Brane Moduli in Higgs Physics and Cosmology

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- 125-GeV Higgs from a Stringy Shift Symmetry

  AH, Knochel, Weigand (1204.2551)

- Fluxbrane Inflation with Shift symmetry

  AH, Kraus, Lüst, Steinfurt, Weigand (1104.5016)
  . . . , **Küntzler** (1207.2766)
  . . . , **Arends, Heimpel, Mayrhofer, Schick** (12xx.xxxx)

Outline

- The 125-GeV-Higgs (without SUSY) from a String-Pheno Perspective
- Main idea: $\lambda = 0$ at some high scale (SUSY-breaking scale) due to shift symmetry in the Higgs sector
- Stringy (Wilson-line) origin of this shift symmetry
- Originally heterotic, but may be as natural in D-branes
- Closely related: The very same symmetry may be reponsible for a flat potential in fluxbrane inflation

Motivation

- We have a Higgs at 125 GeV and nothing else (yet?)

  Of course: low-scale SUSY is still OK
  Also: Muon-$(g-2)$; $h \to \gamma\gamma$ excess; 130-GeV γ-ray line...

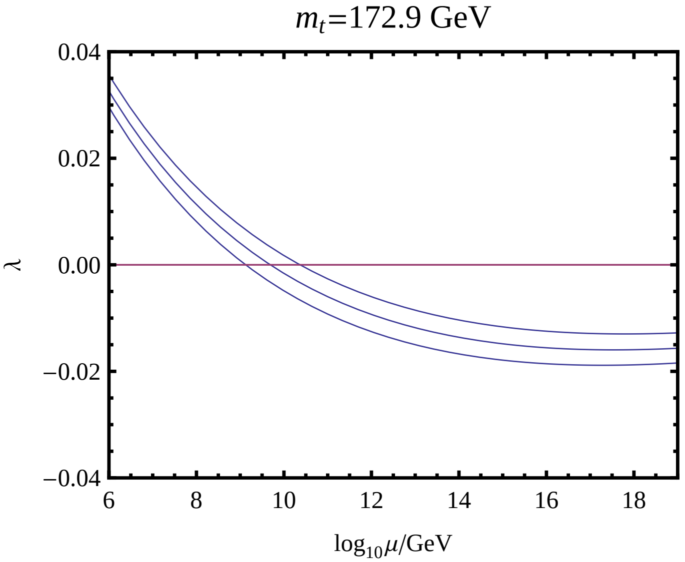
- Nevertheless: What if we just had to accept the fine-tuned non-SUSY SM for a large energy range?

- Well-known: for low m_h, λ runs to zero at some scale $< M_P$ (vacuum stability bound)

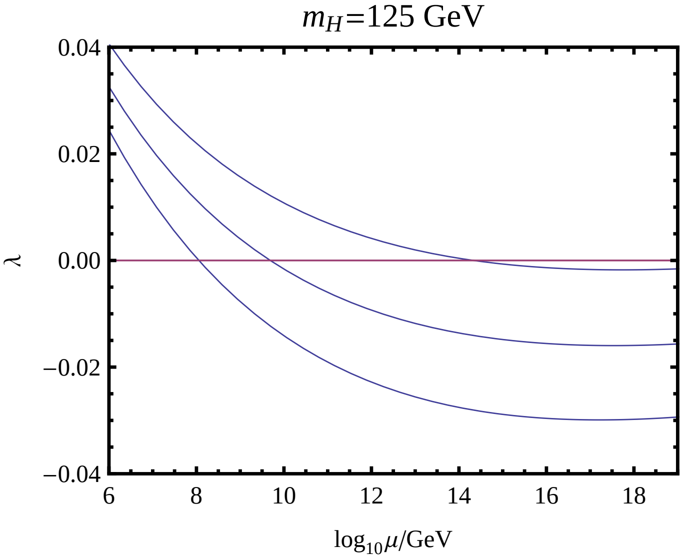
  Lindner, Sher, Zaglauer '89
  Gogoladze, Okada, Shafi '07
  ...
  Shaposhnikov, Wetterich 09'
  Giudice, Isidori, Strumia, Riotto, ...

- It has been attempted to turn this into an m_h prediction

Running of λ (for a ± 1 GeV variation of m_{Higgs})



Running of λ (for a 2-σ variation of $m_{\rm top}$)



String-phenomenologist's perspective

- Insist on stringy UV completion (for conceptual reasons)
- Expect SUSY at string/compactification scale (stability!)
- Natural guess: The special scale $\mu(\lambda = 0)$ is the SUSY-breaking scale
- Crucial formula:

$$\lambda(m_s) = \frac{g^2(m_s) + g'^2(m_s)}{8} \cos^2(2\beta)$$

- Reminder:

$$M_H^2 = \begin{pmatrix} |\mu|^2 + m_{H_d}^2 & b \\ b & |\mu|^2 + m_{H_u}^2 \end{pmatrix} = \begin{pmatrix} m_1^2 & b \\ b & m_2^2 \end{pmatrix}$$

$$\sin(2\beta) = \frac{2b}{m_1^2 + m_2^2}$$

Need this to be 1!

- Of course, high-scale SUSY has been considered before

Arkani-Hamed, Dimopoulos '04
Giudice, Romanino '04, ...

- Also, relations $\tan\beta \leftrightarrow \lambda(m_s) \leftrightarrow m_h$ have been discussed

cf. the 140-GeV-Higgs-mass-prediction of Hall/Nomura, '09

- Our goal:

  Identify as special structure/symmetry leading to $\tan\beta = 1$
  (i.e. to $\lambda = 0$)

- Indeed, such a structure is known in heterotic orbifolds:

Shift symmetry: $K_H \sim |H_u + \overline{H}_d|^2$

Lopes-Cardoso, Lüst, Mohaupt '94
Antoniadis, Gava, Narain, Taylor '94
Brignole, Ibanez, Munoz, Scheich, '95...'97
...
Pena, Nilles, Oehlmann, '12

In more detail: $K_H = f(S, \overline{S})|H_u + \overline{H}_d|^2$

Assuming $F_S \neq 0$ and $m_{3/2} \neq 0$ this gives

$$m_1^2 = m_2^2 = b \quad = \quad \left| m_{3/2} - \overline{F}^S f_{\overline{S}} \right|^2 + m_{3/2}^2 - F^S \overline{F}^S (\ln f)_{S\overline{S}}$$

- This shift-symmetric Higgs-Kähler potential has also been rediscovered/reused in orbifold GUTs

K. Choi et al. '03
AH, March-Russell, Ziegler '08
Brümmer et al. '09...'10
Lee, Raby, Ratz, Ross, ... '11

- In this language, it is easy to see the physical origin:

5d SU(6) $\rightarrow$ SU(5)$\times$U(1) ; $35 = 24 + 5 + \overline{5} + 1$; Higgs$= \Sigma + iA_5$

cf. Gogoladze, Okada, Shafi '07

D-brane origin

- This simple understanding of the shift-symmetry lets us hope that it is more generic

  heterotic WLs $\leftrightarrow$ type IIA / D6-WLs $\leftrightarrow$ type IIB / D7-WLs
  or positions

- These and other origins of the Higgs-shift-symmetry and of $\tan\beta = 1$ have recently also been explored in

  Ibanez, Marchesano, Regalado, Valenzuela '1206...

- Clearly, we eventually need more phenomenological implications of 'stringy high-scale SUSY' (e.g. in cosmology)

  Chatzistavrakidis, Erfani, Nilles, Zavala '1206...
  Higaki, Hamada, Takahashi '1206...
  Anchordoqui, Goldberg, Huang, Lüst, Taylor, Vlcek '1208...

Corrections? Precision?

- The superpotential (e.g. top Yukawa) breaks the shift symmetry
- The crucial point is compactification

  Shift symmetry is exact (gauge symmetry!) in 10d.
  The shift corresponds to switching on a WL.
  This is not a symmetry in 4d (4d-zero modes 'feel' the WL).
  4d-loops destroy the shift symmetry of Kähler potential.
- Optimistic approach to estimating the 'goodness' of our symmetry:

  Symmetry-violating running between m_c and m_s
  $\Rightarrow$ Correction $\delta \sim \ln(m_c/m_s)$

More explicitly:

$$M_H^2 = (|\mu|^2 + m_H^2) \begin{pmatrix} 1 & 1 \\ 1 & 1 \end{pmatrix} + \begin{pmatrix} \delta|\mu|^2 + \delta m_{H_d}^2 & \delta b \\ \delta b & \delta|\mu|^2 + \delta m_{H_u}^2 \end{pmatrix}$$

$$= \quad \text{symmetric} \quad + \quad \text{loop violation}$$

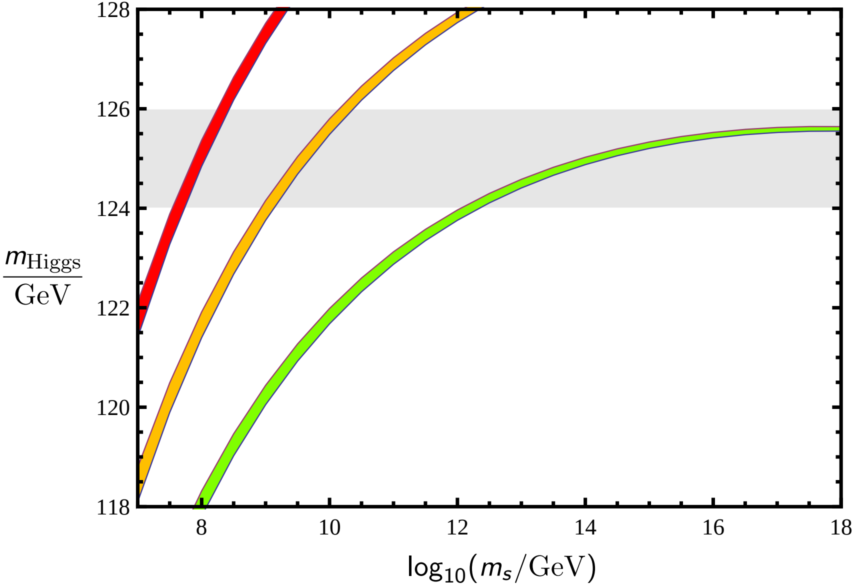
- Leading effects: y_t and gauge

$$\delta M_H^2 = f(\epsilon_y, \epsilon_g, m^i_{\rm soft}) \qquad ; \qquad \epsilon_y = \int_{\ln m_s}^{\ln m_c} dt \, \frac{6|y_t|^2}{16\pi^2}$$

- Enforce det $M_H^2 = 0$ after corrections $\Rightarrow$ $\epsilon_y, \epsilon_g, m^i_{\rm soft}$ are related

$$\cos 2\beta = \epsilon_y \times \{\text{calculable } \mathcal{O}(1) \text{ factor}\}$$

Assumption: $(m_s < m_c < 100 m_S)$



A different application of the same shift symmetry

AH, Kraus, Lüst, Steinfurt, Weigand, 1104.5016
. . . , Küntzler, 1207.2766
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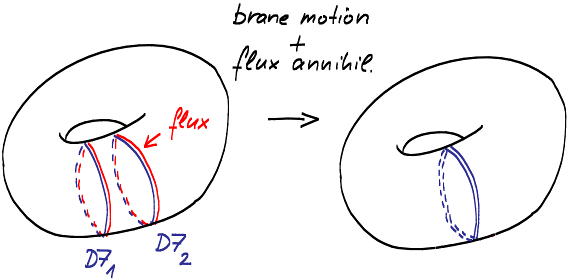
- Fluxbrane inflation with flat direction protected by shift symmetry for D7-brane motion



- Related to WLs by mirror symmetry / T-duality

Fluxbrane inflation

- Crucial fact: At large volume (i.e. weak flux F), the potential is much more flat than in brane-antibrane inflation:

$$V \sim 1 - \frac{g_s}{r^{d_\perp - 2}} \quad \rightarrow \quad V \sim F^2 - F^4 \frac{g_s}{r^{d_\perp - 2}}$$

Hence: $\eta \sim F^2 \ll 1$

- Note: This is conceptually similar to D3/D7 inflation

Dasgupta, Herdeiro, Hirano, Kallosh, '02

and T-dual to inflation from branes at angles and Wilson lines

Garcia-Bellido, Rabadan, Zamora, '01
Avgoustidis, Cremades, Quevedo, '06

Flat direction / shift symmetry

- Chose brane/bulk fluxes such that W_0 does not depend on φ.
- Of course, since $W_0 \not\equiv 0$, the usual 'η-problem of supergravity' is still present:

$$K = -\ln(S + \overline{S} + \kappa(\varphi, \overline{\varphi})) + \cdots \qquad \Longrightarrow \qquad \eta \simeq 1 \text{ from } V_F$$

[Here κ is the Kähler potential on the D7-brane moduli space; similar to situation in KKLMMT.]

- Fact: F-theory on K3×K3 has $\kappa = \kappa(\varphi + \overline{\varphi})$
- We expect this shift-symmetric structure to arise more generally in the large complex structure limit.

Grimm, Ha, Klemm, Klevers, ... '09-'11
Alim, Hecht, Jockers, Mayr, Mertens, ...

Conclusions / Summary

- In the absence of new electroweak physics at a TeV, the 'vacuum stability scale' ($\lambda(\mu) = 0$) may be a crucial hint at new physics
- Well-motivated guess: SUSY broken with $\tan\beta = 1$ at this scale
- Possible structural reason: shift symmetry in Higgs sector
- Interesting task: Explicit realization in D-brane models
- The very same stringy symmetry (but in a different sector) may be crucial to maintain flatness in Fluxbrane inflation