Particle phenomenology with public tools

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Outline

Public tools

SARAH and related tools

Practical part

Spectrum Generators

Purpose

A spectrum generator calculates the mass spectrum of a SUSY model including (the most important) radiative corrections. Some tool make also predictions for decay widths and precision observables.

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- NMSSM: `NMSSMCALC`, `NMSSMTools`, `Next-to-minimal SoftSUSY`

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- NMSSM: `NMSSMCALC`, `NMSSMTools`, `Next-to-minimal SoftSUSY`

Main restriction

All information about a model is hardcoded and only very few models are supported.

Monte Carlo tools

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Models

MC tools are usually delivered with only very few models, but new models can be implemented via specific model files.

Tools for Feynman rules

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Generate model files with all Feynman rules to implement a new model in MC and other tools

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- FeynRules, LanHEP, SARAH

Features

The challenge in implementing new models, the supported output formats, and the range of other information derived by these tools is very different.

Tools for dark matter

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Models

While in `DarkSUSY` the MSSM is hardcoded, the other tools make use of `CalcHep`, `FeynArts` respectively `MadGraph` and can handle many models in principle.

Tools for other observables

Flavour tools

Predict rates of quark flavour violating observables ($b \to s\gamma$, $B_s \to l\bar{l}$, ΔM_{B_s}, ...) in the MSSM or NMSSM

- Superiso, Susy_Flavor

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Higgs tools

Check parameters points against Higgs searches at LEP, Tevatron and LHC.

- HiggsBounds, HiggsSignals

Other tools

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Susyno, Pyr@te

Calculate the two-loop RGEs for SUSY and non-SUSY models.

Main restrictions

Despite the large variety of tools, there are two main bottle necks in using them for non-minimal SUSY models:

- For MC tools, dark matter tools, FeynArts, . . . the corresponding model files are needed

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Both issues are addressed by SARAH.

SARAH and related tools

SARAH and supported models

SARAH

[FS,0806.0538,0909.2863,1002.0840,1207.0906,1309.7223,1503.04200]

SARAH is a Mathematica package to get from a minimal input all important properties of SUSY and non-SUSY models. Models are defined by

- gauge & global symmetries
- particle content
- (super)potential
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- Gauge kinetic mixing fully supported
- An arbitrary number of matter states is possible
- All irreducible representations are supported

Analytical information derived by SARAH

Calculated Lagrangian

- SARAH derives all gauge and matter interactions
- The gauge fixing terms and ghost interactions are added
- For SUSY models, the soft-breaking terms are added
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- Expressions for loop-diagrams

The analytical expressions derived by SARAH can be exported:

Model files for Monte Carlo Tools

- CalcHep/CompHep (can be used with MicrOmegas) [Pukhov et al.],[Boos et al.],[Belanger et al.]
- WHIZARD [Kilian,Ohl,Reuter,0708.4233],[Moretti,Ohl,Reuter,0102195]
- MadGraph & Herwig++ via UFO [Alwall et al.,1106.0522], [Bellm et al.,1310.6877]

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Interface to other tools

- FeynArts/FormCalc [Hahn,hep-ph/0012260],[Hahn,Victoria,hep-ph/9807565]
- Vevacious [Camargo-Molina,O'Leary,Porod,FS,1307.1477]

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Spectrum generators:

- SPheno [Porod,hep-ph/0301101],[Porod,FS,1104.1573]
- Third-party interface to C++ code: FlexibleSUSY [Athron, Park, Stöckinger, Voigt, 1406.2319; flexiblesusy.hepforge.org]

Linking SARAH and SPheno

Status before 2011

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)

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→ A combination of both looked very promising

SARAH and SPheno

'Spectrum Generator Generator'

SARAH writes source-code which can be compiled with SPheno.

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

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Necessary steps:

1. Load Model in SARAH
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Running time and lines of SPheno code:

- MSSM: ∼8min, ∼280k lines
- NMSSM: ∼10min, ∼330k lines
- B-L-SSM: ∼35min, ∼550k lines

Features

The generated SPheno version provides all features of state-of-the-art spectrum generator for any model

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Features of 'SPheno by SARAH' versions

- Full 2-loop running of all parameters and all masses at 1-loop
- Complete 1-loop thresholds at M_Z
- two-loop corrections to Higgs masses
- calculation of flavour and precision observables
- calculation of decay widths and branching ratios
- interface to HiggsBounds and HiggsSignals
- estimate of electroweak Fine-Tuning

collider pheno	dark matter	Higgs constraints	Vacuum stability	CalcHep, HB, WHIZARD, MG5, MicrOmegas, Vevacious
↑	↑	↑	↑	

Flavour observables, Sparticle and Higgs decays

↑

Calculate running parameters, SUSY masses at one-loop, Higgs masses at two-loop, Fine-Tuning

(SPheno)

↑

Create model files for MC tools & Vevacious as well as Fortran code for SPheno

↑

Derive expressions for masses, vertices, RGEs, ...

(SARAH)

↑

Create SARAH input file

↑

Idea for a new model

(User)

Practical part

First lecture, 21.10.

Working with SARAH

- Changing the Implementation of a model:

$$W = \cdots + \mu H_u H_d \quad \to \quad W = \cdots + (\lambda S + \mu) H_u H_d + t_S S + \mu_S S^2 + \kappa S^3$$

- Playing with the new model
  - Checking mass matrices and tadpole equation
  - Calculating vertices
  - Calculating RGEs
  - Generating LaTeX files

Homework

To be prepared for the second lecture, generate the output for the SMSSM in SARAH

Run in Mathematica

```
<<[PATH]/SARAH.m
Start["SMSSM"];
MakeAll[];
```

. . . and wait for 15–20min until SARAH is finished.

In the case of problems, you can also download the output and some additional material from

http://flstaub.web.cern.ch/flstaub/GGI_2015.tar.gz

Second lecture, 23.10.

Using the SARAH output with other tools

- Spectrum calculation with SPheno
- Checking Higgs constraints with HiggsBounds, HiggsSignals
- Calculating the dark matter relic density with MicrOmegas
- Generating events with MadGraph

Second lecture, 23.10.

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If you want to run the examples by your own, please, download and compile the tools before the lecuture:

- SPheno (spheno.hepforge.org): unpack and make
- HB/HS (higgsbounds.hepforge.org): unpack, configure and make
- MO (lapth.in2p3.fr/micromegas): unpack and make
- MG (launchpad.net/mg5amcnlo): unpack