Photon and Neutrino in Holographic Spacetime: A Tale of Broadcast and Isolation

Bhushan poojary
bhushanpoojary@gmail.com
NIMS University

Abstract
This paper explores a novel distinction between photons and neutrinos based on their interaction with spacetime fabrics in a holographic universe [1][2]. While photons are known to propagate universally and act as carriers of information across intersecting holographic layers, we propose that neutrinos traverse a distinct and isolated spacetime fabric. Unlike photons, which copy and broadcast their quantum state to multiple observers and regions, neutrinos retain their state within a localized domain, only interacting when another particle's spacetime address aligns precisely with their own. This framework explains the elusive nature of neutrinos, their weak interaction cross-section, and their negligible role in quantum entanglement. By introducing the concept of "holographic address resonance," we provide a new geometric basis for understanding weak interactions, neutrino oscillations [5][6], and the possible link between hidden sectors and the structure of spacetime. The proposed model complements existing interpretations of the Standard Model while opening avenues for a deeper unification of quantum mechanics and spacetime geometry.

Introduction

The Standard Model of particle physics successfully classifies elementary particles and their interactions, yet certain fundamental questions remain unresolved—among them, the peculiar behavior of neutrinos. Neutrinos possess extremely small masses, exhibit minimal interaction with matter, and yet play essential roles in nuclear processes, cosmology, and possibly dark sector physics. Despite their abundance, neutrinos appear to exist on the edge of observability, interacting only via the weak nuclear force [5][6] and evading detection in all but the most sensitive instruments.

In contrast, photons—the gauge bosons of electromagnetism—are ubiquitous in both classical and quantum phenomena. Photons readily interact with charged particles [8][9], propagate freely through spacetime, and serve as the primary mediators of information across space and time. In quantum mechanics, photons play a central role in measurement, decoherence, and entanglement, seemingly copying and broadcasting quantum states across different regions and observers [9].

This paper proposes that the core distinction between these two particles lies not merely in their mass or interaction type, but in the very **fabric of spacetime through which they travel** [1][2][3]. We hypothesize that photons propagate through a shared, universal holographic spacetime fabric—one that permits quantum states to be reflected and copied across multiple domains. Neutrinos, by contrast, travel in an **isolated spacetime layer**, a distinct geometric domain with minimal overlap with the visible universe. In this framework, interaction occurs only when another particle shares or resonates with the same "holographic address (This address can be interpreted as an encoding of a particle's trajectory, internal quantum numbers, and curvature interaction with spacetime—akin to a dynamic tag in a fiber bundle over spacetime.)," explaining both the weak nature of neutrino interactions and their limited participation in quantum information transfer.

In the following sections, we develop this hypothesis formally, building upon the concept of holographic address space introduced in prior work [15]. We explore its implications for neutrino oscillation, weak force locality, and the broader question of how spacetime structure might encode the rules of particle interaction.

2. Holographic Spacetime and Information Propagation

In recent theoretical frameworks, particularly those inspired by the holographic principle, spacetime is no longer viewed as a continuous, uniform backdrop but rather as a discretized or layered information manifold [1][3][4]. Each point in spacetime may carry a unique "holographic address," representing the encoded state of physical degrees of freedom at that location. This interpretation naturally allows for a geometrization of interaction—particles may not merely move through spacetime but selectively interact based on overlapping or matching address structures.

2.1 The Holographic Address Space

We define a **holographic address** as a unique, multidimensional coordinate in a complexified or curved spacetime fabric. This address may involve real spatial-temporal coordinates along with imaginary components that encode curvature [12][13], entanglement potential, or quantum phase information. In this setting, all particles acquire such an address, but not all particles **broadcast** it.

Photons, due to their role as carriers of electromagnetic force, interact with the curvature and topology of spacetime in a delocalized way. They propagate along geodesics that intersect multiple holographic planes [3][9], thereby **broadcasting their quantum state** across different layers. This aligns with their observable role in quantum measurement, interference, and entanglement phenomena, where information about one region of spacetime becomes accessible from another.

2.2 Local vs. Broadcast Information Propagation

We propose a distinction between **broadcast-type** and **localized-type** information propagation:

Property	**Photon (Broadcast)**	**Neutrino (Localized)**
Spacetime Interaction	Intersects many holographic layers	Constrained to its own isolated layer
Quantum State Behavior	Copied/reflected across multiple regions	Retained within a private trajectory

Property	Photon (Broadcast)	Neutrino (Localized)
Role in Measurement	Facilitates collapse and observation	Weakly observable unless spacetime addresses align
Entanglement Potential	Central to quantum nonlocality	Rare or domain-specific entanglement

This difference may account for the photon's dominance in mediating information and observation, while neutrinos act more as **hidden travelers** [5]—existing across the cosmos but perceptible only when an intersection with matter occurs in the right geometric configuration.

2.3 A Geometric Condition for Interaction

We hypothesize the following condition for neutrino interaction:

A neutrino interacts with matter only when another particle's holographic address matches (or resonates with) the neutrino's isolated trajectory through its specific spacetime layer.

This resonance condition is rare, explaining the exceptionally small cross-section of neutrinos. In contrast, photons effectively lack such a constraint—they always interact with charged particles because the electromagnetic field is universally projected across holographic layers.

Such a geometric reinterpretation of interaction challenges traditional views of force carriers and suggests a deeper **substrate of spacetime connectivity** [10][11] beneath the Standard Model—one in which photons act as open channels and neutrinos as closed circuits requiring precise alignment.

3. Neutrino Isolation and the Geometry of Weak Interactions

Neutrinos are among the most enigmatic particles in the Standard Model. Despite their abundance—they stream through every square centimeter of Earth in vast numbers every second—their interactions with matter are extraordinarily rare. Traditional explanations attribute this behavior to the weakness of the interaction mediated by W and Z bosons. However, within the holographic spacetime framework, we propose a geometric origin for this rarity: **neutrinos exist within an isolated spacetime fabric, and their ability to interact depends on a precise geometric condition of address overlap**.

3.1 The Isolated Trajectory Hypothesis

Building on the holographic address space concept, we propose that each neutrino flavor propagates not through the general four-dimensional spacetime alone but along a **specialized submanifold**—a curved, possibly fractal or imaginary component [13][14] of spacetime that is decoupled from the regions where electromagnetic and strong interactions dominate.

In this model, the **trajectory of the neutrino is not globally visible**; it does not reflect or project its state onto surrounding holographic layers. Instead, it travels silently, retaining its quantum state and interacting only when **another particle's holographic path intersects this hidden sublayer**.

This idea explains the following:

- Why neutrinos **pass through vast amounts of matter without scattering**.
- Why they are **not primary agents of entanglement or measurement collapse**.
- Why detecting them requires **immense detectors and precise geometric conditions** (e.g., long-baseline neutrino experiments).

3.2 Weak Force as Resonant Address Coupling

In the conventional model, weak interactions are short-range and mediated by massive bosons ($W^{\pm}$, Z^{o}), which limits the interaction range [7][10]. We reinterpret this as follows:

Weak force interactions occur only when a holographic resonance condition is met—when the holographic addresses of a neutrino and a target particle coincide or geometrically overlap within a bounded region.

This condition may be formalized as:

$$A_v(t) \cap \ A_x(t) \ \neq \ \emptyset \ \rightarrow interaction\ occurs$$

Where:

- $A_v(t)$ is the time-evolving address trajectory of the neutrino,
- $A_x(t)$ is the corresponding path of another particle,
- $\emptyset$ the intersection implies a shared geometric locality within the hidden fabric.

The **short range** of weak interactions could then be seen as a **consequence of minimal address overlap probability**, rather than the boson mass alone.

3.3 Neutrino Oscillation as Address Drift

Neutrino oscillation—where one flavor transforms into another during flight—can also be viewed geometrically. In this framework, flavor is not merely a quantum state but reflects the **type of submanifold** a neutrino traverses.

Thus:

- **Oscillation corresponds to a drift or transition between adjacent holographic layers [1][14]**, each associated with a different flavor.

- The probability of detecting a particular flavor at a location becomes a function of how that flavor's address layer overlaps with the detector's domain.

This interpretation provides a new geometric view of neutrino oscillation:

$$P(v_\alpha \rightarrow v_\beta) \propto O_{\alpha\beta}(t)$$

Where $O_{\alpha\beta}(t)$ is the overlap function between address layers α and β as a function of time or distance.

4. Comparison with the Standard Model and Experimental Hints

The Standard Model of particle physics successfully describes the known fundamental particles and their interactions using quantum fields. Neutrinos, within this framework, are fermions that participate only in the weak nuclear force, mediated by W and Z bosons, and are known to oscillate between flavors due to mass differences and quantum mixing.

While this description is experimentally robust, it leaves several open questions:

- Why are neutrino masses so small?
- Why do they interact so rarely?
- Why do they not participate significantly in entanglement or measurement-based phenomena, unlike photons or electrons?

Our **holographic spacetime interpretation** does not contradict the Standard Model but proposes a **geometric substrate** beneath it [3][11]—a deeper explanation for these features by interpreting weak interactions and neutrino behavior [5][6] as arising from **address-based constraints in a layered or curved spacetime**.

4.1 Alignment with Standard Observables

Observable	**Standard Model Interpretation**	**Holographic Interpretation**
Weak Interaction Rarity	Due to short-range force and small coupling constants	Due to low probability of holographic address overlap
Neutrino Oscillations	Caused by quantum mass eigenstate mixing [6]	Caused by transition between different spacetime layers
Neutrino Mass	Extremely small, origin unknown	Mass arises as a curvature property of the isolated fabric

Observable	Standard Model Interpretation	Holographic Interpretation
Photon Universality	Interacts with all charged particles	Due to its propagation across all holographic layers
Photon in Entanglement	Enables state transfer and observation	Because it copies state across overlapping spacetime domains

This reinterpretation adds an **ontological structure** beneath the field-theoretic behavior: interactions occur not just because of force carriers, but because of **spacetime geometry alignment**.

4.2 Experimental Hints and Testable Consequences

Though speculative, this model suggests some intriguing testable hints:

1. **Directional Interaction Bias**: If neutrinos exist in a specific curved spacetime sublayer, detectors might show slightly **anisotropic interaction rates** depending on Earth's orientation or motion through spacetime fabric.

2. **Coherence vs. Isolation in Entanglement**: Photons facilitate entanglement between distant systems; neutrinos do not. This suggests **neutrinos cannot serve as entanglement mediators**—a hypothesis that could be tested in future quantum field experiments involving weak interactions [8][9].

3. **Decoupling in the Early Universe**: The cosmic neutrino background decoupled earlier than the CMB. If neutrinos inhabit isolated spacetime layers, this **decoupling could be a geometric separation**, not merely thermal.

4. **Long-Baseline Experiments**: Neutrino oscillations over long distances could reflect **underlying geometric transitions**, and deviations from standard mixing patterns [6][10] might hint at **curvature or topological changes in the neutrino's path**.

5. **Neutrino Imaging vs. Photon Imaging**: Photons allow for electromagnetic imaging across space. Neutrino detection requires direct intersection. The impossibility of "neutrino optics" reflects the **non-broadcast nature** of their trajectory [5].

5. Conclusion and Future Directions

In this paper, we have proposed a geometric reinterpretation of neutrinos and photons grounded in the concept of **holographic address space**. While photons are shown to broadcast their quantum state across multiple intersecting layers of spacetime—enabling entanglement, measurement, and universal interaction—neutrinos are seen as **isolated travelers**, confined to a distinct and hidden spacetime fabric.

Their rare interactions, weak coupling, and limited entanglement potential are not solely consequences of quantum field parameters, but rather a result of **non-overlapping spacetime addresses**.

By introducing the idea of **holographic resonance conditions**, we shift the basis of interaction from being purely field-based to being **geometry-based**—a perspective that could open new avenues for understanding not just neutrinos but all weakly interacting particles, including potential candidates in the dark sector. This framework also offers a reinterpretation of neutrino oscillations as address transitions between layered submanifolds, further embedding flavor transformation into the fabric of spacetime itself.

Though speculative, this approach qualitatively aligns qualitatively with experimental observations and provides several avenues for testable predictions. It encourages a rethinking of the Standard Model's structure from a **flat field-based interaction map** to one built atop **layered, resonant geometries**, perhaps reflecting a deeper unifying substrate that connects quantum mechanics, information theory, and spacetime topology.

Future Work

This preliminary formulation opens several exciting directions for future research:

- **Mathematical Formalism**: Developing a rigorous geometric model of holographic address space using tools from complex differential geometry, fiber bundles, or non-commutative spacetime models.
- **Simulation of Address-Based Interaction**: Creating toy models that simulate resonance conditions between different address layers and predict interaction probabilities.
- **Extension to Other Particles**: Exploring whether similar isolation mechanisms apply to other elusive particles, such as axions or sterile neutrinos.
- **Relation to Quantum Gravity**: Investigating how this framework interfaces with loop quantum gravity, twistor theory, or string-theoretic brane worlds [10][11][12].
- **Entanglement Boundaries**: Studying how this address-based framework limits or enables entanglement across domains—especially in black hole information paradox or cosmological inflation models.

Funding

This research received no external funding.

References

1. Holographic Principle and Spacetime Geometry

1. G. ’t Hooft, “Dimensional Reduction in Quantum Gravity,” *arXiv:gr-qc/9310026* (1993).

2. L. Susskind, “The World as a Hologram,” *Journal of Mathematical Physics*, **36**, 6377–6396 (1995).

3. Raphael Bousso, “The Holographic Principle,” *Reviews of Modern Physics*, **74**, 825 (2002).

4. Brian Greene, *The Hidden Reality*, Chapters on holographic theories and layered spacetime (2011).

2. Neutrino Physics and Oscillations

5. C. Giunti and C. W. Kim, *Fundamentals of Neutrino Physics and Astrophysics*, Oxford University Press (2007).

6. Z. Maki, M. Nakagawa, and S. Sakata, “Remarks on the Unified Model of Elementary Particles,” *Prog. Theor. Phys.*, **28**, 870 (1962). (PMNS matrix origin)

7. K. Nakamura et al. (Particle Data Group), “Review of Particle Physics,” *J. Phys. G: Nucl. Part. Phys.*, **37**, 075021 (2010). (use for neutrino properties)

3. Quantum Entanglement and Measurement

8. Wojciech H. Zurek, “Decoherence, einselection, and the quantum origins of the classical,” *Rev. Mod. Phys.*, **75**, 715–775 (2003).

9. S. Haroche and J.-M. Raimond, *Exploring the Quantum*, Oxford University Press (2006). (Measurement and photon involvement)

4. Spacetime and Field Geometry

10. N. Arkani-Hamed, J. Maldacena, “Cosmological Collider Physics,” *arXiv:1503.08043* [hep-th].

11. Roger Penrose, *The Road to Reality*, Sections on twistor theory and complexified spacetime (2004).

12. H. B. Nielsen and M. Ninomiya, “Complex Action, Prearrangement for Future, and Higgs Broadening,” *arXiv:hep-ph/0612032*.

5. Complex Spacetime and Fractal Geometry (optional additions)

13. M. B. Mensky, “Continuous quantum measurements and path integrals,” *Physics-Uspekhi*, **41**(9), 923–940 (1998).

14. Laurent Nottale, *Fractal Space-Time and Microphysics: Toward a Theory of Scale Relativity*, World Scientific (1993).

15. B. Poojary, “Holographic Address Space: A Framework for Unifying Quantum Mechanics and General Relativity,” TSI Journals (2025). https://www.tsijournals.com/articles/holographic-address-space-a-framework-for-unifying-quantum-mechanics-and-general-relativity.pdf