SPA

SUPERSYMMETRY PARAMETER ANALYSIS

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http://spa.desy.de/spa/

IF SUSY exists, and no new strong interactions in the TeV range

⇒ LHC + ILC will see Higgs particle(s) and establish their connection with EWSB

⇒ LHC + ILC will [likely] see SUSY partners and establish their connection with Higgs particles

Everybody will be happy?

We may have learned: Electroweak symmetry breaking is a consequence of supersymmetry breaking

These facts, by themselves, do NOT tell us very much about the relation of the visible world to the fundamental theory!

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What is the origin of SUSY breaking?

What is the role of neutrinos in this game?

How do symmetries look like in the fundamental theory?

What is the theory relevant for the early universe?

Where should we look for the embedding of gravity?

For all these questions, we probably won't have any direct experimental access, neither underground, nor on earth, nor or in space.

BUT: We can look for traces left in the nature of particles and their interactions. We can analyze data with respect to some particular well-defined SUSY/GUT/breaking model and state how well, in this framework, the relation of observable to fundamental physics can be established.

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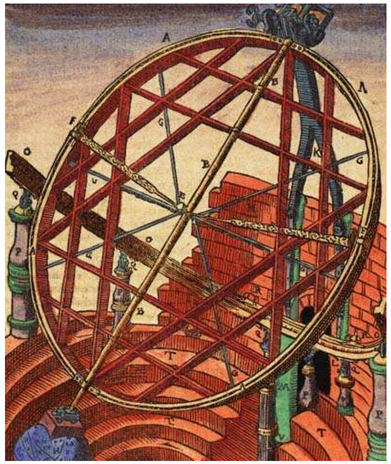
Remember Tycho Brahe: A whole lifetime he measured the positions and motion of planets in the solar system, with the best achievable machinery of his time, and determined parameters of his epicycle theory. These very data allowed his assistant, Johannes Kepler, to set up and finally establish the actual theory of elliptic planetary motion.



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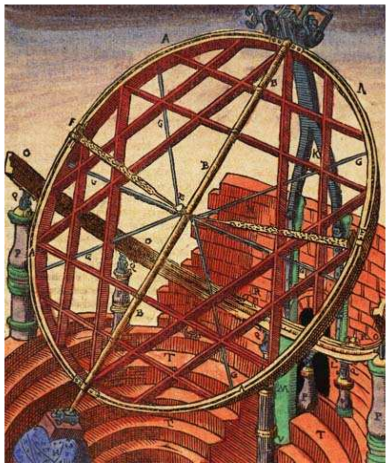

Due to severe cuts in funding after a change in government, Tycho had to move to a different region in order to continue his research.

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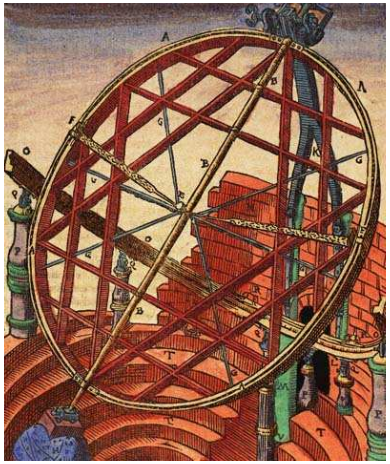

So, let us set up models of SUSY (epicycles?) and show that we can validate them with real data. Without that, Kepler will be unable to start his work.

The SPA project is exactly that:

- Define a framework and machinery for precision SUSY analyses
- Express this in a common language
- Set up testbed models

  . . . and their epicycles

- Find the strong and weak points in validating them with data, improve things where necessary, and use this to establish the relation to the fundamental theory

Status of today: These issues have been ordered, written up and edited. The document has assumed his final form and will be published soon. See the website: http://spa.desy.de/spa/

More than a single 'astronomer' is involved:

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The SPA Convention

The minimal model is the MSSM, properly renormalized (of course). The proposal:

SPA CONVENTION

- The masses of the SUSY particles and Higgs bosons are defined as pole masses.
- All SUSY Lagrangian parameters, mass parameters and couplings, including $\tan\beta$, are given in the $\overline{\rm DR}$ scheme and defined at the scale $\tilde{M} = 1$ TeV.
- Gaugino/higgsino and scalar mass matrices, rotation matrices and the corresponding angles are defined in the $\overline{\rm DR}$ scheme at $\tilde{M}$, except for the Higgs system in which the mixing matrix is defined in the on-shell scheme, the scale parameter chosen as the light Higgs mass.
- The Standard Model input parameters of the gauge sector are chosen as G_F, α, M_Z and $\alpha_s^{\overline{\rm MS}}(M_Z)$. All lepton masses are defined on-shell. The t quark mass is defined on-shell; the b, c quark masses are introduced in $\overline{\rm MS}$ at the scale of the masses themselves while taken at a renormalization scale of 2 GeV for the light u, d, s quarks.
- Decay widths/branching ratios and production cross sections are calculated for the set of parameters specified above.

SUPERSYMMETRY PARAMETER ANALYSIS

The SPA Repository

Nowadays, real physics is done by computer. All tasks related to the SPA project involve computer programs. Therefore, we set up a program repository at `http://spa.desy.de/spa/`:

1. Scheme Translation Tools: Part of many programs, but standalone version useful (coming soon)
2. Spectrum Calculators: From the $\overline{\mathrm{DR}}$ Lagrangian parameters at 1 TeV to the pole masses
3. Calculation of Other Observables:
   (a) Decay Tables: Obviously useful
   (b) Cross Sections: ditto
   (c) Low-Energy Observables: Whatever depends on SUSY, e.g., $b \to s\gamma$, $B_s \to \mu\nu$, $g_\mu - 2$
   (d) Cosmological and Astrophysical Aspects: Dark Matter and more
4. Event Generators: The real stuff.
5. Analysis Programs: Relate data to Lagrangian parameters (No, not the whole ATLAS software!)
6. RGE Programs: Relate Lagrangian parameters to a model for the fundamental theory
7. Auxiliary Programs and Libraries

Some Remarks:

- The repository contains links, not programs.
- Many programs appear in more than one category. Desirable: break them down into exchangeable modules!
- Language for interchanging common data: SUSY Les Houches Accord (SLHA). All program authors are encouraged to support this standard for input and output, as far as applicable.
- No need for a common programming language. SLHA is a file-based data transfer standard.
- The repository is not static, but will be updated as needed.
  (Mail to `wolfgang.kilian@desy.de`)
- Transparencies of talks related to the SPA project (i.e., meetings) also linked

Scheme Translation

SUSY renormalization schemes:

1. On-shell: Useful for phenomenology, but obscures scale dependence
2. $\overline{\rm MS}$: Straightforward, but breaks SUSY. α_s and PDFs are known in $\overline{\rm MS}$.
3. $\overline{\rm DR}$: Compatible with SUSY, but mathematical consistency used to be questionable.
   - ⇒ Proof by D. Stöckinger 2005: $\overline{\rm DR}$ regularization can be formulated in a mathematically consistent way.
   - ⇒ Factorization (i.e., PDFs) can also be consistently formulated in $\overline{\rm DR}$ [Signer, Stöckinger 2005].

SPA: $\overline{\rm DR}$ input provided by SLHA input file. Scale $1\,\rm TeV$ avoids (most) problems with thresholds.

Program repository: Contains library for computing $\overline{\rm MS}$ / OS parameters from SLHA=$\overline{\rm DR}$ input (not yet, but coming soon!)

Observables

SPA aims at a common language for quoting decay widths, cross section, and such.

Decay widths: That's easy: just be completely inclusive.

(Caveat: the notion of a decay width is useful only for factorized production-decay approximations. Not necessarily applicable for precision analyses!)

Cross sections at ILC: Radiative corrections are always large — yes, but mainly due to universal QED corrections.

To be honest: omit all universal effects, so don't include the leading $\log \Delta E/s$ and $\log s/m_f^2$ when quoting/plotting cross sections. Don't include higher-order ISR or beamstrahlung.

(Caveat: applies to the definition of 'cross section'. Don't do that for actual simulations, of course.)

Cross sections at LHC: Less clear, and probably less relevant. Include QCD radiations as far as available, and be as inclusive as possible.

(Caveat: in reality, this has to be sorted out. In particular, results depend on chosen PDF set and errors.)

Tasks

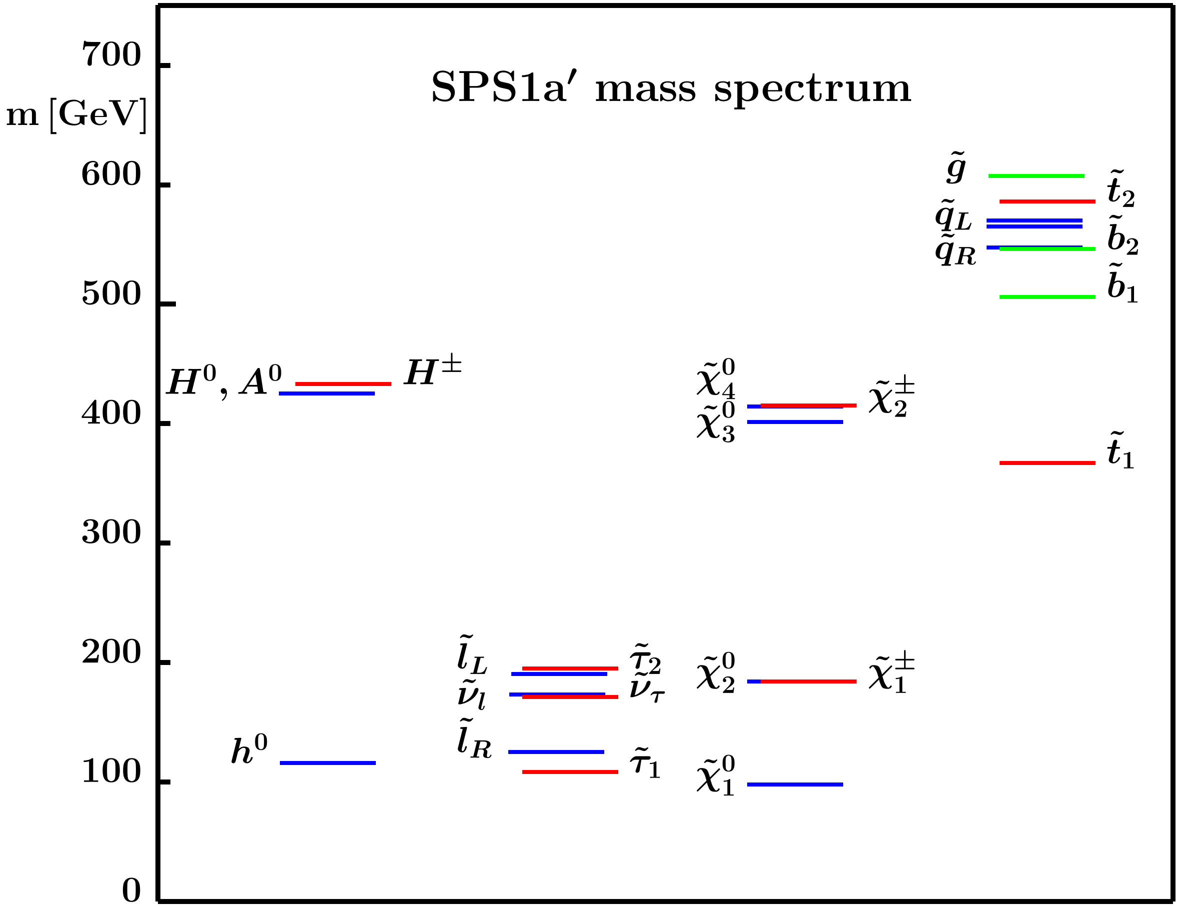
We are not at the end, we are at (actually, before) the beginning of SUSY analyses:

- NLO corrections (and more): Without improvements, no firm conclusions on fundamental parameters possible, and the achievable experimental precision at ILC has limited value.
- $\overline{\mathrm{DR}}$ at higher orders
- Improve the analyses themselves, and identify neglected possibilities. Requires cooperation of theory and experiment, and common language.
- Coherent LHC and ILC analyses.
- Determining SUSY Lagrangian parameters. Reverse the order of calculation!
- Cold Dark Matter. Understanding the SUSY Lagrangian gives a meaning to astrophysical data.
- Extended SUSY scenarios: the epicycles. Don't stick with plain circles (mSUGRA)?!

SPA should provide a platform to discuss these issues and encourage further work.

SPS 1a'

The testbed: SPS 1a' — a mSUGRA scenario.



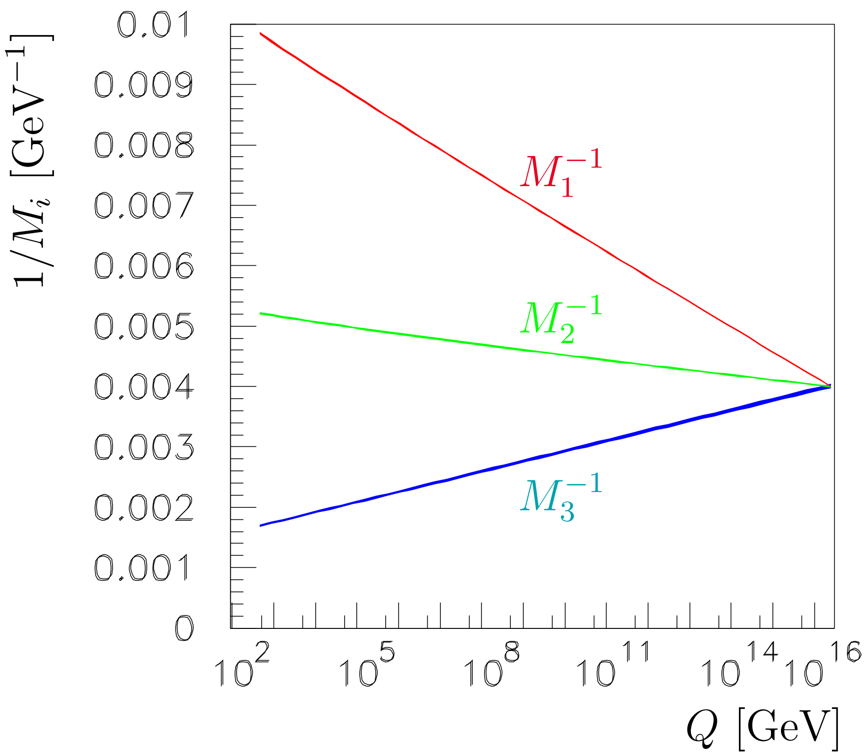
ILC friendly:

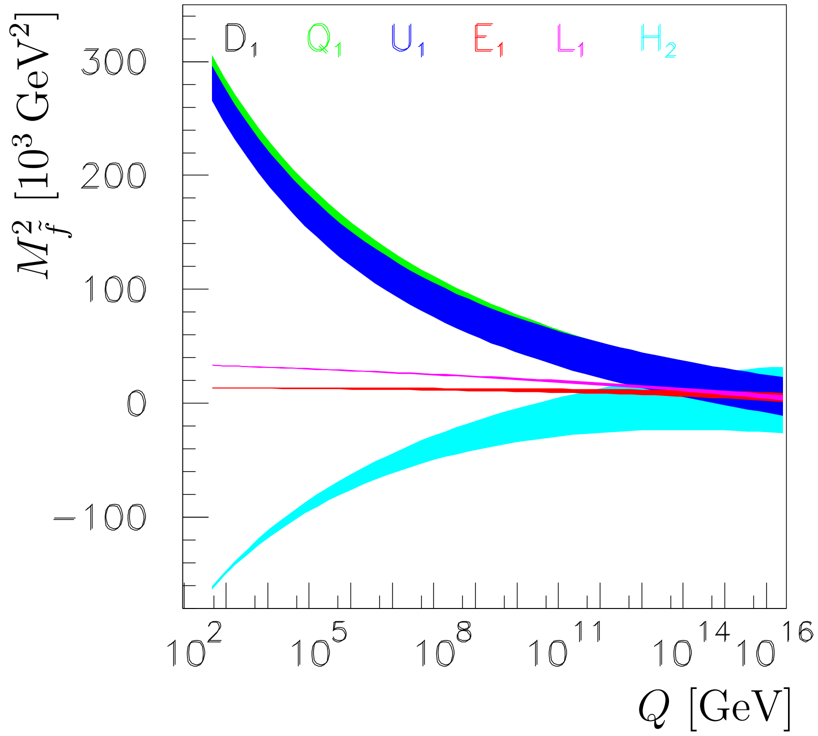
+ All Higgses and charginos within reach (at $1\ \mathrm{TeV}$)
+ Light sleptons
+ Squarks not hopeless ($\tilde{t}$)

LHC friendly:

+ Decay chains end in leptons (τs, in particular)

Extrapolation





Read the fine print!

. . . theoretical errors are assumed to be reduced to the same size [as the experimental errors] in the future.

This is just one particular example (where things are quite favorable).

Conclusions

Quippe mihi non multo minus admirandae videntur occasiones, quibus homines in cognationem rerum coelestium deveniunt; quam ipsa Natura rerum coelestium.

(J.Kepler, Astronomia Nova, 1609)

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To me, it looks not much less admirable how people get to knowledge about fundamental physics, than the Nature of fundamental physics itself.