Commissioning of the ATLAS inner detector with cosmic rays

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Abstract. The inner detector of the ATLAS experiment is in the process of being commissioned using cosmic ray events, first at the surface and then together with the other subdetectors in the ATLAS cavern. The full software chain has been set up in order to reconstruct and analyse this kind of events. Final detector decoders have been developed, pattern recognition algorithms and track fitters have been validated as well as the various alignment and calibration methods. The infrastructure to deal with conditions data coming from the data acquisition, detector control system and calibration runs has been put in place, allowing also to apply alignment and calibration constants. The software has also been essential to monitor the detector performance during data taking. Detector efficiencies, noise occupancies and resolutions have been studied in detail and compared with those obtained from simulation.

At the LHC design luminosity of $10^{34}$ cm$^{-2}$s$^{-1}$ about 25 proton-proton interactions will take place per bunch crossing. This translates into around 1000 particles traversing the ATLAS inner detector every 25 ns. Due to these experimental conditions at the LHC, electronics and sensor elements must be fast and radiation hard. In addition, a very high granularity is needed to handle the particle fluxes and to reduce the influence of overlapping events.

The ATLAS inner detector [1] combines high-resolution detectors close to the interaction point with continuous tracking elements at the outer radii, all contained in a 2 T solenoidal field. The innermost detector is the Pixel detector which consists of three layers of silicon modules in the barrel region and three discs in the endcaps, each containing about 46,000 pixels with a dimension of 50 × 400 µm. In the intermediate region silicon microstrip detectors (SCT) are used with a strip pitch of 80 µm in the barrel and 57 – 90 µm in the endcaps. In the barrel region the SCT consists of 4 layers and each SCT endcap contains 9 disks. The outermost part of the inner detector uses drift (straw) tubes of 4 mm diameter to provide on average 36 measurements per track. In addition it can provide transition radiation detection (TRT). However, during the commissioning phase, Argon is used instead of the nominal Xenon gas, and therefore only the tracking capabilities can be tested.

The commissioning of the inner detector consists of two phases: the first phase took place after the detector integration above ground to verify that the detectors operate within specifications. In addition to noise runs to study the occupancy and check for effects induced by other detectors, also runs with cosmic muons have been recorded to study the tracking performance. Three different setups have been used: an SCT-TRT barrel setup (1/4 of the SCT and 1/8 of the TRT), an SCT-TRT endcap setup (1/4 of one SCT endcap and 1/16 of one TRT endcap) and a
Pixel endcap setup, which is described together with the corresponding results in [2]. Figure 1 shows the SCT-TRT barrel setup: scintillators have been used to trigger on cosmic muons that cross the parts of the detectors that have been read out. The second phase takes place after the installation of the full inner detector in the ATLAS cavern. In these combined runs with other subdetectors, a trigger is provided by the muon trigger chambers and the hadronic calorimeter. One test, with 3/8 of the TRT barrel being read out, provided a data sample containing about 20,000 tracks that can be used for calibration and alignment studies. The SCT has also taken part in this test but reading out noise hits from four SCT module prototypes placed outside the ATLAS detector. For this test the magnets were off.

The full reconstruction chain (Figure 2) has been put in place in order to deal with simulated as well as real data. The reconstruction of real data requires as an additional step the conversion of the byte stream given by the different sub-detector readout drivers into raw data objects. These are then further processed to provide the calibrated position in space: clusters for the silicon detectors and drift circles for the TRT. For this step access to the conditions database is necessary, to retrieve e.g. the drifttime relation, as well as a proper detector description of the corresponding setup. The calibrated objects are then fed into trackfinding algorithms to produce track candidates that are fitted using one of the available track fitting techniques: a global $\chi^2$ minimisation [3] or a Kalman Filter [4], in order to reconstruct the final tracks. In this procedure the differences between cosmic events and events from LHC collisions have been taken into account: cosmic events are not synchronised with the readout clock since they occur randomly and the tracks do not originate from the interaction point. The first difference had to be taken into account in the TRT calibration and in the SCT readout scheme while the second requires to give up any vertex constraint in the trackfinding algorithms.

The full reconstruction chain can be run both offline and online at the event filter level. This was done in these tests to run dedicated monitoring tools that produce histograms based on reconstructed objects. They successfully identified problems during the data taking like e.g. a loss of synchronisation between two subdetectors. Starting with the tests in the cavern, the monitoring was also run offline during the primary reconstruction at the Tier0 producing monitoring histograms that were sent to the data quality webpage. Figure 3 shows an event
Figure 3. Display of a track from cosmic ray data showing the Muon and TRT hits as well as the energy deposited in the hadronic calorimeter.

Figure 4. Hit residuals for one of the barrel modules of the TRT using cosmic tracks recorded in the ATLAS cavern.

display with a reconstructed track from a cosmic test in the cavern. It is also possible to run this event display online to provide immediate visual feedback to the controlroom.

Monte Carlo simulations of the different cosmic setups have been provided to first validate the full reconstruction chain and then to allow for comparison with real data. Details about these simulations can be found in [5].

Runs with random triggers were used to study the noise level in the different subdetectors for many different configurations. All tests showed that the noise level was within specifications: in the Pixel detector the noise occupancy was $1 - 2 \times 10^{-8}$ per bunch crossing while in the SCT the average noise occupancy was less than $5 \times 10^{-5}$. No increase of noise was detected in either SCT or TRT when running together.

Cosmic trigger runs are used to study the detector efficiencies and resolutions. Due to the lack of magnetic field in the data taken so far, the track fit could not be corrected for material effects, leading to not properly estimated uncertainties. Taking this into account and performing first a proper calibration and alignment [6] of the detectors all the efficiencies are in agreement with the expectations, e.g. the SCT hit efficiency was found to be above 99%. Figure 4 shows the residual distribution before drifttime calibration and alignment in one of the TRT modules from cosmic data taken in the cavern. It is expected that the resolution improves to about 230 $\mu$m after calibration and alignment.

The commissioning of the ATLAS inner detector with cosmic ray and noise runs, both above ground and in the cavern, shows that the inner detector is well within specification in terms of noise, efficiency and resolution.

References
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