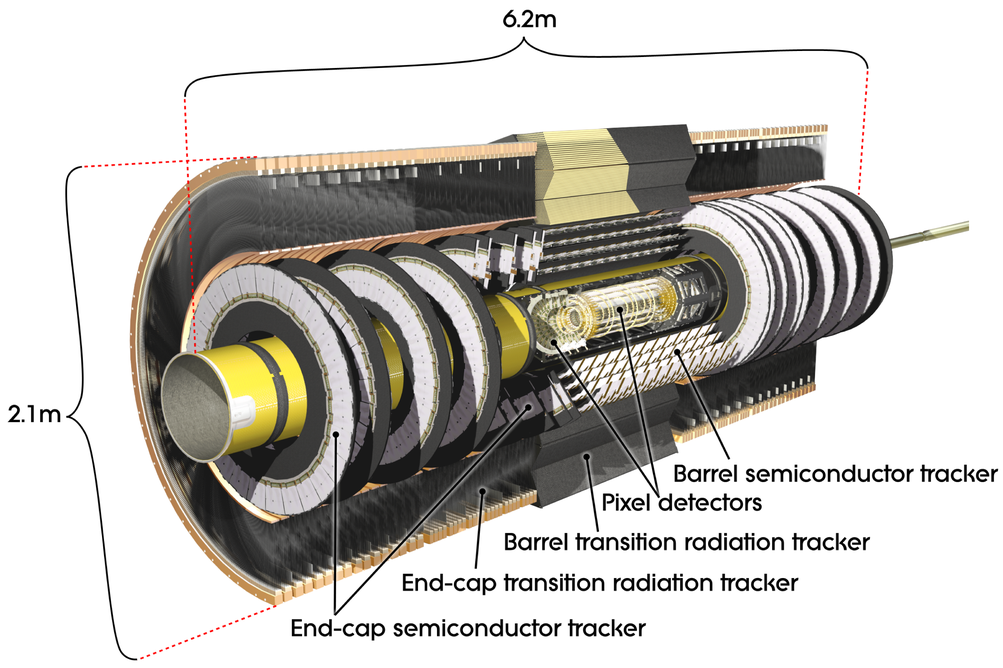
Alignment of the ATLAS Inner Detector Tracking System

Claudio Heller (LMU München) on behalf of the ATLAS collaboration



Introduction

The Inner Detector (ID) is the tracking system of the ATLAS experiment. Its task is to reconstruct trajectories, vertices and measure the momentum of charged particles with high precision and efficiency. The intrinsic resolution of the ID exceeds the achievable assembly precision by 2 orders of magnitude.

An accurate description of the detector geometry is vital to perform precision physics measurements. To determine the position and orientation of each individual active detector module a track based alignment procedure is applied.

Baseline goal: the contribution to the degradation of track parameters from module misalignments should be smaller than 20% with respect to the intrinsic resolution.

The Inner Detector (ID)

The ATLAS ID consists of 3 sub-systems:
the Pixel detector (Pixel), the Semi-Conductor Tracker (SCT) and the Transition Radiation Tracker (TRT).

	Pixel		SCT		TRT	
	Barrel	Endcap	Barrel	Endcap	Barrel	Endcap
Technology	Si Pixel		Si micro-strips		Drift tubes	
# layers/disks	3	2 x 3	4	2 x 9	73	2 x 160
Intrinsic resolution (rφ x rz [μm])	10 x 115		17 x 580		130 (rφ only)	
# modules	1744		2088		176 (350848 straws)	

Alignment Levels

The alignment is performed at different levels of granularity motivated by the mechanical layout of the detector. Each aligneable structure has 6 degrees of freedom (DoF): 3 DoF for translation and 3 DoF for rotation.

- Level 1: Pixel as a whole, SCT barrel and endcaps, TRT barrel and endcaps
- Level 2: Pixel barrel half-shells and endcap disks, SCT barrel layers and endcap disks, TRT barrel modules and endcap wheels
- Level 3: Pixel and SCT modules, TRT straws

For a full ID alignment procedure, several alignment iterations are performed at different levels.

	Pixel	SCT	TRT	Total
Level 1	6	18	17	41
Level 2	72	132	960	1164
Level 3	10464	24528	701696	736688

# of DoF at different alignment levels

Track Based Alignment Algorithm

The ATLAS track based alignment algorithms rely on a track-hit residuals χ^2 minimization. A track-hit residual is the difference between the reconstructed track and the actual hit in the detector.

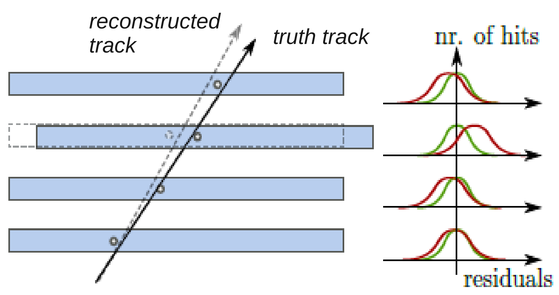
$$\chi^2 = \sum_{tracks} [\vec{r}^{\,T}(\vec{t},\vec{a}) V^{-1} \vec{r}(\vec{t},\vec{a})]$$

$$\vec{t} = (d_0, z_0, \Phi_0, \theta, q/p)$$

$$\vec{a} = (T_x, T_y, T_z, R_x, R_y, R_z)$$

V ≡ Hit covariance matrix

Minimization condition: $\frac{d\chi^2}{d\vec{a}} = 0$

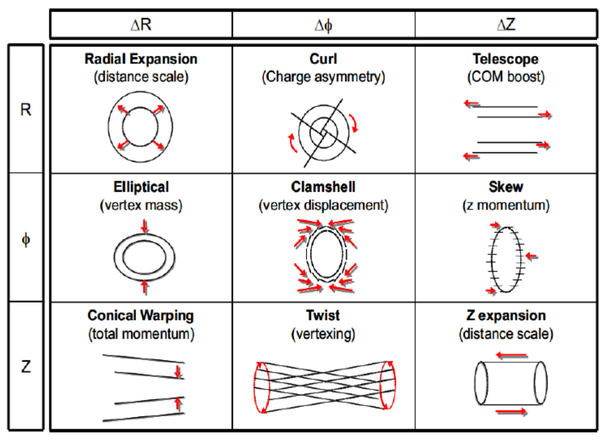


The reconstructed track is fitted using the nominal geometry (dashed). The displacement of one of the modules causes a shift and degradation in the residual distributions (red). In the aligned detector the residual distributions are centered around 0 (green).

This leads to N x N matrix representing a system of N linear equations with N parameters (N = # DoF) that has to be solved.

Weak Modes

Weak modes are systematic deformations of the detector that leave the residuals of the tracks (almost) invariant. Thus the χ^2 algorithm is insensitive to such distortions. A weak mode deformation preserves the helical trajectory of the track but eventually biases the track parameters.



How to deal with weak modes?

- Use different track topologies, e.g. collision tracks, cosmic tracks
- Constraining tracks to the beamspot or a common vertex
- External constraints on tracks, e.g. from the calorimetry or the muon system
- Physics constraints such as invariant mass of resonances

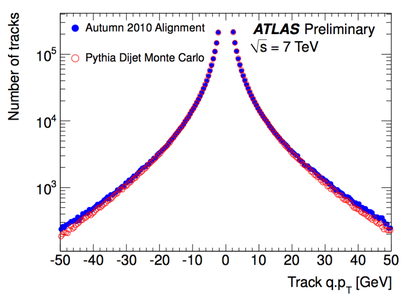
Misaligned geometries simulating weak modes of the detector geometry have been created and are under study. One important goal of these studies is to derive systematic uncertainties from alignment for physics measurements.

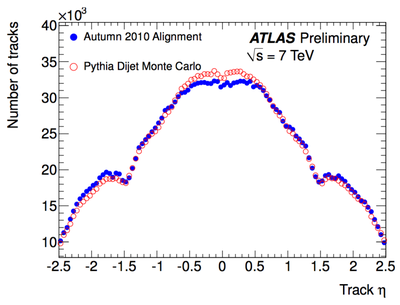
Alignment Performance with 7 TeV Collision Data

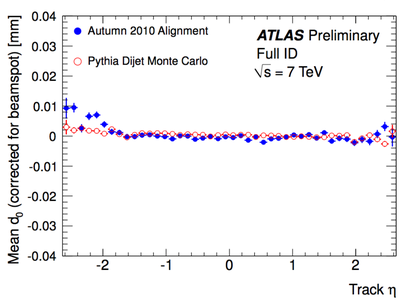
The ATLAS ID tracking system has been aligned using the LHC data taken at √s = 7 TeV during 2010. Two different data samples were used as input for the alignment.

- Collision sample: high p_T and well isolated tracks from the LHC proton-proton collisions selected by the ATLAS high-level trigger.
- Cosmics sample: cosmic-ray tracks collected by the ATLAS cosmic-ray trigger between LHC proton-proton collisions.

Alignment results of the jet trigger data sample reconstructed with the Autumn 2010 Alignment (blue) compared with the perfectly aligned dijet MC simulation sample (red) are shown.

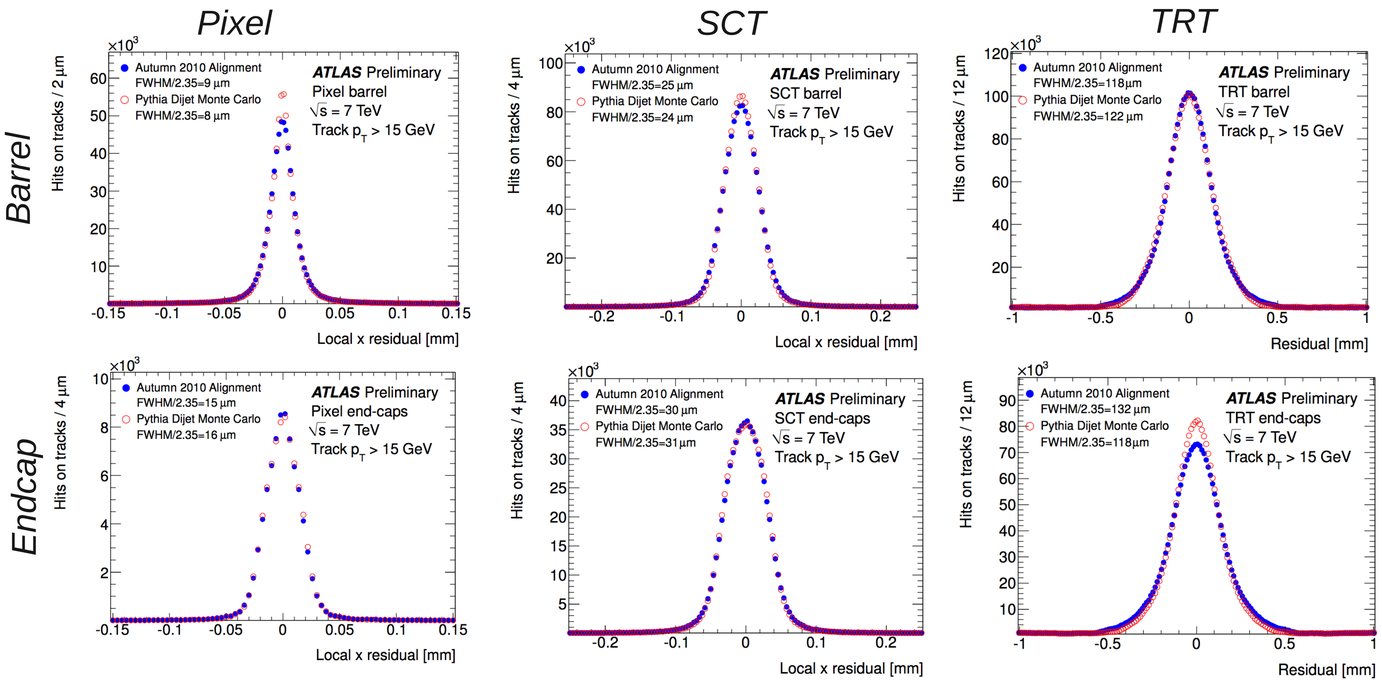






Top left and right: Track p_T and η distributions. The p_T is signed with the charge of the particle.

Right: Mean of the d_0 distribution as a function of track η.



Residual distributions for barrel and endcap of Pixel, SCT and TRT. For Pixel and SCT the residual distributions are shown in local x coordinate. The distributions are integrated over all hits-on-tracks in barrel (top) and endcap (bottom) modules. The tracks are required to have p_T > 15 GeV and the MC distributions are normalized to the number of entries in the data.