Asymptotic safety and Higgs Portal Models

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Higgs couplings Conference

Renormalisation group equations

The renormalisation group equations are:

$$k\frac{\partial g_i(k)}{\partial k} = \beta_i\left(\{g_i(k)\}\right). \tag{1}$$

We can have:

- Landau pole: $g \to \infty$ for some μ_0,
- $g \to \infty$ for $\mu \to \infty$,
- $\forall_i \beta_i\left(\{g_i\}\right) = 0$, then RGE has a fixed point g^*.

Asymptotic safety

If for all the couplings: $g^* = 0$ we call the theory asymptotically free, otherwise if $g^* \neq 0$ we call the theory asymptotically safe.
Fixed point for a given coupling can be:

- repulsive
- attractive

For repulsive fixed point there is only one IR value of a parameter, which will result in asymptotic safe theory!

Standard Model with gravitational corrections

For the Standard Model beta one can calculate the gravitational corrections:

$$\beta(g_j) = \beta_{SM}(g_j) + \beta_{grav}(g_j, k), \tag{2}$$

where due to universal nature of gravitational interactions the β_{grav} are given by:

$$\beta_{grav}(g_j, k) = \frac{a_j k^2}{M_P^2 + 2\xi k^2} g_j, \tag{3}$$

with $\xi \approx 0.024$. The a_j are unknown parameters, however they can be calculated. Then depending of a sign of a_j we have repelling/attracting fixed point.

Standard Model with gravitational corrections: Higgs mass

The Higgs mass (self coupling) was calculated by Mikhail Shaposhnikov and Christof Wetterlich as 126 GeV two years before the detection.

Higgs portal Models

- Sterile complex (real) scalar ϕ coupled to SU(2) doublet:

$$\mathcal{L}_{scalar} = (D_\mu H)^\dagger (D^\mu H) + (\partial_\mu \phi^\star \partial^\mu \phi) - V(H, \phi). \tag{4}$$

$$V(H, \phi) = -m_1^2 H^\dagger H - m_2^2 \phi^\star \phi + \lambda_1 (H^\dagger H)^2 + \lambda_2 (\phi^\star \phi)^2 + 2\lambda_3 (H^\dagger H)\phi^\star \phi. \tag{5}$$

- Higgs particle combined from two mass states:

$$m_1^2 = \lambda_1 v_H^2 + \lambda_3 v_\phi^2, \qquad m_2^2 = \lambda_3 v_H^2 + \lambda_2 v_\phi^2. \tag{6}$$

Conformal Standard Model also includes right handed neutrinos coupled to ϕ with the coupling y_M:

$$\mathcal{L} \ni \frac{1}{2} Y^M_{ji} \phi N^{j\alpha} N^i_\alpha, \tag{7}$$

where $Y^M_{ij} = y_M$.

The running of couplings

We run following couplings: $g_1, g_2, g_3, y_t, \lambda_1, \lambda_2, \lambda_3, y_M$. The CSM beta functions are:

$$\begin{aligned} \hat{\beta}_{y_M} &= \tfrac{5}{2} y_M^3, \\ \hat{\beta}_{\lambda_1} &= \hat{\beta}_{\lambda_1}^{SM} + 4\lambda_3^2 \\ \hat{\beta}_{\lambda_2} &= \left(20\lambda_2^2 + 8\lambda_3^2 + 6\lambda_2 y_M^2 - 3y_M^4\right), \\ \hat{\beta}_{\lambda_3} &= \tfrac{1}{2}\lambda_3 \left[24\lambda_1 + 16\lambda_2 + \right. \\ & \left. 16\lambda_3 - \left(9g_2^2 + 3g_1^2\right) + 6y_M^2 + 12y_t^2\right]. \end{aligned} \tag{8}$$

We impose two conditions:

- absence of Landau poles
- $\lambda_1(\mu) > 0, \quad \lambda_2(\mu) > 0 \quad \lambda_3(\mu) > -\sqrt{\lambda_2(\mu)\lambda_1(\mu)}.$

Coefficient: $a_{\lambda_3} = +3$

For $a_{\lambda_3} = +3$, we get that: $\lambda_3 = 0$. So SM and ϕ decouple.

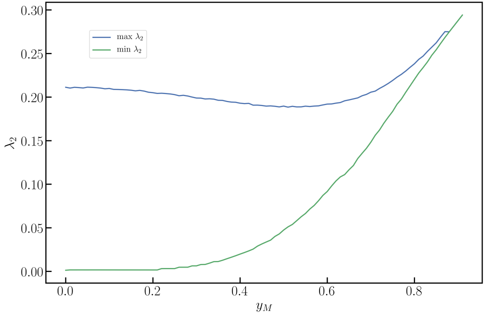

Figure: λ_2 dependence on y_M

Coefficient: $a_{\lambda_3} = -3$

For $a_{\lambda_3} = -3$, we get: $\lambda_3 \in (-0.05, 0.15), \lambda_2 \in (0, 0.25)$. If we assume the following conditions:

- $m_2 > 2m_1$,
- $|\tan\beta| < 0.35$

Then, with the tree level relations:

$$m_1^2 = \lambda_1 v_H^2 + \lambda_3 v_\phi^2, \tag{9}$$

$$m_2^2 = \lambda_2 v_\phi^2 + \lambda_3 v_H^2, \tag{10}$$

we are able to constrain the second scalar mass as:

$$270 \text{ GeV} < m_2 < 328 \text{ GeV}. \tag{11}$$

We can also constraint the neutrino mass with the leptogenesis condition($M_N > y_M v_\phi/\sqrt{2}$):

$$M_N = 683 \pm 83 \text{ GeV} \tag{12}$$

Summary and further work

Take home message:

- Standard Model supplemented by the gravitational corrections can be a fundamental theory, yet not a complete one
- Applying the gravitational corrections can give the quantitive predictions for new particles

Further work:

- The remaining a_i's have to be calculated
- The (higher)-loop corrections have to be taken into account

Thank you for your attention

Talk based on article: arxiv.org/abs/1810.08461

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Manifold of allowed couplings, $a_{\lambda_2} = a_{\lambda_2} = -3$

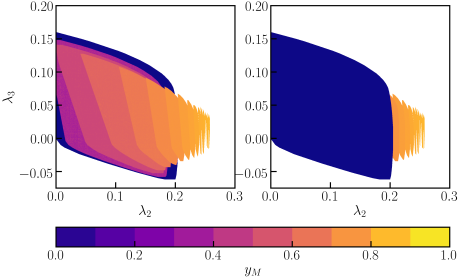

Figure: λ_2, λ_3 dependence on y_M

Higgs self coupling dependence

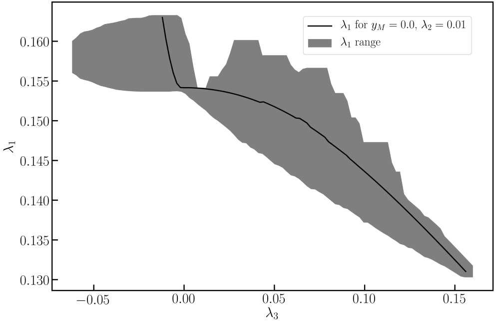

Figure: λ_1 dependence on $\lambda_2, \lambda_3, y_M$

LHC constraints

One can parametrize the discrepancies from SM as:

$$\tan\beta = \frac{\lambda_0 - \lambda_1}{\lambda_3}\frac{v_H}{v_\phi}. \tag{13}$$

We assume that its value is restricted by $|\tan\beta| < 0.35$.