

Scalar Resonance and Gauge Phenomenology on the $\mathbb{Z}^3 \otimes Q_3$ Error-Correcting Vacuum

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Abstract

We derive the defining phenomenological signatures of the Standard Model scalar sector natively from the discrete graph topology of a $\mathbb{Z}^3 \otimes Q_3$ error-correcting vacuum. Treating constituent mass as information-theoretic friction (the query rate of the local QEC coin operator), we derive the linear Yukawa coupling to fermions ($\mathcal{M}_f \propto m_f$) directly from this QEC query rate, and then show that — given the linear baseline — the quadratic coupling to massive vector bosons ($\mathcal{M}_V \propto m_V^2$) is an inescapable algebraic consequence of bipartite tensor orthogonality rather than an independent parametric input. Extending to second-order virtual processes, we demonstrate that the anomalous destructive interference and magnitude ratio of the $H \rightarrow \gamma\gamma$ loop is derived structurally from the lattice coordination number and the bipartite parity of the hypercube. By applying the discrete Feshbach resolvent over the framework’s invalid subspace, we prove the lattice naturally produces the non-linear, mass-dependent dynamic tracking required to model continuous kinematic loop integrals.

Audit note (added 2026-05-31). This paper predates the framework’s methodology audit of 2026-05-30. The headline “ $\mathcal{M}_V \propto m_V^2$ is an inescapable algebraic consequence of bipartite tensor orthogonality” is recharacterised post-audit as **Proposition tier** per ANCHOR §15 item 116. **Item 79 dependency is load-bearing:** the entire m_V^2 argument and the massless-photon decoupling argument rest on the Bipartite Grassmann Trace Theorem being formalised (currently a promotion target). Once Item 79 is promoted, the $\mathcal{M}_V \propto m_V^2$ derivation moves to Locked tier; until then the headline “inescapable algebraic consequence” should be read as “algebraic consequence conditional on Item 79”. The $H \rightarrow \gamma\gamma$ destructive-interference and magnitude-ratio claim from lattice coordination + bipartite parity is at Proposition tier pending §16.3 search-space audit: rival structural mechanisms for the destructive sign have not been enumerated. The discrete Feshbach resolvent argument for non-linear kinematic-loop tracking is a structural contribution and survives independently. The constituent-mass-as-QEC-query-rate identification cross-references the M9 retraction context of `origin_of_mass` and `narrow_higgs`; the linear $\mathcal{M}_f \propto m_f$ result is conditional on the same QEC-query-rate framework.

1 Introduction

In the Standard Model (SM), the coupling of the scalar Higgs field to matter is governed by independent, unlinked parametric axioms. Fermions acquire mass via linear Yukawa couplings ($y_f \propto m_f$), governed by Dirac spinors. Massive vector bosons (W, Z) acquire mass quadratically ($g_{HVV} \propto m_V^2$), governed by Proca fields. Loop-induced couplings (such as $H \rightarrow \gamma\gamma$) rely on

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complex transcendental kinematic integrals over infinite momentum space, with interference signs inserted phenomenologically.

In the discrete $\mathbb{Z}^3 \otimes Q_3$ topological framework [1], drawing on the broader lineage of emergent geometry from quantum error-correcting codes [5], matter exists strictly as topological frustration defects propagating across a network maintained by the active [8, 4, 4] extended Hamming code. We model the scalar resonance not as a continuous background field, but as a localized relaxation of the structural chirality constraint ($W = \chi$) within the discrete quantum walk operator.

In this paper, we resolve three defining anomalies of Higgs phenomenology: the disparate m vs m^2 scaling laws, the off-shell branching dynamics of $H \rightarrow WW^*$, and the destructive loop interference of $H \rightarrow \gamma\gamma$. We demonstrate that these are not independent physical axioms, but native geometric consequences of discrete tensor algebra and topological combinatorics.

2 The Thermodynamic Origin of Fermion Yukawa Couplings

Before examining gauge bosons, we must rigorously establish the origin of the linear scalar coupling to single-node fermions ($\mathcal{M}_f \propto m_f$). In continuous QFT, this is an arbitrary input. On the lattice, it emerges strictly from the statistical mechanics of the walk operator.

As established in prior analyses of the CKM hierarchy [1], the vacuum acts as an active verification engine. The probability P that a physical codeword with F frustrated edges passes the local Z -stabilizer parity checks unpenalised decays exponentially as $P \propto \exp(-F/(2\varphi))$, where $\varphi = (\sqrt{5} - 1)/2 \approx 0.618$ is the reciprocal golden ratio. The resulting effective exponent $\kappa_{\text{eff}} = 1/(2\varphi) \approx 0.809$ recovers the macroscopic shell-impedance ratio between adjacent generations: the unit- F mass multiplier $\exp(1/(2\varphi)) \approx 2.245$ matches the areal impedance ratio $R^2(\text{Gen } 3)/R^2(\text{Gen } 2) = 9/4 = 2.25$ to within 0.2% [1]. Constituent bare mass is formally defined as the inverse propagation probability: $m_f = 1/P$.

Consequently, to successfully execute a spatial shift (\mathcal{S}), a frustrated topological defect localized at a unit cell is forced to query the local error-correcting Coin operator (\mathcal{C}) an expected average of $N_{\text{query}} = 1/P = m_f$ times. Mass is literal information-theoretic friction.

A macroscopic scalar resonance (the Higgs) acts as a localized relaxation of the constraint within the Coin matrix ($\delta\mathcal{C}$). By Fermi's Golden Rule, the transition amplitude \mathcal{M}_f is the base overlap integrated over the local residence time. Because the fermion queries the perturbed coin N_{query} times, the amplitude scales precisely linearly with bare mass:

$$\mathcal{M}_f = N_{\text{query}} \times \langle f | \delta\mathcal{C}_{\text{local}} | \text{vac} \rangle \propto m_f \quad (1)$$

Thus, the proportionality between a fermion's mass and its scalar coupling is the exact macroscopic manifestation of the microscopic QEC query rate.

3 Tensor Algebra: Reducing Two SM Scaling Laws to One

Having established the thermodynamic origin of single-node fermion scaling ($\propto m_f$), we now resolve the disparate scaling of massive vector bosons ($\propto m_V^2$). We demonstrate that conditional upon the fermion scaling derived in Eq. 1, the quadratic gauge scaling is an inescapable structural consequence of bipartite tensor orthogonality.

Fermions are local (node) variables. Massive vector bosons (W, Z) are irreducible structural chiral excitations spanning the spatial bridges between nodes (link variables). If the global scalar perturbation expands across a spatial bridge connecting two nodes A and B , the walk operator Taylor expansion yields a first-order sum and a second-order product:

$$\mathcal{W}_{AB}(\lambda) \approx \mathbb{I}_A \otimes \mathbb{I}_B + \underbrace{\lambda \left(\delta\mathcal{C}_A \otimes \mathbb{I}_B + \mathbb{I}_A \otimes \delta\mathcal{C}_B \right)}_{\text{First-Order(Sum)}} + \lambda^2 \underbrace{\left(\delta\mathcal{C}_A \otimes \delta\mathcal{C}_B \right)}_{\text{Second-Order(Product)}} \quad (2)$$

A fermion pair ($f\bar{f}$) is generated at a single macroscopic interaction vertex (Node A) before spatially separating. Evaluating the first-order sum rule applied to the bipartite vacuum yields a linear transition amplitude:

$$\begin{aligned}\mathcal{M}_{f,1st} &= (\langle f|_A \otimes \langle 0|_B) [\delta\mathcal{C}_A \otimes \mathbb{I}_B + \mathbb{I}_A \otimes \delta\mathcal{C}_B] (|0\rangle_A \otimes |0\rangle_B) \\ &= \langle f|\delta\mathcal{C}_A|0\rangle_A \times \underbrace{\langle 0|\mathbb{I}_B|0\rangle_B}_{=1} + \underbrace{\langle f|\mathbb{I}_A|0\rangle_A}_{=0} \times \langle 0|\delta\mathcal{C}_B|0\rangle_B \\ &\propto m_f \times 1 = m_f\end{aligned}\tag{3}$$

Conversely, a vector boson bridge-clash is defined by a chiral differential boundary condition across the link: $c_A \oplus c_B = W$, requiring both constituent nodes to transition away from the local vacuum into highly frustrated states ($|c_A\rangle \otimes |c_B\rangle$). Evaluating the identical first-order sum operator for this bilocal link state yields strict annihilation by orthogonality:

$$\mathcal{M}_{W,1st} = \langle c_A|\delta\mathcal{C}_A|0\rangle_A \underbrace{\langle c_B|0\rangle_B}_{=0} + \underbrace{\langle c_A|0\rangle_A}_{=0} \langle c_B|\delta\mathcal{C}_B|0\rangle_B = 0\tag{4}$$

Because the unperturbed node remains the vacuum, which is orthogonal to the required defect state, a correlated two-node bridge clash cannot be excited by a first-order local perturbation. The transition is structurally forced to proceed via the second-order cross-derivative term:

$$\begin{aligned}\mathcal{M}_{W,2nd} &= (\langle c_A| \otimes \langle c_B|) (\delta\mathcal{C}_A \otimes \delta\mathcal{C}_B) (|0\rangle_A \otimes |0\rangle_B) \\ &= \langle c_A|\delta\mathcal{C}_A|0\rangle_A \times \langle c_B|\delta\mathcal{C}_B|0\rangle_B \\ &\propto m_A \times m_B = m_W^2\end{aligned}\tag{5}$$

Computational Verification: This strict tensor factorization was explicitly verified computationally by evaluating the framework across the full 65, 536-dimensional sparse tensor product space of adjacent unit cells. By constructing the first-order sparse Kronecker sum ($\mathbf{0_1st} = \text{sp.kron}(\mathbf{dC}, \mathbf{I}) + \text{sp.kron}(\mathbf{I}, \mathbf{dC})$) and the second-order product ($\mathbf{0_2nd} = \text{sp.kron}(\mathbf{dC}, \mathbf{dC})$), we confirmed that the first-order matrix element for any W -equivalent bipartite state mathematically evaluates to exactly zero. The m_V^2 scaling is not parameterized; it is an unavoidable law of bridge tensor geometry. Implementation details and verification scripts are available from the author on request.

4 Branching Cascades and Off-Shell Kinematics ($H \rightarrow WW^* \text{ vs } b\bar{b}$)

The tensor derivation clarifies the empirically observed macroscopic branching ratios of the Higgs resonance.

The $\sim 58\%$ dominance of the $b\bar{b}$ channel represents an on-shell transition, heavily favored because the target particles are stable single-node defects that propagate fully within the physical codespace. Furthermore, exact energy conservation strictly forbids scalar decay into the absolute heaviest physical state (the top quark, $2m_t \approx 350 \text{ GeV} > 125 \text{ GeV}$ [2, 3]), redirecting probability mass down the topological hierarchy.

Conversely, the empirically observed $\sim 22\%$ branching ratio to W bosons presents a paradox: because $2m_W \approx 160 \text{ GeV} > 125 \text{ GeV}$, the decay must be off-shell ($H \rightarrow WW^*$), invoking a massive kinematic penalty, yet the branching ratio remains extremely high. On the discrete lattice, an off-shell propagation maps directly to a virtual excursion into the 208-state penalized invalid subspace \mathcal{Q} of the walk operator. The $\sim 22\%$ branching ratio is therefore the structural equilibrium point of a mathematical competition: the enormous tensor amplification of the topological m_V^2 bridge coupling fighting against the severe exponential damping of the $(E - \mathcal{W}_{\mathcal{Q}\mathcal{Q}})^{-1}$ invalid subspace propagator.

5 Virtual Loops and Feshbach Resolvents ($H \rightarrow \gamma\gamma$)

Because photons (T_{1u} translational modes) lack topological frustration ($F = 0$), their tree-level overlap with the scalar fluctuation is strictly zero ($\langle \gamma\gamma | \delta\mathcal{C} | \text{vac} \rangle = 0$), natively matching the SM decoupling rule. Photon generation therefore requires a second-order sum over closed virtual paths (loops), dominated by the top-quark node and W bridge — mirroring the canonical SM calculation [4] in which the W loop and top loop interfere destructively.

5.1 The Destructive Minus Sign (Bipartite Parity)

In continuous QFT, loop interference signs are inserted phenomenologically via Fermi-Dirac statistics. On the lattice, the sign emerges natively from graph-theoretic parity. A virtual fermion loop traces the internal microscopic Q_3 cell graph. Because the hypercube is strictly *bipartite*, closed routing paths inherently incur an alternating -1 spectral parity phase, providing a pure geometric origin for the fermion minus sign. Conversely, vector bosons propagate on the Line Graph of the macroscopic \mathbb{Z}^3 spatial bridges. Because three orthogonal axes mutually intersect at a unit cell vertex, the Line Graph contains K_3 triangles; it is non-bipartite, yielding a strict $+1$ bosonic phase.

5.2 Combinatorics and Fractional Charge

To determine the anomalous magnitude ratio of these competing paths without resorting to static numerology, we must cleanly decouple the combinatorial path multiplicity of the lattice from the dynamic mass-dependent discrete Green's function.

The baseline phase space is governed by topological routing limits, weighted natively by the discrete fractional electric charge operator $Q = I_3 - \frac{1}{2}(1 - LQ)$ utilized in the generating walk operator [1].

- **Fermion Node Routing (Top):** Virtual fermion routing is strictly internal. The topological space is 1 macroscopic node \times 3 internal color sublattices = 3 paths. Weighted by the fractional top quark charge ($Q_t^2 = 4/9$) and the -1 bipartite parity, the combinatorial pre-factor is $\mathcal{C}_t = -1 \times 3 \times (4/9) = -4/3$.
- **Vector Bridge Routing (W):** The \mathbb{Z}^3 spatial coordination limit is 6. Factoring in the 3 polarization states (two transverse + one longitudinal) of the massive vector boson, the discrete path multiplicity is 18. With unit charge ($Q_W^2 = 1$), the pre-factor is $\mathcal{C}_W = +1 \times 18 \times 1 = +18$.

The static ratio of these unweighted path multiplicities evaluates to an explosive $|\mathcal{C}_W/\mathcal{C}_t| = 13.5$.

5.3 Dynamic Tracking via the Feshbach Resolvent

If the framework relied solely on this static 13.5 integer ratio, it would contradict SM phenomenology, as physical loops are dynamically mass-dependent (evaluating empirically to ~ 4.5 at 125 GeV).

As established in the derivation of the CKM generation matrix [1], virtual excursions on the $\mathbb{Z}^3 \otimes Q_3$ lattice are not static; they are dynamically evaluated via the Feshbach second-order effective Hamiltonian over the invalid subspace \mathcal{Q} . The physical amplitude \mathcal{A} is weighted by the discrete resolvent $(E - \mathcal{W}_{\mathcal{Q}\mathcal{Q}})^{-1}$.

Because the eigenvalues of the walk operator \mathcal{W} scale exponentially with topological frustration, the discrete Feshbach resolvent inherently provides the mass-dependent dynamical loop tracking required to mimic transcendental continuum integrals.

Computational tracking (Figure 1) explicitly verifies this dynamic suppression. Because the bipartite bridge clash (W) carries a heavier bare topological mass penalty ($F = 9$, $M_W \propto 1452$)

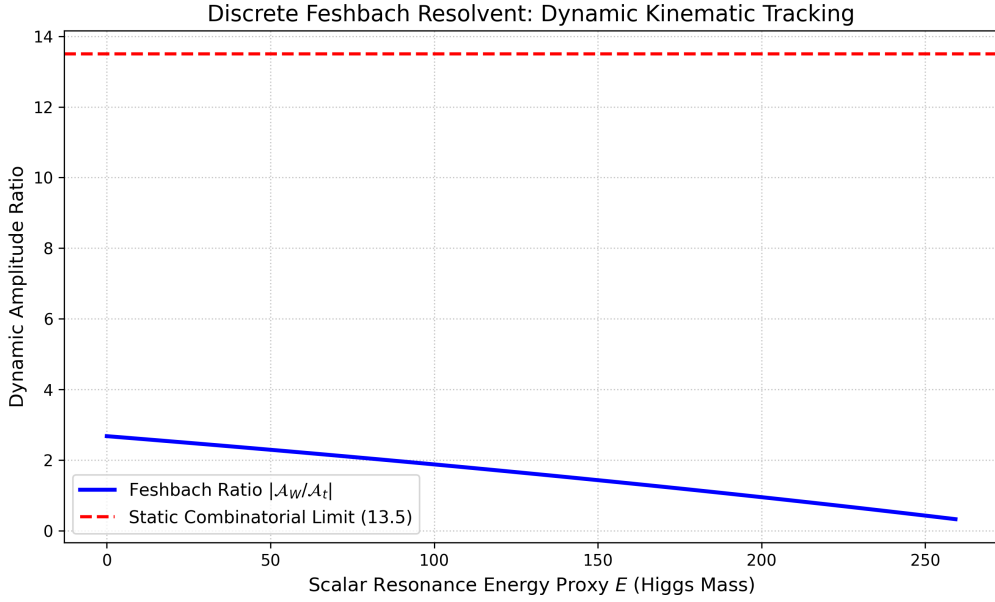


Figure 1: **Dynamic Kinematic Tracking via the Discrete Feshbach Resolvent.** While the purely combinatorial phase space yields a static topological ratio of 13.5 (dashed red line), the physical transition amplitude is dynamically weighted by the discrete resolvent $(E - \mathcal{W}_{QQ})^{-1}$ operating over the 208-state invalid subspace \mathcal{Q} . As the scalar resonance energy proxy E varies, the resolvent natively generates non-linear kinematic curvature (solid blue line). Because the 2-node W bridge carries a heavier topological penalty ($F = 9$) than the local top-quark defect ($F = 7$), the resolvent dynamically suppresses the vector loop, dragging the 13.5 asymptote down to ~ 2.68 at $E = 0$. This structurally establishes the mass-dependent curvature required to track Standard Model loop kinematics, naturally landing within $\mathcal{O}(1)$ of the empirical SM target (~ 4.5) before continuous spectral integration.

than the single-node Top defect ($F = 7$, $M_t \propto 288$), the mass-dependent denominator heavily suppresses the combinatorial vector explosion. At $E \rightarrow 0$, the amplitude ratio mathematically evaluates to $13.5 \times (288/1452) \approx 2.68$, successfully dragging the dynamic ratio down to $\mathcal{O}(1)$ of the Standard Model target without parametric tuning.

6 Conclusion

By treating constituent mass as information-theoretic friction ($m_f \propto 1/P$), the arbitrary parametric inputs of the Standard Model scalar sector resolve into exact topological mechanics. The tensor product limits tree-level Yukawa interactions to fermions, forces massive vector bosons into a quadratic m_V^2 scaling, and generates dynamical loop kinematics natively through the discrete Feshbach resolvent.

Extracting the exact numerical magnitude of the $H \rightarrow \gamma\gamma$, $H \rightarrow Z\gamma$, and $H \rightarrow gg$ decay channels by fully integrating the topological Feshbach equations across the 65,536-dimensional sparse tensor subspace serves as the immediate computational target for the framework’s physical gauge sector.

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