Hidden Valley Higgs Decays in the ATLAS Detector

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1 Introduction

A number of extensions of the Standard Model result in particles that are neutral, weakly-coupled and have macroscopic decay lengths that can be comparable with LHC detector dimensions[1, 2, 3]. These long lived particles occur in many models; in the Hidden Valley (HV) Scenario a new sector is weakly coupled to the Standard Model and results in neutral long lived HV particles (π_v^0) that decay to heavy quark pairs and tau pairs. These particles can be produced in Higgs boson decays, SUSY processes and Z' decays.
We present the results of a first study of the ATLAS Detector performance for the Higgs decay $h^0 \rightarrow \pi_v^0 \pi_v^0$, where π_v^0 is neutral and has a displaced decay mainly to bottom quarks. The initial goal of our study is to obtain benchmark triggers for processes with such non-standard signatures in the ATLAS apparatus.

2 The Hidden Valley Scenario

We begin with some general discussion of the scenario [4]. To the Standard Model is appended a hidden sector, the "v-sector" for short, and a communicator (or communicators) which interacts with both sectors. A barrier (perhaps the communicator's high mass, weak couplings, or small mixing angles) weakens the interactions between the two sectors, making production even of light v-sector particles ("v-particles") rare at low energy. At the LHC, by contrast, production of v-particles, through various possible channels, may be observable. The communicator can be any neutral particle or combination of particles, including the Higgs boson, the Z boson, Z' bosons, neutralinos, neutrinos, or loops of particles charged under both Standard Model and v-sector gauge groups.
The study presented here uses the following parameters:
$m_{h^0} = 140$ GeV[1], $m_{\pi_v} = 40$ GeV and $c\tau_{\pi_v} = 1.5$ m. With these parameters approximately 40% of the decays occur in the ATLAS Inner Detector (ID), 48% in the

[1] At this mass value Higgs production is dominated by gluon fusion (gg). We have also investgated Vector Boson Fusion (VBF) and the W-Higgs production mechanism.

Calorimeters (ECal and HCal) and the remaining 12% in the Muon Spectrometer (MS) system.

3 Detector Signatures and Triggers

A simulation of typical HV Higgs decays $h^0 \rightarrow \pi_v^0 \pi_v^0$ in the ATLAS Detector is shown in Figure 1. Due to the displaced vertices with tracks non pointing to the interaction region and to the low Higgs mass, the standard ATLAS triggers [5] are able to select only a very small fraction of these events, as can be seen in Table 1. A signature driven trigger strategy is therefore required.

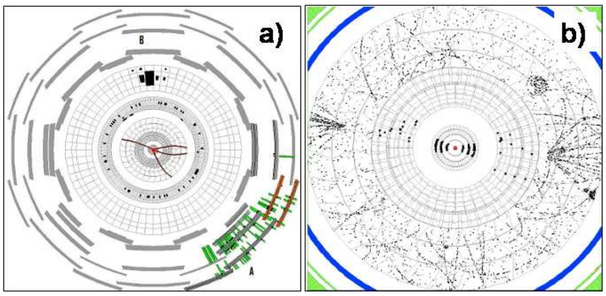

Figure 1: Event display for typical $h^0 \rightarrow \pi_v^0 \pi_v^0$ decays. a) decays in the MS and in HCal; b) decays in the ID.

We consider three detector regions to illustrate the trigger signatures of Hidden Valley particles: 1)Decays in the MS from the end of the HCal to the first muon trigger plane; 2)Decays in the Calorimeters from the end of the ECal to the end of HCal; 3)Decays in the ID beyond the pixel layers to the end of the Transition Radiation Tracker (TRT). Decays in the beam pipe and pixel layers are not considered due to the predominant irreducible Standard Model $b\bar{b}$ background.

Process	Calorimeter triggers	Muon trigger	Total
$h^0 \rightarrow \pi_v^0 \pi_v^0$	4.4%	2.2%	4.7%

Table 1: ATLAS standard triggers efficiency, normalized to the whole sample; Total is the union of Calorimeter and Muon triggers.

3.1 Decays in Muon Tracker

Decays occurring near the end of the HCal and before the first muon trigger plane result in a large number of hadrons traversing a narrow (η, ϕ) region of the Muon Spectrometer. The Level-1 muon trigger will return several RoIs[2] clustered in a small $\Delta R(\eta, \phi)$ area. The muon RoIs from this decay topology will not usually have an associated track in the inner tracker and most will not survive the Level-2 muon trigger. However, this RoI cluster event signature can be used as a stand-alone Level-2 trigger object to select these late decays. Plotted in Figure 2 is the average number of

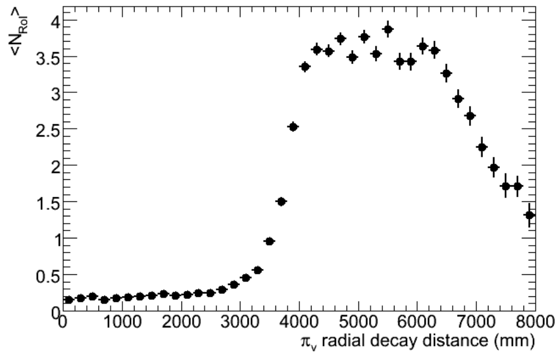

Figure 2: Average number of Level-1 muon RoIs contained in a cone of ΔR=0.4 around the π_v line of flight vs π_v radial decay distance.

Level-1 muon RoIs contained in a cone of radius ΔR=0.4 around the π_v line of flight, as a function of the π_v radial decay distance, L_R. As the π_v decay vertex approaches the end of the HCal (4500mm), the average number of muon RoIs contained in the cone plateaus at ∼3.5 until the π_v decays close to the first trigger plane (7000mm), at which point the charged hadrons are not spatially separated enough to give multiple unique RoIs.

3.2 Decays in the Calorimeters

Events with π_v decays in the Calorimeters near the end of the ECal are characterized by jets with few or no tracks and unique energy distributions. These events often have little energy deposited in the first part of the 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, $\log_{10}(E_{HAD}/E_{EM})$, for jets from π_v decays as a function of the π_v decay distance can be seen in Figure 3. As the π_v decays closer to the end

[2]ATLAS Level-1 trigger object, which defines a Region of Interest, RoI, in (η, ϕ) to be examined at Level-2.

of the ECal (2200mm), the ratio changes from a characteristic (for Standard Model jets) negative to a positive value.

Because most jets with $\log_{10}(E_{HAD}/E_{EM}) \geq 0.5$ are produced by π_v's decaying in

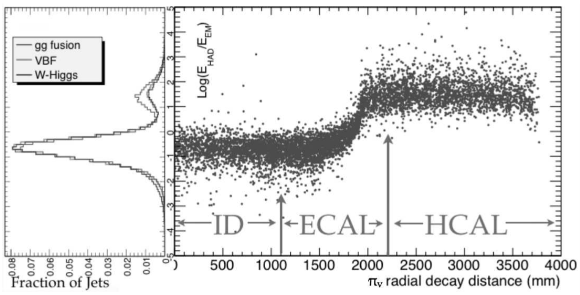

Figure 3: $\log_{10}(E_{HAD}/E_{EM})$ vs π_v decay distance, L_R.

the calorimeter, one would expect to find a lack of activity in the Inner Detector. Using the Level-2 tracking algorithm, we find that the 95% of jets with $|\eta| \leq 2.5$ and a $\log_{10}(E_{HAD}/E_{EM}) \geq 0.5$ have zero tracks reconstructed in a region of 0.2 x 0.2 ($\delta\eta$ x $\delta\phi$) around center of the jet RoI. In contrast, less than 25% of the Standard Model QCD jets with $\log_{10}(E_{HAD}/E_{EM}) \geq 0.5$ have zero reconstructed tracks.

3.3 Decays in the Inner Detector

Displaced decays in the TRT result in low tracking efficiency because tracking requires seed hits in the pixel and silicon strip layers. This suggests that a jet with no tracks reconstructed in the ID at Level-2 may be a good trigger object to select π_v that decay beyond the pixel layers. To reduce Standard Model QCD jets background we require that a Level-1 muon RoI is contained in a cone of radius ΔR=0.4 around the jet axis, which selects a semileptonic $b\bar{b}$ decay.

4 Conclusions

We have implemented in the ATLAS simulation package the new signature based triggers. The resulting trigger acceptances are shown in Table 2. With these new

$\log_{10}(E_{HAD}/E_{EM})$	Trackless jets	Muon cluster	Total HV triggers	All triggers
5.0%	3.8%	9.0%	15.7%	18.5 %

Table 2: HV specific triggers efficiency, normalized to the whole sample. All triggers is the union of the three specific HV triggers and of the standard ATLAS triggers

triggers ATLAS will be able to select $\sim$ 20% of events with displaced decays from $h^0 \rightarrow \pi_v^0 \pi_v^0$.
Standard Model QCD processes are a potential source of significant background at the trigger level. The same trigger objects have been applied to a simulated di-jet samples, resulting in a negligible ($\sim$ 6 nb) cross section acceptance at Level-2.
One important issue is to ensure that our triggers, particularly the muon triggers, be associated with the correct beam crossing. In our model most of the π_v have $\beta > 0.7$, introducing a delay well inside the 25 ns bunch crossing separation.

Long lived particles predicted by a number of Standard Model extensions are challenging to the ATLAS Detector, in particular for the online trigger selection. We have shown that by implementing new signature based triggers it is possible to increase the selection efficiency with a negligible background rate from Standard Model processes.

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