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Physical Reality and Conditional Probability Decomposition of Microscopic Particles

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Abstract

We propose a novel interpretation of quantum mechanics in which microscopic particles possess definite positions, momenta, and spins at every moment, independent of measurement. These physical quantities are not determined by hidden variables but are randomly realized according to the wave function's probability distribution. Measurement outcomes reflect the particle's actual state rather than a wave-function collapse. By treating the measured and measuring systems as a single composite system, we introduce a conditional probability decomposition of the wave function that preserves interference without invoking instantaneous collapse. Potential experimental tests of the conditional probability decomposition are discussed. This framework provides a coherent understanding of quantum measurement, nonlocal correlations, and the EPR paradox, while remaining consistent with all standard quantum predictions including Bell inequality violations and GHZ state.

Keywords: quantum mechanics interpretation; conditional probability decomposition; realism; bell inequality; GHZ state

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Microscopic systems exhibit phenomena such as complementarity, quantum interference, the uncertainty principle, and the violation of Bell's inequalities [1–3], which are fundamentally distinct from classical macroscopic behavior. Quantum mechanics successfully describes these phenomena, however, a consistent account of the measurement process remains elusive. Topics including quantum entanglement [4–6], the EPR paradox [7–10], and delayed-choice quantum erasers [11–13] highlight the centrality of measurement and wave-function collapse in quantum theory.

Consider a particle arriving at a double-slit at time t_1 with wave function:

$$\psi(\vec{x}, t_1) = \frac{1}{\sqrt{2}}[\psi_1(\vec{x}, t_1) + \psi_2(\vec{x}, t_1)], \tag{1}$$

where ψ_1 and ψ_2 are normalized wave functions localized at the left and right slits, respectively. Placing Wilson cloud chambers behind the slits provides which-path information. Standard interpretation assumes wave-function collapse

$$\psi_c(\vec{x}, t_1) = \psi_1(\vec{x}, t_1) \quad \text{or} \quad \psi_c(\vec{x}, t_1) = \psi_2(\vec{x}, t_1). \tag{2}$$

This leads to a conceptual dilemma: quantum mechanics predicts wave-function evolution, but the specific collapse outcome remains fundamentally unpredictable.

To resolve these conceptual issues within the standard quantum framework, it is essential to treat the incident particle and the cloud chamber particles as a single, composite system. The initial wave function of the total system at time t_1 is given by

$$\begin{aligned}
\psi^i(\vec{x},t_1) &= \frac{1}{\sqrt{2}}\left[\psi_1^i(\vec{x},t_1)+\psi_2^i(\vec{x},t_1)\right]\psi^i(\vec{x}_{Li},...,\vec{x}_{Ln},t_1)\psi^i(\vec{x}_{R1},...,\vec{x}_{Rn},t_1) \\
&= \frac{1}{\sqrt{2}}\psi_1^i(\vec{x},t_1)\psi^i(\vec{x}_{L1},...,\vec{x}_{Ln},t_1)\psi^i(\vec{x}_{R1},...,\vec{x}_{Rn},t_1) \\
&\quad +\frac{1}{\sqrt{2}}\psi_2^i(\vec{x},t_1)\psi^i(\vec{x}_{L1},...,\vec{x}_{Ln},t_1)\psi^i(\vec{x}_{R1},...,\vec{x}_{Rn},t_1), \qquad (3)
\end{aligned}$$

where $\vec{X}_L = \{\vec{x}_{L1},\ldots,\vec{x}_{Ln}\}$ and $\vec{X}_R = \{\vec{x}_{R1},\ldots,\vec{x}_{Rn}\}$ represent the coordinates of the particles in the left and right chambers, respectively. $\psi^i(\vec{x}_{L1},...,\vec{x}_{Ln},t_1)$ and $\psi^i(\vec{x}_{R1},...,\vec{x}_{Rn},t_1)$ are their corresponding normalized initial wave functions. After the incident particle enters the chambers (the measurement process) and exits at a later time t_2, the final state evolves into an entangled superposition:

$$\begin{aligned}
\psi^f(\vec{x},t_2) &= \frac{1}{\sqrt{2}}\psi_1^f(\vec{x},t_2)\psi^f(\vec{x}_{L1},...,\vec{x}_{Ln},t_2)\psi^i(\vec{x}_{R1},...,\vec{x}_{Rn},t_2) \\
&\quad +\frac{1}{\sqrt{2}}\psi_2^f(\vec{x},t_2)\psi^i(\vec{x}_{L1},...,\vec{x}_{Ln},t_2)\psi^f(\vec{x}_{R1},...,\vec{x}_{Rn},t_2). \qquad (4)
\end{aligned}$$

This expression reflects the fact that the incident particle has an equal probability of interacting with and leaving a record in either chamber. The resulting probability for detecting the particle on the screen with momentum $\vec{p}$ is then

$$f = |\Psi^f(\vec{p})|^2 + |\Psi^f(\vec{p})|^2[\cos(\vec{p}\cdot(\vec{x}_1-\vec{x}_2))\mathrm{Re}(W) + \sin(\vec{p}\cdot(\vec{x}_1-\vec{x}_2))\mathrm{Im}(W)], \qquad (5)$$

where the factor W is defined by the overlap integral

$$\begin{aligned}
W &= \int d^3x_{L1}...d^3x_{Ln}d^3x_{R1}...d^3x_{Rn} \\
&\quad \times\psi^{f*}(\vec{x}_{L1},...,\vec{x}_{Ln},t_2)\psi^i(\vec{x}_{L1},...,\vec{x}_{Ln},t_2)\psi^{i*}(\vec{x}_{R1},...,\vec{x}_{Rn},t_2)\psi^f(\vec{x}_{R1},...,\vec{x}_{Rn},t_2). \qquad (6)
\end{aligned}$$

Crucially, $W = 1$ without chambers. If the initial and final wave functions of the particles in the left chamber $\psi^i(\vec{x}_{L1},...,\vec{x}_{Ln},t_2)$ and $\psi^f(\vec{x}_{L1},...,\vec{x}_{Ln},t_2)$, or in the right chamber $\psi^i(\vec{x}_{R1},...,\vec{x}_{Rn},t_2)$ and $\psi^f(\vec{x}_{R1},...,\vec{x}_{Rn},t_2)$, are orthogonal, the factor W vanishes. This eliminates the interference term in Eq. (5), causing the disappearance of the interference fringes. It is vital to note that the formalism still describes the particle as being in a superposition of having passed through both chambers. The absence of interference is because of the orthogonal wave function rather than the selection of a single path.

However, this no-collapse explanation faces its own challenges. It struggles to explain the emergence of discrete particle trajectories, such as distinct tracks observed in a cloud chamber. More fundamentally, it does not fully resolve the quantum measurement problem: it describes a universe of evolving potentials but cannot explain why only one of these possibilities becomes our concrete reality. We therefore propose an interpretation that introduces the concept of real particles existing alongside their wave functions. In this view, a particle at any given time possesses a specific position and momentum. These definite physical quantities are not determined by classical hidden variables, but rather appear randomly in accordance with the probabilities dictated by the wave function. Consequently, the appearance of a particle track in a chamber is therefore direct outcome of the particle's definite position and momentum at the moment of interaction. Crucially, these real properties exist independently of measurement. Whether or not a measurement is performed, a particle randomly possesses definite properties at every moment.

To better understand the double-slit experiments, let's consider a one-dimensional quantum system with an initial state given by the Dirac δ-function, $\psi(x,0) = \delta(x-x_0)$. The time evolution of the wave function is governed by the propagator $K(x,t;x')$, defined through

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$$\psi(x,t) = \int_{-\infty}^{\infty} K(x,t;x')\,\psi(x',0)\,dx'. \tag{7}$$

Due to the localized nature of the initial condition, this expression reduces to $\psi(x,t) = K(x,t;x_0)$. For a free particle described by the Hamiltonian $H = p^2/(2m)$, the propagator can be evaluated explicitly as [14–16]

$$K(x,t;x_0) = \left(\frac{m}{2\pi i\hbar t}\right)^{1/2} \exp\left[\frac{im(x-x_0)^2}{2\hbar t}\right]. \tag{8}$$

This result shows that an initially point-localized state evolves into a spatially extended wave function with a quadratic phase, reflecting the dispersive nature of free quantum dynamics. At each intermediate time, every point in the spatial distribution acts as a source of probability amplitude, which propagates to all other points at later times and interferes coherently with contributions from other points.

To formalize the contribution of individual initial positions, consider a system with initial state

$$\psi(x,0) = \sum_i c_i \delta(x - x_i), \tag{9}$$

where c_i are complex coefficients representing the relative amplitudes of the particle being initially localized at x_i. The time evolution under the propagator $K(x,t;x_i)$ is

$$\psi(x,t) = \sum_i c_i K(x,t;x_i). \tag{10}$$

The total probability density is

$$|\psi(x,t)|^2 = \sum_i |c_i K(x,t;x_i)|^2 + \sum_{i\neq j} \mathrm{Re}\left(c_i c_j^* K(x,t;x_i) K^*(x,t;x_j)\right). \tag{11}$$

We decompose this total probability into contributions from each initial position x_i:

$$P(x,t|x_i) = |c_i K(x,t;x_i)|^2 + \frac{|c_i K(x,t;x_i)|^2}{\sum_j |c_j K(x,t;x_j)|^2} \sum_{j\neq k} \mathrm{Re}\left(c_j c_k^* K(x,t;x_j) K^*(x,t;x_k)\right). \tag{12}$$

This decomposition has two key properties:

1. Sum over initial points reproduces the total probability:

$$\sum_i P(x,t|x_i) = |\psi(x,t)|^2, \tag{13}$$

since the weighting factor $\frac{|c_i K(x,t;x_i)|^2}{\sum_j |c_j K(x,t;x_j)|^2}$ ensures that the entire interference contribution is correctly partitioned.

2. Non-negativity: Each $P(x,t|x_i) \geq 0$, because

$$P(x,t|x_i) = |c_i K(x,t;x_i)|^2 \frac{|\sum_j c_j K(x,t;x_j)|^2}{\sum_j |c_j K(x,t;x_i)|^2} \geq 0. \tag{14}$$

Physically, $P(x,t|x_i)$ represents the probability density that a particle, initially localized at x_i, is observed at position x at time t, including interference with all other initial components. This framework naturally aligns with the interpretation in which a particle always possesses definite position and momentum, while the statistical distribution over many repetitions arises from the linear superposition of the evolved wave functions. In particular, it provides a clear way to understand how each possible initial location contributes to the observed interference pattern on the screen, consistent with the no-collapse evolution of the combined particle–apparatus system.

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Our approach differs from conventional interpretations of quantum mechanics in several ways. In standard quantum mechanics, the particle has no definite position and momentum, and interference disappears when which-path information is obtained; there is also no decomposition of total probability into contributions from individual initial points. The many-worlds interpretation [17] avoids collapse and maintains interference within parallel branches, but it lacks a single, physically realized particle trajectory and a non-negative conditional probability decomposition. Bohmian mechanics [18] assigns deterministic trajectories guided by a nonlocal wave function; interference emerges through the guiding equation, and trajectories are not random. In contrast, our framework combines a real particle with definite but randomly realized position and momentum with the unitary evolution of the wave function, while uniquely providing the conditional probability decomposition $P(x, t|x_i)$, which attributes interference contributions to each initial point in a physically meaningful way. Therefore, our approach offers a novel interpretation of quantum phenomena. The framework reproduces all standard quantum statistical predictions while providing a physically intuitive and mathematically consistent description of quantum dynamics and measurement. By bridging the gap between deterministic evolution and probabilistic observation, it distinguishes itself from standard quantum mechanics, the many-worlds interpretation, and Bohmian mechanics.

The decomposition of the total probability in Eq. (12) is consistent with strong measurements, in which the total wave function takes the form given in Eq. (4) and the interference disappears because of the orthogonal wave functions of measuring system. Although complete experimental verification of these conditional distributions is fundamentally limited by the complementarity principle, future experiments using weak measurements may allow statistical reconstruction of the conditional distributions and could potentially probe a continuous transition from weak to strong measurement regimes. Such studies would provide indirect support for the physical reality of particle properties and offer a unified description of the measurement process, connecting the stochastic evolution of particle states with the unitary evolution of the wave function. Experimental efforts along these lines, in the spirit of weak-measurement reconstructions of Bohmian trajectories [19], could help reveal the statistical signature of the proposed conditional probabilities and the classical-like evolution of particle properties.

With the clear understanding of the measurement in quantum mechanics, we can have a reasonable explanation for EPR paradox [7,8]. For example, the two entangled spin-1/2 particles form a spin-0 state. The initial wave function of a spin-0 system is

$$\psi^i(S=0) = \frac{1}{\sqrt{2}}[\psi_1(+u)\psi_2(-u) - \psi_1(-u)\psi_2(+u)], \tag{15}$$

where $+u$ and $-u$ are for the positive and negative spins along any axis. According to our interpretation of measurement, when we measure the spin of one particle, say particle 2, the wave function of the final system including all the interacting particles turns into

$$\psi^f = \frac{1}{\sqrt{2}}[\psi_1(+u)\psi_2(-u)\varphi(\vec{x}_1, ..., \vec{x}_n, t) - \psi_1(-u)\psi_2(+u)\phi(\vec{x}_1, ..., \vec{x}_n, t)], \tag{16}$$

where $\phi(\vec{x}_1, ..., \vec{x}_n, t)$ and $\varphi(\vec{x}_1, ..., \vec{x}_n, t)$ are the wave functions of the particles in the measuring device after interacting with particle 2 with spin $+u$ and $-u$, respectively. If the wave function $\varphi(\vec{x}_1, ..., \vec{x}_n, t)$ and $\phi(\vec{x}_1, ..., \vec{x}_n, t)$ are orthogonal for any operator $\hat{O}$, i.e.

$$\int d^3x_1...d^3x_n \varphi^*(\vec{x}_1, ..., \vec{x}_n, t)\hat{O}\phi(\vec{x}_1, ..., \vec{x}_n, t) = 0, \tag{17}$$

there will be no entanglement between the first and second terms of Eq. (16). From the wave function of Eq. (16), it is evident that the spin of particle 1 remains unchanged when the spin of particle 2 is measured. In other words, no information is transferred instantly from particle 2 to particle 1. In our interpretation, besides the wave function, the particle pair possesses definite opposite spins at the moment of separation. The wave function of this system is global and nonlocal, whereas the spin of each particle constitutes its

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local property. Similar as its position and momentum, a particle's definite spin, which is set randomly by the entangled wave function, remains fixed unless altered by local interactions. Consequently, the EPR paradox can be readily resolved without invoking hidden variables.

Our interpretation of quantum measurement provides a physically intuitive resolution of the EPR paradox without invoking wave-function collapse or local hidden variables. In this framework, each particle has a definite local property (such as spin) at the time of separation. At the same time, the nonlocal wave function encodes correlations between particles, ensuring that joint measurement statistics reproduce the predictions of quantum mechanics. While individual measurement outcomes are definite and locally random, the correlations responsible for the violation of Bell inequalities [20–29] arise naturally from the nonlocality of the wave function. The spin of each particle is not determined by a local hidden variable λ; instead, it is randomly generated according to the probability distribution of the global entangled two-particle wave function. Let a and a' denote two possible measurement settings for the first particle (Alice), and b and b' for the second particle (Bob). The expectation values of the spin correlations, $E(a,b)$, $E(a,b')$, $E(a',b)$, and $E(a',b')$, match exactly the predictions of quantum mechanics.

We have pointed out that the expectation values of our theory are the same as those of quantum mechanics. We still need to explain that our scenario is consistent with each individual measurement. Since the GHZ state [30–34] provides a more stringent test than Bell inequalities, we now give a clear explanation of the consistency between pre-assigned spins and the GHZ state. The GHZ state of three entangled particles is expressed as

$$|\mathrm{GHZ}\rangle = \frac{1}{\sqrt{2}}[|\uparrow_z\uparrow_z\uparrow_z\rangle + |\downarrow_z\downarrow_z\downarrow_z\rangle]. \tag{18}$$

Because the eigenvalues of $\sigma_x\sigma_x\sigma_x$ is $+1$, while the eigenvalues of $\sigma_x\sigma_y\sigma_y$, $\sigma_y\sigma_x\sigma_y$, and $\sigma_y\sigma_y\sigma_x$ are all -1, one might argue that these four conditions cannot be simultaneously satisfied if the spins of each particle are predetermined. In our view, the GHZ state can be expressed in terms of eigenstates of σ_x of each particle as

$$\begin{aligned}|\mathrm{GHZ}\rangle = \frac{1}{4} \quad & [(|\uparrow_x\uparrow_x\uparrow_x\rangle + |\uparrow_x\uparrow_x\downarrow_x\rangle + |\uparrow_x\downarrow_x\uparrow_x\rangle + |\uparrow_x\downarrow_x\downarrow_x\rangle + |\downarrow_x\uparrow_x\uparrow_x\rangle + |\downarrow_x\uparrow_x\downarrow_x\rangle \\ & +|\downarrow_x\downarrow_x\uparrow_x\rangle + |\downarrow_x\downarrow_x\downarrow_x\rangle) + (|\uparrow_x\uparrow_x\uparrow_x\rangle - |\uparrow_x\uparrow_x\downarrow_x\rangle - |\uparrow_x\downarrow_x\uparrow_x\rangle + |\uparrow_x\downarrow_x\downarrow_x\rangle \\ & -|\downarrow_x\uparrow_x\uparrow_x\rangle + |\downarrow_x\uparrow_x\downarrow_x\rangle + |\downarrow_x\downarrow_x\uparrow_x\rangle - |\downarrow_x\downarrow_x\downarrow_x\rangle)]. \end{aligned} \tag{19}$$

Each state in the above equation can then be written in terms of eight eigenstates of $\sigma_y\sigma_y\sigma_y$. For example,

$$\begin{aligned}|\uparrow_x\uparrow_x\uparrow_x\rangle = \quad & -\frac{1+i}{4}|\uparrow_y\uparrow_y\uparrow_y\rangle + \frac{1-i}{4}|\uparrow_y\uparrow_y\downarrow_y\rangle + \frac{1-i}{4}|\uparrow_y\downarrow_y\uparrow_y\rangle + \frac{1+i}{4}|\uparrow_y\downarrow_y\downarrow_y\rangle \\ & +\frac{1-i}{4}|\downarrow_y\uparrow_y\uparrow_y\rangle + \frac{1+i}{4}|\downarrow_y\uparrow_y\downarrow_y\rangle + \frac{1+i}{4}|\downarrow_y\downarrow_y\uparrow_y\rangle - \frac{1-i}{4}|\downarrow_y\downarrow_y\downarrow_y\rangle. \end{aligned} \tag{20}$$

Therefore, the original GHZ state can be separated into 128 (16×8) branches, each corresponding to a specific predetermined spin assignment. We then obtain the conditional probability using a formula similar to Eq. (12)

$$P(\phi_m|\psi_i) = |c_i K_{mi}|^2 + \frac{|c_i K_{mi}|^2}{\sum_j |c_j K_{mj}|^2} \sum_{j\neq k} \mathrm{Re}(c_j c_k^* K_{mj} K_{mk}^*), \tag{21}$$

where $K_{mi} = \langle\phi_m|\psi_i\rangle$, and ψ_i $(i = 1, 2, ..., 128)$ are the normalized branch wavefunctions of the GHZ state, with c_i the corresponding coefficients such that $|\mathrm{GHZ}\rangle = \sum_i c_i|\psi_i\rangle$. ϕ_m $(m = 1, 2, ..., 8)$ are the normalized measured states. $P(\phi_m|\psi_i)$ can be interpreted as the probability of obtaining measurement result ϕ_m given that the system is in the pre-assigned branch. Because of the interference effect among different branches, the measured spin product is not the classical product of the individually pre-assigned spins. For example, even though some branches contain spin products equal to $+1$ (e.g.,

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$|\uparrow_y\uparrow_y\uparrow_x\rangle$ or $|\uparrow_y\downarrow_y\downarrow_x\rangle$), the quantum probabilities of measuring these combinations are zero. In fact, because each term $P(\phi_m|\psi_i)$ in our conditional probability decomposition is non-negative and the total probability $\sum_i P(\phi_m|\psi_i)$ for result ϕ_m is the same as that of quantum mechanics, it follows directly that whenever the total probability is zero, every individual $P(\phi_m|\psi_i)$ must be zero. As a concrete illustration, for the GHZ state under the measurement setting $\sigma_y\sigma_y\sigma_x$ with outcome $|\uparrow_y\uparrow_y\downarrow_x\rangle$, exactly 32 of the 128 branches yield a non-zero conditional probability $1/128$ each, summing to the quantum total $1/4$, while for the impossible outcome $|\uparrow_y\uparrow_y\uparrow_x\rangle$ all branches give zero. This explicit counting confirms the general argument. The interference among different branches is exactly analogous to the double-slit experiment, where although each particle passes through only one slit, the distribution on the screen for particles passing through a given slit still includes an interference contribution. Hence, with the help of conditional probability, the GHZ state can be understood consistently with pre-assigned spins. The same conditional probability decomposition applied to the Bell state (32 branches for 2 particles) yields identical quantum predictions.

In summary, we propose a new interpretation of microscopic particles. On one hand, particles have wave functions that evolve unitarily according to quantum mechanics and follow Born's probability interpretation. On the other hand, regardless of whether a measurement is performed, particles possess the same reality as classical macroscopic objects, i.e., they have definite properties such as position, momentum, and spin at any given moment. These physical quantities are not determined by hidden variables but arise stochastically, governed solely by the wave function. We argue that there is no instantaneous, unpredictable collapse of the wave function, nor any transition from a "potential existence" to an "actual existence". Each specific measurement outcome reflects the particle's pre-existing definite state, rather than being created by measurement-induced collapse. This interpretation reproduces all statistical predictions of standard quantum mechanics, yielding identical expectation values for observables. Our scenario provides a consistent interpretation of definite predetermined physical quantities together with quantum mechanical predictions such as Bell inequality violations and the GHZ state. Moreover, the decomposition of the total probability provides additional information beyond standard quantum mechanics. While direct measurement of the conditional distributions is not possible, weak-measurement-based statistical reconstruction may provide indirect evidence.

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References

1. J. S. Bell, Physics Physique Fizika **1** (1964) 195.
2. A. Fine, Phys. Rev. Lett. **48** (1982) 291.
3. S. L. Braunstein and C. M. Caves, Ann. Phys. **202** (1990) 22.
4. M. K. Joshi et al., Nature **624** (2023) 539.
5. Y. Zhong, Nature **590** (2021) 571.
6. A. Bienfait et al., Science **364** (2019) 368.
7. A. Einstein, B. Podolsky and N. Rosen, Phys. Rev. **47** (1935) 777.
8. D. Bohm and Y. Aharonov, Phys. Rev. **108** (1957) 1070.
9. U. Lucia and G. Grisolia, Mathematics **10** (2022) 2711.
10. J. Bricmont, S. Goldstein and D. Hemmick, Found. Phys. **52** (2022) 53.
11. D.-W. Chiou, Int. J. Theor. Phys. **62** (2023) 120.
12. S. Kim and B. S. Ham, Sci. Rep. **13** (2023) 9758.
13. M. Thenabadu and M. D. Reid, Phys. Rev. A **105** (2022) 062209.
14. P. A. M. Dirac, *Principles of Quantum Mechanics*, 4th ed., Oxford University Press, 1958.
15. J. J. Sakurai and J. Napolitano, *Modern Quantum Mechanics*, 2nd ed., Cambridge University Press, 2017.
16. R. P. Feynman and A. R. Hibbs, *Quantum Mechanics and Path Integrals*, McGraw-Hill, 1965.
17. H. Everett, Rev. Mod. Phys. **29** (1957) 454.
18. D. Bohm, Phys. Rev. **85** (1952) 166.

 doi:10.20944/preprints202605.1789.v1

19. S. Kocsis et al., Science **332** (2011) 1170.
20. S. J. Freedman and J. F. Clauser, Phys. Rev. Lett. **28** (1972) 938.
21. A. Aspect, P. Grangier and G. Roger, Phys. Rev. Lett. **47** (1981) 460.
22. G. Weihs et al., Phys. Rev. Lett. **81** (1998) 5039.
23. J. W. Pan et al., Nature **403** (2000) 515.
24. M. A. Rowe et al., Nature **409** (2001) 791.
25. M. Ansmann et al., Nature **461** (2009) 504.
26. B. G. Christensen et al., Phys. Rev. Lett. **111** (2013) 130406.
27. R. Schmied et al., Science **352** (2016) 441.
28. BIG Bell Test Collaboration, Nature **557** (2018) 212.
29. S. Storz et al., Nature **617** (2023) 265.
30. D. M. Greenberger, M. A. Horne, and A. Zeilinger, "Going beyond Bell's theorem," in *Bell's Theorem, Quantum Theory and Conceptions of the Universe*, M. Kafatos, Ed., 73–76, Springer, 1989.
31. N. D. Mermin. Quantum mysteries revisited. *American Journal of Physics*, 58:731–734, 1990.
32. J.-W. Pan, D. Bouwmeester, M. Daniell, H. Weinfurter, and A. Zeilinger. Experimental test of quantum nonlocality in three-photon GHZ entanglement. *Nature*, 403:515–519, 2000.
33. A. Cabello. Bell's theorem without inequalities and without probabilities for three observers. *Physical Review Letters*, 87:010403, 2001.
34. A. Zeilinger. Experiment and the foundations of quantum physics. *Reviews of Modern Physics*, 71:S288–S297, 1999.