Higgs boson from an extended symmetry: elementary or composite?

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Barbieri, Bellazzini, R, Varagnolo (SNS, Pisa) arXiv:0706.0432

Motivations

General:

Extend the naturalness domain of the Standard Model
More concretely: address the *little hierarchy problem*

Specific:

Higgs boson as a PGB
Little Higgs
Composite Higgs
Intermediate Higgs

Strongly interacting Higgs
Higgs as A_5
Twin Higgs
……

Is there a simple and effective way to describe the relevant phenomenology?

[Giudice, Grojean, Pomarol, Rattazzi]
[Contino, Kramer, Son, Sundrum]

A softly broken SO(5) in top-Higgs sector

Another model? NO, SO(5) already discussed at length.

Agashe, Contino, Pomarol
Contino, Da Rold, Pomarol

Take it as an example of stripping the models to bare bones.

Plan:

1. "Minimal model" at strong coupling
2. Minimal model: perturbative

Discuss (in principle):

- spectrum
- naturalness
- → *EWPT*
- flavor and b-physics
- LHC phenomenology (but only if all other things are OK)

Minimal model @ strong coupling

Standard Model: $\phi_{i=1,\ldots,4} \Rightarrow SO(4)$

Extend to SO(5) broken to SO(4): $\hat{\phi}_{i=1,\ldots,5}$ *with* $\hat{\phi}^2 = f^2$

$$\hat{\phi} = \begin{pmatrix} \phi \\ \\ \hat{\phi}_5 \end{pmatrix}$$

← SO(4) ⊃ [SU(2)xU(1)]$_{SM}$

(SM gauge group not extended)

What matters for EWSB is the orientation:

$\langle\hat{\phi}\rangle = (0,0,0,0,f)$ - *No EWSB*

$\langle\hat{\phi}\rangle = (f,0,0,0,0)$ - *Maximal EWSB:* $v = \sqrt{2}f$

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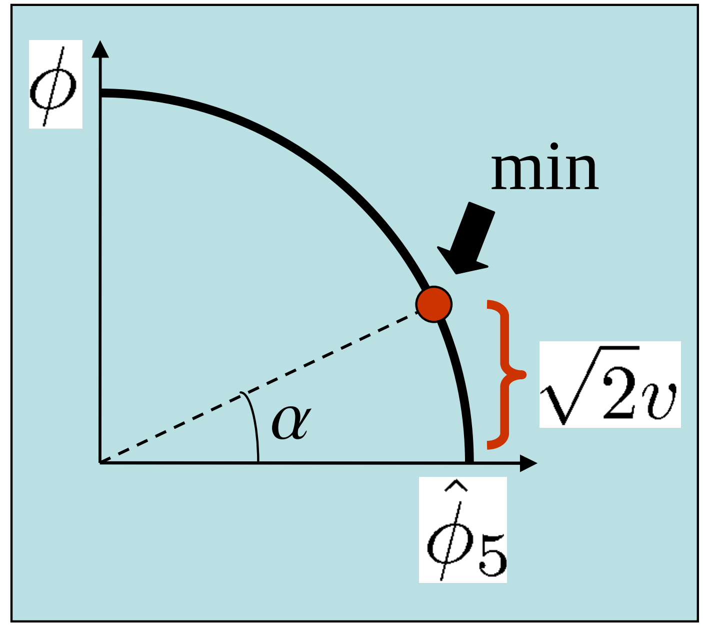
Higgs VEV stabilization [Agashe, Contino, Pomarol]

Minimize potential: *SO(5) + soft breaking*

$$V = \delta(\hat{\phi}^2 - f^2) - Af^2\phi^2 - Bf^3\hat{\phi}_5$$

pushes ϕ | pushes ϕ_5

(SO(5)-breaking quartic $\lambda\phi^4$ small; plays no role)



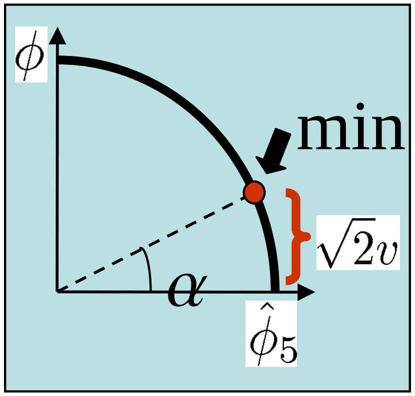
1. we find: $<\phi^2> \equiv 2v^2 = f^2[1-(\frac{B}{2A})^2]$ $\quad v = 175\ GeV$

2. v<<f requires tuning B/2A≈1: $\Delta = \frac{A}{v^2}\frac{\partial v^2}{\partial A} \simeq \frac{f^2}{v^2}$

12% finetune *f*=500 GeV
3% finetune *f*=1 TeV

Better use f ≲500 GeV if want to compete with MSSM

Reduced Higgs couplings and UV cutoff



$$m_h = 2\sqrt{A}v$$

$$\sin\alpha = \sqrt{2}v/f$$

Couplings hVV and h$\psi\psi$ are reduced by cos α (=0.75 for f=500 GeV)

$$\mathcal{A}(W_L W_L \to W_L W_L) = -\frac{G s}{\sqrt{2}} \sin^2\alpha (1+\cos\theta)$$

$$s_c = \frac{s_c^{SM}}{\sin^2\alpha} \approx (2.4\ TeV)^2$$

(for f=500 GeV)

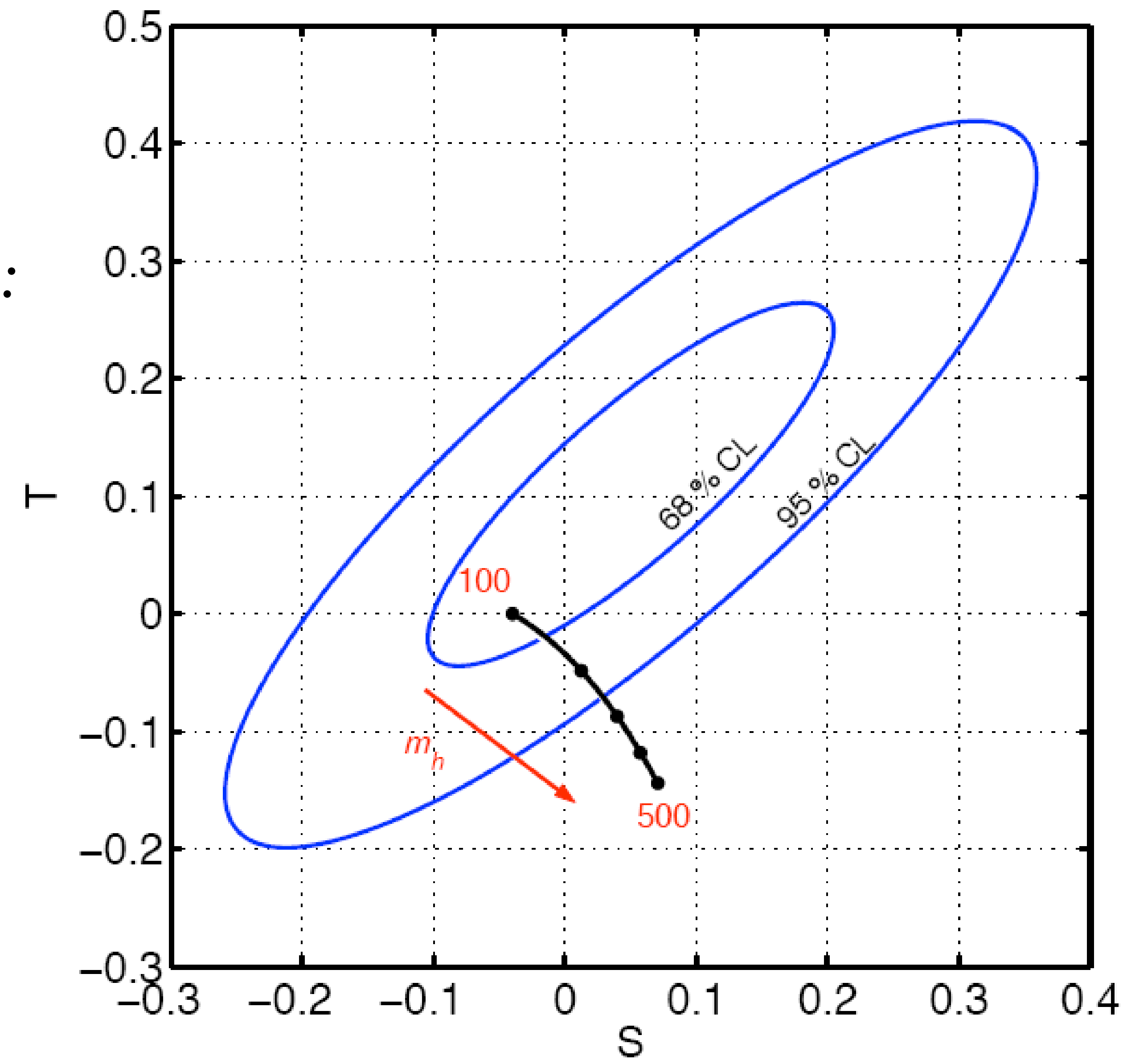
Agrees with the NDA estimate for the strong coupling cutoff:

$$\Lambda_{\rm NDA} = \frac{4\pi f}{\sqrt{N_g}}$$

N_g=4 - # of Goldstones for SO(5)/SO(4)

How about the EWPT?

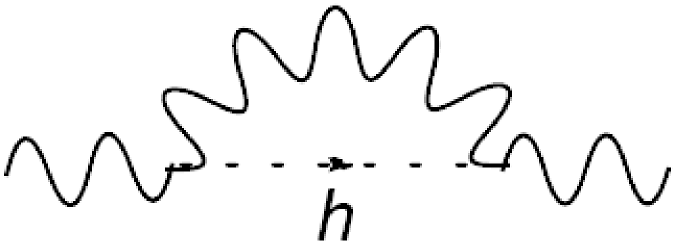
Consistency of the standard Higgs boson with the precision data:



m_h<144 GeV @ 95%

LEPEWWG

1. IR effect in T,S



$$\widehat{S},\widehat{T}|_{SM} = a_{S,T}\log m_H + b_{S,T}$$

$$\widehat{S},\widehat{T}|_{this-model} = a_{S,T}[(\cos\alpha)^2\log m_h + (\sin\alpha)^2\log\Lambda] + b_{S,T}$$

$$= (\hat{T},\hat{S})|_{SM}(m_{EWPT,eff})$$

$$m_{EWPT,eff} = m_h(\Lambda/m_h)^{\sin^2\alpha}$$

For f=500 GeV,
$\sin^2\alpha$=0.25, Λ=2.5 TeV:

$m_{h,}$ GeV	114	200	300	…
$m_{EWPT,eff}$	250	380	500	

Would need f=1 TeV to make $m_{EWPT,eff}$<144 GeV !

2. UV effect in S and request for ΔT

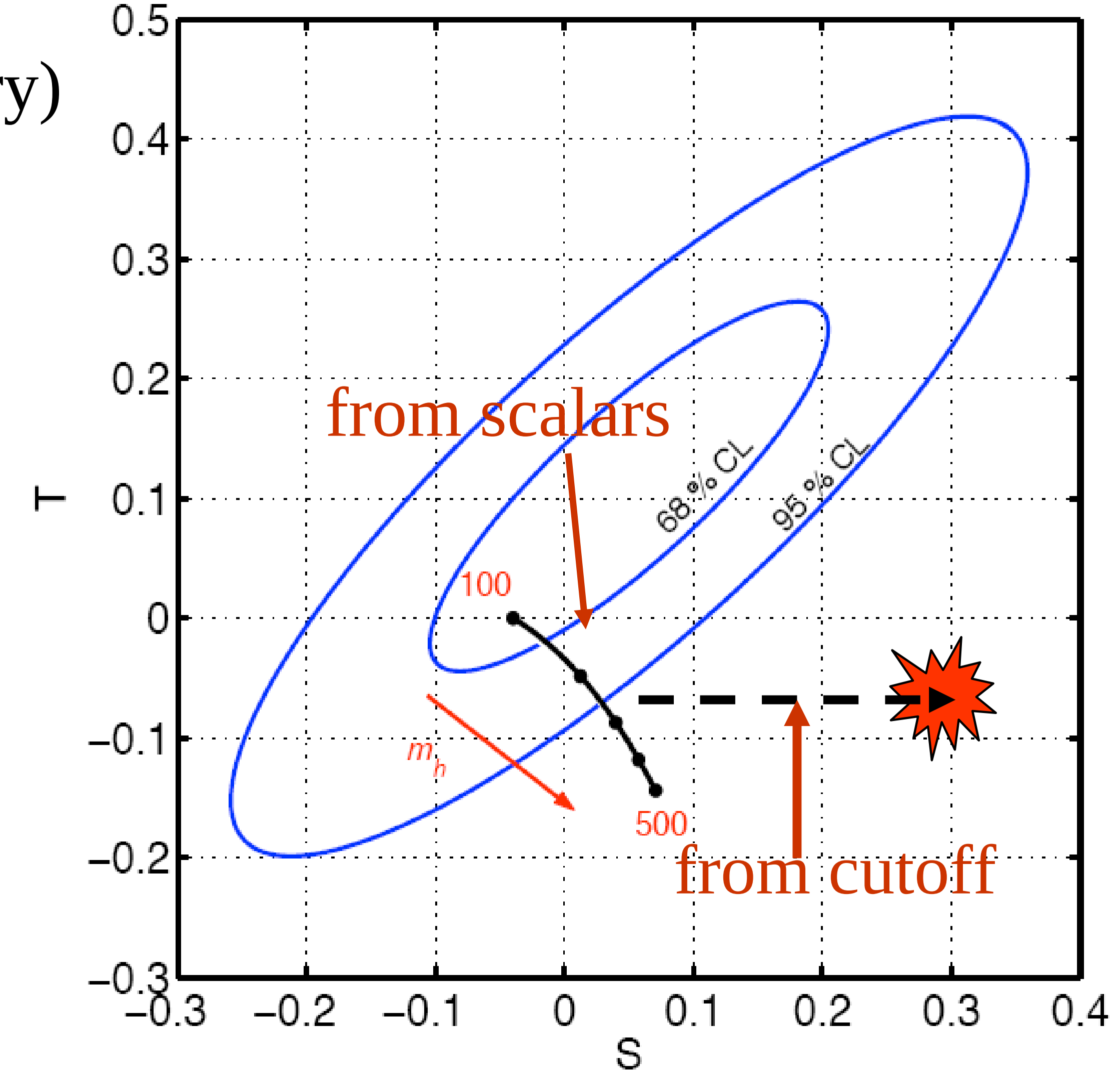
At the cutoff: $\Delta\hat{S} \simeq \frac{g^2 v^2}{\Lambda^2}$

ΔS≈0.25 for f=500 GeV

no ΔT (custodial symmetry)

Summary:

(for f=500 GeV)



Unresolvable tension? Need a source of extra ΔT=0.3-0.5

Extend SO(5) to top sector

1. Reduce sensitivity to the cutoff
2. Extra source of ΔT

Add $\Psi_L=(q,X,T)_L = 5$ of SO(5) (=2+2+1 of SU(2))

Full 3rd generation: $\Psi_L=(q,X,T)_L$; t_R, b_R, X_R, T_R

3 more quarks than normal: $X=(X_{5/3},X_{2/3})$ *and* $T_{2/3}$

$$\mathcal{L}_{\text{top}} = \lambda_1 \bar{\Psi}^i_L \hat{\phi}^i t_R + \lambda_2 f \bar{T}_L T_R + m_X \bar{X}_L X_R \qquad \lambda_t = \frac{\lambda_1 \lambda_2}{\sqrt{\lambda_1^2+\lambda_2^2}}$$

$$m_T = \sqrt{\lambda_1^2+\lambda_2^2} f$$

Physical t_L has admixture $\epsilon_L T_L$ $\quad \epsilon_L = \dfrac{\lambda_T v}{m_T}, \quad \lambda_T = \dfrac{\lambda_1^2}{\sqrt{\lambda_1^2+\lambda_2^2}}$

Physical t_R has admixture $\epsilon_R X_R$ $\quad \epsilon_R = \dfrac{m_t}{m_X}$

NB: b quark completely normal (no state to mix with)

The ρ parameter

$$\Delta\rho_X = -\Delta\rho^{\rm SM}_{\rm top} \times 4\epsilon_R^2 \left(\log\frac{m_X^2}{m_t^2} - \frac{11}{6}\right)$$

[Carena,Ponton,Santiago,Wagner]

$$\Delta\rho_T = +\Delta\rho^{\rm SM}_{\rm top} \times 2\epsilon_L^2 \left(\log\frac{m_T^2}{m_t^2} - 1 + \frac{\lambda_T^2}{2\lambda_t^2}\right)$$

Problems:

1. To suppress negative ρ_X need m_X>1.5 TeV
2. Positive ρ_T of needed size (25-40 % of SM contribution) proceeds via mixing of left top and induces comparable or larger effects in b physics:

Z-> bb, b-> sZ$^{(*)}$, b-> sγ, and BBbar mixing

which are all known to agree with SM with 15-20% uncertainty

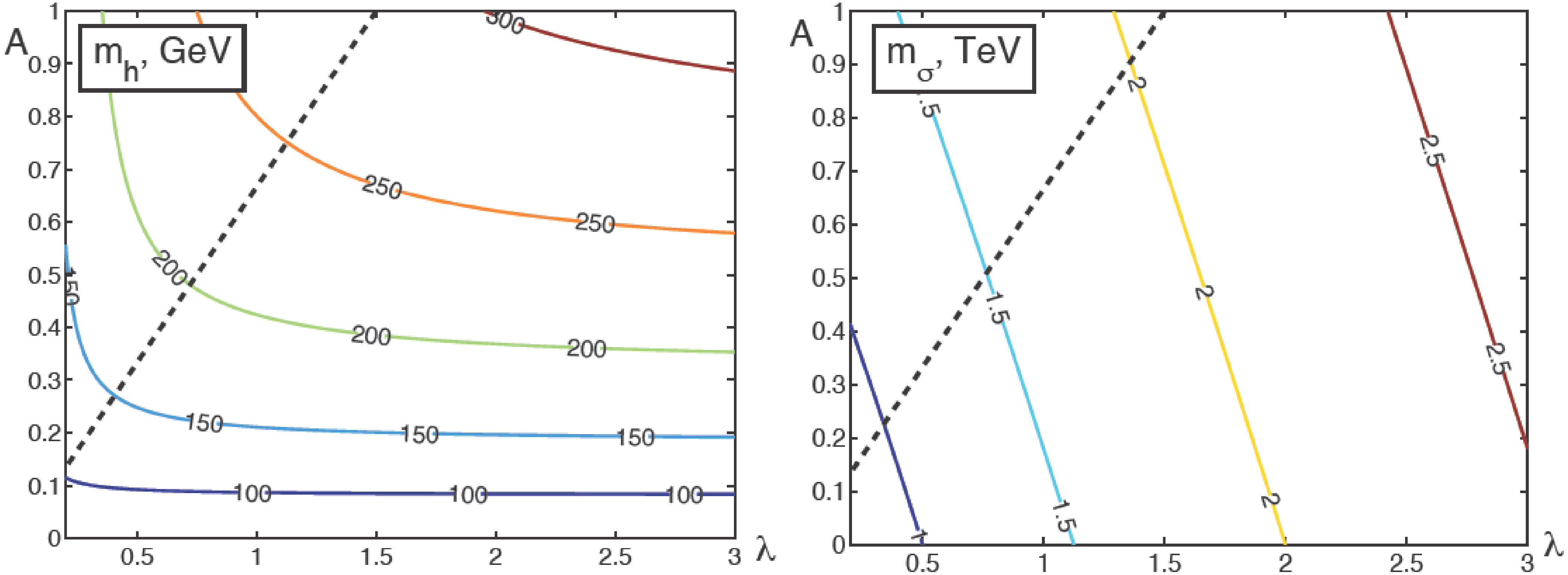
Conclusion: minimal 3rd generation model problematic (models with more extended fermion content may do better)

Minimal model - perturbative

$$V = \lambda(\hat{\phi}^2 - f^2)^2 - Af^2\phi^2 - Bf^3\hat{\phi}_5$$

$$\Lambda_{nat} = \frac{4\pi f}{\sqrt{N+2}} \simeq 2.4TeV \quad (N=5, f=500GeV)$$

$$h = \cos\alpha\,\phi_4 + \sin\alpha\,\phi_5 \qquad \sigma = -\sin\alpha\,\phi_4 + \cos\alpha\,\phi_5$$



EWPT in the perturbative model

1. $$m_{EWPT,eff} = m_h \left(\frac{m_\sigma}{m_h}\right)^{\sin^2\alpha}$$

   reduced with respect to strong coupling case, but still sizeable (easily 200-300 GeV)

2. $S|_{cutoff}$ can be totally eliminated if no vector resonances at the naturalness cutoff

3. Hence much smaller ΔT=0.1-0.2 will suffice

4. Such ΔT can now be provided by the extended top sector without violating b-physics constraints *(but predicting deviations observable in the future)*

Conclusions and outlook

1. To capture relevant phenomenology, it is much more efficient to concentrate on the effective 4d top-Higgs sector = “minimal model”

⇒ *Can study other symmetries (SU(3) or SO(6))*

⇒ *Can make clean and explicit studies of consistency with EWPT*

⇒ *Can extract the relevant “low energy” phenomenology, if any, of LHC*

2. Perturbative vs. composite left as a *(non-trivial)* experimental question

Perturbative models may have better EWPT consistency,
mainly because no S from the cutoff
(but need to exhibit the naturalness sector, SUSY UV-completion?)

3. Extended gauge sector/5d/warping etc only confuses the picture,
while not clearly extending the naturalness and calculability
(see the paper)