PROCEEDINGS OF SCIENCE

Alignment of the ATLAS Inner Detector tracking system

Regina MOLES VALLS[∗ †]
Instituto de Física Corpuscular (IFIC), Centro Mixto UVEG-CSIC,
Apdo.22085, ES-46071 Valencia,
E-mail: Regina.Moles@ific.uv.es

The ATLAS experiment is equipped with a tracking system for charged particles built on two technologies: silicon and drift tube base detectors. These kind of detectors compose the ATLAS Inner Detector (ID). The Alignment of the ATLAS ID tracking system requires the determination of almost 36000 degrees of freedom. From the tracking point of view, the alignment parameters should be know to a few microns precision. This permits to attain optimal measurements of the parameters of the charged particles trajectories, thus enabling ATLAS to achieve its physics goals. The implementation of the alignment software, its framework and the data flow will be discussed. Special attention will be paid to the recent challenges where large scale computing simulation of the ATLAS detector has been performed, mimicking the ATLAS operation, which is going to be very important for the LHC startup scenario. The alignment result for several challenges (real cosmic ray data taking and computing system commissioning) will be also reported.

2008 Physics at LHC
September 29 - 4 October 2008
Split, Croatia

[∗]Speaker.
[†]On behalf of the ATLAS Collaboration

PoS(2008LHC)035

1. Introduction

ATLAS (*A* Toroidal LHC Apparatus)[1] is one of two multi-purpose detectors built to study the LHC (Large Hadron Collider) physics[2]. The LHC is a hadronic machine that will collide protons with a center-of-mass energy of 14 TeV, 40MHz rate and a design luminosity of $10^{34}\text{cm}^{-2}\text{s}^{-1}$.

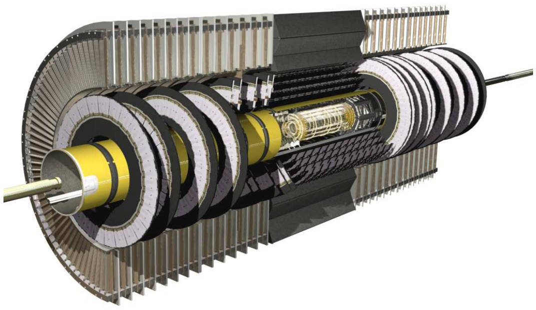

Figure 1: View of the ATLAS Inner Detector

The Inner Detector (ID)[3] is the inner most detector tracker of ATLAS. 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). The Pixel detector main contribution is to help with the impact parameter determination, thus the vertex reconstruction. The modules are composed by pixels with $(50\text{x}400)\mu\text{m}^2$ of size and an intrinsic resolution of 10x115 μm^2. The SCT detector helps in the measurement of the particle momenta and uses micro-strips silicon sensors with a strip pitch of 80μm. Its intrinsic resolution is 17x580μm in rΦ and rz direction respectively. The TRT is the most external sub-detector and it eases in the pattern recognition and momentum measurement. The TRT produces 36 hits per track in average. The technology used is based on straw tube elements with 4mm of diameter and variable length depending on the zone of the detector. The intrinsic resolution is 130μm [4].

The ID has a cylindrical geometry, with a length of 6m and a diameter of 2.3m. The solenoid surrounding the TRT provides an axial B field of 2T. The three sub-detectors have the same layout, several barrel layers around the beam axis and some discs in the end-cap parts. The pixel detector has 3 layers and 2x3 discs (1456 and 2x144 modules respectively), the SCT has 4 layers and 2x9 end-caps (2112 in the barrel and 2x998 in the end-caps) and the TRT has 3 layers and 2x40 end-caps (96 barrel module and 2x398 end-caps modules). The figure 1 shows the layout of the ID.

2. ATLAS Inner Detector Alignment Strategy

The ID is a complex system, with many sub-structures including thousands of modules which need to be aligned. To achieve the expected ATLAS physic performance, the ID alignment requirements have been fixed: ”*The knowledge of the alignment constants should not lead to a significant degradation of the track parameters beyond the intrinsic tracker resolution*”[3]. In order to not compromise the ATLAS physics goals, the allowed degradation of the track parameters due to misalignments has been settle to 20% maximum. Studies show that we need a resolution of 7μm in the Pixels and 12μm in the SCT (in rΦ direction)[5].

The strategy of the ID alignment has different steps. First, we have a knowledge of the structures based on optical and mechanical survey information obtained during the detector assembly and integration. The survey of the ID was performed at different levels (sectors, staves,...) independently for each subsystem. The positions of these structures have been monitored during the assembly.

The FSI (Frequency Scanning Interferometry) is a system installed in the SCT detector. It is a laser alignment system that provides a monitoring of the mechanical stability of the detector. It is based on a geodetic grid of length measurements between nodes on the SCT detector. This system monitors the deformations of the large structures on a short time scale, every 10 minutes, and provides measurements with a precision of 1μm along each grid line and 5μm in the 3 dimension measurements. Although, the ultimate precision can be achieved using track-based algorithms. All track algorithms are based on track-hit residual information and have been implemented within the ATLAS software framework (Athena). There are three algorithms implemented to align the silicon ID subsystem:

- Globalχ^2: Minimizes the χ^2 function with respect to the track parameters (π) and alignment parameters ($\mathbf{a}$), built from the track residuals $\mathbf{r}$ [6]:

$$\chi^2 = \sum_{Tracks} \mathbf{r}(\pi,\mathbf{a})^T V^{-1} \mathbf{r}(\pi,\mathbf{a}) \;\Rightarrow\; \delta\mathbf{a} = -\left(\sum_{Tracks} \frac{\partial \mathbf{r}^T}{\partial \mathbf{a}_0} W \frac{\partial \mathbf{r}}{\partial \mathbf{a}_0}\right)^{-1} \sum_{Tracks} \frac{\partial \mathbf{r}^T}{\partial \mathbf{a}_0} W \mathbf{r} = -M^{-1}\nu \quad (2.1)$$

where $\delta\mathbf{a}$ are the alignment parameters corrections. This method uses biased residuals, works with 6 DoFs per module (3 translations and 3 rotations) and takes module correlations and multiple Coulomb scattering into account. For the alignment of all degrees of freedom, the solution involves the inversion of a big matrix M (35k$\times$35k). For this, matrix diagonalization has been used and solved using parallel processing.

- Localχ^2: This method is based on the χ^2 definition given in equation 2.1. The current implementation uses the unbiased Distance Of Closest Approach as residuals. In the Localχ^2 the correlation between modules is not considered. This makes the alignment matrix 6$\times$6 block diagonal. Therefore, solving the matrix is much faster. However more iterations are needed [7].

- Robust: It's based on centering the residual distributions taking into account the overlaps between adjacent modules. It aligns for 3 DoFs per module (within plane parameters). This method needs even more iterations to converge [8].

Some algorithms presented here are based on the χ^2 information. There are some systematic global deformations of the detector, called *Weak Modes*, that can leave the χ^2 of the fitted track almost unchanged. Global movements like telescope, bowing, curling, twist, etc can produce a bias of the track parameters and can affect the measurement of the ID. There are some possibilities to overcome this problem: using cosmic ray events, beam-halo events, a vertex and beam-spot constraints, E/p constraint, invariant mass constraints, external surveys and the FSI system which give extra information and help to remove the weak modes. Some of these distortions have been included in simulated events to study the impact on the physics performance.

3. Validation of the Alignment Algorithms

The alignment approaches have been tested in several exercises using simulated samples (CSC and FDR) as well as tracks from cosmic rays (SR1 in 2006 and Milestone exercises during 2008).

3.1 CSC (*Computing System Commissioning*)

Within the CSC exercise a realistic ATLAS detector description was simulated. For the ID, the as-built geometry included misalignment of the different subsystems, distorted material and distorted magnetic field. The misalignment range is from $\mathscr{O}$ (1mm) and $\mathscr{O}$(0.1 mrad) for level 1 (misalignment between pixel and SCT detectors) translation and rotation respectively and $\mathscr{O}$(100μm) and $\mathscr{O}$(1 mrad) for level 2 (misalignment between layers and discs) and level 3 (module misalignment).Simulated samples were produced under these conditions. The alignment algorithms used the same samples (multimuons, tops, Z$\rightarrow\mu\mu$, ...) to test the different approaches. Recently, other samples simulating beam gas and beam halo events have been generated using misaligned geometries. These samples provide additional important information for the end-caps alignment.

3.2 FDR (*Full Dress Rehearsal*)

The main objective of the FDR exercises was to test the offline chain during data taking. Several exercises have been undertaken during 2008. A dedicated data stream, *idcalibration*, composed by isolated tracks was defined. In these exercises tracks from collision events and cosmic ray data were combined in a single alignment solution. The outline of the alignment chain can be seen in figure 2. A new set of constants was produced within 24h and checked using the ID alignment monitoring. This monitoring tool uses information about the detector performance and physics observables (invariant mass of resonances) and validates the new set of constants. When the new constants were accepted, they were uploaded into the database for the reprocessing of the events. Within the FDR exercises new software scripts ran on the CERN Analysis Facility and the analysis of the necessary resources to the alignment chain in a 24 hours loop and the timing tests were done.

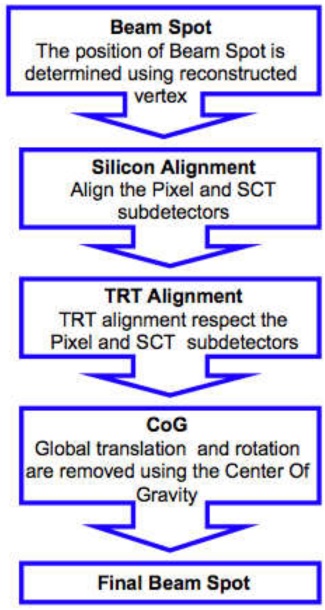

Figure 2: Alignment FDR Chain

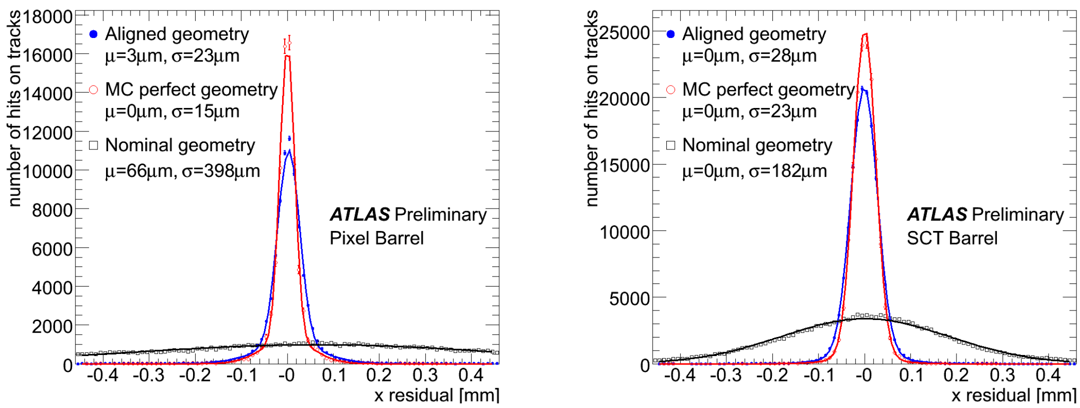

Figure 3: Residual distributions obtained from tracks from cosmic ray events for Pixels local x residual (left) and SCT residual (right). The width of the aligned distributions are 23μm and 28μm respectively.

3.3 Real Cosmic Data

During the year 2008 the ATLAS ID collected real data from cosmic ray events. These data were used to exercise the various alignment approaches and to produce alignment constants which improve the tracking performance. In March the SCT and TRT recorded data in the pit for the first time and collected around 12k events without B field. The alignment algorithms were applied. Typical problems (noise occupancy, different trigger configuration,...) had to be tackled. These data were used to obtain a very preliminary set of alignment constants for the barrel detector. During September/October 2008 the complete ID collected a large statistics sample (1.2M tracks, just for the silicon) with and without B-field. New alignment levels were implemented taking into account the half-shells and ladders of the pixel barrel to mimic better the detector structures. During the alignment, a pixel stave bowing has been observed and corrected. The residual distributions for Pixel and SCT detectors are shown in figure 3 and figure 4 shows the impact parameter when splitting the track in upper and lower segments.

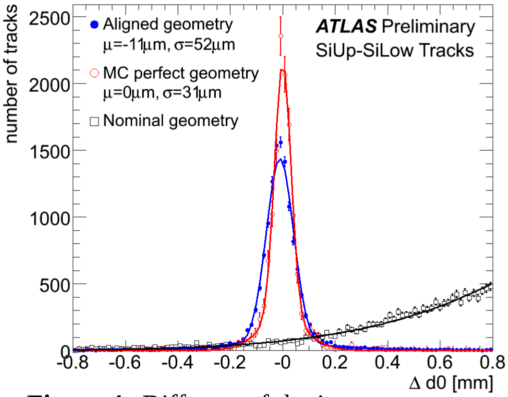

Figure 4: Different of the impact parameter between upper and lower segments.

4. Conclusion

The ID alignment uses survey information, a FSI and a track-based algorithms. The ID Alignment has been tested in various exercises, using simulation events and using cosmic tracks collected at the surface and at the pit. The use of real cosmic ray data has permitted to obtain a first set of alignment constants for the real detector. In summary, the ATLAS ID is ready to reconstruct the charged particle tracks and it can be aligned with the first LHC collision tracks.

References

[1] The ATLAS Collaboration, *ATLAS detector and physics performance Technical design Report*, ATLAS TDR-14 CERN/LHCC/99-14,1999 (VOL.I)

[2] The LHC Study Group, *The Large Hadron Collider*,CERN/AC/95-05(LHC),1995

[3] ATLAS Inner detector Community, *ATLAS, Inner Detector* , ATLAS TDR4 CERN/LHCC/97-16,1997

[4] The ATLAS Coll., *The ATLAS Experiment at the CERN Large Hadron Collider*, JINST3 S08003.

[5] S. Haywood, *Offline alignment and calibration of the Inner Detector*, ATLAS INDET-2000-005,2000.

[6] Brückman, P; Hicheur, A; Haywood, S J *Global χ^2 approach to the Alignment of ATLAS Silicon Tracking Detectors*, ATL-COM-INDET-2005-004, CERN-ATL-INDET-PUB-2005-002, ATL-INDET-PUB-2005-002

[7] ATLAS Collaboration, *Proceedings of the first LHC Detector Alignment Workshop. Cap.Alignment Strategy for the Inner Detector of ATLAS*,CERN,Geneva,Switzerland,Sep.2006

[8] F.Heineman, *Track Based Alignment of the ATLAS Silicon Detectors with the Robust Alignment Algorithm*,CERN-ATL-INDET-PUB-2007-011

PoS(2008LHC)035