Exploring BSM Physics with GAMBIT and GUM

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Overview

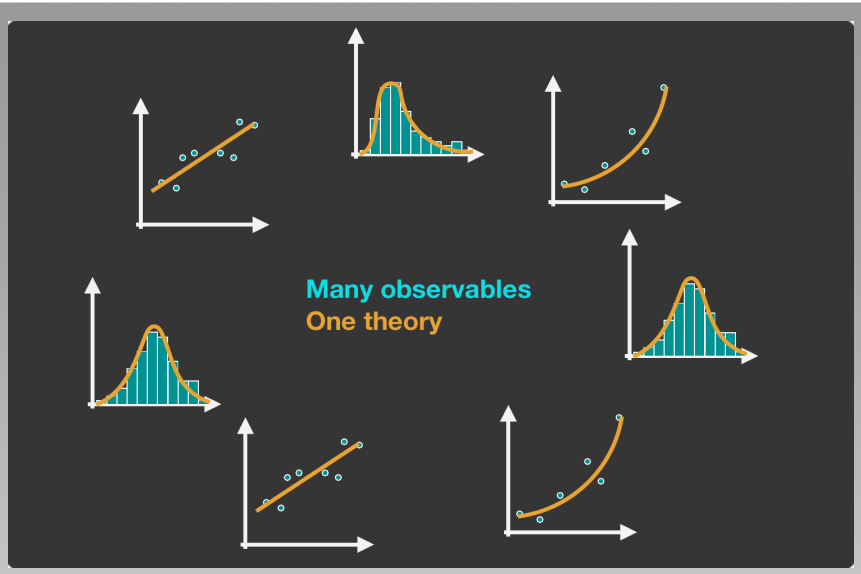
1. Why do global fits
2. What is GAMBIT?
3. How to use GAMBIT?
   - Example 1: Flavour EFT
   - Example 2: Neutrino oscillations
   - Example 3: GUM and MDMSM
4. Bonus: How to write code for GAMBIT?

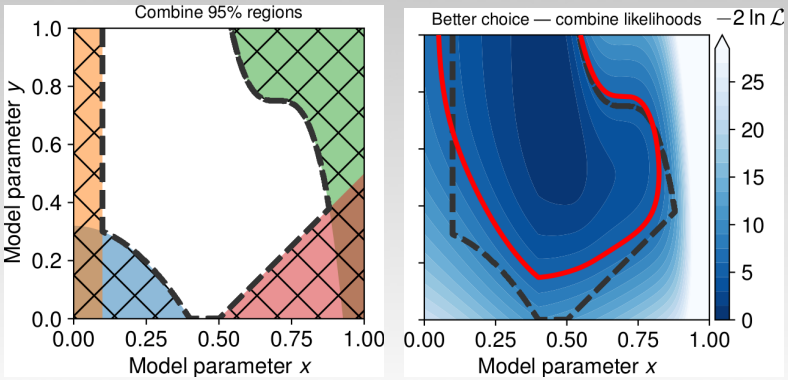
Why do global fits?

Global fits

- Multitude of experimental observables for each model
- Theory predictions $f(x)$
- Experiments measure $\mathcal{L}(\theta)$
- One needs

$$\mathcal{L}(x;\theta) = \frac{\mathcal{L}(\theta;x)\pi(x)}{\pi(\theta)}$$





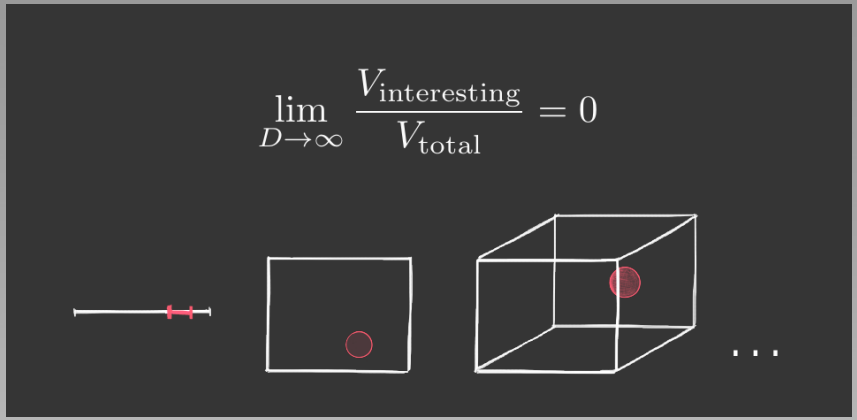
[arXiv:2012.09874 [hep-ph]]

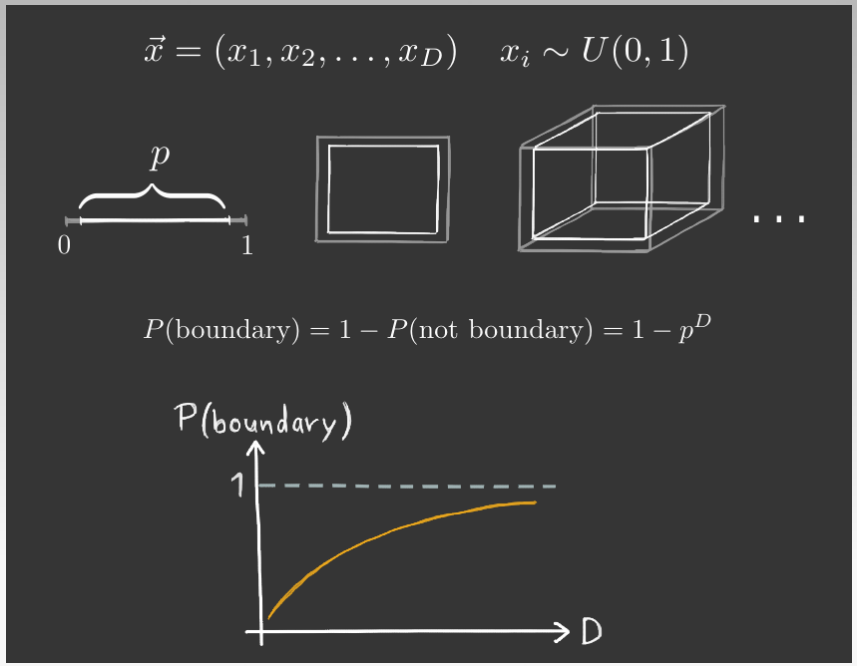
- Exclusion regions do not properly represent the model predictions
- Becomes impossible to analyse signals
- Combine all constraints into a composite likelihood

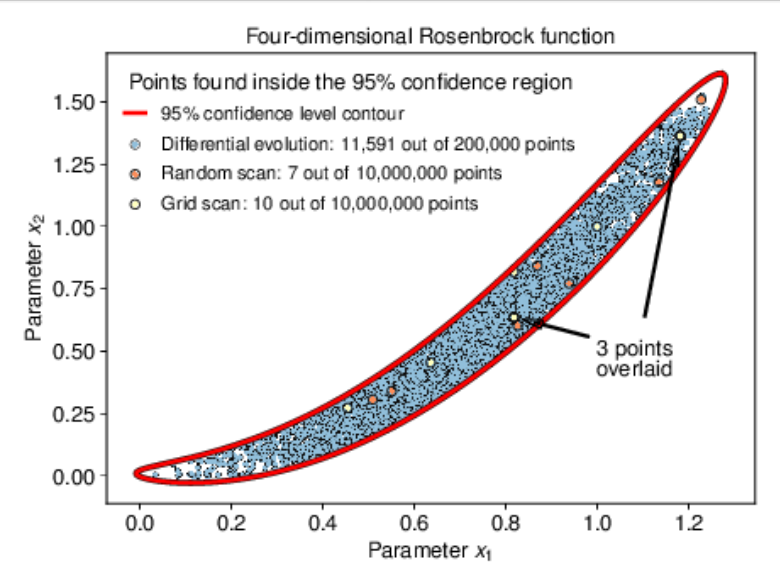
$$\mathcal{L} = \mathcal{L}_{Collider}\mathcal{L}_{Higgs}\mathcal{L}_{DM}\mathcal{L}_{Flavour}\cdots$$

Global fits

- Many BSM models come with many parameters
- Hard to find interesting regions
- Random methods are inefficient
- Mostly sample the boundary
- Need smart sampling strategies (differential, nested, genetic,. . .)





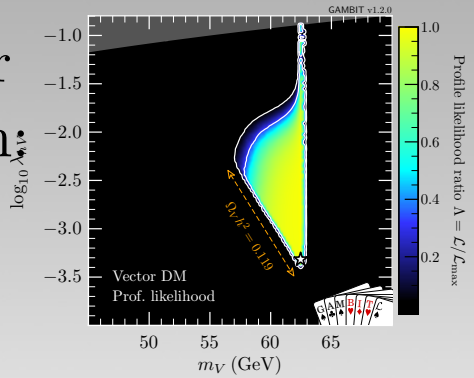


Global fits

- Assessment of validity of models should be done with rigorous statisical interpretations

Frequentist

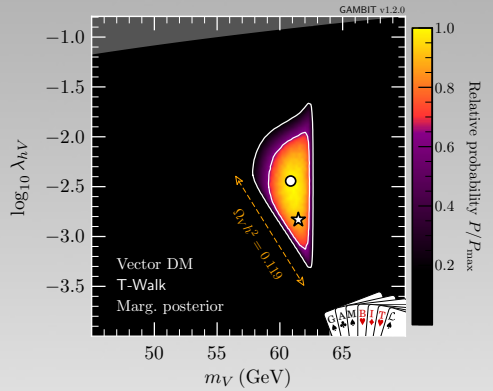
- How well does my model reproduce the data?
- Parameter estimation: profiling $\mathcal{L}/\mathcal{L}_{\max}$



- Goodness-of-fit: p-value
- Must include all tests, LEE

Bayesian

- How much I trust my model given the data?
- Parameter estimation: marginalising $P/P_{\max}$



- Model comparison: Bayes factors
- Prior dependence

- All of this comes with serious computational challenges $\rightsquigarrow$ `GAMBIT`

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What is GAMBIT?

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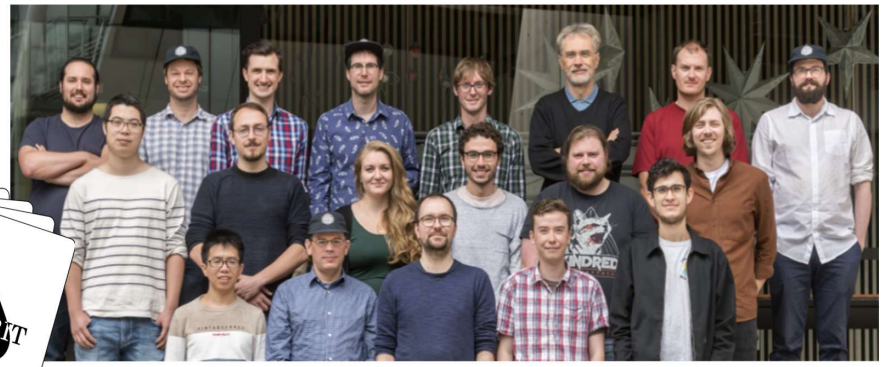
GAMBIT: The Global And Modular BSM Inference Tool

gambit.hepforge.org github.com/GambitBSM EPJC 77 (2017) 784 arXiv:1705.07908

- Extensive model database, beyond SUSY
- Fast definition of new datasets, theories
- Extensive observable/data libraries
- Plug&play scanning/physics/likelihood packages
- Various statistical options (frequentist /Bayesian)
- Fast LHC likelihood calculator
- Massively parallel
- Fully open-source



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

Authors of: BubbleProfiler, Capt'n General, Contur, DarkAges, DarkSUSY, DDCalc, DirectDM, Diver, EasyScanHEP, ExoCLASS, FlexibleSUSY, gamLike, GM2Calc, HEPLike, IsaTools, MARTY, nuLike, PhaseTracer, PolyChord, Rivet, SOFTSUSY, SuperIso, SUSY-AI, xsec, Vevacious, WIMPSim

Recent collaborators: P Athron, C Balázs, A Beniwal, S Bloor, T Bringmann, A Buckley, J-E Camargo-Molina, C Chang, M Chrzaszcz, J Conrad, J Cornell, M Danninger, J Edsjö, T Emken, A Fowlie, T Gonzalo, W Handley, J Harz, S Hoof, F Kahlhoefer, A Kvellestad, P Jackson, D Jacob, C Lin, N Mahmoudi, G Martinez, MT Prim, A Raklev, C Rogan, R Ruiz, P Scott, N Serra, P Stöcker , W. Su, A Vincent, C Weniger, M White, Y Zhang, ++

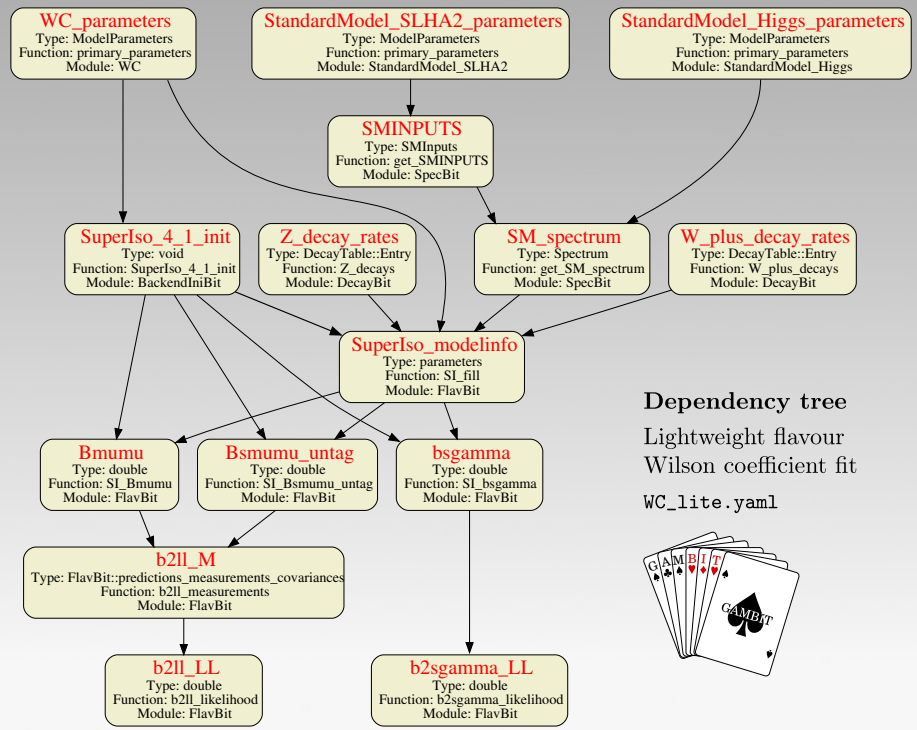
70+ participants in many experiments and numerous major theory codes

Modules (Bits)

- Physics Modules
  - → **ColliderBit**: collider searches [Eur.Phys.J. C77 (2017) no.11, 795]
  - → **DarkBit**: relic density, dd,... [Eur.Phys.J. C77 (2017) no.12, 831]
  - → **FlavBit**: flavour observables [Eur.Phys.J. C77 (2017) no.11, 786]
  - → **SpecBit**: spectra, RGE running [Eur.Phys.J. C78 (2018) no.1, 22]
  - → **DecayBit**: decay widths [Eur.Phys.J. C78 (2018) no.1, 22]
  - → **PrecisionBit**: precision tests [Eur.Phys.J. C78 (2018) no.1, 22]
  - → **NeutrinoBit**: neutrino likelihoods [Eur.Phys.J.C 80 (2020) no.6, 569]
  - → **CosmoBit**: cosmological constraints [JCAP 02 (2021) 022]
- **ScannerBit** : stats and sampling [Eur.Phys.J. C77 (2017) no.11, 761]
  - → Diver, GreAT, Multinest, Polychord, ...
- **Models**: hierarchical model database
- **Core** : dependency resolution [Eur.Phys.J. C78 (2018) no.2, 98]
- **Backends** : External tools to calculate observables
- **GUM**: Autogeneration of code [Eur.Phys.J. C81 (2021) no 12, 1103]

Module functions

- **Module functions** are the building blocks of GAMBIT
- Module functions provide a **capability**
- They have **dependencies** on other capabilities
- They have **backend requirements**
- Can be allowed for specific **models**
- Module functions are wrapped in functors
- GAMBIT resolves the dependeny graph at runtime

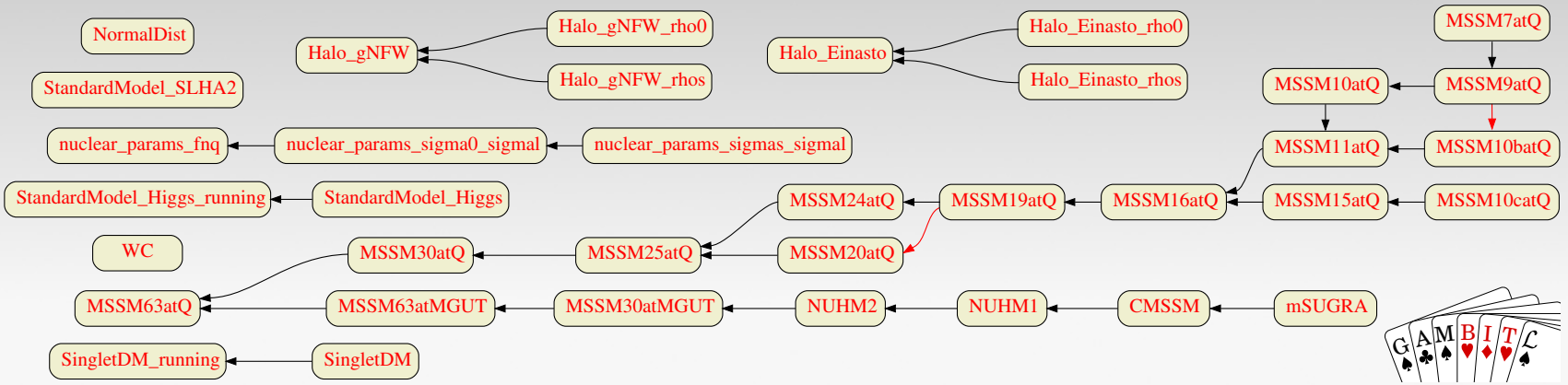


Models

- Extensive model database

SUSY	DM	Cosmo	Others
CMSSM NUHM1,2 MSSM63atQ	Scalar Singlet Fermionic Singlet Vector Singlet Axions	ΛCDM $\Delta N_{\rm eff}$ Power-law inflation	SM RH neutrinos WC nuisance models

- Parent-daughter hierarchy
- Module functions are activated for each model



Backends

- External tools used to compute some physical quantity
- Interfaced with GAMBIT dynamically
- C, Fortran $\rightsquigarrow$ POSIX `dl`
- C++ $\rightsquigarrow$ BOSS + POSIX `dl`
- Mathematica $\rightsquigarrow$ WSTP
- Python $\rightsquigarrow$ pybind11

CosmoBit

AlterBBN 2.2
DarkAges 1.2.0
MontePythonLike 3.3.0
MultiModeCode 2.0.0
classy 2.9.4

DarkBit

CaptnGeneral 1.0
DDCalc 2.2.0
DarkSUSY 6.2.2
MicrOmegas 3.6.9.2
gamLike 1.0.1

ColliderBit

HiggsBounds 4.3.1
HiggsSignals 1.4
Pythia 8.212

FlavBit

SuperISO 3.6

PrecisionBit

FeynHiggs 2.12.0
SUSYHD 1.0.2
gm2calc 1.3.0

SpecBit

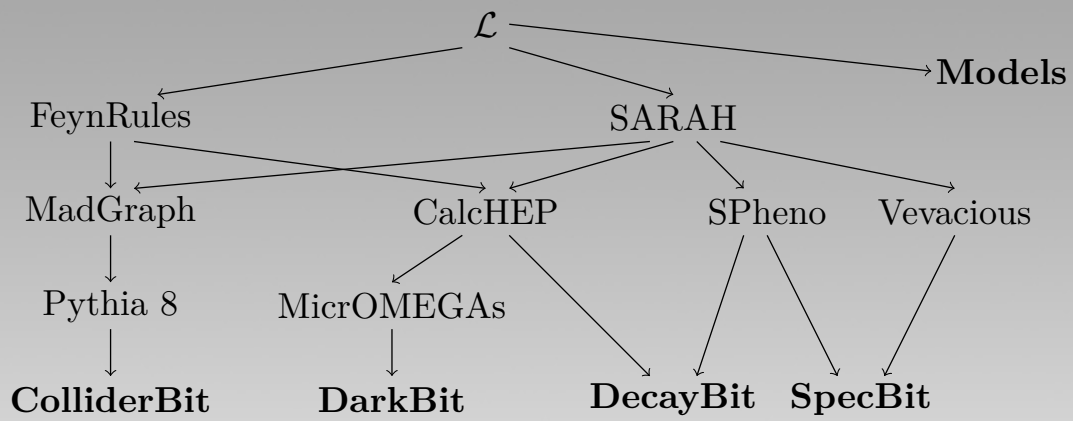
FlexibleSUSY 2.0.1
SPheno 4.0.3

DecayBit

SUSY_HIT 1.5

GUM

- GUM interfaces LLT SARAH and FeynRules with GAMBIT
- Uses existing HEP toolchains

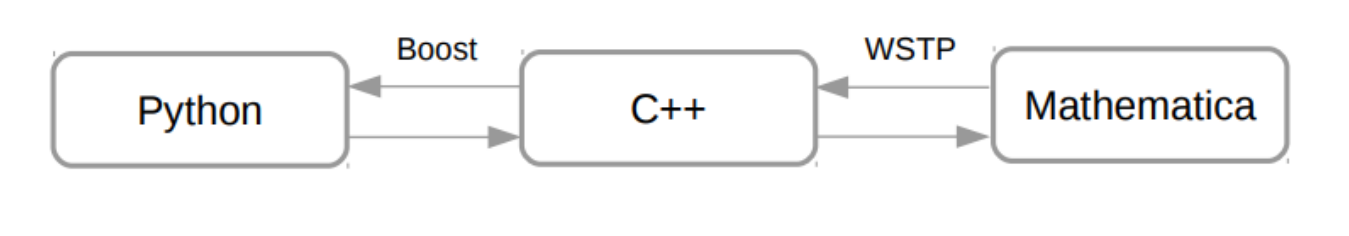


- GAMBIT-compatible outputs from GUM

Generated output	FeynRules	SARAH	Usage in GAMBIT
CalcHEP	✓	✓	Decays, cross-sections
micrOMEGAs (via CalcHEP)	✓	✓	DM observables
Pythia (via MadGraph)	✓	✓	Collider physics
SPheno	✗	✓	Particle mass spectra, decay widths
Vevacious	✗	✓	Vacuum stability

GUM

- Primarily written in Python, with interface to Mathematica via Boost and WSTP

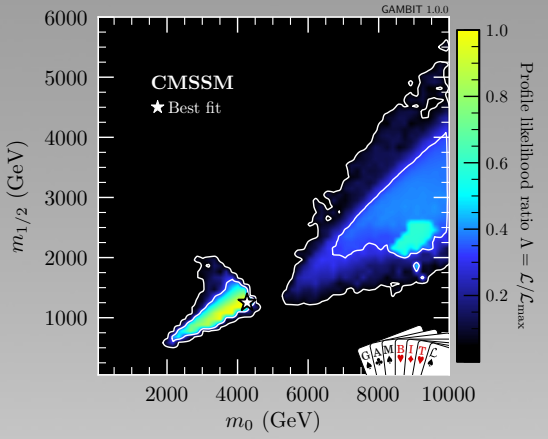


- Automatically generates GAMBIT code
  - → Particles → particle database and parameters → Models
  - → Module functions for ColliderBit, DarkBit, DecayBit and SpecBit
  - → Writes interfaces to requested backends
    - ⇝ `SPheno`, `MicrOMEGAs`, `Pythia`, `Vevacious`
- GUM will soon also do flavour physics via `FlavourKit`

Examples

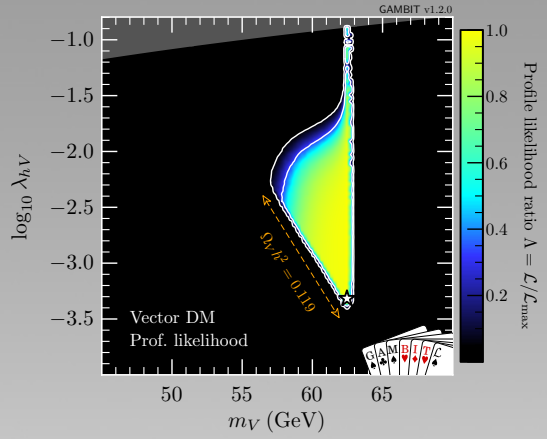
CMSSM

[Eur.Phys.J.C 77 (2017) 12,824]



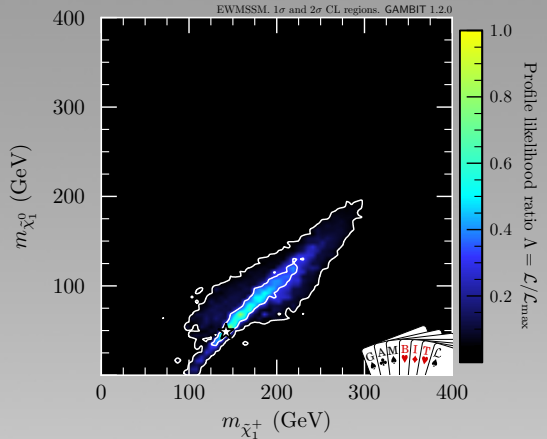
Higgs-portal DM

[Eur.Phys.J.C 79 (2019) 1, 38]



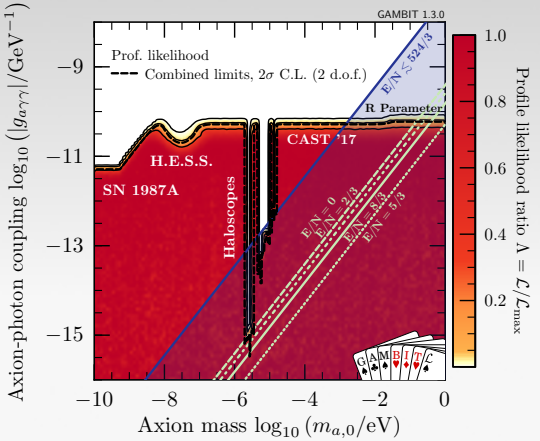
MSSM-EW

[Eur.Phys.J.C 79 (2019) 5, 395]



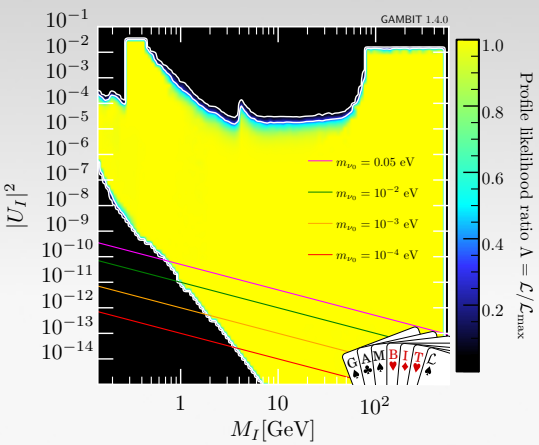
QCD axions

[JHEP 03 (2019) 191]



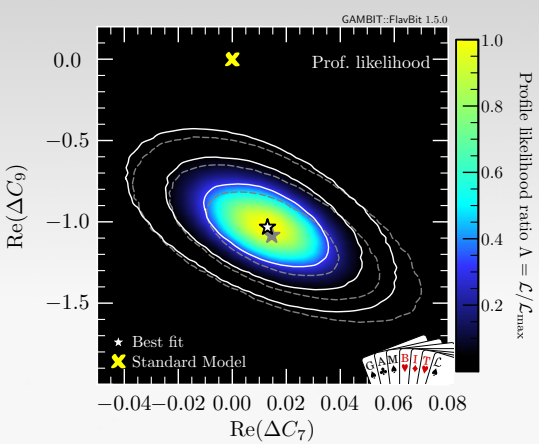
Right-Handed Neutrinos

[Eur.Phys.J.C 80 (2020) 6, 569]



Flavour EFT

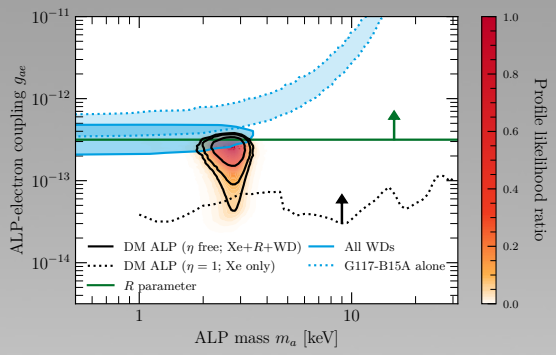
[Eur.Phys.J.C 81 (2021)12,1076]



Examples

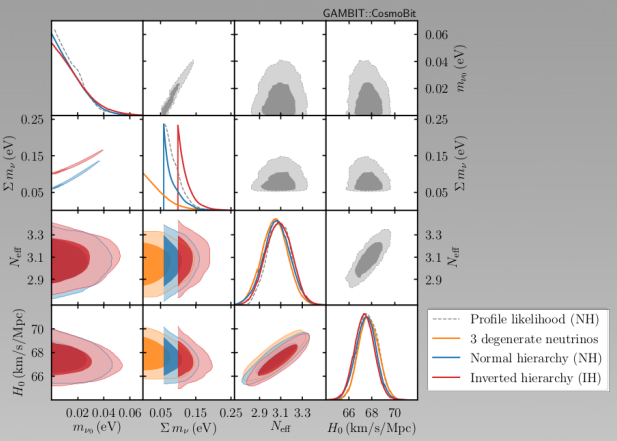
DM ALPs

[JHEP 05 (2021) 159]



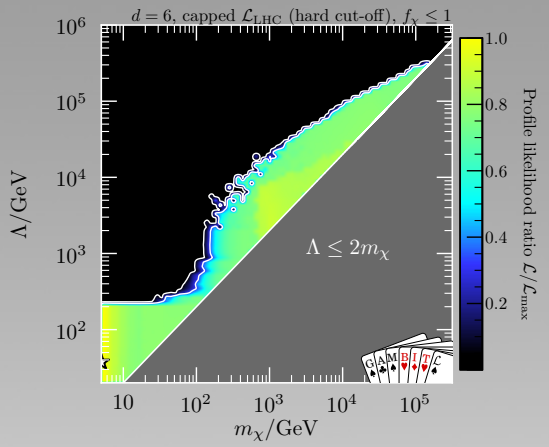
Neutrino Masses

[Phys.Rev.D 103(2021)12,123508]



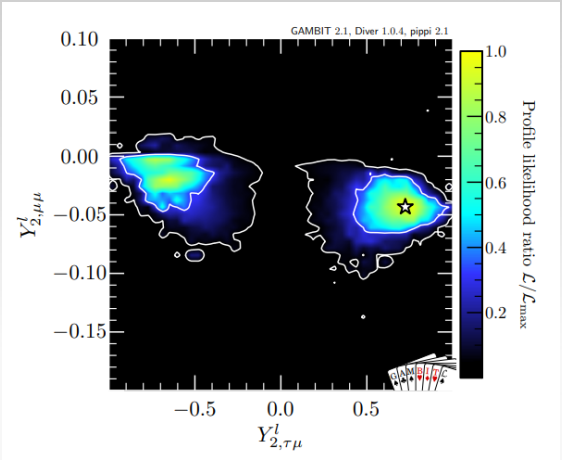
DMEFT

[Eur.Phys.J.C 81 (2021) 11,992]



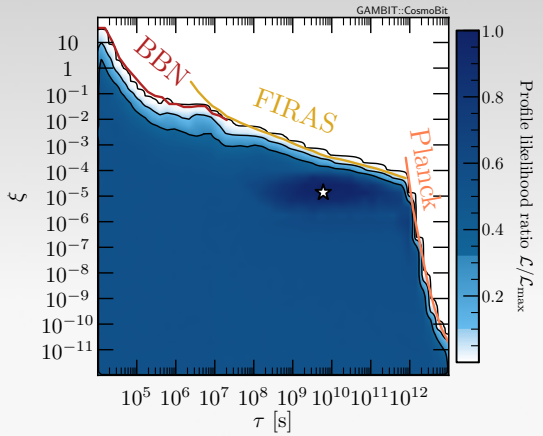
THDM-III

[JHEP 01 (2022) 037]



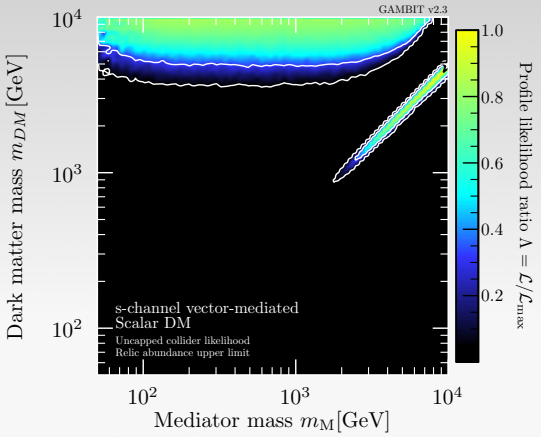
Cosmo ALPs

[arXiv:2205.13549[astro-ph.CO]]



S-channel DM

[arXiv:2209.13266 [hep-ph]]



How to use GAMBIT?

Compilation

- Configure
- Build scanners
- Build backends
- Build main gambit

```
cmake ..
make scanners
cmake ..
make -jn backends
make -jn
```

- Useful configuration options
  - → Build mode: -DCMAKE_BUILD_TYPE=Release
  - → Select compilers: -DCMAKE_CXX_COMPILER=g++
  - → Fix paths -DEIGEN3_INCLUDE_DIR=somepath
  - → Turn on/off MPI: -DWITH_MPI=on
  - → Turn on/off packages: -DWITH_ROOT=on, -DWITH_HEPMC=on
  - → Select FS model: -DBUILD_FS_MODELS=None
  - → Other cmake flags: -DCMAKE_CXX_FLAGS=xx
  - → Ditch modules/backends/stuff: -Ditch="NeutrinoBit;Python;Mathematica;DarkSUSY"

Diagnostics

- Can run diagnostics for all backends, scanners, modules, capabilities

```
./gambit backends
```

BACKENDS	VERSION	PATH TO LIB	STATUS	#FUNC	#TYPES	#CTOR
AlterBBN	2.2	Backends/installed/alterbbn/2.2/libbbn.so	absent/broken	6	0	0
CalcHEP	3.6.27	Backends/installed/calchep/3.6.27/lib/libcalchep.so	absent/broken	18	0	0
CaptnGeneral	2.1	Backends/installed/capgen/2.1/gencaplib.so	absent/broken	7	0	0
DDCalc	1.0.0	Backends/installed/ddcalc/1.0.0/lib/libDDCalc.so	absent/broken	36	0	0
	1.1.0	Backends/installed/ddcalc/1.1.0/lib/libDDCalc.so	absent/broken	38	0	0
	1.2.0	Backends/installed/ddcalc/1.2.0/lib/libDDCalc.so	absent/broken	39	0	0
	2.0.0	Backends/installed/ddcalc/2.0.0/lib/libDDCalc.so	absent/broken	50	0	0
	2.1.0	Backends/installed/ddcalc/2.1.0/lib/libDDCalc.so	absent/broken	49	0	0
	2.2.0	Backends/installed/ddcalc/2.2.0/lib/libDDCalc.so	OK	52	0	0
DarkAges	1.2.0	Backends/installed/darkages/1.2.0/DarkAges_1_2_0	absent/broken	1	0	0
DarkSUSY	5.1.3	Backends/installed/darksusy/5.1.3/lib/libdarksusy.so	absent/broken	81	0	0
DarkSUSY_MSSM	6.1.1	Backends/installed/darksusy/6.1.1/lib/libds_core_mssm.so	absent/broken	63	0	0
	6.2.2	Backends/installed/darksusy/6.2.2/lib/libds_core_mssm.so	absent/broken	64	0	0
	6.2.5	Backends/installed/darksusy/6.2.5/lib/libds_core_mssm.so	OK	63	0	0
DarkSUSY_generic_wimp	6.1.1	Backends/installed/darksusy/6.1.1/lib/libds_core_generic_wimp.so	absent/broken	19	0	0
	6.2.2	Backends/installed/darksusy/6.2.2/lib/libds_core_generic_wimp.so	absent/broken	19	0	0
	6.2.5	Backends/installed/darksusy/6.2.5/lib/libds_core_generic_wimp.so	OK	19	0	0
DirectDM	2.2.0	Backends/installed/directdm/2.2.0/directdm	absent/broken	1	0	0
FeynHiggs	2.11.2	Backends/installed/feynhiggs/2.11.2/lib/libFH.so	absent/broken	14	0	0
	2.11.3	Backends/installed/feynhiggs/2.11.3/lib/libFH.so	absent/broken	14	0	0
	2.12.0	Backends/installed/feynhiggs/2.12.0/lib/libFH.so	absent/broken	14	0	0
HiggsBounds	4.2.1	Backends/installed/higgsbounds/4.2.1/lib/libhiggsbounds.so	absent/broken	10	0	0
	4.3.1	Backends/installed/higgsbounds/4.3.1/lib/libhiggsbounds.so	absent/broken	10	0	0
HiggsSignals	1.4	Backends/installed/higgssignals/1.4.0/lib/libhiggssignals.so	absent/broken	12	0	0

YAML file

- Parameters Node

```yaml
Parameters:

  StandardModel_SLHA2:
    alphaS     :  1.18500000E-01
    mBmB       :  4.18000000E+00
    alphainv   :  1.27940010E+02
    mT         :  1.73340000E+02
    GF         :  1.16637870E-05
    mZ         :  9.11876000E+01
    mTau       :  1.77682000E+00
    mNu3       :                0
    mD         :  4.80000000E-03
    mU         :  2.30000000E-03
    mS         :  9.50000000E-02
    mCmC       :  1.27500000E+00
    mE         :  5.10998928E-04
    mMu        :  1.05658372E-01
    mNu1       :                0
    mNu2       :                0
    CKM_lambda:  0.22537
    CKM_A      :  0.814
    CKM_rhobar:  0.117
    CKM_etabar:  0.353
    theta12    :  0.58376
    theta23    :  0.76958
    theta13    :  0.15495
    delta13    :  0
    alpha1     :  0
    alpha2     :  0

  StandardModel_Higgs:
    mH: 125.09

  WC:
    Re_DeltaC7:
      range: [-0.1, 0.1]
    Im_DeltaC7:  0
    Re_DeltaC9:  0
    Im_DeltaC9:  0
    Re_DeltaC10:
       range: [-3, 3]
    Im_DeltaC10: 0
    Re_DeltaCQ1: 0
    Im_DeltaCQ1: 0
    Re_DeltaCQ2: 0
    Im_DeltaCQ2: 0
```

- Printers

(hdf5, ascii, sqlite,

cout, none)

```yaml
Printer:

  printer: hdf5

  options:
    output_file: "WC.hdf5"
    group: "/WC"
```

- Scanners

(diver, multinest,

polychord, minuit2,

twalk, raster, grid)

```yaml
Scanner:

  use_scanner: de

  scanners:

    multinest:
      plugin: multinest
      like:  LogLike
      nlive: 400
      tol: 0.1

    de:
      plugin: diver
      like: LogLike
      NP: 400
      convthresh: 1e-3
```

- Likelihoods

```yaml
ObsLikes:

  # Likelihoods
  - purpose:    LogLike
    capability: b2ll_LL

  - purpose:    LogLike
    capability: b2sgamma_LL
```

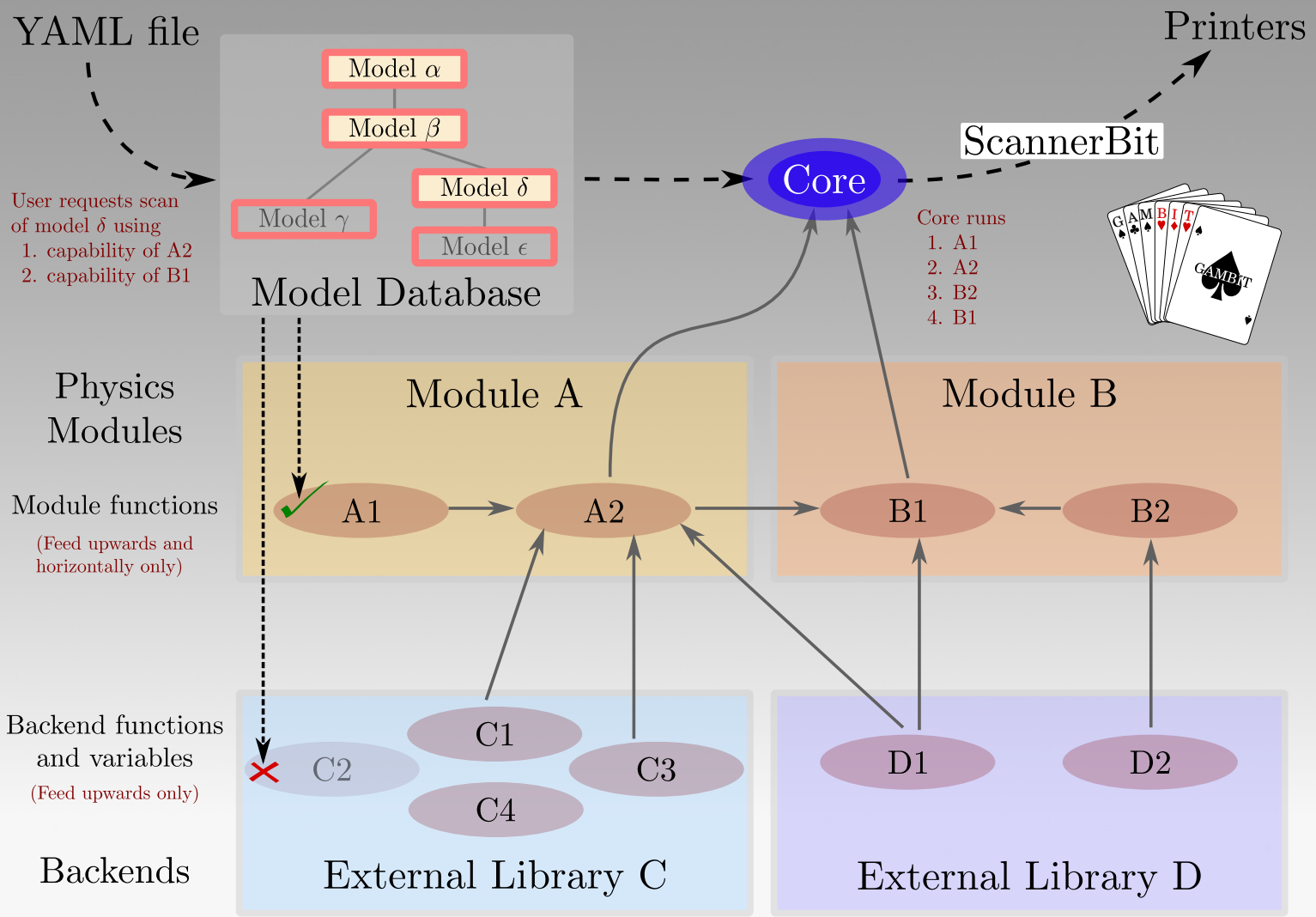
- Rules

```yaml
Rules:

  # Use SuperIso instead of FeynHiggs for b->sgamma
  - capability: bsgamma
    function: SI_bsgamma

  # Use SuperIso instead of FeynHiggs for B_s->mumu
  - capability: Bsmumu_untag
    function: SI_Bsmumu_untag
```

- Other

```yaml
Logger:

  redirection:
    [Debug]   : "debug.log"
    [Default] : "default.log"
    [FlavBit] : "FlavBit.log"


KeyValues:

  default_output_path: "runs/WC_lite"

  debug: true
~
```

An example run



Example 1: Flavour EFT

Flavour EFT

- 2D Wilson coefficient fit

$$\Delta C_x = C_{x,BSM} - C_{x,SM}$$

- Free parameters:

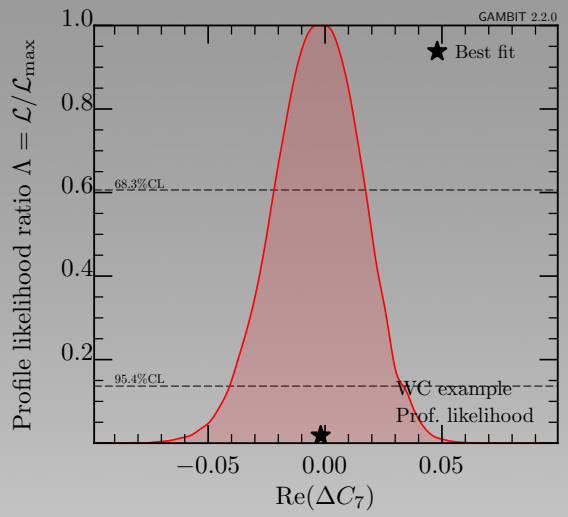
ΔC_7	`Re_DeltaC7`
ΔC_{10}	`Re_DeltaC10`

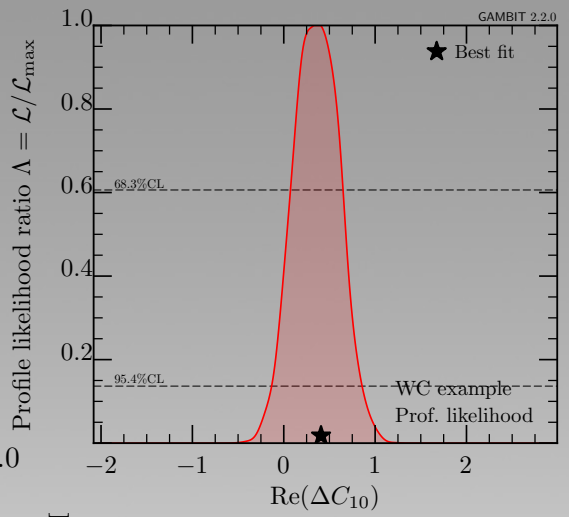
- Likelihoods

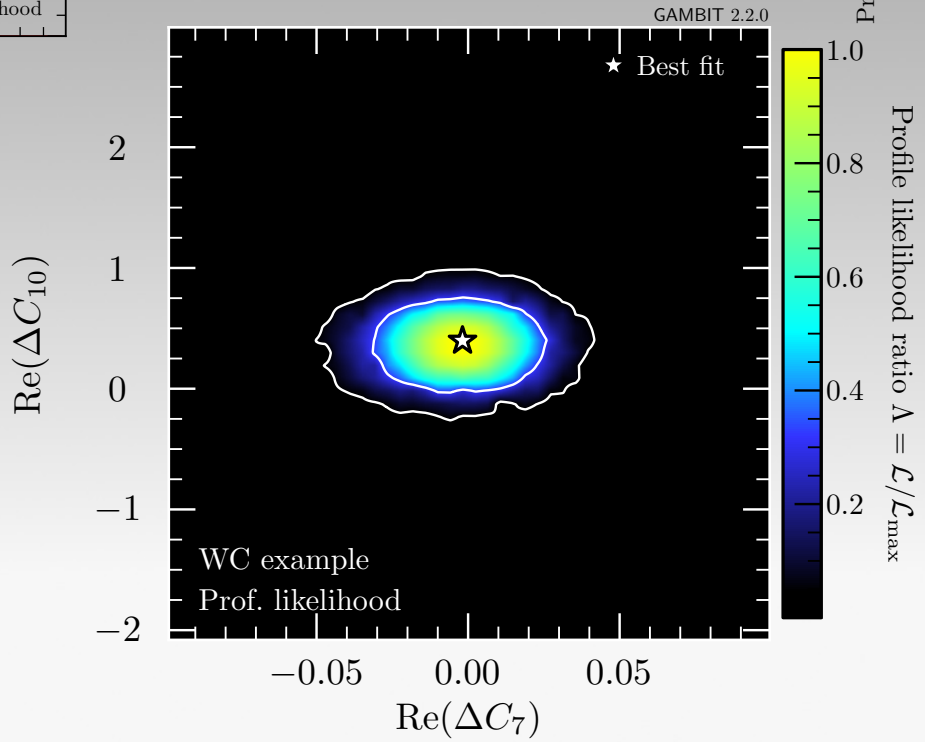
$b \to s\gamma$	`b2sgamma_LogLikelihood`
$B_s \to \mu^+\mu^-$	`B2mumu_LogLikelihood_Altas`
	`B2mumu_LogLikelihood_CMS`
$B_d \to \mu^+\mu^-$	`B2mumu_LogLikelihood_LHCb`

- YAML file `WC_lite.yaml`

Flavour EFT


GAMBIT 2.2.0
Best fit
68.3%CL
95.4%CL
WC example
Prof. likelihood
Profile likelihood ratio $\Lambda = \mathcal{L}/\mathcal{L}_{\max}$
$\mathrm{Re}(\Delta C_7)$


GAMBIT 2.2.0
Best fit
68.3%CL
95.4%CL
WC example
Prof. likelihood
Profile likelihood ratio $\Lambda = \mathcal{L}/\mathcal{L}_{\max}$
$\mathrm{Re}(\Delta C_{10})$


GAMBIT 2.2.0
Best fit
WC example
Prof. likelihood
$\mathrm{Re}(\Delta C_{10})$
$\mathrm{Re}(\Delta C_7)$
Profile likelihood ratio $\Lambda = \mathcal{L}/\mathcal{L}_{\max}$

Example 2: Neutrino oscillations

Neutrino Oscillations

- Mass splittings

Δm^2_{21}	Δm^2_{32}
`dmNu21`	`dmNu31`

- PMNS mixing angles and phase

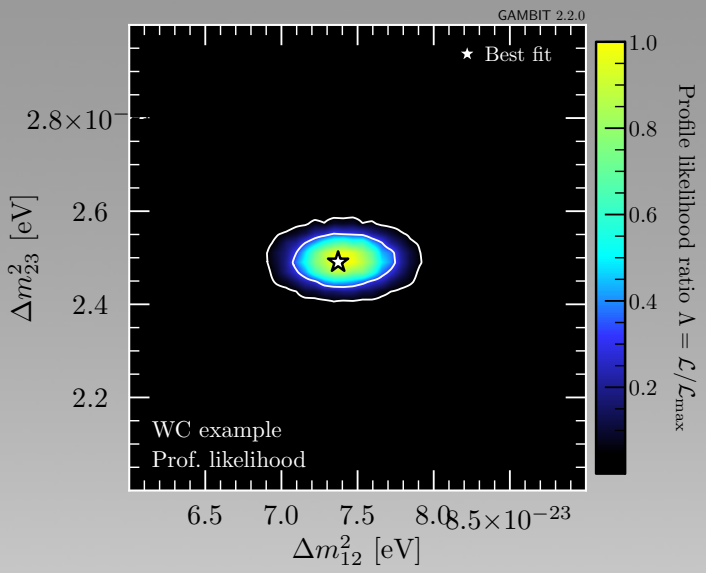
θ_{12}	θ_{13}	θ_{23}	$\delta_{\rm CP}$
`theta12`	`theta13`	`theta23`	`delta13`

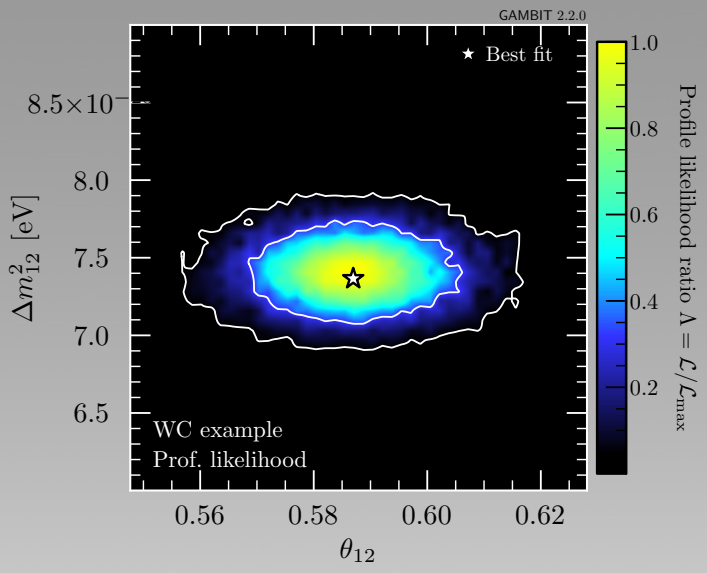
- Likelihoods: NuFit 3.2 [JHEP 01 (2017) 087]

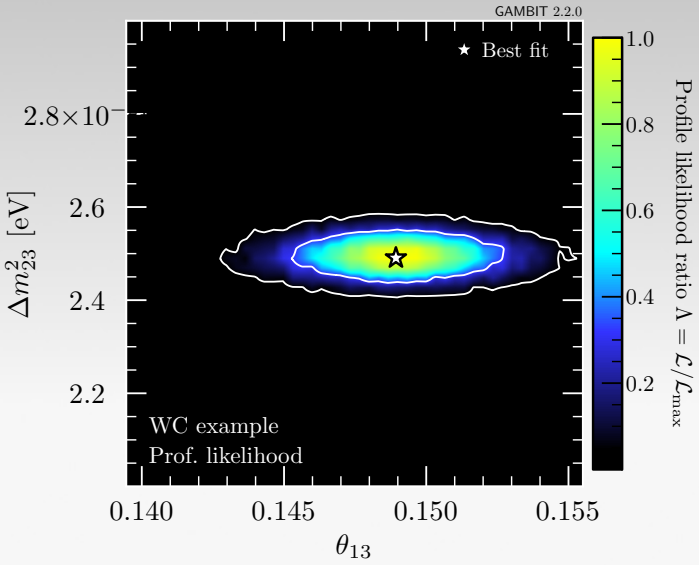
`theta12_NuFit_v3_2_lnL`, `theta23_NuFit_v3_2_lnL`,
`theta13_NuFit_v3_2_lnL`, `deltaCP_NuFit_v3_2_lnL`
`md21_NuFit_v3_2_lnL`, `md31_NuFit_v3_2_lnL`

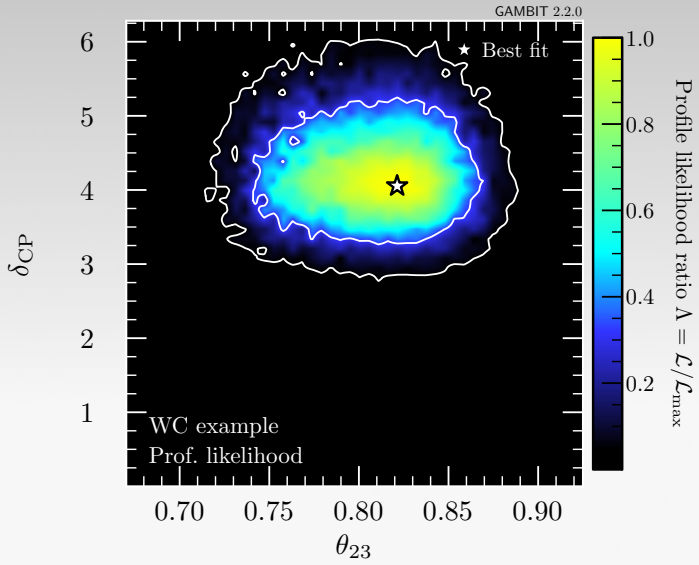
- YAML file `Neutrinos.yaml`

Neutrino Oscillations









Example 3: GUM and MDMSM

Karlsruher Institut für Technologie

The GAMBIT Universal Model Machine

GUM and MDMSM

- Compiling GUM

```
mkdir build && cd build
cmake ..
make
```

- Running GUM

```
./gum -f gum_files/MDMSM.gum
```

- Re-compiling instructions

```
cd ../build
cmake ..
make micromegas_MDMSM
make calchep
```

- Other requirements

```
make diver
cmake ..
make darksusy_generic_wimp
make ddcalc
make gamlike
make -j<n> gambit
```

- Running GAMBIT scan

```
mpirun -np 4 ./gambit -f MDMSM_Tute.yaml
```

- Reseting the Universe

```
./gum -r mug_files/MDMSM.mug
```

GUM and MDMSM

- Majorana DM χ with scalar mediator Y

$$\mathcal{L} = \mathcal{L}_{\rm SM} + \frac{1}{2}\overline{\chi}\left(i\partial\!\!\!/ - m_\chi\right)\chi + \frac{1}{2}\partial_\mu Y \partial^\mu Y - \frac{1}{2}m_Y^2 Y^2 - \frac{g_\chi}{2}\overline{\chi}\chi Y - \frac{c_Y}{2}\sum_f y_f \overline{f} f Y$$

- Free parameters

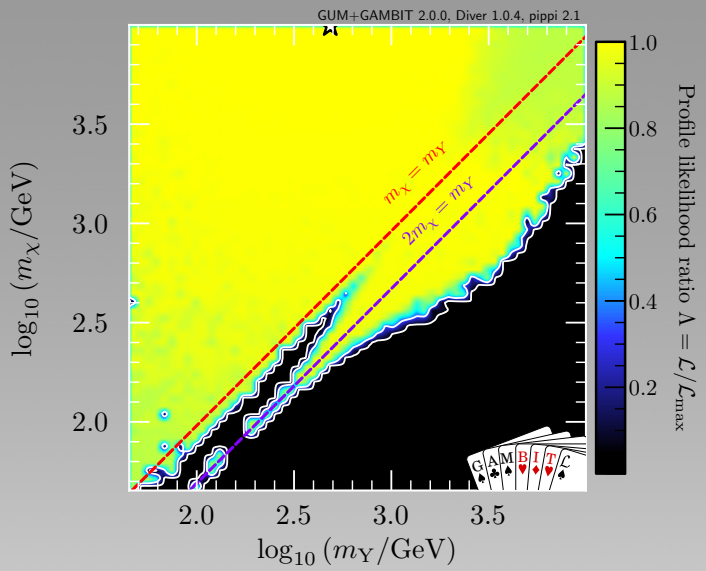
m_χ	m_Y	g_χ	c_Y
`mchi`	`mY`	`gchi`	`cY`

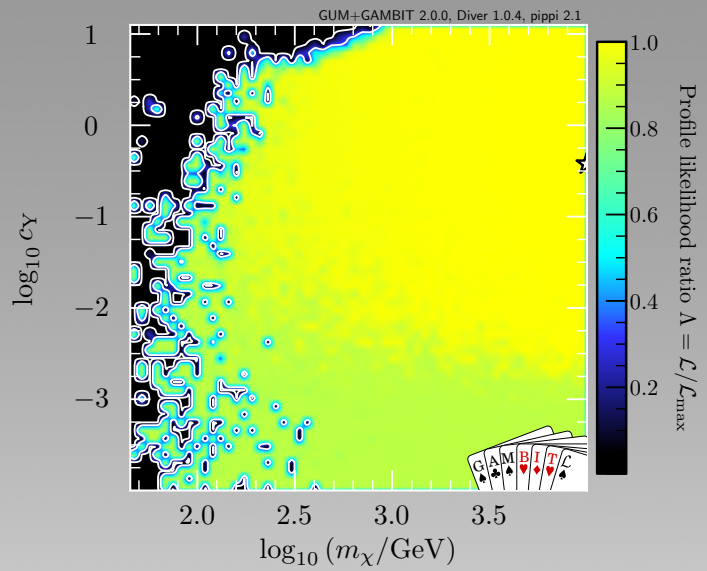
- Likelihoods

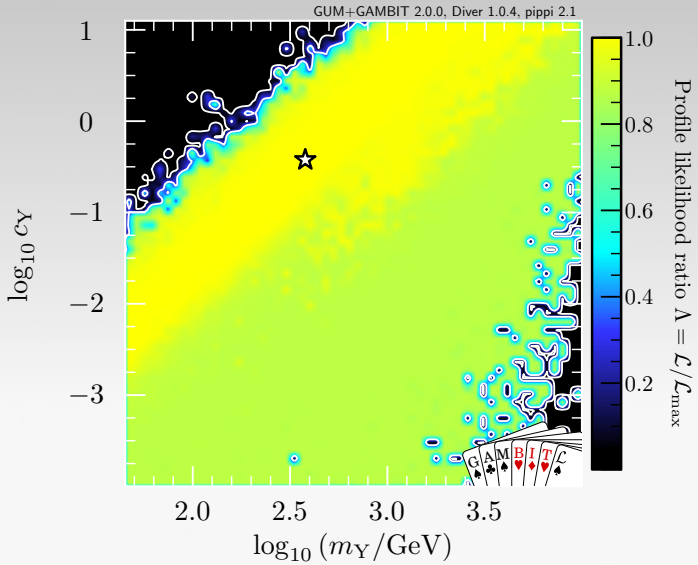
$\Omega_{\rm DM}h^2$	`lnL_oh2`
Indirect detection	`lnL_FermiLATdwarfs`
Direct detection	`LUX_2016_LogLikelihood`
	`XENON1T_2018_LogLikelihood`

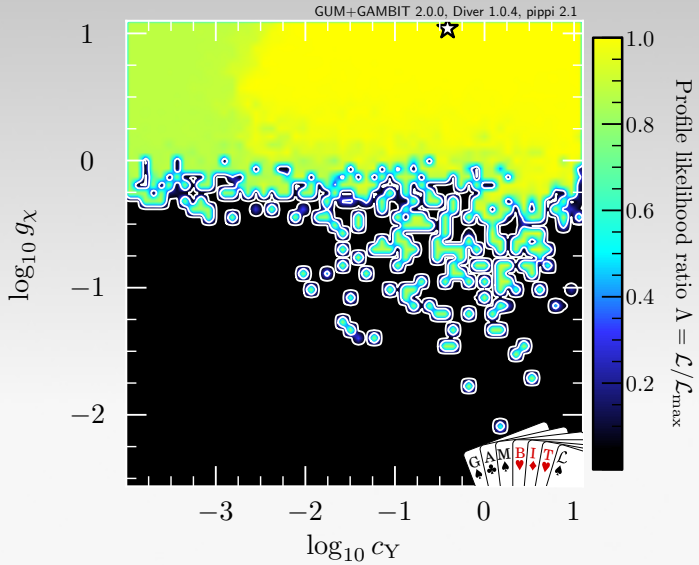
- YAML file `MDMSM_Tute.yaml`

GUM and MDMSM









Bonus: How to write code for GAMBIT?

Module functions

- **Step 1:** Rollcall header

`MyModuleBit/include/gambit/MyModuleBit/MyModuleBit_rollcall.hpp`

```
// Capability
#define CAPABILITY MyCapability
START_CAPABILITY

  // Module function
  #define FUNCTION MyFunction
  START_FUNCTION(double)

  // Dependencies
  DEPENDENCY(OtherCapability, int)

  // Backend requirement
  BACKEND_REQ(BackendCap, (tag), void, (int&, double&))
  BACKEND_OPTION((MyBackend, 1.0.0), (tag))

  // Models
  ALLOW_MODELS(Model_A, Model_B)
  ALLOW_JOINT_MODEL(Model_C, Model_D)

  #undef FUNCTION
#undef CAPABILITY
```

- **Step 2**: Source file

`MyModuleBit/src/MyModuleBit.cpp`

```
// Signature
void MyFunction(double &result)
{

  // Dependency
  int val = *Pipes::MyFunction::Dep::OtherCapability;

  // Backend requirement
  Pipes::MyFunction::BEreq::BackendCap(val, result);

  // Access to parameters
  double param = *Pipes::MyFunction::Param["par1"];

  // Other pipes
  Pipes::MyFunction::ModelInUse("Model_A");
  Pipes::MyFunction::Downstream::subcaps;
  Pipes::MyFunction::Downstream::neededFor("something");
}
```

```
void MyFunction(double &result)
{

  using namespace Pipes::MyFunction;

  int val = *Dep::OtherCapability;

  ...

}
```

Models

- **Step 1**: Declaration

`Models/include/gambit/Models/models/Model_A.hpp`

```
// Model declaration
#define MODEL Model_A
  START_MODEL
  DEFINEPARS(par1,par2,par3) // Up to 10
  DEFINEPARS(par4)
#undef MODEL
```

→ Parent

```
#define MODEL Model_A
#define PARENT Model_B
..
INTERPRET_AS_PARENT_FUNCTION(Model_A_to_Model_B)
#undef PARENT
#undef MODEL
```

→ Friend

```
INTERPRET_AS_X_FUNCTION(Model_C, Model_A_to_Model_C)
```

→ Dependencies

```
INTEPRET_AS_PARENT_DEPENDENCY(aCapability, aType)
INTEPRET_AS_X_DEPENDENCY(Model_C, aCapability, aType)
```

- **Step 2**: *Translation function*

`Models/src/models/Model_A.hpp`

```
#define MODEL Model_A
void MODEL_NAMESPACE::Model_A_to_Model_B(const ModelParameters &myP,
ModelParameters &targetP)
{
  // Set parameters
  targetP.setValue("Par1", myP.getValue("par1"));

  ...
}
#undef MODEL
```

→ Dependencies

```
// Using dependencies
using namespace MODEL_NAMESPACE::Pipes::Model_B_parameters;
aType val = *Dep::aCapability;
```

```
//Shortcut
USE_MODEL_PIPE(Model_B)
aType val = *Dep::aCapability;
```

- **Step 3**: Use it

```
ALLOW_MODELS(Model_B)
```

```
double par1 = *Param["Par1"];
```

Backends

- **Step 1**: Build step `cmake/backends.cmake`

```
set(name "MyBackend")
set(ver "1.0")
set(lib "libmybackend")
set(dl "https://...mybackend_v1.0.tgz")
set(md5 "0000000000000000")
set(dir "${PROJECT_SOURCE_DIR}/Backends/installed/${name}/${ver}")
check_ditch_status(${name} ${ver} ${dir})
if(NOT ditched_${name}_${ver})
  ExternalProject_Add(${name}_${ver}
    DOWNLOAD_COMMAND ${DL_BACKEND} ${dl} ${md5} ${dir} ${name} ${ver}
    SOURCE_DIR ${dir}
    BUILD_IN_SOURCE 1
    CONFIGURE_COMMAND ""
    BUILD_COMMAND ${MAKE_PARALLEL} ${lib}.so
    INSTALL_COMMAND ""
  )
  add_extra_targets("backend" ${name} ${ver} ${dir} ${dl} clean)
  set_as_default_version("backend" ${name} ${ver})
endif()
```

→ Patch it

```
set(patchname "${name}_${ver}.diff")
set(patch "${PROJECT_SOURCE_DIR}/Backends/patches/${name}/${ver}/${patchname}")
...
    BUILD_IN_SOURCE 1
    PATCH_COMMAND patch -p1 < ${patch}
    CONFIGURE_COMMAND ""
...
```

→ BOSS it (C++) `BOSS_backend(${name} ${ver})`

→ Dependencies

```
DEPENDS otherBackend_version
DOWNLOAD_COMMAND ${DL_BACKEND} ${dl} ${md5} ${dir} ${name} ${ver}
```

```
set(ditch_if_absent "staticPackage")
check_ditch_status(${name} ${ver} ${dir} ${ditch_if_absent})
```

```
set(required_modules "python_module")
check_python_modules(${name} ${ver} ${required_modules})
```

Backends

- **Step 2**: Frontend header ~~C++~~

Backends/include/gambit/Backends/frontends/MyBackend_1_0.hpp

```
#define BACKENDNAME MyBackend
#define BACKENDLANG CC  // CC, CXX, Fortran, Mathematica, Python
#define VERSION 1.0.0
#define SAFE_VERSION 1_0_0
#define REFERENCE Bibkey

// Begin
LOAD_LIBRARY

// Allow for models
BE_ALLOW_MODELS(Model_A)

...

// End
#include "gambit/Backends/backend_undefs.hpp"
```

→ Backend Variables

```
BE_VARIABLE(MyVar, int, ("myvar_symbol"), "MyVar_Cap")
```

→ Backend Function

```
BE_FUNCTION(MyFunc, void, (double&), ("myfunc_symbol"), "MyFunc_Cap")
```

→ Convenience functions

```
BE_CONV_FUNCTION(MyConv, int, (bool&, double&), "MyConv_Cap")
```

→ Ini dependencies

```
BE_INI_DEPENDENCY(someCap, double)
```

- **Step 3**: *Frontend source*

Backends/src/frontends/MyBackend_1_0.cpp

→ Convenience functions

```
BE_NAMESPACE
{
  int myConv(bool &a, double &b)
  {
    ...
  }
}
END_BE_NAMESPACE
```

→ Ini function

```
BE_INI_FUNCTION
{
  // Scan-level initialisation
  static bool scan_level = true;
  if (scan_level)
  {
    double val = *Dep::someCap;
    ...
  }
  scan_level = false;


}
END_BE_INI_FUNCTION
```

Backends

- **Step 4**: Backend location

`config/backend_locations.yaml.default`

```
MyBackend:
  1.0:         ./Backends/installed/mybackend/1.0/lib/libmybackend.so
```

- **Step 5**: Reference

`config/bibtex_entries.bib`

```
@article{Bibkey,
    author = "Author, The",
    title = "{My Backend}",
    eprint = "xxxx.xxxxxx",
    archivePrefix = "arXiv",
    primaryClass = "hep-ph",
    year = "2022"
}
```

- **Step 6**: Backend requirement

```
#define FUNCTION MyFunction
START_FUNCTION(double)
...

// Backend requirement
BACKEND_REQ(MyFunc_Cap, (tag), void, (double&))
BACKEND_REQ(MyConv_Cap, (tag), int (bool&, double&))
BACKEND_OPTION((MyBackend, 1.0.0), (tag))

...
#undef FUNCTION
```

- **Step 7**: *BOSS config file*

`Backends/scripts/BOSS/configs/mybackend_1_0.py`

```
...
gambit_backend_name      = 'MyBackend'
gambit_backend_version   = '1.0.0'
gambit_backend_reference = 'Bibkey'
gambit_base_namespace    = ''

input_files =
[
  '../../../Backends/installed/mybackend/1.0.0/file1.h',
  '../../../Backends/installed/mybackend/1.0.0/file2.h'
]
include_paths =
[
  '../../../Backends/installed/mybackend/1.0.0/header1.h',
]
base_paths =
[
  '../../../Backends/installed/mybackend/1.0.0/'
]

header_files_to = '../../../Backends/installed/mybackend/1.0.0/include'
src_files_to    = '../../../Backends/installed/mybackend/1.0.0./src'

load_classes = [
    'ClassOne',
    'SomeNamespace::ClassTwo',
]

load_functions = [
    'SomeNamespace::foo(int, SomeNamespace::ClassTwo)'
]

ditch = []
...
```