Combined searches for light supersymmetry at the LHC with GAMBIT

Pat Scott
on behalf of the GAMBIT Collaboration

Based on GAMBIT Collab, EPJC (2019), arXiv:1809.02097
gambit.hepforge.org
**GAMBIT: The Global And Modular BSM Inference Tool**

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

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

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**40+ participants in 11 experiments and 14 major theory codes**

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Pat Scott – Dec 2 2019 – TeVPA, Sydney
We are interested in the **electroweakinos**:
neutralinos ($\chi^0_1, \chi^0_2, \chi^0_3, \chi^0_4$) + charginos ($\chi^\pm_1, \chi^\pm_2$)

- All other superpartners & new Higgses decoupled
- SM-like Higgs mass set to 125.09 GeV

$\rightarrow$ 4 parameters: $M_1$, $M_2$, $\mu$, $\tan\beta$

\[
\chi^0 = (\tilde{B}, \tilde{W}^0, \tilde{H}_u^0, \tilde{H}_d^0) \quad \chi^\pm = (\tilde{W}^\pm, \tilde{H}^\pm)
\]

\[
M_N = \begin{bmatrix}
M_1 & 0 & -\frac{1}{2}g'v c_\beta & \frac{1}{2}g'v s_\beta \\
0 & M_2 & \frac{1}{2}g'v c_\beta & 0 \\
-\frac{1}{2}g'v c_\beta & \frac{1}{2}g'v c_\beta & 0 & -\mu \\
\frac{1}{2}g'v s_\beta & -\frac{1}{2}g'v s_\beta & -\mu & 0
\end{bmatrix}
\]

\[
M_C = \begin{bmatrix} 0 & X^T \end{bmatrix}
\]

\[
X = \begin{bmatrix} M_2 & \frac{g v s_\beta}{\sqrt{2}} \\
\frac{g v c_\beta}{\sqrt{2}} & \mu \end{bmatrix}
\]
Electroweak analyses 36 fb$^{-1}$ included in likelihood:

- ATLAS multi-lepton: $\tilde{\chi}_2^0 \tilde{\chi}_1^\pm$, $\tilde{\chi}_2^\pm \tilde{\chi}_1^\pm$, $\ell \bar{\ell}$; final states with 2–3 leptons + 0–5 jets
- ATLAS 2/3-lepton recursive jigsaw searches for $\tilde{\chi}_2^0 \tilde{\chi}_1^\pm$
- ATLAS 4-lepton SUSY search
- ATLAS 4-$b$ Higgsino search
- CMS 1lep(H)bb: single-lepton final states including $H \rightarrow bb$
- CMS 2SFOSlep-soft: $\tilde{\chi}_2^0 \tilde{\chi}_1^\pm$, virtual $W^*$ and $Z^* \rightarrow ll$; final state with two same-flav. opp. sign leptons
- CMS 2SFOSlep: as above but with hard leptons ($W$, $Z$ not virtual)
- CMS multi-lepton: similar to ATLAS, but exclusively $\tilde{\chi}_2^0 \tilde{\chi}_1^\pm$ production
- Assorted LEP likelihoods & $h/Z$ invisible widths

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{simplified_model_diagram.png}
\caption{Simplified model diagrams showing SUSY processes at the LHC.}
\end{figure}
What chargino and neutralino masses are excluded?

→ Consider only worse fits than the SM
Excluded electroweakinos

What chargino and neutralino masses are **excluded**?
→ Consider only **worse** fits than the SM

Naive ‘SUSY is dead’ expectation:

(thanks to Anders Kvellestad)
What chargino and neutralino masses are excluded?
→ Consider only worse fits than the SM

Naive ‘SUSY is dead’ expectation:

Actual reality when including all 12 searches:

(thanks to Anders Kvellestad)

Profile likelihood ratio $\Lambda = \frac{L_{cap}}{L_{cap,max}}$
What chargino and neutralino masses are **preferred**?

→ Consider also **better** fits than the SM:

3.3σ (local) combined signal significance
Likelihood contributions of individual analyses
Just taking the points within our $3\sigma$ regions from the LHC fit:

$\Omega_{\chi} h^2 = 0.119$

$\log_{10}(\Omega_{\chi} h^2)$

Profile likelihood ratio $\Lambda = L/L_{\text{max}}$

$0 \leq 20 \leq 40 \leq 60 \leq 80 \leq 100$

$m_{\tilde{\chi}^0}$ (GeV)

$\log_{10}(f \cdot \sigma_{SI} / \text{cm}^2)$

Profile likelihood ratio $\Lambda = L/L_{\text{max}}$

$0 \leq 20 \leq 40 \leq 60 \leq 80 \leq 100$

$m_{\tilde{\chi}^0}$ (GeV)

$Z$ and $h$ funnel mechanisms can give sensible relic densities
→ models consistent with LHC excesses can also naturally explain dark matter

Combined searches for light SUSY at the LHC with GAMBIT
Add $2 \times \text{CMS} + 3 \times \text{ATLAS}$

8 TeV searches

→ best-fit moves higher in mass

$3.3\sigma \rightarrow 2.9\sigma$ significance
Impacts of other data

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- Some new 140 fb$^{-1}$ searches relevant, including new RJ-like ATLAS analysis – impact is small
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- Some new $140\text{fb}^{-1}$ searches relevant, including new RJ-like ATLAS analysis – impact is small
- Impact of including full covariance matrix for CMS multi-lep search will be greater
SUSY is not dead
In fact the LHC basically doesn’t completely exclude any neutralino or chargino mass
3.3$\sigma$ hint of light SUSY in LHC electroweak searches?

GAMBIT global analyses are complete for many other models
All GAMBIT results, samples, run files, best fits, benchmarks, etc are all available to download from Zenodo:
www.zenodo.org/communities/gambit-official/
GAMBIT code is public: gambit.hepforge.org