Multilepton signals of heavier electroweakinos

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JHEP 1711 (2017) 117 with Amitava Datta, Nabanita Ganguly and Sujoy Poddar.

02-12-2017

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- Higgs boson found, but no SUSY signal yet.

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- We try to constrain the EW sector reducing such assumptions, especially on heavier EWinos, as far as practicable.

EW gauginos

- Linear superposition of gauge eigenstates :
  $\rightarrow$ neutralino: $(\tilde{B}, \tilde{W}^3, H_u^0, H_d^0)$ and chargino : $(\tilde{W^{\pm}}, H_{u/d}^{\pm})$.

- Their masses and mixing determined by U(1) and SU(2) gaugino masses M_1 and M_2 and Higgs mass parameter μ.

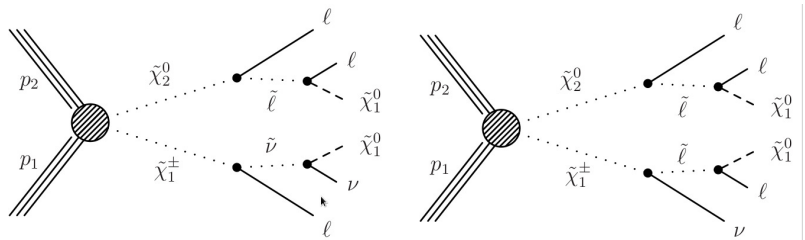
- The neutralino mass matrix:

$$M_N = \begin{pmatrix} M_1 & 0 & -M_Z c\beta s_W & M_Z s\beta s_W \\ 0 & M_2 & M_Z c\beta c_W & -M_Z s\beta c_W \\ -M_Z c\beta s_W & M_Z c\beta c_W & 0 & -\mu \\ M_Z s\beta s_W & -M_Z s\beta c_W & -\mu & 0 \end{pmatrix}$$

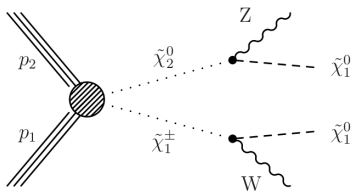
- Chargino mass matrix:

$$M_C = \begin{pmatrix} M_2 & \sqrt{2} M_W \cos\beta \\ \sqrt{2} M_W \sin\beta & \mu \end{pmatrix}$$

- LHC searches restricted to simplified models → all sparticles except those relevant to the signal are taken to be decoupled.
- $3l + \not{E}_T$ searches assume : $\widetilde{\chi}_1^{\pm}$ and $\widetilde{\chi}_2^0$ ⇒ mass-degenerate and purely wino, $\widetilde{\chi}_1^0$ ⇒ bino.



Decay via sleptons



Decay via gauge bosons

- Not only the strong sector sparticles, but the heavier EWinos are also taken to be decoupled.
- The signal from heavier EWinos are within the reach of the LHC. The bounds on the lighter ones are sensitive to their presence.
- We discard the assumption of strict decoupling ⇒ rich phenomenology in $4l$, $SS3OS1l$, $5l$ channels.

We consider mainly three kinds of scenarios.

- **Compressed Scenario :** $M_1 \sim \mu < M_2$, M_2 varied as a free parameter. $m_{\tilde{l}_L} = m_{\tilde{l}_R} = (m_{\widetilde{\chi}_1^\pm} + m_{\widetilde{\chi}_2^\pm})/2$. Consequently, only heavier EWeakinos can decay directly into sleptons with significant BRs.

- **HS scenario :** $M_2 \sim 1.5\mu$. Sleptons midway between $\widetilde{\chi}_2^\pm$ and $\widetilde{\chi}_1^\pm$.

- **LS scenario :** $M_2 \sim 1.5\mu$. Sleptons midway between $\widetilde{\chi}_1^0$ and $\widetilde{\chi}_2^0$. Bounds on $m_{\widetilde{\chi}_1^\pm}$ and $m_{\widetilde{\chi}_1^0}$ gets stronger, multileptons signal produced.

Masses and Cross-sec (fb)	Models		
	P1 (Comp)	P2 (HS)	P3 (LS)
M_1	186	105	249
μ	191	270	300
M_2	350	405	450
$m_{\widetilde{\chi}_1^0}$	151	100	231
$m_{\widetilde{\chi}_2^0}$	198	262	304
$m_{\widetilde{\chi}_3^0}$	213	281	311
$m_{\widetilde{\chi}_4^0}$	389	447	491
$m_{\widetilde{\chi}_1^\pm}$	178	260	291
$m_{\widetilde{\chi}_2^\pm}$	389	447	491
$\sigma(pp \to \text{LEWs})$	621.9	299.5	165.8
$\sigma(pp \to \text{HEWs})$	147.1	81.4	52.0
σ_{tot}	768.9	380.9	217.8

Table :

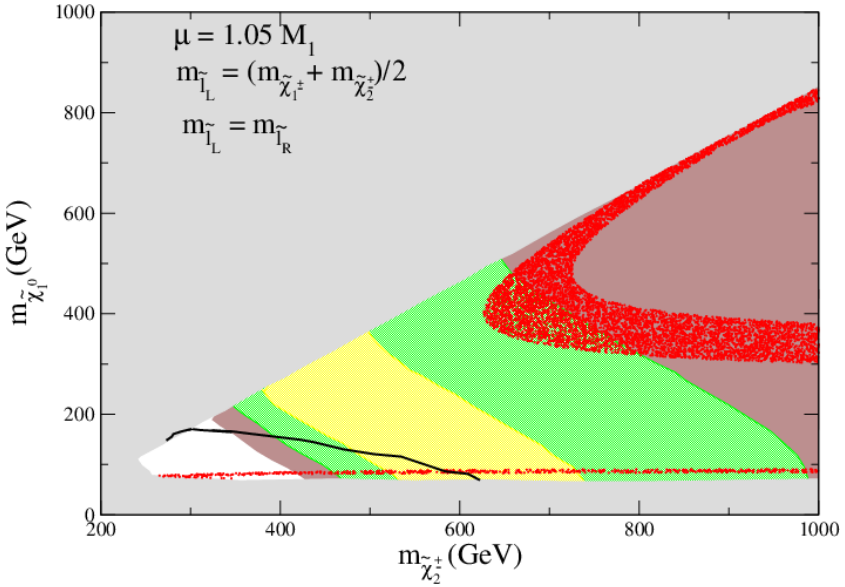
$(\sigma \times \text{BR})_{3l}$	P1	P2	P3
LEWs	9.36	2.41	18.25
HEWs	64.2	4.85	6.23
$(\sigma \times \text{BR})_{4l}$	P1	P2	P3
LEWs	0.212	0.113	0.116
HEWs	20.2	0.764	0.661
$(\sigma \times \text{BR})_{5l}$	P1	P2	P3
LEWs	-	0.008	-
HEWs	4.81	0.134	0.137

Table :

Our analysis

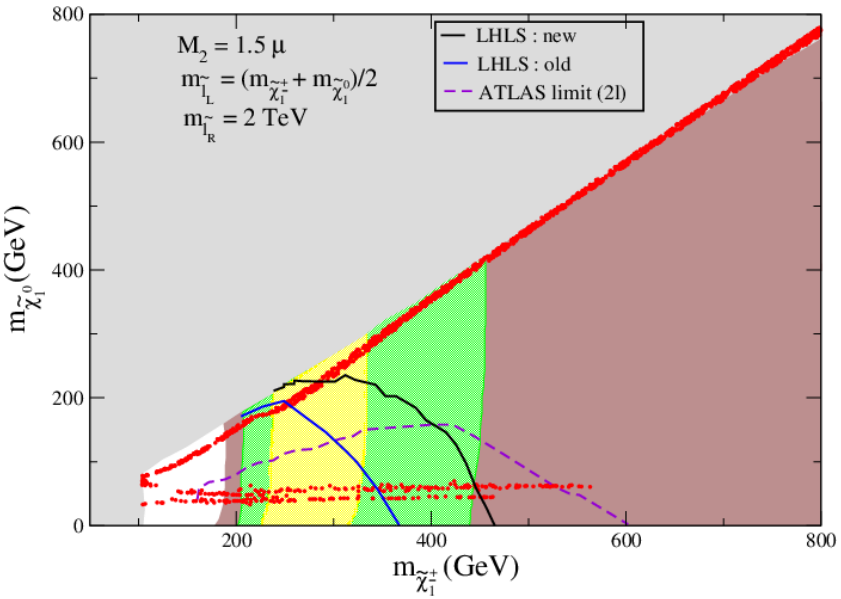
- We follow the analysis by ATLAS collaboration for Run-1 data in the $3l$ channel. Events are generated using Pythia.
- We simulate multilepton signals ($\geq 3l$) at 13 TeV LHC with int. luminosity of 100 fb^{-1}. Backgrounds are generated using ALPGEN.
- Reconstruction of jets $\rightarrow$ anti-kt algorithm by FASTJET with $R = 0.4$. $P_T^j > 20$ GeV and $|\eta^j| < 2.5$.
- $P_T^{e/\mu} > 10GeV$ and $|\eta^{e/\mu}| < 2.5$. In addition to that, each of them is required to pass isolation cuts as defined by the ATLAS/CMS collaboration.

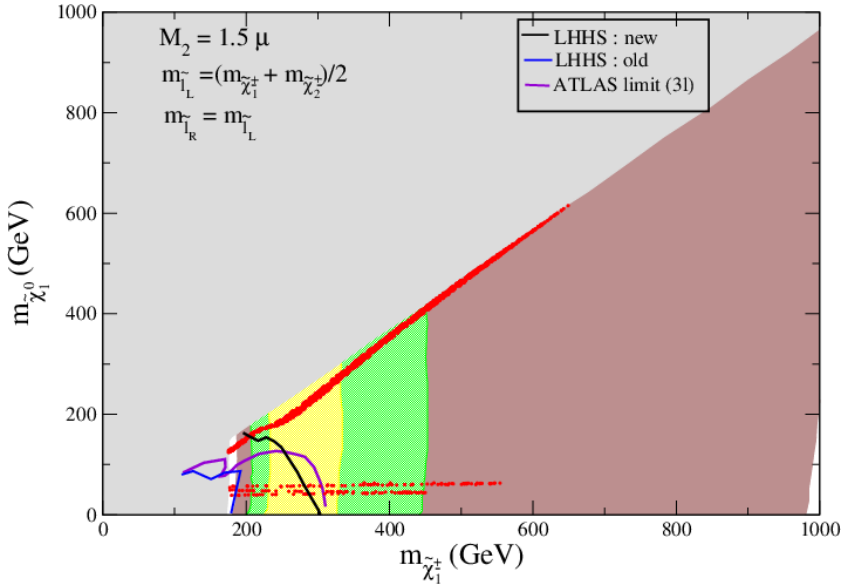
$3l + \not{E}_T$ searches : Compressed Scenario



- $M_1 \sim \mu$, with $M_2 > \mu \Rightarrow$ Compressed spectrum : $m_{\widetilde{\chi}_1^0} \simeq m_{\widetilde{\chi}_1^\pm} \simeq m_{\widetilde{\chi}_2^0} \simeq m_{\widetilde{\chi}_3^0}$.
- $m_{\widetilde{\chi}_2^\pm} \sim m_{\widetilde{\chi}_4^0} \sim M_2$.
- Leptons from lighter EWinos soft $\rightarrow$ hard to detect.
- Situation is improved for non-decoupled $\widetilde{\chi}_2^\pm$ and $\widetilde{\chi}_4^0$.
- Although $\widetilde{\chi}_2^\pm$ and $\widetilde{\chi}_4^0$ have suppressed production cross-sections, they have moderately large lepton yield thanks to their cascade decays involving sleptons, lighter EWeakinos, W and Z bosons all of which can decay leptonically $\Rightarrow$ sizable multilepton (4l and 5l) signals from their cascade decays.

$3l + \not{E}_T$ searches : HS & LS models





Benchmark points

Parameters/	Compressed	HS	LS
Masses	BP1	BP2	BP3
M_1	116	70	277
μ	121.8	349	328
M_2	666	523.5	492
$m_{\widetilde{\chi}_1^0}$	87	70	258
$m_{\widetilde{\chi}_1^\pm}$	123	342	320
$m_{\widetilde{\chi}_2^\pm}$	700	564	530

Table :

Models	BPs	σ_{prod} in fb	σ^{3l}_{eff} in fb				Total $3l$ events	$S/\sqrt{(B)}$
			after $A1$	after $A2$	after $A3$	after $A4$		
Comp	BP1	2817.	5.52	5.27	0.34	0.33	33.8	6.4
HS	BP2	134.8	1.64	0.79	0.46	0.46	46.9	8.9
LS	BP3	151.8	111.2	102.2	1.04	0.98	98.5	18.6

Table : The production cross-sections of all EWeakino pairs and σ^{3l}_{eff} for the BPs.

- Backgrounds : $WZ, ZZ, t\bar{t}Z, VVV$.
- A1 : Events with exactly 3 isolated leptons passing the selection cuts required.
- A2 : The invariant mass of any SFOS lepton pair should not fall within the window $81.2 - 101.2$ GeV.
- A3 : Events must have $\not{E}_T > 200$ GeV.
- A4 : A b-veto is applied to suppress the background coming from $t\bar{t}Z$.

Models	Benchmark Points	σ_{prod} in fb	σ^{4l}_{eff} in fb				Total $4l$ events
			after $B1$	after $B2$	after $B3$	after $B4$	
Compressed	BP1	2817.	0.22	0.19	0.14	0.14	14.1
HS	BP2	134.8	0.13	0.12	0.04	0.03	3.64
LS	BP3	151.8	0.39	0.29	0.15	0.13	13.8

Table : The production cross-sections of all EWeakino pairs and σ^{4l}_{eff} for the BPs.

- Backgrounds : $ZZ, t\bar{t}Z, VVV$.
- B1 : Exactly 4 isolated leptons passing all the selection cuts (see Section IV B) are required.
- B2 : The invariant mass of any SFOS lepton pair should not fall within the window $81.2 - 101.2$ GeV.
- B3 : Events must have $\not{E}_T > 80$ GeV.
- B4 : A b-veto is applied to suppress the background coming from $t\bar{t}Z$.

Conclusion

- Discarding the assumption of strict decoupling of heavier electroweakinos can have significant impact on the LHC analysis.
- In scenarios where lighter EWino spectrum is compressed, heavier particles can play major roles.
- Prospects for $3l, 4l, SS3OS1l, 5l + \not{E}_T$ signals may show up before the next long shutdown of the LHC.


Thank you!