Long lived NMSSM : Analysing some long-lived NSLP signatures in the NMSSM

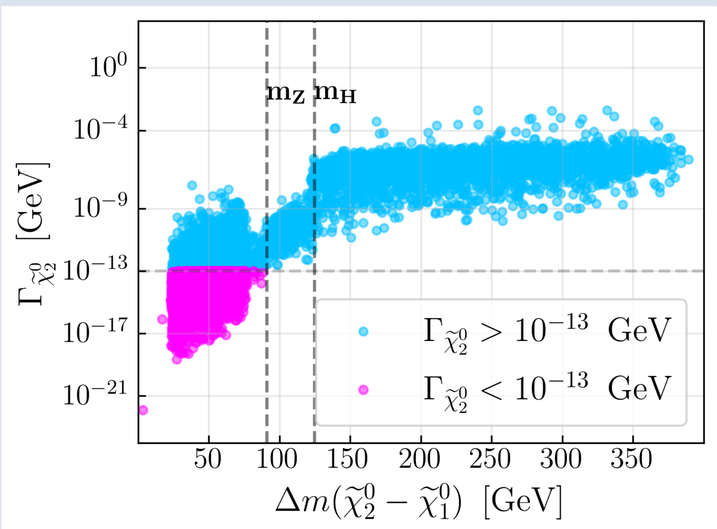
Amit Adhikary[d], Rahool K Barman[b], Biplob Bhattacherjee[a], **Amandip De**[a], Rohini M Godbole[a], Suchita Kulkarni[c]

[a] Centre for High Energy Physics, Indian Institute of Science, India, [b] Oklahoma State University, USA, [c] University of Graz, Austria, [d] University of Warsaw, Poland

Introduction

- A candidate for dark matter (DM) can be the LSP($\tilde{\chi}_1^0$) in R-parity conserving sypersymmetry models like MSSM/NMSSM.
- The prompt decays of heavier neutralinos have been studied extensively at colliders [arxiv:2107.12553,arxiv:2108.07586, arxiv:2106.01676].
- The case of long-lived neutralinos has been explored in the MSSM such as binolike, winolike [arxiv:1506.08779] and higgsinolike [arxiv:1211.5584].
- In NMSSM neutralinos can be an admixture of bino, higgsino, wino & an additional singlino.
- If the LSP (DM) is singlino-like then it couples very weakly to the SM particles and heavier neutralino decays to such $\tilde{\chi}_1^0$ may lead to long-lived-particle (LLP) signatures in NMSSM.
- Note the existence of the LLP in this scenario with singlino LSP is due to reduced couplings and is in contrast with the case in the MSSM where small mass splittings lead to LLP.

Feature of parameter space



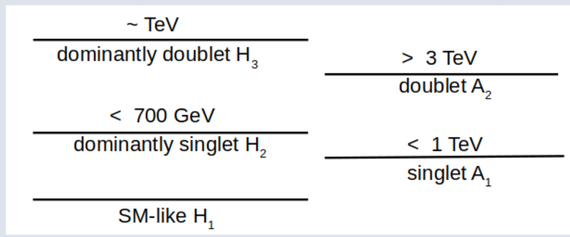
In the kinematically allowed region, bino-like NLSP exhibits decay width $\lesssim 10^{-13}$ GeV, which translates into decay length of $\mathcal{O}(1)$ mm with mass splitting of NLSP & LSP < 90 GeV.

NMSSM, parameter space

- NMSSM superpotential: $W_{MSSM}(\mu = 0) + \lambda \hat{S}\hat{H}_u\hat{H}_d + \frac{1}{3}\kappa\hat{S}^3$
  - Seven physical Higgs states: 3 neutral scalars (H_1, H_2, H_3), 2 neutral psuedo-scalars (A_1, A_2), 2 charged Higgs ($H^\pm$)
  - Five neutralino states from linear combination of bino, neutral wino, neutral higgsinos & singlino as $\tilde{\chi}_i^0 = \hat{N}_{i1}\tilde{B}^0 + \hat{N}_{i2}\tilde{W}_3^0 + \hat{N}_{i3}\tilde{H}_d^0 + \hat{N}_{i4}\tilde{H}_u^0 + \hat{N}_{i5}\tilde{S}^0$
- $\lambda, \kappa \ll 1$ ensures small singlet-doublet mixing in Higgs sector. In this limit $M_{\tilde{\chi}_1^0} \simeq 2\mu|\frac{\kappa}{\lambda}|$ predicts $\mathcal{O}(10^2)$GeV for $|\frac{\kappa}{\lambda}| \lesssim 0.1$.
- The parameter space is constrained by limits from LEP searches, flavor physics, Higgs signal strength, direct and indirect DM detection experiments, and direct electroweakino searches at LHC. However, no limit on DM relic density is in place assuming non-standard cosmological history.

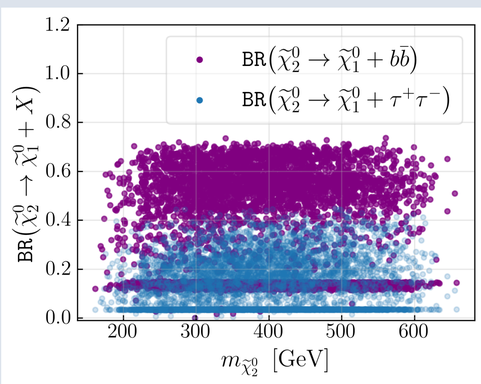
(3rd gen sleptons and squarks are fixed at ~ 2 TeV)

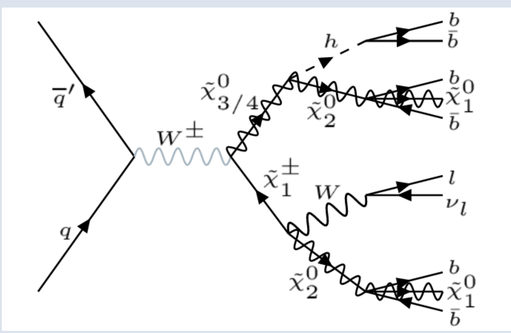
[scanned using NMSSMTools.5.5.3]



How to search at HL-LHC

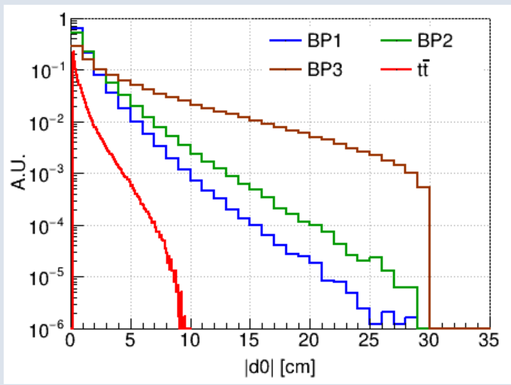
- A long cascade decay can be established from $\tilde{\chi}_{3,4}^0 \to \tilde{\chi}_2^0 + Z/H$ (60 – 80% BR) $\to \tilde{\chi}_2^0$, featuring 3-body decays ($\tilde{\chi}_1^0 + b\bar{b}/\tau^+\tau^-$).
- LLP signature like displaced vertex can be explored through chargino-neutralino pair production for mass ~ 750 GeV with cross section $\mathcal{O}(1)$ fb.
- A tracker restricted analysis can be performed using DELPHES with typical lepton triggers $p_T^{\ell_{1,2}} > 30, 20$ GeV, $\not{E}_T > 50$ GeV.

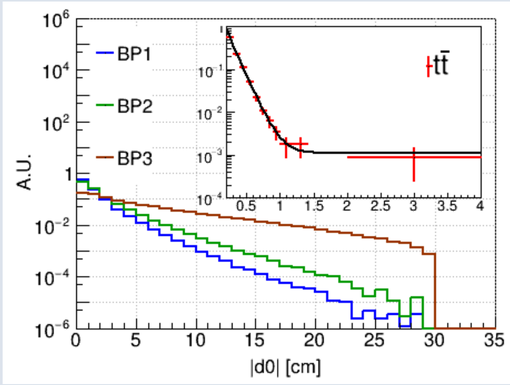




Displaced Vertex

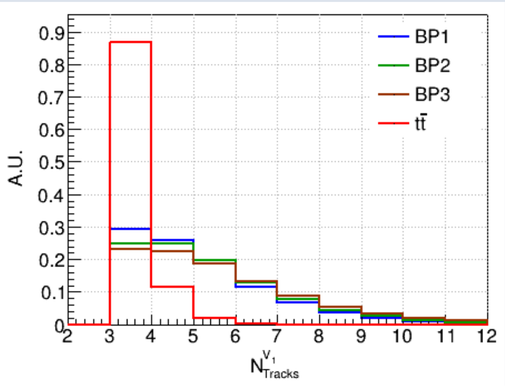
- Displaced vertex (DV) search is carried out using three benchmark points BP1, BP2, BP3 ($\Gamma_{\tilde{\chi}_2^0} \sim 10^{-14}, 10^{-15}, 10^{-16}$ GeV) respectively:
  - Collect high purity tracks with $p_T > 1$ GeV & $|\eta| < 4.5$.
  - Separate tracks originating from primary vertex requiring transverse impact parameter $|d_0| > 2$ mm $\to$ neglect majority of SM background like $t\bar{t}$.
  - At least 3 such tracks within $|\Delta X|, |\Delta Y|, |\Delta Z| < 1$ mm to reconstruct displaced secondary vertex.

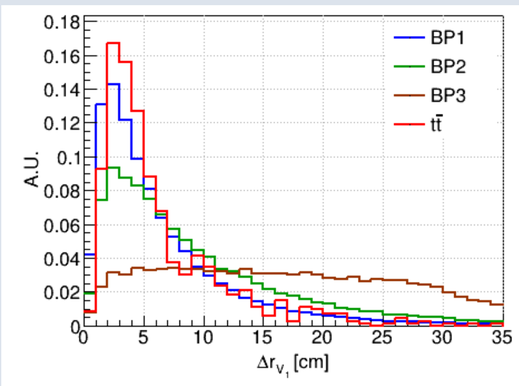


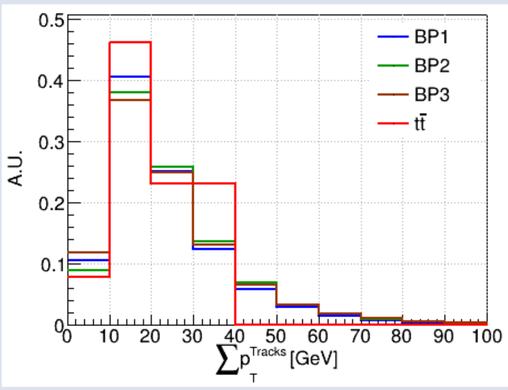


Other Discriminators

Standard track reconstruction have low efficiency for large d_0 values. Hence we have constructed a few variables except d_0 to eliminate the background such as track multiplicity of DV ($N_{\text{Tracks}}^{V_1}$), radial distance of DV from primary vertex (r_{V_1}) & p_T sum of tracks from DV (p_T^{tracks}).







Result

Signal and background yields at HL-LHC show it is possible to eventually arrive at a background free scenario even with relatively lower values of d_0.

Signal and background rates for $\sqrt{s} = 14$ TeV LHC for $\mathcal{L} = 3000$ fb^{-1}

Cuts	BP1	Semilep $t\bar{t}$
Lepton $\lvert d_0\rvert < 2$ mm	563	2×10^8
Lepton $p_T > 30$ GeV	421	1.31×10^8
MET > 50 GeV	409	1×10^8
$\lvert d_0^{\text{trk}}\rvert > 4$ mm	.....	.....
$N_{\text{trk}}^{V_1} > 3$	242	2187
$N_{\text{trk}}^{V_1} > 5$	96	0

amandipde@iisc.ac.in