Exploring Uncharted Soft Displaced Vertices in Open Data

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- Long-lived particles in SUSY and LHT
- Analysis strategies
- Data processing
- Vertex reconstruction and signal efficiencies
- Limit contours

Public collision data from http://opendata.cern.ch
*Displaced vertex* is a novel feature distinguishable from SM backgrounds

- **Feeble couplings:** RPV SUSY, Hidden sector models, freeze-in
- **Heavy mediators:** RHv
- **Phase space squeezing:** Nearly degenerate states (Focus of this study)

[Diagram of displaced vertices and Met+jets +Soft features.]

[Heather Russell, McGill University, 24 April 2017]

[Review: https://arxiv.org/pdf/1903.04497.pdf]

[Link to Indico event: https://indico.cern.ch/event/607314/contributions/2542309/attachments/1447873/2231444/20170424_LLPs.pdf]
Long-lived particles in SUSY and LHT

Generic requirements:
• **Small mass splitting**
• **$Z_2$ symmetry**: the LSP fly outside the detector
• **SM partners**: the NLP should decay into the LSP + some SM particles

**Natural models:**

✓ **SUSY**: stop → $t^* \text{ bino}$

□ **Lightest Higgs Model with T-parity**: $tH \rightarrow t^* \text{ AH} 
(\text{Excluded by current experiments})$

**Bonus**

Lightest stable particle provides a DM candidate
Coannihilation avoids DM being over-abundant

\[
c\tau_t \approx 1.4 \text{ mm} \left( \frac{m_{t}}{500 \text{ GeV}} \right) \left( \frac{20 \text{ GeV}}{\Delta} \right)^8
\]

\[
c\tau_{tH} \approx 7.4 \text{ mm} \left( \frac{m_{tH}}{500 \text{ GeV}} \right) \left( \frac{40 \text{ GeV}}{\Delta} \right)^{10}
\]
Generic collider features
• A pair of displaced vertices
• Each associated to some soft tracks

Challenges
• Hundreds of soft tracks
• Fake and mis-associated tracks

Strategy
➢ PF MET trigger
➢ Monojet
➢ Global displaced vertex reconstruction based on displaced tracks
Data processing

- **Dataset**: CMS 2012 MET primary dataset Run B, Run C, integrated luminosity 11.6 fb$^{-1}$
- **CMSSW 5.3.32** with build-in tools from the Docker image

- **Trigger**: PFMET > 150 GeV
- **Preselection**: at least one jet pT > 150 GeV
- local sample size ~300 G

**Offline analysis**
- Track based analysis
- Beam spot correction
- Trimmed Kalman Vertex Finder
- Compute signal efficiency table
Signal samples
• MG5_aMC@NLO+Pythia8
• MLM 1+2 jets matching
• Fastjet3 for jet clustering
• Simulate stop/tH decay vertices based on their widths, and the Pythia R-hadron decay program.

CMS detector simulation?

- Parametrize signal efficiencies for the MC samples
  • Track efficiencies
  • Vertex reconstruction efficiencies
Track selections

\[ p_T > 1 \text{ GeV} \]
\[ |\eta| < 2.4 \]

Track efficiencies

Reco: 90%

\[
\varepsilon \left( \frac{|d_{xy}|}{\sigma_{d_{xy}}} > 4 \right) = \frac{N(\sigma_{d_{xy}} < |d_{xy}|/4|p_T^0)}{N(\sigma_{d_{xy}} > 0|p_T^0)}
\]

*Zero* refers to the quantities of a sample of high fidelity tracks.
**Parametrized vertex efficiencies for phenomenological studies**

- Signal like events from the CMS ttbar sample
  - Generator level $B_0, \bar{B}_0$ hadronic decays
  - Energy in the range 10-30 GeV
  - Vertex position from the beam-line: 0.5-18 mm

- Two methods to cross check
  - Track fraction method
  - Vertex distance method

- $\geq 4$ displaced tracks
- $d_{BV}$ from 0.1 to 20 mm

| Catalog        | $N_{gen\ tk} = 2$ | $N_{gen\ tk} = 3$ | $N_{gen\ tk} = 4$ | $N_{gen\ tk} = 5$ | $N_{gen\ tk} > 6$ |
|----------------|-------------------|-------------------|-------------------|-------------------|-------------------|
| Efficiency from TF (%) | 23.8 ± 0.4        | 36.6 ± 1.0        | 46.1 ± 2.9        | 45.3 ± 6.2        | 32.4 ± 10.8       |
| Efficiency from VD (%) | 17.5 ± 0.3        | 25.7 ± 1.0        | 32.6 ± 2.4        | 32.6 ± 5.0        | 40.5 ± 12.4       |
| Overlapping fraction (%) | 59.7              | 62.0              | 64.3              | 70.5              | 83.3              |
| Vertex error (μm) | 173               | 170               | 164               | 175               | 155               |
| Vertex error RMS (μm) | 110               | 110               | 103               | 119               | 94.5               |
| Probability of passing $N_{vtx,tk} \geq 2$ | 1.0               | 1.0               | 1.0               | 1.0               | 1.0               |
| Probability of passing $N_{vtx,tk} \geq 3$ | 0.61              | 0.78              | 0.83              | 0.82              | 0.83              |
| Probability of passing $N_{vtx,tk} \geq 4$ | 0.23              | 0.39              | 0.54              | 0.64              | 0.58              |
We have limited data and cannot fully explore signal features

| Selection | Data   | Signal BM |
|-----------|--------|-----------|
| MET primary | 4.3×10^7 | - |
| \( p_T^{\text{jj1}} > 150 \text{ GeV}, \ E_T^{\text{miss}} > 150 \text{ GeV} \) | 1.4×10^6 | 830 |
| One displaced vertex \( (N_{\text{vttx,tk}} \geq 2) \) | 3.7×10^5 | 310 |
| One displaced vertex \( (N_{\text{vttx,tk}} \geq 3) \) | 4.7×10^4 | 240 |
| One displaced vertex \( (N_{\text{vttx,tk}} \geq 4, \text{ default}) \) | 5.5×10^3 | 140 |
| Two displaced vertices | 76 | 9.8 |
| \( p_T^{\text{jj1}} > 300 \text{ GeV}, \ E_T^{\text{miss}} > 300 \text{ GeV} \) | 1 | 3.0 |
| Two displaced vertices with vertex \( H_T < 40 \) | 0 | 3.0 |

\( m_\tilde{\tau} = 360 \text{ GeV}, \quad \Delta = 20 \text{ GeV} \)
Our results (stop-bino model)
- 8 TeV 11.6 fb$^{-1}$
- Most sensitive in the compressed region
- Continuously transits into prompt analysis

Prompt CMS
- 8 TeV 19.7 fb$^{-1}$
- $\tilde{t} \rightarrow bll\tilde{\chi}_1$ channel
- Truncated at $c\tau=0.2$ mm
Our results (stop-bino model)
• 8 TeV 11.6 fb$^{-1}$
• Most sensitive in the compressed region
• Continuously transits into prompt analysis

Prompt CMS
• 13 TeV 35.9 fb$^{-1}$
• $\tilde{\ell} \rightarrow b f f' \tilde{\chi}_1^0$ channel, MVA approach
• Truncated at $c\tau=0.2$ mm
Our results (LHT model)
- 8 TeV 11.6 fb$^{-1}$
- Most sensitive in the compressed region
- Continuously transits into prompt analysis

Prompt CMS
- 8 TeV 19.7 fb$^{-1}$
- Converted from stop-bino limits
- Truncated at $c\tau=0.2$ mm
Displaced vertices reconstructed from soft tracks can be sensitive to BSM long-lived particles

We searched for long-lived stop and $tH$ signals using the 8 TeV CMS open data

We present competitive limits in the compressed region for both of the models

Opendata can be a powerful tool to help theorists study backgrounds of non-conventional new physics searches