ATLAS Inner Detector alignment

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Abstract. ATLAS is one of the four experiments under preparation for the LHC accelerator at CERN in Geneva. The reconstruction of charged particle tracks will be performed by the Inner Detector, consisting of silicon-based and drift-tube-based detectors. To achieve the physics goals of ATLAS, the system with its almost 36000 degrees of freedom must be aligned to a precision of a few micrometers. The algorithms which are used for aligning the Inner Detector with tracks have been exercised on several challenges with simulated as well as testbeam and real data. Results from these challenges are presented, showing that track-based alignment is feasible using the implemented techniques. In order to fulfill the requirements from the computing model, it is foreseen that a dedicated alignment and calibration data stream enables the software to produce updated alignment constants 24 hours after recording the corresponding data.

1. Introduction
1.1. The ATLAS Inner Detector
The ATLAS detector is one of the multipurpose detectors built for the 14 TeV proton-proton Large Hadron Collider (LHC) at CERN. Its Inner Detector (ID) consists of three subdetectors: a drift tube Transition Radiation Tracker (TRT), a silicon strip detector (SemiConductor Tracker, SCT) and a silicon pixel detector. In total, nearly 6000 silicon modules shall determine positions of passing charged particles with a precision of ~20 μm; 36 layers of TRT tubes give a spatial resolution of ~170 μm and a precise momentum measurement [1]. However, the initial position of these modules is only known to a scale of ~100 μm, which makes it necessary to perform an alignment procedure. The ATLAS physics goals require a position precision of each detector component better than 10 μm, which can only be obtained by a track-based alignment procedure.

1.2. Alignment strategy
Together with survey-based alignment and hardware-based alignment during running, track-based alignment will be performed during data-taking of the ATLAS ID [2]. All track-based alignment methods share the principle of optimizing distributions of residuals, defined as the distance between the intersection of the fitted track with a detector element and the hitpoint read out by this detector element. A sample of tracks all originating from the interaction point in the detector will not lead to a unique solution because the corresponding system of equations is underdetermined. In reality, this means that certain deformations of the detector leave the χ² of the tracks unchanged, if a helical track model is assumed. For this reason, additional

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constraints need to be considered in order to make the minimization solution unique, e.g. pair mass constraints from resonance decays, common vertex constraints or cosmic tracks crossing the detector on a non-centric trajectory.

## 2. Alignment algorithms

Within the ATLAS software framework, three methods were developed for the alignment of the silicon part of the detector, each with distinct features and advantages:

- **Robust** [3, 4]: this algorithm uses weighted mean residual and overlap-residual distributions and centers them. It aligns 2 or 3 degrees of freedom (DoF), needs many iterations and is expected to be very robust with respect to initial misalignments.

- **Local $\chi^2$** [5, 6]: this algorithm solves a linearized $\chi^2$ minimization for each detector module separately. Module-to-module correlations and multiple Coulomb scattering (MCS) effects are neglected, thus it needs several iterations. 6 DoF per module are aligned.

- **Global $\chi^2$** [7]: minimizes a $\chi^2$ from a simultaneous fit to all track and alignment parameters, taking MCS and module correlations into account. Thus it needs only a small number of iterations, but also a computing environment facilitating the solving of large linear systems of equations (35k×35k for the full silicon detector).

## 3. Applications

### 3.1. Combined Testbeam

In 2004, the Combined Testbeam (CTB) made it possible to test almost all alignment algorithms on a real detector setup. Different beams from the H8 CERN beamline were used, including e$^+$ and pion enriched beams with varying energies from 2–180 GeV and with or without B-field. The detector setup used mimics a slice of the ID barrel, with 6 pixel and 8 SCT modules. The algorithms used different settings and subsets of available data to extract their final results.

It was found that all algorithms were capable of aligning the present detector elements well, as seen by improved residual and track parameter distributions. Moreover, these distributions agree well with the ones given by the simulation of the CTB. Figure 1 shows the momentum resolution for all e$^+$ runs with B-field versus the reconstructed momentum of the particle, where almost all algorithms agree nicely.

### 3.2. Cosmics data

After assembling the SCT and TRT parts together on the SR1 surface test area in 2006, dedicated cosmic data taking runs were performed and the alignment was carried out. The fully assembled barrel portion was instrumented partially and 400k cosmic tracks could be recorded. To trigger cosmics events, two scintillators were used and no track momentum measurements were possible due to the absence of a B-field. A slab of concrete allowed a momentum cutoff of $\sim$170 MeV. This cutoff still allows large effects from MCS, which were taken into account for track reconstruction and alignment [8].

In addition, the endcap parts of the SCT and TRT detectors were operated on the surface after assembly. As the endcap structures could not be put into an upright position, the multiplicity for cosmic tracks was significantly lower than for the barrel run. Roughly 20k tracks were used to align whole disks of the SCT endcap wheels. Figure 2 shows the evolution of residual widths during global $\chi^2$ alignment.

### 3.3. Simulated data

The most recent test of the alignment algorithms involved aligning the full ATLAS detector using a sample of 1 million simulated multimuon events specially produced for alignment
Figure 1. Momentum resolution vs. momentum of the CTB run for the different alignment algorithms. The slightly worse performance of the Robust algorithm can be attributed to only aligning 2 DoFs.

Figure 2. Evolution of residual widths for the TRT global $\chi^2$ algorithm applied on SCT endcap disks with the SR1 cosmic datasample. Iteration zero describes the widths after taking survey information into account and before alignment iterations were performed.

purposes. A misalignment of the detector was introduced in the simulation to test the algorithms’ performance under conditions close to reality.

Extensive studies are being carried out at the moment which show that the control of global detector deformations is crucial to a successful alignment, since these deformations do not show up in the residual distributions. Additional constraints — as mentioned above — and the control of other quantities, such as track and vertex parameters are essential for the alignment process.

4. Alignment and calibration stream

The ATLAS computing model requires that updated alignment constants are provided within 24 hours after taking the corresponding data [9]. Samples of different track topologies will be used for the alignment procedure and the calibration of the R-t relation of the TRT tubes. While the required number of hits for a sufficient statistical alignment precision is acquired rather quickly for whole disk and layer structures, it is challenging to get hold of enough good quality tracks to align individual modules. On the other hand, global detector distortions affect the alignment a lot more on the superstructure level, making a fully automated alignment processing difficult.

A selection of “good” alignment tracks of different topologies will be written out in a dedicated alignment and calibration stream at the EventFilter stage of the trigger system, where reconstructed tracks are already available. This prevents the alignment algorithm from the time-consuming reconstruction of tracks which will not be used.

5. Conclusion

A track-based algorithm for aligning the ATLAS ID has been developed within the ATLAS software framework. All methods have shown that they can successfully align simulated as well as testbeam and cosmic data. The application to cosmic data taken within the ATLAS cavern is currently underway. Work is in progress to shape the alignment chain such that it fulfills the requirements of the computing model and is capable of producing updated alignment information 24 hours after data taking.
Acknowledgments
Thanks to the whole ATLAS Inner Detector alignment group.

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