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ELECTROWEAK PHASE TRANSITION IN A MODEL WITH AN EXTRA HIGGS TRIPLET BOSON

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RESUMEN

Se estudia el potencial efectivo a temperatura finita a un loop de un modelo extendido del Modelo Estándar (ME) con un triplete escalar extra con el fin de analizar la transición de fase electrodébil de esta extensión. Se encuentra que una transición de fase electrodébil de primer orden fuerte es dependiente de algunos parámetros del modelo. Se obtienen algunas restricciones sobre estos parámetros consistentes con medidas de precisión electrodébil y con cosmología.

Palabras claves: Modelo Estándar, potencial efectivo, transición de fase electrodébil.

ABSTRACT

The one-loop effective potential at finite temperature of an extended model of the Standard Model (SM) with an extra scalar triplet field is studied in detail to analyze the electroweak phase transition of this extension. We find that a strong first-order electroweak phase transition is sensitive to some parameters in the model. We obtain constraints on these parameters consistent with precision electroweak measurements and cosmology.

Keywords: Standard Model, effective potential, electroweak phase transition.

1. INTRODUCTION

The high energy measurements of electroweak observables by LEP, SLC and Tevatron [1], with an impressive level of precision, have confirmed the Glasgow-Weinberg-Salam model of electroweak interactions with great certainty. Although the Standard Model (SM) is a successful theory, we still do not know the nature of the electroweak symmetry breaking: the Higgs mechanism, which allows us to generate the masses of the gauge bosons and of the fermions.

Since there is no direct experimental information regarding the Higgs sector, it is useful to study more complicated symmetry breaking structures, of which the SM is a limiting case. An interesting extension of the SM is a model with an extra Higgs triplet boson because of the behaviour of this extra sector in Little Higgs models [2] and its implications in cosmology.

In this paper, we study the finite temperature behaviour of an extended model of the SM with an extra higgs triplet model [3], in which a real scalar SU(2) triplet with zero hypercharge is added to the usual scalar SU(2) doublet. The physical spectrum contains two extra states, another h0 and a charged h±. The model violates custodial symmetry at tree level giving a prediction for the ρ parameter of [4]

$$\rho = 1 + 4\left(\frac{\eta_c^0}{h_c^0}\right)^2, \qquad (1)$$

but by making the triplet vacuum expectation value small the relation can be satisfied to within the experimental uncertainties [4].

En section 2 we present the model and our notation. In section 3 we calculate in detail the finite temperature effective potential and describe some interesting features of its temperature evolution. In section 4 we present some conclusions.

2. The Triplet Model

The Lagrangian density of this model contains one complex Higgs doublet, Φ, as in the SM, and an additional real Higgs triplet, H, with $Y_\Phi = 1$ and $Y_H = 0$

$$\mathcal{L} = \frac{1}{2}(D_\mu H)^\dagger (D^\mu H) + (D_\mu \Phi)^\dagger (D_\mu \Phi), \qquad (2)$$

with a scalar potencial

$$V(H,\Phi) = \mu_1^2|\Phi|^2 + \lambda_1|\Phi|^4 + \frac{1}{2}\mu_2^2|H|^2 + \frac{1}{4}\lambda_2|H|^4 + \frac{1}{2}\lambda_3|H|^2|\Phi|^2 + \lambda_4\nu\Phi^\dagger\sigma^\alpha\Phi H_\alpha^P, \qquad (3)$$

When the symmetry gets broken, the doublet and the triplet acquire a non-zero vacuum expectation value, with

$$\langle\Phi\rangle = \frac{\nu}{\sqrt{2}} \qquad \langle H\rangle = \frac{\nu}{2}\tan\beta, \qquad (4)$$

Thus, we can write the field components, including the neutral components vacuum expectation values,

$$\Phi = \begin{pmatrix} \phi^+ \\ \frac{1}{\sqrt{2}}(\nu + h^0 + i\phi^0) \end{pmatrix}_{Y=1}$$
$$H = \begin{pmatrix} \eta^+ \\ \frac{1}{2}\nu\tan\beta + \eta^0 \\ -\eta^- \end{pmatrix}_{Y=0}, \qquad (5)$$

Expanding about the vacuum by substituting (5) into the Lagrangian density, we can analyze the mass spectrum. We find two charged Higgs states. The first, $g^\pm$, is massless and is the Goldstone boson to be eaten by the $W^\pm$, and $h^\pm$.

In terms of the original doublet and triplet charged components these are

$$\begin{pmatrix} g^\pm \\ h^\pm \end{pmatrix} = \begin{pmatrix} \cos\beta & -\sin\beta \\ \sin\beta & \cos\beta \end{pmatrix} \begin{pmatrix} \phi^\pm \\ \eta^\pm \end{pmatrix}. \qquad (6)$$

In the neutral sector we have two CP-even states, called H^0 and N^0, which mix with angle γ. The mass eigenstates $\{H^0, N^0\}$ are defined, in terms of the original doublet and triplet components, by

$$\begin{pmatrix} H^0 \\ N^0 \end{pmatrix} = \begin{pmatrix} \cos\gamma & -sin\gamma \\ \sin\gamma & \cos\gamma \end{pmatrix} \begin{pmatrix} h^0 \\ \eta^0 \end{pmatrix}. \qquad (7)$$

The precision electroweak data constraint β to be smaller than about 4^0 [4].

3. Effective Potential at Finite Temperature

In order to investigate the electroweak phase transition in this extension of the SM with an extra Higgs triplet boson and to compare it with the SM, we need to take into account the effective potential at finite temperature. Following the main ideas of Dolan and Jackiw, Linde and Sher [5], we have that, in general, the finite temperature effects for bosons take the form

$$\Delta V_{1B}^{T}(\Phi,T)=\sum_{b}\frac{g_bT^4}{2\pi^2}\int_0^{\infty}dxx^2 ln[1-\exp\left(-\sqrt{x^2+(m_B^2)_b/T^2}\right)]. \tag{8}$$

The fermion contribution has a similar form

$$\Delta V_{1B}^{T}(\Phi,T)=\sum_{b}\frac{g_bT^4}{2\pi^2}\int_0^{\infty}dxx^2 ln[1-\exp\left(-\sqrt{x^2+(m_B^2)_b/T^2}\right)]. \tag{9}$$

We can write the one loop effective potential at finite temperature in the form

$$\begin{aligned}V(\Phi,H,T)&=V(\Phi,H)+\Delta V_1(\Phi,H,T)\\&=V(\Phi,H)+\sum_B\frac{g_BT^4}{2\pi^2}\int_0^{\infty}dxx^2\ln\left(1-\exp\left(-\sqrt{x^2+\beta^2m_B^2}\right)\right)-\\&-\sum_F\frac{g_FT^4}{2\pi^2}\int_0^{\infty}dxx^2\ln\left(1+\exp\left(-\sqrt{x^2+\beta^2m_F^2}\right)\right),\qquad (\end{aligned}$$

(10)

where V(Φ, H) is the effective potential at zero temperature, mB(F) is the mass of a boson (fermion), gB(F) is the number of degrees of freedom, β=1/T and B(F) denotes a sum over bosons (fermions), respectively.

We know that, sometimes, is convenient to approximate the above integrals by using the high temperature expansion. This is used when the temperature is high enough as compared to the particle masses and the integrals can be approximated by expanding them in series in powers of m/T. Thus, we can write the high temperature expansion in the form

$$\begin{aligned}V(\Phi,H,T)&=V(\Phi,H)+\Delta V_1(\Phi,H,T)\\&=V(\Phi,H)+6\left[\frac{m_W^2T^2}{24}-\frac{m_W^3T}{12\pi}-\frac{m_W^4}{64\pi^2}\ln\left(\frac{m_W^2}{C_bT^2}\right)\right]+\\&+3\left[\frac{m_Z^2T^2}{24}-\frac{m_Z^3T}{12\pi}-\frac{m_Z^4}{64\pi^2}\ln\left(\frac{m_Z^2}{C_bT^2}\right)\right]+12\left[\frac{m_t^2T^2}{48}+\right.\\&\left.+\frac{m_t^4}{64\pi^2}\ln\left(\frac{m_t^2}{C_fT^2}\right)\right]+\left[\frac{m_{H_0}^2T^2}{24}-\frac{m_{H_0}^3T}{12\pi}-\frac{m_{H_0}^4}{64\pi^2}\ln\left(\frac{m_{H_0}^2}{C_bT^2}\right)\right]+\\&+\left[\frac{m_{N_0}^2T^2}{24}-\frac{m_{N_0}^3T}{12\pi}-\frac{m_{N_0}^4}{64\pi^2}\ln\left(\frac{m_{N_0}^2}{C_bT^2}\right)\right]+2\left[\frac{m_{h^\pm}^2T^2}{24}-\right.\\&\left.-\frac{m_{h^\pm}^3T}{12\pi}-\frac{m_{h^\pm}^4}{64\pi^2}\ln\left(\frac{m_{h^\pm}^2}{C_bT^2}\right)\right]+2\left[\frac{m_{g^\pm}^2T^2}{24}-\frac{m_{g^\pm}^3T}{12\pi}-\right.\\&\left.-\frac{m_{g^\pm}^4}{64\pi^2}\ln\left(\frac{m_{g^\pm}^2}{C_bT^2}\right)\right]+\left[\frac{m_{\phi^0}^2T^2}{24}-\frac{m_{\phi^0}^3T}{12\pi}-\frac{m_{\phi^0}^4}{64\pi^2}\ln\left(\frac{m_{\phi^0}^2}{C_bT^2}\right)\right],\quad (\end{aligned} \tag{11}$$

where we have, again, the effective potential at zero temperature, V(Φ, H), and we have taken into account only the heaviest fermion contribution, the top quark.

4. Results and Conclusions

In figure 1 we show the behaviour of the effective potential at finite temperature in the SM (left) which gives us information related to the electroweak phase transition. For our choice of parameters is weakly first order under our approximations because of the constraints on the mass of the SM Higgs boson. For this plot MH0=50, 70, 115 GeV. The behaviour of the effective potential at high temperatures in the extended model with an extra Higgs triplet boson is shown on the right. This figure shows us a strong first order phase transition because of the introduction of the new scalars in the extended model (MH0=115 and Mh±= MN0=226 GeV).

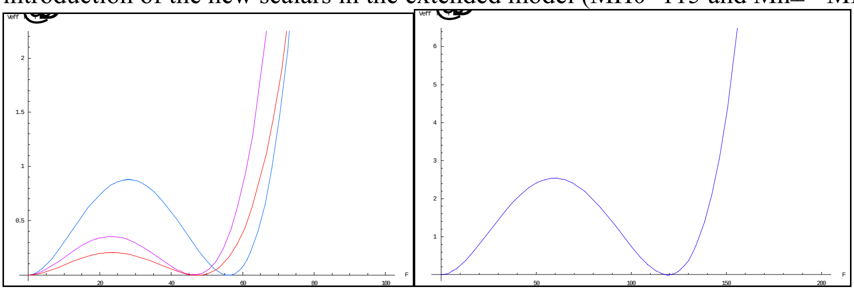

Figure No.1. The effective potential at finite temperature in the SM (left) and in the extension of the SM with a Higgs triplet boson (right).

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