Introduction to SARAH and FlavorKit

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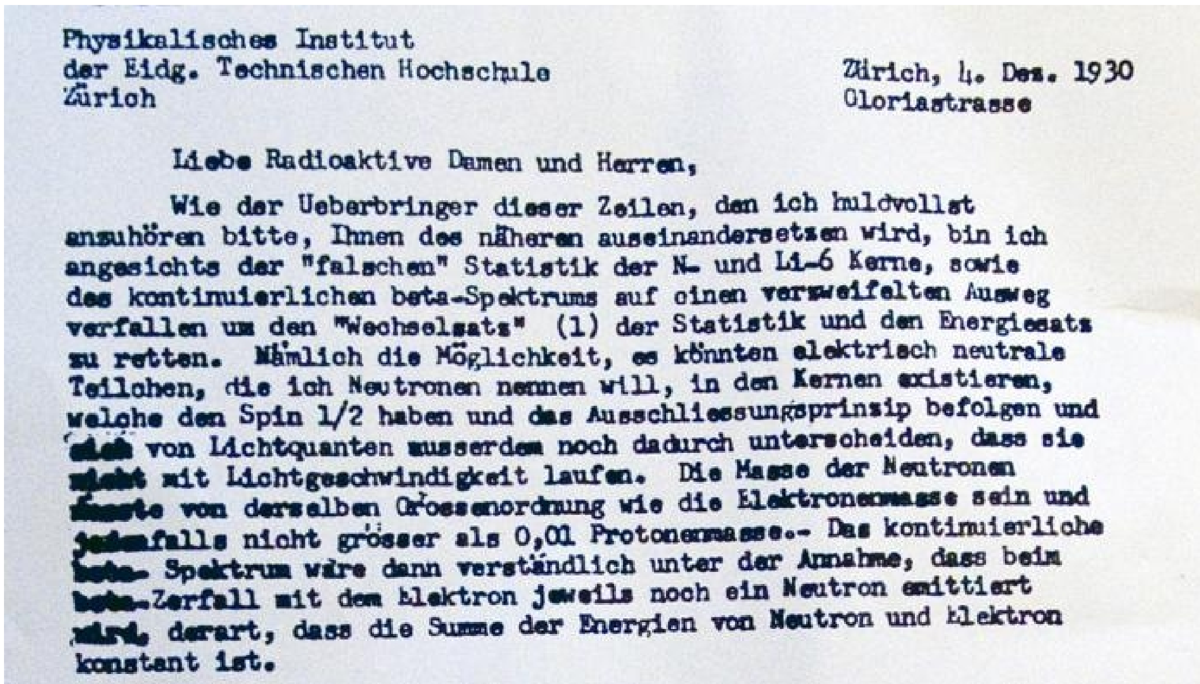
Neutrinos from GUTs down to low energies

Garching
November 25 2015

Dear radiactive Ladies and Gentlemen...



Physikalisches Institut
der Eidg. Technischen Hochschule
Zürich

Zürich, 4. Dez. 1930
Gloriastrasse

Liebe Radioaktive Damen und Herren,

Wie der Ueberbringer dieser Zeilen, den ich huldvollst anzuhören bitte, Ihnen des näheren auseinandersetzen wird, bin ich angesichts der "falschen" Statistik der N- und Li-6 Kerne, sowie des kontinuierlichen beta-Spektrums auf einen verzweifelten Ausweg verfallen um den "Wechselsatz" (1) der Statistik und den Energiesatz zu retten. Nämlich die Möglichkeit, es könnten elektrisch neutrale Teilchen, die ich Neutronen nennen will, in den Kernen existieren, welche den Spin 1/2 haben und das Ausschliessungsprinzip befolgen und sich von Lichtquanten ausserdem noch dadurch unterscheiden, dass sie nicht mit Lichtgeschwindigkeit laufen. Die Masse der Neutronen dürfte von derselben Grossenordnung wie die Elektronenmasse sein und jedenfalls nicht grösser als 0,01 Protonenmasse.- Das kontinuierliche beta- Spektrum wäre dann verständlich unter der Annahme, dass beim beta-Zerfall mit dem Elektron jeweils noch ein Neutron emittiert wird, derart, dass die Summe der Energien von Neutron und Elektron konstant ist.

December 4th, 1930
Letter to his colleagues in Tübingen

1930
Pauli's neutrino hypothesis

Back in the good old times...

Zürich, Dec. 4, 1930

Physics Institute of the ETH

Gloriastrasse

Zürich

Dear Radioactive Ladies and Gentlemen,

As the bearer of these lines, to whom I graciously ask you to listen, will explain to you in more detail, because of the "wrong" statistics of the N- and Li-6 nuclei and the continuous beta spectrum, I have hit upon a desperate remedy to save the "exchange theorem" of statistics and the law of conservation of energy. Namely, the possibility that in the nuclei there could exist electrically neutral particles, which I will call neutrons, that have spin 1/2 and obey the exclusion principle and that further differ from light quanta in that they do not travel with the velocity of light.

(.../...)

But so far I do not dare to publish anything about this idea, and trustfully turn first to you, dear radioactive people, with the question of how likely it is to find experimental evidence for such a neutron if it would have the same or perhaps a 10 times larger ability to get through [material] than a gamma-ray.

I admit that my remedy may seem almost improbable because one probably would have seen those neutrons, if they exist, for a long time. (.../...) Thus, dear radioactive people, scrutinize and judge. - Unfortunately, I cannot personally appear in Tübingen since I amindispensable here in Zürich because of a ball on the night from December 6 to 7. With my best regards to you, and also to Mr. Back, your humble servant

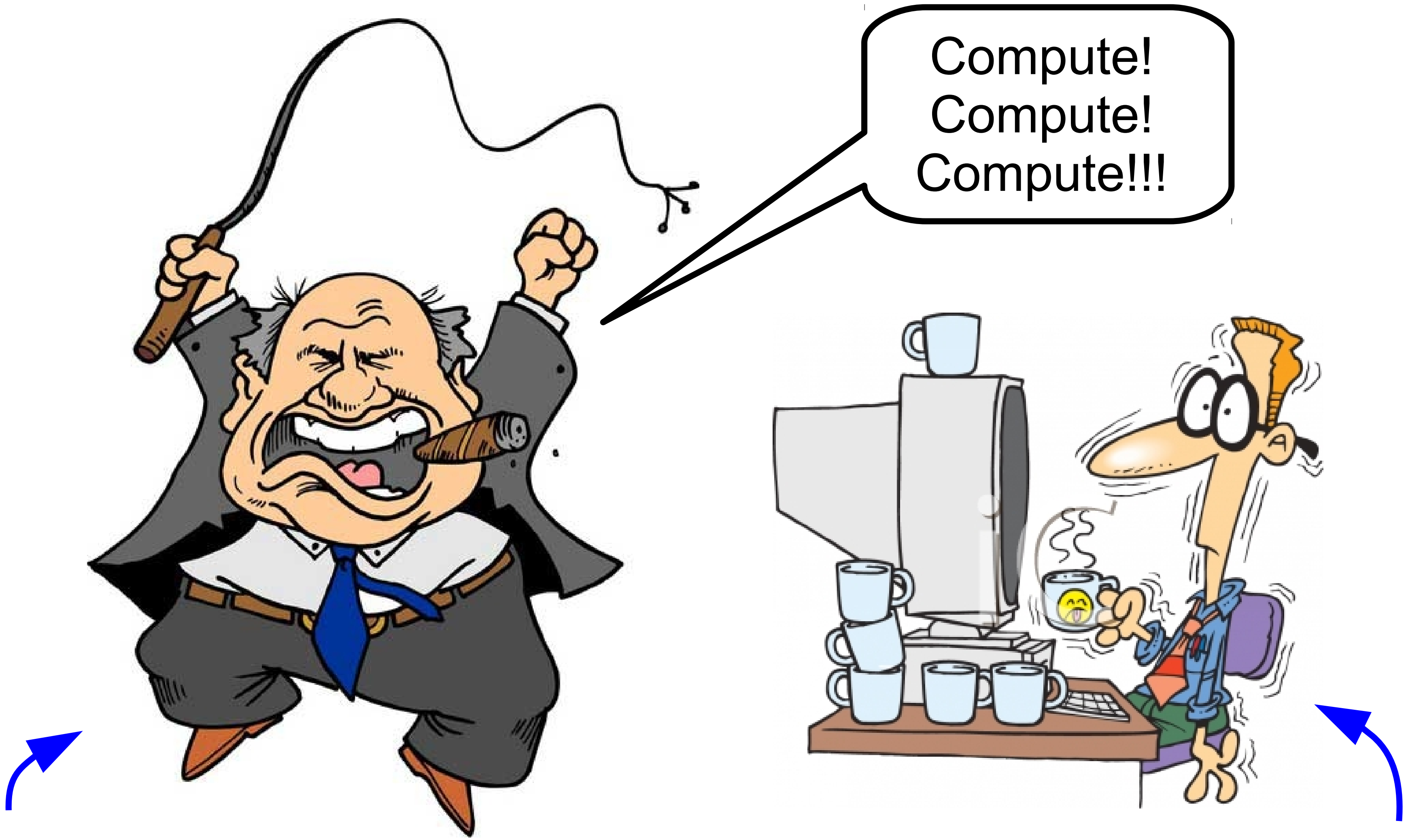
signed W. Pauli

Many new models and particles

An "explosion" of new models and particles. Strategy:

- Analytical derivation of particle masses and vertices, minimization of the scalar potential, renormalization group equations, ...
- Numerical routines: diagonalization, resolution of differential equations, phase space integration...
- Mass spectrum, loop corrections, flavor observables and decay rates
- Dark matter properties: relic density, direct and indirect detection rates, ...
- Collider simulations
- Other

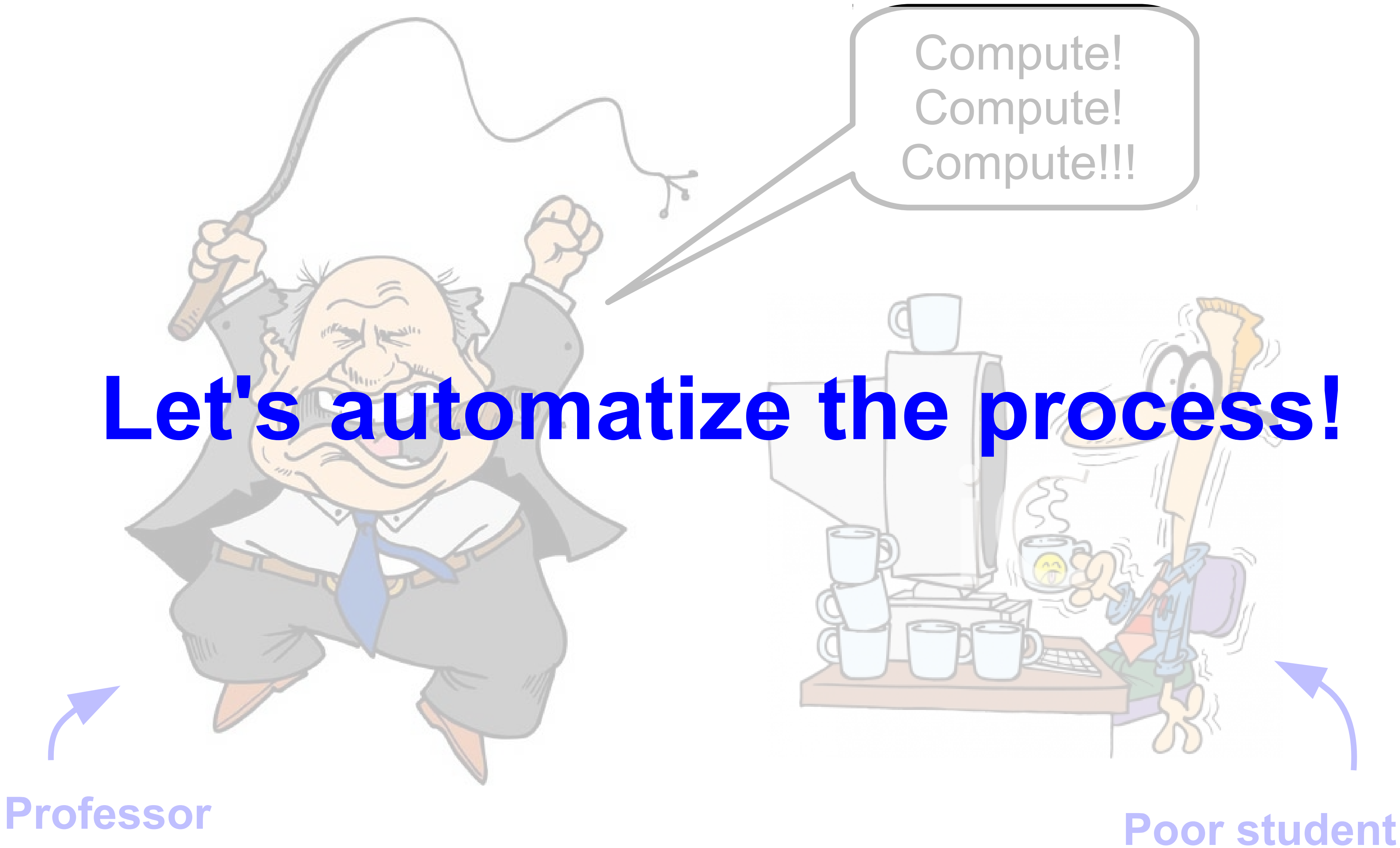
Usual approach



Professor

Poor student

Usual approach



Let's automatize the process!

Message 1

It is not so hard!

What people think about SARAH, SPheno, FlavorKit...

What they really are

Message 2

Do no trust (too much) in codes!

Plan

- **<u>1</u>** : How to implement a model in **SARAH**
- **<u>2</u>** : How to use **SARAH** to obtain basic information about the model
- **<u>3</u>** : How to use **SARAH** to create a numerical code for the model
- **<u>4</u>** : How to compute flavor observables with **SARAH** + **FlavorKit**: numerical and analytical results

References

Lectures

“Computer tools in particle physics”, A. Vicente, [arXiv:1507.06349]

Practical introductions

“Exploring new models in all detail with SARAH”, F. Staub, [arXiv:1503.04200]
(Only for SUSY)

Manuals

SARAH: arXiv:1309.7223
Spheno: arXiv:1104.1573
FlavorKit: arXiv:1405.1434

Websites

http://sarah.hepforge.org/
https://spheno.hepforge.org/
http://sarah.hepforge.org/FlavorKit.html

Let's get started!

Rules:

- You can interrupt and ask questions at any moment
- Suggestion: you can emulate what I do with your own laptop
- I will assume that you already have all the prerequisites installed

SARAH

SARAH

[Staub]

- **Name of the tool:** `SARAH`
- **Author:** Florian Staub (florian.staub@cern.ch)
- **Type of code:** `Mathematica` package
- **Website:** http://sarah.hepforge.org/

SARAH

SARAH [Staub]

- Lagrangian derivation: SUSY and non-SUSY models
- Mass matrices
- All vertices
- Tadpole equations
- 1-loop corrections for tadpoles and self-energies
- 2-loop renormalization group equations
- 1-loop Wilson coefficients for flavor observables
- Input files for other codes

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/

Scotogenic: implementation

generations

$U(1)_Y$

$SU(3)_c$

```
FermionFields[[1]] = {q , 3, uL, dL, 1/6, 2, 3, 1};
```

$SU(2)_L$

$\mathbb{Z}_2$

$$q = \begin{pmatrix} u_L \\ d_L \end{pmatrix}$$

Quark doublet

Scotogenic: implementation

Yukawa Lagrangian

$$\boxed{\texttt{LagFer} \equiv \mathcal{L}_Y = Y_d H^\dagger \, \bar{d} \, q + Y_e H^\dagger \, \bar{e} \, \ell + Y_u H \, \bar{u} \, q + Y_N \, \eta \, \overline{N} \, \ell}$$

Scotogenic: implementation

Scalar decomposition

$$\boxed{\begin{aligned} H^0 &= \frac{1}{\sqrt{2}}\left(v + h + iA\right) \\ \eta^0 &= \frac{1}{\sqrt{2}}\left(\eta_R + i\eta_I\right) \end{aligned}}$$

Scotogenic: exploration

Tadpole equations

$$\frac{\partial \mathcal{V}}{\partial v} = 0$$

Scotogenic: exploration

Tadpole equations

$$\frac{\partial \mathcal{V}}{\partial v} = 0$$

$$\boxed{\frac{1}{2}\lambda_1 v^3 - m_H^2 v = 0 \quad \Rightarrow \quad m_H^2 = \frac{1}{2}\lambda_1 v^2}$$

Scotogenic: exploration

Mass matrices

- Charged leptons

$$\begin{pmatrix} -\frac{v(Y_e)_{11}}{\sqrt{2}} & -\frac{v(Y_e)_{21}}{\sqrt{2}} & -\frac{v(Y_e)_{31}}{\sqrt{2}} \\ -\frac{v(Y_e)_{12}}{\sqrt{2}} & -\frac{v(Y_e)_{22}}{\sqrt{2}} & -\frac{v(Y_e)_{32}}{\sqrt{2}} \\ -\frac{v(Y_e)_{13}}{\sqrt{2}} & -\frac{v(Y_e)_{23}}{\sqrt{2}} & -\frac{v(Y_e)_{33}}{\sqrt{2}} \end{pmatrix}$$

Scotogenic: exploration

Mass matrices

- Right-handed neutrinos

$$\begin{pmatrix} -(M_N)_{11} & -\frac{1}{2}(M_N)_{12} - \frac{1}{2}(M_N)_{21} & -\frac{1}{2}(M_N)_{13} - \frac{1}{2}(M_N)_{31} \\ -\frac{1}{2}(M_N)_{12} - \frac{1}{2}(M_N)_{21} & -(M_N)_{22} & -\frac{1}{2}(M_N)_{23} - \frac{1}{2}(M_N)_{32} \\ -\frac{1}{2}(M_N)_{13} - \frac{1}{2}(M_N)_{31} & -\frac{1}{2}(M_N)_{23} - \frac{1}{2}(M_N)_{32} & -(M_N)_{33} \end{pmatrix}$$

$$\begin{pmatrix} -(M_N)_{11} & -(M_N)_{12} & -(M_N)_{13} \\ -(M_N)_{12} & -(M_N)_{22} & -(M_N)_{23} \\ -(M_N)_{13} & -(M_N)_{23} & -(M_N)_{33} \end{pmatrix}$$

Scotogenic: exploration

Higgs boson mass

$$m_h^2 = \frac{3}{2}\lambda_1 v^2 - m_H^2 \quad \Rightarrow \quad m_h^2 = \lambda_1 v^2$$

Tadpole equations

Scotogenic: exploration

Vertices

$$\ell_i^+ - \ell_j^- - h$$

$$\boxed{\frac{i}{\sqrt{2}} \sum_{m,n=1}^{3} (V_e)^*_{jn} (Y_e)_{mn} (U_e)^*_{im} \; P_L + \frac{i}{\sqrt{2}} \sum_{m,n=1}^{3} (V_e)_{in} (Y_e)^*_{mn} (U_e)_{jm} \; P_R}$$

$$\ell_i^+ - \nu_j - W_\mu^-$$

$$\boxed{-i\frac{g_2}{\sqrt{2}} \sum_{m=1}^{3} (V_e)_{im} (V_\nu)^*_{jm} \; \gamma_\mu P_L = i\frac{g_2}{\sqrt{2}} \sum_{m=1}^{3} K_{ij} \, \gamma_\mu P_L}$$

$$\nu_i - \chi_j - \eta_R$$

$$\boxed{-\frac{i}{\sqrt{2}} \sum_{m,n=1}^{3} (V_\nu)^*_{in} (Y_N)_{mn} (Z_X)^*_{jm} \; P_L - \frac{i}{\sqrt{2}} \sum_{m,n=1}^{3} (V_\nu)_{in} (Y_N)^*_{mn} (Z_X)_{jm} \; P_R}$$

Scotogenic: exploration

Renormalization group equations

$$\frac{dc}{dt} = \beta_c = \frac{1}{16\pi^2}\beta_c^{(1)} + \frac{1}{(16\pi^2)^2}\beta_c^{(2)} + \cdots$$

Scotogenic: exploration

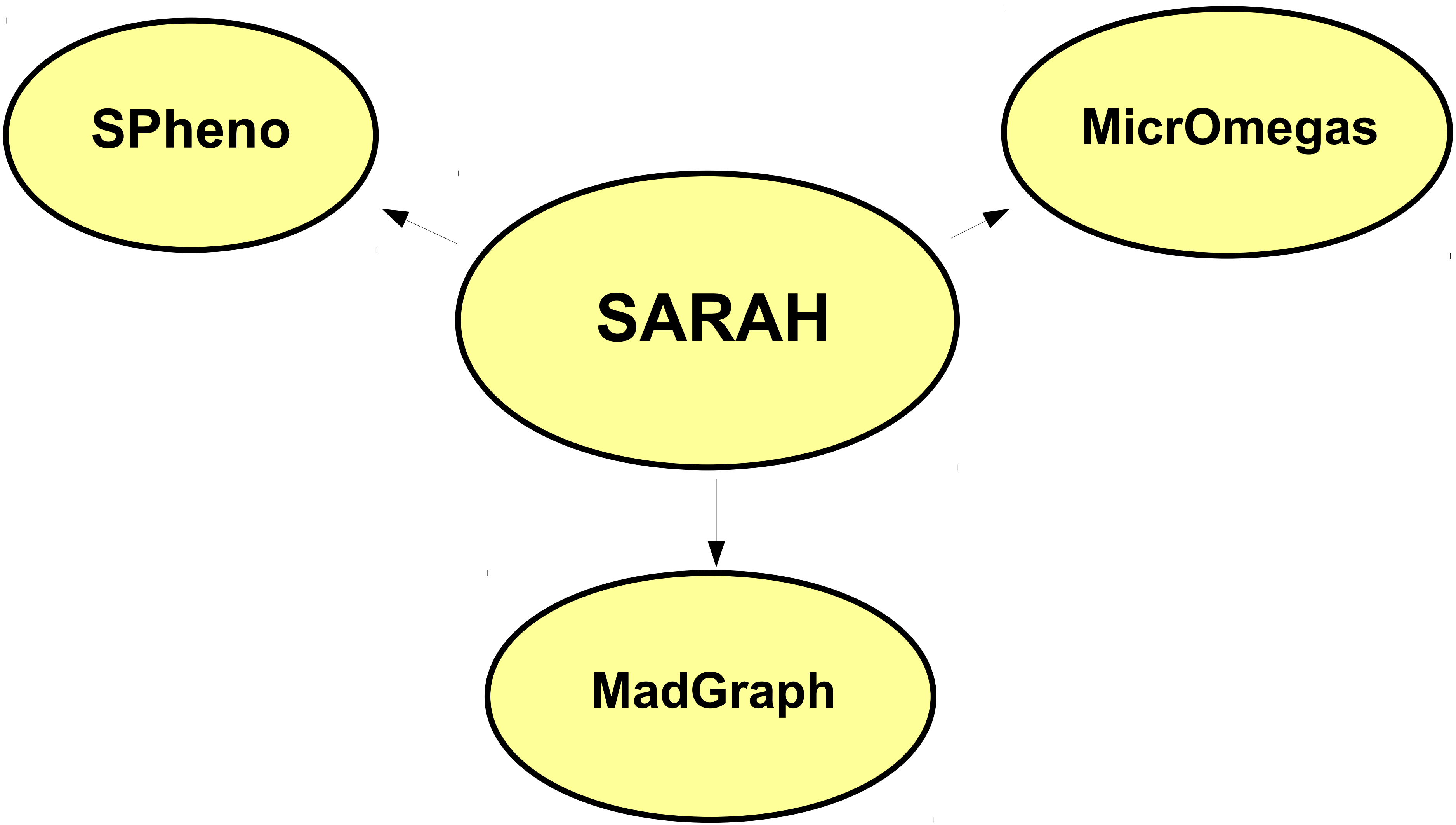
Renormalization group equations

$$\frac{dc}{dt} = \beta_c = \frac{1}{16\pi^2}\beta_c^{(1)} + \frac{1}{(16\pi^2)^2}\beta_c^{(2)} + \cdots$$

$$\boxed{\beta_{g_i}^{(1)} = \left(\frac{21}{5}g_1^3, -3g_2^3, -7g_3^3\right)}$$

$$\begin{aligned}\beta_{m_\eta^2}^{(1)} \quad = \quad & -\frac{9}{2}\left(\frac{1}{5}g_1^2 + g_2^2\right)m_\eta^2 + 6\lambda_2 m_\eta^2 - 2\left(2\lambda_3 + \lambda_4\right)m_H^2 \\ & +2\,m_\eta^2 \mathrm{Tr}\left(Y_N Y_N^\dagger\right) - 4\mathrm{Tr}\left(M_N M_N^* Y_N Y_N^\dagger\right)\end{aligned}$$

SARAH: Input for other codes



SPheno

SPheno

[Porod, Staub]

- **Name of the tool:** `SPheno`
- **Authors:** Werner Porod (porod@physik.uni-wuerzburg.de) and Florian Staub (florian.staub@cern.ch)
- **Type of code:** `Fortran`
- **Website:** http://spheno.hepforge.org/

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.

SARAH	⇒	SPheno
Analytics		Numerics

http://spheno.hepforge.org/

Scotogenic: benchmark point

BS1 benchmark point

$$\lambda_1 = 0.25 \qquad \lambda_2 = 0.5 \qquad \lambda_3 = 0.5$$

$$\lambda_4 = -0.5 \qquad \lambda_5 = 8 \cdot 10^{-11} \qquad m_\eta^2 = 1.85 \cdot 10^5 \, \mathrm{GeV}^2$$

$$M_N = \begin{pmatrix} 345 \, \mathrm{GeV} & 0 & 0 \\ 0 & 4800 \, \mathrm{GeV} & 0 \\ 0 & 0 & 6800 \, \mathrm{GeV} \end{pmatrix}$$

$$Y_N = \begin{pmatrix} 0.0172495 & 0.300325 & 0.558132 \\ -0.891595 & 1.00089 & 0.744033 \\ -1.39359 & 0.207173 & 0.253824 \end{pmatrix}$$

FlavorKit

W. Porod, F. Staub, A. Vicente

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

Flavor observables in a nutshell

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

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

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

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

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

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

Backup

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.

The scotogenic model

[Ernest Ma, 2006]

Field	$SU(2)_L \times U(1)_Y$	Z_2
L_i	$(2,-1/2)$	$+$
e_i	$(1,1)$	$+$
ϕ	$(2,-1/2)$	$+$
N_i	$(1,0)$	$-$
η	$(2,-1/2)$	$-$

σκότος

skotos = darkness

Inert (or dark) doublet

Dark Matter!

$$\mathcal{L}_N = \overline{N_i} \not\partial N_i - \frac{m_{N_i}}{2} \overline{N_i^c} N_i + y_{i\alpha} \eta \overline{N_i} \ell_\alpha + \text{h.c.}$$

$$\begin{aligned} \mathcal{V} = & \quad m_\phi^2 \phi^\dagger \phi + m_\eta^2 \eta^\dagger \eta + \frac{\lambda_1}{2} \left(\phi^\dagger \phi\right)^2 + \frac{\lambda_2}{2} \left(\eta^\dagger \eta\right)^2 + \lambda_3 \left(\phi^\dagger \phi\right) \left(\eta^\dagger \eta\right) \\ & + \lambda_4 \left(\phi^\dagger \eta\right) \left(\eta^\dagger \phi\right) + \frac{\lambda_5}{2} \left[\left(\phi^\dagger \eta\right)^2 + \left(\eta^\dagger \phi\right)^2 \right] \end{aligned}$$

The scotogenic model

[Ernest Ma, 2006]

$$\mathcal{V} = m_\phi^2 \phi^\dagger \phi + m_\eta^2 \eta^\dagger \eta + \frac{\lambda_1}{2} \left(\phi^\dagger \phi\right)^2 + \frac{\lambda_2}{2} \left(\eta^\dagger \eta\right)^2 + \lambda_3 \left(\phi^\dagger \phi\right) \left(\eta^\dagger \eta\right)$$
$$+\lambda_4 \left(\phi^\dagger \eta\right) \left(\eta^\dagger \phi\right) + \frac{\lambda_5}{2} \left[\left(\phi^\dagger \eta\right)^2 + \left(\eta^\dagger \phi\right)^2\right]$$

Inert scalar sector: $\eta^\pm$ $\quad \eta^0 = (\eta_R + i \eta_I)/\sqrt{2}$

$$\begin{aligned} m_{\eta^+}^2 &= m_\eta^2 + \lambda_3 \langle \phi^0 \rangle^2 \\ m_R^2 &= m_\eta^2 + (\lambda_3 + \lambda_4 + \lambda_5) \langle \phi^0 \rangle^2 \\ m_I^2 &= m_\eta^2 + (\lambda_3 + \lambda_4 - \lambda_5) \langle \phi^0 \rangle^2 \end{aligned} \quad \Rightarrow \quad \mathrm{m}_R^2 - m_I^2 = 2\lambda_5 \langle \phi^0 \rangle^2$$

Radiative neutrino masses

[Ernest Ma, 2006]

Tree-level:
Forbidden by the Z_2 symmetry

Radiative generation of neutrino masses

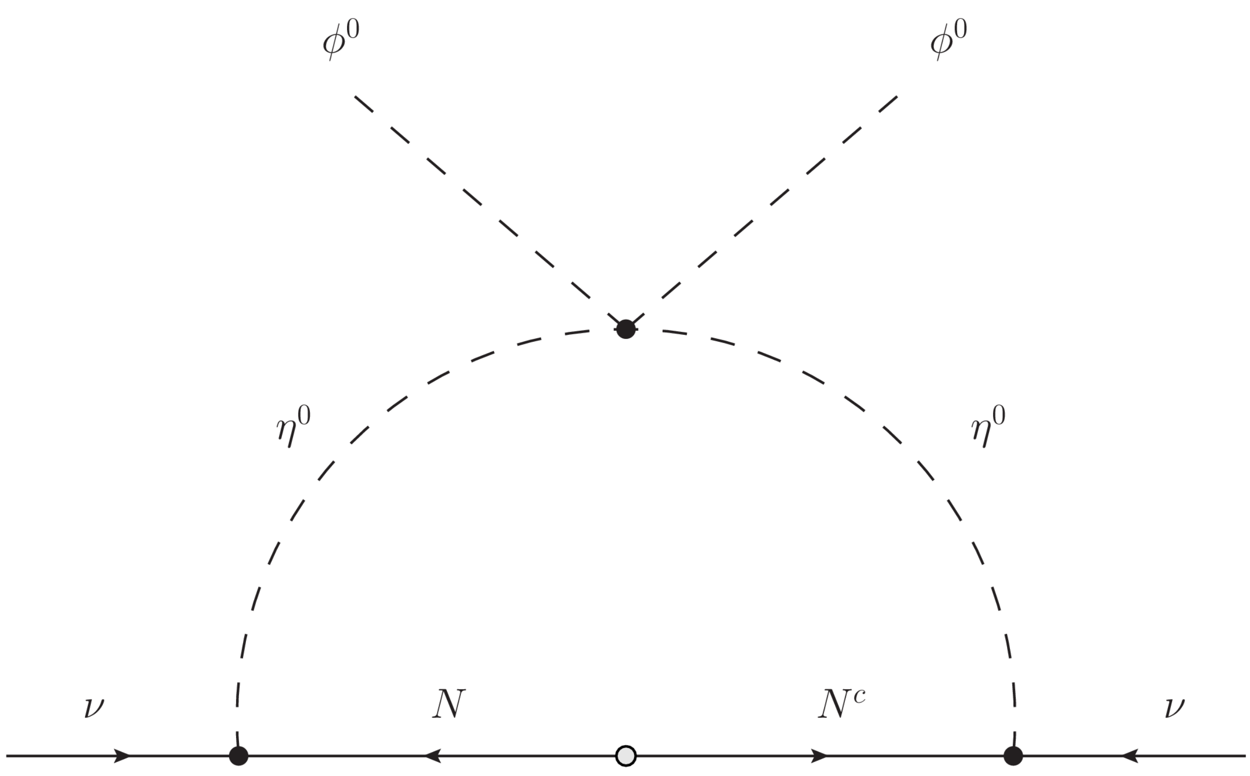
↓

Additional loop suppression

Dark particles in the loop

[Other variations in Restrepo et al, 2013]

1-loop neutrino masses:



Radiative neutrino masses

[Ernest Ma, 2006]

[See also Merle, Platscher, 2015]

$$m_\nu = y^T \Lambda \, y$$

$$\Lambda_{ij} = \frac{m_{N_i}}{2(4\pi)^2} \left[\frac{m_R^2}{m_R^2 - m_{N_i}^2} \log\left(\frac{m_R^2}{m_{N_i}^2}\right) - \frac{m_I^2}{m_I^2 - m_{N_i}^2} \log\left(\frac{m_I^2}{m_{N_i}^2}\right) \right] \delta_{ij}$$

$$y = \sqrt{\Lambda}^{-1} R \sqrt{\hat{m}_\nu} U_{\rm PMNS}^\dagger$$

Modified
Casas-Ibarra parameterization
[Toma, Vicente, 2013]

$$U_{\rm PMNS}^T \, m_\nu \, U_{\rm PMNS} = m_\nu^{\rm diag}$$

Mixing angles θ_{ij} $\quad m_{\nu_1}, \Delta m_{sol}^2, \Delta m_{atm}^2$

Dark matter

The lightest particle charged under Z_2 is stable: dark matter candidate

Fermion Dark Matter: N_1

- It can only be produced via Yukawa interactions
- Potential problems with lepton flavor violation: is it compatible with the current bounds?

J. Kubo, E. Ma, D. Suematsu, PLB 642 (2006) 18, D. Aristizabal Sierra, J. Kubo, D. Restrepo, D. Suematsu, O. Zapata, PRD 79 (2009) 013011, D. Suematsu, T. Toma, T. Yoshida, PRD 79 (2009) 093004, D. Schmidt, T. Schwetz, T. Toma, PRD 85 (2012) 073009, ...

Scalar Dark Matter: the lightest neutral η **scalar,** η_R **or** η_I

- It also has gauge interactions
- Not correlated to lepton flavor violation

R. Barbieri, L. J. Hall, V. S. Rychkov, PRD 74 (2006) 015007, M. Cirelli, N. Fornengo, A. Strumia, NPB 753 (2006) 178, L. L. Honorez, E. Nezri, J. F. Oliver, M. H. G. Tytgat, JCAP 0702 (2007) 028, Q.-H. Cao, E. Ma, PRD (2007) 095011, S. Andreas, M. H. G. Tytgat, Q. Swillens, JCAP 0904 (2009) 004, E. Nezri, M. H. G. Tytgat, G. Vertongen, JCAP 0904 (2009) 014, T. Hambye, F.-S. Ling, L. L. Honorez, J. Roche, JHEP 07 (2009) 090, L. L. Honorez, C. E. Yaguna, JHEP 1009 (2010) 046 and JCAP 1101 (2011) 002, S. Kashiwase, D. Suematsu, PRD 86 (2012) 053001, A. Goudelis, B. Herrman, O. Stål, JHEP 1309 (2013) 106, M. Klasen, C. E. Yaguna, J. D. Ruiz-Alvarez, D. Restrepo, O. Zapata, JCAP 1304 (2013) 044, J. Racker, JCAP 1403 (2014) 02, ...

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:

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

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:

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

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