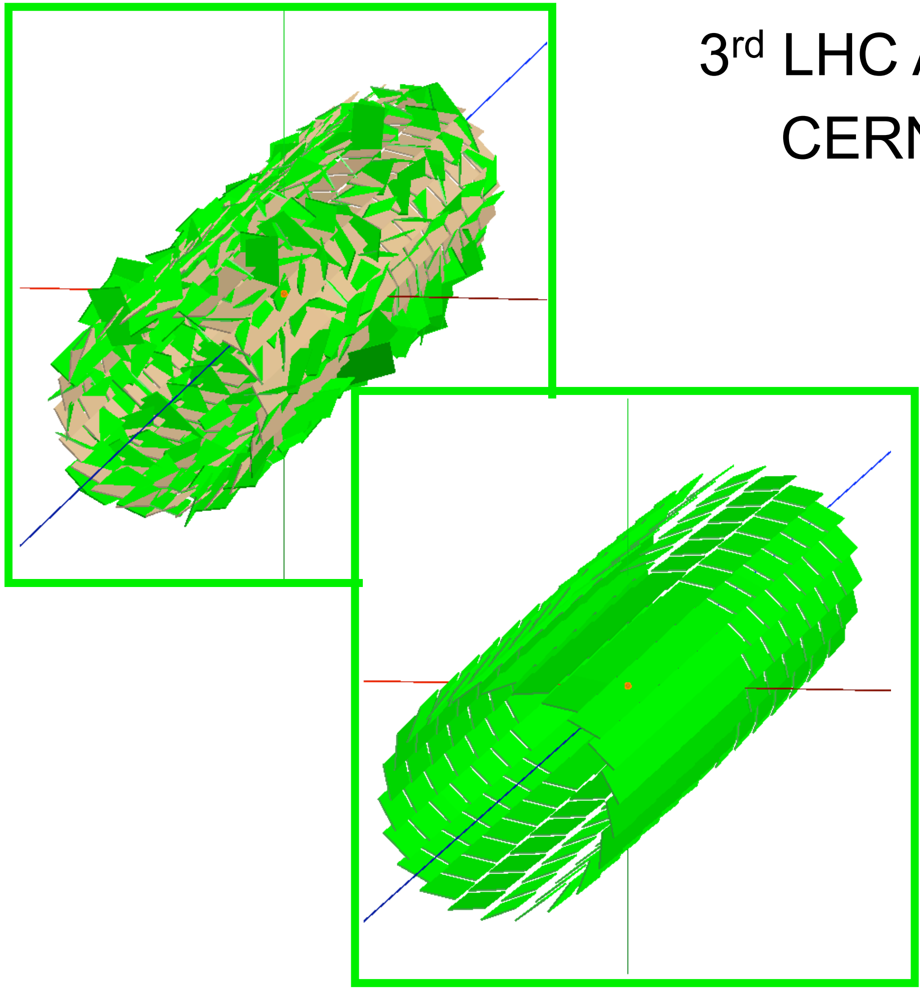
Impact of Alignment on Physics Analysis at ATLAS



3rd LHC Alignment Workshop
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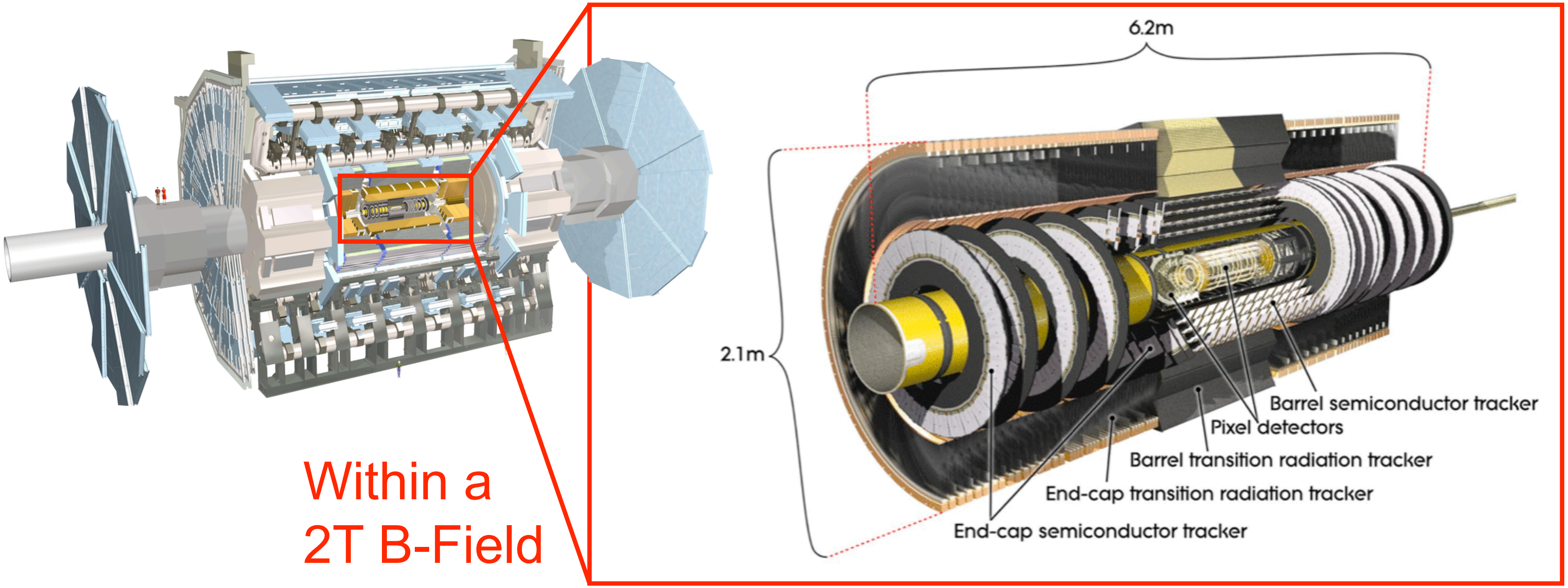
On behalf of the ATLAS Collaboration

ATLAS EXPERIMENT
http://atlas.ch

Introduction

- Examine impact of both ID and MS misalignments on selected physics processes and performance measurements.
- What we show here is a snapshot of current understanding, not the complete picture (many other studies ongoing).
- Why study impact of misalignments on physics?
  - Prepare physics groups for potential impact of misalignments in short and long term (develop alignment robust analysis).
  - Develop tools and techniques to assess errors from misalignments (we will never have a perfectly aligned detector!)
  - Feedback for aligners - where to concentrate efforts.
- Main difficulty: misalignments studied should be realistic, but hard to understand potential size, particularly systematics.

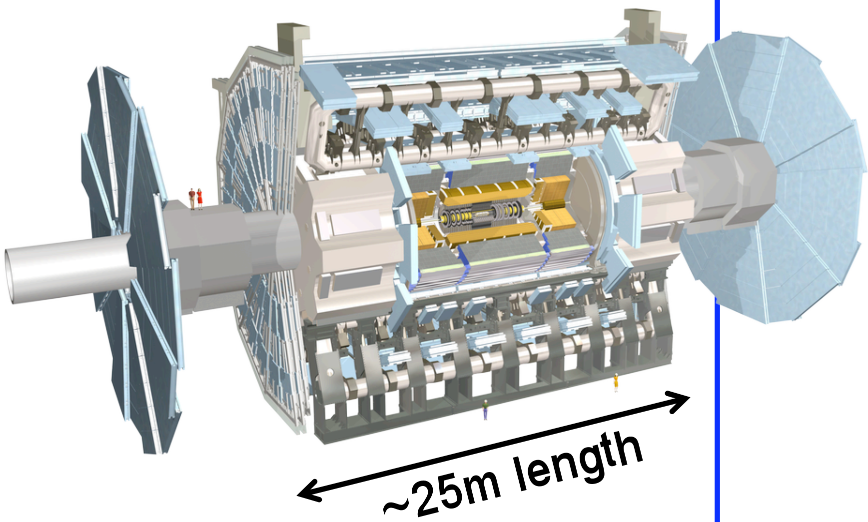
The ATLAS Inner Detector

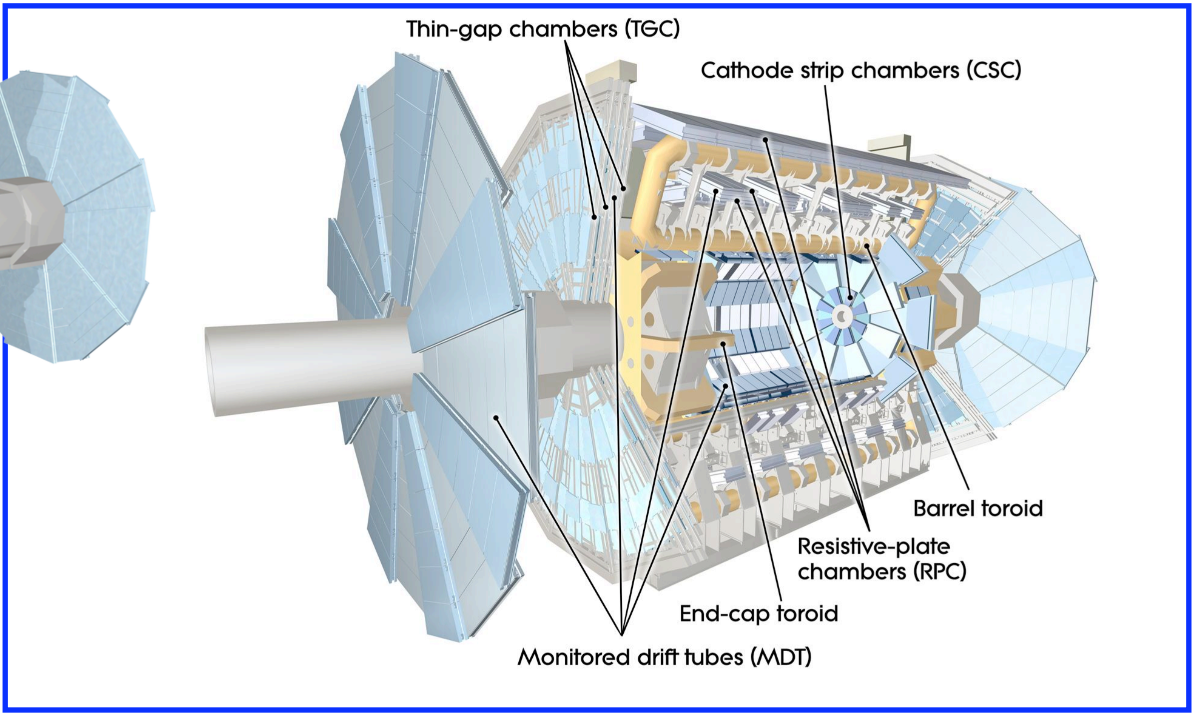


Within a
2T B-Field

	Pixel	**SCT**	**TRT**
Technology	Silicon pixels	Silicon strips	Drift tubes
Resolution	10μm (Rϕ), 115μm (Z)	17μm (Rϕ), 580μm (Z)	130μm (Rϕ)
Number of Layers	3 Barrel, 2x3 Endcap	4 Barrel, 2x9 Endcap	3 Barrel, 2x40 Endcap
Number of Modules	1744	4088	992

The ATLAS Muon Spectrometer





	MDT	CSC	RPC	TGC
Technology	Drift Tube	Cathode Strip	Gas Chamber	Wire Chamber
Chamber Resolution	35μm (z)	40μm (R)	10mm (z), 10mm (ϕ)	2-6mm (R), 3-7mm (ϕ)
# Measurements/track	20	4 (endcap)	6 (barrel)	9 (endcap)
No. of Chambers	1088	32	544	3588

Importance of Alignment to Physics

- High quality track reconstruction in ID and MS vital to ATLAS physics:
  - Muon reconstruction
  - Electron identification
  - Reconstruction of hadronic Tau decays
  - Jet calibration
  - 3-D Primary vertex reconstruction
  - Reconstruction of *B* decays
  - Secondary vertex reconstruction and b-tagging
  - Minimum bias event studies
- Tracking performance limited by alignment:
  - Efficiencies (only suffer with extreme misalignments)
  - Resolutions (random misalignments)
  - Biases (global systematic misalignments)

ID Alignment Requirements

Baseline:
Resolution degradation < 20%

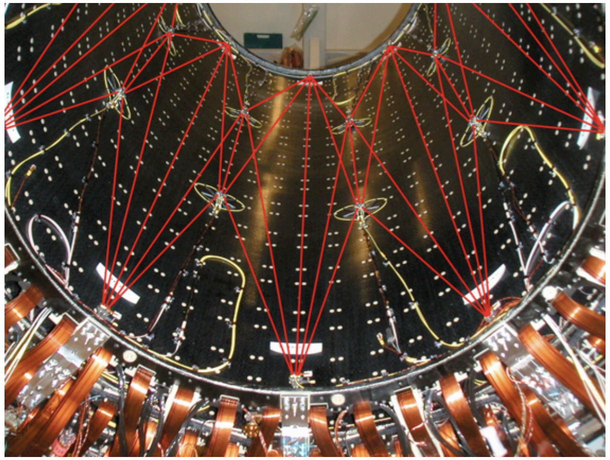
	R-ϕ Alignment Tolerance
Pixel	O(7μm)
SCT	O(12μm)
TRT	O(30μm)

Ultimate goal: reach O(1μm) level!

ID Build Precision:
- O(100μm) module R-ϕ placement
- O(1mm) layer/disk

Need **Track-based Alignment Algorithms**

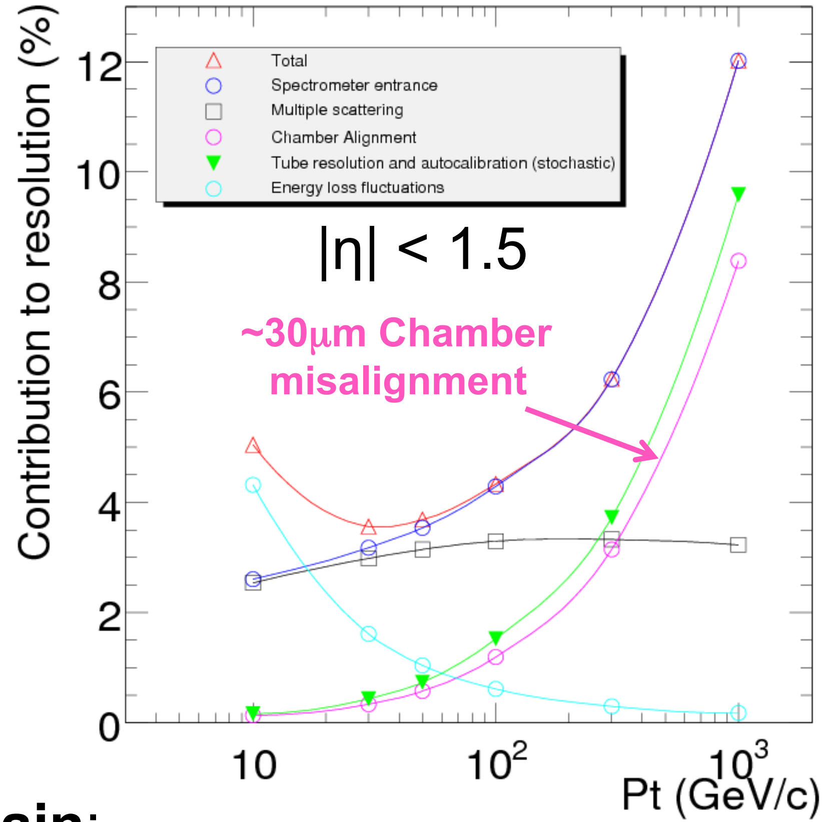
$$\chi^2 = \sum_{tracks} r^T V^{-1} r$$



FSI system: monitor SCT geometry at micron level.

MS Alignment Requirements

Baseline:
10% momentum resolution at 1 TeV → Chamber positions have to be known to ~30μm



MS Build Precision:
O(5mm) chamber placement precision

Optical Alignment System:
monitors relative chamber position at 20-40μm level.

→ **Uncertainties remain**:
- Absolute positions ~200μm (barrel) ~40μm (endcap).
- Relative alignment of small-large sectors, barrel-EC, MS-ID.

→ **Need to combine optical and track-based alignment**

Potential Misalignment Types

- **Inner Detector:**
  - Random module level misalignments. Arise due to:
    - Finite number of tracks used in alignment (not a problem for collision data, but can be for cosmic ray alignment).
    - Degradation in quality of input residuals: miscalibration of “hits”, limitations in material description etc.
  - Residual global systematic misalignments: with certain initial conditions alignment converges on “weak mode”.
  - Individual modules deformations.
- **Muon Spectrometer:**
  - Uncertainties in optical alignment system (sensor positions, calibration) lead to uncertainties in chamber positions. Likely to be correlated.
- **Relative MS-ID misalignments:**
  - Impact combined muon reconstruction.

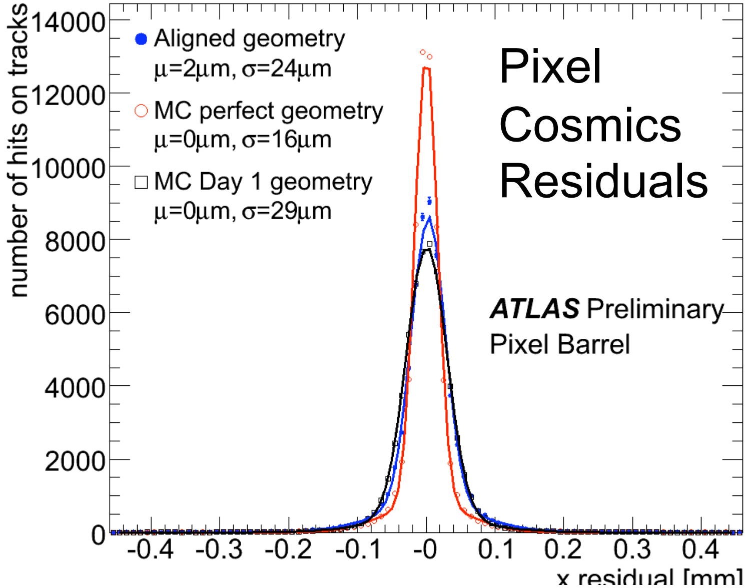
Strategy for Misalignments Studies

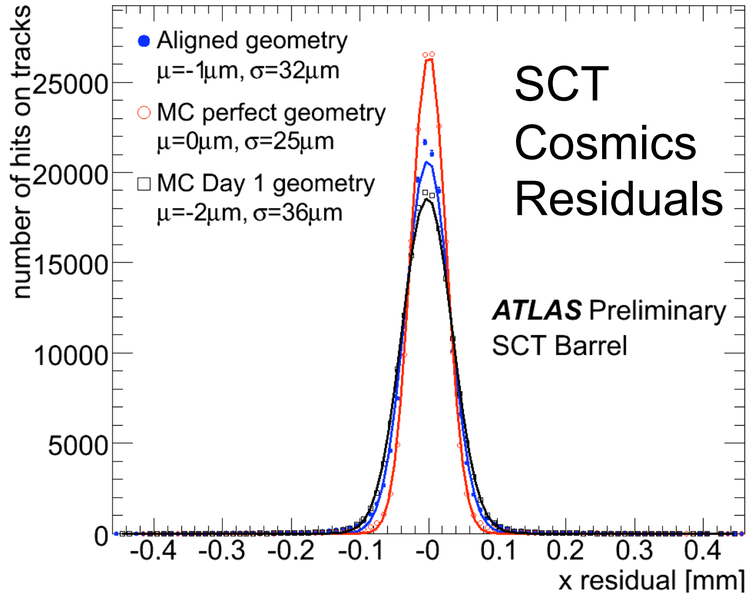
- Monte Carlo physics event samples simulated and digitised with particular ATLAS geometry.
- Reconstruct the events using a different “misaligned” geometry – module positions and/or orientations are different from those used in simulation.
- Compare “misaligned” results to those using ideal alignment.
- In this way we examine impact of:
  - Random misalignments in ID.
  - Global systematic misalignments in ID.
  - Combination of global and systematic misalignments in ID.
  - Random misalignments in MS.

Random ID Misalignments

- 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 goals.

	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

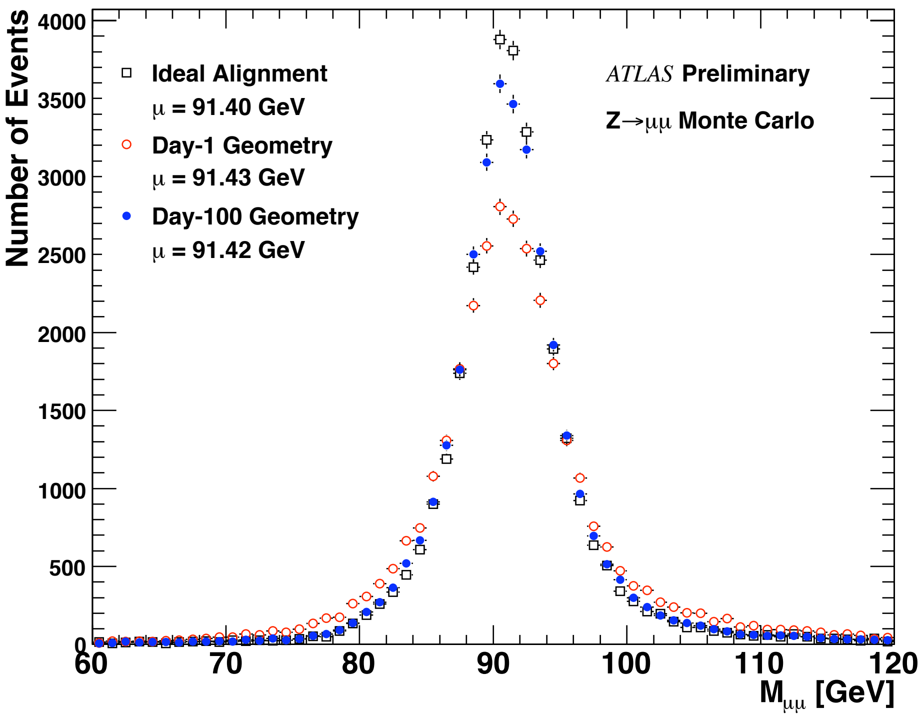




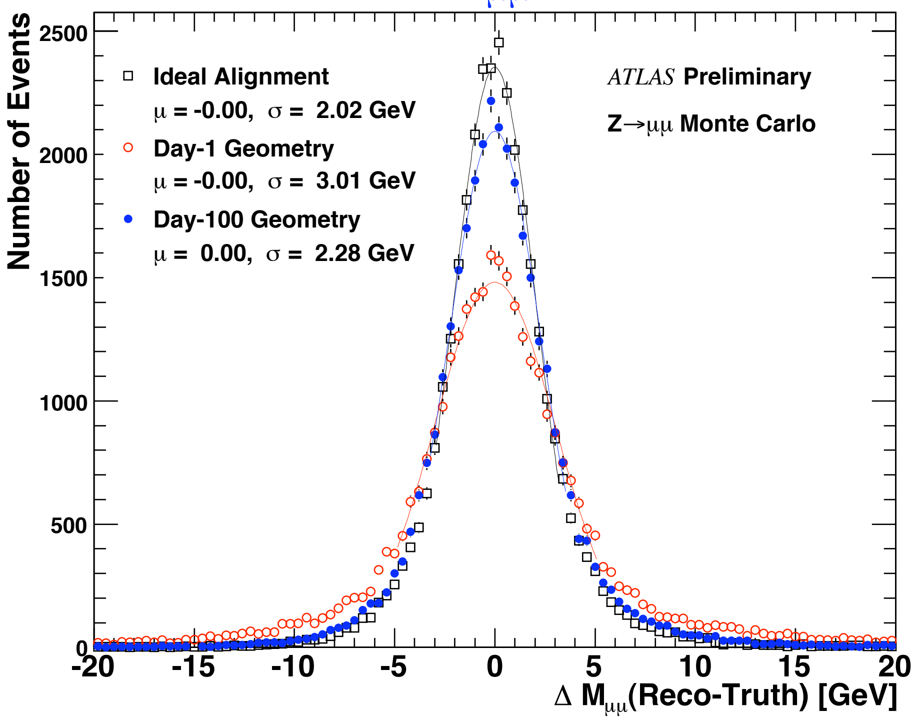
Impact of Random ID on Z→μμ

- Study impact of misalignments on simulated Z→μμ reconstruction.
- Significant impact on Z mass resolution:
  - Day-1 degrades Z resolution by ~50%.
  - Day-100 degrades Z resolution by ~13%.

Reconstructed Z mass



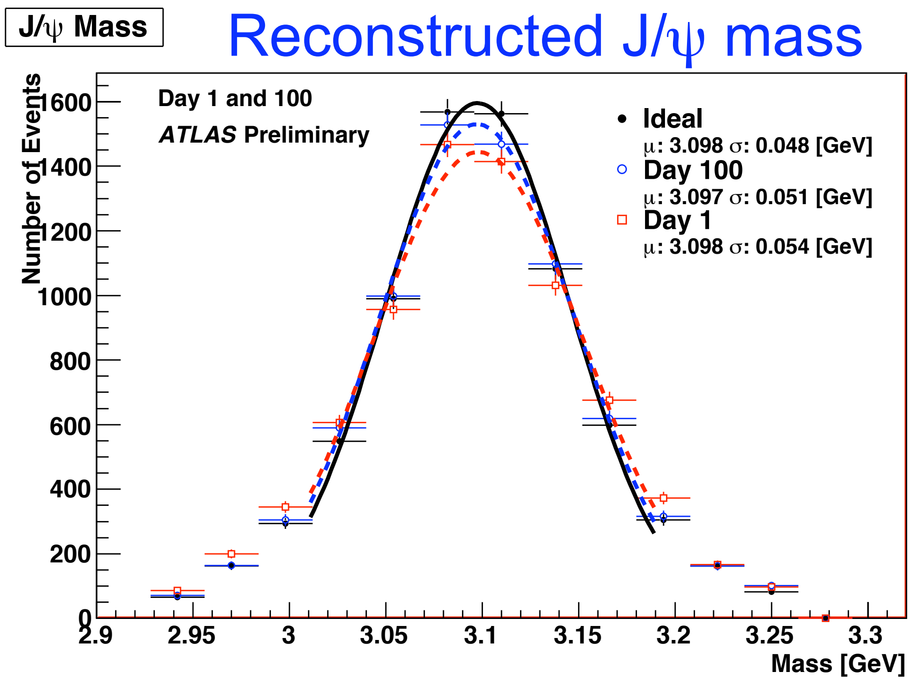
$\Delta M_{\mu\mu}$(Reco - Truth)



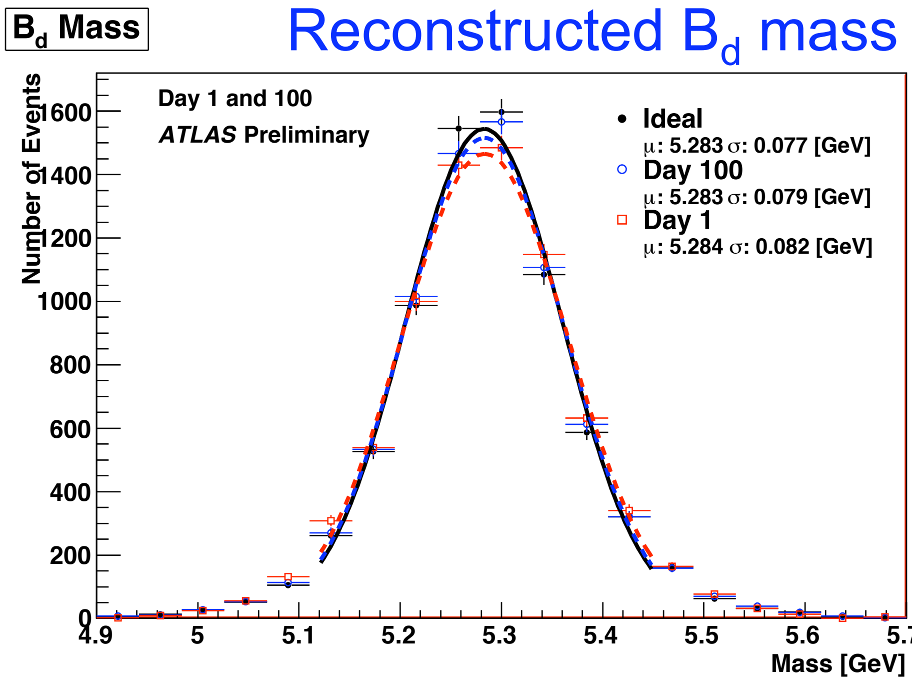
Impact of Random ID on *B*-physics

- Study impact of misalignments on simulated $J/\psi \rightarrow \mu\mu$ and $B^0_d \rightarrow J/\psi K^{0*}$ reconstruction.
- Impact of misalignments much less significant here:
  - Larger Day-1 misalignment produces only ~10% degradation in resolutions. Insignificant affect for Day-100.
- These decays produce lower p_T tracks - dominated by material.

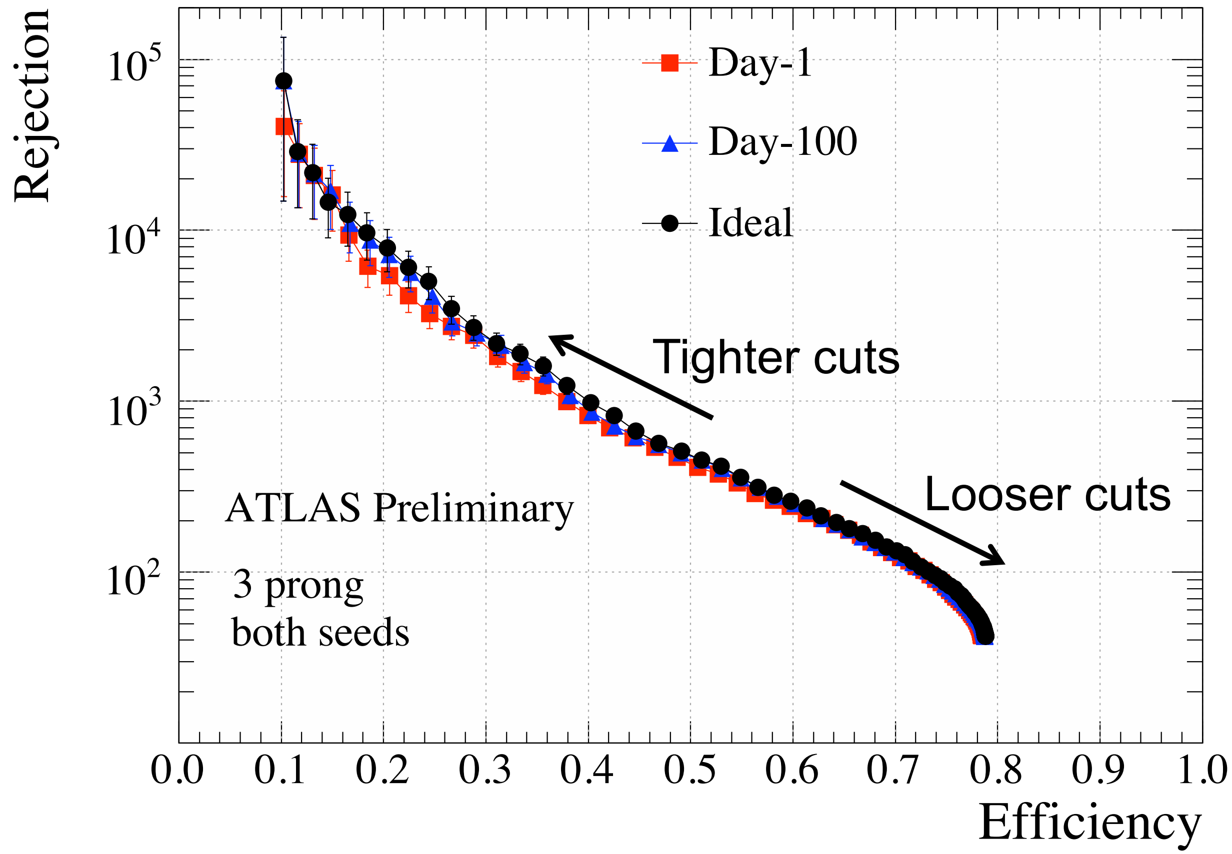
Reconstructed J/ψ mass



Reconstructed B_d mass



Impact of Random ID on τ Reco



- Hadronic Tau decay reconstruction makes use of ID reconstructed charged pion tracks.
- No significant impact of misalignments observed on efficiency or rejection.

Global Systematic ID Misalignments

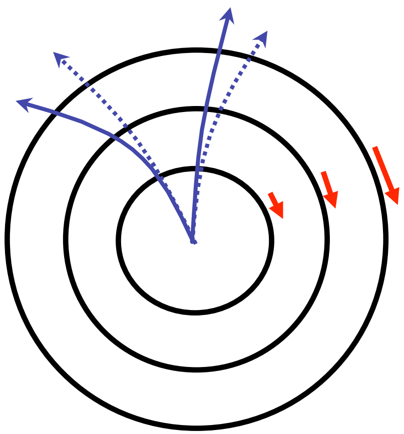
- Created four global systematic ID misalignments “by-hand”.
- 2 magnitudes: “Large” & “Small”. SCT outer layer shift shown.

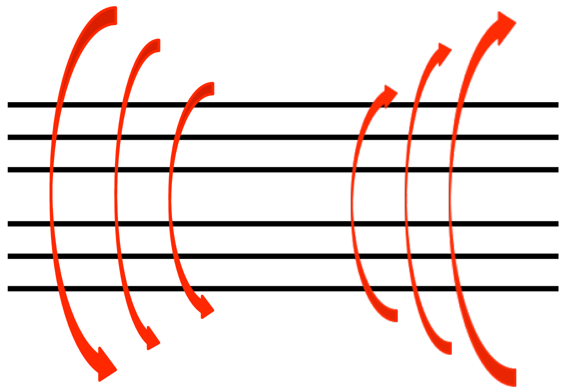
Curl Misalignment

$\Delta\Phi = c_1 R + c_2/R$

Large: 300 μm

Small: Aligned





Twist Misalignment

$\Delta\Phi = c.Z$

Large: 300 μm

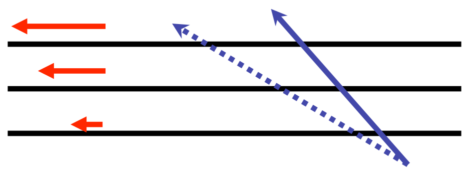
Small: Aligned

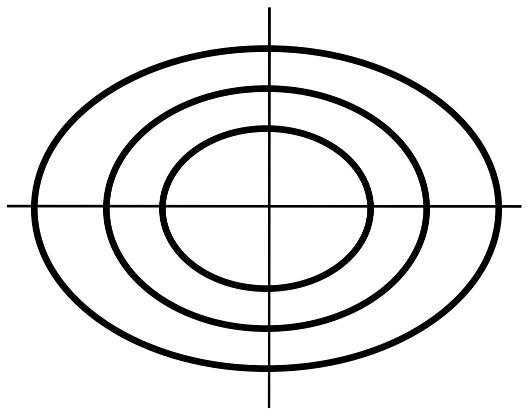
Telescope Misalignment

$\Delta Z = c.R$

Large: 3000 μm

Small: 300 μm





Elliptical Misalignment

$\Delta R = c.R\cos(2\Phi)/2$

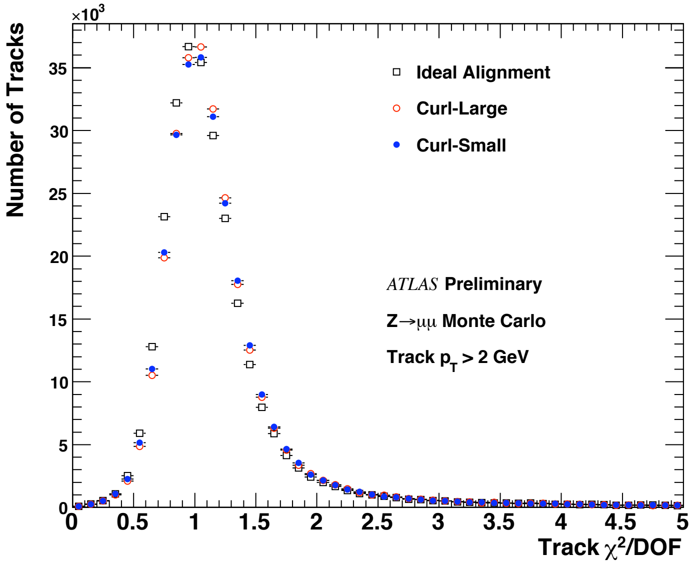
Large: ± 1000 μm

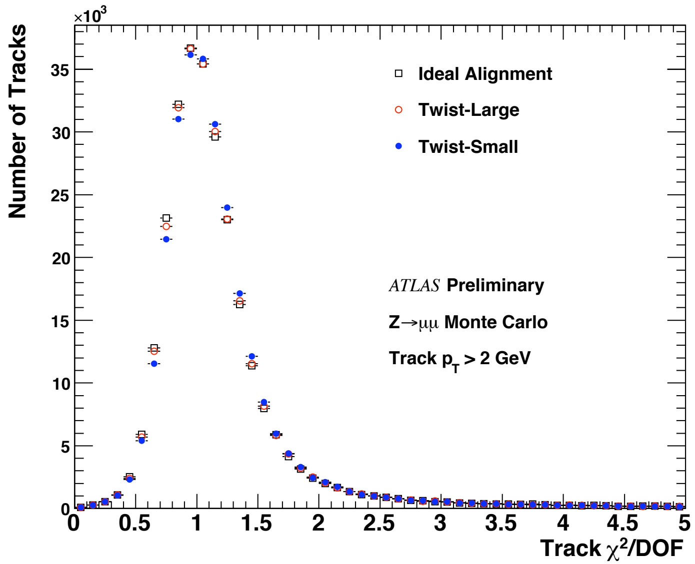
Small: ± 250 μm

Global Systematic ID Misalignments

- Systematic misalignments approximate to weak modes:

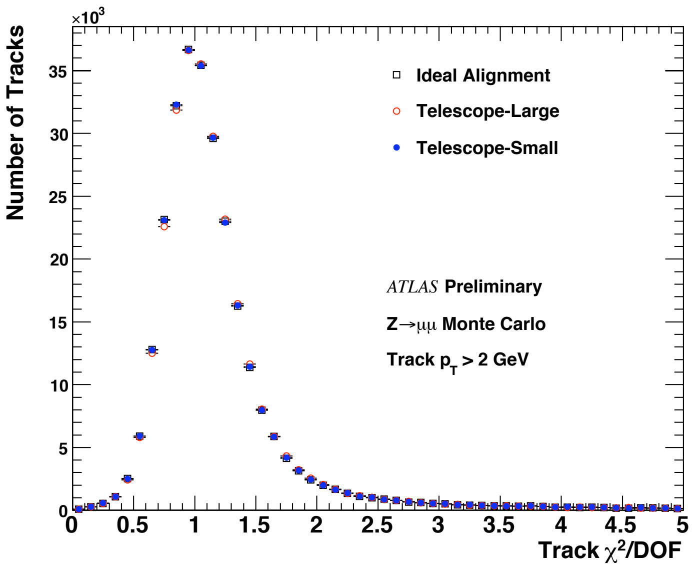
Curl

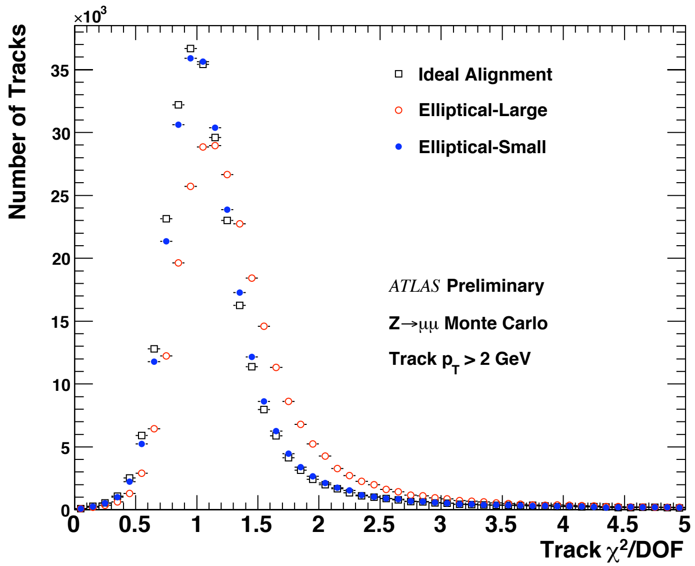




Twist

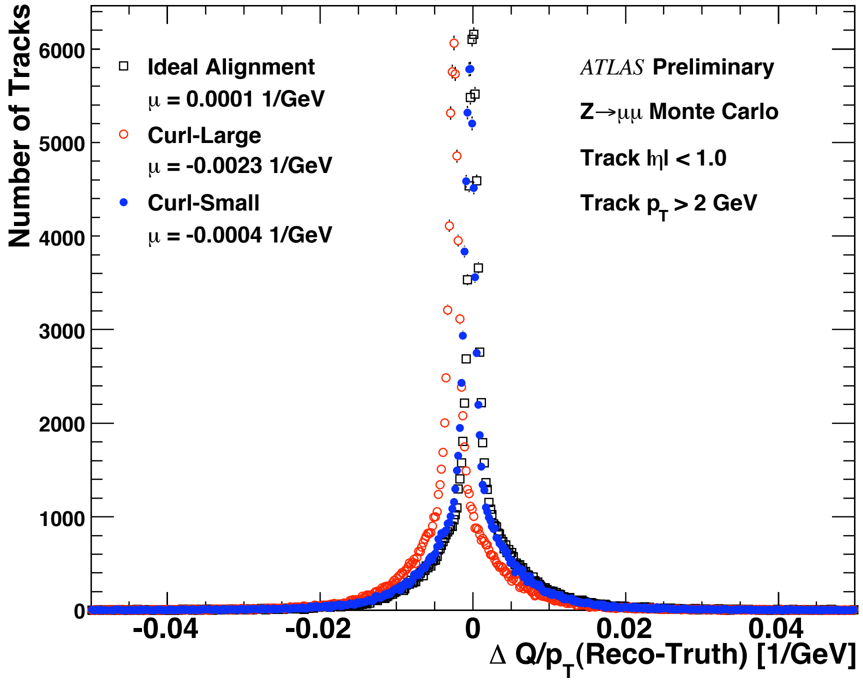
Telescope



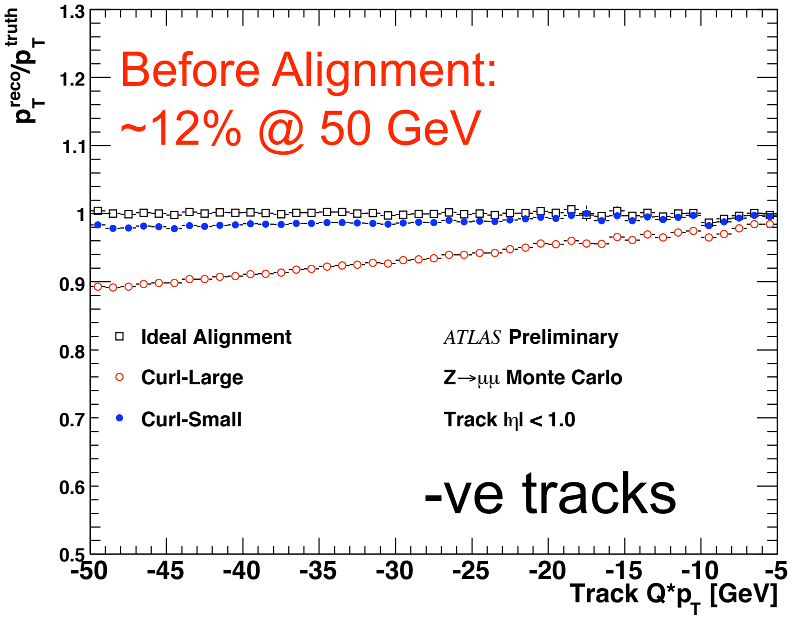


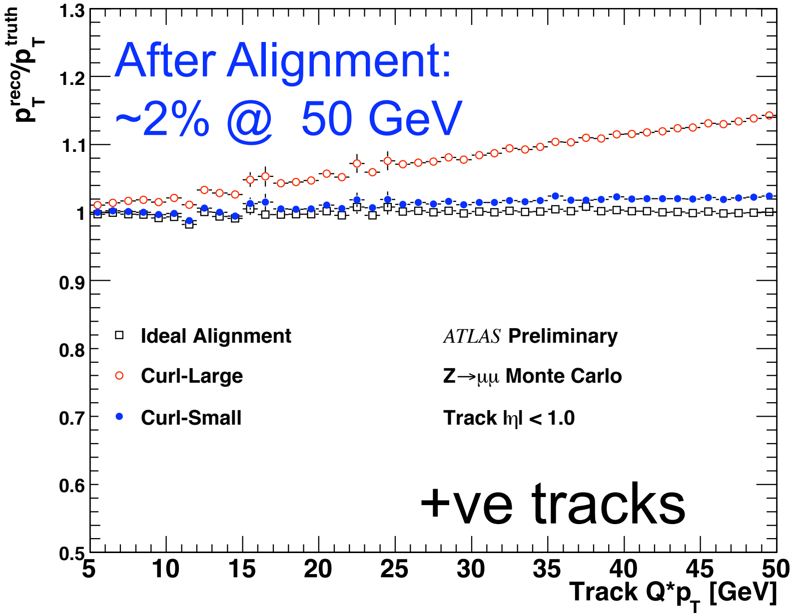
Elliptical

Impact of Curl ID Misalignment



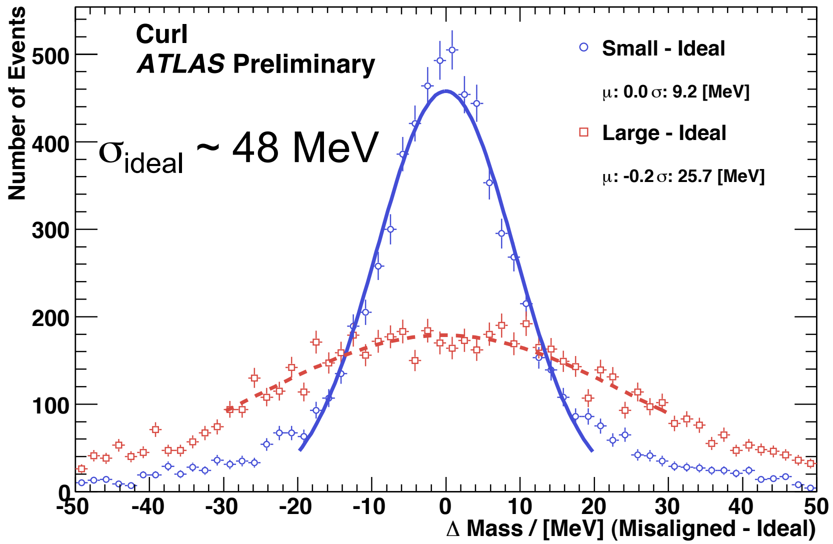
- Curl misalignment produces curvature bias → p_T bias
- Curvature bias is reduced by alignment - smaller p_T bias.
- Curl-Large only approximates weak mode! Can be reduced further with using cosmics.



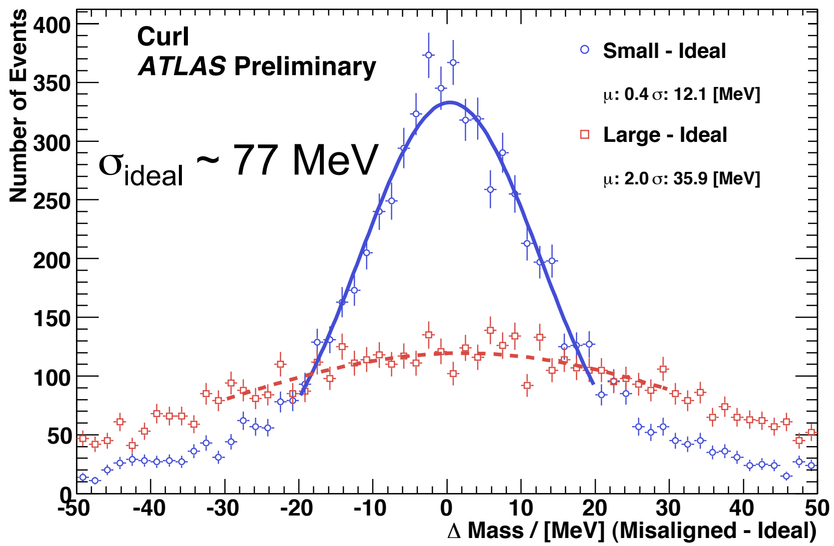


Impact of Curl ID Misalignment

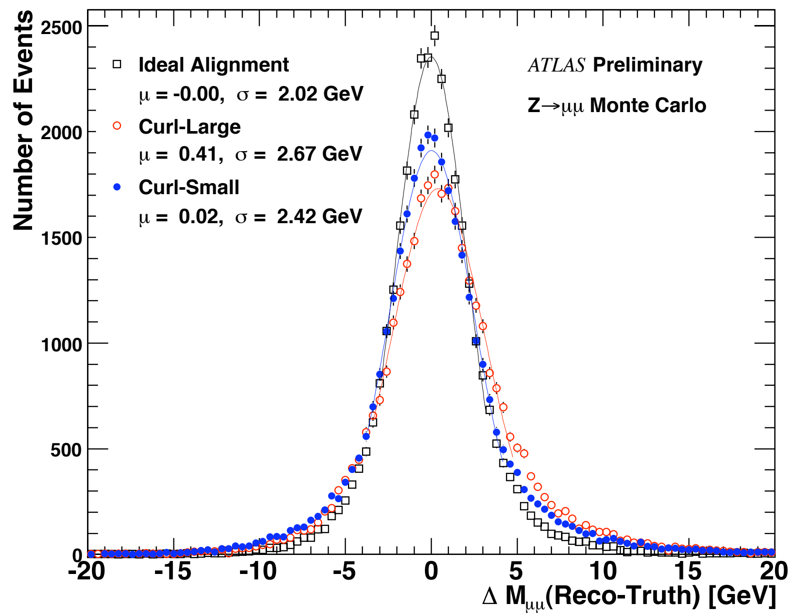
Δ J/ψ Mass (Misaligned - Ideal)



Δ B_d Mass (Misaligned - Ideal)



- Curvature bias: degradation in mass resolutions.
- Not significant for J/ψ→μμ or B_d.
- Significant for Z: Curl-Large 30%. Curl-Small 20%.
- Curl-Small affected by random residual misalignments – could be substantially reduced.

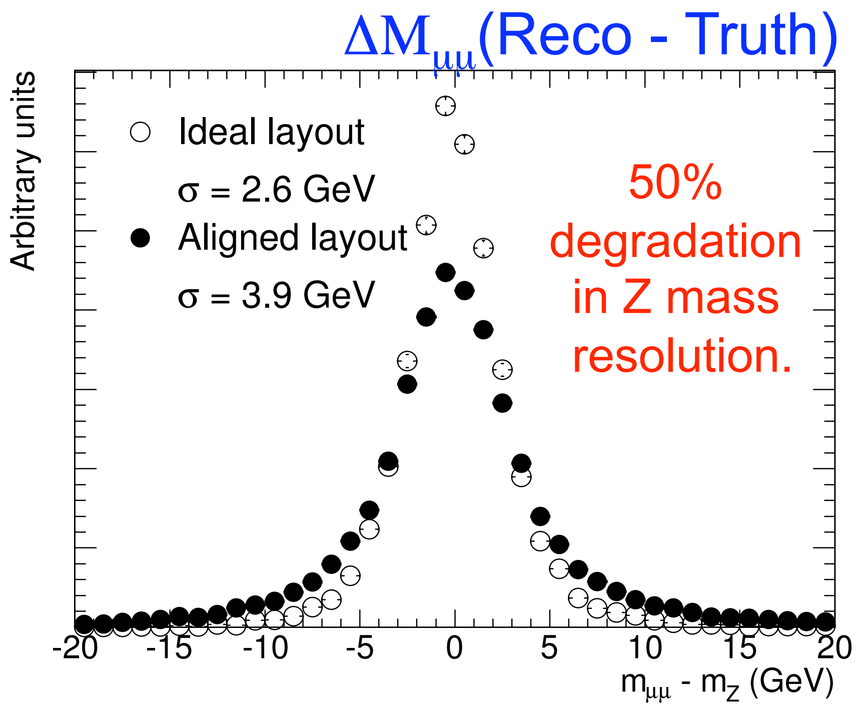


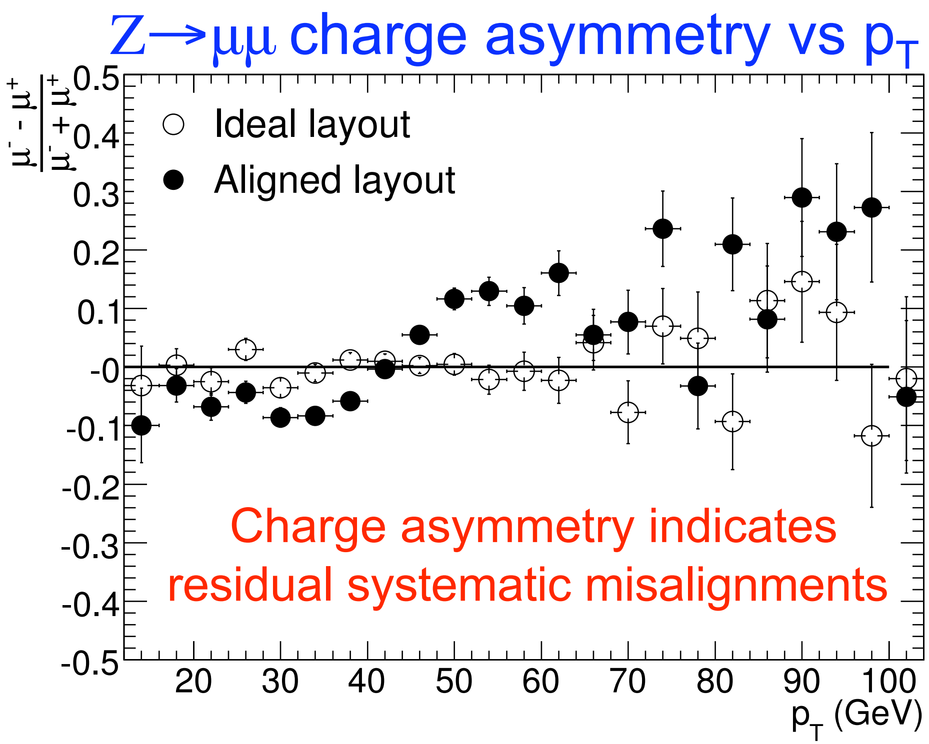
Syst. + Random ID Misalignments

- Road-test alignment procedures on "realistic" misaligned geometry:
  - Random module-level misalignments O(100μm).
  - Systematic misalignments of layers/disks/sub-detectors O(1mm): relative rotation of layers.

"CSC Geometry"

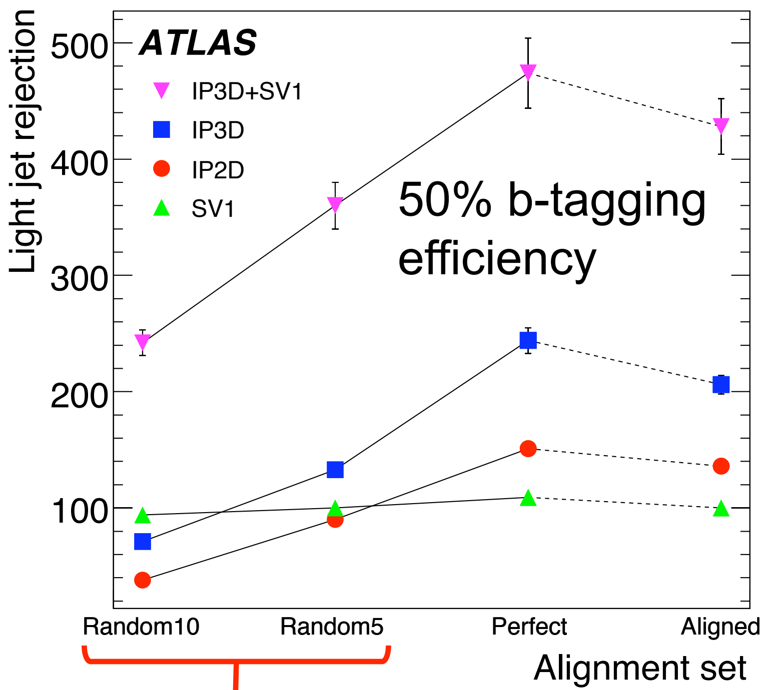
- Run large statistics alignment with simulated collision and cosmic ray data.

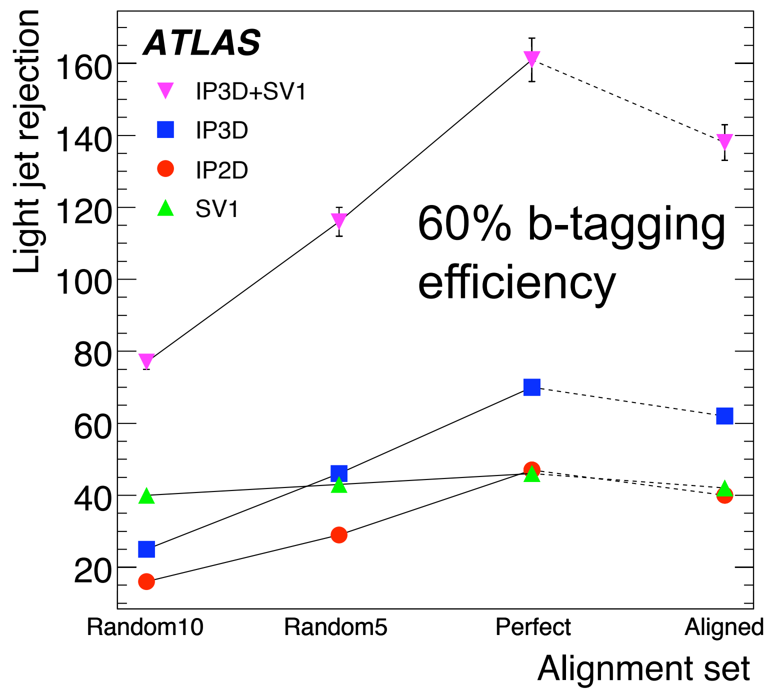




ID Misalignments & b-tagging

- Studied impact on impact parameter and secondary vtx tagging.





"**Random10**": O(10μm)
Random translations/rotations of Pixel modules/layers/ detector (SCT & TRT perfect). Roughly equivalent to Day-1 random misalignments.

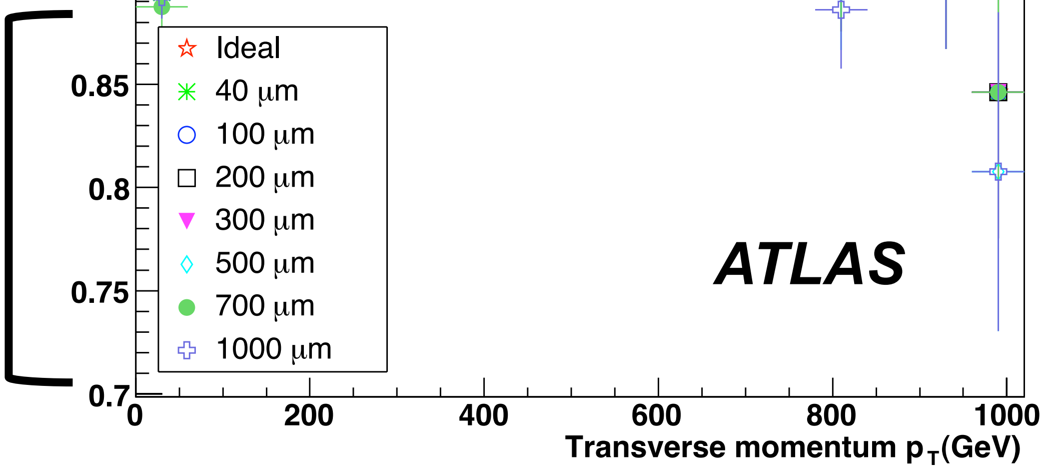
"**Aligned**": CSC Aligned Geometry.

- b-tagging performance relatively robust.
- 50% perf. loss with large random misalignments.
- Only a small perf. loss with CSC Aligned.

Random MS Misalignments

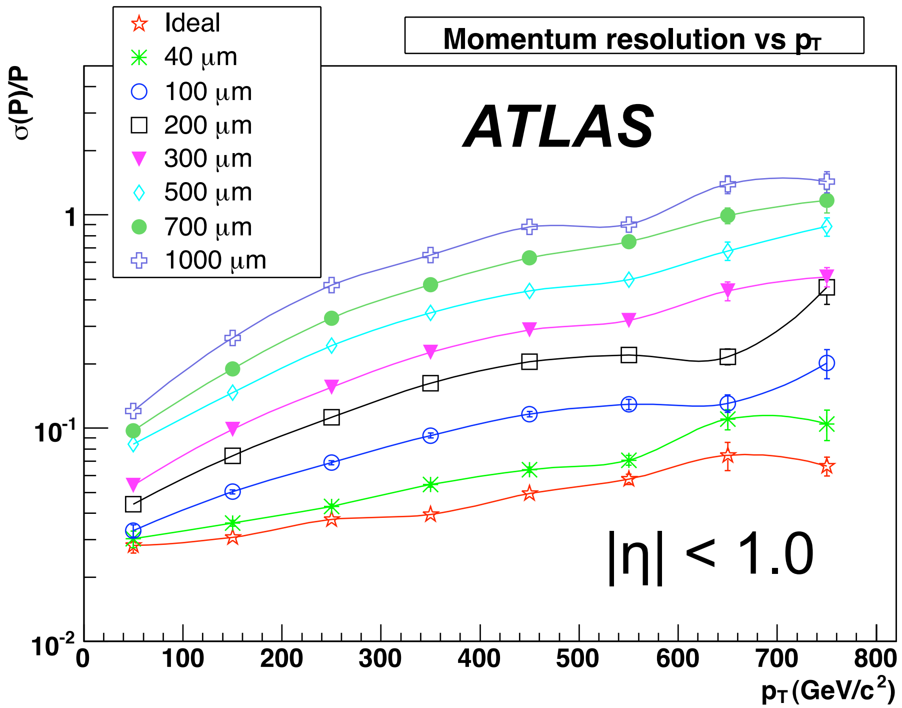
- Study impact of MS misalignments on standalone MS reconstruction of muons from Z' (1 TeV) decay and high mass Drell-Yan (> 300 GeV) decay.
- Generated independent random Gaussian translations and rotations of MS chambers with σ_{rot} (mrad) = 0.5 × σ_{trans} (mm). No correlations.

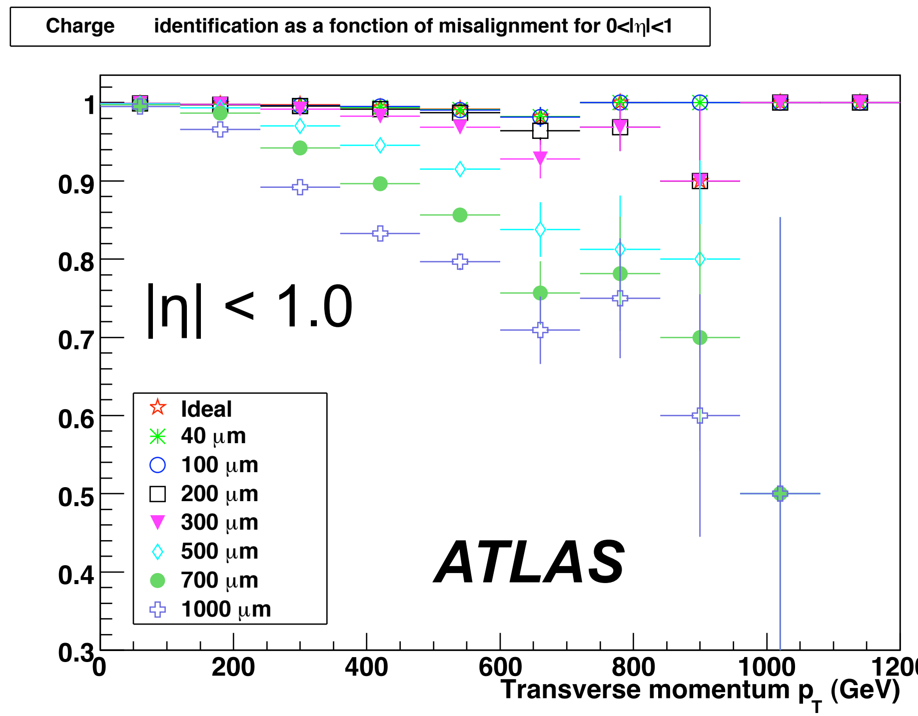
Variation of Gaussian widths from 40μm (target) to 1000μm (~size of sagitta, very pessimistic).



No significant impact on standalone muon efficiency.

Random MS Misalignments

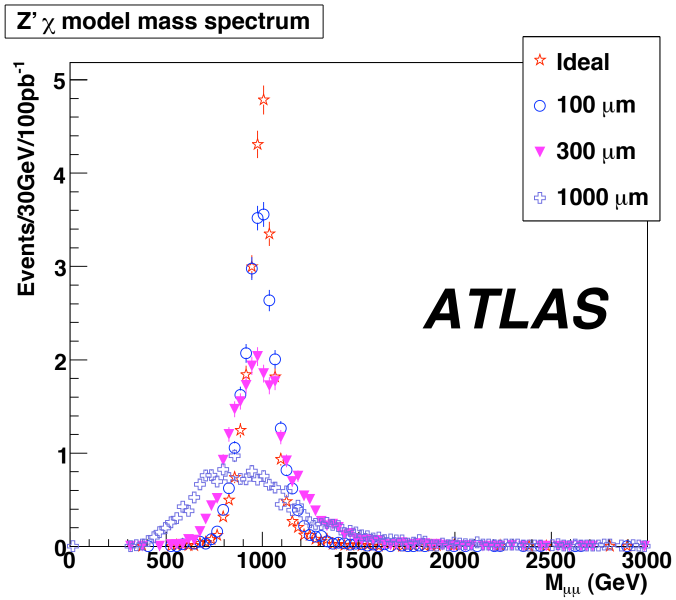


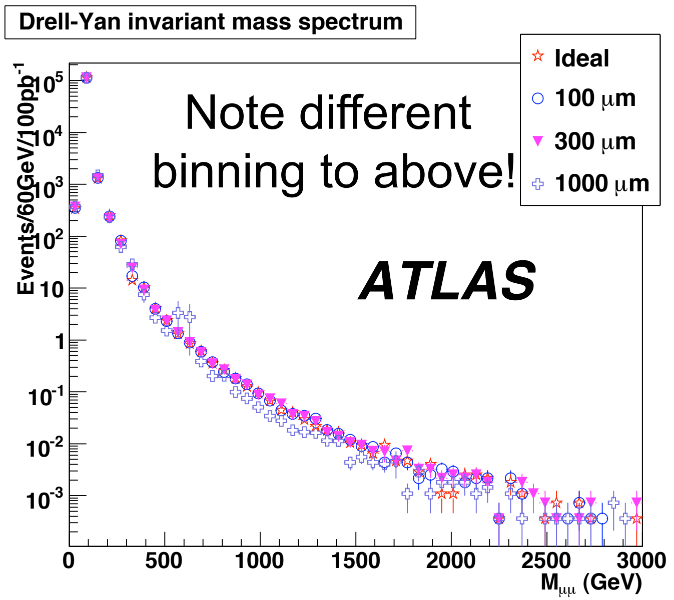


- Misalignments degrade momentum resolution.
- Impact of misalignments larger at larger p_T - as expected.
- At p_T 500 GeV degradation ~100% for ~100μm.

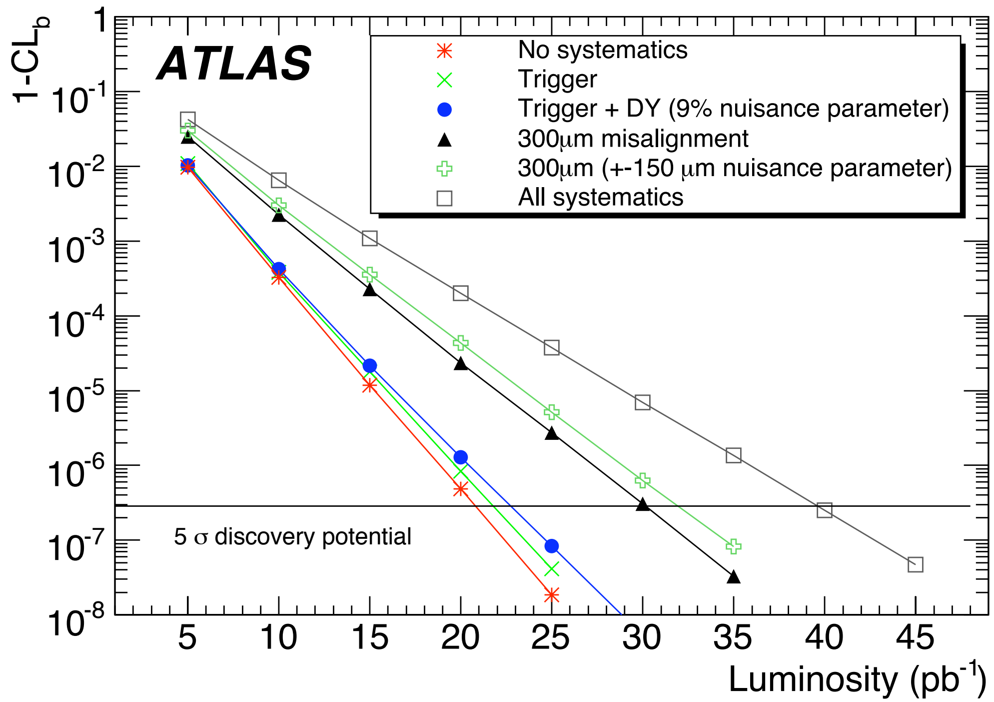
- Misalignments increase charge misidentification fraction.
- Effect only significant when misalignment ~ sagitta.

Impact of Random MS on Z' Search





- Impact on Z'_χ sensitivity evaluated.
- Combined muons used in analysis.
- MS misalignments "wash-out" the signal peak.
- Significant increase in luminosity for 5σ discovery.



Future Studies

- Impact of ID misalignments on electron performance.
- Take vertexing and b-tagging studies further: impact of systematic ID misalignments.
- Extend combined muon performance studies: Impact of internal ID and relative MS-ID misalignments.
- Propagate random ID and MS misalignments to “early data” physics analyses e.g. W/Z cross-sections, Top, minbias studies.
- Improve our understanding of size and type of weak mode ID misalignments that we are susceptible to - robustness tests of alignment algorithms.
- Propagate global systematic misalignments to longer term analyses e.g. Higgs, SUSY searches etc.

Summary & Conclusions

- Presented snapshot of ongoing studies into the impact of misalignments….
- In short term: random and systematic misalignments could be present in the ID and MS.
- Size and nature of longer term systematic misalignments hard to foresee.
- Studied impact of random and systematic ID misalignments on $Z \rightarrow \mu\mu$ $J/\psi \rightarrow \mu\mu$ and $B_d \rightarrow J/\psi K^{0*}$ reconstruction:
  - Significant impact seen in $Z \rightarrow \mu\mu$ mass resolution.
  - Material effects dominate $J/\psi \rightarrow \mu\mu$ and $B_d \rightarrow J/\psi K^{0*}$ mass resolutions.
- Misalignments do not significantly impact Tau performance.
- b-tagging performance relatively robust to misalignments studied so far - should extend to systematic misalignments.
- For high p_T muon analyses control of MS chamber alignment is vital.