Electroweak SUSY signatures

14th Multidark Consolider Workshop

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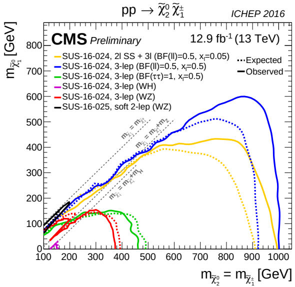
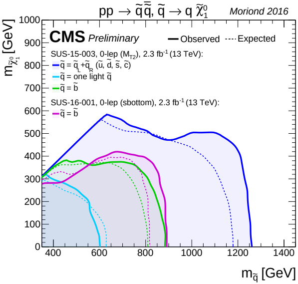
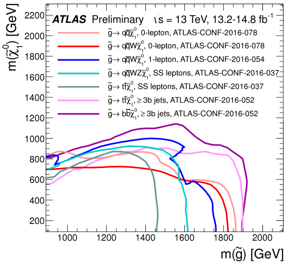
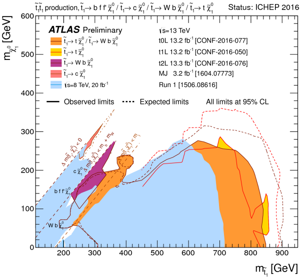
Based on: JHEP 1612 (2016) 149 [1610.03822]
Chiara Arina, Germano Nardini and Mikael Chala

- Unsuccesful SUSY searches in Run1 LHC
- Strong Model Assumptions
  - 1st & 2nd generation squarks and gluinos above 1 TeV
  - $\tilde{b}$ and $\tilde{t}$ greater than 800 GeV
  - Limits on $\tilde{\chi}_i^0$ and $\tilde{\chi}_j^\pm$ above EW scale









SUSY LHC searches

Our outline:

- Present bounds on EWinos
  2ℓ, 3ℓ, 4ℓ + MET in the MSSM and TMSSM
- EWino signatures in future data.
  Number of expected events in each SR of multi-lepton analysis.
- Disentangling the MSSM from other models
  Correlations among the events are sensitive to the EWino sector.

SUSY LHC searches

- SUSY models with light EWinos $\rightarrow$ Neutralino LSP: Dark Matter.

  Two Regimes: *(Pierce '04, Masiero et al. '05, Baer et al. '05, Arkani-Hamed et al. '06, Baer et al. '16)*

  - Well-tempered neutralino: Compressed spectrum
  - Higgs/Z-boson funnel: At least a 40 GeV gap due to LEP chargino bound ($m_{\chi^\pm} >$104 GeV)

Compressed spectrum $\rightarrow$ soft objects (leptons, jets). Difficult to test†.

Cirelli et al '14, Golling et al. '16

Higgs/Z-boson funnel could exhibit a rich LHC phenomenology: Multilepton + MET

† However: *CMS-PAS-SUSY-16-025* $\rightarrow \Delta m = 20$ GeV, $m_{\chi_2^0,\chi_1^\pm} > 195$ GeV

$\{M_1,\ M_2,\ \mu,\ \tan\beta\}$

(Pseudo) Scalar Sector: 2 TeV (except for the 3rd generation squarks)
$\tan\beta = 10$ and stop masses fixed to achieve $m_h = 125$ GeV

$$m^2_{h,tree} = m^2_Z \cos^2 2\beta$$

$$\widetilde{\chi}^0_i,\ (i = 1, ..., 4) \qquad \widetilde{\chi}^\pm_j,\ (i = 1, 2)$$

$$\mathcal{M}^{tree}_{\widetilde{\chi}^0} = \begin{pmatrix} M_1 & 0 & -\frac{1}{2}g_1 v_1 & \frac{1}{2}g_1 v_2 \\ 0 & M_2 & \frac{1}{2}g_2 v_1 & -\frac{1}{2}g_2 v_2 \\ -\frac{1}{2}g_1 v_1 & \frac{1}{2}g_2 v_1 & 0 & -\mu \\ \frac{1}{2}g_1 v_1 & -\frac{1}{2}g_2 v_2 & -\mu & 0 \end{pmatrix}$$

$$\mathcal{M}^{tree}_{\widetilde{\chi}^\pm} = \begin{pmatrix} M_2 & g_2 v \sin\beta \\ g_2 v \cos\beta & \mu \end{pmatrix}$$

$\{M_1,\ M_2,\ \mu,\ \tan\beta,\ \lambda,\ \mu_\Sigma\}$ $(W_{\rm TMSSM} = W_{\rm MSSM} + \lambda H_1 \cdot \Sigma H_2 + \frac{1}{2}\mu_\Sigma {\rm Tr}\Sigma^2)$

(Pseudo) Scalar Sector: 2 TeV (except for the 3rd generation squarks)
$\tan\beta = 3$ and stop masses fixed to achieve $m_h = 125$ GeV
$\lambda = 0.65$ and $\mu_\Sigma = 300, 350$ GeV

$$m^2_{h,tree} = m_Z^2 \cos^2 2\beta + \frac{\lambda^2}{2} v^2 \sin^2 2\beta$$

$$\widetilde{\chi}_i^0,\ (i = 1, ..., 5) \qquad \widetilde{\chi}_j^\pm,\ (i = 1, 2, 3)$$

$$\mathcal{M}^{tree}_{\widetilde{\chi}^0} = \begin{pmatrix} M_1 & 0 & -\frac{1}{2}g_1 v_1 & \frac{1}{2}g_1 v_2 & 0 \\ 0 & M_2 & \frac{1}{2}g_2 v_1 & -\frac{1}{2}g_2 v_2 & 0 \\ -\frac{1}{2}g_1 v_1 & \frac{1}{2}g_2 v_1 & 0 & -\mu & -\frac{1}{2}v_2\lambda \\ \frac{1}{2}g_1 v_1 & -\frac{1}{2}g_2 v_2 & -\mu & 0 & -\frac{1}{2}v_1\lambda \\ 0 & 0 & -\frac{1}{2}v_2\lambda & -\frac{1}{2}v_1\lambda & \mu_\Sigma \end{pmatrix}$$

$$\mathcal{M}^{tree}_{\widetilde{\chi}^\pm} = \begin{pmatrix} M_2 & g_2 v \sin\beta & 0 \\ g_2 v \cos\beta & \mu & -\lambda v \sin\beta \\ 0 & \lambda v \cos\beta & \mu_\Sigma \end{pmatrix}$$

LHC Searches

- Leptons are cleaner than jets $\rightarrow$ leptons + MET searches
- If a deviation is seen, it can be interpreted as the production and subsequent decay to the LSP of EW particles.
- Experimental results are given in SMS $\rightarrow$ 3-lepton searches: $m_{\chi_2^0} = m_{\chi_1^\pm}$, and BR (LSP + leptons) = 100%, then $m_{\chi_1^\pm} > 700$ GeV for $m_{\chi_1^0}$.
- Production channels:
  - $pp \rightarrow \chi_i^\pm \chi_j^\pm$ (2 leptons)
  - $pp \rightarrow \chi_i^0 \chi_j^\pm$ (3 leptons)
  - $pp \rightarrow \chi_i^0 \chi_j^0$ (4 leptons)

Recasting of the experimental searches: 2ℓ + MET

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- **SRm**$_{T2,90}$: SF and DF leptons, Z veto, $m_{T2} > 90$ GeV
- **SRm**$_{T2,110}$: SF and DF leptons, Z veto, $m_{T2} > 110$ GeV
- **SRm**$_{T2,150}$: SF and DF leptons, Z veto, $m_{T2} > 150$ GeV
- **SRWWa**: SF and DF leptons, Z veto, $m_{ll} < 120$ GeV
- **SRWWb**: SF and DF leptons, Z veto, $m_{ll} < 170$ GeV and $m_{T2} > 90$ GeV
- **SRWWc**: SF and DF leptons, Z veto, no cut on m_{ll} and $m_{T2} > 100$ GeV
- **SRZjets**: SF leptons only, two central light jets, the di-lepton invariant mass should be within 10 GeV of the Z boson mass

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- **SR0τa**: $l^{\pm}l^{\mp}l', l^{\pm}l^{\mp}l$, τ flavour veto. This is a complicated SR, with all kinematic variables separated in 20 bins.

Bin	m_{SFOS} [GeV]	m_T [GeV]	E_T^{miss} [GeV]	Z veto	SM background [# events]
1	12-40	0-80	50-90	no	23
2	12-40	0-80	> 90	no	4.2
3	12-40	> 80	$50 - 75$	no	10.6
4	12-40	> 80	> 75	no	8.5
5	40-60	0-80	50-75	yes	12.9
6	40-60	0-80	> 75	no	6.6
7	40-60	> 80	50-135	no	14.1
8	40-60	> 80	> 135	no	1.1
9	60-81.2	0-80	50-75	yes	22.4
10	60-81.2	> 80	50-75	no	16.4
11	60-81.2	0-110	> 75	no	27
12	60-81.2	> 110	> 75	no	5.5
13	81.2 - 101.2	0-110	50-90	yes	715
14	81.2 - 101.2	0-110	> 90	no	219
15	81.2 - 101.2	> 110	50-135	no	65
16	81.2 - 101.2	> 110	> 135	no	4.6
17	> 101.2	0-180	50-210	no	69
18	> 101.2	> 180	50-210	no	3.4
19	> 101.2	0-120	> 210	no	1.2
20	> 101.2	> 120	> 210	no	0.29

Recasting of the experimental searches: 4ℓ + MET

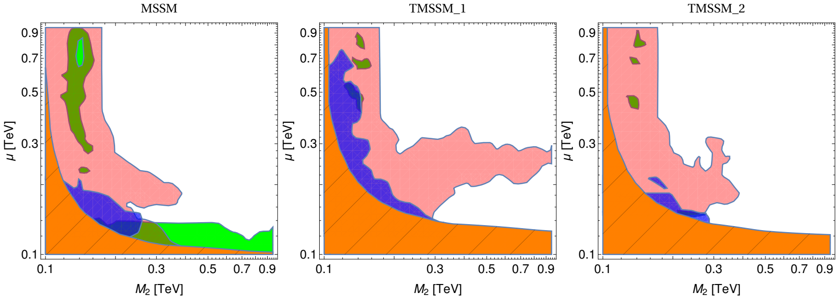
Phys. Rev. D90 (2014), no. 5 052001

- **SR0Z**: at least four light leptons and no τ lepton, SFOS light leptons with an invariant mass between 81.2 GeV and 101.2 GeV. $p_T^{\rm miss} > 75$ GeV
- **SR1Z**: one τ lepton and three light leptons, SFOS light leptons with an invariant mass between 81.2 GeV and 101.2 GeV. $p_T^{\rm miss} > 100$ GeV
- **SR0noZa**: at least four light leptons and no τ lepton, $p_T^{\rm miss} > 50$ GeV, extended veto.
- **SR0noZb**: at least four light leptons and no τ lepton, $p_T^{\rm miss} > 75$ GeV, $m_{\rm eff} > 600$ GeV, extended veto.
- **SR1noZ**: one τ lepton and three light leptons, $p_T^{\rm miss} > 100$ GeV, $m_{\rm eff} > 400$ GeV, extended veto.

Analysis

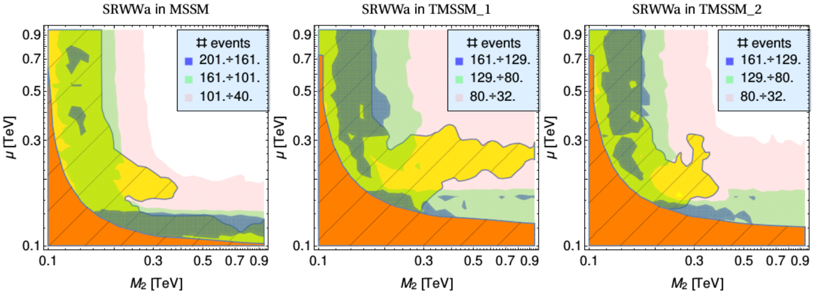
- Event Simulation: MadGraph5_AMC@NLO (500k events)
- Hadronization and showering: Pythiav6
- Detector simulator: Delphes v3
- Experimental analysis implemented in MadAnalysisv5 (3ℓ and 4ℓ validated with Checkmate and SHEER, agreement within 20%)
- Exclusion if the point is excluded in one SR. We do not combine signal regions.

Excluded regions at 95% CL after LHC Run 1 for the MSSM ($\tan\beta = 10$), TMSSM_1 ($\tan\beta = 3$, $\lambda = 0.65$, $\mu_\Sigma = 300$ GeV) and TMSSM_2 ($\tan\beta = 3$, $\lambda = 0.65$, $\mu_\Sigma = 350$ GeV)

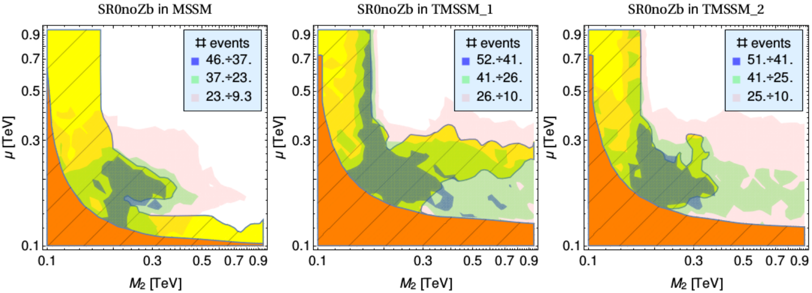


Green: 2 leptons + MET, Pink: 3 leptons + MET, Blue: 4 leptons + MET
Orange: LEP chargino bound

Number of expected signal events for the MSSM, TMSSM_1 and TMSSM_2 in the **SRWWa** for the 2 leptons + MET search at $\sqrt{s} = 13$ TeV and $\mathcal{L} = 100\text{fb}^{-1}$.



Number of expected signal events for the MSSM, TMSSM_1 and TMSSM_2 in the **SR0noZb** for the 4 leptons + MET search at $\sqrt{s} = 13$ TeV and $\mathcal{L} = 100\text{fb}^{-1}$.



Disentangling the TMSSM from the MSSM

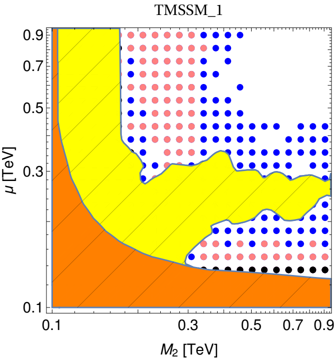
The uncertainty in the signal number events is,

$$\Delta S = \sqrt{D + B} = \sqrt{S + 2B}$$

Our suggested strategy is:

- For each parameter space point of the TMSSM, we check if there exist at least one point of the MSSM for which the expected numbers of events in all the SRs separately are compatible, within twice the standard deviation with those predicted by the selected value of the TMSSM.
- If this is not the case, the latter can be discriminated from the MSSM.
- We adopt this approach instead of comparing the whole SR distributions in order the results to be conservative.

Disentangling the TMSSM from the MSSM



Parameter space regions of the TMSSM_1 and TMSSM_2 that can be disentangled from the MSSM with:

100 fb^{-1}: Black   300 fb^{-1}: Red   3000 fb^{-1}: Blue

Conclusions

- What are the present bounds on EWinos when simplified model spectra assumption adopted in the experimental analysis is relaxed?
- We have obtained the present constraints for the MSSM and TMSSM where the LSP neutralino is Bino-like.
- We also provide forecasts for the multi-lepton signals produced by the EWino sector.
- We also prove that with large enough luminosity, in some cases it is possible to disentangle the MSSM from other SUSY models.

Thank you!