TRIGGERING ON LONG LIVED NEUTRAL PARTICLES IN ATLAS

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Outline

- Overview of ATLAS
- Long-lived particles
- Signatures of displaced decays to jets
  - Decays in the Muon Spectrometer
  - Decays in the Calorimeter
  - Decays in the Inner Detector
2T magnetic field

3 Pixel Layers (5cm - 12cm)

4 Silicon Layers (30cm - 51cm)

50cm of Transition Radiation Tracker (TRT) straw tubes (55cm - 110cm)
Electromagnetic Calorimeter (ECAL)
   Lead accordion with liquid argon scintillator

Hadronic Calorimeter (HCAL)
   Iron with plastic scintillator
Three Layers of Drift Tubes
RPC (TGC) trigger chambers in the Barrel (Endcap)
ATLAS trigger system

**Level 1 (hardware):**
- Uses Calo cells and Muon chambers with reduced granularity.
- e/γ, µ, τ, jet candidates
- Defines Regions of Interest (RoI)

**Level 2 O(500PCs):**
- Seeded by LVL1 RoI
- Full granularity of the detector
- Performs calo-track matching

**Event Filter O(1900PCs):**
- Offline-like algorithms
- Refines LVL2 decision
- Full event building

Raw Data from detector

40 MHz

75 kHz

High Level Trigger (HLT)

2µs

10m

1s

Execution Time

Full Event to tape

100-200 Hz
ATLAS Trigger

- **Level 1:**
  - Course granularity of Calorimeter and Muon System
  - No tracking
  - Identifies Region of Interest (RoI) to be processed at Level 2

- **Level 2:**
  - Full granularity inside of the RoI
  - Tracking available, all tracks required to connect to the IP
  - Only 1 track reconstructed per muon RoI
• Many models predict particles that are NEUTRAL and LONG-LIVED

• gauge mediated SUSY, RPV SUSY, inelastic dark matter, split SUSY, hidden valley, exciting dark matter (XDM), Asymmetric Dark Matter (ADM)

• To investigate ATLAS’s ability to detect (and trigger on) long-lived neutral particles, we have simulated a Hidden Valley model
• “Hidden Valley” (HV) models are a general class of these models

• Hidden Valley and SM only communicate through mediator particles (higgs, Z’, neutralino, ...)

• All valley-particles (v-particles) are NEUTRAL under the SM

• The lightest v-particles, “v-pions” (πᵥ’s) are stable in the v-sector, but can decay back to the SM with long lifetimes

† M. Strassler, K. Zurek  Echoes of a Hidden Valley at Hadron Colliders
arXiv:0810.0713
Higgs decay to long-lived particles

- Using benchmark model of Higgs decaying to non-interacting pseudo-scalars\(^\dagger\)\(^\dagger\) \((\pi_v)\)
  - \(\pi_v\) is NEUTRAL under the SM and long-lived

- 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:
  - \(E_{CM} = 10\text{ TeV}\)
  - \(m_h = 140\text{ GeV}\)
  - \(m_{\pi_v} = 40\text{ GeV}\)
  - \(c\tau_{\pi_v} = 1500\text{ mm}\) (arbitrary choice)

- Events simulated using PYTHIA

\(^\dagger\) see: M. Strassler & K. Zurek, Phys Lett B 661 (2008) 263-267
Hidden Valley events are characterized by highly displaced decays leading to jets appearing throughout the volume of ATLAS.

- Probability for $\nu$ from gg fusion to decay in the 4 detector regions vs $c\tau$ for $|\eta| < 2.5$ (Inner Detector coverage)
- Event Signatures are different for each of the regions
  - Inner Detector
  - EM Calorimeter
  - Hadronic Calorimeter
  - End of HCAL to 1$^{st}$ muon trigger plane
• Event with one $\pi_v$ decay in the Muon System (A) and another $\pi_v$ decay in the Hadronic Calorimeter (B)
Standard ATLAS Triggers

- ATLAS Level-2 muon trigger has 2 stages:
  - Stand-Alone tracking (muFast)
  - Matching with an ID track (muComb)

- Jet triggers: Events with Higgs decays to $\pi\nu$'s are characterized by several low $E_T$ jets
  - Low energy jets are rejected by the Level-2 trigger due to large QCD backgrounds
Standard ATLAS Triggers

- Standard ATLAS triggers are Interaction Point (IP) centric
- Neutral states decaying far from the IP lead to many challenges for the trigger:
  - Muons from displaced vertices do not have reconstructed tracks in the inner detector and fail the standard ATLAS level-2 muon trigger
  - Jets from late decays may not have normal energy deposition and could punch through
  - Depending on where the decay occurs (Inner Detector, Calorimeter, Muon Spectrometer), different approaches are required

Need SIGNATURE DRIVEN TRIGGERS
Decays in the muon system are characterized by a large number of charged tracks and a cluster of “muon” RoIs.

- Little/No energy deposited in the calorimeter
Trigger Timing
Decays in the Muon System

- Trigger will be delayed by the arrival time difference, $\Delta t$, between the $\pi_\nu$ and a $\beta=1$ particle.
- From H8 test beam, the window of 100% BCID efficiency is $\Delta t < 6$ ns.
- Probability for the $\pi_\nu$ to be associated with the correct bunch crossing is > 90% for $m_{\pi_\nu} < m_h/3$. 
Decays in the muon system

- Average number of L1 muon RoIs contained in a cone of $\Delta R=0.4$ centered around the $\pi^\nu$ line of flight versus the $\pi^\nu$ radial decay distance.

- For $\pi^\nu$ decays between the Hadronic Calorimeter (4m) and 1$^{\text{st}}$ trigger plane (7m), the event is characterized by greater than 3 L1 muon RoIs in a small ($|\eta|<1$) region.
Decays in the muon system

- We define a Level 2 trigger using these signatures as:
  - A cluster ($\geq 3$) of Level 1 muon RoIs
  - Isolation wrt jets and Inner Detector tracks
Decays in the muon system
Efficiency for Triggering

>70% Efficient for decays in the Barrel Muon Spectrometer

Efficiency is still high (25%) in the endcap region where UE and pileup can spoil the isolation requirements
Decays in the Hcal

- Decays in the Hadronic Calorimeter (HCAL) are characterized by narrow jets with:
  - Large deposit of energy in the HCAL
  - No energy in the ECAL

- Jets with no reconstructed tracks (with $p_T > 1$ GeV) in the Inner Detector
• Current simulation of calorimeter trigger correctly handles signals from late decays
• For time shifts of $\Delta t \leq 3$ ns, the effect on $E_T$ is $< 1\%$ at Level-2

• Can correct the energy measurements for late ($> 3$ns) decays by fitting the calorimeter line shape during offline processing
Decays in the Hcal

- Jets from decays in the HCAL produce very narrow jets
- Energy is contained in a cone of $\Delta R = 0.1$ as compared to standard jets of size 0.4
- The narrow jet allows us to use a Level-1 $\tau$ trigger to select these decays
Decays in the Hcal

- Jets originating inside the ID/ECAL have the “standard”
  \[ \log_{10}(E_{\text{HAD}}/E_{\text{EM}}) \sim -1 \]

- Jets from \( \pi_v \)'s decaying in the HCAL have \( \log_{10}(E_{\text{HAD}}/E_{\text{EM}}) \sim 1.5 \)
Decays in the Hcal

- We define a Level 2 trigger using these signatures as:
  - \( \log_{10}(E_{\text{HAD}}/E_{\text{EM}}) > 1 \)
  - Isolation wrt Inner Detector tracks
Decays in the HCAL

Efficiency for Triggering

>60% Efficient for decays in the Barrel HCAL
Decays in the Inner Detector are the hardest to trigger on

- Characterized by 1-2 low energy jets that look QCD like to the trigger
- To reduce backgrounds, we require the event to pass a level 1 muon ($p_T \geq 6$ GeV) trigger
Decays in the Inner Detector

- ATLAS Level 2 tracking algorithms require hits in 4 of the first 5 tracking layers --> decays beyond r~12 cm will not have reconstructed tracks
- Displaced decays are then characterized by “trackless” jets
- Trigger object: “trackless” jet that contains a muon inside the jet cone
Decays in the Inner Detector

- Low absolute efficiency is due to requiring the muon in the event
- The Level 2 trigger is ~22% efficient wrt Level 1
- Work is on-going to define a more efficient trigger (possibly) using backtracking and jet substructure in the ECAL
Assuming a branching fraction of 100% and a lifetime of 1.5m (20m) we expect ~400 (200) events per 100 pb\(^{-1}\) of 10 TeV data

Trigger algorithms have been implemented and included in the trigger menu

Cross section/event yield is calculated assuming 100% branching fraction for h\(\rightarrow\pi\nu\bar{\nu}\)
Conclusions

• Signature driven trigger objects have been defined for selection of long lived neutral particles decaying to jets (decays from higgs, Z', SUSY, ..., mediated events)

• High efficiency (60-80%) for selecting decays in the HCAL and Muon Spectrometer

• Triggers have been implemented and included in the 2009/2010 trigger menu
• Tested trigger algorithms on 10 TeV minbias and QCD di-jet samples
• 0 out of 3M minbias events pass the trigger
• di-jet background gives acceptable rates (at $\mathcal{L}=10^{32} \text{ cm}^{-2} \text{ s}^{-1}$) for the level 2 trigger

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<th>Trigger</th>
<th>35 - 70 GeV</th>
<th>70 - 140 GeV</th>
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<tbody>
<tr>
<td></td>
<td>Events</td>
<td>Rate (Hz)</td>
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<tr>
<td>Muon Cluster</td>
<td>21</td>
<td>0.4</td>
</tr>
<tr>
<td>ID-jet+muon</td>
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<td>0.4</td>
</tr>
<tr>
<td>$E_{HAD}/E_{EM}$</td>
<td>5</td>
<td>0.1</td>
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