FlavorKit
Flavor physics beyond the SM

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Manual: arXiv:1405.1434
Website: http://sarah.hepforge.org/FlavorKit.html

Introduction

Before the LHC started operating we all hoped for great discoveries...

LHC expectations

LHC results...

Flavor as the road to new physics

The high-energy frontier has brought us the Higgs boson...
but nothing else

Perhaps it is time to explore the high-intensity frontier

$\Longrightarrow$ Flavor physics

Flavor observables in a nutshell

Step 1: Consider a lagrangian that includes all the operators relevant for the flavor observable

$$\mathcal{L}_{eff} = \sum_i C_i \mathcal{O}_i$$

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Step 3: Plug the results for the Wilson coefficients into a general expression for the flavor observable

Example: $\mathrm{BR}(\mu \to e\gamma)$

[In the SM extended with Dirac neutrino masses]

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$$\mathcal{L}_{\mu e\gamma} = i e\, m_\mu\, \bar{e}\, \sigma^{\mu\nu} q_\nu \left(K_2^L P_L + K_2^R P_R \right) \mu A_\mu + \mathrm{h.c.}$$

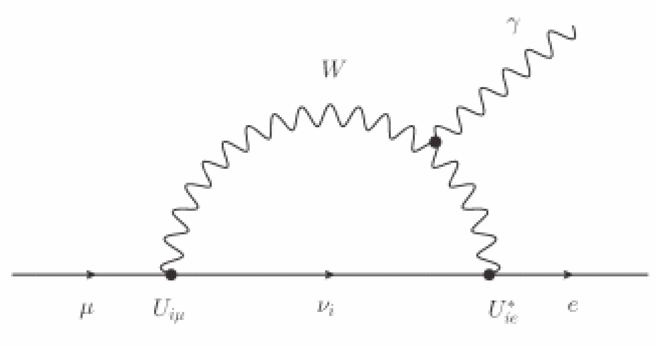
Dipole interaction lagrangian

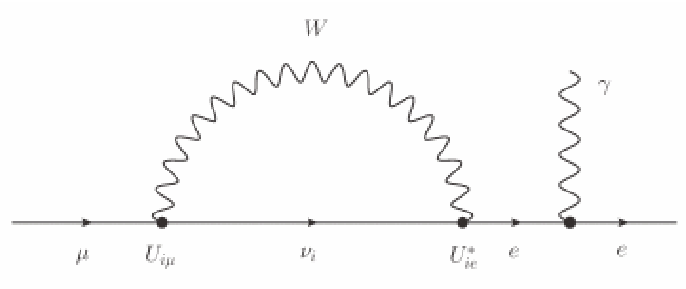
K_2^L, K_2^R : Wilson coefficients

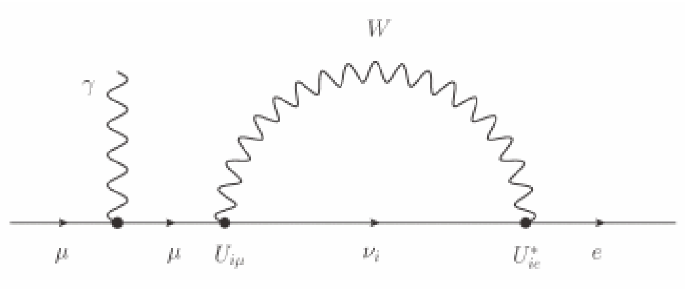
Example: $\mathrm{BR}(\mu \to e\gamma)$

[In the SM extended with Dirac neutrino masses]

Step 2: Compute the Wilson coefficients at a given loop order







$$K_2^L = \frac{G_F}{2\sqrt{2}\pi^2} m_\mu \sum_i U_{i\mu} U^*_{ie} (F_1 + F_2)$$

$$K_2^R = \frac{G_F}{2\sqrt{2}\pi^2} m_e \sum_i U_{i\mu} U^*_{ie} (F_1 - F_2)$$

[Ma, Pramudita, '81]

Example: $\mathrm{BR}(\mu \to e\gamma)$

[In the SM extended with Dirac neutrino masses]

Step 3: Plug the results for the Wilson coefficients into a general expression for the flavor observable

$$\mathrm{BR}\,(\mu \to e\gamma) = \frac{\alpha\, m_\mu^5}{4\,\Gamma_\mu} \left(|K_2^L|^2 + |K_2^R|^2 \right)$$

Flavor observables in a nutshell

Step 1: Consider a lagrangian that includes all the operators relevant for the flavor observable

Some freedom. Requires a good understanding of the observable but technically easy

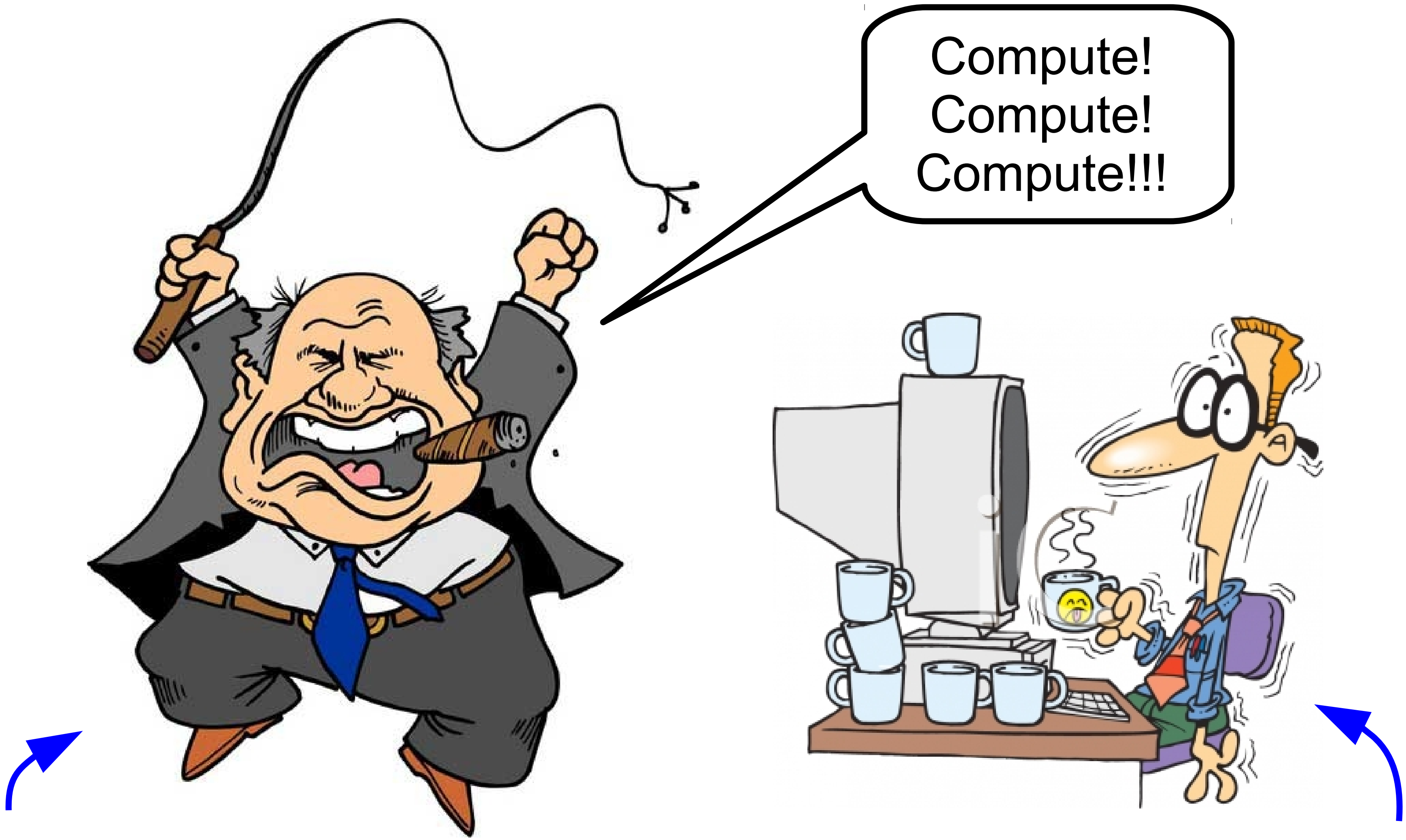
Step 2: Compute the Wilson coefficients at a given loop order

Complicated and model dependent part of the computation

Step 3: Plug the results for the Wilson coefficients into a general expression for the flavor observable

Model independent. Can make use of results in the literature

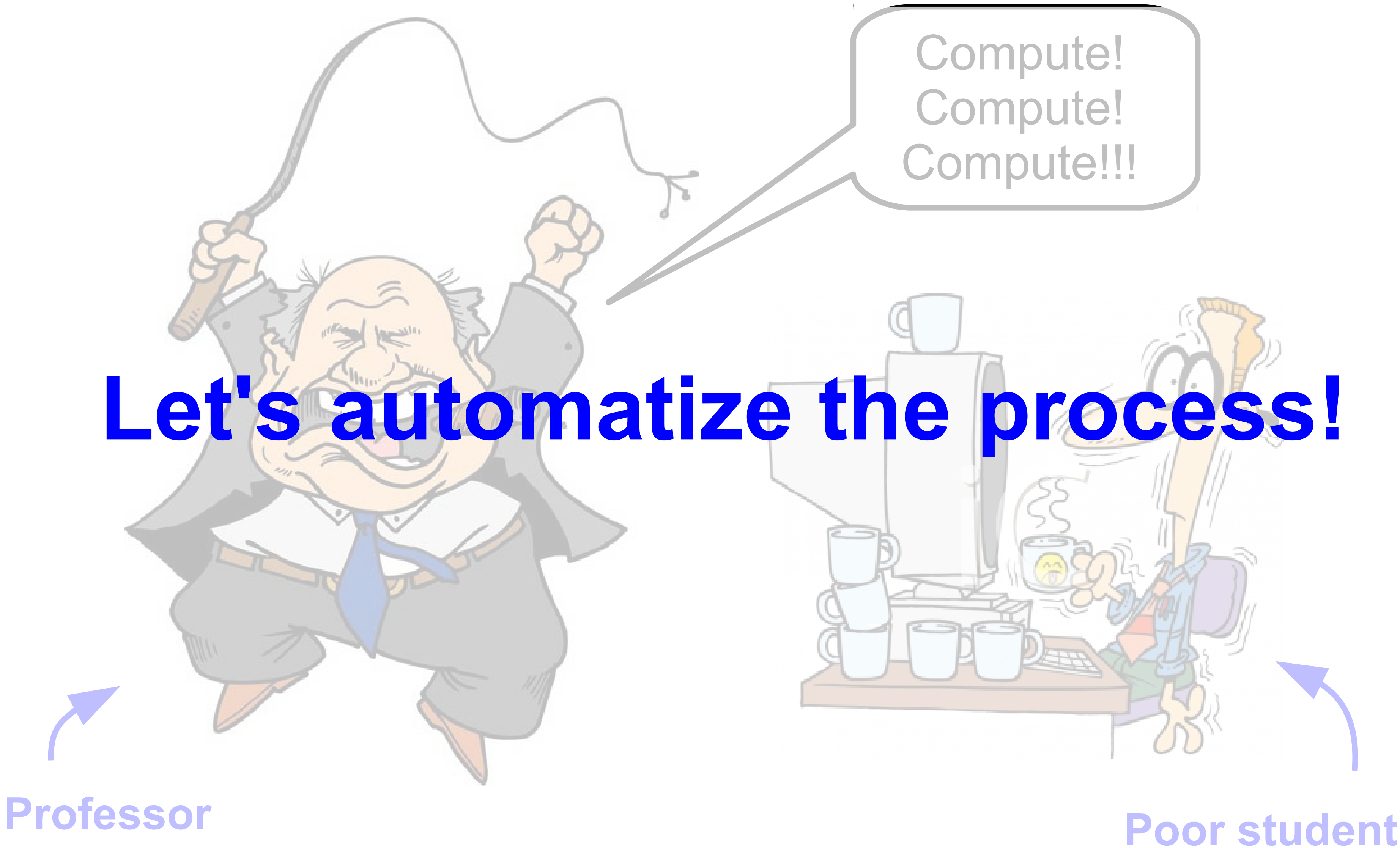
Usual approach



Professor

Poor student

Usual approach



Let's automatize the process!

Other flavor codes

- **MicrOmegas** [Belanger, Boudjema, Pukhov, Semenov]
- **NMSSM-Tools** [Ellwanger, Hugonie]
- **SPheno** [Porod, Staub]
- **SuperIso** [Mahmoudi]
- **SuSeFLAV** [Chowdhury, Garani, Vempati]
- **SUSY_FLAVOR** [Rosiek, Chankowski, Dedes, Jäger, Tanedo] [Crivellin, Rosiek]
- **...**

Restrictions: Only specific models + hard to extend

FlavorKit

W. Porod, F. Staub, A. Vicente

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FlavorKit

To compute flavor observables one needs:

1) Expressions for all vertices and masses

2) Expressions for the Wilson coefficients

3) Expressions for the observables

4) Numerical evaluation

FlavorKit

To compute flavor observables one needs:

1) Expressions for all vertices and masses → SARAH

2) Expressions for the Wilson coefficients → FeynArts/FormCalc

3) Expressions for the observables → Literature

4) Numerical evaluation → SPheno

FlavorKit is the combination of these tools

SARAH and SPheno

SARAH

[Staub]

SARAH is a Mathematica package for analyzing SUSY and non-SUSY models.

It calculates analytically all vertices, mass matrices, tadpoles equations, 1-loop corrections for tadpoles and self-energies and 2-loop RGEs.

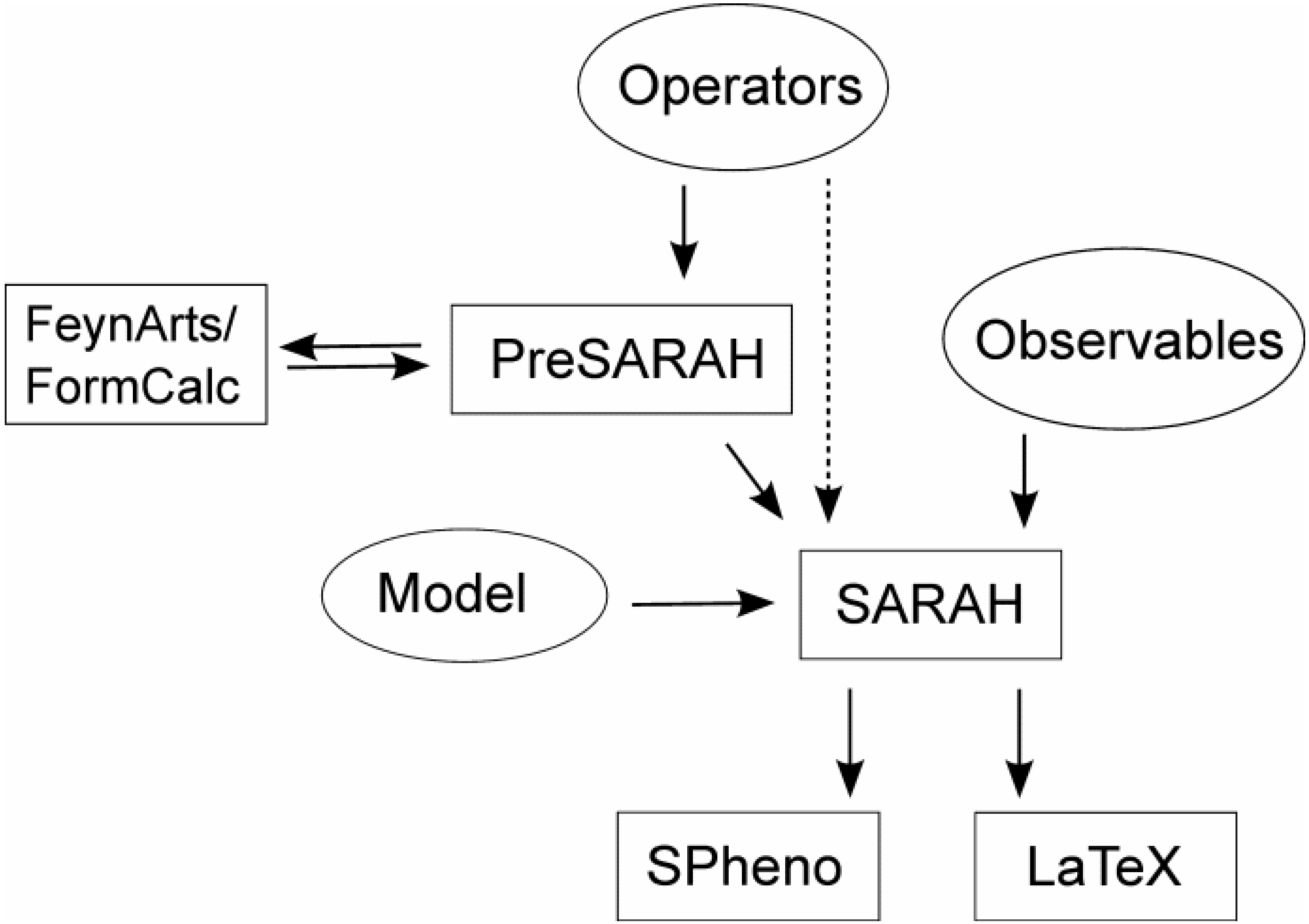
SARAH is also a spectrum-generator-generator: based on the derived analytical expressions it creates Fortran source code for SPheno.

SPheno

[Porod, Staub]

SPheno is a Fortran code. It provides routines for the numerical evaluation of all vertices, masses and decay modes in a given model.

FlavorKit



Operators
FeynArts/
FormCalc
PreSARAH
Observables
Model
SARAH
SPheno
LaTeX

How to use FlavorKit

- **Basic usage**

  For those who do not need any operator nor observable beyond what is already implemented in FlavorKit. In this case, FlavorKit reduces to the standard SARAH package.

Observables already in FlavorKit

Lepton flavor	Quark flavor
$\ell_\alpha \to \ell_\beta \gamma$	$B^0_{s,d} \to \ell^+ \ell^-$
$\ell_\alpha \to 3\,\ell_\beta$	$\bar{B} \to X_s \gamma$
$\mu - e$ conversion in nuclei	$\bar{B} \to X_s \ell^+ \ell^-$
$\tau \to P\,\ell$	$\bar{B} \to X_{d,s} \nu \bar{\nu}$
$h \to \ell_\alpha \ell_\beta$	$B \to K \ell^+ \ell^-$
$Z \to \ell_\alpha \ell_\beta$	$K \to \pi \nu \bar{\nu}$
	$\Delta M_{B_{s,d}}$
	ΔM_K and ε_K
	$P \to \ell \nu$

Ready to be computed in your favourite model!

How to use FlavorKit

Basic usage

For those who do not need any operator nor observable beyond what is already implemented in FlavorKit. In this case, FlavorKit reduces to the standard SARAH package.

Advanced usage

For those with further requirements:

- New observables
- New operators

New observables

Implementing a new observable

Two files: steering file “observable.m” + Fortran code “observable.f90”

```
NameProcess = "LLpGamma";
NameObservables = {{muEgamma, 701, "BR(mu->e gamma)"},
                   {tauEgamma, 702, "BR(tau->e gamma)"},
                   {tauMuGamma, 703, "BR(tau->mu gamma)"}};

NeededOperators = {K2L, K2R};

Body = "LLpGamma.f90";
```

Steering file
LLpGamma.m

Reminder:

$$\mathcal{L}_{\mu e\gamma} = i e\, m_\mu\, \bar{e}\, \sigma^{\mu\nu} q_\nu \left(K_2^L P_L + K_2^R P_R \right) \mu A_\mu + \text{h.c.}$$

New observables

```
Real(dp) :: width
Integer :: i1, gt1, gt2

Do i1=1,3
If (i1.eq.1) Then         ! mu -> e gamma
      gt1 = 2
      gt2 = 1
Elseif (i1.eq.2) Then
      ...
End if

width = 0.25_dp*mf_l(gt1)**5*(Abs(K2L(gt1,gt2))**2 + Abs(K2R(gt1,gt2))**2)*Alpha

If (i1.eq.1) Then
      muEgamma = width/(width+GammaMu)
Elseif (i1.eq.2) Then
      ...
End if
End do
```

Fortran code

LLpGamma.f90

New operators

Implementing a new operator

One file: PreSARAH input file “operator.m”

Generic expressions for the Wilson coefficients of new operators can be computed with the help of an additional package (PreSARAH):

- User friendly definition of new operators
- Uses FeynArts/FormCalc [by T. Hahn] to obtain the generic expressions
- Writes all necessary files for SARAH

Example:

$$\mathcal{L}_{2d2\ell} = \sum_{\substack{I=S,V,T \\ X,Y=L,R}} E^I_{XY} \, \bar{d}_\beta \Gamma_I P_X d_\alpha \, \bar{\ell}_\gamma \, \Gamma_I P_Y \ell_\gamma + \text{h.c.}$$

$$(\Gamma_{S,V,T} = 1, \gamma_\mu, \sigma_{\mu\nu})$$

New operators

```
NameProcess="2d2L";

ConsideredProcess = "4Fermion";
FermionOrderExternal={2,1,4,3};
NeglectMasses={1,2,3,4};


ExternalFields= {DownQuark,bar[DownQuark],ChargedLepton,bar[ChargedLepton]};

CombinationGenerations = {{3,1,1,1}, {3,1,2,2}, {3,1,3,3},{3,2,1,1}, {3,2,2,2}, {3,2,3,3}};


AllOperators={{OddllSLL,Op[7].Op[7]},
                      {OddllSRL,Op[6].Op[7]},
                      ...,
                      {OddllVRR,Op[7,Lor[1]].Op[7,Lor[1]]},
                      ...,
                      {OddllTLL,Op[-7,Lor[1],Lor[2]].Op[-7,Lor[1],Lor[2]]},
                      ...};
```

PreSARAH input file
2d2L.m

Note:

$\mathrm{Op}[7]\ ,\ \mathrm{Op}[6]\ = P_{L,R}$

$\mathrm{Lor}[1]\ = \gamma_\mu$

Limitations

Disclaimer

FlavorKit is a tool intended to be as general as possible. For this reason, there are some limitations compared to codes which perform specific calculations in a specific model:

- Chiral resummation is not included because of its large model dependence
- Higher order corrections cannot be computed (although they can be included in a parametric way)

Summary

FlavorKit is a combination of computer tools that allow the user to get predictions for his/her favourite flavor observables in the model of his/her choice.

No more lengthy loop computations!

It combines the analytical power of SARAH with the numerical routines of SPheno.

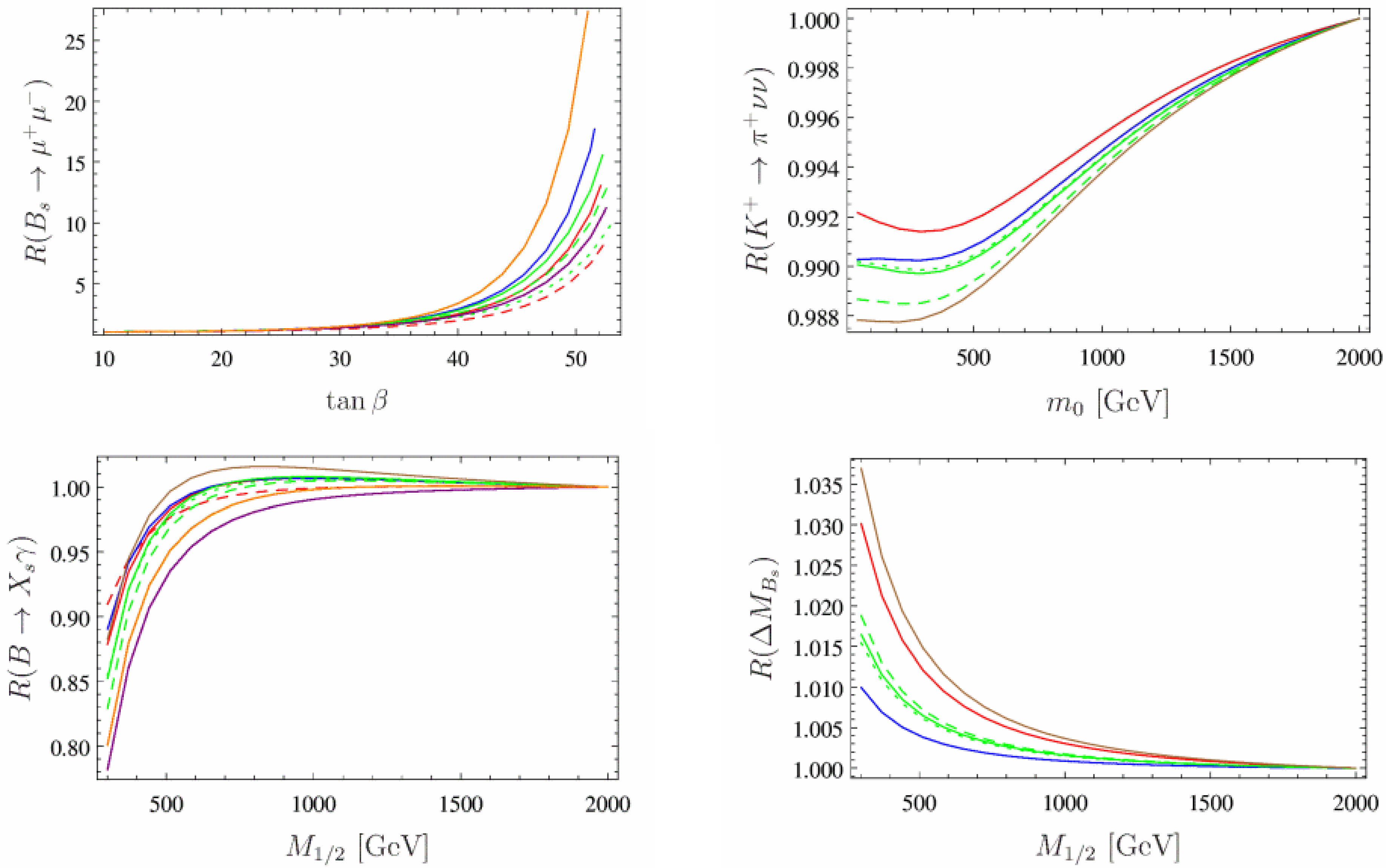
Perfect for phenomenological studies!

Easily extendable: new observables and new operators (thanks to FeynArts/FormCalc).

What are you waiting for? Use FlavorKit!

Backup slides

Validation



FlavorKit, SPhenoMSSM (dashed), SPheno 3.3, SUSY Flavor 1, SUSY Flavor 2, MicrOmegas, SuperIso

Models already in SARAH

Supersymmetric Models

- MSSM [in several versions]
- NMSSM
- Near-to-minimal SSM (near-MSSM)
- General singlet extended SSM (SMSSM)
- DiracNMSSM
- Triplet extended MSSM/NMSSM
- Several models with R-parity violation
- U(1)-extended MSSM (UMSSM)
- Secluded MSSM
- Several B-L extended models
- Inverse and linear seesaws [several embeddings]
- MSSM/NMSSM with Dirac Gauginos
- Minimal R-Symmetric SSM
- Minimal Dirac Gaugino SSM
- Seesaws I-II-III [SU(5) versions]
- Left-right symmetric model
- Quiver model

Non-Supersymmetric Models

- Standard Model
- Inert Higgs doublet model
- B-L extended SM
- B-L extended SM with inverse seesaw
- SM extended by a scalar color octet
- Two Higgs doublet model
- Singlet extended SM
- Singlet Scalar DM

SARAH

http://sarah.hepforge.org/