Fluxbrane Inflation and the "125-GeV-Higgs"

based on work with:
- Kraus, Lüst, Steinfurt, Weigand – 1104....
  ...., Küntzler – 12...
- Knochel, Weigand – 1204....
- ...., Arends, Heimpel, Mayrhofer, Schick, ... – 12...

Outline

- The famous no-go-theorem for brane-inflation and how it is avoided in fluxbrane inflation
- Cosmic strings, moduli stabilization
- Flat direction from shift symmetry
- What does any of this have to do with the Higgs?

Introduction

- $\bar{M}_p = 1$; $\mathcal{L} = \frac{1}{2}(\partial\varphi)^2 - V(\varphi)$

- Goal: $\sqrt{\epsilon} \sim V'/V \ll 1$

  $\eta \sim V''/V \ll 1$

  $N \sim \int d\varphi \frac{V}{V'} \sim 60$

- This is easy to get for "natural functions V" (powers, logs, ...)

  if $\varphi \gg 1$

  & higher-dim. operators are suppressed

- Whether this is possible/natural is hard to argue just in FT.

Introduction - continued

- In ST, the construction of such "large-field" or "chaotic" models has been attempted

  [e.g. "N-flation", Dimopoulos et al.
  "Monodromy...", Silverstein/Westphal ...]

- However, serious doubts exist

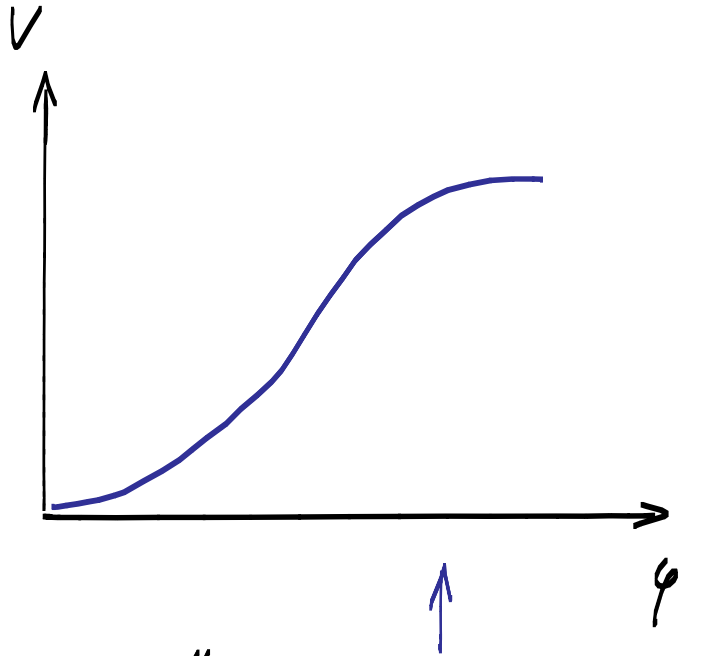
  [e.g. Conlon, '11 .. '12]

- Here, I will ignore "$\varphi \gg 1$" models as well as many other "exotic" ideas (DBI inflation, etc. ...)

- The focus will be: $\boxed{\varphi \ll 1 \;;\; \text{single-field} \;;\; \text{slow-roll}}$

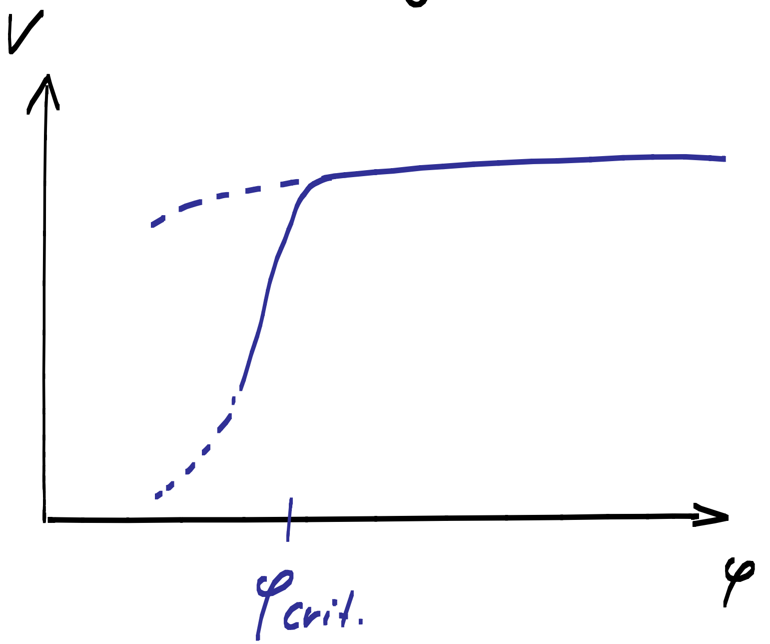
Introduction – continued

- In FT, the method of choice is "hybrid inflation" or "D-term inflation" or "shift symmetries"



$$\frac{V''}{V} \sim \frac{1}{\varphi^2} \gg 1$$

unless severely tuned



shift-symmetric region

Introduction – continued

- In FT, both the "tuned" and the "hybrid / shift-symm." approach are viable
- The challenge is the ST realization
- I will ignore interesting work in the "first approach" (?)

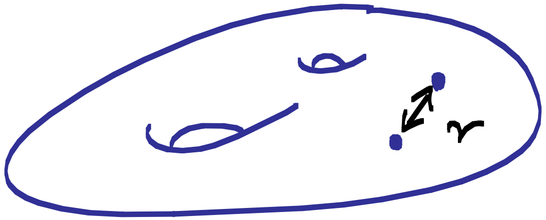
  [e.g. "Kähler moduli inflation", Cicoli, Burgess, Quevedo, ...]
- The focus will be on "Stringy Hybrid Inflation",

  in particular: Brane Inflation

  [Dvali, Tye ;
  Burgess, Majumdar, Nolte, Quevedo, Rajesh, Zhang ;
  Shiu, Tye ; ...]

Recall the

no-go theorem



volume $\mathcal{V}$

$\ell_s = 1$

$$\mathcal{L} \sim g_s^{-2}\, \mathcal{V}\, \mathcal{R} + g_s^{-1}\, \mathcal{V}_{\parallel} \left[(\partial r)^2 - \left(A - B \frac{g_s}{r^{d_\perp - 2}} \right) \right]$$

$$\Downarrow$$

$$\boxed{-\eta \sim \frac{B}{A} \cdot \left(\frac{L_\perp}{r} \right)^{d_\perp}}$$

$$\mathcal{V} = \mathcal{V}_{\parallel} \cdot L_\perp^{d_\perp}$$

Standard Core (KKLMMT): $B/A \ll 1$ due to strong warping

However:

- D3 moduli space is the CY $\Rightarrow$ generically no isometries
- Thus moduli stabilization will destroy flatness
- Need to fine-tune various contributions
  $\rightarrow$ "inflection point inflation"

[e.g. Baumann, McAllister, ...]

Alternatives:

- Inflation from branes at angles [Garcia-Bellido, Rabadan, Zamora]
- D3/D7 inflation [Dasgupta, Herdeiro, Hirano, Kallosh]
- Wilson line inflation [Avgoustidis, Cremades, Quevedo]

... will compare to our proposal below ...

Our main idea:

$$\boxed{\begin{array}{c}\text{brane - antibrane pair}\\ \Downarrow \\ \text{brane - brane pair with gauge-flux } F \text{ \& } -F\end{array}}$$

- attractive force is due to flux $\qquad B \sim |F|^4 \quad$ (not $|F|^2$!)

- when branes collide, only the flux is annihilated $\qquad A \sim |F|^2$

$$-\eta \sim \frac{B}{A}\left(\frac{L_\perp}{r}\right)^{d_\perp} \sim |F|^2\left(\frac{L_\perp}{r}\right)^{d_\perp}$$

$$\Rightarrow \quad -\eta \ll 1$$

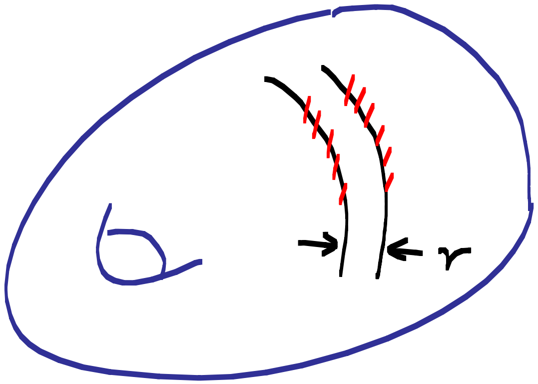
("large volume" has replaced "strong warping")

More motivation:

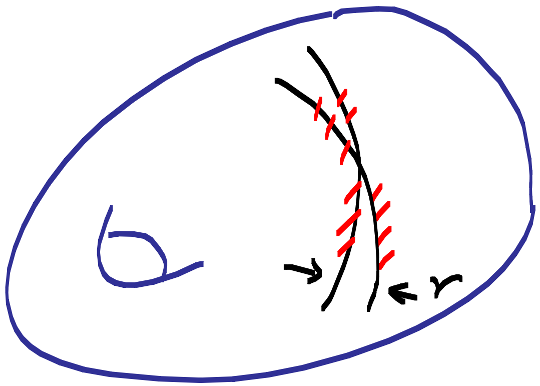
- We want to work in type IIB / F-theory flux landscape
  (moduli stabilization & SUSY-breaking relatively well understood, tuning of cosmol. constant doable, attractive particle phenom.)

- Hence: fluxed D7-branes ; $d_\perp = 2$

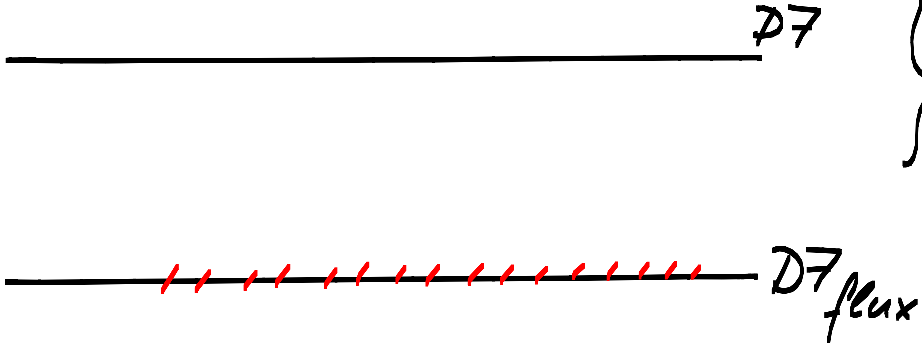
- Geometric setting:



vs.



10d Supergravity calculation



$$ds^2 = Z^{-1/2} ds_{\parallel}^2 + Z^{1/2} ds_{\perp}^2$$

$$Z = 1 - \frac{g_s}{2\pi} \ln \frac{r}{R}$$

$$S_{DBI} \sim \int e^{-\phi} \sqrt{-\det(g + F)}$$

$$\Downarrow$$

no force at $O(F^2)$!

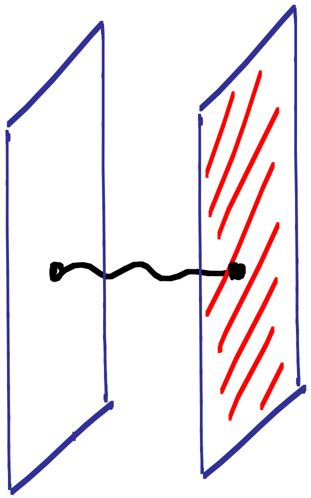
(<u>Intuitively</u>: Higher-dim. analogue of scale-inv. of Electrodyn.)

- No cancellation at next order. Hence:

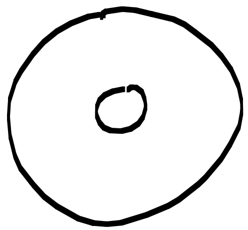
$$\boxed{V \sim F^4 \ln(r/R)}$$

- Next, we repeat this analysis from the

string 1-loop perspective



$\Rightarrow$



annulus (with flux-modified boundary conditions)

$\Rightarrow$ This precisely reproduces the 10d-sugra result above

But now we know it holds also for $r \ll 1$!

Generic CY result

- The F^2-term gives

$$V = \frac{1}{2} g_{YM}^2 \xi^2 \qquad \text{with} \qquad \frac{1}{g_{YM}^2} \sim \int J \wedge J$$

$$\xi \sim \frac{1}{\mathcal{V}} \int J \wedge F$$

- Including the crucial F^4-term, we find

$$\boxed{V = \frac{1}{2} g_{YM}^2 \xi^2 \left[1 + \frac{1}{4} \left\{ \frac{\left(\int J \wedge F\right)^2}{\left(\frac{1}{2}\int J \wedge J\right)^2} - 4 \, \frac{\left(\frac{1}{2}\int F \wedge F\right)^2}{\frac{1}{2}\int J \wedge J} \right\} \frac{1}{2\pi} \ln (r/R) \right]}$$

This can be written as

$$V = \frac{1}{2} g_{YM}^2 \xi^2 \left[1 + \frac{g_{YM}^2}{16\pi^2} \cdot c \cdot \ln(\varphi/\varphi_0) \right]$$

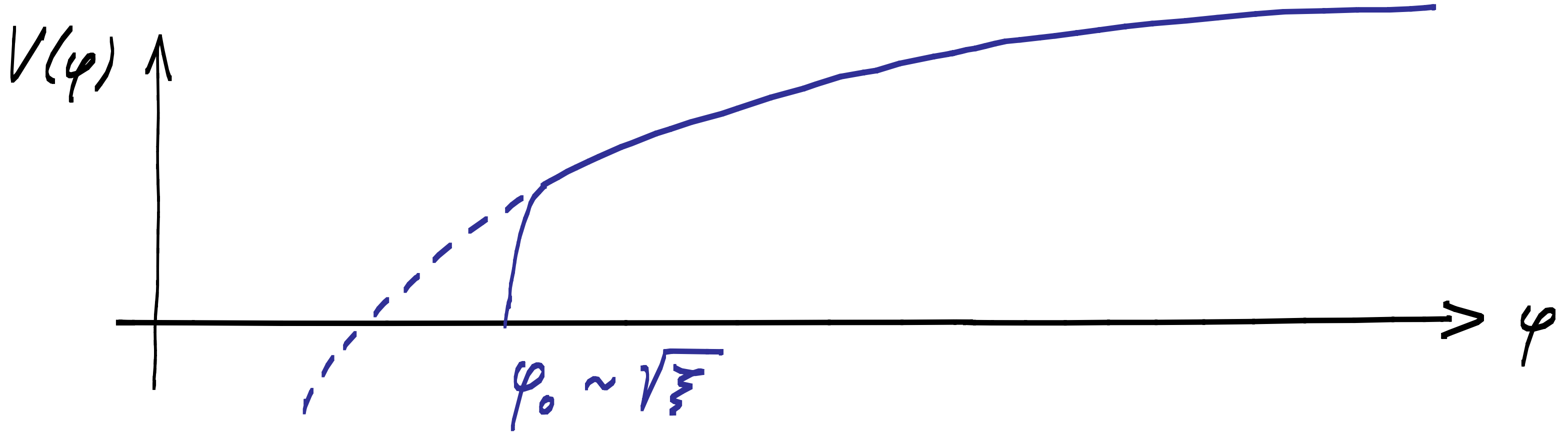
$$c = -2\int F^2 + \left(\int J \wedge F\right)^2 \Big/ \left(\tfrac{1}{2}\int J^2\right)$$

For $c \sim 1$, this is just the generic potential of D-term inflation.

Crucial: If Kähler moduli are appropriately stabilized and $\int F^2 = 0$, we can have $c \ll 1$.
This will allow us to evade the cosmic string bound.

Phenomenology

$$V = V_0 \left(1 + \alpha \ln(\varphi/\varphi_0)\right)$$



$$n_s \simeq 1 - \frac{1}{N} \simeq 0.983 \qquad (\text{WMAP 7: } 0.968 \pm 0.012)$$

$$\tilde{\xi}^2 = \frac{N \int J \wedge J}{2v^2} \qquad (\tilde{\xi}^2 \simeq 2 \cdot 10^{-8}) \qquad \Rightarrow \quad R \sim 10$$

$$\left(\int J \wedge \sqrt{F}\right)^2 \Big/ \tfrac{1}{2} \int J \wedge J \lesssim 0.1 \qquad (\text{Cosmic strings})$$

Moduli stabilization

- $\mathcal{V} \sim 10^6$ $\Rightarrow$ "LARGE volume" [Balasubramanian, Berglund, Conlon, Quevedo]

- in addition: "mild anisotropy" $\Rightarrow$ 3-modulus-models w/ loop corrections

  [Cicoli, Conlon, Quevedo; Cremades, Garcia del Moral, Quevedo, Suruliz]

Explicitly:

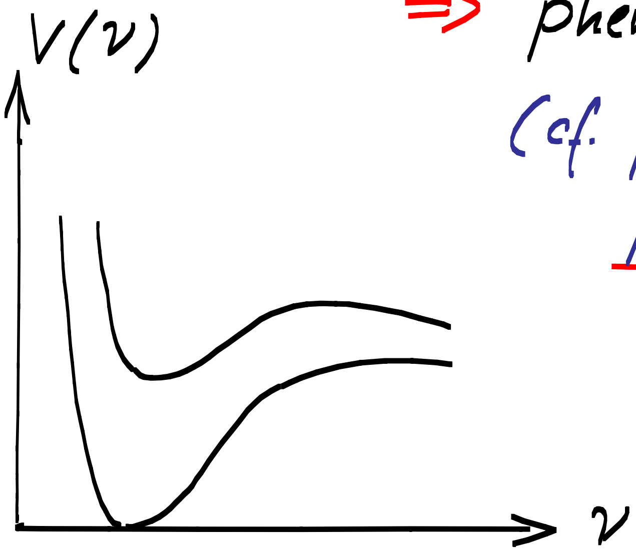
$$W = W_0 + e^{-\tau_s}$$

$$K = -2 \ln (\mathcal{V} + \xi) + \delta K_{loop}$$

where $\mathcal{V} \sim t_1^3 + t_1 t_2^2 - t_3^3$; $\delta K_{loop} \sim \frac{t_2}{\mathcal{V}} + \dots$

Outline of analysis:

- τ_s stabilized as in basic LARGE volume scenario
- $x \sim t_1/t_2$ stabilized by interplay of δV_{loop} & V_D
- $\Rightarrow \quad V(\mathcal{V}) \sim \frac{1}{\mathcal{V}^3}\left(1 + \ln(\mathcal{V})^{3/2} + \mathcal{V}^{5/9}\right)$
- Semi-analytical treatment possible



$\Rightarrow$ phenom. consistent stabilization is demonstrated (cf. paper in preparation & talk of S. Kraus in parallel session of String Pheno)

Flat direction / shift symmetry

- Choose flux such that $W_{\text{brane}} \sim \int_{C_5} \Omega \wedge F_2 \equiv 0$

- Of course, problem remains:

$$K = -\ln\left(S + \bar{S} - \underbrace{k(\zeta, \bar{\zeta})}_{\text{Kähler-pot. on D7-moduli-space}}\right) + \cdots$$

- Fact: For F-theory on $K3 \times K3$, on has $\boxed{k = k(\zeta + \bar{\zeta})}$

- Hope / Expectation (based on work in progress):

> This shift-symmetric structure will arise more generally, in certain regions of IIB moduli space

In more detail

- various T-duals of our "fluxed D7/D7 model" are possible
- brane-parallel direction $\xrightarrow{\text{T-dual.}}$ branes at angles
  (IIA variant of "Fluxbrane infl.")
- brane-perp. direction $\xrightarrow{\text{T-dual.}}$ brane-position becomes Wilson-line
- shift-symmetry (in IIA mirror at large volume) guaranteed
- expectation: shift-symmetry in D7-position-moduli-space
  in IIB at large complex structure
- critical issue: "goodness" of this symmetry in view of
  a) instanton- b) loop-corrections

... the Higgs ...

... shift-symmetric Kähler potentials are known, among many other cases, in heterotic orbifolds

[Lopes Cardoso, Lüst, Mohaupt '94
Antoniadis, Gava, Narain, Taylor :
Brignole, Ibanez, Munoz, Scheich '97]

- Specifically:

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

[cf. also 5d orbifold GUT / Wilson line persp.:

Choi et al. '03
A.H., March-Russell, Ziegler
Brümmer, Fichet, A.H., Krame]

- This means:

$$m_{Higgs}^2 \sim \begin{pmatrix} |\mu^2| + m_{H_d}^2 & B\mu \\ B\mu & \mu^2 + m_{H_u}^2 \end{pmatrix} \sim \begin{pmatrix} 1 & 1 \\ 1 & 1 \end{pmatrix}$$

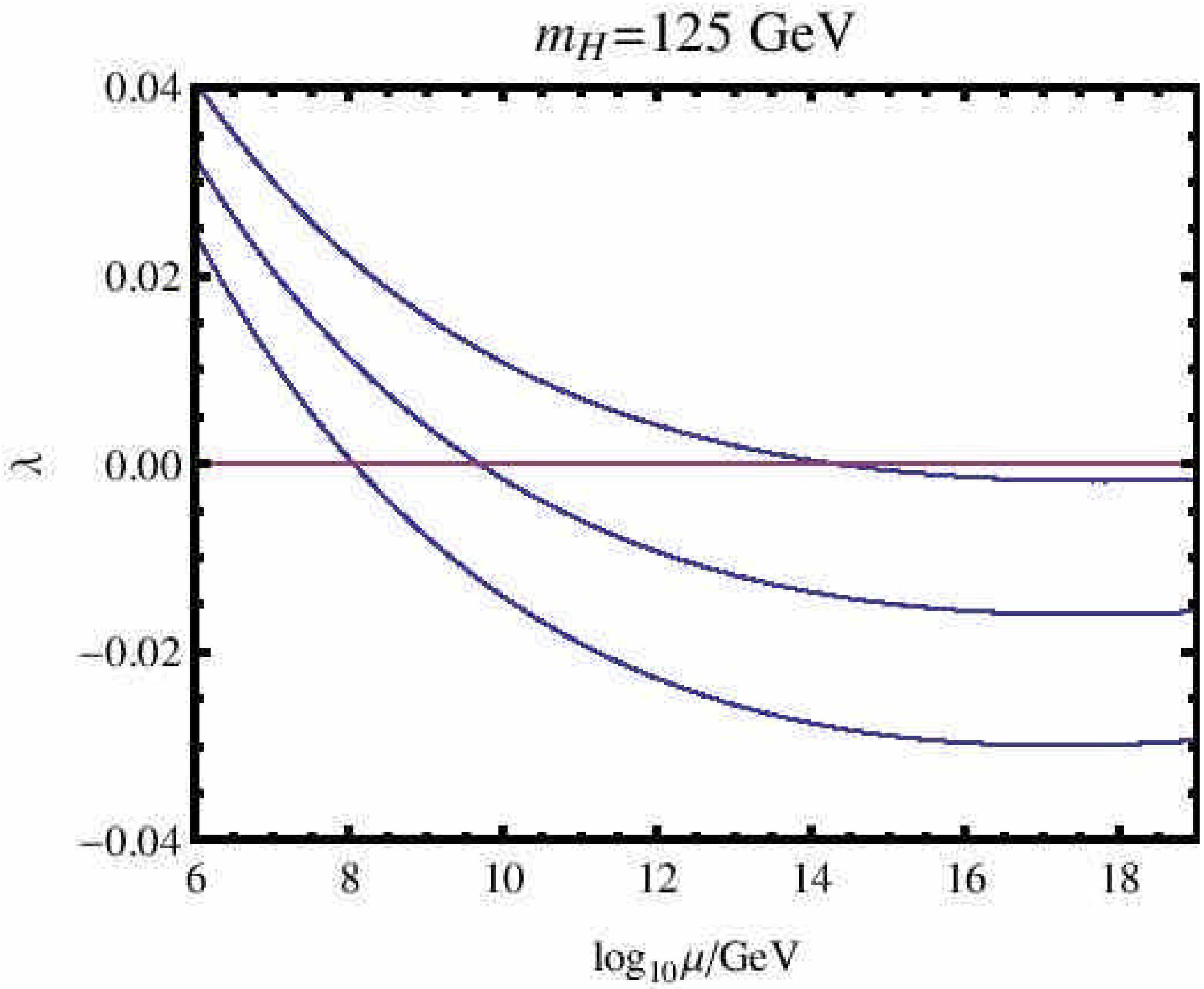
or:

$$\tan\beta \simeq 1$$

or: $$\lambda = \frac{1}{8}\left(g^2 + g'^2\right)\cdot \cos^2(2\beta) = \underline{\underline{0}}$$

- This may be just the right thing to look for, if $\underline{m_{SUSY}\ \text{is high}}$!

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



(cf. "Higgs mass predictions" of Gogoladze, Okada, Shafi ; Shaposhnikov, Wetterich)

Our suggestion / claim:

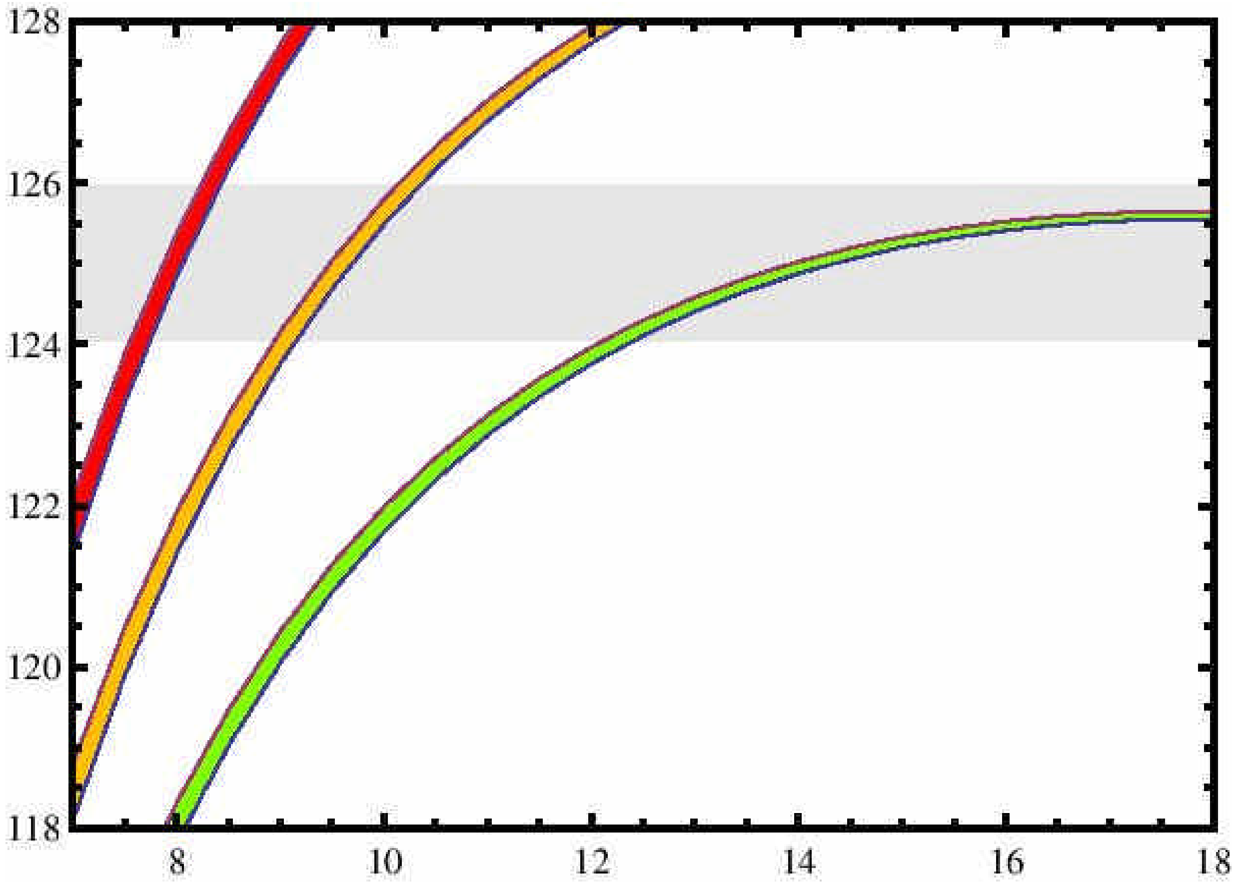
(A.H., Knochel, Weigand '12)

- The "125-GeV-Higgs" may be (in the absense of low-scale SUSY) a hint at a shift-symmetry in the Higgs-Kähler potential.
- Via branes-with-Wilson-lines / shift-symmetric brane positions this may be more generic than naively expected
- To make a "Higgs mass prediction", one needs the values of $\underbrace{m_c/m_s}_{O(1)\,?}$ & $\underbrace{m_s}_{\text{high}\,?}$ ...

  (if we ascribe shift-symm. violation only to loops)
- We consider the "prediction of m_s" as more plausible ...

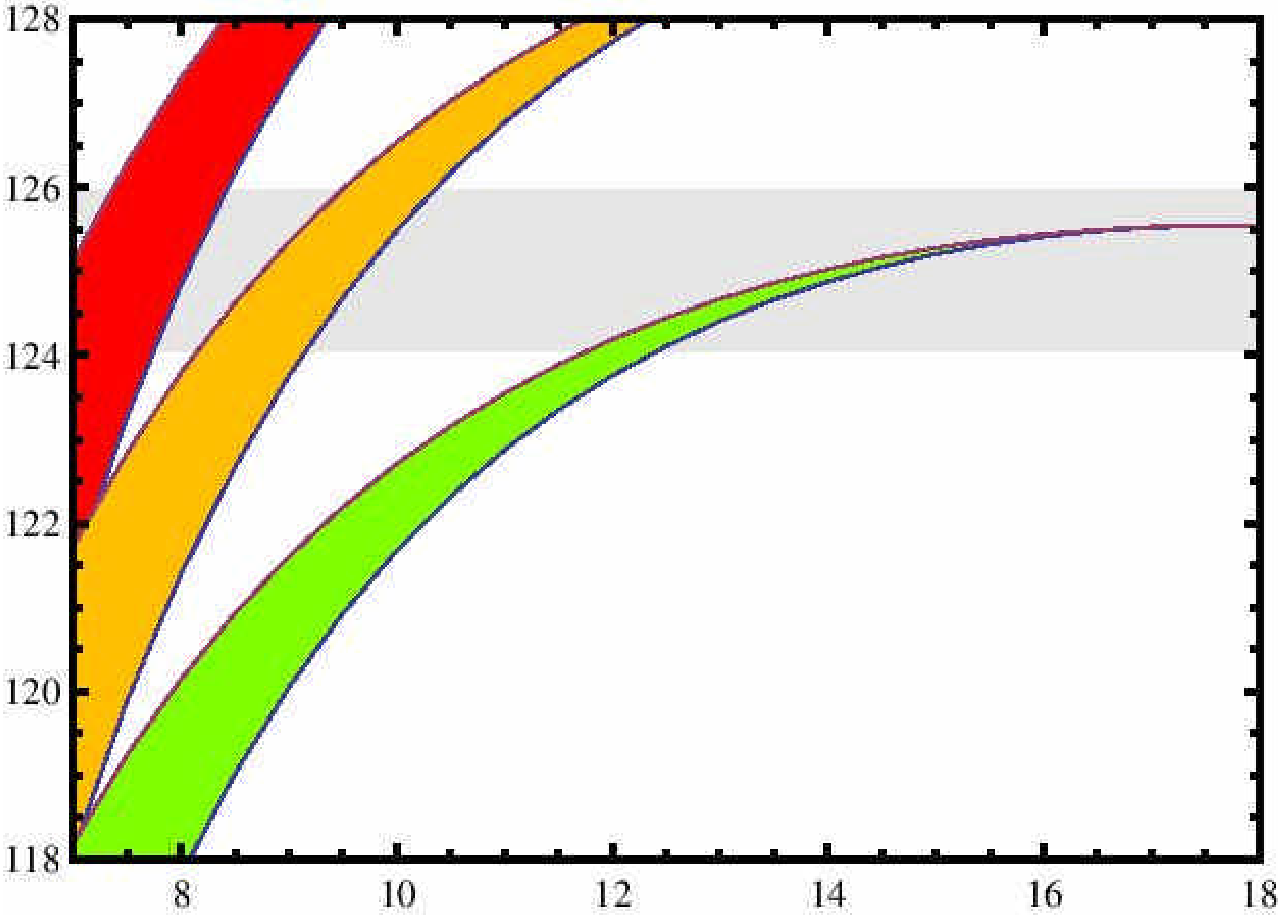
Assumption: $m_c \simeq 1 \cdots 100\ m_s$

$\frac{m_h}{GeV}$



$\log_{10} m_s / GeV$

Assumption: $m_c \simeq m_s \cdots \sqrt{m_s M_P}$



$\frac{m_h}{\text{GeV}}$

$\log_{10} m_s / \text{GeV}$

Summary / Conclusions

- Fluxbrane inflation offers a novel way to avoid the familiar no-go theorem of brane-inflation
- It may be a promising path to "stringy D-term inflation" (cf. cosmic strings!)
- It depends on an (approximate) shift-symmetry, the quality of which is still under investigation...
- Yet, even a rather poor shift-symm. of this type may be phenomenologically interesting in view of the "125-GeV-Higgs"