Flavbit, Gambit module for Flavour Physics

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How to find BSM?

⇛ There is no shortage of BSM models!

- Take either ”top-down” or ”bottom-up” approach.
- We all have our favourites ;)

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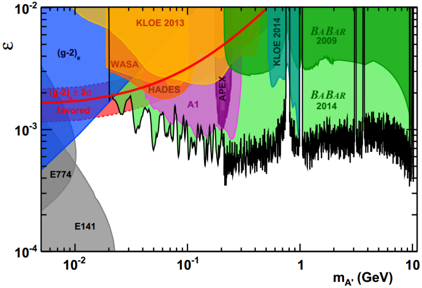
⇛ Any BSM can show up in lots of places:

- Flavour Physics.
- Higgs and supersymmetry searches at the LHC and its predecessors.
- Measurements of the magnetic moment of the muon.
- Beam dump/fixed target (NA62, SHIP,...).
- Electroweak precision tests.
- Dark matter.
- Neutrino mixing.
- Gamma ray searches (e.g. FERMI-LAT, HESS, CTA, etc)
- Radio data.
- etc.

This begs the question...

⇛ How to combine results from all relevant experimental searches?
⇛ This is straightforward for models with few parameters:

- Overlay exclusion curves from different experiments/measurements.
- Look for "excluded" and "non-excluded regions"



What if there are many parameters?

What if there are many parameters?
What if there are many constraints?

What if there are many parameters? What if there are many constraints?

⇛ Much harder:

⇛ Scan the space (need very smart methods for a large number of parameters).

⇛ Interpret the results (Bayesian/frequentist).

⇛ Project down to parameters of interest (marginalise/profile)

Need a global fitting code!

Existing fitting codes

MasterCode	SuperBayeS	Fittino	Rizzo et al.
Monolithic	Monolithic	(∼)Monolithic	Monolithic
Frequentist	Freq./Bayes.	Frequentist	None
Nested sampling, MCMC, grad. descent	Nested sampling, MCMC	MCMC	None (random)
CMSSM$\pm\epsilon$	(p)MSSM-15, CMSSM$\pm\epsilon$, mUED	CMSSM$\pm\epsilon$	(p)MSSM-19
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
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.
m_t, m_Z, $\alpha_{\rm EM}$, hadronic matrix elements	m_t, m_b, α_s, $\alpha_{\rm EM}$, DM halo, hadronic matrix elems.	m_t	None

- 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.
- Not all codes are publicly available!

I had a dream...

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

⇛ e.g. Feynrules → Madgraph interface, CalcHEP interface to Micromegas, MadDM, automated NLO calculations through Madgraph/NLOCT + much, much more.

⇛ The global fit world has not kept up with this.

⇛ Most people hard-code their own solution for each particular study

⇛ Several innovations are need to rectify this:

⇛ How do we store model parameters in a sufficiently abstract way?

⇛ How do we tie disparate codes together?

⇛ How do we make LHC and other constraints model independent?

GAMBIT: a *second-generation* global fit code

GAMBIT: The Global And Modular BSM Inference Tool

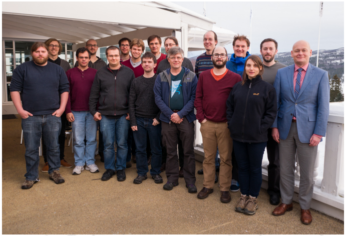
Overriding principles of GAMBIT: flexibility and modularity

- 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

30 Members, 17 institutions, 10 countries, 11 Experiments, 4 major theory codes

ATLAS	A. Buckley, P. Jackson, C. Rogan, M. White,
LHCb	M. Chrzaszcz, N. Serra
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
AMS-02	A. Putze
CDMS, DM-ICE	L. Hsu
XENON/DARWIN	J. Conrad
Theory	P. Athron, C. Balázs, T. Bringmann, J. Cornell, J. Edsjö, B. Farmer, A. Krislock, A. Kvellestad, M. Pato, F. Mahmoudi, A. Raklev, P. Scott, C. Weniger, M. White



+recently joined: T. Gonzales, F. Kahlhoefer, J. McKay, R. Ruiz, R. Trotta
-recently retired: L. Dal, A. Saavedra, C. Savage

Modules

Physics modules

- DarkBit – dark matter observables (relic density, direct + indirect detection)
- ColliderBit – collider observables inc. Higgs + SUSY searches from ATLAS, CMS + LEP
- FlavBit – flavour physics inc. $g-2$, $b \to s\gamma$, B decays (new channels, angular obs., 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
- PrecisionBit – SM likelihoods, precision BSM tests (W mass, $\Delta\rho$ etc)

Each consists of a number of **module functions** that can have **dependencies** on each other

+ScannerBit: manages stats, sampling and optimisation

Backends: mix and match

- Module functions 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 what it decided to do of course)

Backends: mix and match

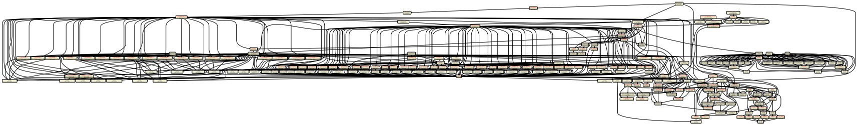
pat@xpspedition: ~/gambit 163x45

All relative paths are given with reference to /home/pat/gambit.

BACKENDS	VERSION	PATH TO LIB	STATUS	#FUNC	#TYPES	#CT
DDCalc0	0.0	Backends/installed/DDCalc/0.0/libDDCalc0.so	OK	62	0	0
DarkSUSY	5.1.1	Backends/installed/DarkSUSY/5.1.1/lib/libdarksusy.so	OK	68	0	0
FastSim	1.0	Backends/installed/fastsim/1.0/libfastsim.so	absent/broken	1	0	0
FeynHiggs	2.11	Backends/installed/FeynHiggs/2.11.2/lib/libFH.so	OK	14	0	0
HiggsBounds	4.2.1	Backends/installed/HiggsBounds/4.2.1/lib/libhiggsbounds.so	OK	10	0	0
HiggsSignals	1.4	Backends/installed/HiggsSignals/1.4.0/lib/libhiggssignals.so	OK	11	0	0
LibFarrayTest	1.0	Backends/examples/libFarrayTest.so	OK	9	0	0
LibFirst	1.0	Backends/examples/libfirst.so	OK	8	0	0
	1.1	Backends/examples/libfirst.so	OK	15	0	0
LibFortran	1.0	Backends/examples/libfortran.so	OK	6	0	0
MicrOmegas	3.5.5	Backends/installed/micromegas/3.5.5/MSSM/MSSM/libmicromegas.so	OK	15	0	0
MicrOmegasSingletDM	3.5.5	Backends/installed/micromegas/3.5.5/SingletDM/SingletDM/libmicromegas.so	OK	13	0	0
Pythia	8.186	Backends/installed/Pythia/8.186/lib/libpythia8.so	absent/broken	0	27	105
	8.209	Backends/installed/Pythia/8.209/lib/libpythia8.so	OK	0	28	107
SUSYPOPE	0.2	no path in config/backend_locations.yaml	absent/broken	3	0	0
SUSY_HIT	1.5	Backends/installed/SUSY-HIT/1.5/libsusyhit.so	OK	55	0	0
SuperIso	3.4	Backends/installed/SuperIso/3.4/libsuperiso.so	OK	32	0	0
gamLike	1.0.0	Backends/installed/gamLike/1.0.0/lib/gamLike.so	OK	3	0	0
nulike	1.0.0	Backends/installed/nulike/1.0.0/lib/libnulike.so	OK	4	0	0

Gambit diagnostic backend line 1 (press h for help or q to quit)

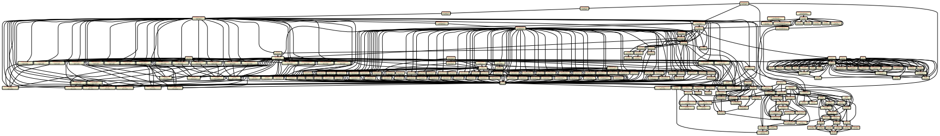
Dependency Resolution



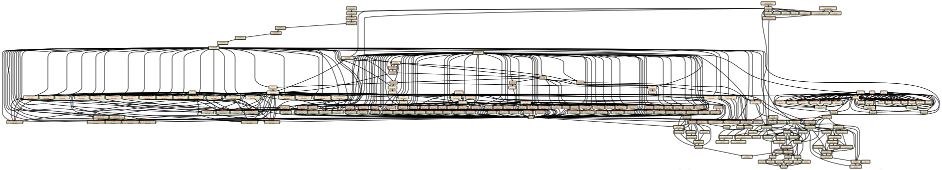
- Module functions and backend functions get arranged into a **dependency tree**
- Starting with requested observables and likelihoods, GAMBIT fills each dependency and backend requirement
- Obeys **rules** at each step: allowed models, allowed backends, constraints from input file, etc
- $\longrightarrow$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

Dependency Resolution

CMSSM:

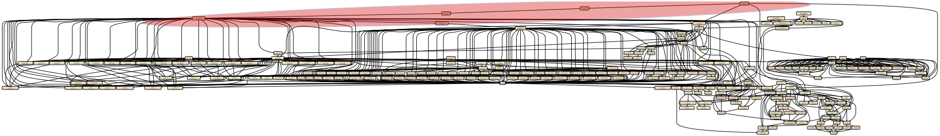


MSSM7:

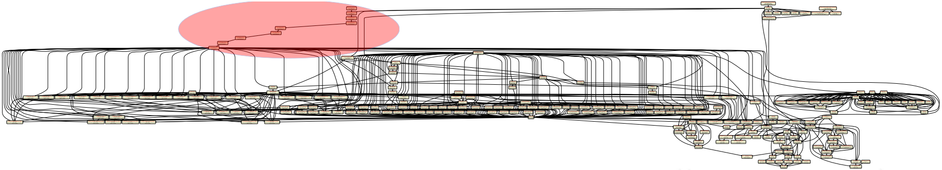


Dependency Resolution

CMSSM:



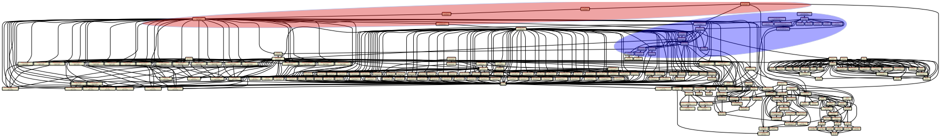
MSSM7:



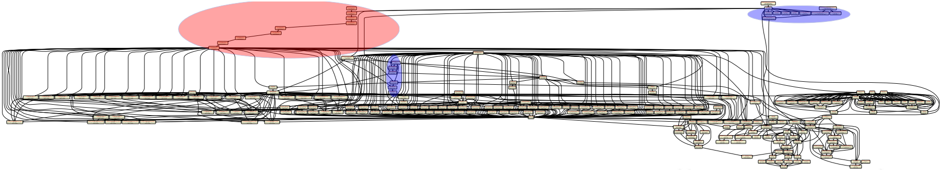
Red: Model parameter translations

Dependency Resolution

CMSSM:



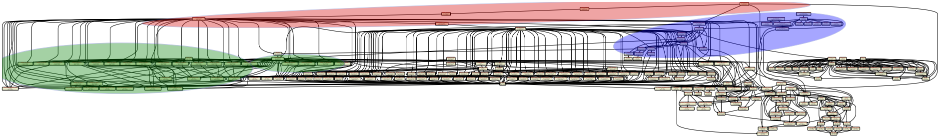
MSSM7:



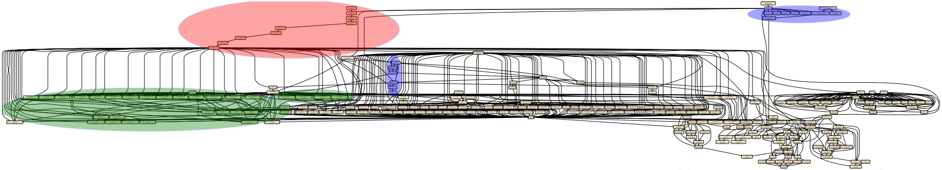
Red: Model parameter translations
Blue: Precision calculations

Dependency Resolution

CMSSM:



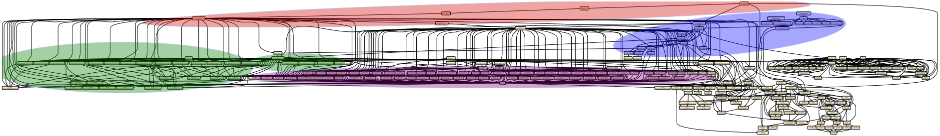
MSSM7:



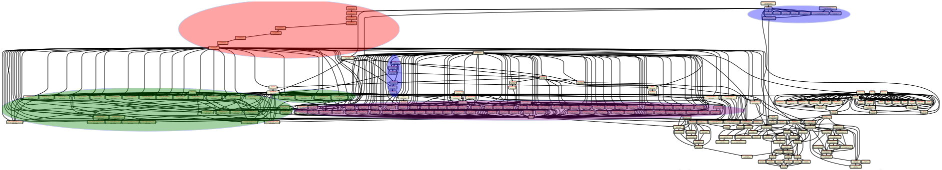
Red: Model parameter translations
Blue: Precision calculations
Green: LEP rates+likelihoods

Dependency Resolution

CMSSM:



MSSM7:



Red: Model parameter translations

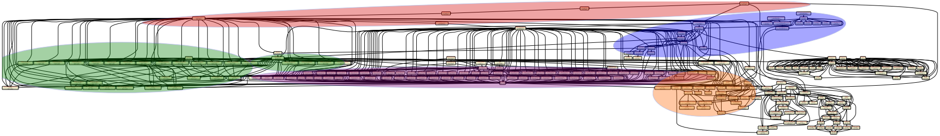
Blue: Precision calculations

Green: LEP rates+likelihoods

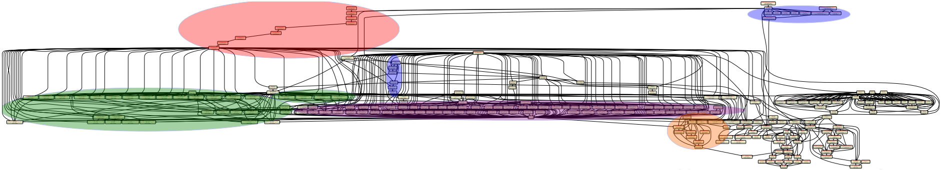
Purple: Decays

Dependency Resolution

CMSSM:



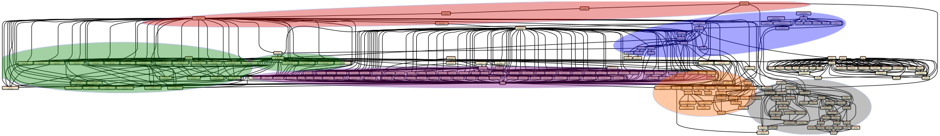
MSSM7:



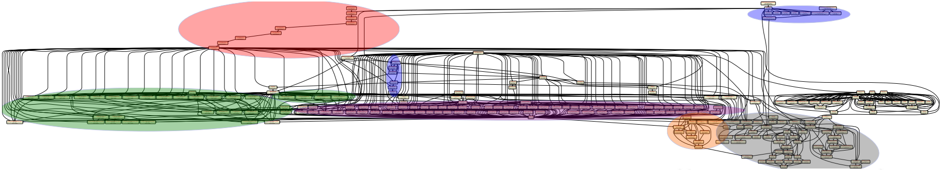
Red: Model parameter translations
Blue: Precision calculations
Green: LEP rates+likelihoods
Purple: Decays
Orange: LHC observables and likelihoods

Dependency Resolution

CMSSM:



MSSM7:



Red: Model parameter translations

Blue: Precision calculations

Green: LEP rates+likelihoods

Purple: Decays

Orange: LHC observables and likelihoods

Grey: DM direct, indirect and relic density

Dependency Resolution

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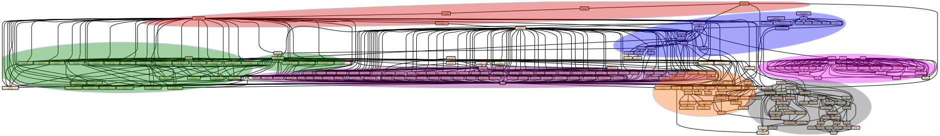
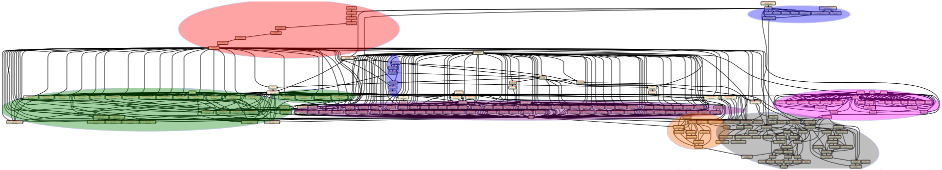


MSSM7:



Red: Model parameter translations

Blue: Precision calculations

Green: LEP rates+likelihoods

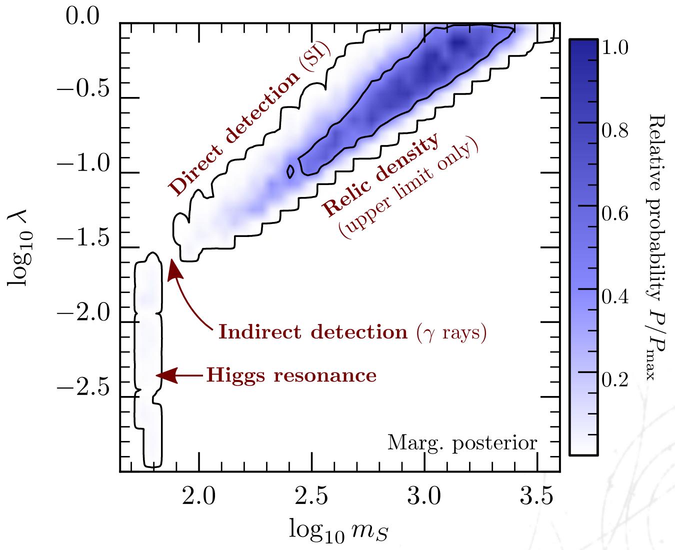
Purple: Decays

Orange: LHC observables and likelihoods

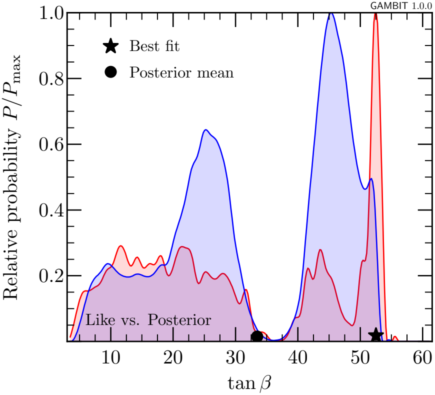
Grey: DM direct, indirect and relic density

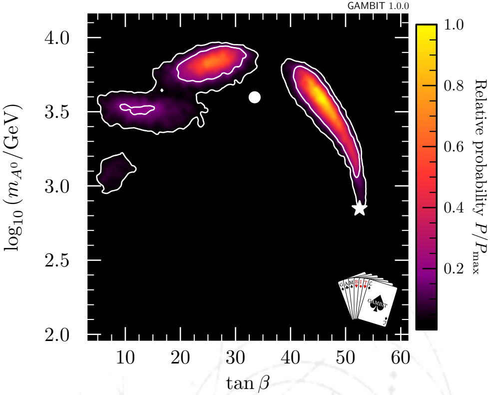
Pink: Flavour physics

Preliminary results: scalar singlet model

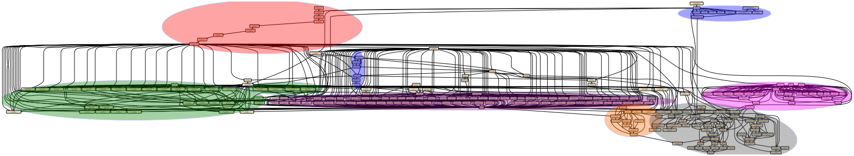


Preliminary results: SUSY (CMSSM – *example only*)





Flavbit - solution to flavour fits!



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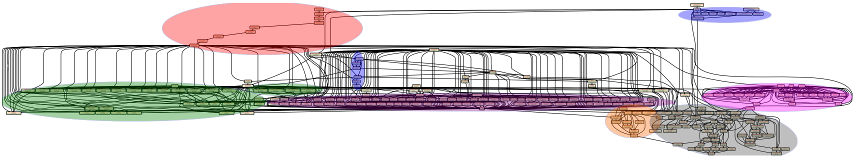
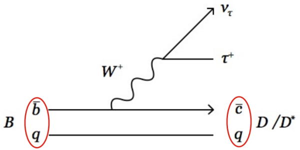


⇛ Flavour is a prime example where we need global fits!

Charged current

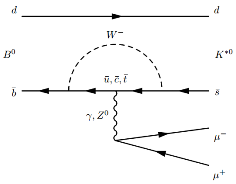


Can proceed via tree level -large O(%) branching fractions.

Factorised up to (small) QED corrections.

When you factorise, QCD part broken down into form-factors.

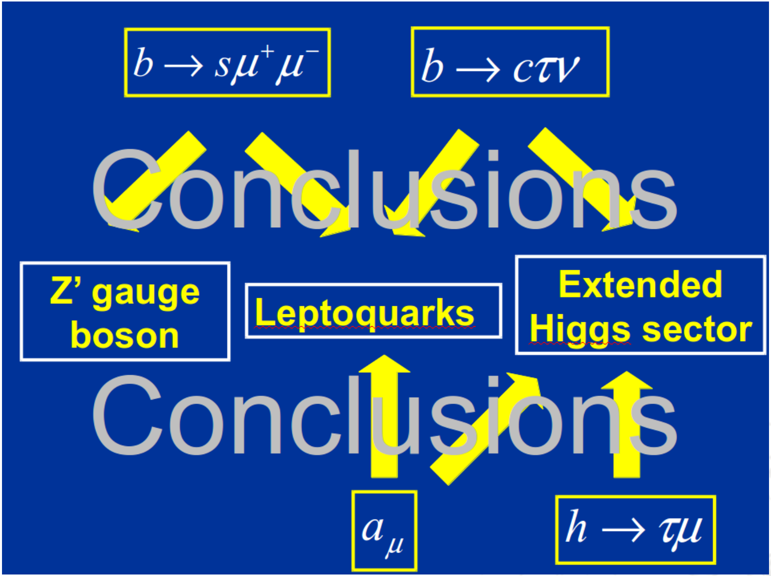
Neutral current



Forbidden at tree level - low O(10^{-6}) branching fractions.

Factorised up to corrections from $B \to h(\to \mu^+\mu^-)h$ decays.

Quo vadis Flavour physics?



⇛ Stolen from A.Criveling, *Higgs and Flavour workshop*, Benasque 2016.

What does Gambit have in terms of flavour

⇛ We really like the anomalies:

- $b \to s\ell\ell$ inside:
  - Angular $B_d^0 \to K^*\mu\mu$, $B_s^0 \to \phi\mu\mu$.
  - Branching fractions: $B \to K^{*\pm,0}\mu\mu$,
  - Branching fractions: $B \to X_s\ell\ell$.
  - Zero cross points for angular observables.
- $B_{s,d} \to \mu\mu$
- Semileptonic:
  - $B \to D\ell\nu$, $\ell = \tau,\ \mu\ , e$, $D = D_s D^*, D$
  - $B \to K/\pi\ell\nu$, $\ell = \tau,\ \mu\ , e$
  - $B \to \ell\nu$, $\ell = \tau,\ \mu$
  - $(g-2)_\mu$.

⇛ We are covering the main anomalies in the Flavour physics!

Quo Vadis Flavbit?

⇛ In summer the Gambit code will be made public.
⇛ The SUSY scans: CMSSM, MSSM7 etc. will be published.

⇛ We are changing orientation a bit:
- ⇛ Put less pressure on SUSY scans.
- ⇛ Focus on EFT.
- ⇛ Leptoquarks.
- ⇛ 3HDM, 2HDM.

⇛ In terms of observables:
- ⇛ Add kaon physics! There is $2.9\ \sigma$ in $\frac{\epsilon'}{\epsilon}$.
- ⇛ Add CP observables + averages!

Summary

⇛ Gambit `V1` is ready and will be realest for public in $\sim$ summer. We can circulate a private version of the code now if needed for B2TiP activities.

⇛ If the $\gamma\gamma$ access goes away the Flavour will be the leader in NP "Hunger Games'.

⇛ Only a consistent picture will convince the community that we found NP!

⇛ Let the games begin!

Backup