Revisiting No-Scale Supergravity Inspired Scenarios

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Phenomenology from scalar potential

$$V \sim e^G \left(G^i (G^{-1})_i^{\bar{j}} G_{\bar{j}} - 3 \right) + \frac{1}{2} f_{ab} D_a D^a$$

- G Kähler function
- f_{ab} Gauge kinetic function

Gravitino mass → Supergravity breaking

Scalar potential at the minimum put to zero by hand

$$\langle V_F \rangle = 0 \rightarrow m_{3/2} = \frac{M_{SUSY}^2}{\sqrt{3} M_{Planck}}$$

A naturally vanishing potential

- $G \supset -3 \ln(z + \bar{z})$ [Cremmer Ferrara Kounnas Nanopoulos 1983]
- $m_{3/2}$ not fixed because of the flatness
- Quantum effects deform the potential, fixing radiatively $m_{3/2}$

What ?

- No-scale already studied here and there
- Lack of a complete up-to-date numerical no-scale framework
- Fixing dynamically soft parameters

How ?

- Define the correct set of parameters and boundary conditions
  all $m_{soft} \propto \mathcal{O}(1) m_{3/2}$
- Define the correct scale-invariant potential
- Be careful with technical and numerical subtleties
  (when using a spectrum calculator : SuSpect in our case)

Why ?

- Reduce the huge supergravity parameter's space
- Define a natural framework for gravitino LSP

At the GUT scale

Switching scales

$$m_{3/2} = c_{3/2}\, m_{1/2}$$

- $c_{3/2}$ is related to the structure of the underlying theory
- $m_{1/2}$ will be fixed dynamically

Most general case : Soft parameters related to unique scale

$$B_0 = b_0 m_{1/2}, \;\; m_0 = x_0 m_{1/2}, \;\; A_0 = a_0 m_{1/2}$$

- Run from GUT scale to EW scale with RGE
- B_0 as input instead of $\tan\beta$
- $\tan\beta(B)$ calculated at EW scale

Usually taken as $V_{eff} = V_{tree} + V_{1-loop}$

- Sufficient to calculate physical quantities
- Known to be scale-dependant

Stability with running scale issue → take into account vacuum energy

$$V_{full} \equiv V_{tree}(Q) + V_{1-loop}(Q) + \tilde{\Lambda}_{vac}(Q)$$

- $\tilde{\Lambda}_{vac}(Q) \equiv \tilde{\eta}(Q) m_{1/2}^4$
- $\eta(Q)$ runs from η_0 at GUT scale to η_{EW} at EW scale.

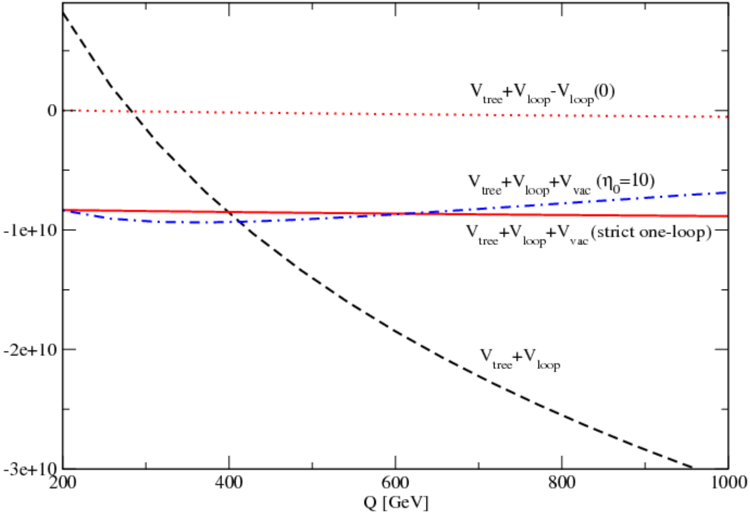
New set of parameters

At GUT scale

$$\eta_0,\ x_0,\ b_0,\ a_0,\ \mathrm{sgn}\mu$$

We don't consider any specific underlying theory

Comparing different choices of V_{eff}



- $V_{tree} + V_{1-loop}$ dangerously scale-dependant
- $V_{tree} + V_{1-loop} + V_{vac}$ much more stable

Breaking conditions

3 minimization equations

$$\text{EWSB} \quad \frac{\partial V}{\partial h_u} = 0\,, \quad \frac{\partial V}{\partial h_d} = 0\,,$$

$$\text{No-scale} \quad \frac{\partial V}{\partial m_{1/2}} = 0$$

EWSB

$$\mu^2 = \frac{1}{2}(\tan 2\beta(m_{H_u}^2 \tan\beta - m_{H_d}^2 \cot\beta) - M_Z^2)$$

$$B\mu = \frac{1}{2}\sin 2\beta(m_{H_u}^2 + m_{H_d}^2 + 2\mu^2)$$

Implicit equation for no-scale

$$V_{full}(m_{1/2}) + \frac{1}{128\pi^2}\sum_n (-1)^{2n} M_n^4(m_{1/2}) + \frac{1}{4} m_{1/2}^5 \frac{d\tilde{\eta}_0}{dm_{1/2}} = 0$$

About the minimum

Controlling all sources of radiative corrections

- Obvious example : Yukawa coupling

$$m_{top}^{pole} = Y_t(Q)v_u(Q)(1+\delta_y^{RC}(Q)+\cdots)\,.$$

Change in $\delta \Rightarrow$ change in $Y_t \Rightarrow$ change the runnings

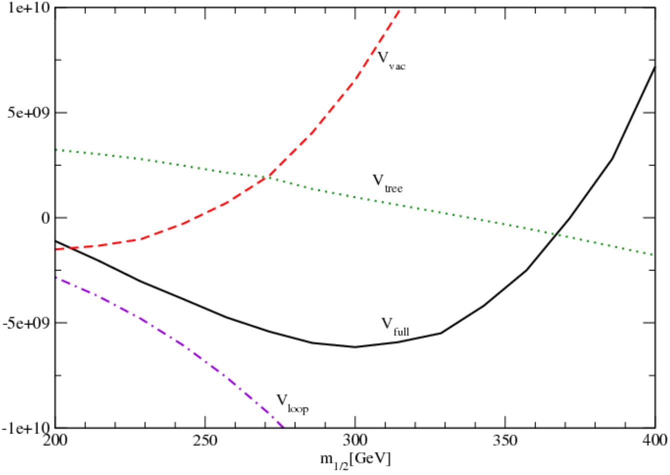
Be careful with physical constraints

$$V_{full}^{EWmin} = -\frac{g^2+g'^2}{8}v^4(1-2s_\beta^2)^2+\ldots$$

not the same as

$$V_{full}^{EWmin}(m_Z\,\mathrm{fixed}) = -\frac{m_Z^4}{2(g^2+g'^2)}(1-2s_\beta^2)^2+\ldots$$

valid only at minimum



- Interplay between V_{vac} term and V_{1-loop} responsible for the existence of the minima (as already noticed by Kounnas, Zwirner, Pavel 94)

“Vacuum energy” contribution 2/2

η_0 and $m_{1/2}$

- Large η_0 leads to trivial minima
- Small η_0 gives large $m_{1/2_{min}}$ (decoupled susy spectrum)

$$0 \lesssim \eta_0(Q_{GUT}) \lesssim 15$$

Existence of minima and η_{EW} bounds

- $\eta_{EW}(Q)$ must give a minimum for $M_z < Q < Q_{EWSB}$
  $-3 \lesssim \eta(Q_{EW}) \lesssim 1.7$

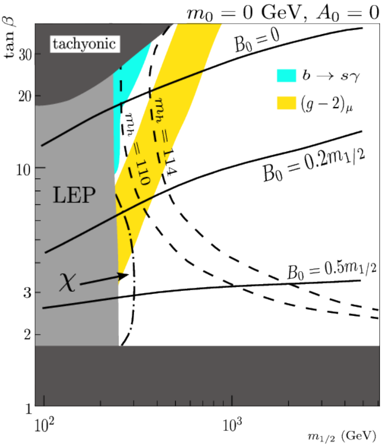
Phenomenological constraints

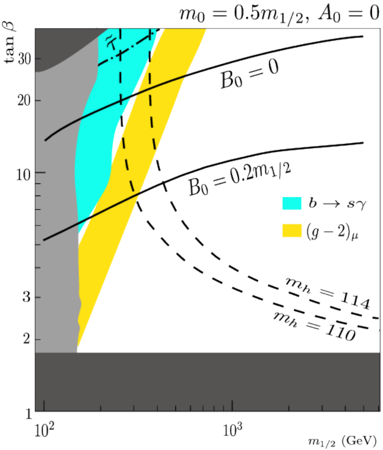
- Just finished to define a satisfying algorithm
- Extensive phenomenological study in progress

Overview of following constraints

- Sparticle mass limits
- Higgs boson mass
- muon anomalous moment
- $b \to s\gamma$
- Dark matter relic density

Collider constraints





- Viable strict no-scale region
- Mostly gravitino LSP, $\tilde{\tau}$ NLSP

- more general case, either gravitino or χ_0 LSP

- Non-thermal contribution (decay of NSLP to gravitino)

$$\Omega_{3/2}^{\mathrm{NTP}} h^2 = \frac{m_{3/2}}{m_{\mathrm{NLSP}}} \Omega_{\mathrm{NLSP}} h^2$$

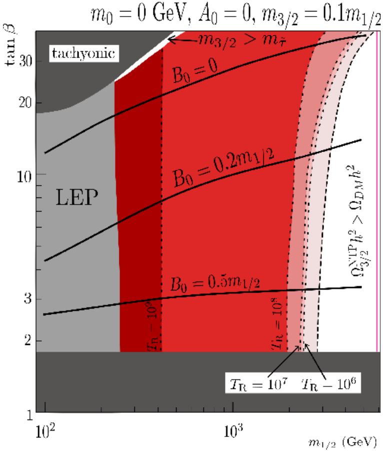
- Thermal contribution (thermal production through process)

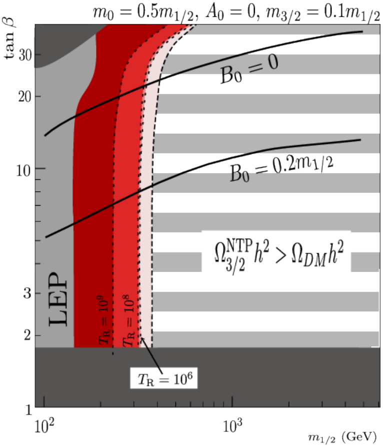
$$\Omega_{3/2}^{\mathrm{TP}} h^2 = m_{3/2} Y_{3/2}^{\mathrm{TP}}(T_0) s(T_0) h^2 / \rho_c$$

Total relic density distribution

$$\Omega_{3/2} h^2 = \Omega_{3/2}^{\mathrm{TP}} h^2 + \Omega_{3/2}^{\mathrm{NTP}} h^2$$

Cosmological constraints





- Gravitino LSP good candidate
- High reheating temperature favored
- Departing from strict no-scale more constrained

Concluding remarks

The no-scale program

- Dynamical determination of $m_{1/2}$ with no-scale mechanism
- Complete analysis with well-defined quantities, all 1-loop RC ...
- Full numerical analysis done within SuSpect (no semi-analytical simplifications)

Phenomenological implications

- Viable strict no-scale region (for $\tan\beta > 20$)
- No-scale favored parameters (mostly $x_0, a_0, b_0 \lesssim \mathcal{O}(1)$, and corresponding $\tan\beta$)
- Favored gravitino LSP, still possible to have χ_0 LSP
- Though reducing sugra space, still have room to avoid constraints
- Interesting gravitino physics

Backup slides

Soft breaking parameters

Non-canonical f_{ab} leads to gaugino mass-term

$$m_{1/2} = \frac{1}{4} \langle G_{\bar{z}} / G_{\bar{z}\bar{z}} \partial f_{ab} \partial z \rangle \, m_{3/2}$$

Specific cases

- Weakly coupled string
  - Moduli (strict no-scale) : $m_0 = A_0 = B_0 = 0$
  - Dilaton : $m_0 = \frac{1}{\sqrt{3}} m_{1/2}$, $A_0 = -m_{1/2}$, $B_0 = \frac{2}{\sqrt{3}} m_{1/2}$
- M-theory
- "Large-volume" IIB string
- ...

Vacuum energy running

$$V_{full} \equiv V_{tree}(Q) + V_{1-loop}(Q) + \tilde{\Lambda}_{vac}(Q)$$

$$V_{1-loop} = \frac{1}{64\pi^2} \sum_n (-1)^{2n} M_n^4 (\ln \frac{M_n^2}{Q^2} - \frac{3}{2})$$

$$\frac{dV}{dt} = 0 \quad \Longrightarrow \quad Q \frac{d}{d\,Q} \tilde{\Lambda}_{vac}(Q) = \frac{1}{32\pi^2} \sum_n (-1)^{2n} M_n^4 (H_u, H_d = 0).$$

No-scale minimization condition

- scaling hypothesis : $m_{soft} \propto \mathcal{O}(1) m_{1/2}$

$$m_{1/2} \frac{\partial}{\partial m_{1/2}} V_{full}(m_{1/2}) = 0$$

$$V_{full}(m_{1/2}) + \frac{1}{128\pi^2} \sum_n (-1)^{2n} M_n^4(m_{1/2}) + \frac{1}{4} m_{1/2}^5 \frac{d\tilde{\eta}_0}{dm_{1/2}} = 0$$

Physical spectrum and minimization

Choose a scale to calculate the spectrum

- the 'default' scale,

$$Q_{EW}^{default} = (m_{\tilde{t}_1} m_{\tilde{t}_2})^{1/2}$$

- the scale Q_{EW}^{loop} such that

$$V_{1-loop}(Q_{EW}^{loop}) = 0$$

- the scale Q_{EW}^{vac} such that

$$\tilde{\Lambda}_{vac}(Q_{EW}^{vac}) = 0$$

Numerically different $\longrightarrow$ stable results

	$Q_{EW}^{default}$	Q_{EW}^{loop}	Q_{EW}^{vac}
Q_{EW}(GeV)	610	307	500
$m_{1/2}(min)$(GeV)	335	332	334

considering the case where $x_0 = a_0 = 0$, $b_0 = 0.2$ and $\eta_0 = 10$