SUSY decays to Higgs bosons and their implications

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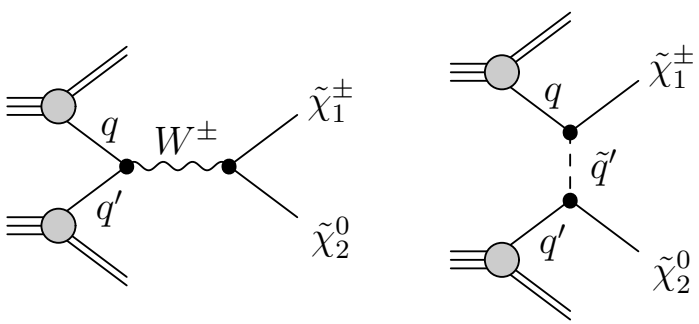
SUSY 2014

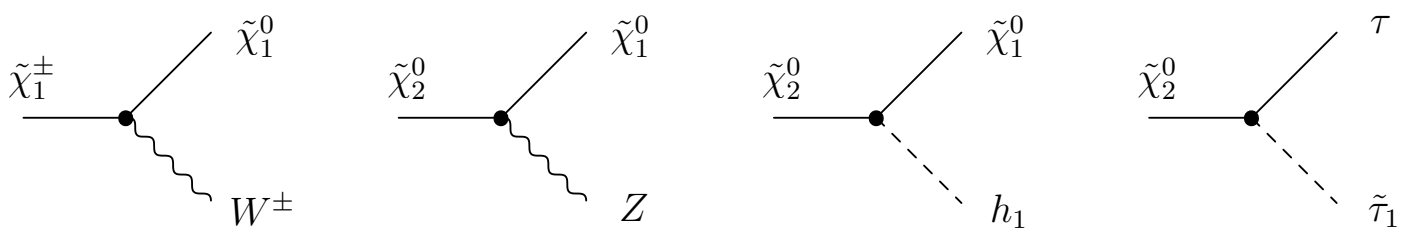
SUSY decays to Higgs bosons and their implications

- Introduction: EWkino searches at the LHC
  - $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ production
  - bounds after LHC8
- Higgs effects
  - Realistic bounds
  - Projection to LHC13/14
  - CP-violating couplings
- Summary

EWino searches @LHC

- Largest production cross sections at the LHC: colored particles
- Direct $\tilde{\chi}^{\pm}/\tilde{\chi}^{0}$ production: LHC sensitive to lower masses
  - Golden EWkino channel: wino-like $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^{0} \to 3$ leptons
    $|\mu| > |M_2| > |M_1|$
  - if $m_{\tilde{\ell}} < m_{\tilde{\chi}_1^{\pm}} \Rightarrow$ most powerfull constraints (~ 700 GeV)





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  - if $m_{\tilde{\ell}} < m_{\tilde{\chi}_1^{\pm}} \Rightarrow$ most powerfull constraints (~ 700 GeV)
  - if $m_{\tilde{\ell}} > m_{\tilde{\chi}_1^{\pm}} \Rightarrow$ most $WZ/Wh + E_t^{\rm miss}$, 3 body decays
  - $|M_2| > |\mu| > |M_1|$ $WZ/Wh + E_t^{\rm miss}$, 3 body decays,
  - $|M_2|$, $|M_1| > |\mu|$: compressed spectra

EWino searches @LHC

- Interpretation of bounds
  - specific models (CMSSM, GMSB, etc.):
    Bounds on $\tilde{\chi}^{\pm}/\tilde{\chi}^{0}$ reflect searches for colored particles
    interpretation of results with more general assumptions difficult/impossible
  - Simplified Model Spectra (SMS) analysis:
    Derive bounds on maximal production cross sections $\times$ BR as function of particle spectra
    Allows interpretation of exclusion bounds in different models

    However, assume 100% BR to WZ or WH

EWino searches @LHC: (ATLAS, $WZ, 3\ell + E_t^{\text{miss}}$)

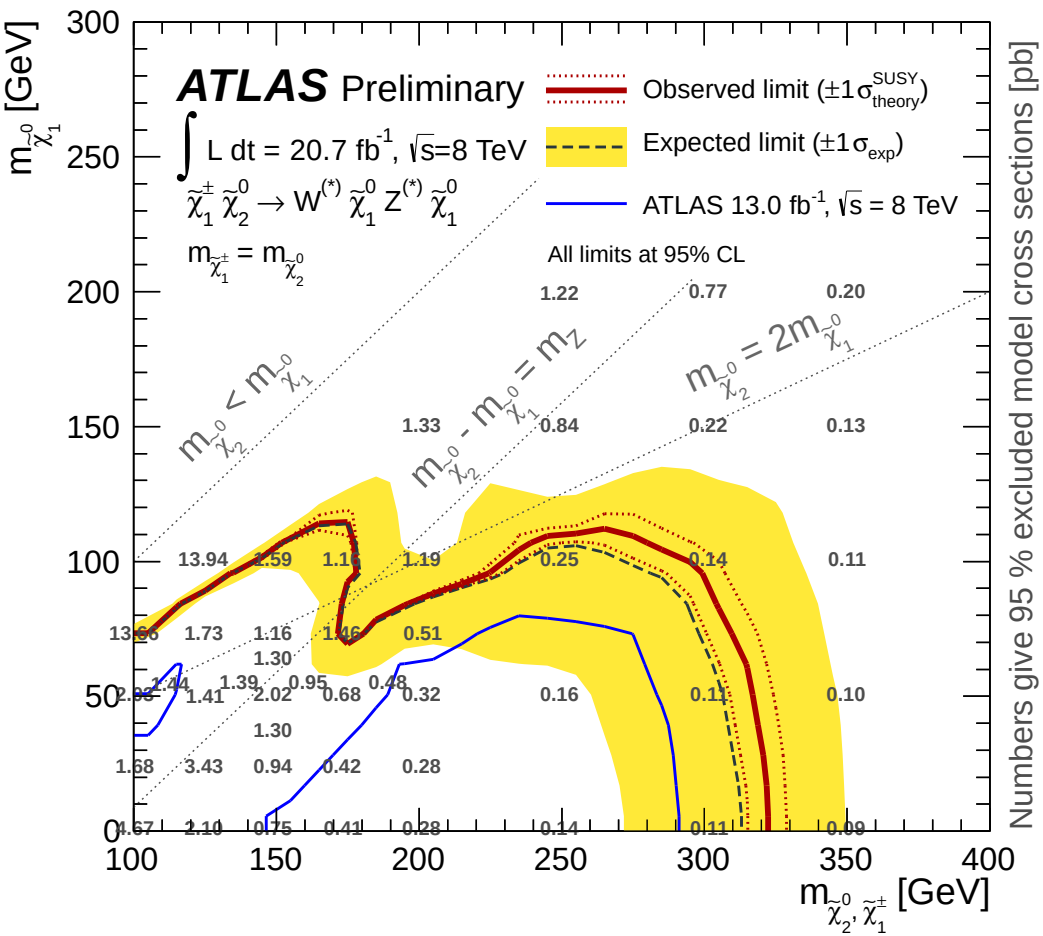
$pp \to \tilde{\chi}_1^{\pm}\tilde{\chi}_2^0 \to W\tilde{\chi}_1^0 Z\tilde{\chi}_1^0$

Assume:

- $m_{\tilde{\chi}_1^{\pm}} \simeq m_{\tilde{\chi}_2^0}$
- heavier sleptons

Exclusion limits for:

- gaugino-like $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$
- bino-like $\tilde{\chi}_1^0$
- BR$(\tilde{\chi}_1^{\pm} \to W^{\pm}\tilde{\chi}_1^0) = 1$
- BR$(\tilde{\chi}_2^0 \to Z\tilde{\chi}_1^0) = 1$



Simplified Model Spectra analysis: interpret carefully

EWino searches @LHC

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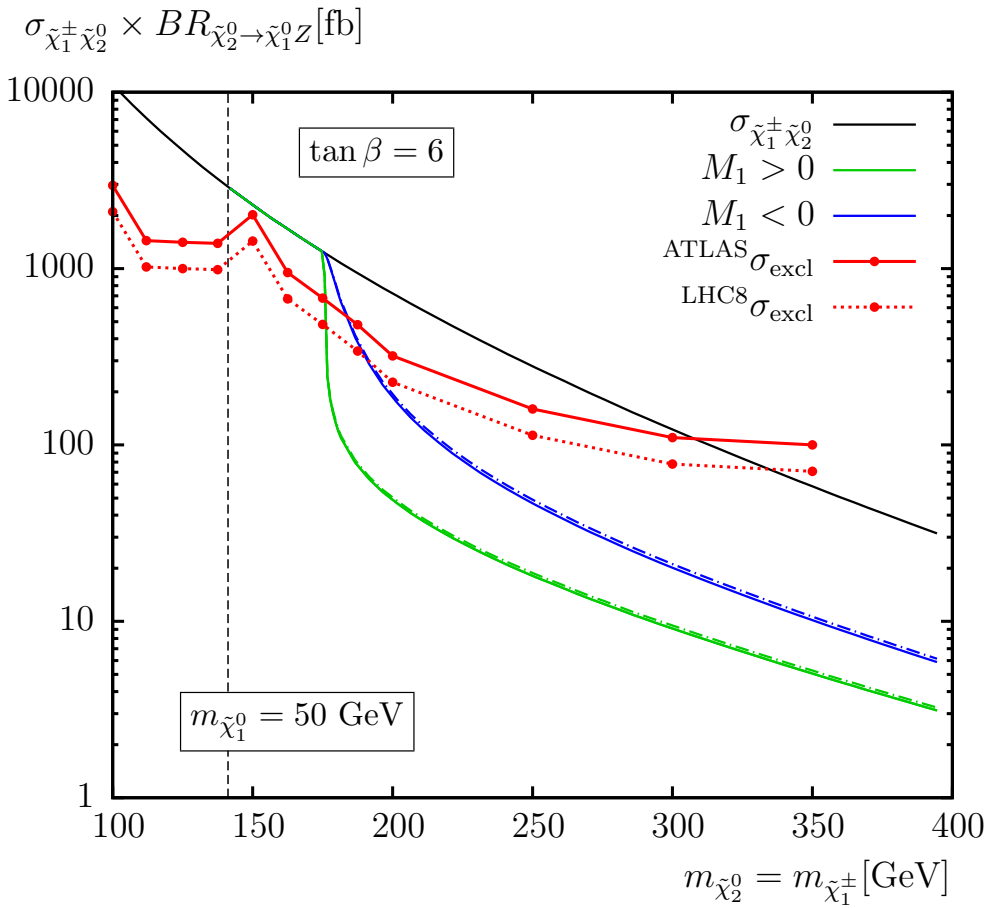
Assume:

- $m_{\tilde{\chi}_1^\pm} \simeq m_{\tilde{\chi}_2^0}$
- heavier sleptons

Exclusion limits for:

- gaugino-like $\tilde{\chi}_1^\pm \tilde{\chi}_2^0$
- bino-like $\tilde{\chi}_1^0$
- including $(\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 h_1)$

[Bharucha,Heinemeyer,FP]



$[\mu \gg M_2 > M_1]$

Simple expressions for decay widths [for $\mu \gg M_2, M_1$, $\tan\beta \gg 1$]

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

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

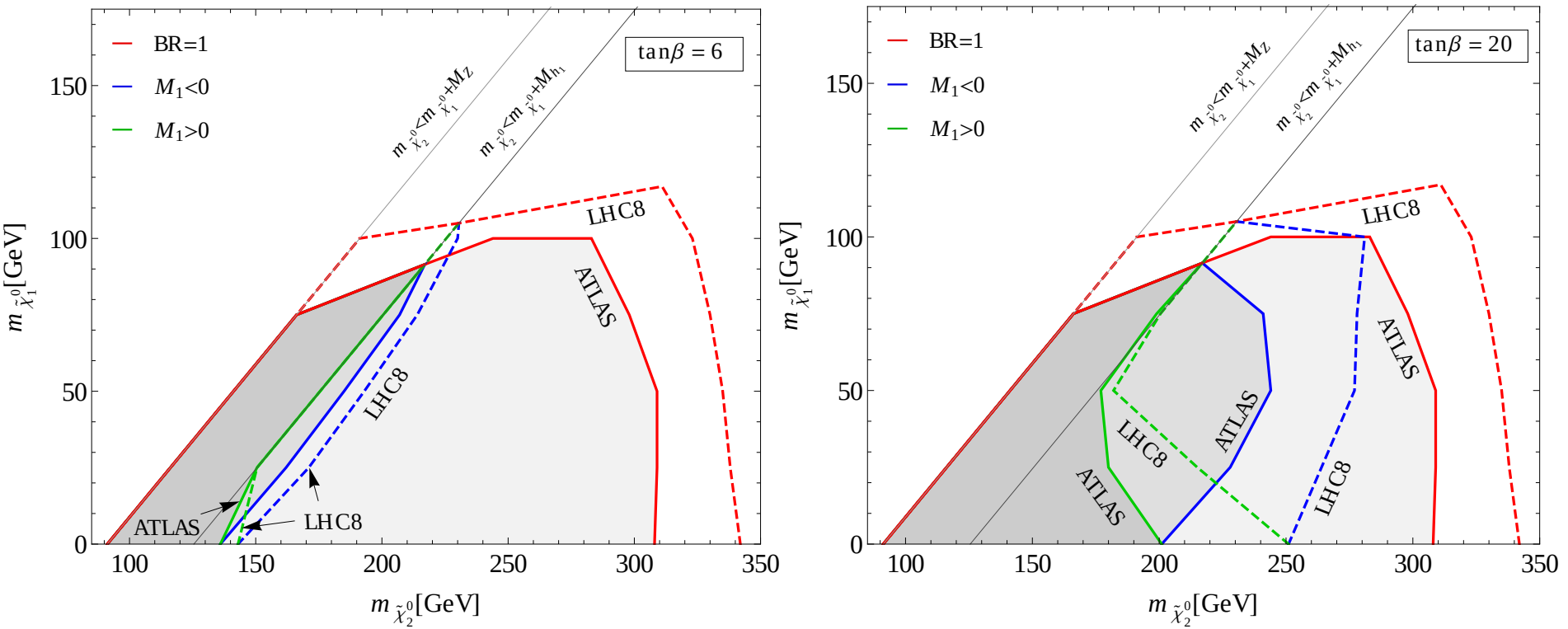
$$\Gamma^{\rm tree}_{\tilde\chi^0_2\to\tilde\chi^0_1 h_1} \approx K(h_1)\left|\frac{M_1+M_2}{\mu}+\frac{4}{\tan\beta}\right|^2\left(m^2_{\tilde\chi^0_2}+m^2_{\tilde\chi^0_1}-m^2_{h_1}+2\cos(\varphi_{M_1})m_{\tilde\chi^0_2}m_{\tilde\chi^0_1}\right) ,$$

with $K(X) \propto \beta^*(\tilde\chi^0_1, \tilde\chi^0_2, X)$

- Higgs-neutralino $C^L_{\tilde\chi^0_1\tilde\chi^0_2 h_1}$: depends on relative phases & $\tan\beta$
- $\varphi_{M_1} = \pi \Rightarrow$ p-wave suppr. $\rightarrow$ thresh. dependence on relat. CP

Effect of including the Higgs channel (ATLAS limits)

$pp \to \tilde{\chi}_1^{\pm}\tilde{\chi}_2^0 \to W\tilde{\chi}_1^0 Z\tilde{\chi}_1^0$ BR=1, M_1>0, M_1<0

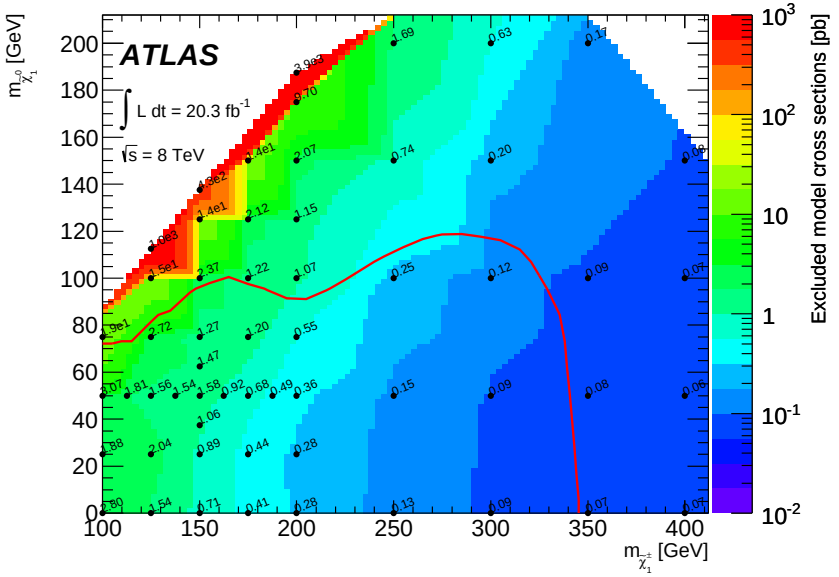


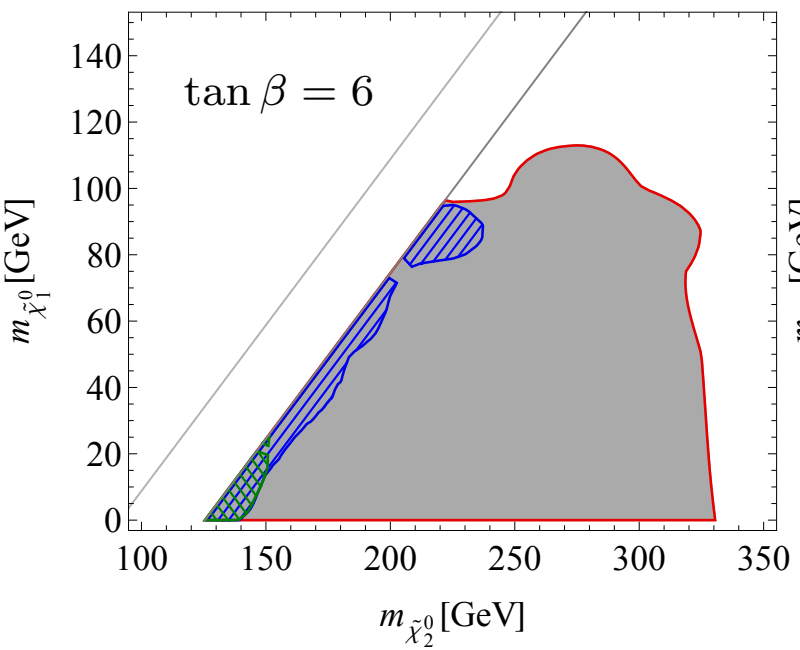
[Bharucha,Heinemeyer,FP]

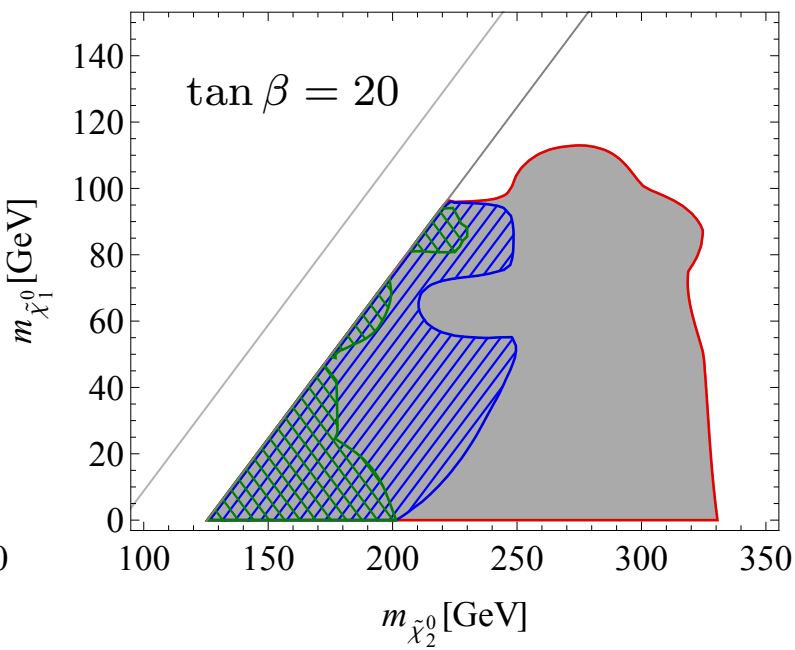
- Dramatic reductiion in sensitivity for $m_{\tilde{\chi}_2^0} - m_{\tilde{\chi}_1^0} > m_{h_1}$
- Effect stronger for small $\tan\beta$ and $M_1 > 0$

Recent updates

ATLAS@8 TeV, 20.3/fb
SUSY-2013-12







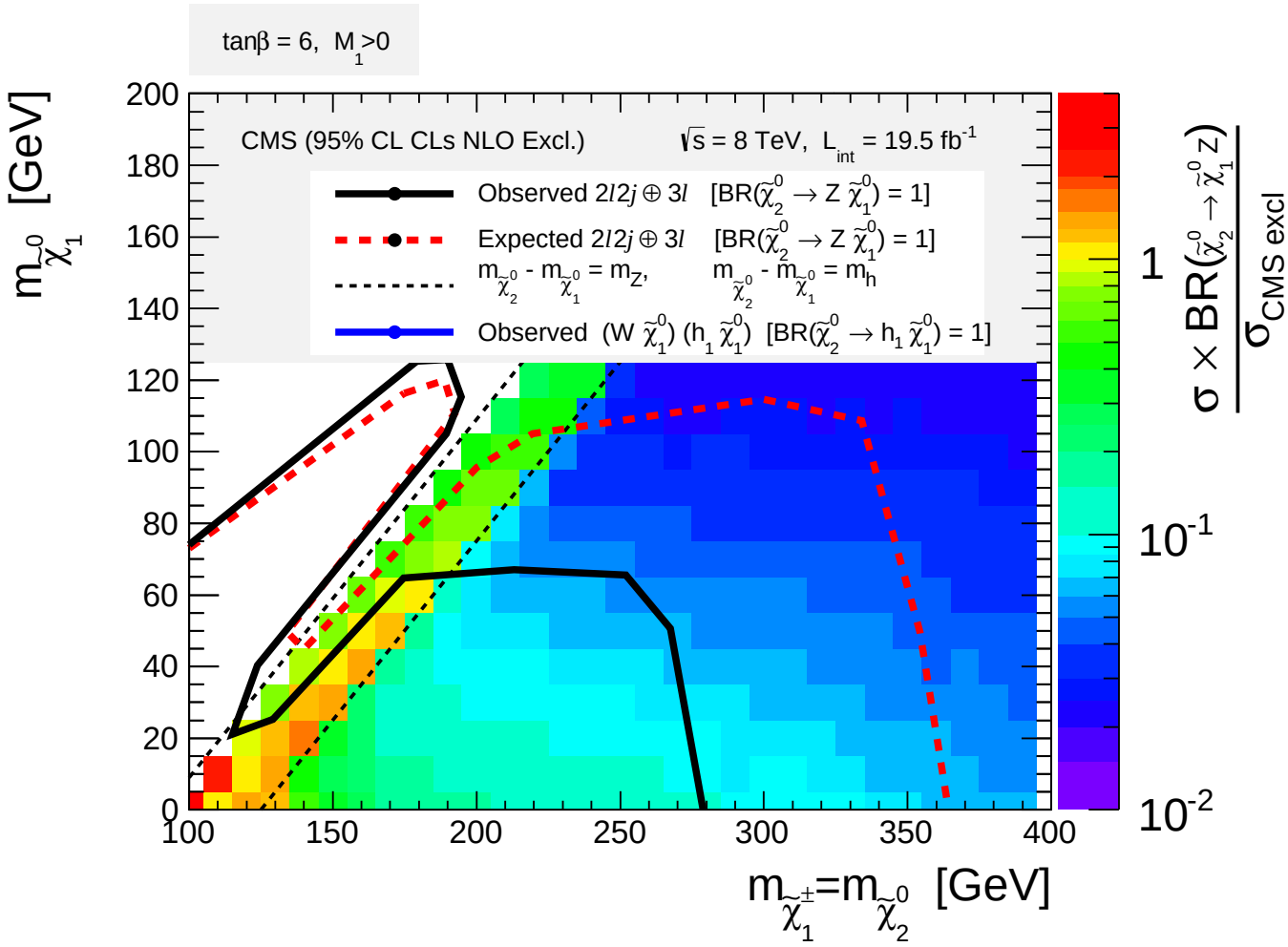
BR=1

$M_1>0$

$M_1<0$

Recent updates

CMS@8 TeV, 19.5/fb
CMS-SUS-13006



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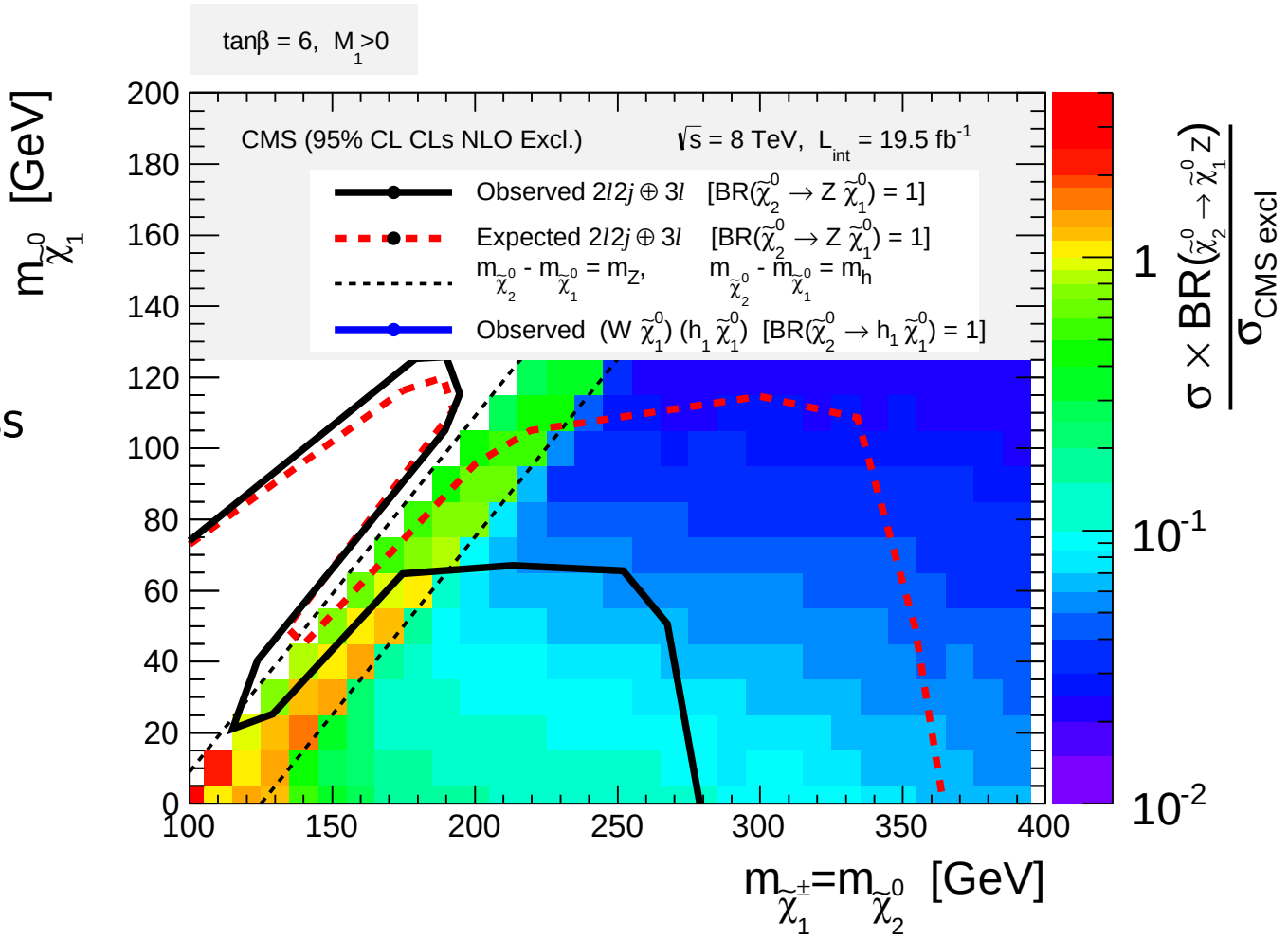
$\tan\beta = 6, M_1 > 0$:

- CMS $1 - 2\sigma$ excess
  $\Rightarrow WZ$ excludes
  $m_{\tilde{\chi}_2^0} - m_{\tilde{\chi}_1^0} < m_h$



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CMS@8 TeV, 19.5/fb
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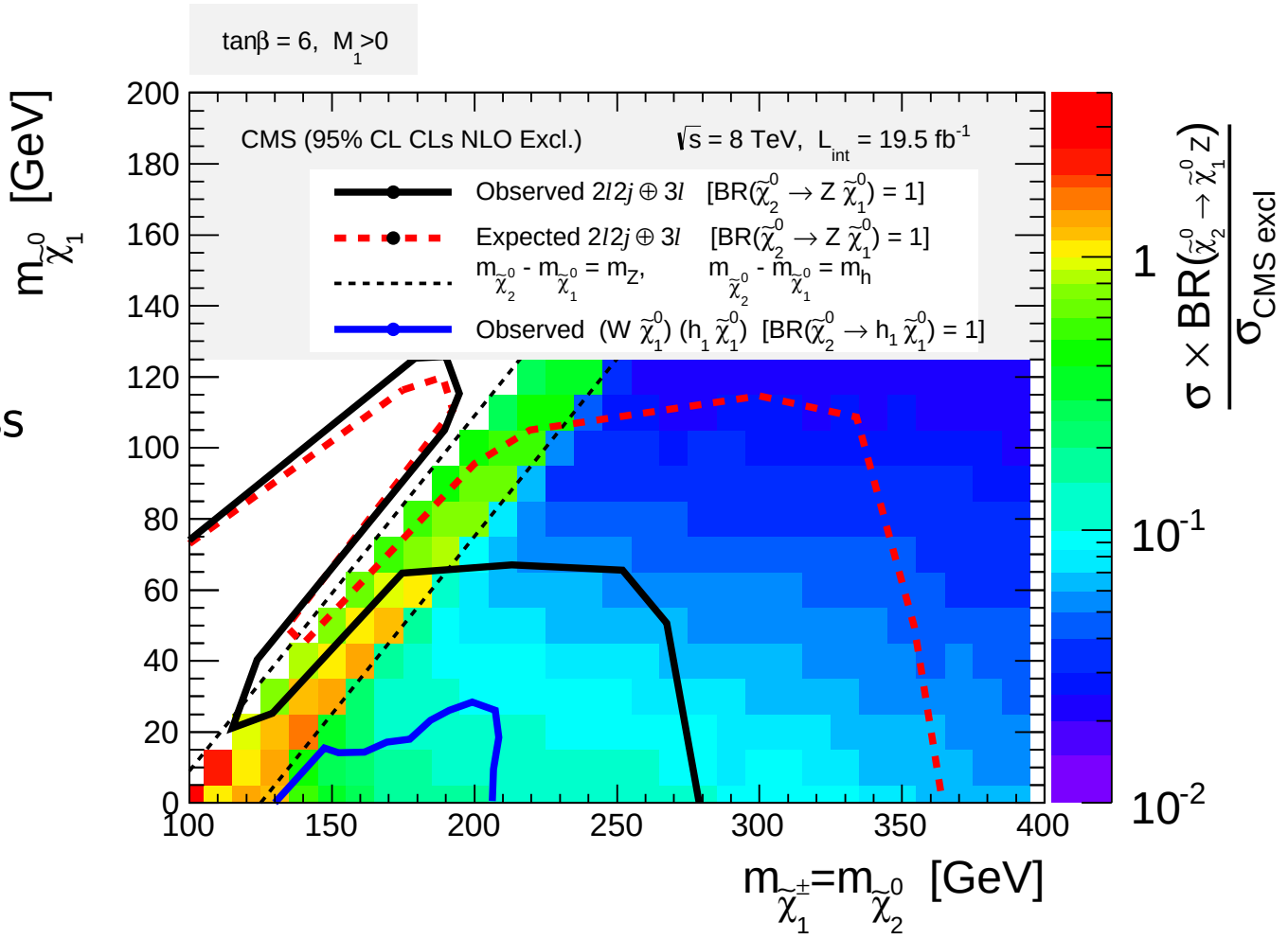
$\tan\beta = 6, M_1 > 0$:

- CMS $1-2\sigma$ excess $\Rightarrow WZ$ excludes $m_{\tilde{\chi}_2^0} - m_{\tilde{\chi}_1^0} < m_h$
- $\Rightarrow Wh$ excludes higher $m_{\tilde{\chi}_2^0}$



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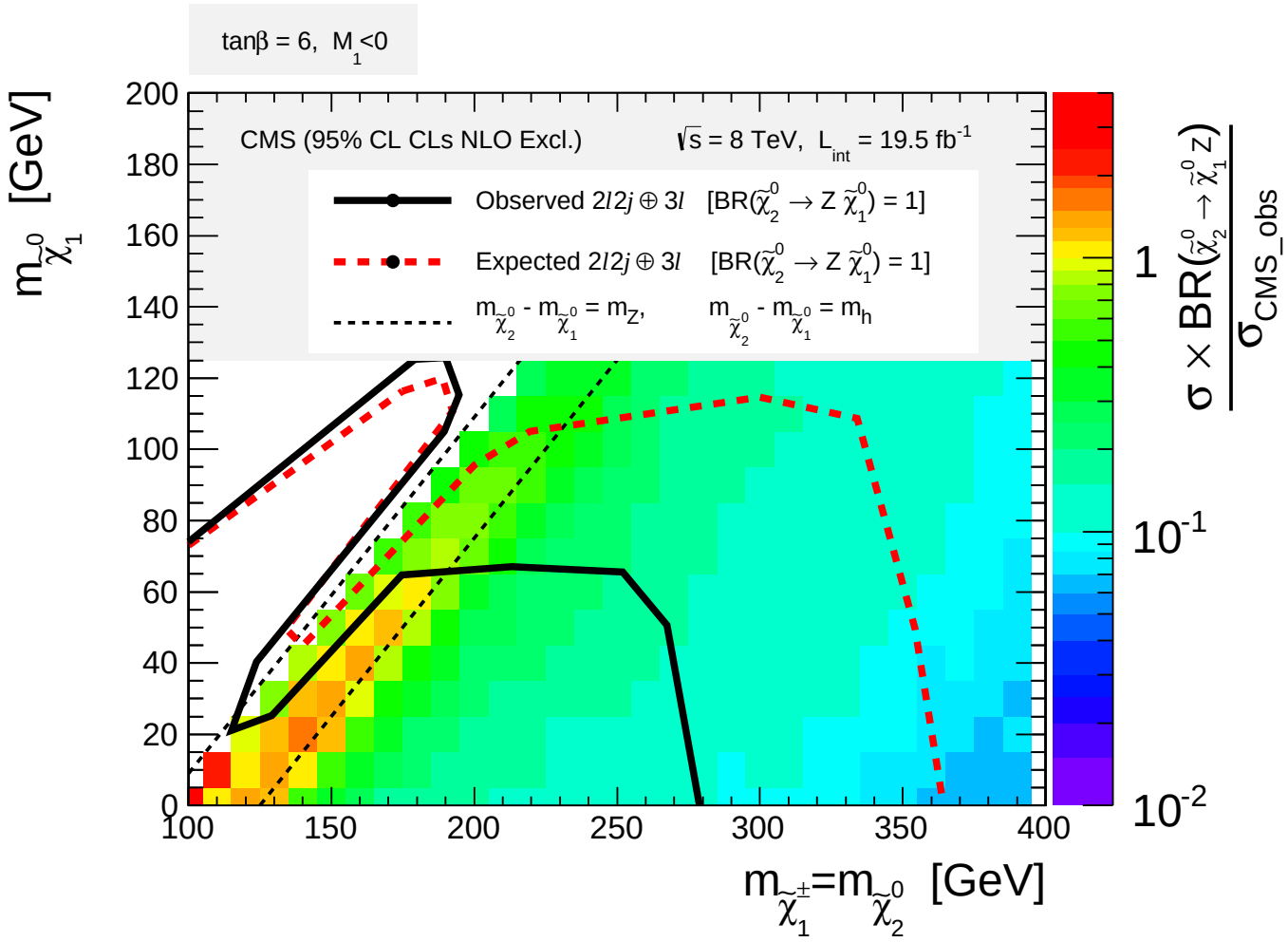

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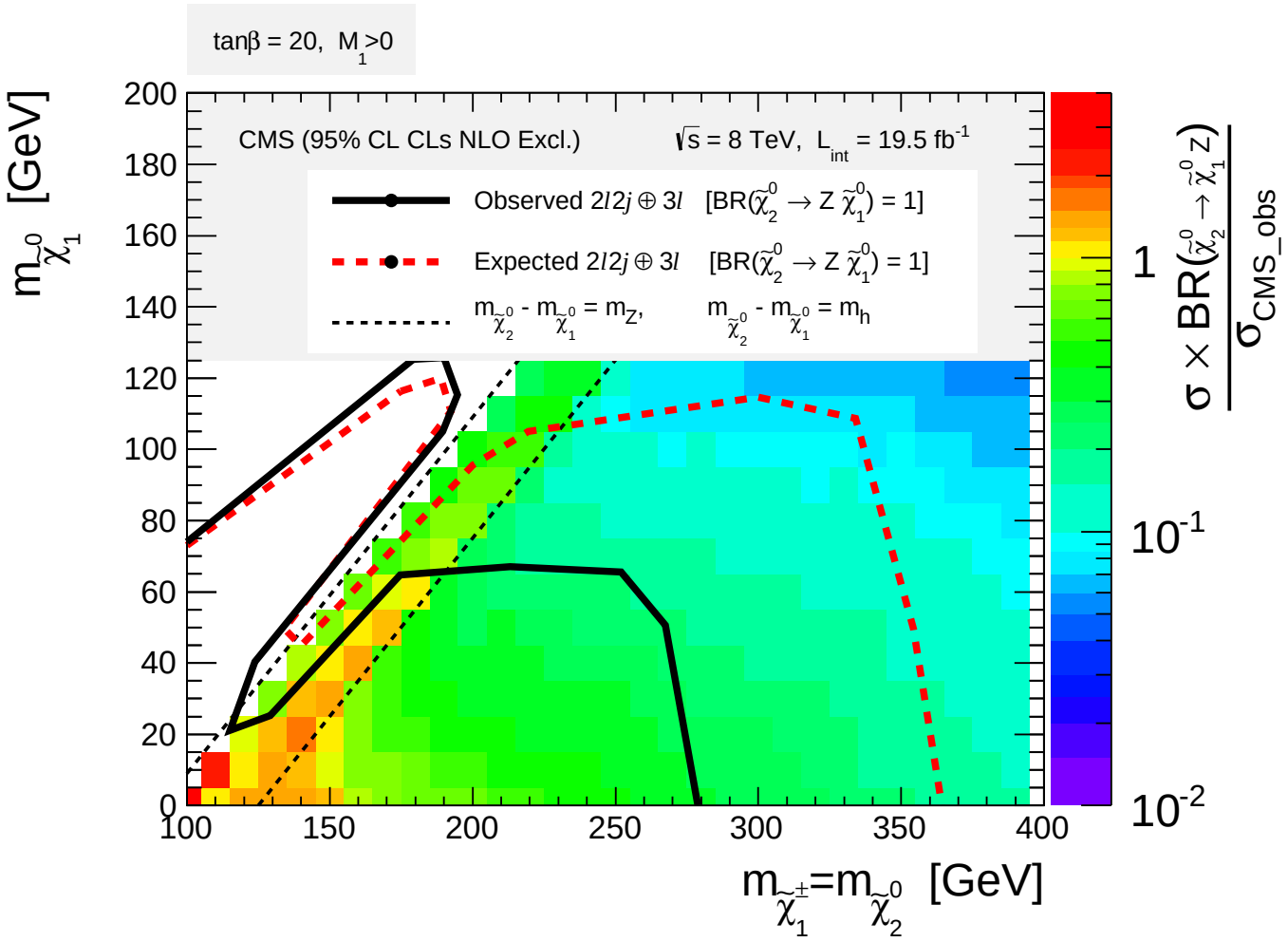

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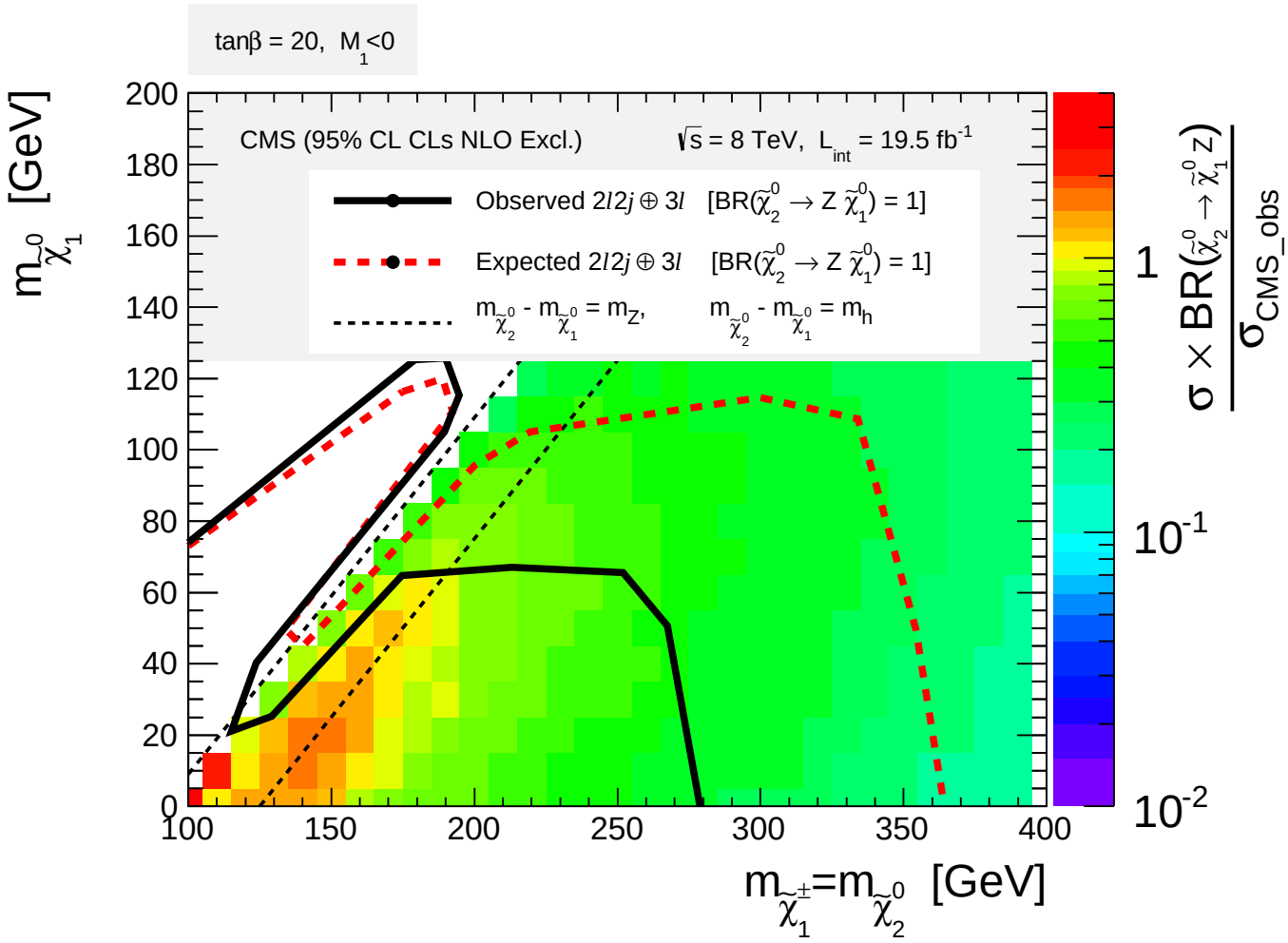

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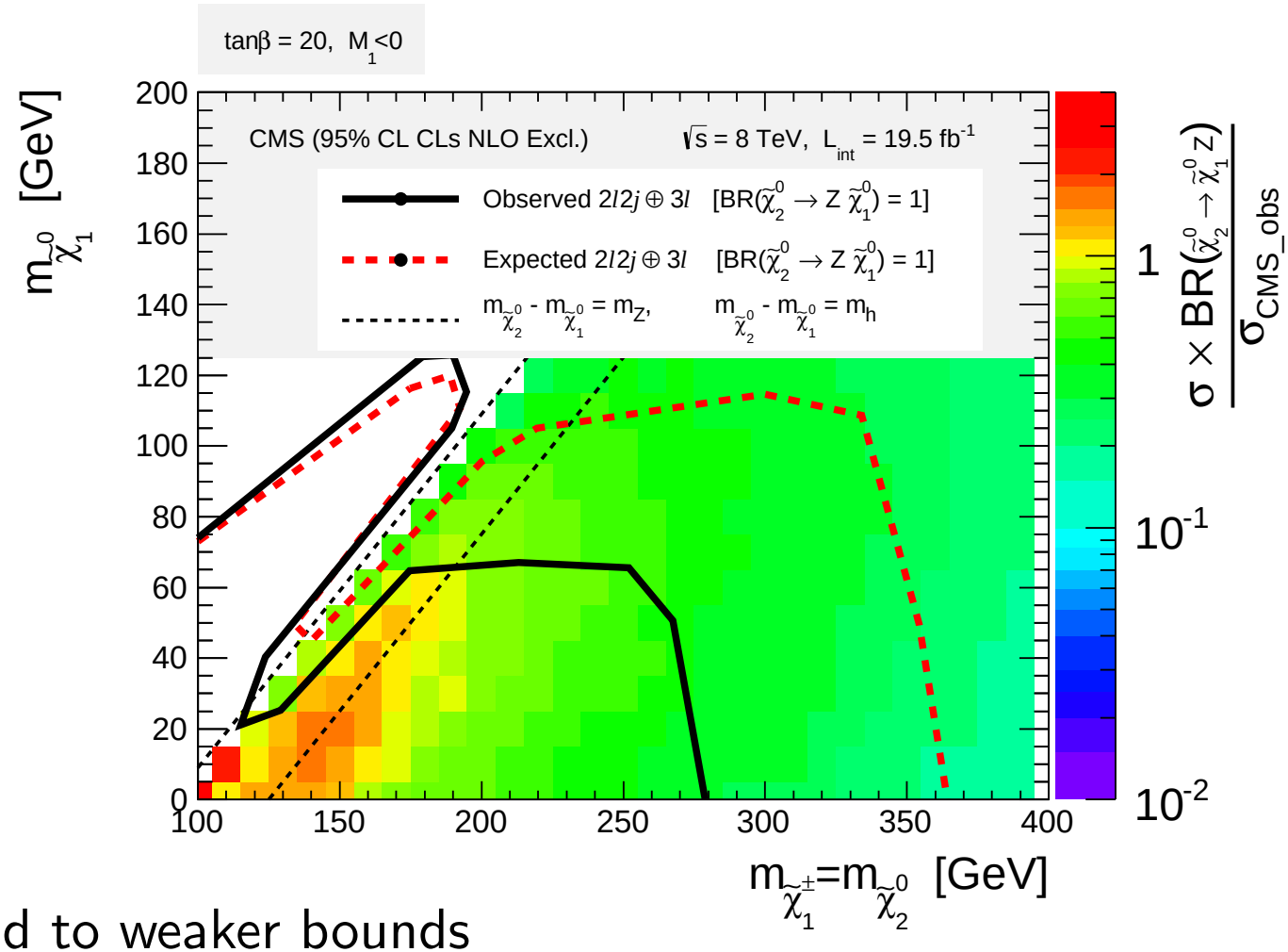
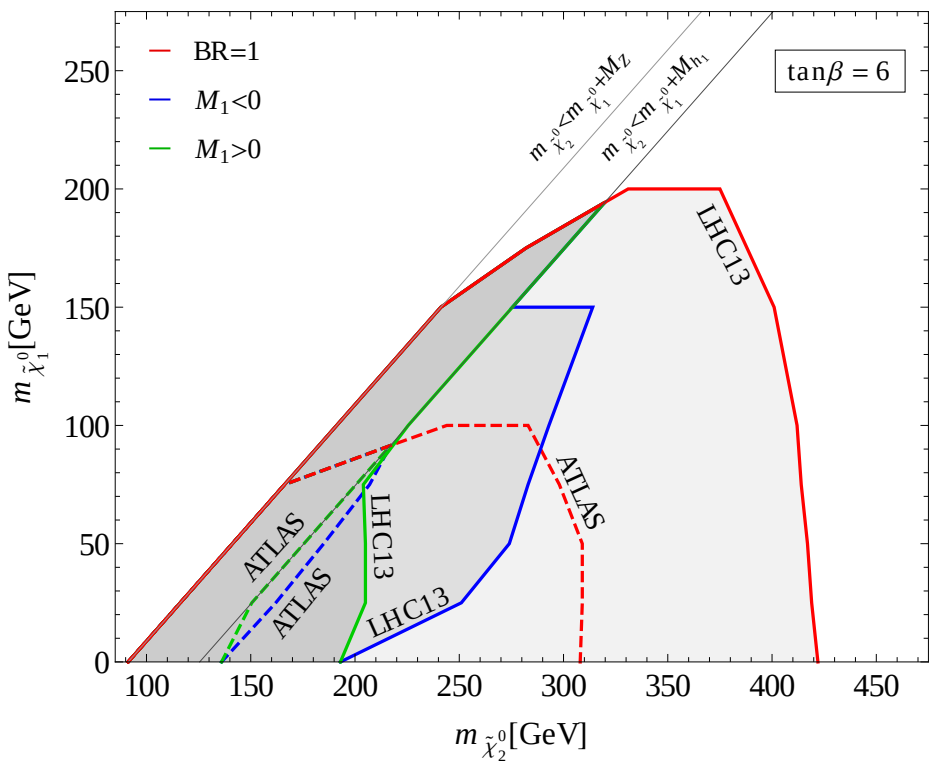
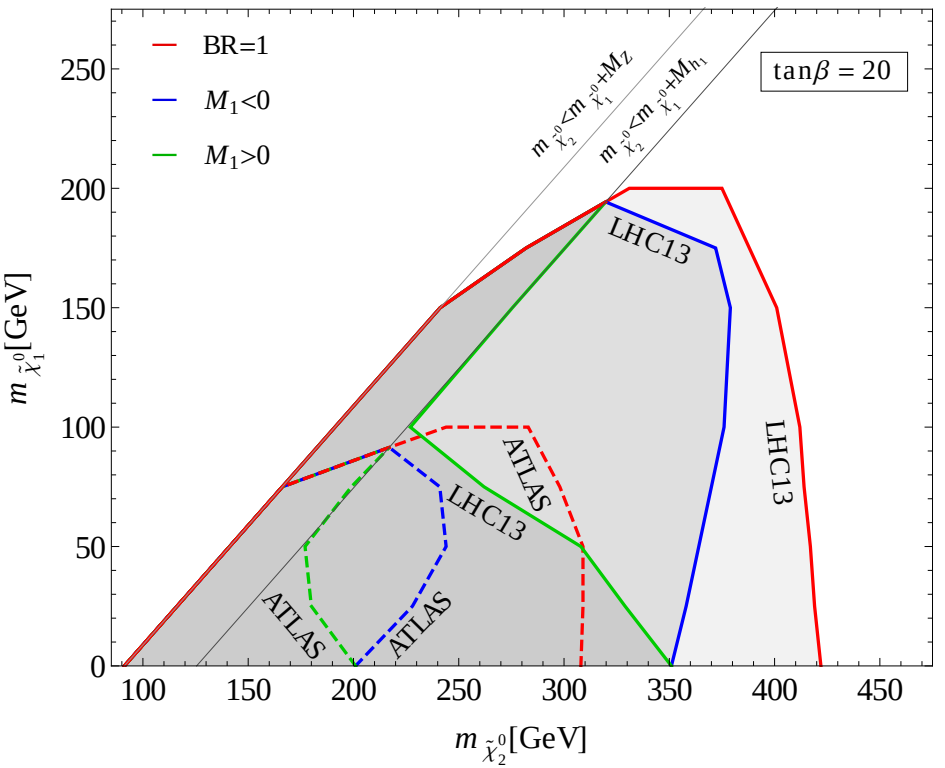


- most scenarios lead to weaker bounds
- only $\mu = -\tan\beta(M_1 + M_2)/4 \rightarrow$ BR(h_1)=0
- higgsino prod.XS significantly weaker: we find no exclusion

EWino searches: Projections for LHC@13TeV

$pp \to \tilde{\chi}_1^{\pm}\tilde{\chi}_2^0 \to W\tilde{\chi}_1^0 Z\tilde{\chi}_1^0$ Naive projection ($L_{int} = 100\ \mathrm{fb}^{-1}$)





Rescale exclusion for LHC8 by factor: $R_{13/8} = \sqrt{R_{\rm bkg}}\,\frac{L_{\rm LHC8}}{L_{\rm LHC13}}$,

$$R_{\rm bkg} = \frac{\sigma_{WZ}(13\mathrm{TeV})}{\sigma_{WZ}(8\mathrm{TeV})}\,\frac{L_{\rm LHC13}}{L_{\rm LHC8}} \quad \Rightarrow R_{13/8} \approx \sqrt{2}\sqrt{\frac{21}{200}} \sim 35\%,$$

EWino searches: Projections for LHC@13TeV

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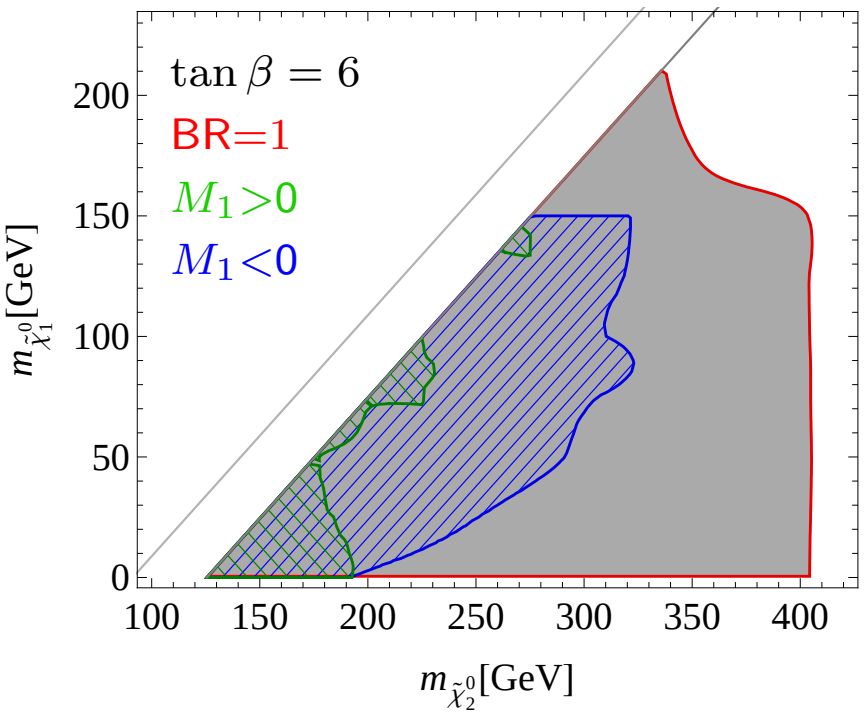
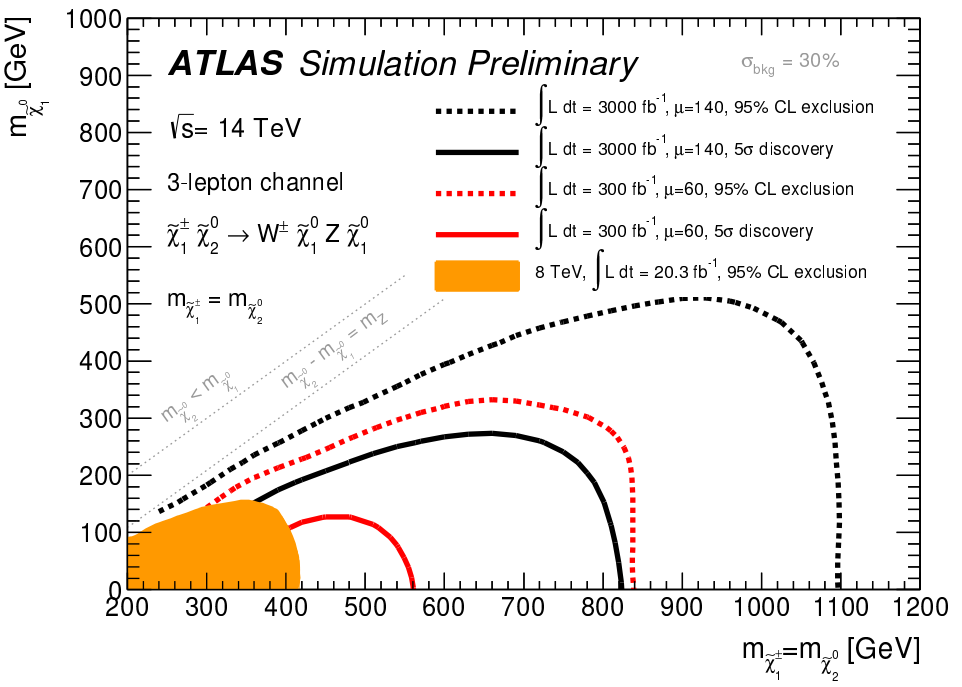
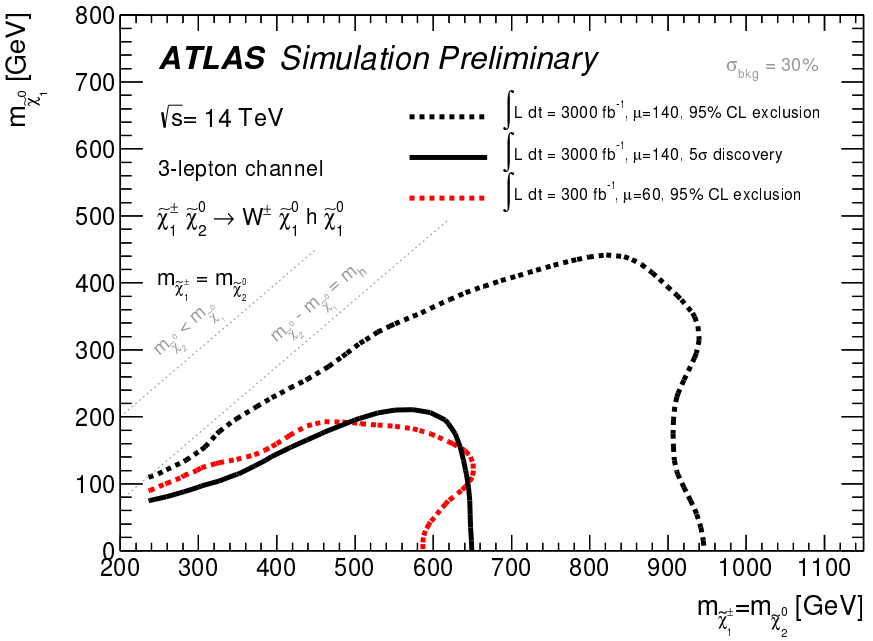


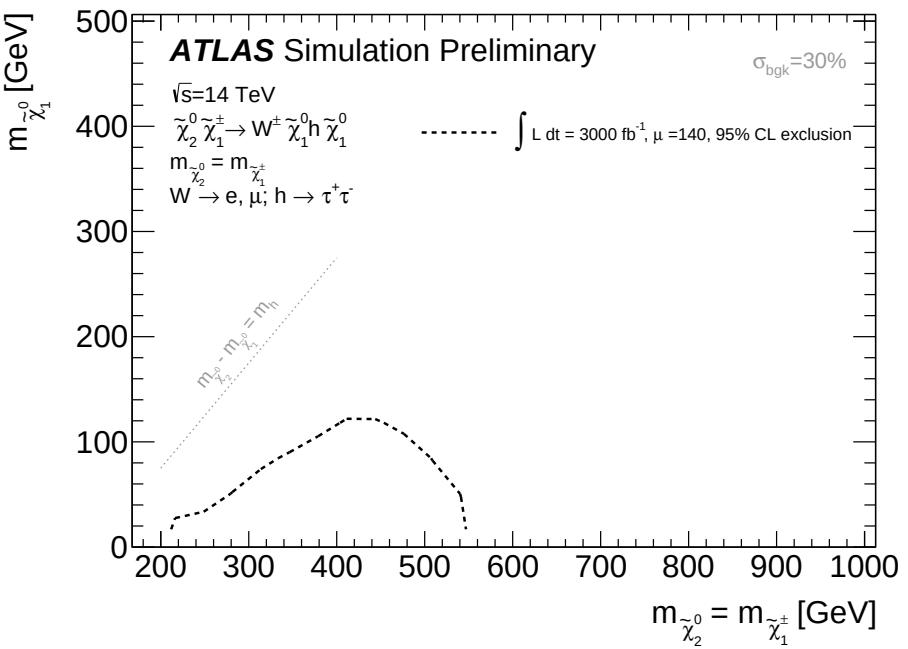


- ATLAS & CMS projections @14TeV 300 fb^{-1}: 95%CL exclusion up to 800 GeV very optimistic.

EWino searches: ATLAS Projections for LHC@14TeV

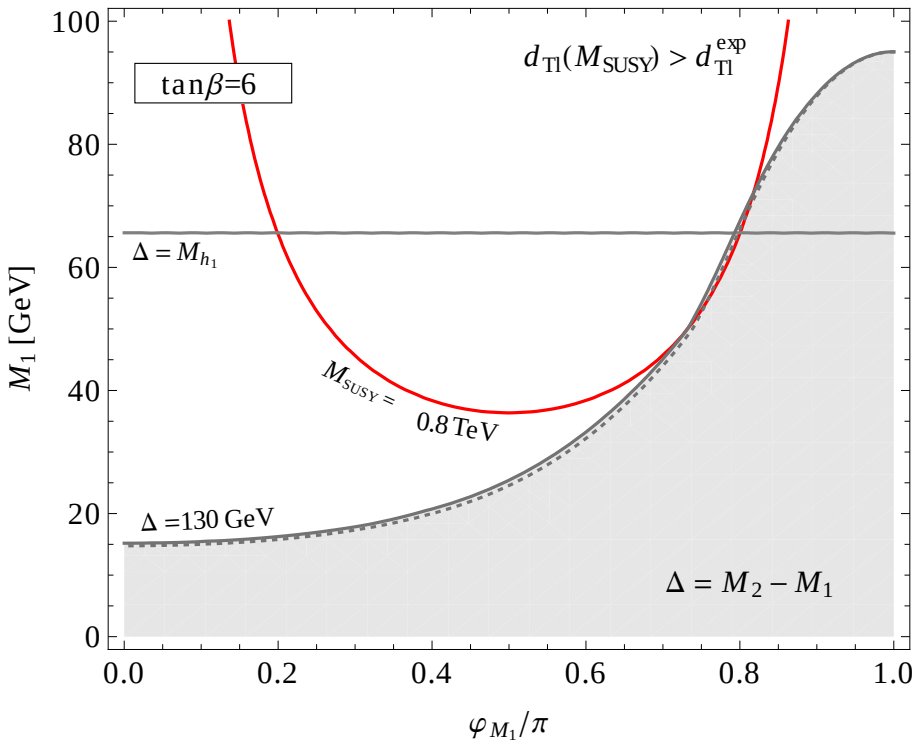
$pp \to \tilde{\chi}_1^{\pm}\tilde{\chi}_2^0 \to W\tilde{\chi}_1^0 h\tilde{\chi}_1^0 \quad (L_{int} = 300/3000 \text{ fb}^{-1})$

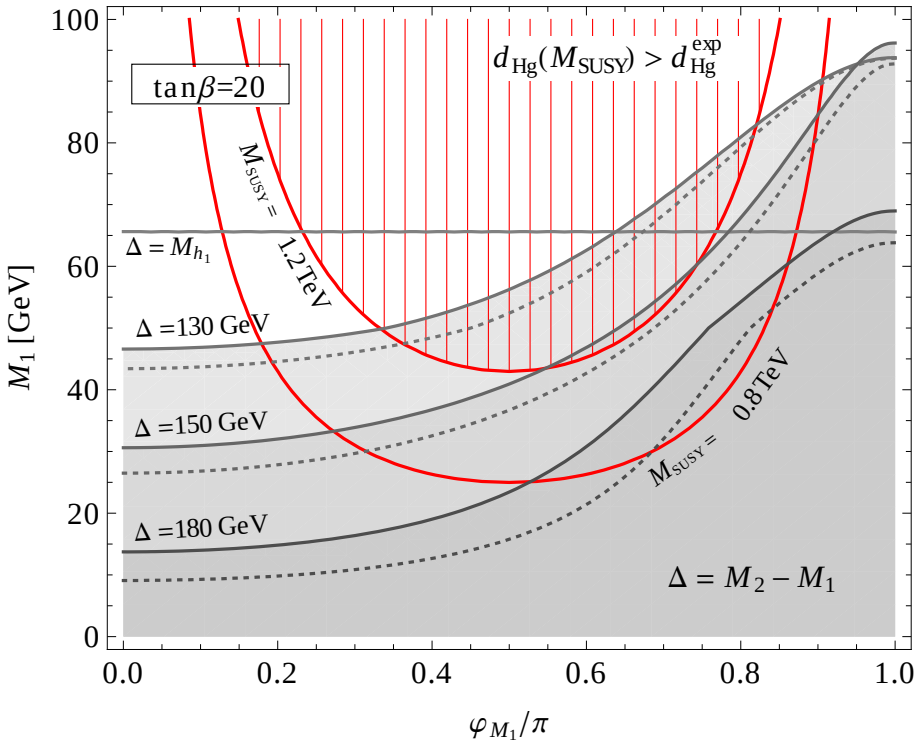




- WZ and $Wh + E_t^{\text{miss}}$ searches complementary, ideally, realistic limits require a combination

Constraining the phase of M_1





- For larger $\tan\beta$ complementarity of EDM limits on ϕ_{M_1}
- Outlook: $\tilde{\chi}_i^0\,\tilde{\chi}_j^0\,h_k$ couplings $\rightarrow$ determine relative CP-phases

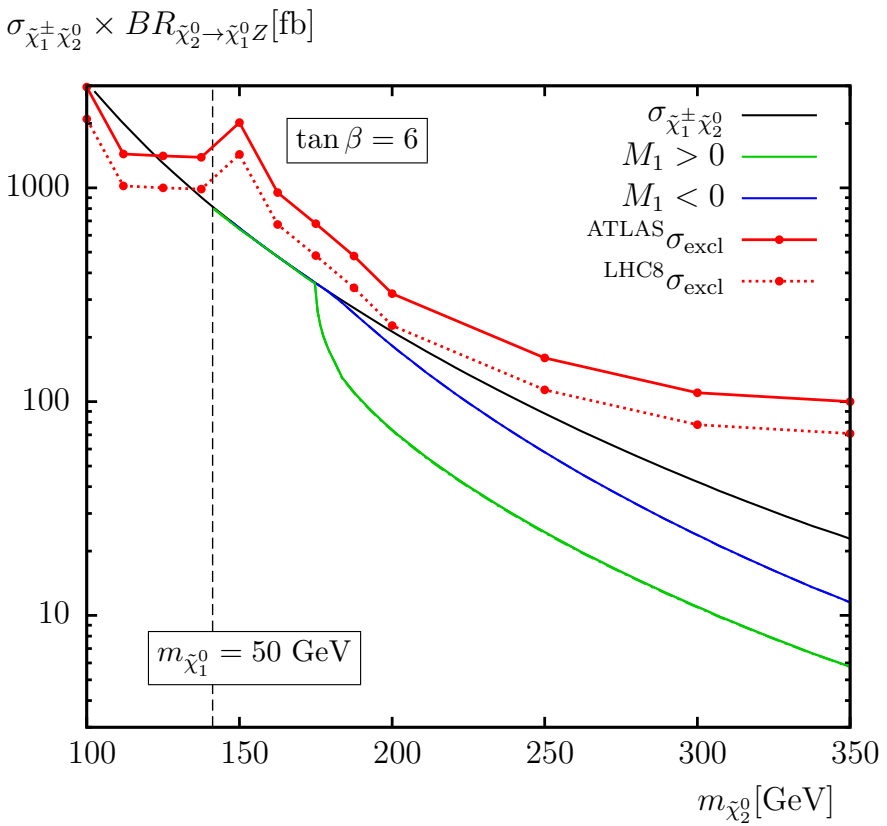
Summary

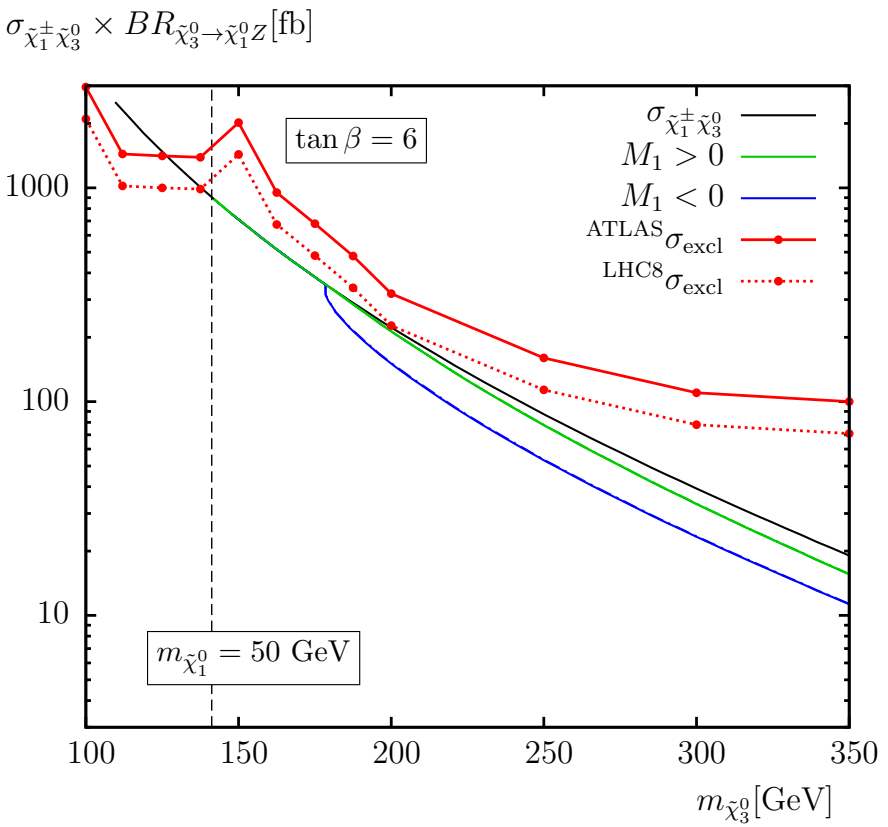
- Electroweakino searches @ LHC: no realistic bounds & discovery reach projections
- Neutralino decays to Higgs bosons potentially most sensitive channel
- use SUSY – Higgs interactions to constrain CP-phases
- similar issues for $\tilde{t}_2 \to \tilde{t}_1 h/Z$ (relevant for light $\tilde{t}_1$),
  $\tilde{b}_2(\tilde{\tau}_2) \to \tilde{b}_1(\tilde{\tau}_1) h/Z$ (relevant for large $\tan\beta$)
  $\tilde{\chi}_2^{\pm} \to \tilde{\chi}_1^{\pm} h/Z$ (heavy gauginos)

backup transparencies

EWino searches: ATLAS exclusion limits

$pp \to \tilde{\chi}_1^{\pm}\tilde{\chi}_2^0 \to W\tilde{\chi}_1^0 Z\tilde{\chi}_1^0$ low-μ scenario ($M_1 < \mu \ll M_2$)



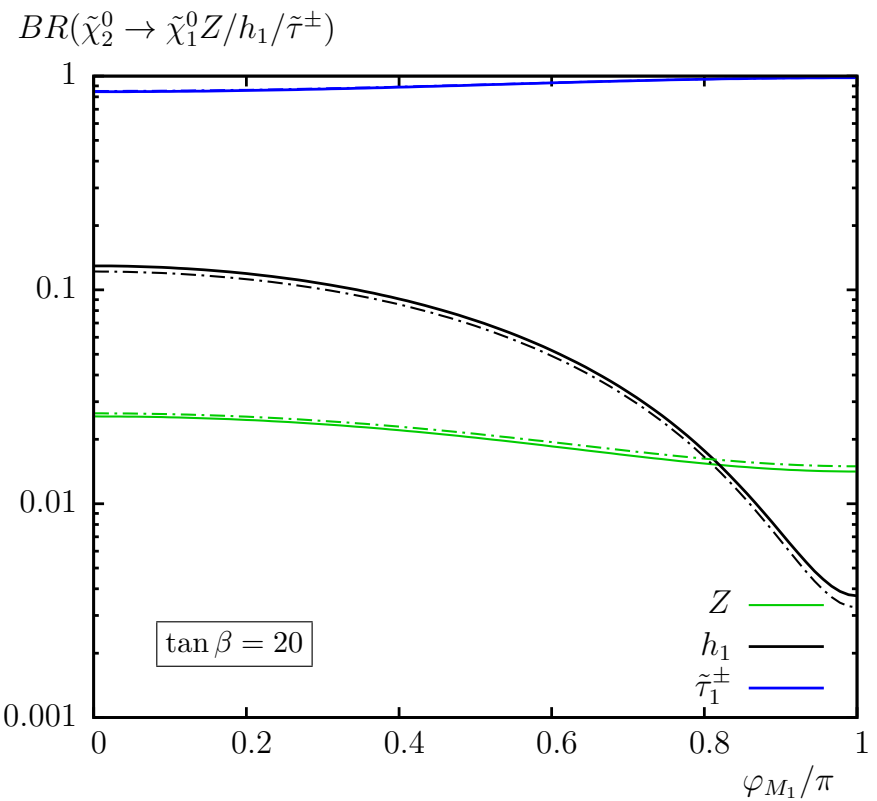


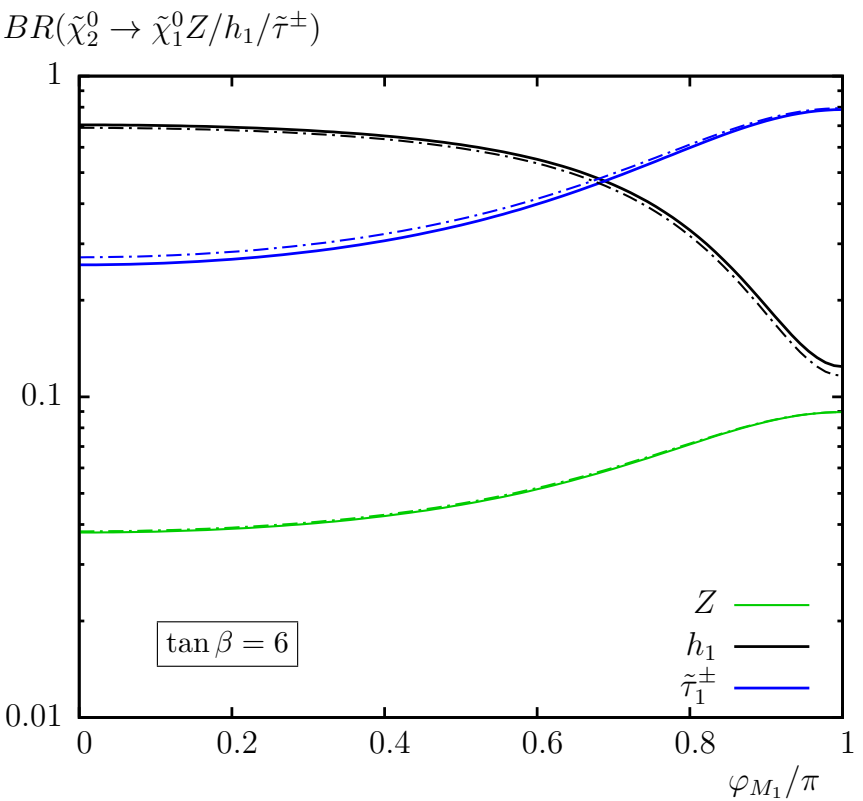
- Complementarity of $\tilde{\chi}_2^0$ and $\tilde{\chi}_3^0$ decays (opposite CP behaviour)
- higgsino-Z couplings unsuppressed: larger BR to $Z\tilde{\chi}_1^0$

RH stau-coannihilation scenario

Neutralino decay BR

$\tilde{\chi}_2^0 \to \{Z, h_1\}\tilde{\chi}_1^0, \quad \tilde{\tau}_1\tau$





[Bharucha,Heinemeyer,FP]

Scenarios

Scenario	φ_{M_1}	μ	$\tan\beta$	$M_{\rm SUSY}$	$M_{\tilde{\tau}_R}$
$S_{\rm ATLAS}$	0	1000	6	2000	$M_{\rm SUSY}$
$S_{\rm ATLAS}^{\varphi_{M_1}}$	$0 \ldots \pi$	1000	6	2000	$M_{\rm SUSY}$
$S_{\rm ATLAS}^{\tan\beta}$	0	1000	$6 \ldots 20$	2000	$M_{\rm SUSY}$
$S^{\rm DM}$	$0 \ldots \pi$	1000	$6, 20$	2000	$\lvert M_1\rvert$
$S_{\rm low-\mu}$	0	$100 \ldots 400$	6	2000	$M_{\rm SUSY}$

$|M_1| = 0 \ldots 200$ GeV, $M_2 = 100 \ldots 400(500)$ GeV, $M_3 = 1.5$ TeV

$S^{\rm DM}$: stau-coannihilation region, $\tilde{\tau}_1 \simeq \tilde{\tau}_R$