Global Fits of the THDM Using GAMBIT

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in collaboration with **Anthony G. Williams**, **Martin White** and the GAMBIT Collaboration

THE UNIVERSITY of ADELAIDE

CoEPP
ARC Centre of Excellence for Particle Physics at the Terascale

Introduction

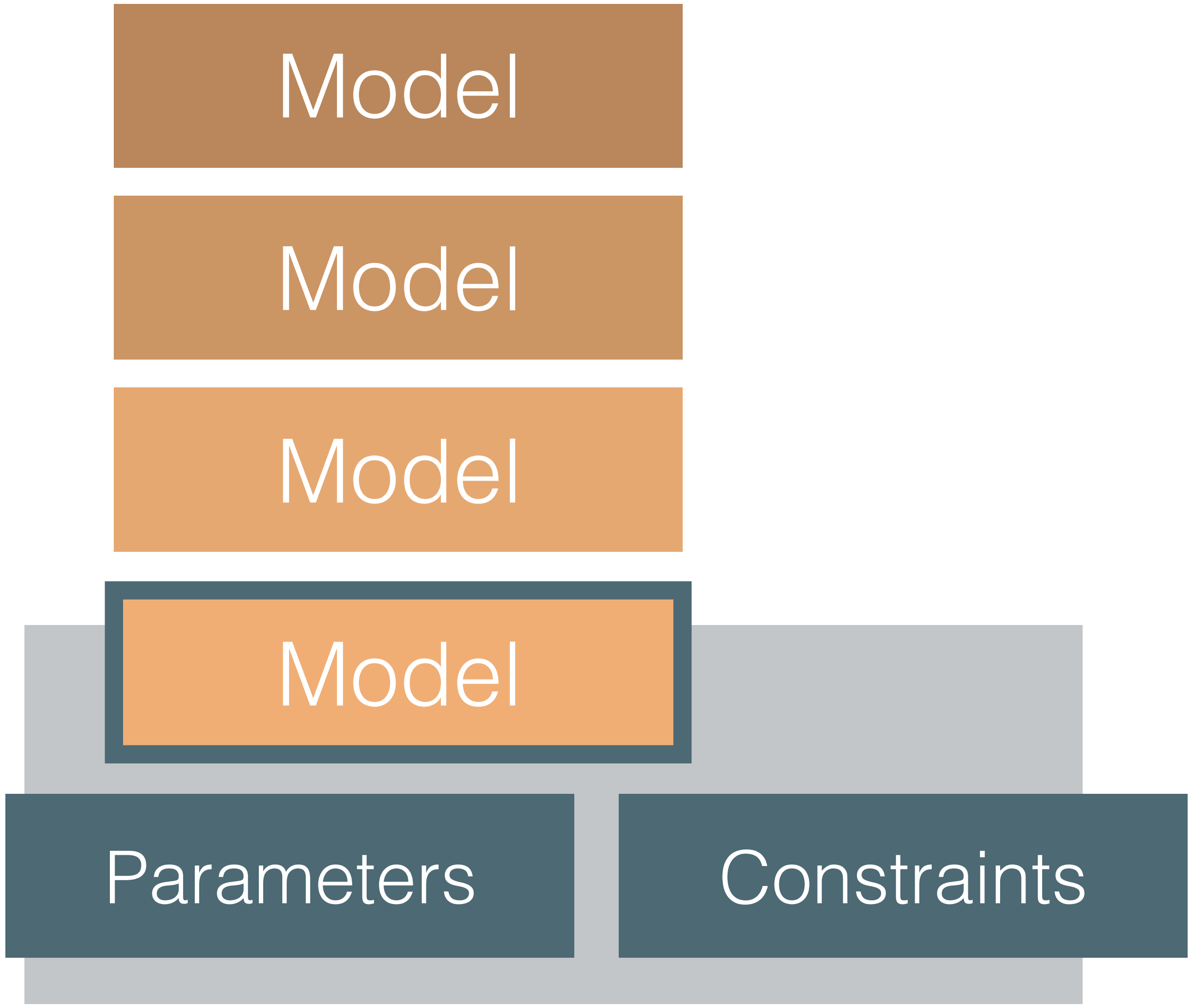
Goal: Merge custom code for THDM global fit with pre release GAMBIT framework. I am not part of the GAMBIT collaboration.

Talk Outline

- Benefits of a statistical global fit.
- What is GAMBIT & how does it work?
- Model introduction.
- Application of theoretical & experimental constraints.
- Scans of the parameter space with Bayesian inference.
- Very preliminary results - status update.
- To come…

Global Fits

- Multiple Models.
- Each with multiple parameters to scan over.
- Each with multiple constraints to apply.



Benefits

1. Statistically compare multiple models - which model best fits the data?
2. Map the parameter space of each model - what regions of parameter space best fit the data?

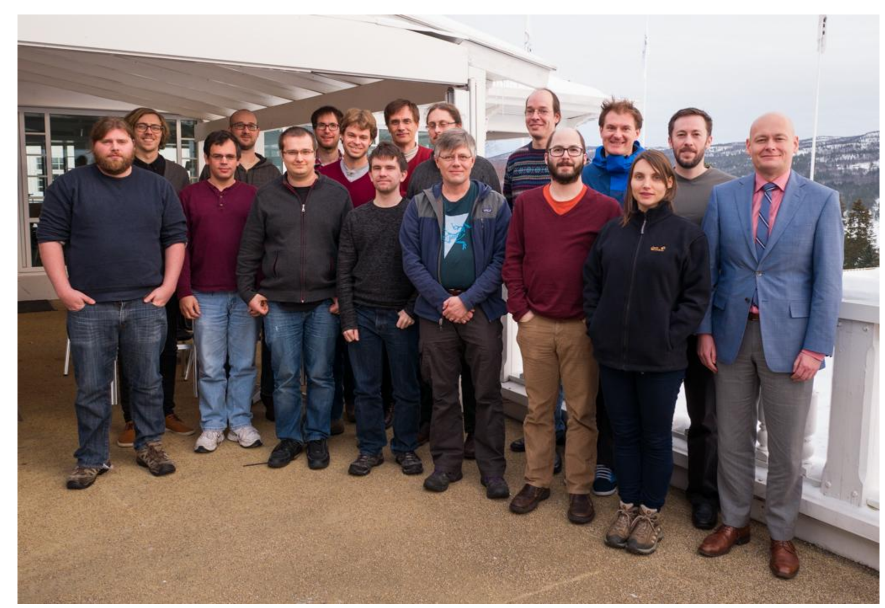
slide courtesy P. Scott (GAMBIT Collaboration)

GAMBIT: The Global And Modular BSM Inference Tool

gambit.hepforge.org

- 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

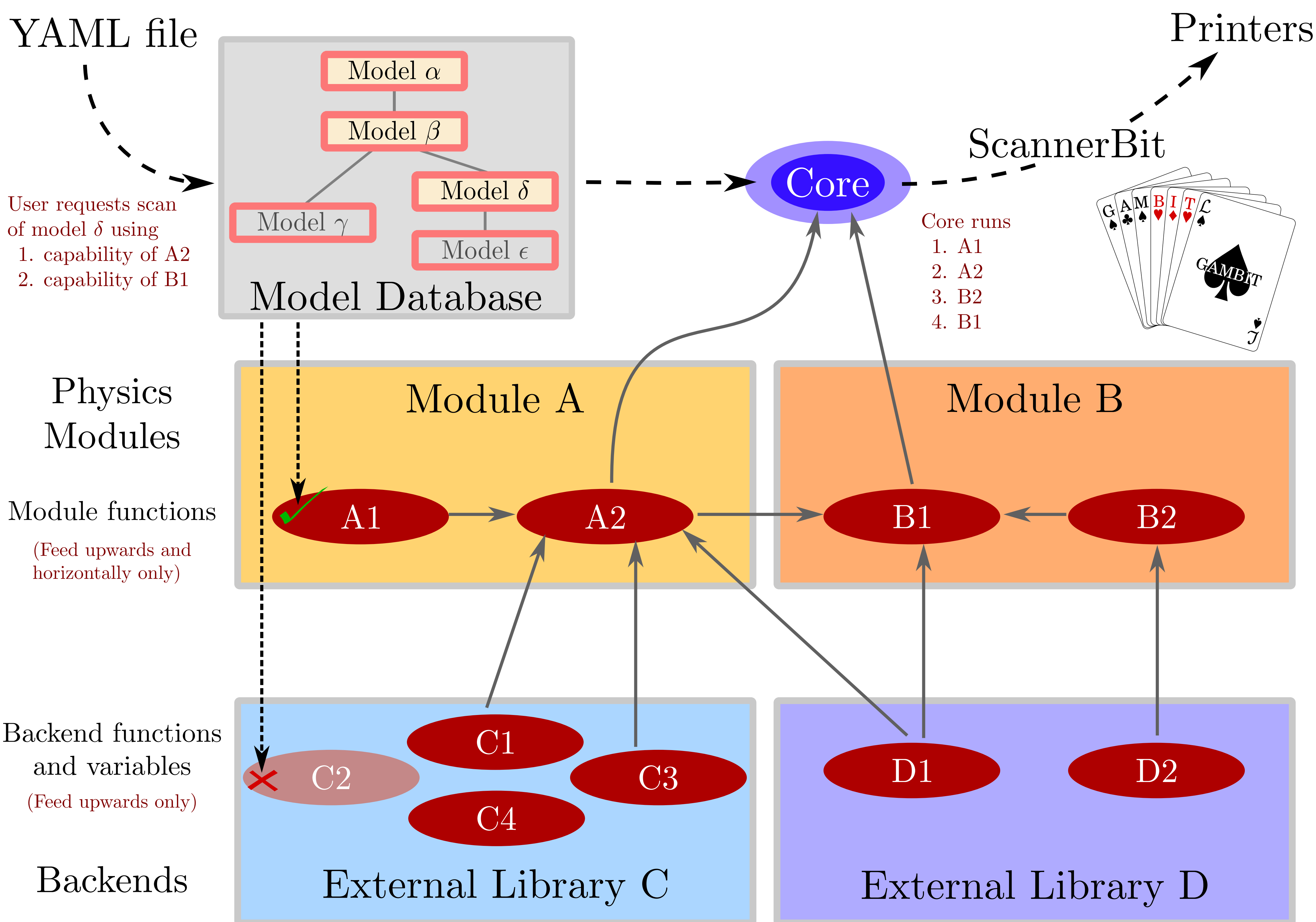
ATLAS	A. Buckley, P. Jackson, C. Rogan, M. White,
LHCb	M. Chrząszcz, N. Serra
Belle-II	F. Bernlochner, P. Jackson
Fermi-LAT	J. Conrad, J. Edsjö, G. Martinez, P. Scott
CTA	C. Balázs, T. Bringmann, J. Conrad, M. White
HESS	J. Conrad
IceCube	J. Edsjö, P. Scott
XENON/DARWIN	J. Conrad, R. Trotta
Theory	P.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



31 Members, 9 Experiments, 4 major theory codes, 11 countries

GAMBIT

slide courtesy P. Scott (GAMBIT Collaboration)



Model Implementation

<u>Model: THDM in alignment limit</u>

J. Bernon, J. F. Gunion, H. E. Haber, Y. Jiang, S. Kraml

arXiv:1507.00933

Model Implementation

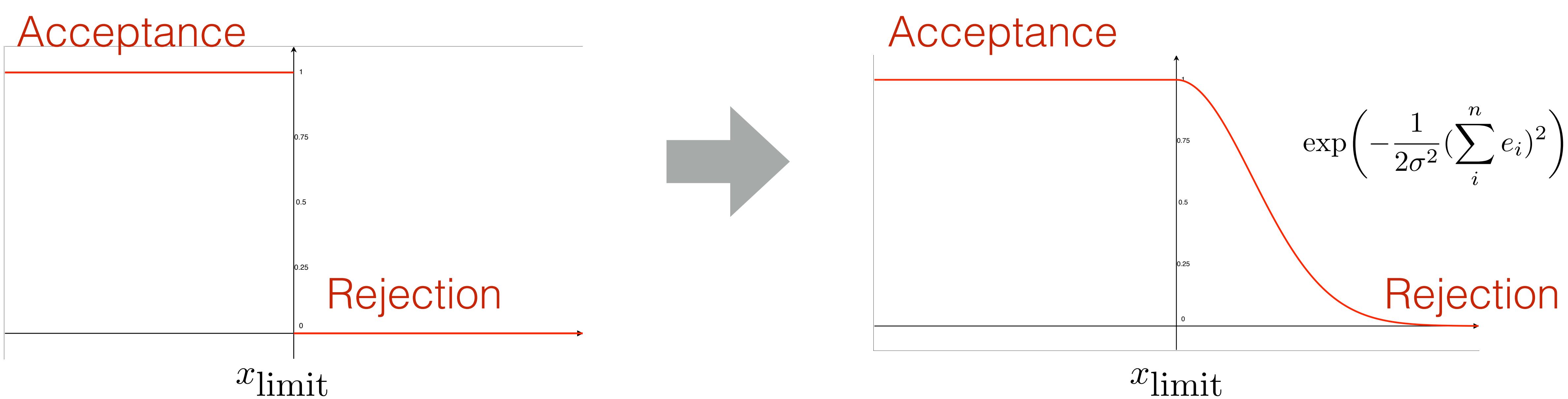
Model: THDM in alignment limit

- Start with most general THDM potential.
- Softly broken discrete $\mathbb{Z}_2$ symmetry $\implies \lambda_6 = \lambda_7 = 0$
- m_{12}^2 is real.

- In alignment limit, physics of the light Higgs approaches that of the SM Higgs: $H_1^0 \rightarrow H_{SM}$
- Alignment limit can be realised when $\sin(\beta - \alpha) \rightarrow 1$

Model Implementation: Constraints

- Each constraint assigned a (Gaussian) likelihood depending on distance from true values $e_i = x_i - x_{\text{true}}$.
- For constraints with limits set by > or < a certain limit value, we replace a ‘hard limit’ of acceptance/rejection with a half Gaussian limit curve.
- Combining each point in parameter space to form a *composite likelihood.*
- Greatly improves ability to discover accepted points.



Model Implementation: Constraints

2HDMC

- Stability of the potential.
- Unitarity of the scattering matrix.
- Perturbativity of quartic Higgs coupling.

$$\log \mathcal{L}_C = -\frac{w_s}{2\sigma_s^2}(\sum_i^{n=4} s_i)^2 - \frac{w_u}{2\sigma_u^2}(\sum_i^{n=12} u_i)^2 - \frac{w_p}{2\sigma_p^2}(\sum_i^{n=256} p_i)^2$$

- Electroweak oblique parameters: S, T & U.

Alignment

- Apply:

$$\sin(\beta - \alpha) > 0.99$$

$$\frac{C_{H_1^0 VV}}{C_{H_{SM} VV}} = \sin(\beta - \alpha)$$

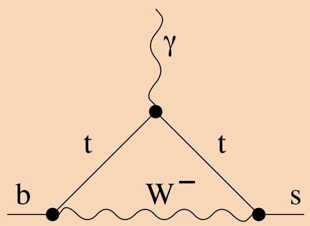
Mode of observation

Model Implementation: Constraints

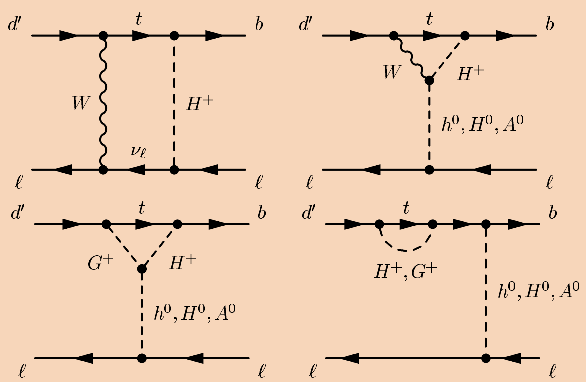
SuperIso

- Flavour Physics observables.
- Charged Higgs (particularly) contribute to rare B meson decay box and penguin diagrams.
- Main SuperIso calculations include:

$$B \to X_s \gamma$$



$$B \to X_s ll, \; B \to ll$$



- Calculation of isospin asymmetry in:

$$B \to K^* \gamma$$

HiggsBounds

- Contains tabulated Higgs expected and observed analysis values at 95% exclusion from LEP/Tevatron/LHC.
- Statistically most excluding channel for quantity Q given by:

$$X_0 = X : \max \frac{Q_{\mathrm{model}(X)}}{Q_{\mathrm{expec}(X)}}$$

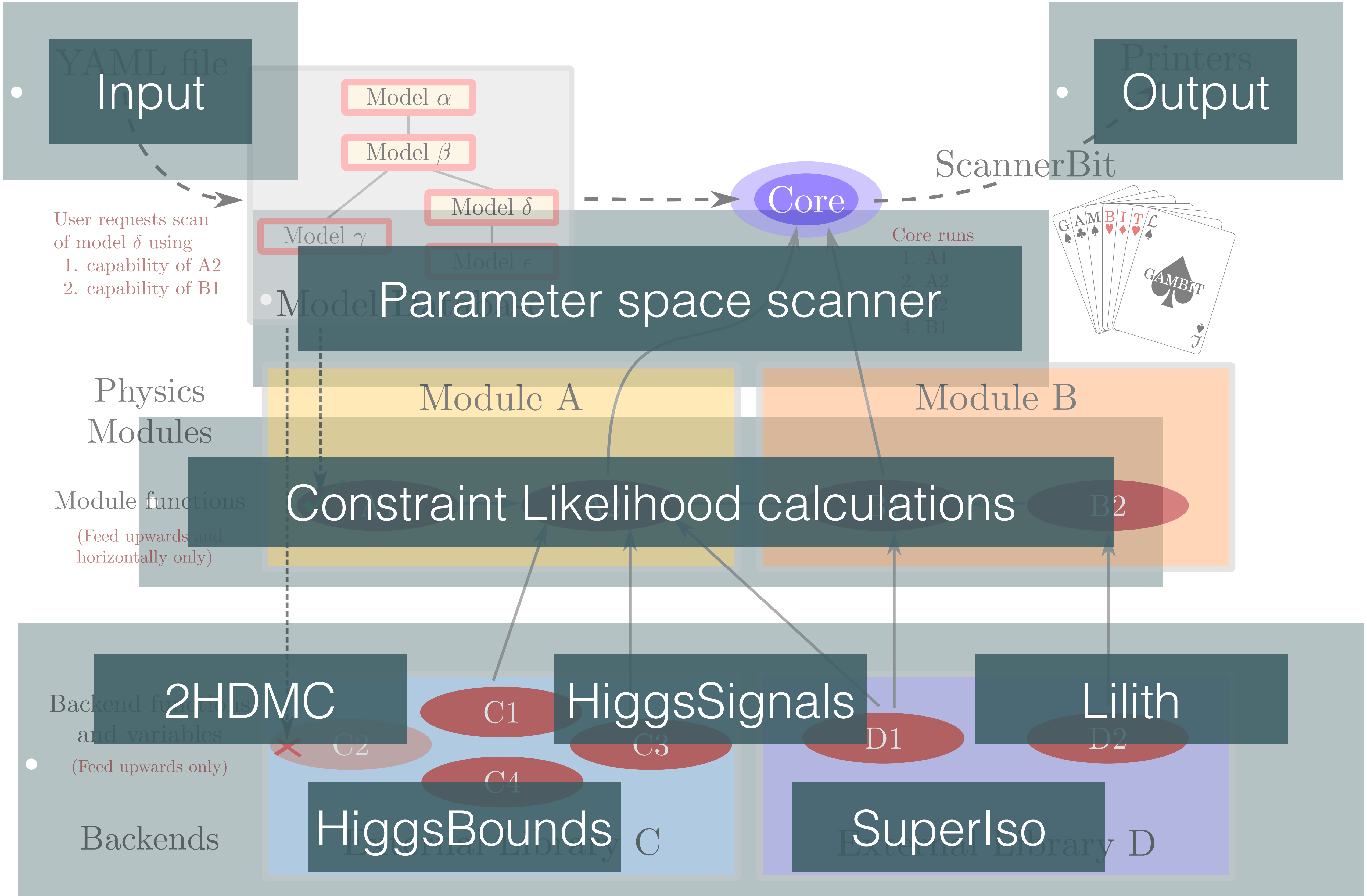
- Observed limit ratio then:

$$k_0 = \frac{Q_{\mathrm{model}(X_0)}}{Q_{\mathrm{obs}(X_0)}}$$

- HiggsBounds log-likelihood function

$$\log \mathcal{L}_{HB} = \begin{cases} 0, & k_0 \leq 1 \\ -\frac{(k_0 - 1)^2}{2\sigma_{HB}^2}, & k_0 > 1 \end{cases}$$

GAMBIT



Input
YAML file
Model α
Model β
Model γ
Model δ
Model ϵ
Model Database
User requests scan of model δ using
1. capability of A2
2. capability of B1
Core
ScannerBit
Printers
Output
Core runs
1. A1
2. A2
3. B2
4. B1
Parameter space scanner
Physics Modules
Module A
Module B
Module functions
(Feed upwards and horizontally only)
Constraint Likelihood calculations
B2
Backend functions and variables
(Feed upwards only)
Backends
2HDMC
HiggsSignals
Lilith
HiggsBounds
SuperIso
C1
C2
C3
C4
D1
D2
External Library C
External Library D

Scanner: MultiNest

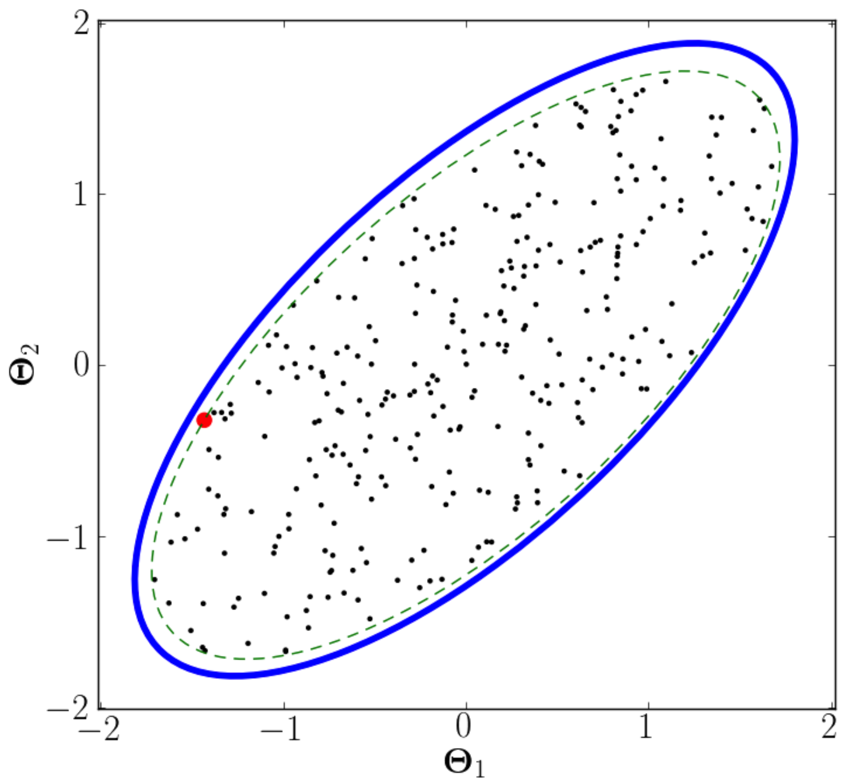
- Bayesian Statistics: Nested Sampling Algorithm

- Bayes Theorem:

$$\Pr(\boldsymbol{\theta}|\mathbf{D}, M) = \frac{\Pr(\mathbf{D}|\boldsymbol{\theta}, M)\Pr(\boldsymbol{\theta}|M)}{\Pr(\mathbf{D}|M)} = \frac{\mathcal{L}(\boldsymbol{\theta})\pi(\boldsymbol{\theta})}{\mathcal{Z}}$$

Useful to map parameter space and compare parameters in single model.

Independent of parameters. Useful to compare different models.



- Compare models 1 & 2:

$$\frac{\Pr(M_1|\mathbf{D})}{\Pr(M_2|\mathbf{D})} = \frac{\mathcal{Z}_1 \Pr(M_1)}{\mathcal{Z}_2 \Pr(M_2)}$$

$$\mathcal{Z} = \int_{\boldsymbol{\theta}} \mathcal{L}(\boldsymbol{\theta})\pi(\boldsymbol{\theta}) d^D\boldsymbol{\theta}$$

Scan Setup: Parameters

J. Bernon, J. F. Gunion, H. E. Haber, Y. Jiang, S. Kraml

arXiv:1507.00933

$$m_{H_1^0} = [124.9 \text{ GeV}, 126.5 \text{ GeV}]$$

$$m_{H_2^0} = [200 \text{ GeV}, 1000 \text{ GeV}]$$

$$m_A = [5 \text{ GeV}, 2000 \text{ GeV}]$$

$$m_{H^\pm} = [300 \text{ GeV}, 2000 \text{ GeV}]$$

$$m_{12}^2 = [(-2 \text{ TeV})^2, (2 \text{TeV})^2]$$

$$\alpha = [-\pi/2, \pi/2]$$

$$\tan\beta = [0.5, 60]$$

Type I Yukawa Couplings

Scan Setup: Parameters

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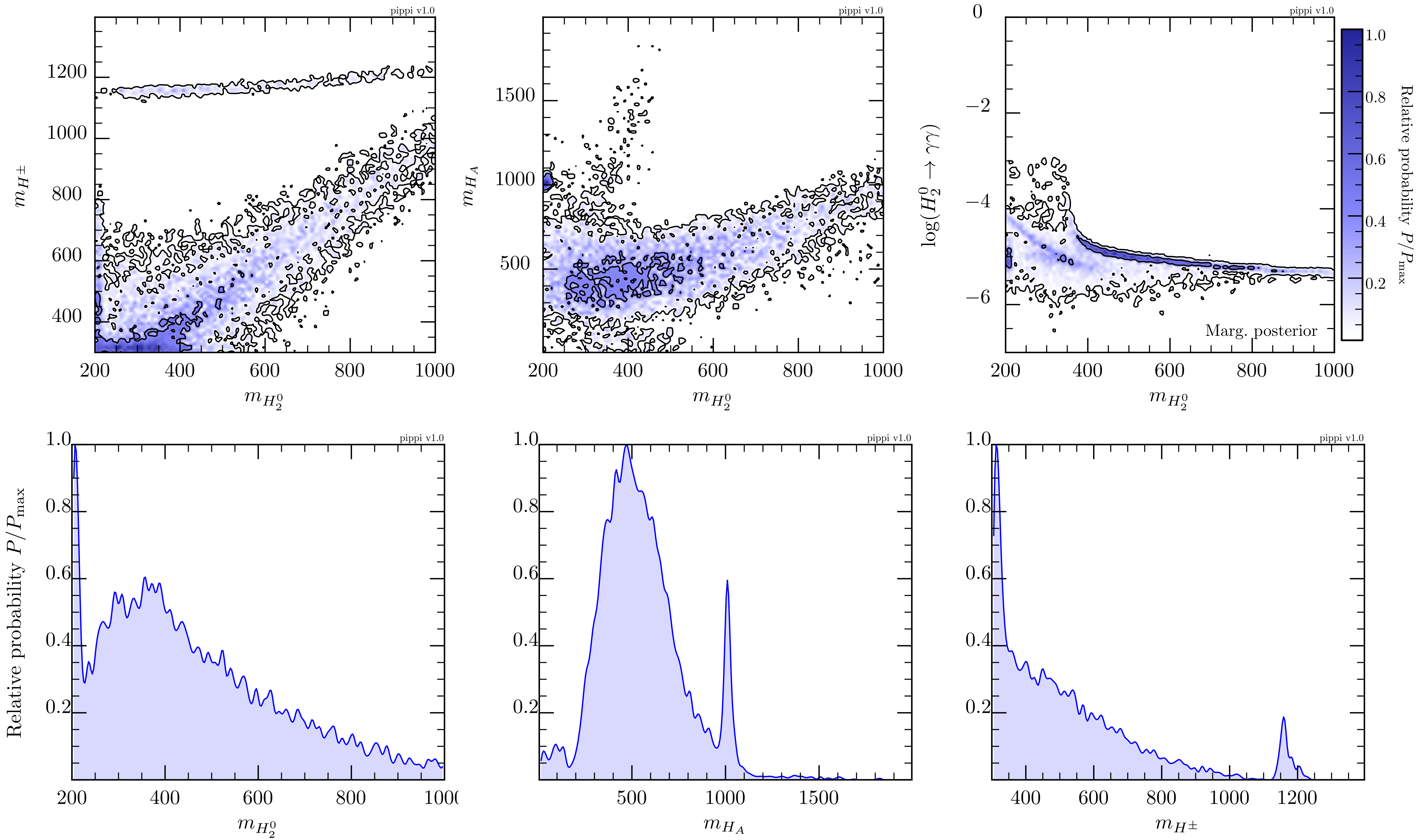
arXiv:1507.00933

- Flat random scan used above.
- Good results but are not statistically meaningful.
- Bayesian inference means we can statistically map the entire parameter space.

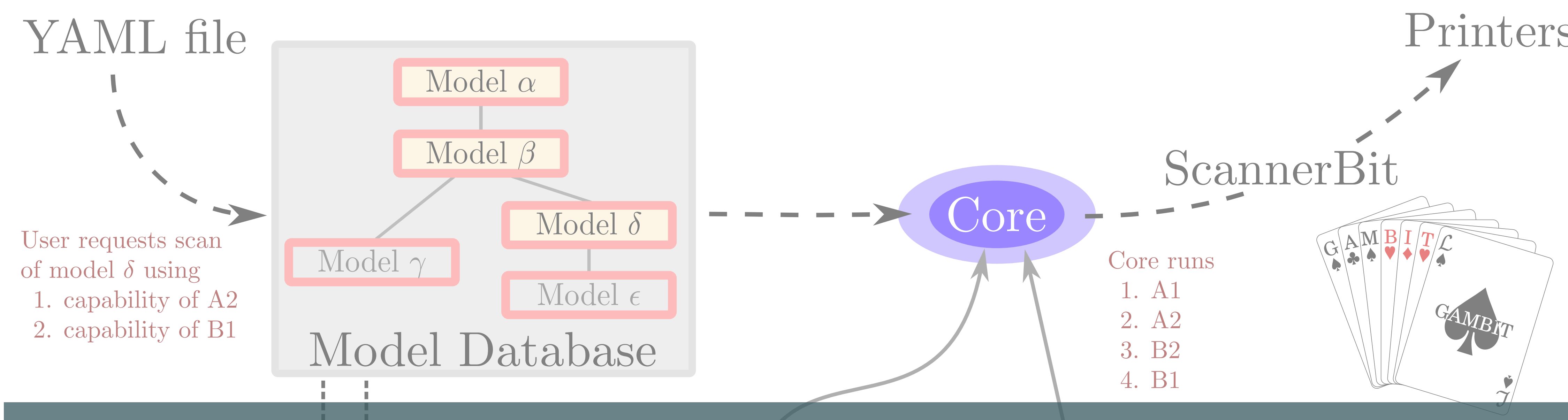
Preliminary Results: Proof of concept

(not yet verified by GAMBIT Collaboration)



Marginalised Posterior PDFs

To come…



- **Verification and integration with GAMBIT Collaboration THDM studies.**
- Higgs production cross section processes and constraints.
- Spectrum calculations using FlexibleSUSY.
- *Improved vacuum stability calculations.*
- Pythia for generation of collider events (???) .
  - <u>THDM + extra content analyses</u>

To come…

Thanks!