What can(-not) multilepton searches tell us about SUSY?

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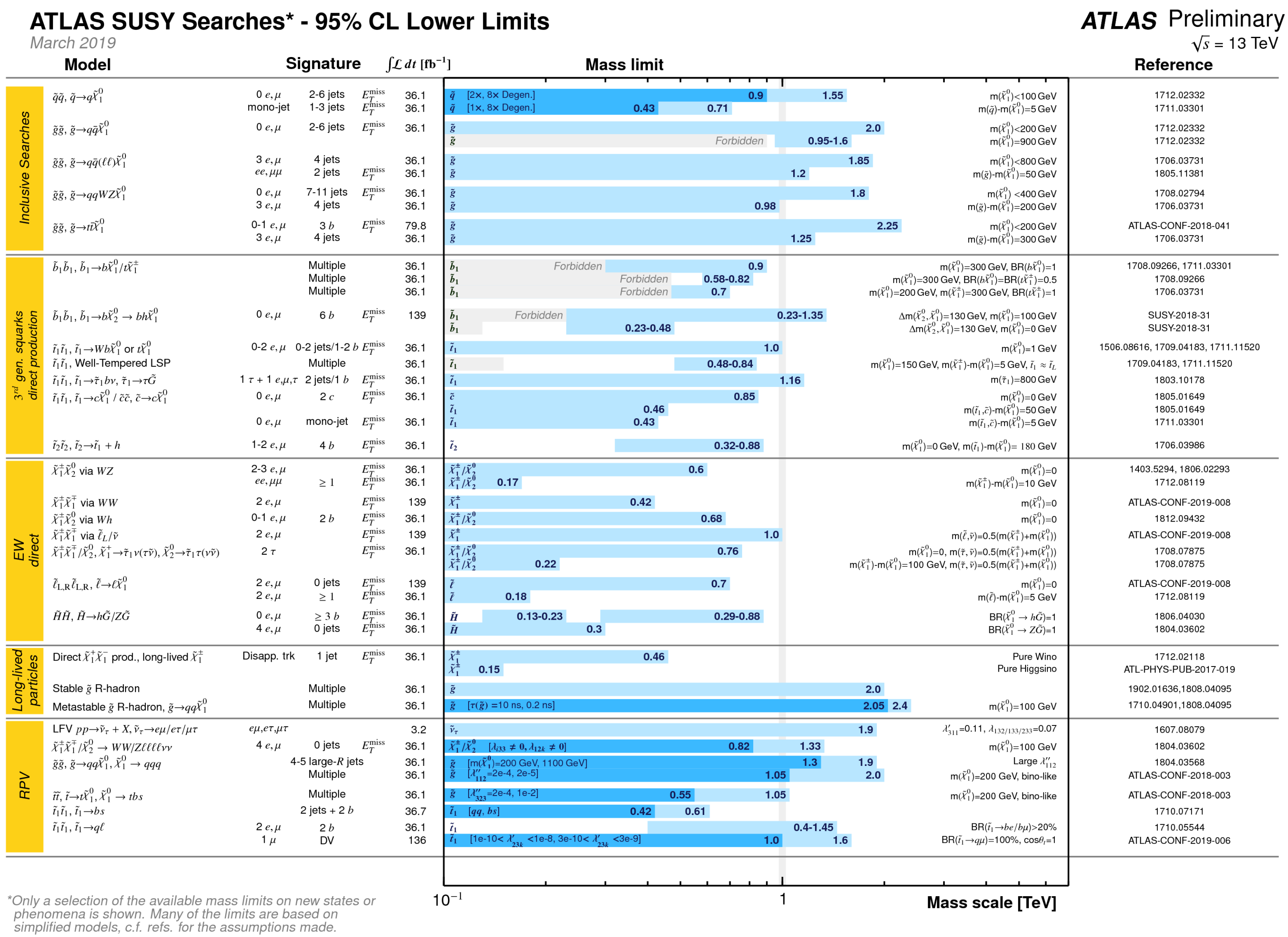
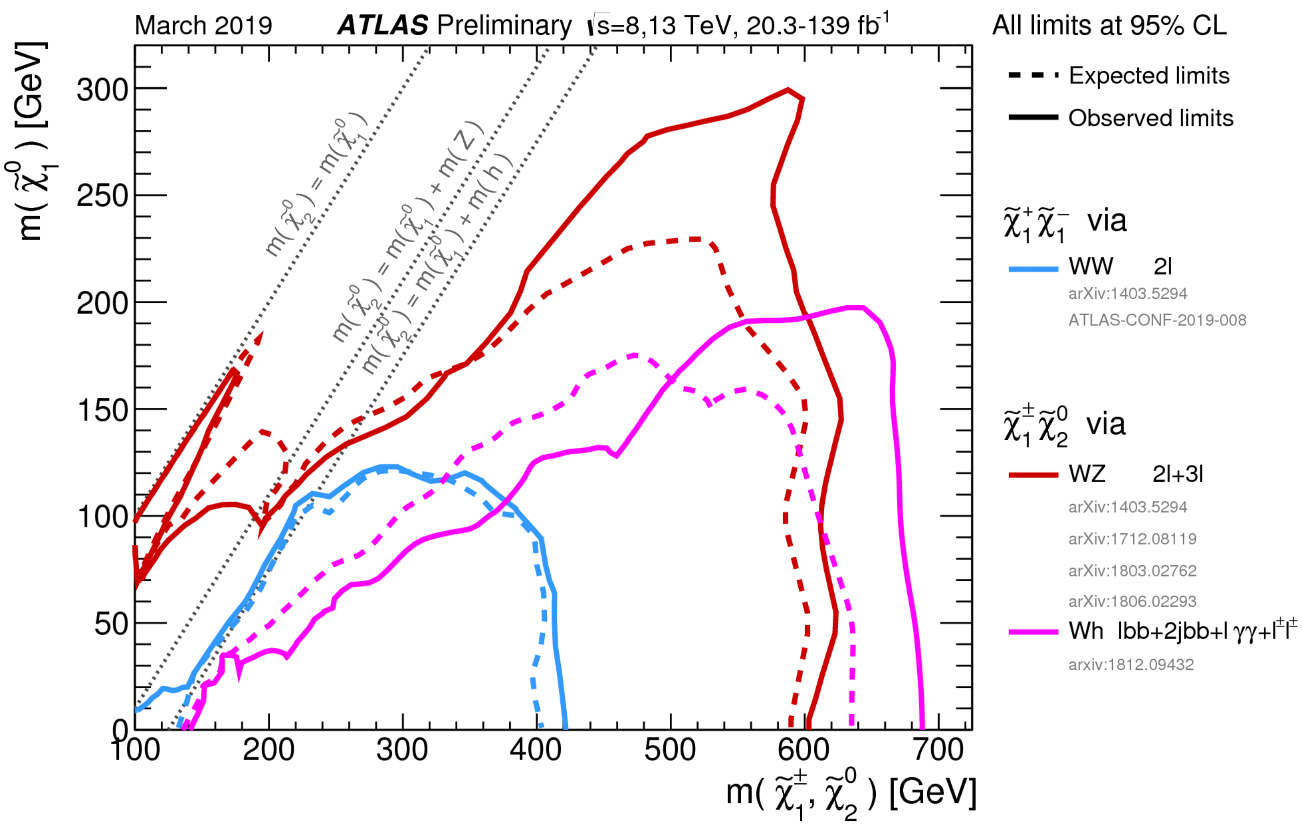
Introduction



Introduction

Electroweakino sector:

Mediated through a vector boson:

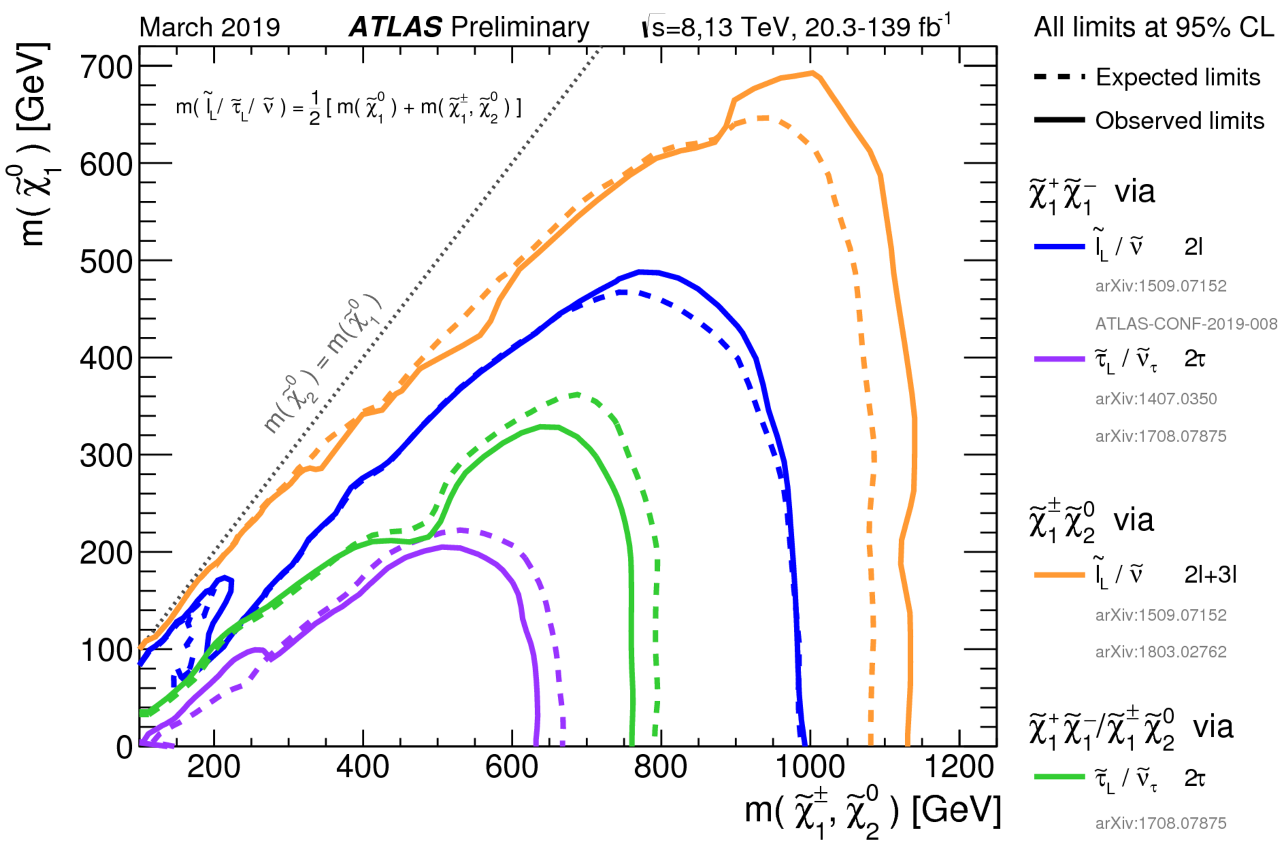


- Multilepton searches are very effective to explore the electroweakino sector
- Up to 600-700 GeV for winos and higgsinos

Introduction

Electroweakino sector:

Mediated through a slepton:



- Multilepton searches are also effective to explore the electroweakino sector in this case
- Up to 1.0 - 1.1 TeV for winos and higgsinos

Introduction

Electroweakino sector:

This is still true even for realistic models. Although the limits are weaker

[See for example: Arina, Chala, ML, Nardini '16]

Multilepton searches are also efficient for other SUSY models like the NMSSM or other extensions

[See for example: Domingo, Kim, ML, Ramiro, Ruiz de Austri '18]

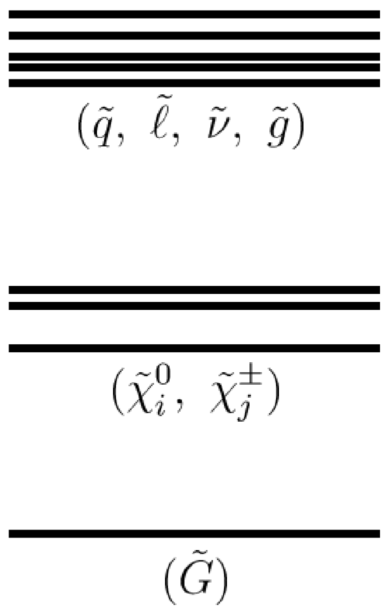
What happens if the electroweakino sector decays differently?

- Gauge Mediation SUSY breaking: [Kim, Krauss, ML '18]
  -Photons
- Stealth and compressed SUSY: [Kim, Krauss, ML, Staub '18]
  -Soft objects (leptons and jets)
  -Photons
- R Parity Violating SUSY: [Dreiner, ML – soon]
  -Leptons

General Gauge Mediation Models

<u>GGM models:</u>

Messenger sector $\rightarrow$ SUSY breaking



Squarks, gluino and sleptons decoupled

Electroweakinos at EW scale: $M_1,\ M_2,\ \mu$

NLSP decays into: $\tilde{\chi}_1^0 \rightarrow \tilde{G}\gamma/h/Z$

Bino: $\tilde{\chi}_1^0 \rightarrow \tilde{G}\gamma$ $(\tilde{\chi}_1^0 \rightarrow \tilde{G}Z)$

Wino: $\tilde{\chi}_1^0 \rightarrow \tilde{G}Z$ $(\tilde{\chi}_1^0 \rightarrow \tilde{G}\gamma)$

Higgsino: $\tilde{\chi}_1^0 \rightarrow \tilde{G}Z/h$

$m_{\tilde{G}} = 1\,\mathrm{eV}$, prompt decays

General Gauge Mediation Models

GGM models:

- Squarks, gluino and sleptons decoupled
- Electroweakinos at EW scale: $M_1, \; M_2, \; \mu$

Scenario	M_1 [GeV]	M_2 [GeV]	μ [GeV]	Description
I	[100, 1000]	[100, 1000]	2000	μ decoupled
II	[100, 1000]	2000	[100, 1000]	M_2 decoupled
IIb	[100, 1000]	2000	[-1000, -100]	M_2 decoupled
III	50	[100, 1000]	[100, 1000]	light bino
IV	2000	[100, 700]	[100, 700]	heavy bino

- $m_{\tilde{G}} = 1\,\mathrm{eV}$, prompt decays

-Still good DM candidate + other candidates

[Viel, Legourges, Hachnelt, Matarrese, Riotto '05]

-Long-lived decays

[Feng et al. '10, Dreiner et al. '12, ATLAS '14]

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Recasting Experimental Searches

Spheno 4.0.0
(Spectrum generator)

[Porod '03]
[Porod, Staub '12]
[Porod, Staub '17]

Pythia 8.219
(Monte Carlo event generator)

[Sjöstrand et al. '15]

CheckMATE
(check against experimental searches)

[Drees et al. '15]
[Dercks et al. '17]

Recasting Experimental Searches

How does CheckMATE work?

For a given search, it compares the number of signal events of a given model, S , with the observed limit at 95% C.L., $S_{\rm exp}^{95}$

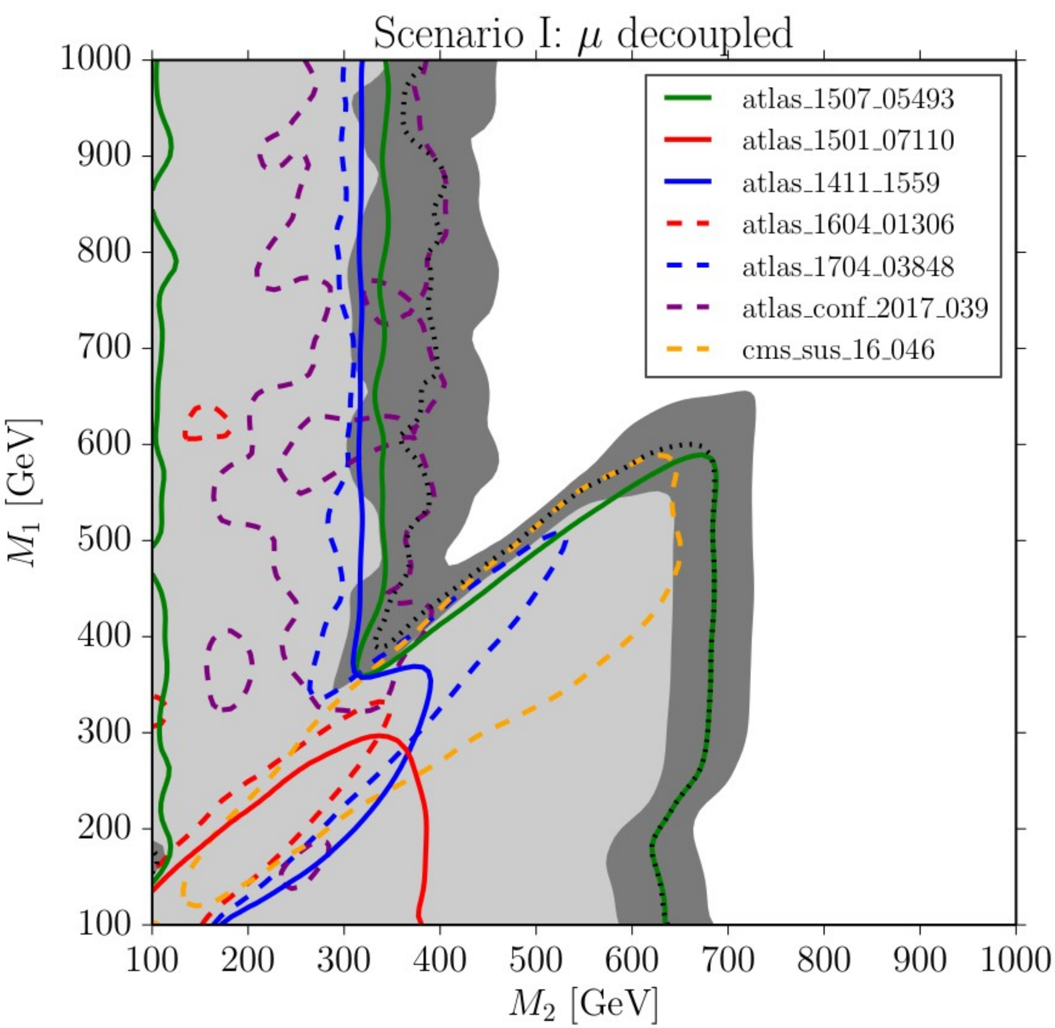
$$r = \frac{S - 1.96 \cdot \Delta S}{S_{\rm exp}^{95}} \qquad (\Delta S = \sqrt{S})$$

$r > 1.5$ Point Excluded

$0.67 < r < 1.5$ Point Ambiguous

$r < 0.67$ Point Allowed

Recasting Experimental Searches



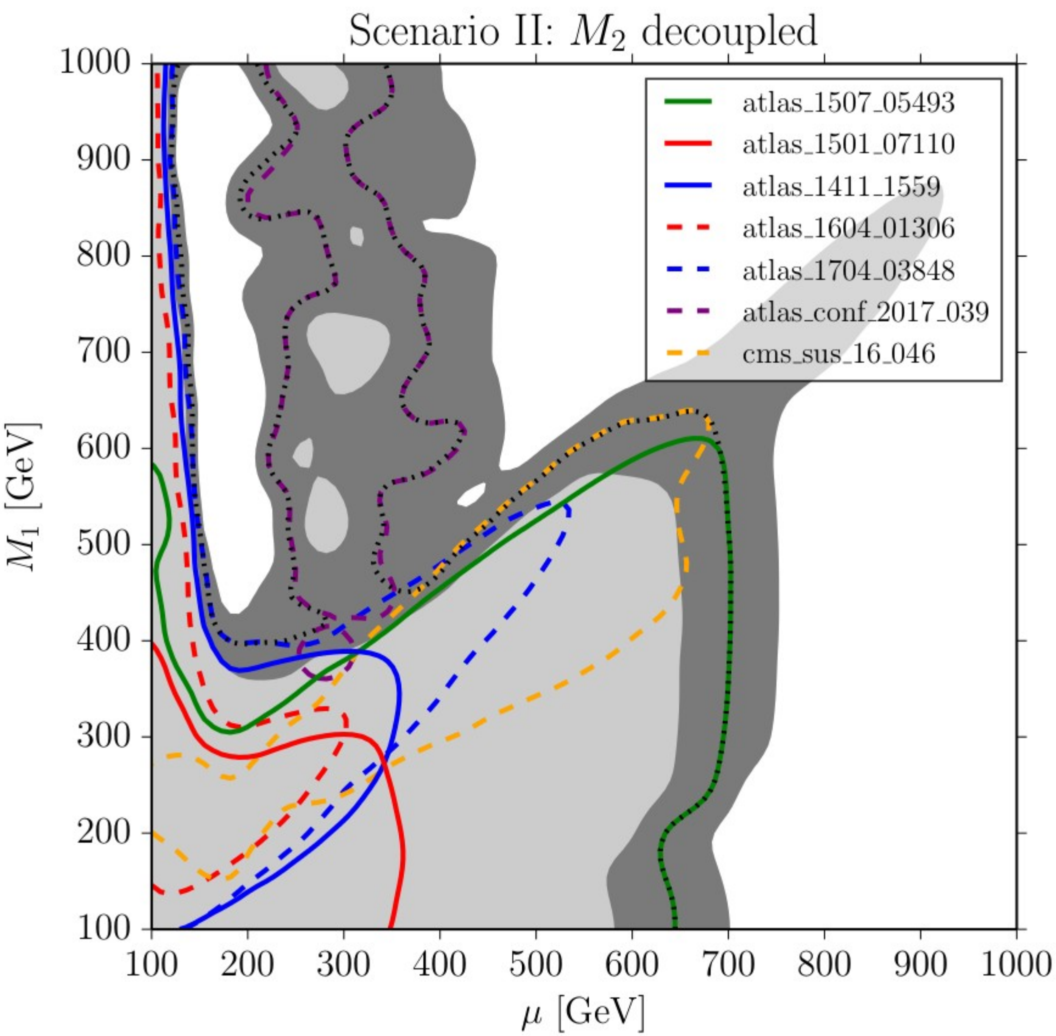
[Kim, Krauss, ML '18]

-Multilepton searches are not efficient

-Searches including photons improve the sensitivity

Line	Search	Model
green solid	$1(2)\gamma + 0(1)\ell$ $+\text{(b)-jets}+\not{E}_T$	(GGM)
red solid	$h + \not{E}_T$	(EWK)
blue solid	$\gamma + \not{E}_T$	(DM)
red dashed	$\gamma + \not{E}_T$	(DM)
blue dashed	$\gamma + \not{E}_T$	(DM)
purple dashed	$2 - 3\,\ell$	(EWK)
yellow dashed	$\gamma + \not{E}_T$	(GGM)

Recasting Experimental Searches



[Kim, Krauss, ML '18]

-Multilepton searches are efficient for only Higgsino scenarios

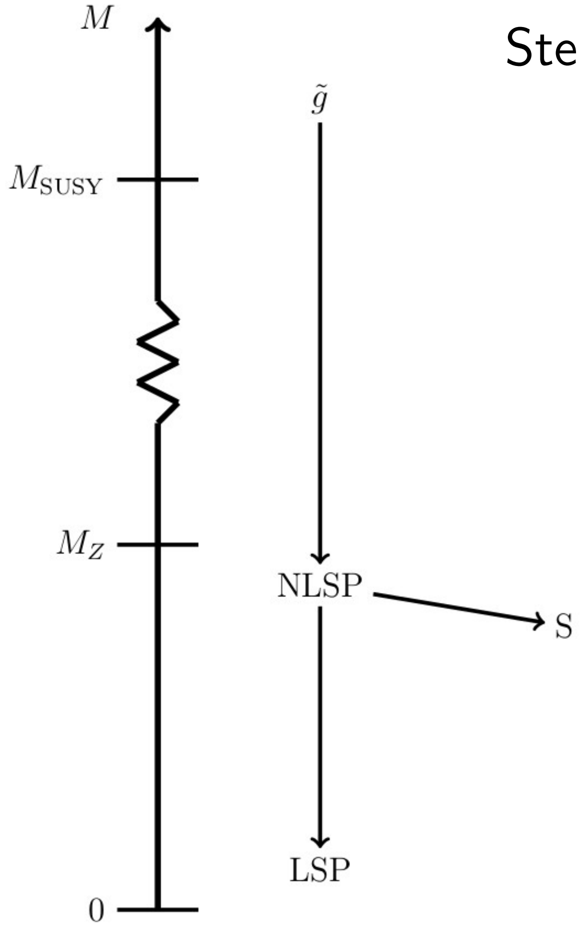
-Searches including photons are not efficient in only-Higgsino scenarios

(green solid line)	$1(2)\gamma + 0(1)\ell$ $+(b)\text{-jets}+\not{E}_T$	(GGM)
(red solid line)	$h + \not{E}_T$	(EWK)
(blue solid line)	$\gamma + \not{E}_T$	(DM)
(red dashed line)	$\gamma + \not{E}_T$	(DM)
(blue dashed line)	$\gamma + \not{E}_T$	(DM)
(purple dashed line)	$2-3\,\ell$	(EWK)
(yellow dashed line)	$\gamma + \not{E}_T$	(GGM)

Stealth SUSY

<u>Stealth SUSY models:</u>

NLSP and S close in mass $\rightarrow$ LSP small momentum ($\cdot\not\!\!E_T$)



Stealth SUSY spectrum hierarchy:

$$m_{\tilde{g}} \gg m_h, m_Z > m_{\tilde{\chi}_2^0} > m_S \gg m_{\tilde{\chi}_1^0}$$

$$m_{\tilde{\chi}_2^0} \simeq m_S + m_{\tilde{\chi}_1^0} + (0.5-1)\,\text{GeV}$$

Particle	Mass [GeV]
$\tilde{g}$	1100 – 2000
$\tilde{\chi}_2^0$	89
$\tilde{\chi}_1^0$	5
S	83

Stealth SUSY

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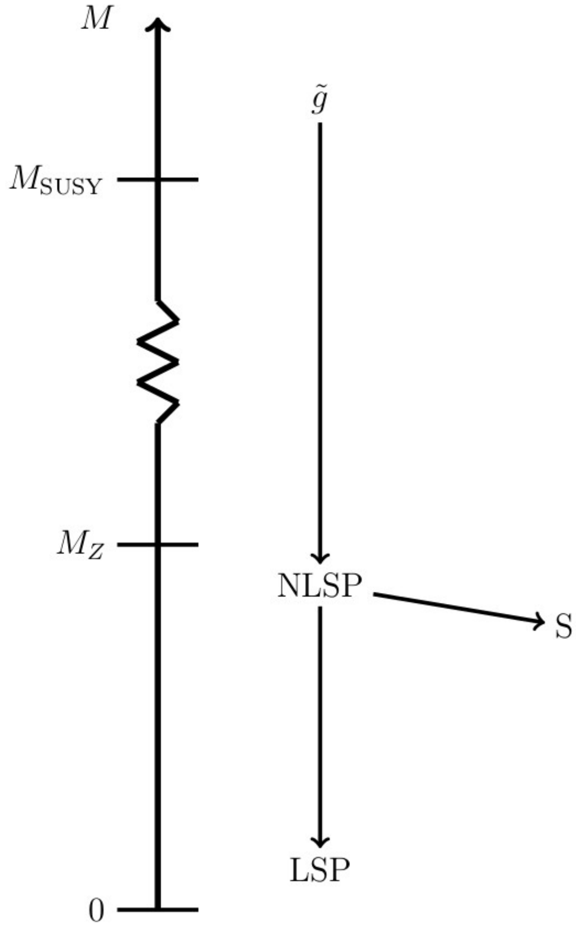
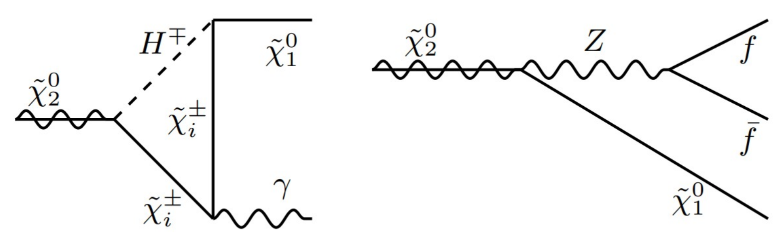
NLSP and S close in mass $\rightarrow$ LSP small momentum ($\cdot\not{E}_T$)



$$pp \rightarrow \tilde{\chi}_1^{\pm}\tilde{\chi}_{3,4}^0 \rightarrow W^{\pm}\,\chi_2^0\,Z/h\,\chi_2^0$$
$$pp \rightarrow \tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\mp} \rightarrow W^{\pm}\,\chi_2^0\,W^{\pm}\,\chi_2^0$$
$$pp \rightarrow \tilde{\chi}_{3,4}^0\tilde{\chi}_{3,4}^0 \rightarrow Z/h\,\chi_2^0\,Z/h\,\chi_2^0$$

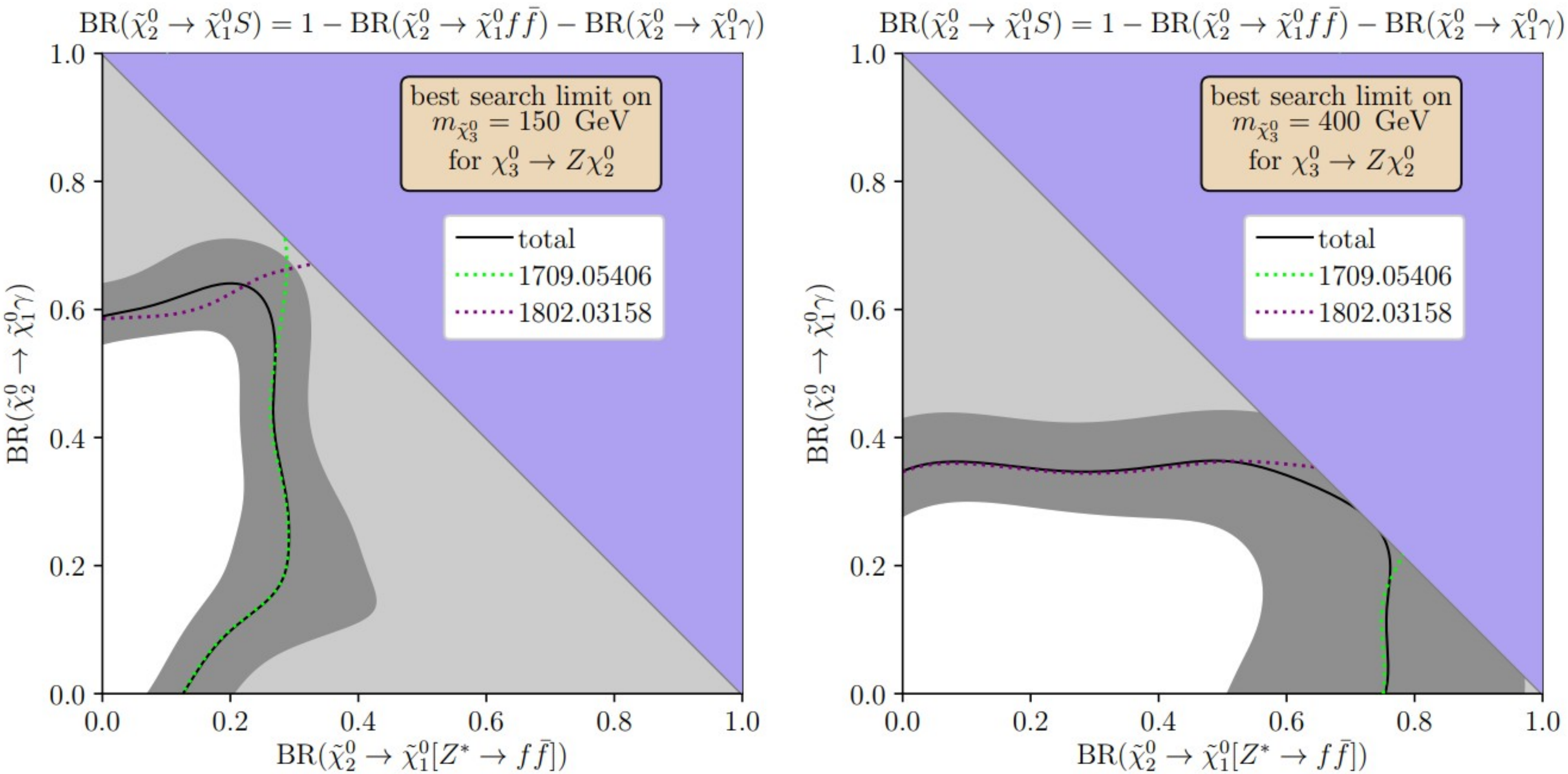
NLSP decays into:

$$\tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0 S$$
$$\tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0 \gamma$$
$$\tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0 Z^* \rightarrow \tilde{\chi}_1^0 f\bar{f}$$



Recasting Experimental Searches

$$\widetilde{\chi}_3^0 \to Z \widetilde{\chi}_2^0$$

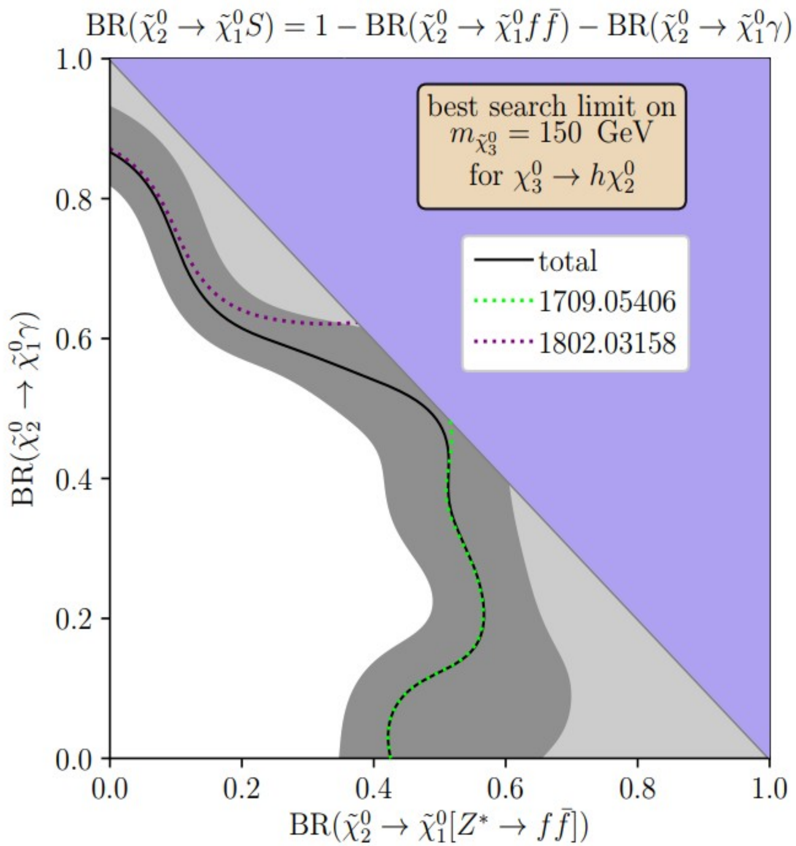


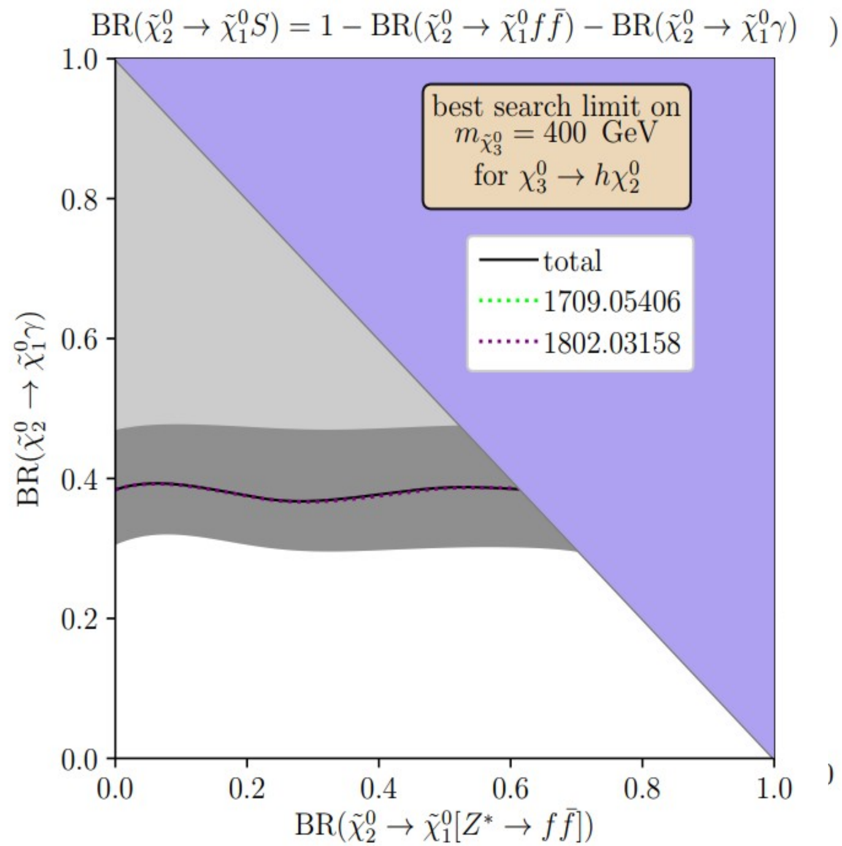
- - - - - $2 - 3\,\ell$ (EWK)   - - - - - $\gamma + \not{E}_T$ (GMSB)

[Kim, Krauss, ML, Staub '18]

Recasting Experimental Searches

$$\widetilde{\chi}_3^0 \to h\widetilde{\chi}_2^0$$





$2-3\,\ell$ (EWK)

$\gamma + \not{E}_T$ (GMSB)

[Kim, Krauss, ML, Staub '18]

RPV SUSY

RPV SUSY:

$$W = \epsilon_{ab}\left[\frac{1}{2}\lambda_{ijk}L_i^a L_j^b \bar{E}_k + \lambda'_{ijk}L_i^a Q_j^b \bar{D}_k - \kappa_i L_i^a H_u^b\right] + \frac{1}{2}\epsilon_{xyz}\lambda''_{ijk}\bar{U}_i^x \bar{D}_j^y \bar{D}_k^z \,.$$

R-Parity is no longer a symmetry ⟶ LSP can decay

The different terms violate Lepton and Barion number ⟶ Proton decay

New Phenomenology!!

RPV SUSY

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The different terms violate Lepton and Barion number ⟶ Proton decay

New Phenomenology!! $pp \to \tilde{\tau}_1\tilde{\tau}_1$

If stau is the LSP: $\tilde{\tau}_1 \to e\nu_\mu$ Leptons + MET!!

$\tilde{\tau}_1 \to \mu\nu_e$

RPV SUSY

Stau LSP:

$$\begin{pmatrix} \tilde{\tau}_1 \\ \tilde{\tau}_2 \end{pmatrix} = \begin{pmatrix} \cos\theta_{\tilde{\tau}} & \sin\theta_{\tilde{\tau}} \\ -\sin\theta_{\tilde{\tau}} & \cos\theta_{\tilde{\tau}} \end{pmatrix} \begin{pmatrix} \tilde{\tau}_L \\ \tilde{\tau}_R \end{pmatrix}$$

If $\theta_{\tilde{\tau}} = 0$ then $\tilde{\tau}_1 = \tilde{\tau}_L$, if $\theta_{\tilde{\tau}} = \frac{\pi}{2}$ then $\tilde{\tau}_1 = \tilde{\tau}_R$

Benchmark Models:

$$\lambda_{ijk} L_i^a L_j^b \bar{E}_k$$

$$\mathbf{Model\,I}: \; L_a L_3 \bar{E}_c, \quad \tilde{\tau}_1^+ \to \ell_c^+ \nu_a,$$

$$\mathbf{Model\,II}: \; L_1 L_2 \bar{E}_3, \quad \tilde{\tau}_1^+ \to (e^+ \bar{\nu}_\mu, \mu^+ \bar{\nu}_e),$$

$$\mathbf{Model\,III}: \; L_a L_3 \bar{E}_3, \quad \tilde{\tau}_1^+ \to (\tau^+ \nu_a, \tau^+ \bar{\nu}_a, \ell_a^+ \nu_\tau)$$

Model	Coupling	$\tilde{\tau}_1$-Decays	Signatures
Ia	λ_{a31}	$e\nu_a$	$e^+e^- + \not{E}_T$
Ib	λ_{a32}	$\mu\nu_a$	$\mu^+\mu^- + \not{E}_T$
II	λ_{123}	$\mu\nu_e, e\nu_\mu$	$e^+e^- + \not{E}_T$
			$\mu^+\mu^- + \not{E}_T$
			$e^\pm\mu^\mp + \not{E}_T$
IIIa	λ_{133}	$e\nu_\tau, \tau\nu_e$	$e^+e^- + \not{E}_T$
			$\tau^+\tau^- + \not{E}_T$
			$e^\pm\tau^\mp + \not{E}_T$
IIIb	λ_{233}	$\mu\nu_\tau, \tau\nu_\mu$	$\mu^+\mu^- + \not{E}_T$
			$\tau^+\tau^- + \not{E}_T$
			$\mu^\pm\tau^\mp + \not{E}_T$

Versatility of multilepton searches

Model Ia: $$\lambda_{a31} L_a L_3 \bar{E}_1$$

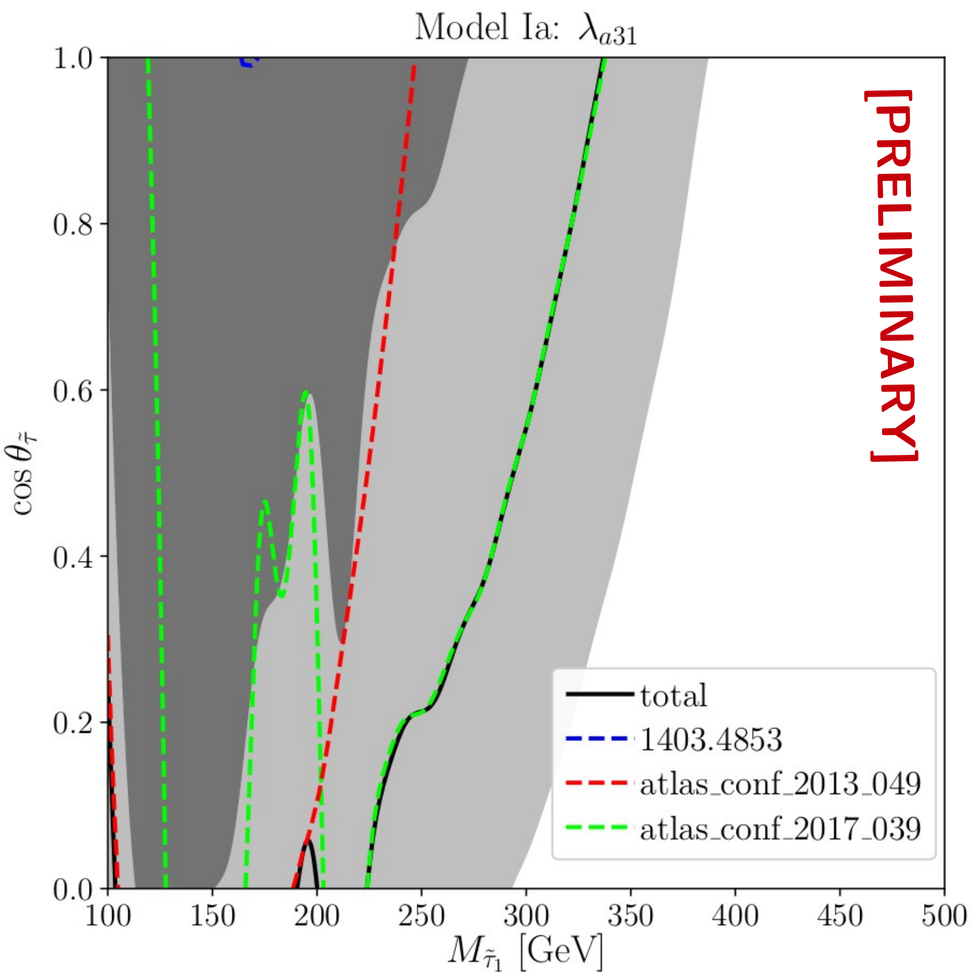
$$\Gamma(\tilde{\tau}_1^+ \to e^+ \nu_a) = |\lambda_{a31}|^2 \cos^2\theta_{\tilde{\tau}} \frac{(M_{\tilde{\tau}_1}^2 - m_e^2)^2}{16\pi M_{\tilde{\tau}_1}^3}$$

2-3 lepton analysis is really powerful

$$m_{\tilde{\tau}_1} < 225\text{GeV}, \quad \cos\theta_{\tilde{\tau}} \to 0$$
$$m_{\tilde{\tau}_1} < 325\text{GeV}, \quad \cos\theta_{\tilde{\tau}} \to 1$$

2 lepton analysis from 8 TeV is useful to constrain lower masses

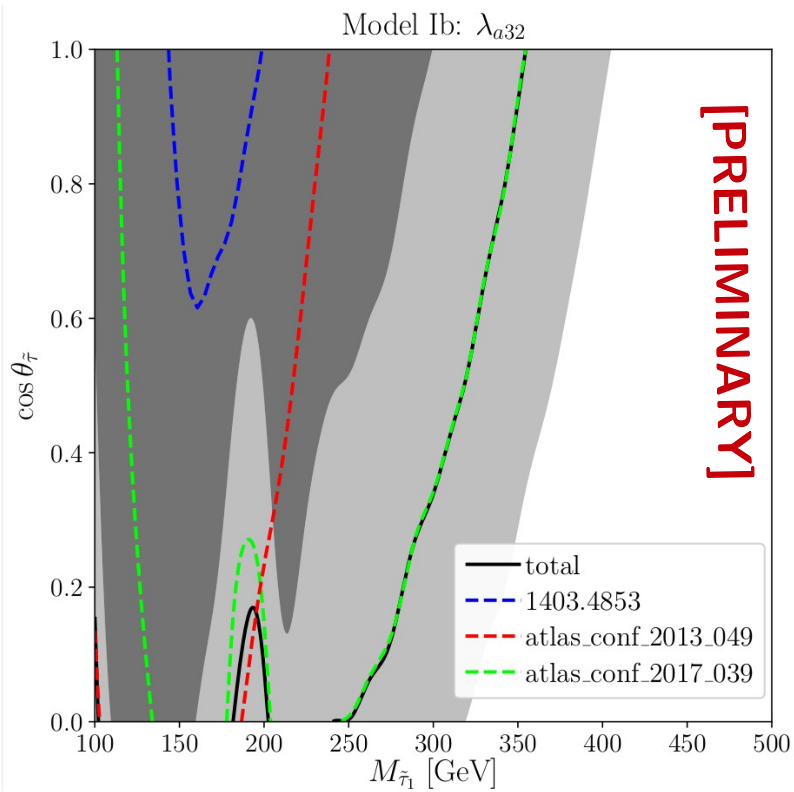
Lower than 100 GeV is still free



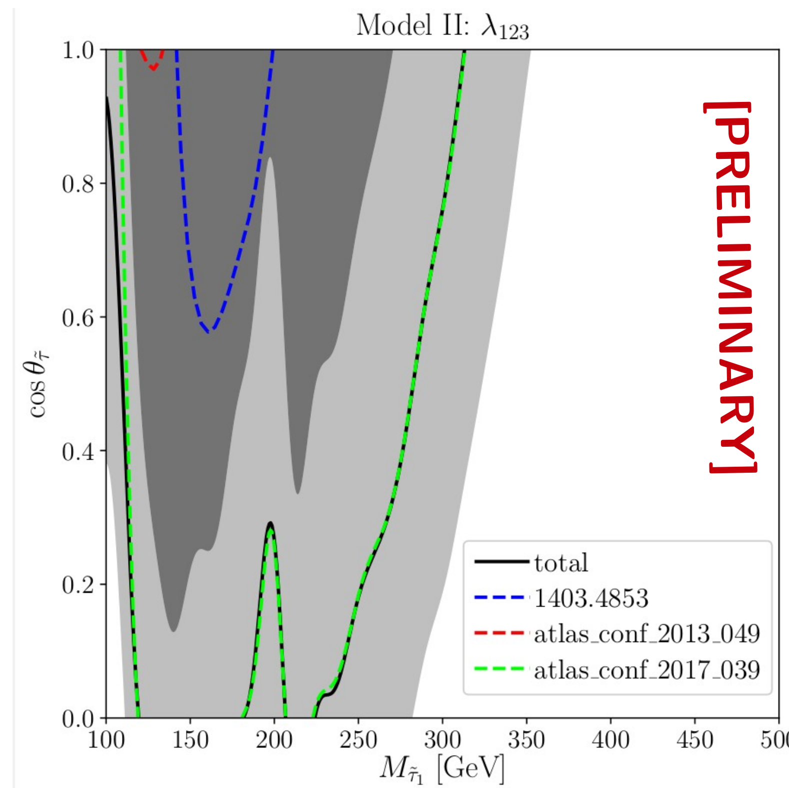
[Dreiner, ML – soon]

Versatility of multilepton searches

Model Ib: $\lambda_{a32} L_a L_3 \bar{E}_2$



Model II: $\lambda_{123} L_1 L_2 \bar{E}_3$



$$m_{\tilde{\tau}_1} < 250\text{GeV}, \quad \cos\theta_{\tilde{\tau}} \to 0$$
$$m_{\tilde{\tau}_1} < 340\text{GeV}, \quad \cos\theta_{\tilde{\tau}} \to 1$$

$$m_{\tilde{\tau}_1} < 175(210-225)\text{GeV}, \quad \cos\theta_{\tilde{\tau}} \to 0$$
$$m_{\tilde{\tau}_1} < 280\text{GeV}, \quad \cos\theta_{\tilde{\tau}} \to 1$$

[Dreiner, ML – soon]

Conclusions

- Multilepton searches are efficient in a wide variety of SUSY scenarios
- If one wants to test different scenarios and cover wider regions of the parameter space, one should make use of non-dedicated searches.
- For GGM and stealth SUSY scenarios the use of dedicated searches, multilepton, and DM-dedicated searches allows to cover vast regions of the parameter space
- However multilepton searches can be used to test other models different from the ones they were designed to
(for example light staus in RPV)

Thank you!!