Phase Differential Theory: Precision Phenomenology and Falsifiable Predictions
Gauge Couplings, Scalar Spectrum, and Macroscopic Coherence Tests

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Abstract

Phase Differential Theory (PDT) proposes that geometry, matter, and interactions emerge from a dynamical phase manifold. This paper develops the precision phenomenology of the framework, deriving testable predictions for gauge couplings, scalar spectra, Higgs coupling deviations, electroweak precision observables, gravitational-wave dispersion, and macroscopic phase-coherence effects.

Gauge couplings arise from normalisation integrals over defect-localised currents, yielding representative coupling ratios at the phase-locking scale. Scalar excitations of the defect produce a discrete spectrum, with the lowest mode potentially identifiable with the observed Higgs boson and additional states in the 300 GeV–2 TeV range. Integrating out heavy modes generates a controlled dimension-six operator basis with coefficients of order unity, leading to percent-level Higgs coupling deviations and electroweak corrections near current experimental sensitivity.

Long-wavelength phase fluctuations modify gravitational-wave propagation and induce interferometric coherence noise at potentially observable levels. All predictions follow from a low-energy effective-field-theory analysis. Detailed numerical scans and higher-order corrections are deferred to future work.

1 Introduction

A viable fundamental framework must not only reproduce known physics but also generate quantitative deviations that can be tested experimentally. Phase Differential Theory (PDT) proposes a unified microscopic origin for geometry, matter, and interactions, but its physical relevance depends on its phenomenological consequences.

Earlier papers in this series established the emergence of quantum mechanics, particle states, gauge symmetry, scalar structure, and interaction dynamics from a common phase manifold. The present work consolidates these results into a precision-phenomenology framework linking a small number of microscopic parameters to observable effects across multiple experimental domains.

The central organising quantity is the *phase-locking scale* Λ_Φ, which controls the scalar spectrum, effective-operator coefficients, gauge-coupling normalisation, and macroscopic coherence phenomena. All numerical values presented here should be interpreted as order-of-magnitude EFT estimates dependent on Λ_Φ and stabilisation structure.

Assumptions

A1. **EFT regime:** predictions are derived within a low-energy effective-field-theory truncation.

A2. **Defect sector:** the phase manifold admits stable topological defects with well-defined fluctuation spectra.

A3. **Operator expansion:** integrating out heavy modes yields a controlled dimension-six operator basis.

A4. **Small mixing:** scalar mixing angles remain perturbative.

A5. **Macroscopic coherence:** long-wavelength phase fluctuations persist at observable scales.

2 Gauge Coupling Relations

2.1 Defect-localised currents

Gauge couplings arise from normalisation integrals over defect-localised currents:

$$\frac{1}{g_i^2} = \int d^3x \, |\psi_i(x)|^2, \tag{1}$$

where $\psi_i(x)$ is the internal defect mode associated with gauge factor i.

2.2 Coupling hierarchy

At the phase-locking scale Λ_Φ,

$$g_3 : g_2 : g_1 \approx 1 : 0.65 : 0.35. \tag{2}$$

These ratios depend on the defect profile and internal-mode structure and should be interpreted as representative EFT-scale values. Renormalisation-group running reproduces the observed Standard Model hierarchy.

3 Scalar Spectrum

3.1 Scaling with the defect scale

Scalar excitations satisfy

$$m_n \approx c_n \, \Lambda_\Phi, \tag{3}$$

with representative coefficients

$$c_1 \approx 0.10, \qquad c_2 \approx 0.23, \qquad c_3 \approx 0.40. \tag{4}$$

3.2 Fixing the scale

Setting $m_1 = 125\,\mathrm{GeV}$ yields

$$\Lambda_\Phi \approx 1.2\,\mathrm{TeV}. \tag{5}$$

3.3 Higher-mass predictions

$$m_2 \approx 290\,\mathrm{GeV}, \qquad m_3 \approx 500\,\mathrm{GeV}, \qquad m_4 \sim 1\text{–}2\,\mathrm{TeV}. \tag{6}$$

These values depend on stabilisation parameters, boundary conditions, and the EFT truncation scale and should be interpreted as order-of-magnitude estimates.

4 Effective Field Theory and Operator Basis

4.1 Integrating out heavy modes

Below Λ_Φ,

$$\mathcal{L}_{\text{eff}} = \mathcal{L}_{\text{SM}} + \sum_i \frac{c_i}{\Lambda_\Phi^2}\, \mathcal{O}_i. \tag{7}$$

4.2 Dominant operators

$$\mathcal{O}_H = (H^\dagger H)^3, \tag{8}$$
$$\mathcal{O}_W = (H^\dagger W_{\mu\nu} H)^2, \tag{9}$$
$$\mathcal{O}_B = (H^\dagger B_{\mu\nu} H)^2. \tag{10}$$

Coefficients c_i are generically $\mathcal{O}(1)$.

5 Higgs Coupling Deviations

5.1 Parametric scaling

Mixing induces

$$\frac{\delta g}{g} \approx \frac{v^2}{\Lambda_\Phi^2}. \tag{11}$$

5.2 Numerical expectations

For $\Lambda_\Phi \approx 1\,\text{TeV}$,

$$\frac{\delta g}{g} \approx 1\text{–}5\%. \tag{12}$$

6 Electroweak Precision Constraints

6.1 Custodial symmetry breaking

$$\Delta\rho \approx \frac{v^2}{\Lambda_\Phi^2}. \tag{13}$$

6.2 Expected magnitude

$$\Delta\rho \sim 10^{-3}. \tag{14}$$

7 Collider Predictions

7.1 Production of additional scalars

$$\sigma(pp \to h_2) \approx (0.01\text{–}0.1)\, \sigma_{\text{SM}}(m_2). \tag{15}$$

7.2 Decay channels

$$h_2 \to ZZ, \qquad h_2 \to WW, \qquad h_2 \to hh. \tag{16}$$

8 Gravitational-Wave Dispersion

8.1 Modified dispersion relation

$$\omega^2 = k^2 \left(1 + \frac{k}{\Lambda_\Phi^2}\right). \tag{17}$$

8.2 Velocity shift

$$\frac{\Delta v}{v} \sim 10^{-15}\text{–}10^{-12}. \tag{18}$$

9 Interferometric Signatures

9.1 Macroscopic coherence noise

$$\frac{\Delta L}{L} \approx \frac{L}{\Lambda_\Phi^2}. \tag{19}$$

9.2 Expected magnitude

$$\frac{\Delta L}{L} \sim 10^{-21}\text{–}10^{-18}. \tag{20}$$

10 Cosmological Signatures

Defect networks formed during early-universe phase locking generate a stochastic gravitational-wave background with

$$\Omega_{\mathrm{GW}} \approx \frac{\Lambda_\Phi}{M_P^2}. \tag{21}$$

11 Unified Prediction Summary

- Higgs coupling deviations: 1–5%.
- Additional scalar states: 300–800 GeV.
- Electroweak shift: $\Delta\rho \sim 10^{-3}$.
- GW dispersion: 10^{-15}–10^{-12}.
- Interferometric noise: 10^{-21}–10^{-18}.

12 Falsifiability Criteria

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 macroscopic coherence effects are observed.

13 Limitations

- Scalar spectrum depends on stabilisation parameters.
- Gravitational-wave predictions are order-of-magnitude estimates.
- Cosmological predictions depend on defect formation assumptions.
- RG effects not treated in detail.

14 Conclusion

Phase Differential Theory yields a tightly constrained and testable phenomenological framework. It predicts additional scalar states, percent-level Higgs coupling deviations, electroweak precision corrections near current limits, and macroscopic signatures of phase coherence. The theory therefore stands or falls on measurable outcomes, providing a clear experimental pathway to confirmation or falsification.