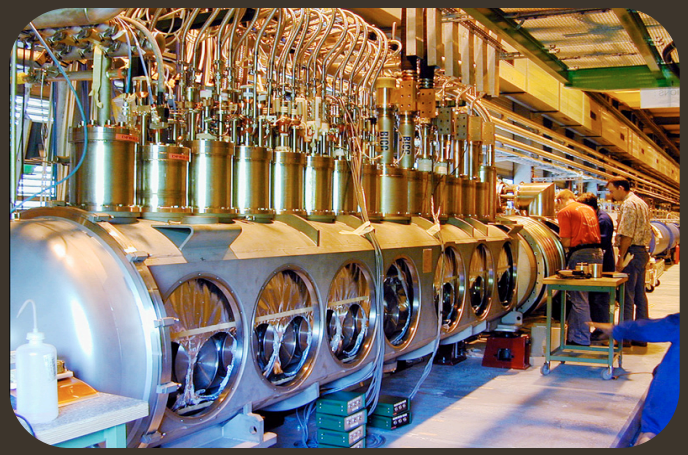
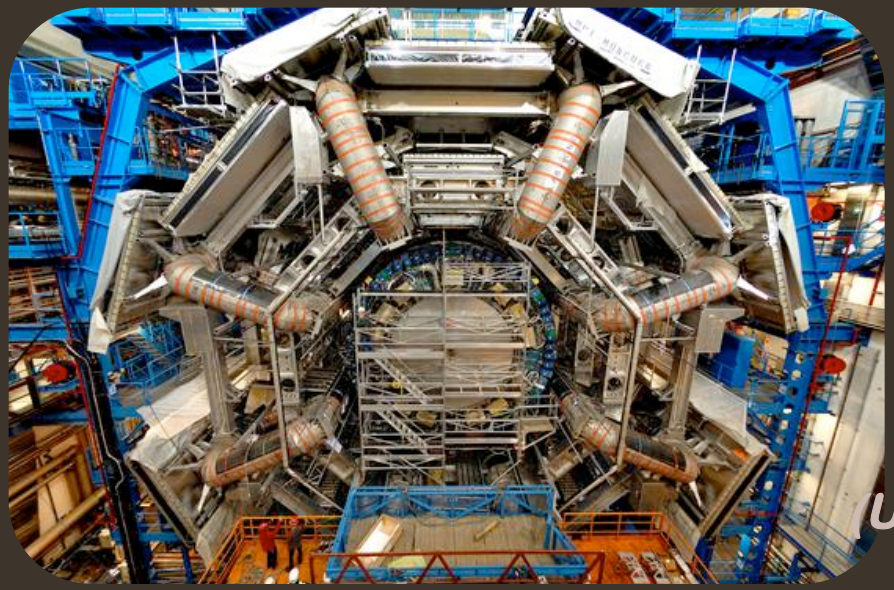
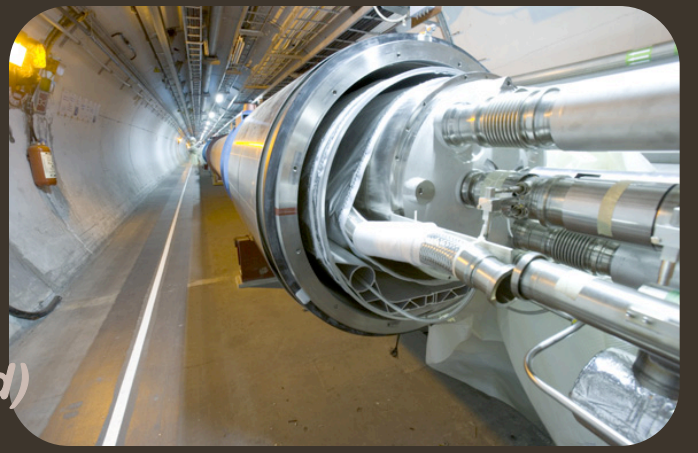


ATLAS
Tau
Workshop
–
Copenhagen
2009

ATLAS
Inner Detector Alignment with M8+ Cosmics & Prospects for 2009 running



Oleg Brandt,
(Univ. of Oxford)

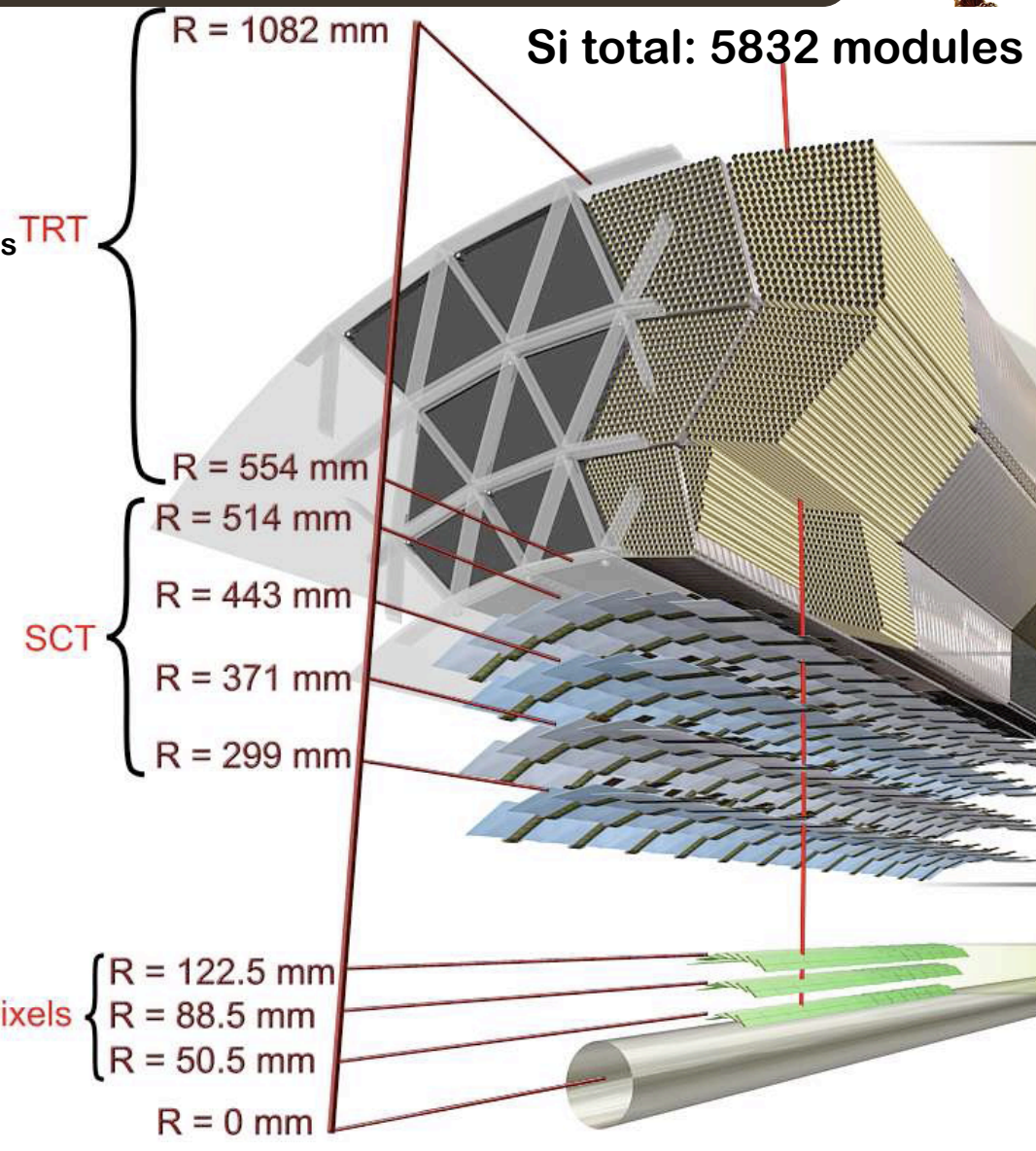


Today's Menu

- The Inner Detector (ID) of ATLAS:
  - Intrinsic resolutions
  - Alignment goals
- The alignment procedure:
  - Alignment levels
  - Alignment sequence
- M8+ Alignment:
  - Main results
- Alignment prospects for 2009+
  - First-pass alignment (summary of M8+ & improvement)
  - Tackling systematic biases
- Summary + Outlook
- (Unresolved alignment riddles so far)
- (ID-related studies with M8+ Cosmics)

ATLAS Inner Detector
Intrinsic Resolutions

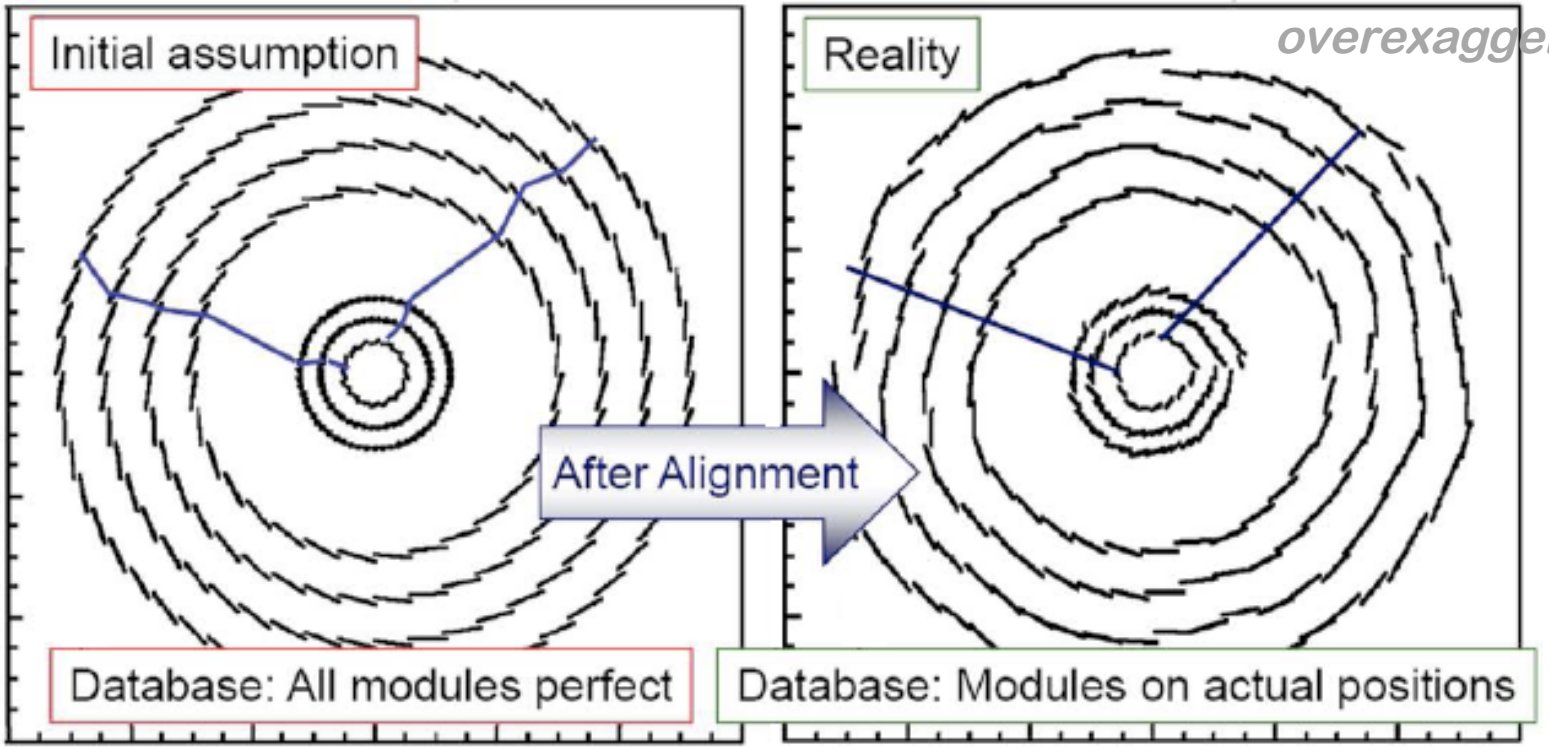
- **TRT:**
  - Polyamide drift tubes
  - 992 modules:
    - Barrel: 3 rings, Σ 73 straw layers
    - ECs: 2x40 wheels: Σ 160 straw planes
  - Intrinsic resolution:
    - 130 μm (RΦ)
- **SCT:**
  - 40 mrad stereo p-n Si microstrips:
    - Nominal pitch: 80 μm
  - 4088 modules à 2 sides & 4 wafers:
    - Barrel: 4 layers, Σ 2112 modules
    - ECs: 2 x 9 rings, Σ 2 x 988 modules
  - Nominal intrinsic resolution:
    - 17 x 580 μm^2 (RΦ x Z)
- **Pixel:**
  - n-type oxygenated Si pixels:
    - Nominal size: 50 x 400 μm^2
  - 1788 modules à 2 wafers:
    - Barrel: 3 layers, Σ 1456 modules
    - ECs: 2 x 3 rings, Σ 2 x 144 modules
  - Intrinsic resolution:
    - 10 x 115 μm^2 (RΦ x Z)



Why Alignment?

- The mounting precision of modules is finite:

Cartoon: 100x overexaggerated



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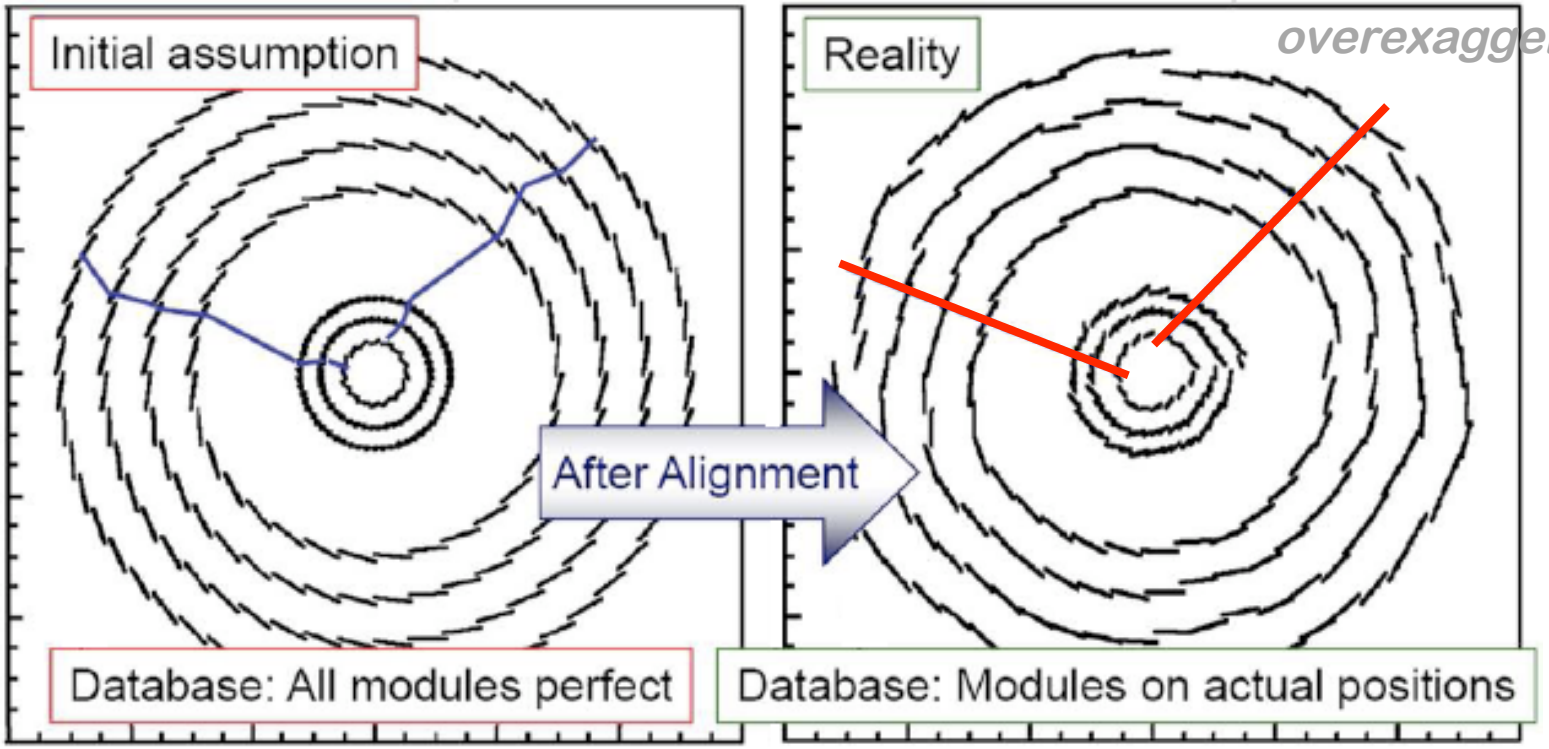

- Determine the position of modules in situ:
  - Hardware-based methods (e.g. optical survey, FSI)
  - Track-based approaches
    - Assume that tracks are helical + d*E*/d*x*

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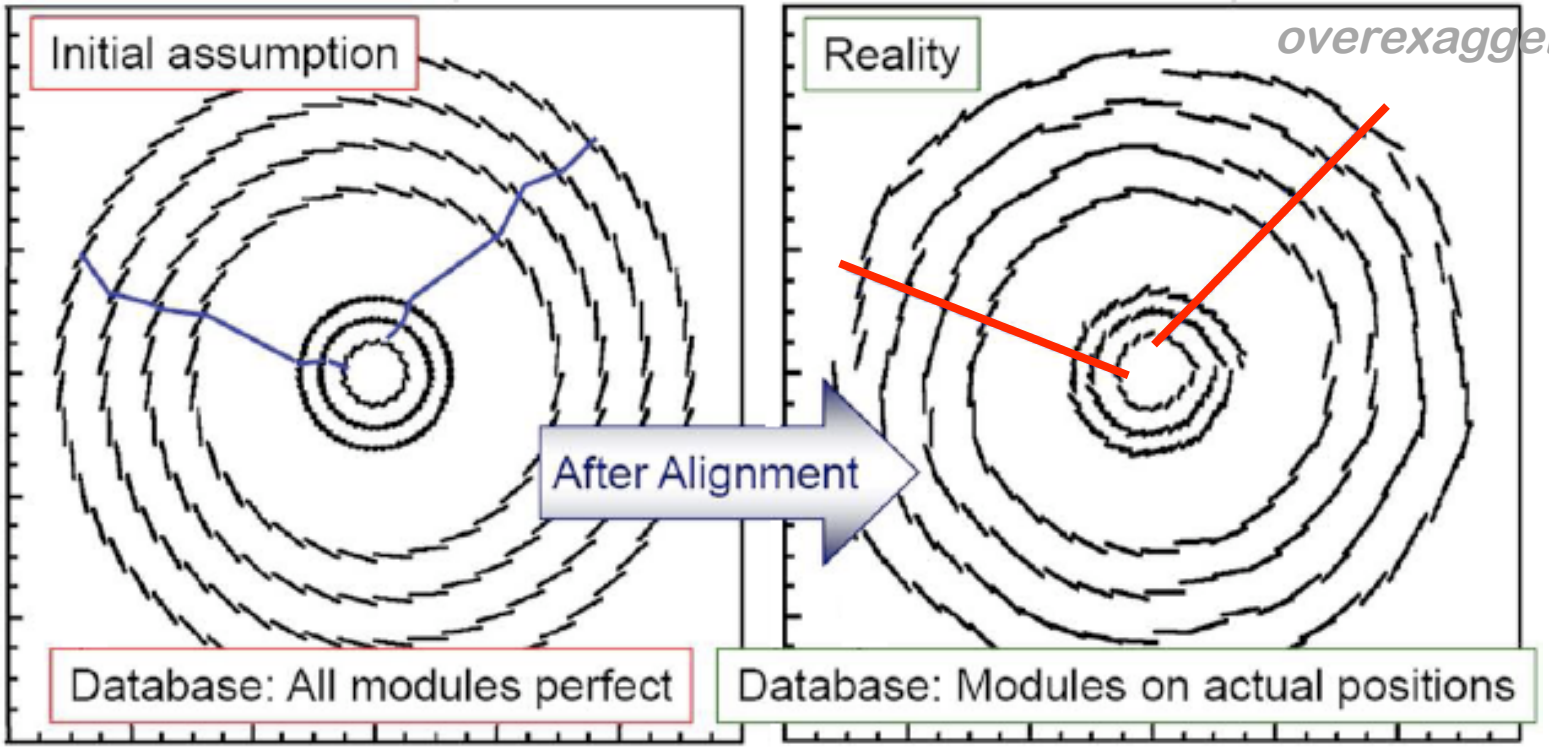

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  - Hardware-based methods (e.g. optical survey, FSI)
  - Track-based approaches
    - Assume that tracks are helical + d*E*/d*x*

Alignment procedure

- References *(+references therein)*:
  - https://twiki.cern.ch/twiki/bin/view/Atlas/GlobalCh2Approach
  - https://twiki.cern.ch/twiki/bin/view/Atlas/LocalChi2Approach
  - https://twiki.cern.ch/twiki/bin/view/Atlas/RobustApproach
  - https://twiki.cern.ch/twiki/bin/view/Atlas/TRTAlignHowTo

Alignment Goals

- Declared TDR goal for alignment:
  - Degradation of tracking parameter resolution by < 20 % due to misalignments!
  - Required alignment precision:
    - Pixels: *O*(7 μm)
    - SCT: *O*(12 μm)
    - TRT: *O*(30 μm)

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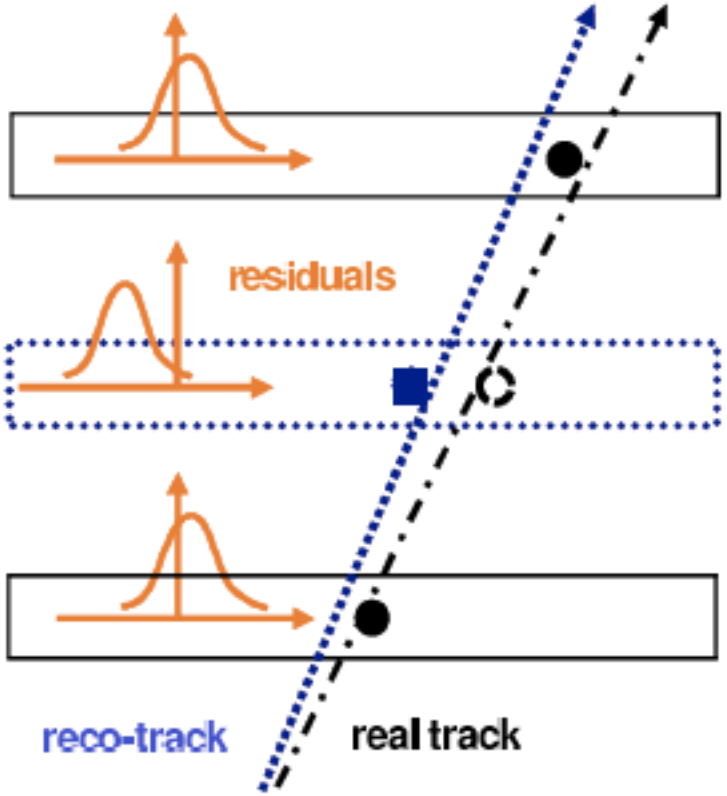
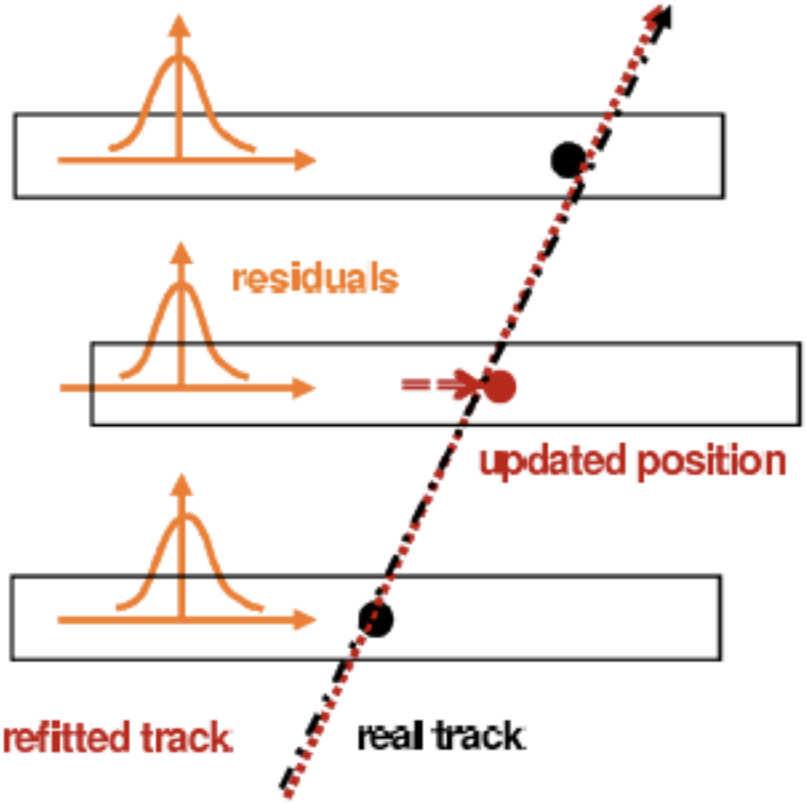
    - Pixels: *O*(7 μm)
    - SCT: *O*(12 μm)
    - TRT: *O*(30 μm)
- The above is for random misalignments
  - Very important, too:
    - Absence of any systematic biases to track parameters!
    - These are due to "Weak mode" deformations of the detector
  - *(covered briefly today, INT or PUB note in spring 2009)*

Track-Based Alignment: Residuals

Misaligned:



Re-aligned:



Alignment "Superstructures": Level 1

- Define superstructures of modules:
  - Reflecting the detector geometry + build specifications
  - Typically: superstructure misalignments large!

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- Define superstructures of modules:
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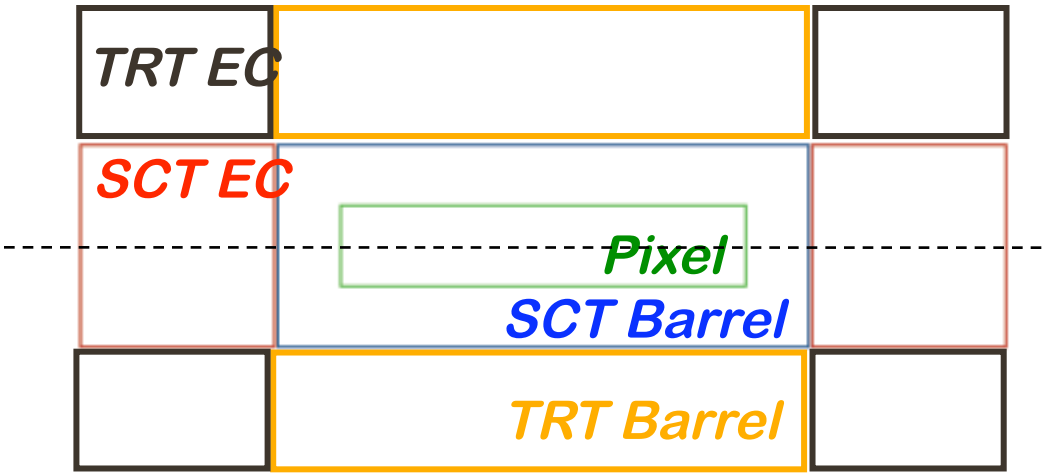
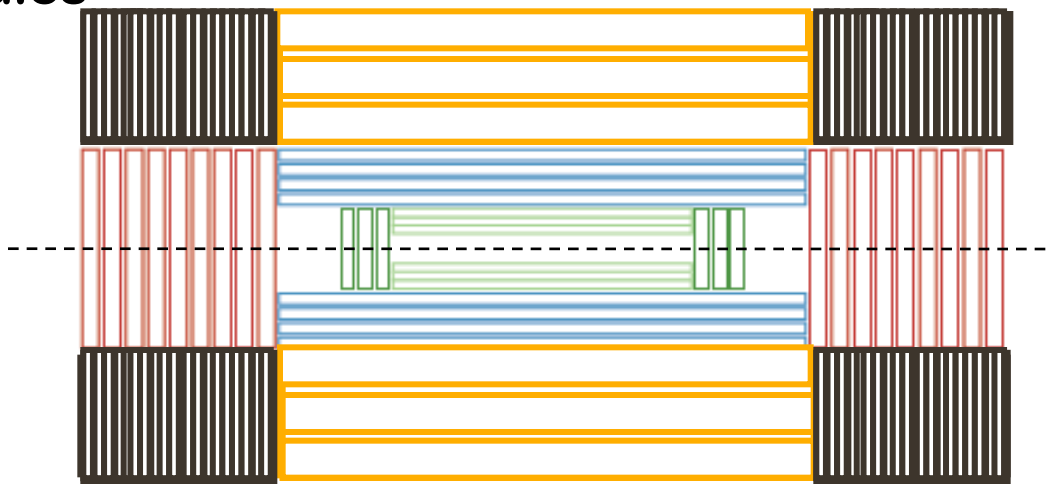
  - Typically: superstructure misalignments large!
- Level 1:
  - Pixel detector
  - SCT barrel
  - SCT EC A
  - SCT EC C
  - TRT Barrel (5 DoF)
  - TRT ECs

  - Σ: 7 superstructures
  - Σ: 41 DoF



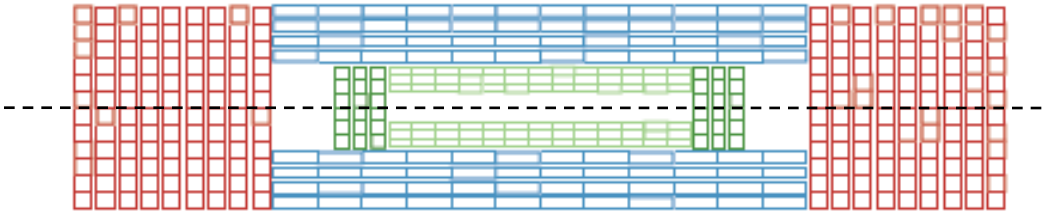
Alignment "Superstructures": Level 2

- Define superstructures of modules:
  - Reflecting the detector geometry + build specifications
  - Typically: superstructure misalignments large!
- Level 2:
  - Pixel Barrel: 3 layers
  - Pixel ECs: 2 x 3 disks
  - SCT barrel: 4 layers
  - SCT ECs: 2 x 9 disks
  - TRT barrel: 32 x 3 modules
  - TRT ECs: 2 x 40 disks
  - Σ: 207 superstructures
  - Σ: 1146 DoF



Alignment "Superstructures": Level 3

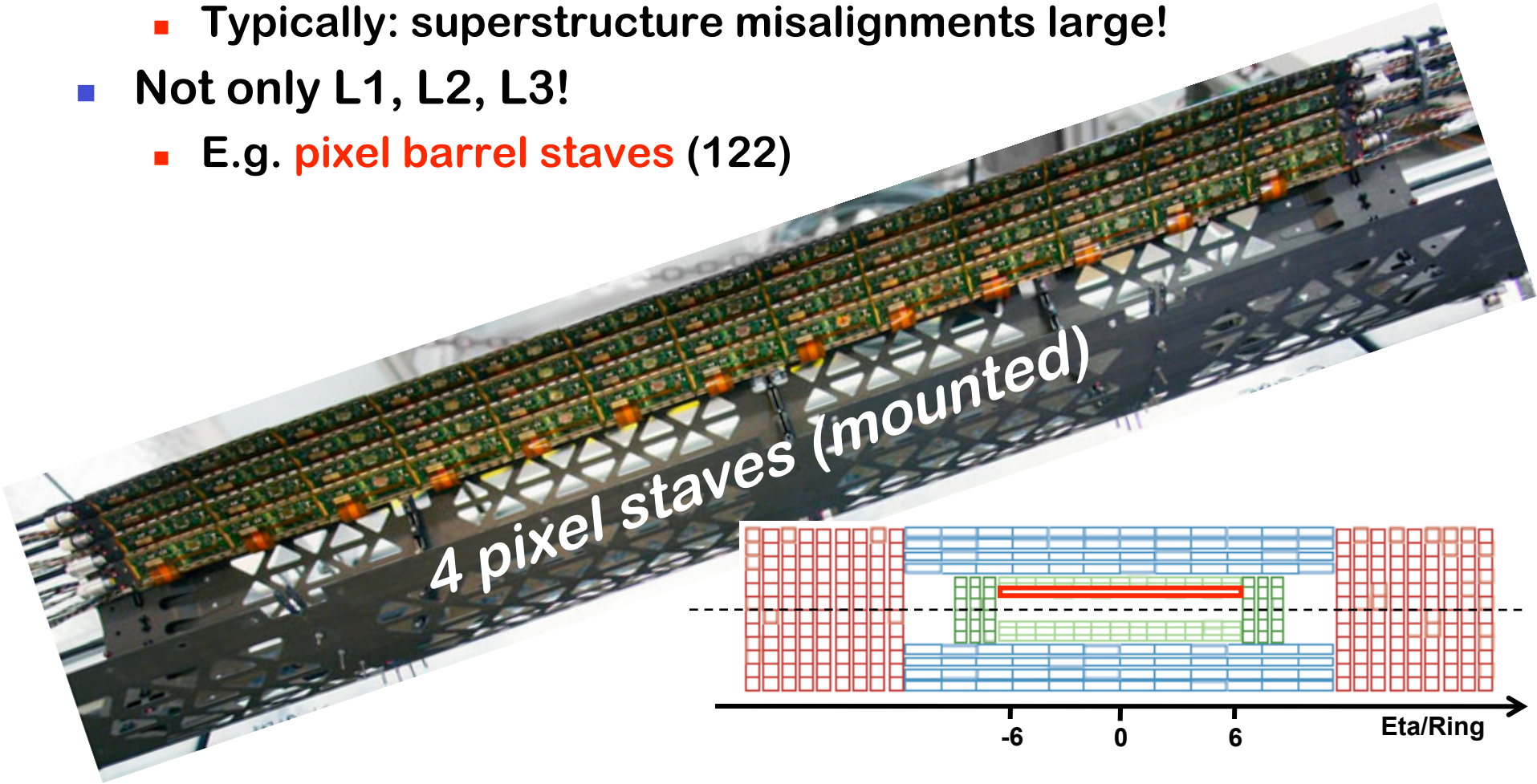
- Define superstructures of modules:
  - Reflecting the detector geometry + build specifications
  - Typically: superstructure misalignments large!
- Level 3:
  - Pixel Barrel: 1456 modules
  - Pixel ECs: 2 x 144 modules
  - SCT barrel: 2112 modules
  - SCT ECs: 2 x 988 modules
  - (no TRT structures at L3)*
  - Σ: 5832 modules
  - Σ: 34992 DoF



* L3 for TRT: individual straw alignment. Not planned in the near future…

Alignment Levels: "Superstructures"

- Define superstructures of modules:
  - Reflecting the detector geometry + build specifications
  - Typically: superstructure misalignments large!
- Not only L1, L2, L3!
  - E.g. pixel barrel staves (122)



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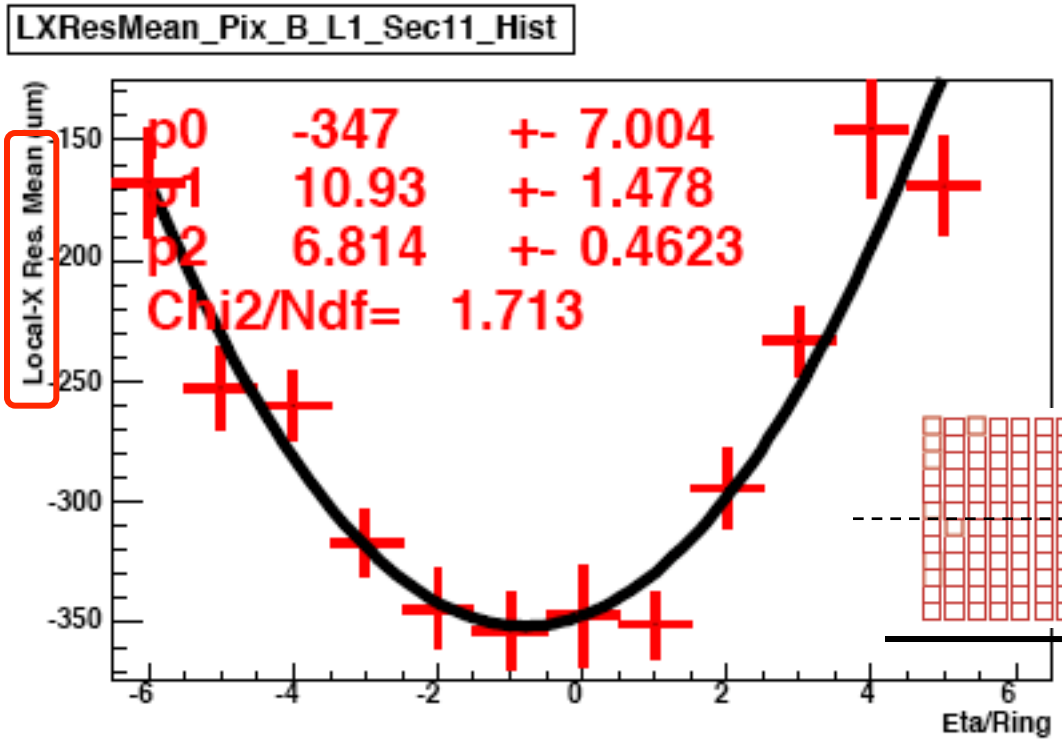
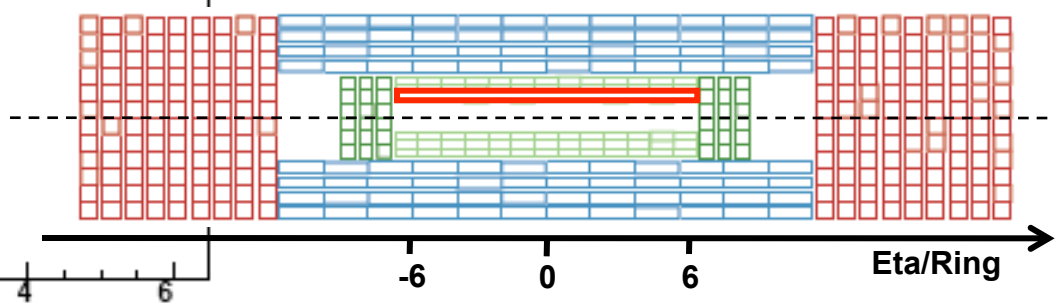
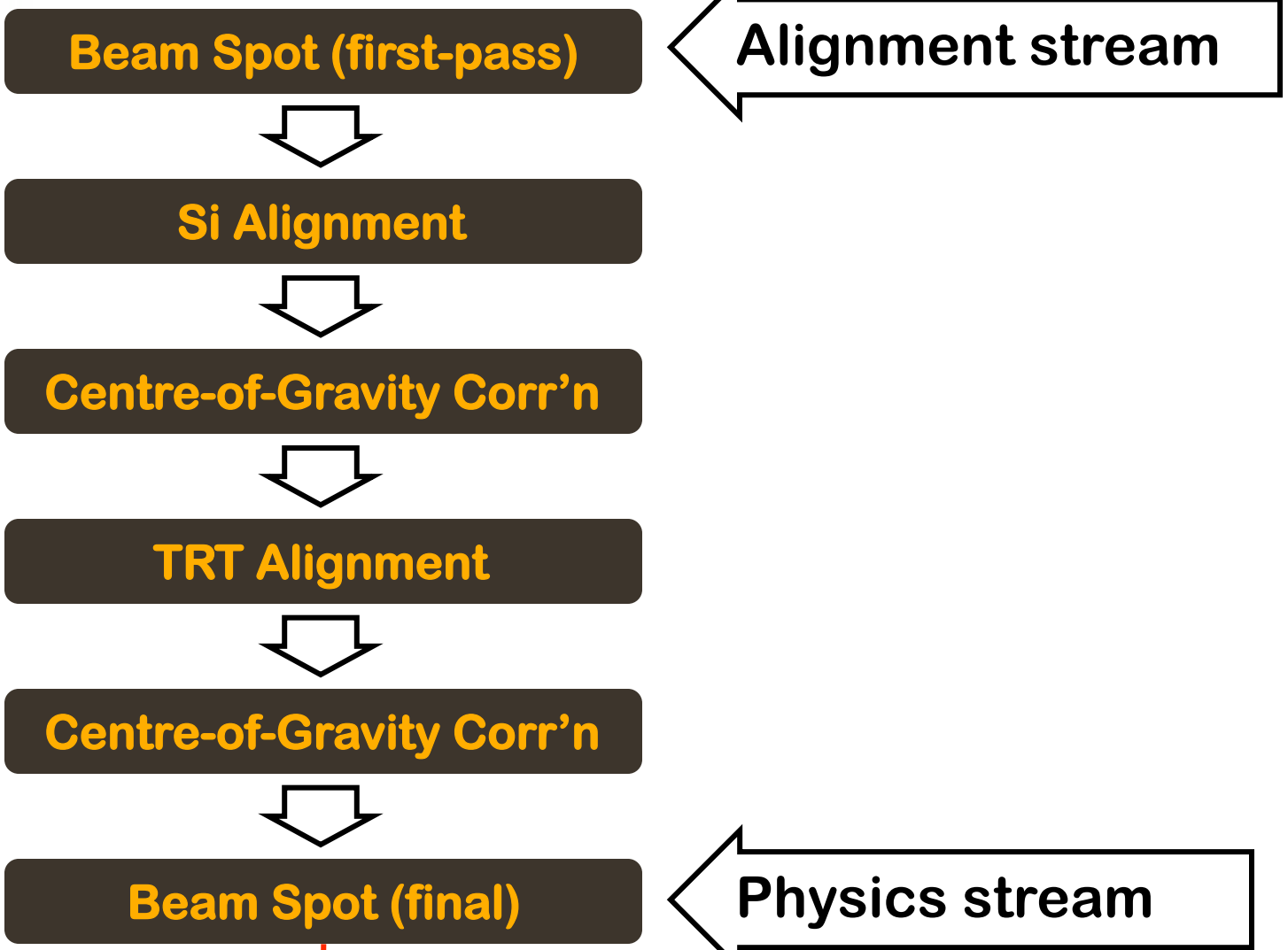


- Parabolic displacement of modules in local x plane of $O(500\ \mu m)$
  - Corrections implemented

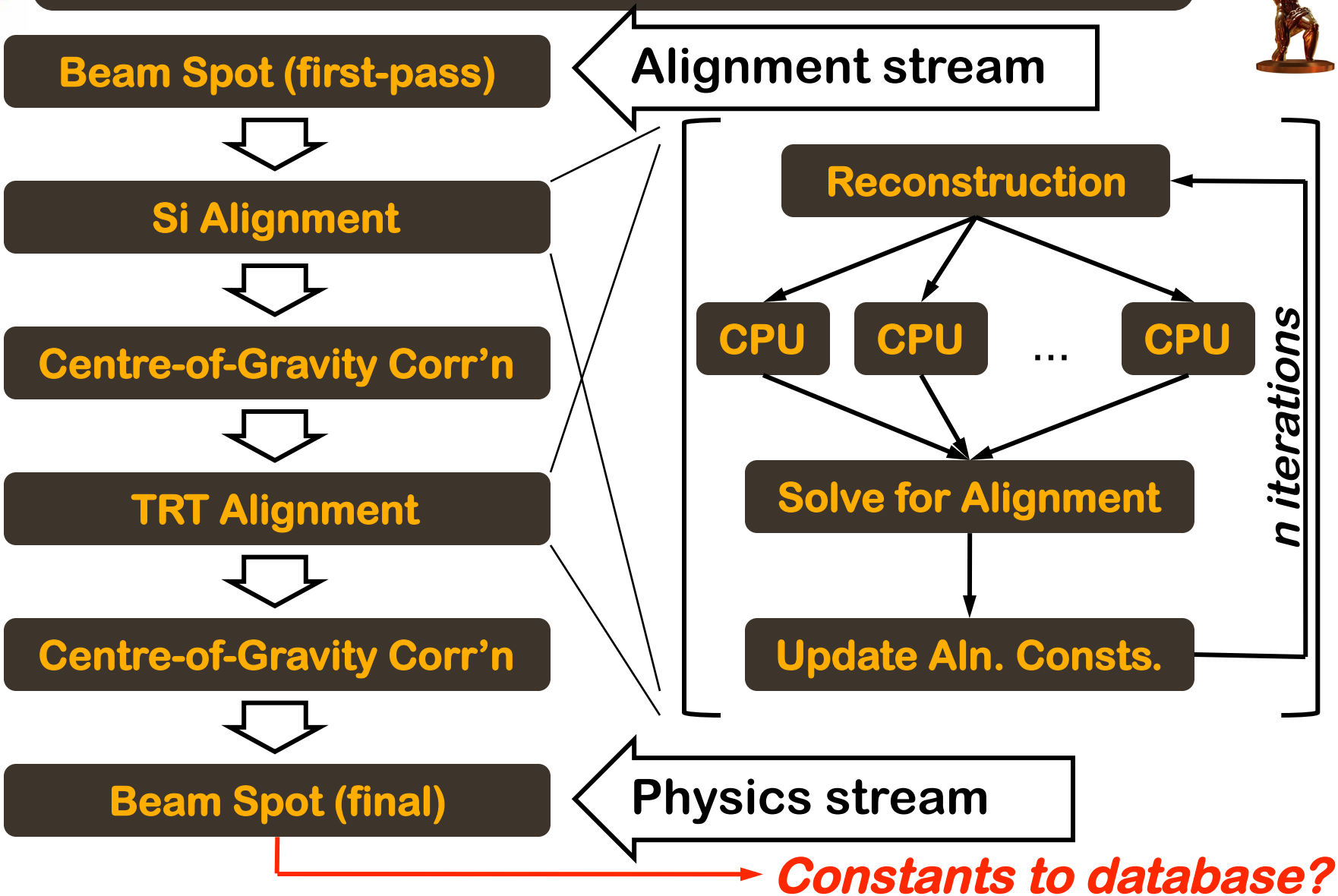


Alignment Chain



Full loop: multiples of 24 h
Cross-checks on shorter time scale

Alignment Chain

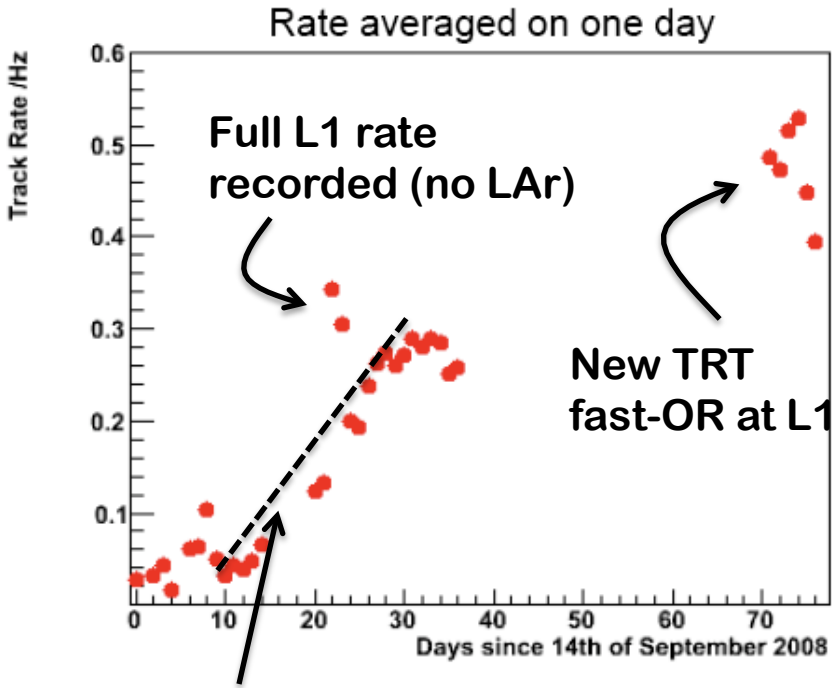


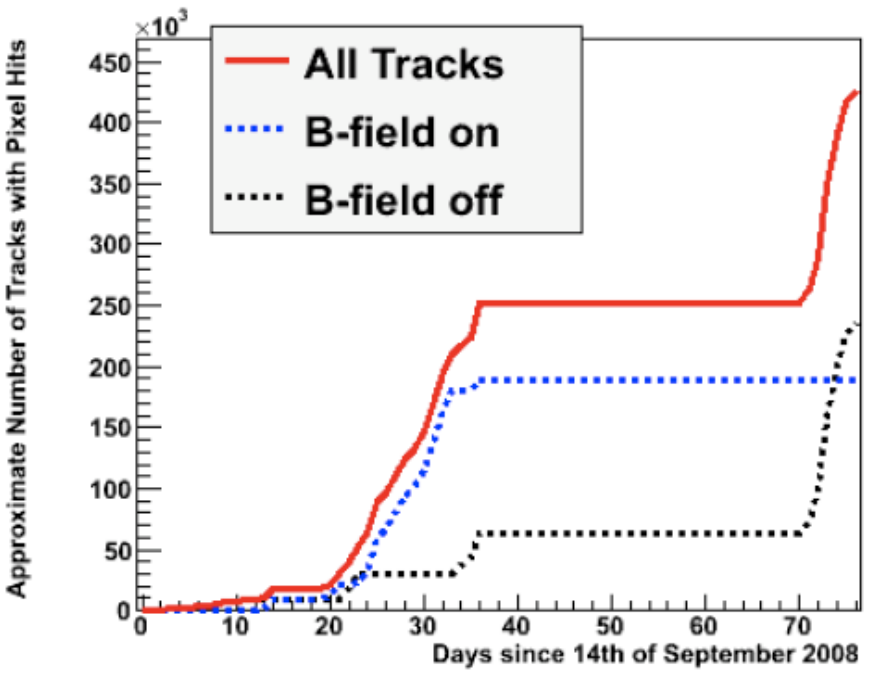
M8+ Results - Alignment -

- References *(+bonus slides)*:
  - https://twiki.cern.ch/twiki/bin/view/Atlas/ApprovedPlotsID
  - https://twiki.cern.ch/twiki/bin/view/Atlas/ApprovedPlotsTRT
  - http://indico.cern.ch/categoryDisplay.py?categId=3l116

Alignment with M8+ Cosmics

- ATLAS was in 24/7 full operation mode Sept.-Dec. 2008!
  - Took cosmics and beam splash data
  - Many lessons learnt (trigger, timing, DAQ, calibration)

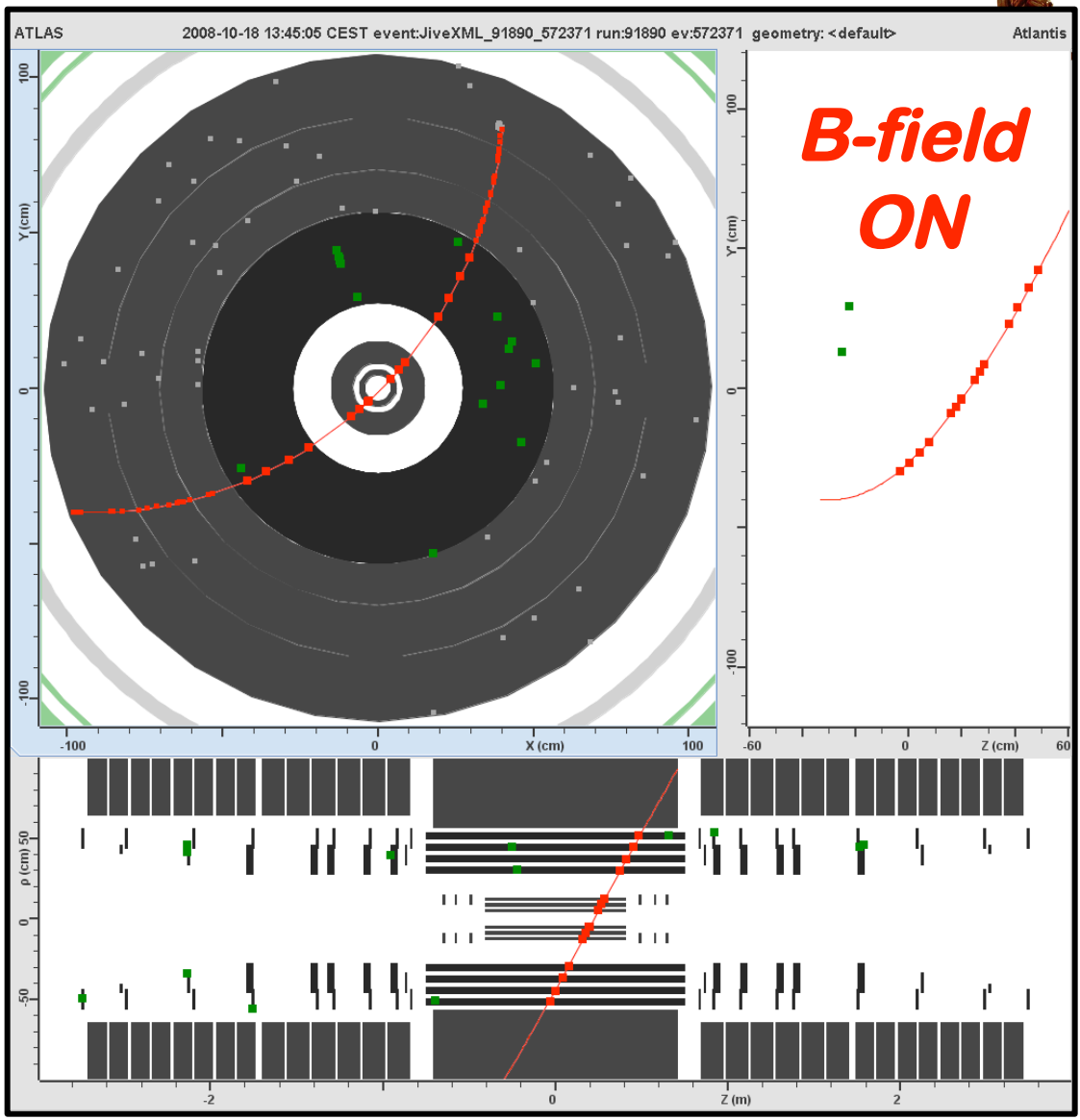




HLT cosmics filtering learning curve:
Timing + tracking efficiency + alignment + reduced prescales!

Alignment with M8+ Cosmics

- Collected cosmics data:
  - With *B*-field ON:
    - 2.6M ID tracks
    - 880k with >0 SCT hits
    - 190k with >0 Pixel hits
  - With *B*-field OFF:
    - 5M ID tracks
    - 2M with >0 SCT hits
    - 230k with >0 Pixel hits



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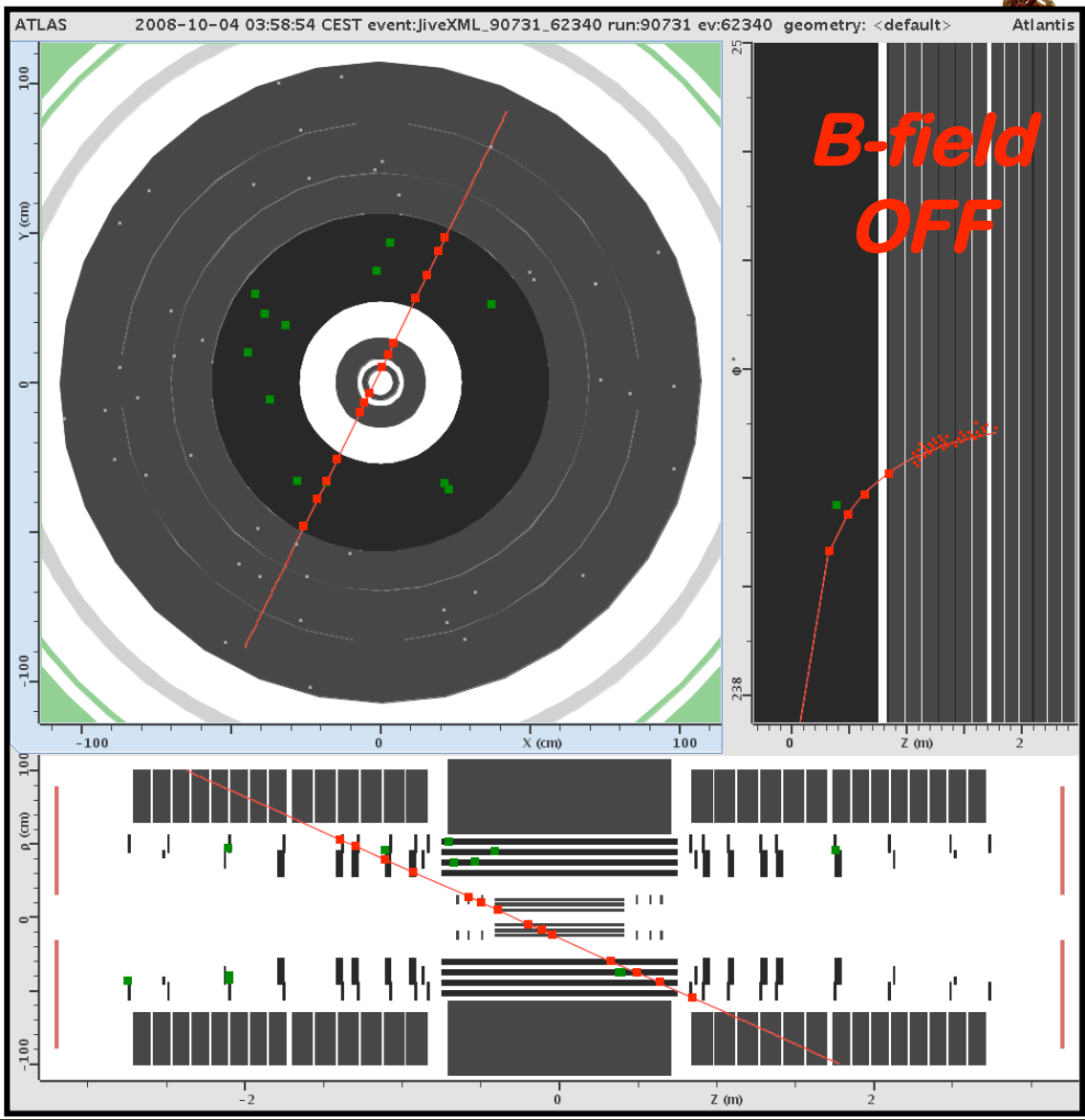
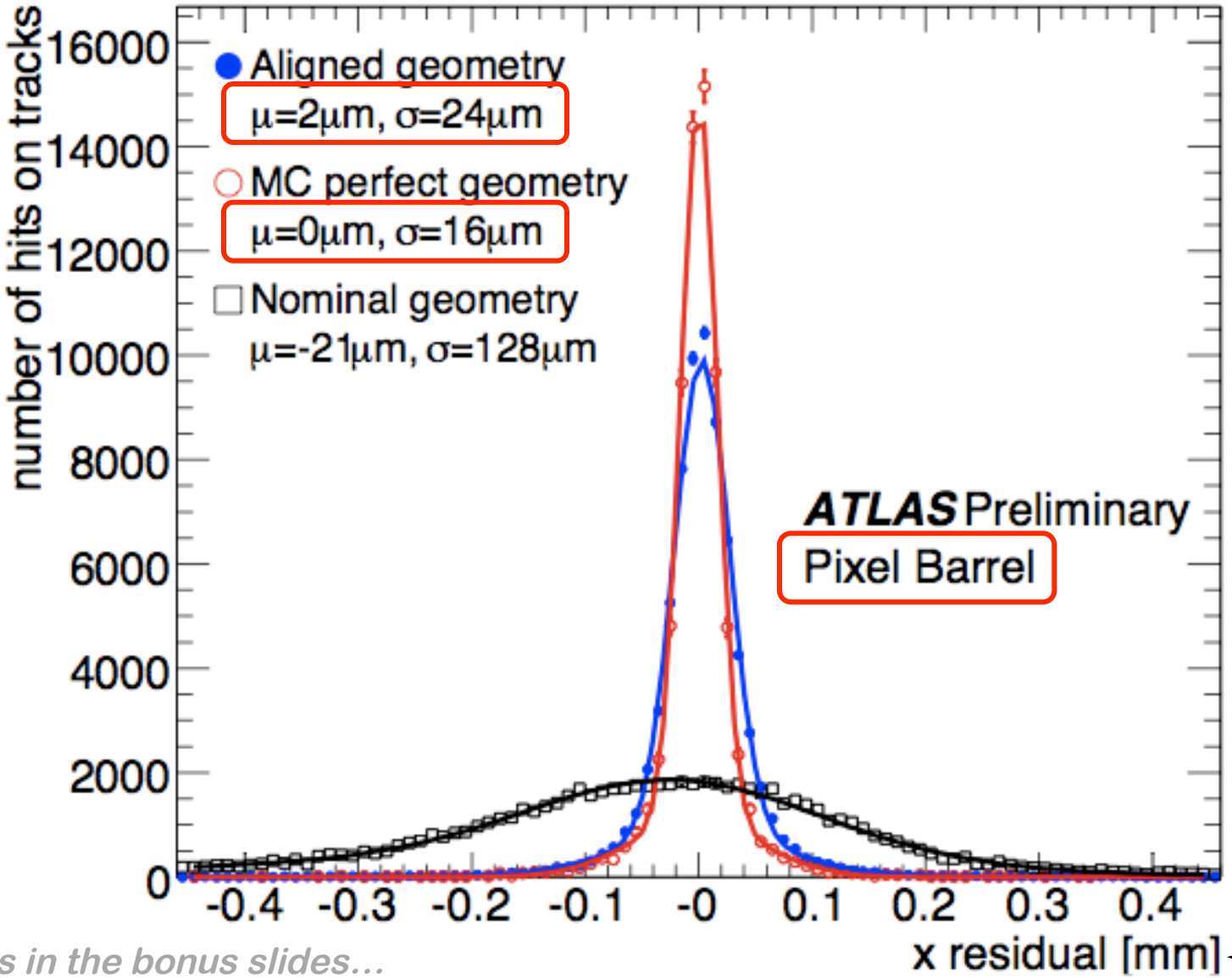


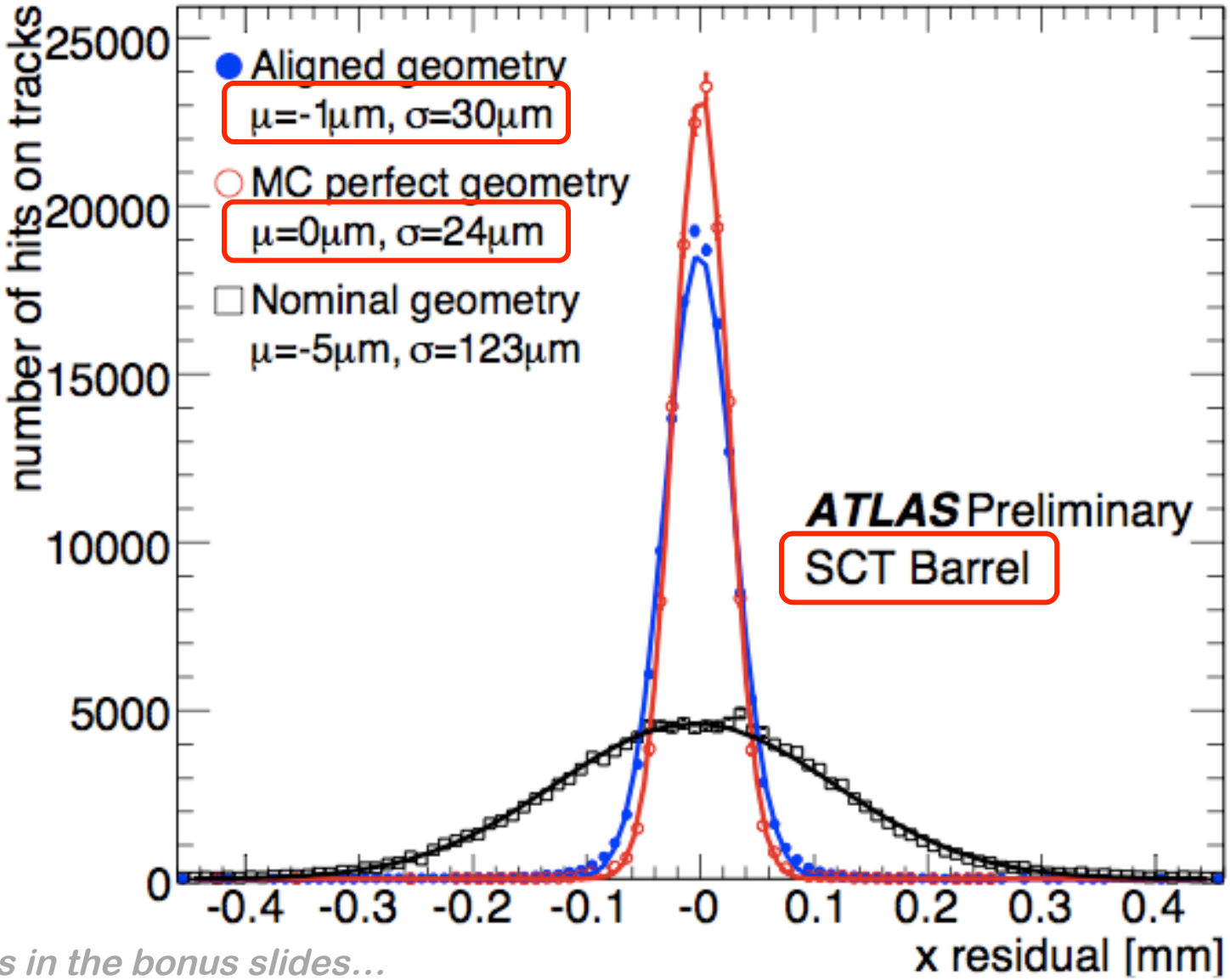
M8+ Alignment: Residuals (Pixel)



In *local* module frame

MORE plots in the bonus slides…

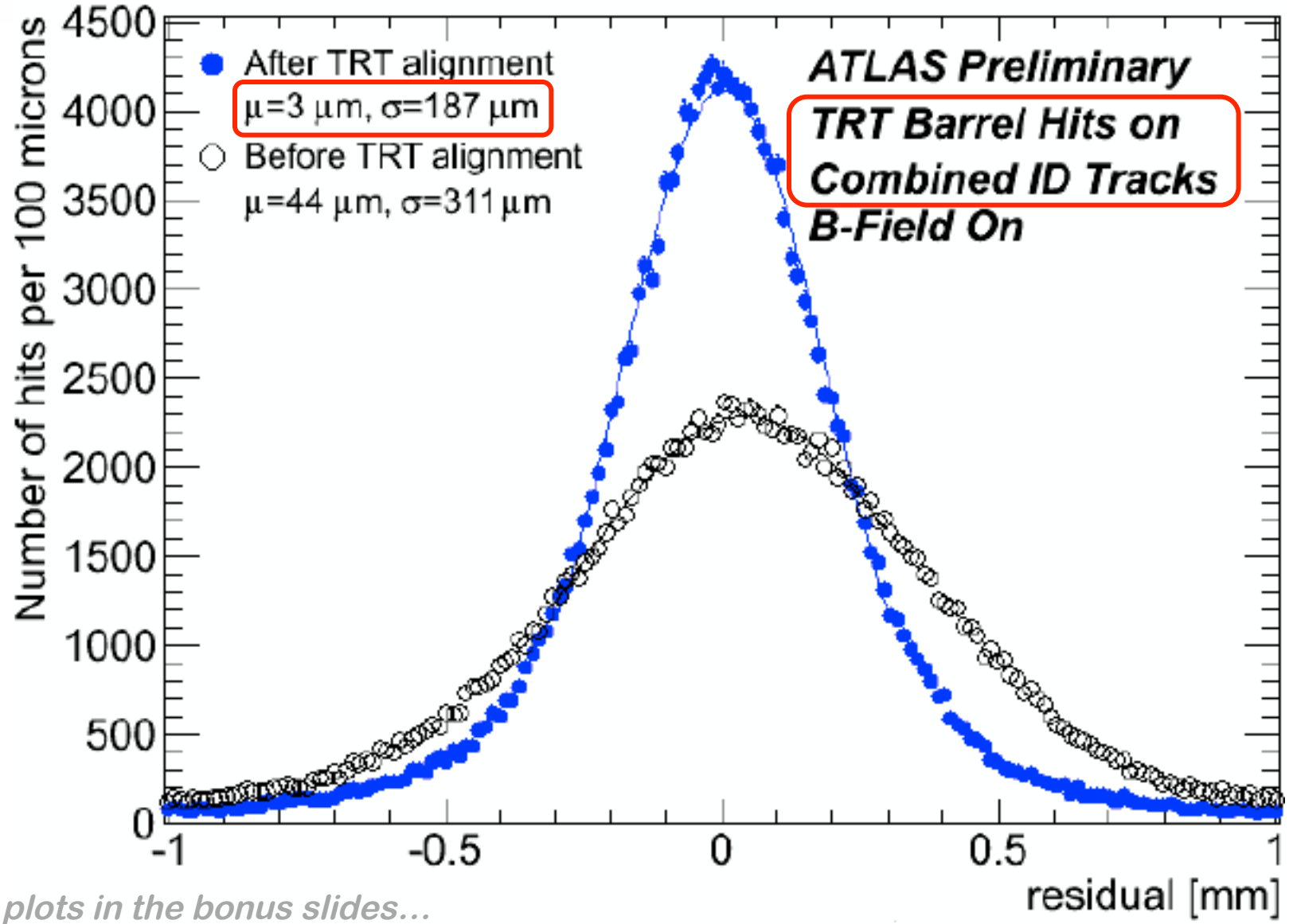
M8+ Alignment: Residuals (SCT)



In *local* module frame

MORE plots in the bonus slides…

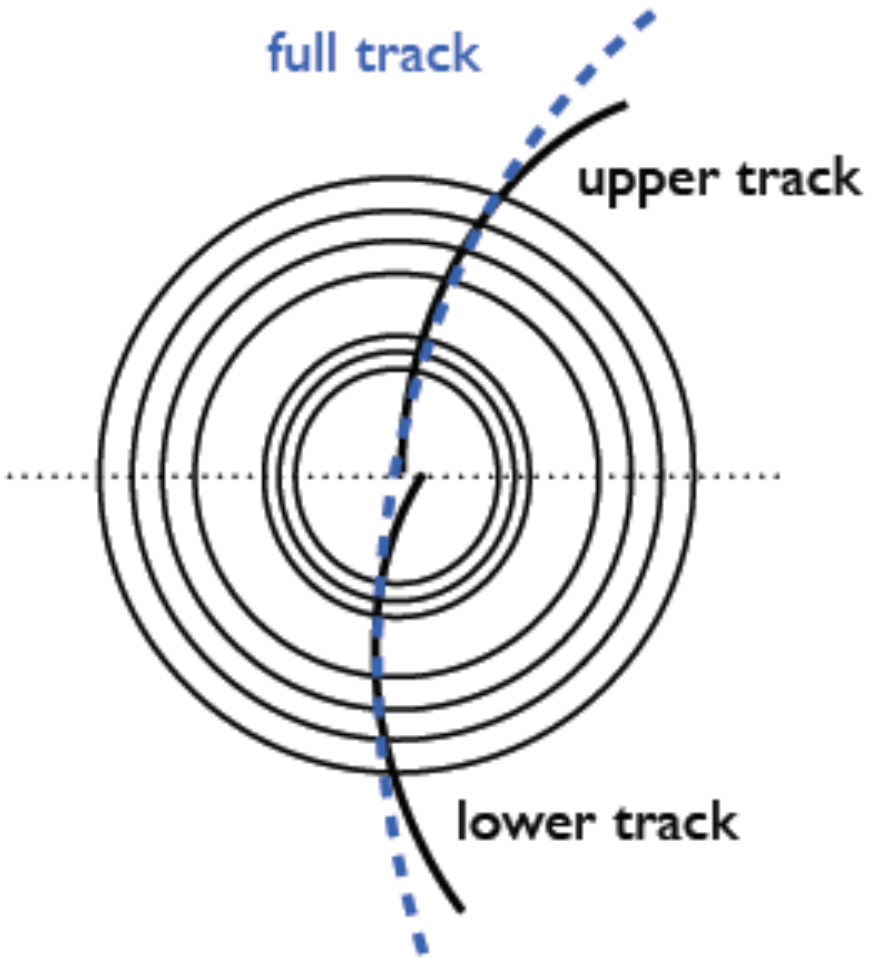
M8+ Alignment: TRT-SCT



MORE plots in the bonus slides…

Alignment with M8+ Cosmics: Results

- Established procedure to estimate uncertainty on track parameters:
  - Split track in 2 halves
  - Refit each
  - Compare track parameters:
    - d_0, z_0, ϕ, q/p, θ



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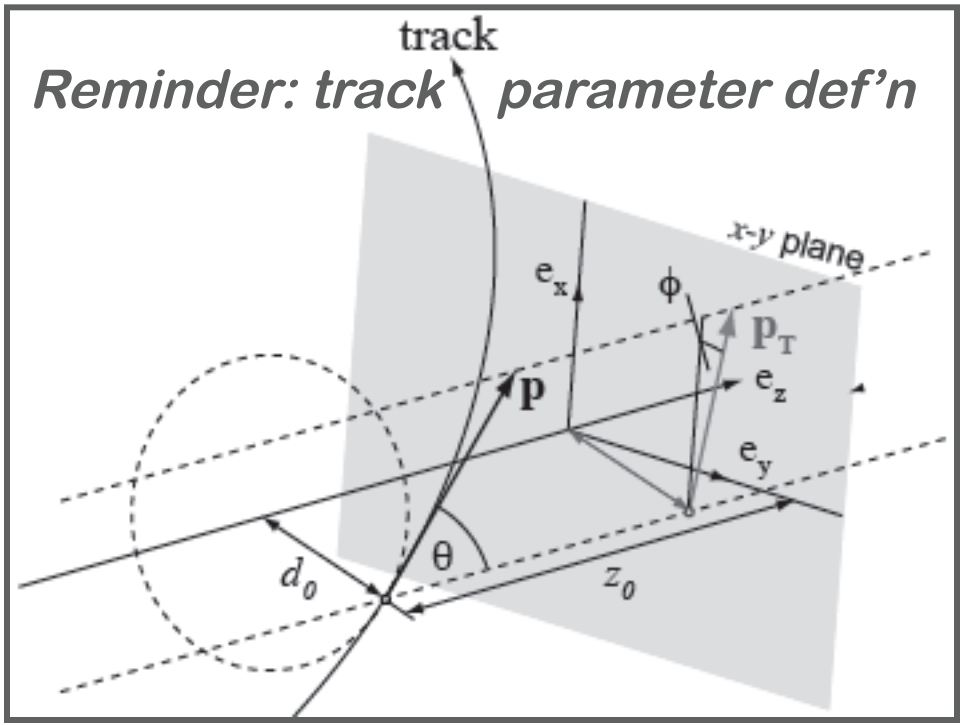
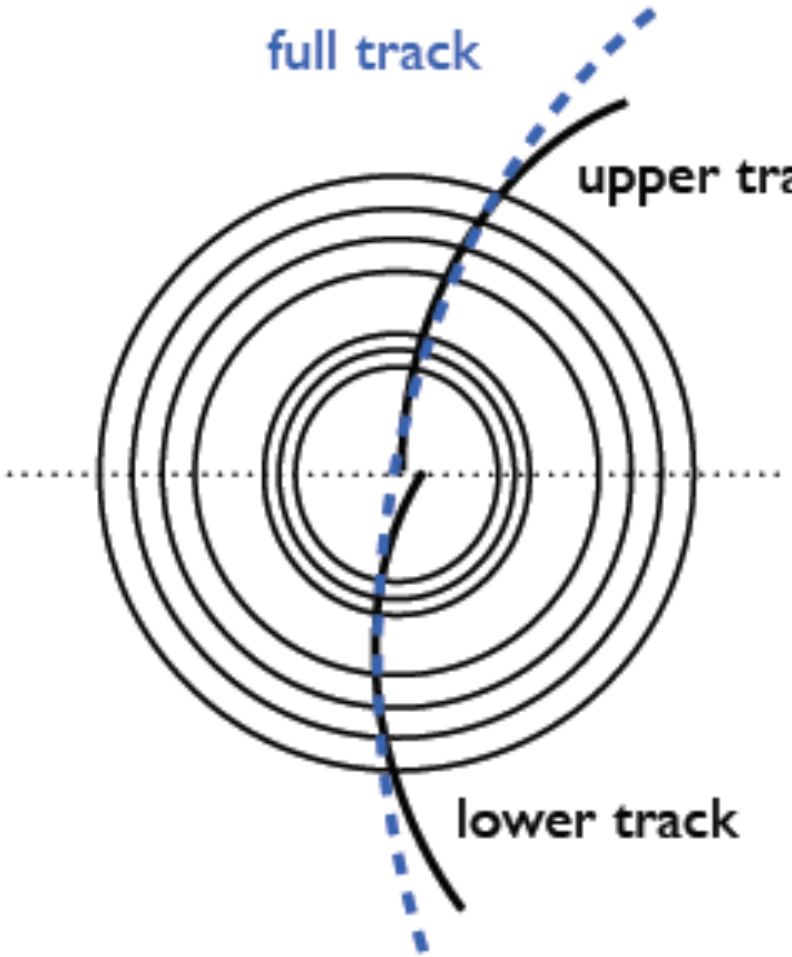
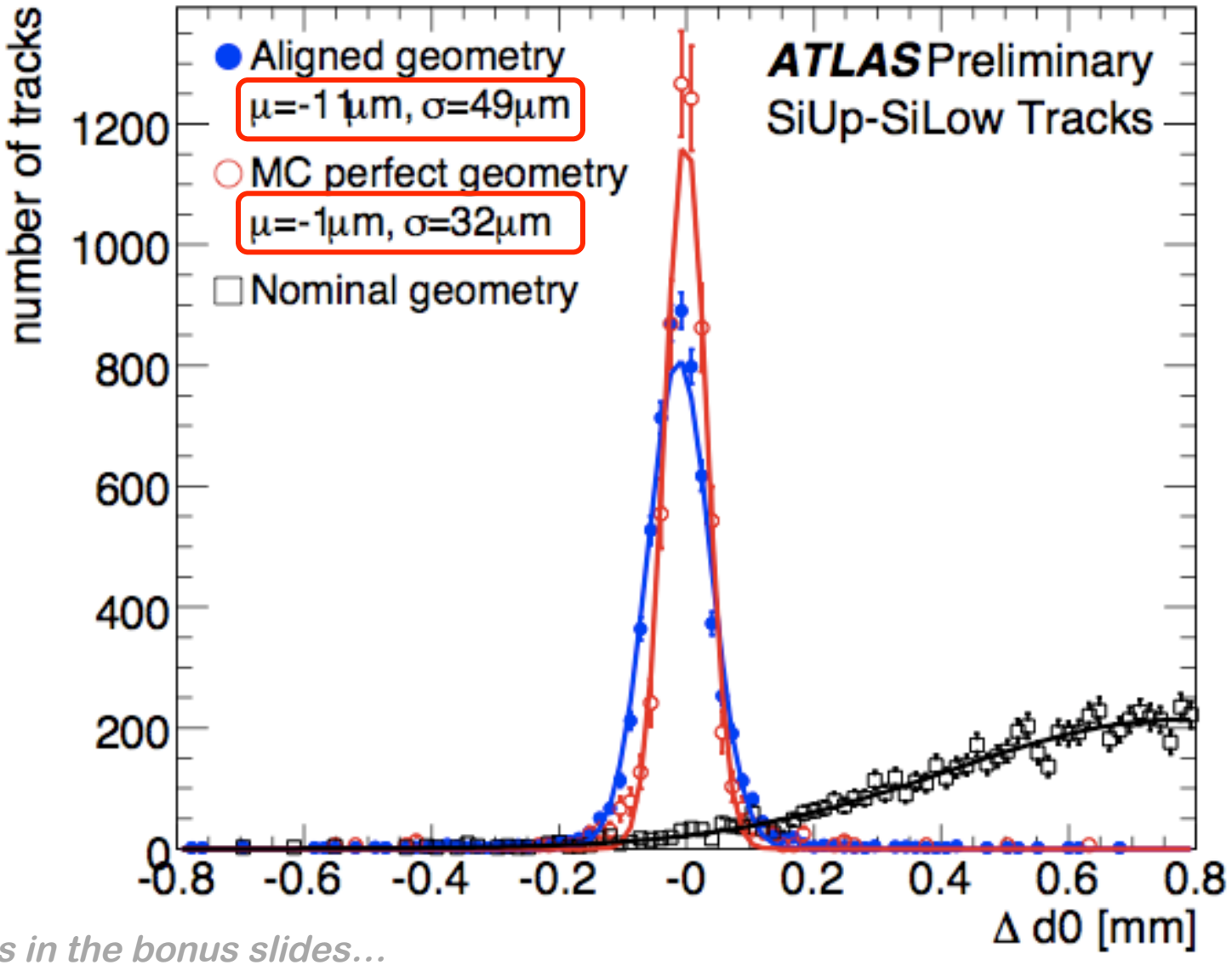


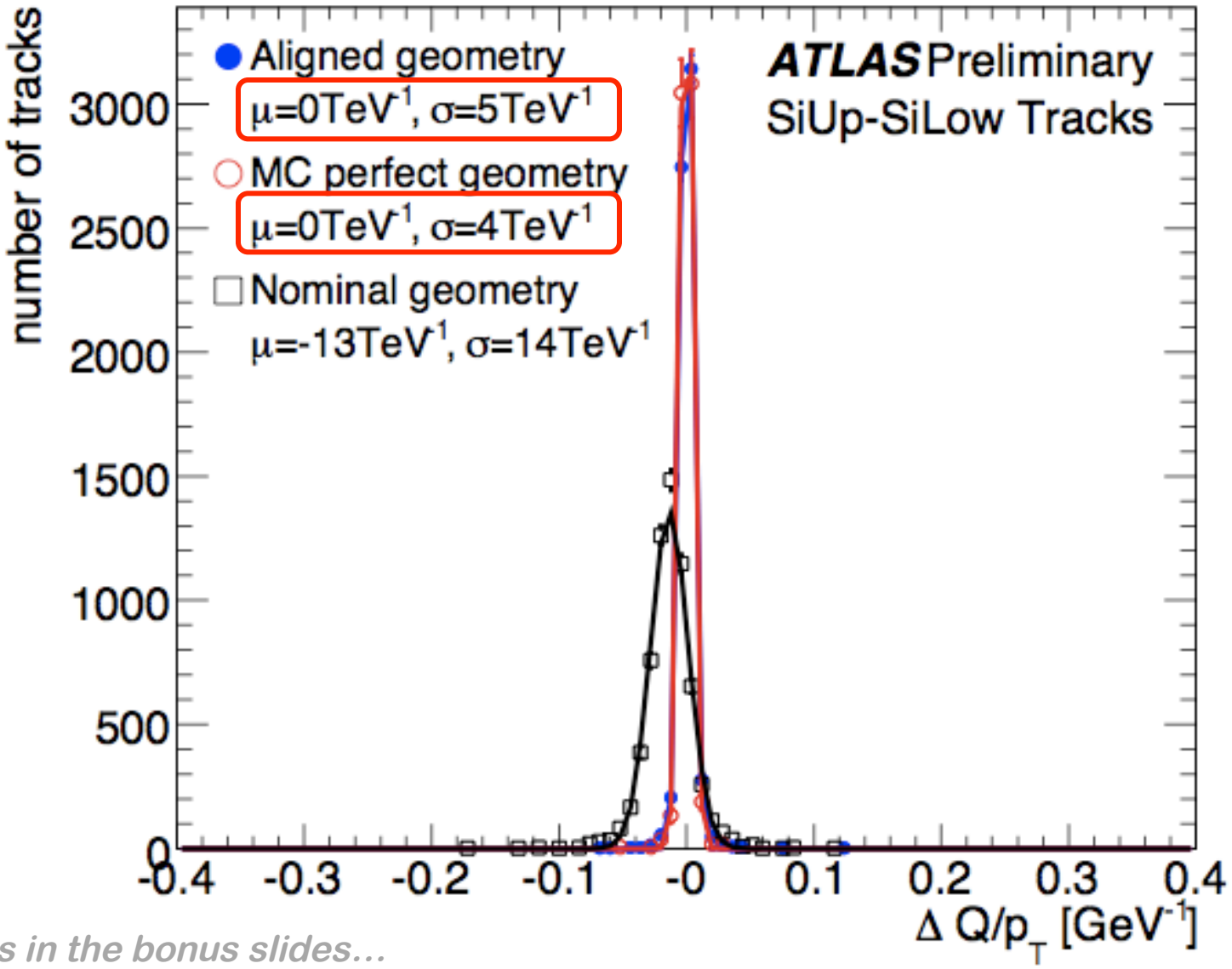


M8+ Alignment: Impact Parameter



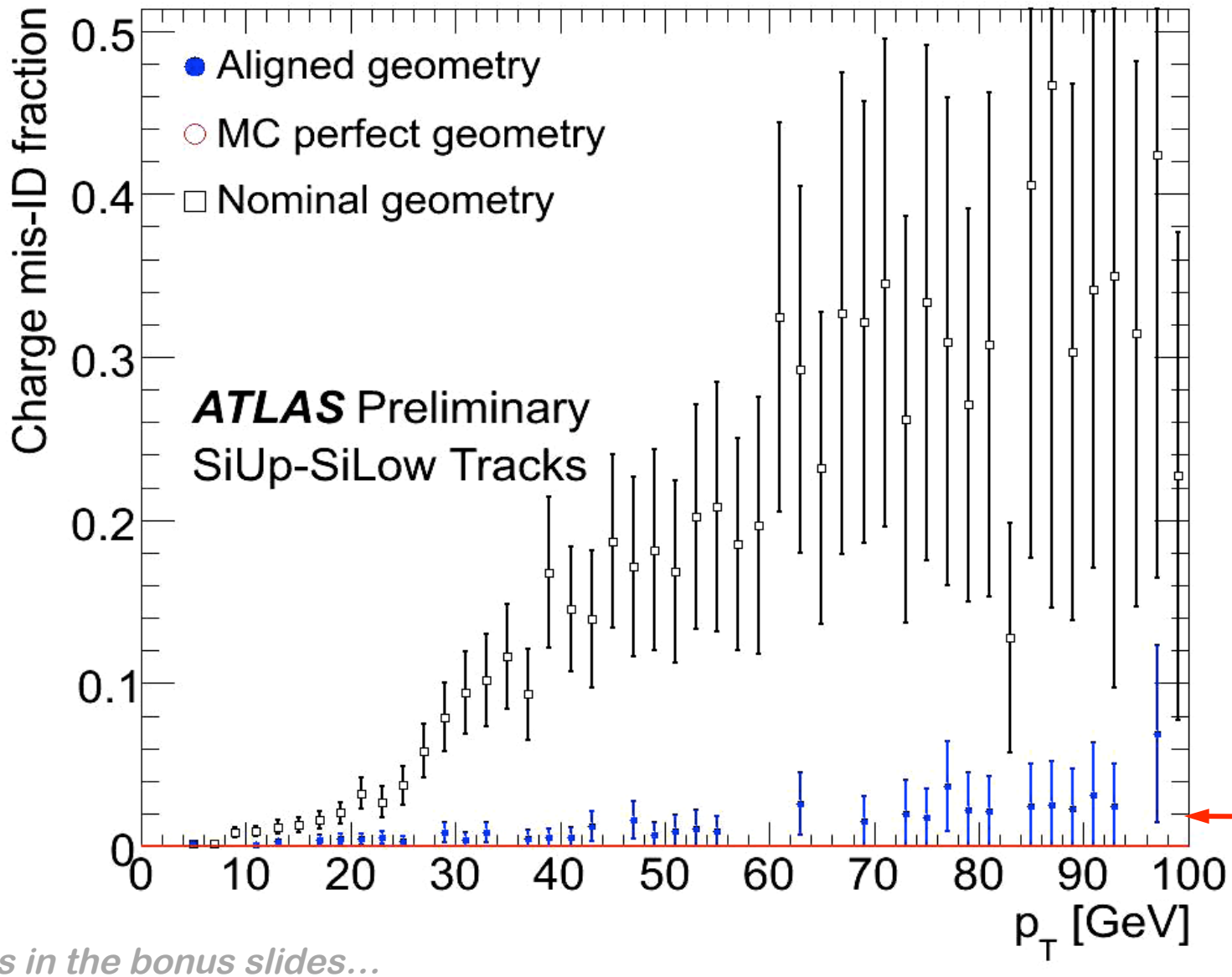
MORE plots in the bonus slides…

M8+ Alignment: q/p_T



MORE plots in the bonus slides…

M8+ Alignment: Charge mis-ID



Charge mis-ID: only ~2% @ 100 GeV!

MORE plots in the bonus slides…

ID Alignment Prospects for 2009

- **Disclaimer:**
  - **The following is what we believe to be a *possible scenario* for the ID alignment in 2009 – no guarantees implied :)**

Good News First!

- We have already quite a decent alignment set:
  - Due to M8+ cosmics!
  - What is shown above is the real performance of our detector on data!
  - Many thanks to the collaboration for collecting M8+ data!

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    - Performance not directly transferrable to collision data:
      - Stronger contribution to performance distributions:
        - well-aligned parts with much statistics!
      - Typical angle of impact different

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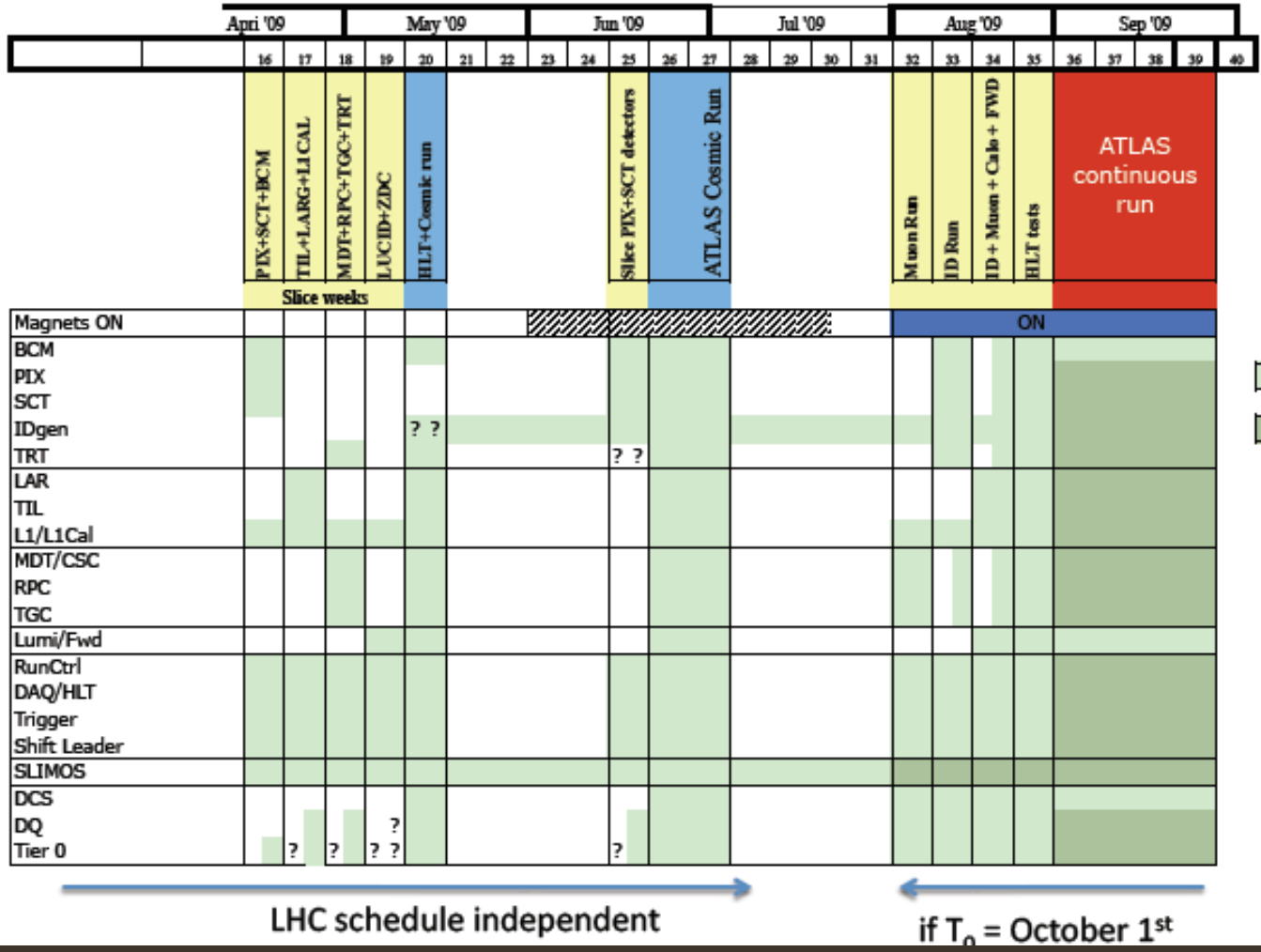
      - Typical angle of impact different
  - Excellent starting point for alignment with collision data!

Before First Beam:
Expected Alignment Performance



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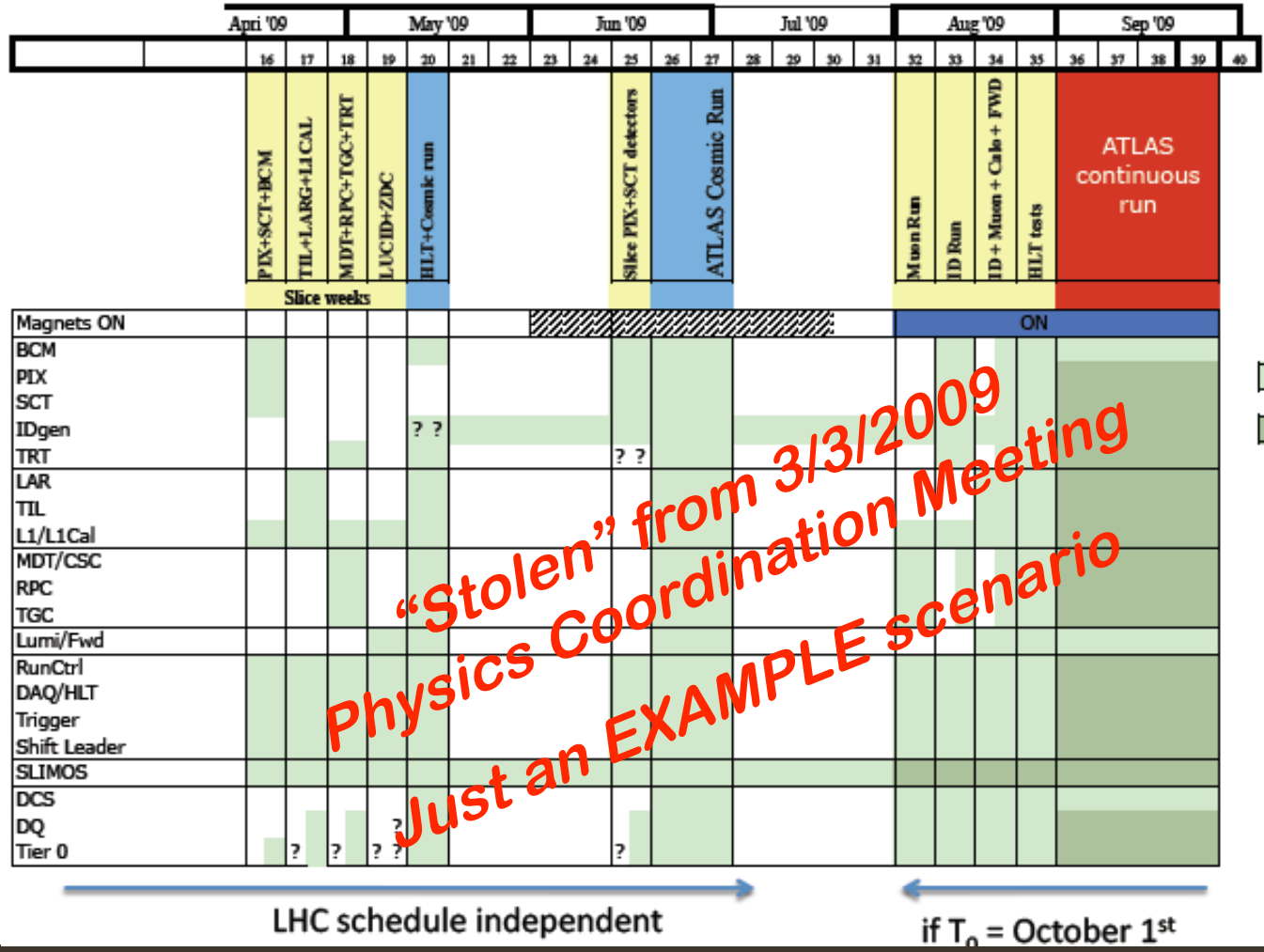
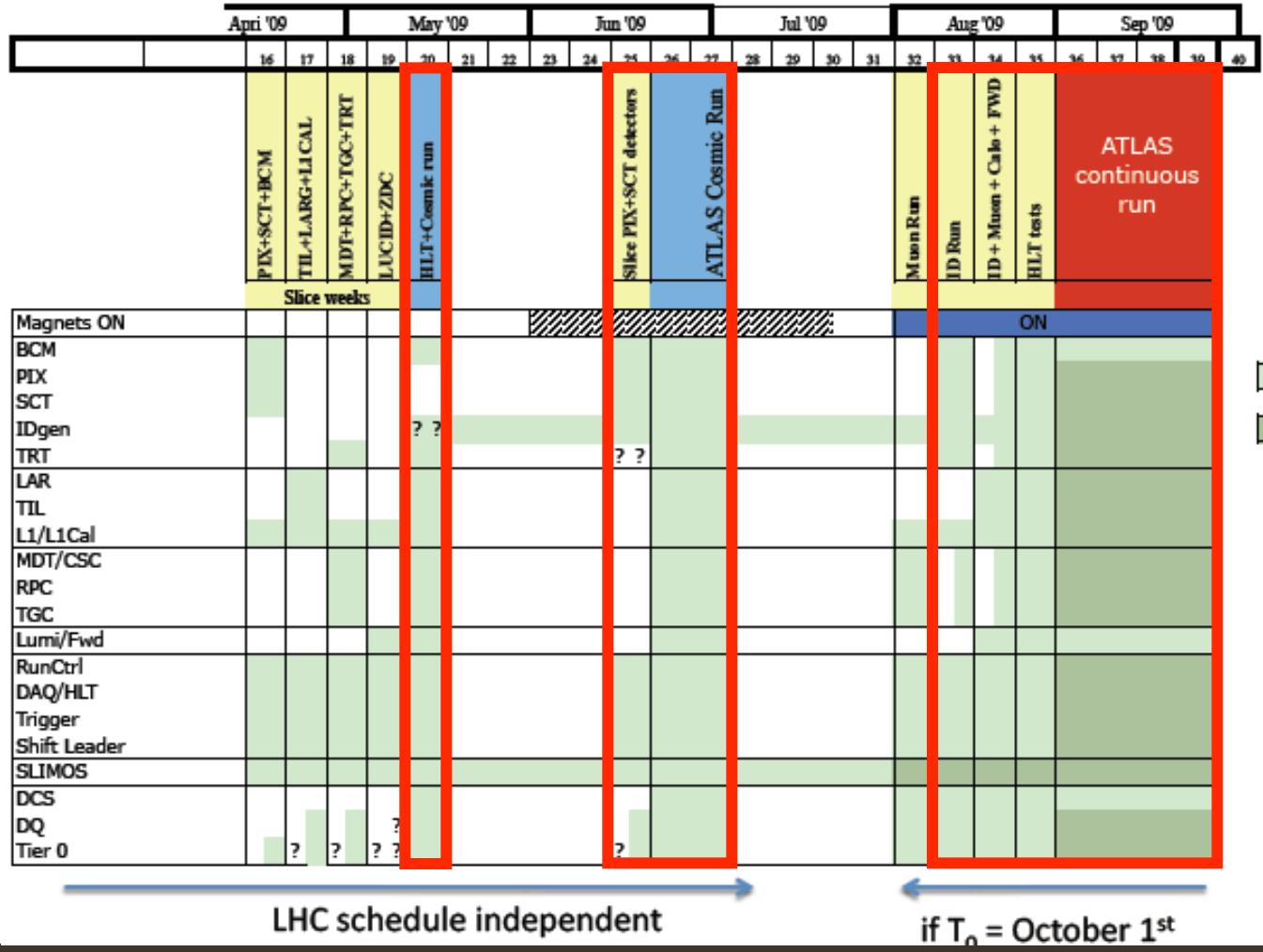


Before First Beam:
Expected Alignment Performance

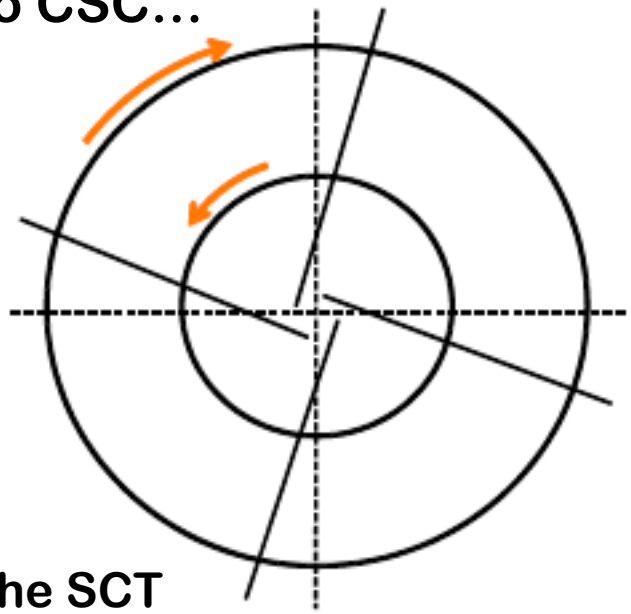
- We hope to quadruple the cosmics statistics:
  - Fast TRT-OR: ~0.25M ID tracks w/ pixel hit per week!
- So far: alignment limited by statistics…
- Expect to reduce the impact of misalignments on track param. resol'n by ~1.5
- Try understand possible biases (deplet'n depth, mechanic instability, etc.)
- Area of highly active research!



After First Beam:
Improving Alignment Performance

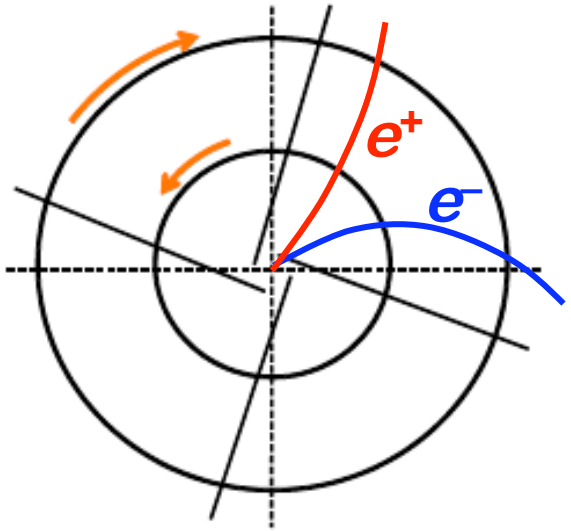
- Very soon *O*(day):
  - Reliable EC alignment (L1, L2)
- Soon *O*(week):
  - Vertical / horizontal modules: similar alignment performance
  - Decent EC alignment (L3)
- Fairly soon *O*(month):
  - Alignment of somewhat similar quality to CSC…
- Reach limit: systematics dominating:
  - Not understood detector effects:
    - e.g. depletion depth?
  - "Weak Mode" deformations:
    - Leave the χ^2 (almost) unchanged
    - Bias track parameters
    - E.g. "curl" around *Z*
    - FSI could detect their change in time in the SCT

log time



½ Year After First Beam:
Start Understanding Weak Mode Deformations

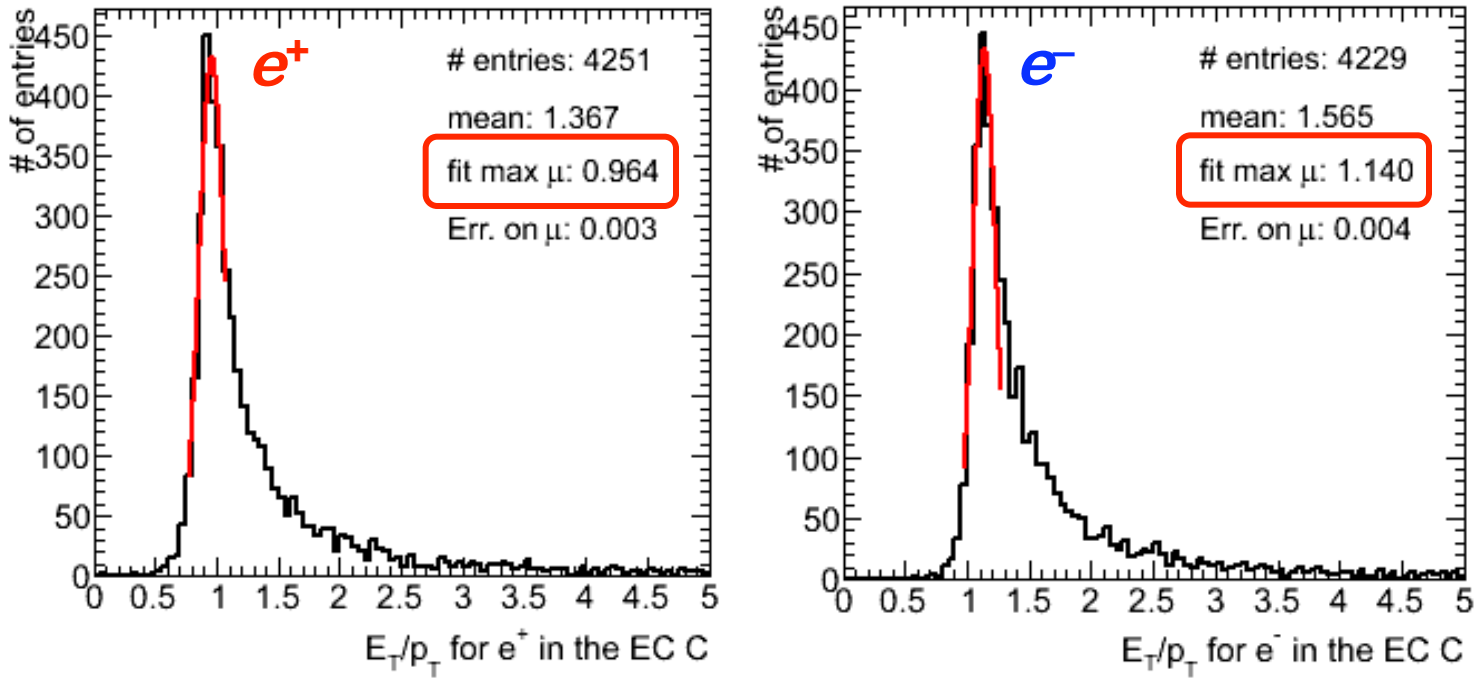
- **Example:** bias-free *q/p* measurement:
- Proof of principle: MC with "curled" geometry $\Delta\phi \sim R$:
  - Bias: $\Delta p/p \sim 13\%$ at 50 GeV since $q/p_T \rightarrow q/p_T + \delta$
- Powerful weapon:
  - **Cosmics**:
    - Traverse all of the ID!
    - Work well only in barrel :(
- End-caps:
  - use ***E/p* constraint**:
    - Ansatz:
      - calo response same(*) for e^+ and e^-
      - Curvature bias in opposite dir'n
    - Therefore:
      - $E_T/p_T = E/p \rightarrow E/p + qE_T\delta$ if



(*) besides $2m_e$ and matter-antimatter detector effects: believe well below 0.5%

½ Year After First Beam:
Weak Mode Deformations Example: E/p constraint

- Look at Z -> ee MC in end-cap C:



- To use $E_T/p_T = E/p \rightarrow E/p + qE_T\delta$:
  - $\langle E_T \rangle \sim 37$ GeV
  - $\delta \sim 0.0024$ GeV^{-1} (consistent with $\delta_{truth} = 0.002464$ GeV^{-1})
- Use δ as an external constraint on χ^2 in alignment
  - Curvature bias recovered! (consistent with 0)

2009: Expected Alignment Performance

- Based on our M8+ experience define two alignment sets:
  - Day 1:
    - InDetSi_Day1-04
    - InDetTRT_Day1-04
  - Day 100:
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    - InDetTRT_Day100-04

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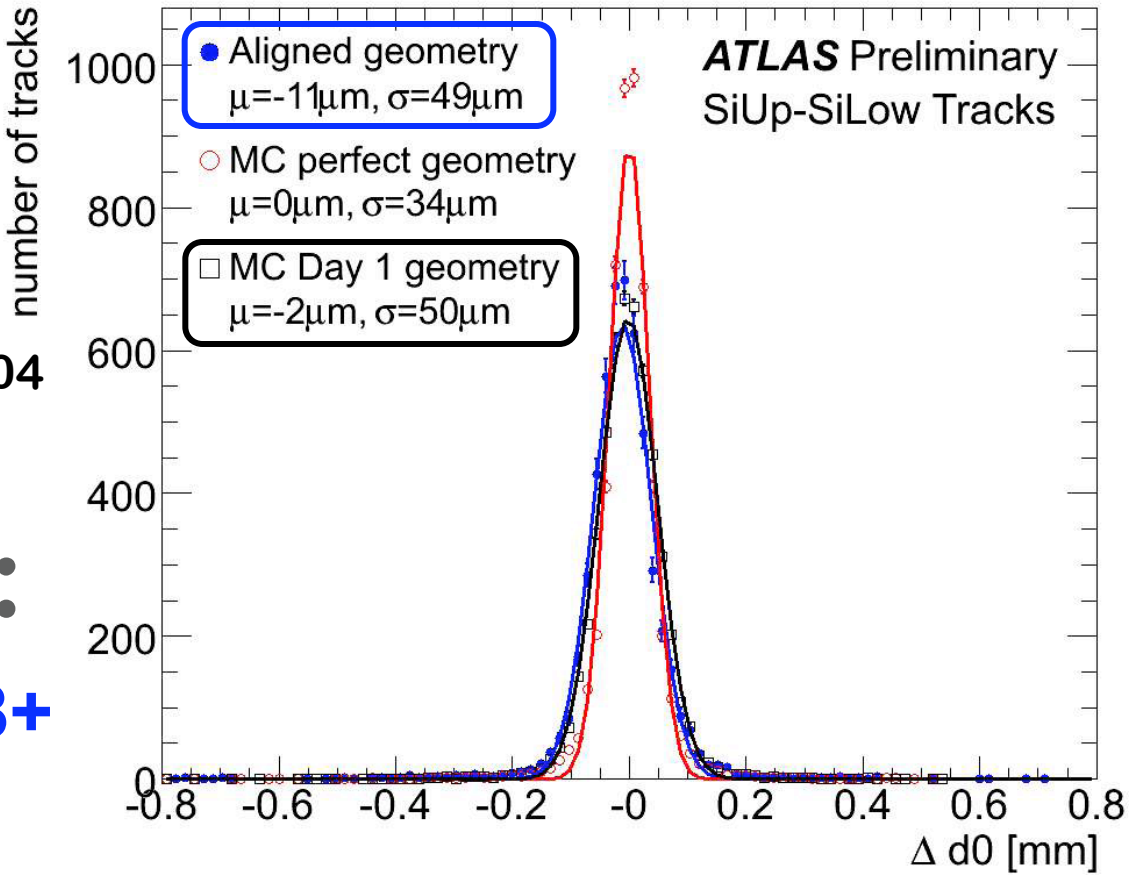

Comparison:

Performance in M8+

vs.

Day 1 Constants

2009: Expected Alignment Performance

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    - InDetTRT_Day1-04
  - Day 100:
    - InDetSi_Day100-04
    - InDetTRT_Day100-04
- More info on Day 1/100 tags:
  - https://twiki.cern.ch/twiki/bin/view/Atlas/InDetAlignmentDataBaseTags
- More validation plots (also for day 100):
  - http://indico.cern.ch/getFile.py/access?contribId=8&resId=0&materialId=slides&confId=55889
- See talk by Sebastian Fleischmann

Summary

- ATLAS Inner Detector alignment progressing well:
  - Serious-size cosmics dataset taken in autumn 2008
  - First constants produced in no-time!
  - Since then constant alignment improvement
    - A lot of reco software improvements, too!
  - Validation plots look good!
    - (see backup slides for more plots)
  - Still some riddles to solve with alignment
    - Many sorted out already!
    - The rest is well addressed!
  - Many ID-related studies underway
    - See Trevor Vickey's talk…
  - Produced misalignment sets:
    - For "day 1"
    - For "day 100"
    - See Sebastian Fleischmann's talk for the tau use case!

Outlook

- Alignment prospects for 2009+ look great!
  - Good first-pass alignment already there!
  - Hope to quadruple cosmics statistics
    - So far clearly statistics-limited
  - Even better alignment once beam is there:
    - Especially in the ECs!
  - Soon after first beam:
    - Tackle systematics!

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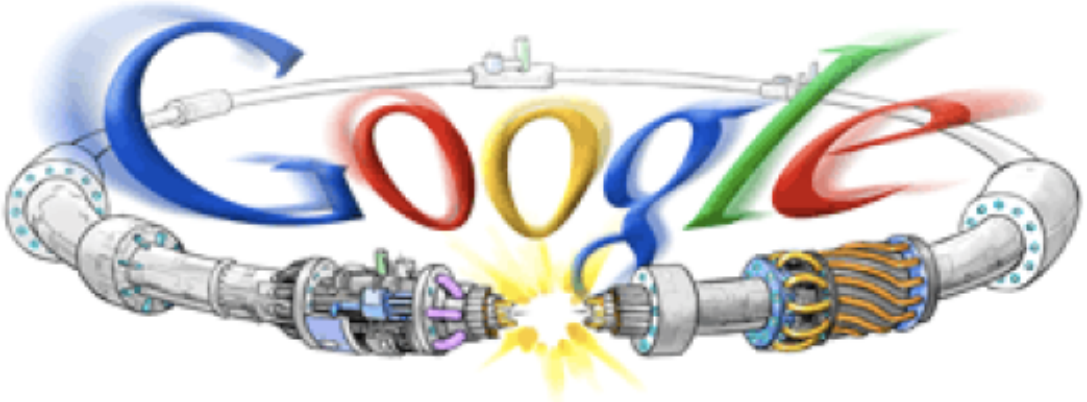

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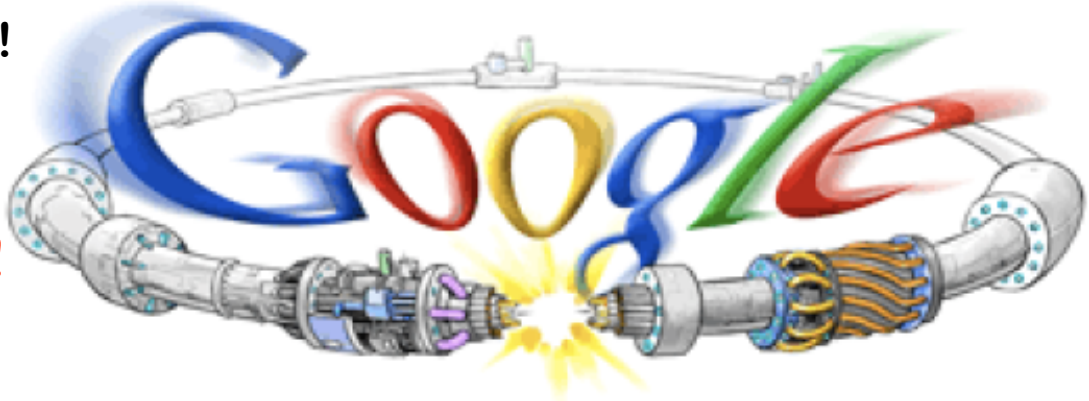


- ATLAS note on ID alignment with M8+ cosmics:
  - In preparation!
- Upcoming:
  - LHC Alignment Workshop (14-15 June 2009)
    - http://indico.cern.ch/conferenceDisplay.py?confId=50502

Bonus

M8+ Results: ID-related

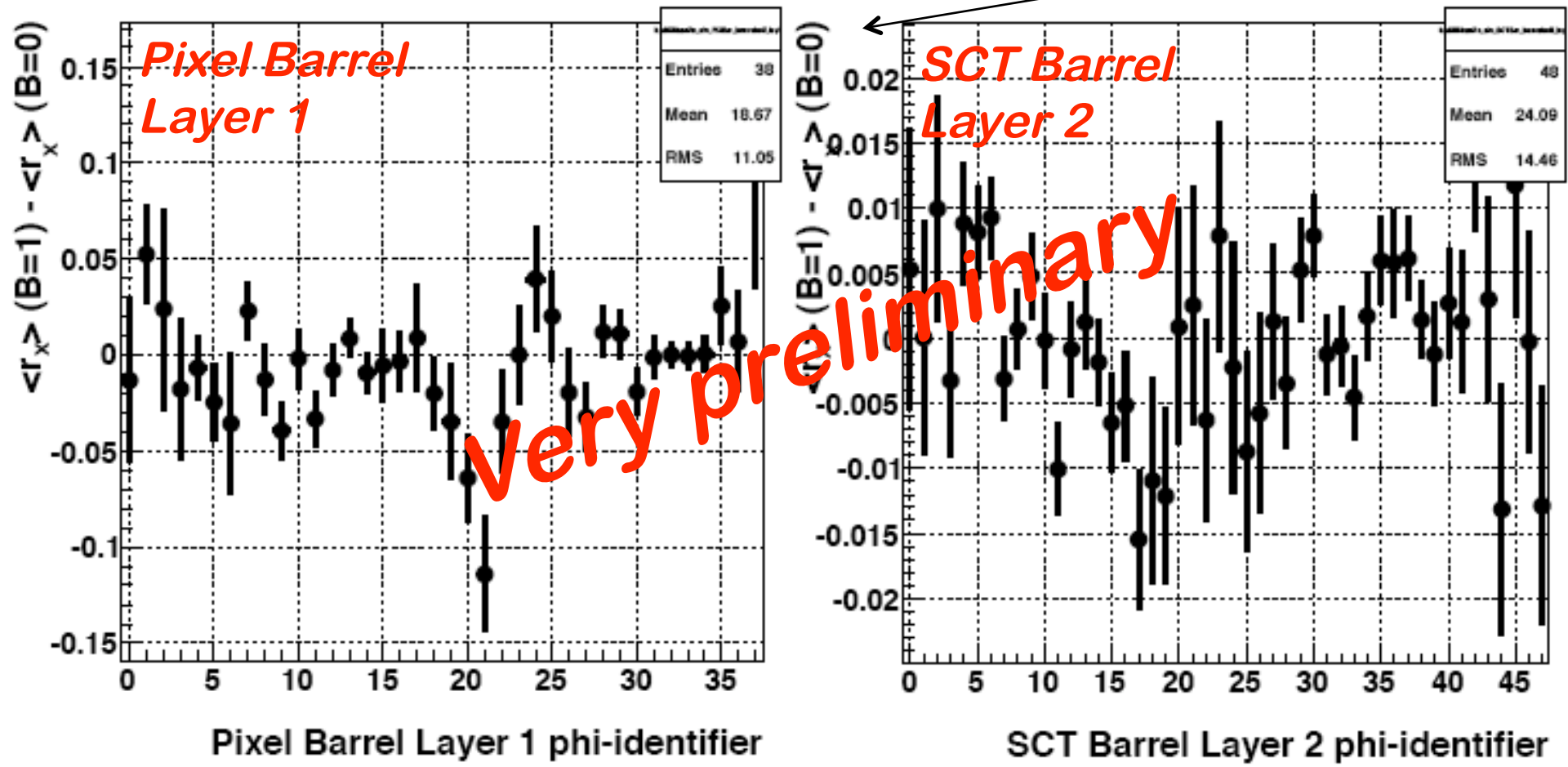
(Un-)resolved Alignment Riddles

- References:
  - ID Alignment EVO Meetings:
    - http://indico.cern.ch/categoryDisplay.py?categId=3l116
  - ID Cosmic data analyses:
    - http://indico.cern.ch/categoryDisplay.py?categId=3l43

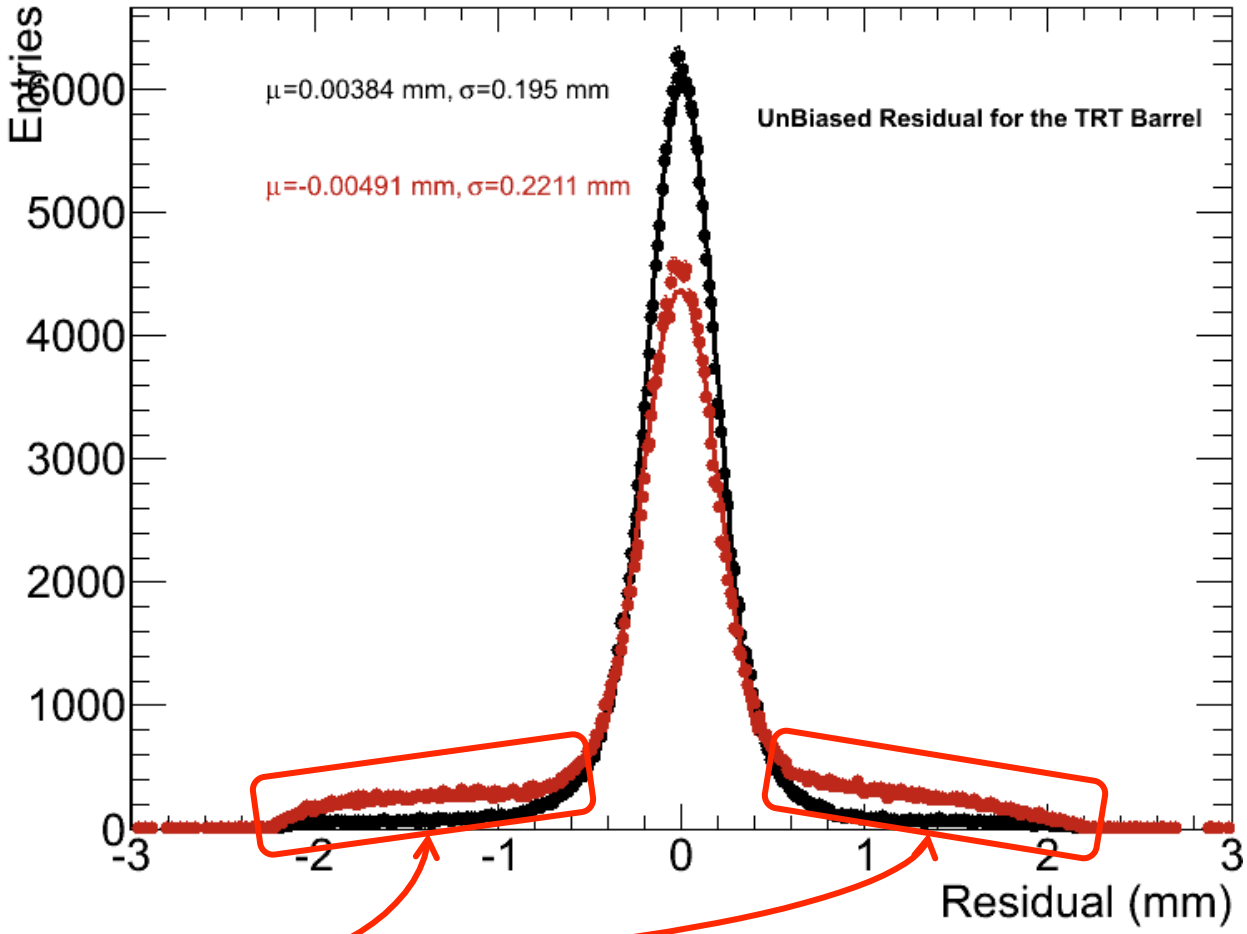
Riddle: B=0 vs. B=1 Discrepancy

- Alignment procedure using *B*-field ON and OFF tracks:
  - $\langle r_x \rangle$(*B*-field ON) – $\langle r_x \rangle$(*B*-field OFF) ~ 5 μm (only!) in pixels
  - Manifestation of detector movement?

Scale 5x smaller



Riddle: TRT-only vs. TRT+Si Track Resolution



- **Understood**:
  - tails from L/R mis-assignments from Si prediction
  - Fixed in 14.5.2!

Riddle: Correlation in Up-Down Biases

- Look at track parameter biases
  - Observe correlation:
    - Δd_0 and global Z
    - $\Delta q/p$ and global Z

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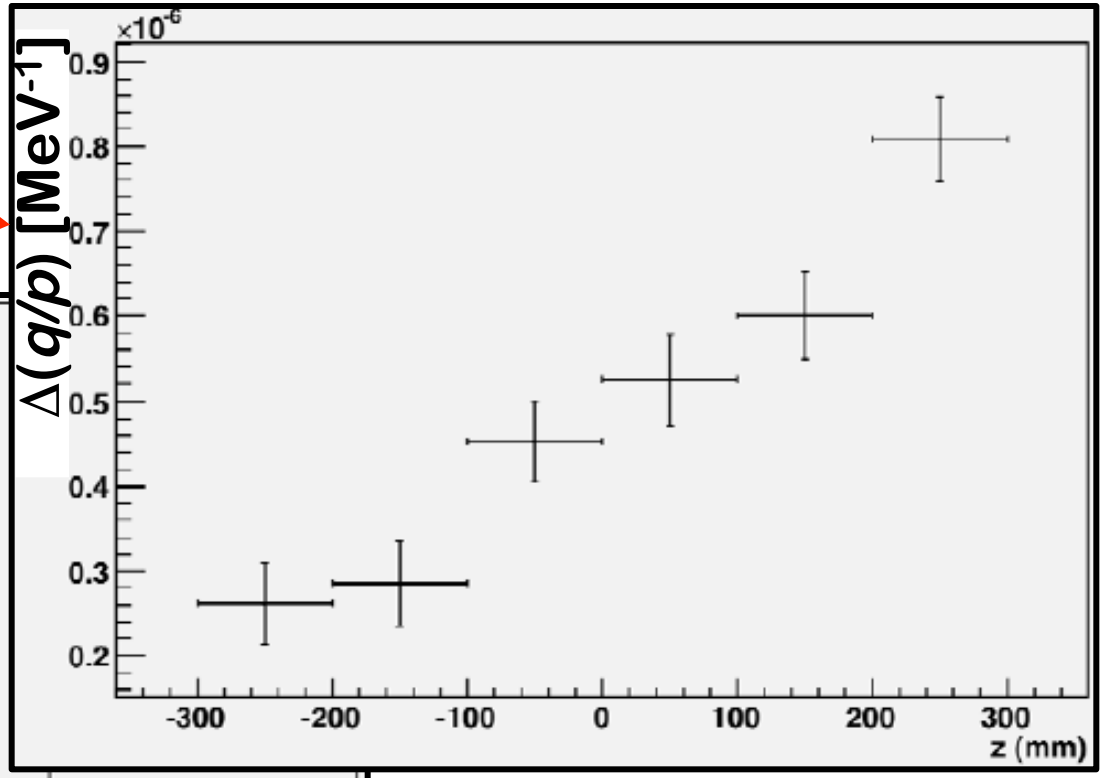
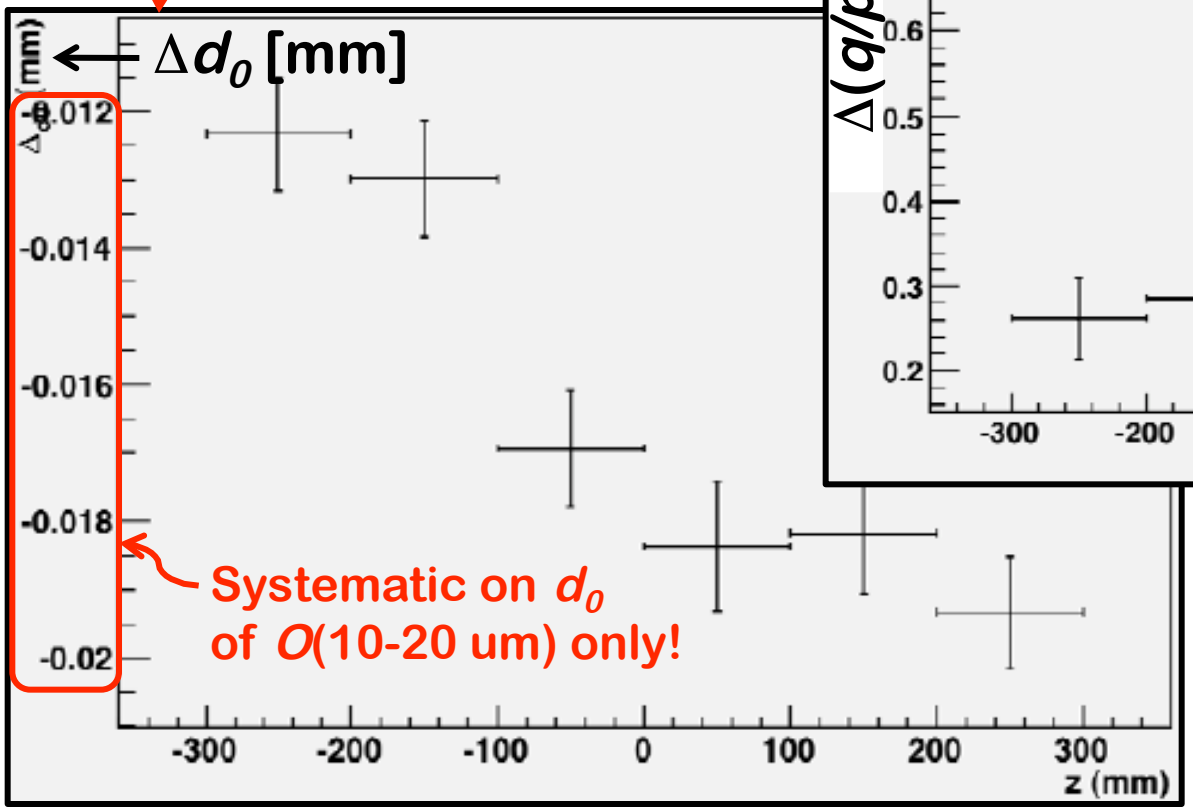


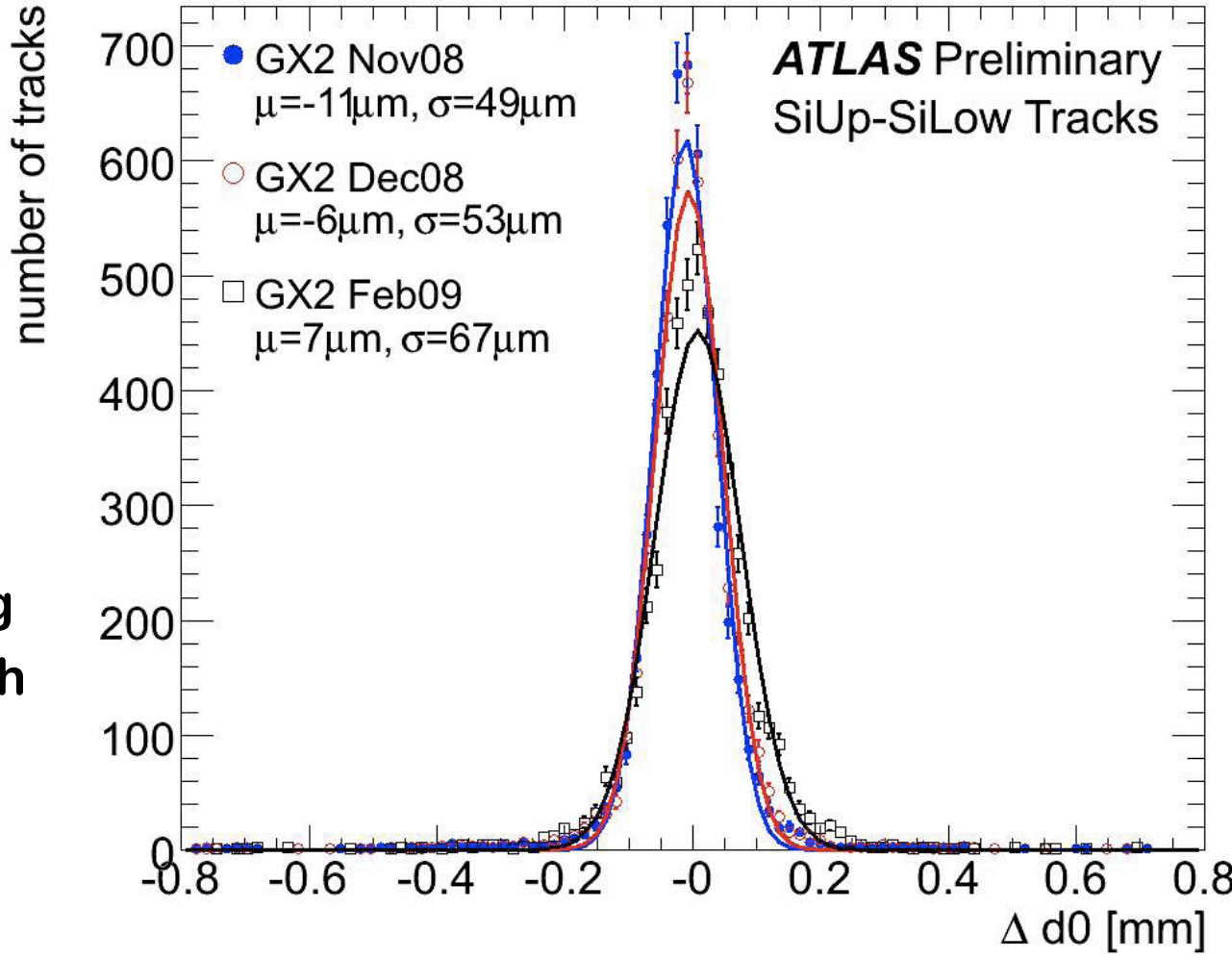


Systematic on d_0 of O(10-20 um) only!

Twist-like deformation?

Riddle: Alignment Constants in Different Releases

- Statistically significant difference in alignment constants between:
  - Nov. 08
  - Dec. 08
  - Feb. 09
- Maybe due to constant improvement of reconstruction software:
  - Pixel clustering
  - Depletion depth
  - High voltage
- Investigations ongoing!

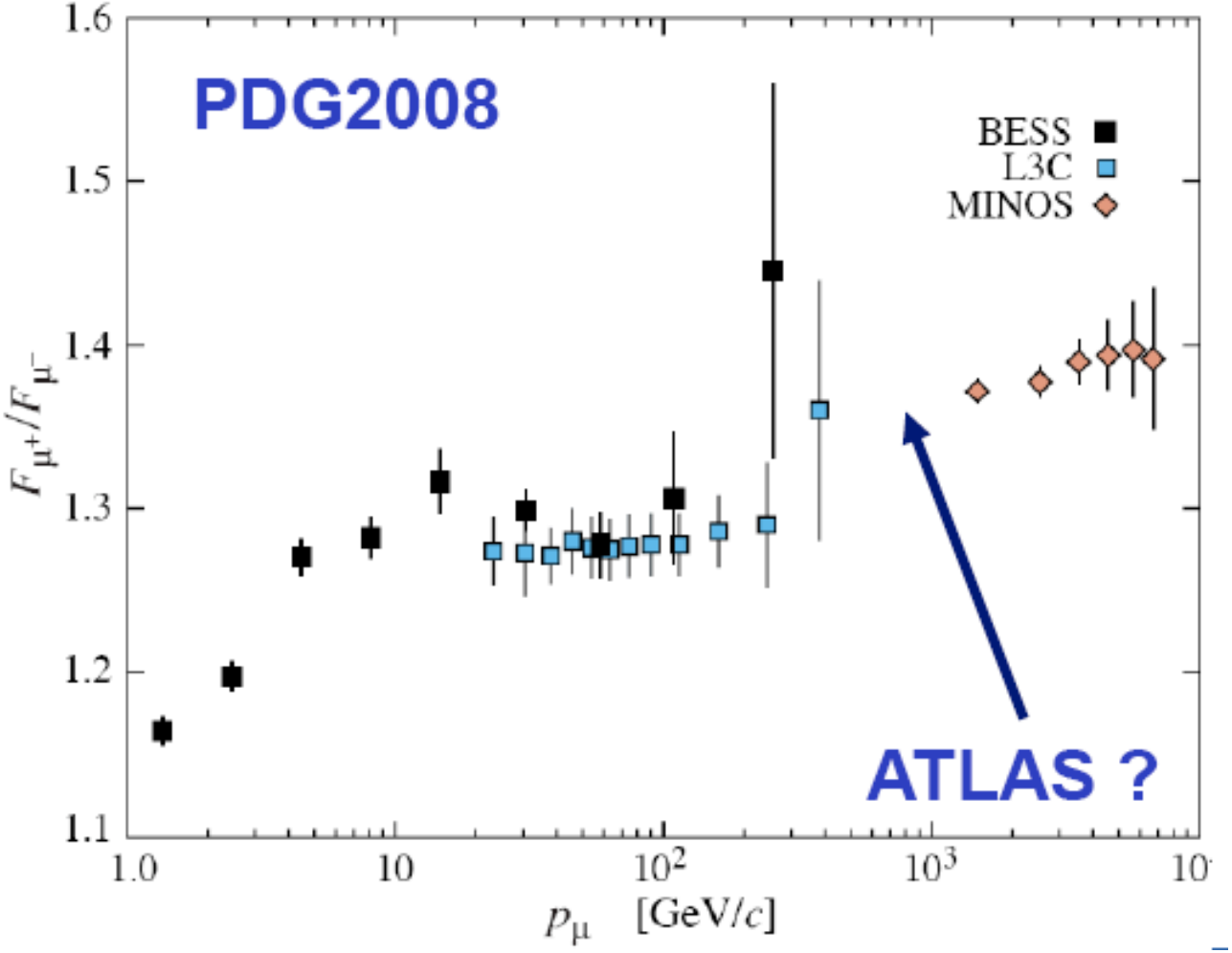


M8+ Results: ID-related

- References:
  - https://twiki.cern.ch/twiki/bin/view/Atlas/ApprovedPlotsID
  - https://twiki.cern.ch/twiki/bin/view/Atlas/ApprovedPlotsTRT
  - μ^+/μ^- ratio: day 3 of jamboree (LBNL) (+ other sources):
    - http://indico.cern.ch/conferenceDisplay.py?confId=52750

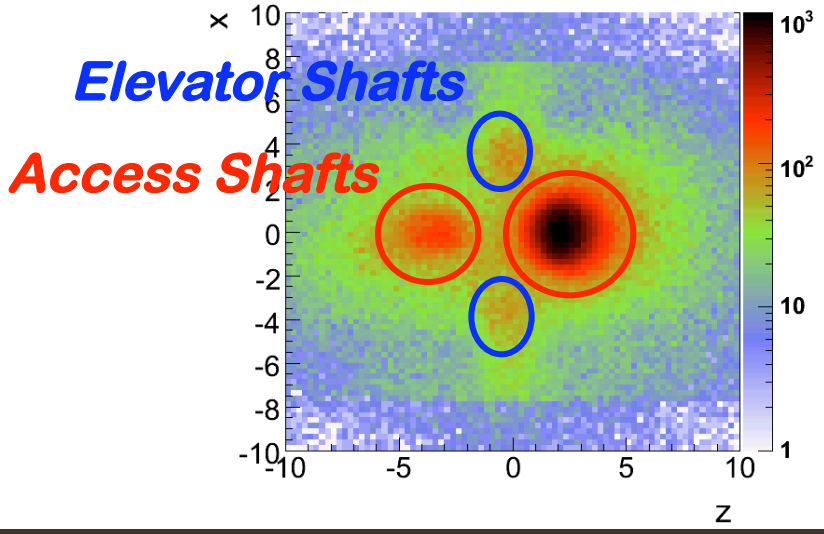
μ^+/μ^- Charge Ratio Measurement: PDG

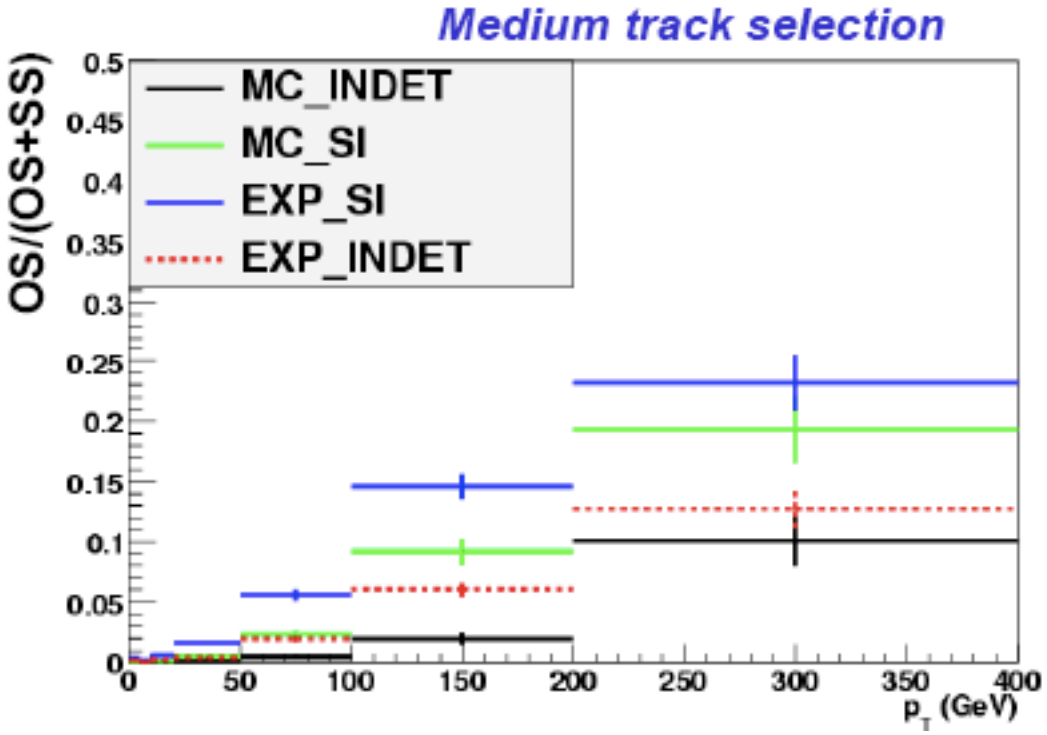
- Could well be the first ATLAS publication:
  - Aim for the PDG!



μ^+/μ^- Charge Ratio: Questions to Address

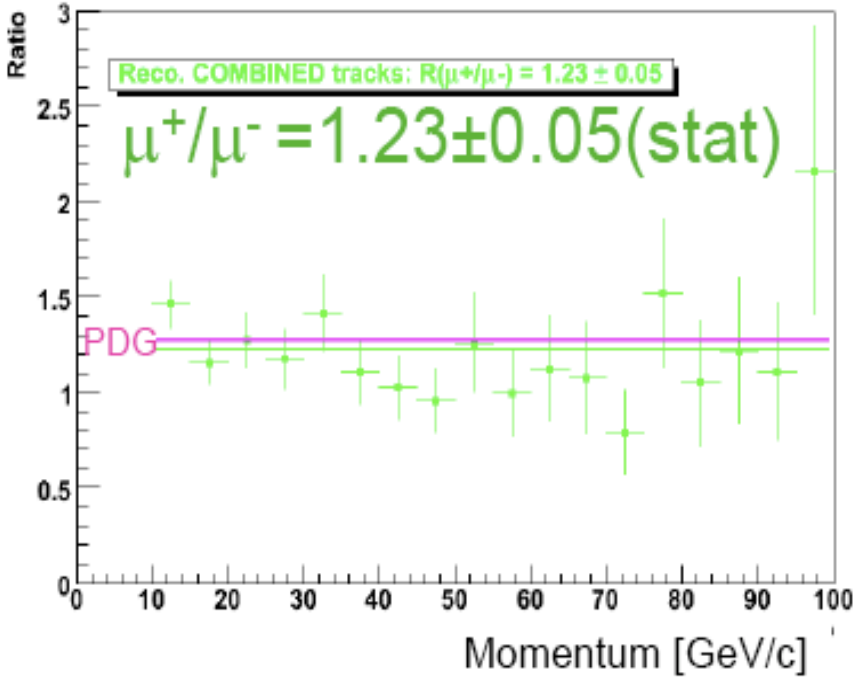
- Understand important issues along the way:
  - Energy loss versus trajectory
  - Acceptance & Efficiency
    - trajectory, trigger, detector, Selection
  - Resolution of track parameters
    - Charge mis-identification
    - p_T bin migration
    - Acceptance edge effects



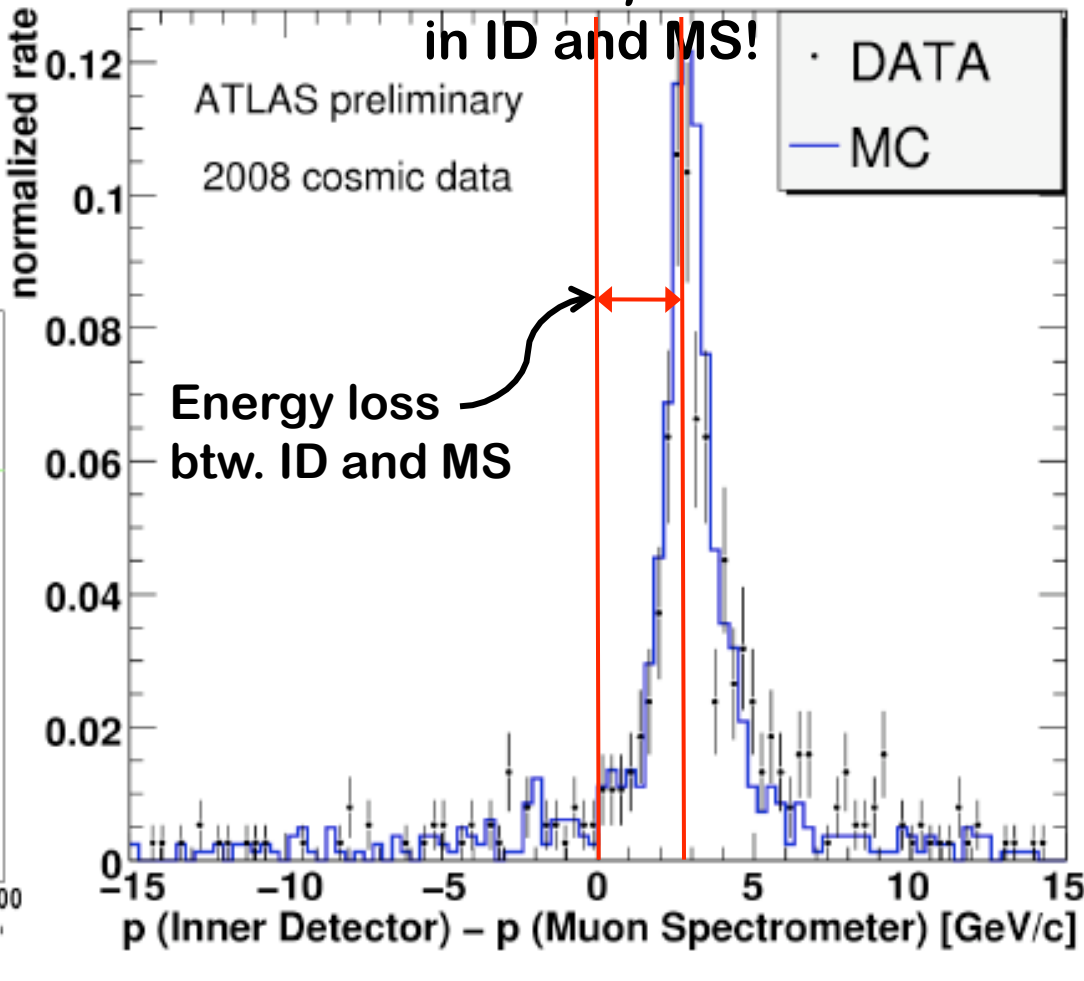


μ^+/μ^- Charge Ratio: Questions to Address

- Just an appetizer:
  - Aim for PDG-class publication!
  - Many more interesting plots to look at and systematics to understand !

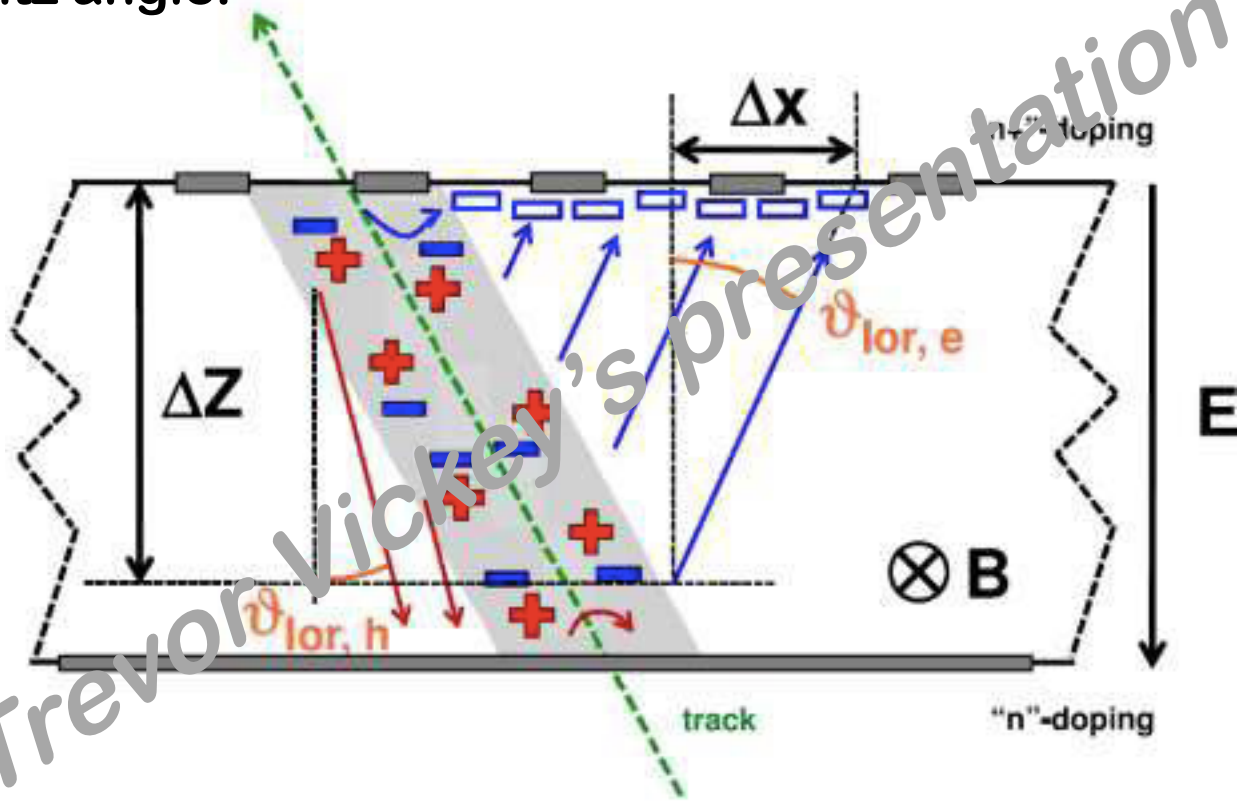


Understand *p* meas'nt in ID and MS!



Lorentz Angle

- One of the first things looked at:
  - Lorentz angle:

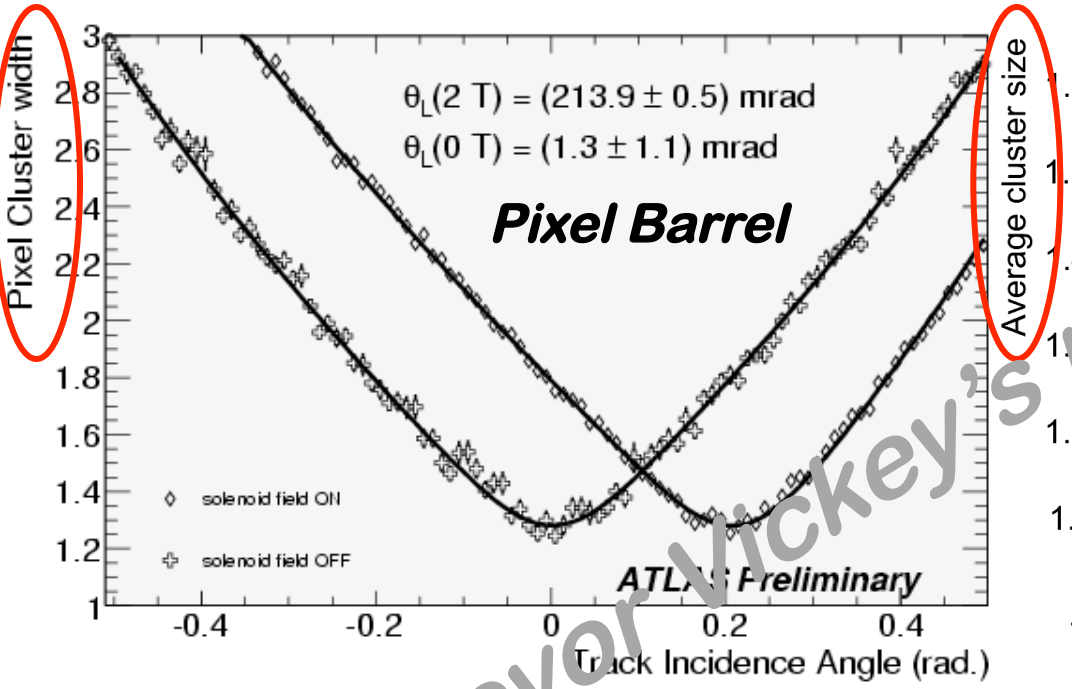


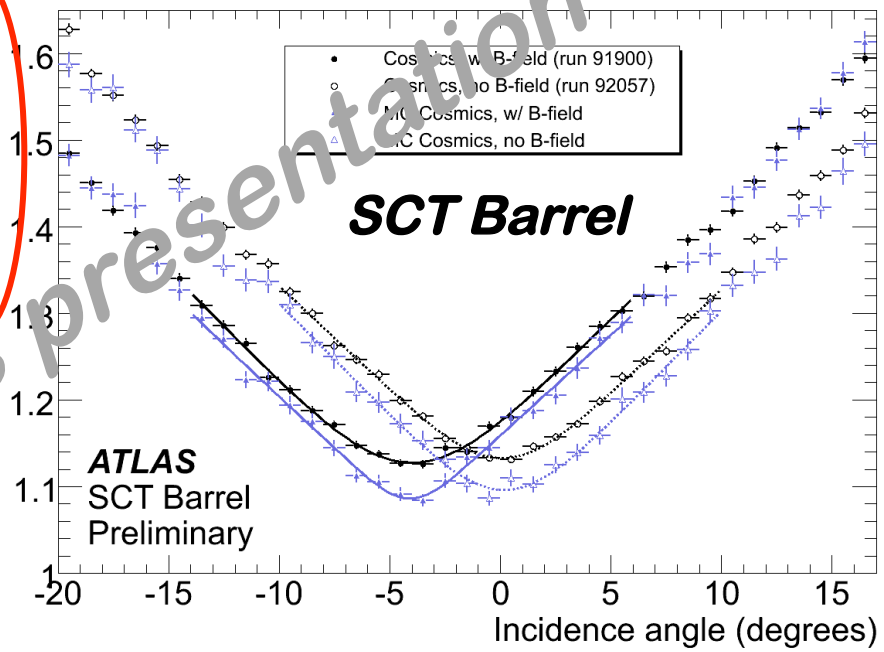
In Trevor Vickey's presentation

    - Understanding crucial for alignment!
      - Depletion depth also important for B=1!
  - Folding our ignorance of Lorentz angle into alignment?

Lorentz Angle in M8+

- Can be determined from average cluster size:



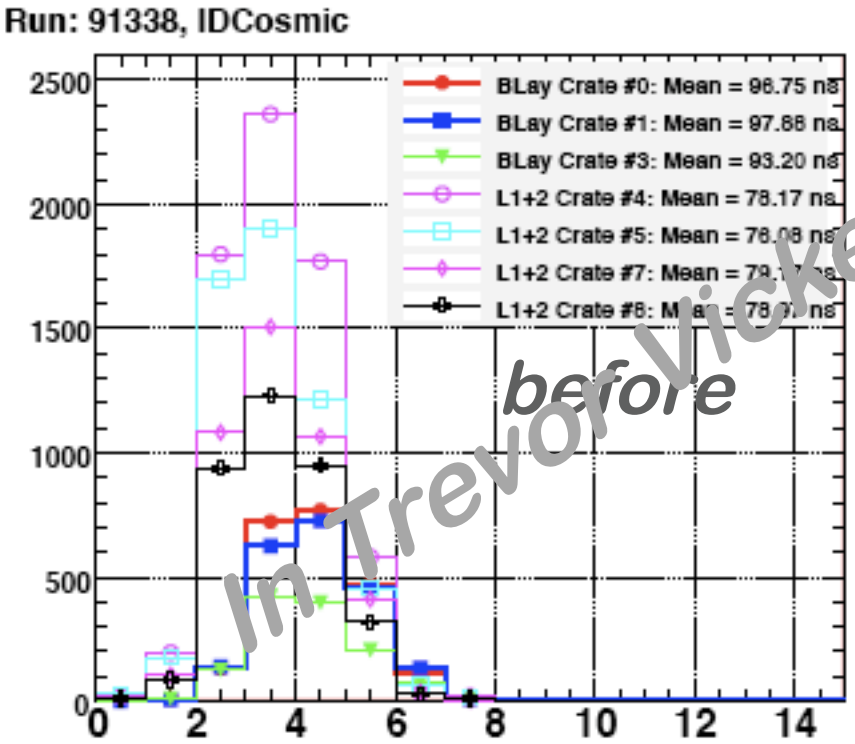


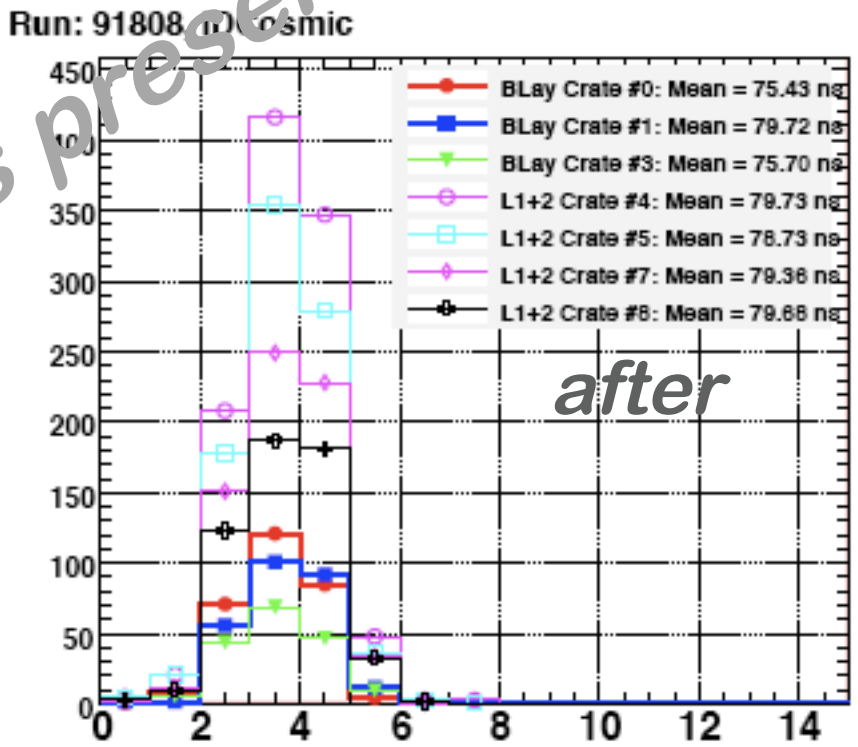
In Trevor Vickey's presentation

- Consistent with expectations for non-irradiated detector!

Pixel Timing Studies

- Very important to get right:
  - Proper calibration -> proper ToT measurement
    - Higher precision in clustering
    - Better vertexing!





In Trevor Vickey's presentation

Backup

Alignment Algorithms at ATLAS

- There are 3 Si and 1 TRT alignment algorithms:
  - Global χ^2:
    - Minimise $\chi^2 \equiv \sum_{\text{tracks}} r^T V^{-1} r$
    - w/r/t alignment parameters:

$$\delta a = -\left(\sum_{\text{tracks}} \frac{dr^T}{da} V^{-1} \frac{dr}{da}\right)^{-1} \sum_{\text{tracks}} \frac{dr^T}{da} V^{-1} r\,, \quad \text{with} \quad \frac{dr}{da} = \frac{\partial r}{\partial a} + \frac{\partial r}{\partial \pi}\frac{d\pi}{da}$$

  - Local χ^2:
    - Similar to Global χ^2, but with

$$\frac{dr}{da} = \frac{\partial r}{\partial a}$$

    - Matrix V^{-1} in block-diagonal form, easy soluble, more iter's
  - Robust Alignment:
    - Based on centering residual and overlap residual distributions
  - TRT Alignment:
    - Similar to the Global χ^2 algorithm
- References: proceedings of talks in:
  - https://twiki.cern.ch/twiki/bin/view/Atlas/AtlasIDAlignPresentations

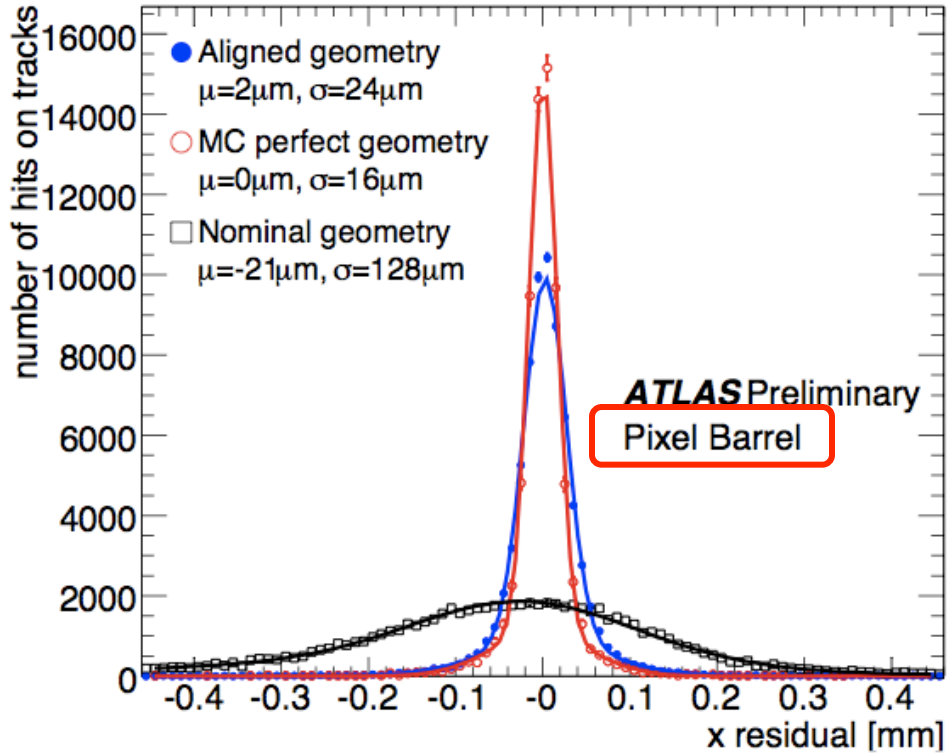
Alignment Levels for Si and TRT

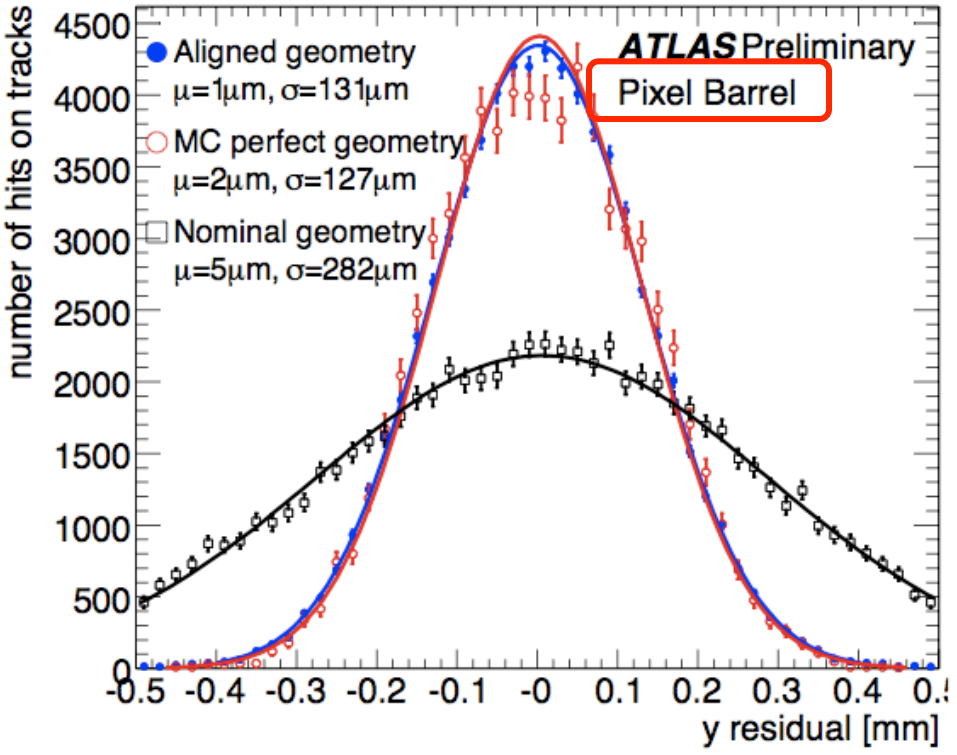
Silicon Alignment Levels					
Geometry Level	Structures (DoFs)	Pixel	Pixel Structures (DoFs)	SCT	SCT Structures (DoFs)
1	4 (24)	complete pixel detector	1 (6)	1 barrel + 2 endcaps	3 (18)
1.5	7 (42)	2 barrel half-shells + 2 endcaps	4 (24)	1 barrel + 2 endcaps	3 (18)
1.6	11 (66)	3*2 barrel half-shells + 2 endcaps	8 (48)	1 barrel + 2 endcaps	3 (18)
2	31 (186)	3 barrel layers + 2*3 endcap discs	9 (54)	4 barrel layers + 2*9 discs	22 (132)
2.1	- (-)	-	- (-)	-	- (-)
2.3	- (-)	-	- (-)	-	- (-)
2.5	- (-)	-	- (-)	-	- (-)
3	5832 (34992)	1456 barrel + 2*144 endcap	1744 (10464)	2112 barrel + 2*988 endcap	4088 (24528)

TRT Alignment Levels			
Geometry Level	TRT	TRT DoFs	comments
1	1 barrel + 2 endcaps	17	no alignment correction around the global Z-coordinate in the barrel
2	32*3 barrel modules+ 40*2 endcap wheels	(32x3) x 5 Dof + (40x2) x 6 Dof = 960	

M8+ Alignment: Residuals (Pixel)

- In all following plots for Si:
  - p_T > 2 GeV, $|d_0|$<50mm, $|z_0|$<400mm (through pixel *b*-layer)
  - "Golden" runs: 91885, 91888, 91890, 91891, 91900, NewT





M8+ Alignment: Residuals (SCT, TRT)

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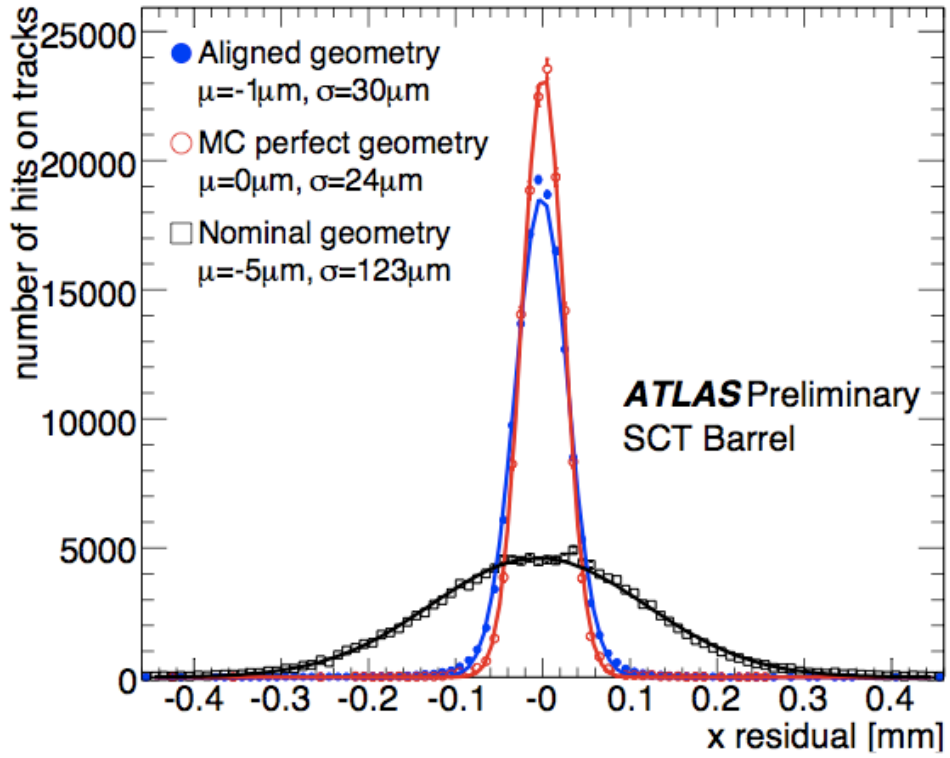
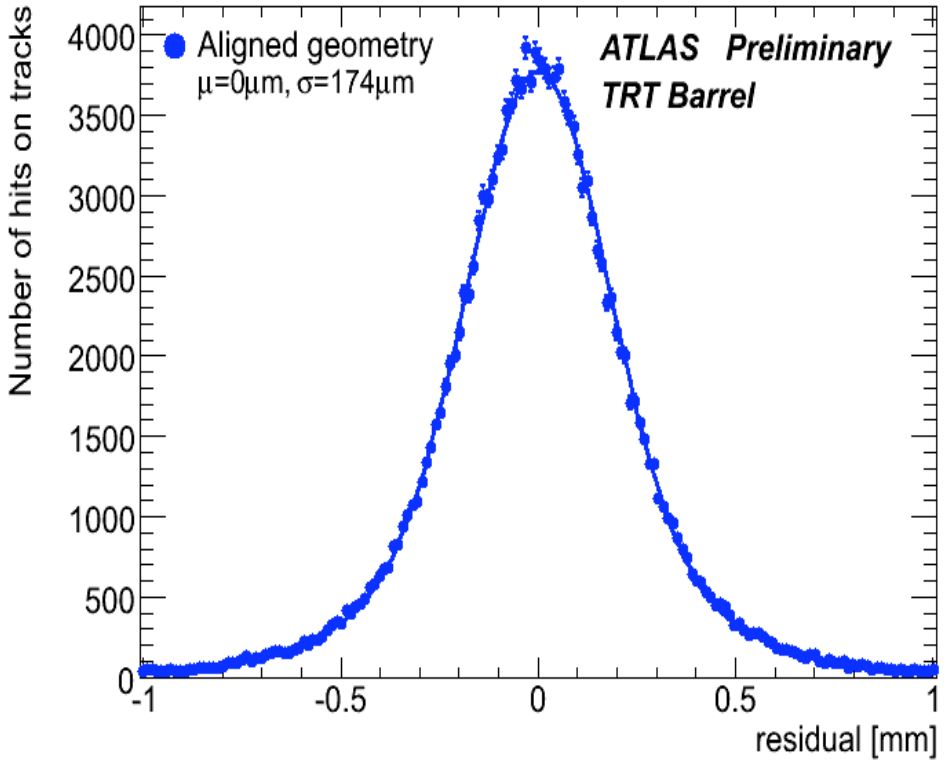
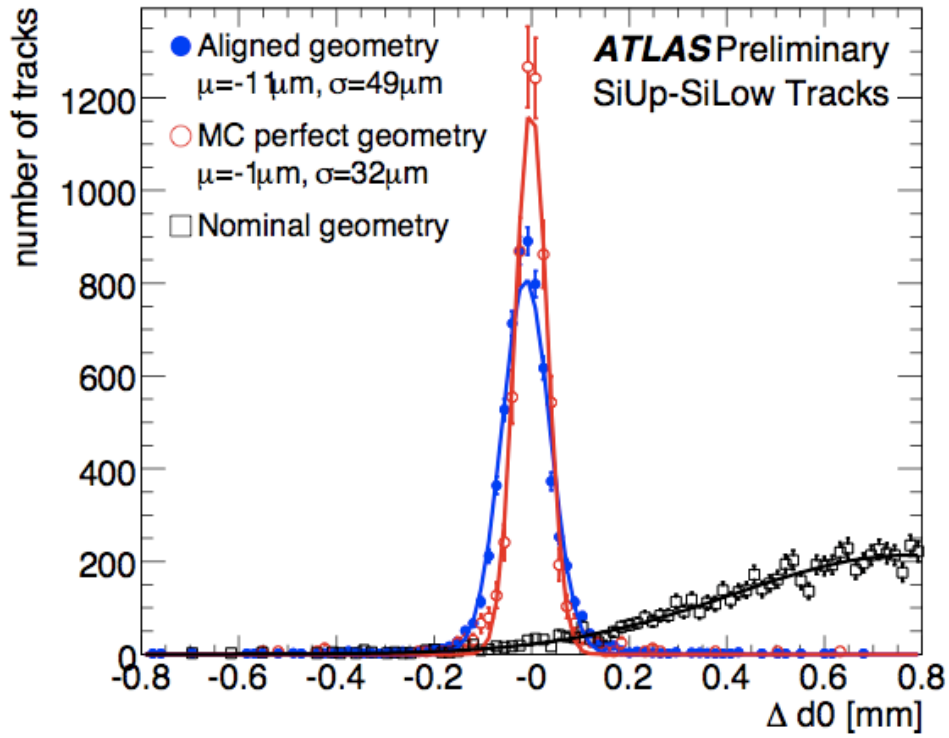


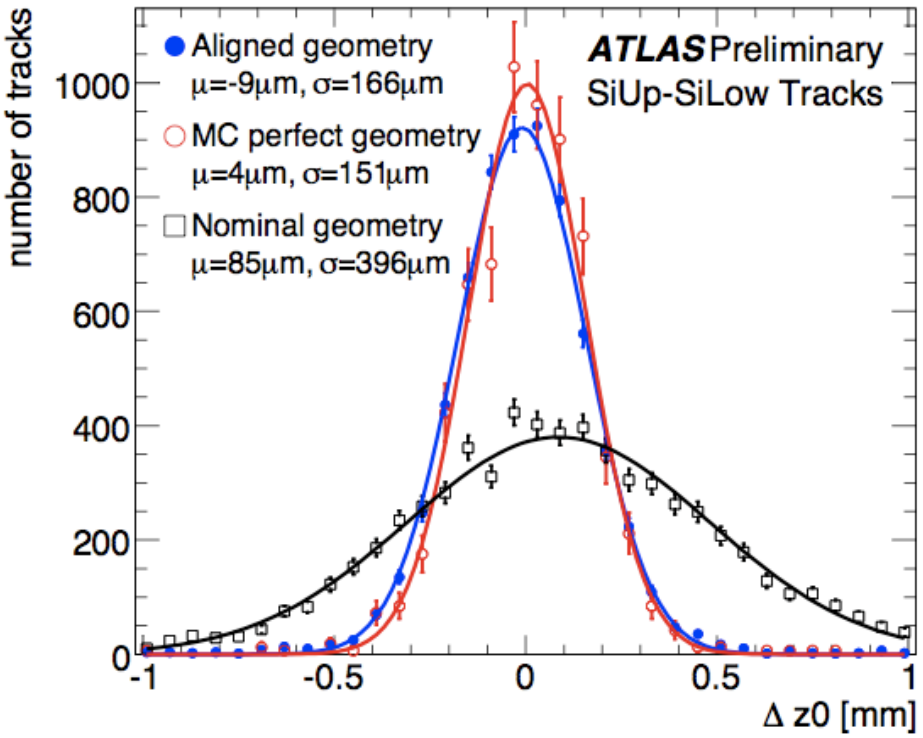


- For TRT:
  - no min. p_T, $|d_0|$<100 mm (through pixel), >45 TRT hits

Alignment with M8+ Cosmics: Results

- In all following plots for Si:
  - p_T > 2 GeV, $|d_0|$<50mm, $|z_0|$<400mm (through pixel *b*-layer)
  - "Golden" runs: 91885, 91888, 91890, 91891, 91900, NewT
  - 7 SCT hits, 3 pixel hits, 1 *b*-layer hit





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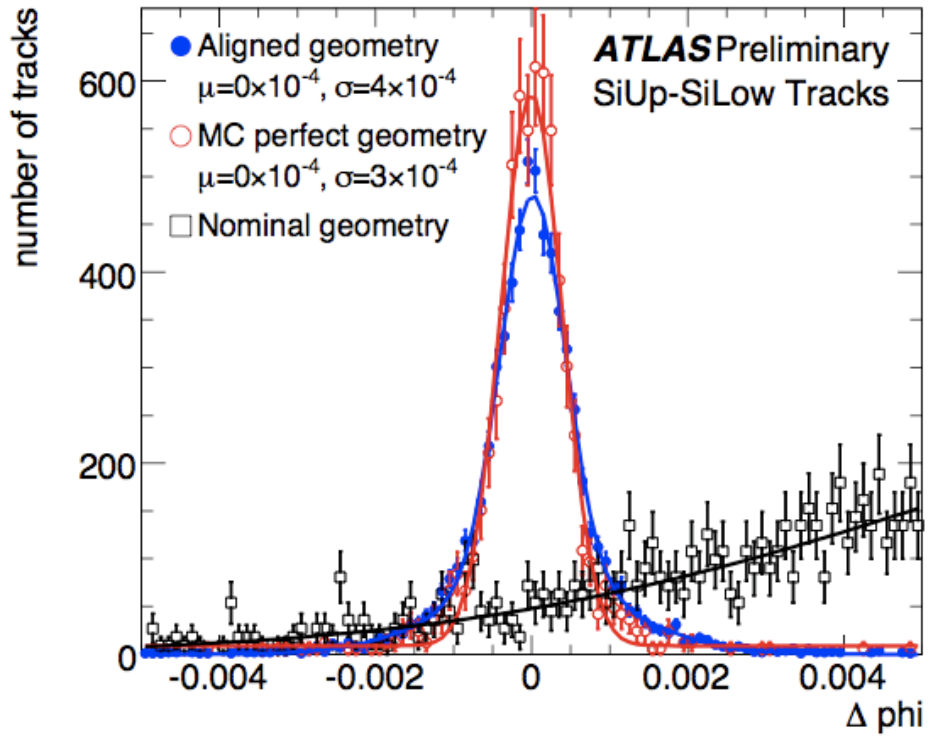

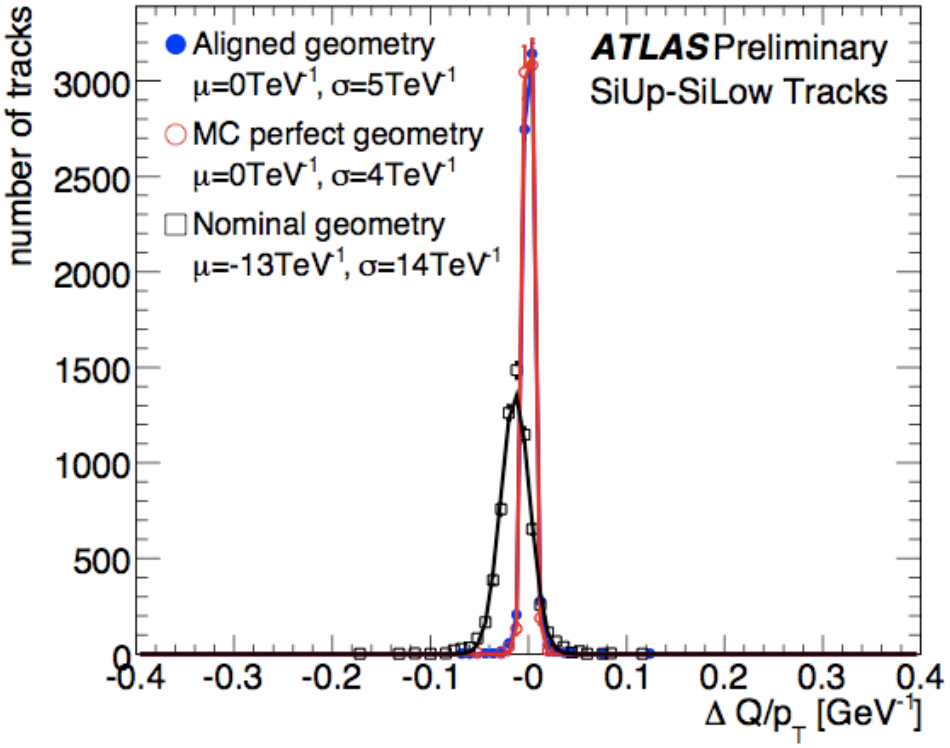

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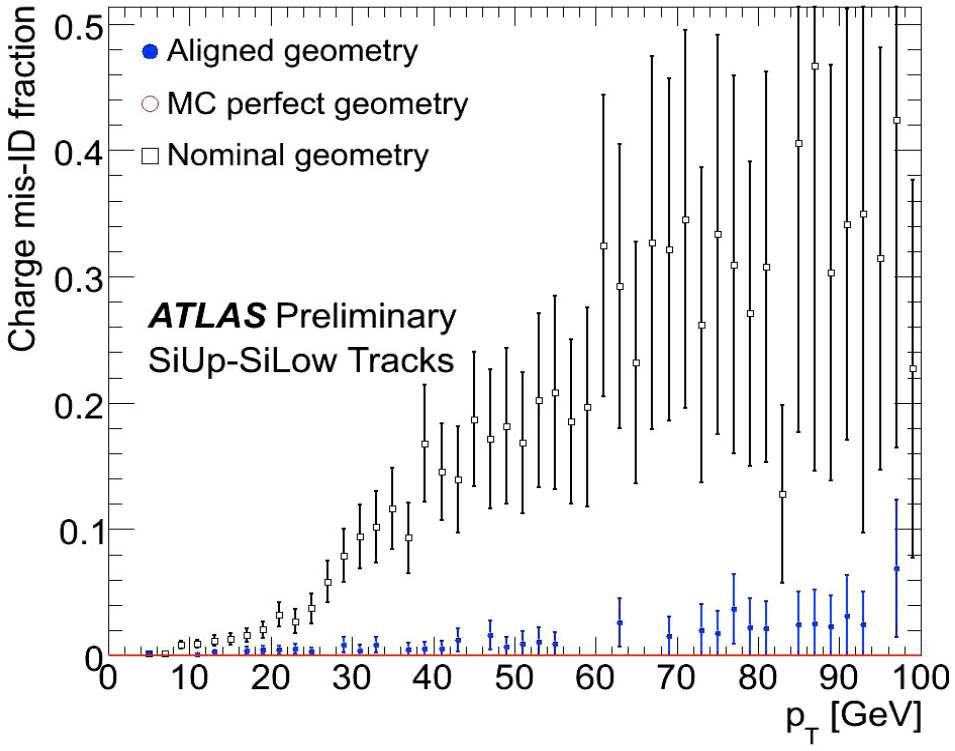

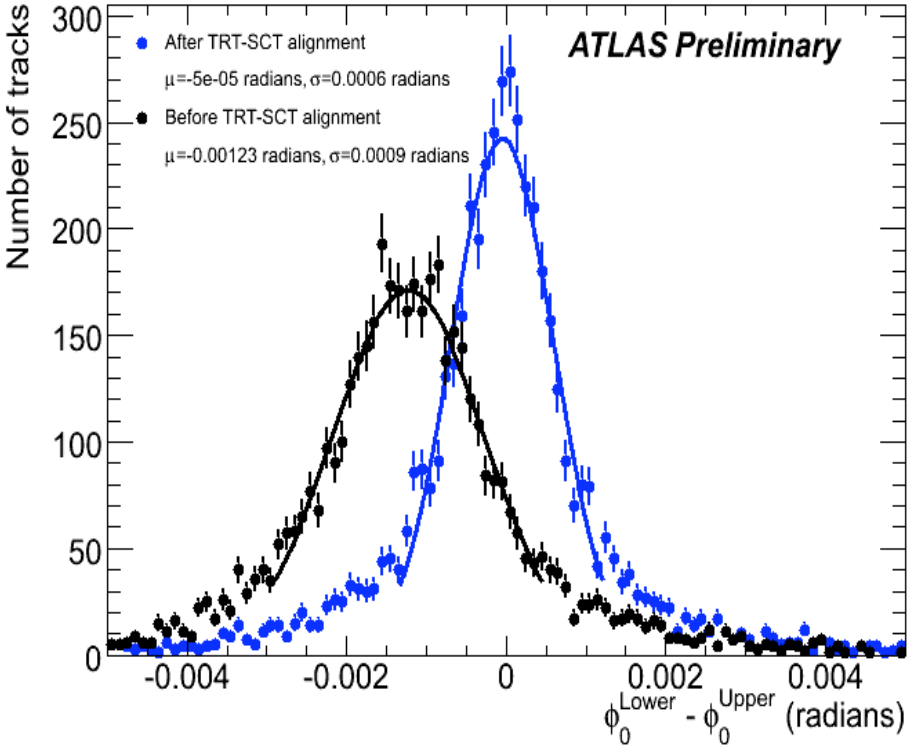

Alignment with M8+ Cosmics: X-checks

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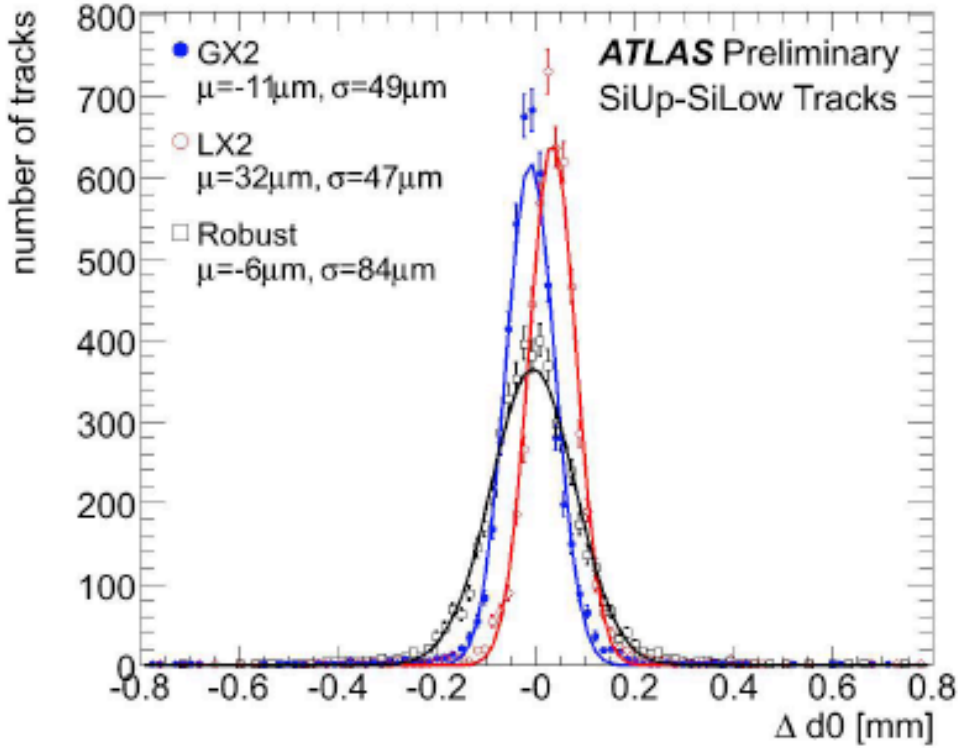
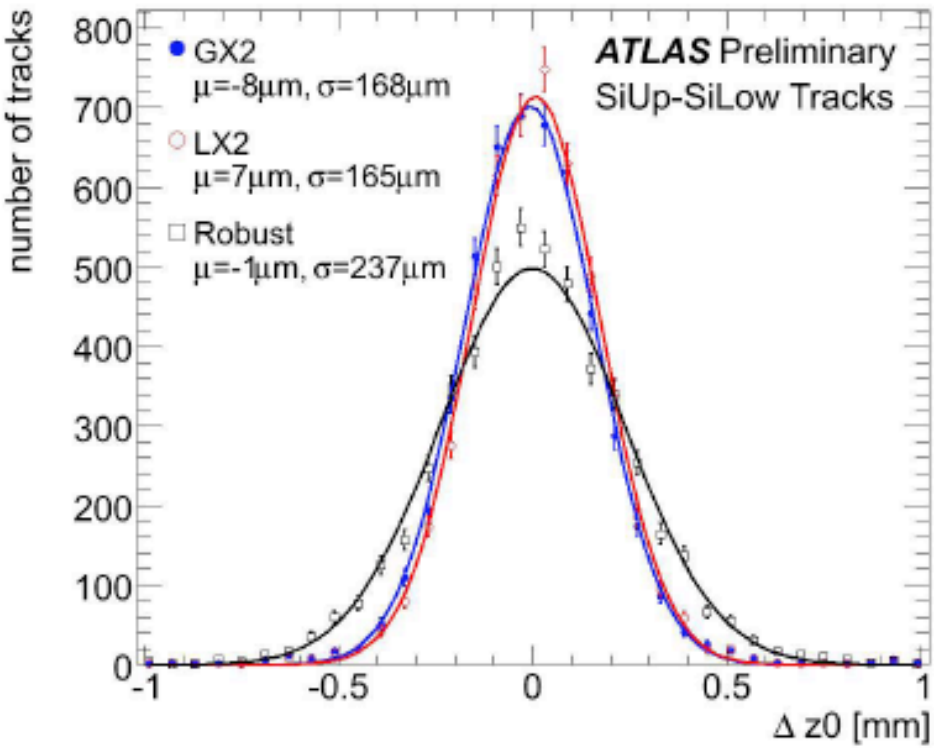
  - "Golden" runs: 91885, 91888, 91890, 91891, 91900, NewT
  - 7 SCT hits, 3 pixel hits, 1 *b*-layer hit
- Cross-check with the Local χ^2 and Robust Alignment:





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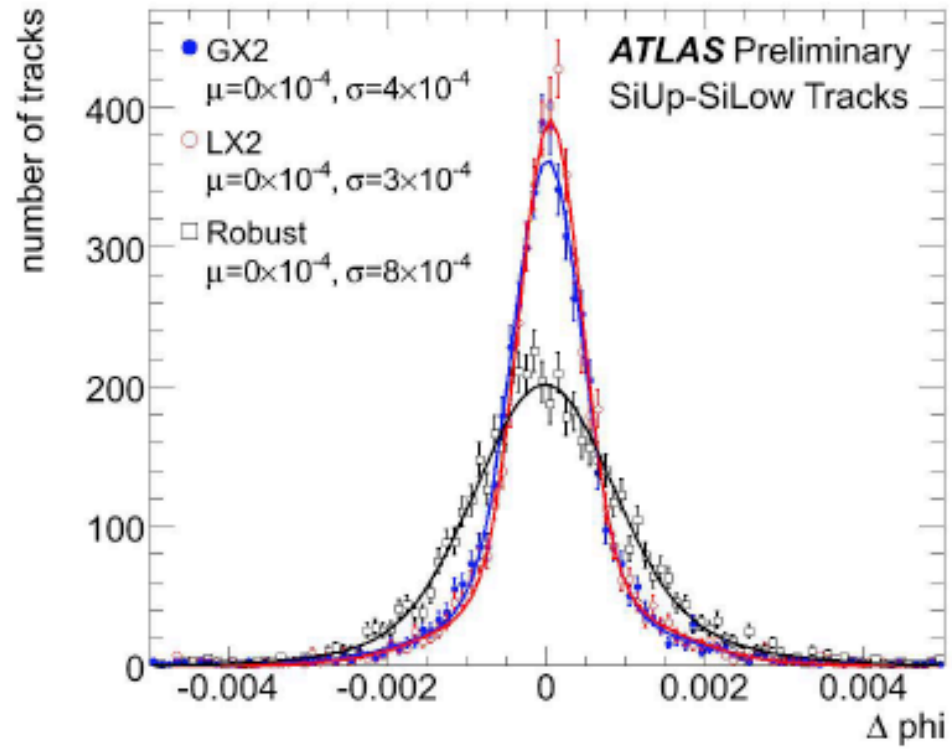
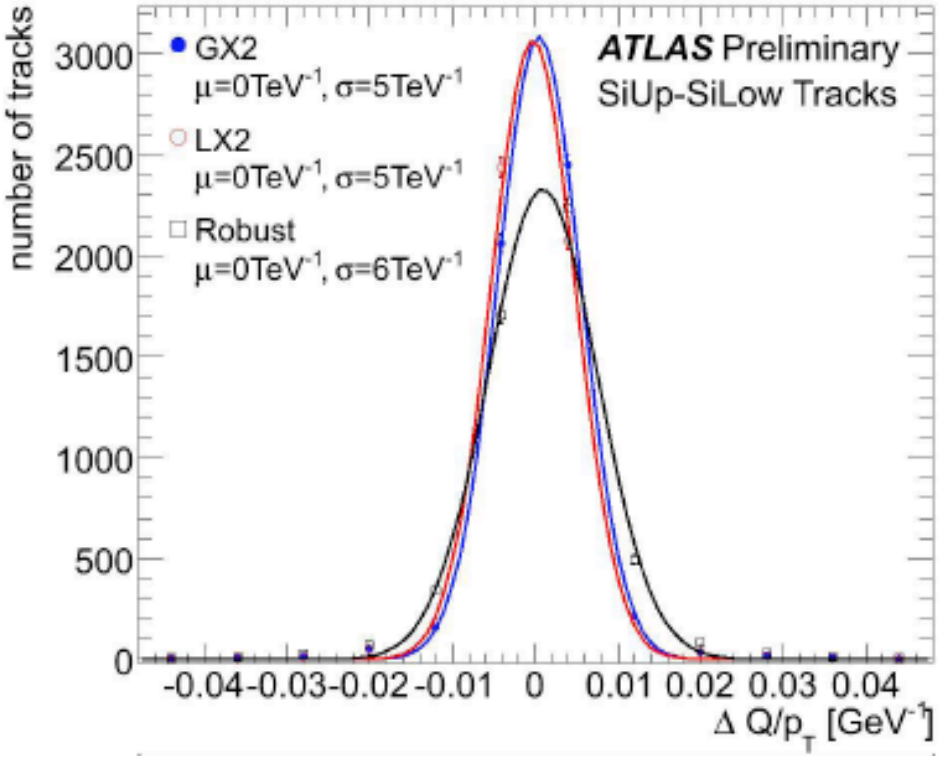
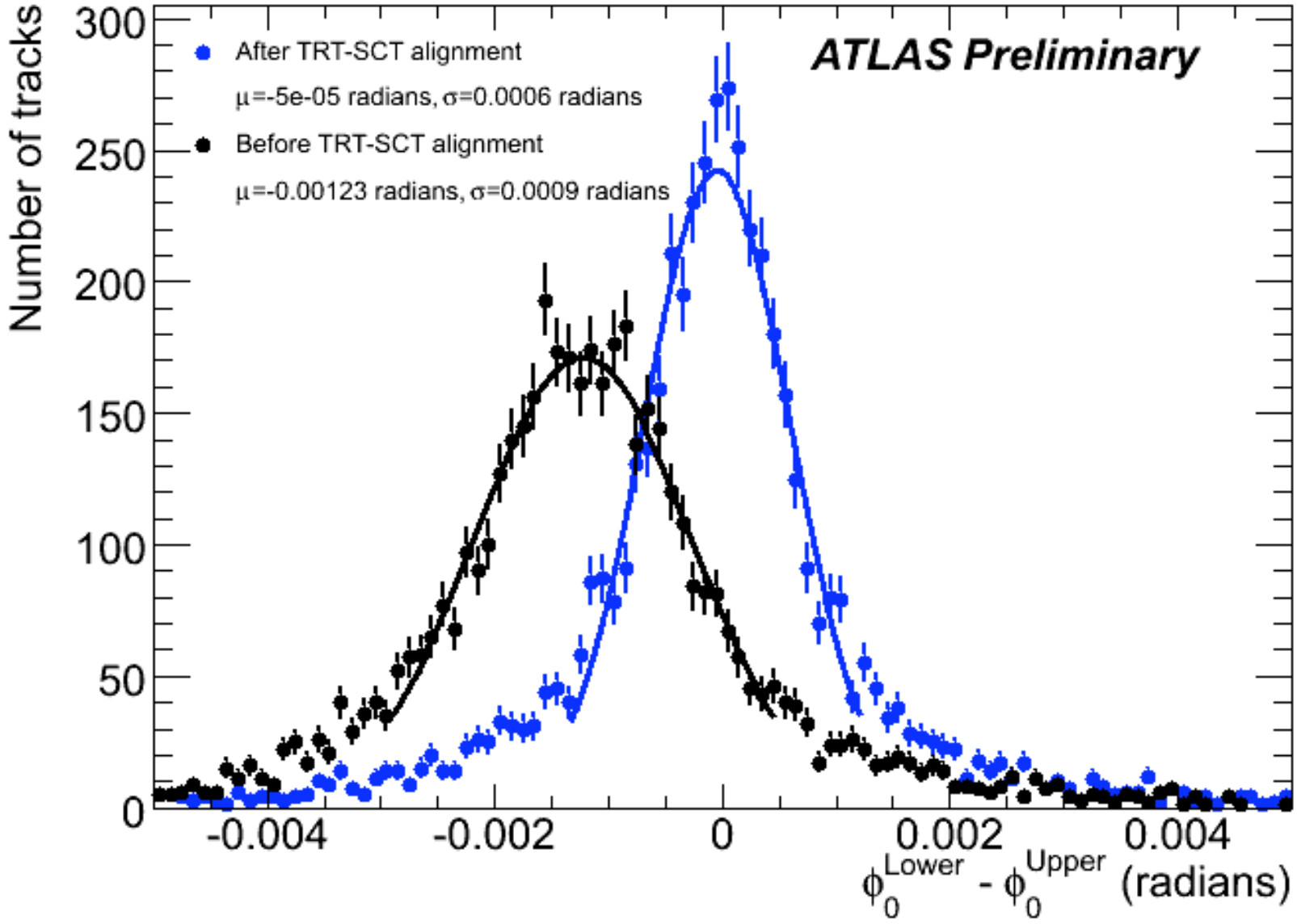




M8+ Alignment: TRT-SCT



MOR

Level 1 Constants Comparison

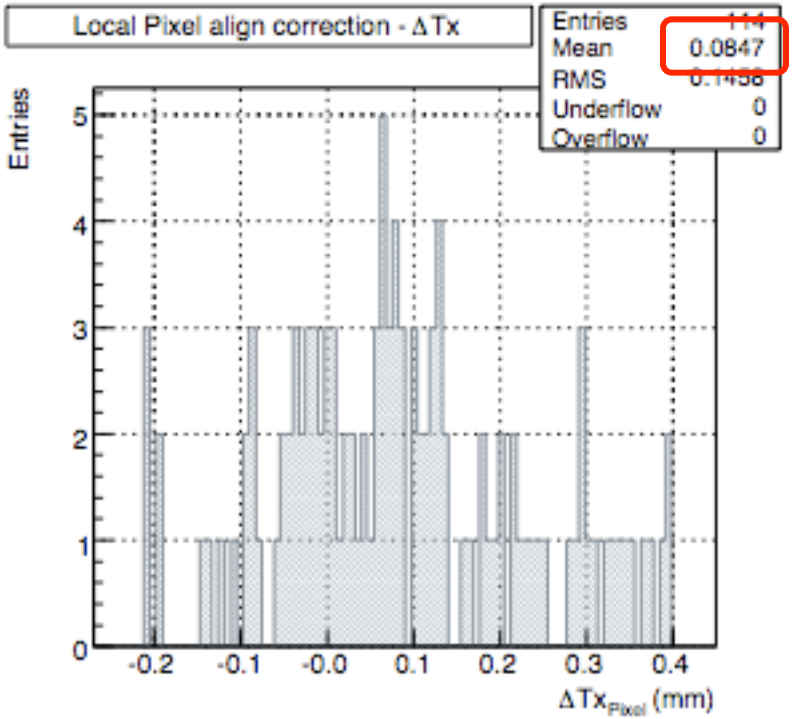
- Compare the constants at L1 between:
  - GX^2: see Vicente's talk in ID week (rel. 15.X.Y nightlies)
  - LX^2: see Roland's talk in ID week (rel. 14.5.0)
  - RA: this talk (rel. 14.5.2)

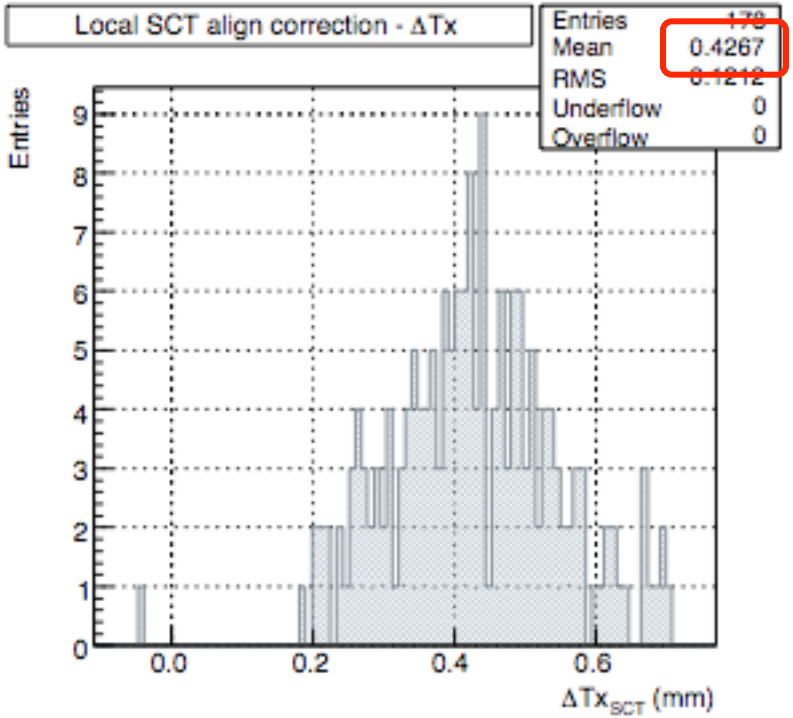
	T_X (mm)	T_Y (mm)	T_Z (mm)	R_X (mrad)	R_Y (mrad)	R_Z (mrad)
GX^2	-0.955	-0.606	-0.400	0.056	0.019	1.107
LX^2	-0.766	-0.376	-0.293	-0.044	0.109	1.901
RA	-0.911	-0.774	-	-	-	2.593
RA Dec.	-0.945	-0.808	-	-	-	2.629

- GX^2, LX^2 -> many thanks to Roland & Vicente

Disclaimer + Some Random Thoughts

- It is not easy to compare the L1 constants:
  - Some of L1 misalignments "absorbed" in L2, L3
  - From Vicente's talk in ID Week (but not GX^2 effect only!):





    - pixel + SCT stave shifts imply a net global rotation -> R_Z!
  - Ways to "retransfer" them into L1?
    - CoG for Pixel and SCT separately?

Alignment Levels: "Superstructures"

- Define superstructures of modules:
  - Reflecting the detector geometry + build specifications
  - Typically: superstructure misalignments large!
- Level 1.5, 1.6, 2.5, 2.6, 2.7, 2.8 et al.:
  - Pixel barrel half-shells (2 x 3)
  - Pixel barrel staves (144), *highlighted below*
  - …
- Alignment Levels:
  - imply chronology
  - Larger superstructures -> larger statistics!