Alignment Validation

Tobias Golling on behalf of

- **Introduction & Overview**
- **Mass resonances: J/Ψ, Υ, Z**
- **Resolution Effects**
- **Degenerate Modes**
- **Monitoring**
- **Validation with MC**
- **Summary**

LHC Alignment Workshop – September 05 2006

Outline

• All 4 experiments have roughly the same ideas for alignment validation

• Much is in common – there are some experiment-dependent peculiarities

• All: Much work to do for the validation of the alignment

➔ I will present the general ideas, using *examples* (incomplete) from the LHC but also from the Tevatron or the SLAC experiments

➔ At the end I will be more specific about the differences between ALICE, ATLAS, CMS and LHCb

Why Validate?

- The residual based alignment has limitations:

A 1-dimensional measure is used to determine 6 DoF per module (underconstrained) – this leads to more than one solution

➔ Physics is biased

➔ Validate to detect “wrong solutions”

Go one step further: Validation ⇒ Constraint

➔ Use as alignment correction, make alignment more robust

however, then we cannot use it anymore to monitor

Rule of thumb:

- “Practical constraint” ⇒ feed back into alignment algorithm as additional constraint (straightforward in global algorithms)
- Else: use as monitor

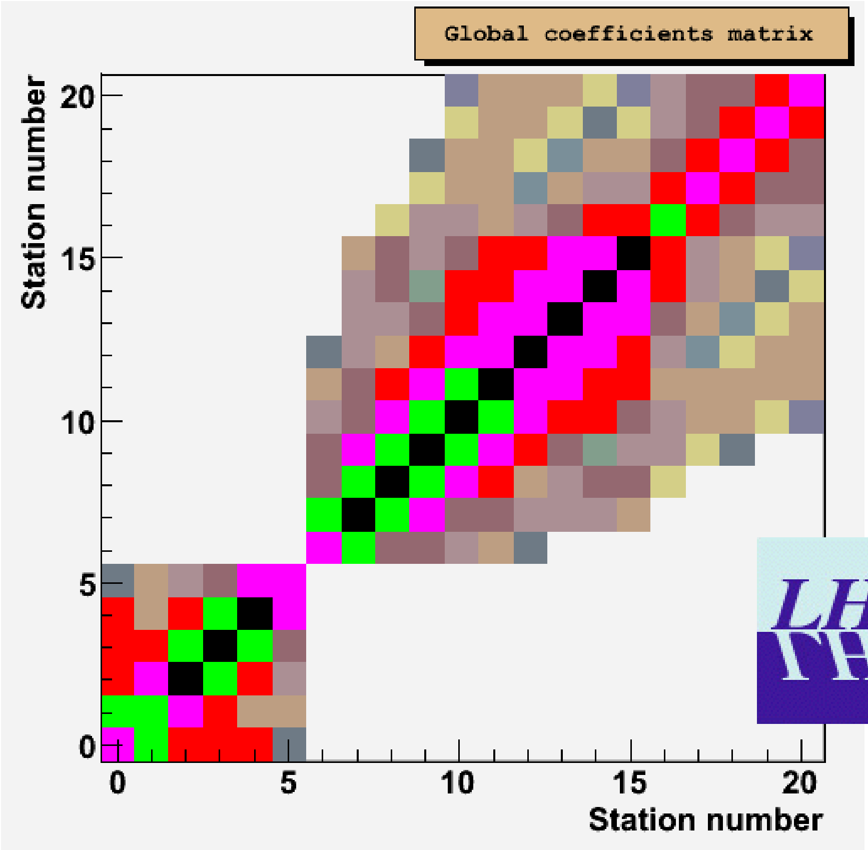
More Reasons for Validation

- Alignment monitoring sensitive to all kinds of (other) problems: tracking, reconstruction,...
- We only need to align what has an impact on physics
  ⇒ Invert the argument:
  If all physics observables look as expected then we have good reason to believe that our detector is sufficiently aligned
- Goal for Day 1: working tracking reconstruction!
  It's always easy to blame alignment – be prepared for this!

Possible Handles

- Tracks correlating different modules, not from beamspot
  - Cosmics ⇒ Barrel, off-axis tracks (can reconstruct?), “two arms” muon trigger, ATLAS: ~40Hz through Inner Detector, ~1Hz through Pixel
    Caveats: Illumination not uniform / low statistics / low momentum
  - Halo muons ⇒ Endcap
  - Beam-gas, Caveat: low momentum (E_{CM}=113GeV)
  - Parasitic collisions at 0.9TeV

Rate, trigger? - ATLAS: Minbias scintillating trigger



Alignment algorithms more robust if parameter matrix well populated

Possible Handles cont'd

- Standard candles: J/Ψ, Υ, Z,...
  - Mass resolution probes pT resolution

  Caveat: Measure only convolution of material description, B-field uncertainty, misalignments ⇒ Disentangle!
  Rate, trigger?

- Overlap hits in the same layer: $\text{residual}_{\text{outer}}$ - $\text{residual}_{\text{inner}}$
  - Not affected by misalignments elsewhere in the detector
  - Errors on $\text{residual}_{\text{outer/inner}}$ are highly correlated and subtract out
  - Less sensitive to MS, use lower pT and higher track density
  - Circumference constraint

  Caveats: Low statistics
  Usually used already in alignment algorithm

- Use redundancy of detectors: E/p, eta-phi match between tracking and calorimetry

- Alignment monitoring:
  - Lifetime, mass, residuals vs. eta, phi, pT, charge, module position,...

Possible Handles cont'd

- Biased track parameters can probe some degenerate modes
  e.g. IP distribution, charge asymmetries,...

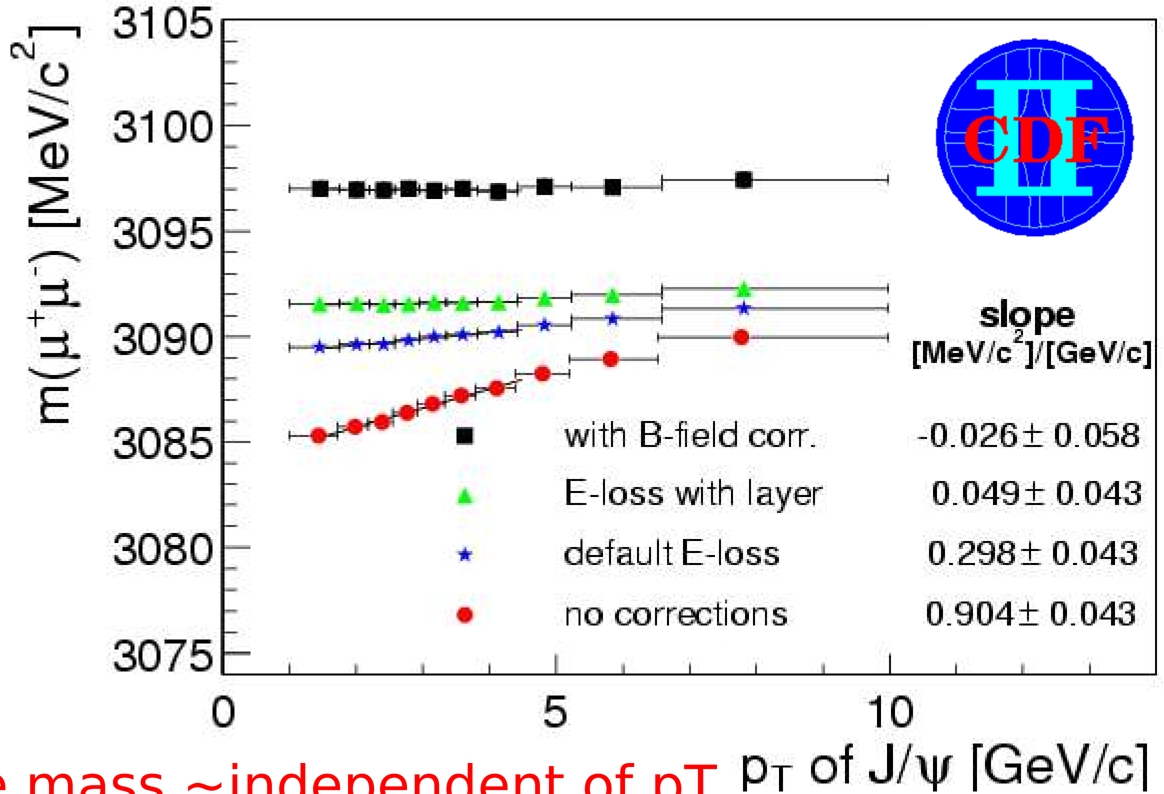
- Vertex constraint: common vertex for a group of tracks

- Compare track-based alignment with survey and hardware alignment
  - ➔ Survey & hardware based alignment doesn't have the problem of "wrong solutions"

- Magnet-off data can eliminate some "wrong solutions"
  Caveat: turning B-field on and off changes the geometry,
  no pT measurement

Disentangle E-loss, B-field, Misalignments

- Use mass resonances: J/Ψ, Υ,Z decaying to $\mu^+\mu^-$
- Plot $m(\mu^+\mu^-)$ vs pT
- At low pT sensitive to E-loss
- B-field effect independent of pT
- At high pT more sensitive to misalignments



Procedure:

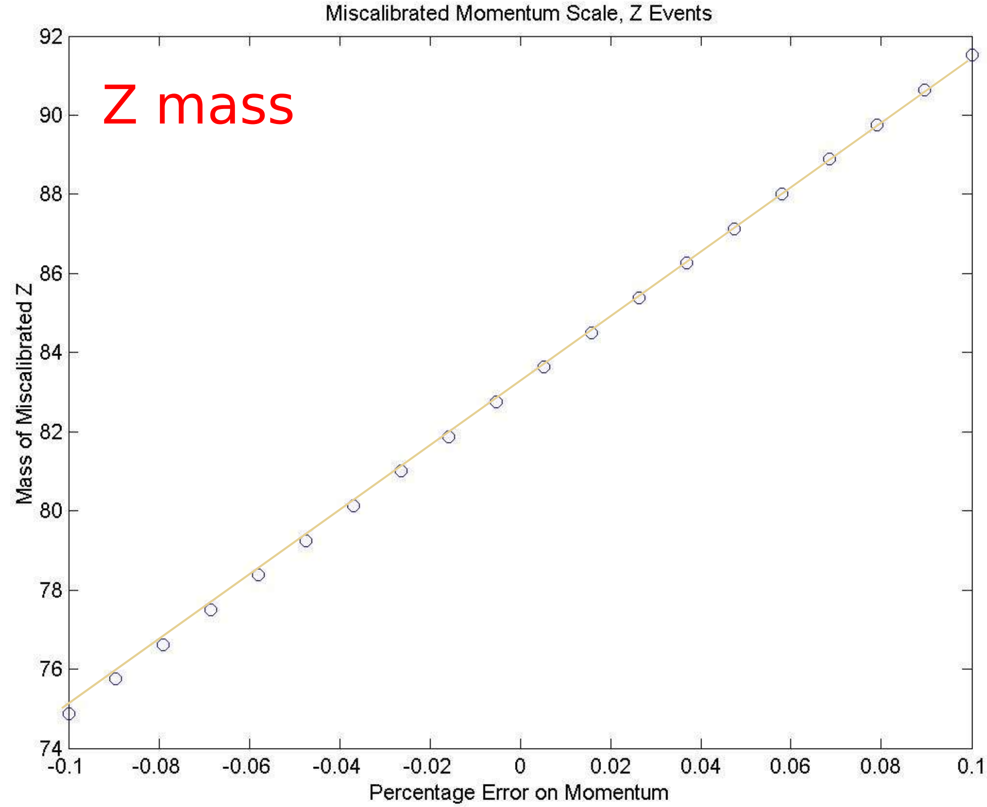
- First fix material budget to make mass ~independent of pT
- Iterative process, also cross check with conversions
- Residual discrepancy attributed to B-field scale (or misalignment)
- Handle: magnetic field effect independent of charge, alignment effect charge dependent ⇒ Look for charge asymmetry of muons

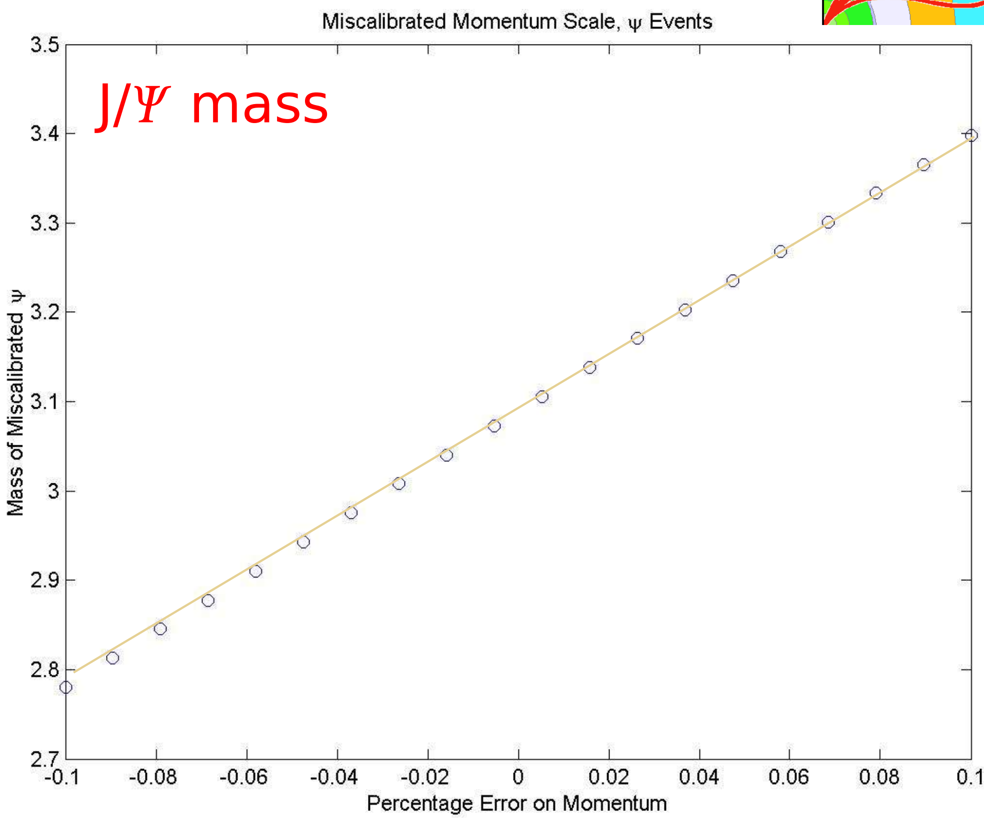
LHCb

- Run alignment with magnet off data
- Small global corrections expected with magnet on
- Residual effects due to B-field or material

J/Ψ and Z Mass

- Probe at different scales: J/Ψ, Z
- Z important for validation of muon alignment





$M^2 = 2P_1P_2(1-\cos\theta_{12})$

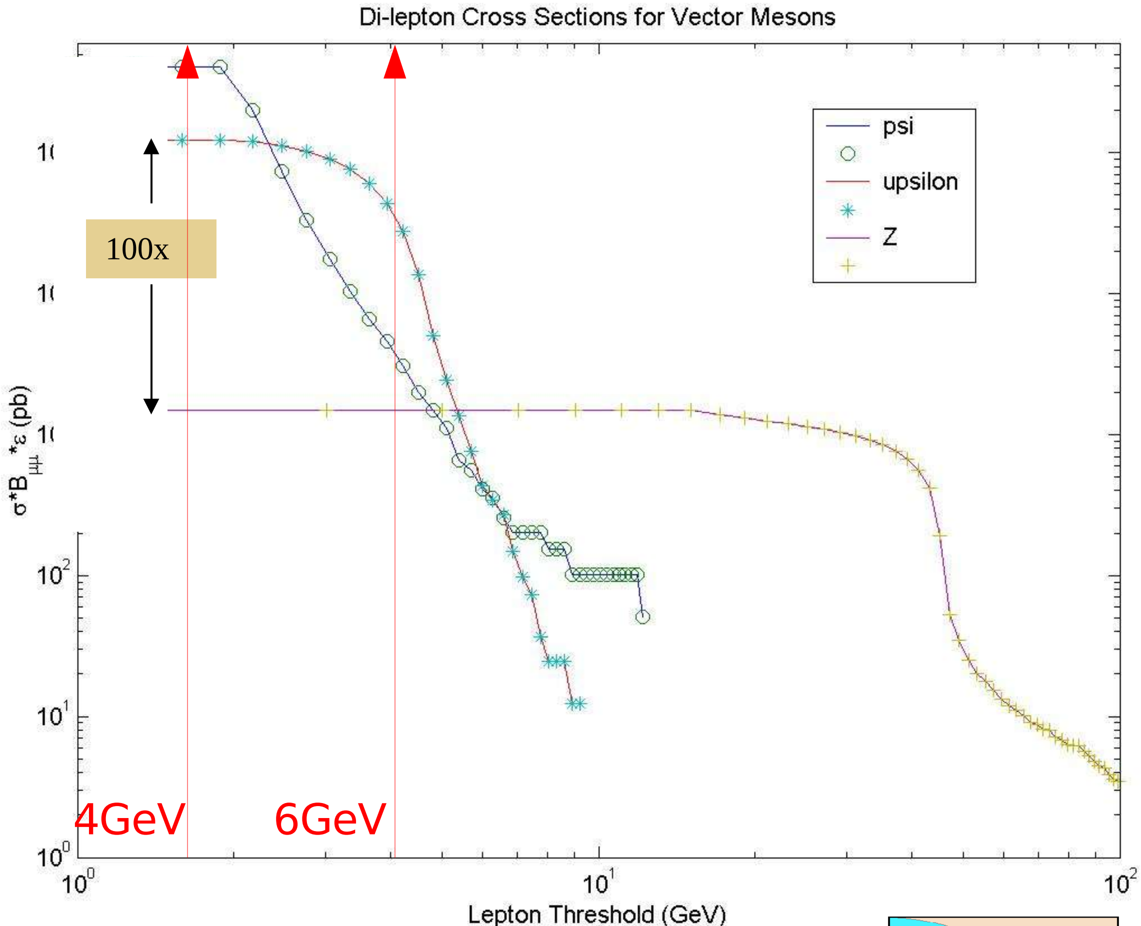
$P \rightarrow P(1+\alpha)$, $\alpha = dP/P$

$(M+dM)^2 = 2P_1P_2(1+\alpha)^2(1-\cos\theta_{12})$

$dM / M \sim \alpha = dP / P = dB / B$

With $P = 0.3\ B(\mathrm{T})\ \rho(\mathrm{m})$

J/Ψ and Υ accessible by Trigger?

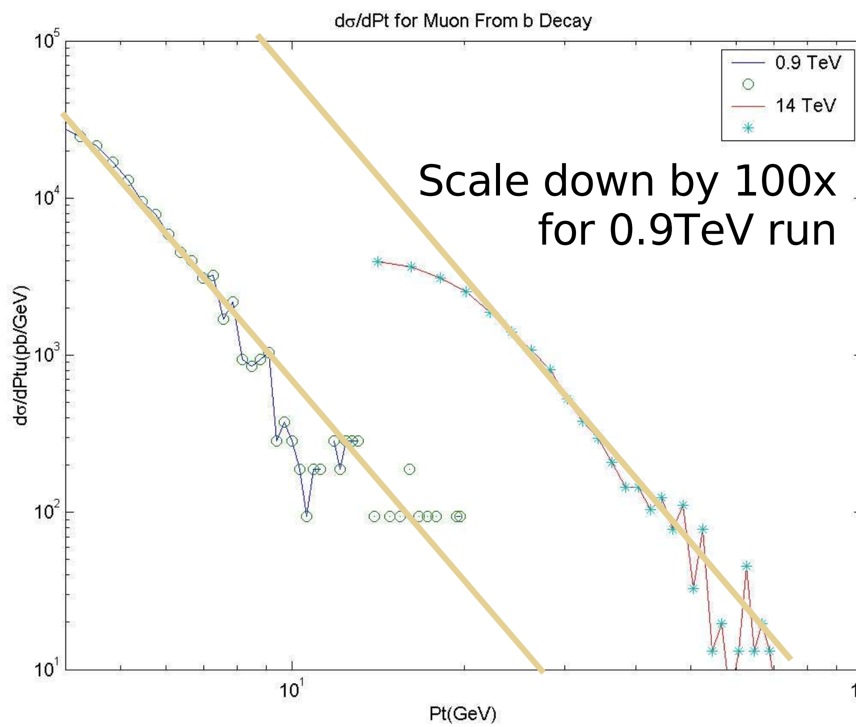


4 GeV trigger threshold possible at low luminosity?

⇒ Use high cross section resonances

Also K_s in Minbias?

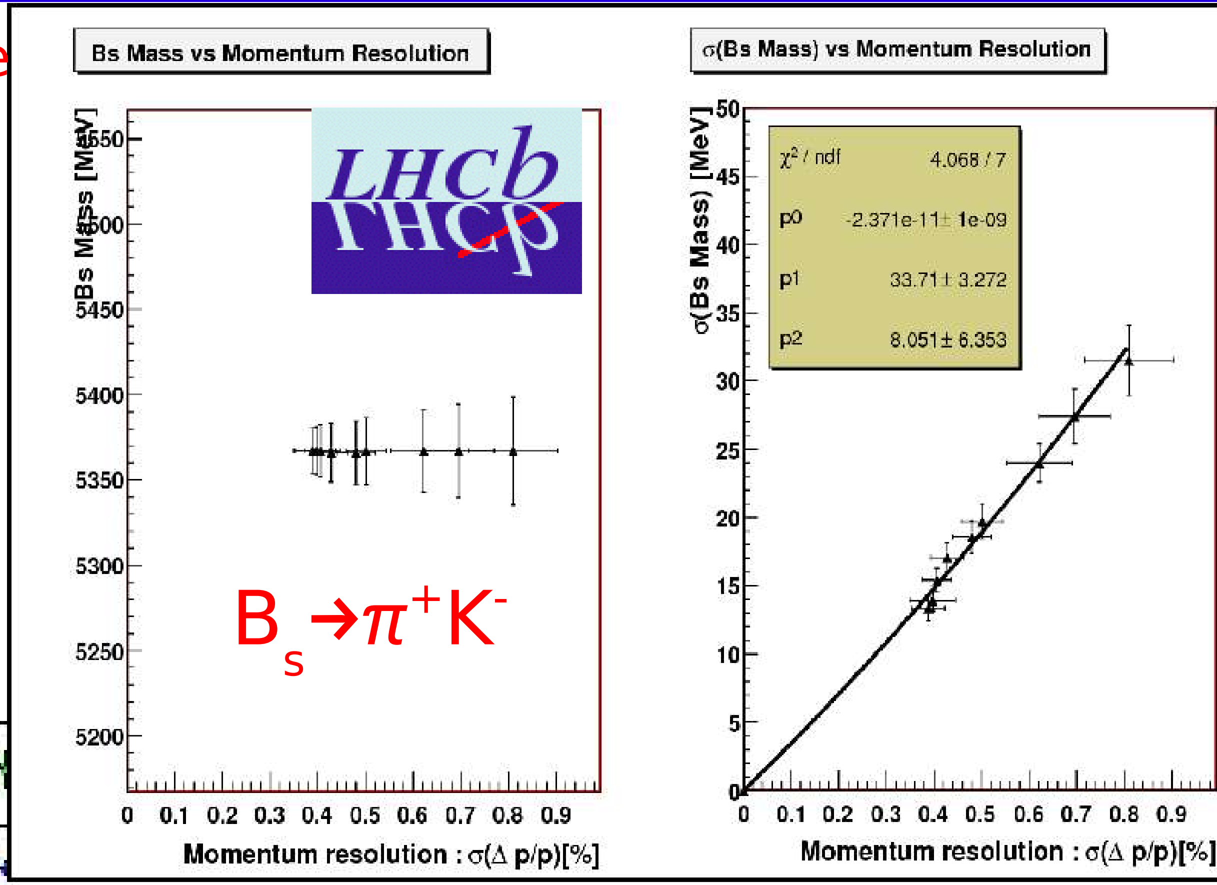
- J/Ψ rate from B decay?
⇒ Lower threshold using vertex and invariant mass cut



- J/Ψ and Υ are "barrel-poor"

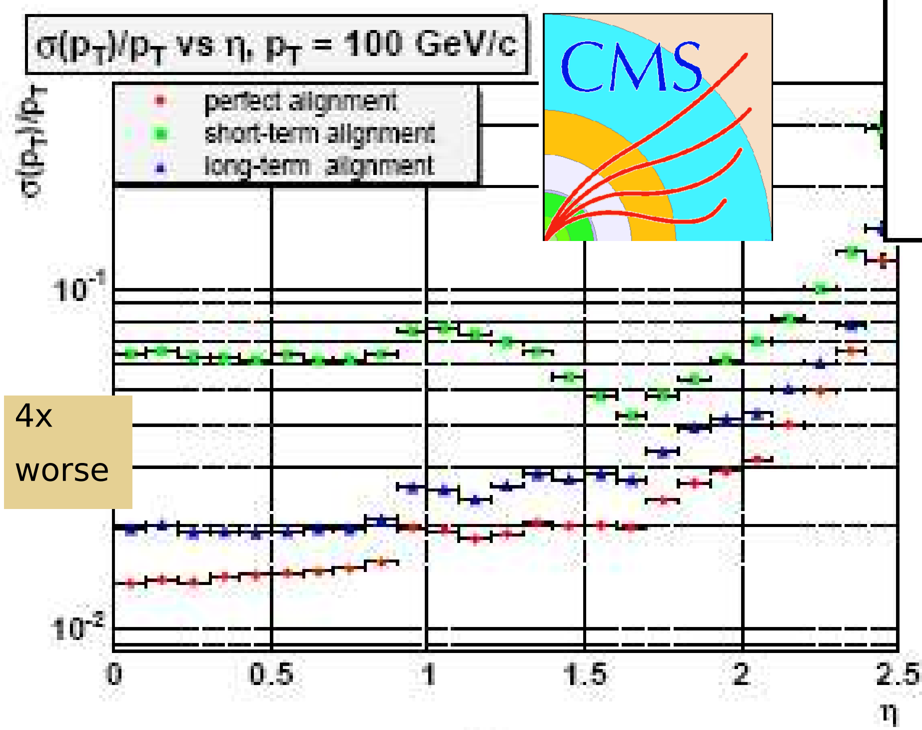
Mass Resolution vs. Momentum Resolution

- Momentum resolution sensitive to both B-field inhomogeneities & misalignments



LHCb: B known with uncertainty < 0.03%

⇒ momentum resolution affected by < 10%



- Mass resolution is a good measure of the momentum resolution

Weakly Defined Degrees of Freedom

- Alignment algorithms based on minimization of track residuals suffer from a class of detector deformations (degenerate modes or χ^2 invariant deformations) that alter the shape of tracks in such a way that they are still helical but with certain properties of the helix modified:
biased track parameters – physics is biased

- Even if tracks with different momenta and sign charge are used

- The barrels are left progressively rotated/translated proportional to $ar^2 + br + c$

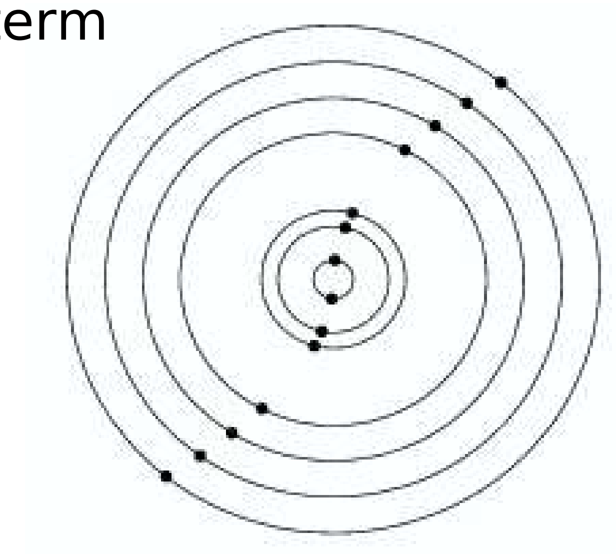
- Deformations typically of the same size as the initial random misalignments

- Low momentum tracks (~< 2 GeV) less affected
  Caveat: Multiple scattering

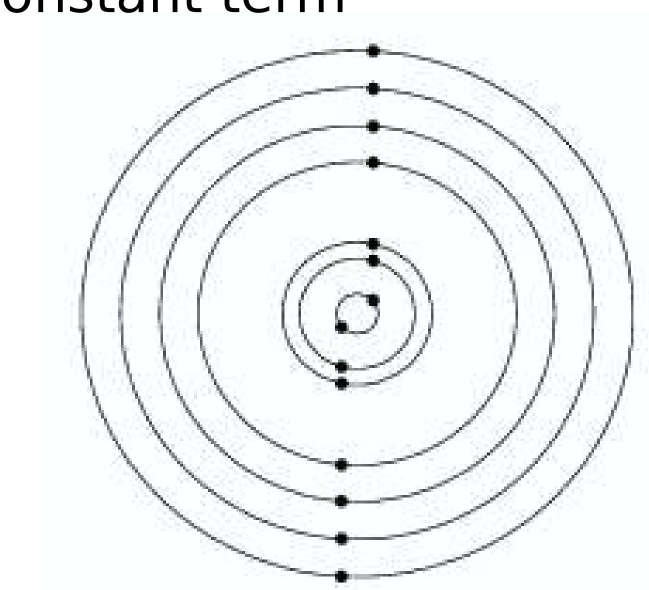
Rphi Rotation

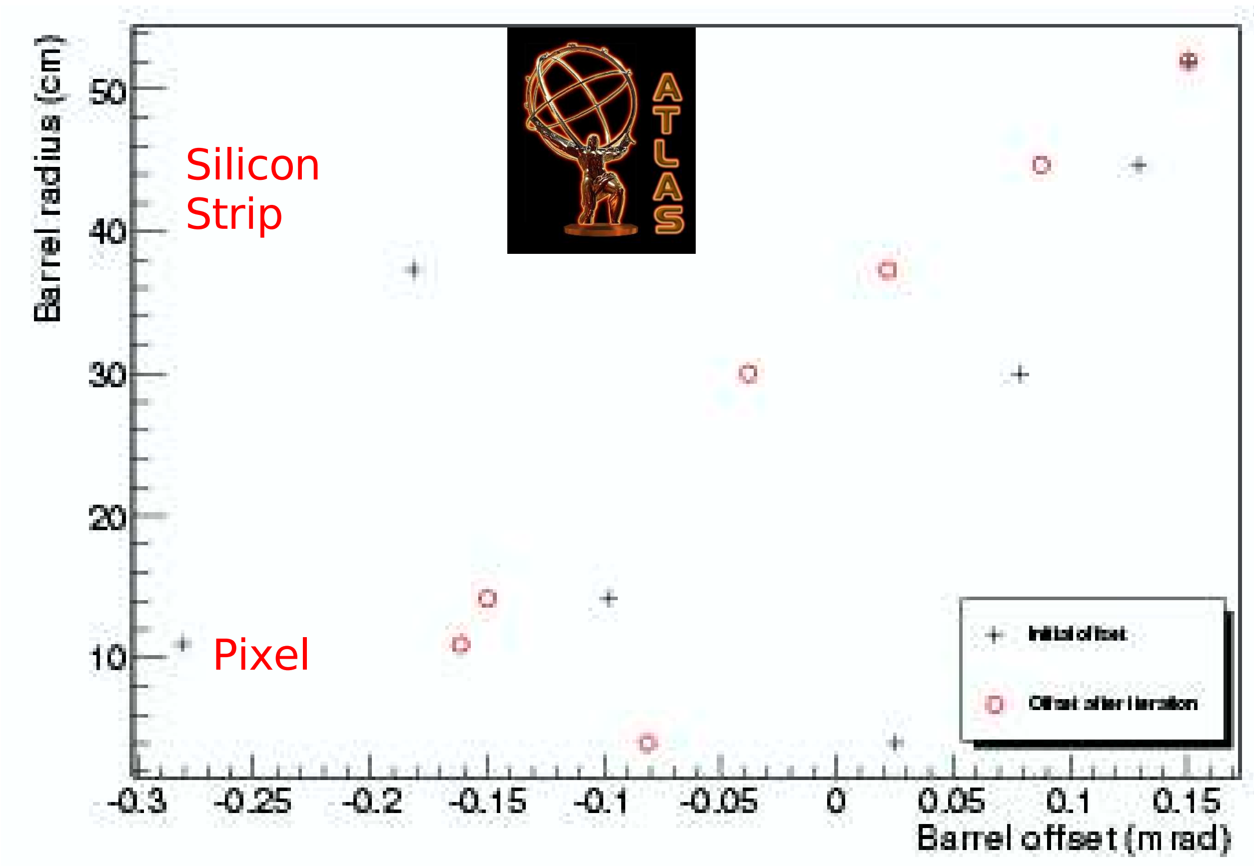
Barrels are progressively rotated as you move away from the beam-line

Quadratic term



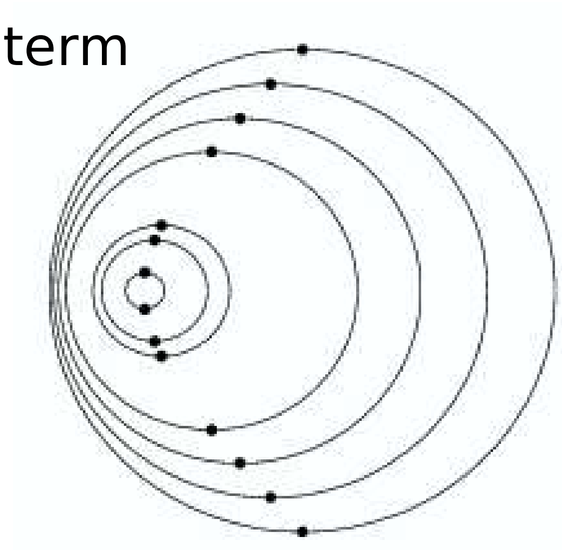
Constant term





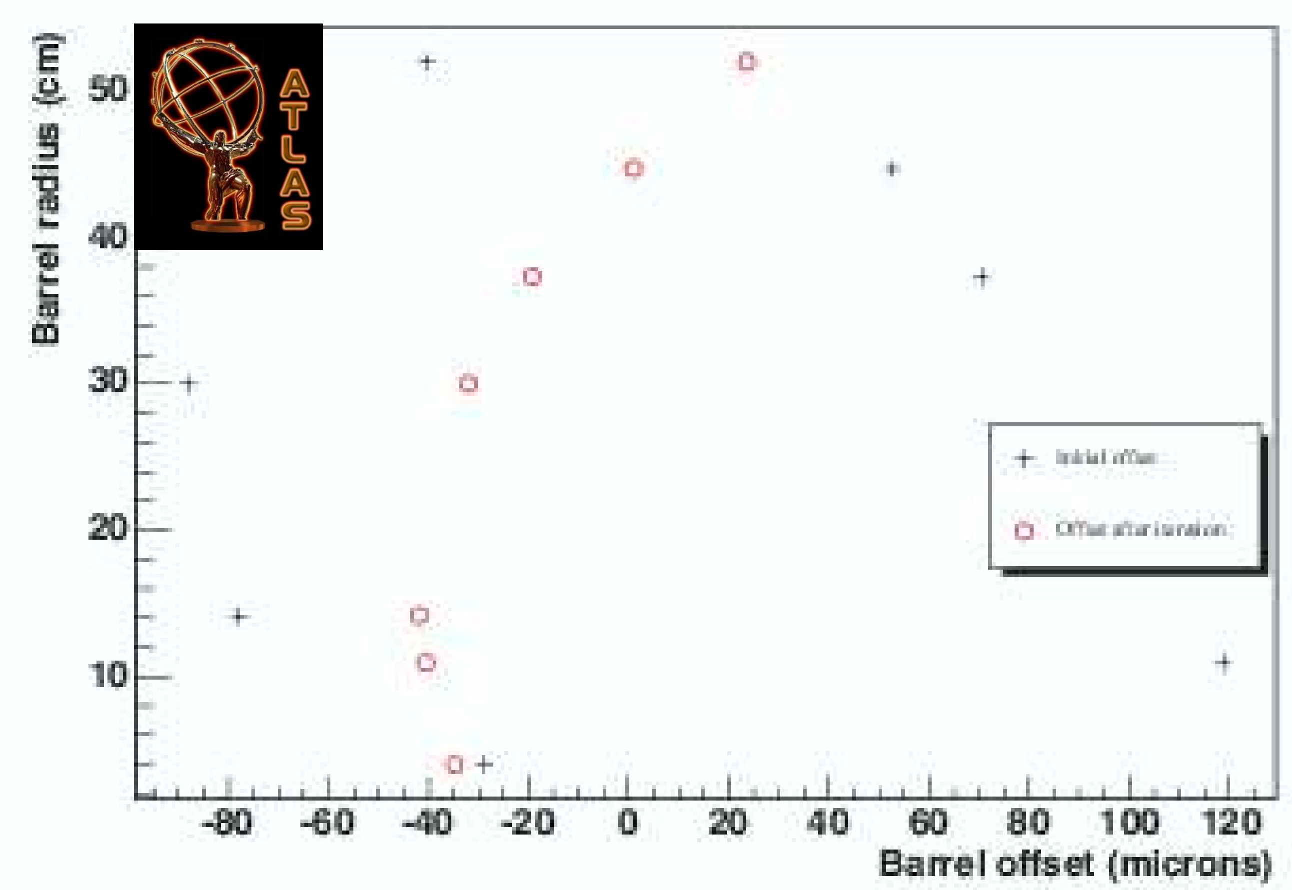
X / Y Translation & Rotation

Quadratic term



X / Y Translation:

Barrels are progressively translated as you move away from the beam-line



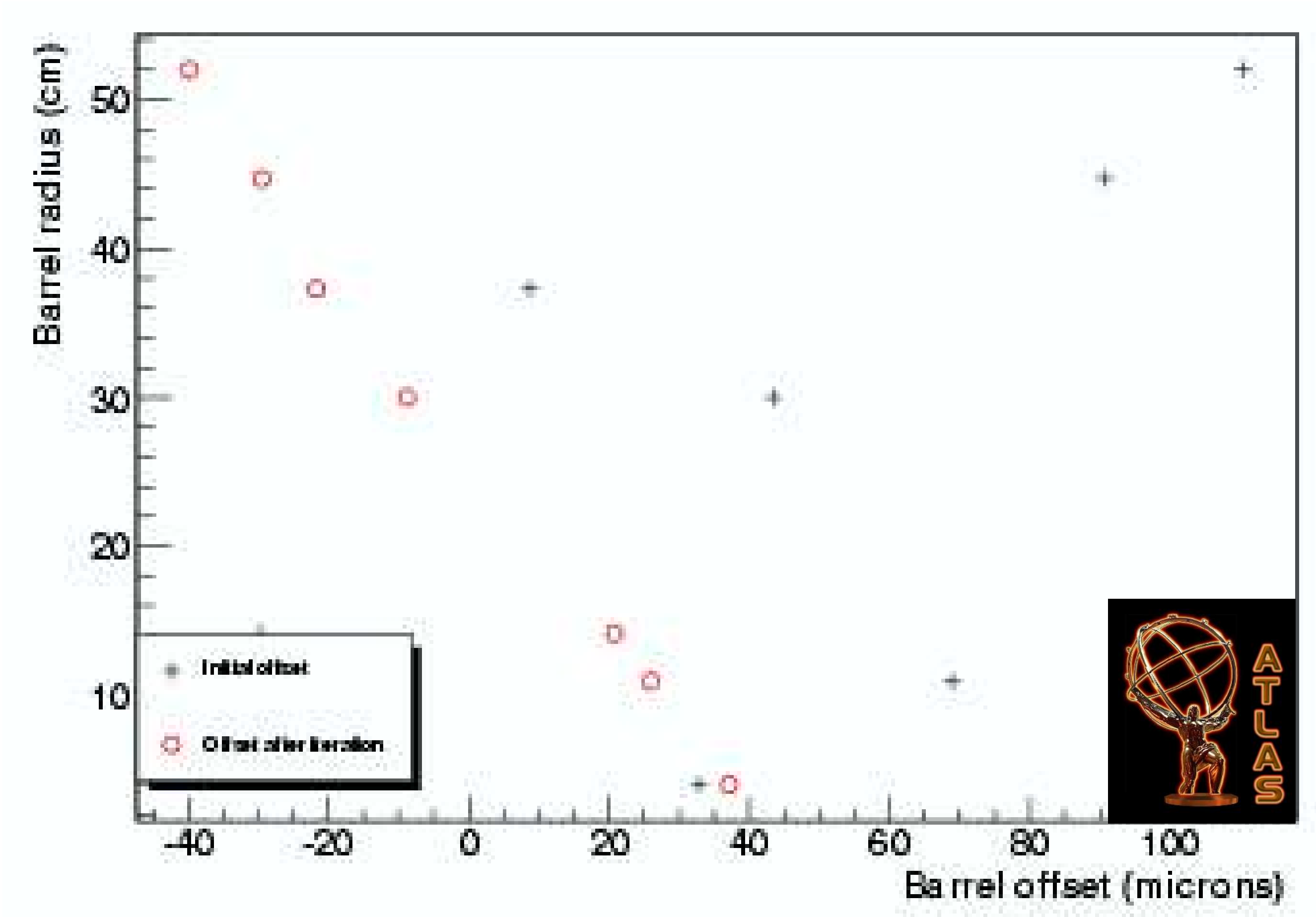
X / Y Rotation:

Barrels are progressively rotated as you move away from the beam-line

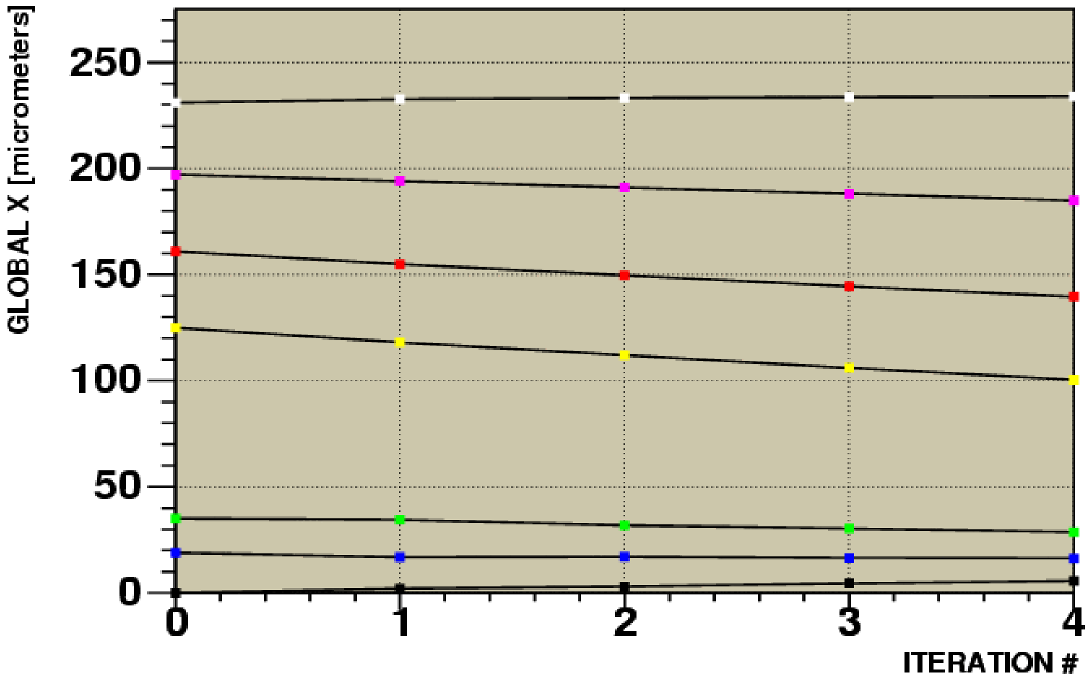
Z Translation

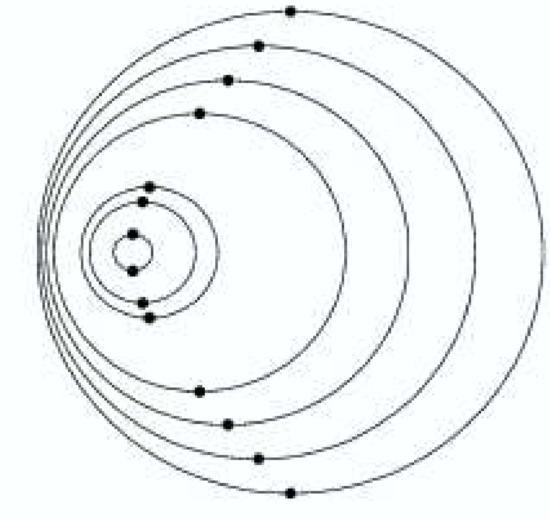
<u>Telescoping (only linear term):</u>

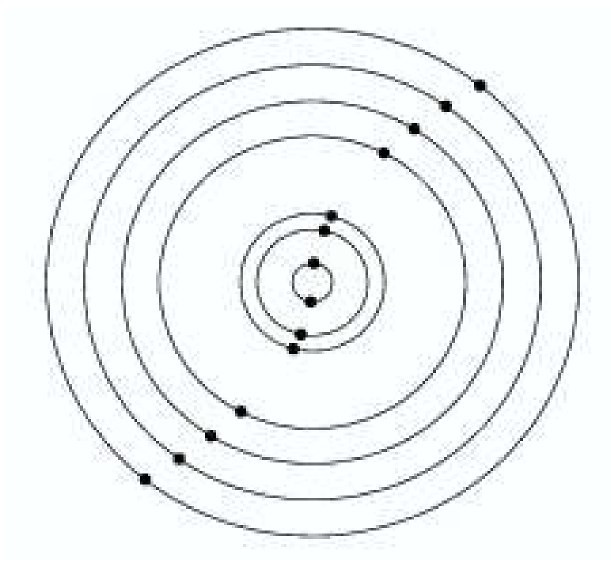
- Projection of high momentum helical tracks onto RZ plane is straight line
- Z misalignments that grow linearly with z keep the tracks as straight lines

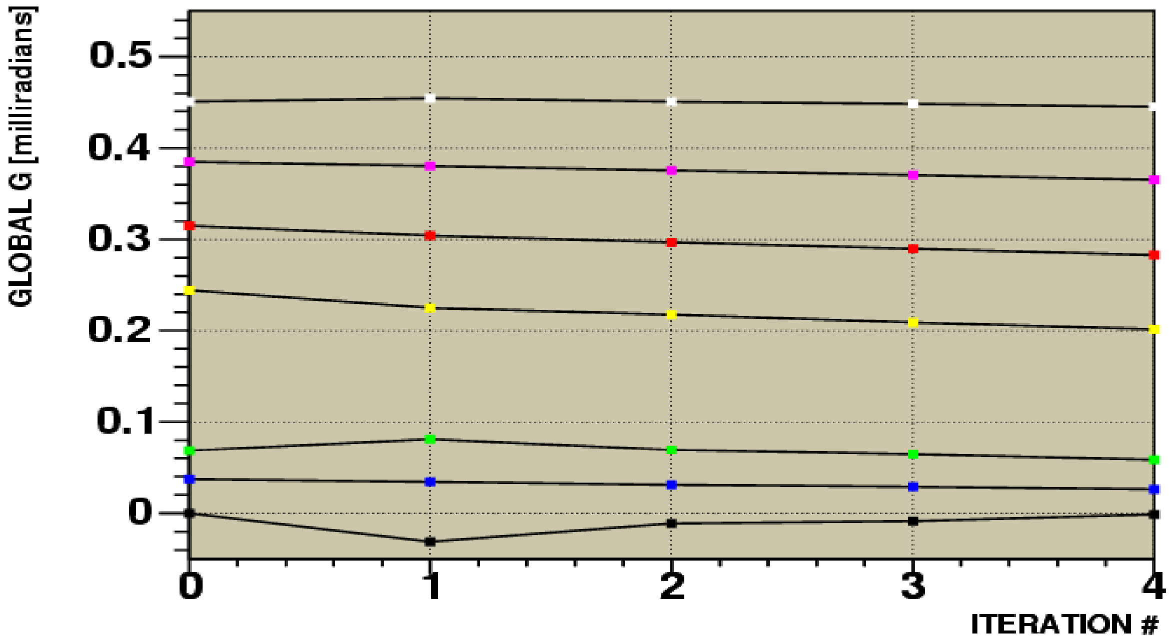


Deformations are stable vs. Iterations









Methods for Removing RPhi Mode

Observable: Bias of pT and IP distribution

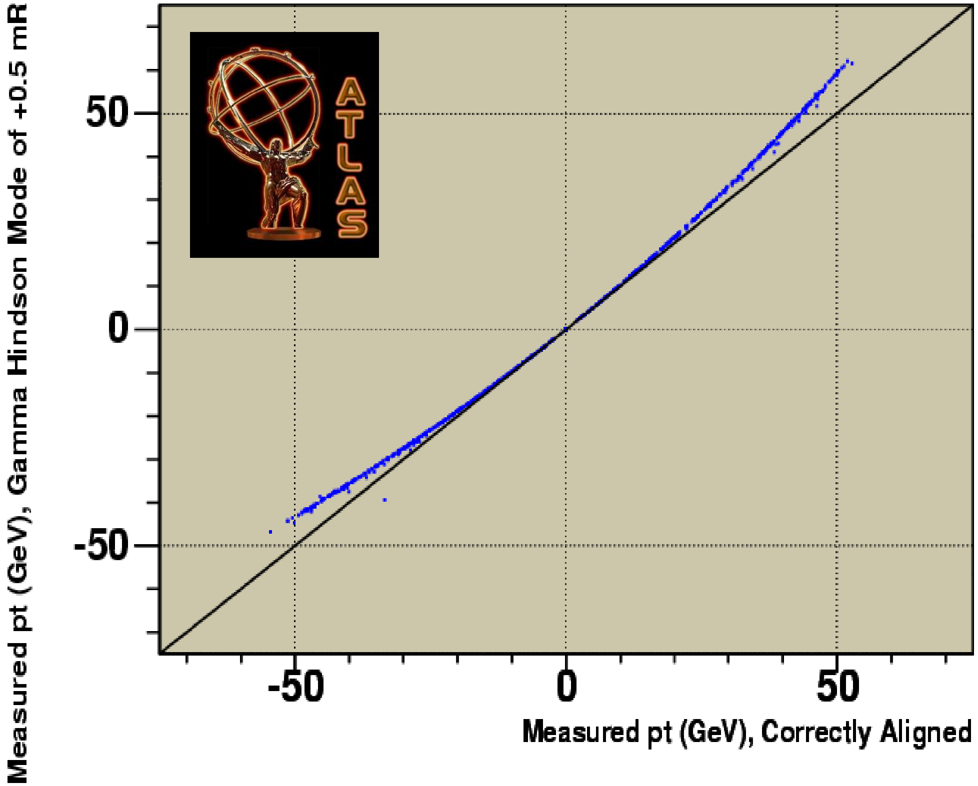
Quadratic term:

- bias on curvature
- Opposite bias for positively and negatively charged tracks
  - ➔ E/p
  - ➔ Known charge-symmetric distributions

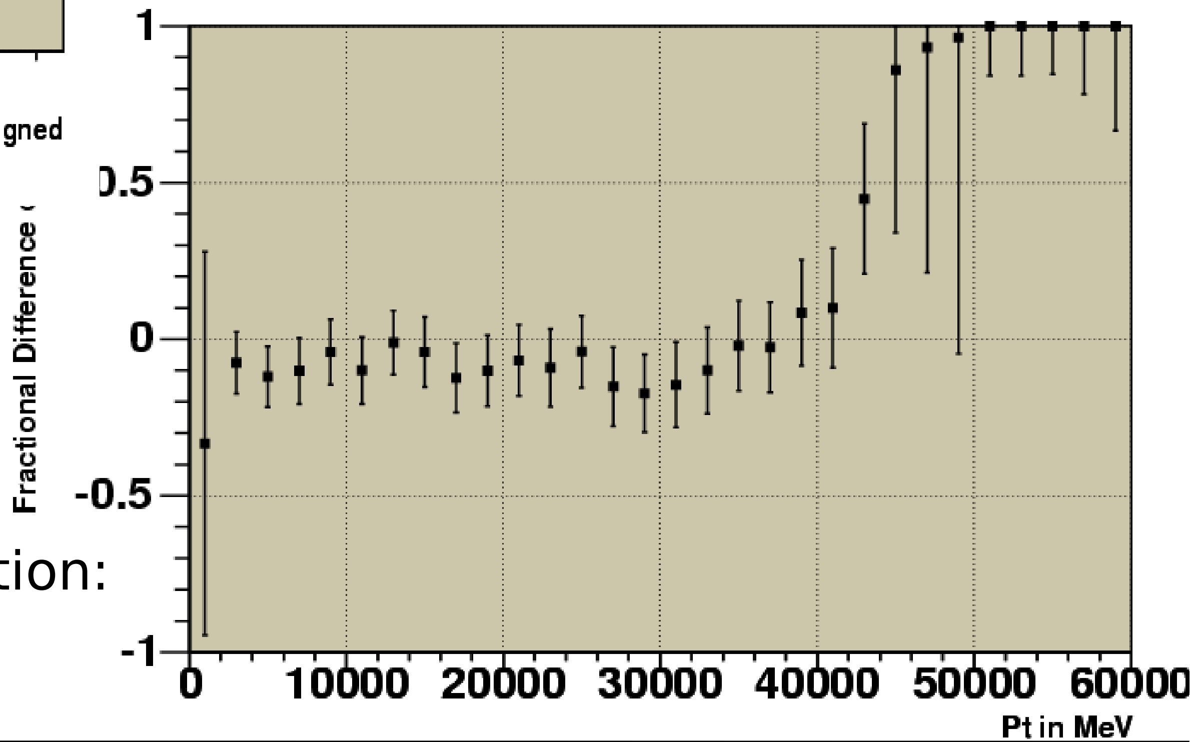
Constant term:

- related to transverse impact parameter

Charge Dependence

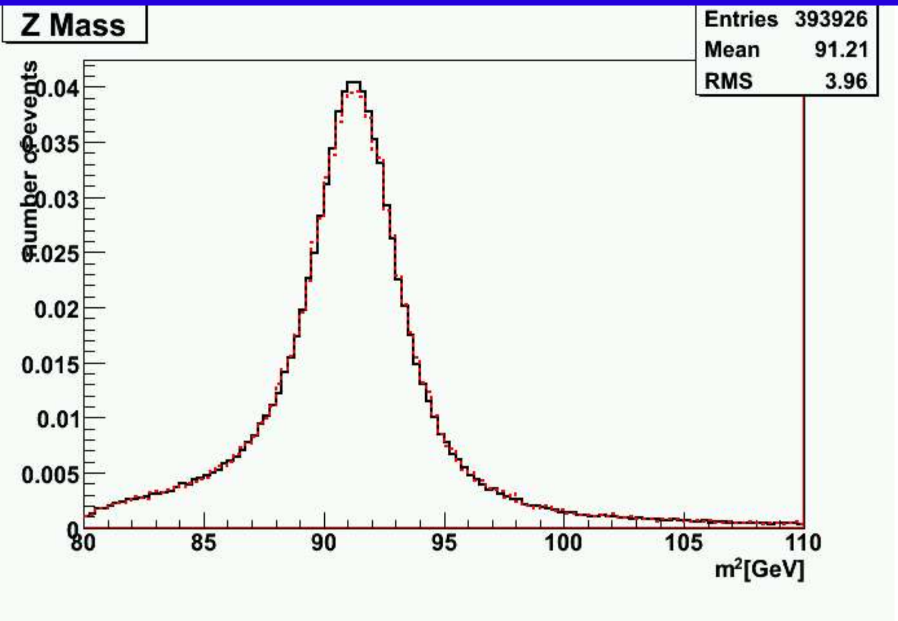


- Opposite bias for negative and positive particles
- Mismeasurement of ~7GeV at 50 GeV for misalignment of 0.5mrad at 50cm
- Charge flip at ~1 TeV



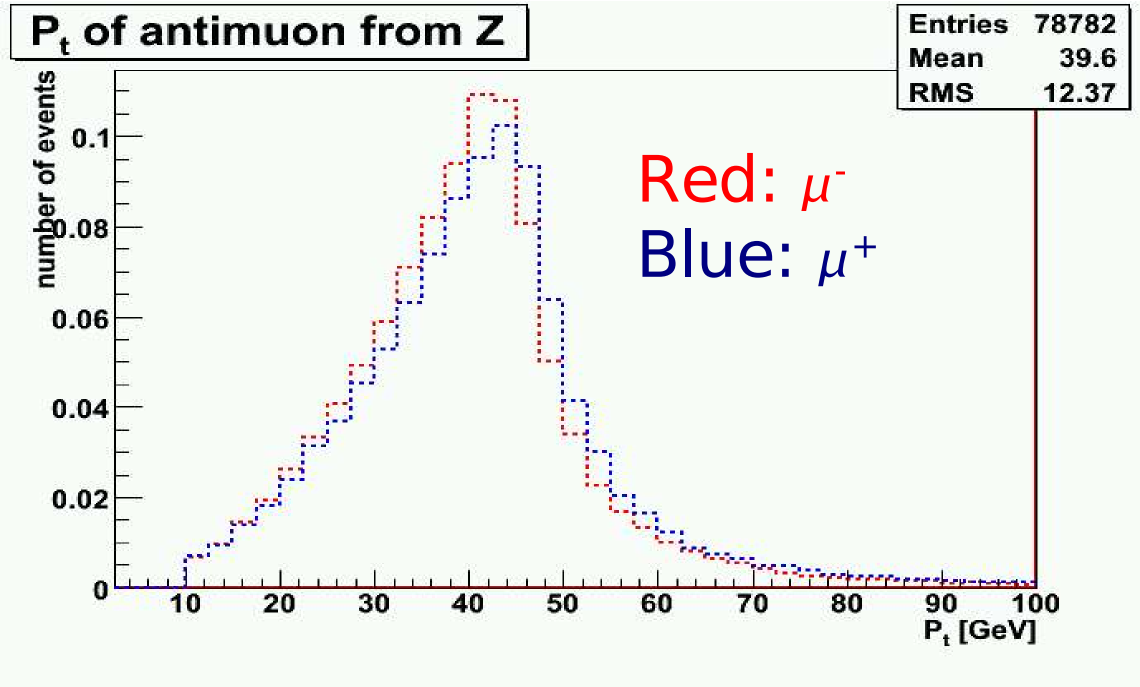
For charge-symmetric pT distribution: plot (pos-neg)/(pos+neg) vs. pT

Charge Dependence



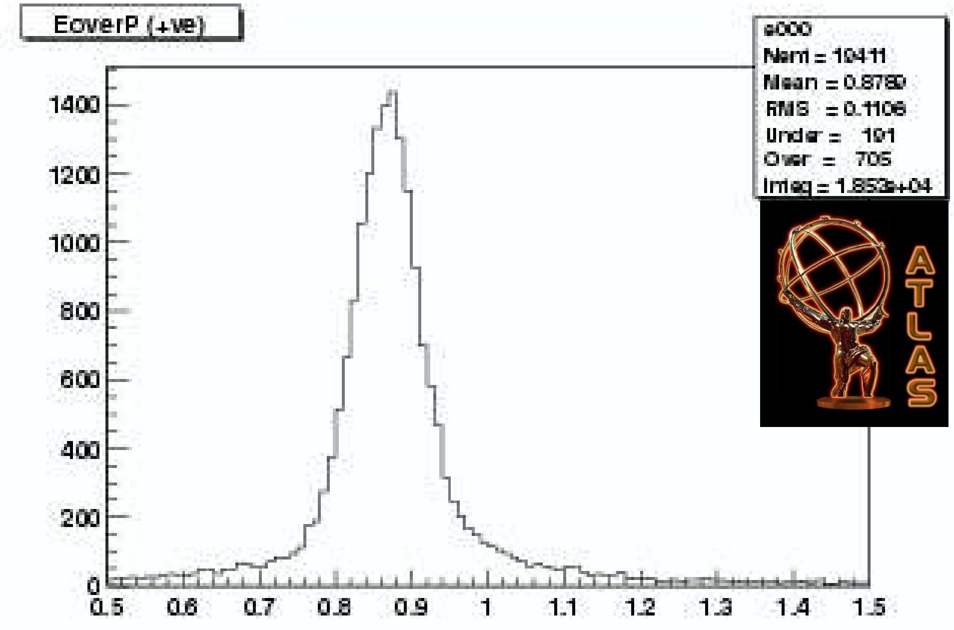
Black: ideal geometry
Red: Rphi rotated geometry

χ^2 and the Z-mass are hardly affected by this misalignment: $M^2 = 2P_1P_2(1\text{-}\cos\theta_{12})$



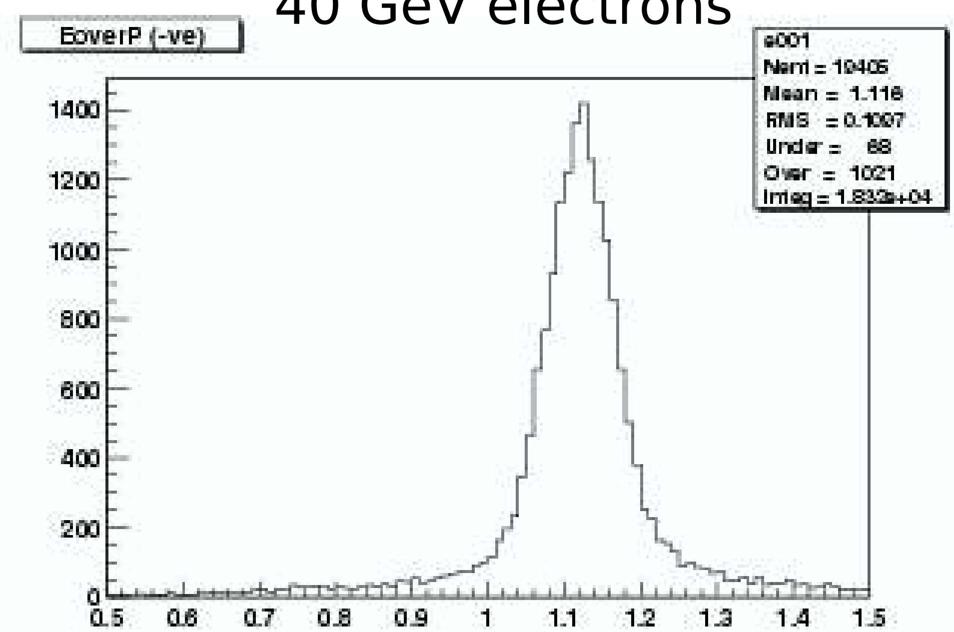
PT distribution of μ^+ and μ^- sensitive to this misalignment

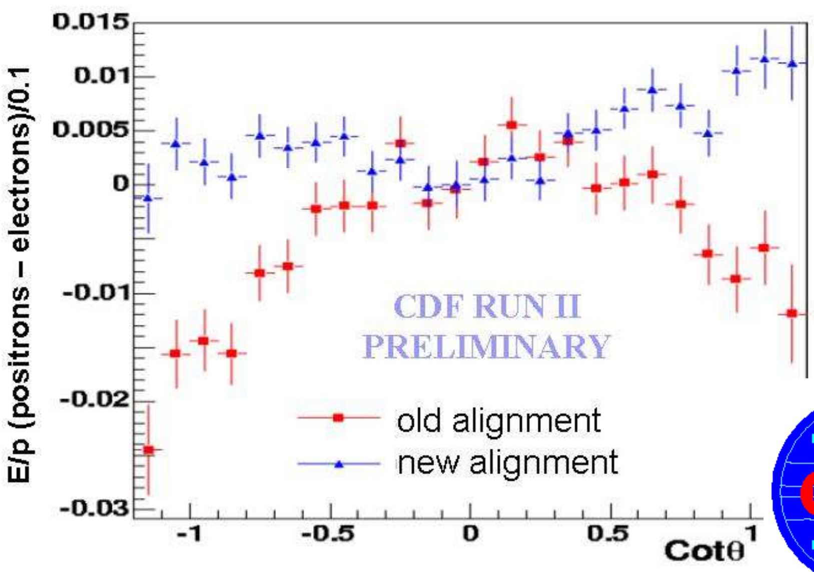
E/p - Quadratic Term



<u>Calorimeter calibration:</u>
Only require that E/p distribution is the same for + and – particles when no misalignments are present

40 GeV electrons

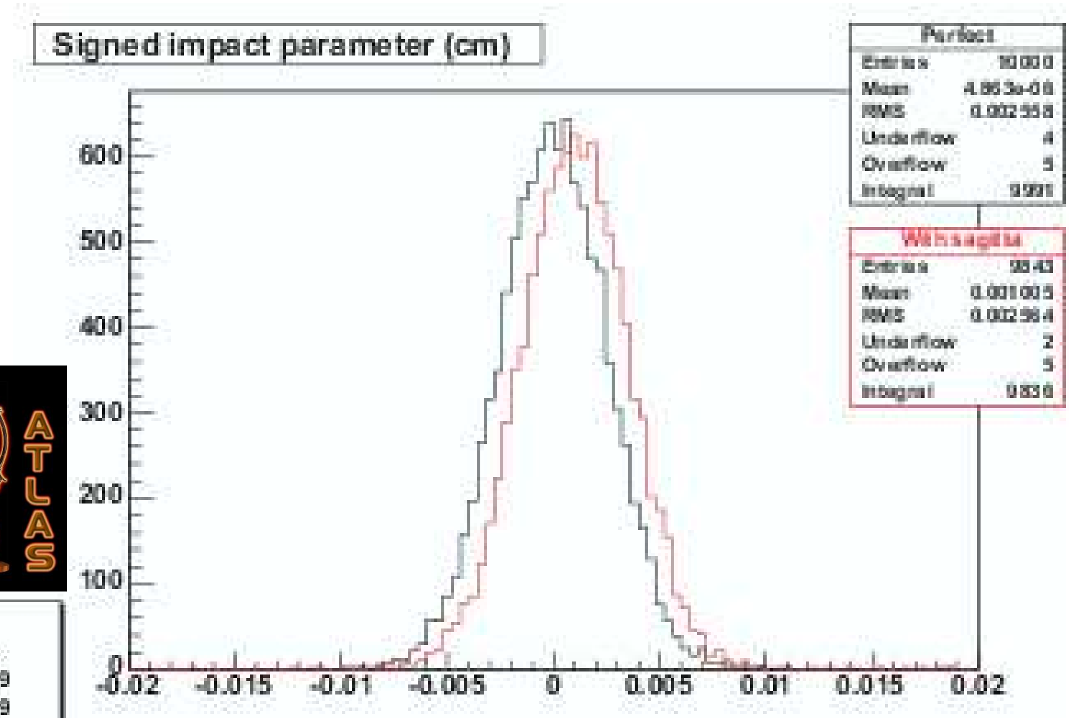


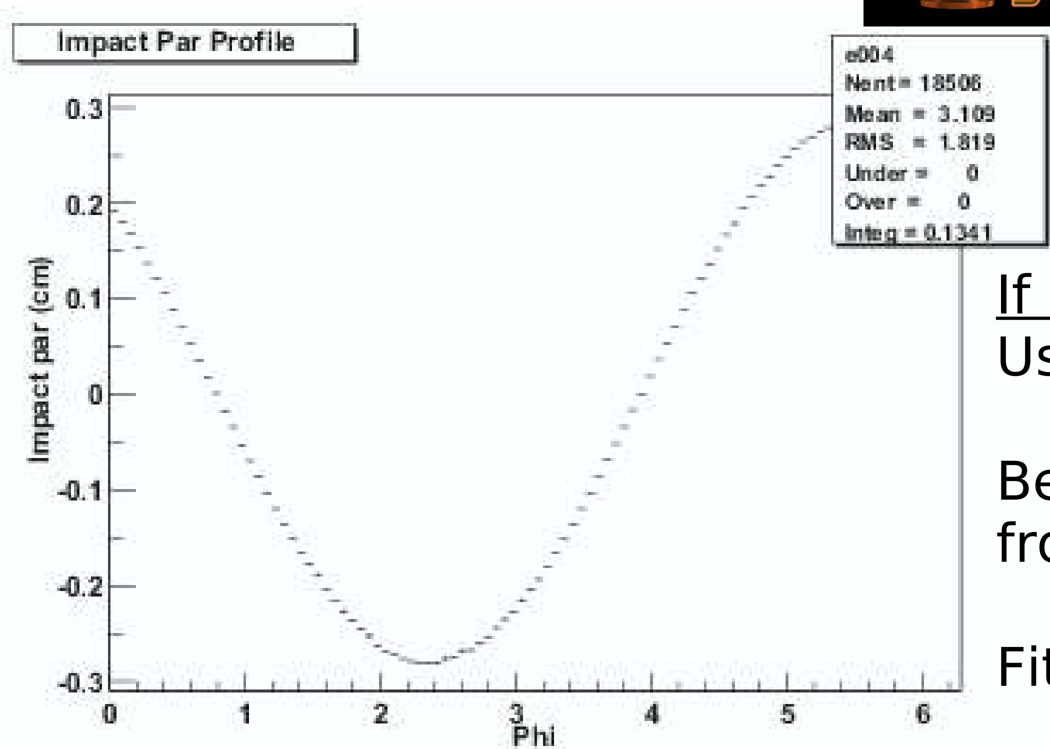


Impact Parameter - Constant Term

Perfect alignment: mean impact parameter expected to be zero

Rphi rotation: mean IP non-zero





<u>If beamspot is offset:</u>

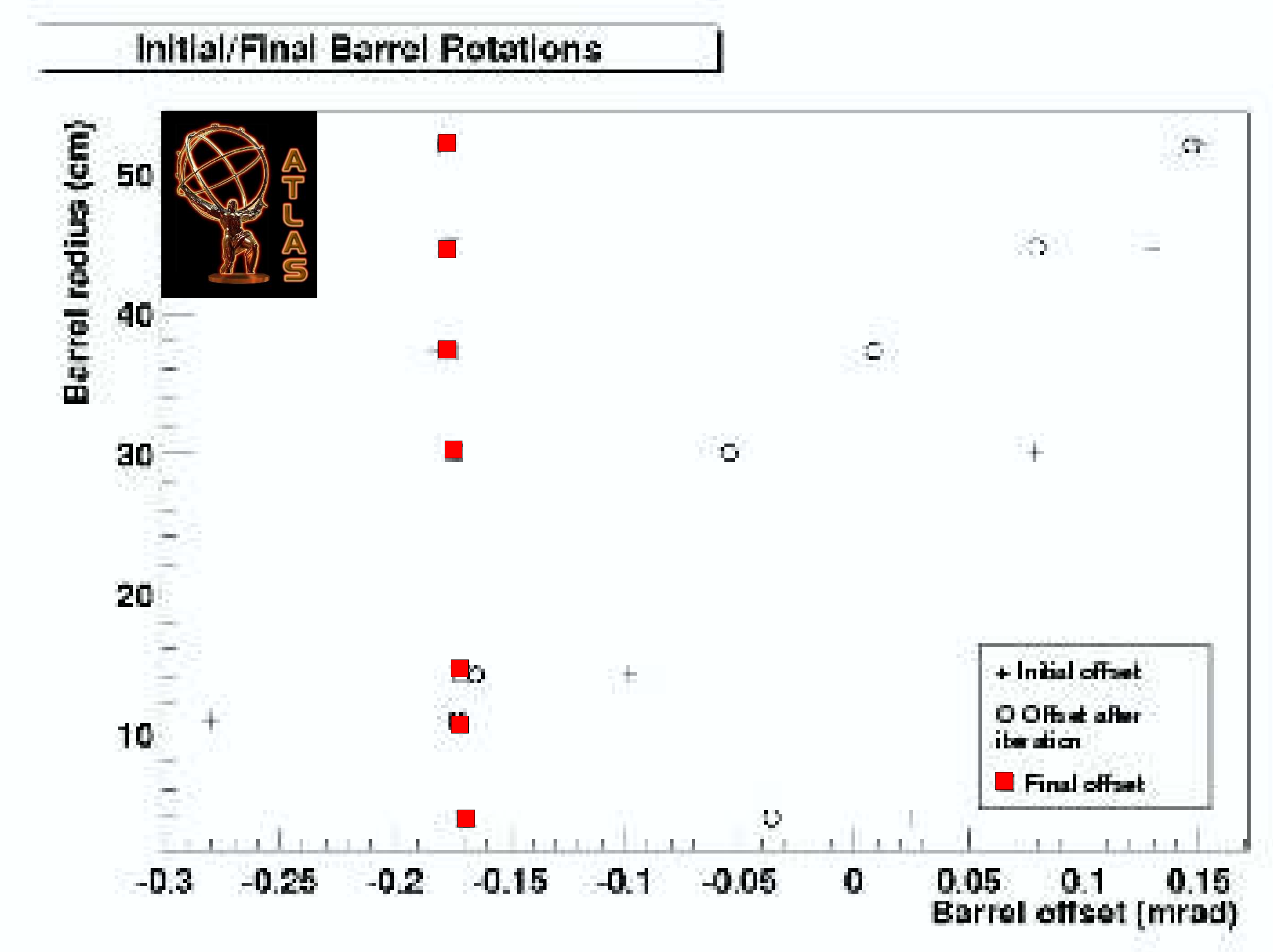
Use profile histogram: Mean IP vs. Phi

Beamspot offset and angle determined from amplitude and phase

Fit sin plus average IP (offset in y-axis)

Result of Sagitta Removal for RPhi

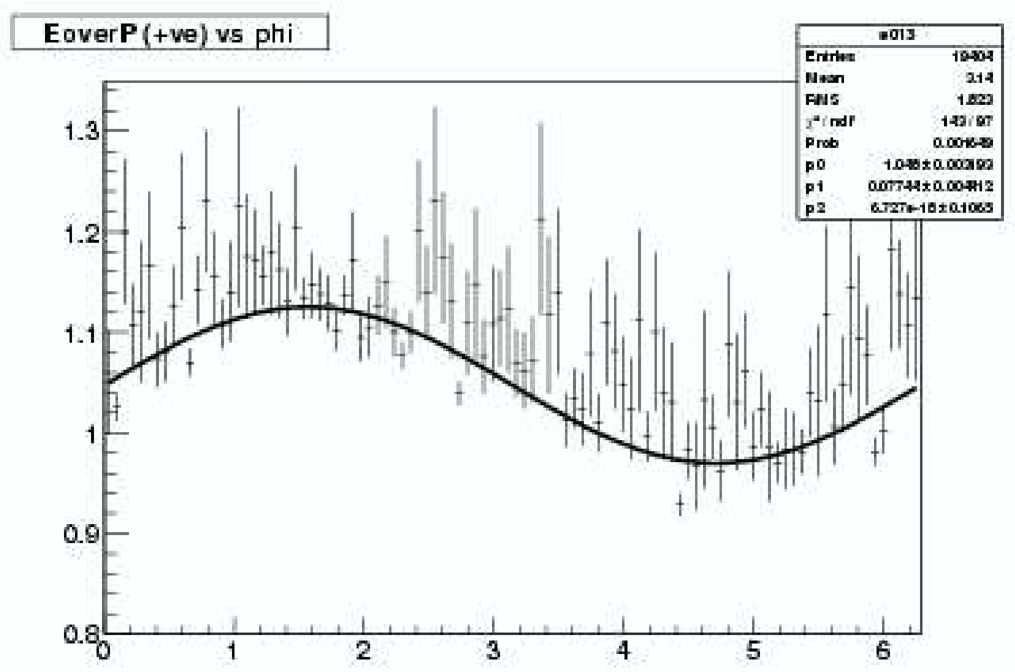
Using E/p and the impact paramter:



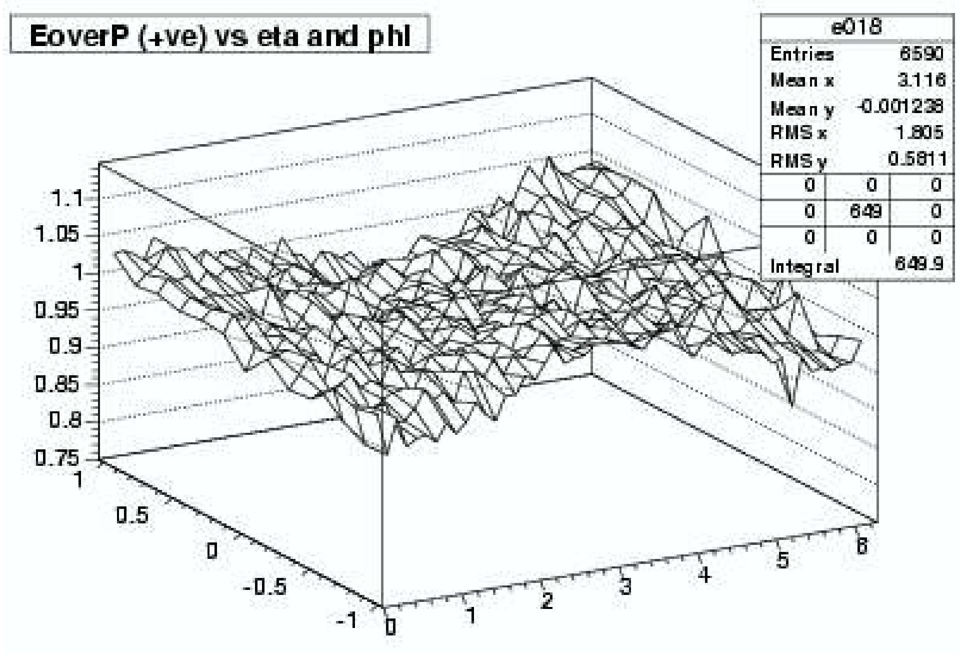
X / Y Translations & Rotations

PT and IP bias varies with eta and phi, e.g.

X / Y translation



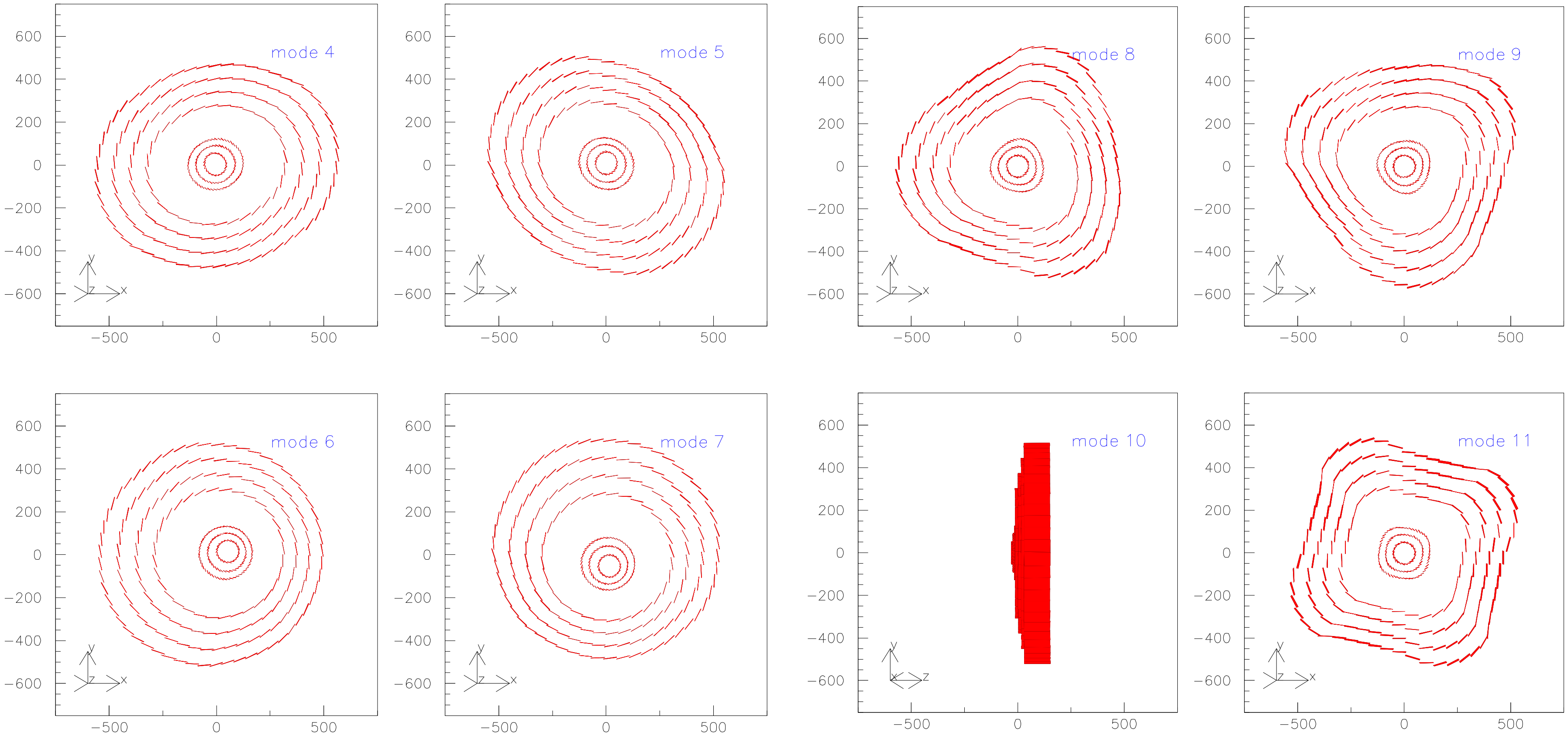
X / Y rotation



Remark: Very weak sensitivity to linear term of X /Y translation

More Generic High Frequency Modes

Weak modes corresponding to low part of eigen-spectrum:



Detailed study in global χ^2 algorithm:

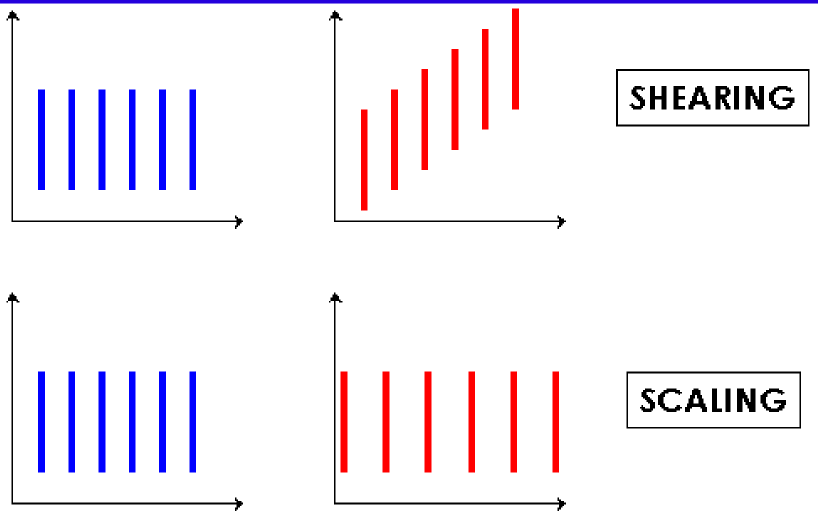
- Vertex constraint
- Track parameter constraint
- Invariant mass constraint
- Constraint on the geometry / on the mode itself

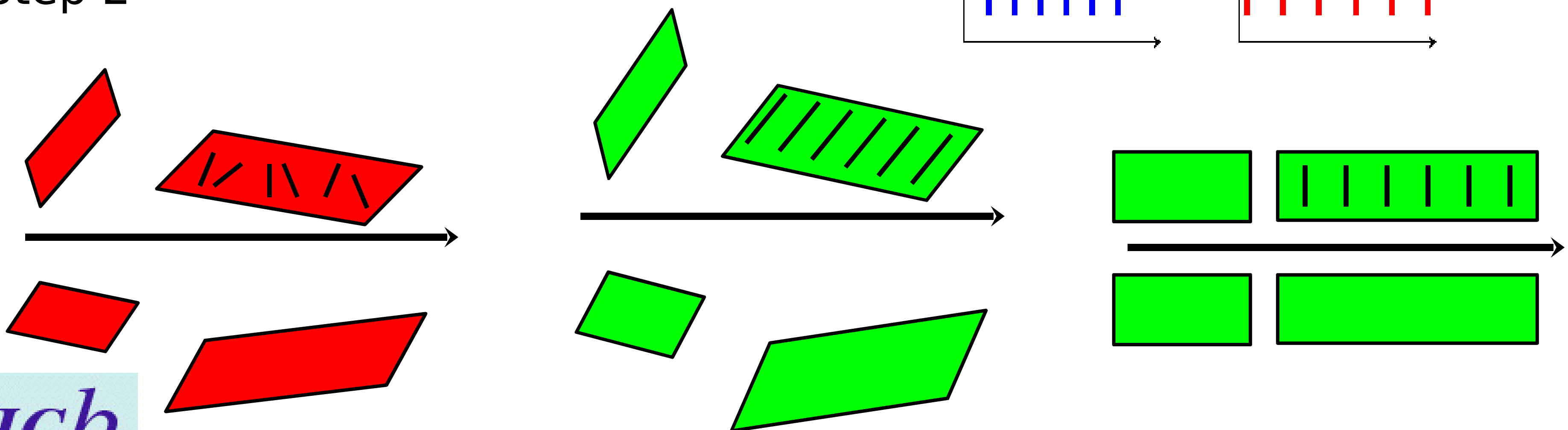
→ Constraints easily implemented in algorithm (same for Millepede)

→ Very encouraging results to constrain these modes

Degenerate Modes at LHCb or Endcaps

- LHCb is an endcap kind of detector
- VELO Alignment run by run, since detector moves between runs (3cm)
- Degenerate modes determined in Step 2





Step 0

Misaligned VELO

→

Step 1

Internally-aligned VELO

Millepede applied on single tracks in the four parts

→

Step 2

Aligned VELO

Align the 4 parts using vertex constraints, overlap tracks,...

Parasitic Collisions

At 0.9TeV beams have no crossing angles, LHCb is displaced
⇒ Head-on collisions at LHCb require parasitic collisions at ALICE, ATLAS and CMS, which can be tuned to occur between 3.75m and 11.25m away from the interaction point, and vice verca

O(10%) of the collisions will be parasitic at a luminosity ratio of ~50% for 11.25m and ~90% for 3.75m

Tracks from the ±3.75m points will make it into the tracking detector without crossing a lot of material

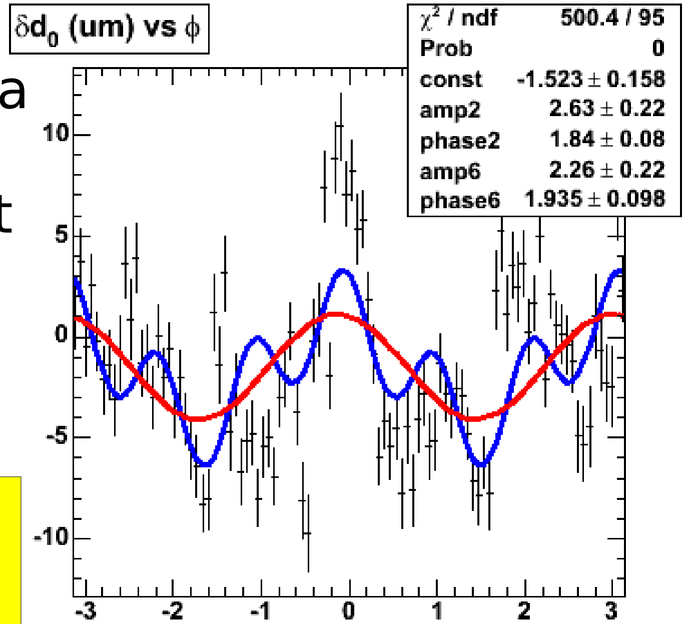
These tracks impose a different set of constraints than tracks from the IP
⇒ add to alignment or use as cross-check

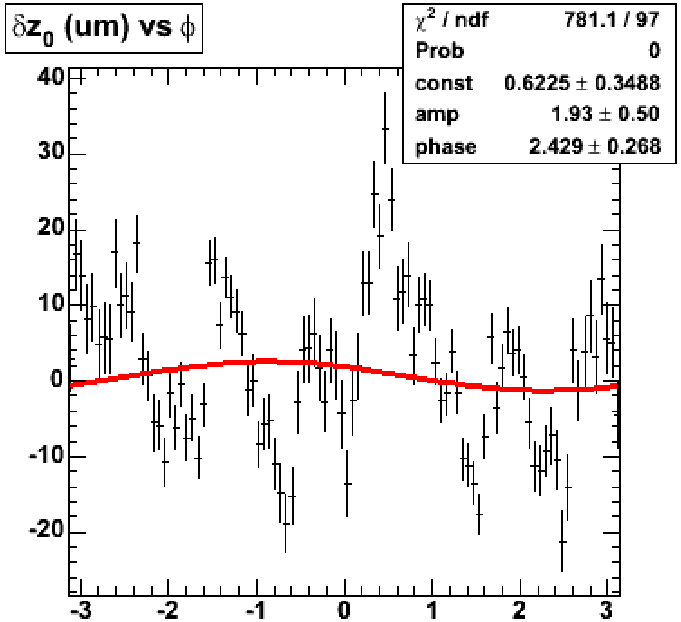
<u>Needs more study:</u>

- Possible to trigger on these events – first ATLAS study suggests that Minbias scintillating trigger would work
- Effect of timing shift – events occur late by half a nominal beam crossing
- pattern recognition / track fitting
- Needs simulation study

BABAR

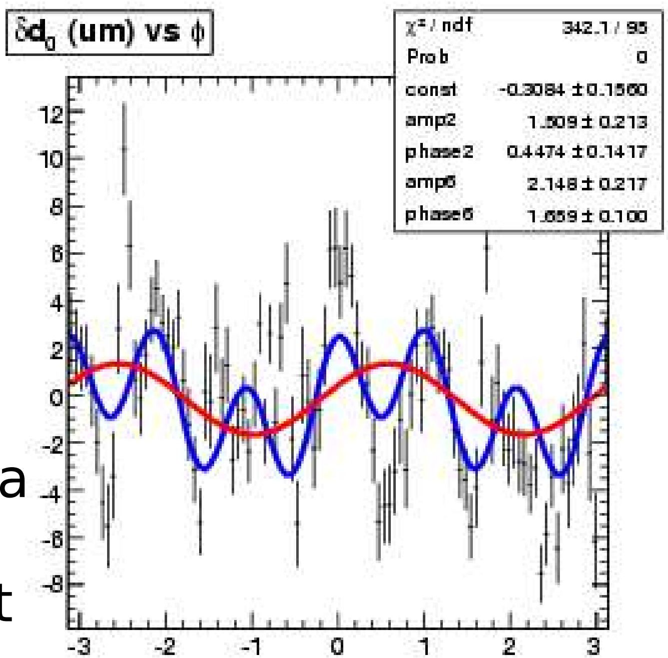
Jan31 data with old alignment

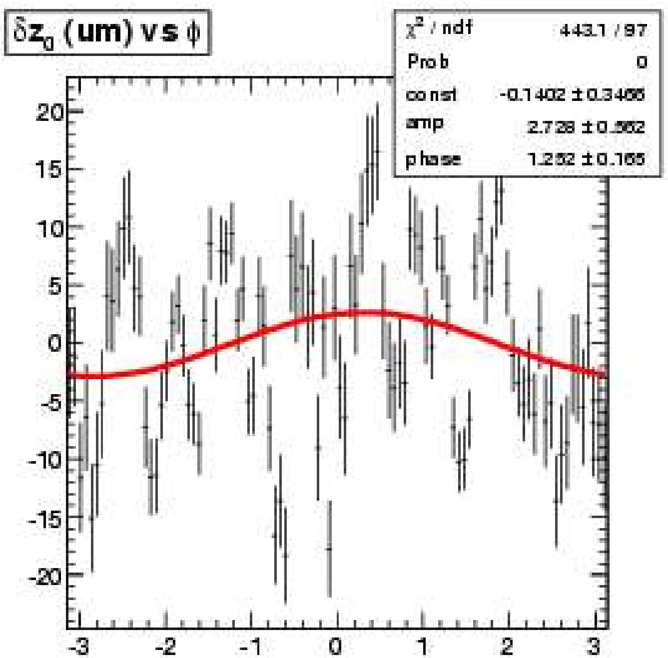




Use monitoring to assess the need for alignment

Decide whether to update alignment constants: human intervention





Jan31 data with new alignment

Alignment Monitoring cont'd

- Histograms on hit, cluster and track level
- Comparison with reference distributions
- Fit to expected modes: look for indications of degenerate modes
- Semi-automatic, human intervention needed in case of discrepancy (user-friendly GUI)

- Pixel example:
Pattern of residual vs. row and column number can give information about
  - residual module rotations and translations
  - module bow and other distortions (Babar)

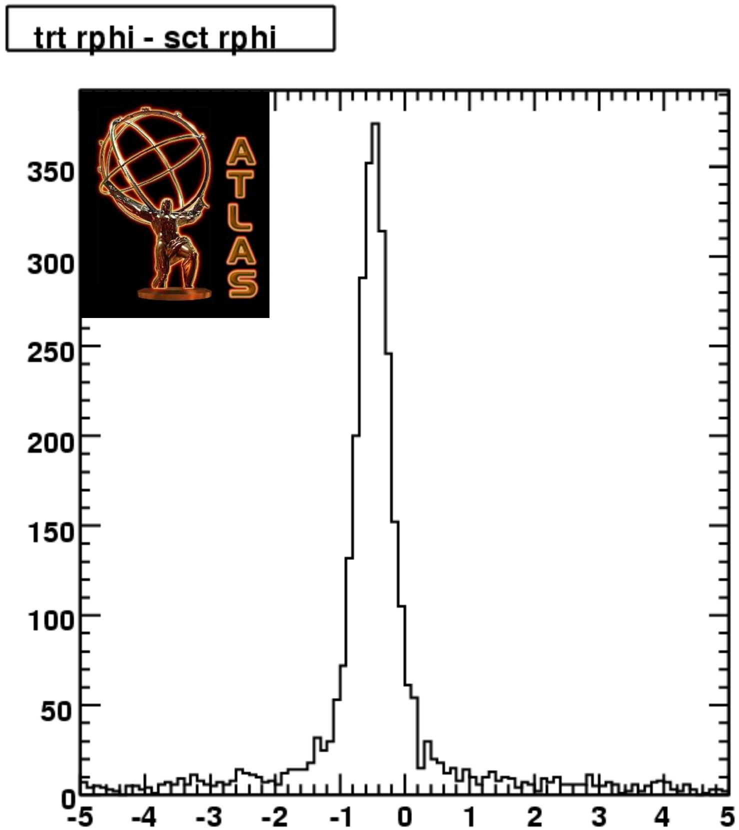
- xy position of primary vertex (mean and sigma) as a function of z, separately for silicon and TRT (CDF)

- μ-pair miss distance (David Brown)

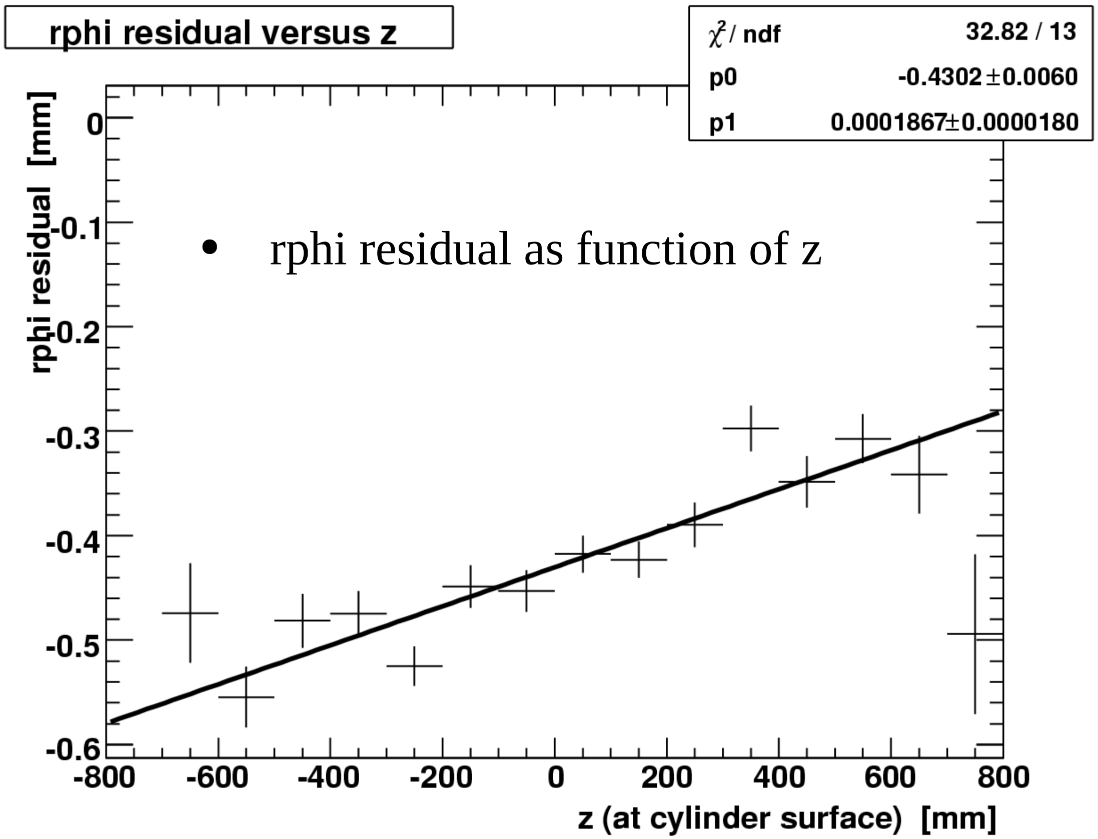
...

Comparison of SCT & TRT Parameters

ATLAS SCT-TRT cosmics run:



$\Delta r\phi$ (TRT-SCT)



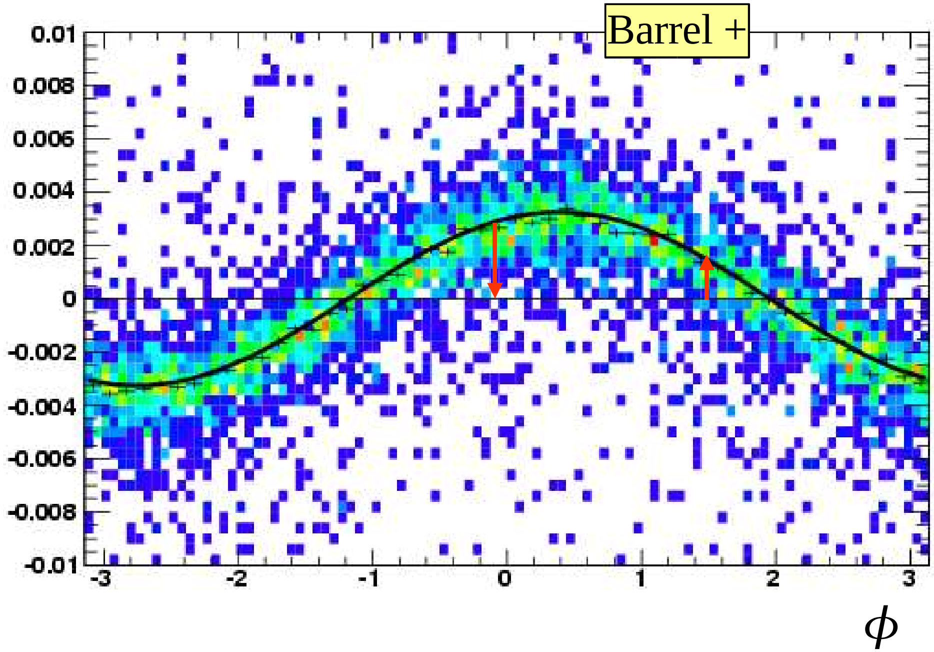
- rphi residual as function of z

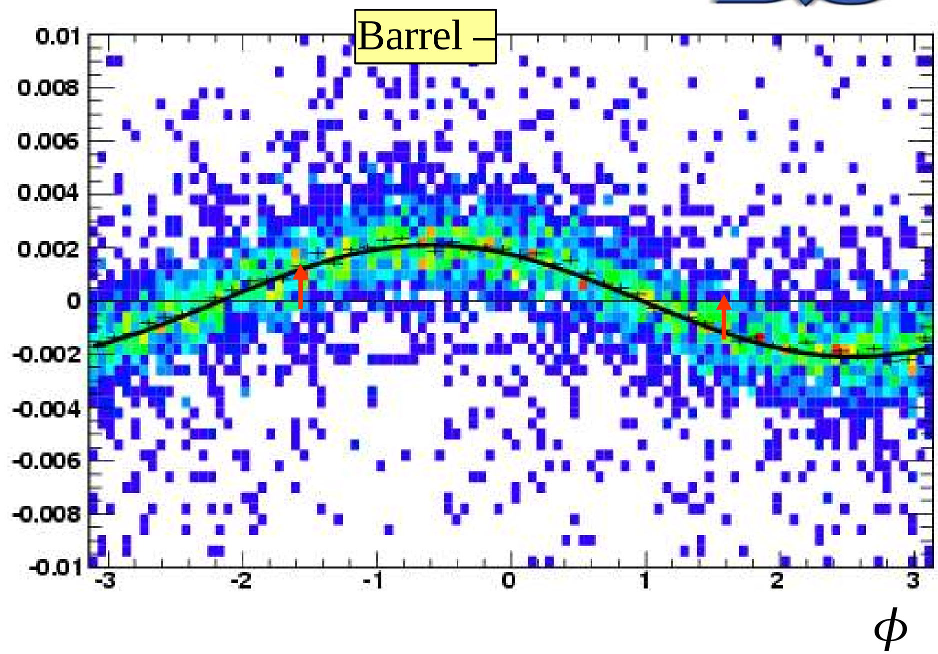
Corresponds to a relative twist of SCT and TRT of 0.2 mrad

Match Subdetectors in η and ϕ

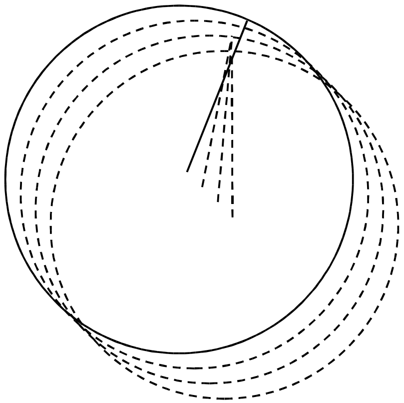
Calorimeter and tracker for electrons:

e.g. $\phi_{track} - \phi_{cluster}$ as a function of ϕ:





Twist: $\Delta\phi$ varies with η



Do same for $\eta_{track} - \eta_{cluster}$ as a function of ϕ

Alignment Validation with MC

- See talk by David Brown yesterday
- Generate a “matrix” of all typical realistic misalignment sets
- Each represents a degenerate mode (e.g. Telescoping, RPhi rotation,...), random misalignments, or other pathologies, etc.
- Apply alignment algorithm and check to what extend the misalignments can be recovered
- This gives an estimate of the expected systematic uncertainties
- Tough to cover all possible misalignments
  Only data can tell: Be prepared for surprises...

Summary

- Central physics
- Cannot use E/p

- Forward physics
- No cosmics (acceptance)

- Soft physics, very little material
- Alignment mainly with magnet off data
- Reverse polarity
- Small magnetic field

- High pT physics, a lot of material
- Alignment mainly with magnet on data
- Do not reverse polarity
- Large magnetic field

Summary

Use all possible handles:

- Various topologies: cosmics, halo muons, beam gas, parasitics
- Overlap hits
- Use redundancy of different subdetectors: $\eta\phi$-match, E/p
- Vertex and mass constraints: J/Ψ, Υ, Z
- Resolutions: mass and IP
- Low level residual and alignment distributions
- Other external constraints: Survey, hardware alignment,...

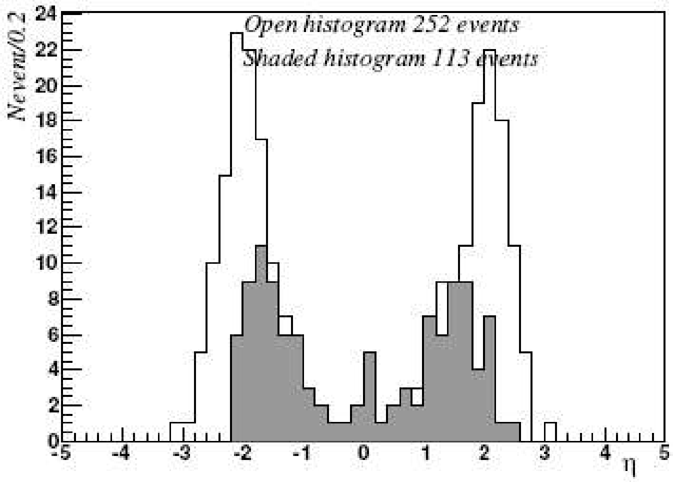
If possible add handle as additional constraint in alignment algorithm

Else: Monitoring, quick turnaround, semi-automatic including human intervention

Test against expected misalignment scenarios in MC
Be prepared for the unexpected!

Back-Up

J/Ψ and Υ are “Barrel poor”



J/Ψ η distribution for two different triggers

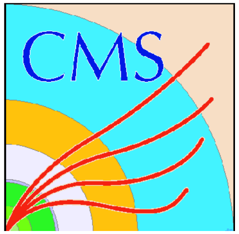


Figure 9.35: The η distribution of J/ψs with both muons triggered by the “Open Level-1” and Level-2 trigger combination (solid-line histogram) as compared with the more stringent Level-1 and Level-2 trigger (shaded histogram). Two opposite-sign Level-1 or 2 opposite-sign Level-2 candidates are required. See text for details.

Υ η distribution for two different triggers

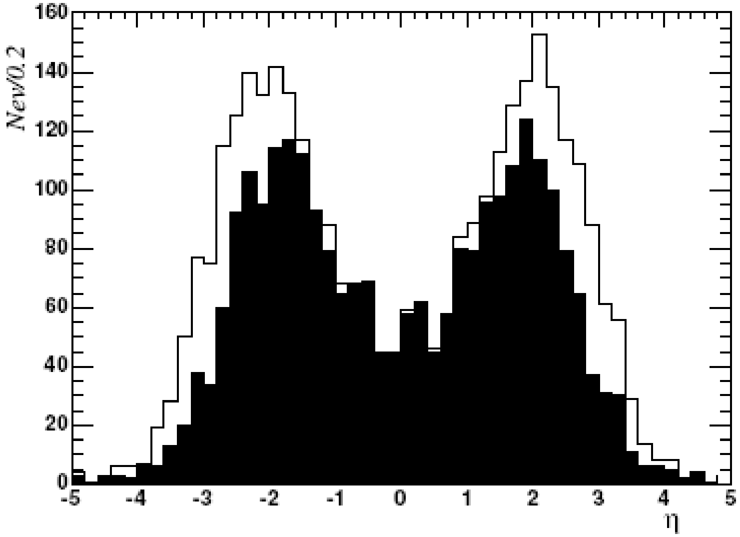


Figure 9.37: The η distribution of Υs with both muons triggered by the Open Level-1 and Level-2 trigger (solid-line histogram) as compared with the Level-1 and Level-2 trigger (shaded histogram). Two opposite-sign Level-1 or 2 opposite-sign Level-2 candidates are required.

Remove Z Translation (Telescoping)

No pT bias but η bias (Caveat: η distribution not known at LHC), can use forward-backward symmetry?

Modules are tilted in RPhi and RZ -> hits in same barrel have different radius -> Some sensitivity to telescoping (but need high statistics)

Needs more studies