Asymptotic safety, cosmology and Conformal Standard Model

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We apply the hypothesis of asymptotic safety of gravity to the extensions of the Standard Model to make specific, experimental predictions for these particles properties. We apply our analysis to the models extended only by one additional scalar field (and possibly some fermionic or vector particles) called Higgs portal models, with the focus on the Conformal Standard Model, which is one of those.
This assumptions will let us calculate the allowed self-coupling parameters (from which we can calculate masses, because the Higgs mass and vacuum expectation value are known experimentally). With the $a_{\lambda_2} > 0$ assumption we obtain exactly one value satisfying the conditions originating from this assumptions.

Keywords: MG15; asymptotic safety; Higgs portal; Conformal Standard Model

1. Introduction

Most of the extensions of the Standard Model proposes introduction of new particles and interactions, keeping the quantum field theory framework. However we cannot predict the properties of this particles from the models themselves. So for example the masses of the particles might be arbitrary, much too big for us to measure them in particle accelerators. Hence narrowing down the possible parameters to a single value or small interval would be a huge advantage in the search for new particles. Since Large Hadron Collider or any other accelerator hasn't discover supersymmetry or other discrepancies from SM, then the minimal extensions are in favor. In a sense they propose only a slight extension of SM. Some of them can not only solve problems of SM but can be, in principle, valid up to the Planck scale (quantum gravity scale) with no new intermediate scales and give possible candidates for dark matter. In particular one can introduce the hidden sectors of $SU(3) \times SU(2) \times U(1)$ singlets. One of the hidden sector can be coupled to SM only via coupling to Higgs particle, like a Higgs portal [1]. So we will call these class of models Higgs portal models. Then after the Higgs particle has been found, one can investigate these hidden sector by analysing the deviations from behaviour of SM Higgs without any Higgs portal particles. One of these models is Conformal Standard Model proposed by Krzysztof Meissner and Herman Nicolai [2–4].
The main qualitative prediction of Higgs portal models is the existence of the second fundamental scalar particle, which we will call 'shadow' Higgs. For our purpose only the extended Higgs sector lagrangian is relevant:

$$\mathcal{L}_{scalar} = (D_\mu H)^\dagger (D^\mu H) + \frac{1}{2}(\partial_\mu \phi^* \partial^\mu \phi) - V(H, \phi), \tag{1}$$

it comes with the potential:

$$V(H,\phi) = -m_1^2 H^\dagger H - m_2^2 \phi\phi^* + \lambda_1 (H^\dagger H)^2 + \lambda_2 (\phi\phi^*)^2 + 2\lambda_3 (H^\dagger H)\phi\phi^*.$$

Moreover the CSM predicts some additional features, see [2–4].
On the other hand we know that gravity isnt perturbatively renormalisable. There were various solutions proposed. Steven Weinberg [5] hypothesised that gravity possesses a UV interacting fixed point, which will allow us to treat it as fundamental theory. Moreover such hypothesis has significant influence on particle physics, since one can calculate the allowed coupling constants values in the low energy physics.

2. Scope of work

Adopting asymptotic safety will allow us to calculate the exact 'shadow' Higgs boson mass for repelling fixed point or allowed range for attracting fixed point. The theory with gravitational corrections can be treated as a fundamental one if it doesn't posses any pathological behaviour up to the Planck scale. So we impose two conditions:

- There should be absence of Landau pole.
- The electroweak vacuum should be stable:

$$\lambda_1(\mu) > 0,\, \lambda_2(\mu)\ \lambda_3(\mu) > -\sqrt{\lambda_2(\mu)\lambda_1(\mu)}. \tag{2}$$

Similar conditions were posed in [4,6].

As a toy model we will assume $\lambda_3 = 0$, because it seems that mixing angle is quite small. Then the equations will split into two parts, one for SM couplings and another for λ_2 and y_M, where y_M is additional coupling introduced in CSM.
For this simplified model we have checked the range of allowed self-couplings at $\lambda_i|_{M_{top}}$ such that they will satisfy the above conditions. We have not only reproduced the results from [6], but also obtained the exact value for λ_2 and allowed interval for y_M, assuming $a_{\lambda_2} > 0, a_{y_M} < 0$, which we expect in analogy with [6]. To calculate the running of coupling constants we employed the numerical methods. One can see [4] that for g_Y, g_w, g_s, y_M the equations can we solved independly and moreover y_t depends only on g_Y, g_w, g_s. So we have started with evolution for these couplings and then plug them into λ_i equations.
Such an analysis was never done in context of Higgs portal models with gauge fields or for the CSM. The Higgs portal models are of high importance and attract a lot of attention, because they can deal, in principle, with the problems of the Standard Model, which cannot be solved just by asymptotic safety assumption. The results would be generic for all Higgs portal models. They could be used in the context of non-minimally coupled inflationary models including Higgs portal term, since the non-minimal gravitational couplings are in the direct relation with the self-couplings.

3. Talk outline and further work

In my talk I will outline the asymptotic safety hypothesis, discuss its implications in the particle physics. I will also briefly describe the Conformal Standard Model and show our preliminary results for the values of self couplings in the CSM for the toy model.
As our further work we will calculate the remaining a_i's, using techniques developed in [7–9] both for generic Higgs portal models and CSM. Moreover we will analyse the model where $\lambda_3 \neq 0$.

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