# TRACK-BASED TRIGGERS FOR EXOTIC SIGNATURES

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**ABSTRACT**

A study of track-based triggers for long-lived particles and unconventional exotic signatures is proposed. The study will assess efficiency as a function of the baseline parameters of a track trigger at future experiments to allow maximum sensitivity across a range of representative signatures.

## 1 Introduction

Many models of new physics predict unconventional track signatures at high energy colliders. For example, long-lived particles have a proper lifetime such that they travel a measurable distance before decaying, resulting in displaced, or anomalous prompt track signatures [1]. Another scenario of interest includes models with a strongly coupled hidden valley, which can result in large multiplicities of soft charged particles [2]. These unconventional signatures pose challenges for offline and trigger level data reconstruction.

Most BSM scenarios lead to jets, photons, or leptons originating from the collision point. These prompt signatures are easily identified in the first, hardware-based, stage of the trigger using a combination of calorimeter and muon spectrometer signals. Limited tracking information is only available at later stages in the trigger decision. This strategy is also sufficient to identify signatures characterised by high missing transverse momentum.

Unfortunately, standard triggers often result in low trigger efficiency for unconventional BSM signatures. If the BSM particle decays at a distance and produces jets or leptons, the decay products will not point back to the collision. Decay products can be mis-identified as pile-up or not identified at all if they do not pass standard quality criteria. If the particle travels a long distance before decaying, its interactions with the detector may look unlike those of a Standard Model particle and a trigger will not identify it. Models with many soft charged particles often do not lead to an easily identifiable calorimeter or muon spectrometer signature.

When searching for these unconventional signatures, the most distinctive feature(s) of the BSM event will be tracks. If track triggers can be developed that are fast enough to use on entire events at a high rate, they will provide a unique opportunity for triggering on these challenging signatures.

## 2 Current state of track triggering

The ability to use tracking in triggering decisions is limited by several factors. In ATLAS and CMS, tracking has only been used in the high-level trigger (HLT). In these cases, the tracking is performed in software, and its main limitation is the amount of CPU required to form tracks given the HLT latency. Because of this, fast algorithms are used, which typically cover only small regions of the detectors, which are chosen based on signatures from calorimeter or muon systems. A tracker functioning in the level 1 trigger (L1) would need to be implemented in hardware, and would be further limited by detector readout rates, the hardware-based tracking technology used, and output rate and latency constraints of the L1 system.

For the HL-LHC, both ATLAS and CMS plan to introduce hardware-based trackers to be used in their trigger systems [3][4]. This opens up the possibility of using tracks at the L1 stage, meaning that for the first time, these experiments could trigger based on track signatures alone. Though it requires additional effort, extending these hardware trackers to include a range of non-prompt tracks is not impossible. This was explored by the Fast TracKer (FTK) system on ATLAS, where it was shown that a $d_0$ range of up to a centimeter could be targeted with small changes in the software configuration only [5].

The possible coverage of a tracker depends on specific tracking algorithms. In general, increasing the maximum curvature, displacement, or target efficiency of a tracker increases complexity, rate, latency, or a combination of these. Put another way, in order to maintain a constant latency but extend its $d_0$ range, a tracker could increase its $p_T$ threshold or decrease its target efficiency. Depending on the tracker design, it may be possible to alter these requirements independently for prompt and displaced tracks, leaving a highly efficient prompt tracker with a low $p_T$ threshold, while also exploring a large range of displacements.

## 3 Expanding track triggering for future experiments

There has been a recent proliferation of studies on the efficacy of track-based triggers for long-lived particles and other exotic signatures, including rare Higgs decays [6], SUEPs [2], and generic displaced signatures [7]. However, because the signatures of these models are so varied, it is challenging to translate these individual studies into an optimal design for a future trigger. In particular, for a realistic rate- and latency-limited trigger, it is unclear which efficiency trade-offs are most beneficial: is it better to expand $d_0$ coverage, reduce $p_T$ thresholds, or maximize overall tracking efficiency?

The answer to this question depends on the design of the trigger being considered, but it also depends on what kind of exotic signatures are being targeted. For hadronic decays, low $p_T$ thresholds are important, but high efficiency may not be needed. For leptonic decays the reverse is true.

The goal of this study is to provide a parameterization of trigger efficiencies for a variety of representative models, to be used as a guide for future trigger design. Specific tracking algorithms will not be discussed, but instead overall efficiency will be provided for a range of models as a function of several basic tracker coverage parameters.

## 4 Details of proposed study

The study will consider three possible triggering strategies: conventional prompt track reconstruction, displaced (high-$d_0$) tracking, and unassociated hit counting.

A selection of models will be chosen to span a wide range of signature types. The following signatures will be considered:

**Displaced leptons**
: Characterised by low track multiplicity, high $p_T$, and high $d_0$. Probable model: RPV SUSY

**Displaced vertex + jets**
: Moderately high $p_T$ and high $d_0$ tracks originating from a displaced vertex. Probable model: RPV SUSY

**Stable charged particles**
: Signature is one or two high $p_T$ isolated tracks. No displacement, but additional special track properties like time of flight and high ionisation energy can be exploited. Probable model: RPV SUSY

**SUEPs**
: High multiplicity of low $p_T$ tracks. Good candidate for trigger based on hit counting. Probable model: Scalar production and decay to prompt charged particles.

The parameters to be considered in the optimisation are the minimum track $p_T$, the maximum track $d_0$, the tracker radius, and possibly the distribution of tracker layers. In addition, different track-level efficiency scenarios will be explored. The metric by which to compare parameter choices will be event-level efficiency.

## References

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