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A Model for the Mass of Higgs Boson

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Abstract

Higgs physics is an active front from both experimental and theoretical aspects. It is a problem how to explain the measured value of Higgs mass, and a simple question like where the quartic coupling potential exactly comes from could not be well answered. This paper described a simple model to calculate the Higgs mass. It seems the Higgs mass may come from the coupling between Hawking energy of the Planck scale Kerr black hole and the thermal energy of cosmological microwave background. And by a logarithm potential, we can naturally get the exact quartic term for the Lagrangian. The Higgs mass we get is proportional to the square root of the temperature of the cosmological thermal background, which may mean it shall be larger at earlier universe.

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I. Introduction

Higgs physics[1–5] is an important field of research on both the experimental and theoretical fronts. The Higgs mechanism plays a crucial role in the standard model[6–8]. We know especially in the classical electroweak model part, a complex scalar Higgs doublet, ϕ, is added to the model for mass generation through spontaneous symmetry breaking with potential given by:

$$V(\phi) = \mu^2\phi^+\phi + \frac{\lambda^2}{2}(\phi^+\phi)^2, \qquad \text{and } \phi \equiv \begin{pmatrix}\phi^+\\ \phi^0\end{pmatrix}$$

Here μ^2 is negative, and ϕ develops a vacuum expectation value with $\frac{\upsilon}{\sqrt{2}} = \frac{|\mu|}{\lambda}$, breaking part of the electroweak gauge symmetry, which gives the mass for $W^{\pm}$ and Z electroweak bosons, and leaves only one neutral Higgs scalar, H, in the physical particle spectrum.

Beyond standard model, people also attempted to expand the Higgs physics from various aspects by building different models[9]. Such as in the minimal supersymmetric model, there appear additional charged and neutral scalar Higgs particles[10]. And in a composite Higgs model, people argued if the scalar is composite rather than elementary, where the idea of a composite Higgs relies on having new strong interactions[11]. People also think the Higgs mass may have a cosmological evolution, and the axion potential help it to choose the electroweak scale[12–14].

While noticing these many active research works, we have to admit that a lot of fundamental problems have not yet been well clarified at this time, including such as, how to explain the measured values of the Higgs mass and vacuum expectation value, and even a sound simple question like where the negative mass term and the $(\phi^+\phi)^2$ term exactly come from could not be answered satisfactorily.

In this paper, we will try to build a simple model to get the value of Higgs mass. The model includes the introduction of the logarithm potential. The logarithm potential was first introduced for a composite system preserving the separability of the product states of uncorrelated subsystems[15]. And then it is used to describe a quantum open system related to the quantum information theory[16,17]. People have also tried to use it to describe the physical vacuum in references[18,19], but the physics there is not shown clear enough, and therefore their model did not get any theoretically reasonable data, such as the value of Higgs mass introduced here. Here a reasonable

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model is built to get the mass of the Higgs boson. We found that the Higgs mass may come from the energy coupling between the Hawking energy of the Planck scale Kerr black hole and the thermal energy of cosmological microwave background. Models and calculations are made in section II. Conclusions are drawn in section III.

II. Model and Calculations

Consider a vector field A_μ, such as a photon field. We know in a vacuum with no charge, A_μ satisfies $\Box A_\mu = 0$. In a former paper, we have conjectured that it would be very possible that there is a tiny Planck scale Kerr black hole net in our universe[20]. Although this has not yet been directly confirmed by experimental work, it does provide an alternative way to quantized the electric charge. And here we will further show that it would have some contribution to the vector field. More exactly, it will generate an background energy of $V_h = k_B T_p ln3$, where T_p is the temperature of the Planck scale Kerr black hole[16,17]. And we shall also take the cosmological microwave background into consideration, which will give the particle an energy of $V_l = k_B T_b \ln(\Omega|A_\mu|^2)$, where T_b is the temperature of the cosmological microwave background[16–19]. The wave function of one photon has the form of:

$$A^\mu(x) = \Sigma_\lambda \int \widetilde{dk} e^{-ikx} \epsilon_\lambda^\mu \phi_\lambda(\vec{k}) \quad (1)$$

For a vector particle generated from the vacuum described by A_μ, it will have the Hamiltonian as:

$$H_g = \frac{1}{2}(V_h + V_l) + \hat{P} \quad (2)$$

Where we assume $V_h \gg P \gg V_l$. And we assumed the vector field has no mass at the beginning. And obviously, this vector particle will be annihilated, which may be described by A_μ^+, and its Hamiltonian has the form of:

$$H_a = -\frac{1}{2}V_h + \hat{P} \quad (3)$$

The reason that there is factor of 1/2 in equation 2 and 3 is that every component of the vector is a scalar field who satisfies the Klein-Gordon equation, and its vacuum zero point energy has a 1/2 factor.

We know there are a lot of argument on whether the Higgs particle is composite or elementary, and people generally will use the four fermion field wave functions to deal with the Higgs particle when they treat them as a composite particle. And here we will also treat the Higgs particle as composite, but we will consider the field of $A^\mu A_\mu^+$. Now let us consider $\Box(A^\mu A_\mu^+)$, which can be expressed as:

$$\Box(A^\mu A_\mu^+) = 2\partial_t A^\mu \partial_t A_\mu^+ - 2\partial_i A^\mu \partial_i A_\mu^+ + (\Box A^\mu)A_\mu^+ + A^\mu(\Box A_\mu^+) \quad (4)$$

and the terms with $\Box A^\mu$ and $\Box A_\mu^+$ on the right hand side of equation (4) equals to zero, so we have:

$$\Box(A^\mu A_\mu^+) = 2\partial_t A^\mu \partial_t A_\mu^+ - 2\partial_i A^\mu \partial_i A_\mu^+ \quad (5)$$

And from equation 2 and 3, we could have:

$$\partial_t A^\mu \partial_t A_\mu^+ \doteq -\frac{1}{4}(V_l \cdot V_h) A^\mu A_\mu^+ + \partial_i A^\mu \partial_i A_\mu^+ \quad (6)$$

so equation (5) becomes:

$$\Box(A^\mu A_\mu^+) = -\frac{1}{2} V_h \cdot V_l \cdot A^\mu A_\mu^+ = -\frac{1}{4} K_B T_p ln3 \cdot K_B T_B \cdot A^\mu A_\mu^+ \ln(\Omega|A^\mu A_\mu^+|^2) \quad (7)$$

Define:

$$\Phi = A^\mu A_\mu^+ \quad (8)$$

By doing this, we treat the Higgs particle as a composite one. And equation (7) has the form of:

$$\Box\Phi = -\frac{1}{4} K_B T_p ln3 \cdot K_B T_B \Phi \ln(\Omega|\Phi|^2) \equiv -\alpha\Phi \ln(\Omega|\Phi|^2) \quad (9)$$

and we can immediately find the potential term of its Lagrangian as[19]:

$$L_V = \frac{1}{2}\alpha\{|\Phi|^2[\ln(\Omega|\Phi|^2) - 1]\} \quad (10)$$

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It can be found that the Lagrangian has a non-trivial minimum at $|\Phi| = 1/\sqrt{\Omega}$, and at this point, the potential can be written as the familiar form as:

$$L_V = -\alpha|\Phi|^2 + \frac{1}{2}\alpha\Omega|\Phi|^4 \quad (11)$$

the mass can then be written as:

$$\mathrm{m} = \sqrt{2\alpha} = \sqrt{\frac{1}{2}k_B^2 T_b T_p ln3} \quad (12)$$

For the Planck scale Kerr black hole with an area of $4ln3$ and spin 2, the temperature T_p could be written as:

$$T_p = \frac{\sqrt{M^2-a^2}}{4\pi M(M+\sqrt{M^2-a^2})}, \quad \text{with} \quad a = \frac{J}{M} \quad (13)$$

Here[20],

$$M^2 = \frac{ln3}{4\pi} + \frac{\pi j(j+1)}{ln3}, \quad \text{with } \mathrm{j} = 2 \quad (14)$$

By choosing $T_b = 2.725K$, from equation (13), we can get $\mathrm{m} = 122.5\mathrm{GeV}$. This mass comes from the coupling of the Hawking energy of the Planck scale Kerr black hole and the current thermal energy of cosmological microwave background. And from equation 13, we notice that the mass is proportional to the square root of the temperature of the cosmological background. This may mean that in earlier universe, Higgs boson may have a larger mass. Such as if $T_b = 272.5K$, then the Higgs bosom may have a mass of 1.225TeV.

We know the CMB can be traced back to the evolution time of $T_b = 3000K$, and earlier than that, there are several other stages, especially such as the stage of inflation. Since by our model the Higgs mass is proportional to the square root of the temperature, this may make the Higgs particle a good candidate of the inflaton now[21], and we will examine this in our future work.

There is still some difference between the value of 122.5GeV and 125GeV, and the difference may be due to some other process such as the radiation correction, and we noticed that such as in the calculations reported in reference 10, an uncertainty of $\pm 3\mathrm{GeV}$ is associated with the Higgs mass prediction[10].

III. Conclusions

In this paper, by a method from the quantum information theory, we get a logarithm potential, whose Lagrangian can naturally get a $|\Phi|^4$ term. The Higgs mass we calculated is proportional to the square root of the Hawking temperature multiplied by the temperature of cosmological thermal background. It has a value of 122.5GeV at $T_b = 2.725K$, which may be larger at earlier universe. The model we give here is quite simple, and it indicates that the Higgs particle may be a composite one, and the Higgs vacuum may come from the coupling of high energy end, i.e. the Planck scale energy end, and low energy end, i.e. the CMB energy end. We here used only one vector field, and it may not be difficult to have more to form the symmetry of standard model.

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