A preview of GAMBIT

Pat Scott

Imperial College London

on behalf of the GAMBIT Collaboration
http://gambit.hepforge.org

Let’s begin with dessert.

GAMBIT: The Global And Modular BSM Inference Tool

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GAMBIT: The **G**lobal **A**nd **M**odular **B**SM **I**nference **T**ool

So what *is* GAMBIT?

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3 things:

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3 things:

- A collaboration of about thirty theorists and experimentalists
- A new public global fitting code
- A program of physics analyses that we're carrying out using the code

First physics results and code release in a few months (i.e. late summer this year)

Outline

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Combining searches I

Question

How do we know which models are in and which are out?

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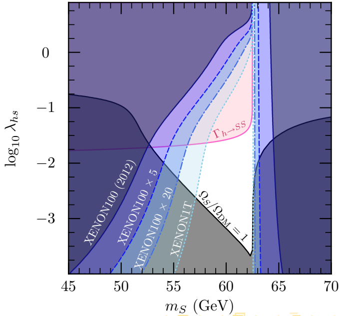
How do we know which models are in and which are out?

Answer

Combine the results from different searches

- Simplest method: take different exclusions, overplot them, conclude things are "allowed" or "excluded"
- Simplest BSM example: the scalar singlet model

(Cline, Kainulainen, PS & Weniger, *PRD*, 1306.4710)



Combining searches II

That's all well and good if there are only 2 parameters and few searches. . .

Question

What if there are many different constraints?

Combining searches II

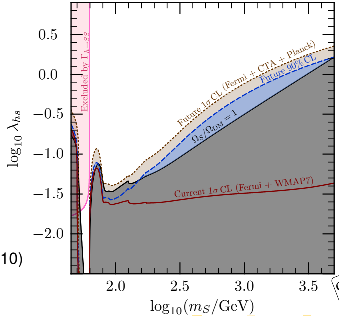
That's all well and good if there are only 2 parameters and few searches…

Question

What if there are many different constraints?

Answer

Combine constraints in a statistically valid way
$\longrightarrow$ composite likelihood



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Combining searches III

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Question

What if there are many parameters?

Combining searches III

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Question

What if there are many parameters?

Answer

Need to

- scan the parameter space (smart numerics)
- interpret the combined results (Bayesian / frequentist)
- project down to parameter planes of interest (marginalise / profile)

$\longrightarrow$ global fits

Beyond-the-Standard-Model Scanning

Goals:

1. Given multiple theories, determine which fit the data better, and quantify how much better
2. Given a particular theory, determine which parameter combinations fit all experiments, and how well

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Why simple IN/OUT analyses are not enough…

- Only partial goodness of fit, no measure of convergence, no idea how to generalise to regions or whole space.
- Frequency/density of models in IN/OUT scans is not proportional to probability $\Longrightarrow$ no statistical meaning.
- $\rightarrow$ statements about a theory's general ability to do one thing or another, based on such scans, are statistically invalid

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The LHC likelihood monster

Time per point:

$\mathcal{O}$(*minute*) in best cases

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About 2 orders of magnitude too slow to actually include LHC data in global fits properly

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→ More in Martin's presentation

Doing genuinely 'model-independent' DM pheno

All experimental limits in terms of simplified models: effective WIMP, one annihilation channel, etc

$\Longrightarrow$ need something to apply limits to arbitrary DD couplings and ID decay/annihilation branching fractions
$\Longrightarrow$ must include accurate treatment of experimental effects

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$\rightarrow$ nulike, gamlike, DDcalc, cascade sim $\rightarrow$ Christoph's talk

Parameter space → Theory space

CMSSM, MSSM, Simplified Models $\neq$ BSM

Want to do model comparison to actually work out which theory is the best…

Challenge:

How do I easily adapt a global fit to different BSM theories?

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Challenge:

How do I easily adapt a global fit to different BSM theories?

Somehow, we must recast things quickly to a new theory

- data
- likelihood functions
- scanning code ‘housekeeping’
- even predictions

$\Longrightarrow$ a new, very abstract global fitting framework

Hitting the wall

Issues with current global fit codes:

- Strongly wedded to a few theories (e.g. constrained MSSM / mSUGRA)
- Strongly wedded to a few theory calculators
- All datasets and observables basically hardcoded
- Rough or non-existent treatment of most experiments (astroparticle + collider especially)
- Sub-optimal statistical methods / search algorithms
- $\Longrightarrow$ *already hitting the wall on theories, data & computational methods*

Outline

GAMBIT: a *second-generation* global fit code

GAMBIT: Global And Modular BSM Inference Tool

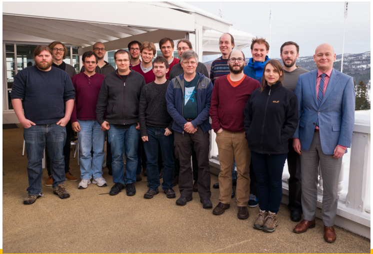
Overriding principles of GAMBIT: flexibility and modularity

- General enough to allow fast definition of new datasets and theoretical models
- Plug and play scanning, physics and likelihood packages
- Extensive model database – not just small modifications to constrained MSSM (NUHM, etc), and not just SUSY!
- Extensive observable/data libraries (likelihood modules)
- Many statistical options – Bayesian/frequentist, likelihood definitions, scanning algorithms
- A smart and *fast* LHC likelihood calculator
- Massively parallel
- Full open-source code release

The GAMBIT Collaboration

26 Members, 15 institutions, 9 countries
8 Experiments, 4 major theory codes

Fermi-LAT	J. Conrad, J. Edsjö, G. Martinez P. Scott
ATLAS	A. Buckley, P. Jackson, C. Rogan, A. Saavedra, M. White
CTA	C. Balázs, T. Bringmann, J. Conrad, M. White
HESS	J. Conrad
LHCb	M. Chrząszcz, N. Serra
IceCube	J. Edsjö, C. Savage, P. Scott
AMS-02	A. Putze
CDMS, DM-ICE	L. Hsu
XENON/DARWIN	J. Conrad
Theory	P. Athron, C. Balázs, T. Bringmann, J. Cornell, L. Dal, J. Edsjö, B. Farmer, A. Krislock, A. Kvellestad, M. Pato, F. Mahmoudi, A. Raklev, C. Savage, P. Scott, C. Weniger, M. White



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Modules

Physics Modules

- ColliderBit (Martin's talk)
- DarkBit (Christoph's talk)
- FlavBit – flavour physics inc. $g-2$, $b \rightarrow s\gamma$, B decays (new channels, theory uncerts, LHCb likelihoods)
- SpecBit – generic BSM spectrum object, providing RGE running, masses, mixings, etc via interchangeable interfaces to different RGE codes
- DecayBit – decay widths for all relevant SM & BSM particles
- EWPOBit – precision tests (mostly by interface to FeynHiggs, alt. SUSY-POPE)

+ScannerBit: manages statistics, parameter sampling and optimisation algorithms

Backends: mix and match

- GAMBIT modules consist of a number of standalone **module functions**
- Module functions can depend on each other, or they can require specific functions from **backends**
- Backends are external code libraries (DarkSUSY, FeynHiggs, etc) that include different functions
- GAMBIT automates and abstracts the interfaces to backends → backend functions are tagged according to what they calculate
- → with appropriate module design, different backends and their functions can be used interchangeably
- GAMBIT dynamically adapts to use whichever backends are actually present on a user's system (+ provides details of wtf it did of course)

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- Module functions can depend on each other, or they can

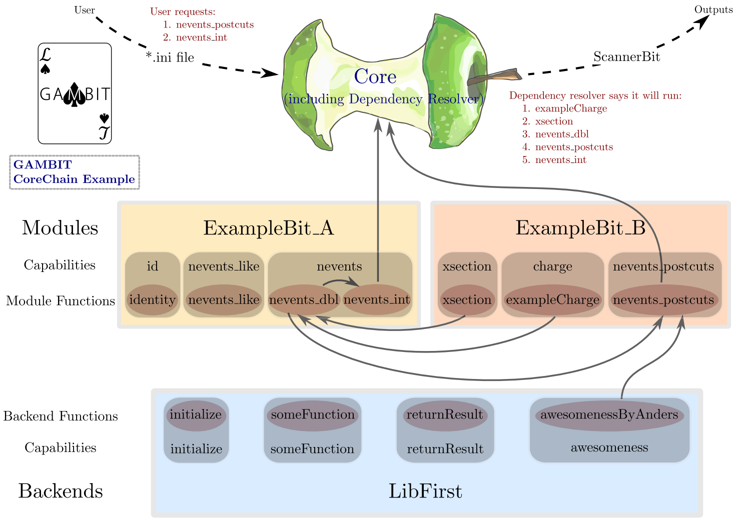
```
crunchbang@crunchbang:/media/Mustang/gambit/modules$ ./gambit backends

This is GAMBIT.

Backends               Version     Path to lib                              Status          #funcs   #types   #ctors
-----------------------------------------------------------------------------------------------------------------------
BOSSMinimalExample     1.0         Backends/lib/libminimal_1_0.so           OK              0        2        4
                       1.1         Backends/lib/libminimal_1_1.so           OK              0        2        4
                       1.2         Backends/lib/libminimal_1_2.so           OK              0        2        4
DDCalc0                0.0         Backends/lib/libDDCalc0.so               OK              44       0        0
DarkSUSY               5.1.1       ../extras/DarkSUSY/lib/libdarksusy.so    OK              44       0        0
FastSim                1.0         Backends/lib/libfastsim.so               absent/broken   1        0        0
FeynHiggs              2.10        Backends/lib/libfeynhiggs.so             absent/broken   11       0        0
HiggsBounds            4.1         Backends/lib/libhiggsbounds.so           absent/broken   8        0        0
HiggsSignals           1.2         Backends/lib/libhiggssignals.so          absent/broken   9        0        0
LibFarrayTest          1.0         Backends/lib/libFarrayTest.so            OK              9        0        0
LibFirst               1.0         Backends/lib/libfirst.so                 OK              8        0        0
                       1.1         Backends/lib/libfirst.so                 OK              12       0        0
LibFortran             1.0         Backends/lib/libfortran.so               OK              6        0        0
MicrOmegas             3.5.5       /no/path/in/config/backend_locations/    absent/broken   14       0        0
Pythia                 8.186       Backends/lib/libpythia8.so               OK              0        6        37
SUSY_HIT               1.4         ../../SUSY-HIT/susyhit.so                OK              51       0        0
SuperIso               3.4         Backends/lib/libsuperiso.so              absent/broken   31       0        0
gamLike                1.0.0       Backends/lib/libgamLike.so               OK              5        0        0
nulike                 1.0.0       ../extras/nulike/lib/libnulike.so        OK              4        0        0
-----------------------------------------------------------------------------------------------------------------------
All relative paths are given with reference to /media/Mustang/gambit/modules.
```

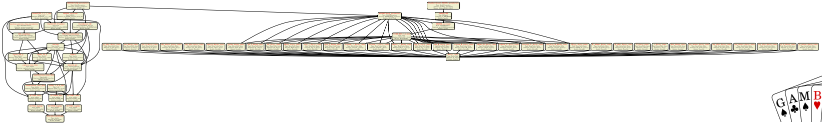
are actually present on a user's system (+ provides details of wtf it did of course)

GAMBIT: a toy example



Dependency Resolution

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



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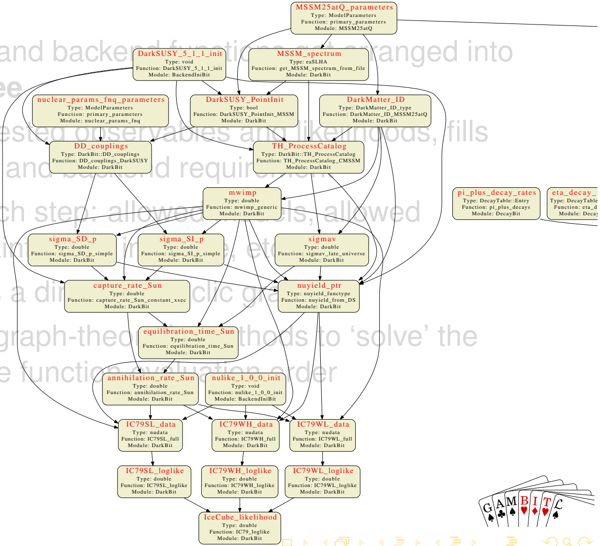
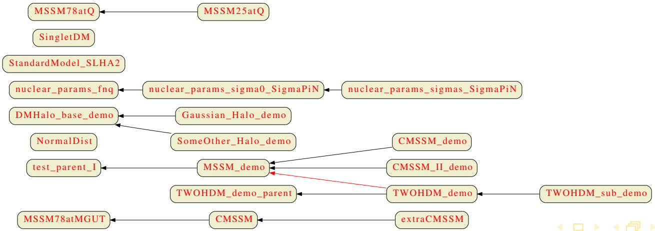


Hierarchical Model Database

- Models are defined by their parameters and relations to each other
- Models can inherit from **parent models**
- Points in child models can be **automatically translated** to ancestor models
- **Friend models** also allowed (cross-family translation)
- Model dependence of every module/backend function is tracked $\Longrightarrow$ maximum safety, maximum reuse



Interface: yaml file

Basic interface for a scan is a YAML initialisation file

- specify parameters, ranges, priors
- select likelihood components
- select other observables to calculate
- define generic rules for how to fill dependencies
- define generic rules for options to be passed to module functions
- set global options (scanner, errors/warnings, logging behaviour, etc)

```yaml
Parameters:
  StandardModel_SLHA2: !import StandardModel_SLHA2_default
  MSSM25atQ: !import LesHouches.in.MSSM_1.yaml

Priors:
    # none: all parameters fixed in this example.

Scanner:

  use_scanner: toy_mcmc

  scanners:
    toy_mcmc:
      plugin: toy_mcmc
      point_number: 2000
      output_file:  output
      like:  Likelihood

ObsLikes:

  # Test DecayBit
  - purpose:      Test
    capability:   decay_rates
    type:         DecayTable

  # 79-string IceCube likelihood
  - capability: IceCube_likelihood
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Rules:

  - capability: MSSM_spectrum
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Expansion: adding new functions

Adding a new module function is easy:

1. Declare the function to GAMBIT in a module's **rollcall header**
   - Choose a capability
   - Declare any **dependencies**
   - Declare any **backend requirements**
   - Declare any specific **allowed models**
   - other more advanced declarations also available

```
#define MODULE FlavBit
START_MODULE

  #define CAPABILITY Kmunu_pimunu                // Observable: BR(K->mu nu)/BR(pi->mu nu)
  START_CAPABILITY
    #define FUNCTION SI_Kmunu_pimunu             // Name of specific function providing the observable
    START_FUNCTION(double)                       // Function calculates a double precision variable
      DEPENDENCY(FlavBit_fill, parameters)       // Needs some other function to caluclate FlavBit_fill data
      BACKEND_REQ(Kmunu_pimunu, (libsuperiso), double, (struct parameters*)) // Needs a function from a backend
      BACKEND_OPTION( (SuperIso, 3.4), (libsuperiso) )                       // Backend must be SuperIso v3.4
      ALLOW_MODELS(MSSM78atQ, MSSM78atMGUT)      // Can be used with GUT-scale or other-scale MSSM-78, and all their children
    #undef FUNCTION
  #undef CAPABILITY
```

2. Write the function as a simple C++ function (one argument: the result)

Other nice technical features

- **Scanners**: MultiNest, Diver (diff. evolution), PIKAIA (genetic algorithms), GreAT (MCMC)
- **Statistics**: Bayesian, Profile Likelihood, later full Neyman
- Mixed-mode **MPI + openMP**, mostly automated
- diskless generalisation of various Les Houches Accords
- **BOSS**: dynamic loading of C++ classes from backends (!)
- **all-in or module standalone** modes – easily implemented from single cmake script
- **automatic getters** for obtaining, configuring + compiling backends[1]
- **flexible output streams** (ASCII, databases, binary, . . .)
- more more more. . .

[1] if a backend breaks, won't compile and/or kills your dog, blame the authors (not us. . . unless we **are** the authors. . .)

GAMBIT vs the rest – in a nutshell

Aspect	GAMBIT	MasterCode	SuperBayeS	Fittino	Rizzo et al.
Design	Modular, Adaptive	Monolithic	Monolithic	($\sim$)Monolithic	Monolithic
Statistics	Frequentist, Bayesian	Frequentist	Freq./Bayes.	Frequentist	None
Scanners	Differential evolution, genetic algorithms, random forests, t-walk, t-nest, particle swarm, nested sampling, MCMC, gradient descent	Nested sampling, MCMC, grad. descent	Nested sampling, MCMC	MCMC	None (random)
Theories	(p)MSSM-25, CMSSM$\pm\epsilon$, GMSB, AMSB, gaugino mediation, E6MSSM, NMSSM, BMSSM, PQMSSM, effective operators, iDM, XDM, ADM, UED, Higgs portals/extended Higgs sectors	CMSSM$\pm\epsilon$	(p)MSSM-15, CMSSM$\pm\epsilon$, mUED	CMSSM$\pm\epsilon$	(p)MSSM-19
Astroparticle	Event-level: IceCube, Fermi, LUX, XENON, CDMS, DM-ICE. Basic: Ω_{DM}, AMS-02, COUPP, KIMS, CRESST, CoGeNT, SIMPLE, PAMELA, Planck, HESS. Predictions: CTA, DARWIN, GAPS	Basic: Ω_{DM}, LUX, XENON	Basic: Ω_{DM}, Fermi, IceCube, XENON	Basic: Ω_{DM}, Fermi, HESS, XENON	Event-level: Fermi. Basic: Ω_{DM}, IceCube, CTA
LHC	ATLAS+CMS multi-analysis with neural net and fast detector simulation. Higgs multi-channel with correlations and no SM assumptions. Full flavour inc. complete $B \to X_s ll$ and $B \to K^* ll$ angular set.	ATLAS resim, HiggsSignals, basic flavour.	ATLAS direct sim, Higgs mass only, basic flavour.	ATLAS resim, HiggsSignals, basic flavour.	ATLAS+CMS +Tevatron direct sim, basic flavour.
SM, theory and related uncerts.	m_t, m_b, α_s, α_{EM}, DM halo, hadronic matrix elements, detector responses, QCD+EW corrections (LHC+DM signal+BG), astro BGs, cosmic ray hadronisation, coalescence and p'gation.	m_t, m_Z, α_{EM}, hadronic matrix elements	m_t, m_b, α_s, α_{EM}, DM halo, hadronic matrix elems.	m_t	None

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Scanners	Differential evolution, genetic algorithms, random forests, t-walk, t-nest, particle swarm, nested sampling, MCMC, gradient descent	Nested sampling, MCMC, grad. descent	Nested sampling, MCMC	MCMC	None (random)
Theories	(p)MSSM-25, CMSSM$\pm\epsilon$, GMSB, AMSB, gaugino mediation, E6MSSM, NMSSM, BMSSM, PQMSSM, effective operators, iDM, XDM, ADM, UED, Higgs portals/extended Higgs sectors	CMSSM$\pm\epsilon$	(p)MSSM-15, CMSSM$\pm\epsilon$, mUED	CMSSM$\pm\epsilon$	(p)MSSM-19
Astroparticle	Event-level: IceCube, Fermi, LUX, XENON, CDMS, DM-ICE. Basic: $\Omega_{\rm DM}$, AMS-02, COUPP, KIMS, CRESST, CoGeNT, SIMPLE, PAMELA, Planck, HESS. Predictions: CTA, DARWIN, GAPS	Basic: $\Omega_{\rm DM}$, LUX, XENON	Basic: $\Omega_{\rm DM}$, Fermi, IceCube, XENON	Basic: $\Omega_{\rm DM}$, Fermi, HESS, XENON	Event-level: Fermi. Basic: $\Omega_{\rm DM}$, IceCube, CTA
LHC	ATLAS+CMS multi-analysis with neural net and fast detector simulation. Higgs multi-channel with correlations and no SM assumptions. Full flavour inc. complete $B \to X_s ll$ and $B \to K^* ll$ angular set.	ATLAS resim, HiggsSignals, basic flavour.	ATLAS direct sim, Higgs mass only, basic flavour.	ATLAS resim, HiggsSignals, basic flavour.	ATLAS+CMS +Tevatron direct sim, basic flavour.
SM, theory and related uncerts.	m_t, m_b, $\alpha_{\rm s}$, $\alpha_{\rm EM}$, DM halo, hadronic matrix elements, detector responses, QCD+EW corrections (LHC+DM signal+BG), astro BGs, cosmic ray hadronisation, coalescence and p'gation.	m_t, m_Z, $\alpha_{\rm EM}$, hadronic matrix elements	m_t, m_b, $\alpha_{\rm s}$, $\alpha_{\rm EM}$, DM halo, hadronic matrix elems.	m_t	None

GAMBIT vs the rest – in a nutshell

Aspect	GAMBIT	MasterCode	SuperBayeS	Fittino	Rizzo et al.
Design	Modular, Adaptive	Monolithic	Monolithic	($\sim$)Monolithic	Monolithic
Statistics	Frequentist, Bayesian	Frequentist	Freq./Bayes.	Frequentist	None
Scanners	Differential evolution, genetic algorithms, random forests, t-walk, t-nest, particle swarm, nested sampling, MCMC, gradient descent	Nested sampling, MCMC, grad. descent	Nested sampling, MCMC	MCMC	None (random)
Theories	(p)MSSM-25, CMSSM$\pm\epsilon$, GMSB, AMSB, gaugino mediation, E6MSSM, NMSSM, BMSSM, PQMSSM, effective operators, iDM, XDM, ADM, UED, Higgs portals/extended Higgs sectors	CMSSM$\pm\epsilon$	(p)MSSM-15, CMSSM$\pm\epsilon$, mUED	CMSSM$\pm\epsilon$	(p)MSSM-19
Astroparticle	Event-level: IceCube, Fermi, LUX, XENON, CDMS, DM-ICE. Basic: $\Omega_{\rm DM}$, AMS-02, COUPP, KIMS, CRESST, CoGeNT, SIMPLE, PAMELA, Planck, HESS. Predictions: CTA, DARWIN, GAPS	Basic: $\Omega_{\rm DM}$, LUX, XENON	Basic: $\Omega_{\rm DM}$, Fermi, IceCube, XENON	Basic: $\Omega_{\rm DM}$, Fermi, HESS, XENON	Event-level: Fermi. Basic: $\Omega_{\rm DM}$, IceCube, CTA
LHC	ATLAS+CMS multi-analysis with neural net and fast detector simulation. Higgs multi-channel with correlations and no SM assumptions. Full flavour inc. complete $B \to X_s ll$ and $B \to K^* ll$ angular set.	ATLAS resim, HiggsSignals, basic flavour.	ATLAS direct sim, Higgs mass only, basic flavour.	ATLAS resim, HiggsSignals, basic flavour.	ATLAS+CMS +Tevatron direct sim, basic flavour.
SM, theory and related uncerts.	m_t, m_b, $\alpha_{\rm s}$, $\alpha_{\rm EM}$, DM halo, hadronic matrix elements, detector responses, QCD+EW corrections (LHC+DM signal+BG), astro BGs, cosmic ray hadronisation, coalescence and p'gation.	m_t, m_Z, $\alpha_{\rm EM}$, hadronic matrix elements	m_t, m_b, $\alpha_{\rm s}$, $\alpha_{\rm EM}$, DM halo, hadronic matrix elems.	m_t	None

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Astroparticle	Event-level: IceCube, Fermi, LUX, XENON, CDMS, DM-ICE. Basic: $\Omega_{\rm DM}$, AMS-02, COUPP, KIMS, CRESST, CoGeNT, SIMPLE, PAMELA, Planck, HESS. Predictions: CTA, DARWIN, GAPS	Basic: $\Omega_{\rm DM}$, LUX, XENON	Basic: $\Omega_{\rm DM}$, Fermi, IceCube, XENON	Basic: $\Omega_{\rm DM}$, Fermi, HESS, XENON	Event-level: Fermi. Basic: $\Omega_{\rm DM}$, IceCube, CTA
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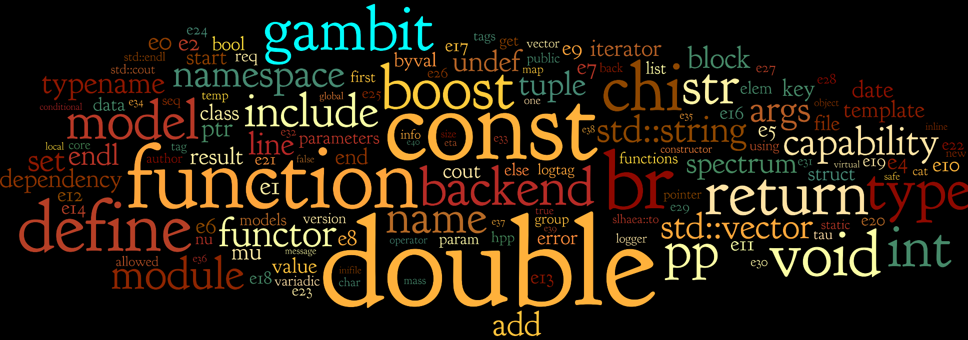
Closing remarks

- Robust analysis of dark matter and BSM physics requires multi-messenger global fits
- GAMBIT is coming:
  - $\longrightarrow$ Global fits to many models for the first time
  - $\longrightarrow$ Better global fits to familiar ones
  - $\longrightarrow$ Highly modular, usable and extendable public code
  - $\longrightarrow$ Faster, more complete and more consistent theory explorations + experimental analysis prototyping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