



Global fits of the scalar singlet model using GAMBIT

on behalf of the GAMBIT collaboration

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Global fits for dark matter and new physics

What do we mean by *global fits*?

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- There exist many beyond standard model theories
 - many parameters
- There are many different experiments and observations
 - many constraints

Consistently combining these constraints to explore the parameter space of a model is a *global fit*. Subsequent global fits of different models enable comparisons to be made.

Global fits for dark matter and new physics

- We need a global fitting tool that can
 - be extended to new models
 - be modular enough to easily include new constraints/improve old ones
 - use a variety of statistical techniques
 - make use of the many existing tools
 - be fast enough to do this for complicated physics/large parameter spaces

What is **modular** and **flexible** enough to achieve this?

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GAMBIT (arXiv:1705.07908)

The GAMBIT Collaboration

29 members in:

- 11 countries
- 9 Experiments
- 12 major theory codes

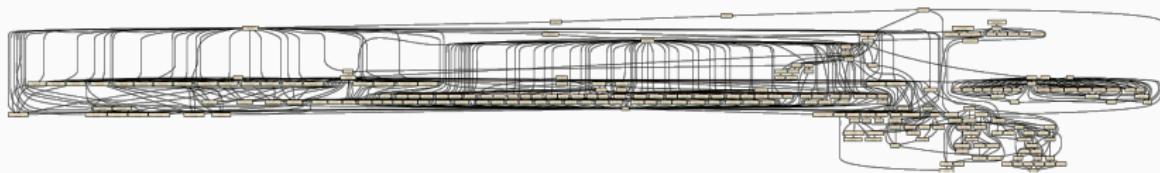


- **ATLAS** F. Bernlochner, A. Buckley, P. Jackson, M. White
- **LHCb** M. Chrzaszcz, N. Serra
- **Belle-II** F. Bernlochner, P. Jackson
- **Fermi-LAT** J. Conrad, J. Edsjö, G. Martinez, P. Scott
- **CTA** C. Balázs, T. Bringmann, J. Conrad, M. White
- **CMS** C. Rogan
- **IceCube** I. Edsjö, P. Scott
- **XENON/DARWIN** J. Conrad, B. Farmer, R. Trotta
- **Theory** P. Athron, C. Balázs, T. Bringmann, J. Cornell, J. Edsjö, B. Farmer, T. Gonzales, A. Fowlie, J. Harz, S. Hoof, F. Kahlhoefer, A. Krislock, A. Kvællestad, M. Pato, F. Mahmoudi, J. McKay, A. Raklev, R. Ruiz, P. Scott, R. Trotta, C. Weniger, M. White, S. Wild.

The Global and Modular Beyond the SM Inference Tool

- **modular and flexible**
- plug and play with other tools for scanning and physics
- a large set of models, not just SUSY – e.g. SingletDM, many MSSM variants + future generalised SingletDM, Minimal DM, 2 Higgs doublet models ...
- Extensive observable/data libraries (likelihood modules)
- Statistical flexibility – Bayesian/frequentist, likelihood definitions, scanning algorithms
- A smart and *fast* LHC likelihood calculator
- Massively parallel
- Full open-source code

GAMBIT – Dependency Resolution



- Module functions and backend functions get arranged into a **dependency tree**
- Starting with requested observables and likelihoods, GAMBIT fills each dependency and backend requirement
- Obeys **rules** at each step: allowed models, allowed backends, constraints from input file, etc
- → tree constitutes a directed acyclic graph
- → GAMBIT uses graph-theoretic methods to ‘solve’ the graph to determine function evaluation order

GAMBIT – Modules

Physics modules

- **DarkBit** – dark matter observables (arXiv:1705.07920)
- **ColliderBit** – collider observables (arXiv:1705.07919)
- **FlavBit** – flavour physics (arXiv:1705.07933)
- **SpecBit** – RGE running, masses, mixings, etc (arXiv:1705.07936)
- **DecayBit** – decay widths (arXiv:1705.07936)
- **PrecisionBit** – SM likelihoods, precision BSM tests (arXiv:1705.07936)
- + **ScannerBit** – manages sampling and optimisation (arXiv:1705.07959)

Physics studies

- Global fits of GUT-scale SUSY models (arXiv:1705.07935)
- A global fit of the MSSM (arXiv:1705.07917)
 - **Higgs and new Physics tomorrow at 15:30 (Anders Kvellestad)**
- Status of the scalar singlet model (arXiv:1705.07931)
 - **Now!**

Scalar singlet results

(arXiv:1705.07931)

Scalar singlet model

One of the simplest classes of dark matter models – one new scalar S

$$\mathcal{L}_S = \frac{1}{2} \partial_\mu S \partial^\mu S + \frac{1}{2} \mu_S^2 S^2 + \frac{1}{2} \lambda_{SH} S^2 |H|^2 + \frac{1}{4} \lambda_S S^4$$

\mathbb{Z}_2 ($S \rightarrow -S$) symmetry stabilises S , $m_s = \sqrt{\mu_S^2 + \frac{1}{2} \lambda_{hS} v_0^2}$.

- Stable dark matter candidate
- Viable regions of parameter space yet to be excluded
- Can stabilise electroweak potential

For this global fit we deal with the $\lambda_S = 0$ model.

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Two beyond standard model parameters λ_{SH} & m_s .

SM and astrophysical nuisance parameters

Parameter	Range	
G_F	$(1.1663775 - 1.1663799) \times 10^{-5}$	
$\alpha_s(M_Z)$	$0.1173 - 0.1197$	
$\alpha^{-1}(M_Z)$	$127.898 - 127.982$	
$m_d(2 \text{ GeV})$	$(4.2 - 5.8) \times 10^{-3} \text{ GeV}$	
$m_u(2 \text{ GeV})$	$(1.3 - 3.7) \times 10^{-3} \text{ GeV}$	
$m_s(2 \text{ GeV})$	$(85 - 105) \times 10^{-3} \text{ GeV}$	
$m_b(m_b)$	$(4.09 - 4.27) \text{ GeV}$	
$m_c(m_c)$	$(1.2 - 1.35) \text{ GeV}$	
m_t	$(171.06 - 175.62) \text{ GeV}$	
m_h	$(124.1 - 127.3) \text{ GeV}$	
σ_s	$27.0 - 59.0 \text{ MeV}$	See (arXiv:1705.07959) for full study into scanner performance with this model
σ_I	$40.0 - 76.0 \text{ MeV}$	
ρ_0	$0.2 - 0.8 \text{ GeV cm}^{-3}$	

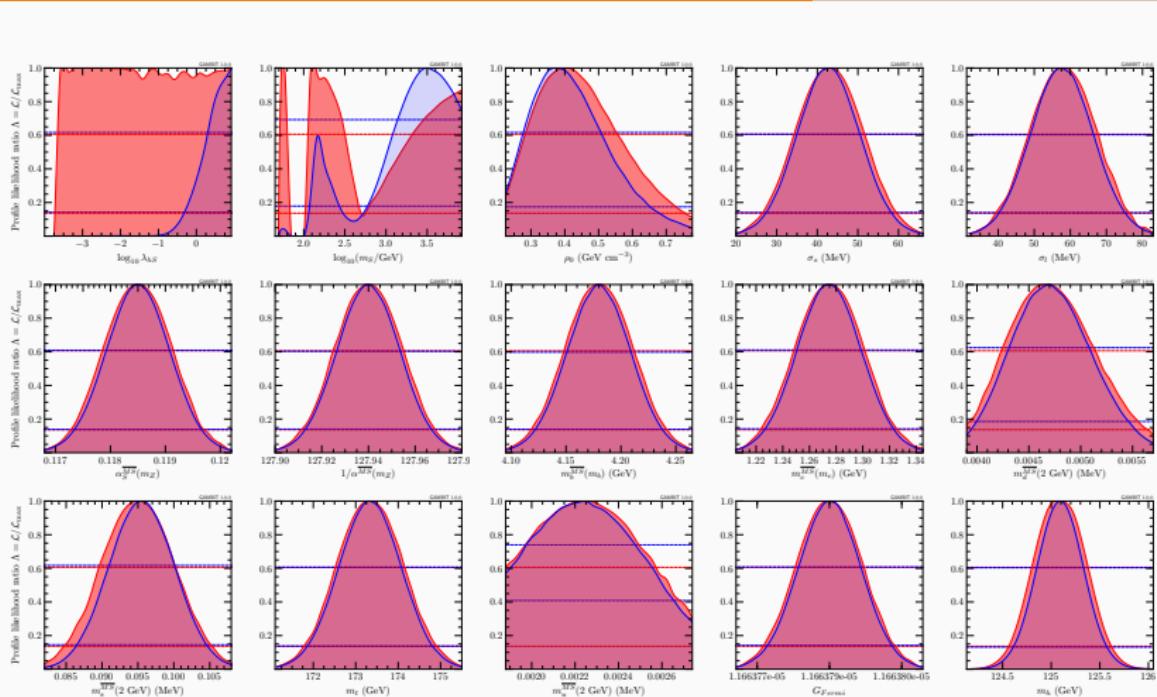
- Four scanners used to generate $\sim 5 \times 10^7$ samples
- **Multinest** Nested sampling
- **GreAT** MCMC
- **T-walk** Ensemble MCMC
- **Diver** Differential evolution

See [\(arXiv:1705.07959\)](#) for full study into scanner performance with this model

Included likelihoods

- SM nuisance parameters – Higgs and quark masses, G_F
- Higgs invisible width
 - simple implementation of LHC limits on $\Gamma_{hh} \rightarrow \text{invisible}$
- Direct detection
 - XENON100 (2012)
 - LUX (2015) + (2016)
 - PandaX (2016)
 - SuperCDMS (2014)
- Indirect detection
 - Fermi-LAT observations of dwarf spheroidal galaxies
- IceCube (79 string) – bounds on DM annihilation to solar neutrinos
- Relic density, Ω , and local DM density, ρ_0
- Nuclear uncertainties – σ_s, σ_I , these affect the Higgs-nucleon coupling – important for direct detection

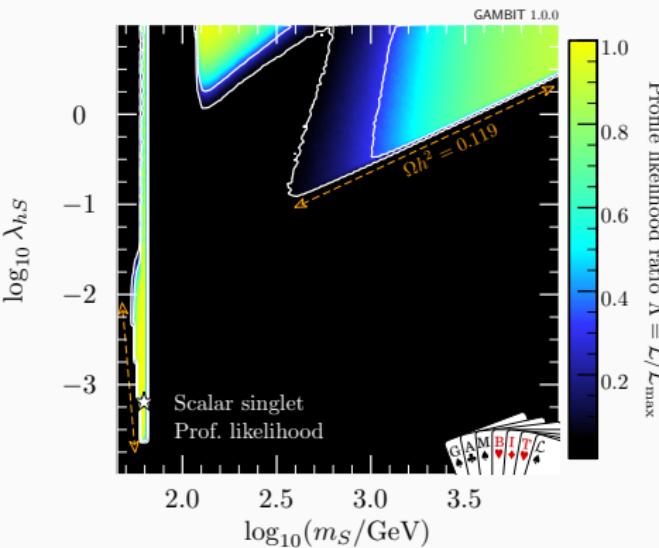
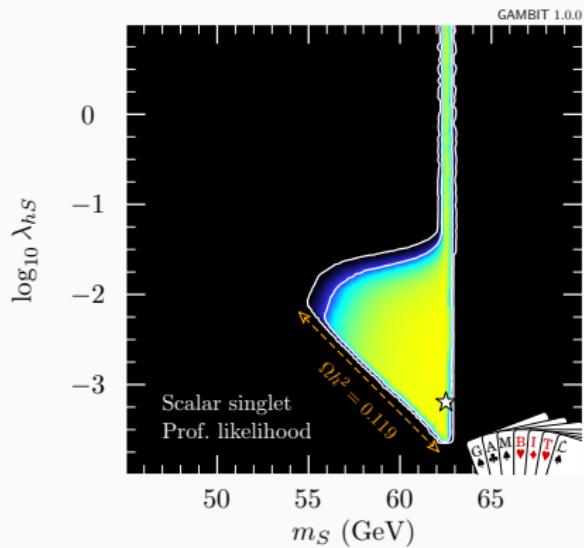
1D profile likelihoods and marginalised posteriors



Blue – posterior distributions

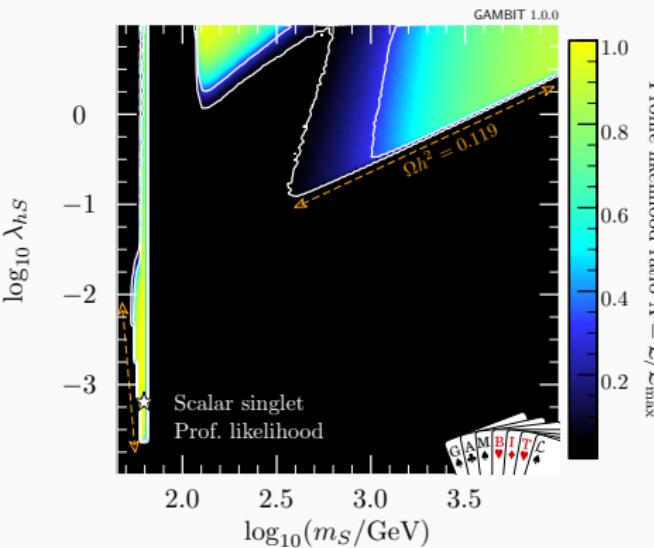
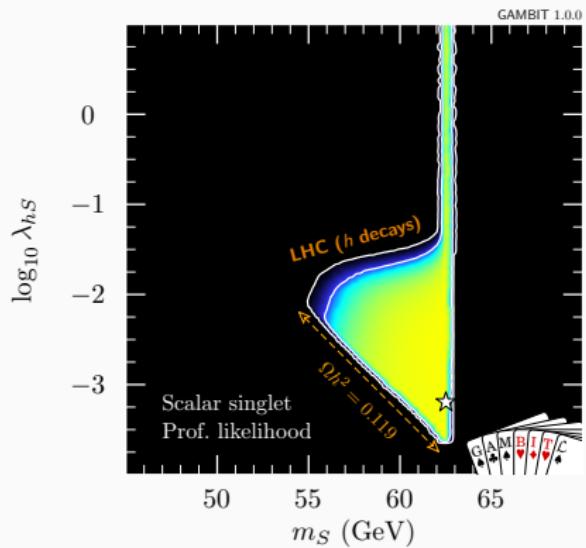
Red – profile likelihoods

Results: Scalar singlet DM (m_S , λ_{hS} + 13 nuisances)



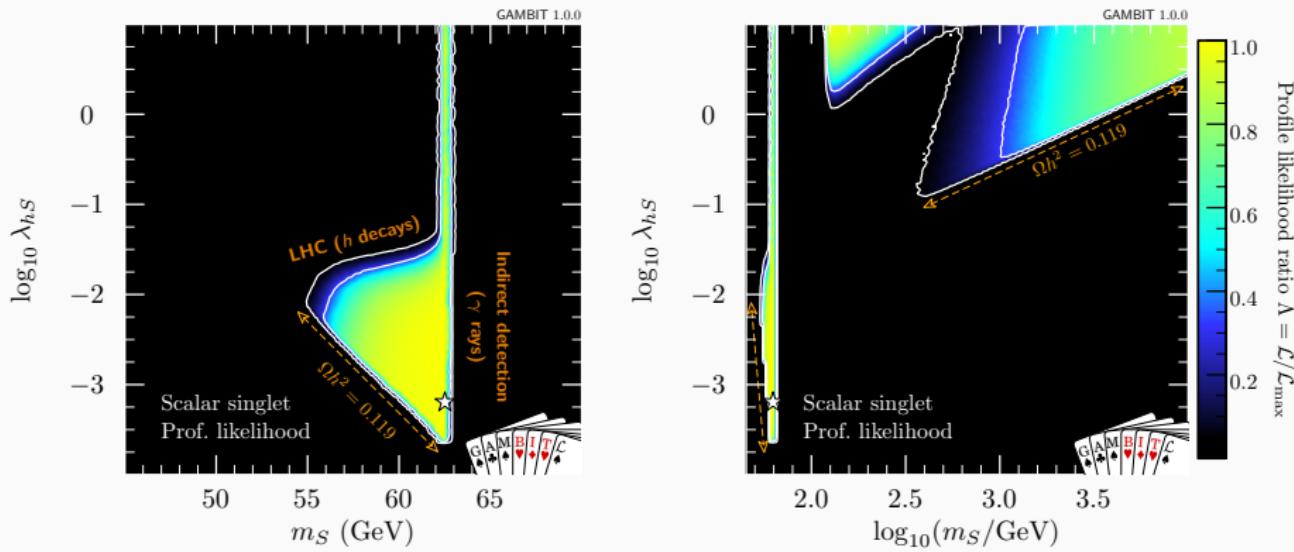
All dark matter signals consistently scaled for predicted abundance

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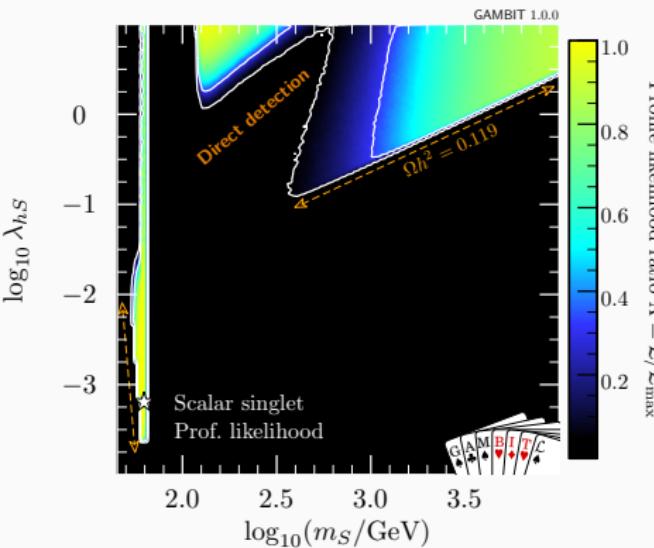
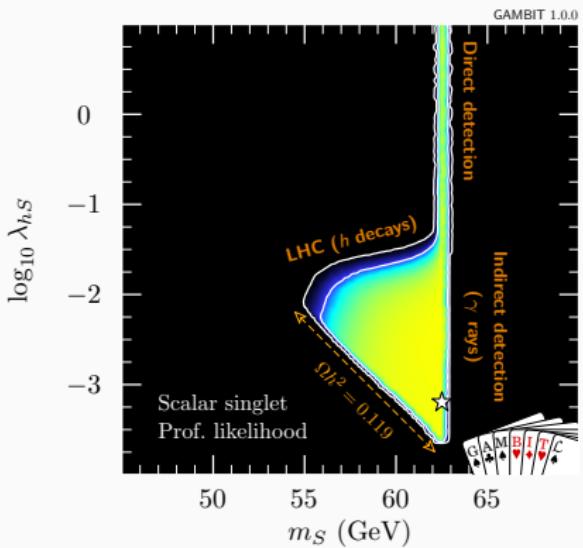
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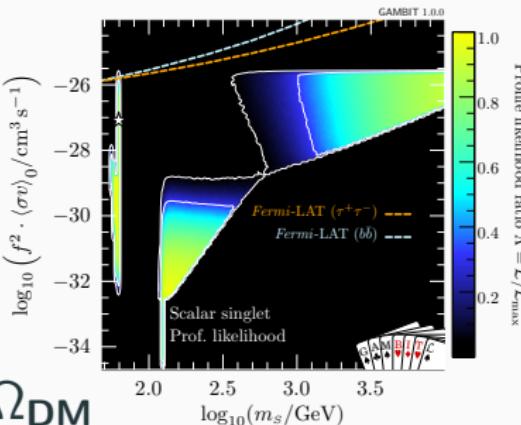
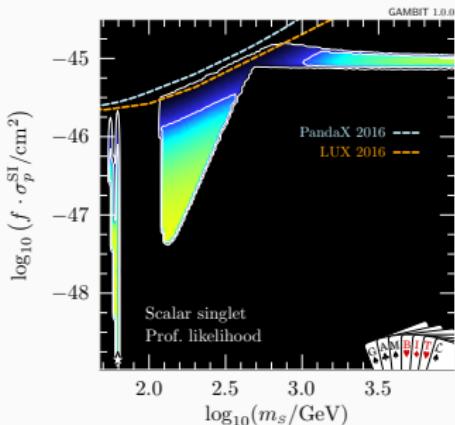
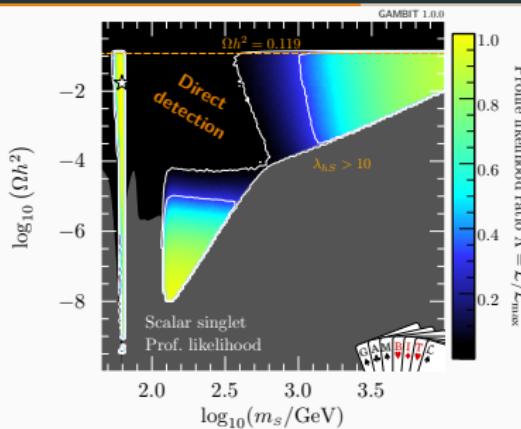
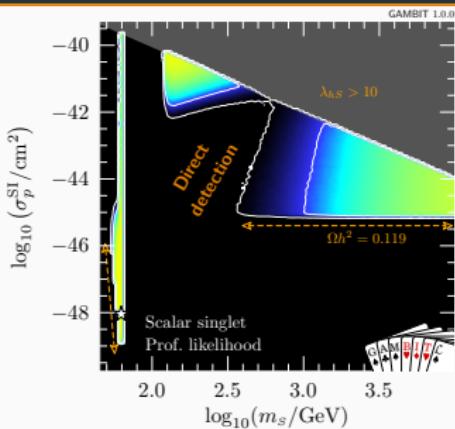
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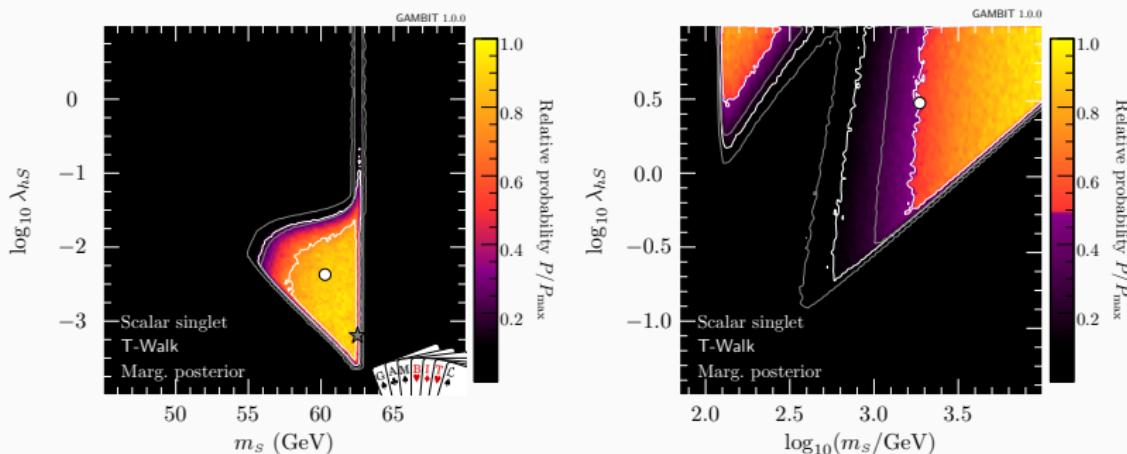
All dark matter signals consistently scaled for predicted abundance

Results: Scalar singlet DM (m_S , λ_{hS} + 13 nuisances)



$$f = \Omega_S / \Omega_{\text{DM}}$$

Marginalised posterior



- scan over full mass range
detects resonance region (as seen on 1D posterior)
small posterior volume penalises this region
→ indicates fine tuning (sensitivity to nuisance parameters such as m_H)
- focused scan over low mass range shows expected distribution

The best-fit point

Best-fit point $(\lambda_{hS}, M_S) =$

- $(6.5 \times 10^{-4}, 62.51 \text{ GeV})$
- $\Delta \log(\mathcal{L}) = 0.107$

Best-fit point with $\Omega \approx \Omega_{\text{DM}}$

- $(2.9 \times 10^{-4}, 62.27 \text{ GeV})$
- $\Delta \log(\mathcal{L}) = 0.242$

Best-fit point in high-mass mode

- $(9.9, 132.5 \text{ GeV})$
- $\Delta \log(\mathcal{L}) = 0.133$

Best-fit point in high-mass mode with
 $\Omega \approx \Omega_{\text{DM}}$

- $(3.1, 9.79 \text{ TeV})$
- $\Delta \log(\mathcal{L}) = 0.362$

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EW vacuum metastable

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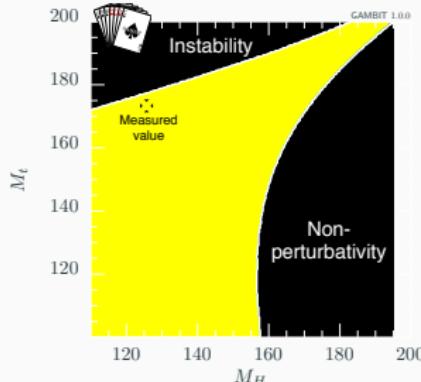
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Best-fit point in high-mass mode with

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- $\Delta \log(\mathcal{L}) = 0.362$

- **However** $(0.5, 1.3 \text{ TeV})$ satisfies these additional constraints
- In preparation study to add renormalisation constraints and study more general scalar singlet models
- For example: RGE running via SpecBit in GAMBIT 1.0:



All results publicly available

The screenshot shows the zenodo website interface. At the top, there is a search bar, an upload button, and a communities section. On the right, there are buttons for 'Log in' and 'Sign up'. Below the header, the date 'June 1, 2017' is displayed. The main content area shows a dataset titled 'Supplementary Data: Status of the scalar singlet dark matter model (arXiv:1705.07931)'. It includes sections for 'The GAMBIT Collaboration', 'Supplementary Data', and 'Status of the scalar singlet dark matter model arXiv:1705.07931'. A detailed description follows, mentioning three YAML files, three hdf5 files, and various plots. The right side of the page contains a 'Publications' section with details like publication date (June 1, 2017), DOI (10.5281/zenodo.801811), keywords (dark matter, beyond standard model, global fits, particle physics, phenomenology, Higgs physics), related identifiers (arXiv:1705.07931), and a license (Creative Commons Attribution 4.0). There is also a 'Files (20.3 GB)' section listing various files with their sizes and download links.

Results available on zenodo.cern.ch

- Parameter point chains (hdf5 files)
- GAMBIT input files
- Plotting routines
- <https://gambit.hepforge.org/pubs>

Name	Size	Actions
RGADMC_Singlet.yaml	2.4 kB	Preview Download
SingleDM.hdf5.tar.gz	21.0 kB	Download
SingleDM.ap	6.1 kB	Download
SingleDM_full.yaml	4.9 kB	Download
SingleDM_lowmass.yaml	4.9 kB	Download
SingleDM_neck.yaml	4.6 kB	Download
SingleDM_TW_hdf5.tar.gz	2.5 kB	Download
SingleDM_TW_ap	6.3 kB	Download
SingleDM_TW_lowmass.hdf5.tar.gz	1.9 kB	Download
SingleDM_TW_lowmass.yaml	5.9 kB	Download
StandardModel_SI_HA2_SingletDM_near_15.yaml	2.9 kB	Download

Summary

- GAMBIT 1.0 available from <https://gambit.hepforge.org/>
- 9 papers: 3 physics papers (SingletDM, GUT-scale MSSM, Weak-scale MSSM), 1 GAMBIT Core paper, 5 module papers
- Future releases with
 - more models!
 - interfaces with SARAH, FeynRules, MadGraph, CalcHEP, etc
- **First SUSY results with GAMBIT**
Higgs and new Physics tomorrow at 15:30 (Anders Kvellestad)