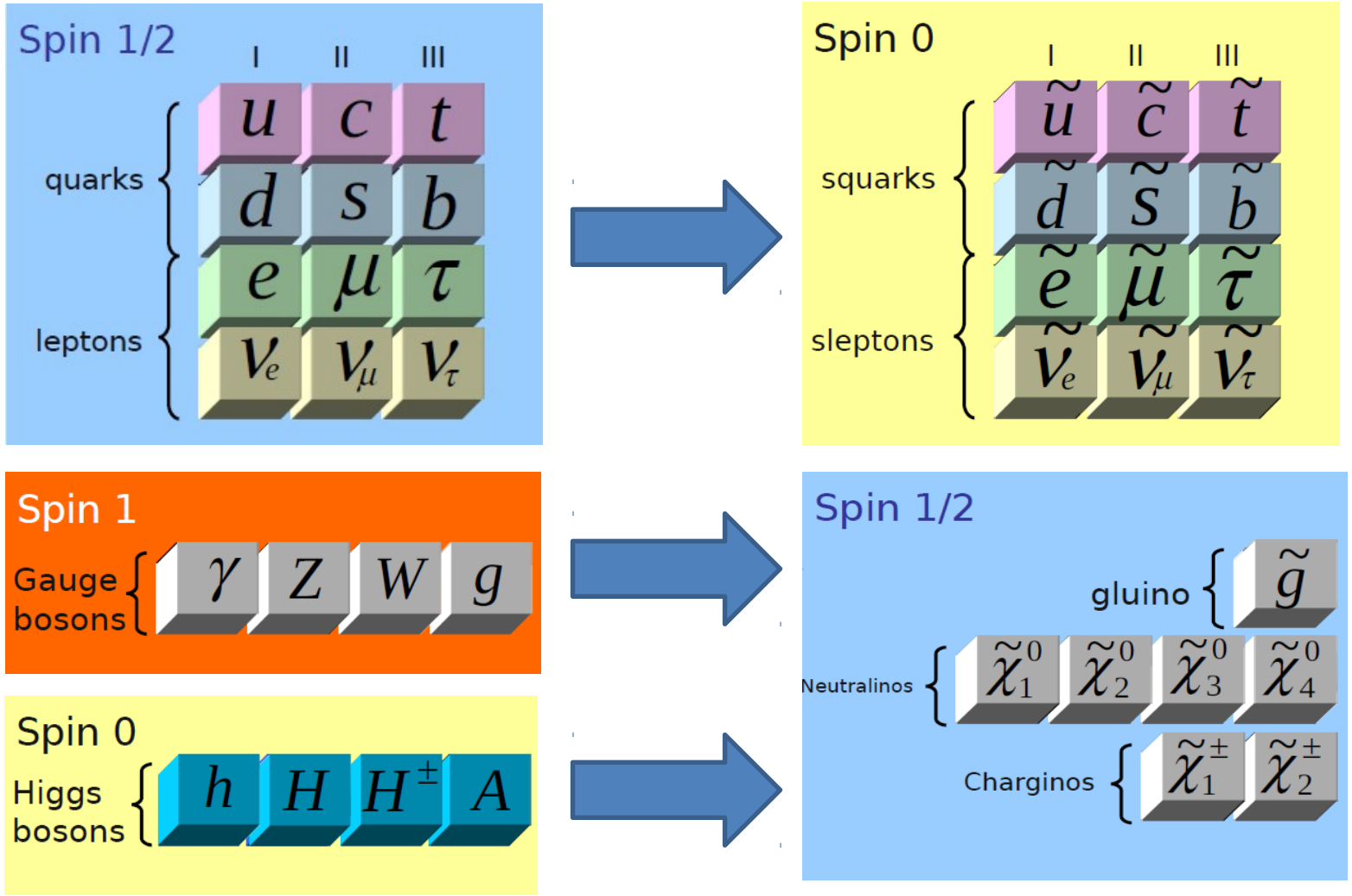
Finding BSM physics at the LHC

Martin White

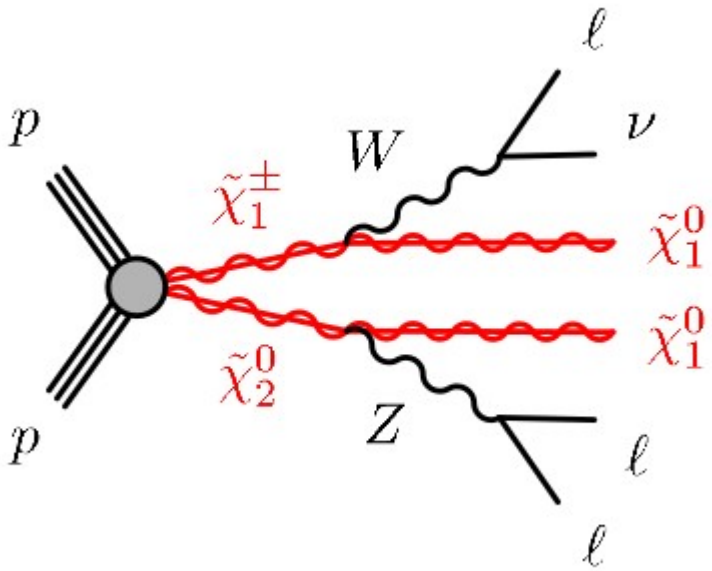
Outline

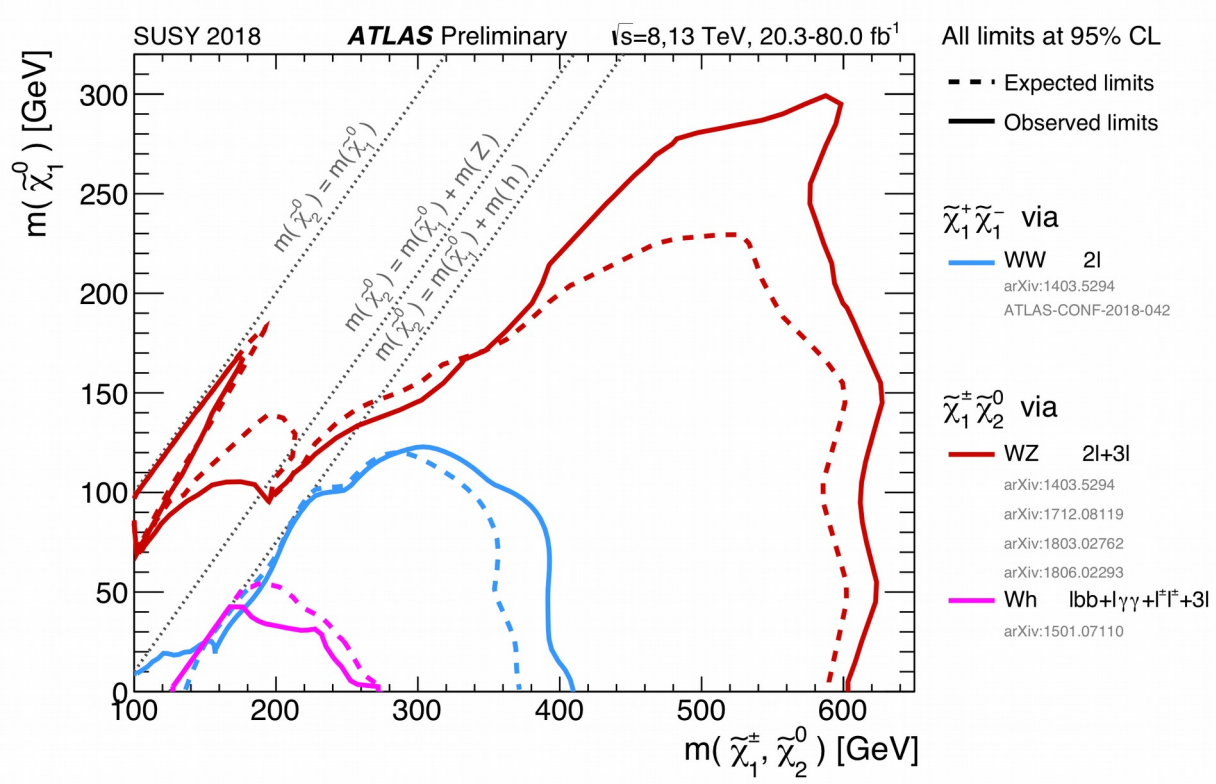
- Despite a decade of (very impressive) searches for BSM physics at the LHC, we have yet to discover anything
- I will present recent evidence that some of the most viable options are flying under the radar of current searches
- I will mention possible solutions for finding these and other models

Supersymmetry



Typical optimisation of an LHC SUSY analysis





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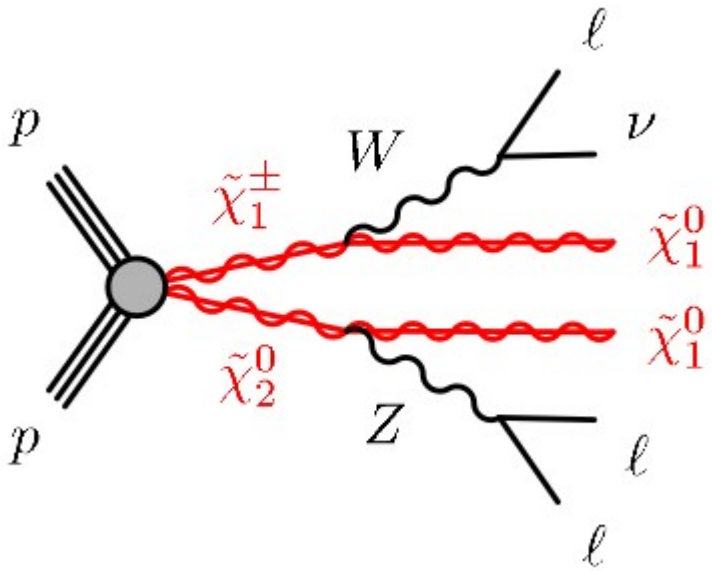

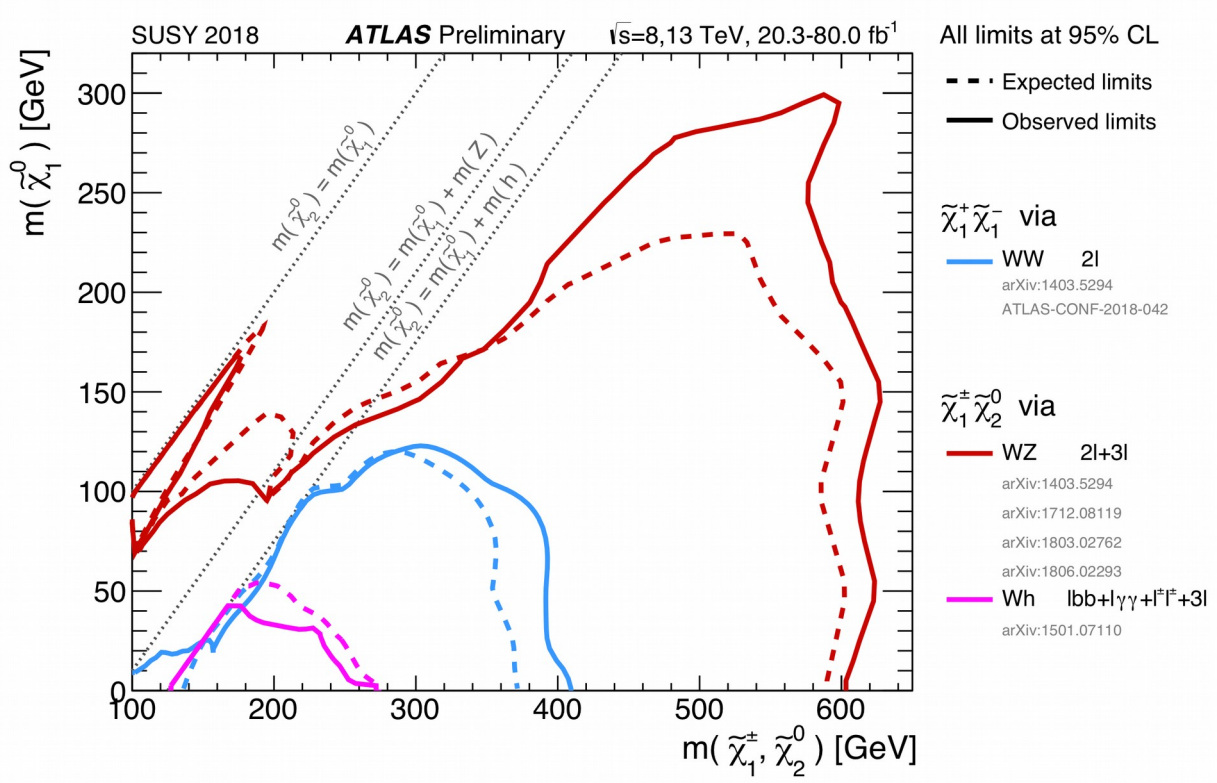

Interpreting the result of the analysis beyond the simplified model is very tough in general

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, CMS, CTA, *Fermi*-LAT, DARWIN, IceCube, LHCb, SHiP, XENON

Authors of: DarkSUSY, DDCalc, Diver, FlexibleSUSY, gamlike, GM2Calc, IsaJet, nulike, PolyChord, Rivet, SOFTSUSY, SuperIso, SUSY-AI, WIMPSim

Collaborators:
Peter Athron, Csaba Balázs, Ankit Beniwal, Florian Bernlochner, Sanjay Bloor, Torsten Bringmann, Andy Buckley, Eliel Camargo-Molina, Marcin Chrząszc, Jan Conrad, Jonathan Cornell, Matthias Danninger, Tom Edwards, Joakim Edsjö, Ben Farmer, Andrew Fowlie, Tomás Gonzalo, Will Handley, Sebastian Hoof, Selim Hotinli, Felix Kahlhoefer, Suraj Krishnamurthy, Anders Kvellestad, Julia Harz, Paul Jackson, Tong Li, Greg Martinez, Nazila Mahmoudi, James McKay, Are Raklev, Janina Renk, Chris Rogan, Roberto Ruiz de Austri, Patrick Stoecker, Roberto Trotta, Pat Scott, Nicola Serra, Daniel Steiner, Puwen Sun, Aaron Vincent, Christoph Weniger, Sebastian Wild, Martin White, Yang Zhang

40+ participants in 10 Experiments & 14 major theory codes

Eur. Phys. J. C manuscript No.
(will be inserted by the editor)

CoEPP-MN-18-7

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

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

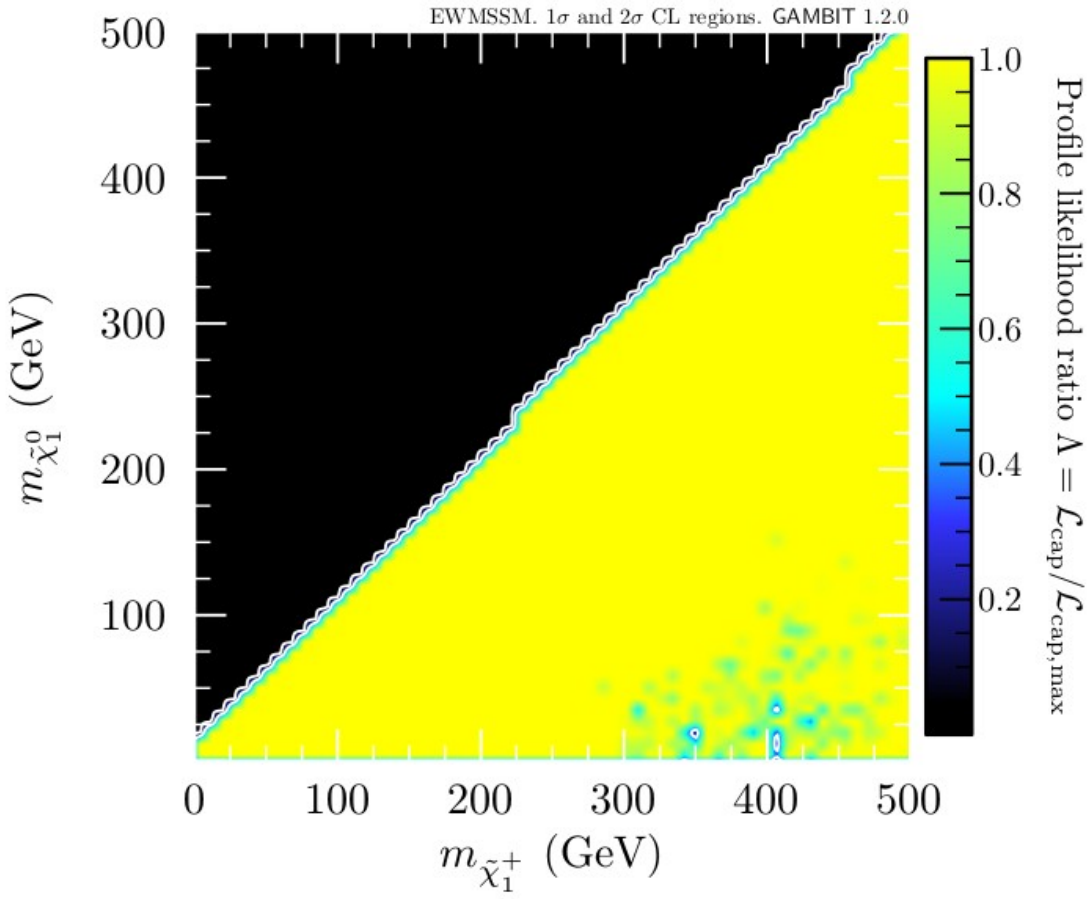
Likelihood label	Source
ATLAS_4b	ATLAS Higgsino search [104]
ATLAS_4lep	ATLAS 4ℓ search [105]
ATLAS_MultiLep_2lep_0jet	ATLAS multilepton EW search [100]
ATLAS_MultiLep_2lep_jet	ATLAS multilepton EW search [100]
ATLAS_MultiLep_3lep	ATLAS multilepton EW search [100]
ATLAS_RJ_2lep_2jet	ATLAS recursive jigsaw 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

LHC searches for SUSY dark matter

- In a test of exclusion power, we find ***no general constraint*** on the MSSM EW sector from the LHC!

arXiv: 1809.02097



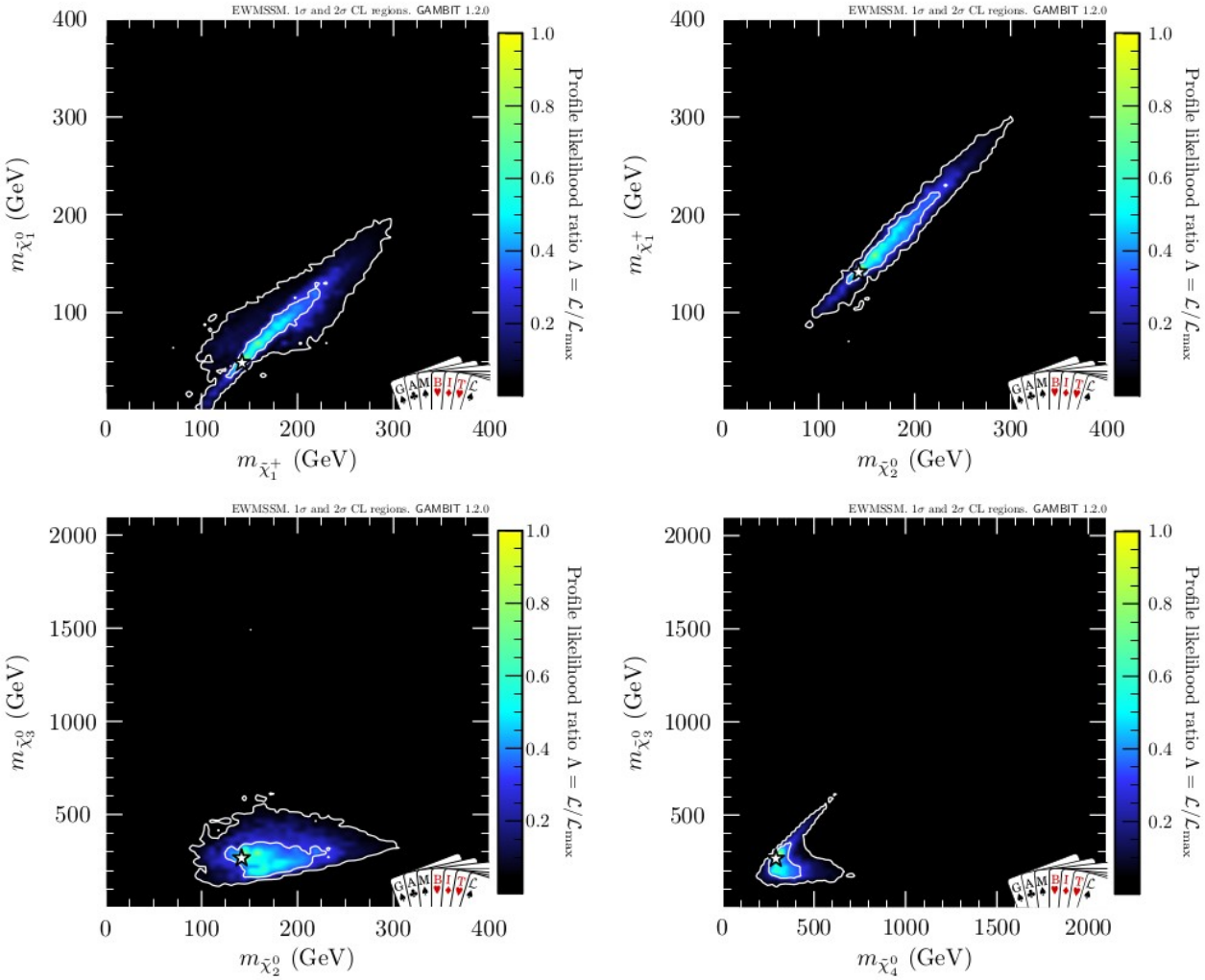
Allowing searches to give positive evidence

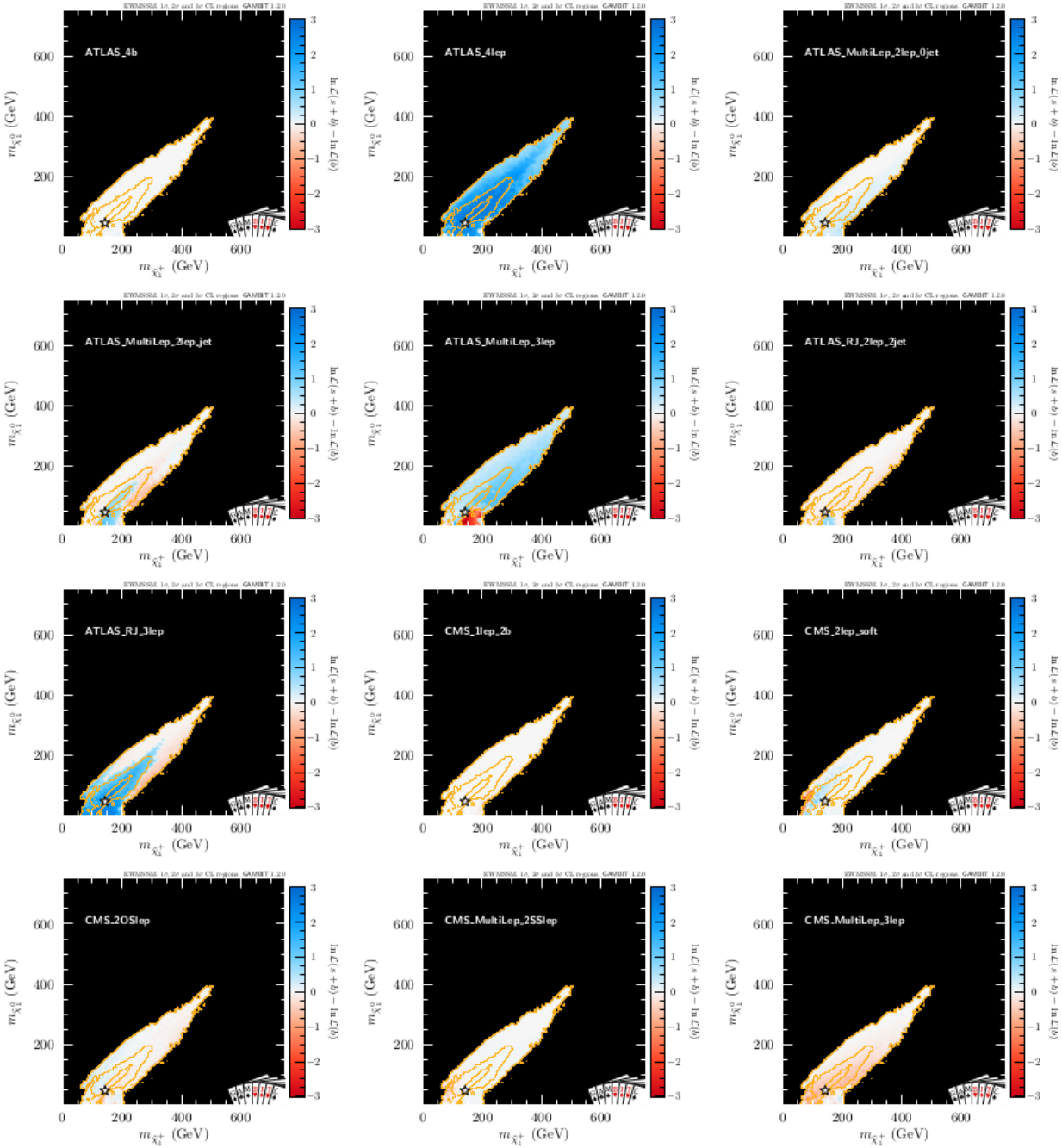
- If we allow for the presence of a signal, our results get more interesting
- A particular mass scale is picked out by a series of anomalies in ATLAS and CMS searches
- All electroweakinos are light, and we either have:

Bino < winos < higgsinos

Or

Bino < higgsinos < winos





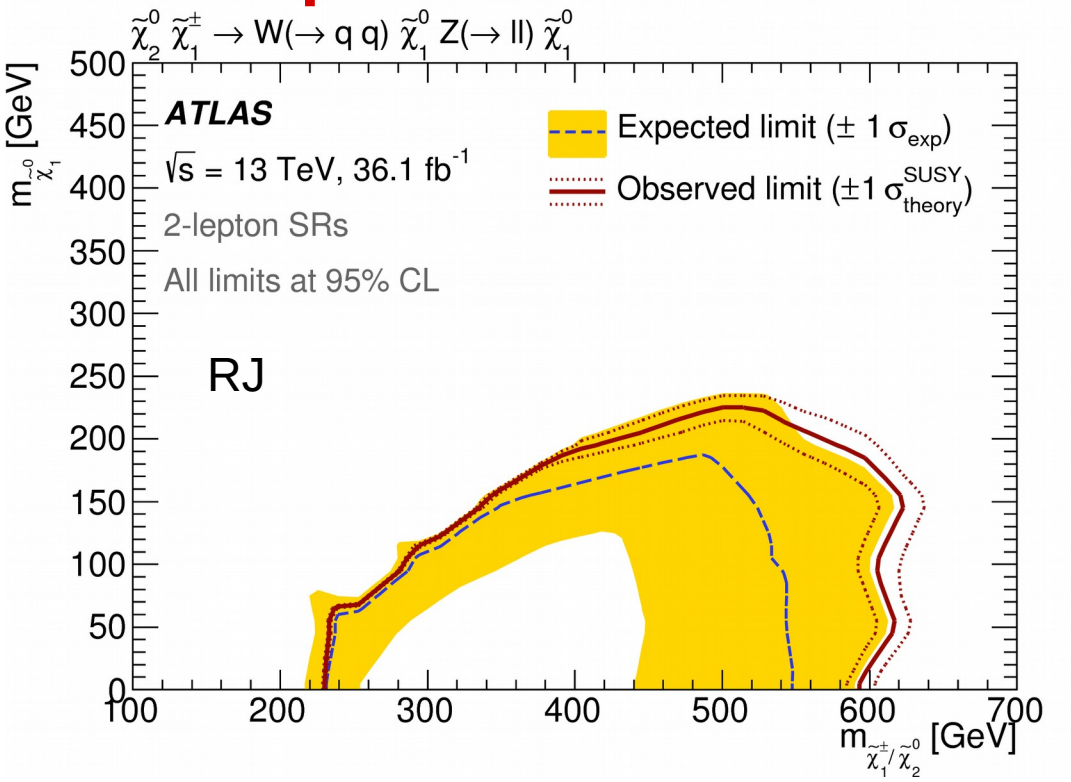
- **Contribution from each analysis** to the 1σ, 2σ and 3σ best-fit regions

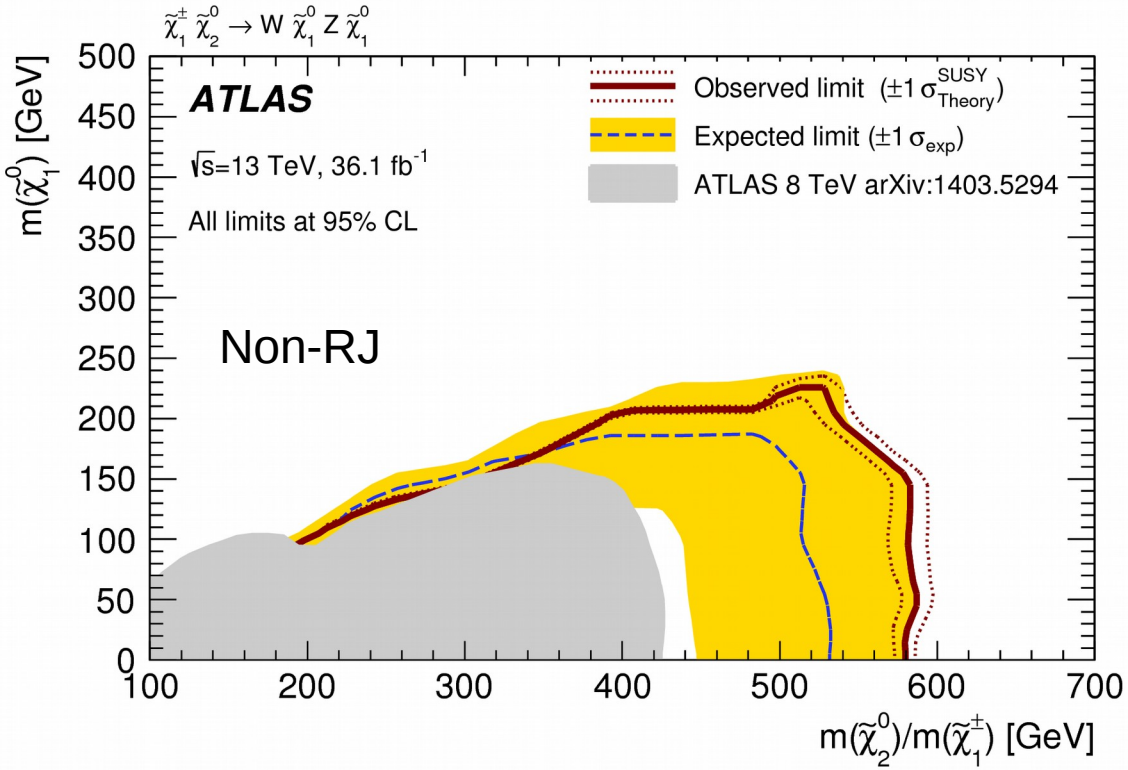
$$\ln \mathcal{L}(s+b) - \ln \mathcal{L}(b)$$

- **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

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

Ideas for improvement

1) Perform dimensional reduction on global fit results to define optimum planes for optimisation (*simple*, but not *simplified* models)

2) Unsupervised learning for LHC searches (see Adam's talk tomorrow)

3) BSM searches using new techniques (hopefully public within the next month or so...)

Summary

- A lot of excellent BSM searches have been performed at the LHC, but they targeted the wrong thing (hindsight is 20/20 of course…)
- Current analyses allow for dramatic discoveries even in the Run II dataset
- There are a variety of new approaches that may yet uncover BSM physics
- GAMBIT results provide an excellent playground for testing new techniques – samples are freely available on Zenodo

https://gambit.hepforge.org/pubs