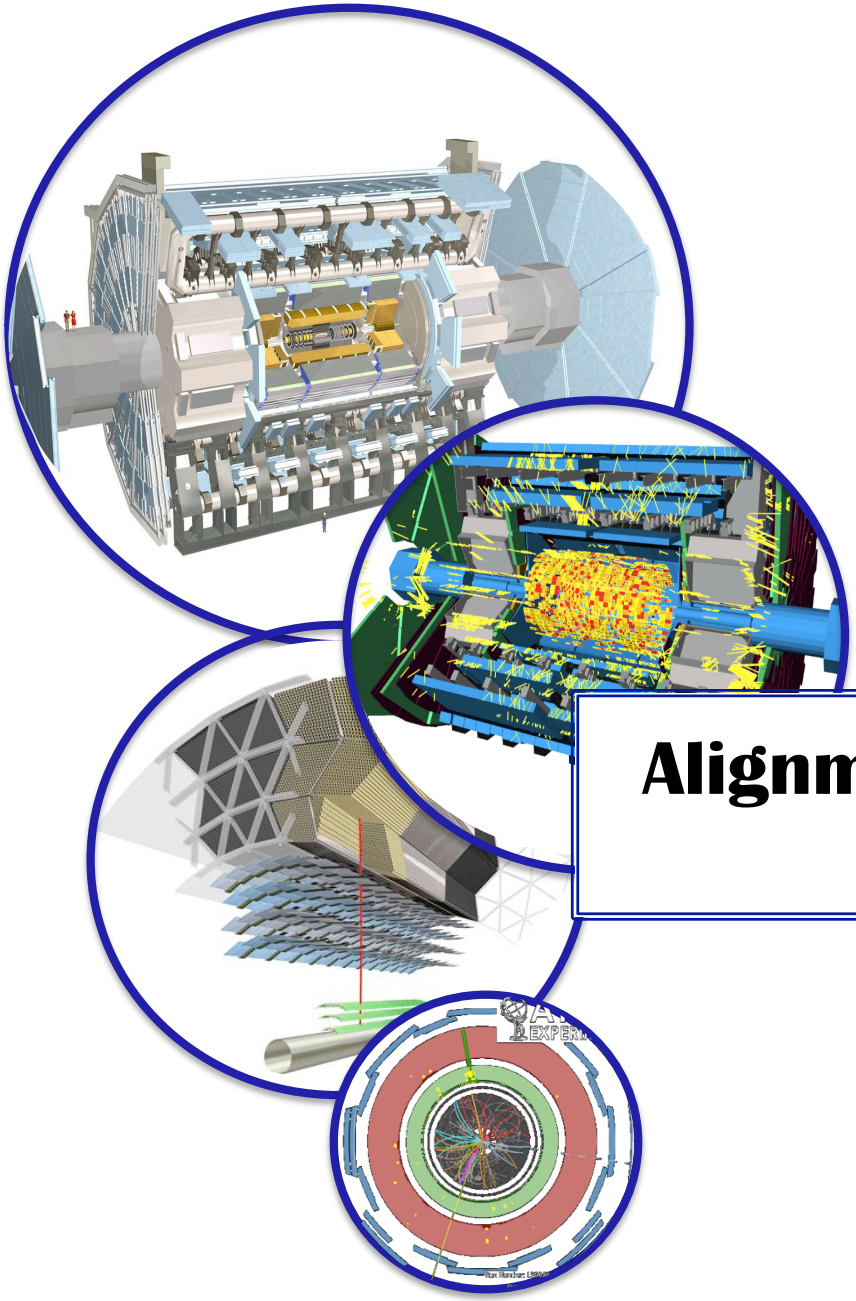
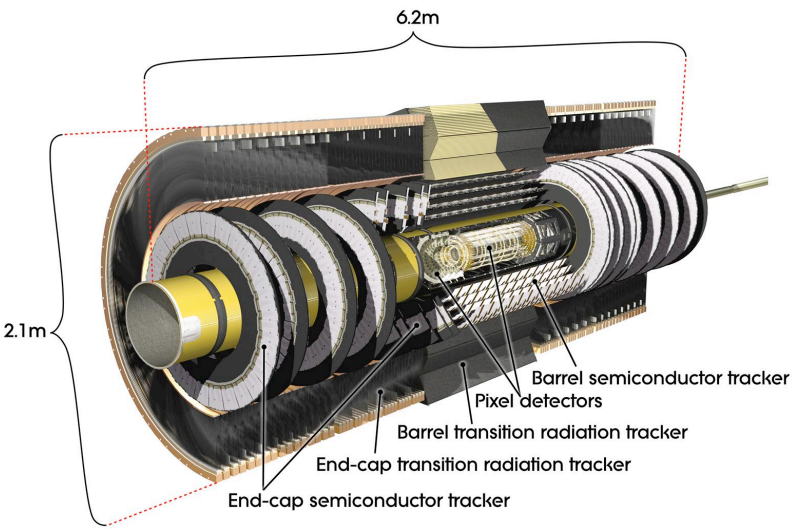
International Workshop on Semiconductor Pixel Detectors for Particles and Imaging
September 6 – 10, 2010 in Grindelwald, Switzerland
PIXEL2010



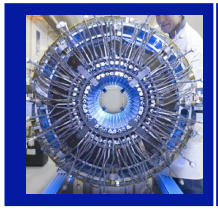
Alignment of the ATLAS Inner Detector tracking system

-Regina Moles-Valls –
On behalf of the ATLAS Collaboration

ATLAS Inner Detector



- The ATLAS Inner Detector (ID) is designed to provide hermetic and robust pattern recognition, excellent momentum resolution and both primary and secondary vertex reconstruction for charged tracks.
- The ID is made of three independent but complementary sub-detectors:



Pixel Detector *Pixel detectors*	
Pixel Size	50x400 μm^2
Intrinsic resolution	10µm (Rϕ) , 115 µm (z)(*)
Number of detectors	1744
Geometrical Layout	3 layers (barrel) 2x3 discs (end-cap)

(*) The ATLAS *experiment at the CERN Large hadron Collider, JINST 3 S08003*

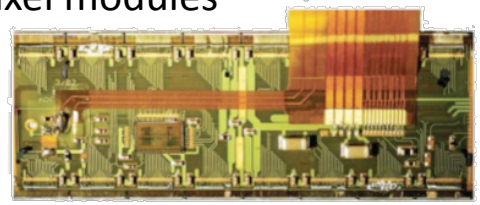
SCT Detector **(SemiConductor Tracker)** *Micro-strips silicon detectors*	
Inter-strip distance	pitch: 80 µm
Intrinsic resolution	17µm (Rϕ) , 580 µm (z) (*)
Number of detectors	4088
Geometric al Layout	4 layers (barrel) 2x9 discs (end-cap)

TRT Detector **(Transition Radiation Tracker)** *Gaseous straw tube elements*	
Straw tube Size	Diameter: 4mm Length:144cm (barrel)
Intrinsic resolution	130 µm (Rϕ) (*)
Number of detectors	176
Geometrical Layout	96 modules in 3 rings (barrel) 2x160 planes in 40 structures (end-cap)

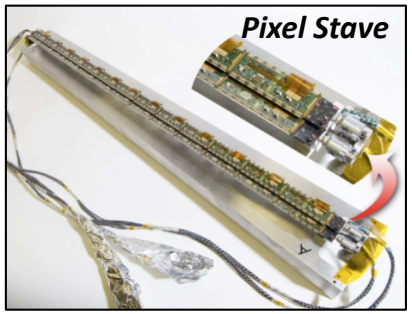
Assembly and Integration

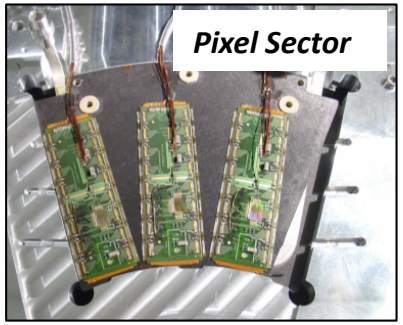
- **PIXEL DETECTOR**

1744 pixel modules

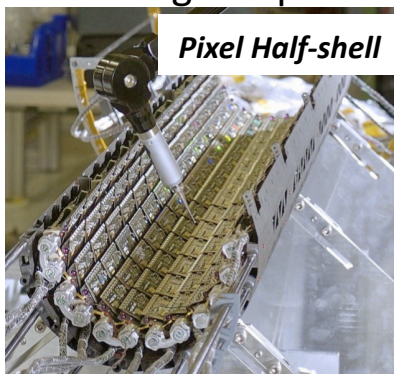


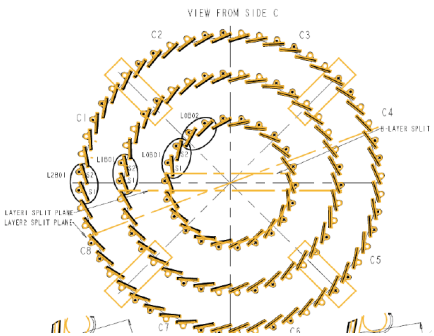
112 barrel staves *(13 pixel modules/stave)*
48 end-cap sectors *(6 end-cap modules/sector)*





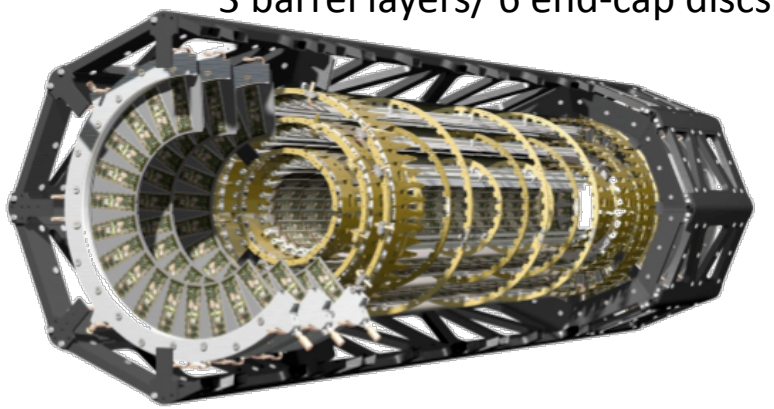
Barrel region split in half-shells





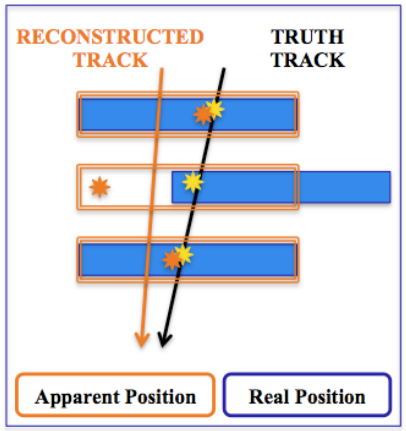
Structure	Assembly Precision	Survey Precision
Modules in Staves	>50µm	5-10µm
Modules in Sectors	>50µm	2µm

3 barrel layers/ 6 end-cap discs



ATLAS Inner Detector Alignment

The real module position do not correspond to the nominal locations due to: assembly precisions, thermal expansion,….



Alignment Requirements to achieve the ATLAS Inner Detector goals:

- The knowledge of the alignment constants should not lead to a significant degradation of the track parameters beyond the intrinsic tracker resolution. Degradation of tracking resolution less than 20% requires a detector alignment with the following resolutions:

	PIXELs	SCT	TRT
Rϕ (μm)	7	12	30

Strategy for the alignment of the Inner Detector:

- Initial knowledge of the module position based on :
  - Optical and mechanical surveys during the assembly and the integration survey.
- Monitoring of relative movement during operations:
  - Frequency Scanning Interferometry (FSI) system in the SCT:
    - The FSI system is up and running
    - Not fully integrate it in the alignment
- <u>Track based offline alignment Algorithm within the ATLAS software framework:</u>
  - Cosmic data with/without B field
  - 900 GeV & 7 TeV collision data

Track-based alignment algorithms

- Alignment algorithms are used to achieve the required alignment precision
- All of them used the **residual(r)** information
- ID detector has more than 35000 degrees of freedom to align

RESIDUAL:

$$r = hit_{measured} - hit(\pi, a)_{extrapolated}$$

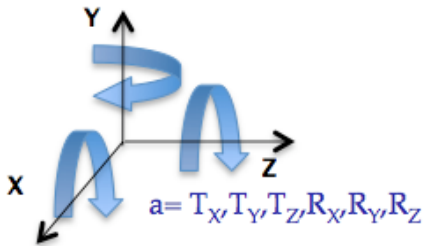
X^2 DEFINITION:

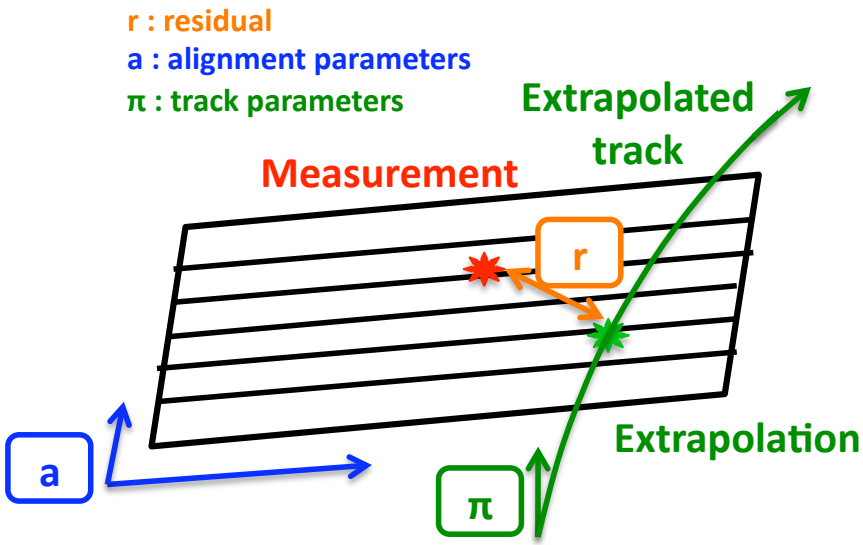
$$\chi^2 = \sum_{Tracks} r^T(\pi,a) V^{-1} r(\pi,a)$$

a: alignmnet constants; **π**: track parameters
V: covariance matrix of the hit measurement

X^2 MINIMIZATION

$$\frac{d\chi^2}{da} = 0$$

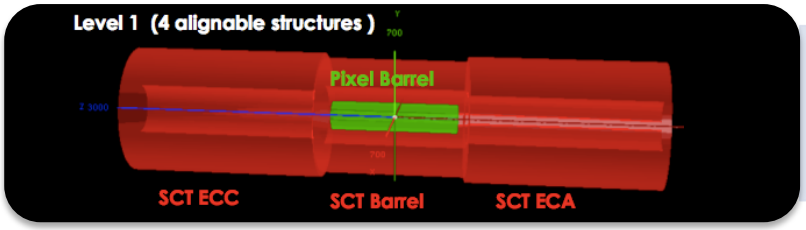




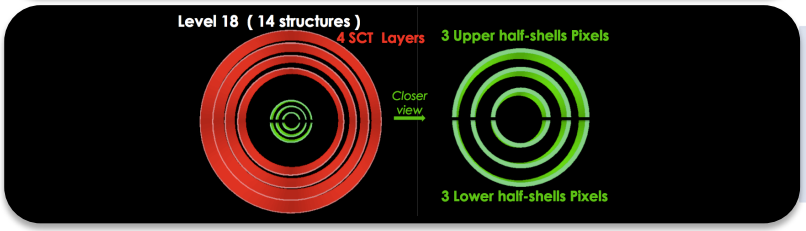
The alignment corrections are obtained at different levels corresponding to mechanical detector structures

Alignment Geometry Levels *(silicon only)*

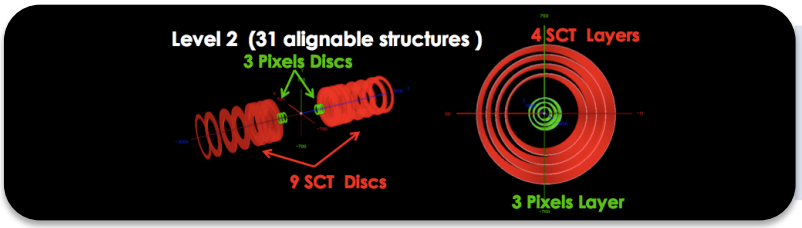
Alignment Geometry description based on alignable objects



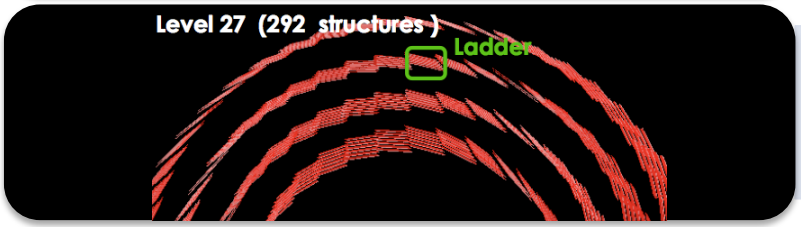
- **Level 1** ➔ *4 structures (24 DoFs)*
  - **PIX: One structure**
  - **SCT: Barrel+2 EC**



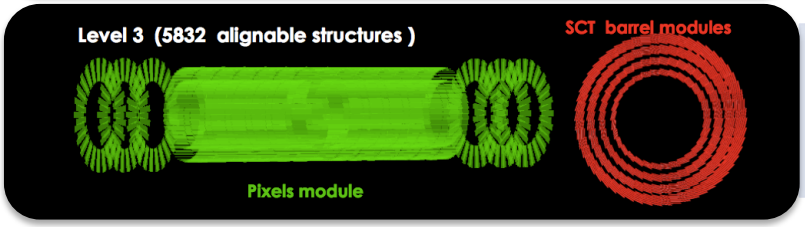
- **Half-shell Level** ➔ *14 structures (84 DoFs)*
  - **PIX: 3*2half-shell barrel + 2 EC**
  - **SCT: 4 barrel layers + 2 EC**



- **Layer/Disc Level** ➔ *31 structures (186 DoFs)*
  - **PIX: 3 barrel layers + 2*3 EC discs**
  - **SCT: 4 barrel layers + 2*9 EC discs**



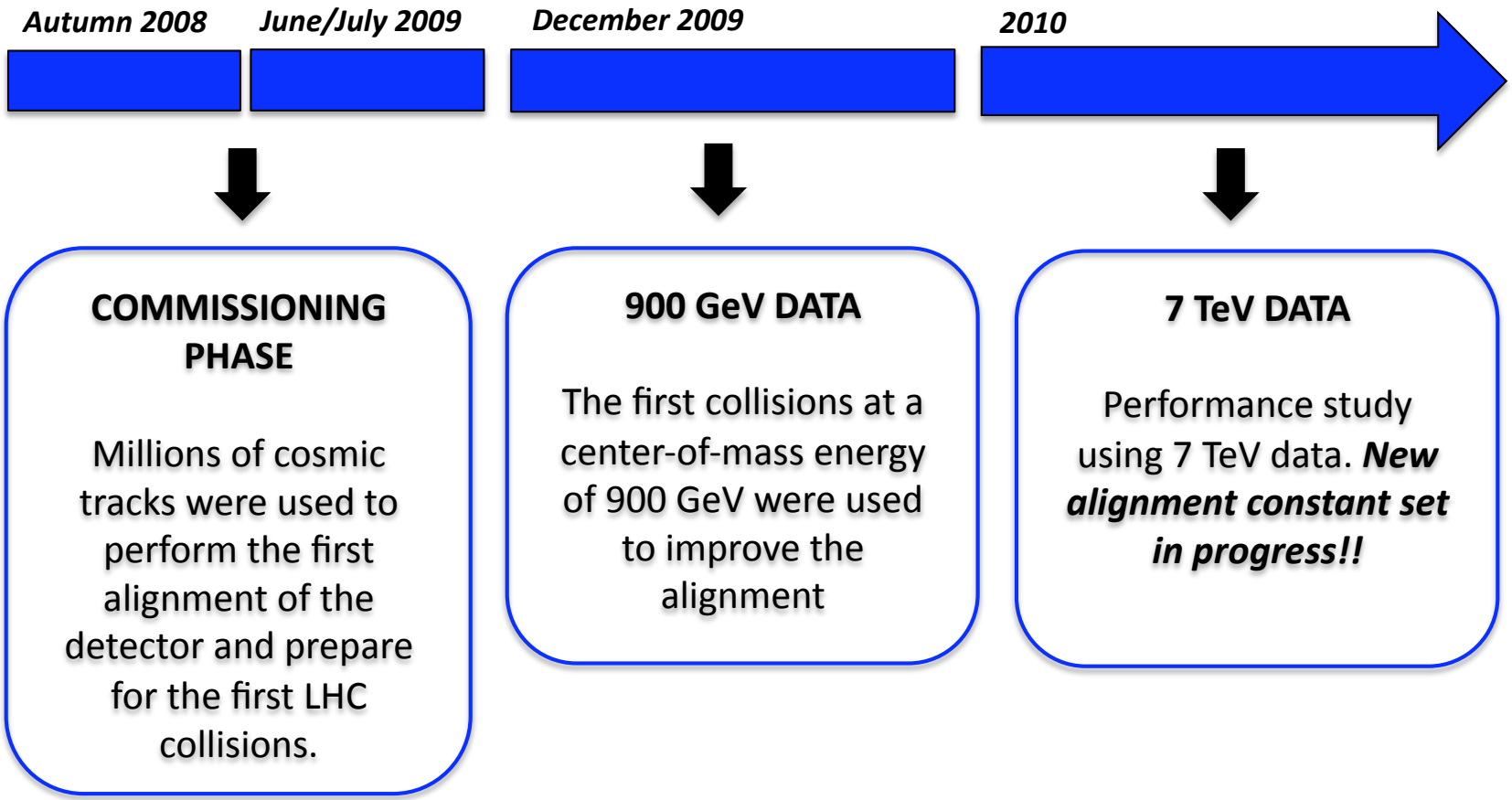
- **Stave Level** ➔ *292 structures (1752DoFs)*
  - **PIX: 112 barrel ladders + EC**
  - **SCT: 176 barrel ladders + 2EC**



- **Module Level** ➔ *5832 structures (34992 DoFs)*
  - **PIX: 1456 modules + 2*144 EC modules**
  - **SCT: 2112 modules + 2*988 EC modules**

Schedule with real data

Alignment steps using real data.

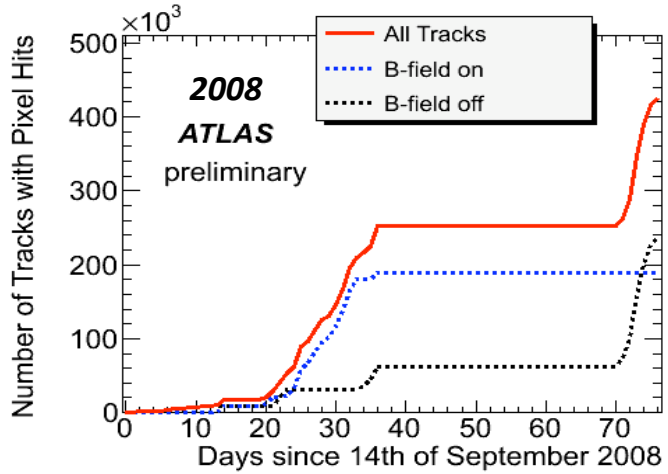


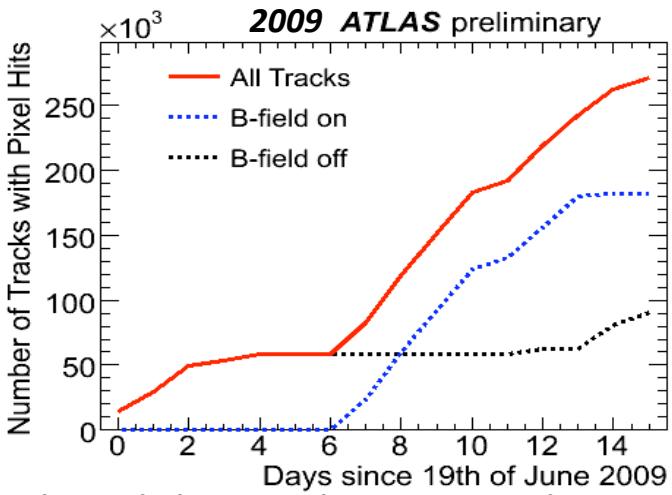
Cosmic Data: *Detector Commissioning*

First real reconstructed tracks with the real detector.

Two periods of data taking: 2008/2009

- Tracks crossing all ID
- Cosmic rays with uneven illumination (more hits on the top and bottom parts of the barrel)





Different alignment constants sets were produced during these periods.

Procedure:

- Initial geometry: Pixel Survey information + Nominal for the other detectors
- Different alignment levels
- *The ATLAS Inner Detector commissioning and calibration*
  arXiv:1004.5293v2[physics.ins-det]7Jun 2010)

Cosmic Data: *Detector Commissioning*

Silicon Alignment:

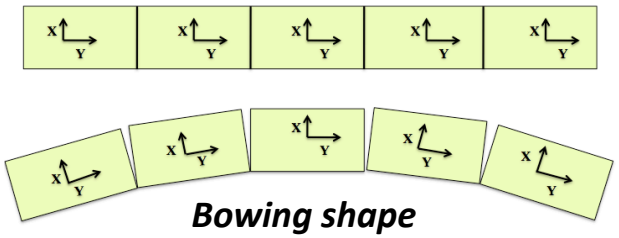
- **PIX vs SCT Level:**
  - 1mm between PIX and SCT barrel
- **Layer-Disc level:**
  - Barrel: O(100 µm)
  - End-cap: O(1mm)
- **Stave Level:**
  - Barrel: O(10µm)
- **Module alignment:**

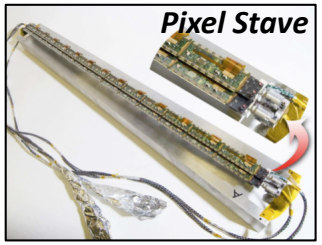
(only used 2DoFs: Tx-Rz)

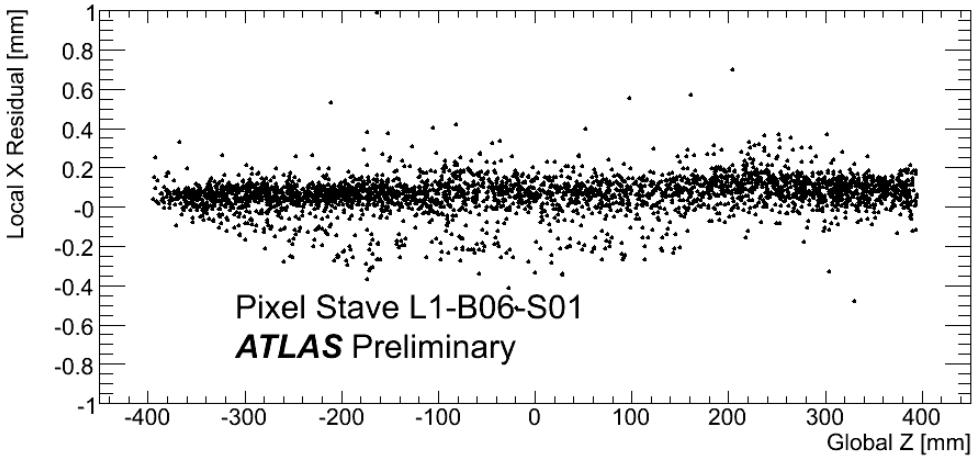
  - Pixel: Internal structure (**bowing**)
  - SCT: No shape distorsions (O(30µm))

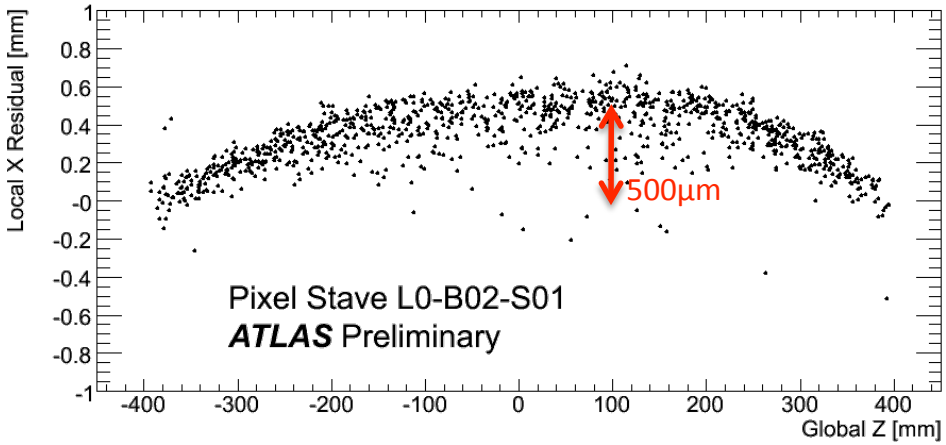
TRT Alignment:

- **Internal TRT alignment Level:**
  - Barrel: O(200-300 µm)
  - Wheels: O(100µm)
- **TRT vs Silicon:**
  - 2mm







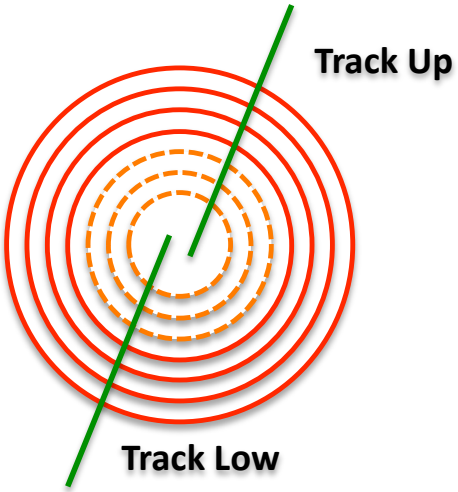


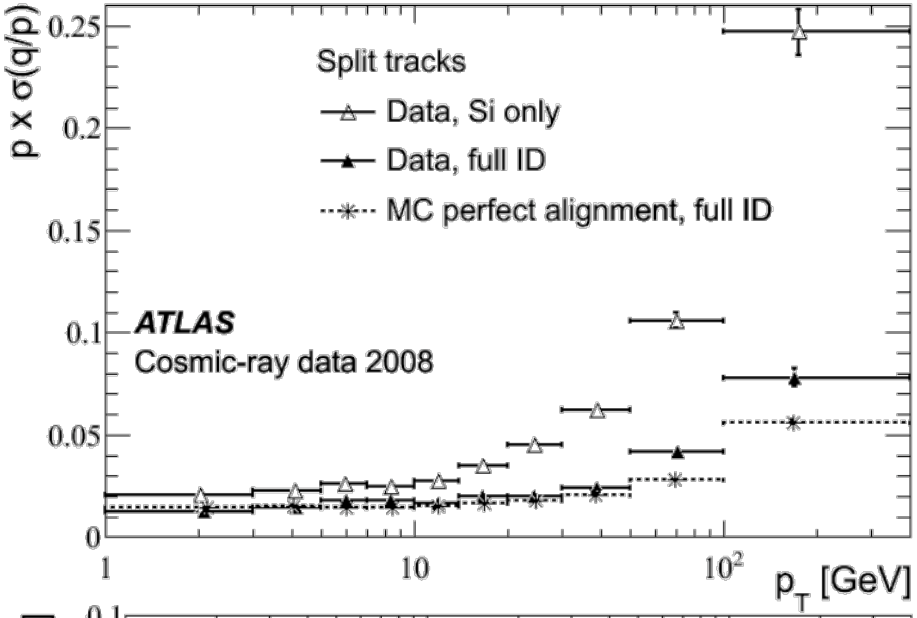
Residual between the track incidence angle and the pixel cluster position in the precision direction (local x) versus the z position of the hit for two example staves.

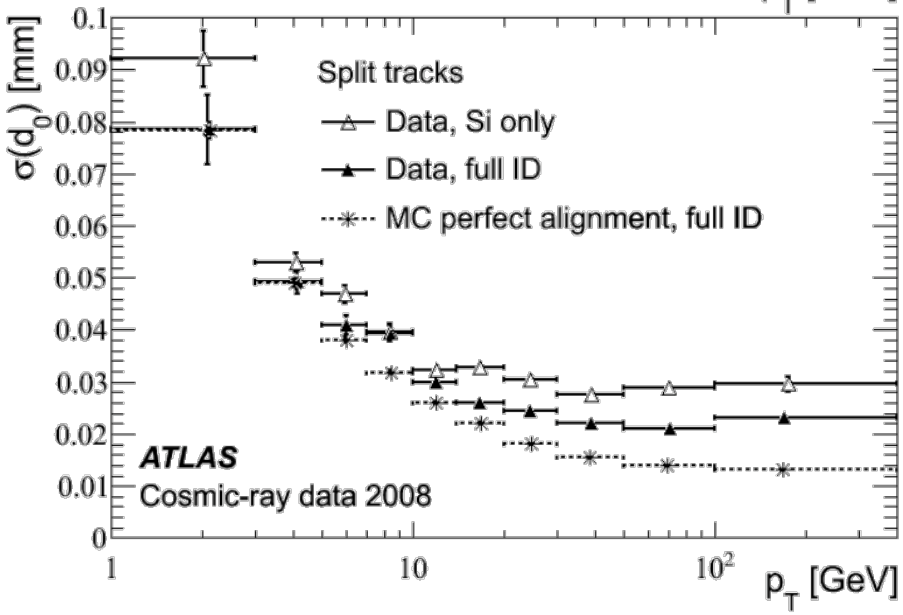
Cosmic Data: *Detector Commissioning*

Track parameter resolutions were studied with split tracks (upper-lower segments):

- The two track segments were refitted independently
- Study of track parameter differences
- Crosscheck with MonteCarlo samples





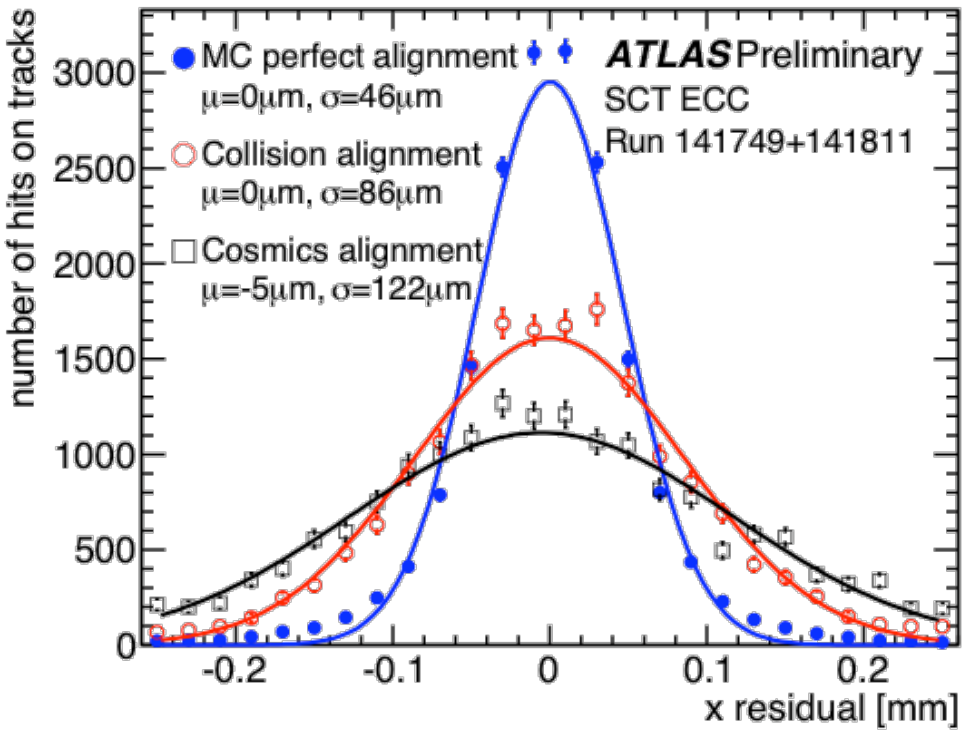


Collisions Data: *End-Cap alignment 900 GeV*

First LHC Collisions Data at 900 GeV (Dec 09)

- Barrel pretty well aligned using cosmic data
- End-caps showed wider residual distributions (*SCT hit efficiency showed an alignment problem in end-cap C*)

Improvement in the end-cap alignment



Events (Alignment Tracks)	60k (6k)
Alignment Cuts	p_t>1 GeV & Silicon_hits>7 hits
Alignment Level	Disc Level

The position and orientation of SCT end-cap discs was updated and the alignment was dramatically improved!

Collision Data: *Refined alignment with 900 GeV*

Alignment was done using different data:

2009 cosmic ray data (solenoid on and solenoid off) : 460k tracks

2009 collision data: 62k tracks

Alignment procedure:

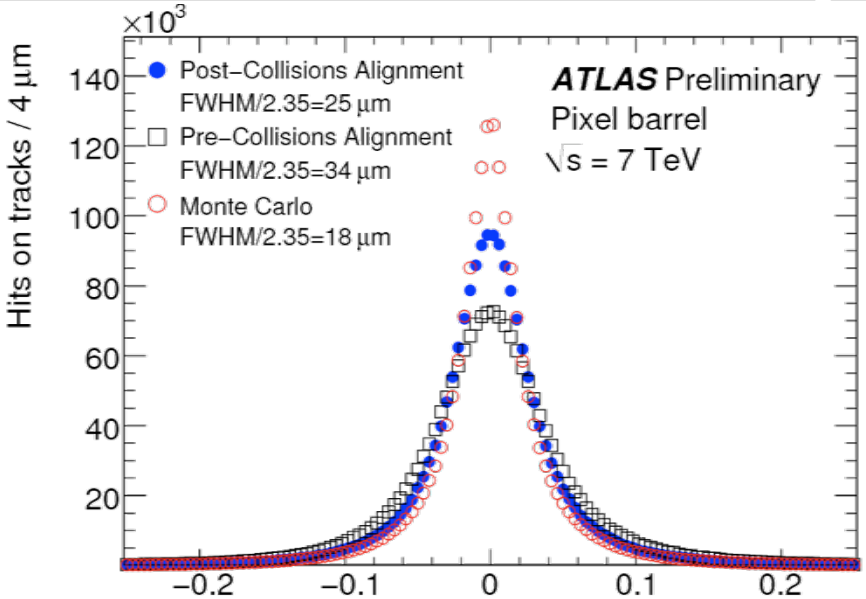
- ID calibration stream used:
  - Provided a high ratio of isolated tracks with an uniform illuminated detector
- Beam spot constraint:
  - This constraint is essential for achieving good transverse IP resolution and consequently quality vertexing
- New alignment levels included:
  - Ring alignment for the SCT discs
- Different track topologies (cosmic and collision) **used to eliminate the weak modes** *(see later)*
- Results:

FWHM/2.35 At 900 GeV

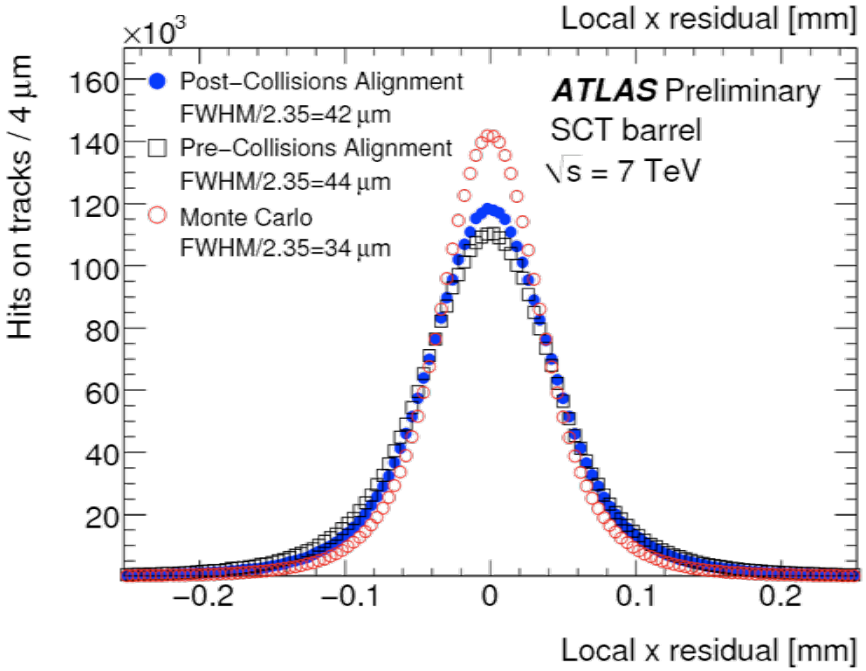
	Pixel		SCT		TRT	
	Barrel	End-cap	Barrel	End-cap	Barrel	End-cap
Data (μm)	28	23	43	45	147	167
MC (μm)	23	20	38	40	145	143

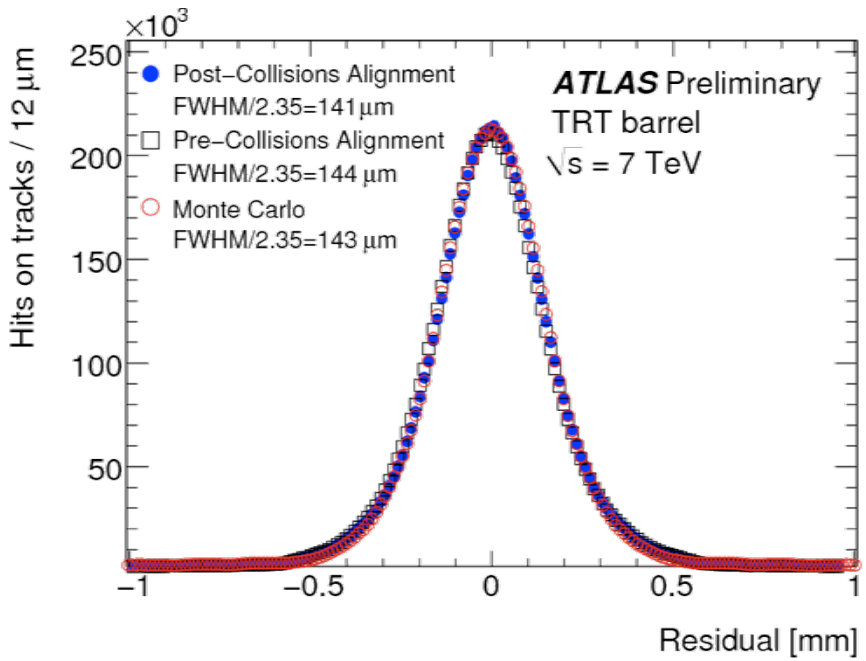
- Pixel detector alignment resolution: 15μm

Collision Data: *Performance with 7 TeV*



FWHM/2.35 At 7 TeV	Pixel		SCT		TRT	
	Barrel	EC	Barrel	EC	Barrel	EC
Data (µm)	25	20	42	45	141	162
MC (µm)	18	19	34	38	143	135

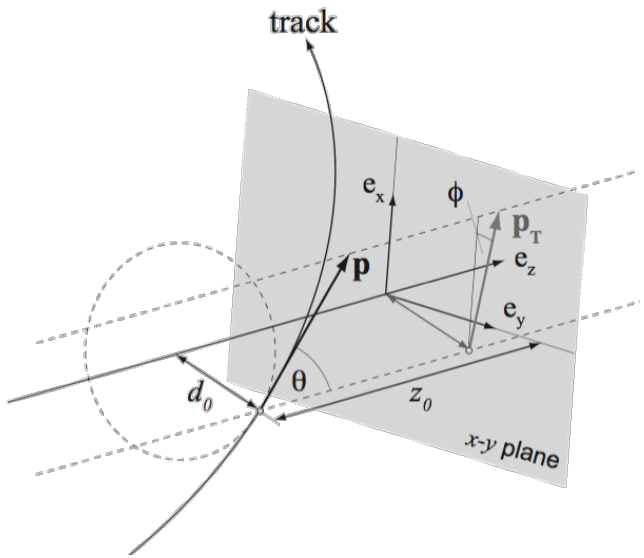


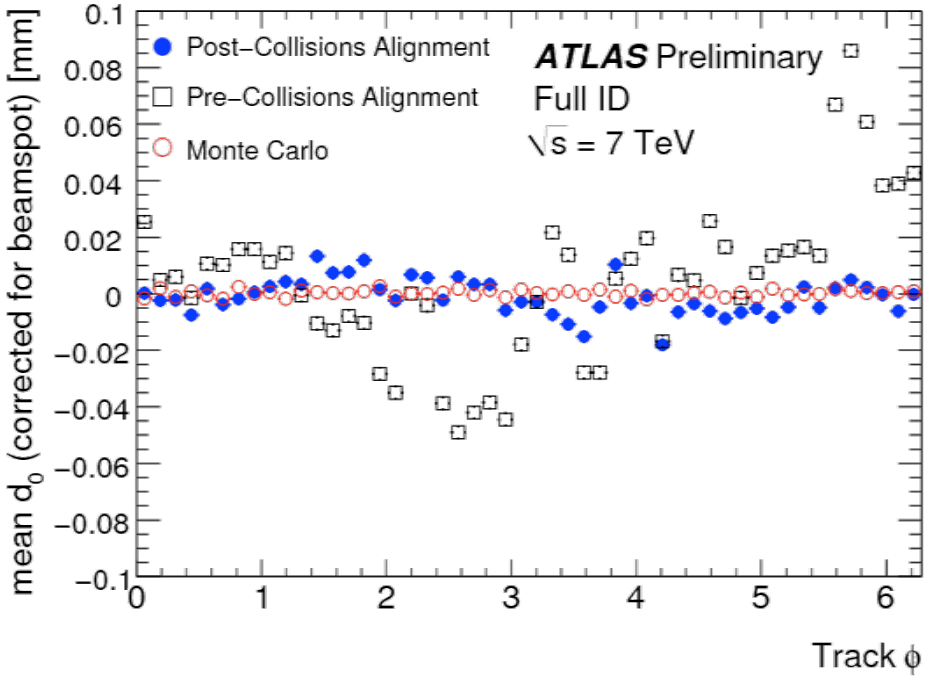


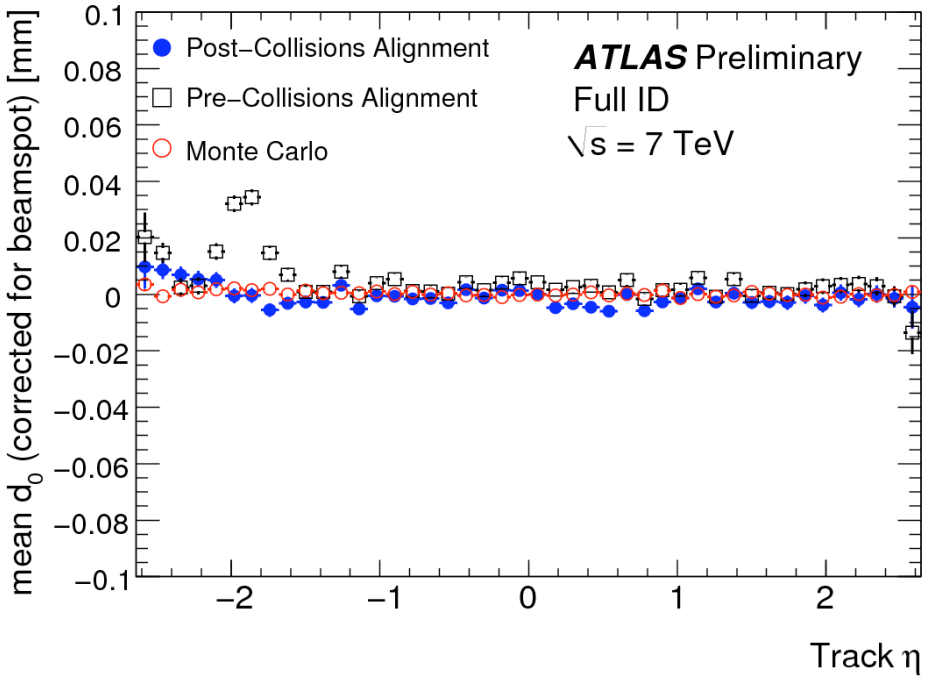
Collision Data: *Performance with 7 TeV*

Transverse impact parameter distributions are studied:

- mean d_0 vs ϕ
- mean d_0 vs η





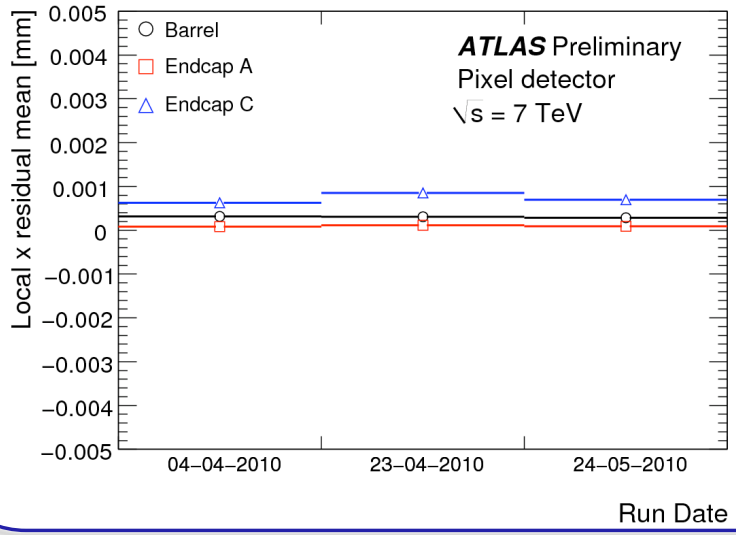


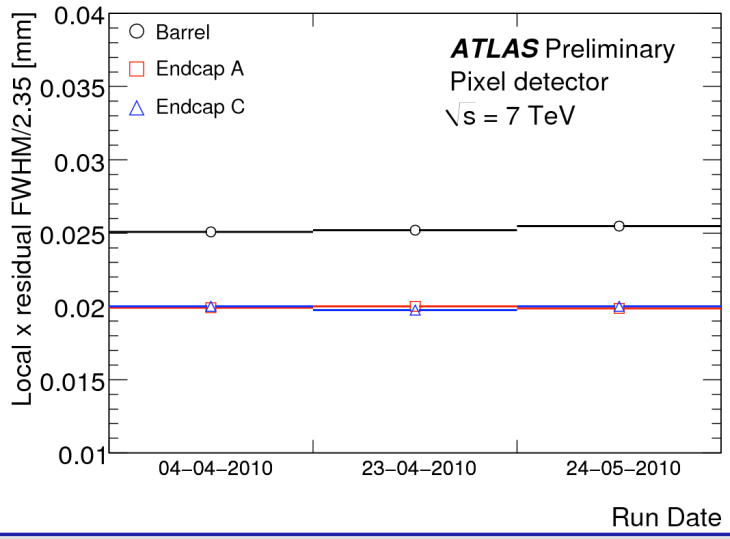
Big improvement observed in the Post-Collision Alignment

Collision Data: *Detector Stability at 7 TeV*

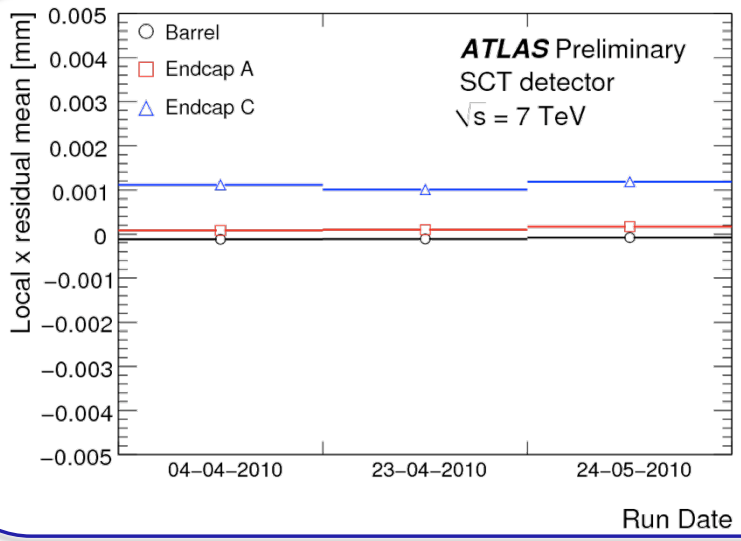
Pixel and SCT alignment stability as a function of time (over a 7 weeks period):

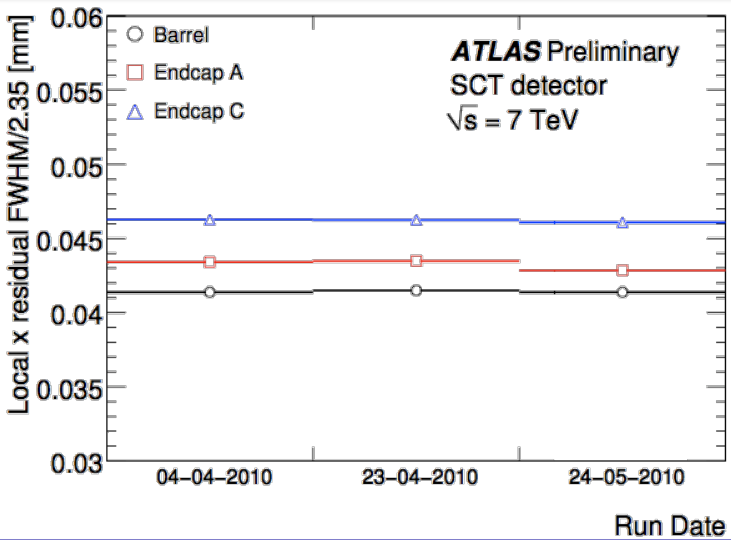
PIXEL DETECTOR





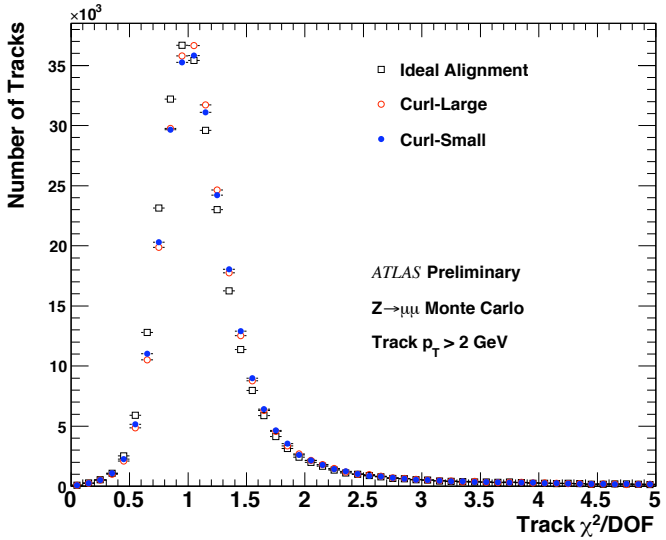
SCT DETECTOR

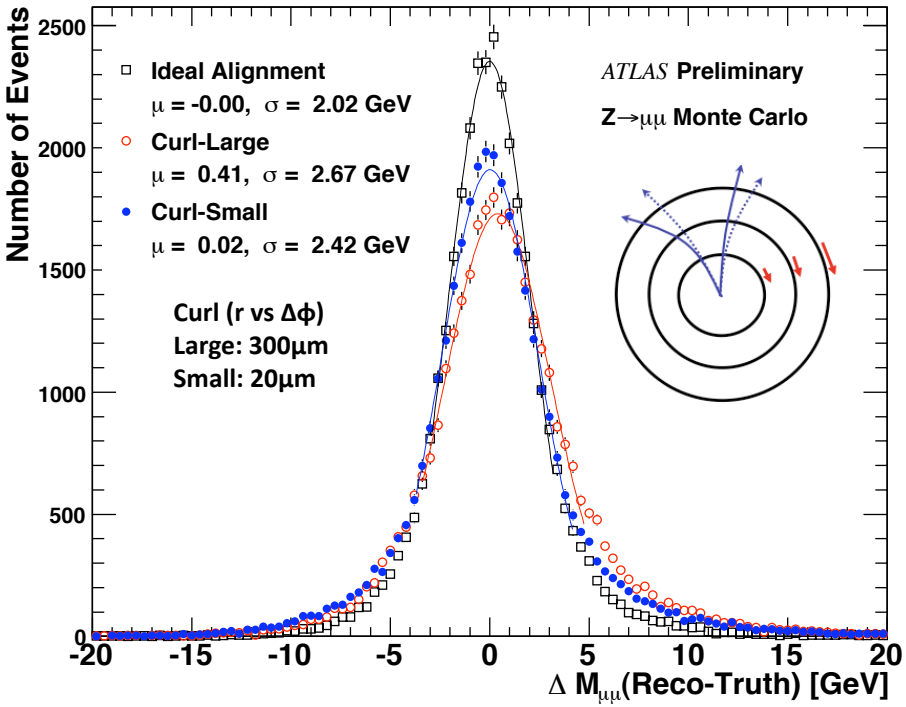




Alignment Validation: Resonances

- The weak modes are deformations that leave the X^2 unchanged
- Some weak modes deformations have been simulated (MC samples) to study the effect
- Resonance mass peak and width are sensitive to alignment effects (K_S , J/ψ , Z …)
- **MonteCarlo study**





- Other distribution studied:
  - Mass vs p_t
  - Mass vs eta
- The study using real data is in progress

Summary

- ATLAS Inner Detector alignment procedure has been presented in this talk
- Several exercises with real data have been done:
  - Commissioning phase with cosmic data:
    - Alignment constants to record first collision data
  - End-cap alignment with the first collisions
  - Accurate alignment combining 900 GeV data and cosmic data
    - Pixel resolution: 15μm
  - New alignment with 7 TeV data is in progress
- Ready for new challenges !!

BACKUP SLIDES

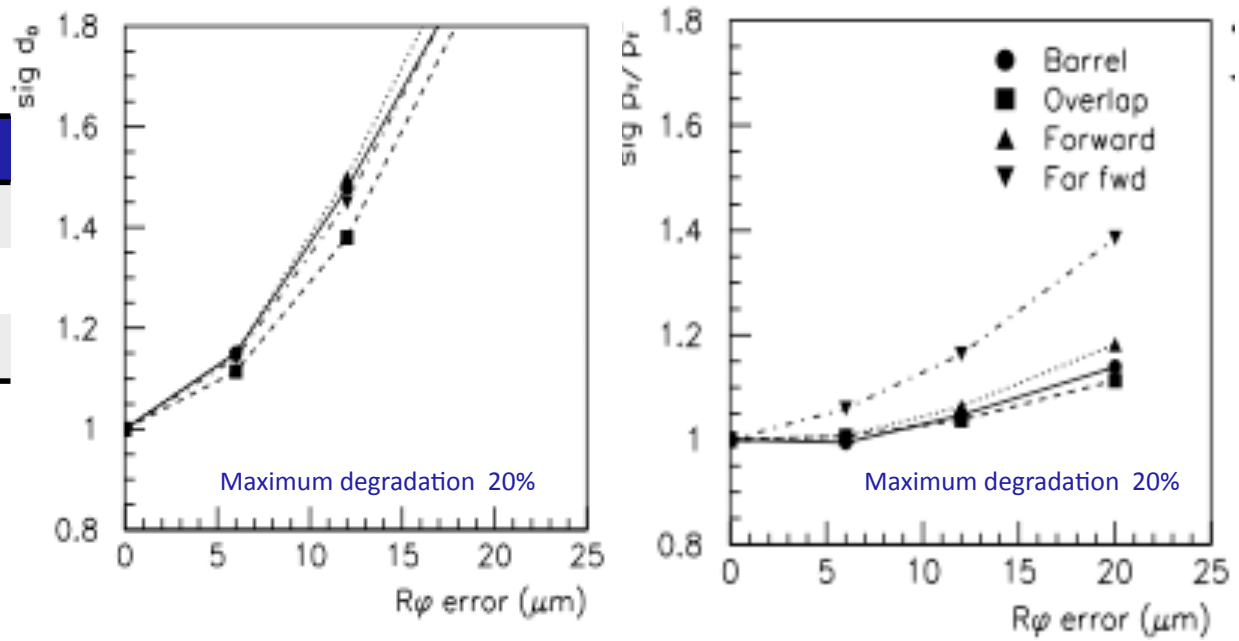
Alignment Requirements

Alignment Requirements to achieve the ATLAS Inner Detector aims:

- The knowledge of the alignment constants should not lead to a significant degradation of the track parameters beyond the intrinsic tracker resolution (degradation of tracking resolution less than 20%).

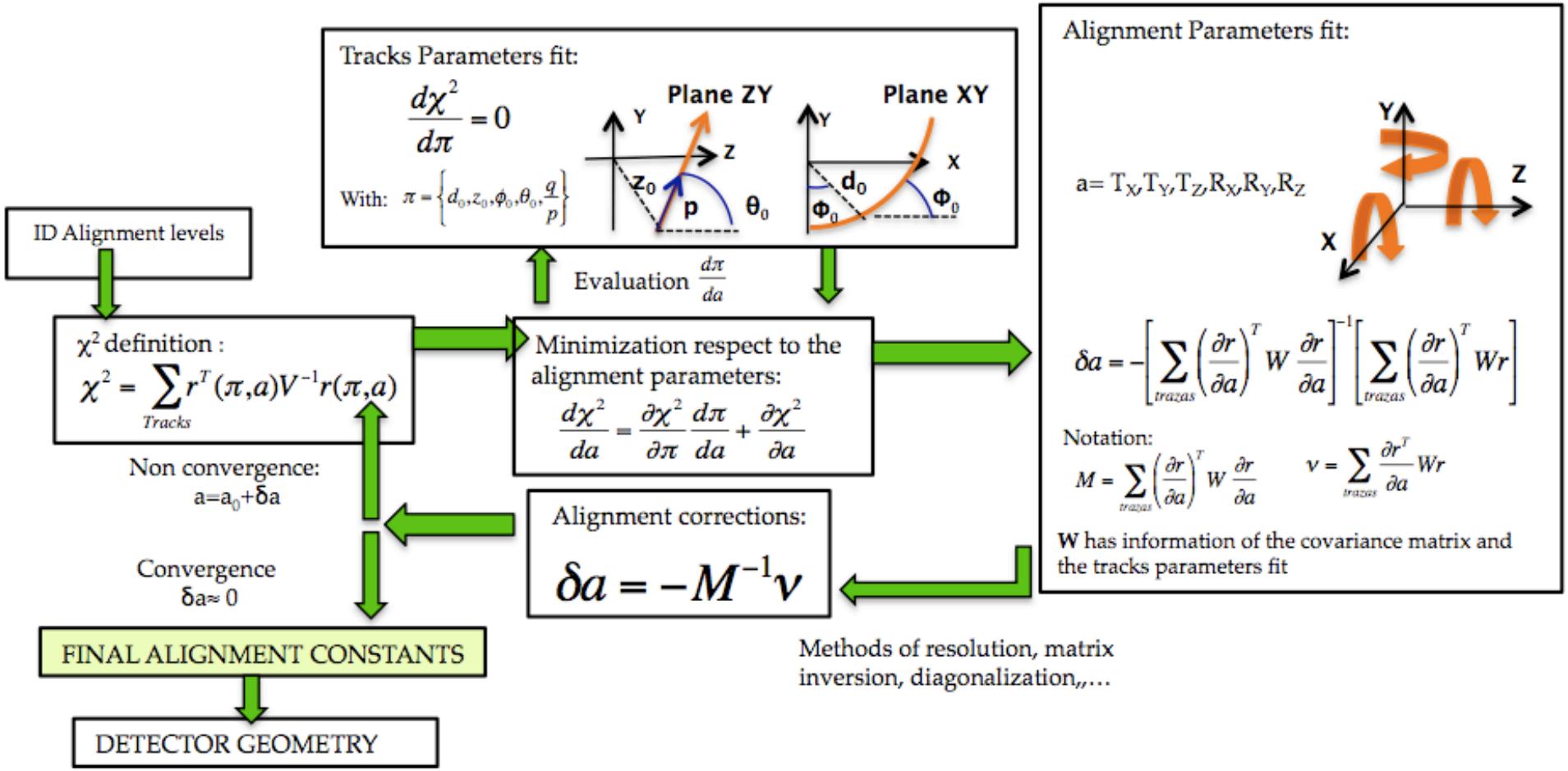
	Pixels		SCT	
Direction	***B***	***EC***	***B***	***EC***
Rϕ (μm)	7	7	12	12
Z (μm)	20	100	50	200

Inner detector resolution for muons with energy 100GeV as a function of the displacements of the modules in Rϕ direction



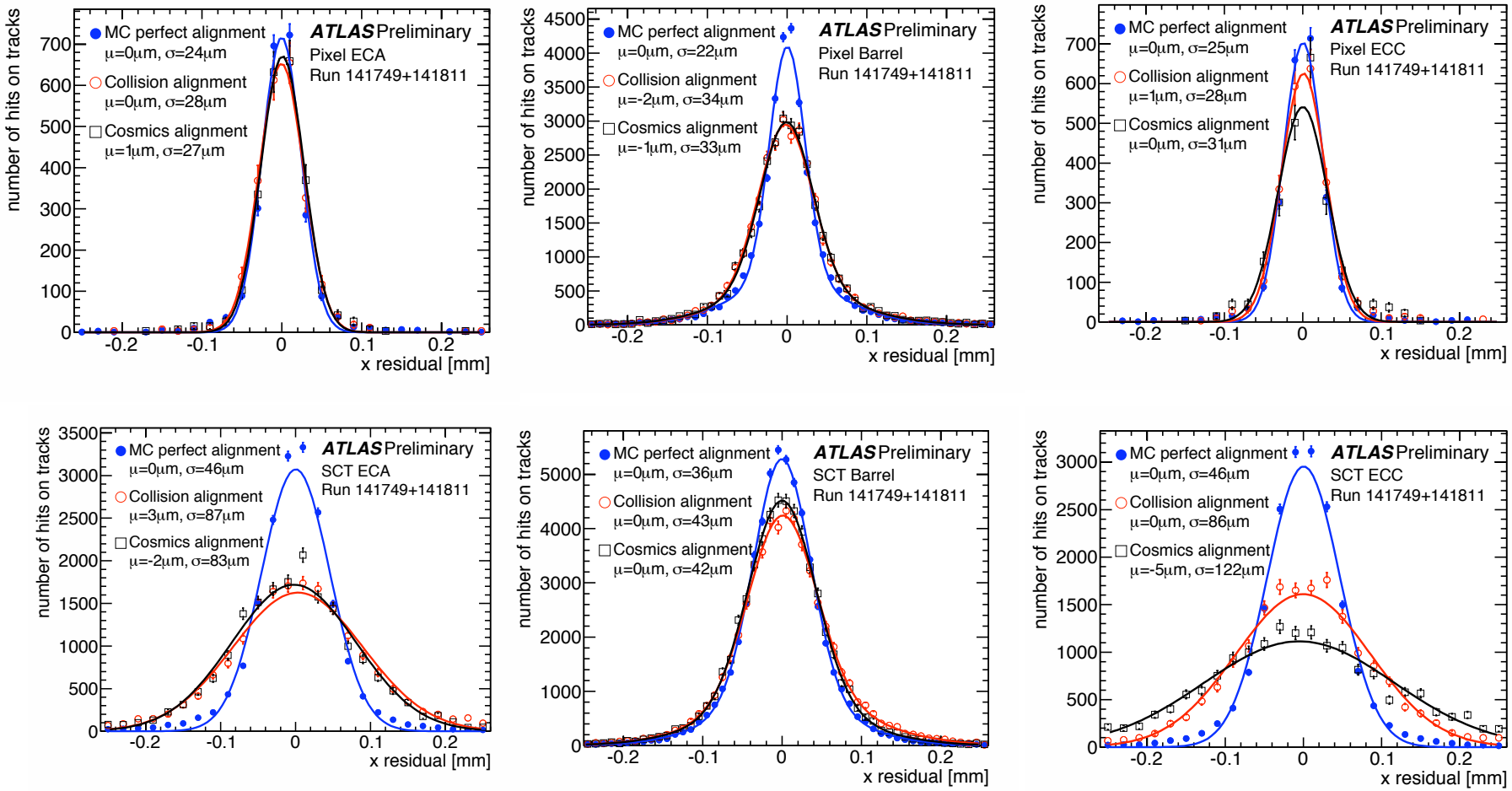
Track-based alignment algorithms

GLOBAL X^2 ALGORITHM:



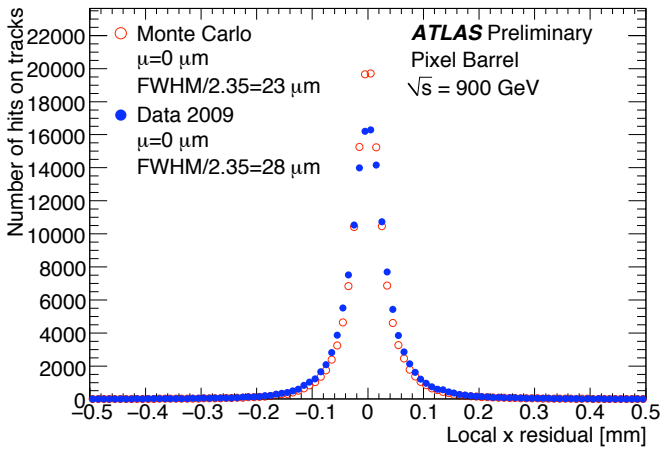
End-cap alignment using 900 GeV data

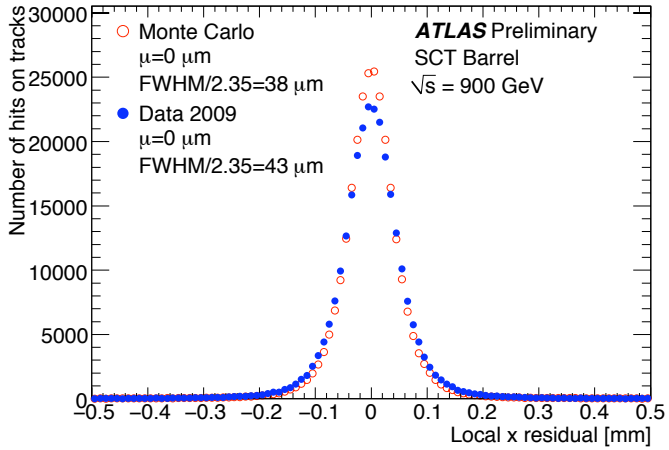
Narrow Gaussian width	PIXELs		SCT	
	Barrel	End-cap	Barrel	End-cap
Data (μm)	34	28	43	86
MC (μm)	22	25	36	46

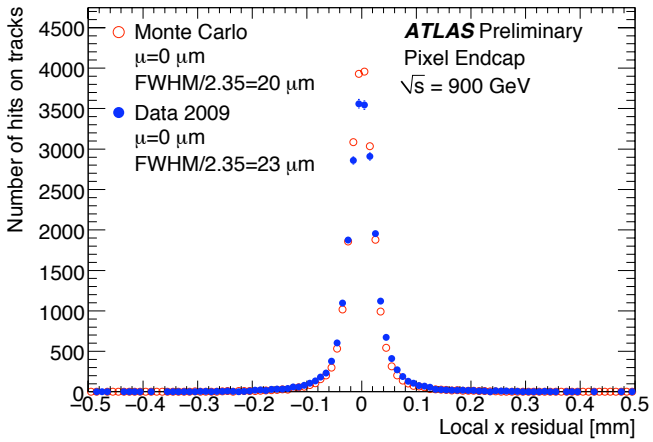


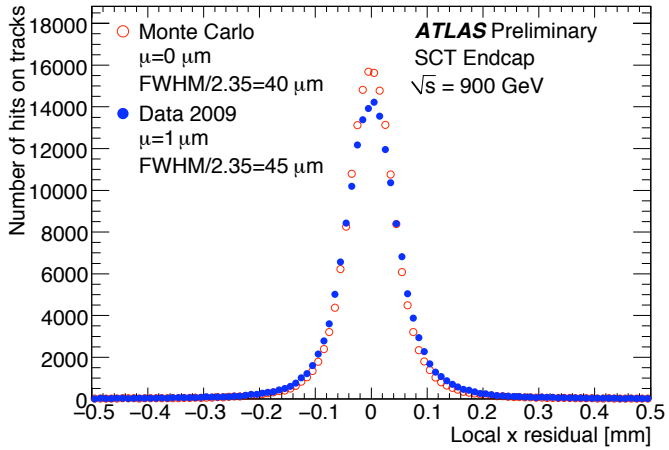
Refined alignment with 900 GeV collision data

FWHM/2.35	Pixel		SCT		TRT	
	Barrel	End-cap	Barrel	End-cap	Barrel	End-cap
Data (μm)	28	23	43	45	147	167
MC (μm)	23	20	38	40	145	143



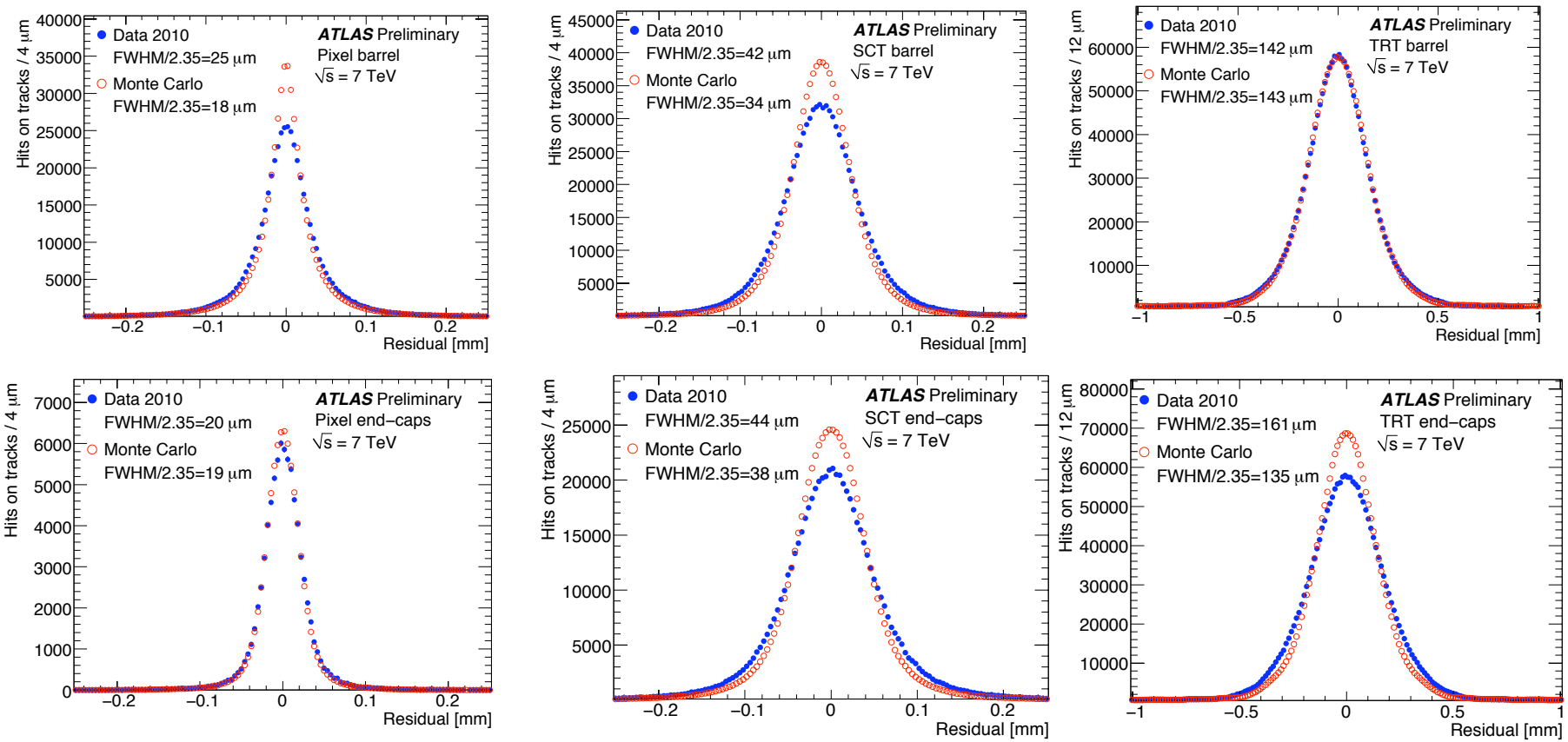






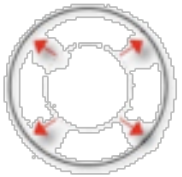
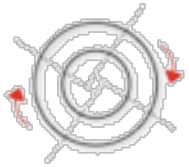
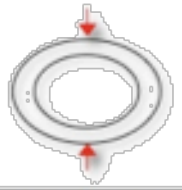
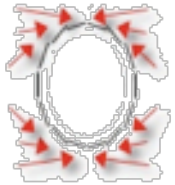
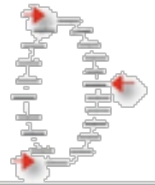
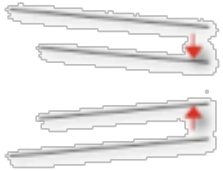
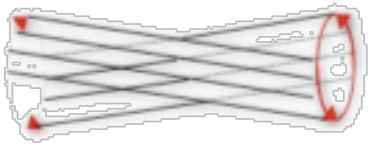
Alignment performance at 7 TeV

FWHM/2.35	Pixel		SCT		TRT	
	Barrel	End-cap	Barrel	End-cap	Barrel	End-cap
Data (μm)	25	20	42	45	141	162
MC (μm)	18	19	34	38	143	135



Alignment Validation: Weak Modes

- The weak modes are deformations that leave the X^2 unchanged
- Some weak modes deformations have been included into MC samples to study the effect

	ΔR	Δϕ	ΔZ
R	**Radial Expansion** (distance scale) 	**Curl** (Charge asymmetry) 	**Telescope** (COM boost) 
ϕ	**Elliptical** (vertex mass) 	**Clamshell** (vertex displacement) 	**Skew** (COM energy) 
Z	**Bowing** (COM energy) 	**Twist** (CP violation) 	**Z expansion** (distance scale)