Alignment of the ATLAS Inner Detector Tracking System

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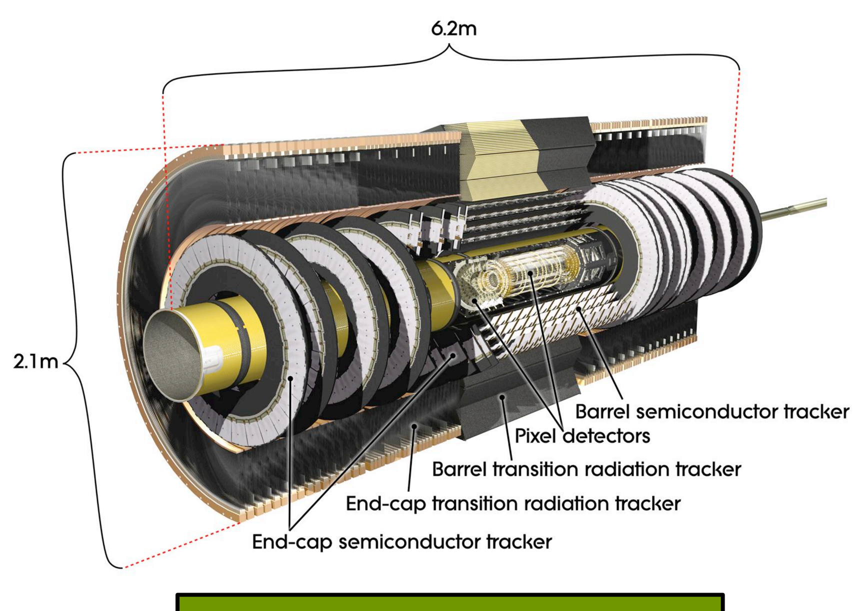
ATLAS EXPERIMENT http://atlas.ch

THE ATLAS INNER DETECTOR

The **ID** (*Inner Detector*) is the innermost system tracker of ATLAS (*A Toroidal LHC Apparatus)*. It 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 of three sub-detectors: **Pixel**, **SCT** (*SemiConductor Tracker*) and **TRT** (*Transition Radiation Tracker*).

	Pixel Detector Pixel	SCT Detector SemiConductor Tracker	TRT Detector Transition Radiation Tracker
Measurement	Discrete space-point	Stereo pairs of silicon micro-strip	Average of 30 hits per track
Detector type	Pixel detector	Micro-strip silicon detectors	Gaseous straw tube elements
Detector Size	Pixel size: 50x400 μm² All modules equals	Micro-strip pitch: ~ 80 μm 6 different types	Diameter: 4mm Length:144cm barrel, 37cm EC
Resolution	14x115 μm² (*)	23μm (Rϕ) , 580 μm (z)(*)	130 μm (*)
Modules	1744	4088	176
Layout	3 layers (barrel) 2x3 discs (end-cap)	4 layers (barrel) 2x9 discs (end-cap)	73 layers in 3 rings (barrel) 2x160 straw planes in 40 four-plane assembly units (end-cap)

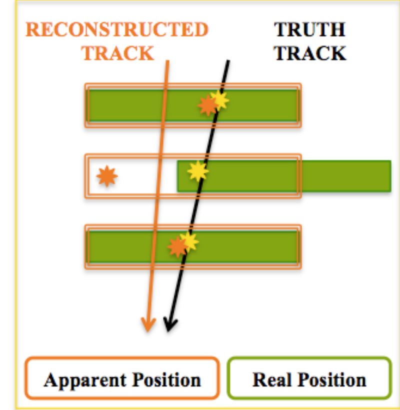


INNER DETECTOR PICTURE

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

ALIGNMENT PROBLEM AND REQUIREMENTS

The detector misalignments affect the track parameters resolution.



The strategy to solve the alignment problem has different steps:

- **Assembly and survey measurements**: External measurements of the as-built detector
- **Frequency Scanning Interferometry**: SCT is equipped with a laser alignment monitoring system
- **Track based alignment algorithms:** To achieve the ultimate precision (μm)

REQUIREMENTS: The knowledge of the alignment constants should not lead to a significant degradation of the track parameters beyond the intrinsic tracker resolution to achieve the ATLAS physics goals. (degradation of tracking resolution less than 20%).

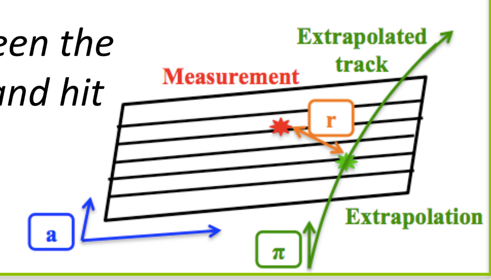
Required precision	Direction	Pixel's Barrel	Pixel's End-Cap	SCT Barrel	SCT End-Cap
	Rϕ (μm)	7	7	12	12
	Z (μm)	20	100	50	200

TRACK BASED ALIGNMENT ALGORITHMS

The alignment algorithms work with a track χ^2 sensitive to misalignments. The χ^2 is built from the track residuals. The χ^2 is an implicit function of the alignment parameters and it has a minimum in the aligned geometry.

RESIDUALS : $r = hit_{measured} - hit(\pi,a)_{extrapolated}$

distance between the hit measured and hit extrapolated



χ^2 **DEFINITION**: $\chi^2 = \sum_{Tracks} r^T(\pi,a)V^{-1}r(\pi,a)$

Where **r** are the residuals that depend on track parameters (π) and **alignment parameters (a)**.

χ^2 **MINIMIZATION**: $\frac{d\chi^2}{da} = 0$

The algorithms use the χ^2 minimization with respect alignment parameters to find the real geometry.

The ID has 6008 modules to align. Most of the modules have 6 DoFs. There are several alignment algorithms working in the ID detector:

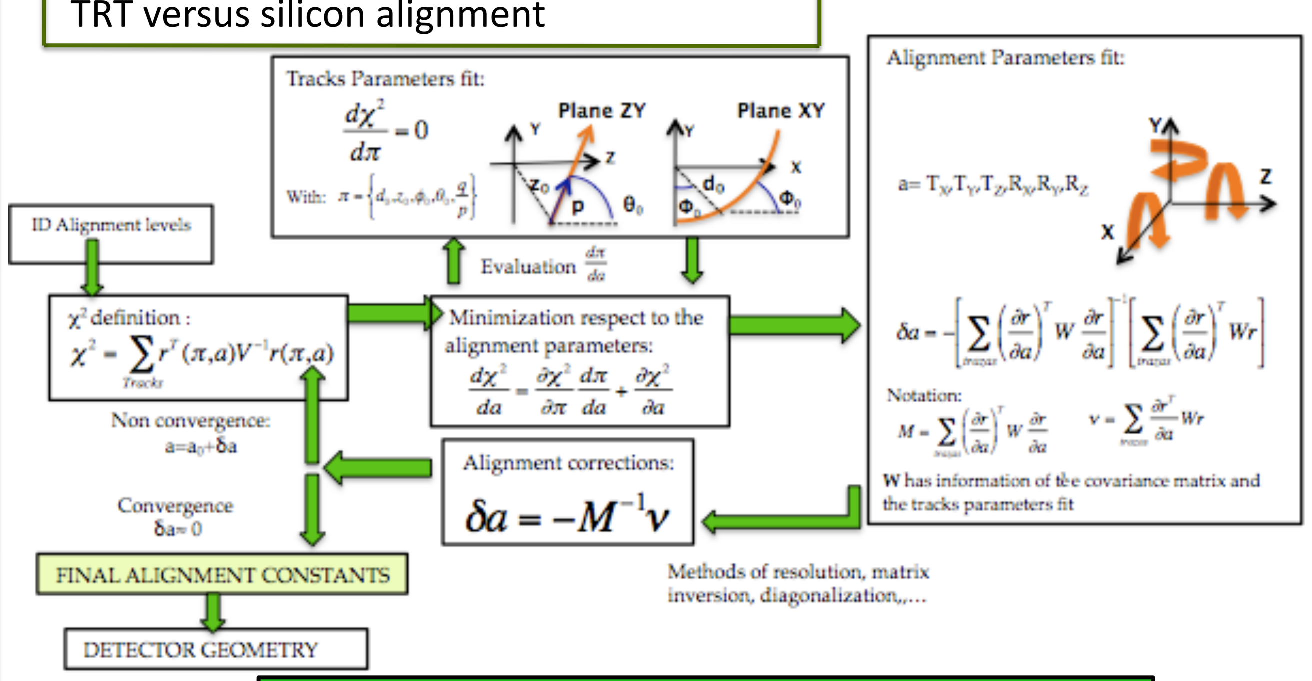
SILICON SYSTEM

-Globalchi2:
Based on the χ^2 minimization.
Use biased residuals.
Inter module correlation and Multiple Coulomb scattering is take into account
Huge symmetric matrix is created (34992 DoFs)

- LocalChi2:
Same principle as the GlobalChi2
Unbiased DOCA residuals
No dependence with respect to the track parameters
No Multiple Coulomb scattering
Solve 6x6 matrices (6DoFs per module)

- Robust :
Centre residuals and overlap distributions.
Use local x and local y residuals
Overlap residuals for adjacent module
3 DoFs per module (plane parameters: Tx, Ty, Rz)

TRT SYSTEM
Based on the the χ^2 minimization
Inter module correlation
TRT versus silicon alignment



GLOBALCHI2 ALIGNMENT ALGORITHM

SURVEY INFORMATION

Several survey and measurements methods are used to determine the final installation position: optical survey, robotic arm survey and more standards tools. It's a difficult task due to the large quantity of ID services and limited space between sub-detectors.

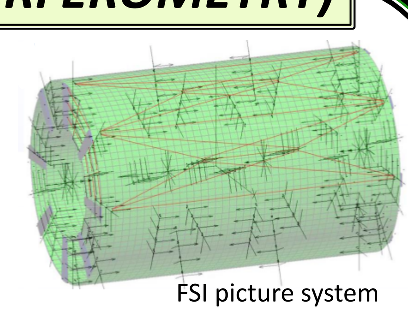
This information gives a first estimate of the detector position and it will be used for the initial positions of the modules in the first step of the alignment procedure.

ATLAS Physics Coordinates		Dx (A)	Dy (A)	Dx (C)	Dy (C)
BARREL	PIXEL	-0.49	0.94	-0.46	1.02
	SCT	0.27	0.64	-0.02	0.86
	TRT	-0.02	0.14	-0.57	0.11
ID ECA	SCT	0.34	1.61	-0.16	0.12
	TRT	0.89	0.57	0.04	0.39
ID ECC	SCT	-0.70	-0.03	-0.07	0.36
	TRT	-0.53	0.79	-1.49	0.75

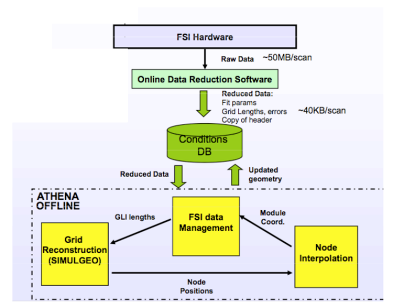
Deviation of the installed ID from the solenoid axis in ATLAS Physics Coordinates. (ATL-I-ER-0013)

FSI (FREQUENCY SCANNING INTERFEROMETRY)

Laser alignment system (geodetic grid of length measurement between nodes) is installed in the SCT detector. The FSI provides knowledge about the stability of the detector with time (842 grid line length are measured simultaneously each 10min). Using FSI can achieve a precision <1μm along 1D length (precision in 3D ~5μm). It can measure relative rotations (clocking of barrel) and radial deformation. Will be used intensively in the early runs.



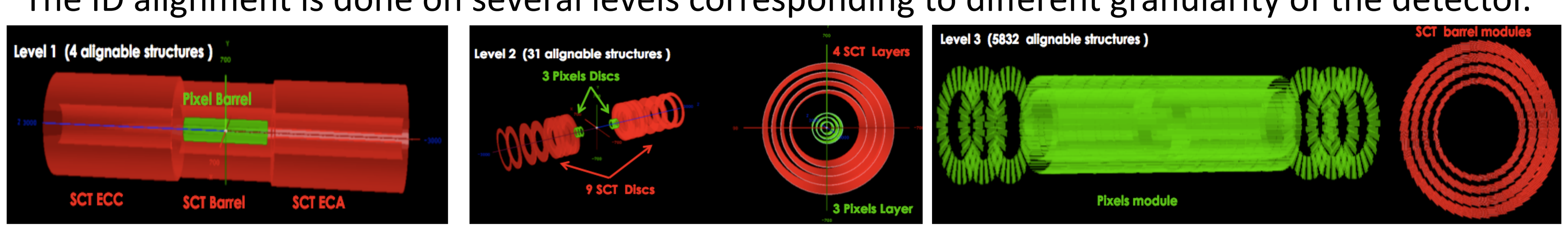
FSI picture system



FSI software chain

SILICON ALIGNMENT LEVELS

The ID alignment is done on several levels corresponding to different granularity of the detector.



LEVEL 1 structures (24 DoFs):
- Whole pixel detector
- SCT barrel
- SCT end-cap A and B

LEVEL 2 structures (186 DoFs):
- Layers in PIXEL's and SCT barrel
- Discs in PIXEL's and SCT end-cap

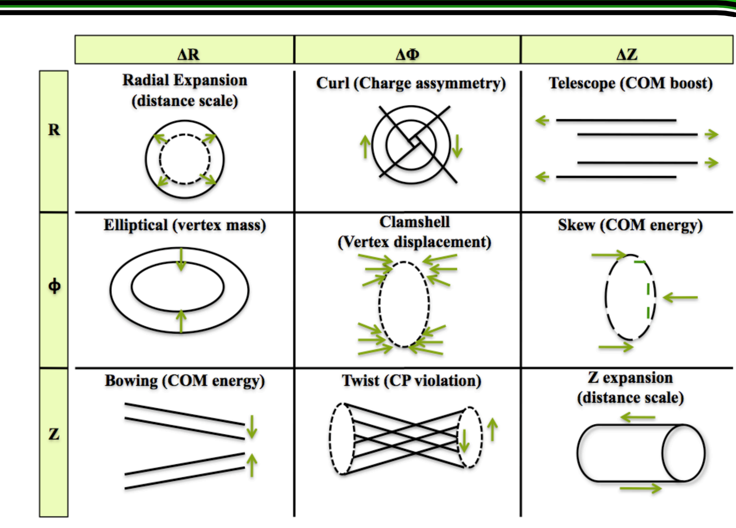
LEVEL 3 structures (34992 DoFs):
- Module level in PIXEL's and SCT detector

WEAK MODES

The Weak Modes are deformations that leave the track χ^2 almost unchanged.

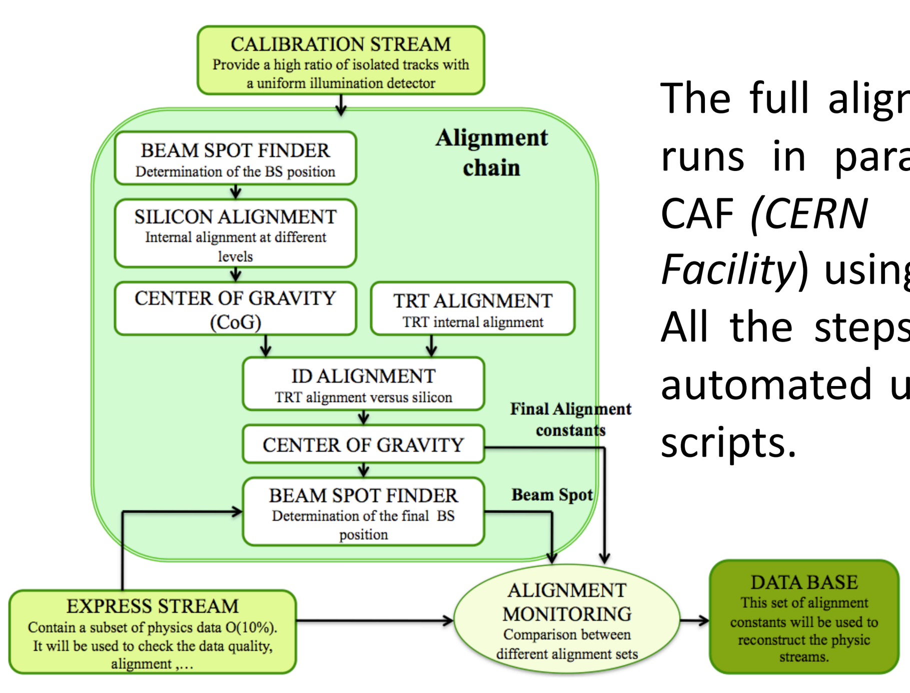
There are some tools to determine these weak modes:

- Cosmic rays and beam halo
- Vertex and beam spot constraint
- External surveys
- Use FSI Information



ID ALIGNMENT PROCEDURE

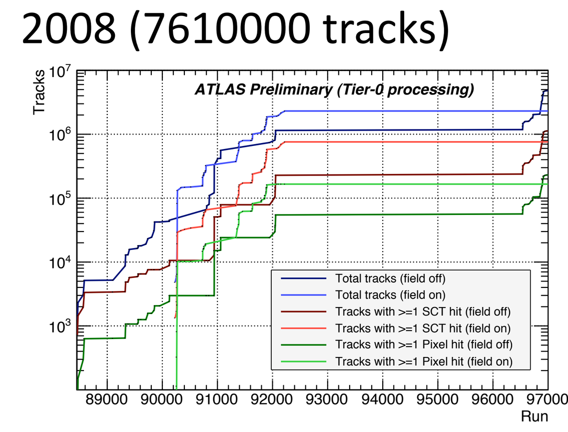
The alignment chain has been tested in the ***Full Dress Rehearsal*** exercises. All the steps have been run in a 24 hour loop producing one new set of alignment constants per day. The ID alignment monitoring checks the constants. When the new constant set is accepted, they are uploaded into the DB for the reprocessing.

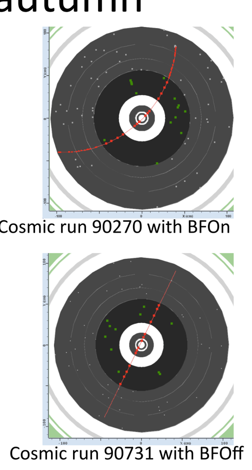


The full alignment chain runs in parallel on the CAF *(CERN Analysis Facility)* using 100 CPU's. All the steps have been automated using python scripts.

COSMIC DATA (M8 PLUS)

Cosmic data was taken in autumn 2008 (7610000 tracks)

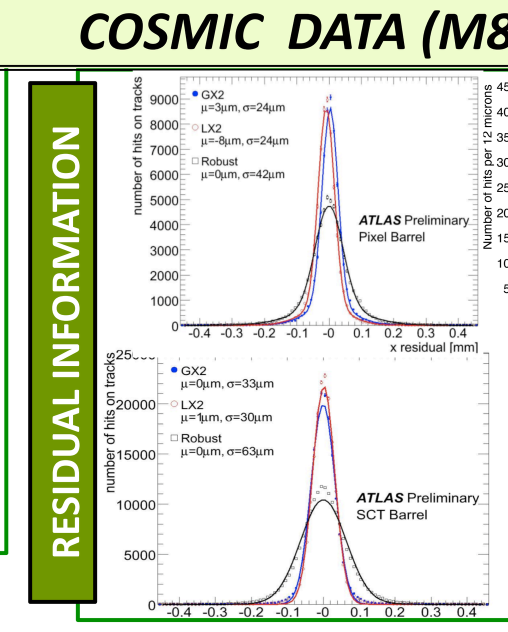




Cosmic run 90270 with BFOn

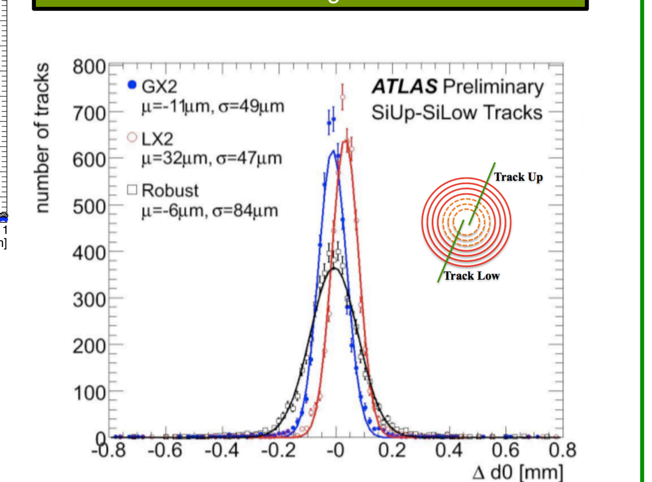
Cosmic run 90731 with BFOff

RESIDUAL INFORMATION



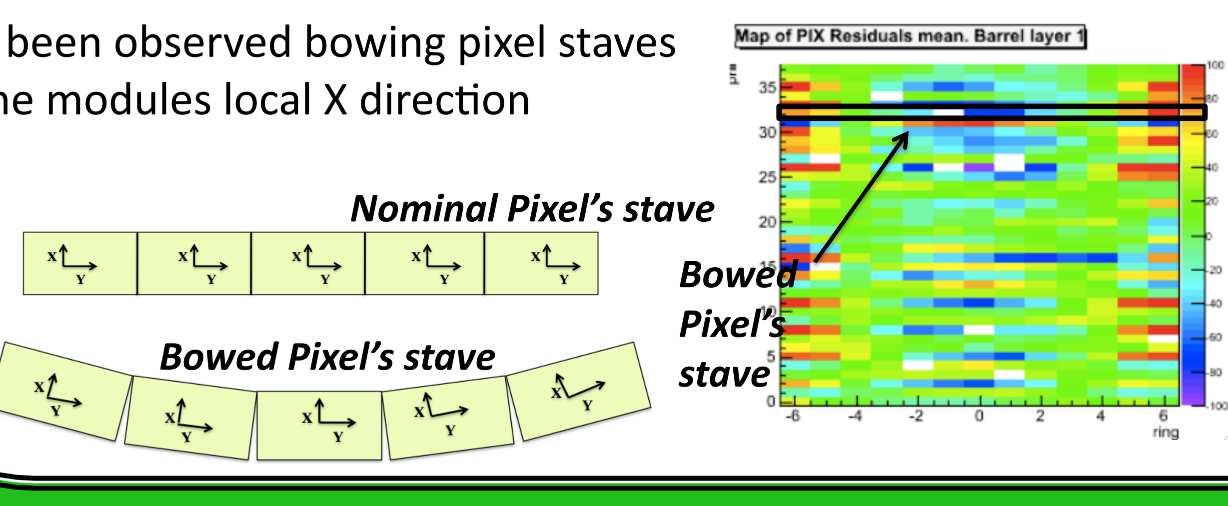
Track selection:
- pT>1GeV,
- |d0|<50mm
- |z0<1200mm
- ≥30 TRT hits
- ≥8 SCT hits

Δd_0



Pixel's BOWING:

Has been observed bowing pixel staves in the modules local X direction



Bowed Pixel's stave

The use of real cosmic ray data has allowed us to obtain a first set of alignment constants for the real detector.

The ATLAS ID is ready to reconstruct the first LHC collision tracks.