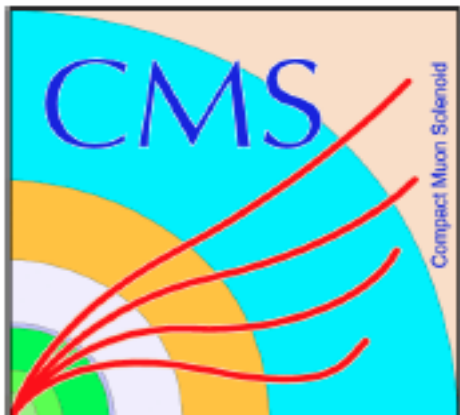


Search for R-Parity violated Supersymmetry at CMS

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Second LHC Physics Meeting at IPM
(7-11 October)



Outline

- Introduction
 - Motivation
- Search for stop in R-parity-violating supersymmetry with three or more leptons and b-tags
- Search for RPV SUSY in the 4-lepton final state in pp collisions at 8 TeV
- Conclusion

Supersymmetry and R parity

- Definition R-Parity: $R = (-1)^{(3B+L+2s)}$ (B)aryon, (L)pton and (s)pin
- R-Parity conserving theory:
 - Super partners produced in pairs.
 - Lightest Supersymmetric particle (LSP) is stable
 - Dark matter candidate
 - Experimental MET signature
- R-Parity Violating (RPV) terms allowed

$$W_{\text{RPV}} = \frac{1}{2}\lambda_{ijk}L_iL_jE_k^c + \lambda'_{ijk}L_iQ_jD_k^c + \frac{1}{2}\lambda''_{ijk}U_i^cD_j^cD_k^c + \mu_iL_iH_u$$

- resonant production of SUSY particles
- unstable SUSY LSP
- Low MET

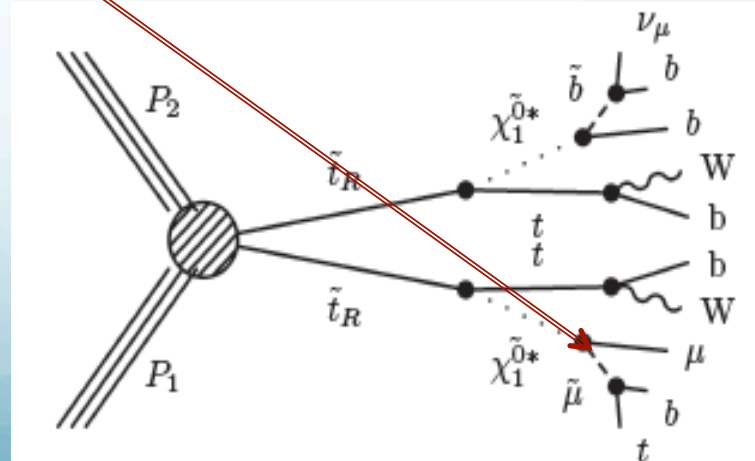
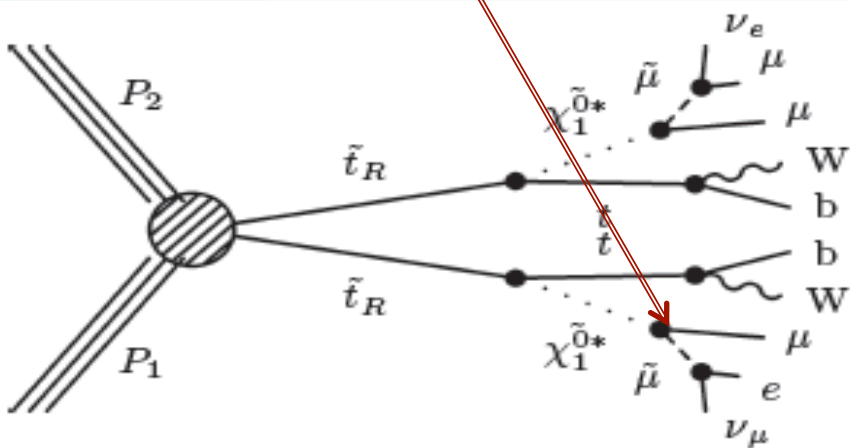
Search For Stop in RPV SUSY

CMS SUS-013-003

Search For Stop in RPV SUSY

- R-parity is violated via either lepton or baryon number violation. Only one of the couplings has a non-zero value

$$\frac{1}{2}\lambda_{ijk}L_iL_jE_k^c + \lambda'_{ijk}L_iQ_jD_k^c + \frac{1}{2}\lambda''_{ijk}U_i^cD_j^cD_k^c + \mu_iL_iH_u$$



Event Selections

- Search for new physics in events with three or more leptons
 - Bin in number of leptons (electrons + muons + taus)
- At least one b-quark
- Remove events with OSSF (opposite sign, same favor) dilepton mass on Z and below 12 GeV J/Ψ events
- In stop RPV scenarios with the stop mass close to the top mass → the amount of $\mathbf{E}_T^{\text{miss}}$ is also really low.
 - Define search regions in different S_T bins

$$\mathbf{S}_T = \mathbf{MET} + \mathbf{HT} + \mathbf{P}_T^{\text{leptons}}$$

MET = Missing Transverse Energy

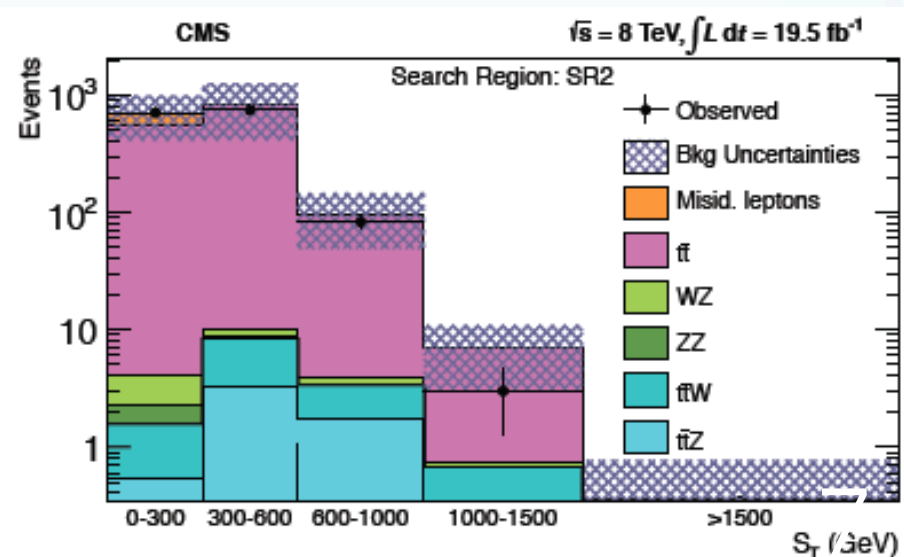
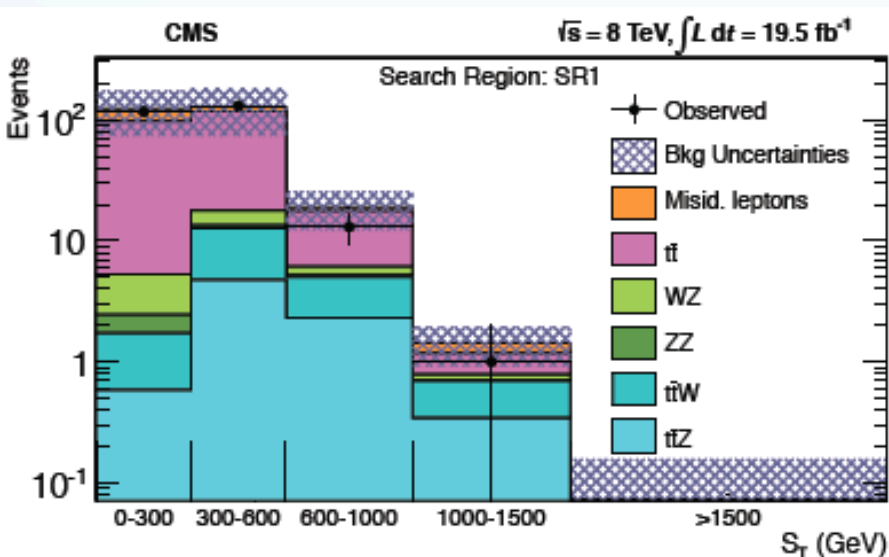
HT = Scalar sum of all selected Jet P_T

P_T^{leptons} = Selected leptons P_T

Results

Observed and Predicted Events in all signal regions

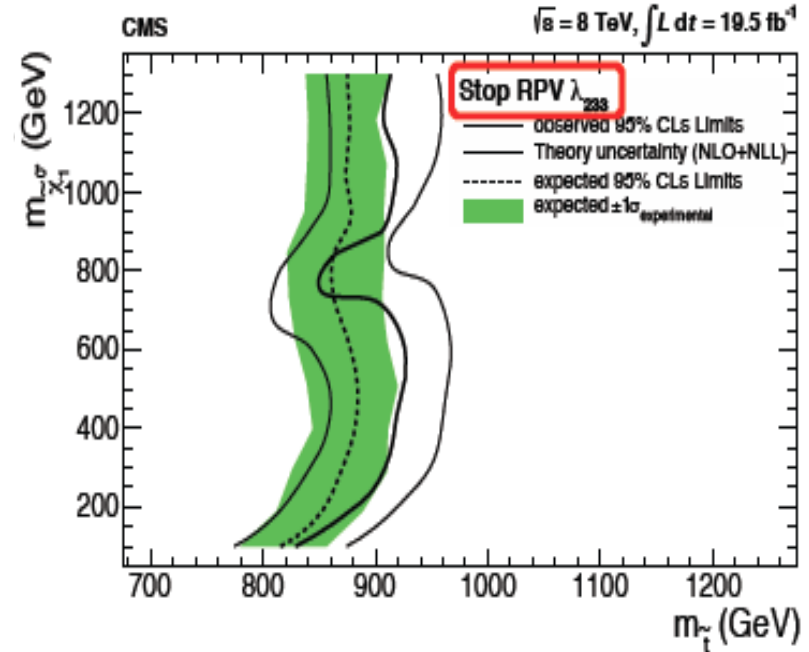
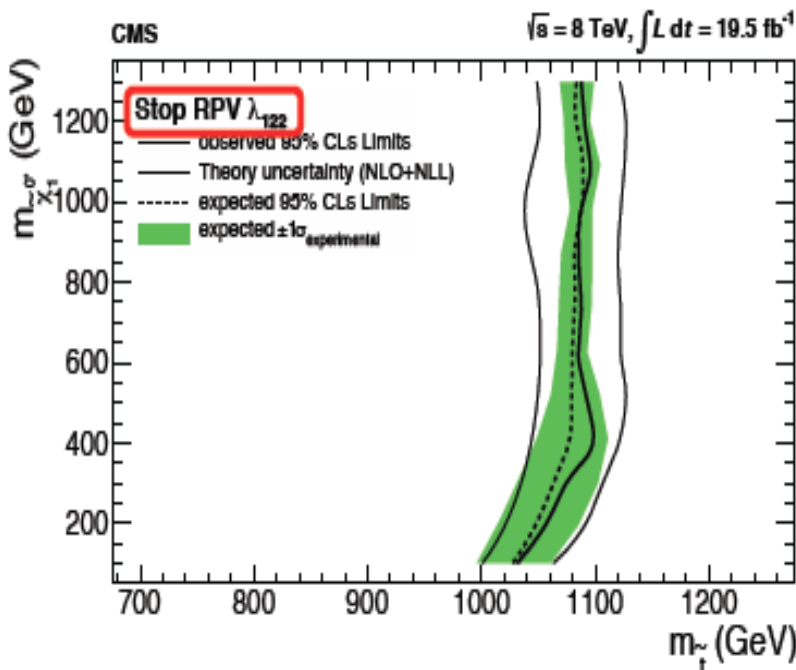
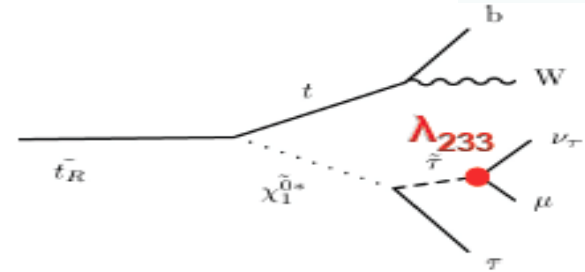
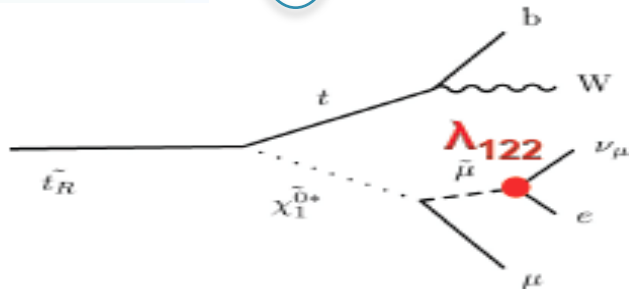
SR	N_L	N_T	$0 < S_T < 300$		$300 < S_T < 600$		$600 < S_T < 1000$		$1000 < S_T < 1500$		$S_T > 1500$	
			obs	exp	obs	exp	obs	exp	obs	exp	obs	exp
			SR1	3	0	116	123 ± 50	130	127 ± 54	13	18.9 ± 6.7	1
SR2	3	≥ 1	710	698 ± 287	746	837 ± 423	83	97 ± 48	3	6.9 ± 3.9	0	0.73 ± 0.49
SR3	4	0	0	0.186 ± 0.074	1	0.43 ± 0.22	0	0.19 ± 0.12	0	0.037 ± 0.039	0	0.000 ± 0.021
SR4	4	≥ 1	1	0.89 ± 0.42	0	1.31 ± 0.48	0	0.39 ± 0.19	0	0.019 ± 0.026	0	0.000 ± 0.021
SR5	3	0	—	—	—	—	165	174 ± 53	16	21.4 ± 8.4	5	2.18 ± 0.99
SR6	3	≥ 1	—	—	—	—	276	249 ± 80	17	19.9 ± 6.8	0	1.84 ± 0.83
SR7	4	0	—	—	—	—	5	8.2 ± 2.6	2	0.96 ± 0.37	0	0.113 ± 0.056
SR8	4	≥ 1	—	—	—	—	2	3.8 ± 1.3	0	0.34 ± 0.16	0	0.040 ± 0.033



Multi-Leptonic Interpretation

Interpret the results in a model with stop-Pair production and λ_{ijk} coupling.

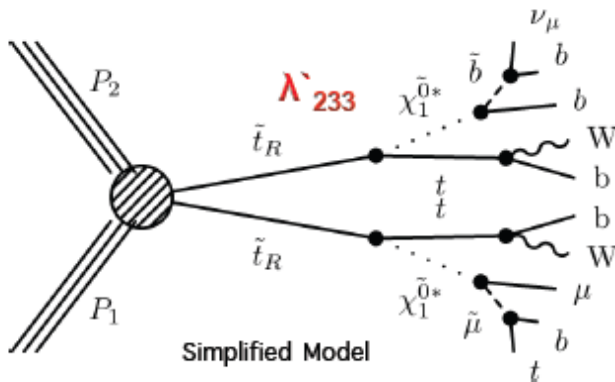
$$\frac{1}{2} \lambda_{ijk} L_i L_j E_k^c + \lambda'_{ijk} L_i Q_j D_k^c + \frac{1}{2} \lambda''_{ijk} U_i^c D_j^c D_k^c + \mu_i L_i H_u$$



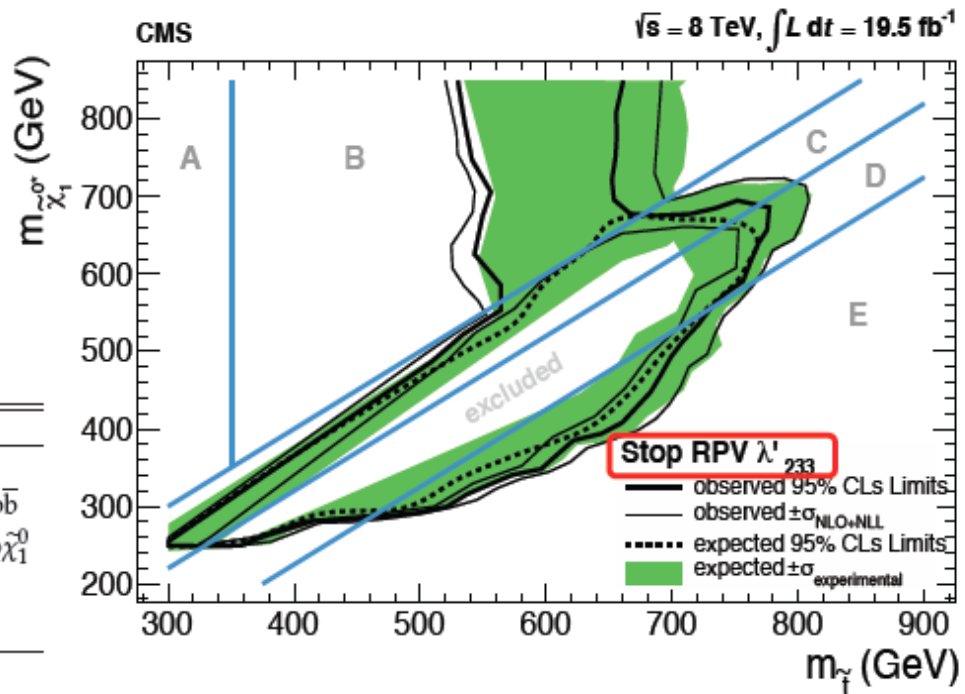
Multi-Leptonic Interpretation

Interpret the results in a model with stop-
Pair production and λ'_{233} .

$$\frac{1}{2}\lambda_{ijk}L_iL_jE_k^c + \lambda'_{ijk}L_iQ_jD_k^c + \frac{1}{2}\lambda''_{ijk}U_i^cD_j^cD_k^c + \mu_iL_iH_u$$



Label	Kinematic region	Decay mode
A	$m_t < m_{\tilde{t}_1} < 2m_b, m_{\tilde{\chi}_1^0}$	$\tilde{t}_1 \rightarrow t\nu b\bar{b}$
B	$2m_t < m_{\tilde{t}_1} < m_{\tilde{\chi}_1^0}$	$\tilde{t}_1 \rightarrow t\mu\bar{b}$ or $t\nu b\bar{b}$
C	$m_{\tilde{\chi}_1^0} < m_{\tilde{t}_1} < m_{W^\pm} + m_{\tilde{\chi}_1^0}$	$\tilde{t}_1 \rightarrow \ell\nu b\tilde{\chi}_1^0$ or $j\nu b\tilde{\chi}_1^0$
D	$m_{W^\pm} + m_{\tilde{\chi}_1^0} < m_{\tilde{t}_1} < m_t + m_{\tilde{\chi}_1^0}$	$\tilde{t}_1 \rightarrow bW^\pm\tilde{\chi}_1^0$
E	$m_t + m_{\tilde{\chi}_1^0} < m_{\tilde{t}_1}$	$\tilde{t}_1 \rightarrow t\tilde{\chi}_1^0$



RPV in Supersymmetry in 4-lepton Final State

CMS SUS-013-010

4 Lepton analysis

$$\frac{1}{2}\lambda_{ijk}L_iL_jE_k^c + \lambda'_{ijk}L_iQ_jD_k^c + \frac{1}{2}\lambda''_{ijk}U_i^cD_j^cD_k^c + \mu_iL_iH_u$$

- **concentrate on lepton number violating term** $\lambda_{ijk}L_iL_j\bar{e}_k$
 - If LSP is a neutralino, each LSP decays into three leptons, two of which are opposite charge. For every SUSY event expect 4 extra charged prompt leptons and two neutrinos on top of regular content of RC part of the event.
- **The dynamic of SUSY production is driven by the RPC part**
 - RPC component also drives all following cascade decays of SUSY particles in the event, until a pair of LSP remains in the end.
 - The RPV component then drives decay of the LSP into non-SUSY particles.
- **Presence of 4 isolated leptons in the event is alone a strong discriminant for SM processes.**
- **No MET, S_T and b-quark jet requirement – decouple from generic SUSY (RPC) searches.**
- **ZZ production is the dominant background.**

4 Lepton Analysis

Expected neutralino decay modes for different non-zero

λ -term	neutralino LSP decay mode
$\lambda_{121} = -\lambda_{211}$	$e\mu\nu_e + e\bar{e}\nu_\mu$
$\lambda_{122} = -\lambda_{212}$	$\mu\mu\nu_e + \mu\bar{e}\nu_\mu$
$\lambda_{123} = -\lambda_{231}$	$\tau\mu\nu_e + \tau\bar{e}\nu_\mu$
$\lambda_{131} = -\lambda_{311}$	$e\tau\nu_e + e\bar{e}\nu_\tau$
$\lambda_{132} = -\lambda_{312}$	$\mu\tau\nu_e + \mu\bar{e}\nu_\tau$
$\lambda_{133} = -\lambda_{331}$	$\tau\tau\nu_e + \tau\bar{e}\nu_\tau$
$\lambda_{231} = -\lambda_{321}$	$e\tau\nu_\mu + e\bar{e}\nu_\tau$
$\lambda_{232} = -\lambda_{322}$	$\mu\tau\nu_\mu + \mu\bar{e}\nu_\tau$
$\lambda_{233} = -\lambda_{321}$	$\tau\tau\nu_\mu + \tau\bar{e}\nu_\tau$

M1: Loop over OSSF pairs, find closest to M_Z

M2: Another OS (OF or SF) pair

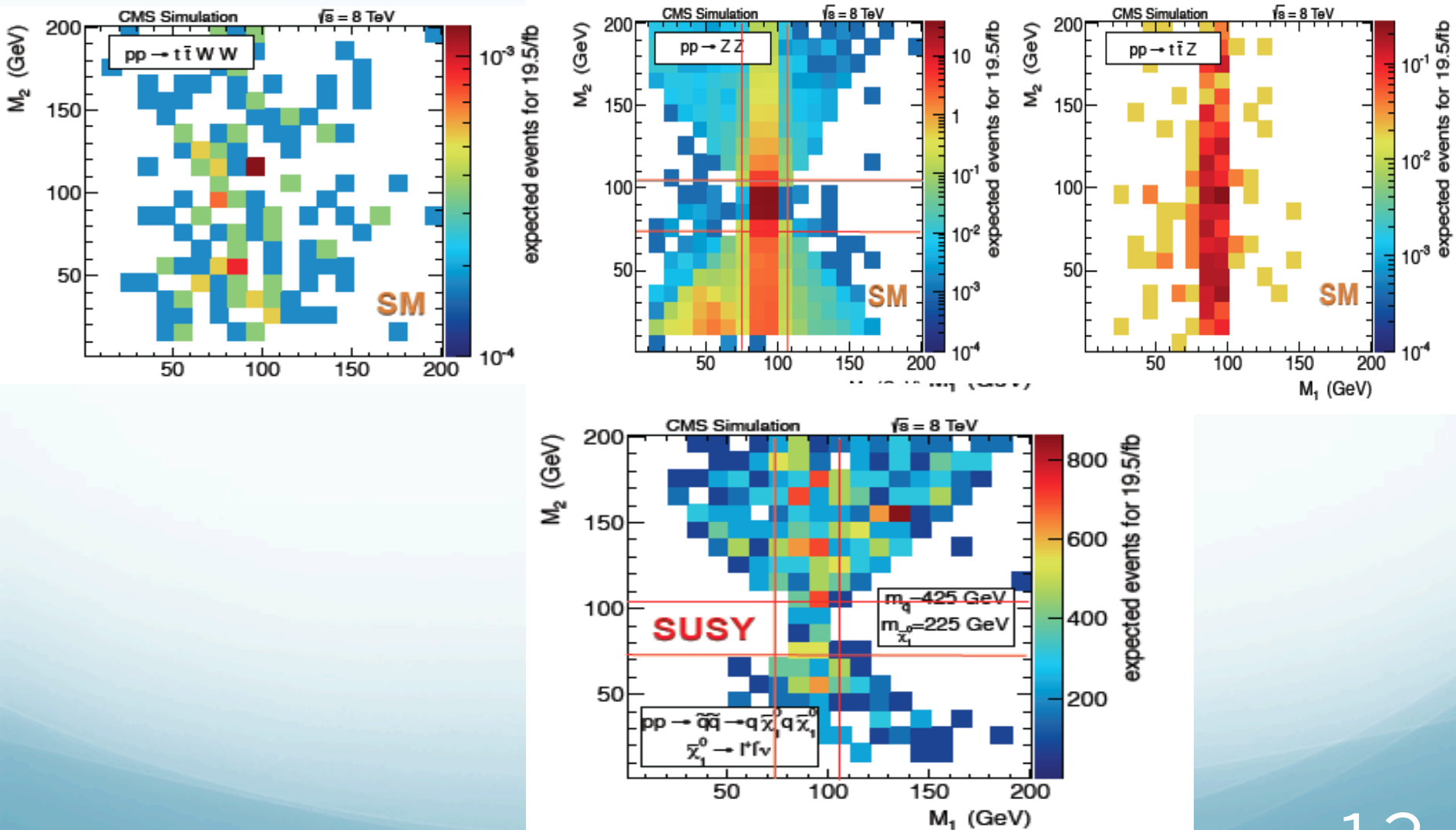
Define 2D plot (M1 vs M2) for different OS regions! 0 – 75 – 105 – Infinity

- “below Z”: $M < 76 \text{ GeV}$
- “in Z”: $76 < M < 106 \text{ GeV}$
- “above Z”: $M > 106 \text{ GeV}$

This study relies on prompt electrons and muons, it has the best sensitivity to λ_{121} , λ_{122} , λ_{211} , λ_{212} .

Background and Signal

M1 Versus M2 for the Backgrounds and Signal



T2+LRPV model, $m_{\tilde{q}} = 425$ GeV, $m_{\tilde{\chi}_1^0} = 225$ GeV

Results

Expected background contributions from different SM processes and observed events in all signal region regions

		$M_1 < 75 \text{ GeV}$	$75 < M_1 < 105 \text{ GeV}$	$M_1 > 105 \text{ GeV}$
$M_2 > 105 \text{ GeV}$	<i>ZZ</i>	0.76 ± 0.18	15 ± 4	0.30 ± 0.07
	rare	0.28 ± 0.13	2.7 ± 1.0	0.12 ± 0.05
	fakes	0.4 ± 0.4	0.7 ± 0.7	0.05 ± 0.05
	all backgrounds	1.4 ± 0.5	18 ± 4	0.47 ± 0.10
	observed	0	20	0
$75 < M_2 < 105 \text{ GeV}$	<i>ZZ</i>	0.10 ± 0.03	150^*	0.05 ± 0.01
	rare	0.12 ± 0.05	2.5 ± 1.2	0.06 ± 0.03
	fakes	0.3 ± 0.3	0.6 ± 0.6	0.05 ± 0.05
	all backgrounds	0.52 ± 0.34	153^*	0.16 ± 0.06
	observed	0	160	0
$M_2 < 75 \text{ GeV}$	<i>ZZ</i>	9.8 ± 2.0	32 ± 8	0.98 ± 0.20
	rare	0.31 ± 0.14	2.5 ± 1.2	0.011 ± 0.005
	fakes	0.3 ± 0.3	0.8 ± 0.8	0.06 ± 0.06
	all backgrounds	10.4 ± 2.0	35 ± 8	1.0 ± 0.2
	observed	14	30	1

Backgrounds estimation

irreducible SM - from MC

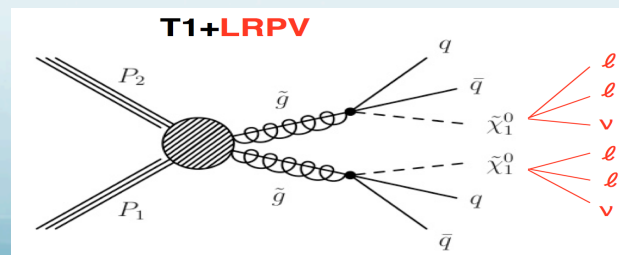
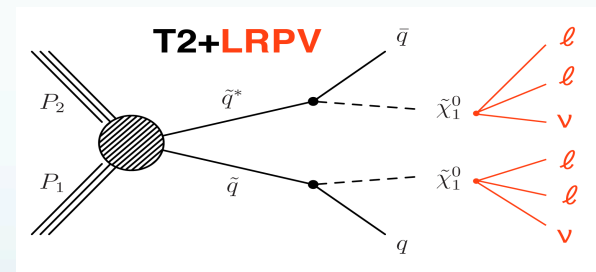
fakes - data driven

Impact of RPC Underlying events

- *Lepton reconstruction efficiency depends on lepton p_T and η*
- *The later distributions for those leptons from LRPV neutralino decays depend from the spectrum of produced neutralinos.*
- *neutralino spectrum affects $M_2 : M_1$ distribution, though the neutralino mass has the most impact on the M_2, M_1 distribution.*

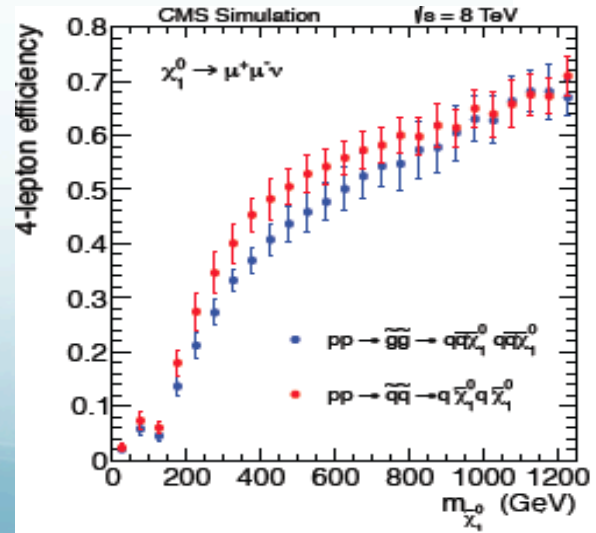
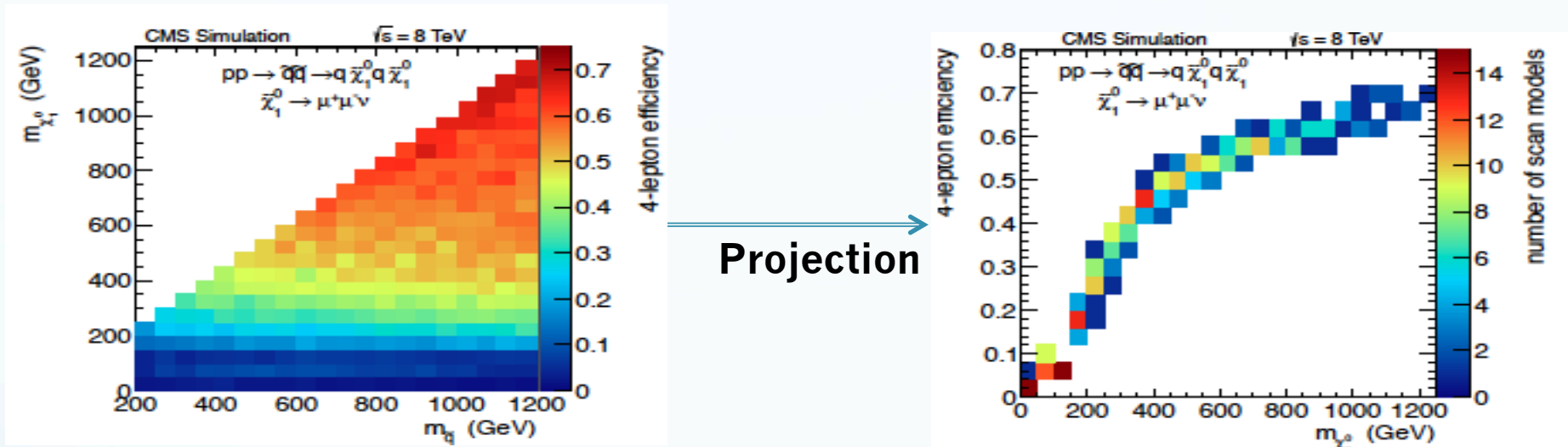
Consider two extreme cases

- *neutralino is produced in 2-body decay of directly produced squark*
 - *the most energetic neutralino*
- *neutralino is produced in the rest*
 - *the most soft neutralino*



Impact of RPC Underlying events

- Efficiency is driven by neutralino mass via signal region masses selection

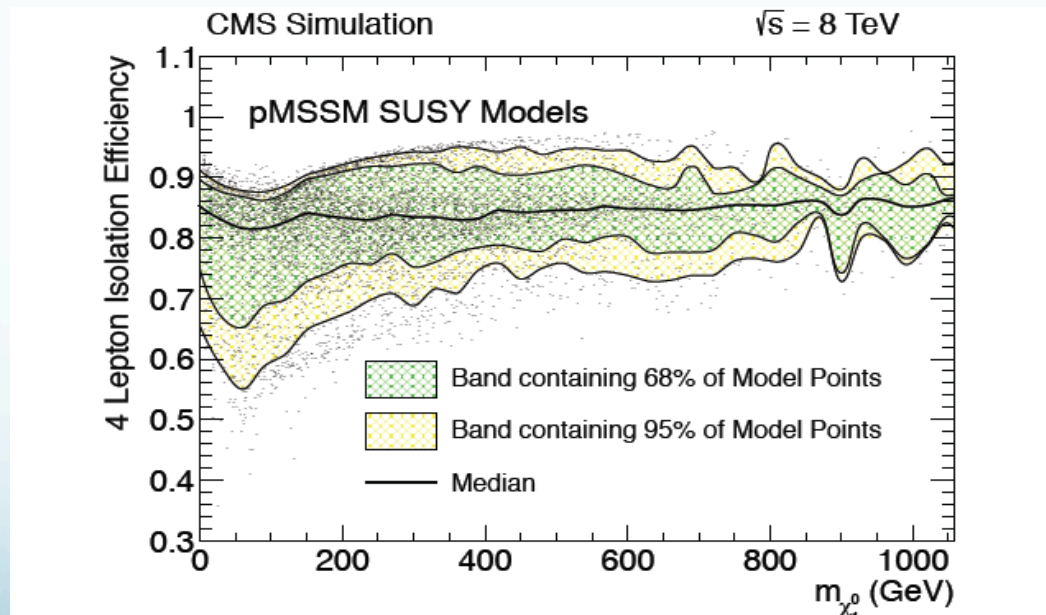


No significant difference in efficiency for both cases

Impact of RPC Underlying events

- Isolation efficiency for tight leptons from RPV decay depends from the occupancy of the event, depends on the content of underlying SUSY event

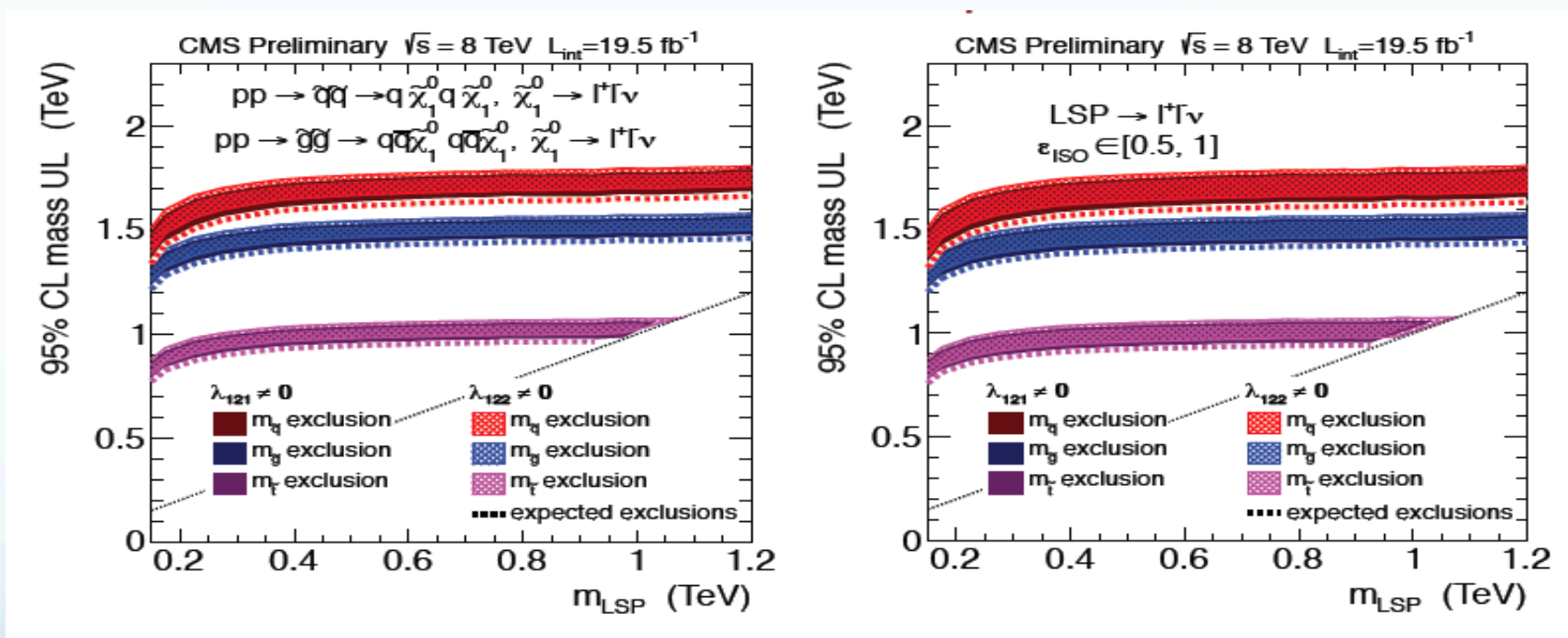
pMSSM model points (~7300), which represents properties of generic MSSM, chosen with flat parameter priors at Electro-weak scale



Efficiency variations well fit a band [0.5, 1]

Interpretation

Mass exclusions for different SUSY production mechanisms



The band in these results covers a wide range of underlying RPC MSSM SUSY physics models

Conclusion

- **CMS searches exclude parameter space in a broad set of different models including all three trilinear RPV Yukawa couplings**
- **No significant excess observed for both multi-lepton final states !**
- **pMSSM model are used to study the impact of generic component of Rparity violated term signatures !**
- **Results are applicable to generic set of MSSM SUSY models and simplified models.**