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# Renormalization group improvement and dynamical breaking of symmetry in a supersymmetric Chern–Simons-matter model

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**Abstract**

In this work, we investigate the consequences of the Renormalization Group Equation (RGE) in the determination of the effective superpotential and the study of Dynamical Symmetry Breaking (DSB) in an $\mathcal{N} = 1$ supersymmetric theory including an Abelian Chern–Simons superfield coupled to $N$ scalar superfields in $(2 + 1)$ dimensional spacetime. The classical Lagrangian presents scale invariance, which is broken by radiative corrections to the effective superpotential. We calculate the effective superpotential up to two-loops by using the RGE and the beta functions and anomalous dimensions known in the literature. We then show how the RGE can be used to improve this calculation, by summing up properly defined series of leading logs (LL), next-to-leading logs (NLL) contributions, and so on... We conclude that even if the RGE improvement procedure can indeed be applied in a supersymmetric model, the effects of the consideration of the RGE are not so dramatic as it happens in the non-supersymmetric case.


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## 1. Introduction

Dynamical Symmetry Breaking (DSB) constitutes a very appealing scenario in field theory, where quantum corrections are entirely responsible for the appearance of nontrivial minima of the effective potential [1]. In the case of a classically scale invariant model, all mass scales are generated by these quantum corrections and are fixed as functions of the symmetry breaking scale. This scenario would be particularly interesting in the Standard Model, but earlier calculations pointed to a dead end: quantum corrections turned the effective potential unstable, rendering DSB impossible [2]. However, it has been shown that this conclusion, based on the effective potential calculated up to the one-loop level, could be modified substantially by using the Renormalization Group Equation (RGE) [3–10] to sum up infinite subsets of higher loop contributions to the effective potential. More than a quantitative correction over the one-loop result, this improvement lead to a new scenario, where DSB was operational [3,4]. More recent calculations were able to include corrections up to five loops in the effective potential [11,12], bringing the prediction for the Higgs mass relatively close to the experimental value indicated by the LHC (for other works regarding conformal symmetry in the Standard Model see for example [13,14]).

Besides being a viable ingredient to the Standard Model phenomenology, DSB also occurs in other contexts, such as lower dimensional theories. Particularly interesting are models involving the Chern–Simons (CS) term in $(2+1)$ spacetime dimensions [15]. The basic renormalization properties of such models have been studied for quite some time [16–22]. We shall be particularly interested in models with scale invariance at the classical level, that is, with a pure CS field coupled to massless scalars and fermions, with Yukawa quartic interactions and scalar $\varphi^6$ self-interactions. In these models, the one-loop corrections calculated using the dimensional reduction scheme [23] are rather trivial, since no singularities appear, and no DSB happens either; at the two-loop level, however, one finds renormalizable divergences. Also, the two-loops effective potential $V_{eff}$ exhibits a nontrivial minimum, signalizing the appearance of DSB. Due to the nontrivial $\beta$ and $\gamma$ functions at two-loop level, one may obtain an improvement in the calculation of $V_{eff}$ by imposing the RGE

$$\left[\mu\frac{\partial}{\partial\mu}+\beta_x\frac{\partial}{\partial x}-\gamma_\varphi\phi\frac{\partial}{\partial\phi}\right]V_{eff}\,(\phi;\mu,\alpha_i,L)=0\,, \tag{1}$$

where $x$ denotes collectively the coupling constants of the theory, $\mu$ is the mass scale introduced by the regularization, $\gamma_\varphi$ is the anomalous dimension of scalar field $\varphi$,

$$L=\ln\left[\frac{\phi^2}{\mu}\right], \tag{2}$$

and $\phi$ is the vacuum expectation value of $\varphi$. This improved effective potential was calculated in [24], and it was shown to imply in considerable changes in the properties of DSB in this model, thus providing another context where the consideration of the RGE is essential to a proper analysis of the phase structure of the model.

Our objective is to verify whether in supersymmetric models containing the CS field, the consideration of the RGE also induces considerable modifications in the scenario of DSB. Supersymmetric CS theories have been studied for quite some time [17,25–28], and have recently attracted much attention due to their relation to M2-branes [29]. The superconformal field theory describing multiple M2-branes is dual to the $D=11$ Supergravity on $AdS_4\times S^7\sim[SO(2,3)/SO(1,3)]\times[SO(8)/SO(7)]\subset OSp(8|4)/[SO(1,3)\times SO(7)]$, therefore the action for multiple M2-branes has $\mathcal{N}=8$ supersymmetry. However, the on-shell degrees of freedom of