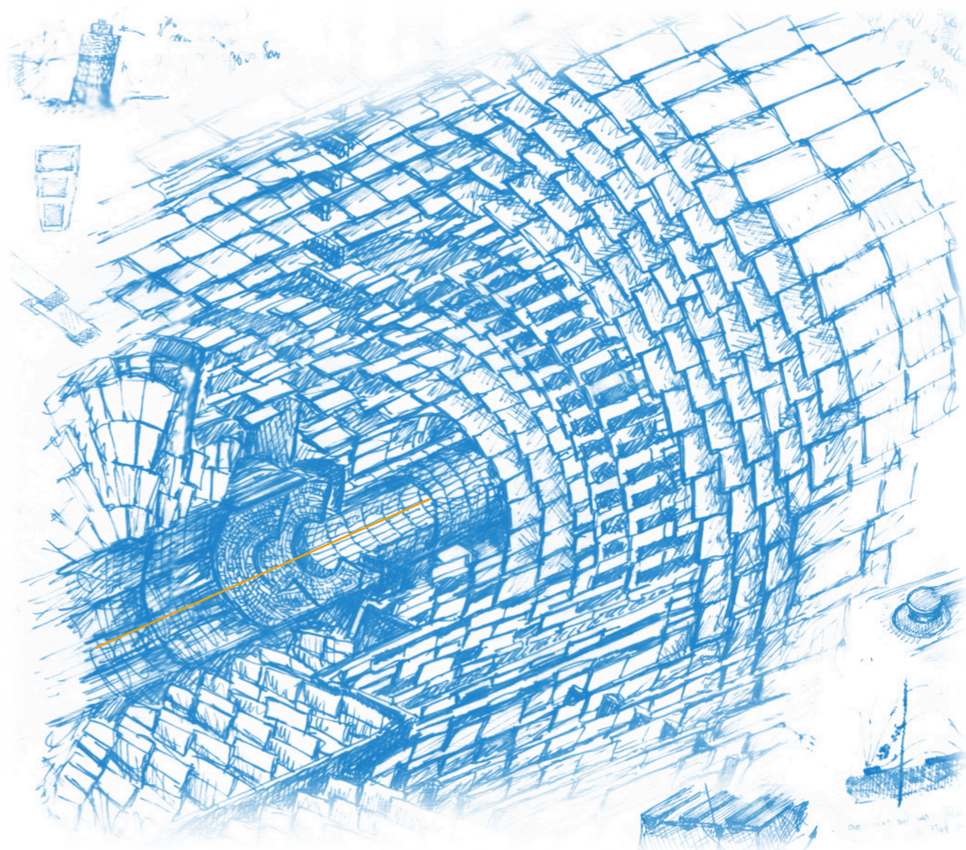
Searches for R-parity Violated Supersymmetry at CMS

On behalf of the CMS Collaboration



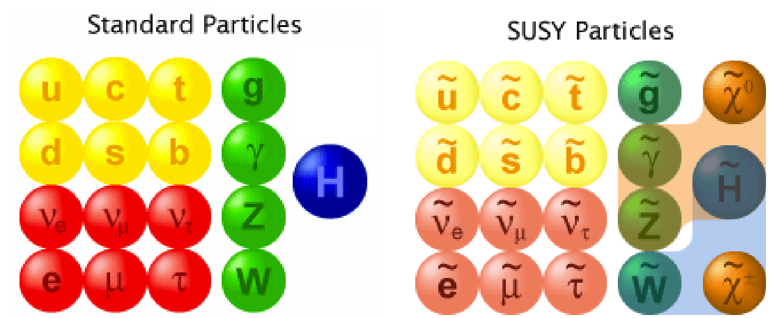
Altan Cakir
DESY

EPS-HEP 2013,
Stockholm, Sweden.

HELMHOLTZ
ASSOCIATION

Supersymmetry and R-parity

- Weak scale supersymmetry (SUSY) is one of the most studied extensions of the Standard Model (SM).
- SUSY postulates super-partners for all SM particles:



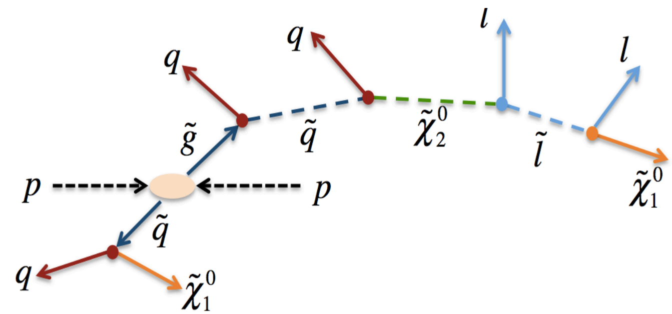
SM fermions	⇔	SUSY bosons
SM bosons	⇔	SUSY fermions

quarks leptons gauge bosons squarks sleptons gauginos

➢ **Definition: R-parity → $R_P = (-1)^{3B+L+2s}$**
(B)aryon and (L)epton number and s for particle spin

- **In case of a R-parity conserving *theory***
  → SM particle fields : $R_P = +1$
  → SUSY particle field : $R_P = -1$

phenomenologically means:
→ Superpartners produced in pairs
→ Lightest Supersymmetric particle (LSP) stable
→ Proton stabilized



Generic SUSY Searches: R-parity conserved scenario
Details can be seen in the following talks:

- Direct stop search, Hongxuan Liu
- Search for multiple W and b quarks, Keith Ulmer
- Searches for Gauginos and Sleptons, L. Shchutska,
- Search for natural SUSY, S. Sekmen,
- Search for inclusive SUSY, C. Autermann

If R-parity is not conserved?

R-Parity Violation in Supersymmetry?

- Proton decay involves violating both lepton and baryon number simultaneously, **no single renormalizable R-parity violating (RPV) coupling leads to proton decay.**

✓ R-parity violation → one set of the R-parity violating couplings are non-zero!

The most general superpotential → $W = W_{MSSM} + W_{RPV}$

$$W_{MSSM} = h^{e}_{ij} L_i H_1 \overline{E}_j + h^{d}_{ij} Q_i H_1 \overline{D}_j + h^{u}_{ij} Q_i H_2 \overline{U}_j + \mu H_1 H_2$$

$$W_{RPV} = \frac{1}{2} \lambda_{ijk} L_i L_j \overline{E}_k + \lambda'_{ijk} L_i Q_j \overline{D}_k + \frac{1}{2} \lambda''_{ijk} U_i D_j \overline{D}_k + \kappa_i L_i H_2 \quad \star$$

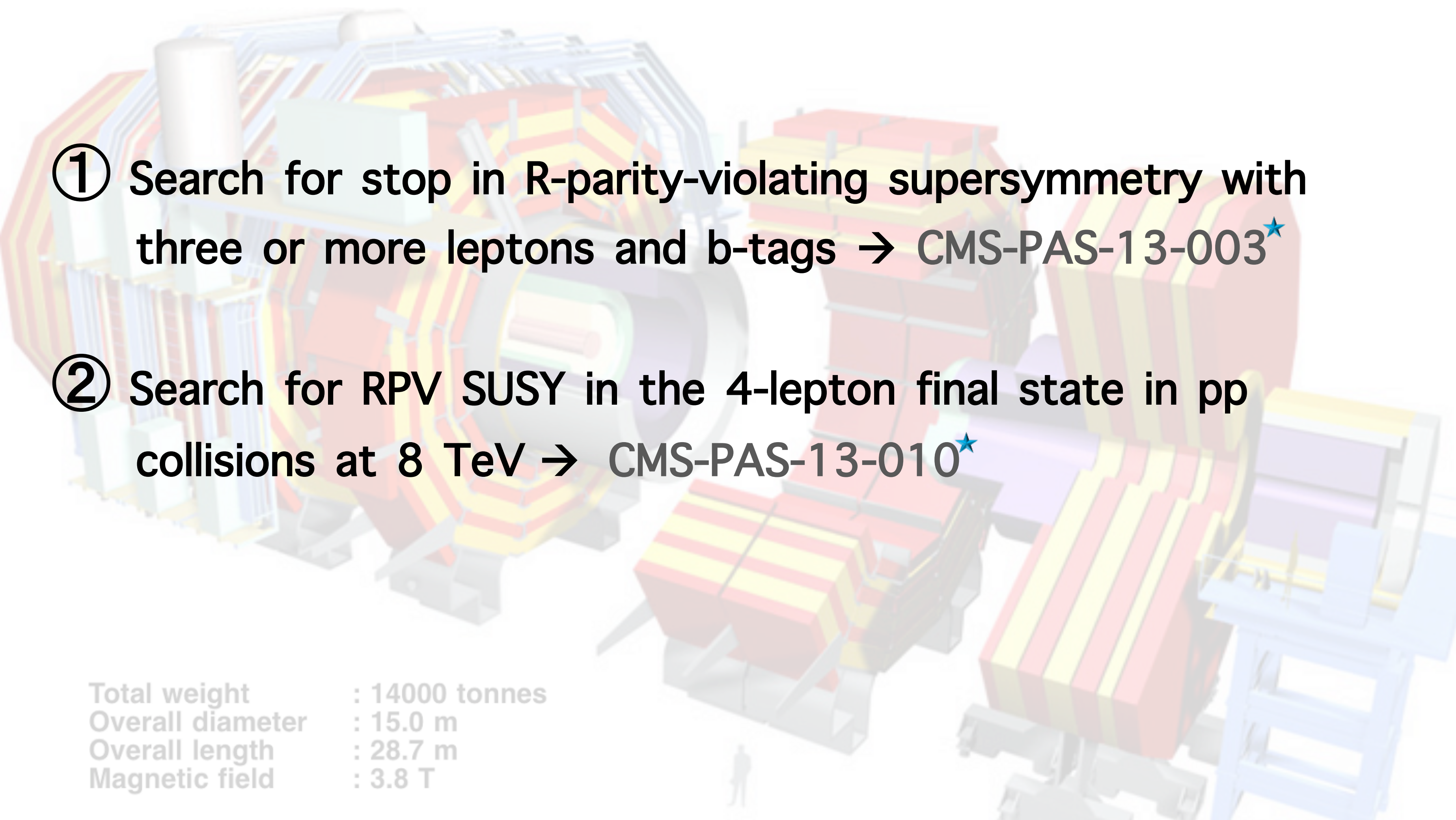
- RPV couplings can violate **lepton and baryon number conservation**
- Can result in **two, three and four body decays** of supersymmetric particles to Standard Model particles
- Couplings chosen to have **prompt decay**, and to satisfy constraints from neutrino mass and proton decay.

★ $L_i(Q_j)$ 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} are Yukawa couplings, κ mass parameter.

Searches for R-parity violated Supersymmetry at CMS

① Search for stop in R-parity-violating supersymmetry with three or more leptons and b-tags → CMS-PAS-13-003*

② Search for RPV SUSY in the 4-lepton final state in pp collisions at 8 TeV → CMS-PAS-13-010*



* https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS

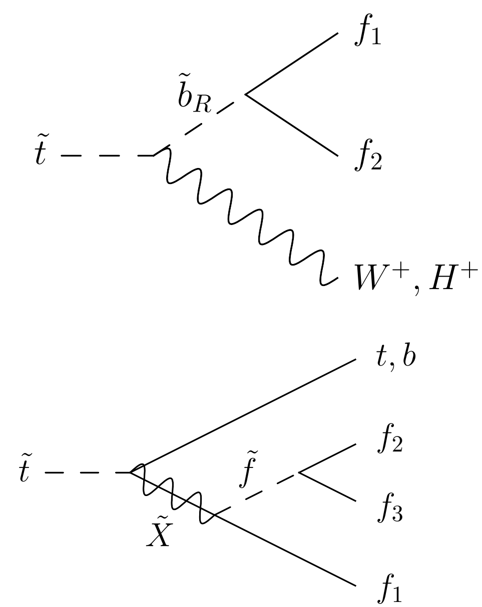
① Stop in RPV Supersymmetry

- Focus on stop pair production, where stop mass changes between 300 GeV to 1250 GeV
- Search for RPV couplings that produce **multi-lepton final states**

$$W_{RPV} = \tfrac{1}{2}\lambda_{ijk} L_i L_j \overline{E}_k + \lambda'_{ijk} L_i Q_j \overline{D}_k + \tfrac{1}{2}\lambda''_{ijk} U_i D_j \overline{D}_k + \kappa_i L_i H_2$$

Leptonic | Mixed | Hadronic

couplings	LLE 122	LLE 233	LQD 233
Decay products for stop	llvt	lTvt, TTvt	Vbbt, lbtt
Stop mass (GeV)	700 - 1250	700 - 1250	300 - 1000
Bino mass (GeV)	100 - 1300	100 - 1300	200 - 850



arXiv:hep-ph/1209.0764

① Event Classification and Results

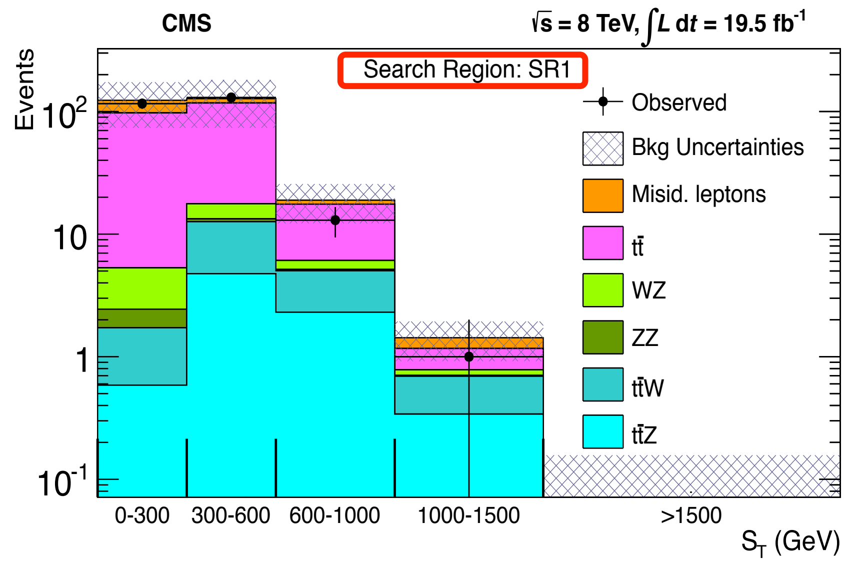
- Using **19.5/fb,** full data set from **2012 CMS data**
- Light lepton p_T must pass 20/10/10(/10) GeV threshold
- Require at least one tagged b-quark jet
- Remove events with OSSF* di-lepton mass on Z and below 12 GeV J/Ψ events
- Define search regions in different **S_T bins,**

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

MET = Missing Transverse Energy

HT = Scalar sum of all selected Jet P_T

$P_T^{leptons}$ = Selected leptons P_T



#Leptons (e, μ)

tau lepton

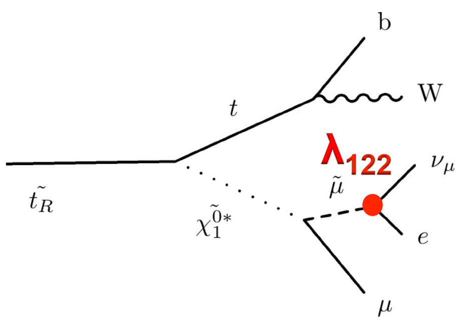
SR	N_L	N_τ	$0 < S_T < 300$ obs	$0 < S_T < 300$ exp	$300 < S_T < 600$ obs	$300 < S_T < 600$ exp	$600 < S_T < 1000$ obs	$600 < S_T < 1000$ exp	$1000 < S_T < 1500$ obs	$1000 < S_T < 1500$ exp	$S_T > 1500$ obs	$S_T > 1500$ exp
SR1	3	0	116	123 ± 50	130	127 ± 54	13	18.9 ± 6.7	1	1.43 ± 0.51	0	0.208 ± 0.096
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

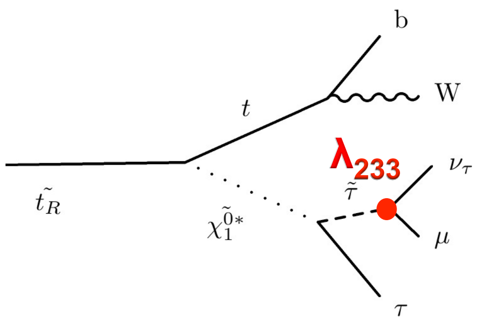
*OSSF: Opposite Sign Same Flavor

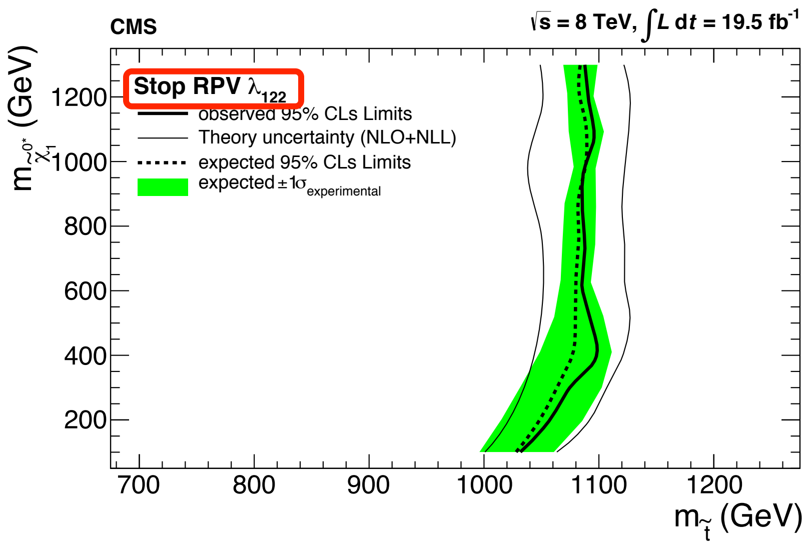
① Interpretation for RPV Stop SUSY Search

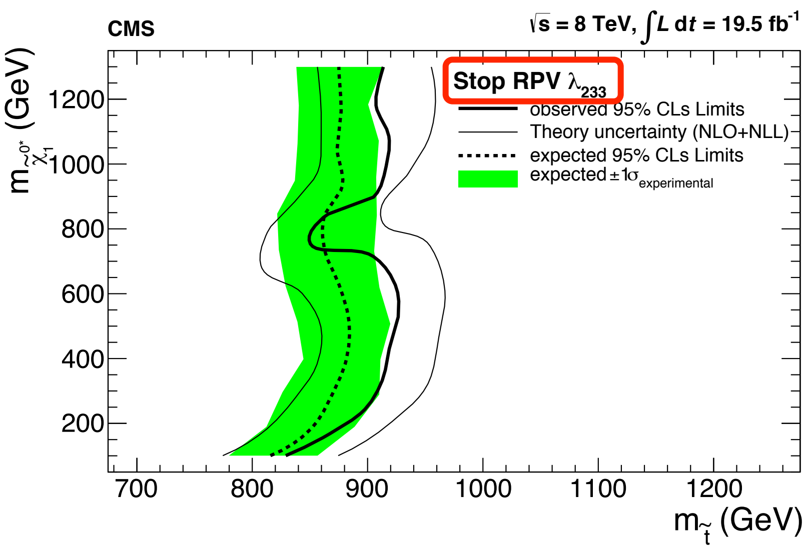
$$W_{RPV} = \frac{1}{2}\lambda_{ijk}L_iL_j\bar{E}_k + \lambda'_{ijk}L_iQ_j\bar{D}_k + \frac{1}{2}\lambda''_{ijk}U_iD_j\bar{D}_k + \kappa_iL_iH_2$$

Leptonic   Mixed   Hadronic





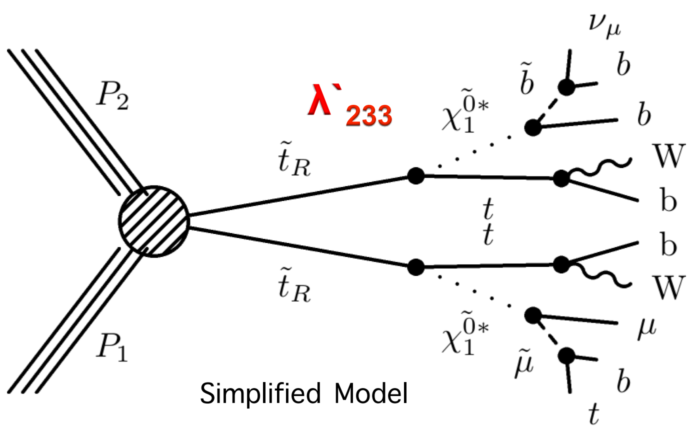




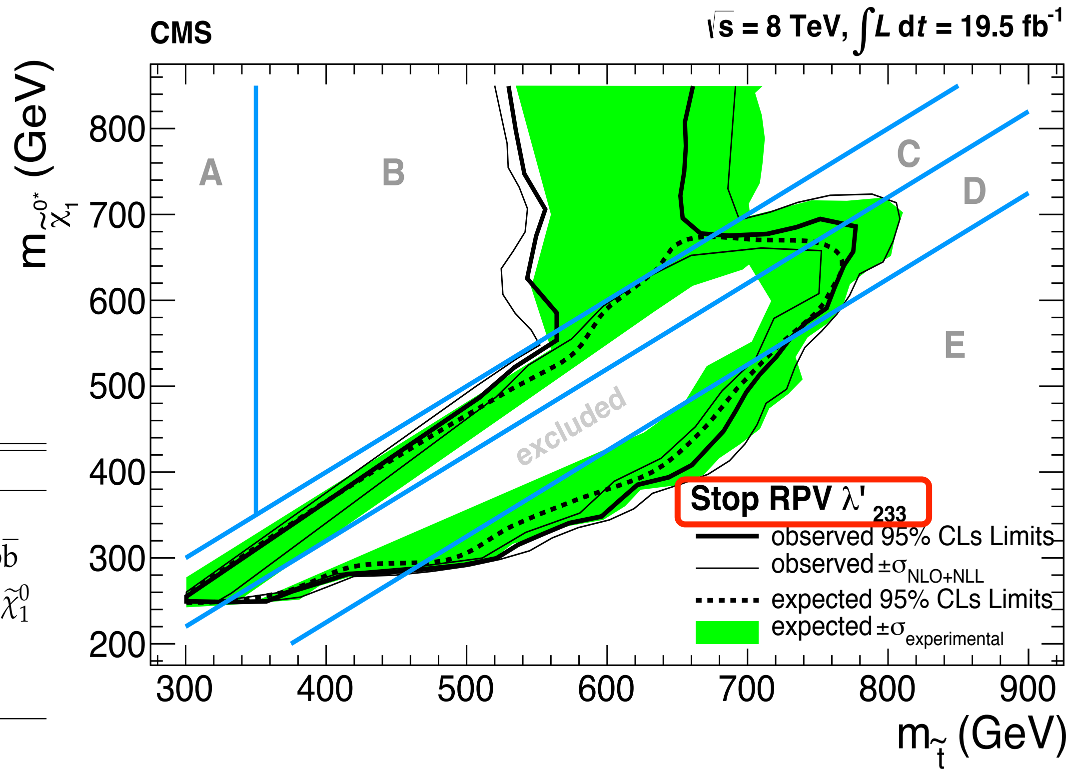
① Interpretation for RPV Stop SUSY Search

$$W_{RPV} = \frac{1}{2}\lambda_{ijk} L_i L_j \overline{E}_k + \lambda'_{ijk} L_i Q_j \overline{D}_k + \frac{1}{2}\lambda''_{ijk} U_i D_j \overline{D}_k + \kappa_i L_i H_2$$

Leptonic | **Mixed** | Hadronic



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



② RPV in Supersymmetry in 4-lepton Final State

- Selection of **4 isolated leptons** in the event is already a strong requirement for SM processes
- 4 leptons requirement needs high lepton identification and reconstruction efficiency!
- The lepton p_T must pass 20/10/10/10 GeV threshold
- No MET, S_T and b-quark jet requirement – decouple from generic SUSY (RPC) searches
- ZZ production is the dominant SM background.

$$W_{RPV} = \frac{1}{2}\lambda_{ijk}L_iL_j\overline{E}_k + \lambda'_{ijk}L_iQ_j\overline{D}_k + \frac{1}{2}\lambda''_{ijk}U_iD_j\overline{D}_k + \kappa_i L_i H_2$$

Leptonic Mixed Hadronic

λ-term	neutralino LSP decay mode
$\lambda_{121} = -\lambda_{211}$	$e\mu\nu_e + ee\nu_\mu$
$\lambda_{122} = -\lambda_{212}$	$\mu\mu\nu_e + \mu e\nu_\mu$
$\lambda_{123} = -\lambda_{231}$	$\tau\mu\nu_e + \tau e\nu_\mu$
$\lambda_{131} = -\lambda_{311}$	$e\tau\nu_e + ee\nu_\tau$
$\lambda_{132} = -\lambda_{312}$	$\mu\tau\nu_e + \mu e\nu_\tau$
$\lambda_{133} = -\lambda_{331}$	$\tau\tau\nu_e + \tau e\nu_\tau$
$\lambda_{231} = -\lambda_{321}$	$e\tau\nu_\mu + e\mu\nu_\tau$
$\lambda_{232} = -\lambda_{322}$	$\mu\tau\nu_\mu + \mu\mu\nu_\tau$
$\lambda_{233} = -\lambda_{323}$	$\tau\tau\nu_\mu + \tau\mu\nu_\tau$

→ Select OSSF pairs and find closest to M_Z **M_1**

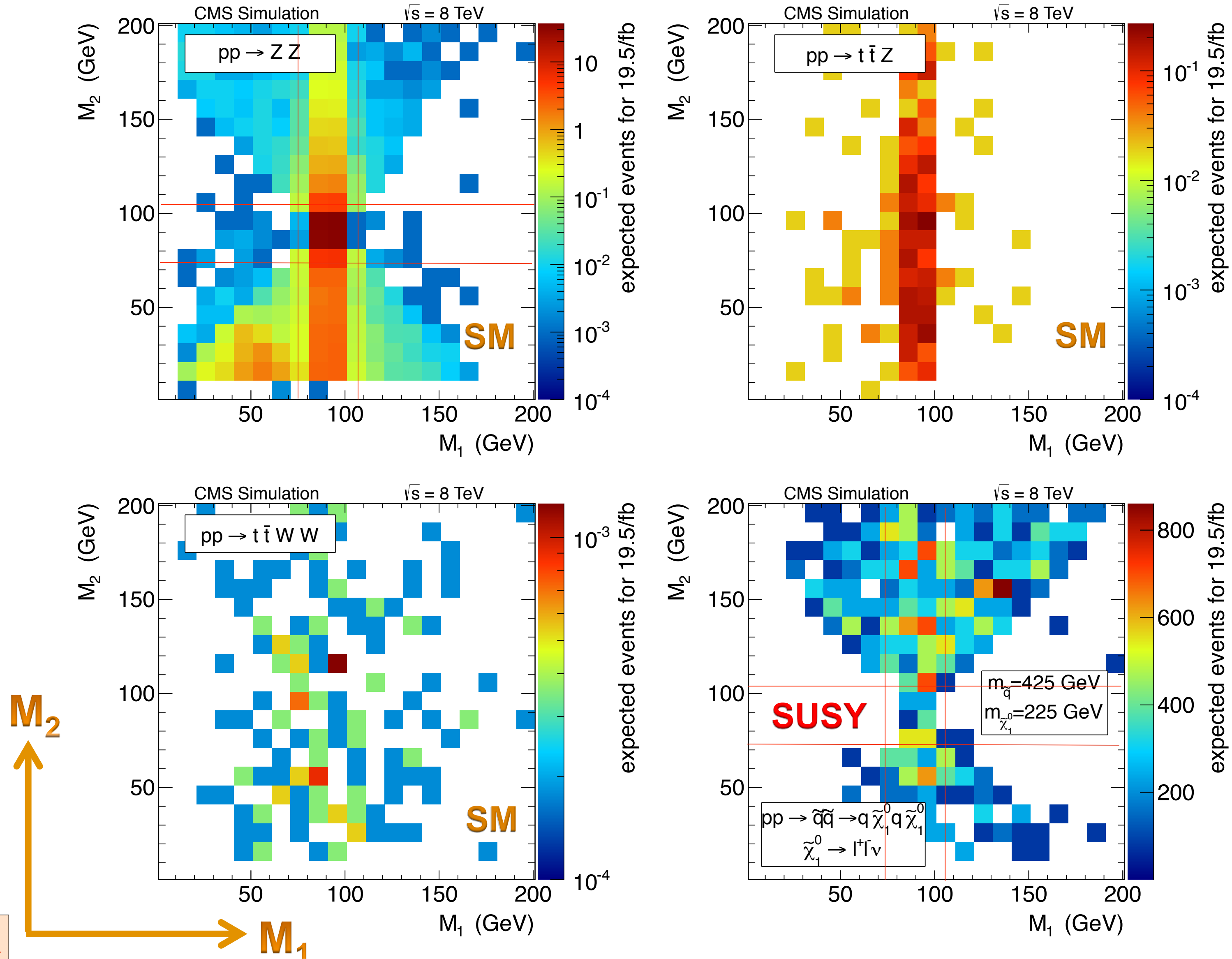
→ Another OS (OF or SF) pair **M_2**

Define 2D plot (M_1 vs M_2) for different OS regions

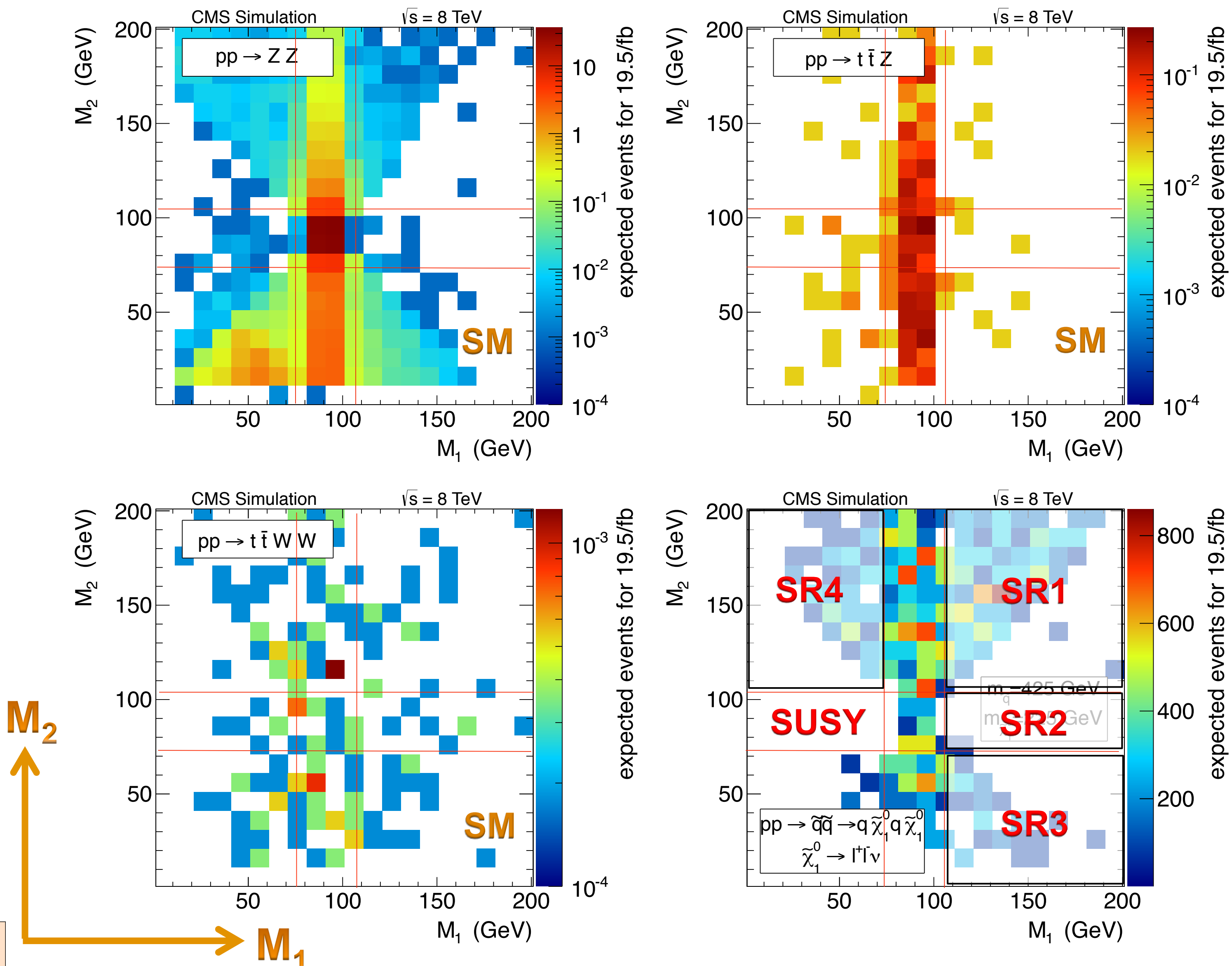
0 – 75 – 105 – Infinity

→ 9 analyses regions

② Backgrounds and SUSY Signal



② Backgrounds and SUSY Signal



② Results

- Expected background contributions from different SM sources and experimentally observed events in all analysis regions.

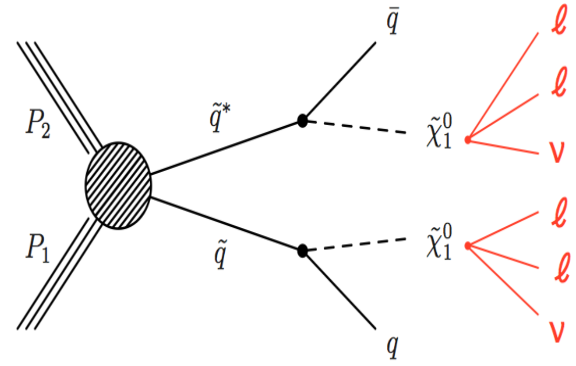
		$M_1 < 75$ GeV	$75 < M_1 < 105$ GeV	$M_1 > 105$ GeV
$M_2 > 105$ GeV	ZZ	0.76±0.18	15±4	0.30±0.07
	rare	0.28±0.13	2.7±1.0	0.12±0.05
	fakes	0.4±0.4	0.7±0.7	0.05±0.05
	all backgrounds	1.4±0.5	18±4	0.47±0.10
	observed	0	20	0
$75 < M_2 < 105$ GeV	ZZ	0.10±0.03	150^*	0.05±0.01
	rare	0.12±0.05	2.5±1.2	0.06±0.03
	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

- Irreducible SM background → estimated from MC
- Fake leptons → data driven estimation method

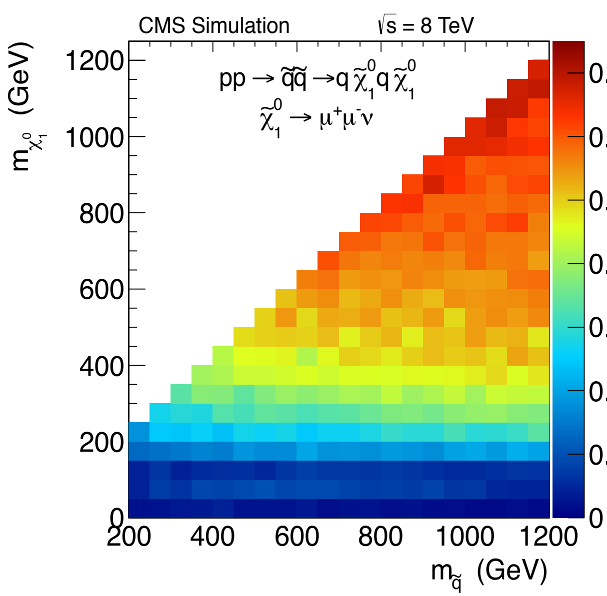
② 4-lepton efficiency for neutralino dynamics

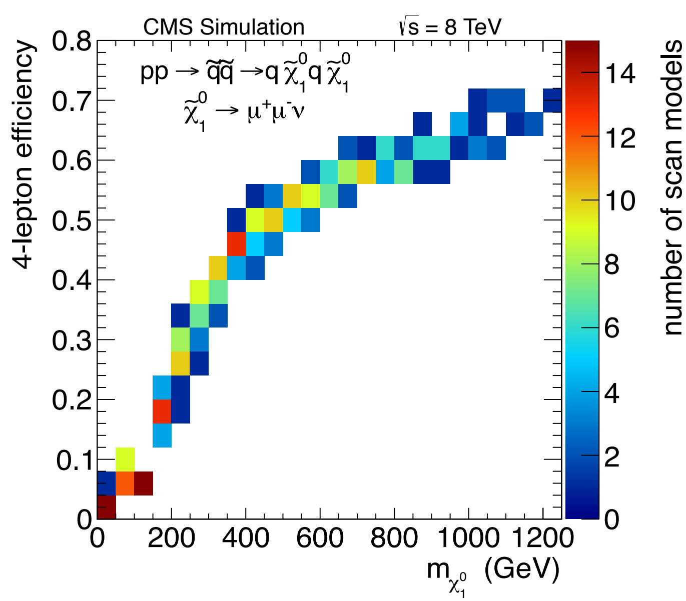
- Two extreme cases are taken into account:

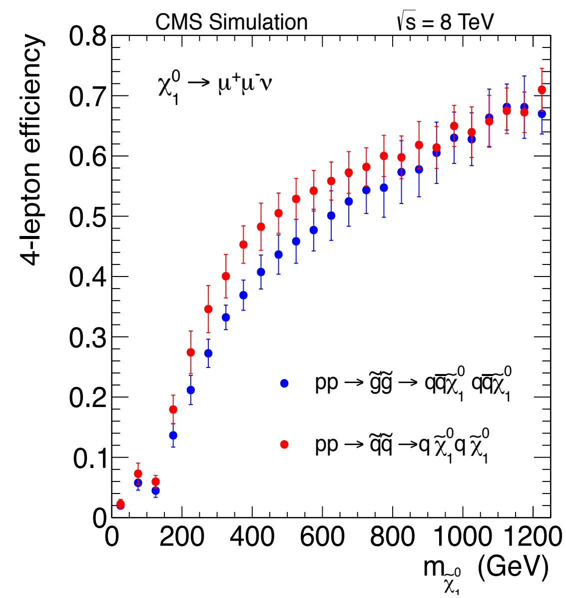
  1. Neutralino is produced in 2-body decay of a directly produced squark → **The most energetic neutralino**
  2. Neutralino produced at rest → **The most soft neutralino**



- No significant difference in efficiency for both cases



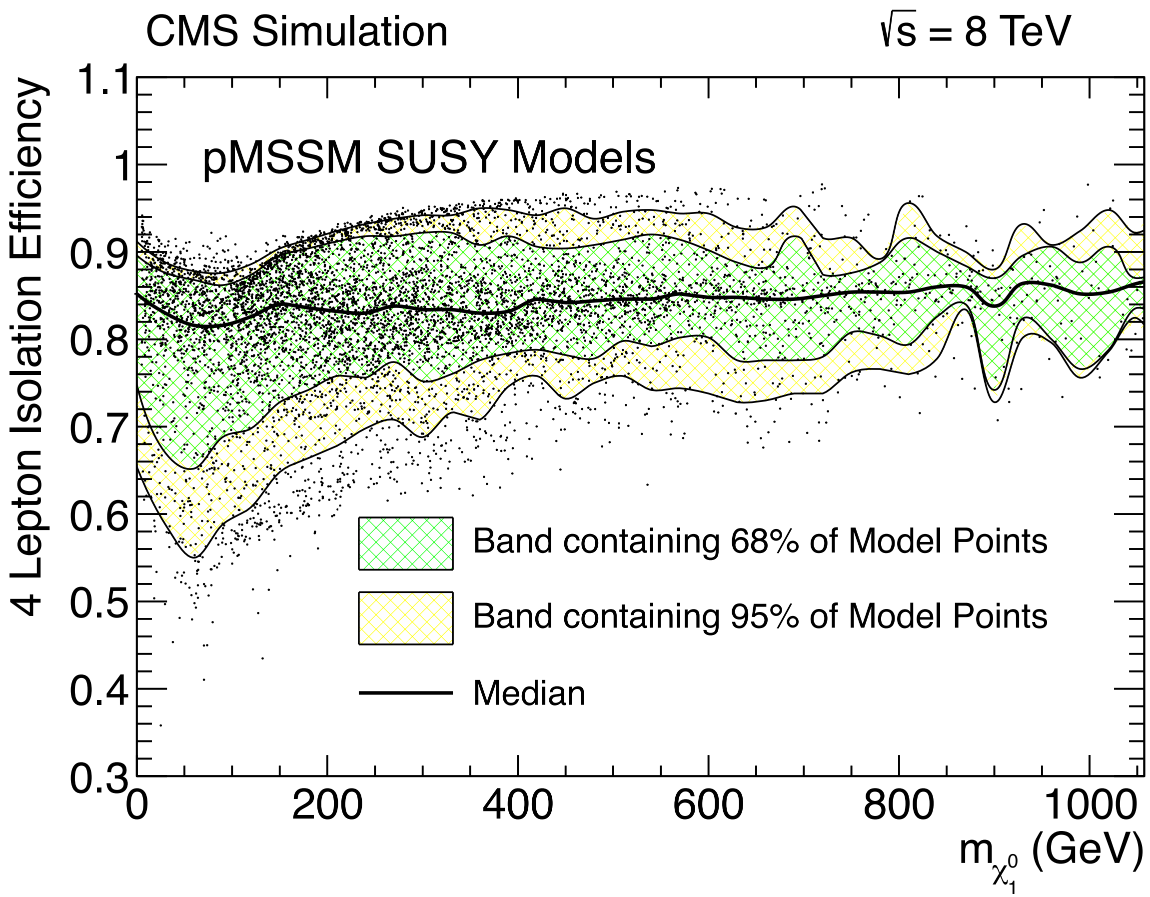




✓ **Efficiency is driven by neutralino mass via signal region selection**

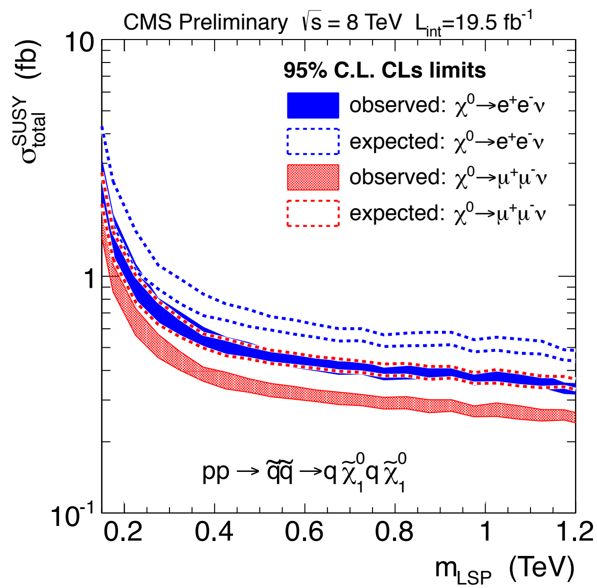
② Interpretation of pMSSM Model

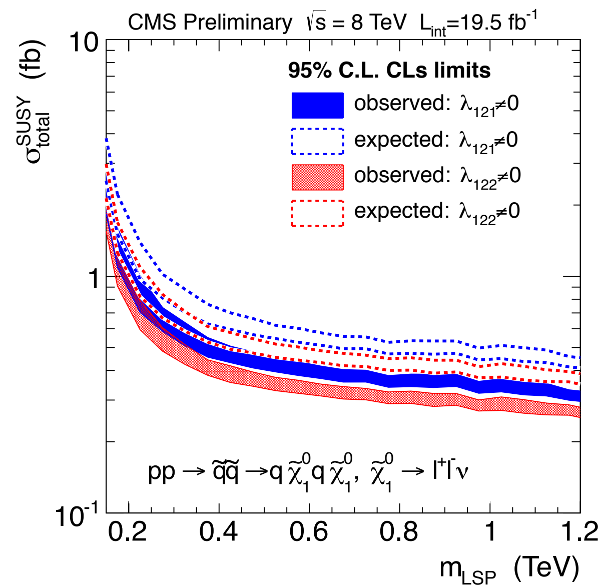
- pMSSM model points (~7300), which represents properties of generic MSSM, chosen with flat parameter priors at Electro-weak scale

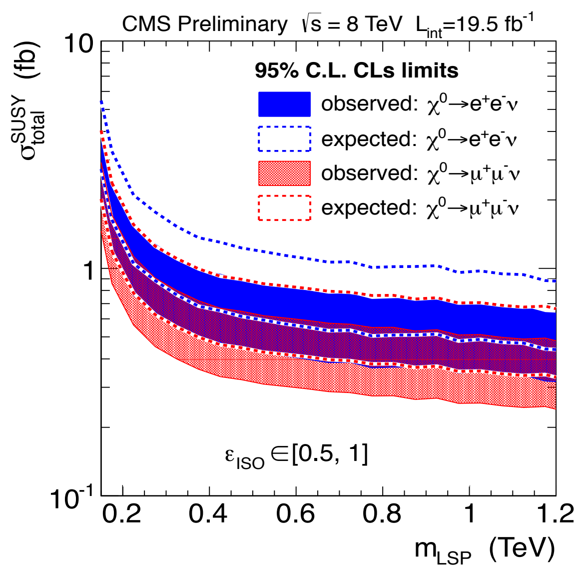


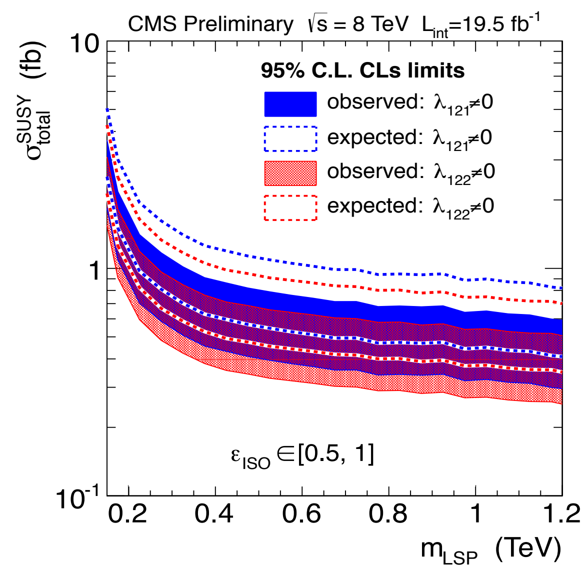
4-lepton isolation efficiency fits very well between 0.5 and 1.

② Upper limit on Cross Section of Simplified and Generic SUSY Models



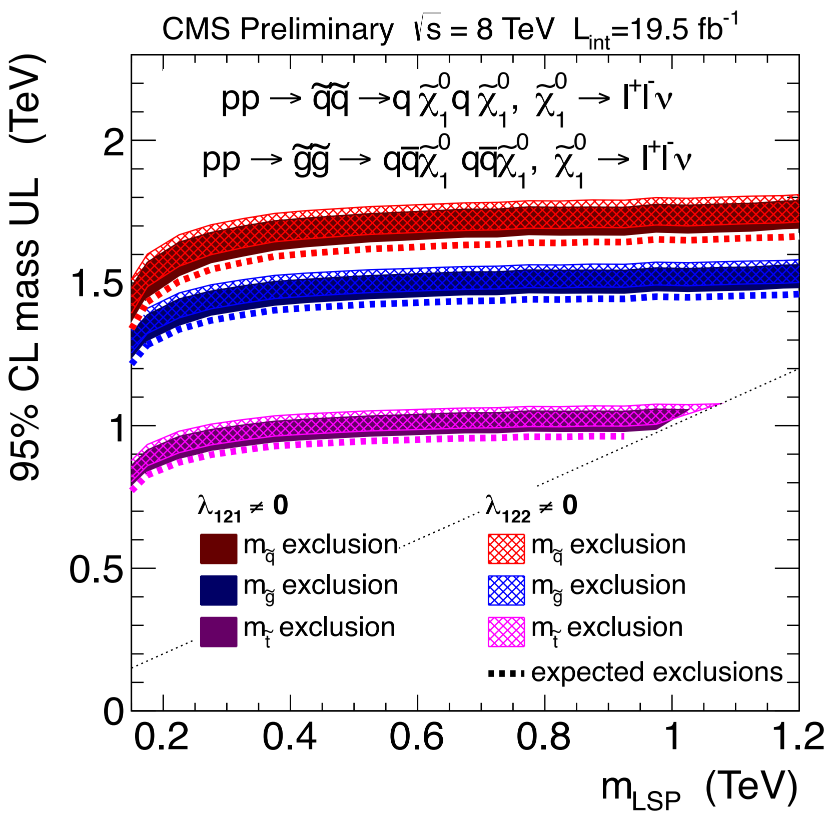


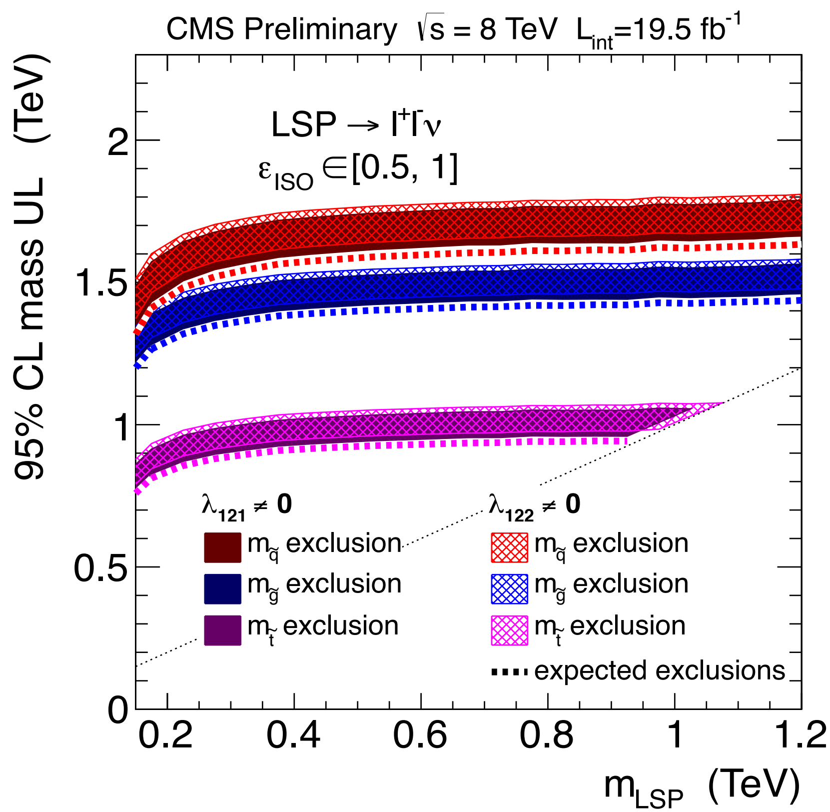


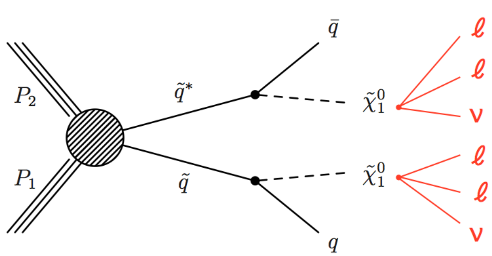


② General interpretation

Mass exclusions for different SUSY production mechanisms







Generic RPV SUSY cross section limit

Conclusions

- **CMS** has an active program searching for **R-parity violated SUSY.**
- **No significant excess** observed over **Standard Model expectations** for multi-lepton final states

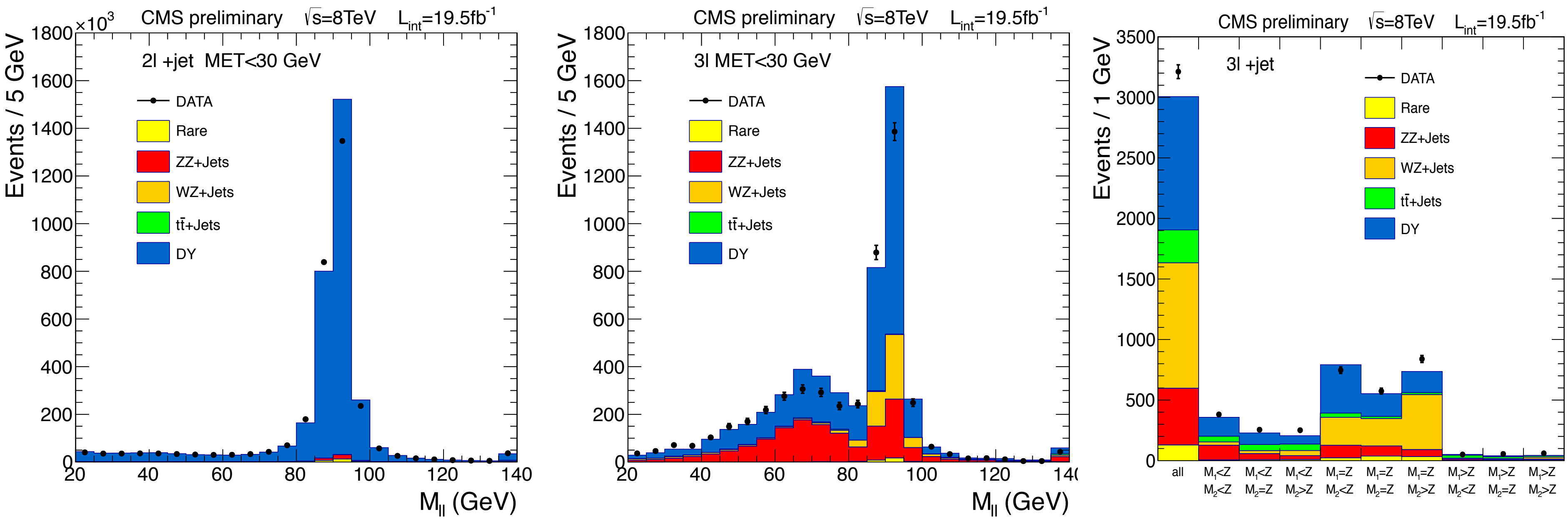
  → Both analyses are used to exclude regions of SUSY parameters space, where RPV couplings are non-zero. RPV Stop search puts limits on the **stop** and **bino** masses.

- **pMSSM model** are used to study the impact of generic component on R-parity violated term signatures

  → Results are applicable to generic set of **MSSM SUSY models** and **simplified models.**


BACKUP

② Fake Rate Techniques



② Ratio of Average Reconstructed Level Isolation Efficiency of all Charged 4-leptons from χ Decays