SARAH 3: Spectrum-Generator-Generator and more

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SARAH [FS,0806.0538,0909.2863,1002.0840,1207.0906]

Mathematica package to obtain many information about a (SUSY) model based on a straightforward and minimal input. Output of CalcHep, WHIZARD, FeynArts and UFO models files.

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Widely used SUSY spectrum generator written in Fortran which also calculates decays, e^+e^- cross sections and precision observables.

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SPheno	SARAH
Restricted mostly to MSSM	Supports many models
RGEs, vertices, ... hardcoded	Calculates everything by its own
Routines for loop integrals, phase space,...	Nothing like that
Numerically fast (Fortran)	Numerically slow (Mathematica)

Combining SARAH and SPheno

'Spectrum Generator Generator'

SARAH writes source-code using the obtained information about a model which can be compiled with SPheno.

→ Implementation of new models in SPheno in a modular way without the need to write any line of source code by hand.

SPheno properties (boundary conditions, free parameter, etc.) easily defined inside SARAH.

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```
[1] <<$SARAH/SARAH.m;
[2] Start["B-L-SSM"];
[3] MakeSPheno[];

> mkdir $SPheno/BLSSM/
> cp $SARAH/Output/B-L-SSM/EWSB/SPheno/* $SPheno/BLSSM/
> cd $SPheno
```

Precise Mass Spectrum Calculation

2-loop Renormalization Group Equations

Full CP and flavor structure [Martin,Vaughn,hep-ph/9311340]

+ Support of kinetic mixing [Fonseca,Malinsky,Porod,FS,1107.2670]

+ Support of Dirac Gauginos [Goodsell,1206.6697]

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Loop corrected Mass Spectrum

- All masses at 1-loop ($\overline{\text{DR}}$-scheme, 't Hooft gauge, p^2 dependence) [Pierce,Bagger,Matchev,Zhang,hep-ph/9606211]
- MSSM 2-loop parts can be linked [Brignole,Degrassi,Dedes,Slavich,Zwirner]

Decay widths and branching ratios

SUSY / Heavy Gauge Boson Decays

- All 2-body decays of sfermions, fermions and vector bosons
- 3-body decays of fermions into three fermions

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Higgs decays

- All 2-body decays into SUSY particles and leptons at tree-level
- 2-body decays into quarks with gluonic NLO corrections
- 2-body decays in real and virtual vector boson included
- Loop induced decays in two photons and gluons including any possible contribution for given model

Precision observables

SARAH creates routines to calculate observables for given model

→ precision comparable with standard SPheno routines for MSSM

Lepton Flavor violating observables

- $l_i \to l_j \gamma$
- $l_i \to 3 l_j$
- μ–e conversion in nuclei
- $Z \to l_i l_j$
- $\tau \to l P^0$ (P^0: π, η, η')

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Other observables

- $\delta\rho$
- $g-2$
- Electric-dipole moments

* [Dreiner,Nickel,Porod,FS,1212.5074]

Other features

SPheno + HiggsBounds

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SPheno + MC tools

- SPheno spectrum files can be directly used with models for CalcHep (and MicrOmegas), MadGraph (UFO format)
- SPheno writes additional input file for WHIZARD

The implementation in SPheno as well as in CalcHep, WHIZARD or MadGraph are based on one implementation in SARAH

→ Spectrum calculator and Monte Carlo tool uses for sure the same conventions

Is this machinery really necessary?

- Kinetic mixing is not necessarily a tiny effect: it can shift the SM-like Higgs mass by several GeV [O'Leary,Porod,FS,1112.4600]
- ...and change the relic density by several orders [Basso,O'Leary,Porod,FS,1207.0507]
- Precise masses are needed: 1-loop Higgs masses can differ significantly from eff. potential approximations known so far for models with Dirac Gauginos [Benakli,Goodsell,FS,1211.0552]
- $\mathrm{BR}(\mu \to 3e) > \mathrm{BR}(\mu \to e\gamma)$ nearly possible in MSSM, but common feature in inverse seesaw or trilinear RpV [Hirsch,FS,Vicente,1202.1825]
- Charginos negligible for $h \to \gamma\gamma$ in MSSM, but they can play a crucial role in singlet extensions [Schmidt-Hoberg,FS,1208.1683]
- ...and could explain simultaneously the Fermi line [Schmidt-Hoberg,FS,Winkler,1211.2835]

SUSY Toolbox [FS,Ohl,Porod,Speckner,1109.5147]

. . . is a collection of scripts to create an environment including

- SARAH [FS,0806.0538],[FS,0909.2863],[FS,1002.0840]
- SPheno [Porod,hep-ph/0301101],[Porod,FS,1104.1573]
- WHIZARD [Kilian,Ohl,Reuter,0708.4233],[Moretti,Ohl,Reuter,0102195]
- HiggsBounds [Bechtle,Brein,Heinemeyer,Weiglein,Williams,1102.1898]
- MadGraph [Alwall et. al,1106.0522]
- CalcHep [Pukhov et. al,hep-ph/9908288
- MicrOmegas [Belanger,Boudjema,Pukhov,Semenov,hep-ph/0405253]
- SSP [FS,Ohl,Porod,Speckner,1109.5147]

and to implement new models into the other tools based on the implementation in SARAH.

http://projects.hepforge.org/sarah/Toolbox.html

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FS,Ohl,Porod,Speckner,1109.5147

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Using the SUSY-Toolbox all tools are downloaded, configured and installed just by:

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> ./configure
> make
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Afterwards, a model is implemented in all tools at once by:

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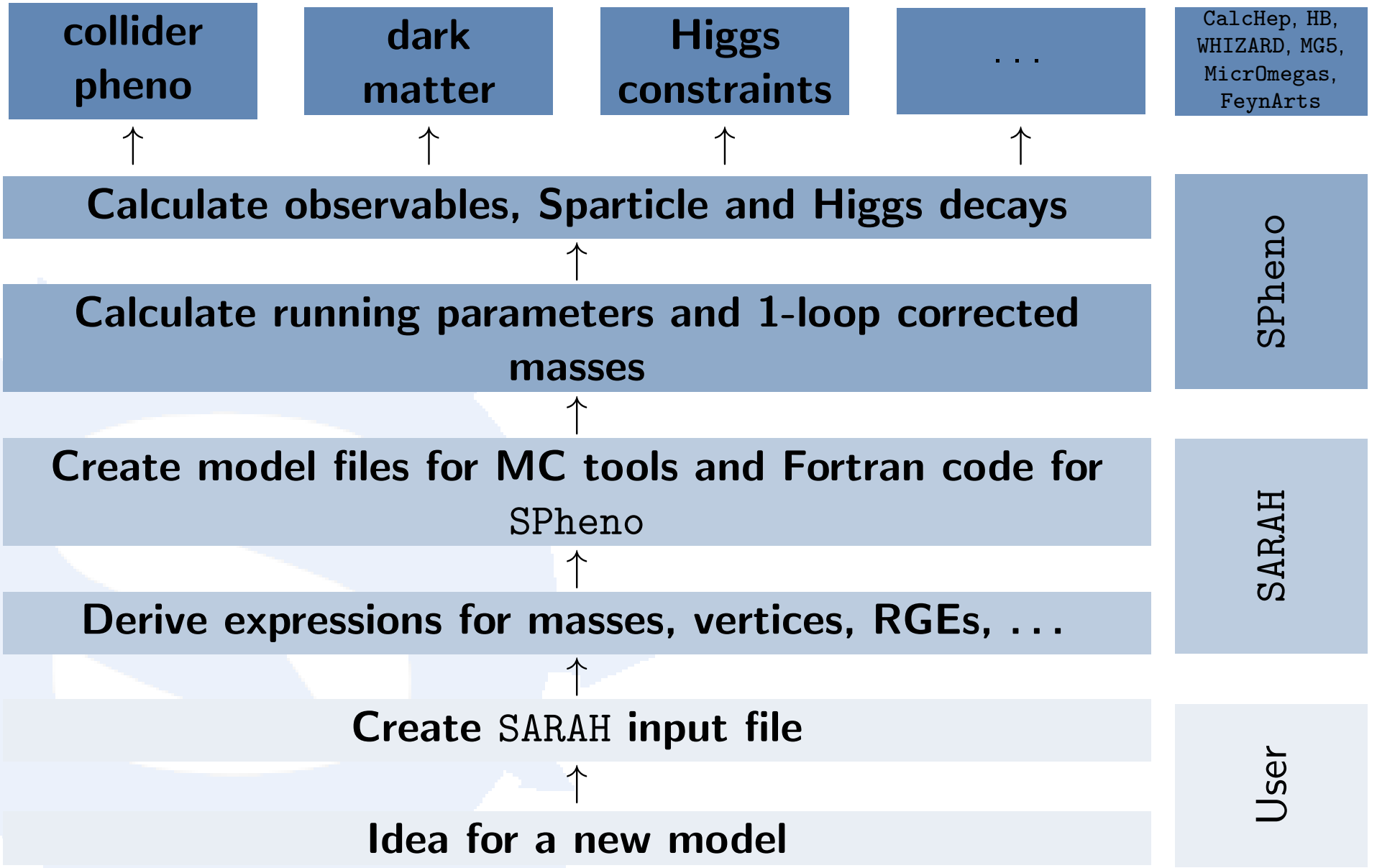
SSP uses the provided infrastructure to perform parameter scans


collider pheno
dark matter
Higgs constraints
. . .
CalcHep, HB, WHIZARD, MG5, MicrOmegas, FeynArts
Calculate observables, Sparticle and Higgs decays
Calculate running parameters and 1-loop corrected masses
SPheno
Create model files for MC tools and Fortran code for SPheno
Derive expressions for masses, vertices, RGEs, . . .
SARAH
Create SARAH input file
Idea for a new model
User

Summary

SARAH can create Fortran code for SPheno to obtain a full-fledged mass spectrum generator for a given model

- Precise mass calculation (2-loop RGEs, 1-loop corrections); potential effects from thresholds and kinetic mixing included
- Calculation of Sparticle and Higgs decays
- Calculation of several precision observables

The SUSY toolbox provides a fast and easy approach for an exhaustive study of MSSM extensions by creating an environment of powerful and well tested tools.

Outlook

Upcoming features for the SPheno output of SARAH

Short-term ($\mathcal{O}$(weeks))

- Check for global minimum of the 1-loop eff. potential [with Carmago,O'Leary,Porod; see also 1212.4146]
- 3-body scalar decays [with Mitzka,Porod]

Medium-term ($\mathcal{O}$(months))

- $\Delta M_{B_{s,d}}$, $b \to s l_i l_j$,... [with Dreiner,Nickel; Abada,Vicente,Weiland]
- Support of non-$SU(N)$ groups: linking Susyno [with Fonseca]
- Non-SUSY RGEs [with Lyonnet,Schienbein,Wingerter]

Long-term

- Let's see ...

→ Your input and suggestions are very welcome