Global Fits of Dark Matter Effective Field Theories with

http://gambit.hepforge.org

Jonathan Cornell, on behalf of

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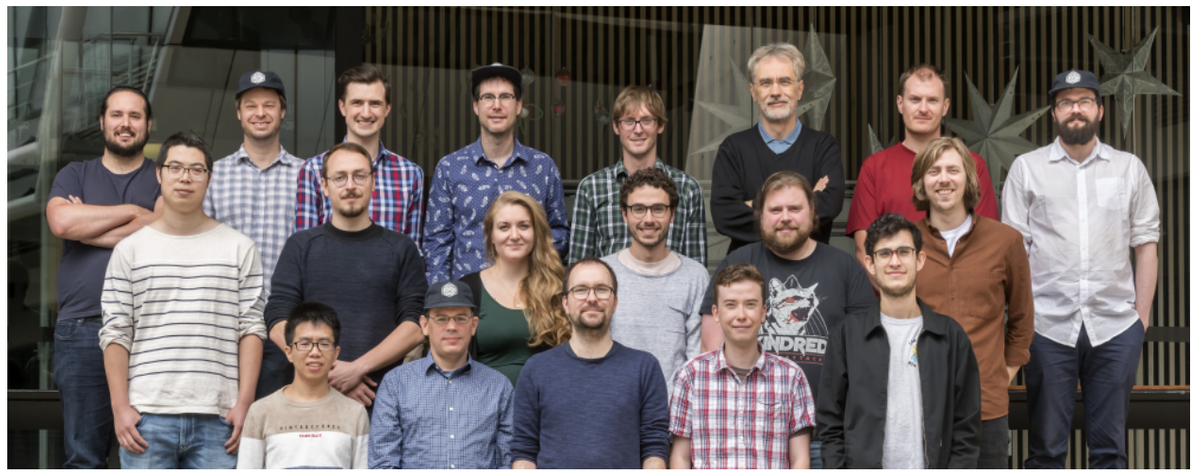
GAMBIT: The Global And Modular BSM Inference Tool

gambit.hepforge.org EPJC **77** (2017) 784 arXiv:1705.07908

- Extensive model database – not just SUSY
- Extensive observable/data libraries
- Many statistical and scanning options (Bayesian & frequentist)
- *Fast* LHC likelihood calculator
- Massively parallel
- Fully open-source

- Fast definition of new datasets and theories
- Plug and play scanning, physics and likelihood packages



Members of:
ATLAS, Belle-II, CLiC, CMS, CTA, *Fermi*-LAT, DARWIN, IceCube, LHCb, SHiP, XENON

Authors of:
DarkSUSY, DDCalc, Diver, FlexibleSUSY, gamlike, GM2Calc, IsaTools, nulike, PolyChord, Rivet, SoftSUSY, SuperISO, SUSY-AI, WIMPSim

Recent collaborators:
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40+ participants in 11 experiments and 14 major theory codes

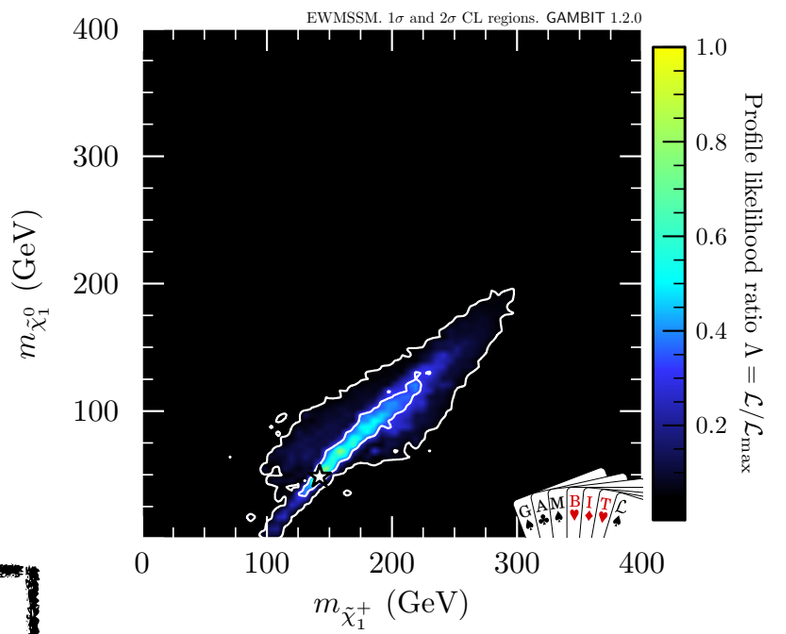
(Some of the) Recent Developments in GAMBIT

- *CosmoBit* – Constraints from large-scale structure, Type Ia supernovae, Big Bang Nucleosynthesis and the cosmic microwave background (arXiv:2009.03286)
- *GAMBIT Universal Model machine (GUM)* – Tool for easy implementation of new particle physics models into GAMBIT (arXiv:2107.00030)
- *New DarkBit Backends* –
  - *DirectDM* – automatic calculation of running and matching of DM EFTs (*Brod, et al.*, arXiv:1708.02678)
  - *Capt'n General* – accurate calculation of capture rate of DM in the sun (*Avis Kozar, et al.*, arXiv:2105.06810)

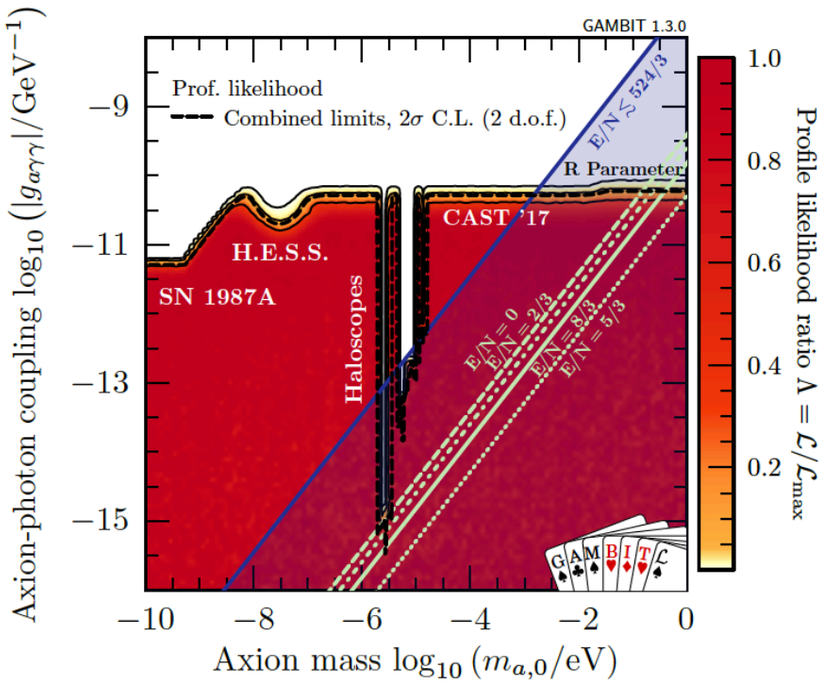
Other Results

Electroweakinos (arXiv:1809.02097)

$$M_1, M_2, \mu, \tan\beta$$



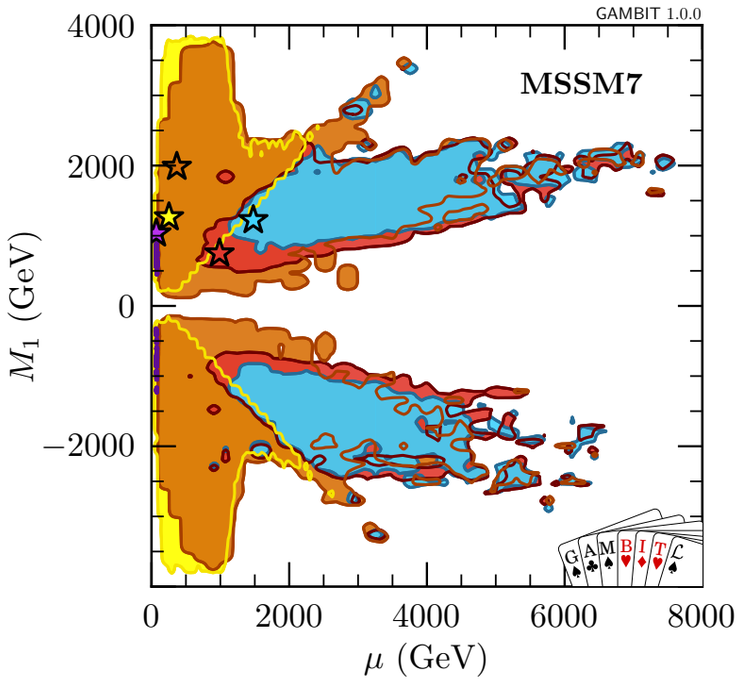
Axions (arXiv:1810.07192)

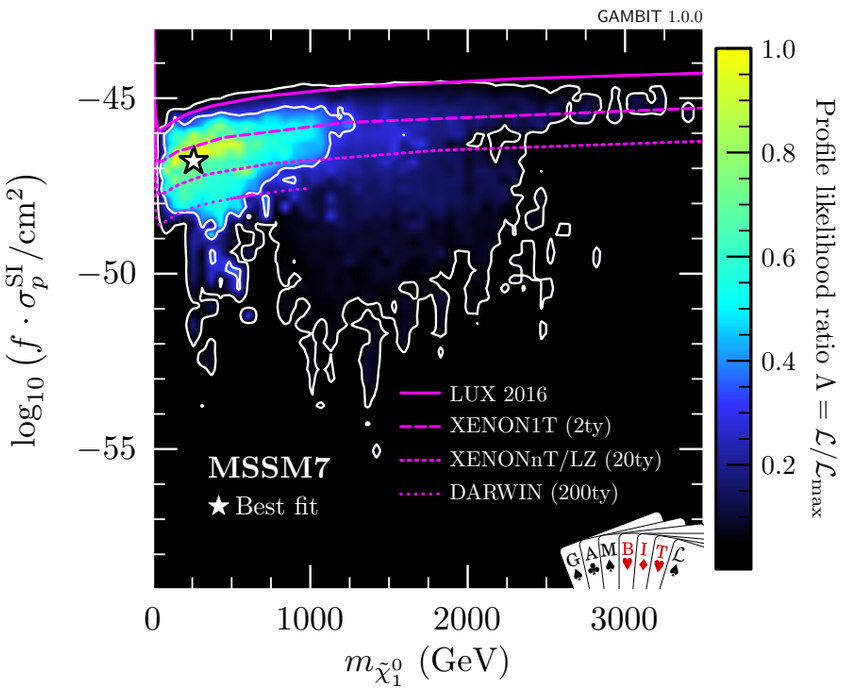


MSSM-7 (arXiv:1705.07917)

$$A_{u_3}, A_{d_3}, M_{H_u}^2, M_{H_d}^2, m_{\tilde{f}}^2, M_2, \tan\beta$$

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





Question

How viable is a generic WIMP that interacts with quarks and/or gluons in light of *all* available constraints?

Model: 14 Operator DM EFT

$$\mathcal{L}_{\rm int} = \sum_{a,d} \frac{\mathcal{C}_a^{(d)}}{\Lambda^{d-4}} \mathcal{Q}_a^{(d)}$$

Dimension 6

$$\mathcal{Q}_{1,q}^{(6)} = (\overline{\chi}\gamma_\mu\chi)(\overline{q}\gamma^\mu q)\,,$$
$$\mathcal{Q}_{2,q}^{(6)} = (\overline{\chi}\gamma_\mu\gamma_5\chi)(\overline{q}\gamma^\mu q)\,,$$
$$\mathcal{Q}_{3,q}^{(6)} = (\overline{\chi}\gamma_\mu\chi)(\overline{q}\gamma^\mu\gamma_5 q)\,,$$
$$\mathcal{Q}_{4,q}^{(6)} = (\overline{\chi}\gamma_\mu\gamma_5\chi)(\overline{q}\gamma^\mu\gamma_5 q)$$

Dimension 7

$$\mathcal{Q}_1^{(7)} = \frac{\alpha_s}{12\pi}(\overline{\chi}\chi)G^{a\mu\nu}G^a_{\mu\nu}\,,$$
$$\mathcal{Q}_2^{(7)} = \frac{\alpha_s}{12\pi}(\overline{\chi}i\gamma_5\chi)G^{a\mu\nu}G^a_{\mu\nu}\,,$$
$$\mathcal{Q}_3^{(7)} = \frac{\alpha_s}{8\pi}(\overline{\chi}\chi)G^{a\mu\nu}\widetilde{G}^a_{\mu\nu}\,,$$
$$\mathcal{Q}_4^{(7)} = \frac{\alpha_s}{8\pi}(\overline{\chi}i\gamma_5\chi)G^{a\mu\nu}\widetilde{G}^a_{\mu\nu}\,,$$
$$\mathcal{Q}_{5,q}^{(7)} = m_q(\overline{\chi}\chi)(\overline{q}q)\,,$$
$$\mathcal{Q}_{6,q}^{(7)} = m_q(\overline{\chi}i\gamma_5\chi)(\overline{q}q)\,,$$
$$\mathcal{Q}_{7,q}^{(7)} = m_q(\overline{\chi}\chi)(\overline{q}i\gamma_5 q)\,,$$
$$\mathcal{Q}_{8,q}^{(7)} = m_q(\overline{\chi}i\gamma_5\chi)(\overline{q}i\gamma_5 q)\,,$$
$$\mathcal{Q}_{9,q}^{(7)} = m_q(\overline{\chi}\sigma^{\mu\nu}\chi)(\overline{q}\sigma_{\mu\nu}q)\,,$$
$$\mathcal{Q}_{10,q}^{(7)} = m_q(\overline{\chi}i\sigma^{\mu\nu}\gamma_5\chi)(\overline{q}\sigma_{\mu\nu}q)$$

24 total parameters to scan over: 14 Wilson coefficients, DM mass, new physics scale, and 8 nuisance parameters

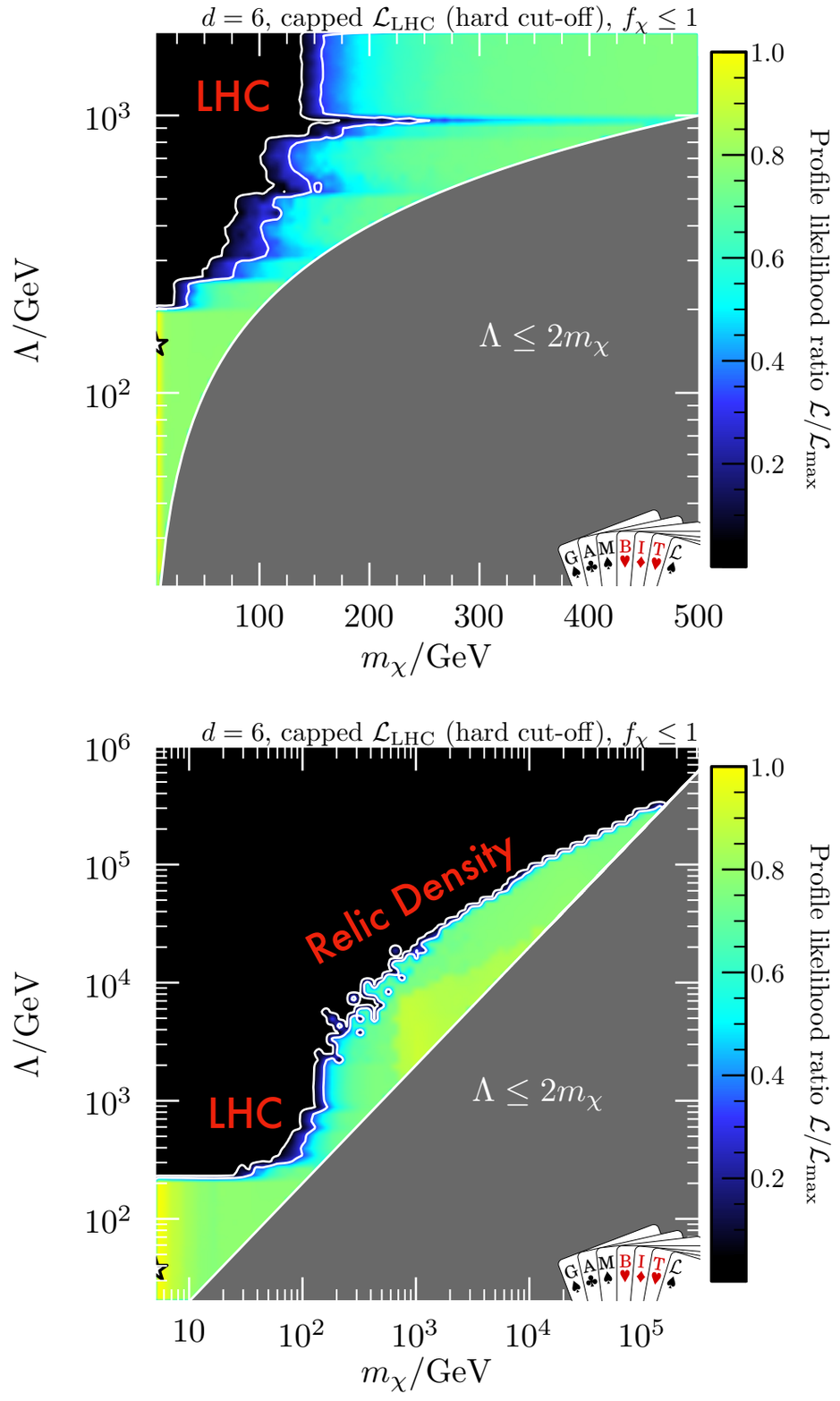
Likelihoods

- *Direct Detection:* Xenon1T, PandaX, DarkSide 50, CRESST-III, etc.
- *Indirect Detection:*
  - *Fermi* search for gamma rays from dwarf spheroidal galaxies
  - IceCube solar neutrinos
- *Large Hadron Collider*: ATLAS and CMS monojet analyses (capped and uncapped)
- *Cosmology - Planck:*
  - DM density (as an overclosure limit)
  - Limits on energy injection from DM annihilation in the early universe
- *Nuisance likelihoods:* DM halo parameters, top quark mass, DD nuclear parameters

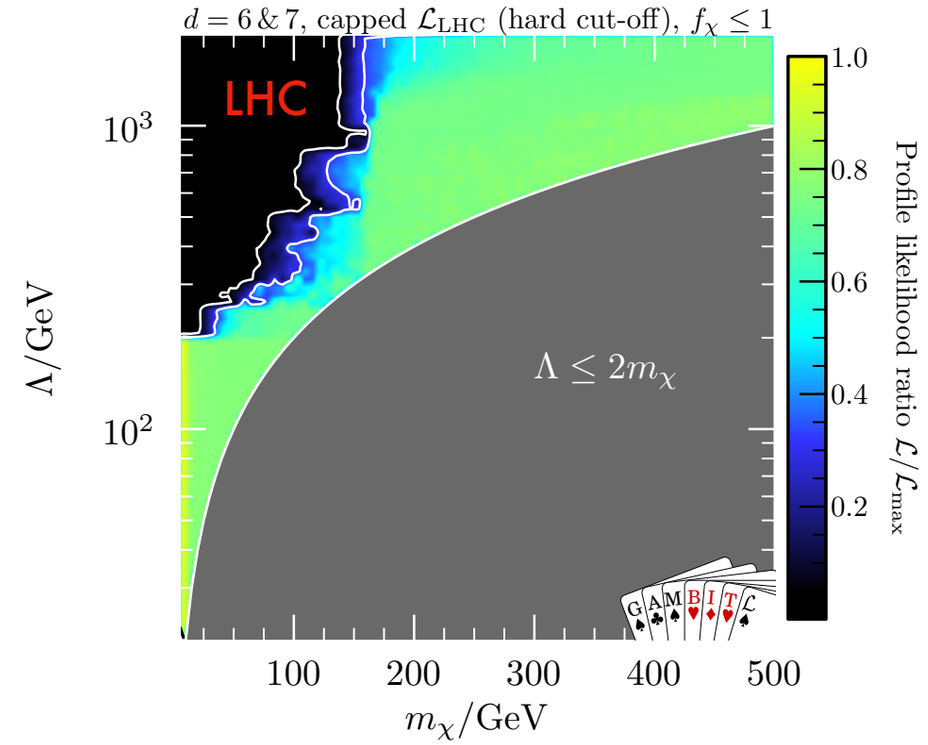
$$\mathscr{L}_{\text{total}} = \mathscr{L}_{\text{DD}} \mathscr{L}_{\text{ID}} \mathscr{L}_{\text{LHC}} \mathscr{L}_{\text{cosmo}} \mathscr{L}_{\text{nuisance}}$$

Limits on DM Mass and New Physics Scale

Dimension 6 Operators



Dimension 6 and 7 Operators

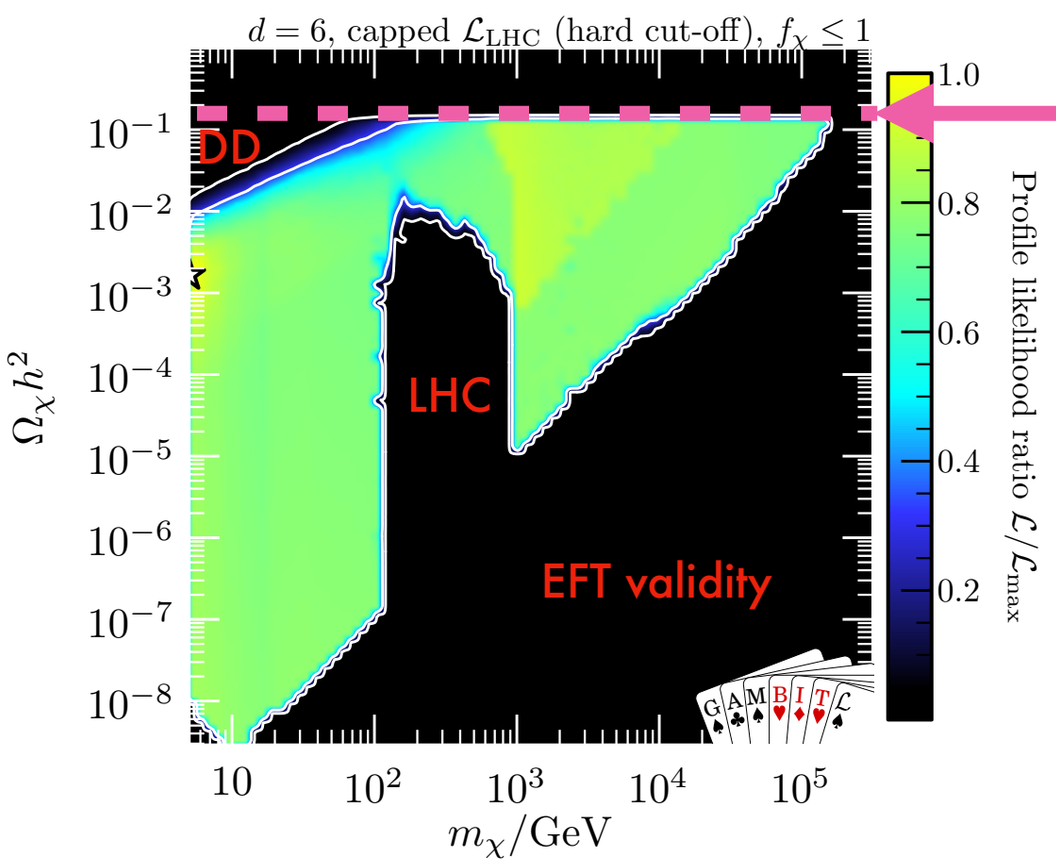


- Little difference between allowed parameter space for the two sets of operators

arXiv:2106.02056

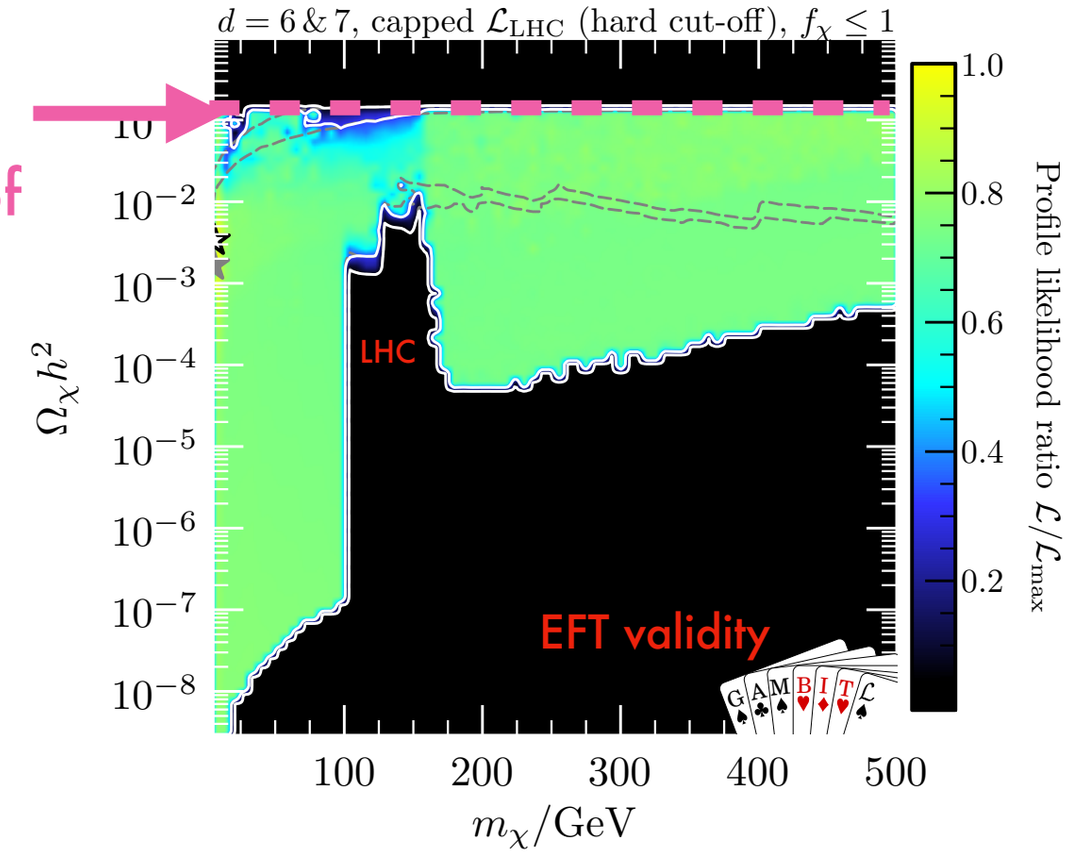
Relic Density

Dimension 6 Operators



χ is 100% of DM

Dimension 6 and 7 Operators

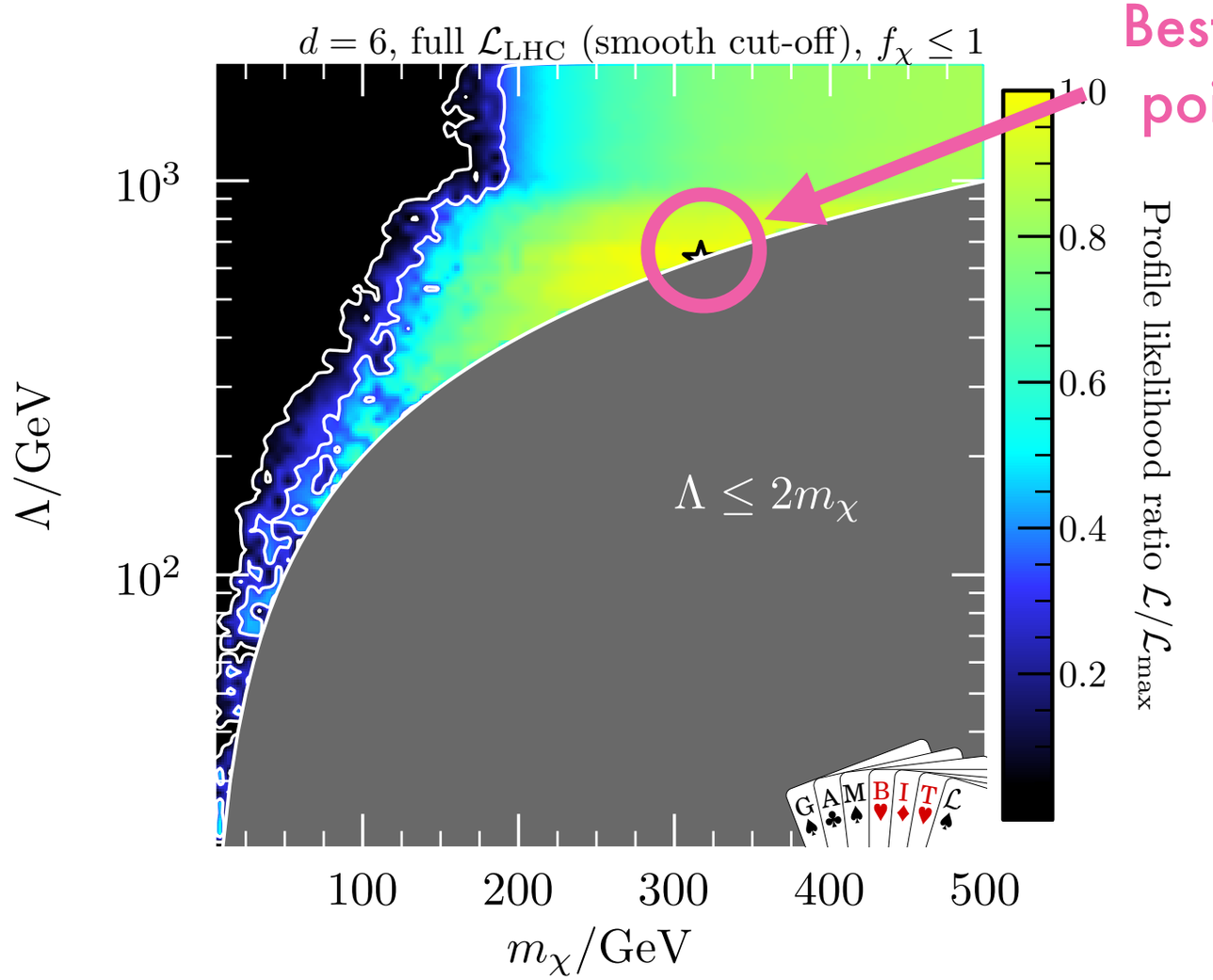


- With just dimension 6 operators, χ can only be a portion of the total DM of the universe when m_χ < 100 GeV

arXiv:2106.02056

Large Hadron Collider

Removing the cap on the LHC likelihood (so that it can exceed the SM value), the best fit region is determined by small excesses in the ATLAS and CMS monojet searches.



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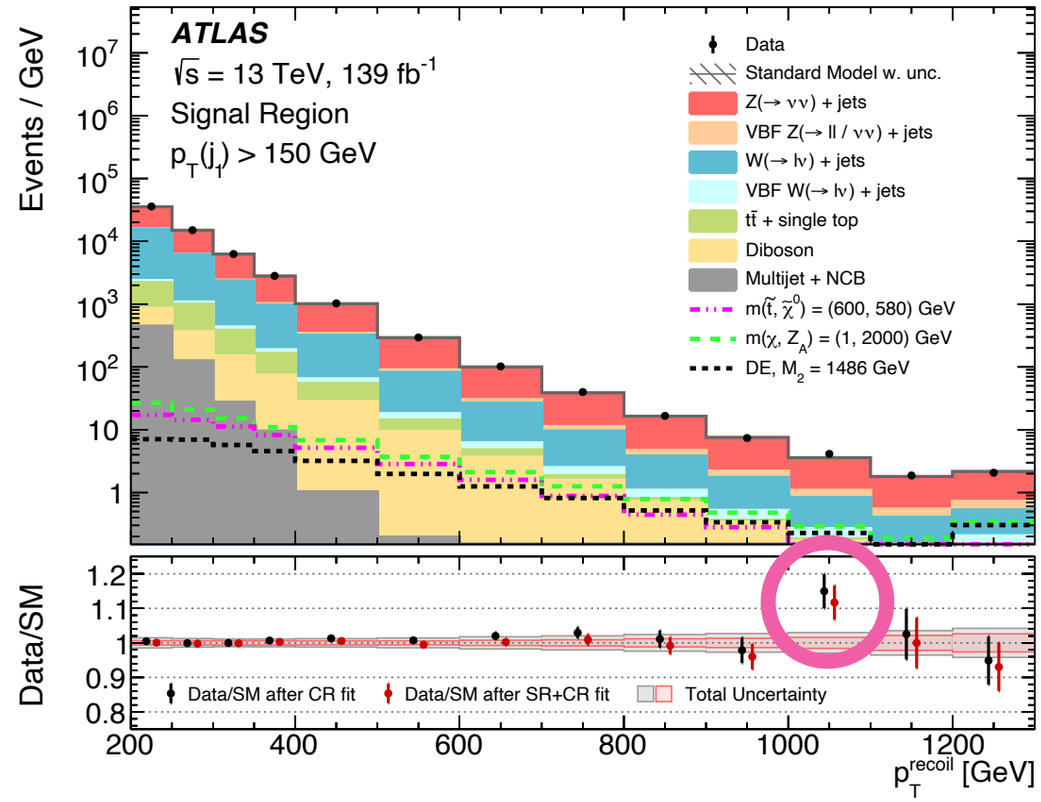

ATLAS, arXiv:2102.10874
also CMS, arXiv:1712.02345

The preferred region here is to some degree an artifact of how we implemented the EFT validity requirement. It should be interpreted *with care!*

Summary

- GAMBIT is a publicly available tool (download it and try it!) for undertaking global fits of essentially any BSM model. It is rapidly growing in scope, with particularly substantial new additions in cosmology.
- We have used this code to do a global fit of a set of EFT operators that give rise to interactions between a WIMP, quarks, and gluons.
- We find that even just considering the dimension 6 operators, nearly all of the WIMP parameter space remains open, and with the addition of the dimension 7 operators, it is possible for this WIMP to make up 100% of the DM down to low masses.

Backups

Operator Properties

	SI scattering	SD scattering	Annihilations
Dimension-6 operators			
$\mathcal{Q}^{(6)}_{1,q} = (\overline{\chi}\gamma_\mu\chi)(\overline{q}\gamma^\mu q)$	unsuppressed	—	s-wave
$\mathcal{Q}^{(6)}_{2,q} = (\overline{\chi}\gamma_\mu\gamma_5\chi)(\overline{q}\gamma^\mu q)$	suppressed	—	p-wave
$\mathcal{Q}^{(6)}_{3,q} = (\overline{\chi}\gamma_\mu\chi)(\overline{q}\gamma^\mu\gamma_5 q)$	—	suppressed	s-wave
$\mathcal{Q}^{(6)}_{4,q} = (\overline{\chi}\gamma_\mu\gamma_5\chi)(\overline{q}\gamma^\mu\gamma_5 q)$	—	unsuppressed	s-wave $\propto m_q^2/m_\chi^2$
Dimension-7 operators			
$\mathcal{Q}^{(7)}_1 = \frac{\alpha_s}{12\pi}(\overline{\chi}\chi)G^{a\mu\nu}G^a_{\mu\nu}$	unsuppressed	—	p-wave
$\mathcal{Q}^{(7)}_2 = \frac{\alpha_s}{12\pi}(\overline{\chi}i\gamma_5\chi)G^{a\mu\nu}G^a_{\mu\nu}$	suppressed	—	s-wave
$\mathcal{Q}^{(7)}_3 = \frac{\alpha_s}{8\pi}(\overline{\chi}\chi)G^{a\mu\nu}\widetilde{G}^a_{\mu\nu}$	—	suppressed	p-wave
$\mathcal{Q}^{(7)}_4 = \frac{\alpha_s}{8\pi}(\overline{\chi}i\gamma_5\chi)G^{a\mu\nu}\widetilde{G}^a_{\mu\nu}$	—	suppressed	s-wave
$\mathcal{Q}^{(7)}_{5,q} = m_q(\overline{\chi}\chi)(\overline{q}q)$	unsuppressed	—	p-wave $\propto m_q^2/m_\chi^2$
$\mathcal{Q}^{(7)}_{6,q} = m_q(\overline{\chi}i\gamma_5\chi)(\overline{q}q)$	suppressed	—	s-wave $\propto m_q^2/m_\chi^2$
$\mathcal{Q}^{(7)}_{7,q} = m_q(\overline{\chi}\chi)(\overline{q}i\gamma_5 q)$	—	suppressed	p-wave $\propto m_q^2/m_\chi^2$
$\mathcal{Q}^{(7)}_{8,q} = m_q(\overline{\chi}i\gamma_5\chi)(\overline{q}i\gamma_5 q)$	—	suppressed	s-wave $\propto m_q^2/m_\chi^2$
$\mathcal{Q}^{(7)}_{9,q} = m_q(\overline{\chi}\sigma^{\mu\nu}\chi)(\overline{q}\sigma_{\mu\nu}q)$	loop-induced	unsuppressed	s-wave $\propto m_q^2/m_\chi^2$
$\mathcal{Q}^{(7)}_{10,q} = m_q(\overline{\chi}i\sigma^{\mu\nu}\gamma_5\chi)(\overline{q}\sigma_{\mu\nu}q)$	loop-induced	suppressed	s-wave $\propto m_q^2/m_\chi^2$

Missing Energy Spectra