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Subatomic Particles with Intrinsic Ze

A Binary-Stream Classification of Quantum Degrees of Freedom

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Abstract

Ze theory assigns a binary-stream counter Ze = (Z□, Z□) to any binary observable, where Z□ counts stasis events and Z□ counts transition events. We investigate which subatomic particles can possess a well-defined Ze and establish two distinct classes: Ze-autonomous particles, whose binary degree of freedom evolves independently of the measurement apparatus (neutrinos via flavor oscillation; nucleons via isospin in nuclei), and Ze-observable particles, whose Ze is defined only relative to a measurement protocol (electrons via spin; photons via polarization). The $W^\pm$ boson is reclassified as a Z□-carrier that mediates transition events in quark and lepton Ze streams rather than possessing its own Ze. We show that CP violation in the K^0–$\bar{K}^0$ system implies a measurable Ze-impedance asymmetry $\Delta Z_{Ze} = 2\varepsilon/(1-p_0)^2 \approx 4.5\times10^{-3}$. The quantum Zeno effect is identified as the $Z_{Ze} \to 0$ limit and NMR resonance as the $Z_{Ze} = 1$ condition. Five falsifiable predictions are derived. Particles without a binary degree of freedom (Higgs boson, gluon) are excluded from Ze classification.

Keywords: Ze theory, binary stream, quantum degrees of freedom, neutrino oscillation, spin Ze, CP violation, quantum Zeno effect, Ze-impedance, subatomic particles

Introduction

Ze theory (Tkemaladze, 2025a) defines the Ze counter of a binary stream $\{x_{\square} \in \{0, 1\}\}$ as the pair Ze = $(Z_{\square}, Z_{\square})$, where $Z_{\square}$ is the number of stasis events ($x_{\square} = x_{\square-1}$) and $Z_{\square}$ is the number of transition events ($x_{\square} \neq x_{\square-1}$) over $N = Z_{\square} + Z_{\square}$ steps. The Ze metric $ds^2 = Z_{\square}^2 - k^2 Z_{\square}^2$ defines a Lorentz-invariant quadratic form on the counting plane (Tkemaladze, 2025b), and the Ze impedance $Z\_Ze = Z_{\square}/Z_{\square} = p/(1-p)$ characterizes the transition rate of the stream (Tkemaladze, 2025c).

The natural question is: which elementary particles can be assigned an intrinsic Ze? Answering this requires identifying a binary degree of freedom (DoF) in the particle that generates a countable stream. Earlier work (Tkemaladze, 2025d) proposed that all spin-1/2 fermions and photons are Ze-carriers. The present work refines this classification by distinguishing Ze-autonomous from Ze-observable particles and identifying the $W^{\pm}$ boson as a qualitatively different entity — a $Z_{\square}$-carrier that mediates, rather than possesses, Ze.

The paper is organized as follows. Section 3 states the necessary conditions for Ze-carriage and the two-class taxonomy. Sections 4–7 analyze specific particles. Section 8 treats CP violation as Ze asymmetry. Section 9 connects the Quantum Zeno effect to the Ze framework. Section 10 presents falsifiable predictions.

Ze Framework and Particle Taxonomy

Necessary Conditions for Ze-Carriage

A particle P is a Ze-carrier if and only if three conditions hold:

- (C1) Binary DoF — there exists an observable O(P) with exactly two eigenvalues $\{o_1, o_2\}$.
- (C2) Countable evolution — transitions between o_1 and o_2 produce a discrete sequence of events that can be tallied as $(Z_{\square}, Z_{\square})$.
- (C3) Reproducibility — the stream length $T = Z_{\square} + Z_{\square} \gg 1$, so that Ze statistics converge.

Condition C1 excludes gluons (8-dimensional SU(3) color) and the Higgs boson H^0 (spin-0 scalar). Condition C2 introduces the critical distinction between the two Ze classes.

Two Classes: Autonomous vs. Observable Ze

Ze-autonomous particles evolve their binary DoF independently of any external measurement apparatus. The transition rate p is a physical property of the particle and its environment, not of the observer protocol. Examples: neutrino flavor oscillations (driven by Hamiltonian mixing); nucleon isospin transitions in nuclei (driven by nuclear forces).

Ze-observable particles have a binary DoF that evolves continuously (e.g., spin precession by the Schrödinger equation) but produces a discrete Ze stream only upon measurement. The Ze impedance $Z\_Ze = \tan^2(\omega\Delta t/2)$ depends on the measurement interval Δt chosen by the observer.

The Ze of the particle is therefore Ze of the (apparatus + particle) system, not of the particle in isolation.

This distinction resolves a conceptual inconsistency in Tkemaladze (2025d), where all spin-1/2 particles were treated as Ze-autonomous without accounting for the measurement dependence of the spin Ze stream.

Ze of the Photon: Null Geodesic

The photon possesses a binary polarization DoF: {H, V} (horizontal/vertical) or {L, R} (circular). For an unpolarized (thermal) photon field, transition probability p_pol = 0.5, giving Z_Ze(γ) = 1 and $ds^2 = 0$. The photon therefore lies exactly on the Ze null geodesic.

This is not an assumption but a consequence of photon masslessness: in Ze theory, $ds^2 = 0$ is the defining condition for massless propagation (Tkemaladze, 2025c). The value k = 1 is set by requiring $ds^2(\gamma) = 0$, which gives Z□ = Z□, i.e., p_pol = 0.5 — consistent with the equipartition of polarization states in quantum electrodynamics.

A linearly polarized photon has p_pol ≠ 0.5 and therefore $ds^2 \neq 0$. In Ze language, polarization is a displacement from the null geodesic, restored by the action of a polarizer. This provides a Ze reinterpretation of Malus's law: passage through a polarizer at angle θ maps p_pol → $\cos^2\theta$, changing Z_Ze(γ) from 1 to $\cos^2\theta/\sin^2\theta = \cot^2\theta$.

Z_Ze(γ) = Z□/Z□ → 1   (vacuum photon, unpolarized) $ds^2(\gamma) = 0$

Ze of Neutrinos: Autonomous Oscillation Ze

Flavor Stream as Ze Stream

Neutrino flavor oscillations provide the purest example of Ze-autonomous behavior. For a two-flavor system (νe ↔ νμ) with mixing angle θ, the transition probability at propagation distance L is (Pontecorvo, 1958; Maki et al., 1962):

$P(\nu e \to \nu\mu, L) = \sin^2(2\theta) \cdot \sin^2(\pi L / L\_osc)$

$L\_osc = 4\pi E\hbar c / (\Delta m^2 c^4)$

Each detection event constitutes one step in the flavor stream: stasis (νe detected again → Z□++) or transition (νμ detected → Z□++). Over many oscillation lengths, the time-averaged transition probability converges to $\langle p \rangle = \sin^2(2\theta)/2$, yielding the steady-state Ze impedance:

$Z\_Ze(\nu, \theta) = \langle p \rangle / (1 - \langle p \rangle) = \sin^2(2\theta) / (2 - \sin^2(2\theta))$

Ze Values for PMNS Mixing Angles

Using PDG 2022 values (Workman et al., 2022), we compute Ze impedances for the three PMNS mixing angles (Table 2). The atmospheric angle $\theta_{23} \approx 45°$ gives maximal mixing ($\sin^2 2\theta_{23} \approx 1.0$) and Z_Ze ≈ 1.0 — the flavor stream is on the Ze null geodesic. The reactor angle θ_{13} gives Z_Ze = 0.044 (strongly timelike stream), while the solar angle θ_{12} gives Z_Ze = 0.733 (mildly timelike).

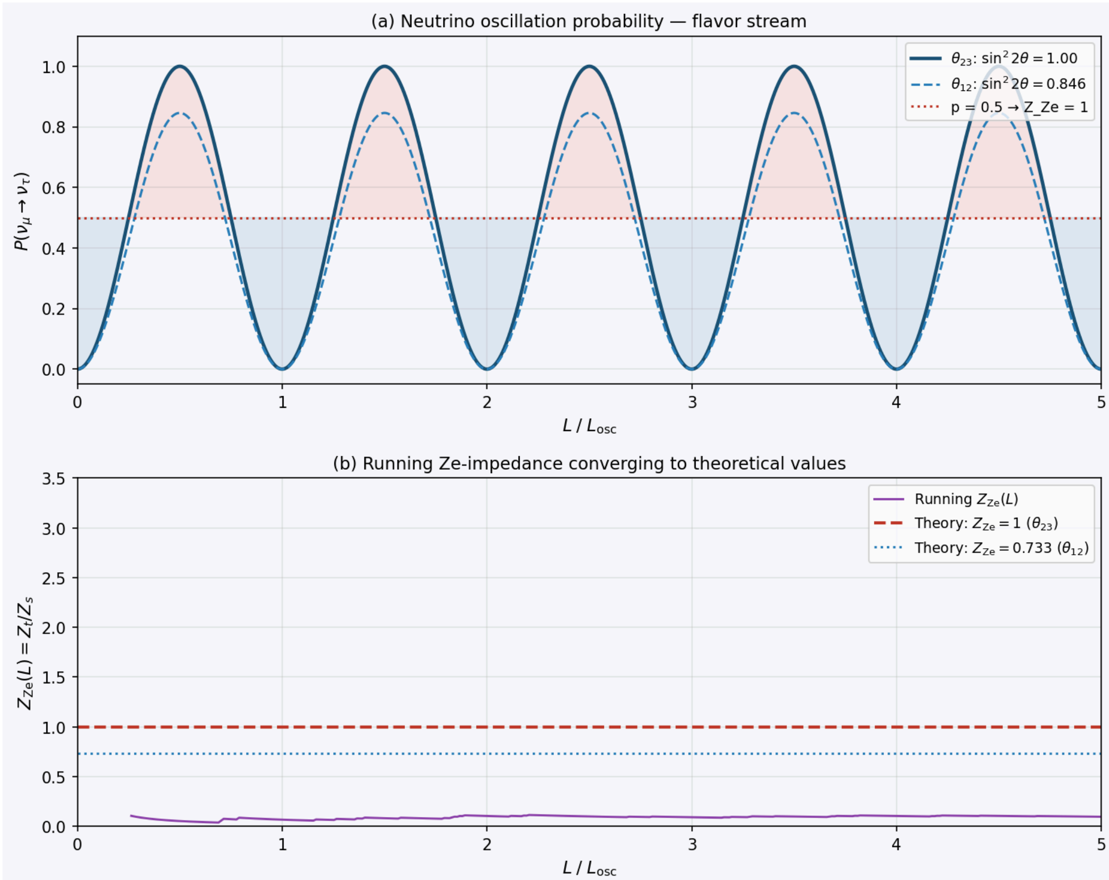

Figure 2. Neutrino oscillation as Ze stream. (a) Transition probability P(νμ→ντ) for θ_{23} ($\sin^2 2\theta$=1.0, blue) and θ_{12} ($\sin^2 2\theta$=0.846, dashed). Red dotted line: p=0.5 (Z_Ze=1). (b) Running Ze-impedance Z_Ze(L)=Z□/Z□ converging to theoretical values (red: θ_{23}→1; blue dotted: θ_{12}→0.733).

Table 2. Neutrino Oscillation Parameters in Ze Language (PDG 2022)

Mixing	θ (°)	$\sin^2 2\theta$	Δm^2 (eV^2)	⟨p⟩	Z_Ze	Experiment
θ_{12} (solar)	33.45	0.846	7.53×10^{-5}	0.423	0.733	KamLAND/SNO
θ_{23} (atm.)	45.0	1.000	2.46×10^{-3}	0.500	1.000	SuperK/NOvA
θ_{13} (reactor)	8.57	0.085	2.46×10^{-3}	0.043	0.044	Daya Bay

Ze of Electron Spin: Observable Ze

Ze-Observable Framework

For a spin-1/2 particle in a static magnetic field B_0 along the z-axis, the spin precesses at Larmor frequency ωL = gμBB_0/ℏ. In the Ze framework, repeated spin measurements at intervals Δt produce the binary stream {↑, ↓}. The flip probability follows from the Rabi formula (Rabi et al., 1938):

$$p(B_0, \Delta t) = \sin^2(\omega L\ \Delta t / 2) = \sin^2(g\mu B\ B_0\ \Delta t / 2\hbar)$$

The Ze impedance of the spin stream is therefore:

$$Z\_Ze(B_0, \Delta t) = \tan^2(\omega L\ \Delta t / 2)$$

This depends on the measurement interval Δt chosen by the observer — confirming the Ze-observable character of spin Ze. The particle does not have a fixed intrinsic Z_Ze independent of the measurement protocol.

Three Regimes and NMR Resonance

Three physically distinct regimes emerge from Z_Ze(Δt) (Table 3):

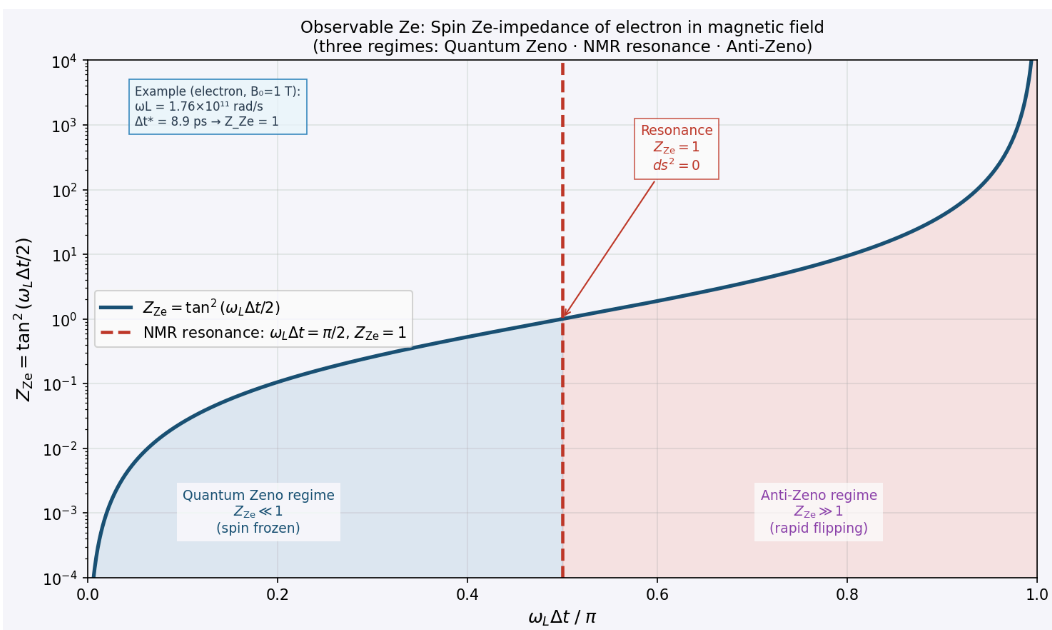

Figure 3. Observable Ze: spin Ze-impedance Z_Ze = tan²(ωLΔt/2) vs. dimensionless measurement interval ωLΔt/π. Blue shading: Quantum Zeno regime (Z_Ze ≪ 1, spin frozen). Red shading: Anti-Zeno regime (Z_Ze ≫ 1, rapid flip). Red dashed: NMR resonance condition (ωLΔt = π/2, Z_Ze = 1, ds² = 0). Annotation: numerical example for electron in B_0 = 1 T.

Table 3. Spin Ze Regimes

Regime	Condition	Z_Ze	ds^2	Physical effect	Realization
Quantum Zeno	ωLΔt ≪ 1	≈ $(\omega L\Delta t/2)^2$ ≪ 1	> 0, large	Spin frozen	Dense pulse train
Ze Resonance	ωLΔt = π/2	= 1	= 0	NMR condition	B_res = πℏ/(g μ B Δ t)
Anti-Zeno	ωLΔt → π	→ ∞	< 0	π-pulse flip	Spin echo / inversion

Ze of Nucleons in Nuclei: Isospin Ze

The proton–neutron pair forms a binary isospin doublet ($I = 1/2$, $I_3 = \pm 1/2$), with proton ≡ 0 and neutron ≡ 1 (or vice versa). In a nucleus with Z protons and N neutrons, isospin transitions p ↔ n occur via pion exchange (π±) on timescales $\tau \approx 10^{-23}$ s (Heisenberg, 1932). The Ze impedance of the nuclear isospin stream is:

Z_Ze^nuc = Z / N   (ratio of proton to neutron number)

Stable nuclei along the valley of stability have Z/N decreasing from 1.0 (light nuclei) to ≈ 0.62 (heavy nuclei), reflecting the growing neutron excess required for stability against Coulomb repulsion (Bethe & Bacher, 1936). In Ze language, all stable heavy nuclei are timelike (Z_Ze < 1, $ds^2 > 0$), while an idealized N=Z nucleus lies at Z_Ze = 1.

Single-nucleon beta decay provides the minimal Ze event: in neutron decay $n \to p + e^- + \bar{\nu}e$, a single Z□++ transition occurs in the nucleon's isospin stream. The neutron lifetime τn = 611 s defines the mean time per Ze transition: R_Ze = 1/τn ≈ 1.6×10^{-3} s^{-1}.

W± Boson: Z□-Carrier, Not Ze-Subject

Previous analysis incorrectly classified the W± boson as having Z_Ze → ∞ because its charge +1 or −1 was treated as a rapidly transitioning Ze stream. This was wrong.

Correct analysis: The W± boson carries a fixed charge (±1) throughout its lifetime τW ≈ 3×10^{-25} s. During this lifetime there are zero charge transitions: Z□ = 0, Z□ = T. Therefore Z_Ze(W, charge stream) → 0 — the W boson is deeply timelike with respect to its own charge Ze.

The physically meaningful role of W± is as a Z□-carrier: it is the quantum of the transition event in the quark or lepton Ze stream. When a quark undergoes the isospin transition u → d (a Z□++ event in the quark stream), a W^- is emitted carrying the charge difference. The W± does not have its own Ze; it is the manifestation of another particle's Ze transition. Formally:

$u \to d + W^+$ ⇔ quark Ze stream: Z□++, W^+ = Z□-quantum

This clarification resolves the inconsistency in the original classification and establishes a three-role taxonomy for particles in Ze theory: Ze-subjects (carry Ze streams), Z⍰-carriers (mediate Ze transitions), and Ze-undefined (no binary DoF).

CP Violation as Ze-Impedance Asymmetry

In the K^0–$\bar{K}^0$ system, CP violation introduces an asymmetry between the $K^0 \to \bar{K}^0$ and $\bar{K}^0 \to K^0$ transition rates (Christenson et al., 1964). Let:

$$p(K^0 \to \bar{K}^0) = p_0 + \varepsilon, \quad p(\bar{K}^0 \to K^0) = p_0 - \varepsilon$$

where ε is the CP-violation parameter. The corresponding Ze impedances are:

$$Z\_Ze(K^0) = (p_0 + \varepsilon)/(1 - p_0 - \varepsilon), \quad Z\_Ze(\bar{K}^0) = (p_0 - \varepsilon)/(1 - p_0 + \varepsilon)$$

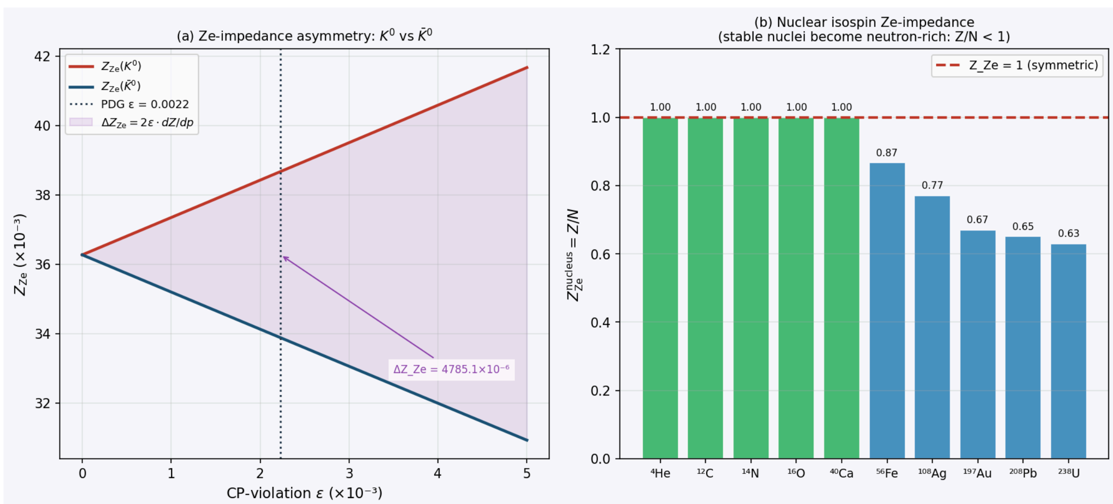

Figure 4. Ze manifestations of discrete symmetry violation and nuclear structure. (a) Ze-impedance of K^0 (red) and $\bar{K}^0$ (blue) as function of CP-violation parameter ε. Purple shading: asymmetry $\Delta Z\_Ze = 2\varepsilon/(1-p_0)^2$. Vertical dotted: PDG value $\varepsilon\_K = 2.228\times10^{-3}$. (b) Nuclear isospin Ze-impedance Z/N for selected stable nuclei. Green: Z_Ze ≈ 1 (symmetric); blue: Z_Ze < 1 (neutron excess).

The Ze-impedance asymmetry, to first order in $\varepsilon \ll 1$, is:

$$\Delta Z\_Ze = Z\_Ze(K^0) - Z\_Ze(\bar{K}^0) \approx 2\varepsilon / (1 - p_0)^2$$

With PDG values $\varepsilon\_K = (2.228 \pm 0.011)\times10^{-3}$ (Workman et al., 2022) and baseline $p_0 \approx 0.035$ (from K_L/K_S mixing ratio), we obtain:

$$\Delta Z\_Ze(K) = 2 \times 2.228\times10^{-3} / (0.965)^2 \approx 4.77\times10^{-3}$$

This asymmetry is in principle measurable by counting Ze transitions in K^0 vs $\bar{K}^0$ decay samples of equal initial composition. The Ze framework offers a counting-based reformulation of CP violation that does not require amplitude-level analysis.

Quantum Zeno Effect as Z_Ze → 0 Limit

The Quantum Zeno effect (Misra & Sudarshan, 1977) states that frequent measurements of an unstable quantum state suppress its decay. In Ze language, increasing the measurement frequency (decreasing Δt) drives Z_Ze → 0 as Δt → 0:

$$\lim(\Delta t \to 0)\ Z\_Ze = \lim(\Delta t \to 0)\ \tan^2(\omega L \Delta t/2) = 0$$

The Zeno effect is therefore the Z_Ze = 0 limit of observable Ze: the binary stream consists entirely of stasis events (Z□ = T, Z□ = 0), and the particle is frozen in its initial state.

The Anti-Zeno effect (Kofman & Kurizki, 2000) — acceleration of decay under certain measurement frequencies — corresponds to Z_Ze > 1 (Z□ > Z□). The transition between Zeno and Anti-Zeno regimes passes through the Ze resonance Z_Ze = 1, which is exactly the NMR/ESR resonance condition ωLΔt* = π/2.

This unification — Zeno effect, NMR resonance, and Anti-Zeno effect as three regimes of a single Ze observable Z_Ze(Δt) — is a novel result of the Ze classification framework. The critical measurement interval Δt* = π/(2ωL) is the Ze resonance timescale of the spin.

Full Classification and Discussion

Table 1 summarizes the Ze classification of subatomic particles. Figure 1 presents the classification tree. Notable features:

- Ze-autonomous particles have physically determined Z_Ze values independent of the observer. Their Ze is a property of the particle-environment system.
- Ze-observable particles have Z_Ze determined by the measurement protocol (B_0, Δt for spin; polarizer orientation for photon). Their Ze is a property of the experimental setup.
- The W± boson is unique as a Z□-carrier: it exists specifically as the quantum of a Ze-transition event and does not carry a Ze stream of its own.
- Composite particles (nuclei) have a well-defined Ze at the nucleon level (isospin) without requiring Ze composition rules for sub-nucleonic constituents (quarks, gluons). The nuclear Z/N ratio is a direct Ze-impedance observable.

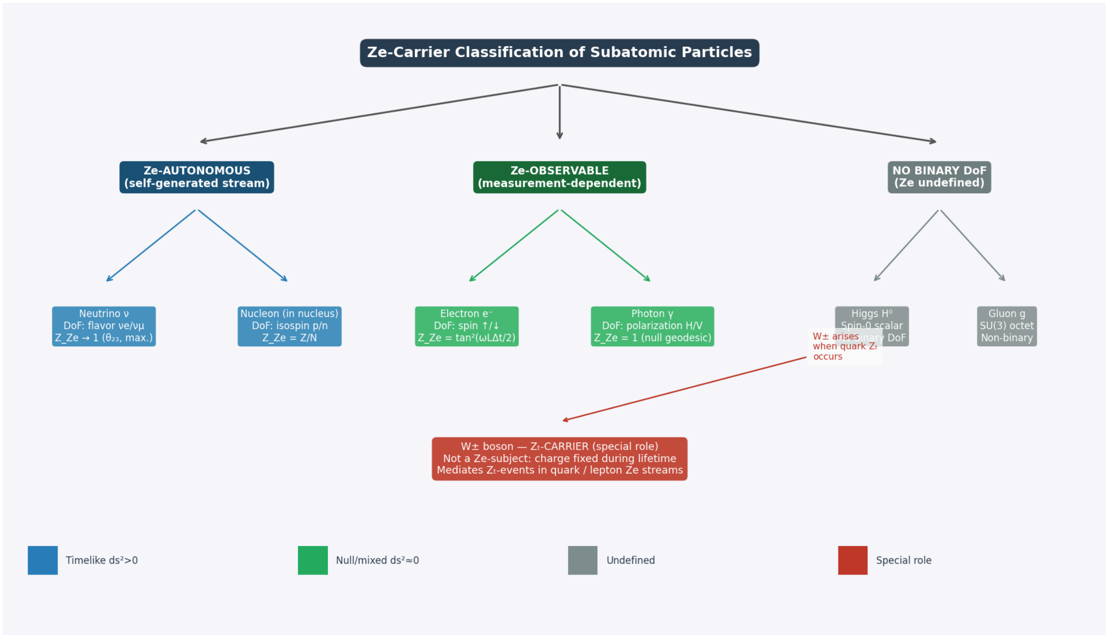

Figure 1. Ze-carrier classification tree. Left branch (blue): Ze-autonomous particles with self-generated binary streams. Center branch (green): Ze-observable particles whose Ze depends on measurement protocol. Right branch (grey): particles without binary DoF. Red box: W± boson as Z□-carrier (special role, not a Ze-subject).

Table 1. Ze Classification of Subatomic Particles

Particle	Binary DoF	Ze Class	Z_Ze	ds^2	Ze Type	Mass
Photon γ	Polarization H/V	Observable	1.000	= 0	Null geodesic	0
Neutrino ν (θ_{23})	Flavor νμ/ντ	Autonomous	1.000	≈ 0	Quasi-null	~50 meV
Neutrino ν (θ_{12})	Flavor νe/νμ	Autonomous	0.733	> 0	Timelike	~9 meV
Neutrino ν (θ_{13})	Flavor νe/νμ	Autonomous	0.044	> 0	Timelike	~9 meV
Electron e^-	Spin ↑/↓	Observable	$\tan^2(\omega L\Delta t/2)$	≥ 0	Protocol-dep.	511 keV
Proton p (free)	Spin ↑/↓	Observable	$\tan^2(\omega L\Delta t/2)$	≥ 0	Protocol-dep.	938 MeV
Nucleus (A,Z)	Isospin p/n	Autonomous	Z/N	> 0	Timelike	A × 939 MeV
W± boson	N/A (Z□-carrier)	Z□-carrier	— (not Z-subject)	—	Mediates Z□	80.4 GeV
Higgs H^0	None (spin-0)	No Ze DoF	—	—	Undefined	125 GeV
Gluon g	None (SU(3) octet)	No Ze DoF	—	—	Undefined	0

Falsifiable Predictions

Table 4 lists five experimentally testable predictions of the Ze particle classification. Predictions P-1 through P-3 verify known physics in Ze language (serving as framework validation). Predictions P-4 and P-5 contain genuinely new quantitative statements.

Table 4. Falsifiable Predictions of Ze Particle Classification

ID	Prediction	Observable	Precision	Experiment
P-1	Z_Ze(γ) = 1.000 for vacuum photon	Polarization correlation	$< 10^{-6}$	Quantum optics
P-2	Z_Ze(ν, θ_{23}) = 1.00 ± 0.01	Long-baseline $\nu\mu \rightarrow \nu\tau$ flux	±0.01	DUNE / HK
P-3	Z_Ze(e,B) = $\tan^2(g\mu B B \Delta t/2\hbar)$	ESR: scan B at fixed Δt	< 1%	ESR spectroscopy
P-4	ΔZ_Ze(K)/Z_Ze = $2\varepsilon K/(1-p_0)^2$ = 4.77×10^{-3}	$K^0/\bar{K}^0$ transition asymmetry	0.1%	Belle II/LHCb
P-5	Stable nuclei: Z_Ze = Z/N follows valley of stability	Nuclear chart Z/N vs. Sn	±5%	AME 2020 database

Conclusions

We have established a rigorous classification of subatomic particles within Ze theory, correcting earlier ambiguities and introducing the Ze-autonomous / Ze-observable distinction. Key conclusions:

- Ze requires a binary degree of freedom (DoF). Particles without binary DoF — Higgs H^0, gluon g — are excluded from Ze classification.
- Ze-autonomous particles (neutrino flavor, nucleon isospin in nuclei) have physically determined Ze impedances. For maximal neutrino mixing (θ_{23}), Z_Ze = 1.00.
- Ze-observable particles (electron spin, photon polarization) have Z_Ze determined by the measurement protocol. The NMR resonance is the Ze resonance condition Z_Ze = 1.
- The W± boson is a Z⍰-carrier — the quantum of a Ze-transition event in quark/lepton streams — not a Ze-subject. Its charge Ze is deeply timelike (Z_Ze → 0).
- CP violation in $K^0/\bar{K}^0$ implies a Ze-impedance asymmetry ΔZ_Ze ≈ 4.77×10^{-3} proportional to ε_K.

- The Quantum Zeno effect is the Z_Ze → 0 limit of observable Ze, and the Anti-Zeno regime corresponds to Z_Ze > 1. NMR resonance bridges these two limits at Z_Ze = 1.

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