Supersymmetry, Exotics, and Intriguing Hints of New Physics

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Dark Matter/Collider Workshop
Mitchell Institute, Texas A&M University
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- **Natural Supersymmetry and the Muon Magnetic Moment**

  Paul Padley, KS, K. Wang (ongoing)

- **CMS Leptoquark Searches and a Connection to Dark Matter**

  F. Queiroz, KS, A. Strumia (2014)

- **CMS Dilepton Excess: SUSY or Exotics?**

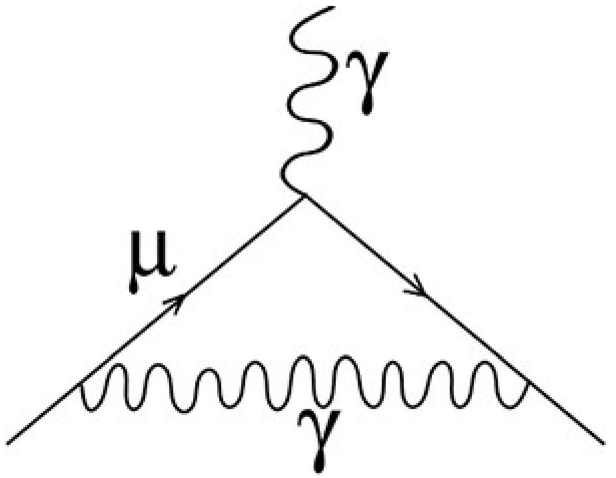
  A. Alves, B. Allanach, F. Queiroz, KS, A. Strumia (2015)

Supersymmetry
and
Muon Magnetic Moment

- **Muon Magnetic Moment**

- $H = -\vec{\mu}\cdot\vec{B}$, $\vec{\mu} = g\left(\frac{e}{2\mathrm{m}}\right)\vec{S}$

- **g-factor**
  - $g = 2$ **tree**
  - $g \neq 2$ **loop**
  - $a_\mu = (g-2)/2$



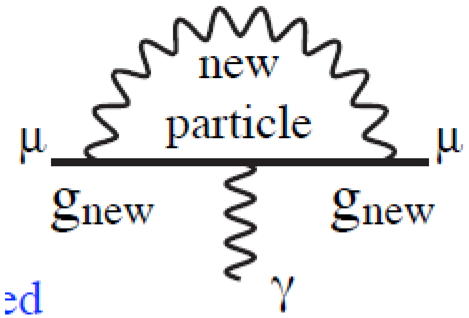
- $$a_\mu^{\mathrm{exp}} - a_\mu^{SM} = \begin{cases} (261 \pm 80) \times 10^{-11} \\ (287 \pm 80) \times 10^{-11} \end{cases} > 3\sigma$$

- **Muon Magnetic Moment**

- $$\Delta a_\mu \sim \frac{g_{new}^2}{16\pi^2} \frac{(m_\mu^2 \sim 106\, MeV)^2}{(\Lambda^2)}$$

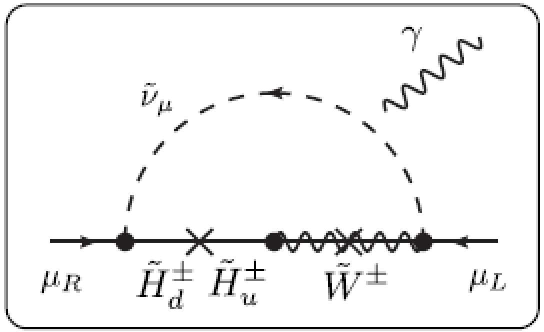
- $$\Delta a_\mu \sim EW \;\; contribution$$

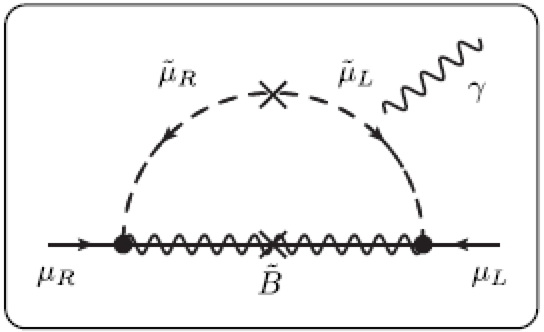
  - $g_{new} = g_{weak}$
  - $\Lambda = 100 \;\; GeV$



- **SUSY (similar to WIMP arguments)**

- # Muon Magnetic Moment





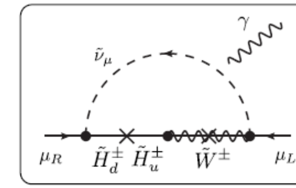
- **chargino/sneutrino**
- **neutralino/smuon**

- $$a_\mu(SUSY) \sim \frac{g_2^2}{16\pi^2} \frac{m_\mu^2}{m_{soft}^2} \tan\beta$$

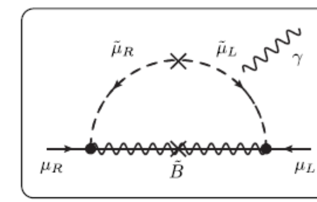
  - $\tan\beta$ **enhancement**
  - $m_{\tilde{l}},\ m_{\tilde{\chi}^\pm},\ m_{\tilde{\chi}^0} \sim O(100)\ GeV$

- **SUSY contributions**

  - $$\Delta_{\tilde{\chi}_1^{\pm}\tilde{\nu}_\mu} = \frac{g_2^2}{16\pi^2}\frac{m_\mu^2 \tan\beta}{\mu M_2} \times F\left(\frac{\mu^2}{m_{\tilde{\nu}_\mu}^2}, \frac{M_2^2}{m_{\tilde{\nu}_\mu}^2}\right)$$



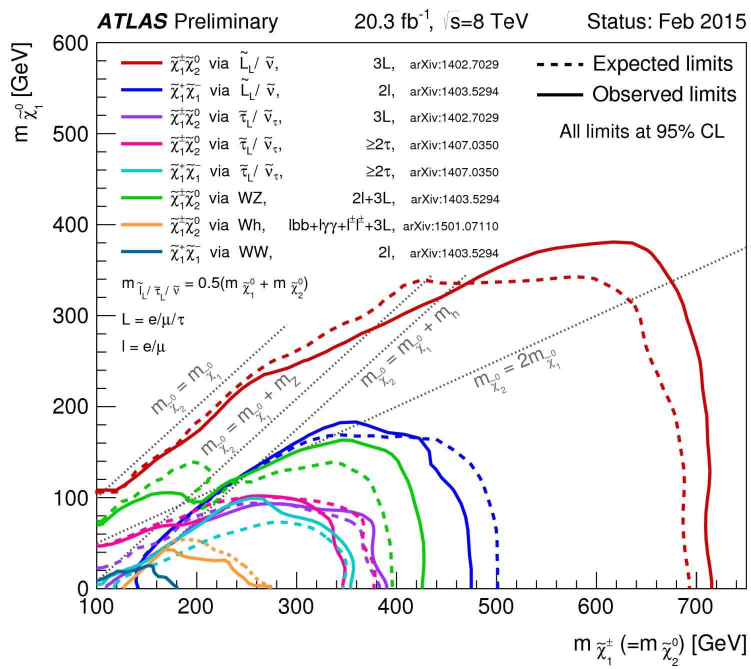
  - $$\Delta_{\tilde{\chi}_1^0\tilde{\mu}} = \frac{g_2^2}{16\pi^2}\frac{m_\mu^2 M_1 \mu}{m_{\tilde{\mu}_L}^2 m_{\tilde{\mu}_R}^2} \tan\beta \times G\left(\frac{m_{\mu_R}^2}{M_1^2}, \frac{m_{\mu_L}^2}{M_1^2}\right)$$



- **Small** μ, M_2 **enhance** $\Delta_{\tilde{\chi}_1^{\pm}\tilde{\nu}_\mu}$ **contribution**

- **Either left or right smuon has to be light**

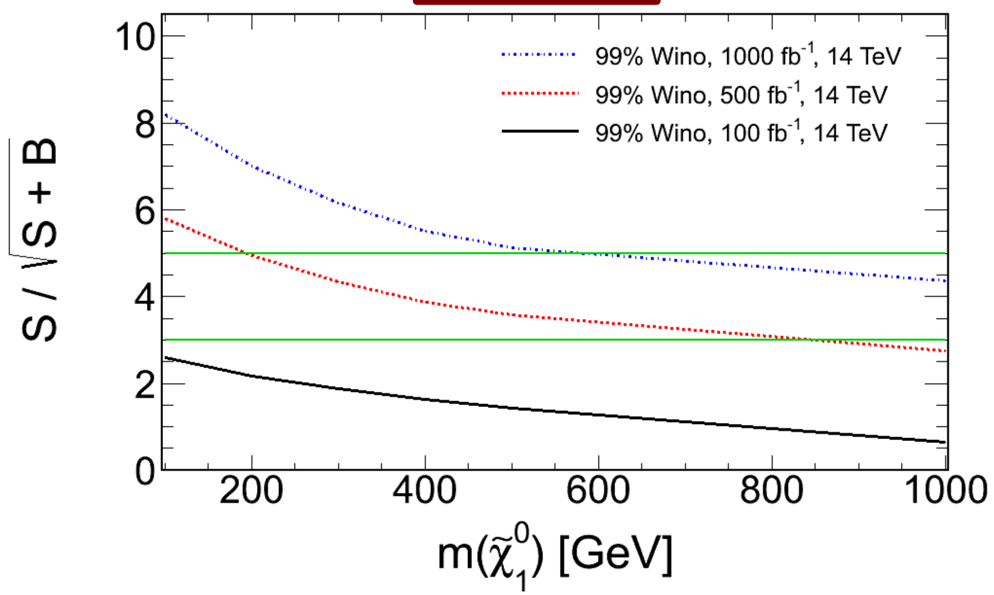
- **Small μ, M_2 enhance $\Delta_{\tilde{\chi}_1^{\pm} \tilde{\nu}_{\mu}}$ contribution**



ATLAS, trilepton, arXiv: 1402.7029
20 ifb luminosity

- Small μ, M_2 enhance $\Delta_{\tilde{\chi}_1^{\pm} \tilde{\nu}_\mu}$ contribution
- $pp \rightarrow 2j + E_T$
- 2 VBF tagging jets, b-veto, l-veto, central jet veto

VBF



- $\mu \sim O(400) GeV, \; 5\sigma, \; 1000 \, fb^{-1}$
  Cut and count, shape analysis

  Dutta, Gurrola, Kamon, KS, Wang, Wu (2013)

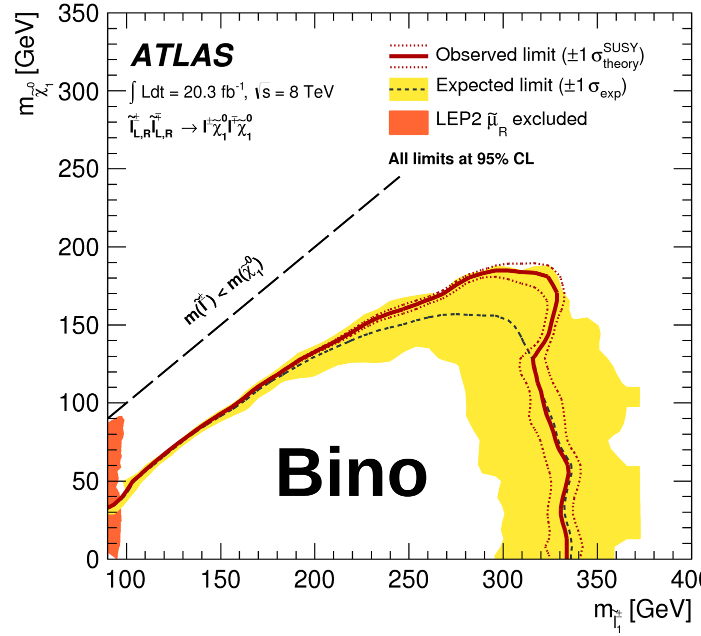
- $\mu \sim O(125) GeV, \; 1\%$ systematics
  Cut and count

  Berlin, Lin, Low, L-T Wang (2015)
  Cirelli, Sala, Taoso (2014)

- **Either left or right slepton has to be light**

- **Reinterpret for Higgsino LSP**

- $$\frac{M_1}{M_2} \sim 1, \quad \tan\beta > 10$$
  $$\tilde{l}_L \to l\,\tilde{\chi}_1^0 \quad Br \sim 100\,\%$$
  $$\tilde{\nu} \to l\,\tilde{\chi}_1^{\pm} \quad Br \sim 30\,\%$$



Eckel, Ramsey-Musolf, Shepherd, Su (2014)

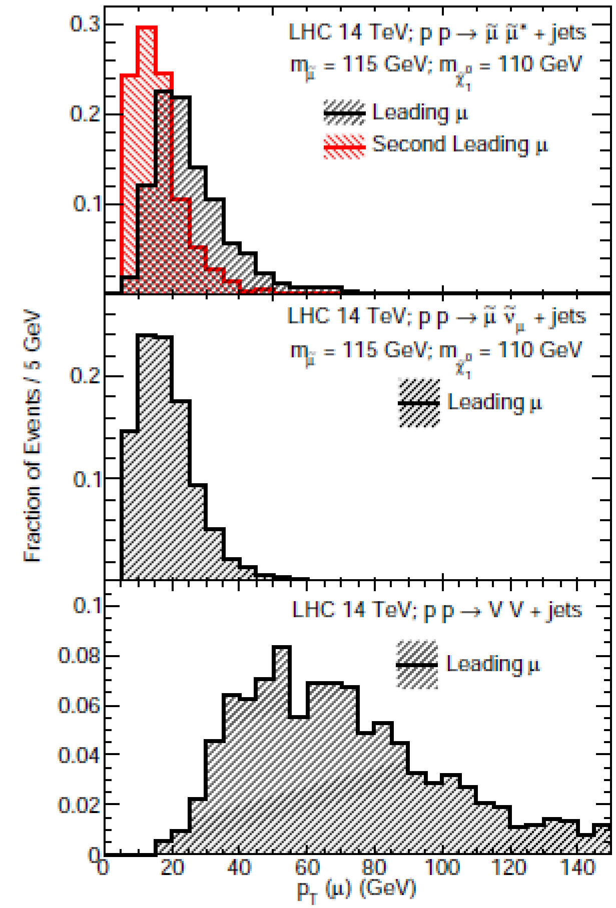
ATLAS, dilepton, arXiv: 1403.5294
20 ifb luminosity

- **Extra 30% gives little more reach**
- **Near special points, branching may drop**
- **Be conservative, use Bino limits**

- **Either left or right slepton has to be light**

VBF

ΔM	$m_{\tilde{l}}$	$m_{\tilde{\chi}_1^0}$	2-muon final state			1-muon final state			Combined	
			Cross-section	Significance	Significance	Cross-section	Significance	Significance	Significance	
	[GeV]		[fb]	CC	Shape	[fb]	CC	Shape	CC	Shape
25	135	110	0.0014	1.33	1.75	0.0021	0.75	1.26	1.63	2.32
15	135	120	0.0021	2.06	2.60	0.0029	1.03	1.51	2.46	3.16
10	135	125	0.0019	2.06	2.91	0.0044	1.76	2.93	2.94	4.49
5	135	130	0.0004	0.30	0.49	0.0036	1.45	2.22	1.50	2.08
15	125	110	0.0024	2.44	3.06	0.0035	1.31	1.82	2.98	3.75
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]



- $pp \rightarrow l_L l_L jj, \; l_L \nu jj$

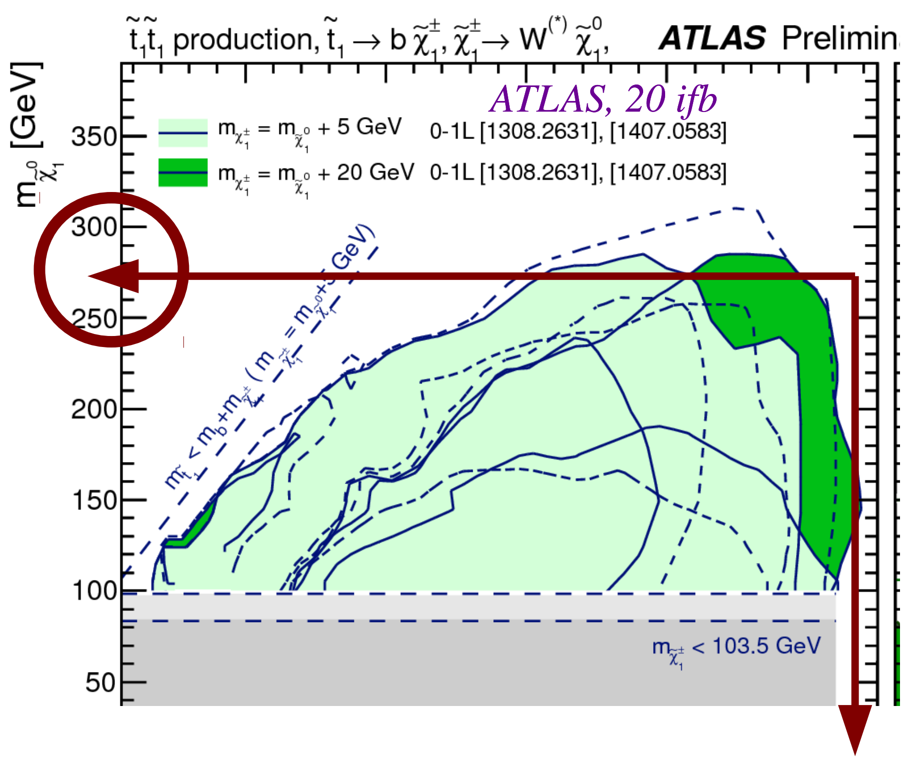
- $2j + 2l + E_T, \; 2j + 1l + E_T$

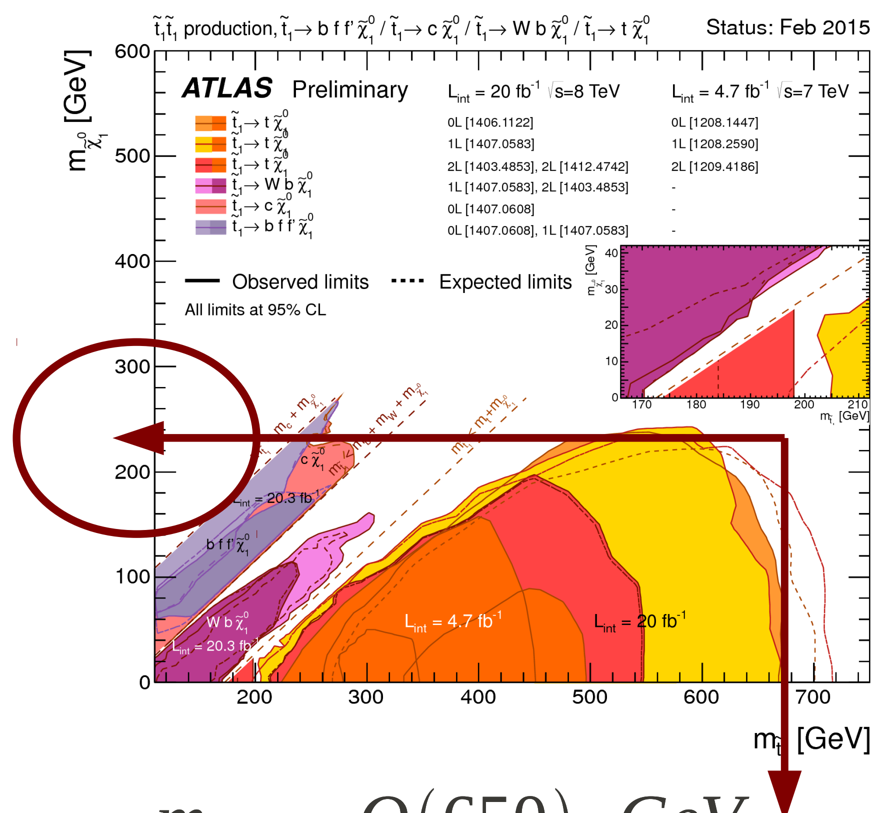
- **b-veto, 2 tagging jets, 2 central leptons, Z-veto**

- **CC, profile likelihood analysis of** $p_T(\mu)$

Dutta, Ghosh, Gurrola, Kamon, KS, Wang, Wu (2014)

- **Natural SUSY: light Higgsinos, light stops**
- **Stop-assisted chargino/neutralino production bounds**





$$m_{\tilde{t}} \sim O(600) \;\; GeV$$

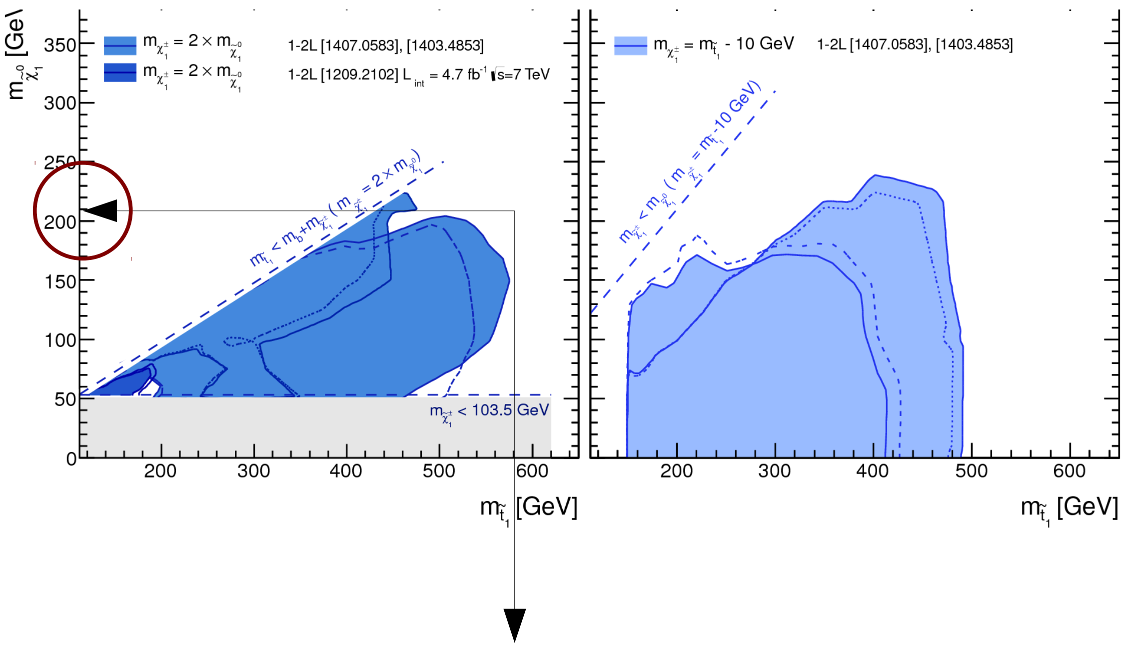
$$m_{\tilde{\chi}_1^0} \sim m_{\tilde{\chi}_1^\pm} \sim O(250) \;\; GeV$$

$$m_{\tilde{t}} \sim O(650) \;\; GeV$$

$$m_{\tilde{\chi}_1^0} \sim O(220) \;\; GeV$$

- **Natural SUSY: light Higgsinos, light stops**

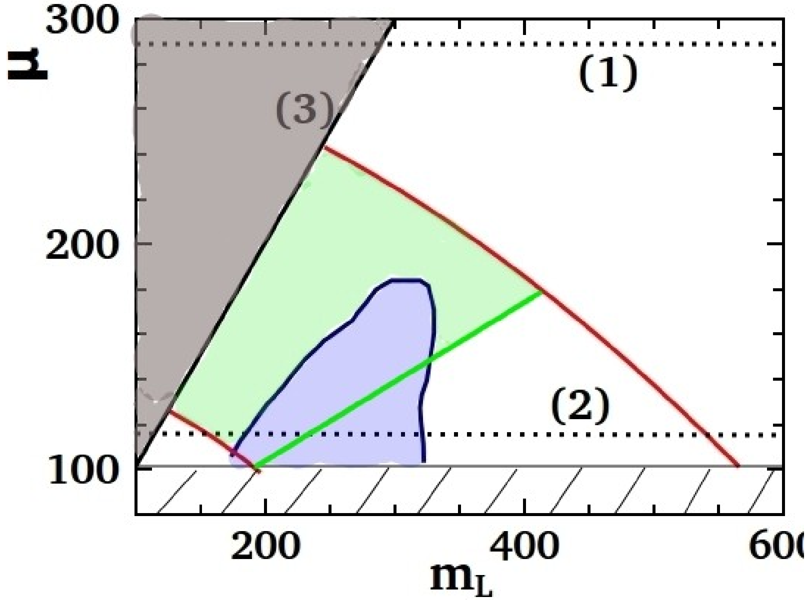
- **Stop-assisted chargino/neutralino production bounds**



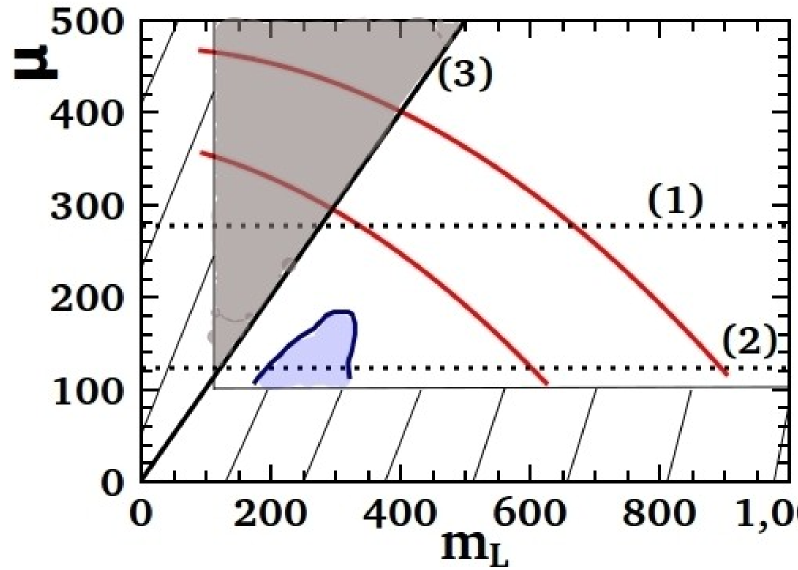
$$m_{\tilde{t}} \sim O(600) \;\; GeV$$

$$m_{\tilde{\chi}_1^0} \sim 2\mathrm{m}_{\tilde{\chi}_1^{\pm}} \sim O(400) \;\; GeV$$

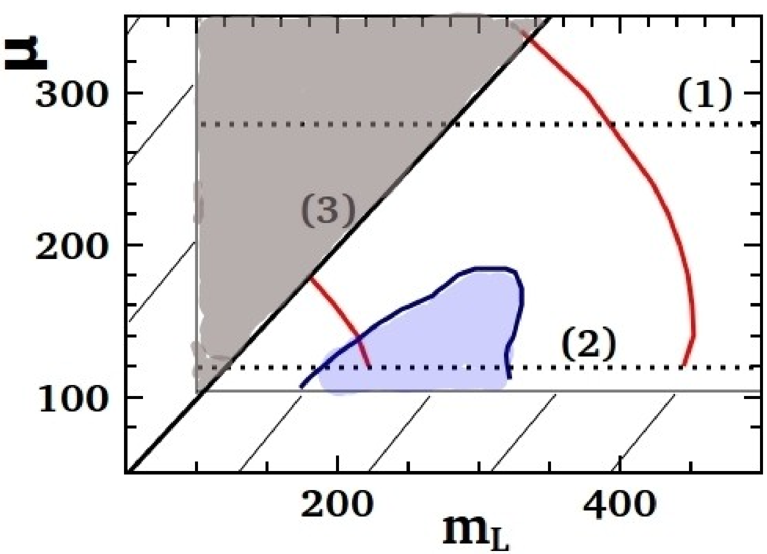
$\tan\beta = 10, \quad M_2 = 2\mu$



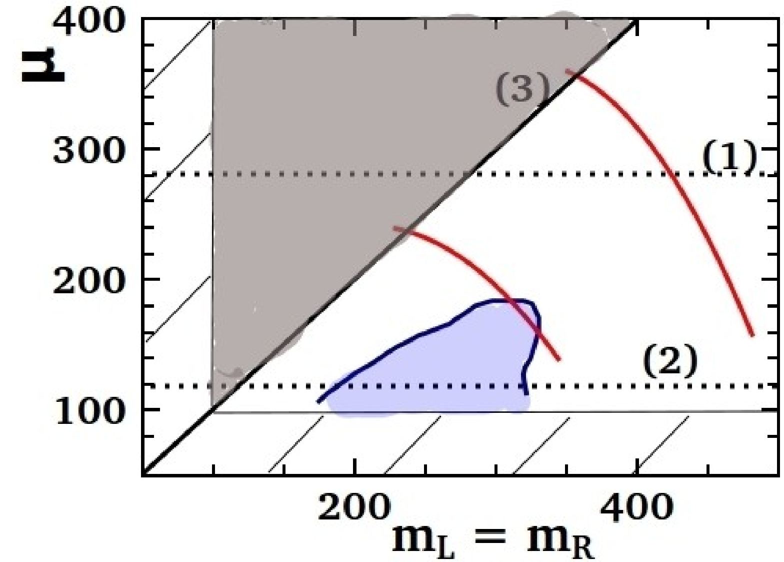
$\tan\beta = 40, \quad M_2 = 2\mu$



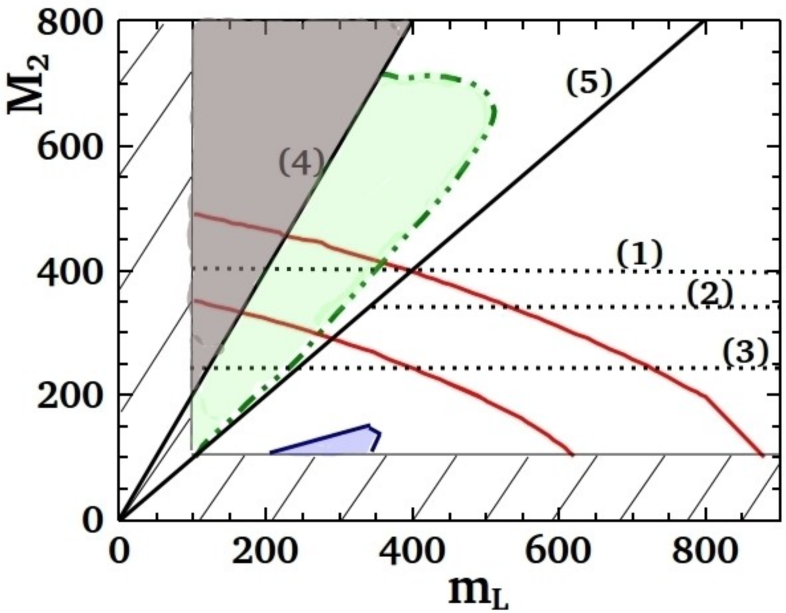
$\tan\beta = 40, \quad M_2 = 1\,TeV$



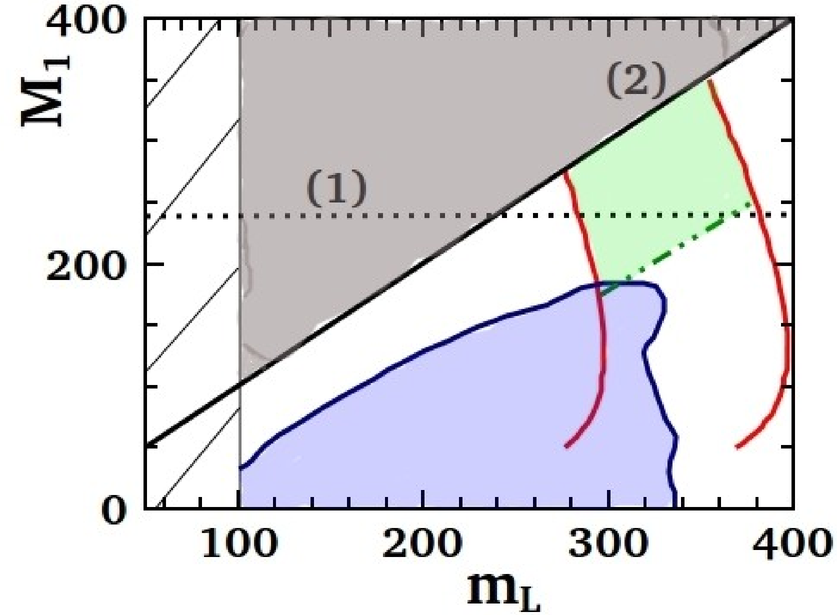
$\tan\beta = 40, \quad M_2 = 1\,TeV, m_L \sim m_R$



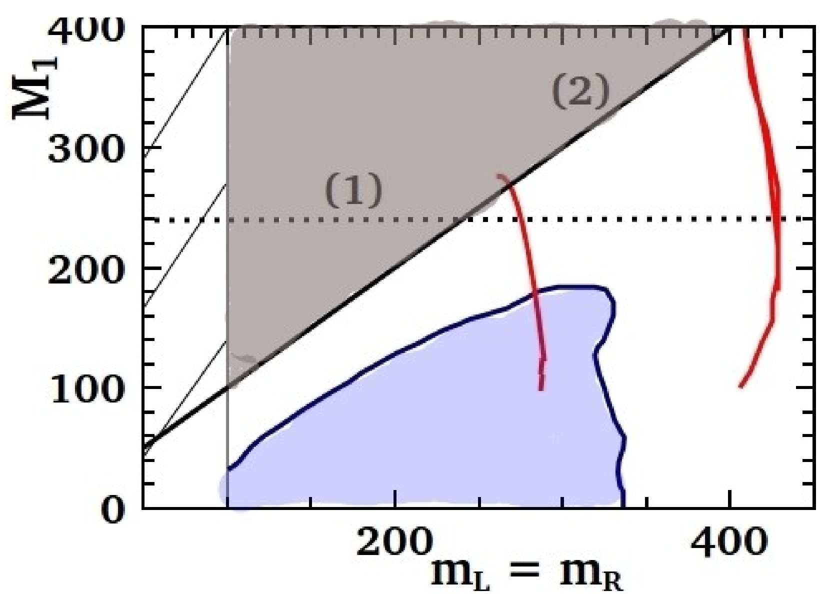
$\tan\beta=40, \quad \mu=2M_2, \quad M_1=\frac{1}{2}M_2$



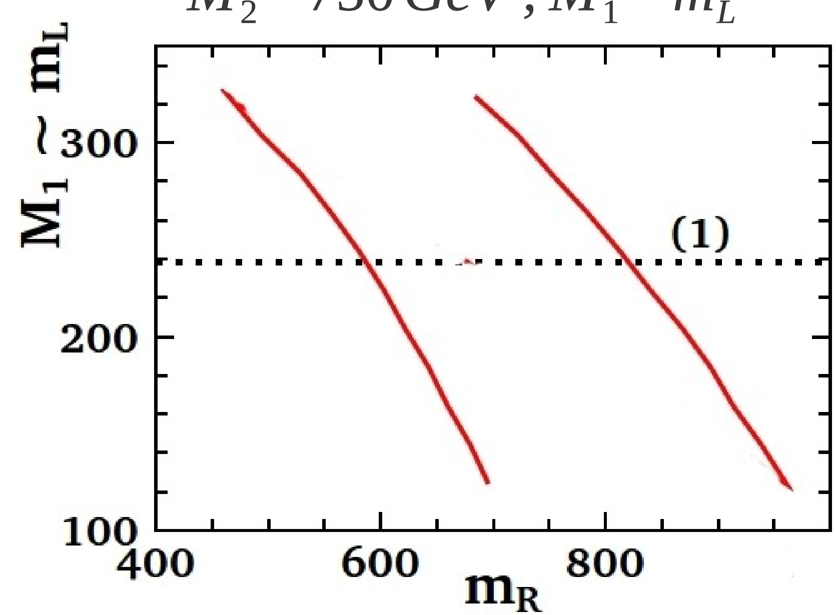
$\tan\beta=40, \quad \mu=2\,TeV, \quad M_1=\frac{1}{2}M_2$



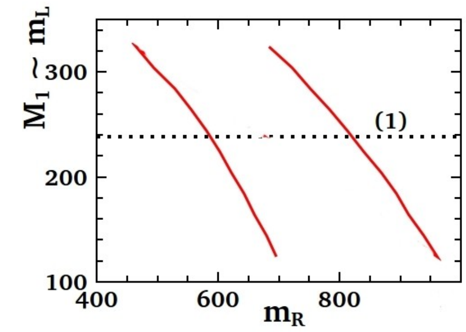
$\tan\beta=10, \quad \mu=M_2=5\,TeV, \quad m_L=m_R$



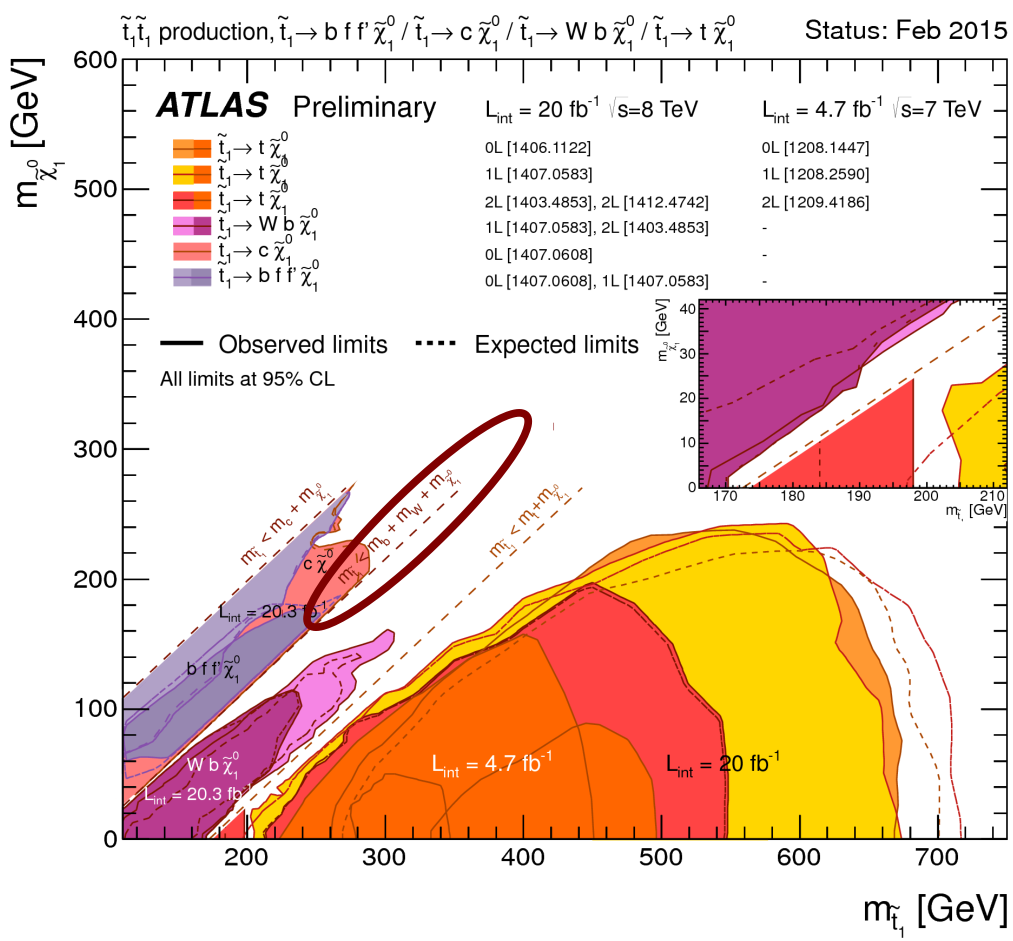
$\tan\beta=40, \mu=3\,TeV,$
$M_2\sim 750\,GeV, M_1\sim m_L$



- **Blind spots/Crevices**
- $\tilde{t} \rightarrow b(\tilde{\chi}_1^{\pm})^* \rightarrow b\,\tilde{l}\,\nu\,(\tilde{\nu}\,l) \rightarrow b\,l\,\nu\,\tilde{\chi}_1^0$

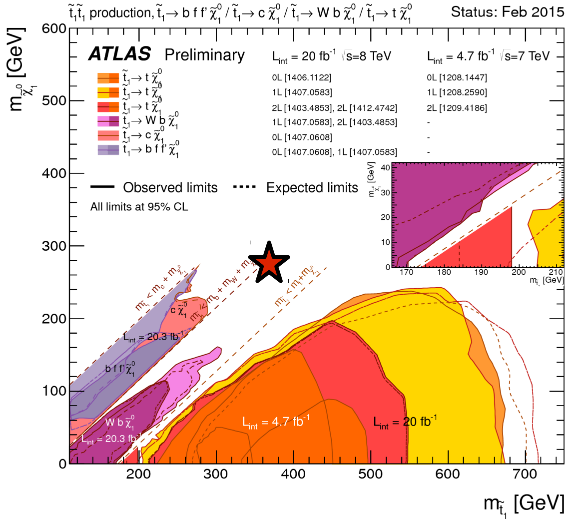


- **Competitive**
- $M_2 \sim 750\,GeV\,,\,\mu \sim 3\,TeV$
- $M_1 \sim m_L$ **coannihilation**
- **Acceptable b-jet efficiency even in compressed regions?**



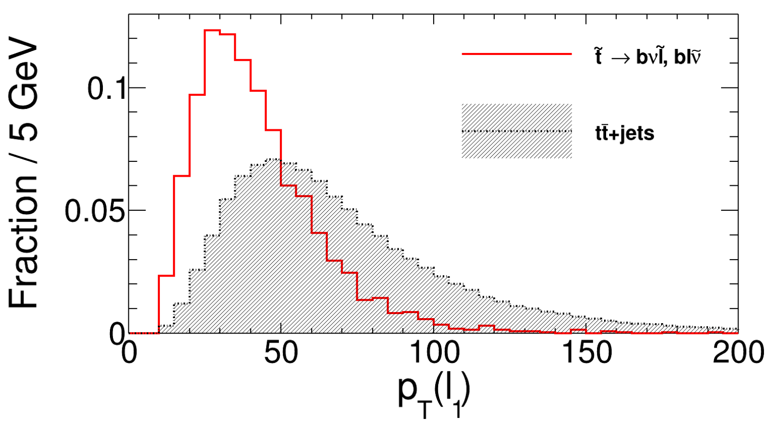
- # Spectrum

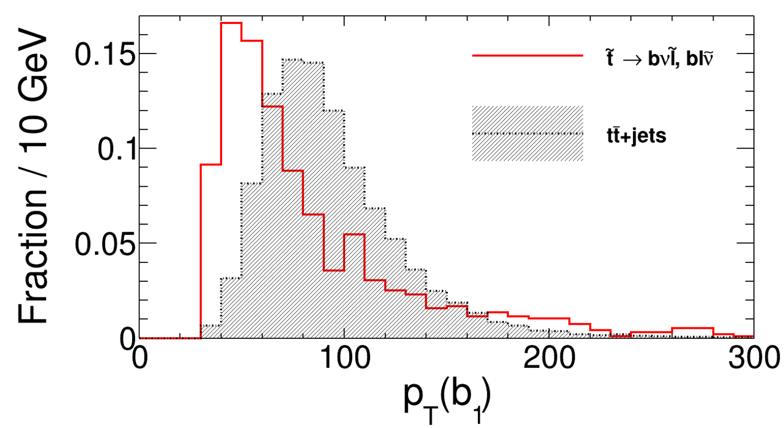
Particle	Mass (GeV)	Br
$\tilde{t}_1$	348	38% $(b\ell\tilde{\nu}_\ell)$, 62% $(b\tilde{\ell}\nu_\ell)$
$\tilde{\ell}_L$	302	100% $(\ell\tilde{\chi}_1^0)$
$\tilde{\ell}_R$	594	100% $(\ell\tilde{\chi}_1^0)$
$\tilde{\chi}_1^0$	269	



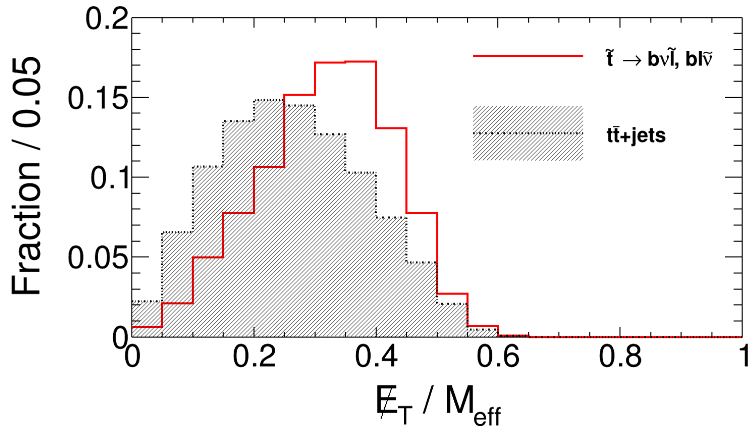
- # Preselections

  - **2 leptons** $p_T > 10 \;\; GeV$
  - **2 b-jets** $p_T > 30 \;\; GeV$





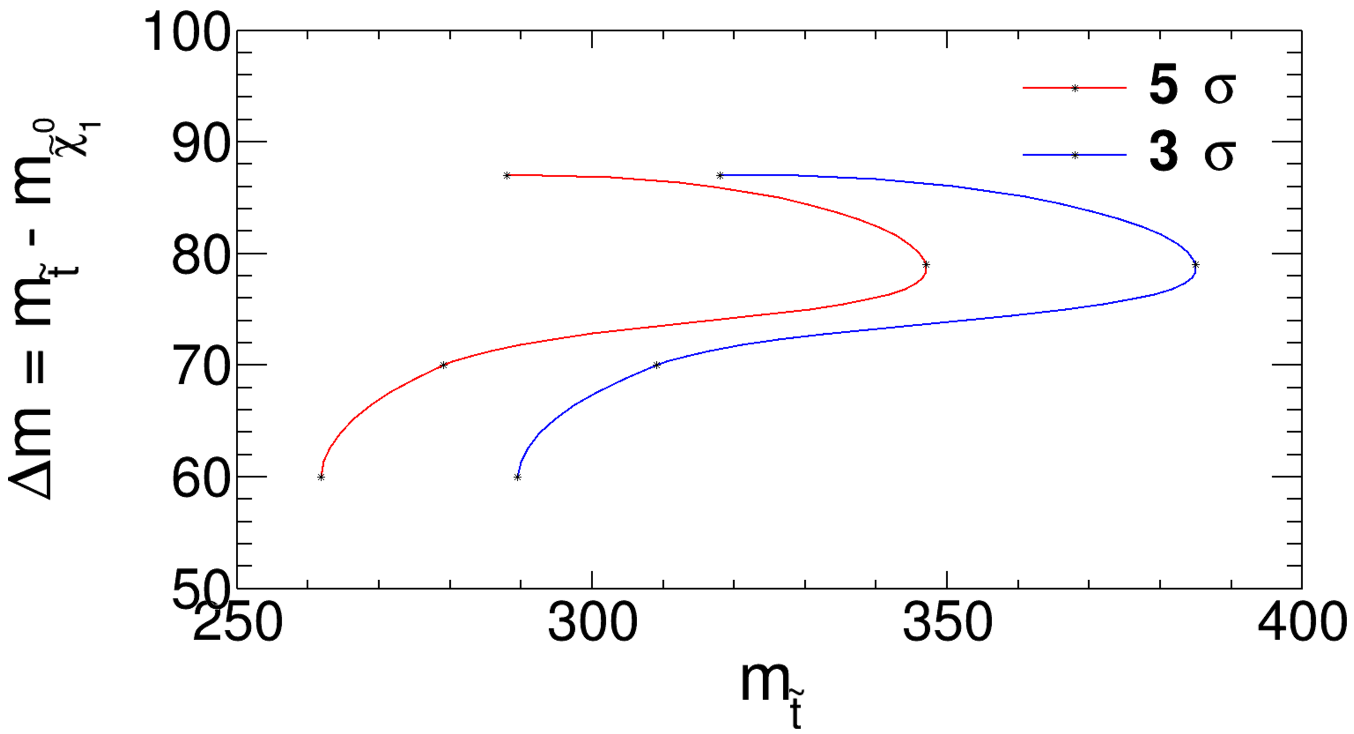
- **Leptons** $p_T(l_1) < 50\ GeV, \quad p_T(l_2) < 25\ GeV$
- **b-jets** $p_T(b_1) < 60\ GeV, \quad p_T(b_2) < 40\ GeV$
- **Missing energy** $\not{E}_T / M_{eff} > 0.25$



- **Cut flow**

Selection	Signal	Background
Preselection	7.4	16888
Lepton p_T	4.2	3251
$\not{E}_T/M_{eff} > 0.25$	3.1	1697
b-jet p_T	0.8	87.5
$MT_2 < 290$	0.74	66.9

- **Mass reach**



- **Systematics + Shape Analysis**

- $O(100)$ GeV **reduction in mass reach for 3 percent systematics**

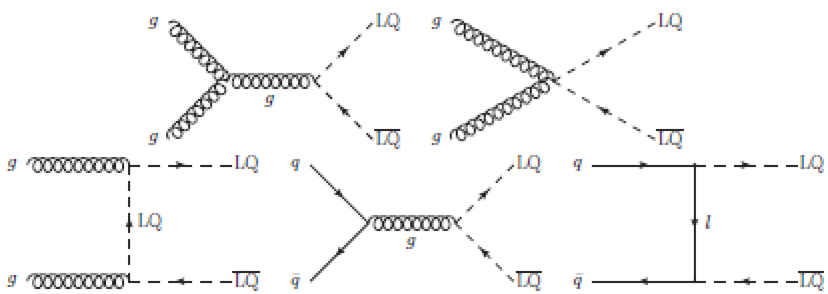
- **Muon magnetic moment**
  - **Slepton searches, dilepton channel** — $\tan\beta \sim O(10)$
  - **Chargino searches, trilepton channel** — $\tan\beta \sim O(40)$
  - **Stop-assisted production: most of parameter space will be probed**
  - **Compressed stop decay through off-shell chargino**
  - **Close out remaining parameter space**
  - **A stop discovery would make life much, much simpler**

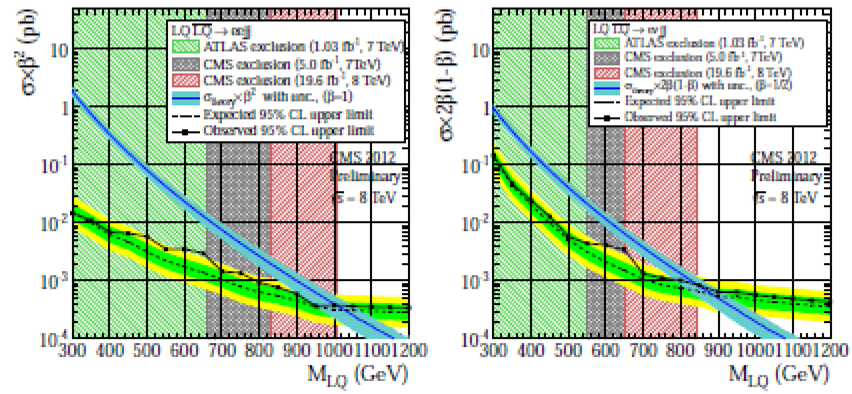
- **Until that happens, crucial searches:**
  - **Pure Higgsino/Wino**
  - **Pure slepton, compressed**
  - **Compressed stop searches**

CMS Leptoquark Search

Queiroz, KS, Strumia (arXiv: 1409.6301)

CMS First Gen Leptoquark Search





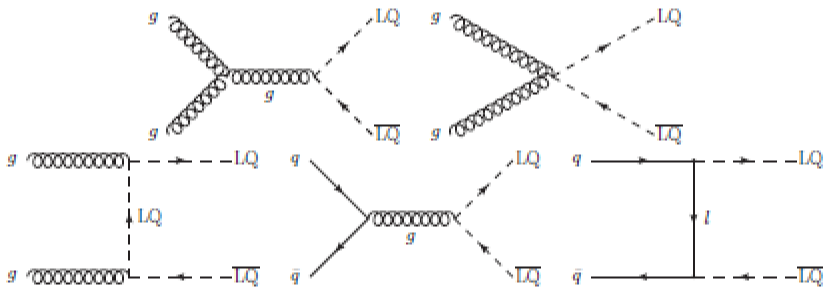
CMS-PAS-EXO-12-041 eejj final state

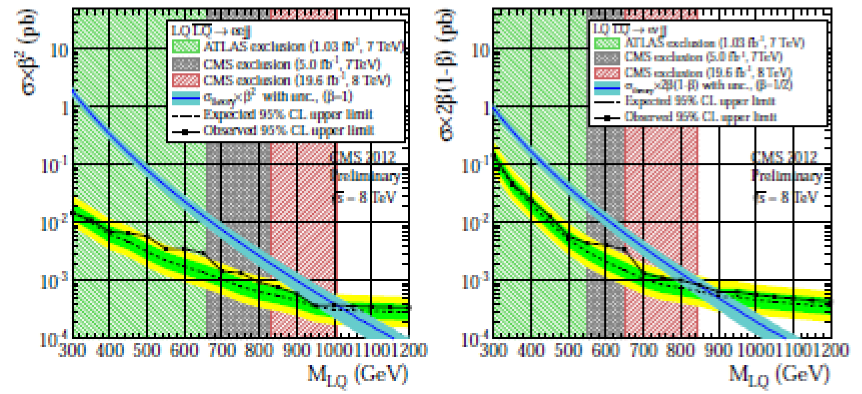
M_{LQ}	LQ Signal	Z+Jets	$t\bar{t}$ (from data)	QCD (from data)	Other	Data	Total Background	Significance
Presel	-	10538.4 ± 35.8	1566.6 ± 29.2	10.87 ± 0.10	303.8 ± 7.4	12442	12419.6 ± 46.8	NA
300	13560.2 ± 80.1	462.2 ± 7.4	724.3 ± 19.8	5.282 ± 0.052	62.1 ± 4.6	1244	$1253.94 \pm 21.67 \pm 30.08$ (syst)	0.0
350	6473.9 ± 33.3	332.1 ± 6.2	352.0 ± 13.8	3.215 ± 0.036	37.7 ± 3.6	736	$725.10 \pm 15.57 \pm 24.99$ (syst)	0.0
400	3089.3 ± 15.0	203.2 ± 4.8	153.7 ± 9.1	1.696 ± 0.023	23.8 ± 2.9	389	$382.40 \pm 10.72 \pm 15.00$ (syst)	0.0
450	1508.1 ± 7.2	112.9 ± 3.5	86.9 ± 6.9	0.890 ± 0.016	11.8 ± 2.0	233	$212.44 \pm 7.99 \pm 13.33$ (syst)	0.0
500	767.4 ± 3.6	66.5 ± 2.7	47.2 ± 5.1	0.485 ± 0.011	7.4 ± 1.6	148	$121.61 \pm 5.96 \pm 6.03$ (syst)	1.8
550	410.5 ± 1.9	37.4 ± 2.1	25.8 ± 3.7	0.2758 ± 0.0084	3.7 ± 1.1	81	$67.24 \pm 4.40 \pm 3.39$ (syst)	0.7
600	225.7 ± 1.0	22.2 ± 1.6	14.2 ± 2.8	0.1527 ± 0.0065	3.12 ± 1.00	57	$39.66 \pm 3.35 \pm 2.42$ (syst)	2.1
650	125.85 ± 0.58	14.0 ± 1.2	5.4 ± 1.7	0.0760 ± 0.0040	1.05 ± 0.47	36	$20.49 \pm 2.14 \pm 2.45$ (syst)	2.4
700	72.88 ± 0.33	8.16 ± 0.93	4.3 ± 1.5	0.0448 ± 0.0029	0.21 ± 0.12	17	$12.74 \pm 1.80 \pm 2.15$ (syst)	0.9
750	43.10 ± 0.20	4.88 ± 0.69	1.55 ± 0.90	0.0258 ± 0.0023	0.078 ± 0.038	12	$6.53 \pm 1.13 \pm 1.09$ (syst)	1.6
800	26.17 ± 0.12	2.93 ± 0.52	1.04 ± 0.73	0.0193 ± 0.0022	0.078 ± 0.038	7	$4.06 \pm 0.90 \pm 0.89$ (syst)	1.1
850	15.978 ± 0.072	2.34 ± 0.48	0.52 ± 0.52	0.0111 ± 0.0015	0.042 ± 0.028	5	$2.91 \pm 0.71 \pm 0.71$ (syst)	0.0
900	9.813 ± 0.044	1.23 ± 0.36	0.52 ± 0.52	0.0069 ± 0.0012	0.022 ± 0.020	3	$1.77 \pm 0.63 \pm 0.37$ (syst)	0.0
950	6.086 ± 0.028	0.89 ± 0.29	$0.00^{+1.14}_{-0.00}$	0.00451 ± 0.00085	0.022 ± 0.020	1	$0.912^{+1.178}_{-0.295} \pm 0.27$ (syst)	0.0
1000	3.860 ± 0.018	0.56 ± 0.22	$0.00^{+1.14}_{-0.00}$	0.00374 ± 0.00082	0.0025 ± 0.0025	1	$0.567^{+1.162}_{-0.223} \pm 0.17$ (syst)	0.0
1050	2.576 ± 0.011	0.56 ± 0.22	$0.00^{+1.14}_{-0.00}$	0.00374 ± 0.00082	0.0025 ± 0.0025	1	$0.567^{+1.162}_{-0.223} \pm 0.17$ (syst)	0.0
1100	1.6936 ± 0.0072	0.56 ± 0.22	$0.00^{+1.14}_{-0.00}$	0.00374 ± 0.00082	0.0025 ± 0.0025	1	$0.567^{+1.162}_{-0.223} \pm 0.17$ (syst)	0.0
1150	1.1272 ± 0.0047	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible] 0.17 (syst)	0.0
1200	0.7498 ± 0.0030	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible] 0.17 (syst)	0.0

leptoquark mass hypothesis under consideration. In both channels, a significant excess is observed in the final selection optimized for leptoquarks with a mass of 650 GeV. The excess in the $e\nu jj$ channel in particular makes it impossible to exclude leptoquarks with a mass of 650 GeV and $\beta < 0.15$. However, limits may still be placed with 95% CL on first generation scalar leptoquarks with masses less than 950 (845) GeV, assuming $\beta = 1.0(0.5)$. This is to be compared

Queiroz, KS, Strumia (arXiv: 1409.6301)

CMS First Gen Leptoquark Search





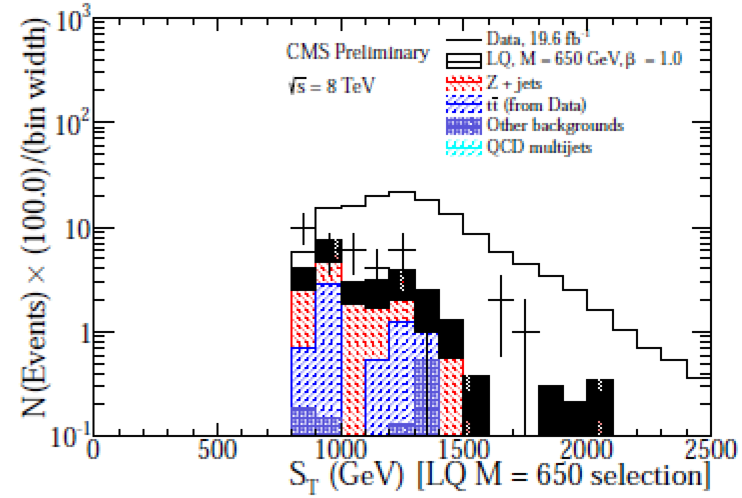
- **550 GeV LQ (eejj)**
  - **NLO QCD** $\sigma = 43\ fb$

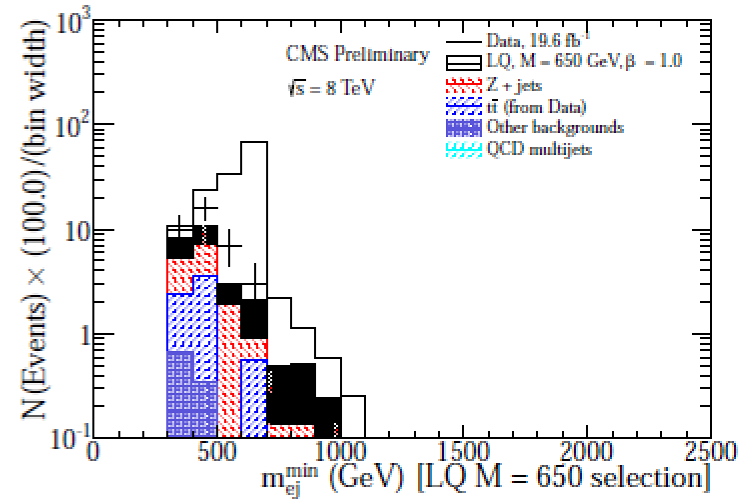
    Kramer, Plehn, Spira, Zerwas (1996, 2004)
  - **Cut efficiency 49%**
  - **Expected events @ 20 ifb: 411**
  - **Observed excess over background: 14**
  - **Branching ~ 15%**

- **Backgrounds:** $Z/W+j,\ t\bar{t}+j$
- **Cuts**
  - **Preselection with** μ **veto**
  - **Invariant mass** $m_{ee} > 155\ GeV$
  - **Scalar sum of** p_T **for** e **and two leading jets**

    $S_T > 850\ GeV$
  - m_{ej}^{min} **(LQ mass reconstruction)**

    $m_{ej}^{min} > 360\ GeV$





- **Scalar LQs**

Buchmuller, Ruckl, Wyler (1986)

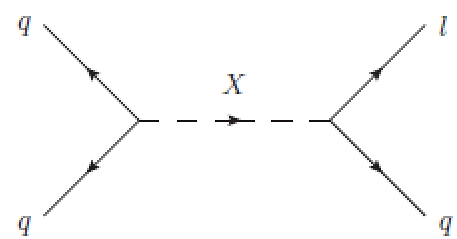
leptoquark notation	leptoquark couplings	$SU(3) \times SU(2) \times U(1)$ representation of LQ
R_2	$R_2 \overline{Q} e$, $R_2 L \overline{u}$	$(3, 2, 7/6)$
$\widetilde{R}_2$	$\widetilde{R}_2 L \overline{d}$	$(3, 2, 1/6)$
S_1	$S_1 \overline{QL}$, $S_1 \overline{ue}$	$(3, 1, -1/3)$
S_3	$S_3 \overline{QL}$	$(3, 3, -1/3)$
$\widetilde{S}_1$	$\widetilde{S}_1 \overline{d}\, \overline{e}$	$(3, 1, -4/3)$

$S_1 QQ, \quad S_1 u d$

$S_3 QQ$

$\widetilde{S}_1 u u$

TABLE I. Interaction terms for scalar LQs allowed by symmetries. Note that all the LQ candidates have $L = -1$, $B = 1/3$, $B - L = 4/3$.



- **Proton decay prefers doublets**

Arnold, Fornal, Wise (2013)

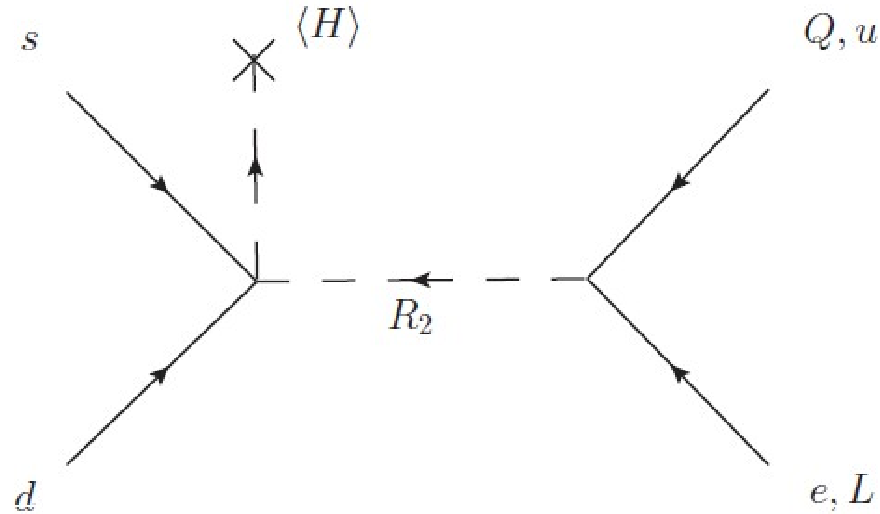
$$L \supset L_{SM} - \lambda_d^{ij} \overline{d}_R^i \widetilde{R}_2^T \epsilon L_L^j$$

- **Doublets need** Z_3

$$\mathcal{L}(R_2) \supset \frac{1}{\Lambda} g^{ab} d^a_{R\alpha} d^b_{R\beta} (H^\dagger R_{2\gamma}) \epsilon^{\alpha\beta\gamma}$$

$$\mathcal{L}(\widetilde{R}_2) \supset \frac{1}{\Lambda} g^{ab} u^a_{R\alpha} d^b_{R\beta} (H^\dagger \widetilde{R}_{2\gamma}) \epsilon^{\alpha\beta\gamma}$$

$$\mathcal{L}(\widetilde{R}_2) \supset \frac{1}{\Lambda} g^{ab} u^a_{R\alpha} e^b_{R} (\widetilde{R}_{2\beta} \epsilon \widetilde{R}_{2\gamma}) \epsilon^{\alpha\beta\gamma} \; .$$



- $\widetilde{R}_2 = (3,2,1/6)$ **engineer decay to dark matter**

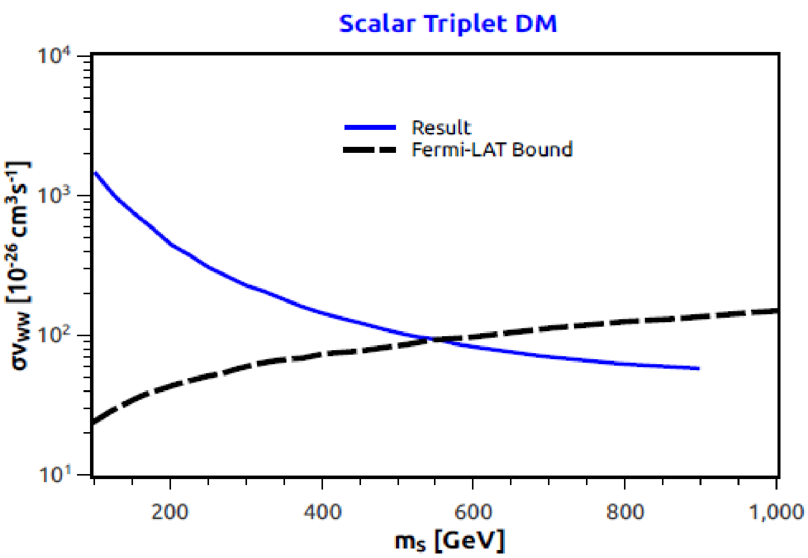
  $\chi = (1,3,0)_-$

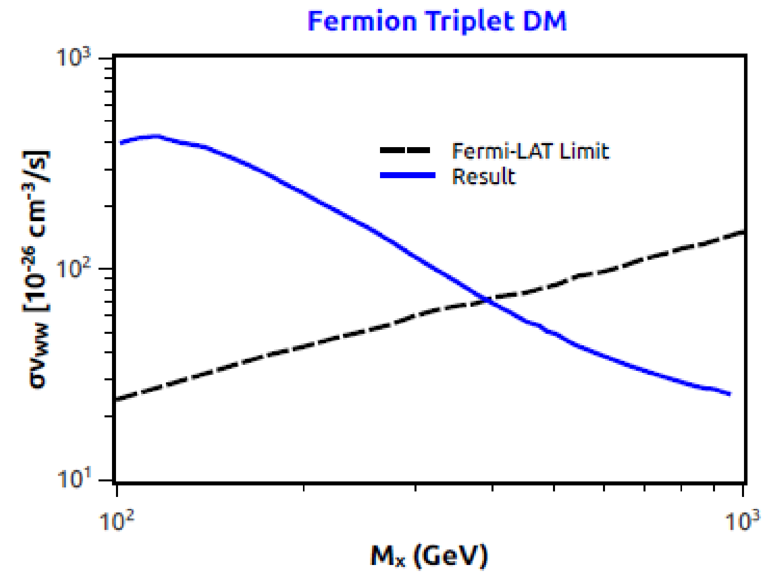
  $S = (1,1,0)_-$

  dark sector with $Y=0$

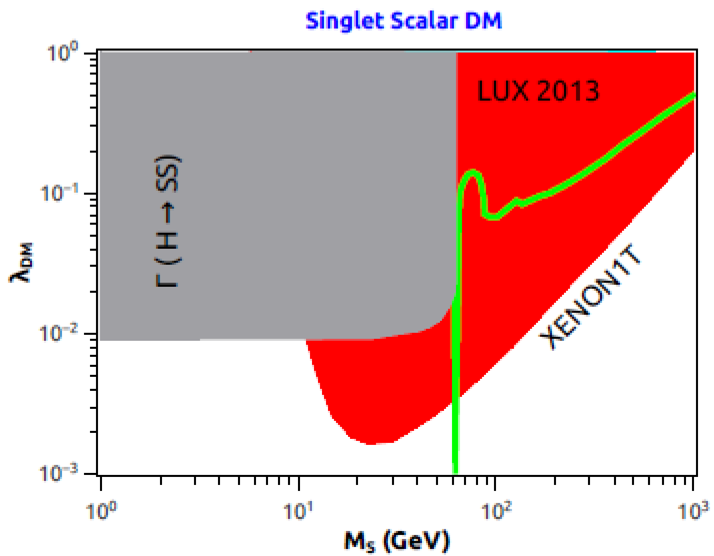
- **Matter content** $\widetilde{R}_2 = (3,2,1/6)$
  - **Dark Sector** $\chi = (1,3,0)_-$, $S = (1,1,0)_-$
- **Lagrangian**
  - $L \supset L_{SM} - \lambda_d^{ij} \overline{d}_R^i \widetilde{R}_2^T \epsilon L_L^j - \frac{1}{\Lambda_1} h_i S \overline{Q} \chi \widetilde{R}_2 - \frac{1}{\Lambda_2} h'_i S \overline{L} \chi H$
  - $\Lambda_1 \sim 1\,TeV, \quad h \sim 1$
  - **LQ** → **MET + jets**
- **Variations**
  - $\chi = (1,1,0)_-$, $S = (1,1,0)_-$
  - $\chi = (1,1,0)_-$, $S = (1,3,0)_-$

- **Triplets: ruled out by indirect detection**





- **Singlets: will be ruled out by direct detection**



- W_R **search:** $pp \to W_R \to e N_e \to eejj$

  2.8σ **excess**

  Bai, Berger (2014), Dobrescu, Martin (2014), etc.

- **LHCb anomaly in** $R_K = \frac{Br(B \to K \mu\mu)}{Br(B \to K e e)} = 0.745$

  Schmaltz, Hiller (2014)

- **IceCube neutrino flux**

  Barger, Keung (2013), Dutta, Gao, Li, Rott, Strigari (2015)

- **CMS dilepton edge anomaly**

  Allanach, Alves, Queiroz, Sinha, Strumia (2015)

CMS Dilepton Edge Anomaly

CMS Dilepton Edge Search

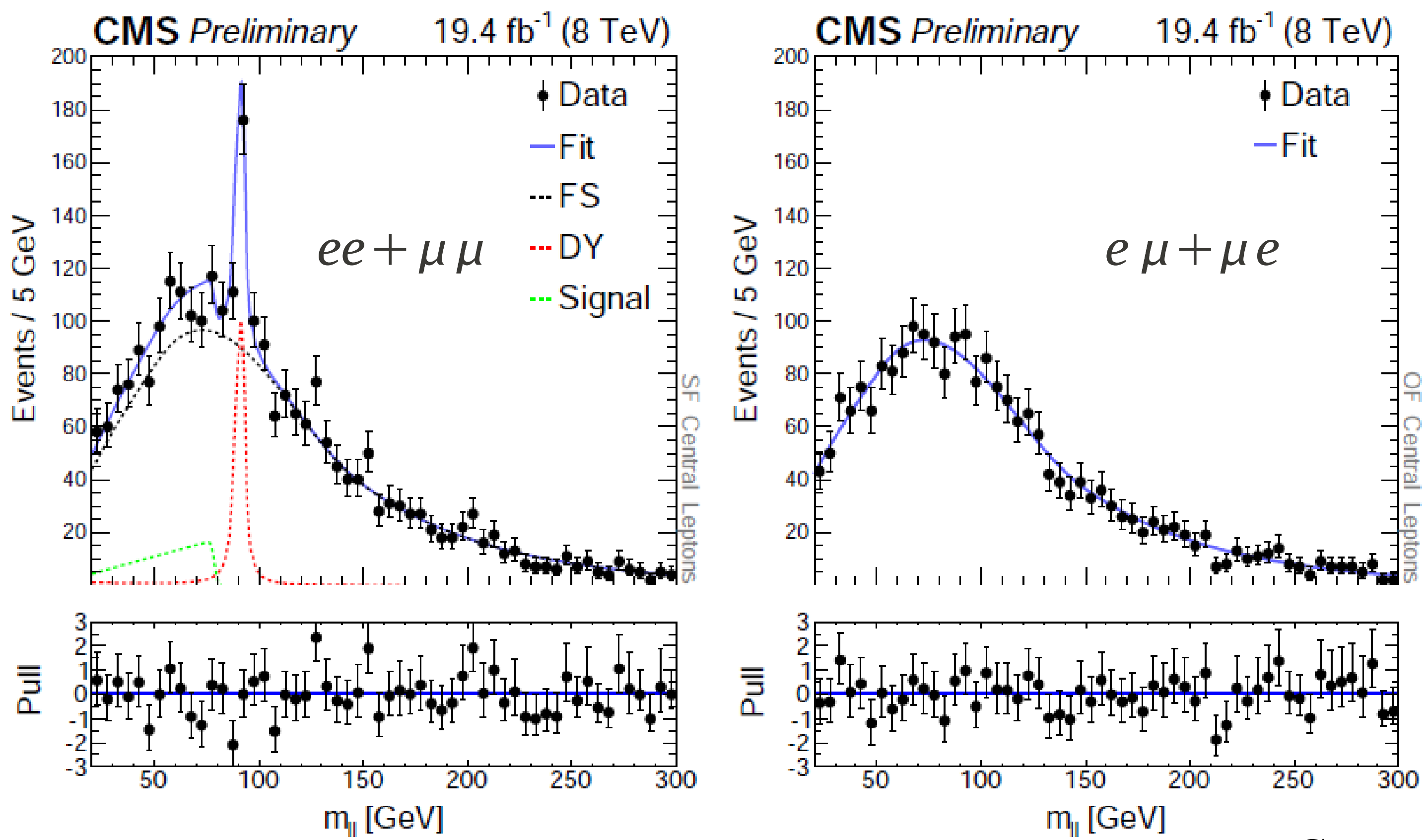
	Central	Forward
Observed [SF]	860	163
Flav. Sym. [OF]	$722 \pm 27 \pm 29$	$155 \pm 13 \pm 10$
Drell–Yan	8.2 ± 2.6	1.7 ± 1.4
Total estimates	730 ± 40	157 ± 16
Observed – Estimated	130^{+48}_{-49}	6^{+20}_{-21}
Significance [σ]	2.6	0.3

$N_j \geq 2$

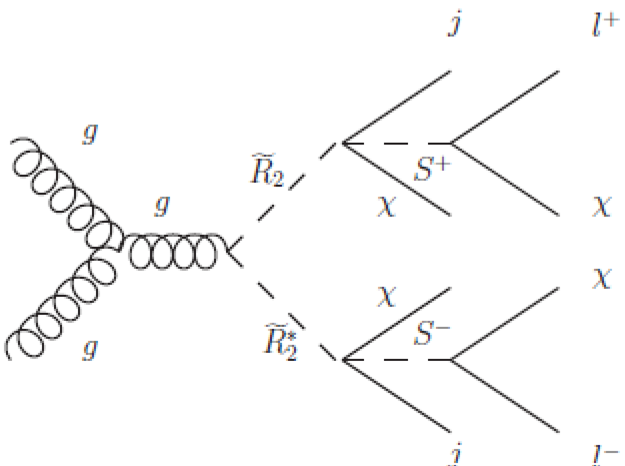
$MET \geq 150\,GeV$

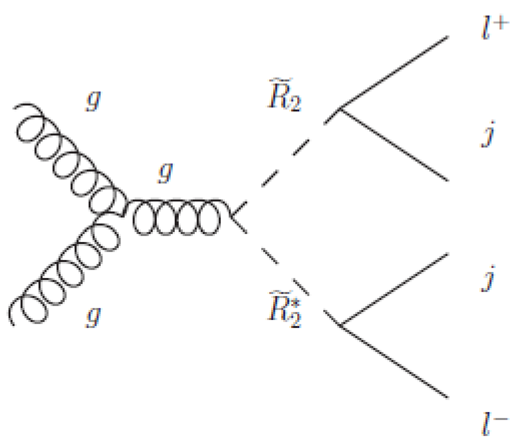
2 oppositely signed leptons

CMS PAS SUS-12-019



- **Lagrangian**
  - $L \supset L_{SM} - \lambda_d^{ij} \overline{d}_R^i \widetilde{R}_2^T \epsilon L_L^j - \frac{1}{\Lambda_1} h_i S \overline{Q} \chi \widetilde{R}_2 - \frac{1}{\Lambda_2} h_i' S \overline{L} \chi H$
  - $\Lambda_1 \sim 1 TeV, \quad h \sim 1$
  - **LQ** ⟶ **MET + jets**





- **CMS** $l^+ l^- j j \not{E}_T$
- **CMS** $eejj, \; e \nu jj$

- **Constraints**
  - **CMS, ATLAS** $j \not{E}_T$ **search**

    $$m_S + m_\chi > 300\, GeV$$

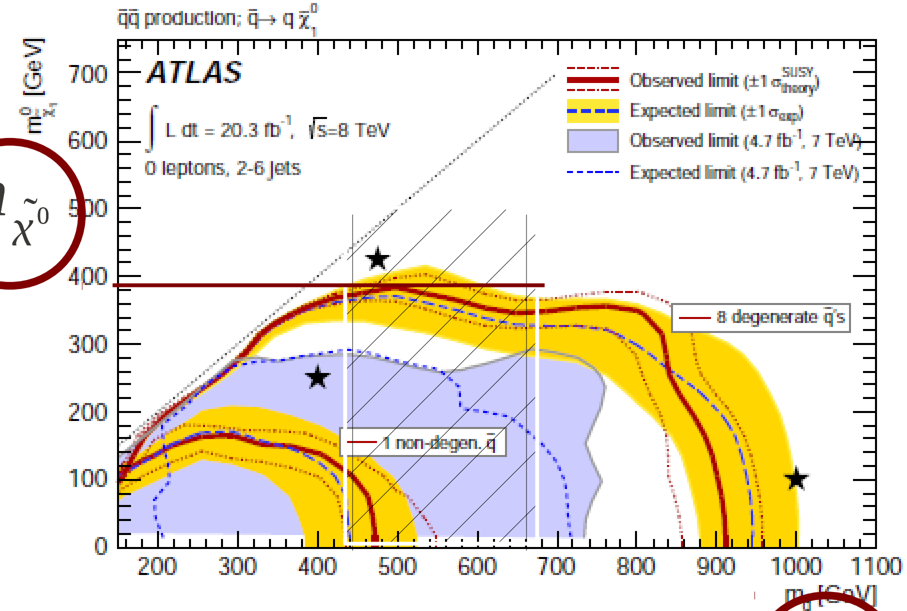
  - **CMS** $l^+ l^- \, j \, j \, \not{E}_T$

    $$m_S - m_\chi \sim 20 - 40\, GeV$$

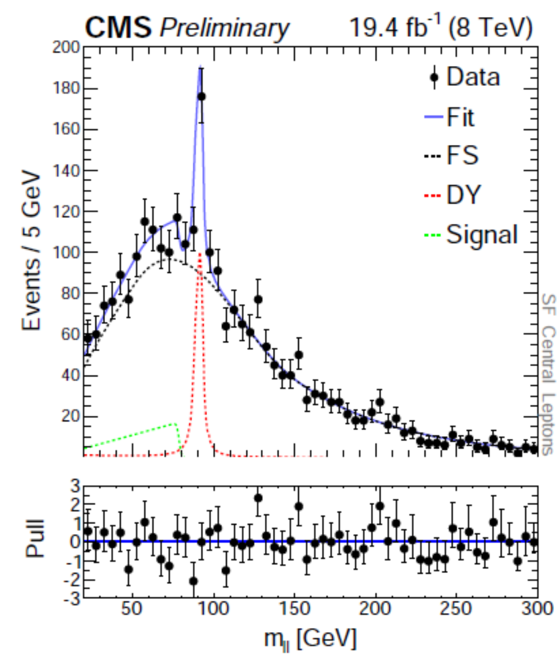
  - **CMS** $eejj\,,\ e\,\nu\, jj$

    $$Br(ej)\ \sim\ 0.15$$

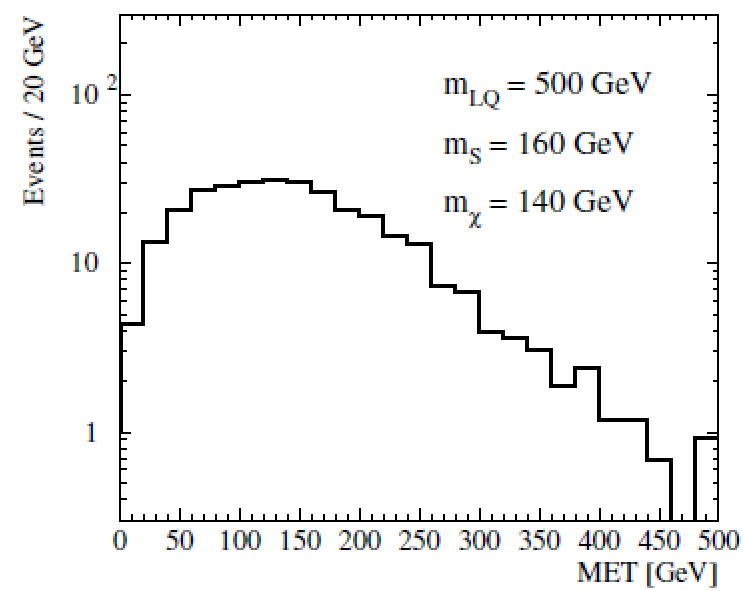
$m_{\tilde{\chi}^0}$



m_{LQ} ← $m_{\tilde{q}}$

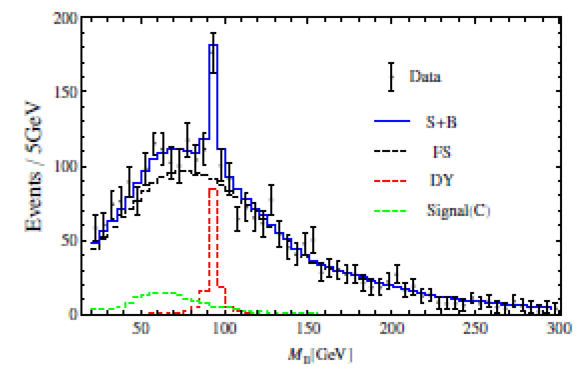


- **Cuts**
  - **2 OSSF leptons** $p_T > 20\,GeV$ **in** $\eta < 1.4$
  - $\geq 2\,j$ **with** $p_T > 40\,GeV$ **in** $\eta < 3.0$
- **Selections**
  - $2\,j$ **with** $\not{E}_T > 150\,GeV$ **OR** $3\,j$ **with** $E_T > 100\,GeV$



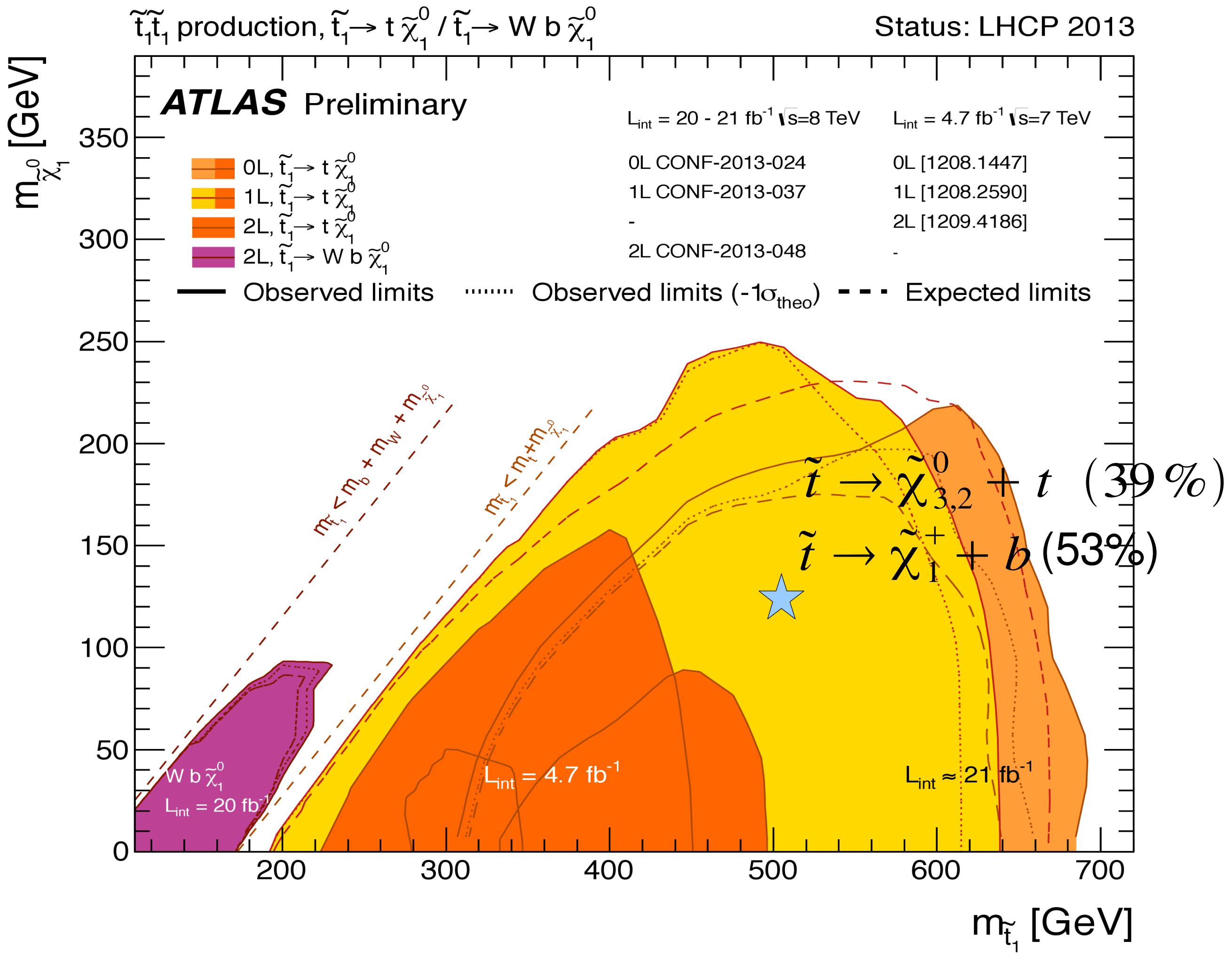
Cut-flow Table

$(m_{\tilde{R}_2}, m_S, m_\chi, h_i/\Lambda_1)$	Selection	Signal (fb)
$A:$ (450, 200, 170, 0.025)	preselection	138.3
	Cut (i)	37.3
	Cut (ii)	9.7
	$20 < m_{\ell\ell} < 70$	5.3(103)
	$m_{\ell\ell} > 100$	1.7(34)
$B:$ (500, 200, 170, 0.012)	preselection	97.2
	Cut (i)	26.2
	Cut (ii)	10.7
	$20 < m_{\ell\ell} < 70$	5.2(101)
	$m_{\ell\ell} > 100$	2.1(41)
$C:$ (500, 160, 140, 0.006)	preselection	111.7
	Cut (i)	16.8
	Cut (ii)	8.9
	$20 < m_{\ell\ell} < 70$	5.1(100)
	$m_{\ell\ell} > 100$	0.98(19)
$D:$ (500, 190, 160, 0.010)	preselection	103.4
	Cut (i)	29.0
	Cut (ii)	13.4
	$20 < m_{\ell\ell} < 70$	6.5(126)
	$m_{\ell\ell} > 100$	2.5(48)
$E:$ (550, 200, 170, 0.007)	preselection	56.9
	Cut (i)	15.9
	Cut (ii)	8.5
	$20 < m_{\ell\ell} < 70$	4.1(79)
	$m_{\ell\ell} > 100$	1.6(31)



Model	χ^2	p-value
A	40.1	0.04(1.8σ)
B	44.5	0.10(1.3σ)
C	43.2	0.07(1.5σ)
SUSY	38.1	0.02(2.1σ)
Background	59.0	0.53(0.08σ)

Bhaskar Dutta, Teruki Kamon, Nikolay Kolev, KS, Kechen Wang, Sean Wu



"To Bino/Higgsino LSP"

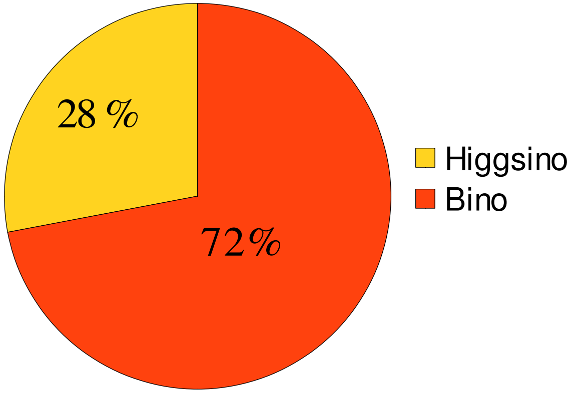
Top Squark Searches Using Dilepton Invariant Mass Distributions and Bino-Higgsino Dark Matter
Phys Rev D.*87.095007 [arXiv:1302.3231]*

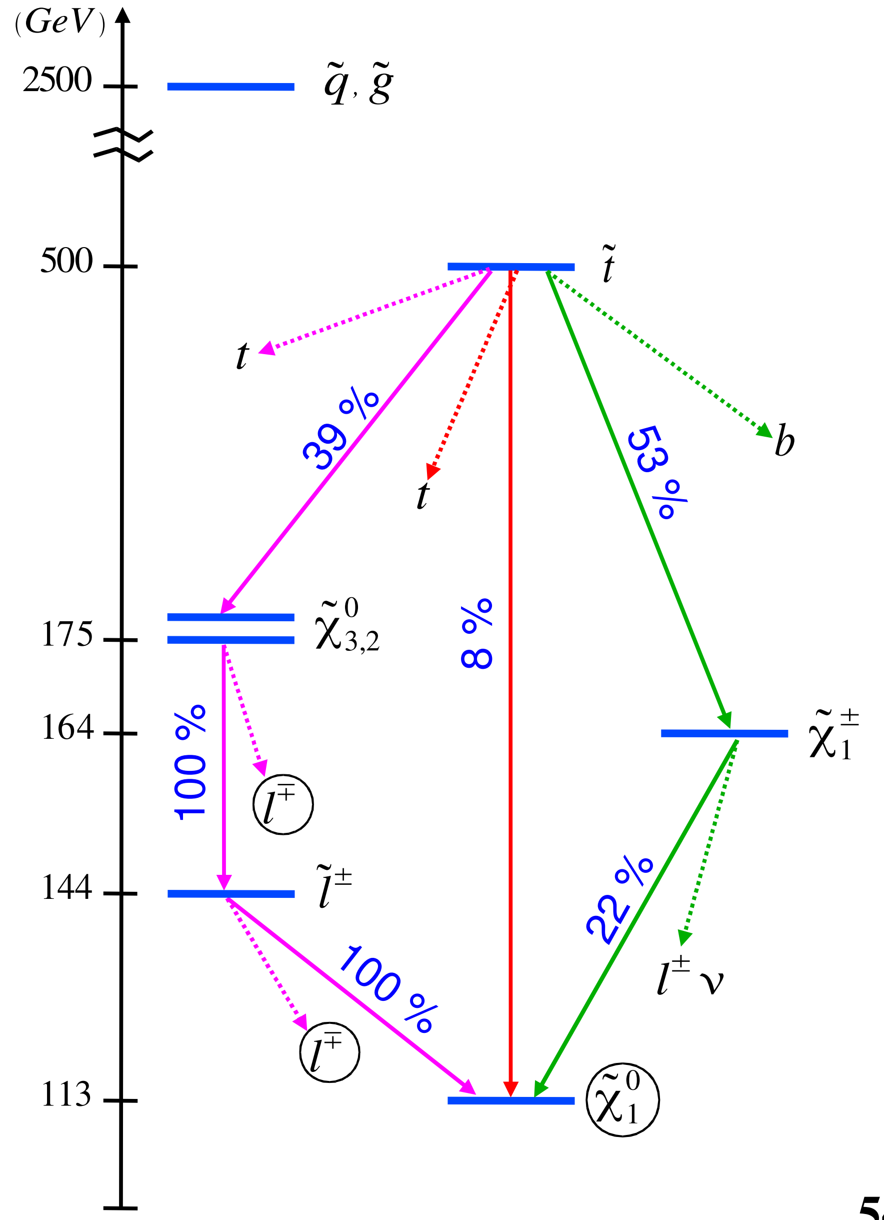
Goal:
$\tilde{t}$ decay ⟶ dark matter sector
in a scenario: $\tilde{\chi}_1^0 \sim (\tilde{B}+\tilde{H})$

Motivation:
Light $\tilde{t}$ and light $\tilde{H}$ ⟵ Naturalness
$\tilde{\chi}_1^0 \sim (\tilde{B}+\tilde{H})$ ⟵ Correct relic density

Since if $\tilde{\chi}_1^0 \sim \tilde{H}$ ⟶ small relic density

Composition of $\tilde{\chi}_1^0$
in our light slepton case





Kuver Sinha

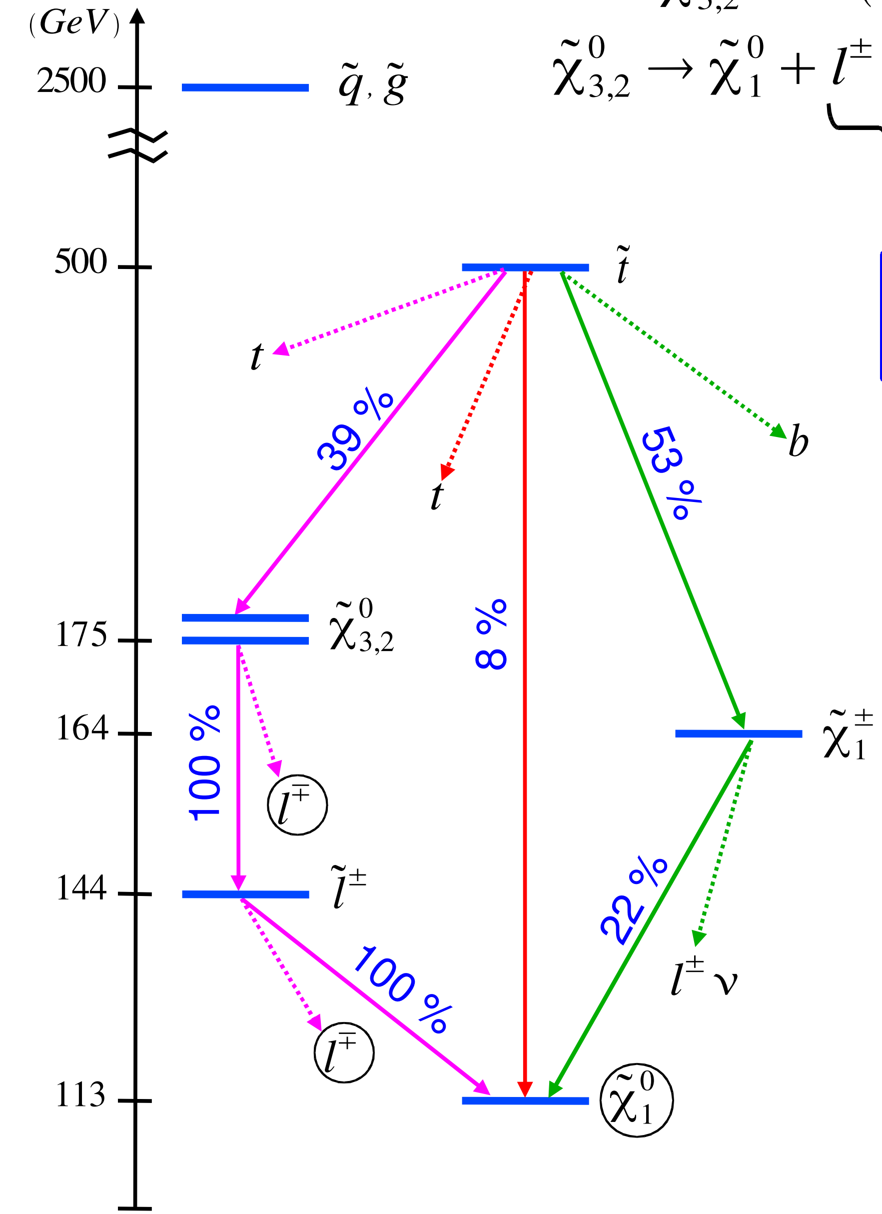
$\tilde{\chi}_2^0, \tilde{\chi}_3^0$ almost degenerate

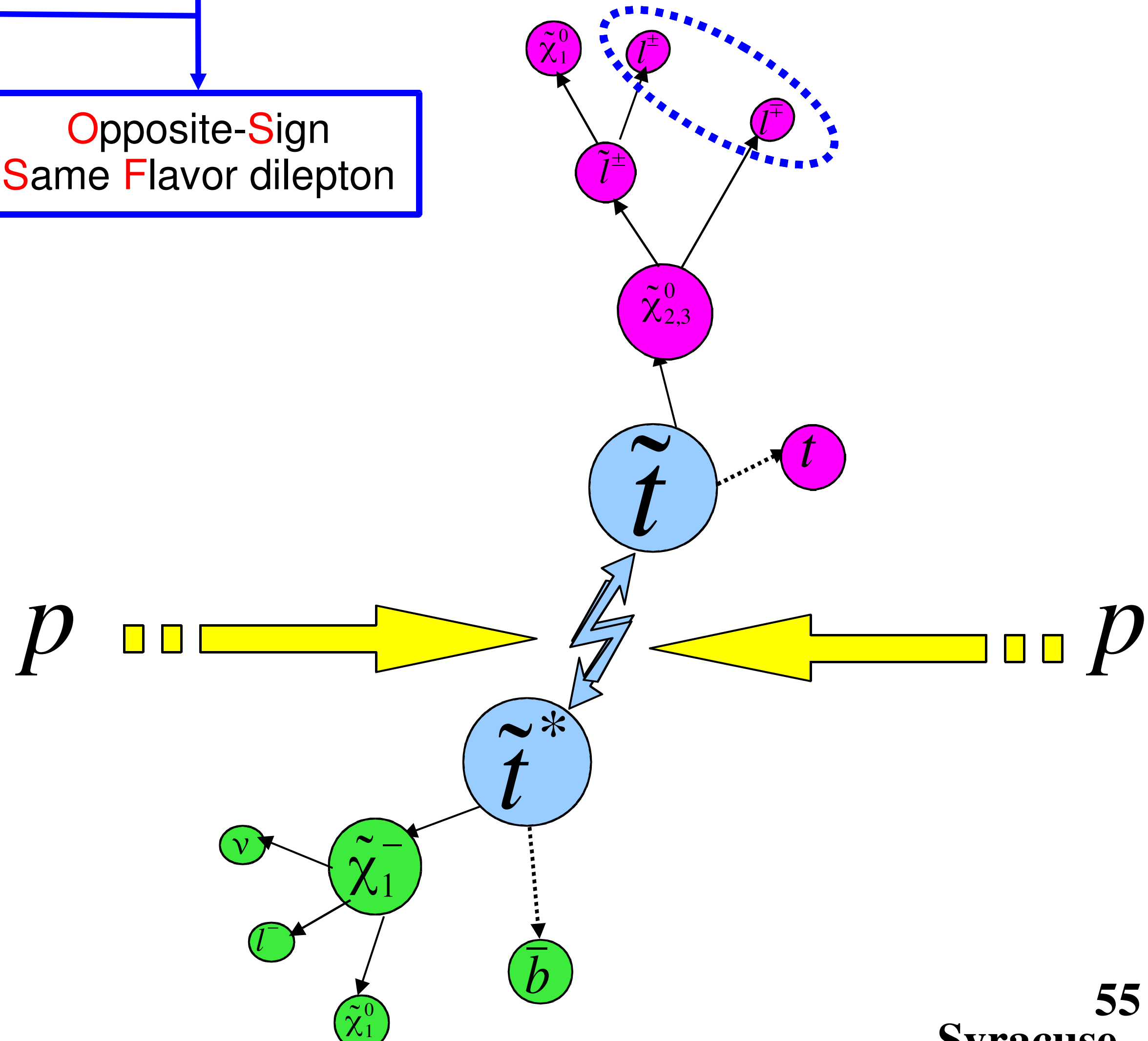
$$M_{ll}^{edge} \sim \Delta M = m_{\tilde{\chi}_2^0} - m_{\tilde{\chi}_1^0}$$

$$\tilde{t} \rightarrow \tilde{\chi}_{3,2}^0 + t \quad (39\,\%)$$

$$\tilde{\chi}_{3,2}^0 \rightarrow \tilde{\chi}_1^0 + \underbrace{l^\pm + l^\mp}\quad (100\,\%,\ via\ \tilde{e}^\pm \text{ or } \tilde{\mu}^\pm)$$

Opposite-Sign
Same Flavor dilepton



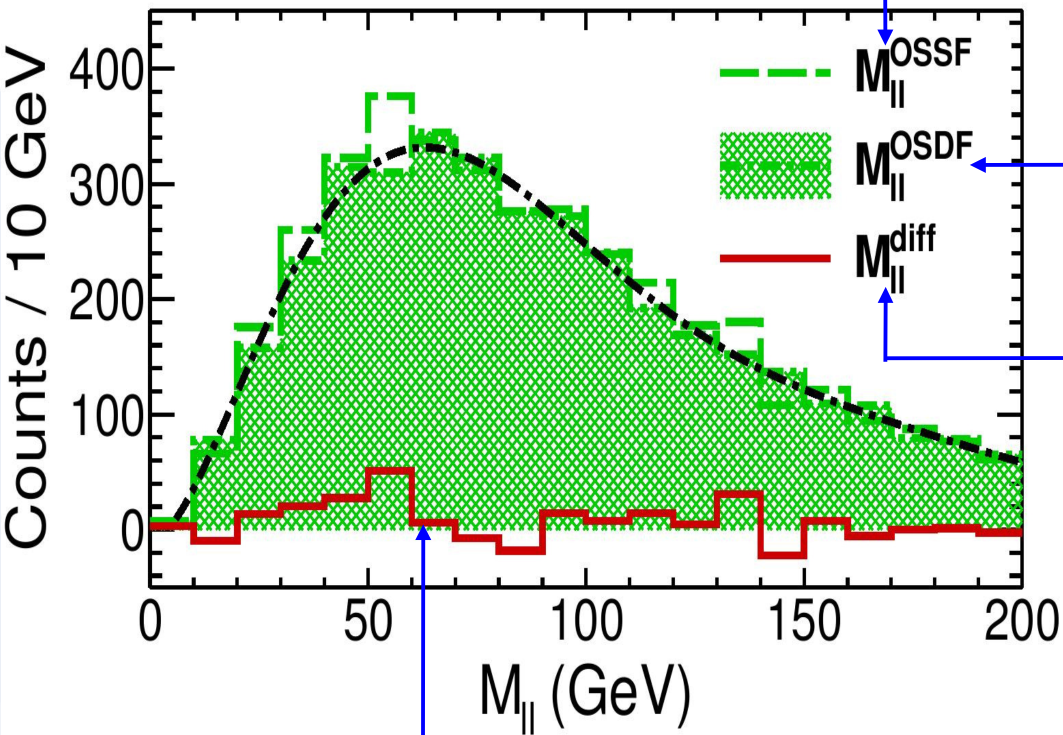


Final State:
2 l + 2 j + 1 b + large MET
MET > 150 GeV
H_T > 100 GeV

Dominant SM BG: $t\,\bar{t} + jets$

30 ifb LHC8

$$\tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0 + l^{\pm} + l^{\mp}$$



OSSF $(e^{\pm}e^{\mp} + \mu^{\pm}\mu^{\mp})$
$\tilde{t}_1\tilde{t}_1^*$ and $t\,\bar{t} + (0-4)\,jets$

OSDF $(e^{\pm}\mu^{\mp} + \mu^{\pm}e^{\mp})$
$\tilde{t}_1\tilde{t}_1^*$ and $t\,\bar{t} + (0-4)\,jets$

OSSF – OSDF

A clear egde around
$\Delta M = m_{\tilde{\chi}_2^0} - m_{\tilde{\chi}_1^0} = 63\ GeV$.

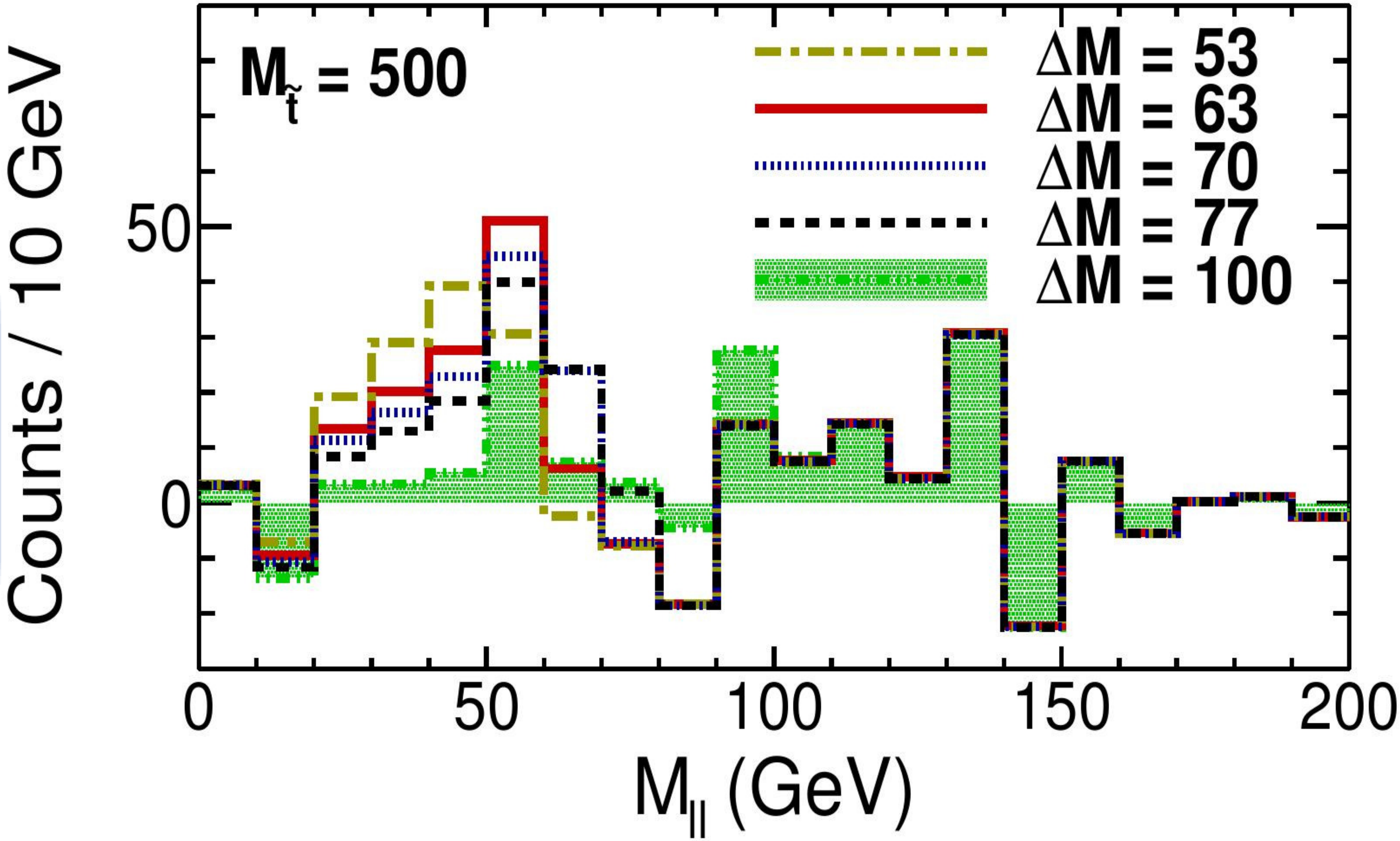
BG data simulation:
MadGraph + PYTHIA + PGS4

Signal data simulation:
ISAJET + PYTHIA + PGS4

The edge shifts with $\Delta M = m_{\tilde{\chi}_2^0} - m_{\tilde{\chi}_1^0}$.

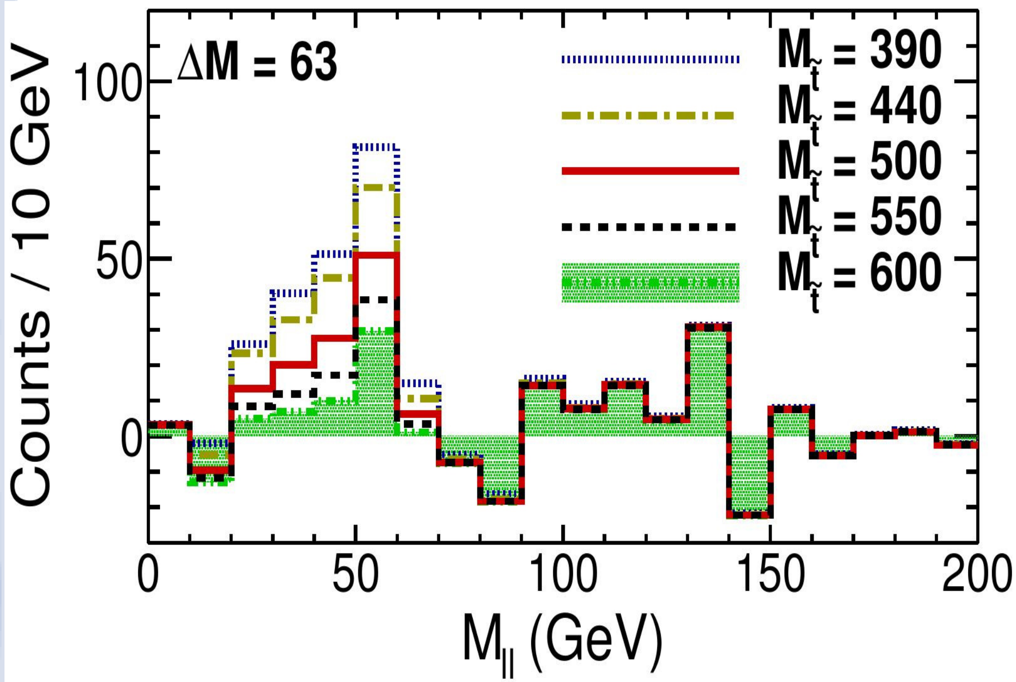
30 ifb
LHC8

$\tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0 + l^{\pm} + l^{\mp}$ $(100\%, via\ \tilde{e}^{\pm}$ or $\tilde{\mu}^{\pm})$



30 ifb LHC8

30 fb^{-1} luminosity, 8 TeV

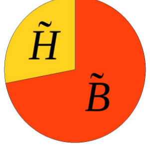


$$20\,GeV < M_{ll} < 70\,GeV \qquad s = \frac{N_S}{\sqrt{N_S + N_B}}$$

$m_{\tilde{t}}$ (GeV)	Signal (N_S)	Background (N_B)	significance (s)
390	212	1392	5.3
440	180	1368	4.6
500	117	1354	3.1
550	78	1348	2.1
600	51	1345	1.4

distinguishable edge, for $m_{\tilde{t}} \leqslant 550\,GeV$.

significance $\sim 3\sigma$, for $m_{\tilde{t}} = 500\,GeV$.



$m_{\tilde{\chi}_1^0} = 113\ GeV \qquad \Delta M = m_{\tilde{\chi}_2^0} - m_{\tilde{\chi}_1^0}$

30 ifb
LHC8

Masses	$\tilde{B}$	$\tilde{H}$	Ωh^2	s	Comments
(GeV)	(%)	(%)		(30 fb^{-1})	
$\Delta M=160$					Mainly Bino DM
$m_{\tilde{l}}=123$	96	4	0.11	0.44	(Coannihilation)
$m_{\tilde{t}}=500$					
$\Delta M=63$					Bino-Higgsino DM
$m_{\tilde{l}}=144$	72	28	0.11	3.1	(Light slepton scenario)
$m_{\tilde{t}}=500$					
$\Delta M=62$					Bino-Higgsino DM
$m_{\tilde{l}}=4000$	67	33	0.11	1.1	(Heavy slepton scenario)
$m_{\tilde{t}}=390$					

(a) $\tilde{\chi}_1^0 \sim \tilde{B}$, need coannihilation.
a low p_T lepton $\longrightarrow$ small significance.

(b) $\tilde{\chi}_1^0 \sim (\tilde{B}+\tilde{H})$ and light $\tilde{l}$,
$\longrightarrow$ edge around ΔM .

(c) $\tilde{\chi}_1^0 \sim (\tilde{B}+\tilde{H})$ and heavy $\tilde{l}$,
$Z \to ll \longrightarrow$ small significance.

- **Conclusions**

  - **Run II will tell us a lot about supersymmetry as a solution to the muon g-2 anomaly**

  - **Surprises may come from exotic searches**

  - **CMS LQ search: a connection to dark matter?**