Mathematical Formulation of the Higgs Mechanism in Time-Mass Duality

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Zusammenfassung

This work develops a precise mathematical formulation of the Higgs mechanism within the framework of the T0 model, a novel time-mass duality theory. Assuming that time and mass are complementary aspects of the same fundamental reality, it demonstrates how the Higgs mechanism serves as a mediator between two equivalent descriptions: the conventional view with time dilation and constant rest mass, and an alternative view with absolute time and variable mass. The formulation not only leads to an elegant mathematical structure but also provides concrete, experimentally testable predictions that deviate from the Standard Model of particle physics.

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1 Introduction

Modern theoretical physics is based on two fundamental yet incompletely reconciled theories: relativity and quantum mechanics. While relativity describes time and space as dynamic, observer-dependent quantities, quantum mechanics treats time as an external parameter. This conceptual tension might hint at a deeper structure that could unify both perspectives.

In this work, we explore an alternative theoretical foundation based on the idea of a fundamental duality between time and mass. Similar to the wave-particle duality in quantum mechanics, we propose that time and mass represent two complementary descriptions of the same physical reality. Whereas conventional relativity treats time as relative (time dilation) and rest mass as constant, we suggest a mathematically equivalent perspective in which time is absolute and mass is variable.

The Higgs mechanism plays a special role in this context, as it is responsible for generating particle masses in the Standard Model. In our dual formulation, the Higgs field becomes the central mediator between both perspectives, defining both the rest mass and the intrinsic timescale of all particles. Particularly noteworthy is that the unique position of the Higgs boson in the particle zoo—as the only particle without a clear "mirror image"—finds a natural explanation within this framework.

In the following, we develop a mathematically precise formalism for this time-mass duality, reformulate the fundamental field equations, and derive concrete experimental implications. This theory does not represent a break with established physics but extends its interpretive framework and could uncover deeper connections between seemingly independent phenomena such as quantum coherence, Higgs interactions, and cosmological observations.

2 Starting Point: Higgs Mechanism in the Standard Model

In the Standard Model, the Higgs field is introduced as a complex scalar doublet:

$$\Phi = \begin{pmatrix} \phi^+ \\ \phi^0 \end{pmatrix} \tag{1}$$

The Lagrangian density for the Higgs field is:

$$\mathcal{L}_{\text{Higgs}} = (D_\mu \Phi)^\dagger (D^\mu \Phi) - V(\Phi) \tag{2}$$

with the Higgs potential:

$$V(\Phi) = -\mu^2 \Phi^\dagger \Phi + \lambda (\Phi^\dagger \Phi)^2 \tag{3}$$

The Yukawa coupling describes the interaction of the Higgs field with fermions:

$$\mathcal{L}_{\text{Yukawa}} = -y_f \bar{\psi}_L \Phi \psi_R + \text{h.c.} \tag{4}$$

After spontaneous symmetry breaking, the Higgs field acquires a vacuum expectation value (VEV):

$$\langle \Phi \rangle = \frac{1}{\sqrt{2}} \begin{pmatrix} 0 \\ v \end{pmatrix} \tag{5}$$

The fermion masses are then given by:

$$m_f = \frac{y_f v}{\sqrt{2}} \tag{6}$$

3 Reformulation within the Framework of Time-Mass Duality

3.1 Time Dilation Perspective (Standard Relativity)

In this perspective, the rest mass of particles remains constant, while time is relative (time dilation). The mass-energy relation is:

$$E = \gamma_{\text{Lorentz}} m_0 c^2 \tag{7}$$

where $\gamma_{\text{Lorentz}} = \frac{1}{\sqrt{1-v^2/c^2}}$ is the Lorentz factor.

Time dilation is described by:

$$t' = \gamma_{\text{Lorentz}} t \tag{8}$$

The Yukawa coupling in this perspective directly yields a constant rest mass:

$$m_0 = \frac{y_f v}{\sqrt{2}} \tag{9}$$

3.2 Mass Variation Perspective (T0 Model)

In this alternative perspective, time T_0 is absolute (constant), while mass is variable. The intrinsic time field is defined as:

$$T(x) = \frac{\hbar}{\max(mc^2, \omega)} \tag{10}$$

where mc^2 applies to massive particles and ω to photons (as energy) to ensure a unified treatment. The transformation relation to the standard perspective is:

$$m = \gamma_{\text{Lorentz}} m_0 \tag{11}$$

and

$$T(x) = \frac{T_0}{\gamma_{\text{Lorentz}}} \tag{12}$$

where $T_0 = \frac{\hbar}{m_0 c^2}$ is the intrinsic time at rest.

4 The Higgs Field as a Mediator of Time-Mass Duality

4.1 Modified Higgs Lagrangian Density

In the T0 model, the Higgs Lagrangian density is modified:

$$\mathcal{L}_{\text{Higgs-T}} = |T(x)(\partial_\mu + igA_\mu)\Phi + \Phi\partial_\mu T(x)|^2 - V(T(x), \Phi) \tag{13}$$

where $V(T(x), \Phi) = -\mu^2\Phi^\dagger\Phi + \lambda(\Phi^\dagger\Phi)^2$ is the Higgs potential, and the modified covariant derivative is defined as:

$$T(x)(\partial_\mu + igA_\mu)\Phi + \Phi\partial_\mu T(x) = T(x)(\partial_\mu + igA_\mu)\Phi + \Phi\partial_\mu T(x) \tag{14}$$

4.2 Modified Yukawa Coupling

The Yukawa coupling is reformulated in the T0 model:

$$\mathcal{L}_{\text{Yukawa-T}} = -y_f \bar{\psi}_L \Phi \psi_R + \text{h.c.} \tag{15}$$

This leads to a velocity-dependent mass:

$$m(v) = \gamma_{\text{Lorentz}} \cdot \frac{y_f v}{\sqrt{2}} = \gamma_{\text{Lorentz}} m_0 \tag{16}$$

while the intrinsic time field scales accordingly:

$$T(x)(v) = \frac{\hbar}{m(v)c^2} = \frac{\hbar}{\gamma_{\text{Lorentz}} m_0 c^2} = \frac{T_0}{\gamma_{\text{Lorentz}}} \tag{17}$$

4.3 Higgs Field as a Bridge Between Perspectives

In the new framework, the Higgs field plays a dual role:

1. It generates the rest mass m_0 through its VEV in the standard perspective.
2. It defines the intrinsic timescale $T_0 = \frac{\hbar}{m_0 c^2}$ in the duality perspective.

The fundamental connection is expressed by:

$$T_0 \cdot m_0 c^2 = \hbar \tag{18}$$

This relationship holds in both perspectives, as:

$$T(x) \cdot mc^2 = \frac{T_0}{\gamma_{\text{Lorentz}}} \cdot \gamma_{\text{Lorentz}} m_0 c^2 = T_0 \cdot m_0 c^2 = \hbar \tag{19}$$

5 Field Equations in Dual Formulation

5.1 Klein-Gordon Equation

The standard Klein-Gordon equation for the Higgs boson is:

$$(\Box + m_H^2) h(x) = 0 \tag{20}$$

In the T0 model, it is modified to:

$$i\hbar T(x) \frac{\partial h_T}{\partial t} + i\hbar h_T \frac{\partial T(x)}{\partial t} + \frac{\hbar^2}{2m_H} \nabla^2 h_T = 0 \tag{21}$$

6 Lagrangian Formulation

The total Lagrangian density of the T0 model is:

$$\mathcal{L}_{\text{Total}} = \mathcal{L}_{\text{Boson}} + \mathcal{L}_{\text{Fermion}} + \mathcal{L}_{\text{Higgs-T}} + \mathcal{L}_{\text{intrinsic}},$$
$$\mathcal{L}_{\text{intrinsic}} = \frac{1}{2} \partial_\mu T(x) \partial^\mu T(x) - \frac{1}{2} T(x)^2 - \frac{\rho}{T(x)} \tag{22}$$

7 Cosmological Implications

The T0 model implies:

- Modified Gravitational Potential: $\Phi(r) = -\frac{GM}{r} + \kappa r$, where κ has dimension $[E]$ in natural units, with $\kappa^{\mathrm{SI}} \approx 4.8 \times 10^{-11}\,\mathrm{m/s^2}$
- Cosmic Redshift: $1 + z = e^{\alpha^{\mathrm{SI}} d}$, $\alpha^{\mathrm{SI}} \approx 2.3 \times 10^{-18}\,\mathrm{m^{-1}}$
- Wavelength Dependence: $z(\lambda) = z_0(1 + \beta_{\mathrm{T}}^{\mathrm{SI}} \ln(\lambda/\lambda_0))$, with $\beta_{\mathrm{T}}^{\mathrm{SI}} \approx 0.008$

Gravitation arises from $\nabla T(x)$.

8 Conversion and Interpretation of β_{T}

The parameter $\beta_{\mathrm{T}}^{\mathrm{nat}}$ plays a central role in the T0 model and is set exactly to 1 in natural units, as established in the unified framework of natural units. This assignment is not an empirical adjustment but a theoretical necessity.

The standard formulation of $\beta_{\mathrm{T}}^{\mathrm{nat}}$ in natural units is:

$$\beta_{\mathrm{T}}^{\mathrm{nat}} = \frac{\lambda_h^2 v^2}{16\pi^3 m_h^2 \xi} \tag{23}$$

Setting $\beta_{\mathrm{T}}^{\mathrm{nat}} = 1$ determines the value of ξ:

$$\xi = \frac{\lambda_h^2 v^2}{16\pi^3 m_h^2} \approx 1.33 \times 10^{-4} \tag{24}$$

This dimensionless parameter defines the characteristic length scale of the model as $r_0 = \xi \cdot l_P$, with l_P being the Planck length.

The conversion to SI units follows:

$$\beta_{\mathrm{T}}^{\mathrm{SI}} = \beta_{\mathrm{T}}^{\mathrm{nat}} \cdot \frac{\xi \cdot l_{P,\mathrm{SI}}}{r_{0,\mathrm{SI}}} \tag{25}$$

With $l_{P,\mathrm{SI}} = 1.616 \times 10^{-35}\,\mathrm{m}$ and the characteristic T0 length scale $r_{0,\mathrm{SI}} \approx 2.15 \times 10^{-39}\,\mathrm{m}$, we obtain $\beta_{\mathrm{T}}^{\mathrm{SI}} \approx 0.008$.

This value aligns with empirical estimates from cosmological observations, such as wavelength-dependent redshift. The apparent discrepancy between $\beta_{\mathrm{T}}^{\mathrm{nat}} = 1$ (natural units) and $\beta_{\mathrm{T}}^{\mathrm{SI}} \approx 0.008$ (SI units) does not indicate theoretical uncertainty but is merely a consequence of unit conversion, analogous to converting the speed of light from $c = 1$ (natural units) to $c = 3 \times 10^8\,\mathrm{m/s}$ (SI units).

Experimental validation of the exact value of $\beta_{\mathrm{T}}^{\mathrm{SI}}$ can be achieved through precision measurements of wavelength-dependent redshift, as described in Section 5.1 “JWST Spectroscopy,” where a variation of $\Delta z/z \approx 3.85\%$ across the JWST range is predicted.

9 Conclusion

The dual formulation of the Higgs mechanism in the T0 model offers a mathematically coherent reformulation that is not only conceptually elegant but also provides concrete, testable predictions. The theory interprets the Higgs mechanism not merely as a mass generator but also as a mediator between two complementary perspectives of reality: the conventional view with time dilation and constant rest mass, and an alternative view with absolute time and variable mass.

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