Non-Minimal SUSY — Computation of observables and fit to experimental data

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Outline

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1. Introduction
2. Motivation
3. Discuss research plan

- This is not a normal talk
- Start with motivating non-minimal SUSY
- Then outline our research plans
- Aim: discuss what is necessary/possible, how should we proceed to make utmost use of `Fittino`, should `Fittino` be changed somehow, should we provide interfaces?

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- Minimality was never an argument! These motivations hold equally well in minimal and non-minimal SUSY!

Why is it difficult to realize SUSY at the EW scale?

- No spontaneous SUSY breaking possible at EW scale
- Need hidden sector, leads to explicit (soft) SUSY breaking
- Many parameters, in general too much Flavour- and CP-violation
- Need organizing principles/assumptions such as mSugra
- Typically, some discrete symmetry needed to prevent rapid proton decay

Properties/problems of the MSSM

- Minimal particle content $\rightarrow$ nevertheless extra Higgs dublet predicted
- μ-problem
  - $\mu H_u H_d$=dimensionful parameter in superpotential
  - unrelated to SUSY breaking — why should μ be $\mathcal{O}$(TeV)?
  - however, this is necessary for phenomenology
- lightest Higgs mass predicted, but very (too?) small
- little hierarchy problem?

Non-minimal SUSY models

- Should improve the μ-problem and/or other properties
- Possibilities
  - More Higgs fields
  - More matter fields
  - More gauge fields — larger gauge group

Examples

- NMSSM, E_6SSM, USSM, MSSM+Z',...

Non-minimal SUSY models and grand unification

Assume grand unification with SU(5) or larger group

- Matter should comprise complete SU(5) multiplets
  - known quarks and leptons do that — new exotic matter should consist of new full multiplets
  - gauge coupling unification is not affected by the new exotic matter (and its mass scale)
- Higgs fields should comprise complete SU(5) multiplets
  - two MSSM Higgs doublets don't do that — new Higgs fields must also comprise incomplete multiplets
  - gauge coupling unification depends on the mass of the extra Higgs fields — generally:
  - either incomplete multiplets at the TeV scale or no gauge coupling unification

Conclusion

- We have no single, “completely nice” realisation of TeV-scale SUSY
- Experiment needs to guide us!
- We should remain as open as possible on how SUSY is realized
- There could be manifestations of non-minimal SUSY at the TeV-scale:
  - new exotic matter/Higgs fields, which might or might not for complete SU(5) multiplets
  - new gauge bosons
  - these are not just a bunch of new particles but they satisfy SUSY relations for masses, quantum numbers and interactions!
- Need to identify how/which SUSY model is realized
- $\Rightarrow$ learn about the mechanism of EWSB
- potentially learn about GUT scale physics and the mechanism of SUSY breaking

Outline

Questions and Goals

1. If the LHC experiments find manifestations of SUSY, how can we make sure whether SUSY is realized in the minimal or a non-minimal version?
2. How can we identify which — if any — non-minimal SUSY model is realized in Nature?
3. Assuming a specific model such as the E_6SSM is realized, how can we measure the appropriate model parameters?

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General goals:

- Answer these questions!
- Ideal situation:
  - automatically generate Feynman rules, calculate all observables in all competing models
  - automatically generate calculator libraries which are linked to `Fittino`
  - `Fittino` scans over model space and finds best fit points for each model and finds the best fitting model!

General tasks in detail

1. compute observables in competing non-minimal models
   - either for each model, derive Feynman rules, figure out which observables are interesting and compute them
   - or, ideally: Feynman rule generator, automatic observable calculator which outputs a library with well-defined interface
2. fit to experimental data using `Fittino`
   - either for each model, define interface and write dedicated `Fittino` version
   - or, ideally: automatic generation of `Fittino` version for all models, `Fittino` might even be able to carry out fits over model space

Our Dresden plans — Fittino viewpoint

Peter Athron, Alexander Voigt, DS + Xavier Prudent + ???

	Masses	EWPO & LE	LHC	model-file generator	Fittino
E_6SSM	1A	1B	1C	3A	4A
SUSY Z'	2A		2B	3A	4B
general	3B			3A	4C

- Provide necessary tools, computations, analyses
- start with E_6SSM, then generalize
- technical subgoal: complete and coherent framework that allows to easily test and compare different SUSY models to data.

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- Provide necessary tools, computations, analyses
- start with E_6SSM, then generalize
- technical subgoal: complete and coherent framework that allows to easily test and compare different SUSY models to data.
- Ultimately: link code libraries to `Fittino`, use this extended framework for coherent tests of SUSY models, to test different models in parallel, discriminate between them, and to determine model parameters within each candidate model.

Individual steps

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- Precise mass spectrum
  - additional, exotic states, spectrum of MSSM-particles altered (light gluino)
  - cE_6SSM vs CMSSM: different high-scale input: no m_0, $m_{1/2}$! (reason: μ, $B\mu$ not independent!) $\to$ technical obstacle for spectrum generator
  - currently, 2L RGE, 1L threshold corrections, but no 1L pole masses
  - what precision should we aim for? $\mathcal{O}$(10 GeV) needed/feasible?

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- EWPO and low-energy observables
  - contributions to μ-decay, M_W, etc could be significant (two sources: exotic matter and Z') — unknown
  - $g-2$ probably small — check
  - public code for these observables useful?

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- LHC production and decay observables in the E_6SSM
  - NB: different mass hierarchies compared to MSSM
  - idea: library that coherently predicts all relevant production/decay patterns (not the same precision as e.g. Prospino possible — sufficient?) Which observables are most important?
  - automatic Feynman rule generator would be very handy

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- General Z' models:
  - MSSM plus extra U(1) gauge group $\to Z'$ and $\tilde{Z}'$ (extra neutralino), Z' mass $\mathcal{O}$(TeV)
  - e.g USSM: extra U(1) and extra Higgs singlet $\to$ no μ-problem
  - unspecified Z' couplings, unspecified extra matter

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- Suppose, a Z' exists and is found at LHC
- then, we need new tools to study SUSY Z' models
  - Z' effects (D-terms) in mass spectrum computation
  - Z' effects in EWPOs
  - goal: library that predicts the Z' mass and other observables, *corrected for effects from the Z' and its superpartner* as function of Z' charges and other SUSY parameters — feasible/required interface?

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- General non-minimal models
  - highly automated framework where all relevant observables are computed fast and to low-order precision
  - sufficient for a comparison of different models to experimental data (?)
  - automatic generation of Feynman rules, computation of mass eigenvalues, mixing angles, etc
  - automatic generation of RGEs, spectrum generator
  - need to define format for models, parameters, particles, etc
  - automatic computation of observables (NB M_h very model-dependent)

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- Interface to `Fittino` and global analyses of SUSY models
  - coherent and complete tests of general supersymmetric models
  - test/falsify/discriminate between different models and determine model parameters

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- General Fittino requirements
  - different/more model parameters than in MSSM possible? (develop interface with Xavier?)
  - non-MSSM observables need to be usable
  - "first-step" tree-level approx. required?
  - speed — how critical?

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- Fittino usage:
  - E_6 version: regular global E_6SSM analyses
  - Z' version: regular global Z' analyses
  - general: regular global analyses of general SUSY models
- $\Rightarrow$ find out how SUSY is realized!