Recent results from the GAMBIT collaboration

Martin White

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

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

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

Recent collaborators:
Peter Athron, Csaba Balázs, Ankit Beniwal, Sanjay Bloor, Torsten Bringmann, Andy Buckley, José Eliel Camargo-Molina, Marcin Chrząszcz, Jonathan Cornell, Matthias Danninger, Joakim Edsjö, Ben Farmer, Andrew Fowlie, Tomás E. Gonzalo, Will Handley, Sebastian Hoof, Selim Hotinli, Felix Kahlhoefer, Anders Kvellestad, Julia Harz, Paul Jackson, Farvah Mahmoudi, Greg Martinez, Are Raklev, Janina Renk, Chris Rogan, Roberto Ruiz de Austri, Pat Scott, Patrick Stöcker, Aaron Vincent, Christoph Weniger, Martin White, Yang Zhang

40+ participants in 11 experiments and 14 major theory codes

GAMBIT sampling (c.f. DM Sampling Project)

Eur. Phys. J. C manuscript No.
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Comparison of statistical sampling methods with ScannerBit, the GAMBIT scanning module

The GAMBIT Scanner Workgroup: Gregory D. Martinez[1,a], James McKay[2,b], Ben Farmer[3,4,c], Pat Scott[2,d], Elinore Roebber[5], Antje Putze[6], Jan Conrad[3,4]

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Received: date / Accepted: date

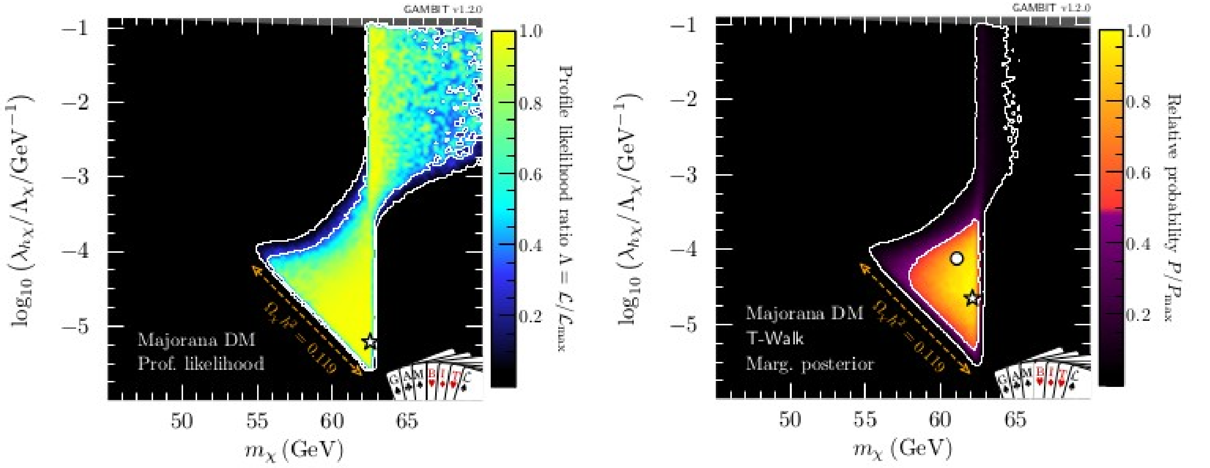
Abstract We introduce ScannerBit, the statistics and sampling module of the public, open-source global fitting framework GAMBIT. ScannerBit provides a standardised interface to different sampling algorithms, enabling the use and comparison of multiple computational methods for inferring profile likelihoods, Bayesian posteriors, and other statistical quantities. The current version offers random, grid, raster, nested sampling, differential evolu-

ten or more dimensions, Diver substantially outperforms the other three samplers on all metrics.

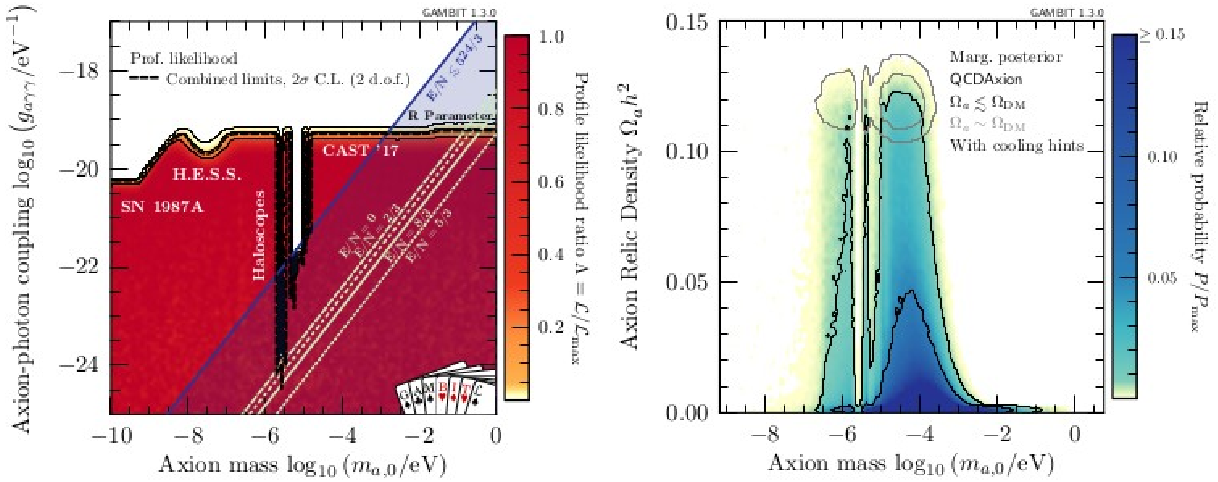
Contents

Recent GAMBIT physics results

- Higgs portal dark matter: arXiv: 1808.10465



- Axion models: 1810.07192



- (Today): EWinos in the MSSM: arXiv:1809.02097

How the MSSM might appear...

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

Decoupled

Source: Anders Kvellestad

Parameters

Theory: parameter space

M_1 M_2 μ $\tan\beta$

Neutralinos

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

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

Charginos

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

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

Source: Anders Kvellestad

GAMBIT

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(will be inserted by the editor)

CoEPP-MN-18-7

arXiv: 1809.02097

Combined collider constraints on neutralinos and charginos

The GAMBIT Collaboration: Peter Athron[1,2], Csaba Balázs[1,2], Andy Buckley[3], Jonathan M. Cornell[4], Matthias Danninger[5], Ben Farmer[6], Andrew Fowlie[1,2,9], Tomás E. Gonzalo[10], Julia Harz[11], Paul Jackson[2,12], Rose Kudzman-Blais[5], Anders Kvellestad[6,10,a], Gregory D. Martinez[13], Andreas Petridis[2,12], Are Raklev[10], Christopher Rogan[14], Pat Scott[6], Abhishek Sharma[2,12], Martin White[2,12,b], Yang Zhang[1,2]

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Abstract Searches for supersymmetric electroweakinos have entered a crucial phase, as the integrated luminosity of the Large Hadron Collider is now high enough to compensate for their weak production cross-sections. Working in a framework where the neutralinos and charginos are the only light sparticles in the Minimal Supersymmetric Standard Model, we use GAMBIT to perform a

relic density can be obtained through the Higgs-funnel and Z-funnel mechanisms, even assuming that all other sparticles are decoupled. All samples, GAMBIT input files and best-fit models from this study are available on Zenodo.

Contents

- The GAMBIT collaboration have just performed the most comprehensive study of the MSSM electroweakino sector to date

- We focussed on collider constraints from LHC and LEP, but also looked at the implications for dark matter (precise implications depend on the mass scale of the sparticles that we decoupled)

Included constraints

- Z and Higgs invisible decays

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

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

- LEP cross-section 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 [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]

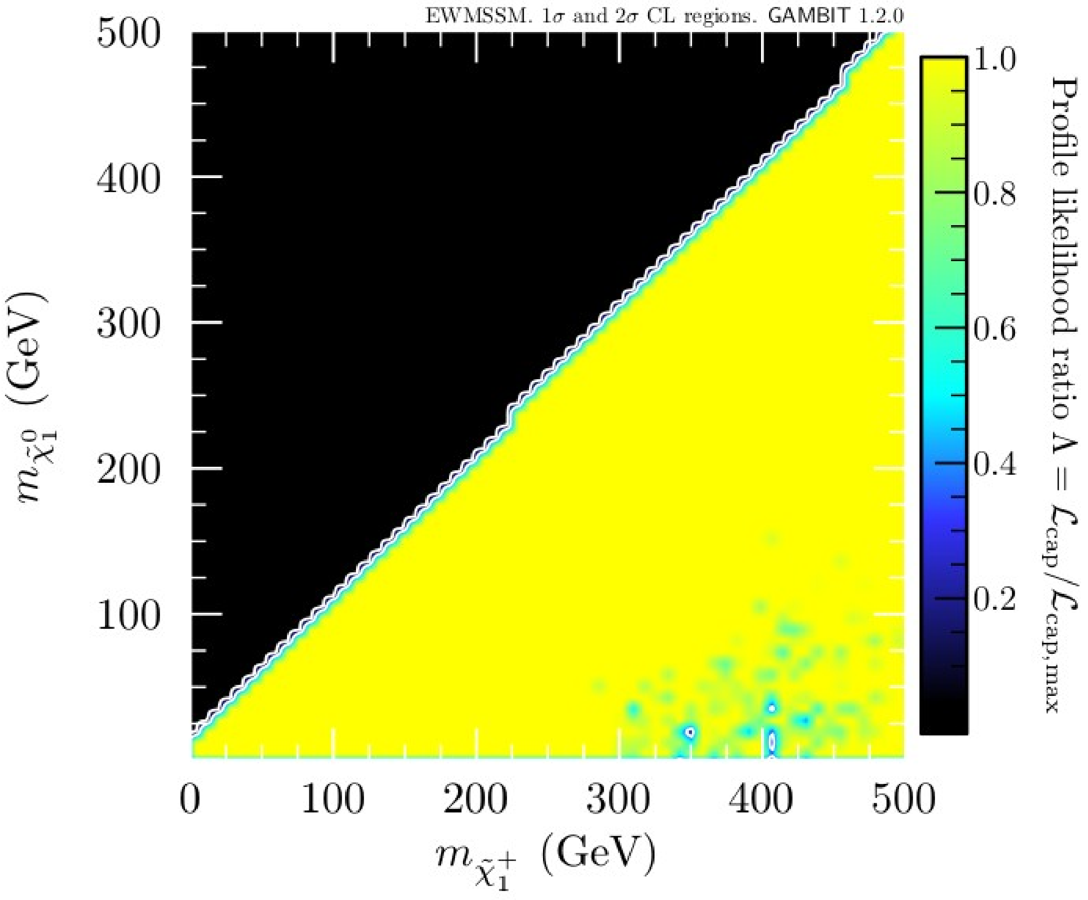
- LHC searches for EW SUSY

Likelihood label	Source
ATLAS_4b	ATLAS Higgsino search [104]
ATLAS_4lep	ATLAS 4ℓ search [105]
ATLAS_MultiLep_2lep_0jet	ATLAS multilepton EW search [100]
ATLAS_MultiLep_2lep_jet	ATLAS multilepton EW search [100]
ATLAS_MultiLep_3lep	ATLAS multilepton EW search [100]
ATLAS_RJ_2lep_2jet	ATLAS recursive jigsaw EW search [101]
ATLAS_RJ_3lep	ATLAS recursive jigsaw EW search [101]
CMS_1lep_2b	CMS Wh search [106]
CMS_2lep_soft	CMS 2 soft opposite-charge lepton search [109]
CMS_2OSlep	CMS 2 opposite-charge lepton search [110]
CMS_MultiLep_2SSlep	CMS multilepton EW search [111]
CMS_MultiLep_3lep	CMS multilepton EW search [111]

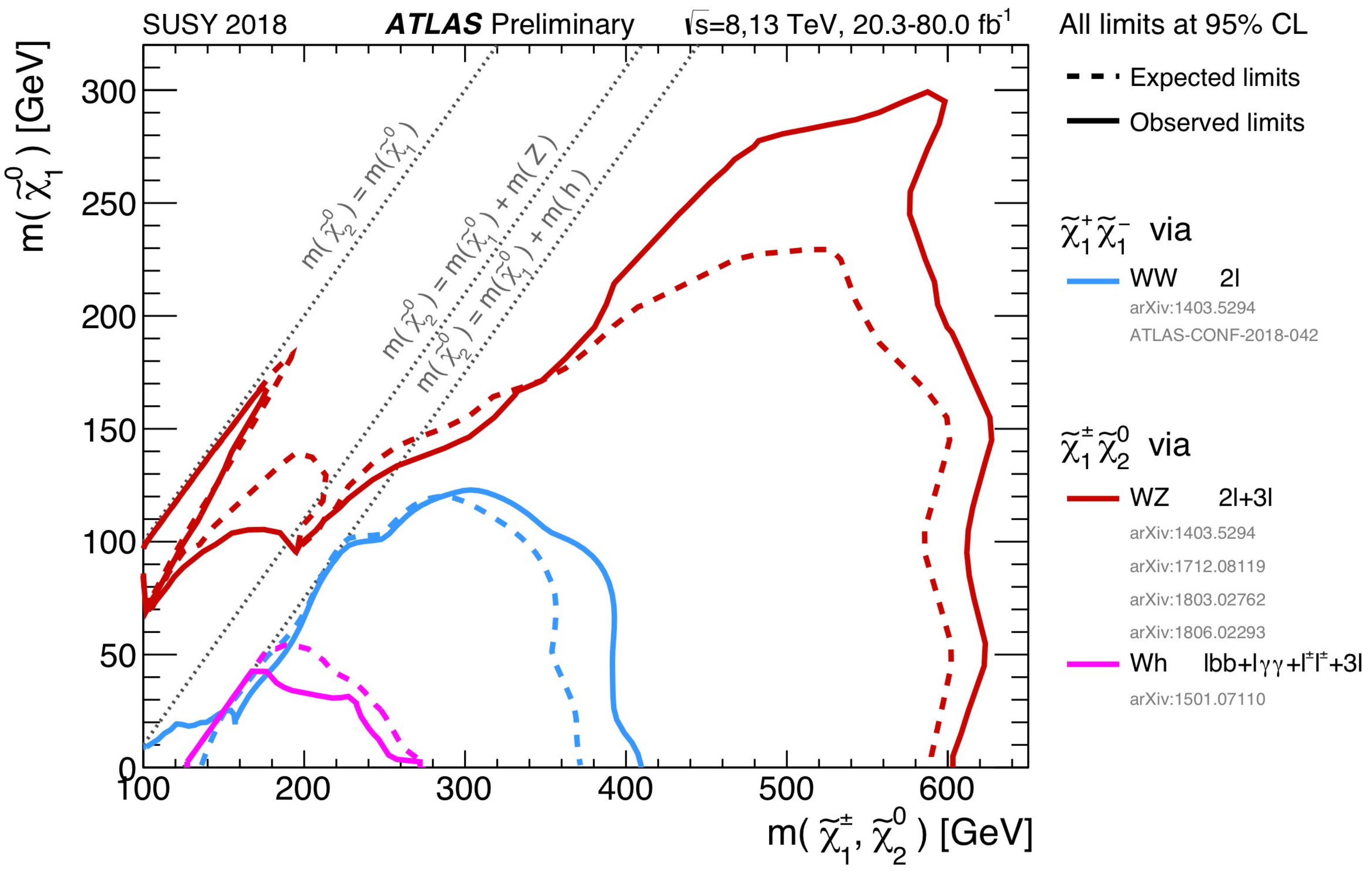
Source: Anders Kvellestad

What if we assume there is no SUSY?

- We have the option of "capping" the LHC likelihood in our scan results, to prevent potential signals from providing a better fit to the data than the SM
- This amounts to testing the exclusion power of the included LHC searches
- We find no general constraint on the MSSM EW sector from the LHC in this case, and we also explain why (the searches are over-optimised on specific simplified SUSY models)



Typical optimisation of an LHC analysis



Allowing searches to give positive evidence

- If we allow for the presence of a signal, our results get more interesting

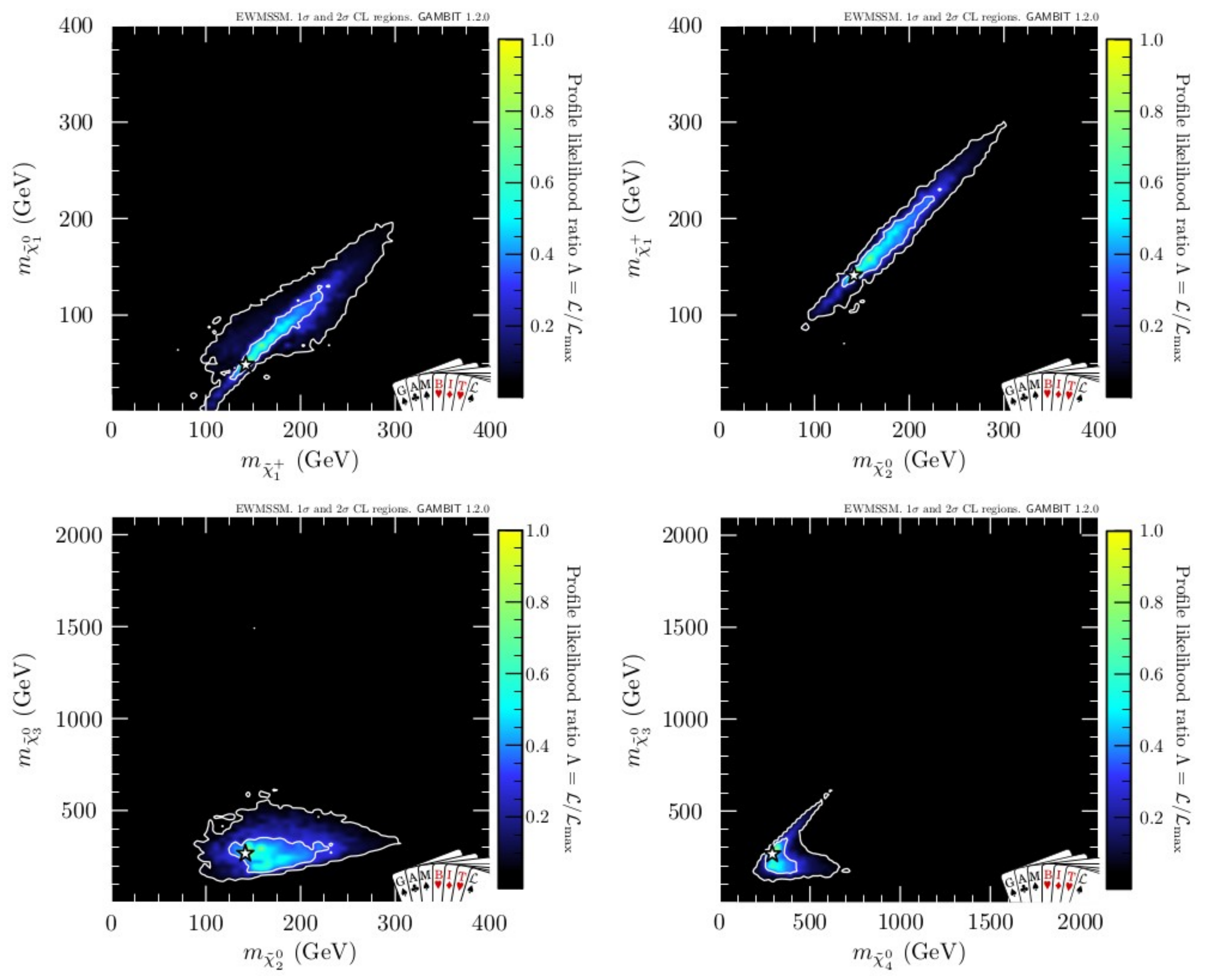
- A particular mass scale is picked out by a series of anomalies in ATLAS and CMS searches

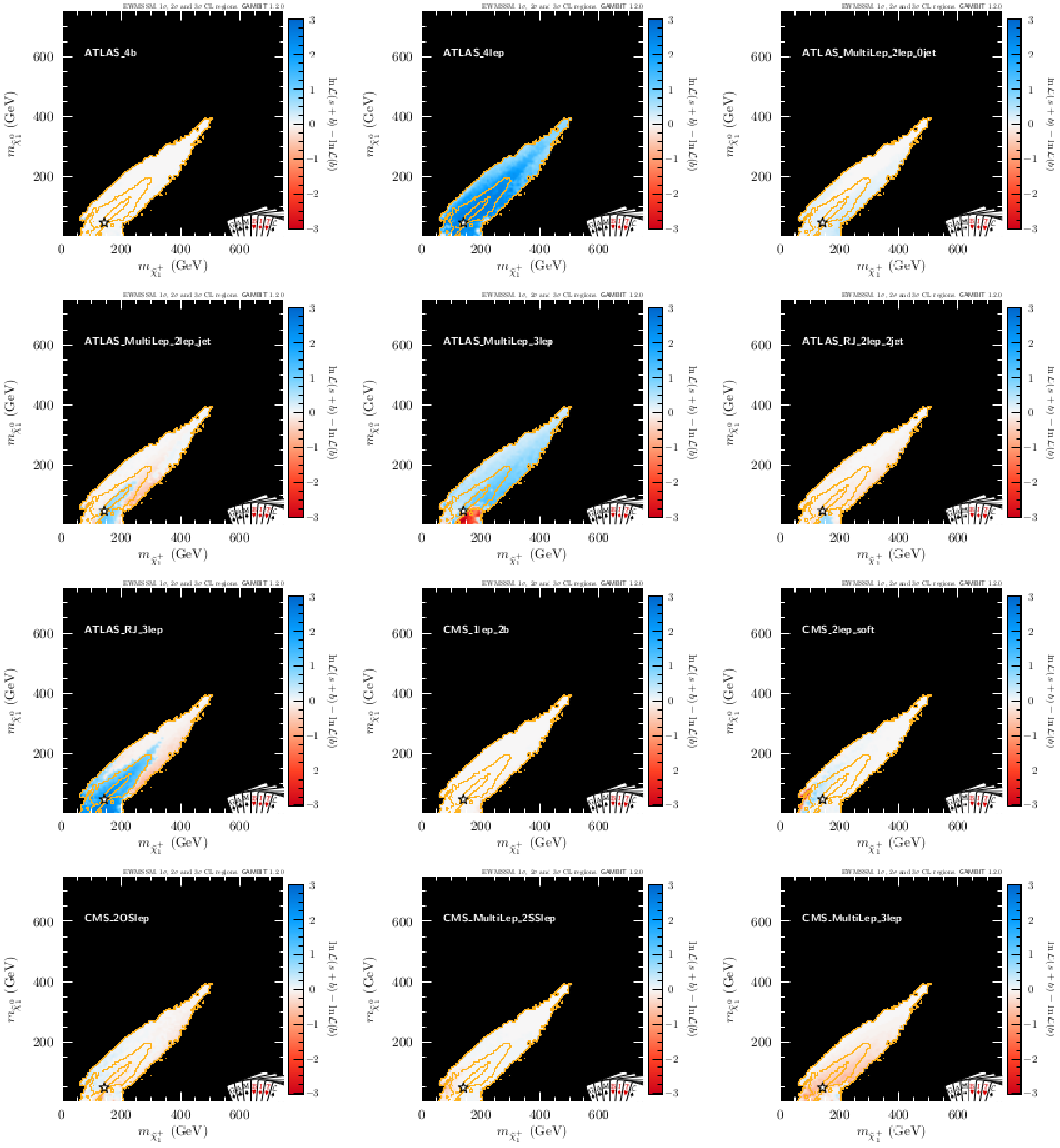
- All electroweakinos are light, and we either have:

Bino < winos < higgsinos

Or

Bino < higgsinos < winos





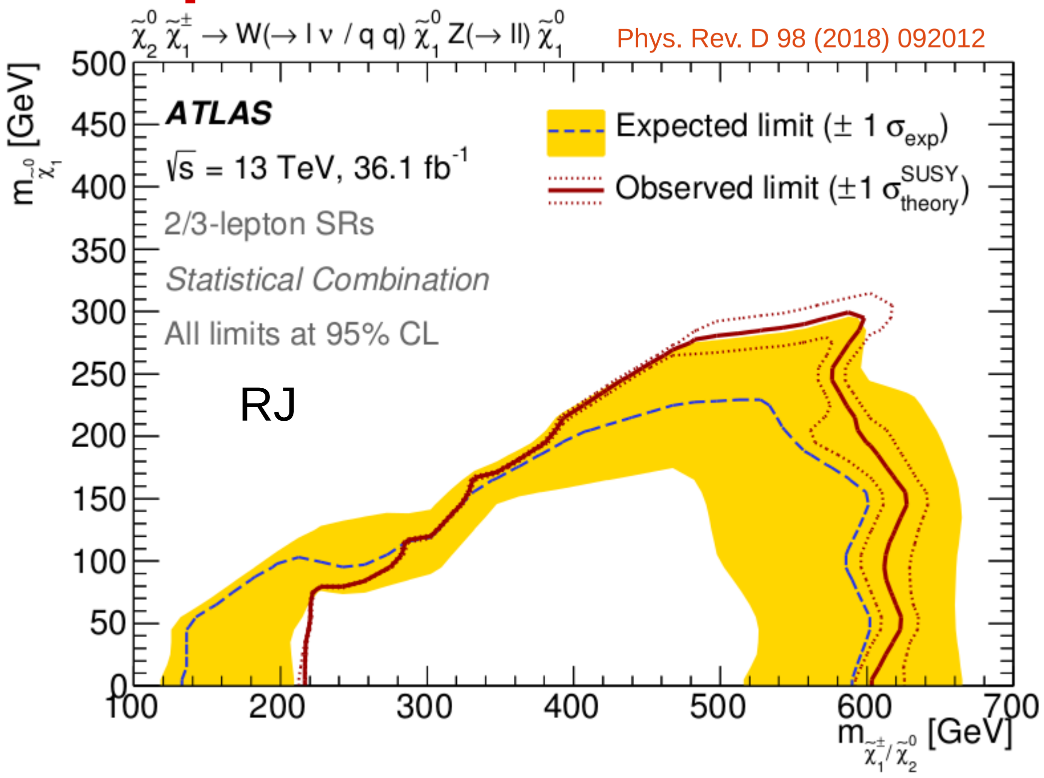
- **Contribution from each analysis** to the 1σ, 2σ and 3σ best-fit regions

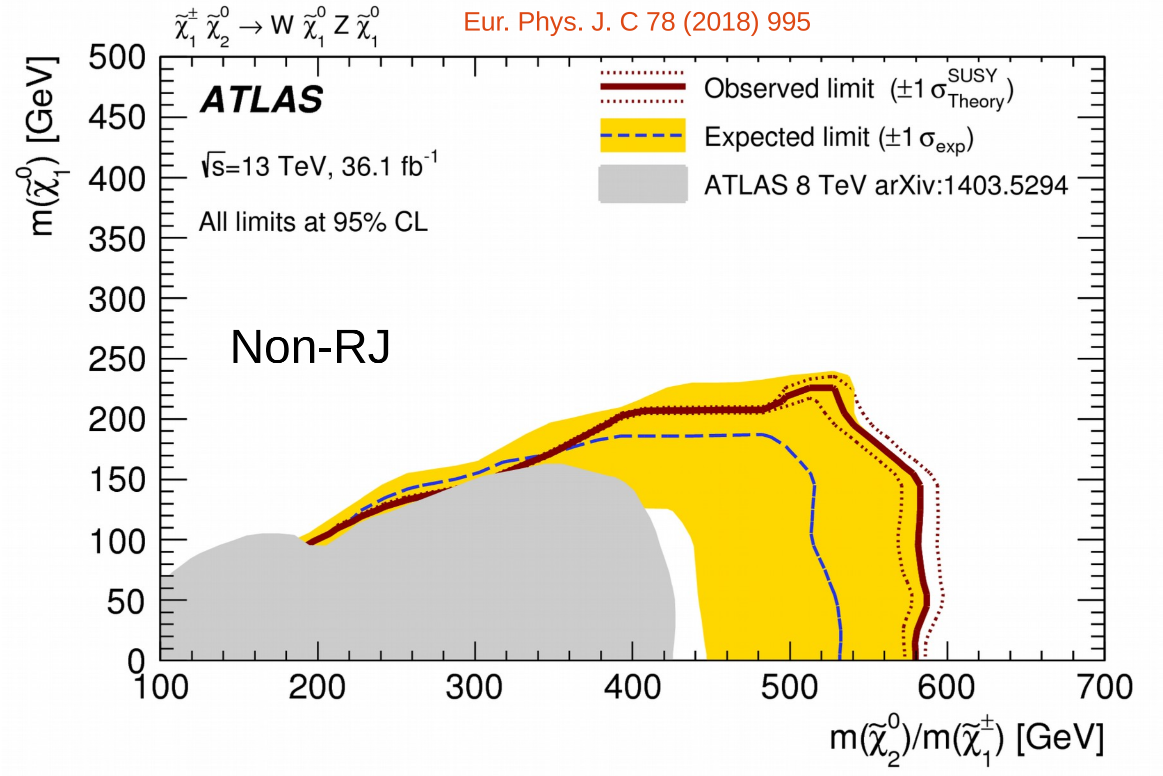
$$\ln \mathcal{L}(s+b) - \ln \mathcal{L}(b)$$

- **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**

Simplified model: conventional wisdom





- “The ATLAS RJ excesses hint at a signal in a mass range that is clearly excluded by the other analysis”
- “This can't possibly be right”, etc

As heard at ICHEP & SUSY 2018

What's going on?

- The ATLAS simplified model only allows chi2-charge1 production
- Our best fit model has other light EW-inos and we get more complex processes
- Frequently get 4 gauge bosons in the final state → get jets as well as leptons!

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

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

– `SR3_WZ_0Ja`: expected background 21.7 ± 2.9, observed 21

– `SR3_WZ_0Jb`: expected background 2.7 ± 0.5, observed 1

– `SR3_WZ_1Jc`: expected background 1.3 ± 0.3, observed 4

What about dark matter?

- Our scan did not include dark matter likelihoods

- We did, however, post-process our scan results with:

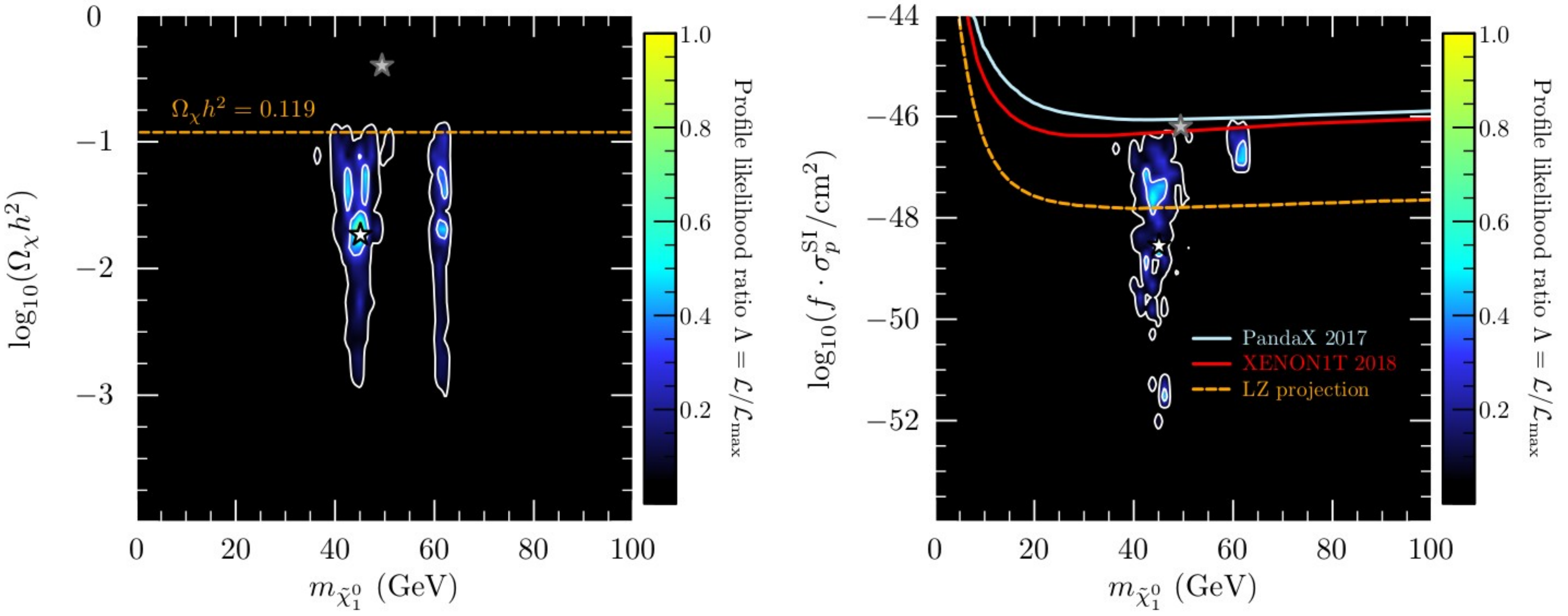
1) The Planck relic density measurement (applied as an upper limit)

2) Direct search limits from LUX, PandaX, Xenon1T, CDMSLite, CRESST-II, PICO-60, DarkSide-50 and IceCube

3) Gamma ray limits from Fermi-LAT (15 dwarf spheroidal observations)

- This allows a *rough check* of the ability of our preferred region to explain dark matter (but note that much useful SUSY phenomenology is turned off in our model)

Relic density and direct detection



- Can spot the existence of two *funnel* regions here, involving the *Z* boson and the Higgs boson, that allow the relic density constraint to be met via resonant annihilation

- Note that our scenarios are *not good* for indirect detection: $f^2 \langle \sigma v \rangle_0 < 10^{-28}\,\mathrm{cm}^3\,\mathrm{s}^{-1}$

Summary

- The EWinos could all be light, without being excluded by current LHC searches
- This strongly motivates new searches for supersymmetric dark matter!
- Current analyses allow for dramatic discoveries even in the Run II dataset (including 8 TeV results does not change the overall conclusion)
- GAMBIT results are freely available on Zenodo (see gambit.hepforge.org/pubs for links)
- Am happy to chat about possible use cases for our samples