LHC Coverage of RPV Supersymmetry

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Supersymmetry with Broken R-Parity

- Reminder: $R_p = (-\mathbf{1})^{3B+L+2S}$

- Superpotential: $W = W_{MSSM} + W_{RpV}$

$$W_{MSSM} = \epsilon_{ab}[(Y_E)_{ij} L_i^a H_d^b \bar{E}_j + (Y_D)_{ij} Q_i^a H_d^b \bar{D}_j$$

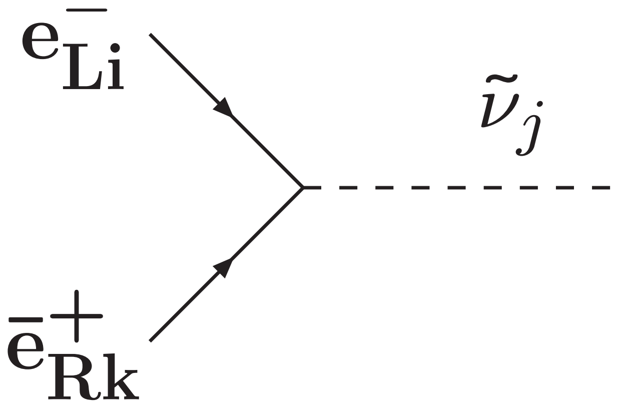
$$+(Y_U)_{ij} Q_i^a H_u^b \bar{U}_j + \mu H_d^a H_u^b]$$

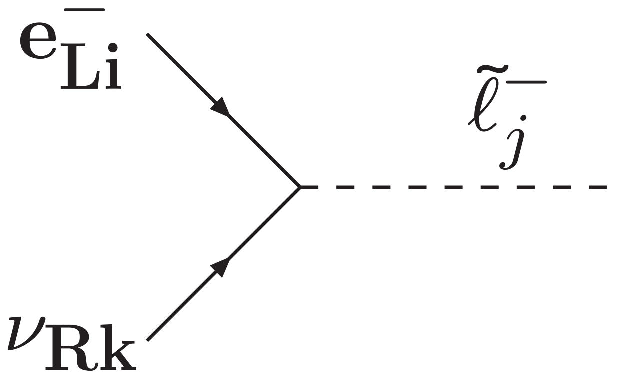
$$W_{RpV} = \epsilon_{ab}[\lambda_{ijk} L_i^a L_j^b \bar{E}_k + \lambda'_{ijk} L_i^a Q_j^b \bar{D}_k + \kappa_i L_i^a H_u^b]$$

$$+\lambda''_{ijk} \epsilon_{xyz} \bar{U}_i^x \bar{D}_j^y \bar{D}_k^z$$

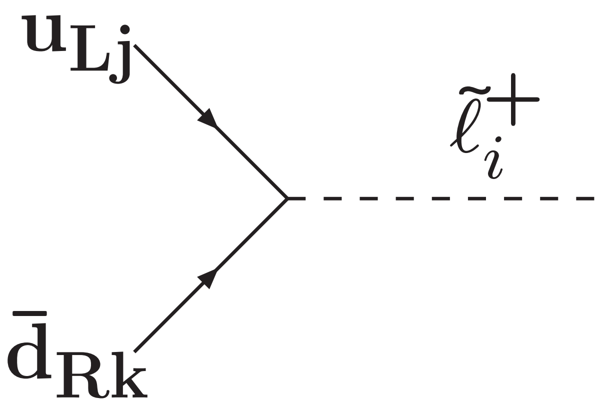
New Couplings (superpotential)

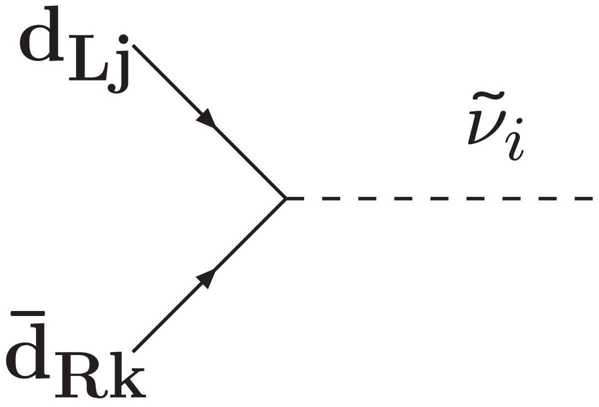
- $L_iL_jE_k$



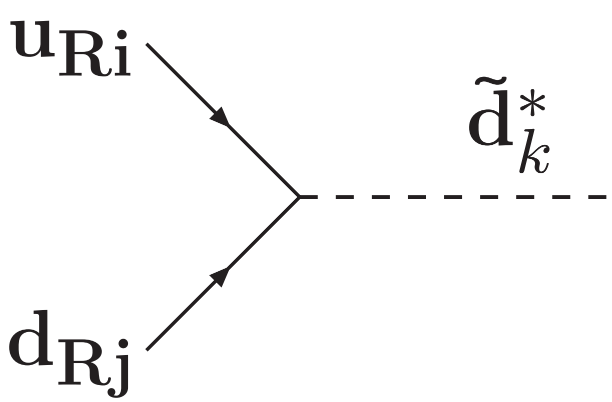


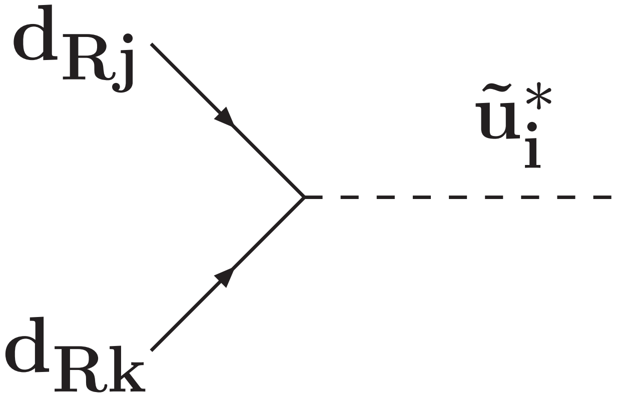
- $L_iQ_jD_k$





- $U_iD_jD_k$





Change in Phenomenology

- Single sparticle production

$$u_{Lj} + \bar{d}_{Rk} \to \ell_i^+ , \quad \text{via } \lambda'_{ijk} \gtrsim 10^{-3}$$

- LSP decays: no dark matter constraint

- Baryon and Lepton Number Violation

- How well is RpV covered by LHC searches?

- Nice paper to classify general RpC SUSY signatures by:

Konar, Matchev, Park, Sarangi; PRL 105 (2010)

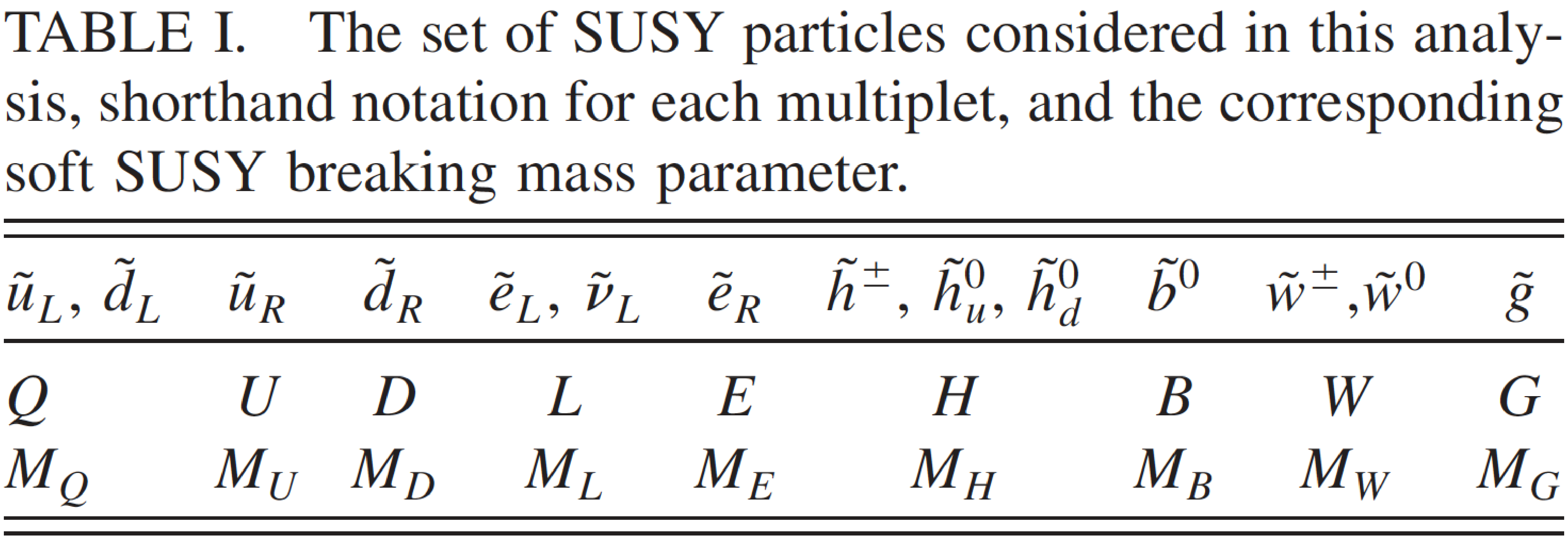
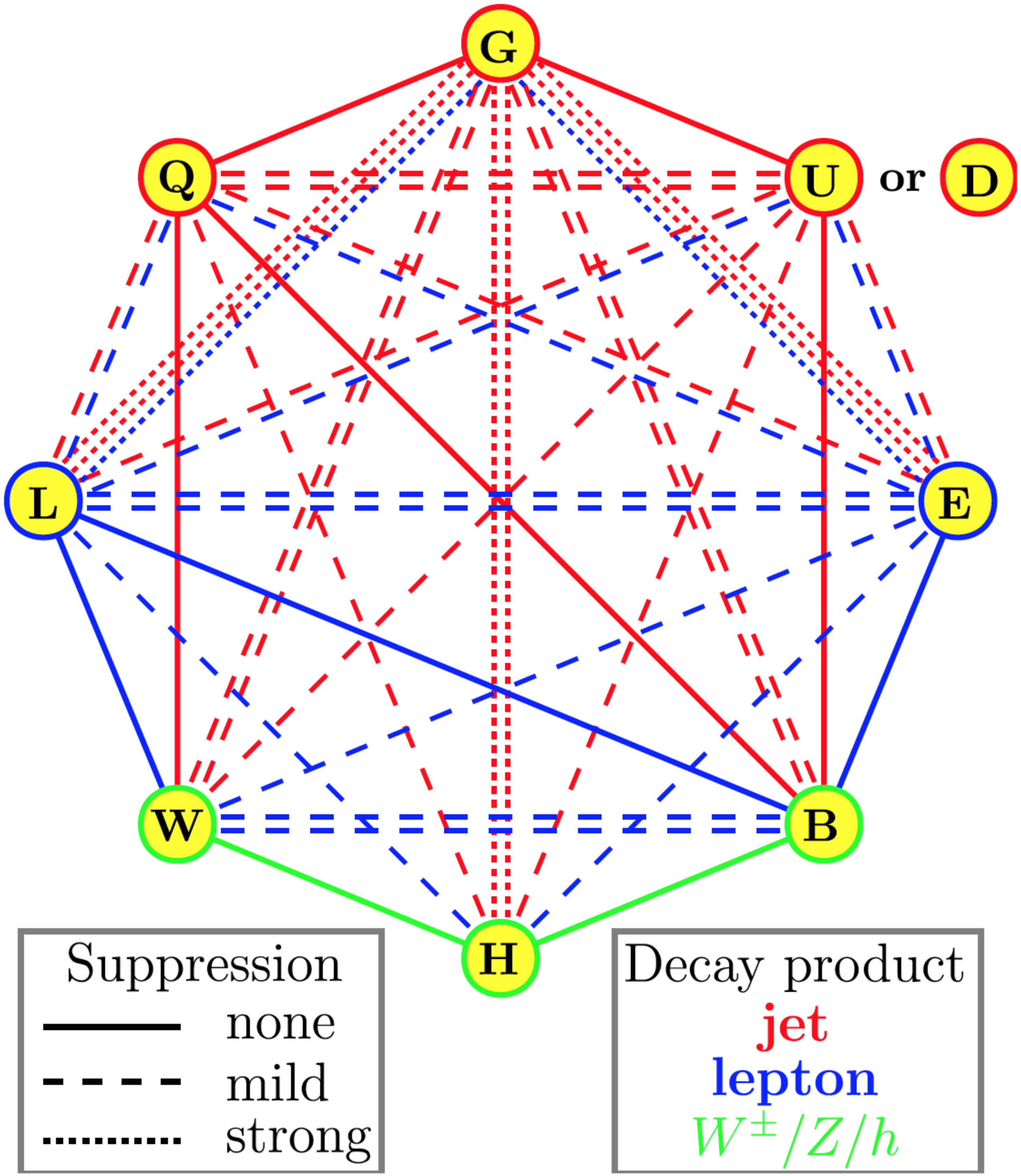


TABLE I. The set of SUSY particles considered in this analysis, shorthand notation for each multiplet, and the corresponding soft SUSY breaking mass parameter.

$\tilde{u}_L, \tilde{d}_L$	$\tilde{u}_R$	$\tilde{d}_R$	$\tilde{e}_L, \tilde{\nu}_L$	$\tilde{e}_R$	$\tilde{h}^{\pm}, \tilde{h}^0_u, \tilde{h}^0_d$	$\tilde{b}^0$	$\tilde{w}^{\pm}, \tilde{w}^0$	$\tilde{g}$
Q	U	D	L	E	H	B	W	G
M_Q	M_U	M_D	M_L	M_E	M_H	M_B	M_W	M_G

Classify Decays: strong, mild, none



- General ordering: $GQUDHLWEB;$
- Corresponds to:

$\tilde{\chi}_1^0$ LSP

$$M_G > M_Q > M_U > M_D > M_H > M_L > M_W > M_E > M_B$$

LCP: lightest colored particle

- Signature: $\tilde{d} \to d + \tilde{\chi}_1^0$
- Allow also for CHAMP or R-hadron LSP

(Konar et al.)

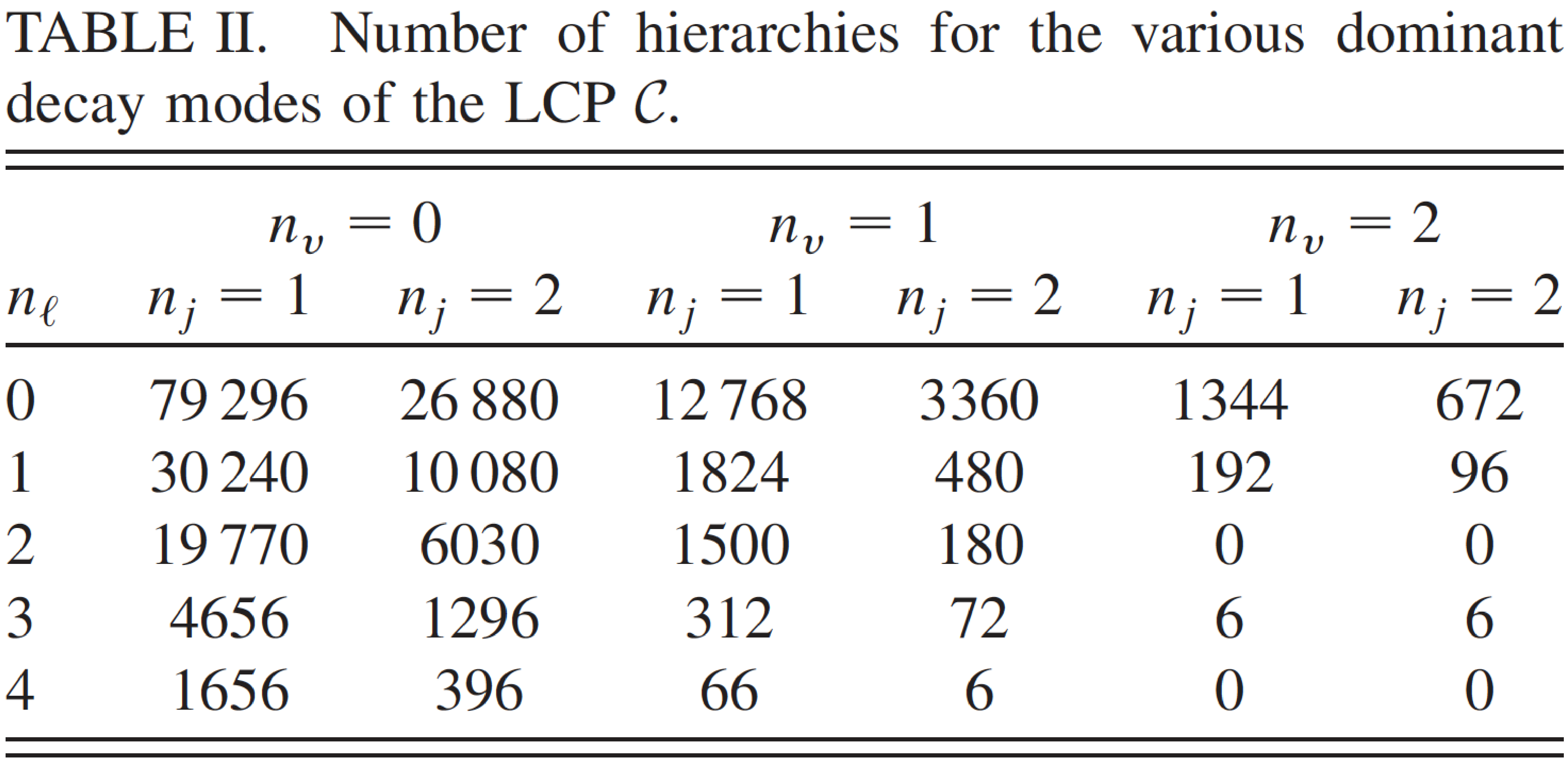


TABLE II. Number of hierarchies for the various dominant decay modes of the LCP $\mathcal{C}$.

	$n_v = 0$		$n_v = 1$		$n_v = 2$	
n_ℓ	$n_j = 1$	$n_j = 2$	$n_j = 1$	$n_j = 2$	$n_j = 1$	$n_j = 2$
0	79 296	26 880	12 768	3360	1344	672
1	30 240	10 080	1824	480	192	96
2	19 770	6030	1500	180	0	0
3	4656	1296	312	72	6	6
4	1656	396	66	6	0	0

General MSSM signatures at the LHC w/ and w/o R-parity

HKD, F. Staub, A. Vicente, W. Porod

PRD86 (2012) 035021

- Have gone beyond Konar et al
    - Allowed for separate 3rd generation parameters
    - Allow for all LSPs and RpV decays
- Redo the dominant decay picture
- Determine final states

LLE Case

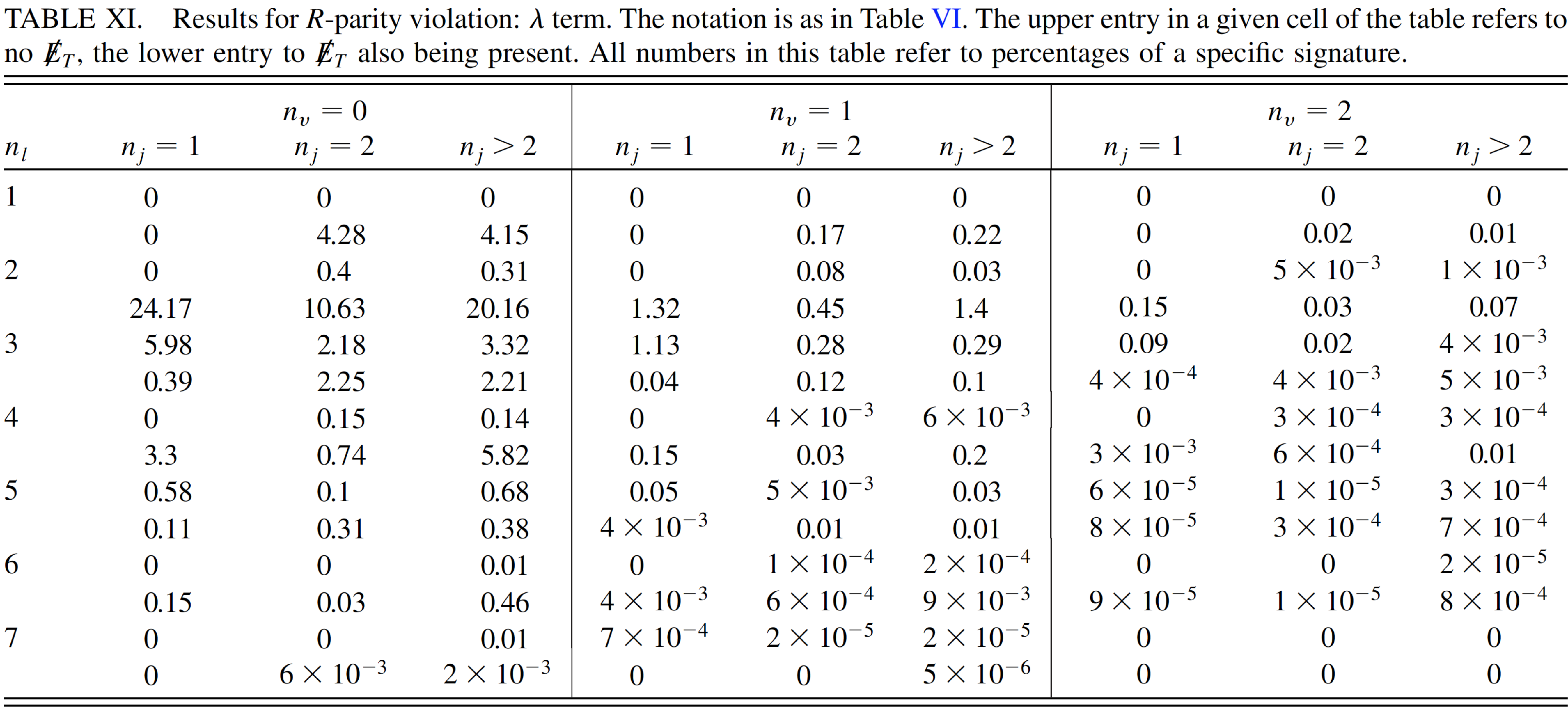


TABLE XI. Results for R-parity violation: λ term. The notation is as in Table VI. The upper entry in a given cell of the table refers to no $\not{E}_T$, the lower entry to $\not{E}_T$ also being present. All numbers in this table refer to percentages of a specific signature.

	$n_v = 0$			$n_v = 1$			$n_v = 2$		
n_l	$n_j = 1$	$n_j = 2$	$n_j > 2$	$n_j = 1$	$n_j = 2$	$n_j > 2$	$n_j = 1$	$n_j = 2$	$n_j > 2$
1	0	0	0	0	0	0	0	0	0
	0	4.28	4.15	0	0.17	0.22	0	0.02	0.01
2	0	0.4	0.31	0	0.08	0.03	0	5×10^{-3}	1×10^{-3}
	24.17	10.63	20.16	1.32	0.45	1.4	0.15	0.03	0.07
3	5.98	2.18	3.32	1.13	0.28	0.29	0.09	0.02	4×10^{-3}
	0.39	2.25	2.21	0.04	0.12	0.1	4×10^{-4}	4×10^{-3}	5×10^{-3}
4	0	0.15	0.14	0	4×10^{-3}	6×10^{-3}	0	3×10^{-4}	3×10^{-4}
	3.3	0.74	5.82	0.15	0.03	0.2	3×10^{-3}	6×10^{-4}	0.01
5	0.58	0.1	0.68	0.05	5×10^{-3}	0.03	6×10^{-5}	1×10^{-5}	3×10^{-4}
	0.11	0.31	0.38	4×10^{-3}	0.01	0.01	8×10^{-5}	3×10^{-4}	7×10^{-4}
6	0	0	0.01	0	1×10^{-4}	2×10^{-4}	0	0	2×10^{-5}
	0.15	0.03	0.46	4×10^{-3}	6×10^{-4}	9×10^{-3}	9×10^{-5}	1×10^{-5}	8×10^{-4}
7	0	0	0.01	7×10^{-4}	2×10^{-5}	2×10^{-5}	0	0	0
	0	6×10^{-3}	2×10^{-3}	0	0	5×10^{-6}	0	0	0

UDD Case

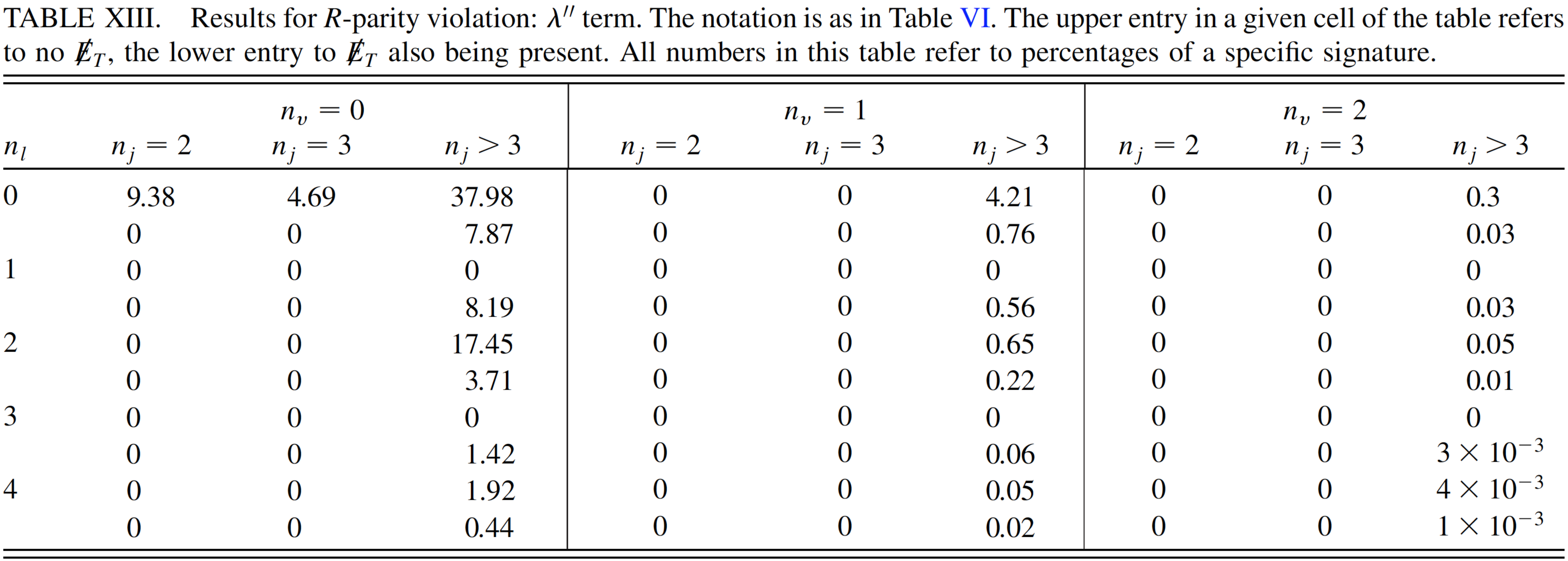


TABLE XIII. Results for R-parity violation: λ'' term. The notation is as in Table VI. The upper entry in a given cell of the table refers to no $\not{E}_T$, the lower entry to $\not{E}_T$ also being present. All numbers in this table refer to percentages of a specific signature.

		$n_v = 0$			$n_v = 1$			$n_v = 2$	
n_l	$n_j = 2$	$n_j = 3$	$n_j > 3$	$n_j = 2$	$n_j = 3$	$n_j > 3$	$n_j = 2$	$n_j = 3$	$n_j > 3$
0	9.38	4.69	37.98	0	0	4.21	0	0	0.3
	0	0	7.87	0	0	0.76	0	0	0.03
1	0	0	0	0	0	0	0	0	0
	0	0	8.19	0	0	0.56	0	0	0.03
2	0	0	17.45	0	0	0.65	0	0	0.05
	0	0	3.71	0	0	0.22	0	0	0.01
3	0	0	0	0	0	0	0	0	0
	0	0	1.42	0	0	0.06	0	0	3×10^{-3}
4	0	0	1.92	0	0	0.05	0	0	4×10^{-3}
	0	0	0.44	0	0	0.02	0	0	1×10^{-3}
]

UDD Case

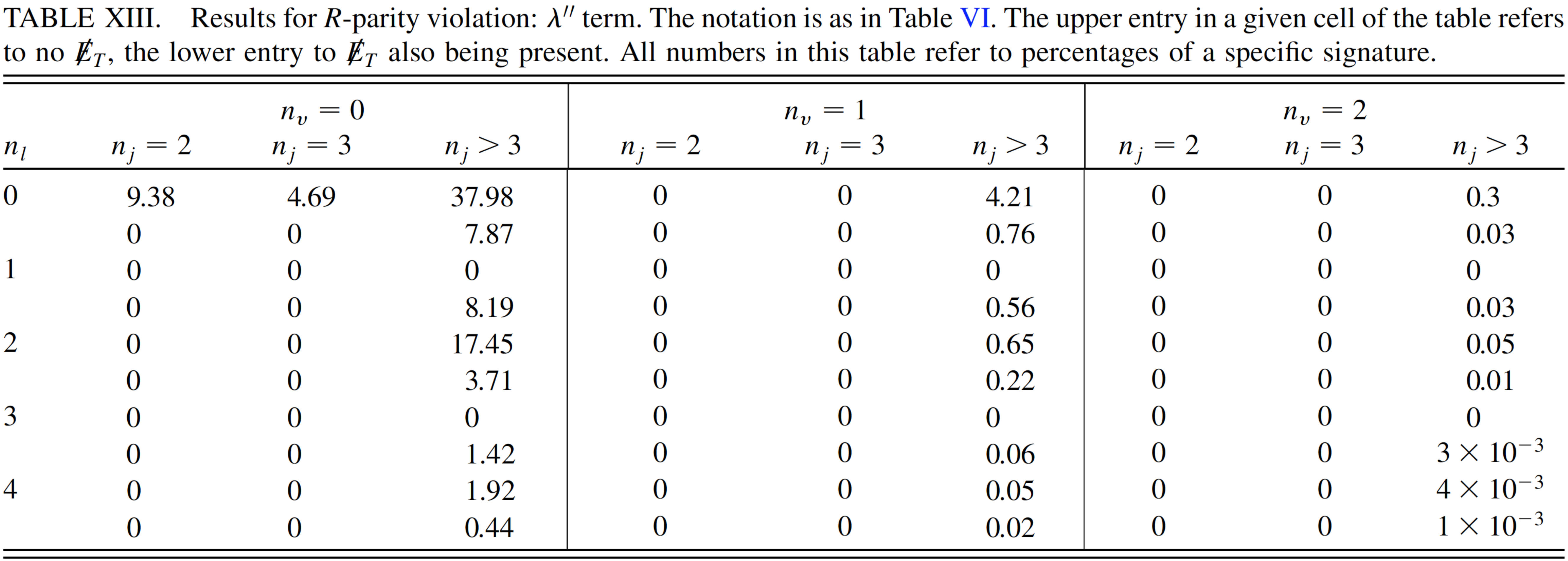


TABLE XIII. Results for R-parity violation: λ'' term. The notation is as in Table VI. The upper entry in a given cell of the table refers to no $\not{E}_T$, the lower entry to $\not{E}_T$ also being present. All numbers in this table refer to percentages of a specific signature.

		$n_v = 0$			$n_v = 1$			$n_v = 2$	
n_l	$n_j = 2$	$n_j = 3$	$n_j > 3$	$n_j = 2$	$n_j = 3$	$n_j > 3$	$n_j = 2$	$n_j = 3$	$n_j > 3$
0	9.38	4.69	37.98	0	0	4.21	0	0	0.3
	0	0	7.87	0	0	0.76	0	0	0.03
1	0	0	0	0	0	0	0	0	0
	0	0	8.19	0	0	0.56	0	0	0.03
2	0	0	17.45	0	0	0.65	0	0	0.05
	0	0	3.71	0	0	0.22	0	0	0.01
3	0	0	0	0	0	0	0	0	0
	0	0	1.42	0	0	0.06	0	0	3×10^{-3}
4	0	0	1.92	0	0	0.05	0	0	4×10^{-3}
	0	0	0.44	0	0	0.02	0	0	1×10^{-3}

- For the rest of the talk focus on RpV-CMSSM
- See what has already been covered, possibly by recasting

RpV-CMSSM LHC Searches

- Consider strong pair production: $\tilde{g}\tilde{g},\ \tilde{q}\tilde{q}$
- Followed by cascade decay to $\tilde{\chi}_1^0$ LSP
- For prompt LSP-decay $(\ell = e,\ \mu)$

LLE: $$\tilde{\chi}_1^0 \to \begin{cases} \ell^\pm \ell^\mp \nu, & L_1 L_{2,3} \bar{E}_{1,2},\ L_2 L_3 \bar{E}_{1,2} \\ \ell^\pm \tau^\mp \nu, & L_1 L_{2,3} \bar{E}_3,\ L_2 L_3 \bar{E}_3 \end{cases}$$

UDD: $$\tilde{\chi}_1^0 \to \begin{cases} 3\,\mathrm{j}, & \bar{U}_{1,2} \bar{D}_1 \bar{D}_2 \\ b + 2\,\mathrm{j}, & \bar{U}_{1,2} \bar{D}_{1,2} \bar{D}_3 \\ t + 2\,\mathrm{j}, & \bar{U}_3 \bar{D}_1 \bar{D}_2 \\ t + b + \mathrm{j}, & \bar{U}_3 \bar{D}_{1,2} \bar{D}_3 \end{cases}$$

LHC Searches

LQD:

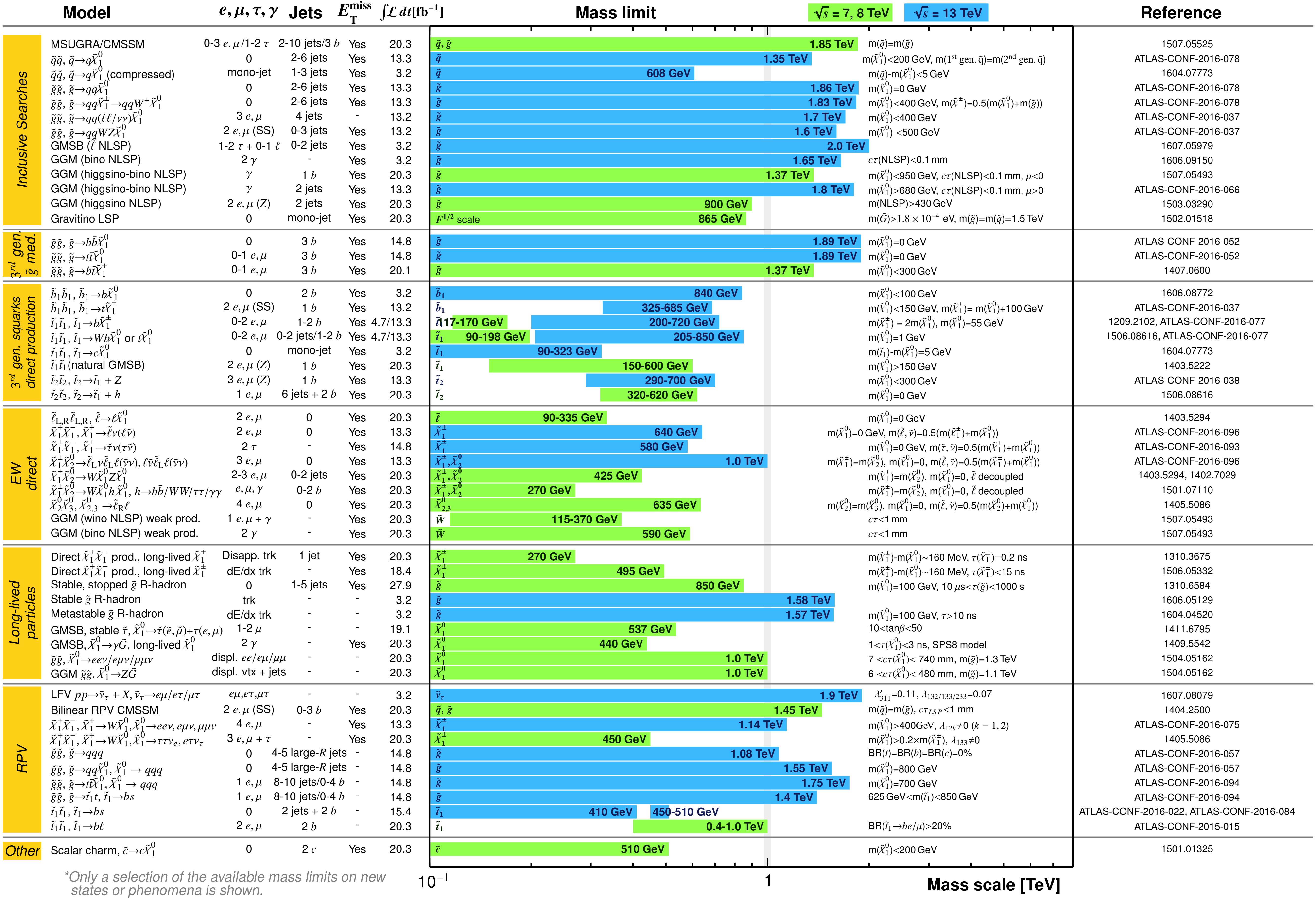
$$\tilde{\chi}_1^0 \rightarrow \begin{cases} \ell^{\pm} + 2\,\mathrm{j}, & L_{1,2}Q_{1,2}\bar{D}_{1,2} \\ \tau^{\pm} + 2\,\mathrm{j}, & L_3Q_{1,2}\bar{D}_{1,2} \\ \ell^{\pm} + b + \mathrm{j}, & L_{1,2}Q_{1,2}\bar{D}_3 \\ \tau^{\pm} + b + \mathrm{j}, & L_3Q_{1,2}\bar{D}_3 \\ \ell^{\pm} + t + \mathrm{j}, & L_{1,2}Q_3\bar{D}_{1,2} \\ \tau^{\pm} + t + \mathrm{j}, & L_3Q_3\bar{D}_{1,2} \\ \ell^{\pm} + t + b, & L_{1,2}Q_3\bar{D}_3 \\ \tau^{\pm} + t + b, & L_3Q_3\bar{D}_3 \end{cases}$$

ATLAS SUSY Searches* - 95% CL Lower Limits

Status: August 2016

ATLAS Preliminary

$\sqrt{s}$ = 7, 8, 13 TeV



	Model	e,μ,τ,γ	Jets	E_T^{miss}	$\int\mathcal{L}\,dt[\mathrm{fb}^{-1}]$	Mass limit			Reference
Inclusive Searches	MSUGRA/CMSSM	0-3 e,μ/1-2 τ	2-10 jets/3 b	Yes	20.3	$\tilde{q},\tilde{g}$	🟩 1.85 TeV	$m(\tilde{q})=m(\tilde{g})$	1507.05525
	$\tilde{q}\tilde{q}$, $\tilde{q}\to q\tilde{\chi}_1^0$	0	2-6 jets	Yes	13.3	$\tilde{q}$	🟦 1.35 TeV	$m(\tilde{\chi}_1^0)$<200 GeV, m(1st gen. $\tilde{q}$)=m(2nd gen. $\tilde{q}$)	ATLAS-CONF-2016-078
	$\tilde{q}\tilde{q}$, $\tilde{q}\to q\tilde{\chi}_1^0$ (compressed)	mono-jet	1-3 jets	Yes	3.2	$\tilde{q}$	🟦 608 GeV	$m(\tilde{q})$-$m(\tilde{\chi}_1^0)$<5 GeV	1604.07773
	$\tilde{g}\tilde{g}$, $\tilde{g}\to q\bar{q}\tilde{\chi}_1^0$	0	2-6 jets	Yes	13.3	$\tilde{g}$	🟦 1.86 TeV	$m(\tilde{\chi}_1^0)$=0 GeV	ATLAS-CONF-2016-078
	$\tilde{g}\tilde{g}$, $\tilde{g}\to qq\tilde{\chi}_1^\pm\to qqW^\pm\tilde{\chi}_1^0$	0	2-6 jets	Yes	13.3	$\tilde{g}$	🟦 1.83 TeV	$m(\tilde{\chi}_1^0)$<400 GeV, $m(\tilde{\chi}^\pm)$=0.5($m(\tilde{\chi}_1^0)$+$m(\tilde{g})$)	ATLAS-CONF-2016-078
	$\tilde{g}\tilde{g}$, $\tilde{g}\to qq(\ell\ell/\nu\nu)\tilde{\chi}_1^0$	3 e,μ	4 jets	-	13.2	$\tilde{g}$	🟦 1.7 TeV	$m(\tilde{\chi}_1^0)$<400 GeV	ATLAS-CONF-2016-037
	$\tilde{g}\tilde{g}$, $\tilde{g}\to qqWZ\tilde{\chi}_1^0$	2 e,μ (SS)	0-3 jets	Yes	13.2	$\tilde{g}$	🟦 1.6 TeV	$m(\tilde{\chi}_1^0)$ <500 GeV	ATLAS-CONF-2016-037
	GMSB ($\tilde{\ell}$ NLSP)	1-2 τ + 0-1 ℓ	0-2 jets	Yes	3.2	$\tilde{g}$	🟦 2.0 TeV		1607.05979
	GGM (bino NLSP)	2 γ	-	Yes	3.2	$\tilde{g}$	🟦 1.65 TeV	$c\tau$(NLSP)<0.1 mm	1606.09150
	GGM (higgsino-bino NLSP)	γ	1 b	Yes	20.3	$\tilde{g}$	🟩 1.37 TeV	$m(\tilde{\chi}_1^0)$<950 GeV, $c\tau$(NLSP)<0.1 mm, μ<0	1507.05493
	GGM (higgsino-bino NLSP)	γ	2 jets	Yes	13.3	$\tilde{g}$	🟦 1.8 TeV	$m(\tilde{\chi}_1^0)$>680 GeV, $c\tau$(NLSP)<0.1 mm, μ>0	ATLAS-CONF-2016-066
	GGM (higgsino NLSP)	2 e,μ (Z)	2 jets	Yes	20.3	$\tilde{g}$	🟩 900 GeV	m(NLSP)>430 GeV	1503.03290
	Gravitino LSP	0	mono-jet	Yes	20.3	$F^{1/2}$ scale	🟩 865 GeV	$m(\tilde{G})>1.8\times10^{-4}$ eV, $m(\tilde{g})=m(\tilde{q})$=1.5 TeV	1502.01518
3^{rd} gen. $\tilde{g}$ med.	$\tilde{g}\tilde{g}$, $\tilde{g}\to b\bar{b}\tilde{\chi}_1^0$	0	3 b	Yes	14.8	$\tilde{g}$	🟦 1.89 TeV	$m(\tilde{\chi}_1^0)$=0 GeV	ATLAS-CONF-2016-052
	$\tilde{g}\tilde{g}$, $\tilde{g}\to t\bar{t}\tilde{\chi}_1^0$	0-1 e,μ	3 b	Yes	14.8	$\tilde{g}$	🟦 1.89 TeV	$m(\tilde{\chi}_1^0)$=0 GeV	ATLAS-CONF-2016-052
	$\tilde{g}\tilde{g}$, $\tilde{g}\to b\bar{t}\tilde{\chi}_1^+$	0-1 e,μ	3 b	Yes	20.1	$\tilde{g}$	🟩 1.37 TeV	$m(\tilde{\chi}_1^0)$<300 GeV	1407.0600
3^{rd} gen. squarks direct production	$\tilde{b}_1\tilde{b}_1$, $\tilde{b}_1\to b\tilde{\chi}_1^0$	0	2 b	Yes	3.2	$\tilde{b}_1$	🟦 840 GeV	$m(\tilde{\chi}_1^0)$<100 GeV	1606.08772
	$\tilde{b}_1\tilde{b}_1$, $\tilde{b}_1\to t\tilde{\chi}_1^\pm$	2 e,μ (SS)	1 b	Yes	13.2	$\tilde{b}_1$	🟦 325-685 GeV	$m(\tilde{\chi}_1^0)$<150 GeV, $m(\tilde{\chi}_1^\pm)$= $m(\tilde{\chi}_1^0)$+100 GeV	ATLAS-CONF-2016-037
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to b\tilde{\chi}_1^\pm$	0-2 e,μ	1-2 b	Yes	4.7/13.3	$\tilde{t}_1$	🟩 117-170 GeV 🟦 200-720 GeV	$m(\tilde{\chi}_1^\pm)$ = 2$m(\tilde{\chi}_1^0)$, $m(\tilde{\chi}_1^0)$=55 GeV	1209.2102, ATLAS-CONF-2016-077
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to Wb\tilde{\chi}_1^0$ or $t\tilde{\chi}_1^0$	0-2 e,μ	0-2 jets/1-2 b	Yes	4.7/13.3	$\tilde{t}_1$	🟩 90-198 GeV 🟦 205-850 GeV	$m(\tilde{\chi}_1^0)$=1 GeV	1506.08616, ATLAS-CONF-2016-077
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to c\tilde{\chi}_1^0$	0	mono-jet	Yes	3.2	$\tilde{t}_1$	🟦 90-323 GeV	$m(\tilde{t}_1)$-$m(\tilde{\chi}_1^0)$=5 GeV	1604.07773
	$\tilde{t}_1\tilde{t}_1$ (natural GMSB)	2 e,μ (Z)	1 b	Yes	20.3	$\tilde{t}_1$	🟩 150-600 GeV	$m(\tilde{\chi}_1^0)$>150 GeV	1403.5222
	$\tilde{t}_2\tilde{t}_2$, $\tilde{t}_2\to\tilde{t}_1+Z$	3 e,μ (Z)	1 b	Yes	13.3	$\tilde{t}_2$	🟦 290-700 GeV	$m(\tilde{\chi}_1^0)$<300 GeV	ATLAS-CONF-2016-038
	$\tilde{t}_2\tilde{t}_2$, $\tilde{t}_2\to\tilde{t}_1+h$	1 e,μ	6 jets + 2 b	Yes	20.3	$\tilde{t}_2$	🟩 320-620 GeV	$m(\tilde{\chi}_1^0)$=0 GeV	1506.08616
EW direct	$\tilde{\ell}_{L,R}\tilde{\ell}_{L,R}$, $\tilde{\ell}\to\ell\tilde{\chi}_1^0$	2 e,μ	0	Yes	20.3	$\tilde{\ell}$	🟩 90-335 GeV	$m(\tilde{\chi}_1^0)$=0 GeV	1403.5294
	$\tilde{\chi}_1^+\tilde{\chi}_1^-$, $\tilde{\chi}_1^+\to\tilde{\ell}\nu(\ell\tilde{\nu})$	2 e,μ	0	Yes	13.3	$\tilde{\chi}_1^\pm$	🟦 640 GeV	$m(\tilde{\chi}_1^0)$=0 GeV, $m(\tilde{\ell},\tilde{\nu})$=0.5($m(\tilde{\chi}_1^\pm)$+$m(\tilde{\chi}_1^0)$)	ATLAS-CONF-2016-096
	$\tilde{\chi}_1^+\tilde{\chi}_1^-$, $\tilde{\chi}_1^+\to\tilde{\tau}\nu(\tau\tilde{\nu})$	2 τ	-	Yes	14.8	$\tilde{\chi}_1^\pm$	🟦 580 GeV	$m(\tilde{\chi}_1^0)$=0 GeV, $m(\tilde{\tau},\tilde{\nu})$=0.5($m(\tilde{\chi}_1^\pm)$+$m(\tilde{\chi}_1^0)$)	ATLAS-CONF-2016-093
	$\tilde{\chi}_1^\pm\tilde{\chi}_2^0\to\tilde{\ell}_L\nu\tilde{\ell}_L\ell(\tilde{\nu}\nu)$, $\ell\tilde{\nu}\tilde{\ell}_L\ell(\tilde{\nu}\nu)$	3 e,μ	0	Yes	13.3	$\tilde{\chi}_1^\pm,\tilde{\chi}_2^0$	🟦 1.0 TeV	$m(\tilde{\chi}_1^\pm)$=$m(\tilde{\chi}_2^0)$, $m(\tilde{\chi}_1^0)$=0, $m(\tilde{\ell},\tilde{\nu})$=0.5($m(\tilde{\chi}_1^\pm)$+$m(\tilde{\chi}_1^0)$)	ATLAS-CONF-2016-096
	$\tilde{\chi}_1^\pm\tilde{\chi}_2^0\to W\tilde{\chi}_1^0Z\tilde{\chi}_1^0$	2-3 e,μ	0-2 jets	Yes	20.3	$\tilde{\chi}_1^\pm,\tilde{\chi}_2^0$	🟩 425 GeV	$m(\tilde{\chi}_1^\pm)$=$m(\tilde{\chi}_2^0)$, $m(\tilde{\chi}_1^0)$=0, $\tilde{\ell}$ decoupled	1403.5294, 1402.7029
	$\tilde{\chi}_1^\pm\tilde{\chi}_2^0\to W\tilde{\chi}_1^0h\tilde{\chi}_1^0$, $h\to b\bar{b}/WW/\tau\tau/\gamma\gamma$	e,μ,γ	0-2 b	Yes	20.3	$\tilde{\chi}_1^\pm,\tilde{\chi}_2^0$	🟩 270 GeV	$m(\tilde{\chi}_1^\pm)$=$m(\tilde{\chi}_2^0)$, $m(\tilde{\chi}_1^0)$=0, $\tilde{\ell}$ decoupled	1501.07110
	$\tilde{\chi}_2^0\tilde{\chi}_3^0$, $\tilde{\chi}_{2,3}^0\to\tilde{\ell}_R\ell$	4 e,μ	0	Yes	20.3	$\tilde{\chi}_{2,3}^0$	🟩 635 GeV	$m(\tilde{\chi}_2^0)$=$m(\tilde{\chi}_3^0)$, $m(\tilde{\chi}_1^0)$=0, $m(\tilde{\ell},\tilde{\nu})$=0.5($m(\tilde{\chi}_2^0)$+$m(\tilde{\chi}_1^0)$)	1405.5086
	GGM (wino NLSP) weak prod.	1 e,μ + γ	-	Yes	20.3	$\tilde{W}$	🟩 115-370 GeV	$c\tau$<1 mm	1507.05493
	GGM (bino NLSP) weak prod.	2 γ	-	Yes	20.3	$\tilde{W}$	🟩 590 GeV	$c\tau$<1 mm	1507.05493
Long-lived particles	Direct $\tilde{\chi}_1^+\tilde{\chi}_1^-$ prod., long-lived $\tilde{\chi}_1^\pm$	Disapp. trk	1 jet	Yes	20.3	$\tilde{\chi}_1^\pm$	🟩 270 GeV	$m(\tilde{\chi}_1^\pm)$-$m(\tilde{\chi}_1^0)$~160 MeV, $\tau(\tilde{\chi}_1^\pm)$=0.2 ns	1310.3675
	Direct $\tilde{\chi}_1^+\tilde{\chi}_1^-$ prod., long-lived $\tilde{\chi}_1^\pm$	dE/dx trk	-	Yes	18.4	$\tilde{\chi}_1^\pm$	🟩 495 GeV	$m(\tilde{\chi}_1^\pm)$-$m(\tilde{\chi}_1^0)$~160 MeV, $\tau(\tilde{\chi}_1^\pm)$<15 ns	1506.05332
	Stable, stopped $\tilde{g}$ R-hadron	0	1-5 jets	Yes	27.9	$\tilde{g}$	🟩 850 GeV	$m(\tilde{\chi}_1^0)$=100 GeV, 10 μs<$\tau(\tilde{g})$<1000 s	1310.6584
	Stable $\tilde{g}$ R-hadron	trk	-	-	3.2	$\tilde{g}$	🟦 1.58 TeV		1606.05129
	Metastable $\tilde{g}$ R-hadron	dE/dx trk	-	-	3.2	$\tilde{g}$	🟦 1.57 TeV	$m(\tilde{\chi}_1^0)$=100 GeV, τ>10 ns	1604.04520
	GMSB, stable $\tilde{\tau}$, $\tilde{\chi}_1^0\to\tilde{\tau}(\tilde{e},\tilde{\mu})+\tau(e,\mu)$	1-2 μ	-	-	19.1	$\tilde{\chi}_1^0$	🟩 537 GeV	10<tanβ<50	1411.6795
	GMSB, $\tilde{\chi}_1^0\to\gamma\tilde{G}$, long-lived $\tilde{\chi}_1^0$	2 γ	-	Yes	20.3	$\tilde{\chi}_1^0$	🟩 440 GeV	1<$\tau(\tilde{\chi}_1^0)$<3 ns, SPS8 model	1409.5542
	$\tilde{g}\tilde{g}$, $\tilde{\chi}_1^0\to ee\nu/e\mu\nu/\mu\mu\nu$	displ. $ee/e\mu/\mu\mu$	-	-	20.3	$\tilde{\chi}_1^0$	🟩 1.0 TeV	7 <$c\tau(\tilde{\chi}_1^0)$< 740 mm, $m(\tilde{g})$=1.3 TeV	1504.05162
	GGM $\tilde{g}\tilde{g}$, $\tilde{\chi}_1^0\to Z\tilde{G}$	displ. vtx + jets	-	-	20.3	$\tilde{\chi}_1^0$	🟩 1.0 TeV	6 <$c\tau(\tilde{\chi}_1^0)$< 480 mm, $m(\tilde{g})$=1.1 TeV	1504.05162
RPV	LFV $pp\to\tilde{\nu}_\tau+X$, $\tilde{\nu}_\tau\to e\mu/e\tau/\mu\tau$	$e\mu,e\tau,\mu\tau$	-	-	3.2	$\tilde{\nu}_\tau$	🟦 1.9 TeV	λ'_{311}=0.11, $\lambda_{132/133/233}$=0.07	1607.08079
	Bilinear RPV CMSSM	2 e,μ (SS)	0-3 b	Yes	20.3	$\tilde{q},\tilde{g}$	🟩 1.45 TeV	$m(\tilde{q})=m(\tilde{g})$, $c\tau_{LSP}$<1 mm	1404.2500
	$\tilde{\chi}_1^+\tilde{\chi}_1^-$, $\tilde{\chi}_1^+\to W\tilde{\chi}_1^0$, $\tilde{\chi}_1^0\to ee\nu, e\mu\nu, \mu\mu\nu$	4 e,μ	-	Yes	13.3	$\tilde{\chi}_1^\pm$	🟦 1.14 TeV	$m(\tilde{\chi}_1^0)$>400GeV, $\lambda_{12k}\neq0$ ($k=1,2$)	ATLAS-CONF-2016-075
	$\tilde{\chi}_1^+\tilde{\chi}_1^-$, $\tilde{\chi}_1^+\to W\tilde{\chi}_1^0$, $\tilde{\chi}_1^0\to\tau\tau\nu_e, e\tau\nu_\tau$	3 e,μ + τ	-	Yes	20.3	$\tilde{\chi}_1^\pm$	🟩 450 GeV	$m(\tilde{\chi}_1^0)$>0.2×$m(\tilde{\chi}_1^\pm)$, $\lambda_{133}\neq0$	1405.5086
	$\tilde{g}\tilde{g}$, $\tilde{g}\to qqq$	0	4-5 large-R jets	-	14.8	$\tilde{g}$	🟦 1.08 TeV	BR(t)=BR(b)=BR(c)=0%	ATLAS-CONF-2016-057
	$\tilde{g}\tilde{g}$, $\tilde{g}\to qq\tilde{\chi}_1^0$, $\tilde{\chi}_1^0\to qqq$	0	4-5 large-R jets	-	14.8	$\tilde{g}$	🟦 1.55 TeV	$m(\tilde{\chi}_1^0)$=800 GeV	ATLAS-CONF-2016-057
	$\tilde{g}\tilde{g}$, $\tilde{g}\to t\bar{t}\tilde{\chi}_1^0$, $\tilde{\chi}_1^0\to qqq$	1 e,μ	8-10 jets/0-4 b	-	14.8	$\tilde{g}$	🟦 1.75 TeV	$m(\tilde{\chi}_1^0)$=700 GeV	ATLAS-CONF-2016-094
	$\tilde{g}\tilde{g}$, $\tilde{g}\to\tilde{t}_1t$, $\tilde{t}_1\to bs$	1 e,μ	8-10 jets/0-4 b	-	14.8	$\tilde{g}$	🟦 1.4 TeV	625 GeV<$m(\tilde{t}_1)$<850 GeV	ATLAS-CONF-2016-094
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to bs$	0	2 jets + 2 b	-	15.4	$\tilde{t}_1$	🟦 410 GeV 🟦 450-510 GeV		ATLAS-CONF-2016-022, ATLAS-CONF-2016-084
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to b\ell$	2 e,μ	2 b	-	20.3	$\tilde{t}_1$	🟩 0.4-1.0 TeV	BR($\tilde{t}_1\to be/\mu$)>20%	ATLAS-CONF-2015-015
Other	Scalar charm, $\tilde{c}\to c\tilde{\chi}_1^0$	0	2 c	Yes	20.3	$\tilde{c}$	🟩 510 GeV	$m(\tilde{\chi}_1^0)$<200 GeV	1501.01325

*Only a selection of the available mass limits on new states or phenomena is shown.

Long-l *partic*	Metastable $\tilde{g}$ R-hadron	dE/dx trk	-	-	3.2	$\tilde{g}$
	GMSB, stable $\tilde{\tau}$, $\tilde{\chi}_1^0 \to \tilde{\tau}(\tilde{e},\tilde{\mu})+\tau(e,\mu)$	1-2 μ	-	-	19.1	$\tilde{\chi}_1^0$
	GMSB, $\tilde{\chi}_1^0 \to \gamma\tilde{G}$, long-lived $\tilde{\chi}_1^0$	2 γ	-	Yes	20.3	$\tilde{\chi}_1^0$
	$\tilde{g}\tilde{g}, \tilde{\chi}_1^0 \to ee\nu/e\mu\nu/\mu\mu\nu$	displ. $ee/e\mu/\mu\mu$	-	-	20.3	$\tilde{\chi}_1^0$
	GGM $\tilde{g}\tilde{g}, \tilde{\chi}_1^0 \to Z\tilde{G}$	displ. vtx + jets	-	-	20.3	$\tilde{\chi}_1^0$
RPV	LFV $pp \to \tilde{\nu}_\tau + X, \tilde{\nu}_\tau \to e\mu/e\tau/\mu\tau$	$e\mu,e\tau,\mu\tau$	-	-	3.2	$\tilde{\nu}_\tau$
	Bilinear RPV CMSSM	2 e,μ (SS)	0-3 b	Yes	20.3	$\tilde{q}, \tilde{g}$
	$\tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^+ \to W\tilde{\chi}_1^0, \tilde{\chi}_1^0 \to ee\nu, e\mu\nu, \mu\mu\nu$	4 e,μ	-	Yes	13.3	$\tilde{\chi}_1^\pm$
	$\tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^+ \to W\tilde{\chi}_1^0, \tilde{\chi}_1^0 \to \tau\tau\nu_e, e\tau\nu_\tau$	3 $e,\mu + \tau$	-	Yes	20.3	$\tilde{\chi}_1^\pm$
	$\tilde{g}\tilde{g}$, $\tilde{g} \to qqq$	0	4-5 large-R jets	-	14.8	$\tilde{g}$
	$\tilde{g}\tilde{g}$, $\tilde{g} \to qq\tilde{\chi}_1^0, \tilde{\chi}_1^0 \to qqq$	0	4-5 large-R jets	-	14.8	$\tilde{g}$
	$\tilde{g}\tilde{g}$, $\tilde{g} \to t\bar{t}\tilde{\chi}_1^0, \tilde{\chi}_1^0 \to qqq$	1 e,μ	8-10 jets/0-4 b	-	14.8	$\tilde{g}$
	$\tilde{g}\tilde{g}$, $\tilde{g} \to \tilde{t}_1 t$, $\tilde{t}_1 \to bs$	1 e,μ	8-10 jets/0-4 b	-	14.8	$\tilde{g}$
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1 \to bs$	0	2 jets + 2 b	-	15.4	$\tilde{t}_1$
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1 \to b\ell$	2 e,μ	2 b	-	20.3	$\tilde{t}_1$
Other	Scalar charm, $\tilde{c} \to c\tilde{\chi}_1^0$	0	2 c	Yes	20.3	$\tilde{c}$

λ''

**Only a selection of the available mass limits on new states or phenomena is shown.*

ATLAS-Aug 2016

ATLAS RpV-Searches

Analysis	final state	process	RPV couplings	Notes	CM?
explicit RPV searches					
ATLAS-CONF-2016-057, see 1	multi-jet (N b-jets)	$\tilde{g} \to qqq$ and $\tilde{g} \to qq\tilde{\chi}_1^0 \to 5q$	λ''	new 13 TeV data	
PRD 91 112016, see 2	$\geq$ 6-jet or $\geq$ 7-jet Total jet mass (large-R)	$\tilde{g} \to qqq$ $\tilde{g} \to qq[\tilde{\chi}_1^0 \to qqq]$	$\lambda''_{112}, \lambda''_{113}, \lambda''_{123}, \lambda''_{312}, \lambda''_{331}, \lambda''_{332}$ λ''_{ijk}		
PRL 115 031801, see 3	$e^\pm\mu^\mp, e^\pm\tau^\mp, \mu^\pm\tau^\mp$	$q\bar{q} \to \tilde{\nu}_\tau \to \ell^\pm\ell^\mp$	$\lambda'_{311} \times \{\lambda_{132}, \lambda_{133}, \lambda_{232}\}$	only considered $\tilde{\nu}_\tau$ mediator	✓
PRD 90 052001, see 4 (ATLAS-CONF-2015-018)	$\geq 4\ell$ where $\geq \{0,1,2\}$ are τ's	$\tilde{\chi}_1^\pm \to W[\tilde{\chi}_1^0 \to \ell\ell\nu]$ $\tilde{\ell} \to \ell[\tilde{\chi}_1^0 \to \ell\ell\nu]$ $\tilde{\nu} \to \nu[\tilde{\chi}_1^0 \to \ell\ell\nu]$ $\tilde{g} \to qq[\tilde{\chi}_1^0 \to \ell\ell\nu]$	$\lambda_{121}, \lambda_{122}, \lambda_{133}, \lambda_{233}$		
JHEP 06 (2014) 035, see 5 (ATLAS-CONF-2015-018)	SS or $3\ell + \geq \{0,1,3\}$ b-jets	$\tilde{g} \to t[\tilde{t} \to bs]$ $\tilde{g} \to qq[\tilde{\chi}_1^0 \to \ell\ell\nu]$ $[\tilde{\chi}_1^\pm \to \ell bb][\tilde{\chi}_1^\pm \to \ell W]$ $[\tilde{t} \to t(\tilde{\chi}_1^\pm \to \nu W)] \ldots$ $\ldots [\tilde{t} \to t(\tilde{\chi}_1^0 \to \nu bb)]$	$\lambda''_{323} = 1$ λ_{ijk} κ_i κ_i	includes τ's in ℓ	✓
JHEP 04 (2015) 116, see 6 (ATLAS-CONF-2015-018)	isolated ℓ + jets	$\tilde{g} \to qq[\tilde{\chi}_1^0 \to \ell/\nu qq]$ $\tilde{q} \to q[\tilde{\chi}_1^0 \to \ell/\nu qq]$	λ_{ijk} λ_{ijk}	includes τ's in ℓ includes τ's in ℓ	
JHEP 09 (2014) 176, see 7 (ATLAS-CONF-2015-018)	2–6 jets	$\tilde{g} \to qq[\tilde{\chi}_1^0 \to \ell/\nu qq]$ $\tilde{q} \to q[\tilde{\chi}_1^0 \to \ell/\nu qq]$	λ'_{ijk} with $j \neq 3$	MET > 160 GeV! optimised for RPC	
JHEP 10 (2013) 130, see 8 (ATLAS-CONF-2015-018)	7–10 jets	$\tilde{g} \to qq[\tilde{\chi}_1^0 \to \nu qq]$	λ'_{ijk} with $j \neq 3$		
ATLAS-CONF-2015-015, see 9	$e^\pm e^\mp b\bar{b}, e^\pm\mu^\mp b\bar{b}, \mu^\pm\mu^\mp b\bar{b}$	$\tilde{t} \to b\ell$	$\lambda'_{133}, \lambda'_{233}$		
JHEP 06 (2016) 067, see 10	$b\bar{b}s\bar{s}$	$\tilde{t} \to \bar{s}\bar{b}$	λ''_{323}	see also 1210.4826 for 7 TeV analysis	
ATLAS-CONF-2016-022, see 11	$b\bar{b}s\bar{s}$	$\tilde{t} \to \bar{s}\bar{b}$	λ''_{323}	same as above	
leptoquark searches					
Eur.Phys.J. C76 (2016) 1, 5, see 12 (CERN-PH-EP-2015-179)	$eejj, \mu\mu jj$ $\nu_\tau\bar{\nu}_\tau b\bar{b}, \nu_\tau\bar{\nu}_\tau t\bar{t}$	$\tilde{q} \to \ell j$ $\tilde{q} \to \nu b$	λ'_{ijk}		
displaced vertices					
PRD 92 072004, see 13	DV + $\{e, \mu, \text{jets}, E_T^{\text{miss}}\}$ Displaced ee, $e\mu$ or $\mu\mu$ pairs	$\tilde{g} \to qq[\tilde{\chi}_1^0 \to \ell\ell'\nu]$ $\tilde{q} \to q[\tilde{\chi}_1^0 \to \ell/\nu qq]$	$\lambda_{121}, \lambda_{122}$ $\lambda'_{113}, \lambda'_{123}, \lambda'_{213}, \lambda'_{223}, \lambda'_{211}$		
Long lived particles and R-hadrons					
PRD 88 112003, see 14					
JHEP 01 (2015) 068, see 15	long-lived charged particle				
ATLAS-CONF-2015-013, see 17	metastable charged particles			almost indep. of final state	
LHCb-PAPER-2015-002, see ??	long-lived charged particles			LHCb analysis!	
Other scenarios					
CERN-PH-2016-143, see ??	resonant $W' \to \ell\nu$	$\tilde{\ell} \to \ell\tilde{\chi}^0$ or $\to \tilde{\ell}\nu$ $\tilde{\nu} \to \ell\tilde{\chi}^\pm$, $\tilde{\chi}^\pm \to$invisible	LQD, LLE LQD, LLE		
Still to add					
JHEP 12 (2012) 086, see ??	pair prod of X $\to 3j$	$g \to 3q$	UDD		

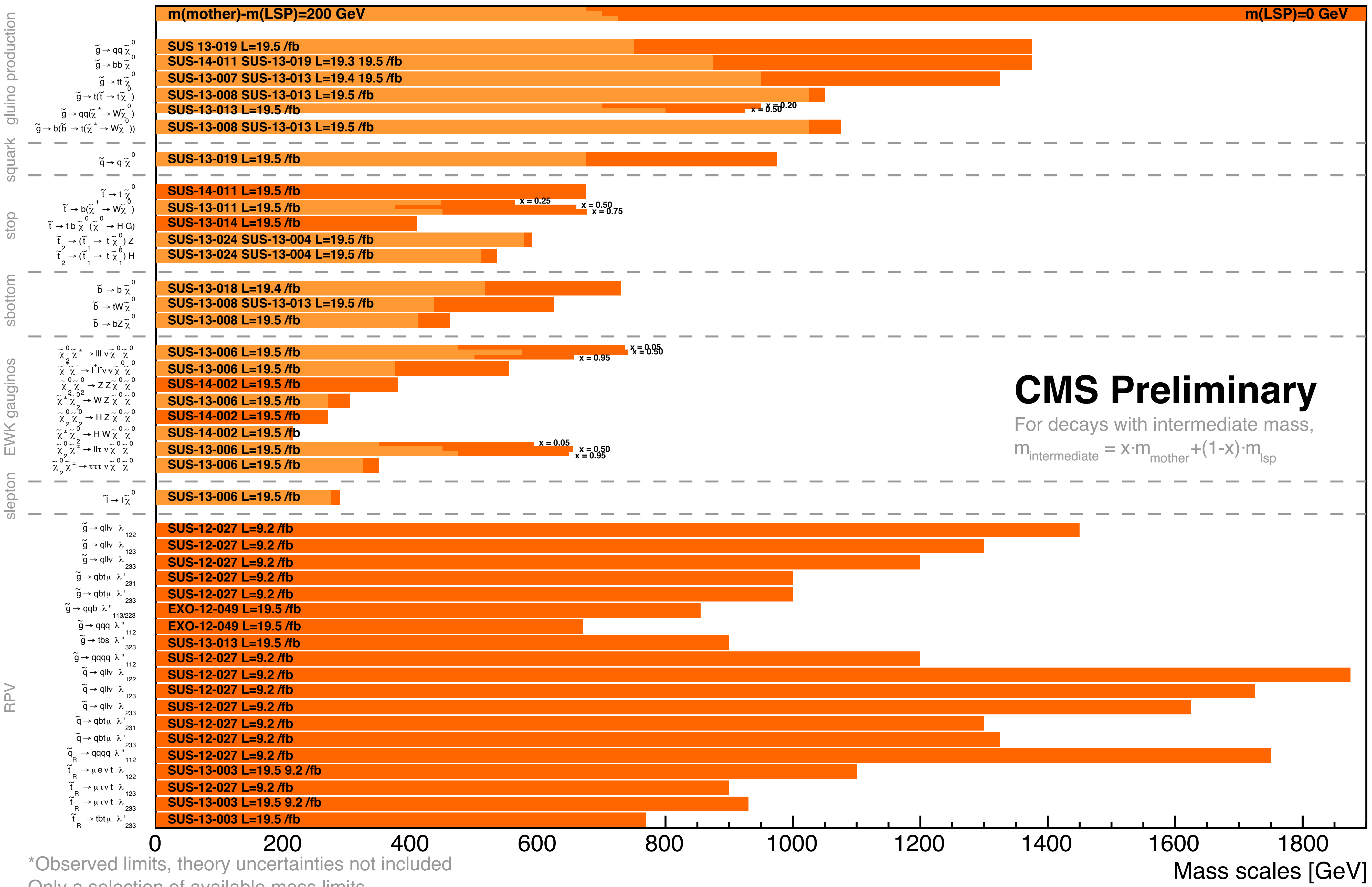
Compilation: Derks, HKD, Krauss, Opferkuch, Reinert

ATLAS RpV-Searches (our summary)

Analysis	final state	process	RPV couplings	Notes	CM?
explicit RPV searches					
ATLAS-CONF-2016-057, see 1	multi-jet (N b-jets)	$\tilde{g} \to qqq$ and $\tilde{g} \to qq\tilde{\chi}_1^0 \to 5q$	λ''	new 13 TeV data	
PRD 91 112016, see 2	$\geq$ 6-jet or $\geq$ 7-jet Total jet mass (large-R)	$\tilde{g} \to qqq$ $\tilde{g} \to qq[\tilde{\chi}_1^0 \to qqq]$	$\lambda''_{112}, \lambda''_{113}, \lambda''_{123}, \lambda''_{312}, \lambda''_{331}, \lambda''_{332}$ λ''_{ijk}		
PRL 115 031801, see 3	$e^\pm\mu^\mp, e^\pm\tau^\mp, \mu^\pm\tau^\mp$	$q\bar{q} \to \tilde{\nu}_\tau \to \ell^\pm\ell^\mp$	$\lambda'_{311} \times \{\lambda_{132}, \lambda_{133}, \lambda_{232}\}$	only considered $\tilde{\nu}_\tau$ mediator	✓
PRD 90 052001, see 4 (ATLAS-CONF-2015-018)	$\geq 4\ell$ where $\geq \{0,1,2\}$ are τ's	$\tilde{\chi}_1^\pm \to W[\tilde{\chi}_1^0 \to \ell\ell\nu]$ $\tilde{\ell} \to \ell[\tilde{\chi}_1^0 \to \ell\ell\nu]$ $\tilde{\nu} \to \nu[\tilde{\chi}_1^0 \to \ell\ell\nu]$ $\tilde{g} \to qq[\tilde{\chi}_1^0 \to \ell\ell\nu]$	$\lambda_{121}, \lambda_{122}, \lambda_{133}, \lambda_{233}$		
JHEP 06 (2014) 035, see 5 (ATLAS-CONF-2015-018)	SS or $3\ell + \geq \{0,1,3\}$ b-jets	$\tilde{g} \to t[\tilde{t} \to bs]$ $\tilde{g} \to qq[\tilde{\chi}_1^0 \to \ell\ell\nu]$ $[\tilde{\chi}_1^\pm \to \ell bb][\tilde{\chi}_1^\pm \to \ell W]$ $[\tilde{t} \to t(\tilde{\chi}_1^\pm \to \nu W)] \ldots$ $\ldots [\tilde{t} \to t(\tilde{\chi}_1^0 \to \nu bb)]$	$\lambda''_{323} = 1$ λ_{ijk} κ_i κ_i	includes τ's in ℓ	✓
JHEP 04 (2015) 116, see 6 (ATLAS-CONF-2015-018)	isolated ℓ + jets	$\tilde{g} \to qq[\tilde{\chi}_1^0 \to \ell/\nu qq]$ $\tilde{q} \to q[\tilde{\chi}_1^0 \to \ell/\nu qq]$	λ_{ijk} λ_{ijk}	includes τ's in ℓ includes τ's in ℓ	
JHEP 09 (2014) 176, see 7 (ATLAS-CONF-2015-018)	2–6 jets	$\tilde{g} \to qq[\tilde{\chi}_1^0 \to \ell/\nu qq]$ $\tilde{q} \to q[\tilde{\chi}_1^0 \to \ell/\nu qq]$	λ'_{ijk} with $j \neq 3$	MET $>$ 160 GeV! optimised for RPC	
JHEP 10 (2013) 130, see 8 (ATLAS-CONF-2015-018)	7–10 jets	$\tilde{g} \to qq[\tilde{\chi}_1^0 \to \nu qq]$	λ'_{ijk} with $j \neq 3$		
ATLAS-CONF-2015-015, see 9	$e^\pm e^\mp b\bar{b}, e^\pm\mu^\mp b\bar{b}, \mu^\pm\mu^\mp b\bar{b}$	$\tilde{t} \to b\ell$	$\lambda'_{133}, \lambda'_{233}$		
JHEP 06 (2016) 067, see 10	$b\bar{b}s\bar{s}$	$\tilde{t} \to \bar{s}\bar{b}$	λ''_{323}	see also 1210.4826 for 7 TeV analysis	
ATLAS-CONF-2016-022, see 11	$b\bar{b}s\bar{s}$	$\tilde{t} \to \bar{s}\bar{b}$	λ''_{323}	same as above	
leptoquark searches					
Eur.Phys.J. C76 (2016) 1, 5, see 12 (CERN-PH-EP-2015-179)	$eejj, \mu\mu jj$ $\nu_\tau\bar{\nu}_\tau b\bar{b}, \nu_\tau\bar{\nu}_\tau t\bar{t}$	$\tilde{q} \to \ell j$ $\tilde{q} \to \nu b$	λ'_{ijk}		
displaced vertices					
PRD 92 072004, see 13	DV + $\{e, \mu, \text{jets}, E_T^{\text{miss}}\}$ Displaced ee, $e\mu$ or $\mu\mu$ pairs	$\tilde{g} \to qq[\tilde{\chi}_1^0 \to \ell\ell'\nu]$ $\tilde{q} \to q[\tilde{\chi}_1^0 \to \ell/\nu qq]$	$\lambda_{121}, \lambda_{122}$ $\lambda'_{113}, \lambda'_{123}, \lambda'_{213}, \lambda'_{223}, \lambda'_{211}$		
Long lived particles and R-hadrons					
PRD 88 112003, see 14					
JHEP 01 (2015) 068, see 15	long-lived charged particle				
ATLAS-CONF-2015-013, see 17	metastable charged particles			almost indep. of final state	
LHCb-PAPER-2015-002, see ??	long-lived charged particles			LHCb analysis!	
Other scenarios					
CERN-PH-2016-143, see ??	resonant $W' \to \ell\nu$	$\tilde{\ell} \to \ell\tilde{\chi}^0$ or $\to \tilde{\ell}\nu$ $\tilde{\nu} \to \ell\tilde{\chi}^\pm$, $\tilde{\chi}^\pm \to$invisible	LQD, LLE LQD, LLE		
Still to add					
JHEP 12 (2012) 086, see ??	pair prod of X $\to 3j$	$g \to 3q$	UDD		

Summary of CMS SUSY Results* in SMS framework

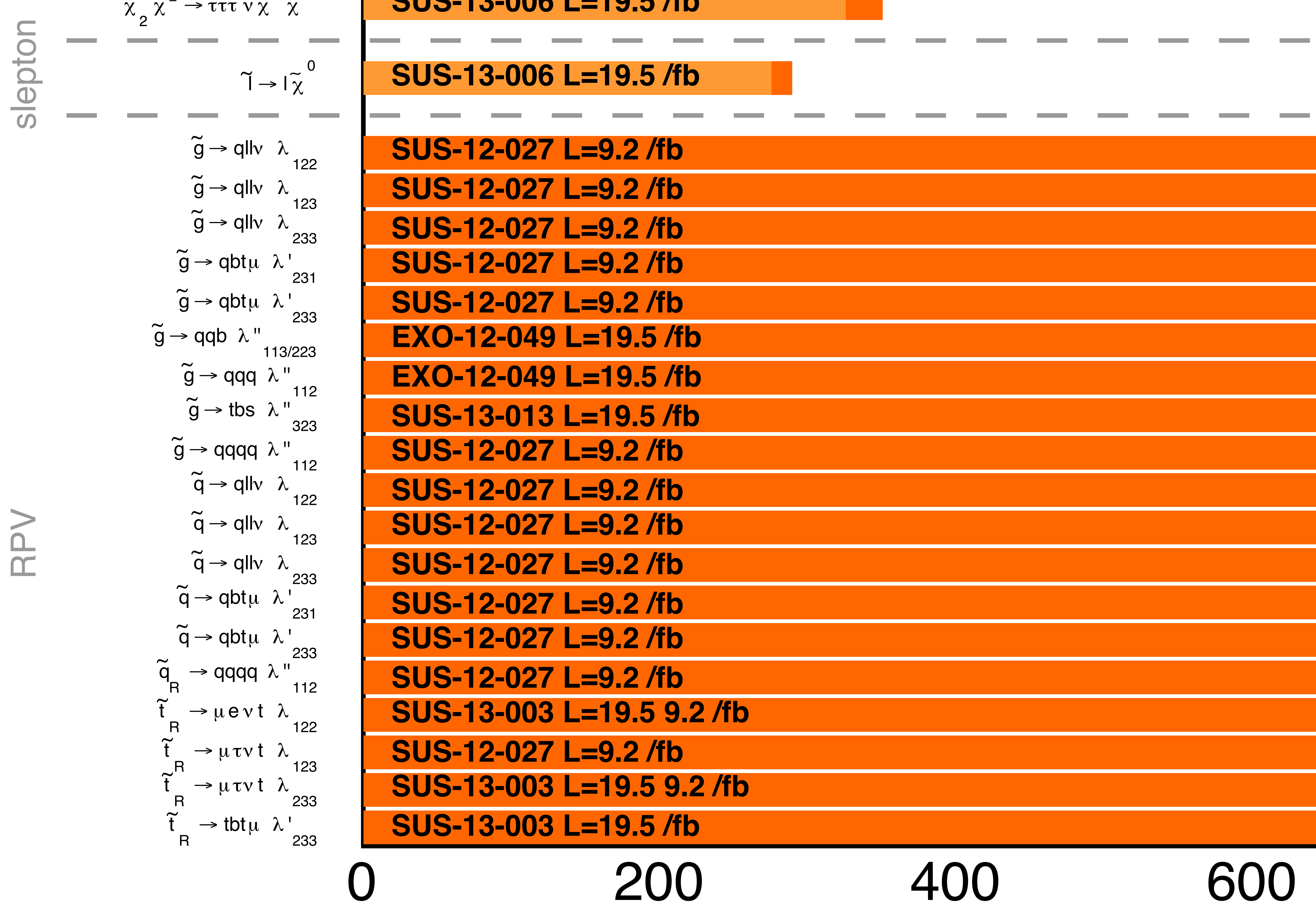
ICHEP 2014



*Observed limits, theory uncertainties not included

Only a selection of available mass limits

Probe *up to* the quoted mass limit



*Observed limits, theory uncertainties not included

Only a selection of available mass limits

CMS RpV-Searches

Analysis	final state	process	RPV couplings	Notes	CM?
explicit RPV searches					
CMS-SUS-16-013, see **??**	many jets, b-tags, 0-1 leptons	Gluino pair prod., $\tilde{g} \to tbs$	λ''_{323}		
CMS-EXO-13-001, see 2	8- and 10-jet events	$\tilde{g}$ pair prod., $\tilde{g} \to q\tilde{q} \to qq\tilde{H} \to 5q$	$\lambda''_{212,213}$		
CMS-SUS-14-003, see 1	0-4 leptons + jets		$\lambda''_{331,332}, \lambda_{12i,233}, \lambda'_{131,233,331,333}$		
CMS-SUS-13-013, see 3	$\ell^\pm\ell^\pm$ and jets	$\tilde{g}$ pair prod., $\tilde{g} \to tbs$	λ''_{323}		✓
CMS-SUS-13-010, see 4	4ℓ, isolated	$\tilde{q}/\tilde{g}$ ($\tilde{g} \to \tilde{q}q$)pair prod. $\tilde{q} \to q[\tilde{\chi}_1^0 \to \ell\ell\nu]$	$\lambda_{121}, \lambda_{122}$		✓
CMS-SUS-13-005, see 5	2μ, (2+N) j	resonant 2nd gen. slepton prod. e.g. $\tilde{\mu} \to \mu[\tilde{\chi}_1^0 \to \mu u\bar{d}]$ e.g. $\tilde{\nu}_\mu \to \mu\tilde{\chi}_1^\pm \to (...) \to \mu\mu 4j$	λ'_{211}	Limits on λ'_{211} as $f(m_0, M_{1/2})$ and $f(m_{\tilde{\mu}}, m_{\tilde{\chi}_1^0})$	
CMS-SUS-13-003, see 6	(3+N) ℓ, N b-tags	$\tilde{t}_R$ pair prod.; $\tilde{t}_R \to t\tilde{\chi}_1^0(=\tilde{B})$ $\tilde{\chi}_1^0 \to \mu t\bar{b}/\nu_\mu b\bar{b}$ (λ'_{233}); $\to \nu_i\ell_j\ell_k/\ell_i\nu_j\ell_k$ (λ_{ijk})	* λ'_{233} $\lambda_{122}, \lambda_{233}$		
CMS-SUS-12-027, see 7	(3+N) $\ell_{\text{iso,max.}1\tau}$, N b	light stop pair prod. $\tilde{q}/\tilde{g}$ pair prod.; $\tilde{\chi}_1^0$ LSP CMSSM with non-zero λ_{122}	$\lambda_{122}, \lambda_{123}, \lambda_{233}$ $\lambda_{122}, \lambda_{123}, \lambda_{233}, \lambda'_{231}, \lambda'_{233}, \lambda''_{112}$ λ_{122}		
CMS-EXO-14-013, see 8	$\ell_i^+\ell_i^-$, (5+N) jets, low $\not{E}_T$	$\tilde{t}$ pair prod., $\tilde{t}_1 \to b[\tilde{\chi}_1^\pm \to \ell jj]$	$\lambda'_{2ij}, \lambda'_{1ij}$		
CMS-EXO-14-008, see 9	$2t2\tau$	$\tilde{b} \to t\tau$	λ'_{333}		
CMS-EXO-13-002, see 10 2	$e\mu$ pairs	resonant $\tilde{\nu}_\tau$ prod. assume $d\bar{d} \to \tilde{\nu}_\tau \to e\mu$	$\lambda_{132}, \lambda'_{311}$	NWA: Limits on $\sigma \times B \propto \frac{2\lambda'^2_{311}\lambda^2_{132}}{3\lambda'^2_{311}+2\lambda^2_{132}}$ Limits from $\mu - e$ conv.	
CMS-EXO-12-052, see 11	$\geq 4j$ (2 jet pairs)	$\tilde{t}$ pair prod., $\tilde{t} \to qq$	$\lambda''_{312}, \lambda''_{323}$	model BG analytically with 4-param. funct.	(×)
CMS-EXO-12-049, see 12	$\geq 6j$	$\tilde{g}$ pair prod., $\tilde{g} \to 3j$	$\lambda''_{112}, \lambda''_{113}, \lambda''_{223}$	all comb. of signal triplets model BG analytically	(×)
leptoquark searches					
CMS-EXO-12-041, see 13	$\ell_i\ell_i jj + 4b$, $i = 1, 2$	$\tilde{t}$ pair prod.; $\tilde{t} \to b[\tilde{H}^\pm \to \ell_i qb]$	$\lambda'_{132}, \lambda'_{232}$		
CMS-EXO-12-032, see 14	$\ell\tau_{\text{hadr.}}$, (2+N) j(1+X b-tags) $\ell\tau_{\text{hadr.}}$, (5+N) j(1+X b-tags)	$\tilde{t}$ pair prod., $\tilde{t} \to b\tau$ $\tilde{t} \to b[\tilde{\chi}_1^{\pm\,*} \to \tau q\bar{q}]$	λ'_{333} λ'_{3ij}		
CMS-EXO-11-030, see 15	$2b\,2\nu_\tau/2b\,2\tilde{\chi}_1^0$	maybe applic. f. LQD, $\tilde{b} \to b\nu$?	maybe λ'_{333}	not too sensitive for RPV	
displaced vertices					
CMS-EXO-12-037, see 16	displaced ee or $\mu\mu$ pairs	$\tilde{q}$ pair prod., $\tilde{q} \to q[\tilde{\chi}_1^0 \to \nu\ell^+\ell^-]$	$\lambda_{i22}, \lambda_{i11}$		(✓)
CMS-EXO-12-038, see 17	displaced dijet pairs	$\tilde{q}$ pair prod., $\tilde{q} \to q[\tilde{\chi}_1^0 \to \mu jj]$	λ'_{211}		(✓)
CMS-B2G-12-024, see 18	displaced e and μ from separate vertices	$\tilde{t}$ pair prod., $\tilde{t} \to b\ell$ assumes $\lambda_{133} = \lambda_{233} = \lambda_{333}$	λ'_{i33} also applic. to λ'_{ijk}	No requirements on jets, MET	(✓)
CMS-SUS-14-020, see 19	2 displaced vertices, emerging jets	$\tilde{\chi}_1^0$ or $\tilde{g}$ to jets	λ''		
... and many more leptoquark searches which don't add new signatures as far as I'm aware. E.g. CMS-EXO-12-002 ($b\tau$, limits on λ'_{333})					
more, overlooked so far					
CMS-EXO-11-028 , see 21	$\ell\ell jj/\ell\nu jj$, $\ell = \mu, e$			solely LQ search	
CMS-SUS-14-001 , see 22	jj(b-tags), multijet(t-tag)	3rd gen squark pair prod.	applic to λ' f. $m_{\tilde{\chi}_1^0} \to 0$		
CMS-EXO-12-043 , see 20	$eej/\mu\mu j$			LQ search. Not relevant!	

Compilation: Derks, HKD, Krauss, Opferkuch, Reinert

	Final State Topology			Coverage and Luminosity		
	$\ell = e\,, \mu$ (τ-tagged)	jets (b-tagged)	$E_T^{\rm miss}$	$\sqrt{s} = 7\,\mathrm{TeV}$	$8\,\mathrm{TeV}$	$13\,\mathrm{TeV}$
ATLAS	-	≥ 6 / 7 jets (0-2b)	-	$4.6\,\mathrm{fb}^{-1}$	$20.3\,\mathrm{fb}^{-1}$	$14.8\,\mathrm{fb}^{-1}$
	ℓ-veto	≥ 7 jets (0-2b)	Yes	$4.7\,\mathrm{fb}^{-1}$	$20.3\,\mathrm{fb}^{-1}$	$18.2\,\mathrm{fb}^{-1}$
	-	≥ 2 jets (2b)	-	$4.6\,\mathrm{fb}^{-1}$	$17.4\,\mathrm{fb}^{-1}$	$15.4\,\mathrm{fb}^{-1}$
	2ℓ (SS)	≥ 5 jets ($\geq 3b$) / ≥ 3 jets ($\geq 1b$)	Yes	$4.6\,\mathrm{fb}^{-1}$	$20.3\,\mathrm{fb}^{-1}$	$13.3\,\mathrm{fb}^{-1}$
	3ℓ	≥ 5 jets ($\geq 3b$) / ≥ 4 jets	Yes	$4.6\,\mathrm{fb}^{-1}$	$20.3\,\mathrm{fb}^{-1}$	$13.3\,\mathrm{fb}^{-1}$
	4ℓ (0-2τ)	-	Yes	$4.7\,\mathrm{fb}^{-1}$	$20.3\,\mathrm{fb}^{-1}$	$13.3\,\mathrm{fb}^{-1}$
	2ℓ (OS)	2 jets (2b)	-	-	$20.3\,\mathrm{fb}^{-1}$	-
	1ℓ	≥ 8 jets (0 or 3b)	-	-	-	$14.8\,\mathrm{fb}^{-1}$
	$e\mu$, $e\tau$, $\mu\tau$ (OS)	-	-	-	$20.3\,\mathrm{fb}^{-1}$	$3.2\,\mathrm{fb}^{-1}$
	2e / 2μ	≥ 2 jets	-	$1.03\,\mathrm{fb}^{-1}$	$20.3\,\mathrm{fb}^{-1}$	$3.2\,\mathrm{fb}^{-1}$
	-	2 jets (2b) / ≥ 3 jets (2b)	Yes	$4.7\,\mathrm{fb}^{-1}$	$20.3\,\mathrm{fb}^{-1}$	$3.2\,\mathrm{fb}^{-1}$
	1ℓ	≥ 4 jets ($\geq 1b$)	Yes	-	$20.3\,\mathrm{fb}^{-1}$	$3.2\,\mathrm{fb}^{-1}$
CMS	-	≥ 4 jets ($\geq 0b$) 2-jet pairs	-	$5.0\,\mathrm{fb}^{-1}$	$19.4\,\mathrm{fb}^{-1}$	-
	-	≥ 6 jets (0 / $\geq 2b$) 3-jet pairs	-	$5.0\,\mathrm{fb}^{-1}$	$19.4\,\mathrm{fb}^{-1}$	-
	-	8 jets (0,$\geq 1b$) / 10 jets (0,$\geq 1b$)	-	-	$19.6\,\mathrm{fb}^{-1}$	$2.7\,\mathrm{fb}^{-1}$
	1ℓ	6 jets ($\geq 3b$)	-	-	$19.5\,\mathrm{fb}^{-1}$	$2.7\,\mathrm{fb}^{-1}$
	2ℓ	≥ 4 jets ($\geq 2b$)	-	-	$19.5\,\mathrm{fb}^{-1}$	-
	4ℓ (SFOS)	-	-	$4.7\,\mathrm{fb}^{-1}$	$19.5\,\mathrm{fb}^{-1}$	-
	$e\mu$	-	-	-	$19.7\,\mathrm{fb}^{-1}$	-
	3ℓ (0-1τ) / 4ℓ (0-1τ)	0-1 jets (all b's)	-	$2.1\,\mathrm{fb}^{-1}$	$19.5\,\mathrm{fb}^{-1}$	-
	$\geq 2\ell$ (SS)	≥ 2 jets ($\geq 0b$)	-/Yes	$4.98\,\mathrm{fb}^{-1}$	$19.5\,\mathrm{fb}^{-1}$	-
	2e / 2μ (OS)	≥ 5 jets ($\geq 1b$)	Yes	-	$19.7\,\mathrm{fb}^{-1}$	-
	$\mu\tau$ (SS)/$\ell\tau$	≥ 2 jets / ≥ 3 jets	- / Yes	-	$19.7\,\mathrm{fb}^{-1}$	-
	2ℓ (SS) / 1ℓ	2 jets	- / Yes	$5.0\,\mathrm{fb}^{-1}$	$19.7\,\mathrm{fb}^{-1}$	$2.6\,\mathrm{fb}^{-1}$
	$\ell\tau$	≥ 2 jets ($\geq 1b$) / ≥ 5 jets ($\geq 1b$)	-	-	$19.7\,\mathrm{fb}^{-1}$	$12.9\,\mathrm{fb}^{-1}$
	ℓ-veto	2 jets (2b)	Yes	$4.7\,\mathrm{fb}^{-1}$	-	-

Summary $\tilde{\chi}_1^0$ LSP in RpV-CMSSM

- LLE: covered (including τ cases)
- UDD: covered (including $N_t = 0, 1,\ N_b = 0, 1$)
- LQD: some small gaps
  - $\tilde{g},\ \tilde{q}$ cascade via $\tilde{\chi}_1^0$ to explicit τ

    (could reinterpret $e,\ \mu$ searches with leptonicly decaying τ)
  - $\tilde{g},\ \tilde{q}$ cascade followed by LSP decay:

$$\tilde{\chi}_1^0 \to e^- + t + \mathrm{j}$$

Non-$\tilde{\chi}_1^0$-LSP Searches

- LSP unstable, thus any s-particle can be LSP

$$\boxed{\mathrm{LSP} \in \{\tilde{\chi}_1^0,\ \tilde{\chi}_1^+,\ \tilde{\nu}_L,\ \tilde{\ell}_{L,R}^{\pm},\ \tilde{\tau}_1^{\pm},\ \tilde{q}_{L,R},\ \tilde{t}_1,\ \tilde{g}\}}$$

- Special cases searched for: direct RpV decays
  - Leptoquark searches: $\tilde{q} \to (\ell q',\ \nu q'')$
  - Stop pair production: $\tilde{t} \to (bs, b\ell)$
  - Sbottom pair production: $\tilde{b} \to t\tau$
  - Resonant sneutrino production: $d\bar{d} \to \tilde{\nu} \to \left\{ \begin{array}{l} e\mu \\ e\tau \\ \mu\tau \end{array} \right.$

    (beyond single coupling hypothesis)

General Signatures

$$\begin{pmatrix} \text{pair production: } \tilde{q}\tilde{q},\ \tilde{q}\tilde{g},\ \tilde{g}\tilde{g} \\ \text{resonant } \tilde{\ell} \text{ production} \end{pmatrix} \otimes \begin{pmatrix} \underline{\textbf{LSP}} \\ \tilde{\chi}_1^0 \\ \tilde{\chi}_1^+ \\ \tilde{\nu}_L \\ \tilde{\ell}^{\pm}_{L,R} \\ \tilde{\tau}_1^{\pm} \\ \tilde{q}_{L,R} \\ \tilde{t}_1 \\ \tilde{g} \end{pmatrix} \otimes \begin{pmatrix} \underline{\textbf{Operator}} \\ L_1 L_2 \bar{E}_1 \\ \vdots \\ L_2 L_3 \bar{E}_3 \\ L_e Q_1 \bar{D}_1 \\ \vdots \\ L_\mu Q_1 \bar{D}_1 \\ \vdots \\ L_\tau Q_3 \bar{D}_3 \\ \bar{U}_i \bar{D}_j \bar{D}_k \end{pmatrix}$$

- Consider LSPs in RpV-CMSSM

LSPs in the RpV CMSSM

- Parameters: $M_0,\ M_{1/2},\ A_0,\ \tan\beta,\ \mathrm{sgn}(\mu), \Lambda_{\mathrm{RpV}}$

single RpV coupling at M_X

- Use SPheno RGEs, including RpV to find possible LSPs

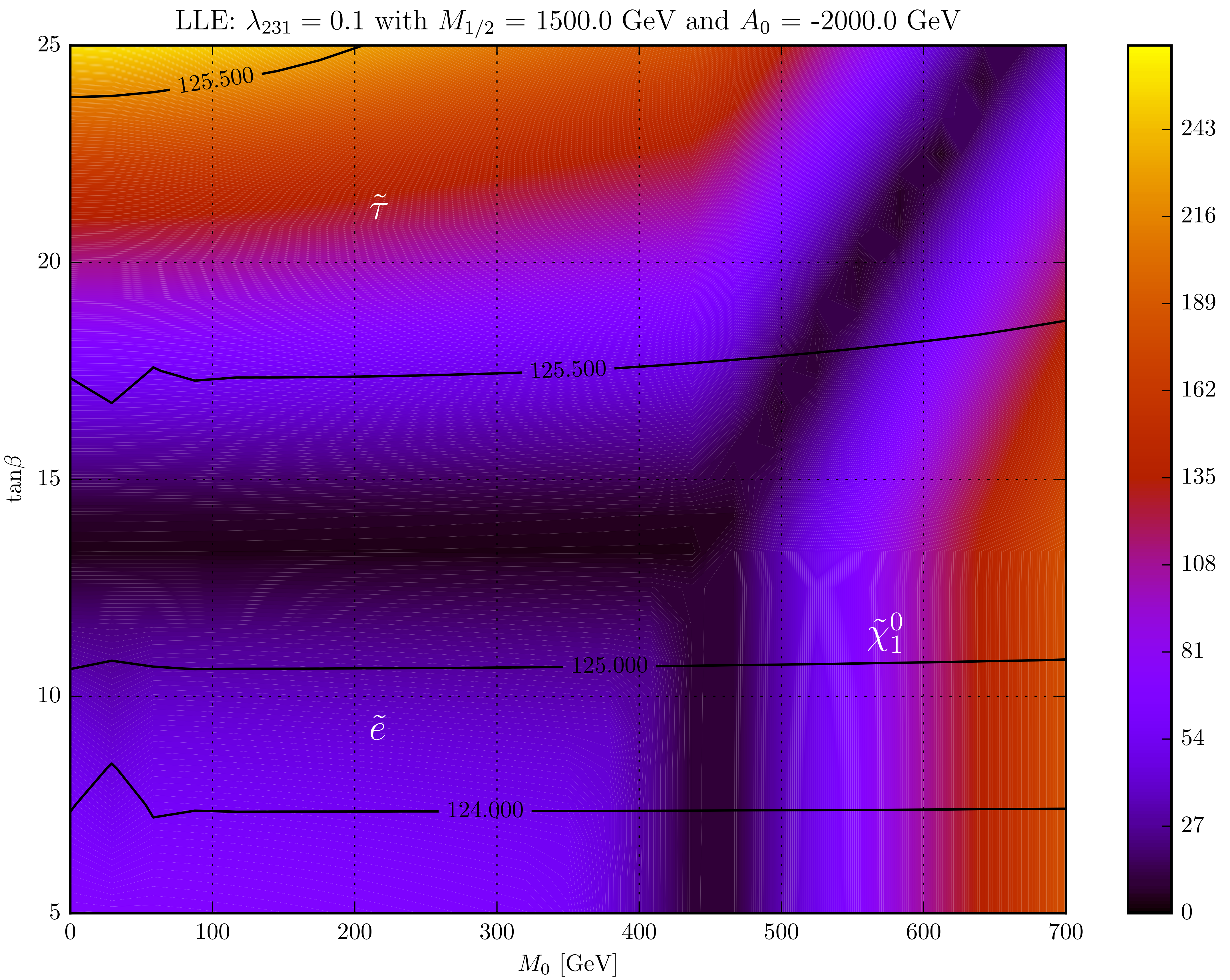
- For $\Lambda_{\mathrm{RpV}} = 0$ get $\tilde{\chi}_1^0$ and $\tilde{\tau}$ LSP

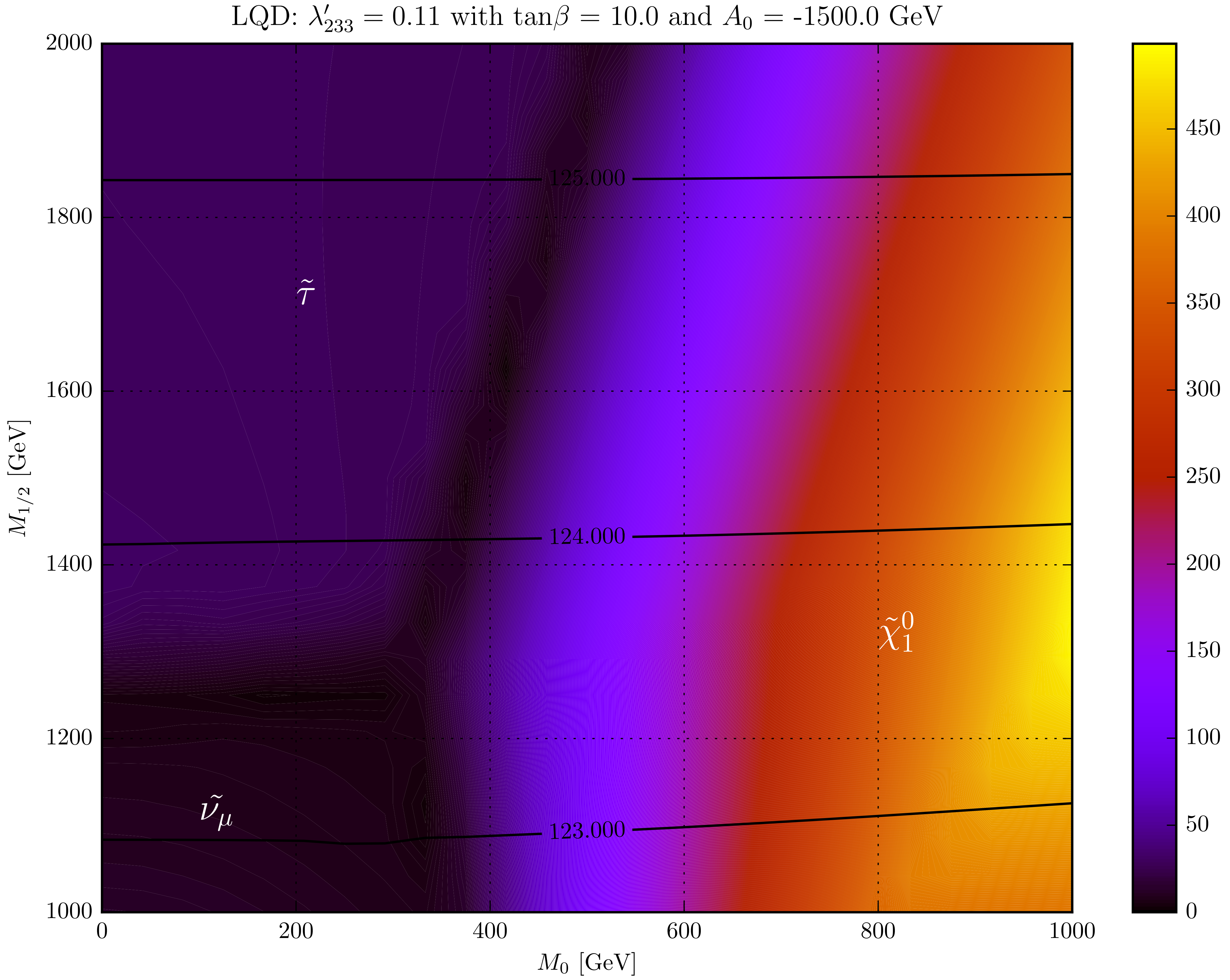
LSPs in the RpV CMSSM

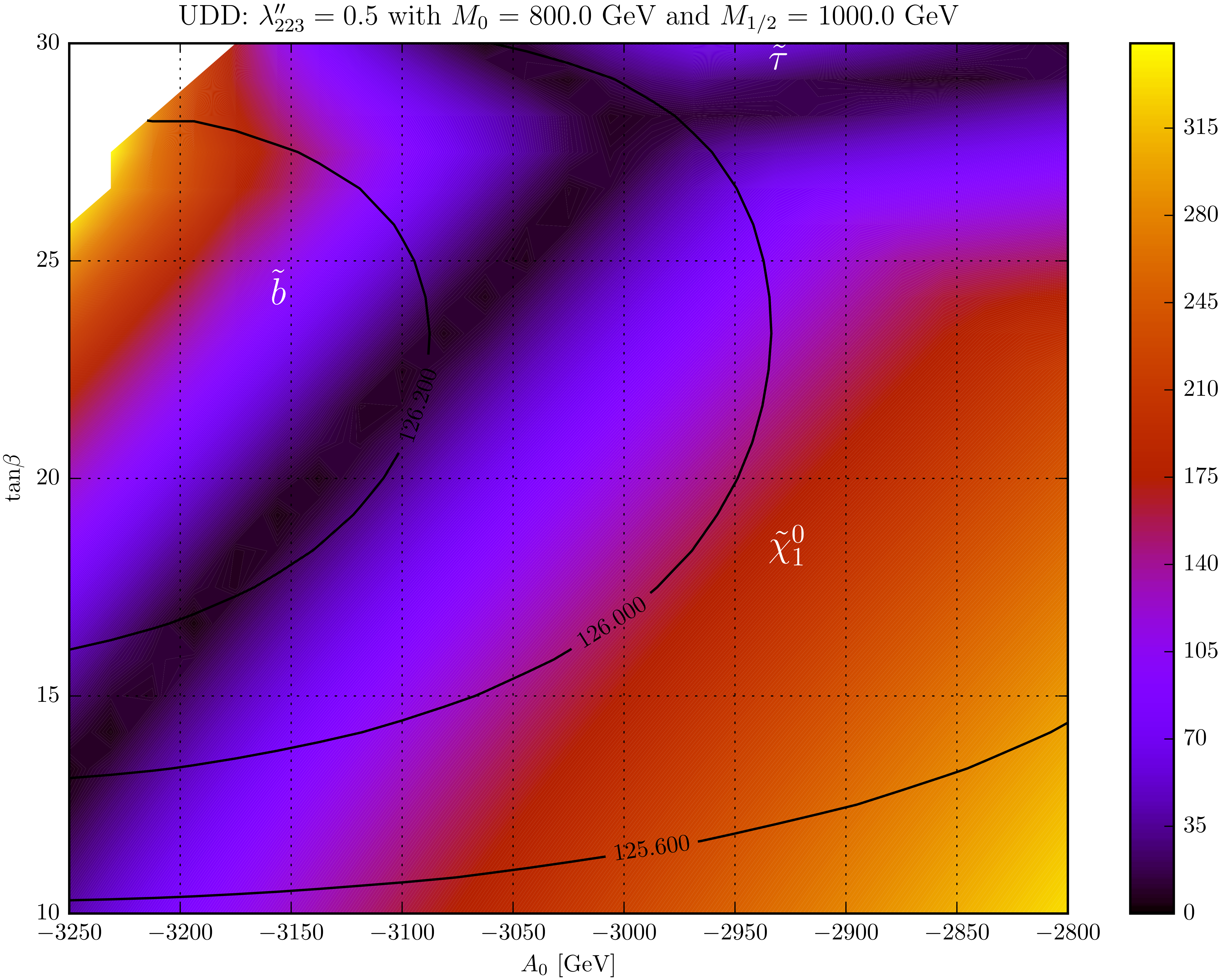
LSP	**RpV Operators**
$\tilde\tau_R$	$\Lambda \ll 1$ (RpC-like); $L_iL_j\bar E_3$, (enlarged regions)
$\tilde\tau_L$	$L_3Q_j\bar D_k$
$\tilde\mu_R$	$L_1L_3\bar E_2,\ L_1L_2\bar E_2,\ L_2L_3\bar E_2$
$\tilde e_R$	$L_2L_3\bar E_1,\ L_1L_2\bar E_1,\ L_2L_3\bar E_1$
$\tilde\nu_e$	$L_1Q_j\bar D_k,\ (j,k) \neq (1,1)$
$\tilde\nu_\mu$	$L_2Q_j\bar D_k$
$\tilde\nu_\tau$	X
$\tilde t_R$	$\bar U_3\bar D_i\bar D_j$
$\tilde b_R$	$\bar U_1\bar D_2\bar D_3,\ \bar U_2\bar D_1\bar D_3,\ \bar U_2\bar D_2\bar D_3,$

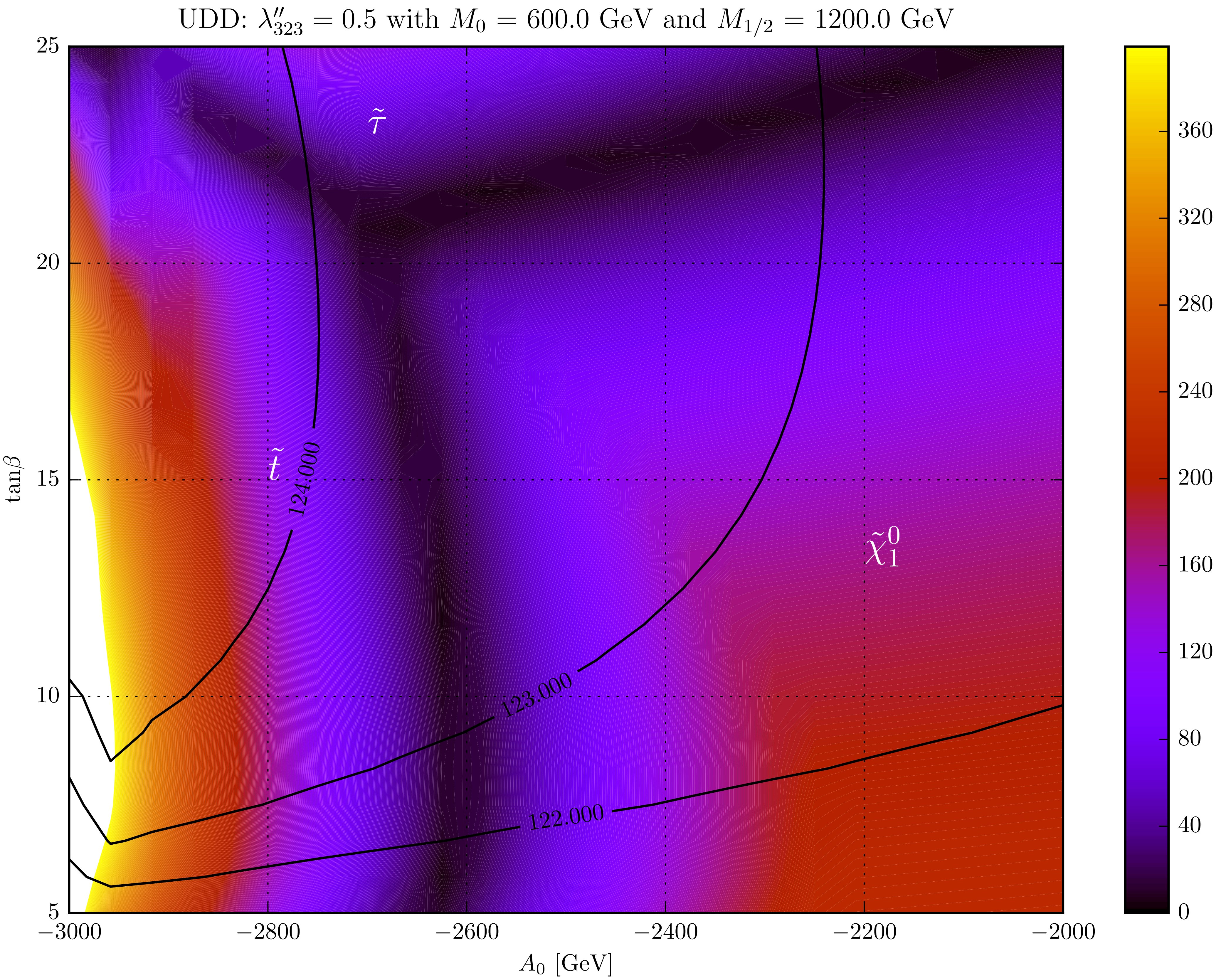
(Using SPheno RGEs, including RpV)

- Update of HD, S. Grab; PLB 679, ’09, including Higgs constraint


LLE: λ_{231} = 0.1 with $M_{1/2}$ = 1500.0 GeV and A_0 = -2000.0 GeV
tanβ
25
20
15
10
5
0
100
200
300
400
500
600
700
M_0 [GeV]
125.500
125.500
125.000
124.000
$\tilde{\tau}$
$\tilde{e}$
$\tilde{\chi}_1^0$
243
216
189
162
135
108
81
54
27
0


LQD: $\lambda'_{233} = 0.11$ with $\tan\beta = 10.0$ and $A_0 =$ -1500.0 GeV
$M_{1/2}$ [GeV]
M_0 [GeV]
2000
1800
1600
1400
1200
1000
0
200
400
600
800
1000
125.000
124.000
123.000
$\tilde{\tau}$
$\tilde{\nu_\mu}$
$\tilde{\chi}_1^0$
450
400
350
300
250
200
150
100
50
0


UDD: $\lambda''_{223} = 0.5$ with $M_0 = 800.0$ GeV and $M_{1/2} = 1000.0$ GeV
$\tilde{\tau}$
$\tilde{b}$
$\tilde{\chi}_1^0$
126.200
126.000
125.600
$\tan\beta$
30
25
20
15
10
−3250
−3200
−3150
−3100
−3050
−3000
−2950
−2900
−2850
−2800
A_0 [GeV]
0
35
70
105
140
175
210
245
280
315


UDD: $\lambda''_{323} = 0.5$ with $M_0 = 600.0$ GeV and $M_{1/2} = 1200.0$ GeV
$\tan\beta$
25
20
15
10
5
A_0 [GeV]
−3000
−2800
−2600
−2400
−2200
−2000
$\tilde{\tau}$
$\tilde{t}$
$\tilde{\chi}_1^0$
124.000
123.000
122.000
360
320
280
240
200
160
120
80
40
0

LSPs in the RpV CMSSM

LSP	RpV Operators
$\tilde{\tau}_R$	$\Lambda \ll 1$ (RpC-like); $L_i L_j \bar{E}_3$, (enlarged regions)
$\tilde{\tau}_L$	$L_3 Q_j \bar{D}_k$
$\tilde{\mu}_R$	$L_1 L_3 \bar{E}_2, \; L_1 L_2 \bar{E}_2, \; L_2 L_3 \bar{E}_2$
$\tilde{e}_R$	$L_2 L_3 \bar{E}_1, \; L_1 L_2 \bar{E}_1, \; L_2 L_3 \bar{E}_1$
$\tilde{\nu}_e$	$L_1 Q_j \bar{D}_k, \; (j,k) \neq (1,1)$
$\tilde{\nu}_\mu$	$L_2 Q_j \bar{D}_k$
$\tilde{\nu}_\tau$	X
$\tilde{t}_R$	$\bar{U}_3 \bar{D}_i \bar{D}_j$
$\tilde{b}_R$	$\bar{U}_1 \bar{D}_2 \bar{D}_3, \; \bar{U}_2 \bar{D}_1 \bar{D}_3, \; \bar{U}_2 \bar{D}_2 \bar{D}_3,$

all not explicitly searched for

experimentally covered

Benchmarks

LSP	**RpV Operators**
$\tilde{\tau}_R$	$\Lambda \ll 1$ (RpC-like); $L_i L_j \bar{E}_3$, (enlarged regions)
$\tilde{\tau}_L$	$L_3 Q_j \bar{D}_k$
$\tilde{\mu}_R$	$L_1 L_3 \bar{E}_2,\ L_1 L_2 \bar{E}_2,\ L_2 L_3 \bar{E}_2$
$\tilde{e}_R$	$L_2 L_3 \bar{E}_1,\ L_1 L_2 \bar{E}_1,\ L_2 L_3 \bar{E}_1$
$\tilde{\nu}_e$	$L_1 Q_j \bar{D}_k$, $(j,k) \neq (1,1)$
$\tilde{\nu}_\mu$	$L_2 Q_j \bar{D}_k$
$\tilde{\nu}_\tau$	X
$\tilde{t}_R$	$\bar{U}_3 \bar{D}_i \bar{D}_j$
$\tilde{b}_R$	$\bar{U}_1 \bar{D}_2 \bar{D}_3,\ \bar{U}_2 \bar{D}_1 \bar{D}_3,\ \bar{U}_2 \bar{D}_2 \bar{D}_3,$

- preliminary benchmarks for the various LSPs and couplings

- Determine full spectrum with many possible signatures
- Check if at least one signature for each benchmark is covered by existing searches

Idea of Program for Recasting

- Determine all RpV exclusive final state signatures for a given LSP scenario benchmark: $\text{prod.} \otimes \text{cascades}^2$

- Compute: $\sigma_{\text{prod}} \times (\text{Br})^n$ for each of these signatures

- Retain those with an observable rate

- List experimental final state signature ``vectors” for all exclusive RpV LHC searches

- Compare the two

Details of Program

Choose RpV-CMSSM Benchmark:

$M_0,\ M_{1/2},\ A_0,\ \tan\beta,\ \mathrm{sgn}(\mu), \Lambda_{\mathrm{RpV}}$

Compute spectrum and decay tables with SPheno; include RpV in RGEs; only 2- and 3-body decays

($\tilde{\tau}$ LSP can have 4-body decay)

Compute Xsections with Prospino and NLL-fast

$\tilde{g}\tilde{g},\ \tilde{g}\tilde{q},\ \tilde{q}\tilde{q}, \tilde{q}\tilde{q}^*$

Comments

- In RpV important to distinguish squark flavor:

  $\tilde{q}_{L,R} \in \{\tilde{u},\, \tilde{d},\, \tilde{c},\, \tilde{s},\, \tilde{t},\, \tilde{b}\}$

- As specific RpV coupling, e.g.: $L_2 Q_3 \bar{D}_1$ distinguishes

- VERY large number of processes

- Require: $\sigma_{\rm prod} \cdot \mathcal{L} > 0.03$

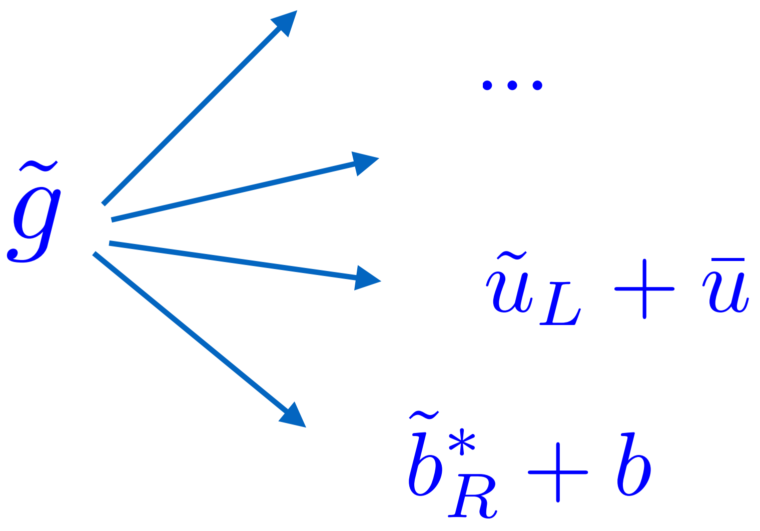
Details of Program (cont.)

Compute Xsections with Prospino and NLL-fast

$$\tilde{g}\tilde{g},\ \ \tilde{g}\tilde{q},\ \ \tilde{q}\tilde{q},\tilde{q}\tilde{q}^*$$

For each produced sparticle iteratively compute all possible cascades, and their Br's using SPheno decay tables

- Again impose a cut to keep numerics manageable



$$Br < \frac{1\%}{N_{\rm decays}} Br_{\rm max}(\text{all}\,\tilde{g}\,\text{decays})$$

and also

$$\mathrm{Br_{tot}} = \prod \mathrm{Br_i}$$

(still many many possibilities)

Add all cascades with same final state

Product: $\text{cascades}_1 \otimes \text{cascades}_2$

Associate analysis array vector with each combined decay tree

$(N_{\text{jets}},\ N_{\text{b}-\text{jets}},\ N_\ell, SS,\ N_\tau,\ E_T^{\text{miss}},\ Z-\text{veto},\ \text{resonances})$

Classify all Exclusive RpV Searches

- Create vectors for experimental analyses as well

$$(N_{\mathrm{jets}},\ N_{\mathrm{b-jets}},\ N_{\ell}, SS,\ N_{\tau},\ E_T^{\mathrm{miss}},\ Z-\mathrm{veto},\ \mathrm{resonances})$$

Compare the two to see if final state has been looked for

Example

BP8: $\lambda'_{132}|_{M_{\rm GUT}} = 0.1$

$$\mathrm{LSP} = \tilde{\nu}_e, \; m = 441\,\mathrm{GeV}$$
$$\mathrm{NLSP} = \tilde{e}_L, \; m = 450\,\mathrm{GeV}$$
$$\mathrm{NNLSP} = \tilde{\chi}_1^0, \; m = 470\,\mathrm{GeV}$$

Signature: 6 jets with 2 b; MET; 2 (j b)-resonances

Cascade: $p\,p \to \tilde{q}\tilde{q};$ $\sigma_{\rm prod.} \times (\mathrm{Br})^n = 0.4\,\mathrm{fb}$

$$\tilde{q} \to q\;\tilde{\chi}_1^0$$
$$\tilde{\chi}_1^0 \to \nu_e \tilde{\nu}_e \to \nu_e (\bar{s} b)$$

Atlas search: PRD 91 (2015) 112016

Summary

- RpV signatures can be very different

- Standard Neutralino LSP in RpV-CMSSM is searched for at LHC

- Other LSPs in RpV-CMSSM Many extensions not yet covered

- Our new mapping tool indicates that most of them can be recast into existing analyses

Bonn Particle Physics Show

- 2hr show, journey through history of particle physics, with 25 live experiments

- Available on the arXiv

arXiv:1607.07478