Search for new physics with long-lived particles

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Abstract. Various models of new physics, including hidden valley models and some supersymmetric models, predict the existence of long-lived particles decaying a significant distance from the interaction point, or leaving the detector undecayed. We present ATLAS strategies to improve triggering and reconstruction of these events, and discuss prospects for searches in early LHC data.

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INTRODUCTION

Some new physics models predict long-lived neutral particles which travel a significant distance before decaying [1]-[7]. Among these are Hidden Valley (HV) Scenarios, extensions of the Standard Model which append a new weakly coupled sector. Finding such signatures at the LHC will require new strategies which can capitalize on these unique signatures. This note will highlight work done improving triggering and reconstruction at ATLAS for events producing Hidden Valley particles through Higgs decays [8].

HIDDEN VALLEY SCENARIO

Beyond the Standard Model is a hidden sector (or v-sector) and a communicator which interacts with both sectors [9]. A barrier due to the communicator’s high mass or due to weak couplings between the sectors makes production of v-particles rare at low energies, but production of v-particles may be observable at LHC energies. Some v-particles may be stable (dark matter candidates) and others may decay to Standard Model particles within the ATLAS detector.

The studies in this note use events simulated using PYTHIA [10] in the following HV Scenario: neutral, pseudo-scalar v-pions are produced via Higgs decays and decay mainly to bottom quarks within the ATLAS detector but a significant distance from the interaction point. Two different samples are used to study trigger strategies for this process, an ideal sample containing signal only, and a sample containing both the signal and background caused by multiple interactions or interactions from multiple beam crossings which is simulated with a luminosity of $10^{32}$ cm$^{-2}$s$^{-1}$, 4.1 collisions/crossing, and a bunch spacing of 450 ns. The model parameters are as follows:

- Higgs Mass = 140 GeV
- v-pion Mass = 40 GeV
- $c\tau$ for v-pion = 1500 mm
The ATLAS trigger consists of three levels which select 200 Hz of events from 40 MHz of raw data from the detector. The Level 1 trigger uses reduced granularity of muon chambers and calorimeter cells to define Regions of Interests (RoI) for $\mu$, electron, $\tau$, and jet candidates. Level 1 RoIs are used to seed the Level 2 trigger which uses the full detector granularity. Track matching is also performed at Level 2. Finally, the Event Filter, the third level of the trigger uses algorithms similar to offline reconstruction code to refine the Level 2 decisions.

**Hidden Valley Challenges**

Neutral states decaying far from the interaction point lead to special challenges in the trigger. Primary ATLAS triggers are intended for particles originating from the interaction point. The invisible long-lived Hidden Valley particles will decay throughout the detector volume and the signature which can be used for triggering will depend on where the decay occurs in ATLAS. Dedicated triggers are needed for the decay signature produced in each system.

**DECAYS WITHIN THE DETECTOR**

The ATLAS detector is described in [11]. For the purposes of this note we will examine the signatures that could be expected from v-pion decays in each of the three major sub-detector groups: the Muon Spectrometer, the Calorimeter, and the Inner Detector(ID). Figure 1 shows the probability for a v-pion to decay in each detector region for $|\eta| < 2.5$ over a range of possible lifetimes.
Muon Spectrometer

The v-pion decays that occur inside the volume of the Muon Spectrometer are characterized by little or no energy deposited in the calorimeters. Additionally, these events contain a large number of charged tracks and a cluster of muon Regions of Interest (RoI). In a standard muon trigger only 1 muon is reconstructed per muon RoI. We have created a new Level 2 trigger algorithm to capitalize on these signatures. At least 3 muon RoIs are required at the Level 1 trigger, but they must be isolated with respect to any jets or ID tracks. The Level 2 trigger defined in this way is > 70% efficient for decays in the barrel Muon Spectrometer, and > 25% efficient in the Spectrometer’s endcap region.

Calorimeter

In the hadronic calorimeter v-pion decays produce very narrow jets and are associated with no reconstructed tracks in the Inner Detector. These events are characterized by large energy deposits in the Hadronic Calorimeter (HCAL) and very little energy deposited in the corresponding region of Electromagnetic Calorimeter (ECAL). Level-1 \( \tau \) triggers which also have a narrow jet shape are used to seed the Level 2 trigger which we define as having \( \log_{10}(E_{HCAL}/E_{ECAL}) > 1 \) and isolation with respect to Inner Detector tracks. This Level 2 trigger is > 60% efficient for decays in the HCAL barrel, and > 25% efficient in the HCAL endcap. Decays occurring in the volume of the ECAL are difficult to trigger on since energy is deposited in both calorimeters and no new strategy has yet been developed.

Inner Detector

Normal tracking algorithms are very inefficient for v-pion decays occurring in the Inner Detector volume. Instead of using tracks we trigger on calorimeter jets containing muons with which no track is associated. Level 1 muon triggers are used to seed a dedicated Level trigger requiring an ECAL jet containing at least 35 GeV \( E_T \) and no reconstructed tracks. This technique gives a low absolute efficiency, about 2%, primarily because of the muon requirement. Studies are ongoing to define a more efficient trigger in the Inner Detector including outside-in tracking techniques, Inner Detector vertex finding, and using jet substructure in the ECAL.

PROSPECTS

New Level 2 triggers have been created to reconstruct long-lived neutral particles decaying in ATLAS leading to an improvement in overall Higgs to Hidden Valley event efficiency from around 2% to >20%. The trigger efficiency for each of the following triggers and the total efficiency for v-pion decays is shown in Figure 2:

- Cluster of Muon objects isolated from tracks and jets (uses L1 di-\( \mu \) trigger)
Two studies have been performed to estimate trigger backgrounds for $v$-pion decays. One study examined a sample of 10 TeV di-jet events at a luminosity of $10^{32}$ cm$^{-2}$s$^{-1}$. A cumulative rate of less than 1 Hz was found for all three Level 2 triggers. A second study examined 3 million ATLAS minimum bias events, none of which passed any of the $v$-pion triggers.

In conclusion, the capability of ATLAS to trigger on decays of long-lived neutral particles found in several models of physics has been improved by an order of magnitude. We also expect ongoing work on detecting decay signatures in the Inner Detector and refining Event Filter trigger selection to contribute further improvements.

REFERENCES

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