Alignment of the ATLAS Inner Detector

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Abstract. In order to reach the track parameter accuracy motivated by the physics goals of the experiment, the 700,000 degrees of freedom of the ATLAS tracking system need to be determined accurately. The precision required for the alignment of the silicon sensors is below 10\,\mu m. 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 alignment software relies on the tracking information (track-hit residuals) but also includes the capability to set constraints on the beam-spot and primary vertex, as well as the use of the momentum measured by the Muon System or the $E/p$ determined from the calorimeter. The results of the alignment of the ATLAS tracker using the 2011 collision data are presented.

1. Introduction

The ATLAS experiment \textsuperscript{[1]} is a general purpose experiment at the Large Hadron Collider (LHC) at CERN. The Inner Detector (ID) \textsuperscript{[2]} provides the ATLAS tracking system, occupying a cylindrical volume of 2.1m in diameter and 6.2m in length around the interaction point that surrounds the beam-pipe. The ID consists of two silicon subsystems: the Pixel Detector and the Semiconductor Tracker (SCT), complemented by the Transition Radiation Tracker (TRT) composed of straw tubes. Figure 1 shows an overview of the ID.

The Pixel detector consists of a barrel region with three cylindrical layers and two symmetric end-caps each containing three disks for tracking in the forward region. All pixel modules (1744 in total) are identical, with a sensor segmented into $50\times400\mu m$ pixels providing a 2D readout with a resolution of $10\mu m$ and $115\mu m$ in the azimuth ($r$-$\phi$) and transverse planes ($r$-$z$), respectively. The SCT is made of four layers in the barrel region and nine disks in each of the two end-caps. Different types of modules have been installed in the SCT, all with the same components but differing in geometry. Each one of the 4088 modules is composed of two pairs of single-sided silicon micro-strip detectors glued back-to-back with a relative stereo angle of 40mrad. The strip pitch is $80\mu m$ for the barrel and varying from $55\mu m$ to $90\mu m$ for end-cap modules due to their keystone geometry. The intrinsic resolution in the $r$-$\phi$ and $r$-$z$ planes is $17\mu m$ and $580\mu m$, respectively. The TRT is the outermost and largest of the ID sub-detectors. It is made of straw drift tubes which have a single hit resolution of $130\mu m$ in the ($r$-$\phi$) plane. The straw tubes are arranged in 32 modules in each of the three barrel layers and $2\times40$ end-cap wheels (176 modules in total).

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2. Alignment Strategies

Several independent algorithms have been developed and validated in the ATLAS offline software framework. All are iterative and make use of the residuals of the reconstructed hits on tracks. The main idea is that the sum of the residuals over a large number of reconstructed tracks should be minimal for the aligned geometry. This can be formulated as a large $\chi^2$ minimization problem $[5][6]$. The alignment corrections are obtained by applying the minimization condition to the $\chi^2$ and by making use of the linear expansion of the residuals around their initial estimates.

The alignment is done at different levels of granularity, motivated by the mechanical structure of the ID. First, the largest structures, sub-detector barrels and end-caps, are aligned (L1). A second level of alignment (L2) treats barrel layers and end-cap disks or wheels as separate alignable objects. At this level, more structures, and consequently more degrees-of-freedom, are aligned. The final alignment level consists of the module-by-module (Pixel, SCT) or wire-by-wire (TRT) alignment. This third alignment level has the most degrees-of-freedom and requires the greatest statistics.

An infrastructure for running the alignment on Grid has been developed and is extensively used. Traditionally, the ID alignment is run on the CERN batch system (CAF). With the increasing LHC data statistics, the CPU and storage resources for ID alignment are no longer sufficient. The datasets accessible on CAF are quite limited too. The Grid environment offers access to nearly all ATLAS datasets and massively larger CPU and disk storage resources. Another advantage is that there are more powerful and convenient tools and interfaces for job management. A mechanism that can automatically run the L1/L2 alignment in the calibration loop also has been implemented.

3. Weak Modes

The minimization of track residuals is necessary but not sufficient. The global distortions which preserve the helical trajectory of tracks and leave the $\chi^2$ unchanged while systematically biasing the track parameters are known as weak modes. These kinds of distortions are difficult to remove by the minimization of the residuals; on the other hand they are very dangerous to physics results. Two main kinds of methods can deal with the weak modes. The first is the use of different track topologies such as cosmic rays, beam...
halo and beam gas, etc.. The second is the use of constraints. These include beam-spot and vertex constraints, constraints on invariant masses of well known resonant decays, constraints on momentum from other systems (such as the measurement from the Muon Spectrometer and $E/p$, where the energy is measured by the calorimeter).

4. Alignment performance

For the ATLAS 2011 summer reprocessing, preliminary results indicate significant performance improvement, especially in the endcap regions. The mass resolution of the $Z \rightarrow \mu^+\mu^-$ resonance decay very nearly reproduces the one expected from the perfectly aligned MC [5]. Figure 2 shows the $Z$ mass resolution in different ID regions; the black circles are for the Spring 2011 alignment, the red circles for the Summer 2011 alignment, the shaded area shows the expectations from perfect geometry.

5. Summary

Alignment of the Inner detector of ATLAS is a very complex and challenging task. After a fast learning phase, already now the resolution on the reconstructed track parameters very closely approaches the MC expectation from a perfect geometry. The ID Alignment is making a significant contribution to ATLAS precision measurements and new physics searches.

References