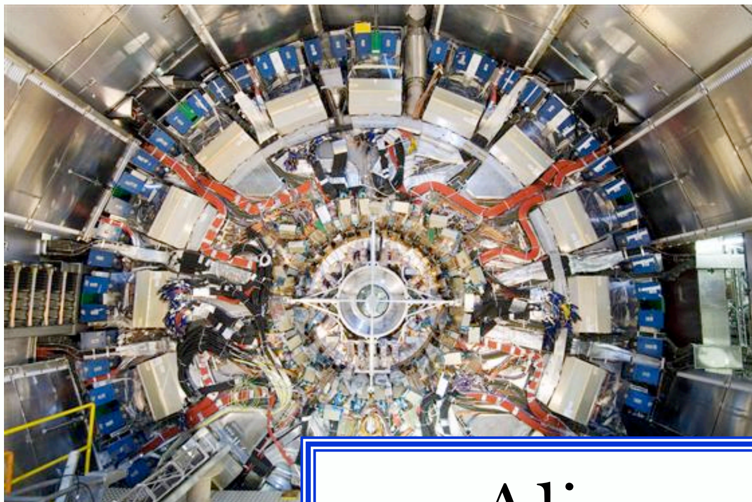


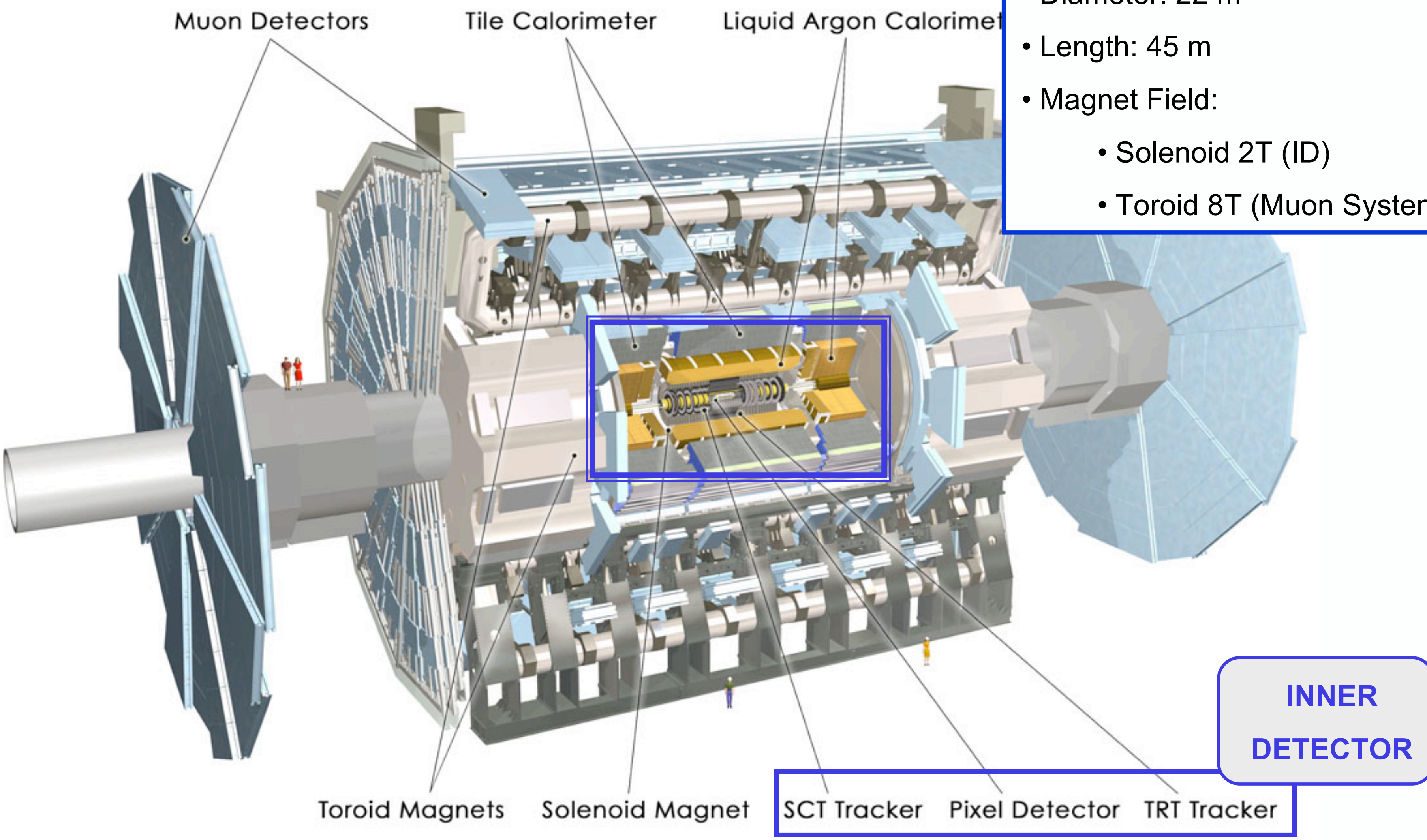
Alignment of the ATLAS Inner Detector Tracking System

– On behalf of the ATLAS Collaboration –

Physics at LHC 2008, Split, Croatia

• ATLAS (*A Toroidal LHC Apparatus*) :

- Weight: 7000T
- Diameter: 22 m
- Length: 45 m
- Magnet Field:
  - Solenoid 2T (ID)
  - Toroid 8T (Muon System)



ATLAS Inner Detector

• The ATLAS Inner Detector (ID) is designed to provide hermetic and robust pattern recognition, excellent momentum resolution and both primary and secondary vertex reconstruction for charged tracks. The ID is made for three independent but complementary sub-detectors:

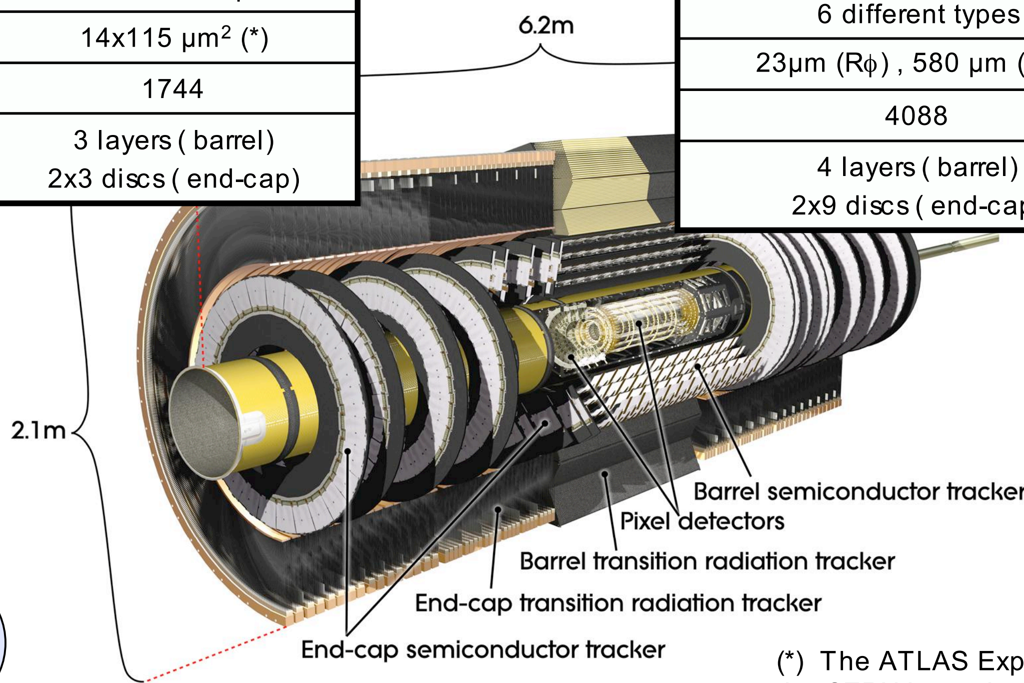
Table information:

- Main contribution (signal)
- Technology
- Size of components
- Intrinsic resolution
- Number of detectors
- Geometrical layout

Pixel Detector *Pixel* (1)
Vertices reconstruction Discrete space-point
Pixel detector
Pixel size: 50x400 μm^2 All modules equals
14x115 μm^2 (*)
1744
3 layers (barrel) 2x3 discs (end-cap)

SCT Detector *SemiConductor Tracker* (2)
Particle momenta Stereo pairs of silicon micro-strips
Micro-strips silicon detectors
Strip pitch: ~ 80 μm 6 different types
23μm ($R\phi$) , 580 μm (z) (*)
4088
4 layers (barrel) 2x9 discs (end-cap)

TRT Detector *Transition Radiation Tracker* (3)
Ease the pattern recognition and momentum Average of 36 hits per track
Gaseous straw tube elements
Diameter :4mm Length:144cm barrel, 37cm EC
130 μm (*)
992
3 layers (barrel) 14x2 (end-cap)



(*) The ATLAS Experiment at the CERN Large hadron Collider, JINST3 S08003

ATLAS Inner Detector Alignment

Alignment Requirements to achieve the ATLAS Inner Detector aims:

- The knowledge of the alignment constants should not lead to a significant degradation of the track parameters beyond the intrinsic tracker resolution. (degradation of tracking resolution less than 20%)

We need:

	PIXELs		SCT	
	Barrel	EndCap	Barrel	EndCap
Rϕ (μm)	7	7	12	12
Z (μm)	20	100	50	200

The strategy for the alignment of the Inner Detector:

- Initial knowledge of the module position (optical and mechanical surveys during the assembly and the integration survey).
- Track-based offline alignment Algorithm (different levels)
- Frequency Scanning Interferometry (FSI) system in the SCT

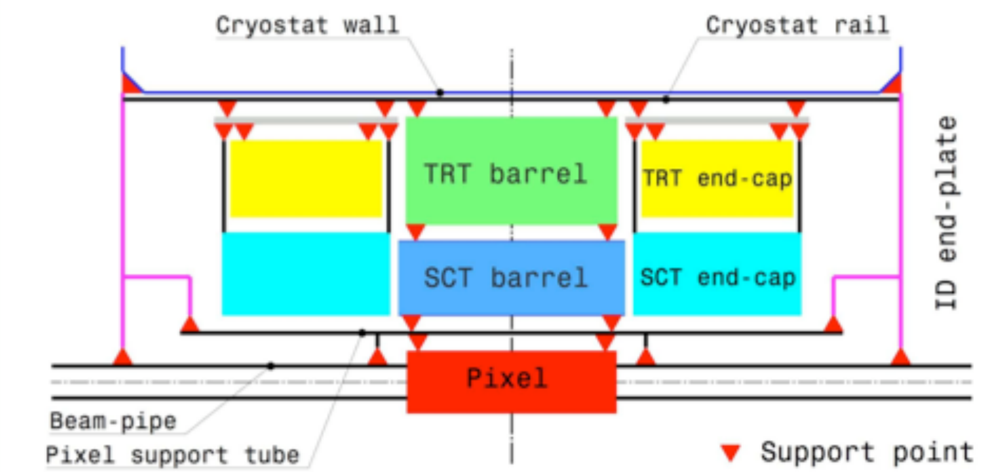
The strategy apply must achieve a absolutely position of the detector devices at the micron accuracy (*) in the rϕ plane.

(*) long term target, once material and calibration effects have been understood

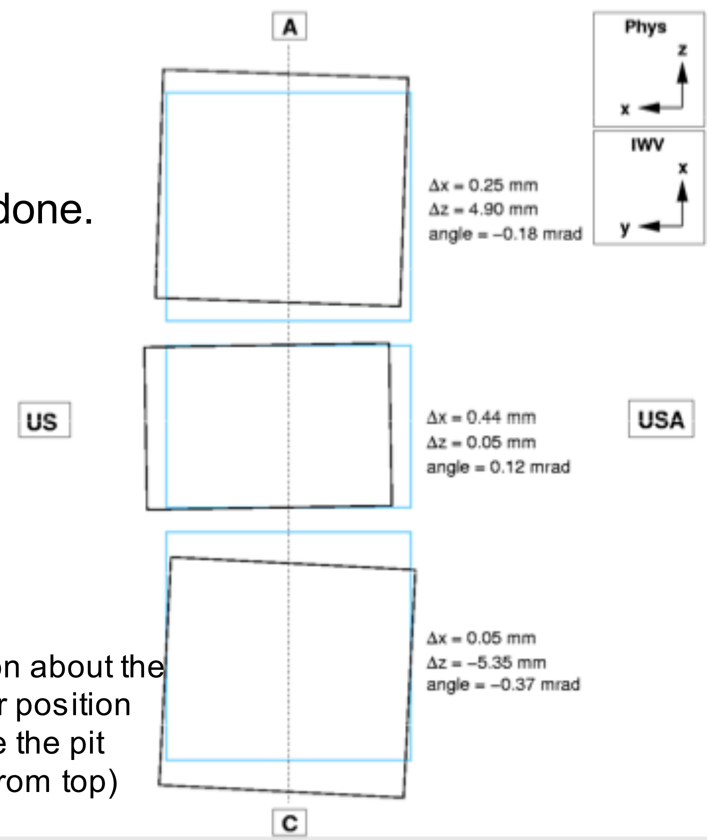
Assembly and Integration

Initial knowledge of the structures/module position optical and mechanical surveys during the assembly and the integration survey have been obtained:

- The three subsystems have been independently surveyed
- The survey has been done at different stages of the assembly (sectors , staves,..)
  - All components has been mounted with a fixed precision.
    - Pixel's ~ 5μm
    - SCT End-cap < 50 μm
    - TRT wire position O(30 μm)
- The study of detector places inside the ATLAS has been done.



Schematic top view of the Inner Detector subsystem



Information about the detector position inside the pit (view from top)

Frequency Scanning Interferometry

• The SCT is equipped with a laser alignment system (geodetic grid of length measurement between nodes)

• The FSI can provide a knowledge about the stability of the detector (measured each 10min)

• 842 grid line length are measured simultaneously (FSI system fully connected for barrel and EndCaps)

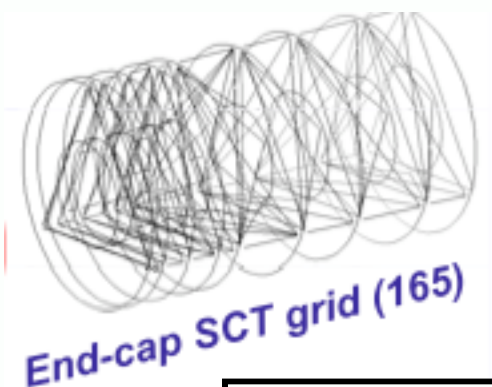
• Using FSI can achieved a precision <1μm along 1D length (precision in 3D ~5μm)

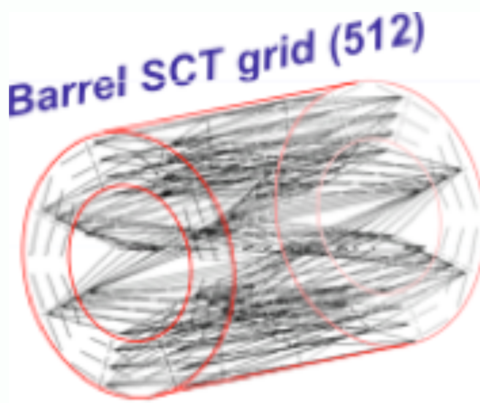
• FSI monitor shapes of 4 SCT barrel layers and separated grids for the EndCaps

• Measure relative rotations clocking of barrel and radial deformation.

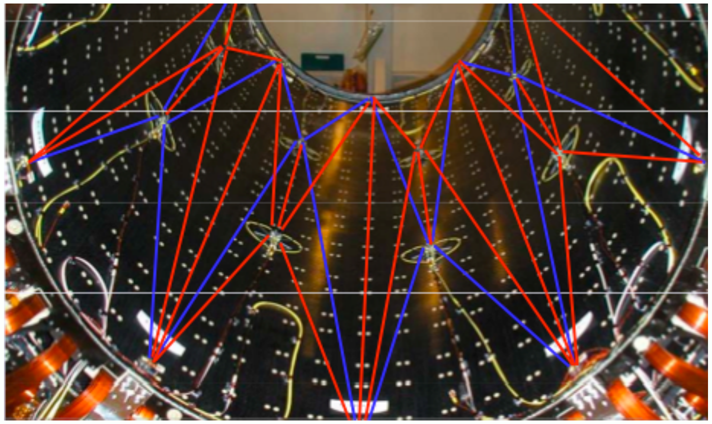
• Complete commissioning of the FSI

• Will be used intensively before and during the early runs





SCT grid for Barrel and End-Caps



Alignment Algorithms

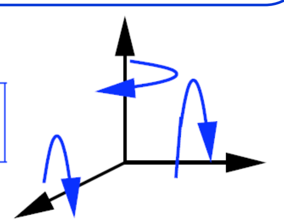
- Ultimate precision must be achieved with track-based algorithms (~ μm)
- All of them make use of the residual information (distance to the reconstructed hit to the recorded hit)
- Are implemented in the ATLAS framework (Athena)
- Silicon and TRT has different algorithms (relative alignment to the TRT vs silicon)
- Validation with monitoring tools

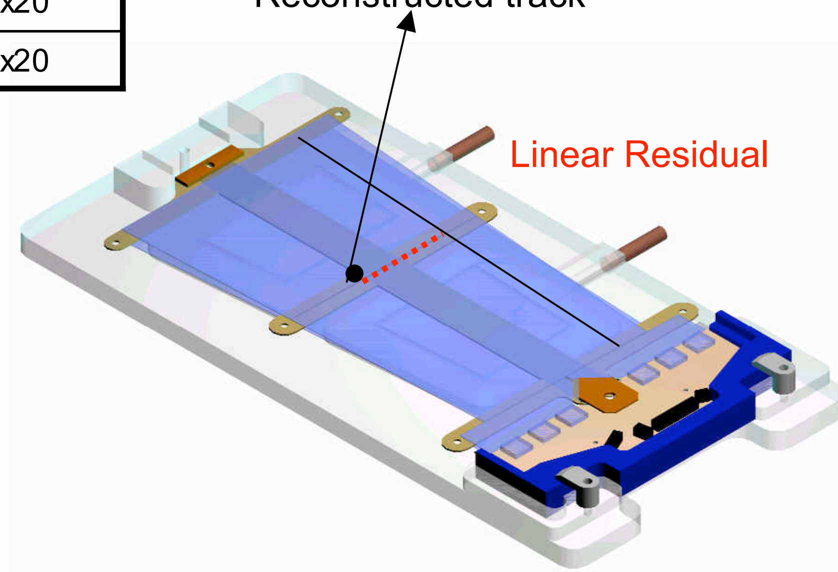
		SILICON SYSTEM		TRT
		PIXELS	SCT	
BARREL	LAYER	3	4	3
	N.MODULES	1456	2112	96
ENDCAP	DISCS	2x3	2 x 9	2x20
	N.MODULES	2x114	2x988	2x20

The Inner detector has 5968 modules, each structure has 6 DoF (3 translation and 3 rotation).

We have **35808** DoFs !!!!!!!

$$a = T_x, T_y, T_z, R_x, R_y, R_z$$





- Silicon Alignment algorithms :

GlobalChi2:

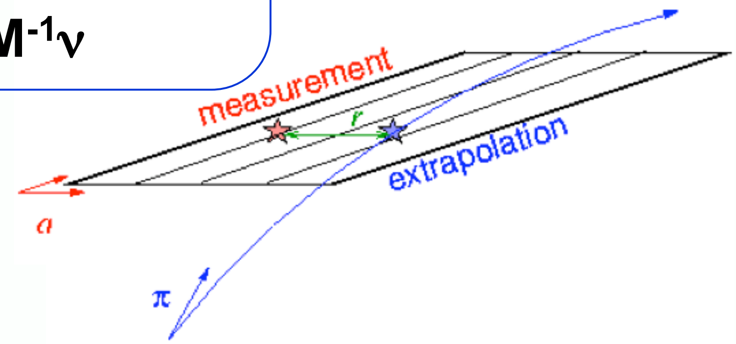
- Based on the minimization with respect to the alignment parameters of the Chi2 function
- Biased residuals
- Inter module correlation
- MCS is take account
- 6 DoFs per module
- M is a huge symmetric matrix
  (For silicon system 35k x 35k)

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

$r = r\,(a,\pi)$

$V = V$ (hit measure)+V (MCS)

$$\delta a = -M^{-1}\nu$$



LocalChi2:

- Same principle as the GlobalChi2
- Unbiased DOCA residuals
- No dependence respect the track parameters
- No MCS
- Solve 6x6 matrices (6DoFs per module)
- Need more iteration

Robust:

- Centre residuals and overlap distributions without minimization
- Use residuals:
  - Local x, y residuals
  - Overlap residuals for adjacent module
- 3 DoFs per module (plane parameters:Tx,Ty,Rz)
- Need many iterations

CSC Challenge

The CSC (Computing System Commissioning) exercise simulated a realistic ATLAS detector description (accounting for the assembly imperfections and material description).

This one was a ideal scenario to test the alignment and calibration algorithms.

Elaborate the strategy for the alignment procedure:

Level	PIXELs	SCT	TRT
1	Whole detector	Barrel End-Caps	Barrel End-Caps
2	Barrel Layers End-Cap Disks	Barrel Layers End-Cap Disks	Barrel Modules
3	Barrel Modules Endcap Modules	Barrel Modules Endcap modules	-

For the Inner Detector the as-built geometry include:

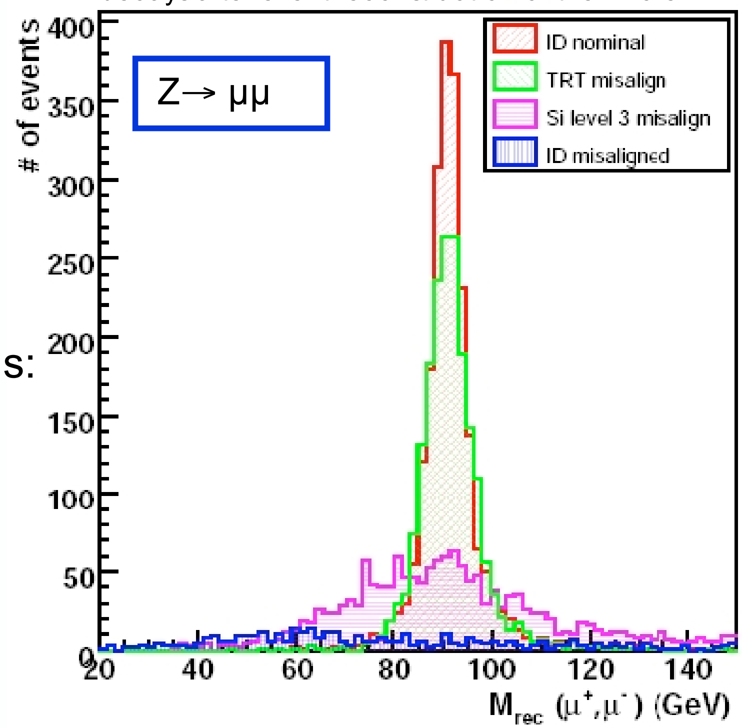
•Misalignment introduced at the CSC for the different levels:

- Level 1: O(1mm) and O(mrad)
- Level 2: O(100µm) and O(0.1 mrad)
- Level 3: O(100µm) and O(0.1 mrad)

• Distorted material

• Distorted magnetic field

Mass resolution of the muon pair from Z→ µµ decays after event reconstruction of the whole ID



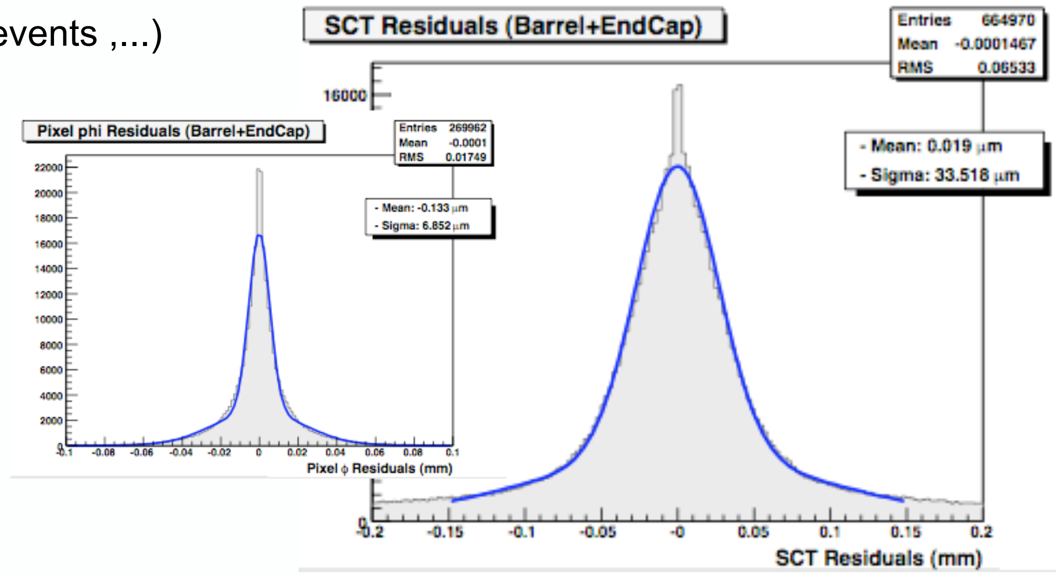
Several exercises have been done using CSC misalignment geometry:

- Multimuon sample: 10^5 events, 10 muons/event, the primary vertex has been generated from Gaussian distributions, uniform distribution in η and ϕ, p_t=[2,50] GeV
- Physics sample ($Z \rightarrow \mu\mu$, minbias, top events ,...)
- Cosmic sample

During these exercises we learn:

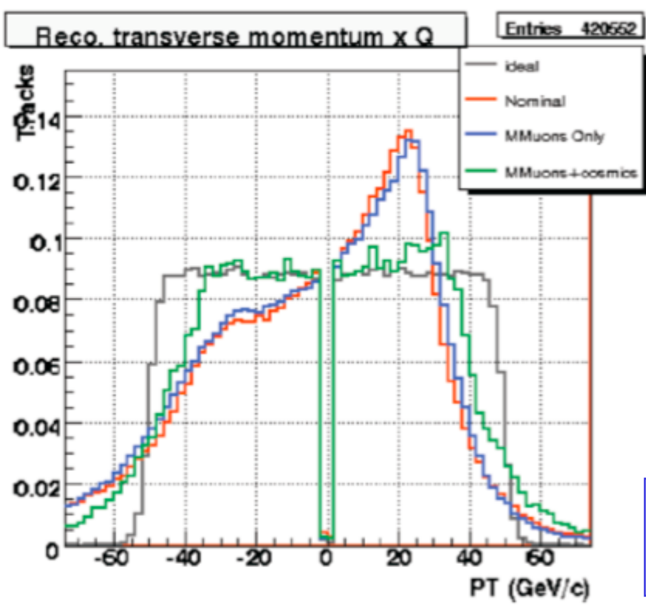
Perfect residuals do not necessarily mean good alignment.

- We can have weak modes in our alignment and need remove it



Residuals distributions after alignment with multimuons only look as expected

- centred at zero and width close to intrinsic resolution



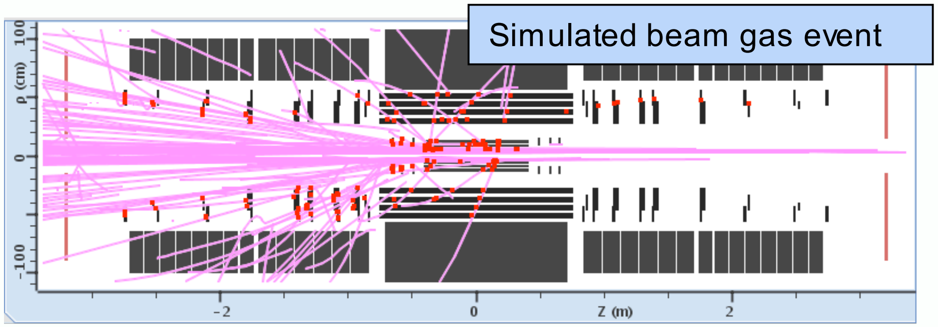
- Cosmic samples give complementary alignment information
  - cosmics help to remove the weak modes

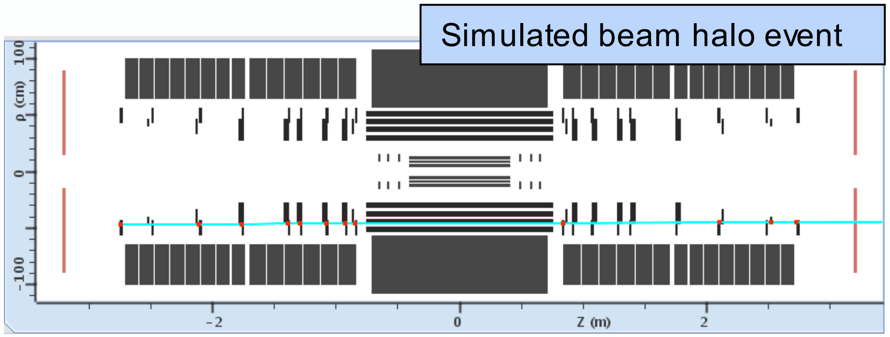
Adding cosmic improve the momentum distribution.

In this exercise mix multimuons and cosmic

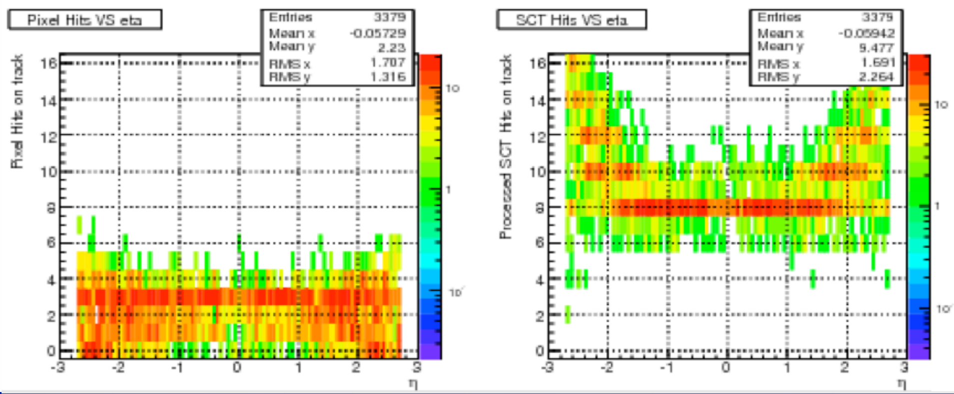
Beam Gas & Beam Halo

- Others important samples for the alignment:
  - Beam gas: Interaction of beam with atoms in the beam pipe
  - Beam halo: Interaction with steering magnets, collimators,...





- Recently beam halo events has been simulated with misalignment geometry.
- They can give a interesting information about the end-caps movements.
- Beam gas in the end-caps is like cosmics in the barrel
- These samples are under study:

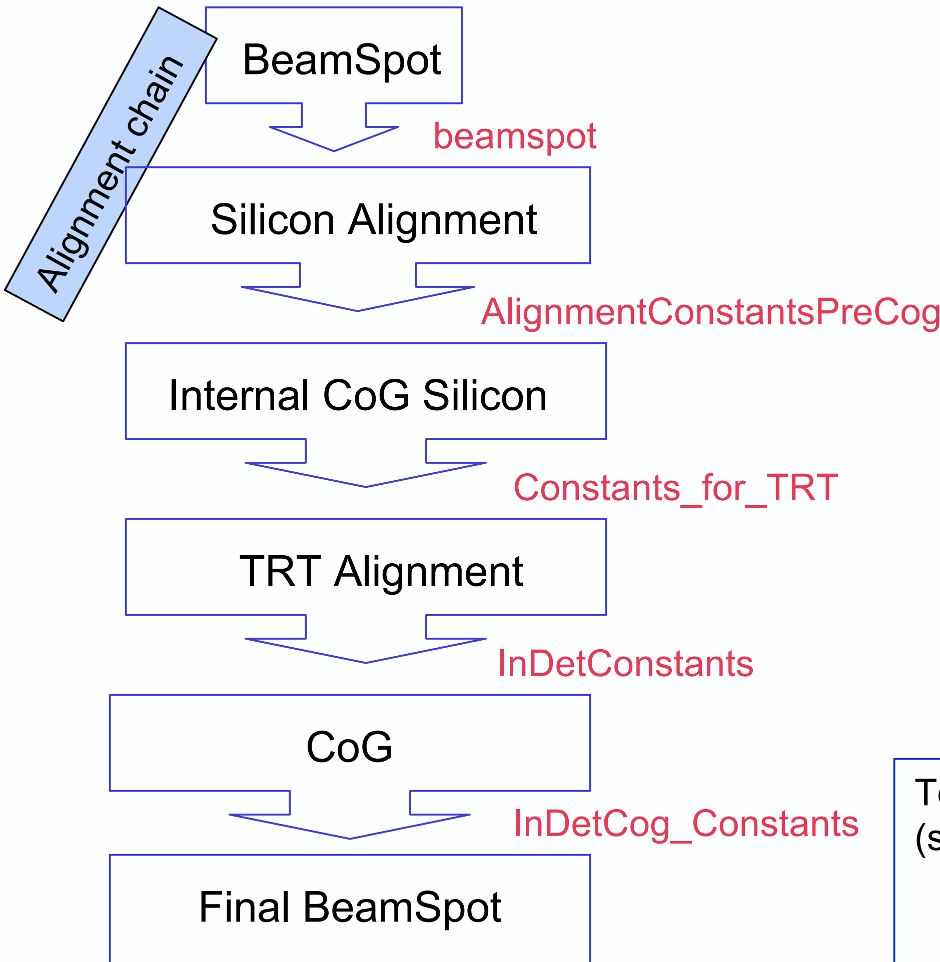


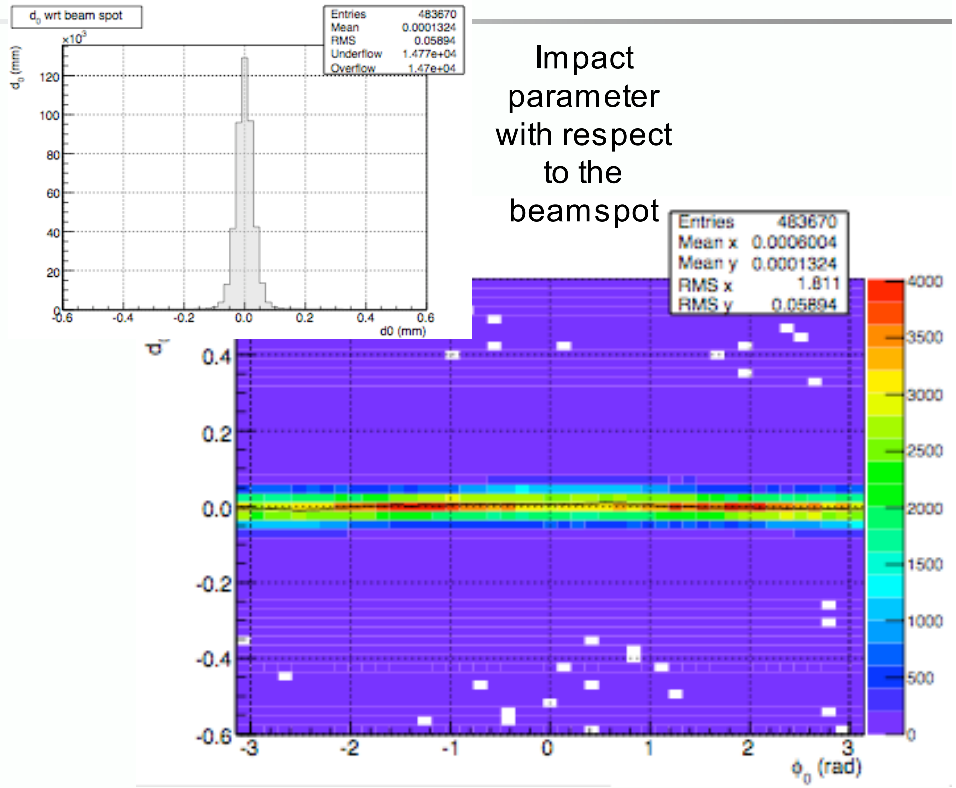
Processed hits vs eta for Pixels and SCT (beam gas sample)

FDR Exercise

The main objective to the Full Dress Rehearsal exercises is to test the offline during the data taking.

For the alignment point of view these exercises has been a perfect scenario where the alignment chain has been tested:





Impact parameter with respect to the beamspot

To test the alignment have used idcalibration stream (sample filtered with tracking L2 trigger):

- 1M single tracks events (single pions) with uniform pT=[10-50] GeV/c
- 15k cosmic events with B field

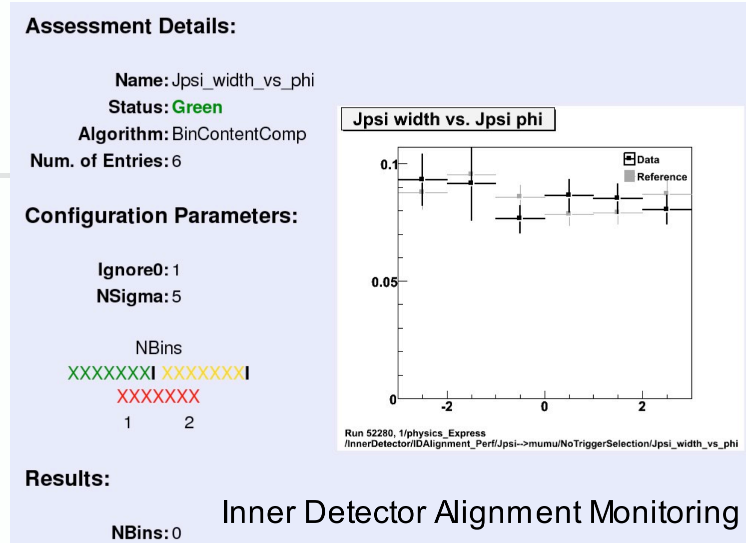
FDR Exercise

This exercises has permitted:

- Analyze collisions and cosmic data together
- Analyze the necessary resources for the alignment
- Test all steps in the chain (timing tests)
- Automatic scripts for iterations (queue system)
- Provide a consistent ID alignment over 24h
- Check the constants and update them to the db.
  (if they are good constants)
- Reprocess physics streams with the new constants
- Inner Detector Monitoring:
  - detector performance
  - physics observables
- FDR2 exercises :

FDR2 Constants → FDR2_FU1, FDR2_FU2, FDR2c

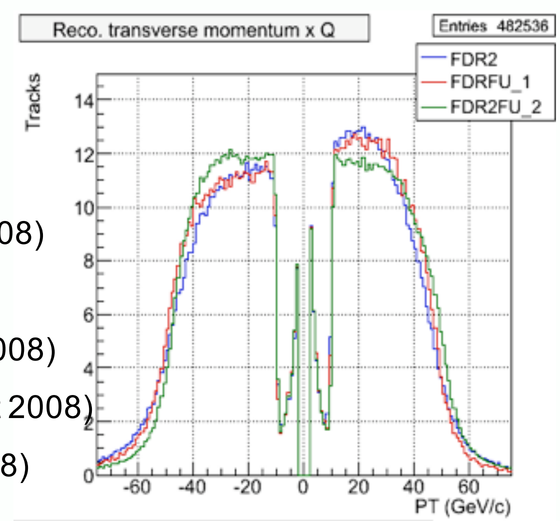
Output provided the local module position for the others exercises.



Inner Detector Alignment Monitoring

Tests done:

- FDR1 (February 2008)
- FDR2 (March 2008)
- FDR2_FU1 (July 2008)
- FDR2_FU2 (August 2008)
- FDR2c (August 2008)



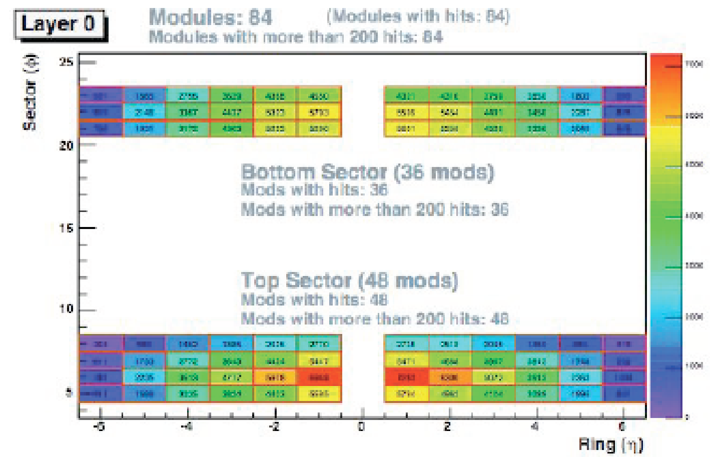
Real Data Taking

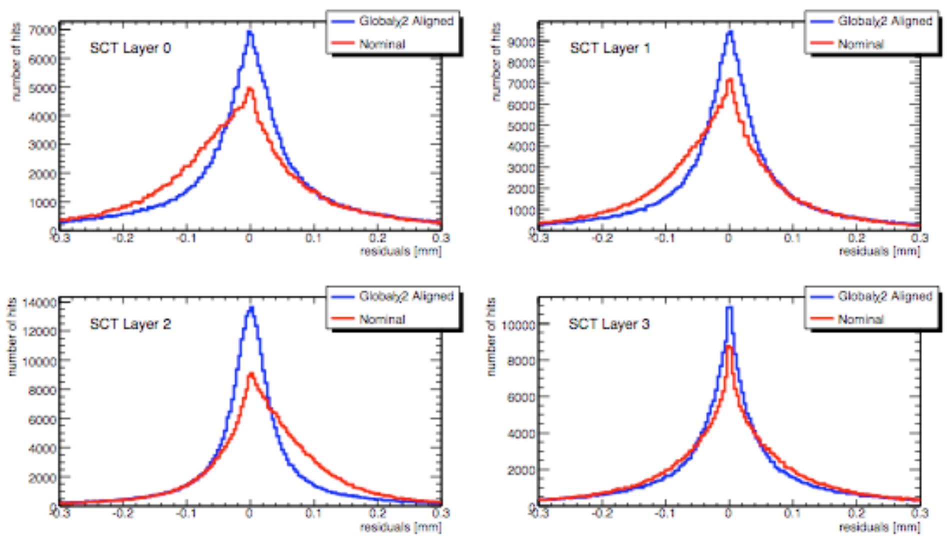
The real cosmic data taking is a very important exercise to test the alignment algorithms.

The alignment algorithms have been worked during different challenges: SR1(2006), M6 (March 2008) and M8plus (September 2008).

SR1 (2006)

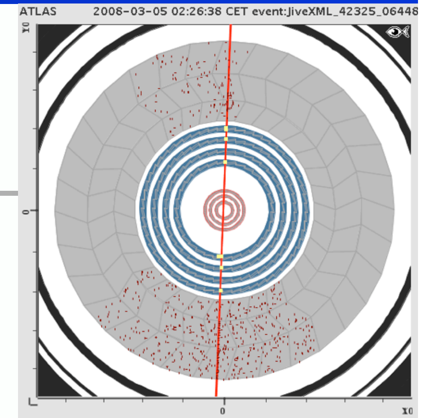
- First ever SCT+TRT cosmic data.
- Data taking at surface
- 400k events were stored
- 22% of the SCT Barrel and 13% of the TRT Barrel (452 modules were aligned)
- No B Field
- The residuals converged after 3 iterations





Real Data Taking

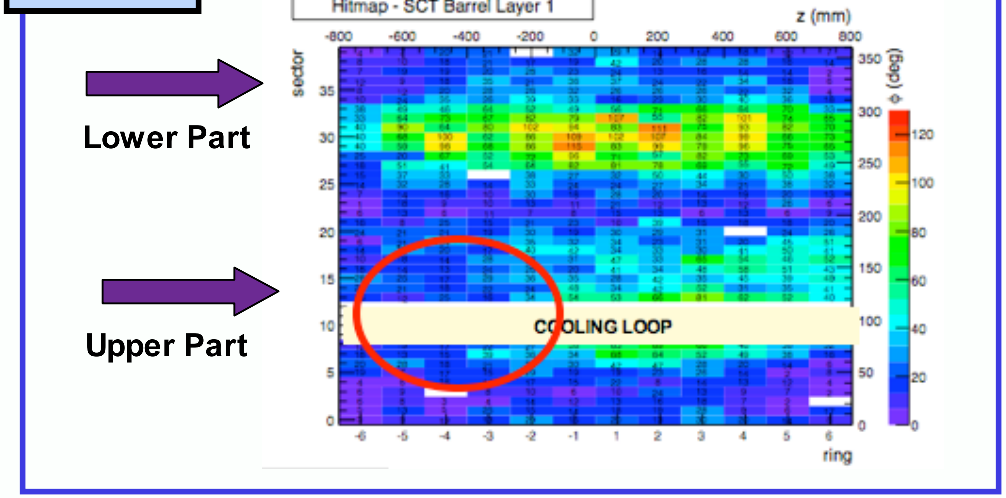
M6 (March 2008)



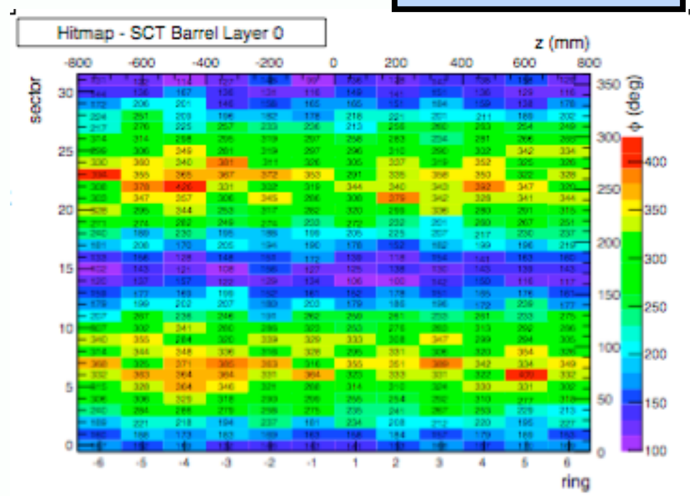
ATLANTIS: Run 42325 , event 6448

- The ID took data in the pit
- Only SCT and TRT were operated (no PIXELs yet)
- 12k good events (~ 5k good tracks for silicon & 4k for TRT)
- Test with no B Field
- During M6 study the different occupancy between lower and upper part due to trigger, the detector wasn't uniformly illuminated. (could be a source of alignment problem)

Real Data

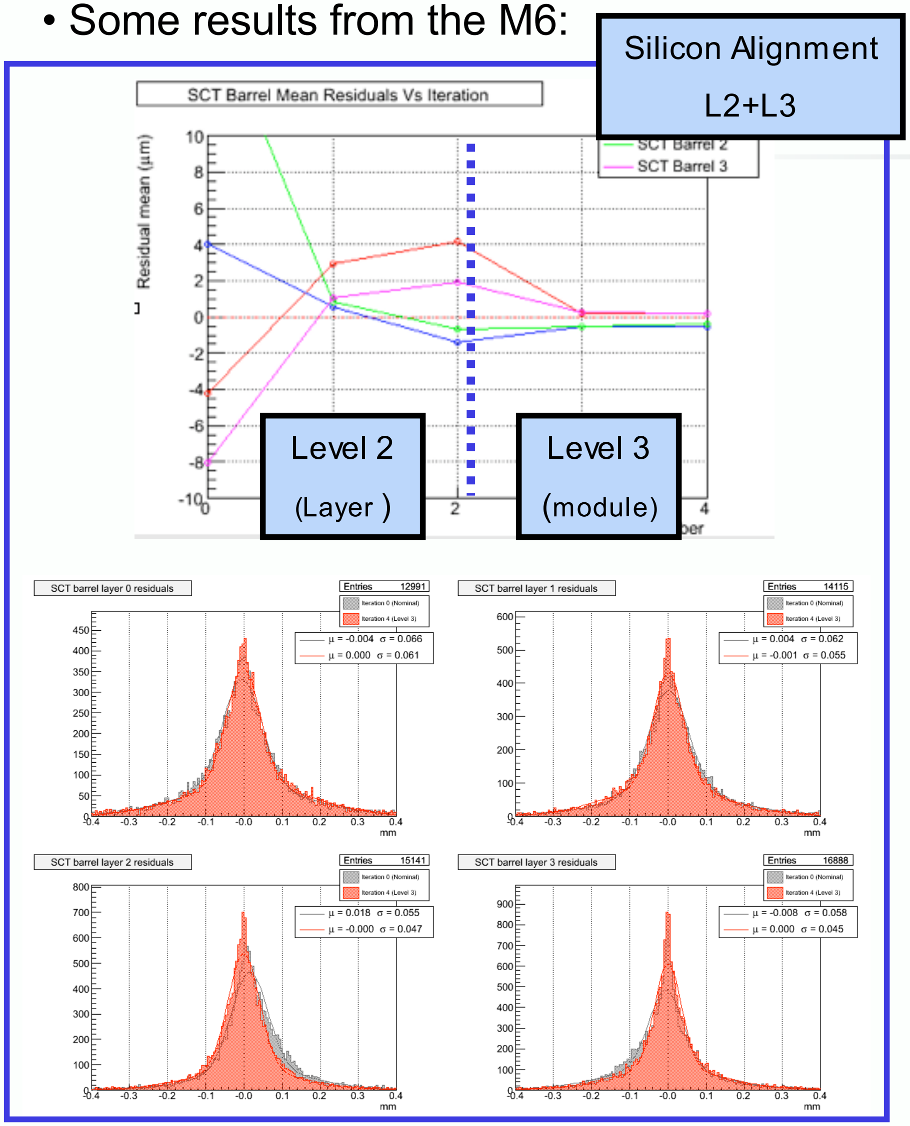


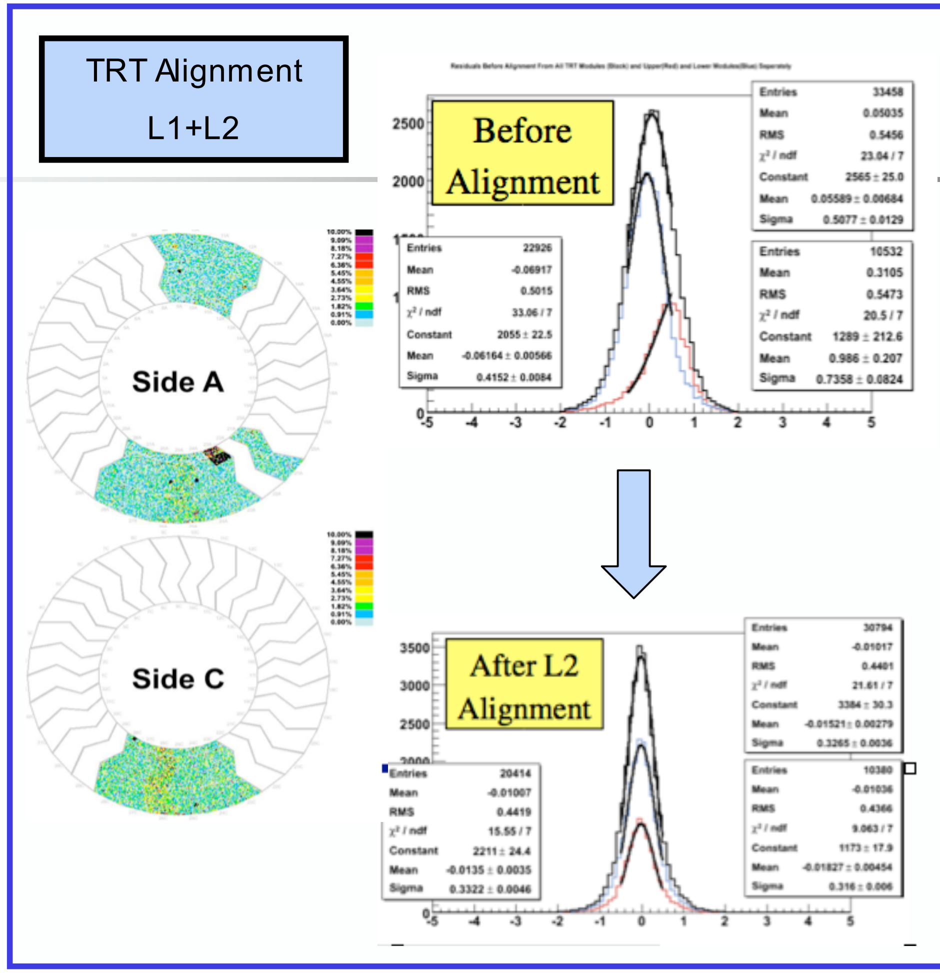
Simulated Data



Real Data Taking

• Some results from the M6:



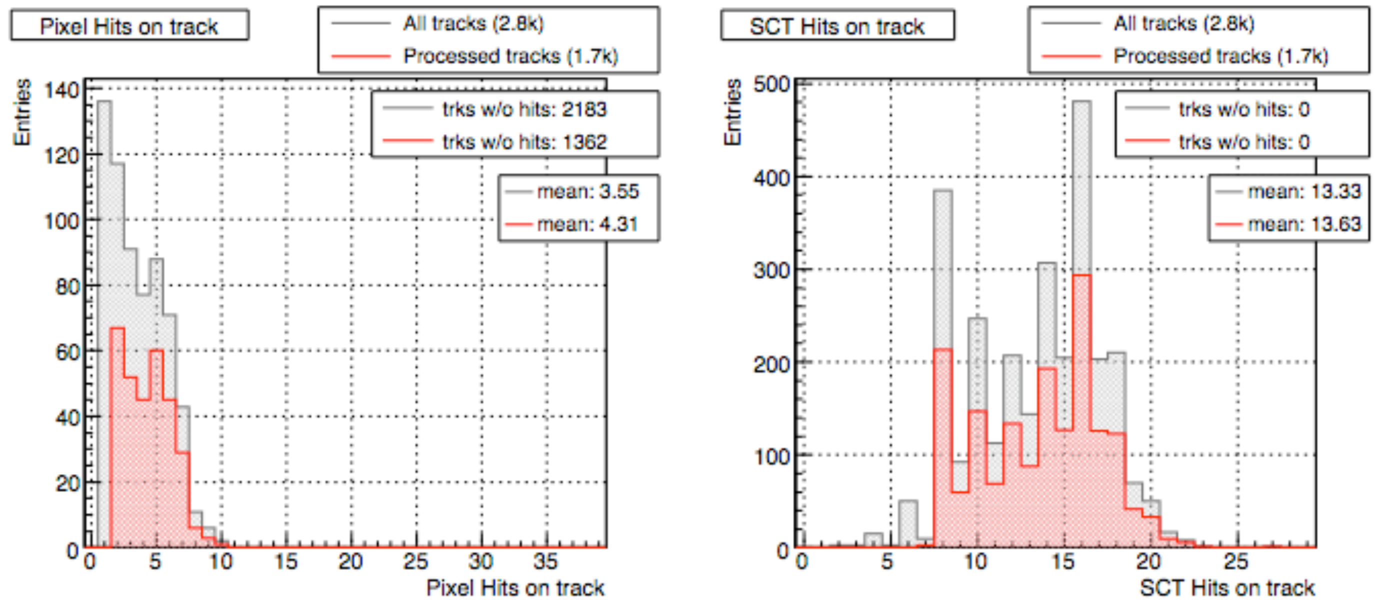


• The residuals improve after iterations to silicon and TRT

• First set of constants for the real detector were uploaded to the DB

M8 (September 2008)

• Pixels, SCT and TRT took date in the pit during M8plus



• First ever alignment with real data for pixels and SCT.

• ~4.5k tracks (267 track with pixels)

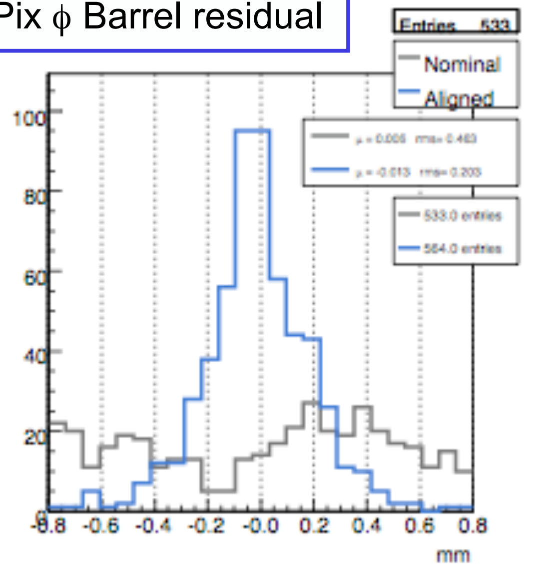
• Level1 (barrel level) and Level2 (layer level) alignment

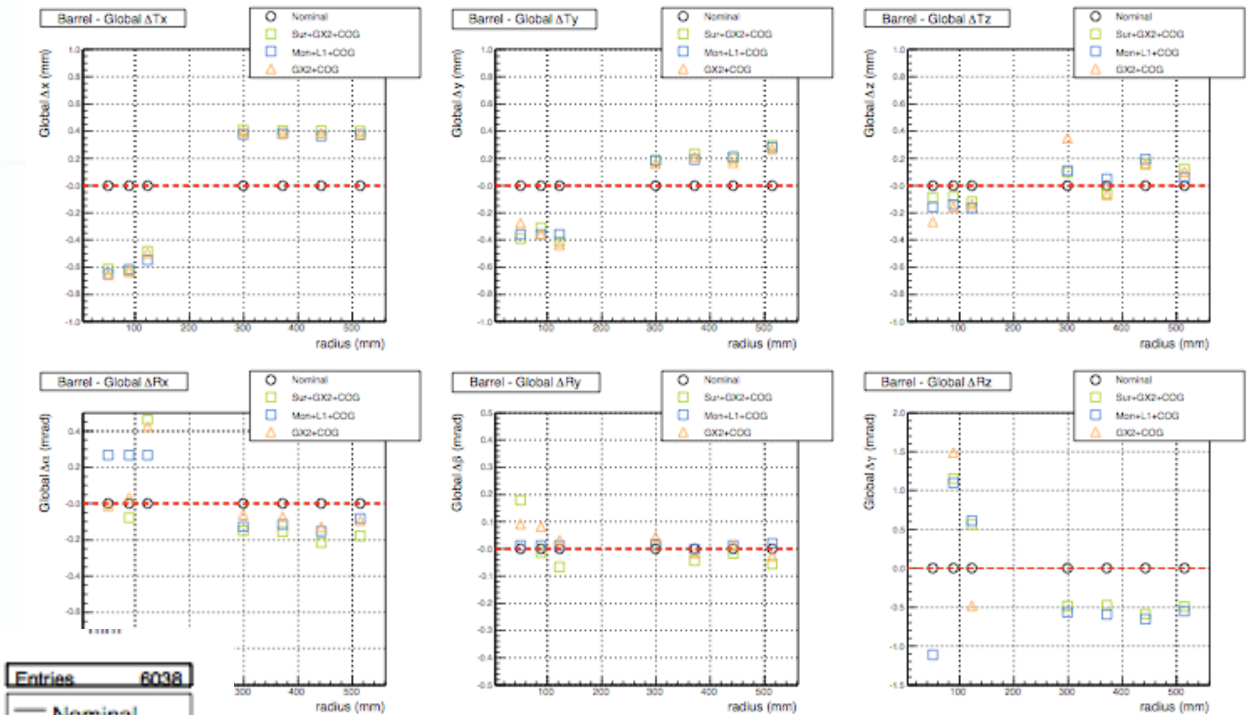
• Use pixel Level3(module level) survey

• Now, we are doing the same exercise with more statistics.

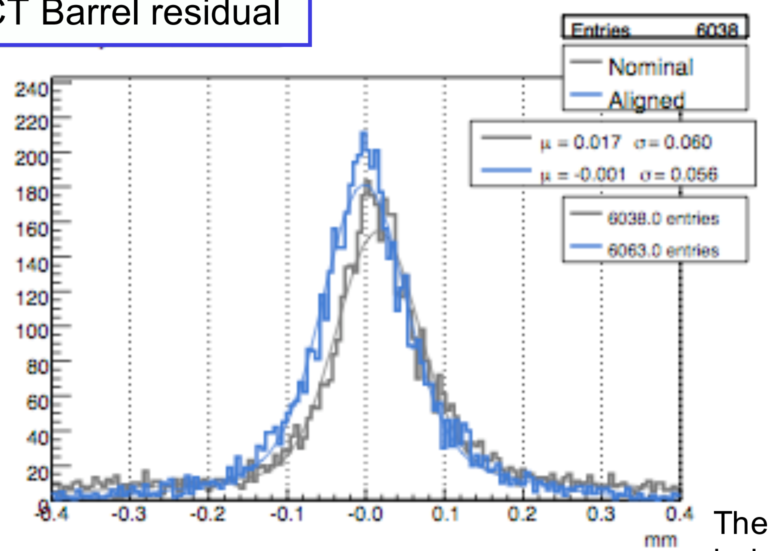
Real Data Taking

Pix ϕ Barrel residual





SCT Barrel residual



Pix+SCT alignment constants

(different alignment approaches were evaluated and give consistent results)

The residuals for the SCT barrel show a behaviour similar to the M6 results.

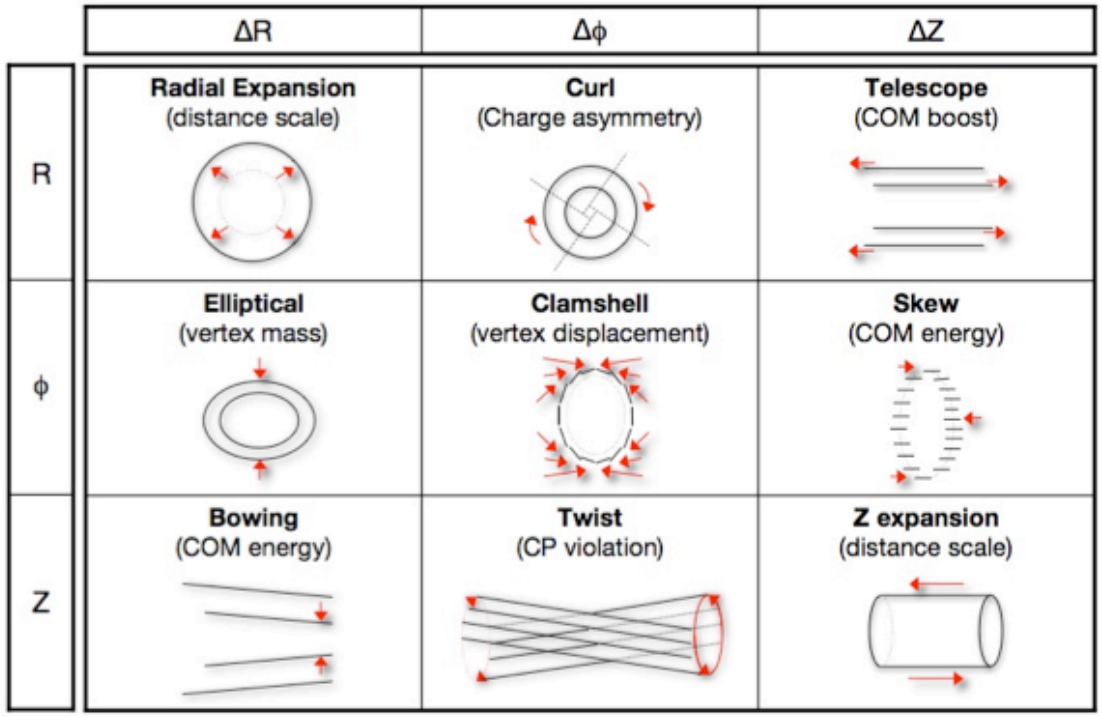
Weak Modes

• The ***Weak Modes*** are deformations that leave the Chi2 unchanged.

• The algorithms based on the residual minimization can not detected it, we need external information to find these movements.

• The are some candidates to help us in this issue:

- Cosmic rays and beam halo
- Vertex and beamspot constrain
- Fix generic asymmetry on the Pt
- External surveys
- Use FSI Information



• Strategy to affront the weak modes:

- Several samples has been simulated with global distortions.
- Some of them has been included in the physics groups to study the impact in the physics results.
- Evaluation of the weak mode impact is underway with physic sample.

Summary

- The status of the ATLAS Inner Detector Alignment has been reviewed.
- The Inner Detector Alignment works on:
  - Assembly survey information
  - FSI
  - Track-based algorithms
- The Inner Detector Alignment has been tested in many exercises:
  - Using simulated sample:
    - CSC exercises as a proof of principle
    - FDR: Integration of the alignment loop in the ATLAS offline software chain.
  - Cosmic real data:
    - SR1 first test with the real detector (SCT+TRT) at surface
    - M6 first test done on the pit (SCT+TRT)
    - M8 first test with pixel's detector. The detector geometry is ready to reconstruct the first collisions.

Thank you very much for your attention!!!