# SUSY Models: Non-Prompt Decays

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September 25, 2014

# Outline

# 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
   - $\Lambda = \dfrac{\langle F_S \rangle}{M_{\mathrm{m}}}$ : An effective visible SUSY breaking scale,
   - $M_{\mathrm{m}}$ : The messenger scale,
   - $N_5$ : Parametrization of the SU(5) messenger fields,
   - $sgn(\mu)$ : The sign of the Higssino mass term
   - $\tan\beta = \dfrac{\langle H_u^0 \rangle}{\langle H_d^0 \rangle}$ : 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,
   - $\mu$ : SUSY higgs and Higgsino mass parameters,
   - $c\tau_{NLSP}$: NLSP lifetime.
3. PGGM : $M_{mess}, \Lambda_G, \Lambda_S$

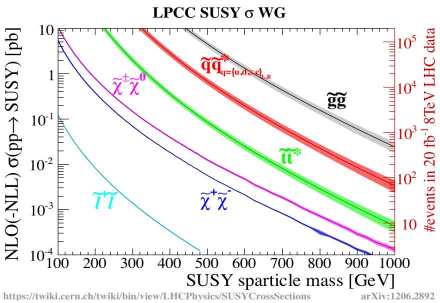
# NLSP Production

## Strong Production:

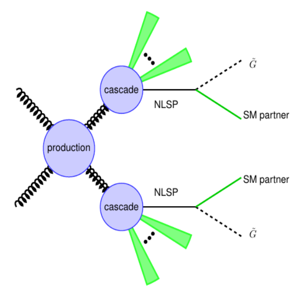
$$pp \to \tilde{q}\tilde{q}, \tilde{q}\tilde{q}^*, \tilde{q}\tilde{g}, \tilde{g}\tilde{g} + X \quad (1)$$

## Weak Production:

$$pp \to \tilde{\chi}_2^0\tilde{\chi}_3^0, \tilde{\chi}_2^\pm\tilde{\chi}_1^0, \tilde{\chi}_1^-\tilde{\chi}_1^+, \tilde{\chi}_2^0\tilde{\chi}_1^\pm + X \quad (2)$$



# NLSP Decay




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

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

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

$$\mathrm{L} = c\tau_{NLSP}\,(\beta\gamma)_{NLSP}\,(mm) \quad (4)$$

2. Theory/kinematics

$$c\tau_{NLSP} = 9.9 \times 10^{-8} \frac{1}{k_{1\gamma}} \left(\frac{m_{NLSP}}{100\,GeV}\right)^{-5} \left(\frac{\sqrt{\mathrm{F}}}{10\,TeV}\right)^{4} \quad (5)$$

$$(\beta\gamma)_{NLSP} = \frac{|p|}{m_{NLSP}} = \sqrt{\left(\frac{E_{NLSP}}{m_{NLSP}}\right)^{2} - 1} \quad (6)$$

# 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 $\mathrm{F}$ 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 $N\tilde{LSP} \rightarrow \gamma + \tilde{G}$. I used information from GMSB to produce MC samples.

# Sensitivity Study

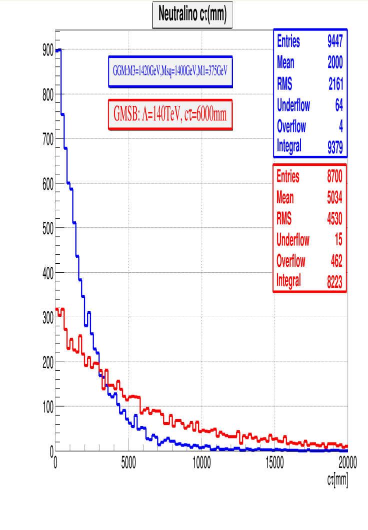



Figure : $c\tau_{\chi_1^0}$[mm]

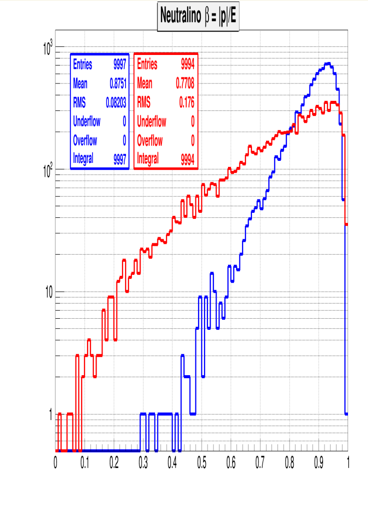



Figure : $Boost_{\chi_1^0}$