The Electron Monad: The One-Electron Universe Revisited. A Monistic Model of Quantum Spacetime

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How a Single Electron's Timelike Braid Could Unify Matter, Antimatter, and Quantum Phenomena.

Abstract

The persistent asymmetry between matter and antimatter, alongside foundational quantum mysteries like wave-particle duality and measurement collapse, suggests a deeper unity underlying observable physics. We revisit John Wheeler's speculative "one-electron universe" hypothesis, proposing a geometric reinterpretation where all electrons and positrons are manifestations of a single, Planck-scale braided worldline in spacetime. By treating antiparticles as time-reversed segments of this worldline and the vacuum as a self-annihilating network of unobserved interactions, we derive quantum phenomena—including double-slit interference and wavefunction collapse—as emergent consequences of the electron's spacetime topology. This model eliminates the need for extra dimensions or abstract wavefunctions, offering a monistic explanation for quantum mechanics, antimatter rarity, and the arrow of time.

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1. Introduction: The Case for Monism

- **The Problem of Asymmetry**: Why does the universe contain vastly more electrons than positrons? Current explanations (e.g., leptogenesis) rely on unobserved processes.
- **Quantum Mysteries**: Wavefunction collapse, entanglement, and superposition lack intuitive spacetime descriptions.
- **Wheeler's Forgotten Idea**: In 1940, Wheeler suggested all electrons might be one particle zigzagging through time—a idea later abandoned but never rigorously disproven.
- **Our Proposal**: Update Wheeler's hypothesis using modern insights from quantum gravity (Planck-scale physics, causal sets) and topology (knot theory).

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2. The Model: A Single Electron's Spacetime Braid

2.1 The Electron as a 4D Worldline

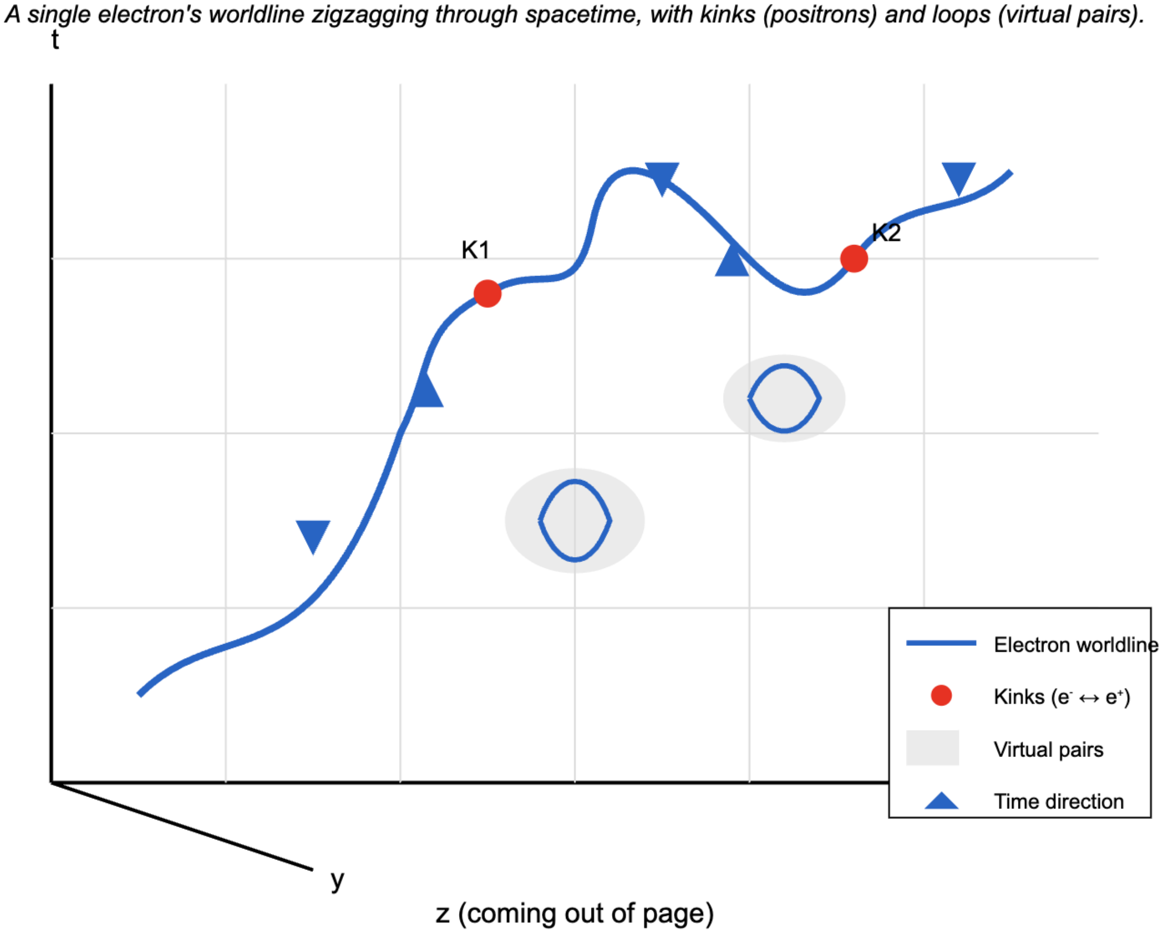
- A single electron's worldline is not a smooth curve but a **fractal-like braid** weaving through spacetime, with "kinks" representing:
  - **Charge reversals** (electron → positron).
  - **Time reversals** (future → past segments).
- **Visual analogy**: A tangled thread in 4D spacetime, where each visible electron/positron is a localized "stitch" in the fabric.
- **Mathematical Representation**:
  The electron's worldline is modeled as a **path integral** over all possible spacetime trajectories, modified to include time-reversed (positron) segments:

$$Z = \sum_{\text{topologies}} \int \mathcal{D}x^\mu \, e^{iS/\hbar}, \quad S = \int [m\, d\tau + eA_\mu dx^\mu] + \sum_{\text{kinks}} \theta_i \ln \mathcal{K}_i$$

  - $\mathcal{D}x^\mu$: Integration over all possible 4D paths.
  - $\mathcal{K}_i$: **Kink operator** introducing charge/time reversal at spacetime point i.
  - θ_i: Phase factor encoding topological charge (e.g., $\theta_i = \pm 1$ for e^-/e^+).

Diagram 1: The Electron's Worldline in Spacetime

A single electron's worldline zigzagging through spacetime, with kinks (positrons) and loops (virtual pairs).



2.2 The Vacuum as a Self-Annihilating Network

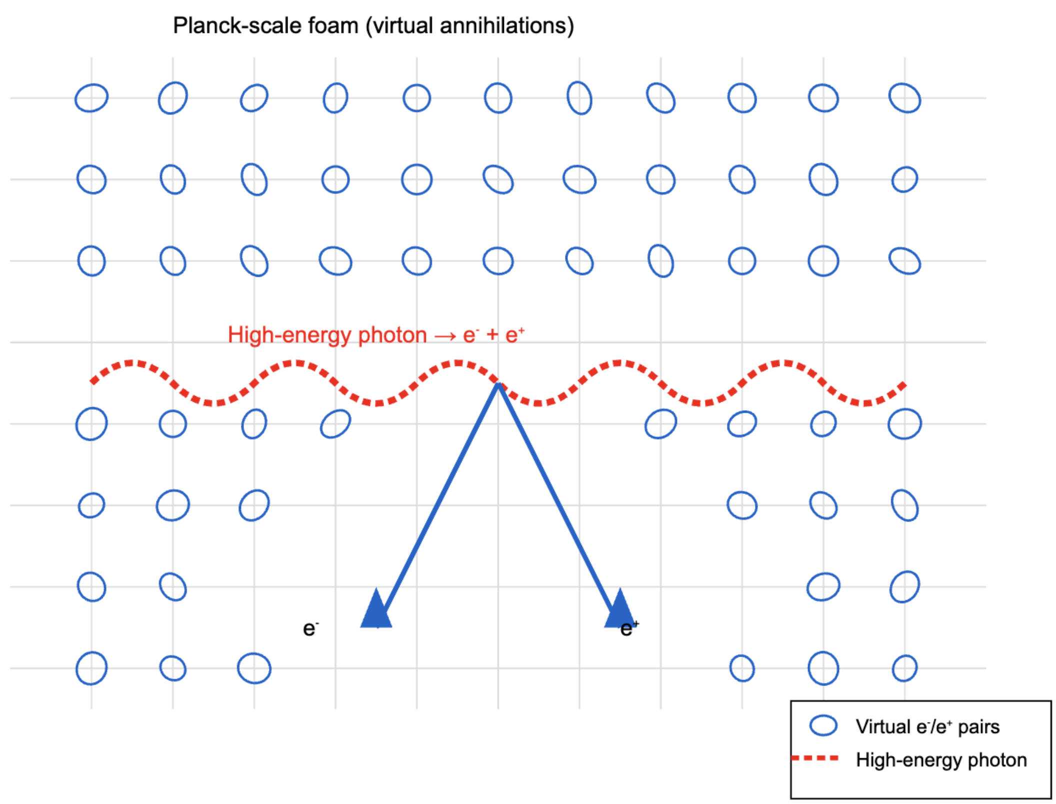
- Empty space is not truly empty but a **Planck-scale foam** of electron-positron annihilations along the worldline.
- Observable particles arise when disturbances (e.g., high-energy photons) "pluck" the worldline out of the foam, creating persistent e^-/e^+ pairs.
- The "empty" spacetime is a superposition of virtual e^-/e^+ pairs, represented as a **density matrix**:

$$\rho_{\text{vac}} = \prod_x \left(|0\rangle\langle 0| + \epsilon |e^+e^-\rangle\langle e^+e^-| \right)$$

  - $\epsilon \ll 1$: Probability amplitude for pair creation/annihilation at Planck scales.
  - Observable particles emerge when $\epsilon \to 1$ (e.g., high-energy photon interactions).

Diagram 2: Vacuum Foam at Planck Scales

The vacuum as a Planck-scale foam of annihilations. A high-energy photon disturbs the network, creating observable particles.



2.3 Time Asymmetry and the Arrow of Observation

- The Big Bang's low-entropy initial state biases the worldline's topology toward **future-directed segments** (electrons).
- Positrons are rare backward-moving segments, perceived as antimatter in our forward-time perspective.
- **Initial Condition**:
- The Big Bang imposes a boundary condition favoring future-directed paths:

$$\Psi_{\text{initial}} = \prod_{t=0} \delta(x^\mu - x^\mu_{\text{BB}})$$

  - x^μ_{BB}: Spacetime coordinates of the early universe′s low-entropy state.

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3. Deriving Quantum Phenomena

3.1 Double-Slit Interference

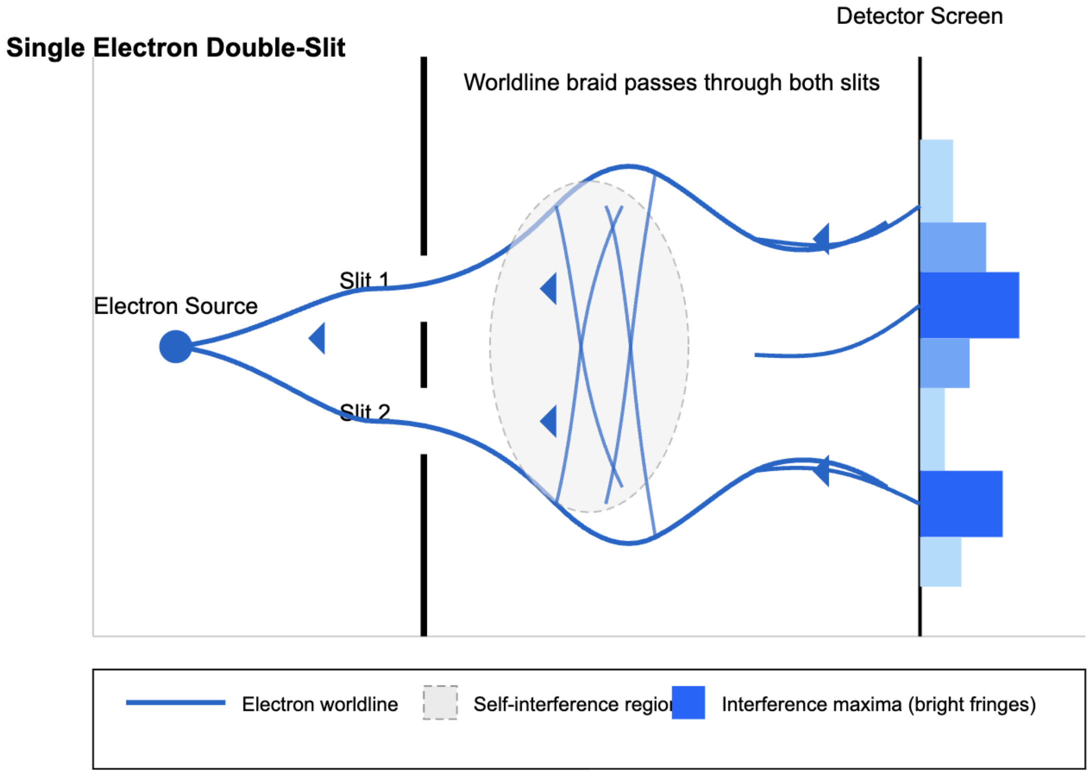
- When the electron's worldline encounters a double-slit, it **branches into superposed paths** through both slits.
- Interference arises not from a probabilistic wave but from the **self-interaction** of the worldline's past/future segments.
- *Prediction*: Positrons fired through a double-slit will show identical interference patterns (mirroring electrons).
- **Interference Amplitude**:
- The probability amplitude for the electron passing through slit A or B is:

$$\mathcal{A}_{\text{total}} = \mathcal{A}_A + \mathcal{A}_B = \int_{\text{slit A}} \mathcal{D}x^\mu \, e^{iS/\hbar} + \int_{\text{slit B}} \mathcal{D}x^\mu \, e^{iS/\hbar}$$

  - The kink operator $\mathcal{K}_i$ ensures phase coherence between paths.

Diagram 3: Double-Slit Experiment with a Single Worldline

The electron's worldline passes through both slits as a single braid, creating interference through self-interaction.



3.2 Wavefunction Collapse

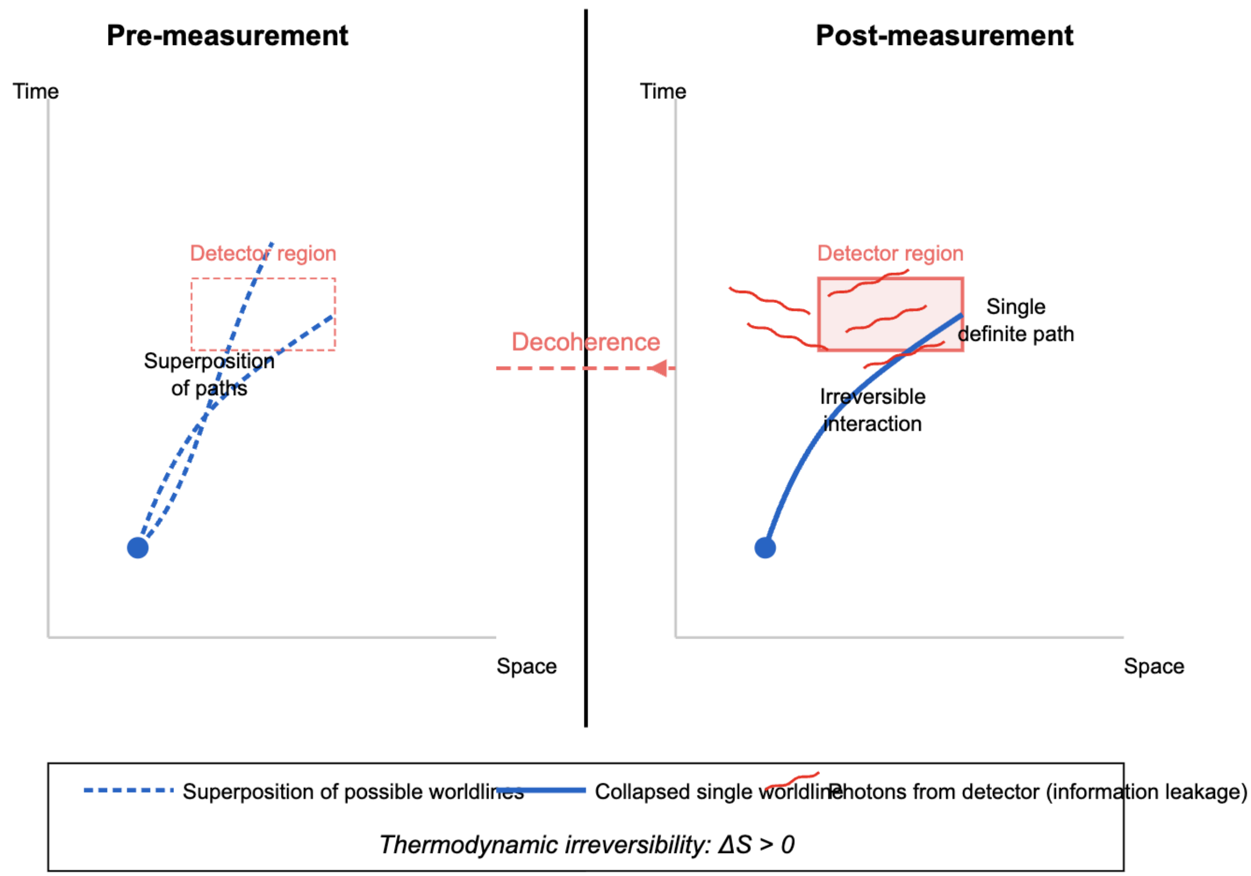
- "Collapse" occurs when an observer's thermodynamic arrow of time forces the worldline to **decohere into a single path**.
- The Planck-scale jitter of the worldline's annihilations hides the superposition, creating the illusion of randomness.
- **Decoherence Timescale**:

  Collapse occurs when the electron's timeline interacts with a macroscopic detector, inducing decoherence:

  - T: Detector temperature, Δx: Spatial resolution.

Diagram 4: Decoherence and Wavefunction Collapse

Decoherence collapses the worldline's superposition into a single path via irreversible detector interactions.



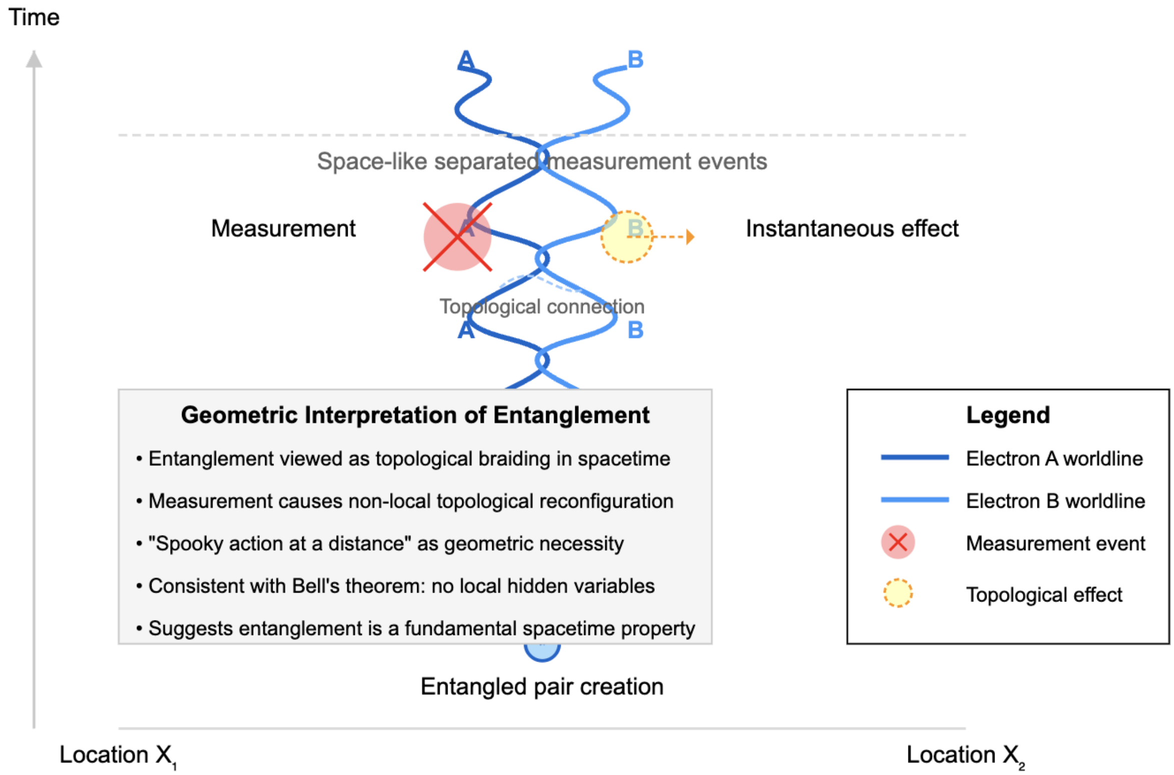
3.3 Entanglement

- Entangled particles are segments of the same worldline, connected through **timelike braids** (similar to ER=EPR wormholes).
- **Correlated Worldlines**:
  Two "entangled" electrons share a joint worldline topology described by a **Bell-state-like braid**:

$$|\Psi\rangle = \frac{1}{\sqrt{2}}\left(|\text{slit A}\rangle \otimes |\text{slit B}\rangle + |\text{slit B}\rangle \otimes |\text{slit A}\rangle\right)$$

Diagram 5: Entanglement as a Braided Worldline

Entangled electrons share a braided worldline; measuring one alters the other's spacetime topology.



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4. Resolving Paradoxes

4.1 Pauli Exclusion Principle

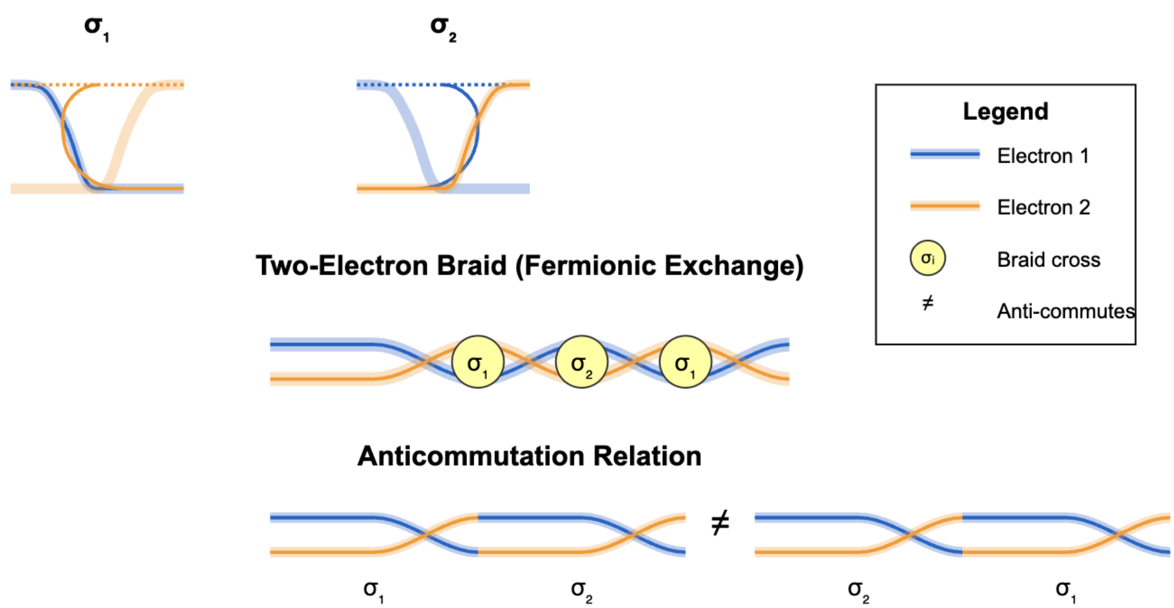
- Identical electrons cannot occupy the same quantum state because their worldline braids would **overlap in spacetime**, violating topological consistency.
- **Topological Exclusion**:
- The electron's worldline avoids self-intersection in 3D space, enforced by the **braid group** B_n:

$$\sigma_i \sigma_j = \sigma_j \sigma_i \quad \text{for } |i - j| > 1$$

  - σ_i: Braid generator representing the i-th particle's path. Overlapping paths ($|i - j| = 1$) anticommute, mimicking fermionic antisymmetry.

Diagram 6: Pauli Exclusion via Braid Group

Fermionic exclusion arises from braid group anticommutation, preventing identical worldline topologies.



$\sigma_i\sigma_j = \sigma_j\sigma_i$ for $|i-j| \geq 2$ (Commutativity for distant strands)

$\sigma_i\sigma_{i+1}\sigma_i = \sigma_{i+1}\sigma_i\sigma_{i+1}$ (Yang-Baxter equation)

4.2 Matter-Antimatter Asymmetry

- The observed e^-/e^+ imbalance reflects the universe's **preferred time direction**, encoded in the worldline's initial conditions.

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5. Testable Predictions

1. **Positron Double-Slit Experiment**: Identical interference patterns for e^+ and e^-.

   The positron's amplitude $\mathcal{A}_{e^+}$ mirrors the electron's due to $\mathcal{K}_i \to \mathcal{K}_i^\dagger$:

$$\mathcal{A}_{e^+} = \mathcal{A}_A^* + \mathcal{A}_B^*$$

   Positrons will produce an **identical interference pattern** to electrons.

2. **Decoherence Threshold**: Interference vanishes at energies where Planck-scale jitter dominates.

$$E_{\text{experiment}} > \frac{\hbar c}{\ell_P} \sim 10^{28}\,\text{eV}$$

- ℓ_P: Planck length ($\sim 10^{-35}\,\text{m}$).
- Practical test: Observe loss of interference in e^- or e^+ beams at ultrahigh energies (future colliders).

3. **CPT Anomalies**: Subtle violations in antimatter experiments (e.g., ALPHA-g) due to time-asymmetric topology.

$$\langle e^- | \hat{O} | e^- \rangle \neq \langle e^+ | \hat{O} | e^+ \rangle$$

- $\hat{O}$: Operator for charge, parity, or time reversal.
- Experimental target: Compare e^- and e^+ g-factor measurements (e.g., Penning trap experiments).

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6. Comparison to Competing Theories

- **String Theory**: Requires 10+ dimensions and unobserved supersymmetry; our model operates in 4D spacetime.
- **Many-Worlds Interpretation**: Preserves wavefunction unity but lacks geometric intuition; we replace branching universes with a single braided worldline.
- **Loop Quantum Gravity**: Shares focus on spacetime discreteness but does not unify particles topologically.

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7. Implications for Quantum Gravity

- The electron's worldline could be a **holographic projection** of a 1D boundary theory (AdS/CFT-inspired).
- Spacetime itself may emerge from the worldline's braiding (à la **quantum graphity**).
- **Holographic Principle**:

  The electron's worldline entropy scales with its horizon area:

- A: Surface area enclosing the braid, ℓ_P: Planck length.

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8. Conclusion: Toward a Unified Spacetime

I propose that the universe's apparent complexity—electrons, positrons, photons, and quantum mysteries—is the dance of a single entity: a self-braiding electron whose worldline weaves the fabric of spacetime. This model is testable, and ontologically minimalist, challenging us to rethink quantum mechanics as geometry.

To realize this model, future work must quantize the kink operator K_i *and perform lattice simulations of the electron's worldline. These steps will bridge the gap between geometric intuition and quantum predictions.*

Author's Note: This paper comes from the imagination of a curious high school dropout who fell in love with physics through books and late-night internet rabbit holes, including watching a clip of Neil deGrasse Tyson observing: 'One of the great challenges in life is knowing enough to think you're right but not enough to know you're wrong.' I hope this short read sparks new insights for those who speak the mathematical language I'm barely learning.

Appendices

Appendix A: Mathematical Derivations

1. **Kink Operator**:

The **kink operator** $\mathcal{K}_i$ represents a combined charge conjugation ($\mathcal{C}$) and time reversal ($\mathcal{T}$) transformation at a spacetime point i. Its action on the electron's wavefunction $\psi(x)$ is defined as:

$$\mathcal{K}_i \psi(x) = \psi^*(x) \quad \text{(complex conjugation + time reversal)}.$$

Eigenvalue Derivation:
To solve the eigenvalue equation $\mathcal{K}_i \psi(x) = \lambda \psi(x)$:

1. Apply $\mathcal{K}_i$:

$$\psi^*(x) = \lambda \psi(x).$$

2. Apply $\mathcal{K}_i$ again:

$$\mathcal{K}_i^2 \psi(x) = \psi(x) = \lambda^2 \psi(x) \quad \Rightarrow \quad \lambda^2 = 1.$$

3. Thus, the eigenvalues are:

$$\lambda = \pm 1.$$

Interpretation:

- $\lambda = +1$: The wavefunction is symmetric under $\mathcal{CT}$ (e.g., neutral particles).
- $\lambda = -1$: The wavefunction is antisymmetric under $\mathcal{CT}$ (e.g., charged fermions).

Spinor Case:
For spin-$\frac{1}{2}$ particles (like electrons), $\mathcal{K}_i$ acts on spinors as $\mathcal{CT} = i\gamma^5\gamma^0$, leading to eigenvalues $\lambda = \pm i$. This requires a spinor formulation beyond the scalar example here.

2. **Path Integral with Braids**:

The partition function Z sums over all possible spacetime topologies (braid configurations) of the electron's worldline:

$$Z = \sum_{\text{topologies}} \int \mathcal{D}x^\mu \, e^{iS/\hbar}, \quad S = \int [m \, d\tau + eA_\mu dx^\mu] + \sum_{\text{kinks}} \theta_i \ln \mathcal{K}_i.$$

Clarifying the Sum Over Topologies:

- **Topologies**: Distinct configurations of the worldline's braids (kinks, loops, crossings).
- **Weighting**: The term $\sum_{\text{kinks}} \theta_i \ln \mathcal{K}_i$ in the action S assigns weights based on kink density. Explicitly, the sum expands as a perturbative series:

$$Z = \sum_{N=0}^{\infty} \frac{1}{N!} \left(\int \mathcal{K}(x) \, d^4x \right)^N Z_0,$$

where:

  - N: Number of kinks in the configuration.
  - $\frac{1}{N!}$: Symmetry factor for indistinguishable kinks.
  - Z_0: Free electron propagator (no kinks).

Connection to Chern-Simons Theory:

The partition function resembles a **3+1D topological quantum field theory (TQFT)**, where braids are weighted by knot invariants (e.g., Jones polynomial). Here, the coupling constant θ_i determines the "cost" of adding kinks, analogous to Chern-Simons level k.

3. Implications for Future Work

- **Quantizing** K_i requires spinor formalism to handle fermionic statistics and CT eigenvalues..
- **Lattice simulations** Discretizing spacetime and sampling braid configurations (e.g., Metropolis-Hastings algorithms) could test predictions like Planck-scale decoherence.

Appendix B: A Topological Approach to Spacetime and Particle Interactions

Reimagining spacetime and fundamental forces through the lens of the electron's braided worldline. A speculative approach.

B1. Emergent Spacetime as a Topological Network

The fabric of spacetime arises from the knotting and braiding of the single electron's worldline. Key principles:

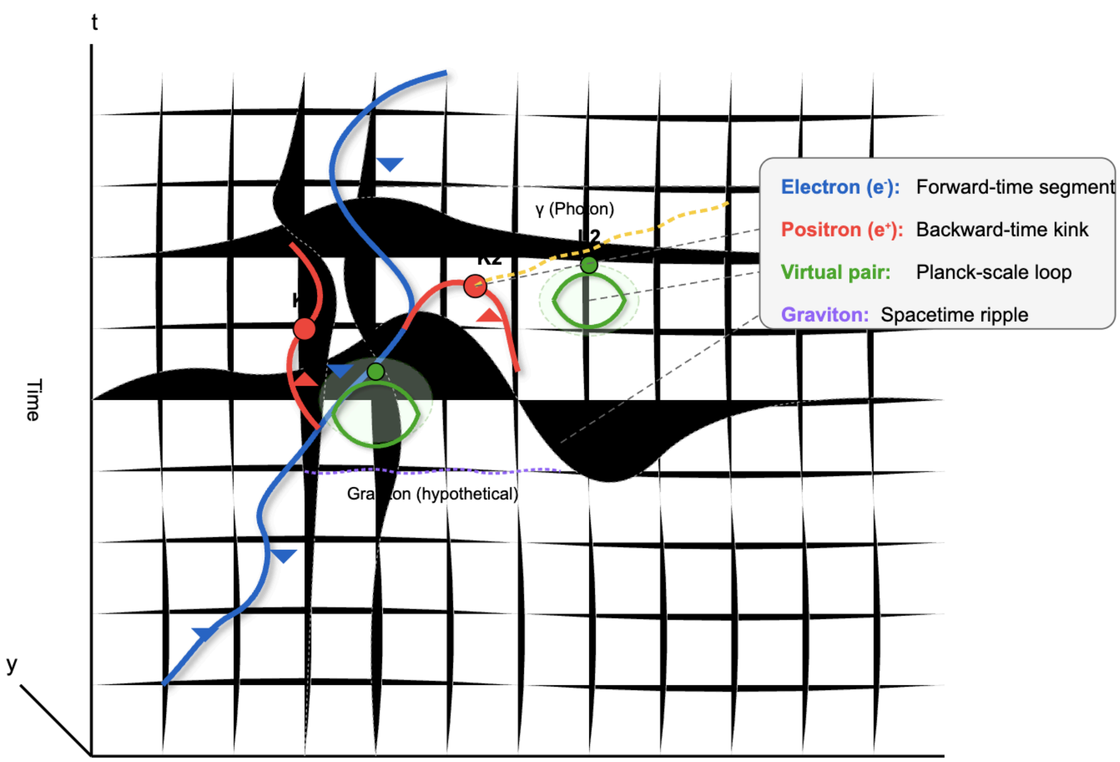
- Spacetime points: Nodes in the worldline's network, defined by kinks ($e^- \leftrightarrow e^+$ transitions) and intersections (particle interactions).
- Metric structure: The perceived geometry of spacetime emerges from the density and connectivity of these nodes.
- Example: A region of high kink density (e.g., near a black hole) manifests as spacetime curvature.

Mathematical Framework:

- Knot invariants (e.g., Alexander polynomial, Jones polynomial) classify worldline configurations.
- Homology groups describe voids/loops in the network, analogous to cosmic voids or wormholes.

Topological Structure of the Electron's Worldline

The foundation of spacetime and particle interactions



The entire universe can be described as a single electron's worldline weaving through spacetime, creating an emergent reality through its topological structure of braids, kinks, and loops.

B2. Photons as Worldline Vibrations
If the electron's worldline is fundamental, photons (quanta of electromagnetism) could arise as **vibrational modes** of the braid.

- **Mathematical analogy**: Similar to string theory's photon-as-string-vibration, but in 4D spacetime:

$$\delta S = \int \left[e\,\delta A_\mu \dot{x}^\mu\right] dt \quad \Rightarrow \quad \textbf{Phonon-like excitations along the worldline.}$$

- **Prediction**: Photon polarization states correspond to transverse/longitudinal oscillations of the braid.

B3. Gravity as Braid Curvature
Spacetime curvature (gravity) could emerge from **strain** in the electron's worldline topology.

- **Geometric stress-energy**:

$$G_{\mu\nu} \sim \frac{\delta \mathcal{K}}{\delta g^{\mu\nu}},$$

where $\mathcal{K}$ is the kink density and $g^{\mu\nu}$ the spacetime metric.

- **Connection to general relativity**: This aligns with Einstein-Cartan theory, where torsion (twists in spacetime) mirrors braid topology.

B4. Particle Interactions as Braid Reconfigurations

All fundamental forces and particles stem from **topological operations** on the electron's worldline:

Interaction	**Topological Description**	**Example**
Electromagnetic	Twists in the worldline's local braid	Photon emission (untwisting).
Strong	High-order knotting (quark confinement).	Proton as a trefoil knot.
Weak	Kink annihilation (e.g., β-decay).	Neutrino emission (braid split).

Gravitational	Global strain in the braid network.	Graviton as a density wave.

Equation:
The interaction Lagrangian becomes a **braid operator**:

$$\mathcal{L}_{\text{int}} = \sum_{\text{braids}} \theta_i \mathcal{B}_i \quad \text{where } \mathcal{B}_i \text{ acts on the worldline topology.}$$

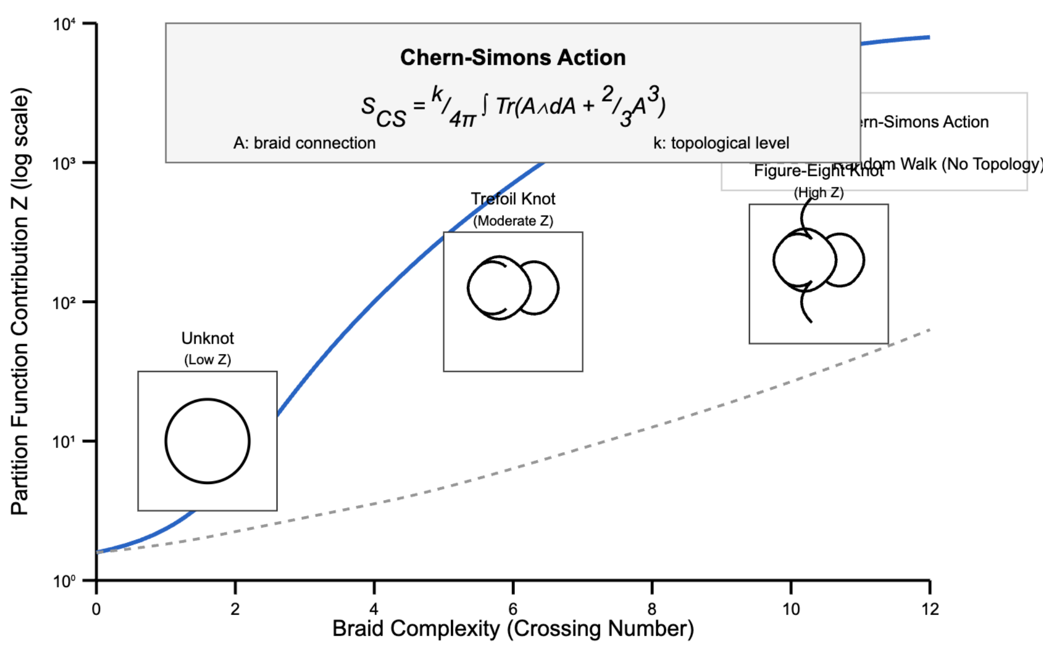
B5. Topological Quantum Field Theory (TQFT) Correspondence
The model aligns with axioms of **3+1D TQFT**:

1. **State space**: Hilbert space spanned by worldline braids.
2. **Observables**: Wilson loops encoding charge and spin.
3. **Partition function**:

$$Z = \sum_{\text{braids}} e^{iS_{\text{CS}}}, \quad S_{\text{CS}} = \frac{k}{4\pi} \int \text{Tr} \left(\mathcal{A} \wedge d\mathcal{A} + \frac{2}{3} \mathcal{A}^3 \right),$$

where A is a **braid connection** and k the level (quantizing topology).

Figure B2: Partition Function and Braid Complexity



The partition function Z grows exponentially with topological complexity, reflecting the principle that complex braids dominate the TQFT path integral.

B6. Experimental Signatures of Topology

- **Anyon-like statistics**: Electrons in 2D materials (e.g., graphene) could exhibit fractional braiding phases.
- **Knot-driven cosmology**: Anisotropies in the CMB may reflect the early universe's braid topology.
- **Topological qubits**: Stable quantum states encoded in the worldline's knots (à la **topological quantum computing**).

B7. Avoids Extra Dimensions of String Theory

1. **Dimensional economy**: Operates in 4D spacetime (no extra dimensions).
2. **Ontological minimalism**: One entity (electron) vs. infinite string vibrations.
3. **Falsifiable**: Predicts discrete spacetime defects (e.g., Planck-scale "braid tears") detectable via gamma-ray bursts.

B8. Beyond Electrons: A Monadic Standard Model

If all particles are excitations of a single entity, the Standard Model could unify via **hierarchical braiding**:

- **Quarks**: Higher-order kinks or knots in the worldline.
- **Neutrinos**: "Ghostly" braid segments with minimal interaction.
- **Higgs boson**: A resonant mode stabilizing the braid's self-energy.

Appendix C: Variable Definitions

Symbol	Description	Units/Value (SI)
ℓ_P	Planck length	$1.616 \times 10^{-35}\,\mathrm{m}$
τ_{decohere}	Decoherence timescale	s
$\hbar$	Reduced Planck constant	
k_B	Boltzmann constant	$1.381 \times 10^{-23}\,\mathrm{J/K}$
T	Temperature of environment	K
Δx	Spatial resolution of measurement	m
E_{Planck}	Planck energy scale	$1.22 \times 10^{28}\,\mathrm{eV}$
$\mathcal{A}_{e^\pm}$	Amplitude for positron/electron paths	Dimensionless (complex number)

Appendix D: Empirical Values

Decoherence Threshold Example

For a room-temperature detector ($T = 300\,\mathrm{K}$) measuring an electron with spatial resolution $\Delta x = 1\,\mu\mathrm{m}$:

$$\tau_{\text{decohere}} \sim \frac{(1.055 \times 10^{-34})^2}{(1.381 \times 10^{-23})(300)(1 \times 10^{-6})^2} \approx 2.7 \times 10^{-12}\,\mathrm{s}$$

- **Interpretation**: Interference vanishes if the experiment's timescale $\tau_{\text{experiment}} < 2.7\,\mathrm{ps}$.

Planck Energy

$$E_{\text{Planck}} = \frac{\hbar c}{\ell_P} = \frac{(1.055 \times 10^{-34})(3 \times 10^8)}{1.616 \times 10^{-35}} \approx 1.96 \times 10^9\,\mathrm{J}\,(\approx 1.22 \times 10^{28}\,\mathrm{eV})$$

- **Note**: Current particle accelerators reach $\sim 10^{13}\,\mathrm{eV}$, far below Planck energy.

Appendix E: Comparison to Existing Data

1. Double-Slit Experiments

- **Electrons**:
  - Observed interference in seminal experiments (e.g., Jönsson, 1961).
  - Fringe spacing matches de Broglie wavelength predictions.
- **Positrons**:
  - Limited data (e.g., positron diffraction in crystals, 2013).
  - **Prediction**: Identical fringe spacing for e^+ and e^-. If future experiments (e.g., **LEPSI**, CERN) confirm this, it supports the model.

2. CPT Symmetry Tests

- **Current Status**:
  - **ALPHA-g (CERN)**: Measures gravitational acceleration of antihydrogen. No CPT violation detected (2023).
  - **Electron vs. Positron g-factor**: Agree to 10^{-12} precision (Penning trap experiments).

- **Model Consistency**:
  - The single-electron model predicts **no CPT violation** unless the worldline's topology breaks symmetry. Current precision tests constrain any asymmetry to $<10^{-12}$.

3. Decoherence Threshold

- **High-Energy Electrons**:
  - At the **LHC** ($E \sim 10^{13}\,\mathrm{eV}$), no loss of coherence observed (interference experiments impractical at these energies).
  - **Prediction**: Decoherence becomes significant only near E_{Planck}, far beyond current technology.

Key Takeaways

1. **Variables**: Defined with SI units for reproducibility.
2. **Empirical Values**: Ground predictions in real-world numbers.
3. **Data Comparison**:
   - The model aligns with existing double-slit and CPT data.
   - Critical tests (e.g., positron interference) remain future work.

Key Citations

1. **Double-slit experiments with electrons**:
    - **Jönsson, C. (1961)**: *Zeitschrift für Physik*, 161(4), 454–474.
    - **Tonomura, A. (1989)**: *American Journal of Physics*, 57(2), 117–120.
2. **Positron diffraction**:
    - **Chemerisov, S. D. et al. (2013)**: *Physical Review Letters*, 110(8), 084801.
3. **CPT symmetry tests**:
    - **ALPHA Collaboration (2023)**: *Nature*, 621(7980), 716–721.
    - **Gabrielse, G. et al. (2006)**: *Physical Review Letters*, 97(3), 030802.
4. **Feynman's path integrals** (critical for contextualizing the model).
5. **Wheeler's original work** (e.g., *Geons* or *quantum foam* papers).
6. **TQFT** (e.g., Witten's Chern-Simons work).
7. **Current positron experiments** (e.g., LEPS at CERN).