

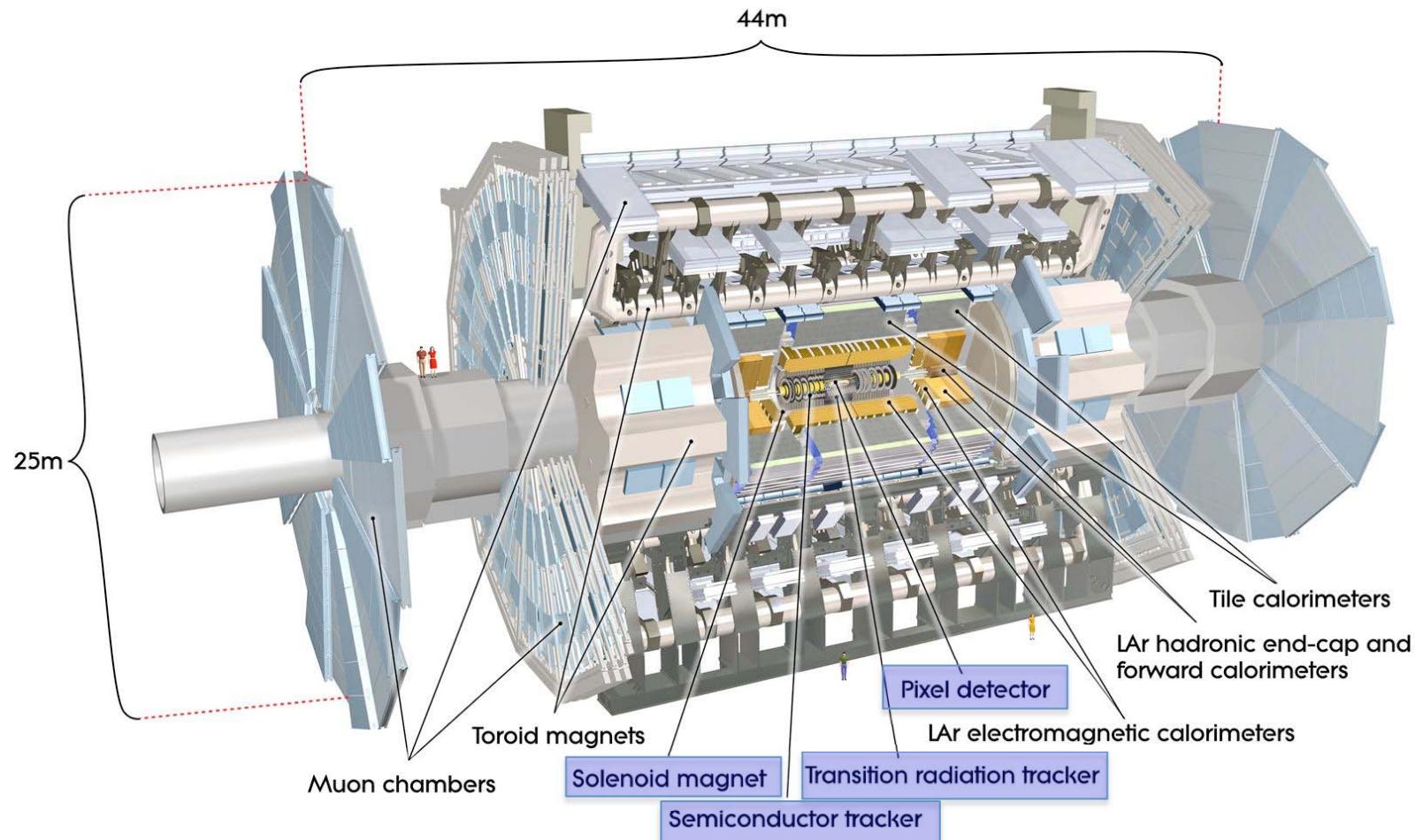
Alignment of the ATLAS Inner Detector with first Data

Jochen Schieck

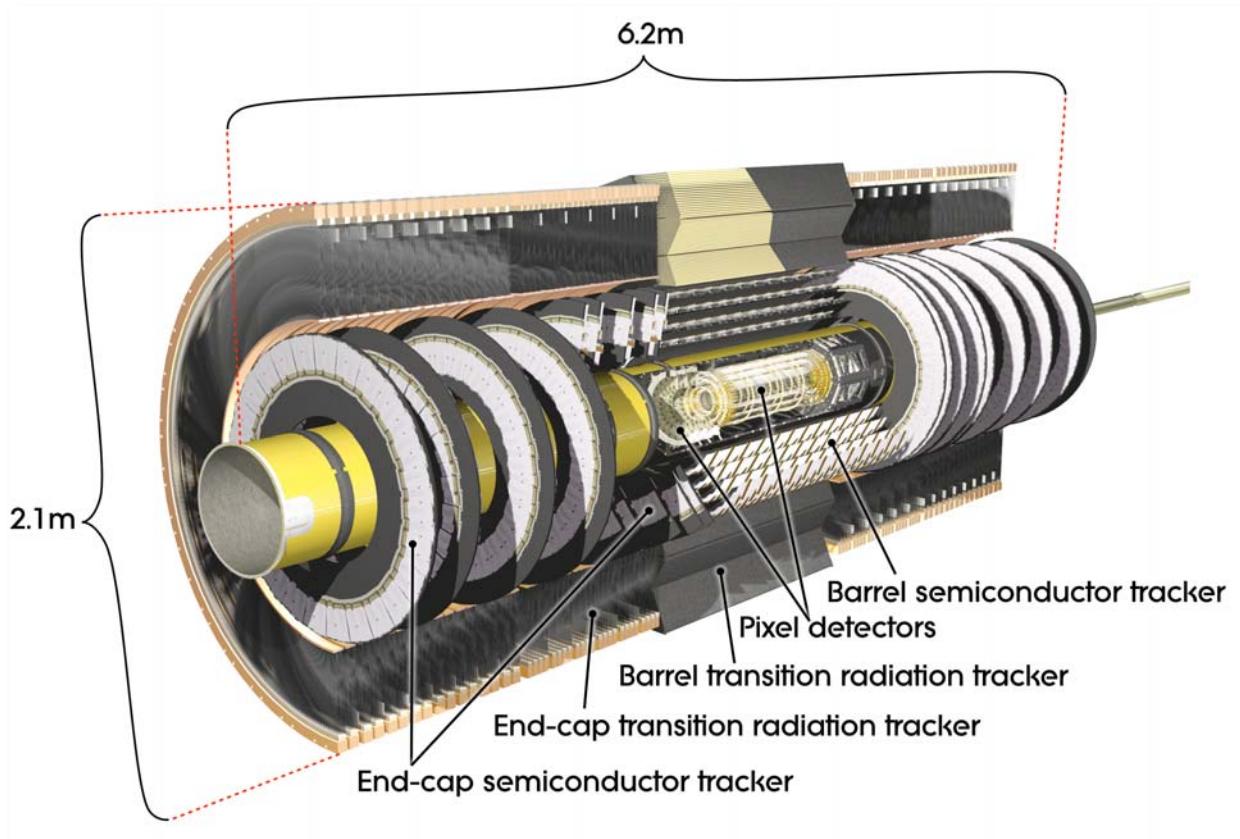
Max-Planck-Institut für Physik
for the ATLAS Collaboration

The ATLAS Inner Detector

Outline of the ATLAS Detector



ATLAS Inner Detector



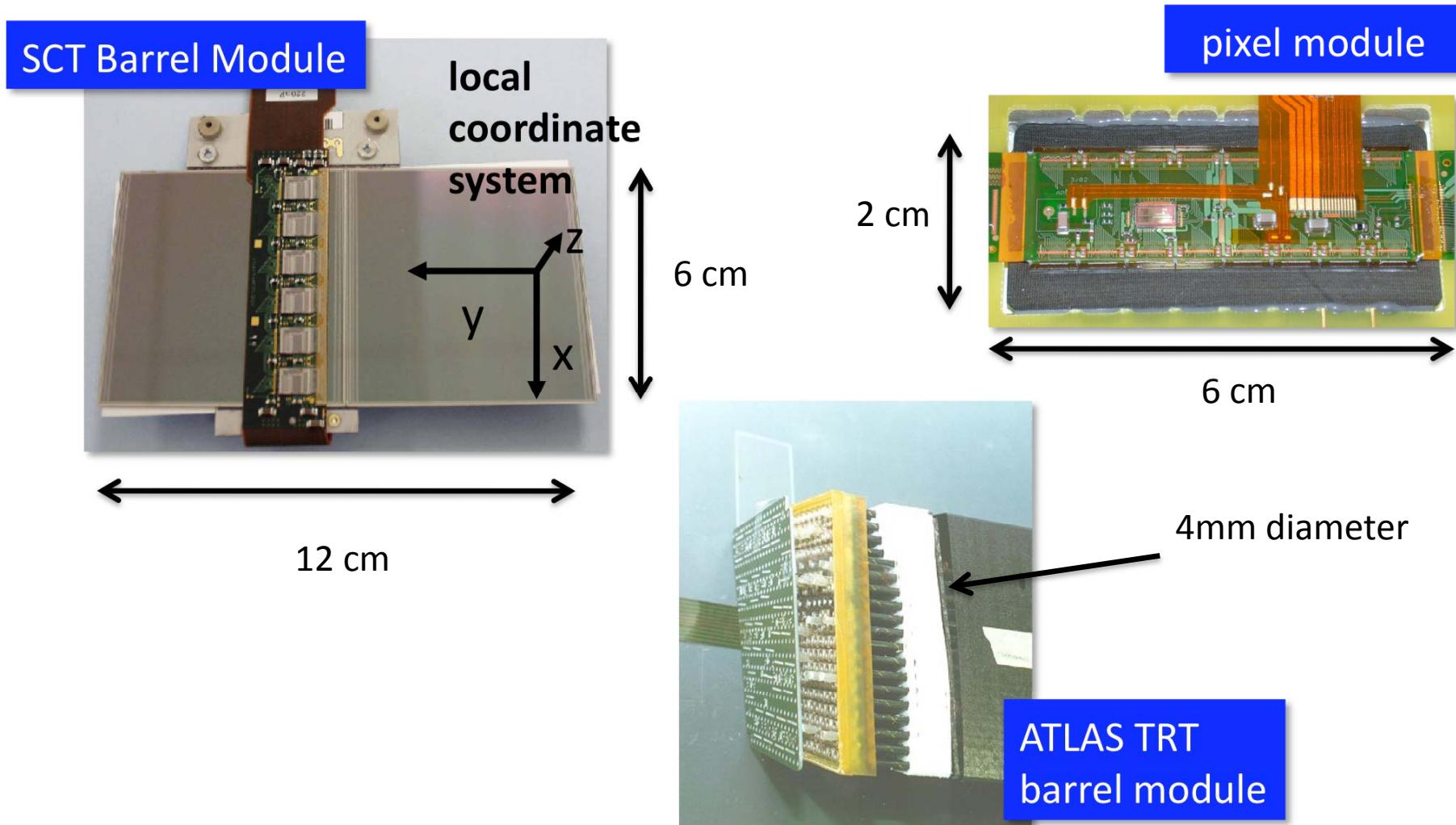
- located in 2T solenoidal field
 - divided in barrel region ($|\eta| < 1$) and endcap region ($1 < |\eta| < 2.5$)
- depends on the subdetector

ATLAS Inner Detector

subdetector	r (cm)	element size	resolution (X * Y)	hits/ track (Barrel)	channels
Pixel (Silicon)	5-12.5	50µm * 400µm	10µm * 115µm	3	80×10^6
SCT (Silicon Strip)	30-52	80µm * 12cm (stereo)	17µm * 580µm	4	6×10^6
TRT (straw tubes)	56-107	4mm (diameter)	130µm	30 (average)	0.4×10^6

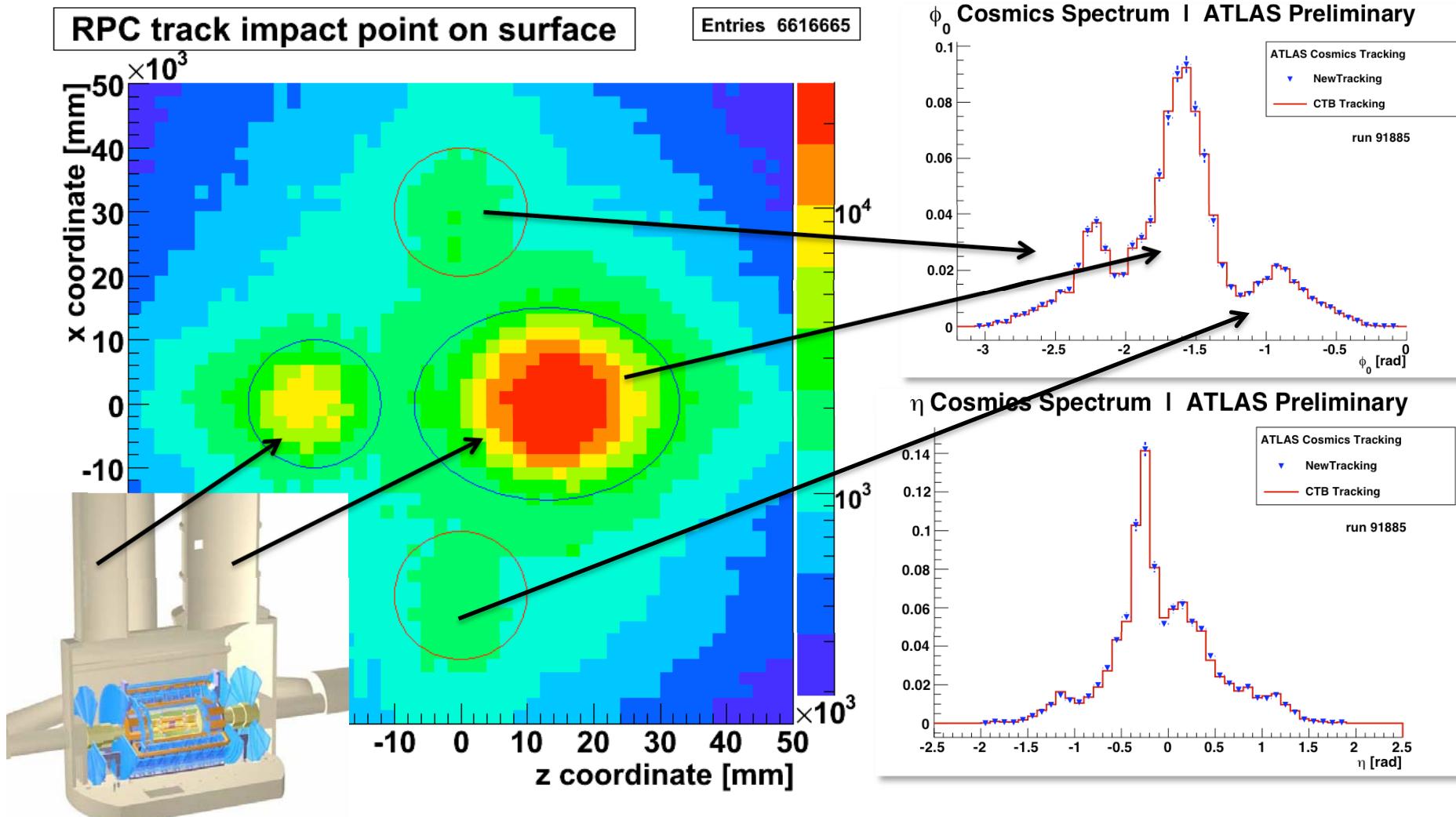
- 5832 Si modules
 - SCT: 2112 barrel + 1976 endcap
 - pixel: 1456 barrel + 288 endcap
- TRT
 - 3 x 32 barrel modules
 - 2 x 40 endcap wheels

ATLAS Inner Detector



Cosmic Data Taking 2008

Distribution of Cosmic Ray Events

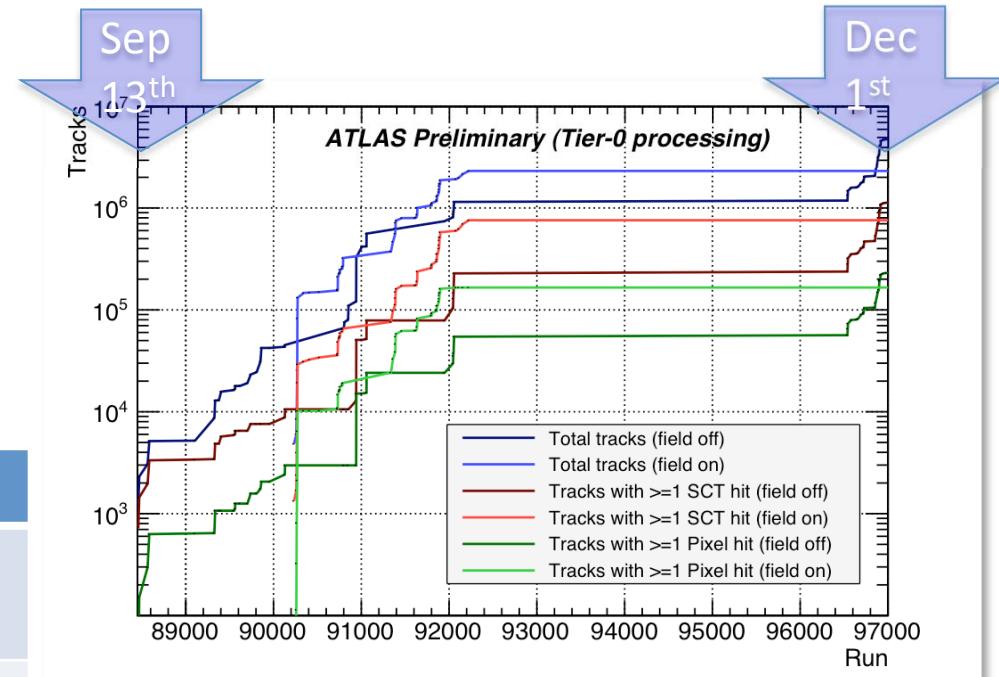


Cosmic Data Taking 2008

cosmic data collected with the Inner Detector in 2008

- dominated by data taken without magnetic field

	Field Off	Field On	total
All tracks	4.94 M	2.67 M	7.61 M
with SCT hit	1.15M	0.88 M	2.03 M
with Pixel hit	0.23 M	0.19 M	0.42 M

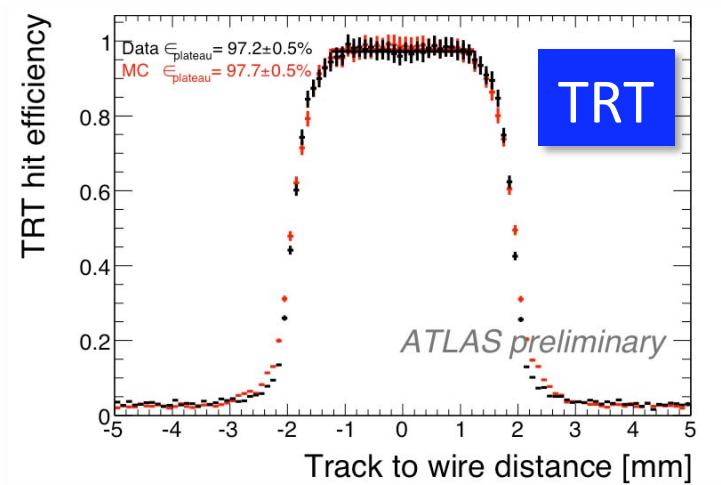
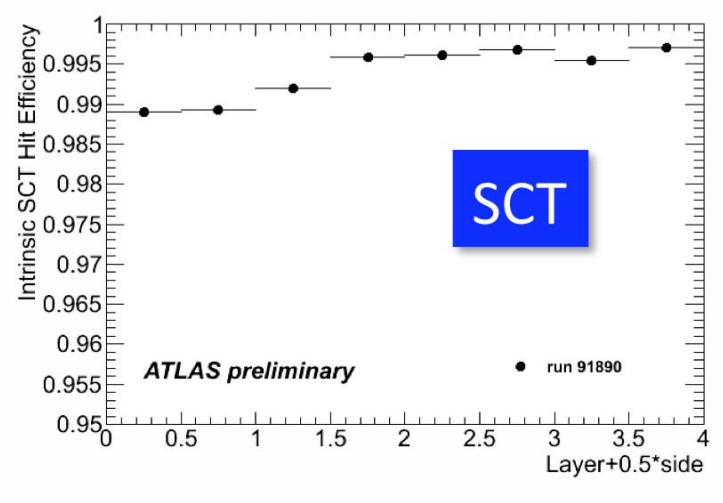
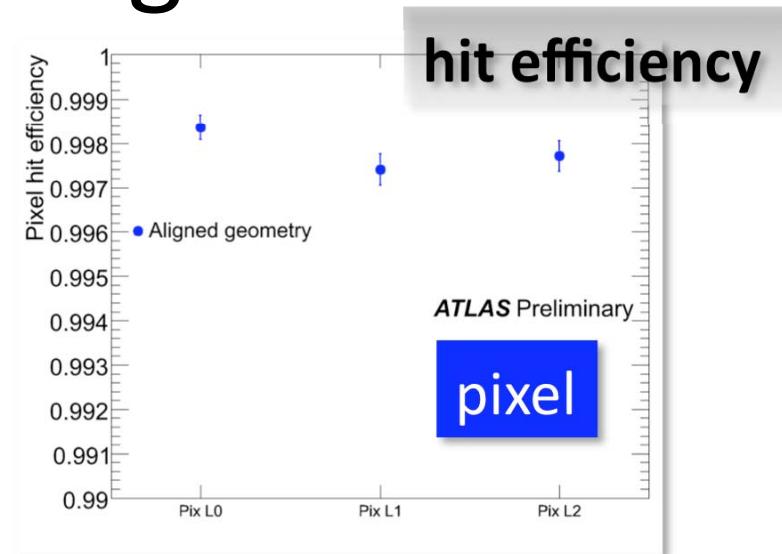


ATLAS combined run:
September 13th- October 26th
Inner Detector run (no Bfield):
November 26th- December 1st

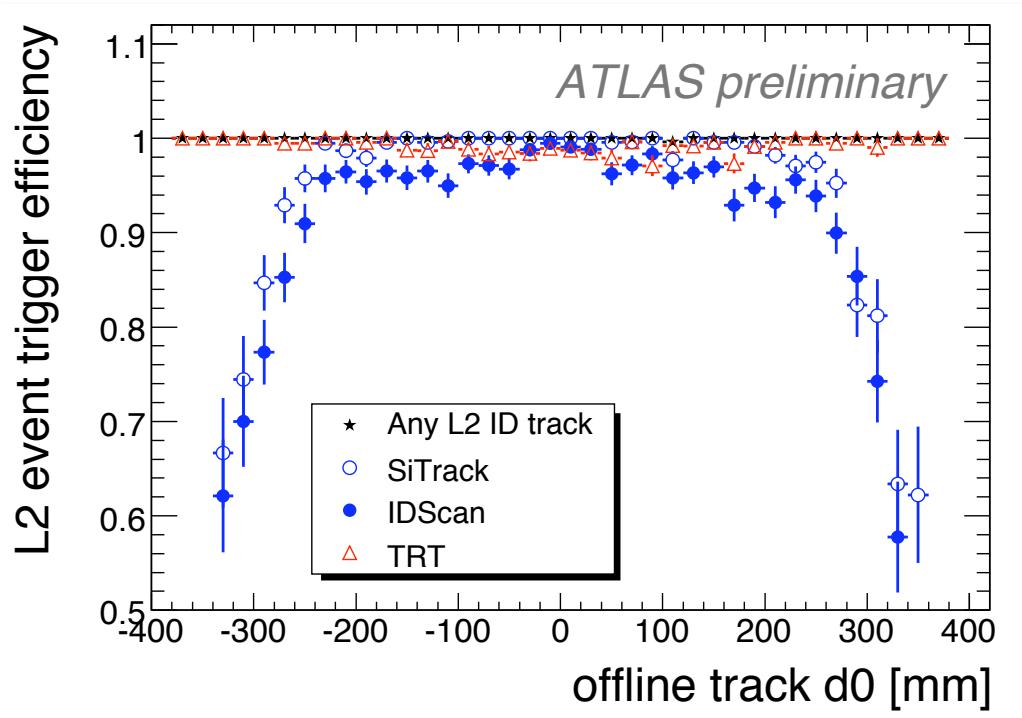
Cosmic Data Taking 2008

2008 detector operation:

- pixel: 98.5% operational
- SCT: 99% barrel and 97% endcap
- TRT: 98% operational



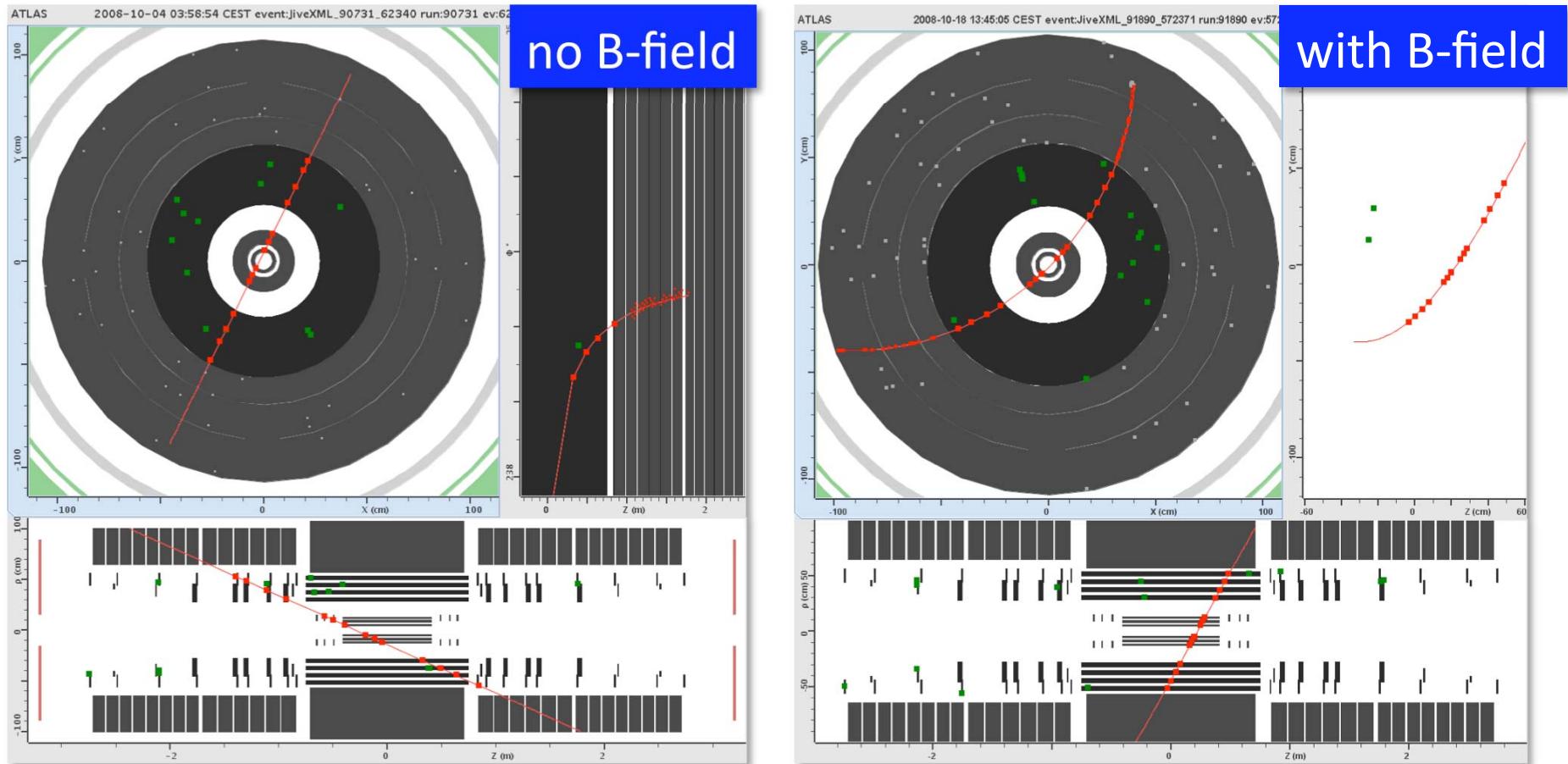
Triggering of Cosmic Ray Events



ID acceptance reduced compared to Muon and Calorimeter

- no ID signals for LVL1 trigger decision during data taking
 - dedicated TRT-based trigger for cosmic runs
- ID information at LVL2 for track reconstruction
 - similar efficiency as offline track reconstruction

Cosmic Event Display



14.06.2009

Alignment with Cosmic Ray Events

Alignment using Cosmic Events

- alignment using cosmic tracks first exercised summer 2006
 - SCT and TRT only, no magnetic field (SR1)
 - published in JINST 3:P08003,2008
 - tests with cosmics passing pixel endcap
- 2008 alignment with cosmic tracks
 - first operation under real detector conditions
 - data taking with and without B-field
 - first track reconstruction using pixel barrel information
 - first set of constants was ready on September 18th

Alignment using Cosmic Events

- no hardware based information used (SCT-FSI) for alignment
- pixel module survey information partly used as starting point
 - minor impact on final alignment
- alignment sequence
 - Si internal alignment
 - TRT internal alignment
 - perform TRT with respect to the Si

Si Alignment Algorithm

- different alignment approaches

- global χ^2

- take full correlation into account
 - invert $6N \times 6N$ matrix

- local χ^2

- Si-only, ignore correlation between objects $\frac{dr}{da} \approx \frac{\partial r}{\partial a}$
 - invert $N 6 \times 6$ matrices

- robust approach

- Si-only, not aligning for rotation around axis
 - takes information from overlap residuals into account

- pixel standalone approach

- pixel only cross check
 - study coherent pixel module changes (“pixel bow”)

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

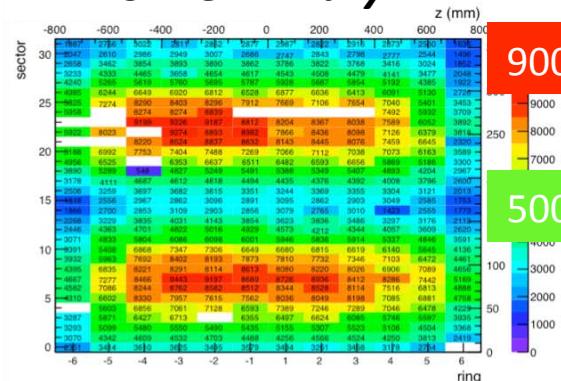
$$\frac{d\chi^2}{da} = 0$$

$$\Rightarrow \sum_{\text{tracks}} \left\{ \left(\frac{dr}{da}^T V^{-1} \frac{dr}{da} \right) \delta a + \left(\frac{dr}{da} \right)^T V^{-1} \mathbf{r} \right\} = 0$$

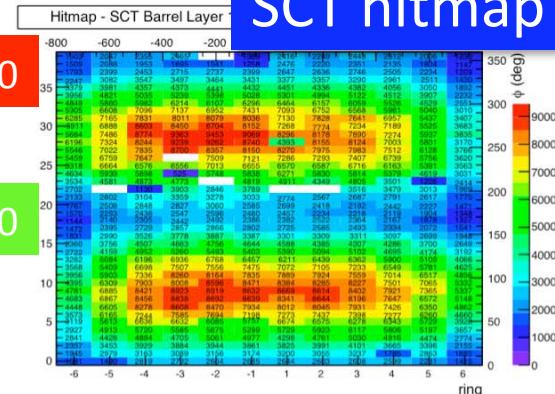
Illumination of Si Modules

- structure of cosmic event distribution clearly visible in hit distribution
- fewer hits in the horizontal layers
- endcap discs less illuminated
- track selection: $N_{SCT\text{Hits}} \geq 10$

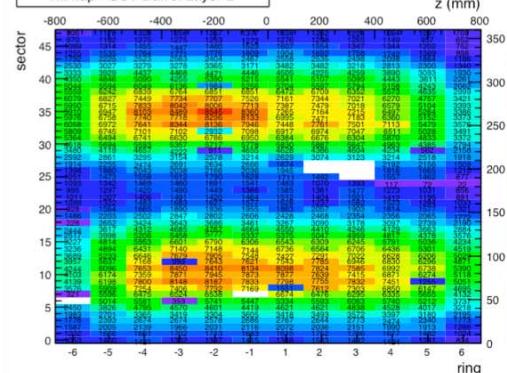
ATLAS Preliminary



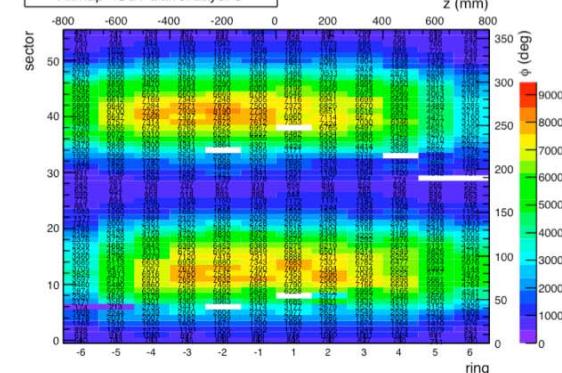
SCT hitmap



Hitmap - SCT Barrel Layer 2



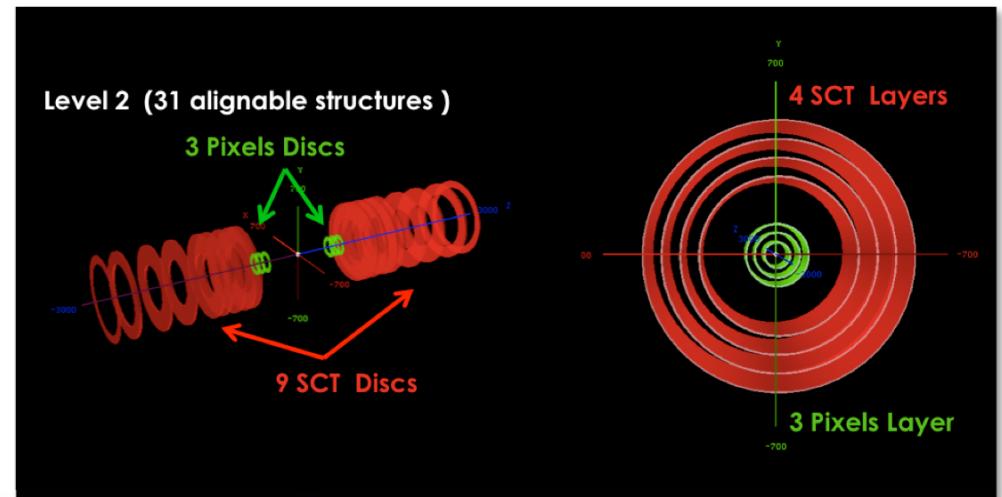
Hitmap - SCT Barrel Layer 3



→statistical uncertainty at $O(\mu\text{m})$ level
→uncertainty dominated by systematics

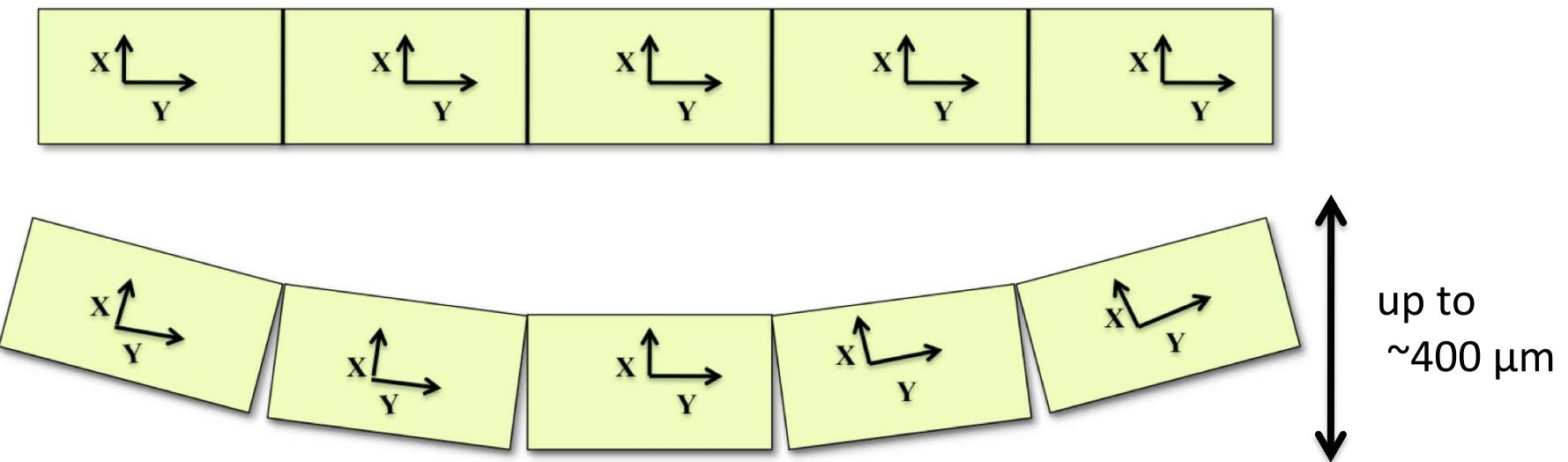
Si Alignment Algorithm

- alignment sequence mapping the substructure of the detector
 - **L1:** align pixel with respect to SCT barrel and endcap (24 D.o.F.)
 - **pixel half shell alignment:** 3x2 pixel barrel half-shells and two endcaps, and 4 SCT layers and endcaps (84 D.o.F)
 - **ladder alignment:** 112 pixel barrel ladders and two endcaps, 176 SCT barrel ladders and two endcaps (292 D.o.F.)

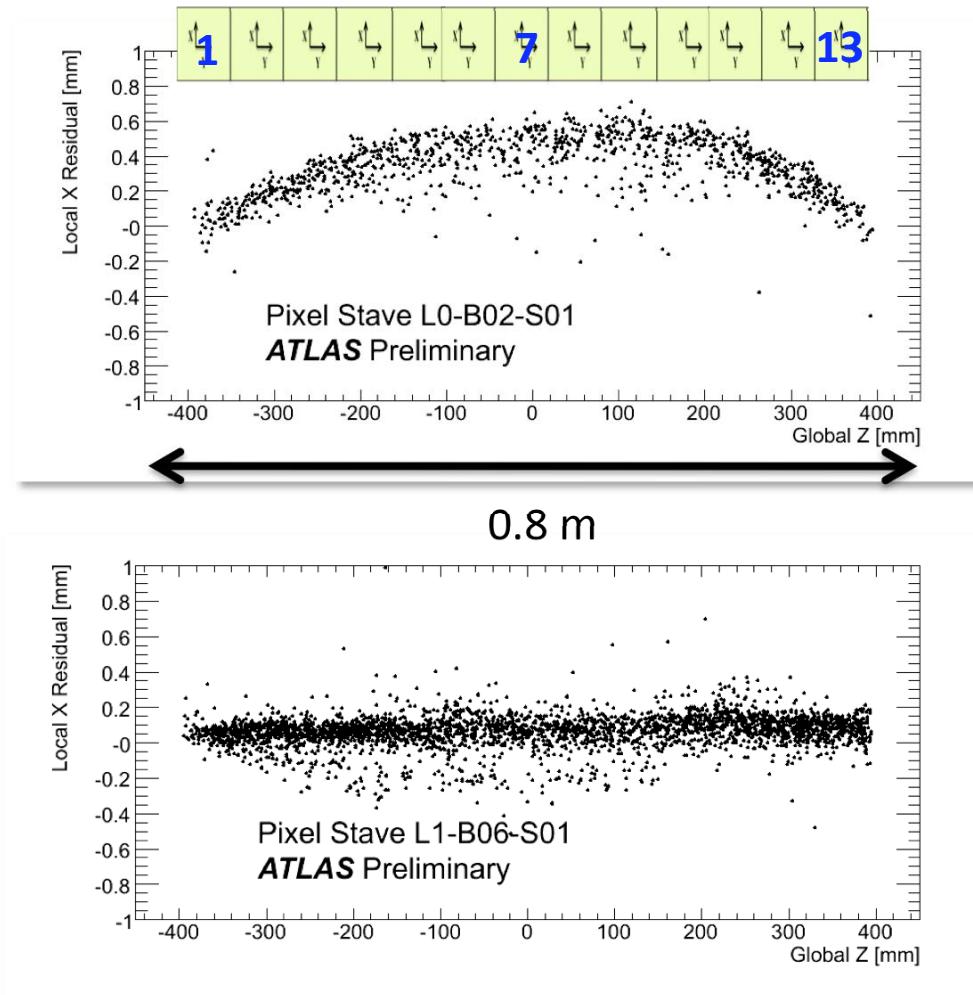


Alignment Algorithm

- L3: 1456 pixel barrel modules and 2112 SCT barrel modules and 2x2 endcaps
 - do not align for 6 D.o.F., only parallel to the most sensitive coordinate (local X) and rotation in the plane

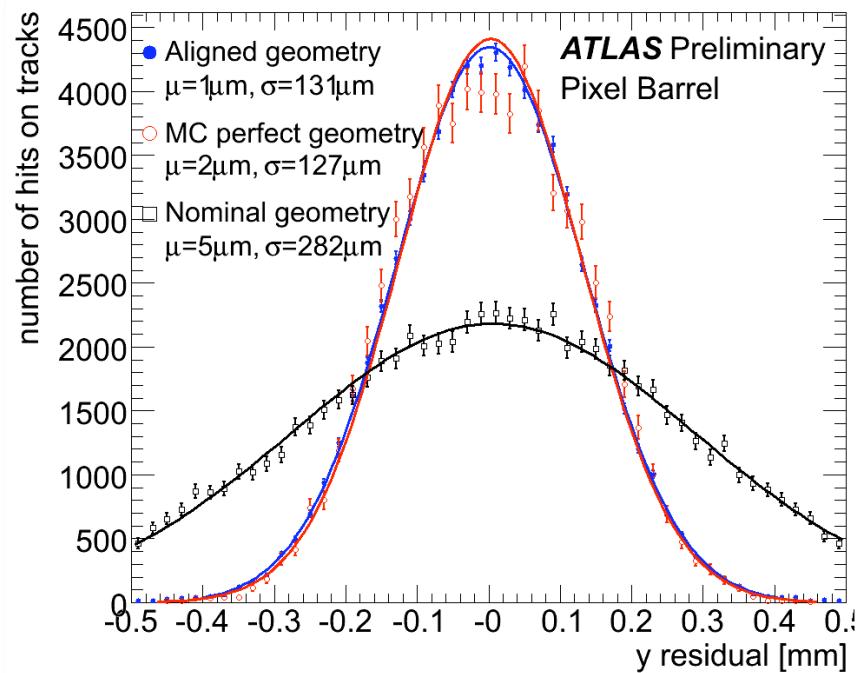
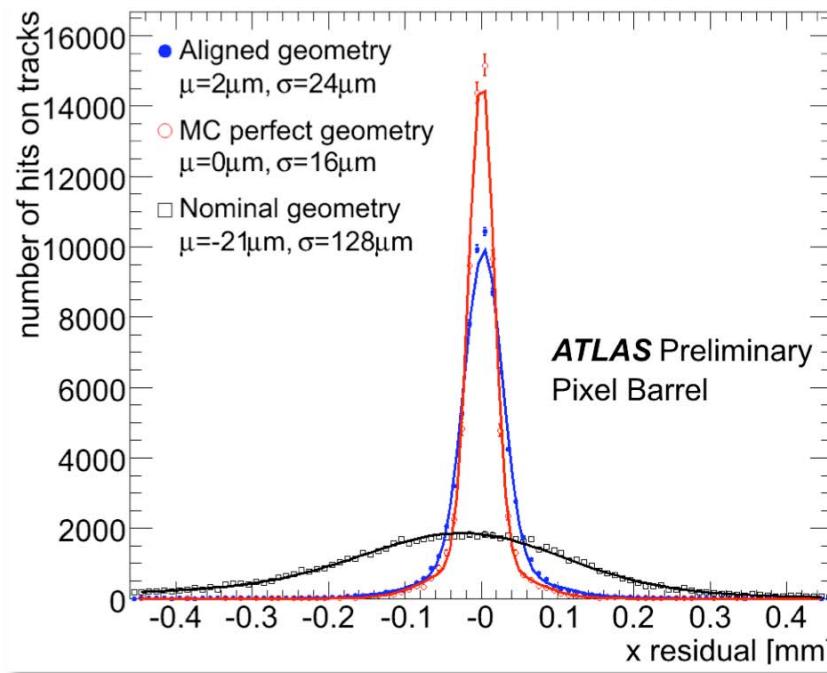


Alignment Using Cosmic Tracks



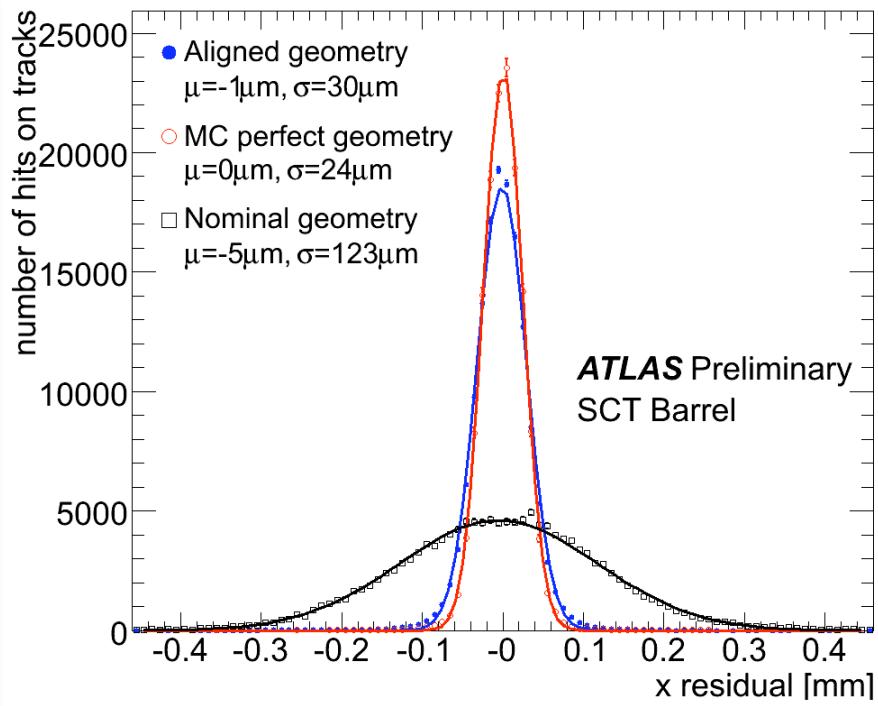
- each stave contains 13 modules
- observe stave bow up to 400 μm
- also ‘valley’ and ‘S-curve’ structure visible
- alignment removes bow structure in the residual distribution

Pixel Residual Distribution



- residual distribution centered around zero with reduced width
- due to cosmic vertical distribution alignment for modules at the top and bottom much better than modules at the sides

SCT Residual Distribution

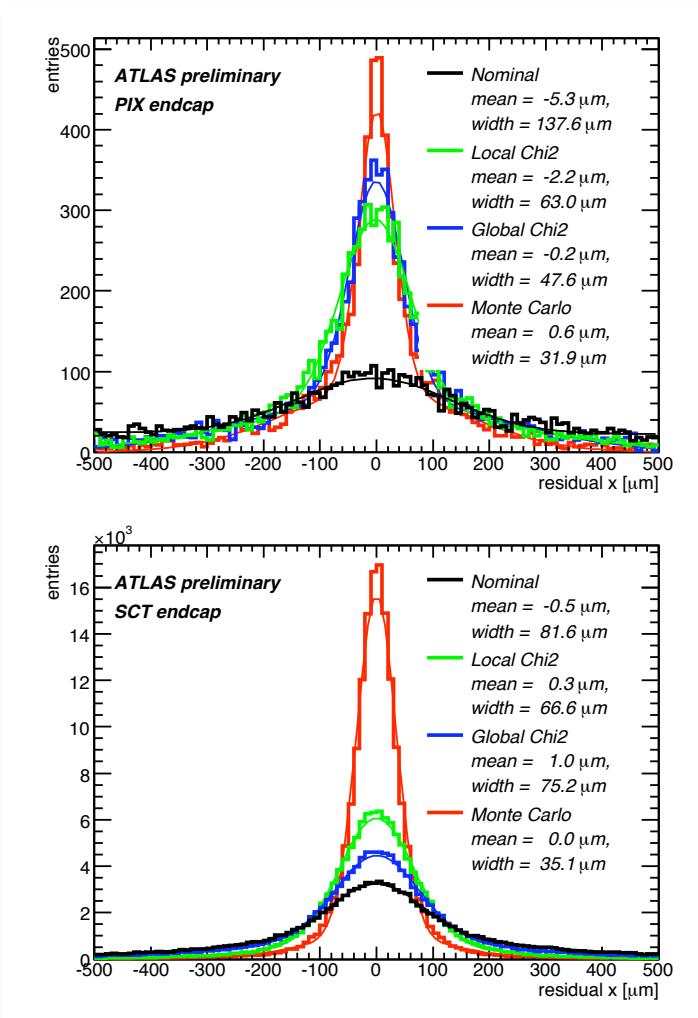


- alignment performed with combination of B-field on and off data
- difference in mean value of pixel residual distribution using B-field on and B-field off between 0 and 5 μm
 - to be understood

➤ width of residual distribution consistent with random module misalignment $O(20\text{ }\mu\text{m})$

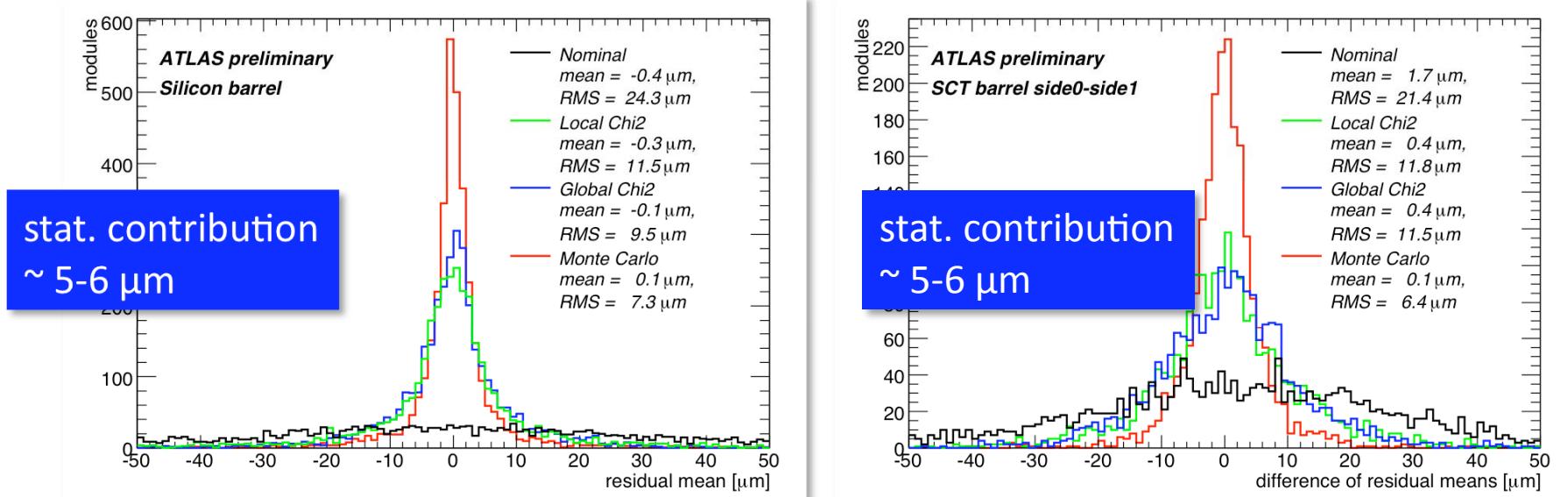
($\sim 10\text{ }\mu\text{m}$ necessary to achieve initial physics goals)

Endcap Residual Distribution



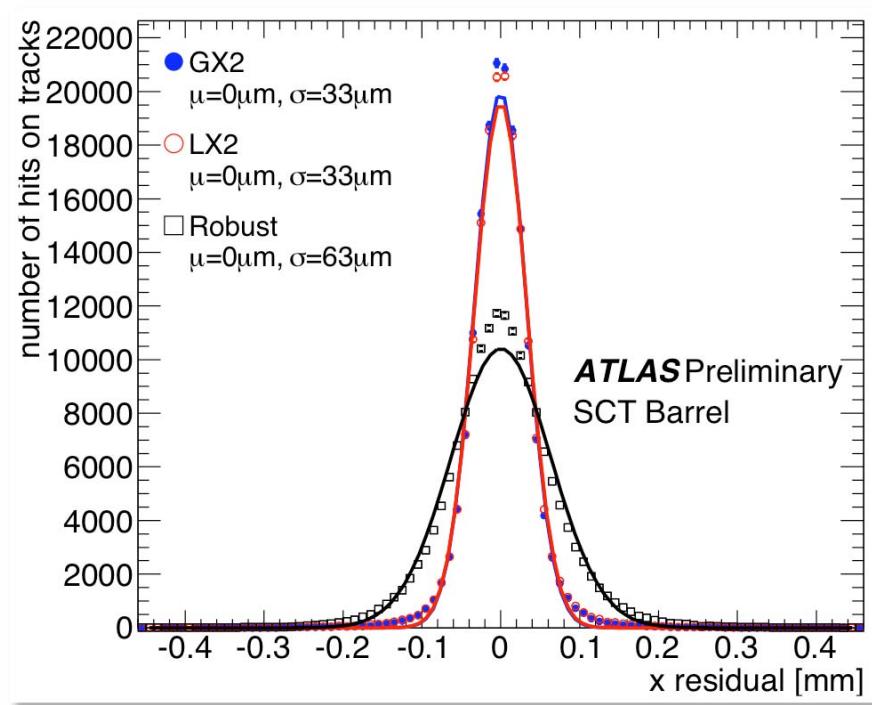
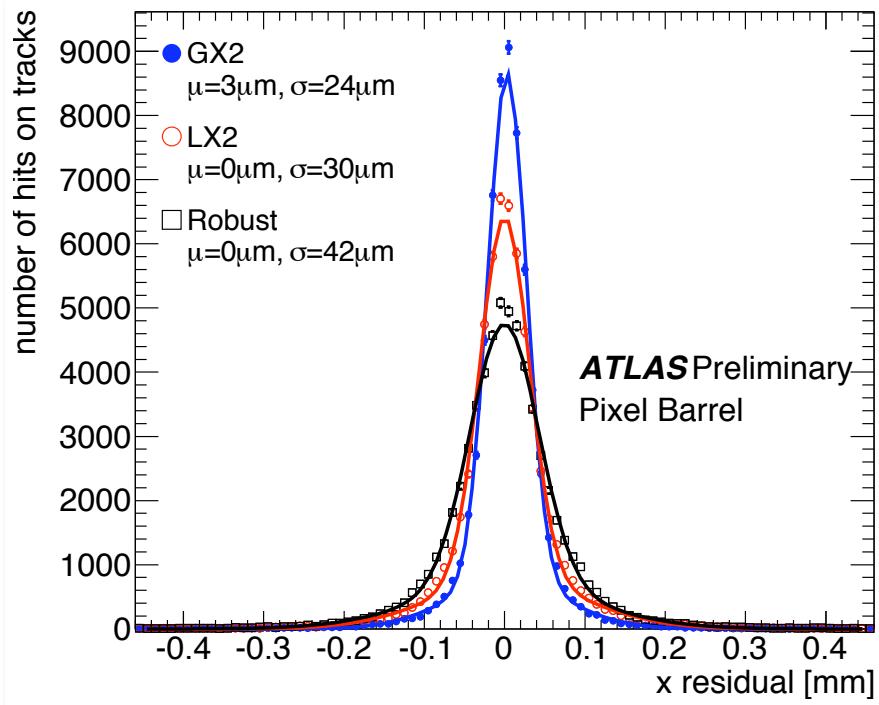
- endcap have much less hits and no alignment at module level is possible
- align endcaps at disk level
 - improved residual distribution

Residual distribution



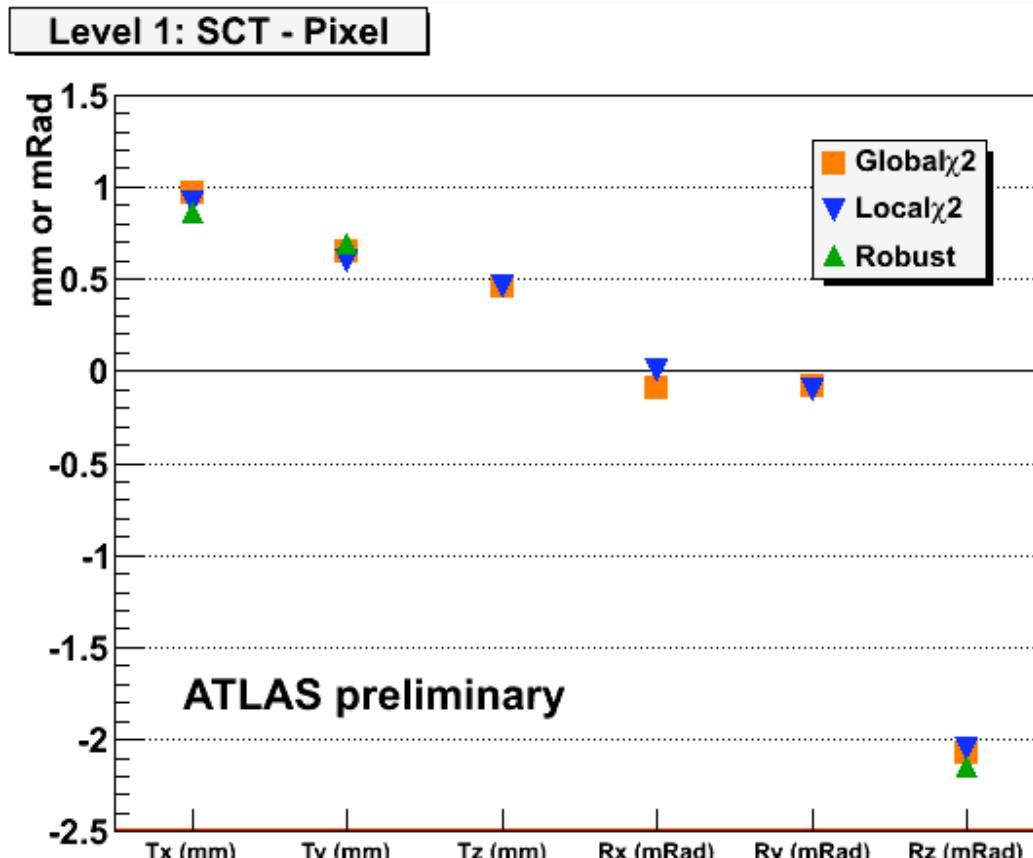
- distribution of mean value of residual distribution module by module
- difference between SCT front-back residual distribution
- $2\times 8 \mu\text{m}$ front-back building precision requirement

Alignment Performance with Different Algorithms



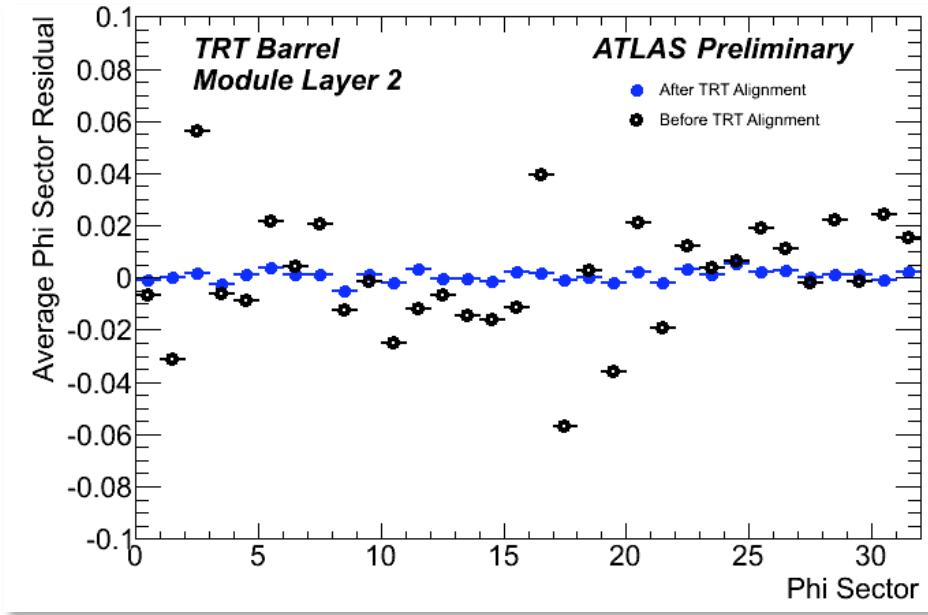
- global χ^2 based algorithm performs best in terms of residual width
- identical SCT performance for χ^2 based algorithm

Comparison between Algorithms



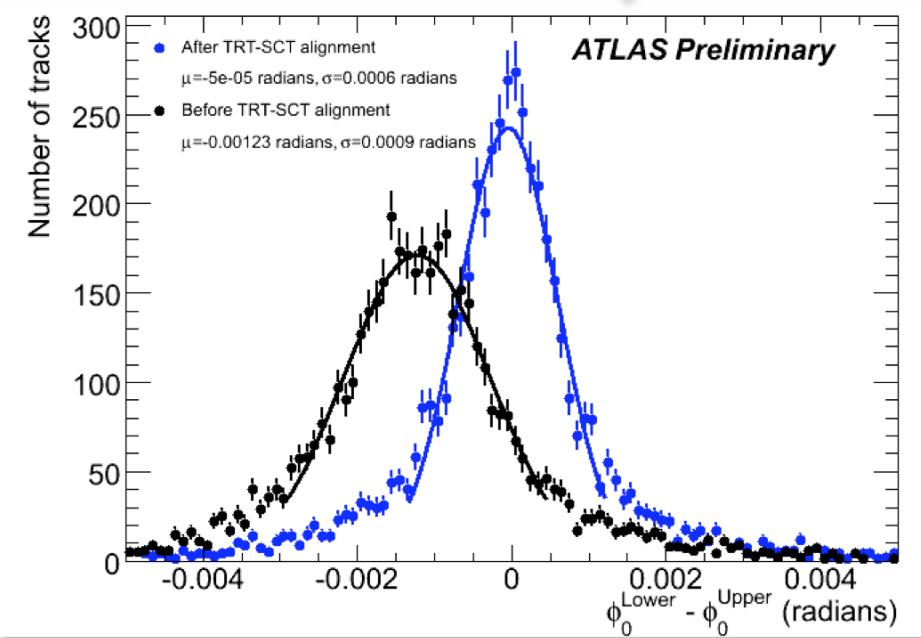
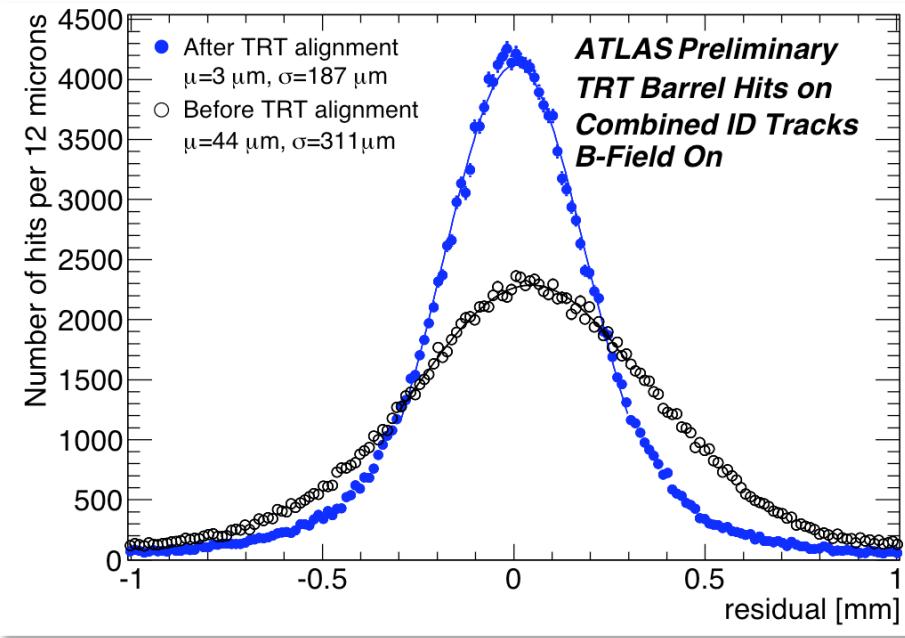
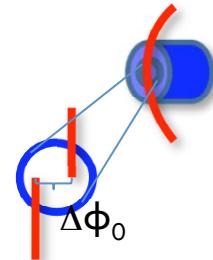
- displacement between pixel and SCT barrel about $O(1\text{mm})$
- three independent approaches return consistent results

TRT Alignment



- global χ^2 -type alignment algorithm for TRT-alignment
- TRT internal alignment performed module by module (L2)
- TRT aligned with respect to Si

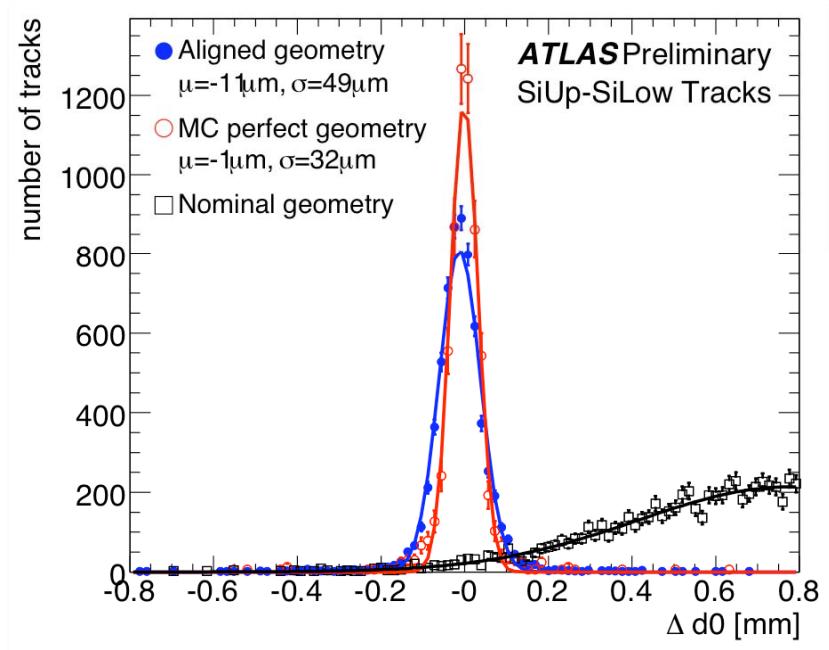
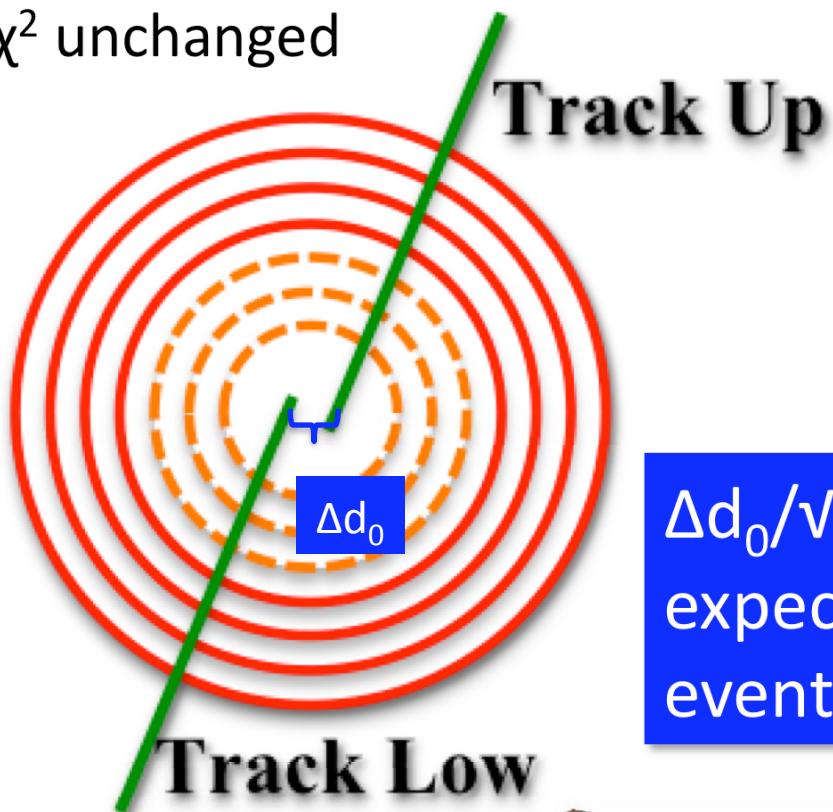
TRT Alignment



- improved residual and track matching obtained after alignment
- R-t calibration calibration required for tracking

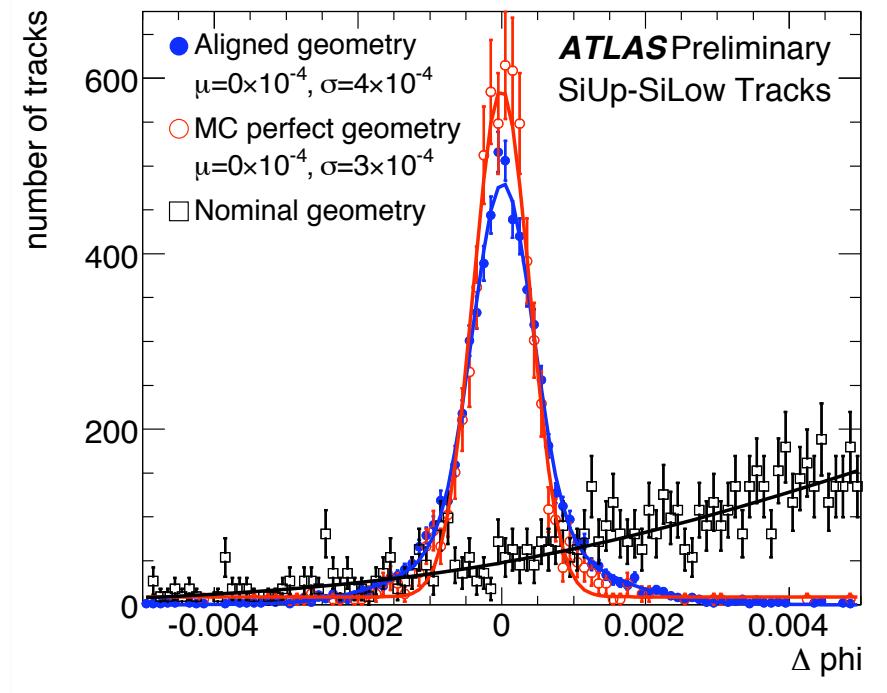
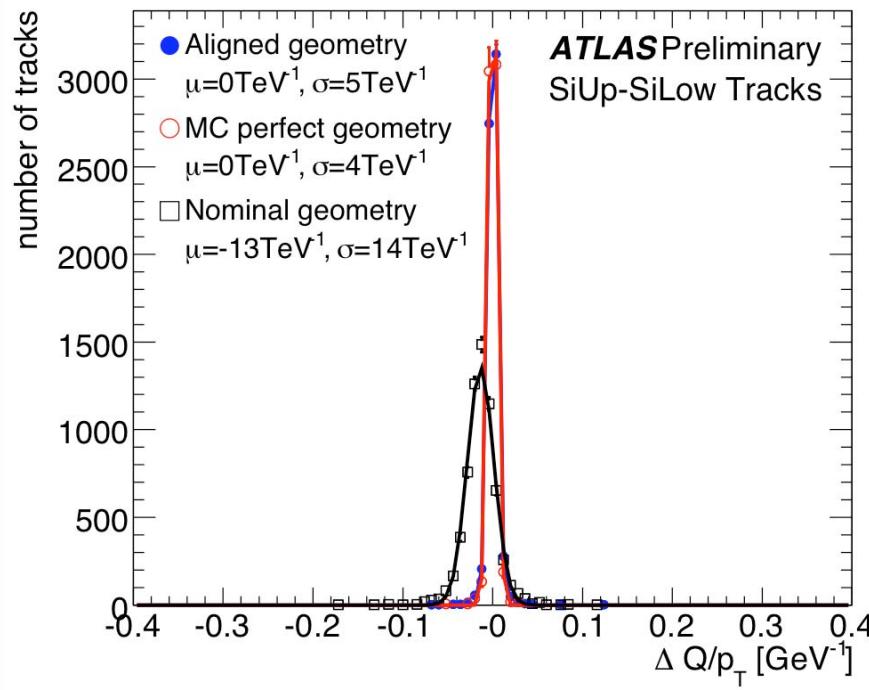
Residual Independent Quality Monitoring

- minimization of hit residuals is required, but not sufficient
- blind to deformations which leave χ^2 unchanged



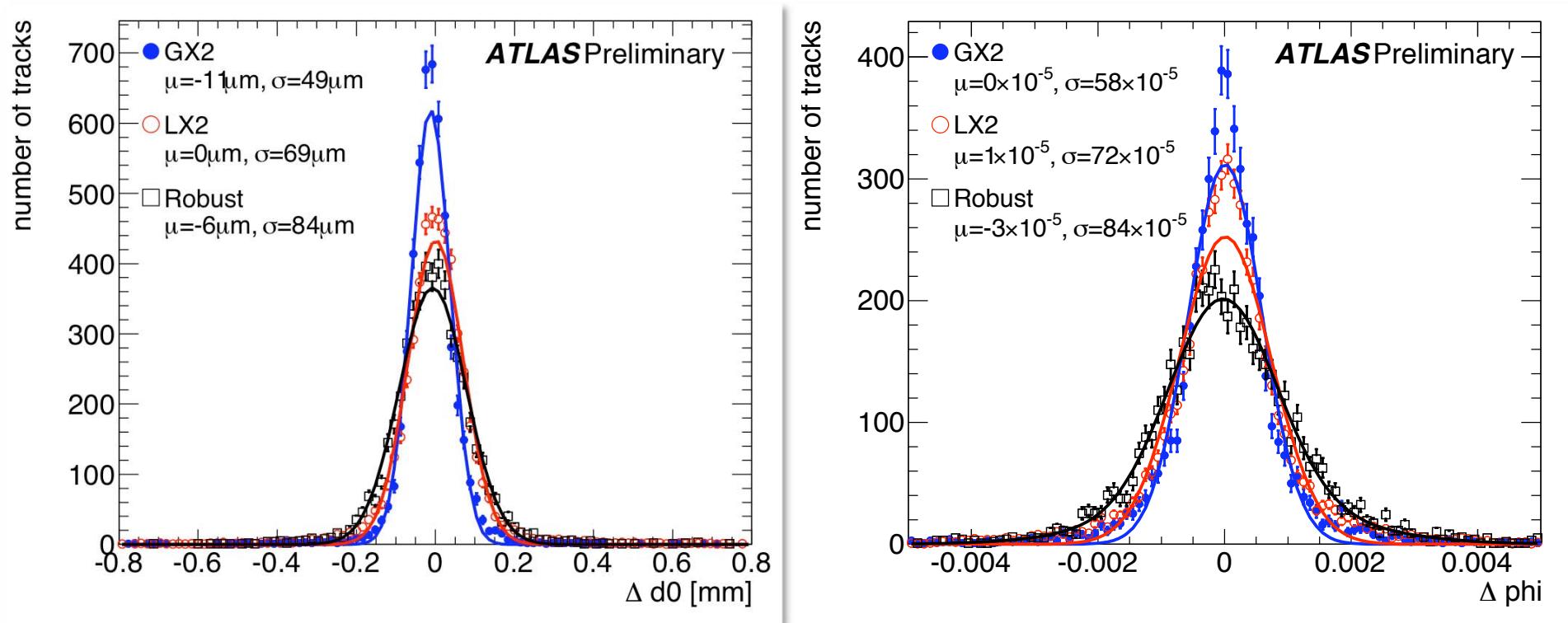
$\Delta d_0/\sqrt{2} = 35 \mu\text{m}$
expectation from simulated collision events: $\sigma(d_0)$ at 5 GeV $\sim 20 \mu\text{m}$

Track Segment Matching



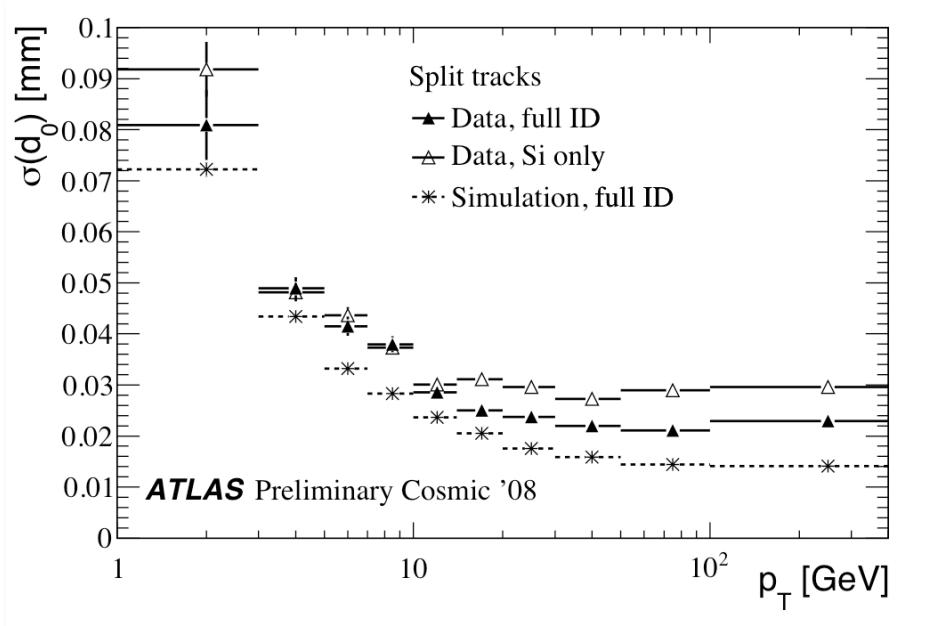
- alignment improves tracking performance considerably
- offset in the d_0 distribution visible → remaining puzzle

Alignment Performance with Different Algorithms

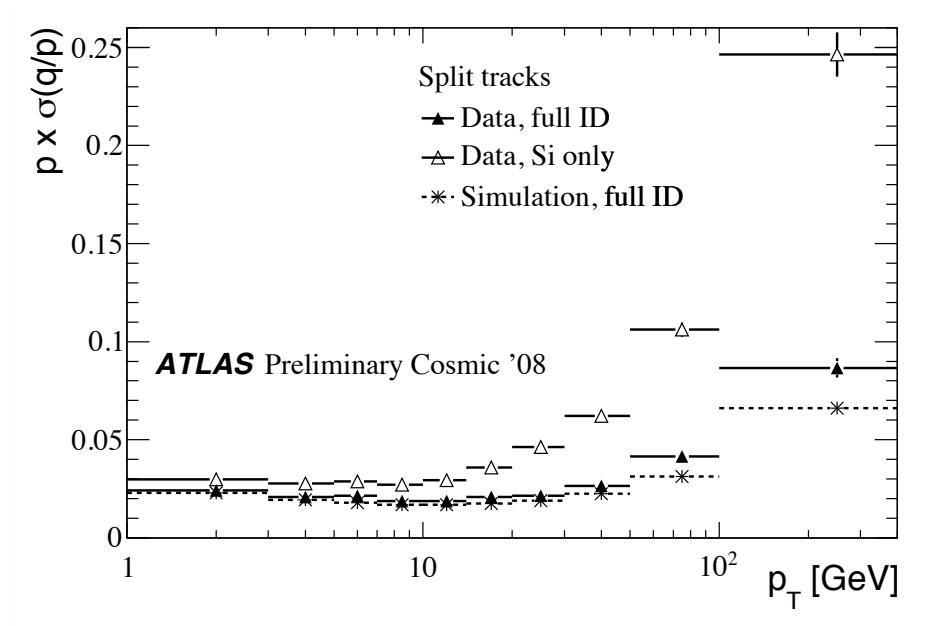


- best d_0 and ϕ resolution for global χ^2 algorithms
- origin of offset currently under investigation

Track Matching versus Momentum

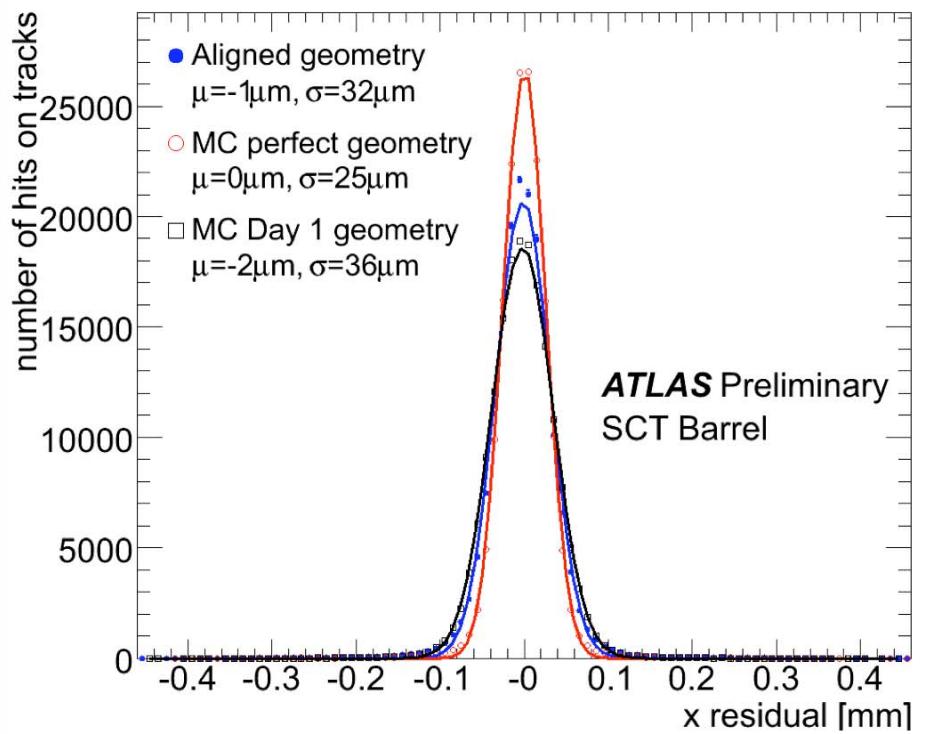
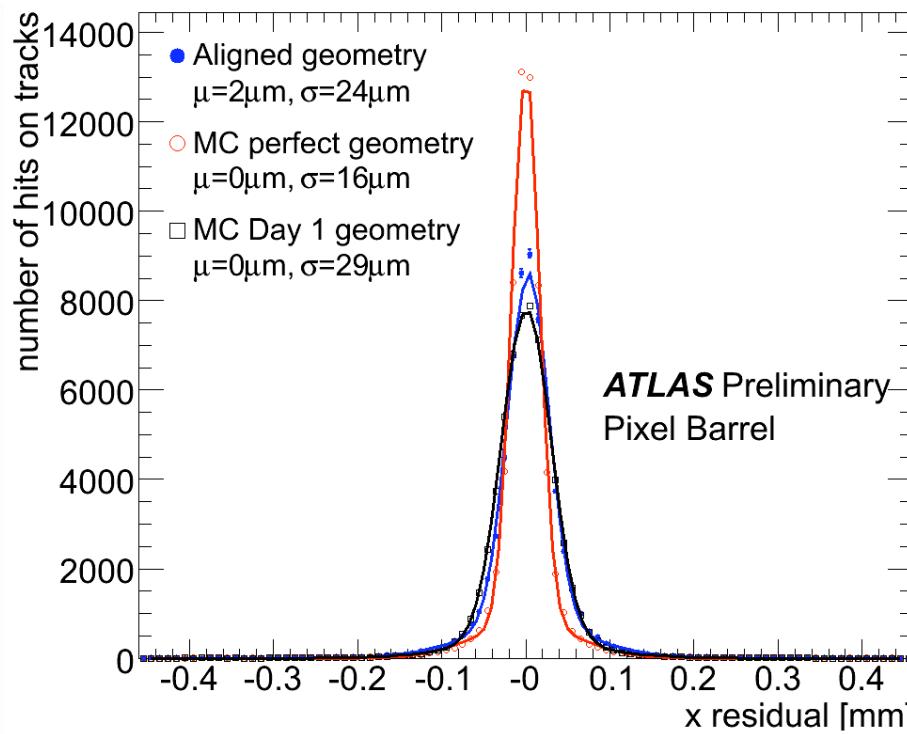


d_0 resolution decreases with increasing momentum



improved momentum measurement with complete ID

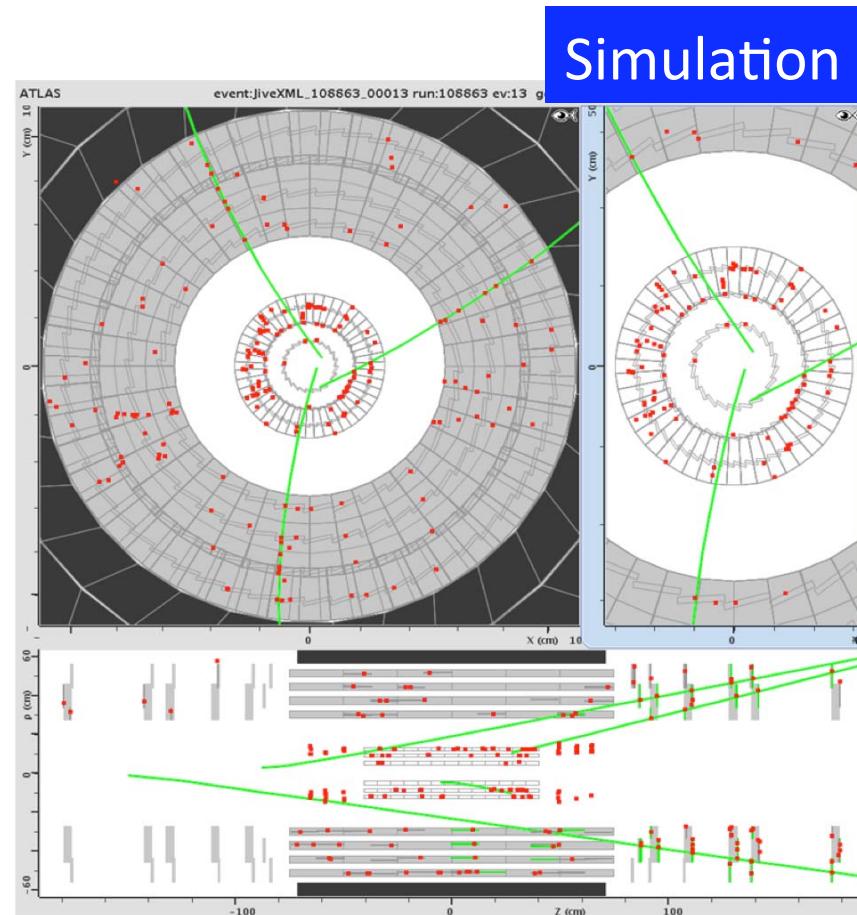
Alignment Expectation for first Data



- residual distribution can be obtained with simulated events reconstructed with a random smearing of 20 μm at module level
- systematic ‘weak deformations’ are not simulated and can bias tracks
- other non alignment effects could also widen residual distribution

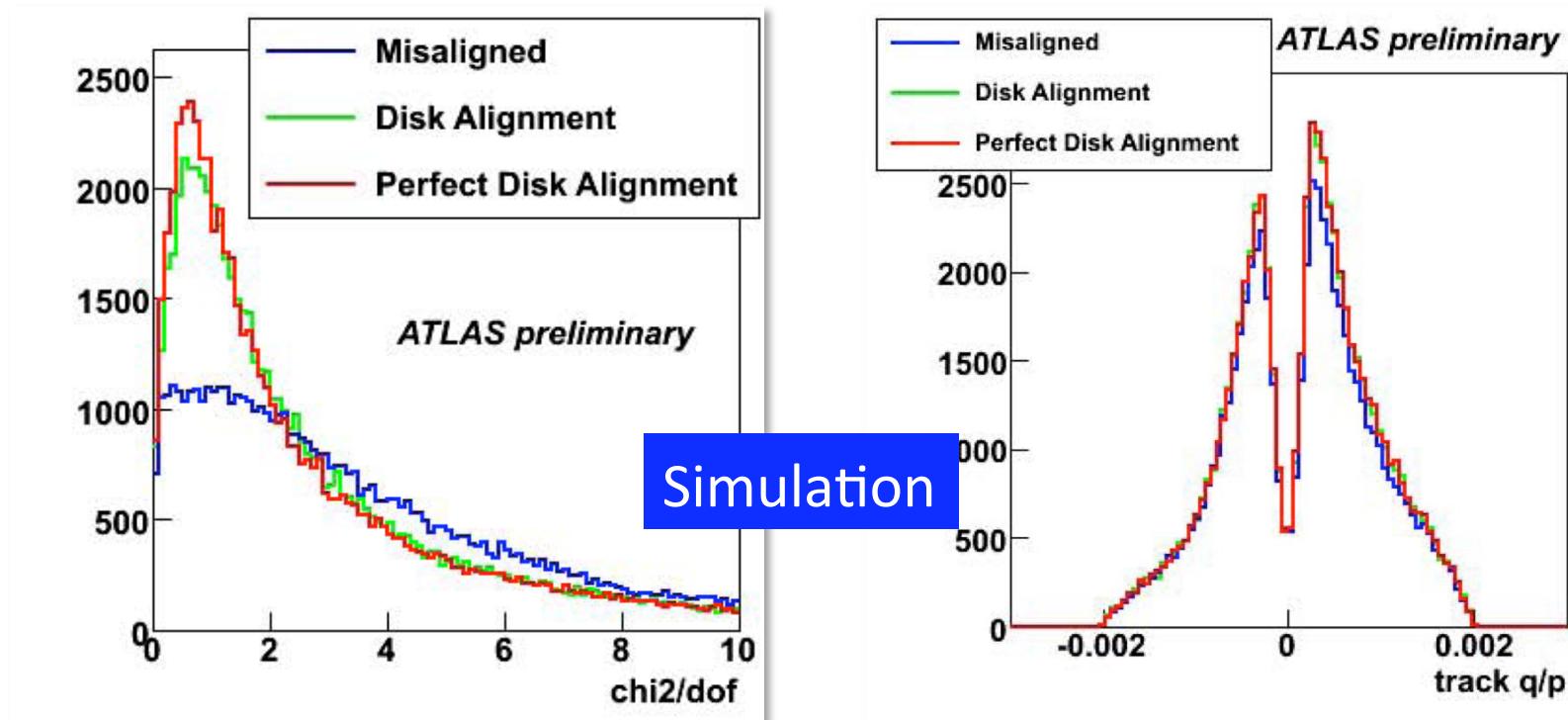
Alignment using Beam Gas Events

- SCT endcap disks only powered at 20V bias voltage with 1.2fC threshold (normal operation: 150V, 1fC)
- SCT barrel and pixel powered off
- O(1000) events passed to high level trigger
- use simulated events to study performance with beam gas events



Alignment using Beam Gas Events

- alignment with beam gas events supplementary to cosmics
- perform disk alignment with beam gas events
 - recover performance identical to perfect disc alignment

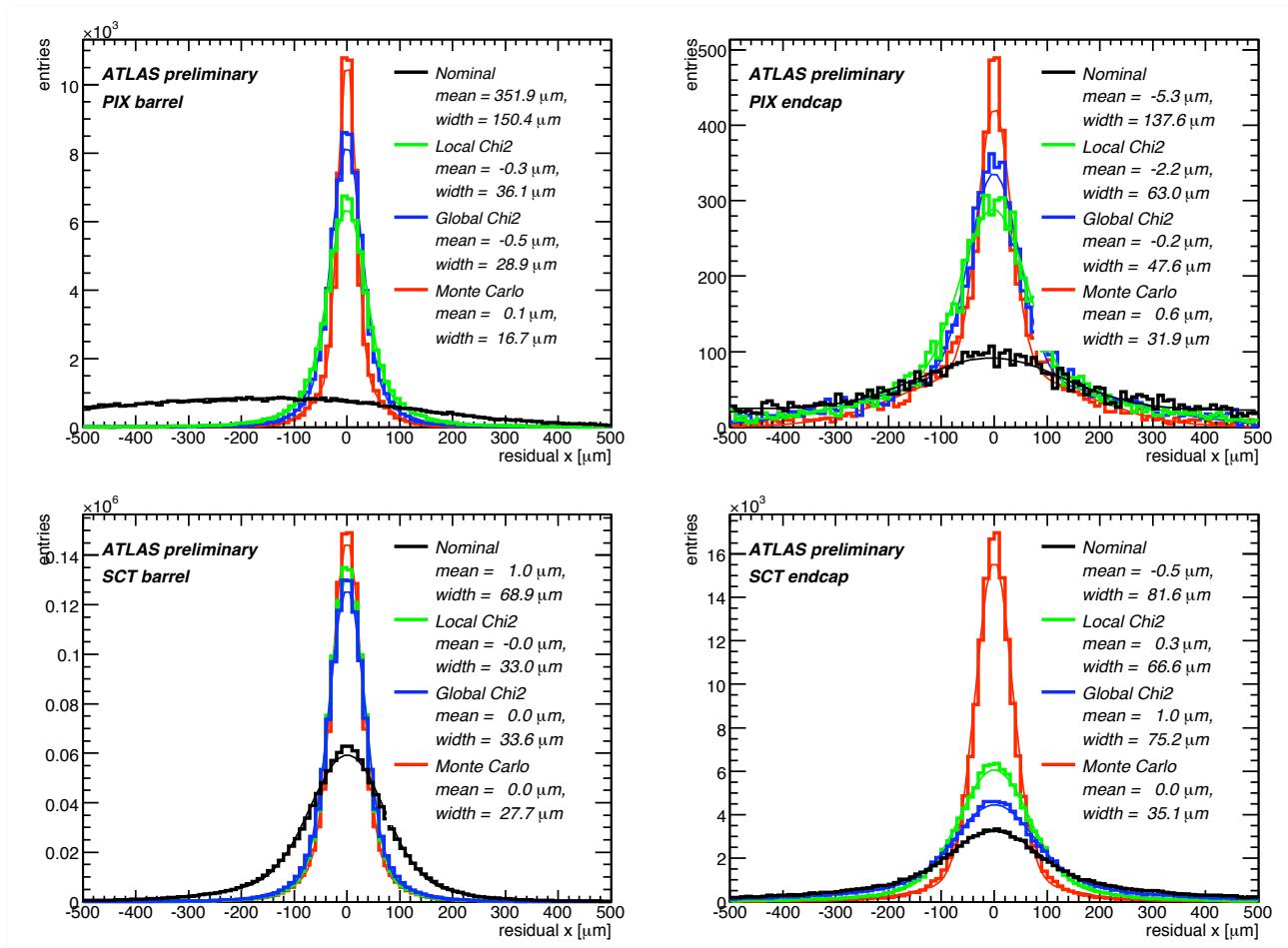


Summary

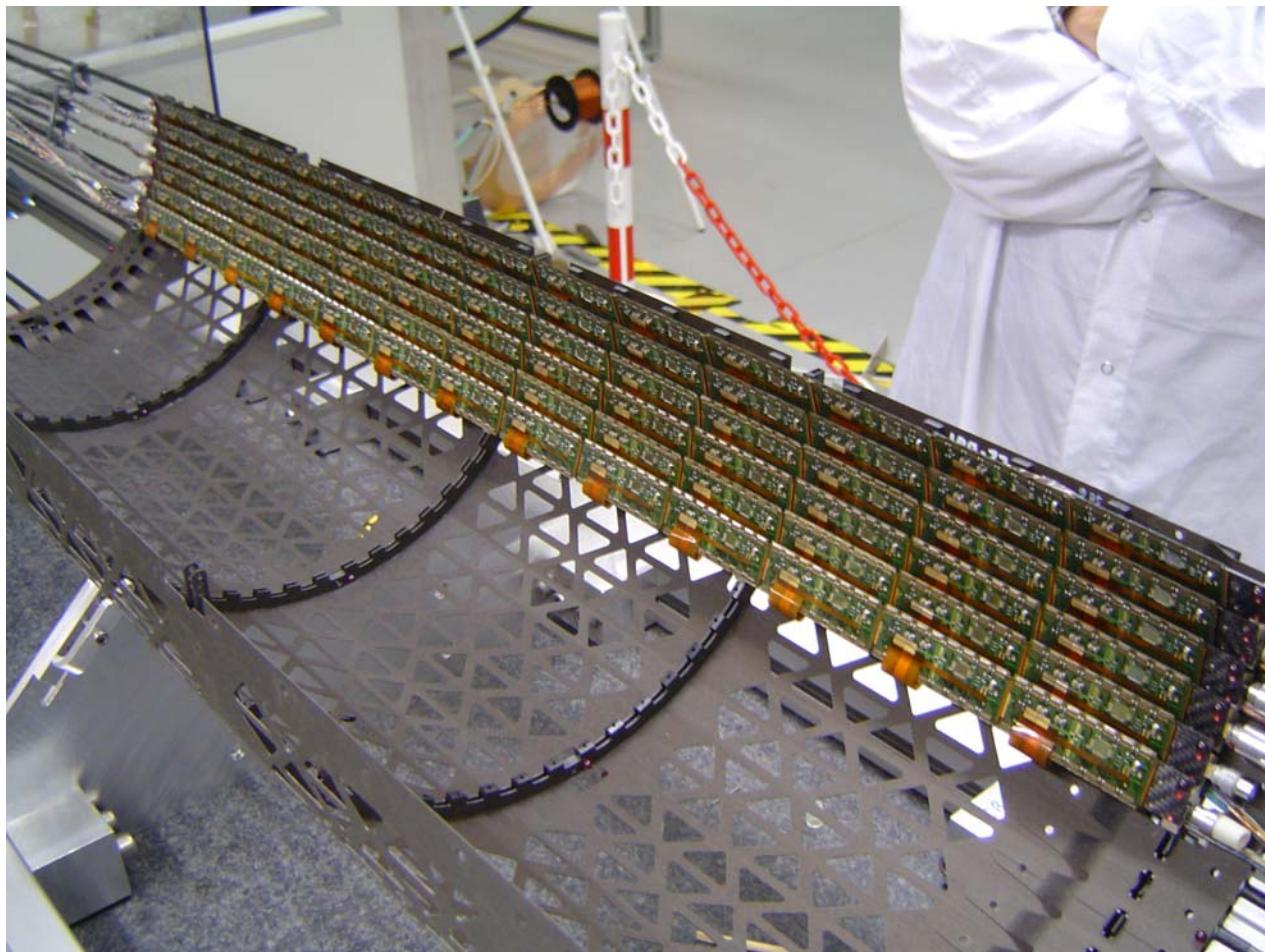
- ATLAS Inner Detector successfully collected several million cosmic ray tracks ($\sim \frac{1}{3} B_{on} + \sim \frac{2}{3} B_{off}$)
- track based alignment algorithm applied to pixel, SCT and TRT
- few remaining puzzles to be solved
- width of residual distribution consistent with about 20 μm random misalignment
- alignment algorithms ready to align detector and will be ready for first collisions

Backup

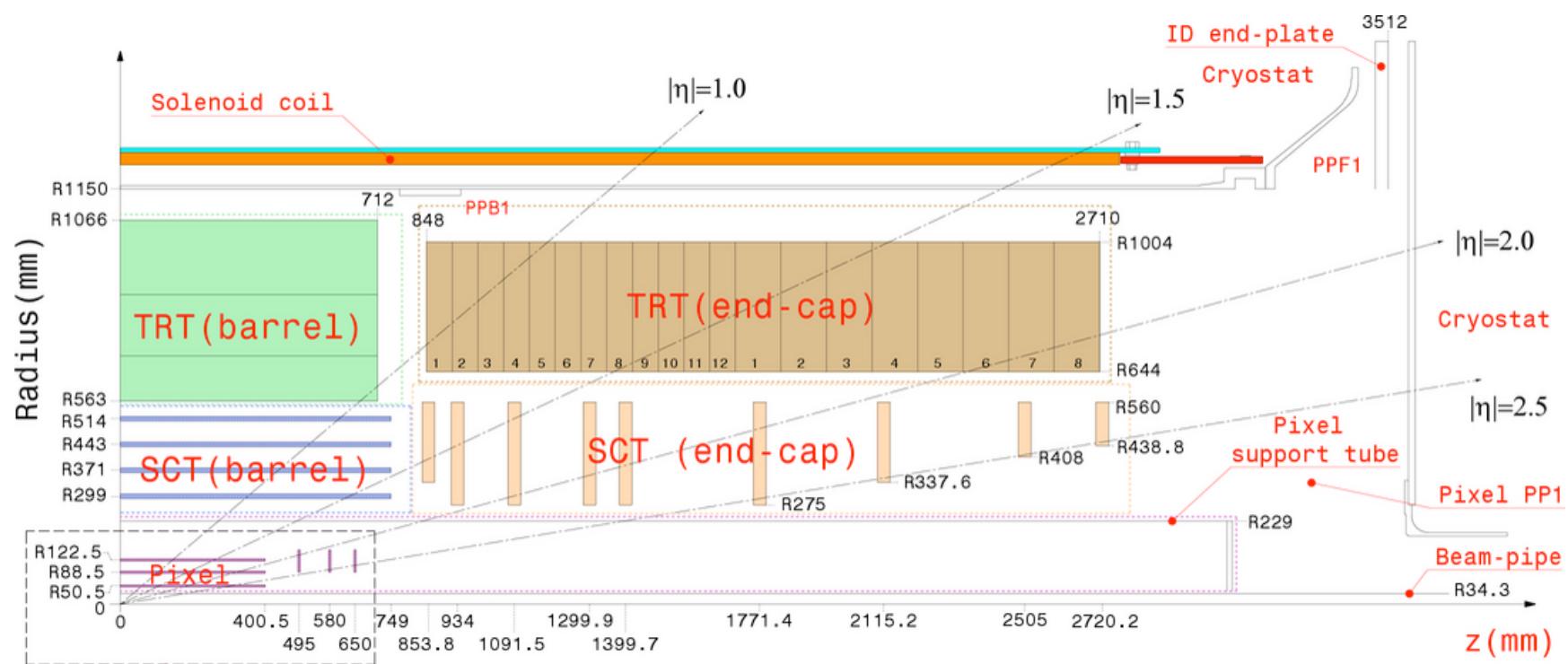
Residual Distribution



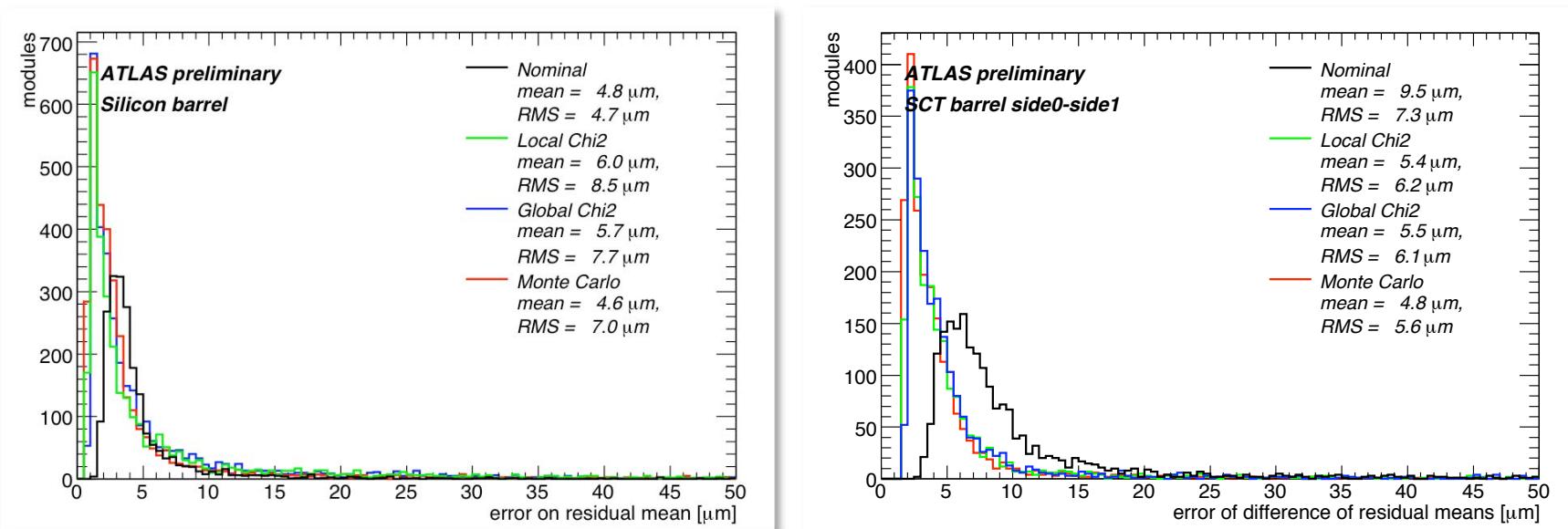
Pixel half Shells



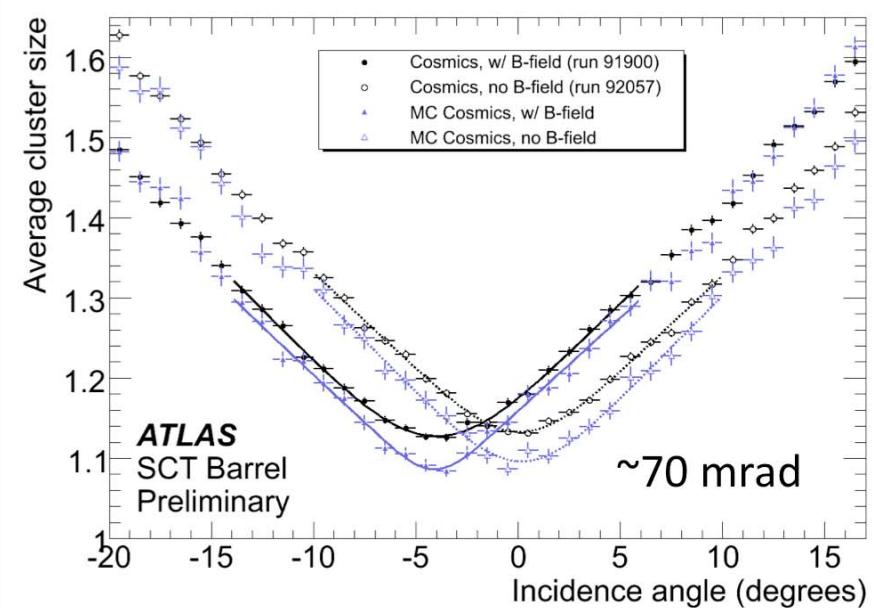
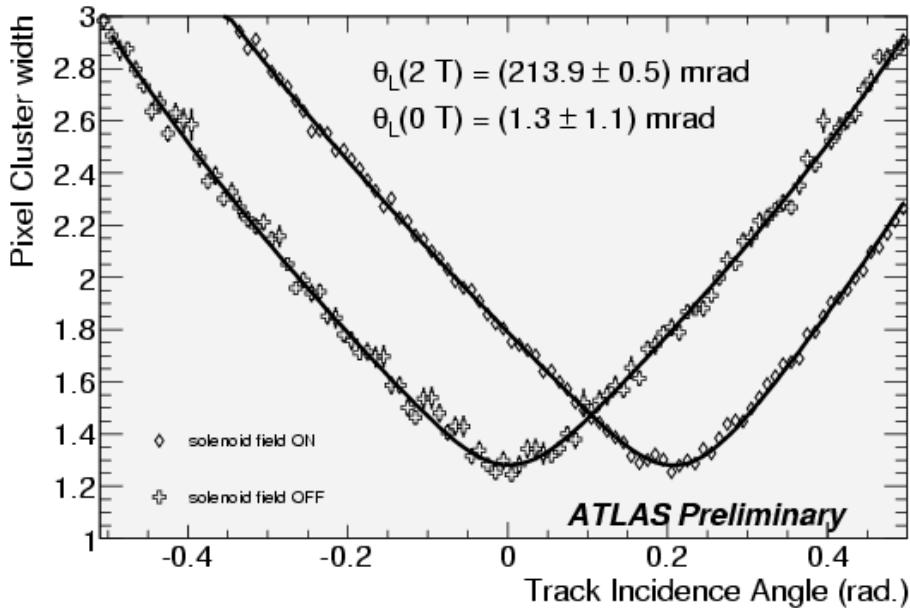
ATLAS Inner Detector



Uncertainty on Residual Mean Distribution



Lorentz Angle Determination



- drift of charge in silicon effected by $E \times B$ -effect
- obtain Lorentz angle by measurement of cluster size as a function of incident angle