Scale invariance and Naturalness of the Higgs potential (mass)

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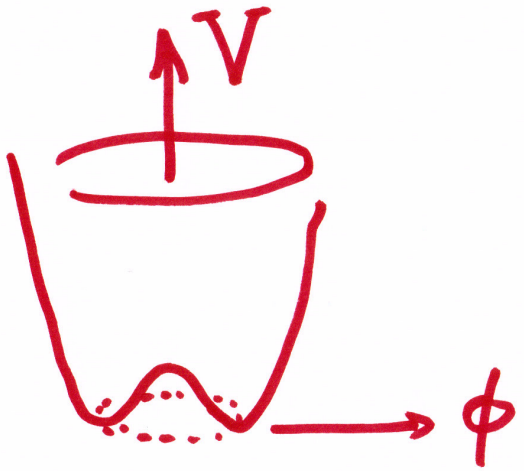
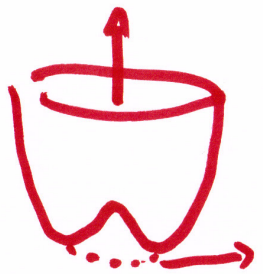


Moriond 2014

Standard Model Higgs potential

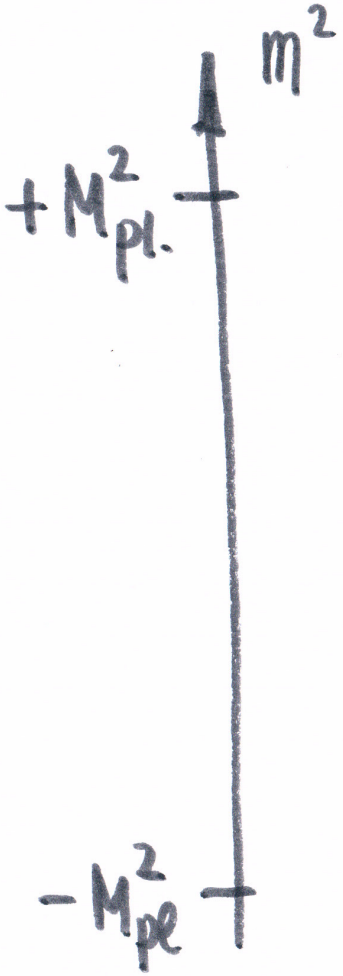


$$V = -\frac{m^2}{2}\phi^*\phi + \frac{\lambda}{4}(\phi^*\phi)^2$$

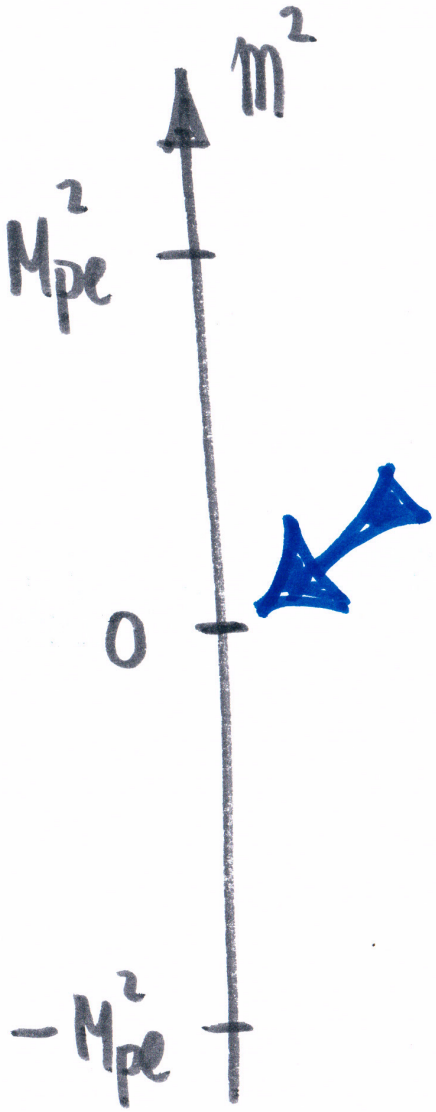
$(125\,\text{GeV})^2$

0.5

What is a natural value for m^2 ?



- dimensional analysis: $\sim M_{PE}^2$
- "calculation" $\phi \ldots \bigcirc \ldots \phi \sim -\frac{3\lambda_t^2}{8\pi^2} M_{PE}^2 + m_0^2 + \ldots$



NOT a special point!

$m^2=0$ is only special if it enhances the symmetry of the problem.

possible symmetries of $\frac{m^2}{2}\phi^*\phi$ scalar mass

0. unitary symmetry $\phi \to e^{i\alpha}\phi$

$\phi^*\phi$ invariant $\Longrightarrow$ $m^2=0$ does not enhance the symmetry

{ fermion mass $m\psi_L^+\psi_R$ not invariant under

chiral symmetry $\psi_L \to e^{i\alpha_L}\psi_L$

$\psi_R \to e^{i\alpha_R}\psi_R$ }

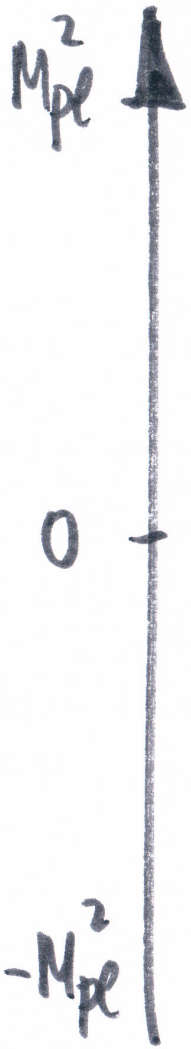
weird symmetries and $\frac{m^2}{2}\phi^*\phi$

1. susy $\phi \leftrightarrow \psi_L$

2. shift symmetry $\phi \to \phi + \text{const}$

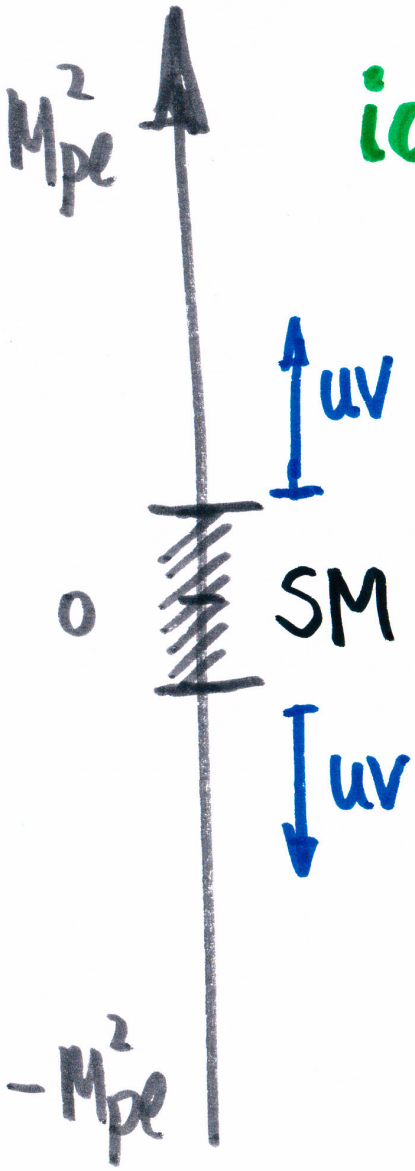
3. scale symmetry rescale all length $\sim \frac{1}{\text{momentum}}$ $\sim \frac{1}{\text{mass}}$ scales

$\Longrightarrow$ no explicit mass scales allowed in $\mathcal{L}$.



the Standard Model does not have any of 1, 2, 3.

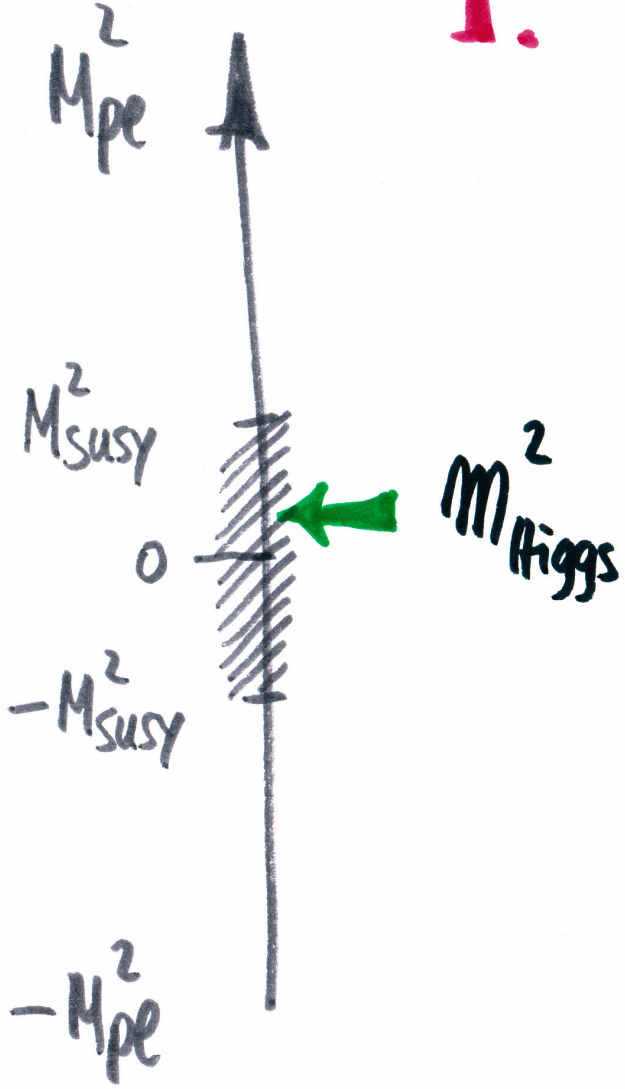
$\Rightarrow$ $m^2=0$ is NOT special in SM.



idea: extend the SM in the UV so that it does have the symmetry for $E^2 \gg m^2_{Higgs}$

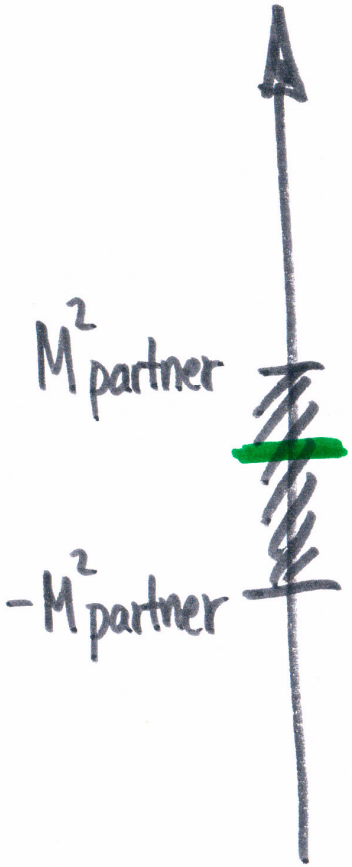
$\Longrightarrow$ $m^2 \approx 0$ is special in UV theory

1. SUSY → MSSM



m_{Higgs}^2 can be natural as long as $m_{Higgs}^2 \gtrsim m_{susy}^2 / 16\pi^2$

2. shift symmetry ⟶ "Little Higgs", pseudo-Goldstone



natural as long as

$$m^2_{Higgs} \lesssim \frac{m^2_{partner}}{16\pi^2}$$

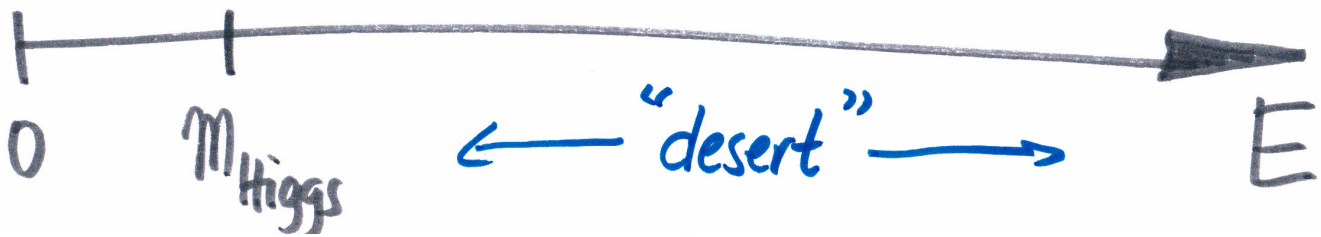
3. scale symmetry ⟶ ?

nok: for $E^2 \gg m^2_{Higgs}, m^2_{top}, m^2_{W,Z}, \ldots$

the SM is automatically scale invariant* !

3. scale symmetry → ? SM ?

if $m_{Higgs} \sim m_{top}$ are the largest scales in Nature / the SM then m^2_{Higgs} is automatically natural



3. scale symmetry ⟶ SM ?

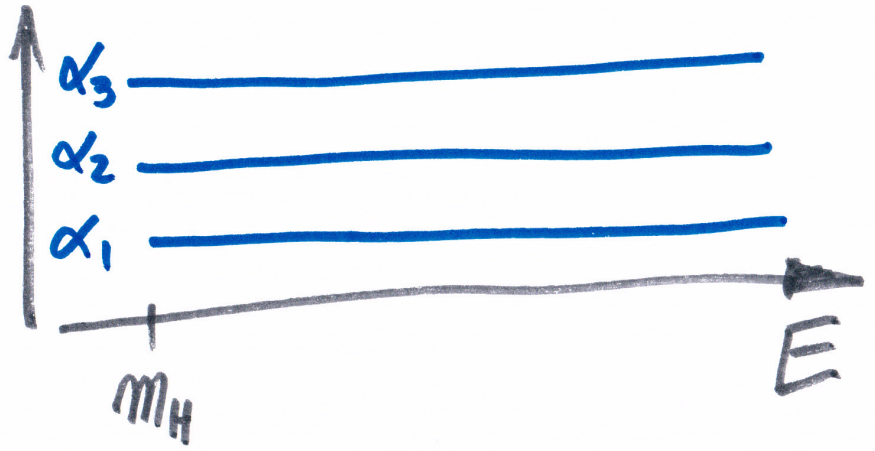
" maybe gravity is different "

- 't Hooft 1980
- Dubovsky, Gorbenko, Mirbabayi 2013
- ....

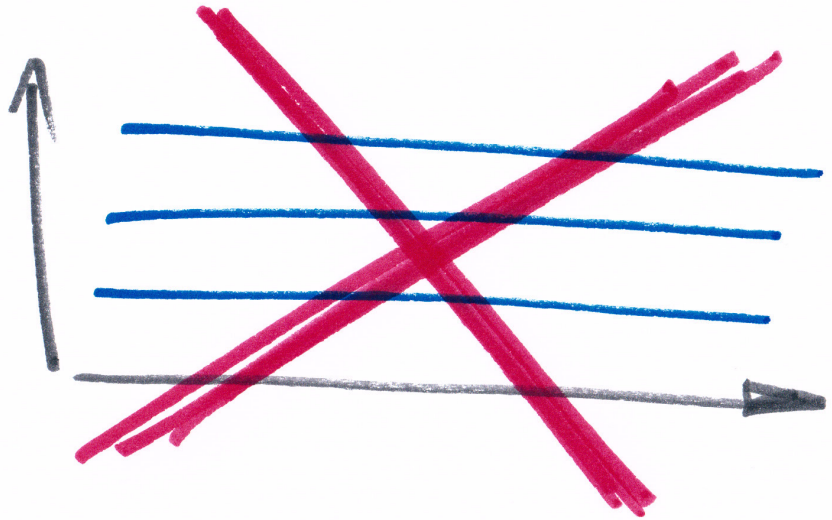
⟶ ignore gravity, M_{pl}

3. scale symmetry ⟶ SM ?

scale invariant couplings



3. scale symmetry ⟶ SM?

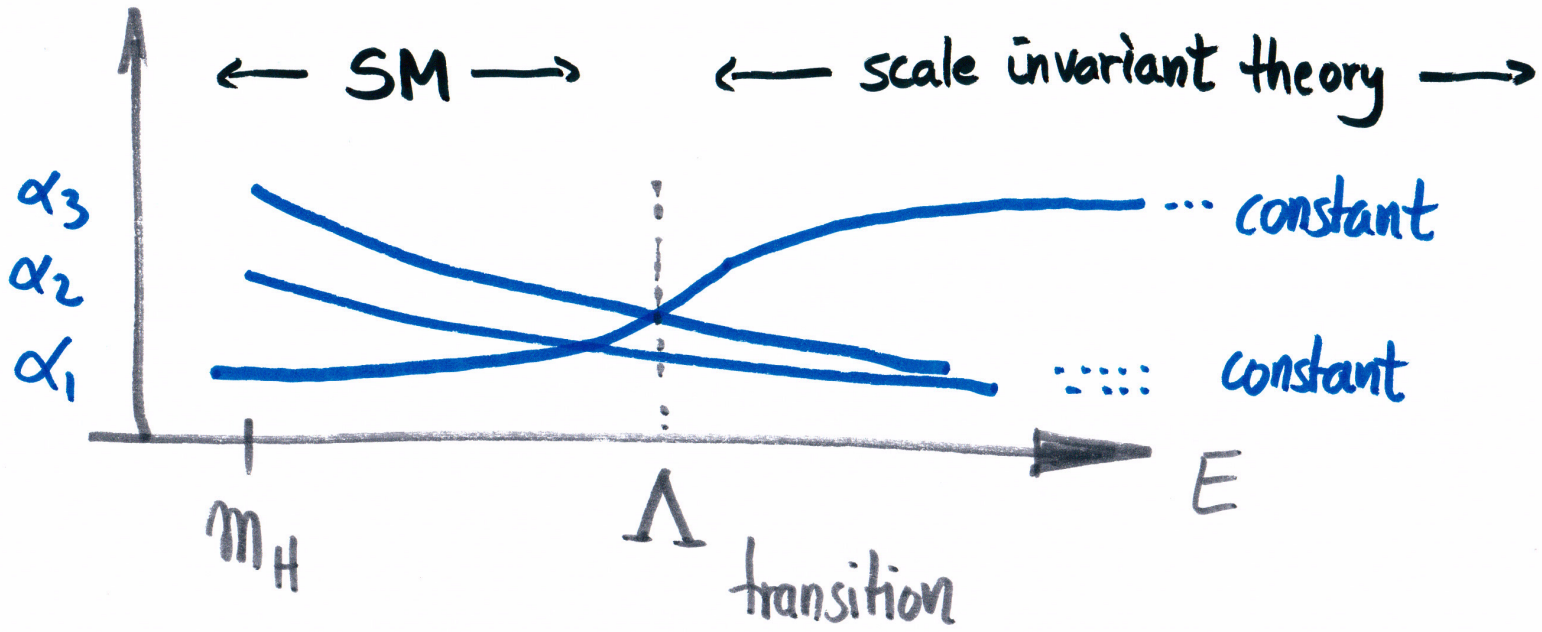


Couplings run !

SM is not scale-invariant in UV.

M_{Landau}

3. scale symmetry ⟶ ?

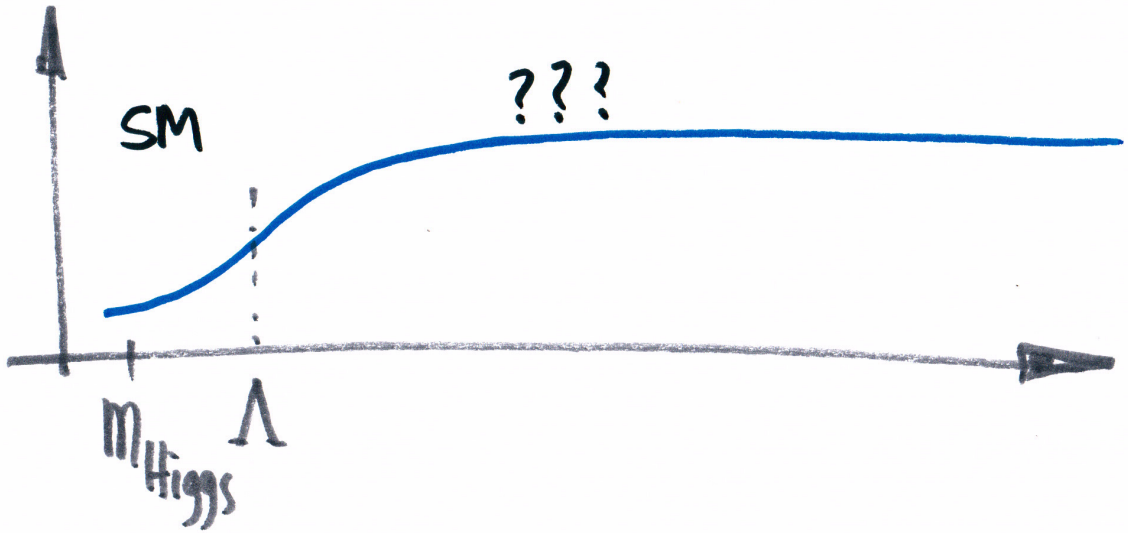


natural only if $m_H^2 \lesssim \frac{\Lambda^2}{16\pi^2}$

DGM 2013
Marques Tavares, Skiba, M.S. 2013

(... even in dim. reg w. $\overline{MS}$, no massive particles, ...)

3. experimental consequences ?



- running of α, changes
- new charged vector bosons @ few TeV scale

  W', Z'

Conclusions

- Scale symmetry can make the Higgs mass natural
- the SM is not scale invariant
- any natural scale-invariant BSM theory must have new particles at the TeV scale