Status of global SUSY fits

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Outline

1. Global Fits
   - What?
   - Why?
   - How?
2. Likelihoods and constraints
   - Collider searches
   - Dark matter constraints
   - Precision observables
   - Flavour physics
3. Results
   - GUT-scale SUSY: CMSSM, NUHM1, NUHM2
   - Weak-scale SUSY: MSSM7, pMSSM10, pMSSM11
   - Other SUSY models
4. Summary and outlook

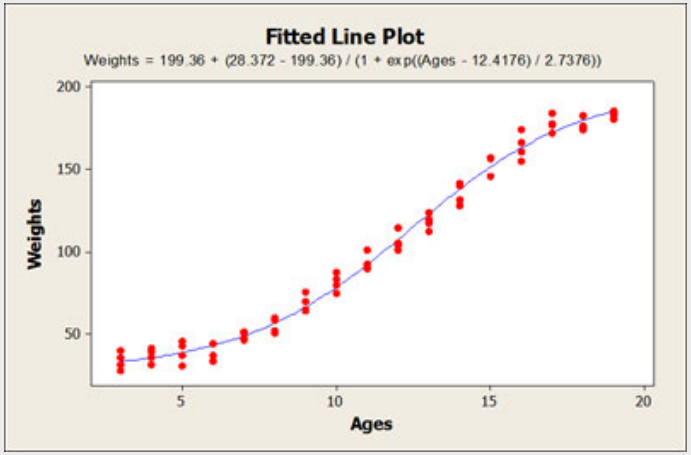
Global Fits

What are global fits?

Global fit in statistics

Statistical fit of one or more **models** to several **data** sets simultaneously

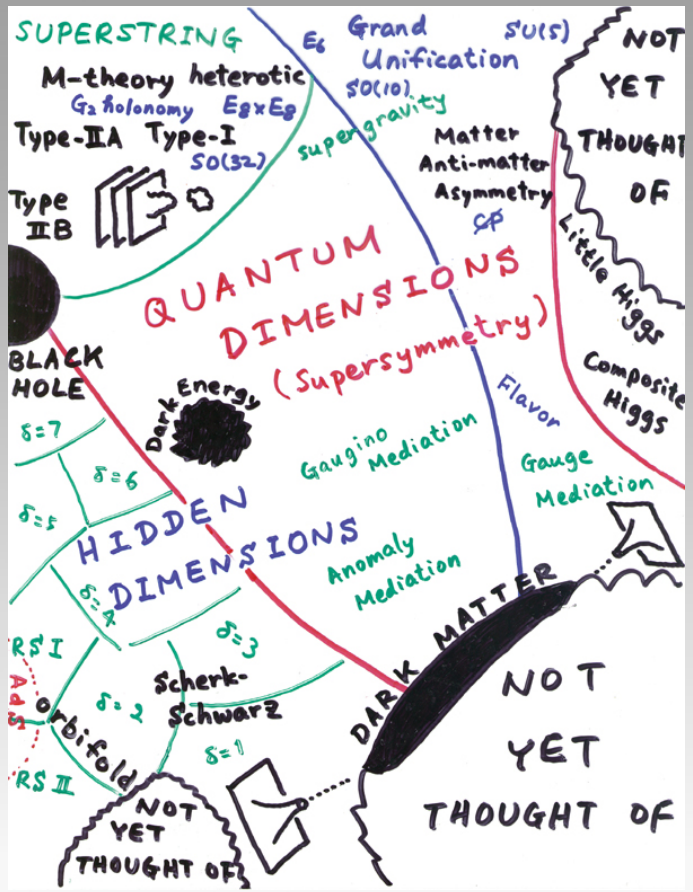
- Generalisation of non-linear regression
- **Goodness-of-fit**
- **Parameter estimation**
- **Comparison of models**



Global Fits

Why do we need global fits?

- Many SUSY theories
  - Which one is better?
- SUSY models have a large amount of parameters
  - Explore full parameter space
  - Where is my theory valid?
- Many experimental constraints
  - Collider searches, dark matter, precision observables, flavour anomalies,. . .
  - Simultaneously include all constraints
  - Does my theory fit the experimental data?



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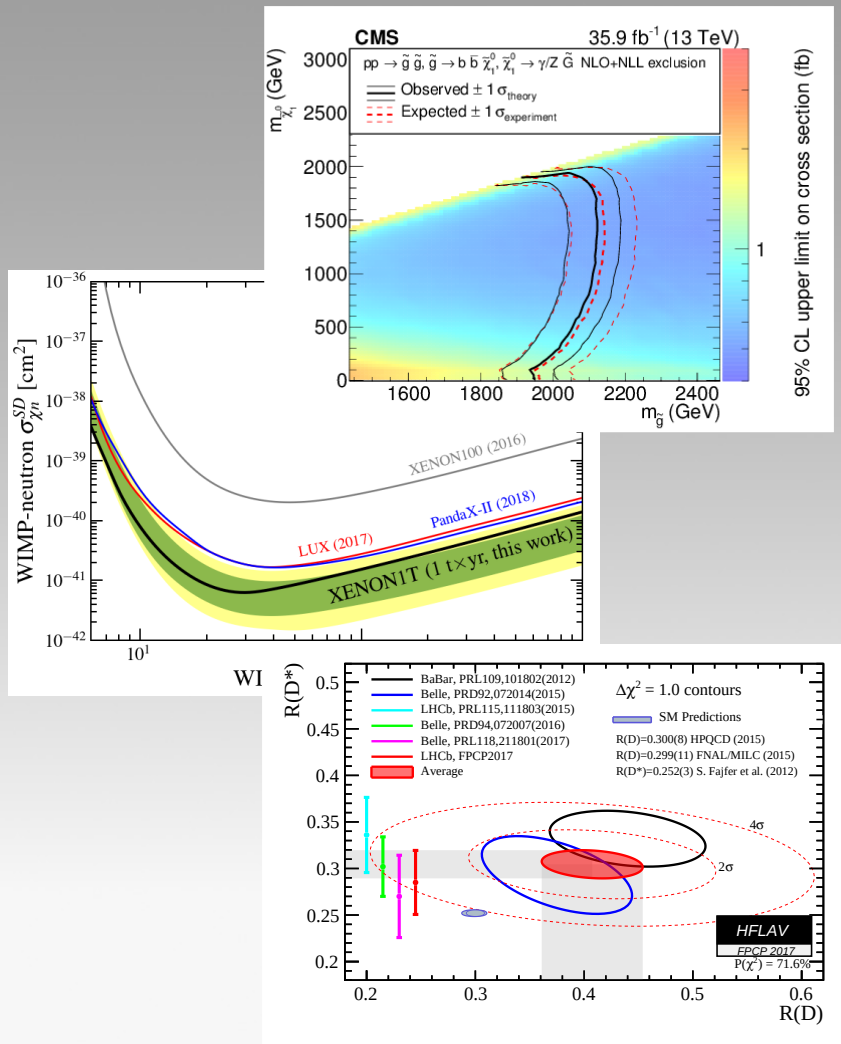


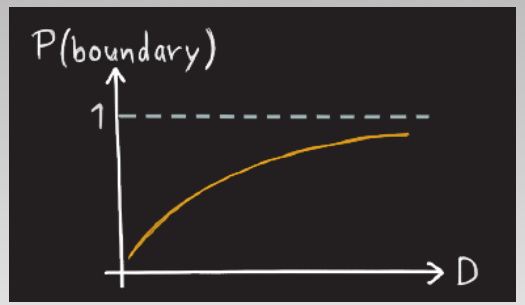
Global Fits

How do we do global fits?

- Combine all constraints into a **composite likelihood**

$$\mathcal{L} = \mathcal{L}_{Collider}\mathcal{L}_{Higgs}\mathcal{L}_{DM}\mathcal{L}_{Flavour}\cdots$$

- Perform an extensive **parameter scan**
  - Old-school sampling methods (random, grid) are inefficient
  - Impossible to make statement about statistics
  - Need **smart sampling strategies** (differential, nested, genetic,...)



- **Rigorous** statistical interpretation (frequentist/Bayesian)
  - Goodness-of-fit
  - Parameter estimation
  - Model comparison

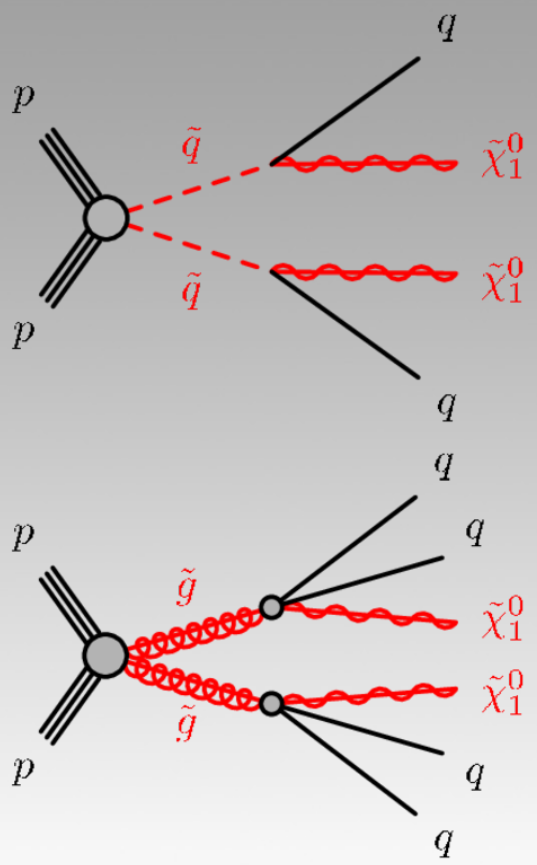
Likelihoods and constraints

Likelihoods

Collider searches

- LHC searches for SUSY particles
  - $\tilde{q}$, $\tilde{g}$: 0-lepton + $\not{E}_T$ searches
  - $\tilde{t}$, $\tilde{b}$: b-jets or (0-2) leptons + $\not{E}_T$
  - $\tilde{\chi}_i^0$, $\tilde{\chi}_i^\pm$, $\tilde{l}$: ≥ 2 leptons + $\not{E}_T$
  - $\tilde{\chi}_i^0$: monojet + $\not{E}_T$
- LEP SUSY searches
  - $\tilde{\chi}_i^0$, $\tilde{\chi}_i^\pm$, $\tilde{l}$
  - relevant for light, degenerate spectra
- Higgs physics
  - mass constraint $m_h \approx 125$ GeV
  - signal strengths from LHC and LEP
  - invisible Higgs decays
    BF($h \to$ inv.) ≤ 0.26

    [ATLAS, arXiv:1904.05105]



[ATLAS, Eur. Phys. J. C 76 (2016) 392]

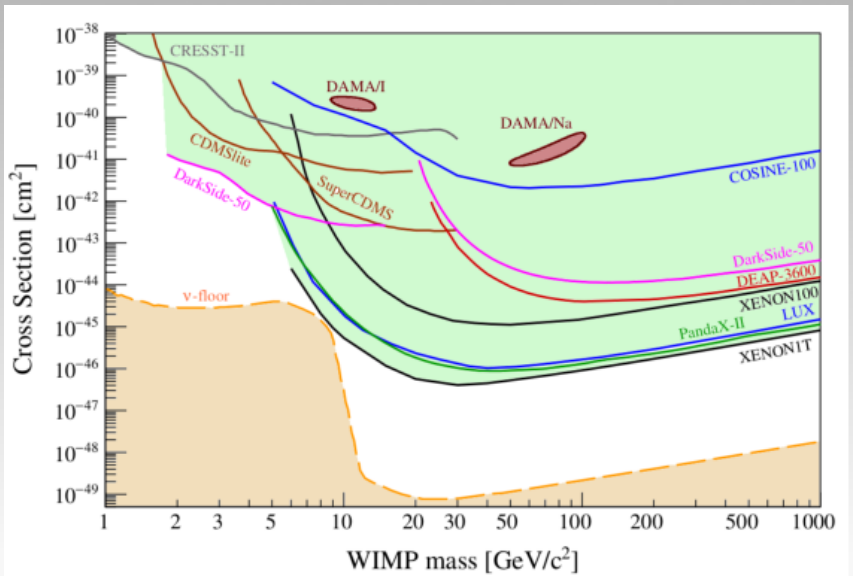
Likelihoods

Dark matter constraints

- Relic density of DM
  - $\tilde{t}$, $\tilde{b}$, $\tilde{\tau}$ coannihilation
  - $\tilde{\chi}$-$\tilde{\chi}$ coannihilation
  - $h/Z/A/H$ resonant annihilation
- Direct detection
  - Spin-independent: LUX, XENON1T, PandaX
  - Spin-dependent: IceCube, PICO-60
- Indirect detection
  - γ-rays from DM ann.: Fermi-LAT
  - νs from DM ann. in the sun: IceCube

$$\Omega_c h^2 = 0.1188 \pm 0.0010$$

[Planck, Astron. Astrophys. 594, A13 (2016)]

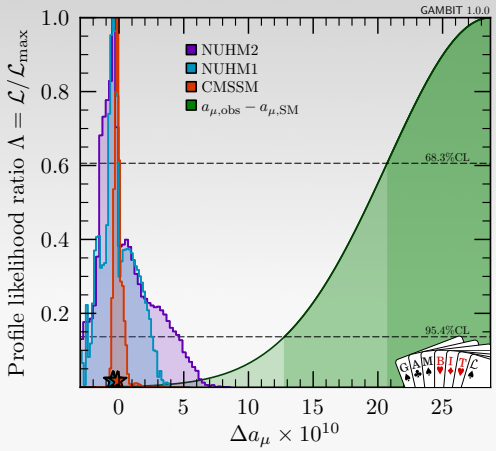


[Schumann, M., arXiv:1903.03026]

Likelihoods

Precision observables

- Electroweak precision
  - $m_W = 80.385 \pm 0.015$ GeV [PDG, Chin. Phys. C38 (2014) 090001]
  - $\sin^2\hat{\theta}(M_Z) = 0.23153 \pm 0.00016$ [CMS & LHCb, Nature 522 (2015) 68]
  - $\Gamma(Z \to \text{inv.}) = 499.0 \pm 1.5$ MeV [PDG, Chin. Phys. C40 (2016) 090001]
- Anomalous magnetic moment μ
  - $a_\mu^{\text{SM}} = (11659180.2 \pm 4.9) \times 10^{-10}$ [M. Davier et al, Eur. Phys. J. C71 (2011) 1515]
  - $a_\mu^{\text{exp}} = (11659208.9 \pm 6.3) \times 10^{-10}$ [G.W. Bennett et al, Phys. Rev. D73 (2006) 072003]



[GAMBIT, Eur. Phys. J. C77 (2017) no.12, 824]

Likelihoods

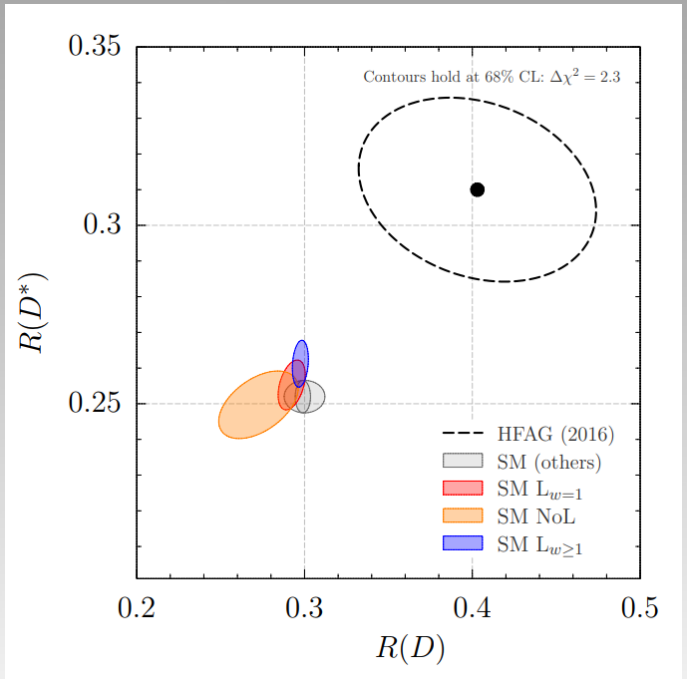
Flavour physics

- B and D meson decays
  - Tree-level (semi)leptonic decays
  - Electroweak penguins $B^0 \to K^{*0}\mu^+\mu^-$

    [LHCb, JHEP 02 (2016) 104]
  - Rare leptonic decays
    $B^0 \to \mu^+\mu^-$ & $B_s^0 \to \mu^+\mu^0$

    [CMS, Phys. Rev. Lett. 11 (2013) 101804]

    [LHCb, Phys. Rev. Lett. 11 (2013) 101805]
  - $B \to X_s\gamma$
- Lepton flavour universality ratios
  - $R_{K^{(*)}} = \frac{\mathrm{BF}(B\to K^{(*)}\tau\nu_\tau)}{\mathrm{BF}(B\to K^{(*)}l\nu_l)}$
  - $R_{D^{(*)}} = \frac{\mathrm{BF}(B\to D^{(*)}\tau\nu_\tau)}{\mathrm{BF}(B\to D^{(*)}l\nu_l)}$



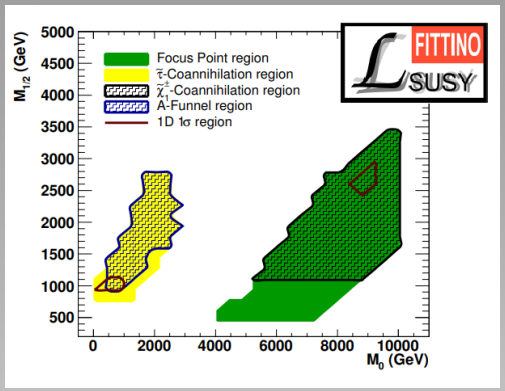
[F. U. Bernlochner et al, Phys. Rev. D95 (2017), 115008]

Results

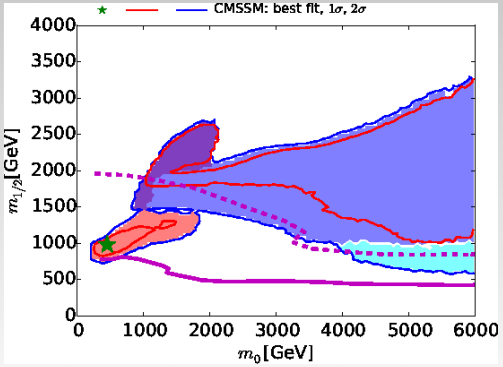
GUT-scale SUSY

CMSSM

- m_0, $m_{1/2}$, A_0, $\tan\beta$, sign(μ)
- LHC Run 1, LUX 2013
  - $\tilde{\chi}^+$ coann / A-funnel at large m_0
  - $\tilde{\tau}$ coann region at low mass



[Fittino, EPJC 76 (2016) no.2, 96]



[MasterCode, EPJC 74 (2014) 2922]

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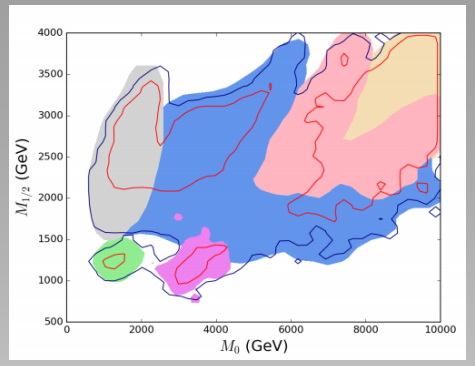
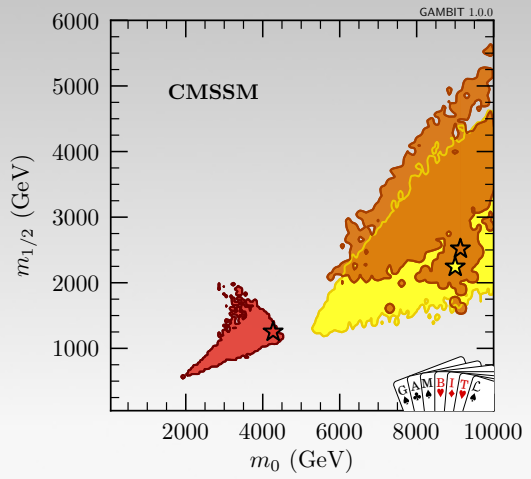
  - $\tilde{\tau}$ coann region is gone (95%CL)
  - $\tilde{t}$ coann region at low mass



[EasyScanHEP, PLB 769 (2017) 470-476]



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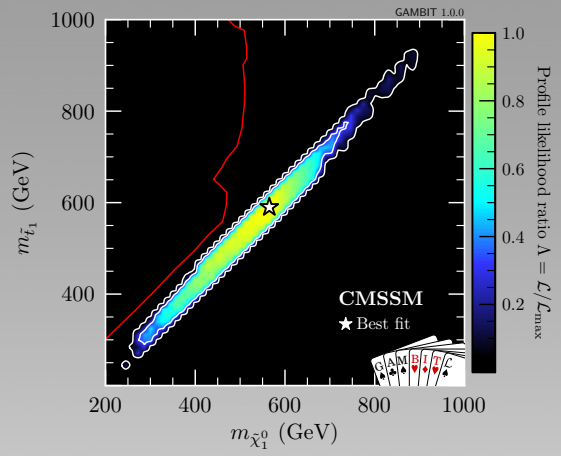
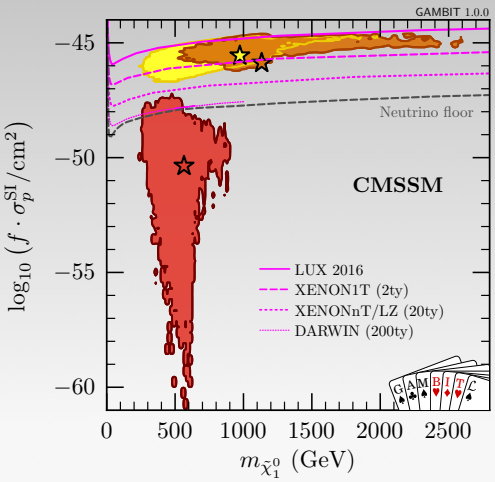
  - $\tilde{\tau}$ coann region is gone (95%CL)
  - $\tilde{t}$ coann region at low mass
- Long lived and compressed spectra searches can probe $\tilde{t}$ coann region
- XENON1T, LZ and Darwin can exclude χ^+/A-funnel



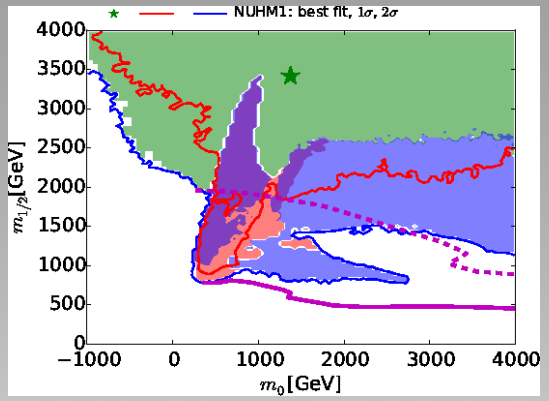


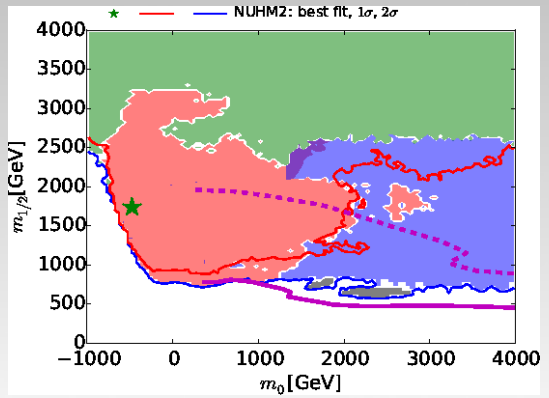
[GAMBIT, EPJC 77 (2017) no.12 824]

GUT-scale SUSY

NUHM

- NUHM1: $m_0 \to m_0,\, m_H$
- NUHM2: $m_0 \to m_0,\, m_{H_u},\, m_{H_d}$
- LHC Run 1, LUX 2013
  - No upper limit on $m_{1/2}$ and $m_0 < 0$
  - Large $\tilde{\tau}$ coann region





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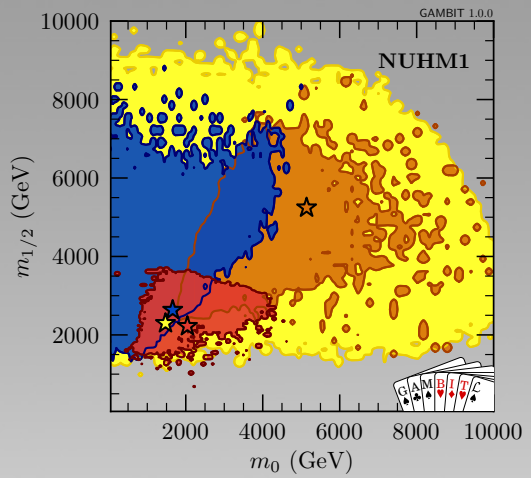
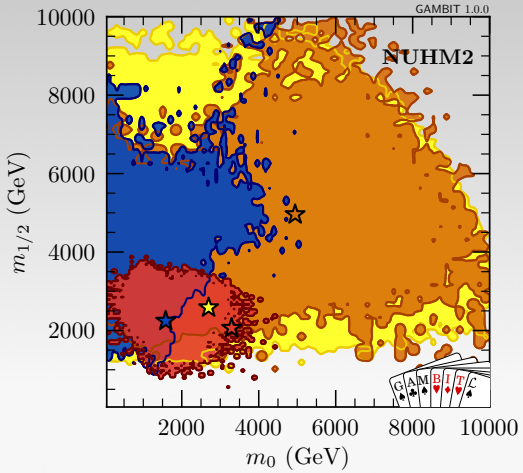
  - Increased $\tilde{t}$ coann
  - No lower limit on m_0 for all $m_{1/2}$





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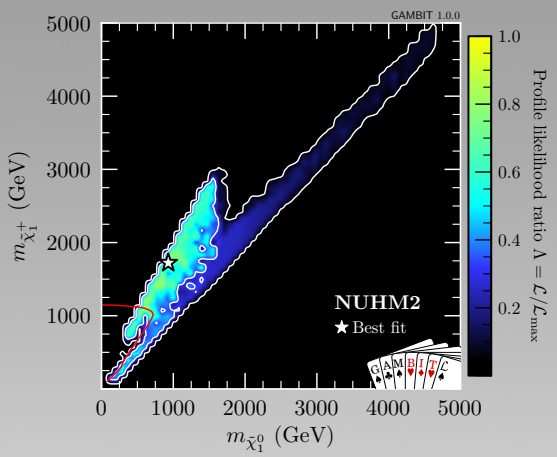

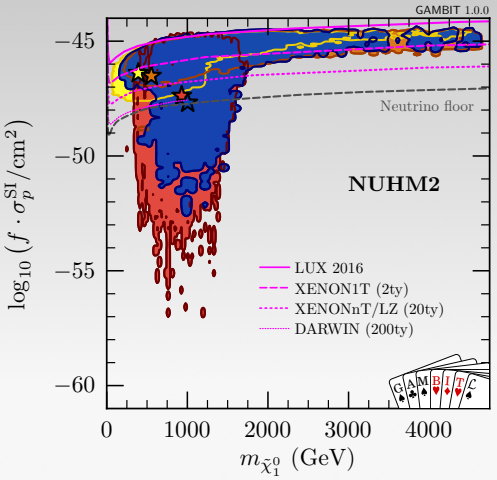

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- LHC Run 2, LUX 2016
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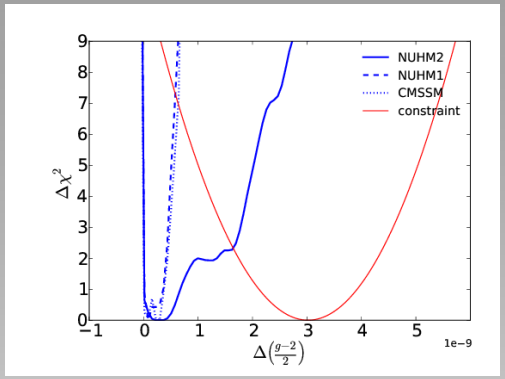
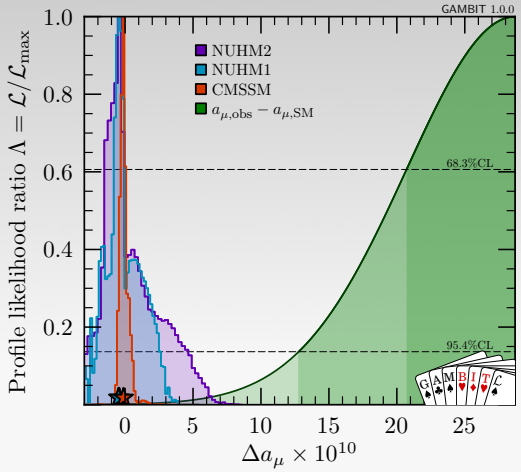
  - Increased $\tilde{t}$ coann
  - No lower limit on m_0 for all $m_{1/2}$
- Can be probed by compressed $\tilde{\chi}$ and DM direct detection
- No longer good prediction for a_μ



[MasterCode, EPJC 74 (2014) no.12, 3212]

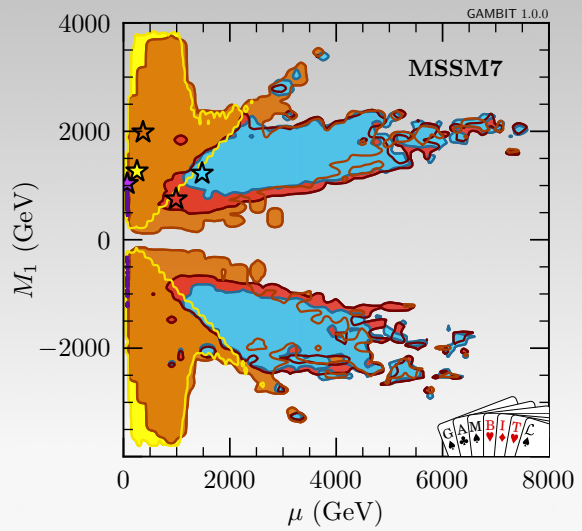


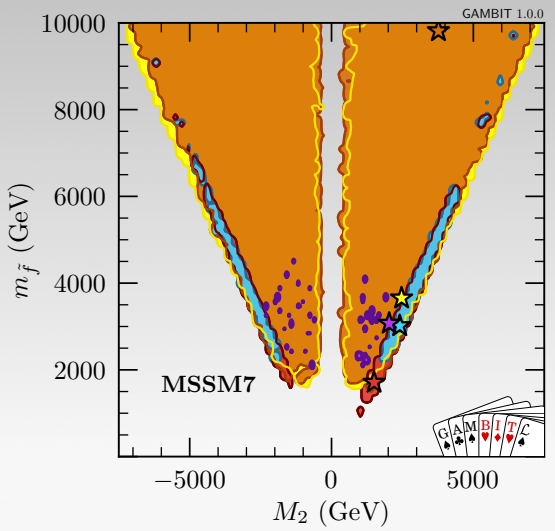
[GAMBIT, EPJC 77 (2017) no.12 824]

Weak-scale SUSY

MSSM7

- A_{u_3}, A_{d_3}, m_{H_u}, m_{H_d}, $m_{\tilde{f}}$, M_2, $\tan\beta$, sign(μ) at $Q = 1$ TeV
- $\tilde{\chi}^+$ coann region ($\mu < M_1$), with contributions from A/H-funnel and h/Z-funnel
- $\tilde{t}$, $\tilde{b}$ coann region, with A/H-funnel (no $\tilde{\tau}$ coann)
- Compressed $\tilde{t} - \tilde{\chi}^0$ or $\tilde{\chi}^0 - \tilde{\chi}^+$ (Run 2)





[GAMBIT, EPJC 77 (2017) no.12, 879]

Weak-scale SUSY

MSSM7

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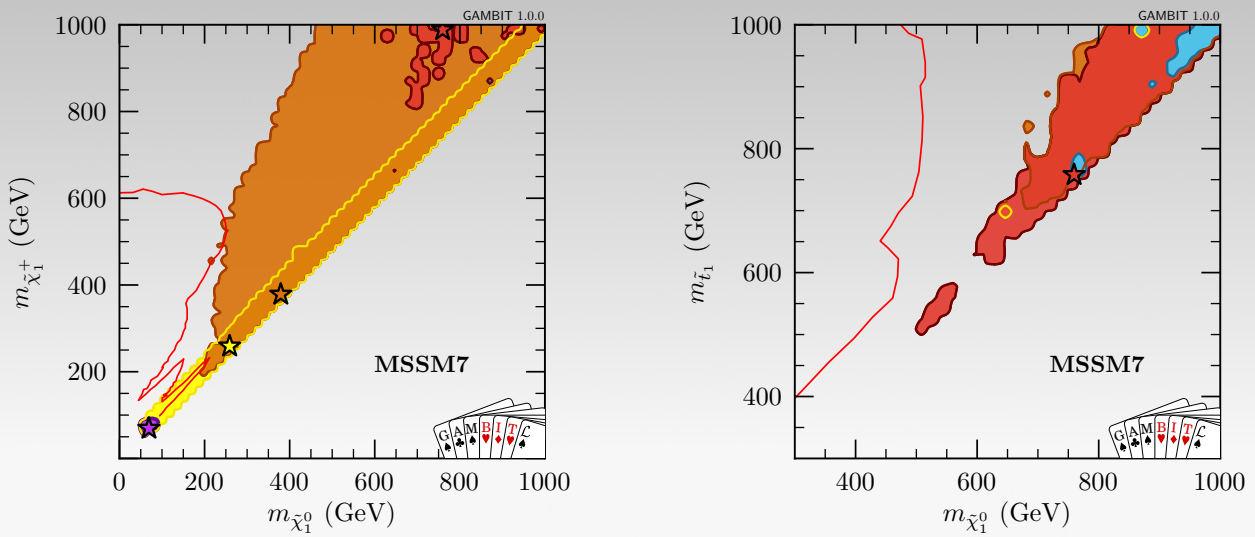
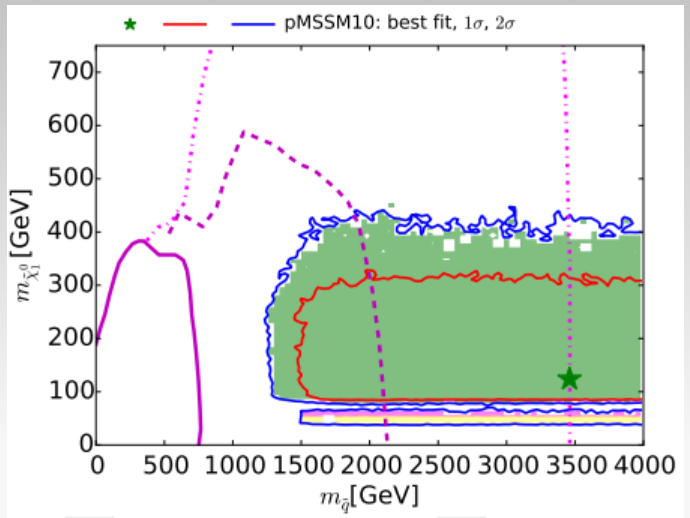


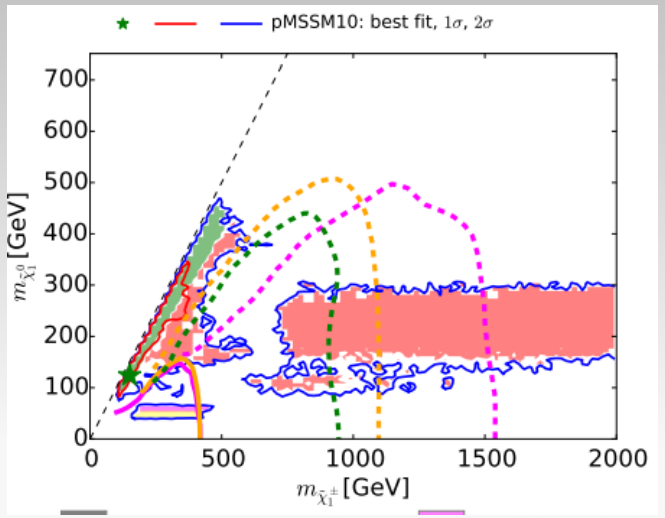
[GAMBIT, EPJC 77 (2017) no.12, 879]

Weak-scale SUSY

pMSSM10

- M_1, M_2, M_3, $m_{\tilde{q}}$, $m_{\tilde{q}_3}$, $m_{\tilde{l}}$, A, μ, M_A, $\tan\beta$ at M_{SUSY}
- Dominant $\tilde{\chi}^+$ coann, with minor h/Z-funnel and $\tilde{\tau}$ coann
- Target h/Z-funnel and $\tilde{\tau}$ coann, but miss $\tilde{\chi}^+$ coann (Run 1)
- SI direct detection can probe $\tilde{\chi}^+$ coann
- Great fit to a_μ due to light $\tilde{\chi}^+$ and $\tilde{l}$





[MasterCode, EPJC 75 (2015) no.9, 422] [Mastercode, EPJC 75 (2015) 500]

Weak-scale SUSY

pMSSM10

- M_1, M_2, M_3, $m_{\tilde{q}}$, $m_{\tilde{q}_3}$, $m_{\tilde{l}}$, A, μ, M_A, $\tan\beta$ at M_{SUSY}
- Dominant $\tilde{\chi}^+$ coann, with minor h/Z-funnel and $\tilde{\tau}$ coann
- Target h/Z-funnel and $\tilde{\tau}$ coann, but miss $\tilde{\chi}^+$ coann (Run 1)
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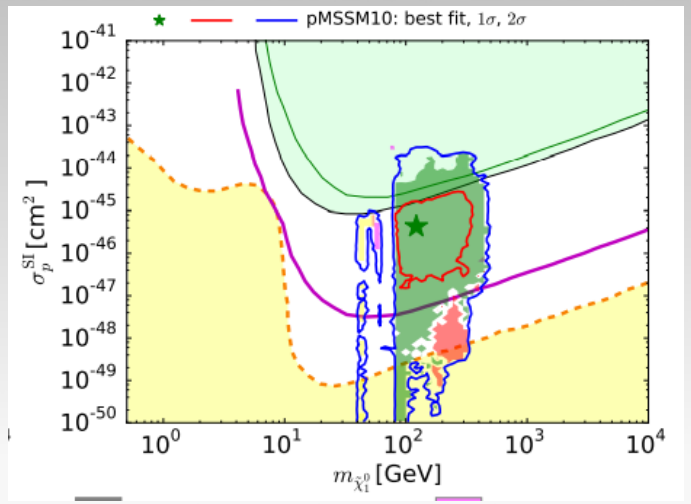
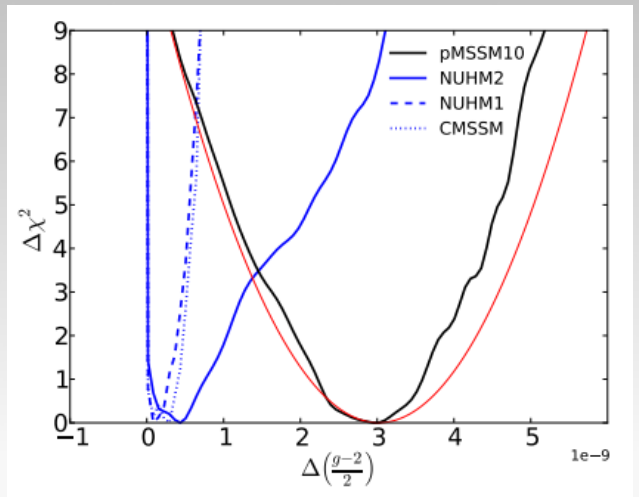


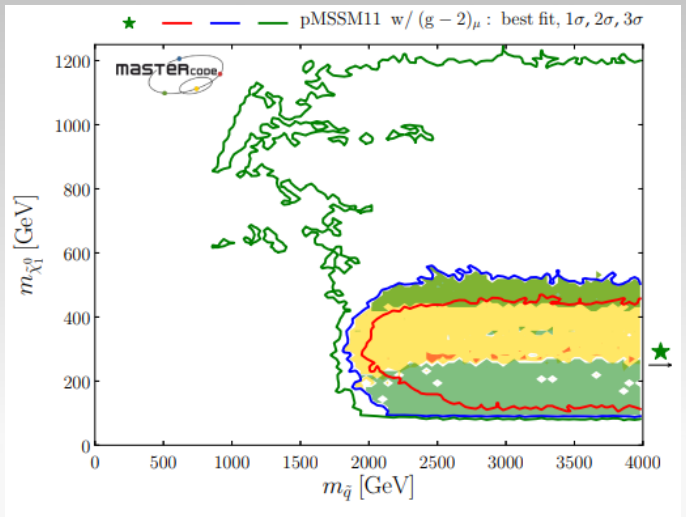


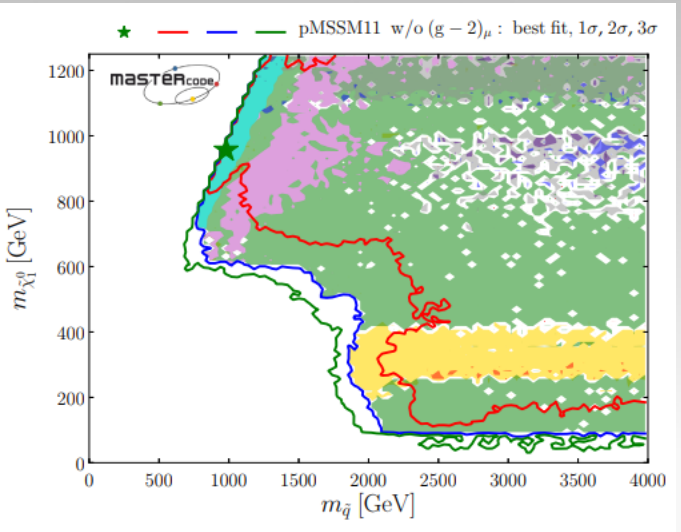
[MasterCode, EPJC 75 (2015) no.9, 422] [Mastercode, EPJC 75 (2015) 500]

Weak-scale SUSY

pMSSM11

- M_1, M_2, M_3, $m_{\tilde{q}}$, $m_{\tilde{q}_3}$, $m_{\tilde{l}}$, $m_{\tilde{l}_3}$, A, μ, M_A, $\tan\beta$ at M_{SUSY}
- Run 2 searches push $\tilde{q}$, $\tilde{g}$ and $\tilde{\chi}^0$ masses (h/Z-funnel gone)
- New coann mechanisms open
- Great fit to a_μ constraint, strong effect on $\tilde{\chi}$ composition
- Future SI direct detection (LZ, XENONnT) can probe 1σ





[MasterCode, EPJC 78 (2018) no.3, 256]

pMSSM11

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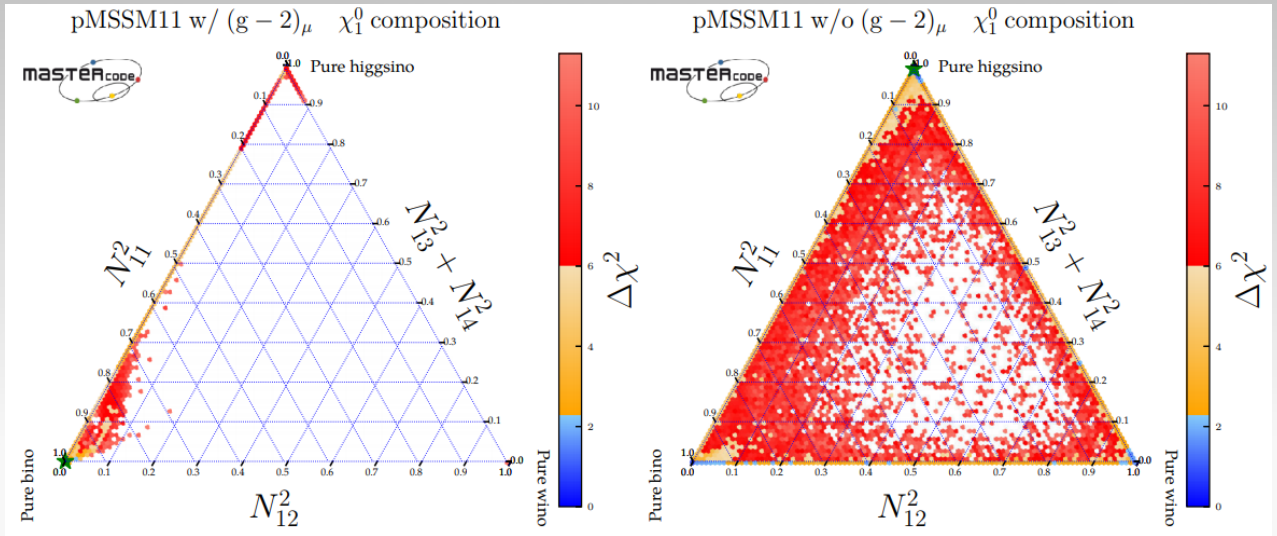
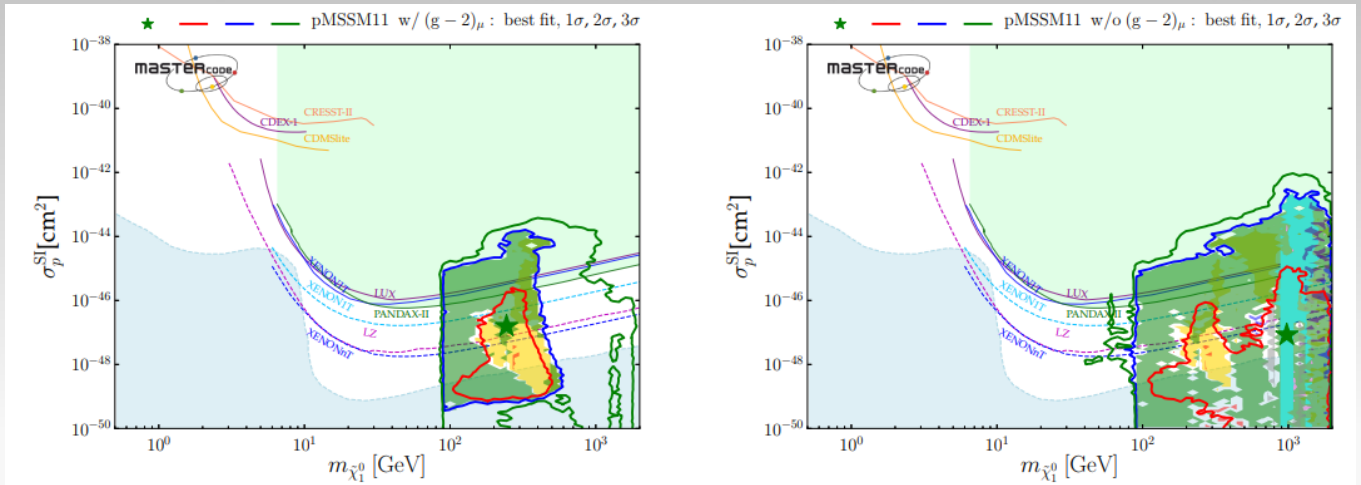


[MasterCode, EPJC 78 (2018) no.3, 256]

Weak-scale SUSY

pMSSM11

- M_1, M_2, M_3, $m_{\tilde{q}}$, $m_{\tilde{q}_3}$, $m_{\tilde{l}}$, $m_{\tilde{l}_3}$, A, μ, M_A, $\tan\beta$ at M_{SUSY}
- Run 2 searches push $\tilde{q}$, $\tilde{g}$ and $\tilde{\chi}^0$ masses (h/Z-funnel gone)
- New coann mechanisms open
- Great fit to a_μ constraint, strong effect on $\tilde{\chi}$ composition
- Future SI direct detection (LZ, XENONnT) can probe 1σ

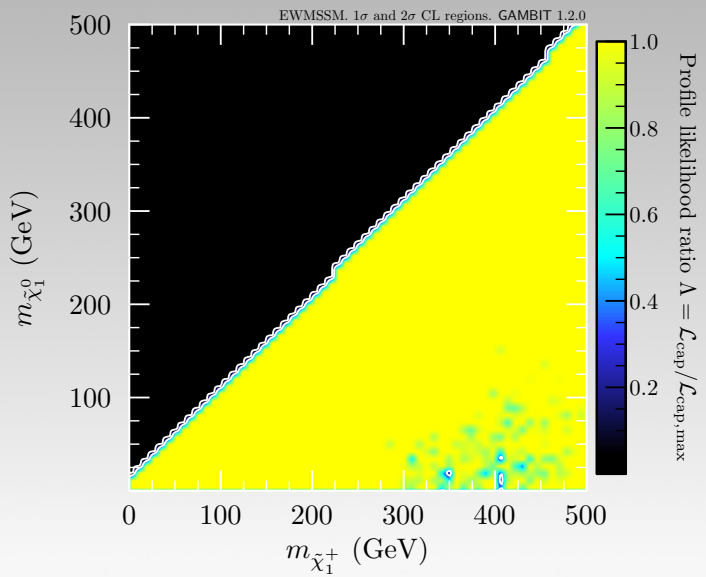


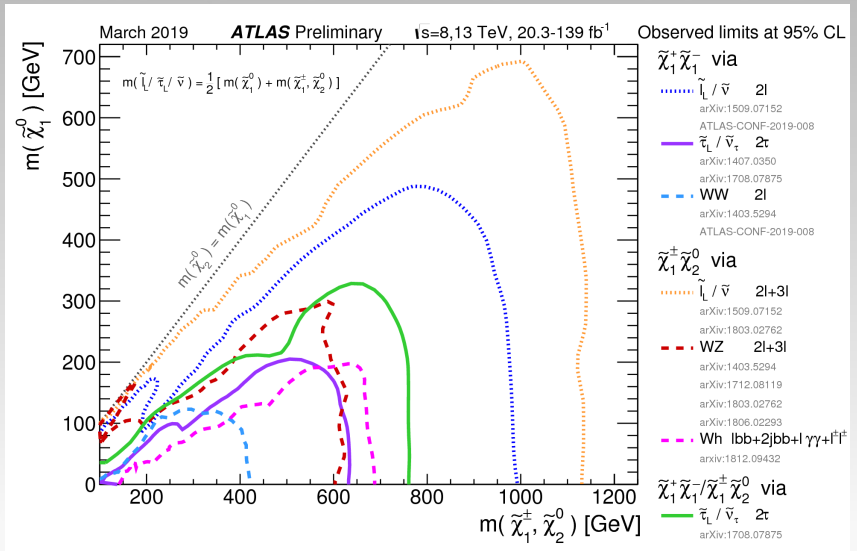
[MasterCode, EPJC 78 (2018) no.3, 256]

Other SUSY models

EWMSSM

- M_1, M_2, μ, $\tan\beta$, $\quad A_i = 0$, $m_{\tilde{l},\tilde{q}} = 3$ TeV, M_3, $m_A = 5$ TeV
- LHC Run 2 searches for light electroweakinos
- No exclusion for light electroweakinos



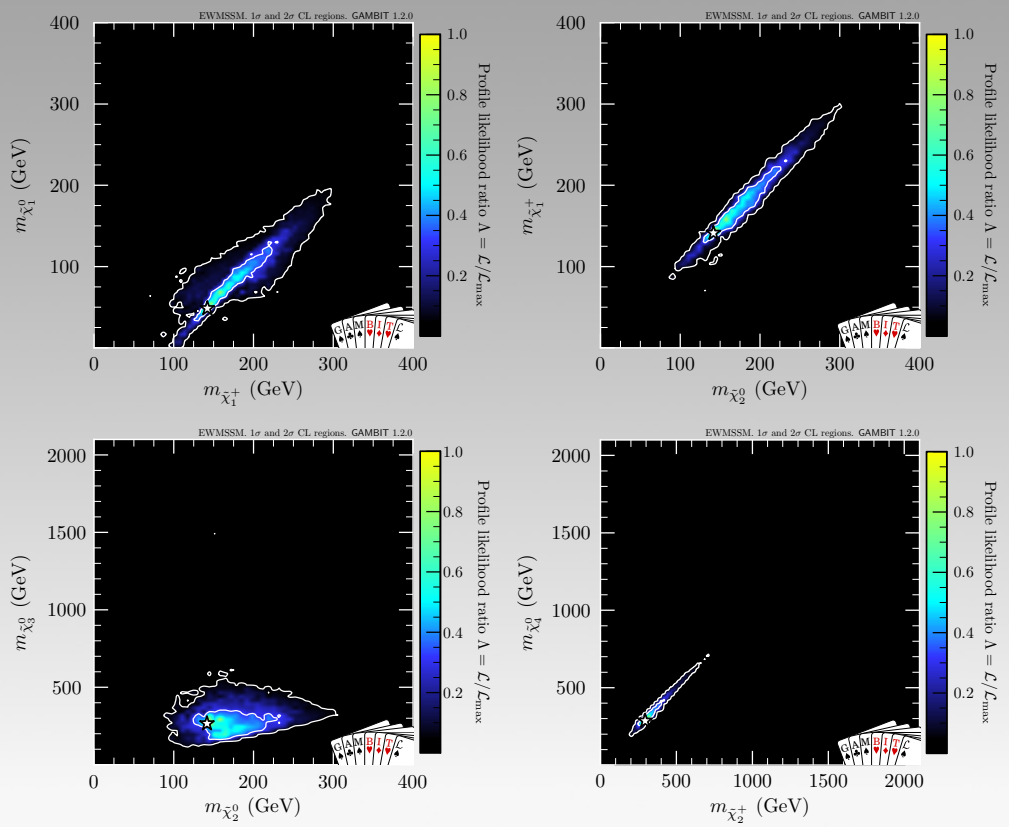


[GAMBIT, EPJC 79 (2019) no.5, 395]

Other SUSY models

EWMSSM

- Profile likelihoods for $m_{\tilde{\chi}_i^{0,\pm}}$
- Clear preference for light electroweakinos
- Fits mild excesses shown in ATLAS multi-lep analyses
- Best fit bino LSP $m_{\tilde{\chi}_1^0} \sim 50$ (67) GeV
- Local significance 3.3σ (2.9σ)



[GAMBIT, EPJC 79 (2019) no.5, 395]

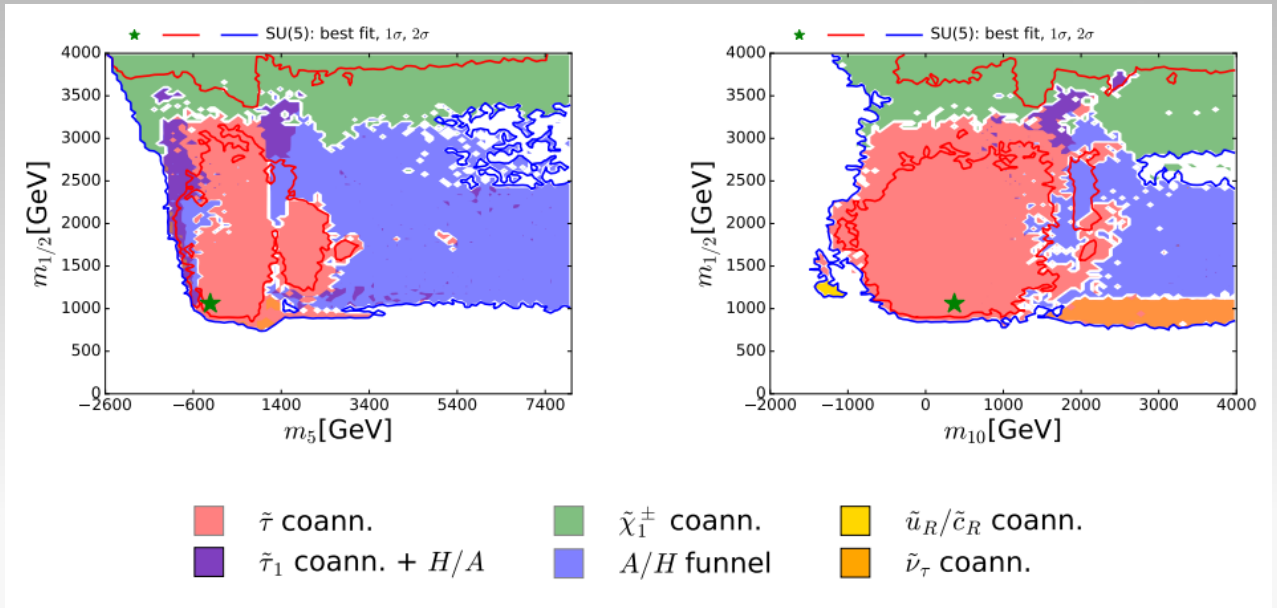
Other SUSY models

SU(5)

- Variation of NUHM2 $m_0 \to m_5$, m_{10}

$$(q_L, u_L^c, e_L^c) \in \mathbf{10},\ (l_L, d_L^c) \in \bar{\mathbf{5}}$$

- New coann mechanisms: $\tilde{u}_R/\tilde{c}_R$ and $\tilde{\nu}_\tau$
- Compressed $\tilde{\chi} - \tilde{q}$ might evade detection

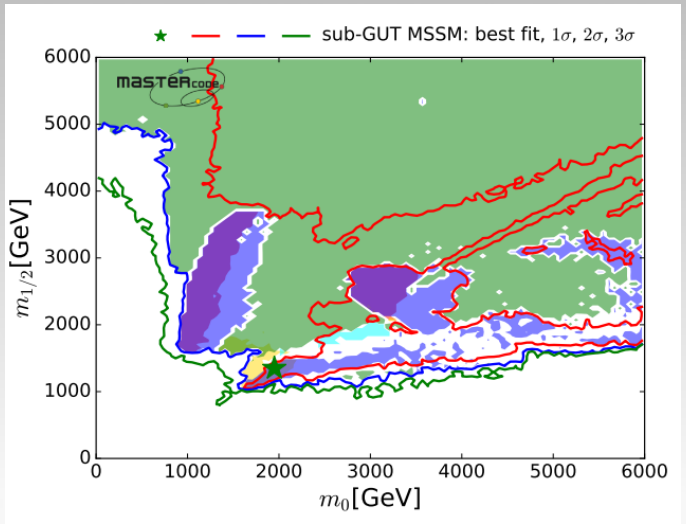


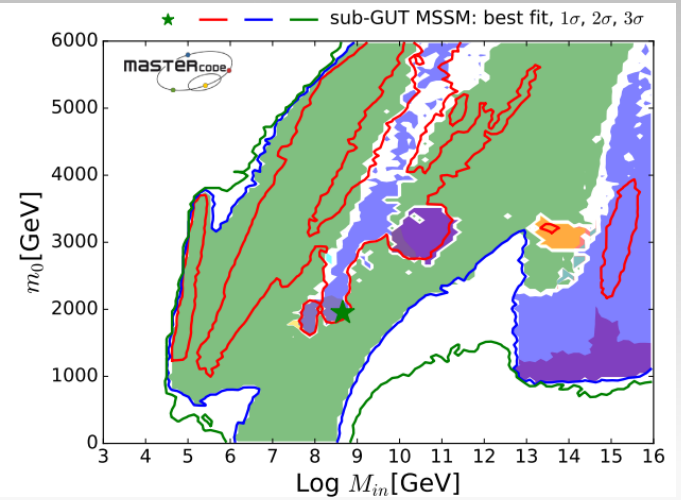
[MasterCode, EPJC 77 (2017) no.2, 104]

Other SUSY models

Sub-GUT

- m_0, $m_{1/2}$, A_0, $\tan\beta$, sign(μ), $M_{\rm in} \in (10^3, 10^{16})$ GeV
- Best fit at $M_{\rm in} \sim 10^8$ GeV
- Slight better fit the CMSSM, due to BR($B_{s,d} \to \mu^+\mu^-$)
- Preference for hybrid A/H-funnel and $\tilde{t}$ coann



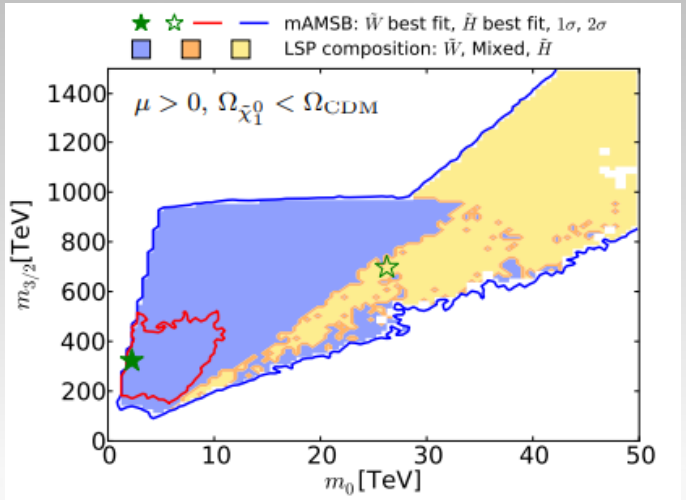


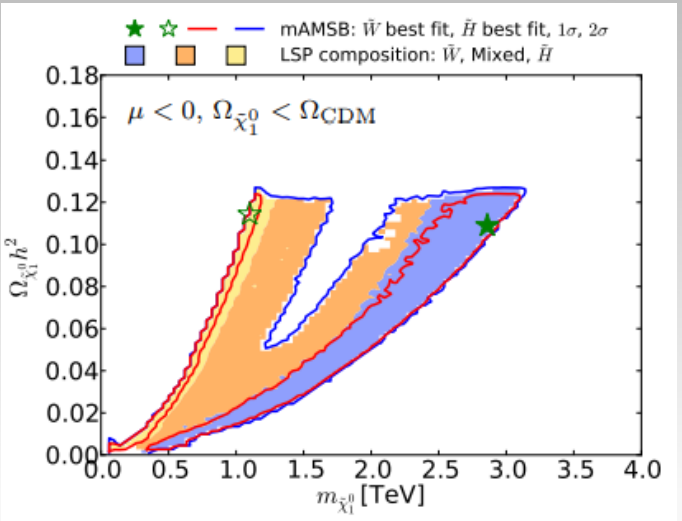
[MasterCode, EPJC 78 (2018) no.2, 158]

Other SUSY models

mAMSB

- m_0, $m_{3/2}$, $\tan\beta$, sign(μ) [A_i, M_i determined by anomalies]
- Different hierarchy of gauginos $M_2 < M_1 < M_3$
- $\tilde{\chi}^0$ is wino, Higgsino or mixed
- Heavy spectrum if DM is only $\tilde{\chi}^0$, lighter if part





[MasterCode, EPJC 77 (2017) no.4, 268]

Summary

Summary and outlook

Conclusions

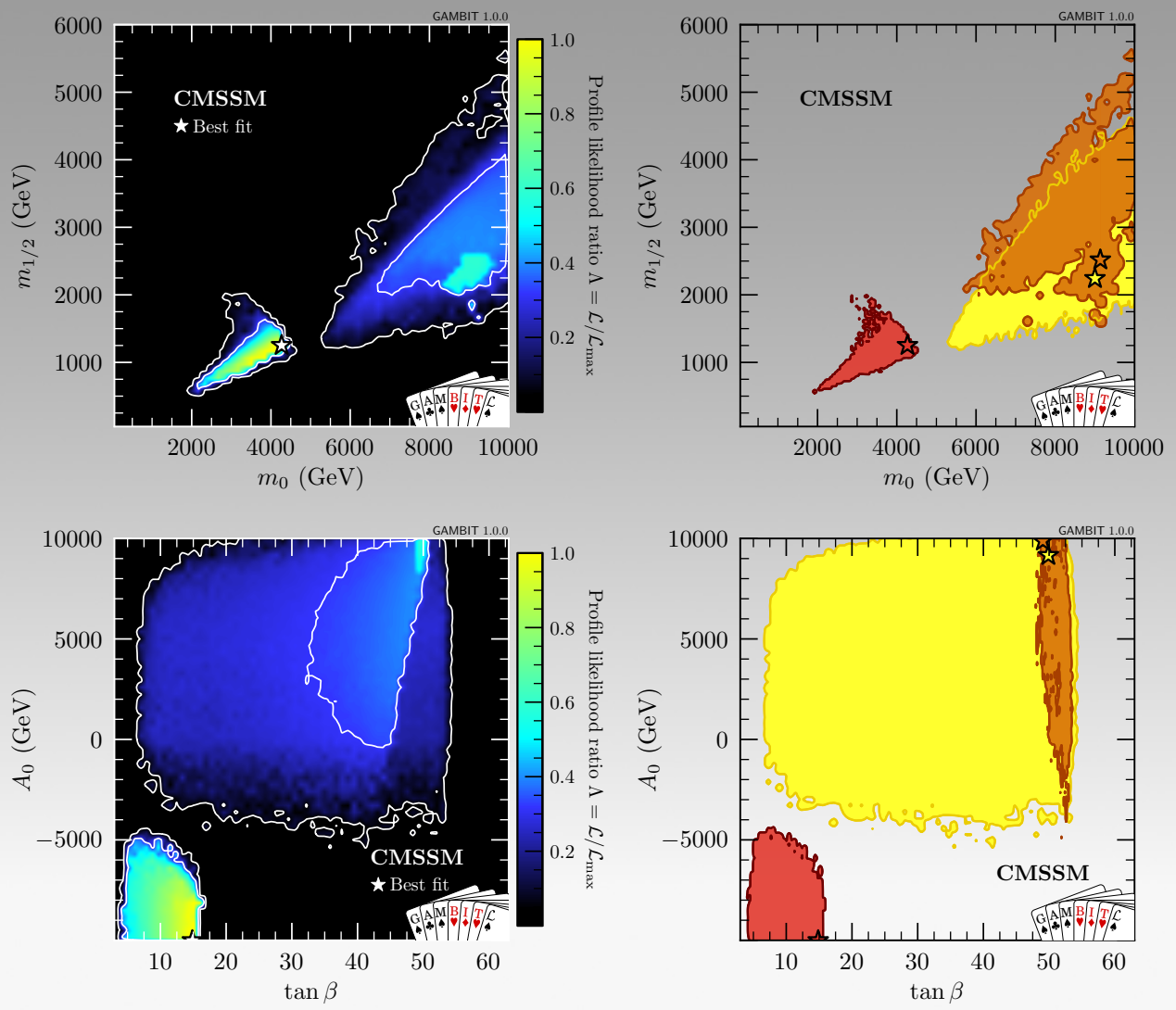
- SUSY global fits are the way forward
  - Smart sampling of models with many parameters
  - Composite likelihoods with multitude of constraints
- Run 2 data and new DD detection push to heavy spectra
  - Compressed $\tilde{\chi}^0 - \tilde{\chi}^+$ or $\tilde{\chi}^0 - \tilde{t}$ might evade searches
  - LZ, XENON will probe A/Z-funnel and $\chi - \tilde{\chi}$ coann
- Weak-scale models allow more freedom
  - Other mechanisms of coann (h/Z, $\tilde{l}$, $\tilde{q}$)
  - Can fit a_μ, strongly affects spectrum ($\tilde{\chi}$ composition, light $\tilde{l}$)
- Other models present different phenomenology
  - Light $\tilde{u}_R$, $\tilde{\nu}_\tau$ in SU(5)
  - Different hierarchy of gauginos in mAMSB
- Recasts of simplified model analyses can give surprising results, even hints of new physics

Thanks!

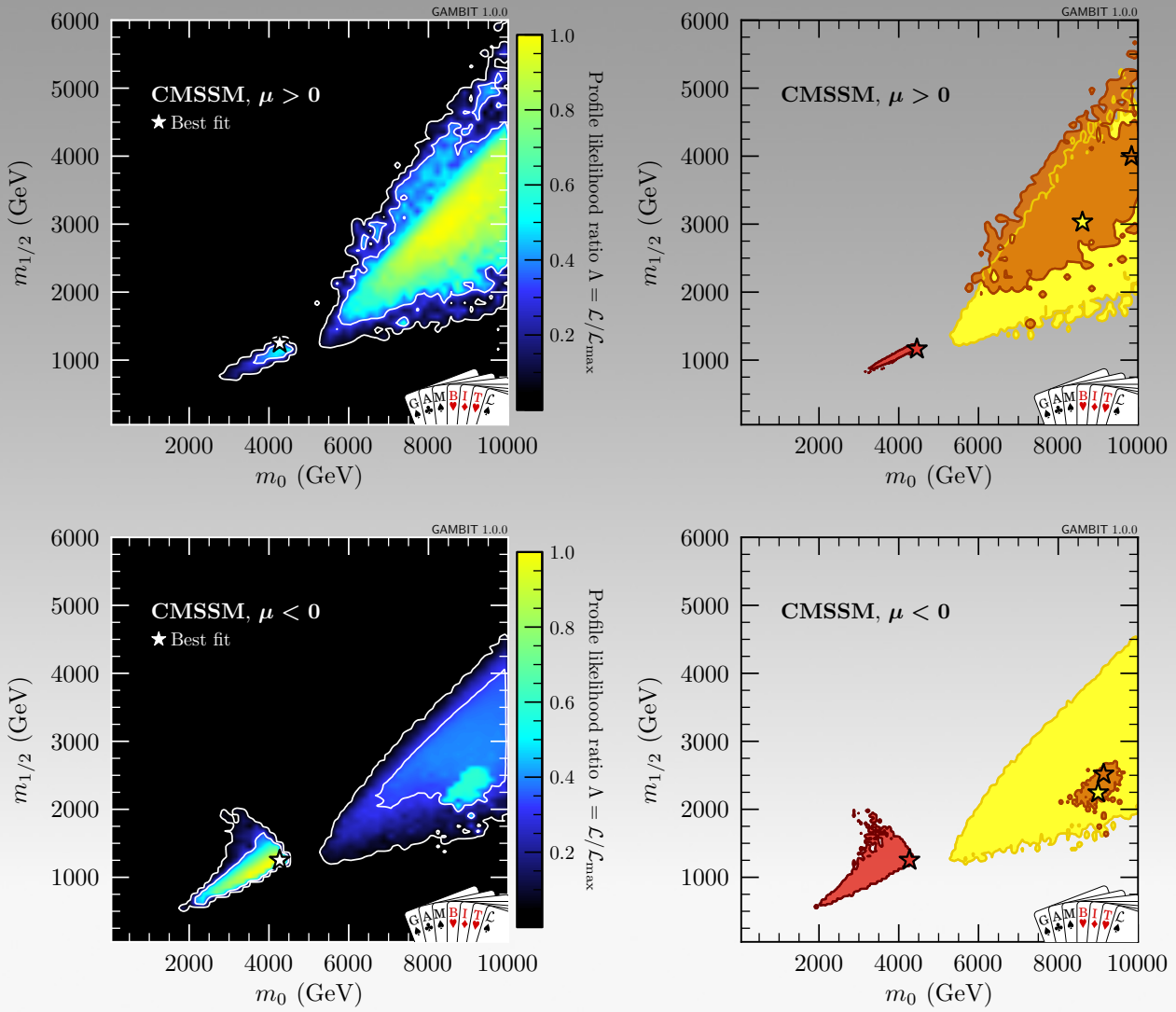
Supersymmetry will never die.
People who do SUSY will.
-Folklore

Backup

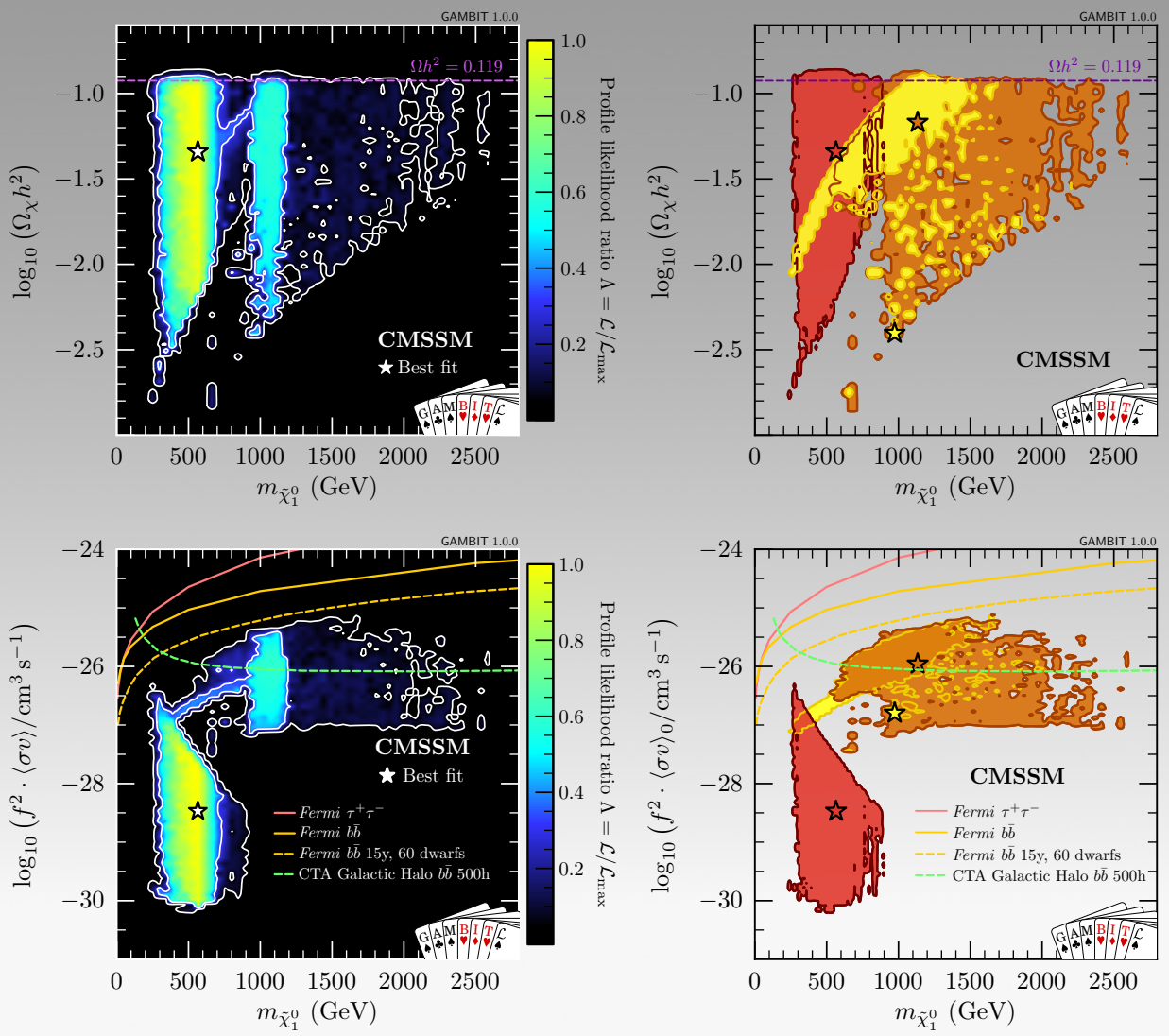
CMSSM


GAMBIT 1.0.0
CMSSM
★ Best fit
$m_{1/2}$ (GeV)
m_0 (GeV)
Profile likelihood ratio $\Lambda = \mathcal{L}/\mathcal{L}_{\max}$
A_0 (GeV)
$\tan\beta$

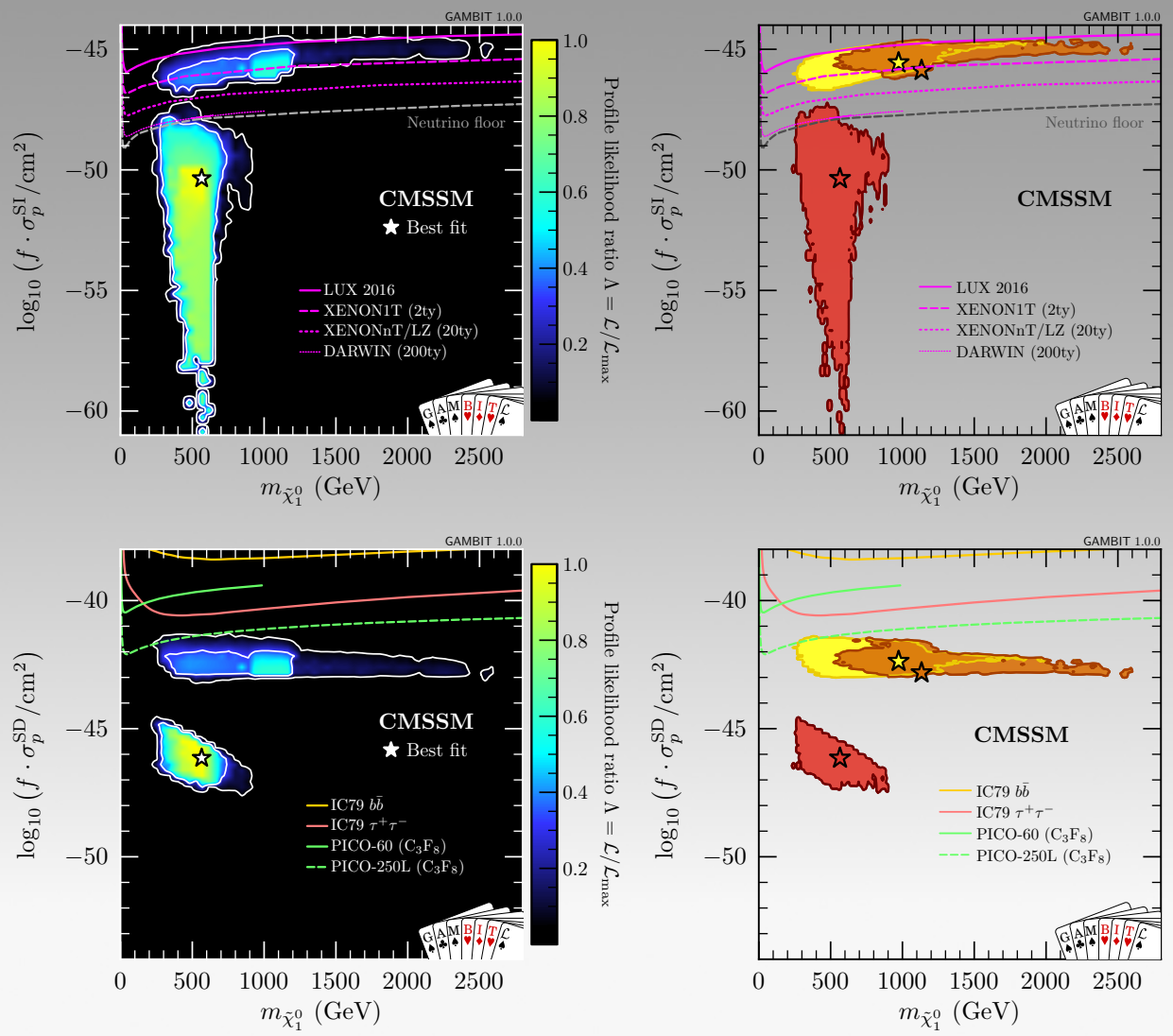
CMSSM


GAMBIT 1.0.0
CMSSM, $\mu > 0$
★ Best fit
$m_{1/2}$ (GeV)
m_0 (GeV)
Profile likelihood ratio $\Lambda = \mathcal{L}/\mathcal{L}_{\max}$
CMSSM, $\mu < 0$

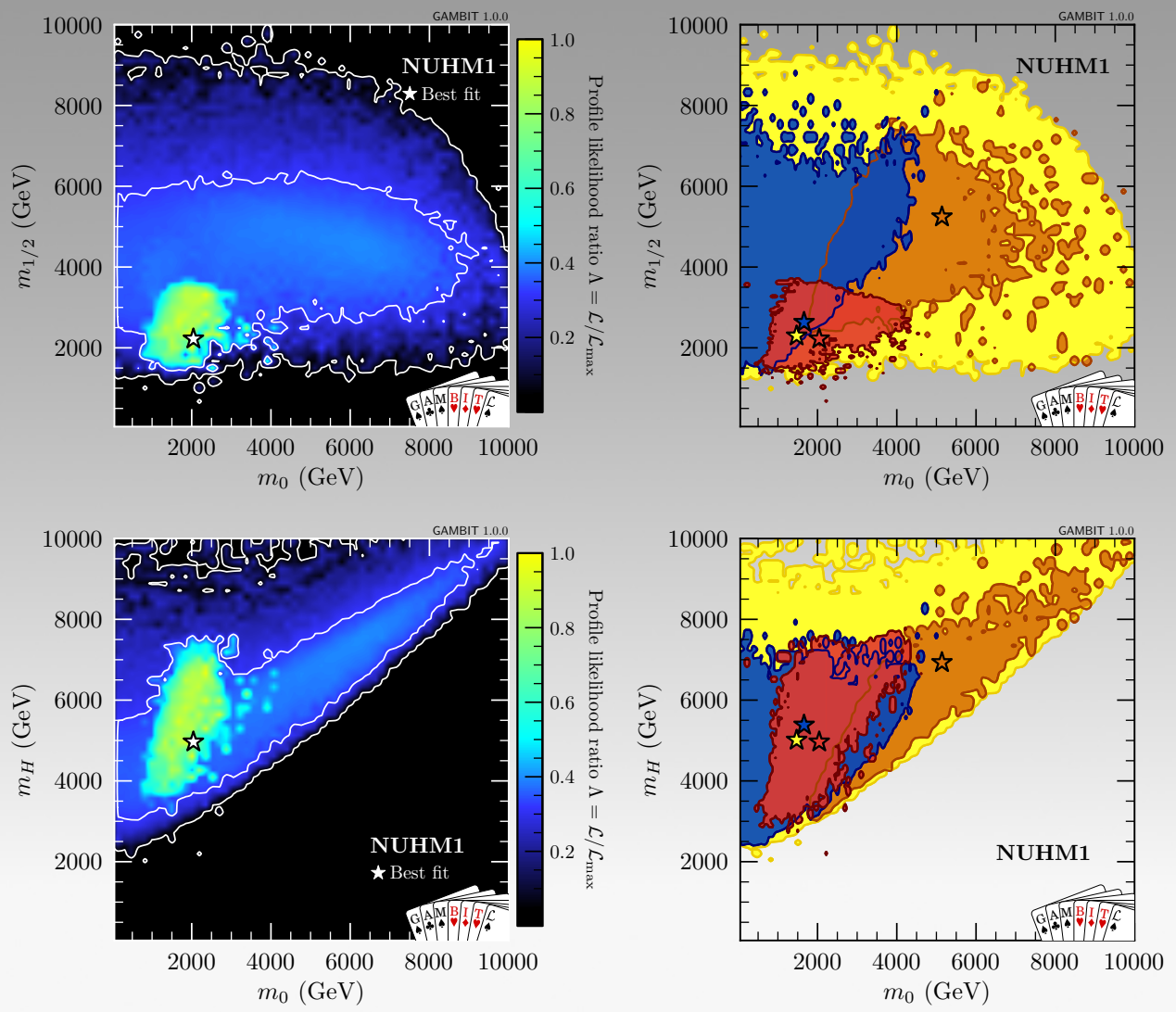
CMSSM


GAMBIT 1.0.0
$\Omega h^2 = 0.119$
$\log_{10}(\Omega_\chi h^2)$
$m_{\tilde{\chi}_1^0}$ (GeV)
Profile likelihood ratio $\Lambda = \mathcal{L}/\mathcal{L}_{\max}$
CMSSM
★ Best fit
$\log_{10}(f^2 \cdot \langle\sigma v\rangle/\mathrm{cm}^3\,\mathrm{s}^{-1})$
$\log_{10}(f^2 \cdot \langle\sigma v\rangle_0/\mathrm{cm}^3\,\mathrm{s}^{-1})$
Fermi $\tau^+\tau^-$
Fermi $b\bar{b}$
Fermi $b\bar{b}$ 15y, 60 dwarfs
CTA Galactic Halo $b\bar{b}$ 500h

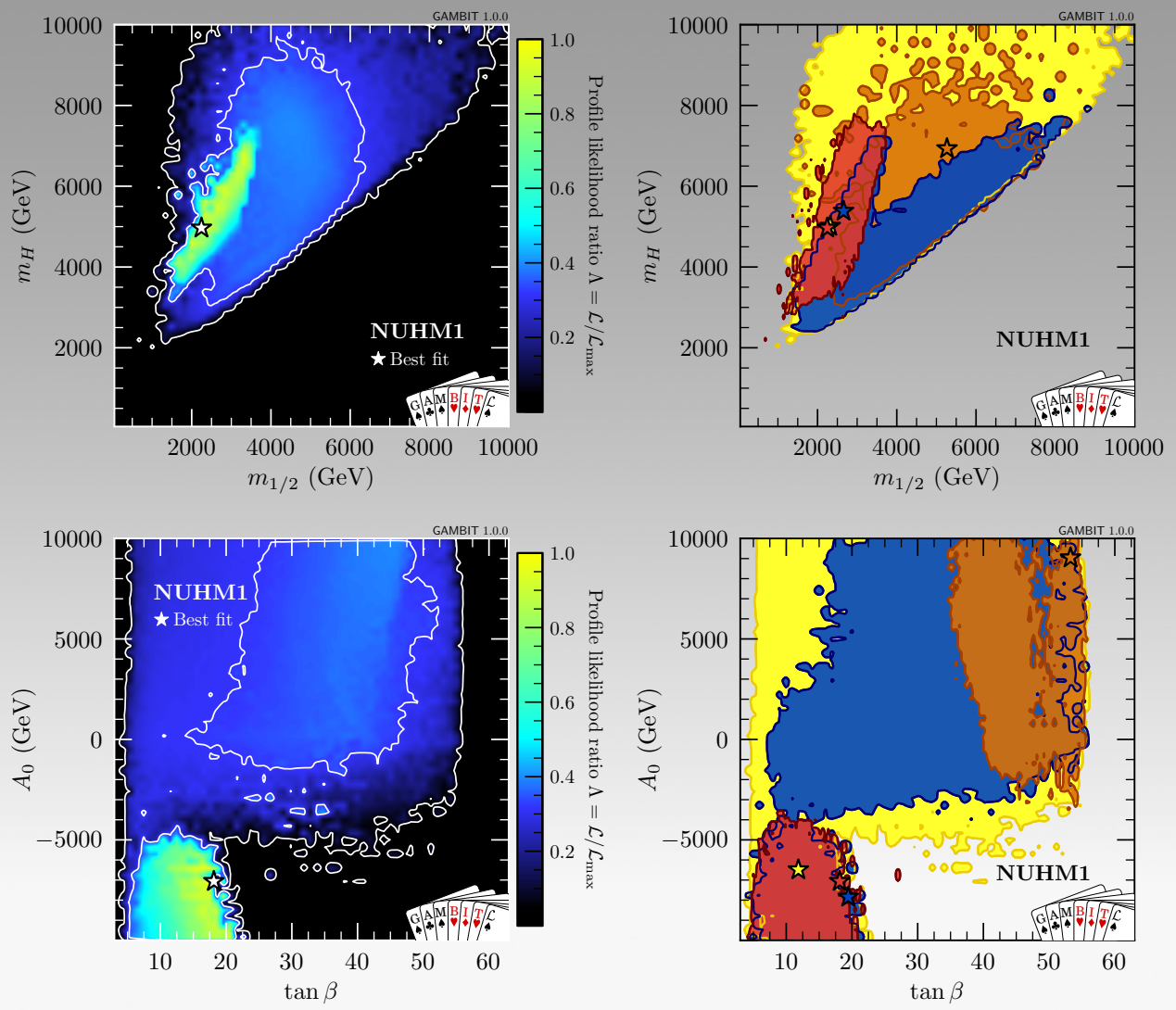
CMSSM


GAMBIT 1.0.0
CMSSM
Best fit
Neutrino floor
LUX 2016
XENON1T (2ty)
XENONnT/LZ (20ty)
DARWIN (200ty)
IC79 $b\bar{b}$
IC79 $\tau^+\tau^-$
PICO-60 (C_3F_8)
PICO-250L (C_3F_8)
$\log_{10}(f \cdot \sigma_p^{SI}/\mathrm{cm}^2)$
$\log_{10}(f \cdot \sigma_p^{SD}/\mathrm{cm}^2)$
$m_{\tilde{\chi}_1^0}$ (GeV)
Profile likelihood ratio $\Lambda = \mathcal{L}/\mathcal{L}_{\max}$

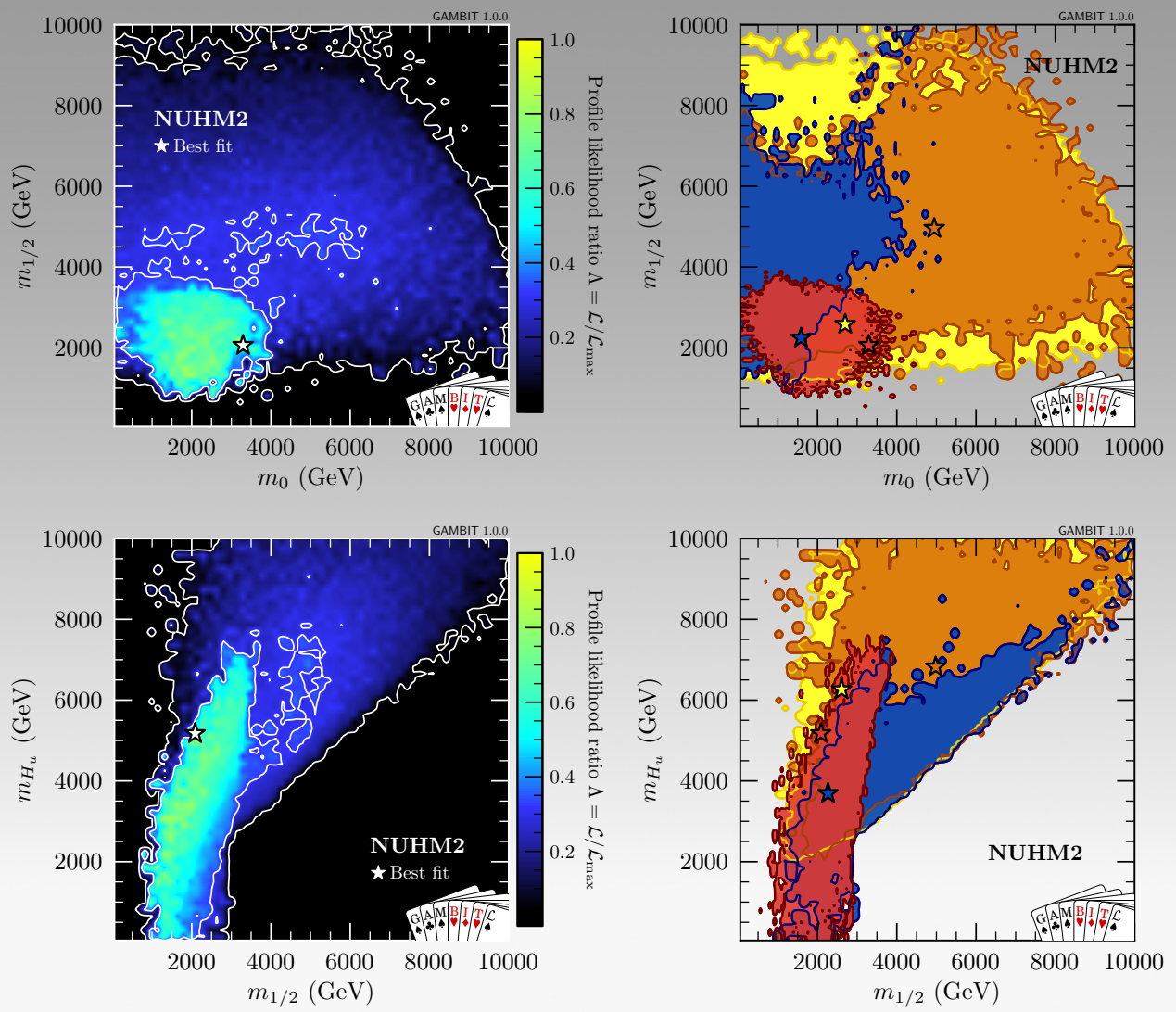
NUHM1


GAMBIT 1.0.0
NUHM1
Best fit
$m_{1/2}$ (GeV)
m_0 (GeV)
m_H (GeV)
Profile likelihood ratio $\Lambda = \mathcal{L}/\mathcal{L}_{\max}$
10000
8000
6000
4000
2000
1.0
0.8
0.6
0.4
0.2

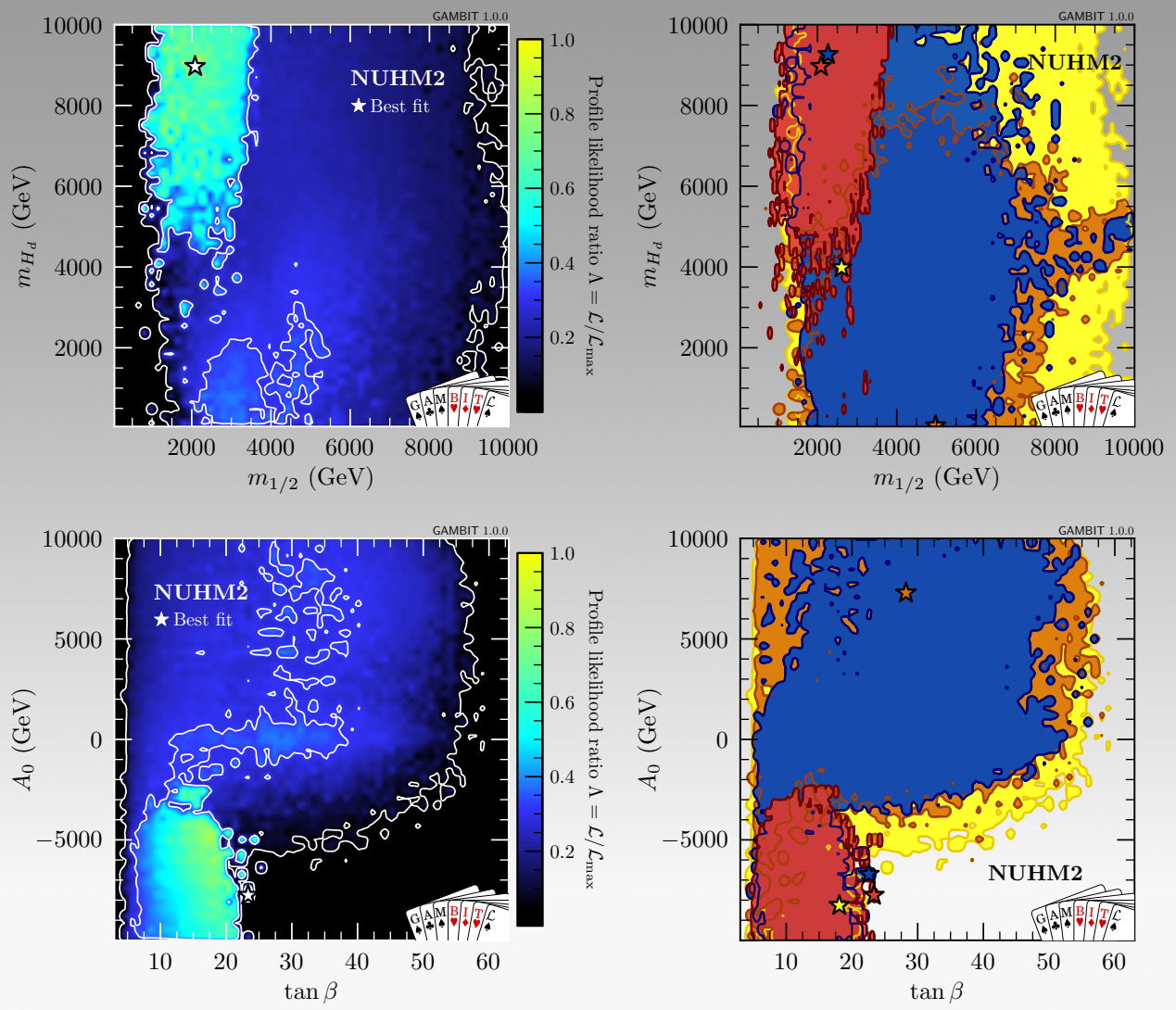
NUHM1


GAMBIT 1.0.0
NUHM1
★ Best fit
m_H (GeV)
$m_{1/2}$ (GeV)
A_0 (GeV)
$\tan\beta$
Profile likelihood ratio $\Lambda = \mathcal{L}/\mathcal{L}_{\max}$

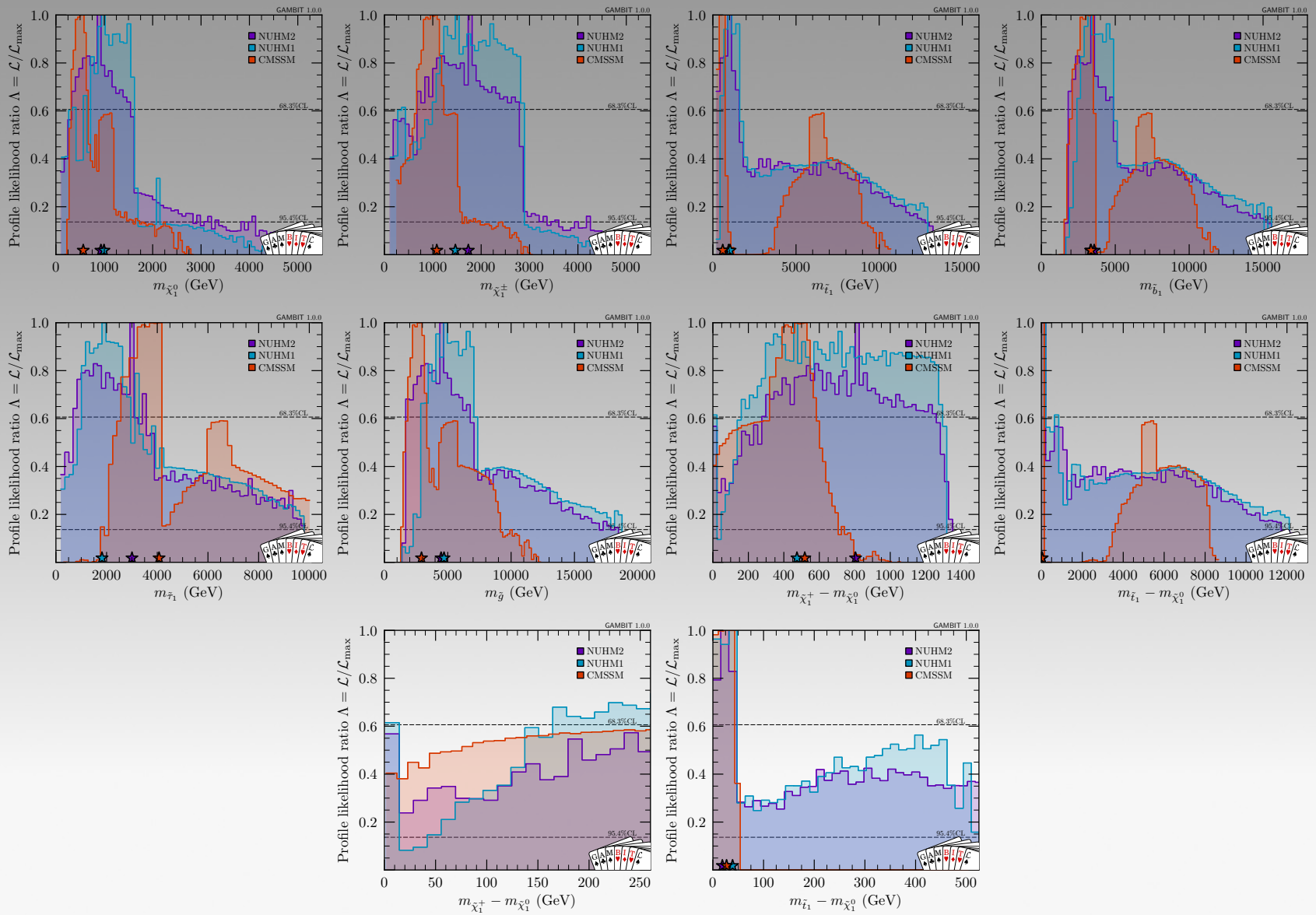
NUHM2


GAMBIT 1.0.0
NUHM2
★ Best fit
$m_{1/2}$ (GeV)
m_0 (GeV)
m_{H_u} (GeV)
Profile likelihood ratio $\Lambda = \mathcal{L}/\mathcal{L}_{\max}$
10000
8000
6000
4000
2000
1.0
0.8
0.6
0.4
0.2

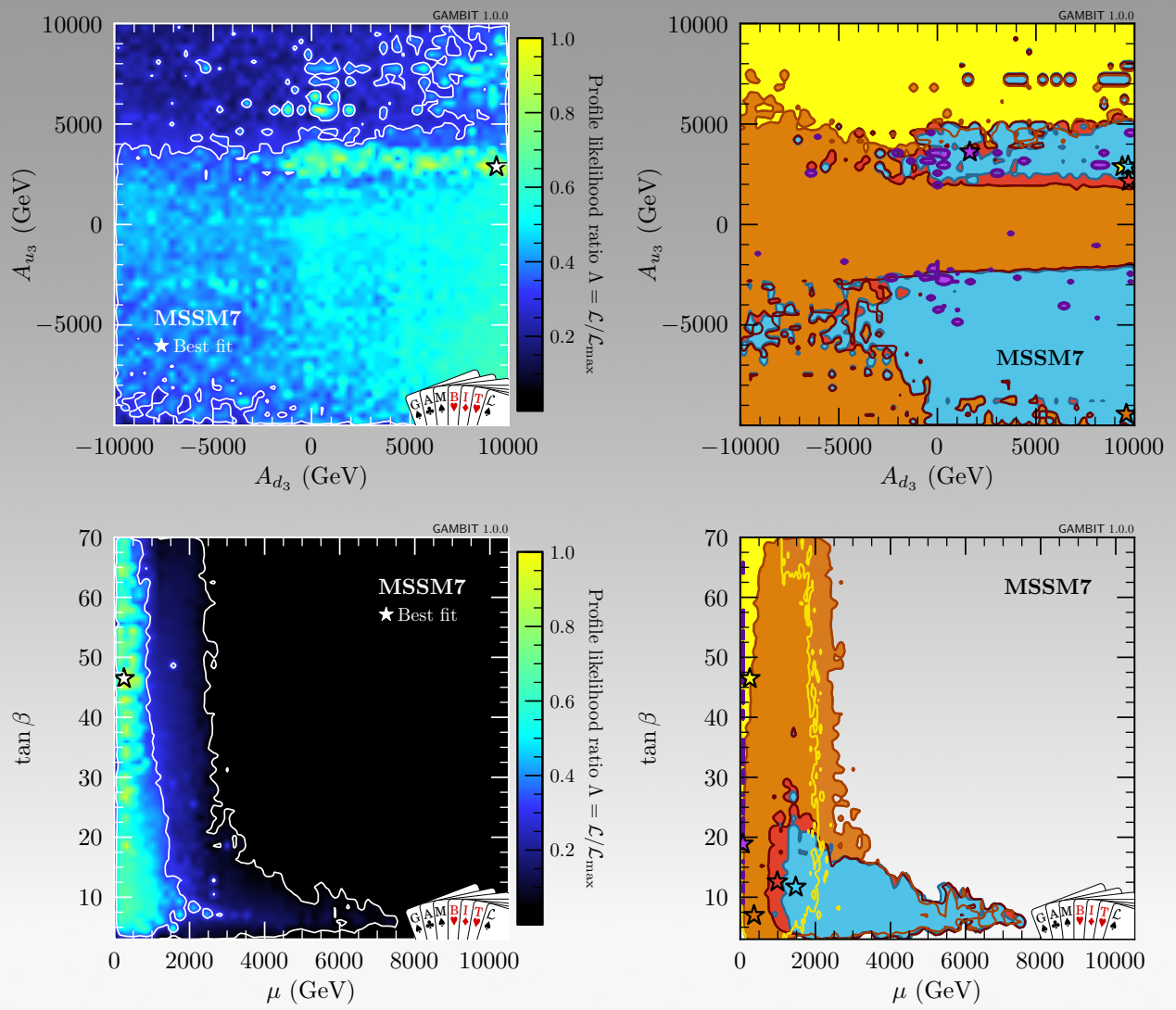
NUHM2


GAMBIT 1.0.0
NUHM2
★ Best fit
m_{H_d} (GeV)
$m_{1/2}$ (GeV)
A_0 (GeV)
$\tan\beta$
Profile likelihood ratio $\Lambda = \mathcal{L}/\mathcal{L}_{\max}$

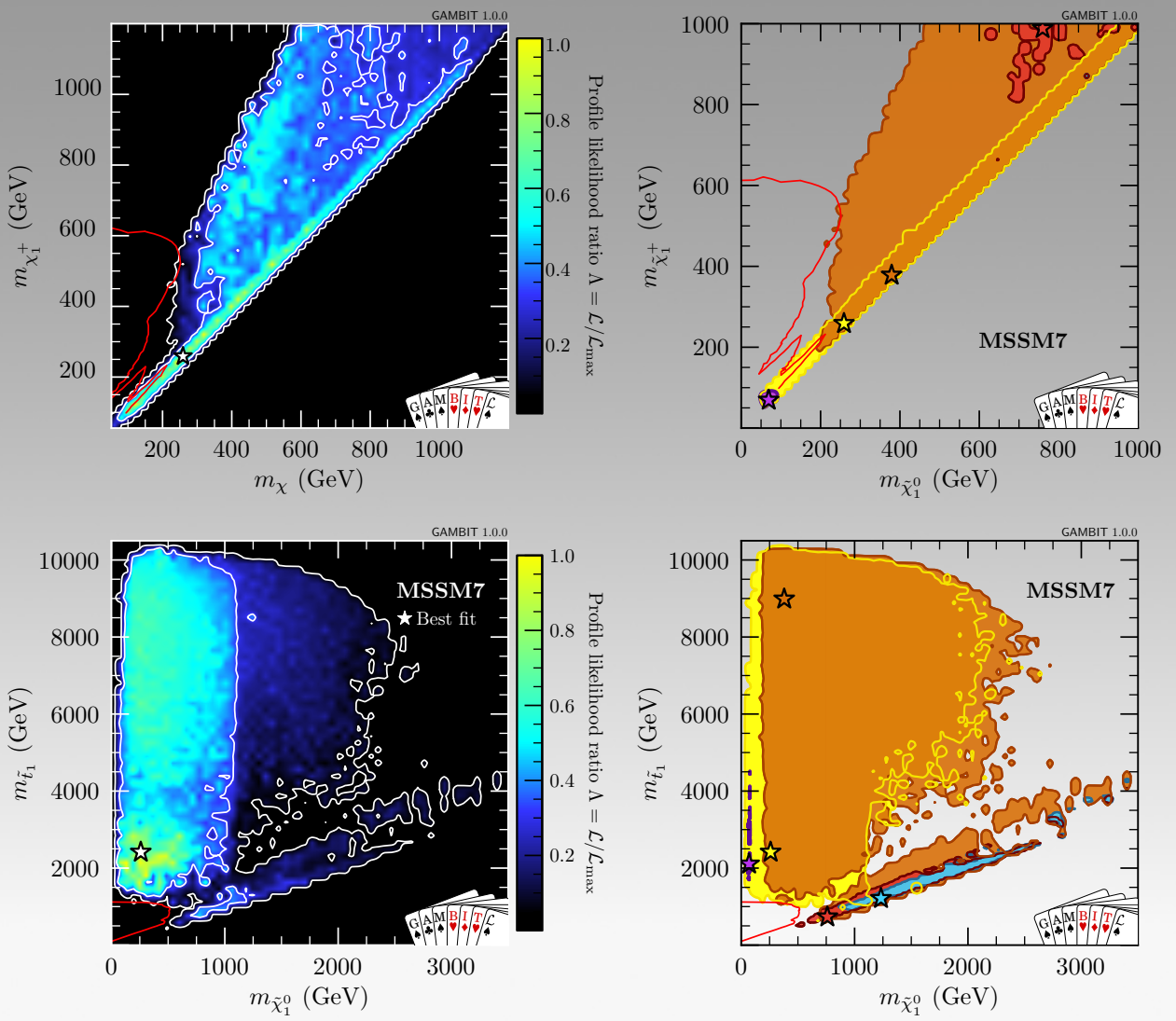
CMSSM, NUHM1, NUHM2



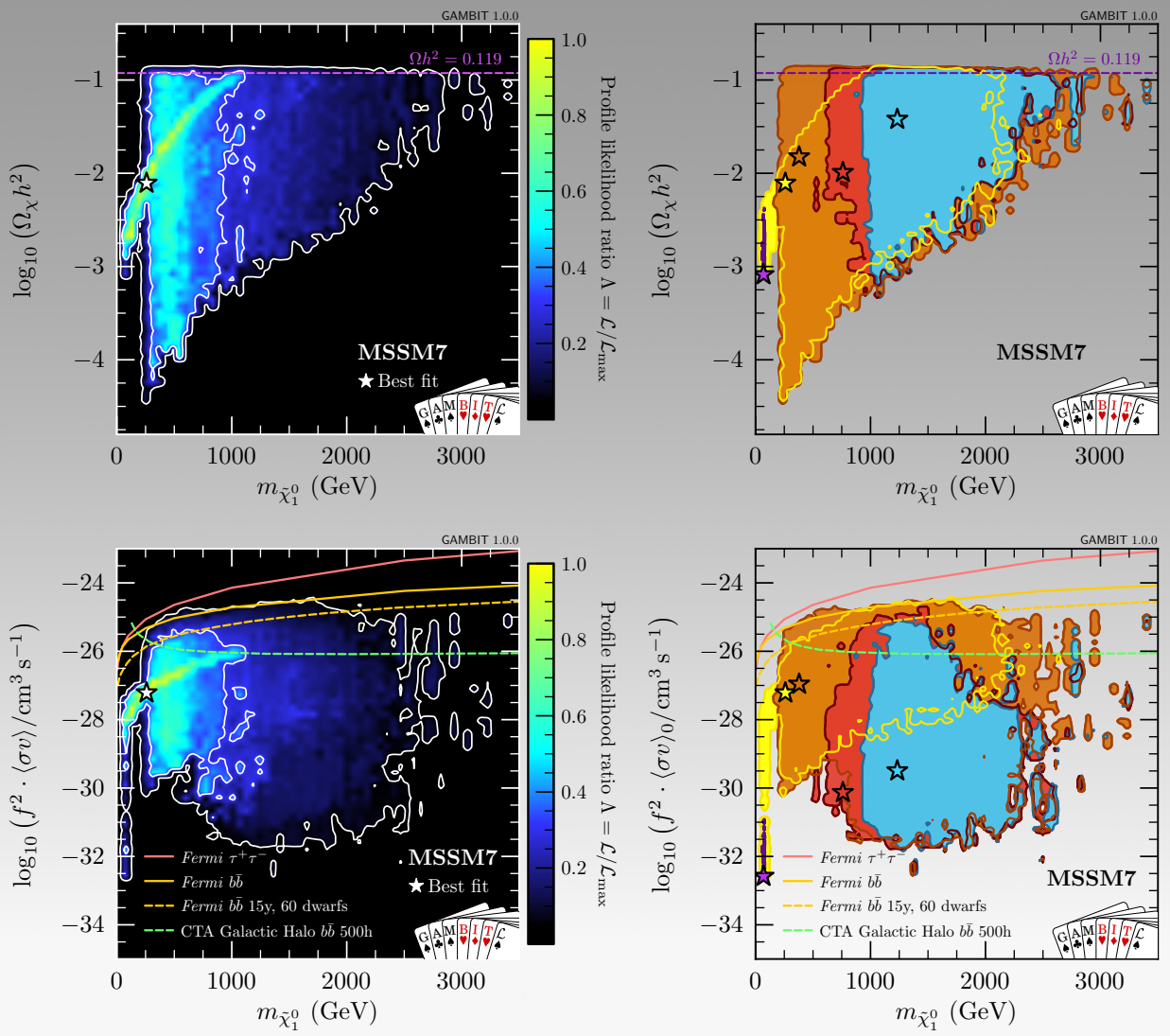
MSSM7


GAMBIT 1.0.0
MSSM7
Best fit
A_{u_3} (GeV)
A_{d_3} (GeV)
Profile likelihood ratio $\Lambda = \mathcal{L}/\mathcal{L}_{\max}$
$\tan\beta$
μ (GeV)

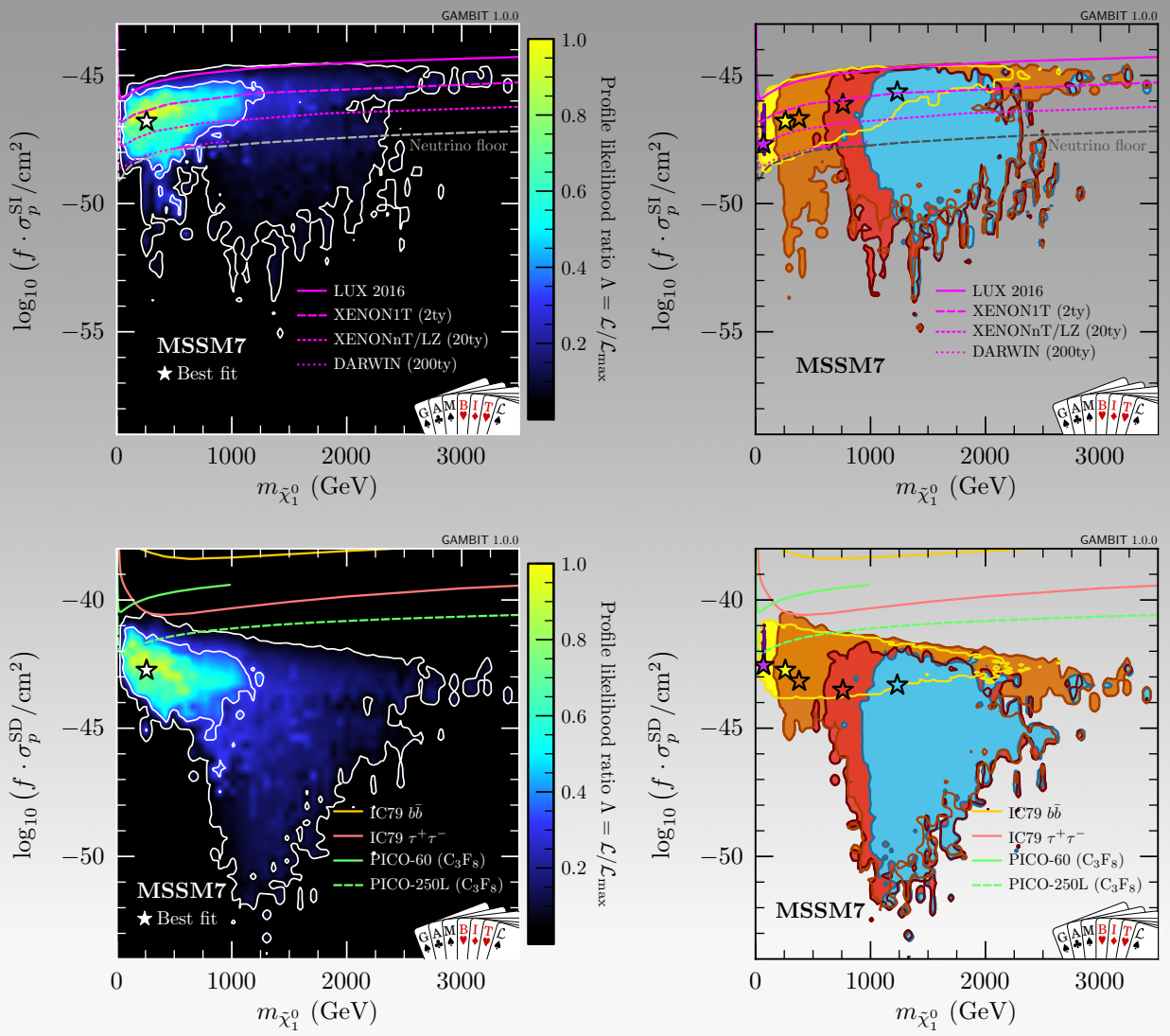
MSSM7


GAMBIT 1.0.0
$m_{\chi_1^+}$ (GeV)
m_χ (GeV)
Profile likelihood ratio $\Lambda = \mathcal{L}/\mathcal{L}_{\max}$
MSSM7
$m_{\tilde{\chi}_1^0}$ (GeV)
$m_{\tilde{t}_1}$ (GeV)
Best fit

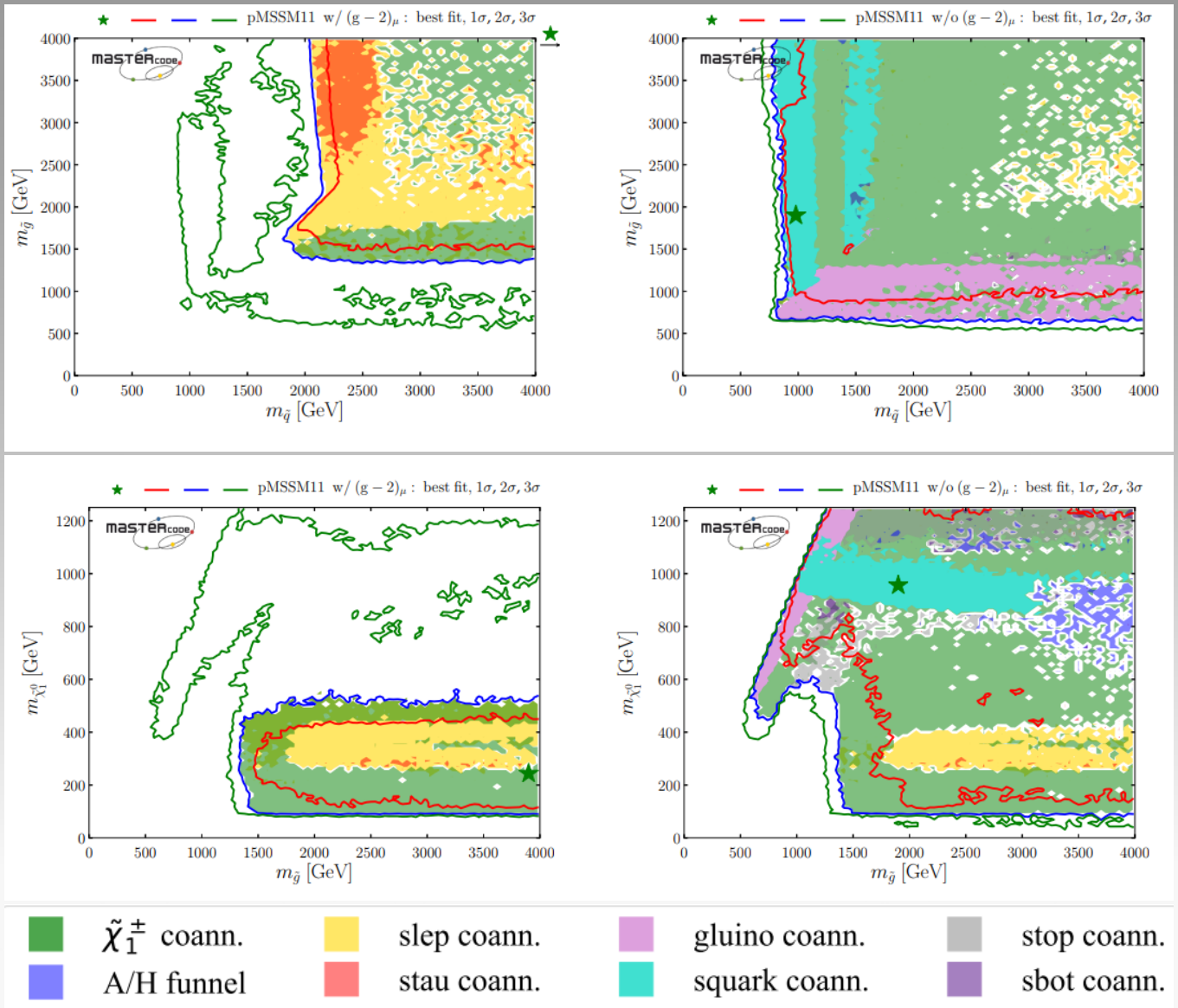
MSSM7


GAMBIT 1.0.0
$\Omega h^2 = 0.119$
$\log_{10}(\Omega_\chi h^2)$
$m_{\tilde{\chi}_1^0}$ (GeV)
Profile likelihood ratio $\Lambda = \mathcal{L}/\mathcal{L}_{\max}$
MSSM7
★ Best fit
$\log_{10}(f^2 \cdot \langle\sigma v\rangle/\mathrm{cm}^3\,\mathrm{s}^{-1})$
$\log_{10}(f^2 \cdot \langle\sigma v\rangle_0/\mathrm{cm}^3\,\mathrm{s}^{-1})$
Fermi $\tau^+\tau^-$
Fermi $b\bar{b}$
Fermi $b\bar{b}$ 15y, 60 dwarfs
CTA Galactic Halo $b\bar{b}$ 500h

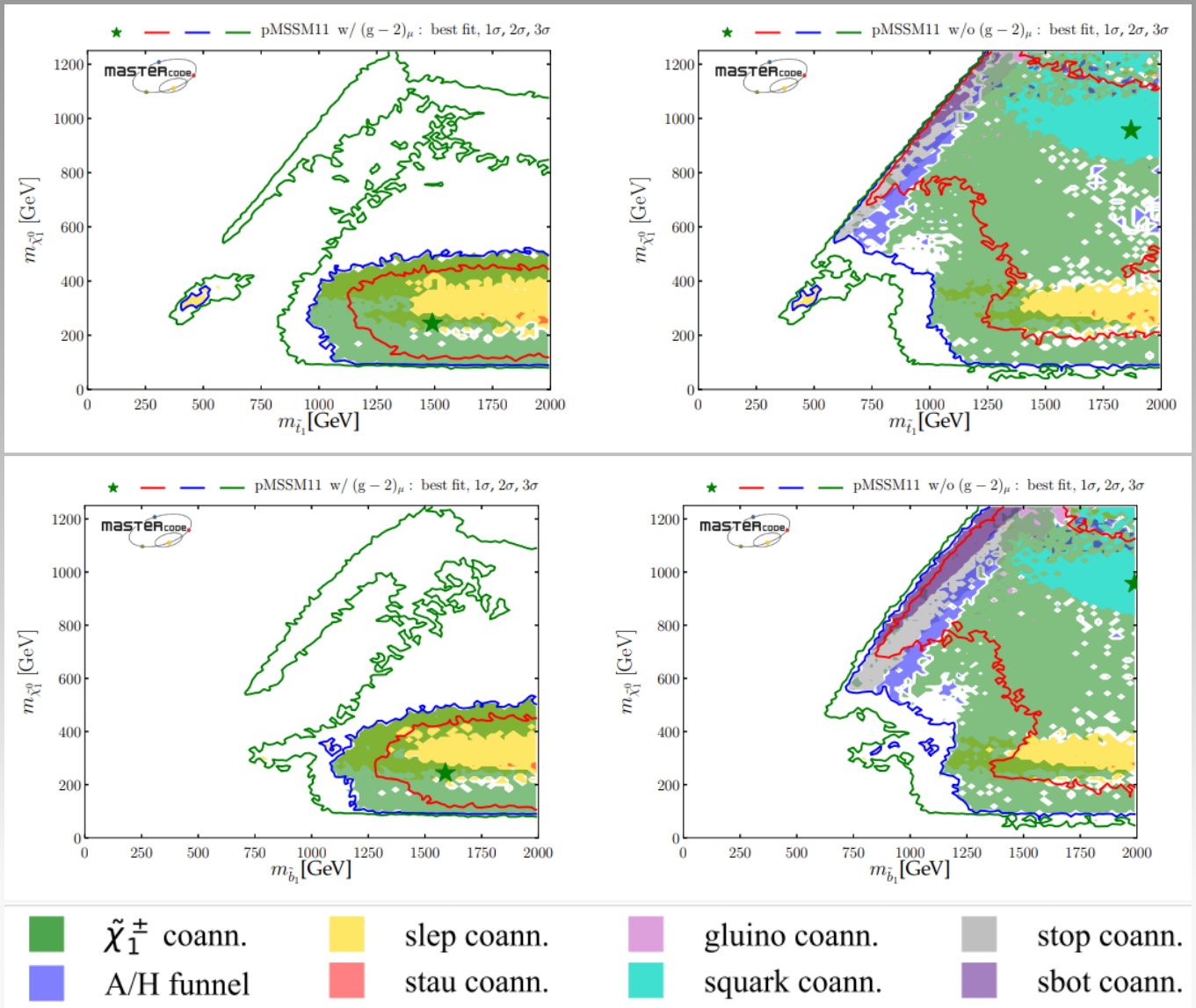
MSSM7


GAMBIT 1.0.0
MSSM7
Best fit
LUX 2016
XENON1T (2ty)
XENONnT/LZ (20ty)
DARWIN (200ty)
Neutrino floor
IC79 $b\bar{b}$
IC79 $\tau^+\tau^-$
PICO-60 (C_3F_8)
PICO-250L (C_3F_8)
Profile likelihood ratio $\Lambda = \mathcal{L}/\mathcal{L}_{max}$
$\log_{10}(f \cdot \sigma_p^{SI}/cm^2)$
$\log_{10}(f \cdot \sigma_p^{SD}/cm^2)$
$m_{\tilde{\chi}_1^0}$ (GeV)

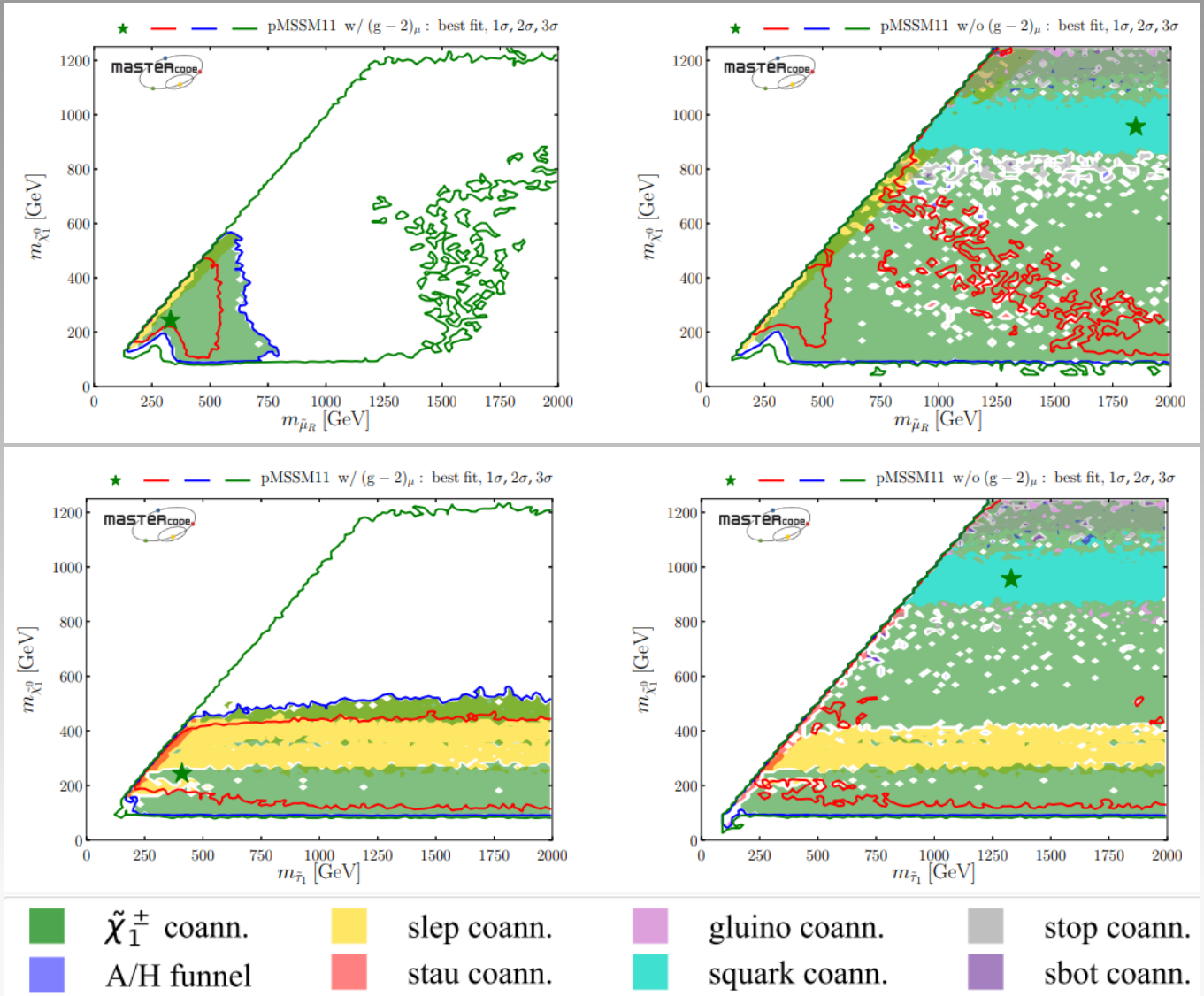
pMSSM11


pMSSM11 w/ $(g-2)_\mu$: best fit, $1\sigma, 2\sigma, 3\sigma$
pMSSM11 w/o $(g-2)_\mu$: best fit, $1\sigma, 2\sigma, 3\sigma$
$m_{\tilde{g}}$ [GeV]
$m_{\tilde{q}}$ [GeV]
$m_{\tilde{\chi}_1^0}$ [GeV]
$\tilde{\chi}_1^\pm$ coann.
A/H funnel
slep coann.
stau coann.
gluino coann.
squark coann.
stop coann.
sbot coann.

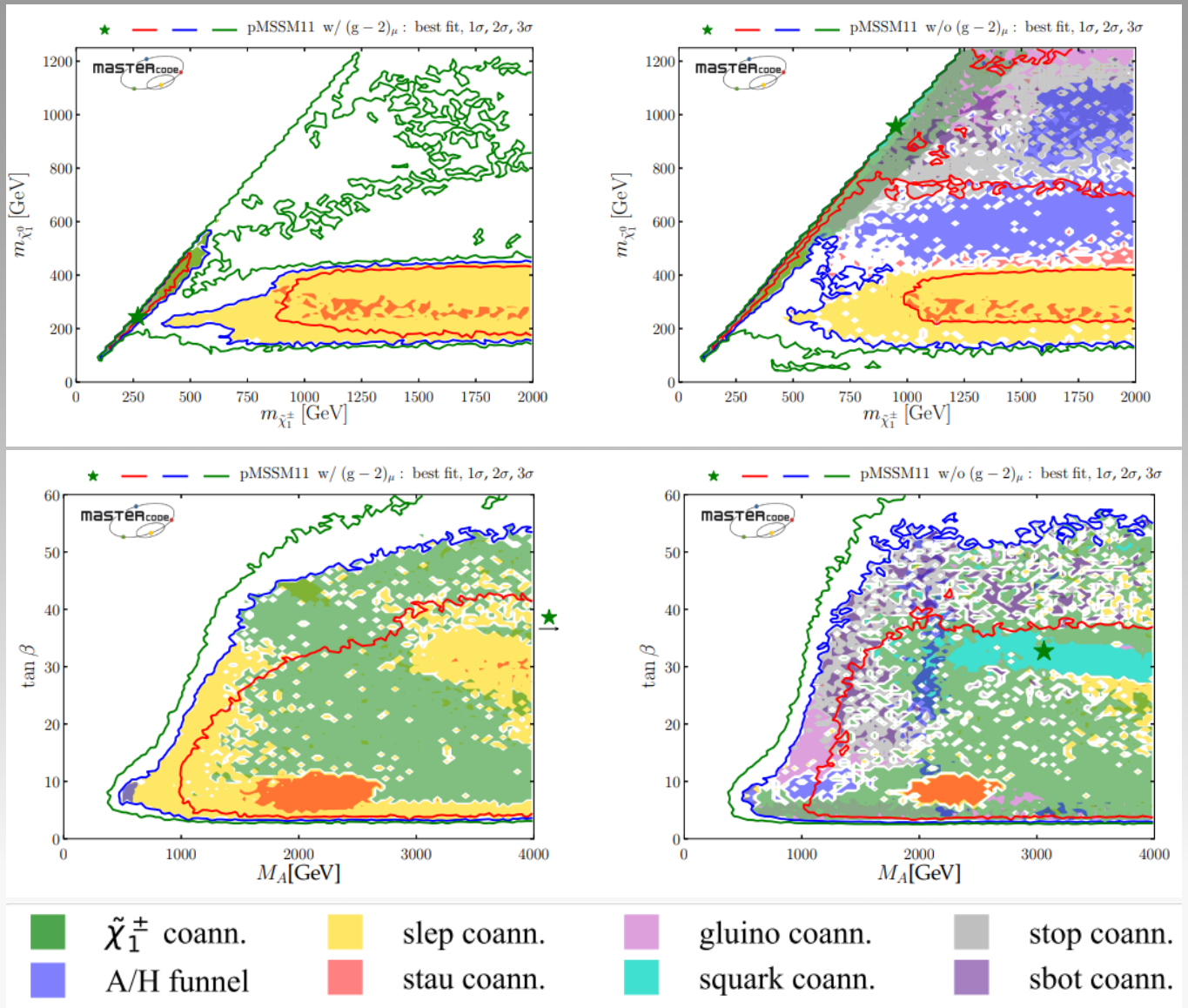
pMSSM11


pMSSM11 w/ $(g-2)_\mu$: best fit, 1σ, 2σ, 3σ
pMSSM11 w/o $(g-2)_\mu$: best fit, 1σ, 2σ, 3σ
MASTERCODE
$m_{\tilde{\chi}_1^0}$ [GeV]
$m_{\tilde{t}_1}$ [GeV]
$m_{\tilde{b}_1}$ [GeV]
$\tilde{\chi}_1^\pm$ coann.
A/H funnel
slep coann.
stau coann.
gluino coann.
squark coann.
stop coann.
sbot coann.

pMSSM11


pMSSM11 w/ $(g-2)_\mu$: best fit, $1\sigma, 2\sigma, 3\sigma$
pMSSM11 w/o $(g-2)_\mu$: best fit, $1\sigma, 2\sigma, 3\sigma$
$m_{\tilde{\chi}_1^0}$ [GeV]
$m_{\tilde{\mu}_R}$ [GeV]
$m_{\tilde{\tau}_1}$ [GeV]
$\tilde{\chi}_1^\pm$ coann.
A/H funnel
slep coann.
stau coann.
gluino coann.
squark coann.
stop coann.
sbot coann.

pMSSM11


pMSSM11 w/ $(g-2)_\mu$: best fit, $1\sigma, 2\sigma, 3\sigma$
pMSSM11 w/o $(g-2)_\mu$: best fit, $1\sigma, 2\sigma, 3\sigma$
$m_{\tilde{\chi}_1^0}$ [GeV]
$m_{\tilde{\chi}_1^\pm}$ [GeV]
$\tan\beta$
M_A[GeV]
$\tilde{\chi}_1^\pm$ coann.
A/H funnel
slep coann.
stau coann.
gluino coann.
squark coann.
stop coann.
sbot coann.

EW MSSM

MSSM field content

Name	Spin	Gauge ES	Mass ES
Higgs bosons	0	$H_u^0\ H_d^0\ H_u^+\ H_d^-$	$h\ H\ A\ H^\pm$
squarks	0	$\tilde{u}_L\ \tilde{u}_R\ \tilde{d}_L\ \tilde{d}_R$	-
		$\tilde{c}_L\ \tilde{c}_R\ \tilde{s}_L\ \tilde{s}_R$	-
		$\tilde{t}_L\ \tilde{t}_R\ \tilde{b}_R\ \tilde{b}_R$	$\tilde{t}_1\ \tilde{t}_2\ \tilde{b}_1\ \tilde{b}_2$
sleptons	0	$\tilde{e}_L\ \tilde{e}_R\ \tilde{\nu}_e$	-
		$\tilde{\mu}_L\ \tilde{\mu}_R\ \tilde{\nu}_\mu$	-
		$\tilde{\tau}_L\ \tilde{\tau}_R\ \tilde{\nu}_\tau$	$\tilde{\tau}_1\ \tilde{\tau}_2\ \tilde{\nu}_\tau$
neutralino	1/2	$\tilde{B}\ \tilde{W}^3\ \tilde{H}_u^0\ \tilde{H}_d^0$	$\tilde{\chi}_1^0\ \tilde{\chi}_2^0\ \tilde{\chi}_3^0\ \tilde{\chi}_4^0$
chargino	1/2	$\tilde{W}^\pm\ \tilde{H}_u^+\ \tilde{H}_d^-$	$\tilde{\chi}_1^\pm\ \tilde{\chi}_2^\pm$
gluino	1/2	$\tilde{g}$	-

EW MSSM

Parameters

- 4-D parameter space $(m_{H_d}^2, m_{H_u}^2 \to \mu, m_A)$

$$m_h \to 125 \text{ GeV}$$
$$M_3, m_A \to 5 \text{ TeV} \qquad \{M_1, M_2, \mu, \tan\beta\}$$
$$m_{\tilde{l}}, m_{\tilde{q}} \to 3 \text{ TeV}$$
$$A_u, A_d, A_e \to 0$$

- Parameter ranges

Parameter	Range	Priors
$M_1(Q)$	[-2 TeV, 2 TeV]	hybrid, flat
$M_2(Q)$	[0, 2 TeV]	hybrid, flat
$\mu(Q)$	[-2 TeV, 2 TeV]	hybrid, flat
$\tan\beta(m_Z)$	[0, 70]	flat

EW MSSM

Likelihoods

- Invisible decays $\Gamma(Z \to \text{inv.}) = 499.0 \pm 1.5$ MeV $\quad \text{BF}(h \to \text{inv.}) \leq 0.19$

- LEP limits

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

- LHC searches

Likelihood label	Source
ATLAS_4b	ATLAS Higgsino search
ATLAS_4lep	ATLAS 4ℓ search
ATLAS_MultiLep_2lep_0jet	ATLAS multilepton EW search
ATLAS_MultiLep_2lep_jet	ATLAS multilepton EW search
ATLAS_MultiLep_3lep	ATLAS multilepton EW search
ATLAS_RJ_2lep_2jet	ATLAS recursive jigsaw EW search
ATLAS_RJ_3lep	ATLAS recursive jigsaw EW search
CMS_1lep_2b	CMS Wh search
CMS_2lep_soft	CMS 2 soft opposite-charge lepton search
CMS_2OSlep	CMS 2 opposite-charge lepton search
CMS_MultiLep_2SSlep	CMS multilepton EW search
CMS_MultiLep_3lep	CMS multilepton EW search

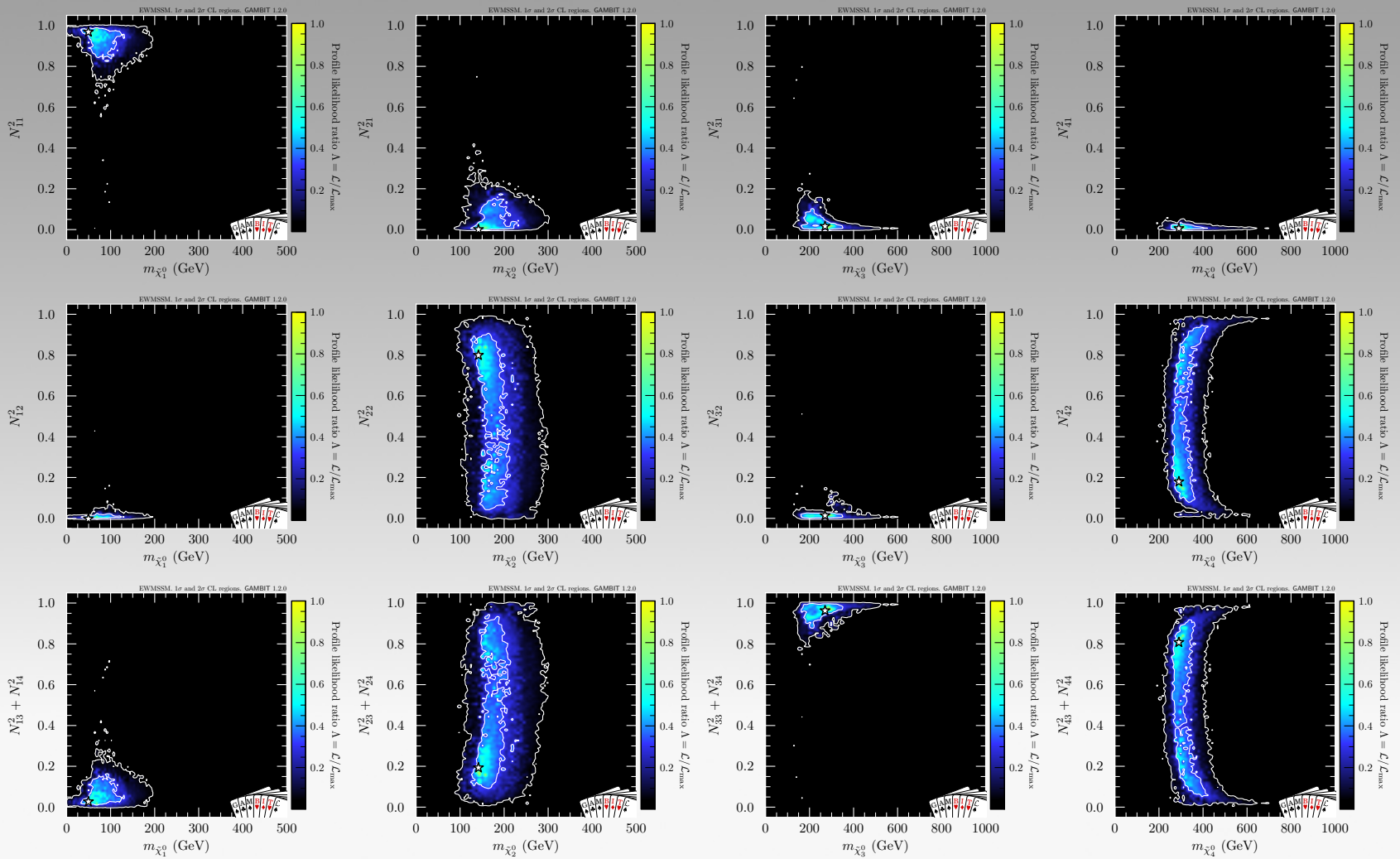
EW MSSM

Scan strategy

- First scans
  - Differential evolution scanner (Diver) on jDE mode
  - Flat & hybrid (log-flat-log) priors
  - Targeted scans for $M_2 < 500$ GeV and $\mu < 500$ GeV
  - Simulated 100k/500k Pythia events per parameter point
  - Samples contain ∼2.4M valid points
- Sampling issues
  - Large MC uncertainty
  - Signal region flip-flop
- Postprocessing
  - More Pythia events
    - $2\sigma/3\sigma \geq$ 4M events
    - $1\sigma \geq$ 16M events
    - best 500 points $\geq$ 4M events
  - $\sim$ 240k valid samples

EW MSSM

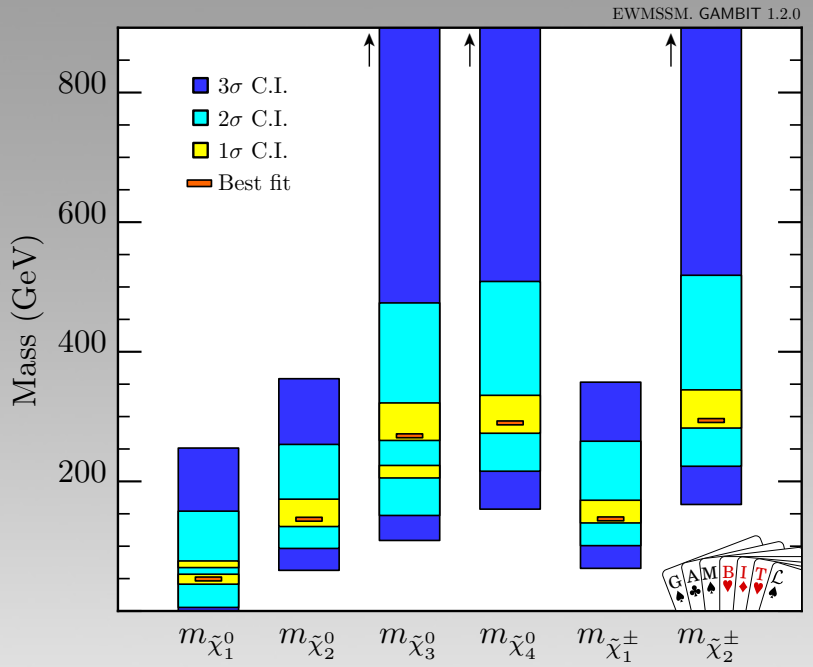
Results



EW MSSM

Conclusions

- No clear exclusion for light electroweakinos
  - Careful with simplified models
- Favoured by several analyses
  - ATLAS $4l$,
  - ATLAS RJ $3l$,
  - ATLAS multi-l ($2l$, $3l$)
- Minor excess
  - $m_{\tilde{\chi}_1^0} \sim 50$ GeV
  - Local significace 3.5σ
- Might be a hint of new physics



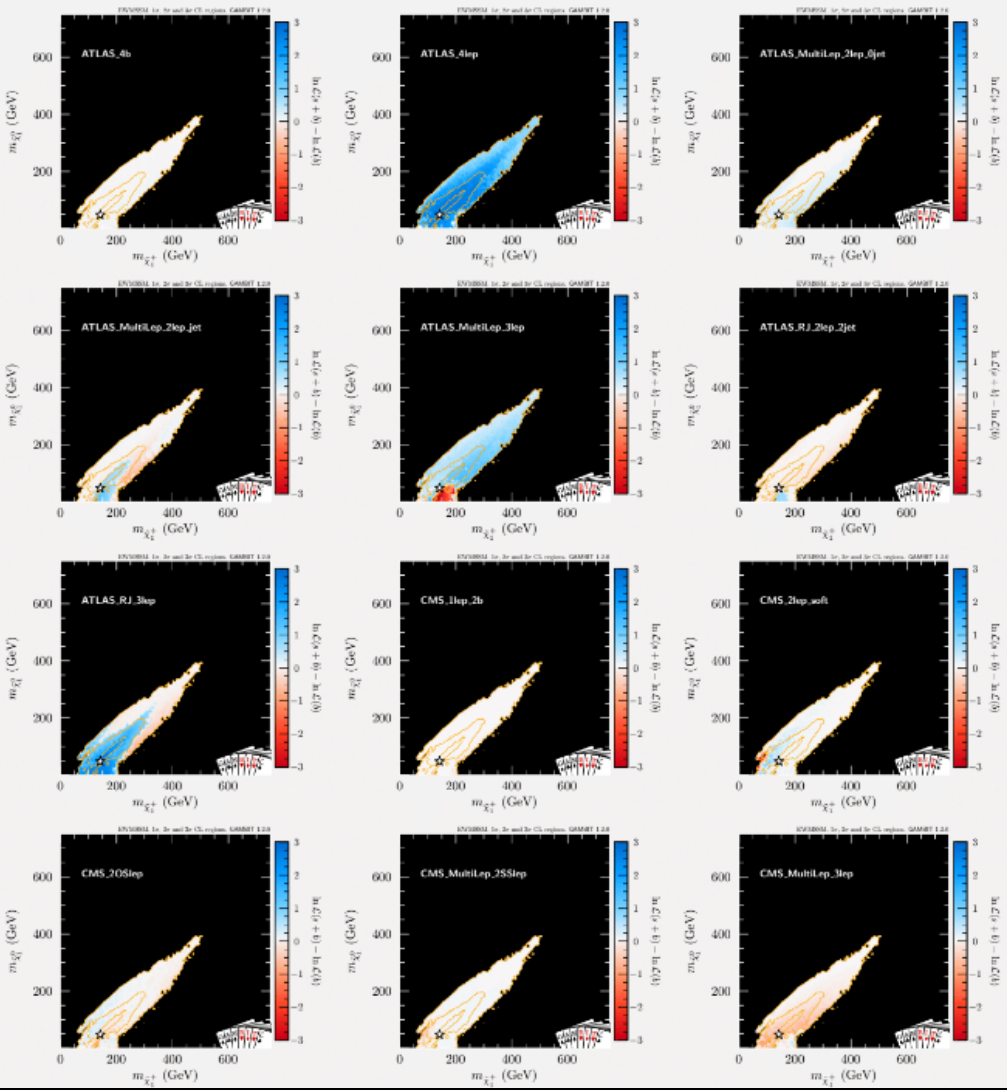
Analysis: results

- **Contribution from each analysis** to the 1σ, 2σ and 3σ best-fit regions

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

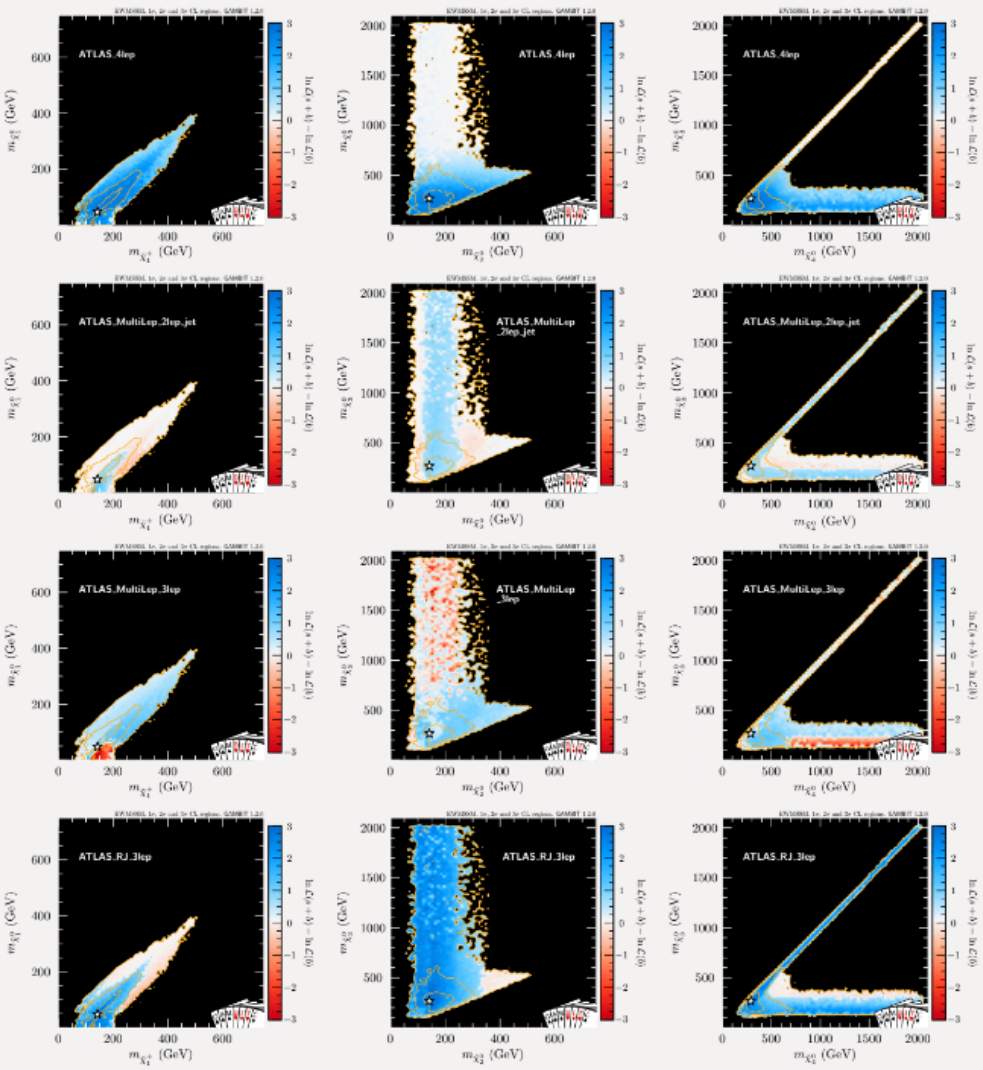
- **Blue**: **better** than background-only
  Red: **worse** than background-only

- Most important contributions to best-fit region:
  - **ATLAS_4lep**
  - **ATLAS_RJ_3lep**
  - **ATLAS_MultiLep_2lep_jet**
  - **ATLAS_MultiLep_3lep**
  - **CMS_MultiLep_3lep**



Analysis: results

- More detailed look on
  - **ATLAS_4lep**
  - **ATLAS_RJ_3lep**
  - **ATLAS_MultiLep_2lep_jet**
  - **ATLAS_MultiLep_3lep**
- Sudden changes in likelihood due to changes in most sensitive SR
- Light $\tilde{\chi}_3^0$ preferred by **ATLAS_4lep** and **ATLAS_MultiLep_3Lep**
- Heavy $\tilde{\chi}_4^0$ disfavoured by **ATLAS_MultiLep_2lep_jet** and **ATLAS_MultiLep_3Lep**
- The «expected» tension between **ATLAS_MultiLep_3Lep** and **ATLAS_RJ_3lep** observed for heavy $\tilde{\chi}_4^0$ (production of higgsino $\tilde{\chi}_2^0, \tilde{\chi}_3^0, \tilde{\chi}_1^\pm$)



EW MSSM

Results

Lots of processes relevant for the best-fit point:

- $\tilde{\chi}_2^0\tilde{\chi}_3^0$ production, with e.g.
  $\tilde{\chi}_2^0 \to Z + \tilde{\chi}_1^0$, $\tilde{\chi}_3^0 \to W^- + \tilde{\chi}_1^+ \to W^- + W^+ + \tilde{\chi}_1^0$
- $\tilde{\chi}_2^\pm\tilde{\chi}_2^\mp$ production, with e.g.
  $\tilde{\chi}_2^\pm \to W^\pm + \tilde{\chi}_2^0 \to W^\pm + Z + \tilde{\chi}_1^0$
- $\tilde{\chi}_2^\pm\tilde{\chi}_3^0$ production, with e.g.
  $\tilde{\chi}_2^\pm \to W^\pm + \tilde{\chi}_1^0$, $\tilde{\chi}_3^0 \to Z + \tilde{\chi}_2^0 \to Z + Z + \tilde{\chi}_1^0$
- $\tilde{\chi}_2^\pm\tilde{\chi}_3^0$ production, with e.g.
  $\tilde{\chi}_2^\pm \to W^\pm + \tilde{\chi}_2^0 \to W^\pm + Z + \tilde{\chi}_1^0$,
  $\tilde{\chi}_3^0 \to W^- + \tilde{\chi}_1^+ \to W^- + W^+ + \tilde{\chi}_1^0$
- $\tilde{\chi}_2^\pm\tilde{\chi}_4^0$ production, with e.g.
  $\tilde{\chi}_2^\pm \to W^\pm + \tilde{\chi}_2^0 \to W^\pm + Z + \tilde{\chi}_1^0$, $\tilde{\chi}_4^0 \to Z + \tilde{\chi}_1^0$
- $\tilde{\chi}_2^\pm\tilde{\chi}_2^0$ production, with e.g.
  $\tilde{\chi}_2^\pm \to h + \tilde{\chi}_1^\pm \to h + W^\pm + \tilde{\chi}_1^0$, $\tilde{\chi}_2^0 \to Z + \tilde{\chi}_1^0$
- $\tilde{\chi}_1^\pm\tilde{\chi}_3^0$ production, with e.g.
  $\tilde{\chi}_1^\pm \to W^\pm + \tilde{\chi}_1^0$, $\tilde{\chi}_3^0 \to W^- + \tilde{\chi}_1^+ \to W^+ + W^- + \tilde{\chi}_1^0$
- $\tilde{\chi}_2^\pm\tilde{\chi}_4^0$ production, with e.g.
  $\tilde{\chi}_2^\pm \to Z + \tilde{\chi}_1^\pm \to Z + W^\pm + \tilde{\chi}_1^0$,
  $\tilde{\chi}_4^0 \to h + \tilde{\chi}_2^0 \to h + Z + \tilde{\chi}_1^0$

...