SUSY Global Fits

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On behalf of the GAMBIT collaboration
Why Global Fits?

All realistic SUSY models (even the CMSSM) have:

- A large multidimensional parameter space
- Many collider & astrophysical observables

To understand the impact of SUSY searches we need to:

1) Explore the full parameter space (intelligent scanning algorithms)
2) Combine experimental results (needs rigorous statistics)
3) Project onto planes of interest (marginalise / profile)

Global Fits

Previously there has been a lot of activity on MSSM Global Fits:

- MasterCode
- BayesFit
- Allanach, AbdusSalam.
- Fittino
- SFITTER
- EasyScan HEP
GAMBIT

GAMBIT: The Global And Modular BSM Inference Tool
https://gambit.hepforge.org/

- Public Tool for BSM global fits (MSSM / non-minimal SUSY / non-SUSY)
- A BSM global fitting collaboration

29 members, 10 countries,
10 experiments, 10 major theory codes

Current Members:
P. Athron, C. Balazs, F. Bernlochner, T. Bringmann,
A. Buckley, M. Chrzaszcz, J. Conrad, J. Cornell,
J. Edsjö, B. Farmer, A. Fowlie T. Gonzalo, J. Harz,
S. Hoof, F. Kahlhoefer, P. Jackson, A. Kvellestad,
N. Mahmoudi, G. Martinez, J. McKay, A. Raklev,
C. Rogan, R. Ruiz, P. Scott, N. Serra, R. Trotta, C.
Weniger, M. White, S. Wild

Theory: DarkSUSY, FlexibleSUSY, GM2Calc, SoftSUSY, SupeBayes,
SuperIso, DDCalc, gamLike, Isajet and nuLike

Experiment: ATLAS, Belle-II, CTA, DARWIN, Fermi-LAT, HESS,
IceCube, LHCb, SHiP and XENON experiments
Global Fits of MSSM models

- GAMBIT code is split up into modules or “Bits”
- User chooses backends - many options with GAMBIT 1.0.0 release

For the MSSM global fits here we used:

**ScanBit**
Scanning via Diver + MultiNest-3.10

**DecayBit**
Decay BRs and widths via SUSYHIT-1.5 (HDECAY & SDECA3Y)

**ColliderBit**
Native recast tool for SUSY searches
uses Pythia-8.212 + BuckFast
Higgs searches: HiggsBounds-4.3.1, HiggsSignals-1.4.0

**SpecBit**
Spectrum via FlexibleSUSY-1.5.1

**PrecisionBit**
$(g - 2)_\mu$ via GM2Calc-1.3.1
Native likelihoods for MW,

**FlavBit**
Flavour physics observables
(semi-leptonic B decays, b to s transitions, leptonic decays of B and $D_s$ mesons ) - SuperIso-3.6

**DarkBit**
Relic Density – microOMEGAs-3.6.9.2
Direct Detection Cross sections – DarkSUSY 5.1.3
DD Likelihoods – DDCalc-1.0.0
Indirect detection – GamLike, nuLike 1.0.4, DarkSUSY 1.5.3
CMSSM Global Fits

Scan: $m_0, m_{1/2}, A_0, \tan \beta, \text{sign}(\mu)$ + 5 nuisances inc. $\alpha_s, m_t$

- No stau co-annihilation region within 2 sigma contours after including run II
- Large stop co-annihilation region (red) which survives LHC limits and LUX 2006
- Heavy chargino (yellow) and A-funnel (brown) regions with sfermions and gauginos out of reach of the LHC
CMSSM Global Fits

- EasyScan HEP also saw the stau co-annihilation region shrink with LHC run II, but not disappear (green).
- Also see stop co-annihilation region (purple, c.f. red on right panel).
- Heavy hybrid stau-co-annihilation / A-funnel (grey). GAMBIT finds better Higgs signals fit at high mass suppressing this.
- Lighter A-funnel region (blue, c.f. brown on right panel).

EasyScan HEP 2017 PLB769, 470-476
Stop co-annihilation

- Could be probed by long lived sparticle or compressed spectra searches
- Stop pair production within range for a multi-TeV linear collider
- Red line indicates current limits from CMS compressed spectra
- Some opportunity to probe further at colliders
- Vacuum stability issues exist in this region, requires careful study also involving precise determination of Higgs mass
Charginos

- Don’t penalise under abundant relic density \rightarrow Light Higgsinos
- Mass difference always small \rightarrow Challenging to detect
- For stop co-annihilation lightest charged wino almost in range
NUHM Global Fits

- Lighter 1\textsuperscript{st}/2\textsuperscript{nd} generations squarks
- Stau co-annihilation region re-emerges, large region in both models, light stau possible but still too heavy for LHC
- Some of stop co-annihilation region may already be excluded by searches for compressed spectra
- Heavier stop co-annihilation much more challenging
NUHM Global Fits

- Mastercode results using LHC run I and LUX 2013
- Mastercode found stau co-annihilation (pink and purple) expand in NUHM2. GAMBIT already saw large expansion in NUHM1.
- GAMBIT has no gap at low m0. Consequence of allowing under-abundant relic density of DM.
- Matercode see no stop co-annihilation, due to smaller range of A0 considered.

Mastercode: EPJC 75, (2015) 500
Direct Detection of Dark Matter

- Xenon1T, nT and LZ will test the entire CMSSM chargino co-annihilation region
- Stop co-annihilation and stau co-annihilation can be well out of reach
- Prospects for discovering sfermion co-annihilation in the NUHM models better, but still have many scenarios out of reach
- Collider searches can probe some of the sfermion co-annihilation region so there is complementarity. Very challenging to probe the entire region though.
MSSM7 Global Fits

- Left plot shows that we have Higgsino-like DM ($\mu \ll M_1$), bino-like DM ($\mu \gg M_1$) and "well-tempered" DM ($\mu \approx M_1$)
- Light neutralinos and charginos that are Higgsino in nature have compressed spectra so challenging to detect
- Stop co-annihilation present, with associated compressed spectra
- No stau co-annihilation, as model takes a common sfermion mass at the electroweak scale
Conclusions

- CMSSM has only Heavy A-funnel / chargino co-annihilations regions well out of LHC reach but within reach of future direct detection experiments.
- NUHM1/2 have significantly lighter scenarios, greater scope for LHC impact.
- Previous global fits found stau co-annihilation scenarios and recent EasyScan HEP paper with LHC run II and LUX 2016 find a small region remaining.
- GAMBIT finds that the stau co-annihilation region is excluded at the 2 sigma level, due to poorer fit to Higgs data than heavier regions and run II data.
- Stau co-annihilation reappears in NUHM1/2 from greater freedom in Higgs sector.
- GAMBIT and EasyScan now find Stop co-annihilation region at large and negative A0.
- Compressed spectra searches at LHC able to probe some of this region.
BACK UP SLIDES
Scalar Singlet Model and beyond

- GAMBIT is not only for minimal SUSY nor just SUSY
- Most thorough and up-to-date fit of the scalar singlet model completed and already submitted to EPJC (see plot below)
- Work in progress on two Higgs doublet models, axions, Dirac Fermion Higgs portal DM and many more to come...
CMSSM Global Fits

Scan: $m_0, m_{1/2}, A_0, \tan \beta, \text{sign}(\mu) + 5$ nuisances inc. $\alpha_s, m_t$

- A-funnel region at very large than beta where b-physics measurements can have an impact
- Stop co-annihilation region restricted to large negative universal trilinear and low tan beta
CMSSM Global Fits

- Fittino with LHC run 1 and LUX 2013
- Large stau co-annihilation strip at lighter masses overlapping with A-funnel
- Heavier chargino co-annihilation region (c.f. yellow on right panel)
CMSSM Global Fits

- Mastercode with LHC run 1 and LUX 2013
- stau co-annihilation strip (pink and purple) at lighter masses.
- Extensive A-funnel region with (blue, c.f. brown region on right panel)
- Focus point at large m0 (light blue, c.f. yellow region on right panel)