MUSE

a SUSY spectrum evaluator

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SUSY

1. … is beautiful, like the snow in Jerusalem…
2. … but then, it melts, and everything gets muddy…
   - we know that SUSY is broken
   - we need a whole lot of SUSY breaking Soft terms
     and even more if we allow them to be complex,
     not even speaking of allowing R-parity breaking
   - is there still room for SUSY?
     LHC is closing the parameter space
   - CMSSM and mSUGRA…
   - … but full of teaching

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mSUGRA

1. a long-standing, popular solution:
   only four unified SUSY breaking terms at GUT scale
   - $M_{1/2}$
   - m_0
   - A_0
   - $\tan\beta$
   - $\mathrm{sgn}\,\mu$
2. finding the grand Unification Scale Λ_{GUT}
   by running up the gauge parameter from M_Z
3. running down all SUSY breaking parameters
   as well as gauge and Yukawa couplings
4. getting the physical spectrum
   (all particles and sparticles masses)

mSUGRA

1. the set of all beta function:

   up to order-3 for gauge coupling and superpotential, order-2 for others

2. a good way to integrate them from initial condition ODE
3. a way to solve simultaneously
   - the high energy ($\sim 10^{16}$ GeV) unification constraint finding the grand Unification Scale

     by running up the gauge parameter from M_Z
   - the low scale (M_Z) constraint on the couplings...
   - ...the others low scales constraints on the known masses, at each scale

$$m_f \quad = \quad \hat{m}_f(Q = m_f) - \Sigma(m_f) \qquad \text{implicit equation}$$

   $\Rightarrow$ a non-linear system solver

4. running down all SUSY breaking parameters

   $\Rightarrow$ build the SUSY Spectrum

Contenders (1)

- ISAJET 1993
- Pythia 1996
- SuSpect 1997
- SPheno 2003

- ⇒ no non-linear solver
  simply stabilizing iteratively
- ⇒ no adaptative RGE
  ol'CERNlib with 800 fixed steps
- ⇒ Threshold behaviour: only two scales
- MUSE 1998, 15 kSLOC: understand and reconcile them
  MUltiscale Spectrum Evaluator

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Contenders (2)

	MUSE-1	MUSE-2	MUSE-2E	MUSE-2'	Isajet	SuSpect	Spythia
loops							
• gauge	1	2	2	2	2	2	1
• Yukawa	1	2	1	1	1	1	1
• soft breaking	1	2	1	1	1	1	1
thresholds	yes	yes	yes	yes	yes	yes	no
unification	exact	exact	exact	exact	“exact”	approx	exact
unified $\hat{\alpha}_S(M_Z)$	yes	yes	yes	yes	yes	yes	no
Higgs routine	CQW	CQW	CQW	CQW		CQWs	CQWp
Λ_{EWSB}	M_Z	M_Z	Λ_E	M_Z	Λ_E	low	

CQW=Carena, Quirós, Wagner, CQWs=SuSpect version, CQWp=Pythia version, FH=FeynHiggs

$$\Lambda_E = \sqrt{m_{\tilde{t}_1} m_{\tilde{t}_2}}$$

Table: Configurations

RGE ODE integration

ϵ	Step Doubling	Cash Karp	Bulirsch Stoer (polynomial)	Bulirsch Stoer (rational)	Predictor Corrector	Predictor Corrector (stiff)
5.10^{-4}	277	79	107	55	18	482
5.10^{-8}	507	130	136	110	42	233
5.10^{-12}	3221	742	225	226	100	535
5.10^{-16}	21227	4706	607	10270	204	1406

Xtra smooth

Table: Average number of derivative evaluations required to get a relative accuracy of ϵ when integrating one-loop β functions between M_Z and Λ_{GUT} (without thresholds).

Such accuracy is useless for physics, but useful for numerical purposes, as the RGE ODE are the core computation

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Constraint solving

- $\hat{\alpha}(M_Z)$ and $\sin^2\hat{\theta}_W(M_Z)$
  $\Rightarrow \alpha_{\text{em}}$ and G_F ($\overline{\text{DR}}$ scheme)
- trinification? $\quad g_1 = g_2 \overset{?}{=} g_3$
  α_{s} set from the high-scale or low-scale?
  $\alpha_{\text{s}}|_{\overline{\text{MS}}}(M_Z) = \hat{\alpha}_{\text{s}}|_{\overline{\text{DR}}}(M_Z)(1 - \Delta\hat{\alpha}_s) \Rightarrow$ 10% to 15%! driving role of α_{s}
- Symmetry breaking: $M_Z(\Lambda_{\text{EW}})$ and $\tan\beta(\Lambda_{\text{EW}})$
  $\Rightarrow$ potential minimisation condition.
- Pole masses: m_t, m_b, and $m_\tau \Rightarrow$
  $m_f + \text{Re}\,\Sigma_f^T(Q) = \hat{m}_f(Q) = \frac{y_f(Q)v(Q)}{\sqrt{2}} \times \begin{matrix}\sin\beta \\ \cos\beta\end{matrix}(Q)$
- The "low" scale amount to about 7% of the full running range

Constraint solving (2)

1. `MUSE` approach is to solve simultaneously those constraints
2. ...works well for couplings, EW breaking and Yukawa's from pole masses
3. ...but not so well for implicit constraints such as building sparticle pole masses

$$m_f \quad = \quad \hat{m}_f(Q = m_f) - \Sigma(m_f)$$

4. NL solvers $\Longleftrightarrow$ minimization to 0
$\Rightarrow$ half of the accuracy is **lost** in a minimization process.

$$\eta = \sqrt{\epsilon}$$

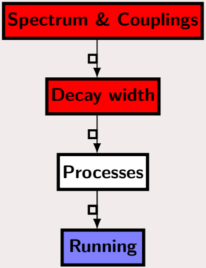
Switches:


```
4       'ODE method : 1=CK, 2=SD, 3=BS, 4=PC, 5=PCS'
.t.     'polynomial extrapolation in BS method'
.t.     'uses MinPack routines ?'
2       'loop(s) for gauge  couplings RGE'
1       'loop(s) for yukawa couplings RGE'
1       'loop(s) for soft breaking RGE'
.t.     'uses thresholds in RGE'
.t.     'computed threshold ?'
.t.     'mSUGRA ?'
.t.     'unification at Lambda'
.t.     'gauge trinification'
.t.     'convert alpha strong from MSbar to DRbar'
.t.     'EW breaking enforcement'
.t.     'one-loop potential minimisation'
.t.     'Higgs correction by Carena et al.'
.f.     'All corrections to top mass in Carena et al.'
```

Conclusion

1. the simple case looks already mostly eliminated
2. many assumptions:
   $\Rightarrow$ when there is convergence, the discrepancy can be explained by the underlying assumptions
   $\Rightarrow$ the more interesting case is when all programs don't converge: exploring the border
3. no program has yet the full generality
   $\Rightarrow$ would require to compute **decay width** and **processes** with loops, on the run
   $\Rightarrow$ spectrum is the core computation and as such require most accuracy

Principle...



… Machine Learning?