Global fits with

http://hepforge.gambit.org

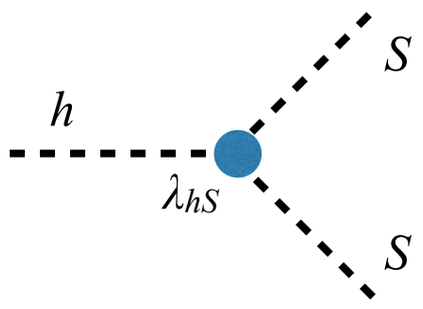
Jonathan Cornell, on
behalf of the collaboration

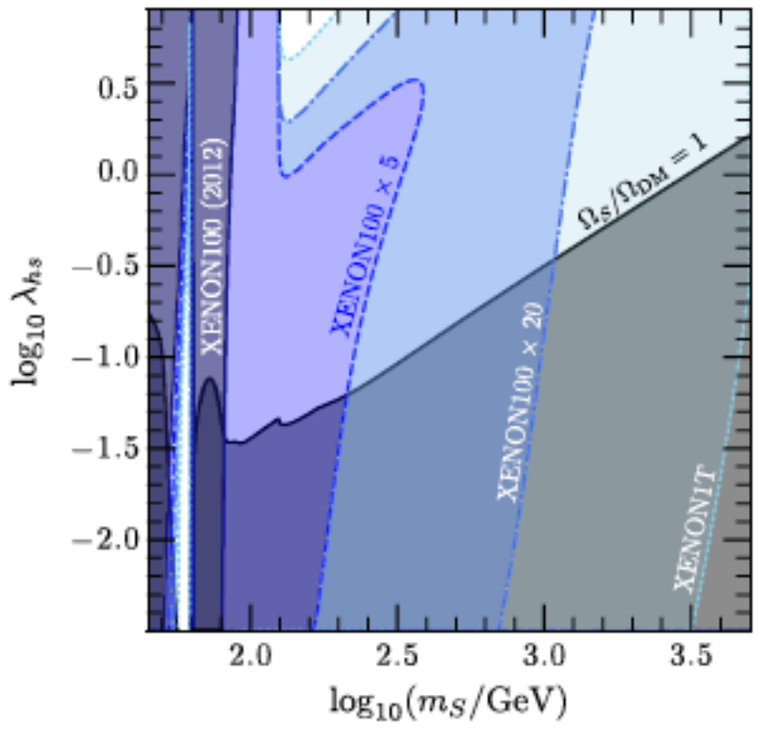
McGill

Topics in Astroparticle and Underground Physics 2017

- There is a menagerie of new physics models.
- One approach to determining their validity: overlay limits in parameter space:

Scalar Singlet DM Model





Cline, et. al. (2013)

- But what if you have more complicated parameter spaces, or have many constraints, or what if we discover something…

Another approach: Global Fits

- Calculate a combined *consistent* likelihood from all relevant experimental results:

$$\mathcal{L} = \mathcal{L}_{\rm Collider}\mathcal{L}_{\rm DM}\mathcal{L}_{\rm Flavor}\cdots$$

- Scan over the parameter space of theories to determine:

  1. The best fit regions of parameter space of a particular theory.

  2. Which theories give the best fit to the data.

- Existing codes to do this for BSM (*i.e.* MSSM-like) models: MasterCode, Fittino, SuperBayes, SFitter…

GAMBIT: The **G**lobal **A**nd **M**odular **B**eyond-the-standard-model **I**nference **T**ool

arXiv:1705.07908

The design philosophy is based on the concepts of ***modularity and flexibility.***

- Large (and growing) database of models, SUSY and others
- Extensive library of observables/likelihoods that can easily be enabled or disabled for a particular scan
- Tools for simple interfacing with external codes
- Many statistical options – Bayesian/frequentist, likelihood definitions, scanning algorithms
- Massively parallel, both OpenMP and MPI
- Easy to add new models, observables, likelihoods, and scanners!

The Collaboration

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30 members 11 countries 9 experiments

ATLAS, Belle-II, CMS, CTA, DARWIN, Fermi-LAT, IceCube, LHCb, Xenon

The Bits

- *DarkBit* — dark matter relic density, event rates and likelihoods for indirect and direct searches (**arXiv:1705.07920**)
- *ColliderBit* — LHC and LEP searches for new particle production, Higgs constraints (**arXiv:1705.07919**)
- *FlavBit* – flavor physics, particularly B decays. Likelihoods from LHCb measurements. (**arXiv:1705.07933**)
- *SpecBit* – generic BSM spectrum object, providing RGE running, masses, mixings, etc. via interchangeable interfaces to different RGE codes (**arXiv:1705.07936**)
- *DecayBit* – decay widths for all relevant SM & BSM particles (**arXiv:1705.07936**)
- *PrecisionBit* – SM likelihoods, muon g – 2, precision BSM tests (W mass, Δρ, etc.) (**arXiv:1705.07936**)

\+ *ScannerBit* – manages stats, sampling and optimization (**arXiv:1705.07959**)

Bits can also be used as standalone codes.

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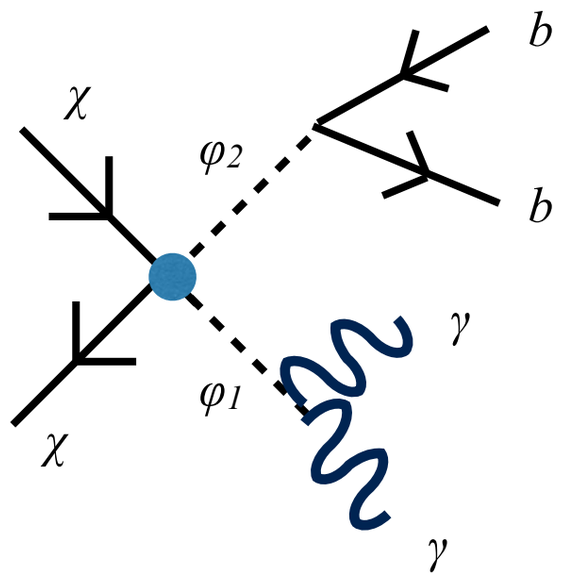
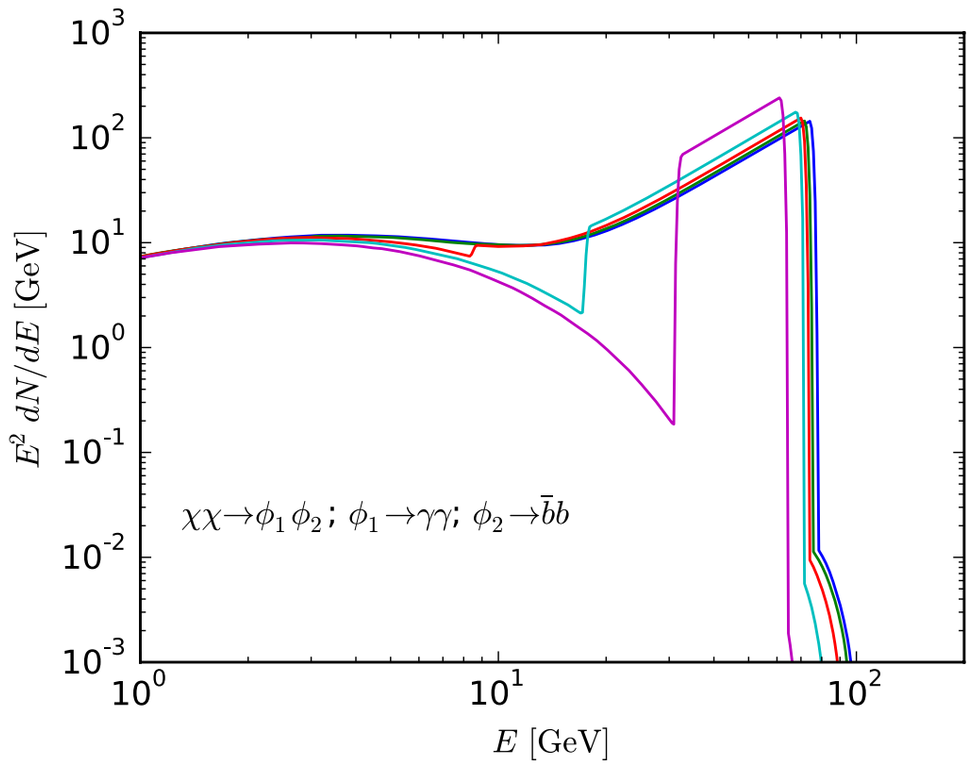
DarkBit: Indirect Detection

Gamma rays:

- Theoretical spectra calculated using branching fractions and tabulated gamma-ray yields
- Non-SM final state particles and Higgs are decayed on the fly with cascade Monte Carlo
- *gamLike* (gamlike.hepforge.org): New standalone code with likelihoods for DM searches from Fermi-LAT (dwarf spheroidals, galactic centre) and H.E.S.S. (galactic halo)



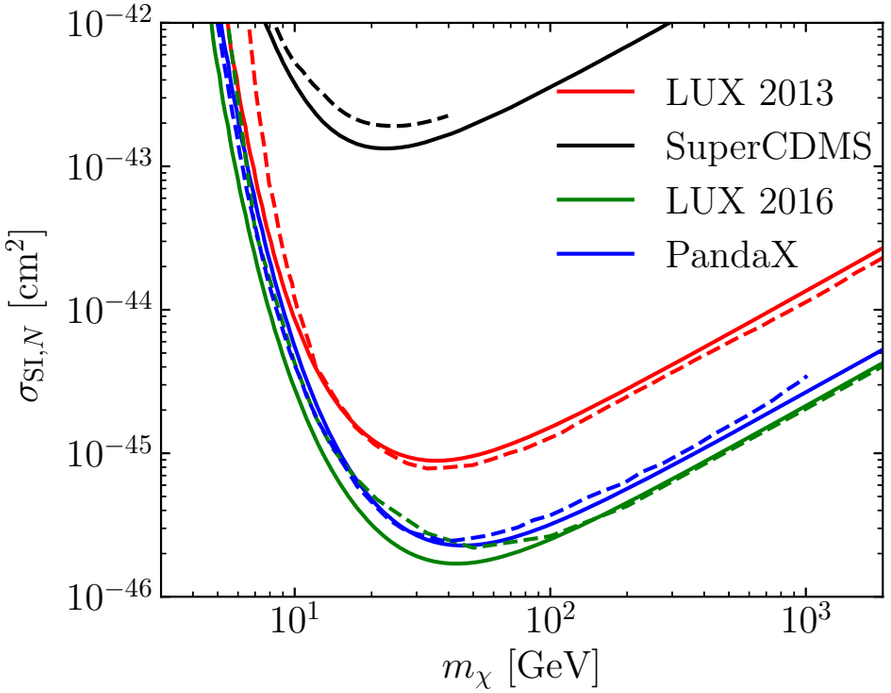


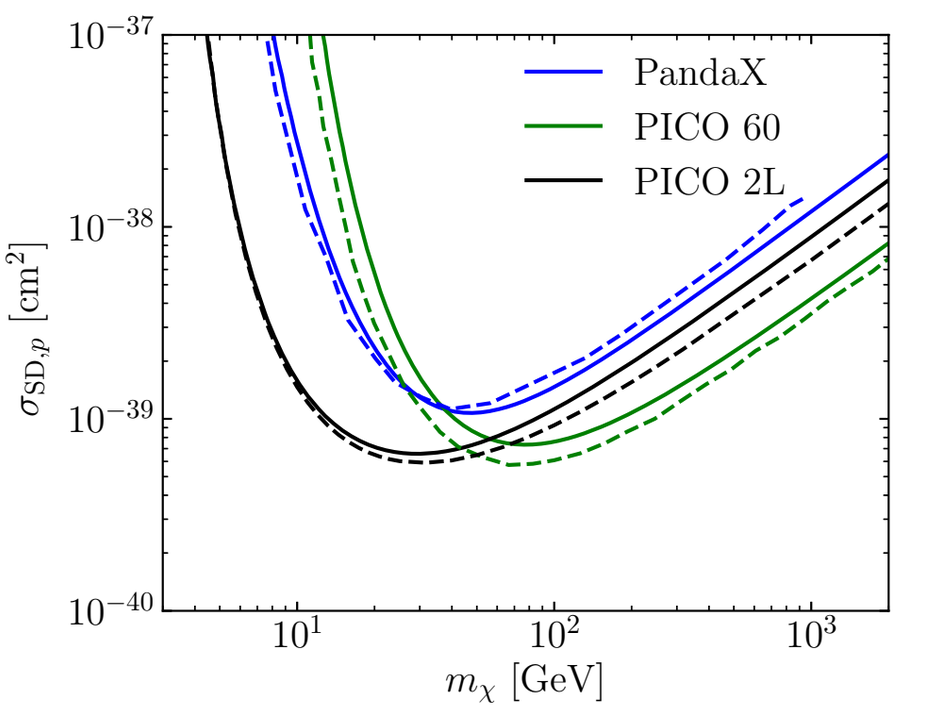
Solar neutrinos:

- Yields from DM annihilation in sun calculated by DarkSUSY. IceCube likelihoods contained in *nulike* (nulike.hepforge.org) standalone code.

DarkBit: Direct Detection

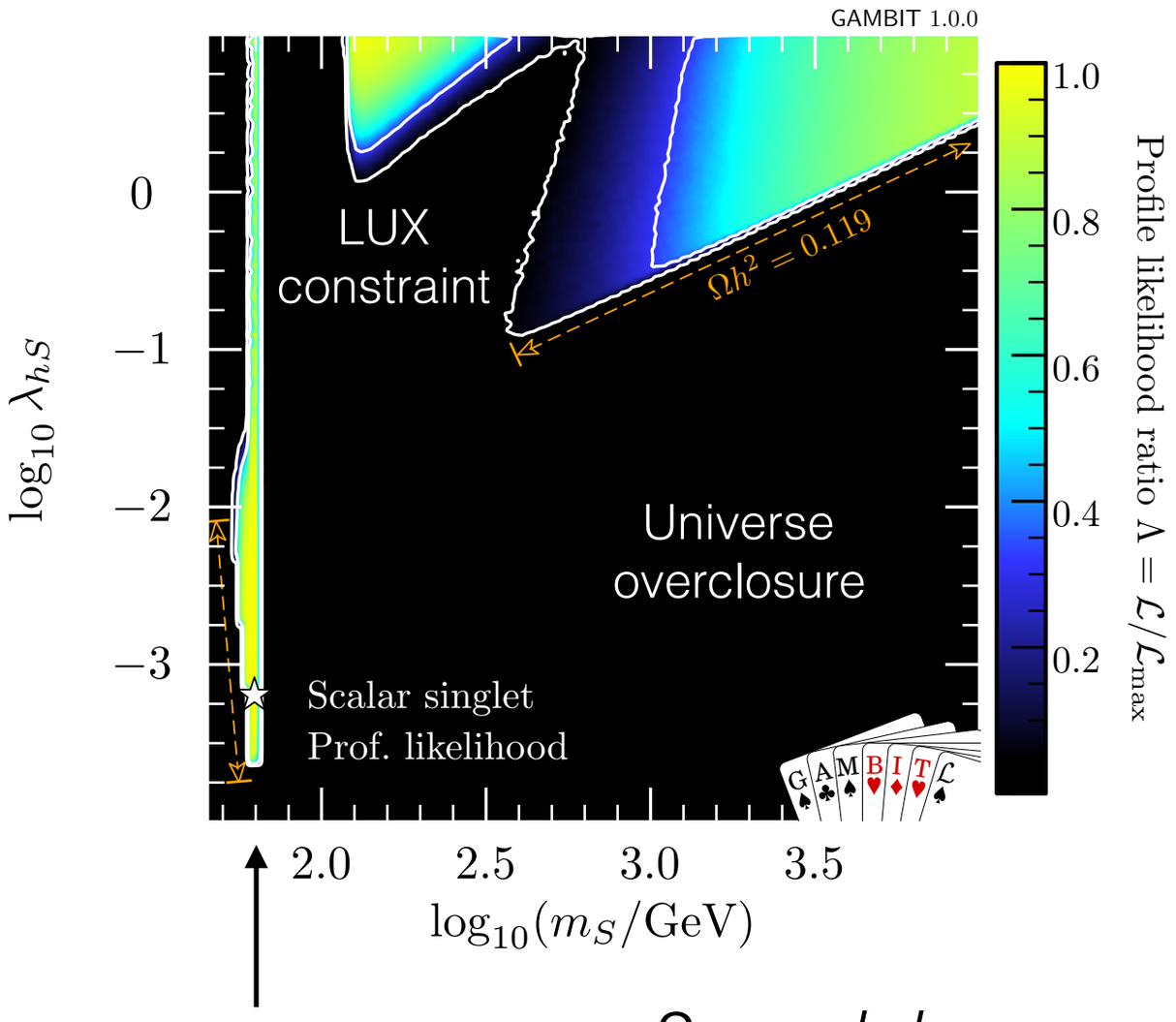
- In parallel with GAMBIT, we introduce *DDCalc* (ddcalc.hepforge.org), a tool to calculate event rates and complete likelihood functions for direct detection experiments taking into account:
  - A mix of both spin-independent and dependent contributions to the scattering rate.
  - Halo parameters (local density, DM velocity dispersion, etc.) chosen by the user.
- We currently have implemented likelihoods for Xenon(1T, 100), LUX, PandaX, SuperCDMS, PICO(60, 2L), and SIMPLE





Scalar Singlet DM

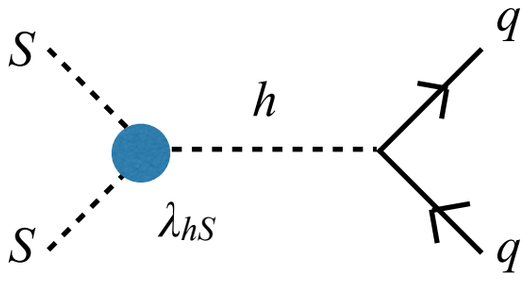
arXiv:1705.07931



Likelihoods include:

- Relic density (upper limit)
- Fermi-LAT DM searches in dwarf spheroidals
- Direct Detection (LUX, PandaX, etc..)
- IceCube limits on DM scattering from solar neutrinos
- Higgs invisible width

Higgs resonance



2 *model* parameters: λ_{hS}, M_S

15 *nuisance* parameters:

- 10 SM (m_h, m_q, G_F, α_S, α_{EM})
- 2 nuclear (σ_s, σ_l),
- Local DM density (ρ_0)

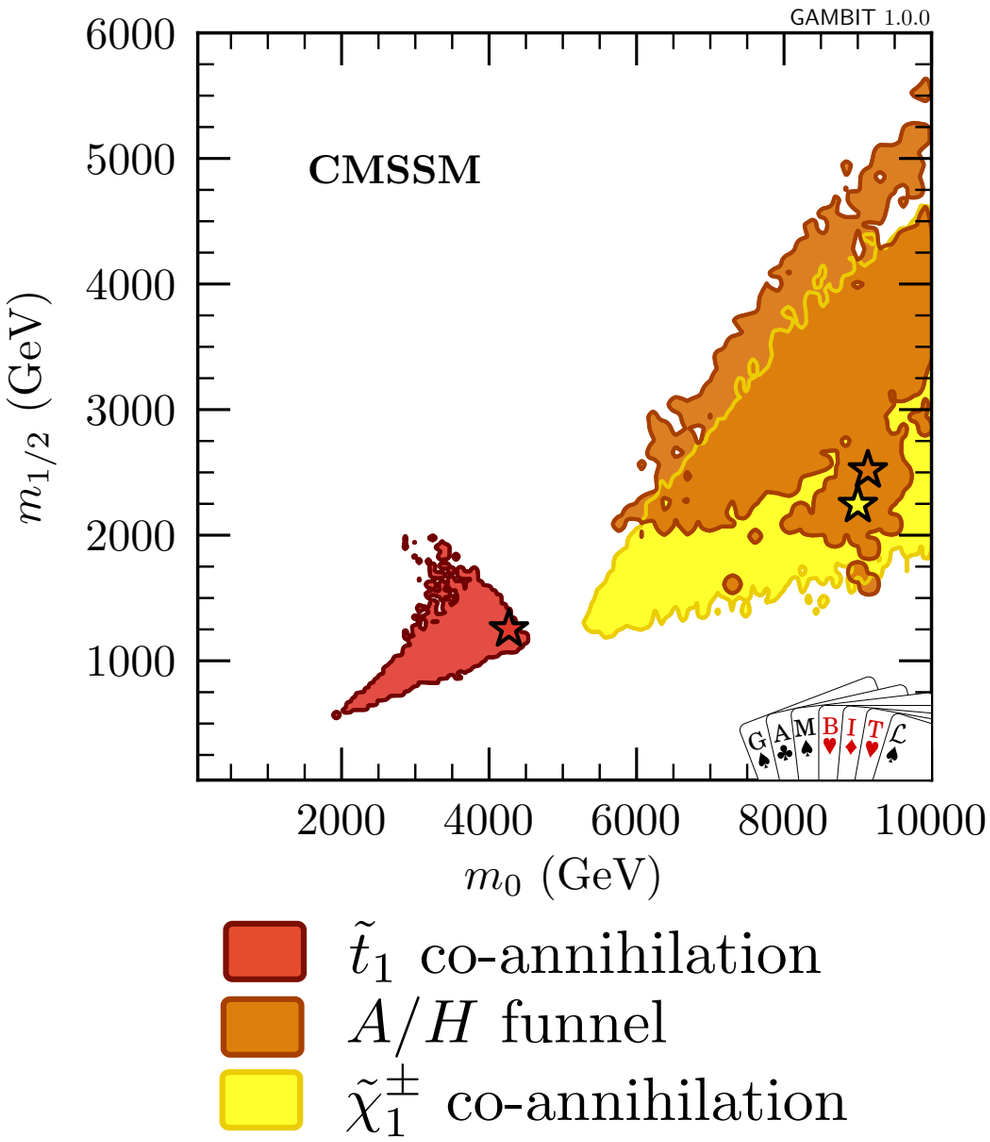
Constrained MSSM

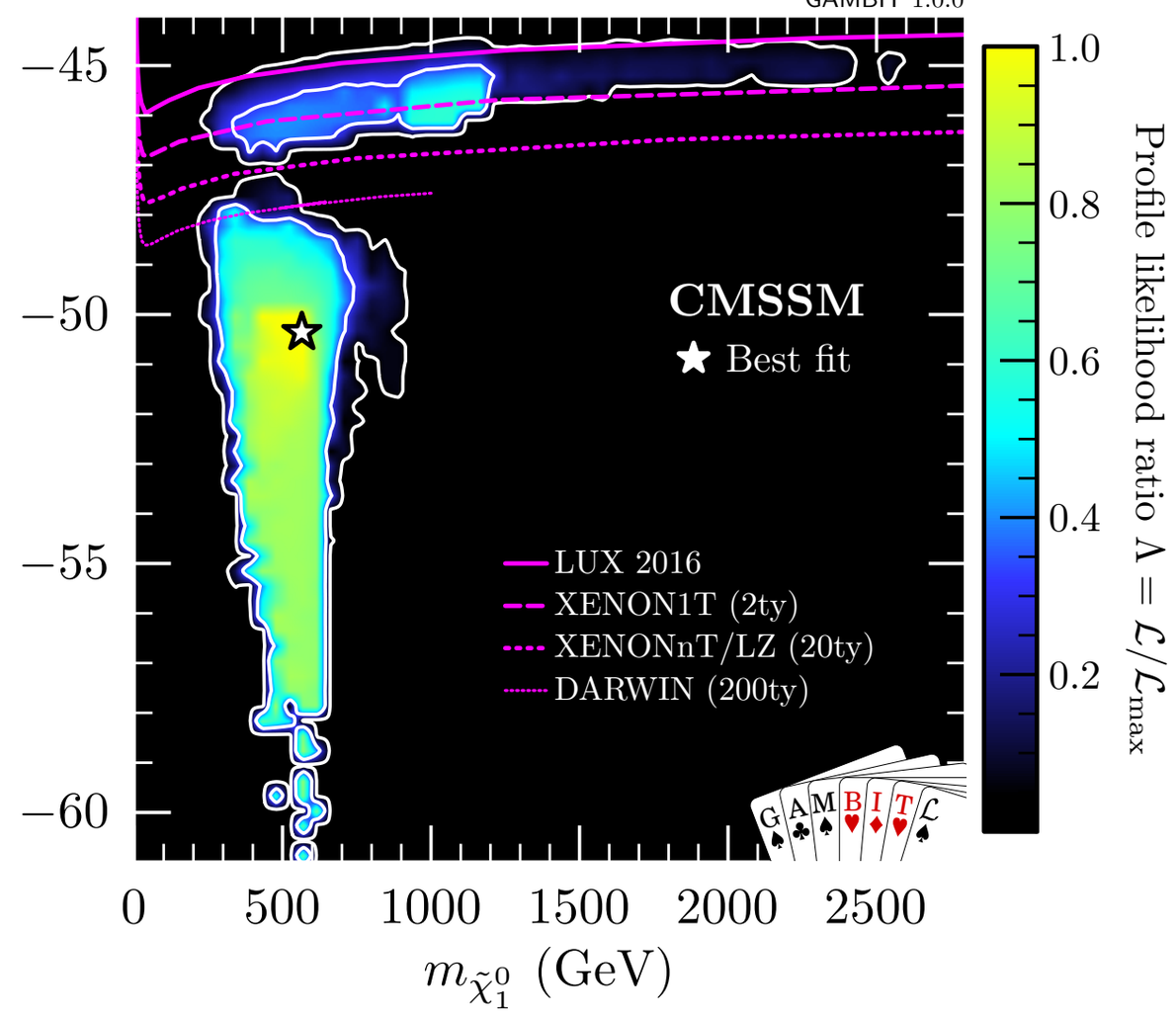
arXiv:1705.07935

- 5 *model* parameters, defined at GUT scale:
  - $m_0, m_{1/2}$ Unified scalar, gaugino mass parameters
  - A_0 Universal trilinear coupling
  - $\tan\beta$ Higgs sector parameters
    $\mathrm{sign}(\mu)$
- 5 *nuisance* parameters:
  - α_s, m_t SM parameters: strong coupling and top mass
  - ρ_0 Local DM density
  - σ_s, σ_l Hadronic matrix elements
- The same *likelihoods* as for Scalar Singlet DM +:
  - LHC run 1 SUSY searches (and 0 lepton run 2 search)
  - LHC Higgs constraints
  - flavour physics limits from LHCb

Constrained MSSM

arXiv:1705.07935





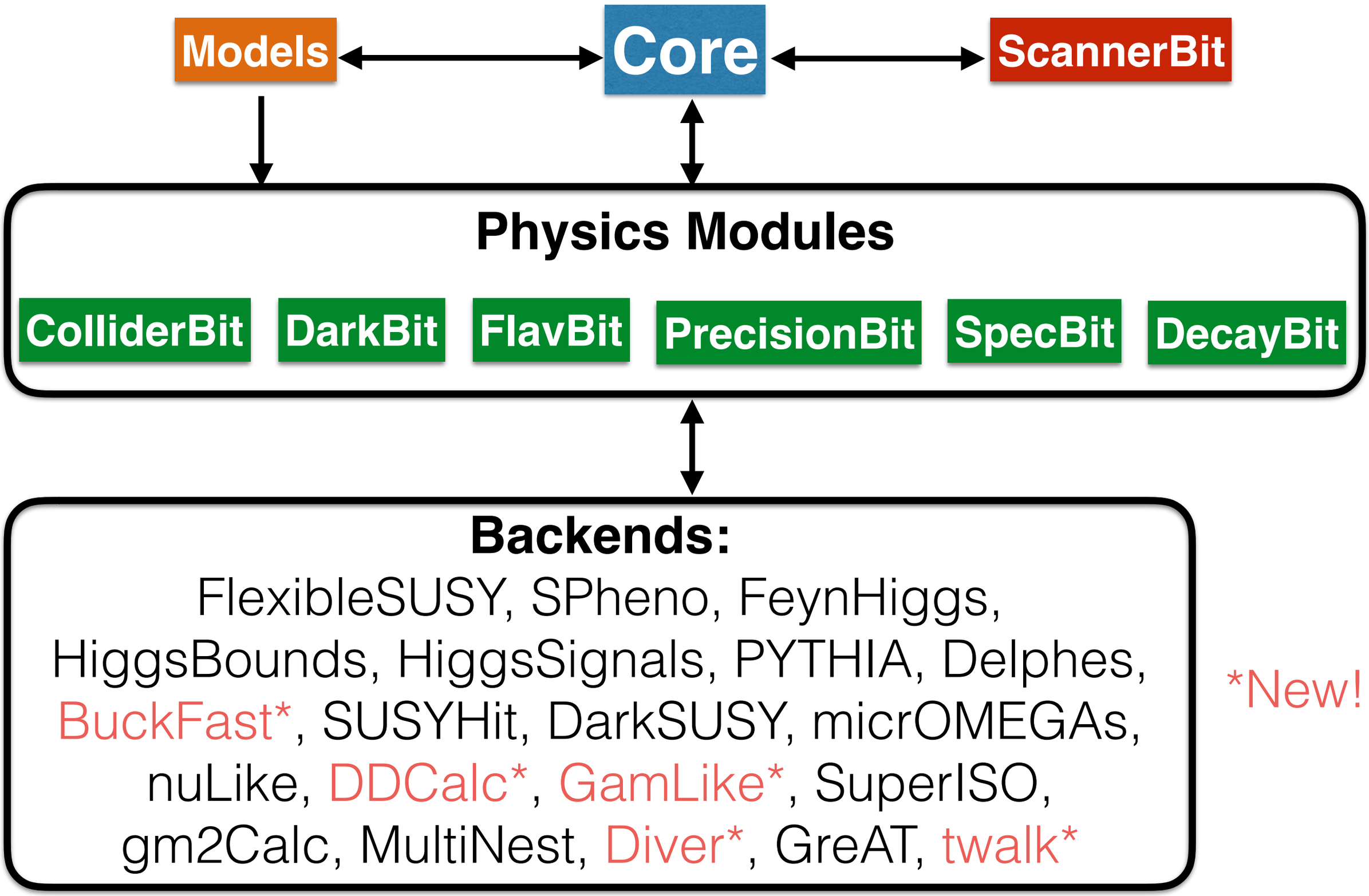
- stau coannihilation now disfavoured at 95% CL
- Future DD searches will fully probe A/H funnel and chargino co-annihilation regions

Summary and Future Plans

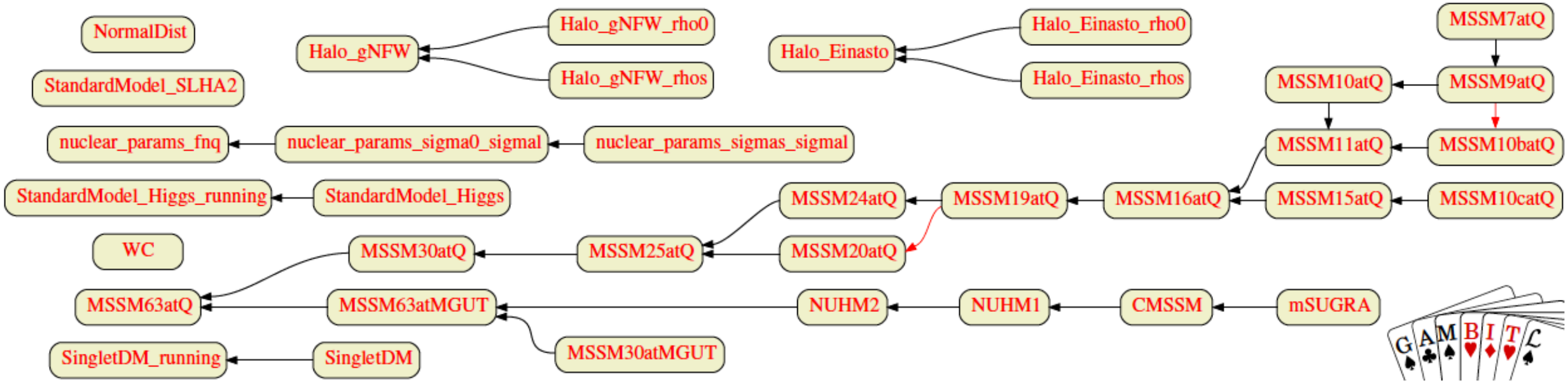
- GAMBIT, a new fitting framework for BSM theories that includes a wide range of experimental results, is now publicly released! (Download here: gambit.hepforge.org)
- We have used the code to do scans the scalar singlet DM model, and both GUT scale and weak scale (not presented here) SUSY models
- **Future Plans**
  - More models (axions, Higgs portal DM, more general MSSM's, right handed neutrinos …) and observables
  - New modules (neutrinos and cosmology)
  - Improved integration with matrix element generators (CalcHEP and Madgraph) for easy implementation of new models

Backups

Code Structure



Hierarchical Model Database

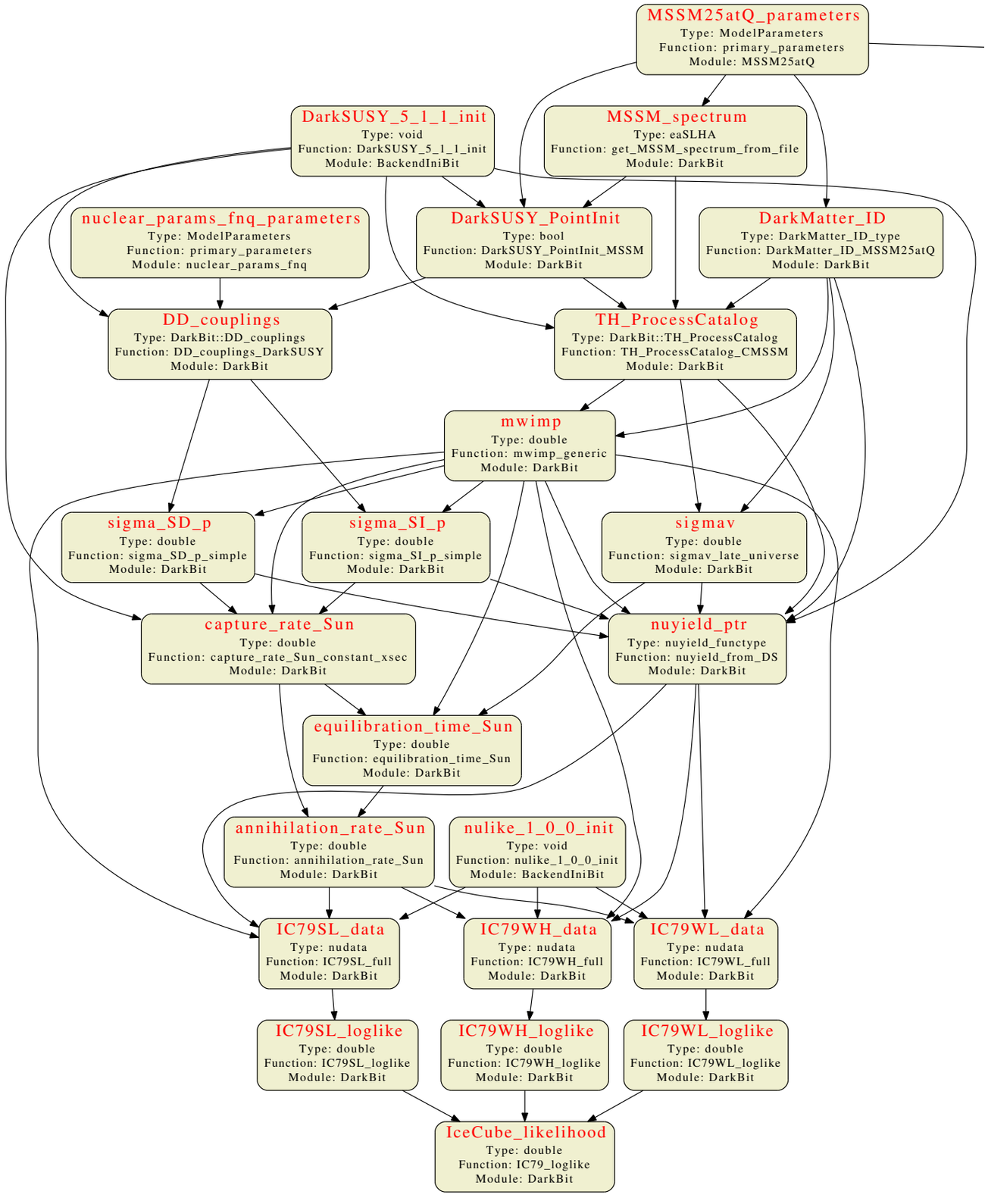


- Large and easily extensible model database.

- Models for BSM physics (SUSY / Singlet DM) and nuisance parameters (SM, DM halo, nuclear parameters). More BSM models to come!

- Model hierarchy allows for conversion between various parameterizations based on what is needed for a calculation.

Dependency Resolution



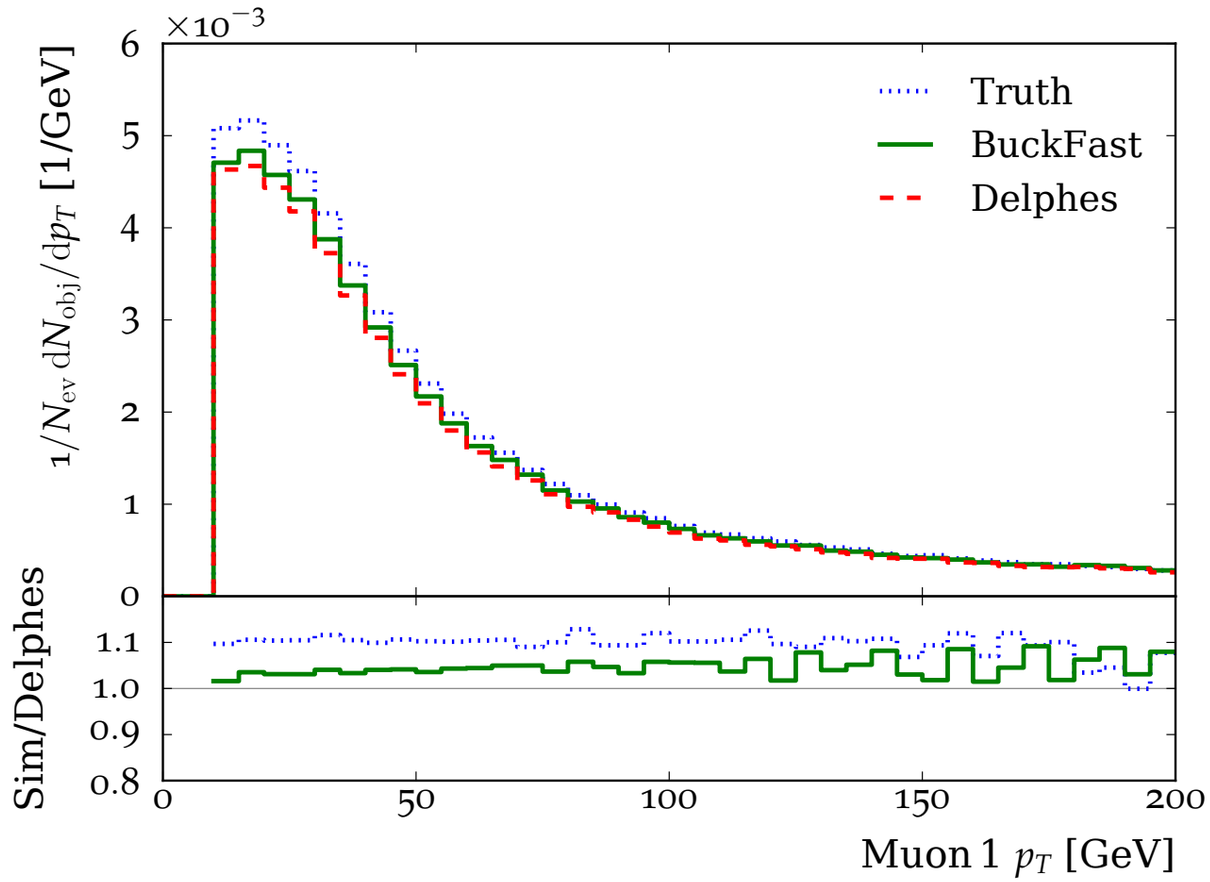
- Automatic generation of dependency tree for calculation of likelihoods and all necessary intermediate values.

- No redundancy — each needed quantity calculated once per point in the scan.

- Can change how calculations are done by specifying rules in input file.

Collider Bit

- Full analysis chain for doing LHC recasts (focus on speed):
  - Cross section calculation and event generation using parallelized version of Pythia
  - Fast detector simulation using 4-vector smearing (BuckFast)

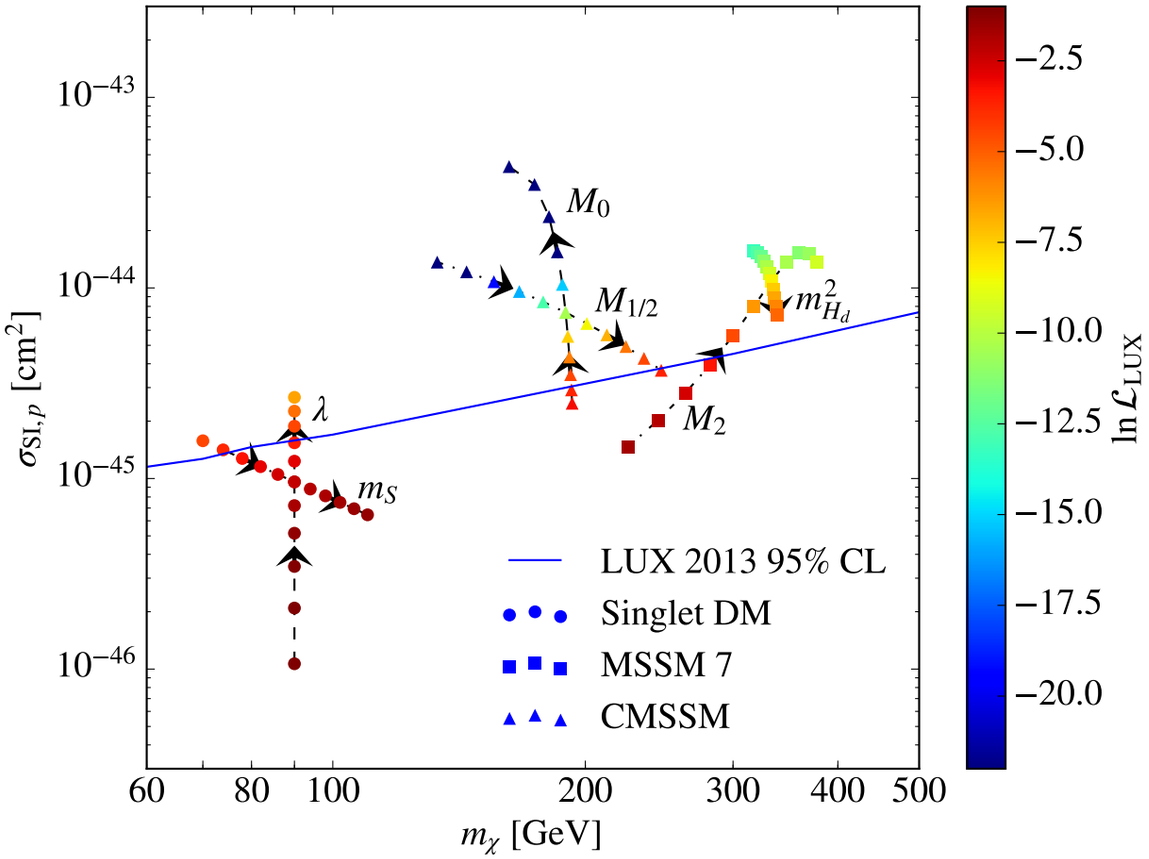


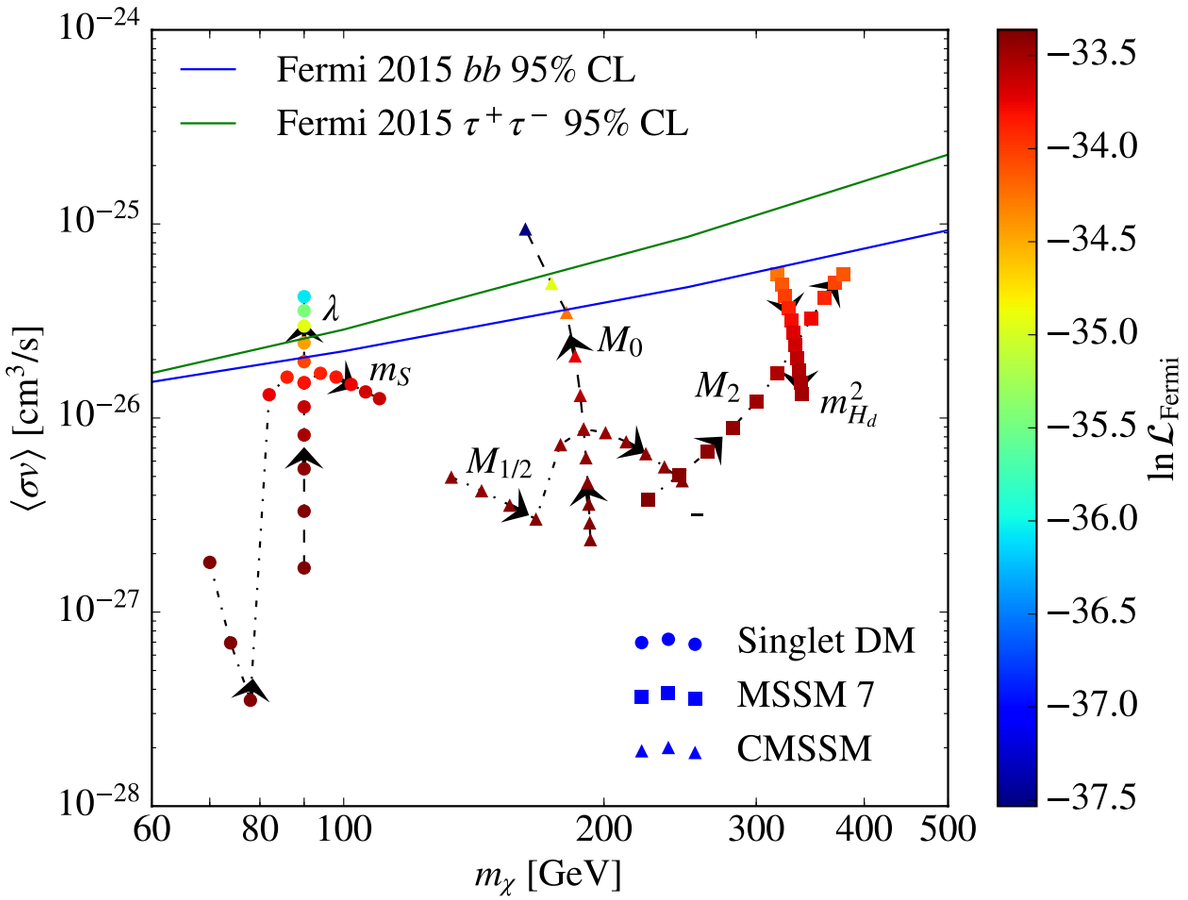
Currently includes (LHC 8 TeV):

- ATLAS SUSY searches (0l, 0/1/2l $\tilde{t}$, b jets + MET, 2/3l EW)
- CMS multi-l SUSY
- CMS DM (monojet)
- Higgs physics from HiggsSignals and HiggsBounds

+ (LHC 13 TeV) ATLAS 0l SUSY search

Dark Bit


10^{-43}
10^{-44}
10^{-45}
10^{-46}
$\sigma_{\mathrm{SI},p}$ [cm^2]
M_0
$M_{1/2}$
$m_{H_d}^2$
λ
M_2
m_S
LUX 2013 95% CL
Singlet DM
MSSM 7
CMSSM
60
80
100
200
300
400
500
m_χ [GeV]
−2.5
−5.0
−7.5
−10.0
−12.5
−15.0
−17.5
−20.0
$\ln \mathcal{L}_{\mathrm{LUX}}$


10^{-24}
10^{-25}
10^{-26}
10^{-27}
10^{-28}
$\langle\sigma v\rangle$ [cm^3/s]
Fermi 2015 bb 95% CL
Fermi 2015 $\tau^+\tau^-$ 95% CL
λ
m_S
M_0
M_2
$m_{H_d}^2$
$M_{1/2}$
Singlet DM
MSSM 7
CMSSM
60
80
100
200
300
400
500
m_χ [GeV]
−33.5
−34.0
−34.5
−35.0
−35.5
−36.0
−36.5
−37.0
−37.5
$\ln \mathcal{L}_{\mathrm{Fermi}}$

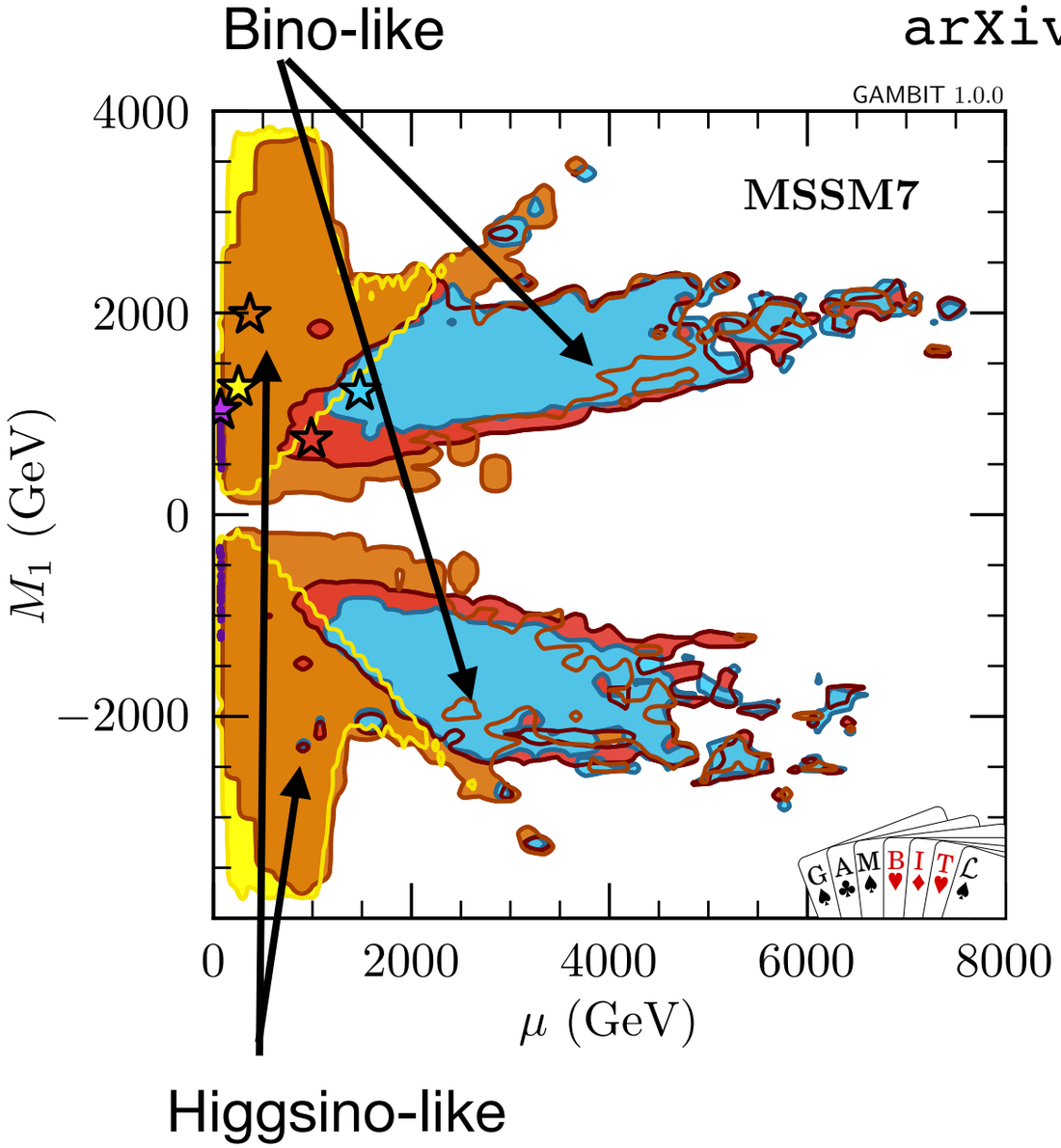
MSSM-7

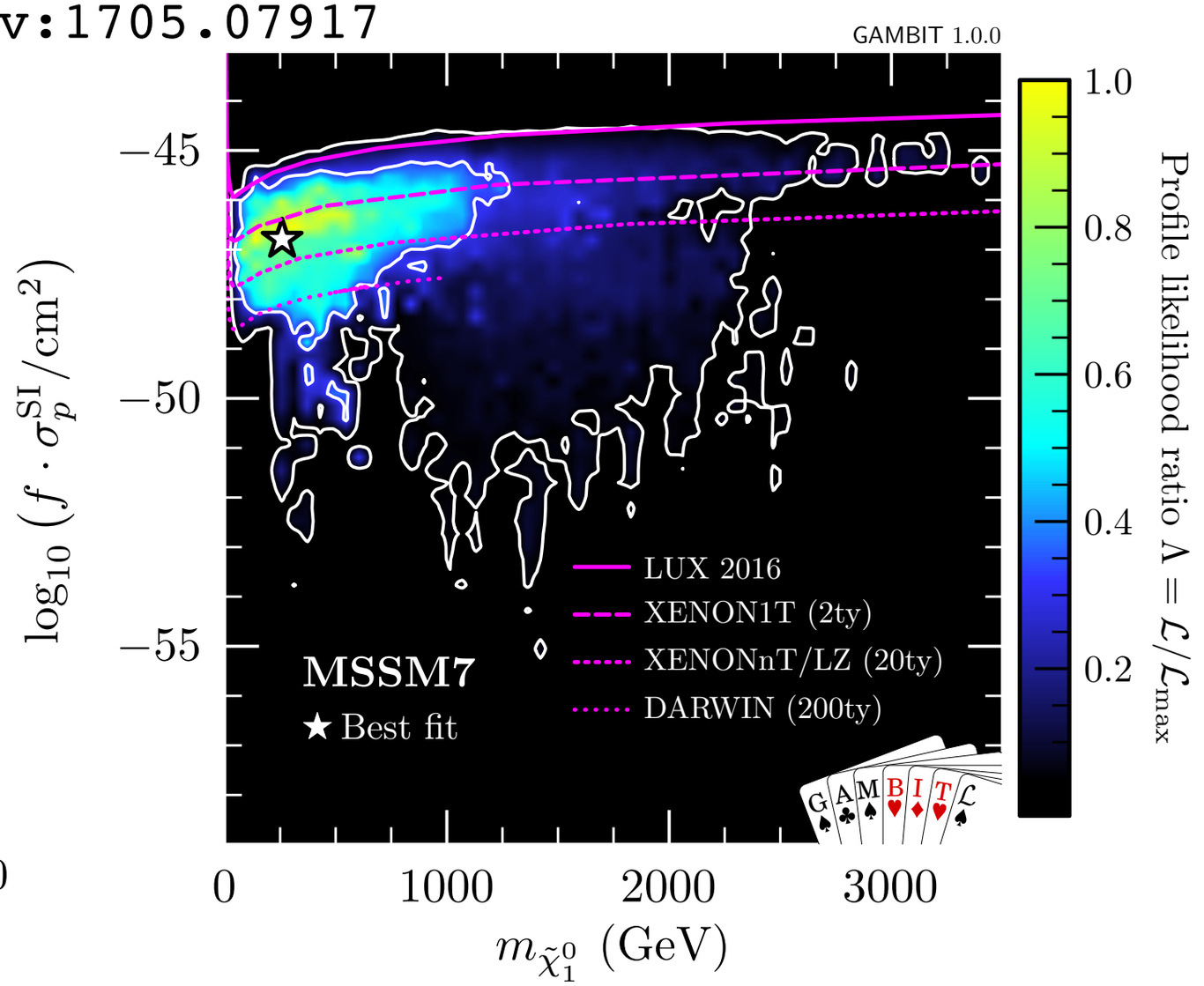
arXiv:1705.07917

- 7 *model* parameters, defined at a lower energy scale (1 TeV):
  - M_2 Wino mass parameter (related to M_1 and M_3 via GUT scale relation).
  - M_{H_u}, M_{H_d} Higgs doublet mass parameters
  - A_{u_3}, A_{d_3} Trilinear couplings
  - $m^2_{\tilde{f}}$ Unified sfermion mass parameter
  - $\tan\beta$ Ratio of Higgs vevs
- All *nuisance* parameters and *likelihoods* same as before.

MSSM-7

arXiv:1705.07917





$\tilde{t}_1$ co-annihilation A/H funnel $\tilde{\chi}_1^\pm$ co-annihilation $\tilde{b}_1$ co-annihilation h/Z funnel

- Preference for light (m_χ < 1 TeV at 68% CL) Higgsino-like neutralino