Two component Dark Matter

with neutrino masses

Diego Restrepo

Sep 6, 2019 - IPP - Natal [PDF: http://bit.ly/SARAHIIP]

Instituto de Física
Universidad de Antioquia
Phenomenology Group
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UNIVERSIDAD DE ANTIOQUIA
1803

Preliminars

Information

This is the website for the course 'Computer tools in particle physics' by Avelino Vicente.

- CINVESTAV, México City (México) 2015
- IFIC, Valencia (Spain) 2016
- Universidad de Antioquia, Medellín (Colombia) 2016
- IFIC, Valencia (Spain) 2017

References

The course focuses on the material contained in the following notes:

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

For two-loops RGEs see also:
"Exploring new models in all detail with SARAH", Florian Staub, arXiv:1503.04200 [PDF]

SARAH:
"SARAH 4: A tool for (not only SUSY) model builders", Florian Staub, arXiv:1309.7223 [PDF]

About

This is the website for the course 'Computer tools in particle physics'.

Links

- SARAH

  V1.0 August 2009: Susy Only
  V4.0 September 2013: non-Susy
  V4.14.2 (Transfered to W.Porod)

- SPheno
- MicrOMEGAs
- MadGraph
- MadAnalysis
- FlavorKit

Contact

Avelino Vicente
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Office B-6-0

For questions and comments, you can send me an e-mail.

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Information

This is the website for the course Computer tools in particle physics by Avelino Vicente, to take place at Instituto de Física Corpuscular (CSIC/Universidad de Valencia).

Dates: Monday 22/05/2017 - Friday 26/05/2017
Place: IFIC - Sala de Audiovisuales (Nave experimental)
Time: 15:00
Duration: 1.5 h for the first session and 1 h for the rest

Material and required programs

This will be a hands-on course, where all participants are encouraged to run all codes in their own laptops. The only required programas are Mathematica, a LaTeX compiler and Fortran 90 and C++ compilers. If you wish to fully participate please download the following files:

- **For lecture 1:** run_sarah_Scotogenic.nb and Scotogenic.tar.gz
- **For lecture 2:** micromegas_4.2.5.tgz
- **For lecture 4:** run_sarah_DarkBS.nb, DarkBS.tar.gz and plotDarkBS.txt

You should also download the latest versions of the codes we are going to use (exception: for lecture 2 we will use an old version of MicrOMEGAs, see above). You can find them in their official websites (links on your right). Finally, the slides of the course are available here: introduction, lecture 1, lecture 2, lecture 3, lecture 4 and lecture 5.

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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!

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Models already in SARAH

Supersymmetric Models

- MSSM [in several versions]
- NMSSM [in several versions]
- Near-to-minimal SSM (near-MSSM)
- General singlet extended SSM (SMSSM)
- DiracNMSSM
- Triplet extended MSSM/NMSSM
- Several models with R-parity violation
- Several U(1)-extended models
- Secluded MSSM
- Several B-L extended models
- Inverse and linear seesaws
- 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
- Models with vector-like superfields

Non-Supersymmetric Models

- Standard Model
- Two Higgs doublet models (including inert)
- Singlet extensions
- Triplet extensions
- U(1) extensions
- SM extended by a scalar color octet
- Gauged Two Higgs doublet model
- Singlet extended SM
- Singlet Scalar DM
- Singlet-Doublet DM
- Models with vector-like fermions
- Model with a scalar SU(2) 7-plet
- Leptoquark models
- Left-right models
- 331 models (with and without exotics)
- Georgi-Machacek model

More info: http://sarah.hepforge.org/

Models already in SARAH

Supersymmetric Models

Always check any version of SARAH and SPheno with this one!

- MSSM
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```
git clone --recursive https://github.com/restrepo/BSM-Submodules.git
cd BSM-Submodules/
emacs SARAH/Models/SSDM/SSDM.m
```

$$\mathsf{SU}(3)_c \times \mathsf{SU}(2)_L \times \mathsf{U}(1)_Y \times Z_2$$

$$
\begin{aligned}
\mathcal{D}_\mu = \partial_\mu &- i g_1 Y B_\mu \\
&- i g_2 T W^B_\mu \\
&- i g_3 \Lambda G_\mu \, .
\end{aligned}
$$

```
Off[General::spell]

Model`Name = "SSDM";
Model`NameLaTeX ="Singlet scalar Dark Matter";
Model`Authors = "Diego Restrepo ...";
Model`Date = "2015-11-16";

(* 2013-01-24: ...*)

(* Global Symmetries *)

Global[[1]] = {Z[2], Z2};

(* Gauge Groups *)

Gauge[[1]]={B,   U[1], hypercharge, g1,False,1};
Gauge[[2]]={WB, SU[2], left,        g2,True,1};
Gauge[[3]]={G,  SU[3], color,       g3,False,1};
```

	N_F	Lorentz	Y	SU(2)$_L$	SU(3)$_c$	Z_2
Q	3	$(u_L\ d_L)^\top$	1/6	**2**	**3**	$+$
L	3	$(\nu_L\ e_L)^\top$	$-1/2$	**2**	**1**	$+$
d^c	3	$(d_R)^\dagger$	1/3	**1**	$\overline{\mathbf{3}}$	$+$
u^c	3	$(u_R)^\dagger$	$-2/3$	**1**	$\overline{\mathbf{3}}$	$+$
e^c	3	$(e_R)^\dagger$	1	**1**	**1**	$+$
H	1	$(H^+\ H^0)$	1/2	**2**	**1**	$+$
S	1	s	0	**1**	**1**	$-$

$$\mathcal{L} = (\mathcal{L}_C + \text{h.c})$$
$$+ \mathcal{L}_R\,,$$
$$\mathcal{L}_C = -\,Y_e e^c \widetilde{H}\cdot L - Y_d d^c \widetilde{H}\cdot Q - Y_u u^c H\cdot Q\,,$$
$$\mathcal{L}_R = -\,\mu^2 \widetilde{H}\cdot H - \lambda_1(\widetilde{H}\cdot H)^2$$
$$-\,M_S^2 S^2 - \lambda_{SH} S^2 \widetilde{H}\cdot H - \lambda_S S^4\,.$$
$$Y_e \to N_F \times N_F, \cdots$$

```
(* Matter Fields *)

FermionFields[[1]] = {q, 3, {uL, dL},      1/6, 2,  3,1};
FermionFields[[2]] = {l, 3, {vL, eL},     -1/2, 2,  1,1};
FermionFields[[3]] = {d, 3, conj[dR],      1/3, 1, -3,1};
FermionFields[[4]] = {u, 3, conj[uR],     -2/3, 1, -3,1};
FermionFields[[5]] = {e, 3, conj[eR],       1, 1,  1,1};

ScalarFields[[1]] = {H, 1, {Hp, H0},      1/2, 2,  1,1};
ScalarFields[[2]] = {S, 1, ss,              0, 1,  1,-1};
RealScalars = {S};

(*------------------------------------------------*)
(*   DEFINITION                                   *)
(*------------------------------------------------*)

NameOfStates={GaugeES, EWSB};

(* ----- Before EWSB ----- *)

DEFINITION[GaugeES][LagrangianInput]= {
  {LagHC, {AddHC->True}},
  {LagNoHC,{AddHC->False}}
};


LagHC =   -(Ye e.conj[H].l + Yd d.conj[H].q + Yu u.H.q);

LagNoHC = -(mu2 conj[H].H + Lambda1/2 conj[H].H.conj[H].H
          + MS2/2 S.S + LamSH S.S.conj[H].H  + LamS/2 S.S.S.S);
```

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$$\begin{pmatrix} B^\mu \\ W_3^\mu \end{pmatrix} = Z^{\gamma Z} \begin{pmatrix} A^\mu \\ Z^\mu \end{pmatrix} = \begin{pmatrix} \cos\theta_W & \sin\theta_W \\ -\sin\theta_W & \cos\theta_W \end{pmatrix} \begin{pmatrix} A^\mu \\ Z^\mu \end{pmatrix}$$

$$H^0 = \frac{iA + (h + v)}{\sqrt{2}}\,.$$

$$d_L = V_d D_L\,, \qquad\qquad (d_R)^\dagger = D_R^c U_d\,,$$

$$V_d \to N_F \times N_F, \cdots$$

$$\Psi_d = \begin{pmatrix} D_L \\ D_R \end{pmatrix}$$

```
(* Gauge Sector *)

DEFINITION[EWSB][GaugeSector] =
{
  {{VB,VWB[3]},{VP,VZ},ZZ},
  {{VWB[1],VWB[2]},{VWp,conj[VWp]},ZW}
};

(* ----- VEVs ---- *)

DEFINITION[EWSB][VEVs]=
{{H0,{v,1/Sqrt[2]}, {Ah,\[ImaginaryI]/Sqrt[2]},{hh,1/Sqrt[2]}} };


DEFINITION[EWSB][MatterSector]=
    {{{{dL}, {conj[dR]}}, {{DL,Vd}, {DR,Ud}}},
     {{{uL}, {conj[uR]}}, {{UL,Vu}, {UR,Uu}}},
     {{{eL}, {conj[eR]}}, {{EL,Ve}, {ER,Ue}}}};

(*-------------------------------------------------------*)
(* Dirac-Spinors *)
(*-------------------------------------------------------*)

DEFINITION[EWSB][DiracSpinors]={
 Fd ->{  DL, conj[DR]},
 Fe ->{  EL, conj[ER]},
 Fu ->{  UL, conj[UR]},
 Fv ->{  vL, 0}};
```

$$\begin{pmatrix} B^\mu \\ W_3^\mu \end{pmatrix} = Z^{\gamma Z} \begin{pmatrix} A^\mu \\ Z^\mu \end{pmatrix} = \begin{pmatrix} \cos\theta_W & \sin\theta_W \\ -\sin\theta_W & \cos\theta_W \end{pmatrix} \begin{pmatrix} A^\mu \\ Z^\mu \end{pmatrix}$$

$$H^0 = \frac{iA + (h+v)}{\sqrt{2}}.$$

$$d_L = V_d D_L, \qquad\qquad (d_R)^\dagger = D_R^C U_d,$$

$$V_d \to N_F \times N_F, \cdots$$

Chuck Norris fact of the day

Chuck Norris lost his virginity before his dad

```
(* Gauge Sector *)

DEFINITION[EWSB][GaugeSector] =
{
  {{VB,VWB[3]},{VP,VZ},ZZ},
  {{VWB[1],VWB[2]},{VWp,conj[VWp]},ZW}
};

(* ----- VEVs ---- *)

DEFINITION[EWSB][VEVs]=
{{H0,{v,1/Sqrt[2]}, {Ah,\[ImaginaryI]/Sqrt[2]},{hh,1/Sqrt[2]}} };

DEFINITION[EWSB][MatterSector]=
    {{{{dL}, {conj[dR]}}, {{DL,Vd}, {DR,Ud}}},
     {{{uL}, {conj[uR]}}, {{UL,Vu}, {UR,Uu}}},
     {{{eL}, {conj[eR]}}, {{EL,Ve}, {ER,Ue}}}};

(*-------------------------------------------------------*)
(* Dirac-Spinors *)
(*-------------------------------------------------------*)

DEFINITION[EWSB][DiracSpinors]={
 Fd ->{  DL, conj[DR]},
 Fe ->{  EL, conj[ER]},
 Fu ->{  UL, conj[UR]},
 Fv ->{  vL, 0}};
```

./parameters.m

```
     ...
{g1,        { Description -> "Hypercharge-Coupling"}},
{g2,        { Description -> "Left-Coupling"}},
{g3,        { Description -> "Strong-Coupling"}},
...
{v,          { Description -> "EW-VEV",
               DependenceNum -> Sqrt[4*Mass[VWp]^2/(g2^2)],
               DependenceSPheno -> None  }},

{ThetaW,    { Description -> "Weinberg-Angle",
              DependenceNum -> ArcSin[Sqrt[1 - Mass[VWp]^2/Mass[VZ]^2]]}},

{ZZ, {Description -> "Photon-Z Mixing Matrix"}},

    ...
```

```
    ...
{{Description -> "Photon-Z Mixing Matrix",
      Dependence ->  {{Cos[ThetaW],-Sin[ThetaW]},
                       {Sin[ThetaW],Cos[ThetaW]}},
      Real ->True,
      LaTeX -> "Z^{\\gamma Z}",
      LesHouches -> None,
      OutputName -> ZZ }},
    ...
```

```
./particles.m

    ...
  ParticleDefinitions[EWSB] = {

   {hh   , {  Description -> "Higgs",
              PDG -> {25},
              PDG.IX -> {101000001},
              Mass -> LesHouches,
              FeynArtsNr -> 1,
              LaTeX -> "h",
              ElectricCharge -> 0,
              LHPC -> {1},
              OutputName -> "h"  }},

   {ss   , {  Description -> "Singlet",
              PDG -> {6666635},
              PDG.IX -> {101000002},
              FeynArtsNr -> 10,
              Mass -> LesHouches,
              LaTeX -> "S",
              ElectricCharge -> 0,
              LHPC -> {"gold"},
              OutputName -> "Ss" }},
         ...
       }
   ...
```

```
OnlyLowEnergySPheno = True;

MINPAR={{1,Lambda1IN},
        {2,LamSHIN},
        {3,LamSIN},
        {4,MSinput}
        };
 ...
ListDecayParticles = {Fu,Fe,Fd,hh};
ListDecayParticles3B = {{Fu,"Fu.f90"},{Fe,"Fe.f90"},{Fd,"Fd.f90"}};

....

DefaultInputValues ={Lambda1IN -> 0.28, LamSHIN -> 0.01, LamSIN -> 0,
                     MSinput -> 200};
```

```
math << EOF
<<./SARAH/SARAH.m
Start["SSDM"]
MakeSPheno[]
EOF
```

```
Mathematica 11.0.0 for Linux x86 (64-bit)
...
In[1]:= SARAH 4.14.1
by Florian Staub, 2018
...
In[2]:= Preparing arrays
 ...
Model files loaded
  Model   : SSDM
  Author(s): Diego Restrepo (based on SM model by F.Staub)
  Date    : 2015-11-16
*****************************************************
Loading Susyno functions for the handling of Lie Groups
Based on Susyno v.2.0 by Renato Fonseca (1106.5016)
webpage: web.ist.utl.pt/renato.fonseca/susyno.html
*****************************************************
...
Finished! SPheno code generated in 170.872s
....
The following steps are now necessary to implement the model in SPheno:
```

```
cp -r SARAH/Output/SSDM/EWSB/SPheno SPheno/SSDM
cd SPheno
make Model=SSDM # Be sure that Makefile use gfortran!
```

```
cd SSDM ; make F90=gfortran version=400.00
make[1]: Entering directory '****/BSM-Submodules/SPHENO/SSDM'
.
.
.
make[2]: Leaving directory '****/BSM-Submodules/SPHENO/SSDM'
gfortran -o SPhenoSSDM -g   SPhenoSSDM.o ../lib/libSPhenoSSDM.a ../lib/libSPheno.a
mv SPhenoSSDM ../bin
rm SPhenoSSDM.o
make[1]: Leaving directory '****/BSM-Submodules/SPHENO/SSDM'
```

```
# Return to parent directory: BSM-Submodules
cd ../
```

```
cd micromegas
make # Recompile everything!
make # twice
```

```
make -C CalcHEP_src  MICROMEGAS=MICROMEGAS
...
#-------------------------------------------------------
# CalcHEP has compiled successfuly and can be started.
# The manual can be found on the CalcHEP website:
#      http://theory.sinp.msu.ru/~pukhov/calchep.html
# The next step is typically to run
#      ./mkWORKdir  <new_dir>
# where <new_dir> is the new directory where you will do
# your calculations.  After creating this directory, you
# should cd into it and run calchep or calchep_batch.
# Please see the manual for further details.
#-------------------------------------------------------"
...
make[1]: Leaving directory '****/BSM-Submodules/micromegas/sources'
```

Build micrOMEGAs model

```
./newProject SSDM
cd .. # return to parent directory
```

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```
math << EOF
<<./SARAH/SARAH.m
Start["SSDM"]
MakeCHep[]
EOF
```

```
Mathematica 11.0.0 for Linux x86 (64-bit)
...
Write main file for MicrOmegas
Done. Model files generated in 31.044s
Output is saved in ****/BSM-Submodules/SARAH/Output/SSDM/EWSB/CHep/
```

```
cp SARAH/Output/SSDM/EWSB/CHep/* micromegas/SSDM/work/models/
cd micromegas/SSDM/
cp work/models/*.cpp .
# check your micrOMEGAs version
make main=CalcOmega_with_DDetection_MOv5.cpp
```

```
make -C work
...
g++     -g -fPIC  -o CalcOmega_with_DDetection_MOv5 CalcOmega_with_DDetection_MOv5.cpp ... -lpthread
cd ../../ #Return to parent directory
```

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Check Madgraph

```
math << EOF
<<./SARAH/SARAH.m
Start["SSDM"]
MakeUFO[]
EOF
```

```
Mathematica 11.0.0 for Linux x86 (64-bit)
...
Writing effective diphoton and digluon vertices

Done. UFO files generated in 30.716s
Output is saved in ****/BSM-Submodules/SARAH/Output/SSDM/EWSB/UFO/
```

```
cp -r SARAH/Output/SSDM/EWSB/UFO/ madgraph/models/SSDM
madgraph/bin/mg5_aMC << EOF
import model SSDM
check u u~ > mu+ mu-
EOF
```

```
Process         Min element      Max element      Relative diff.   Result
u u~ > mu+ mu-  4.9949890843e-03 4.9949890843e-03 5.2093911919e-15 Passed
Summary: 1/1 passed, 0/1 failed
```

```
cp SPheno/SSDM/Input_Files/LesHouches.in.SSDM .
emacs LesHouches.in.SSDM
```

```
File  Edit  Options  Buffers  Tools  Help
  🗋  📁  💾  ✖  💾Save    ⟲Undo      ✂  🔲  📋    🔍

Block MODSEL       #
 1 1               #  1/0: High/low scale input
 2 1               # Boundary Condition
 6 1               # Generation Mixing
Block SMINPUTS     # Standard Model inputs
 2 1.166370E-05    # G_F,Fermi constant
 3 1.187000E-01    # alpha_s(MZ) SM MSbar
 4 9.118870E+01    # Z-boson pole mass
 5 4.180000E+00    # m_b(mb) SM MSbar
 6 1.735000E+02    # m_top(pole)
 7 1.776690E+00    # m_tau(pole)
Block MINPAR       # Input parameters
 1    2.8000000E-01    # Lambda1IN
 2    1.0000000E-02    # LamSHIN
 3    0.0000000E+00    # LamSIN
 4    2.0000000E+02    # MSinput
Block SPhenoInput  # SPheno specific input
  1 -1              # error level
  2  0              # SPA conventions
  7  0              # Skip 2-loop Higgs corrections
  8  3              # Method used for two-loop calculation
  9  1              # Gaugeless limit used at two-loop
 10  0              # safe-mode used at two-loop
 11 1               # calculate branching ratios
 13 1               # 3-Body decays: none (0), fermion (1), scalar (2), both (3)
 14 0               # Run couplings to scale of decaying particle
 12 1.000E-04       # write only branching ratios larger than this value
 15 1.000E-30       # write only decay if width larger than this value
 16 1               # One-loop decays
 1̶6̶ ̶2̶               # Matching order ( 2:automatic   1:pole  0,2: tree, one, & two loop)
-:---  LesHouches.in.SSDM   Top L16    (Fundamental)
menu-bar options menu-set-font
```

```
Block MODSEL        #
 1 1                #  1/0: High/low scale input
 2 1                # Boundary Condition
 6 1                # Generation Mixing
Block SMINPUTS      # Standard Model inputs
 2 1.166370E-05     # G_F,Fermi constant
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 5 4.180000E+00     # m_b(mb) SM MSbar
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 7 1.776690E+00     # m_tau(pole)
Block MINPAR        # Input parameters
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 3   0.0000000E+00    # LamSIN
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11 1                # calculate branching ratios
13 1                # 3-Body decays: none (0), fermion (1), scalar (2), both (3)
14 0                # Run couplings to scale of decaying particle
12 1.000E-04        # write only branching ratios larger than this value
15 1.000E-30        # write only decay if width larger than this value
16 1                # One-loop decays
```

menu-bar options menu-set-font

Run SPheno

```
BSM-Submodules$ SPheno/bin/SPhenoSSDM  LesHouches.in.SSDM
Calculating branching ratios and decay widths
Calculating one loop decays
Loop masses not calculated: tree-level masses used for kinematics
Loop masses not calculated: no U-factors are applied
Calculating one-loop decays of Fu
Calculating one-loop decays of Fe
Calculating one-loop decays of Fd
Calculating one-loop decays of hh
Calculating low energy constraints
Calculating unitarity constraints
Writing output files
Finished!
BSM-Submodules$ emacs SPheno.spc.SSDM
```
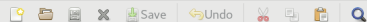
```
# SUSY Les Houches Accord 2 - SSDM Spectrum + Decays + Flavor Observables
# SPheno module generated by SARAH
# ----------------------------------------------------------------------
# SPheno v4.0.3
#   W. Porod, Comput. Phys. Commun. 153 (2003) 275-315, hep-ph/0301101
#   W. Porod, F.Staub, Comput.Phys.Commun.183 (2012) 2458-2469, arXiv:1104.1573
# SARAH: 4.14.1
#   F. Staub; arXiv:0806.0538 (online manual)
#   F. Staub; Comput. Phys. Commun. 181 (2010) 1077-1086; arXiv:0909.2863
#   F. Staub; Comput. Phys. Commun. 182 (2011)  808-833; arXiv:1002.0840
#   F. Staub; Comput. Phys. Commun. 184 (2013)  1792-1809; arXiv:1207.0906
#   F. Staub; Comput. Phys. Commun. 185 (2014)  1773-1790; arXiv:1309.7223
# Including the calculation of flavor observables based on the FlavorKit
#   W. Porod, F. Staub, A. Vicente; Eur.Phys.J. C74 (2014) 8, 2992; arXiv:1405.1434
# Two-loop masss corrections to Higgs fields based on
#   M. D. Goodsell, K. Nickel, F. Staub; Eur.Phys.J. C75 (2015) no.6, 290; arXiv:1411.0675
#   M. D. Goodsell, K. Nickel, F. Staub; Eur.Phys.J. C75 (2015) no.1, 32; arXiv:1503.03098
#   M. D. Goodsell, F. Staub; arXiv:1511.01904
#
# in case of problems send email to florian.staub@kit.edu and goodsell@lpthe.jussieu.fr
# ----------------------------------------------------------------------
# Created: 19.09.2019,  22:47
Block SPINFO         # Program information
    1   SPhenoSARAH      # spectrum calculator
    2   v4.0.3     # version number of SPheno
    9   4.14.1     # version number of SARAH
Block MODSEL  # Input parameters
    1 1   #  GUT scale input
    2 1   #  Boundary conditions
    6 1   #  switching on flavour violation
Block MINPAR  # Input parameters
    1    2.80000000E-01  # Lambda1IN
    2    1.00000000E-02  # LamSHIN
    3    0.00000000E+00  # LamSIN
    4    2.00000000E+02  # MSinput
Block gaugeGUT Q= -1.00000000E+00  # (GUT scale)
    1    0.00000000E+00  # g1(Q)
    2    0.00000000E+00  # g2(Q)
    3    0.00000000E+00  # g3(Q)
Block SMINPUTS  # SM parameters
```

```
   3   3      9.95678124E-01   # Real(Yu(3,3),dp)
Block Yd Q=  1.60000000E+02   # (Renormalization Scale)
   1   1      2.87184285E-05   # Real(Yd(1,1),dp)
   1   2      0.00000000E+00   # Real(Yd(1,2),dp)
   1   3      0.00000000E+00   # Real(Yd(1,3),dp)
   2   1      0.00000000E+00   # Real(Yd(2,1),dp)
   2   2      5.45650142E-04   # Real(Yd(2,2),dp)
   2   3      0.00000000E+00   # Real(Yd(2,3),dp)
   3   1      0.00000000E+00   # Real(Yd(3,1),dp)
   3   2      0.00000000E+00   # Real(Yd(3,2),dp)
   3   3      2.40086062E-02   # Real(Yd(3,3),dp)
Block Ye Q=  1.60000000E+02   # (Renormalization Scale)
   1   1      2.93501725E-06   # Real(Ye(1,1),dp)
   1   2      0.00000000E+00   # Real(Ye(1,2),dp)
   1   3      0.00000000E+00   # Real(Ye(1,3),dp)
   2   1      0.00000000E+00   # Real(Ye(2,1),dp)
   2   2      6.06868478E-04   # Real(Ye(2,2),dp)
   2   3      0.00000000E+00   # Real(Ye(2,3),dp)
   3   1      0.00000000E+00   # Real(Ye(3,1),dp)
   3   2      0.00000000E+00   # Real(Ye(3,2),dp)
   3   3      1.02047490E-02   # Real(Ye(3,3),dp)
Block MASS  # Mass spectrum
#   PDG code        mass          particle
        25      1.30287679E+02   # hh
   6666635      2.83944658E+01   # ss
        23      9.11887000E+01   # VZ
        24      8.03497269E+01   # VWp
         1      5.00000000E-03   # Fd_1
         3      9.50000000E-02   # Fd_2
         5      4.18000000E+00   # Fd_3
         2      2.50000000E-03   # Fu_1
         4      1.27000000E+00   # Fu_2
         6      1.73500000E+02   # Fu_3
        11      5.10998930E-04   # Fe_1
        13      1.05658372E-01   # Fe_2
        15      1.77669000E+00   # Fe_3
Block UDLMIX Q=  1.60000000E+02   # ()
   1   1      1.00000000E+00   # Real(ZDL(1,1),dp)
   1   2      0.00000000E+00   # Real(ZDL(1,2),dp)
   1   3      0.00000000E+00   # Real(ZDL(1,3),dp)
```

$\longrightarrow \quad M_S = 28 \ \text{GeV}$

```
File Edit Options Buffers Tools Help
   [toolbar icons]   Q
      52    0.00000000E+00  # Ignore negative masses
      53    0.00000000E+00  # Ignore negative masses at MZ
      55    0.00000000E+00  # Calculate one loop masses
      56    1.00000000E+00  # Calculate two-loop Higgs masses
      57    1.00000000E+00  # Calculate low energy
      60    1.00000000E+00  # Include kinetic mixing
      65    1.00000000E+00  # Solution of tadpole equation
Block HiggsBoundsInputHiggsCouplingsFermions #
   1.00000000E+00    0.00000000E+00         3          25         5        5 # h_1 b b coupling
   1.00000000E+00    0.00000000E+00         3          25         3        3 # h_1 s s coupling
   1.00000000E+00    0.00000000E+00         3          25         6        6 # h_1 t t coupling
   1.00000000E+00    0.00000000E+00         3          25         4        4 # h_1 c c coupling
   1.00000000E+00    0.00000000E+00         3          25        15       15 # h_1 tau tau coupling
   1.00000000E+00    0.00000000E+00         3          25        13       13 # h_1 mu mu coupling
Block HiggsBoundsInputHiggsCouplingsBosons #
   1.00000000E+00         3          25         24        24 # h_1 W W coupling
   1.00000000E+00         3          25         23        23 # h_1 Z Z coupling
   0.00000000E+00         3          25         23        22 # h_1 Z gamma coupling
   1.04284942E+00         3          25         22        22 # h_1 gamma gamma coupling
   1.02186767E+00         3          25         21        21 # h_1 g g coupling
   0.00000000E+00         4          25         21        21        23 # h_1 g g Z coupling
   0.00000000E+00         3          25         25        23 # h_1 h_1 Z coupling
Block EFFHIGGSCOUPLINGS # values of loop-induced couplings
      25           22          22    0.33598689E-04 # H-Photon-Photon
      25           21          21    0.65965686E-04 # H-Gluon-Gluon
      25           22          23    0.00000000E+00 # H-Photon-Z (not yet calculated by SPheno)
Block SPhenoLowEnergy # low energy observables
       1   -0.00000000E+00   # T-parameter (1-loop BSM)
       2    0.00000000E+00   # S-parameter (1-loop BSM)
       3    0.00000000E+00   # U-parameter (1-loop BSM)
      20    1.99137438E-23   # (g-2)_e
      21    2.00436756E-14   # (g-2)_mu
      22    9.10708358E-10   # (g-2)_tau
      23    0.00000000E+00   # EDM(e)
      24    0.00000000E+00   # EDM(mu)
      25    0.00000000E+00   # EDM(tau)
      39   -3.57242562E-04   # delta(rho)
Block FlavorKitQFV # quark flavor violating observables
     200    3.15000000E-04   # BR(B->X_s gamma)
     201    1.00000000E+00   # BR(B->X_s gamma)/BR(B->X_s gamma) SM
-:---   SPheno.spc.SSDM   22% L186   (Fundamental)
```
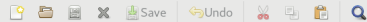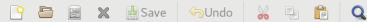
```
Block FlavorKitQFV # quark flavor violating observables
  200   3.15000000E-04 # BR(B->X_s gamma)
  201   1.00000000E+00 # BR(B->X_s gamma)/BR(B->X_s gamma)_SM
  300   5.89291589E-04 # BR(D->mu nu)
  301   9.98950690E-01 # BR(D->mu nu)/BR(D->mu nu)_SM
  400   5.57245359E-03 # BR(Ds->mu nu)
  401   9.98836301E-01 # BR(Ds->mu nu)/BR(Ds->mu nu)_SM
  402   5.44600001E-02 # BR(Ds->tau nu)
  403   9.98836361E-01 # BR(Ds->tau nu)/BR(Ds->tau nu)_SM
  500   5.05883016E-07 # BR(B->mu nu)
  501   9.91645649E-01 # BR(B->mu nu)/BR(B->mu nu)_SM
  502   1.12565752E-04 # BR(B->tau nu)
  503   9.91645649E-01 # BR(B->tau nu)/BR(B->tau nu)_SM
  600   6.32329549E-01 # BR(K->mu nu)
  601   9.99267926E-01 # BR(K->mu nu)/BR(K->mu nu)_SM
  602   2.47647734E-05 # R_K = BR(K->e nu)/(K->mu nu)
  603   2.47611475E-05 # R_K_SM = BR(K->e nu)_SM/(K->mu nu)_SM
 1900   1.89083877E+01 # Delta(M_Bs)
 1901   1.00057830E+00 # Delta(M_Bs)/Delta(M_Bs)_SM
 3902   4.22518370E-01 # Delta(M_Bd)
 1903   1.00031573E+00 # Delta(M_Bd)/Delta(M_Bd)_SM
 4000   1.06152026E-15 # BR(B^0_d->e e)
 4001   1.00000649E+00 # BR(B^0_d->e e)/BR(B^0_d->e e)_SM
 4002   7.18891179E-14 # BR(B^0_s->e e)
 4003   1.00000036E+00 # BR(B^0_s->e e)/BR(B^0_s->e e)_SM
 4004   4.53469508E-11 # BR(B^0_d->mu mu)
 4005   1.00000648E+00 # BR(B^0_d->mu mu)/BR(B^0_d->mu mu)_SM
 4006   3.07110160E-09 # BR(B^0_s->mu mu)
 4007   1.00000036E+00 # BR(B^0_s->mu mu)/BR(B^0_s->mu mu)_SM
 4008   9.49161543E-09 # BR(B^0_d->tau tau)
 4009   1.00000355E+00 # BR(B^0_d->tau tau)/BR(B^0_d->tau tau)_SM
 4010   6.51320069E-07 # BR(B^0_s->tau tau)
 4011   1.00000357E+00 # BR(B^0_s->tau tau)/BR(B^0_s->tau tau)_SM
 5000   1.64141441E-06 # BR(B-> s e e)
 5001   9.91674299E-01 # BR(B-> s e e)/BR(B-> s e e)_SM
 5002   1.59101657E-06 # BR(B-> s mu mu)
 5003   9.91417390E-01 # BR(B-> s mu mu)/BR(B-> s mu mu)_SM
 6000   1.09904183E-07 # BR(B -> K mu mu)
 6001   9.99136770E-01 # BR(B -> K mu mu)/BR(B -> K mu mu)_SM
 6002   1.09904183E-07 # BR(B -> K mu mu)
 6003   9.99136770E-01 # BR(B -> K mu mu)/BR(B -> K mu mu)_SM
 7000   3.88642090E-05 # BR(b->s nu nu)
 7001   1.00000000E+00 # BR(B->s nu nu)/BR(B->s nu nu)_SM
 7002   8.07379395E-07 # BR(B->d nu nu)
 7003   1.00000000E+00 # BR(B->d nu nu)/BR(B->d nu nu)_SM
 8000   1.38845648E-10 # BR(K^+ -> pi^+ nu nu)
 8001   1.00000000E+00 # BR(K^+ -> pi^+ nu nu)/BR(K^+ -> pi^+ nu nu)_SM
 8002   1.62288751E-43 # BR(K_L -> pi^0 nu nu)
 8003   1.00000000E+00 # BR(K_L -> pi^0 nu nu)/BR(K_L -> pi^0 nu nu)_SM
 8004   0.00000000E+00 # BR(K^0_L -> e mu)
 8005   0.00000000E+00 # BR(K^0_L -> e mu)/BR(K^0_L -> e mu)_SM
 9100   1.94643051E-15 # Delta(M_K)
 9102   9.99934210E-01 # Delta(M_K)/Delta(M_K)_SM
 9103   1.84370744E-03 # epsilon_K
 9104   1.00000000E+00 # epsilon_K/epsilon_K^SM
Block FlavorKitLFV # lepton flavor violating observables
  701   0.00000000E+00 # BR(mu->e gamma)
  702   0.00000000E+00 # BR(tau->e gamma)
  703   0.00000000E+00 # BR(tau->mu gamma)
  800   0.00000000E+00 # CR(mu-e, Al)
  801   0.00000000E+00 # CR(mu-e, Ti)
  802   0.00000000E+00 # CR(mu-e, Sr)
  803   0.00000000E+00 # CR(mu-e, Sb)
  804   0.00000000E+00 # CR(mu-e, Au)
  805   0.00000000E+00 # CR(mu-e, Pb)
  901   0.00000000E+00 # BR(mu->3e)
  902   0.00000000E+00 # BR(tau->3e)
  903   0.00000000E+00 # BR(tau->3mu)
  904   0.00000000E+00 # BR(tau- -> e- mu+ mu-)
  905   0.00000000E+00 # BR(tau- -> mu- e+ e-)
  906   0.00000000E+00 # BR(tau- -> e+ mu- mu-)
  907   0.00000000E+00 # BR(tau- -> mu+ e- e-)
 1001   0.00000000E+00 # BR(Z->e mu)
 1002   0.00000000E+00 # BR(Z->e tau)
 1003   0.00000000E+00 # BR(Z->mu tau)
 1101   0.00000000E+00 # BR(h->e mu)
 1102   0.00000000E+00 # BR(h->e tau)
 1103   0.00000000E+00 # BR(h->mu tau)
 2001   0.00000000E+00 # BR(tau->e pi)
 2002   0.00000000E+00 # BR(tau->e eta)
 2003   0.00000000E+00 # BR(tau->e eta')
 2004   0.00000000E+00 # BR(tau->mu pi)
 2005   0.00000000E+00 # BR(tau->mu eta)
 2006   0.00000000E+00 # BR(tau->mu eta')
Block FWCOEF Q= 1.60000000E+02 # Wilson coefficients at scale Q
 0305 4422 00 0 -0.16461706E-08 # coeffC7sm
 0305 4422 00 2 -0.16461706E-08 # coeffC7
 0305 4322 00 2 -0.37370893E-10 # coeffC7p
 0305 4422 00 1  0.00000000E+00 # coeffC7NP
 0305 4322 00 0 -0.37370893E-10 # coeffC7pNP
 0305 6421 00 0 -0.85476718E-09 # coeffC8sm
 0305 6421 00 2 -0.85476718E-09 # coeffC8
 0305 6421 00 2 -0.19386485E-10 # coeffC8p
 0305 6421 00 1  0.00000000E+00 # coeffC8NP
 0305 6321 00 0 -0.19386485E-10 # coeffC8pNP
03051111 4133 00 0  0.16563545E-08 # coeffC9eeSM
03051111 4133 00 2  0.10161545E-08 # coeffC9ee
03051111 4133 00 2  0.21615055E-14 # coeffC9Pee
03051111 4233 00 0  0.00000000E+00 # coeffC9NPee
```
-1:--- Sphwno.spc.SSUM   29% L282   (Fundamental)
menu-bar options menu-set-font

```
Block FlavorKitQFV # quark flavor violating observables
     200   3.15000000E-04  # BR(B->X_s gamma)
     201   1.00000000E+00  # BR(B->X_s gamma)/BR(B->X_s gamma)_SM
     300   9.09291500E-04  # BR(D->mu nu)
     301   9.80950696E-01  # BR(D->mu nu)_SM
     400   5.57245350E-03  # BR(Ds->mu nu)
     401   9.98836361E-01  # BR(Ds->mu nu)/BR(Ds->mu nu)_SM
     402   5.44600001E-02  # BR(Ds->tau nu)
     403   9.98836361E-01  # BR(Ds->tau nu)/BR(Ds->tau nu)_SM
     500   5.05883816E-07  # BR(B->mu nu)
     501   9.01645649E-01  # BR(B->mu nu)/BR(B->mu nu)_SM
     502   1.12565752E-04  # BR(B->tau nu)
     503   9.01645649E-01  # BR(B->tau nu)/BR(B->tau nu)_SM
     600   6.32329540E-01  # BR(K->mu nu)
     601   9.99267920E-01  # BR(K->mu nu)/BR(K->mu nu)_SM
     602   2.45647734E-05  # R R_K = BR(K->e nu)/(K->mu nu)
     603   4.76114756E-05  # R R*SM = BR(K->e nu)_SM/(K->mu nu)_SM
    1900   1.89083877E+01  # Delta(M_Bs)
    1901   1.80057830E+00  # Delta(M_Bs)/Delta(M_Bs)_SM
    1902   4.22518370E-01  # Delta(M_Bd)
    1903   1.00031573E+00  # Delta(M_Bd)/Delta(M_Bd)_SM
    4000   1.06152020E-15  # BR(B^0 d->e e)
    4001   1.00000640E+00  # BR(B^0 d->e e)/BR(B^0_d->e e)_SM
    4002   7.18001179E-14  # BR(B^0 s->e e)
    4003   1.00000030E+00  # BR(B^0 s->e e)/BR(B^0_s->e e)_SM
    4004   4.53469500E-11  # BR(B^0 d->mu mu)
    4005   1.00000640E+00  # BR(B^0 d->mu mu)/BR(B^0_d->mu mu)_SM
    4006   3.07110160E-09  # BR(B^0 s->mu mu)
    4007   1.00000035E+00  # BR(B^0 s->mu mu)/BR(B^0_s->mu mu)_SM
    4008   4.09161543E-09  # BR(B^0 d->tau tau)
    4009   1.00000355E+00  # BR(B^0 d->tau tau)/BR(B^0_d->tau tau)_SM
    4010   6.51320069E-07  # BR(B^0 s->tau tau)
    4011   1.00000357E+00  # BR(B^0 s->tau tau)/BR(B^0_s->tau tau)_SM
    5000   1.64141441E-06  # BR(B-> s e e)
    5001   9.91617429E-01  # BR(B-> s e e)/BR(B-> s e e)_SM
    5002   1.59101657E-06  # BR(B-> s mu mu)
    5003   9.91417300E-01  # BR(B-> s mu mu)/BR(B-> s mu mu)_SM
    6000   1.19904183E-07  # BR(B -> K mu mu)
    6001   9.99136779E-01  # BR(B -> K mu mu)/BR(B -> K mu mu)_SM
    6002   1.19904183E-07  # BR(B -> K mu mu)
    6003   9.99136779E-01  # BR(B -> K mu mu)/BR(B -> K mu mu)_SM
    7000   3.00642090E-05  # BR(B->s nu nu)
    7001   1.00000000E+00  # BR(B->s nu nu)/BR(B->s nu nu)_SM
    7002   8.07279395E-07  # BR(B->d nu nu)
    7003   1.00000000E+00  # BR(B->d nu nu)/BR(B->d nu nu)_SM
    8000   1.30845648E-10  # BR(K^+ -> pi^+ nu nu)
    8001   1.00000000E+00  # BR(K^+ -> pi^+ nu nu)/BR(K^+ -> pi^+ nu nu)_SM
    8004   1.62288751E-43  # BR(K_L -> pi^0 nu nu)
    8005   1.00000000E+00  # BR(K_L -> pi^0 nu nu)/BR(K_L -> pi^0 nu nu)_SM
    8004   0.00000000E+00  # BR(K^0 L -> e e)
    8005   0.00000000E+00  # BR(K^0_L -> e e mu)/BR(K^0_L -> e e mu)_SM
    9100   1.34643051E-15  # Delta(M_K)
    9102   9.99934216E-01  # Delta(M_K)/Delta(M_K)_SM
    9103   1.84370746E-03  # epsilon_K
    9104   1.00000000E+00  # epsilon_K/epsilon_K_SM
Block FlavorKitLFV # lepton flavor violating observables
     701   0.00000000E+00  # BR(mu->e gamma)
     702   0.00000000E+00  # BR(tau->e gamma)
     703   0.00000000E+00  # BR(tau->mu gamma)
     800   0.00000000E+00  # CR(mu-e, Al)
     801   0.00000000E+00  # CR(mu-e, Ti)
     802   0.00000000E+00  # CR(mu-e, Sr)
     803   0.00000000E+00  # CR(mu-e, Sb)
     804   0.00000000E+00  # CR(mu-e, Au)
     805   0.00000000E+00  # CR(mu-e, Pb)
     901   0.00000000E+00  # BR(mu->3e)
     902   0.00000000E+00  # BR(tau->3e)
     903   0.00000000E+00  # BR(tau->3mu)
     904   0.00000000E+00  # BR(tau- -> e- mu+ mu-)
     905   0.00000000E+00  # BR(tau- -> mu- e+ e-)
     906   0.00000000E+00  # BR(tau- -> e+ mu- mu-)
     907   0.00000000E+00  # BR(tau- -> mu+ e- e-)
    1001   0.00000000E+00  # BR(Z->e mu)
    1002   0.00000000E+00  # BR(Z->e tau)
    1003   0.00000000E+00  # BR(Z->mu tau)
    1101   0.00000000E+00  # BR(h->e mu)
    1102   0.00000000E+00  # BR(h->e tau)
    1103   0.00000000E+00  # BR(h->mu tau)
    2001   0.00000000E+00  # BR(tau->e pi)
    2002   0.00000000E+00  # BR(tau->e eta)
    2003   0.00000000E+00  # BR(tau->e eta')
    2004   0.00000000E+00  # BR(tau->mu pi)
    2005   0.00000000E+00  # BR(tau->mu eta)
    2006   0.00000000E+00  # BR(tau->mu eta')
Block FWCOEF Q= 1.60000000E+02 # Wilson coefficients at scale Q
 0305 4422 00 0  -0.18461786E-08  # coeffC7sm
 0305 4422 00 2  -0.16461786E-08  # coeffC7
 0305 4322 00 2  -0.37370803E-10  # coeffC7p
 0305 4422 00 1   0.00000000E+00  # coeffC7NP
 0305 4322 00 1  -0.37370803E-10  # coeffC7pNP
 0305 6421 00 0  -0.85476718E-08  # coeffC8sm
 0305 6421 00 2  -0.85476718E-08  # coeffC8
 0305 6421 00 2  -0.19386485E-10  # coeffC8p
 0305 6321 00 1   0.00000000E+00  # coeffC8NP
 0305 6321 00 1  -0.19386485E-10  # coeffC8pNP
 03051111 4133 00 0   0.16563545E-08  # coeffC9eeSM
 03051111 4133 00 2   0.16563545E-08  # coeffC9ee
 03051111 4133 00 2  -0.10163545E-08  # coeffC9eep
 03051111 4133 00 0   0.00000000E+00  # coeffC9Vee
```



```
Block FlavorKitLFV # lepton flavor violating observables
     701      0.00000000E+00   # BR(mu->e gamma)
     702      0.00000000E+00   # BR(tau->e gamma)
     703      0.00000000E+00   # BR(tau->mu gamma)
```

```
01050105 3232      00    0     0.00000000E+00    # coeffBB_SRRSM
01050105 3132      00    0     0.00000000E+00    # coeffBB_SLRSM
01050105 4141      00    0     0.00000000E+00    # coeffBB_VLLSM
01050105 4242      00    0     0.00000000E+00    # coeffBB_VRRSM
01050105 4142      00    0     0.00000000E+00    # coeffBB_VLRSM
01050105 4343      00    0     0.00000000E+00    # coeffBB_TLLSM
01050105 4444      00    0     0.00000000E+00    # coeffBB_TRRSM
03050305 3131      00    0     0.00000000E+00    # coeffBsBs_SLLSM
03050305 3232      00    0     0.00000000E+00    # coeffBsBs_SRRSM
03050305 3132      00    0     0.00000000E+00    # coeffBsBs_SLRSM
03050305 4141      00    0     0.00000000E+00    # coeffBsBs_VLLSM
03050305 4242      00    0     0.00000000E+00    # coeffBsBs_VRRSM
03050305 4142      00    0     0.00000000E+00    # coeffBsBs_VLRSM
03050305 4343      00    0     0.00000000E+00    # coeffBsBs_TLLSM
03050305 4444      00    0     0.00000000E+00    # coeffBsBs_TRRSM
Block TREELEVELUNITARITY #
       0    1.00000000E+00   # Tree-level unitarity limits fulfilled or not
       1    1.67207372E-02   # Maximal scattering eigenvalue
Block TREELEVELUNITARITYwTRILINEARS #
       0    1.00000000E+00   # Tree-level unitarity limits fulfilled or not
       1    1.61576897E-02   # Maximal scattering eigenvalue
       2    2.00000000E+03   # best scattering energy
      11    1.00000000E+03   # min scattering energy
      12    2.00000000E+03   # max scattering energy
      13    5.00000000E+00   # steps
DECAY         4    3.82261015E-13   # Fu_2
#     BR                NDA      ID1      ID2
#     BR                NDA      ID1      ID2       ID3
      3.05502575E-02     3        2       -1        1   # BR(Fu_2 -> Fu_1 Fd_1^* Fd_1 )
      5.45954987E-01     3        2       -1        3   # BR(Fu_2 -> Fu_1 Fd_1^* Fd_2 )
      1.56486313E-03     3        2       -3        1   # BR(Fu_2 -> Fu_1 Fd_2^* Fd_1 )
      2.79270154E-02     3        2       -3        3   # BR(Fu_2 -> Fu_1 Fd_2^* Fd_2 )
      1.07295183E-02     3        1      -11       12   # BR(Fu_2 -> Fd_1 Fe_1^* Fv_1 )
      1.01645236E-02     3        1      -13       14   # BR(Fu_2 -> Fd_1 Fe_2^* Fv_2 )
      1.91744771E-01     3        3      -11       12   # BR(Fu_2 -> Fd_2 Fe_1^* Fv_1 )
      1.81364064E-01     3        3      -13       14   # BR(Fu_2 -> Fd_2 Fe_2^* Fv_2 )
DECAY         6    1.55526925E+00   # Fu_3
#     BR                NDA      ID1      ID2
      1.67597777E-03     2        3       24   # BR(Fu_3 -> Fd_2 VWp )
      9.98288583E-01     2        5       24   # BR(Fu_3 -> Fd_3 VWp )
```

```
      2.15252618E-03   3          2        -12       11   # BR(Fd_3 -> Fu_1 Fv_1^* Fe_1 )
      2.14490780E-03   3          2        -14       13   # BR(Fd_3 -> Fu_1 Fv_2^* Fe_2 )
      5.83957751E-04   3          2        -16       15   # BR(Fd_3 -> Fu_1 Fv_3^* Fe_3 )
      1.59069889E-01   3          4        -12       11   # BR(Fd_3 -> Fu_2 Fv_1^* Fe_1 )
      1.58104211E-01   3          4        -14       13   # BR(Fd_3 -> Fu_2 Fv_2^* Fe_2 )
      1.96896118E-02   3          4        -16       15   # BR(Fd_3 -> Fu_2 Fv_3^* Fe_3 )
DECAY         25   6.42252863E-03   # hh
#         BR        NDA      ID1       ID2
      1.93338706E-03   2         22        22   # BR(hh -> VP VP )
      5.96211424E-02   2         21        21   # BR(hh -> VG VG )
      2.82490956E-02   2         23        23   # BR(hh -> VZ VZ )
      2.33261695E-01   2        -24        24   # BR(hh -> VWp^* VWp_virt )
      1.33790716E-04   2         -3         3   # BR(hh -> Fd_2^* Fd_2 )
      3.58433068E-01   2         -5         5   # BR(hh -> Fd_3^* Fd_3 )
      1.45065926E-04   2        -13        13   # BR(hh -> Fe_2^* Fe_2 )
      4.18774507E-02   2        -15        15   # BR(hh -> Fe_3^* Fe_3 )
      1.68995783E-02   2         -4         4   # BR(hh -> Fu_2^* Fu_2 )
      2.59445280E-01   2    6666635   6666635   # BR(hh -> ss ss )
```

$$\mathrm{BR}(h \to S\,S) = 26\%$$

```
DECAY1L        4   1.11448989E-23   # Fu_2
#         BR        NDA      ID1       ID2
      9.80578882E-01   2          2        21   # BR(Fu_2 -> Fu_1 VG )
      1.94211179E-02   2          2        22   # BR(Fu_2 -> Fu_1 VP )
DECAY1L        6   1.40218346E+00   # Fu_3
#         BR        NDA      ID1       ID2
      1.67434891E-03   2          3        24   # BR(Fu_3 -> Fd_2 VWp )
      9.98290247E-01   2          5        24   # BR(Fu_3 -> Fd_3 VWp )
DECAY1L        3   1.38160366E-20   # Fd_2
#         BR        NDA      ID1       ID2
      9.93677595E-01   2          1        21   # BR(Fd_2 -> Fd_1 VG )
      6.32240539E-03   2          1        22   # BR(Fd_2 -> Fd_1 VP )
DECAY1L        5   4.50364203E-14   # Fd_3
#         BR        NDA      ID1       ID2
      2.05693613E-02   2          1        21   # BR(Fd_3 -> Fd_1 VG )
      9.74708472E-01   2          3        21   # BR(Fd_3 -> Fd_2 VG )
      4.62332156E-03   2          3        22   # BR(Fd_3 -> Fd_2 VP )
DECAY1L       25   8.26580363E-03   # hh
#         BR        NDA      ID1       ID2
      3.55304437E-04   2         -3         3   # BR(hh -> Fd_2^* Fd_2 )
      6.75629528E-01   2         -5         5   # BR(hh -> Fd_3^* Fd_3 )
      1.19436199E-04   2        -13        13   # BR(hh -> Fe_2^* Fe_2 )
```

```
micromegas/SSDM/CalcOmega_with_DDetection_MOv5 SPheno.spc.SSDM
```

```
Masses of odd sector Particles:
~Ss  : MSs   =   28.4 ||
PROCESS: ~Ss,~Ss->AllEven,1*x{h,g,A,Z,Wp,Wm,nu1,Nu1,nu2,Nu2,nu3,Nu3,d1,D1,d2,D2,d3,D3,u1,U1,u2,U2,u3,U3,e1,E1,e2,E2,e3,
     E3
Xf=1.64e+01 Omega h^2=2.28e+01

# Channels which contribute to 1/(omega) more than 1%.
# Relative contributions in % are displayed
   85% ~Ss ~Ss ->d3 D3
    8% ~Ss ~Ss ->e3 E3
    4% ~Ss ~Ss ->u2 U2
    2% ~Ss ~Ss ->g g

==== Calculation of CDM-nucleons amplitudes  =====
         TREE LEVEL
PROCESS: QUARKS,~Ss->QUARKS,~Ss{d1,D1,d2,D2,d3,D3,u1,U1,u2,U2,u3,U3
Delete diagrams with _S0_!=1,_V5_,A
....
CDM-nucleon cross sections[pb]:
 proton  SI 2.407E-09  SD 0.000E+00
 neutron SI 2.471E-09  SD 0.000E+00

======== Direct Detection ========
73Ge: Total number of events=1.29E-03 /day/kg
Number of events in 10 - 50 KeV region=4.19E-04 /day/kg
131Xe: Total number of events=2.66E-03 /day/kg
```

Dirac neutrino masses
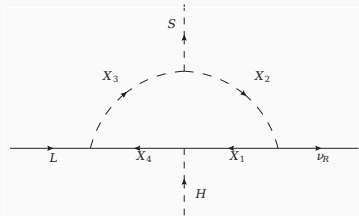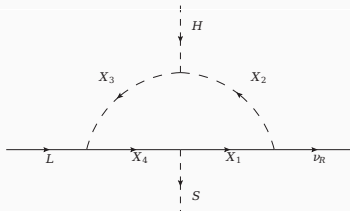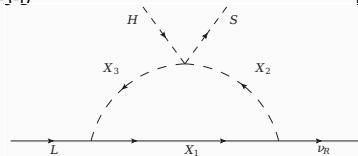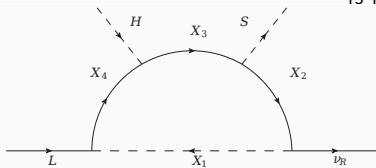
Chang-Yuan Yao and Gui-Jun Ding, arXiv:1802.05231 [PRD]
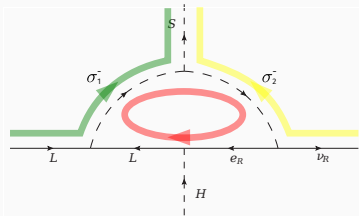
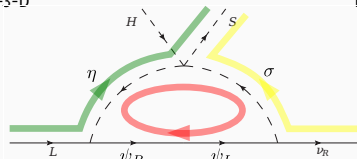T1-3-D
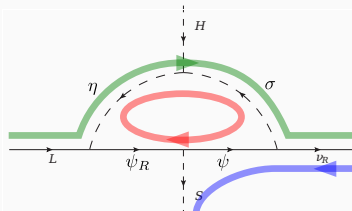
T1-3-E

T3-1-A

T1-2-A

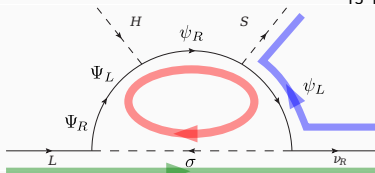T1-2-B

$\psi_{L,R} \rightarrow$ Singlet fermions

$\Psi_{L,R} \rightarrow$ Vector-like doublet fermions
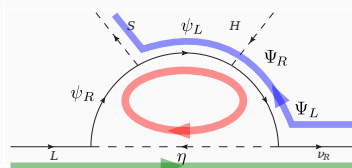
$\sigma \rightarrow$ Singlet scalar

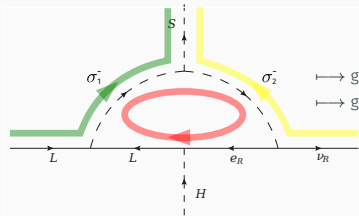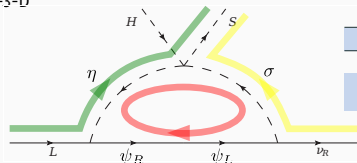with J. Calle, C. Yaguna, and O. Zapata, arXiv:1812.05523 [PRD]

$\longmapsto$ generalization to two and three loops: S. Saad arXiv:1902.07259 [NPB]

$\longmapsto$ generalization to U(1)$_R$: *et al*, S. Saad arXiv:1904.07407

T1-3-D

$\psi_{L,R} \rightarrow$ Singlet fermions (vector-like)

$\sigma \rightarrow$ Singlet scalar

T3-1-A

Fields: f_i	$(\nu_{R3})^\dagger$	$(\nu_{R2})^\dagger$	$(\nu_{R1})^\dagger$	ψ_L	$(\psi_R)^\dagger$	S
(A)	+4	+4	−5	−r	r	+3

Anomaly cancellation conditions

$$\sum_i f_i = 3$$

$$\sum_i f_i^3 = 3$$

21

SARAH implementation

```
cp -r BSM/SARAH/Models/B-L/ SARAH/Models/
math << EOF
<<./SARAH/SARAH.m
Start["B-L/DZ"]
MakeSPheno[]
EOF
```

```
cp -r SARAH/Output/B-L-DZ/EWSB/SPheno SPheno/BLDZ
cd SPheno
make Model=BLDZ
cd .. # Return to parent directory
```

```
cp -r SARAH/Output/BLDZ/EWSB/SPheno SPheno/BLDZ
cd SPheno
make Model=BLDZ # Be sure that Makefile use gfortran!
cd .. # Return to parent directory
```

```
cp SPheno/SSDM/Input_Files/LesHouches.in.BLDZ .
```

```
SPheno/bin/SPhenoBLDZ   LesHouches.in.BLDZ
```

EXTRA

2nd Chuck Norris fact of the day

Chuck Norris can run collider simulations with MadGraph on an abacus