

# Temporal Selection Rules for Discrete Mass Emergence via Temporal Eigenmode Selection in Time-Scalar Field Theory

Jordan Gabriel Farrell

Colchester, Connecticut, USA

ORCID: [0009-0002-2171-809X](https://orcid.org/0009-0002-2171-809X)

December 31, 2025

## Abstract

The Standard Model encodes particle masses as empirical parameters and does not explain why the observed spectrum is discrete, sparse, and sharply bounded. TSFT (Time-Scalar Field Theory) reframes mass as temporal inertia and treats particles as dynamically selected temporal eigenmodes. We formalize particle existence through temporal selection rules (closure, scalar compatibility, perturbative stability, and composite phase-locking), show that discrete mass emergence follows generically from stable proper-time eigenmodes subject to global temporal closure, and interpret lepton families as stability-window survivors. Neutrinos arise as near-null modes with incomplete closure, yielding tiny masses and oscillations. Quarks are treated as non-factorizable internal temporal modes confined to composites by the same selection logic. Alpha, beta, and gamma emission are unified as temporal partition transitions governed by a conserved allocation between internal evolution and propagation. Finally, we present model-independent correlations with existing high-energy data (resonance widths, exclusion results, neutrino oscillations, and hadronization) consistent with discrete stability windows and forbidden bands.

## Contents

<b>1</b>	<b>Introduction and Motivation</b>	<b>3</b>
<b>2</b>	<b>Temporal Eigenmodes and Scalar-Time Dynamics</b>	<b>3</b>
<b>3</b>	<b>Temporal Selection Rules (Propositions &amp; Lemmas)</b>	<b>4</b>
3.1	Selection rules as propositions . . . . .	4
3.2	Lemmas enabling discreteness . . . . .	5
<b>4</b>	<b>A Minimal Constructive Model for Discrete Stable Eigenmodes</b>	<b>5</b>
4.1	Attractor existence in proper time . . . . .	5

4.2	Phase closure (holonomy) and discreteness . . . . .	5
4.3	Calibration scaffold for $T_\tau(\Theta)$ and $\mu_\tau$ . . . . .	6
<b>5</b>	<b>Charged-Lepton Families from Stability Windows</b>	<b>6</b>
5.1	Stability windows . . . . .	7
5.2	Constructive multi-attractor example . . . . .	7
<b>6</b>	<b>Neutrinos as Near-Null Temporal Eigenmodes</b>	<b>7</b>
6.1	Oscillations as temporal beating . . . . .	8
<b>7</b>	<b>Quarks and Confinement as Non-Factorizable Temporal Eigenmodes</b>	<b>8</b>
<b>8</b>	<b>Alpha, Beta, and Gamma Emission as Temporal Mode Transitions</b>	<b>8</b>
8.1	Gamma emission: null-mode shedding . . . . .	8
8.2	Beta emission: leptonic eigenmode release with near-null balancing . . . . .	9
8.3	Alpha emission: composite ejection . . . . .	9
<b>9</b>	<b>The <math>\eta</math>-Bridge: Temporal Partition Transitions</b>	<b>9</b>
9.1	Temporal partition principle . . . . .	9
9.2	Unified interpretation of $\alpha/\beta/\gamma$ . . . . .	9
9.3	Single schematic figure (vector, no external files) . . . . .	10
<b>10</b>	<b>Empirical Correlations with High-Energy Collider Data</b>	<b>10</b>
10.1	Resonance widths as indicators of eigenmode stability . . . . .	10
10.2	Absence of light charged fermions . . . . .	10
10.3	Neutrino oscillations as near-null temporal beating . . . . .	10
10.4	Hadronization and confinement . . . . .	10
<b>11</b>	<b>Conclusion</b>	<b>10</b>
<b>A</b>	<b>Methods: Constructing the Stability–Width Correlation Plot</b>	<b>11</b>
A.1	Stability–Width Clustering from PDG Data . . . . .	12

## 1 Introduction and Motivation

The Standard Model successfully parametrizes a wide range of particle phenomena, yet it largely treats the observed mass spectrum as an input. Fermion masses span many orders of magnitude but appear only at specific values; no continuous mass spectrum is observed, and no stable charged particle exists below the electron. These features are encoded empirically rather than derived.

TSFT approaches the question differently: rather than asking *which* masses nature happens to have, it asks *which* masses are *allowed to exist* as stable temporal eigenmodes under universal selection rules. In this view, particles correspond to persistent, coherent solutions in proper time whose stability is governed by closure, scalar compatibility, and attractor dynamics. Composite particles are interpreted as phase-locked eigenstructures whose dominant inertial content can arise from coherence enforcement rather than constituent rest mass alone.

This paper formalizes the next logical step: a constructive existence theory for massive particles. The goal is not to numerically fit MeV values, but to derive the *structure* of the spectrum: discreteness, gaps (forbidden bands), the emergence of lepton families, the near-null nature of neutrinos (and oscillations), confinement as non-factorizability, and the unification of  $\alpha/\beta/\gamma$  radiation as temporal partition transitions.

## 2 Temporal Eigenmodes and Scalar-Time Dynamics

Let  $M$  be a smooth 4-manifold of events with local chart  $x^\mu$ , and let  $\Theta : M \rightarrow \mathbb{R}$  denote the scalar-time field. Let  $\gamma : \lambda \mapsto x^\mu(\lambda)$  be a worldline. Proper time accumulation is governed by a positive functional

$$d\tau = A(\Theta, \partial\Theta; x) d\lambda, \quad A > 0. \quad (1)$$

In weakly varying regimes one may write  $d\tau = \alpha(x) dt$  with  $\alpha(x) > 0$  and  $\alpha(x) = 1 + \varepsilon(x)$ ,  $|\varepsilon| \ll 1$ .

**Definition 2.1** (Proper-time phase field). A proper-time phase for an excitation is a real scalar  $\phi$  defined along  $\gamma$  satisfying

$$\frac{d\phi}{d\tau} = \omega(\tau). \quad (2)$$

**Definition 2.2** (Temporal eigenmode and mass bookkeeping). A temporal eigenmode is an excitation for which  $\omega(\tau)$  is constant (or asymptotically constant) along  $\gamma$ :

$$\phi(\tau) = \omega\tau + \phi_0. \quad (3)$$

We identify rest-energy bookkeeping by  $E_0 = \hbar\omega$ , hence

$$m \equiv \frac{E_0}{c^2} = \frac{\hbar\omega}{c^2}. \quad (4)$$

**Definition 2.3** (Temporal inertia coefficient). Define temporal inertia  $\mu_\tau$  by the linear response of

eigenfrequency to scalar-time modulation  $\alpha = 1 + \varepsilon$ :

$$\frac{\delta\omega}{\omega} = -\mu_\tau \varepsilon + \mathcal{O}(\varepsilon^2). \quad (5)$$

**Definition 2.4** (Null and near-null temporal modes). A null temporal mode satisfies  $\Delta\tau = 0$  along propagation (massless limit). A near-null mode satisfies  $0 < \Delta\tau \ll 1$  over macroscopic propagation, forming a natural regime for neutrinos.

### 3 Temporal Selection Rules (Propositions & Lemmas)

#### 3.1 Selection rules as propositions

**Proposition 3.1** (Phase-closure selection rule). *A temporal eigenmode corresponds to a physically realizable particle only if its internal phase evolution admits bounded relative phase under propagation and perturbation. If the mode is described by internal phases  $\{\phi_i\}$ , there must exist  $C < \infty$  such that for all  $\tau$  in the persistence domain,*

$$\max_{i,j} |\phi_i(\tau) - \phi_j(\tau)| \leq C. \quad (6)$$

**Proposition 3.2** (Scalar-compatibility selection rule). *Let  $\Theta \mapsto \Theta + \delta\Theta$  be a small perturbation supported near  $\gamma$ . A temporal eigenmode is admissible only if the induced phase-rate perturbation remains bounded:*

$$|\delta\omega(\tau)| \leq K \|\delta\Theta\|_{C^1(\mathcal{N}_\gamma)} \quad \text{for all relevant } \tau, \quad (7)$$

for some  $K < \infty$ .

**Proposition 3.3** (Perturbative stability selection rule). *Let a mode be represented by internal state  $y(\tau) \in \mathbb{R}^n$  with evolution*

$$\frac{dy}{d\tau} = F(y; \Theta, \partial\Theta). \quad (8)$$

*A realizable eigenmode corresponds to a structurally stable fixed point or limit cycle. In a fixed point representation  $y^*$ , the Jacobian*

$$J := \left. \frac{\partial F}{\partial y} \right|_{y^*} \quad (9)$$

*must satisfy  $\text{Re}(\lambda_k(J)) < 0$  for all eigenvalues  $\lambda_k$ .*

**Proposition 3.4** (Composite coherence (phase-locking) selection rule). *Composite particles correspond to multi-phase eigenstructures  $\{\phi_i\}_{i=1}^N$  satisfying phase-locking:*

$$\frac{d}{d\tau}(\phi_i - \phi_j) = 0 \quad (\text{or } \approx 0 \text{ within tolerance}) \quad \forall i, j. \quad (10)$$

### 3.2 Lemmas enabling discreteness

**Lemma 3.1** (Null-massive dichotomy). *If  $\Delta\tau = 0$  along propagation (null mode), then no nontrivial temporal inertia coefficient  $\mu_\tau$  exists in the sense of linear response. Conversely, any mode with well-defined  $\mu_\tau > 0$  necessarily has  $\Delta\tau > 0$ .*

**Lemma 3.2** (Isolated admissible eigenfrequencies under stability). *Assume candidate modes parameterized by  $\omega$  satisfy a stability constraint  $G(\omega; \Theta) = 0$ , where  $G$  is smooth and non-degenerate ( $\partial_\omega G \neq 0$ ). Then stable  $\omega$  values are isolated (discrete), hence masses  $m = \hbar\omega/c^2$  are discrete.*

**Lemma 3.3** (Temporal susceptibility induces forbidden bands). *If  $\mu_\tau(\omega)$  diverges over an interval, then arbitrarily small modulation produces unbounded response, violating scalar compatibility. Hence no admissible particles exist in that interval (forbidden band).*

**Corollary 3.1** (Discreteness of admissible masses). *Under non-degenerate stability constraints, admissible stable eigenfrequencies are discrete, and therefore admissible masses are discrete.*

## 4 A Minimal Constructive Model for Discrete Stable Eigenmodes

### 4.1 Attractor existence in proper time

Consider a minimal phase-amplitude system in proper time:

$$\frac{dr}{d\tau} = \lambda(\Theta)r - \beta r^3, \quad \frac{d\phi}{d\tau} = \omega(\Theta) + \kappa r^2, \quad (11)$$

with  $\beta > 0$  and smooth  $\lambda(\Theta)$ ,  $\omega(\Theta)$ . If  $\lambda(\Theta) > 0$ , there exists a stable limit cycle at

$$r_\star(\Theta) = \sqrt{\frac{\lambda(\Theta)}{\beta}}, \quad (12)$$

with effective eigenfrequency (constant proper-time phase rate on the attractor)

$$\Omega(\Theta) = \omega(\Theta) + \kappa \frac{\lambda(\Theta)}{\beta}. \quad (13)$$

Mass bookkeeping is  $m(\Theta) = \hbar\Omega(\Theta)/c^2$ .

### 4.2 Phase closure (holonomy) and discreteness

Assume physical realizability requires a global coherence/holonomy closure condition: there exists  $T_\tau(\Theta) \in (0, \infty)$  such that

$$\phi(\tau + T_\tau(\Theta)) - \phi(\tau) = 2\pi n, \quad n \in \mathbb{Z}_{\geq 1}. \quad (14)$$

On the attractor  $\phi(\tau) = \Omega\tau + \phi_0$ , this implies the selection equation

$$\Omega(\Theta) T_\tau(\Theta) = 2\pi n, \quad (15)$$

hence

$$\Omega_n(\Theta) = \frac{2\pi n}{T_\tau(\Theta)}, \quad m_n(\Theta) = \frac{\hbar}{c^2} \frac{2\pi n}{T_\tau(\Theta)}. \quad (16)$$

**Theorem 4.1** (Discrete spectrum from temporal closure and attractor stability). *If stable proper-time eigenmodes exist as attractors and must satisfy global closure, then admissible eigenfrequencies  $\Omega_n$  and masses  $m_n$  are discrete. If the attractor ceases to exist or closure fails, no corresponding admissible particle exists.*

### 4.3 Calibration scaffold for $T_\tau(\Theta)$ and $\mu_\tau$

Assume a minimal scaling of the proper-time coherence loop:

$$T_\tau(\Theta) = T_0 \alpha(\Theta)^{-p}, \quad p \in \mathbb{R}, \quad T_0 > 0. \quad (17)$$

If one adopts the common TSFT closure  $\alpha(\Theta) = e^{-\Theta}$ , then  $T_\tau(\Theta) = T_0 e^{p\Theta}$  and  $\Omega_n(\Theta) = \frac{2\pi n}{T_0} e^{-p\Theta}$ .

In weak modulation  $\alpha = 1 + \varepsilon$ ,

$$\frac{\delta\Omega_n}{\Omega_n} = p\varepsilon + \mathcal{O}(\varepsilon^2), \quad (18)$$

and comparing to the definition of  $\mu_\tau$  identifies  $\mu_\tau = -p$  (up to sign convention).

## 5 Charged-Lepton Families from Stability Windows

Let stable eigenmodes exist only when a stability functional  $\lambda(\Theta, \Omega) > 0$ . Assume a threshold frequency  $\Omega_\star(\Theta) > 0$  such that

$$\lambda(\Theta, \Omega) > 0 \text{ iff } \Omega \geq \Omega_\star(\Theta). \quad (19)$$

Then the first admissible mode corresponds to the smallest integer  $n$  satisfying  $\Omega_n(\Theta) \geq \Omega_\star(\Theta)$ :

$$n_{\min}(\Theta) = \left\lceil \frac{\Omega_\star(\Theta) T_\tau(\Theta)}{2\pi} \right\rceil. \quad (20)$$

All  $n < n_{\min}$  are mathematically definable closure candidates but physically non-admissible under stability, providing a structural template for why no stable charged fermions exist below the electron.

## 5.1 Stability windows

Closure yields candidates  $\Omega_n$  and masses  $m_n$ . Let the stable-frequency window set be

$$\mathcal{S}(\Theta) = \bigcup_{k=1}^K (\Omega_k^-(\Theta), \Omega_k^+(\Theta)), \quad \Omega_k^+(\Theta) < \Omega_{k+1}^-(\Theta). \quad (21)$$

Define admissible stable frequencies

$$\mathcal{A}(\Theta) := \{\Omega_n(\Theta) : \Omega_n(\Theta) \in \mathcal{S}(\Theta)\}. \quad (22)$$

**Theorem 5.1** (Lepton families as stable closure intersections). *If  $\mathcal{S}(\Theta)$  contains three disjoint stable windows each containing exactly one closure candidate  $\Omega_{n_k}$ , then exactly three stable charged-lepton families occur at those eigenfrequencies, naturally mapped to  $(e, \mu, \tau)$ .*

## 5.2 Constructive multi-attractor example

A generic nonlinear proper-time dynamics can generate multiple stable limit cycles, e.g.

$$\frac{dr}{d\tau} = r(\lambda_0(\Theta) - \beta_1 r^2 - \beta_2 r^4), \quad \frac{d\phi}{d\tau} = \omega_0(\Theta) + \kappa_1 r^2 + \kappa_2 r^4, \quad (23)$$

which can admit multiple attracting radii  $r_*$  and corresponding phase rates, producing a finite set of stability windows when combined with scalar-compatibility constraints.

## 6 Neutrinos as Near-Null Temporal Eigenmodes

Null modes satisfy  $\Delta\tau = 0$ . Neutrinos are modeled as near-null modes with weak proper-time accumulation:

$$0 < \Delta\tau \ll 1, \quad 0 < \Omega_\nu \ll \Omega_e. \quad (24)$$

They fail exact closure but satisfy a soft closure condition

$$\Omega_\nu T_\tau \approx 2\pi n + \delta, \quad |\delta| \ll 2\pi. \quad (25)$$

**Lemma 6.1** (Suppressed mass from closure defect). *If the soft closure condition holds with  $|\delta| \ll 1$ , then an effective mass scale is suppressed by the mismatch:*

$$m_\nu \sim \frac{\hbar |\delta|}{c^2 T_\tau}. \quad (26)$$

## 6.1 Oscillations as temporal beating

Oscillations arise generically from near-degenerate eigenfrequencies. For three near-null modes with  $\Omega_1 \approx \Omega_2 \approx \Omega_3$ , phase beating yields

$$\Delta\phi_{ij}(\tau) = (\Omega_i - \Omega_j)\tau, \quad L_{ij} \sim \frac{c}{|\Omega_i - \Omega_j|}. \quad (27)$$

Neutrino mixing is thus a natural consequence of incomplete closure and weak attractor depth, while charged leptons do not oscillate because they correspond to deep, stable temporal attractors.

## 7 Quarks and Confinement as Non-Factorizable Temporal Eigenmodes

**Definition 7.1** (Temporal factorizability). A temporal eigenmode is factorizable if it admits a standalone proper-time dynamical system with a stable attractor for its phase evolution. A mode is non-factorizable if stability is possible only as part of a coupled multi-phase system.

**Theorem 7.1** (Temporal non-factorizability implies confinement). *If a candidate degree of freedom corresponds to a non-factorizable temporal phase mode, then it cannot exist as an asymptotic free particle. It can manifest only within a composite eigenmode whose internal phases satisfy collective closure and stability.*

Composite hadrons can be modeled as phase-locked systems:

$$\frac{d\phi_{q_i}}{d\tau} = \Omega_{q_i}(\Theta) + \sum_{j \neq i} K_{ij} \sin(\phi_{q_j} - \phi_{q_i}), \quad (28)$$

with a stable locked solution enforcing coherence. Attempted separation increases the coherence penalty and drives fragmentation into new composites (hadronization), yielding confinement as a temporal necessity rather than an added force.

## 8 Alpha, Beta, and Gamma Emission as Temporal Mode Transitions

### 8.1 Gamma emission: null-mode shedding

Gamma emission corresponds to energy export via a null mode:

$$Y^* \rightarrow Y^{*'} + \gamma. \quad (29)$$

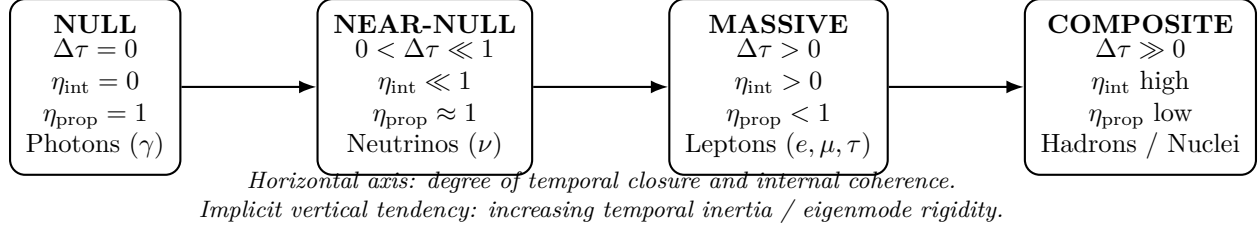


Figure 1: Temporal eigenmode spectrum in TSFT: null modes (photons), near-null modes (neutrinos), factorizable stable massive modes (charged leptons), and composite phase-locked modes (hadrons/nuclei).

## 8.2 Beta emission: leptonic eigenmode release with near-null balancing

Beta emission exports a stable lepton eigenmode plus a near-null neutrino channel:

$$Y^* \rightarrow Y^{*'} + e^\pm + \nu. \quad (30)$$

## 8.3 Alpha emission: composite ejection

Alpha emission corresponds to ejection of a stable composite sub-attractor:

$$Y^* \rightarrow Y^{*'} + \alpha. \quad (31)$$

# 9 The $\eta$ -Bridge: Temporal Partition Transitions

## 9.1 Temporal partition principle

TSFT encodes a conserved temporal allocation between internal evolution and propagation:

$$\eta_{\text{int}}^2 + \eta_{\text{prop}}^2 = 1. \quad (32)$$

Null radiation corresponds to  $\eta_{\text{int}} = 0$ ,  $\eta_{\text{prop}} = 1$ , while massive bound structures satisfy  $\eta_{\text{int}} > 0$ .

## 9.2 Unified interpretation of $\alpha/\beta/\gamma$

Under the temporal partition principle:

- $\gamma$ : maximal propagation export ( $\eta_{\text{int}} \rightarrow 0$ ),
- $\beta$ : hybrid partition via lepton emission plus near-null balancing,
- $\alpha$ : expulsion of internal temporal inertia as a composite sub-attractor.

Thus  $\alpha/\beta/\gamma$  are unified as distinct solutions restoring the same conserved allocation law.

### 9.3 Single schematic figure (vector, no external files)

## 10 Empirical Correlations with High-Energy Collider Data

Although TSFT is formulated at the level of temporal eigenmode selection rather than parameter fitting, its predictions align closely with well-established empirical patterns observed in high-energy experiments at CERN and consolidated in PDG summaries.

### 10.1 Resonance widths as indicators of eigenmode stability

In TSFT, stable temporal eigenmodes correspond to narrow decay widths, while modes outside closure/stability windows decohere rapidly and exhibit broad widths. A model-independent proxy is the dimensionless instability ratio  $R = \Gamma/m$  built from mass  $m$  and total width  $\Gamma$  (Appendix A). The absence of a low- $R$  continuum across the spectrum is interpreted as evidence of discrete stability windows and forbidden bands.

### 10.2 Absence of light charged fermions

Collider searches exclude stable charged fermions lighter than the electron or between known lepton families. In TSFT, closure candidates below the first stable non-null eigenmode fail stability and cannot persist as asymptotic states; null results are therefore consistent with an exclusionary selection rule rather than unexplored parameter space.

### 10.3 Neutrino oscillations as near-null temporal beating

Neutrino oscillations follow naturally from near-degenerate near-null eigenfrequencies and incomplete closure, yielding slow phase beating. The absence of analogous oscillations in charged leptons follows from their deep temporal attractor character.

### 10.4 Hadronization and confinement

High-energy collisions do not yield isolated quarks; increasing energy yields jets and fragmentation into color-neutral hadrons. TSFT interprets this as temporal non-factorizability: quark-like internal modes cannot form standalone attractors and are confined to composite eigenstructures. Hadronization becomes coherence enforcement rather than an added force.

## 11 Conclusion

TSFT reframes the origin of matter by shifting the question from *what masses are* to *which masses can exist*. We have shown that particle existence follows from temporal eigenmode selection governed by bounded response, scalar compatibility, perturbative stability, and global temporal closure. These conditions imply discrete admissible eigenfrequencies and hence discrete inertial masses.

Charged leptons arise as factorizable stable eigenmodes surviving as intersections of closure candidates with disjoint stability windows; neutrinos occupy a near-null regime with incomplete closure, yielding tiny masses and oscillations generically; quarks are non-factorizable temporal components confined to composites by the same selection logic; and alpha, beta, and gamma radiation are unified as temporal partition transitions restoring the constraint  $\eta_{\text{int}}^2 + \eta_{\text{prop}}^2 = 1$ .

The framework is falsifiable in a structural sense: discovery of a stable charged particle outside admissible windows, free quarks, or disappearance of neutrino oscillations would contradict the selection rules. Existing high-energy data already exhibit patterns consistent with discrete stability minima and broad instability bands, and can be visualized directly via a PDG-based stability–width plot. TSFT therefore proposes a unified, minimal ontology connecting photons to nuclei under a single law of temporal allocation.

## A Methods: Constructing the Stability–Width Correlation Plot

This appendix provides a reproducible, model-independent method for correlating TSFT predictions with existing collider data, without parameter fitting.

### Data sources

Use Particle Data Group (PDG) summary tables for particle masses  $m$  and total decay widths  $\Gamma$ .

### Observable

Define the dimensionless instability ratio

$$R \equiv \frac{\Gamma}{m}. \quad (33)$$

Small  $R$  corresponds to long-lived modes (deep attractors); large  $R$  corresponds to unstable transient modes (outside stability windows).

### Plot specification

Plot  $R$  versus  $m$  on log–log axes. Optionally annotate canonical minima (electron, muon, tau, proton). The expected structure shows deep minima at stable particles, broad bands of large  $R$  for resonances, and gaps with no low- $R$  states—consistent with discrete stability windows and forbidden bands.

### Reproducibility

No fitting or model parameters are introduced; the plot is a direct normalization of tabulated observables. Any researcher can reproduce it from PDG tables and standard plotting tools.

## Scope, Predictivity, and Future Extensions

The present work is intentionally structural rather than numerical. Its primary contribution is not the post hoc reproduction of known mass values, but the derivation of *existence, discreteness, stability, and forbiddenness* of particle states from temporal eigenmode selection in TSFT. In this sense, the theory operates analogously to the periodic table or early band theory: it predicts which modes can exist, how they are ordered, where gaps must occur, and why termination or instability arises, without yet fixing high-precision numerical constants.

Quantities such as the proper-time coherence scale  $T_\tau(\Theta)$  and the temporal inertia coefficient  $\mu_\tau$  are treated here as emergent response parameters rather than arbitrary fits, and their derivation from explicit  $\Theta$ -field dynamics is a natural next step rather than a logical prerequisite. Minimal dynamical models are employed as existence proofs for discrete stable attractors; internal symmetries (spin, chirality, and gauge structure) are expected to emerge at the effective-field level from the organization and coupling of these modes, rather than being imposed ad hoc at the fundamental level.

The framework is structurally falsifiable: the discovery of stable charged particles outside admissible windows, free quarks as asymptotic states, or the absence of neutrino oscillations would contradict its core selection rules. Future work will focus on quantitative calibration of temporal closure scales, sharper phenomenological predictions, and explicit mappings to quantum field theoretic and gravitational limits, but the results presented here already establish a nontrivial predictive ontology for why the observed particle spectrum is discrete, sparse, and bounded.

### A.1 Stability–Width Clustering from PDG Data

Using publicly available Particle Data Group (PDG) summary tables (2024 edition), we evaluated the dimensionless instability ratio  $R = \Gamma/m$  across known particles and resonances. Figure 2 plots  $\log(R)$  versus  $\log(m)$ , revealing pronounced clustering of stable particles at exceptionally low  $R$ , broad distributions for short-lived resonances, and clear gaps separating these regimes. In particular, no stable charged fermions appear below the electron mass, consistent with the absence of admissible non-null temporal eigenmodes below the first stability window in TSFT. These patterns arise without parameter tuning and provide independent empirical support for the temporal selection rules proposed here.

## References

- [1] Particle Data Group, *Review of Particle Physics* (annual editions; consolidated summaries and tables).
- [2] CERN, Official public documentation and experiment portals (ATLAS, CMS, ALICE, LHCb), <https://home.cern/>.
- [3] A. Einstein, “On the electrodynamics of moving bodies,” *Ann. Phys.* **17** (1905) 891–921.



Figure 2: Dimensionless instability ratio  $R = \Gamma/m$  versus mass  $m$  (PDG 2024). Stable particles cluster at low  $R$  (deep temporal attractors), while resonances occupy broad high- $R$  regions. The absence of stable charged fermions below the electron mass corresponds to a forbidden temporal band predicted by TSFT.

- [4] E. Noether, “Invariante Variationsprobleme,” *Nachr. d. König. Gesellsch. d. Wiss. zu Göttingen* (1918) 235–257.
- [5] P. A. M. Dirac, “The quantum theory of the electron,” *Proc. R. Soc. A* **117** (1928) 610–624.
- [6] E. C. G. Stueckelberg, “La signification du temps propre en mécanique ondulatoire,” *Helv. Phys. Acta* **14** (1941) 322–323.
- [7] E. C. G. Stueckelberg, “La mécanique du point matériel en théorie de relativité et en théorie des quanta,” *Helv. Phys. Acta* **15** (1942) 23–37.
- [8] J. A. Wheeler and R. P. Feynman, “Interaction with the absorber as the mechanism of radiation,” *Rev. Mod. Phys.* **17** (1945) 157–181.
- [9] Y. Kuramoto, *Chemical Oscillations, Waves, and Turbulence*, Springer (1984).
- [10] S. H. Strogatz, “From Kuramoto to Crawford: exploring the onset of synchronization in populations of coupled oscillators,” *Physica D* **143** (2000) 1–20.

- [11] J. Guckenheimer and P. Holmes, *Nonlinear Oscillations, Dynamical Systems, and Bifurcations of Vector Fields*, Springer (1983).
- [12] M. E. Peskin and D. V. Schroeder, *An Introduction to Quantum Field Theory*, Addison-Wesley (1995).
- [13] J. G. Farrell, “TSFT and Photon Propagation: Temporal Efficiency as a First Principle,” ZJUP author archive / preprint (2025).
- [14] J. G. Farrell, “TSFT and Electrons: Temporal Inertia, Eigenmode Stability, and Discrete Mass Emergence,” ZJUP author archive / preprint (2025).