Collider constraints on electroweakinos in the presence of a light gravitino

paper hitting arXiv soon...

Tomasz Procter
(On behalf of the GAMBIT community)

With thanks to many previous GAMBIT speakers for slides and inspiration

OUTLINE

- What is GAMBIT? How does ColliderBit work?
    - **NEW:** ColliderBit – Rivet/Contur interface.
- The Model: EWMSSM + Gravitino
- Results
    - Impact of Contur Likelihoods
- Summary

What is GAMBIT?

GAMBIT: The Global And Modular BSM Inference Tool

gambit.hepforge.org   github.com/GambitBSM   EPJC 77 (2017) 784   arXiv:1705.07908

- Extensive model database, beyond SUSY
- Fast definition of new datasets, theories
- Extensive observable/data libraries
- Plug&play scanning/physics/likelihood packages
- Various statistical options
  - (frequentist /Bayesian)
- 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: BubbleProfiler, Capt'n General, Contur, DarkAges, DarkSUSY, DDCalc, DirectDM, Diver, EasyScanHEP, ExoCLASS, FlexibleSUSY, gamLike, GM2Calc, HEPLike, IsaTools, MARTY, nuLike, PhaseTracer, PolyChord, Rivet, SOFTSUSY, Superlso, SUSY-AI, xsec, Vevacious, WIMPSim


Recent collaborators: P Athron, C Balázs, A Beniwal, S Bloor, T Bringmann, A Buckley, J-E Camargo-Molina, C Chang, M Chrzaszcz, J Conrad, J Cornell, M Danninger, J Edsjö, T Emken, A Fowlie, T Gonzalo, W Handley, J Harz, S Hoof, F Kahlhoefer, A Kvellestad, P Jackson, D Jacob, C Lin, N Mahmoudi, G Martinez, MT Prim, A Raklev, C Rogan, R Ruiz, P Scott, N Serra, P Stöcker , W. Su, A Vincent, C Weniger, M White, Y Zhang, ++

70+ participants in many experiments and numerous major theory codes

See Chris's talk tomorrow!

CollliderBit: GAMBIT's collider physics module

- The collider physics module of GAMBIT
- LEP limits (SUSY): Calculate and check σxBR against published limits.
- LHC particle searches: Full Poisson likelihood from fast MC simulation of LHC searches
  - Parallellized MC event generation and analysis loop inside ColliderBit
  - Event generation with Pythia 8
  - Fast detector simulator: BuckFast (4-vector smearing)
- **NEW:** LHC measurements' Likelihoods via Rivet and Contur.
- Focus on speed, as required for use in global fits
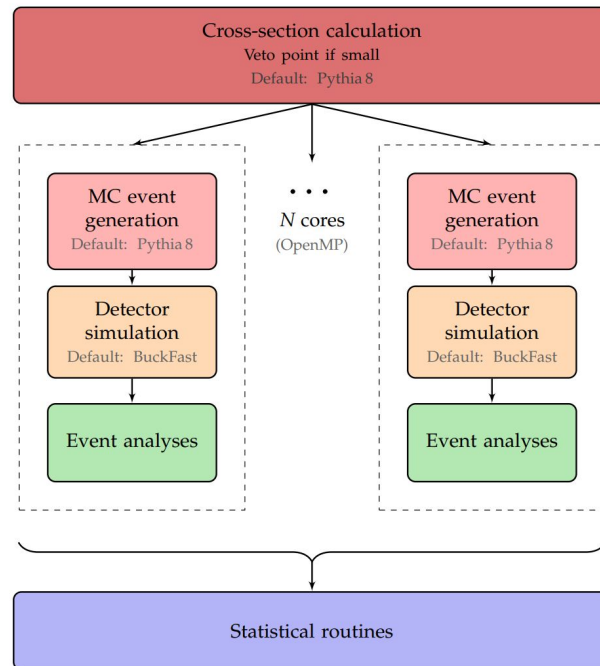
Interfacing ColliderBit to Rivet and Contur

- Rivet: C++ package backended using GAMBIT's BOSS (see arxiv: 1705.07908)
- Rivet analyses HepMC events provided by ColliderBit, then creates a summary YODA object.

- Contur interfaced using Python - receives yoda streams from GAMBIT, and calculates likelihood.
  - And, if requested, likelihood per analysis pool
- Likelihood used by GAMBIT
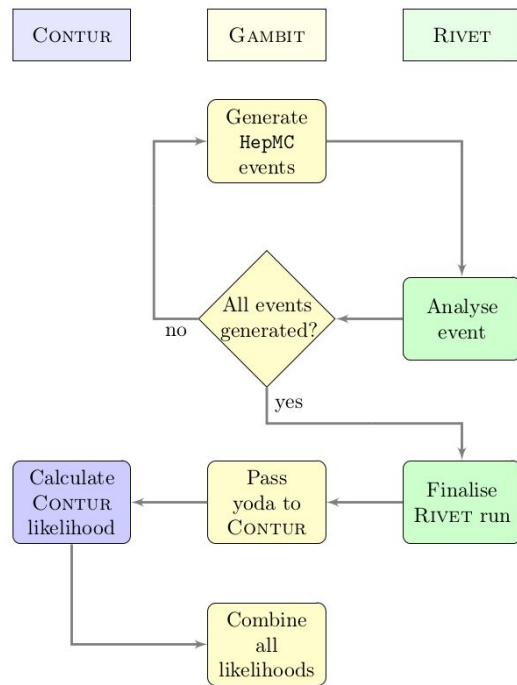
Changes to Rivet and Contur

Rivet (and YODA):

- Output as a yodastream rather than YODA file - minimises file read/write.
- Tidying up of exit statements.
- *(Coming Rivet 3.2.0, not actually used here)* Thread-Safety

Contur:

- Call main function supplying a dictionary of arguments – including YODA streams.
- Increased number of possible output types:
  - CLs
  - LLR
  - CLs or LLR per pool
  - Tag of limiting histogram(s') bin(s).
- Obtainable before - but only if you really knew what you were doing...
- Logger redirection.

These should all be useful for others wanting to use these programs in another context!
(particularly on HPC)

Postprocessing with Rivet and Contur: strategy

- Interface not ready before main scans run – only used in postprocessing.
- 100 000 MC events at every point from the main scan.
  - Due to higher acceptance of measurements, need significantly fewer events than the searches.
- Rivet (as of 3.1.4) was **not** thread safe
  - Run with one OpenMP thread, but **many** MPI threads to maximise efficiency.
- Contur 2.1.1 run using then-standard "Data==SM" assumption
  - Can only exclude, not favour.

Model

Model

TL;DR: GAMBIT EWMSSM + light gravitino

Neutralinos

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

$$M_1 \quad M_2 \quad \mu \quad \tan\beta$$

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

Charginos

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

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

+

light gravitino, fixed to 1eV

$$\tilde{G}$$

(Thanks to Anders Kvellestad for the EWSSM graphic!)

Rest of SUSY? Decoupled.

Model - Collider Phenomenology

- Gravitino LSP

- Lightest Neutralino is nearly always NLSP

  - Small region where chargino is NLSP

- Main collider signature: production and decay of light EWinos

- Neutralino -> Gauge Boson + Gravitino

  - Photon decay always kinematically allowed: dominates a lot of the space.

- Varied Collider signatures (primarily up to choice of gauge boson):

  - MET (escaping gravitinos)

  - Distinctive gauge boson signatures:

    - E.g. Z->leptons, h->leptons, photons

Results
(Searches + Measurements + LEP limits)

Profile Likelihoods:
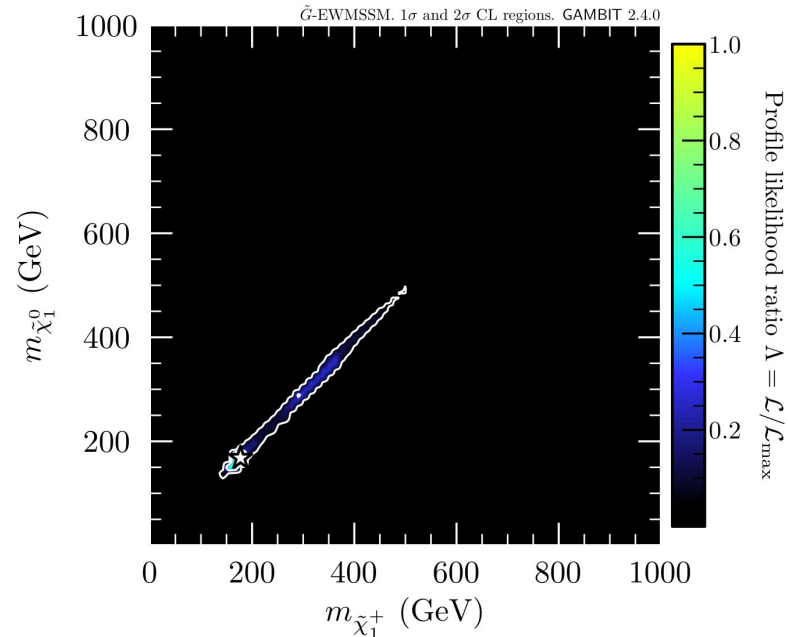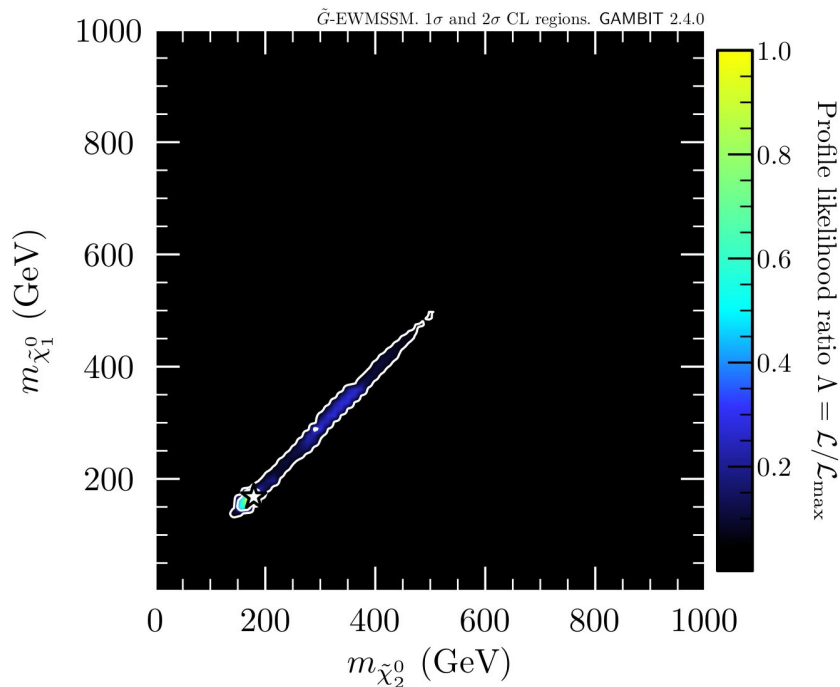
- 3 near-degenerate higgsinos.
- Dominant decay to higgs + gravitino.
- Low BR to photons means these points escape the otherwise highly constraining photons + MET searches
- Model fits to small excesses in:
  - ATLAS b-jets + MET
  - ATLAS & CMS leptons + MET
  - (c.f. GAMBIT EWino study)

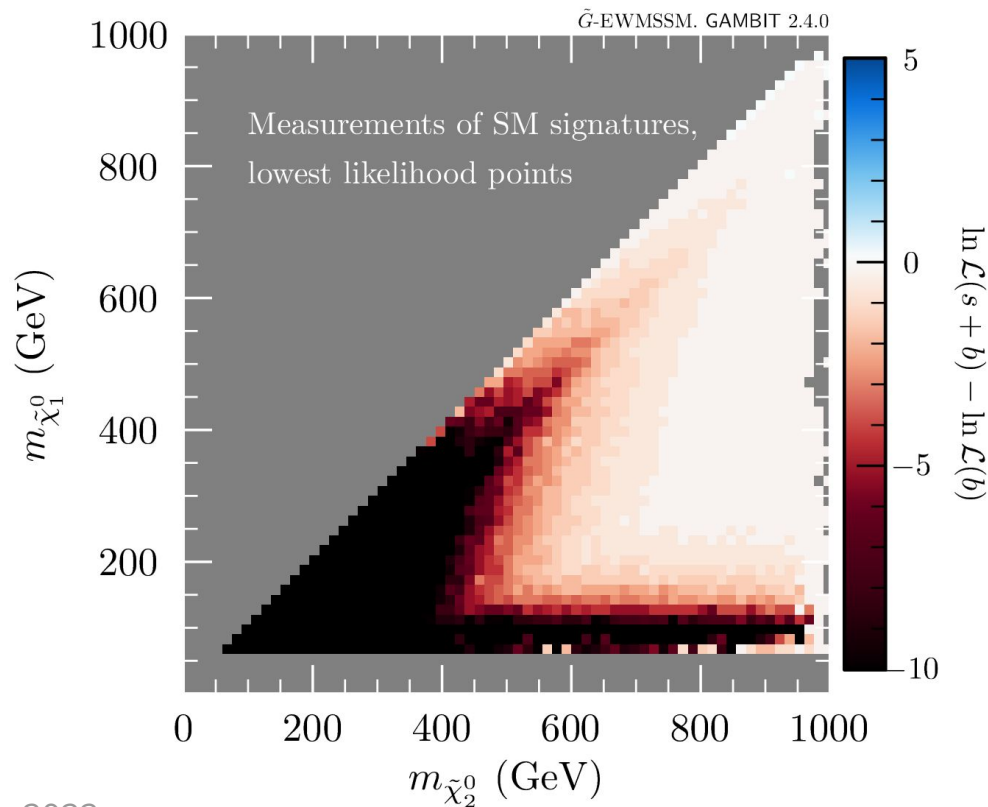# Capped Likelihoods: Most of the sub-TeV space is excluded... but not all.
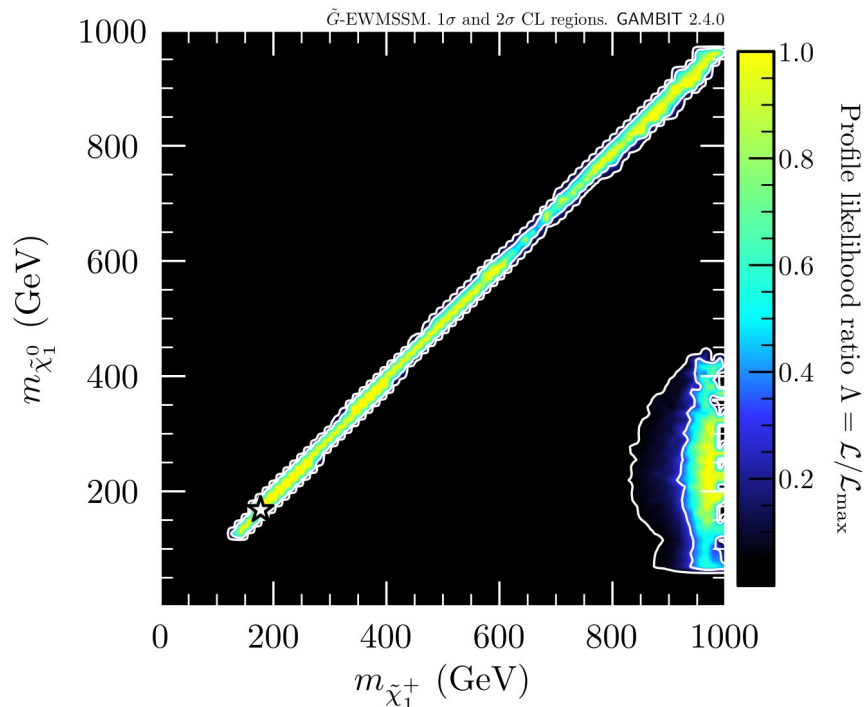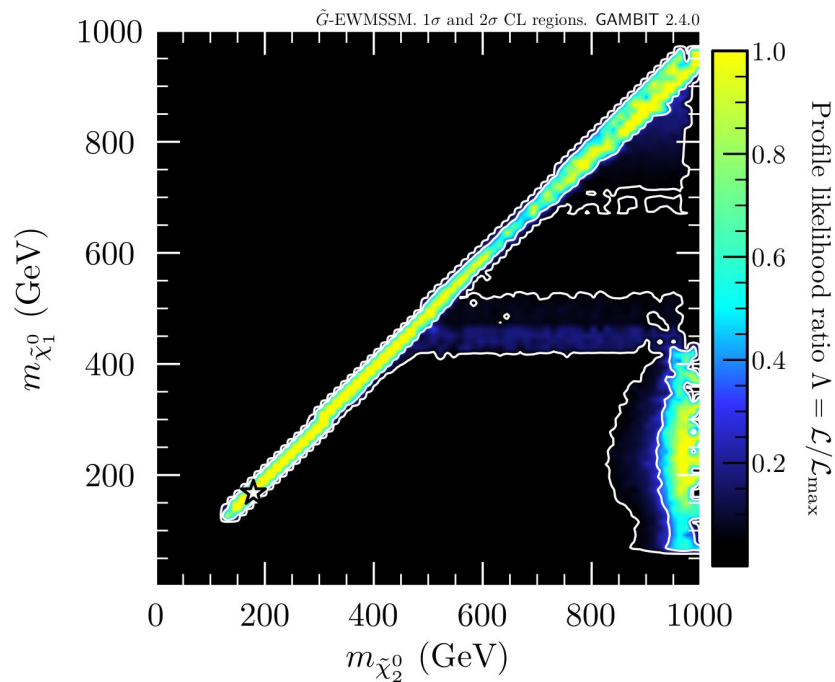
Capped Likelihoods: Four non-excluded regions

$\tilde{G}$-EWMSSM. 1σ and 2σ CL regions. GAMBIT 2.4.0
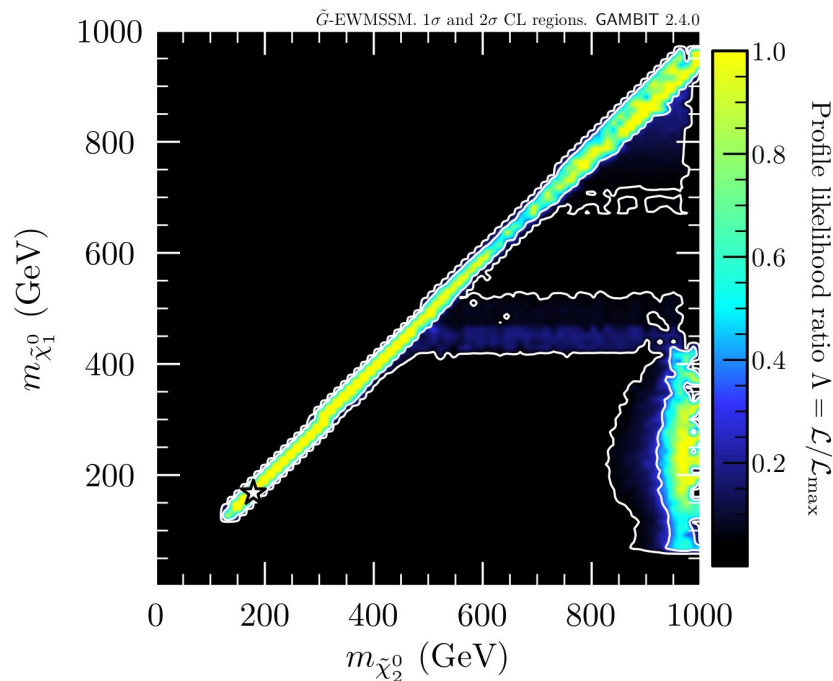
- Regions:
  a. degenerate higgsinos > 130 GeV
  b. degenerate winos 400-500 GeV
  c. degenerate winos > 700 GeV
  d. bino >~ 62 GeV, decoupled from higgsinos/winos > 800 GeV
- Prospects for exclusion in Run 3/HL-LHC:
  a. Will be hard to exclude, but higher XS, new analysis techniques will help – n.b also importance of 4l measurement.
  b. Should be excluded.
  c. & d.   Will be pushed to higher masses.

Impact of Contur results

$\tilde{G}$-EWMSSM. GAMBIT 2.4.0

Measurements of SM signatures, lowest likelihood points

$m_{\tilde{\chi}_1^0}$ (GeV) vs $m_{\tilde{\chi}_2^0}$ (GeV), colour scale $\ln \mathcal{L}(s+b) - \ln \mathcal{L}(b)$

Impact of Contur results - important measurements

pp→ℓℓℓℓ+X (incl. Z, H, ZZ inv. Mass regions - ATLAS)
Arxiv:2103.01918
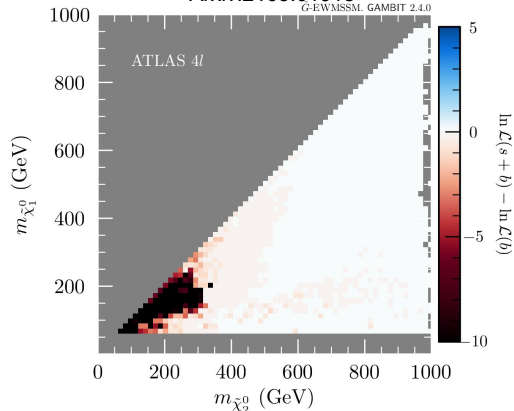
pp→WW+MET+(j) (ATLAS)
Arxiv:2103.01918, 2103.10319
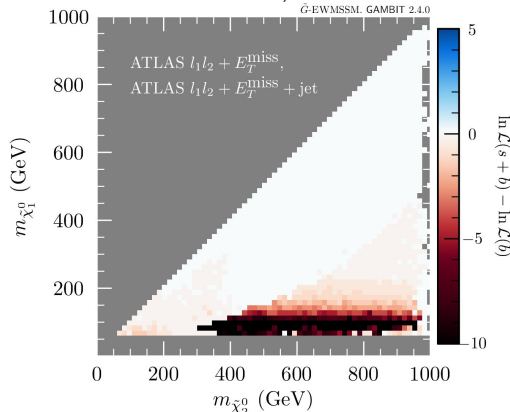
pp→Z(ℓℓ)+γ (ATLAS)
Arxiv:2103.01918
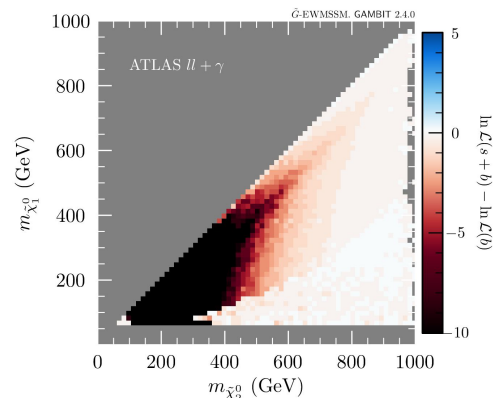
C.f. Branching ratios:
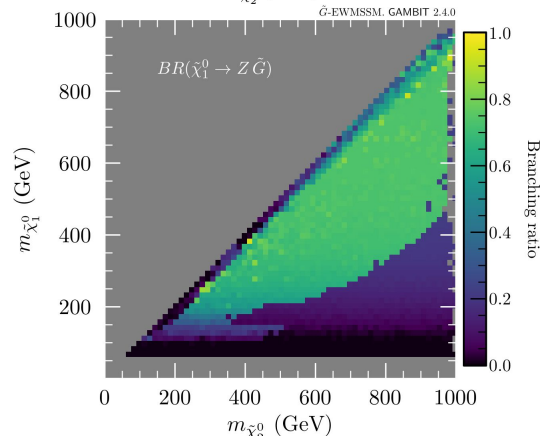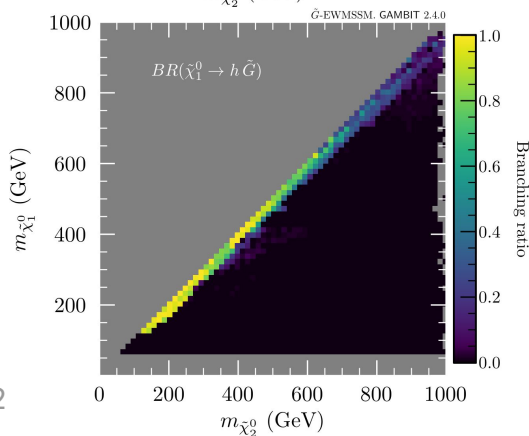
Impact of Contur results - 8 TeV

- Very low-mass favoured points would have been in reach of 8TeV analyses
- Too computationally intense to rerun everything - ran 200 most favoured points, Contur only.
- As expected, low mass points more impacted (though not particularly significant)
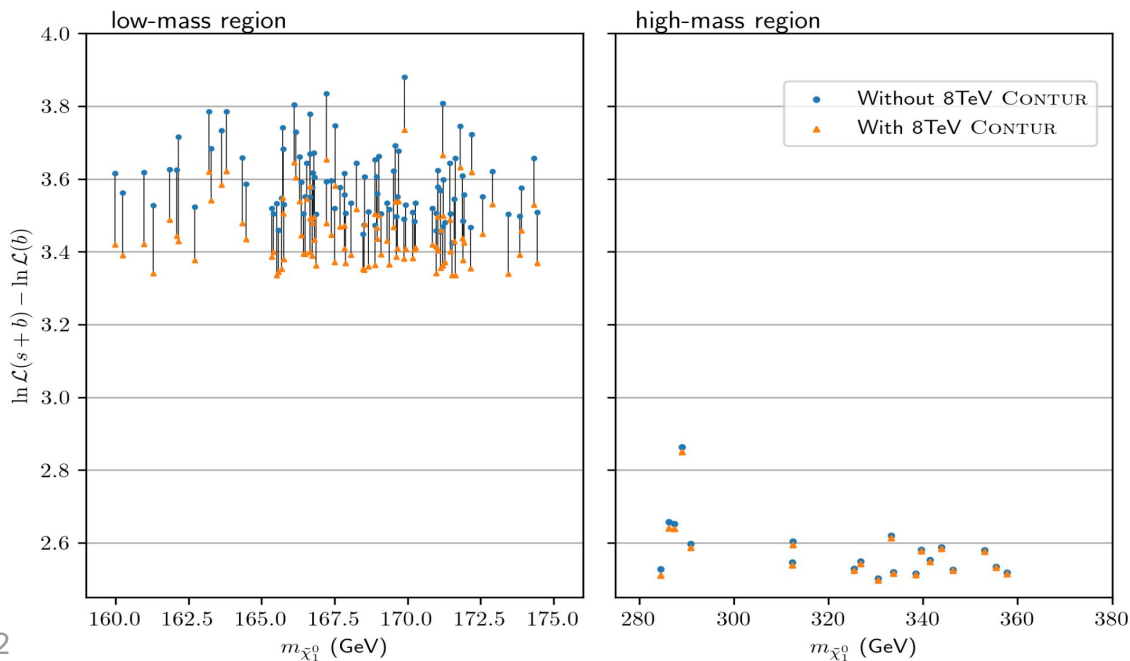
Summary

Summary

- First use of LHC measurements in a Global Fit.
  - And they were useful
- Majority of the sub- 1 TeV EWino space (in G-EWMSSM) is excluded by Collider Measurements + Searches (+ LEP limits).
- But there still remain (even slightly favoured) regions.
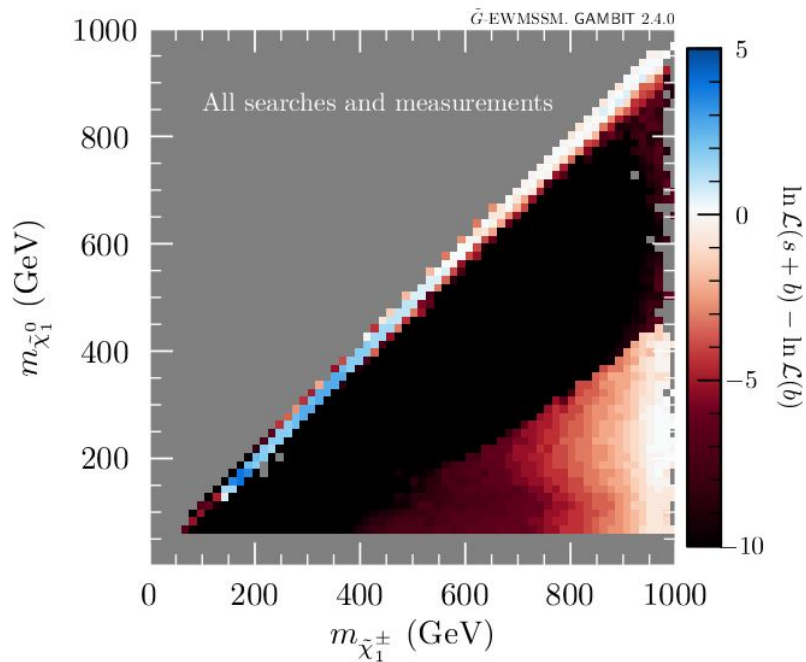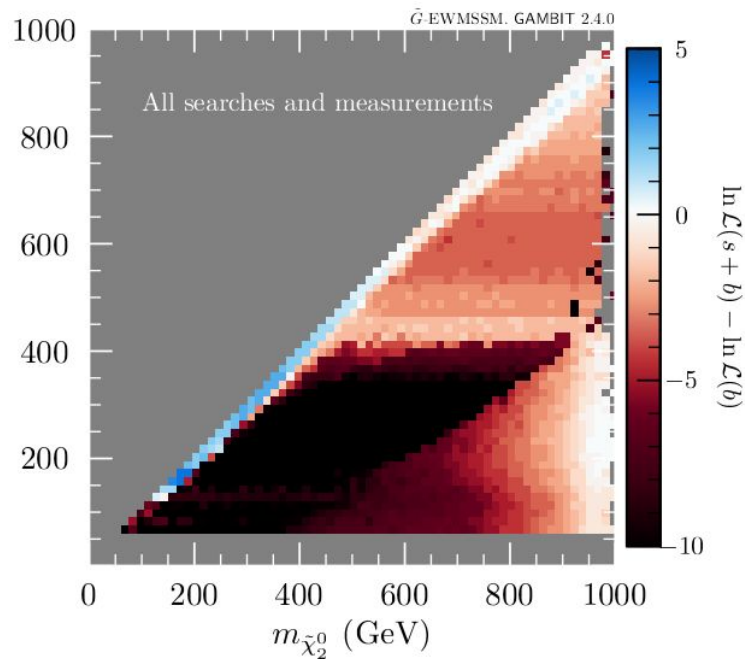- These may be accessible to dedicated Run-3 and HL-LHC searches.
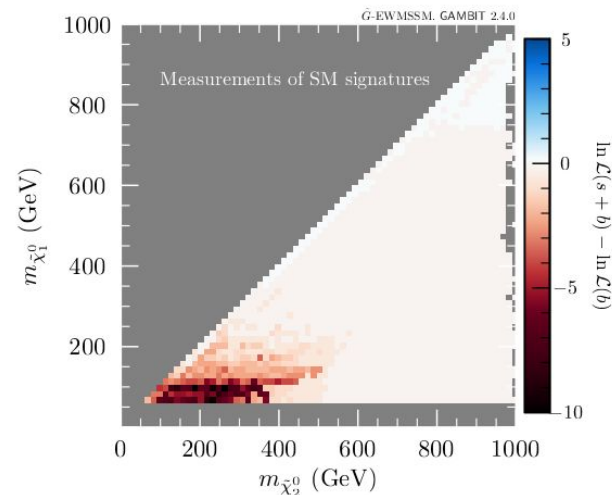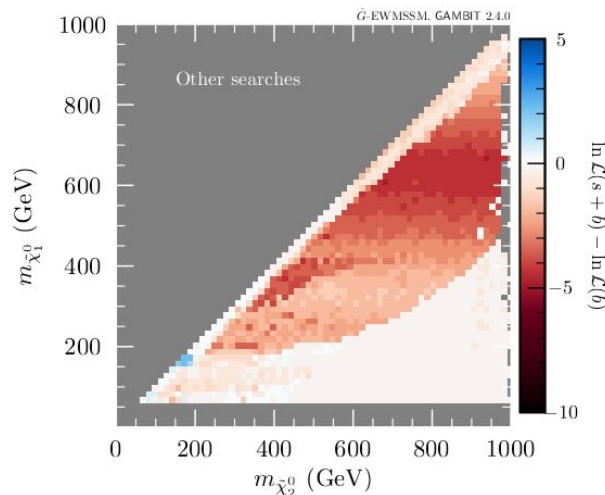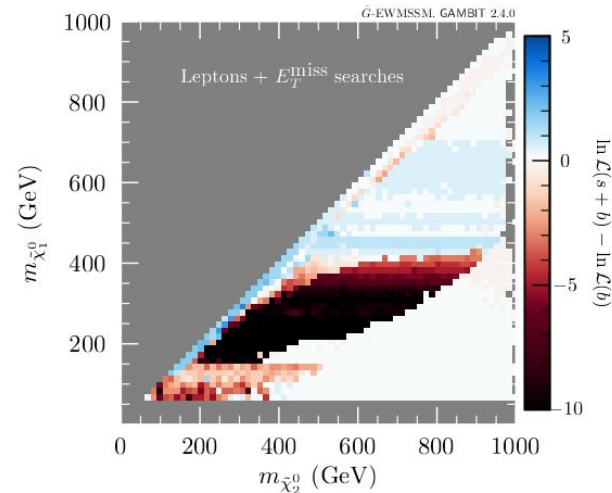
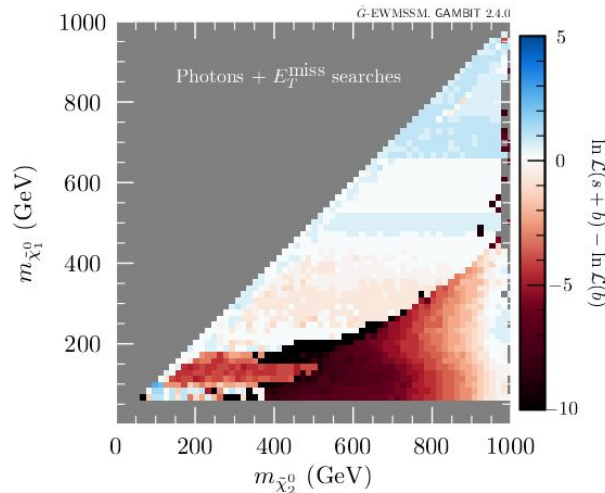# BONUS

What is Contur?

- Constraints on BSM using SM measurements.
- SM measurements - high degree of model independence.
- Uses the library of Rivet measurement analyses.

- Recent news:
  - By default, compares to SM theory
    - But will also run DATA==BKG, and expected.
  - See recent papers:
    - arXiv:2204.10577 (leptophobic Top-Colour)
    - arXiv:2212.01268 (dark photons – n.b. No Contur devs involved!)
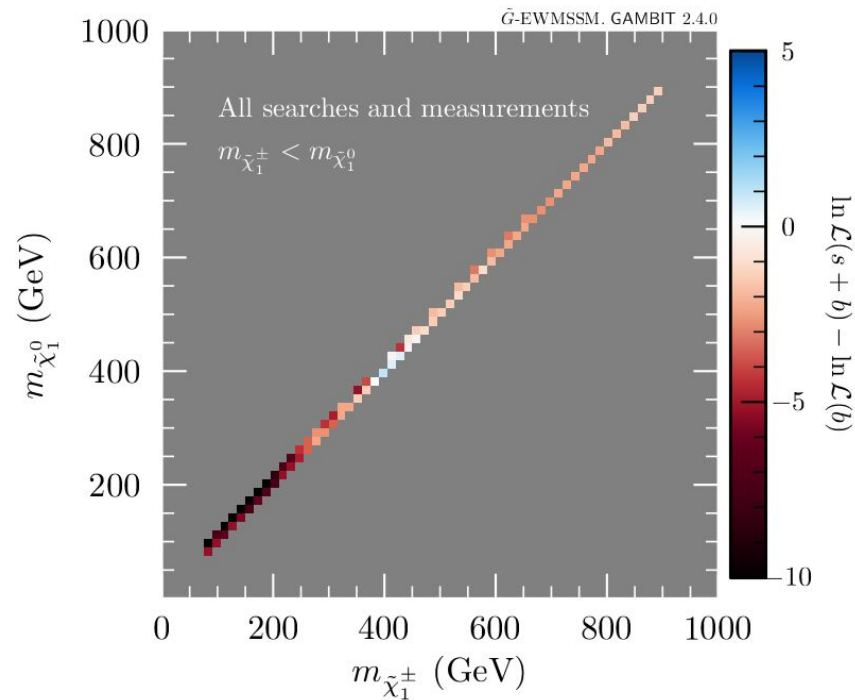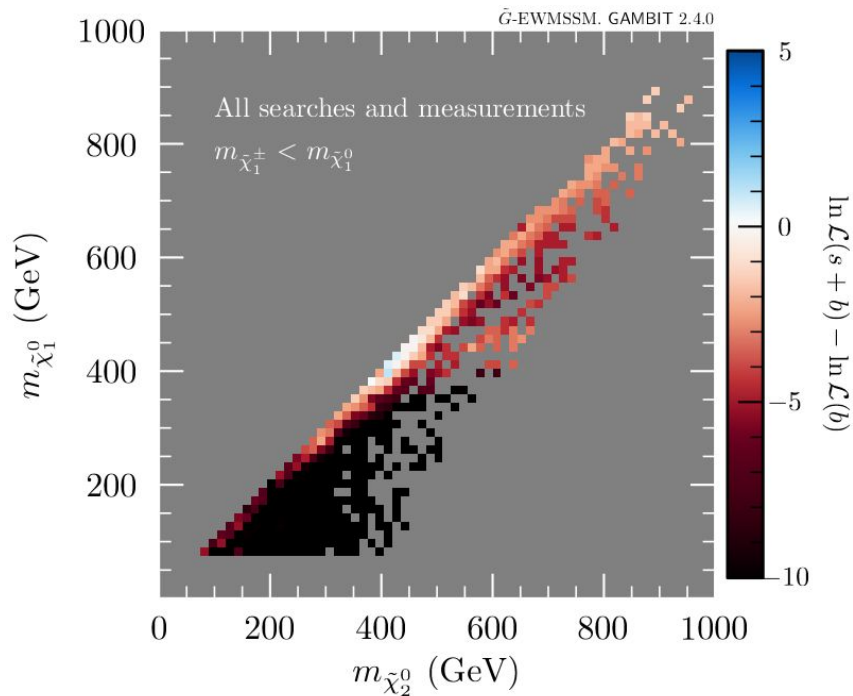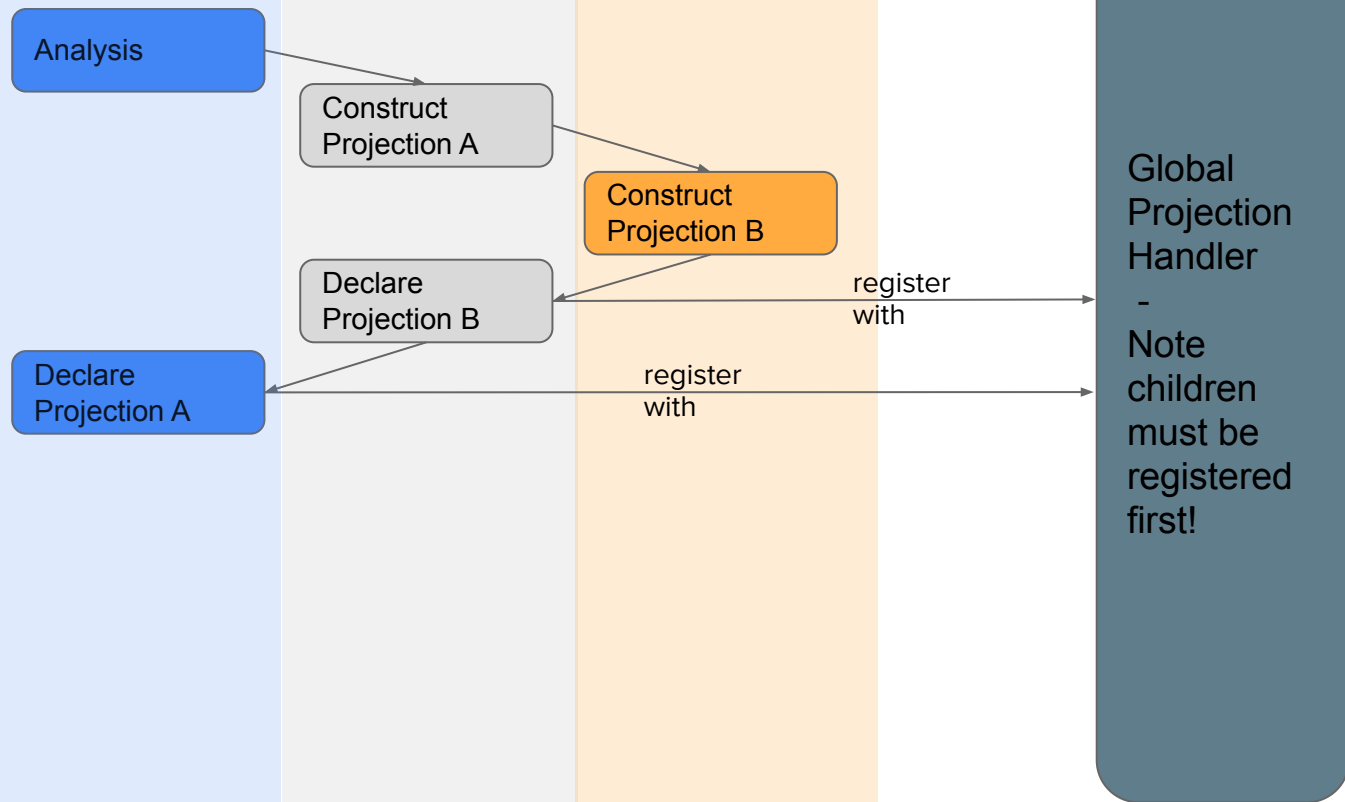   - arXiv:2202.05882 (Contur Oracle)

Total LLR

LLR by search type

Chargino NLSP

Rivet Thread Safety - How it worked before

Analysis → Construct Projection A → Construct Projection B

Declare Projection B

Declare Projection A

Construct Projection B → register with → Global Projection Handler

Declare Projection A → register with → Global Projection Handler

Global Projection Handler - Note children must be registered first!

Rivet Thread Safety - How it will work