Field Theory and Quantum Correlations: A New Perspective on Instantaneity

Johann Pascher

March 28, 2025

Abstract

This work develops a new perspective on the phenomenon of quantum correlations and their apparent instantaneity. By introducing a fundamental field approach, it demonstrates how the non-local properties of quantum mechanics can be understood as a natural consequence of an underlying field structure. Particular attention is paid to the role of the quantum background and the interpretation of modern Bell experiments. This consideration complements the time-mass duality theory and provides a consistent framework for understanding quantum phenomena within a comprehensive field concept.

Contents

1 Introduction

Modern quantum physics faces a fundamental challenge: The apparent instantaneity of quantum correlations seems to contradict our classical notions of locality and causality. Since the groundbreaking Bell experiments, particularly the loophole-free tests since 2015 [10], we know with certainty that the quantum world exhibits non-local properties. Nevertheless, the question about the *nature* of this non-locality and its compatibility with relativity theory remains open.

1.1 A New Approach

This work develops an alternative perspective on the problem of quantum correlations by proposing a fundamental field approach. Instead of separate quantum fields, a unified basic field is postulated in which particles appear as field nodes and quantum correlations as field properties [22]. This viewpoint makes it possible to understand the apparent 'spooky action at a distance' as a natural consequence of the field structure.

1.2 Theoretical Foundations

The proposed approach is based on three core concepts:

- The vacuum as an active quantum background with defined properties (ε_0, μ_0)
- Particles as stable nodes or excitation patterns in the fundamental field
- Quantum correlations as inherent properties of field coherence

These concepts are directly connected with the time-mass duality theory [17], where intrinsic time $T = \hbar/mc^2$ is considered as a fundamental quantity. The properties of the quantum background determine both the time evolution of the system and the structure of the field nodes perceived as matter.

1.3 Experimental Evidence

The theory is supported by modern experiments, particularly:

- The Vienna experiments of 2015, which closed all classical loopholes [8]
- The 'Big Bell Test' of 2018 with its unique methodology [4]
- Various analogies to classical field phenomena

1.4 Mathematical Framework

The fundamental field equation can be written as:

$$\Box\Psi + V(\Psi) = 0 \tag{1}$$

where $\Box = \frac{\partial^2}{\partial t^2} - c^2\nabla^2$ is the d'Alembert operator and $V(\Psi)$ a potential term ensuring the stability of field nodes. In connection with time-mass duality, this equation can be reformulated as:

$$\left(\frac{\partial^2}{\partial(t/T)^2} - \nabla^2 + m_H^2\right) h_T(x) = 0 \tag{2}$$

for scalar fields like the Higgs field, and for fermions according to the modified Dirac equation:

$$\left(i\gamma^0 \frac{\partial}{\partial(t/T)} + i\gamma^i\partial_i - m_f\right) \psi_T(x) = 0 \tag{3}$$

where the modified time derivative $\partial_{t/T} = \frac{\partial}{\partial(t/T)} = T\frac{\partial}{\partial t}$ is used [17]. This leads to a modified dispersion relation:

$$\omega_T^2 = \mathbf{k}^2 + \frac{m_H^2 c^4}{\hbar^2} \cdot T^2 \tag{4}$$

2 The Vacuum as Quantum Background

The vacuum is not simply 'nothing', but an active quantum background with defined physical properties [13].

2.1 Fundamental Constants of the Vacuum

The electric constant (ε_0) and the magnetic constant (μ_0) characterize the fundamental properties of the vacuum as quantum background. They determine the interactions in the electromagnetic field and are directly related to the speed of light:

$$c = \frac{1}{\sqrt{\varepsilon_0 \mu_0}} \tag{5}$$

These constants are not merely mathematical quantities but expressions of the physical structure of the quantum background [1]. In the time-mass duality theory, they directly influence the intrinsic time T and thus the energy scale of field nodes [17].

2.2 The Vacuum as Carrier of the Field

The quantum background serves as the carrier medium for the electromagnetic field and all other fundamental fields. This perspective makes it possible to:

- Explain the propagation of waves in 'empty' space
- Understand non-local correlations as field-inherent properties
- Overcome the limitations of classical particle concepts

The homogeneity of the vacuum and its properties (ε_0, μ_0) is crucial for the constancy of the speed of light and thus for the validity of special relativity [21].

3 Quantum Correlations in the Field Model

3.1 Polarization and Entanglement

The polarization of a photon can be described as a superposition of horizontal (H) and vertical (V) polarization [7]:

$$|\psi\rangle = \alpha|H\rangle + \beta e^{i\phi}|V\rangle \tag{6}$$

For entangled photon pairs, a joint state emerges like:

$$|\psi\rangle = \frac{1}{\sqrt{2}}(|H\rangle_A|H\rangle_B + |V\rangle_A|V\rangle_B) \tag{7}$$

In the field model, these states are not considered as isolated particle properties but as coherent field patterns extended over the entire space [24]. The correlation between measurements on particles A and B is an inherent property of this field pattern, not the result of instantaneous 'communication' between the particles.

3.2 Bell Inequalities and Local Realism

Bell inequalities and their experimental violation show the limits of local realistic theories [3]. In the field model, this can be understood as:

$$|E(a,b) - E(a,c)| \leq 1 + E(b,c) \tag{8}$$

The experimentally observed violation of this inequality (for certain angles a, b, c) demonstrates that the quantum world cannot be described by local hidden variables [2]. The field model provides a natural explanation for this: The fundamental field is non-local in its nature as it permeates all space.

3.3 The Vienna Experiment of 2015

The experiment by Anton Zeilinger's group in Vienna in 2015 was one of the first truly loophole-free tests of Bell's theorem [8]. It combined:

- Very high detection efficiency (>97% using SNSPDs)
- Sufficient spatial separation of measurements
- Fast, independent quantum random number generators

The observed violation of Bell's inequality with a statistical significance of 11.5 standard deviations confirms the non-locality of the quantum world. In the field model, this non-locality is a natural property of the fundamental field and its coherent structure [24].

3.4 The "Big Bell Test" of 2018

The "Big Bell Test" used decisions from over 100,000 people worldwide to control measurement settings in 13 different laboratories [4]. This human component addressed the free-choice loophole in a new way. The results showed violations of Bell inequalities with statistical significances up to 70 standard deviations.

These experiments confirm the non-local nature of the quantum world, which in the field model can be understood as an expression of the coherent field structure.

4 Field Theory and Instantaneity

4.1 Sound Waves as Analogy

Sound waves provide a helpful analogy for understanding the field concept [5]:

- Sound exists as a pressure wave permeating all space
- A microphone locally measures the vibration, but the wave itself is globally present
- The simultaneity of measurement at different microphones arises from the coherent structure of the sound wave

In the field model, entangled particles are like nodes in a global quantum field. The correlations between them are not 'action at a distance' but existing properties of the field that are only locally sampled during measurement. The Higgs field plays a special role here as a universal medium that not only mediates mass but also determines the intrinsic time scale of all particles, as described in the time-mass duality theory [17].

4.2 Why is this Analogy Important?

4.2.1 Resolution of the Paradox

Non-locality only appears paradoxical if particles are viewed as separate objects. In the field model, they are parts of a whole - like sound wave points in space [5].

4.2.2 Reality of the Field

The quantum field is not an abstraction but the fundamental entity [21]. Its properties (coherence, non-locality) are as real as those of a sound wave.

4.2.3 Experimental Consequence

When Alice and Bob measure entangled photons, they are essentially 'listening' with two microphones sampling the same sound wave. The correlations are already contained in the field, not created during measurement [24].

Within the framework of time-mass duality theory, these correlations gain an additional temporal dimension: The intrinsic time $T = \hbar/mc^2$ determines the time scale of field correlations and provides a natural explanation for the observed coherence times and their mass dependence [17]. The Higgs-Yukawa coupling

$$\mathcal{L}_{\text{Yukawa-T}} = -y_f \bar{\psi}_L \Phi_T \psi_R \cdot \gamma + \text{h.c.} \tag{9}$$

not only defines particle masses but simultaneously their intrinsic time scale according to

$$T_0 = \frac{\hbar\sqrt{2}}{y_f v c^2} \tag{10}$$

This relationship establishes a fundamental connection between the Higgs mechanism and quantum coherence.

5 Field Equations in Dual Formulation

Based on time-mass duality theory, modified field equations emerge that integrate variable mass and position the Higgs field as mediator between the two perspectives.

5.1 Modified Quantum Mechanics with Variable Mass

Unlike the conventional Schrödinger equation:

$$i\hbar\frac{\partial}{\partial t}\Psi(x,t) = \hat{H}\Psi(x,t) \tag{11}$$

where time (t) is treated as an external, classical parameter and mass as constant, time-mass duality leads to a fundamental modification:

$$i\hbar\frac{\partial}{\partial(t/T)}\Psi = \hat{H}\Psi \tag{12}$$

This modified equation uses intrinsic time $T = \hbar/mc^2$ and considers that time evolution is no longer uniform for all objects but depends on their mass. For systems with variable mass, this can be rewritten as:

$$i\hbar\frac{\partial}{\partial t}\Psi(x,t) = \hat{H}(m(t))\Psi(x,t) \tag{13}$$

For multi-particle systems with different masses, as occur in entangled systems, the modified equation takes the form:

$$i(m_1 + m_2)c^2\frac{\partial}{\partial t}\Psi(x_1, x_2, t) = \hat{H}\Psi(x_1, x_2, t) \tag{14}$$

This extension has profound implications for our understanding of quantum correlations and the apparent instantaneity of entangled states [17].

5.2 Klein-Gordon Equation and Higgs Field

The standard Klein-Gordon equation for the Higgs boson is:

$$(\Box + m_H^2)h(x) = 0 \tag{15}$$

In the time-mass duality picture, it becomes:

$$\left(\frac{\partial^2}{\partial(t/T)^2} - \nabla^2 + m_H^2\right)h_T(x) = 0 \tag{16}$$

This leads to a modified dispersion relation:

$$\omega_T^2 = \mathbf{k}^2 + \frac{m_H^2c^4}{\hbar^2}\cdot T^2 \tag{17}$$

This modification means that wave propagation in the Higgs field itself depends on intrinsic time, which could lead to measurable deviations from the standard model.

5.3 Dirac Equation for Fermions

The Dirac equation for fermions in the standard model:

$$(i\gamma^\mu\partial_\mu - m_f)\psi(x) = 0 \tag{18}$$

becomes in the time-mass duality picture:

$$\left(i\gamma^0\frac{\partial}{\partial(t/T)} + i\gamma^i\partial_i - m_f\right)\psi_T(x) = 0 \tag{19}$$

5.4 Variable Mass as Hidden Variable

A particularly fascinating consequence of this consideration is that variable mass could serve as a fundamental hidden variable explaining the apparent indeterminism of quantum mechanics. Unlike classical hidden variable theories, which have been largely ruled out by Bell experiments, variable mass in time-mass duality is a fundamental quantity already anchored in physics.

The modified Lagrangian density formalizing this approach is:

$$\mathcal{L}_{\text{total}} = \mathcal{L}_{\text{Standard}} + \mathcal{L}_{\text{intrinsic}} \tag{20}$$

where the additional term accounts for intrinsic time:

$$\mathcal{L}_{\text{intrinsic}} = \bar{\psi}\left(i\hbar\gamma^0 \frac{\partial}{\partial(t/T)} - i\hbar\gamma^0 \frac{\partial}{\partial t}\right)\psi \tag{21}$$

This extension might pave the way for a deterministic quantum theory confirming Einstein's intuition that 'God does not play dice' [17].

6 Field Theory and Locality

6.1 Local-realistic Models and Hidden Variables

In a local-realistic theory, measurement results would have to be determined by local hidden variables λ [3]. The correlation function would then be:

$$E(a,b) = \int A(a,\lambda)B(b,\lambda)\rho(\lambda)d\lambda \tag{22}$$

Bell experiments however show that this assumption cannot explain the observed correlations [2].

6.2 The Wave Field Model as Alternative

The wave field model offers an alternative that can explain quantum correlations without violating locality [5]:

- The entangled system is considered as a unified, coherent field.
- Measurements at different locations are local samplings of this global field.
- The correlations are inherent properties of the field, not the result of instantaneous communication.

This model is consistent with time-mass duality theory, as both approaches consider the fundamental field and its inherent correlations as primary reality [17]. The Higgs field can be understood in this context as a universal medium described by the modified Lagrangian density

$$\mathcal{L}_{\text{Higgs-T}} = (D_{T\mu}\Phi_T)^\dagger(D_T^\mu\Phi_T) - V_T(\Phi_T) \tag{23}$$

The covariant derivative

$$D_{T\mu} = \partial_{t/T,\mathbf{x}} + ig\mathbf{A}_\mu \tag{24}$$

contains the temporal modification regarding intrinsic time, making the Higgs field the central mediator between space, time and mass.

6.3 Field Coherence and Non-Locality

Non-locality is not interpreted as 'spooky action at a distance' in the field model but as an expression of the coherence of an extended system [24]:

- The entangled wave field directly connects the measurement locations through its coherent properties.
- The apparent 'communication' is in this model not information transfer but the result of a common field state.

Time-mass duality theory complements this picture by identifying intrinsic time T as the characteristic time scale of field correlations. This explains the observed coherence times and their mass dependence [17]. For quantum systems of different mass, the coherence times τ_1 and τ_2 of two otherwise identical quantum systems with masses m_1 and m_2 should follow the ratio:

$$\frac{\tau_1}{\tau_2} = \frac{m_2}{m_1} \tag{25}$$

This prediction could be verified by precision experiments with entangled particles of different mass and would establish a direct connection between classical non-locality and the mass-dependent time scale of the quantum system.

7 Field Theory and Relativity

7.1 The Wave Field Model and Relativity

The wave field model can be reconciled with relativity [12]:

- No true information transfer: The correlations between entangled particles do not arise through signal transmission.
- Locality of measurement results: Each measurement value is determined locally, even if the results are globally correlated.
- Extended field: The field extends over all space but is limited by the light cone structure of spacetime.

7.2 Relativistic Quantum Field Theory and Variable Mass

The wave field model is also compatible with relativistic quantum field theory [21]:

- Entanglement in spacetime: Quantum correlations are fully describable in relativistic quantum field theory.
- No absolute reference time: Relativity requires that there is no preferred time coordinate. The wave field model requires no such assumption.

These considerations show that the concepts of locality and realism must be reinterpreted without violating fundamental principles like relativity. Time-mass duality theory offers a promising approach here by connecting two complementary perspectives:

- The standard model with constant mass and time dilation (the usual relativistic framework)

- The complementary model with absolute time and variable mass

This duality enables a new interpretation of relativistic phenomena and quantum processes, with the Higgs field acting as mediator between both descriptions. The modified dispersion relation

$$\omega_T^2 = \mathbf{k}^2 + \frac{m_H^2 c^4}{\hbar^2} \cdot T^2 \tag{26}$$

shows how this duality manifests in wave propagation [17].

7.3 The Instantaneity Paradox and the Role of Variable Mass

The apparent instantaneity of quantum correlations remains one of the most persistent paradoxes of quantum mechanics. The idea that measurements on entangled particles, regardless of their spatial separation, instantaneously yield correlated results seems to contradict relativity, which prohibits superluminal information transfer.

Time-mass duality theory offers an elegant solution to this paradox:

- In conventional consideration, quantum correlations appear instantaneous because we view time as a universal, constant parameter.
- Within the framework of time-mass duality with variable mass, however, it becomes apparent that the mass-dependent intrinsic time $T = \hbar/mc^2$ represents a more fundamental time scale than external laboratory time.
- The correlations do not occur instantaneously in the system's intrinsic time but follow a dynamics described by the modified Schrödinger equation

$$i\hbar \frac{\partial}{\partial(t/T)} \Psi = \hat{H}\Psi \tag{27}$$

This reformulation resolves the paradox naturally: What appears as instantaneous action in laboratory time is actually a process occurring in the intrinsic time of the quantum system, with variable mass acting as hidden variable [17]. The modified Lagrangian density

$$\mathcal{L}_{\text{intrinsic}} = \bar{\psi}\left(i\hbar\gamma^0 \frac{\partial}{\partial(t/T)} - i\hbar\gamma^0 \frac{\partial}{\partial t}\right)\psi \tag{28}$$

formally captures the discrepancy between time evolution in absolute time and mass-dependent intrinsic time.

8 What We Know and What's Missing

8.1 What We Know: The Established Findings

- **Non-locality is real**: Bell experiments show that entangled particles exhibit correlations that cannot be explained by local hidden variables [10].
- **No classical communication**: The correlations arise without energy or information being exchanged between the particles [8].
- **Loopholes are closed**: Experiments like Delft (2015) [10], Micius (2017) [23] and the BIG Bell Test (2018) [4] closed locality, detection and freedom-of-choice loopholes.

8.2 What's Missing: The Open Question of Time Measurement

Despite all progress, the **temporality of correlations** remains unclear:

- **Correlation $\neq$ Causality**: The experiments measure *statistical agreements*, not the *causal speed* of a physical mechanism [19].
- **Relativity of simultaneity**: The idea of 'absolute instantaneity' is relativistically problematic [12].
- **Technical limitations**: To measure the 'speed' of correlations, one would need to determine the exact timing of the state collapse of both particles with enormous precision.

Time-mass duality theory offers a promising approach here: If intrinsic time T is the fundamental time scale, the seemingly instantaneous correlations could be understood as expression of a common intrinsic time evolution [17].

One of the central predictions of this theory is that the coherence times τ of different particles should stand in a certain ratio to their masses:

$$\frac{\tau_1}{\tau_2} = \frac{m_2}{m_1} \tag{29}$$

This would directly link the modified dispersion relation $\omega_T^2 = k^2 + (m^2c^4/\hbar^2) \cdot T^2$ with correlation behavior and offers an experimentally verifiable approach to the nature of quantum time.

8.3 Why This Matters: The Conceptual Gap

- **Interpretations of quantum mechanics**:
  - The **Copenhagen interpretation** describes collapse as instantaneous but not as physical process [18].
  - The **Bohmian mechanics** postulates a non-local pilot wave - yet its 'speed' is not measurable [5].
  - The **Many-worlds interpretation** avoids collapse completely [20].

Without direct time measurement, these interpretations remain metaphysical speculations. Field theory on the other hand offers a physically interpreted model based on the time derivative $\partial_{t/T} = T(\partial/\partial t)$ that directly links quantum time with mass [17].

8.4 Possible Solution Approaches

To realize 'true time measurement', one would need:

1. **Entangled quantum clocks**: Clocks whose time measurement is correlated through entanglement [11].
2. **Cosmic Bell tests**: Using light from quasars to extend the time axis of correlations [9].
3. **Quantum networks with satellites**: Experiments over intercontinental distances combined with optical clocks [23].

These experiments could also directly test the predicted effects of time-mass duality theory, including:

- The modified energy-momentum relation: $E^2 = (pc)^2 + (mc^2)^2 + \alpha\hbar c/T$
- The photon energy loss: $E(r) = E_0 e^{-\alpha r}$ with $\alpha = \frac{H_0}{c}$
- The modified gravitational potential: $\Phi(r) = -\frac{GM}{r} + \kappa r$
- The nonlinear Higgs couplings: $g_H \propto m\left(1 + \delta \cdot \ln\left(\frac{m}{m_0}\right)\right)$

Particularly the absorption coefficient $\alpha = \frac{H_0}{c} \approx 2.3 \times 10^{-28}$ m^{-1} and the gravitational modification $\kappa \approx 4.8 \times 10^{-7}$ GeV/cm$\cdot$s^{-2} could leave detectable signatures in cosmological observations [17].

9 Concluding Remarks

9.1 Quantum Mechanics as Tool

Quantum mechanics has proven to be an incredibly precise and useful mathematical tool for making predictions about experiments [6]. It successfully describes how quantum objects behave without necessarily revealing the 'true nature' of these objects.

9.2 Field Theory as More Realistic Model

Field theories, as used in electrodynamics and quantum field theory, might be closer to reality as they describe the world as a continuum present everywhere [22]. This harmonizes better with the notion that wave fields are more fundamental than particles.

9.3 The Higgs Vacuum as Active Quantum Background

A particularly important extension of our understanding comes from considering the Higgs vacuum as active quantum background. In the standard model, the Higgs field generates through spontaneous symmetry breaking a vacuum expectation value

$$\langle \Phi \rangle = \frac{1}{\sqrt{2}} \begin{pmatrix} 0 \\ v \end{pmatrix} \tag{30}$$

present everywhere in space. In time-mass duality theory, this omnipresent field gains additional significance: It defines not only the masses of all elementary particles but also their intrinsic time scales according to

$$T_0 = \frac{\hbar}{m_0 c^2} = \frac{\hbar\sqrt{2}}{y_f v c^2} \tag{31}$$

This dual role of the Higgs field as mass generator and time scale mediator offers an elegant mechanism to understand the apparent paradoxes of quantum correlations. The intrinsic Higgs-time relationship implies that correlations between particles require no mysterious action at a distance but emerge as natural properties of a fundamental field that mediates both mass and time [17].

9.4 This Perspective Resolves Several Apparent Paradoxes

- **The 'spooky action at a distance' becomes naturally explainable**:
  - The field is present everywhere
  - Changes are properties of the total field
  - No true 'action at a distance' needed
- **Compatibility with relativity**:
  - No information transfer in classical sense
  - The field itself respects relativistic limits
  - Correlations are field properties

9.5 Connection to Time-Mass Duality Theory

The field theory presented here ideally complements time-mass duality theory [17]:

- Both consider the fundamental field as primary reality
- The intrinsic time $T = \hbar/mc^2$ provides the natural time scale for field correlations
- The field node structure explains both particle properties and entanglement phenomena
- The modified field equations provide a mathematical framework for the described phenomena

The modified Lagrangian density for the Higgs field in time-mass duality theory:

$$\mathcal{L}_{\text{Higgs-T}} = (D_{T\mu}\Phi_T)^\dagger(D_T^\mu\Phi_T) - V_T(\Phi_T) \tag{32}$$

and the modified Yukawa coupling:

$$\mathcal{L}_{\text{Yukawa-T}} = -y_f\bar{\psi}_L\Phi_T\psi_R \cdot \gamma + \text{h.c.} \tag{33}$$

provide a formal framework to understand quantum correlations and their apparent instantaneity as properties of the fundamental field. The intrinsic time-Higgs relationship $T_0 = \frac{\hbar\sqrt{2}}{y_f v c^2}$ directly connects the Higgs mechanism with the time structure of the field.

Together, these theories offer a conceptual framework that makes quantum phenomena appear more natural and embeds the apparent paradoxes of quantum mechanics into a more comprehensive understanding of reality.

The modified energy density and the resulting modified energy-momentum relation $E^2 = (pc)^2 + (mc^2)^2 + \alpha\hbar c/T$ could have experimentally verifiable consequences, particularly in quantum gravity and cosmological observations. Especially relevant is the predicted photon energy loss $E(r) = E_0 e^{-\alpha r}$ with $\alpha = \frac{H_0}{c}$, which might allow a new interpretation of the observed cosmic redshift [17].

10 Conclusion

Bell experiments have proven the **non-locality** of the quantum world - but they have not shown that these correlations are 'instantaneous' or 'faster than light' [19].

- **What's missing**: An experimental method to measure the *causal time sequence* of quantum correlations, free from interpretation ambiguity.
- **What remains**: Quantum mechanics forces us to abandon classical notions of time and causality. Until 'true time measurement' succeeds, the question about the **nature of quantum time** remains one of physics' greatest mysteries.

"Time is what you read on a clock" - Albert Einstein.
In the quantum world, however, there is no clock measuring the collapse of entanglement.

Time-mass duality theory might close this gap by considering intrinsic time T as a fundamental quantity directly linked with the structure of the quantum field and its correlations [17]. In particular, the Higgs-mediated intrinsic time

$$T_0 = \frac{\hbar\sqrt{2}}{y_f v c^2} \tag{34}$$

provides a natural time scale for each elementary particle that determines its coherence time and correlation properties. This might bridge the gap between the apparent instantaneity of quantum correlations and the relativistic causality structure of our world.

References

[1] Aitchison, I. J. R. (2004). *An informal introduction to gauge field theories*. Cambridge University Press.

[2] Aspect, A., Grangier, P., & Roger, G. (1982). Experimental realization of Einstein-Podolsky-Rosen-Bohm Gedankenexperiment: A new violation of Bell's inequalities. *Physical Review Letters*, 49(2), 91-94.

[3] Bell, J. S. (1964). On the Einstein Podolsky Rosen paradox. *Physics Physique Fizika*, 1(3), 195-200.

[4] BIG Bell Test Collaboration. (2018). Challenging local realism with human choices. *Nature*, 557(7704), 212-216.

[5] Bohm, D. (1980). *Wholeness and the Implicate Order*. Routledge.

[6] Feynman, R. P. (1965). *The Character of Physical Law*. MIT Press.

[7] Fox, M. (2006). *Quantum Optics: An Introduction*. Oxford University Press.

[8] Giustina, M., Versteegh, M. A., Wengerowsky, S., Handsteiner, J., Hochrainer, A., Phelan, K., ... & Zeilinger, A. (2015). Significant-loophole-free test of Bell's theorem with entangled photons. *Physical Review Letters*, 115(25), 250401.

[9] Handsteiner, J., Friedman, A. S., Rauch, D., Gallicchio, J., Liu, B., Hosp, H., ... & Zeilinger, A. (2017). Cosmic Bell test: measurement settings from Milky Way stars. *Physical Review Letters*, 118(6), 060401.

[10] Hensen, B., Bernien, H., Dréau, A. E., Reiserer, A., Kalb, N., Blok, M. S., ... & Hanson, R. (2015). Loophole-free Bell inequality violation using electron spins separated by 1.3 kilometres. *Nature*, 526(7575), 682-686.

[11] Jozsa, R., Abrams, D. S., Dowling, J. P., & Williams, C. P. (2000). Quantum clock synchronization based on shared prior entanglement. *Physical Review Letters*, 85(9), 2010-2013.

[12] Maudlin, T. (2011). *Quantum Non-Locality and Relativity: Metaphysical Intimations of Modern Physics*. John Wiley & Sons.

[13] Milonni, P. W. (1994). *The Quantum Vacuum: An Introduction to Quantum Electrodynamics*. Academic Press.

[14] Pascher, J. (2024). *Time-Mass Duality: A New Approach to Unifying Fundamental Forces*.

[15] Pascher, J. (2024). *Mathematical Formulation of the Higgs Mechanism in Time-Mass Duality*.

[16] Pascher, J. (2024). *The Necessity of Extending Standard Quantum Mechanics and Quantum Field Theory*.

[17] Pascher, J. (2024). *Time-Mass Duality: A New Approach to Unifying Fundamental Forces*. This essay derives the fundamental relationship between intrinsic time and mass.

[18] Schlosshauer, M. (2013). *Elegance and Enigma: The Quantum Interviews*. Springer.

[19] Shimony, A. (2017). Bell's theorem. In *The Stanford Encyclopedia of Philosophy* (Fall 2017 Edition), Edward N. Zalta (ed.).

[20] Wallace, D. (2012). *The Emergent Multiverse: Quantum Theory according to the Everett Interpretation*. Oxford University Press.

[21] Weinberg, S. (1995). *The Quantum Theory of Fields, Volume 1: Foundations*. Cambridge University Press.

[22] Wilczek, F. (2008). *The Lightness of Being: Mass, Ether, and the Unification of Forces*. Basic Books.

[23] Yin, J., Cao, Y., Li, Y. H., Liao, S. K., Zhang, L., Ren, J. G., ... & Pan, J. W. (2017). Satellite-based entanglement distribution over 1200 kilometers. *Science*, 356(6343), 1140-1144.

[24] Zeilinger, A. (2010). *Dance of the Photons: From Einstein to Quantum Teleportation.* Farrar, Straus and Giroux.