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Alignment of the ATLAS Inner Detector tracking system

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The Large Hadron Collider (LHC) at CERN is the world's largest particle accelerator. It will collide two proton beams at an unprecedented centre of mass energy of 14 TeV. ATLAS is equipped with a charged-particle tracking system built on two technologies: silicon and drift-tube based detectors, constituting the ATLAS Inner Detector (ID). The alignment of the tracking system poses a challenge, requiring the solution of a linear equation with almost 36000 degrees of freedom. The required precision for the alignment of the silicon sensors in the most sensitive direction is just a few microns. This limit comes from the requirement that the misalignment should not worsen the resolution of the track parameter measurements by more than 20%. So far the proposed alignment algorithms are exercised on several applications. We will present the outline of the alignment approach and results using real data from cosmic rays and large-scale computing simulation of physics samples mimicking the ATLAS operation during real data taking. The full alignment chain is tested using that stream and alignment constants are produced and validated within 24 hours. Cosmic ray data serves to produce an early alignment of the real ATLAS Inner Detector even before the LHC start-up. The impact of the alignment on physics measurements will be discussed.

Summary

Introduction
The LHC is a proton-proton collider located at the CERN laboratory in Geneva, Switzerland. After many years of commissioning, the LHC managed to circulate the first proton beams during September 2008. It is expected that end of the year 2009 the LHC will collide proton beams at an unprecedented 10 TeV center of mass energy. ATLAS is a general-purpose experiment that will record the LHC collisions in search for new physics phenomena.
In order to achieve its scientific goals, ATLAS is equipped among others with a very precise tracking system (the Inner Detector). The ATLAS Inner Detector consists of about 6000 modules in its Silicon Tracker combined with several hundred drift tube based detector modules. The silicon modules use both technologies: pixel and microstrip. Pixel modules determine the position of passing particle tracks with an accuracy ~10 microns, whilst microstrip modules accuracy is about 20 microns. The drift tube based detector modules resolution is ~130 microns. However, the position of the devices after construction is only known much less accuracy than the intrinsic resolution. Therefore a track based alignment procedure has to be applied to determine the absolute position of the sensitive devices to a better precision.
The goal is to align the modules with such precision that the track parameters determination is not worsened by more than a 20% with respect to those derived with the intrinsic tracker resolution. Therefore position precision required for physics measurements is ~10 microns.

Method
The position of the detector modules is determined iteratively by a $\chi 2$ minimization of track residuals together with a minimization of track parameters. The determination of the alignment constants is closely related to the solution of a system with a large number of degrees of freedom. In the case of the ATLAS Inner Detector one has about 36000 degrees of freedom. Several types of events can be used in order to add robustness to the alignment and avoid systematic biases. Therefore the collision data is being combined with cosmic ray as well as beam-gas events. There is also a Frequency Scan Interferometer (FSI), which is a hardware system that monitors the distance of a 3D grid of points mounted the semiconductor tracker supporting structure. It can be run on short periods (every 10 minutes). In this way one can account for short-term deformations. Its information may be also feed in to the track based alignment as an additional constraint.
Implementation of the Inner Detector Alignment in the ATLAS computing model
The ATLAS computing model requires the supply of alignment constants within 24 hours after data taking. The constants will then be used for the bulk reconstruction of the data and as input for the triggering of events. This requirement demands a sophisticated solution for the implementation of the alignment infrastructure. There is a PC farm devoted to run the alignment jobs. The input data consists on a dedicated calibration stream of high Pt isolated tracks selected by the ATLAS level 2 trigger. After completion, the alignment constants

are uploaded to the Data Base. In order to validate the constants the ATLAS express stream is reconstructed using these constants and physics observables as well as detector performance are monitored. If validation is successful, the ATLAS physics streams will be subsequently reconstructed with the new set of constants.

Current Status
The ATLAS ID alignment group has participated in many data challenges. As a result, the algorithms and computing resources are ready. The alignment challenges have comprised tests with real data (test beams, cosmic ray) and with simulation. The alignment has also been run on the full dress rehearsals of the ATLAS offline, producing and validating constants within 24 h. Large scale simulation was performed with a distorted geometry and the alignment algorithm proved its capability to find and correct the distortions. More sophisticated tests are being performed using weak modes. The weak modes are deformations of the tracking system that leave the track $\chi 2$ almost invariant whilst track parameters are wrongly measured. Geometries with weak modes are also being investigated from the alignment point of view and from their impact on physics observables.
Currently, the ATLAS detector is operational and cosmic rays are being collected with the real detector. These data have been used to align the Inner Detector. In this way alignment constants have been obtained and the detector calibrated, and its performance studied. The ATLAS Inner Detector is thus ready to reconstruct the LHC collisions.

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