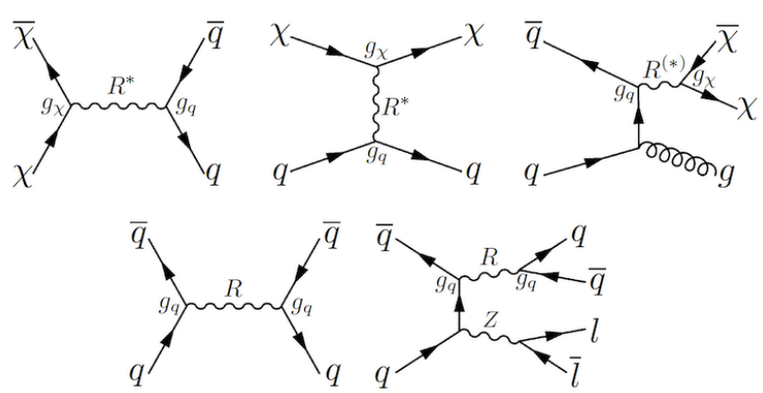
Global fits of supersymmetry
— can we still have light neutralino DM?

Are Raklev



Dark Matter @ LHC 2020

Outline

- The electroweak sector of the MSSM (EWMSSM)
- LHC searches (see also previous talk)
- Global fits
- A fit of the EWMSSM
- Conclusions

The EWMSSM

The MSSM particle content

Name	Spin	P_R	Gauge Eigenstates	Mass Eigenstates
Higgs bosons	0	+1	$H_u^0 \quad H_d^0 \quad H_u^+ \quad H_d^-$	$h^0 \quad H^0 \quad A^0 \quad H^\pm$
squarks	0	-1	$\widetilde{u}_L \quad \widetilde{u}_R \quad \widetilde{d}_L \quad \widetilde{d}_R$	(same)
			$\widetilde{s}_L \quad \widetilde{s}_R \quad \widetilde{c}_L \quad \widetilde{c}_R$	(same)
			$\widetilde{t}_L \quad \widetilde{t}_R \quad \widetilde{b}_L \quad \widetilde{b}_R$	$\widetilde{t}_1 \quad \widetilde{t}_2 \quad \widetilde{b}_1 \quad \widetilde{b}_2$
sleptons	0	-1	$\widetilde{e}_L \quad \widetilde{e}_R \quad \widetilde{\nu}_e$	(same)
			$\widetilde{\mu}_L \quad \widetilde{\mu}_R \quad \widetilde{\nu}_\mu$	(same)
			$\widetilde{\tau}_L \quad \widetilde{\tau}_R \quad \widetilde{\nu}_\tau$	$\widetilde{\tau}_1 \quad \widetilde{\tau}_2 \quad \widetilde{\nu}_\tau$
neutralinos	1/2	-1	$\widetilde{B}^0 \quad \widetilde{W}^0 \quad \widetilde{H}_u^0 \quad \widetilde{H}_d^0$	$\widetilde{\chi}_1^0 \quad \widetilde{\chi}_2^0 \quad \widetilde{\chi}_3^0 \quad \widetilde{\chi}_4^0$
charginos	1/2	-1	$\widetilde{W}^\pm \quad \widetilde{H}_u^+ \quad \widetilde{H}_d^-$	$\widetilde{\chi}_1^\pm \quad \widetilde{\chi}_2^\pm$
gluino	1/2	-1	$\widetilde{g}$	(same)

The MSSM particle content

Name	Spin	P_R	Gauge Eigenstates	Mass Eigenstates
Higgs bosons	0	+1	$H_u^0 \quad H_d^0 \quad H_u^+ \quad H_d^-$	$h^0 \quad H^0 \quad A^0 \quad H^\pm$
squarks	0	-1	$\widetilde{u}_L \quad \widetilde{u}_R \quad \widetilde{d}_L \quad \widetilde{d}_R$	(same)
			$\widetilde{s}_L \quad \widetilde{s}_R \quad \widetilde{c}_L \quad \widetilde{c}_R$	(same)
			$\widetilde{t}_L \quad \widetilde{t}_R \quad \widetilde{b}_L \quad \widetilde{b}_R$	$\widetilde{t}_1 \quad \widetilde{t}_2 \quad \widetilde{b}_1 \quad \widetilde{b}_2$
sleptons	0	-1	$\widetilde{e}_L \quad \widetilde{e}_R \quad \widetilde{\nu}_e$	(same)
			$\widetilde{\mu}_L \quad \widetilde{\mu}_R \quad \widetilde{\nu}_\mu$	(same)
			$\widetilde{\tau}_L \quad \widetilde{\tau}_R \quad \widetilde{\nu}_\tau$	$\widetilde{\tau}_1 \quad \widetilde{\tau}_2 \quad \widetilde{\nu}_\tau$
neutralinos	1/2	-1	$\widetilde{B}^0 \quad \widetilde{W}^0 \quad \widetilde{H}_u^0 \quad \widetilde{H}_d^0$	$\boxed{\widetilde{\chi}_1^0} \quad \widetilde{\chi}_2^0 \quad \widetilde{\chi}_3^0 \quad \widetilde{\chi}_4^0$
charginos	1/2	-1	$\widetilde{W}^\pm \quad \widetilde{H}_u^+ \quad \widetilde{H}_d^-$	$\widetilde{\chi}_1^\pm \quad \widetilde{\chi}_2^\pm$
gluino	1/2	-1	$\widetilde{g}$	(same)

The MSSM particle content

Name	Spin	P_R	Gauge Eigenstates	Mass Eigenstates
Higgs bosons	0	+1	$H_u^0 \quad H_d^0 \quad H_u^+ \quad H_d^-$	$h^0 \quad H^0 \quad A^0 \quad H^\pm$
squarks	0	-1	$\widetilde{u}_L \quad \widetilde{u}_R \quad \widetilde{d}_L \quad \widetilde{d}_R$	(same)
			$\widetilde{s}_L \quad \widetilde{s}_R \quad \widetilde{c}_L \quad \widetilde{c}_R$	(same)
			$\widetilde{t}_L \quad \widetilde{t}_R \quad \widetilde{b}_L \quad \widetilde{b}_R$	$\widetilde{t}_1 \quad \widetilde{t}_2 \quad \widetilde{b}_1 \quad \widetilde{b}_2$
sleptons	0	-1	$\widetilde{e}_L \quad \widetilde{e}_R \quad \widetilde{\nu}_e$	(same)
			$\widetilde{\mu}_L \quad \widetilde{\mu}_R \quad \widetilde{\nu}_\mu$	(same)
			$\widetilde{\tau}_L \quad \widetilde{\tau}_R \quad \widetilde{\nu}_\tau$	$\widetilde{\tau}_1 \quad \widetilde{\tau}_2 \quad \widetilde{\nu}_\tau$
neutralinos	1/2	-1	$\widetilde{B}^0 \quad \widetilde{W}^0 \quad \widetilde{H}_u^0 \quad \widetilde{H}_d^0$	$\widetilde{\chi}_1^0 \quad \widetilde{\chi}_2^0 \quad \widetilde{\chi}_3^0 \quad \widetilde{\chi}_4^0$
charginos	1/2	-1	$\widetilde{W}^\pm \quad \widetilde{H}_u^+ \quad \widetilde{H}_d^-$	$\widetilde{\chi}_1^\pm \quad \widetilde{\chi}_2^\pm$
gluino	1/2	-1	$\widetilde{g}$	(same)

The MSSM particle content

Name	Spin	P_R	Gauge Eigenstates	Mass Eigenstates
Higgs bosons	0	+1	$H_u^0 \quad H_d^0 \quad H_u^+ \quad H_d^-$	$h^0 \quad H^0 \quad A^0 \quad H^\pm$
squarks	0	-1	$\widetilde{u}_L \quad \widetilde{u}_R \quad \widetilde{d}_L \quad \widetilde{d}_R$	(same)
			$\widetilde{s}_L \quad \widetilde{s}_R \quad \widetilde{c}_L \quad \widetilde{c}_R$	(same)
			$\widetilde{t}_L \quad \widetilde{t}_R \quad \widetilde{b}_L \quad \widetilde{b}_R$	$\widetilde{t}_1 \quad \widetilde{t}_2 \quad \widetilde{b}_1 \quad \widetilde{b}_2$
sleptons	0	-1	$\widetilde{e}_L \quad \widetilde{e}_R \quad \widetilde{\nu}_e$	(same)
			$\widetilde{\mu}_L \quad \widetilde{\mu}_R \quad \widetilde{\nu}_\mu$	(same)
			$\widetilde{\tau}_L \quad \widetilde{\tau}_R \quad \widetilde{\nu}_\tau$	$\widetilde{\tau}_1 \quad \widetilde{\tau}_2 \quad \widetilde{\nu}_\tau$
neutralinos	1/2	-1	$\widetilde{B}^0 \quad \widetilde{W}^0 \quad \widetilde{H}_u^0 \quad \widetilde{H}_d^0$	$\widetilde{\chi}_1^0 \quad \widetilde{\chi}_2^0 \quad \widetilde{\chi}_3^0 \quad \widetilde{\chi}_4^0$
charginos	1/2	-1	$\widetilde{W}^\pm \quad \widetilde{H}_u^+ \quad \widetilde{H}_d^-$	$\widetilde{\chi}_1^\pm \quad \widetilde{\chi}_2^\pm$
gluino	1/2	-1	$\widetilde{g}$	(same)

The MSSM particle content

Name	Spin	P_R	Gauge Eigenstates	Mass Eigenstates
Higgs bosons	0	+1	$H_u^0 \quad H_d^0 \quad H_u^+ \quad H_d^-$	$h^0 \quad H^0 \quad A^0 \quad H^\pm$
squarks	0	-1	$\widetilde{u}_L \quad \widetilde{u}_R \quad \widetilde{d}_L \quad \widetilde{d}_R$	(same)
			$\widetilde{s}_L \quad \widetilde{s}_R \quad \widetilde{c}_L \quad \widetilde{c}_R$	(same)
			$\widetilde{t}_L \quad \widetilde{t}_R \quad \widetilde{b}_L \quad \widetilde{b}_R$	$\widetilde{t}_1 \quad \widetilde{t}_2 \quad \widetilde{b}_1 \quad \widetilde{b}_2$
sleptons	0	-1	$\widetilde{e}_L \quad \widetilde{e}_R \quad \widetilde{\nu}_e$	(same)
			$\widetilde{\mu}_L \quad \widetilde{\mu}_R \quad \widetilde{\nu}_\mu$	(same)
			$\widetilde{\tau}_L \quad \widetilde{\tau}_R \quad \widetilde{\nu}_\tau$	$\widetilde{\tau}_1 \quad \widetilde{\tau}_2 \quad \widetilde{\nu}_\tau$
neutralinos	1/2	-1	$\widetilde{B}^0 \quad \widetilde{W}^0 \quad \widetilde{H}_u^0 \quad \widetilde{H}_d^0$	$\widetilde{\chi}_1^0 \quad \widetilde{\chi}_2^0 \quad \widetilde{\chi}_3^0 \quad \widetilde{\chi}_4^0$
charginos	1/2	-1	$\widetilde{W}^\pm \quad \widetilde{H}_u^+ \quad \widetilde{H}_d^-$	$\widetilde{\chi}_1^\pm \quad \widetilde{\chi}_2^\pm$
gluino	1/2	-1	$\widetilde{g}$	(same)

Decoupled

The MSSM particle content

Name	Spin	P_R	Gauge Eigenstates	Mass Eigenstates
Higgs bosons	0	+1	$H_u^0 \quad H_d^0 \quad H_u^+ \quad H_d^-$	$h^0 \quad H^0 \quad A^0 \quad H^\pm$
squarks	0	-1	$\widetilde{u}_L \quad \widetilde{u}_R \quad \widetilde{d}_L \quad \widetilde{d}_R$	(same)
			$\widetilde{s}_L \quad \widetilde{s}_R \quad \widetilde{c}_L \quad \widetilde{c}_R$	(same)
			$\widetilde{t}_L \quad \widetilde{t}_R \quad \widetilde{b}_L \quad \widetilde{b}_R$	$\widetilde{t}_1 \quad \widetilde{t}_2 \quad \widetilde{b}_1 \quad \widetilde{b}_2$
sleptons	0	-1	$\widetilde{e}_L \quad \widetilde{e}_R \quad \widetilde{\nu}_e$	(same)
			$\widetilde{\mu}_L \quad \widetilde{\mu}_R \quad \widetilde{\nu}_\mu$	(same)
			$\widetilde{\tau}_L \quad \widetilde{\tau}_R \quad \widetilde{\nu}_\tau$	$\widetilde{\tau}_1 \quad \widetilde{\tau}_2 \quad \widetilde{\nu}_\tau$
electroweakinos — EWMSSM				
neutralinos	1/2	-1	$\widetilde{B}^0 \quad \widetilde{W}^0 \quad \widetilde{H}_u^0 \quad \widetilde{H}_d^0$	$\widetilde{\chi}_1^0 \quad \widetilde{\chi}_2^0 \quad \widetilde{\chi}_3^0 \quad \widetilde{\chi}_4^0$
charginos	1/2	-1	$\widetilde{W}^\pm \quad \widetilde{H}_u^+ \quad \widetilde{H}_d^-$	$\widetilde{\chi}_1^\pm \quad \widetilde{\chi}_2^\pm$
gluino	1/2	-1	$\widetilde{g}$	(same)

Decoupled

Neutralinos & charginos

Neutralinos

$$\psi^0 = (\tilde{B}, \tilde{W}^0, \tilde{H}_d^0, \tilde{H}_u^0)$$

$$M_N = \begin{pmatrix} M_1 & 0 & -\frac{1}{2}g'vc_\beta & \frac{1}{2}g'vs_\beta \\ 0 & M_2 & \frac{1}{2}gvc_\beta & -\frac{1}{2}gvs_\beta \\ -\frac{1}{2}g'vc_\beta & \frac{1}{2}gvc_\beta & 0 & -\mu \\ \frac{1}{2}g'vs_\beta & -\frac{1}{2}gvs_\beta & -\mu & 0 \end{pmatrix}$$

Charginos

$$\psi^\pm = (\tilde{W}^+, \tilde{H}_u^+, \tilde{W}^-, \tilde{H}_d^-)$$

$$M_C = \begin{pmatrix} 0 & X^T \\ X & 0 \end{pmatrix}, \quad \text{where} \quad X = \begin{pmatrix} M_2 & \frac{gvs_\beta}{\sqrt{2}} \\ \frac{gvc_\beta}{\sqrt{2}} & \mu \end{pmatrix}.$$

Modified from original slide courtesy of Anders Kvellestad

Neutralinos & charginos

Neutralinos

M_1

$$\psi^0 = (\tilde{B}, \tilde{W}^0, \tilde{H}_d^0, \tilde{H}_u^0)$$

$$M_N = \begin{pmatrix} M_1 & 0 & -\frac{1}{2}g'vc_\beta & \frac{1}{2}g'vs_\beta \\ 0 & M_2 & \frac{1}{2}gvc_\beta & -\frac{1}{2}gvs_\beta \\ -\frac{1}{2}g'vc_\beta & \frac{1}{2}gvc_\beta & 0 & -\mu \\ \frac{1}{2}g'vs_\beta & -\frac{1}{2}gvs_\beta & -\mu & 0 \end{pmatrix}$$

Charginos

$$\psi^\pm = (\tilde{W}^+, \tilde{H}_u^+, \tilde{W}^-, \tilde{H}_d^-)$$

$$M_C = \begin{pmatrix} 0 & X^T \\ X & 0 \end{pmatrix}, \quad \text{where} \quad X = \begin{pmatrix} M_2 & \frac{gvs_\beta}{\sqrt{2}} \\ \frac{gvc_\beta}{\sqrt{2}} & \mu \end{pmatrix}.$$

Modified from original slide courtesy of Anders Kvellestad

Neutralinos & charginos

Neutralinos

M_1 M_2

$$\psi^0 = (\tilde{B}, \tilde{W}^0, \tilde{H}_d^0, \tilde{H}_u^0)$$

$$M_N = \begin{pmatrix} M_1 & 0 & -\frac{1}{2}g'vc_\beta & \frac{1}{2}g'vs_\beta \\ 0 & M_2 & \frac{1}{2}gvc_\beta & -\frac{1}{2}gvs_\beta \\ -\frac{1}{2}g'vc_\beta & \frac{1}{2}gvc_\beta & 0 & -\mu \\ \frac{1}{2}g'vs_\beta & -\frac{1}{2}gvs_\beta & -\mu & 0 \end{pmatrix}$$

Charginos

$$\psi^\pm = (\tilde{W}^+, \tilde{H}_u^+, \tilde{W}^-, \tilde{H}_d^-)$$

$$M_C = \begin{pmatrix} 0 & X^T \\ X & 0 \end{pmatrix}, \quad \text{where} \quad X = \begin{pmatrix} M_2 & \frac{gvs_\beta}{\sqrt{2}} \\ \frac{gvc_\beta}{\sqrt{2}} & \mu \end{pmatrix}.$$

Modified from original slide courtesy of Anders Kvellestad

Neutralinos & charginos

Neutralinos

M_1 M_2 μ

$$\psi^0 = (\tilde{B}, \tilde{W}^0, \tilde{H}_d^0, \tilde{H}_u^0)$$

$$M_N = \begin{pmatrix} M_1 & 0 & -\frac{1}{2}g'vc_\beta & \frac{1}{2}g'vs_\beta \\ 0 & M_2 & \frac{1}{2}gvc_\beta & -\frac{1}{2}gvs_\beta \\ -\frac{1}{2}g'vc_\beta & \frac{1}{2}gvc_\beta & 0 & -\mu \\ \frac{1}{2}g'vs_\beta & -\frac{1}{2}gvs_\beta & -\mu & 0 \end{pmatrix}$$

Charginos

$$\psi^\pm = (\tilde{W}^+, \tilde{H}_u^+, \tilde{W}^-, \tilde{H}_d^-)$$

$$M_C = \begin{pmatrix} 0 & X^T \\ X & 0 \end{pmatrix}, \quad \text{where} \quad X = \begin{pmatrix} M_2 & \frac{gvs_\beta}{\sqrt{2}} \\ \frac{gvc_\beta}{\sqrt{2}} & \mu \end{pmatrix}.$$

Modified from original slide courtesy of Anders Kvellestad

Neutralinos & charginos

M_1 M_2 μ $\tan\beta$

Neutralinos

$$\psi^0 = (\tilde{B}, \tilde{W}^0, \tilde{H}_d^0, \tilde{H}_u^0)$$

$$M_N = \begin{pmatrix} M_1 & 0 & -\frac{1}{2}g' v c_\beta & \frac{1}{2}g' v s_\beta \\ 0 & M_2 & \frac{1}{2}g v c_\beta & -\frac{1}{2}g v s_\beta \\ -\frac{1}{2}g' v c_\beta & \frac{1}{2}g v c_\beta & 0 & -\mu \\ \frac{1}{2}g' v s_\beta & -\frac{1}{2}g v s_\beta & -\mu & 0 \end{pmatrix}$$

Charginos

$$\psi^\pm = (\tilde{W}^+, \tilde{H}_u^+, \tilde{W}^-, \tilde{H}_d^-)$$

$$M_C = \begin{pmatrix} 0 & X^T \\ X & 0 \end{pmatrix}, \quad \text{where} \quad X = \begin{pmatrix} M_2 & \frac{g v s_\beta}{\sqrt{2}} \\ \frac{g v c_\beta}{\sqrt{2}} & \mu \end{pmatrix}.$$

Modified from original slide courtesy of Anders Kvellestad

Neutralinos & charginos

Neutralinos

$$\psi^0 = (\tilde{B}, \tilde{W}^0, \tilde{H}_d^0, \tilde{H}_u^0)$$

M_1 M_2 μ $\tan\beta$

Rough summary:

M_1 controls the mass of **one neutralino (bino)**

M_2 controls the mass of **one neutralino** and **one chargino (winos)**

μ controls the mass of **two neutralinos** and **one chargino (higgsinos)**

M_N

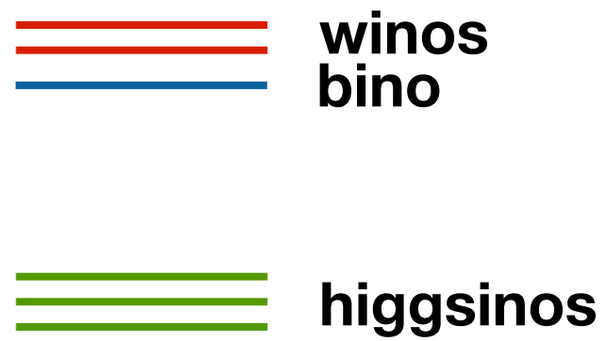
$\begin{pmatrix} X & 0 \end{pmatrix}$, where it

$\begin{pmatrix} \frac{gv_d}{\sqrt{2}} & \mu \end{pmatrix}$

Modified from original slide courtesy of Anders Kvellestad

Mass hierarchies

$M_2 \ll M_1, \mu$

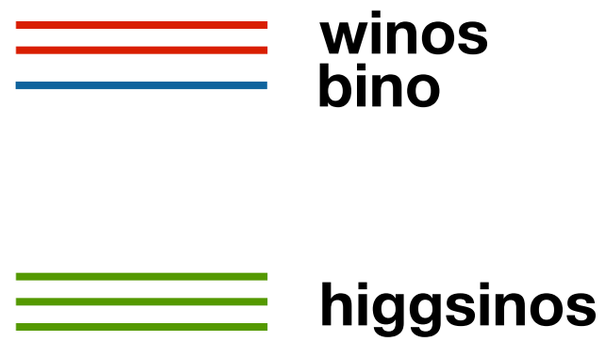


$\mu \ll M_1, M_2$

Degenerate wino/ higgsino LSPs

Mass hierarchies

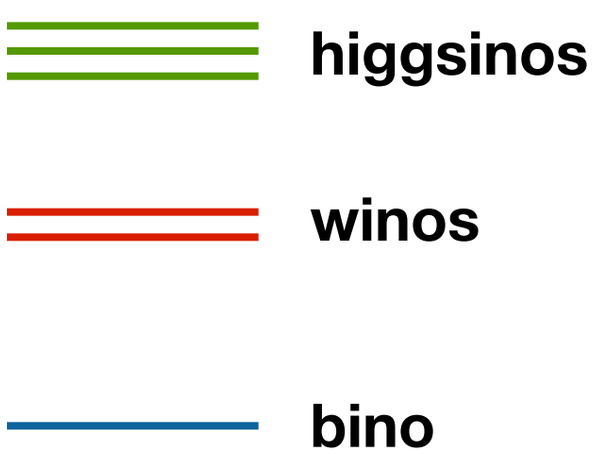
$M_2 \ll M_1, \mu$



$\mu \ll M_1, M_2$

Degenerate wino/ higgsino LSPs

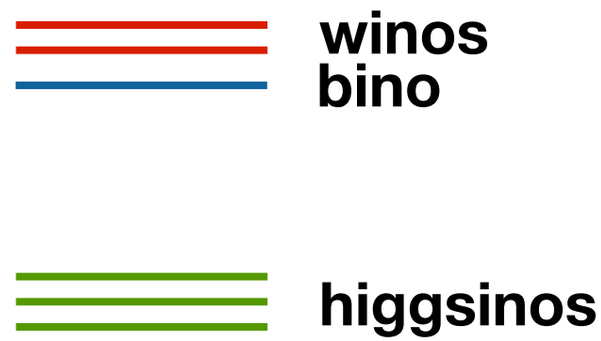
Wino NLSP(s) $\tilde{\chi}_2^0, \tilde{\chi}_1^\pm$



$M_1 < M_2 < \mu$

Mass hierarchies

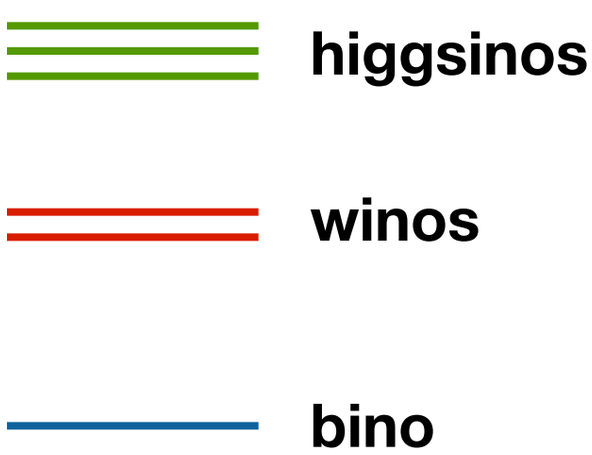
$M_2 \ll M_1, \mu$



$\mu \ll M_1, M_2$

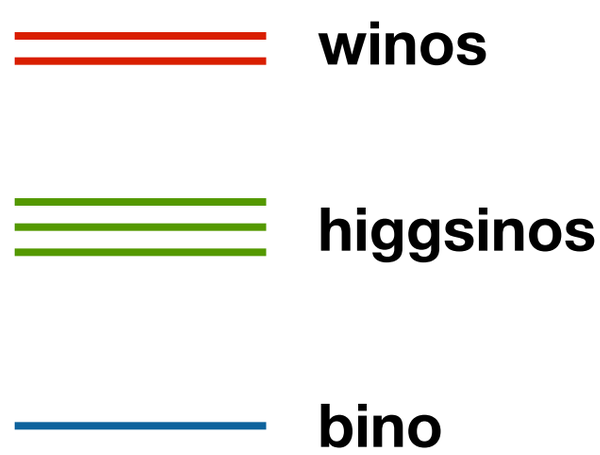
Degenerate wino/ higgsino LSPs

Wino NLSP(s) $\tilde{\chi}_2^0, \tilde{\chi}_1^\pm$



$M_1 < M_2 < \mu$

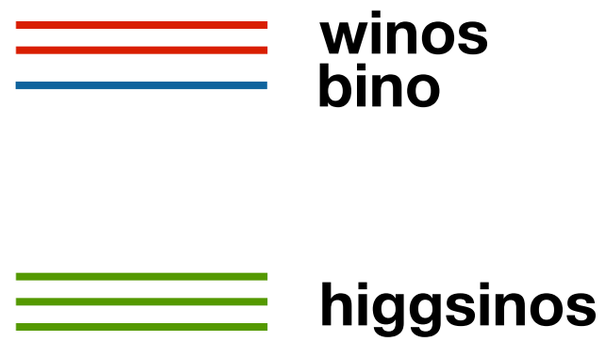
Higgsino NLSP(s) $\tilde{\chi}_2^0, \tilde{\chi}_3^0, \tilde{\chi}_1^\pm$



$M_1 < \mu < M_2$

Mass hierarchies

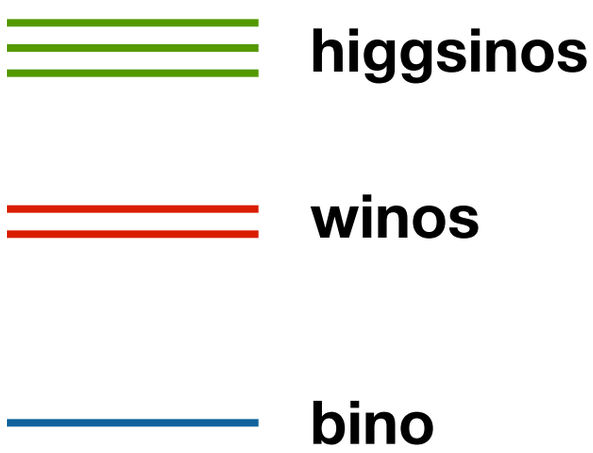
$M_2 \ll M_1, \mu$



$\mu \ll M_1, M_2$

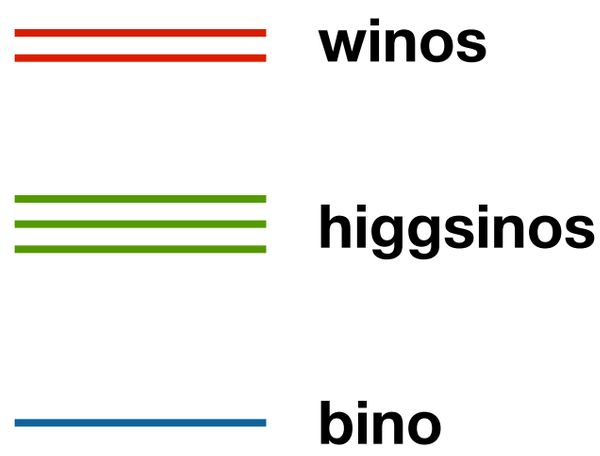
Degenerate wino/ higgsino LSPs

Wino NLSP(s) $\tilde{\chi}_2^0, \tilde{\chi}_1^\pm$



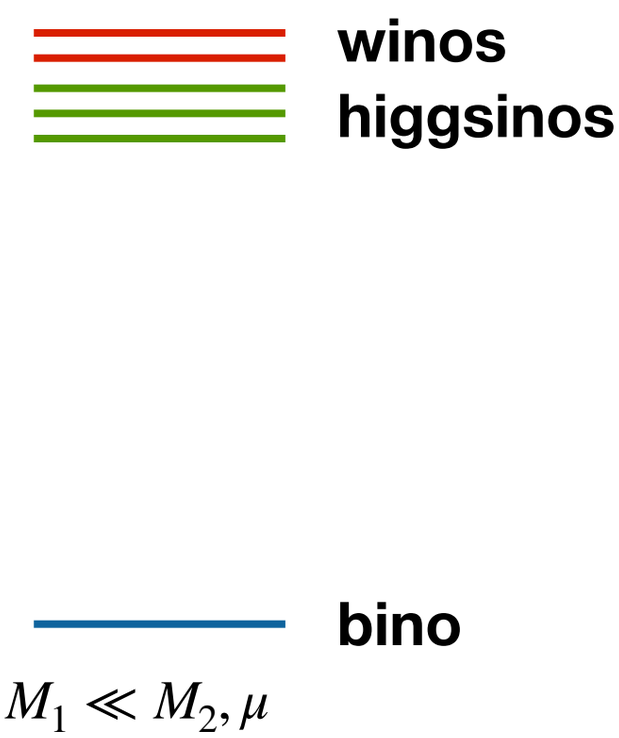
$M_1 < M_2 < \mu$

Higgsino NLSP(s) $\tilde{\chi}_2^0, \tilde{\chi}_3^0, \tilde{\chi}_1^\pm$



$M_1 < \mu < M_2$

Lonely bino

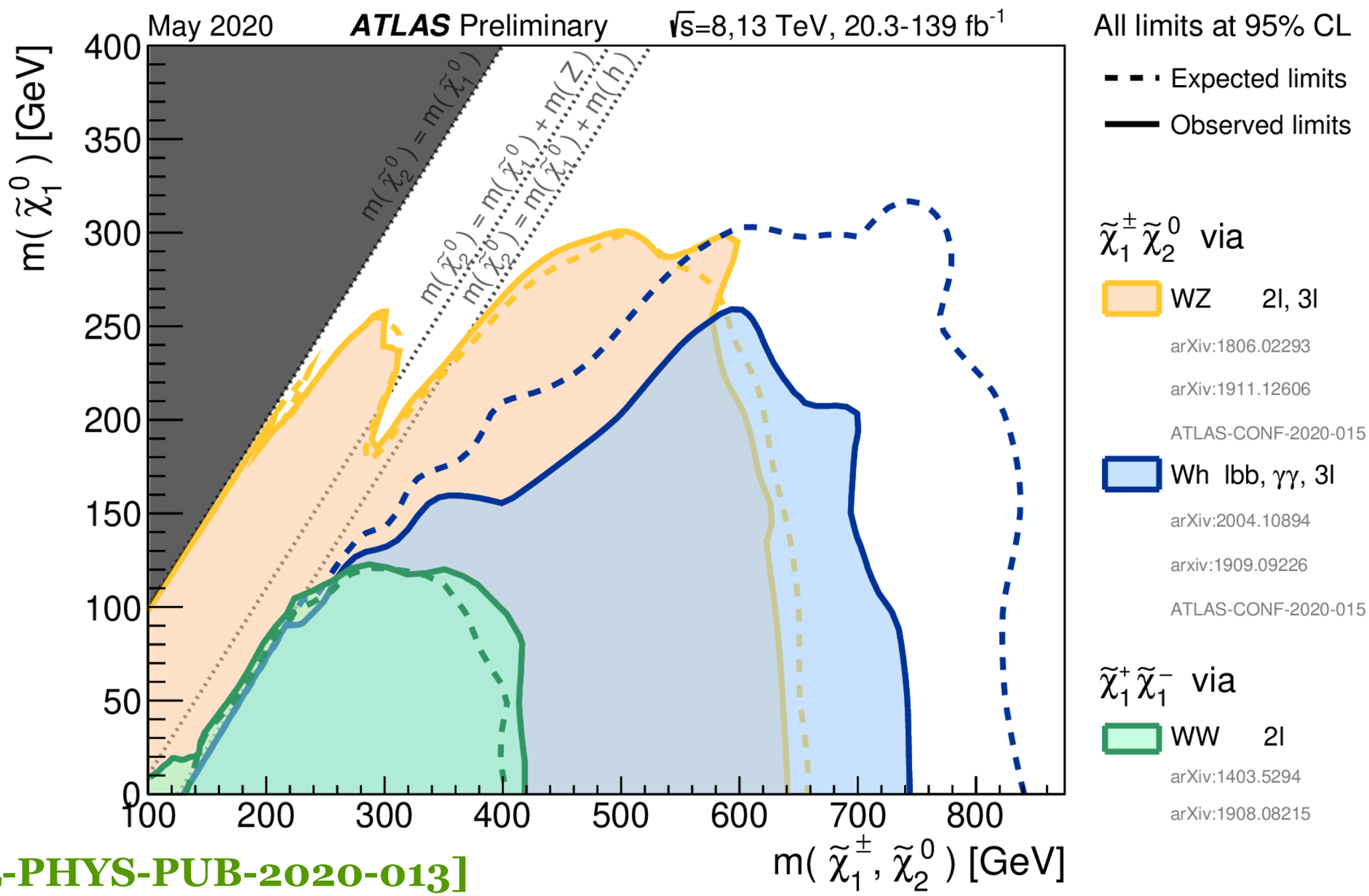


$M_1 \ll M_2, \mu$

LHC searches

LHC searches

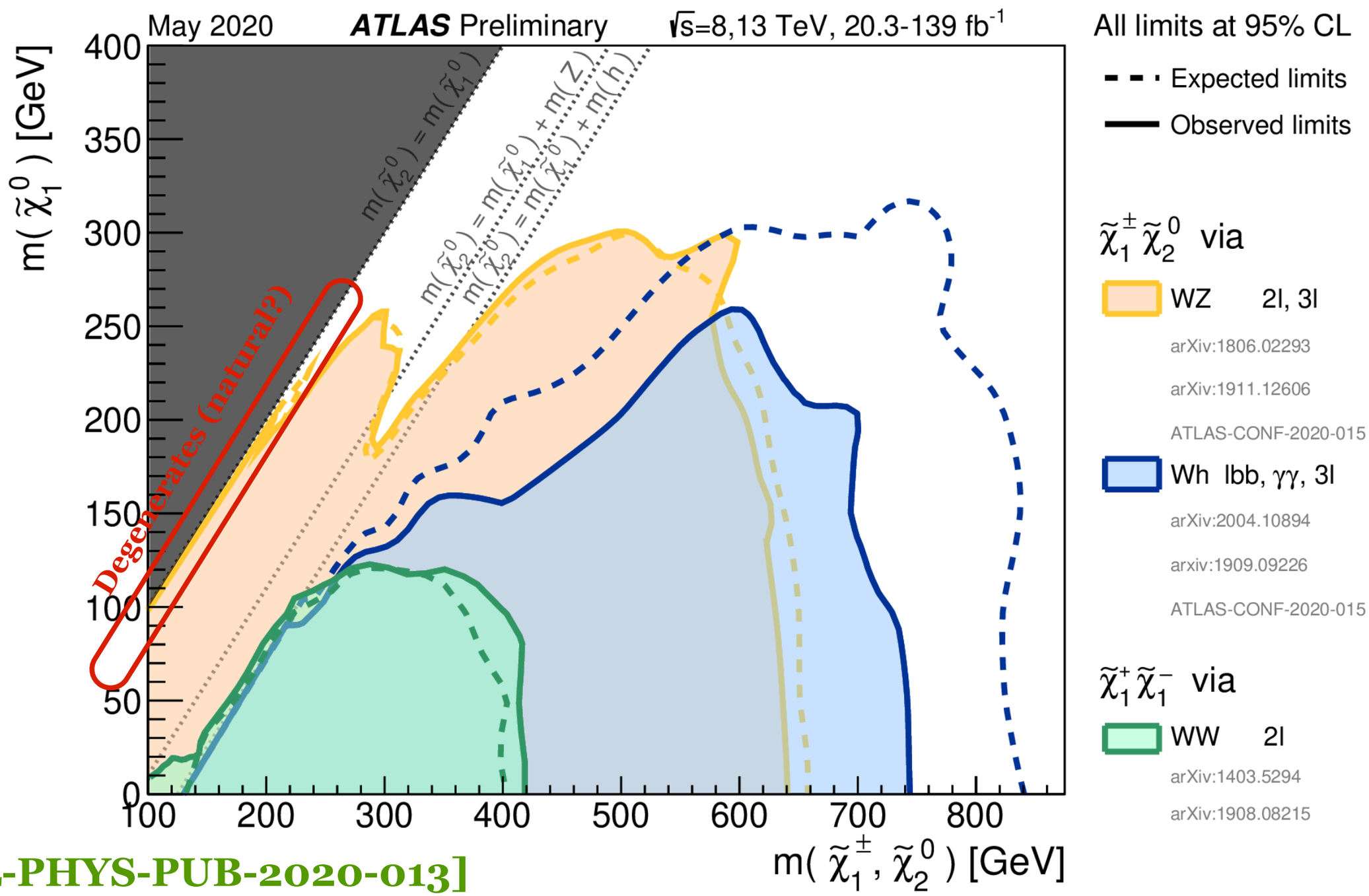
- The LHC experiments have done a spectacular job of searching for neutralino DM



[ATL-PHYS-PUB-2020-013]

LHC searches

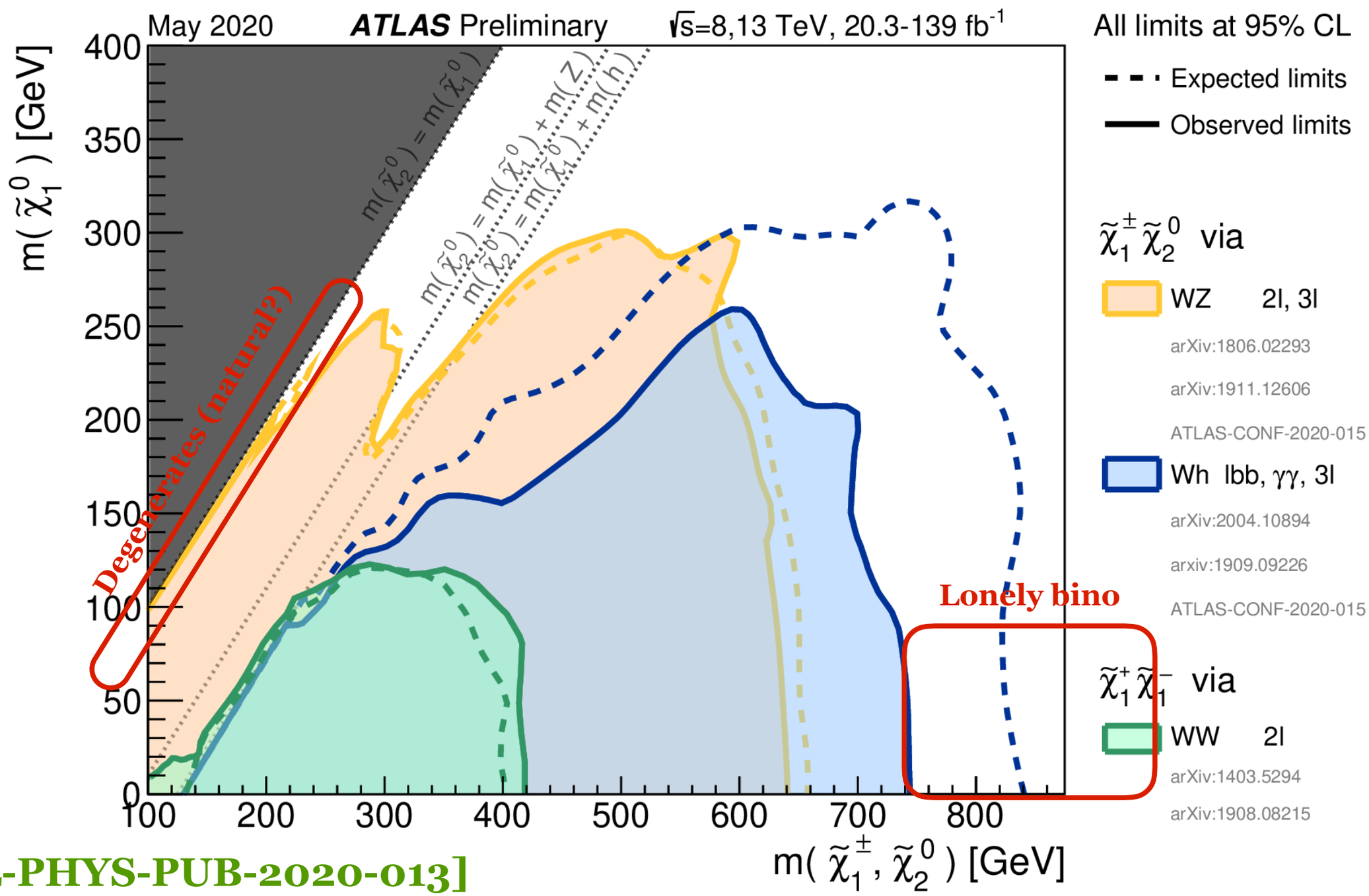
- The LHC experiments have done a spectacular job of searching for neutralino DM



[ATL-PHYS-PUB-2020-013]

LHC searches

- The LHC experiments have done a spectacular job of searching for neutralino DM



[ATL-PHYS-PUB-2020-013]

However…

- Summary plot assumes wino production cross sections (generically smaller for bino & higgsino).
- For each channel a 100% BR is assumed.
- What happens when you join searches instead of overlaying the strongest ones?
- (What happens if you go beyond the MSSM?)

Global fits

Global fits

- Choose your BSM model and parameterisation.

- Calculate a *combined consistent likelihood* from relevant experimental results:

$$\mathscr{L} = \mathscr{L}_{\text{Collider}}\mathscr{L}_{\text{Higgs}}\mathscr{L}_{\text{Flavour}}\mathscr{L}_{\text{DM}}\mathscr{L}_{\text{Precision}}\cdots$$

- Use a sophisticated scanning technique to explore the likelihood function across the parameter space of the model to determine:

  - The best fit regions of parameter space of a particular theory.

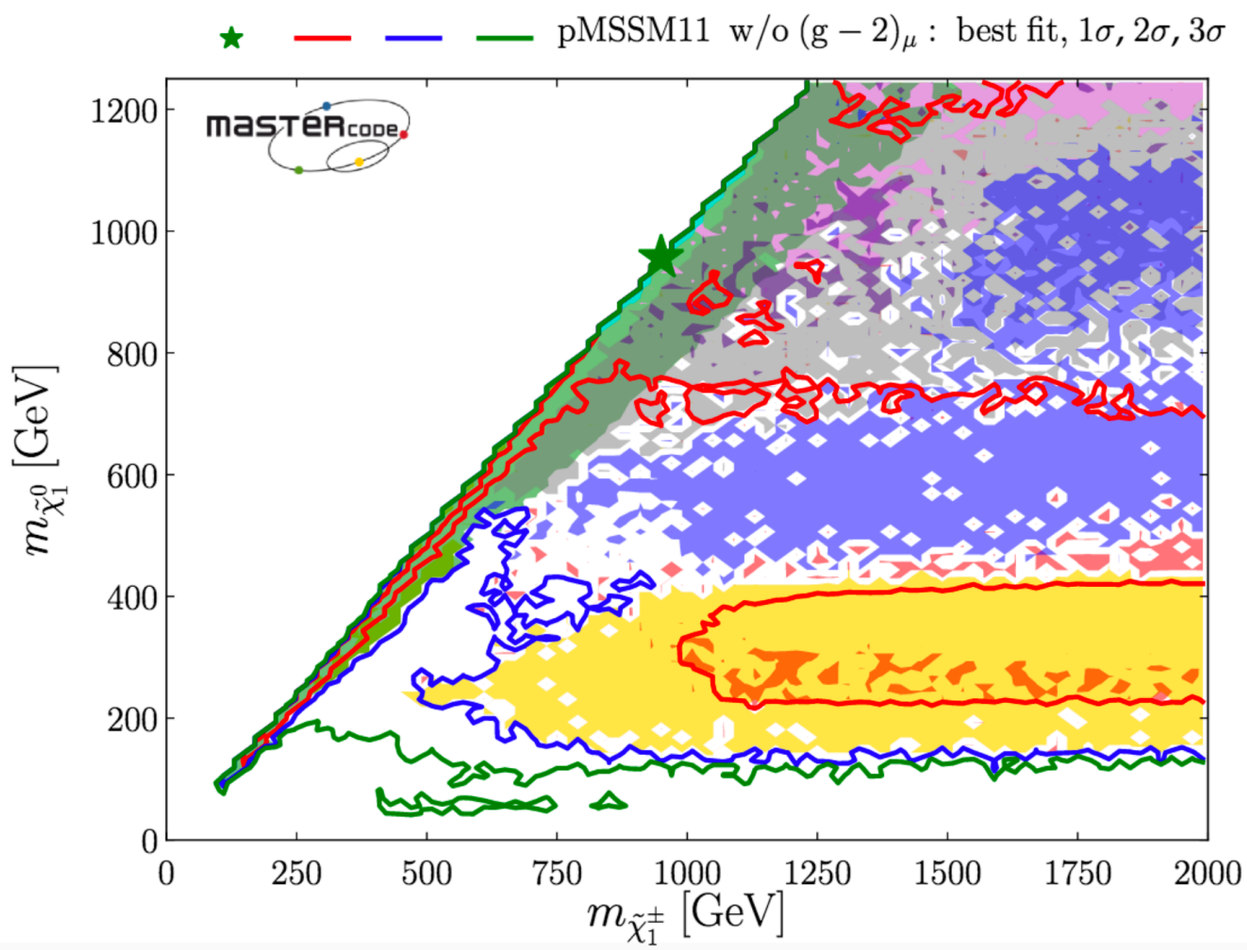
  - Which theories give (comparatively) the best fit to the data.

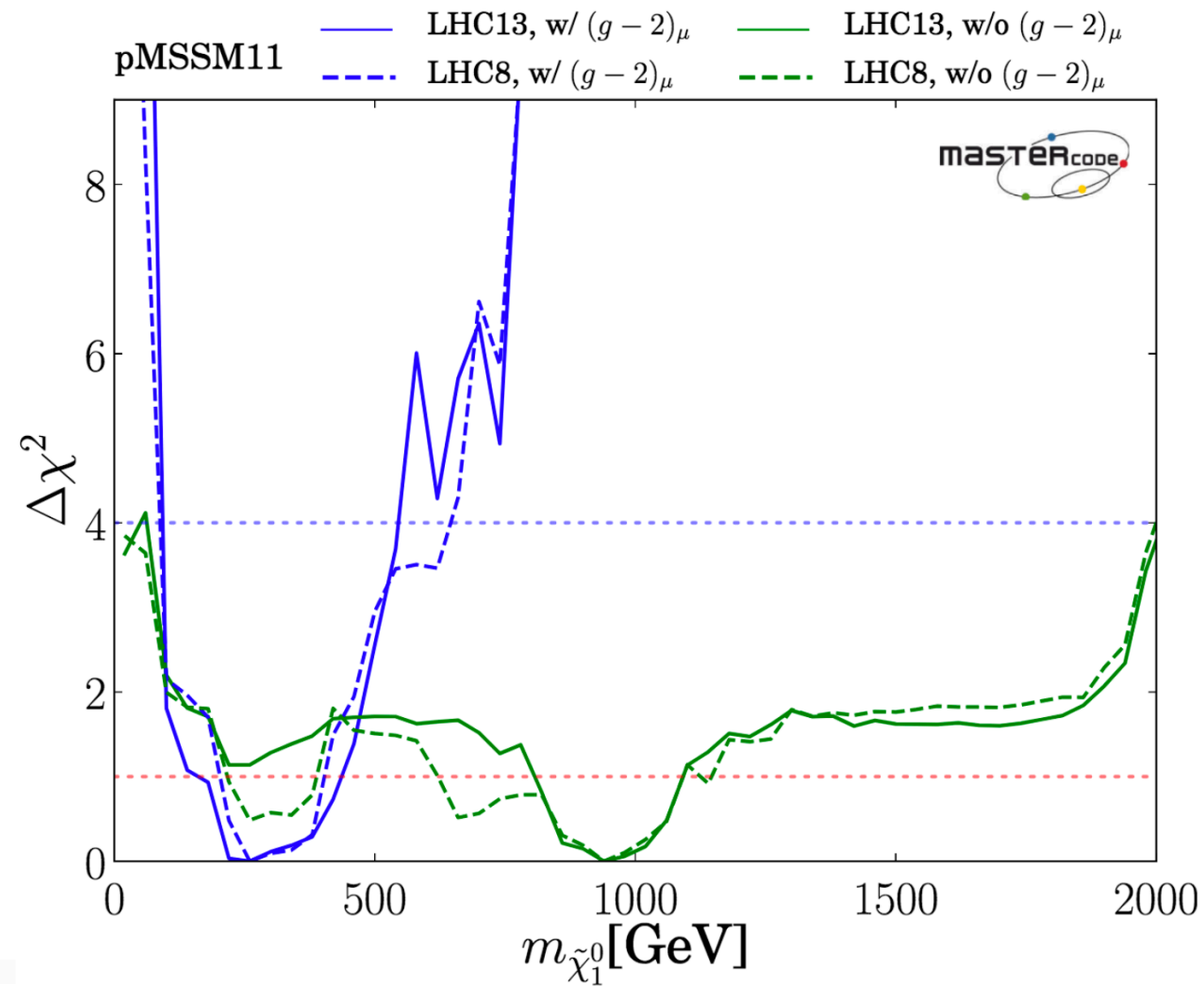
- Sensible statistical interpretation (inference):

  - Not just counting number of points.

  - Choice of approach: frequentist/Bayesian.

Recent results

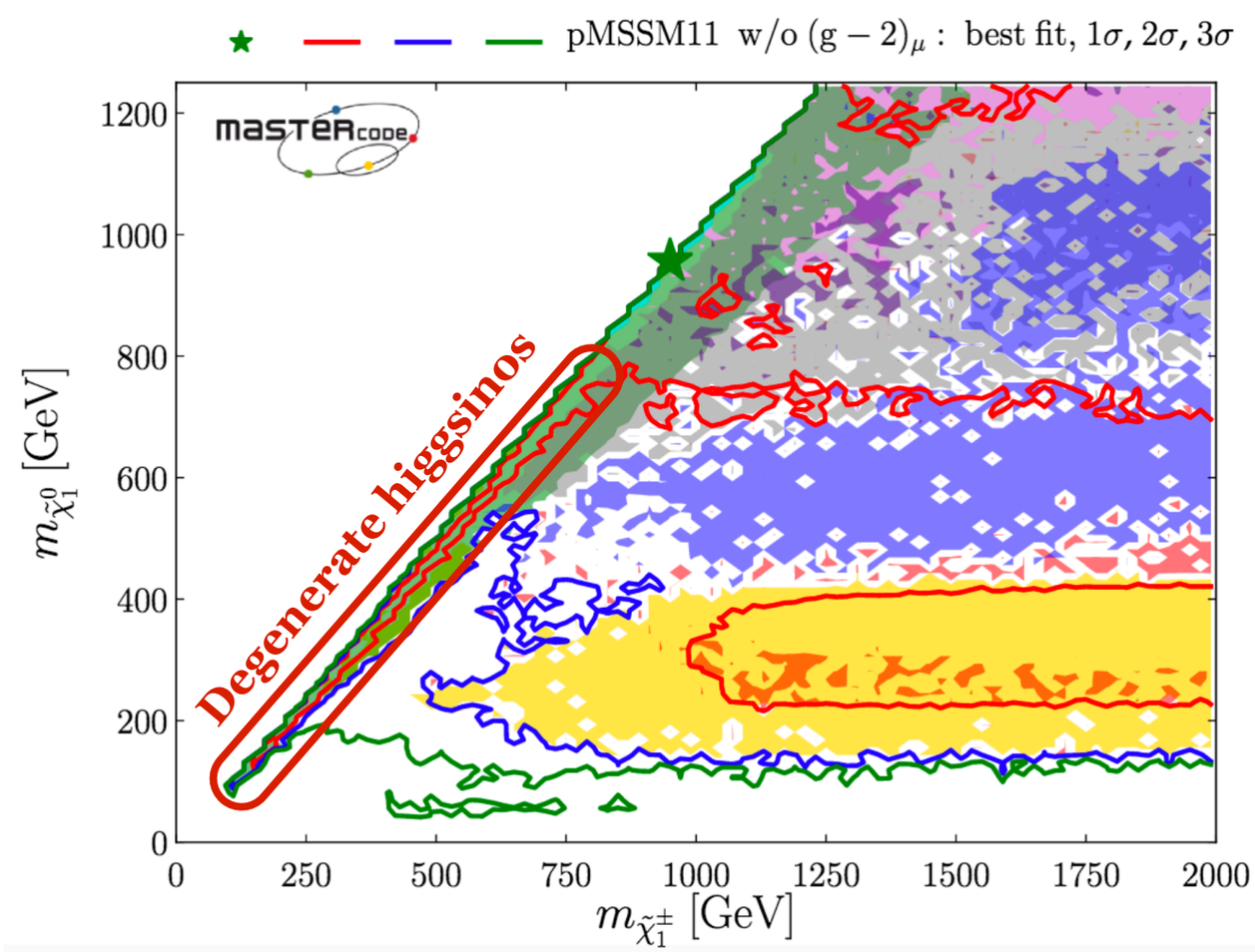


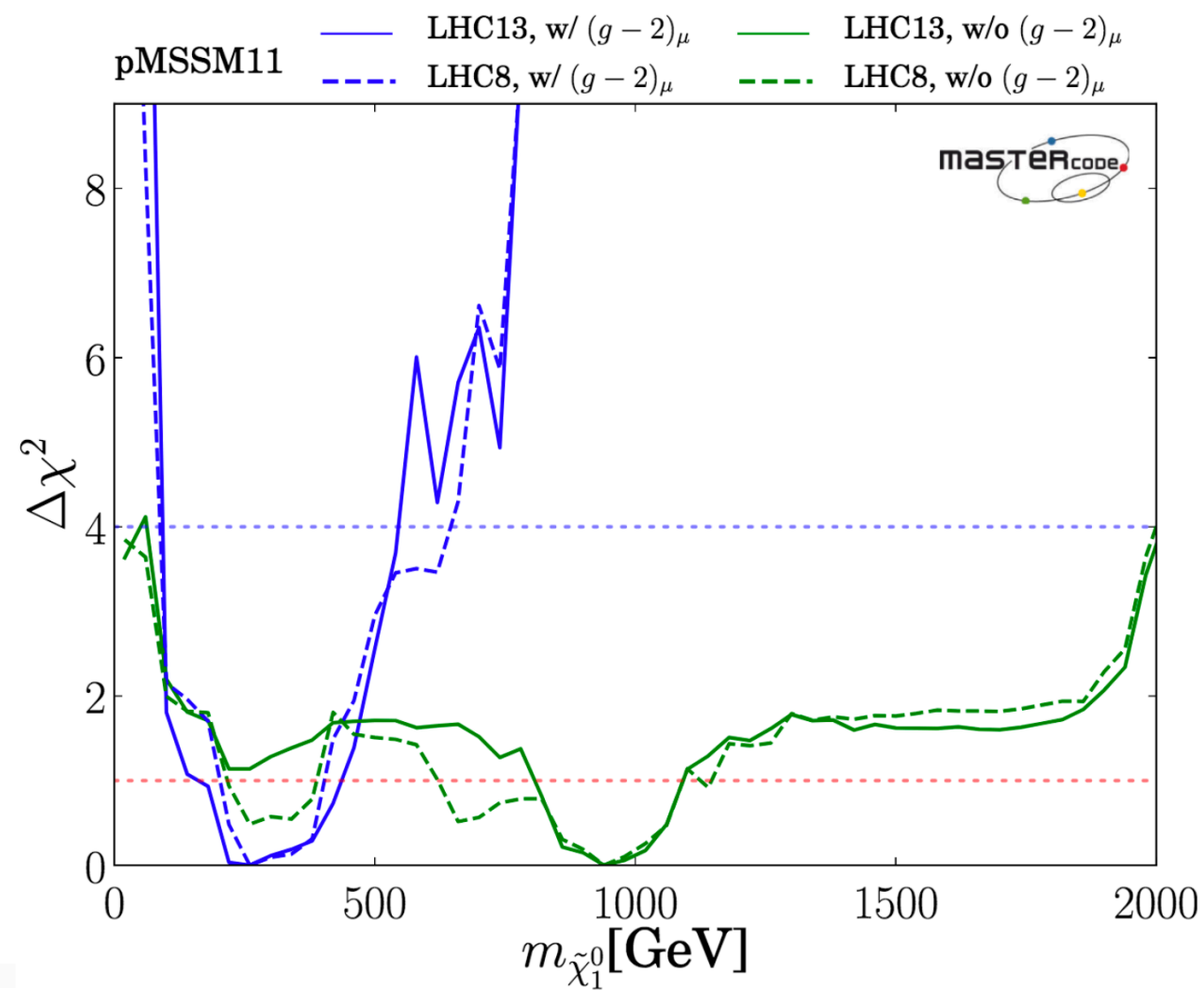


[MasterCode, 1710.11091]

Chargino coannihilation region starting from $m_{\tilde{\chi}_1^\pm} \sim m_{\tilde{\chi}_1^0} \sim 100$ GeV with degenerate Higgsinos.

Recent results





[MasterCode, 1710.11091]

Chargino coannihilation region starting from $m_{\tilde{\chi}_1^\pm} \sim m_{\tilde{\chi}_1^0} \sim 100$ GeV with degenerate Higgsinos.

A fit of the EWMSSM

Scan setup

[The GAMBIT Collaboration, 1809.02097]

Parameter	Minimum	Maximum	Priors
$M_1(Q)$	-2 TeV	2 TeV	hybrid, flat
$M_2(Q)$	0 TeV	2 TeV	hybrid, flat
$\mu(Q)$	-2 TeV	2 TeV	hybrid, flat
$\tan\beta(m_Z)$	1	70	flat
Q	3 TeV		fixed
$\alpha_s^{\overline{MS}}(m_Z)$	0.1181		fixed
Top quark pole mass	171.06 GeV		fixed

Scans

- Diver (differential evolution) scanner (`https://diver.hepforge.org/`)
- ~2.4M parameter point samples
- Up to 500k Pythia 8 events per point for LHC simulations

Post-processing

- Re-run points in preferred parameter regions with higher MC statistics
- 3σ region: ≥4M events, 1σ region: ≥16M events, 500 best points: 64M events
- ~240k parameter point samples

~3 hours per point, using
68 CPUs x4 hyperthreading

Likelihoods

LHC likelihoods

Likelihood label	Source
ATLAS_4b	ATLAS Higgsino search [116]
ATLAS_4lep	ATLAS 4ℓ search [117]
ATLAS_MultiLep_2lep_0jet	ATLAS multilepton EW search [112]
ATLAS_MultiLep_2lep_jet	ATLAS multilepton EW search [112]
ATLAS_MultiLep_3lep	ATLAS multilepton EW search [112]
ATLAS_RJ_2lep_2jet	ATLAS recursive jigsaw EW search [113]
ATLAS_RJ_3lep	ATLAS recursive jigsaw EW search [113]
CMS_1lep_2b	CMS Wh search [118]
CMS_2lep_soft	CMS 2 soft opposite-charge lepton search [121]
CMS_2OSlep	CMS 2 opposite-charge lepton search [122]
CMS_MultiLep_2SSlep	CMS multilepton EW search [123]
CMS_MultiLep_3lep	CMS multilepton EW search [123]

All LHC searches included use 13 TeV data (up to 36 fb^{-1}).
Roughly corresponds to March 2018 status.

Can light neutralinos be excluded?

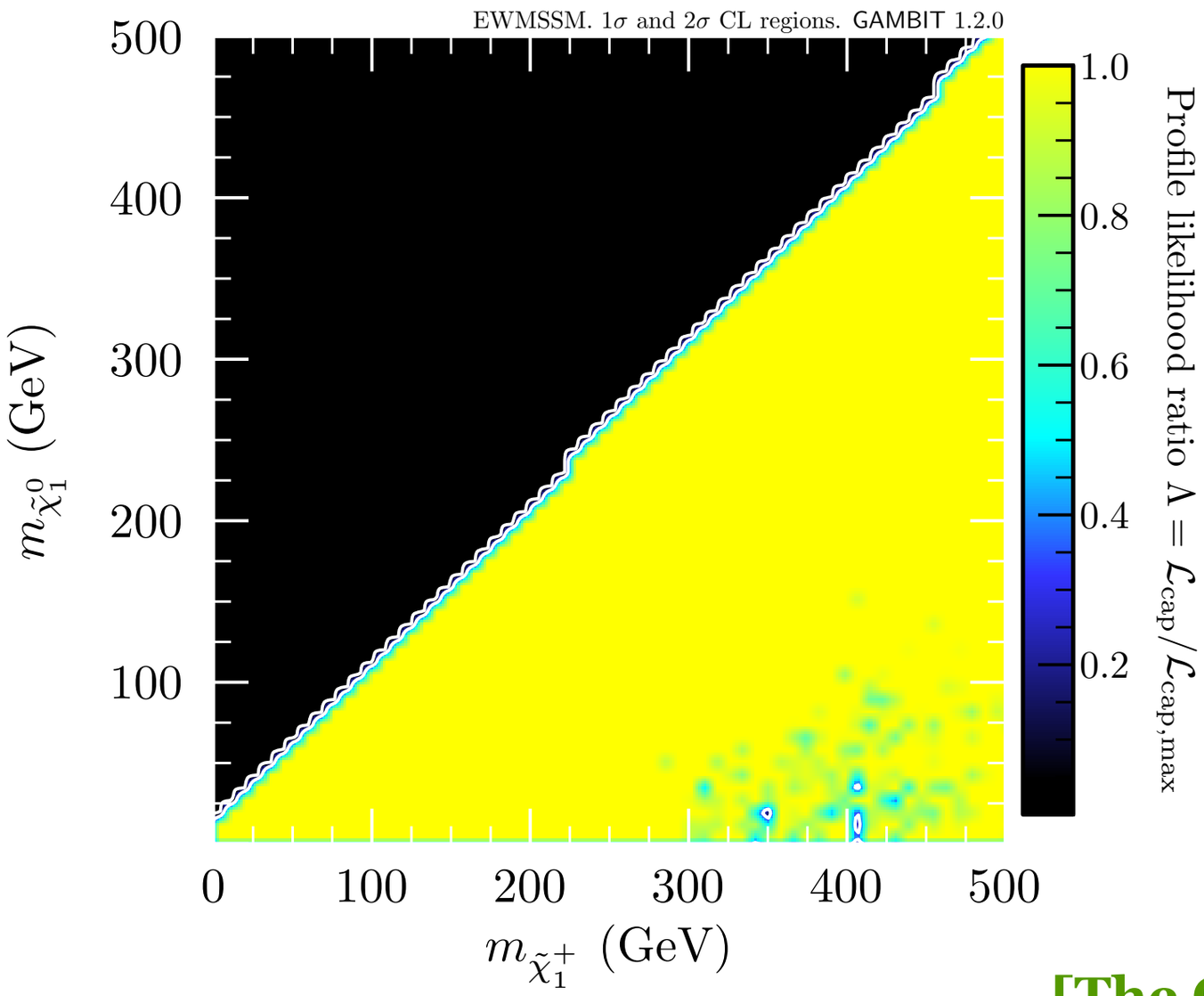
Use a **capped likelihood** where the model can not do better than the SM background model:

$$\mathscr{L}_{\text{cap}} = \min[\mathscr{L}(s+b), \mathscr{L}(b)]$$

If **profile likelihood ratio = 1,** a parameter point with those masses exists which fits just as well as the SM.

[The GAMBIT Collaboration, 1809.02097]

Can light neutralinos be excluded?



Use a **capped likelihood** where the model can not do better than the SM background model:

$$\mathscr{L}_{\rm cap} = \min[\mathscr{L}(s+b), \mathscr{L}(b)]$$

If **profile likelihood ratio = 1,** a parameter point with those masses exists which fits just as well as the SM.

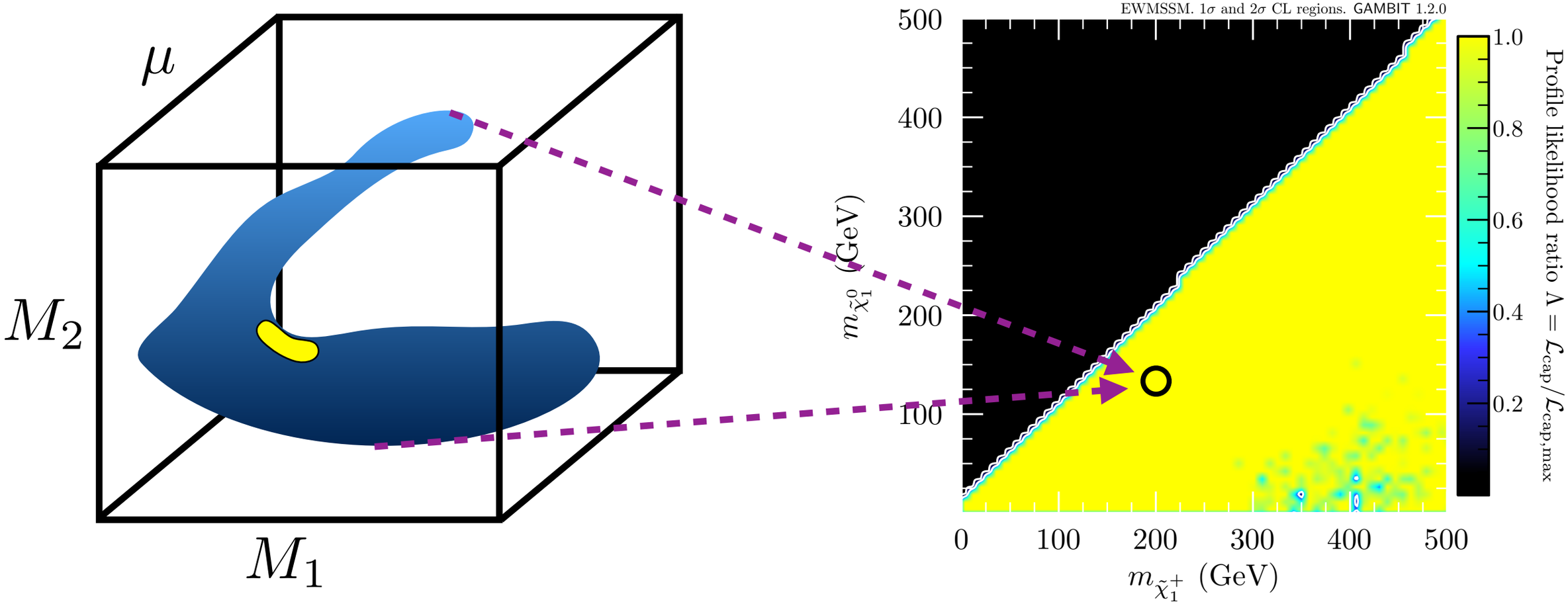
[The GAMBIT Collaboration, 1809.02097]

So, virtually no neutralino masses are excluded!

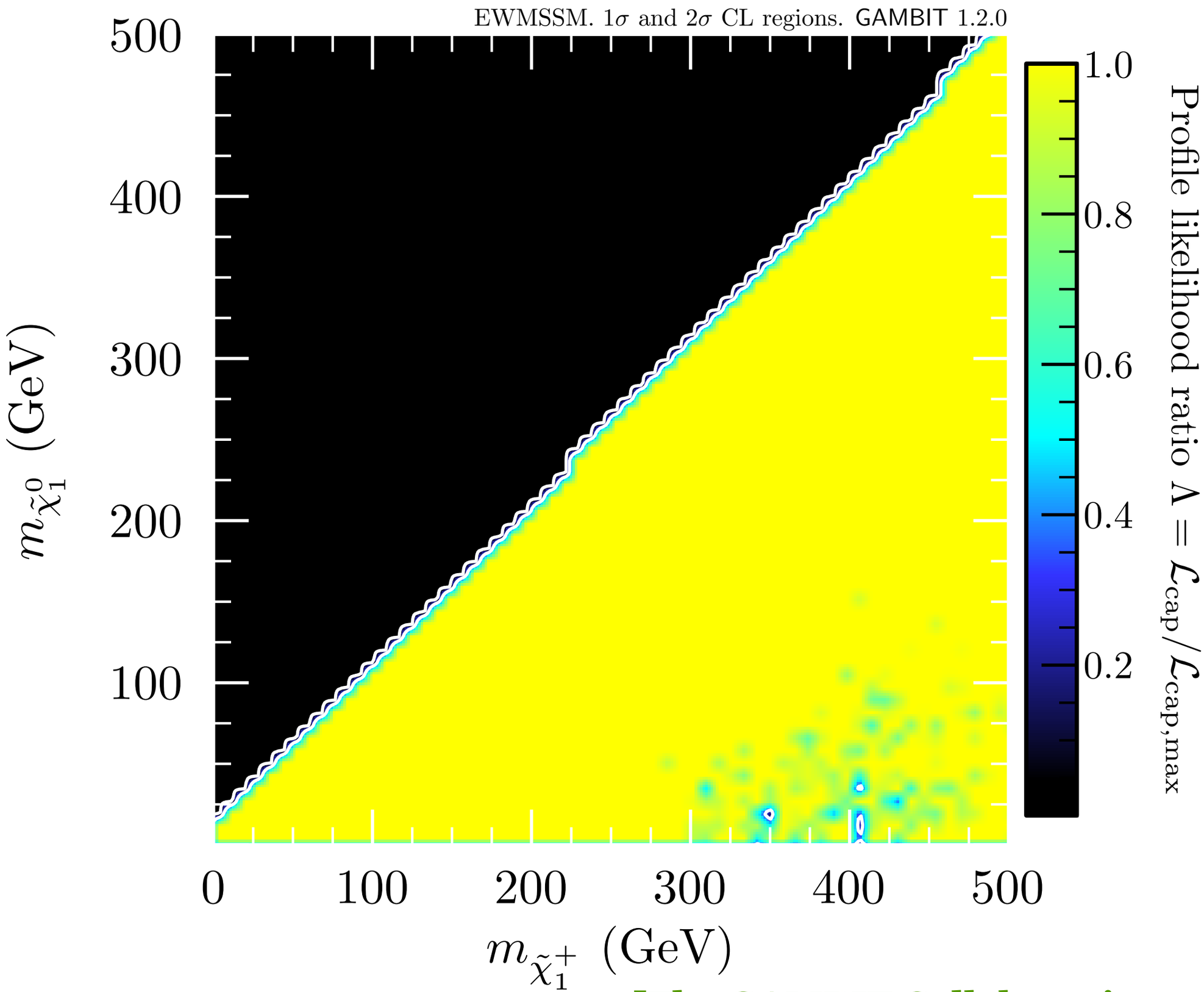
Can light neutralinos be excluded?

Interpretation of profile likelihood: For every point in the mass plane, there is *at least one point* in the EWMSSM parameter space that fits the data as well as the given ratio value.

This does not tell us anything about *the size* of the viable parameter space...

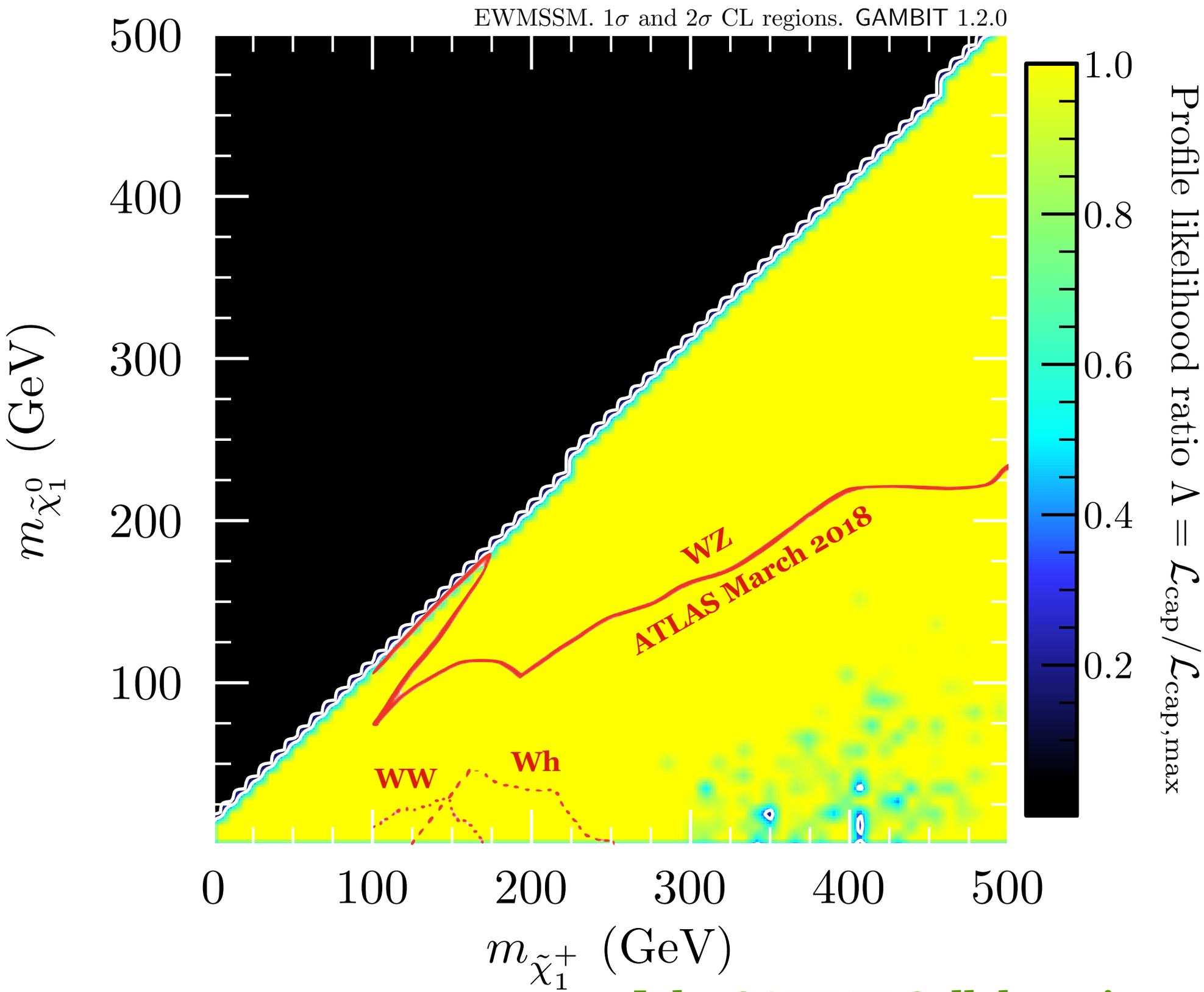


Can light neutralinos be excluded?



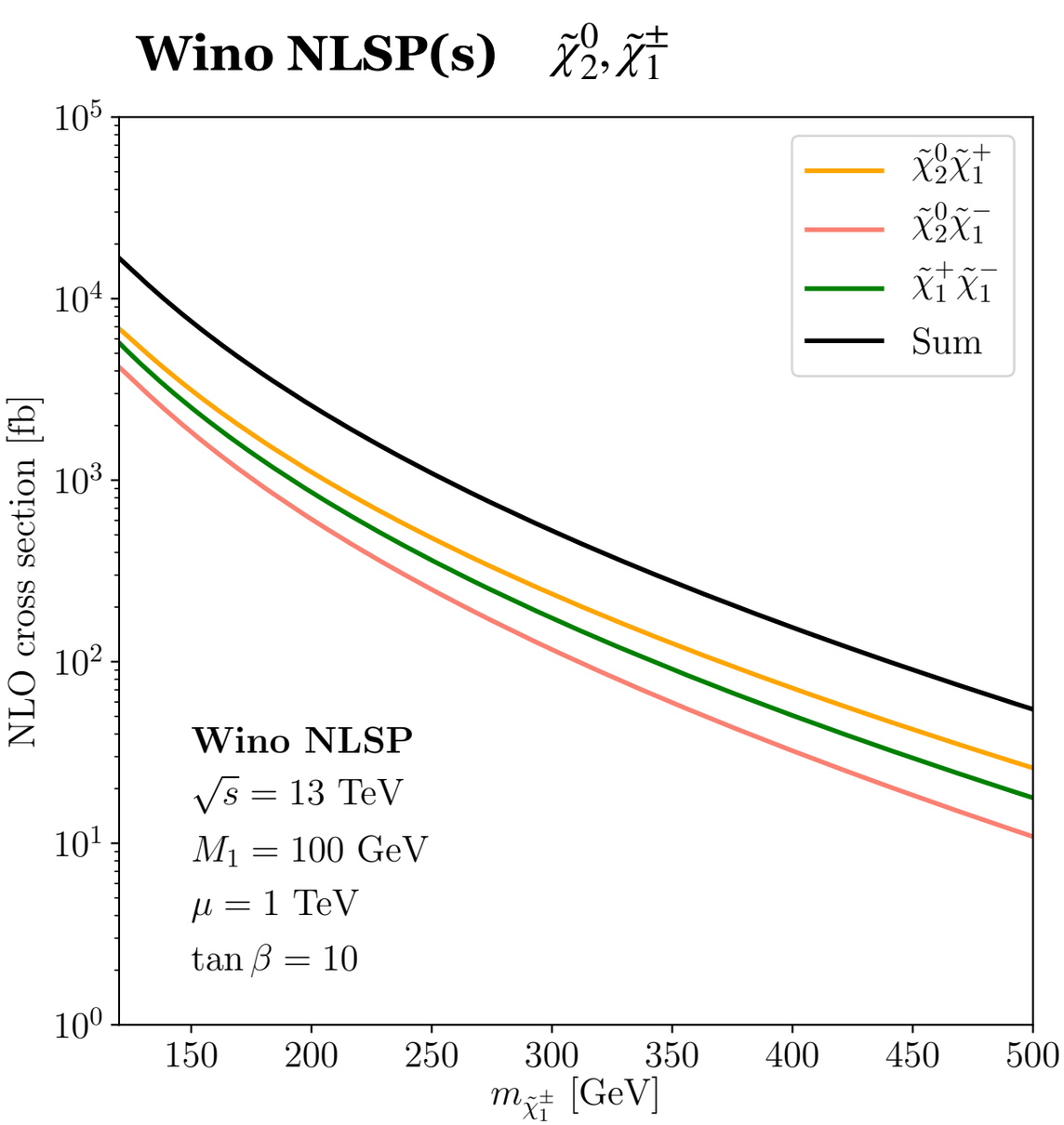
[The GAMBIT Collaboration, 1809.02097]

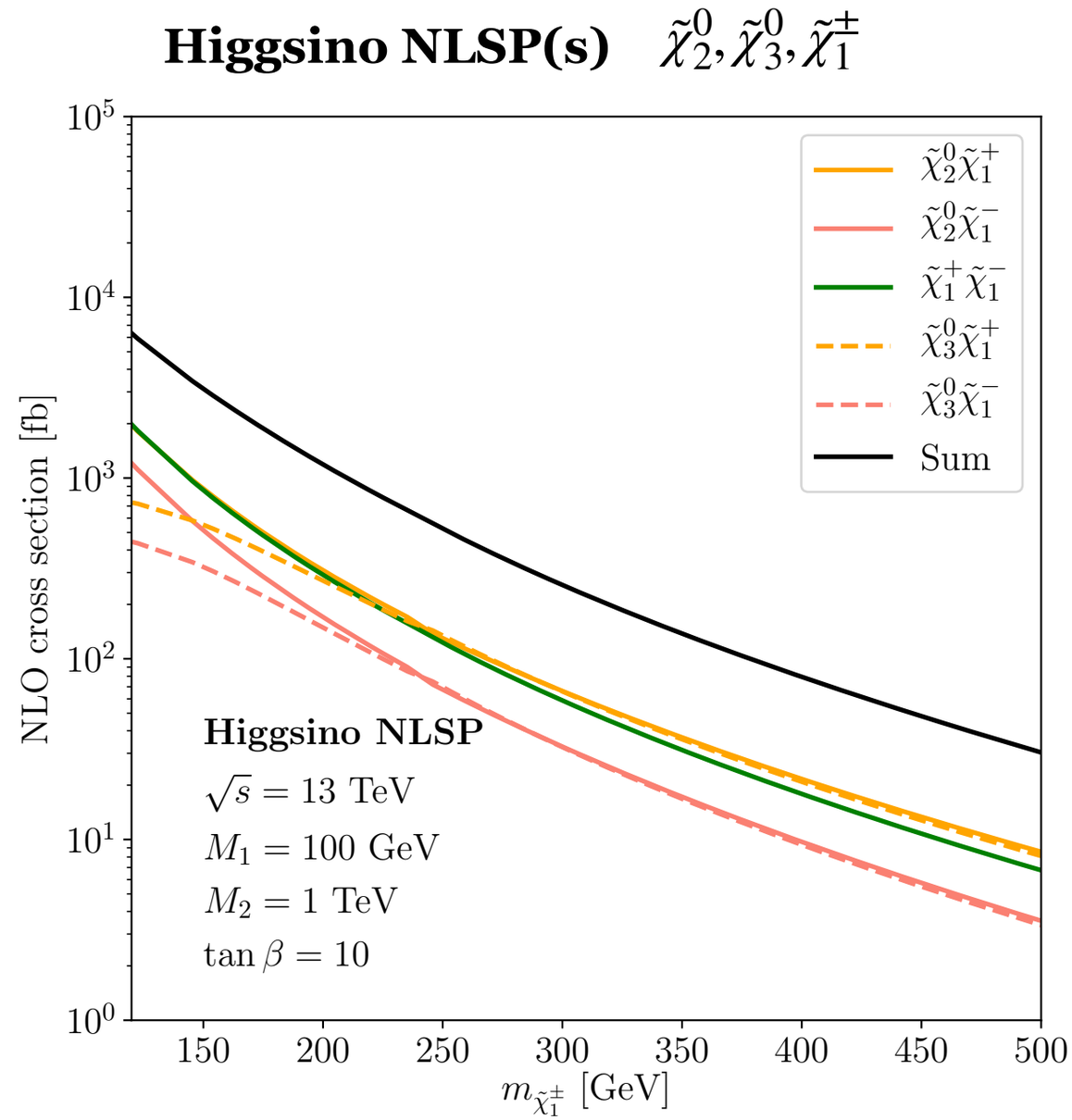
Can light neutralinos be excluded?



[The GAMBIT Collaboration, 1809.02097]

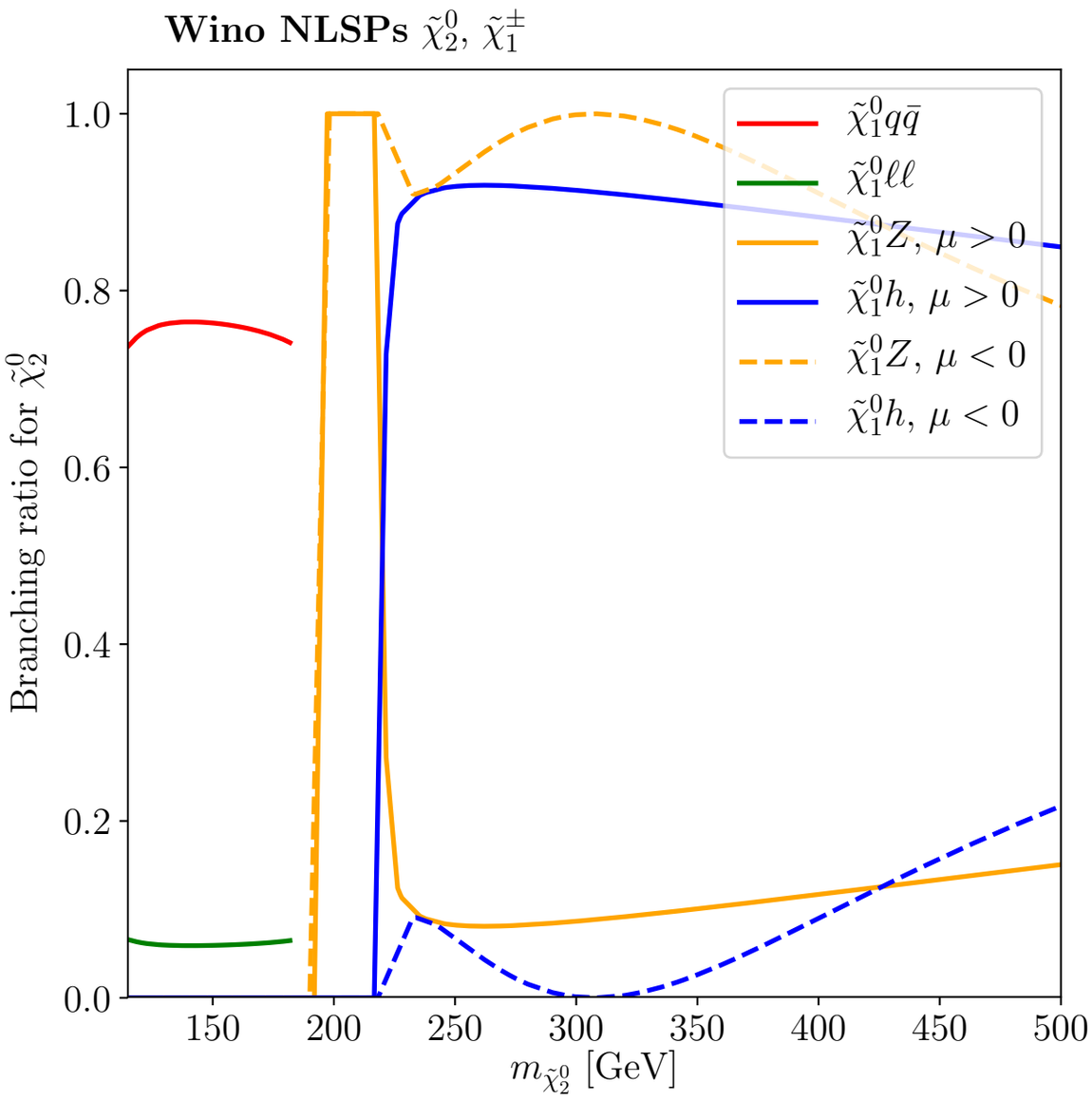
What is going on?

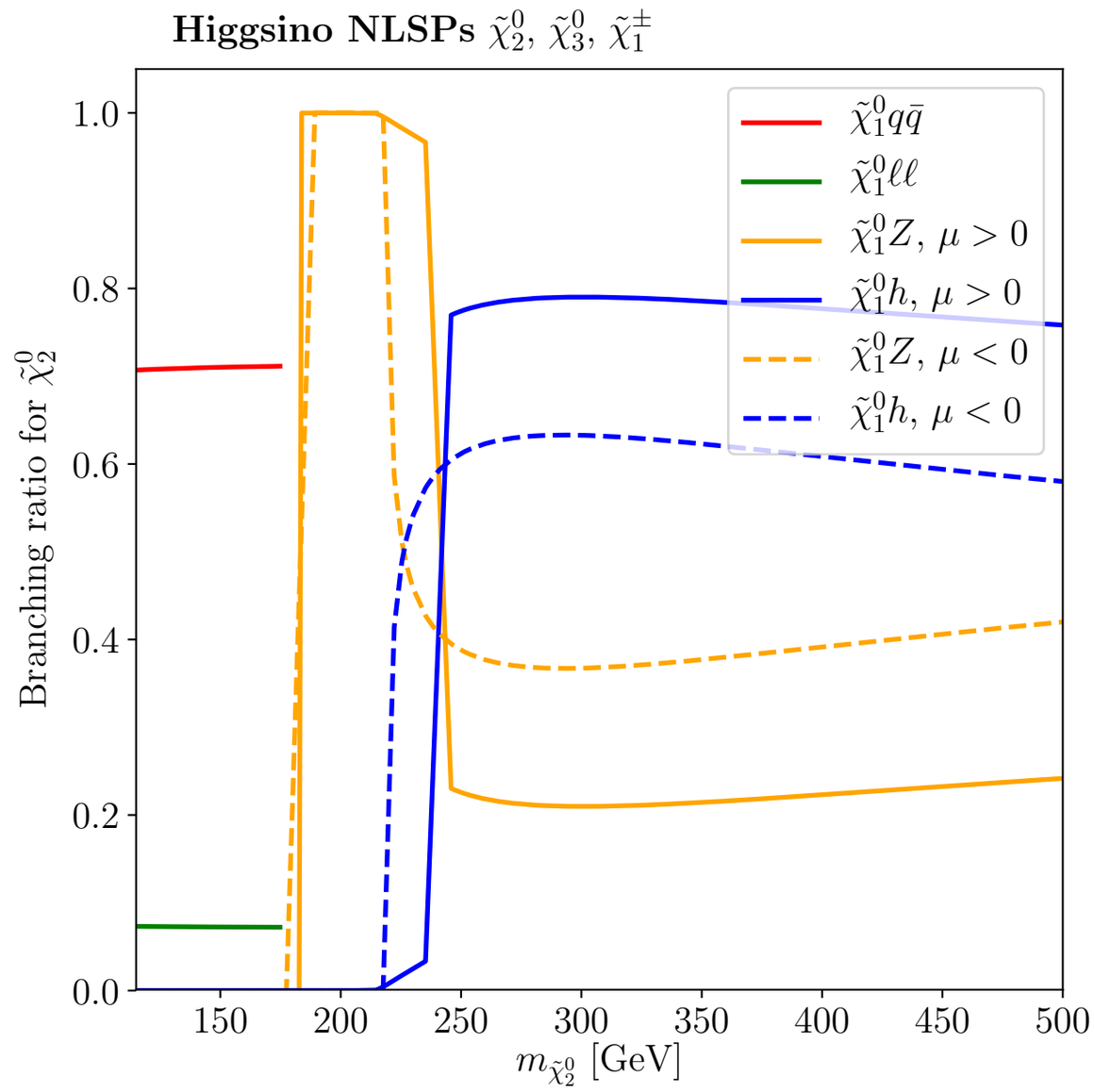




Total relevant production cross sections ~2-3 times smaller for Higgsino NLSPs

What is going on?

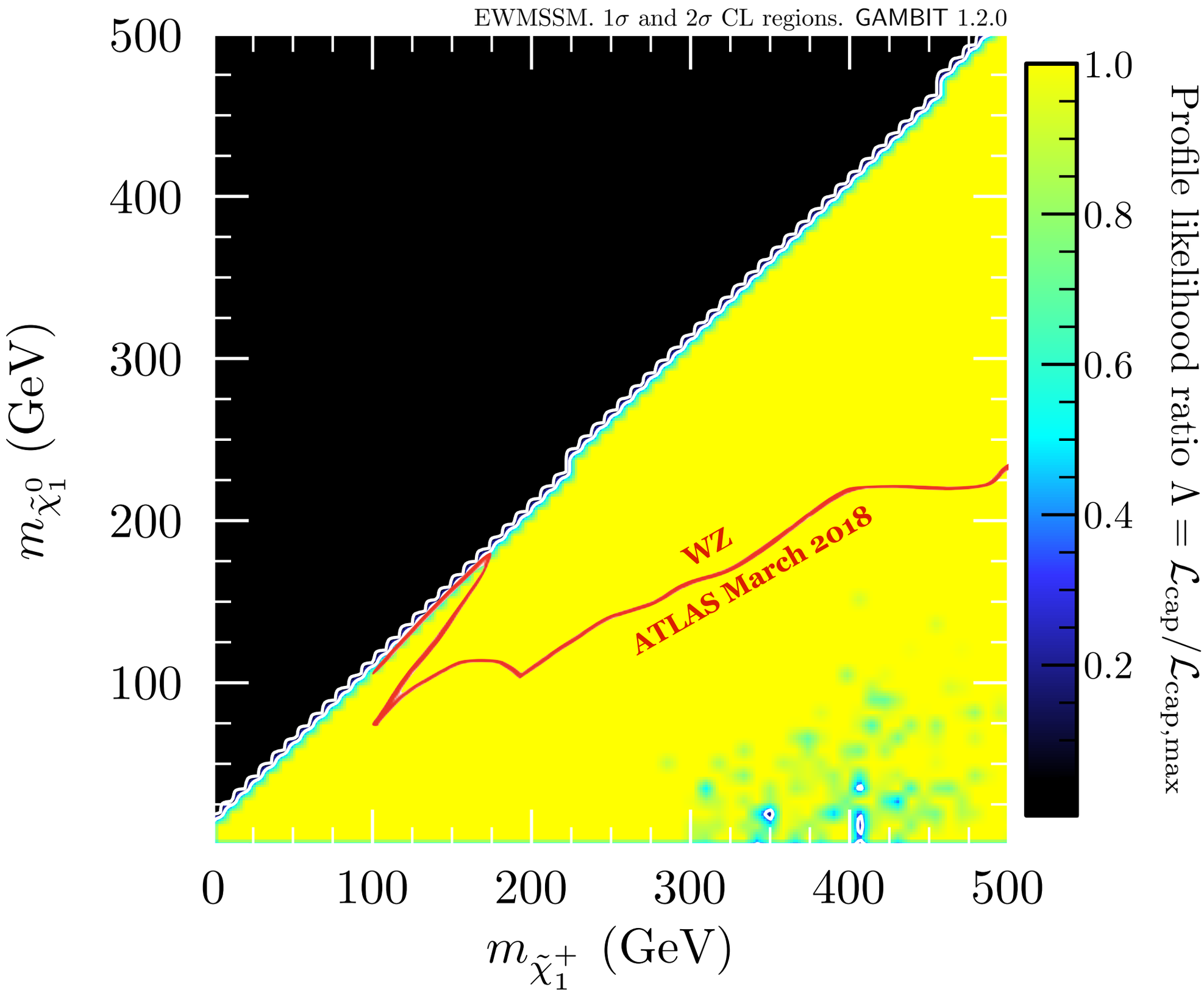




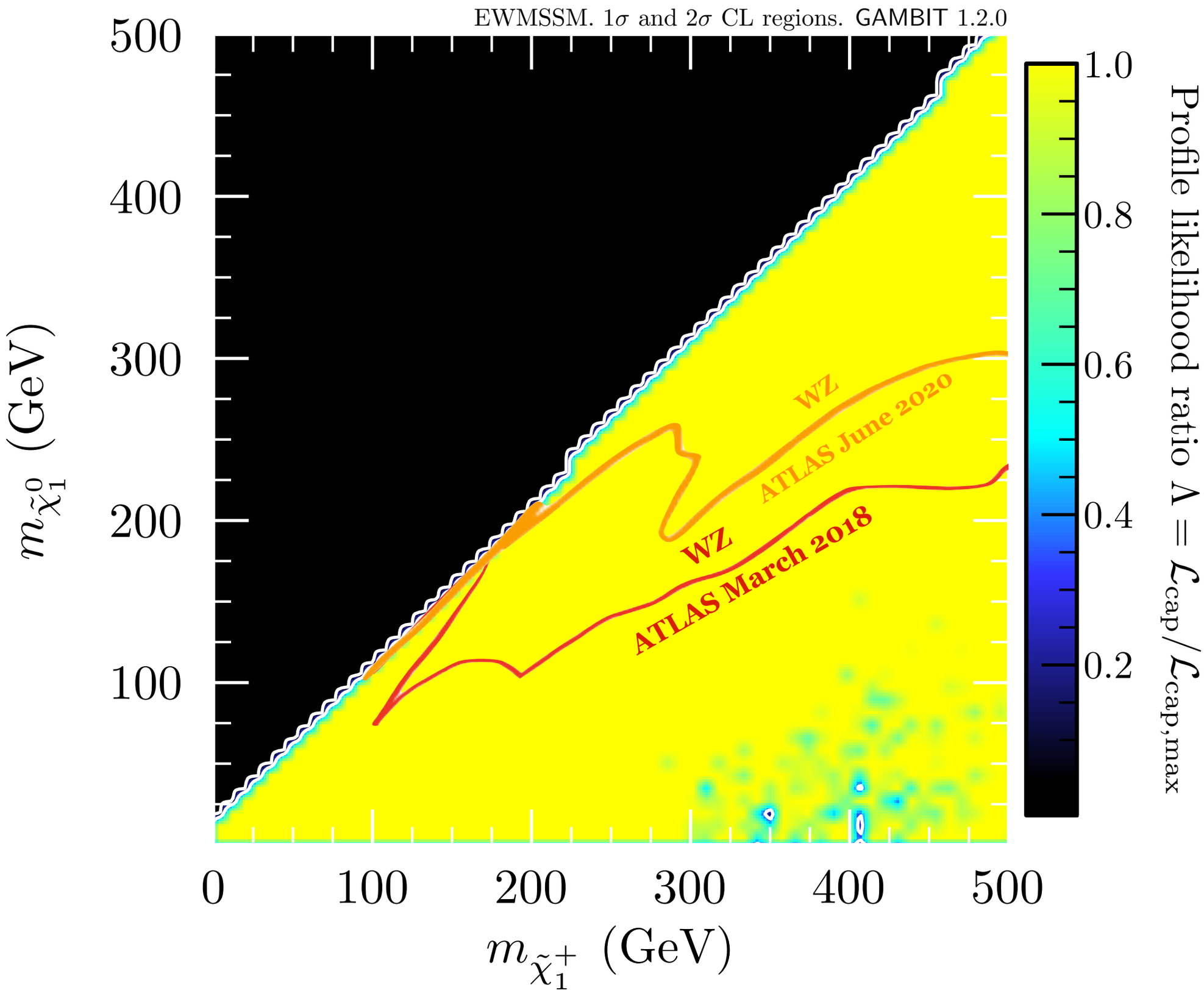
Assumptions of 100% BR.

For Wino NLSPs, when $m_{\tilde{\chi}_2^0} > m_{\tilde{\chi}_1^0} + m_h$, the $\tilde{\chi}_2^0$ BR to h and Z can be flipped between ~0.9 and ~0.1 by switching the sign of μ

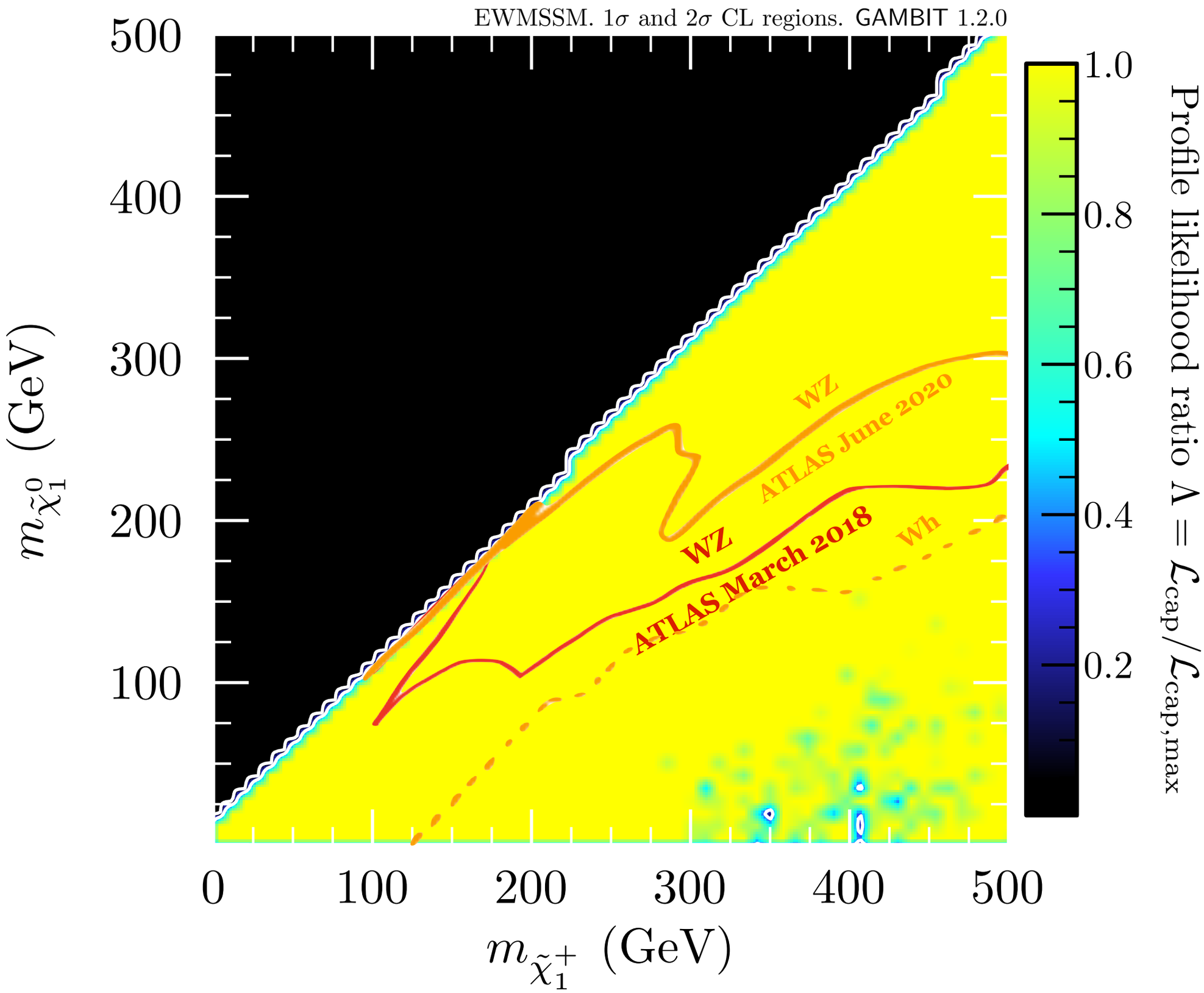
Can light neutralinos be excluded now?



Can light neutralinos be excluded now?



Can light neutralinos be excluded now?



Conclusions

- Important to go beyond simplified models to reach firm conclusions about the possibilities of light neutralino DM.

- A global fit of the MSSM electroweak sector using GAMBIT showed (as of March 2018) no model independent absolute bounds on neutralinos from the LHC.

  - Recent increases in luminosity from 36 fb^{-1} up to 140 fb^{-1} may change this conclusion, however, bounds in all probability much weaker in full parameter space.

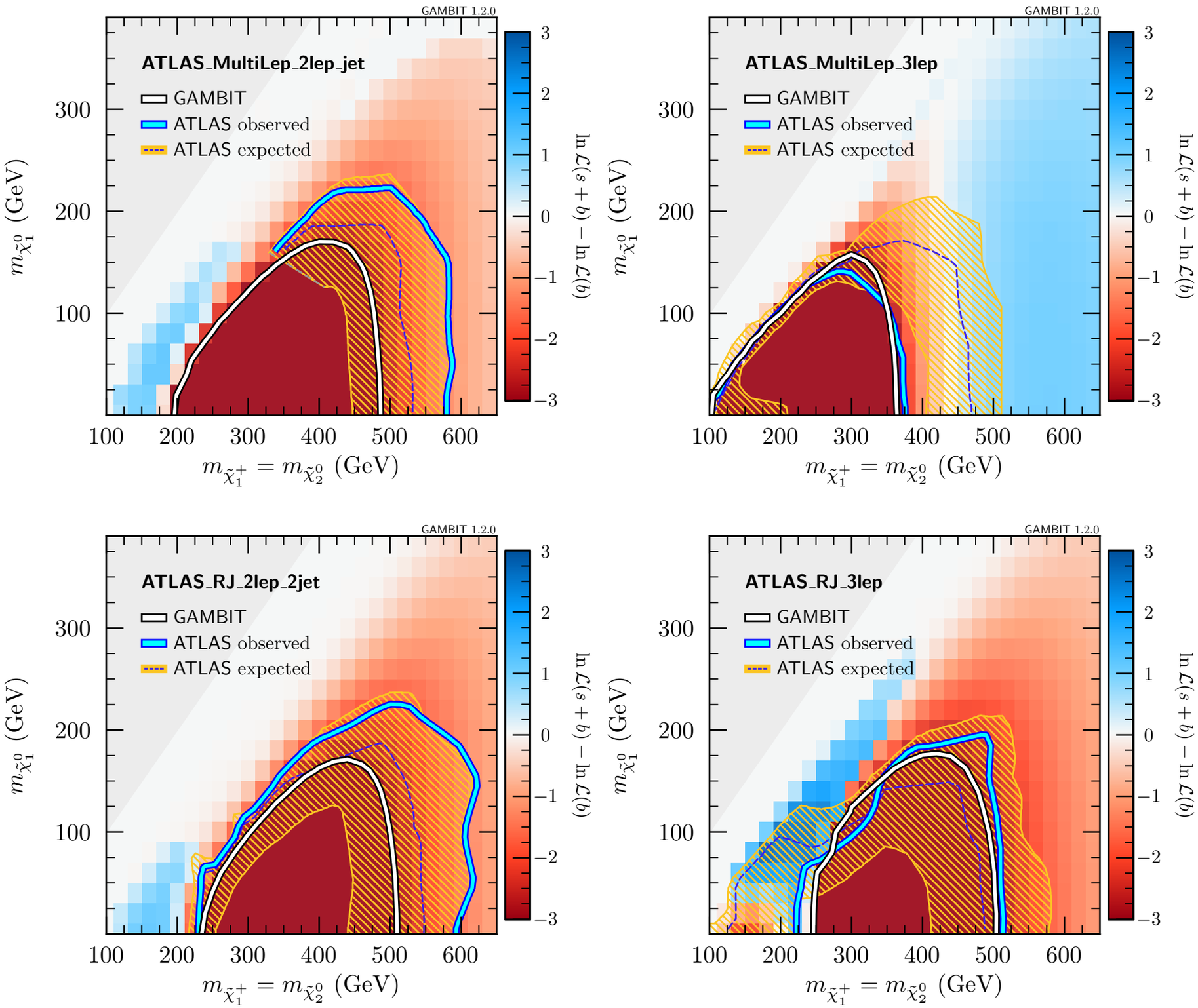
- Since capacity of the experiments to analyse all possible full models is limited, the reinterpretation of results is crucial for the community.

  - Strong bounds need detailed information, e.g. full likeliehoods, correlations between signal regions etc.

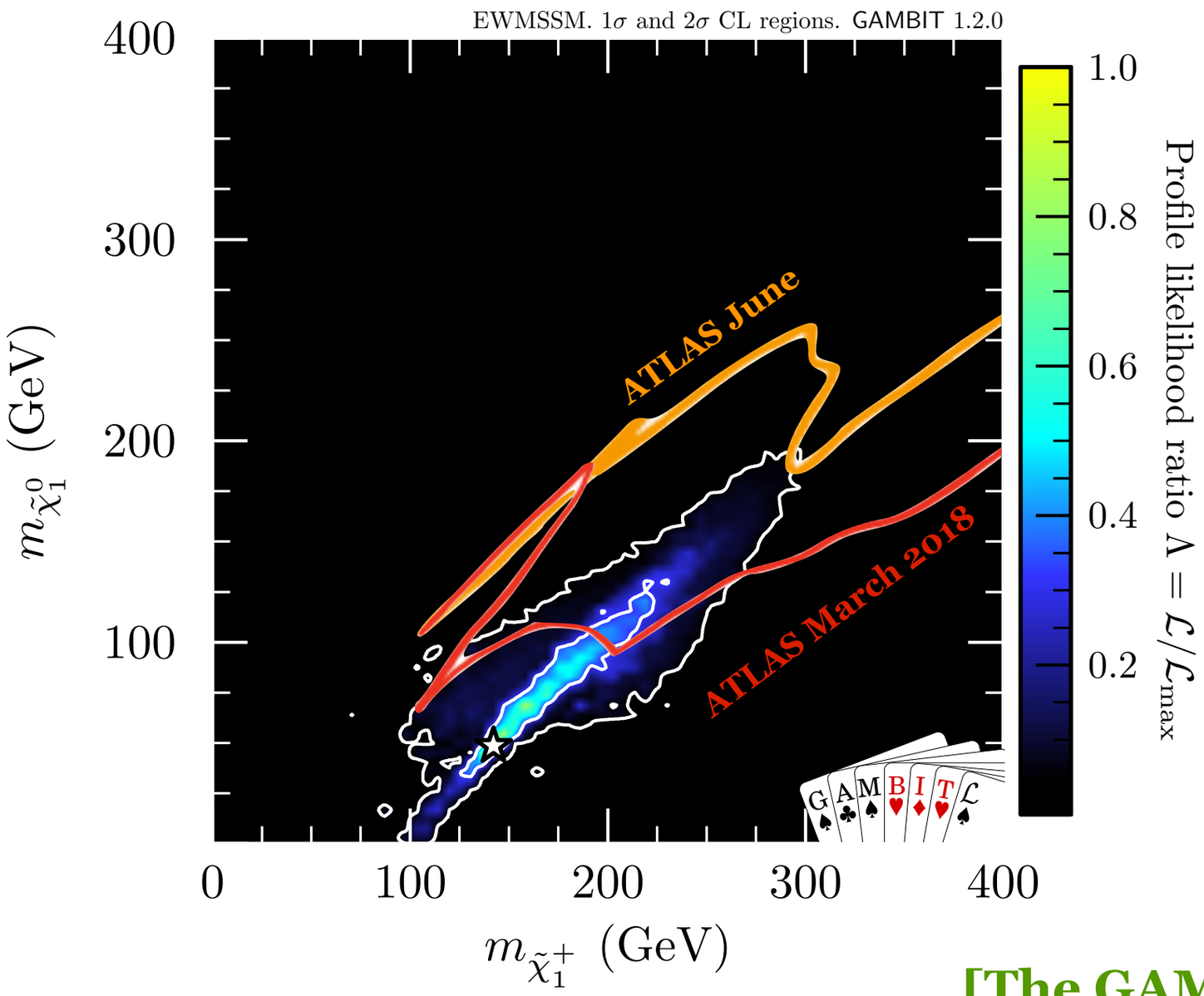
[LHC Reinterpretation Forum, 2003.07868]

Bonus material

ColliderBit validation



EWMSSM

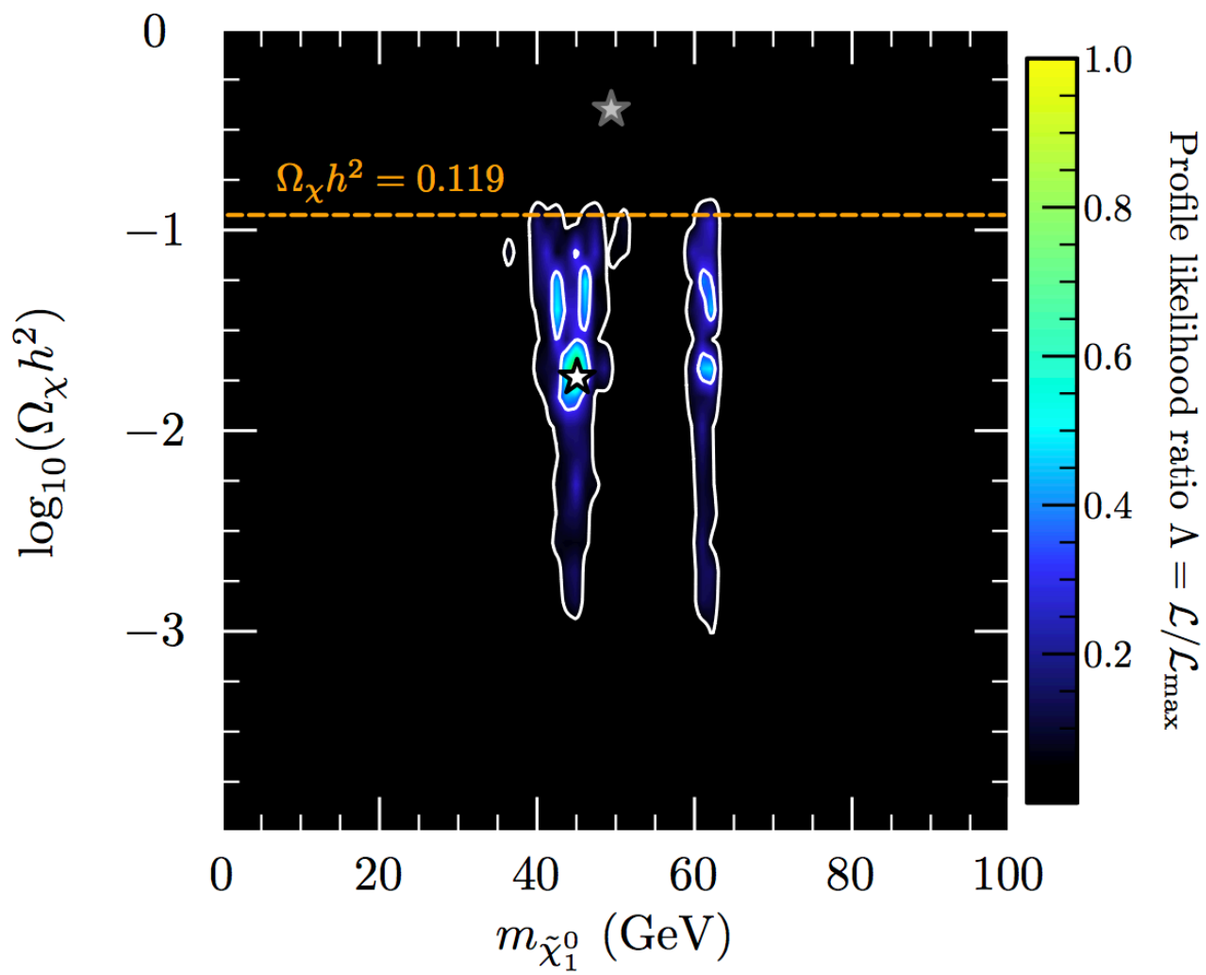


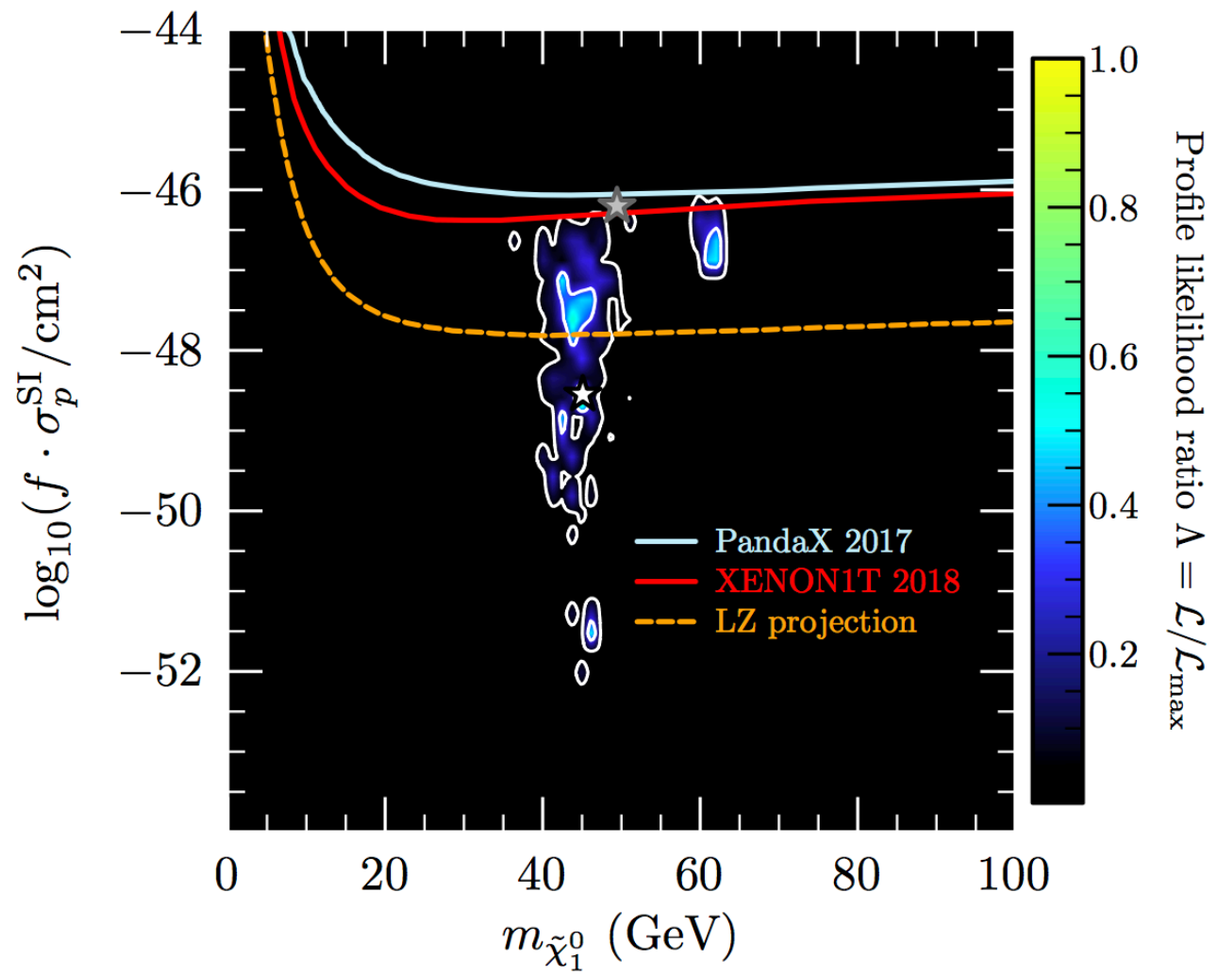
[The GAMBIT Collaboration, 1809.02097]

With an **uncapped likelihood** we have closed 2σ contours

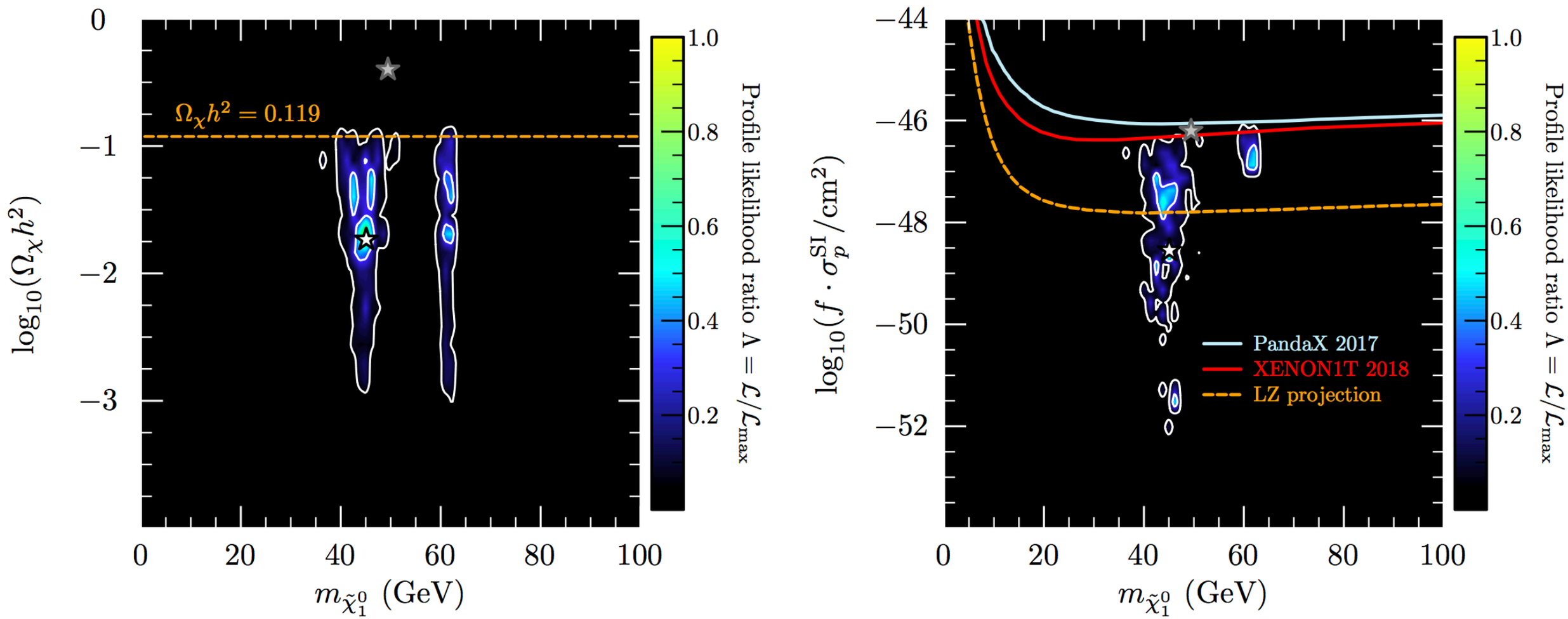
Preference for $m_{\tilde{\chi}_2^0} \sim m_{\tilde{\chi}_1^\pm} \sim m_{\tilde{\chi}_1^0} + m_Z$

DM properties



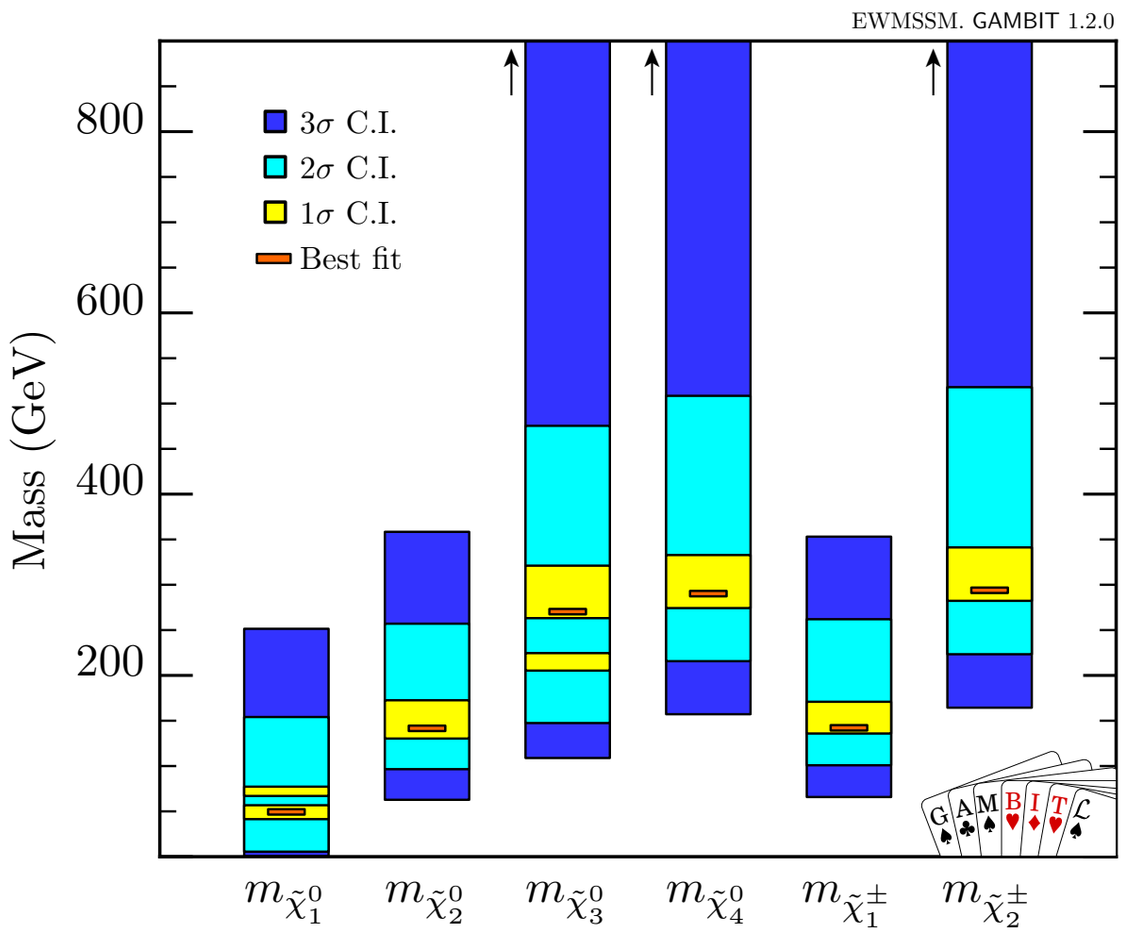


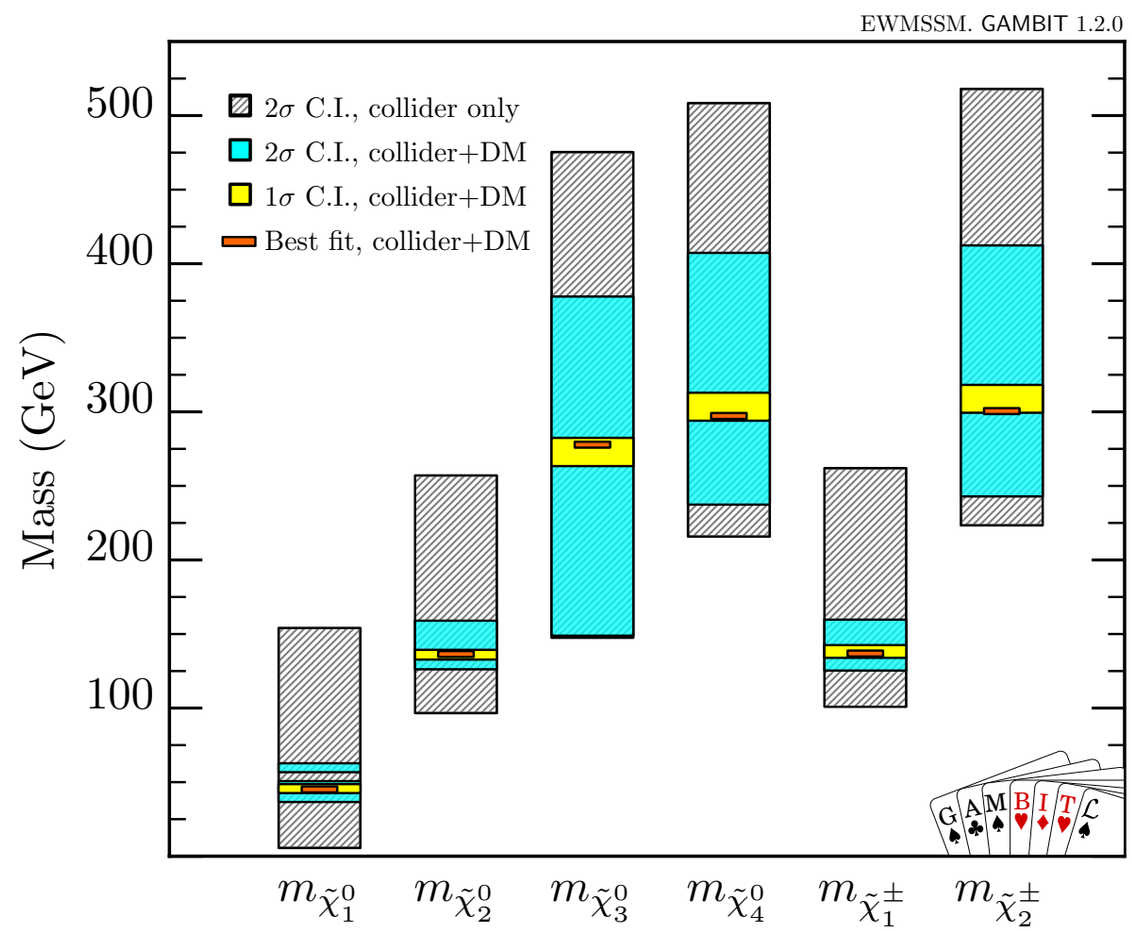
DM properties



DM relic density bound is satisfied through Higgs- and Z-funnels.

Adding DM likelihoods





[The GAMBIT Collaboration, 1809.02097]

DM likelihoods: Planck DM density (upper limit), direct detection searches from LUX, PandaX, XENON1T, CDMSlite, CRESST- II, PICO-60, DarkSide-50, and IceCube, indirect detection gamma-ray limits from Fermi-LAT observations of 15 Milky Way dwarf spheroidal galaxies.

But what about LEP etc.?

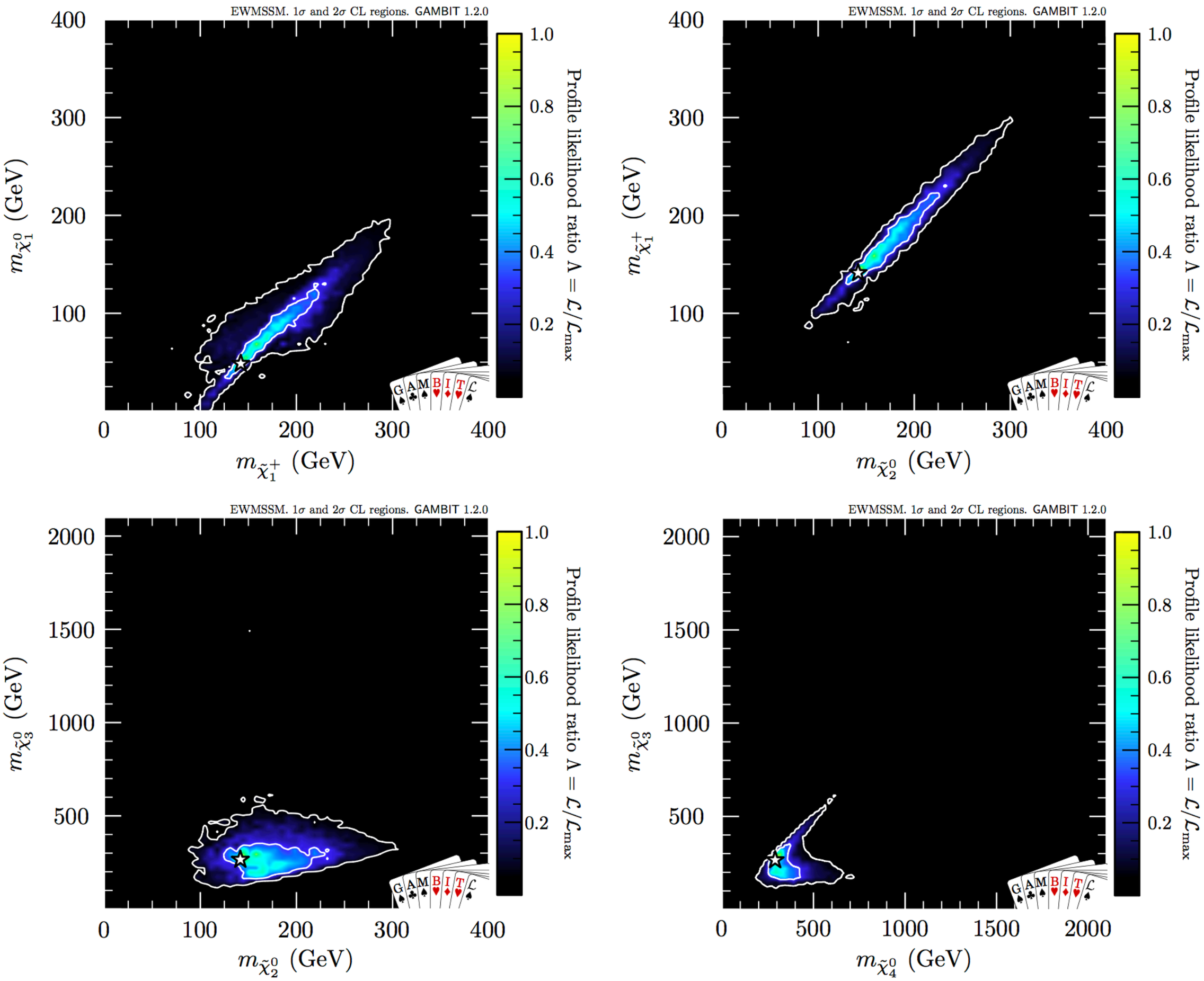
LEP likelihoods

Production	Signature	Experiment
$\tilde{\chi}_i^0 \tilde{\chi}_1^0$	$\tilde{\chi}_i^0 \to q\bar{q}\tilde{\chi}_1^0$	OPAL [53]
$(i = 2, 3, 4)$	$\tilde{\chi}_i^0 \to \ell\bar{\ell}\tilde{\chi}_1^0$	L3 [98]
$\tilde{\chi}_i^+ \tilde{\chi}_i^-$	$\tilde{\chi}_i^+ \tilde{\chi}_i^- \to q\bar{q}' q\bar{q}' \tilde{\chi}_1^0 \tilde{\chi}_1^0$	OPAL [53]
$(i = 1, 2)$	$\tilde{\chi}_i^+ \tilde{\chi}_i^- \to q\bar{q}' \ell\nu \tilde{\chi}_1^0 \tilde{\chi}_1^0$	OPAL [53]
	$\tilde{\chi}_i^+ \tilde{\chi}_i^- \to \ell\nu\ell\nu \tilde{\chi}_1^0 \tilde{\chi}_1^0$	OPAL [53], L3 [98]
	ISR γ + missing energy	OPAL [99]

Invisible width likelihoods

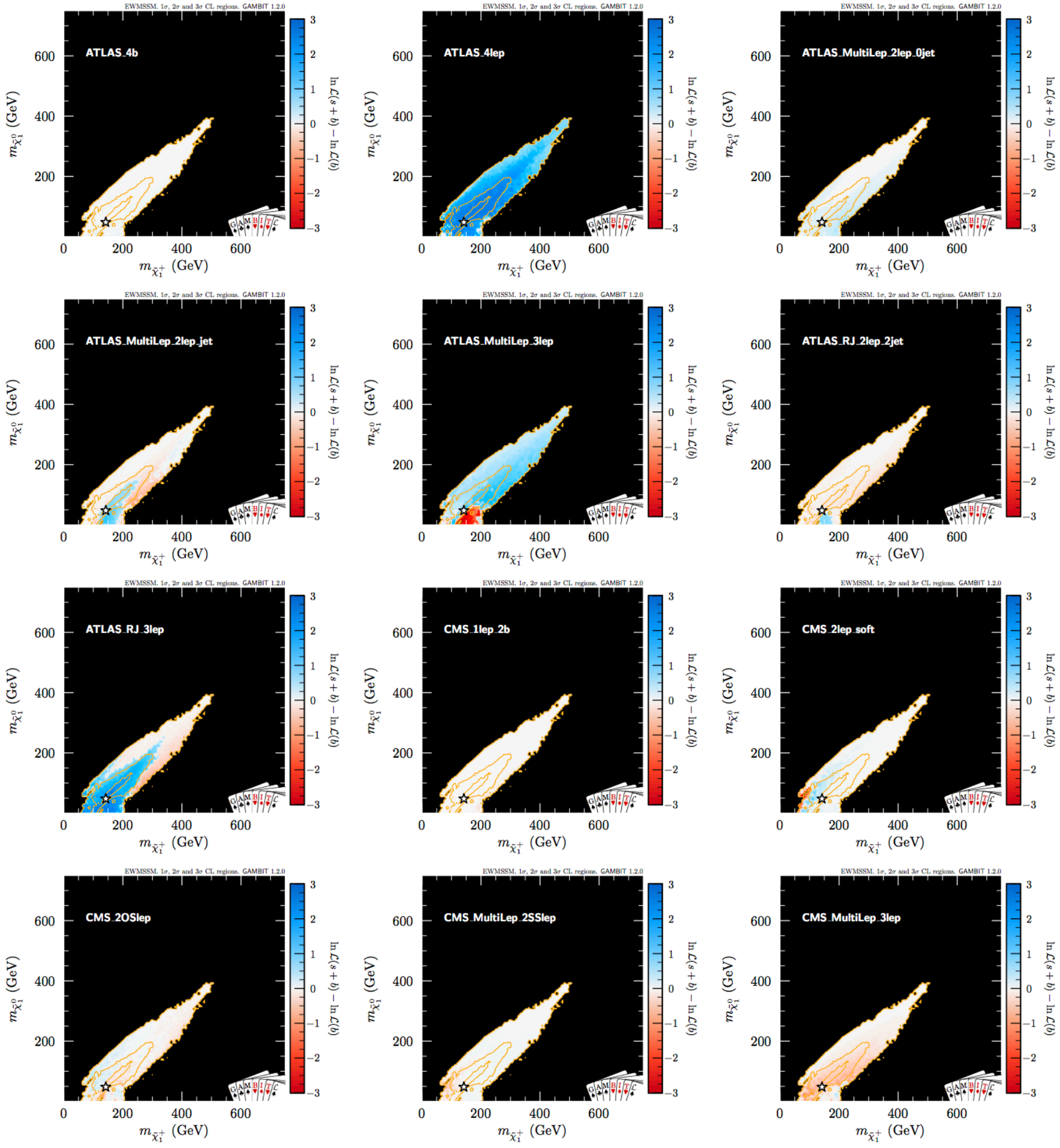
$$\Gamma(Z \to \text{inv.}) = 499.0 \pm 1.5\,\text{MeV} \quad \text{(LEP)}$$

$$\text{BF}(h \to \text{inv.}) \leq 0.19 \quad \text{(LHC)}$$



[The GAMBIT Collaboration, 1809.02097]

[The GAMBIT Collaboration, 1809.02097]



Individual analysis contributions to the 3σ best-fit region:

$$\ln \mathcal{L}(s+b) - \ln \mathcal{L}(b)$$

Blue: **better** than background-only
Red: **worse** than background-only

Most important contributions:

- **ATLAS_4lep**
- **ATLAS_RJ_3lep**
- **ATLAS_MultiLep_2lep_jet**
- **ATLAS_MultiLep_3lep**
- **CMS_MultiLep_3lep**

Local significance & goodness-of-fit

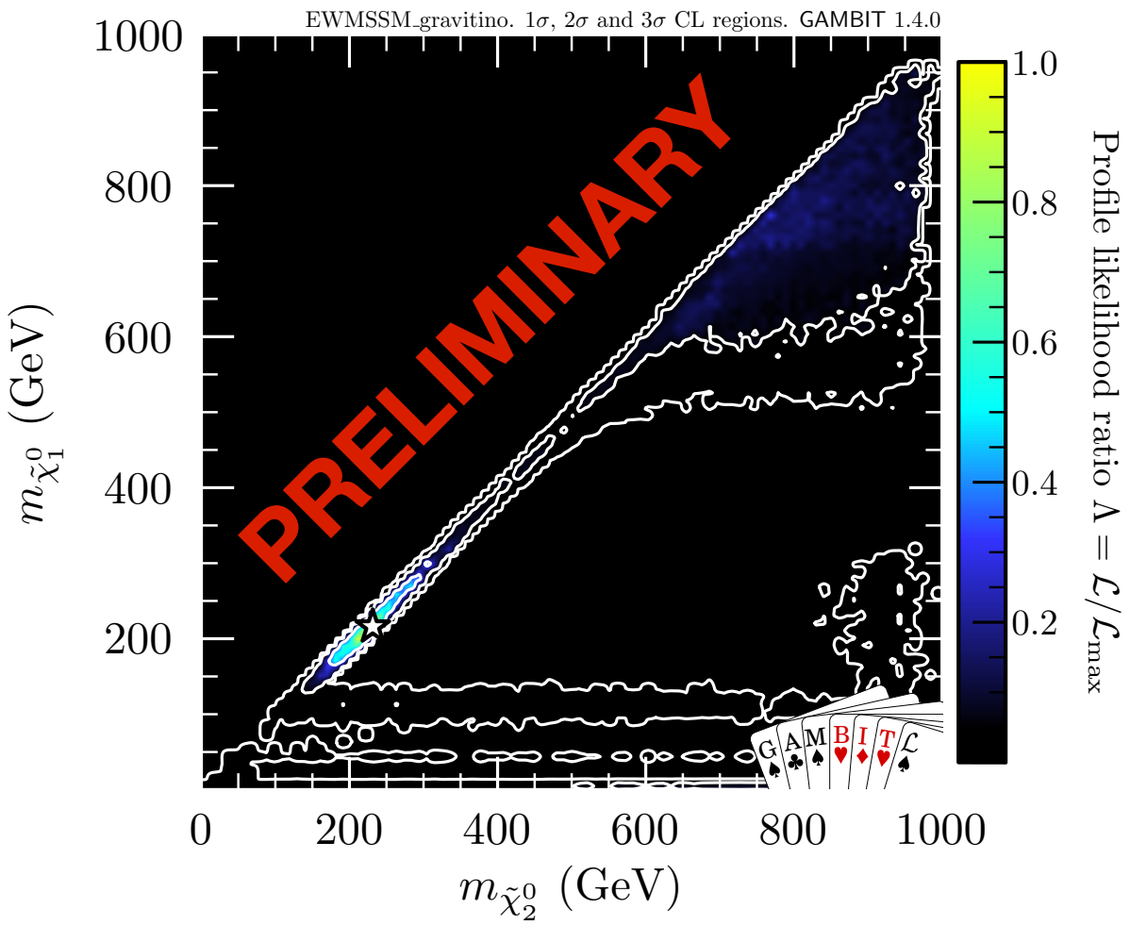
	Best expected SRs				All SRs; neglect correlations			
Analysis	Local signif. (σ)	SM fit (σ)	EWMSSM fit (σ)	#SRs	Local signif. (σ)	SM fit (σ)	EWMSSM fit (σ)	#SRs
Higgs invisible width	0.9	0.3	0.2	1	0.9	0.3	0.2	1
Z invisible width	0	1.3	1.3	1	0	1.3	1.3	1
ATLAS_4b	0.7	0	0	1	2.1	0	0	2^*
ATLAS_4lep	2.3	2.0	0	1	2.5	1.0	0	4
ATLAS_MultiLep_2lep_0jet	0.9	0.3	0.1	1	1.3	0	0	6
ATLAS_MultiLep_2lep_jet	0	0	0.5	1	0.8	0.5	0.3	3
ATLAS_MultiLep_3lep	1.8	1.6	0.6	1	1.2	0.4	0.3	11
ATLAS_RJ_2lep_2jet	0	0.3	0.5	1	1.5	1.8	1.5	4
ATLAS_RJ_3lep	2.8	2.4	1.0	1	3.5	2.6	0.5	4
CMS_1lep_2b	0.9	0.3	0.3	1	0	0	0	2
CMS_2lep_soft	0.4	0.2	0.2	12	0.4	0.2	0.2	12
CMS_2OSlep	0	0.4	0.6	7	0	0.4	0.6	7
CMS_MultiLep_2SSlep	0.2	0	0	1	0.2	0	0	2
CMS_MultiLep_3lep	0	0	0.5	1	0	0	0	6
Combined	3.5	1.5	0.3	31	4.2	1.3	0	65

Optimist view: Early hint of a signal in multi-lepton states?

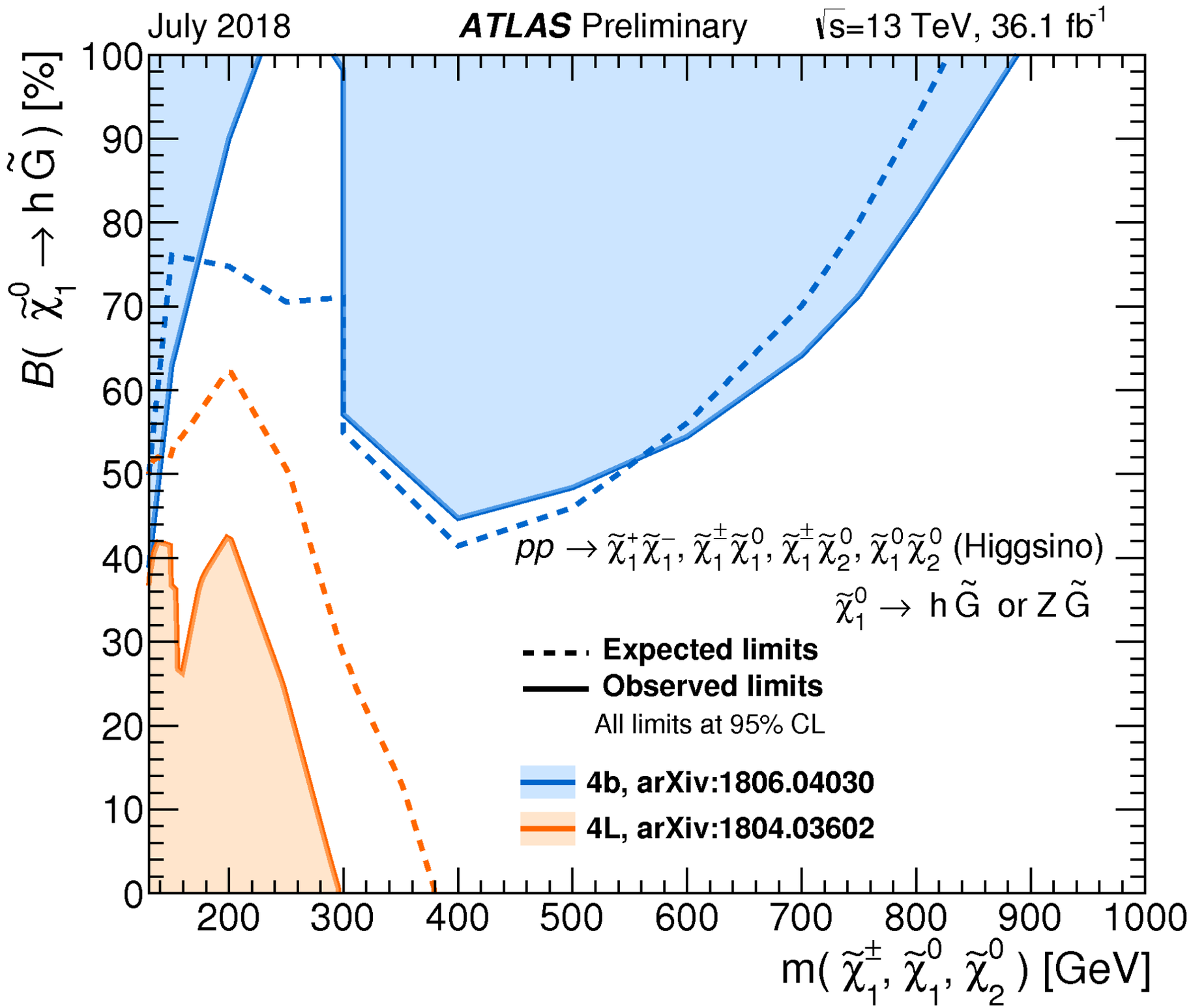
Realist view: Very light electroweakinos still allowed in the MSSM

Beyond the MSSM

- EWMSSM + light gravitino (prompt NLSP decay)
  - Extra Z, γ, or h from decay of NLSP changes which searches are sensitive
- NMSSM
  - Singlino component in neutralinos can reduce cross sections and open decays to further Higgs states



Excess in gravitino model?



GAMBIT: The Global And Modular BSM Inference Tool

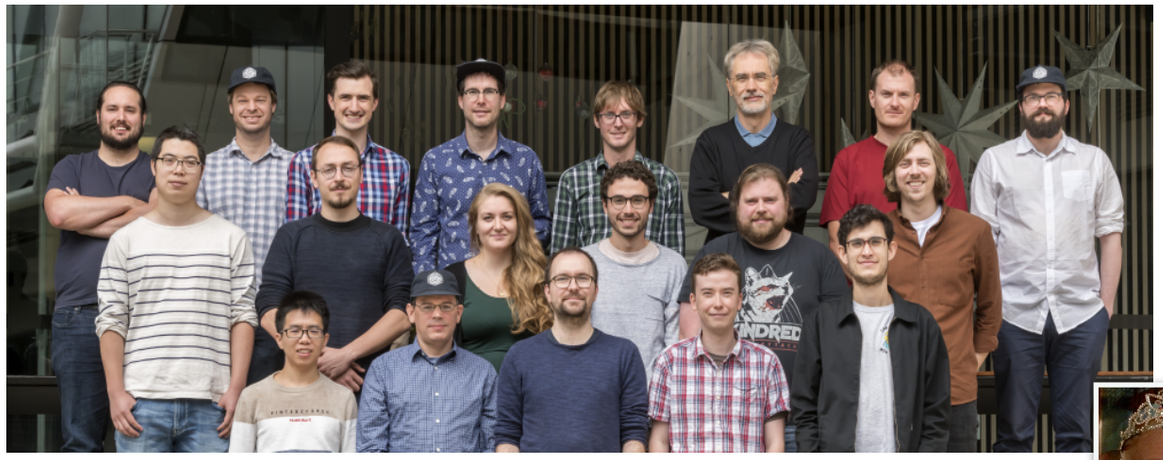
gambit.hepforge.org EPJC **77** (2017) 784 arXiv:1705.07908

- Extensive model database – not just SUSY
- Extensive observable/data libraries
- Many statistical and scanning options (Bayesian & frequentist)
- *Fast* LHC likelihood calculator
- Massively parallel
- Fully open-source

Members of:
ATLAS, Belle-II, CLiC, CMS, CTA, *Fermi*-LAT, DARWIN, IceCube, LHCb, SHiP, XENON

Authors of:
DarkSUSY, DDCalc, Diver, FlexibleSUSY, gamlike, GM2Calc, IsaTools, nulike, PolyChord, Rivet, SoftSUSY, SuperISO, SUSY-AI, WIMPSim

- Fast definition of new datasets and theories
- Plug and play scanning, physics and likelihood packages



+

Recent collaborators:
P Athron, C Balázs, A Beniwal, S Bloor, T Bringmann, A Buckley, J Eliel Camargo-Molina, C Chang, M Chrzaszcz, J Conrad, J Cornell, M Danninger, J Edsjö, B Farmer, A Fowlie, T Gonzalo, P Grace, W Handley, J Harz, S Hoof, F Kahlhoefer, N Avis Kozar, A Kvellestad, P Jackson, R Jardine, A Ladhu, N Mahmoudi, G Martinez, M Prim, F Rajec, A Raklev, J Renk, C Rogan, R Ruiz, I Sáez Casares, N Serra, A Scaffidi, P Scott, P Stöcker, W Su, J Van den Abeele, A Vincent, C Weniger, M White, Y Zhang

40+ participants in 11 experiments and 14 major theory codes

Public results

- Documentation for open source codebase: `gambit.hepforge.org`

- All physics results publicly available on `zenodo.cern.ch`, including:

zenodo

Search

Upload Communities

Log in Sign up

September 7, 2018

Dataset Open Access

Supplementary Data: Combined collider constraints on neutralinos and charginos

The GAMBIT Collaboration

Supplementary Data
Combined collider constraints on neutralinos and charginos.

The files in this record contain data for the EWMSSM model considered in the GAMBIT paper on constraints on electroweakinos.

Preview

1,371 views

195 downloads

See more details...

Indexed in

OpenAIRE

Public results

- Documentation for open source codebase: `gambit.hepforge.org`
- All physics results publicly available on `zenodo.cern.ch`, including:
  - GAMBIT input yaml files for scans
  - Parameter point chains (hdf5 files)
  - SLHA1 and SLHA2 files for the best-fit point in each subregion of each fit
  - Plotting routines

How to start using GAMBIT

- Clone the git repository

  `github.com/patscott/gambit_1.4`

- Or download tarball from: `gambit.hepforge.org`

- Compiles with CMake using gcc or intel compilers

- Or get the pre-compiled docker version (around 6 GB)

```
docker run -it gambitbsm/gambit-pippi
```

- Run with

```
gambit -f yaml_files/CMSSM.yaml
```