Commissioning and Alignment of the ATLAS Inner Detector using Cosmic Data

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Commissioning of the ATLAS Pixel Detector with Cosmic Data
Sep 30, 9:15

Nick Barlow
Operation of the ATLAS Semiconductor Tracker
Sep 30, 10:30

On behalf of ATLAS Collaboration

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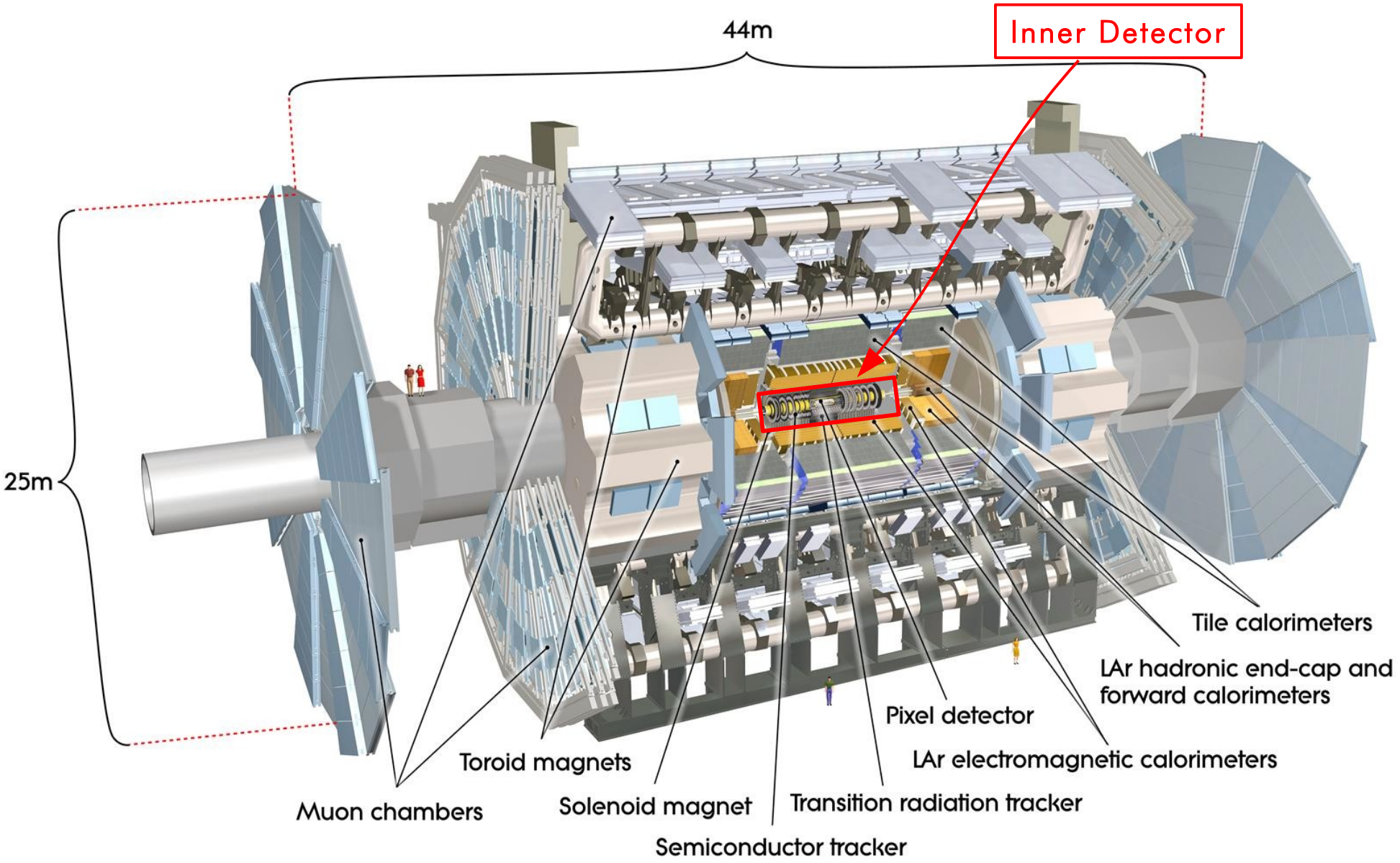
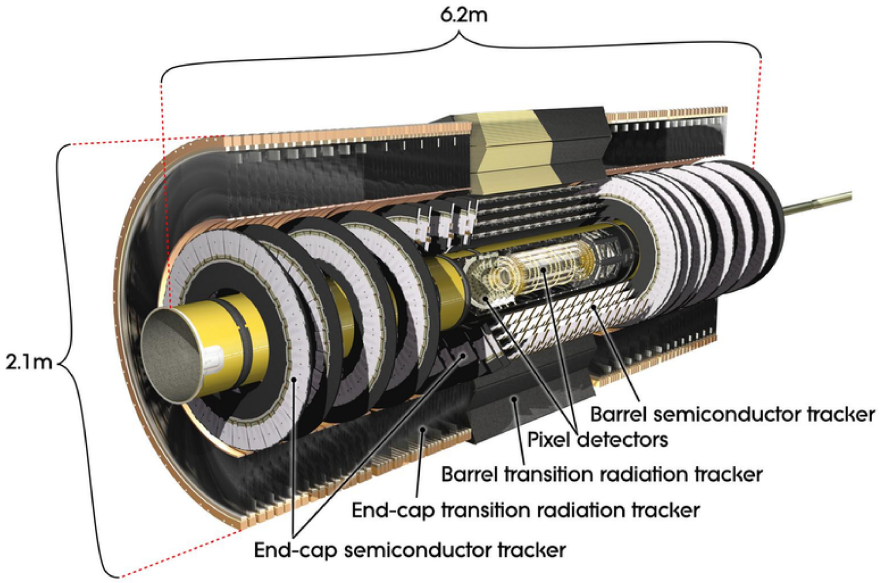
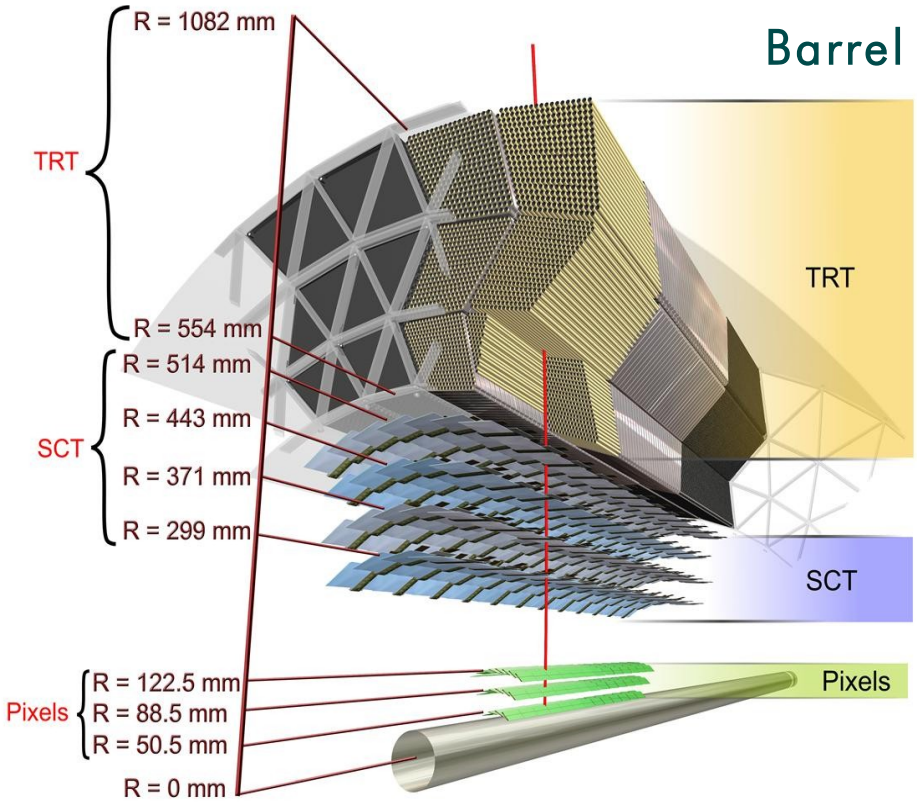
The ATLAS detector at the LHC



ATLAS Inner Detector





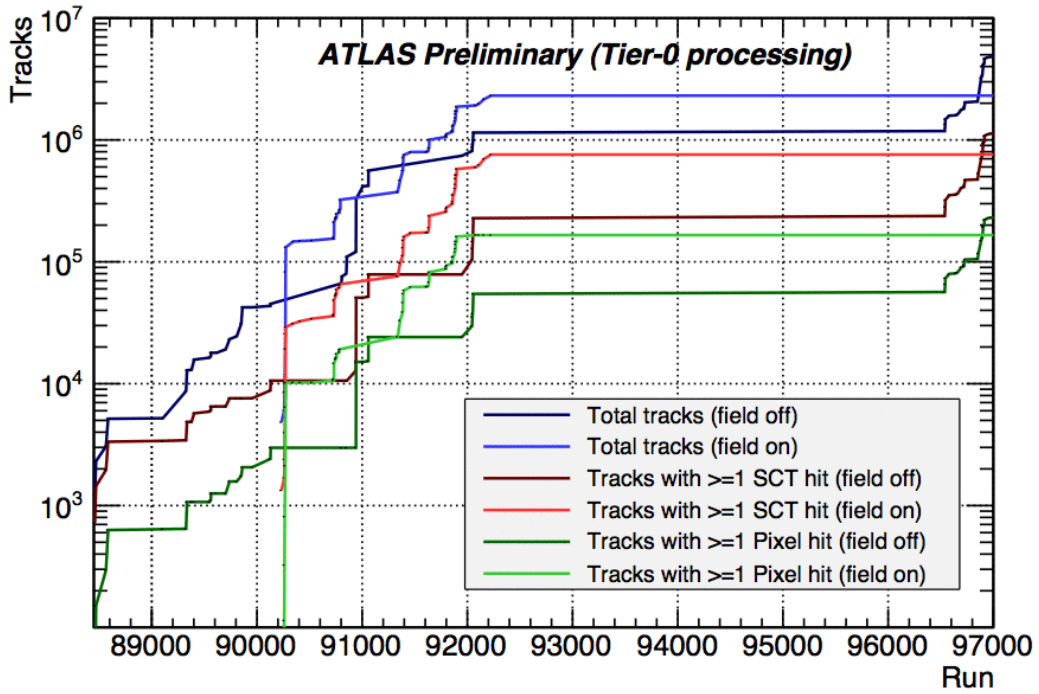
- tracking coverage $|\eta| < 2.5$
- magnetic field $B = 2$ T
- momentum resolution
  $\sigma(p_T)/p_T = 1.5\% \oplus 3.4 \times 10^{-4}\ p_T$ [GeV/c]
- impact parameter resolution
  $\sigma(d_0) = 10\ \mu m \oplus 140/p_T$ [GeV/c]

Detector	Type	Modules	Channels	Intrinsic resolution
Pixel	silicon pixel modules	1774	~80M	10 μm ($r\varphi$), 115 μm (rz)
SCT	silicon micro-strip detectors	4088	~6M	17 μm ($r\varphi$), 580 μm (rz)
TRT	straw drift tubes	176	~350k	130 μm ($r\varphi$)

Cosmic data taking 2008

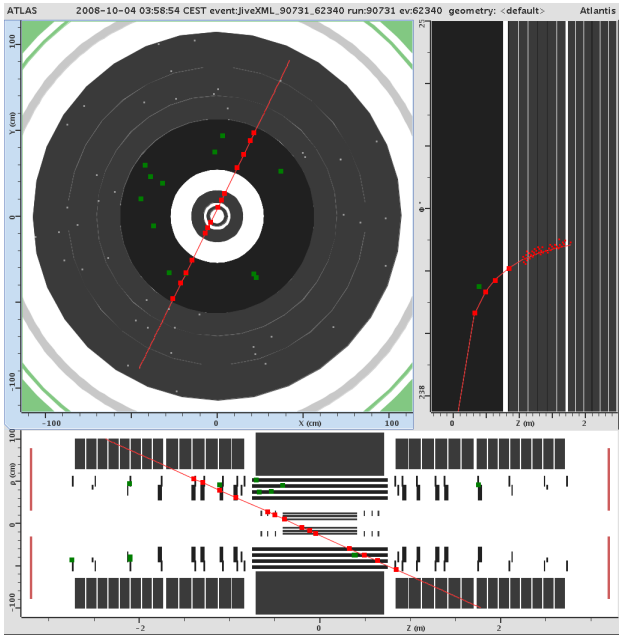
- Sept to Dec 2008
- several hundred million cosmic events in ATLAS collected in various detector configurations
- with and without B field
- using tracking in level 2 trigger – boost of Inner Detector tracks
- Inner Detector track statistics:

Magnetic field	OFF	ON
All InDet tracks	4.9M	2.7M
SCT tracks	1.2M	880k
Pixel tracks	230k	190k

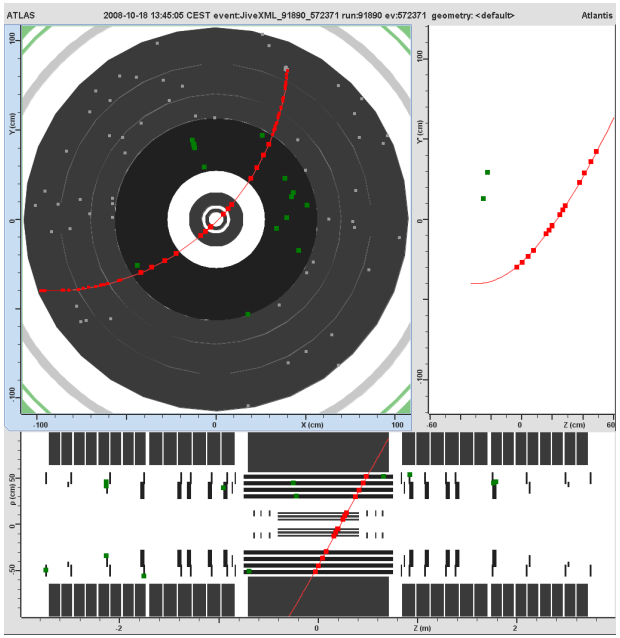


Cosmic events in the Inner Detector

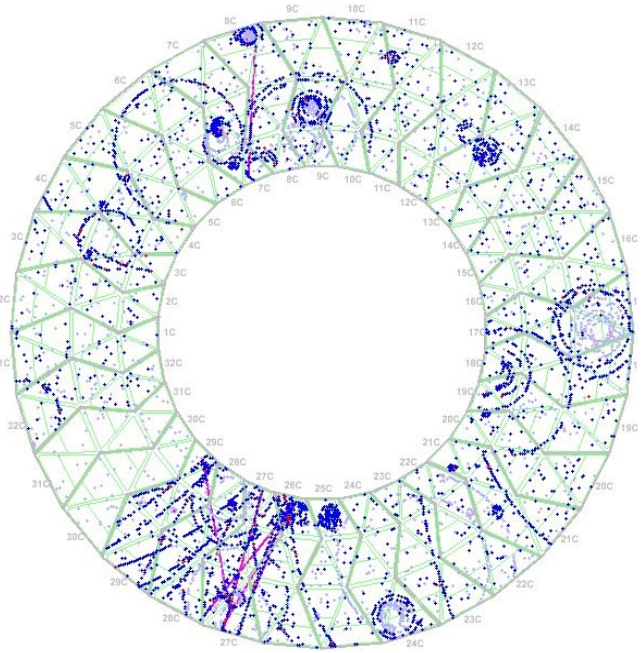
B field OFF



B field ON



Secondaries in the TRT



Commissioning with cosmics:

- debugging of the experiment → fixing problems
- calibration and alignment
- performance studies
- gain operational experience

↳ PREPARATION FOR THE COLLISIONS

Alignment of the Inner Detector

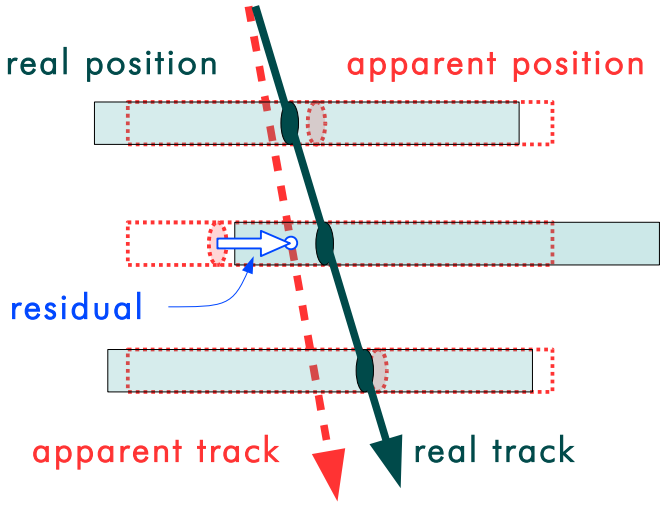
GOAL: degradation of resolution on track parameters should be $< 20\%$

- ultimate precision can be reached using track-based alignment algorithms
- alignment is based on the minimization of track-hit residuals r

$$\chi^2 = \sum_{\text{tracks}} r^T V^{-1} r \quad \text{where} \quad r = r(\pi, \alpha)$$

V - track covariance matrix
π - track parameters
α - alignment parameters

- solution $\dfrac{d\chi^2}{d\alpha} = 0$



Global χ^2

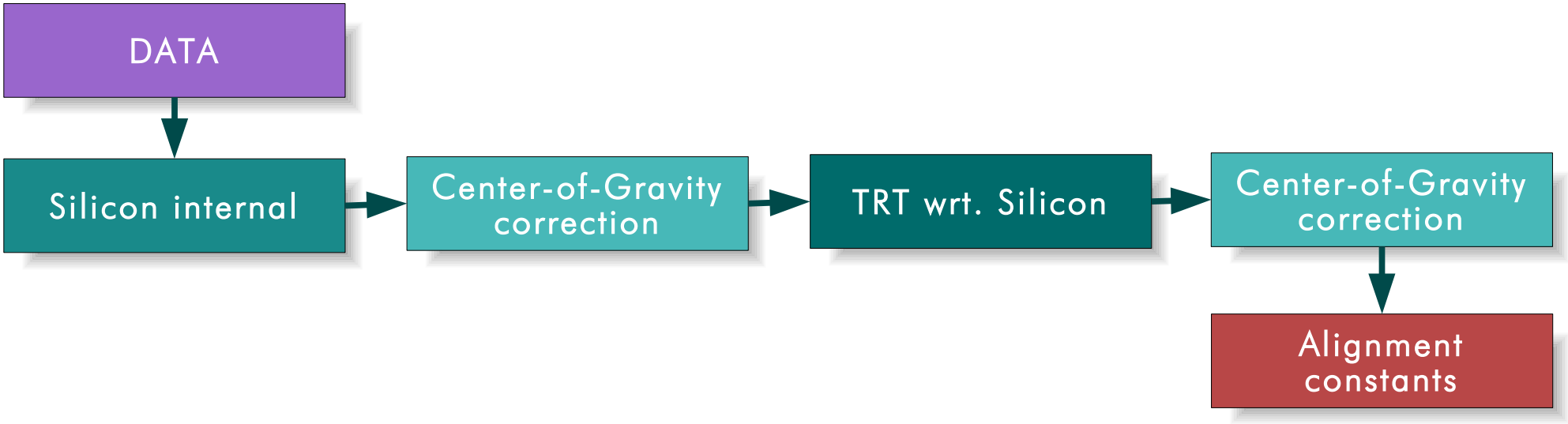
- single large matrix including all the correlations
- for 6 degrees-of-freedom per module and N modules requires solving of linear system of $6N$ parameters → ~ 40,000 for the full Inner Detector
- requires usage of fast solving techniques

Local χ^2 – solving of N linear systems of 6 parameters, ignoring explicit correlations between modules,
– correlations are restored via iterations, needs many iterations

Robust – uses overlap residuals between modules

Alignment procedure

Alignment sequence



Alignment implementation

- currently alignment implemented separately for Silicon and TRT
- needs to be run sequentially - not possible to align Silicon and TRT at the same time

- new alignment code with extra functionality is being tested (allows alignment of Si + TRT at the same time)
- goal is to have it ready for the data taking

Alignment strategy

- aligning large structures first
  - expected largest misalignments, smaller statistics needed, smaller system to solve
- adding degrees-of-freedom depending on expected misalignments given by the construction
- limited illumination of the detector taken into account
  - cosmic tracks mostly vertical → end-caps and sides of the barrel have limited statistics

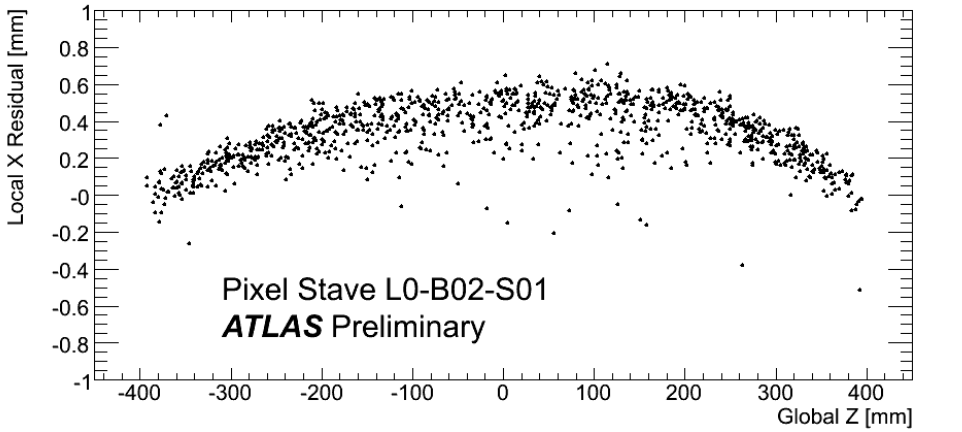
Silicon:

- relative subsystem alignment
  - Pixel, SCT barrel, 2 x SCT end-cap
- barrel layer/half-shell alignment
- end-cap disk alignment
- barrel stave alignment
- barrel module alignment

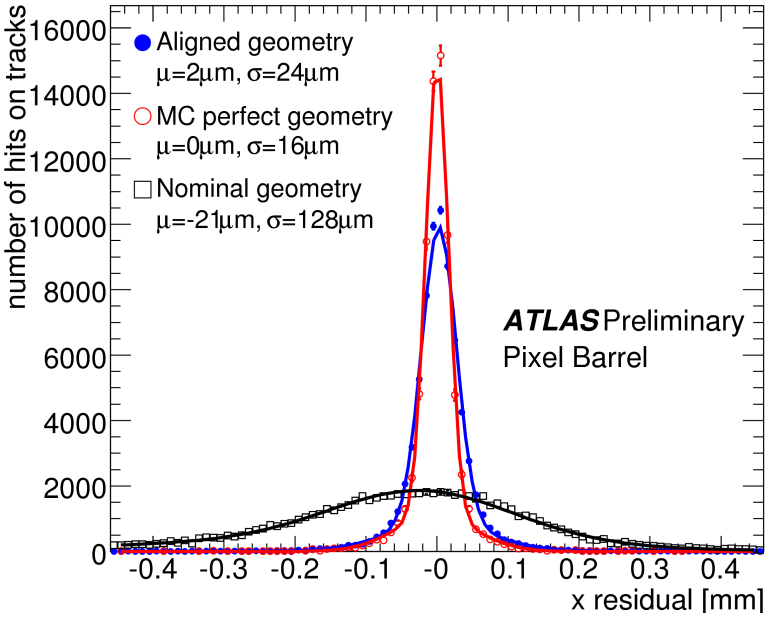
TRT:

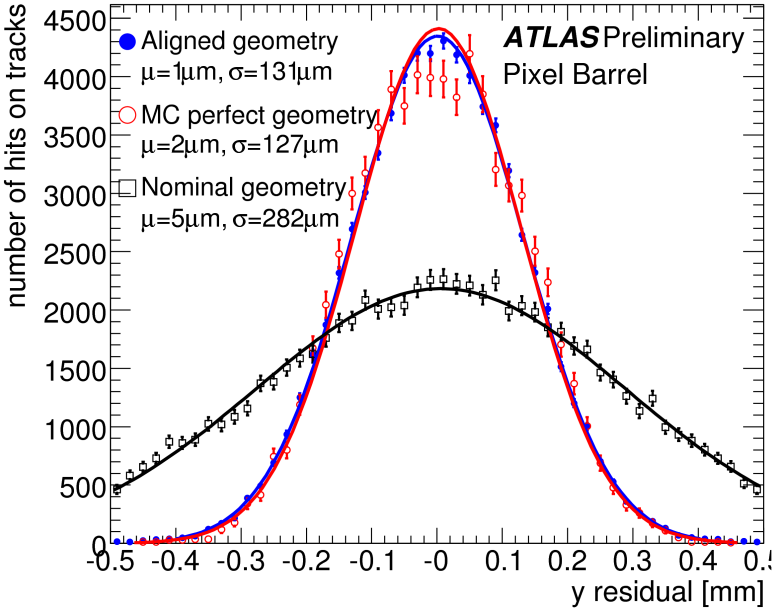
- TRT barrel + 2 x TRT end-cap
- barrel module alignment

example Pixel stave bow

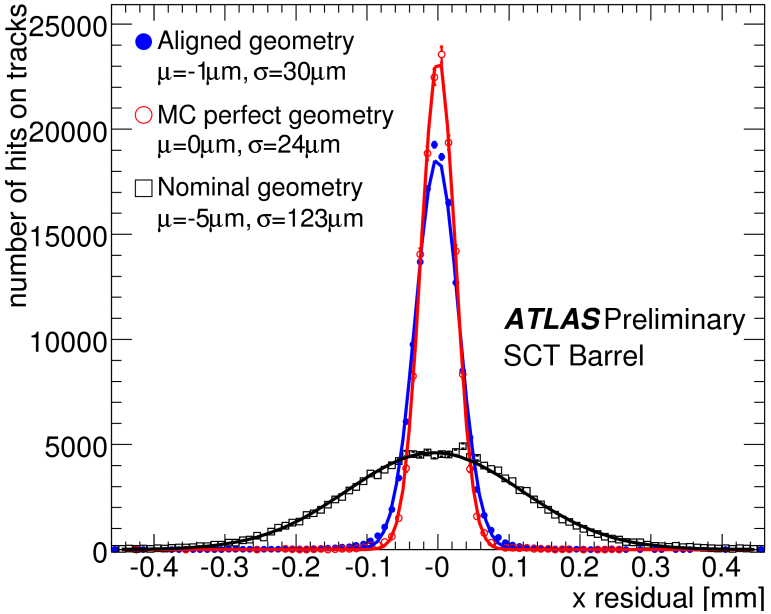


Residual distributions - Silicon





- 2008 cosmic-ray data
- using mixture of *B*-on and *B*-off data
- obtained consistent set of alignment constants for the Inner Detector
- **significant improvement of residual distributions after alignment**
- no offset, width close to what is expected from MC with perfectly aligned geometry

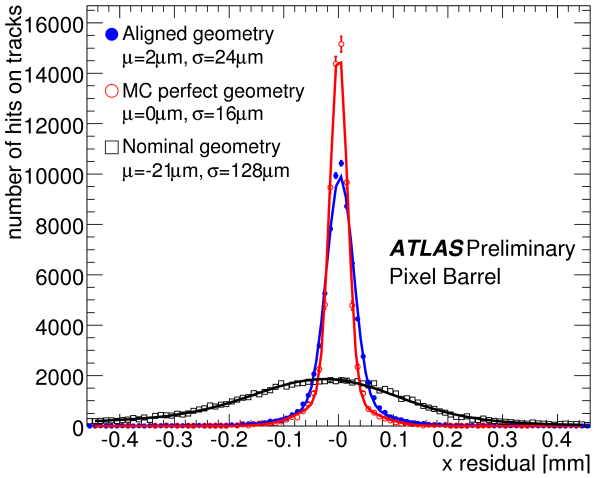


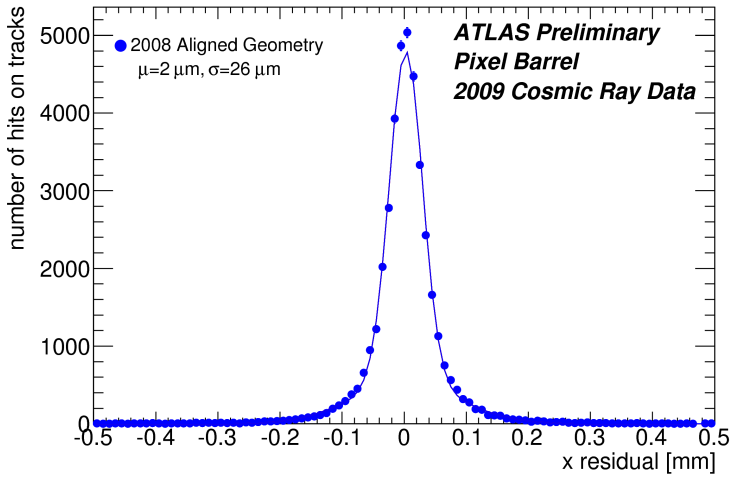
Alignment stability 2008 → 2009

- residual distribution for 2009 cosmic data obtained using 2008 aligned geometry
- difference only few microns → detector stable

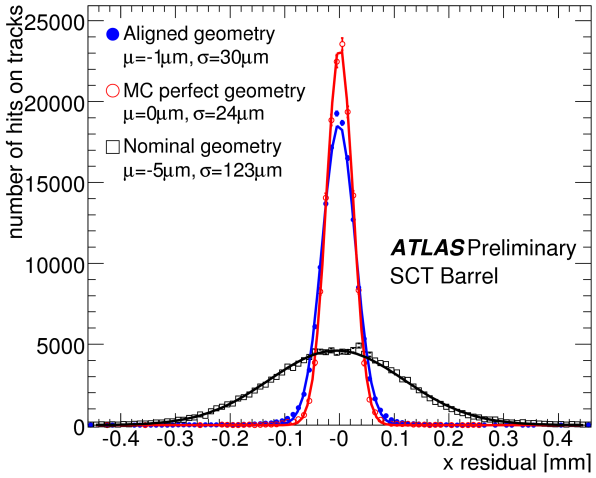
2008 2009

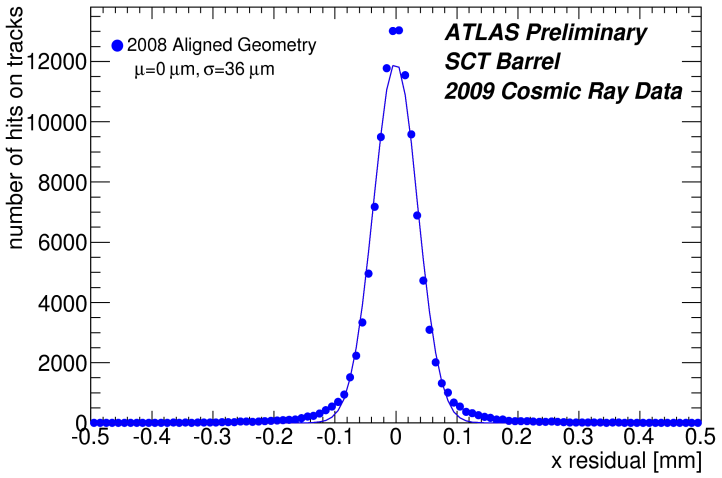
Pixel x residual





SCT x residual

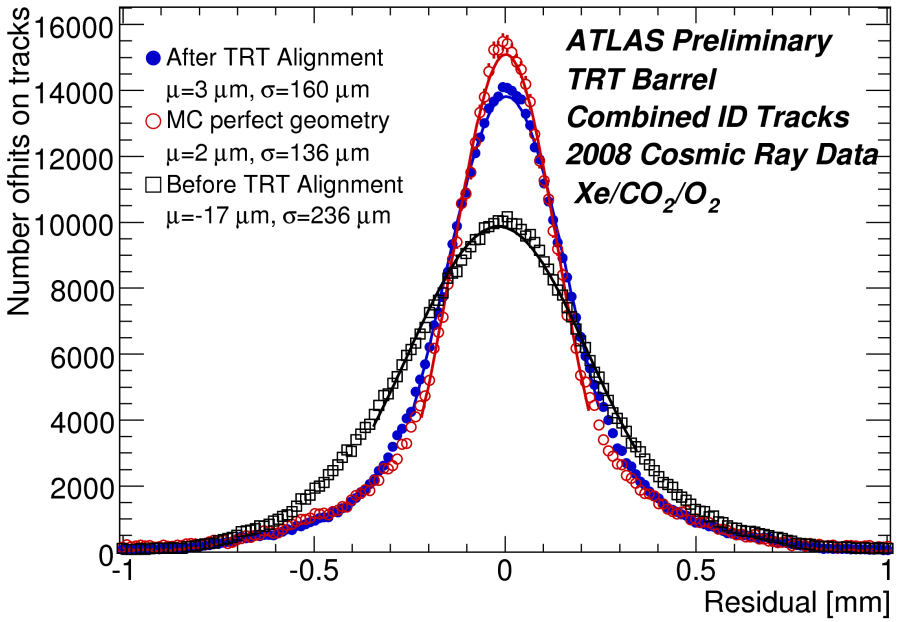




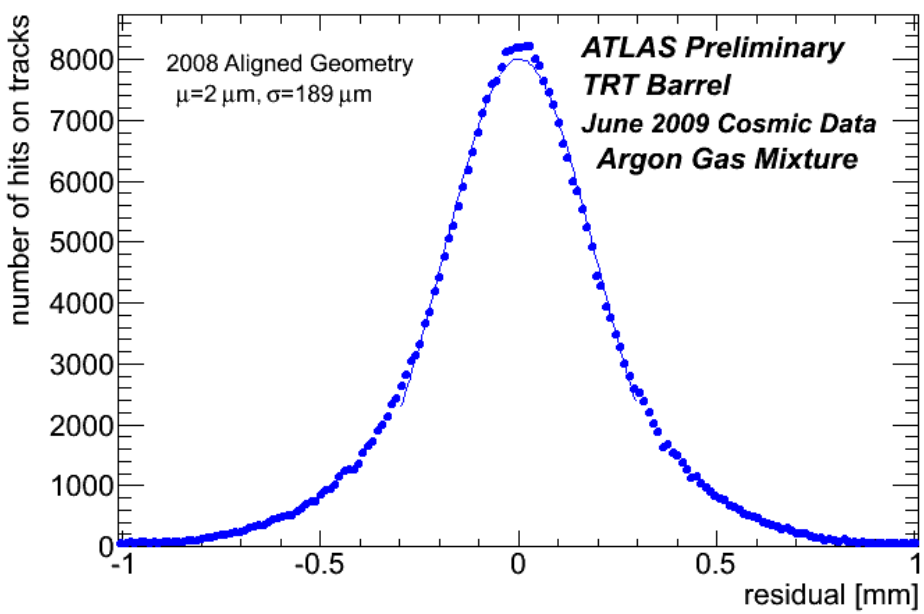
Residual distributions - TRT

- significant improvement after alignment and consistency between 2008 and 2009 cosmic also seen in the TRT
- slightly worse resolution in 2009 is expected
  - using Argon instead of Xenon

2008

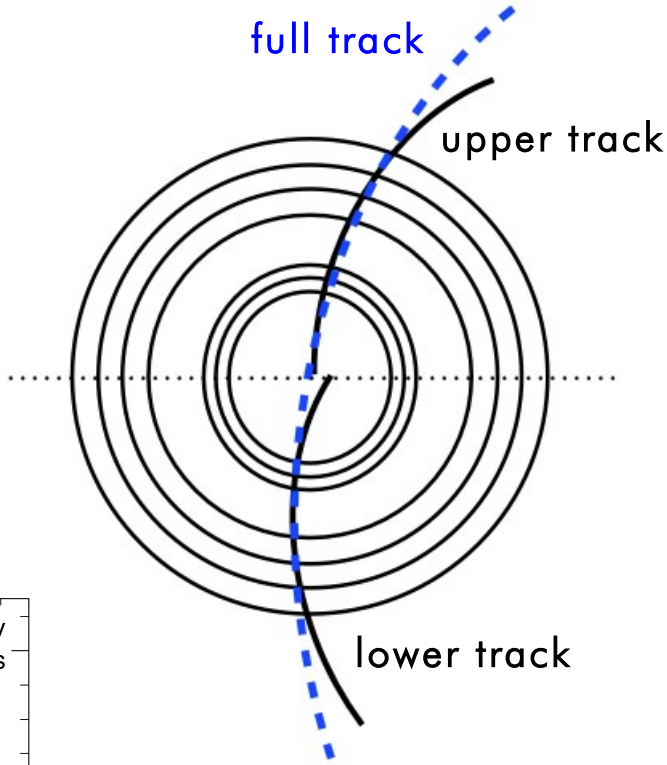


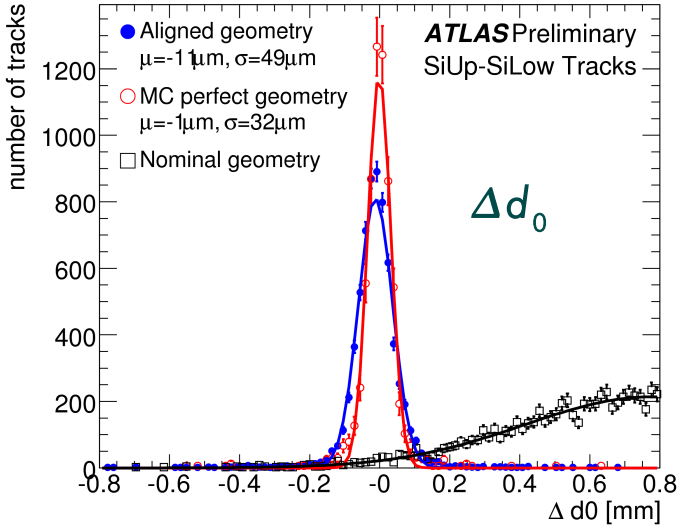
2009

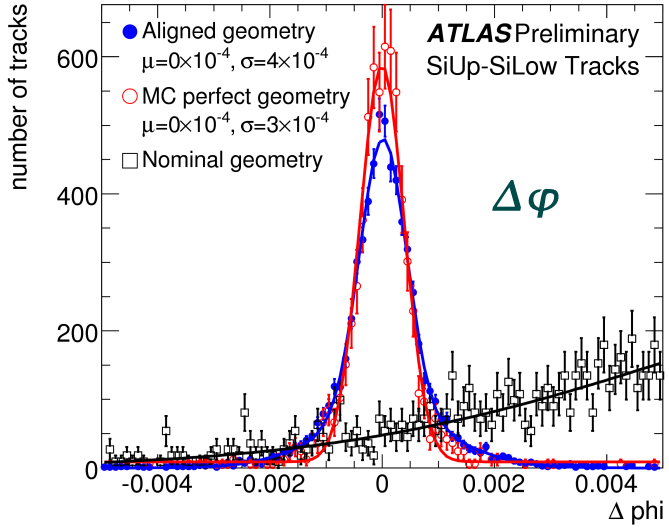


Tracking performance

- cosmic tracks cross both upper and lower hemisphere of the Inner Detector
- tracks are split into upper and lower half
- two **collision-like tracks** are refitted separately as independent tracks
- track parameters are compared at the perigee
- **provides direct measurement of the track parameter resolution and bias**
- **huge improvement after alignment**
- remaining small biases are being investigated







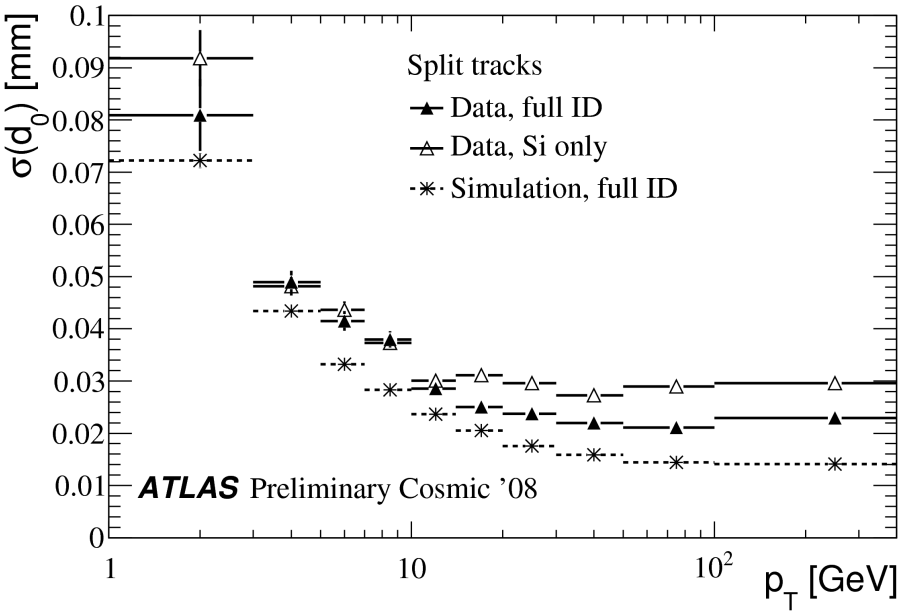
$$\text{resolution} = \frac{\sigma}{\sqrt{2}}$$

Track parameter resolution

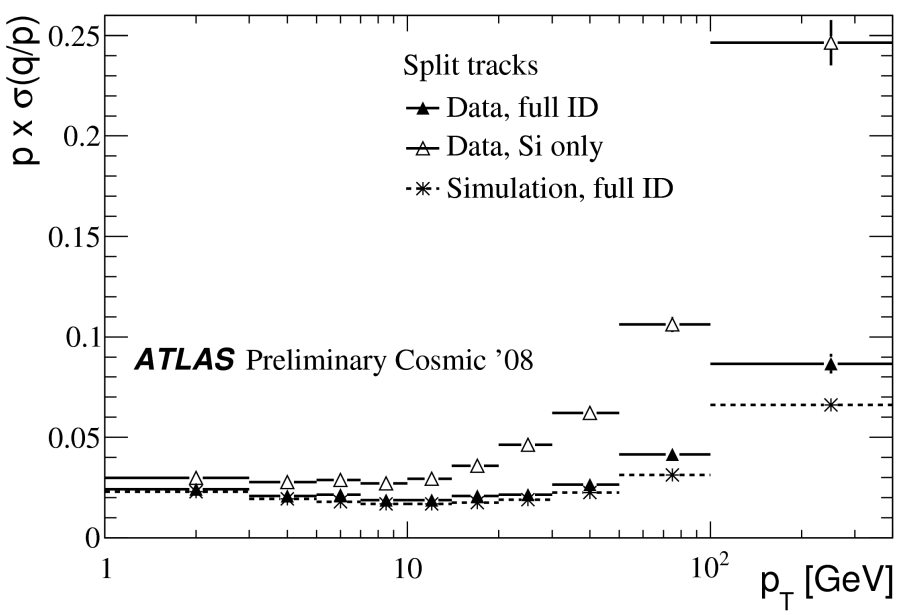
- comparison of track parameter resolution between Silicon-only tracks and full Inner Detector tracks as function of p_T
- resolutions are better when TRT is included
  - many more hits
  - bigger lever-arm
- good starting point for collisions

- **low p_T region**
  - dominated by multiple scattering
- **high p_T region**
  - dominated by intrinsic resolution and misalignments

Impact parameter resolution

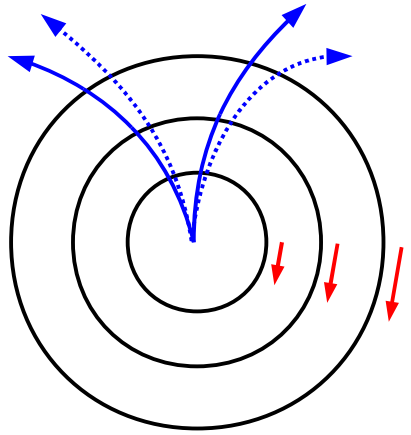


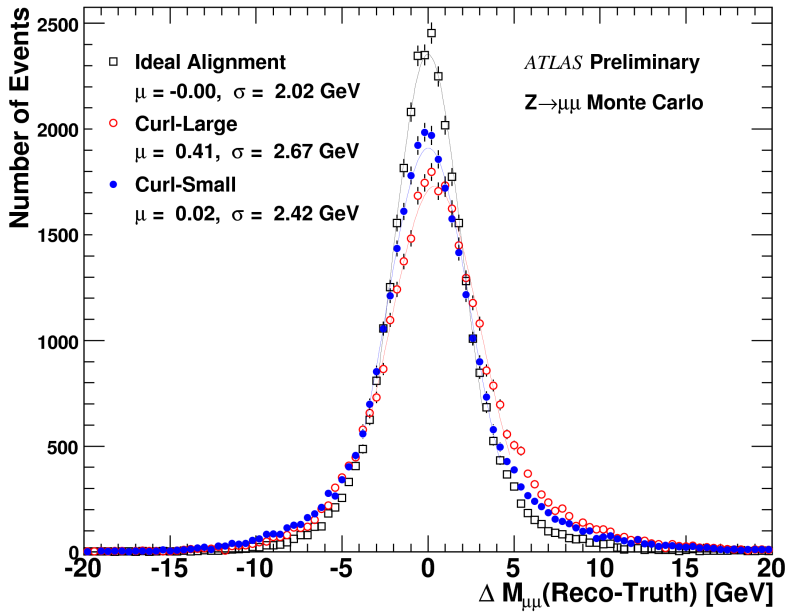
Relative momentum resolution



Weak modes

- systematic deformations which don't change the χ^2 of the track but systematically bias the track parameters
- studies of physics impact of weak modes are ongoing
- example: Curl ➞ introduces momentum bias
- impact of Curl deformation on the reconstructed mass of the di-muon pair from $Z \rightarrow \mu\mu$ decay
  - Curl-Large : 300 μm at outermost layer
  - Curl-Small : after alignment with collision data only
  - difference to ideal is consistent with residual misalignment of 20 μm
- cosmic tracks help remove the weak modes
- further handles on weak modes:
  - beam halo events
  - survey, vertex and beam spot constraints
  - E/p asymmetry for e^+ and e^-
  - physics signatures, e.g. $Z \rightarrow \mu\mu$, $J/\psi \rightarrow \mu\mu$





Summary

- The ATLAS Inner Detector has been commissioned with 2008 cosmic data
  - gained operational experience, performed calibration and alignment, performance studies
  - after alignment the tracking performance very good
  - good starting conditions for the collision data
- 2009 cosmic data taking
  - checked stability of the alignment
  - still ongoing – further improvements are expected
- Waiting for collision data
  - needed for further improvements in detector understanding
  - expected fast improvement of the alignment, especially for the end-caps and for the weak modes

ATLAS Inner Detector is well prepared for the first collisions.