Hunting Squarks in Higgsino LSP scenarios at the LHC

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References

- EA, A. Delgado, R. A. Morales and M. Quirós, arXiv:2112.09198 [hep-ph], under review in PRD.

Outline

1.- Introduction

2.- Collider strategy

3.- Results

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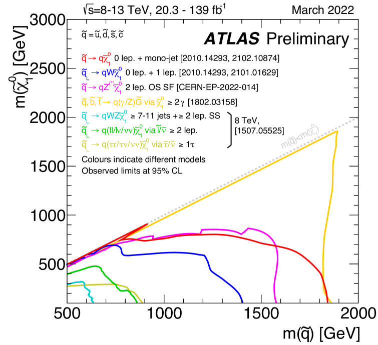
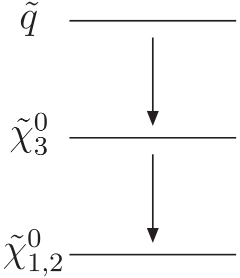
Introduction

- SUSY/MSSM still remains as viable extension of the SM.
- Most of LHC analyses assumed LSP ($\tilde{\chi}_1^0$) as bino-like neutralino with $\mathrm{BR}(\tilde{q} \to \tilde{\chi}_1^0 j) = 100\%$.

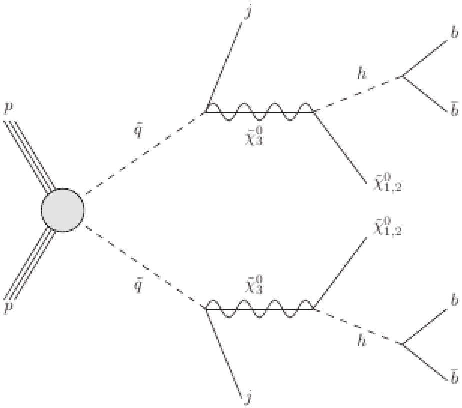


- More interesting: intermediate neutral state ($\tilde{\chi}_3^0$) between $\tilde{q}$ and LSP ($\mu < M_1 < M_{\tilde{q}} < M_2$).



- $\tilde{q} \to \tilde{\chi}_3^0 j$ and then $\tilde{\chi}_3^0 \to \tilde{\chi}_1^0 h$.

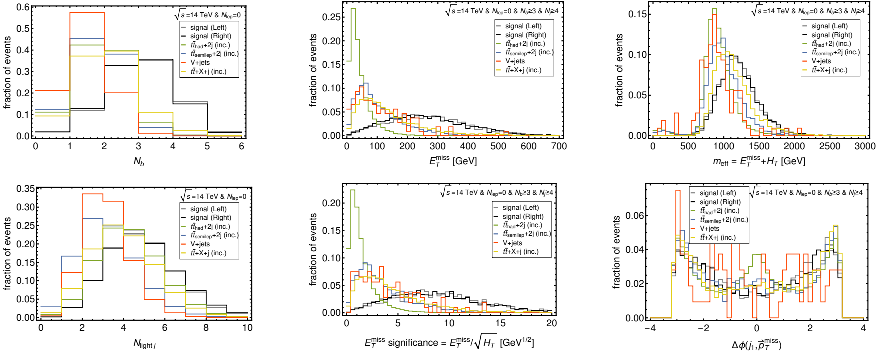
Collider strategy: signal and background



- LHC signature: $2j + 4b + E_T^{\text{miss}}$.
- Backgrounds: QCD multijet; $t\bar{t}$ production; $t\bar{t} + X$ ($X = W$, Z, γ^*, h); Z + jets and W + jets productions; and diboson production (WW, ZZ, WZ, Wh, and Zh) plus jets.

Collider strategy: signal characterization

- MC events generated with MadGraph + Pythia + Delphes.
- $\sqrt{s} = 14$ TeV and $\mathcal{L} = 1$ ab^{-1}.
- All benchmarks validated with CheckMATE 2.0.24.
- SUSY spectrum: $M_{\tilde{q}} = 1$ TeV, $M_{\tilde{\chi}^0_3} = 750$ GeV, $M_{\rm LSP} = 500$ GeV.



Collider strategy: signal regions

SR1

- selection cuts
  $N_b \geq 4\,,\;\; N_j \geq 4\,,\;\; N_\ell = 0,$
- $\chi_{HH} < 2,$
- MET cuts
  $E_T^{\rm miss} > 150$ GeV,
  $|\Delta\phi(j_1,\, \vec{p}_T^{\rm miss})| > 0.4,$
  $m_{\rm eff} > 1300$ GeV.

SR2

- selection cuts
  $N_b \geq 3\,,\;\; N_j \geq 4\,,\;\; N_\ell = 0,$
- p_T cuts
  $p_T^{j_1} > 200$ GeV, $p_T^{j_2} > 150$ GeV, $p_T^{j_3} > 80$ GeV, $p_T^{j_4} > 40$ GeV,
  $p_T^{b_1} > 100$ GeV, $p_T^{b_2} > 60$ GeV, $p_T^{b_3} > 35$ GeV.
- MET cuts
  $E_T^{\rm miss} > 150$ GeV,
  $|\Delta\phi(j_1,\, \vec{p}_T^{\rm miss})| > 0.4,$
  $m_{\rm eff} > 1400$ GeV.

Results: cut flows for SR1

- $\tilde{q}_L \tilde{q}_L$ production

Process	signal	$t\bar{t}_{\rm had} + 2j$ (inc.)	$t\bar{t}_{\rm semilep} + 2j$ (inc.)	V+jets	$t\bar{t}X + j$ (inc.)	$\mathcal{S}$
Expected	2110	2.4×10^6	0.74×10^6	3.56×10^5	2.9×10^3	2×10^{-3}
selection cuts	173.1	2697	90.2	7.95	13.2	1.3×10^{-2}
χ_{HH} cut	38.6	364.8	12.7	0	1.7	0.32
MET and $m_{\rm eff}$ cuts	6.9	1.1	0	0	0.1	3.16
$\mathcal{L} = 300$ fb^{-1}	2.1	0.3	0	0	0	1.89

- $\tilde{q}_R \tilde{q}_R$ production

Process	signal	$t\bar{t}_{\rm had} + 2j$ (inc.)	$t\bar{t}_{\rm semilep} + 2j$ (inc.)	V+jets	$t\bar{t}X + j$ (inc.)	$\mathcal{S}$
Expected	1701	2.4×10^6	0.74×10^6	3.56×10^5	2.9×10^3	1.6×10^{-3}
selection cuts	136.7	2697	90.2	7.95	13.2	0.16
χ_{HH} cut	31.9	364.8	12.7	0	1.7	0.27
MET and $m_{\rm eff}$ cuts	5.7	1.1	0	0	0.1	2.74
$\mathcal{L} = 300$ fb^{-1}	1.72	0.3	0	0	0	1.63

Cut flows for SR1 with $\mathcal{L} = 1000$ fb^{-1}. Significances with a systematic uncertainty in the background of 30%. A QCD multijet estimate of 0.7 events [2010.14293] is taken into account for the significances of the last cut-flow step.

Results: cut flows for SR2

- $\tilde{q}_L\tilde{q}_L$ production

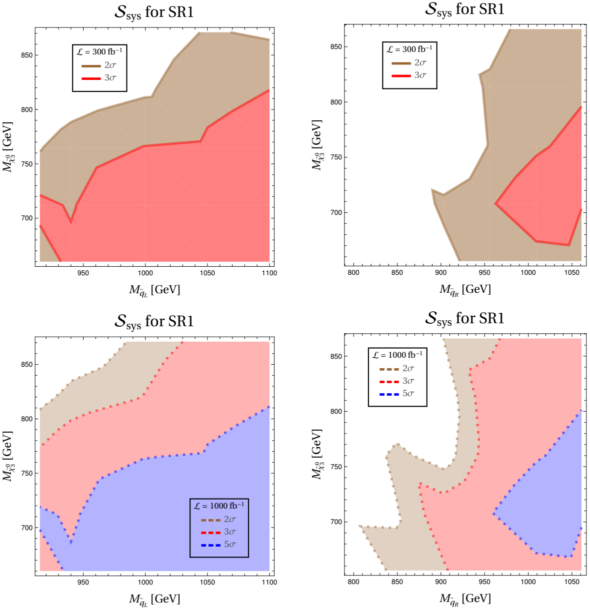
Process	signal	$t\bar{t}_{\text{had}} + 2j$ (inc.)	$t\bar{t}_{\text{semilep}} + 2j$ (inc.)	V+jets	$t\bar{t}X + j$ (inc.)	$\mathcal{S}$
Expected	2110	2.4×10^6	0.74×10^6	3.56×10^5	2.9×10^3	2×10^{-3}
selection cuts	616.9	3.06×10^4	2025	145.7	94.1	0.06
p_T cuts	35.9	216.7	4.1	0	2.1	0.49
MET and m_{eff} cuts	16.8	0	0.3	0	0.	7.22
$\mathcal{L} = 300$ fb^{-1}	5	0	0.1	0	0	4.32

- $\tilde{q}_R\tilde{q}_R$ production

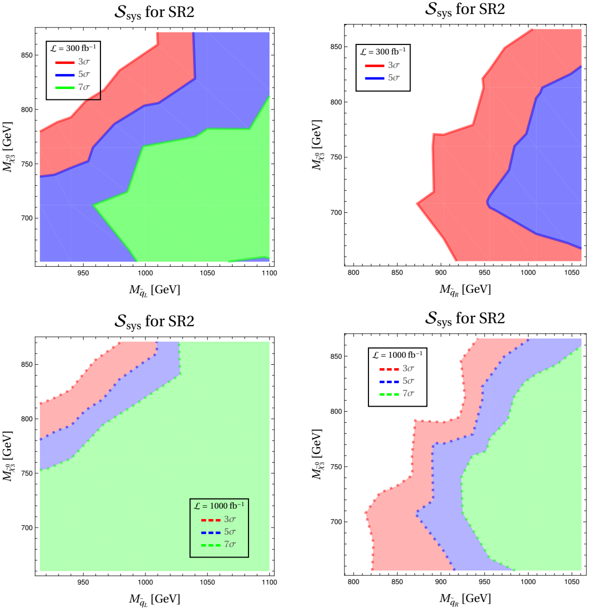
Process	signal	$t\bar{t}_{\text{had}} + 2j$ (inc.)	$t\bar{t}_{\text{semilep}} + 2j$ (inc.)	V+jets	$t\bar{t}X + j$ (inc.)	$\mathcal{S}$
Expected	1701	2.4×10^6	0.74×10^6	3.56×10^5	2.9×10^3	1.6×10^{-3}
selection cuts	508.9	3.06×10^4	2025	145.7	94.1	0.05
p_T cuts	38.3	216.7	4.1	0	2.1	0.05
MET and m_{eff} cuts	18.1	0	0.3	0	0.	7.58
$\mathcal{L} = 300$ fb^{-1}	5.4	0	0.1	0	0	4.55

Cut flows for SR2 with $\mathcal{L} = 1000$ fb^{-1}. Significances with a systematic uncertainty in the background of 30%. A QCD multijet estimate of 0.7 events [2010.14293] is taken into account for the significances of the last cut-flow step.

Results: contour lines for SR1 in the plane $[M_{\tilde{q}}, M_{\tilde{\chi}_3^0}]$



Results: contour lines for SR2 in the plane $[M_{\tilde{q}}, M_{\tilde{\chi}_3^0}]$



Conclusions

- When one deviates from assumption of 100% branching fractions of SUSY decays to LSP, the current searches have a different interpretation.
- Particular spectrum: first two squark generations heavier than mostly bino neutralino ($\tilde{\chi}_3^0$), heavier than mostly higgisino set of states ($\tilde{\chi}_{1,2}^0$, $\tilde{\chi}_1^+$). Squark-pair production will generate cascade decay via $\tilde{\chi}_3^0$, since direct decay to LSP is Yukawa suppressed.
- For mass values considered, current LHC searches provide no bounds.
- Feasibility of discovery of signal with 2 light-jets + 4 b-quarks + MET.
- Very promising results, specially SR2 case where one can obtain even 7σ significances for 300 fb^{-1}.

Main take-home message: one needs to deviate from simplified models to be able to cover a wide range of the parameter space in this class of BSM scenarios

BACKUP

Collider strategy: simulation details

- MadGraph_aMC@NLO 2.8.1 for MC generation of signal and background with $\sqrt{s} = 14$ TeV and $\mathcal{L} = 1$ ab^{-1}.
- PYTHIA 8.2 for parton showering and hadronization.
- Delphes 3.3.3 for detector response simulation.
- Spectrum validated with CheckMATE 2.0.24.
- Generator-level cuts for background simulation:

$$p_T^{j_1} > 180\,\text{GeV}\,, \quad p_T^{j_2} > 140\,\text{GeV}\,, \quad p_T^{j_3} > 70\,\text{GeV}\,, \quad p_T^{j_4} > 35\,\text{GeV}\,,$$
$$p_T^{b_1} > 90\,\text{GeV}\,, \quad p_T^{b_2} > 20\,\text{GeV}\,, \quad p_T^{b_3} > 20\,\text{GeV}\,, \quad p_T^{b_4} > 20\,\text{GeV}\,.$$

- *b*-tagging working point: efficiency of 0.75; misidentification rate of 0.01 for light jets and 0.1 for *c*-jets.
- MLM algorithm implemented for jet matching and merging: xqcut chosen to be 20 for all generated samples and qcut equal to 30, 50, and 250 for $t\bar{t}$, backgrounds with bosons, and signal, respectively.

Signal significance [1007.1727]

$$\mathcal{S} = \sqrt{2\left((B+S)\log\left(\frac{(S+B)(B+\sigma_B^2)}{B^2+(S+B)\sigma_B^2}\right) - \frac{B^2}{\sigma_B^2}\log\left(1+\frac{\sigma_B^2 S}{B(B+\sigma_B^2)}\right)\right)}\,.$$

- S number of signal events.
- B number of background events.
- $\sigma_B = (\Delta B)B$, with $\Delta B = 30\%$.

Benchmark points

Benchmark points computed with SOFTSUSY.4.1.10:

$$S_{exp} = \sigma(pp \to \tilde{q}\tilde{q}) \times \left(BR(\tilde{q} \to q\tilde{\chi}_3^0) \cdot BR(\tilde{\chi}_3^0 \to \tilde{\chi}_{1,2}^0 h) \cdot BR(h \to b\bar{b})\right)^2 \times \mathcal{L}\,.$$

$M_{\tilde{\chi}_3^0}$[GeV] / $M_{\tilde{q}_L}$[GeV]	915	925	940	1000	1050	1100
660	4.207	3.917	3.582	2.413	1.746	1.269
712	4.515	4.216	3.934	2.727	2.000	1.469
765	3.642	3.491	3.368	2.500	1.888	1.414
818	2.008	2.107	2.265	2.035	1.645	1.283
871	0.259	0.445	0.747	1.306	1.265	1.083

$M_{\tilde{\chi}_3^0}$[GeV] / $M_{\tilde{q}_R}$[GeV]	795	849	903	956	1009	1061
656	4.746	3.398	2.388	1.702	1.182	0.852
708	5.466	4.322	3.100	2.220	1.541	1.112
760	2.409	3.951	3.106	2.280	1.599	1.159
813	(x)	1.815	0.499	2.210	1.588	1.161
866	(x)	(x)	1.294	1.947	1.522	1.139