Preliminary

PHENO 2021

Exploring Uncharted Soft Displaced Vertices in Open Data

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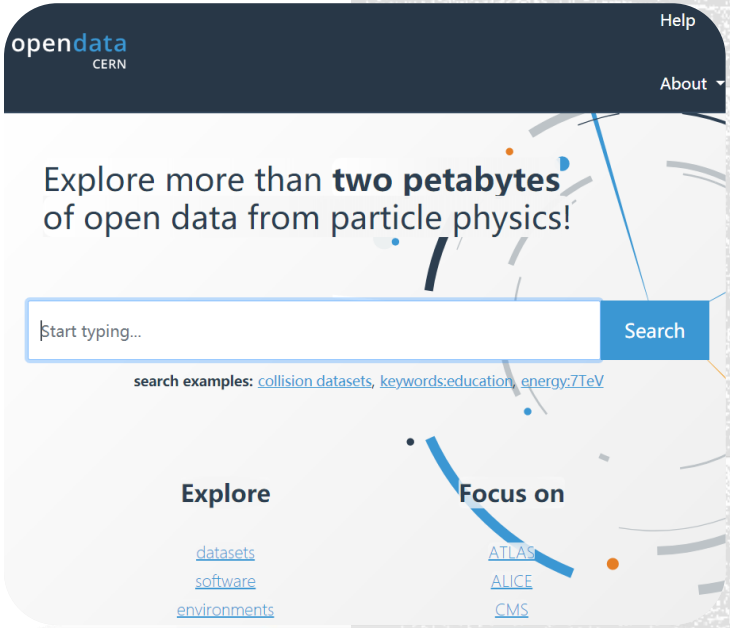
OUTLINE

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

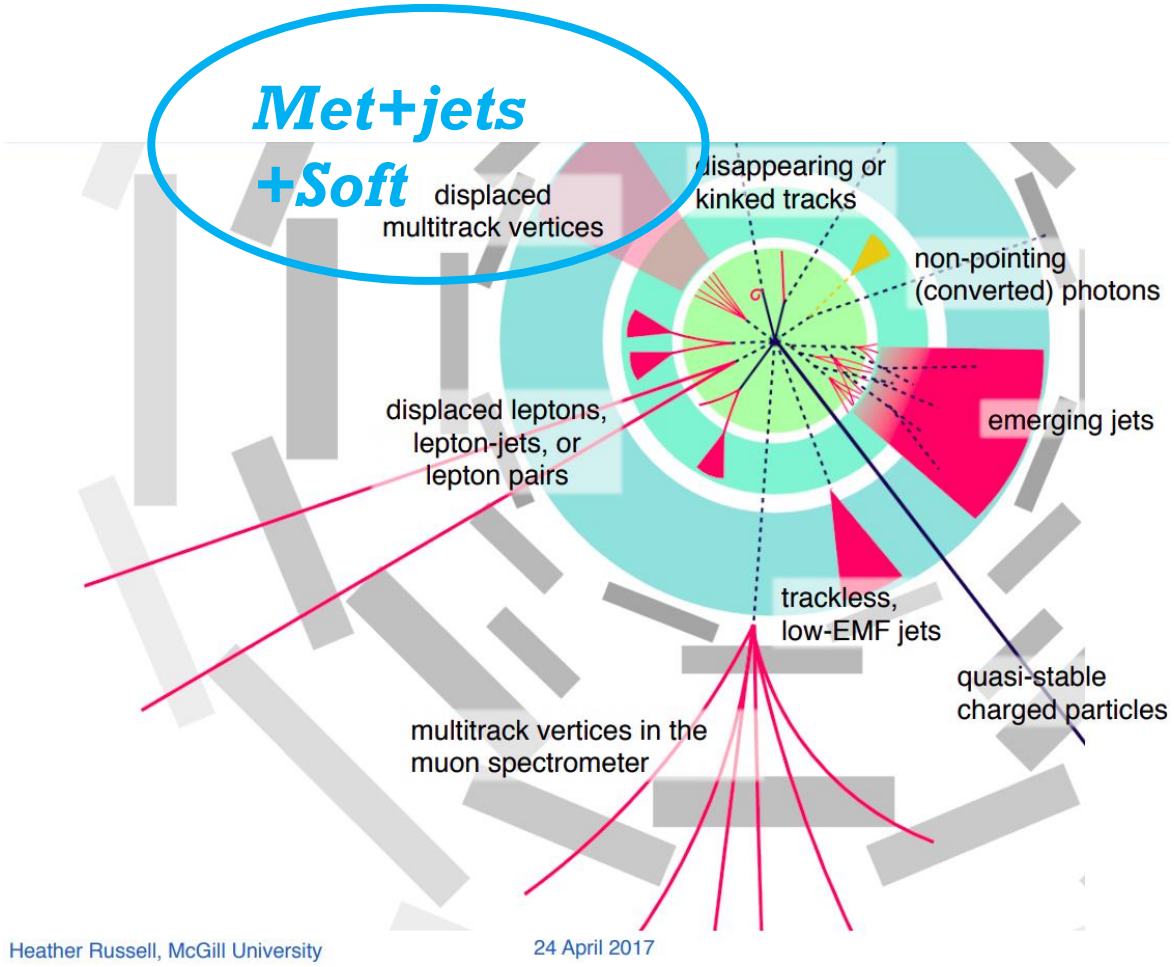
Public collision data from http://opendata.cern.ch



Long-lived particles in SUSY and LHT

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)



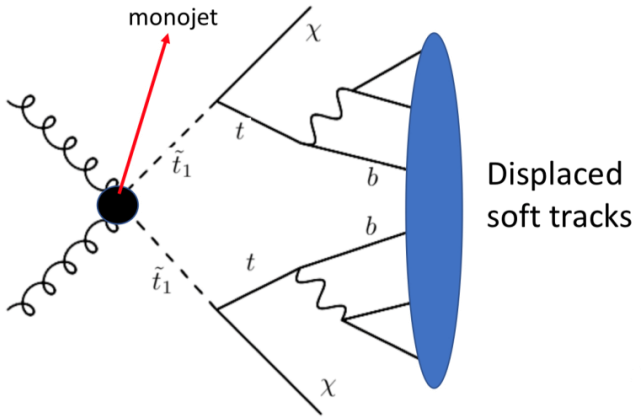
https://indico.cern.ch/event/607314/contributions/2542309/attachments/1447873/2231444/20170424_LLPs.pdf

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

Long-lived particles in SUSY and LHT

Generic requirements:

- Small mass splitting
- Z2 symmetry: the LSP fly outside the detector
- SM partners: the NLP should decay into the LSP + some SM particles



Natural models:

✓ SUSY: stop -> t* bino

$$c\tau_{\tilde{t}} \approx 1.4 \text{ mm} \left(\frac{\text{m}_{\tilde{\text{t}}}}{500 \text{ GeV}}\right) \left(\frac{20 \text{ GeV}}{\Delta}\right)^8$$

☐ Lightest Higgs Model with T-parity: tH -> t* AH
(*Excluded by current experiments*)

$$c\tau_{t_H} \approx 7.4 \text{ mm} \left(\frac{m_{t_H}}{500 \text{ GeV}}\right) \left(\frac{40 \text{ GeV}}{\Delta}\right)^{10}$$

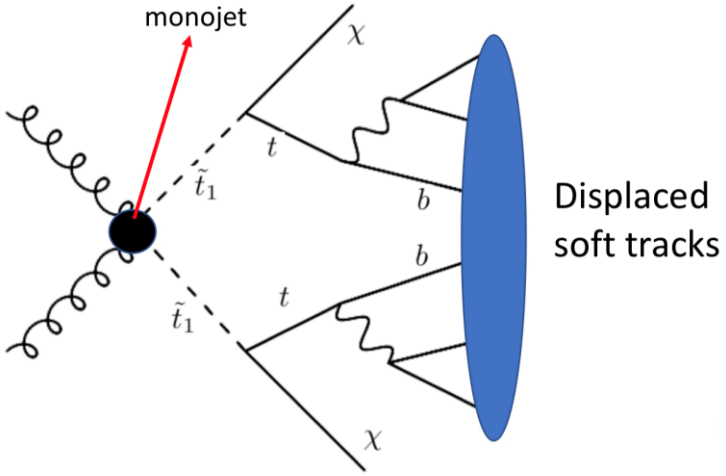
Bonus

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

Analysis strategies

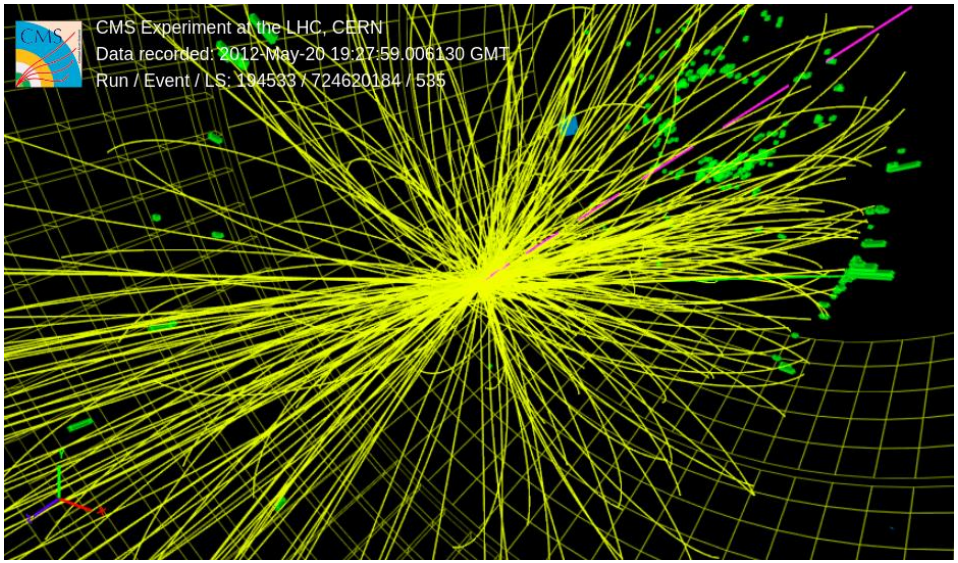
Generic collider features

- 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

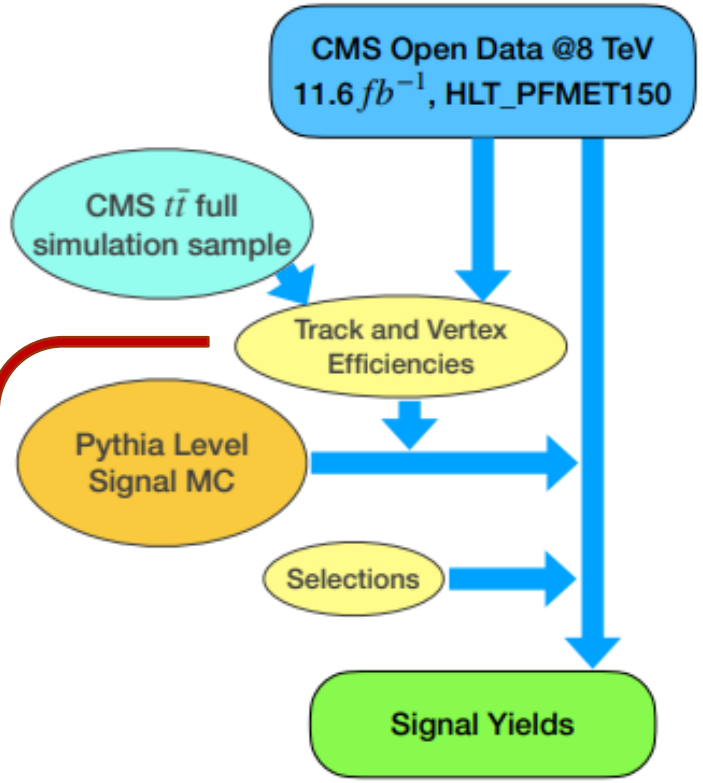
- Track based analysis
- Beam spot correction
- Trimmed Kalman Vertex Finder
- Compute signal efficiency table

Vertex reconstruction and signal efficiencies

Signal samples

- MG5_aMC@NLO+Pythia8
- MLM 1+2 jets matching
- Fastjet3 for jet clustering
- Simulate stop/tH decay vertices based on the 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 selection and efficiencies

Track selections

$p_T > 1$ GeV

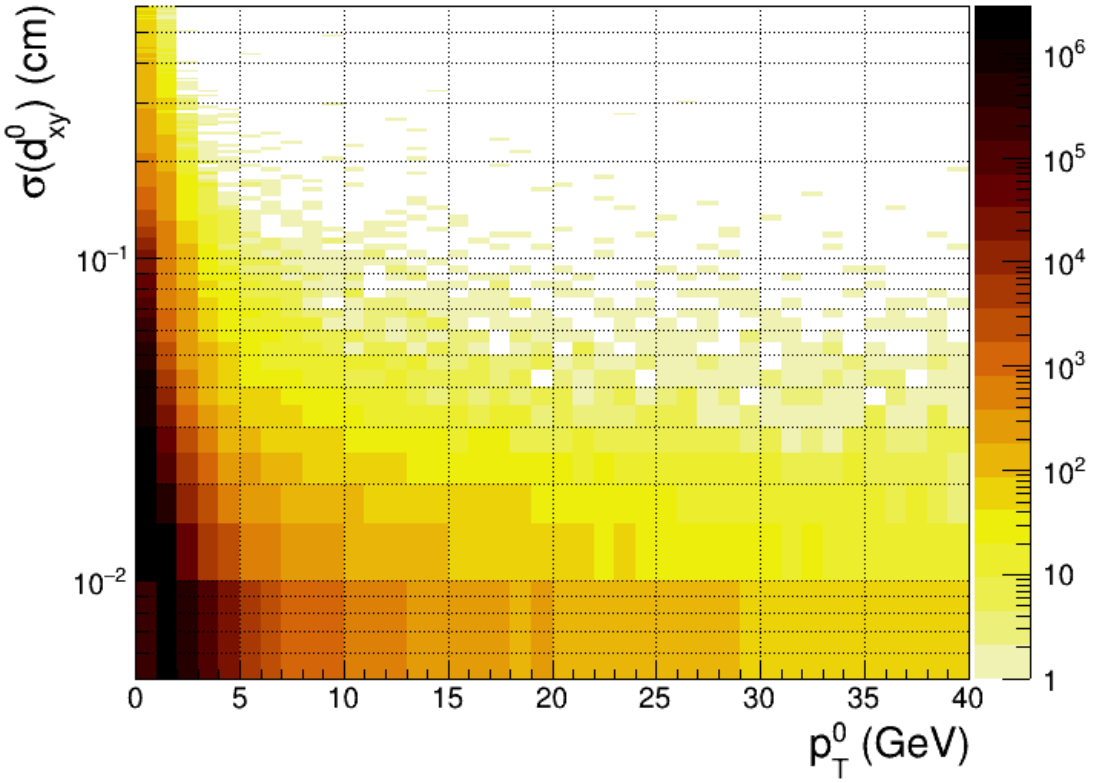
$|\eta|$<2.4

Track efficiencies

Reco: 90%

$$\varepsilon(|d_{xy}/\sigma_{d_{xy}}|>4) = \frac{N(\sigma_{d_{xy}}<|d^0_{xy}|/4|p^0_T)}{N(\sigma_{d_{xy}}>0|p^0_T)}$$

Zero refers to the quantities of a sample of high fidelity tracks.



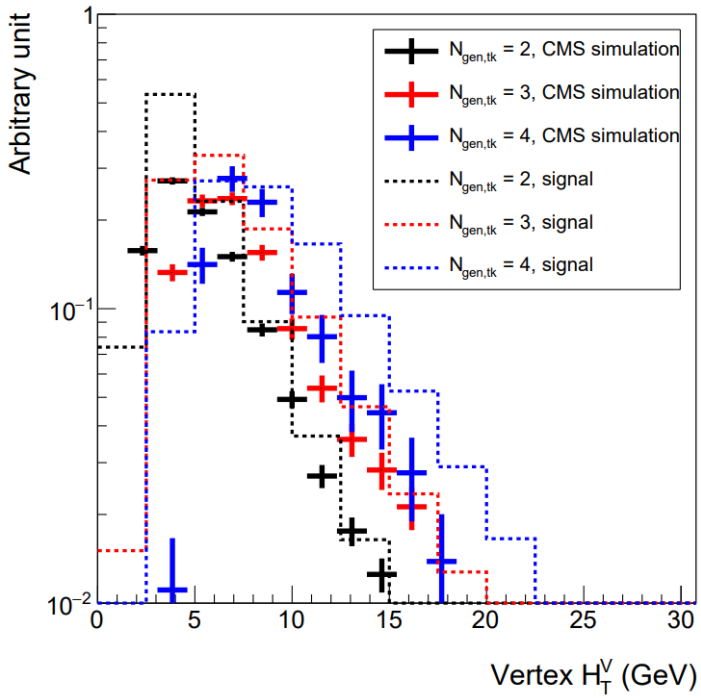
Vertex reconstruction and signal efficiencies

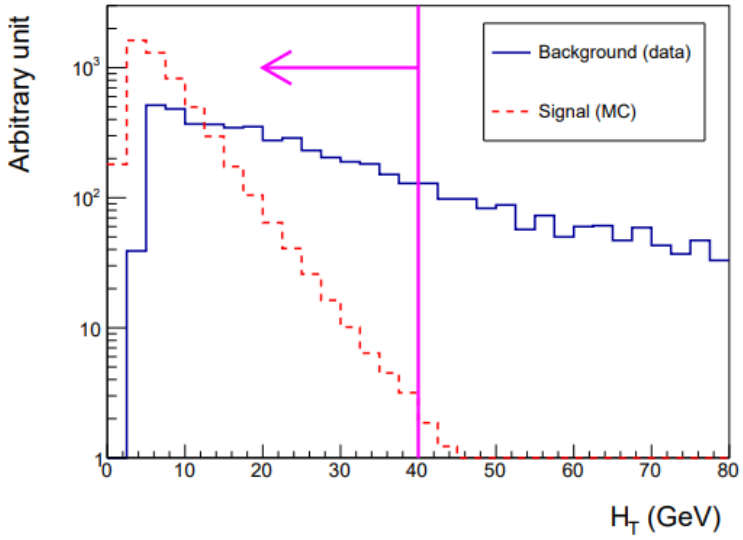
Parametrized vertex efficiencies for phenomenological studies

- 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
- ≥ 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

Vertex reconstruction and signal efficiencies





We have limited data and cannot fully explore signal features

Selection	Data	Signal BM
MET primary	4.3×10^7	-
$p_T^{j1} > 150$ GeV, $E_T^{miss} > 150$ GeV	1.4×10^6	830
One displaced vertex ($N_{vtx,tk} \geq 2$)	3.7×10^5	310
One displaced vertex ($N_{vtx,tk} \geq 3$)	4.7×10^4	240
One displaced vertex ($N_{vtx,tk} \geq 4$, default)	5.5×10^3	140
Two displaced vertices	76	9.8
$p_T^{j1} > 300$ GeV, $E_T^{miss} > 300$ GeV	1	3.0
Two displaced vertices with vertex $H_T < 40$	0	3.0

$m_{\tilde{t}} = 360$ GeV, $\Delta = 20$ GeV

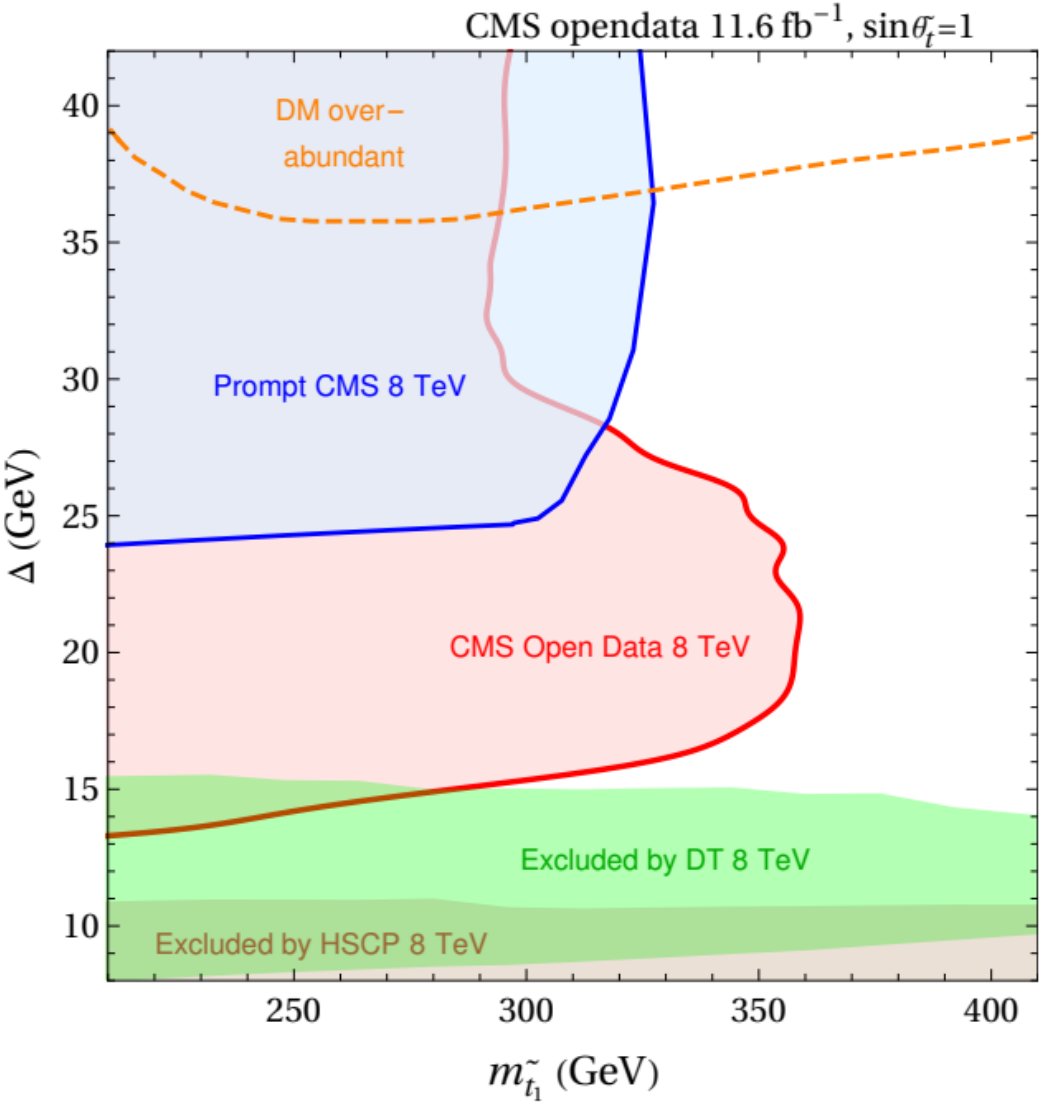
Limit contours: SUSY stop-bino model

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}**
- $\tilde{t} \to bl\bar{l}\tilde{\chi}_1^0$ **channel**
- Truncated at $c\tau$=0.2 mm



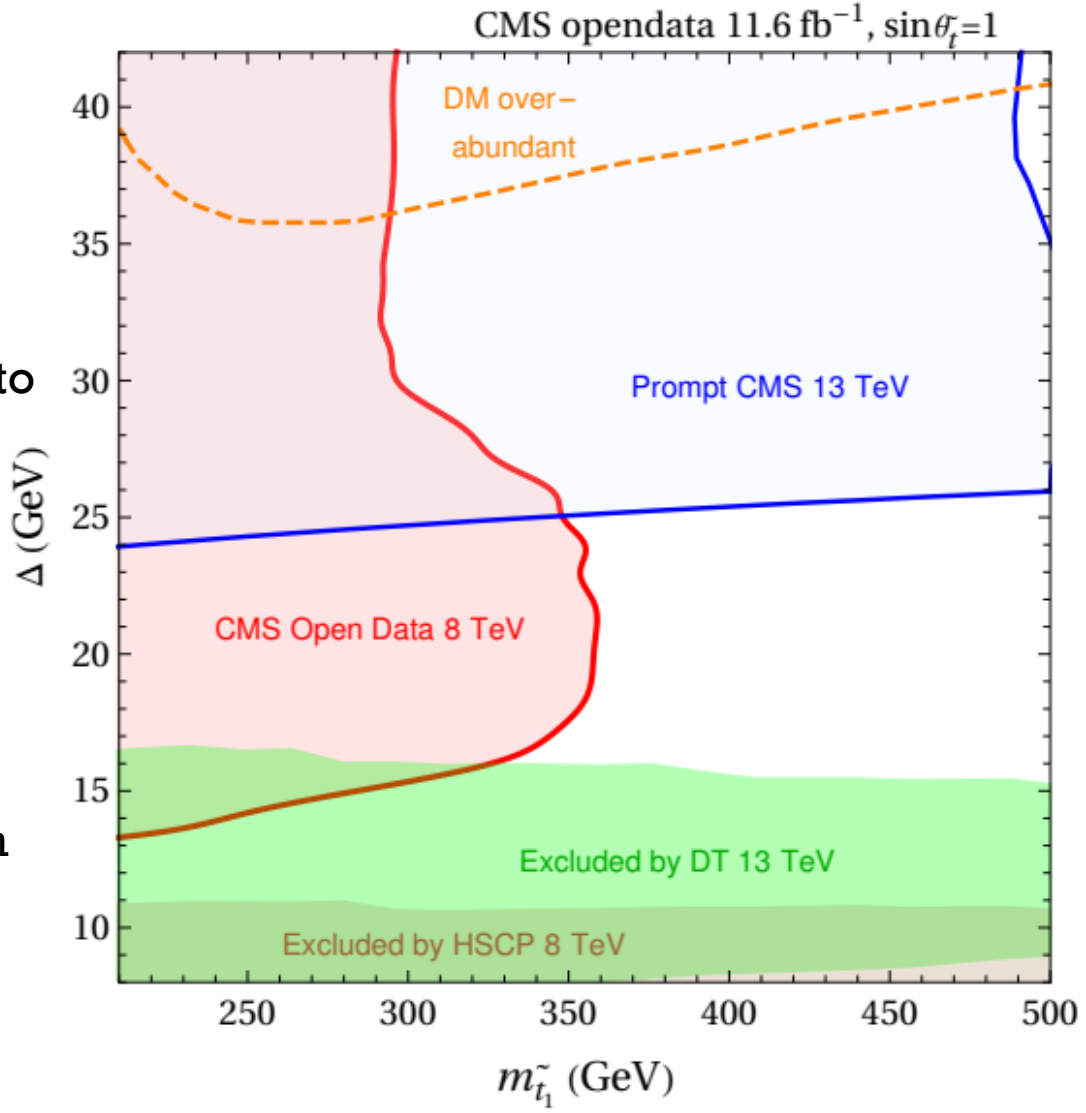
Limit contours: SUSY stop-bino, comparing with 13 TeV limits

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}**
- $\tilde{t} \to bff'\tilde{\chi}_1^0$ **channel**, MVA approach
- Truncated at $c\tau$=0.2 mm



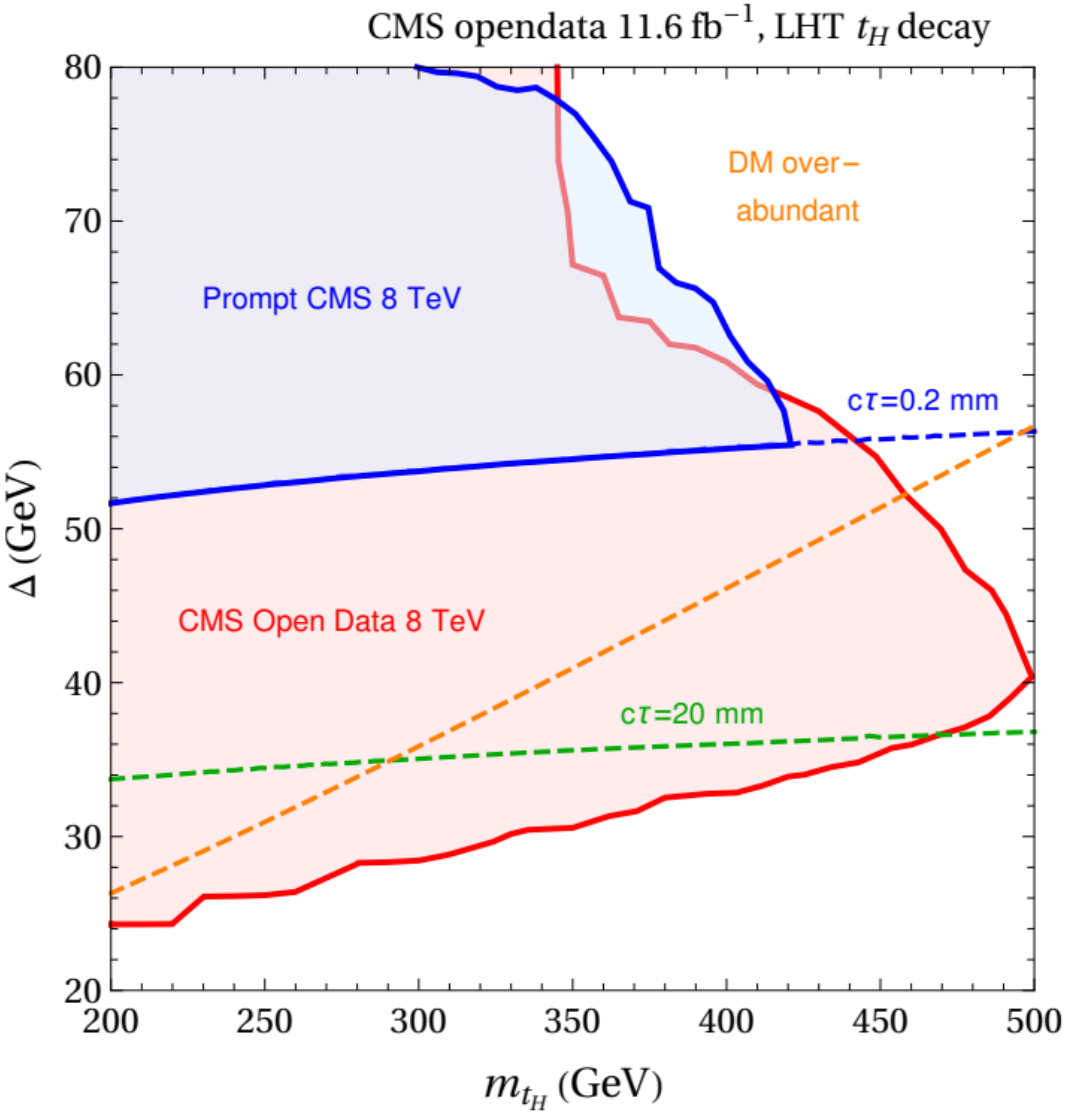
Limit contours: LHT tH decay model

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



SUMMARY

- 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