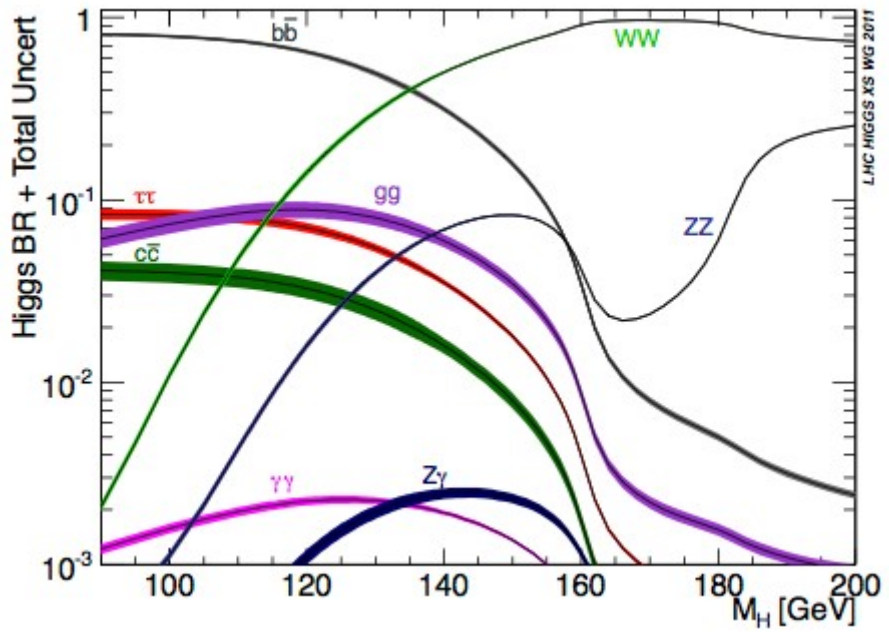
The Global and Modular BSM Inference Tool

Martin White

The Higgs discovery in 2012 gave us:

- The last piece of the SM
- The last occasion when we could unambiguously tell what a collider has discovered

What happens if the LHC sees a dramatic missing energy signature?




LIVE
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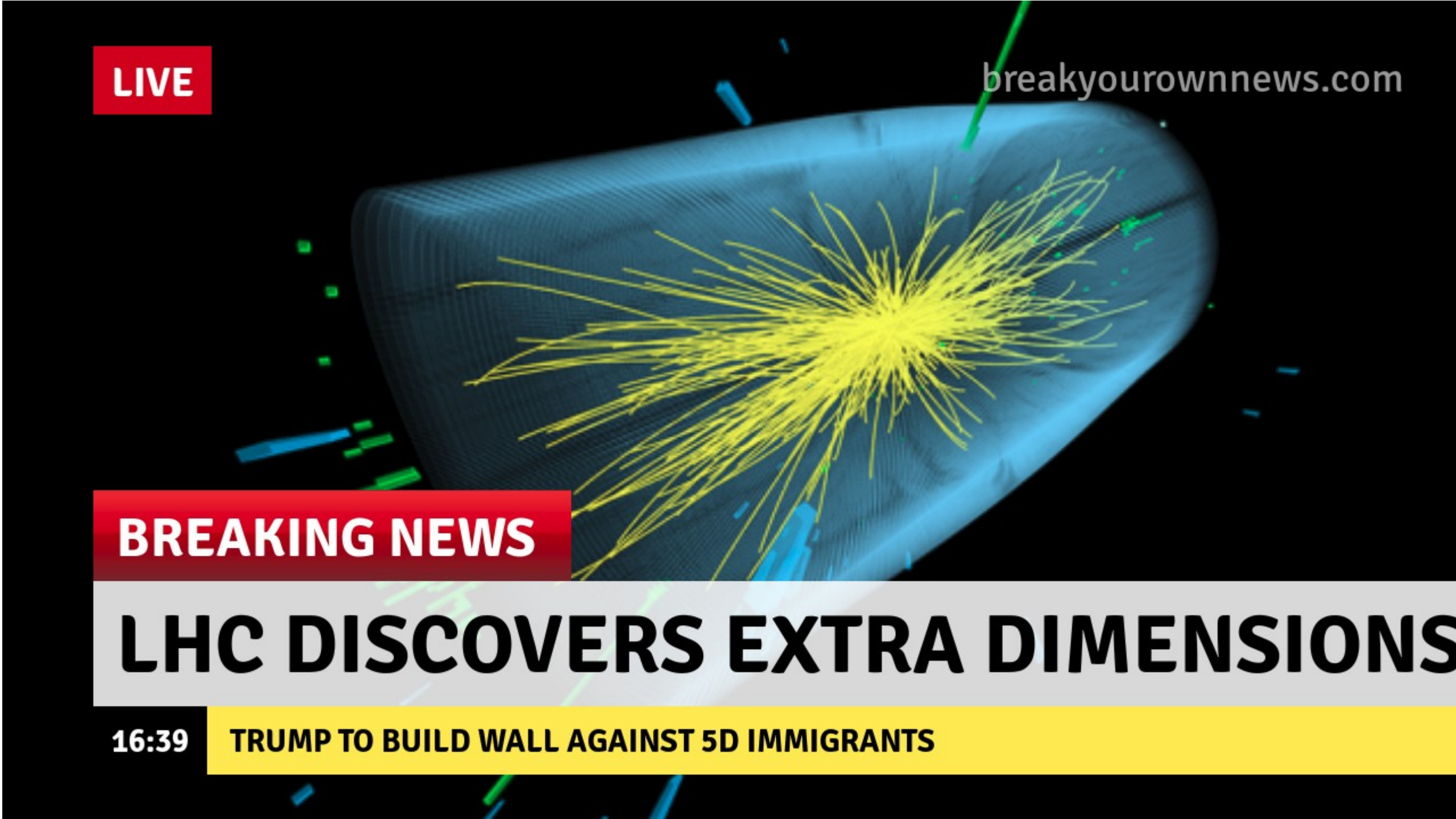
BREAKING NEWS
LHC DISCOVERS SUPERSYMMETRY
16:36
GORDON KANE "PREDICTED MASS SPECTRUM IN 2003"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BREAKING NEWS
LHC DISCOVERS EXTRA DIMENSIONS
16:39
TRUMP TO BUILD WALL AGAINST 5D IMMIGRANTS


LIVE
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BREAKING NEWS
LHC DISCOVERS DARK MATTER
10:33
EXCEPT IT MIGHT NOT BE: WE ONLY KNOW IT IS STABLE ON DETECTOR TIMESCALES

Possible discoveries and assumptions

- We might discover something decaying visibly:

Default assumption: something to do with EWSB

- We might discover something decaying (semi-) invisibly

Default assumption: something to do with DM

- We might discover nothing extra at all at the LHC

How do we make further progress?

BSM physics might show up anywhere...

- colliders (LHC + previous)
- measurements of the magnetic moment of the muon
- electroweak precision tests
- dark matter direct detection experiments
- searches for antimatter in cosmic rays, nuclear cosmic ray ratios
- radio astronomy data
- effects of dark matter on reionisation, recombination and helioseismology
- relic density (CMB + other data)
- neutrino masses and mixings
- Indirect DM searches (e.g. FERMI-LAT, HESS, CTA, IceCube, etc)

NEED TO COMBINE DATA FROM LOTS OF SOURCES

How to combine data

- Correct answer is to use a global statistical fit
- Frequentist or Bayesian methods available
- Calculate a **combined likelihood**:

$$\mathcal{L} = \mathcal{L}_{\text{collider}} \mathcal{L}_{\text{DM}} \mathcal{L}_{\text{flavor}} \mathcal{L}_{\text{EWPO}} \cdots$$

Parameter estimation

Given a particular model, which set of parameters best fits the available data

(Rigorous exclusion limits and parameter measurements)

Model comparison

Given a set of models, which is the best description of the data, and how much better is it?

(Model *X* is now worse than model *Y*)

The dream

Global fit results

- Recent years have seen an explosion of tools that make study of user-defined Lagrangians easier

  - e.g. Feynrules → Madgraph, CalcHEP → Micromegas, MadDM, NLOCT + much, much more

- Even so, a general global fit tool requires some very tricky innovations:

  - calculations are not allowed to know about Lagrangian parameters – how do you do that?
  - how do you make an easy interface for tying existing code together?
  - how do you store parameters in a scale independent way, but reintroduce scales in calculations?
  - how do you make LHC constraints model independent?
  - how do you make astrophysical constraints model independent?
  - ***how do we do all of this fast enough to get convergence within the age of the universe?***

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, CMS, CTA, *Fermi*-LAT, DARWIN, IceCube, LHCb, SHiP, XENON

Authors of: DarkSUSY, DDCalc, Diver, FlexibleSUSY, gamlike, GM2Calc, IsaJet, nulike, PolyChord, Rivet, SOFTSUSY, SuperIso, SUSY-AI, WIMPSim

Collaborators:
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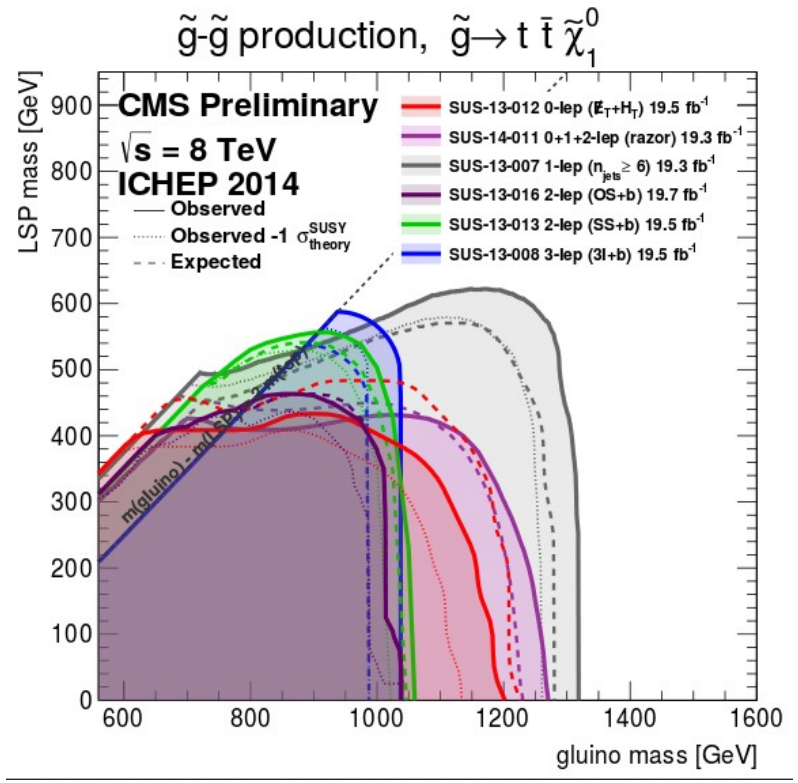
40+ participants in 10 Experiments & 14 major theory codes

GAMBIT modules

- **ColliderBit:** collider observables including Higgs + SUSY Searches from ATLAS, CMS, LEP
- **DarkBit:** WIMP dark matter observables (relic density, direct & indirect detection), plus axions
- **FlavBit:** including $g-2$, $b \to s\gamma$, B decays (new channels), angular obs., theory unc., LHCb likelihoods
- **SpecBit:** generic BSM spectrum object, providing RGE running, masses, mixings
- **DecayBit:** decay widths for all relevant SM and BSM particles
- **PrecisionBit:** precision EW tests (mostly via interface to FeynHiggs or SUSY-POPE)
- **ScannerBit:** manages stats, sampling and optimisation
- **NeutrinoBit:** likelihoods to right-handed neutrino studies

- **CosmoBit:** See Janina Renk, cosmology stream, 16.45 Thursday

LHC limits: the problem



ColliderBit

- Handles LHC and LEP limits
- LEP: complete recast of sparticle xsec limits
- SUSY & Exotic LHC search limits from real-time MC simulation
- LHC Higgs-like resonance search limits from HiggsBounds+HiggsSignals
- Future: new resonance limits

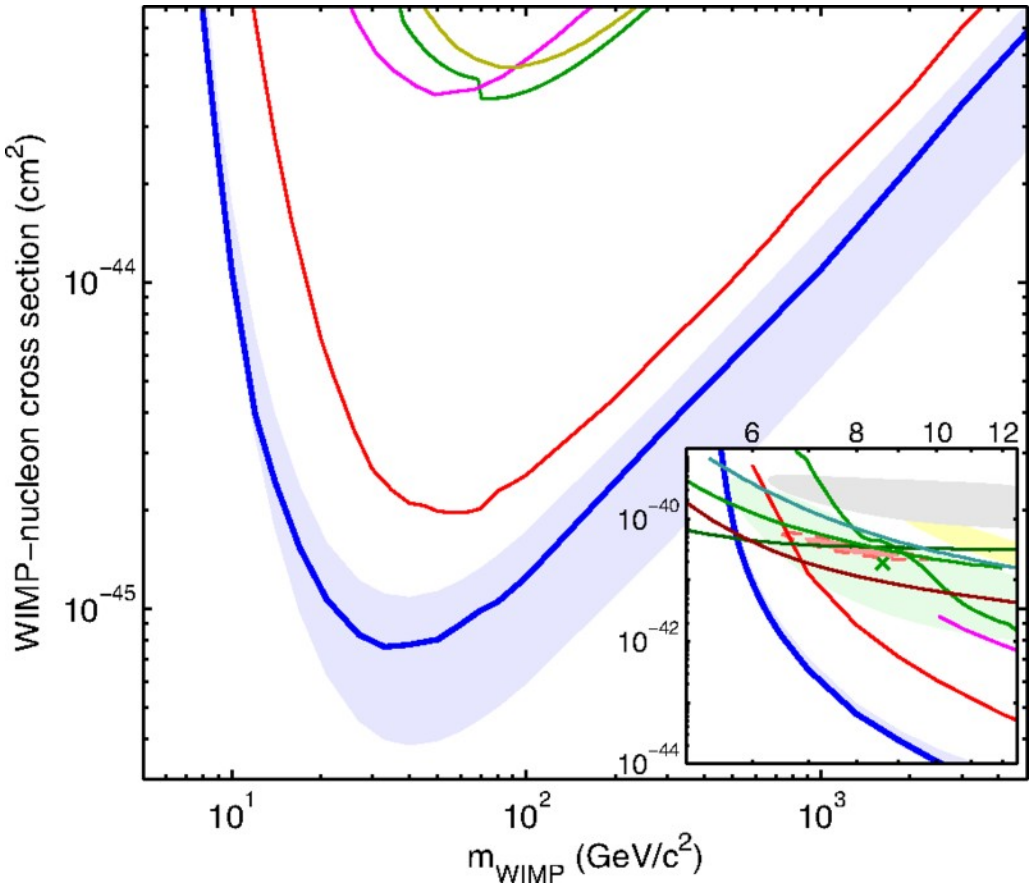
Model independent LHC limits

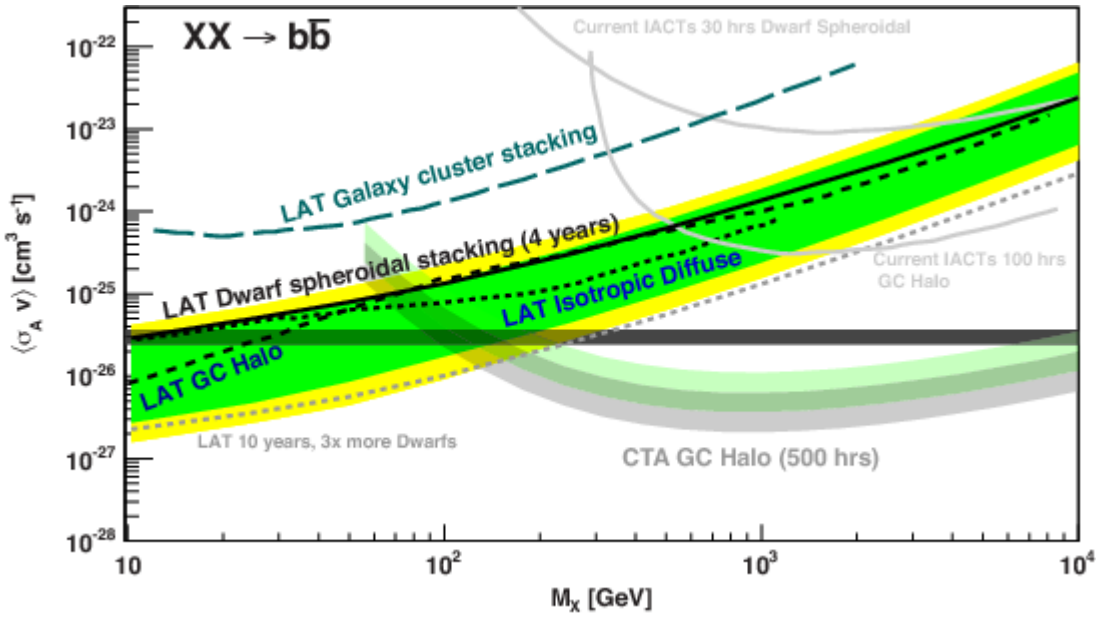
- Custom parallelised Pythia MC + custom detector sim
- Can generate 20,000 events on 12 cores in < 5 s
- Then apply Poisson likelihood with nuisance parameters for systematics
- Combine analyses using best expected exclusion
- The best you can do without extra public info from the experiments. ATLAS & CMS are getting better at this:

https://cds.cern.ch/record/2242860/files/NOTE2017_001.pdf

http://cds.cern.ch/record/2684863

Astro limits: the problem

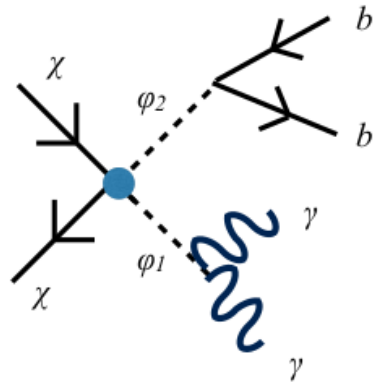


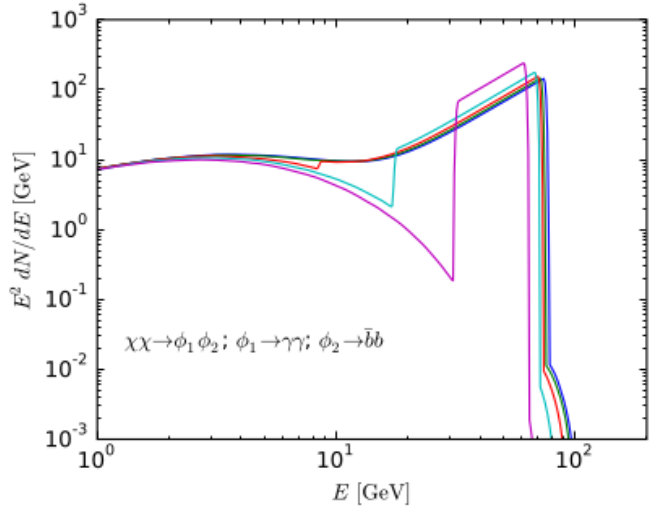


DarkBit: indirect detection

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)



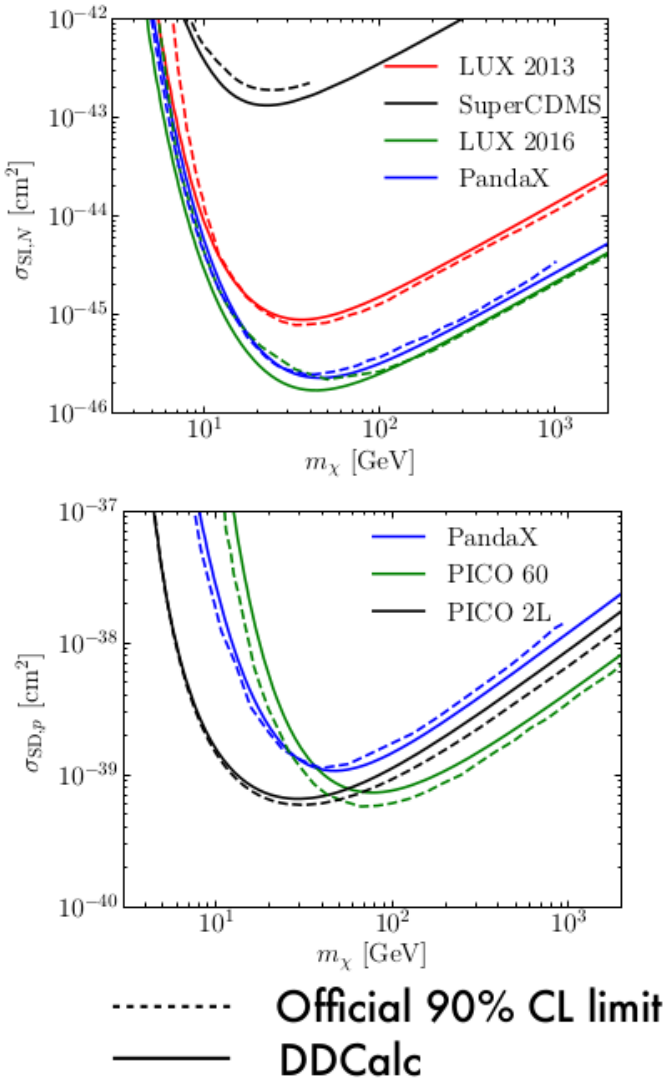


Solar neutrinos:

- 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



This afternoon

- Pat's talk: Recent GAMBIT EWMSSM results
- Sanjay's talk: more details of how GAMBIT works, plus the new GAMBIT Universal Model system
- Tomas Gonzalo: Recent GAMBIT right-handed neutrino results
- Ankit Beniwal (DM stream): Higgs portal results

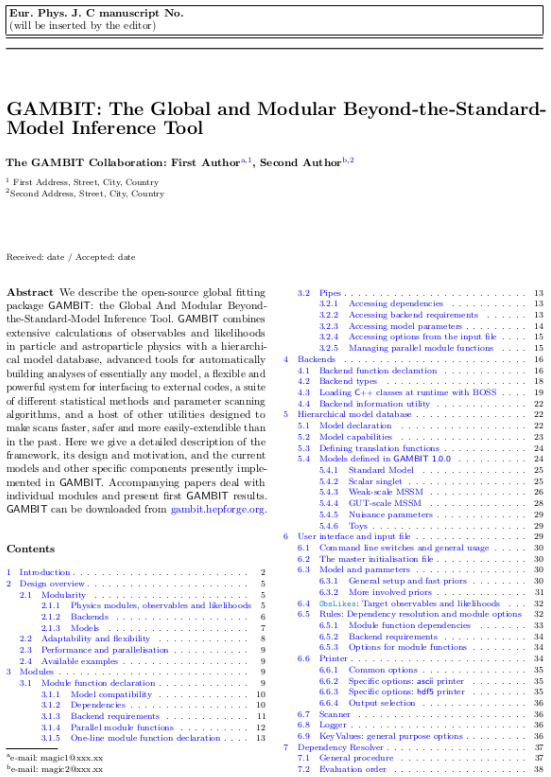
Summary

- GAMBIT is an excellent ***open source public tool*** for particle astrophysics global fits

- Lots of public results (design, manual + physics studies of CMSSM/NUHM1/NUHM2, MSSM7, EWMSSM, RH neutrinos, axions, Higgs portal DM)

- Samples from all current studies are available for study (e.g. developing new LHC search techniques)

- See **gambit.hepforge.org** for more info



Eur. Phys. J. C manuscript No.
(will be inserted by the editor)

GAMBIT: The Global and Modular Beyond-the-Standard-Model Inference Tool

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Received: date / Accepted: date

Abstract We describe the open-source global fitting package GAMBIT: the Global And Modular Beyond-the-Standard-Model Inference Tool. GAMBIT combines extensive calculations of observables and likelihoods in particle and astroparticle physics with a hierarchical model database, advanced tools for automatically building analyses of essentially any model, a flexible and powerful system for interfacing to external codes, a suite of different statistical methods and parameter scanning algorithms, and a host of other utilities designed to make scans faster, safer and more easily-extendible than in the past. Here we give a detailed description of the framework, its design and motivation, and the current models and other specific components presently implemented in GAMBIT. Accompanying papers deal with individual modules and present first GAMBIT results. GAMBIT can be downloaded from gambit.hepforge.org.

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