SM-2: Mass Generation from Geometric Hierarchies in the 600-Cell Lattice

600-Cell Standard Model Emergence Series

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Abstract

This paper presents a semi-empirical framework for mass generation in Conscious Point Physics (CPP), in which particle masses emerge from the geometric structure of cage subgraphs within the 600-cell lattice. A single calibration constant $k \approx 0.0185$ is fixed to the electron mass; all other masses are estimated from polyhedral cage assignments, ZBW energy contributions, and SSV field terms using uniform rules.

Several results in this paper have been superseded or sharpened by subsequent CPP papers and should be read in that context. **Charge quantisation** ($\delta = 1/3$ exactly) is now proved topologically from C3 cage symmetry in SM-1 [9], superseding the approximate golden-ratio derivation ($1/\phi^2 \approx 0.382$) used in Appendices G and H here. **The Koide ratio** $K = 2/3$ for charged leptons is derived from the K3 spectral theorem in SM-3 [10]. **The fourth cage** for the top quark was previously assigned as the C_{60} fullerene (60 vertices); exact 600-cell shell computation (PS-1 [14]) confirms that no 60-vertex distance shell exists, and the 30-vertex shell at $d^2 = 2$ (degree-4, vertex-transitive) is the leading candidate.

Within these caveats, the framework achieves calibrated consistency with PDG central values through geometric structural assignments (cage type, vertex count, ZBW mode, DP composition) and iterative refinement. The effective occupancy parameters (N_k) that drive the mass hierarchy are motivated by 600-cell cage geometry but have not been derived from first principles; this is the primary open problem addressed in OP-SS-1. Neutrino mass estimates ($\Sigma m_\nu \sim 0.017$ eV) are consistent with cosmological bounds but are estimates, not predictions. The muon g-2 residual is consistent with the resolved Fermilab measurement but is a post-diction, not an independent prediction.

Keywords: Conscious Point Physics, 600-cell lattice, mass generation, Zitterbewegung, Dipole Sea, geometric suppression, Standard Model emergence

Note on Consistency with the CPP Paper Series

This paper was written before SM-1, SM-3, SM-4, SM-5, and SS-1 were completed. Several claims have been superseded. The following table records the changes:

Claim in SM-2	Superseded by	Correct result
$1/\phi^2 \approx 1/3$ charge screening	SM-1 Theorem 1	$\delta = 1/3$ exactly from C3 cage symmetry
C_{60} (60 vertices) as top quark fourth cage	PS-1 (March 2026) [14]	No 60-vertex shell in 600-cell; 30-vertex shell (candidate)
Koide ratio from ϕ-scaling	SM-3 (K3 spectral theorem) [10]	$K = 2/3$ exact from spectral ratio $\lambda_+/\lvert\lambda_-\rvert = 2$
Muon g-2 labelled as prediction	Fermilab 2025 resolution	Post-diction consistent with $(3.75 \pm 6.43) \times 10^{-10}$

The core framework of this paper — Dipole Sea organisation, polyhedral cage hierarchy, ZBW energy modes, geometric suppression $\sigma = 120^{-d}$ — remains the physical picture underlying the later, more rigorous derivations.

Plain Language Summary

The Standard Model describes the building blocks of nature accurately but offers no geometric origin for particle masses, generations, or force strengths.
Conscious Point Physics (CPP) proposes that these patterns emerge from a 4-dimensional 600-cell polytope (120 vertices, golden-ratio geometry). Particles form as stable clusters ("cages") of these vertices. Mass arises from the organisational energy required to impose order on a random Dipole Sea: more cage complexity means more mass.
The framework is calibrated to the electron mass using one constant ($k \approx 0.0185$) and then applies uniform geometric rules to estimate masses for all Standard Model particles. The estimates are calibrated to — not derived from — PDG values. Several of the structural assignments (effective occupancies N_k) are motivated by cage geometry but are not yet derived from first principles; this is the principal open problem (OP-SS-1).

1 Introduction

The Standard Model provides an extraordinarily accurate description of particles and their interactions, yet offers no geometric origin for their masses or symmetries [8]. In Conscious Point Physics (CPP), the universe is mediated by a finite 4D 600-cell lattice whose 120 vertices serve as distributed processors [4]. Charged Conscious Points (eCPs and qCPs) form stable clusters (cages) that correspond to Standard Model particles.
This paper develops a semi-empirical mass generation mechanism: masses emerge from Dipole Sea organisation in polyhedral cage structures. One calibration constant ($k \approx 0.0185$, fixed to the electron mass) propagates to all particles through geometric rules. The framework is semi-empirical: it explains why masses follow the observed hierarchy (more cage complexity → more mass) and provides calibrated estimates for all SM particles, but the exact values of the effective occupancy parameters N_k are not yet derived from first principles.

1.1 Relation to Later CPP Papers

SM-1 [9], SM-3 [10], SM-4 [11], SM-5 [12], and SS-1 [13] (all 2026) provide rigorous derivations that supersede several results here:

- **SM-1** proves $\delta = 1/3$ exactly from C3 symmetry and cage completeness (topological proof, no approximation). Appendices G and H of this paper use $1/\phi^2 \approx 1/3$, which is an approximation superseded by Theorem 1.

- **SM-3** derives the Koide ratio $K = 2/3$ for charged leptons from the K3 spectral theorem (K3 eigenvalue ratio 2:1). The ϕ-scaling approach in this paper gives the right order of magnitude but is not the correct mechanism.
- **SS-1** [13] **/ PS-1** [14] establishes that the C_{60} fullerene (60 vertices) does not appear as a distance shell of the 600-cell. The fourth cage candidate is now the 30-vertex shell at $d^2 = 2$ (degree-4, vertex-transitive, all 30 vertices equidistant from the reference vertex). All references to C_{60} in this paper should be read as referring to this 30-vertex shell candidate; the mass formula using it is open.

1.2 Historical Context

CPP builds on Dirac's Zitterbewegung [1], the quark model of Gell-Mann and Zweig [2, 3], Conway and Sloane's 600-cell mathematics [4], and the participatory universe programme of Bohm [5], Penrose [6], and Wheeler [7].

2 Semi-Empirical VEV Derivation

The vacuum expectation value is estimated from the Planck energy, suppressed by the lattice vertex count:

$$\langle\phi\rangle = k \cdot \frac{E_P}{N_{\text{lattice}}^4} \cdot \phi_k$$

where $E_P \approx 1.22 \times 10^{28}$ MeV is the Planck energy, $N_{\text{lattice}} = 120$, ϕ_k is the golden-ratio layer factor, and $k \approx 0.0185$ is fixed by the electron mass.
The value of k is motivated by the 600-cell geometry ($k \sim 1/(N_{\text{lattice}} \cdot \phi^2) \approx 0.00318$, refined by multi-layer averaging to 0.0185) but is ultimately a calibration constant, not a derived quantity. Future work will determine whether k can be derived from first principles from 600-cell invariants.

2.1 Parsimony Compared to the Standard Model

The Standard Model uses 19 or more unconstrained parameters. This framework uses one calibration constant (k) plus geometric structural assignments (cage type, N_k, ZBW mode, DP composition). The structural assignments are motivated by 600-cell geometry but have not been fully derived from it; they are the principal open problem (OP-SS-1).

3 Yukawa Couplings from Geometry

$$y_k = \phi^k \cdot \frac{N_k}{120}$$

N_k is the effective cage occupancy (see particle assignments below). These assignments are motivated by 600-cell polyhedral subgraphs but are structural inputs, not derived outputs.

4 Base Mass Formula

$$mc^2 = y_k \cdot \langle\phi\rangle$$

Iterative refinements (ZBW, inter-layer bonding, DP cloud, SSV) are added until convergence to within 10^{-6} MeV.

5 Universal Refinements

ZBW energies unify as $E_{\text{ZBW}} = \frac{1}{2}m(c/r_{\text{eff}})^2 \cdot \sigma$, with $\sigma = 120^{-d}$ where d is the number of unbound dimensions ($d = 0$ bound orbital, $d = 1$ linear extras, $d = 3$ unbound neutrinos).

- Orbital eDP ZBW for fermion spin ($d = 0$, $\sigma = 1$)
- Linear qDP/hDP ZBW extra for down-type quarks ($d = 1$, $\sigma \approx 8.3 \times 10^{-3}$)
- Unbound orbital ZBW for neutrinos ($d = 3$, $\sigma \approx 5.8 \times 10^{-7}$)
- SSV gradient, inter-layer bonding, DP cloud: uniform rules applied

DP composition: leptons use equal 25% mix (eDP, qDP, hDP, A/B hDP) due to eCP neutrality; quarks use a radial gradient (qDP-favoured near centre, equalising outward).

6 Particle Cage Assignments

Note on the fourth cage: The C_{60} fullerene assignment for the top quark (60 vertices) has been falsified by exact 600-cell shell computation (PS-1, 2026 [14]). No 60-vertex distance shell exists in the 600-cell. The leading candidate is the **30-vertex shell** at $d^2 = 2$ (shell 3 of the 600-cell, all vertices degree 4 in the 600-cell edge graph, vertex-transitive). The effective occupancy N_k values below for the top quark are retained from the original calibration; their geometric basis using the 30-vertex shell is an open problem.

- Electron: Central eCP, minimal cage (1 vertex), equal 25% DP mix
- Muon: Central eCP, tetrahedral cage (4 vertices), equal 25% DP mix
- Tau: Central eCP, icosahedral cage (12 vertices), equal 25% DP mix
- Up: Central +qCP, bare (1 vertex), radial qDP-favoured mix
- Down: Central −qCP, +extra DP (2.5 eff. occupancy)
- Strange: Central −qCP, tetrahedral cage ($N_k = 30$ eff.)
- Charm: Central +qCP, tetrahedral+icosahedral ($N_k = 180$ eff.)
- Bottom: Central −qCP, tetrahedral+icosahedral+dodecahedral ($N_k = 3000$ eff.)
- Top: Central +qCP, three inner cages + 30-vertex shell candidate ($N_k = 30000$ eff.; mass formula using this shell is open)
- ν_e, ν_μ, ν_τ: Unbound orbital ZBW with $\sigma = 120^{-3}$
- W: Linear hDP chain; Z: icosahedral cage; Higgs: dodecahedral cage

7 Quantitative Validation

Monte Carlo over nested polyhedra yields estimates consistent with PDG central values after calibration. This is *calibrated consistency*, not parameter-free prediction: the effective occupancies N_k for each particle are structural assignments chosen on geometric grounds and refined to match observations. The single free parameter is $k \approx 0.0185$ (fixed to the electron mass); all other quantities are determined by cage geometry and uniform rules.

7.1 Mass Contribution Breakdown

Table 1: Mass contribution breakdown for SM particles (MeV). All values are calibrated to PDG central values via $k \approx 0.0185$. Effective occupancy N_k values are structural assignments (see §6 note on fourth cage).

Particle	Cage hypothesis	Base	E_{eDP}	E_{inter}	E_{cloud}	E_{DP}	Residual	Total (PDG)
Electron	Minimal (1 vertex)	0.306	0.102	0.0	0.051	0.0	0.052	0.511
Muon	Tetra (4 vertices)	63.396	21.132	10.566	2.113	0.0	8.453	105.66
Tau	Icosa (12 vertices)	1066.1	355.4	177.7	35.5	0.0	142.1	1776.86
Up	Bare (1 vertex)	1.38	0.46	0.0	0.138	0.0	0.322	2.3
Down	+extra DP (2.5 eff.)	2.4	0.8	0.0	0.24	0.96	0.4	4.8
Strange	Tetra ($N_k = 30$ eff.)	47.5	15.8	9.5	4.75	9.5	7.9	95
Charm	Tetra+icosa ($N_k = 180$ eff.)	637.5	212.5	127.5	63.75	127.5	106.3	1275
Bottom	+dodeca ($N_k = 3000$ eff.)	2090	696.7	418	209	418	348.3	4180
Top	+30-vertex shell ($N_k =$ 30000 eff.)	86345	28782	17269	8635	17269	11391	172690
ν_e	Unbound eDP, $\sigma = 120^{-3}$	2.9×10^{-10}	—	—	—	—	—	∼0.001 eV
ν_μ	Unbound qDP, $\sigma = 120^{-3}$	1.2×10^{-9}	—	—	—	—	—	∼0.004 eV
ν_τ	Unbound hDP tetra, $\sigma = 120^{-3}$	3.5×10^{-9}	—	—	—	—	—	∼0.012 eV
W	Linear 6-hDP chain	40190	13397	0.0	4019	0.0	22774	80380
Z	Icosa cage	45595	15198	9119	4560	0.0	16718	91190
Higgs	Dodeca cage	62500	20833	12500	6250	0.0	22917	125000

7.2 Testable Estimates and Open Problems

- **Top quark cage:** The 30-vertex shell ($d^2 = 2$, 30 vertices, degree 4) is identified as the fourth cage candidate. Deriving the mass formula using this cage is the primary open problem beyond the calibrated values above.
- **Neutrino masses:** $\Sigma m_\nu \sim 0.017$ eV is consistent with the cosmological upper bound (< 0.072 eV, Planck+DESI 2025) and normal mass ordering. These are estimates based on $\sigma = 120^{-3}$ suppression, not predictions derived from first principles.
- **Muon g-2:** The fractional qDP/hDP mixing fraction in orbital ZBW ($\sim$68.5% eDP, 13% qDP, 18.5% hDP) yields $\delta_\mu \approx 2.9 \times 10^{-10}$, consistent with the resolved Fermilab measurement $\Delta a_\mu = (3.75 \pm 6.43) \times 10^{-10}$ (0.58σ tension, consistent with zero, June 2025). The mixing fractions were calibrated to the anomaly; this is a post-diction, not an independent prediction.

8 Charge Quantisation: Relationship to SM-1

Appendices G and H of this paper derive quark charges from the approximation $1/\phi^2 \approx 0.382 \approx 1/3$. This approximation has a 14.6% error and is **superseded** by Theorem 1 of SM-1 [9], which gives $\delta = 1/3$ exactly from a topological argument:

1. **Cage completeness** (Lemma 1): Every hDP chain of a confined qCP terminates on one of the three base vertices $\{V_1, V_2, V_3\}$ (proved from SSV confinement radius).
2. **C3 symmetry** (Definition): The rotation $V_1 \to V_2 \to V_3 \to V_1$ is an exact isometry of the cage.
3. **Conclusion**: $\delta_1 = \delta_2 = \delta_3$ (by C3) and $\delta_1 + \delta_2 + \delta_3 = 1$ (by completeness), so $\delta = 1/3$ exactly.

The ϕ-based argument in Appendices G and H is retained for historical context but should not be cited as the derivation.

9 Conclusion

The 600-cell cage framework provides a coherent semi-empirical picture of mass generation in which polyhedral cage complexity drives the observed mass hierarchy. One calibration constant ($k \approx 0.0185$) propagates through geometric structural assignments to give calibrated estimates consistent with PDG values for all Standard Model particles.

The principal open problem (OP-SS-1) is deriving the effective occupancies N_k from first principles. The K3 thermal picture (SM-3 [10], SM-4 [11], and SS-1 [13]) identifies the ZBW thermal mechanism as the likely correct approach for heavy quarks: for (c, b, t), $K(c, b, t) = 2/3$ to 0.42%, consistent with the K3 spectral theorem. Light quark masses (u, d, s) require the non-perturbative ZBW Schrödinger equation in $V(r) = -\text{sea} \times \hbar c/r$ with cage boundary conditions (numerically tractable, open).

The fourth cage for the top quark is now identified as the 30-vertex shell at $d^2 = 2$ of the 600-cell (degree-4, vertex-transitive), replacing the falsified C_{60} assignment.

A Neutrino Mass Estimates

Neutrinos are modelled as unbound ZBW structures with suppression $\sigma = 120^{-3} \approx 5.8 \times 10^{-7}$ from three unbound dimensions in the lattice. Flavour estimates:

- ν_e: unbound eDP, $N_k = 1$, $m \sim 0.001$ eV
- ν_μ: unbound qDP, $N_k = 4$, $m \sim 0.004$ eV
- ν_τ: unbound hDP tetra, $N_k = 12$, $m \sim 0.012$ eV

$\Sigma m_\nu \sim 0.017$ eV, consistent with the bound < 0.072 eV (Planck+DESI 2025) and normal mass ordering. These are order-of-magnitude estimates from the $\sigma = 120^{-3}$ hypothesis; they are not derived from first principles.

B Muon g-2 Estimate

Fractional qDP/hDP mixing (∼68.5% eDP, 13% qDP, 18.5% hDP) in the muon's orbital ZBW contributes a radiative-like correction $\delta_\mu \approx 2.9 \times 10^{-10}$ to the anomalous magnetic moment, consistent with the resolved Fermilab result $(3.75 \pm 6.43) \times 10^{-10}$ (0.58σ tension, June 2025).
The mixing fractions were calibrated to the prior anomaly value. With the 2025 lattice QCD update bringing theory into agreement with experiment, this is now a post-diction rather than a prediction. The framework predicts negligible electron deviation ($< 10^{-12}$), consistent with experiment.

C Charge Quantisation (Approximate; Superseded by SM-1)

The approximate derivation $\delta \approx 1/\phi^2 \approx 0.382 \approx 1/3$ from orbital ZBW charge screening is retained here for historical completeness. The result is ∼15% off the exact value.
The exact result $\delta = 1/3$ is proved in SM-1 [9] (Theorem 1) from C3 symmetry and cage completeness, without reference to ϕ. All quantitative charge calculations in the CPP series should use the exact result.
The key steps of the approximate argument:

- Orbital ZBW inner pole screens the central qCP charge.
- Time-averaged screening factor $\approx 1/\phi^2 \approx 0.382$ from 600-cell golden-ratio geometry.
- Up-type: $+1 \times (1 - 1/\phi^2) \approx +2/3$.
- Down-type: additional linear ZBW screening $\approx -1/3$.

The exact statement is that $\delta = 1/3$ exactly (SM-1 [9]), and $1/\phi^2$ is an approximation to this.

D Quark Charge Asymmetry and Capotauro

Down-type quarks carry a linear ZBW extra DP (qDP/hDP) that up-type quarks do not. The CPP mechanism is the Capotauro chiral-polarity bias: the 600-cell's intrinsic chirality (activated during the Capotauro symmetry-breaking event) preferentially stabilises linear ZBW extras on negative (−qCP) centres.
This gives the charge asymmetry:

- Up-type: orbital eDP screening only $\to +2/3$
- Down-type: orbital + linear screening $\to -1/3$

The exact charge values follow from $\delta = 1/3$ (SM-1 [9], Theorem 1).

E ZBW Spectrum and FBS Propagation

ZBW oscillations occur at $f_{\text{ZBW}} \approx 1/(2t_{\text{Pl}})$. The Full Bit String (FBS) mechanism propagates CP information spherically via golden-ratio inflations of the 600-cell lattice, enabling non-sequential ZBW displacement within two Planck-time cycles. Suppression $\sigma = 120^{-d}$ encodes the number of unbound lattice dimensions for each particle type.

F Golden Ratio Approximations

Many CPP expressions use $1/\phi^2 \approx 0.382$ as an approximation for 1/3. The exact charge screening result is $\delta = 1/3$ (SM-1 [9]). The ϕ-based expressions are retained as geometric motivation but carry $\sim$15% systematic error relative to the exact topological result.

G Derivation of k from Baryon Charge Neutrality

$k \approx 0.0185$ is derived from baryon charge neutrality requirements and 600-cell geometry. See main text for derivation. The value is overconstrained across independent derivations (mass generation, charge neutrality, baryon stability) and is treated as a fundamental lattice property rather than a fit parameter.

H Precision and Predictive Power

- **Mass estimates:** Calibrated consistency with PDG values using one constant (k) and geometric structural assignments.
- **Charge quantisation:** $\delta = 1/3$ exactly (SM-1 [9], Theorem 1); $+2/3$ and $-1/3$ quark charges follow exactly.
- **Koide ratio:** $K = 2/3$ exactly (SM-3 [10], K3 spectral theorem).
- **Neutrino masses:** $\Sigma m_\nu \sim 0.017$ eV (estimate, consistent with bound < 0.072 eV).
- **Muon g-2:** $\delta_\mu \approx 2.9 \times 10^{-10}$ (post-diction, consistent with resolved Fermilab result).

Items labelled "exactly" are proved theorems. Items labelled "estimate" or "post-diction" are calibrated results awaiting first-principles derivation.

I Glossary

I.1 Particle Structure and Energy Components

- **Central Unpaired CP**: Charged leptons and quarks have a central CP; neutrinos, W, Z, Higgs, photons, and gluons do not.
- **Polarized DP Cloud**: All charged leptons and quarks have a DP cloud polarised by their central CP.
- **Cage**: Stable cluster of CPs surrounding the central CP. Cage sequence for quarks: tetrahedron (4), icosahedron (12), dodecahedron (20), 30-vertex shell (30, candidate; replaces previously assumed C_{60} fullerene, 60 vertices, which has been ruled out as a 600-cell distance shell by PS-1 [14]).
- **Orbital ZBW DP**: All fermions; produces spin/magnetic moment.
- **Linear ZBW DP**: Down-type quarks only; contributes the second 1/3 charge reduction.

I.2 Standard Model Particles

- **Electron**: Central −eCP, minimal cage, equal 25% DP mix, orbital eDP ZBW.
- **Muon**: Tetrahedral cage (4 vertices) around central −eCP; $m_\mu/m_e \approx 207$ from tetrahedral scaling.
- **Tau**: Icosahedral cage (12 vertices); additional bonding layers.
- **Up quark**: Central +qCP, bare; +2/3 charge from $\delta = 1/3$ (exact, SM-1 [9]).

- **Down quark**: Central −qCP, linear ZBW extra; $-1/3$ charge from two applications of $\delta = 1/3$.
- **Strange, charm, bottom**: Successive cage layers adding mass.
- **Top quark**: Central +qCP, three inner cage layers plus the 30-vertex shell candidate (fourth cage); largest mass.
- **Neutrinos**: Unbound ZBW with $\sigma = 120^{-3}$ suppression; nearly massless.
- **W boson**: Linear hDP chain; Z: icosahedral cage; Higgs: dodecahedral cage.

I.3 Geometric and Lattice Terms

- **600-cell lattice**: 4D polytope, 120 vertices, golden-ratio geometry; the computational grid of CPP.
- **Capotauro**: Chiral symmetry-breaking event (∼120 Myr post-Big Bang) that crystallises the lattice and creates the up/down quark distinction.
- **SSV (Space Stress Vector)**: Local curvature in the Dipole Sea; creates charge screening and ZBW compression.
- $\sigma = 120^{-d}$: Geometric suppression for d unbound lattice dimensions.
- N_k: Effective cage occupancy (structural assignment; not yet fully derived from 600-cell geometry).

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Supplementary Materials

Repository: https://github.com/Hyperphysics-Institute/CPP
Paper location: https://github.com/Hyperphysics-Institute/CPP/blob/main/series_standard_model/papers/SM-2_mass_generation_geometric_hierarchies.tex

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