RADIATIVE SYMMETRY BREAKING WITH MULTIPLE SCALAR FIELDS

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WORK IN PROGRESS
IN COLLABORATION WITH T. PROKOPEC AND L. CHATAIGNIER MOREIRA DA ROCHA

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We consider classically conformal theory.
All mass scales generated dynamically.

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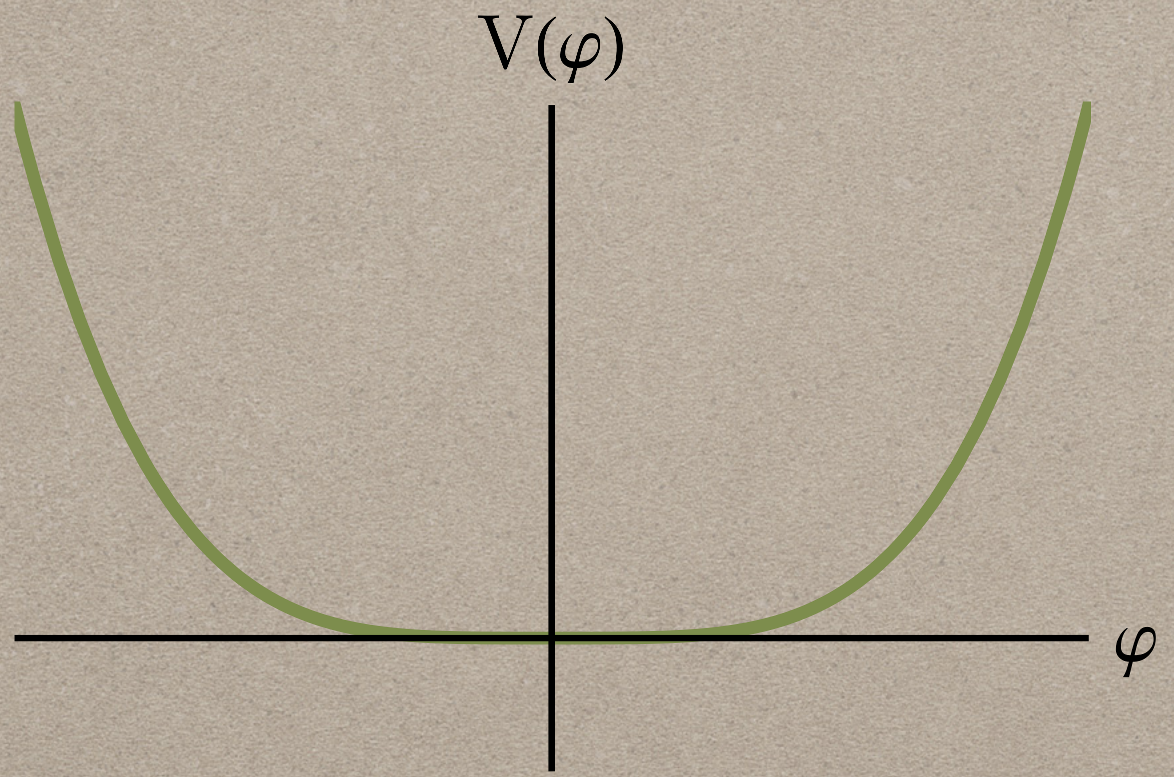
MOTIVATION

- Hierarchy problem
- Baryogenesis
- Vacuum stability

See also the talk of M. Lindner

RADIATIVE SYMMETRY BREAKING



pure scalar theory

$$V_0(\varphi) = \frac{\lambda}{4}\varphi^4$$

[S. Coleman, E. J. Weinberg, PRD 7 (1973) 1888, cited 3863 times]

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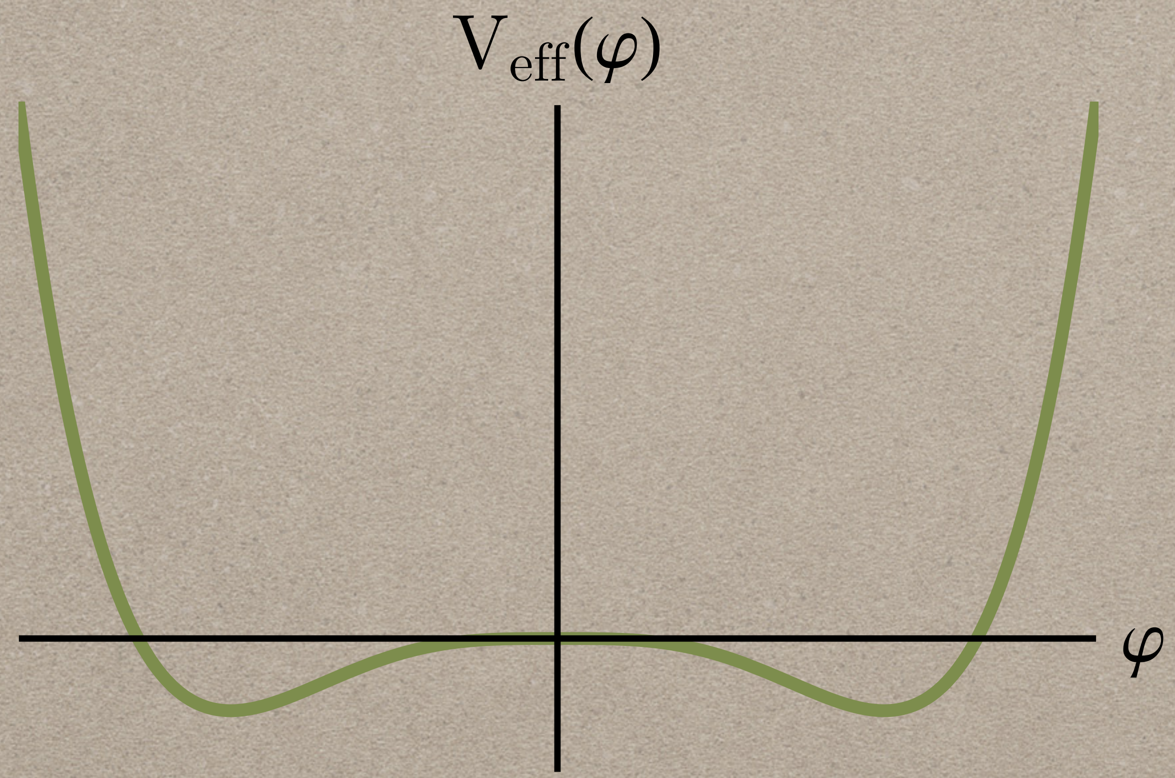

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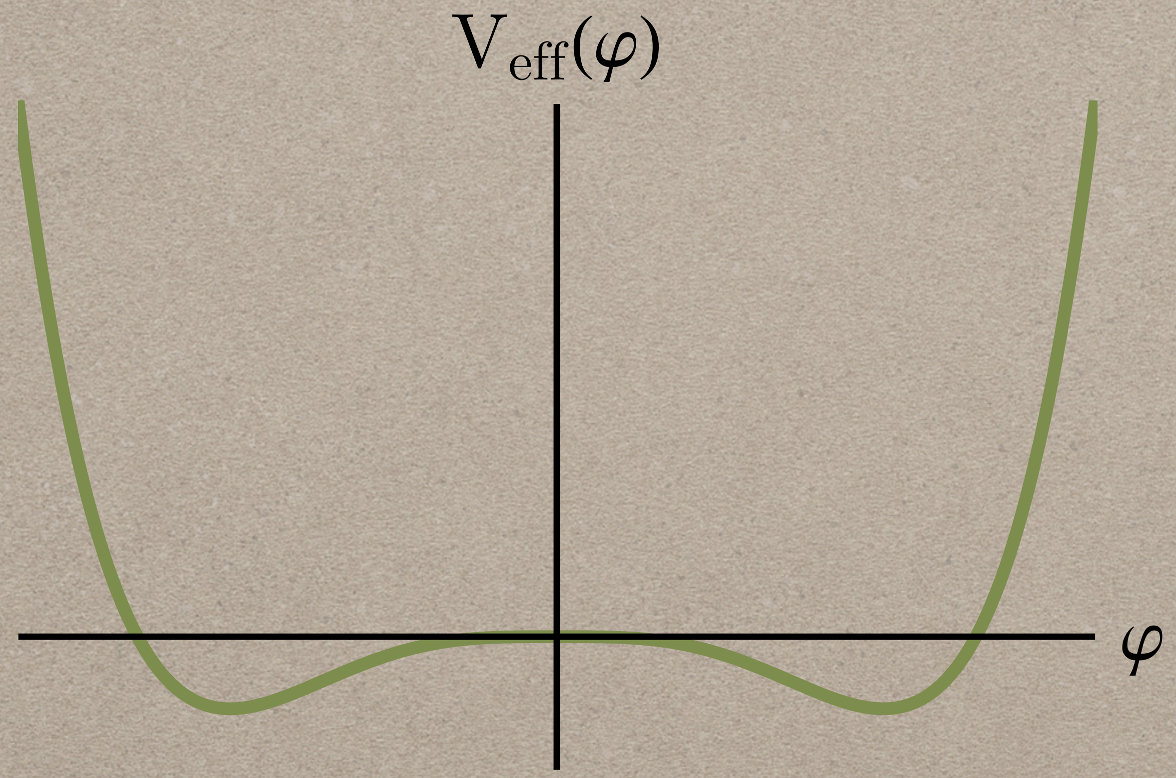

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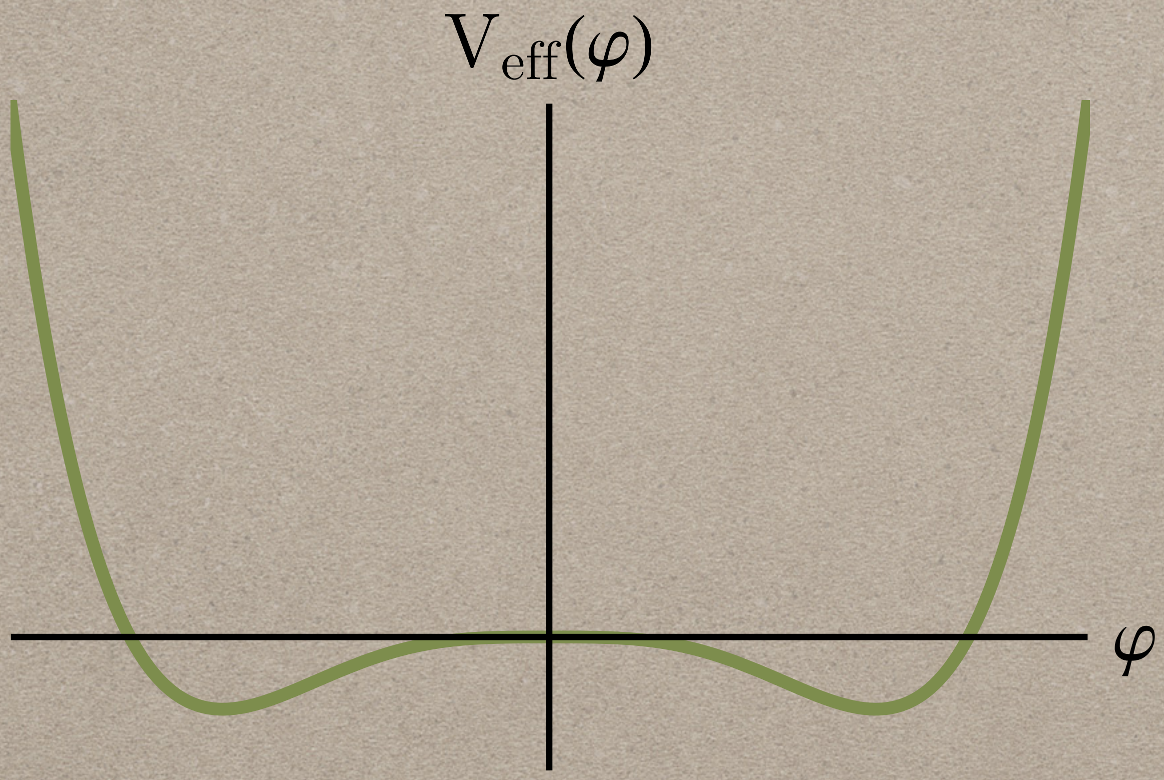

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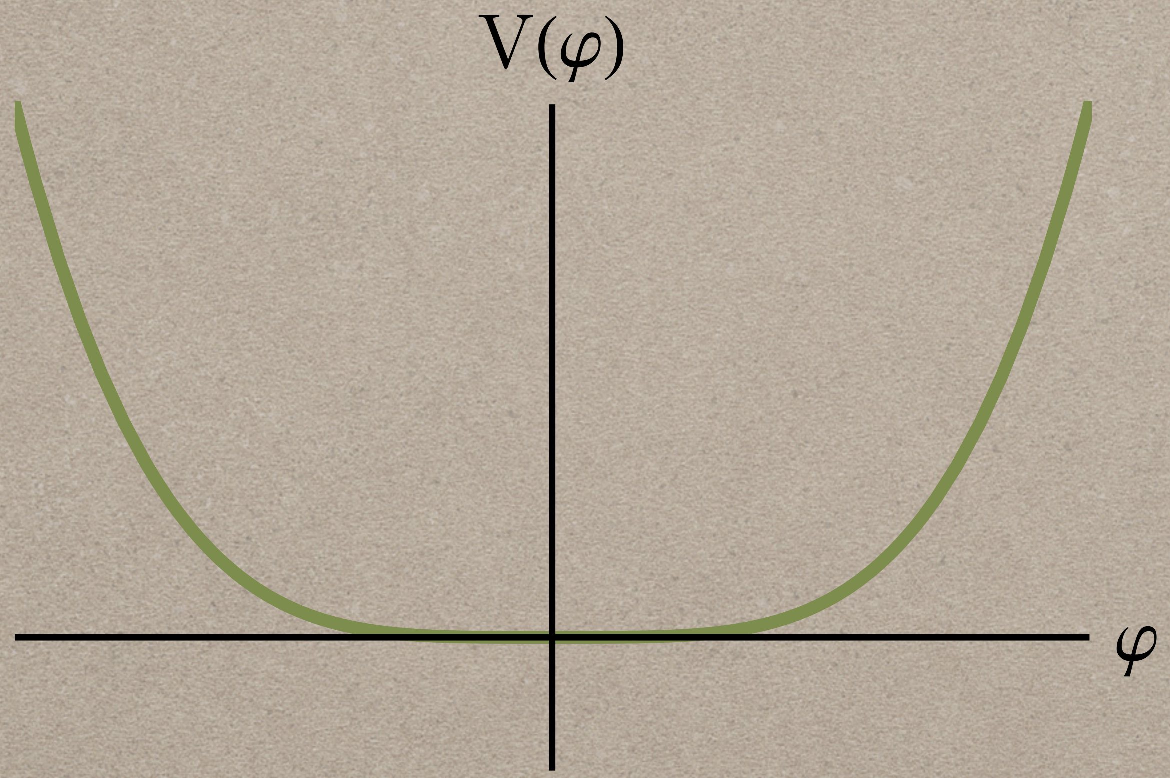

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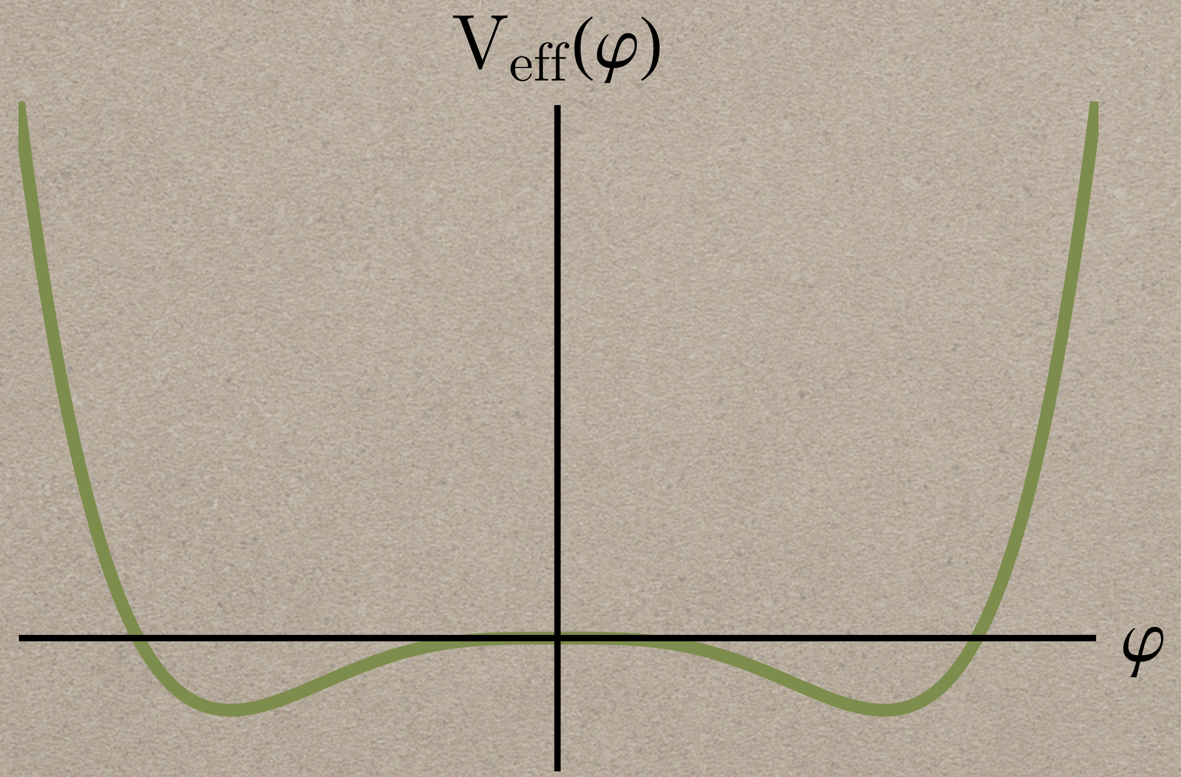

$$V_0(\varphi) = \frac{\lambda}{4}\varphi^4$$

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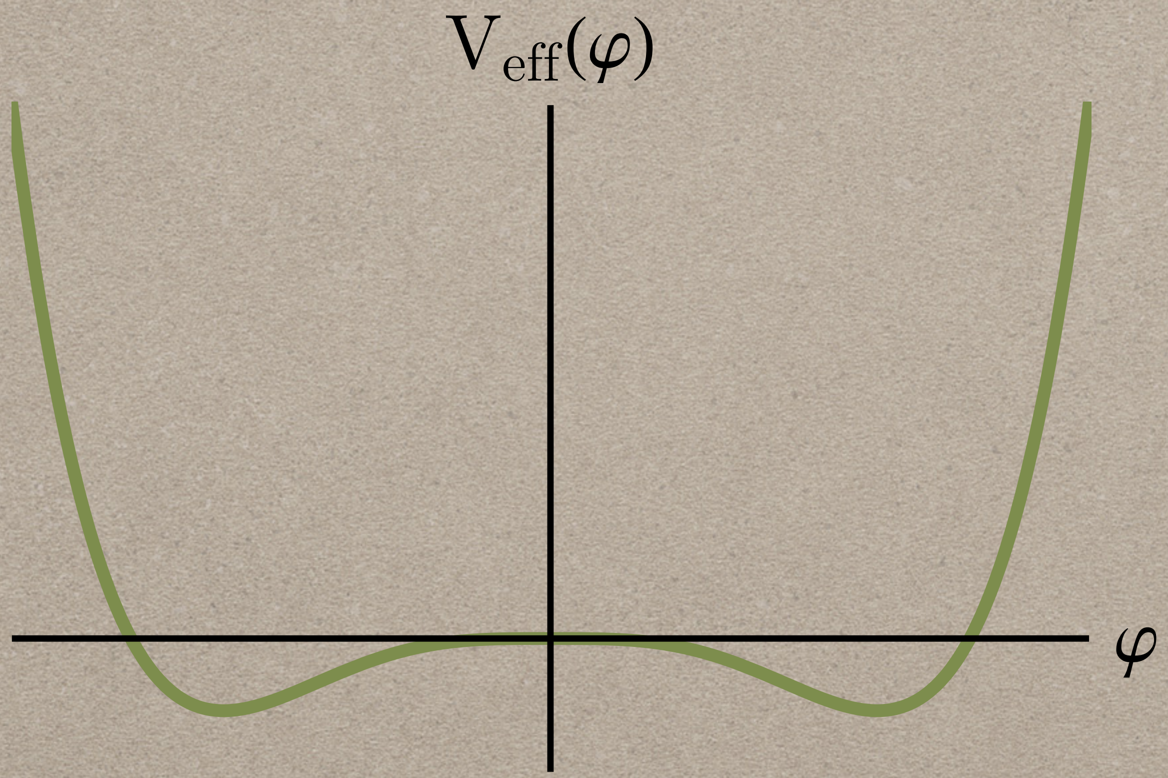

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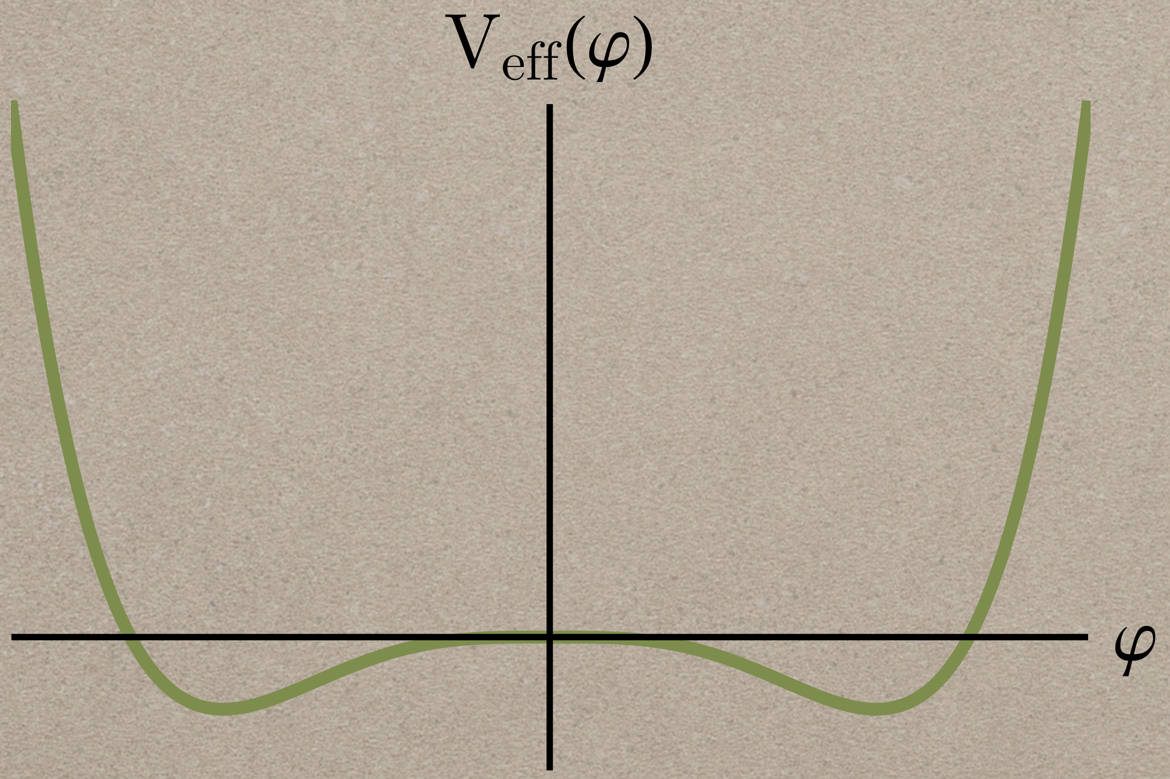

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Also important for gauge-dependence

$$\lambda \sim \mathcal{O}(e^4)$$

The minimum is real – scale generated radiatively through dimensional transmutation

IS CW MECHANISM REALISED?

Mass of the Higgs

$$M_h^2 = 8B/v^2 \quad B = \frac{1}{64\pi^2} \sum N_i M_i^4$$

In SM B dominated by top quark (#dof = -12)

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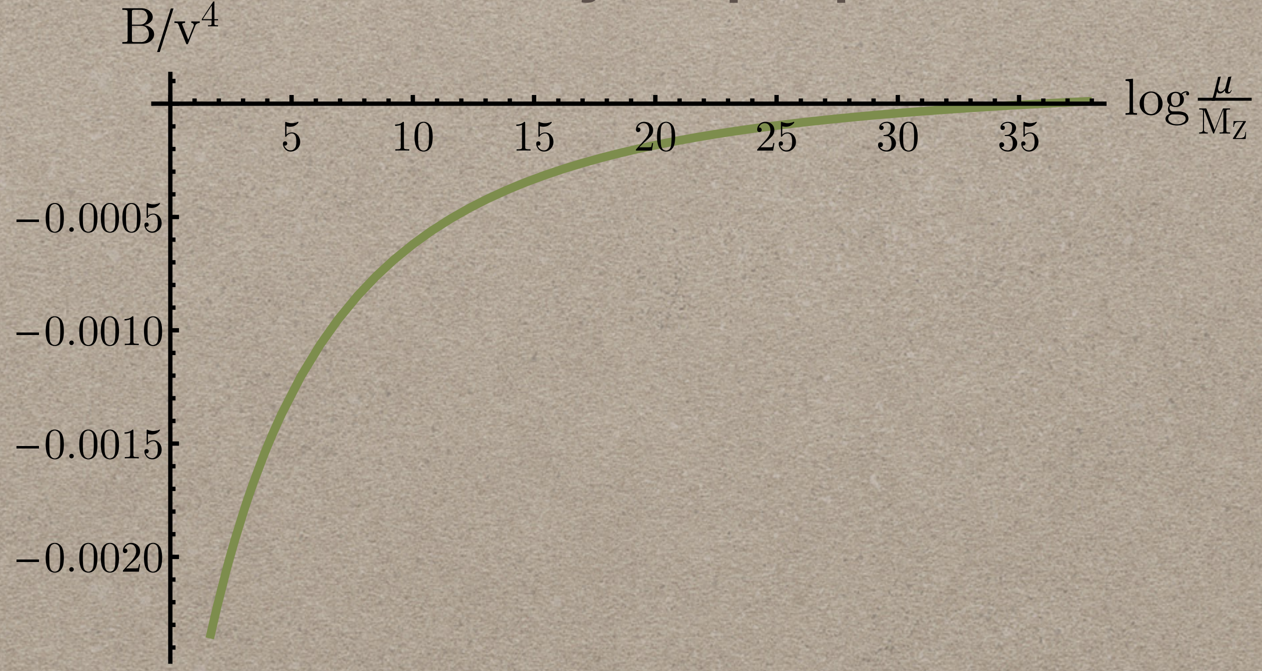

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Extended scalar sector   Extended gauge group

HIGGS PORTAL MODEL

SM + scalar singlet

$$V_0 = \lambda_1 \left(\Phi^\dagger \Phi\right)^2 + \frac{1}{2}\lambda_2 \left(\Phi^\dagger \Phi\right)\varphi^2 + \frac{1}{4}\lambda_3 \varphi^4$$

The singlet couples to the SM only through the Higgs

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The effective potential is a function of two scalar fields

$$V_{\mathrm{CW}} = \frac{1}{64\pi^2} \sum_i f_i M_i^4 \left(\log \frac{M_i^2}{\mu^2} - C_i\right)$$

QUESTIONS

- Pattern of symmetry breaking?
- What the physics is like at the minimum? Can we obtain correct masses and small couplings up to the Planck scale?
- Gauge dependence of the result?
- If not a singlet than what?

[K. Meissner, H. Nicolai, PLB 648 (2007) 312, R. Foot, A. Kobakhidze, R.R. Volkas, PLB 655 (2007) 156, J.R. Espinosa, M. Quiros, PRD 76 (2007) 076004, J.R. Espinosa, T. Konstandin, J.M. No, M. Quiros, PRD 78 (2008) 123528]

PATTERN OF SYMMETRY BREAKING

$$\lambda \sim \mathcal{O}(e^4) \longrightarrow \lambda_i \sim ?\ (\mathcal{O}(g^2),\ \mathcal{O}(g^4))$$

$$\left.\frac{\partial V}{\partial h}\right|_{h=v,\varphi=w} = \lambda_1 v^3 + \frac{\lambda_2}{2} v w^2 + \frac{\partial V_{\mathrm{CW}}}{\partial h} = 0$$

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$$\lambda_1 \sim \mathcal{O}(g^4)$$

GW:
$\lambda_i \sim \mathcal{O}(g^2)$

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$\lambda_i \sim \mathcal{O}(g^2)$

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$w = 0$
SM-like

$w \neq 0$
$\det M^2 \sim B_{\mathrm{SM}}$

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"FLAT" DIRECTION ALONG H

$$\lambda_1 \sim \mathcal{O}(g^4),\ w = 0$$

- Singlet acquires a tree-level mass

$$M_\varphi^2 = \frac{\lambda_2}{2} v^2$$

- Mass for the Higgs generated radiatively. Apart from the SM part, contribution from the singlet.
- The mass correct only if portal coupling is big.
- Running of the scalar couplings destabilised.

Even more scalars needed?

GW SCENARIO

$\lambda_i \sim \mathcal{O}(g^2)$

- Flat direction at tree level (at a certain scale)
- One scalar massive at tree level, the other mass generated by loop corrections

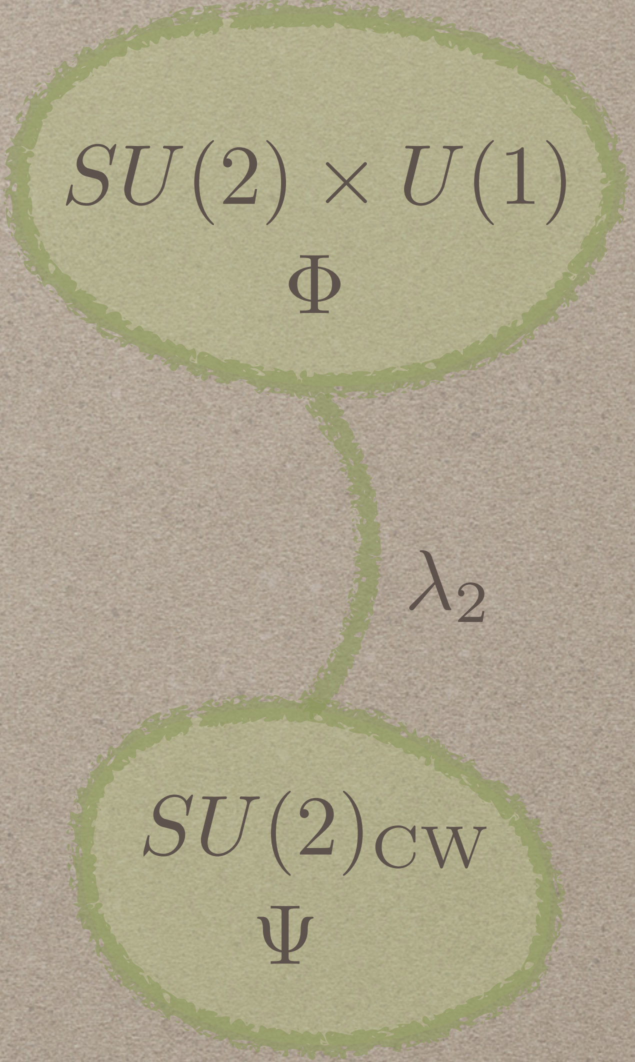
$$M \sim B$$

- If the mass of the singlet is radiative – it is negative
- If the mass of the Higgs is radiative – too big coupling required

More gauge bosons needed?

HIDDEN GAUGE SECTOR

Extra gauge bosons can increase the value of B and help to account for radiative symmetry breaking



[R. Hempfling, PLB 379 (1996) 153, W.F. Chang, J.N. Ng, J.M.S. Wu, PRD 75 (2007) 115016, V.V. Khoze, C. McCabe, G. Ro, JHEP 1408 (2014) 026]

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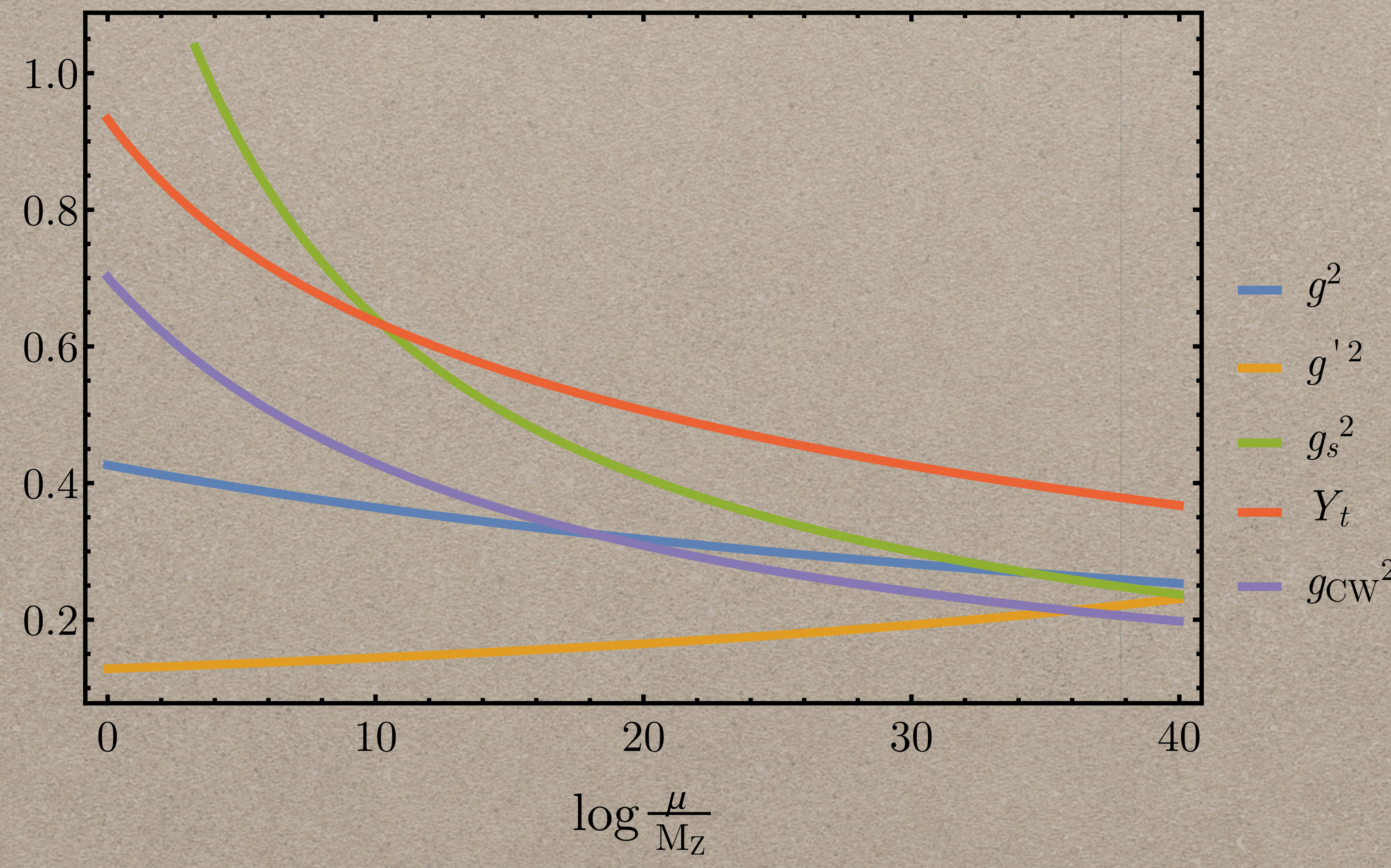

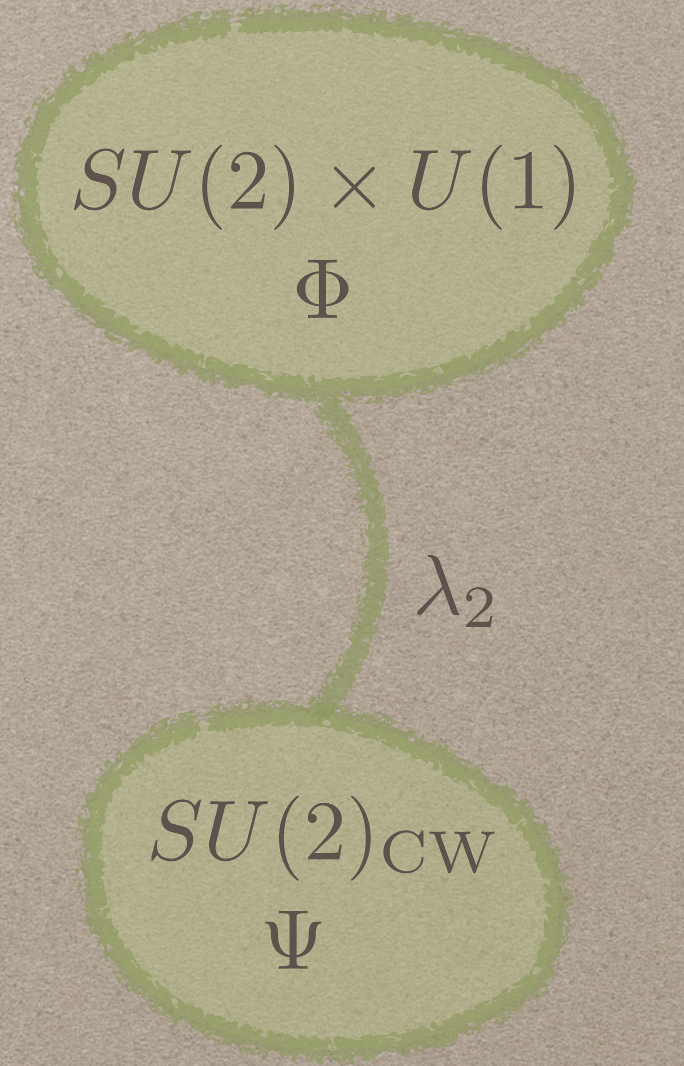

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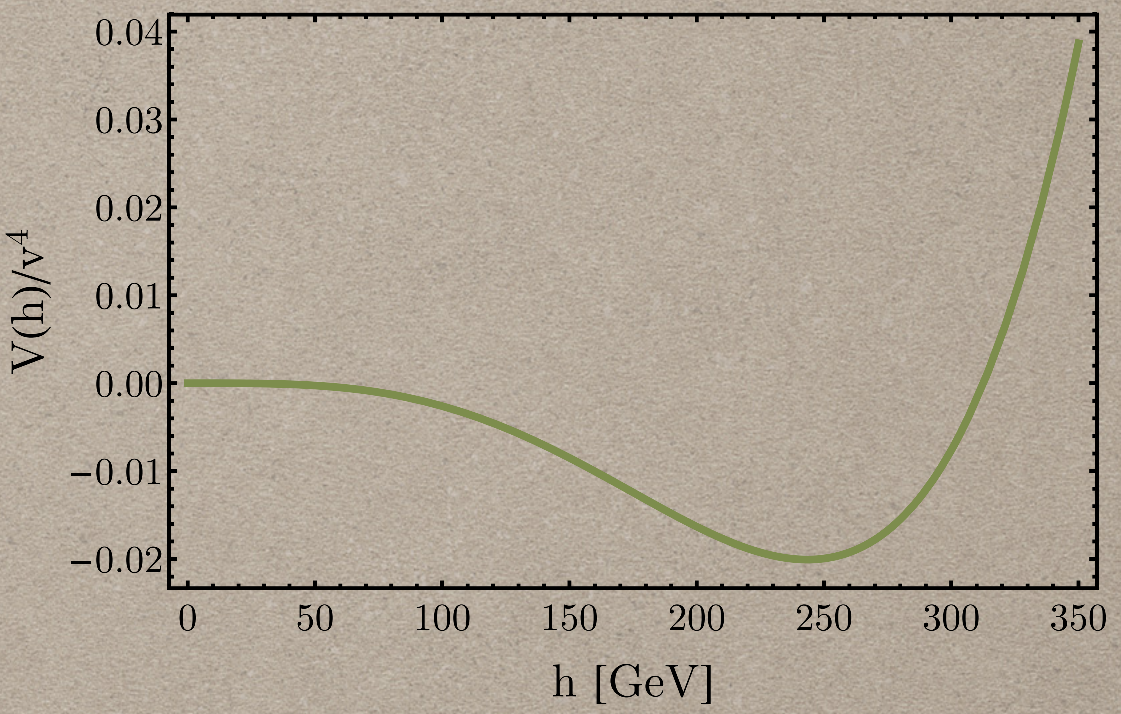
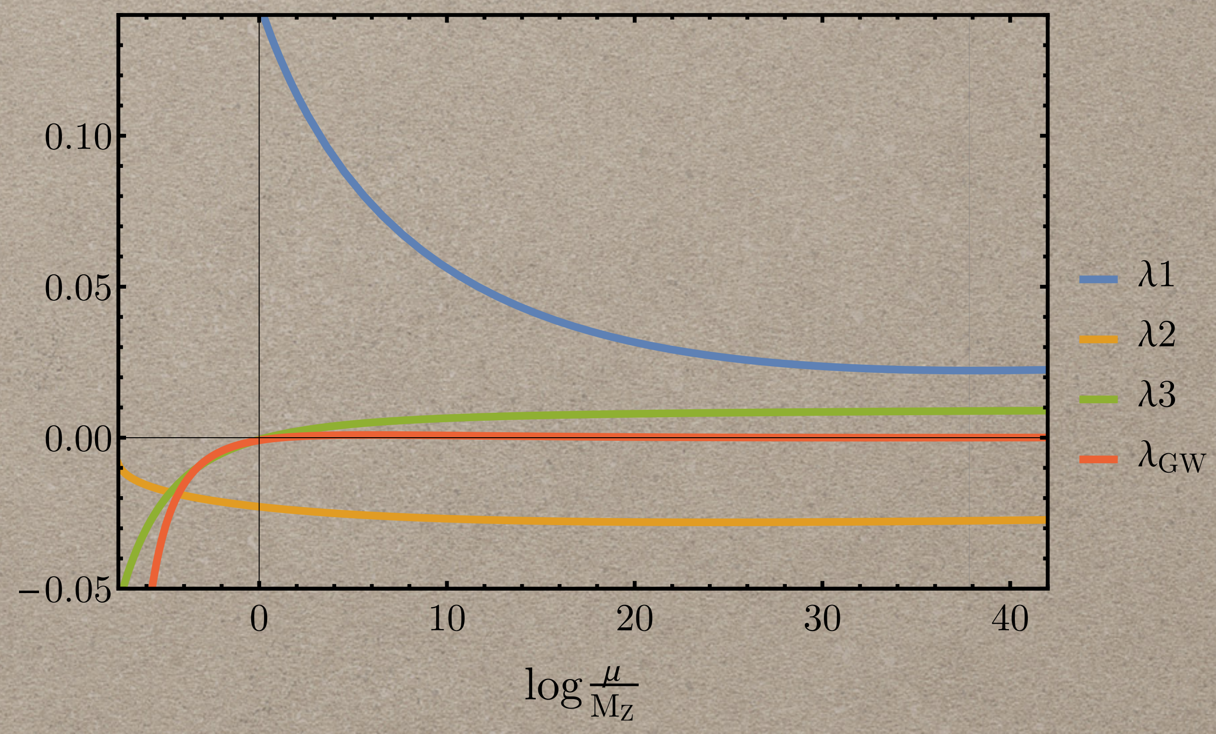
HIDDEN GAUGE SECTOR

- GW method
- Stable minimum
- Correct Higgs mass
- All couplings small up to the Planck scale





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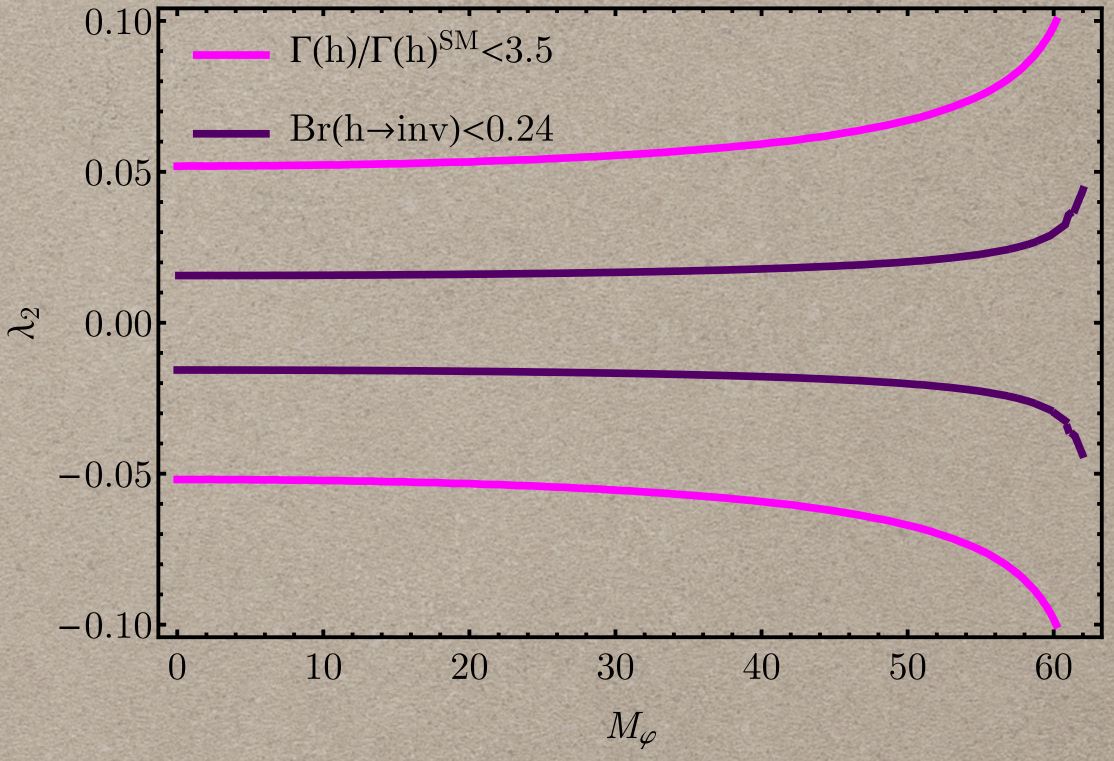

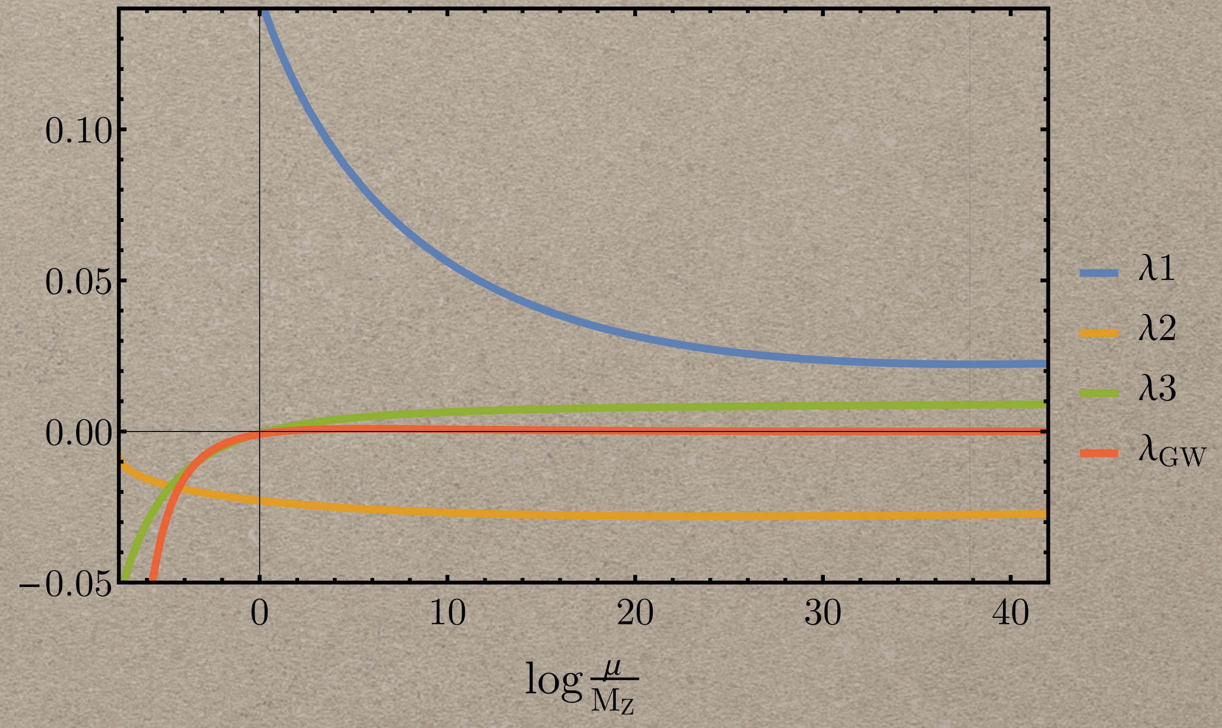

GAUGE DEPENDENCE

- Fermi gauge – Goldstone mixed with longitudinal W

$$M_{G^{\pm}}^2 = \frac{1}{2}\left(M^2 \pm \sqrt{M^2\left(M^2 - \xi g_2^2 h^2\right)}\right)$$

Mass of the Goldstone in Landau gauge
vanishes at the tree-level minimum

- V explicitly gauge dependent
- In our case terms ~ λ_i^2 can be neglected so the result is gauge independent.

CONCLUSIONS

- Rich pattern of symmetry breaking in Higgs portal model.
- Cannot account for RSB in Higgs portal model with single scalar.
- Hidden gauge group facilitates RSB.
- Work in progress…

BACKUP

“SEQUENTIAL” SSB

If the portal coupling sufficiently small the two sectors are decoupled

1. CW symmetry breaking in the dark sector
2. The dark VEV generates a “mass term” for the Higgs

[V.V. Khoze, C. McCabe, G. Ro, JHEP 1408 (2014) 026, W. Altmannshofer, W.A. Bardeen, M. Bauer, M. Carena, J.D. Lykken, JHEP 1501 (2015) 032]

RGE IMPROVEMENT

RGE-improvement needed when logs get large – e.g. for stability considerations.

$$\left(\mu\partial\mu + \beta_i\partial\lambda_i - \frac{1}{2}\gamma_j\partial\phi_j\right)V(\mu,\lambda_i,\phi_j) = 0$$

Potential constant along characteristic curves

$$V(\mu_0,\lambda_{i0},\phi_{j0}) = V(\mu(t),\lambda_i(t),\phi_j(t))$$

RGE WITH TWO FIELDS

- We look for a surface where quantum corrections vanish
- Implicit relation for t that takes us from arbitrary point to the tree-level surface – depends on fields and couplings evaluated at t

Take the first approximation to t

- With t_0 we manage to reproduce the GW minimum.

Tree-level surface