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Detection of long-lived neutral particles with ATLAS

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Summary. — A number of extensions of the Standard Model result in particles that are neutral, weakly coupled and have macroscopic decay lengths comparable with LHC detector dimensions. These long-lived particles occur in many models: gauge-mediated SUSY extensions of the MSSM (addition of one singlet field), MSSM with R-parity violation, split SUSY, inelastic dark matter and Hidden Valley (HV) Scenarios in which a new sector is weakly coupled to the Standard Model. In the HV models long-lived particles decaying to heavy quark pairs and tau pairs can be produced in SUSY processes, Z' decays and Higgs boson decays. For the purpose of exploring the challenges to the trigger posed by long-lived neutral particles, the Hidden Valley scenario serves as an excellent setting. Results are presented of a first study of the ATLAS Detector performance for the Higgs decay $h^0 \to \pi_v^0 \pi_v^0$, where π_v^0 is neutral and has a displaced decay mainly to bottom quarks. The initial goal of the study is to obtain benchmark triggers for processes with such non-standard signatures in the ATLAS apparatus.

PACS `12.90.+b` – Miscellaneous theoretical ideas and models.
PACS `14.80.Cp` – Non-standard-model Higgs bosons.
PACS `29.85.Ca` – Data acquisition and sorting.

1. – The Hidden Valley Scenario

In the Hidden Valley models [1-3], 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 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.

(*) On behalf of the ATLAS Collaboration.

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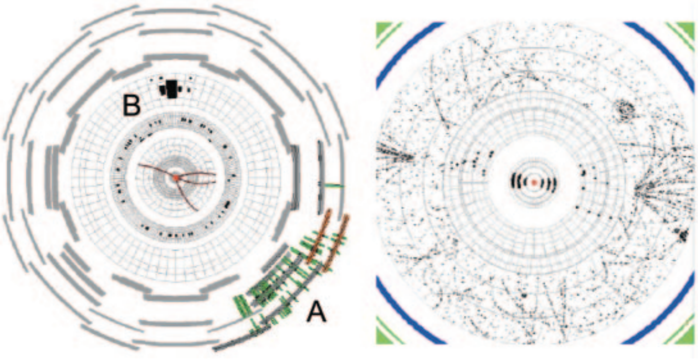

Fig. 1. – Event display for typical $h^0 \to \pi_v^0 \pi_v^0$ decays. Left: decay in the MS (A) and in HCal (B); right: decay in the ID.

Here a study of $h^0 \to \pi_v^0 \pi_v^0 \to b\bar{b}b\bar{b}$ is reported. The following parameters were used to simulate this process in PYTHIA: $E_{\rm cm} = 14\,\text{TeV}$, $m_{h^0} = 140\,\text{GeV}$, $m_{\pi_v} = 40\,\text{GeV}$ and $c\tau_{\pi_v} = 1.5\,\text{m}$. With these parameters approximately 40% of the decays occur in the ATLAS Inner Detector (ID), 48% in the Calorimeters (ECal and HCal) and the remaining 12% in the Muon Spectrometer (MS) system.

2. – Detector signatures and triggers

A simulation of typical HV Higgs decays in the ATLAS Detector is shown in fig. 1. Hidden Valley events are characterized by highly displaced decays, leading to jets appearing throughout the volume of ATLAS. Due to the low Higgs mass resulting in soft jets and tracks that do not point to the interaction point coming from the highly displaced vertex, the standard ATLAS high-level (software) triggers [4] are able to select only a small fraction of these events. But it is possible to use the displaced vertex signature to design signature-driven triggers to increase the fraction of events accepted.

2˙1. *Decays in the Muon Spectrometer*. – Decays occurring near the end of the HCal and before the first muon trigger plane result in a large number of charged hadrons traversing a narrow (η, ϕ) region of the MS. The first (hardware) level of the ATLAS muon trigger will return several Regions of Interest (RoI) clustered in a small $R(\eta, \phi)$ area (see decay A in fig. 1 left). This is illustrated by fig. 2 that gives the average number

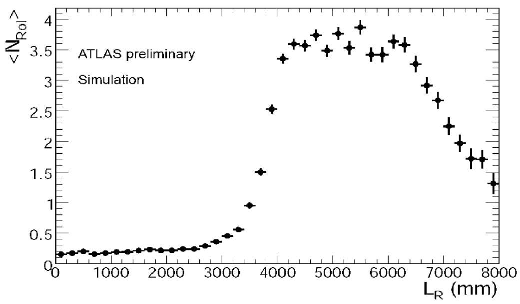

Fig. 2. – Average number of Level 1 muon RoIs *vs.* π_v decay distance.

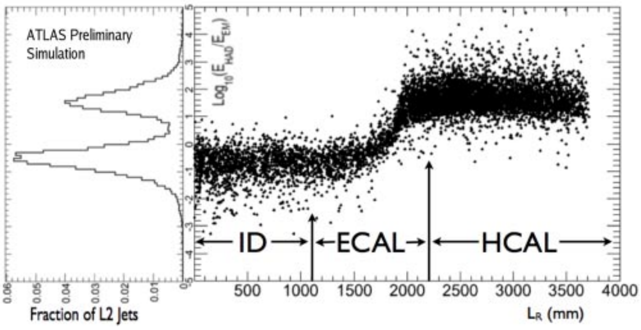

Fig. 3. – $\log(E_{\mathrm{HAD}}/E_{\mathrm{EM}})$ for all jets coming from π_v decays as a function of the π_v decay position.

of muon RoIs in a cone of $\Delta R = 0.4$ around the π_v's line of flight as a function of the π_v radial decay distance. As the π_v decays close to the end of the HCal (4500 mm), the average number of muon RoIs contained in the cone increases rapidly due to the charged tracks from the π_v decay. The number of RoIs remains large and approximately constant until the π_v decays close to the first muon trigger plane (7000 mm), at which point the charge hadrons are not separated enough to give multiple unique RoIs. Moreover, little to no energy is deposited in the calorimeters and no visible track connects the RoI cluster with the Interaction Point (IP). This RoI cluster event signature can be used as a high-level trigger object to select these decays.

2˙2. *Decays in calorimeters.* – If the π_v decays in or beyond the ECal the ratio of energy deposited in the HCal to that in the ECal will be larger than that which is normally observed for jets originating at the IP. Decay B in fig. 1 (left) illustrates this decay topology.

This is illustrated by fig. 3 that shows the distribution of the log of the hadronic to electromagnetic energy ratio for jets from π_v decays as a function of the π_v decay distance. As the π_v decays closer to the end of the ECal (2200 mm), the ratio changes from a characteristic negative to a positive value.

Figure 3 also shows the $\log(E_{\mathrm{HAD}}/E_{\mathrm{EM}})$ plotted for each jet in the event. Two distributions are clearly present. The distribution centered at ~ -0.75 is from π_v decays in the ID(^{1}), while the second distribution, centered at $\sim +1.5$, is from π_v decays occurring inside of the calorimeters. The separation of the two distributions suggests that $\log(E_{\mathrm{HAD}}/E_{\mathrm{EM}})$ could be used as a new trigger object. Moreover, because jets with $\log(E_{\mathrm{HAD}}/E_{\mathrm{EM}}) \geq 1$ are produced by π_v's decaying in the calorimeter, one would expect to find a lack of activity in the ID.

2˙3. *Decays in the outer ID.* – Decays in the outer ID lead to jets with no connecting track to the IP (trackless jets). Figure 1 right shows two π_v decays in the ID. Selecting such events at Level 2 requires a Level 2 ID vertex finding algorithm using tracks with large impact parameters, which is not currently available. Thus for this first study a trackless jets is examined as trigger objects for this event signature. The QCD

(^{1}) Standard QCD jets give a similar distribution centered at ~ -0.75.

background to a trackless jet trigger can be significantly reduced by requiring that the trackless jet contains at least a muon from semileptonic decays of the b quark in the jet cone. In Standard Model jets that originate at the IP, the muon will typically be prompt and leave a track in the ID spoiling the trackless requirement, whereas in events with displaced decays, the muon will be produced beyond the inner most tracking layers and thus have no reconstructible ID track. A trackless jet with a muon in the jet cone is the trigger object.

2˙4. *Decays near the interaction point.* – Decays in the Beam Pipe or in the innermost ID look like decays of heavy flavors produced in Standard Model processes. The b-tagging algorithms should find these events with good efficiency and consequently new triggers are not needed.

3. – Conclusions

Three new trigger objects based on the signal characteristics shown in the previous Section have been designed. Details are given in [5]. The new signature based triggers have been implemented in the ATLAS trigger software framework and they will be inserted in the trigger menu for the first LHC run. For a lifetime of 1.5 m, our signal acceptance times cross-section is 5.5 pb and for a lifetime of 20 m, is 3 pb. Standard Model QCD processes are a potential source of significant background at the trigger level. The same trigger objects have been applied to simulated QCD jet samples, resulting in a (6 nb) cross section accepted by the ATLAS High Level Trigger. Long-lived particles predicted by a number of Standard Model extensions are challenging to the ATLAS Detector, in particular for the online trigger selection. By implementing new signature-driven triggers it is possible to increase the selection efficiency with a negligible background rate from Standard Model processes.

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