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

Orin Harris - University of Washington, Seattle - on behalf of the ATLAS Collaboration

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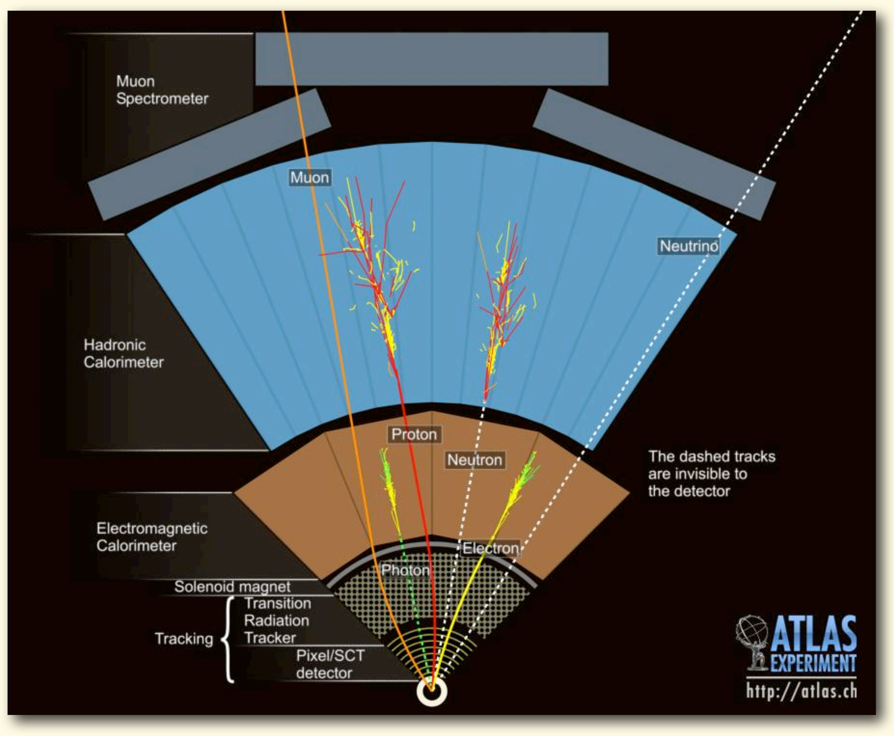
Introduction

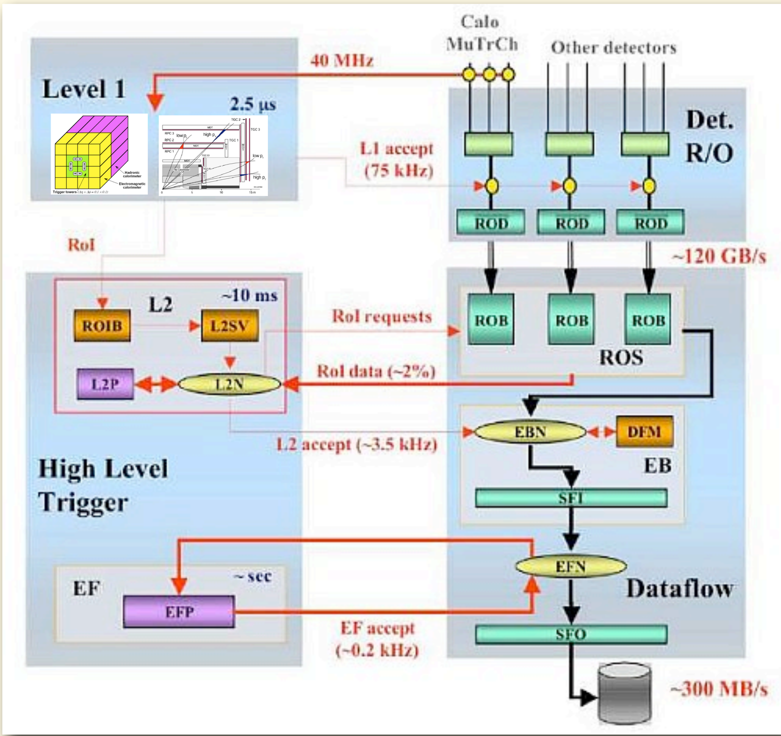
- Long-lived particles that can decay mid-detector are predicted by a large class of theoretical models
  The Hidden Valley (HV) scenario, SUSY with R-parity violation, gauge-mediated SUSY, Split-SUSY, inelastic dark matter, mSUGRA, 4th generation fermions, ...
  - unique signature, large cross section not excluded: **potential for early discovery**
- **Hidden Valley** models are a general class of models that can give rise to **long-lived, neutral particles** (LLNP)
  - 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
  - could profoundly affect supersymmetric phenomenology
- In this paper we focus on the most problematic signatures: **very displaced jets with (relatively) low p_T, low missing energy**

ATLAS experiment @ LHC



- High sensitivity to a wide spectrum of final states
- Operating conditions
  - 14TeV p-p collisions (7 TeV for early running)
  - L=10^{34} $cm^{-2}s^{-1}$ (10^{31} $cm^{-2}s^{-1}$ initial luminosity)
- Central Solenoid (2 T)
- Three air Toroid Magnet Systems
- Inner Detector (ID) (7 m x 1.15 m, $\sigma_{R\phi}$=12-18 μm, σ_Z=60-580 μm)
- LAr Electromagnetic Calorimeter (ECal) (13.3 m x 2.25 m, σ_E/E=10%/√E±1%)
- Hadronic Calorimeter (HCal) (12.2 m x 4.25 m, σ_E/E=50%/√E±3%)
- Muon Spectrometer (MS) (46 m x 11 m, σ_{pT}/p_T=10% at 1 TeV)

ATLAS trigger system



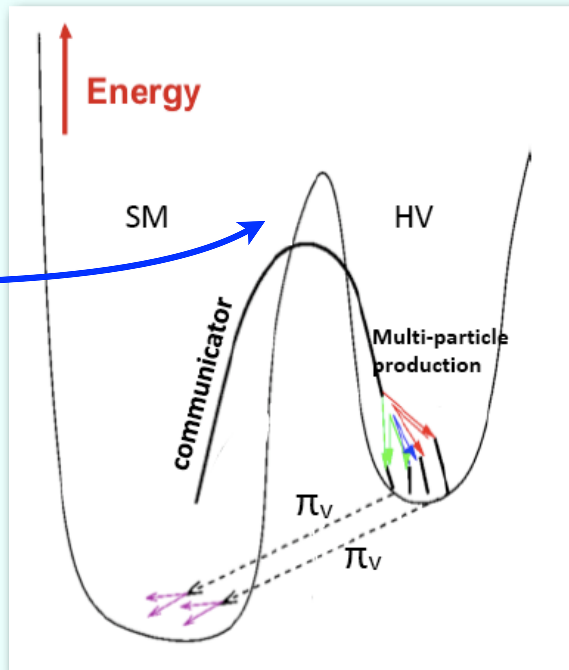
Three level trigger

- Level 1 (L1)
  - hardware trigger, coarse granularity, only calorimeter and muon information
  - identifies Region of Interest (RoI) for further processing
- High Level
  - Level 2 (L2)
    - refines L1 decision using software trigger with more complex algorithms and full detector granularity
    - precision Muon Spectrometer and Inner Detector measurements in regions defined by L1 RoI
      - tracks required to connect back to the interaction point
  - Event Filter (EF)
    - refines L2 selection using offline-like algorithms
    - alignment and calibration data available
    - complete event topology

Hidden Valley Scenario[1]

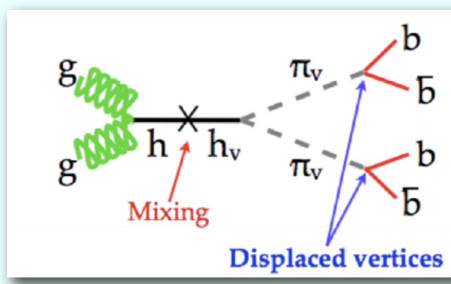
[1] M. Strassler and K. Zurek, Phys. Lett. B651 (2007) 374

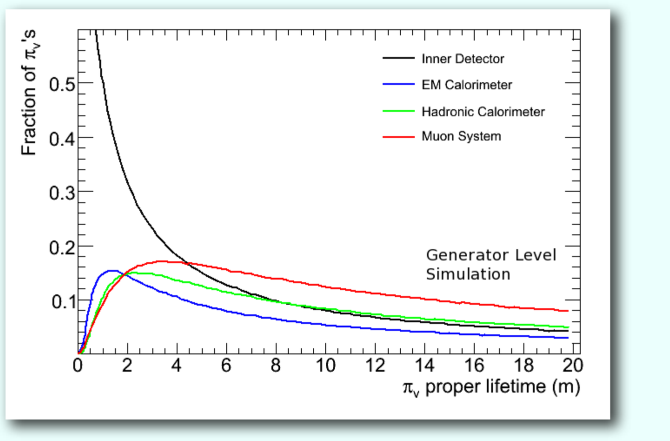
- Append to the Standard Model (SM) a hidden sector, the v-sector and a communicator (Higgs, Z'...) that interacts with both sectors
- All v-particles are neutral under the SM
- Barrier (communicator's high mass, weak couplings...) makes production of v-particles rare at low energies
  - The LHC may easily produce v-particles
- Hadronization in v-sector can lead to high-multiplicity final states
- Some v-hadrons can be stable (dark matter candidates) and others decay to Standard Model particles with "long" lifetimes
- Lightest v-particles are v-pions (π_v)
  - pseudoscalar neutral π_v's decay to fermion pairs
  - helicity suppressed: decay mainly to heavy flavor (b-pairs)



Benchmark channel for LLNP signal

- Higgs decay to heavy flavor jets
  - can result in highly-displaced b-jet vertices
  - standard production cross section for Higgs
  - BR($h\to\pi_v\pi_v$) for light Higgs can reach 100% tagging LLNP could be necessary for Higgs discovery



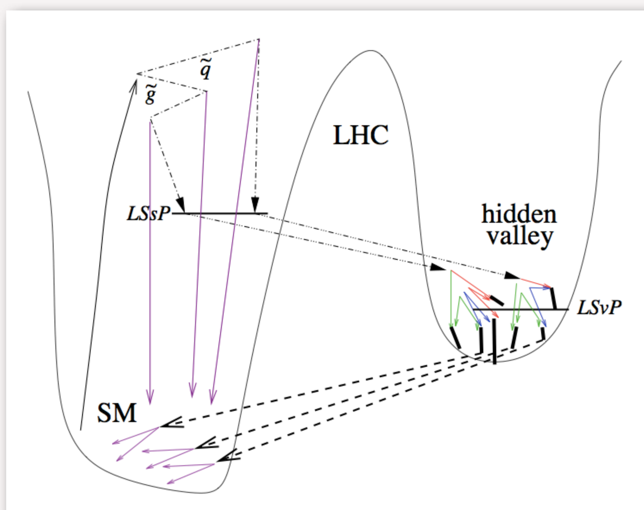


- 10 TeV signal samples used for this study
  - PYTHIA based simulation
    - m_h = 140 GeV, $m_{\pi v}$ = 40 GeV, $c\tau_{\pi v}$=1.5 m
      - 40% decay in Inner Detector
      - 48% decay in Calorimeter
      - 12% decay in Muon Spectrometer
  - signal + pileup sample: L=$10^{32}cm^{-2}s^{-1}$, 450 ns bunch spacing, 4.1 interactions/collision

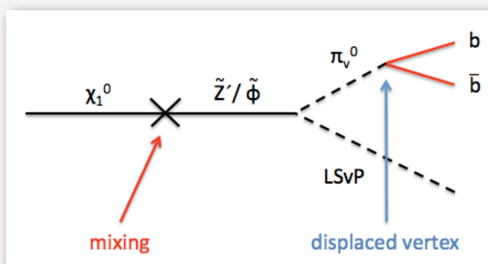
Supersymmetry + Hidden Valley[2]

[2] M.J. Strassler, Possible effects of a hidden valley on supersymmetric phenomenology, [hep-ph/0607160]

- The existence of a hidden valley sector might have a profound impact on classic supersymmetric phenomenology
- If the LSP lies in the valley sector (LSvP), the lightest standard model superpartner (LSsP) may be unstable, decaying to the v-sector through the communicator (neutralino, Z'...)
  - Lightest supersymmetric v-particle (LSvP) is stable
  - LSsP decays provide a "tagging" signal not present in ordinary SUSY events
    - LSsP → v-particles (+ SM-particles)
    - v-particles → LSvP + v-pions
  - LSsP and v-pion lifetimes are largely unconstrained
  - Standard SUSY missing energy signals may be greatly reduced: triggering on LLNP could enhance SUSY discovery potential



SUSY+HV models under study



- Neutralinos decay to the LSvP plus one or more π_v
  - long-lived LSsP and/or π_v
  - can result in highly-displaced b-jet vertices and lowered missing energy
  - depending on mass spectrum can have many π_v per event
  - MC samples currently in production for varied MSSM points
- Focus on problematic regions of MSSM parameter space with low standard SUSY trigger rates
  - Heavy colored spectrum and degenerate electroweak spectrum
  - Light stop and sbottom roughly degenerate with LSP
  - LSPs produced back-to-back
- Low missing energy, jet and lepton multiplicity - LLNPs could provide a needed handle

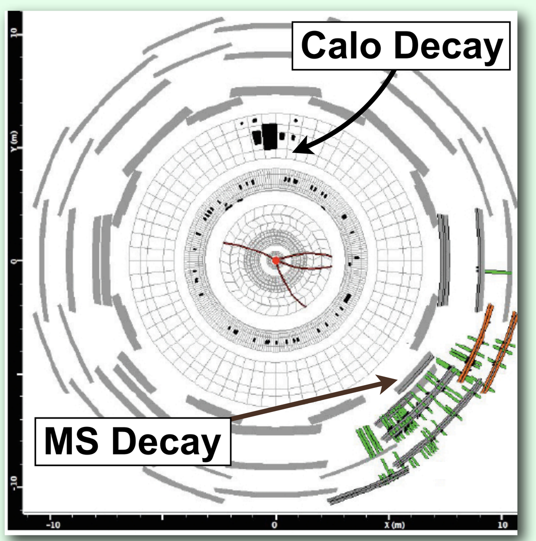
Triggering on LLNP in ATLAS[3]

Current ATLAS High Level triggers are Interaction Point (IP) centric

- only ~2-3% of HV Higgs decays survive L2
- need to define new L2 and EF trigger algorithms

Decays in the Muon Spectrometer (MS)

- many L1 muon RoIs clustered in a small R(η,φ) area of the Muon Spectrometer
  - Muon Cluster L2 trigger: ≥3 muon RoIs contained in a cone ΔR=0.4 and no L2 jets with Log(E_H/E_{EM})≤0.5 within ΔR=0.7 around RoI cluster and no tracks having P_T≥2GeV in Inner Detector
  - efficiency ~70% (30%) if the decay occurs in the barrel (endcap) MS

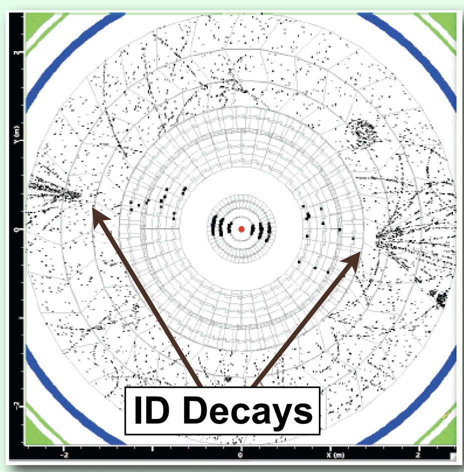


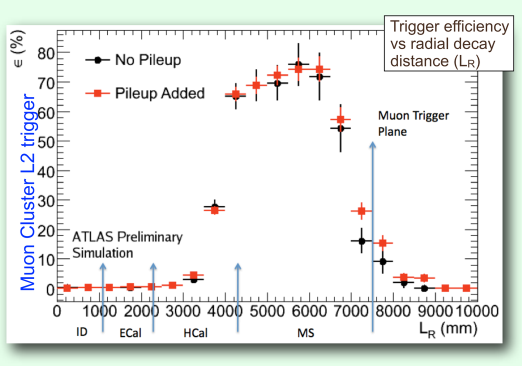
Decays in the Beam Pipe or in the innermost ID

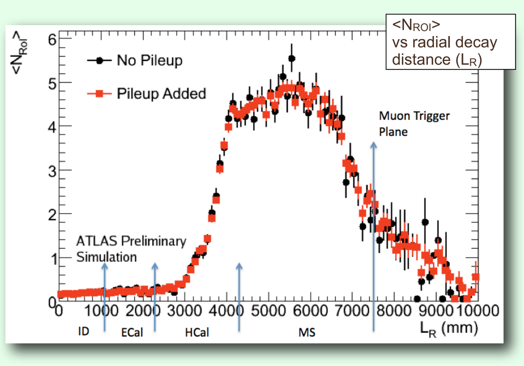
- look like SM heavy flavor decays
- b-tagging algorithms should find these events with good efficiency: new triggers are not needed

Decays in the Inner Detector (no tracks to IP)

- ID-Jet + Muon L2 trigger: a L2 jet with E_T≥35GeV with no reconstructed tracks in the Inner Detector having P_T≥1GeV and with a L1 muon RoI within a cone ΔR=0.4 around the jet direction
- Efficiency ~2.5% (2%) if the decay occurs in the barrel (endcap) outer Inner Detector
- further studies ongoing to define a more efficient trigger
  - using backtracking and vertex finding in ID

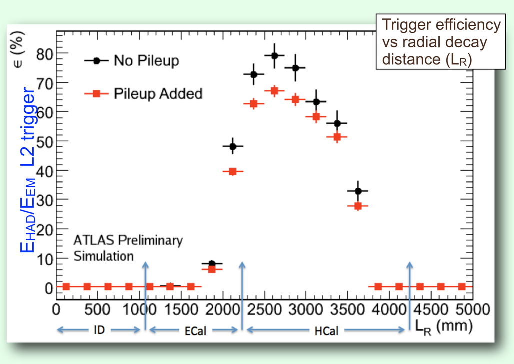


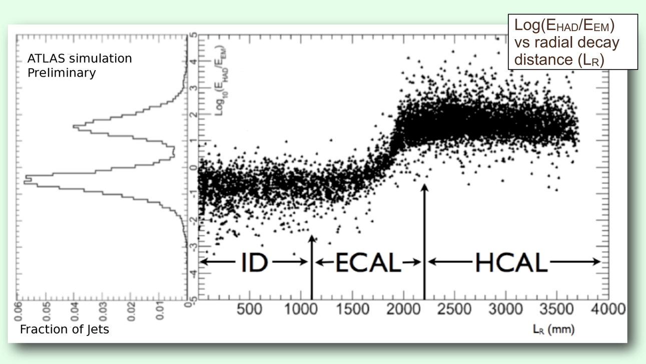




Decays in or beyond the ECal and in the HCal

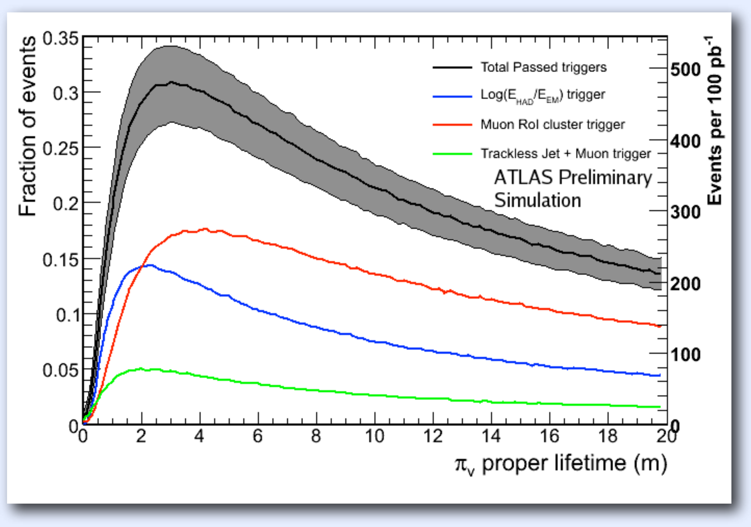
- large energy deposited in the HCal and little energy in the ECal
- the ratio of energy E_{HAD}/E_{EM} will be larger than observed for jets originating at the IP (QCD jets)
  - E_{HAD}/E_{EM} L2 trigger: a L2 jet with|η|<2.5, E_T≥35GeV and Log(E_H/E_{EM}) ≥1 with zero reconstructed tracks having P_T≥1GeV in the ID
  - efficiency ~50% (25%) if the decay occurs in the barrel (endcap) HCal





Performance[3]

- Signature driven trigger objects for the selection of long-lived neutral particles have been defined and implemented in the ATLAS software framework
- Early discovery potential for BR ($h\to\pi_v\pi_v\to$ bbbb)=100% for cτ in [1,20] m



[3] The ATLAS Collaboration, ATL-PHYS-PUB-2009-082

Background rates @ 10^{32} $cm^{-2}s^{-1}$

- J2 10TeV QCD di-jet sample (~300k evts)
  - energy of the leading jet 35GeV<P_T<70GeV (σ ~56μb)
- J3 10TeV QCD di-jet sample (~250k evts)
  - energy of the leading jet 70GeV<P_T<140GeV (σ ~3.2μb)

	35 - 70 GeV		70 - 140 GeV	
Trigger	Events	Rate (Hz)	Events	Rate (Hz)
Muon Cluster	21	0.4	22	0.03
ID-jet+muon	21	0.4	71	0.10
E_{HAD}/E_{EM}	5	0.1	10	0.01

Minimum bias rates @ 10^{32} $cm^{-2}s^{-1}$

- 10 TeV minimum bias sample (~3 M evts) (σ ~ 65 mb)
  - no events passing the triggers
- Poor statistics (~10^{-4} pb^{-1}) → real data needed

Plans

- Development of EF algorithms ongoing
- Performance studies in SUSY environment are moving forward
- Ongoing work using similar strategies for LLNP decaying to lepton jets