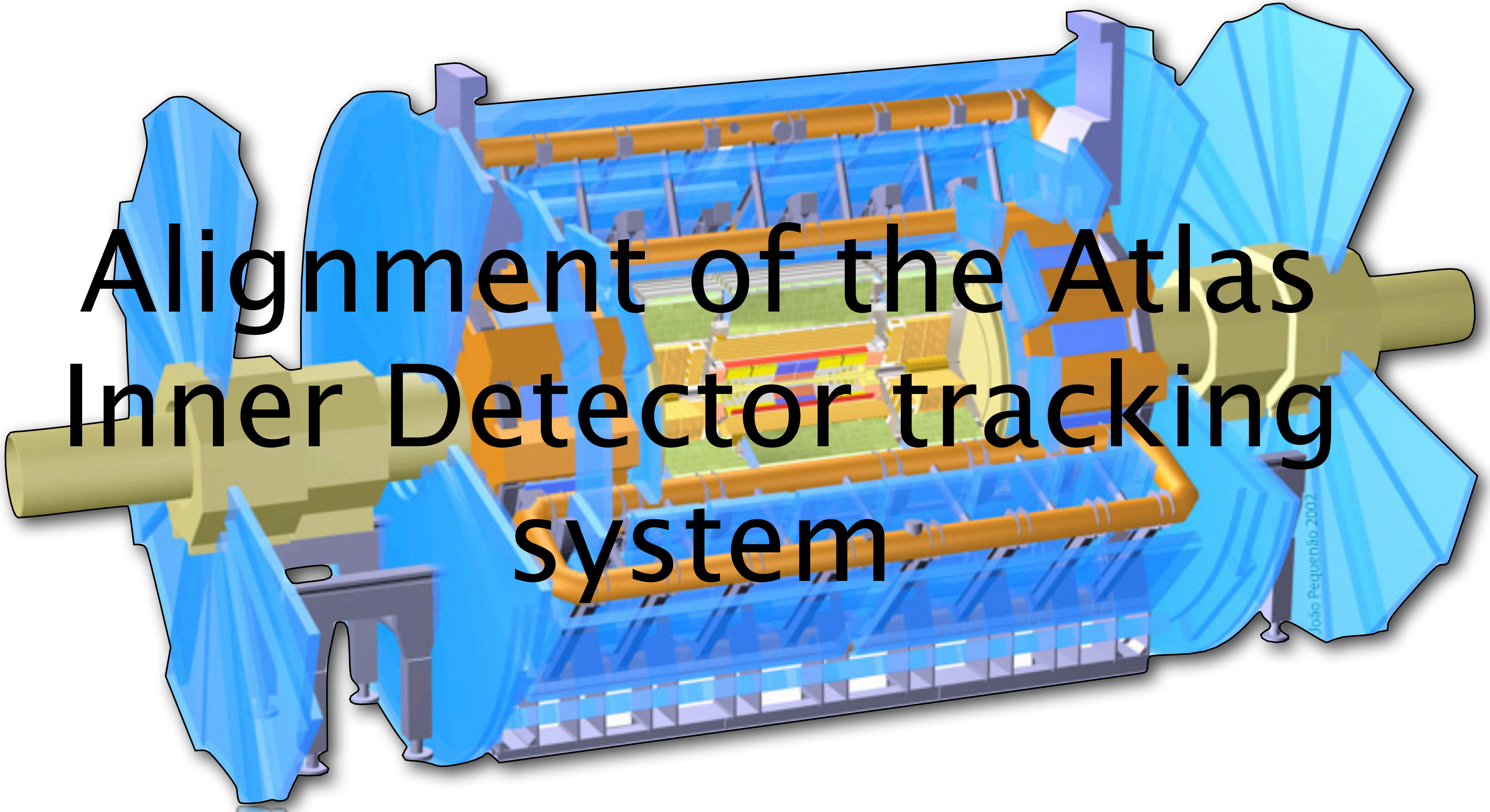
Alignment of the Atlas Inner Detector tracking system



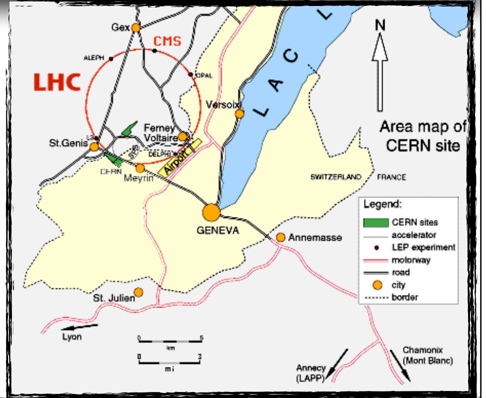
Vicente Lacuesta *on behalf of the ATLAS collaboration*

IFIC (CSIC - UV)

13 - 3 -2009

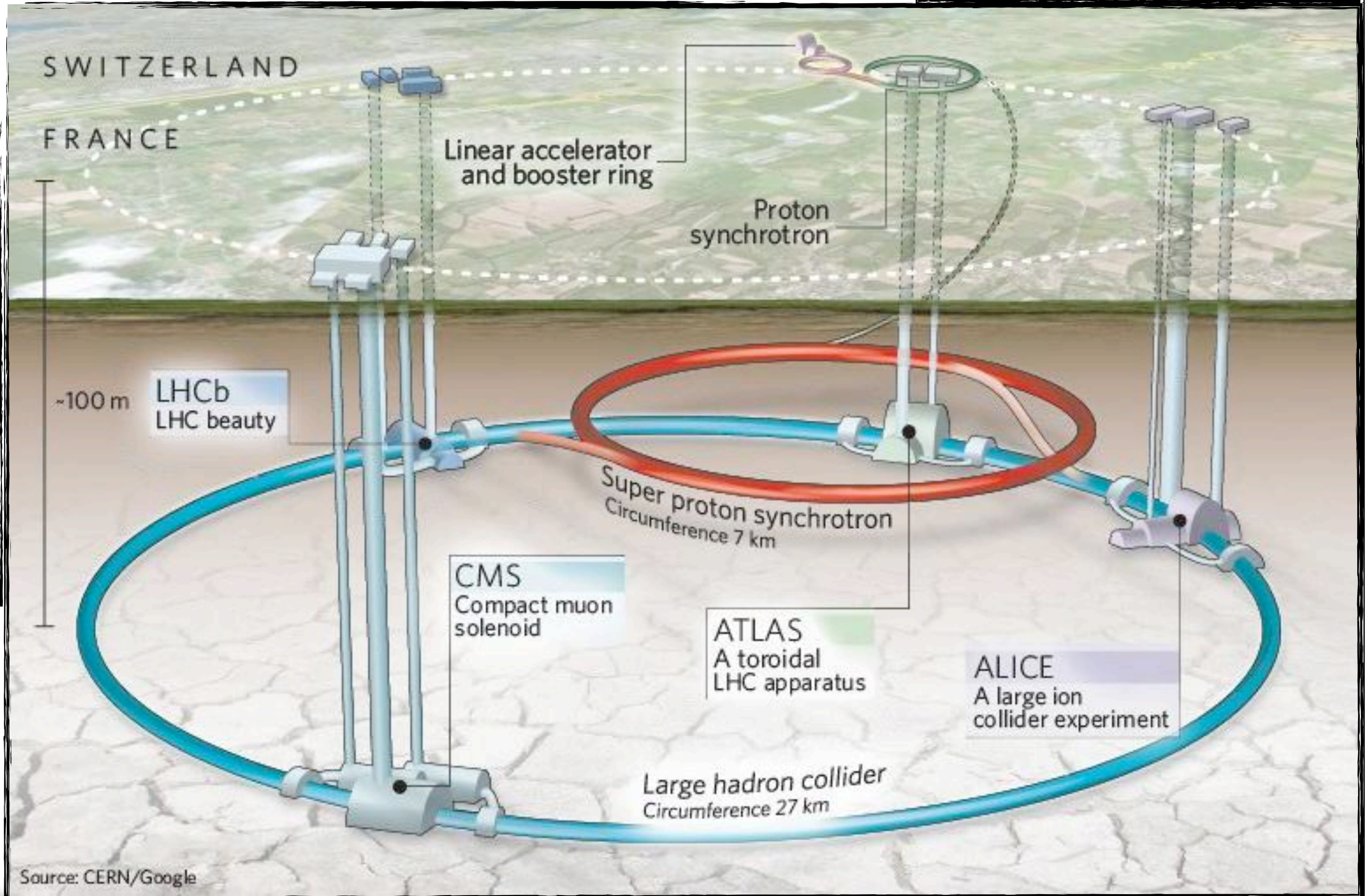
Large Hadron Collider

- The Large Hadron Collider (LHC) is a proton-proton collider situated at CERN, in Geneva (Switzerland)
- 4 experiments have been designed for the LHC:
  - A Large Ion Collider Experiment (ALICE)
  - Large Hadron Collider beauty experiment (LHCb)
  - A Toroidal LHC ApparatuS (ATLAS)
  - Compact Muon Solenoid (CMS)



Main parameters of the LHC

- Collision energy: 2x7 TeV
  - 2x5 TeV at 2009 start-up
- 27 km of circumference with superconducting magnets:
  - Bipolar field: 8.33 T
  - Temperature: 1.9 K
- Luminosity: 10^{34} $cm^{-2}s^{-1}$
  - 10^{32} $cm^{-2}s^{-1}$ at start-up
- Bunch separation: 25 ns
- Particles per bunch: $1.1\ 10^{11}$

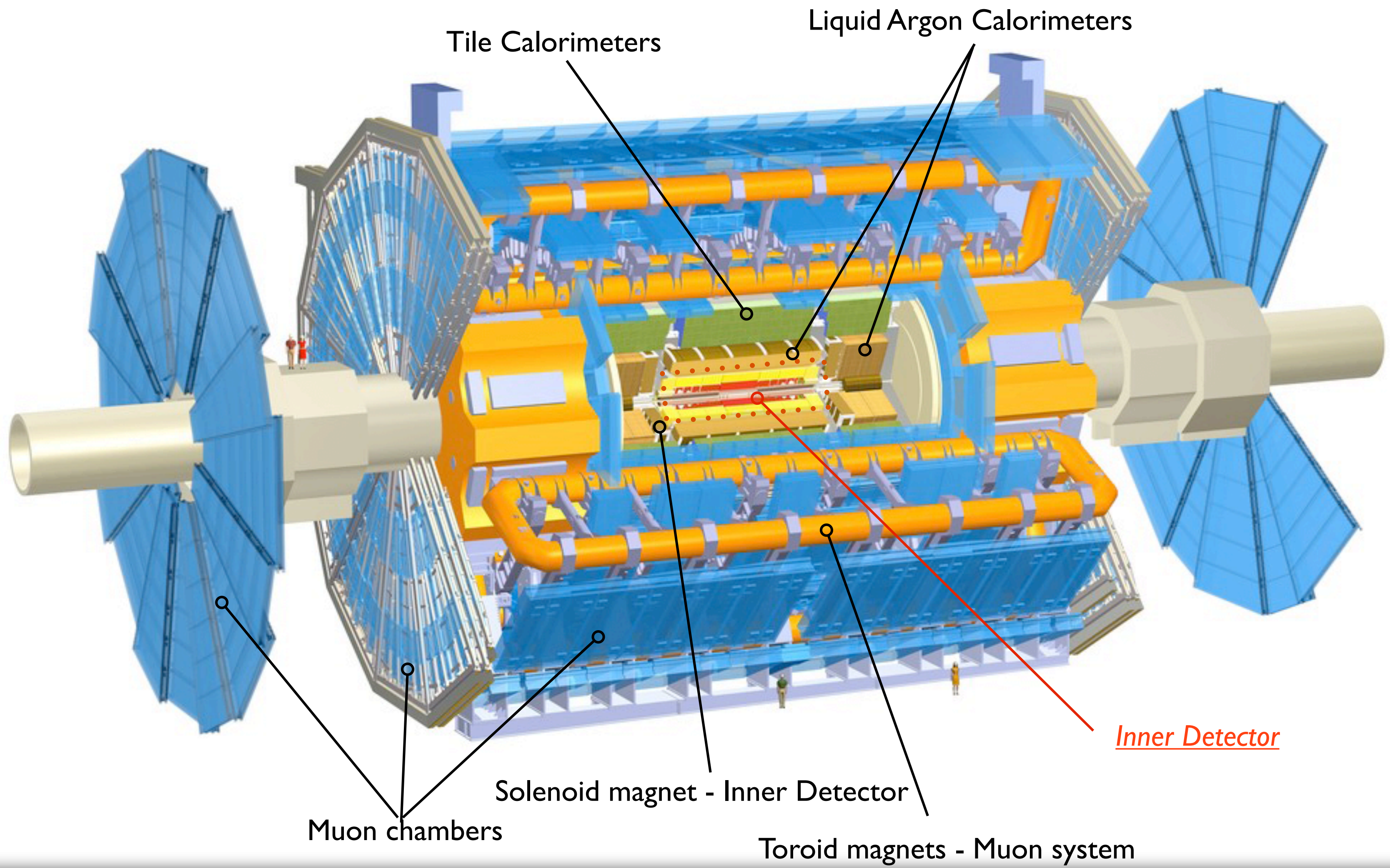


The ATLAS detector

ATLAS: A Toroidal LHC ApparatuS

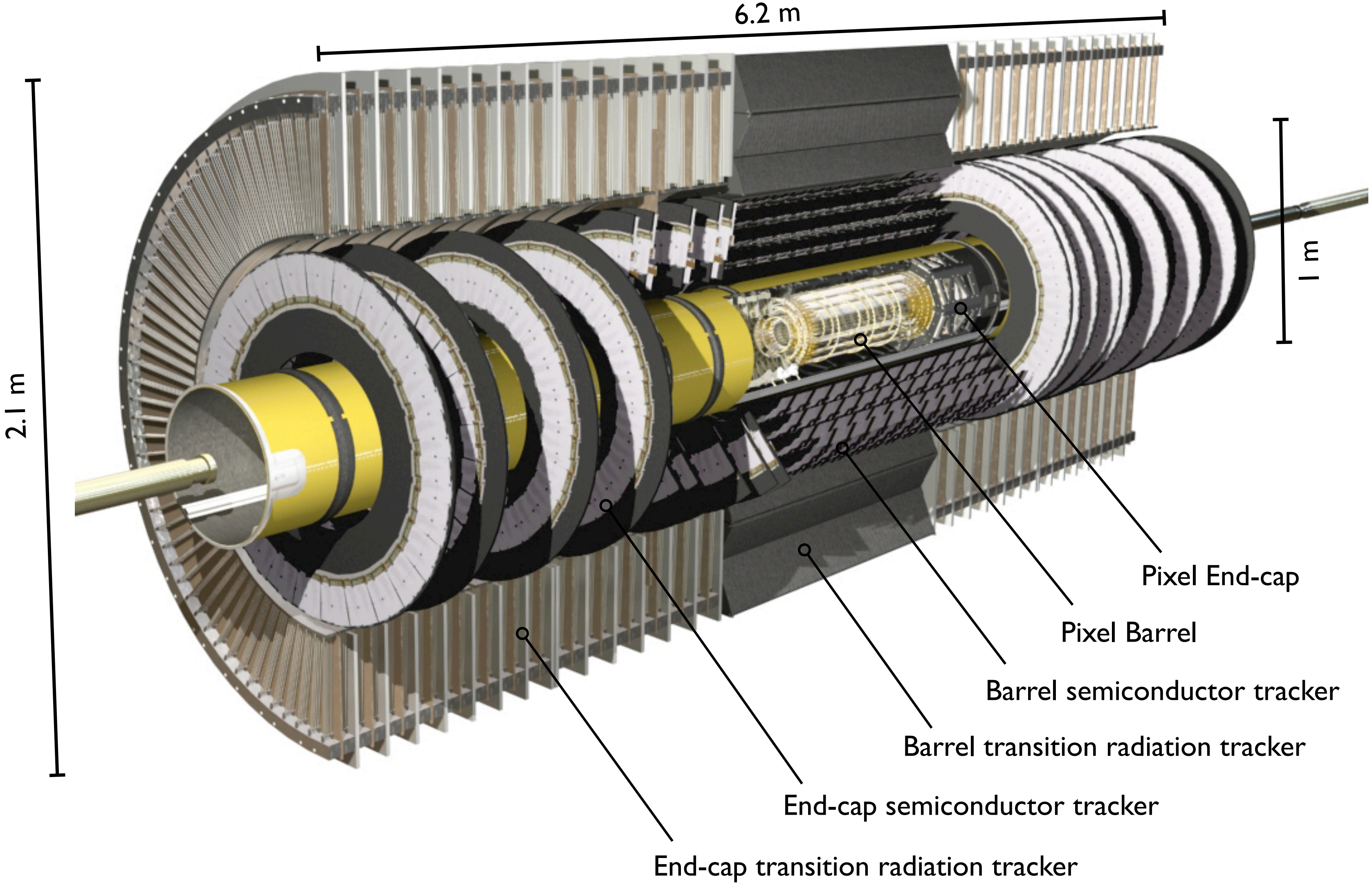
- A general purpose detector
- Diameter: 25 m
- Length: 44 m
- Weight: 7.000 T

- Two magnet fields:
  - Solenoid (Inner Detector): 2 T
  - Toroid (Muon spectrometer) : 2 - 8 Tm

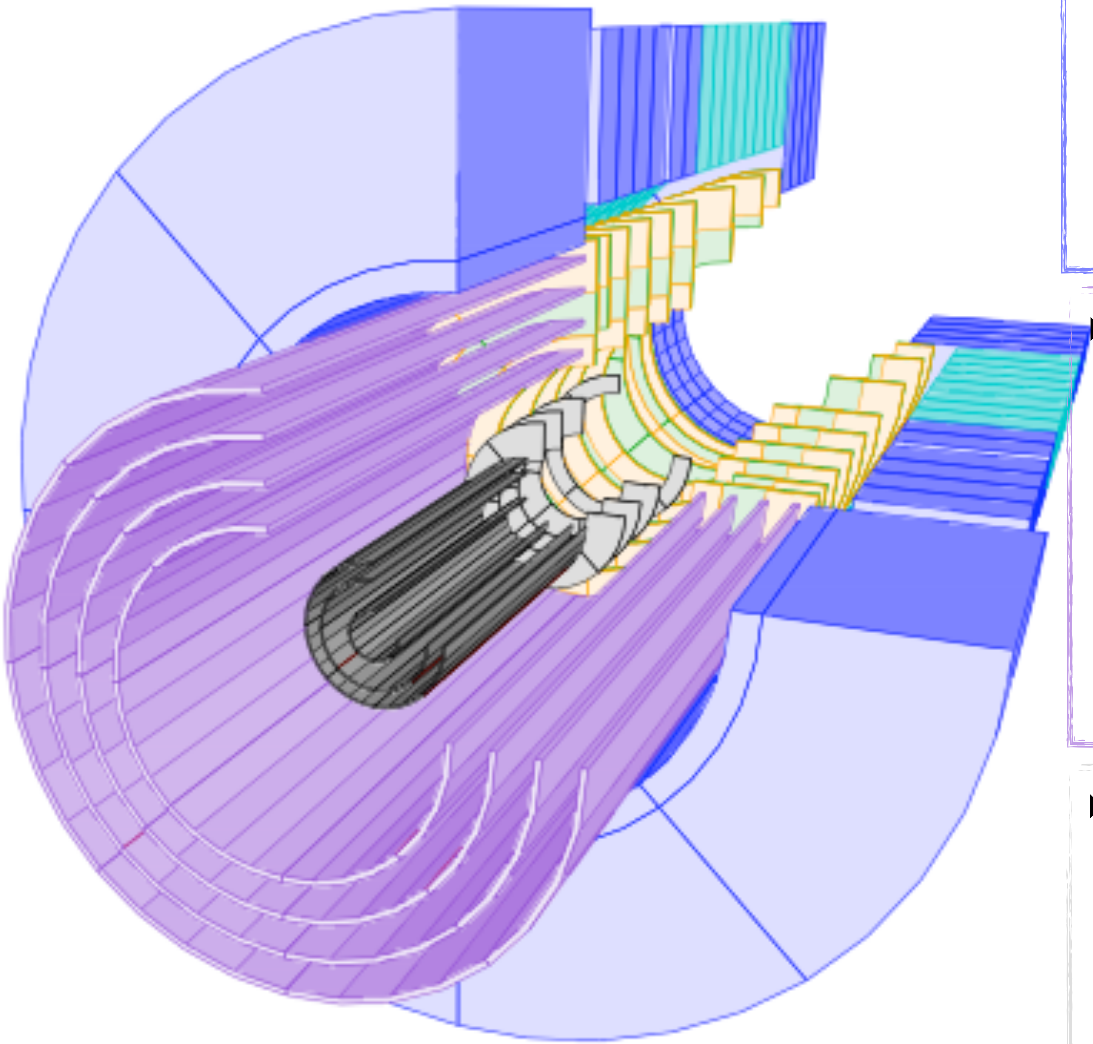


ATLAS Inner Detector tracking system

- Hermetic and robust pattern recognition
- Excellent momentum resolution
- Primary and secondary vertex measurements for charged tracks



The Inner Detector



Total silicon modules: 5832

- TRT detector:
  - Polyamide drift tubes
  - Intrinsic Resolution:
    - 130 μm (rφ)
  - 992 modules arranged in:
    - Barrel: 73 layers of straws interleaved with fibers arranged in 3 rings
    - End-caps: 160 straw planes interleaved with foils arranged in 2x40 wheels

- SCT Detector:
  - p-n micro-strips detectors:
    - Pitch: 80 μm (barrel modules)
  - Intrinsic Resolution:
    - 17 μm (rφ)
    - 580 μm (rz)
  - 4088 modules (double sided) arranged in:
    - 4 barrel layers (2112 modules)
    - 2 end-caps each with 9 disk layers (2x988 modules)

- Pixel detector:
  - Silicon Pixel detectors:
    - Pixel size: 50 x 400 μm^2
  - Intrinsic Resolution:
    - 10 μm (rφ)
    - 115 μm (rz)
  - 1744 identical pixel sensors arranged in:
    - 3 barrel layers (1456 modules)
    - 2 end-caps each with 3 disk layers (2x144 modules)

Inner Detector alignment

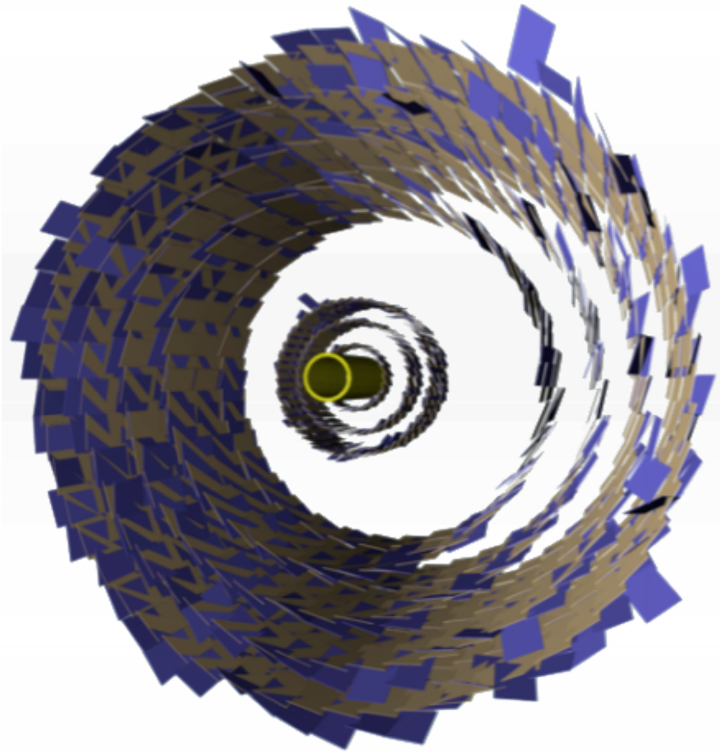
The modules nominal positions do not correspond with the "real" locations.
The goal of the alignment is to obtain the corrections of the modules positions in order to describe accurately the real detector.

- Objective:
  - Determine the position of the modules in order to:
    - Efficient track and vertex reconstruction
    - Accurate track parameter determination

  - Misalignments should not contribute more than a 20% for the degradations of the track parameters.
  - The alignment tolerances* should be:
    - O(7 μm) in Pixel
    - O(12 μm) in SCT
    - O(30 μm) in TRT

- Strategy for the Inner Detector alignment:
  - Initial knowledge of the module positions based on:
    - Surveys during the assembly and integration of the detectors
    - Frequency Scanning Interferometry (FSI):
      - Laser based monitoring system of the SCT structures
  - Track-based algorithms:
    - TRT alignment
    - Silicon alignment

Simulation of Misaligned Silicon Barrel (x100)



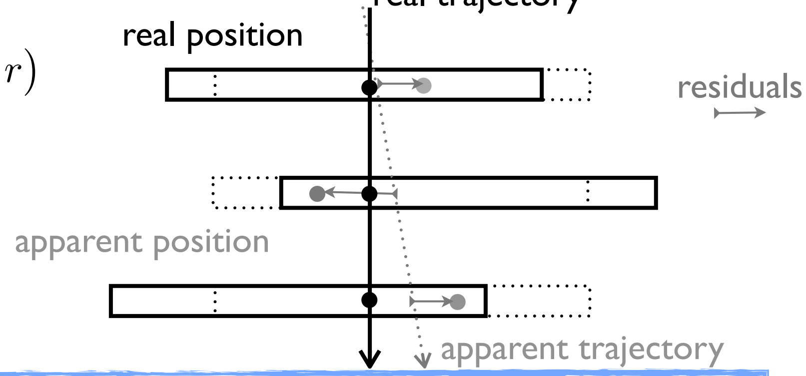
* Inner Detector TDR

Alignment methods

Track-based alignment offline algorithms.

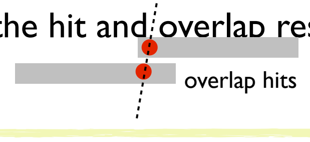
Complemented with a hardware alignment (FSI)

Based on the minimization of the χ^2: $$^{2} = \sum_{\text{tracks}} (r^T V^{-1} r)$$



$$\frac{d\chi^2}{d\mathbf{a}} = 0 \longrightarrow \left(\frac{d\mathbf{r}}{d\mathbf{a}}\right)^T V^{-1} \left(\frac{d\mathbf{r}}{d\mathbf{a}}\right) \delta\mathbf{a} + \left(\frac{d\mathbf{r}}{d\mathbf{a}}\right)^T V^{-1}\mathbf{r} = 0$$

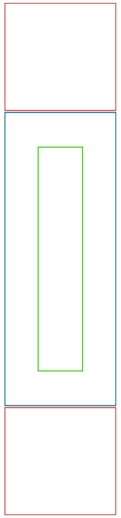
- Silicon alignment algorithms:
  - Global Chi2:
    - It consists of minimizing a Chi2 with respect the alignment parameters where $$\frac{d\mathbf{r}}{d\mathbf{a}} = \frac{\partial\mathbf{r}}{\partial\boldsymbol{\pi}}\frac{d\boldsymbol{\pi}}{d\mathbf{a}} + \frac{\partial\mathbf{r}}{\partial\mathbf{a}}$$
    - 6 degrees of freedom per module.
    - It needs to perform a huge matrix diagonalization in the case of module alignment (35k x 35k) of ~5 GB size.
    - It is a big challenge in terms of CPU, memory and numerical precision. Fast solver may be used in intermediate iterations
  - Local Chi2:
    - Same principe as the Global Chi2 algorithm but ignores the correlation terms between different modules as well as the Coulomb scattering. $$\frac{d\mathbf{r}}{d\mathbf{a}} \rightarrow \frac{\partial\mathbf{r}}{\partial\mathbf{a}}$$
    - 6 degrees of freedom per module.
    - Needs to solve 6x6 matrices.
  - Robust:
    - Iterative method correcting for shifts in the module plane from measurements of the hit and overlap residuals .
    - 3 degrees of freedom per module within plane corrections.



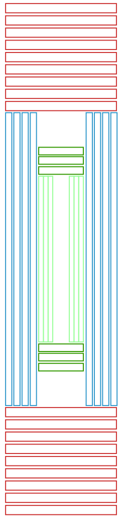
- TRT internal alignment uses a Global Chi2 algorithm

Alignment levels

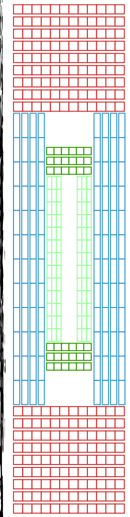
The alignment can be performed using a different set of “alignable structures”



- Level 1:
  - 4 Big structures:
    - Pixel detector
    - SCT Barrel
    - SCT End-cap A
    - SCT End-cap C
  - 24 DoF



- Level 2:
  - 31 Layer structures:
    - 4 SCT Barrel Layers
    - 2x9 SCT End-cap disks
    - 3 Pixel Barrel Layers
    - 2x3 Pixel End-cap disks
  - 186 DoF



- Level 3:
  - 5832 Modules:
    - 2112 SCT Barrel Modules
    - 2 x 988 SCT End-cap modules
    - 1456 Pixel Barrel modules
    - 2 x 144 Pixel End-cap Modules
  - 34992 DoF

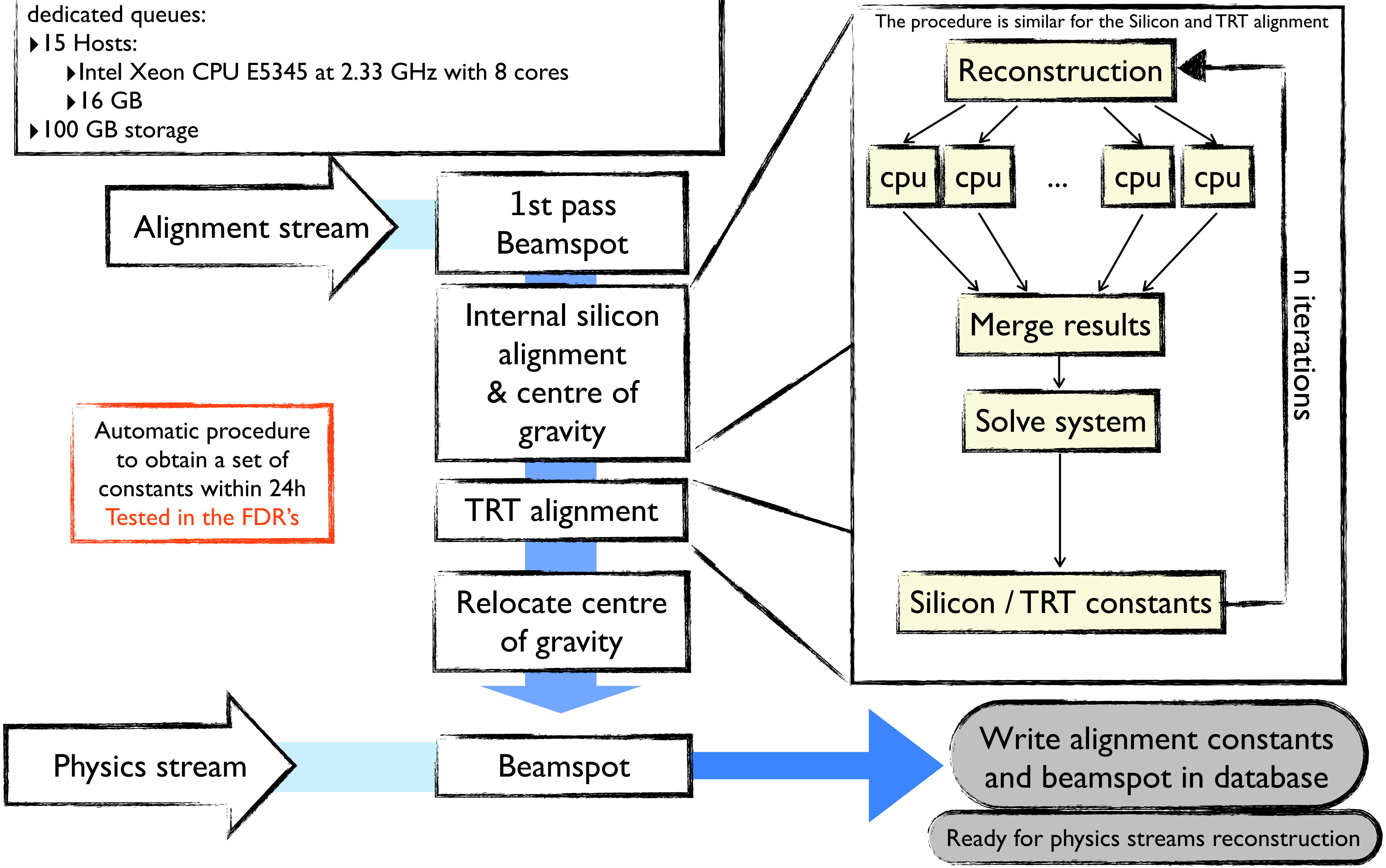
- Intermediate levels:
  - Pixel Barrel half-shells

- Intermediate levels:
  - SCT Barrel Rings
  - SCT Barrel Staves
  - Pixel Barrel Staves

- The different alignable structures can be combined:
  - Ex: Pixel half-shells + SCT layers

Alignment chain

The alignment is performed at CERN analysis facility (CAF) dedicated queues:
- 15 Hosts:
  - Intel Xeon CPU E5345 at 2.33 GHz with 8 cores
  - 16 GB
- 100 GB storage



Automatic procedure to obtain a set of constants within 24h
Tested in the FDR's

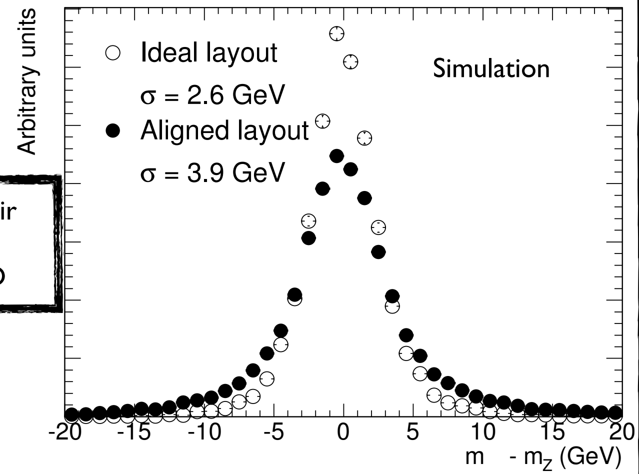
Alignment challenges with simulated data

Various challenges have allowed to test the alignment chain using large samples simulated data

- Computing System Commissioning (CSC):
  - The CSC exercise simulated a realistic ATLAS detector description:
    - Shifted and rotated magnetic field
    - Material distortions
    - Misalignments
  - The misalignments introduced in the Inner Detector were:
    - Level 1: Translations O(1 mm), rotations O(1 mrad)
    - Level 2: Translations O(100 μm), rotations O(0.1 mrad)
    - Level 3: Translations O(100 μm), rotations O(0.1 mrad)

Data used to align:
10^6 multimuon events with 10 tracks each one
Simulated cosmic events

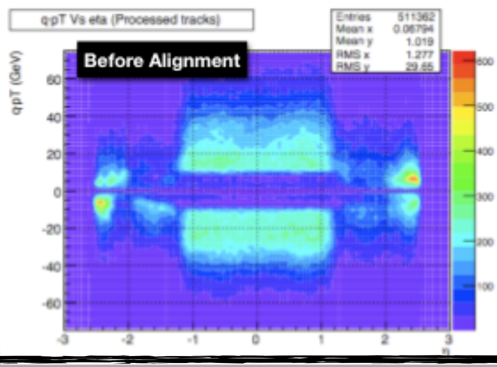
Mass resolution of the muon pair $Z\rightarrow\mu\mu$ decays after event reconstruction of the whole ID

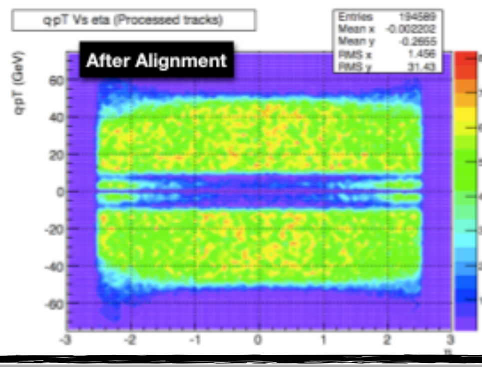


- Full Dress Rehearsal (FDR):
  - The objective of the FDR was to test the full data acquisition, calibration and alignment chain for real data operation.
    - Conditions equivalent to 4 days of data taking were simulated.
  - This was a perfect exercise to test the readiness alignment chain.
    - Physic and calibration samples were simulated with the same misalignments as in the CSC.
    - Calibration and alignment was run within a 24 hours loop.
    - Alignment constants were provided, validated and uploaded to the database for each 24 hours loop.

Data used to align:
1 Million single track events (pions) with uniform Pt (10-50 GeV/c)
15k cosmic events with B Field

q Pt distribution vs. η in FDR simulated data

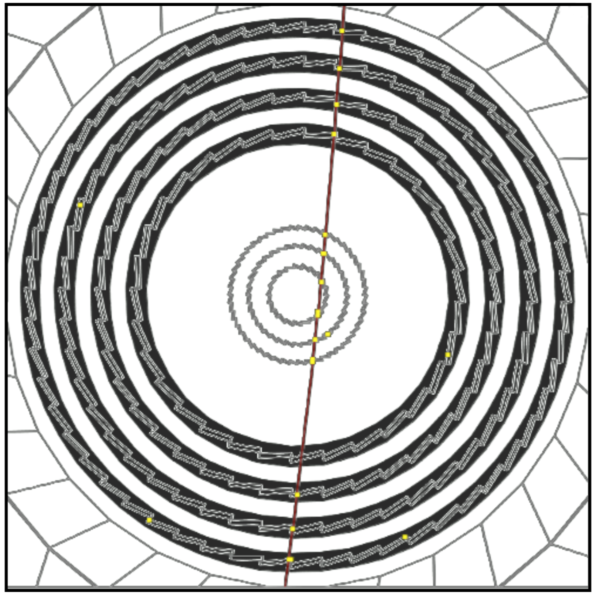


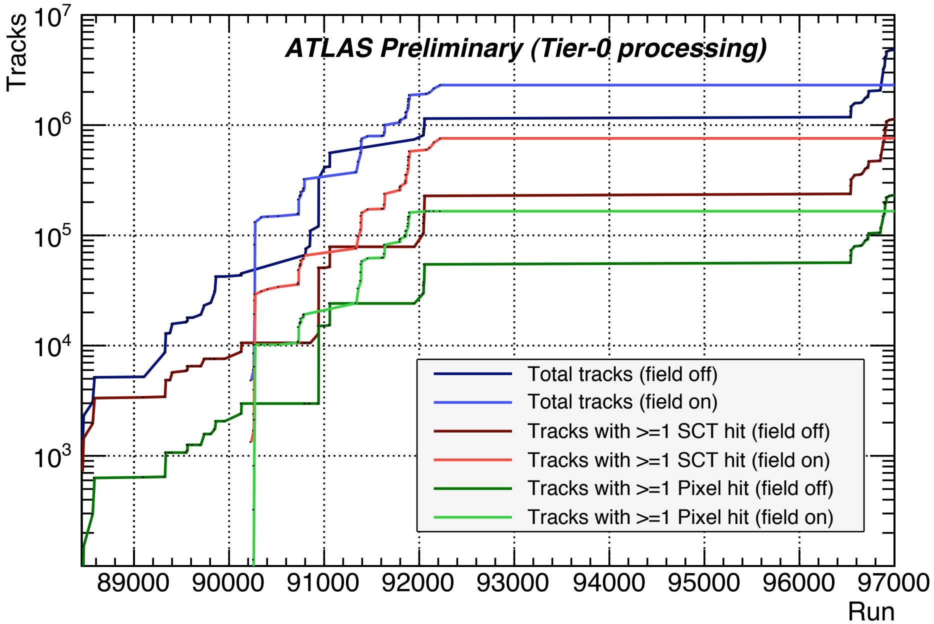


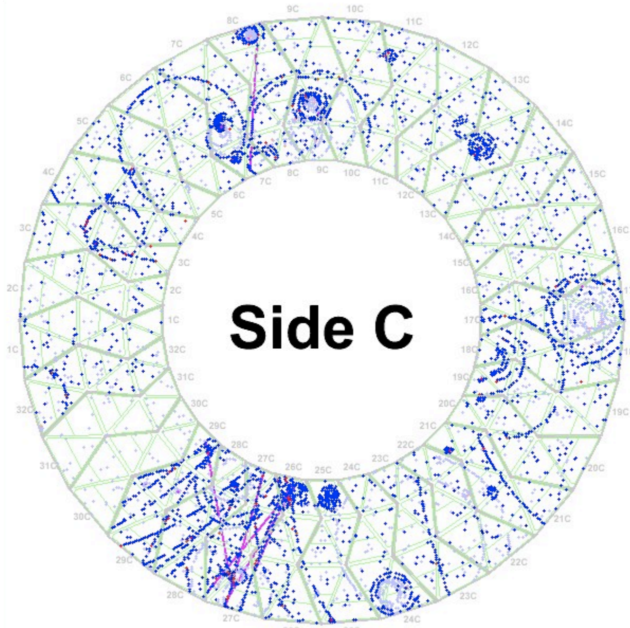
Commissioning Cosmic rays

- Global cosmic ray data taken in fall 2008
- Cosmic data with magnetic field :
  - 2.6 Million tracks
  - 880k ID tracks with SCT hits
  - 190k ID tracks with Pixel hit
- Cosmic data without magnetic field:
  - 5 Million tracks
  - 2 Million tracks with SCT hits
  - 230k tracks with Pixel hits

October 18th 2008 cosmic ray in the Inner Detector



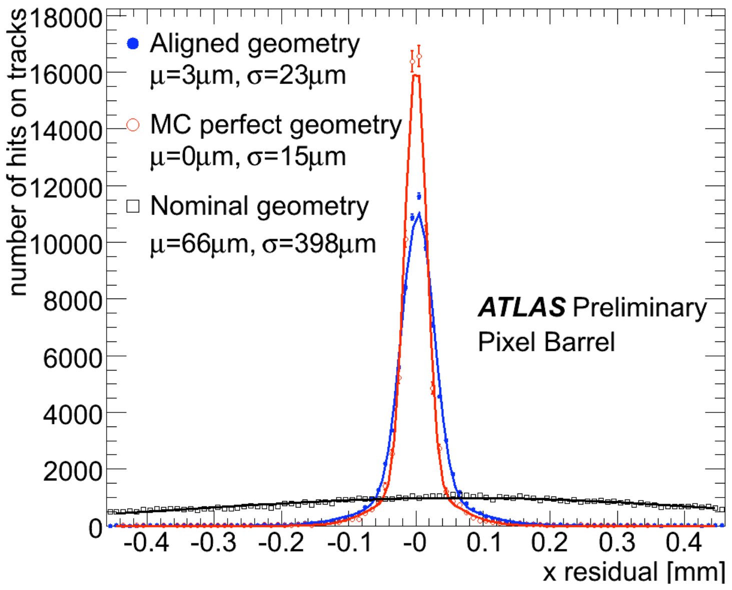


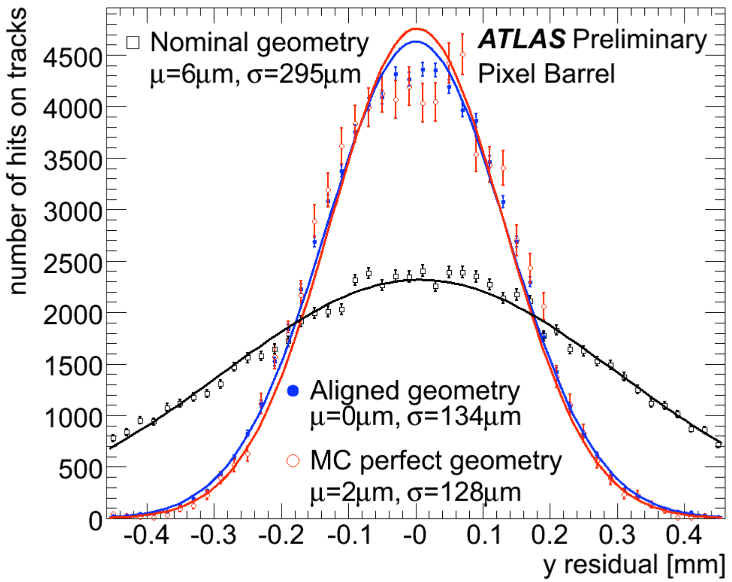


Event with tracks from cosmic particles observed in the ATLAS TRT Barrel (Aug 2008)

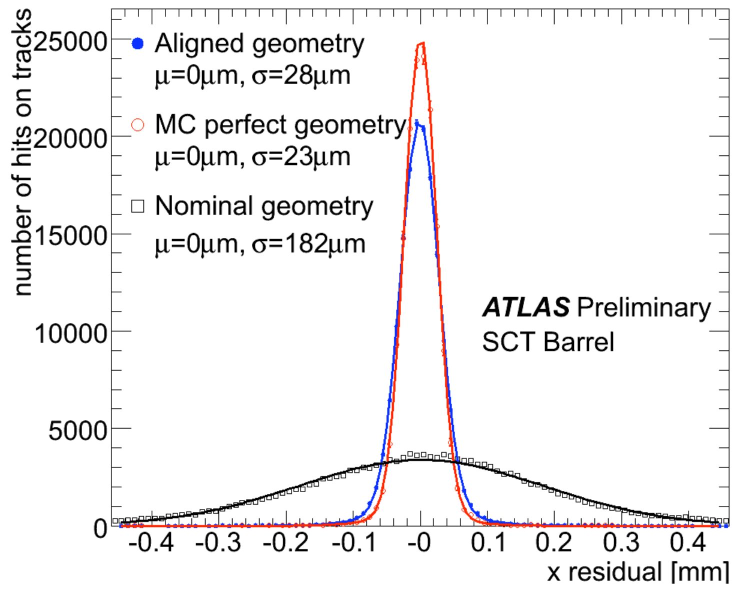
Alignment results with real cosmics

Pixel residuals

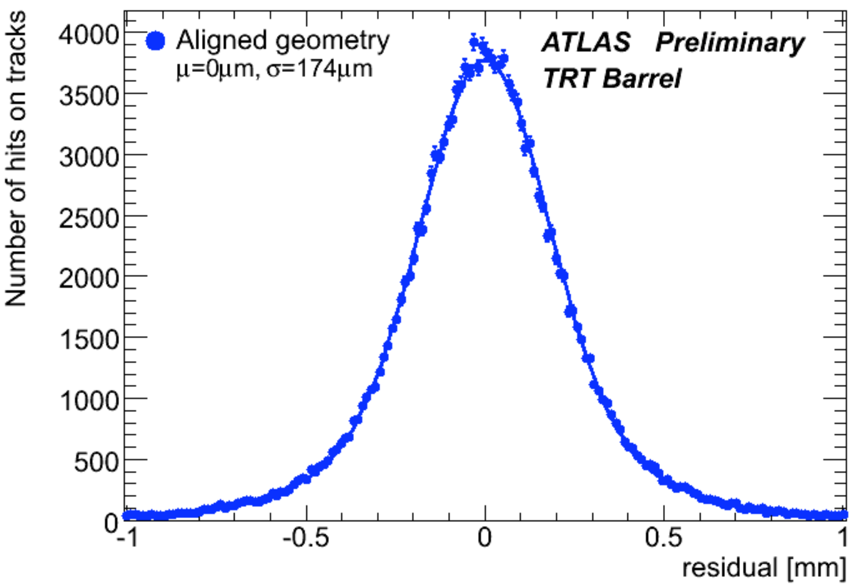




SCT residuals

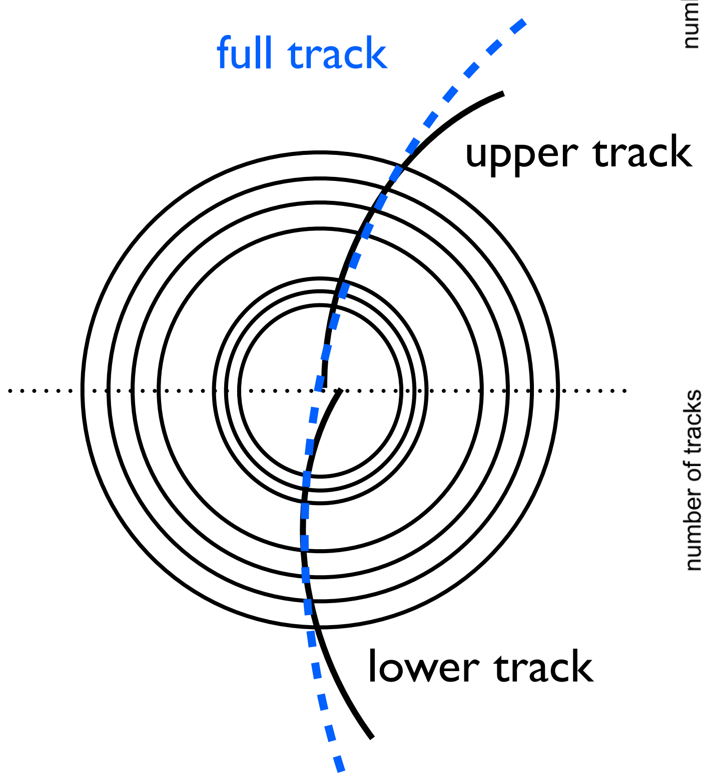


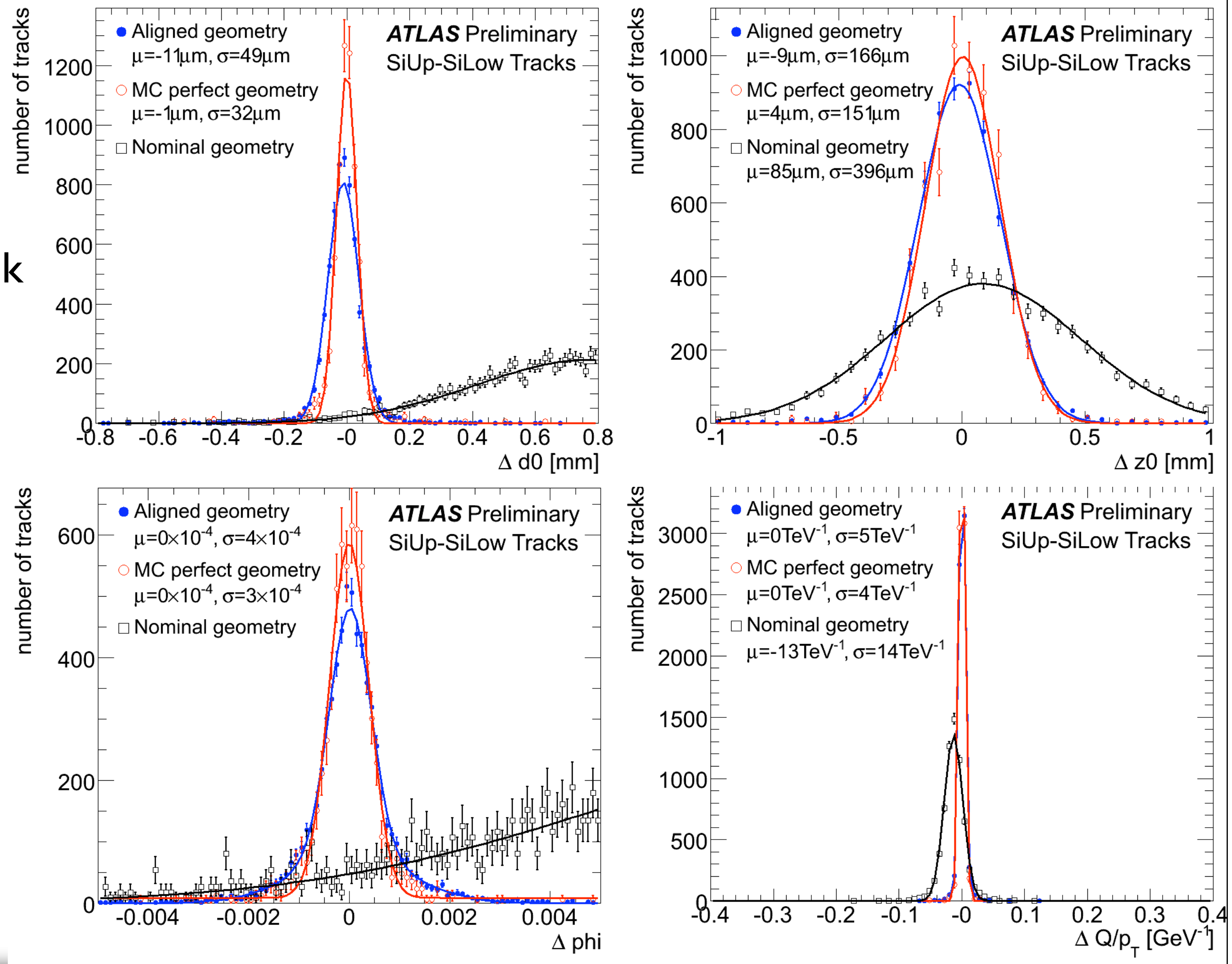
TRT residuals



Alignment validation with real cosmics

- Track parameter resolution:
  - A full ID track is splitted in two segments: upper and lower
  - The two tracks segments are refitted
  - The difference between the track parameters of the two tracks segments is used to validate the alignment

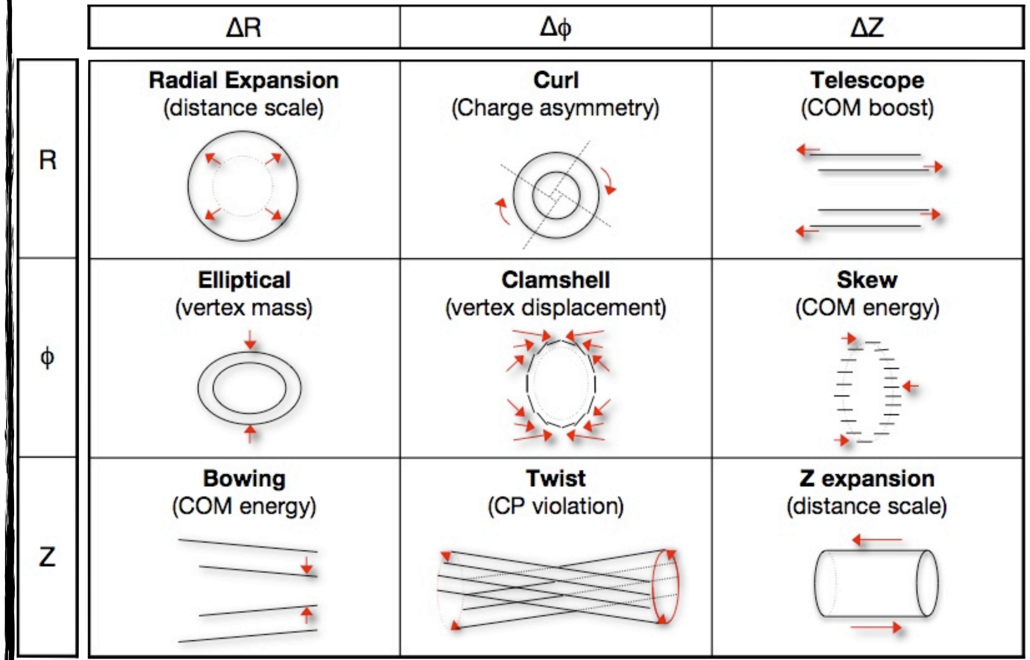


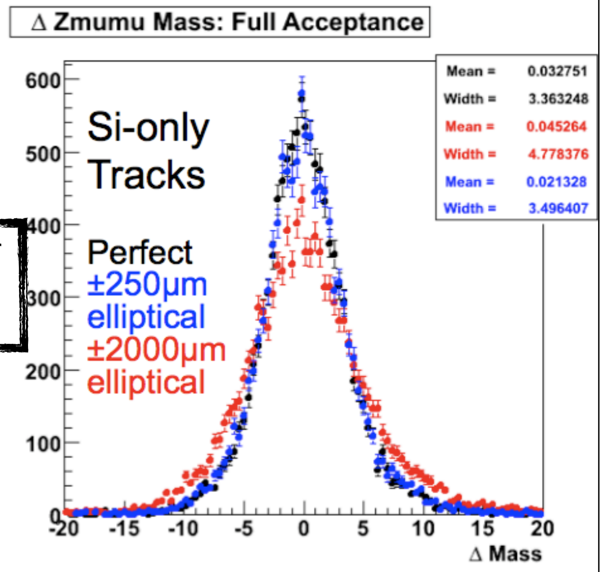


Global distortions, aka Weak modes

- *Weak modes*: Fictitious deformations of the detector that leave the $\chi 2$ almost unchanged:
  - They are not real movements of the detectors but they are alignment solutions that preserve the helicoidal path of the tracks, thus biasing the track parameters.
- How can we detect and correct these movements?
  - The use external information, called "external constraints", can help us:
    - External constrains of the alignment parameters:
      - Frequency Scanning Interferometry (FSI)
      - Survey
      - ...
    - Constrains on track parameters:
      - Beam spot position, E/p, ...
  - Use of different samples of data with different sensitivity to the weak modes:
    - Cosmic data: they help to avoid a telescope deformation.
    - Common vertex for tracks of the same event.
    - Beam halo, Beam Gas ,...
  - Physical observables:
    - B lifetime
    - Resonance masses
    - ...

Classification of global distortions





Simulation of the effect of a elliptical deformation in the Z mass

Summary

- Alignment crucial during the commissioning of the ATLAS Inner Detector
- Alignment successfully tested with simulated events and real data using cosmic rays.
- Alignment integrated into the 24 calibration loop of ATLAS
- Looking forward to first collision data in 2009

Thank you for your attention!

Backup Slides