Search for R-Parity violated Supersymmetry at CMS

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Second LHC Physics Meeting at IPM

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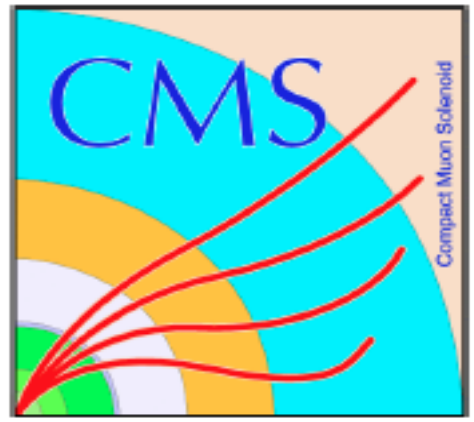


Outline

- 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)epton 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

$$W_{RPV} = \frac{1}{2}\lambda_{ijk} L_i L_j E^c_k + \lambda'_{ijk} L_i Q_j D^c_k + \frac{1}{2}\lambda''_{ijk} U^c_i D^c_j D^c_k + \mu_i L_i H_u$$

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

$L_i(Q_j)$ are lepton(quark) $SU(2)_L$ doublet, $\overline{E}_j(\overline{D}_j, \overline{U}_j)$ are the electron (down- and up-quark) $SU(2)_L$ singlet, λ_{ijk}, λ'_{ijk}, λ''_{ijk} Yukawa couplings, κ mass parameter.

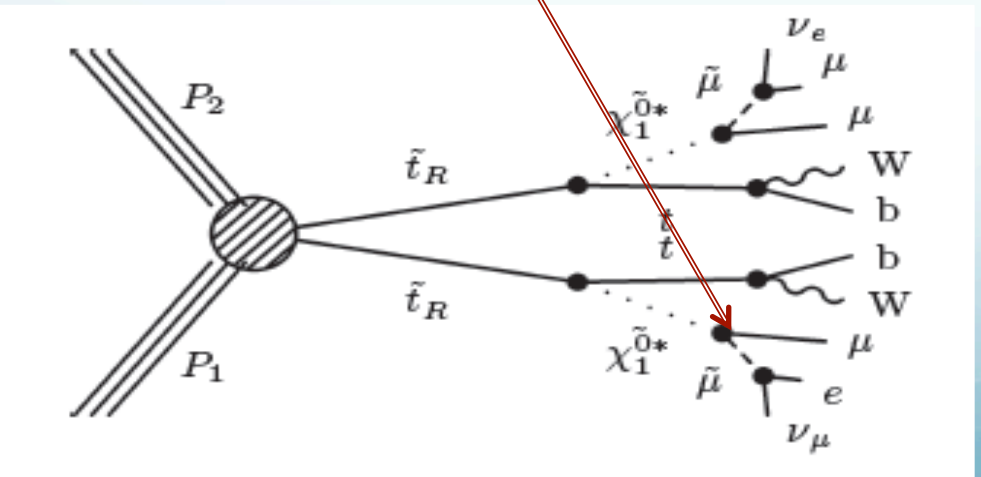
Search For Stop in RPV SUSY

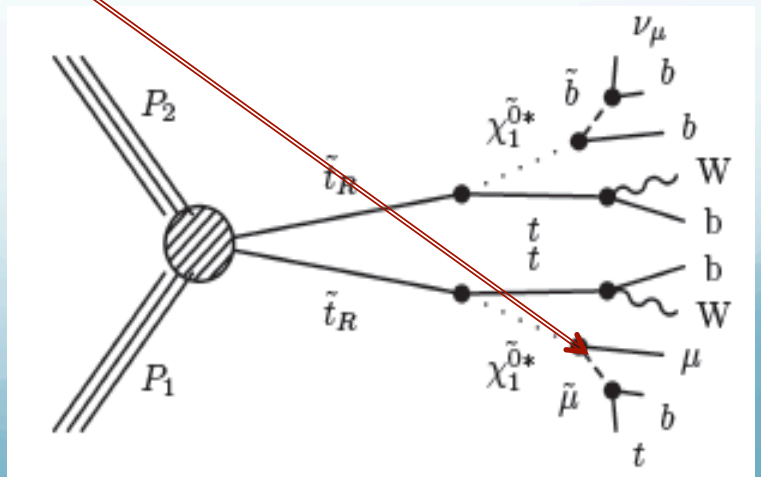
CMS SUS-013-003

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

$$\frac{1}{2}\lambda_{ijk}L_iL_jE^c_k + \lambda'_{ijk}L_iQ_jD^c_k + \frac{1}{2}\lambda''_{ijk}U^c_iD^c_jD^c_k + \mu_iL_iH_u$$





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) di-lepton 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 $\mathbf{E}_T^{miss}$ is also really low.
  - Define search regions in different S_T bins

$$S_T = MET + HT + P_T^{leptons}$$

MET = Missing Transverse Energy

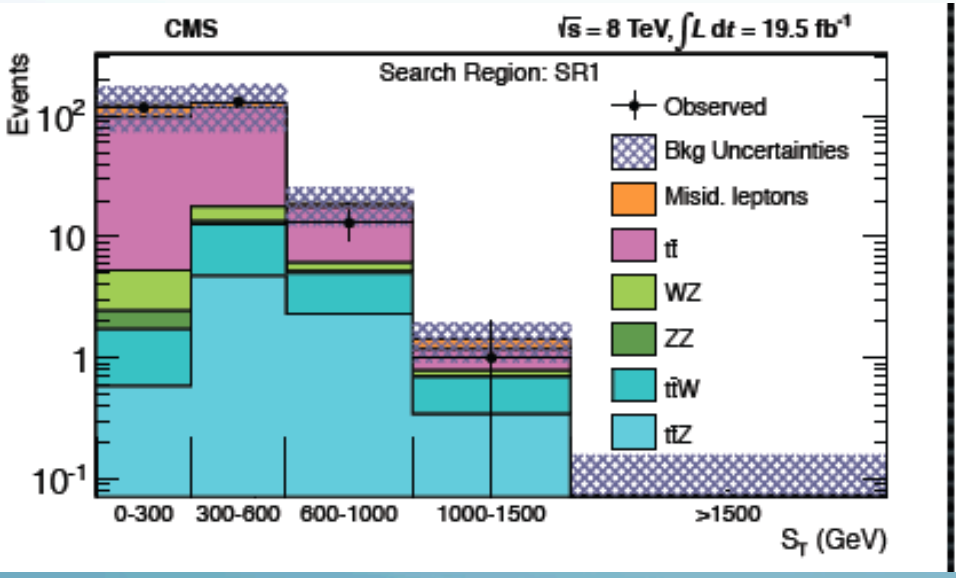
HT = Scalar sum of all selected Jet P_T

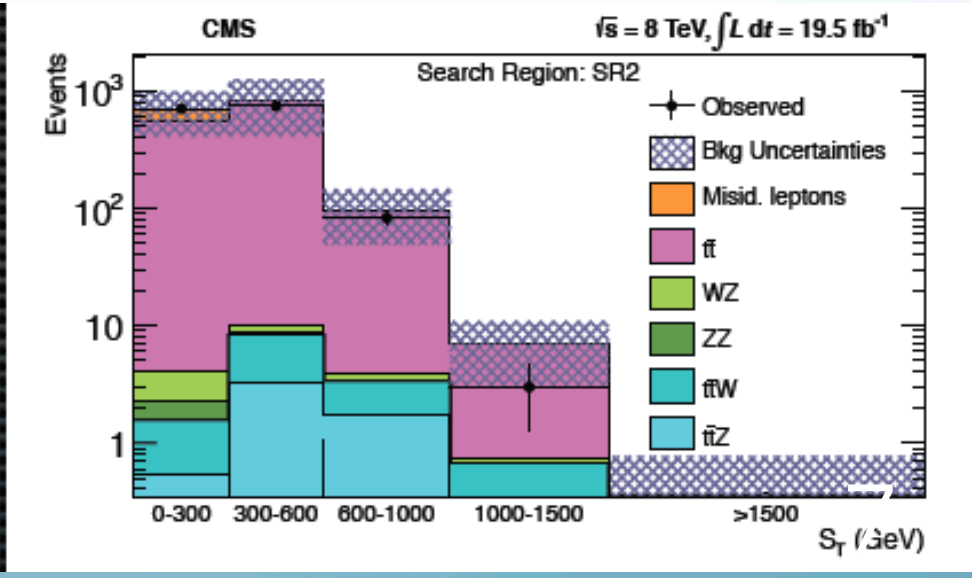
$P_T^{leptons}$ = Selected leptons P_T

Results

Observed and Prdicted Events in all signal regions

SR	N_L	N_τ	$0 < S_T < 300$		$300 < S_T < 600$		$600 < S_T < 1000$		$1000 < S_T < 1500$		$S_T > 1500$	
			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	1.43 ± 0.51	0	0.208 ± 0.096
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

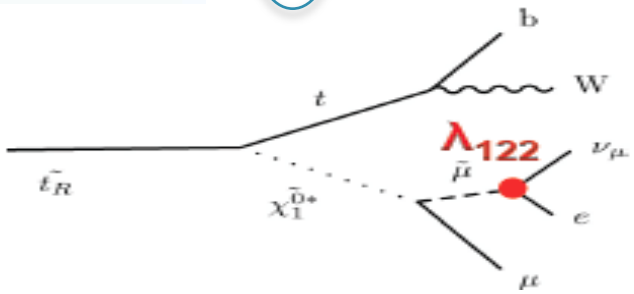


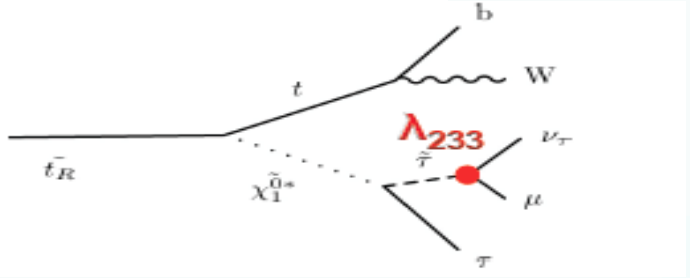


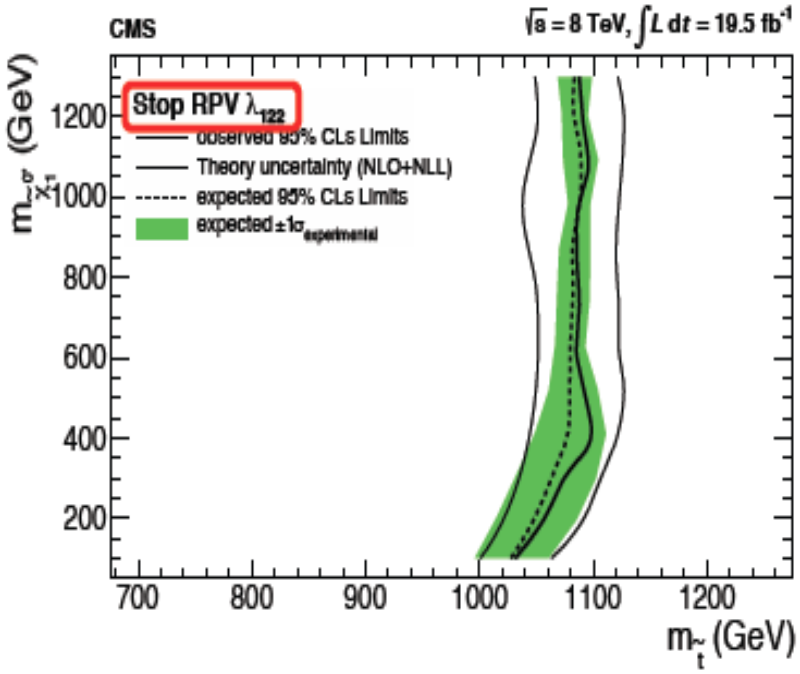
Multi-Leptonic Interpretation

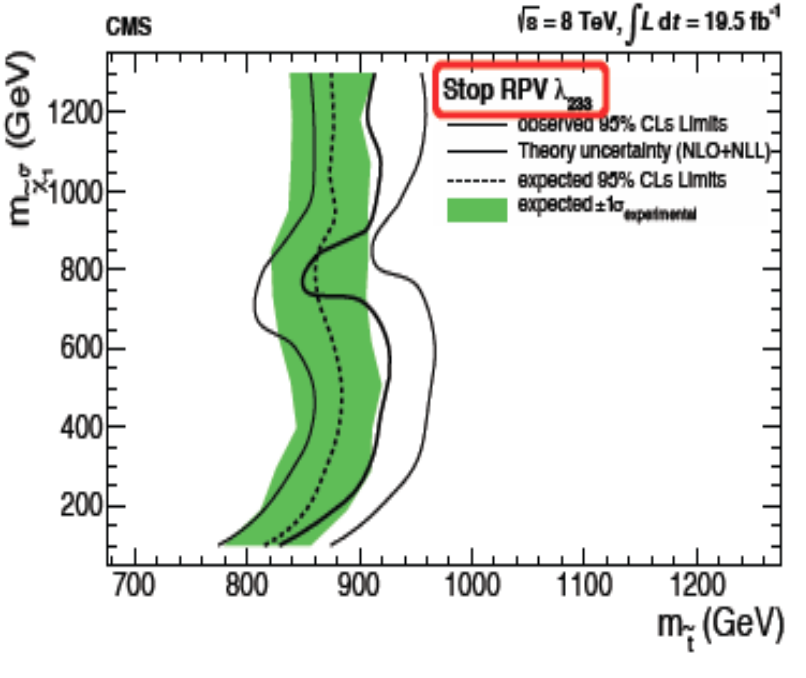
Interpret the results in a model with stop-Pair production and λ_{ijk} coupling.

$$\frac{1}{2}\lambda_{ijk}L_iL_jE^c_k + \lambda'_{ijk}L_iQ_jD^c_k + \frac{1}{2}\lambda''_{ijk}U^c_iD^c_jD^c_k + \mu_iL_iH_u$$





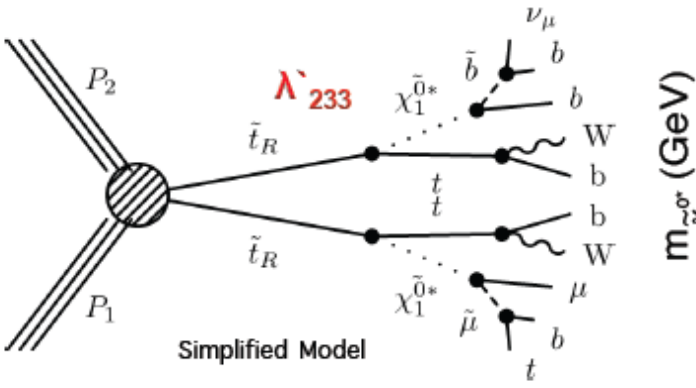




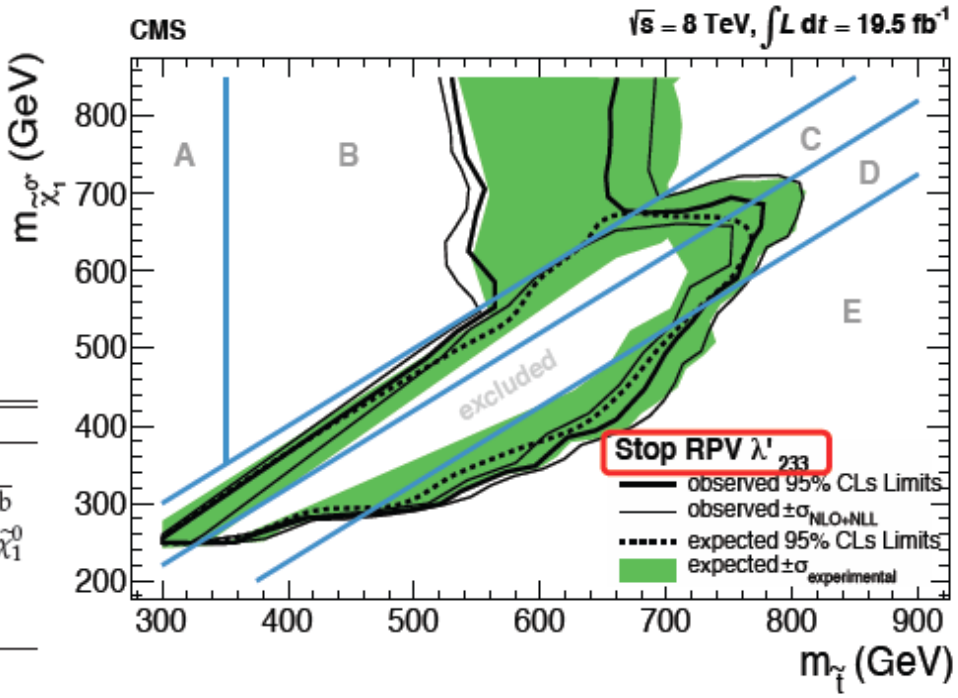
Multi-Leptonic Interpretation

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

$$\frac{1}{2}\lambda_{ijk}L_iL_jE^c_k + \lambda'_{ijk}L_iQ_jD^c_k + \frac{1}{2}\lambda''_{ijk}U^c_iD^c_jD^c_k + \mu_iL_iH_u$$



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



RPV in Supersymmetry in 4-lepton Final State

CMS SUS-013-010

4 Lepton analysis

$$\frac{1}{2}\lambda_{ijk}L_iL_jE^c_k + \lambda'_{ijk}L_iQ_jD^c_k + \frac{1}{2}\lambda''_{ijk}U^c_iD^c_jD^c_k + \mu_iL_iH_u$$

- **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
$\lambda_{121} = -\lambda_{211}$	$e\mu\nu_e + ee\nu_\mu$
$\lambda_{122} = -\lambda_{212}$	$\mu\mu\nu_e + \mu e\nu_\mu$
$\lambda_{123} = -\lambda_{231}$	$\tau\mu\nu_e + \tau e\nu_\mu$
$\lambda_{131} = -\lambda_{311}$	$e\tau\nu_e + ee\nu_\tau$
$\lambda_{132} = -\lambda_{312}$	$\mu\tau\nu_e + \mu e\nu_\tau$
$\lambda_{133} = -\lambda_{331}$	$\tau\tau\nu_e + \tau e\nu_\tau$
$\lambda_{231} = -\lambda_{321}$	$e\tau\nu_\mu + e\mu\nu_\tau$
$\lambda_{232} = -\lambda_{322}$	$\mu\tau\nu_\mu + \mu\mu\nu_\tau$
$\lambda_{233} = -\lambda_{321}$	$\tau\tau\nu_\mu + \tau\mu\nu_\tau$

M1: Loop over OSSF pairs, find closest to M_Z

M2: Another OS (OF or SF) pair

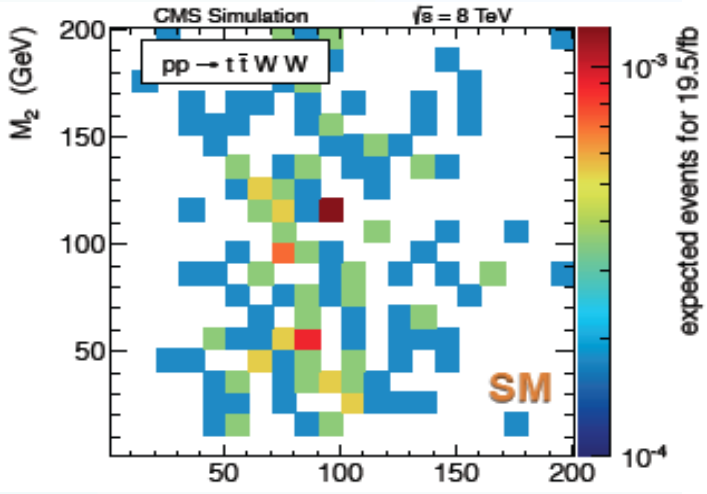
Define 2D plot (M1 vs M2) for different OS regions! 0 – 75 – 105 – Infinity

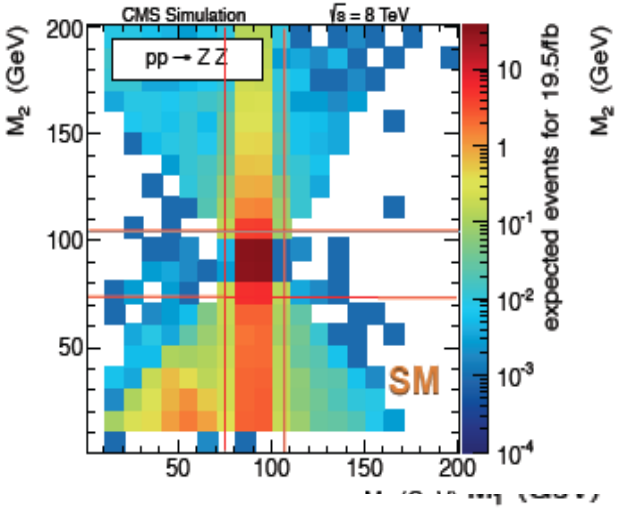
- "below Z": $M < 76\ GeV$
- "in Z": $76 < M < 106\ GeV$
- "above Z": $M > 106\ GeV$

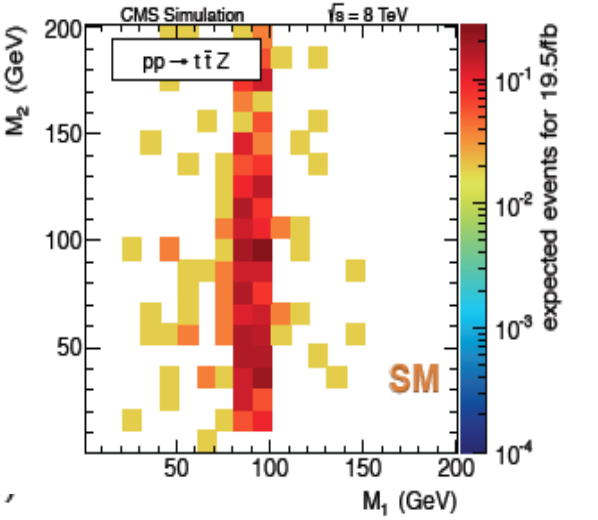
This study relies on prompt electrons and muons, it has the best sensitivity to λ_{121}, λ_{122}, λ_{211}, λ_{212}.

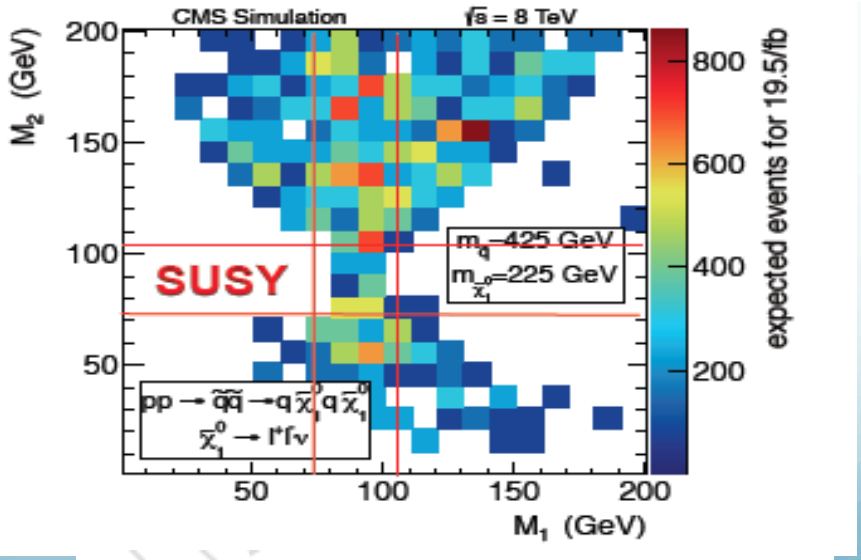
Background and Signal

M1 Versus M2 for the Backgrounds and Signal









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

Results

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

		$M_1 < 75\ GeV$	$75 < M_1 < 105\ GeV$	$M_1 > 105\ GeV$
$M_2 > 105\ GeV$	ZZ	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
$75 < M_2 < 105\ GeV$	ZZ	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
$M_2 < 75\ GeV$	ZZ	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

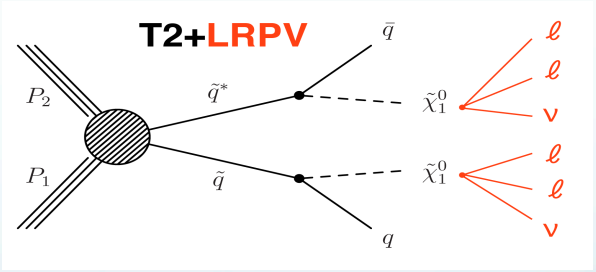
fakes - data driven

Impact of RPC Underlying events

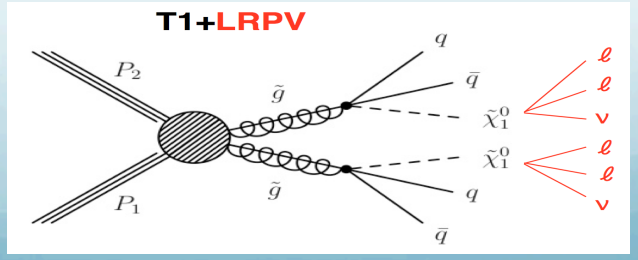
- *Lepton reconstruction efficiency depends on lepton pT and η*
- *The later distributions for those leptons from LRPV neutralino decays depend from the spectrum of produced neutralinos.*
- *neutralino spectrum affects M2 : M1 distribution, though the neutralino mass has the most impact on the M2,M1 distribution.*

Consider two extreme cases

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

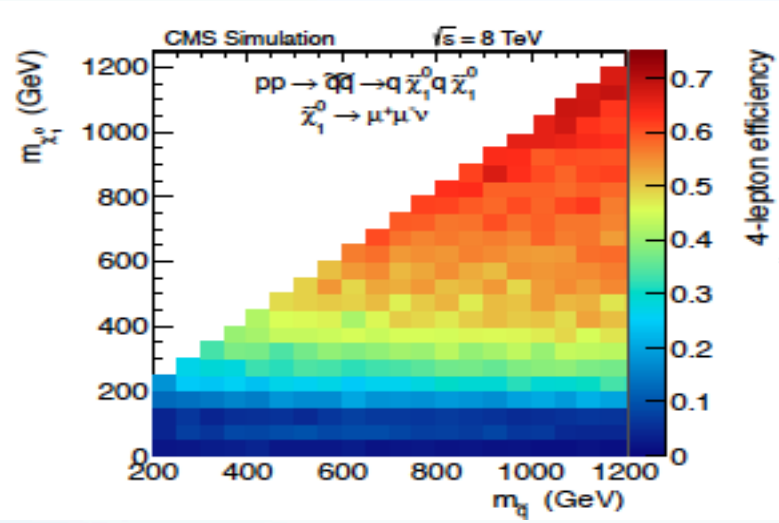


- *neutralino is produced in the rest*
  - the most soft neutralino

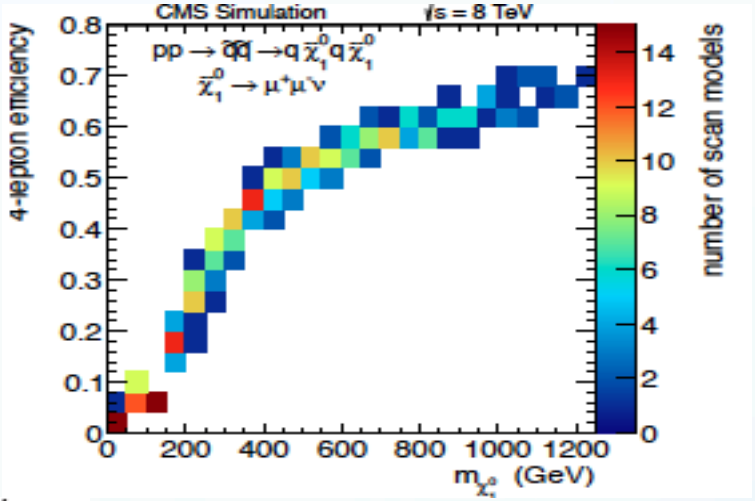


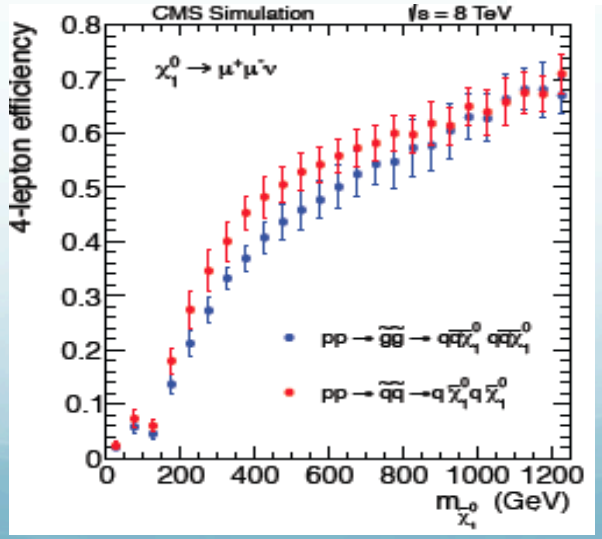
Impact of RPC Underlying events

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



Projection



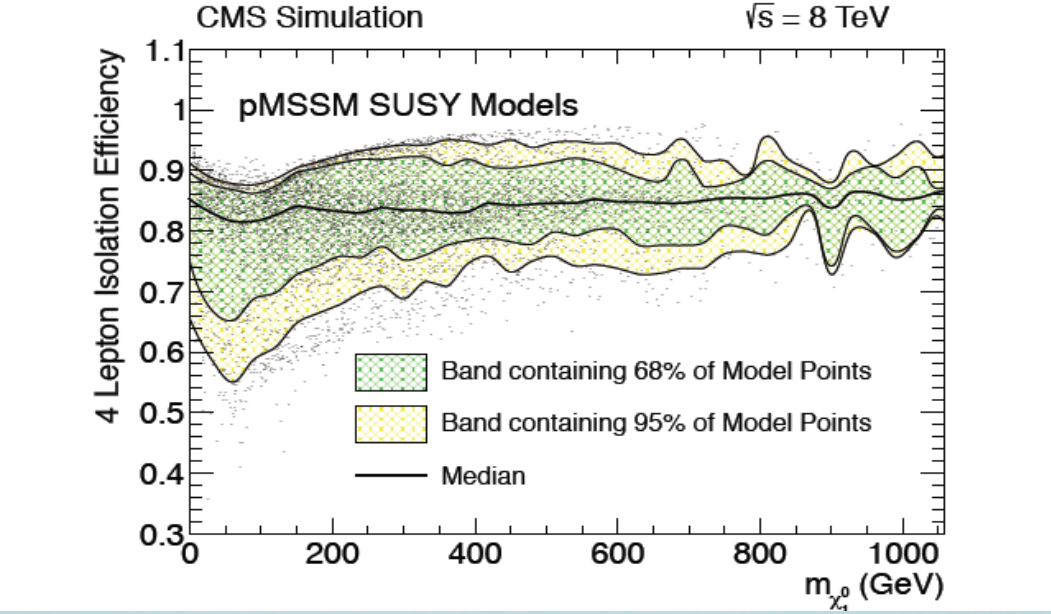


No significant difference in efficiency for both cases

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 underlaying SUSY event**

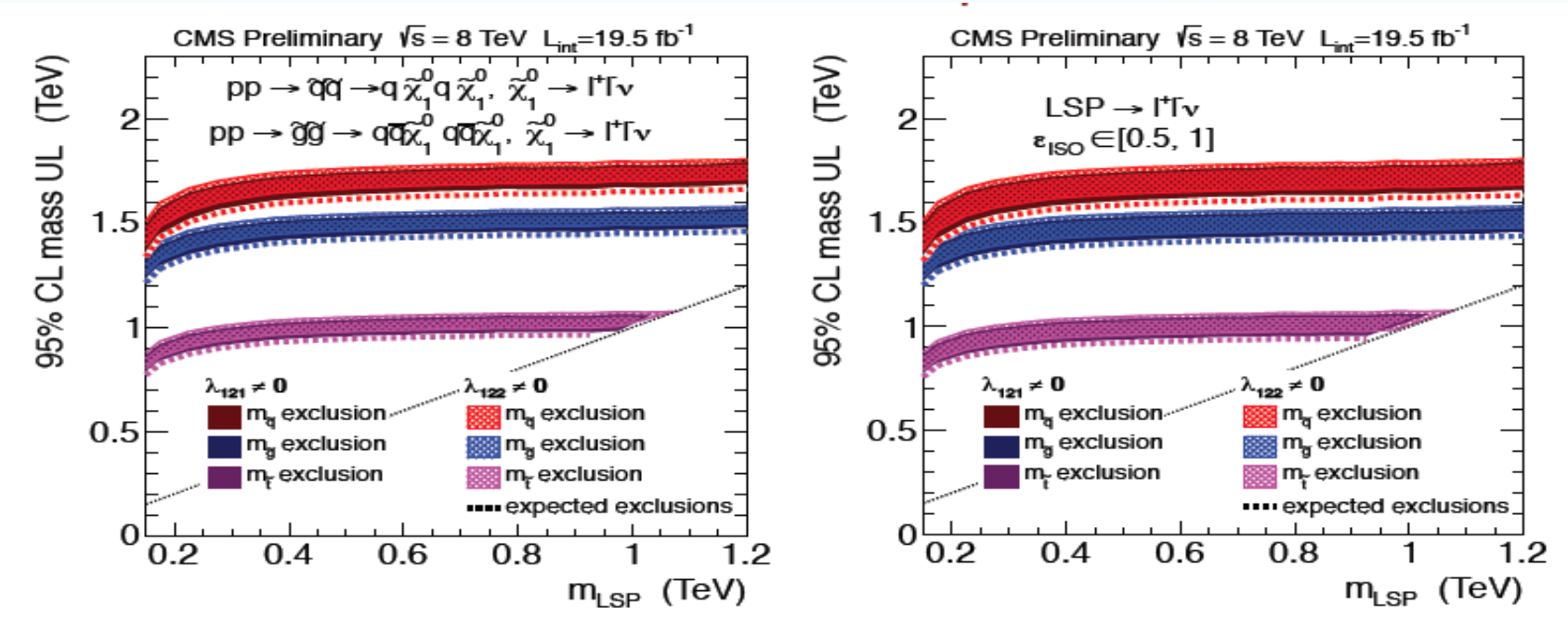
pMSSM model points (~7300), which represents properties of generic MSSM, chosen with flat parameter priors at Electro-weak scale



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.**