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Search for New Physics with Long-Lived Neutral Particles in ATLAS: The Hidden Valley Scenario

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With the start of the Large Hadron Collider a new energy frontier will be accessible to experimental particle physics, and many new models and extensions to the Standard Model will be tested. A unique class of these new models are those in which long-lived particles can decay mid-detector, leaving atypical signatures that are often missed by standard LHC-detector triggers. Such models include the Hidden Valley models and some supersymmetric models. Prospects for triggering-on and detecting long-lived neutral particles in the ATLAS detector are presented.

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1. Long-lived neutral particles in ATLAS

Long-lived particles that can decay mid-detector are predicted by a large class of theoretical models, including The Hidden Valley (HV) scenario and some supersymmetric models. The decays of long-lived neutral particles (LLNP) produce unique signatures, and because large cross sections are not excluded in many models, they present a potential for early discoveries. They also present significant experimental challenges, in particular triggering on atypical topologies involving highly non-pointing tracks, tracks not connected back to the interaction point, trackless jets, and jets with an abnormal ratio of electromagnetic to hadronic calorimetric energy deposition.

Hidden Valley models are a general class of models that can give rise to LLNP, and serve as an excellent setting for exploring the challenges to the trigger (and to analyses) posed by the peculiar decay topologies, and for designing new strategies to maximize the discovery potential. It will also be important to explore the challenges and opportunities presented by the significant impact a Hidden Valley can have on supersymmetric phenomenology. In this paper we focus on the problematic signature: very displaced jets with (relatively) low p_T, and low missing energy.

2. The Hidden Valley Scenario

In the Hidden Valley Scenario [1], a hidden sector, the v-sector, is appended to the Standard Model (SM). All particles in the v-sector (v-particles) are neutral under the SM, but a communicator (the Higgs, a Z', or a neutralino, for example) interacts with both sectors. A barrier, such as the communicator's high mass, and/or weak couplings, makes production of v-particles rare at low energies, but possibly large at LHC energies. The lightest v-particles are v-pions (π_v) that can be stable (dark matter candidates) or can decay (through the communicator) back to the SM with long lifetimes. Hadronization in the v-sector can result in high-multiplicity π_v final states, with the pseudoscalar π_v^0s decaying primarily to heavy fermion pairs.

The branching ratio of a light Higgs communicator to v-particles can be close to 100%, and therefore tagging LLNPs could be necessary for a Higgs discovery. Similarly, the existence of a hidden valley sector might have a profound impact on supersymmetric phenomenology [2]. If the LSP lies in the valley sector (LSvP), the lightest SM superpartner (LSsP) may be unstable, decaying to the v-sector through the communicator, providing a tagging signal not present in ordinary SUSY events. In these scenarios, both LSsP and π_v^0 lifetimes are largely unconstrained, and standard SUSY missing energy signals may be greatly reduced. It is therefore possible that triggering on the decay of LLNP can provide a profitable handle in SUSY discovery searches.

3. Trigger for long-lived neutral particles in ATLAS

We have studied the Hidden Valley model Higgs decay $h^0 \to \pi_v^0 \pi_v^0$ as a benchmark channel for a LLNP signal [3]. In this model a 140 GeV Higgs decays to two 40 GeV π_v^0 which have displaced decays to bottom quark pairs. The π_v^0s are given a lifetime $c\tau = 1.5m$ so that approximately 40% of the π_v^0 decay in the Inner Detector, 48% decay in the Calorimeter, and 12% decay in the Muon Spectrometer. The standard ATLAS triggers select only a small fraction of these unique events. However, the displaced decay signature can be used as a trigger object in order to increase the

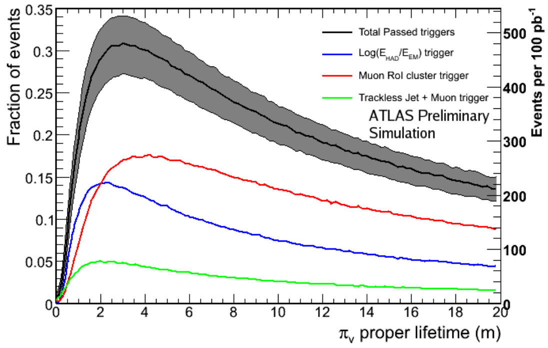

Figure 1: $h^0 \to \pi_v^0 \pi_v^0$ events accepted by our long-lived particle triggers vs the π_v^0 lifetime. Left axis: fraction of events accepted. Right axis: number of events for an integrated luminosity of $100 pb^{-1}$ assuming Br($h^0 \to \pi_v^0 \pi_v^0$) = 100%. A 140 GeV mass for the h_0 and 40 GeV for the π_v^0 have been assumed, at 10 TeV cm energy. The shaded band represents the statistical error of the result.

fraction of events accepted. We consider three detector regions and illustrate signature driven triggers that can be used to preferentially select the Hidden Valley events:

1) Decays in the Muon Spectrometer (MS) produce a large number of charged hadrons in a small (η,ϕ) region, resulting in many clustered muon level 1 trigger objects (Regions of Interest (RoI)) accompanied by a lack of activity in the Inner Detector (ID) and Calorimeters. These events are rejected by the current ATLAS High Level Trigger (HLT) trigger which requires a matching ID track for the level 1 trigger muons. However, the cluster of RoIs can be used as HLT trigger to select these HV events decaying in the MS with an efficiency of ~70% (~25%) in the barrel (endcap) and with minimal SM backgrounds.

2) Decays occurring inside the Hadronic Calorimeter (HCal) are characterized by jets with few/no tracks in the ID and little energy deposited in the EM Calorimeter (ECal). This leads to jets with more energy deposited in the HCal than in the ECal. The logarithm of the hadronic to electromagnetic energy ratio for these decays changes from a characteristic negative for SM jets to a positive value with no expected activity in the ID. This jet characteristic has been used to build a HLT object selecting decays in the barrel (endcap) HCal with an efficiency of ~60% (~30%).

3) Decays in the outer ID lead to jets with no connecting track to the IP (trackless jets). The QCD background can be significantly reduced by requiring that the trackless jet contain at least a muon from semileptonic decays of the b quark in the jet cone. A trackless jet with a muon in the jet cone is the trigger object (~2% efficient in the outer ID).

4) Decays in the Beam Pipe or in the innermost ID should be found by the b-tagging algorithms with good efficiency and new triggers are not needed.

We have implemented in the ATLAS simulation package the three new signature-based triggers [3]. Figure 1 shows the expected fraction of detected events vs the π_v^0 lifetime. We expect a significant fraction of events in a wide range of lifetimes. Applying these trigger objects on simulated di-jet samples results in a negligible trigger rate. Nevertheless, trigger background from Standard Model QCD processes will need to be better understood with real data. Trigger studies involving Hidden Valley models in the presence of Supersymmetry are under way.

References

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