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Track Reconstruction in the ATLAS High Level Trigger Using Cosmic Ray Muons

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***Abstract*—The large collision rate together with the complicated event signatures at the LHC implies critical requirements on the trigger system. One very important ingredient of the event selection is the track reconstruction capability. We present the track reconstruction performed in the ATLAS trigger system and the results obtained from cosmic ray muon tracks used for the trigger decision. The first results show a good overall performance, consistent with expectations.**

I. Introduction

The ATLAS detector [1] is a general purpose detector designed to search for new physics using the 14 TeV centre of mass energy proton-proton collisions provided by the Large Hadron Collider (LHC) at the CERN laboratory in Geneva. Since collisions are not expected until late 2009, ATLAS has been recording cosmic ray data during a number of dedicated running periods. The data considered here were taken in June/July 2009, when over 90 million cosmic ray events were recorded, and give valuable information about the expected performance of the detector once collisions arrive. It has also been used to align the detector.

ATLAS has a three-level trigger system which has the challenging task of reducing the 40 MHz collision rate to O(200 Hz), which can be written to tape, whilst still retaining the interesting physics events. The first level is a purely electronics based trigger. The remaining two levels are software based and, together, form the High Level Trigger (HLT). This work focuses on the reconstruction of charged particle tracks inside the Inner Detector (ID) within the HLT. Since many interesting physics signatures include charged particles such as electrons or muons in the final state, it is crucial that these particle tracks can be identified by the HLT in order that the event is retained. The ID is discussed in detail in section II and the HLT in section III, while section IV describes the methods used to reconstruct charged particle tracks in the HLT. Section V gives visualisations of example cosmic ray events and, finally, sections VI and VII describe the measured track parameters and reconstruction efficiencies.

II. The ATLAS Inner Detector

The ID is contained within a 2 T solenoid magnetic field and is used to reconstruct charged tracks with transverse momentum $p_T > 0.5$ GeV and pseudorapidity $|\eta| < 2.5$. Three sub-detectors provide complimentary information about the particle trajectories, and are shown in figure 1. Each sub-detector consists of a central cylindrical barrel region, plus an endcap on either side. A brief description of each sub-detector is given below, however a more complete description can be found in [2].

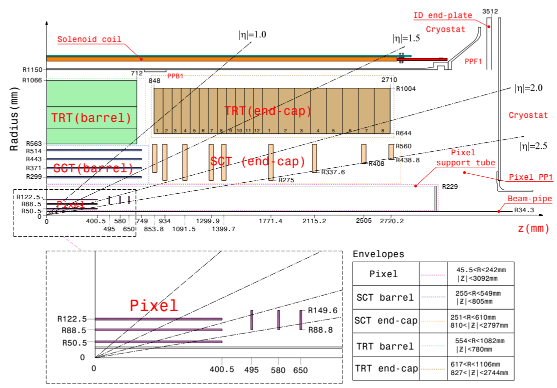


Fig. 1. Cutaway view of the ATLAS ID showing all three subdetectors.

Closest to the beamline is the pixel detector. Three silicon pixel layers in the barrel and each endcap provide a total of 80 million channels with pixel size 50x400 μm. These give very precise information about particle trajectories, and are also used to determine the position of the primary vertex from the proton-proton collision. The Semi-Conductor Tracker (SCT) consists of silicon strips over 4 barrel and 2x9 endcap layers. Each layer is formed from two back to back strips with a 40 mrad stereo angle, allowing a 3d measurement to be recorded. Finally, the Transition Radiation Tracker (TRT) is made up of gaseous straw tube detectors interleaved with transition radiation material. Since a charged particle will leave O(30) TRT hits, this provides many extra hits for use in track reconstruction. Additionally, the transition radiation is used to distinguish between electron and pion tracks.

III. The ATLAS High Level Trigger

The ATLAS trigger is expected to reduce the design bunch crossing rate of 40 MHz to O(200 Hz) by selecting events containing interesting physics signatures. A schematic diagram is shown in figure 2. At Level 1 (L1), custom built electronics reduce the event rate to a maximum of 75 kHz. The ID information is not used, as the 2.5 μs latency is too short to access the data. The L1 selects Regions of Interest (RoIs) based only on coarse granularity muon and calorimeter information.

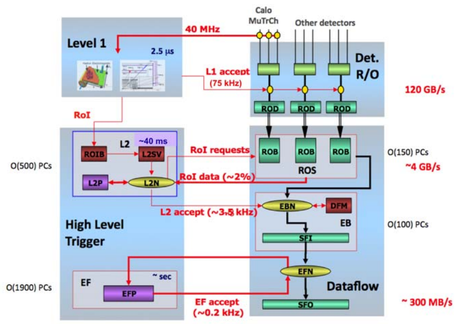


Fig. 2. Schematic view of the ATLAS trigger system.

The software based HLT consists of Level 2 (L2) and the Event Filter (EF). L2 is seeded by the L1 RoIs and can access the full ID information within these regions. The average processing time is 40 ms and the event rate is reduced to O(3 kHz). The EF further reduces the rate to O(200 Hz) using algorithms from the full offline reconstruction that are adapted for use in the HLT. Each event takes around 4 s to process.

IV. Cosmic Track reconstruction in the HLT

Track reconstruction in the HLT is based on silicon hits from the pixel and SCT detectors, plus TRT hits. At L2 there are two silicon based algorithms, IDSCAN and SiTrack, which use 3d space points created from silicon hits. Space point formation from pixel hits is trivial, since the pixel position provides a 3d measurement. In the SCT, the 3d measurement is made possible by the stereo angle between back to back strips. An additional algorithm, TRTSegmentFinder, performs track finding based on the TRT hits. These three algorithms are described in detail in [3].

The EF shares code used in the full offline event reconstruction. However, some adaptations of the offline code reduce processing time, allowing each event to be processed within the time constraints of the HLT. For example, RoIs can be used rather than processing the full event information, and different cuts can be applied to track parameters. The main tracking mode used is referred to as 'inside-out' tracking and has a modular structure as shown in figure 3. More detail can be found in [4].

The track reconstruction used for cosmic ray events is based on collision tracking. However, modifications

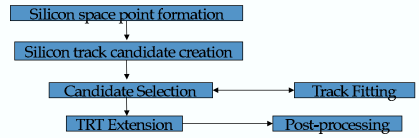


Fig. 3. The modular structure of the inside-out tracking used in the EF.

are required to allow tracks to be reconstructed far from the nominal interaction point, since the cosmic rays are distributed across the whole of the detector. For comic data taking, a complimentary TRT-only tracking method was also employed. However, these events were not considered in this study since we aim to understand the performance of the HLT tracking in a collision-like scenario where the inside-out tracking is most relevant. From this point onwards, all tracks considered can be assumed to be from the inside-out tracking and are referred to as InDet tracks.

V. Visualisation of Cosmic Ray events in the HLT

This work considers runs where the pixel, SCT and TRT detectors were all operational. Both solenoid on and off configurations were used. The cosmic events considered in these tracking studies were triggered by either the TRTFast-OR trigger (a dedicated L1 cosmic trigger based on the TRT detector) or by an ID track found at L2. The EF was run online, in order to assess its performance, however we rely on the TRTFast-OR and L2 to trigger the events.

Figures 4 and 5 show the track reconstructed in the Inner Detector due to a high p_{T} and a low p_{T} cosmic event, respectively. The position of the pixel detector is shown in turquoise, the SCT in light blue, and the TRT in purple. The fitted track is shown in orange. The SCT hits are shown as short orange stripes if they are associated with the track, or yellow otherwise. The central grey ring is a surface on which to display the barrel TRT hits, since the TRT barrel does not make a measurement of the z (longitudinal) co-ordinate. Similarly, the endcap TRT hits are displayed on a cylindrical surface, since the TRT endcap does not measure the radius, r, from the beampipe. TRT hits associated with the track are shown as orange dots. Otherwise, they are shown in white.

VI. Event Filter Track Parameters

Figures 6(a), 6(b), 6(c) and 6(d) show respectively the transverse and longitudinal impact parameters d0 and z0, along with the pseudorapidity η and azimuthal angle ϕ of InDet EF tracks from 100k events recorded with the solenoid field on. The small number of tracks

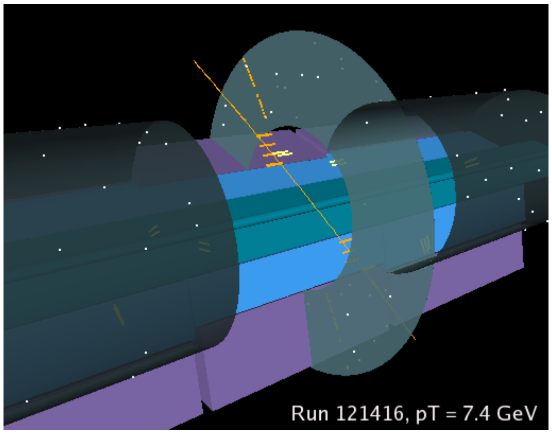


Fig. 4. Visualisation of a cosmic track measured by the Event Filter to have a p_{T} of 7.4 GeV.

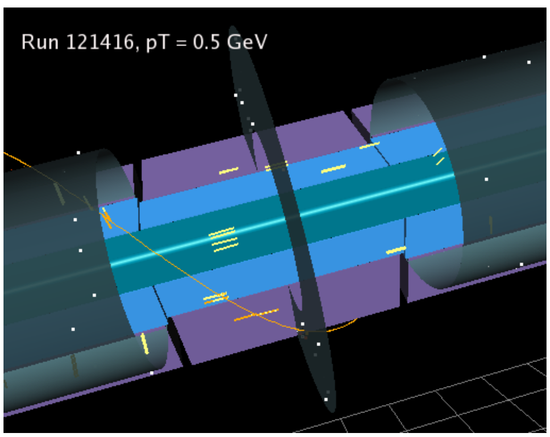


Fig. 5. Visualisation of a cosmic track measured by the Event Filter to have a p_{T} of 0.5 GeV.

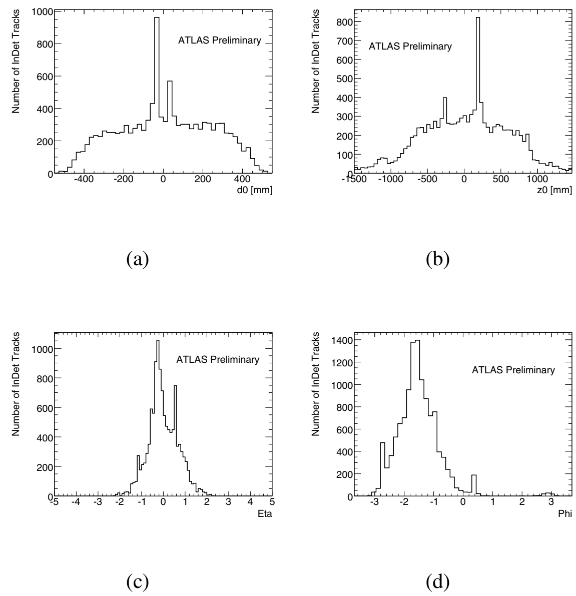


Fig. 6. The track parameters a) d0, b) z0, c) eta and d) phi of all EF tracks in 100k events of the run 121416.

with positive ϕ originate from events where the EF fits two halves of the cosmic track separately. The two sharp peaks seen, for example, in the distributions of figure 6(a) are thought to be due to noisy modules. They also appear in the other parameter distributions, but are not seen in all runs, or in the offline reconstruction. Since the inside-out track reconstruction in the offline has tighter selection critera than in the EF (for example requiring at least 8 silicon hits on the track, compared with 6 in the EF) it is likely that these peaks originate from tracks in noisy regions of the detector.

VII. Event Filter Tracking Efficiencies

The cosmic tracks reconstructed by the offline were used as a baseline to measure the reconstruction efficiency for EF tracks. All InDet offline and EF tracks were selected. A set of loose, medium and tight quality cuts were then applied to the offline tracks. These cuts are shown in table I. Each offline track was associated with the closest EF track in δ R, where δ R is given by:

$$\delta\ R = \sqrt{(\eta_{offline} - \eta_{EF})^2 + (\phi_{offline} - \phi_{EF})^2}. \quad (1)$$

One to one mapping was required between the EF and offline tracks. The efficiency was measured per track and calculated separately for each track selection category. The efficiency is given by

$$\epsilon = \frac{N_{EF}}{N_{offline}} \quad (2)$$

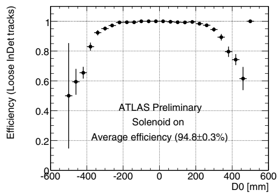
and the uncertainty is given by:

$$\sigma_\epsilon = \sqrt{\frac{N_{EF}}{N_{offline}} \cdot \left(1 - \frac{N_{EF}}{N_{offline}}\right) / N_{offline}}. \quad (3)$$

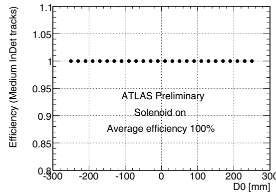
Figures 7(a), 7(b) and 7(c) show the tracking efficiency as a function of d0 for 100k events of the solenoid on run 121416. Figures 8(a), 8(b) and 8(c) show the tracking efficiency as a function of d0 for 100k events of the solenoid off run 122189. Table II summarises these efficiencies. For comparison, shown in table II are the efficiencies for two other runs from this data taking period. The measured efficiencies appear to be consistent between runs.

VIII. Summary

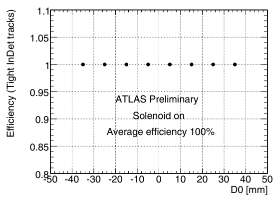
During June and July 2009, over 90 million cosmic ray events were recorded by ATLAS. This provided



(a)

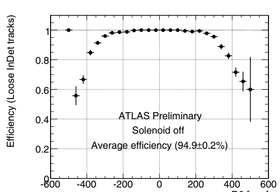


(b)

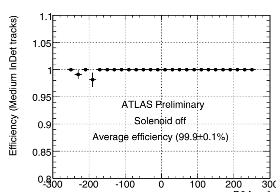


(c)

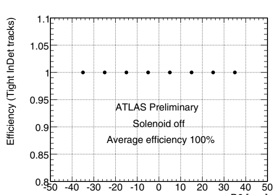
Fig. 7. Track efficiencies for a) loose, b) medium and c) tight InDet tracks using run 121416. The average efficiencies are 94.8 % for loose tracks (based on 5.2k offline tracks), 100 % for medium tracks (1.7k offline tracks) and 100 % for tight tracks (120 offline tracks).



(a)



(b)



(c)

Fig. 8. Track efficiencies for a) loose, b) medium and c) tight InDet tracks using run 122189. The average efficiencies are 94.9 % for loose tracks (based on 8.4k offline tracks), 99.9 % for medium tracks (2.7k offline tracks) and 100 % for tight tracks (200 offline tracks).

Track category	Cut
Loose	$\geq$8 barrel Si hits OR $\geq$30 barrel TRT hits $\lvert d0\rvert < 500$ mm $pT > 1$ GeV -10 ns $<$ TRTEventPhase $<$ 40 ns
Medium	$\geq$10 barrel Si hits $\geq$20 barrel TRT hits $\lvert d0\rvert < 250$ mm $pT > 1$ GeV -5 ns $<$ TRTEventPhase $<$ 30 ns
Tight	$\geq$4 barrel pixel hits $\geq$12 barrel SCT hits $\geq$50 barrel TRT hits $\lvert d0\rvert < 40$ mm $pT > 1$ GeV -5 ns $<$ TRTEventPhase $<$ 30 ns

TABLE I
CLASSIFICATIONS FOR OFFLINE TRACKS. THE NUMBER OF SI HITS IS DEFINED AS $2\times$N PIXEL HITS+NSCT HITS. THE TRTEVENTPHASE IS THE TIMING OF THE COSMIC TRACK AS MEASURED BY THE TRT DETECTOR. FOR A LARGE TRTEVENTPHASE, THE TRIGGER WAS FIRED EARLY AND THE TRT READOUT WINDOW MAY HAVE MISSED EITHER SOME FRACTION OF THE HITS, OR THE WHOLE EVENT.

Run	Field Status	Eff Loose	Eff Medium	Eff Tight
121416	On	94.8$\pm$0.3	100	100
121630	On	94.4$\pm$0.3	99.9$\pm$0.1	100
122129	Off	95.2$\pm$0.2	99.9$\pm$0.1	100
122189	Off	94.9$\pm$0.2	99.9$\pm$0.1	100

TABLE II
THE PERCENTAGE EFFICIENCY TO RECONSTRUCT EF INDET TRACKS IN EACH OFFLINE TRACK CATEGORY, OVER A SELECTION OF RUNS FROM THE JUNE 2009 COSMIC DATA TAKING PERIOD.

a valuable opportunity to test the detector and trigger systems before collisions arrive at the end of 2009. Inner Detector tracks were successfully reconstructed in the High Level Trigger. The Event Filter track parameters have been shown for a solenoid on configuration, and are well-understood. The efficiency to reconstruct Event Filter tracks has been measured with respect to the full offline reconstruction and is consistent between runs. In a collisions scenario, tracks will have a transverse impact parameter d0 close to zero. In this limit, the performance of the Event Filter and offline reconstruction is almost identical.

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