Searches for long-lived particles at HL-LHC on ATLAS

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Introduction

- New long-lived particles are both theoretically and experimentally motivated
  - small couplings
  - phase-space suppression
  - conserved (or nearly conserved) symmetries

- LLP searches are signature-driven, and signatures are a product of
  - electric charge
  - mass
  - lifetime
  - decay products

“Prompt particle searches are all alike; every special LLP search is special in its own way” — few sigma Tolstoy reinterpretation
Run 2 LLP analyses on ATLAS

- Disappearing tracks
- Displaced multi-track vertices in ID + MET, jets, leptons
- Displaced leptons, lepton jets, or lepton pairs
- Displaced multi-track vertices in Muon Spectrometer
- Emerging jets
- Non-prompt photons
- Stable or meta-stable charged particles
- Trackless jets with low EMfrac
- Graphic credit: Heather Russell
Focus of HL-HLC LLP studies on ATLAS

• Focus on interaction between upgraded detector design and search, rather than on analysis improvement or effect of more luminosity or pileup

• Therefore, studies focus on new pieces, including (but not limited to):
  • ITk
  • expanded calo trigger capabilities
  • expanded muon trigger capabilities

Existing ID

![Existing ID Diagram]

ITk

![ITk Diagram]
Upgrade studies overview

- Disappearing tracks
  - projection in ATLAS Pixel TDR plan for PUB note before yellow report

- Multi-track displaced vertices in ID + MET
  - tracking studies in ATLAS Pixel TDR, plan for PUB note before yellow report

- Lepton jets / displaced vertex in Muon Spectrometer
  - muon trigger studies in ATLAS TDAQ TDR

- Jets in Hadronic calo with low EMfrac
  - calo trigger studies in Tile TDR

- High Granularity Timing Detector
  - work ongoing toward TDR; interest in LLPs

- Displaced DV in ID w/ leptons
  - possible tracking contribution but physics-projection may be too late
Disappearing tracks
Physics projection study

• Sensitivity
  • charged particle with lifetime \(\sim 10\) ps - 10 ns which decays to “invisible”

• Favorite models
  • particular sensitive to pure wino or pure higgsino SUSY LSP, in which case the lightest chargino naturally picks up lifetime
    • pure wino: \(\sim 0.2\) ns
    • pure higgsino: \(\sim 0.05\) ns

• Event selection (in Pixel TDR) re-optimization underway
  • MET > 450 GeV
  • one jet > 300 GeV
  • tracklet with 4 pixel hits and pT > 250 GeV which disappears in strips

• Background
  • estimated from a combination of upgrade simulation samples and data from Run 2
  • mostly fake tracklets

\[
\begin{align*}
\pi^\pm & \sim 160\text{ MeV} = \text{“invisible”} \\
\text{Run 2 higgsino result}
\end{align*}
\]
Disappearing Tracks

- **Results**
  - with 3000 fb$^{-1}$, expect to exclude at least
    - $> 800$ GeV for pure wino, $\tau = 0.2$ ns
    - $> 250$ GeV for pure higgsino, $\tau = 0.05$ ns

- **Interesting observations**
  - fakes significant, can add more signal regions (3,4,5 hits)
  - standard tracking produces more kinked tracks for pions than current ID
  - one of the few analyses that loses efficiency (at low lifetimes) from detector design

- **Next steps**
  - further optimization of selection to reject fakes
  - some interest in an HE-LHC projection

*Question to theorists: how much interest in longer tracklets?*
Multi-track displaced vertices in ID + MET

Tracking study, physics projection underway

- **Sensitivity**
  - neutral or charged LLP which decays within ID to at least one vertex with >= 5 tracks and mDV >= 10 GeV, plus MET
  - \( \tau \sim 10 \text{ ps} - 10 \text{ ns} \)

- **Favorite models**
  - gluino R-hadrons, decays to neutralino and jets

- **Event selection**
  - relies on reconstructing displaced tracks
    - using a dedicated large-radius-tracking setup in current detector
    - using a truth-level projection, extrapolated through geometry and material, for ITk
  - relies on reconstructing displaced vertices from displaced tracks
  - veto of vertices in detector material
  - MET > 200 GeV

selections from Run 2 analysis, certainly tunable

Run 2 Efficiency versus true MET
Multi-track displaced vertices in ID + MET

Results
- significant increase in efficiency of reconstructing displaced tracks up to 400 mm, and increases reach up to 500 mm

Next steps
- calculate efficiency of material veto in ITk for benchmark R-hadron samples
- use reinterpretation material from public Run 2 result to extrapolate MET and vertexing efficiency
- scale background to 3000 fb$^{-1}$
- estimate physics reach

Question to theorists: strong interest in specific EW or lower x-sec models that we should be targeting here?
Displaced vertices in Muon Spectrometer

Trigger study

• Sensitivity
  • neutral LLP decays before MS into pairs of multiple pairs of collimated leptons

• Favorite models
  • hidden valley models with dark photon decays to leptons (muons)

• Current trigger
  • two-muon resolution limited to ~0.2 in $\Delta \phi(\mu, \mu)$
  • single muon pT threshold ~ 25 GeV

• Phase II trigger
  • new muon sector logic and NSW and MDT trigger processors allow development of di-muon trigger within Region-of-Interest
  • reduce threshold to ~10 GeV for $\Delta \phi(\mu, \mu) = 0.01$
  • significant gain in trigger eff. for close muons

• Next steps
  • further optimizations in $\Delta \phi(\mu, \mu)$ in new alg.
  • studies of efficiency gain v. lifetime
Jets in Hadronic Calo with low EMfrac

Trigger study

Fraction of energy deposited versus decay radius

Tile BC Layer

Tile D Layer

- Sensitivity
  - neutral LLP that decays to jets inside hadronic calorimeter

- Favorite models
  - hidden sector scalar boson decays to more hidden sector particles which decay to (heavy) SM fermions

- Current trigger
  - dedicated level-1 trigger based on tau candidates + low EMfrac

- Phase-II trigger idea
  - low EMfrac will be hurt by pileup activity in EM calo
  - use increased longitudinal Level-1 granularity in Tile to compare energy deposits per layer and reduce sensitivity to pileup while maintaining efficiency for LLPs
High Granularity Timing Detector

Input welcome

- **Detector**
  - 2-3 layers of low gain silicon avalanche detectors with pixels of 1.3 x 1.3 mm$^2$
  - located at $z = \pm 3.5$ m
  - eta coverage from 2.4 to 4.0
  - timing resolution of 30 ps per track

- **LLP possibility**
  - precision timing may allow to measure — and trigger on — charged particles which arrive late to HGTD
    - if timing window is large enough
  - strong interest in models with slow (or late) *forward* charged LLPs welcome :)

Input welcome
Conclusions and Outlook

• Significant effort went into detector TDRs for various LLP efforts
  • Important to take LLP concerns into account in detector design

• Physics projections underway for a subset of LLP analyses
  • mostly which use the ID / ITk as main detector

• Successful strategy to use Run 2 lessons and upgrade simulation
  • especially useful when Run 2 analyses provide public reinterpretation material

• Aim is to have several PUB notes out in time for the yellow report
  • though only for a subset of LLP analyses
    • no foreseen contribution on longer lifetime meta- or detector-stable charged particle searches
    • no planned effort on interplay between prompt and LLP analysis
  • even for analyses w/ projection, large investments in detector / tracking / performance / analysis optimizations will still remain in order to take full advantage of physics potential ahead!
\( \tilde{g} \) (R-hadron) \( \rightarrow q\bar{q} \tilde{\chi}_1^0 \); \( m(\tilde{\chi}_1^0) = 100 \text{ GeV} \)

- **RPC 0L 2-6 jets** (\( \sqrt{s}=13 \text{ TeV}, 36 \text{ fb}^{-1} \))
- **Displaced vertices** (\( \sqrt{s}=13 \text{ TeV}, 33 \text{ fb}^{-1} \))
- **Pixel dE/dx** (\( \sqrt{s}=13 \text{ TeV}, 3.2 \text{ fb}^{-1} \))
- **Stable charged** (\( \sqrt{s}=13 \text{ TeV}, 3.2 \text{ fb}^{-1} \))
- **Stopped gluino** (\( \sqrt{s}=7,8 \text{ TeV}, 5.0, 23 \text{ fb}^{-1} \))

**ATLAS Preliminary**

- Expected
- Observed

95% CL limits