SUSY Global Fits

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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:

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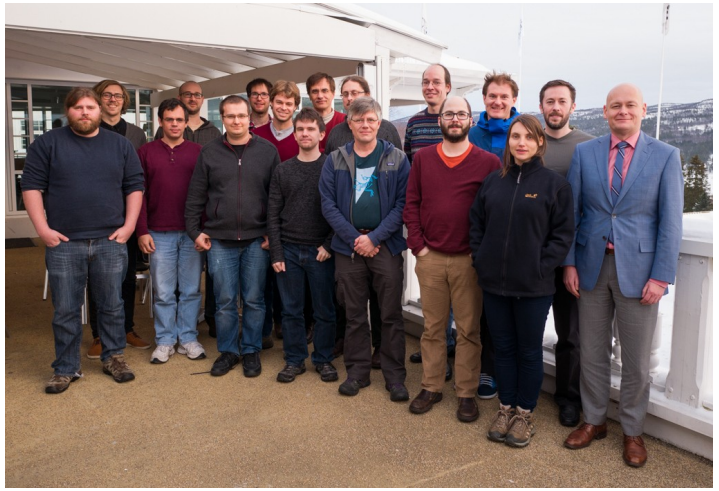


Theory: DarkSUSY, FlexibleSUSY, GM2Calc, SoftSUSY, SupeBayes, SuperIso, DDCalc, gamLike, Isajet and nuLike

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 & SDECAY)

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

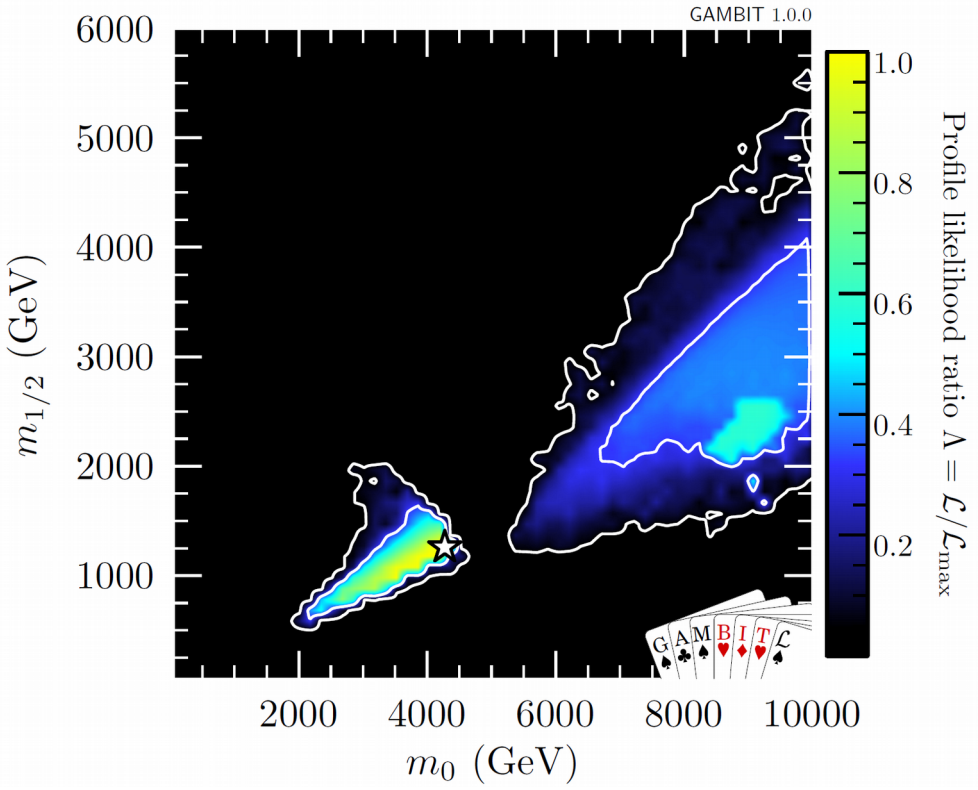
DarkBit

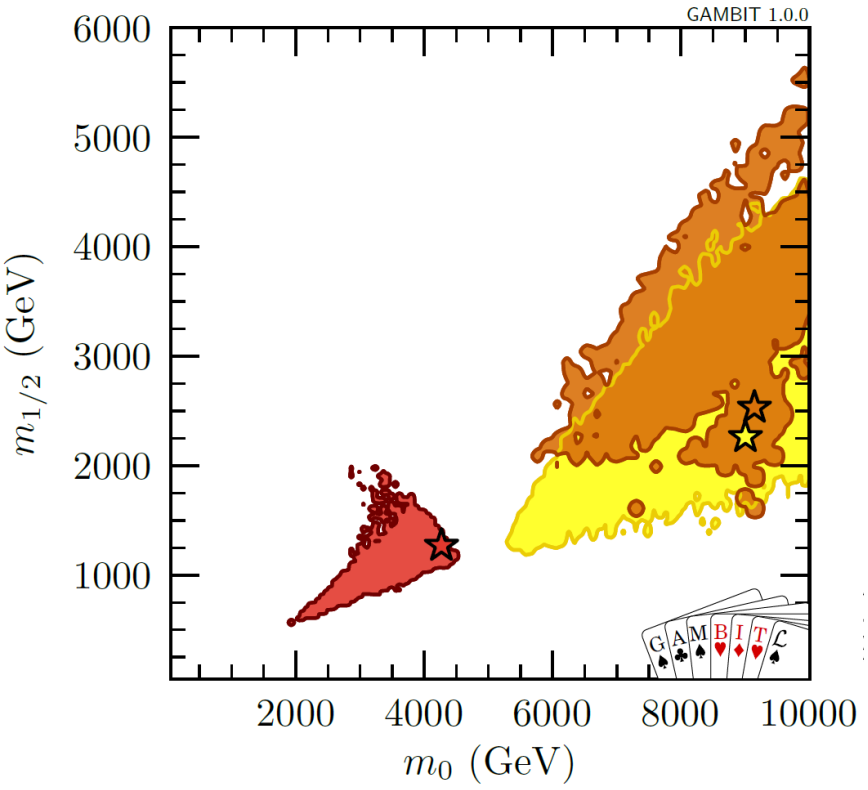
Relic Density – microOMEGAs-3.6.9.2
Direct Detection Cross sections – DarkSUSY 5.1.3
DD Likelihoods – DDCalc-1.0.0
Indirect detection – GamLike, nuLike 1.0.4, DarkSUSY 1.5.3

CMSSM Global Fits

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

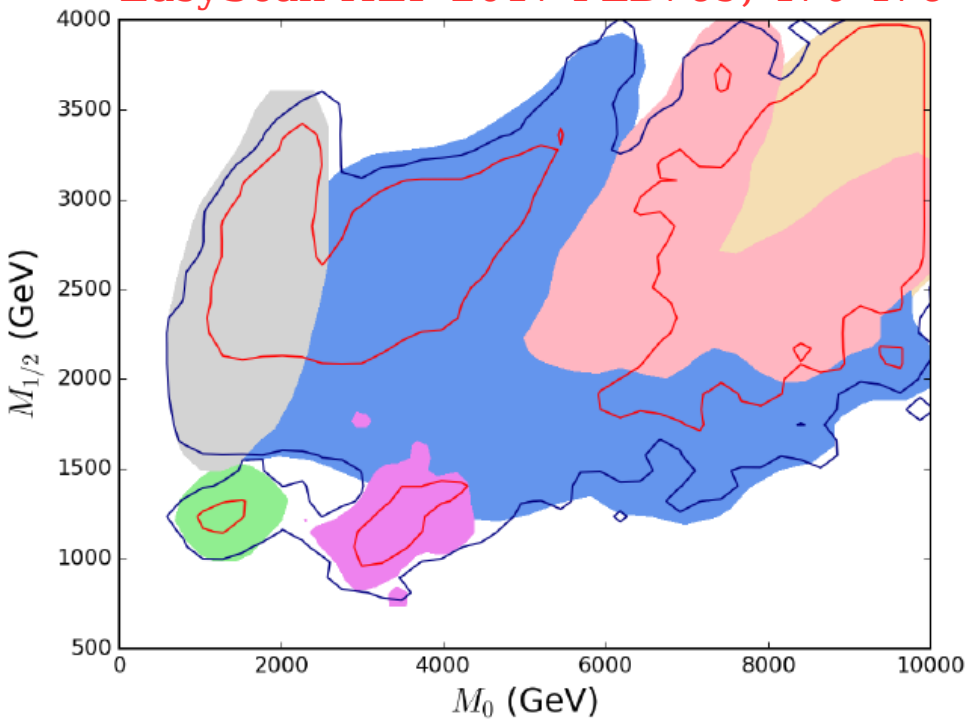


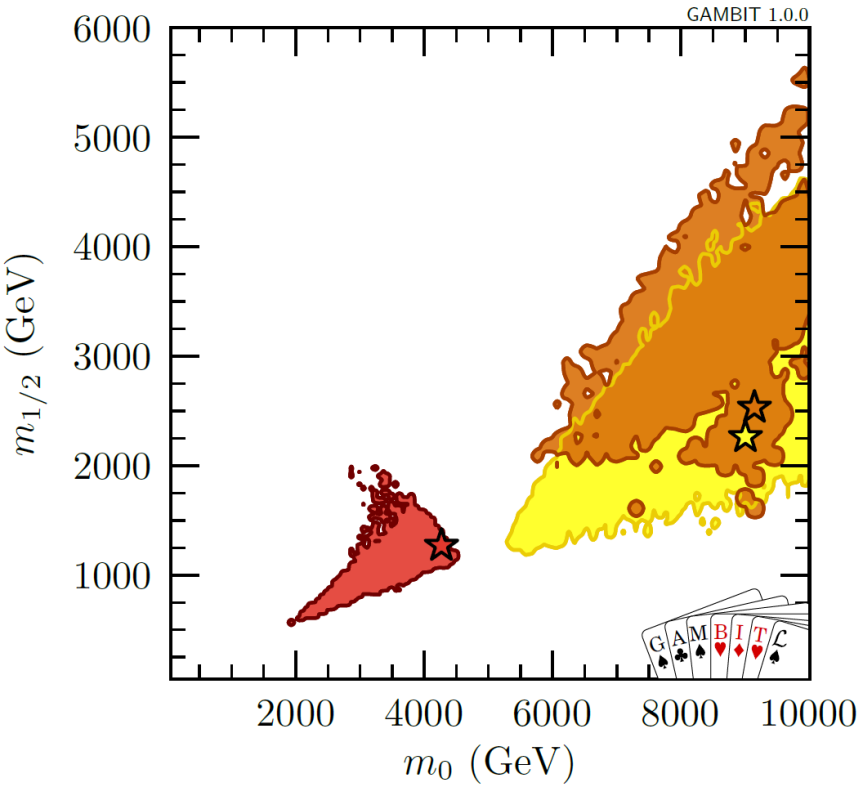


CMSSM Global Fits

- EasyScan HEP also saw the stau co-annihilation region shrink with LHC run II, but not does not disappear (green)
- Also see stop co-annihilatioon region (purple, c.f. red on right pnel)
- 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)

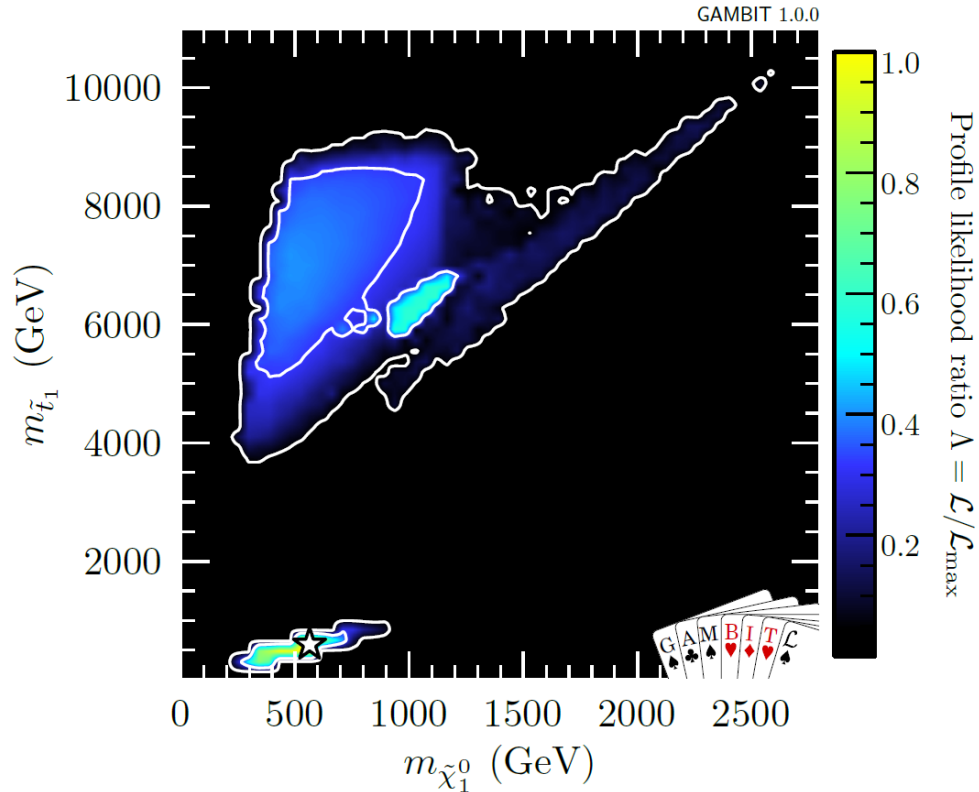
EasyScan HEP 2017 PLB769, 470-476

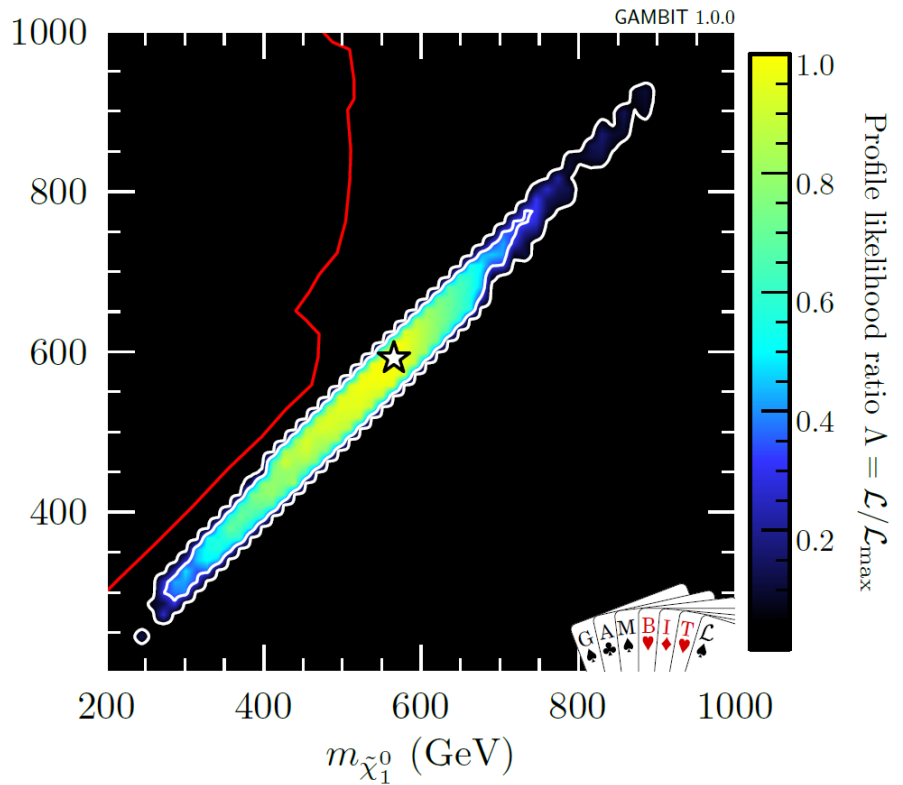




Stop co-annihilation

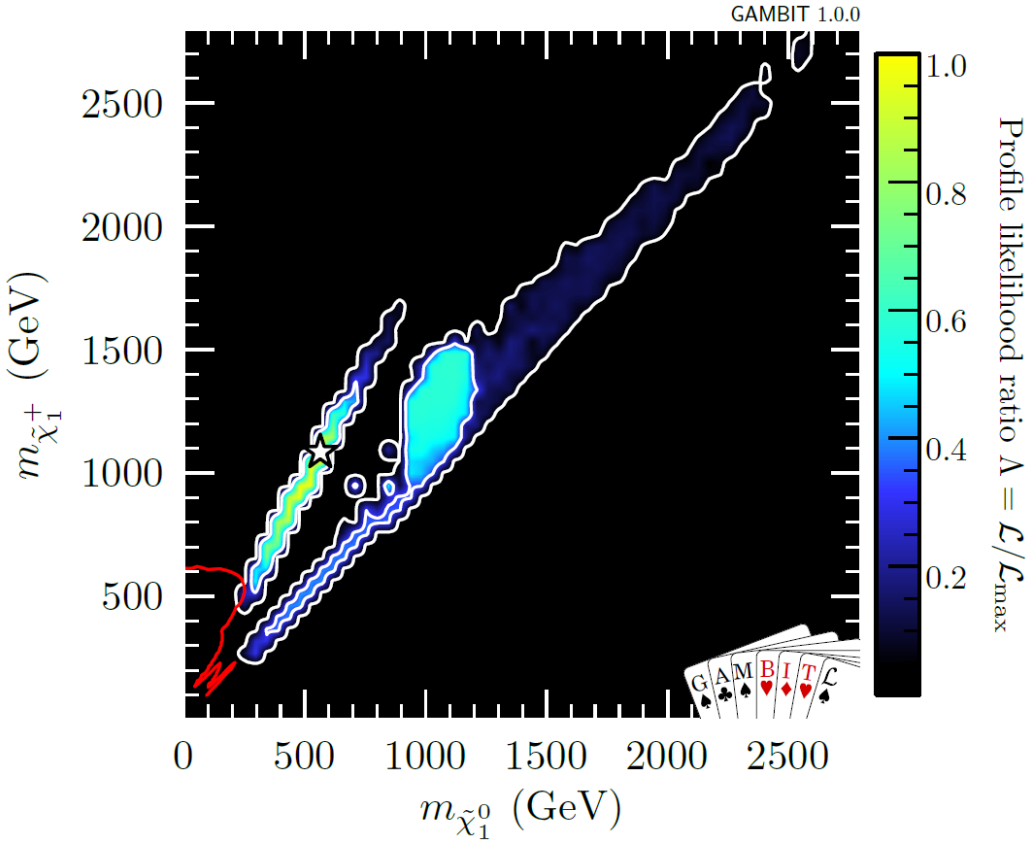
- Could be probed by long lived sparticle or compressed spectra searches
- Stop pair production within range for a multi-TeV linear collider
- Red line indicates current limits from CMS compressed spectra
- Some opportunity to probe further at colliders
- Vacuum stability issues exist in this region,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

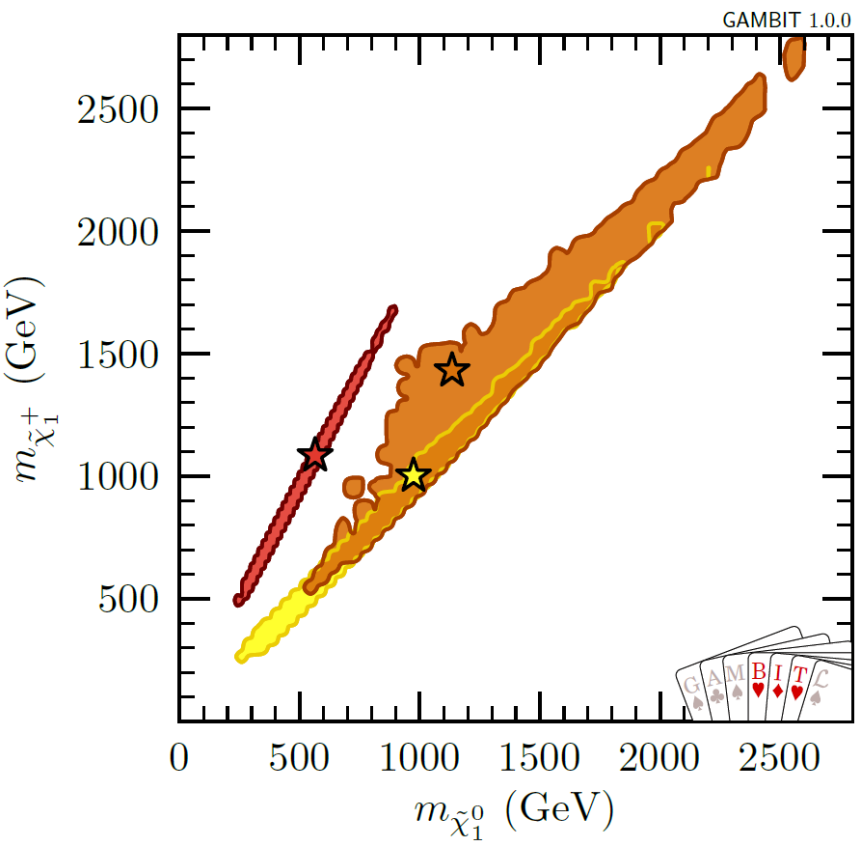




Charginos

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

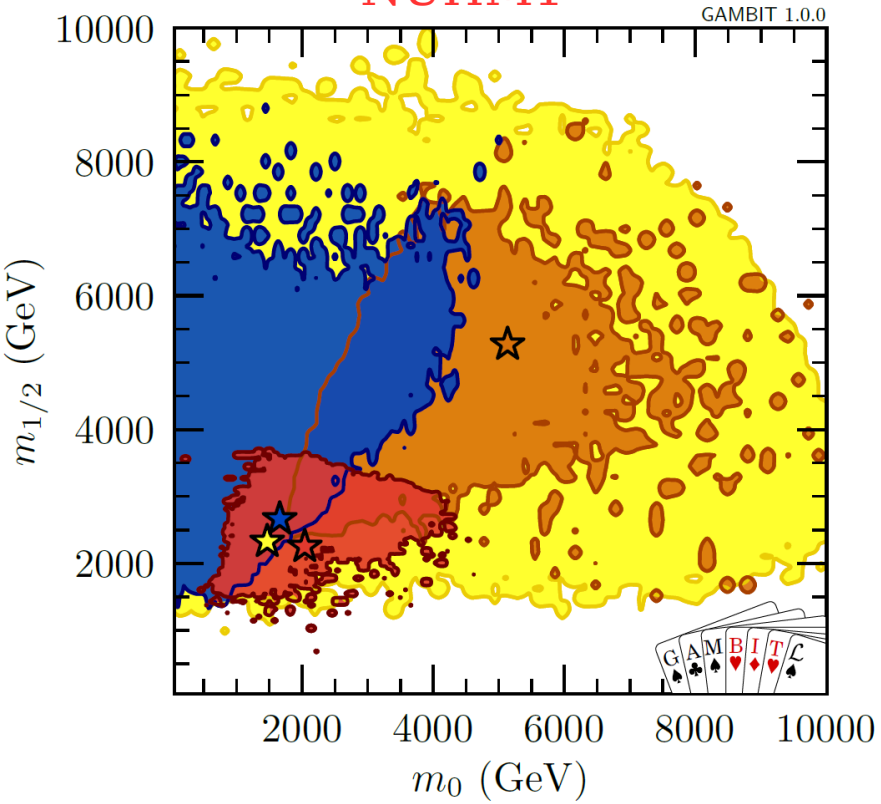




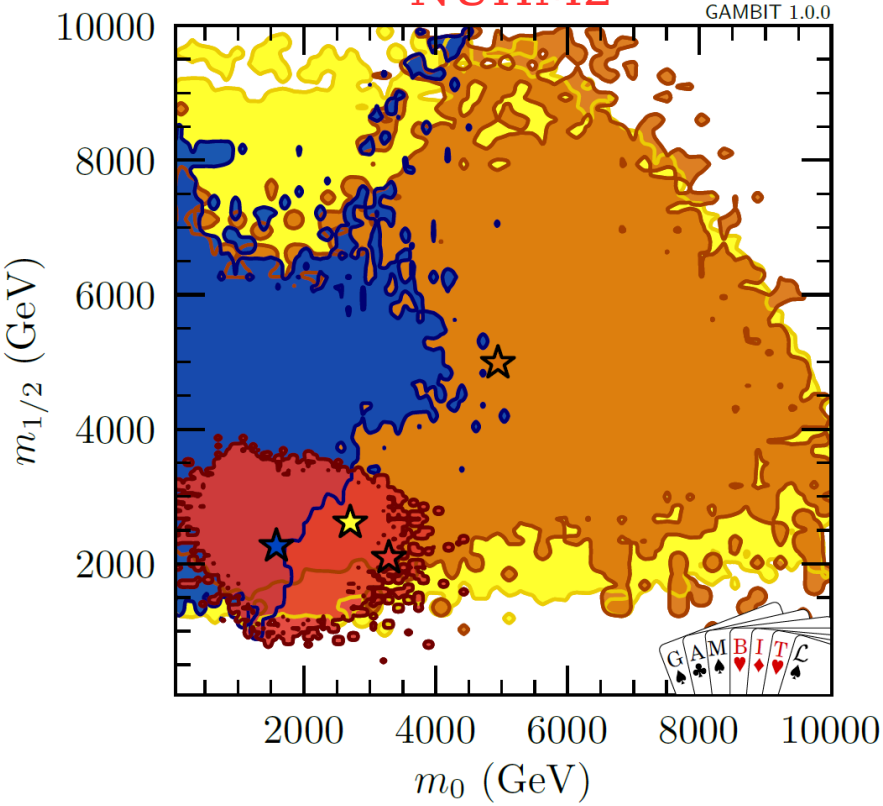
NUHM Global Fits

- Lighter 1st/2nd 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

NUHM1



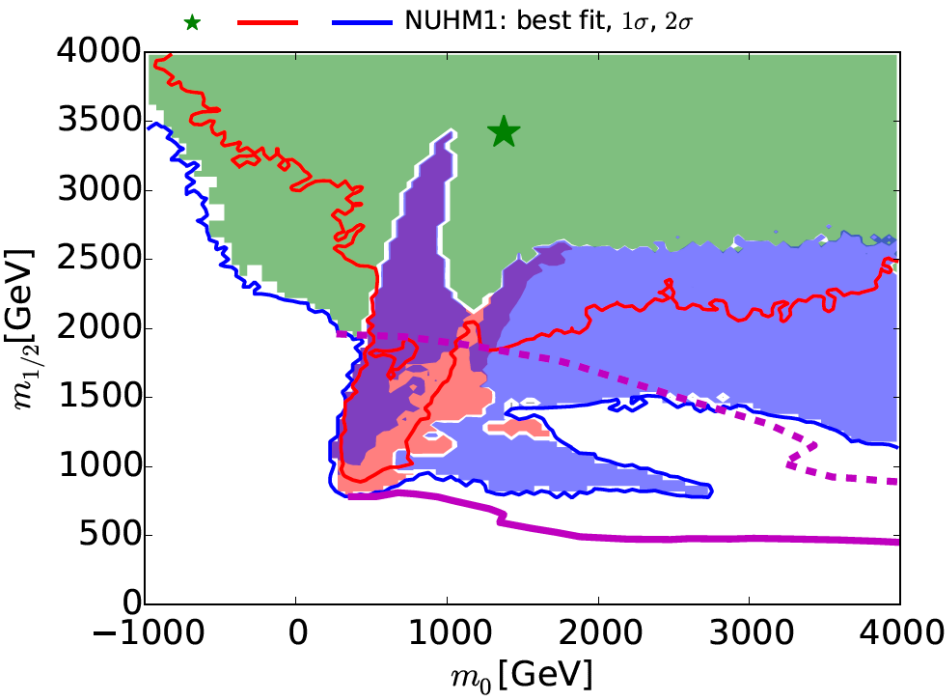
NUHM2

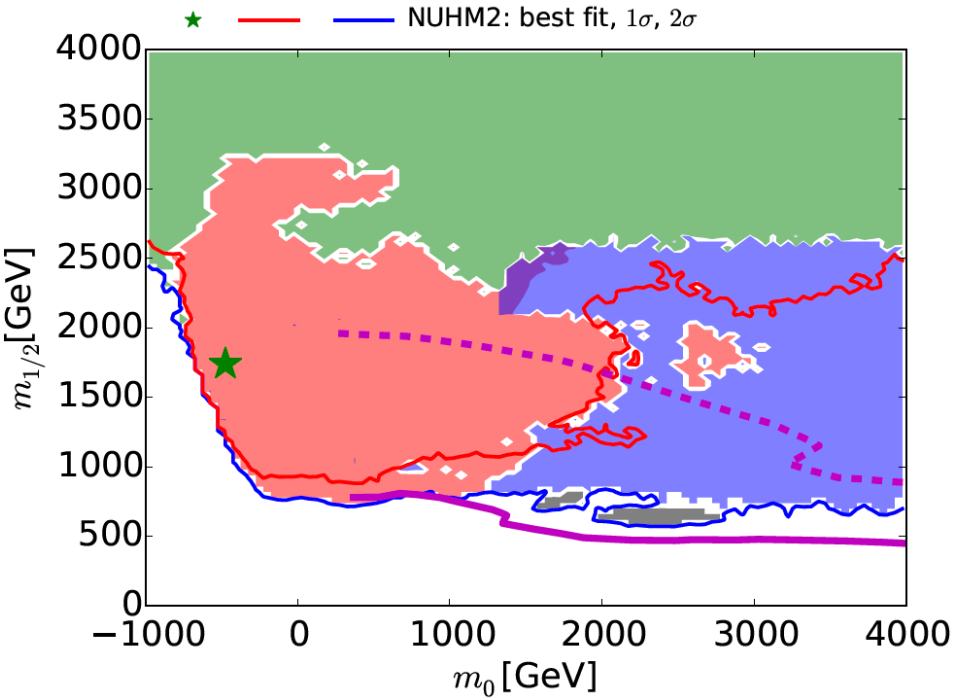


NUHM Global Fits

- 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.

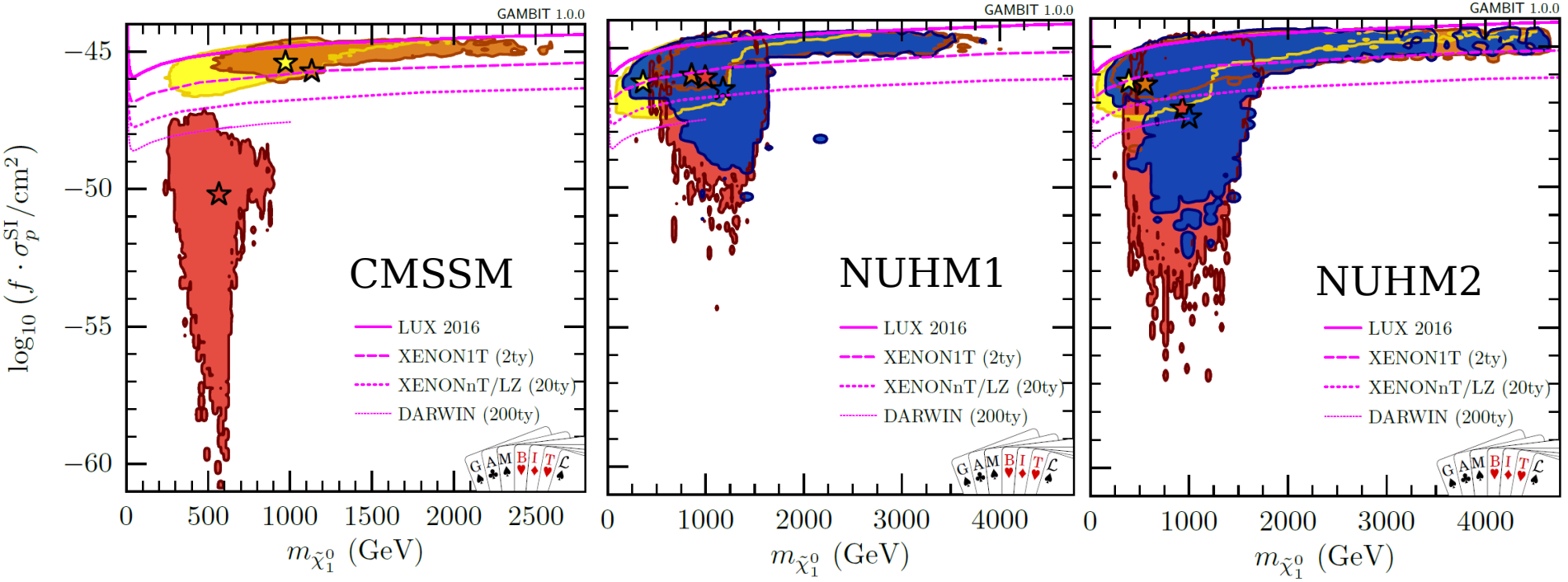
Mastercode: EPJC 75, (2015) 500





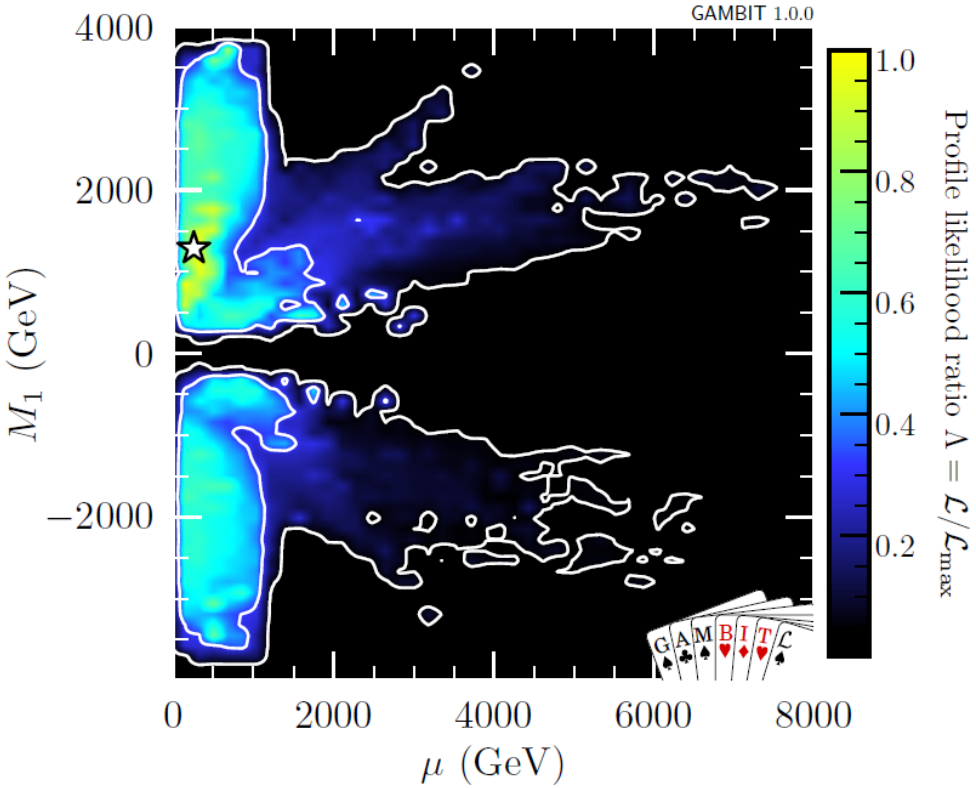
Direct Detection of Dark Matter

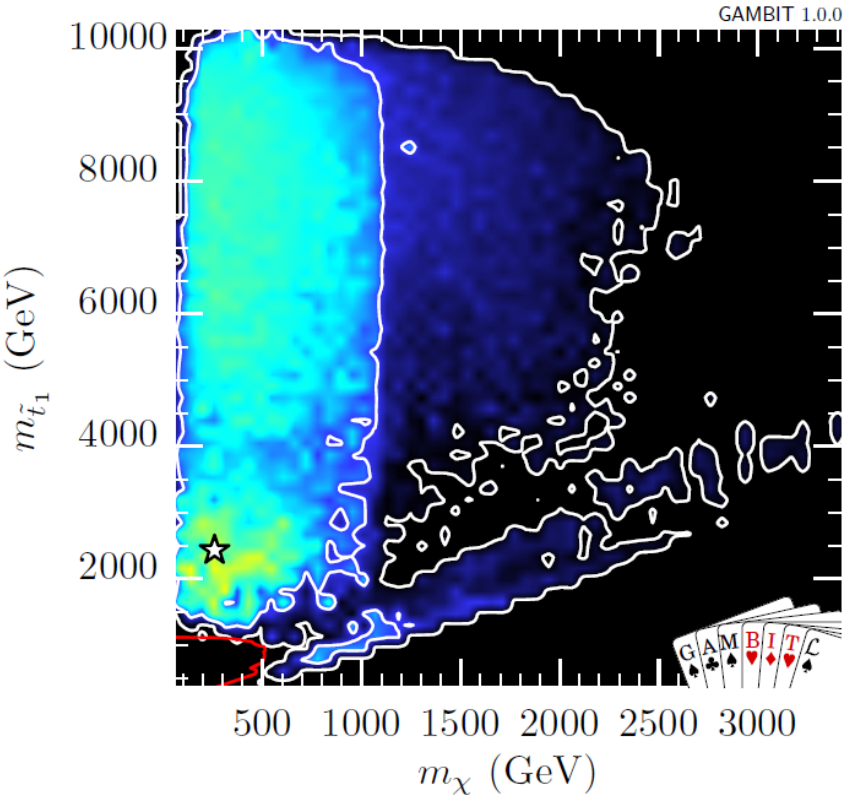
- Xenon1T, nT and LZ will test the entire CMSSM chargino co-annihilation region
- Stop co-annihilation and stau co-annihilation can be well out reach
- Prospects for discovering sfermion co-annihilation in the NUHM models better, but still have many scenarios out of reach
- Collider searches can probe 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





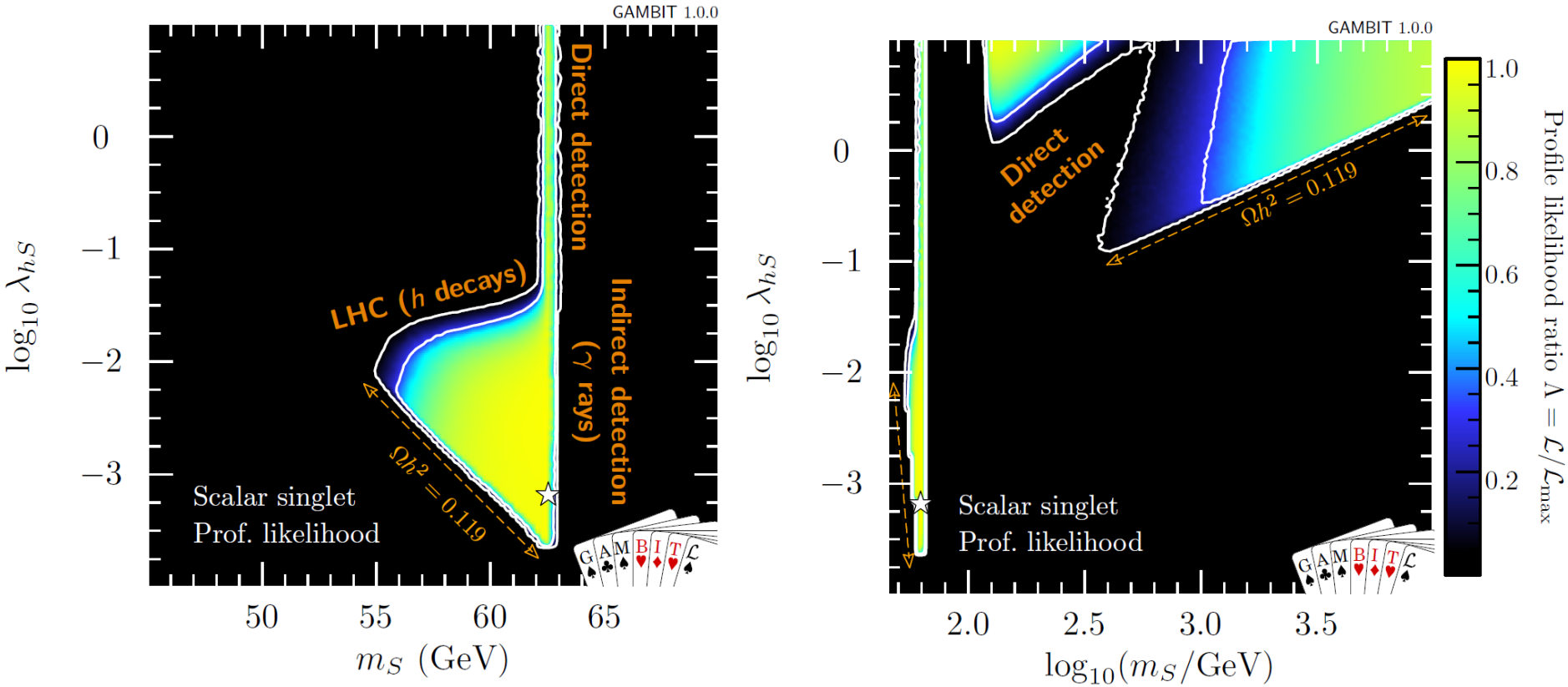
Conclusions

- 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

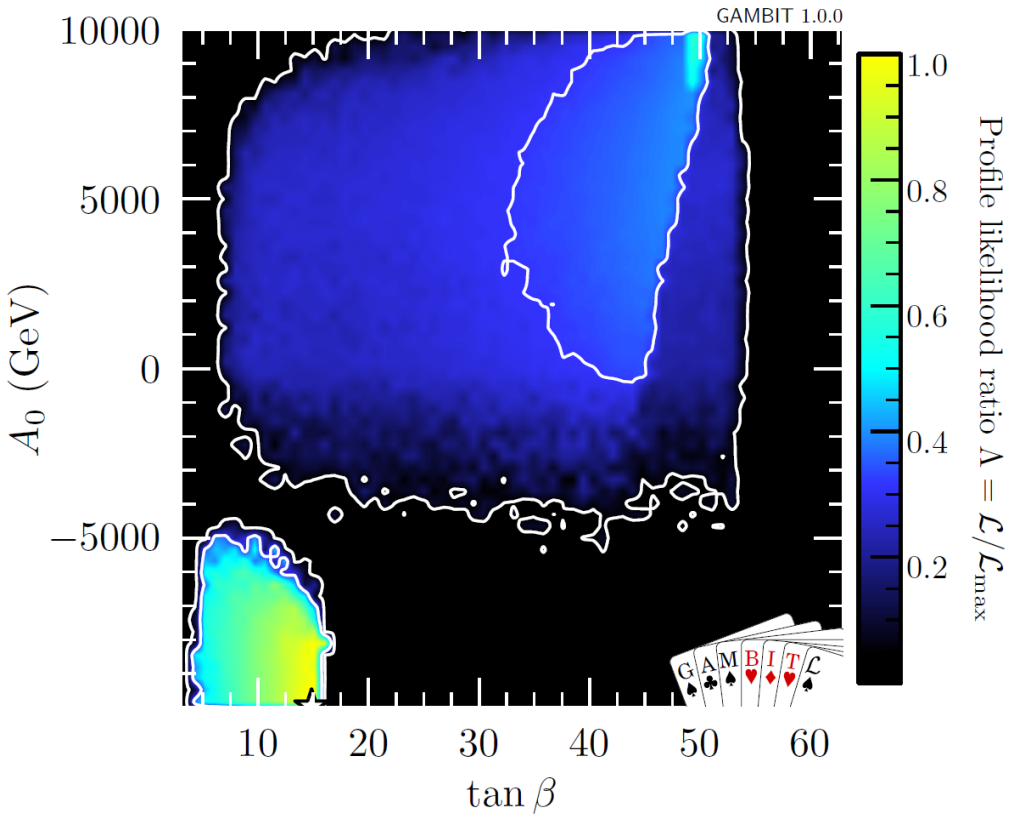
- GAMBIT is not only for minimal SUSY nor just SUSY
- Most thorough and uptodate fit of the scalar singlet model completed and already submitted to EPJC (see plot below)
- Work in progress on two Higgs doublet models, axions, Dirac Fermion Higgs portal DM and many more to come...

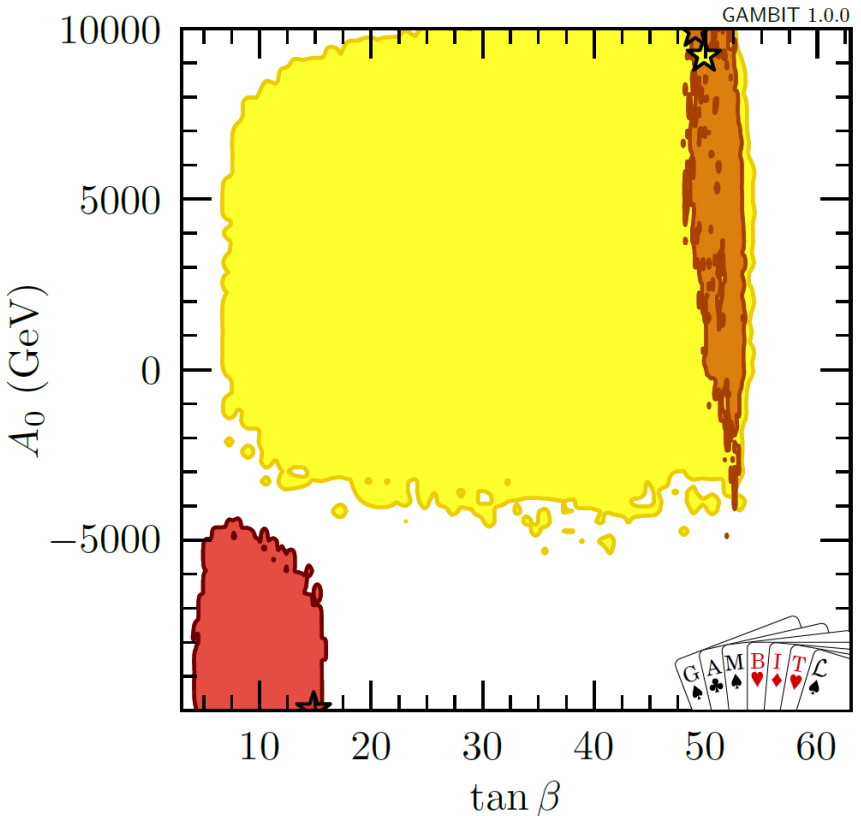


CMSSM Global Fits

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

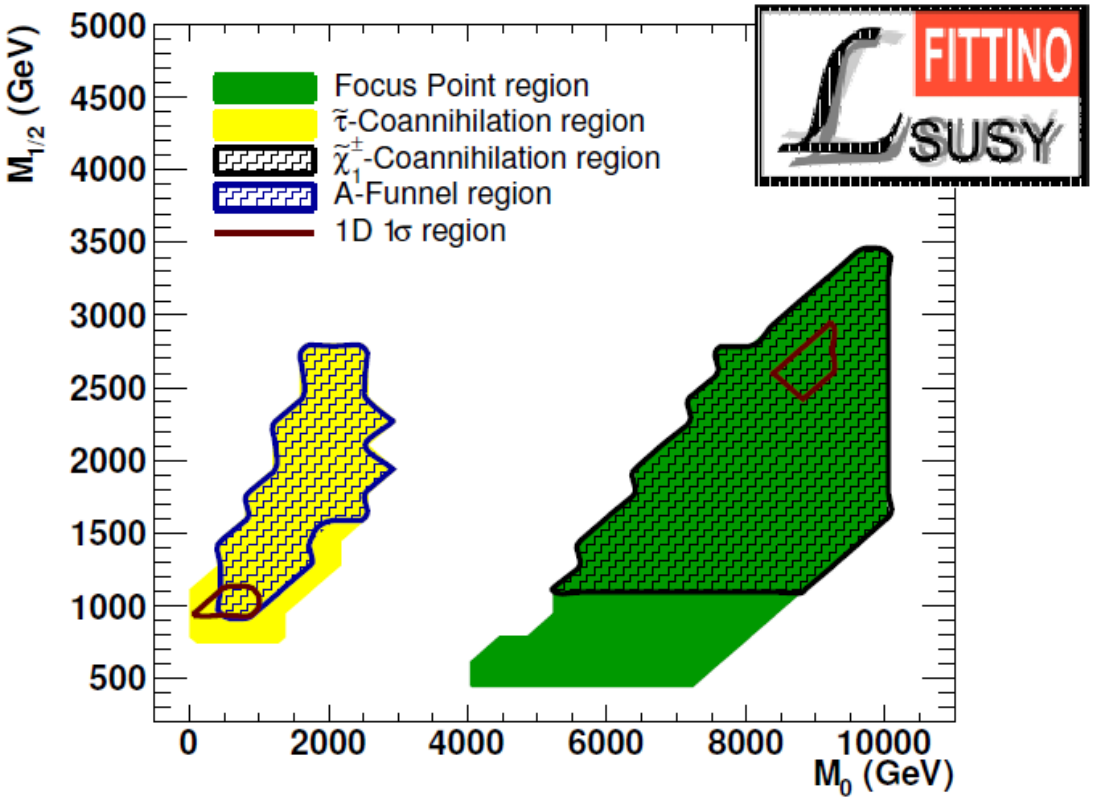
- A-funnel region at very large than beta where b-physics measurements can have an impact
- Stop co-annihilation region restricted to large negative universal trilinear and low tan beta

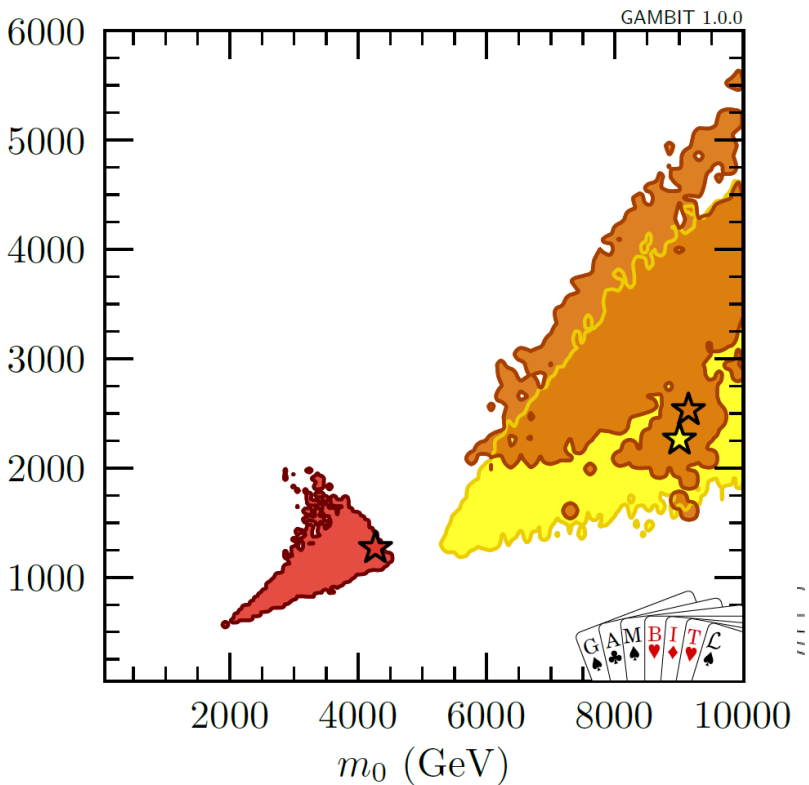




CMSSM Global Fits

- 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)