# Hiding the little hierarchy problem in the NMSSM

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# Motivation: After the LHC

- No SUSY particles found up to TeV range .
- A $126$GeV Higgs particle is discovered .
  It is consistent with range predicted by MSSM

$$m_h^2 = m_h^{2\,tree} + \delta m_h^2(M_s)$$

  $m_h^{tree} \leq \mathsf{M_z}$ thus puts a lower bound $\mathsf{M}_s \gtrsim 1$TeV.
- but a *Little Hierarchy problem* (LHP)

$$\mathsf{M}_\mathsf{z}^2 = 2\,( \; -\mu^2 + \underbrace{\hat{m}^2}_{\text{soft terms}} \; )$$

  large cancellation between $\mu$ and $\hat{m}$ is needed for electroweak symmetry breaking

# Motivation: Multiverse or Naturalness?

# Motivation: Little Hierarchy problem

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- Matter content: Next-to-Minimal Standard Model [Ellwanger,Hugonie, Texeira '09]

  - Solves the mu problem (scale invariant version)
  - Additional tree level contribution to the Higgs mass
  - New regions of parameter space for $\hat{m}$ are allowed

# Motivation: Little Hierarchy problem

- Pattern of soft terms.

  They encode the information about physics at high scales and rely on how supersymmetry breaking occurs and how it is mediated.

  However, they usually assume some "minimalistic" choices.

  e.g mSUGRA $\{\mathsf{M}_0,\ m_0, A, B, \mu\}$

$$\hat{m}^2 \simeq c_1 \mathsf{M}_0^2 + c_2 \mathsf{m}_0^2 \quad , c_1 \sim \mathcal{O}(1), c_2 \ll 1$$

  If $\mathsf{M}_0$ and $m_0$ are related s.t. $\hat{m}^2 = c\,\mathsf{M}_0^2$ , $c \ll 1 \rightarrow$ no LHP [Brümmer,Buchmüller '14]

# Setup at the GUT scale

- We consider non universal Higgs masses (no risk of FCNC)
- Natural embedding in higher dimensional orbifold GUTs

## Soft terms

$$m_0^2 = m_{h_u}^2 = m_{h_d}^2 \;, \qquad m_{q_3}^2 = m_{u_3}^2 = m_{d_3}^2 = m_s^2 = 0,$$
$$\mathsf{M}_0 = \mathsf{M}_{i=1,2,3} \;, \qquad A_u = A_\lambda = A_\kappa = 0 \;,$$

We assume

$$\mathsf{M}_0 = k\, m_0$$

and calculate the $k$ for which $\hat{m} \ll \mathsf{M}_s$.

# Low energy parameters

The NMSSM superpotential we consider

$$\mathsf{W} = \underbrace{(\mu_h + \lambda S)}_{\mu} H_u H_d + \kappa S^3 + \sum_{\text{generations}} \text{Yukawas}$$

free parameters at the GUT scale

$$\{\mathsf{M}_0,\ m_0,\ \mu\,, \tan\beta, \kappa_0, \lambda_0\}$$

We fix $\kappa_0 \simeq 1$, and assume $\mathsf{M}_0 = k\, m_0$.

After solving the RGEs $\hat{m}$ can be parametrized by

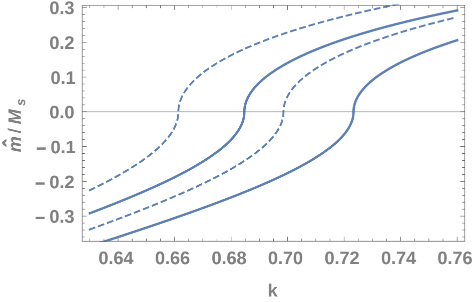
$$\hat{m}^2 = c(\lambda_0, \tan\beta, k)\mathsf{M}_0^2\,.$$

and calculate $k$ for which $\hat{m} \ll \mathsf{M}_s$

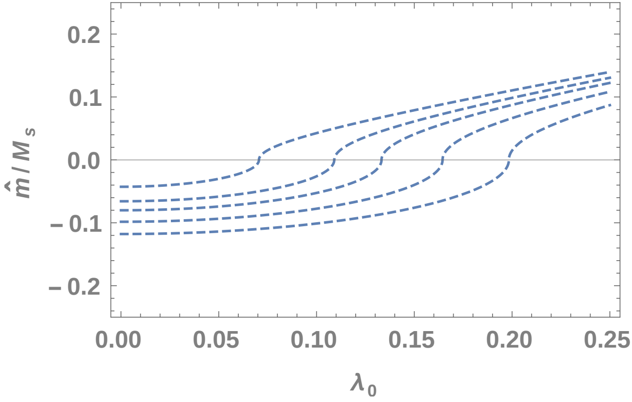
# Calculation of k

$M_s = 3$TeV, $\kappa_0 \simeq 1$ for different values of $\lambda_0 = 0.4, 0.001$ and $\tan\beta = 6, 15$ (dashed-thick).

effective MSSM, $\lambda_0 \to 0$
$0.70 \lesssim k \lesssim 0.76$
moderate $\tan\beta$, all $\lambda_0$
$0.66 \lesssim k \lesssim 0.76$



# Calculation of $k$




$k = 0.71$ varying $\tan\beta$ ,$M_s = 3$TeV

The region between $(-0.2, 0.2)$ lies within EW scale

# Phenomenological implications

- Light higgsinos $\simeq 100 - 400$ GeV below Bino and Wino.
- Depending on the range of $\lambda_0$ the singlet scalar and singlino are found above or below the Higgs mass!
  - $10^{-3} \lesssim \lambda_0 \lesssim 10^{-1}$

$$m_h \lesssim m_s, \chi_s \lesssim \mathcal{O}(\text{TeV}) \,, \quad \text{(NLSP)}$$

  - $0 \lesssim \lambda_0 \lesssim 10^{-4}$

$$\mathcal{O}(1)\text{GeV} \lesssim m_s, \chi_s \lesssim m_h \,, \qquad \text{(LSP)}$$

  Signatures at the upcoming LHC [Curtis et al.'13][Curtis et al.'14]

- Light Gravitino (few GeV) LSP or NLS depending on the value of $\lambda_0$
  Gravitino LSP [Buchmüller et al.]
- Light pseudoscalar $\simeq \mathcal{O}(1) - \mathcal{O}(100)$GeV [Dobrescu,Matchev '00] [Bomark et al. '14],[Curtis et al.'14]

# Supersymmetry breaking

Soft terms arise from non renormalizable terms involving hidden sector ($F \neq 0$) and observable sector (NMSSM) suppressed by the cutoff scale

- Supergravity ($M_p$) , $m_{\frac{3}{2}} = \frac{F}{M_p}$ [Kaplunovsky, Louis '93]
- Effective theory with cutoff $\Lambda$ (global susy picture)

$$m_{\text{soft}} = \frac{F}{\Lambda}$$

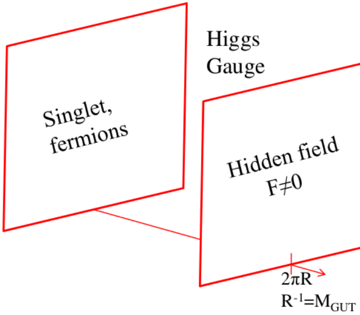
e.g. gaugino mediation [Chacko et al '99]
gauge mediation [Giudice,Ratazzi '98]

We computed the soft terms for effective theories with cutoff $\Lambda$ in model independent way

# A simple example

Higher dimensional setup with cutoff $\Lambda$

- Motivated by higher dimensional orbifold Guts in 5 and 6 dimensions [Hebecker,March-Russell '01],[Hall et al.'02],[Kawamura'01], [Altarelli, Feruglio '01],[Buchmüller et al. '02]




- No FCNC
- Realises the structure of soft terms we studied !
  but to specify their values we need to specify the Lagrangian

# Soft terms I

We parametrize the couplings in terms of unknown coefficients (to leading order):

$$K = (1 + \rho\ |\hat{\Sigma}|^2)\ (|H_u|^2 + |H_d|^2) + \mu_k\,(\hat{\hat{\Sigma}} H_u H_d + \text{c.c.})\ ,$$
$$f = 1 + \gamma\ \hat{\Sigma}\ , \qquad \mathsf{W} = \mu_{\mathsf{w}}\,(1 + \hat{\Sigma}) H_u H_d\ .$$

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**Example:** Naïve dimensional analysis (NDA)[Luty '97],[Cohen et al '97]

Assumes that couplings, and higher loop corrections, at energies $\sim \Lambda$ are $\mathcal{O}(1)$ in units of $\Lambda$ (Strongly coupled regime)[Kaplan,Kribs,Schmaltz'99] [Chacko,Luty,Nelson,Ponton '99] [Chacko,Luty,Ponton '99],

# Soft terms II

$$\mu_h \text{ free }, \quad b_h = \text{free},$$

$$M_0 = \alpha \cdot m_0 \quad \text{with } \alpha = \left( \frac{l_d}{l_4 \Lambda^{d-4} V_{d-4}} \right)^{\frac{1}{2}},$$

[Brümmer,Buchmüller '14]

Replacing by $V = (2\pi R_l)^d$ with $R_l^{-1} \simeq M_c$, $1.24\mathrm{M}_c \lesssim \Lambda \lesssim \mathrm{M}_{p,d}$, for $d = 5$ it yields

$$0.3 \lesssim \alpha \lesssim 0.8$$

and thus provides the relation could solve the little hierarchy problem

# Summary

- We studied a setup at the GUT scale with soft terms for the Higgs sector and gaugino masses, with natural embedding in higher dimensional GUTs

  We computed the relation between gaugino and soft scalar masses required to solve the LHP
- Investigated phenomenological implications.
- We derived soft terms for effective NR theories with global susy .
- The necessary relation to solve the LHP was obtained from a quite simple model

Thanks for your attention!.