The Higgs and Stringy High Scale SUSY

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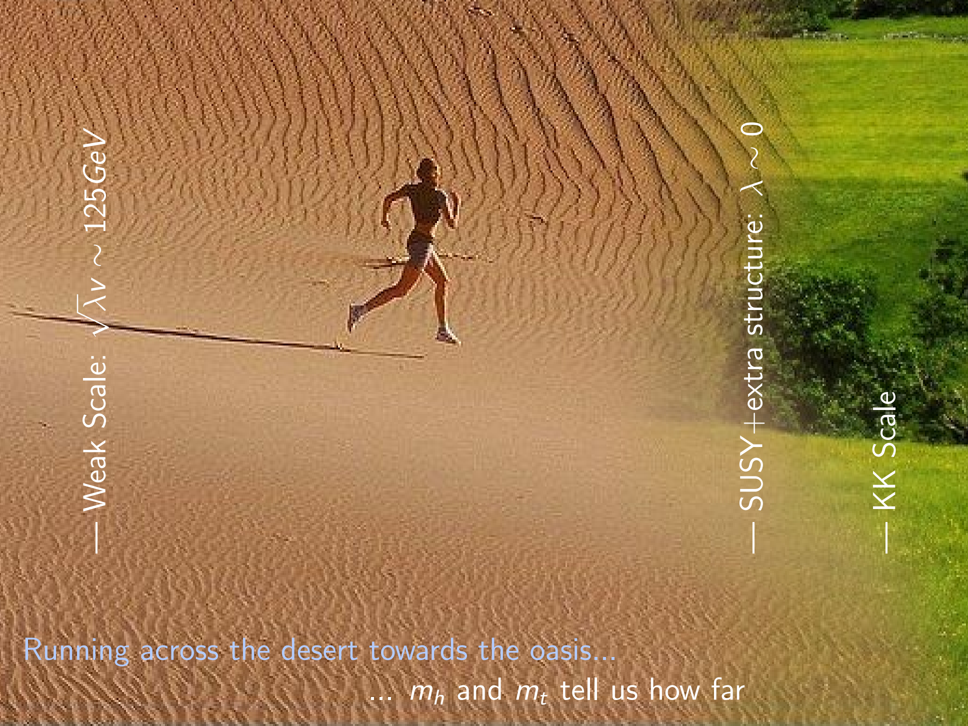
In collaboration with A. Hebecker, T. Weigand

Partly based on 1204.2551 **(JHEP)**, 1304.2767 **(Nucl. Phys. B)**



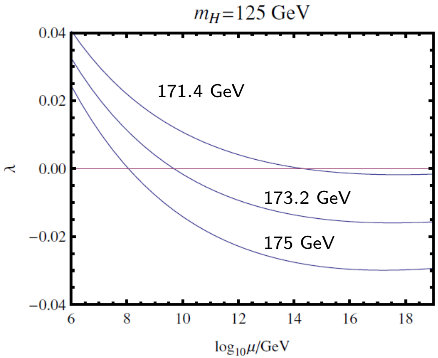
Running across the desert towards the oasis...

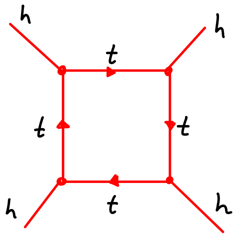
... m_h and m_t tell us how far

SM RG Running

The observed higgs mass $m_h \sim v\sqrt{\lambda} \sim 125 \ldots 126$ GeV is close to the "instability" bound.

$$16\pi^2 \frac{\partial \lambda}{\partial \log \mu} \sim \lambda(-9g_2^2 - 3g_1^2 + 12y_t^2) + 24\lambda^2 + \frac{3}{4}g_2^4 + \frac{3}{8}(g_1^2 + g_2^2)^2 - 6y_t^4$$





UV Boundary Conditions

Imposing $\lambda(UV)$ allows predictions for m_h:

Weak scale and m_h may be finetuned, but...

Only one fine tuning

$m_W \ll M_{Pl}$ gives $m_h \ll M_{Pl}$!

UV boundary conditions from Symmetry

String-inspired premise:

- $\mathcal{N} = 1$ SUSY at *some* scale $m_S < M_{pl}$
- SM(+Axion CDM?) below m_S

[Hall, Nomura, arXiv:0910.2235]

High scale SUSY breaking, landscape arguments for $\tan\beta \gg 1$

$$\longrightarrow \lambda(M_{GUT}) \sim (g_1^2 + g_2^2)/8$$

$$\longrightarrow \quad m_h \sim 141 \text{ GeV}, \text{ruled out}$$

Apparently, the high scale theory possesses additional structure...

UV boundary conditions from Symmetry

Our proposal: $\lambda = 0$ at SUSY scale due to symmetries

Prediction of SUSY scale:

$$m_S \sim \Lambda(\lambda = 0) = 10^8 \text{ GeV} \ldots 10^{18} \text{ GeV}$$

Uncertainty mainly due to top mass

$$m_t = 173.5 \pm .6 \pm .8 \text{ GeV}$$

followed by error in m_h and α_s.

Some previous work considering $\lambda(UV) = 0$ (and $\beta_\lambda(UV) = 0$):

[Shaposhnikov, Wetterich '09] (asymptotic safety) [Gogoladze, Okada, Shafi '07] (GHU)

Shift Symmetry

[A. Hebecker, AK, T. Weigand: A Shift Symmetry in the Higgs Sector (arXiv:1204.2551)]

Demand a shift symmetry *in the Higgs sector*:

$$H_u \longrightarrow H_u + c, \quad H_d \longrightarrow H_d - \overline{c}$$

This gives us $\mu(\mathcal{W}) = 0$ and $\mathcal{K} = \mathcal{K}(H_u + \overline{H}_d)$,

$$\mathcal{K} = f(S, \overline{S})|H_u + \overline{H}_d|^2 + \dots$$

SUSY breaking $F^S \neq 0 \Longrightarrow$ special relations between soft parameters!

see e.g. [Ibáñez, Muñoz]

$$B\mu \quad = \quad |\mu|^2 + m_{H_u}^2 \quad = \quad |\mu|^2 + m_{H_d}^2$$

Shift Symmetry

Higgs mass matrix from shift symmetry:

$$V = \begin{bmatrix} H_u \\ \overline{H}_d \end{bmatrix}^\dagger \begin{bmatrix} |\mu|^2 + m_H^2 & |\mu|^2 + m_H^2 \\ |\mu|^2 + m_H^2 & |\mu|^2 + m_H^2 \end{bmatrix} \begin{bmatrix} H_u \\ \overline{H}_d \end{bmatrix}$$

SM Higgs from the light (massless) eigenstate $H^{light} = \frac{1}{\sqrt{2}}(H_u - \overline{H}_d)$

$$|\alpha| = 45^\circ, \quad \tan\beta = 1$$

Mass eigenstates $\sim$ flat directions of MSSM D-Term potential

$$V \sim (|H_u^0|^2 - |H_d^0|^2)^2$$

The quartic coupling λ_{tree} of the light Higgs vanishes at the "soft" scale

Exchange Symmetry

Alternative proposal [Ibáñez, Marchesano, Regalado, Valenzuela (arXiv:1206.2655)]

$$H_u \longleftrightarrow \overline{H}_d$$

$$V = \begin{bmatrix} H_u \\ \overline{H}_d \end{bmatrix}^\dagger \begin{bmatrix} |\mu|^2 + m_H^2 & B\mu \\ B\mu & |\mu|^2 + m_H^2 \end{bmatrix} \begin{bmatrix} H_u \\ \overline{H}_d \end{bmatrix}$$

- Weak scale not automatically small at tree level (but we had to fine tune at 1-Loop anyhow)
- Tuning weak scale light $\Rightarrow \tan\beta = 1$ as before!

Proposed field theory and stringy realizations

Shift symmetry:

- Field theory models with Susy GHU [Choi et al. '93][Hebecker, March-Russell, Ziegler '03][Brümmer, Fichet, Hebecker, Kraml '09]
- Untwisted states in Heterotic Orbifolds [Lopes Cardoso, Lüst, Mohaupt '94][Antoniadis, Gava, Narain '94] [Brignole, Ibáñez, Munñoz, Scheich '97][Lebedev, Nilles, Raby, Ramos-Sanchez, Ratz, Vaudrevange, Wingerter '06]...
- Wilson lines on D6 [A. Hebecker, AK, T. Weigand '12]
- D7 bulk Higgs [A. Hebecker, AK, T. Weigand '13]
- IIB Intersection Matter [Ibáñez, Marchesano, Regalado, Valenzuela '12]

Exchange symmetry:

- "Non-SUSY" IIA compactifications [Ibáẽz, Marchesano, Regalado, Valenzuela '12]
- PQ breaking [Hebecker, AK, Weigand '13]

Interesting aspects not explored in detail in this talk:

- Minimal models: Stabilizing new physics comes right at scale of instability (c.f. later in this talk)
- Typical UV scales $\to f_a$ for CDM Axions [Hebecker, AK, Weigand '12] e.g. Axions from Kähler moduli [Ibáñez, Marchesano, Regalado, Valenzuela '12][Nilles et al. '12]
- $\leftrightarrow$ Gauge unification+Neutrino Masses [Ibáñez, Marchesano, Regalado, Valenzuela '12][Ibáñez, Valenzuela '13]
- Dark Radiation and shift symmetry [Conlon et al.][Cicoli et al.][Hikagi et al.]

High scale radiative corrections to m_h

Radiative corrections

I. Violation of Higgs sector shift/exchange symmetry

$$\mathcal{W} = y_t H_u T_R Q_L$$

(remember: $\tan\beta = 1 \Rightarrow y_t \gg y_b$)

Assume the symmetry to be good at $m_C \gg m_S$ and consider RG evolution of mass matrix. This yields [A. Hebecker, AK, T. Weigand '12]

$$\lambda_{tree}(m_S) = \delta\lambda_{SV}(m_S) \approx \frac{g_2^2 + g_1^2}{8} \left| \frac{6\overline{y_t^2}}{16\pi^2} \log\left(\frac{m_S}{m_C}\right) \right|^2 .$$

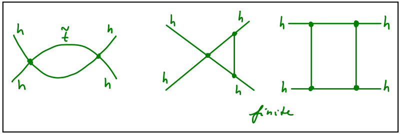
We are lucky: $y_t^4(m_S) \ll 1!$ [Hall, Nomura]

Threshold effects

Naively, λ at m_S is given by SUSY tree relation - but what is m_S?

m_S is unphysical - need 1-Loop decoupling to determine where $\lambda = \lambda_{tree}$

II. Threshold corrections to λ



$$\delta\lambda_T(m_S) = \frac{3y_t^4}{16\pi^2}\left[\frac{X_t^2}{m_{\tilde t}^2}\left(1 - \frac{X_t^2}{12 m_{\tilde t}^2}\right) + 2\log\left(\frac{m_{\tilde t}}{m_S}\right)\right]$$

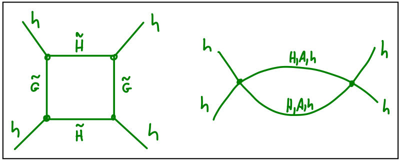
$X_t \sim A_t - \mu$

[Okada, Yamaguchi, Yanagida '91] ...

We are again lucky that $y_t^4(m_S) \ll 1$

Threshold effects

Furthermore: gauginos, Higgsinos, heavy Higgs sector



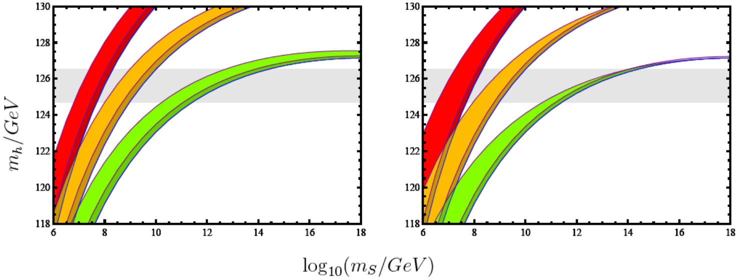
$$\delta\lambda^{LL}_{GH+A} \approx \frac{\tilde{b}_\lambda}{16\pi^2}\left[\log\frac{m_\chi}{m_S} - \frac{1}{4}\log\frac{m_A}{m_S}\right]$$

$m_\chi = \max(M, \mu)$, $\tilde{b}_\lambda < 0$ see also [Hollik et al. '02][Giudice, Strumia '11]

Effective SUSY scale at leading log:

$$m_S^{eff} = \left[m_A^{-\tilde{b}_\lambda/3} m_{\tilde{t}}^{8y_t^4} m_\chi^{4\tilde{b}_\lambda/3}\right]^{1/(\tilde{b}_\lambda + 8y_t^4)}$$

Results for m_h (Thresholds/SV effects)



(fat bands: worst cases $X_t = \sqrt{6} m_{\tilde{t}}$ and $m_C^2 \sim m_S M_{Pl}$)

Various $\delta\lambda$ thresholds and "stop mixing" effects generically cancel in scenarios where $M \sim m_0 \sim \mu$

$\Rightarrow \delta m_h < 2$ GeV for $m_S \sim 10^9$ GeV.

Effects from extended SUSY/MSSM

Effects from extended SUSY

If Higgs originates from higher dimensional bulk or some sector with $\mathcal{N} = 2$ locally such as a non-generic D6 system

$$\mathcal{L} \supset \cdots + \frac{1}{2}\vec{P}^2 + g\phi^A \vec{P} \cdot \vec{\sigma}_A{}^B \, \phi^\dagger_B + \cdots$$

where e.g. $\vec{P} \sim (F_{5,6}, D)$

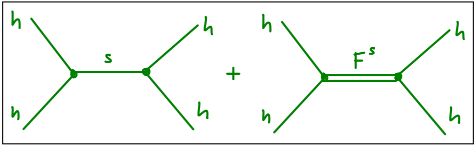
The relation
"tan $\beta = 1 \Rightarrow \lambda = 0$"
relies on SUSY decoupling of P^1, P^2!

This might be problematic for "non-SUSY model" explanations of $\lambda = 0$
For a discussion of this see [A. Hebecker, AK, T. Weigand '13]

4D effective description as F term:

$$\mathcal{W} \sim \kappa S H_u H_d + \frac{M}{2} S^2$$

Below scale M, S and in particular F^s decouple.



(Nice twist: make SUSY gauge sector heavy via Dirac masses and decouple D term rather than F term: small λ for arbitrary $\tan\beta$! [Fox, Nelson, Weiner '02][J. Unwin '12])

Consider soft mass term

$$\mathcal{L}_{soft} = -m_s^2 s^\dagger s$$

$m_s \neq 0$: decoupling of F^s is not exact:

$$V_{\Lambda=M} = \kappa^2 \frac{m_s^2}{m_s^2 + M^2} |H_u H_d|^2$$

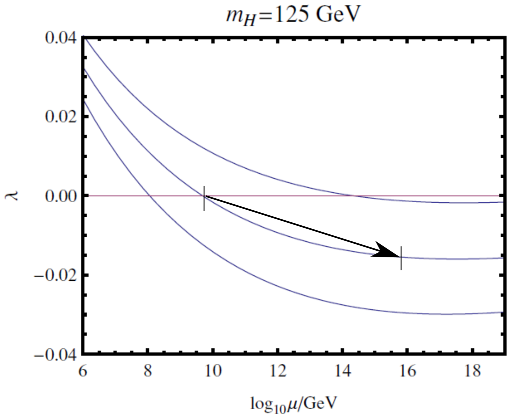
Amusing feature:

- negative mass squared results in quartic (not tachyonic!) instability

$\kappa \sim \sqrt{2}g \sim 1$, so a small hierarchy

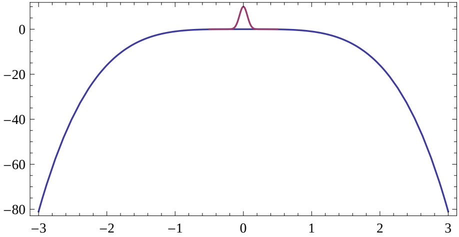
$$-M^2 < m_s^2 < 0, \quad |m_s| \sim M/10$$

would bring us to arbitrarily high scales:



UV completion in unstable regime?

Can we reliably match SM to our UV SUSY model in the $\lambda < 0$ regime?



- $\lambda < 0$ does not introduce a time scale of instability
- Localized vacuum state near $h \sim 0$ can live long compared to m_S^{-1} (limited by loop suppressed instabilities and IR cutoff)
- This should be sufficient to allow perturbative matching $\lambda \to \lambda_{SM}$
- RG running towards IR $\to$ $h = 0$ quickly becomes local minimum again

Conclusions

- In absence of SUSY@LHC, SM Higgs hints at new scale > 1000 TeV where $\lambda \sim 0$
- UV completions with an approximately flat Higgs potential at an intermediate — high SUSY scale might be *the* way to proceed in String Pheno
- Several promising approaches in Het. and Type II exist
- Work remains to be done wrt. Axion phenomenology, cosmology + inflation
- Effects from the extended sector may place the UV completion in the unstable regime $\lambda < 0$ and/or alleviate the constraints on $\tan\beta = 1$

Thank you for your attention!