Alignment of the Inner Detector and of the Muon Spectrometer of the ATLAS experiment

Igor Potrap for the ATLAS Collaboration

Max-Planck-Institut für Physik, Munich, Germany

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The ATLAS experiment at the Large Hadron Collider at CERN is equipped with two tracking systems: the Inner Detector and the Muon Spectrometer. To achieve the desired tracking performance, these subdetectors have to be aligned with the precision of better than 10 micrometers for the Inner Detector and of better than 30 micrometers for the Muon Spectrometer. Track based alignment approaches in combination with optical sensor measurements are used to fulfil these requirements. The alignment corrections have been successfully applied to the LHC collision data. The results show that the precision of current alignment already allows for a good tracking performance.

1 Alignment of the ATLAS Inner Detector

The Inner Detector is the main part of the ATLAS tracking system. It consists of three subdetectors enclosed inside a superconducting solenoid magnet. The Pixel Detector, the innermost one, consists of silicon modules with the intrinsic resolution of 10 μm in the precision coordinate ($r\phi$). The Semiconductor Tracker (SCT) consists of double-layer silicon microstrip modules with the combined resolution of 17 μm. The Transition Radiation Tracker (TRT) is constructed of straw drift tubes. Relatively low tube resolution of 130 μm is compensated by the large number of tube layers in the TRT detector.

Several track-based alignment algorithms have been developed for the Inner Detector. Two of them, *Global* χ^2 and *Local* χ^2, are based on least-square minimization of track residuals. The *Global* χ^2 algorithm takes into account all correlations between alignment parameters, but it requires inversion of a single huge (about 36 000 x 36 000) matrix. The *Local* χ^2 algorithm requires inversion of a large number of small (6 x 6) matrices which takes much less computing resources. In this case the correlations between different modules are lost. Many iterations of the alignment procedure are needed to restore these correlations. There so-called *Robust* alignment algorithm is based on shifting modules according to their observed residual offsets. All three independent approaches were tested and have shown consistent results.

1.1 Performance with collision data

The first alignment results for the Inner Detector have been produced with cosmic data collected during the ATLAS commissioning period [1]. The alignment of the Inner Detector is performed at different levels of granularity: starting from large structures such as the alignment of the whole subdetectors with respect to each other, then continuing with the alignment of the barrel layers and the end-cap disks and ending with the alignment of each individual module. Due to the poor illumination of the end-caps with cosmic rays, only the barrel part of the inner detector was aligned at the individual module level. With the start of LHC collisions, the first reliable alignment of the end-caps became available. The combination of collision and cosmic ray data has been used to produce alignment corrections for 7 TeV collision data. The use of cosmic tracks helps to cure some weak modes of the alignment. Unbiased residuals for Pixel, SCT and TRT detectors in the barrel and in the end-cap regions produced with 7 TeV collision data are presented in Figure 1 in comparison with the results from the perfectly aligned simulation. The distributions are very close to the simulated ones. The results show that current alignment already provides good tracking performance.

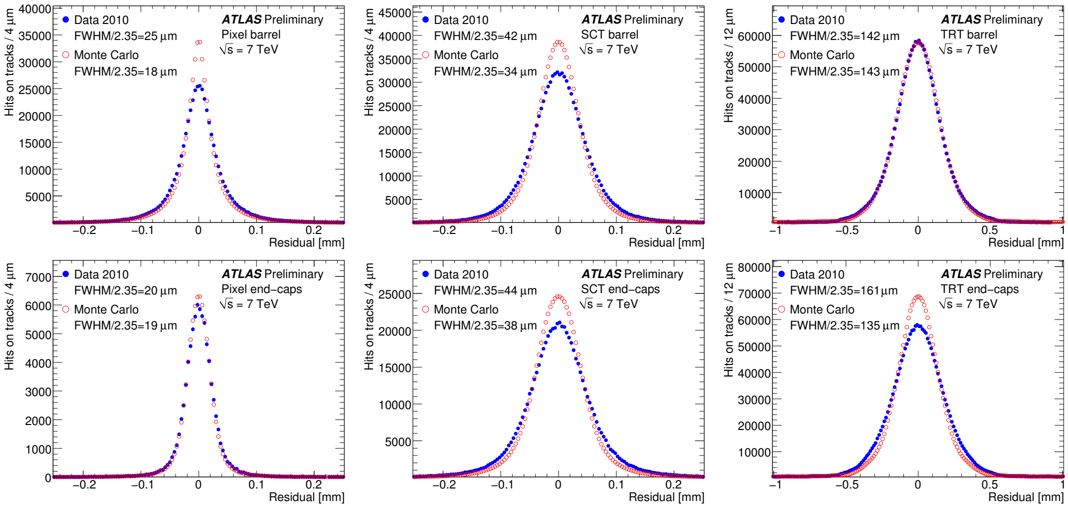

Figure 1: Unbiased residual distributions produced in the barrel (top plots) and in the end-cap (bottom plots) regions of the Pixel, SCT and TRT detectors using 7 TeV collision data.

2 Alignment of the ATLAS Muon Spectrometer

The Muon Spectrometer of the ATLAS experiment is designed to measure muon momenta of up to 1 TeV with a resolution of better than 10% [2]. It consists of three layers of precision drift tube chambers located in a toroidal field of superconducting air-core magnets. To achieve the desired momentum resolution with the 3-point track sagitta measurement, the muon chambers have to be aligned with an accuracy of better than 30 micrometers in the track bending plane. The muon optical alignment system [3] is designed to continuously monitor muon chamber positions and deformations with time. It is based on optical sensors forming two independent subsystems in the barrel and in the end-caps of the Muon Spectrometer. Apart from the optical alignment there are also several alignment tasks which require track based approaches. Those are alignment of the *small* barrel sectors with respect to the *large* ones [1], alignment of the barrel

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[1] The barrel part of the Muon Spectrometer consists of the *large* and the *small* sectors with the toroid magnet coils located inside the *small* sectors.

part of the Muon Spectrometer with respect to the end-cap part and alignment of the whole Muon Spectrometer with respect to the Inner Detector. Also, initial chamber positions have to be determined with straight muon tracks from cosmic rays and from proton-proton collisions in a dedicated run of the ATLAS detector with the toroid magnets switched off.

2.1 End-cap performance

The end-cap optical alignment system is designed to provide the accuracy on track sagitta measurement of about 40 μm. In Figure 2 the sagitta distributions for straight cosmic tracks in the end-cap region are shown for the cases of the nominal detector geometry and the geometry including alignment corrections. The sagitta of straight tracks is expected to be zero. The mean value of the distribution with alignment corrections is compatible with zero while the width of it is dominated by multiple scattering.

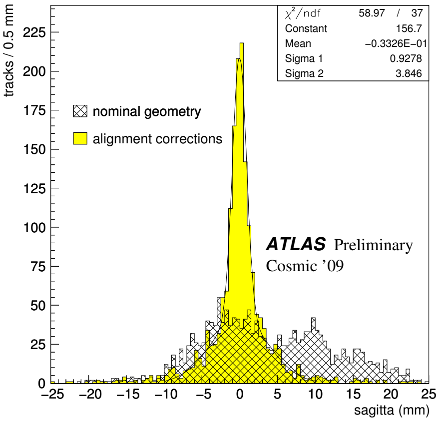

Figure 2: End-cap sagitta distribution for straight cosmic tracks reconstructed using alignment corrections (filled histogram) in comparison with nominal geometry results (hashed histogram).

2.2 Barrel performance

The barrel optical alignment system can monitor geometry changes leading to track sagitta measurement degradation of about 10–20 μm while the absolute accuracy on sagitta measurements is expected to be at the level of 100–200 μm only. The problem comes from the uncertainties on the optical sensors positions due to the precision of the optical sensors mounting and calibrations. To solve this problem, alignment with straight tracks is used to determine the initial geometry. Once it is determined, the optical alignment system monitors all chamber movements with the desired accuracy.

The performance of the alignment procedure in the barrel part of the Muon Spectrometer has been checked with straight cosmic tracks. Special cosmic runs with toroidal magnet field switched off but solenoidal field switched on were used to perform sagitta resolution studies as a function of muon momentum measured inside the Inner Detector. The widths of track sagitta distributions determined in each momentum bin are plotted as a function of muon momentum in Figure 3 for the *large* and the *small* barrel sectors separately.

There are two contributions to sagitta resolution: from multiple scattering and from the intrinsic resolution of the Muon Spectrometer. The contribution from multiple scattering decreases with muon momentum. It is about a factor of two larger for the *small* sectors because of the presence of the toroid magnet coils. The intrinsic resolution has contributions from the drift tube resolution, the muon chamber alignment and non-ideal internal chamber geometry which was not yet taken into account. The intrinsic resolution term was determined to be at the level of 80 μm inside the *large* barrel sectors and at the level of 100 μm inside the *small* barrel sectors.

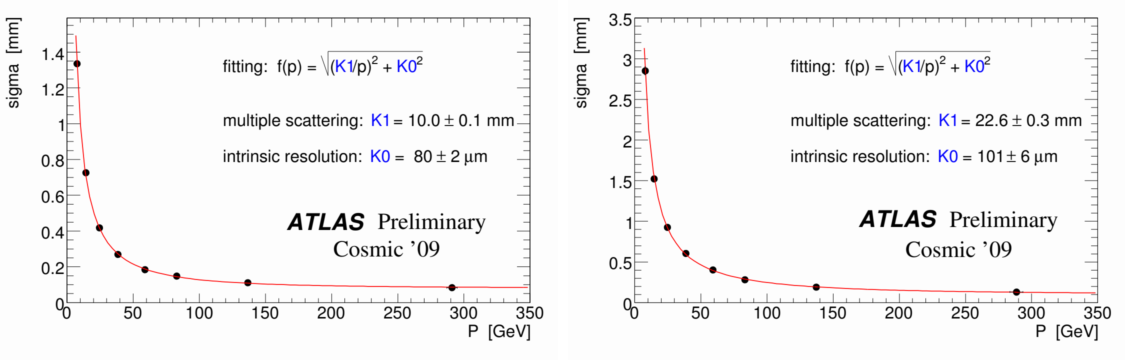

Figure 3: The track sagitta resolution measured inside the *large* (left plot) and inside the *small* (right plot) barrel sectors of the Muon Spectrometer as a function of the muon momentum.

3 Summary

Alignment of the ATLAS tracking systems was well prepared for the first LHC collisions. The distributions of unbiased residuals are very close to the ideal geometry simulations for each of the Inner Detector subsystems. The current alignment precision already provides good tracking performance. Improvements are expected for the Inner Detector alignment with larger statistics and with better treatment of weak modes. The optical alignment system is used to continuously monitor chamber positions of the ATLAS Muon Spectrometer. The results produced with cosmic ray tracks show that the combination of track-based and optical alignment procedures allows to achieve the required level of accuracy. Special runs of proton-proton collisions with the magnetic field switched off are planned to improve the alignment of the ATLAS Muon Spectrometer in the regions which are poorly illuminated by cosmic ray tracks.

References

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[3] ATLAS muon alignment PDR (2001), Available at: http://atlas-muon-align.web.cern.ch/atlas-muon-align/PDR/pdr_doc.html.