Alignment of the ATLAS Inner Detector Tracking System

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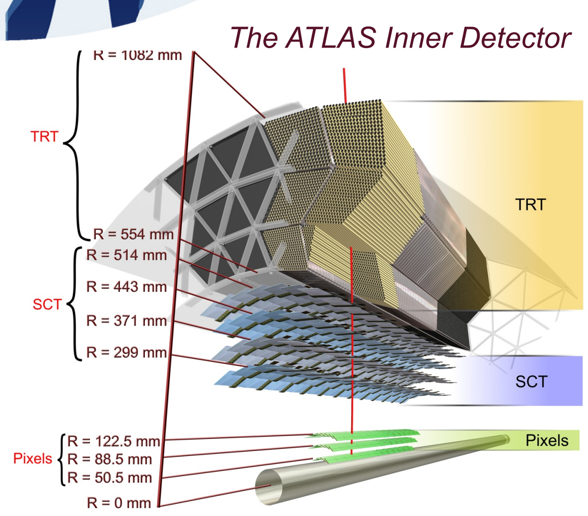


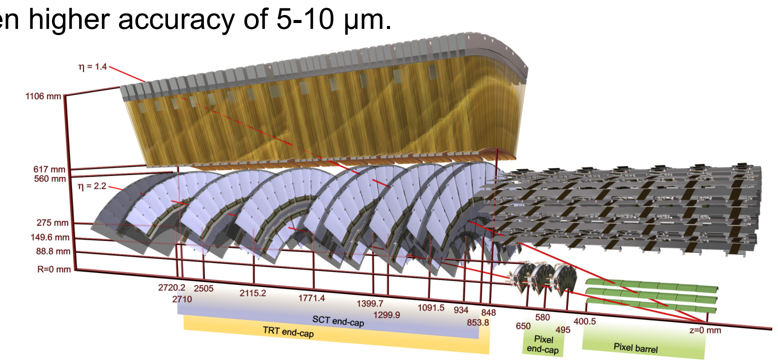
Inner Detector Overview

ATLAS is equipped with an inner tracking system which consists of three independent, yet complimentary, subsystems: the Pixel detector, the Semiconductor Tracker (SCT), and the Transition Radiation Tracker (TRT). Built using different technologies (silicon pixels, silicon microstrips, and drift tubes), they together constitute the Inner Detector (ID) which is embedded in a 2 T solenoidal field.

Accurate vertex finding, reconstructing trajectories of charged particles, and precisely measure their momenta is of crucial importance for physics analyses. In order to achieve its scientific goals, an alignment of the inner tracking system is required to accurately determine almost 36,000 degrees of freedom for the silicon detectors and 700,000 for the TRT.

Alignment Goals

The baseline goal of the ID alignment is to, with high precision, determine position and orientation of detector modules, such that the limited knowledge of sensor locations should not deteriorate the resolution of track parameters by more than 20% with respect to the intrinsic tracker resolution. Precision measurements require even higher accuracy of 5-10 μm.



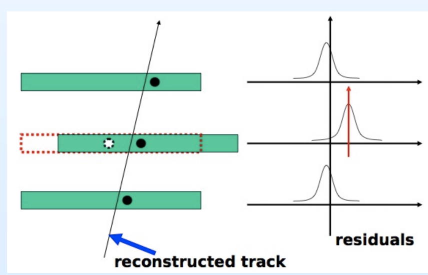
Subdetector	Alignable Structures	Element Size	Intrinsic Resolution
Pixel	1774 modules	50 μm x 400 μm	10 μm (Rϕ), 115 (Rz)
SCT	4088 modules	80 μm x 12 cm	17 μm (Rϕ), 580 μm (Rz)
TRT	350,848 straws	4 mm (diameter)	130 μm (Rϕ)

Alignment Procedure

The alignment is performed in three stages and consists of relative alignment of subdetectors (L1), relative alignment of the separate layers in a subdetector (L2), and relative alignment of individual modules or straws within each detector layer (L3).

To minimize multiple scattering effects, the alignment relies on high-p_T tracks from collision and cosmic ray events. Collision tracks with p_T > 9 GeV are selected online by the High Level Trigger and written to a special calibration stream.

The alignment is based on track-hit residuals, the distance between the extrapolated track position on a given module to the recorded hit position in the same module. Three independent alignment algorithms have been developed:



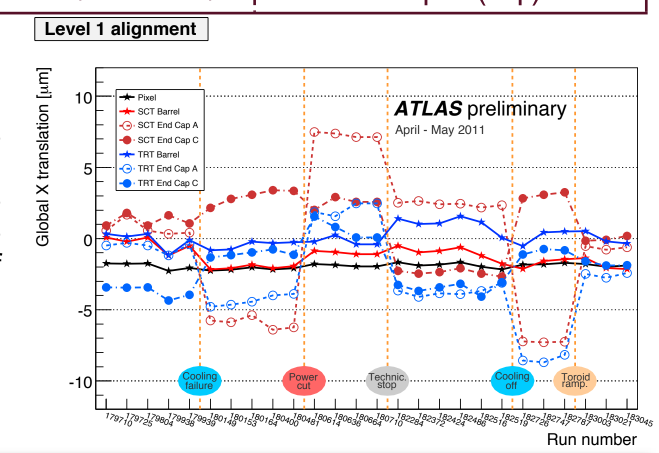
Global χ^2 ***alignment*** Simultaneous fit of all track and alignment parameters by minimizing a χ^2, resulting in a linear system with a size of the number of alignment degrees of freedom.
Local χ^2 ***alignment*** Aligning each detector module separately, requiring solving a system of 6x6 linear equations for each module.

Various constraints may be imposed during the alignment, including beamspot and vertex constraints, and knowledge from survey assembly data, such as pixel module deformations. A powerful, recently employed method is to derive momentum constraints from E/p of high p_T electrons. Constraining the ID momentum measurement based on information from the Muon Spectrometer (MS) is an additional potential method.

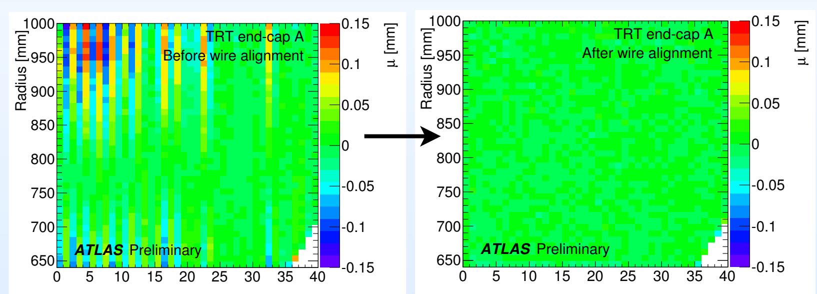
Detector Stability

During spring 2011 it became noticeable that the different subdetectors of the ID were moving. The detector movements are primarily correlated to sudden temperature changes and correspond to a typical size of < 10 μm. The ID is otherwise stable with movements of < 1 μm.

Right: Run by run L1 alignment corrections.

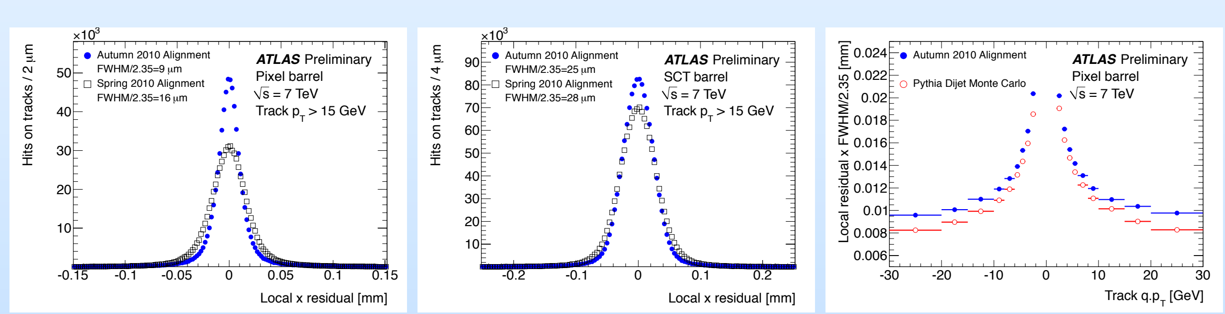


Results of Alignment with 7 TeV Collision Data



Left: Twist of TRT 4-plane wheels shown before/after module alignment.

Below: Pixel/SCT residuals for tracks with p_T > 15 GeV, comparing alignment from fall 2010, spring 2010, and predictions from perfectly aligned MC.



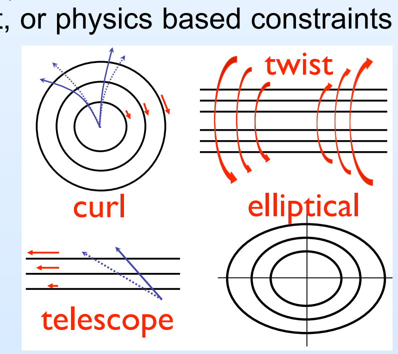
Global Systematic Distortions

Global systematic detector distortions leave track-hit residuals unbiased for tracks originating from the same interaction point, and standard track-based alignment algorithms are thus insensitive to such misalignments. Several approaches for removing systematic biases may be considered:

Different track topologies Use tracks from cosmic ray or beam halo events, or tracks collected during times when the solenoidal field was off.
Alignment constraints Apply additional constraints during the alignment procedure, such as constraining tracks to the beamspot or a common vertex, constraints based on the momentum as measured by the MS, E/p constrained alignment, or physics based constraints from invariant mass of well known resonance decays.

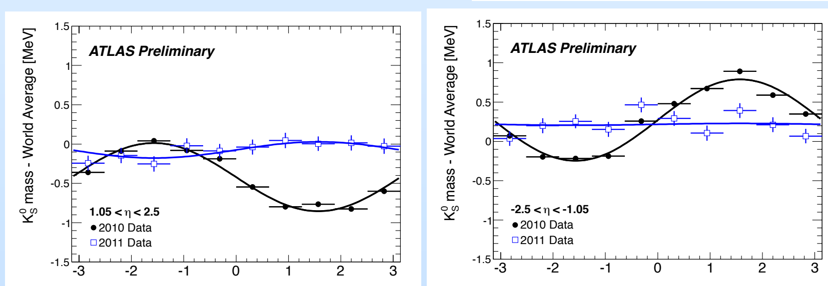
	ΔR	Δϕ	Δz
R	Radial expansion	Curl	Telescope
ϕ	Elliptical	Clamshell	Skew
z	Bowing	Twist	Z expansion

Above: Simplest examples of global system distortions



Tilt of the Solenoid Field

A tilt of the solenoid field was found as a bias in the K^0_S and J/ψ masses vs phi (shown on the right). The shift was corrected for by a 0.55 mrad rotation of the field around the x-axis.



Alignment Performance with $Z \to \mu\mu$ Decays

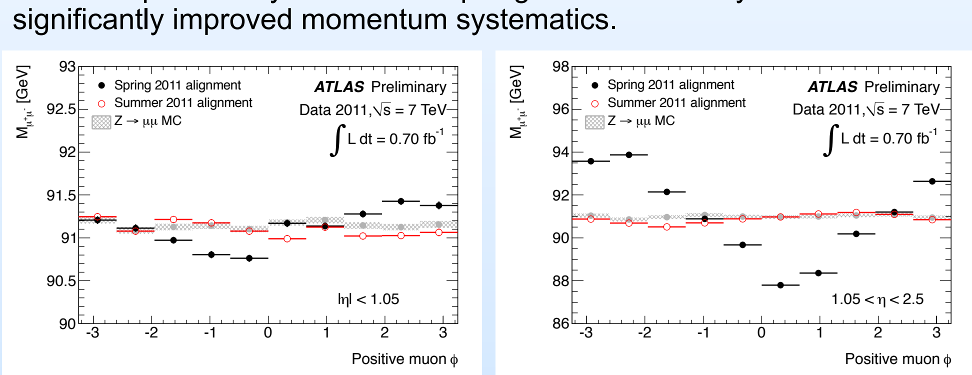
The Z resonance, with its decay to oppositely charged muons provides a clean signature and a powerful tool for studying alignment performance and probing systematic effects.

With well-known intrinsic resolution, the estimated resolution of the dimuon invariant mass is a measure of detector effects. Muons from Z decays tend to have considerably high p_T and are less sensitive to systematic effects in material description compared to lower mass resonances.

Z candidate events are selected using isolated muons with combined ID+MS tracks and p_T > 20 GeV. The invariant mass is formed using ID track parameters to probe alignment effects in the inner tracking system.

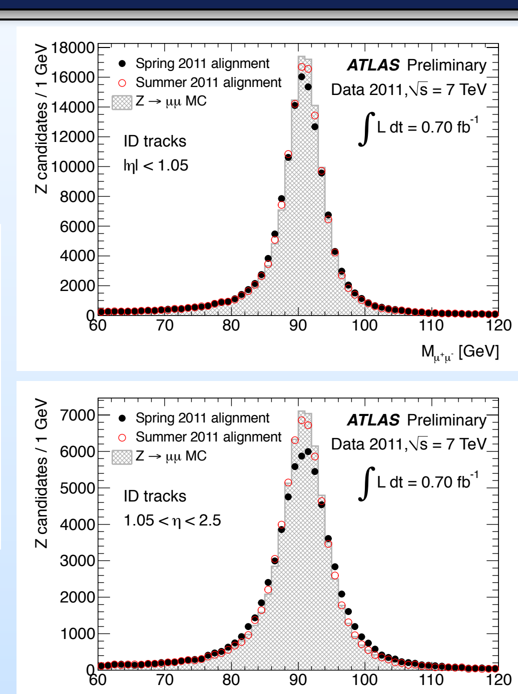
E/p Constrained Alignment

For summer 2011 data reprocessing, constraints derived from electron E/p were imposed. The goal is to reduce large observed momentum biases in particularly in the endcap regions. Preliminary results indicate significantly improved momentum systematics.



Above: Mean Z mass vs phi for positive muons in barrel vs endcap A., showing large improvements in observed momentum biases.

Right: Z invariant mass distribution for muons in barrel and endcap A.



Outlook

The ATLAS Inner Detector has been aligned using cosmic ray tracks collected by cosmic triggers between the LHC collisions, as well as using well isolated, high-p_T tracks from the 7 TeV LHC data.

The ID alignment performance is approaching design resolutions, and focus is now shifting towards understanding more subtle effects such as global systematic detector distortions.

Clear improvements in alignment performance are observed after performing the alignment using constraints from electron E/p.

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