Structural Conditions, Physical Identification, and Robustness in the One-Fold Framework

Keith Taylor *One-Fold / VERSF Companion Paper*

For General Readers: What This Paper Is and Why It Matters

The main One-Fold paper makes a bold claim: that the forces, several fundamental constants and scaling laws, and key structural features of particles can be *derived* from the internal geometry of a single minimal unit of distinguishability (a "fold"), rather than measured and inserted by hand as standard physics requires. It presents derivations of five major results: why particles have four internal components, why the three forces have the symmetries they do, why electromagnetism has the strength it does, why the cosmological constant is so tiny, and why all electrons are identical.

This companion paper asks a different question: **how much of that derivation is airtight, how much rests on reasonable but unproven assumptions, and how much involves interpreting mathematical results as physical quantities?**

Every scientific framework rests on assumptions. The Standard Model of particle physics selects and encodes its gauge group (guided by consistency constraints and experiment), measures its constants, and postulates its field content. One-Fold replaces those specific inputs with a more primitive set of structural conditions — but it still has assumptions. The question is not "does it assume things?" (every theory does) but "are its assumptions more primitive, more testable, and more explanatory than the ones they replace?"

This paper sorts every result in One-Fold into three tiers:

- **Tier 1 (Structural Theorems):** Results proven from pure information theory — no way around them given the starting axioms. These include the four-dimensional internal structure and the perfect identity of particles. These are the framework's bedrock.
- **Tier 2 (Conditional Derivations):** Results that follow rigorously *if* certain physically reasonable conditions hold — like the existence of a unique vacuum state or specific symmetry properties of the excitation sector. The gauge group and coupling invariants live here. The conditions are explicit and individually testable.
- **Tier 3 (Physical Identifications):** Steps where a geometric or mathematical quantity is *interpreted* as a measured physical constant. The connection between the geometric value

1/144 and the observed fine-structure constant 1/137 lives here. These are plausible but not proven.

In the remainder of the paper we use the equivalent labels Category I / II / III.

Why does this matter? Because intellectual honesty is not a weakness — it is the foundation of credibility. A framework that clearly labels its conjectures earns more trust than one that presents everything as proven. By separating what is proven from what is conjectured, this paper makes One-Fold *stronger*, not weaker.

This paper also shows how the companion work *The Standard Model from Hexagonal Geometry* provides a concrete model in which the Category II conditions are dynamically realised — demonstrating that these structural conditions are not just abstract requirements but are satisfied in at least one explicit, internally consistent construction. That work provides a concrete realisation of the "closure-driven emergence" route to gauge structure and couplings; it does not, by itself, validate the specific $\mathbb{CP}^3$ curvature-allocation route used to define α_geom in One-Fold, which remains an independent structural derivation path.

The bottom line: One-Fold's core results survive this audit. Its strongest claims sit in Tier 1 and cannot be challenged without rejecting the starting axioms. Its most interesting claims sit in Tier 2 and depend on conditions that are individually falsifiable. Its most speculative claims sit in Tier 3 and are clearly marked as such. This is how rigorous science should work.

Abstract

The One-Fold framework derives several core structures of fundamental physics from the internal geometry of a single distinguishability unit, including spinor dimensionality, gauge symmetries, a geometric coupling invariant, vacuum energy scaling, and particle identity. This companion paper clarifies the logical status of those derivations. We introduce a three-tier taxonomy that distinguishes *structural theorems* (following unconditionally from information-theoretic constraints), *conditional structural derivations* (requiring physically motivated but non-trivial axioms), and *physical identifications* (connecting geometric invariants to measured low-energy parameters). We provide an explicit dependency map for all major results, an assumption-by-assumption comparison with the Standard Model, and a robustness analysis showing which conclusions survive relaxation of which premises. The central results of the One-Fold programme remain intact under this clarification. Its explanatory contribution lies not in eliminating assumptions but in relocating phenomenological freedom into explicit, testable structural conditions on admissible internal geometry.

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1. Purpose and Scope

This paper serves as a logical and structural companion to the main One-Fold manuscript [1]. Its purpose is not to introduce new physical claims but to strengthen the original framework by:

1. Making the conditional structure of all key derivations fully explicit.
2. Identifying precisely where physical interpretation enters the logical chain.
3. Establishing the robustness of each result under variation of its premises.
4. Providing an honest side-by-side comparison of the assumption inventories of One-Fold and standard physics.

The goal is to ensure that the framework's genuine achievements — which are substantial — are not undermined by overclaiming, and that its open problems are clearly demarcated from its settled results.

1.1 Relation to Companion Work on the Standard Model

While the present paper focuses exclusively on the logical status and robustness of the One-Fold framework as a structural programme, a separate companion work demonstrates that these structural conditions admit a concrete realisation reproducing the gauge–Higgs–confinement core of the Standard Model.

Specifically, *The Standard Model from Hexagonal Geometry* [2] constructs an explicit microscopic model (the Hexagonal Closure Field Model) in which the Category II structural conditions identified here — closure, finite entropy density, representation constraints, and response-space structure — are dynamically realised, and in which the emergent long-wavelength effective theory reproduces U(1), SU(2), and SU(3) gauge sectors, the Higgs scalar, confinement, and associated coupling relations as conditional theorems.

The logical role of that work is *realisational* rather than *foundational*: it shows that the structural conditions analysed in the present paper are not merely abstract constraints, but are satisfied in at least one explicit, internally consistent construction. The arguments of the present paper do not depend on that realisation, but its existence strengthens the interpretation and scope of the One-Fold framework. Nothing in the present audit requires that the hexagonal model be the unique realisation; its role is to demonstrate non-emptiness of the condition set. In particular, it supports the non-emptiness of the Category II condition set; it does not alter the Category I base axioms of One-Fold.

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2. Taxonomy of Results

We classify every result in the One-Fold framework into one of three categories.

Category I — Structural Theorems. Results that follow from the core information-theoretic axioms (A1–A5) together with standard quantum mechanics. No additional physical input is required. These results are the load-bearing walls of the framework; if they fail, the programme fails.

Category II — Conditional Structural Derivations. Results that follow rigorously from representation theory, geometry, or analysis *given* additional axioms that are physically motivated but not derivable from A1–A5 alone. These axioms (V1, GG2′–GG5, G3, L1–L4) constitute the framework's explicit structural conditions. They are individually testable, and if any is violated, the corresponding derived result fails in a predictable way. In some cases, these structural conditions are shown to arise dynamically in explicit models (see Section 1.1 and companion work), though their logical role in the present analysis remains conditional.

Category III — Physical Identifications. Interpretive steps that connect geometric or information-theoretic invariants to measured low-energy parameters. These are conjectural mappings — physically plausible and internally consistent, but not mathematical theorems. They represent the interface between the One-Fold formalism and empirical physics.

The value of this taxonomy is that it makes criticisms precise: a challenge to a Category III identification does not threaten a Category I theorem, and revising a Category II axiom changes specific downstream results without collapsing the entire framework.

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3. Dependency Structure

The logical dependencies among the major results are as follows:

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CATEGORY I (Information-Theoretic Base)
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A1–A5 (Core Axioms)
  ├─→ Theorem D2: Binary directionality (ℤ₂)        [from A2, A5]
  ├─→ Theorem T1/1: dim(ℋ_fold) = 4                  [from A2, A5, QM]
  │      └─→ State space is ℂℙ³                       [from T1 +
normalisation]
  └─→ Theorem 5: Particle identity                     [from fiber uniqueness]

CATEGORY II (Conditional Derivations)
────────────────────────────────────────────────────────────────
T1 + V1 (Unique void state)
  └─→ Lemma GG2: 3⊕1 decomposition (ℂ³ ⊕ ℂ¹)       [dim = 4 − 1]

GG2 + GG2′ + GG3 + GG4 + GG5
  └─→ Theorem 4: G ≅ SU(3) × SU(2) × U(1)          [representation theory]
       └─→ 12 gauge generators

A5 + G3 (Democratic allocation, derived from no-extra-bits condition)
  └─→ Each generator gets curvature fraction 1/12
       └─→ Theorem 5.1: αₐ = fₐ²                      [functional analysis on
ℂℙ³]
            └─→ Geometric invariant: α_geom = (1/12)² = 1/144

L1–L4 (Vacuum energy axioms)
  └─→ Theorem 3: Λ / Λ_Planck = C · f²                [Taylor expansion + dim.
analysis]

CATEGORY III (Physical Identifications)
────────────────────────────────────────────────────────────────
α_geom = 1/144  ──[gauge-coupling identification]──→  α_UV at Planck scale
                 ──[3⊕1 impedance correction]──────→  δ ≈ 0.025 enhancement
                 ──[RG flow + impedance framework]──→  α(0) ≈ 1/137.036

C · f² · Λ_Planck ──[C ≈ 4π estimate, f ≈ 5 × 10⁻⁶²]──→  Λ ≈ 1.2 × 10⁻⁵² m⁻²
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This map makes several things immediately visible. The strongest results (dim = 4, particle identity) sit entirely in Category I. The gauge group and coupling constant require Category II axioms. The specific numerical match to observation requires Category III identifications. Each layer adds explanatory power but also introduces assumptions that are, in principle, separable from the layers above and below.

4. Category I Results: What Is Unconditionally Established

4.1 Four-Dimensional Internal Hilbert Space (Theorem T1/1)

The derivation proceeds: one classical bit (A5) requires two orthogonal quantum states; reversibility (A2) forces a direction label $d \in \{\pm 1\}$; the four configurations (b, d) require four orthogonal states; extra dimensions would encode extra classical information, violating A5.

Therefore:

$\dim(\mathscr{H}\_\text{fold}) = 4$

The four basis states are $|b, d\rangle$ for $b \in \{0, 1\}$ and $d \in \{+1, -1\}$, spanning $\mathbb{C}^4$. The orthogonality condition $\langle b, d \mid b', d' \rangle = \delta\_bb' \, \delta\_dd'$ is required by quantum mechanics for distinguishable configurations.

Status: Theorem. No additional axioms required beyond A1–A5 and standard quantum mechanics.

Robustness: This result fails only if A5 (one-bit minimality) is wrong — i.e., if the fundamental distinguishability unit stores more than one classical bit. In that case, the internal dimension increases, and all downstream results change in predictable ways.

4.2 Binary Directionality (Theorem D2)

The reversible transformations on a single bit form $S_2 \cong \mathbb{Z}_2 = \{\text{id}, \text{swap}\}$. The group has exactly two elements: the identity (leave the bit unchanged) and the swap (flip the bit). This is the only group of order two, making the result unique.

Status: Theorem.

Note on physical interpretation: The identification of $d = +1$ with "particle" and $d = -1$ with "antiparticle" is a Category III physical interpretation, not part of the Category I result. What is proven is that reversible bit dynamics carry a binary label. That this label corresponds to particle/antiparticle structure requires additional physical context (CPT structure, Lorentz invariance) that is not established at this stage of the framework.

4.3 Particle Identity (Theorem 5)

Given fiber uniqueness — one $\mathbb{C}^4$ at every site — all same-type particles are mathematically identical. An electron at site i is $|i\rangle \otimes |e\rangle$ and an electron at site j is $|j\rangle \otimes |e\rangle$, where $|e\rangle \in \mathbb{C}^4$ is the same internal state at both locations. The fragility theorem (Section 7.12 of the main paper [1]) strengthens this: any non-zero distinguishability destroys quantum statistics entirely [20, 21].

Status: Theorem, given the fiber bundle structure [13, 14] $\mathscr{H}\_{global} = \ell^2(\Lambda) \otimes \mathbb{C}^4$.

Robustness: This result is among the most secure in the framework. It fails only if there exist multiple inequivalent internal fibers — a scenario that would require fundamental revision of the entire One-Fold ontology.

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5. Category II Results: Conditional but Constraining

5.1 The 3⊕1 Decomposition (Lemma GG2)

Axiom required: V1 (Unique Void State) — each fold has a unique gauge-invariant ground state $|\Omega\rangle$ satisfying $U|\Omega\rangle = e^{i\theta(U)} |\Omega\rangle$ for all gauge transformations $U \in G$.

What follows: Given $\dim(\mathscr{H}\_{fold}) = 4$ (Category I) and a one-dimensional invariant subspace $W = \mathbb{C}|\Omega\rangle$ (V1), the orthogonal complement $V = W^\perp$ is three-dimensional:

$$\mathbb{C}^4 = W \oplus V \cong \mathbb{C}^1 \oplus \mathbb{C}^3$$

The "3" in what becomes SU(3) is therefore 4 − 1, not a phenomenological input.

Status of V1: Physically natural (every quantum system has a ground state; minimal-entropy states are generically unique) but not derivable from A1–A5. Confidence ~90%.

If V1 fails: The 3⊕1 split would need alternative justification. The gauge group derivation and the 3⊕1 impedance correction to α both depend on it.

5.2 Gauge Group Classification (Theorem 4)

Axioms required: V1, GG2′ (nontrivial action on excitations), GG3 (complex irreducible representation, not self-conjugate), GG4 (weak isospin doublet), GG5 (hypercharge U(1)).

What follows: Given these axioms, representation theory uniquely yields:

$$G \cong SU(3)\_c \times SU(2)\_L \times U(1)\_Y$$

with 8 + 3 + 1 = 12 generators total. The proof is mathematically rigorous.

Category II status of each axiom:

Axiom	Content	Motivation	Confidence
V1	Unique void state	Standard ground-state physics	~90%
GG2′	Nontrivial excitation sector	Required for non-trivial gauge structure	~85%

Axiom	Content	Motivation	Confidence
GG3	Complex, irreducible, not self-conjugate	d = ±1 structure + physical requirement	~70%
GG4	Weak isospin doublet	Nielsen–Ninomiya [5, 6] + staggering	~80%
GG5	Hypercharge U(1)	Standard QM phase + gauge principle	~85%

The commutant-of-K derivation (Appendix D.5 of [1]) provides the strongest realisation: SU(3) × SU(2) × U(1) emerges as the commutant of a diagonal matrix K with $3\oplus1$ block structure acting on $\mathbb{C}^4$:

$G = \{ U \in U(4) \mid [K, U] = 0 \}$

This is pure linear algebra, but it requires K to have the specified block structure — which itself depends on V1.

If GG3 fails: The colour sector could be real rather than complex, yielding SO(3) instead of SU(3). This is experimentally falsifiable.

If GG4 fails: The weak sector would differ. Alternative lattice doublet mechanisms might restore it.

5.3 Democratic Allocation and the Geometric Coupling Invariant (Theorem 2)

Axiom required: G3 (equal Fubini–Study norms for all 12 generators).

Derivation of G3: The curvature-bit argument (Section 5.2 of [1]) derives G3 from A5, *conditional on the premise that the curvature profile is the only potential source of additional gauge-invariant classical information beyond (b, d)*. This conditional should be stated precisely:

Theorem (G3, conditional): If no gauge-invariant, reversible protocol can extract classical information from a single fold beyond the primary bit b and direction label d, then all 12 generators must have equal Fubini–Study norms:

$\|T^1\|^2_{FS} = \|T^2\|^2_{FS} = \cdots = \|T^{12}\|^2_{FS} = K_{tot} / 12$

The antecedent condition — that no additional sources of classical information exist — is a substantive physical claim. Potential alternative sources include topological labels, relational information between a fold and its neighbours, or emergent degrees of freedom not captured by the single-fold analysis. The conditional theorem remains valid regardless; what is empirically testable is the antecedent.

What follows from G3: Each generator gets curvature fraction $f_a = 1/12$. The coupling–curvature law (Theorem 5.1, proven by functional analysis on $\mathbb{CP}^3$) gives:

$\alpha_a = f_a^2 = (1/12)^2 = 1/144$

Status: The geometric invariant α_geom = 1/144 is a Category II result — rigorous given G3, which is itself derived under an explicit conditional.

5.4 Cosmological Constant Scaling (Theorem 3)

Axioms required: L1 (vacuum free energy depends on fractional usage), L2 (void is stationary: dF/df |_(f=0) = 0), L3 (analyticity near f = 0), L4 (Planck-scale normalisation).

What follows: By L2 and L3, the Taylor expansion of the vacuum free energy around f = 0 has no linear term:

$$F(f) = F(0) + \tfrac{1}{2} F''(0) \cdot f^2 + \mathcal{O}(f^3)$$

For $f \approx 10^{-62} \ll 1$, higher terms are negligible. Combined with L4 (dimensional analysis):

$$\Lambda / \Lambda\_\text{Planck} = C \cdot f^2$$

where C is a dimensionless geometric constant of order unity.

Robustness: The f^2 scaling survives even if f is wrong by three orders of magnitude — the prediction changes by only 10^6, still 10^{114} times better than QFT's 10^{120} discrepancy [9]. The scaling is the principal achievement; the specific numerical match is secondary.

If L2 fails: A linear term in f would dominate, yielding $\Lambda \propto f$ rather than f^2. This would change the prediction by $\sim 10^{62}$ and is experimentally distinguishable (it would predict a much larger Λ or require an unnaturally small coefficient).

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6. Category III Results: Physical Identifications

These are the interpretive bridges between the One-Fold formalism and measured quantities. They are physically motivated and internally consistent, but they are not theorems.

6.1 Identifying α_geom with the Physical Fine-Structure Constant

Two coupling routes. The programme currently contains two distinct derivation routes to electromagnetic coupling: (i) the One-Fold route defines a geometric invariant α_geom from curvature allocation on $\mathbb{CP}^3$, yielding α_geom = 1/144 before dressing corrections; and (ii) the Hexagonal Closure route [2] defines a dressed closure resistance α_hex from closure rarity and nullity-1 channel dressing, yielding α^{-1}_hex ≈ 137.14. These quantities are not assumed identical *a priori*; establishing their relationship — equivalence, matching, or hierarchy — is a testable cross-consistency problem for the programme. The present section concerns route (i) only.

The geometric invariant $\alpha\_geom = (1/12)^2 = 1/144$ is a property of the $\mathbb{CP}^3$ curvature structure. Identifying this with the physical coupling constant measured in QED scattering experiments requires:

1. **Gauge-coupling identification:** The Fubini–Study norm $\|T^a\|^2\_FS$ of a generator corresponds to the Yang–Mills coupling normalisation via the FS–YM correspondence:

   $\|T^a\|^2\_FS = \frac{1}{4} \mathrm{Tr}(T^a T^a) = \frac{1}{8}$

   for each of the 12 generators under standard normalisation $\mathrm{Tr}(T^a T^b) = \frac{1}{2} \delta^{ab}$. This is supported by Schur's lemma and standard differential geometry [13, 14] (Lemma 5.0 of [1]). Status: well-motivated, ~90% confidence.

2. **The 3⊕1 impedance correction:** The unique void state (V1) introduces a structural asymmetry in curvature allocation. A ~2.5% enhancement of the electromagnetic direction shifts 1/144 toward 1/137. Specifically, if $f\_EM = (1 + \delta)/12$, then:

   $\alpha\_EM = f^2\_EM = (1 + \delta)^2 / 144$

   and fitting to $\alpha\_obs \approx 1/137.036$ [18] gives $\delta \approx 0.025$. **This correction is currently reverse-engineered from the known answer.** The required δ is determined by fitting to observation, not derived from BCB/TPB dynamics. Until the correction is derived from first principles, it constitutes a Category III identification, not a prediction. Status: mechanism identified, magnitude natural, formal derivation pending. Confidence ~60% as a *prediction*; ~88% as a *consistency check*.

3. **RG flow from UV to IR:** Connecting α_geom at the Planck scale to $\alpha(m_e) \approx 1/137.036$ requires standard renormalisation group running [16, 17] with threshold matching. The impedance framework provides the IR anchor at $\alpha(0) = Z_0 / (2R\_K)$. The full UV → IR bridge has not been explicitly constructed. Status: well-defined future work.

Summary: The chain $\alpha\_geom = 1/144 \to \alpha \approx 1/137$ involves one Category II result (the geometric invariant), one Category III identification (gauge-coupling mapping), one Category III conjecture (3⊕1 correction), and one standard-physics calculation (RG flow, not yet performed for BCB). The overall status is: *geometric base strong, physical identification plausible, specific numerical match not yet derived end-to-end.*

6.2 Cosmological Constant Numerical Prediction

The f^2 scaling is Category II. The specific prediction $\Lambda \approx 1.2 \times 10^{-52}$ m^{-2} involves two Category III inputs:

- **C ≈ 4π:** Geometric estimate from surface/volume considerations. Confidence ~60%.
- **$f \approx 5 \times 10^{-62}$:** Rests on a bulk-boundary comparison (volumetric lattice capacity $N\_void \approx 4 \times 10^{184}$ bits versus Bekenstein–Hawking holographic entropy [7, 8, 11, 12] $N\_cosmic \approx 2 \times 10^{123}$ bits) that is a working hypothesis, not a derivation. Confidence ~75–80%.

Given stated uncertainties, the prediction spans approximately $\Lambda \in [10^{-58}, 10^{-46}]$ m^{-2}, a roughly 12-order-of-magnitude window. This is still 10^{80} to 10^{108} times more precise than QFT's vacuum energy estimate [9], making it a dramatic improvement even at the boundaries of the uncertainty range.

6.3 Particle/Antiparticle Interpretation of $\mathbb{Z}_2$

The mathematical result ($d \in \{\pm1\}$ from reversibility) is Category I. The identification of $d = +1$ as "particle" and $d = -1$ as "antiparticle" is Category III — it requires connecting the abstract direction label to CPT structure in the emergent continuum limit.

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7. Comparison of Assumption Inventories

The One-Fold framework does not eliminate assumptions; it replaces one set with another. The question is whether the replacement is explanatorily productive.

7.1 Standard Model Inputs

The Standard Model requires the following inputs that are not derived from internal principles [16, 17, 18]:

Input	Type	Count
Gauge group $SU(3) \times SU(2) \times U(1)$	Structural choice	1
Field content (fermion representations)	Structural choice	1
Coupling constants (g_1, g_2, g_3)	Free parameters	3
Yukawa couplings (masses)	Free parameters	13
CKM mixing parameters	Free parameters	4
PMNS mixing parameters	Free parameters	4*
Higgs parameters (μ^2, λ)	Free parameters	2
Cosmological constant Λ	Free parameter	1
θ_{QCD}	Free parameter	1
Total		**~25–30**

*Depends on whether neutrinos are Majorana.

7.2 One-Fold Inputs

Input	Category	Status
A1: Discrete spacetime	I (axiom)	Core
A2: Bit conservation	I (axiom)	Core

Input	Category	Status
A3: Locality	I (axiom)	Core
A4: Quantum substrate	I (axiom)	Core
A5: Minimal complexity	I (axiom)	Core
V1: Unique void state	II (axiom)	Motivated
GG2′: Nontrivial excitations	II (axiom)	Motivated
GG3: Complex irreducible rep	II (axiom)	Motivated
GG4: Weak isospin doublet	II (axiom)	Motivated
GG5: Hypercharge U(1)	II (axiom)	Motivated
L1–L4: Vacuum energy axioms	II (axioms)	Motivated
Gauge-coupling identification	III (conjecture)	Plausible
$3\oplus 1$ impedance correction	III (conjecture)	Mechanism identified
$C \approx 4\pi$	III (estimate)	Order-of-magnitude
f from bulk-boundary comparison	III (hypothesis)	~80%
Total		**~15**

7.3 What the Comparison Shows

One-Fold has fewer total inputs (~15 vs. ~25–30), but more importantly, the *type* of input differs. The Standard Model's free parameters are dimensionless numbers that must be measured; One-Fold's Category II axioms are structural conditions that can be stated in natural language and are individually falsifiable. One-Fold targets several of the Standard Model's historically unexplained structural inputs — spinor structure, gauge symmetry structure, coupling invariants and scaling laws, and particle identity — while leaving flavour, detailed mass hierarchies, and mixing parameters open.

The honest summary: One-Fold compresses a subset of the Standard Model's phenomenological inputs into more primitive structural conditions. It does not yet address the full parameter space. This is a genuine explanatory advance within its scope, not a complete replacement.

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8. Robustness Analysis

For each major result, we identify what would need to be wrong to invalidate it.

Result	Depends on	Fails if…	Consequence
$\dim(\mathscr{H}) = 4$	A2, A5	Fold stores > 1 bit	Higher-dim internal space; all downstream results change
$\mathbb{Z}_2$ directionality	A2, A5	Reversible bit transforms $\neq S_2$	Impossible (S_2 is unique); result is unconditional

Result	Depends on	Fails if…	Consequence
Particle identity	Fiber uniqueness	Multiple fiber types exist	Different particle species from different fibers
3⊕1 split	V1	No unique void state	Colour sector dimension changes
Gauge group	V1, GG2′–GG5	Any of GG2′–GG5 fails	Different gauge group; specific failure mode depends on which axiom
α_geom = 1/144	G3 (+ T4)	Extra classical bits in fold geometry	Non-democratic allocation; different α_geom
$\alpha \approx 1/137$	α_geom + Cat. III	Physical identification wrong	Geometric invariant exists but doesn't map to QED coupling
$\Lambda \propto f^2$	L1–L4	Void non-stationary (L2 fails)	Linear scaling; prediction off by $\sim 10^{62}$
$\Lambda \approx 10^{-52}$	f^2 + Cat. III	C or f wrong	Prediction shifts within $[10^{-58}, 10^{-46}]$ window

The critical observation: the Category I results (dim = 4, $\mathbb{Z}_2$, particle identity) are robust against failure of any Category II or III element. The framework degrades gracefully rather than collapsing catastrophically.

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9. Open Problems Explicitly Delineated

For completeness, we list the principal open problems, classified by type.

Mathematical (well-defined, solvable in principle):

- Explicit RG flow connecting α_geom = 1/144 to $\alpha(m_e)$ via the impedance IR anchor
- Derivation of the 3⊕1 impedance correction $\delta \approx 0.025$ from BCB/TPB dynamics
- Precise determination of C in $\Lambda = C \cdot f^2 \cdot \Lambda$_Planck from the BCB Hamiltonian
- Lattice discretisation corrections to α
- Ground state dynamics verifying V1 and GG2′–GG5 emergence

Conceptual (requiring new ideas):

- Origin of three fermion generations
- Particle mass spectrum and Yukawa couplings
- CP violation mechanism
- Gravitational sector and spacetime curvature from entropy gradients
- Derivation of bulk-boundary correspondence for f from BCB dynamics

Experimental (testable in principle):

- Lorentz violation at $\xi \sim (E / E\_Planck)^2$

- Entanglement anisotropy from cubic lattice structure
- Precision tests of $w = -1$ (LSST [23], Euclid [24])
- Constancy of α at high redshift [25, 26]

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10. Conclusion

By making the conditional structure of the One-Fold framework fully explicit, this companion paper achieves three things.

First, it protects the framework's strongest results — the four-dimensional internal Hilbert space, binary directionality, and particle identity — from criticism directed at its more speculative elements. These Category I theorems stand on the information-theoretic base alone.

Second, it makes the Category II structural conditions (V1, GG2′–GG5, G3, L1–L4) individually visible and individually testable. If the gauge group derivation is challenged, the challenge must specify which axiom it targets and what replaces it.

Third, it honestly demarcates the Category III physical identifications — the mapping from geometric invariants to measured constants — as conjectural bridges rather than proven theorems. This does not weaken the framework; it strengthens it, because a clearly labelled conjecture invites productive engagement, while an unlabelled one invites dismissal.

The One-Fold programme does not claim to derive physics from nothing. It claims to derive specific physical structures from a smaller, more primitive, and more explicitly stated set of structural conditions than the Standard Model requires. Whether that claim withstands scrutiny depends on the quality of its logical architecture. This companion paper is an effort to ensure that architecture is transparent.

Finally, while this paper is concerned with logical structure rather than explicit model-building, it is worth noting that the structural conditions identified here have been shown elsewhere to admit a concrete realisation reproducing a large subset of known physics (see Section 1.1). This separation between structural necessity and dynamical realisation is intentional and central to the One-Fold programme.

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11. References

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