Alignment of the ATLAS Inner Detector Tracking System

Grant Gorfine

(University of Wuppertal)

On behalf of the

ATLAS Collaboration

2009 Meeting of the Division of Particle and Fields of the American Physical Society (DPF 2009)

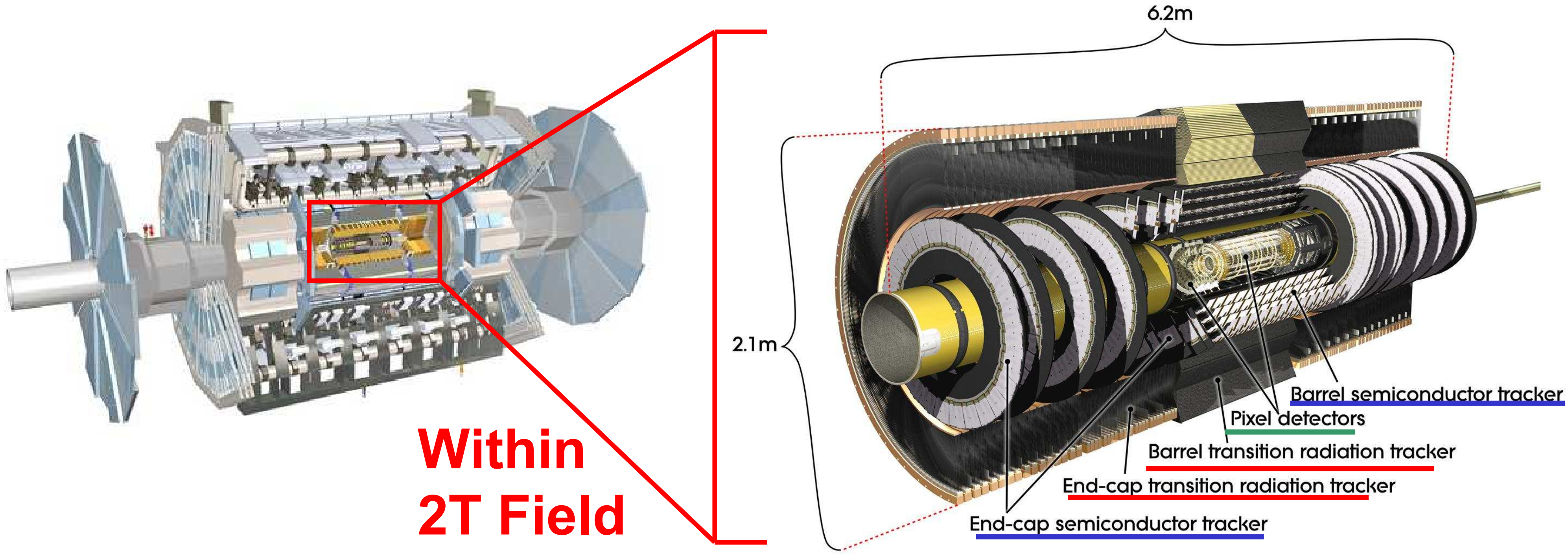
Detroit

26 – 31 July 2009

Outline

- Overview of ATLAS Inner Detector
- Cosmic data collection
- Alignment algorithms
- Alignment strategy
- Results
- Prospects for collision data taking.

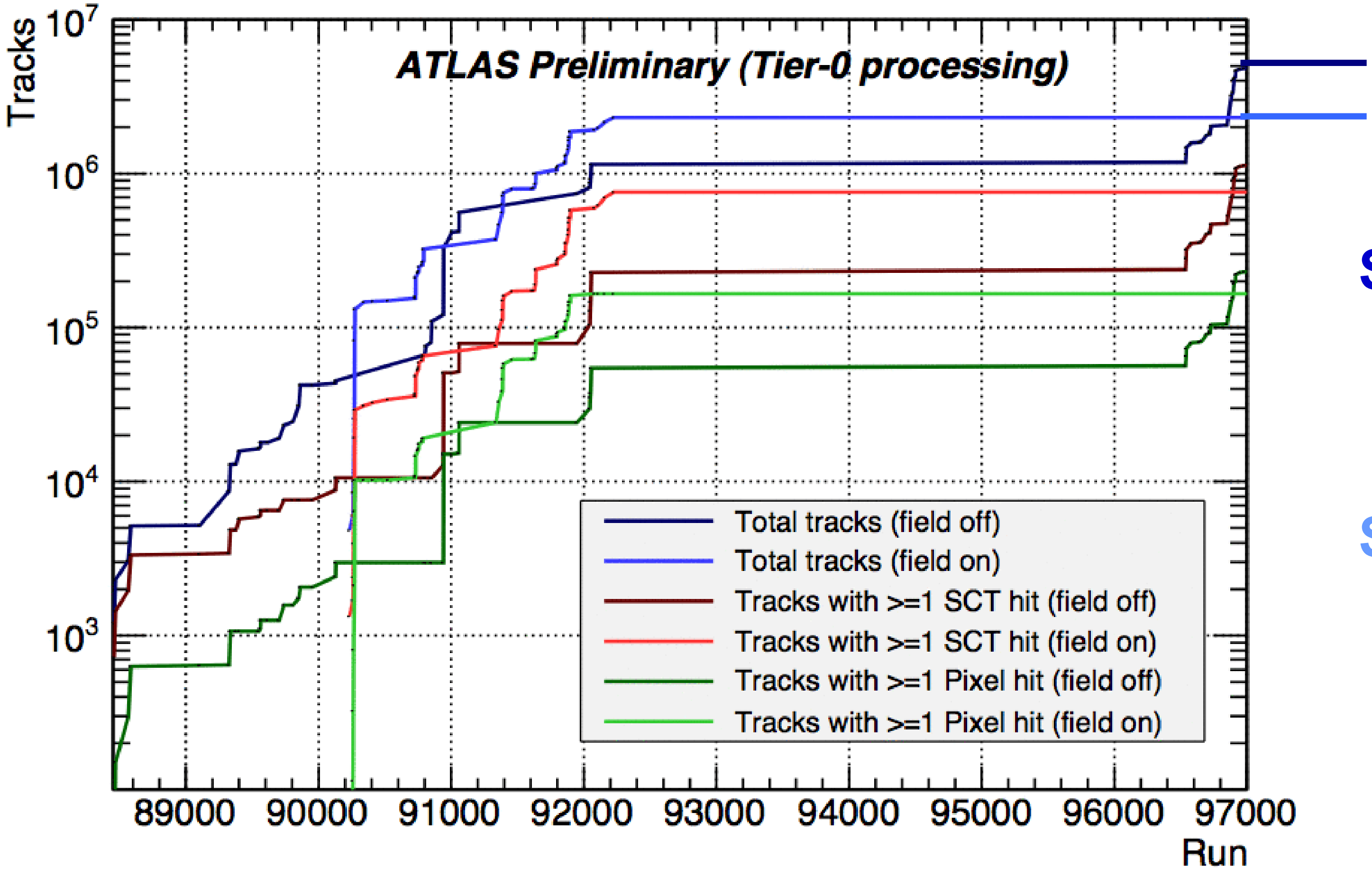
ATLAS Detector and Inner Detector



Detector	Layers/Discs	Modules	Element size	Resolution
Pixel (silicon pixels)	3 barrel layers: 2 x 3 endcap discs	1456 288	50 μm (φ) x 400 μm (z,r)	10 μm (φ) x 115 μm (z,r)
SCT (silicon strips)	4 barrel layers 2 x 9 endcap discs	2112 1976	80 μm. 2 sides: 40 mrad stereo	17 μm (φ) x 580μm (z,r)
TRT (straw drift tubes)	3 x 32 barrel modules 2 x 40 endcap wheels	96 80	4 mm diameter	130 μm (φ)

Cosmic Data Taking 2008

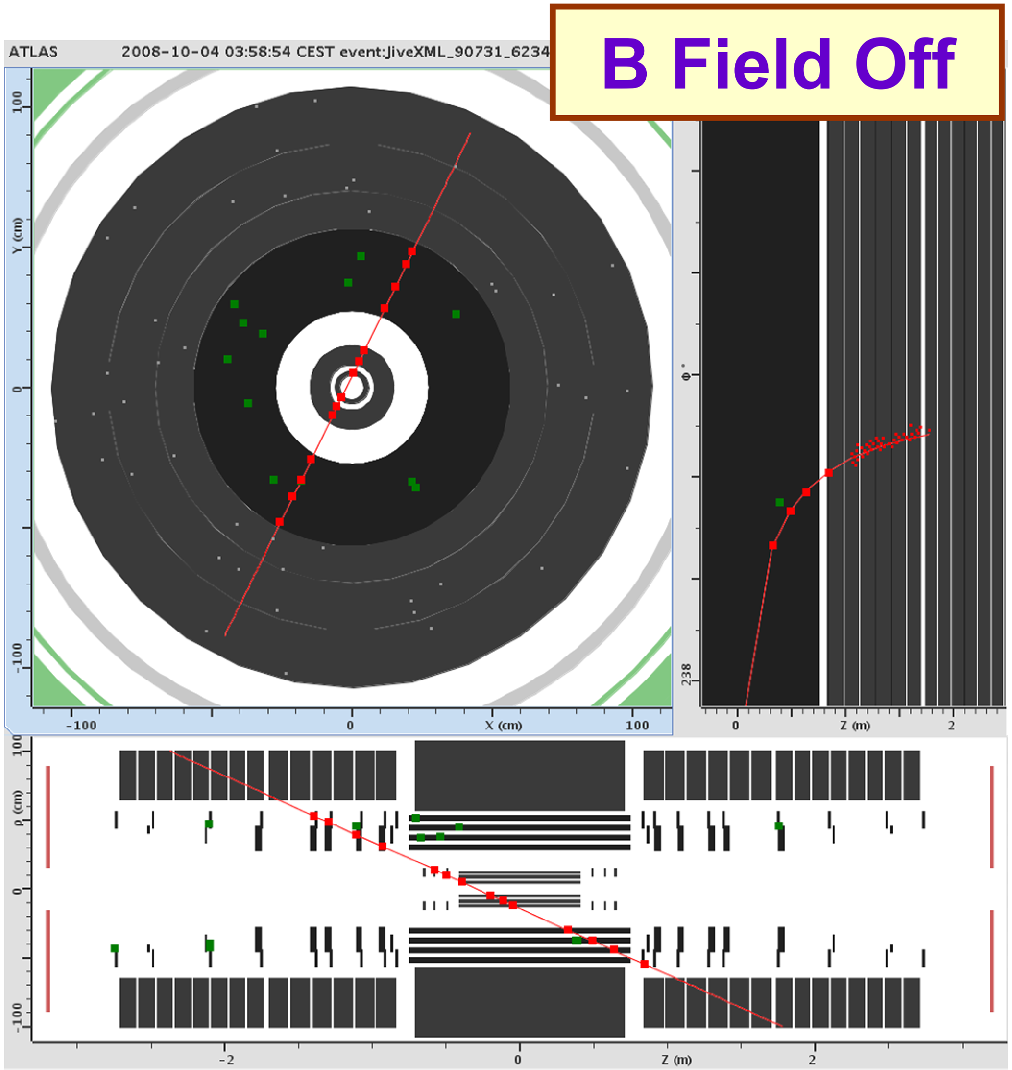
- Cosmic data taking: Sep to Dec 2008.
- With B field on and off.
- LVL2 tracking trigger to boost Inner Detector tracks

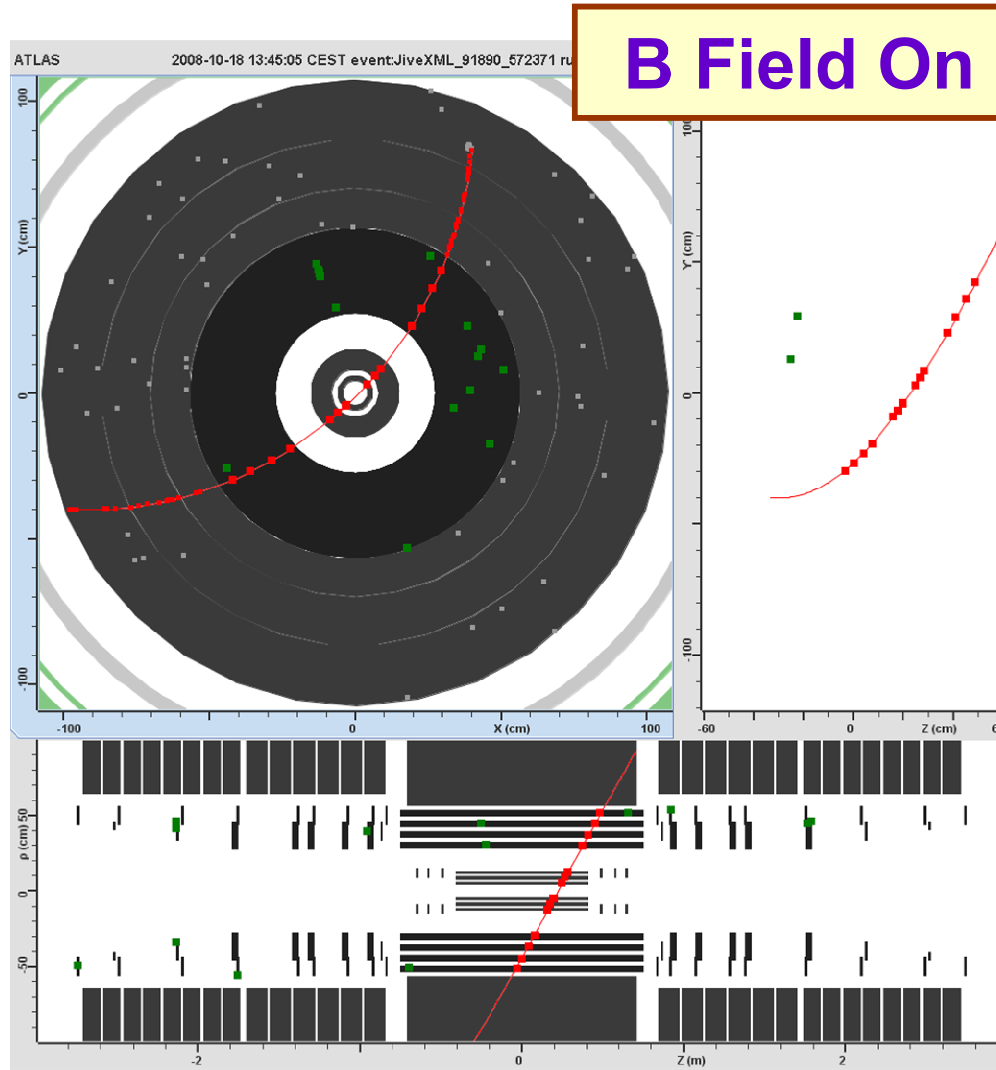


Solenoid OFF:
- 5M ID tracks
- 2M with SCT hits
- 230k with Pixel hits

Solenoid ON:
- 2.6M ID tracks
- 880k with SCT hits
- 190k with Pixel hits

Example Cosmic Events





Alignment Algorithms

- χ^2 minimization

$$\chi^2 = \sum_{tracks} r^T V^{-1} r$$

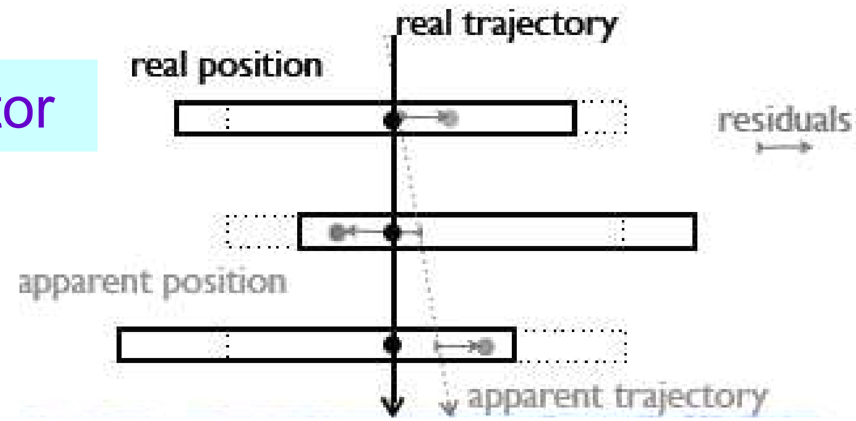
r = residual vector

measurement error + MCS

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

a = alignment parameters

Solution of form $a = M^{-1}b$.



Requires matrix inversion: Full diagonalization (eg LAPACK) or fast solving techniques (eg MA27) - possible with sparse matrix.

- **Global χ^2 (current baseline).**
  - One 6N x 6N matrix (ie 36k x 36k for all modules) – full correlations
  - Few iterations still needed (due to non linearities)
- **Local χ^2**
  - N 6x6 matrices (drop correlation between modules)
  - Several iterations (correlations come through the iterations)

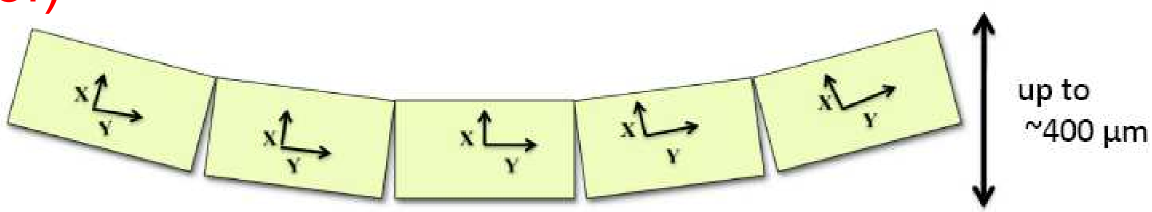
- Other Methods
  - **Robust approach**: Si only, no rotations. Makes use of hit + overlap residuals
  - **Standalone pixel**: For cross checks. Study coherent deformations such as ladder bow

Alignment Strategy

- No hardware based information.
  - Frequency Scanning Interferometer installed in SCT (can monitor alignment changes) but turned off during cosmic data taking.
- Pixel survey used as starting point.
- Alignment Sequence
  - Silicon (Pixel+SCT) internal alignment
  - TRT internal alignment
  - TRT wrt to Silicon
  - Center-of-Gravity correction.

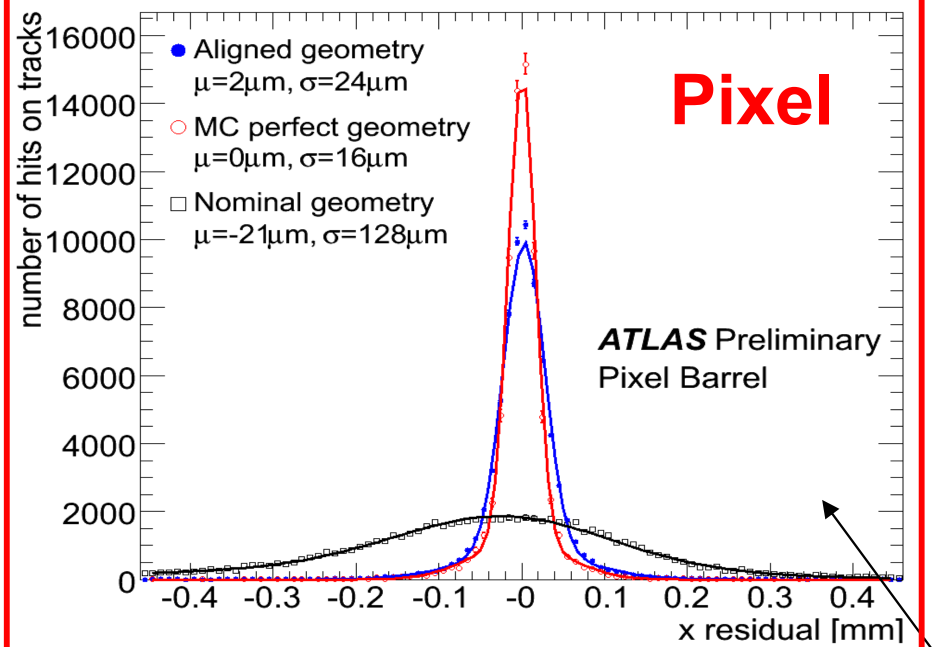
Alignment Strategy

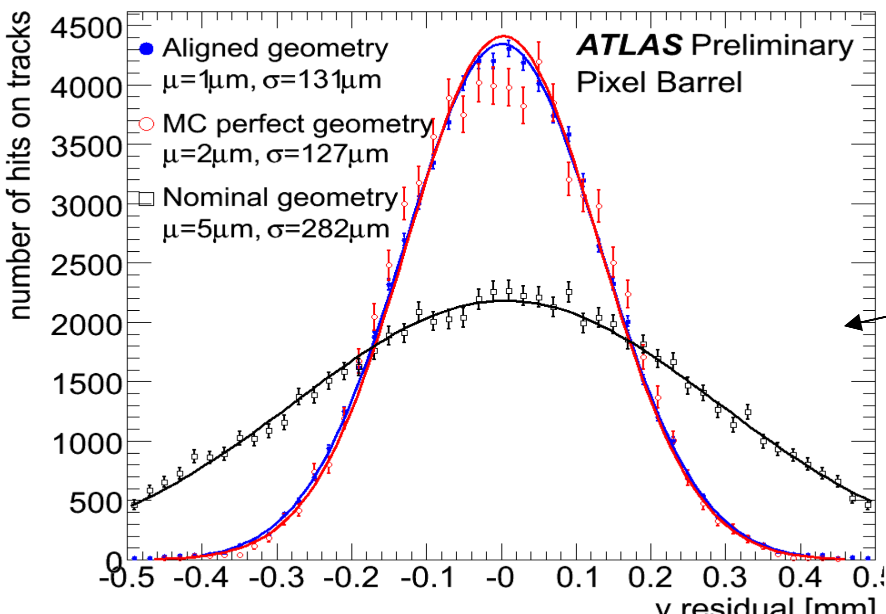
- Strategy maps to substructure of detector
- Strategy used for alignment with cosmic data:
  - Subsystem: Pixel + SCT (Barrel + 2 Endcap) (24 dof)
  - Layer/Half shell alignment: 3x2 pixel half shell, 4 SCT layers, endcaps as whole (84 dof)
  - Ladders: 112 pixel ladders, 176 SCT ladders, endcaps (1752 dof)
  - Modules: 2 dof per barrel modules (translation in most sensitive direction (local x) and rotation in plane – corrects bow of pixel ladder). Endcaps as whole (7160 dof)

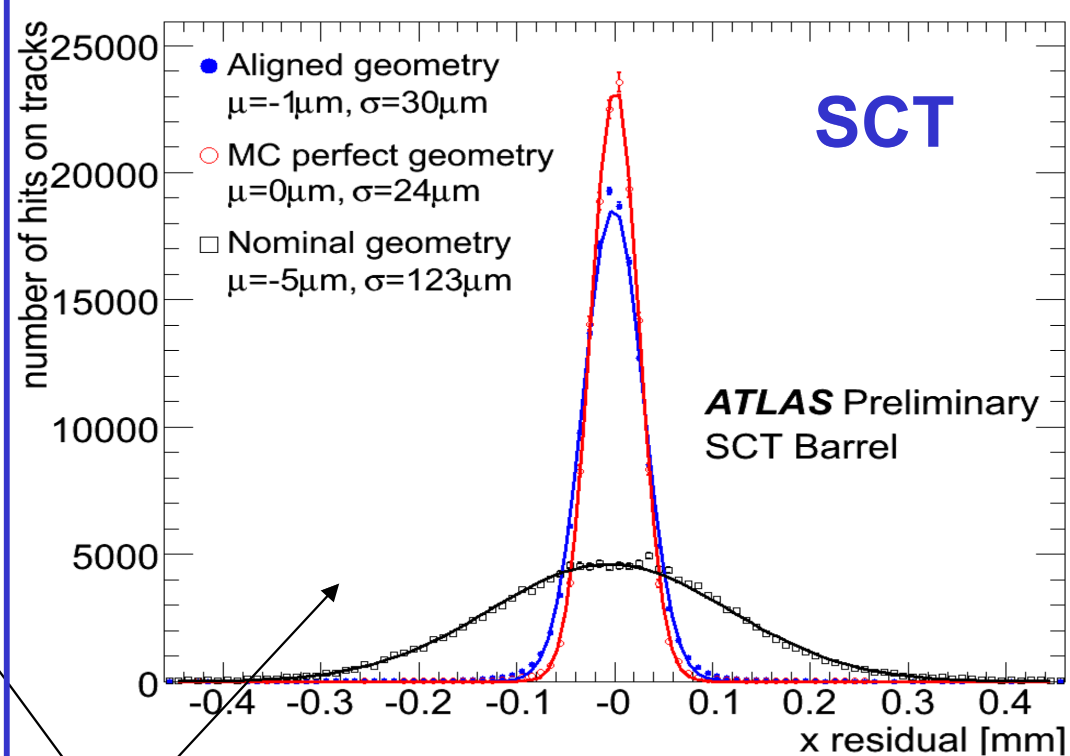


- Conservative approach. More degrees of freedom gradually added as we gained experience. Not all modules well illuminated (side of barrel and the endcaps). Plan to use full degrees of freedom when we have collision data.

Results: Residuals (2008 data)





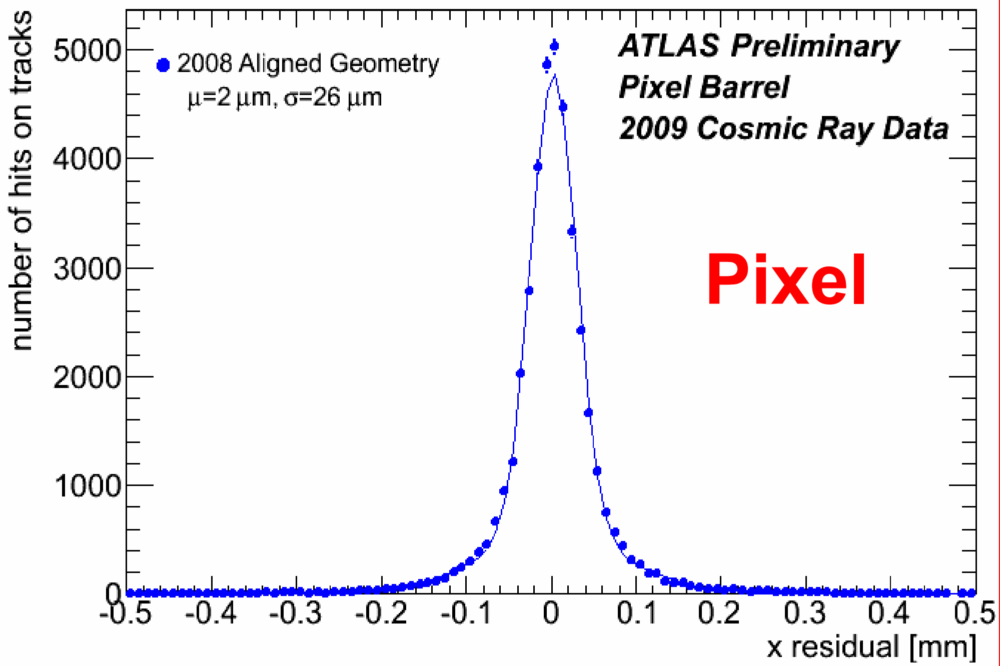


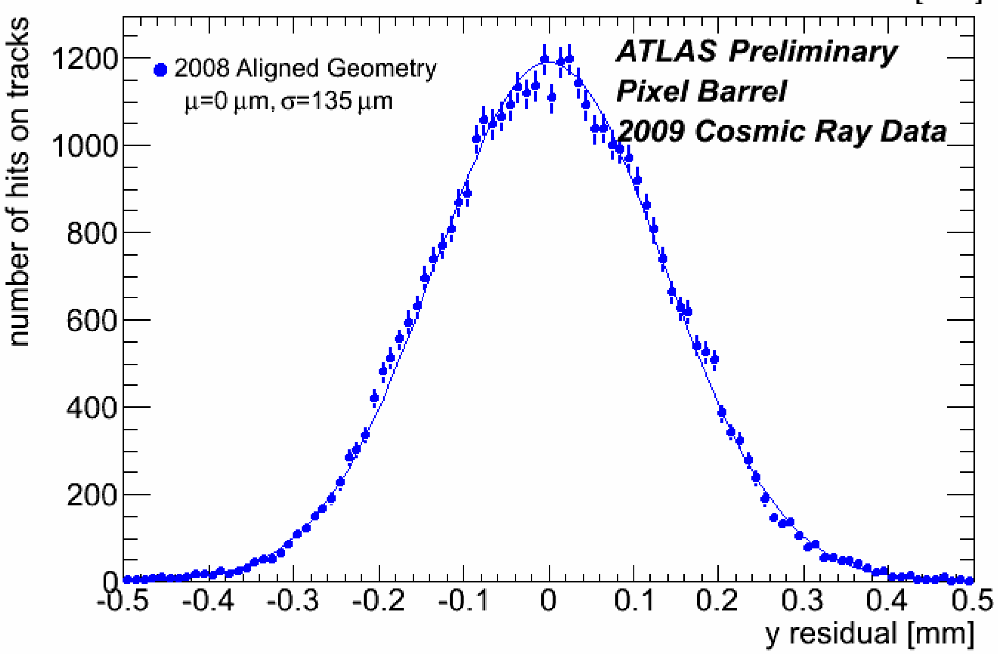
Local x : Most sensitive measurement direction (φ)

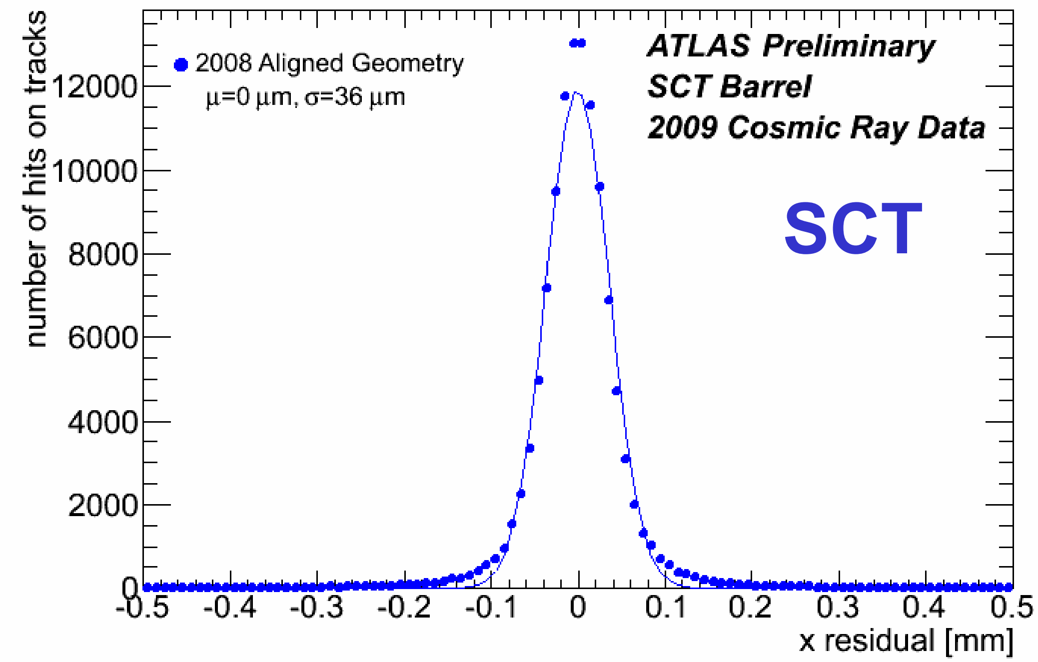
Local y : Orthogonal measurement direction (z, r)

Width reduced and well centered on 0.
Width increase consistent with O(20) μm smearing.

Comparison with 2009 run (June 2009)



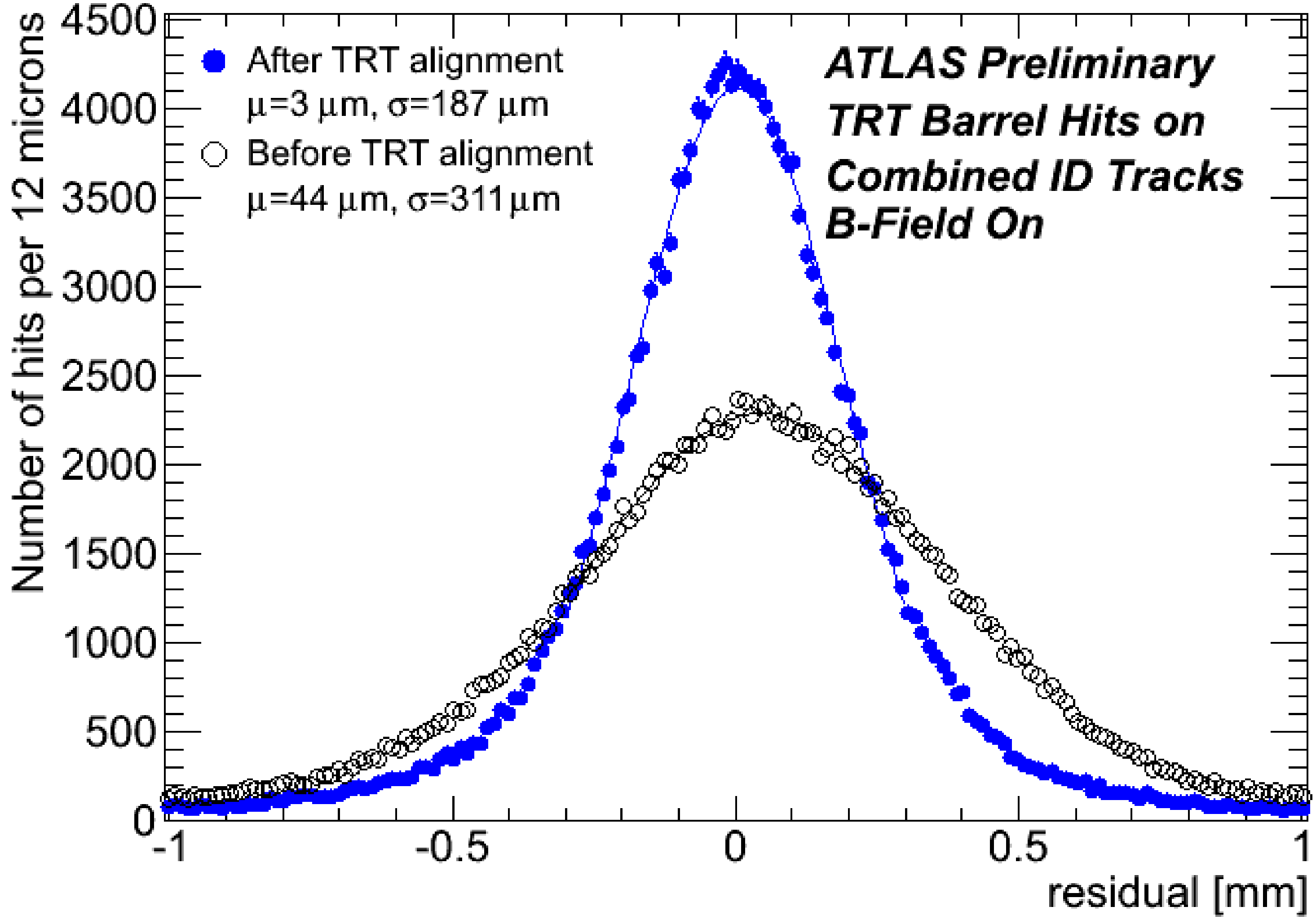




- Residuals consistent between 2008 and 2009 run with same alignment set (ie alignment derived from 2008 data).

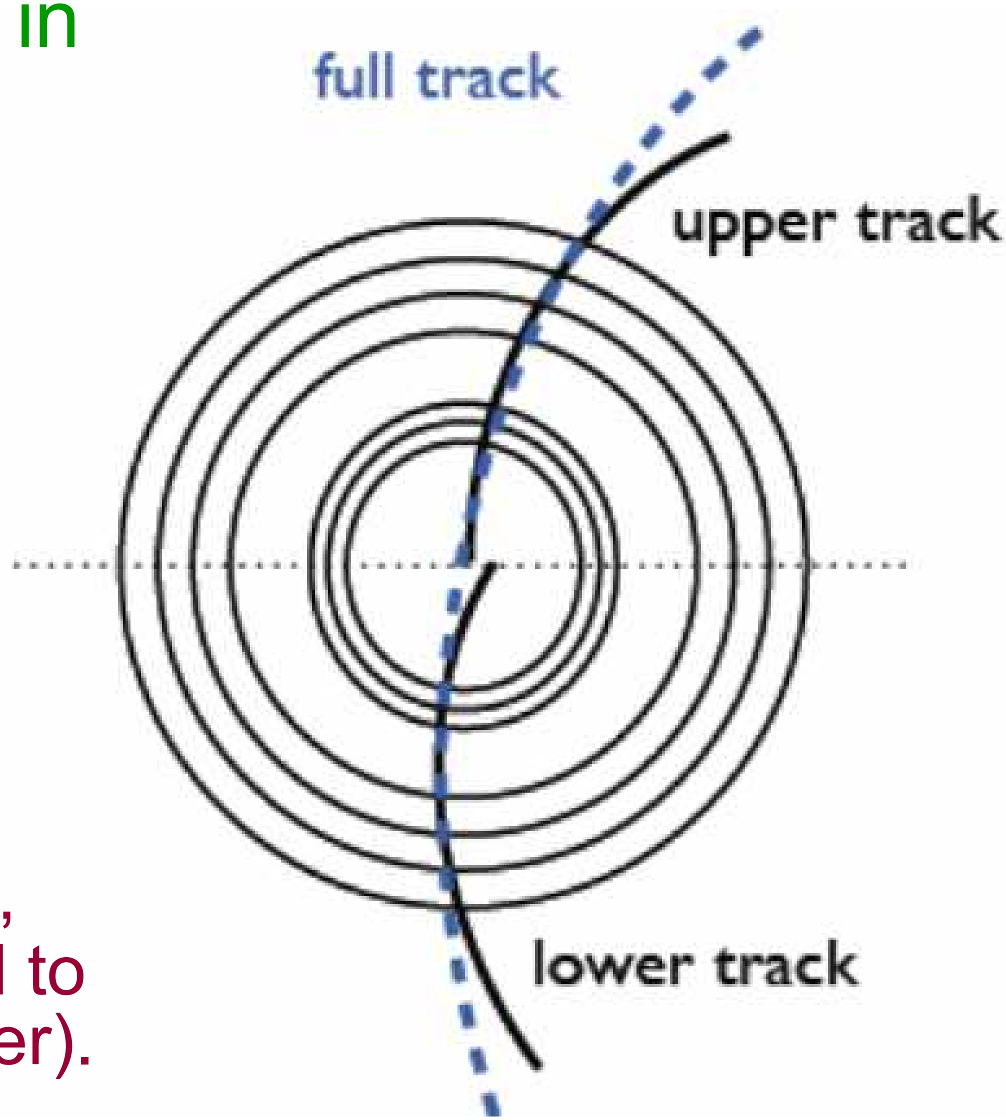
→Detector stable

Results: TRT Residuals (2008 data)

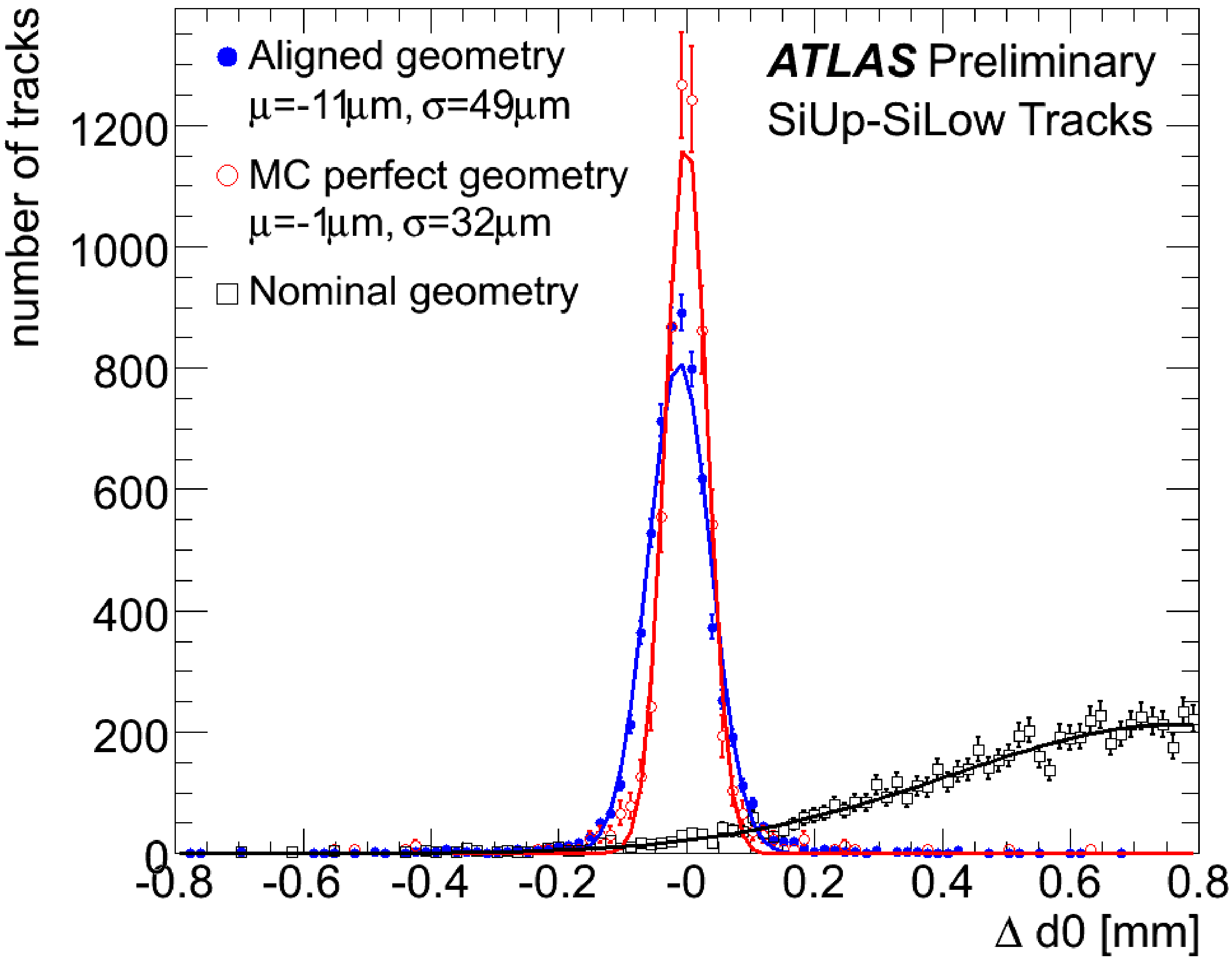


Quality Monitoring with Track Matching

- Can split cosmic tracks in upper and lower half.
- Refit as independent tracks
- Compare track parameters.
  - d_0, φ, θ, q/p, z_0
- ~ collision like tracks selected.
  - pT > 2 GeV, |d0|<50mm, |z0|<400mm (ie required to go through first pixel layer).



Track Matching: Impact parameter



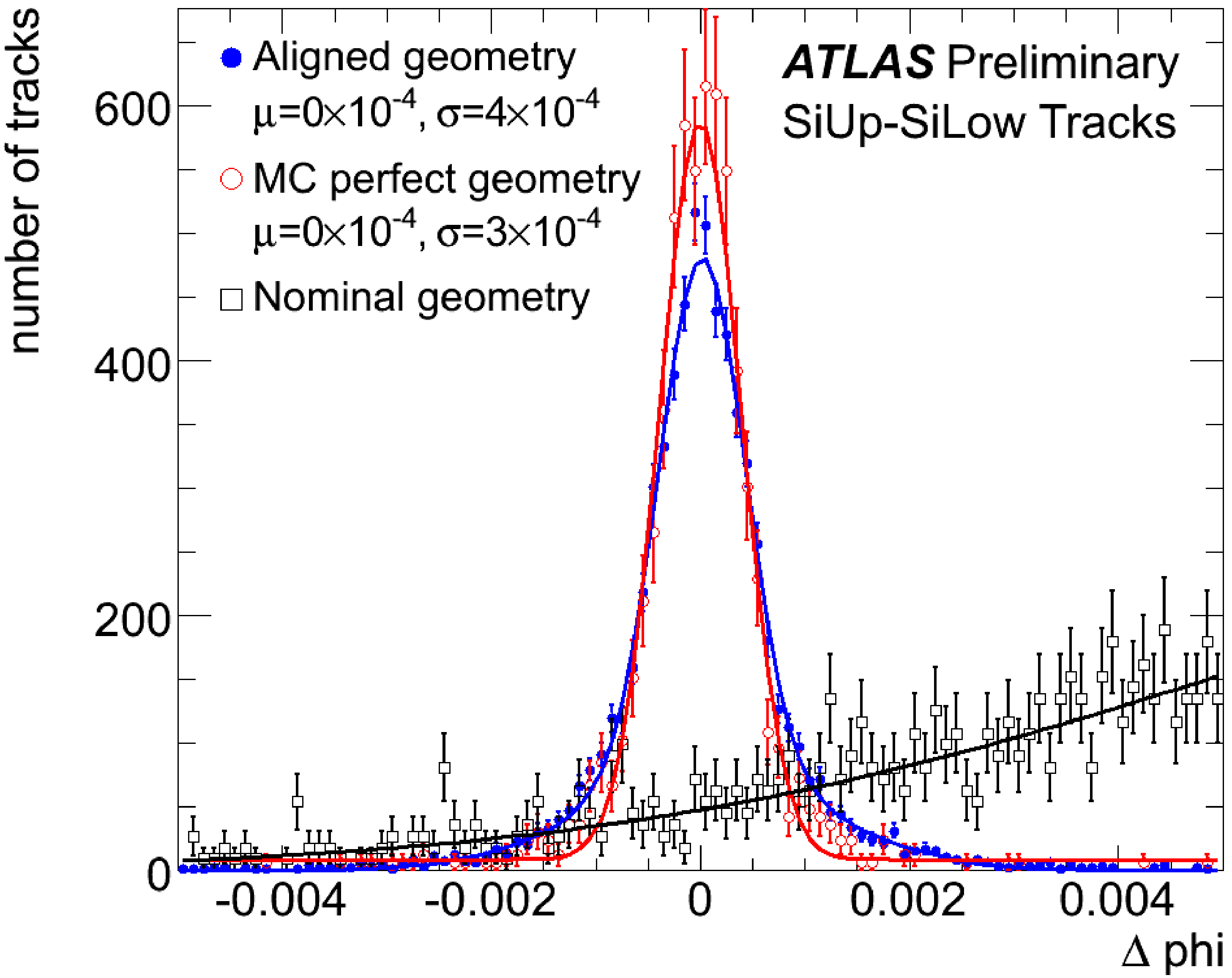
$d_0/\sqrt{2}$=35 μm

Expectation from simulated collision events:

$\sigma(d_0)$ = 20 μm @ p_T = 5 GeV

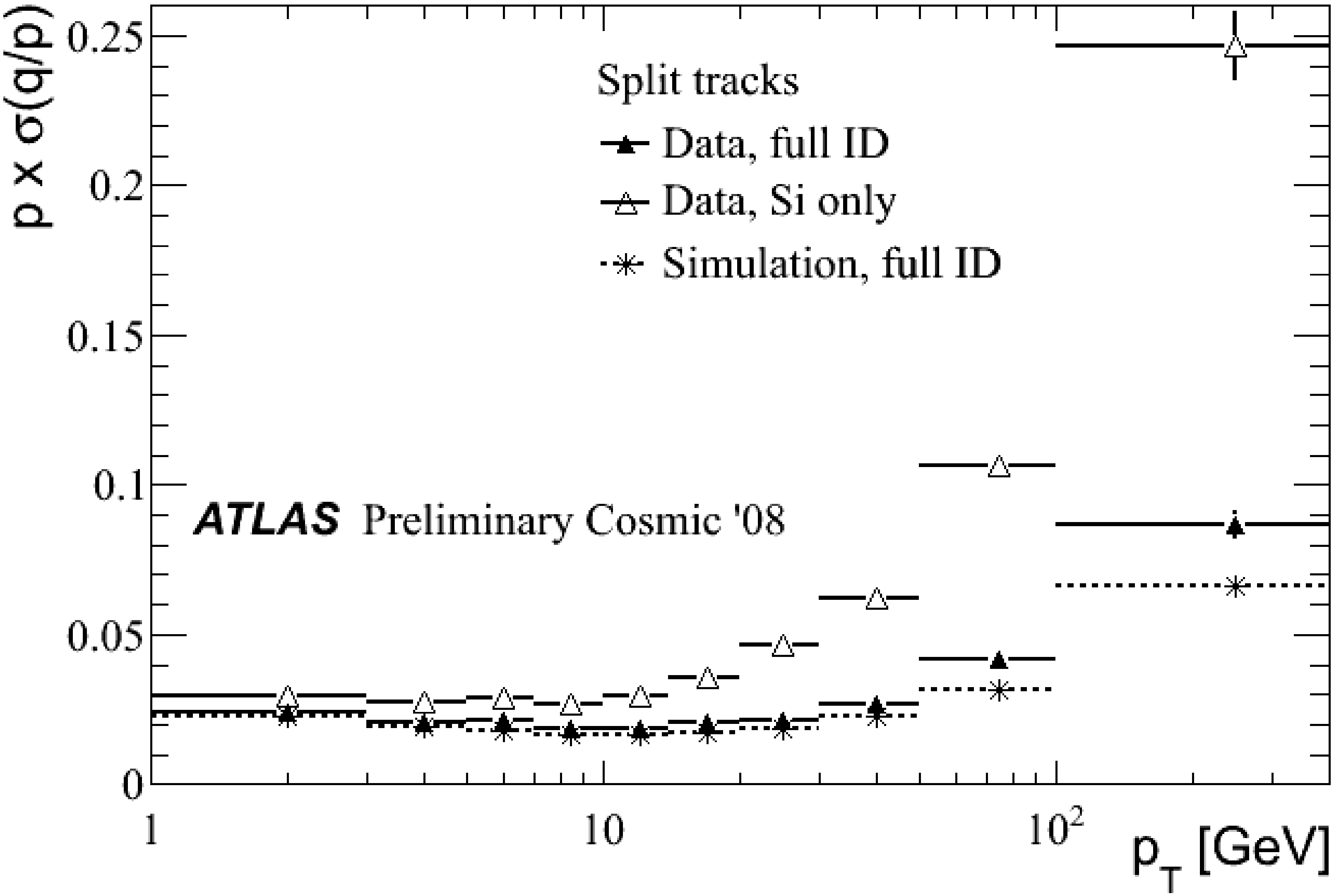
Shift wrt to perfect not yet fully understood.

Track Matching: Phi



Good matching after alignment

Track Matching: Momentum resolution



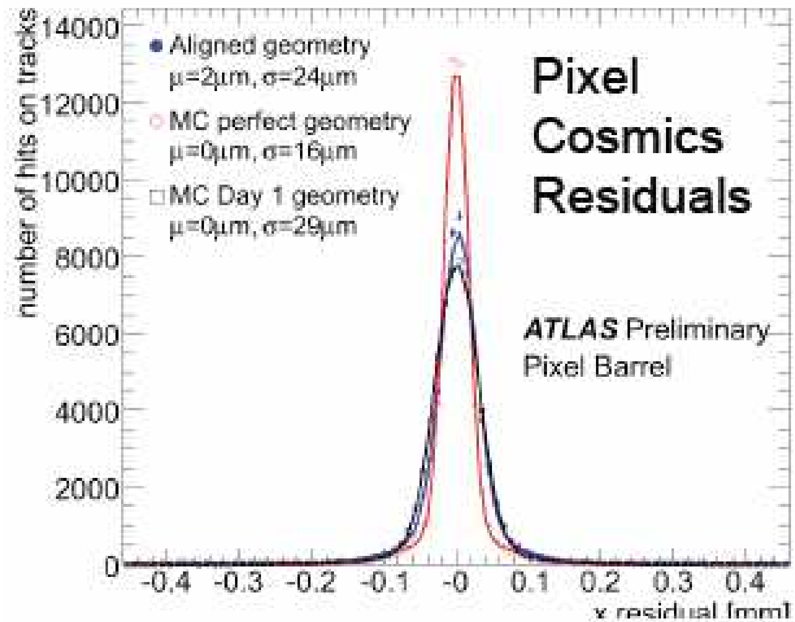
Low p_T: Multiple scattering dominates.

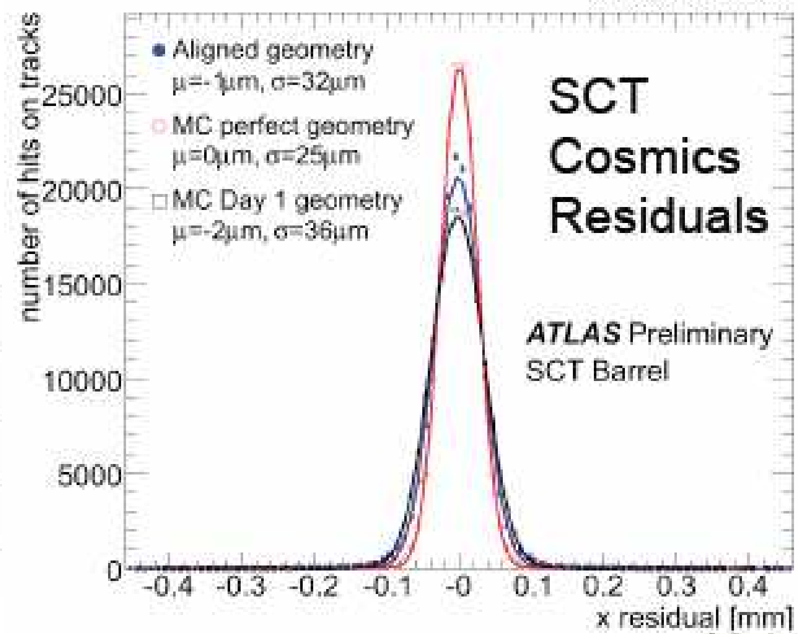
High p_T: Misalignments become important.

Alignment Expectation for First Collision Data

- Gaussian smearing of module positions in module plane.
- **Day-1 Misalignments**:
  Gaussian widths chosen to reproduce approx. residual widths observed in aligned cosmic ray data.
- **Day-100 Misalignments**:
  estimate of situation after 100 days collisions data. Approaching baseline alignment requirements for initial physics.
- **But no systematic deformations**

	Day-1 Barrel	Day-1 Endcap	Day-100 Barrel	Day-100 Endcap
Pixel	20 μm	50 μm	10 μm	10 μm
SCT	20 μm	50 μm	10 μm	10 μm
TRT	100 μm	100 μm	50 μm	50 μm

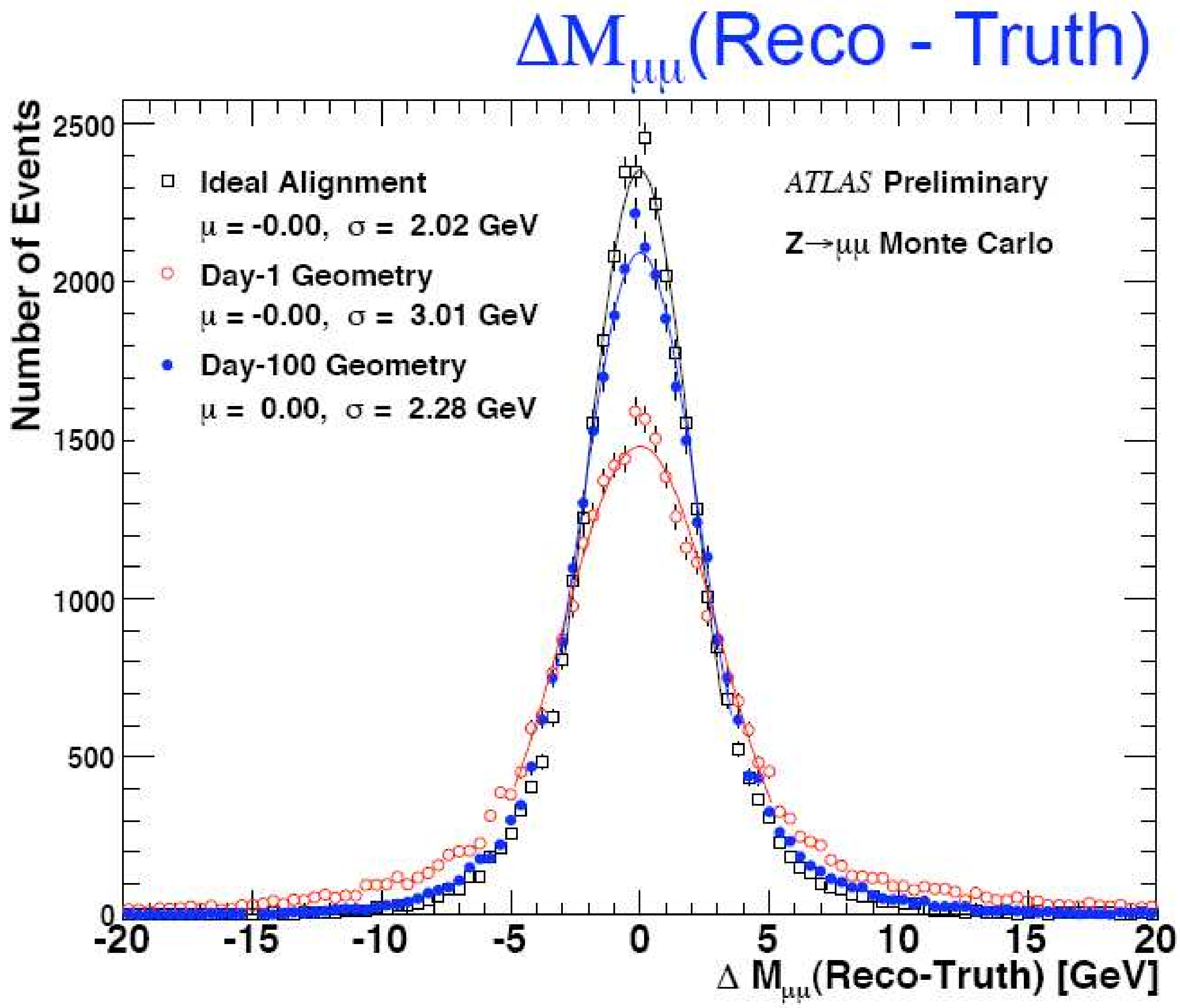




Impact on Z→μμ

M_Z resolution (momentum from Inner Detector only):

- Day-1: degraded ~50%
- Day-100: degraded ~13%

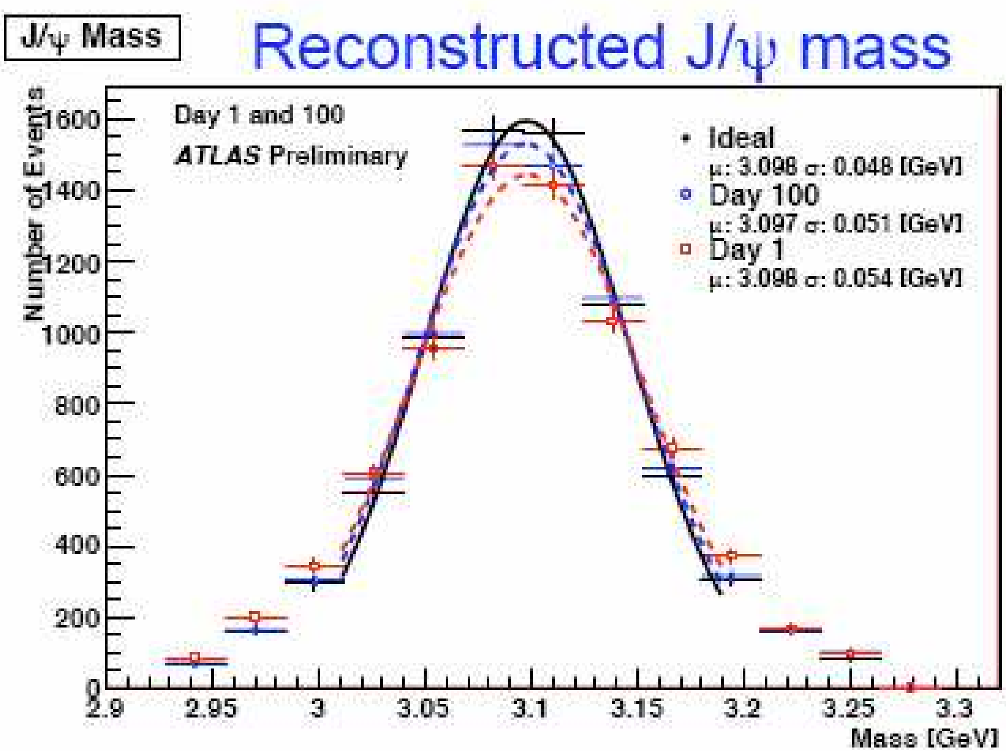


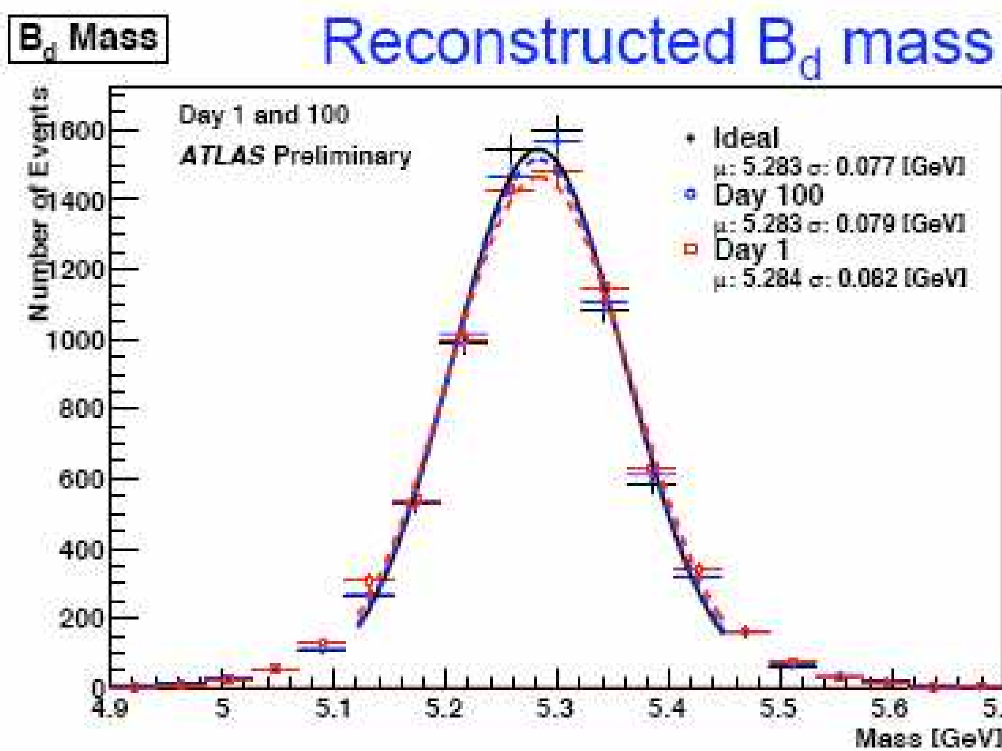
Impact on B physics

$J/\psi \rightarrow \mu\mu$ and $B^0_d \rightarrow J/\psi K^{0*}$

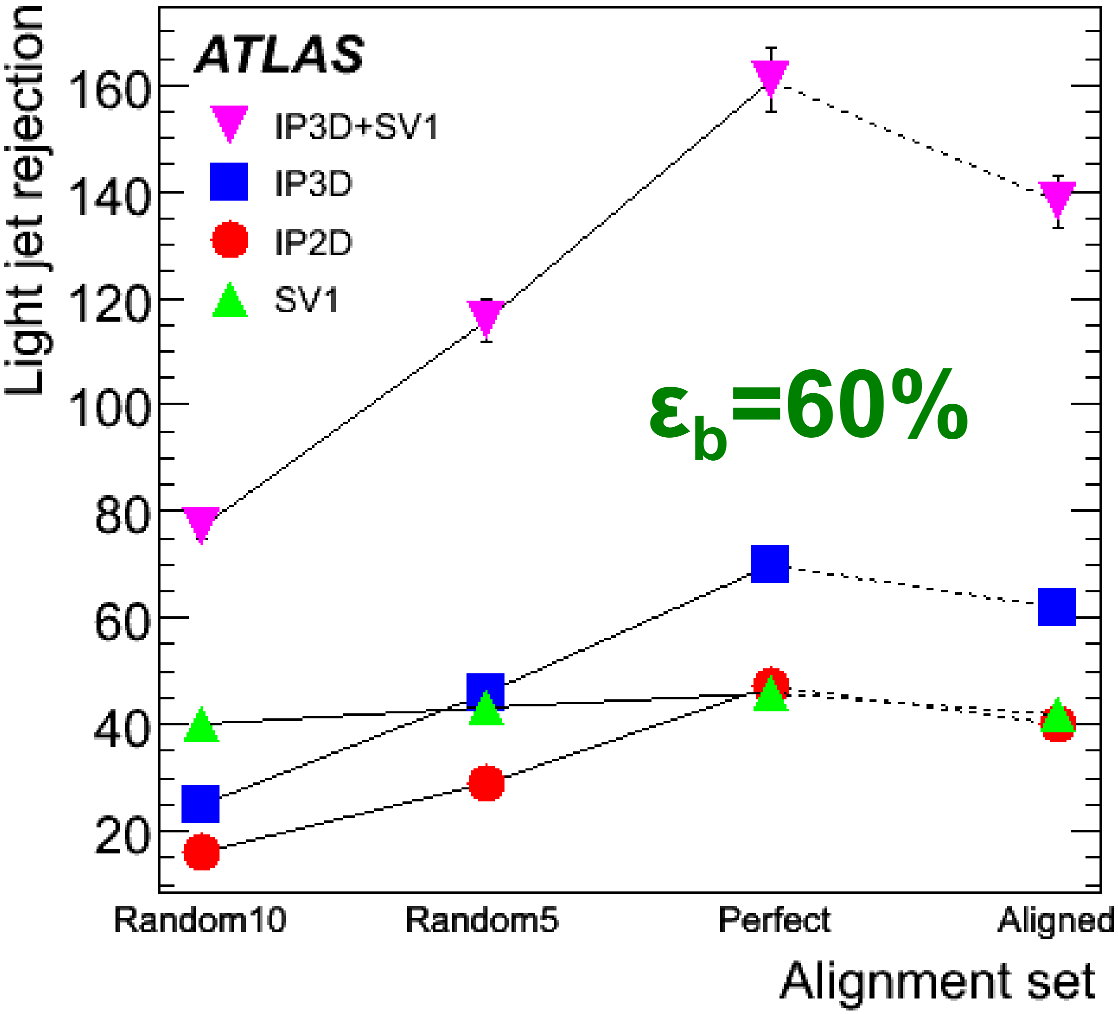
Impact of misalignment much less due to lower p_T tracks (resolution dominated by material)

- **Day-1: Degradation ~ 10%**
- **Day-100: Insignificant effect.**





Impact on b-tagging



SV1: secondary vertex **IP2D: d_0**
IP3D: d_0, z_0 **IP3D+SV1: combined**

Perfect: Perfectly aligned detector

Random10: Shifts/rotations in Pixel detector, layers/disks and modules of order 10 μm (SCT and TRT perfect)

- Roughly equivalent to Day-1 scenario.
- ~50 % degradation

Random5: ~ half as big

Aligned: Misalignments put in simulation typical of expected assembly. Then aligned with actual ATLAS alignment procedures (collision + cosmics)

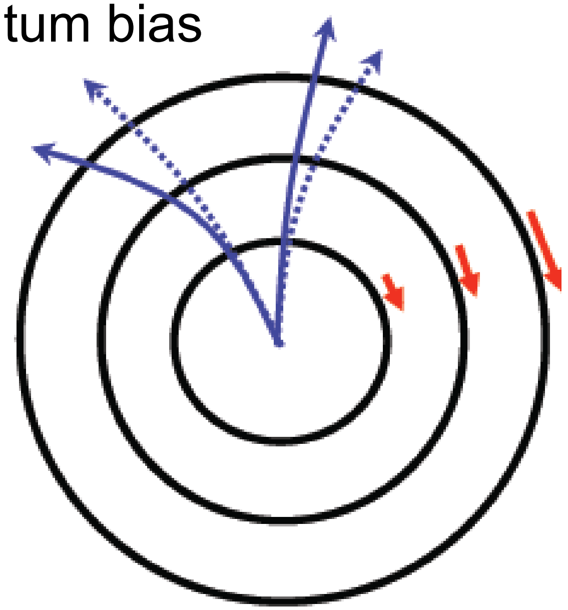
- Moderate (~15%) degradation wrt to Perfect alignment

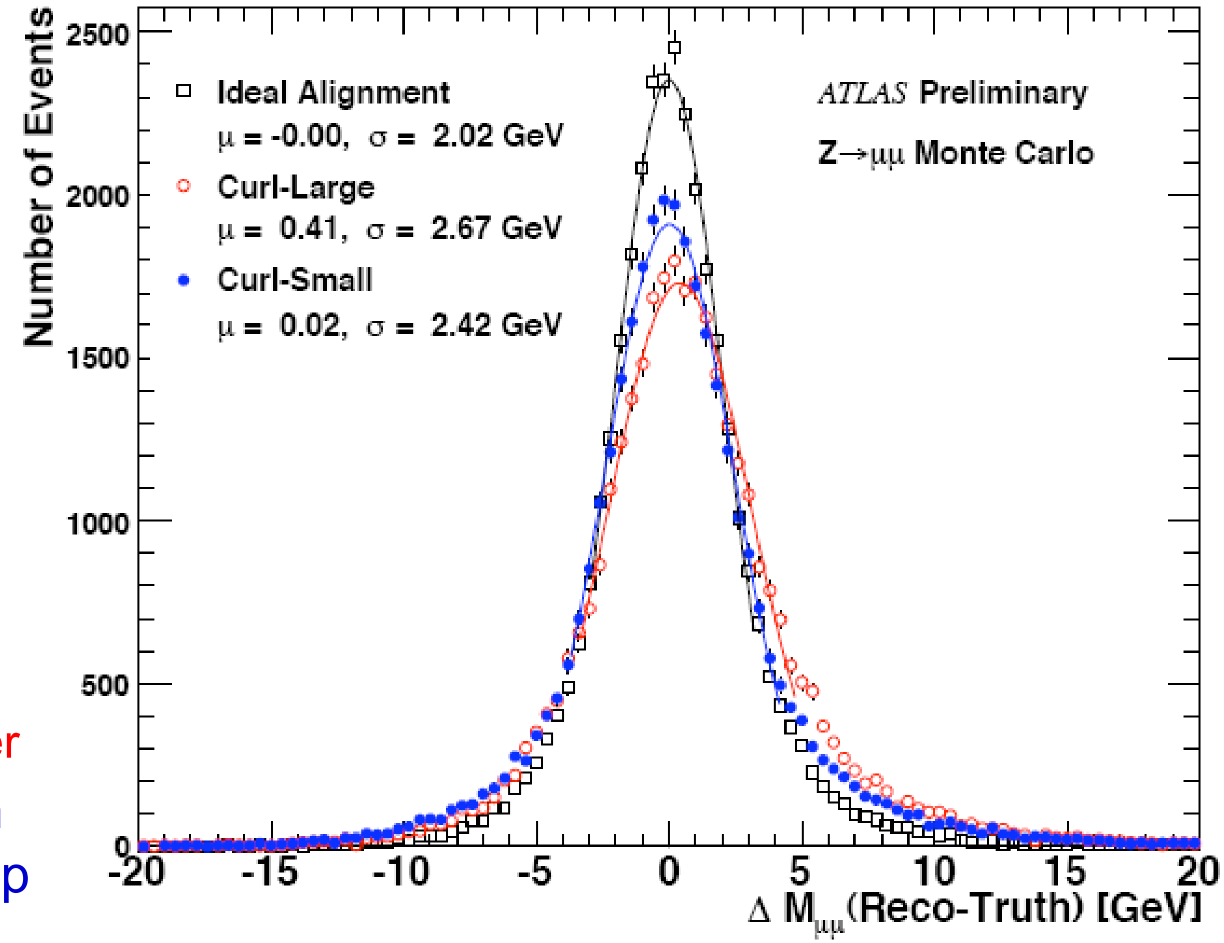
Investigating Systematic Distortions

- Systematic distortions that leave tracks as helices can be difficult to remove.

Curl Misalignment

→Momentum bias





Curl-Large: 300 μm @ outer layer

Curl-Small: After alignment with collision tracks only. (Cosmics help further)

Summary

- Good alignment achieved with first cosmic data.
- Alignment experience gained with full working Inner Detector
- A good starting alignment for collision data.
  - Already minimal impact on low p_T physics.
- Expect much more cosmic data before collision data taking - so expect further improvements.
- Alignment algorithms ready for first collisions and expect rapid improvement in alignment with collision data.
- Tackling systematic deformations will be a challenge though - combining cosmic and collision data helps (as studied with simulation)