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Research Article

Quantum Entanglement and the Possible Role of Backward-Propagating Pulses: A Time-Symmetric Perspective on Quantum Correlations

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ABSTRACT

Quantum entanglement remains one of the most intriguing and conceptually challenging phenomena in quantum mechanics. While the standard quantum formalism accurately predicts entanglement, the physical mechanism underlying the emergence of nonlocal quantum correlations remains the subject of ongoing debate. In this work, we propose a theoretical framework suggesting that backward-propagating solutions of the Schrödinger equation may provide an alternative interpretation of the origin of quantum entanglement. Building upon perturbative solutions previously introduced by Qian (2026), we examine the spatiotemporal influence regions of two complementary wave solutions and analyze their contributions to the density operator. We argue that when only forward-propagating solutions are considered, the complementary nature of the influence regions suppresses coherence between distinct states. By introducing a time-reversed propagation model, overlapping spacetime regions become possible, allowing the appearance of off-diagonal coherence terms in the density operator commonly associated with quantum entanglement. The proposed interpretation is discussed alongside existing time-symmetric approaches, including the Transactional Interpretation, the Two-State Vector Formalism, Klyshko's Advanced Wave Picture, and recent developments in quantum optics. Rather than replacing conventional quantum mechanics, this work offers a complementary theoretical perspective that may contribute to ongoing discussions concerning the foundations of quantum nonlocality, retrocausality, and time symmetry. Possible experimental approaches for evaluating the proposed framework are also outlined.

1. Introduction

Quantum entanglement is one of the most remarkable and conceptually challenging phenomena in modern physics. Since the pioneering work of Einstein, Podolsky, and Rosen (1935), followed by Bell's formulation of nonlocal correlations and numerous experimental confirmations, entanglement has become a cornerstone of quantum information science, quantum computing, quantum cryptography, and quantum communication. Although the mathematical formalism of quantum mechanics predicts entanglement with extraordinary precision, the underlying physical origin of the nonlocal correlations remains the subject of continuing debate.

Several interpretations of quantum mechanics have attempted to explain these correlations from different conceptual perspectives. The Copenhagen Interpretation attributes observed correlations to the quantum state together with the measurement postulate, whereas the Many-Worlds Interpretation explains them through universal unitary evolution without wavefunction collapse. Bohmian Mechanics introduces deterministic hidden variables guided by a nonlocal pilot wave, while more recent approaches, including the Transactional Interpretation, the Two-State Vector Formalism, and retrocausal models, investigate the possibility that quantum processes possess an intrinsically time-symmetric structure involving both forward- and backward-evolving quantum states.

Recent developments in quantum foundations have renewed interest in time-symmetric descriptions of physical processes. These approaches seek to reconcile quantum correlations with relativistic causality by considering mathematical solutions that evolve in both temporal directions. Although these interpretations differ significantly in their physical assumptions, they share the common objective of providing a more intuitive spacetime description of quantum phenomena while remaining consistent with the experimentally verified predictions of conventional quantum mechanics.

In a recent study, Qian (2026) derived perturbative solutions of the Schrödinger equation that separate naturally into two complementary spacetime influence regions, referred to as Situation 3 and Situation 4. Within that framework, the complementary nature of the two regions raises an important conceptual question. If the corresponding probability amplitudes never coexist within the same spacetime region under purely forward propagation, under what conditions do the off-diagonal coherence terms of the density operator become physically realized?

The present work investigates this question by exploring whether backward-propagating solutions may provide a possible physical interpretation for the emergence of quantum coherence and entanglement. Rather than proposing a modification of the mathematical formalism of quantum mechanics, this study develops an interpretational framework that remains compatible with conventional quantum theory while offering an alternative spacetime perspective on the origin of off-diagonal coherence.

The principal objectives of this study are:

- To examine the perturbative solutions introduced by Qian (2026) within the density operator formalism.
- To investigate the conditions under which off-diagonal coherence terms may become physically realized when forward- and backward-propagating solutions are considered simultaneously.
- To compare the proposed interpretation with existing time-symmetric approaches, including the Transactional Interpretation, the Two-State Vector Formalism, and Klyshko's Advanced Wave Picture.
- To discuss the conceptual implications of the proposed framework for quantum coherence, nonlocality, causality, and future experimental investigation.

The remainder of this paper is organized as follows. Section II reviews previous work on time reversal, advanced-wave descriptions, retrocausal interpretations, and related developments in quantum optics. Section III presents the mathematical framework underlying the proposed interpretation. Section IV discusses its conceptual implications, compares the framework with existing interpretations of quantum mechanics, and outlines its limitations and possible experimental tests. Finally, Section V summarizes the principal conclusions and identifies directions for future theoretical and experimental research.

2. Literature Review

2.1 Time Reversal in Quantum Mechanics

Time reversal symmetry occupies a central position in quantum mechanics. The time-reversal operator T is an antiunitary operator that transforms a state evolving forward in time into one evolving backward (Sakurai & Napolitano, 2017). For the Schrödinger equation, time reversal involves complex conjugation of the wavefunction, reflecting the fact that the equation is first-order in time.

Laforest et al. (2018) investigated the application of time-reversal formalism to maximal bipartite entanglement in the context of quantum teleportation. They demonstrated that the outcome of a teleportation-like circuit is consistent with the usual tensor product treatment and is independent of the physical quantum system used to encode information. Their experimental results on a liquid-state NMR quantum information processor were consistent with the interpretation that **information can be seen as flowing backward in time through entanglement**. This finding provides empirical support for the notion that backward-in-time propagation is not merely a mathematical abstraction but a physically meaningful description of entanglement phenomena.

The authors further noted that Bennett and Schumacher had previously presented the notion of "conditional time travel" in the teleportation context, suggesting that conditional on the outcome of the Bell measurement, the scheme can be seen as a single qubit of information evolving along and against the arrow of time of an external observer. Coecke later developed a complete mathematical theory based on this interpretation, analyzing the "seemingly acausal flow of information" in the language of functional programming.

2.2 Advanced Waves and the Wheeler-Feynman Absorber Theory

The concept of advanced waves—solutions to wave equations that propagate backward in time—has a long history in physics. Wheeler and Feynman (1945) developed their absorber theory of radiation, which eliminated the need for self-interaction by positing that radiation is the result of a symmetrical interaction between emitters and absorbers, involving both retarded (forward) and advanced (backward) waves.

In the Wheeler-Feynman framework, an accelerated charge emits both retarded and advanced waves. The advanced wave travels backward in time to the absorber, which then emits a wave that returns to the emitter. The interference between these waves produces the familiar retarded radiation observed in nature. While the Wheeler-Feynman theory did not gain widespread acceptance due to its reliance on a cosmological absorber, the mathematical framework of advanced waves has persisted as a valuable theoretical tool.

Beil (2003) explored the consequences of assuming the existence of **antiphotons which propagate backward in time**, noting that this is "obviously permitted mathematically" and has "physical justification in the Wheeler-Feynman advanced radiation". Beil argued that interesting consequences of this assumption include explanations of the attractive Coulomb force as an exchange of antiphotons, **quantum entanglement and "teleportation,"** the problem of action at a distance, and some characteristics of emission and absorption of radiation.

2.3 Klyshko's Advanced Wave Picture

Klyshko's advanced wave picture (AWP) provides a powerful framework for understanding quantum optics phenomena through the lens of time-reversed propagation. The AWP uses the optical reciprocity theorem to relate the quantum correlations between photons created via spontaneous parametric down-conversion (SPDC) and the classical intensity of an appropriate beam (Klyshko, 1988).

Recent experimental work has demonstrated the practical utility of the AWP. Shekel et al. (2024) proposed and demonstrated a new feedback mechanism inspired by Klyshko's advanced wave picture, in which a classical laser beam counter-propagates with one of the entangled photons and co-propagates with the other. This Klyshko feedback allows compensation of scattering in arbitrary samples and even in situations where each photon propagates through a different scattering medium. The authors emphasized that "since the advanced wave picture applies whenever optical reciprocity is valid, such Klyshko optimization can be used across a wide range of configurations, offering a robust and alignment-free setup".

This experimental demonstration is significant because it shows that the advanced wave picture—which mathematically corresponds to backward propagation—has concrete, practical applications in quantum technology. The fact that the AWP successfully describes and enables compensation of scattering in entangled photon systems provides strong evidence that backward-propagating solutions are not merely mathematical curiosities but physically meaningful components of quantum optical systems.

2.4 Retrocausal Interpretations of Quantum Entanglement

The possibility of using retrocausality to obtain a fundamentally relativistic account of Bell correlations has gained increasing recognition in recent years. Retrocausal interpretations propose that causal influences can travel backward in time, providing a potential resolution to the tension between quantum nonlocality and special relativity.

Higuchi (2025) presented a detailed interpretation of simultaneous correlation in quantum entanglement with retro-causality, focusing on the fact that the **uncertainty relationship between energy and time allows photons to travel backward in time** and explains the long-range correlation between two photons without contradicting the requirements of the theory of relativity. Higuchi noted that "in quantum optics, time reversal is an antiunitary transformation, and the state vector becomes the complex conjugate of the original. If the original state vector is the ket vector, its complex conjugate is the bra vector. When the bra vector generated by time reversal meet the ket vector on the time axis, they form braket and its state is established". This mechanism explains how the states of photons going back into the past are determined and provides a reason for the simultaneous correlation between distant photons in Aspect's experiment.

Higuchi identified three major theoretical frameworks incorporating forward and backward propagation in time:

1. **The transactional interpretation of quantum mechanics (TI)** by Cramer, in which anterograde and retrograde waves are exchanged between the observed wave emitter and the observed wave absorber
2. **The two-state vector formalism (TSVF)** by Aharonov et al., which employs both forward and backward evolving state vectors
3. **The absorber theory (AT)** by Pegg, which draws on Wheeler-Feynman radiation theory

These frameworks share the common feature of treating backward-propagating solutions as physically meaningful components of quantum systems.

2.5 Backward Pulses and Entanglement Generation

The generation of entangled states through backward-propagating pulses has been investigated in several contexts. Research on resonant superradiant backward-scattering from a Bose-Einstein condensate has shown that atom pair production via backward-scattering can serve as a source for many-particle entanglement. By driving the superradiant process with two frequencies, researchers can extend both the range of pulse duration and intensity and obtain full control over the number of scattered atoms in forward and backward directions.

Studies on voltage pulses applied to mesoscopic forks have demonstrated that spin-entangled pairs of electrons can be generated through post-selection. The presence of these entangled pairs can be observed in Bell inequality measurements based on particle-number cross-correlators. These results suggest that pulse-based approaches to entanglement generation may be more broadly applicable than previously recognized.

3. Mathematical Framework

3.1 Perturbation Solutions of the Schrödinger Equation

Following Qian (2026), we consider the perturbation solution of the Schrödinger equation. The solutions corresponding to two distinct situations—labeled "situation 3" and "situation 4"—are of particular interest.

Situation 3: The shaded area in Figure 1 (from Qian, 2026) represents the region where the solution for situation 3 is valid. The spatiotemporal expression for this region is:

$$a_3^{(1)}(t) \neq 0, \quad a_4^{(1)}(t) = 0 \tag{1}$$

This indicates that in the influence region of situation 3, only the forward-propagating solution $a_3^{(1)}(t)$ is non-zero, while the situation 4 solution vanishes.

Situation 4: The shaded area in Figure 2 represents the region where the solution for situation 4 is valid. The spatiotemporal expression for this region is:

$$a_4^{(1)}(t) \neq 0, \quad a_3^{(1)}(t) = 0 \tag{2}$$

Similarly, in the influence region of situation 4, only the backward-propagating solution $a_4^{(1)}(t)$ is non-zero, while the situation 3 solution vanishes.

Crucially, as shown in Figures 1 and 2 of Qian (2026), **these two shaded areas span the entire four-dimensional space and are complementary with each other, with no overlapping areas or common regions**. This non-overlapping nature is the key insight that motivates the introduction of backward pulses.

3.2 Density Operator and Entanglement

The density operator provides a powerful formalism for describing quantum states, particularly mixed states and subsystems of entangled systems. For a coherent superposition state, the wavefunction can be denoted by the ket:

$$\lvert \psi \rangle = \alpha \lvert 3 \rangle + \beta \lvert 4 \rangle \tag{3}$$

The corresponding bra is:

$$\langle \psi \rvert = \alpha^* \langle 3 \rvert + \beta^* \langle 4 \rvert \tag{4}$$

The density operator is therefore (Cohen-Tannoudji et al., 2020):

$$\rho = \lvert \psi \rangle \langle \psi \rvert = \lvert \alpha \rvert^2 \lvert 3 \rangle \langle 3 \rvert + \lvert \beta \rvert^2 \lvert 4 \rangle \langle 4 \rvert + \alpha \beta^* \lvert 3 \rangle \langle 4 \rvert + \alpha^* \beta \lvert 4 \rangle \langle 3 \rvert \tag{5}$$

The first two terms on the right-hand side represent **self-entanglement** of states $\lvert 3 \rangle$ and $\lvert 4 \rangle$, respectively. The third and fourth terms represent **cross-entanglement**—the terms that are characteristic of quantum entanglement between the two states.

Following Dirac's notation (Dirac, 1947), $\lvert n \rangle \langle m \rvert$ can be understood as a linear operator or, equivalently, as a second-order tensor or dyad:

$$\lvert n \rangle \langle m \rvert = \lvert n \rangle \otimes \langle m \rvert \tag{6}$$

3.3 Conditions for the Emergence of Off-Diagonal Coherence

Before examining the role of backward-propagating solutions, it is useful to establish the mathematical conditions under which the off-diagonal terms of the density operator become physically meaningful.

For a coherent quantum superposition,

$$|\psi\rangle=\alpha|3\rangle+\beta|4\rangle,$$

the density operator is

$$\rho=|\psi\rangle\langle\psi|.$$

The off-diagonal components,

$$\alpha\beta^{*}|3\rangle\langle4|$$

and

$$\alpha^{*}\beta|4\rangle\langle3|,$$

represent quantum coherence between the two basis states. These terms are responsible for interference phenomena and constitute the mathematical signature of coherent superposition within the density matrix formalism.

In conventional quantum mechanics, these coherence terms arise whenever the corresponding probability amplitudes coexist within the same quantum state. In the present framework, however, the perturbative solutions derived by Qian (2026) introduce an additional spacetime constraint. The amplitudes associated with Situation 3 and Situation 4 occupy complementary influence regions that do not overlap under purely forward propagation.

Consequently, the coexistence of both amplitudes at a common spacetime event is prevented. Within this interpretation, the absence of simultaneous support for both wave amplitudes suppresses the physical realization of the off-diagonal coherence terms, even though they remain mathematically present in the formal expression of the density operator.

This distinction between mathematical existence and physical realization is central to the present work. The following section therefore investigates whether backward-propagating solutions can generate overlapping spacetime regions that permit the physical manifestation of these coherence terms.

3.4 A Spacetime Interpretation of Off-Diagonal Coherence

From equations (1) and (2), we can see that $\langle 3 \rvert$ and $\lvert 3 \rangle$ occupy the same influence region (situation 3), while $\langle 4 \rvert$ and $\lvert 4 \rangle$ occupy the same influence region (situation 4). The cross-entanglement terms $\lvert 3 \rangle \langle 4 \rvert$ and $\lvert 4 \rangle \langle 3 \rvert$ require the coexistence of $\lvert 3 \rangle$ with $\langle 4 \rvert$ and $\lvert 4 \rangle$ with $\langle 3 \rvert$, respectively.

However, since $\lvert 3 \rangle$ and $\langle 4 \rvert$ are in different influence regions, **at any point in four-dimensional space where** $\lvert 3 \rangle \neq 0$**, we must have** $\lvert 4 \rangle = 0$. Similarly, since $\langle 3 \rvert$ and $\lvert 3 \rangle$ are in the same influence region, and $\langle 4 \rvert$ and $\lvert 4 \rangle$ are in the same influence region, **wherever** $\lvert 3 \rangle \neq 0$**, we must have** $\lvert 4 \rangle = 0$, and conversely, wherever $\lvert 4 \rangle \neq 0$, we must have $\lvert 3 \rangle = 0$.

Therefore, the two cross-entanglement terms in equation (5) vanish:

$$\lvert 3 \rangle \langle 4 \rvert = 0, \quad \lvert 4 \rangle \langle 3 \rvert = 0 \tag{7}$$

This leaves only the self-entanglement terms:

$$\rho = \lvert \alpha \rvert^2 \lvert 3 \rangle \langle 3 \rvert + \lvert \beta \rvert^2 \lvert 4 \rangle \langle 4 \rvert \tag{8}$$

This is a crucial result: without backward-propagating solutions, quantum entanglement—as manifested by cross-terms in the density operator—cannot arise.

3.5 A Proposed Role for Backward-Propagating Solutions

The analysis presented above indicates that, under the assumptions of the perturbative framework introduced by Qian (2026), purely forward-propagating solutions occupy complementary spacetime influence regions. Within this interpretation, these complementary regions limit the simultaneous physical realization of the two probability amplitudes required for off-diagonal coherence.

We now consider a theoretical extension in which the solution associated with Situation 4 is interpreted as a backward-propagating wave. In such a description, the temporal evolution of this solution is reversed with respect to the forward solution while remaining a valid mathematical solution of the Schrödinger equation under time-reversal symmetry.

The principal consequence of this interpretation is the possibility that the forward- and backward-propagating amplitudes intersect within common regions of spacetime. In these overlap regions,

$$|3\rangle \neq 0,\qquad \langle4| \neq 0,$$

and similarly,

$$|4\rangle \neq 0,\qquad \langle3| \neq 0.$$

The simultaneous presence of both amplitudes allows the corresponding off-diagonal density-matrix elements,

$$|3\rangle\langle4|$$

and

$$|4\rangle\langle3|,$$

to acquire physical significance within the proposed interpretation. These terms describe quantum coherence between the two basis states and are responsible for the interference effects characteristic of coherent quantum systems.

It is important to emphasize that this argument does not modify the mathematical structure of the density operator used in conventional quantum mechanics. Rather, it proposes an alternative physical interpretation regarding the spacetime conditions under which these coherence terms become physically realized.

Accordingly, backward-propagating solutions should be viewed not as experimentally established entities but as a theoretical mechanism that may account for the emergence of quantum coherence within a time-symmetric description of quantum mechanics. Whether such solutions correspond to physically observable processes remains an open question that requires further theoretical development and experimental investigation.

4. Analysis and Discussion

4.1 Spatiotemporal Interpretation of Quantum Coherence

The theoretical framework developed in this study provides an alternative spacetime interpretation of quantum coherence. Rather than modifying the mathematical structure of quantum mechanics, the proposed model seeks to interpret how coherence may emerge when the temporal evolution of quantum states is considered within a time-symmetric framework.

In conventional quantum mechanics, the density operator completely describes the statistical properties of a quantum system and accurately predicts interference and entanglement phenomena. The present work does not challenge these predictions. Instead, it proposes that the perturbative solutions introduced by Qian (2026) may offer additional insight into the spacetime conditions under which the coherence represented by the off-diagonal elements of the density operator becomes physically realized.

Within the proposed interpretation, forward-propagating solutions alone occupy complementary spacetime influence regions. If this description is accepted, the simultaneous realization of the corresponding amplitudes becomes limited. By extending the framework to include backward-propagating solutions, overlapping influence regions become possible, providing a conceptual mechanism through which quantum coherence may emerge.

This interpretation should not be regarded as a replacement for established quantum theory. Instead, it represents one possible physical picture that is compatible with time-symmetric formulations of quantum mechanics. Similar conceptual ideas have previously appeared in the Transactional Interpretation, the Two-State Vector Formalism, and other retrocausal approaches, although the present work develops the argument from a different mathematical starting point.

Consequently, the principal contribution of this study is interpretational rather than predictive. The mathematical formalism of quantum mechanics remains unchanged; however, the proposed spacetime perspective may provide additional intuition concerning the physical origin of quantum correlations and motivate future theoretical and experimental investigations.

4.2 Relationship to Existing Experimental Studies

Although the framework proposed in this paper is theoretical, several experimental and theoretical developments in quantum physics provide conceptual motivation for investigating time-symmetric descriptions of quantum phenomena.

Studies of quantum teleportation have shown that time-reversal formalisms can reproduce the predictions of conventional quantum mechanics while offering an alternative interpretation of information flow. Likewise, Klyshko's Advanced Wave Picture has proven highly successful as a computational and conceptual tool in quantum optics, particularly in the analysis of entangled-photon experiments and scattering compensation. These results demonstrate that time-reversed mathematical descriptions can possess significant explanatory and practical value, even when interpreted within the conventional quantum formalism.

Similarly, retrocausal models, the Transactional Interpretation, and the Two-State Vector Formalism provide examples of theoretical frameworks in which forward- and backward-evolving quantum states coexist within a time-symmetric description. While none of these approaches has been experimentally established as the unique interpretation of quantum mechanics, their continued development demonstrates that time-symmetric reasoning remains an active area of foundational research.

Accordingly, the present work should be viewed as contributing to this broader family of interpretational approaches. The framework proposed here is consistent with several existing time-symmetric ideas but does not claim that current experimental evidence uniquely confirms the existence of physically propagating backward waves.

4.3 Comparison with Other Interpretations of Quantum Mechanics

Quantum entanglement has been successfully described within several competing interpretations of quantum mechanics. The Copenhagen Interpretation explains observed correlations through the quantum state and the measurement postulate without assigning a detailed physical mechanism to wavefunction collapse. The Many-Worlds Interpretation attributes quantum correlations to universal unitary evolution across multiple branches of reality, while Bohmian Mechanics introduces deterministic hidden variables guided by a nonlocal pilot wave.

The present framework differs from these interpretations by focusing on the spacetime realization of quantum coherence. Rather than modifying the mathematical formalism of quantum mechanics, it proposes that the coexistence of forward- and backward-propagating solutions may provide an intuitive physical picture for understanding how coherence represented by the off-diagonal density-matrix elements becomes established.

Because all of these interpretations reproduce the experimentally verified predictions of quantum mechanics, the present work should be regarded as an alternative conceptual framework rather than a replacement for existing theories. Future theoretical analysis and experimental investigation will be required to determine whether the proposed spacetime interpretation yields unique, testable consequences that distinguish it from competing approaches.

4.4 Limitations and Future Directions

Several limitations of the present study should be acknowledged.

First, the proposed framework is entirely theoretical and is based upon perturbative solutions previously derived by Qian (2026). Although the mathematical interpretation developed here is internally consistent, direct experimental verification of backward-propagating quantum solutions has not yet been achieved.

Second, the proposed interpretation does not alter the predictive structure of standard quantum mechanics. Instead, it offers an alternative physical interpretation of how quantum coherence may emerge within a time-symmetric spacetime description. Consequently, the framework should not be interpreted as disproving conventional quantum mechanics but rather as providing an additional conceptual perspective.

Third, further mathematical work is required to establish whether the proposed mechanism can be generalized beyond the perturbative solutions considered in this study. Extending the analysis to relativistic quantum field theory, many-body systems, and open quantum systems would significantly strengthen the theoretical foundation of the model.

Finally, the most important challenge for future research is experimental validation. It will be necessary to identify observable predictions that distinguish the proposed framework from other interpretations of quantum mechanics. Possible directions include delayed-choice experiments, weak-measurement protocols, quantum teleportation, Bell-test configurations, and advanced-wave optical systems capable of probing time-symmetric effects. Such investigations would determine whether the present interpretation possesses experimentally distinguishable consequences beyond those of conventional quantum theory.

5. Conclusion

This study has presented a theoretical framework exploring the possible role of backward-propagating solutions in the formation of quantum coherence and entanglement. Building upon the perturbative solutions introduced by Qian (2026), the analysis examined the spatiotemporal structure of complementary influence regions and investigated how a time-symmetric interpretation may provide an alternative physical perspective on the emergence of the off-diagonal coherence terms of the density operator.

Within the proposed framework, purely forward-propagating solutions occupy complementary spacetime regions that restrict the simultaneous physical realization of distinct probability amplitudes. By introducing backward-propagating solutions as a theoretical extension, overlapping spacetime regions become possible, providing a conceptual mechanism through which quantum coherence may be physically interpreted. This interpretation is compatible with several existing time-symmetric approaches to quantum mechanics, including the Transactional Interpretation, the Two-State Vector Formalism, and Klyshko's Advanced Wave Picture.

It is important to emphasize that the present work does not modify the mathematical formalism or predictive success of conventional quantum mechanics. Instead, it proposes an alternative interpretational framework that seeks to provide additional physical insight into the spacetime origin of quantum correlations. The conclusions presented here should therefore be understood as theoretical hypotheses rather than experimentally established facts.

The framework also highlights several open questions that warrant further investigation. In particular, additional mathematical analysis is needed to determine whether the proposed interpretation can be generalized beyond the perturbative solutions considered here. Equally important is the identification of experimentally testable predictions capable of distinguishing this framework from other interpretations of quantum mechanics.

Future work may explore applications of the proposed model to relativistic quantum systems, quantum field theory, delayed-choice experiments, weak-measurement protocols, Bell-test experiments, and advanced-wave quantum optical systems. Such investigations will ultimately determine whether backward-propagating solutions constitute a useful interpretational tool or represent physically observable components of quantum dynamics.

In summary, this work contributes to the continuing discussion of the foundations of quantum mechanics by presenting a time-symmetric interpretation of quantum coherence that complements, rather than replaces, the conventional quantum formalism. It is hoped that the ideas presented here will stimulate further theoretical analysis and experimental investigation into the role of time symmetry in quantum phenomena.

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