Alignment of the ATLAS Inner Detector tracking system

Jike Wang* **on behalf of the ATLAS Collaboration**
Institute of Physics-Academia Sinica
E-mail: jike.wang@cern.ch

The ATLAS Inner Detector (ID) consists of two silicon subsystems, the Pixel detector and the Semiconductor Tracker (SCT), complemented by the Transition Radiation Tracker (TRT) composed of drift tubes. After the assembly of the detector, the position of the individual modules is known with much worse accuracy than their intrinsic resolution. The baseline goal of the track-based alignment is to determine the position and orientation of the modules with such precision that the track parameters determination is not worsened by more than 20% with respect to that expected from the perfectly aligned detector. This is crucial for efficient track reconstruction and precise momentum measurement and vertex reconstruction.

The alignment of the ID requires the determination of its large number of degrees of freedom (DoF) with high accuracy. Thus the demanded precision for the alignment of the silicon sensors is below 10 μm. The implementation of the track based alignment within the ATLAS software framework unifies different alignment approaches and allows the alignment of all tracking subsystems together. The results of the alignment using real data recorded during the LHC start up run in 2009 plus the recent 7 TeV data collected during 2010 run will be presented.

35th International Conference of High Energy Physics
July 22-28, 2010
Paris, France

*Speaker.

PoS(ICHEP 2010)045

ATL-INDET-PROC-2010-035
07 November 2010

1. Track-Based Alignment Algorithms

Three independent algorithms which are "Global χ^2", "Local χ^2" and "Robust Alignment", have been developed, validated and implemented within the ATLAS[1] software framework. All are based on the residuals of the reconstructed hits on tracks. A residual is the distance between the measured hit position and the track extrapolated one. The "Global χ^2" is the baseline alignment algorithm [2], which simultaneously fits all particle track parameters and alignment parameters. This scheme can be applied to different levels of alignment: sub-detectors, assembly structures (barrel layers and end cap disks) and finally to individual modules. The typical size of the corrections varies from 1 *mm* (sub-detector level) to 10 μm (module level).

1.1 Residual χ^2 Minimization

Let $\mathbf{r}(\mathbf{a},\tau)$ be the vector of the residuals of the track hits. Residuals depend on both the alignment parameters ($\mathbf{a}$) and the track parameters (τ). V is the covariance matrix of the hit measurements. The alignment χ^2 is built as follows :

$$\chi^2 = \sum_{tracks} [\mathbf{r}(\mathbf{a},\tau)]^T V^{-1} \mathbf{r}(\mathbf{a},\tau) \tag{1.1}$$

The alignment corrections ($\delta\mathbf{a}$) are obtained by requiring the minimum condition to the χ^2 and by making use of the linear expansion of the residuals around $\mathbf{r}_0$ (their initial estimates). This requires solving linear systems of the size equal to the number of the alignment DoFs as follows:

$$\frac{d\chi^2}{d\mathbf{a}} = 0 \implies \delta\mathbf{a} = -\left[\sum_{tracks}\left(\frac{d\mathbf{r}}{d\mathbf{a}}\right)^T V^{-1}\left(\frac{d\mathbf{r}}{d\mathbf{a}}\right)\right]^{-1}\cdot\left[\sum_{tracks}\left(\frac{d\mathbf{r}}{d\mathbf{a}}\right)^T V^{-1}\mathbf{r}_0\right] = -A^{-1}B \tag{1.2}$$

Solving the equation 1.2 gives the alignment corrections, but this is computing challenging. First, up to millions of data events are processed in parallel on multiple CPUs, then merged to obtain the final matrix A and vector B. An infrastructure to submit parallel jobs to the Grid has been put in place too. Second, depending on the granularity of the alignment, different matrix solving techniques are used, such as Lapack, ScaLapack, MA27[3]. The number of matrix DoF can reach 36,000 and can be far from sparse, then solving is very computationally intensive.

1.2 Beam-spot and Vertex Constraints

Beam-spot and vertex constraints are essential for high quality alignment. The corresponding tools have been implemented. The basic idea consists of adding either beam-spot or vertex information to the collection of track measurements. A subsequent track refit provides updated measurement residuals and corresponding derivatives.

2. Weak Modes

Some detector global distortions preserve the helicoidal trajectory of the tracks. Therefore the track-based algorithms have a low sensitivity to those distortions and it is difficult to correct them. These are called "weak modes" of alignment. The methods to deal with weak modes are: first, use different track topologies: such as cosmics, beam-gas, beam-halo, second, use constraints: such as beam-spot, vertex constraint, constraint on invariant masses of well known resonant decays, constraint on momentum from other systems.

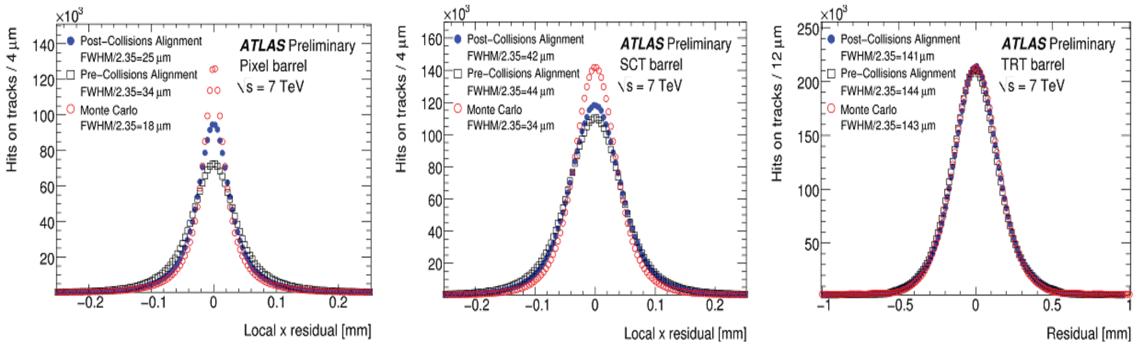

Figure 1: Residuals comparison among Post-Collisions Alignment, Pre-Collisions Alignment and Monte Carlo with perfect geometry

3. Alignment Performance with 7 TeV Collision Data

In Figure 1, the three plots are the results for 7 TeV data reconstructed with Post-Collisions Alignment (using 2009 cosmics + 900 GeV data), Pre-Collisions Alignment (using 2008 cosmics) and for Monte Carlo with perfect geometry. Minimum Bias events are used. The width of the residual distributions of the three subdetectors (Pixel, SCT and TRT) becomes narrower once the detector has been aligned using LHC collision data. By comparing the width of the real data residuals and the MC ones, one can extract the contribution by random misalignments. For the barrel part of the pixel detector this contribution is 17 μm.

4. Summary

The alignment of the ATLAS Inner Detector tracker uses a track-based algorithm that minimizes a χ^2 which is built up on track-hit residuals. The alignment constants obtained with the cosmic-ray data were used to reconstruct the first LHC proton-proton collisions. The use of 900 GeV collision data improved the ID alignment. The results with the 7 TeV data collected during 2010 show that the current alignment precision is about 17 μm for the Pixel barrel sensors. When more high p_T tracks will be collected, a further improvement of the alignment is expected.

References

[1] ATLAS Collaboration, G. Aad *et al.*, The ATLAS experiment at the CERN Large Hadron Collider, Journal of Instrumentation **3** (2009) S08003.

[2] P. Bruckman, A. Hicheur and S. Haywood, Global χ^2 approach to the alignment of the ATLAS Silicon Tracking Detectors, ATLAS Note ATL-INDET-PUB-2005-002.

[3] LAPACK – Linear Algebra PACKage, www.netlib.org/lapack