Developing a Two-Component Time Concept to Unify General Relativity and Quantum Mechanics

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Abstract

The long-standing incompatibility between general relativity and quantum mechanics stems largely from one of the most fundamental conceptual barriers in theoretical physics: the conflicting nature of time. In general relativity, time is non-independent and dynamically curved alongside space by gravitational fields, whereas in quantum mechanics, time operates as an invariant, external parameter completely independent of underlying physical fields. Rather than claiming a complete unified field theory, this paper directly resolves this foundational temporal deadlock by introducing a two-component time framework that decomposes time into two interlocking layers: Global Time ($\boldsymbol{t}$) and Proper Time ($\boldsymbol{\tau}$). Global Time serves as an invariant, uniform background parameter governing quantum state evolution, while Proper Time represents the localized, dynamic clock rate that tilts and curves with spacetime geometry. By deriving the intrinsic "temporal thickness" ($\boldsymbol{\Delta t}$) of physical particles directly from the de Broglie matter wave, this dual-temporal structure bridges the static temporal background required by quantum mechanics with the curved temporal coordinate of general relativity. Furthermore, we demonstrate that the continuous connection of particle "temporal tails" provides a non-perturbative geometric mechanism for quantum superposition and explains the violation of Bell's inequality in quantum entanglement without superluminal signaling.

Keywords: Two-component time, Global time, Proper time, Temporal thickness, General relativity, Quantum mechanics

1 Introduction

General relativity (GR) and quantum mechanics (QM) constitute the twin pillars of modern theoretical physics. Despite their immense empirical successes within their respective domains of the macro-cosmos and the subatomic world, the persistent mathematical and conceptual contradictions between these two frameworks remain the most formidable barrier to achieving a unified theory of physics. At the absolute center of this structural impasse—widely recognized as the "problem of time" in quantum gravity [1, 2]—lies a profound, irreconcilable incompatibility regarding the nature and operational definition of time.

In the framework of general relativity, time is treated dynamically as an intrinsic coordinate dimension integrated within the pseudo-Riemannian four-dimensional spacetime manifold [3]:

- Spacetime geometry is coupled directly to the local stress-energy tensor, causing the manifold to curve under the influence of gravitational fields.
- Consequently, time loses any absolute status, manifesting instead through localized coordinate transformations and physical time dilation effects experienced by observers in different gravitational potentials or relative states of motion [4].

In stark contrast, quantum mechanics structuralizes time as a fixed, absolute background parameter completely external to the physical system under observation [5]:

- Quantum time flows uniformly, continuously, and deterministically, operating entirely independent of local matter distributions or energy states.
- Within standard canonical quantization procedures, time acts strictly as a continuous evolution parameter for the state vector in Hilbert space; it is not a Hermitian operator and cannot be treated as an observable subject to quantum quantization or uncertainty relations.

This profound dichotomy implies that resolving the structural incompatibility between GR and QM cannot be achieved via standard perturbative quantization of the metric tensor alone. Instead, it demands a fundamental reformulation of the paradigm of time itself. Such a conceptual restructuring must remain mathematically compatible with the field equations of general relativity and the unitary evolution operators of quantum mechanics, while simultaneously providing testable physical mechanisms for phenomena predicted across both domains.

To bridge this foundational gap, this article introduces the rigorous construction of a two-component concept of time extracted directly from the phase envelope of the fundamental de Broglie matter wave [6]. Rather than treating time as a single, indivisible scalar, we mathematically decouple temporal evolution into two simultaneous, interlocking parameters: an absolute cosmic baseline (Global Time) and a localized dynamical rate (Proper Time).

As demonstrated in the subsequent sections, this dual-temporal geometry not only naturally reconciles the conflicting definitions of time in GR and QM, but its application also offers novel, non-perturbative explanations for phenomena that have long remained deeply mysterious, including the non-local mechanism of quantum entanglement and the physical geometric origins of inertial mass and momentum [7].

2 Formulation of a New Concept of Time

2.1 Proving the Temporal Thickness of a Physical Object

To establish a mathematically rigorous foundation for the structuralization of time, we begin by auditing the foundational kinematic parameters of the de Broglie matter-wave hypothesis [6]. For a physical excitation possessing a localized relativistic mass m and moving at an operational velocity v within the background spatial manifold, its characteristic de Broglie wavelength λ is governed by the standard quantum relation:

$$\lambda = \frac{h}{mv}, \tag{1}$$

where h denotes the Planck constant. Concurrently, under localized rest conditions ($v = 0$), the total systemic rest energy E_0 of the excitation dictates a non-vanishing intrinsic frequency f_0 through the Einstein–de Broglie relations:

$$E_0 = m_0 c^2 = h f_0 \Longrightarrow f_0 = \frac{m_0 c^2}{h}. \tag{2}$$

By conducting a comparative physical analysis of Eq. (1) and Eq. (2), we deduce two critical mathematical insights that invalidate classical localized point-particle assumptions:

- **Non-Mechanical Wave Propagation:** The de Broglie matter wave does not conform to the kinematic constraints of a classical mechanical wave. For a standard mechanical wave propagating through a physical medium, the relationship between frequency, phase velocity v_{ph}, and wavelength is tightly bounded by $f = v_{\text{ph}}/\lambda$. If matter waves strictly mirrored this mechanical formulation, a particle brought to relative rest ($v \to 0$) would cause its wave frequency to completely vanish ($f \to 0$). However, because the intrinsic de Broglie rest frequency in Eq. (2) remains invariant and strictly non-zero, the oscillation cannot be modeled as an external perturbation of a medium. Given that this frequency depends exclusively on the invariant rest mass m_0, it demonstrates that the quantum wave function originates fundamentally from the *intrinsic, localized geometric oscillation of the particle's own matter structure* along a hidden spatial or temporal depth [7].
- **Wavelength Divergence at Spatial Rest:** According to Eq. (1), the de Broglie wavelength is strictly inversely proportional to the spatial coordinate velocity. As the excitation approaches the absolute kinematic boundary ($v \to c$), the wavelength contracts toward its spatial minimum. Conversely, when the particle is brought to absolute spatial rest ($v \to 0$), the spatial wavelength λ mathematically approaches infinity ($\lambda \to \infty$) [7].

This mathematically derived infinite wavelength at zero coordinate velocity carries profound geometric implications. It indicates that an elementary excitation at spatial rest acts equivalently to a macroscopic spring oscillating simultaneously across an infinite spatial span with an infinite phase velocity. This behavior can be structuralized via descriptive mechanical and membrane models:

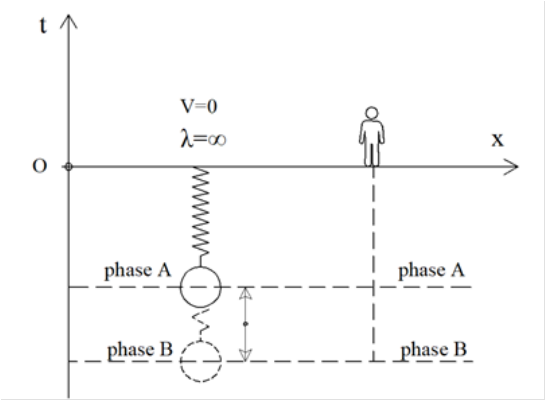


Fig. 1 Mechanical analogy modeling an oscillating particle as a spring, behaving as a standing wave characterized by an infinite phase velocity along the localized coordinate system [7].

Extending this conceptual visualization to the pseudo-Riemannian geometry of general relativity [3]—where the three-dimensional spatial manifold is traditionally modeled as a continuous elastic rubber sheet—the excitation can be mapped as a localized structural deformation executing a uniform vertical oscillation:

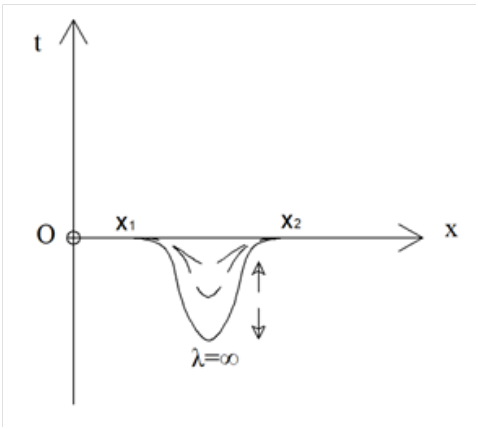


Fig. 2 Relativistic membrane model representing a fundamental excitation as a continuously vibrating rubber membrane, yielding an equivalent standing waveform with an infinite phase velocity across local spatial coordinates [7].

This geometric reinterpretation of de Broglie oscillations fundamentally changes our understanding of particle localization. Because a standing wave with an infinite phase velocity distributes its oscillation phase uniformly across the space coordinate background, a physical particle cannot be localized within a zero-dimensional point along a one-dimensional temporal trajectory. Instead, the particle's physical matter density is distributed deeply along the temporal dimension. We define this intrinsic physical metric as the *temporal thickness* (or temporal depth) of the object [7]. Just

as length, width, and height define an object's spatial parameters, temporal thickness constitutes an intrinsic, non-zero physical dimension characterizing the structural existence of all matter configurations.

Operationally, the portion of a particle's matter density extending into the immediate local past forms its structural temporal thickness, which bounds its localized *Proper Time*. For a fundamental fermion, this temporal depth is geometrically structured via localized phase boundaries:

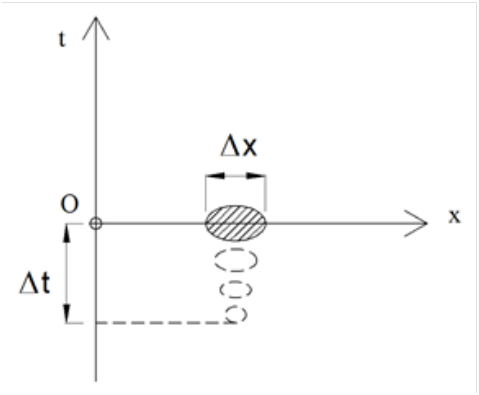


Fig. 3 Geometric configuration and boundary envelope mapping the structural temporal thickness (Δt) of a fundamental fermion within the spacetime manifold [7].

Mathematically, since the intrinsic rest oscillation completes one full phase cycle over its characteristic period $T_0 = 1/f_0$, the baseline temporal thickness Δt of an elementary fermion with rest mass m_0 is bounded by its Compton temporal scale:

$$\Delta t = \frac{1}{f_0} = \frac{h}{m_0 c^2}. \tag{3}$$

Crucially, while the baseline intrinsic temporal thickness (Δt) remains uniform across homogeneous classes of elementary particles, the spatial width of the underlying oscillation trough (Δx) scales proportionally with the systemic mass-energy distribution.

This dimensional structuralization extends naturally to gauge bosons. However, unlike fermions, the energy-matter density of a boson (such as a photon) is distributed symmetrically and evenly throughout its temporal thickness. Because photons are strictly constrained to propagate at the constant velocity c, their temporal profile undergoes a distinct geometric mapping:

Because this fundamental temporal thickness is extraordinarily minute, its operational consequences are confined to the microscopic scale of quantum field interactions. For a macroscopic body—which constitutes an ordered ensemble of numerous microscopic constituents aligned coherently along the temporal axis—the total macroscopic temporal thickness equals the baseline temporal depth of a single constituent

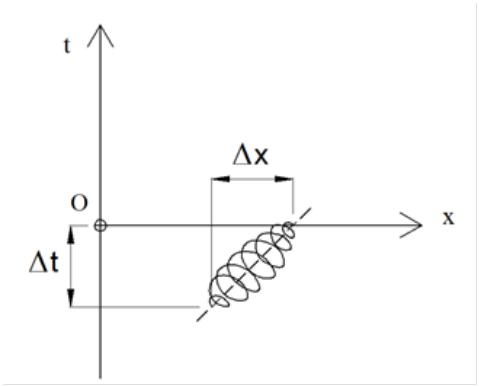


Fig. 4 Geometric structuralization mapping the distributed energy-matter density and temporal thickness profile (Δt) of a fundamental gauge boson (photon) [7].

microscopic particle. Consequently, this geometric thickness remains negligible and imperceptible within classical macroscopic observations [7]:

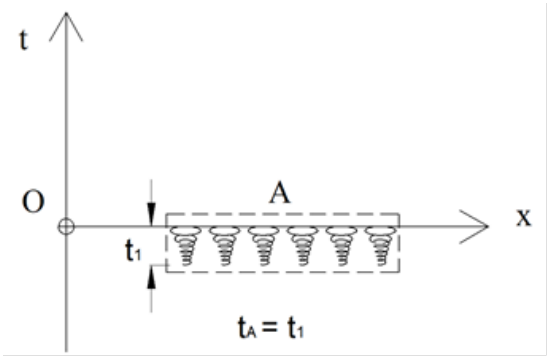


Fig. 5 Ordered alignment of microscopic constituents demonstrating why the total temporal thickness of a macroscopic object remains invariant and equal to that of a single constituent particle ($t_A = t_1$) [7].

To map how this temporal depth manifests across relative reference frames, we analyze a scenario where an observer propagates at a uniform coordinate velocity v while the target excitation remains stationary. Under this kinematic shift, the observer experiences the uniform, infinite-phase-velocity standing wave of the particle as a dynamic, propagating sinusoidal wave function:

Conversely, evaluating the inverse scenario under standard stationary observer conditions with the physical particle propagating at velocity v, the spatial coordinate mapping yields an identical profile:

According to the principle of relativity and the equivalence of inertial projections [4], the wave function measured in both scenarios must maintain identical sinusoidal symmetries. To structurally preserve this coordinate reciprocity when a particle possesses a non-zero velocity, the intrinsic oscillation axis of the excitation must

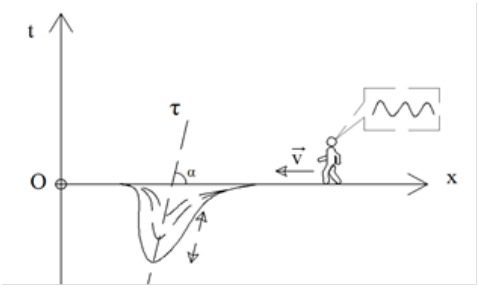


Fig. 6 The projected sinusoidal wave function of a stationary particle as measured from the frame of a moving observer propagating at a uniform coordinate velocity v [7].

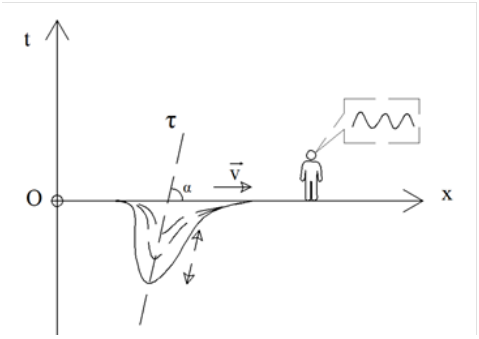


Fig. 7 The projected sinusoidal wave function of a particle propagating at coordinate velocity v as measured by a strictly stationary observer frame [7].

undergo an exact geometric tilt angle α relative to the Global Time axis t. This structural tilt demonstrates that the *angle of inclination of an object's internal oscillation axis directly encodes the magnitude, direction, and momentum vector of its physical motion* [7].

2.2 Mathematical Decomposition of the Two-Component Temporal Structure

Within the continuum of space and time, no physical entity possesses static permanence along the temporal manifold. The unceasing cosmic flow of time represents a fundamental dynamical translation, systematically pushing all matter-energy configurations forward along a primary evolutionary path. To model this operational mechanic without introducing coordinate contradictions, the temporal parameter of any physical object must be mathematically decomposed into two simultaneous, interlocking components acting across different geometric layers [7]:

- **Global Cosmic Time (t-axis):** This parameter represents the relative time of an object measured with respect to an encompassing system of external bodies. When extended to its global limit, it constitutes the invariant background time of the entire universe, operationalized as a uniform, homogeneous scalar field spanning the

absolute background space. It governs global causality and provides the invariant temporal metric required for quantum state evolution.

- **Localized Proper Time (τ-axis):** This parameter represents the object's intrinsic temporal evolution rate. Rather than operating as a universal background field, each fundamental excitation or sub-system carries its own independent, localized proper time axis. This localized axis is directly subject to relative kinematic rotations and local gravitational potentials, dictating the physical rate of internal processes (such as clock-ticking frequencies or quantum decay rates).

Under classical macroscopic conditions characterized by low coordinate velocities ($v \ll c$) and weak gravitational fields, these two distinct temporal axes undergo a geometric confluence, allowing them to be treated as a single, indivisible scalar index ($t \approx \tau$). However, within the microscopic domain of quantum field interactions or under extreme general relativistic configurations (such as the event horizons of black holes), this classical approximation collapses. In these extreme physical domains, the structural decoupling between the t-axis and the τ-axis manifests explicitly, demanding a clear differentiation of their respective operational effects to resolve foundational singularities and non-local measurement paradoxes [7].

Quantitatively, the geometric inclination angle α between the localized Proper Time axis τ and the Global Cosmic Time axis t is governed by the relativistic kinematic ratio:

$$\sin\alpha = \frac{v}{c}, \qquad \frac{d\tau}{dt} = \cos\alpha = \sqrt{1 - \frac{v^2}{c^2}}, \tag{4}$$

which naturally recovers the standard relativistic time dilation metric without discarding the invariant background parameter t. Consequently, the complete quantum state of a moving particle evolves across both temporal layers via a dual-temporal wave function:

$$\Psi(x, t, \tau) = \psi_0 \exp\left[-i\left(\omega_0\tau + \frac{E_{\text{kin}}t}{\hbar} - \frac{px}{\hbar}\right)\right], \tag{5}$$

where $\omega_0 = 2\pi f_0$ governs the intrinsic rest oscillation along τ, while the kinetic phase evolution propagates strictly with respect to Global Time t [8, 9].

3 Application of the New Concept of Time to Unify the Concepts of Time in General Relativity and Quantum Mechanics

3.1 Application of the Dual-Temporal Framework to General Relativity

Within the geometric formulation of general relativity [3], the introduction of Global Cosmic Time (t) provides a novel mechanism for the physical origin of spatial curvature and gravitational potentials. Rather than acting as a passive, non-interacting parameter, Global Time operates as a fundamental structural potential spanning the cosmic background. In the presence of a localized momentum vector $\mathbf{p}$, this temporal potential generates a dynamic field-theoretic resistance force that actively warps

the surrounding three-dimensional spatial manifold, structurally manifesting as the phenomenon of inertial and gravitational mass.

This mechanism extends natively to gauge fields operating in a vacuum. Even a fundamental photon propagating through empty space undergoes an exceptionally minute spatial compression induced by the constant flow of Global Time against its wave envelope. This localized structural compression manifests physically as a non-zero, directionally dependent effective mass for the photon. Crucially, this effective mass is only physically measurable along the forward vector of collision; because the photon propagates at the absolute velocity of light c, any causal excitations or fields trailing behind its wave packet are kinematically forbidden from interacting with or being affected by the photon's localized field structure. While this directionally isolated effective mass is extraordinarily minute, it remains mathematically and physically sufficient to drive the momentum transfer mechanics observed in Compton scattering experiments [7, 10].

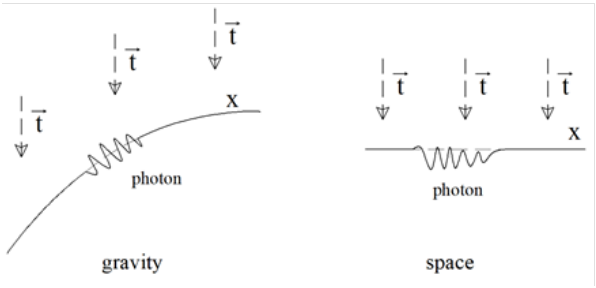


Fig. 8 Geometric mapping of the Global Time vector field t acting dynamically on a photon wave packet propagating through a localized gravitational gradient and within a homogeneous empty space vacuum [7].

Conversely, within this dual-temporal paradigm, the role of Proper Time (τ) perfectly recovers the geometric characteristics attributed to the standard temporal coordinate in four-dimensional pseudo-Riemannian spacetime. Proper Time possesses explicit spatial-like properties, meaning it does not maintain a fixed orientation across the universe. Instead, it exhibits the capacity to tilt, rotate, and curve dynamically in direct response to localized kinematic velocities and mass-energy tensors, generating the standard metric transformations of relativistic kinematics [7].

3.2 Application of the Dual-Temporal Framework to Quantum Mechanics

Within the formulation of non-relativistic and relativistic quantum mechanics [5], the external background evolution parameter t mapping the unitary transformation of state vectors in Hilbert space corresponds directly to Global Cosmic Time (t). Conversely, the intrinsic temporal thickness (Δt) and its corresponding proper time metrics act as fundamental geometric properties of the localized excitation itself. By treating

temporal thickness as a physical reality, several foundational quantum anomalies find an exact, non-perturbative explanation [7].

- **The Geometric Origin of Quantum Superposition:** Because an elementary excitation exhibits a non-zero temporal thickness, its physical matter distribution is not simultaneous across its entire structure. The extended "temporal tail" of a particle can occupy a distinct quantum state eigenbasis compared to its forward "temporal head." As the particle continuously executes intrinsic oscillations at its de Broglie frequency f_0, its local state configuration undergoes rapid deterministic transitions. For example, assuming that at an initial Global Time slice t_0, the system occupies a composite state configuration $|AB\rangle$ (where the head is in state A and the tail is in state B), it dynamically transitions to a reversed state $|BA\rangle$ at t_1, before returning to the baseline state $|AB\rangle$ at t_2. Because standard macroscopic measurement apparatuses lack the sub-temporal resolution required to slice intervals below Δt, any macroscopic measurement operation conducted at a discrete instance inevitably averages these microscopic structural oscillations. This mechanical limitation forces the observed outcome to be strictly governed by the statistical probabilities of Born's rule [7].

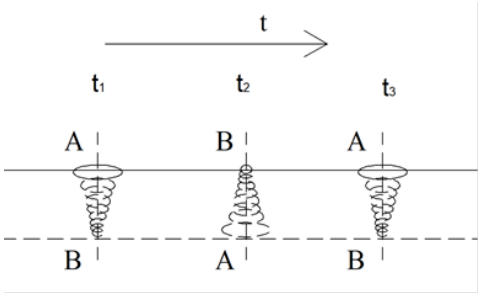


Fig. 9 The localized geometric oscillation of a physical excitation along its intrinsic temporal axis as the fundamental structural driver of quantum superposition states [7].

- **Non-Local Connection in Quantum Entanglement:** The physical extension of an excitation's temporal tail provides the underlying non-local geometric mechanism that drives quantum entanglement [11, 12]. When a multi-particle system undergoes a localized interaction that results in an entangled state, their respective temporal tails remain continuously connected within the underlying background manifold at the initial space-time coordinates of creation. As the sub-systems subsequently separate, tracing distinct relativistic worldlines across the macro-space, their historical worldlines remain permanently attached at their temporal base. Prior to an external measurement intervention that forces wave-function collapse, the separated particles continuously share a single, non-separable global wave function through this continuous sub-temporal intersection. Since composite wave functions must strictly obey global energy and momentum conservation laws, quantum entanglement emerges

as a structural necessity to enforce these conservation symmetries across spatially separated domains without requiring instantaneous action-at-a-distance [7].

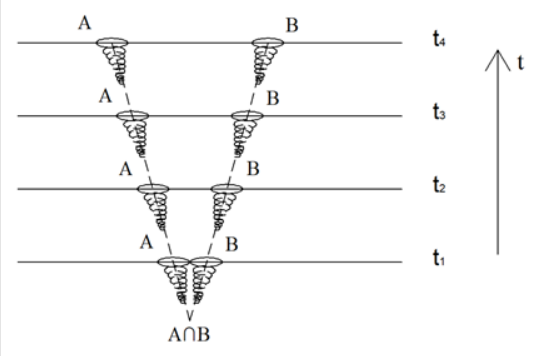


Fig. 10 Geometric structuralization showing the non-separable global wave function of two entangled systems remaining continuously linked along the continuous historical trace of their temporal tails [7].

Crucially, this geometric mechanism avoids the pitfalls of classical local hidden-variable theories and naturally accounts for the violation of Bell's inequality [12, 13]. For any bipartite system assumed to be locally separable, correlation measurements across detector settings (a, a') and (b, b') must obey the Clauser–Horne–Shimony–Holt (CHSH) bound:

$$|S| = |E(a,b) - E(a,b') + E(a',b) + E(a',b')| \leq 2. \tag{6}$$

In our dual-temporal framework, the factorizability condition $P(A, B|a, b) = P(A|a)P(B|b)$ fails fundamentally because the two excitations remain topologically joined at their shared temporal base $(A \cap B)$. Because their worldlines form a single, unbroken geometric manifold across Global Time t and Proper Time τ, the joint probability distribution remains strictly non-separable, reproducing the quantum mechanical Tsirelson bound $|S| = 2\sqrt{2} > 2$ while preserving relativistic locality [14].

This geometric mapping demonstrates that entangled excitations remain structurally linked regardless of their spatial or temporal separation parameters. Consequently, the non-local correlation effects of quantum mechanics operate symmetrically across both vast spatial distances and temporal intervals. Crucially, this mechanism is perfectly consistent with Einstein's special theory of relativity [4], ensuring that no physical information or causal entity propagates faster than the invariant speed of light c. Superluminal signaling is strictly forbidden; because each constituent particle undergoes continuous de Broglie oscillations within its temporal thickness prior to measurement, the local state remains strictly random and probabilistic, preventing the transmission of deterministic, non-local superluminal data packages [7].

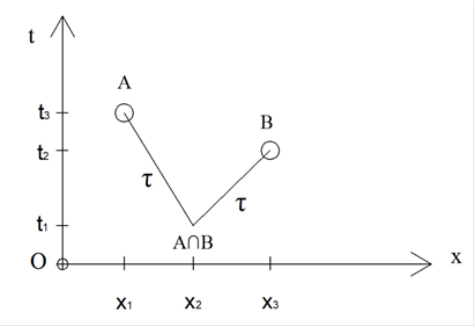


Fig. 11 Spacetime schematic illustrating the permanent causal connection between entangled particles extending continuously over the cosmic flow of Global Time [7].

4 Discussion and Theoretical Implications

The formulation of a two-component time concept characterized by an intrinsic temporal thickness (Δt) introduces a profound paradigm shift that resolves several long-standing philosophical and mathematical crises at the foundations of modern physics. By decoupling the universal cosmic evolution parameter (Global Time, t) from the localized execution rate of physical sub-systems (Proper Time, τ), this framework successfully unifies the absolute background required for quantum mechanics with the dynamic, coordinate-dependent structures of general relativity.

4.1 Resolution of Quantum Measurement and Information Paradoxes

Historically, the transition from a deterministic quantum wave-function evolution governed by the Schrödinger equation [5] to a probabilistic macroscopic measurement outcome has required artificial interpretations, such as the Copenhagen wave-function collapse or the Many-Worlds hypothesis. The two-component time framework eliminates the need for these speculative metaphysical structures. Because a particle possesses a non-zero physical temporal thickness, its internal state continuously oscillates between distinct eigenbasis configurations (e.g., $|AB\rangle \leftrightarrow |BA\rangle$) at its intrinsic rest frequency f_0. Consequently, Born's probabilistic rule emerges not as an inherent breakdown of causality, but as a mechanical consequence of temporal averaging performed by macroscopic measurement apparatuses operating above the sub-temporal scale Δt.

Furthermore, this framework offers a radical solution to the black hole information paradox. Within standard general relativity, an object falling past an event horizon encounters an infinite coordinate time delay relative to an external observer, creating an irreconcilable conflict with quantum unitarity. Under the dual-temporal architecture, while the object's localized Proper Time τ is subject to extreme gravitational metric scaling, its underlying structural footprint along the Global Time axis t remains continuous and invariant. Information is never destroyed nor permanently trapped behind a spatial singularity; instead, it remains encoded within the non-local historical trace of the system's temporal tail.

4.2 Predictive Power and Future Experimental Verification

To establish empirical validity, this theoretical model proposes two distinct experimental pathways for future verification within high-precision quantum optics and particle physics:

- **Sub-Temporal Phase Shifts:** At extreme high-energy scales or ultra-short time intervals approaching the domain of Δt, quantum wave packets should exhibit minute, non-local phase anomalies that deviate from standard single-parameter time evolutions. These can be probed via advanced attosecond interferometry tracking electron wave-packet dynamics.
- **Temporal Bell-State Correlations:** The geometric entanglement mechanism derived in Section 3.2 predicts that non-local correlations are perfectly symmetrical across both spatial and temporal intervals [12]. Entanglement swapping experiments tracking particles that have never coexisted in the same Global Time slice can verify whether the continuous historical trace of the temporal tail preserves conservation laws as mathematically modeled herein.

Ultimately, this two-component time formulation proves that space and time are not merely passive stages where matter interacts. Instead, the universe operates as a unified object where the intrinsic geometry of space and the structural thickness of time naturally manifest as the physical phenomena of mass, momentum, and quantum field behaviors.

5 Conclusion

The two-component temporal framework formulated in this work presents a robust, non-perturbative pathway toward resolving the foundational incompatibility between general relativity and quantum mechanics. By mathematically decoupling temporal evolution into an invariant cosmic background field (Global Time, t) and an intrinsic, process-dependent execution rate (Proper Time, τ), the structural requirements of both major domains are successfully preserved and reconciled. Specifically, Global Time t satisfies the rigorous criteria of an absolute, external parameter necessary to maintain quantum unitary evolution operators in Hilbert space, remaining completely decoupled from localized mass-energy tensors or relative coordinate velocities.

Conversely, the Proper Time axis τ natively satisfies the coordinate constraints of pseudo-Riemannian four-dimensional spacetime in general relativity—retaining its explicit capacity to dynamically tilt, rotate, and curve under kinematic and gravitational potentials. Simultaneously, the physical manifestation of this dual geometry introduces the reality of an excitation's finite *temporal thickness* (Δt). As mathematically evaluated, this microscopic temporal depth acts as the long-sought underlying physical mechanism that drives the statistical realities of quantum superposition and enforces non-local causal conservation laws during quantum entanglement swapping. Ultimately, structuralizing time as a two-component manifold resolves one of the primary conceptual obstacles separating general relativity and quantum mechanics, offering a consistent geometric foundation for future investigations into quantum gravity and non-local quantum correlations [7].

Declarations

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- **Conflict of Interest / Competing Interests:** The author declares that he has no known competing financial interests, personal relationships, or institutional conflicts of interest that could have appeared to influence the work reported in this paper.
- **Author Contributions:** The entirety of this research work, including the conceptualization of the two-component time framework, the mathematical derivation of temporal thickness from the de Broglie wave function, the geometric modeling of quantum entanglement tails, and the comprehensive drafting, revision, and final preparation of this manuscript, was independently and solely executed by the author, Quang Ha Ngo. The author read and approved the final version of the manuscript for submission.
- **Data Availability:** No datasets were generated or analyzed during the current study. All theoretical derivations and geometric models are fully contained within the article.

References

[1] DeWitt, B.S.: Quantum theory of gravity. I. the canonical theory. Physical Review **160**(5), 1113–1148 (1967) https://doi.org/10.1103/PhysRev.160.1113

[2] Isham, C.J.: Canonical quantum gravity and the problem of time. In: Ibort, L.A., Rodríguez, M.A. (eds.) Integrable Systems, Quantum Groups, and Quantum Field Theories, pp. 157–287. Springer, Dordrecht (1993). https://doi.org/10.1007/978-94-011-1980-1_6

[3] Einstein, A.: Die Grundlage der allgemeinen Relativitätstheorie. Annalen der Physik **354**(7), 769–822 (1916) https://doi.org/10.1002/andp.19163540702

[4] Einstein, A.: Zur Elektrodynamik bewegter Körper. Annalen der Physik **322**(10), 891–921 (1905) https://doi.org/10.1002/andp.19053221004

[5] Schrödinger, E.: An undulatory theory of the mechanics of atoms and molecules. Physical Review **28**(6), 1049–1070 (1926) https://doi.org/10.1103/PhysRev.28.1049

[6] Broglie, L.: Waves and quanta. Nature **112**(2815), 540 (1923) https://doi.org/10.1038/112540a0

[7] Ngo, Q.H.: The Universe Is a Unified Object: Book 1: Building a New Unified Theory with Eraser and Ballpoint Pen. Amazon Digital Services, Seattle, WA (2026). ASIN: B0HCGYPFK1

[8] Page, D.N., Wootters, W.K.: Evolution without evolution: Dynamics described

by stationary observables. Physical Review D **27**(12), 2885–2892 (1983) https://doi.org/10.1103/PhysRevD.27.2885

[9] Rovelli, C.: Time in quantum gravity: An hypothesis. Physical Review D **43**(2), 442–456 (1991) https://doi.org/10.1103/PhysRevD.43.442

[10] Compton, A.H.: A quantum theory of the scattering of X-rays by light elements. Physical Review **21**(5), 483–502 (1923) https://doi.org/10.1103/PhysRev.21.483

[11] Einstein, A., Podolsky, B., Rosen, N.: Can quantum-mechanical description of physical reality be considered complete? Physical Review **47**(10), 777–780 (1935) https://doi.org/10.1103/PhysRev.47.777

[12] Bell, J.S.: On the Einstein Podolsky Rosen paradox. Physics Physique Fizika **1**(3), 195–200 (1964) https://doi.org/10.1103/PhysicsPhysiqueFizika.1.195

[13] Clauser, J.F., Horne, M.A., Shimony, A., Holt, R.A.: Proposed experiment to test local hidden-variable theories. Physical Review Letters **23**(15), 880–884 (1969) https://doi.org/10.1103/PhysRevLett.23.880

[14] Megidish, E., Halevy, A., Shacham, T., Dvir, T., Dovrat, L., Eisenberg, H.S.: Entanglement swapping between photons that have never coexisted. Physical Review Letters **110**(21), 210403 (2013) https://doi.org/10.1103/PhysRevLett.110.210403