



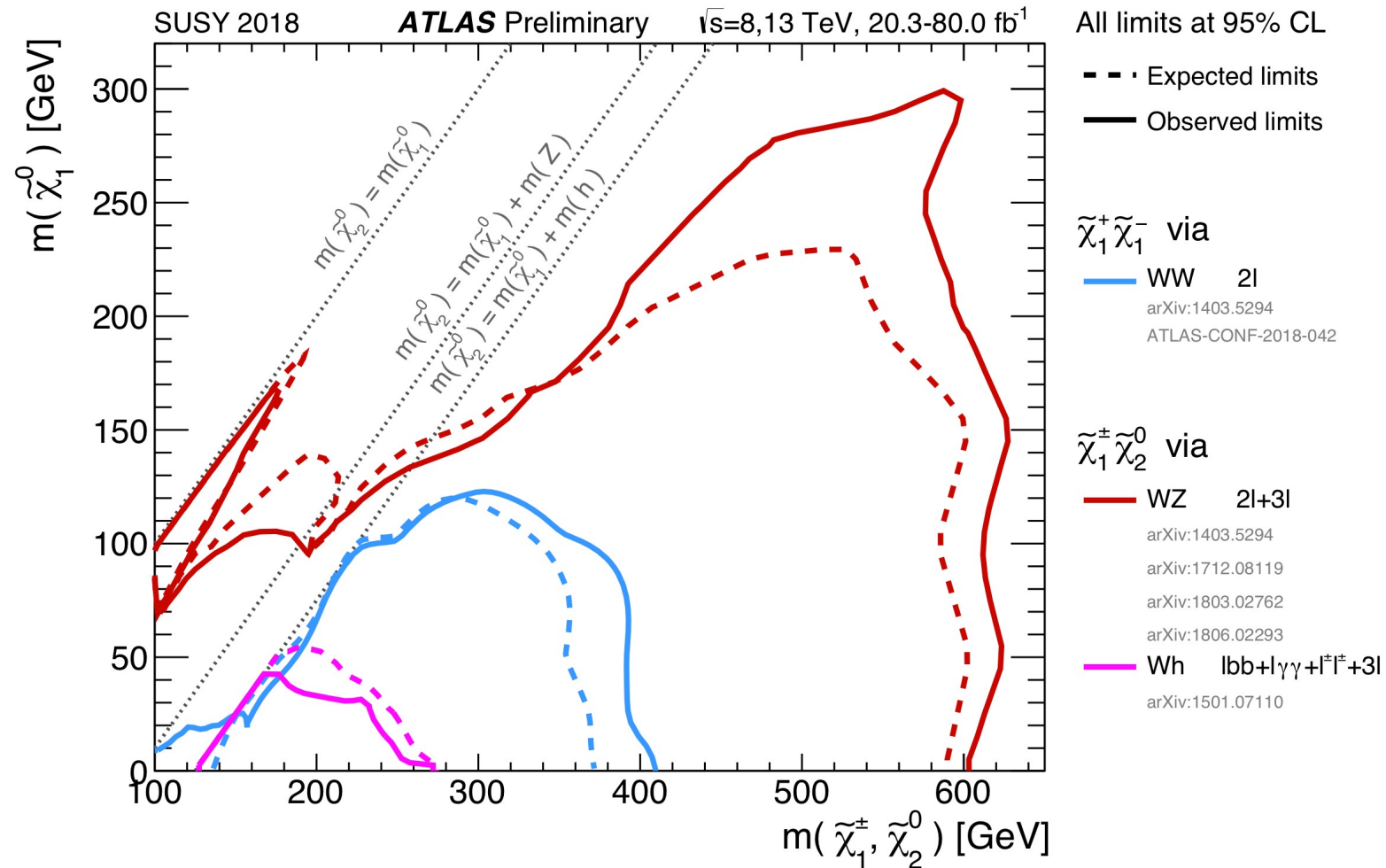
Optimising the search for the next discovery in particle physics

Martin White

Outline

- As of June 2018, we have a joint Adelaide/Cambridge/Monash/Paris grant to develop new techniques for optimising LHC searches for BSM physics
- The current approach based on “simplified models” is clearly deficient (even though the searches are very clever)
- We have started developing ideas for what should be done instead

Typical optimisation of an LHC analysis



The grant in a nutshell

- Use GAMBIT to perform global fits of BSM physics models
- Work out how best to optimise ATLAS searches for SUSY (and other things) based on the global fit results
- (+ do other things that aren't relevant for today)

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 Chrzęszc, Jan Conrad, Jonathan Cornell, Matthias Danninger, Tom Edwards, Joakim Edsjö, Ben Farmer, Andrew Fowlie, Tomás Gonzalo, Will Handley, Sebastian Hoof, Selim Hotinli, Felix Kahlhofer, 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

Combined collider constraints on neutralinos and charginos

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Received: date / Accepted: date

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

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

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

- LEP cross-section limits

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

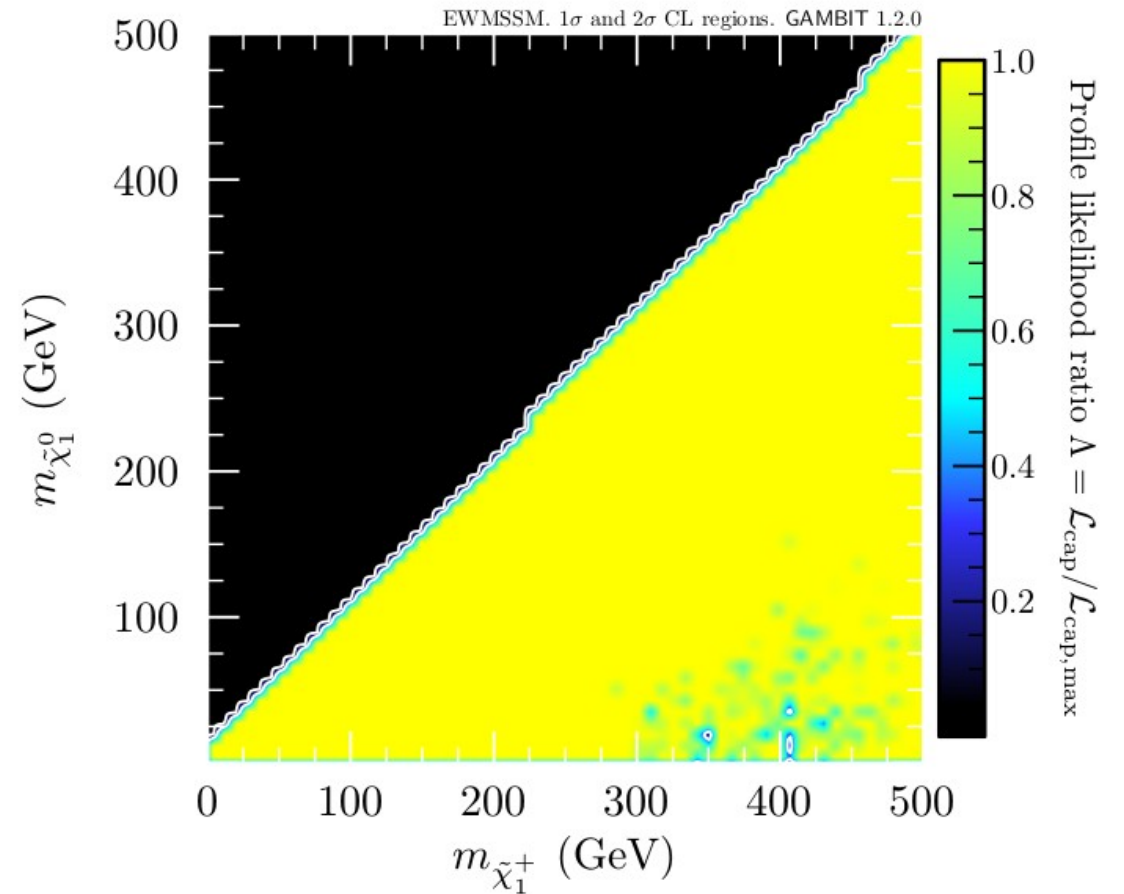
- LHC searches for EW SUSY

Likelihood label	Source
ATLAS_4b	ATLAS Higgsino search [104]
ATLAS_4lep	ATLAS 4 ℓ 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

Testing exclusion power of LHC searches

- 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!



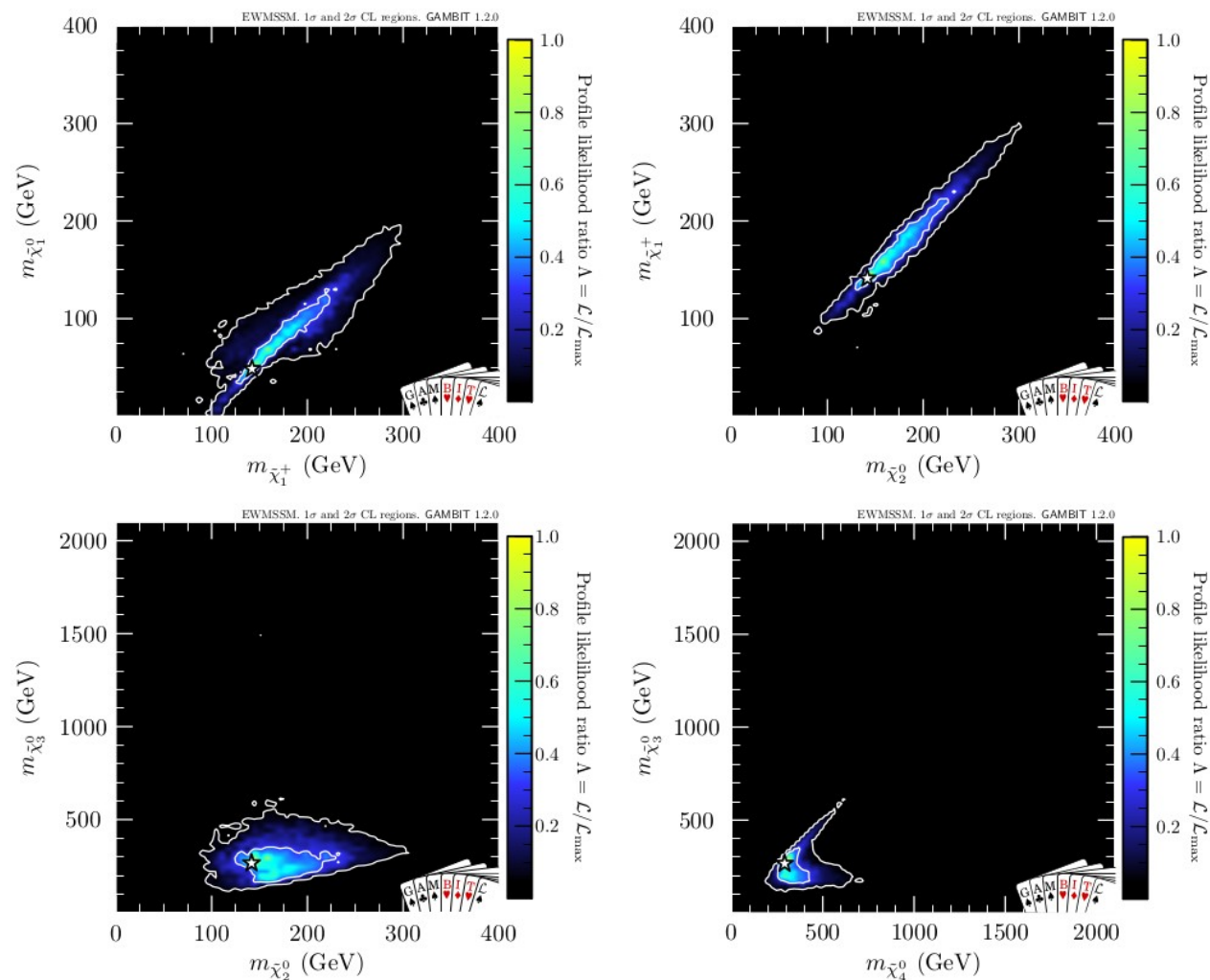
Allowing searches to give positive evidence

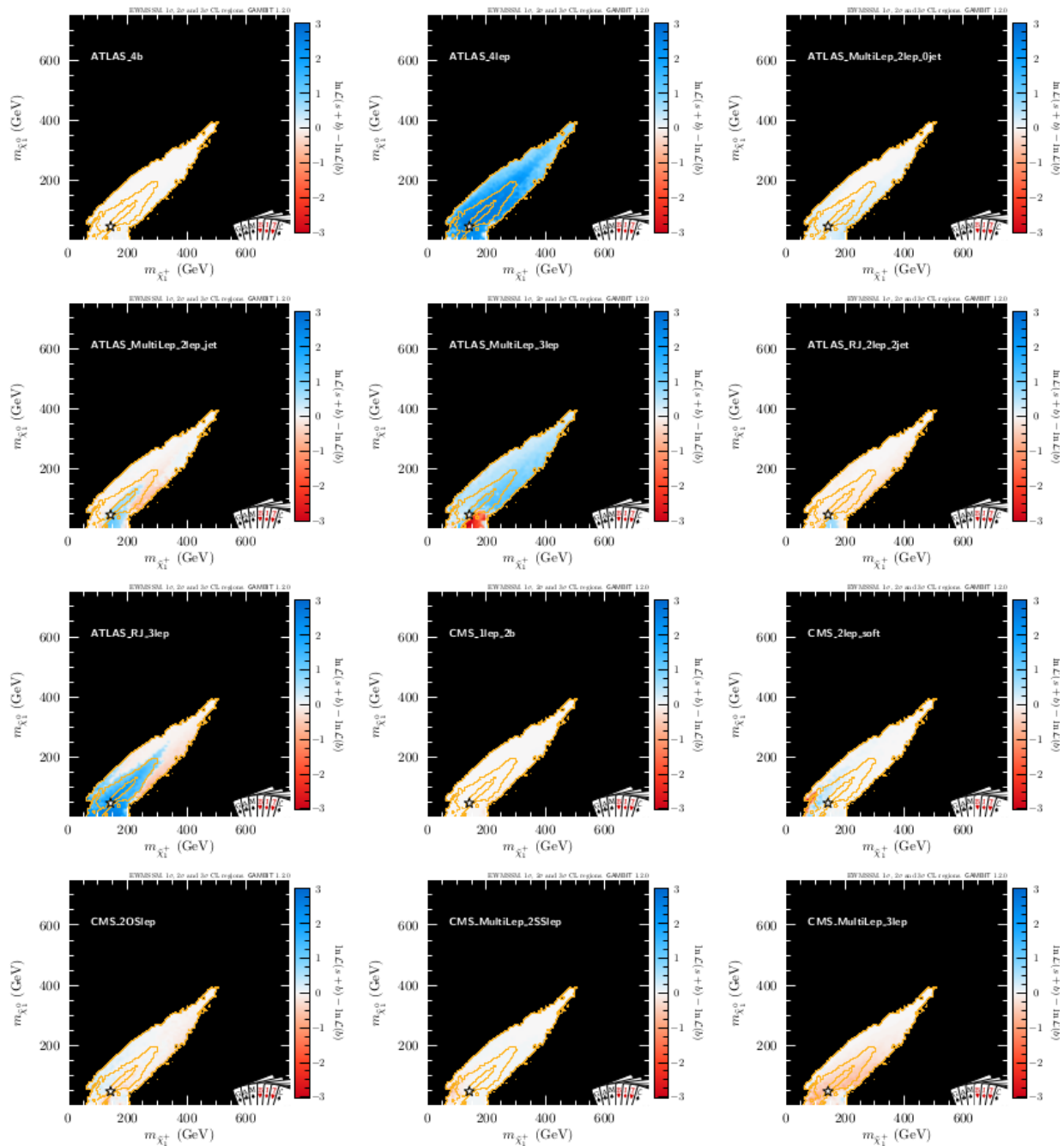
- If we allow for the presence of a signal, our results get more interesting
- A particular mass scale is picked out by a series of anomalies in ATLAS and CMS searches
- All electroweakinos are light, and we either have:

Bino $<$ winos $<$ higgsinos

Or

Bino $<$ higgsinos $<$ winos





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

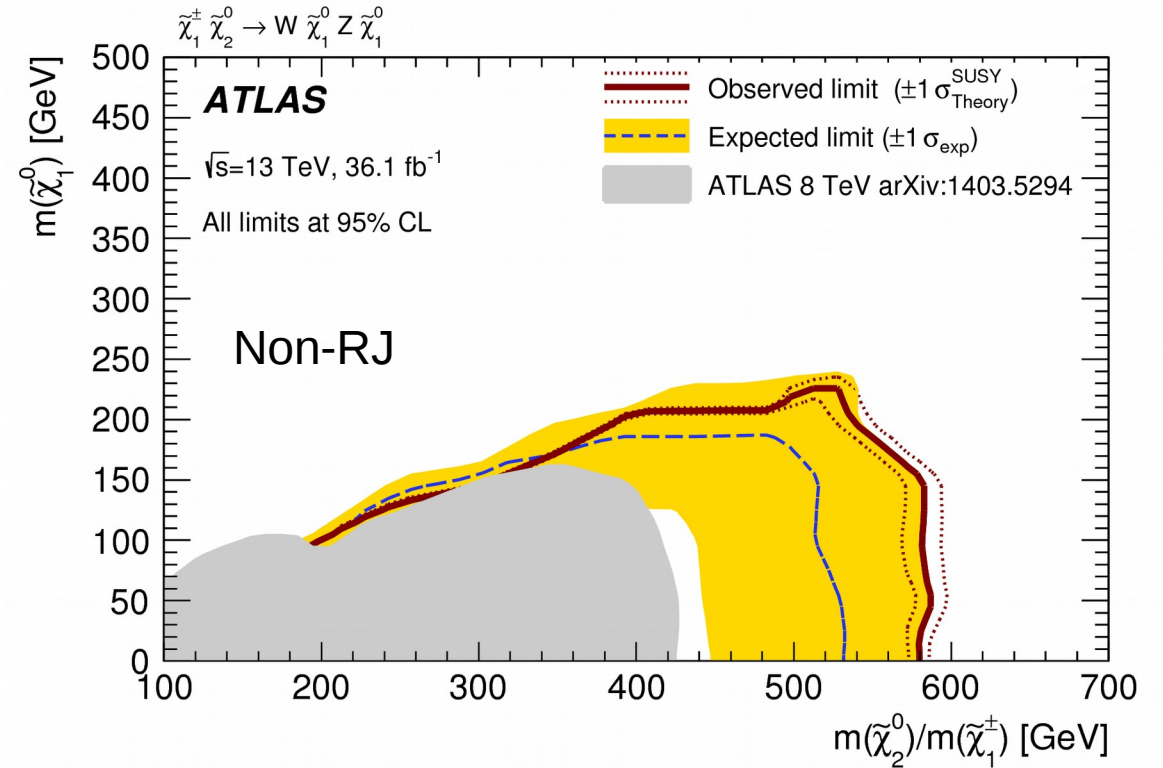
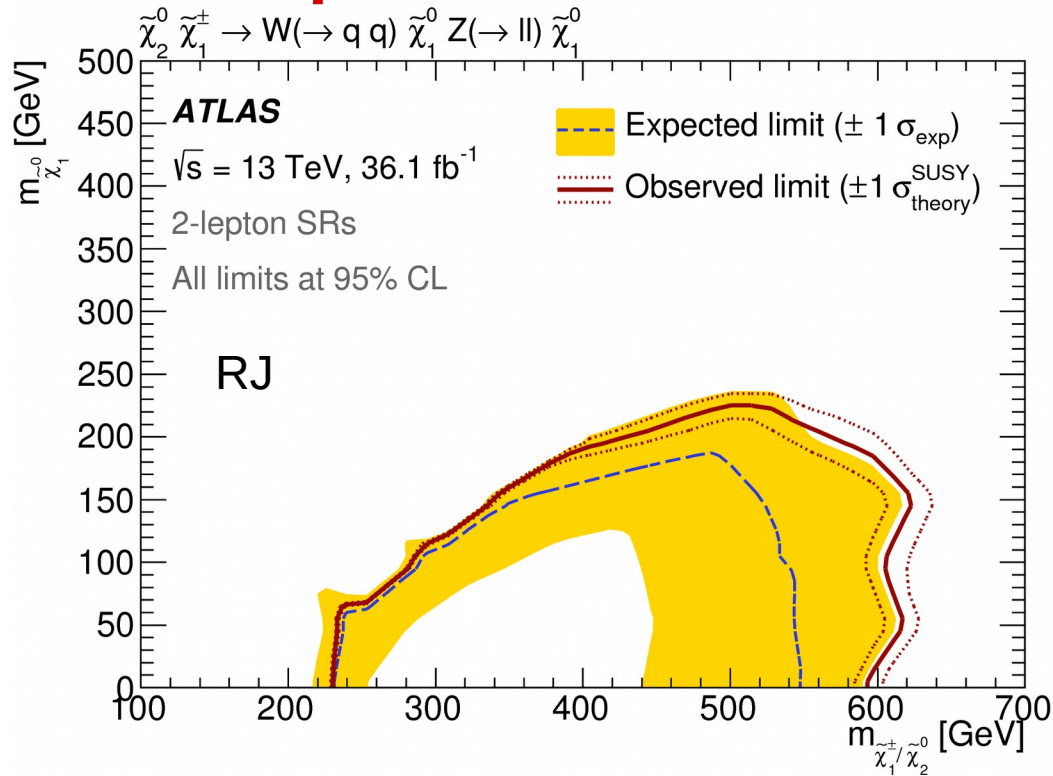
$$\ln \mathcal{L}(s + b) - \ln \mathcal{L}(b)$$

- **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. $\tilde{\chi}_1^+ \rightarrow W^+ + \tilde{\chi}_1^0, \tilde{\chi}_3^0 \rightarrow Z\tilde{\chi}_1^0$

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

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

– $\tilde{\chi}_2^0 \tilde{\chi}_3^0$ production, with e.g. $\tilde{\chi}_2^0 \rightarrow Z + \tilde{\chi}_1^0, \tilde{\chi}_3^0 \rightarrow Z + \tilde{\chi}_1^0$

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

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

– $\tilde{\chi}_1^\pm \tilde{\chi}_4^0$ production, with e.g. $\tilde{\chi}_1^+ \rightarrow W^+ + \tilde{\chi}_1^0, \tilde{\chi}_4^0 \rightarrow W^+ + \tilde{\chi}_1^- \rightarrow W^+ + W^- + \tilde{\chi}_1^0$

– 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



2) Model-independent BSM searches using new techniques



Summary

- A lot of excellent BSM searches have been performed at the LHC, but they all targeted the wrong thing (hindsight is 20/20 of course...)
- Current analyses allow for dramatic discoveries even in the Run II dataset
- We are developing promising approaches for better-optimised LHC searches