A Shift Symmetry for the Higgs and the Inflaton

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Outline

- The 125-GeV-Higgs (without SUSY) from a String-Pheno-Perspective

  ↪ 1204.2551 with A. Knochel & T. Weigand

- Main Idea: $\lambda = 0$ at some high scale ($\equiv$ ~~SUSY~~-scale) due to Shift-Symmetry in Higgs sector

- Stringy Origin of this Symmetry: mostly ↪ T. Weigand's talk

- Closely related: The very same symmetry may be responsible 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 ; 130-GeV-γ-line ; $h \to \gamma\gamma$ excess ...)

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

- Well-known: For low m_H, λ runs to zero at some scale $< M_P$

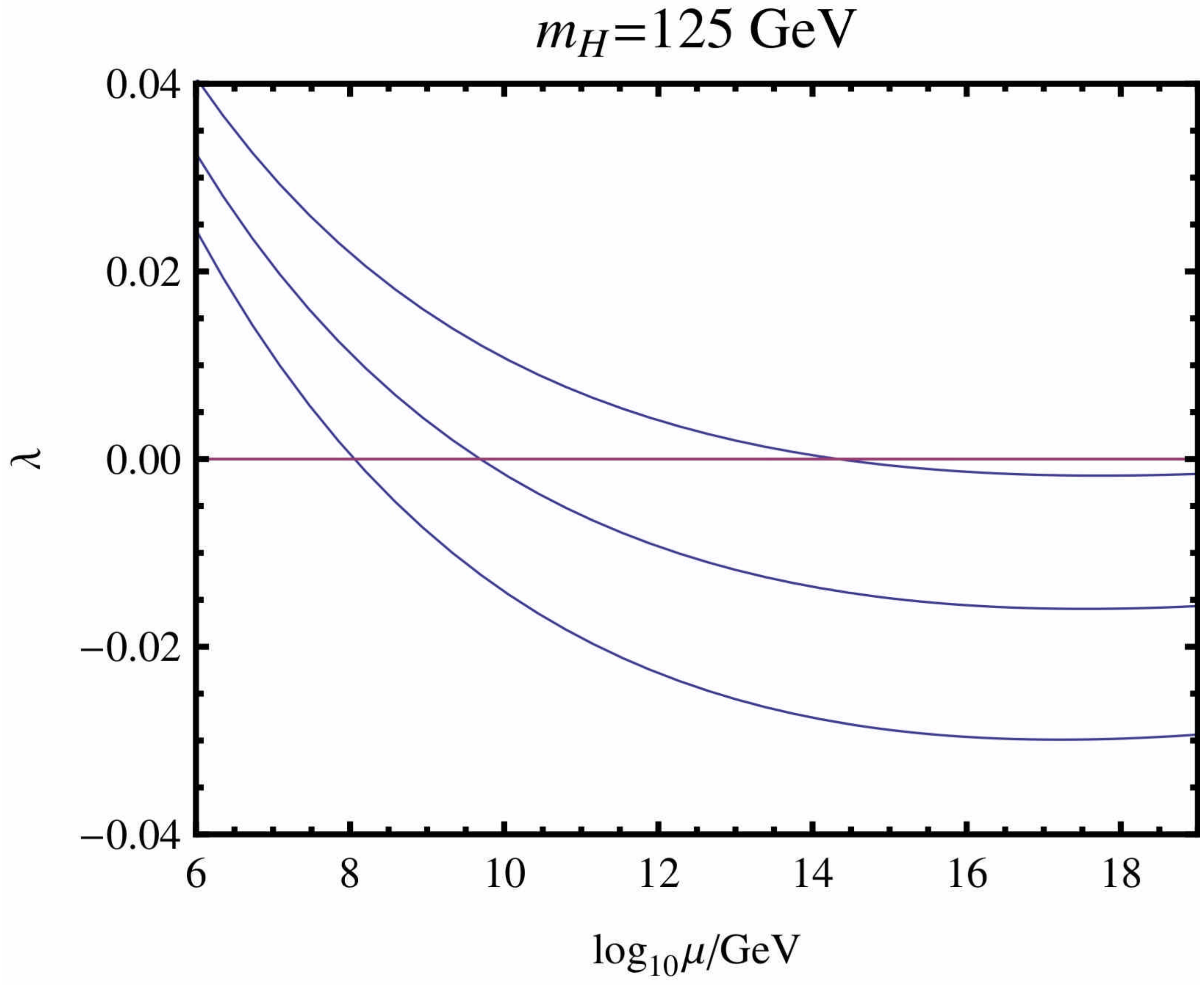
  ("vacuum stability bound")

(Lindner, Sher, Zaglauer '89 ... Gogoladze, Okada, Shafi '07 ...

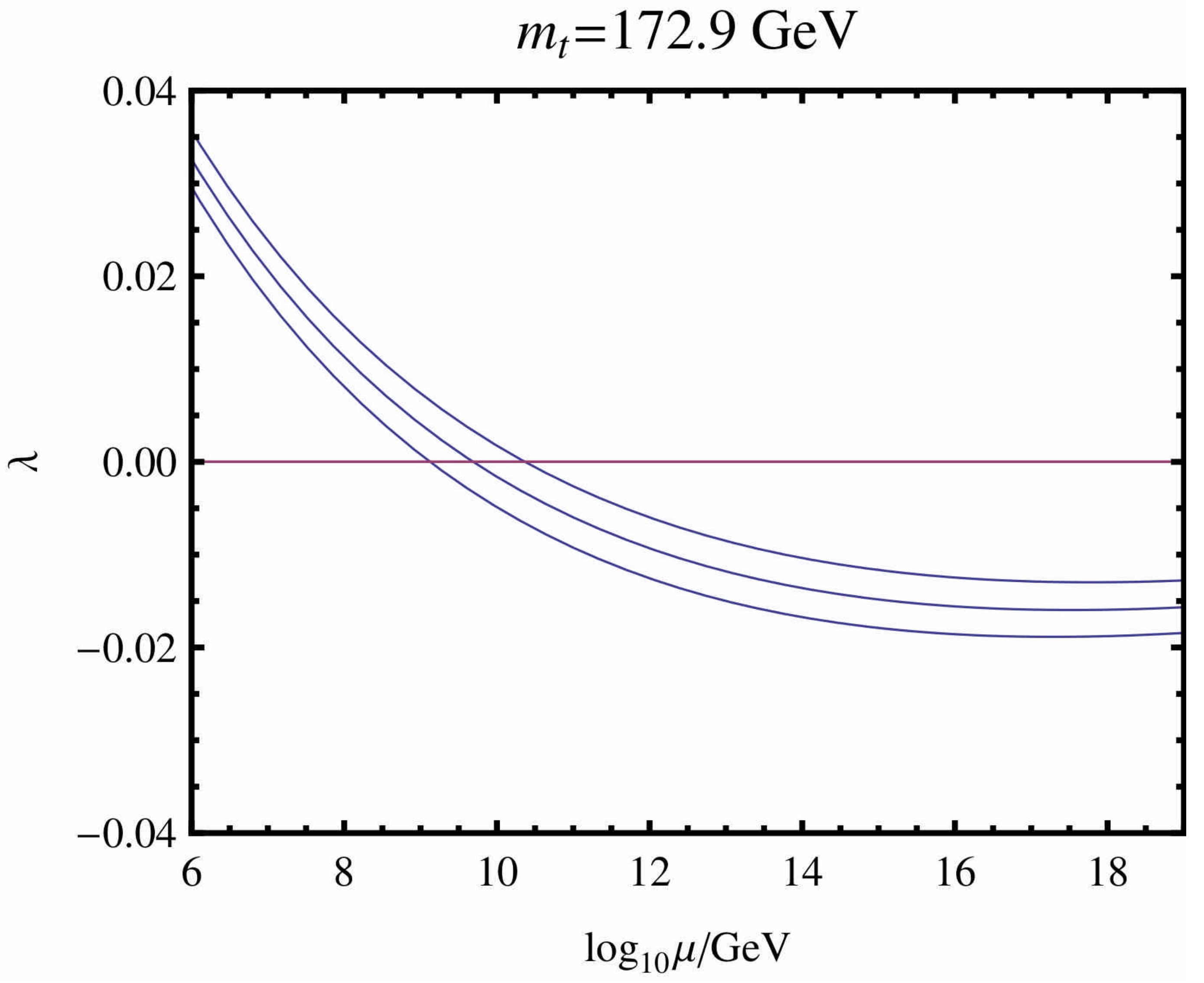
... Shaposhnikov, Wetterich '09 ... Giudice, Isidori, Strumia, Riotto, ...)

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

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



Running of λ (for a ± 1 GeV variation of m_H)



String - Phenomenologist's perspective:

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

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

Recall:

$$M_H^2 = \begin{pmatrix} |\mu|^2 + m_{H_d}^2 & b \\ b & |\mu|^2 + m_{H_u}^2 \end{pmatrix} = \begin{pmatrix} m_1^2 & m_3^2 \\ m_3^2 & m_2^2 \end{pmatrix} \quad ; \qquad \sin 2\beta = \frac{2 m_3^2}{m_1^2 + m_2^2}$$

- Obviously, high-scale-~~SUSY~~ has been considered before

  (↪ e.g. Arkani-Hamed/Dimopoulos; Giudice/Romanino '04)

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

  (↪ e.g. 140 GeV-prediction of Hall/Nomura '09)

- Our goal: Identify a special structure / symmetry leading unambiguously to $\tan\beta = 1$ (i.e. $\lambda = 0$)

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

Shift-Symmetry

$$K \sim |H_u + \bar{H}_d|^2$$

Lopes-Cardoso, Lüst, Mohaupt '94
Antoniadis, Gava, Narain, Taylor '94
Brignole, Ibanez, Munoz, Scheich '95-'97

- In more detail: $K_H = f(s,\bar{s})\,|H_u + \bar{H}_d|^2 + \cdots$

$$\Big\downarrow \quad F_s \neq 0 \;;\; m_{3/2} \neq 0$$

$$m_1^2 = m_2^2 = m_3^2 = \boxed{|m_{3/2} - \bar{F}^s f_{\bar{s}}|^2 + m_{3/2}^2 - F^s \bar{F}^{\bar{s}} (\ln f)_{s\bar{s}}}$$

- This shift-symmetric Higgs-kähler-potential has been later rediscovered / reused in orbifold GUTs

[K. Choi et al., '03
A.H., March-Russell, Ziegler '08,
Brümmer et al '09 - '10
Lee, Raby, Ratz, ... '11]

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

$$5d\text{-}SU_6 \longrightarrow SU_5 \times U_1 \;;\quad 35 = 24 + \underbrace{5 + \bar{5}}_{\text{Higgs} \,\hat{=}\, \Sigma + iA_5} + 1$$

(cf. Gogoladze, Okada, Shafi)

Comments:

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

(heterotic WLs ↔ IA/D6-WLs ↔ IB/D7-WLs …)

↪ Talk of T. Weigand

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

Ibanez, Marchesano, Regalado, Valenzuela, 1206…

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

↪ Chatzistavrakidis, Erfani, Nilles, Zavala, 1207…
Higaki, Kamada, Takahashi 1207…

Corrections ? Precision ?

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

[Shift-symm. is exact (gauge-symm.!) in 10d.
The shift corresponds to switching on a WL, which is not a symmetry in 4d.
4d-zero-modes "feel" the WL and their loops break the symmetry.]

⇒ Optimistic approach to estimating the "Goodness" of our symmetry:

$$m_c \underbrace{\gg}_{\text{symm.- violating running}} m_s \quad \Rightarrow \quad \delta \sim \underbrace{\ln(m_c/m_s)}_{\text{set this} \sim O(1)}$$

$$M_H^{\,2} = \underbrace{\left(|\mu|^2 + m_H^2\right)\begin{pmatrix}1 & 1\\ 1 & 1\end{pmatrix}}_{\text{symmetric}} + \underbrace{\begin{pmatrix}\delta|\mu|^2 + \delta m_{H_d}^2 & \delta b\\ \delta b & \delta|\mu|^2 + \delta m_{H_u}^2\end{pmatrix}}_{\text{loop - violation}}$$

- leading effects: y_t & gauge

$$\hookrightarrow \quad \delta M_H^2 = f(\epsilon_y \, ; \, \epsilon_g)$$

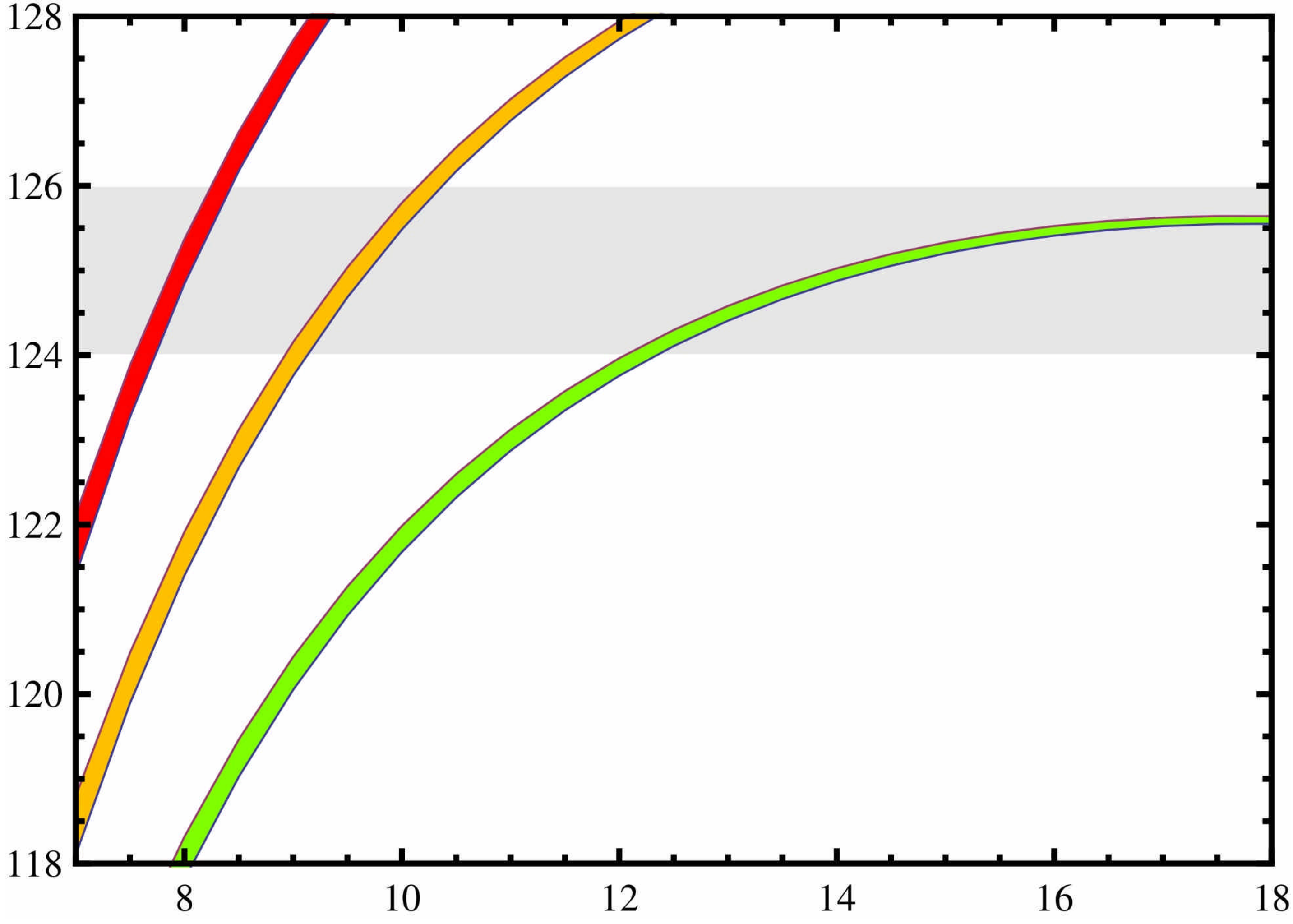
$$\uparrow$$

$$\epsilon_y \equiv \int_{\ln m_c}^{\ln m_s} \frac{6|y_t|^2}{16\pi^2}\, dt$$

- Enforce det $M_H^2 = 0$ after corr.s $\longrightarrow$ ϵ_y & ϵ_g related

$$\longrightarrow \quad \underline{\underline{\cos 2\beta = \epsilon_y \cdot \begin{Bmatrix}\text{calculable}\\ O(1)\text{- factor}\end{Bmatrix}}}$$

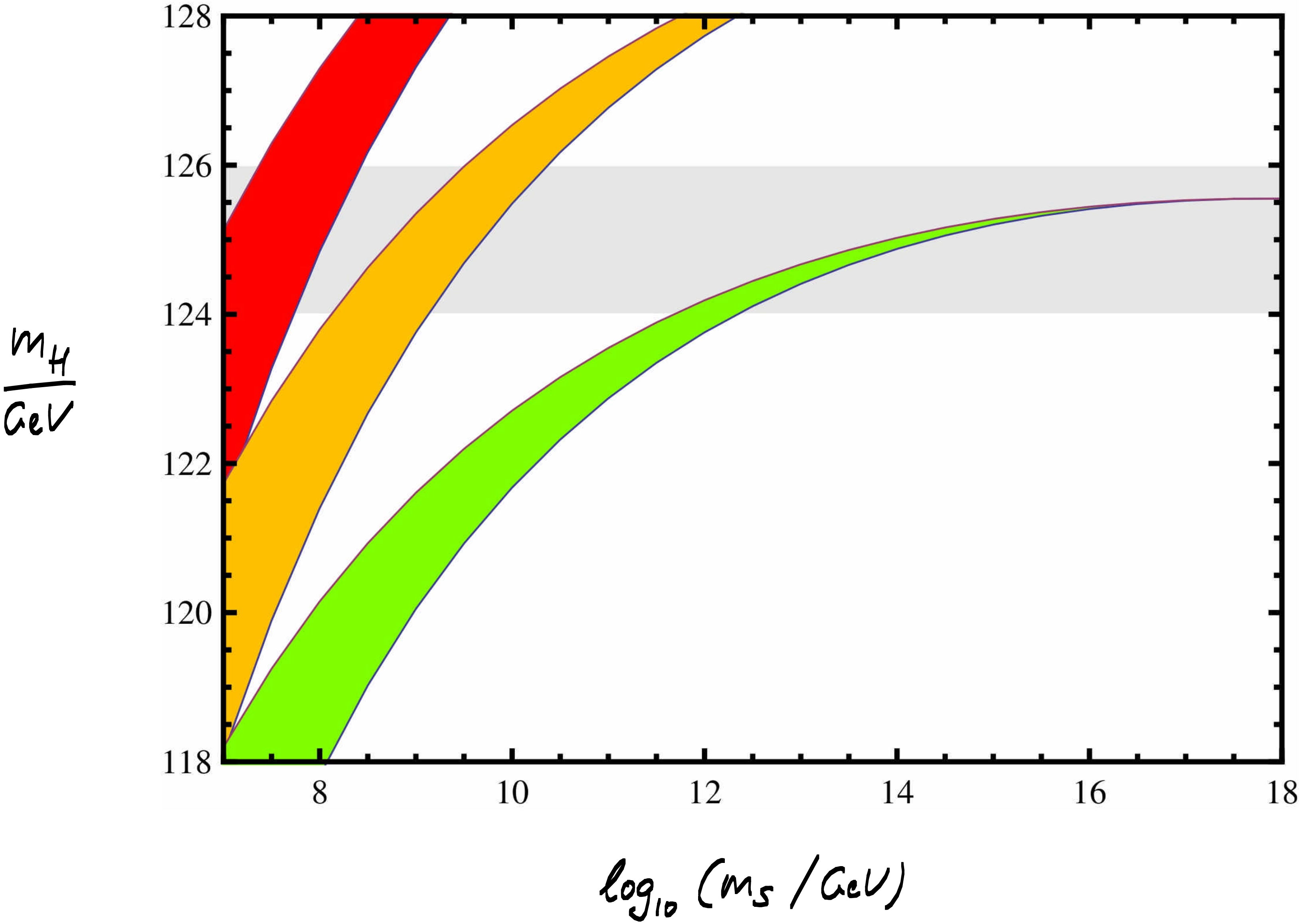
Assumption: $m_s \leq m_c \leq 100\, m_s$



$\frac{m_H}{\mathrm{GeV}}$

$\log_{10} (m_s / \mathrm{GeV})$

Assumption: $m_s \leq m_c \leq \sqrt{m_s M_P}$

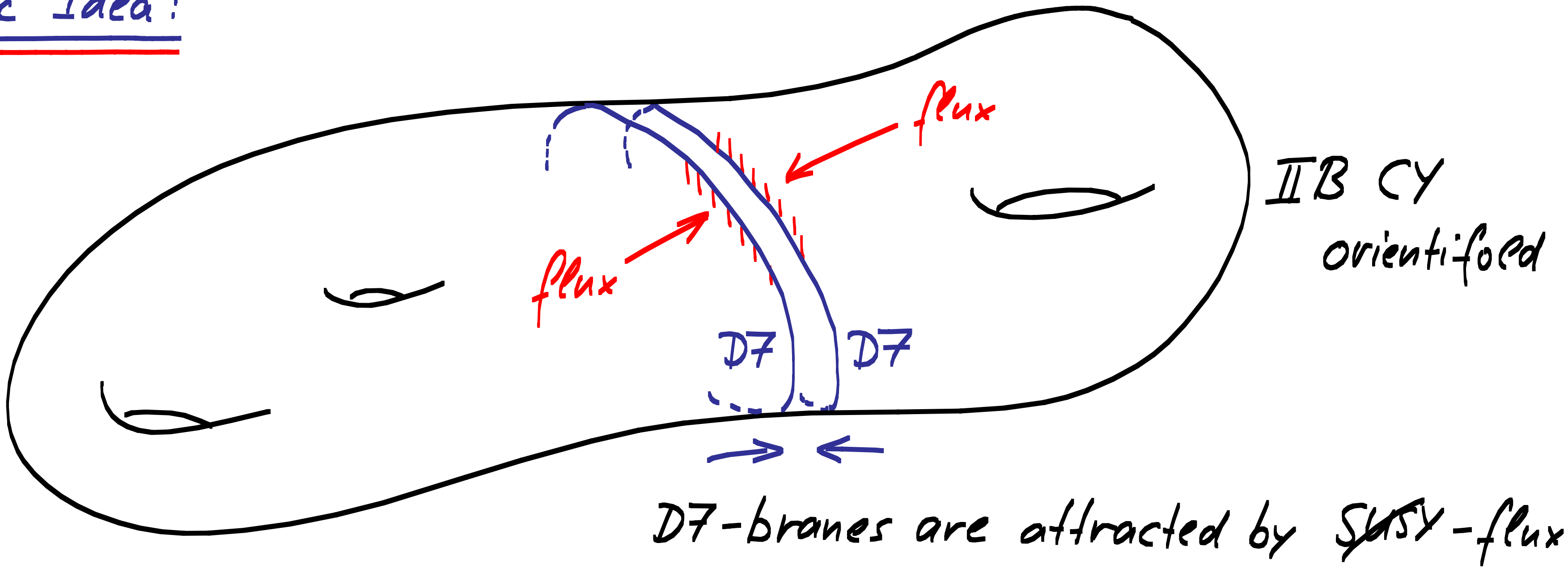


... and now for something (apparently) completely different:

Fluxbrane Inflation & Shift Symmetry

based on work with – Kraus, Lüst, Steinfurt, Weigand – 1104...
... + Küntzler – 1207...
... + Arends, Heimpel, Mayrhofer, Schick – ...

Basic Idea:



D7-branes are attracted by ~~SUSY~~-flux, which eventually annihilates (reheating)

To appreciate the technical advantages recall:

- Dp - $\overline{Dp}$ - inflation generically does not work

  [Burgess et al., '01]

- The "standard" way out is warping

  [KKLMMT, '03]

- However, the D3-moduli-space is the CY itself (no isometries → no shift symm.). This spoils flatness.

Here:

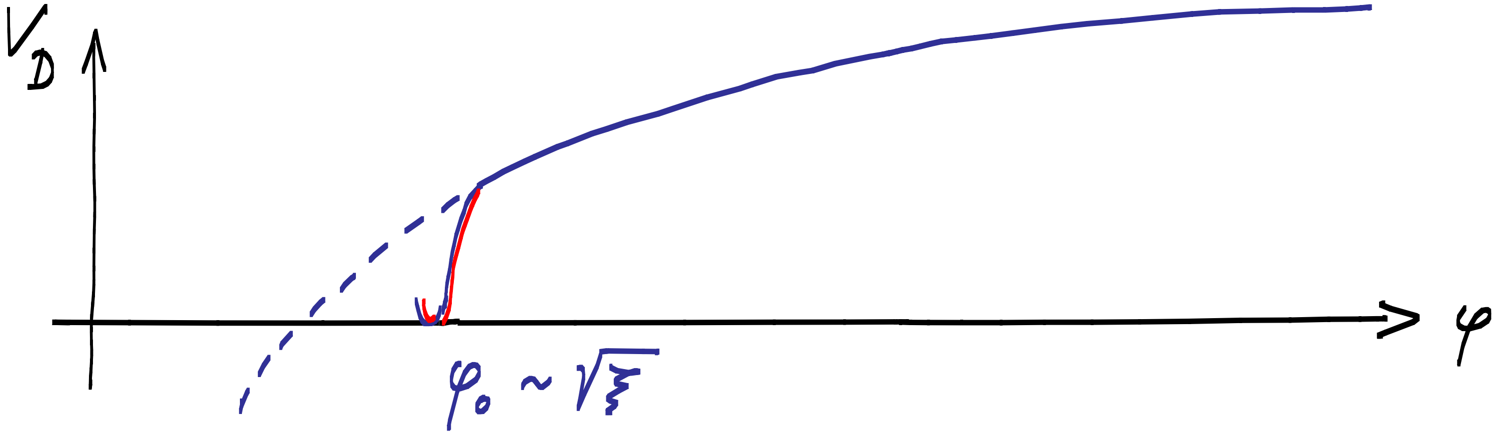
- Inflaton-kinetic-term ~ D7-brane-mass
- Inflaton-potential ~ Flux [cf. D3/D7 of Dasgupta et al. '02]

  ↪ Naturally flat (leading-order) potential

- Fluxbrane inflation has a well-understood SUGRA-description:

(Binetruy/Dvali, Halyo)

$$V_D = \frac{1}{2} g^2 \xi^2 \left(1 + c \cdot \frac{g^2}{16\pi^2} \cdot \ln(\varphi/\varphi_0)\right)$$



$\xi \sim \frac{\int J \wedge F}{\mathcal{V}_{CY}}$ – sets the scale (must be small to describe CMB)

$g^2 \sim 1/\mathcal{V}_{D7}$ – automatically small too

$c \sim (\int J \wedge F)^2/\mathcal{V}_{D7}$ – in general $O(1)$ number

- One easily finds

$$\left(\frac{\Delta T}{T}\right)_{CMB} \sim \frac{V^{3/2}}{V'} \sim \xi \sim \mathcal{V}_{CY}^{-2/3} \quad \Rightarrow \quad \mathcal{V}_{CY} \sim 10^6$$

- Thus, we need to appeal to the "Large Volume Scenario" for stabilisation:

$$V = \underbrace{V_D}_{\text{see above}} + \underbrace{V_F}$$

- G_3-flux
- $\underbrace{\alpha' + \text{non-pert.} + g_s\text{-corrs.}}_{\text{to stabilise all Kähler moduli}}$

[Balasubramanian, Berglund, Conlon, Quevedo, Suruliz - '05]

Two problems:

- Cosmic string bound marginally violated (generic issue in D-term-infl.)
- We are dealing with D-term-uplifting of non-SUSY-AdS

  (problematic, since generically $V_D \gg V_F$ ⇒ instability)

Our solution:

- Use hierarchical version of Large Volume Stabilization

  ↓

$$\frac{\left(\int J \wedge F\right)^2}{\int J \wedge J} \ll 1$$

[cf. Cremades, García del Moral, Quevedo '07
Krippendorf, Quevedo
Cicoli, Goodsell, Jäckel, Ringwald '11
Cicoli, Krippendorf, Mayrhofer, Quevedo, Valandro]

by using two large 4-cycles with $\tau_2 \ll \tau_1$.

- However, after all this is done, "usual" η-problem is still unsolved:

$$V_D \sim V_F \quad ; \quad V_F \sim e^{K}\left(|DW|^2 - 3|W|^2\right)$$

$$K = -\ln\big(S + \bar{S} + \underbrace{k(\varphi,\bar{\varphi})}_{}\big) + \cdots$$

generically induces

$$\eta = \frac{V''}{V} = O(1)$$

- Our (proposed) solution:

go to region of moduli space where $k \approx k(\varphi + \bar{\varphi})$

(approximate shift symmetry in D7-moduli-space)

Why should this be possible ?

On Tori:

Fluxbrane inflation is T-dual to "Inflation from branes at angles"

[Garcia-Bellido, Rabadan, Zamora]

and to (stringy) "Wilson line inflation"

[Avgoustidis, Cremades, Quevedo]

On CY:

Fluxbrane inflation (large complex structure) is mirror-dual to a IIA-model (large volume) with $\underbrace{\text{shift-symmetric WLs}}_{\text{as in Higgs proposal above...}}$

Summary / Conclusions

- In the absence of new electroweak physics at a TeV, the vacuum stability scale ($\lambda(\mu) = 0$) is a crucial hint at new physics.

- Well-motivated guess: ~~SUSY~~ with $\tan\beta = 1$ at this scale

- A possible structural reason: Shift-Symmetry in Higgs sector

  (Predictivity, i.e. $m_H + \alpha_s + m_t \Rightarrow m_s$, remains strong even if symmetry is "poor")

- The very same stringy symmetry (but in a different sector) may be crucial to maintain flat potential in FLUXBRANE INFLATION