SUSY Models: Non-Prompt Decays

Tambe E. Norbert

University of Minnesota,
Email: norbert@physics.umn.edu

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Introduction

1. Non-prompt decay of SUSY particles occur in the following SUSY breaking models:
   - Minimal Gauge Mediating SUSY Breaking (**GMSB**)
   - General Gauge Mediating SUSY Breaking (**GGM**)
   - Pure General Gauge Mediating SUSY Breaking (**PGGM**)
2. These models predict the existence of a Next-to-lightest sparticle (NLSP) decaying to a lightest sparticle (LSP).
3. The LSP can be (non)stable depending on R-Parity conserving(violation) RPC(RPV).
4. In RPC, NLSP decays to Gravitino($\tilde{G}$)) and SM-partner($\gamma, Z(\ell^+\ell^-)$, Higgs).
5. Focus: Scenario where NLSP could be any SUSY particle decaying to a photon i.e $\tilde{NLSP} \rightarrow \gamma + \tilde{G}$

NLSP SUSY Models

SUSY models are defined by a set of parameters.

1. GMSB
   - $\Lambda = \frac{\langle F_S \rangle}{M_m}$: An effective visible SUSY breaking scale,
   - M_m : The messenger scale,
   - N_5 : Parametrization of the SU(5) messenger fields,
   - $sgn(\mu)$: The sign of the Higgsino mass term
   - $\tan\beta = \frac{\langle H_u^0 \rangle}{\langle H_d^0 \rangle}$: At electroweak scale,
   - c_{grav} : The gravitino mass scaling factor.
2. GGM
   - M1: The Bino($\tilde{B}^0$) mass,
   - M2: The Wino($\tilde{W}^0$) mass,
   - M3: The Gluino ($\tilde{g}$) mass,
   - μ : SUSY higgs and Higgsino mass parameters,
   - $c\tau_{NLSP}$: NLSP lifetime.
3. PGGM : $M_{mess}, \Lambda_G, \Lambda_S$

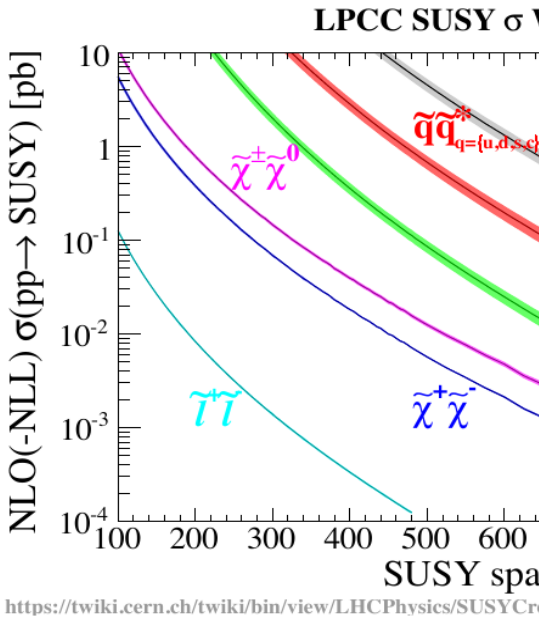
NLSP Production

Strong Production:

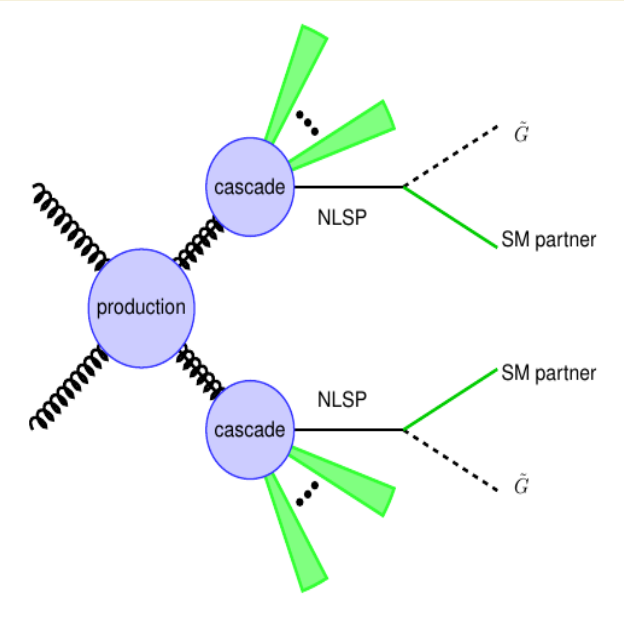
$$pp \to \tilde{q}\tilde{q}, \tilde{q}\tilde{q}^*, \tilde{q}$$

Weak Production:

$$pp \to \tilde{\chi}_2^0\tilde{\chi}_3^0, \tilde{\chi}_2^\pm\tilde{\chi}_1^0, \tilde{\chi}$$



NLSP Decay



Cascade Decays		
Particle	**Mass**	**Decay**
$\tilde{g}$	$M_{\tilde{g}}$	$\tilde{g} \to \mathrm{j}\tilde{q}^*$
$\tilde{q}$	$M_{\tilde{q}}$	$\tilde{q} \to \tilde{\chi}_1^0\mathrm{j}, \tilde{g}\mathrm{j}$
$\tilde{\chi}_2^0$	M_{wino}	$\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 h^{(*)}/Z^{(*)}$
$\tilde{\chi}_1^\pm$	M_{wino}	$\tilde{\chi}_1^\pm \to \tilde{\chi}_1^0 W^{\pm(*)}$

NLSP Type and Decay Modes		
NLSP Type	**Decay Mode**	**Final states(+ MET)**
Bino-Like	$\tilde{\chi}_1^0 \to \gamma + \tilde{G}$	$\gamma\gamma, \gamma + \mathrm{jets}$
Wino-Like	$\tilde{\chi}_1^0 \to \gamma + \tilde{G}$	$\ell\gamma, \gamma\gamma, \gamma + \mathrm{jets}, \ell + \mathrm{jets}$
Z-rich higgsino	$\tilde{\chi}_1^0 \to Z/Z^* + \tilde{G}$	$Z(\ell\ell)\mathrm{or}Z(\ell^{'}\ell^{'}) + \mathrm{jets}$

NLSP Decay Length

1. The probability for a NLSP produced with energy E_{NLSP} in the lab frame to decay before travelling a distance x is given as:

$$\mathcal{P}(x) = 1 - \exp\left(-\frac{x}{\mathrm{L}}\right) \quad (3$$

2. Theory/kinematics

$$c\tau_{NLSP} = 9.9 \times 10^{-8} \frac{1}{k_{1\gamma}}$$

$$(\beta\gamma)_{NLSP} = \frac{|p|}{m_{NLSP}}$$

NLSP Parameter Space

1. In GMSB, NLSP decay length is determined by:
   - Fundamental SUSY breaking scale is related to the gravitino mass through $\mathrm{F} = \mathrm{m}_{3/2} \times \sqrt{3}\mathrm{M}_{\mathrm{p}}$
   - The m_{NLSP} which can be related to F through $M_i = \frac{\alpha_i}{4\pi} N_5 \Lambda, i = 1, 2, 3$
   - From $m_{3/2} = \frac{\langle \mathrm{F} \rangle}{\lambda \langle F_S \rangle} \times \frac{\Lambda M_m}{\sqrt{3} M_p} = C_{grav} \frac{\Lambda M_m}{\sqrt{3} M_p}$, Thus, for NLSP to be long-lived $C_{grav} \gg 1$ implying $m_{\tilde{G}} \gg \ eV$
   - In MC production, NLSP is long-lived when $C_{grav} \gg 1$ is used and $m_{\tilde{G}} \approx 0$
2. For GGM, Is there such a parameter as C_{grav} to change NLSP inherent $c\tau_{NLSP}$?
3. For PGGM, at least the way $c\tau_{NLSP}$ is expressed, the NLSP lifetime depends on model input parameters: $M_{mess}, \Lambda_G, \Lambda_S$

MC Production

1. MC production of signal samples for GMSB/GGM/PGGM must span parameter grid space for which:
   - NLSP is long lived(reasonable $c\tau_{NLSP}$),
   - NLSP is boosted,
   - NLSP is massive enough.
   - NLSP decays with enough MET.
   - Consistent with SUSY cross section limits .
2. Tentative Parameter space to scan

NLSP Parameter Space			
NLSP Mass	$c\tau_{NLSP}$	**Parent Mass**	**NJets**
M1,M2	$C_{grav}, \Lambda_S, \Lambda_G$	M3, $M_{\tilde{q}}$	Pt_{jets}

3. Prelimanary studies using SLHE files from Yevgeny Kats(GGM) and Khoze et al(PGGM), however, these SLHE do not allow decay $\tilde{NLSP} \rightarrow \gamma + \tilde{G}$. I used information from GMSB to produce MC samples.

Sensitivity Study

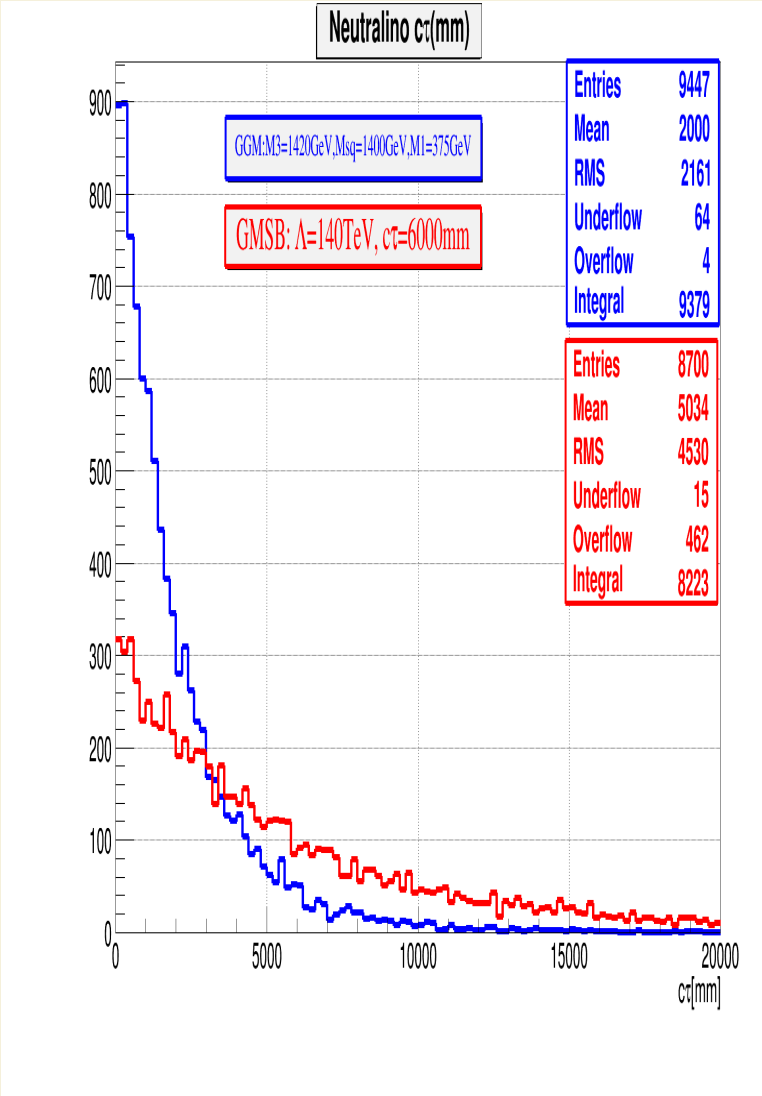


Figure : $c\tau_{\chi_1^0}$[mm]

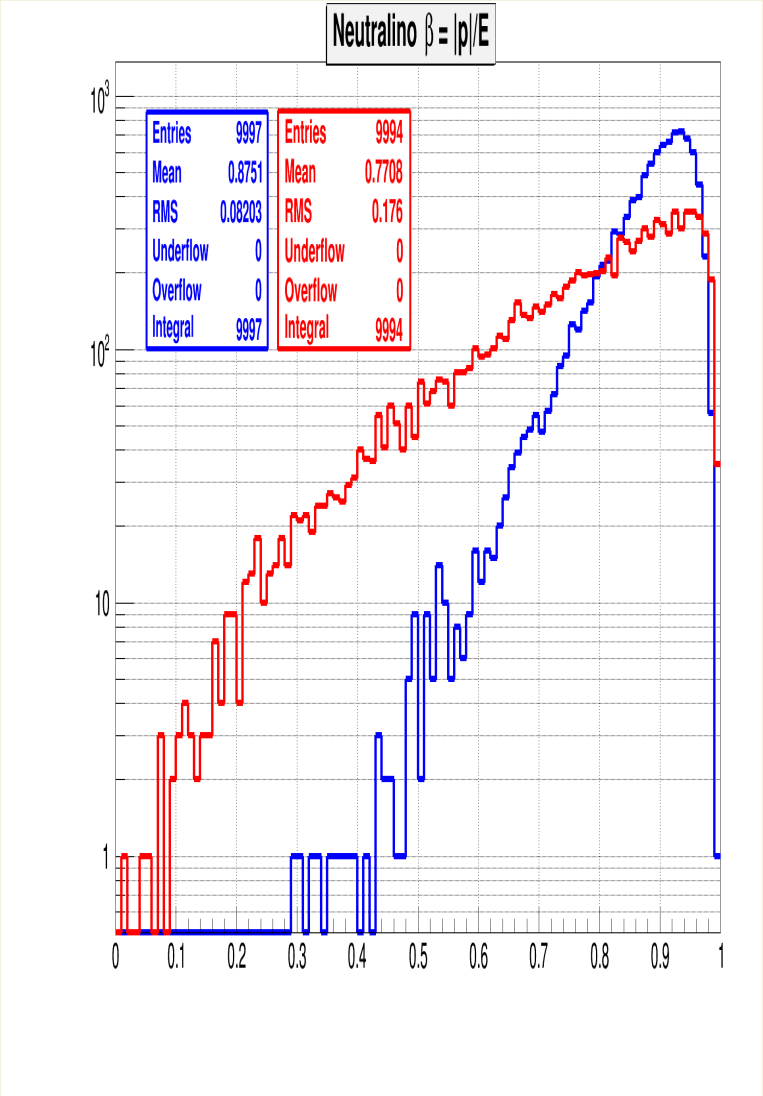
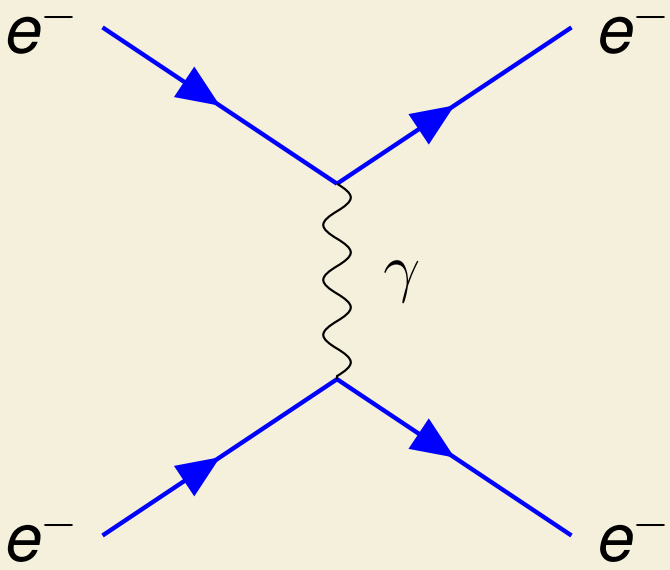


Figure : $Boost_{\chi_1^0}$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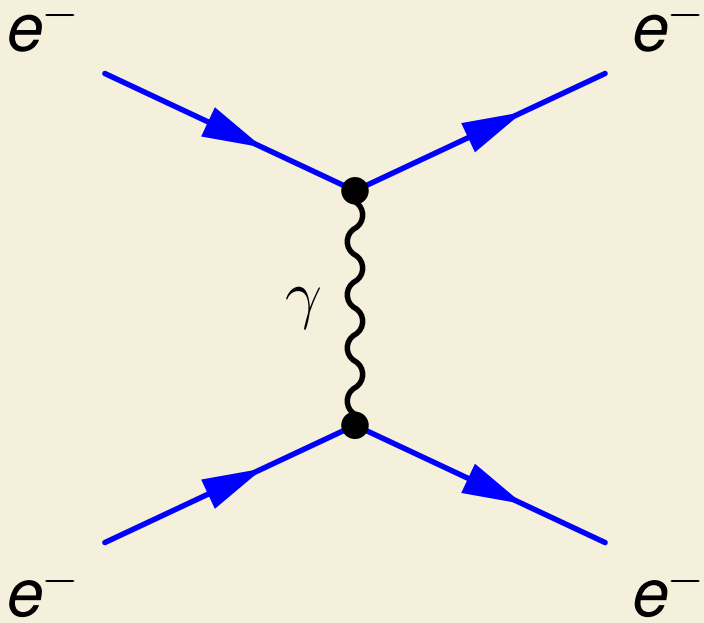
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