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The new ATLAS triggers for long-lived particles that leave unconventional signatures in the tracking detectors

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The Large Hadron Collider (LHC) provides unique opportunities to directly search for new physics Beyond the Standard Model (BSM). Long-lived particles (LLPs) with large masses, which are absent in the Standard Model, can occur in many theories of physics BSM. These new massive LLPs can decay into other particles away from the LHC collision point, resulting in unusual experimental signatures and hence requiring customized and complex experimental techniques to identify them. Previously, the ATLAS experiment did not have dedicated triggers to explicitly identify massive LLPs decaying in the inner tracking detectors using tracking information. To enhance the sensitivity of searches, a series of new triggers customized for various unconventional tracking signatures, such as "displaced" tracks and short tracks which "disappear" within the tracking detector, have been developed and will be utilized in the upcoming Run-3 data taking starting from 2022. The development of these triggers and their expected performance will be presented.

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1. Introduction

Long-lived particles are predicted by many Beyond the Standard Model theories (BSM). Such particles will decay at a position displaced from the collision point, in the transverse plane. The ATLAS detector was designed to identify prompt particles. Long-lived particles therefore require specialised approaches to enable searches. For Run 3 several new dedicated triggers have been developed for ATLAS which aim to increase the sensitivity to a variety of BSM processes particularly those including long-lived particles.

The ATLAS Inner Detector (ID) is made up of several sub-detectors [1]. The Pixel detector surrounds the interaction point, the Semiconductor tracker (SCT) surrounds the Pixel detector. Both the Pixel and SCT detectors consist of silicon modules and provide precision tracking. Finally the TRT detector which surrounds the SCT and consists of gas filled straws is used to provide additional measurements on each track. The entire ID is located inside a 2 Tesla magnetic field to enable momentum measurement.

The trigger system [2] [3] consists of 2 levels, a custom electronic system called Level 1 (L1) and the High Level Trigger (HLT) which is software based. The Level 1 trigger uses information from the Muon and Calorimeter systems to produce a fast decision with a rate of accepted events of up to 100 kHz. The HLT has access to the full readout of the detector and a full reconstruction of the event is performed. Events are saved to permanent storage following a HLT accept with a rate of approximately 1 kHz. Some algorithms run at the HLT consider only part of the detector known as a Region of Interest (RoI) defined as a region of detector surrounding an object of interest, which can be defined using information from the L1 system or from another HLT algorithm.

2. Large Radius Tracking

Track reconstruction in the trigger in Run 2 was limited to prompt particles as it only reconstructed tracks with low d_0 (transverse impact parameter with respect to the beam spot), preventing tracking of particles from displaced decays such as those associated with long-lived particles. The standard tracking in the trigger is performed using a fast trigger specific algorithm, the Fast Track Finder (FTF), and subsequently using a more precise offline like reconstruction algorithm. The FTF first converts hits from the ID into a seed of two hits. This seed is then extended to a triplet and then propagated through the full ID volume by combinatorial track following [4] [5] [6]. Large Radius Tracking (LRT) is a modified version of the FTF algorithm with several modifications including an increased maximum seed d_0, from 10 mm to 300 mm [7].

Tracking can be run in both Fullscan and RoI modes. When run in Fullscan mode the whole of the ID is considered. The Fullscan implementation of LRT includes an optimisation, hits which have already been used to form tracks using the standard tracking algorithm are ignored by LRT ensuring that hits are not shared between tracks. In RoI mode only a subset of the ID is considered.

Several new triggers for electrons and muons have been created using LRT tracking. This significantly increases the sensitivity to leptons with large production radii, this can be seen in Figure 1. These triggers will improve the sensitivity of searches for displaced leptons.

In addition to the RoI based tracking, the performance of Fullscan tracking has been evaluated. Although the CPU costs of Fullscan LRT prevent its use online, it can be used to perform a

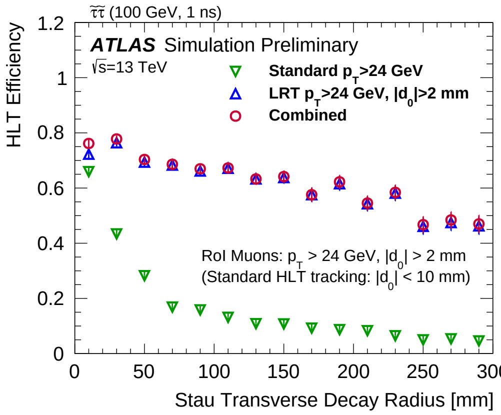

Figure 1: The efficiency for track reconstruction in a sample of supersymmetric staus with a mass of 100 GeV and lifetime of 1 ns. The addition of LRT (blue upward pointing triangles) significantly increases the efficiency of reconstruction for tracks with large production radii, compared to the standard tracking (green downward pointing triangles). The combination efficiency (red circles) is dominated by LRT [8].

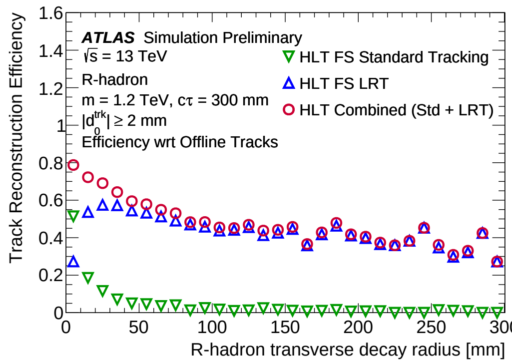

Figure 2: The efficiency of LRT for the decay products of a 1.2 TeV R-hadron as a function of the truth transverse decay radius of the R-hadron with respect to offline tracks which have been matched to charged truth particles with $|\eta| < 2.5$, $p_T \geq 1$ GeV and $|d_0^{\mathrm{trk}}| \geq 2$ mm. A significant gain in efficiency can be seen by comparing the LRT (blue upwards pointing triangles) to the Standard Tracking (green downwards pointing triangles). The combined efficiency (red circles) is dominated by LRT [8].

generic assessment of the performance, as well as facilitating the development of future triggers utilising LRT. The performance of Fullscan LRT is shown in Figure 2. The CPU cost of the LRT reconstruction can be seen in Figure 3, which shows the relative runtime of LRT compared to standard tracking for both RoI and Fullscan applications. The fullscan LRT takes on average 1.71 times longer than standard tracking, due to additional seeds. The RoI LRT runtime is on average 0.36 times that of standard tracking, this is due to fewer seeds being created.

3. Disappearing track trigger

Some BSM theories predict new charged particles which can decay into neutral particles, for example the chargino can decay into a neutralino and a pion [9]. If the chargino decays inside the

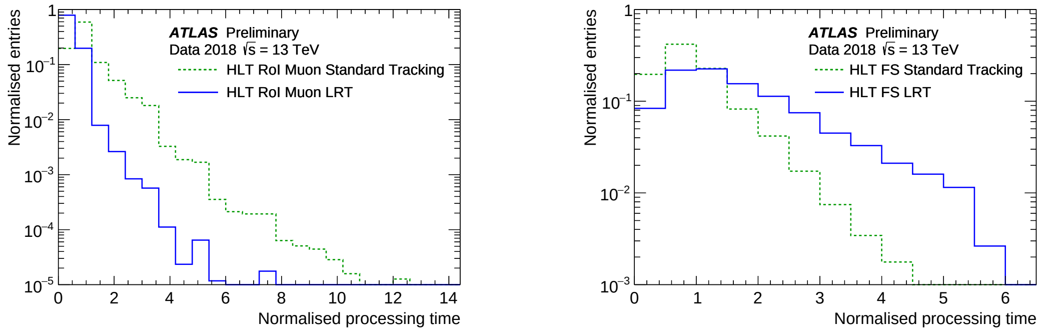

Figure 3: The processing times for the tracking algorithms normalised to the mean of the standard track algorithm's time [10].

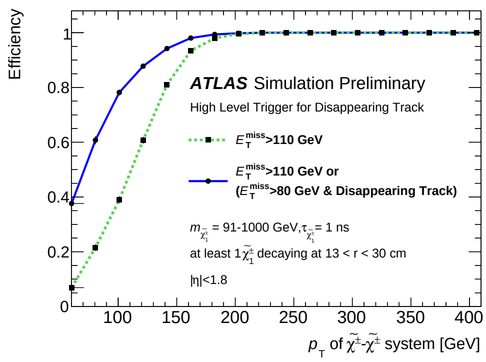

Figure 4: The efficiency of the disappearing track trigger for a chargino pair system as a function of transverse momentum. The disappearing track trigger shown as the solid blue line has a lower E_T^{miss} threshold of 80 GeV compared to the standard trigger with a threshold of 110 GeV [11].

pixel detector, no further hits will be produced in the SCT as the neutralino has no charge. This results in a track which vanishes partway through the ID.

The disappearing track trigger [11] aims to find such tracks by using a modified version of the FTF which reconstructs tracks from seeds which would normally be rejected due to the low number of hits. The extra tracks created are passed to a set of Boosted Decision Trees (BDTs) based on the hit content, to reduce the number of fake tracks. These BDTs have been trained using an MC sample of chargino production as signal and Run 2 data as background.

The trigger is based on an existing missing E_T (MET) trigger, which is then extended to include the disappearing track selection, allowing the MET cut to be lowered without significantly increasing the overall rate of the trigger. The gain in efficiency at low MET can be seen in Figure 4.

4. Conclusion

The ATLAS trigger system has been improved for Run 3, including the addition of several new dedicated triggers for unconventional signatures in the Inner Detector, including LRT based triggers and the trigger for disappearing tracks, such signatures are associated with a variety of long-lived particles decays. These triggers will increase the sensitivity of searches for BSM physics.

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