Supersymmetric Challenges

Manuel Drees

Bonn University

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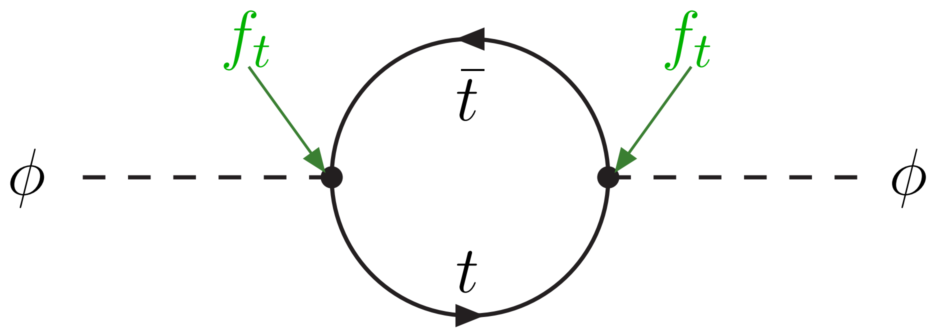
1 Introduction: Finetung Problem

In SM: loop corrections to Higgs boson mass diverge quadratically:



$$\delta m^2_{\phi,t} = \frac{3 f_t^2}{8\pi^2}\Lambda^2 + \mathcal{O}(\Lambda/m_\phi)$$

Λ: cut–off for momentum in loop.

m_ϕ Likes to be at *highest* relevant mass scale, e.g. $M_{\mathrm{GUT}} \sim 10^{16}$ GeV, $M_{\mathrm{Planck}} \sim 10^{18}$ GeV!

If $m^2_{\phi,\mathrm{phys.}} = m^2_{\phi,0} + \delta m^2_\phi \overset{!}{=} \simeq (100\ \mathrm{GeV})^2$: Need to finetune $m^2_{\phi,0}$ to 1 part in 10^{30}!

Nature abhors finetuning

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- Quantum corrections to gauge or Yukawa couplings, as well as fermion masses, at worst diverge logarithmically: not so bad even for $\Lambda = M_{\rm Planck}$.
- Standard cosmology has "flatness problem":

$$\Omega_{\rm BBN} - 1 \simeq 10^{-16} \left(\Omega_{\rm now} - 1 \right)$$

Here: $\Omega = \rho / \rho_{\rm crit}$; $\Omega = 1$ means flat Universe.

Is solved by inflation, which predicts:

  - $\Omega_{\rm now} \simeq 1$
  - Approximately scale invariant spectrum of density perturbations

Both predictions were confirmed by WMAP!

Supersymmetry solves finetuning problem

Postulate symmetry between bosons and fermions:

boson $\rightarrow$ fermion, fermion $\rightarrow$ boson

This is called a supersymmetry to distinguish it from the usual (gauge) symmetries.

Requires doubling of particle spectrum: each known particle gets superpartner!

In particular: higgsino $\tilde{h}$ is superpartner of Higgs boson ϕ.

Quantum corrections:

$$\delta m_\phi \underset{\text{SUSY}}{=} \delta m_{\tilde{h}} \propto \ln \frac{\Lambda}{m_\phi}$$

No quadratic divergencies!

Primary virtue of SUSY!

Secondary Virtues of Supersymmetry

- Biggest possible symmetry of interacting QFT:
  (Lorentz symmetry) $\otimes$ (gauge symmetry) $\otimes$ Supersymmetry !
  HLS theorem
- Local supersymmetry invariance implies invariance under coordinate trafos, i.e. GR: local SUSY $\equiv$ SUGRA
- New particles *automatically* lead to unification of gauge couplings at scale $M_{\rm GUT} \simeq 2 \cdot 10^{16}$ GeV.
- *Automatically* contains good Dark Matter candidate, if $R-$parity is conserved.

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- Postulate simple form of supersymmetry breaking at some high energy scale: Good for global analyses.
- Allow general values for parameters relevant for specific process: Good for dedicated phenomenological analyses; too many parameters for analysis of all LHC data?

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Works in all models discussed here!

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  - $m_{\widetilde{G}}, m_{\rm moduli} \sim m_{\tilde{f}}$ gives cosmological problems

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  - No $A-$term $\Longrightarrow$ smaller m_h $\Longrightarrow$ "Little hierarchy problem" worse than in mSUGRA.

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- Difficulties: Universality?

3 The Little Hierarchy Problem

R. Barbieri, . . .

- Recall: Correction to Higgs mass parameter (in potential)

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- Need $m_h \geq 114$ GeV, $m_{H_u}^2 \sim M_Z^2 \Longrightarrow$ few % finetuning inevitable?

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  - “Normal hierarchy” (H. Baer et al., hep–ph/0403214): 3rd generation sfermions heavier than 1st/2nd generation: worse finetuning, but easier DM

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- Worry about finetuning only if LHC does not find SUSY!

4 $R-$parity

Is it broken or not?

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- Show it's SUSY: If $m_{\tilde{q},\tilde{g}} \lesssim 1.5$ TeV: Easy to strongly motivate (see lots of new particles, large spread in spectrum); difficult to "prove" (test SUSY relations for couplings)
- Determine parameters: Need to use all available information: kinematical distributions, (ratios of) cross sections for different final states. For $m_{\tilde{q},\tilde{g}} \lesssim 1.5$ TeV: no. of observables $>$ no. of parameters!

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- Analyses should be model–independent, or one needs sufficiently many analyses to cover all cases
- Data will quickly narrow down field of candidate models