Search for new physics with long-lived particles

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Introduction

- Various models of new physics predict long-lived particles which travel a significant distance from the interaction point before decaying
- Strategies capitalizing on the unique signatures improve triggering and reconstruction for such events at ATLAS
- This talk will focus on Hidden Valley particles produced through Higgs decays

Outline

- Hidden Valley Scenario
- Experimental Challenges
- ATLAS Trigger
- Decays within the Detector
 - Muon Spectrometer
 - Calorimeter
 - Inner Detector
- Status and Plans

Hidden Valley[†] Scenarios

- Beyond the Standard Model is a hidden sector (or v-sector) and a communicator interacts with both sectors
- A barrier “hides” the v-sector making production of v-particles rare at low energies
 - Communicator’s high mass
 - Weak couplings....
- Production of v-particles may be observable at the LHC
- Some v-particles may be stable (dark matter candidates) and others decay to Standard Model particles

[†]see:

M. Strassler, K. Zurek Echoes of a Hidden Valley at Hadron Colliders, Phys. Lett. B651 (2007) 374-379

Arkani-Hamed, et al. LHC signals for a SuperUnified Theory of Dark Matter, arXiv:0810.0713

Hidden Valley & Higgs Decays

Higgs decay to v-pions

see also:

- M. Strassler & K. Zurek, Phys Lett B 661 (2008) 263-267
- S. Chang et al. arXiv:hep-ph/0511250
- L. Carpenter et al. arXiv:hep-ph/0607204

- V-pion is neutral pseudo-scalar
 - Displaced decay mainly to bottom quark
- We use 2 samples to study trigger strategies for this process:
 - Ideal sample (signal only)
 - Signal with pileup
 - pileup for $L=10^{32} \text{ cm}^{-2} \text{ s}^{-1}$
 - 4.1 collisions/crossing
 - 450ns bunch spacing
- Parameters:
 - Higgs Mass = 140 GeV
 - π_v Mass = 40 GeV
 - $\pi_v c\tau = 1500 \text{ mm}$
- Events simulated using PYTHIA
- Work in collaboration with M. Strassler

Experimental Challenges

- Neutral states decaying far from the interaction point lead to challenges for the trigger
 - Current ATLAS triggers center on particles originating from the Interaction Point
- Long-lived Hidden Valley particles will decay throughout the detector volume
 - Depending on where the decay occurs different approaches are required
- We need special triggers for each the signature produced in each system

ATLAS Trigger

Raw Data from detector
40 MHz

Level 1 (hardware):

Uses Calo cells and Muon chambers with reduced granularity.
 e/γ , μ , τ , jet candidates
Defines Regions of Interest (RoI)

75 kHz

High Level Trigger (HLT)

Level 2 O(500PCs):

Seeded by LVL1 RoI
Full granularity of the detector
Performs calo-track matching

1-2 kHz

Event Filter O(1900PCs):

Offline-like algorithms
Refines LVL2 decision
Full event building

Full Event to tape
100-200 Hz

$2\mu\text{s}$

10ms

1s

Execution Time

Decays within ATLAS Detector

Probability for π_0 from gg fusion to decay in each detector region vs $c\tau$ for $|\eta| < 2.5$ (Inner Detector coverage)

Decays in Muon Spectrometer

- Little or no energy deposited in the calorimeter
- Characterized by a large number of charged tracks and a cluster of muon Regions of Interest (Rols)
- Only 1 muon reconstructed per muon Rol with standard trigger

Decays in Muon Spectrometer

- Define a new Level 2 trigger algorithm using these signatures as:
 - At least 3 muon Regions of Interest at Level 1
 - Isolation wrt jets and Inner Detector tracks
- >70% Efficient for decays in the barrel Muon Spectrometer
- >25% in the endcap region

Decays in the Hadronic Calorimeter

- Decays in the calorimeter produce very narrow jets
- No reconstructed tracks in the Inner Detector
- Large energy deposited in the Hadronic Calorimeter (HCAL)
- Little energy in the Electromagnetic Calorimeter (ECAL)

Decays in the Hadronic Calorimeter

- Narrow jet shape allows of use a Level-1 τ trigger to select these decays
- We define a Level 2 trigger using these signatures as:
 - $\text{Log}10(E_{\text{HCAL}}/E_{\text{ECAL}}) > 1$
 - Isolation wrt Inner Detector tracks

Decays in the Inner Detector

- Decays in the Inner Detector:
 - low efficiency for normal tracking algorithms
 - Trigger on trackless jets containing muons
- Level 2 jet trigger
 - $E_T \geq 35 \text{ GeV}$ in Electromagnetic Calorimeter (ECAL)
 - no reconstructed tracks
 - Seed with Level 1 muon
- Absolute efficiency $\sim 2\%$ (due to requiring the muon in the event)
- Studies ongoing to define a more efficient trigger in the Inner Detector
 - Backtracking and vertex finding in ID
 - jet substructure in the ECAL

Status of Improvements

- New L2Trigger Algorithms
 - Cluster of Muon objects isolated from tracks and jets
 - LI dimuon trigger
 - Narrow trackless jets with high hadronic/EM Energy
 - LI tau trigger
 - Trackless EM jet with a muon
 - LI muon & LI jet triggers
- Backgrounds
 - None of 3M minbias events pass the triggers
 - Sample of 10 TeV di-jet events at $10^{32}\text{cm}^{-2}\text{s}^{-1}$ have less than 1 Hz combined L2 trigger rates

Related Searches

- Ongoing work using similar strategies for neutral long-lived particles decaying to lepton jets (Weiner et al., Lin-Tao et al.)
- Trigger and reconstruction improvements for charged stable massive particles in each part of ATLAS
 - Muon system (see talk by Shlomit Tarem)
 - Calorimeters (see talk by Philippe Mermod)
 - Ongoing work on Inner Detector

Conclusions

- New signature-based triggers have been created to reconstruct long-lived neutral particles decaying in ATLAS
 - Improvement in overall Higgs to Hidden Valley event efficiency from $\sim 2\%$ to $>20\%$
- Ongoing work on Inner Detector Decays and Event Filter trigger selection may contribute further improvements
- We are developing strategies to use ATLAS to search for neutral and charged massive long-lived particles in new physics models