Dartmouth

TRIUMF

The lecture will begin shortly. Please mute your microphone until you are ready to speak.

Introduction to GAMBIT

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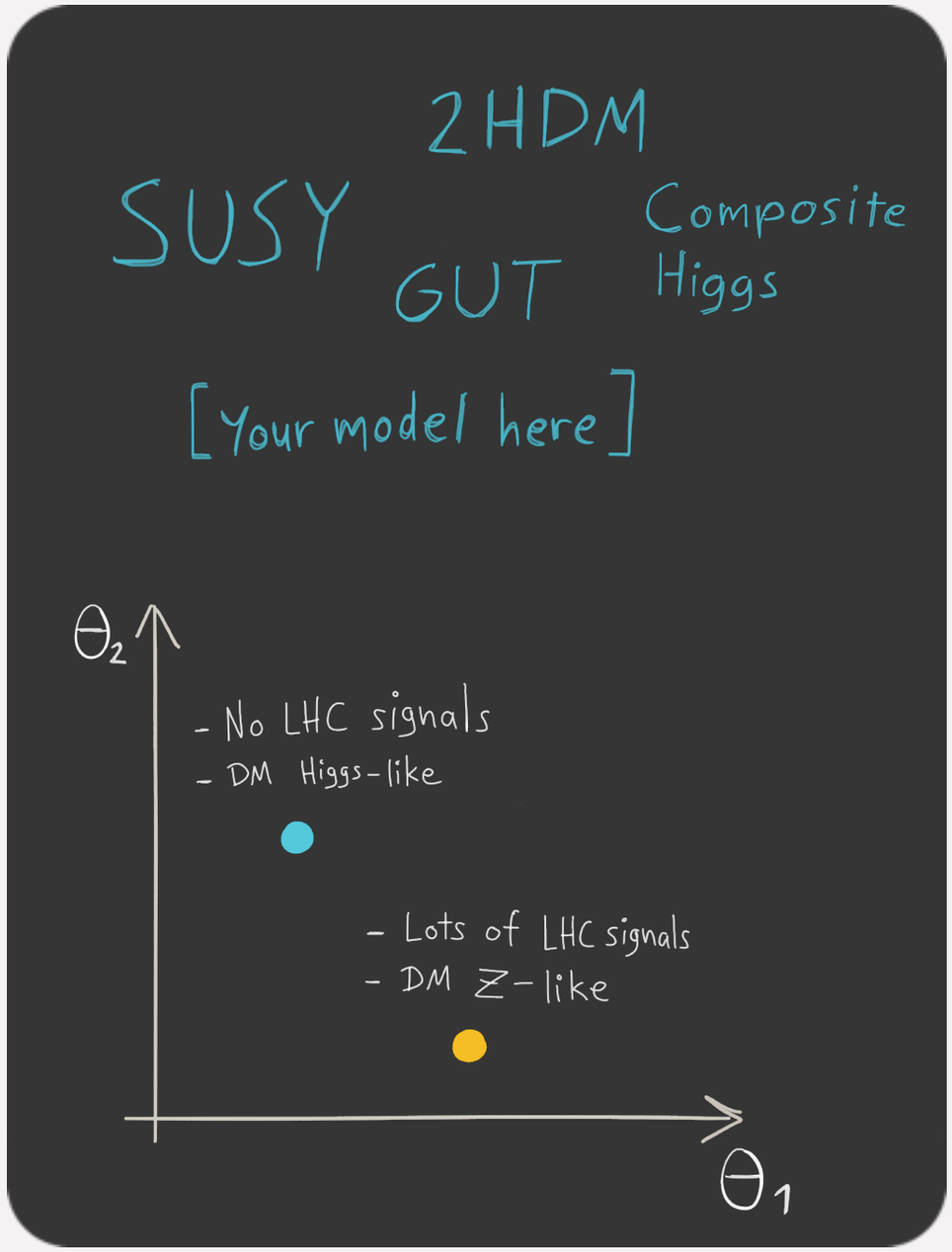
on behalf of the GAMBIT Collaboration

Dartmouth-TRIUMF HEP/Cosmo tools bootcamp — 26/10/17

UiO : University of Oslo

Comparing BSM theories to data

- Lots of theories for BSM physics
- For each theory, a parameter space of varying phenomenology
- Many different experiments can constrain each theory



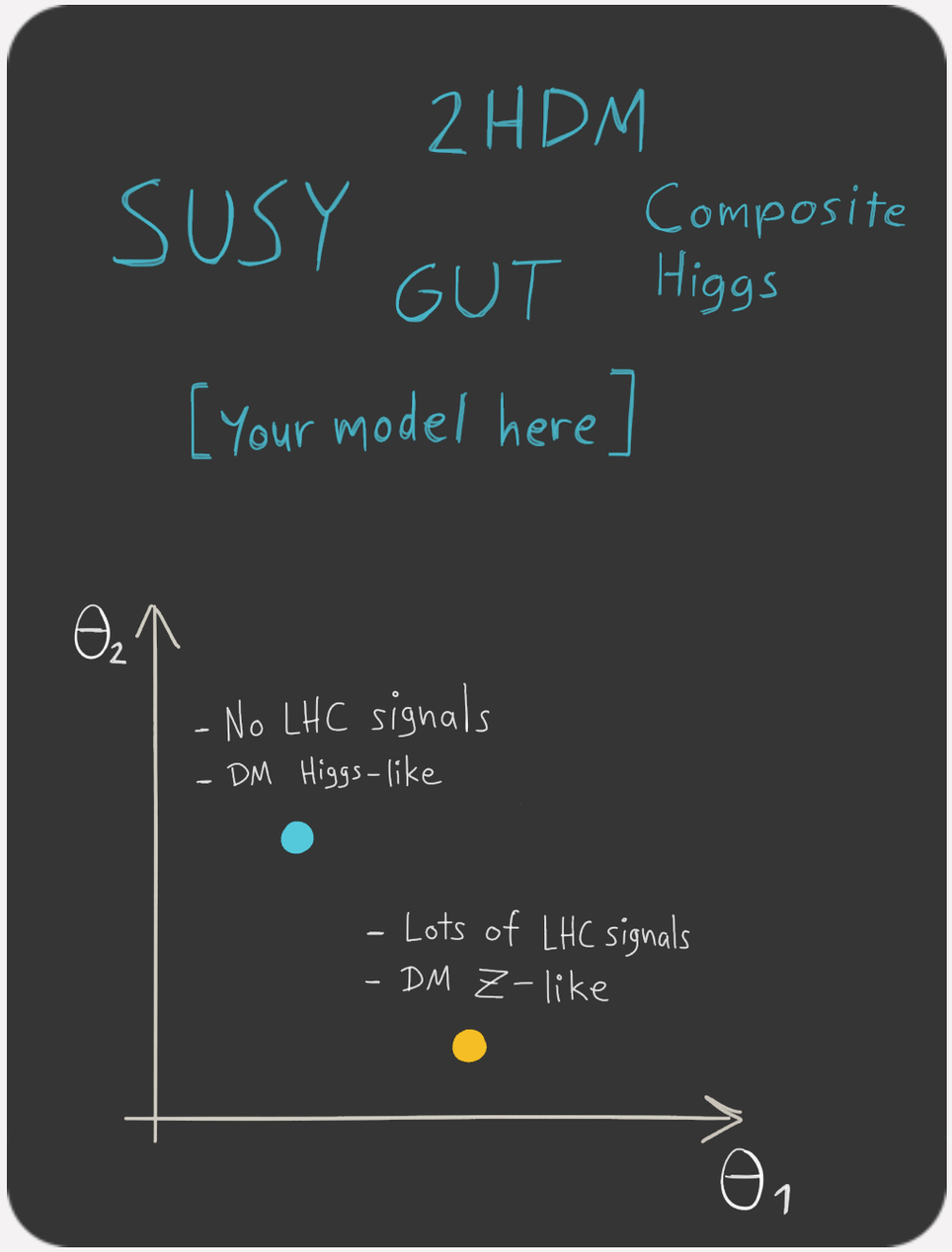
Comparing BSM theories to data

- Lots of theories for BSM physics

- For each theory, a parameter space of varying phenomenology

- Many different experiments can constrain each theory

  *Consistently compare theories against **all** available data: **global fits***



Global fits

- Calculate **combined likelihood function** including observables from collider physics, dark matter, flavor physics, +++

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

- Use **sophisticated scanning techniques** to explore likelihood function across the parameter space of the theory

- Test **parameter regions** in a statistically sensible way — not just single points *(parameter estimation)*

- Test **different theories the same way** *(model comparison)*

Need a tool designed to work with different theories, scanners, observables and theory calculators

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The Global And Modular BSM Inference Tool

- A new framework for BSM **global fits**
- Fully **open source**
- **Modular design:** easily extended with
  - new models
  - new likelihoods
  - new theory calculators
  - new scanning algorithms
- Use external codes (**backends**) as **runtime plugins**
  - Currently supported:
    C, C++, Fortran, Mathematica
  - Working on: Python
- **Two-level parallellization** with MPI and OpenMP
- **Hierarchical** model database
- **Flexible output streams** (ASCII, HDF5, …)
- Many **scanners** and **backends** already included

gambit.hepforge.org

GAMBIT: The Global And Modular BSM Inference Tool

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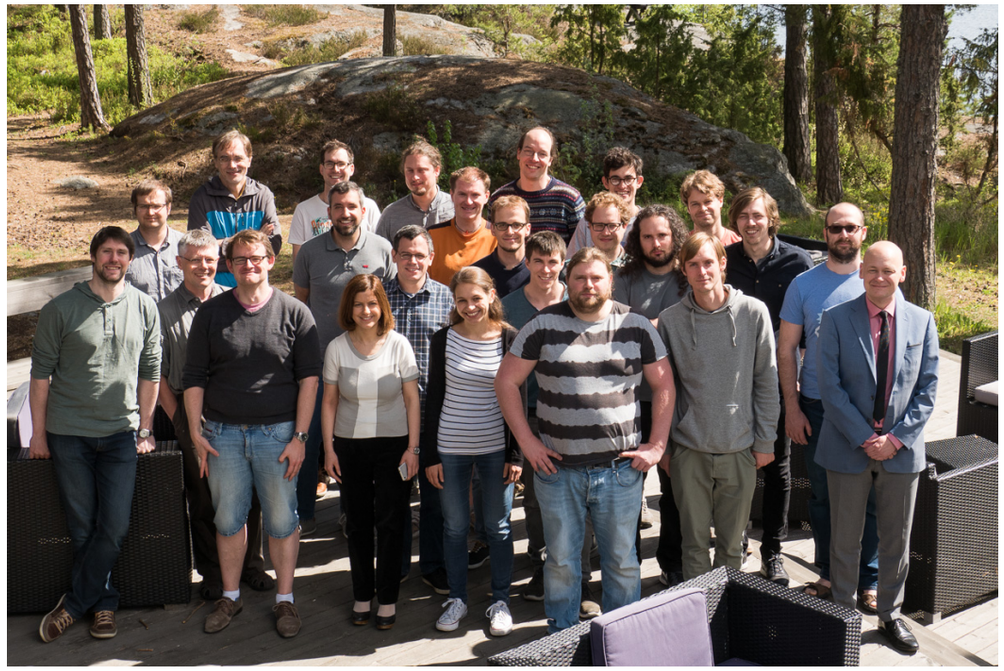
- Fast definition of new datasets and theoretical models
- Plug and play scanning, physics and likelihood packages
- Extensive model database – not just SUSY
- Extensive observable/data libraries
- Many statistical and scanning options (Bayesian & frequentist)
- *Fast* LHC likelihood calculator
- Massively parallel
- Fully open-source

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



29 Members in 9 Experiments, 12 major theory codes, 11 countries

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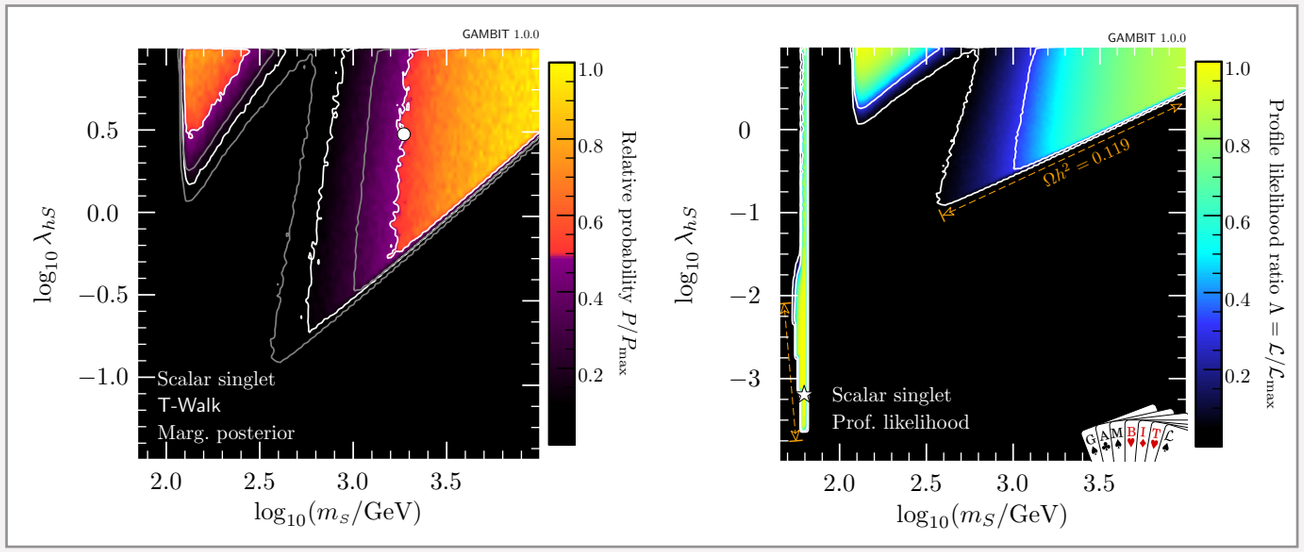
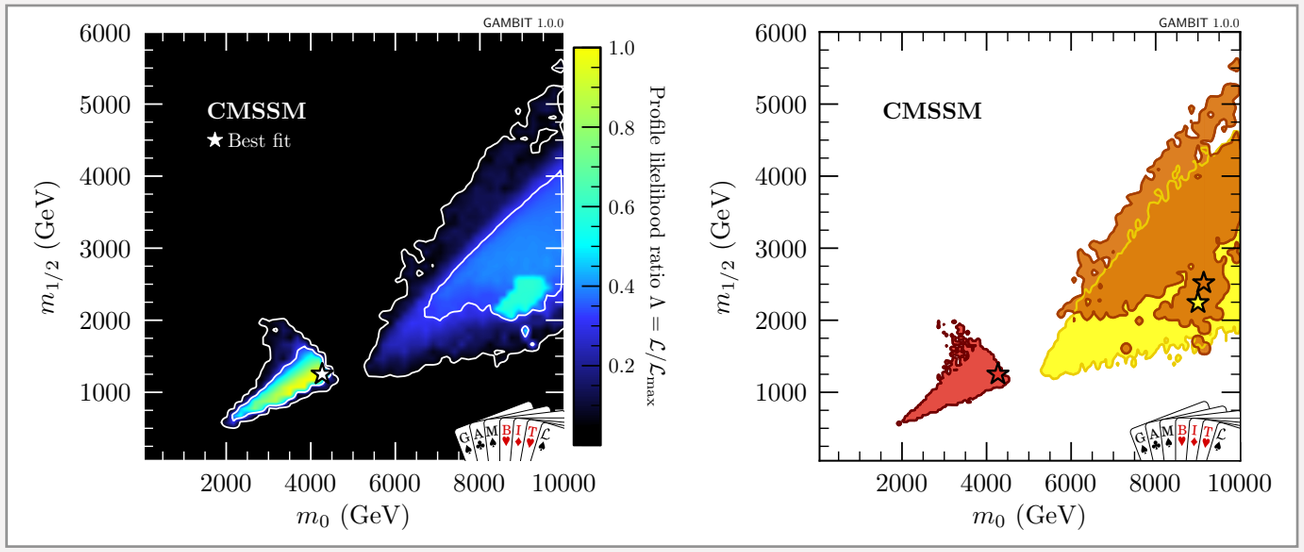
First physics results

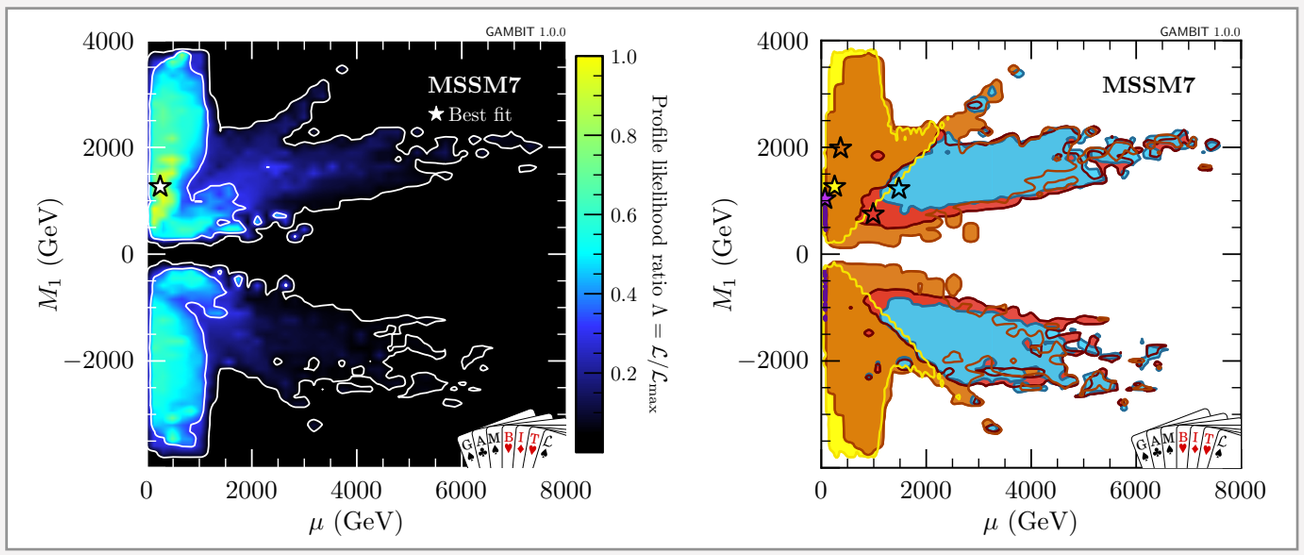
- **Scalar singlet dark matter**
  arXiv:1705.07931

- **GUT-scale MSSM**
  CMSSM, NUHM1, NUHM2
  arXiv:1705.07935

- **Weak-scale MSSM7**
  arXiv:1705.07917







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What's in the box?

Core

- Models — arXiv:1705.07908

Physics modules

- ColliderBit: *fast* LHC sim, Higgs searches, LEP SUSY limits — arXiv:1705.07919
- DarkBit: relic density, gamma ray signal yields, ID/DD likelihoods — arXiv:1705.07920
- FlavBit: wide range of flavour observables & likelihoods — arXiv:1705.07933
- SpecBit: spectrum objects, RGE running
- DecayBit: decay widths — arXiv:1705.07936
- PrecisionBit: precision BSM tests

Statistics and sampling

- ScannerBit: stats & sampling (Diver, MultiNest, T-Walk, ++) — arXiv:1705.07959

Backends (external tools)

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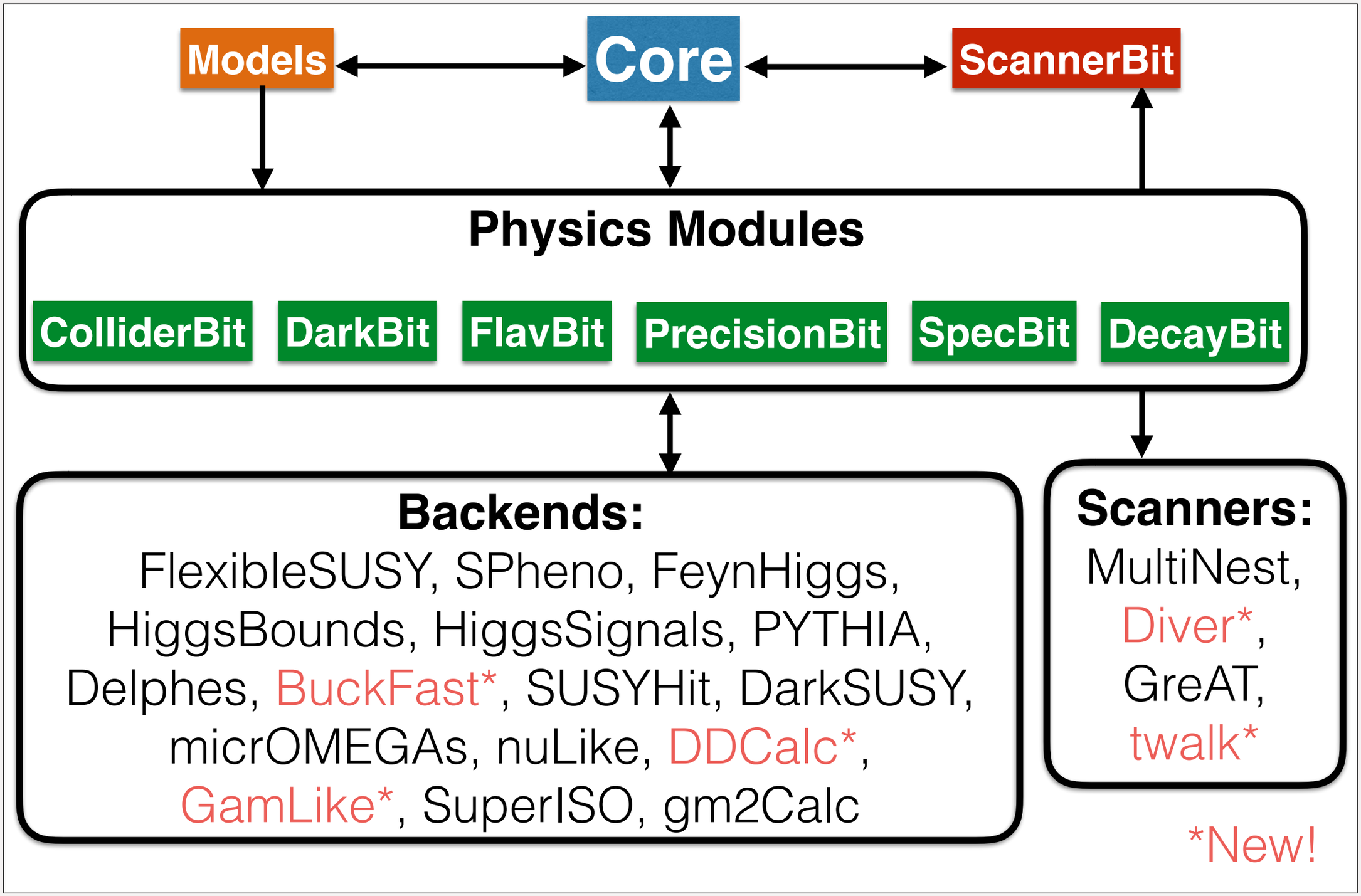
Code structure



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Code structure

- Basic building blocks: **module functions**
- A physics module: **a collection of module functions** related to the same physics topic
- Each module function has a single **capability** (what it calculates)
- A module function can have **dependencies** on the results of other module functions
- A module function can declare which **models** it can work with
- GAMBIT determines which module functions should be run in which order for a given scan (**dependency resolution**)

```
void function_name(double &result)
{
  ...
  result = ... // something useful
}
```

```
// Observable: BR(B -> tau nu)
#define CAPABILITY Btaunu
START_CAPABILITY
  #define FUNCTION SI_Btaunu
  START_FUNCTION(double)
  DEPENDENCY(SuperIso_modelinfo, parameters)
  BACKEND_REQ(Btaunu, (libsuperiso), double, (const parameters*))
  BACKEND_OPTION( (SuperIso, 3.6), (libsuperiso) )
  #undef FUNCTION
#undef CAPABILITY
```

```
  /// Br B->tau nu_tau decays
  void SI_Btaunu(double &result)
  {
    using namespace Pipes::SI_Btaunu;

    parameters const& param = *Dep::SuperIso_modelinfo;
    result = BEreq::Btaunu(&param);
  }
```

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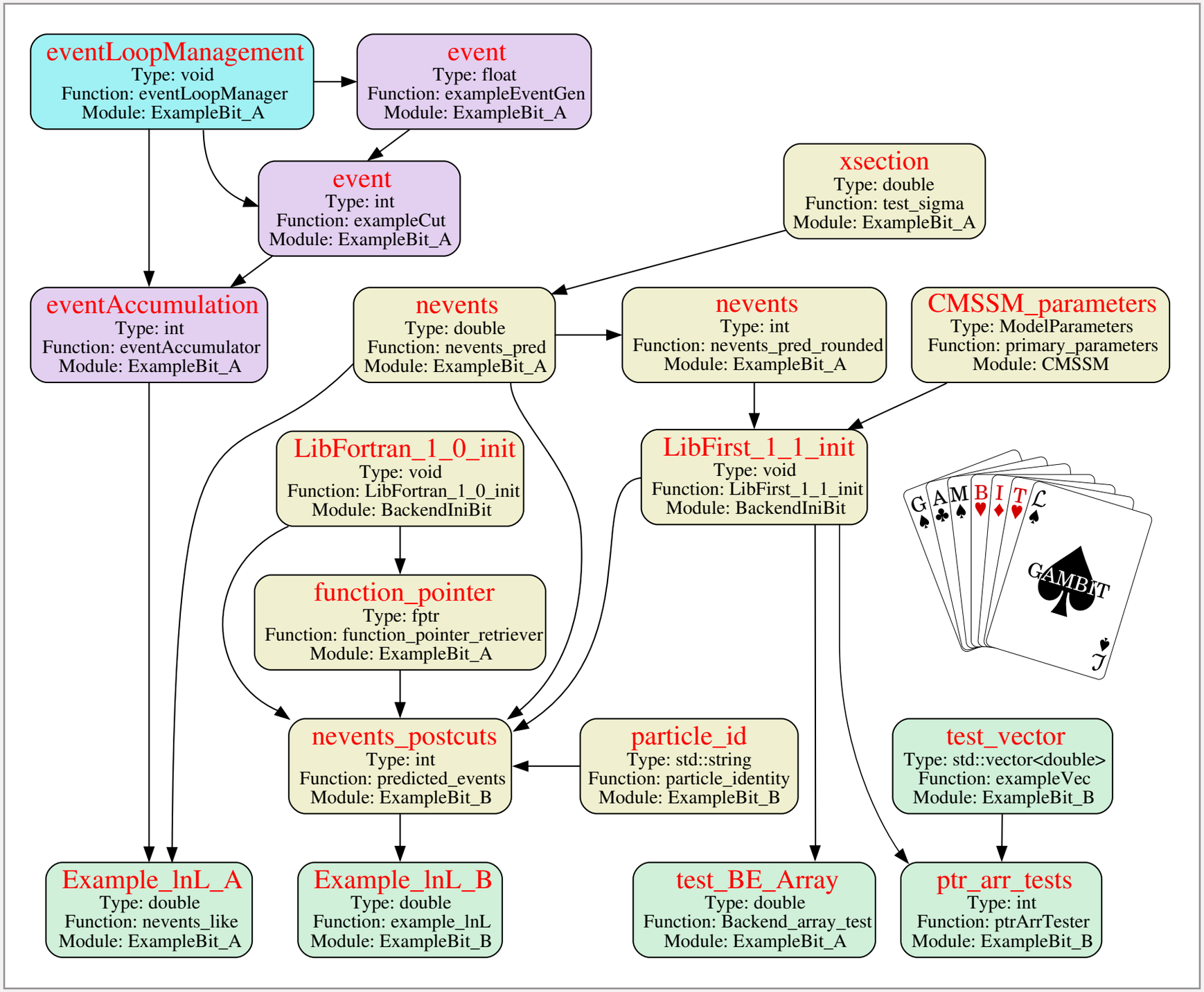
Dependency resolution



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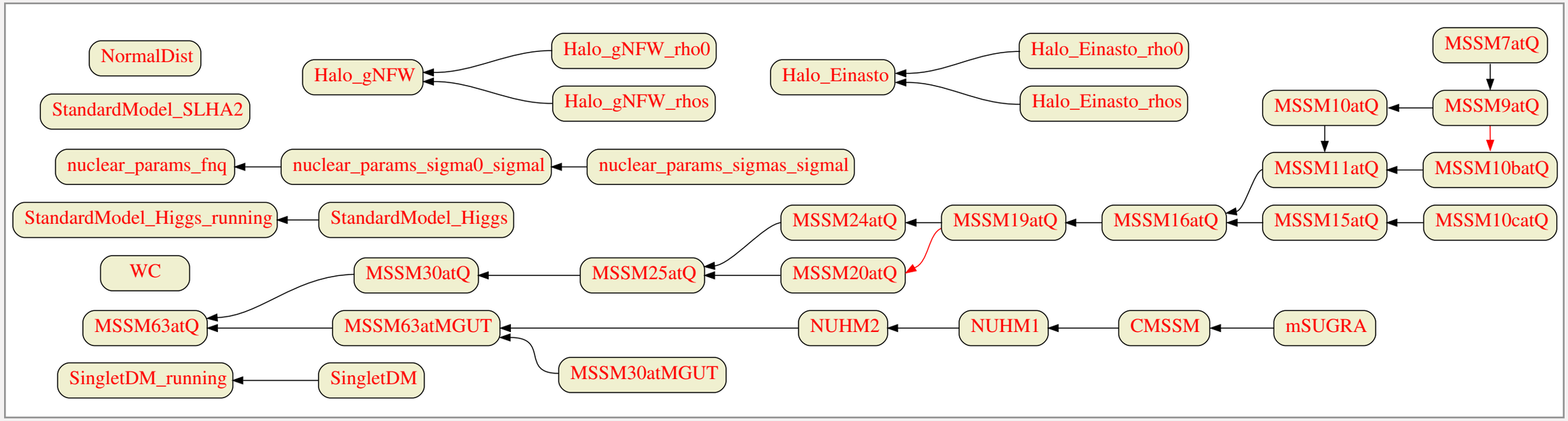
Hierarchical model database

- A **model** is a collection of named parameters
- Models can be **related** (e.g. MSSM9 is a parent of MSSM7)
- Points in child model **automatically translated** to ancestor models
- Ensures **maximum reuse** of calculations and minimizes risk of mistakes



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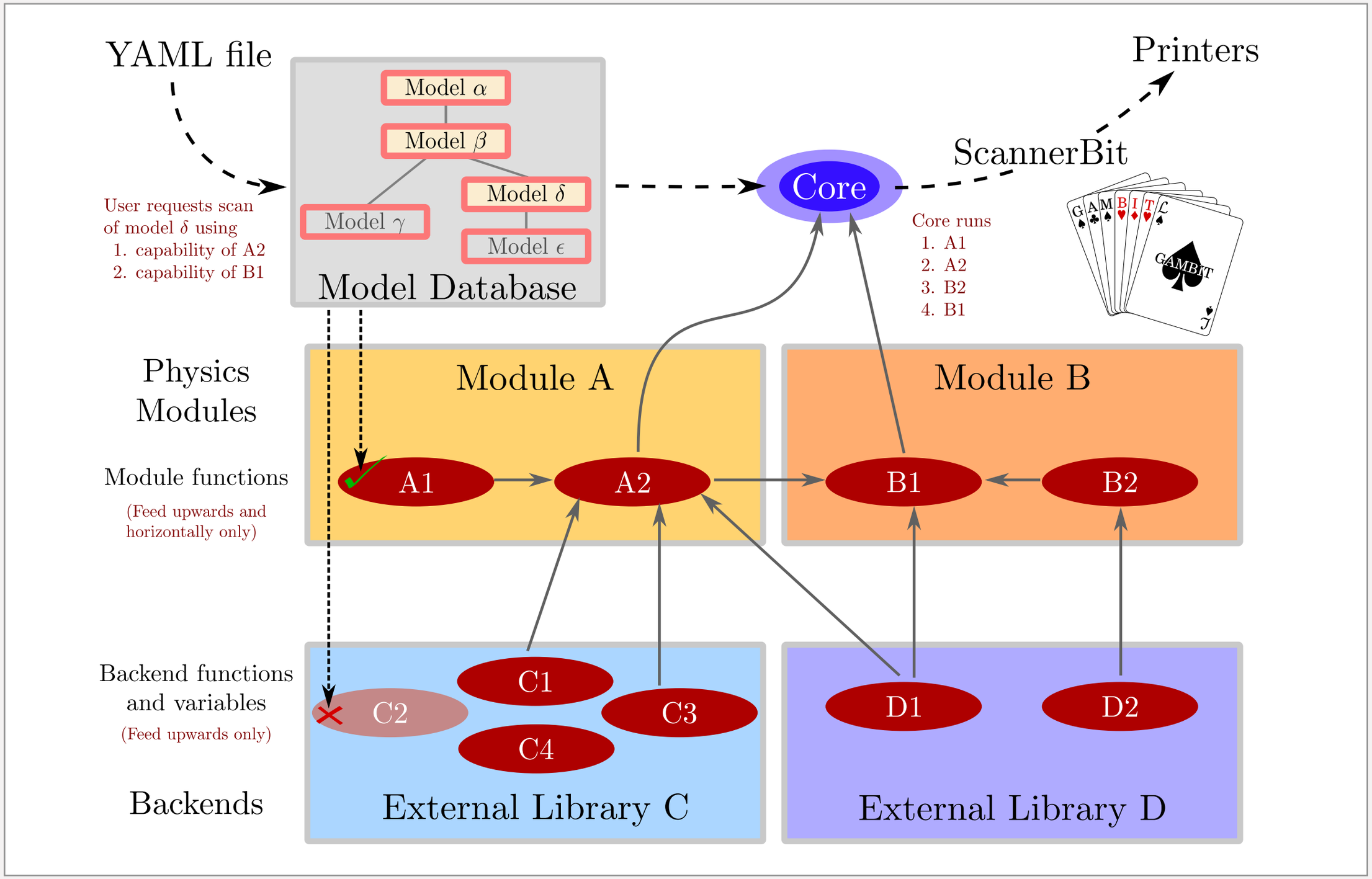
Scan illustration



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YAML files

```
GAMBIT steering files
=====================


Functionality/configuration demos and minimal examples
------------------------------------------------------

spartan.yaml                    --- Simplest example of using GAMBIT: a toy-model MultiNest scan
spartan_CMSSM.yaml              --- Simple example of using GAMBIT in a random scan of CMSSM params

ColliderBit_CMSSM.yaml          --- LEP and LHC direct search observables in a MultiNest scan of the CMSSM
ColliderBit_ExternalModel.yaml  --- LHC likelihood demo on a single point of a Pythia external model

DarkBit_MSSM7.yaml              --- DM constraint demo with a MultiNest scan of the MSSM7 model
DarkBit_SingletDM.yaml          --- DarkBit demo with a simple of MultiNest scan of Singlet DM model

DecayBit_MSSM20.yaml            --- Test of DecayBit, printing out a decay table for MSSM20 at a single model point
DecayBit_SingletDM.yaml         --- Test of DecayBit, printing out a decay table for Singlet DM at 10 model points

FlavBit_CMSSM.yaml              --- Flavour physics fits to CMSSM with Diver scan

PrecisionBit_MSSM20.yaml        --- Precision EW observable demo on a single MSSM20 point

ScannerBit.yaml                 --- Example of configuring the scanner system

SpecBit_MSSM.yaml               --- Single-point test of mass spectrum generation in MSSM sub-models
SpecBit_vacuum_stability.yaml   --- 50x50 grid scan of vacuum stability in [mT,mH]


Physics model scan configurations
---------------------------------

CMSSM.yaml      --- Diver scan of CMSSM model
MSSM7.yaml      --- Diver scan of MSSM7 model
NUHM1.yaml      --- Diver scan of NUHM1 model
NUHM2.yaml      --- Diver scan of NUHM2 model
SingletDM.yaml  --- Diver scan of Singlet DM model
WC.yaml         --- MultiNest scan of flavour physics Wilson Coeffs


Config fragments containing parameters for inclusion in other steering files
----------------------------------------------------------------------------

StandardModel_SLHA2_defaults.yaml
StandardModel_SLHA2_scan.yaml
```

GAMBIT

Tutorial

Today:

- YAML steering files, GAMBIT diagnostics system, perform a simple 2D fit, plot results

Tomorrow (Jonathan Cornell)**:**

- Introduction to the ColliderBit and DarkBit modules, implementing a new model and calculating DM likelihoods, run a scan of this model

A first GAMBIT example

A simple and quick 2D Wilson coefficient fit

Material

Files on Indico:

- **Installation instructions**: `Installation_before_tutorial.txt`
  (Hopefully you have already done this…)

- **Tutorial steps**: `tutorial_commands.txt`

- **Input files** for GAMBIT and pippi: `WC_lite.yaml`, `WC_lite.pip`

References

- Web: gambit.hepforge.org
- GAMBIT manual: arxiv.org/pdf/1705.07908.pdf
- FlavBit manual: arxiv.org/pdf/1705.07933.pdf
- ScannerBit manual: arxiv.org/pdf/1705.07959.pdf

Effective field theory

$$\mathcal{H}_{\text{eff}} = -\frac{4G_F}{\sqrt{2}} V_{tb}V_{ts}^* \sum_{i=1}^{10} \Big(C_i(\mu)\mathcal{O}_i(\mu) + C_i'(\mu)\mathcal{O}_i'(\mu) \Big)$$

Wilson Coefficients

$$\mathcal{O}_1 = (\bar{s}\gamma_\mu T^a P_L c)(\bar{c}\gamma^\mu T^a P_L b)$$

$$\mathcal{O}_2 = (\bar{s}\gamma_\mu P_L c)(\bar{c}\gamma^\mu P_L b)$$

$$\mathcal{O}_3 = (\bar{s}\gamma_\mu P_L b)\sum_q (\bar{q}\gamma^\mu q)$$

$$\mathcal{O}_4 = (\bar{s}\gamma_\mu T^a P_L b)\sum_q (\bar{q}\gamma^\mu T^a q)$$

$$\mathcal{O}_5 = (\bar{s}\gamma_{\mu_1}\gamma_{\mu_2}\gamma_{\mu_3} P_L b)\sum_q (\bar{q}\gamma^{\mu_1}\gamma^{\mu_2}\gamma^{\mu_3} q)$$

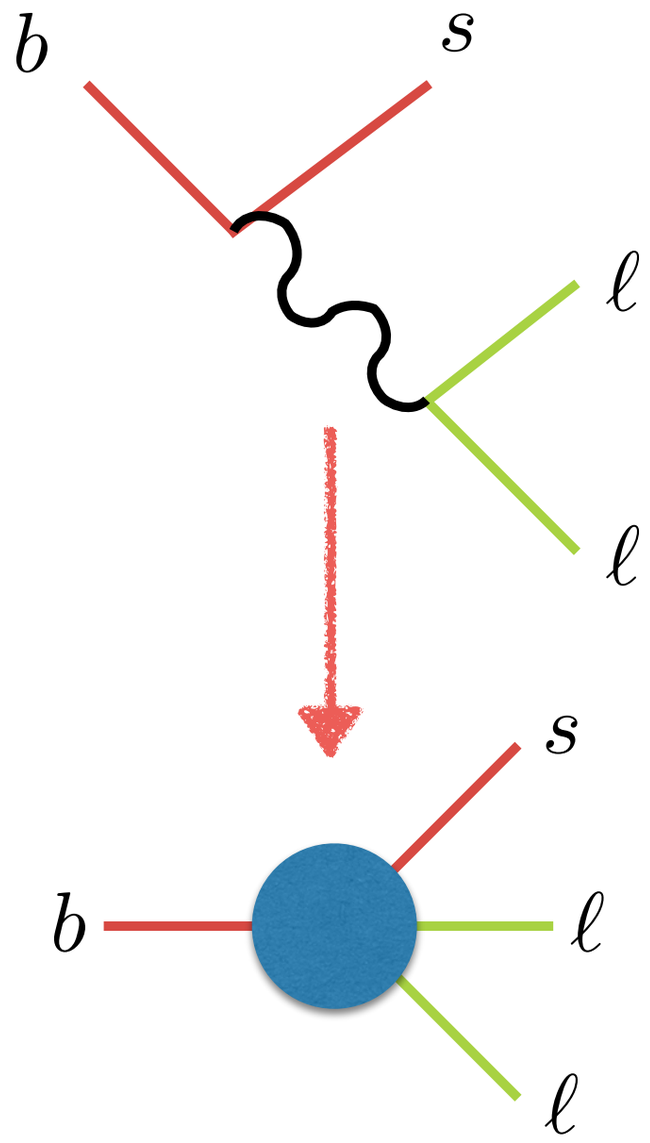
$$\mathcal{O}_6 = (\bar{s}\gamma_{\mu_1}\gamma_{\mu_2}\gamma_{\mu_3} T^a P_L b)\sum_q (\bar{q}\gamma^{\mu_1}\gamma^{\mu_2}\gamma^{\mu_3} T^a q)$$

$$\mathcal{O}_7 = \frac{e}{(4\pi)^2} m_b (\bar{s}\sigma^{\mu\nu} P_R b) F_{\mu\nu}$$

$$\mathcal{O}_8 = \frac{g}{(4\pi)^2} m_b (\bar{s}\sigma^{\mu\nu} T^a P_R b) G^a_{\mu\nu}$$

$$\mathcal{O}_9 = \frac{e^2}{(4\pi)^2} (\bar{s}\gamma^\mu P_L b)(\bar{\ell}\gamma_\mu \ell)$$

$$\mathcal{O}_{10} = \frac{e^2}{(4\pi)^2} (\bar{s}\gamma^\mu P_L b)(\bar{\ell}\gamma_\mu \gamma_5 \ell)$$



The least global global fit ever...

- 2D Wilson coefficient fit

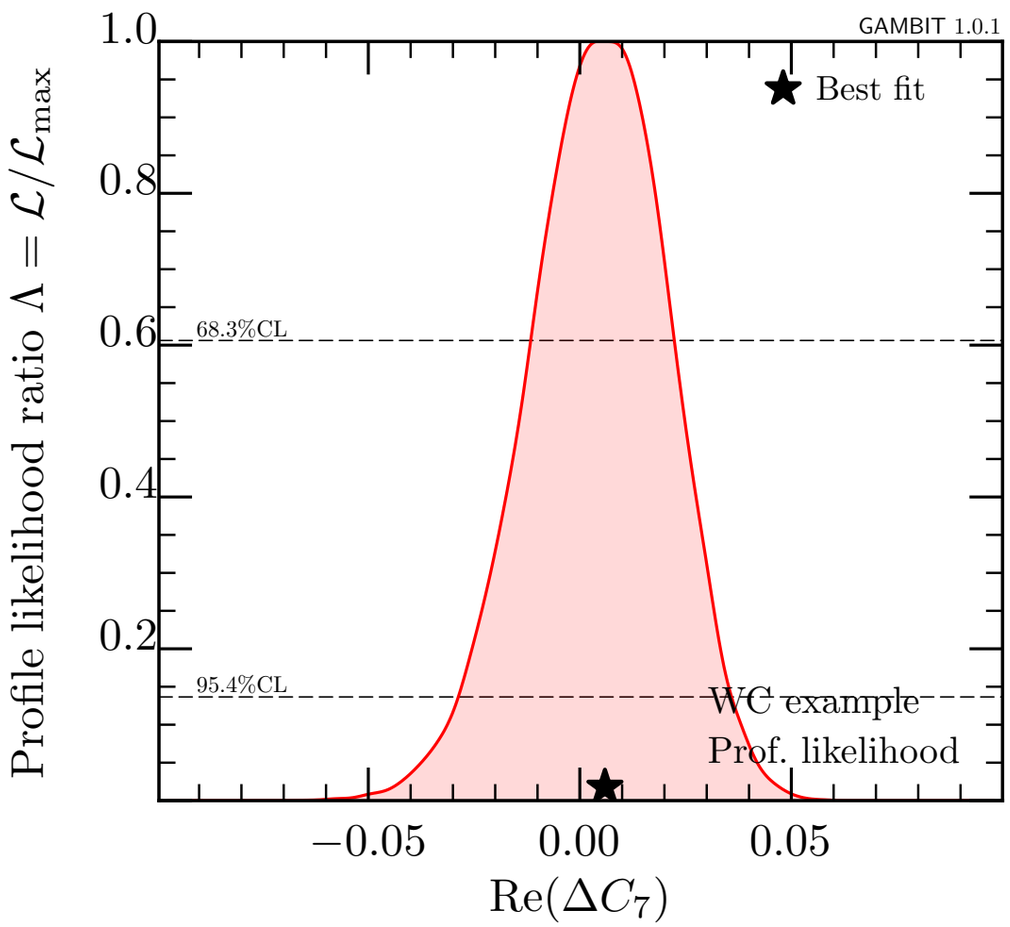
$$\Delta C_x \equiv C_{x,BSM} - C_{x,SM}$$

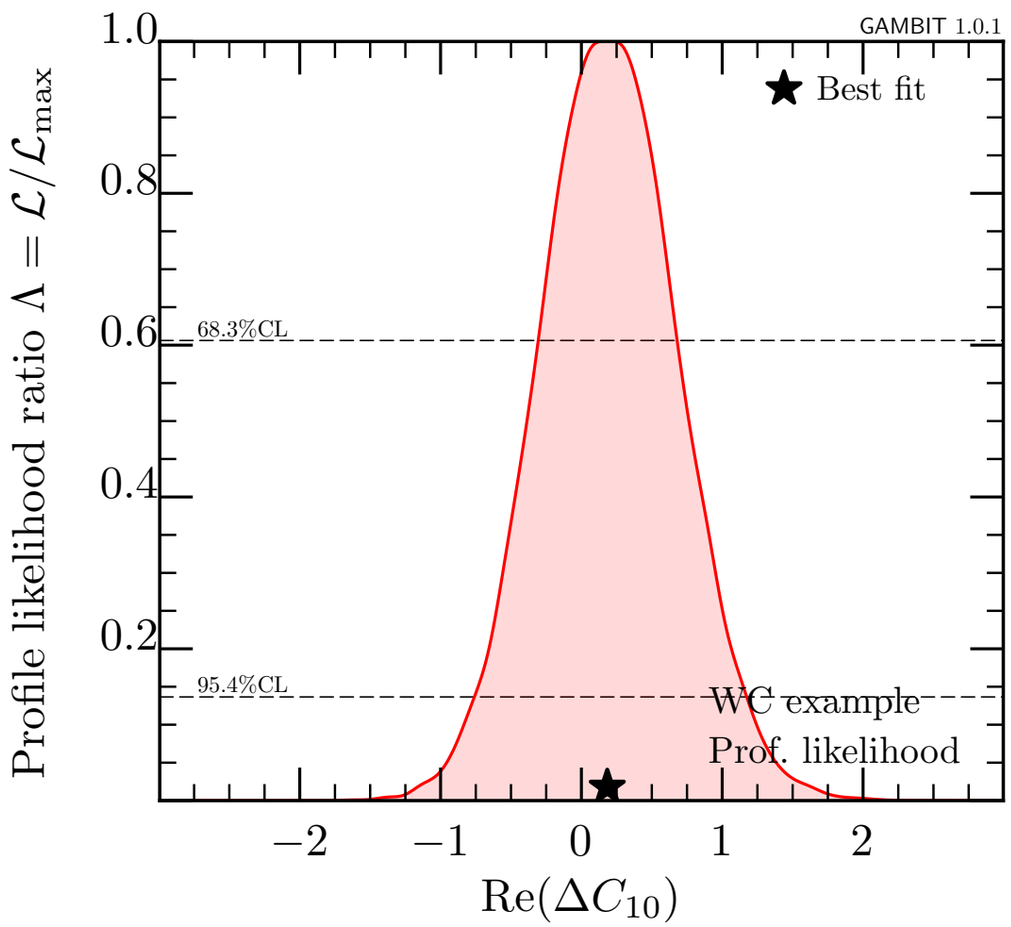
- Free parameters: ΔC_7 `Re_DeltaC7`
  ΔC_{10} `Re_DeltaC10`

- Observables: $BR(B \to X_s\gamma)$ `b2sgamma`
  $BR(B_d \to \mu^+\mu^-)$
  $BR(B_s \to \mu^+\mu^-)$ `b2ll`

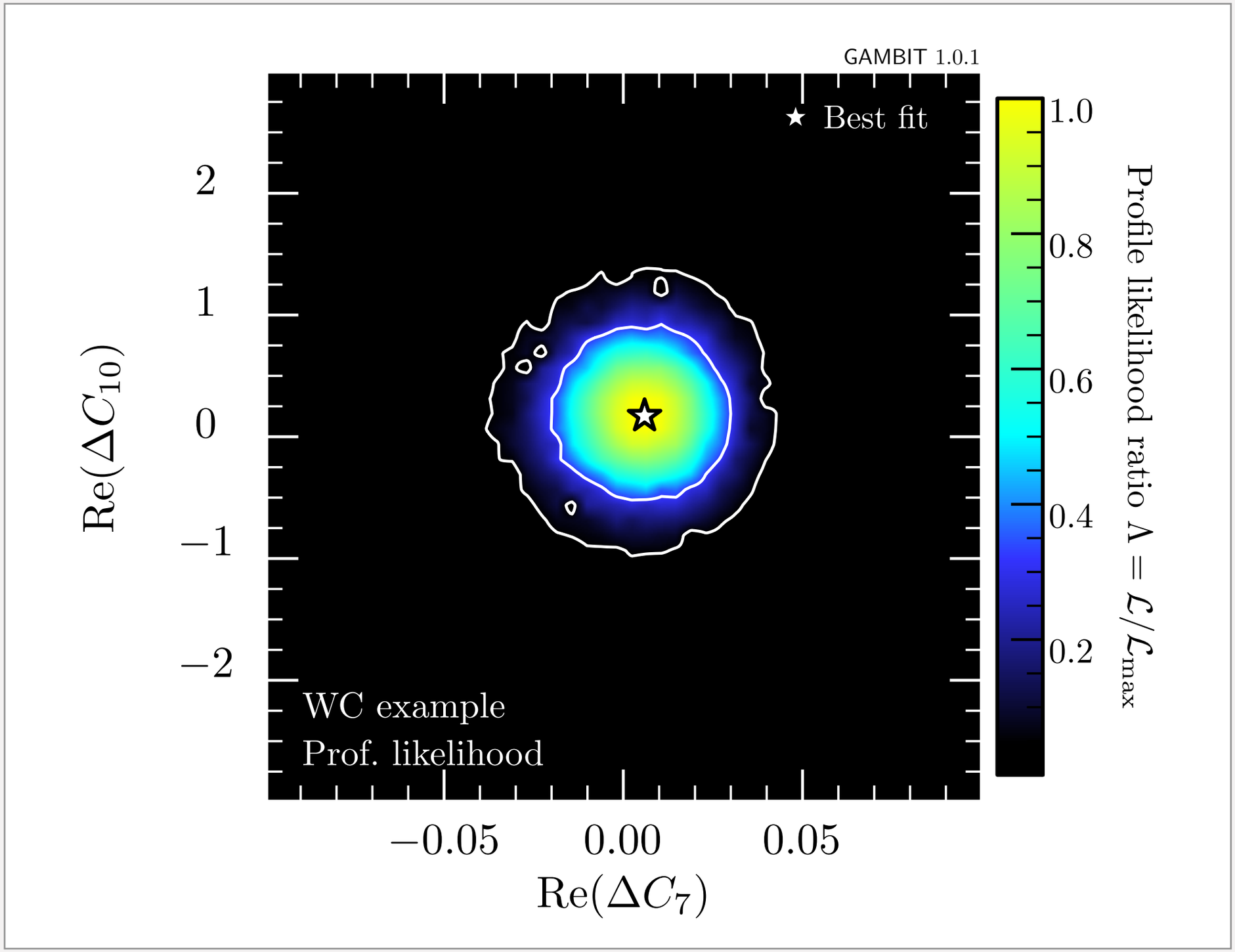
Follow the steps in `tutorial_commands.txt`

Results — Diver scan

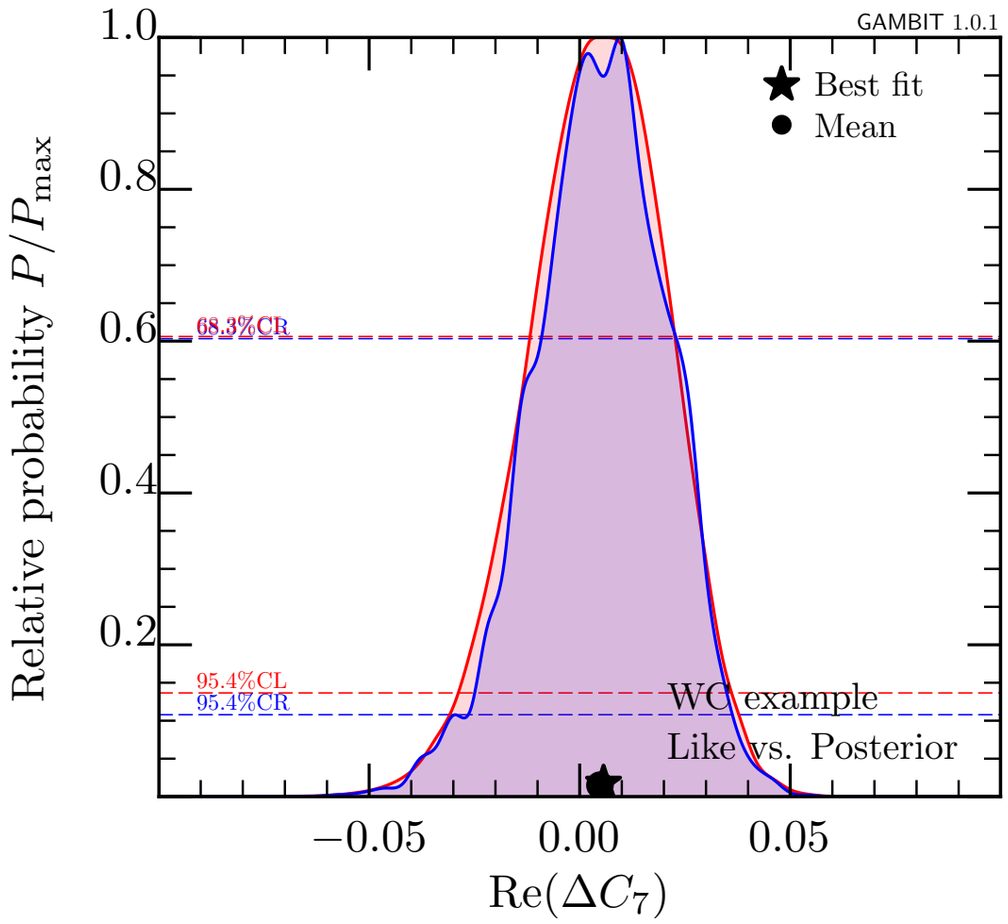


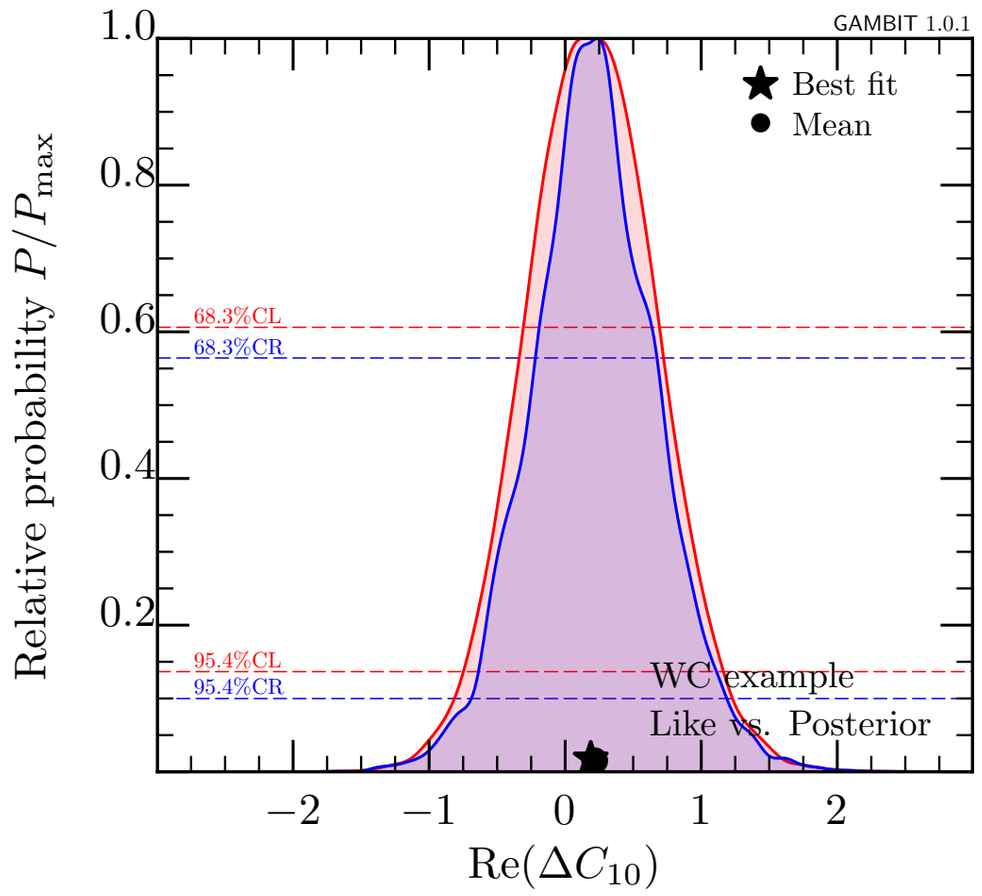


Results — Diver scan

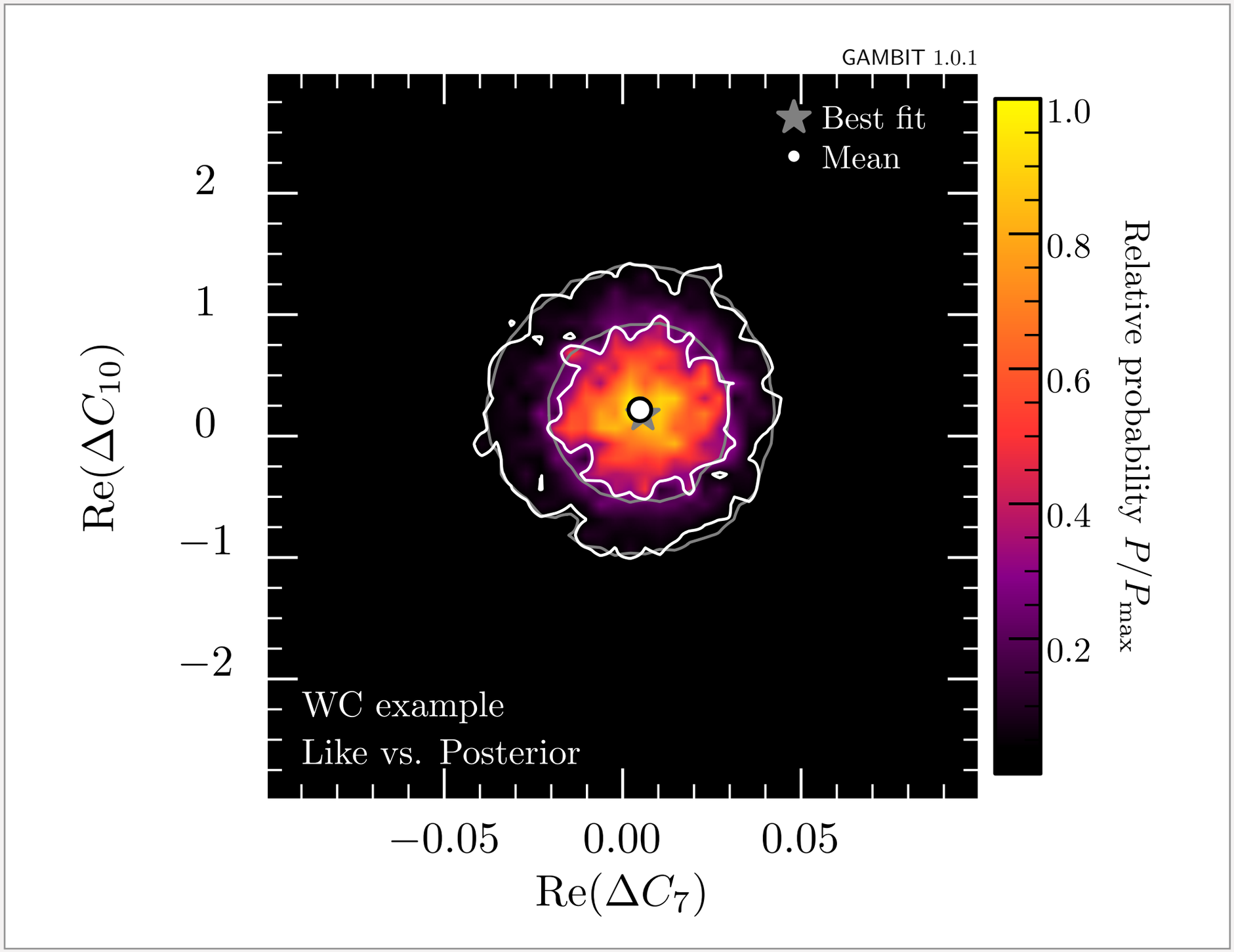


Results — MultiNest scan





Results — MultiNest scan

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