Particle Physics in the Generative-Collapse Kernel: Ten Tier-2 Theorems from the Standard Model

Caleb Pruett[1,*] and Clement Paulus[2]

[1] *UMCP Reference Implementation, GitHub*
[2] *UMCP / GCD / RCFT Canon*

(Dated: February 11, 2026)

We show that the seven-metric kernel of the Universal Measurement Contract Protocol (UMCP) — originally constructed for generic computational-workflow validation — encodes nontrivial structure when applied to the Standard Model of particle physics. Using PDG-tabulated quantum numbers for 17 fundamental particles and 14 composite hadrons, we construct 8-channel trace vectors $\mathbf{c} \in [\varepsilon, 1-\varepsilon]^8$ and prove ten theorems at Tier-2 (domain expansion), each verified by between 5 and 19 automated tests (74 total, 0 failures). The theorems connect spin-statistics to the fidelity–drift split (T1), demonstrate strict generation monotonicity in F (T2), identify confinement as a 98% collapse of the integrity coefficient IC (T3), map 13 orders of magnitude in mass to a bounded fidelity interval (T4), detect charge quantization via IC suppression (T5), establish cross-scale universality from femtometers to nanometers (T6), show that electroweak symmetry breaking amplifies generation structure (T7), verify CKM unitarity as a kernel identity with visible CP violation (T8), reproduce asymptotic freedom as monotonic kernel flow (T9), and recover the nuclear binding curve through kernel–binding-energy anti-correlation (T10). All results follow from Tier-1 identities ($F + \omega = 1$, $\mathrm{IC} \le F$, $\mathrm{IC} = e^{\kappa}$) applied to physically motivated trace vectors, with duality $F + \omega = 1$ verified to machine precision across all particles. The formalism provides a Tier-2 diagnostic lens through which Standard Model phenomenology becomes kernel-visible without modifying the underlying physics.

I. INTRODUCTION

The Universal Measurement Contract Protocol (UMCP) [1, 2] is a contract-first validation framework built on a single axiom: *"What Returns Through Collapse Is Real."* Its computational core is a seven-metric kernel that maps any set of coherence coordinates $\mathbf{c} \in [0, 1]^n$ with weights $\mathbf{w}$ (summing to unity) to invariants $(\omega, F, S, C, \kappa, \mathrm{IC}, \tau_R)$. Three Tier-1 identities are provably exact [3]:

$$F + \omega = 1, \quad \mathrm{IC} \le F \text{ (AM-GM)}, \quad \mathrm{IC} = e^{\kappa}. \tag{1}$$

Tier-1 identities are immutable — they hold for any input by construction. The question we address is: *when the inputs encode real physics, what Tier-2 structure emerges?*

We apply the kernel to the Standard Model (SM) of particle physics, encoding each particle's quantum numbers as an 8-channel trace vector. Ten theorems emerge, each proven computationally against Particle Data Group (PDG) values and verified by automated tests. The reference implementation is publicly available [4].

II. KERNEL REVIEW

Definition 1 (GCD Kernel)**.** *Given coordinates* $\mathbf{c} = (c_1, \ldots, c_n) \in [\varepsilon, 1-\varepsilon]^n$ *and weights* $\mathbf{w} = (w_1, \ldots, w_n)$ *with* $\sum_i w_i = 1$*, the kernel computes:*

$$F = \sum_i w_i \, c_i, \tag{2}$$

$$\omega = 1 - F, \tag{3}$$

$$S = -\sum_i w_i \big[c_i \ln c_i + (1-c_i) \ln(1-c_i)\big], \tag{4}$$

$$C = \frac{1}{0.5} \, \mathrm{std}(\mathbf{c}), \tag{5}$$

$$\kappa = \sum_i w_i \ln(c_i + \varepsilon), \tag{6}$$

$$\mathrm{IC} = \exp(\kappa). \tag{7}$$

The AM-GM gap $\Delta \equiv F - \mathrm{IC} \ge 0$ measures channel heterogeneity: $\Delta = 0$ if and only if all c_i are equal. This gap is the central diagnostic in what follows.

III. TRACE-VECTOR CONSTRUCTION

Each Standard Model particle is mapped to an 8-channel trace vector $\mathbf{c} \in [\varepsilon, 1-\varepsilon]^8$ via the following channels:

Equal weights $w_i = 1/8$ are used throughout. The guard band $\varepsilon = 10^{-8}$ prevents $\ln(0)$ singularities. All 17 fundamental particles and 14 composite hadrons pass Tier-1 identities exactly.

* caleb@umcp.dev

TABLE I. Eight-channel encoding for SM particles. Each observable is normalized to $[\varepsilon, 1-\varepsilon]$.

i	Channel	Source	Normalization
1	mass_log	$\log_{10}(m/\text{GeV})$	Linear to $[0, 1]$
2	spin_norm	$s/s_{\max}$	$s_{\max} = 2$
3	charge_norm	$\lvert Q\rvert/Q_{\max}$	$Q_{\max} = 2$
4	color	Color multiplicity	$\{1, 3, 8\} \to [0, 1]$
5	weak_isospin	$\lvert I_3^W\rvert$	Direct
6	lepton_num	$\lvert L\rvert$	Binary
7	baryon_num	$\lvert B\rvert$ or $B/3$	Per quark
8	generation	Gen/3	$\{1, 2, 3\}$

IV. TEN THEOREMS

A. T1: Spin-Statistics Kernel Theorem

Theorem 2 (Spin-Statistics Split). *Let $\mathcal{F}$ and $\mathcal{B}$ denote the sets of fundamental fermions and bosons respectively. Then*

$$\langle F\rangle_{\mathcal{F}} > \langle F\rangle_{\mathcal{B}}, \tag{8}$$

with a split of 0.194 *(*0.615 *vs.* 0.421*). Furthermore, every quark satisfies $F_q > \langle F\rangle_{\mathcal{B}}$.*

Remark 1. *The theorem holds per-generation: within each of generations 1–3, fermion $\langle F\rangle$ exceeds boson $\langle F\rangle$. The split arises because fermions occupy more kernel channels (nonzero lepton/baryon number, generation index) than bosons.*

B. T2: Generation Monotonicity

Theorem 3 (Generation Ordering). *Partition the 12 fundamental fermions by generation $g \in \{1, 2, 3\}$. Then*

$$\langle F\rangle_{g=1} < \langle F\rangle_{g=2} < \langle F\rangle_{g=3}, \tag{9}$$

with values $0.576 < 0.620 < 0.649$. The monotonicity holds independently for quarks and for leptons.

Remark 2. *This reflects the mass hierarchy: higher-generation fermions have larger masses, which map to larger c_1 (mass_log channel), pulling F upward. The generation channel $c_8 = g/3$ reinforces the ordering.*

C. T3: Confinement as IC Collapse

Theorem 4 (IC Collapse under Binding). *Let $\text{IC}_q^{\min}$ be the minimum integrity coefficient among all quarks, and let IC_h denote that of any composite hadron. Then:*

1. *$\text{IC}_h < \text{IC}_q^{\min}$ for all 14 hadrons tested.*
2. *The average IC drops by 98.1% from quarks to hadrons.*
3. *The AM-GM gap amplifies by a factor of $10.8\times$ upon binding.*

The IC collapse is driven by the loss of the generation and lepton-number channels in composite particles: hadrons have $c_6 = c_8 = \varepsilon$, which sends $\kappa \to -\infty$ via $\ln(\varepsilon)$. This is the kernel signature of confinement — individual quark quantum numbers become invisible.

D. T4: Mass–Kernel Logarithmic Mapping

Theorem 5 (Logarithmic Compression). *The 17 fundamental particles span 13.2 orders of magnitude in mass. The kernel maps this range to $F \in [0.37, 0.73]$. Among quarks, the Spearman rank correlation between mass and F is $\rho = 0.77$.*

The logarithmic compression is a consequence of the $\log_{10}$ normalization in channel 1. The bounded output is a feature, not a bug: the kernel measures *coherence heterogeneity*, not magnitude.

E. T5: Charge Quantization Signature

Theorem 6 (Neutral Suppression). *Neutral particles (photon, gluon, Z^0, neutrinos) have $\text{IC} \ll \text{IC}_{charged}$. The ratio*

$$\frac{\langle \text{IC}\rangle_{neutral}}{\langle \text{IC}\rangle_{charged}} = 0.020 \tag{10}$$

represents a $50\times$ suppression. The photon has $\text{IC} = 7.6 \times 10^{-4}$, the smallest of any fundamental particle.

Remark 3. *Neutral particles carry $c_3 = \varepsilon$ (charge channel near zero). Since $\text{IC} = \exp(\sum w_i \ln c_i) = \prod c_i^{w_i}$ is a weighted geometric mean, even one channel near ε catastrophically suppresses IC. This is the AM-GM inequality at work: neutrality creates maximal channel heterogeneity.*

F. T6: Cross-Scale Universality

Theorem 7 (Scale Ordering). *Let $\langle F\rangle$ denote the mean fidelity for three particle classes — fundamental (fm scale), atomic (pm scale), and composite (fm scale, bound). Then*

$$\langle F\rangle_{composite} < \langle F\rangle_{atomic} < \langle F\rangle_{fundamental}, \tag{11}$$

with values $0.444 < 0.516 < 0.558$.

The same kernel, applied at three different length scales (10^{-15} m, 10^{-12} m, 10^{-10} m), produces a consistent ordering: binding reduces fidelity, and composite systems sit below their constituents.

G. T7: Symmetry Breaking as Trace Deformation

Theorem 8 (EWSB Amplification)**.** *Electroweak symmetry breaking (EWSB) enters the kernel through the mass_log channel via Yukawa couplings* $y_f = \sqrt{2}\, m_f/v$ *(*$v = 246.22$ *GeV). Define the generation spread* $\sigma_g \equiv \max_g \langle F \rangle_g - \min_g \langle F \rangle_g$*. Then the broken theory has*

$$\sigma_g^{broken} = 0.073 > \sigma_g^{unbroken} = 0.046. \tag{12}$$

Higher generations gain more fidelity from the Higgs: $\Delta F_{g=3} > \Delta F_{g=2} > \Delta F_{g=1}$*.*

Before EWSB, all fermions share a common mass channel ($c_1 = 0.5$); after EWSB, Yukawa couplings differentiate them. The kernel makes the symmetry breaking visible as a monotonically increasing ΔF per generation.

H. T8: CKM Unitarity as Kernel Identity

Theorem 9 (CKM in the Kernel)**.** *Each row of the CKM matrix* V_{CKM}*, treated as a 3-channel trace vector* $(|V_{ij}|^2)_{j=1}^3$*, passes all Tier-1 identities. Furthermore:*

1. *Row 1 has a larger AM-GM gap than Row 2, because* $|V_{ub}|^2 \approx 10^{-5}$ *acts as an extreme zero-channel.*
2. *The Jarlskog invariant* $J_{CP} = 3.0 \times 10^{-5}$ *(CP violation) is kernel-visible.*

The Wolfenstein parametrization ($\lambda = 0.2257$, $A = 0.814$, $\rho = 0.135$, $\eta = 0.349$) generates rows whose $\sum |V_{ij}|^2$ departs from unity by $O(\lambda^4) \approx 0.002$. The kernel classifies this as the "Tension" regime — appropriate for an approximation at third order.

I. T9: Running Coupling as Kernel Flow

Theorem 10 (Asymptotic Freedom)**.** *The one-loop QCD running coupling*

$$\alpha_s(Q^2) = \frac{\alpha_s(M_Z^2)}{1 + \frac{b_0 \alpha_s(M_Z^2)}{2\pi} \ln\left(\frac{Q^2}{M_Z^2}\right)} \tag{13}$$

with $b_0 = 11 - \frac{2}{3} n_f = 7$ *is monotonically decreasing for* $Q \geq 10$ *GeV. At* $Q = M_Z$*,* $\alpha_s = 0.118$ *(perturbative). At* $Q = 0.5$ *GeV, the formula exceeds unity, signaling confinement ("NonPerturbative" regime).*

The kernel provides a natural regime classification: $\alpha_s < 0.3$ is perturbative (Stable); $0.3 \leq \alpha_s < 1$ is transitional (Watch); $\alpha_s \geq 1$ is nonperturbative (Collapse). Asymptotic freedom maps to a monotonic flow from Stable to Collapse as Q decreases.

J. T10: Nuclear Binding Curve Correspondence

Theorem 11 (Binding–Gap Anti-correlation)**.** *Using the Bethe–Weizsäcker semi-empirical mass formula to compute binding energy per nucleon* B/A *for elements* $Z = 1, \ldots, 118$*, and the 12-channel cross-scale kernel to compute the AM-GM gap* Δ*:*

1. $r(B/A, \Delta) = -0.41$ *(Pearson anti-correlation).*
2. B/A *peaks at* $Z \in [23, 30]$ *(Cr–Zn region), consistent with the Fe/Ni experimental peak.*
3. *Nuclear magic numbers (*$Z \in \{2, 8, 20, 28, 50, 82\}$*) are detectable through the magic-proximity channel.*

The anti-correlation means: elements with higher binding energy per nucleon have *smaller* AM-GM gaps — they are more coherent in the kernel sense. Iron-group nuclei sit at both the binding-energy maximum and a local gap minimum.

V. DUALITY AND CONSISTENCY

The duality identity $F + \omega = 1$ is verified to machine precision ($\max |\delta| = 0$) across all 17 fundamental particles, confirming that the trace-vector construction preserves Tier-1 exactly.

All 74 individual tests pass with zero failures. The complete test suite runs in under 200 ms on commodity hardware, making the formalism suitable for continuous integration.

VI. TIER-2 DIAGNOSTIC INTERPRETATION

These ten theorems demonstrate that the GCD kernel functions as a *diagnostic lens* for particle physics, not a replacement for it. The kernel does not predict masses or coupling constants; instead, it provides a uniform language in which existing SM results become visible as kernel patterns:

- **Spin-statistics** (T1) appears as a fidelity split.
- **The mass hierarchy** (T2, T4) appears as generation monotonicity and logarithmic compression.
- **Confinement** (T3) appears as IC collapse — the loss of individual quantum numbers upon binding.
- **Charge quantization** (T5) appears as IC suppression via the AM-GM inequality.
- **Universality** (T6) appears as scale-ordered fidelity.
- **Symmetry breaking** (T7) appears as trace deformation amplifying generation structure.

- **Flavor mixing** (T8) appears as CKM rows in the kernel, with CP violation as a measurable Jarlskog invariant.
- **Asymptotic freedom** (T9) appears as monotonic coupling flow within kernel regimes.
- **Nuclear stability** (T10) appears as binding–gap anti-correlation, with magic numbers as detectable features.

The value of this lens is threefold: (1) it provides a *single diagnostic framework* spanning subatomic, atomic, and nuclear scales; (2) it connects disparate phenomena (confinement, EWSB, CKM mixing) through the common algebra of the AM-GM gap; (3) it is computationally cheap and fully automated, enabling continuous monitoring via CI pipelines.

VII. HOW TO USE IT: PRACTICAL GUIDE

The formalism is implemented as a standalone Python module (`particle_physics_formalism.py`) in the UMCP repository [4].

A. Running the Theorems

```
pip install -e ".[all]"
python closures/standard_model/\
  particle_physics_formalism.py
```

Output: 10/10 PROVEN, 74/74 tests, runtime $<$ 200 ms.

B. Adding a New Particle

To extend the formalism to a new particle (e.g., a BSM candidate):

1. Add the particle to the `FUNDAMENTAL_PARTICLES` dictionary in `subatomic_kernel.py` with its quantum numbers.
2. Run `particle_physics_formalism.py` — existing theorems automatically include the new entry.
3. If needed, add new theorems as functions `theorem_T11()`, etc., following the `TheoremResult` dataclass pattern.

C. Reading the Output

Each theorem produces a structured result:

```
T3 Confinement as IC Collapse
  Statement: Binding quarks into hadrons
    collapses IC by >90%
  Tests: 19/19 PASSED
  Verdict: PROVEN
  Details:
    quark_avg_IC = 0.0225
    hadron_avg_IC = 0.000434
    ic_collapse_pct = 98.07%
    gap_amplification = 10.82x
```

The verdict is PROVEN when all sub-tests pass, FAILED otherwise. This maps directly to UMCP's three-valued logic: PROVEN $\rightarrow$ CONFORMANT, FAILED $\rightarrow$ NONCONFORMANT.

VIII. WHAT IT LOOKS LIKE: REALITY THROUGH THE KERNEL

The kernel provides a specific *perceptual frame* for particle physics. Through this lens:

The Standard Model is a fidelity landscape. Each particle lives at a point (F, IC, Δ) in kernel space. Fermions cluster at high F (~ 0.6); bosons at lower F (~ 0.4). The photon sits at the extreme: $F = 0.37$, $\mathrm{IC} = 7.6 \times 10^{-4}$, $\Delta = 0.37$ — it is the most heterogeneous fundamental particle, with most channels near ε.

Confinement is visible as a cliff. The IC landscape drops by two orders of magnitude at the quark$\rightarrow$hadron boundary. This cliff is not put in by hand — it emerges from the loss of generation and lepton-number channels when quarks bind into color-singlet states.

The mass hierarchy is a slope. Plotting F against generation number yields a monotonically rising curve. The slope is steeper for quarks than leptons, reflecting the stronger mass splitting in the quark sector.

Symmetry breaking is a deformation. Before EWSB, all fermions have the same mass channel ($c_1 = 0.5$). After EWSB, Yukawa couplings spread the mass channel, and the generation slope steepens. The kernel makes this transition quantitatively visible: σ_g increases from 0.046 to 0.073.

CP violation is a gap asymmetry. The CKM matrix, viewed as three kernel trace vectors (one per row), shows that Row 1 has a larger gap than Row 2. The physical origin is $|V_{ub}| \ll |V_{cb}|$: the extreme smallness of V_{ub} creates maximal heterogeneity in Row 1. The Jarlskog invariant $J = 3.0 \times 10^{-5}$ quantifies the CP violation that accompanies this asymmetry.

Nuclear stability is an anti-correlation. The most tightly bound nuclei (iron group) have the smallest AM-GM gaps. Moving away from the iron peak in either direction increases the gap — lighter nuclei are surface-dominated (less coherent), heavier nuclei are Coulomb-dominated (less coherent). Magic-number nuclei appear as local dips in the gap landscape.

This is what the Standard Model "looks like" through the GCD kernel: a structured landscape of fidelity, integrity, and gap, where known physics manifests as geometric features (slopes, cliffs, dips, asymmetries) that are computable, testable, and continuous-integration–ready.

IX. CONCLUSIONS

We have demonstrated that the GCD kernel, a domain-agnostic diagnostic tool designed for computational workflow validation, produces nontrivial and physically meaningful structure when applied to the Standard Model. Ten theorems, each testable and reproducible, connect kernel observables (F, IC, Δ) to established SM phenomena.

No new physics is introduced. The kernel acts as a *translation layer*: it does not explain why the top quark is heavy or why $|V_{ub}|$ is small, but it provides a uniform diagnostic language in which these facts become kernel-visible, testable, and comparable across scales (subatomic $\to$ atomic $\to$ nuclear).

Future directions include:

1. BSM sensitivity: can the kernel detect deviations from SM predictions in new particles or anomalous couplings?
2. Higher-order embeddings: channel counts beyond 8, incorporating decay widths, lifetimes, or form factors.
3. Dynamic kernel flow: tracking kernel invariants as functions of energy scale Q, connecting to renormalization group evolution.
4. Experimental anchoring: using measured cross sections and branching ratios as direct kernel inputs, bypassing the theoretical trace-vector construction.

The reference implementation, including all ten theorems and 74 automated tests, is available at `https://github.com/calebpruett927/GENERATIVE-COLLAPSE-DYNAMICS`.

ACKNOWLEDGMENTS

C.P. thanks C.Pau. for the frozen-contract discipline and the axiom that grounds this work. Reference implementation: `https://github.com/calebpruett927/GENERATIVE-COLLAPSE-DYNAMICS`.

[1] C. Paulus, Universal measurement contract protocol, Manuscript (2025), contract-first measurement discipline; Tier-1 invariants reserved.

[2] C. Paulus, The physics of coherence: Recursive collapse & continuity laws (2025), pOST canon anchor; Weld-ID: W-2025-12-31-PHYS-COHERENCE.

[3] C. Paulus, Umcp casepack publication (2026), runnable CasePack publication anchor.

[4] C. Pruett, Generative-collapse-dynamics (2026), reference implementation repository (GitHub).