How to interpret the LHC exclusion limits

on direct electroweakino production

adapted from [arXiv:1307.4237]

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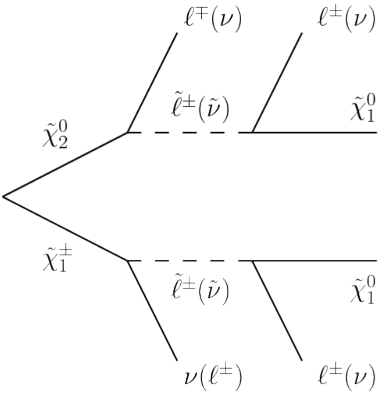
SUSY 2013

Direct electroweakino production

What simplified models are considered by ATLAS in e.g. ATLAS-CONF-2013-007?[1]



- The most studied EWino production channel is $\tilde{\chi}_2^0\tilde{\chi}_1^{\pm}$ (see Tina Potter's talk)
- Simplified models assume that the squarks are very heavy, and that the EWinos are wino-like, and decay either via sleptons

[1] Apologies to CMS: we will mainly discuss ATLAS results here as they provided the numbers we needed when we needed them but also see PAS-SUS-13-006 and Ben Hooberman's talk

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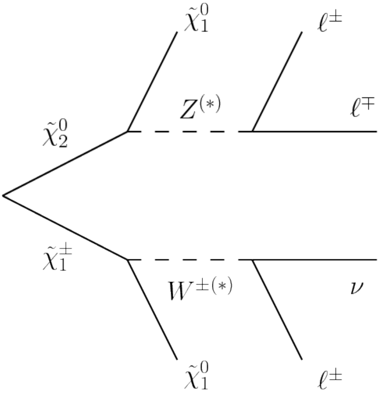

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- Simplified models assume that the squarks are very heavy, and that the EWinos are wino-like, and decay either via sleptons or via $W^{(*)}Z^{(*)}$
- We assume that we are in the region where the sleptons are inaccessible, so will only consider the latter

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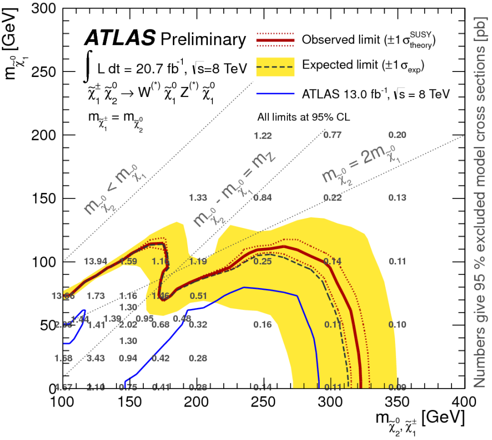
Exclusion Bounds assuming SMS

How far have the experiments cut into EW-ino parameter space?



- Here we see the bounds in the $\tilde{\chi}_2^0$–$\tilde{\chi}_1^0$ plane assuming the 3l come from $W^{(*)}Z^{(*)}$
- However, as soon as the $\tilde{\chi}_2^0 - \tilde{\chi}_1^0 > m_{h_1}$, the Higgs channel comes into the game
- What are the ACTUAL bounds in this region?

Outline

- Simplify expressions for decay widths (φ_{M_1} dependence)
- Introduce calculating neutralino decays at NLO
- Discuss and motivate choice of scenarios
- Show results for limits in $\tilde{\chi}_2^0$–$\tilde{\chi}_1^0$ plane

I've included some additional slides in Backup:

- Summary of the impact of loop corrections
- Discussion of stau coannihilation region
- Naïve projections for LHC13

Calculation in the complex MSSM

Cross section requires production and decay

- Calculated $\sigma(\tilde{\chi}_2^0\tilde{\chi}_1^\pm)$ using `Prospino 2.1` (neglect φ_{M_1})[2]
- Production of wino pairs dominates, largest contribution from s-channel gauge bosons[3]
- Consider scenarios where $\tilde{\chi}_1^\pm \to \tilde{\chi}_1^0 W^\pm \sim 100\%$, so the BRs for $\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 Z$, $\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 h_1$, $\tilde{\chi}_2^0 \to \tilde{\tau}_1^\pm \tau^\mp$ are only relevant ones
- Calculate decays at NLO using `FeynArts/LoopTools/FormCalc/FeynHiggs`[4]
- Decay $\tilde{\chi}_2^0$ to $\tilde{\chi}_1^0 h_1$ most sensitive to φ_{M_1} due to the the relative $\mathcal{CP}$ between the bino-like $\tilde{\chi}_1^0$ and the wino-like $\tilde{\chi}_2^0$

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[2] NLL corrections to the gaugino production cross section calculated in Fuks et al. 2012 are not included, and we estimate effect to be $\mathcal{O}(\%)$.

[3] Although the t and u-channel suppressed if squarks heavy, destructive interference of the t-channel squark exchange and s-channel gauge bosons can be significant

[4] A. Bharucha, S. Heinemeyer, F. von der Pahlen and C. Schappacher, arXiv:1208.4106 [hep-ph], Phys. Rev D. LO results (e.g. J. Gunion and H. Haber, Phys. Rev. D 37 (1988) 2515) encoded in SDECAY(M. Mühlleitner, A. Djouadi and Y. Mambrini, Comput. Phys. Commun. 168 (2005) 46)

Simple expressions for the decay widths for $M_Z < M_1 \sim M_2 \ll \mu$ and $t_\beta \ll 1$

and the dependence on φ_{M_1}

$$C^L_{\tilde{\chi}^0_1\tilde{\chi}^0_2 Z} \approx \frac{e}{2}\frac{M_Z^2}{\mu^2}\exp\left(\frac{i\varphi_{M_1}}{2}\right) ,$$

$$C^L_{\tilde{\chi}^0_1\tilde{\chi}^0_2 h_1} \approx \frac{e}{2}\frac{M_Z}{\mu}\left(\frac{M_1+M_2}{\mu}+\frac{4}{\tan\beta}\right)\exp\left(\frac{-i\varphi_{M_1}}{2}\right) ,$$

$$\Gamma^{\rm tree}_{\tilde{\chi}^0_2\to\tilde{\chi}^0_1 Z} \approx \frac{K(Z)}{\mu^2/M_Z^2}\left(m^2_{\tilde{\chi}^0_2}+m^2_{\tilde{\chi}^0_1}-2M_Z^2+\frac{(m^2_{\tilde{\chi}^0_2}-m^2_{\tilde{\chi}^0_1})^2}{M_Z^2}+6\cos(\varphi_{M_1})m_{\tilde{\chi}^0_2}m_{\tilde{\chi}^0_1}\right)$$

$$\Gamma^{\rm tree}_{\tilde{\chi}^0_2\to\tilde{\chi}^0_1 h_1} \approx K(h_1)\left|\frac{M_1+M_2}{\mu}+\frac{4}{\tan\beta}\right|^2\left(m^2_{\tilde{\chi}^0_2}+m^2_{\tilde{\chi}^0_1}-m^2_{h_1}+2\cos(\varphi_{M_1})m_{\tilde{\chi}^0_2}m_{\tilde{\chi}^0_1}\right)$$

where we define

$$K(X)=\frac{e^2\beta^*(\tilde{\chi}^0_1,\tilde{\chi}^0_2,X)}{64\pi m_{\tilde{\chi}^0_2}}\frac{M_Z^2}{\mu^2}$$

Scenarios

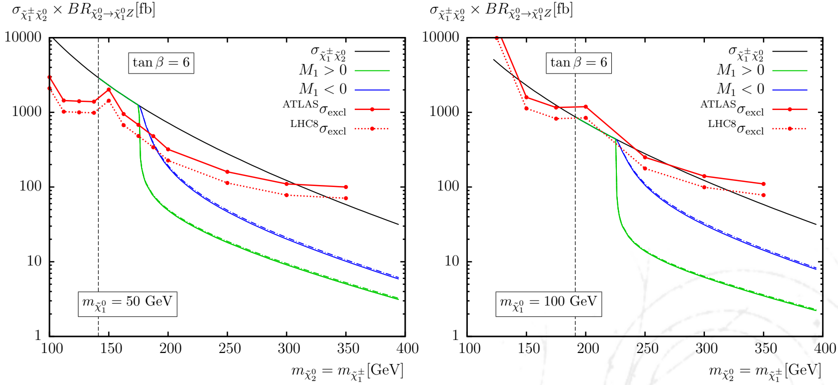
Central benchmark and deviations in various directions

Scenario	φ_{M_1}	μ	$\tan\beta$	M_{SUSY}	$M_{\tilde{\tau}_R}$
S_{ATLAS}	0	1000	6	2000	M_{SUSY}
$S_{\mathrm{ATLAS}}^{\varphi_{M_1}}$	$0\ldots\pi$	1000	6	2000	M_{SUSY}
$S_{\mathrm{ATLAS}}^{\tan\beta}$	0	1000	$6\ldots20$	2000	M_{SUSY}
S^{DM}	$0\ldots\pi$	1000	6, 20	2000	$\lvert M_1\rvert$
$S_{\mathrm{low}-\mu}$	0	$100\ \ldots400$	6	2000	M_{SUSY}

$$|M_1| = 0\ldots200\ \mathrm{GeV},\ M_2 = 100\ldots400(500)\ \mathrm{GeV},$$
$$M_3 = 1.5\ \mathrm{TeV},\ M_{\tilde{q}_{1,2}} = M_{\tilde{q}_3} = M_{\tilde{\ell}} = 2\ \mathrm{TeV},\ A_t \approx 2.8\ \mathrm{TeV}\ .$$

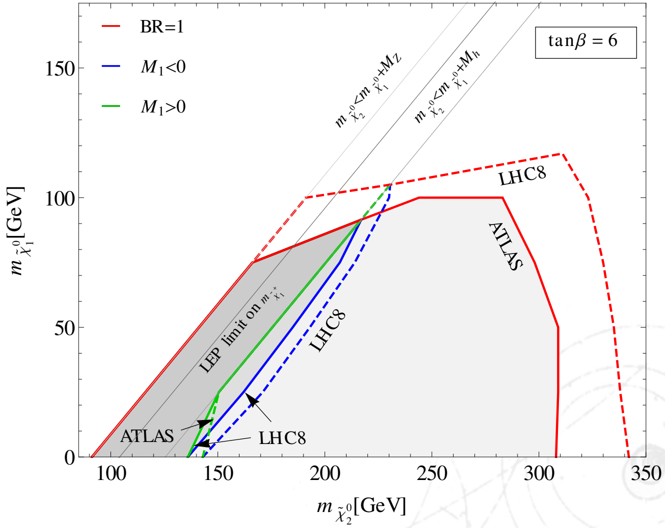
Results

another look at the exclusion limits



Results

in the $\tilde{\chi}_2^0$–$\tilde{\chi}_1^0$ plane



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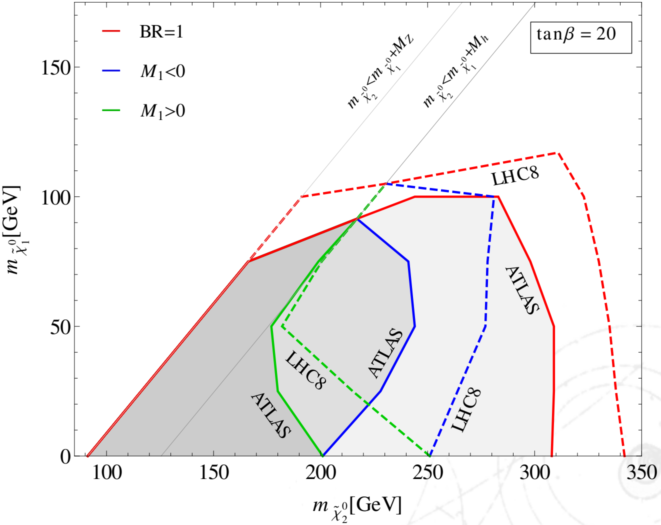
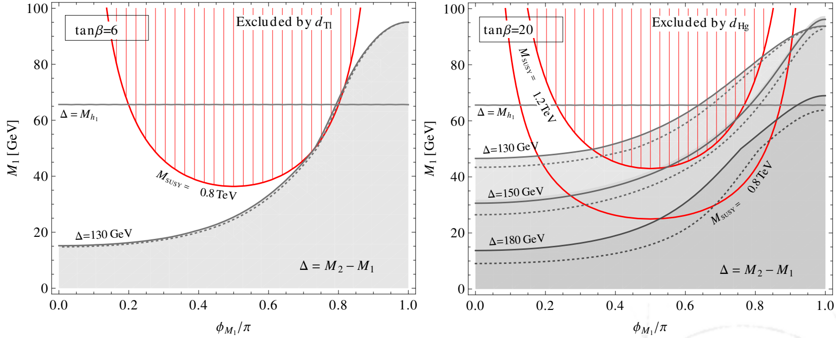


Results

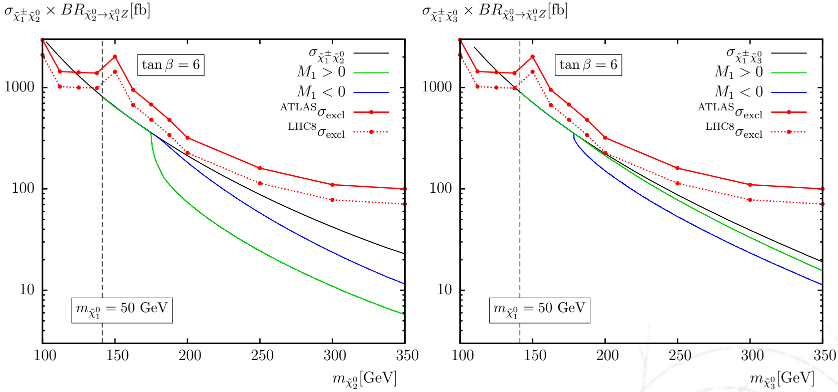
exploring the effect of φ_{M_1}: a new constraint?



- Strong dependence of M_1 exclusion on φ_{M_1}, no exclusion for $\tan\beta = 6$, $\Delta = 150$ GeV and $\tan\beta = 20$, $\Delta = 210$ GeV
- Interesting complementarity with EDM limits on φ_{M_1} for $\tan\beta = 20$

Results

natural SUSY:the low μ scenario



- Notice green and blue lines swap: complementarity of $\tilde{\chi}_2^0$ and $\tilde{\chi}_3^0$ production (opposite CP behaviour)
- Suppressed production cross-section (couplings) only partially overcome by combining channels: No limit so far

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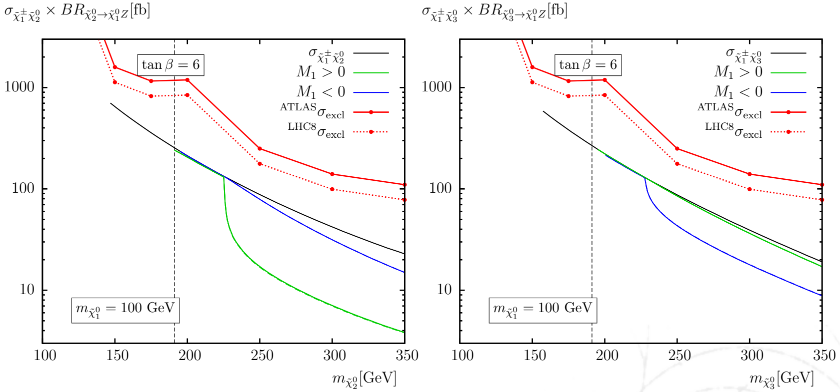

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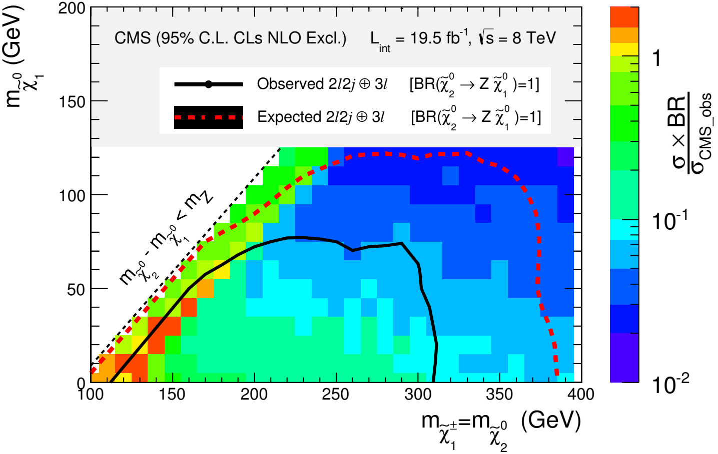
Summary

and Outlook

tanβ=6, M_1>0



Summary

and Outlook

Exclusion limits on charginos and neutralinos:

- When sleptons are heavy ($WZ + E_T^{\rm miss}$ search), above threshold decay to h_1 dominates
- Simplified model limits ($m_{\tilde{\chi}_2^0} > 300$ GeV) very optimistic, especially for low $\tan\beta$

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Exploring variations of the central benchmark scenario:

- Limits strongly depend on sign of M_1/φ_{M_1}: constrain φ_{M_1} complementary to EDMs
- In low μ region, suppression→no limit at present (even combining $\tilde{\chi}_2^0/\tilde{\chi}_3^0$)

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A glimpse of the future:

- Combining the $WZ + E_T^{\rm miss}$ and $Wh_1 + E_T^{\rm miss}$ searches will further improve the reach
- NLO results for neutralino decays to be implemented into `FeynHiggs`

Thanks for listening![5]

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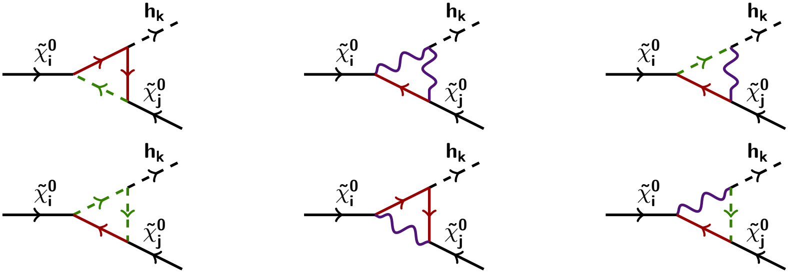
Neutralino decays at one loop



- LO results[6] and NLO in real MSSM[7] calculated.
- Loops contain EW-inos/leptons/quarks, $\tilde{q}$s/$\tilde{l}$s/Hs or Ws or Zs
- Calculate using `FeynArts/LoopTools/FormCalc/FeynHiggs`[8], including hard and soft QED radiation and Renormalize

[6] e.g. J. Gunion et al, Phys. Rev. D (1988), M. Mühlleitner et al, Comput. Phys. Commun. (2005)

[7] N. Baro and F. Boudjema, Phys. Rev. D 80 (2009) 076010 [arXiv:0906.1665 [hep-ph]], S. Liebler and W. Porod, Nucl. Phys. B 849 (2011) 213 [arXiv:1011.6163 [hep-ph]]

[8] also see A. C. Fowler and G. Weiglein, JHEP **1001** (2010) 108 [arXiv:0909.5165 [hep-ph]].

Results

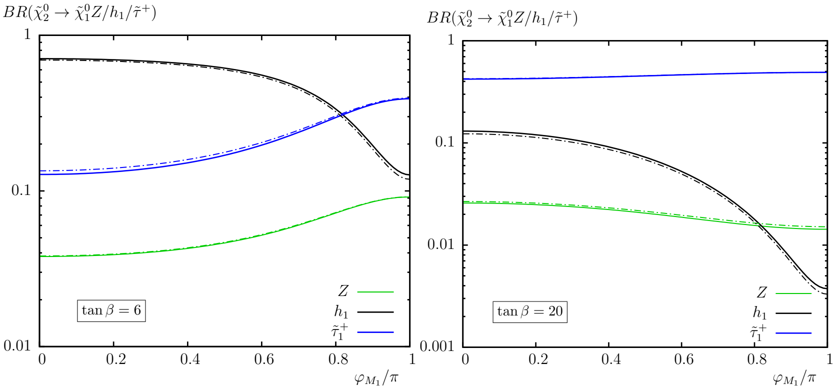
The impact of loop corrections

$$\Delta\Gamma^{\text{loop}} := \frac{\Gamma^{\text{NLO}} - \Gamma^{\text{tree}}}{\Gamma^{\text{tree}}}, \quad \Delta\text{BR}^{\text{loop}} := \frac{\text{BR}^{\text{NLO}} - \text{BR}^{\text{tree}}}{\text{BR}^{\text{tree}}}.$$

Scenario	$\lvert M_1 \rvert$	M_2	φ_{M_1}	μ	$\tan\beta$	M_{SUSY}	$M_{\tilde{\tau}_R}$	$\Delta\text{BR}^{\text{loop}}$	$\Delta\Gamma^{\text{loop}}$
S_{ATLAS}	100	250	0	1000	6	2000	M_{SUSY}	8%	$<$ 1%
S_{ATLAS}	100	250	π	1000	6	2000	M_{SUSY}	4%	1%
$S_{\text{ATLAS}}^{\varphi_{M_1}}$	100	250	$\pi/2$	1000	6	2000	M_{SUSY}	8%	$<$ 1%
$S_{\text{ATLAS}}^{\tan\beta}$	100	250	0	1000	20	2000	M_{SUSY}	8%	$<$ 1%
$S_{\text{ATLAS}}^{\tan\beta}$	100	250	π	1000	20	2000	M_{SUSY}	4%	1%
S_{ATLAS}^{μ}	100	250	0	2000	6	2000	M_{SUSY}	7%	-5%
$S_{\text{ATLAS}}^{\text{SUSY}}$	100	250	0	1000	6	1200	M_{SUSY}	12%	-4%
$S_{\text{ATLAS}}^{\text{SUSY}}$	100	250	π	1000	6	1200	M_{SUSY}	11%	-2%
S^{DM}	100	250	0	1000	6	2000	$\lvert M_1 \rvert$	5%	-1%
S^{DM}	100	250	π	1000	6	2000	$\lvert M_1 \rvert$	5%	-1%
$S_{\text{low}-\mu}$	100	500	0	250	6	2000	M_{SUSY}	-1%	2%
$S_{\text{low}-\mu}$	100	500	0	350	6	2000	M_{SUSY}	-1%	4%

Results

the DM scenario: avoiding overabundance of LSP with $M_{\tilde{\tau}_R} = M_1$



- Decay to $\tilde{\tau}_R$ is Yukawa suppressed
- Sensitive to off-diagonal $= m_\tau \, \mu \tan\beta$ $(A_\tau = 0)$
- Decay to Z suppressed to 2-3%, max 9% at $\varphi_{M_1} = \pi$

Results

Simple projection to LHC13 with $100\,\mathrm{fb}^{-1}$

- $R_{13/8} = \sqrt{R_{\mathrm{bkg}}} \times \frac{\mathcal{L}_{\mathrm{LHC8}}}{\mathcal{L}_{\mathrm{LHC13}}}$

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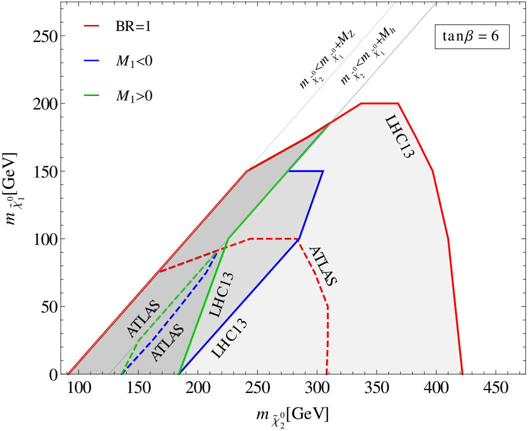
- Improvement $\sim 35\%$ with uncertainty $\pm 50\%$



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