ATLAS InnerDetector: alignment with tracks

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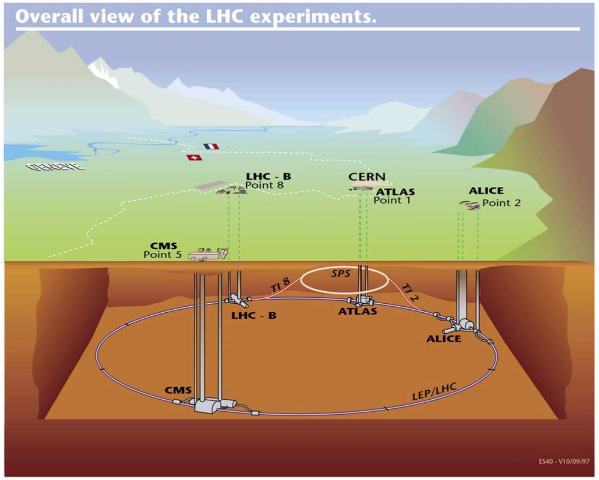
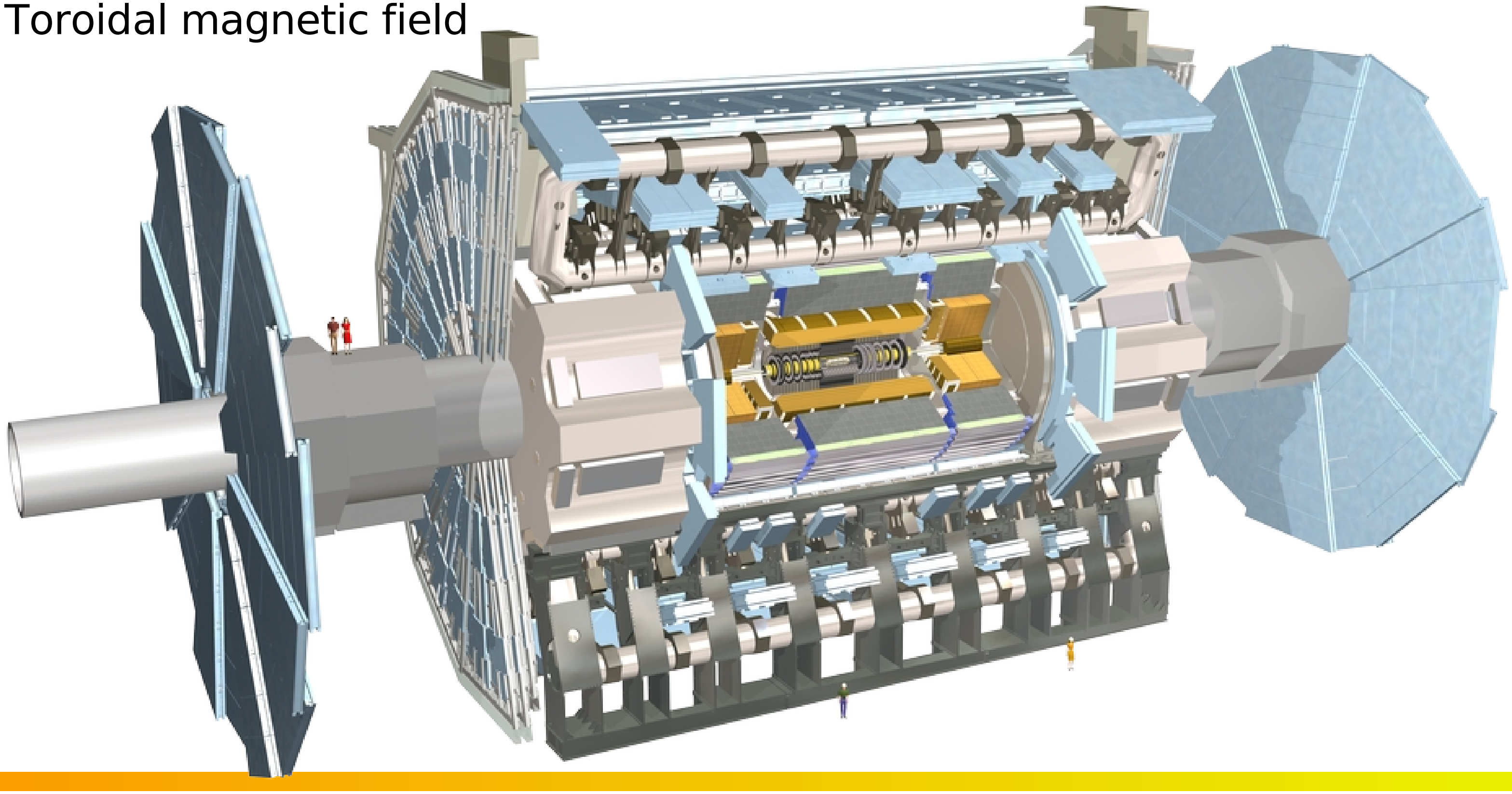
Introduction

- Tracking based alignment of the ATLAS Inner detector
- ATLAS
  - ID: pixel, SCT & TRT
  - Assembly status & survey
- CSC challenge
  - Goals
  - Material and B field distortion
  - ID misalignments
  - Multimuons sample
- Track based alignment algorithms
  - Robust, Localχ^2 and Globalχ^2
  - Residuals, impact parameter and P_t
  - Physics samples: top & $Z \rightarrow \mu\mu$ events
- TRT alignment
- Cosmics at the pit
  - Combine multimuons and cosmic
- Summary and conclusions

ATLAS

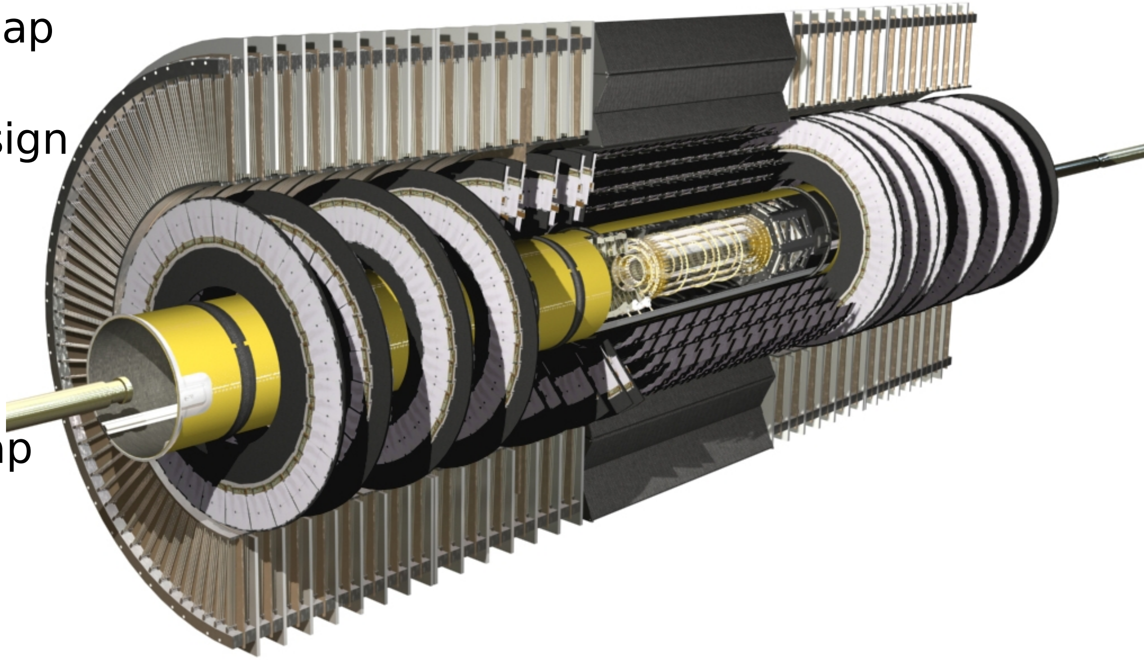
- General purpose experiment for the LHC
  - Tracking system (ID) within a 2T magnetic field:
    - Efficient track reconstruction
    - Precise momentum & IP determination
    - B-tagging
  - Calorimetry
    - Electron & photon
    - Hadrons
  - Muon spectrometer (see O. Kortner talk)
    - Toroidal magnetic field





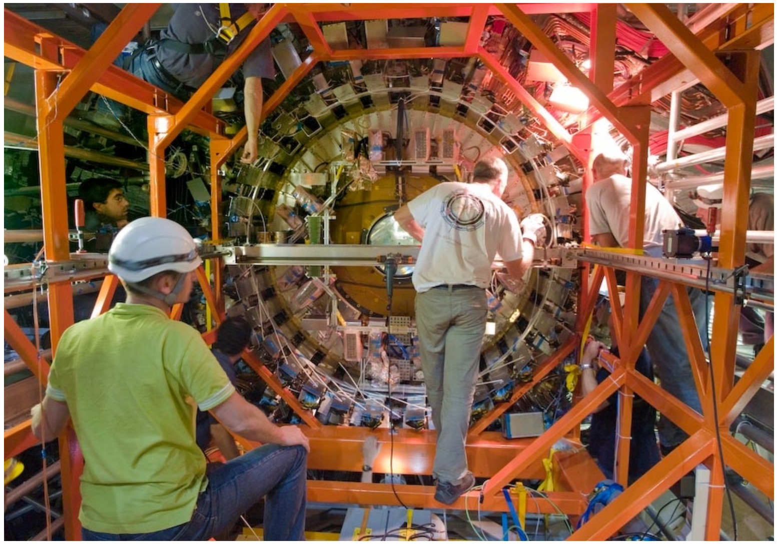
Inner Detector: tracking system

- Three technologies used: pixel, microstrip (SCT), straw drift tubes (TRT)
  - All mounted in a barrel and 2 end caps
  - Pixels:
    - Single module design, analogue readout
    - Size: 50x400 μm^2
    - Intrinsic point resolution:
      - 14x115 μm^2
    - 3 layers in barrel, 3 discs/end cap
  - SCT
    - Barrel and end cap module design
    - Binary readout
    - 3D SP by stereo angle
    - Barrel strip pitch: 80 μm
    - Resolution 23 μm
    - End cap strips: fan structure
    - 4 layers in barrel, 9 disc/end cap
  - TRT
    - Straw tube diameter 2mm
    - Drift time
    - Straw resolution 170 μm
    - Radii: 56 cm $\rightarrow$ 107 cm
    - 35 points/track on average

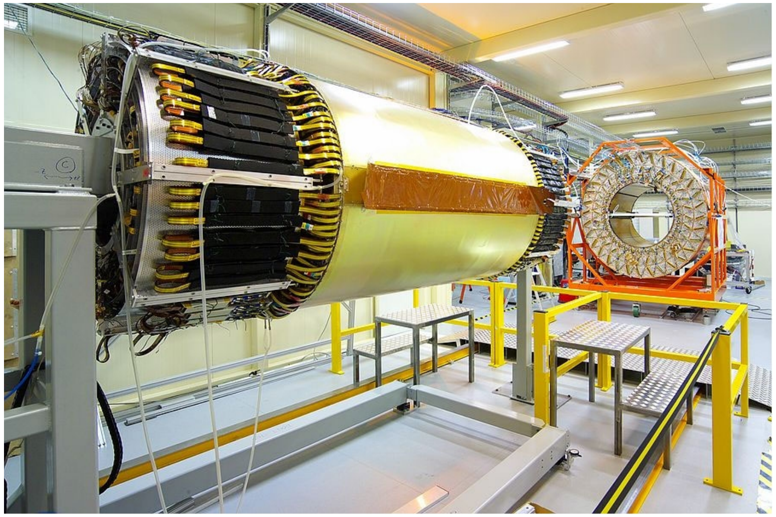


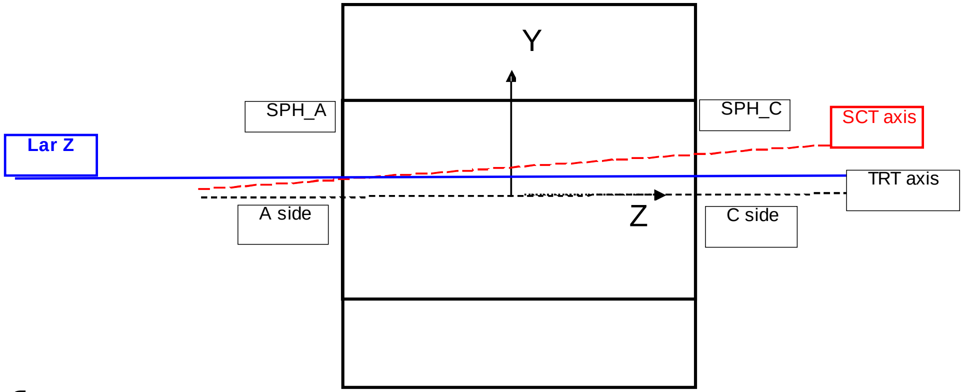
Status of ATLAS ID assembly

- All parts of the ATLAS ID are in the pit
  - Hot news: last bit, ID end cap C was installed on 19th/June/2007
  - Services installation already started
    - Cosmic run with tracking system
      - see C. Schmitt talk



  - Survey of the SCT and TRT positioning
    - Shifts of the order of mm
    - X, Y, Z and rotations



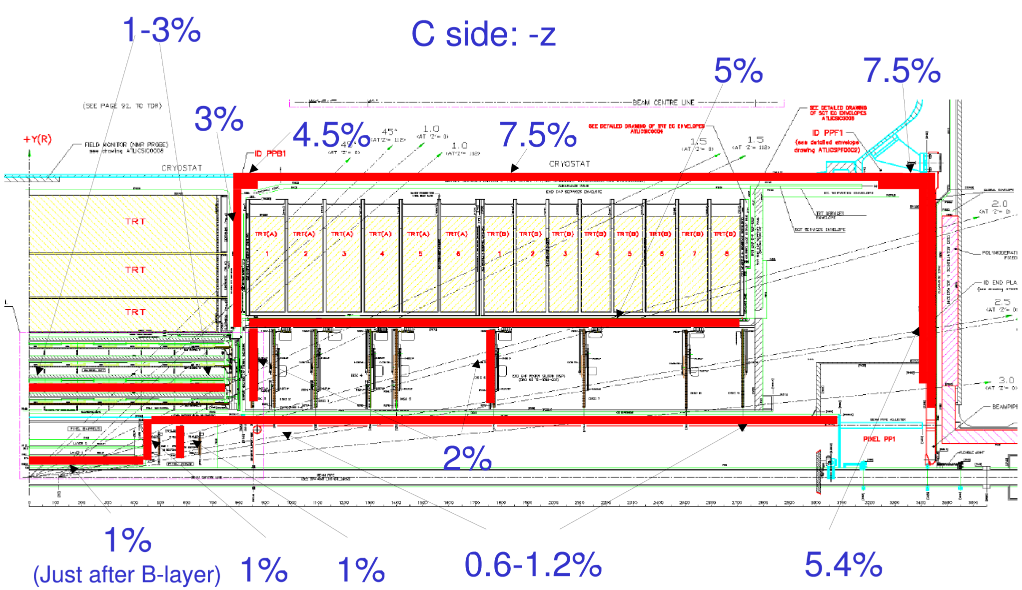


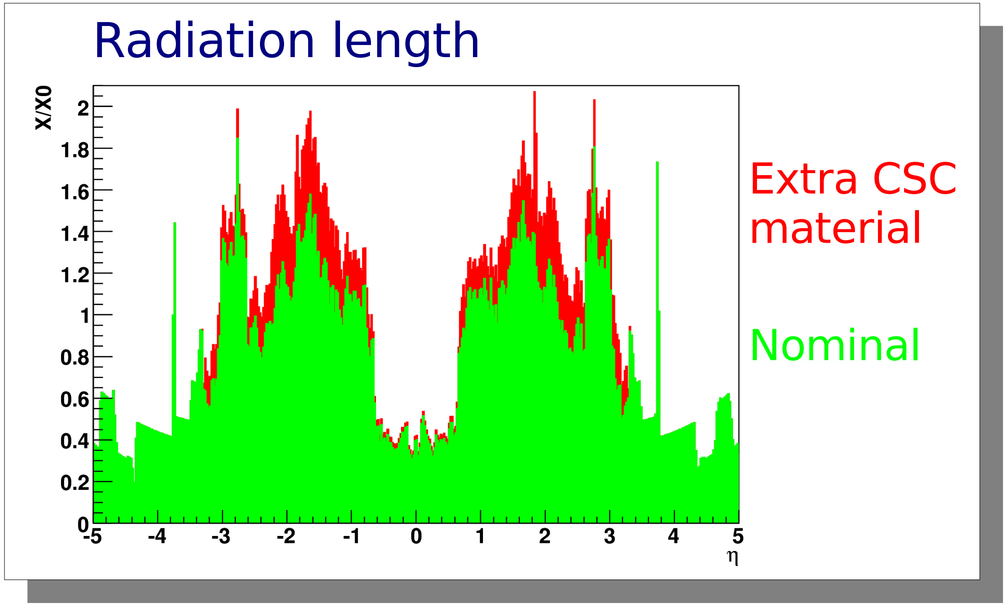
  - Those misalignments were foreseen
    - Simulation of calibration and physics samples

The ATLAS CSC challenge

- The Computing System Commissioning challenge
  - Its aim is to test the ATLAS software & computing infrastructure for:
    - Calibration and alignment procedures and conditions DB
    - Full trigger chain
    - Event reconstruction and data analysis
  - Huge samples of physics and calibration events were simulated with a *realistic* detector
    - uncalibrated and misaligned
    - Inhomogeneous axial ID magnetic field
    - Distorted material
      - Extra radiation lengths
      - Forward-backward asymmetry
      - ϕ- asymmetry

B Filed shifts	X	Y	Z
Trans. (mm)	1.0	-3.5	2.0
Rot. (mrad)	0.0	0.1	0.2





CSC: Inner Detector misalignment

- Misalignment set at three levels:
  - L1: barrel/end cap, L2: layer/disc L3: module

	LEVEL 1	X	Y	Z	α	β	γ
TRT	TRT Barrel	+1	+1	+1	0.20	-0.05	0
	TRT Endcap A	+2	-1	+2	-0.15	0.10	0
	TRT Endcap C	-2	+2	-3	-0.20	-0.15	0
SCT	SCT Barrel	+0.70	+1.20	+1.30	0.10	0.05	0.80
	SCT Endcap A	+2.10	-0.80	+1.80	-0.25	0.00	-0.50
	SCT Endcap C	-1.90	+2.00	-3.10	-0.10	0.05	0.40
Pixel	Whole	+0.60	+1.05	+1.15	-0.10	0.25	0.65

(displacements in **mm**; rotations in **mrad**)

L2	Layer	Systematic radial shift	Random shift in X,Y
TRT	Layer 0	+1.0 mm	0.2 mm
	Layer 1	-0.5 mm	0.1 mm
	Layer 2	+1.5 mm	0.3 mm

LEVEL2

	Layer/Disk	X	Y	Z	α	β	γ
Pixel Barrel	0	0.020	0.010	0	0	0	0.006
	1	-0.030	0.030	0	0	0	0.005
	2	-0.020	0.030	0	0	0	0.004
SCT Barrel	0	0	0	0	0	0	-0.001
	1	0.050	0.040	0	0	0	0.009
	2	0.070	0.080	0	0	0	0.008
	3	0.100	0.090	0	0	0	0.007
SCT Endcap A	1	0.050	0.040	0	0	0	-0.001
	2	0.010	-0.080	0	0	0	0
	3	-0.050	0.020	0	0	0	0.001
	4	-0.080	0.060	0	0	0	0.002
	5	0.040	0.040	0	0	0	0.003
	6	-0.050	0.030	0	0	0	0.004
	7	-0.030	-0.020	0	0	0	0.005
	8	0.060	0.030	0	0	0	0.006
	9	0.080	-0.050	0	0	0	0.007
SCT Endcap C	1	0.050	-0.050	0	0	0	0.008
	2	0	0.080	0	0	0	0
	3	0.020	0.010	0	0	0	0.001
	4	0.040	-0.080	0	0	0	-0.008
	5	0	0.030	0	0	0	0.003
	6	0.010	0.030	0	0	0	-0.004
	7	0	-0.060	0	0	0	0.004
	8	0.030	0.030	0	0	0	0.006
	9	0.040	0.050	0	0	0	-0.007

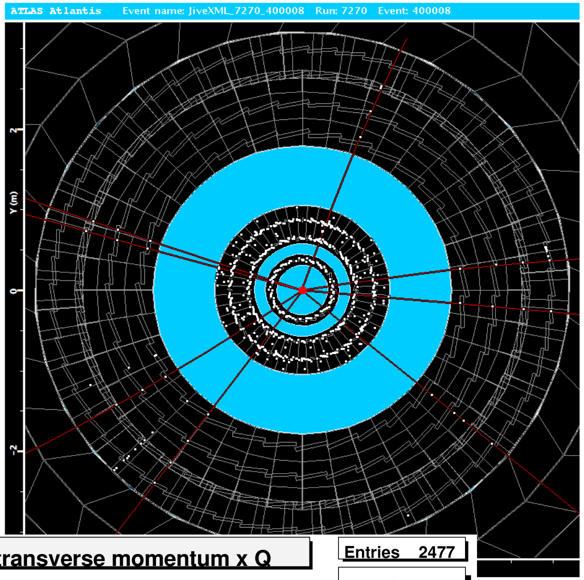
LEVEL3

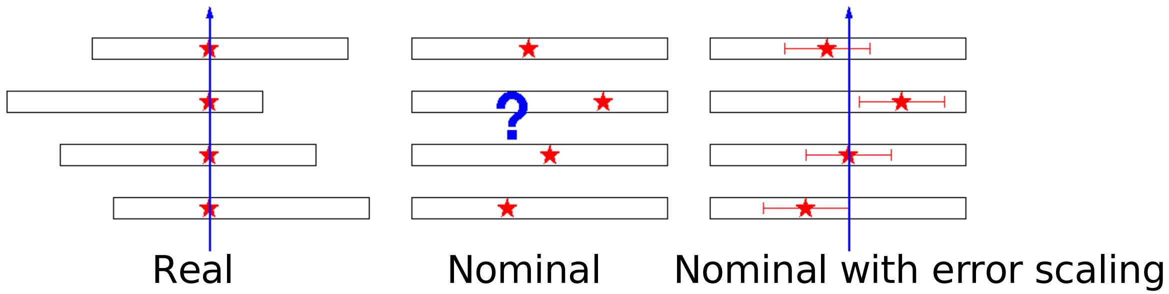
	x	y	z	α	β	γ
Pixel Barrel modules	0.030	0.030	0.050	0.001	0.001	0.001
Pixel Endcap modules	0.030	0.030	0.050	0.001	0.001	0.001
SCT Barrel modules	0.150	0.150	0.150	0.001	0.001	0.001
SCT Endcap modules	0.100	0.150	0.150	0.001	0.001	0.001

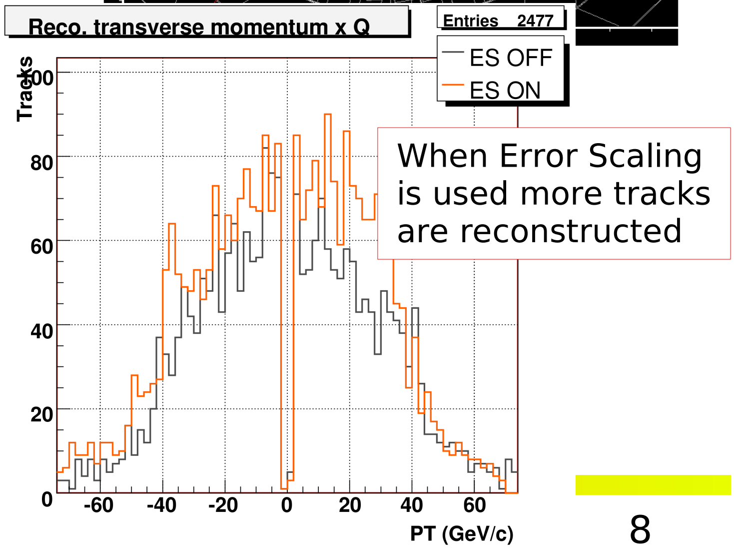
- Shifts are realistic !
  - Though may seem huge
  - Surveyed during assembly

CSC Multimuons for alignment

- CSC calibration sample: 100K multimuon events were generated with a misaligned setup
  - Level 1, Level 2 and Level 3
  - 10 muons per event originated at a common vertex (PrimVtx)
    - $\sigma_{x,y} = 0.015$ mm, $\sigma_z = 56$ mm
  - Flat $|\eta| < 2.7$
  - Flat Pt: [2, 50] GeV/c
  - Flat ϕ: $[0,2\pi]$
- Simulation and digitization
  - Performed with the misaligned detector
- Reconstruction run on simulation with
  - Perfect knowledge of the modules locations
  - Modules at their nominal position
    - i.e. blind to the misalignment
    - Error scaling for clusters $\sigma'^2_h = a^2 \cdot \sigma^2_h + c^2$

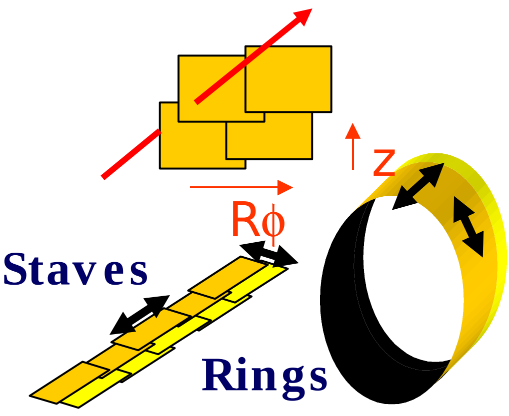






ID track based alignment algs.

- Track based algorithms used for the silicon part
  - Robust, Localχ^2 and Globalχ^2 for the silicon part (pixels and SCT)
  - TRT alg.: can switch between Local and Global χ^2
    - Needs calibration for R-t relation
- Robust:
  - Center overlap residuals from adjacent modules
  - Center non overlap residuals as well
  - 2 Dof (within plane) + average radial shift
  - Iterative algorithm



- Localχ^2:
  - Distance of closest approach
  - Invert 6x6 matrices
  - Correlations taken into account by iterations

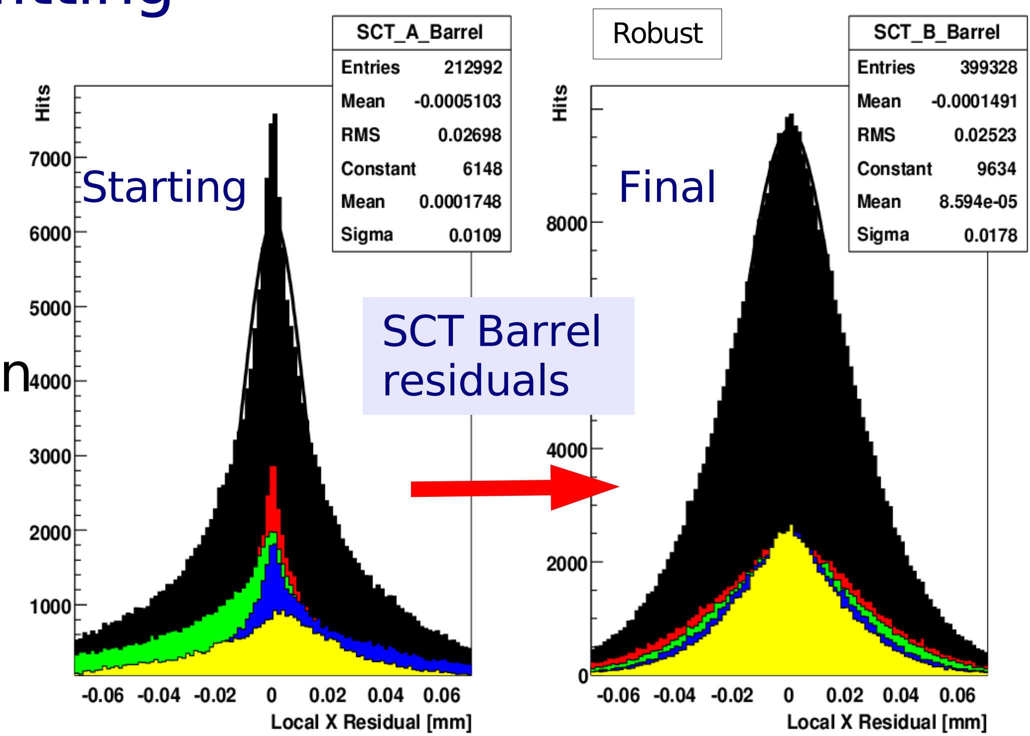
$$\Delta a_i = \left[\sum_{hits} \left(\frac{2}{\sigma^2} \frac{\partial r}{\partial a_j} \frac{\partial r}{\partial a_i} \right) \right]^{-1} \cdot \sum_{hits} \left(\frac{2}{\sigma^2} r \frac{\partial r}{\partial a_i} \right)$$

- Globalχ^2:
  - Within plane residuals
  - Need to invert a 35000x35000 matrix
  - Test performed on barrel geometry
    - Fast solvers: MA27…
    - Full solution on ALINEATOR: parallel processing with SCALAPACK, 32 GB memory. Solution takes <1 hour (14000 dofs)

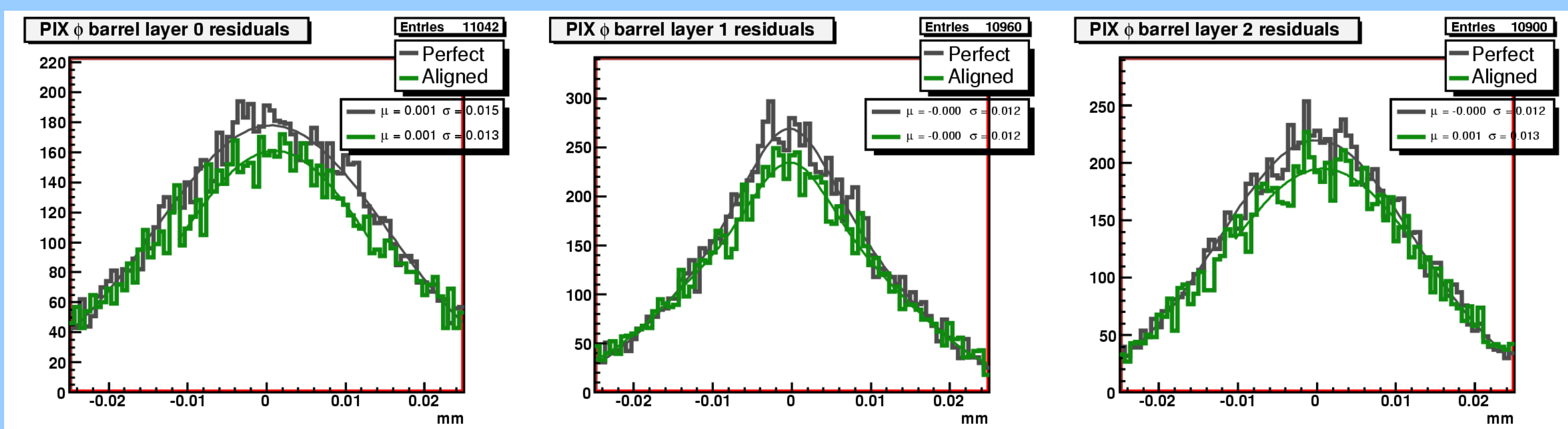
$$\delta a = -\left(\sum_{tracks} \frac{\partial r^T}{\partial a_i} W \frac{\partial r}{\partial a_j} \right)^{-1} \left(\sum_{tracks} \frac{\partial r^T}{\partial a_i} W r \right) = MV$$

CSC multimuons alignment

- Run reconstruction and track fitting
  - Starting from nominal position
  - Iterate
- Residuals look almost perfect!
  - More hits per module
  - Centered around 0
  - Sigma close to naïve expectation



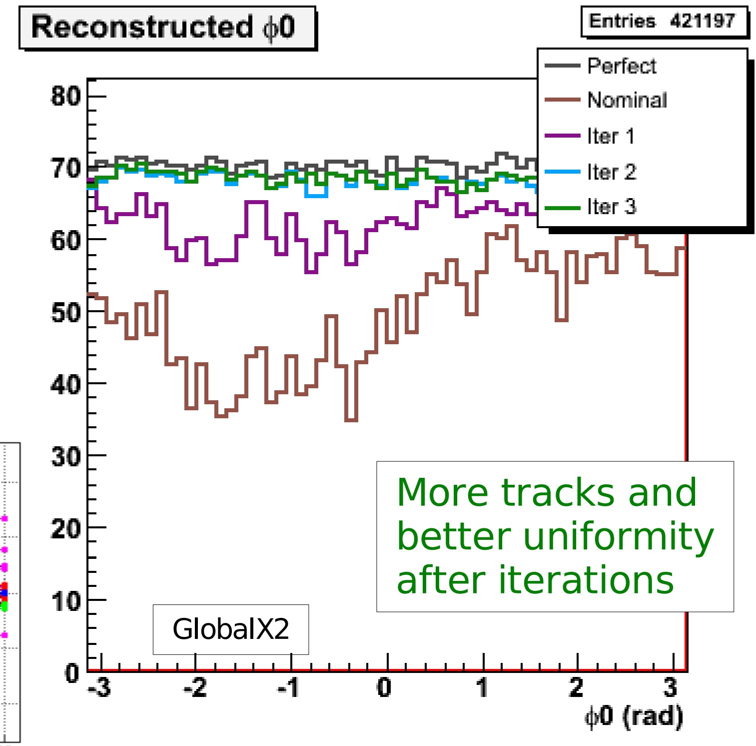
Pixel Barrel residuals

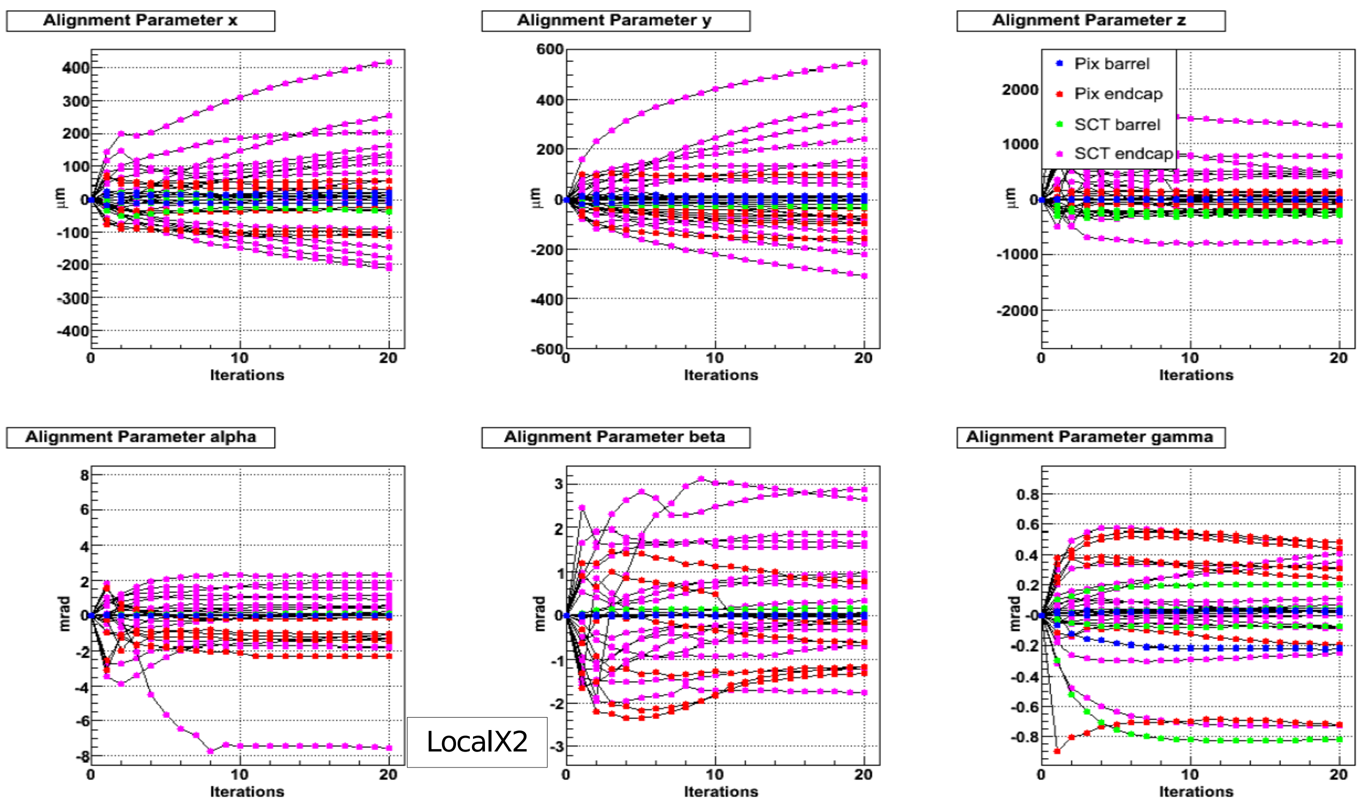


CSC multimuons alignment (ii)

- Iterations improve
  - Residuals (as already seen)
  - Recovery of track efficiency

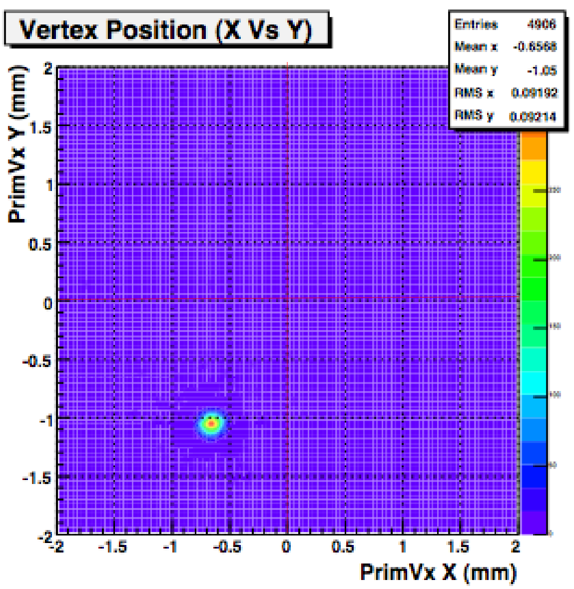
- Convergence is found



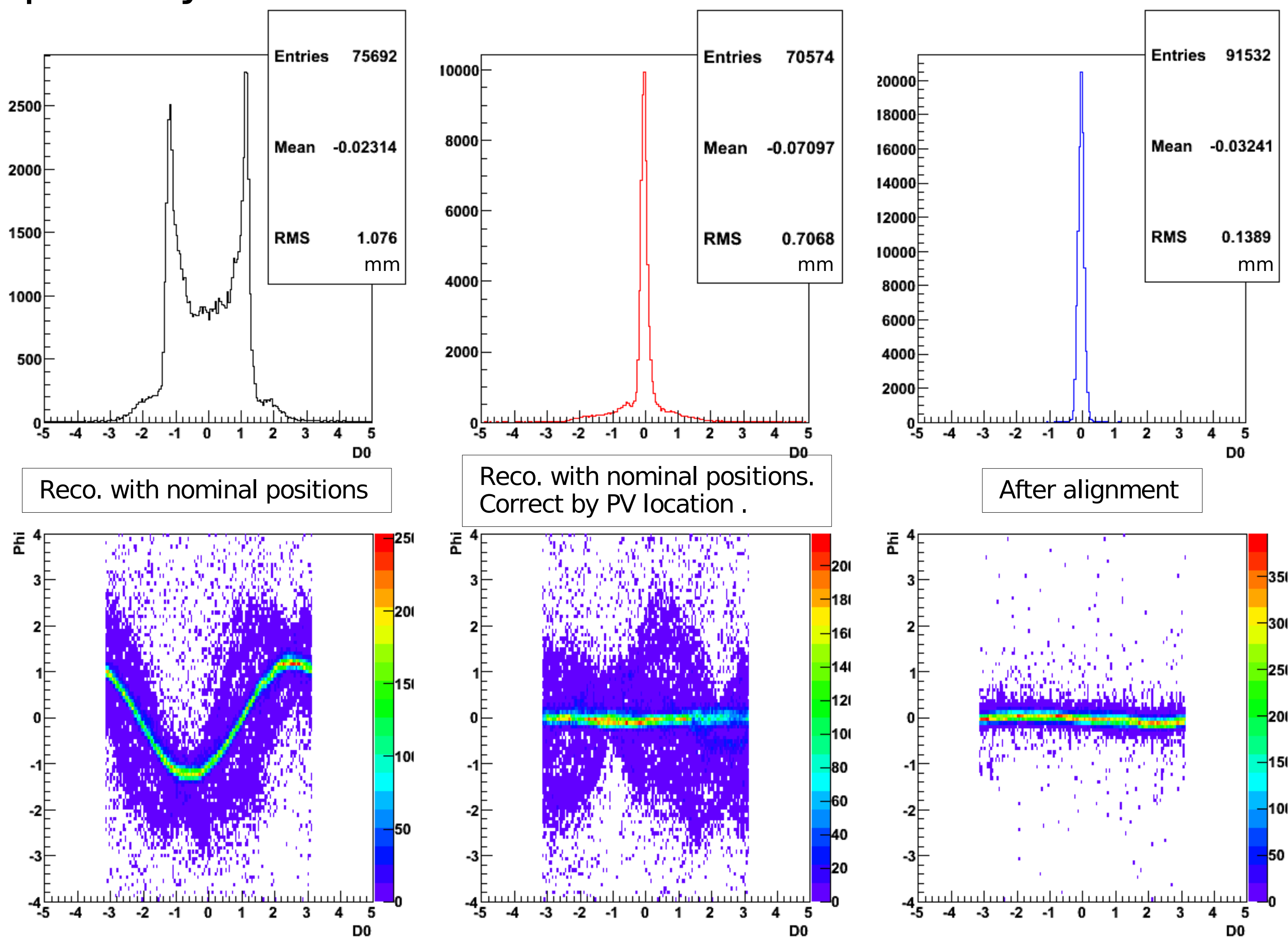


Impact Parameter

- Level 1 shifted by (0.60, 1.05) mm the pixel modules
  - Impact parameter distribution distorted
  - Need for primary vertex fit
  - Track refit with primary vertex

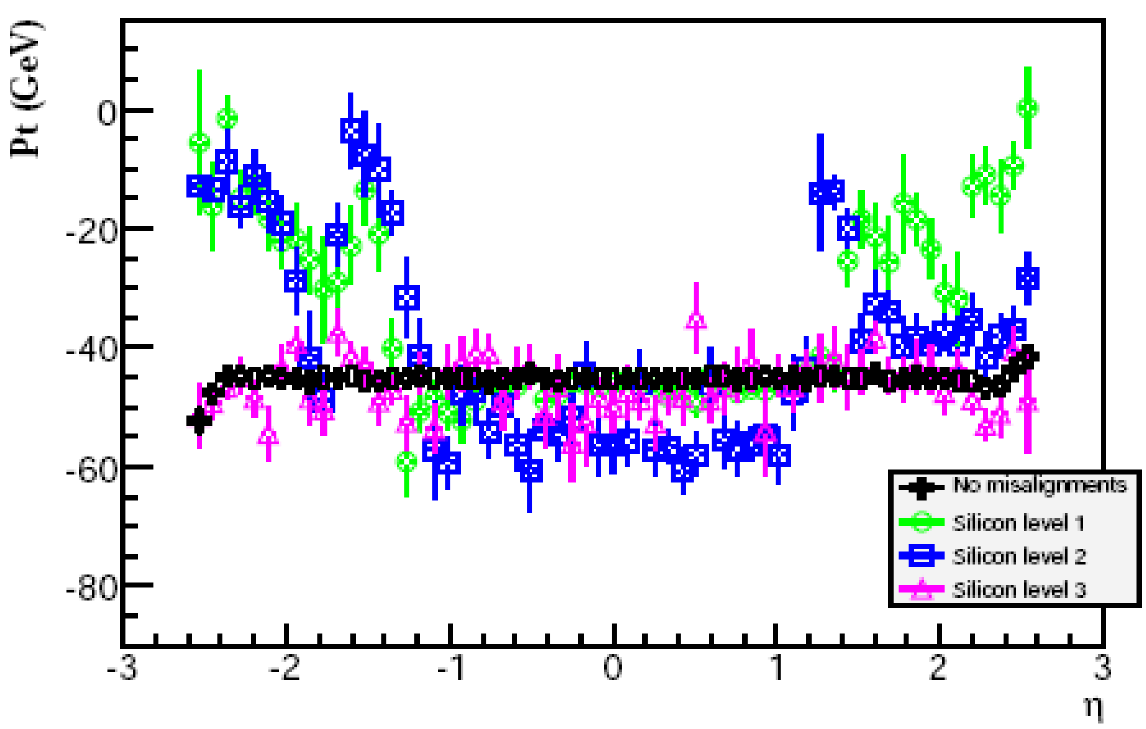


PV matches well the pixels level 1 shift

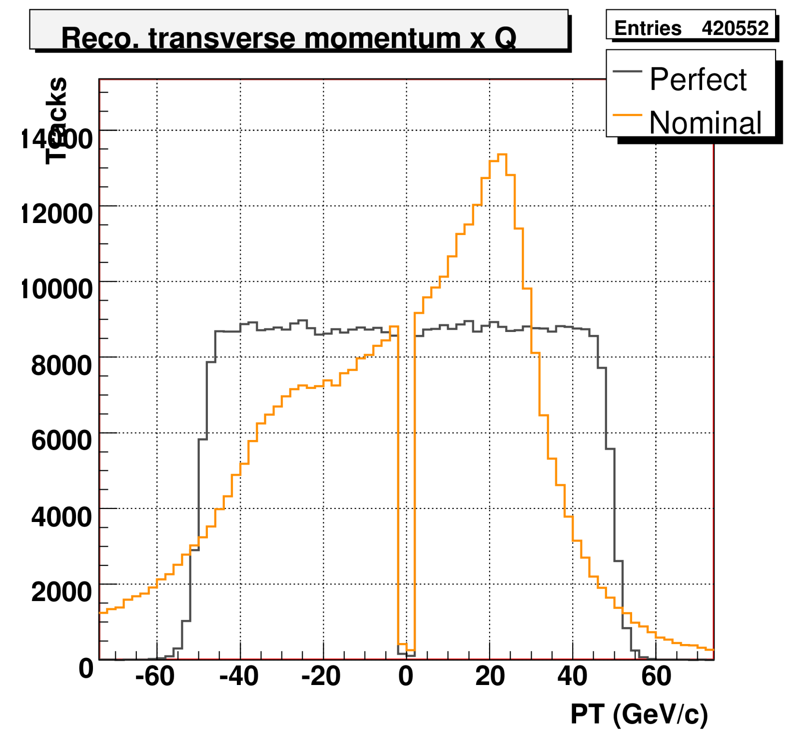


- Effects of the Level 1, 2 and 3 on P_t
  - L1: pixels to SCT, to TRT, barrel to end cap shifts
  - L2: layer to layer shift
  - L3: module to module shift

Muons of Pt = 45 GeV/c

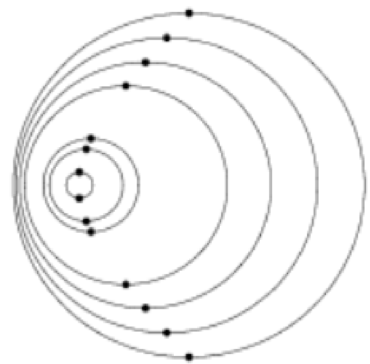


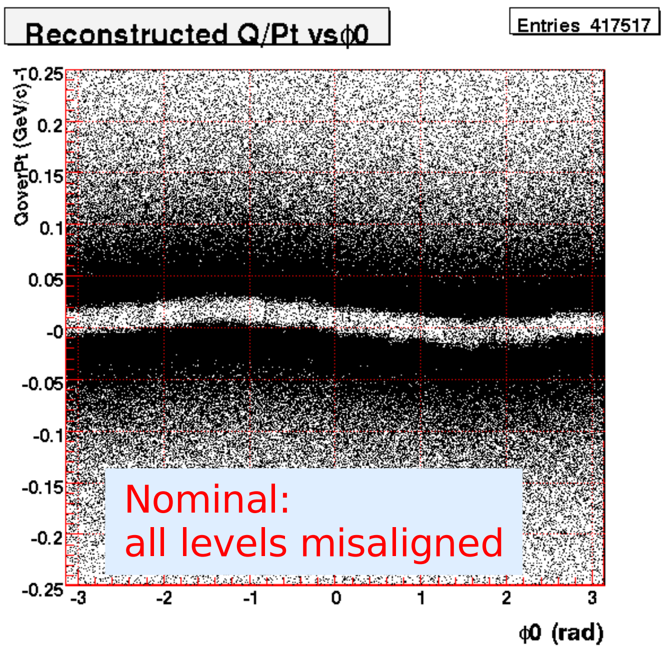
Multimuons: barrel tracks only

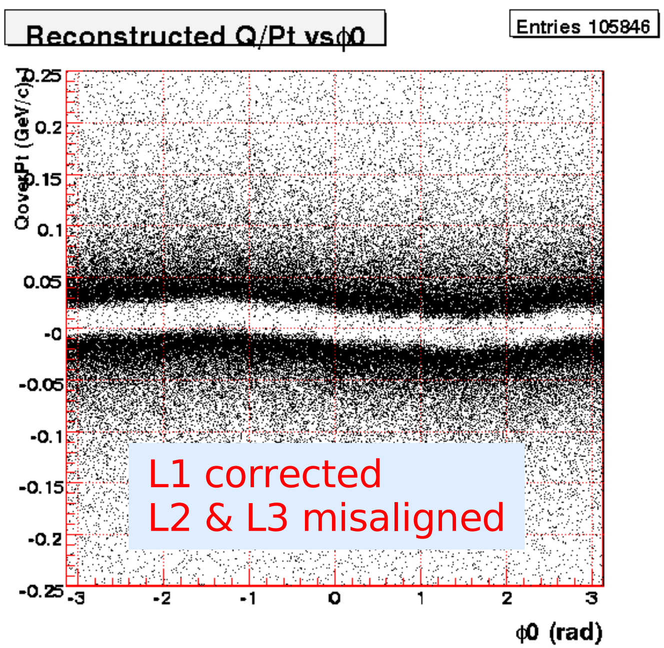


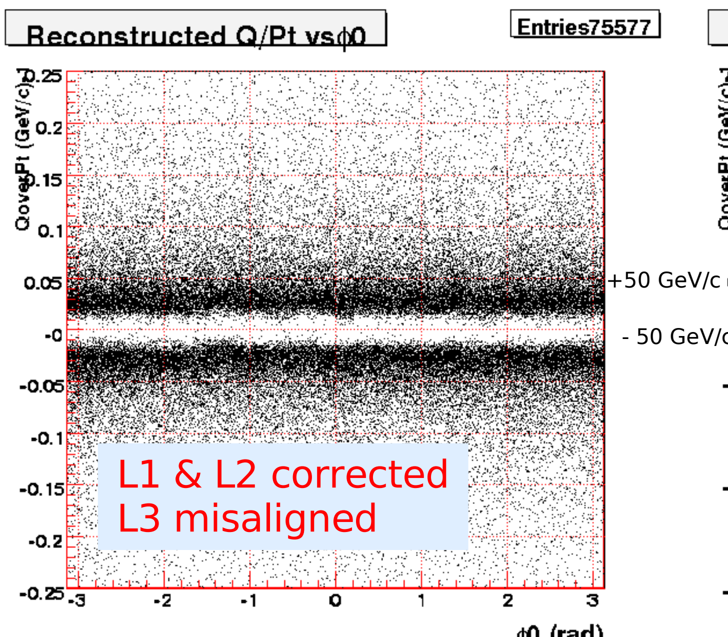
P_t reconstruction (ii)

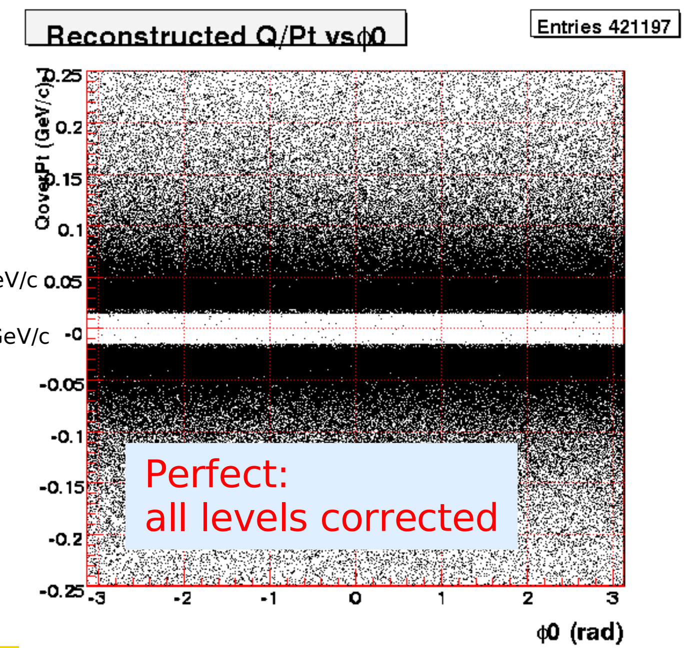
- Effects of the Level 1, 2 and 3 on P_t
  - L1: pixels to SCT shift
  - L2: layer to layer shift
  - Sagitta introduced
    - P_t depends on ϕ_0
  - Need to correct L2
    - At least







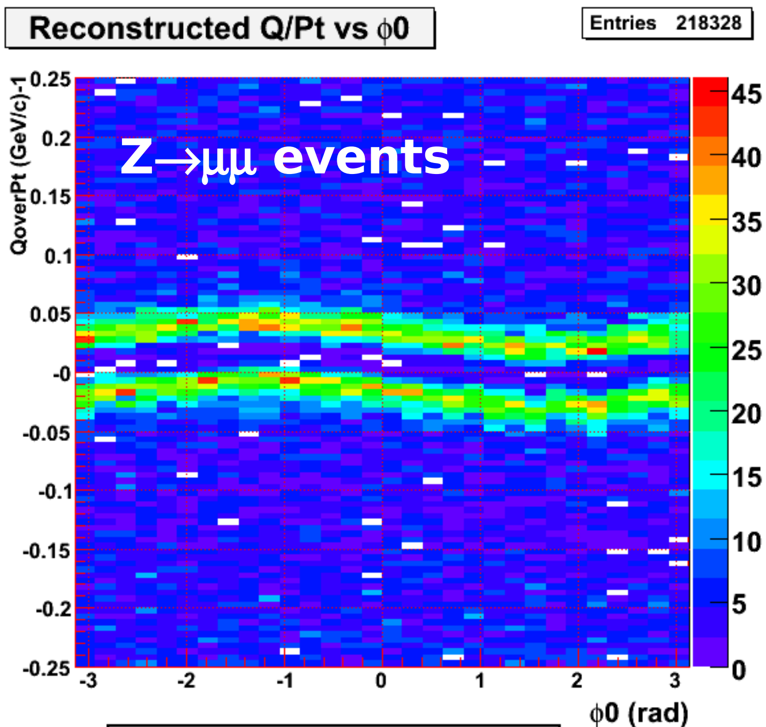


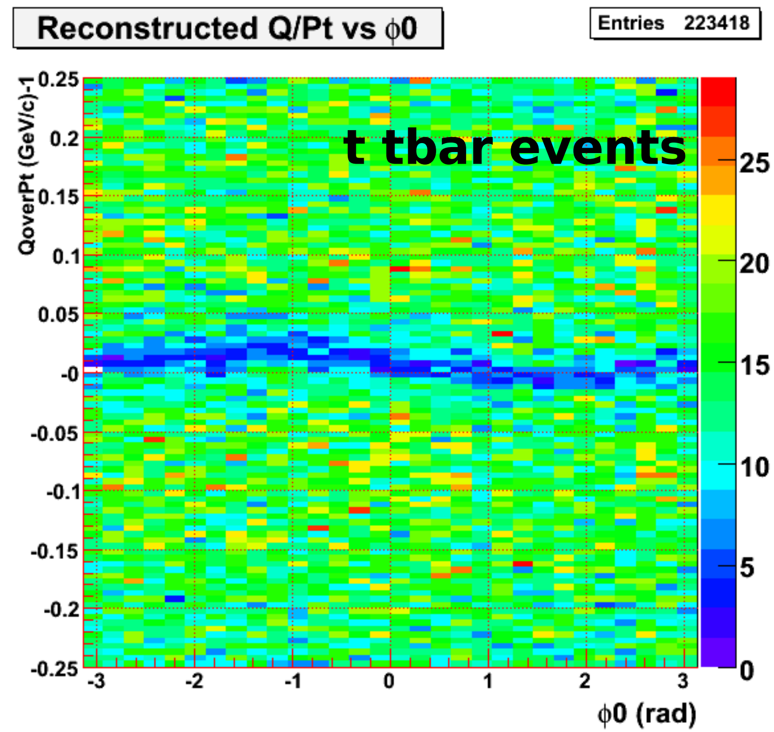


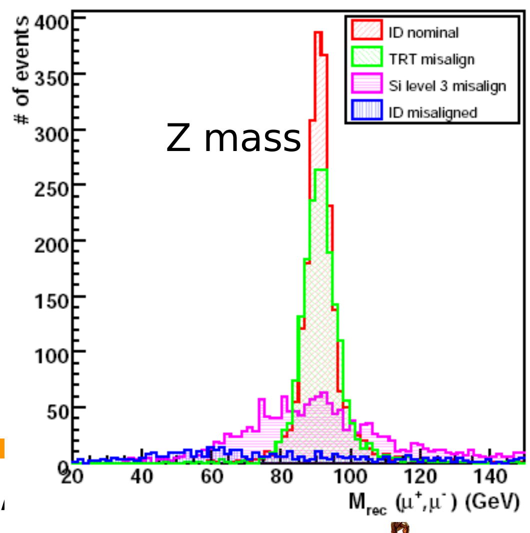
P_t from physics samples

- Can the sagitta distortions be spot on physics samples?
  - Plot Q/Pt vs ϕ_0

NOMINAL setup







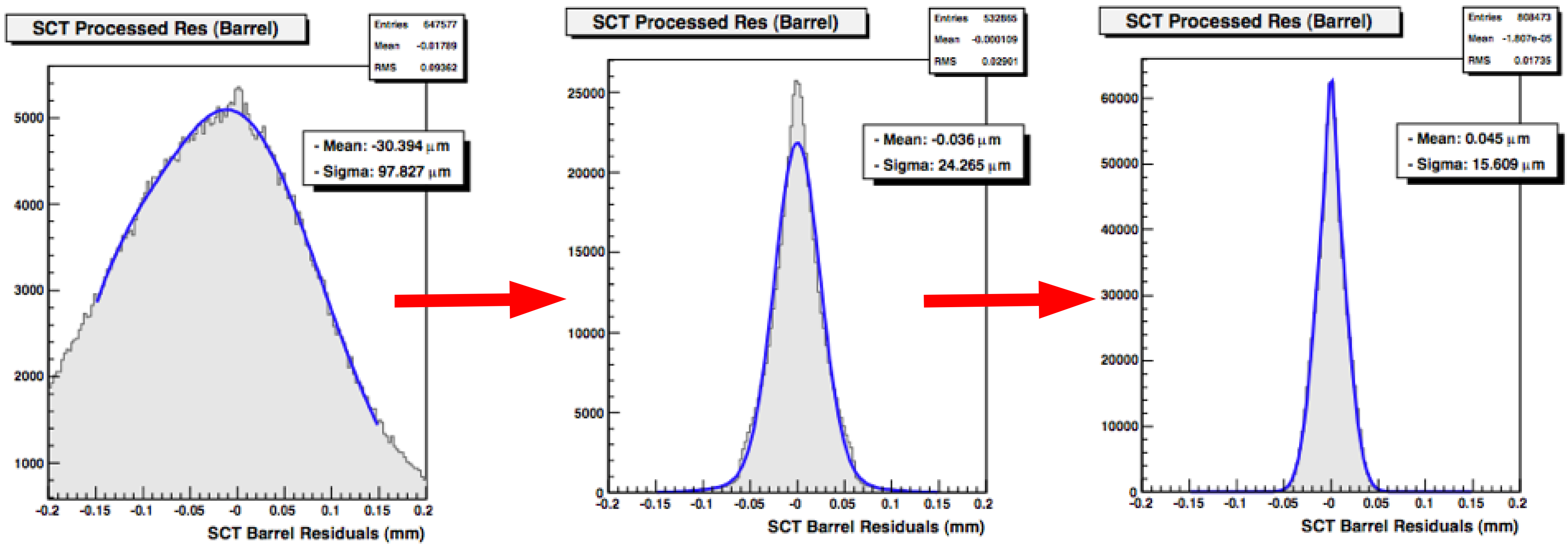
Residuals

- Effects of level 1, 2 and 3 on the residuals

Nominal:
all levels misaligned

L1 & L2 corrected
L3 misaligned

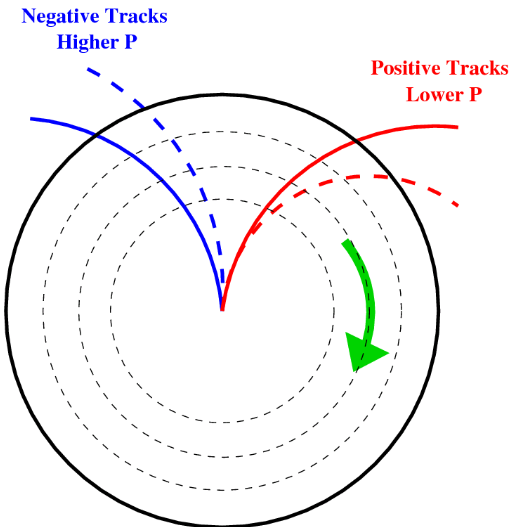
Perfect:
all levels corrected

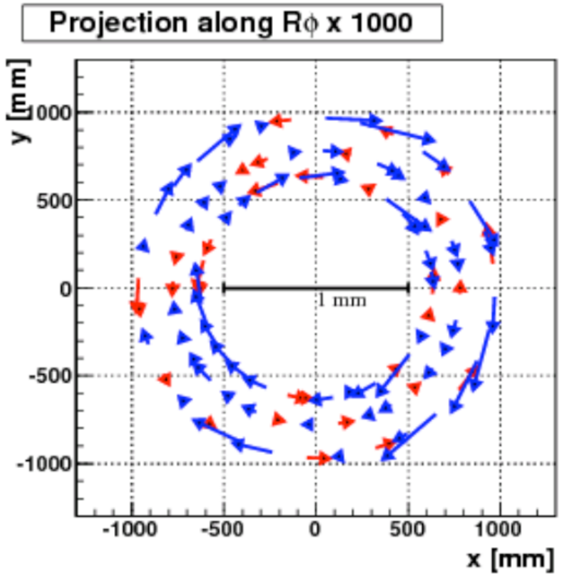


- Correcting levels 1 and 2 produces already quite good residuals
  - As well as momentum and impact parameter

CSC misalignments on TRT

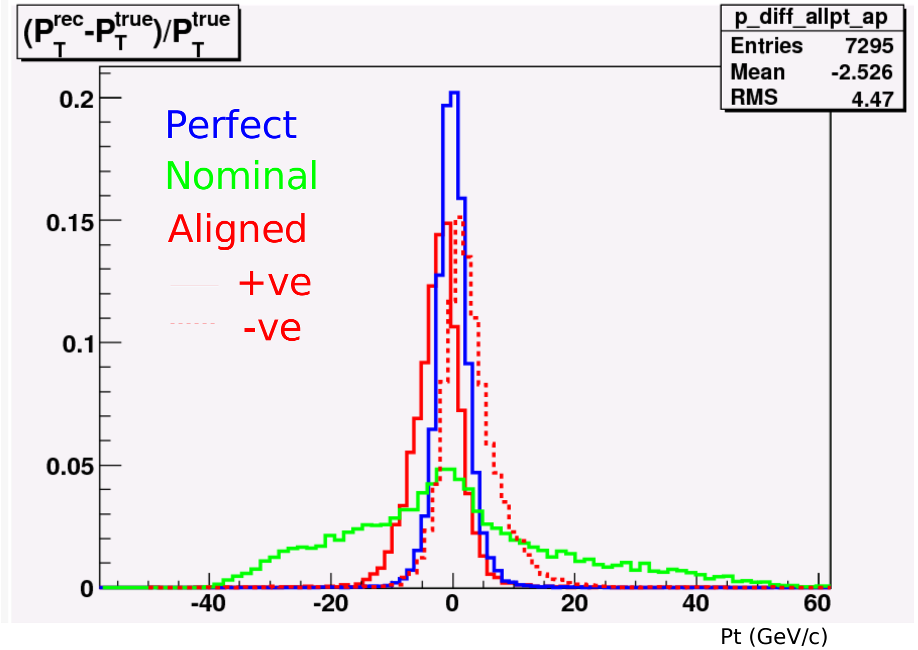
- Check Pt reconstruction with TRT
  - When TRT aligned, Pt suffers a clocking effect
  - Implicit clocking effect in CSC
    - No explicit rotation around Z axis
    - due to TRT modules:
      - Radial plus X & Y translations





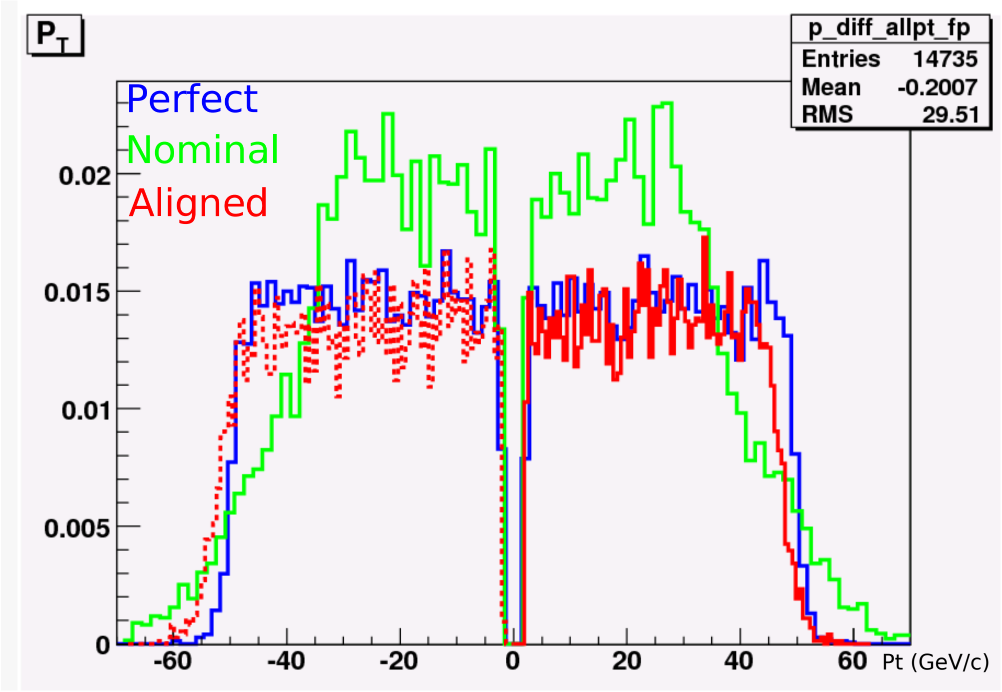
clockwise

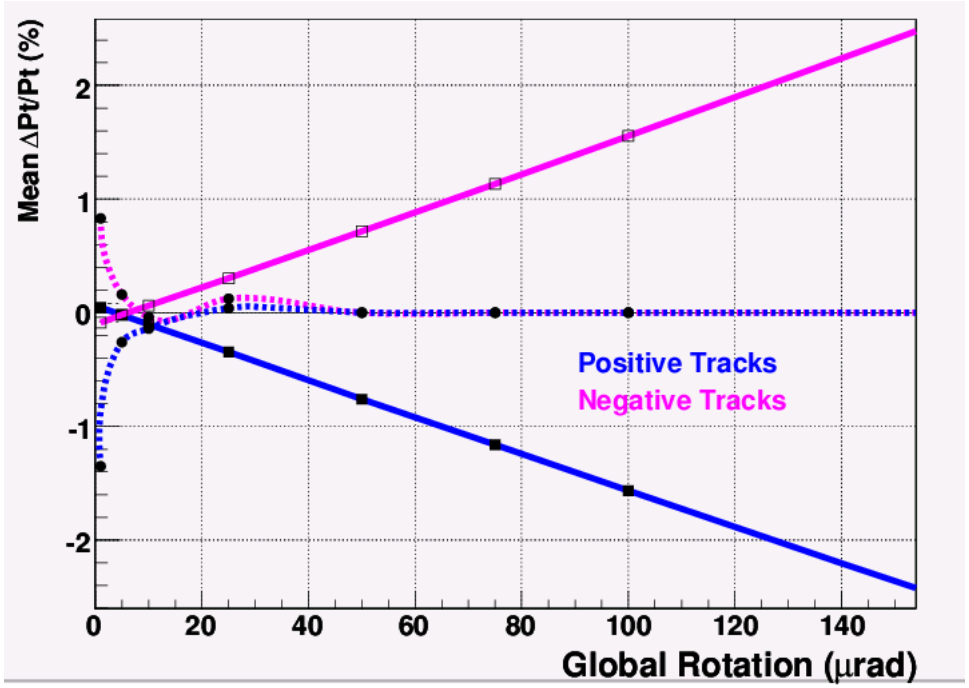
counter-clockwise



CSC misalignments on TRT (ii)

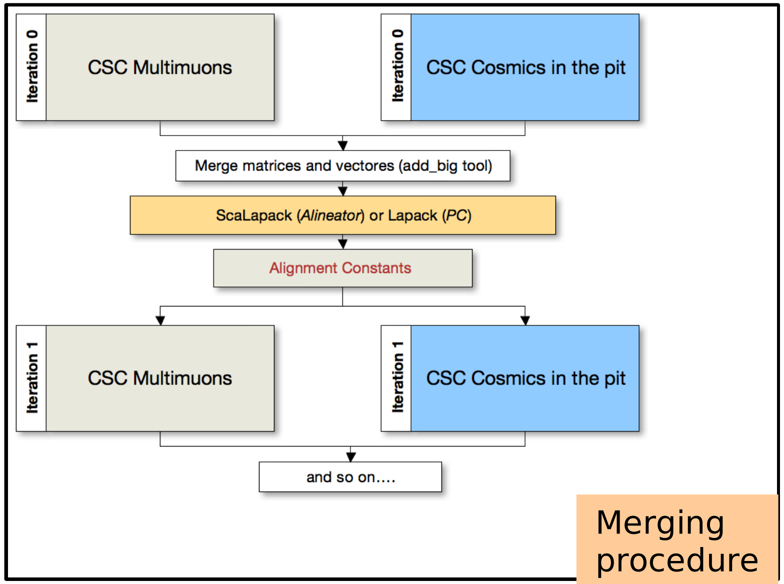
- After alignment:
  - Global rotation around Z axis looks negligible: 0.08 mrad
    - However the Pt systematic shift is due to this
    - One needs to achieve a 0.01 mrad precision for a 0.1% momentum measurement



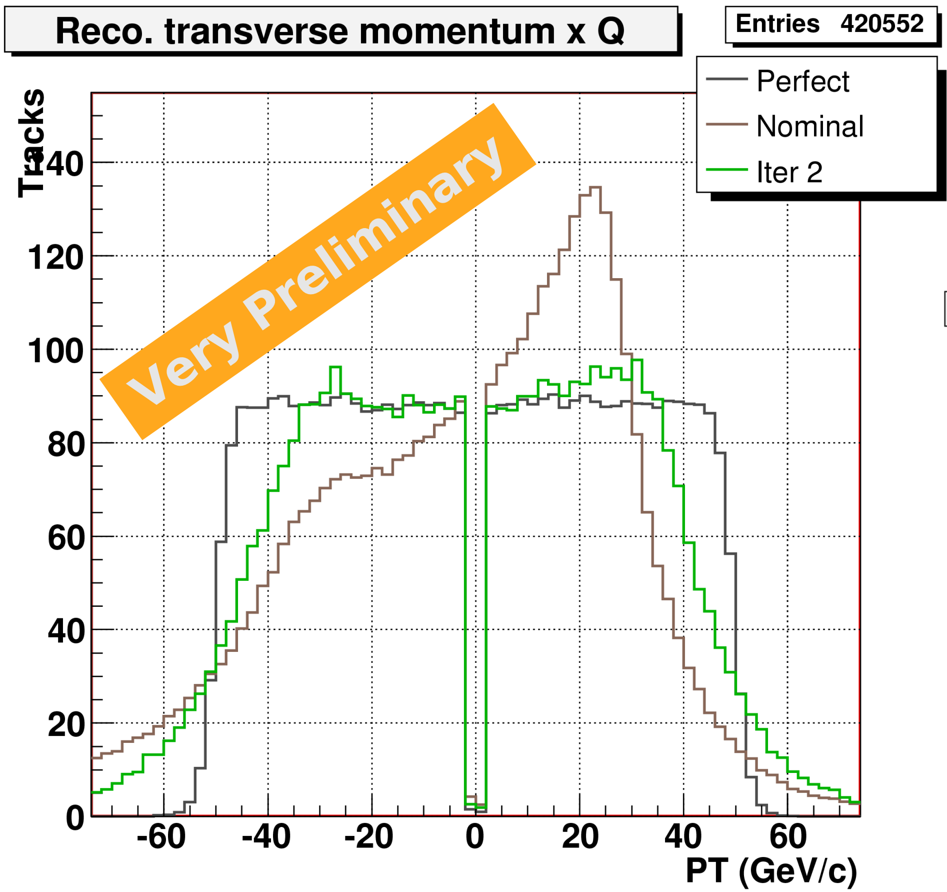


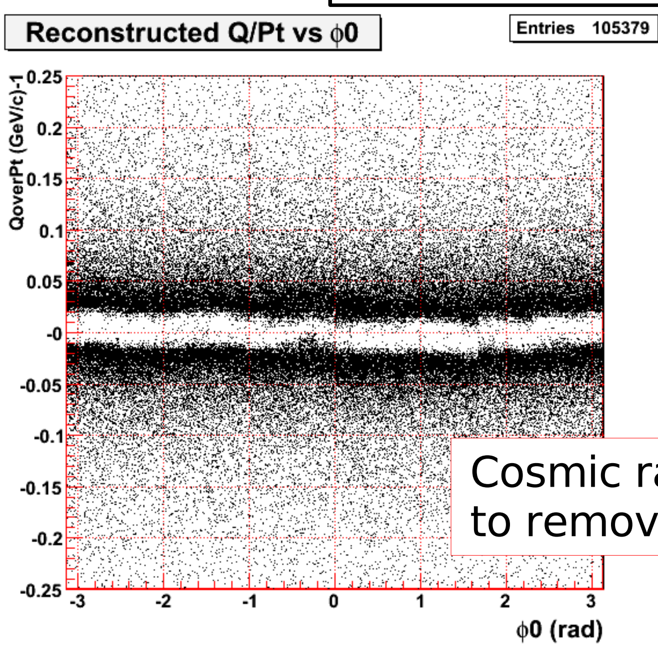
Using cosmics in the pit

- Coscmic ray tracks introduce different correlations between modules
  - They may help to constrain weak modes
  - Globalχ^2 matrices become not sparse



Merging procedure





Cosmic rays help to remove sagitta

Summary & conclusions

- ATLAS CSC challenge sample has proven to be very useful for the alignment exercise
  - Try to align shifts of mm
    - From large structure movements
  - Minimizing residuals is not enough
    - Residuals distribution may look as good as perfect
    - track parameter may remain poorly determined
    - Weak modes may not be detected
  - Good news is:
    - lots of developments within the alignment algorithms
    - Some observables proven to give a hint on misalignment
      - Impact parameter (d0), its error, d0 vs phi0
      - Pt asymmetry for $Q>0$ and $Q<0$
    - Primary Vertex and track refit will help
      - Able to detect and correct global shifts in the XY plane
    - Pt reconstruction reasonable good at level 2
    - Gaining valuable experience
  - Use of cosmic ray
    - Helps constraining weak modes
    - Improve track parameter determination