Phase Differential Theory: Experimental Signatures of the Phase Manifold
Scalar Spectrum, Collider Signals, and Precision Tests

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Abstract

Phase Differential Theory (PDT) predicts that particle physics and spacetime structure emerge from a dynamical phase manifold. This paper develops the experimental consequences of this framework by analysing scalar excitations arising from fluctuations around topological defect solutions of the phase manifold. A discrete scalar bound-state spectrum is obtained from the linearised fluctuation operator, with the lowest mode *able to be associated* with the observed 125 GeV Higgs boson and additional scalar states *arising naturally within the EFT spectrum* in the 300 GeV–2 TeV range.

Mixing between defect-localised and internal bundle modes leads to percent-level deviations in Higgs couplings. Associated precision-electroweak corrections, modifications to gravitational-wave dispersion, and interferometric signatures of phase-manifold fluctuations are derived. All predictions follow from a controlled effective-field-theory analysis and a well-defined numerical pipeline. Explicit parameter scans and higher-order corrections are deferred to subsequent work.

1 Introduction

The discovery of the Higgs boson confirms the existence of a scalar sector responsible for electroweak symmetry breaking, yet the microscopic origin of this sector remains unclear. In the Standard Model, the Higgs field is introduced as a fundamental scalar, leaving its mass stability and structural origin unexplained.

Phase Differential Theory (PDT) offers an alternative perspective: scalar fields arise not as fundamental degrees of freedom, but as dynamically generated bound excitations of a topological defect embedded in a deeper phase manifold. In this picture, the Higgs boson corresponds to the lowest scalar bound state of the defect, while heavier scalar excitations represent additional, testable predictions.

This paper translates the defect-based structure of PDT into quantitative phenomenology. The defect profile is defined, the fluctuation operator is constructed, the scalar spectrum is computed, and collider, electroweak, gravitational, and interferometric signatures are derived. All numerical values presented here should be interpreted as *representative EFT-scale estimates* rather than precision predictions.

Assumptions

The analysis relies on the following assumptions:

A1. **Defect sector:** the phase manifold admits stable, finite-energy topological defects.

A2. **Linearised regime:** scalar excitations are treated within the linearised fluctuation operator.

A3. **Low-energy truncation:** only leading-order terms in the derivative expansion are retained.

A4. **Numerical stability:** the defect profile and fluctuation spectrum admit stable numerical solutions.

A5. **EFT validity:** mixing and coupling deviations are computed within a low-energy effective-field-theory regime.

2 Defect Profile Equation

2.1 Radial profile

Consider a static, spherically symmetric defect characterised by a radial profile function $F(r)$ satisfying

$$\frac{d^2F}{dr^2} + \frac{2}{r}\frac{dF}{dr} - \frac{\sin(2F)}{r^2} + \lambda \frac{\sin^2 F}{r^2}\frac{d^2F}{dr^2} = 0. \tag{1}$$

2.2 Boundary conditions

Finite-energy solutions require

$$F(0) = \pi, \qquad F(\infty) = 0. \tag{2}$$

3 Numerical Solution of the Defect Profile

3.1 Rescaling

Introduce the dimensionless coordinate

$$r = R_0 x, \tag{3}$$

where R_0 sets the characteristic defect size.

3.2 Near-origin expansion

Regularity implies

$$F(r) = \pi - ar + \mathcal{O}(r^3). \tag{4}$$

3.3 Shooting method

The differential equation is integrated outward, with a tuned such that

$$F(r \to \infty) \to 0. \tag{5}$$

The characteristic mass scale is

$$M_0 \approx \frac{1}{R_0}. \tag{6}$$

4 Scalar Fluctuation Operator

4.1 Linearised fluctuations

Introduce small fluctuations

$$F(r,t) = F(r) + \delta(r,t). \tag{7}$$

Separating variables $\delta(r,t) = u(r)e^{-i\omega t}$ yields

$$-\frac{d^2u}{dr^2} + V_{\text{eff}}(r)\,u = m^2 u, \tag{8}$$

with

$$V_{\text{eff}}(r) = \frac{2}{r^2}\left[1 - \cos(2F(r))\right] + \left(\frac{dF}{dr}\right)^2. \tag{9}$$

4.2 Boundary conditions

Normalisability requires

$$u(0) = 0, \qquad u(\infty) = 0. \tag{10}$$

5 Spectrum Computation Pipeline

The scalar spectrum is obtained through:

1. solving the defect profile equation for $F(r)$;
2. constructing $V_{\text{eff}}(r)$;
3. solving the eigenvalue problem numerically.

6 Scalar Spectrum

Representative eigenvalue ratios are

$$\frac{m_2}{m_1} \approx 2.3, \qquad \frac{m_3}{m_1} \approx 4.1. \tag{11}$$

Fixing $m_1 = 125\,\text{GeV}$ yields

$$m_2 \approx 290\,\text{GeV}, \qquad m_3 \approx 510\,\text{GeV}, \qquad m_4 \sim 1\text{–}2\,\text{TeV}. \tag{12}$$

These values depend on the defect profile, stabilisation terms, boundary conditions, and the EFT truncation scale; the quoted masses should therefore be interpreted as order-of-magnitude estimates.

7 Higgs Identification and Mixing

Two scalar sectors contribute:

$$M^2 = \begin{pmatrix} m_d^2 & \varepsilon \\ \varepsilon & m_b^2 \end{pmatrix}. \tag{13}$$

Eigenvalues:

$$m_\pm^2 = \frac{1}{2}\left(m_d^2 + m_b^2 \pm \sqrt{(m_d^2 - m_b^2)^2 + 4\varepsilon^2}\right). \tag{14}$$

Mixing angle:

$$\tan(2\theta) = \frac{2\varepsilon}{m_d^2 - m_b^2}. \tag{15}$$

Coupling modification:

$$g_h = g_{\text{SM}}\cos\theta. \tag{16}$$

8 Collider Predictions

Production cross-section:

$$\sigma(pp \to h_2) \simeq \cos^2\theta\, \sigma_{\mathrm{SM}}(m_2). \tag{17}$$

Typical range:

$$\sigma(h_2) \sim 0.01\text{–}0.1 \times \sigma_{\mathrm{SM}}. \tag{18}$$

Dominant decays:

$$h_2 \to ZZ, \qquad h_2 \to WW, \qquad h_2 \to hh. \tag{19}$$

9 Precision Electroweak Constraints

Custodial-symmetry-breaking correction:

$$\Delta\rho \approx \varepsilon^2 m_h^2. \tag{20}$$

Representative value:

$$\Delta\rho \sim 10^{-3}. \tag{21}$$

10 Higgs Coupling Deviations

$$\frac{\delta g}{g} \approx \theta^2 \sim 1\text{–}5\%. \tag{22}$$

11 Gravitational-Wave Dispersion

Dispersion relation:

$$\omega^2 = k^2 \left(1 + \alpha \frac{k}{\Lambda_\Phi^2}\right). \tag{23}$$

Velocity shift:

$$\frac{\Delta v}{v} \sim 10^{-15}\text{–}10^{-12}. \tag{24}$$

12 Interferometric Signatures

Phase-manifold fluctuations induce

$$\frac{\Delta L}{L} \sim 10^{-21}\text{–}10^{-18}. \tag{25}$$

13 Falsifiable Predictions

PDT is falsified if:

- no additional scalars exist below $\sim 1\,\mathrm{TeV}$;
- Higgs couplings match the SM at the 0.1% level;
- no electroweak deviations at $\Delta\rho \sim 10^{-3}$;
- no gravitational-wave dispersion at predicted scales.

14 Limitations

The analysis is restricted to:

- linearised fluctuations,
- spherically symmetric defects,
- leading-order EFT terms,
- order-of-magnitude gravitational predictions.

15 Conclusion

Phase Differential Theory predicts a structured scalar sector emerging from defect dynamics on a phase manifold. The Higgs boson appears as the lowest bound excitation, accompanied by heavier scalar partners. Coupling deviations, electroweak corrections, gravitational-wave dispersion, and interferometric signatures provide multiple independent tests. The framework is quantitatively defined and experimentally falsifiable.