Exotic signals from NMSSM with RH sneutrino LSP

Osamu Seto

(Hokkai-Gakuen Univ.)

Starting point

- We ❤ SUSY

- Heavy Higgs → (1) Heavy stop and/or large A

  (2) beyond MSSM   **NMSSM**

  + seesaw

- No MET → (1) Continue to search

  (2) another more exotic signature

  Displaced vertex or **Long-lived charged particle**

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- Displaced vertex
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§ Model: NMSSM with right-handed neutrino

Model [D. G. Cerdeño, C. Muñoz and OS (2009)]

- ## Superpotential [R. Kitano and K. y. Oda, (2000)]

The superpotential is given by

$$W = W_{\text{NMSSM}} + \lambda_N S N N + y_N L \cdot H_2 N, \tag{2.1}$$

$$W_{\text{NMSSM}} = Y_u H_2 \cdot Q u + Y_d H_1 \cdot Q d + Y_e H_1 \cdot L e - \lambda S H_1 \cdot H_2 + \frac{1}{3}\kappa S^3, \tag{2.2}$$

where flavour indices are omitted and the dot denotes the $SU(2)_L$ antisymmetric product.

- Right-handed sneutrino can be the LSP.
- Right-handed Majorana neutrino mass

$$M_N = 2\lambda_N v_s$$

Model [D. G. Cerdeño, C. Muñoz and OS (2009)]

- Left-handed Majorana neutrino mass

$$m_{\nu_L} = \frac{y_N^2 v_2^2}{M_N} \approx 0.1 \text{ eV}$$

from RH neutrino $\quad M_N = 2\lambda_N v_s$

- By seesaw with a weak scale M_N,

  y_N is of order of y_e !

The origin of long-lived

§ Benchmark points

Benchmark

| Scenarios	S1			S2			S3	
$\tan\beta$	2.0			2.5			2.7	
$M_1,\ M_2,\ M_3$	500, 650, 1950			300, 600, 1800			345, 575, 2500	
$m_{L,E}$	300			250			1000,350	
$m_{Q,U,D_{1,2}}$	2000			2000			2000	
m_{Q,U,D_3}	1500			2000			2000	
$m_{H_1^0},\ m_{H_2^0},\ m_{H_3^0}$	99.5, 125.8, 358.6			125.7, 225.7, 446.2			125.8, 656.9, 1650.5	
$m_{\tilde{\chi}_1^\pm},\ m_{\tilde{\chi}_2^\pm}$	144.9, 674.1			173.6, 627.5			530.6, 676.5	
$m_{\tilde{\tau}_1},\ m_{\tilde{\tau}_2}$	290.5, 312.9			245.9, 259.5			352.0, 1000.8	
Benchmark Points	**S1a**	**S1b**	**S1c**	**S2a**	**S2b**	**S2c**	**S3a**	**Sb3**
λ_N	0.165	0.091	0.017	0.067	0.033	0.017	0.083	0.151
$m_{\tilde{N}}$	92.2	128.9	80.6	68.5	130.9	42.5	190.7	179.2
A_{λ_N}	-250	-250	-250	-150	-150	-150	-500	-750
y_N	10^{-7}	10^{-6}	10^{-5}	10^{-6}	10^{-6}	10^{-5}	10^{-7}	10^{-7}
$m_{\tilde{N}_1}$	20	100	70	70	130	40	200	65
M_N	100	55	10	40	20	10	170	310

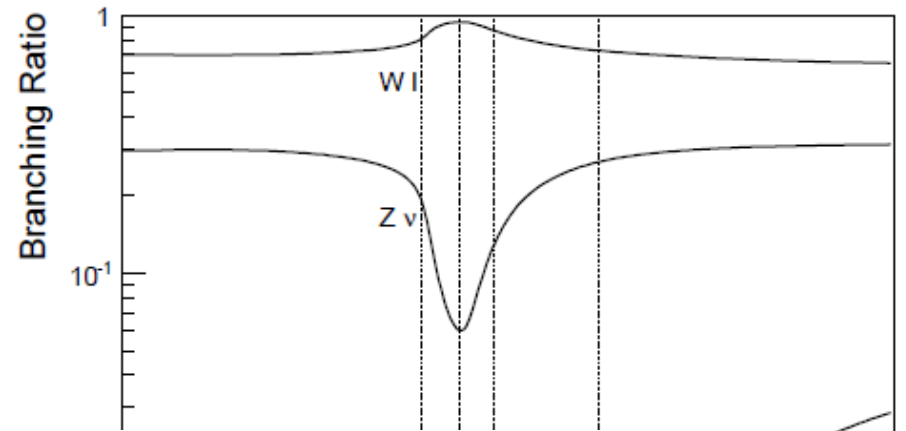# § Displaced vertex

Processes

- Production
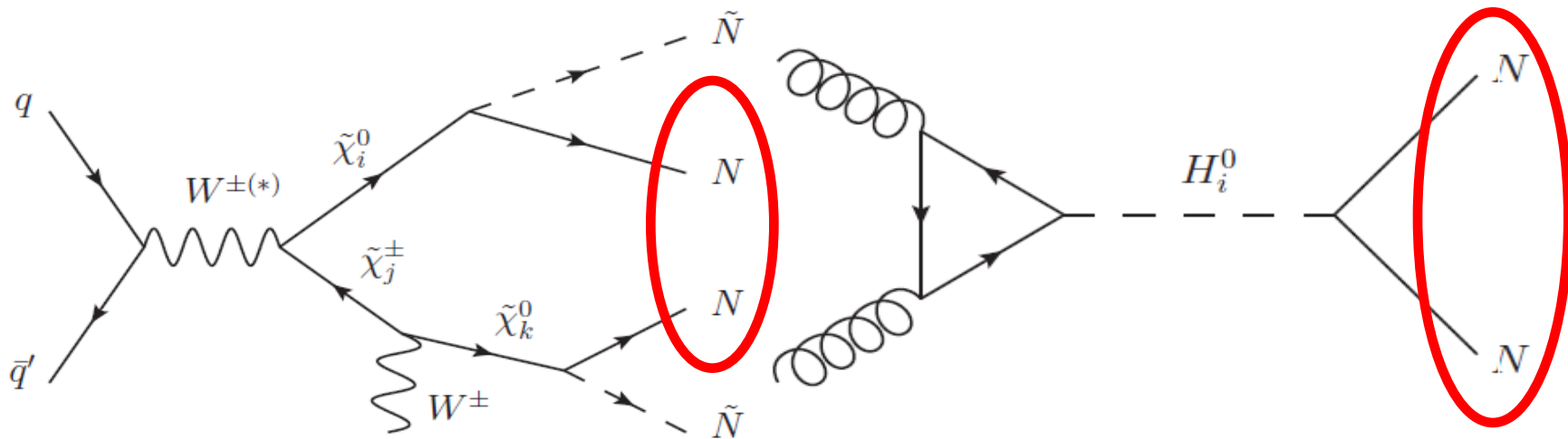
	$\sigma_{H_i^0}^{8\text{TeV}}$	$\sigma_{\tilde{\chi}_j^\pm \tilde{\chi}_i^0}^{8\text{TeV}}$	$\sigma_{H_i^0}^{13\text{TeV}}$	$\sigma_{\tilde{\chi}_j^\pm \tilde{\chi}_i^0}^{13\text{TeV}}$	M_N	$m_{\tilde{N}_1}$	$m_{\tilde{\chi}_1^0}$
S1a	2×10^{-5}	0.87	3×10^{-4}	1.94	100	20	127
S1b	0.89	–	2.06	–	55	100	127
S1c	0.54	0.87	1.24	1.94	10	70	127

Processes

Traveling distance
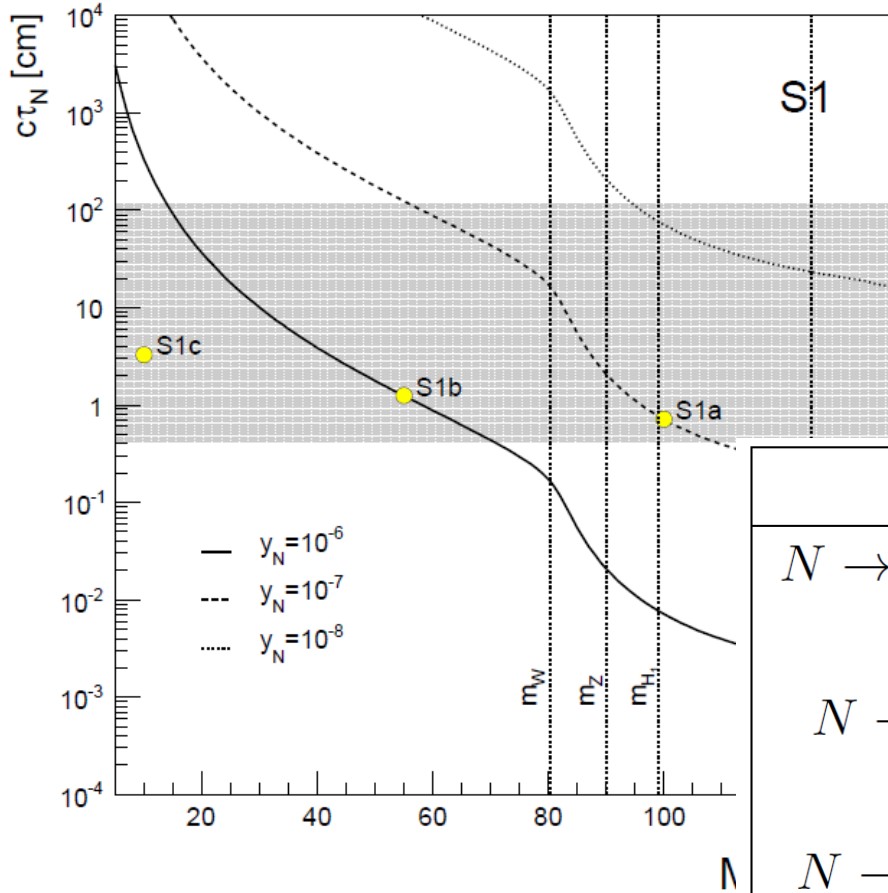
Decay

Process	Signature
$N \to W^\pm l_i^\mp \to \nu_j l_j^\pm l_i^\mp$	$2\ell(+\not{E}_T)$
$\to q\bar{q}' l_i^\mp$	$\ell j j$
$N \to Z\nu_i \to \nu_i l_j^\pm l_j^\mp$	$2\ell(+\not{E}_T)$
$\to \nu_i q\bar{q}$	$2j(+\not{E}_T)$
$N \to H_i^0 \nu_i \to \nu_i l_j^\pm l_j^\mp$	$2\ell(+\not{E}_T)$
$\to \nu_i q\bar{q}$	$2j(+\not{E}_T)$
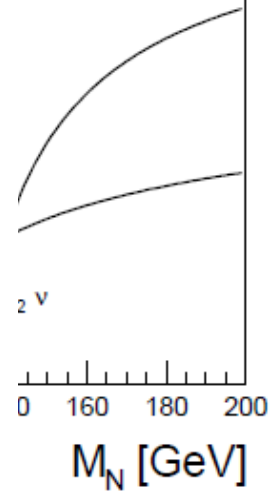
Results

- Under certain kinematical cuts,
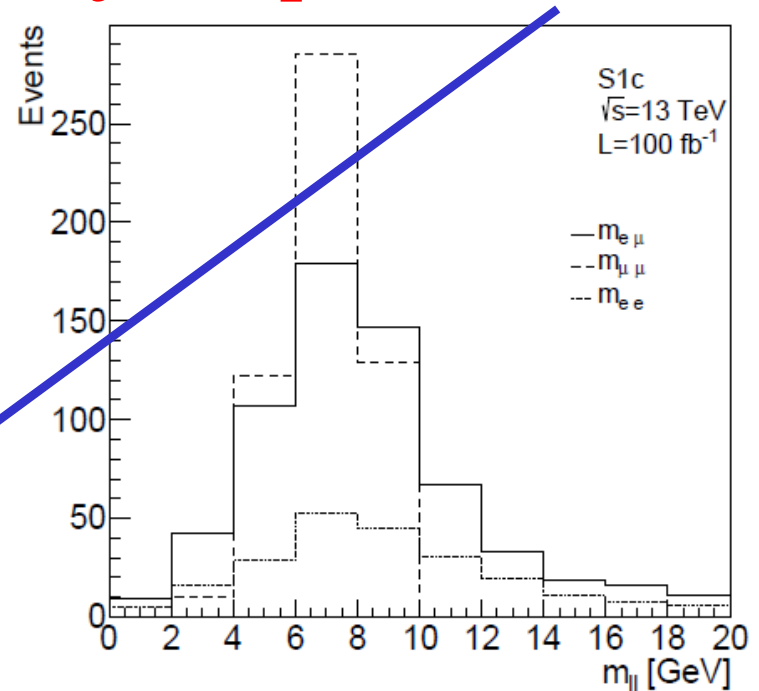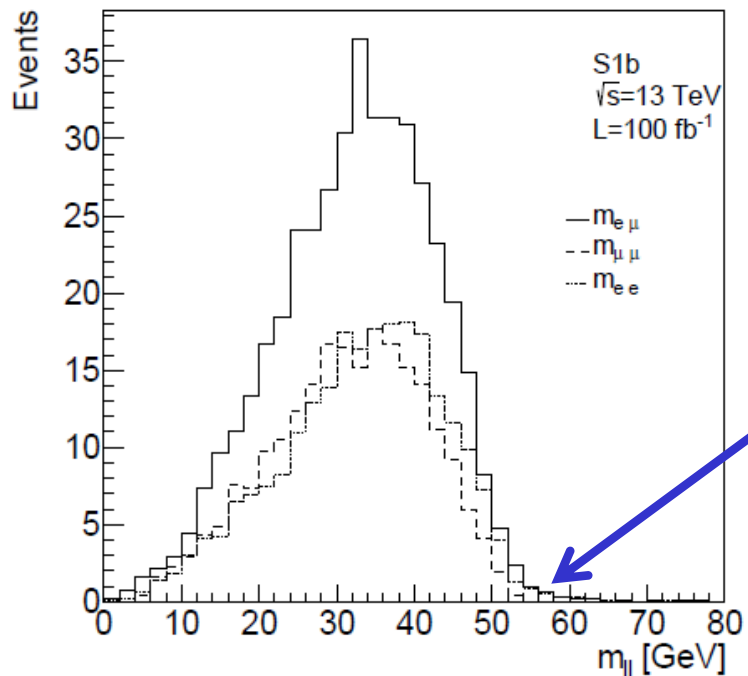
  2 l + MET by ν

  8 TeV *invariant mass for leptons*
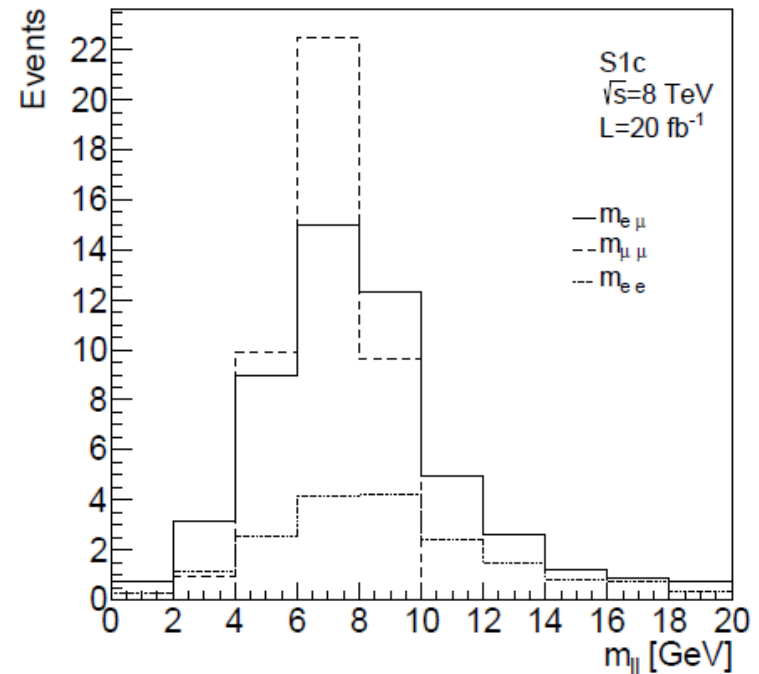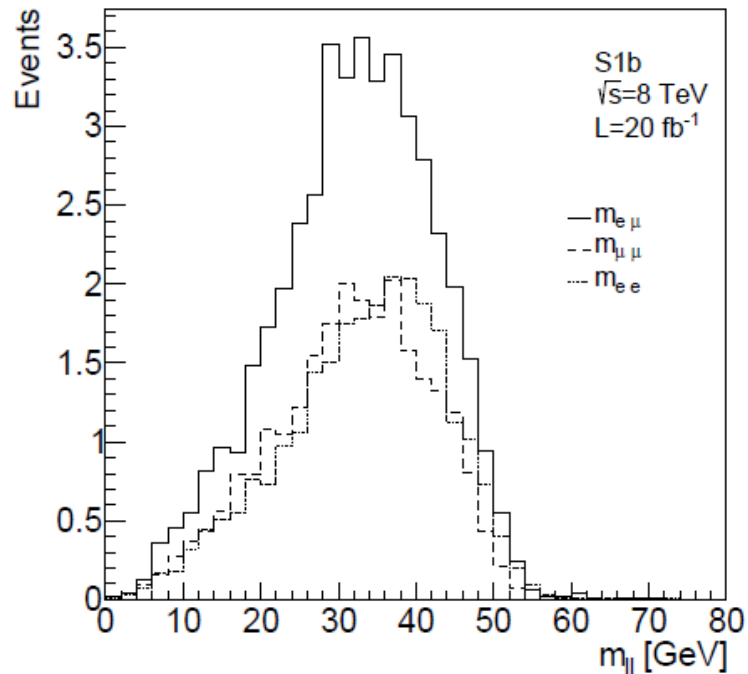
Results

- Under certain kinematical cuts,

  $2\,l + \text{MET}$ by v

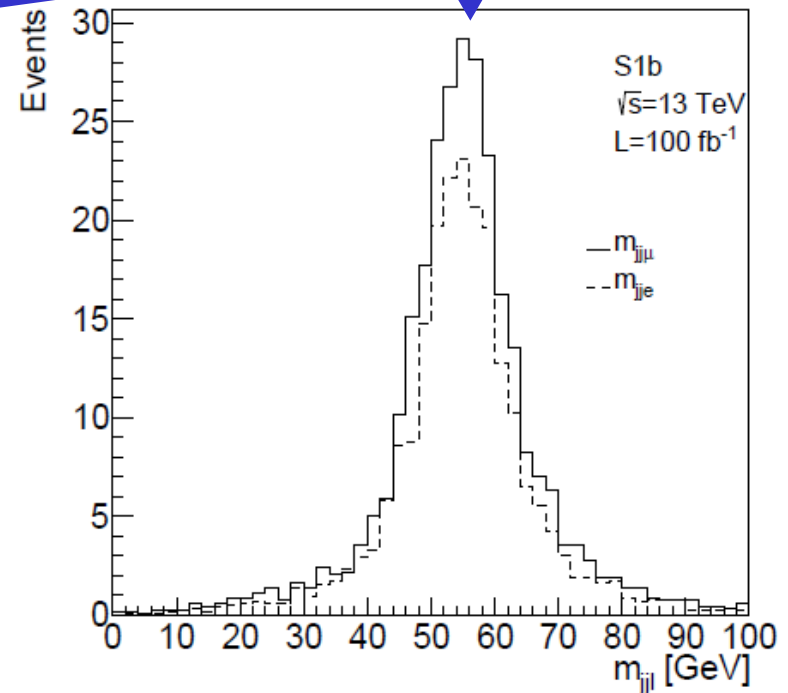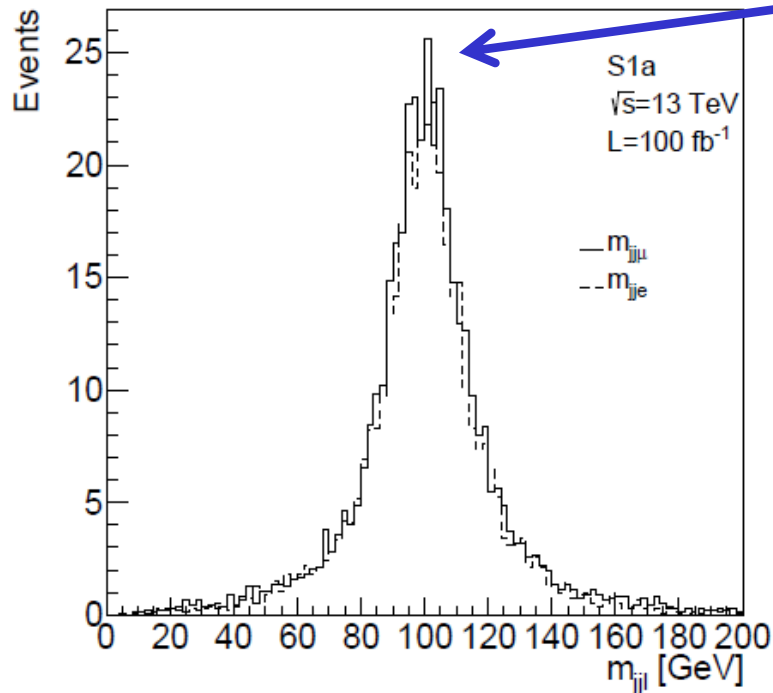 13 TeV *invariant mass for leptons* *N mass*

Results

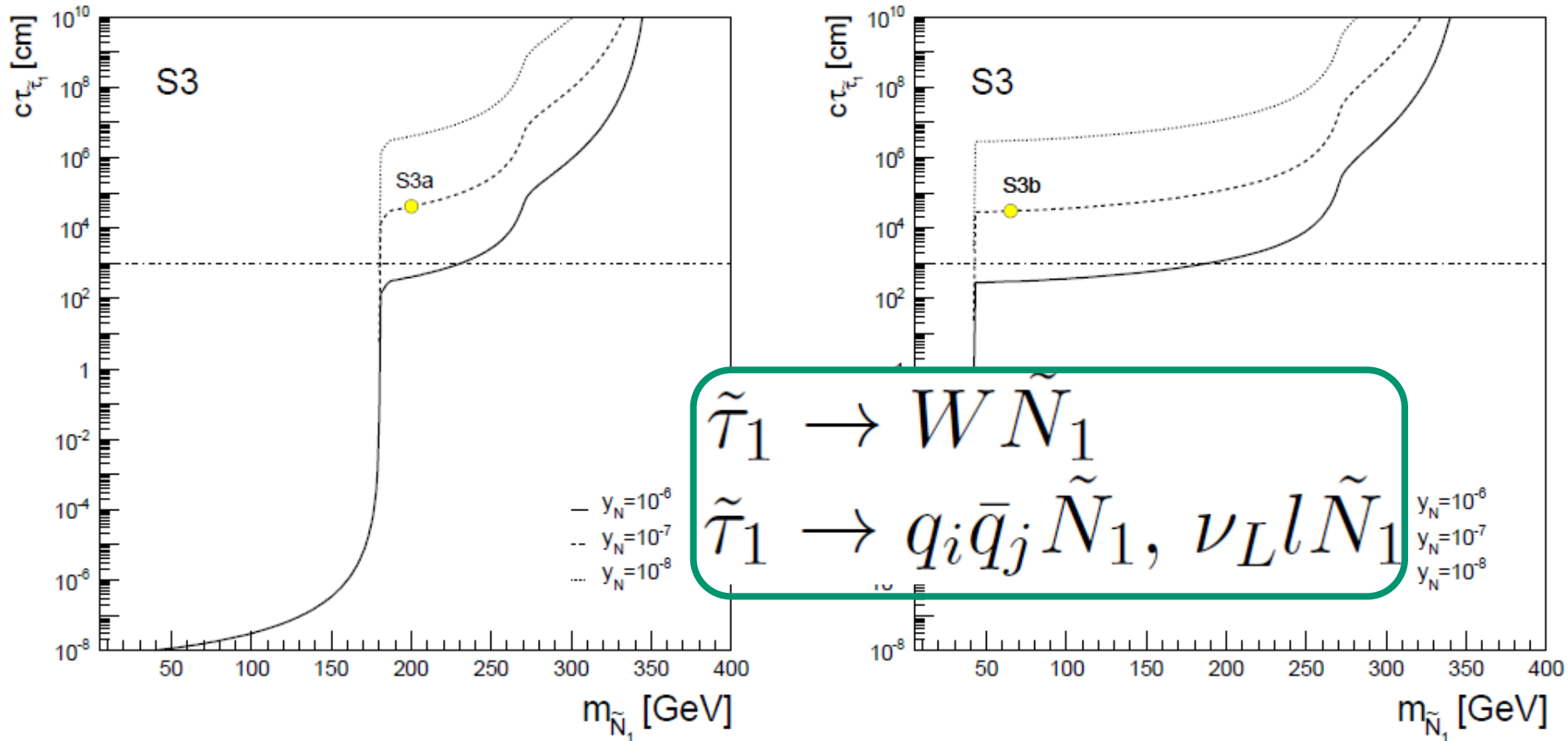- Under certain kinematical cuts,

  ljj @ 13 TeV   *invariant mass*   *N mass*

§ Long-lived charged particle

Processes

Decay and Traveling distance

$$\tilde{\tau}_1 \rightarrow W\tilde{N}_1$$
$$\tilde{\tau}_1 \rightarrow q_i\bar{q}_j\tilde{N}_1, \; \nu_L l\tilde{N}_1$$

Processes

- Production of stau NLSP
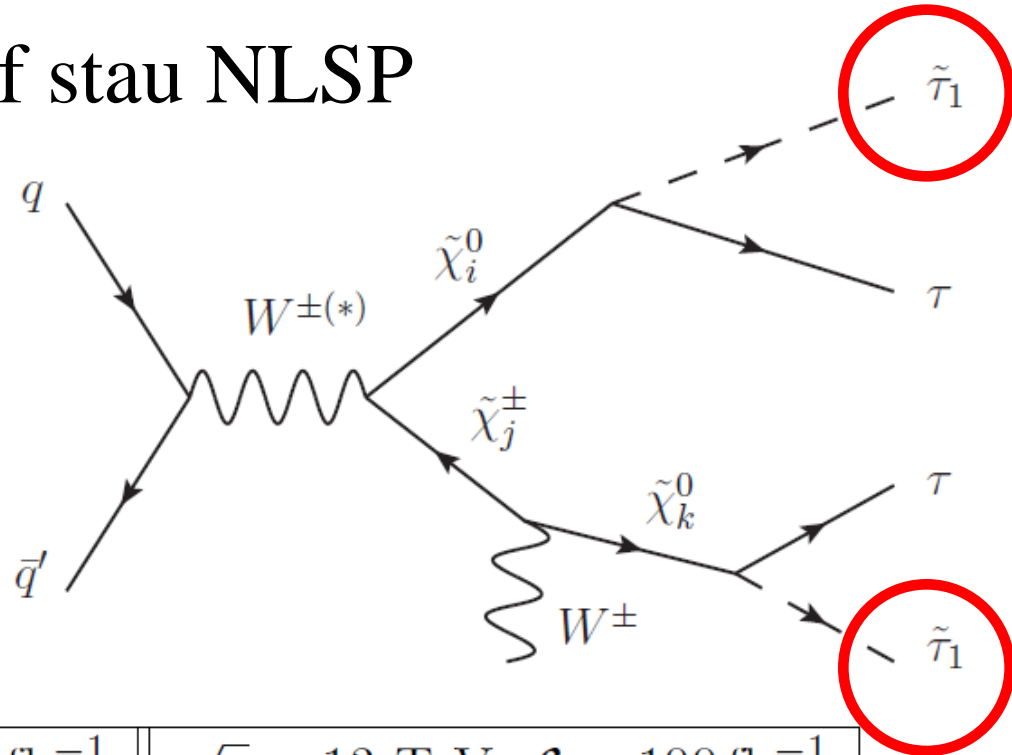
	$\sqrt{s} = 8 \text{ TeV}, \mathcal{L} = 20 \text{ fb}^{-1}$ $\sigma^{8\,\text{TeV}}_{\tilde{\chi}^{\pm}_j \tilde{\chi}^0_i} = 1.17 \text{ fb}$	$\sqrt{s} = 13 \text{ TeV}, \mathcal{L} = 100 \text{ fb}^{-1}$ $\sigma^{13\,\text{TeV}}_{\tilde{\chi}^{\pm}_j \tilde{\chi}^0_i} = 4.77 \text{ fb}$
S3a	1.7	30.3
S3b	1.5	28.9

§ Summary

Exotic signals in the NMSSM with RH sneutrino

- Displaced vertex by RH neutrino, long-lived stau NLSP.
- A $\chi^0 \bar{\chi}^0$ pair production is important.
- @13 TeV LHC, $\mathcal{O}(\mathbf{10})$ **events are expected.**

- Rich physics, e.g.,

   Measurement of M_N,

   Discrimination with other models (GMSB, $R\!\!\!/p$,...)