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Exploring Uncharted Soft Displaced Vertices in Open Data

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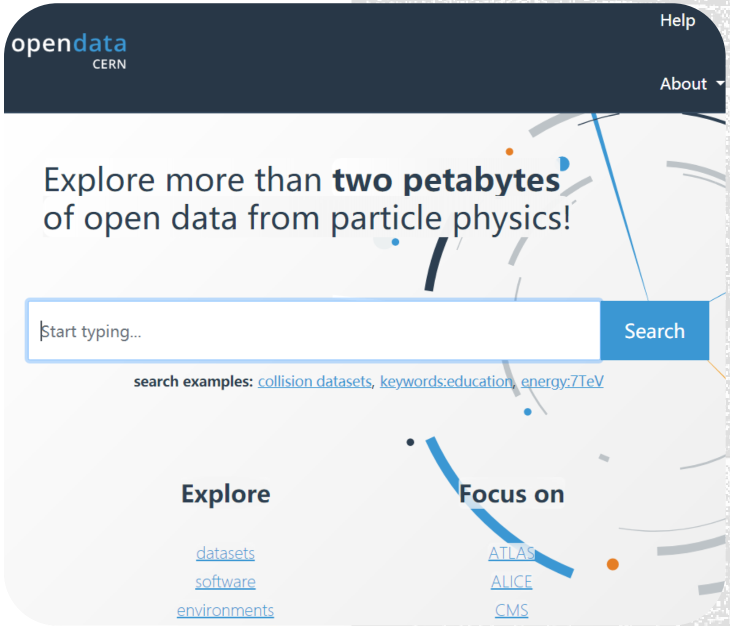
OUTLINE

- Co-annihilating DM and long lived NLP
- Analysis strategies
- Data processing
- Vertex reconstruction and signal efficiencies
- Limit contours

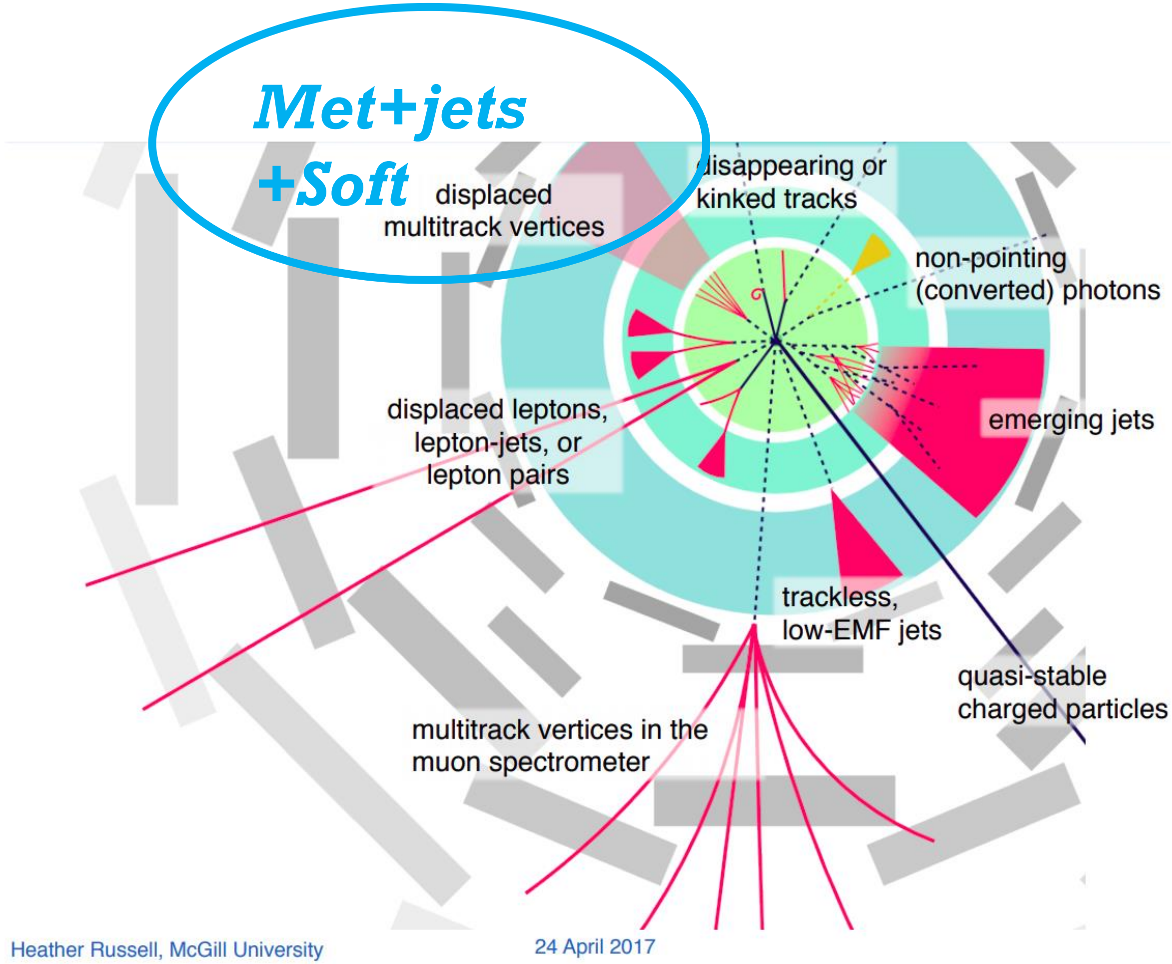
Public collision data from http://opendata.cern.ch



Co-annihilating DM and long lived NLP

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)

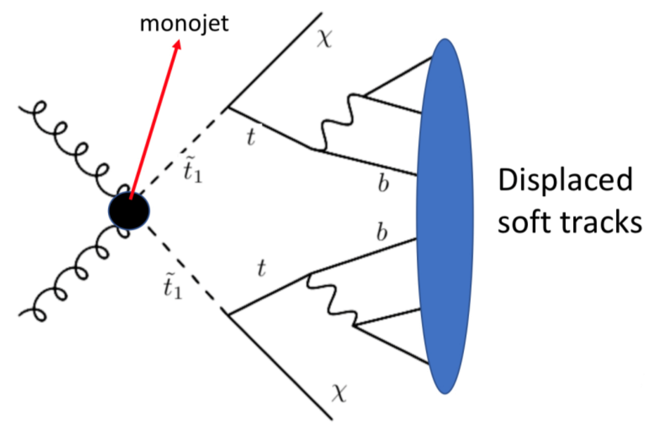


https://indico.cern.ch/event/607314/contributions/2542309/attachments/1447873/2231444/20170424_LLPs.pdf

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

Generic requirements to produce the signatures of interest

- 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:

- Fermionic DM (SUSY):
  stop -> t* bino

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

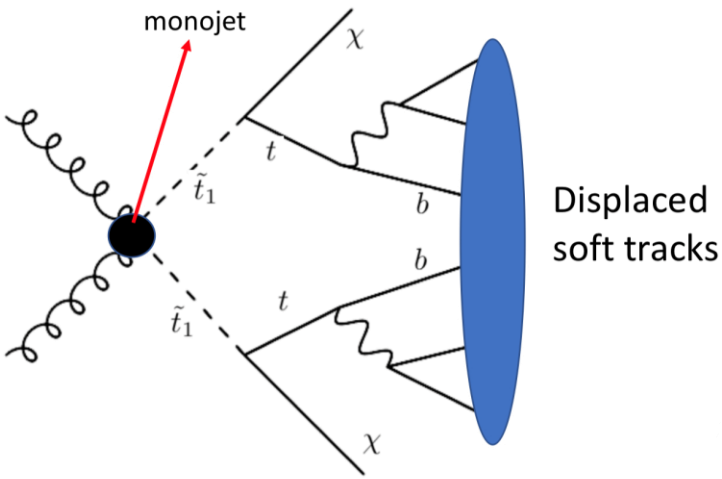
- Bosonic DM (Extra-dim/LHT):
  tH -> t* AH

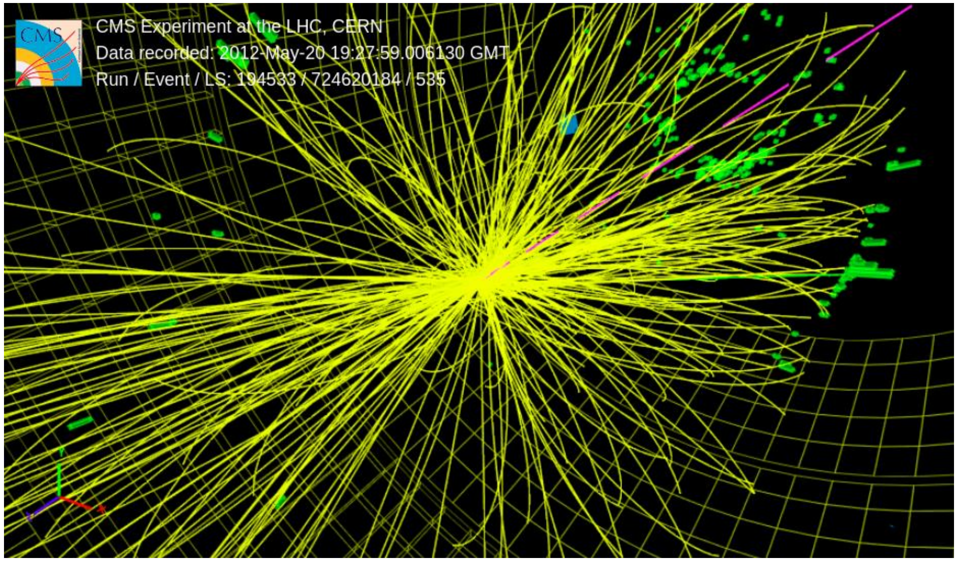
$$c\tau_{t_H} \approx 7.4 \text{ mm} \left(\frac{m_{t_H}}{500 \text{ GeV}}\right)\left(\frac{40 \text{ GeV}}{\Delta}\right)^{10}$$

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

Signatures

- PF MET trigger
- Reconstruct displaced vertices based on some displaced tracks





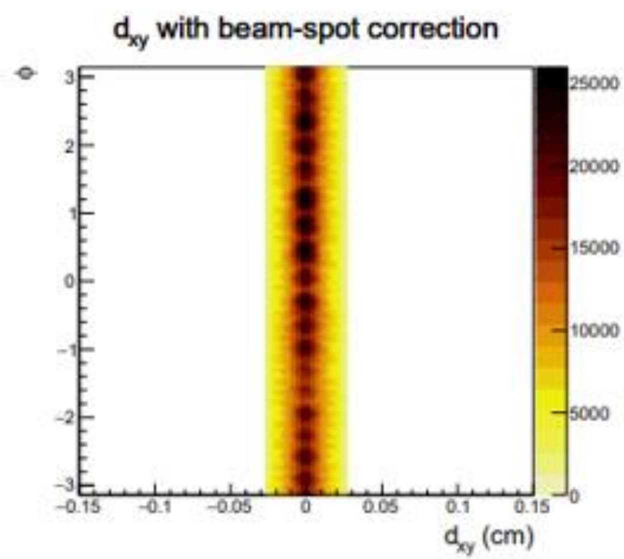
Challenges

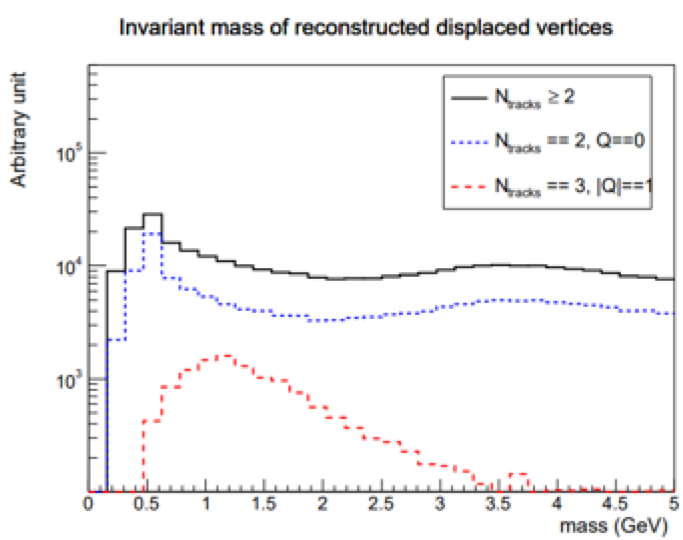
- Hundreds of soft tracks
- Background from misidentified track
- Mis-association of tracks in vertex reconstruction

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



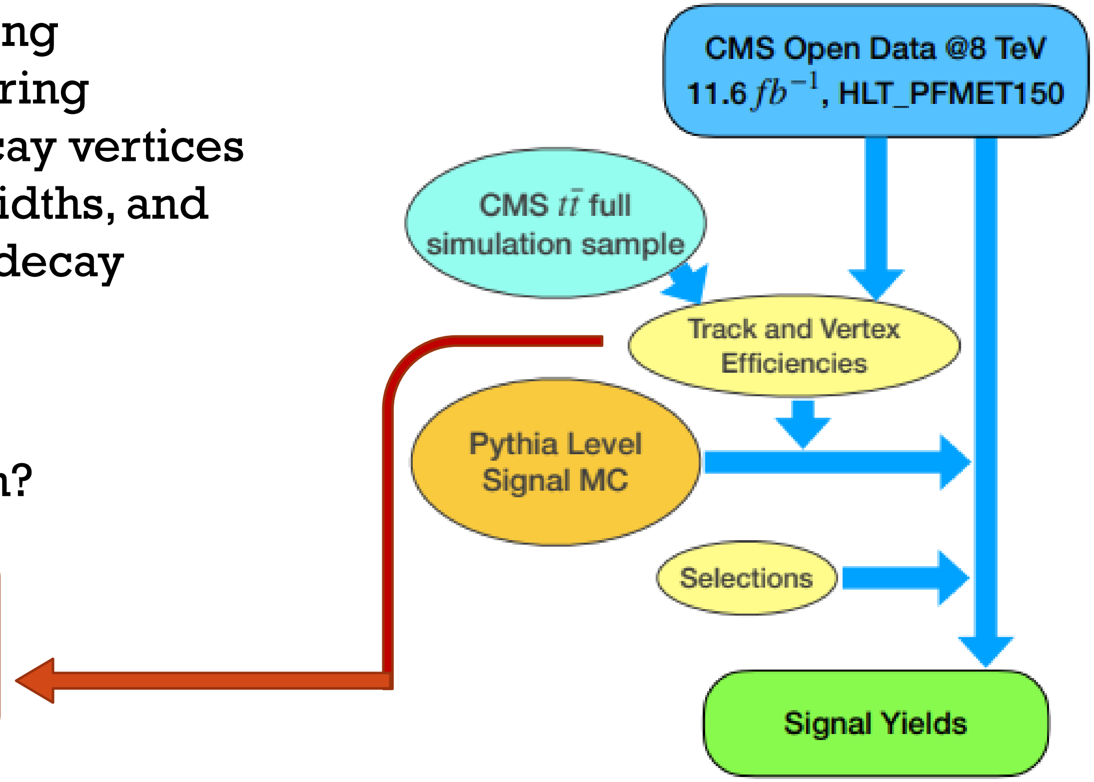


Vertex reconstruction and signal efficiencies

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?



➢ Compute KEY 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

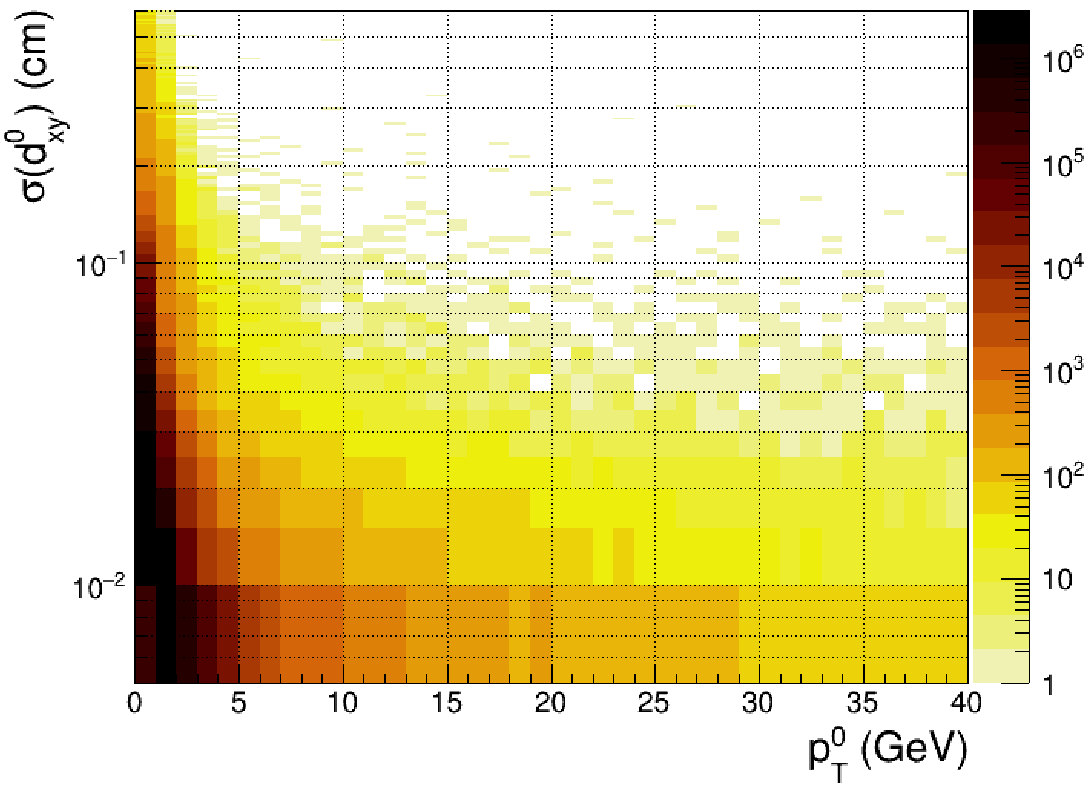
Reco: 90%

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

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

High fidelity tracks:

- *Uncertainty distribution of real tracks*



Vertex reconstruction and signal efficiencies

Parametrized vertex efficiencies for phenomenological studies

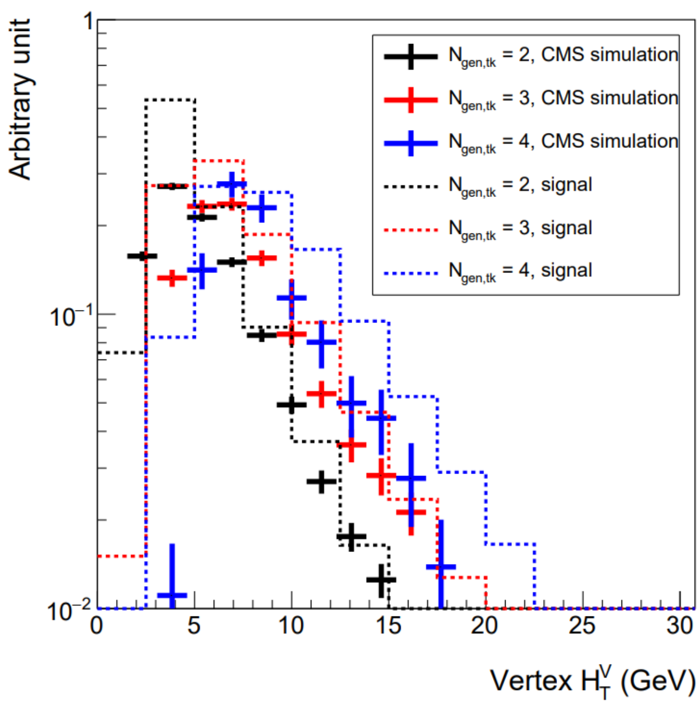
- Signal like events from the CMS ttbar sample
  - Generator level $B_0, \bar{B}_0$ hadronic decays
  - Energy in the range 10-30 GeV
  - Vertex position from the beam-line: 0.5-18 mm
- Two methods for a proof of principle (large overlap fractions)
  - Track fraction method
  - Vertex distance method
- $\geq$ 4 displaced tracks
- d_{BV} from 0.1 to 20 mm

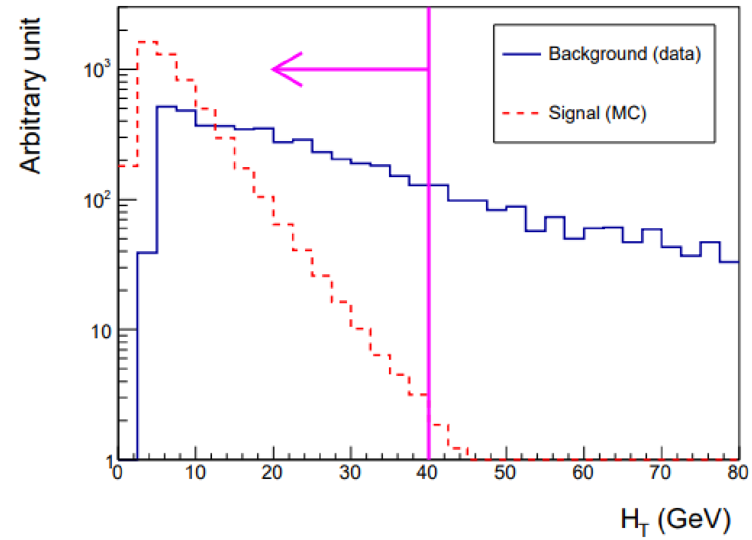
$N_{simulated,displaced}$=N1

Catalog	$N_{gen,tk}=2$	$N_{gen,tk}=3$	$N_{gen,tk}=4$	$N_{gen,tk}=5$	$N_{gen,tk}\geq 6$
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

N_{reco}=N2

Vertex reconstruction and signal efficiencies





We have limited data and cannot fully exploit 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, $\quad \Delta = 20$ GeV

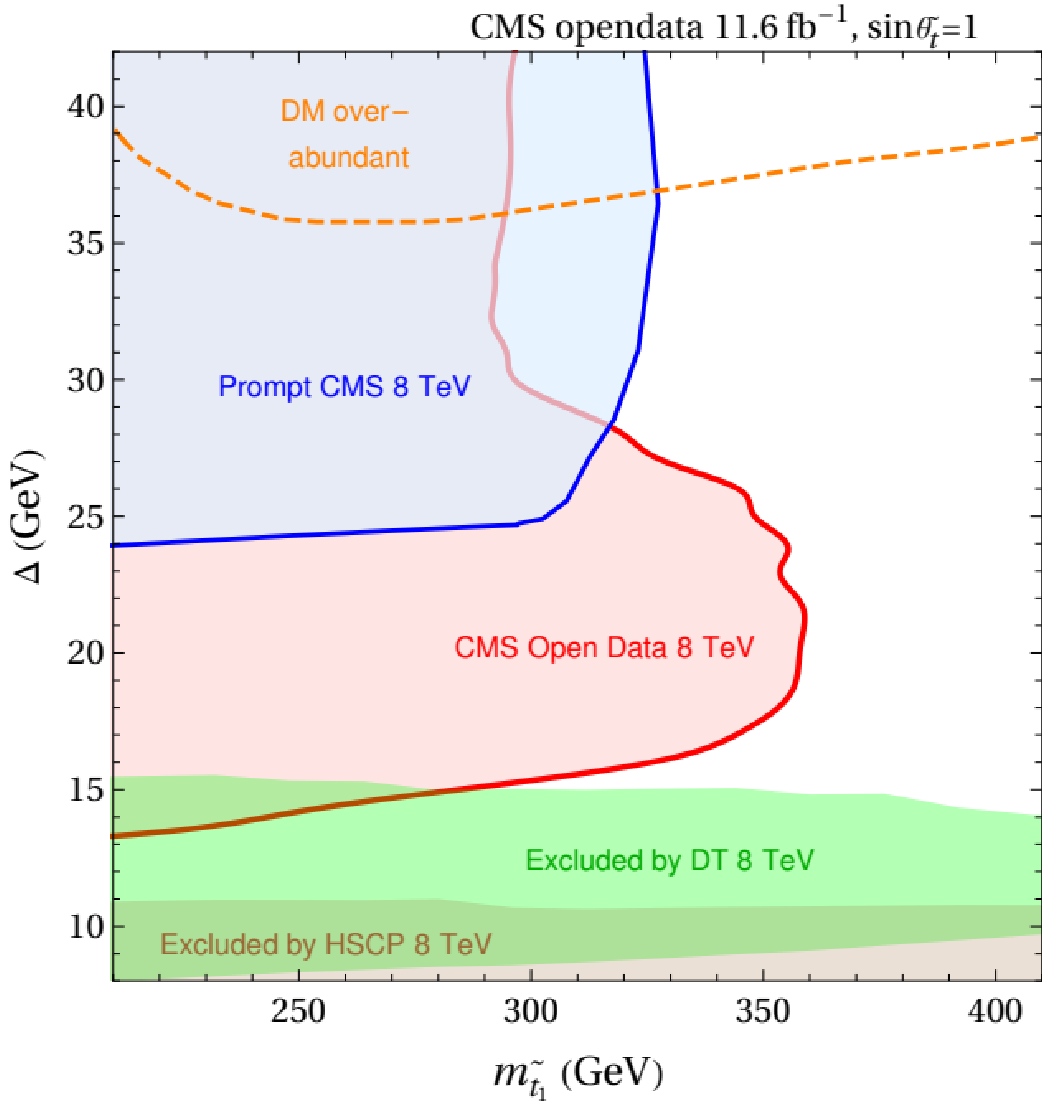
Limit contours: SUSY stop-bino model

Our results (stop-bino model)

- 8 TeV 11.6 fb^{-1}
- 95 % CL FC limit
- Most sensitive in the compressed region
- Continuously transits into prompt analysis

Prompt CMS

- **8 TeV 19.7 fb^{-1}**
- $\tilde{t} \to b l \bar{l} \tilde{\chi}_1^0$ **channel**
- Truncated at $c\tau$=0.2 mm



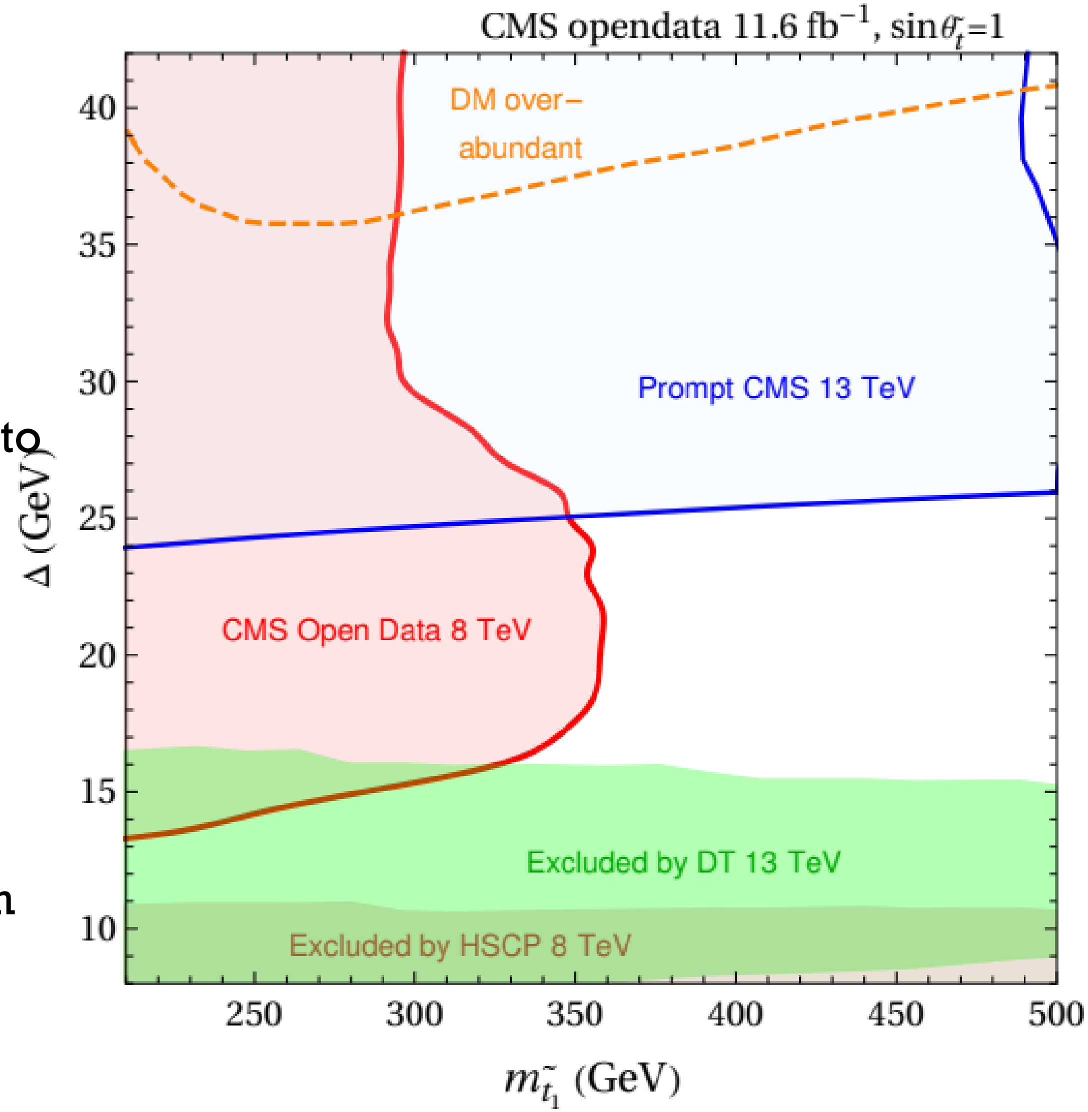
Limit contours: SUSY stop-bino, comparing with 13 TeV limits

Our results (stop-bino model)

- 8 TeV 11.6 fb^{-1}
- 95 % CL FC limit
- Most sensitive in the compressed region
- Continuously transits into prompt analysis

Prompt CMS

- **13 TeV 35.9 fb^{-1}**
- $\tilde{t} \to b f f' \tilde{\chi}_1^0$ **channel**, MVA approach
- 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 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

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BACKUP

Beam-spot correction

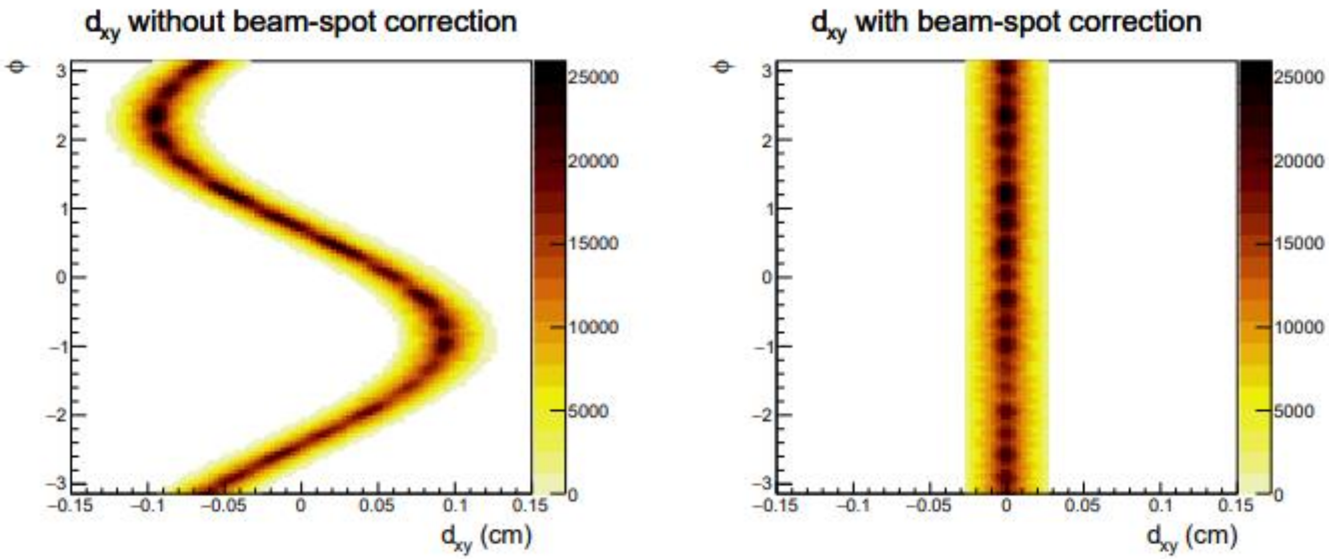


FIG. 8. Transverse track impact parameter distribution, computed with (right) and without (left) beam-spot correction. The figure is made using tracks from 10k data events.

Quality of vertex reconstruction

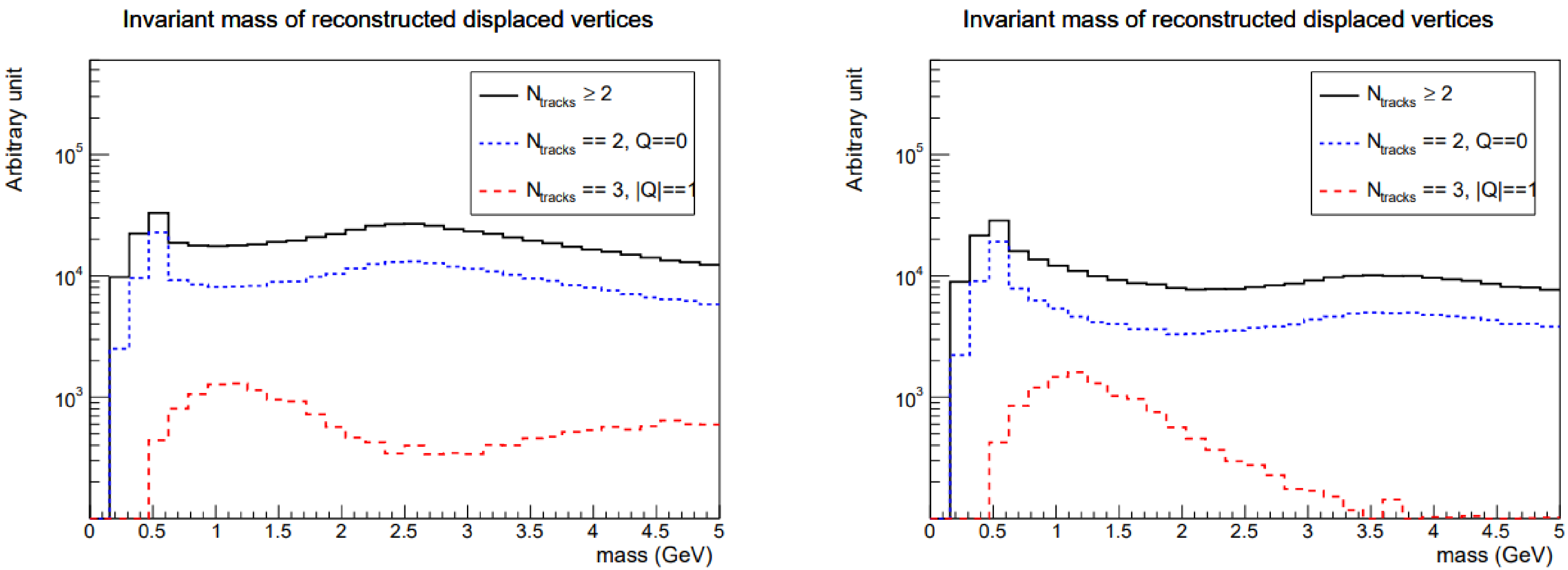


FIG. 4: Invariant mass of reconstructed displaced vertices using the Trimmed Kalman vertex filter with track p_{T} threshold 1 GeV (left) and 1.5 GeV (right).

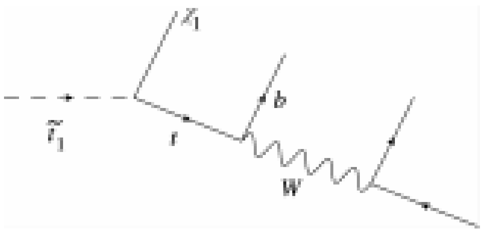
Setting limits

Number of observed events	Number of background events	95% CL limit
0	0	3.1
0	1	2.3
0	2	1.8
0	0	3.1
1	0	5.1
2	0	6.7

Table 1: The Feldman-Cousins limit on the number of signal events under various scenarios of different number of observed and assumed background events.

Stop life time in the compressed region

- Tree level analysis



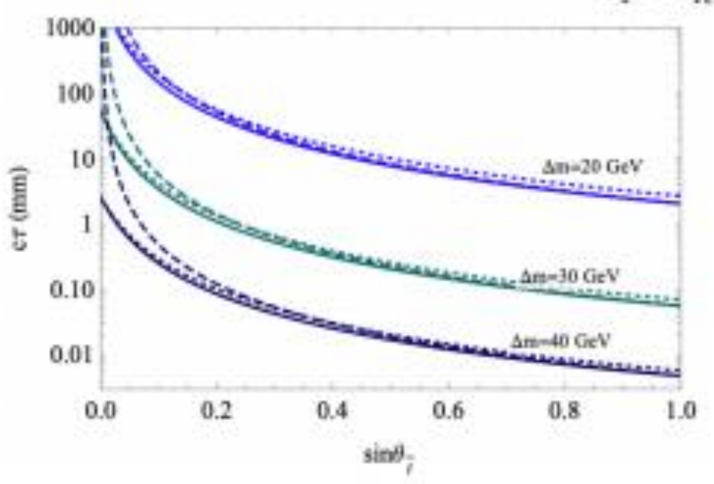
$$\tilde{t}_1 \equiv \cos\theta_{\tilde{t}}\tilde{t}_L + \sin\theta_{\tilde{t}}\tilde{t}_R$$

$$\chi_1^0 \equiv N_{11}\tilde{B} + N_{12}\tilde{W}_3 + N_{13}\tilde{H}_u + N_{14}\tilde{H}_d$$

$$\mathcal{L}^{\mathrm{tr}} = C_R^{(\ell)}\mathcal{O}_R^{(\ell)} + C_R^{(h)}\mathcal{O}_R^{(h)} + C_L^{(\ell)}\mathcal{O}_L^{(\ell)} + C_L^{(h)}\mathcal{O}_L^{(h)}$$

$\tilde{t}_1 = \tilde{t}_L$

$\tilde{t}_1 = \tilde{t}_R$



For pure right handed stop and pure bino

$$\Gamma = \frac{g_2^4 g_1^2 \Delta m^8}{20160\pi^5 m_W^4 m_t^2 m_{\tilde{t}}}$$

$$c\tau \approx 1.4\ \mathrm{mm} \times \left(\frac{20\ \mathrm{GeV}}{\Delta m}\right)^8$$