Entangled Projections: A Dual Nature of Quantum Measurement

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Abstract

We propose a novel framework in which quantum measurement is interpreted as a dual entropic projection at a thermodynamic interface—specifically, a dynamically active event horizon (EH) that connects an AdS-like quantum domain with a dS-like geometric spacetime. Building on earlier work on dual-holographic cosmology and thermodynamic gravity, we suggest that the EH field Φ serves as an informational screen, where both position and spin are projected independently from a common superposed quantum state.

At the core of this model lies the entropic structure of the EH potential, which naturally exhibits a Gaussian profile. This structure encodes a global equilibrium condition $dS = 0$ that characterizes both the interior (AdS) and exterior (dS) domains. We interpret quantum measurement as a thermodynamic sampling from this global standard distribution: a projection occurs when a local fluctuation creates a momentary "gap"—an entropic deviation—that allows one component of the superposition to "fall" into a classically observable state.

This process respects conservation laws of energy, momentum, and helicity, but breaks local determinism, aligning with Bell's theorem through a nonlocal variable encoded in the EH geometry. The duality of projection—spin from AdS, position from dS—leads to correlated outcomes without signal exchange, suggesting a fundamentally entangled but thermodynamically governed universe. The statistical symmetry that underlies quantum mechanics may thus reflect the thermodynamic drive toward global equilibrium in a dual holographic setting.

1 Introduction: The Universe as a Normal Distribution

"The distribution of errors follows a bell curve." – Carl Friedrich Gauss

The interpretation of quantum mechanics and the thermodynamic structure of spacetime are often treated as separate domains. Yet, both appear to be governed by a shared statistical signature: the normal (Gaussian) distribution. This statistical form not only emerges in the behavior of quantum measurements but also appears to underlie the entropic flow across gravitational boundaries and the thermodynamic dynamics of the observable universe.

In previous work, the notion of a *Dual-Holographic Cosmology* was developed, in which the universe is modeled as a projection from a finite interface between an AdS-like (quantum mechanical) interior and a dS-like (cosmological) exterior [8]. This interface, described by a dynamic event horizon field Φ, connects a negatively curved, microscopic domain with a positively curved, macroscopic domain, acting as a bidirectional holographic screen.

It was further proposed that both regions follow a unifying thermodynamic tendency: the reduction of entropy differentials $dS \to 0$. In the AdS interior, this process corresponds to the stabilization of gravitational collapse, as described by Grey Holes (GHs), while in the dS exterior, it manifests as cosmic expansion approaching thermodynamic equilibrium. Even the EH field itself exhibits this entropic flattening: it evolves toward a configuration of vanishing entropy and zero heat capacity, enabling a smooth projection of quantum and geometric information.

Building on this thermodynamic framework, a second development explored how quantum information, when projected through the EH field, can be modeled as a dual assignment of conserved quantities—such as position and spin—across two entangled but complementary projections: one into AdS (quantum spin domain), and one into dS (spatial localization domain) [**?**]. This dual projection mechanism aligns closely with the structure of quantum measurement, and suggests that superposition is not an intrinsic "undetermined" state, but a placeholder awaiting compatibility with the global statistical structure.

In this work, we propose a statistical foundation for both spacetime projection and quantum measurement based on the global normal distribution. Specifically, we argue that each realized measurement outcome corresponds to a *stochastic insertion* into a pre-existing Gaussian entropy landscape. Superposed quantum states are not undefined; rather, they remain unprojected until the entropic gradient permits a consistent integration—akin to drawing a statistically consistent sample from a global distribution.

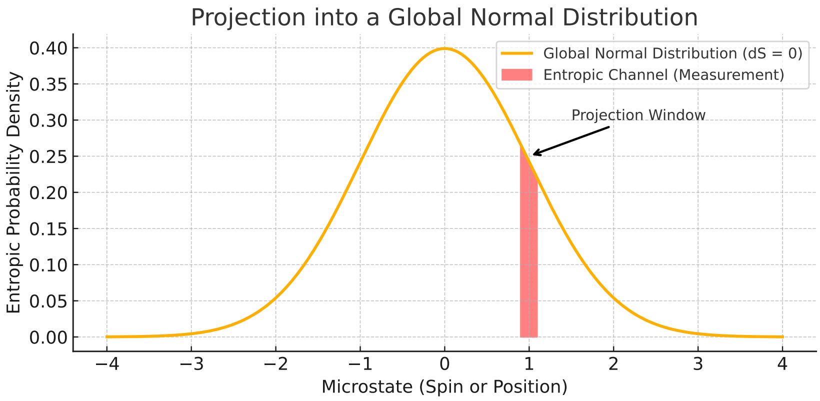

Figure 1: Schematic global entropy landscape modeled by a standard normal distribution. The small entropic "channel" marks a region where a measurement becomes thermodynamically admissible (i.e., $dS = 0$), allowing projection of superposed quantum information.

This view offers a unified narrative: the statistical regularity observed in quantum outcomes and the entropic structure of spacetime are not coincidental, but two manifestations of the same projection principle. Our analysis leads to a reinterpretation of the measurement process, Bell correlations, and conservation laws in terms of entropic compatibility with a Gaussian statistical background.

In what follows, we present the thermodynamic structure of this entropic projection, its implications for quantum entanglement, and its role in the emergence of measurable reality at the dual-holographic interface.

2 The Dual Projection Framework

The entropic model of the universe proposed here builds on a holographic interface, the event horizon (EH), separating two complementary domains: a quantum mechanical interior (AdS-like) and a geometric, expanding exterior (dS-like). In this structure, the EH field Φ serves as a dynamic projector, assigning information across both regions. But crucially, it does so in a way that preserves a global thermodynamic consistency: each projection must be compatible with a surrounding entropy potential that defines the statistical structure of reality.

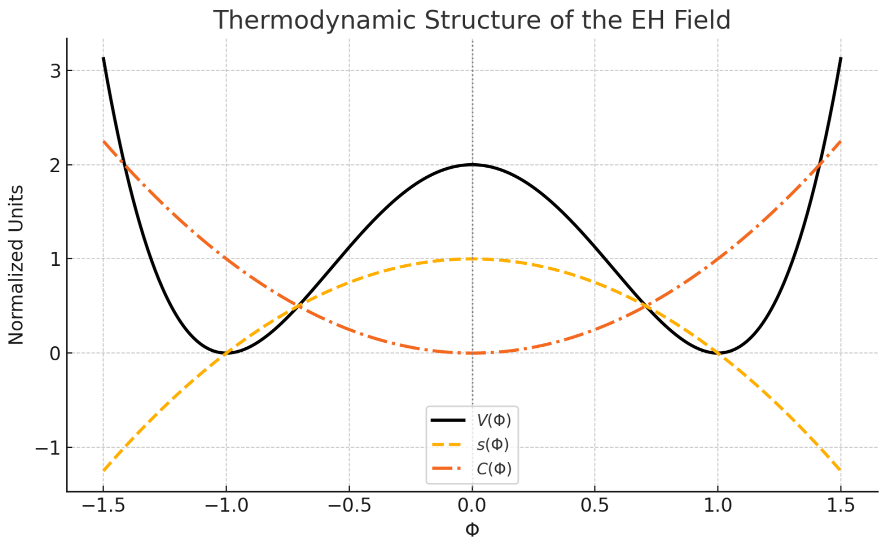

Figure 2: Thermodynamic structure of the EH field [8]. The entropy potential $S(\Phi)$ forms a central peak representing the superposed state. Projection occurs along two entropic slopes: one into the AdS domain (encoding spin and quantum numbers), and one into the dS domain (encoding position and classical information). The entropic minimum ($dS = 0$) defines the stable states of measurement.

The entropy landscape shown above plays a central role in determining when and how quantum states collapse into observable outcomes. The central peak symbolizes a superposition state—not as an indeterminate blur, but as a well-defined informational saddle that has not yet found thermodynamic compatibility with the surrounding entropy field.

As time evolves or external perturbations affect the EH configuration, small entropic channels may open in the landscape, temporarily reducing $dS \to 0$ locally and allowing a projection to occur. The result is a dual assignment of information: one projection stabilizes into the AdS sector, encoding quantum attributes like spin; the other stabilizes into the dS sector, determining localization and measurable position.

This projection is not passive—it respects fundamental conservation laws and reflects the informational symmetry structure of the system. Specifically:

- Quantum numbers such as spin (AdS side) and spatial coordinates (dS side) are entangled across the EH.
- Projections are constrained by global thermodynamic symmetry conditions, as we will formalize in the following sections.
- The act of measurement corresponds to an entropic alignment—akin to inserting a statistically valid sample into a normal distribution landscape.

In this picture, the EH field acts not as a mere boundary, but as a computational membrane. Its entropic profile defines what measurements are possible, when, and under what thermodynamic symmetry constraints. Measurement outcomes are not "chosen" randomly, but thermodynamically permitted—emerging from a deeper compatibility with the global statistical form of reality.

This framework provides a natural explanation for why superpositions exist, how they collapse, and why the universe appears classical after measurement, while still respecting quantum structure beneath. It also aligns with existing holographic dualities, which we explore next.

3 Thermodynamic Symmetry Axis and Entangled Conservation

At the core of our model lies a thermodynamic symmetry principle that governs both the quantum interior (AdS) and the cosmological exterior (dS) of the EH field. This principle manifests as a dynamic evolution toward vanishing entropy gradients ($dS \to 0$) in both domains—a condition realized under equilibrium, but projected asymmetrically in the dual-holographic framework.

This symmetry axis, defined by the entropic topology of the EH potential Φ, connects the two regimes through a bidirectional projection: one encoding quantum information (AdS/spin) and the other spacetime localization (dS/position). Crucially, both projections aim to restore global thermodynamic balance—entropically represented by a Gaussian (normal) distribution centered at $dS = 0$.

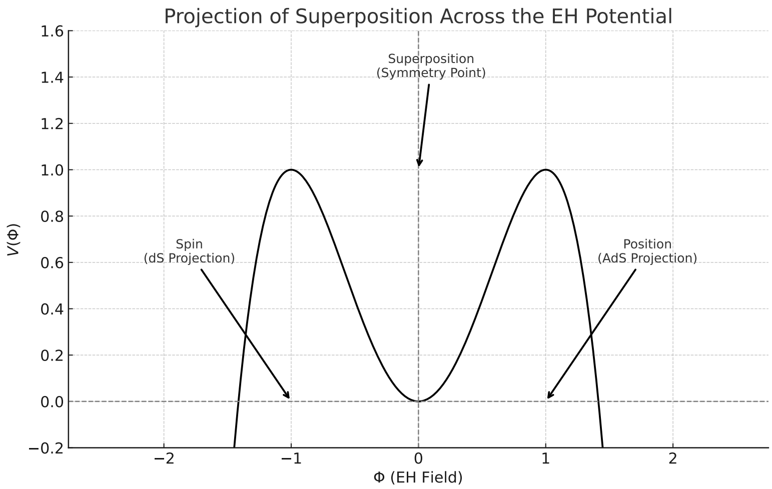

Figure 3: Schematic structure of the entropic projection in the EH field. The central peak represents a superposed quantum state. The two descending entropy pathways correspond to projections into AdS (quantum spin space) and dS (spacetime localization). The shaded background illustrates a global standard normal distribution ($dS = 0$), into which the measurement must seamlessly integrate.

This diagram captures a central insight: that quantum measurement is not merely a local collapse, but an entropic alignment within a global information distribution. A successful projection corresponds to a valid sample from the global Gaussian—ensuring that thermodynamic balance remains undisturbed. This view allows us to interpret superposition as an informational state that waits for a "fit" within the thermodynamic symmetry of the universe.

The AdS projection governs spin-related, quantum mechanical degrees of freedom; the dS projection governs position and localization. These two are not separate realms, but entangled through shared conservation laws—most notably energy, momentum, and (as we argue) helicity. We now turn to these conserved quantities as structural anchors of projection, encoded along the symmetry axis of the EH field.

In the following section, we formalize this idea through a symmetry-based table of conserved quantities, establishing the thermodynamic conditions for consistent projection onto either side of the EH.

4 Entropic Correlation and Conservation Symmetry

The informational structure imposed by the EH field Φ not only enables the dual projection of quantum and geometric degrees of freedom but also demands strict conservation laws to maintain coherence between the AdS- and dS-projected domains. These conserved quantities emerge from the symmetries of the entropic potential and form the foundation of measurement stability and entanglement behavior.

In this framework, a quantum system remains in a superposed state until its projected properties align with a symmetry-preserving configuration embedded in the global entropy distribution $dS = 0$. This constraint mirrors the behavior of statistical samples drawn from a normal distribution: only when the projected result fits into the global entropic landscape without distorting its structure can it be realized as a classical outcome.

Symmetry Matching: A Dual Conservation Matrix

Conserved Quantity	AdS Projection (Quantum)	dS Projection (Geometric)
Energy E	Discrete eigenvalue spectrum	Effective mass-energy content
Momentum p	Spin / phase shift	Position / spatial localization
Speed of Light c	Phase velocity	Signal propagation constraint
Helicity / Chirality	Quantum number (non-local)	Angular orientation / directionality
Proper Time τ	Internal clock (QM evolution)	Worldline length in dS frame

The simultaneity of entangled measurements can be understood as the result of this conservation structure: each projected degree of freedom is constrained to preserve a symmetry balance across the EH, forcing the two particles to collapse into states that together reconstruct a globally valid configuration.

Temporal Symmetry and the Higgs/Anti-Higgs Framework

A key insight into the simultaneity of entangled measurements can be gained by analyzing the symmetry between the Higgs field and its geometric counterpart—the Anti-Higgs projection—within the dual-holographic context.

In this picture, each particle of an entangled pair propagates through a complementary domain:

- The **first particle** travels through the Higgs field, where it experiences temporal evolution: its projection follows a trajectory primarily through internal time. This direction corresponds to the AdS-like domain, where quantum degrees of freedom are encoded.
- The **second particle** propagates through the Anti-Higgs field, moving primarily through spatial projection. This corresponds to the dS-like exterior, where spacetime geometry dominates.

From the dual-holographic standpoint, these two paths form a complete projection only when they jointly conserve the system's entropic balance: the measurement occurs precisely when the combined information can be embedded in the global entropy potential $S[\Phi] \sim 0$. The apparent simultaneity arises because both particles fall into the same *entropic well*—the same location within the global normal distribution that allows a valid, symmetry-preserving measurement.

This provides a thermodynamic explanation for why entangled particles exhibit non-local correlations: each part of the entangled pair traverses a distinct projection axis (time vs. space), yet the outcome must lie on a common axis of entropic symmetry. The matching condition across the event horizon enforces the conservation of all relevant quantum numbers, including energy, momentum, and helicity.

Hence, simultaneity is not enforced by classical synchronization, but by *thermodynamic selection*—only when the total projection fulfills all conservation rules across the EH potential is the measurement finalized.

5 Discussion and Entropic Consistency

The dual projection structure proposed in this work leads to a novel interpretation of quantum measurement, superposition, and entanglement—grounded not in abstract wavefunction collapse, but in the thermodynamic behavior of information itself. Within the EH potential Φ, the entropy gradient imposes a directional constraint: only configurations that reduce global dS back toward zero can manifest as physical outcomes. This reframes measurement as an entropic realignment rather than an irreversible decoherence process.

Projective Entropy and the Arrow of Time

The EH potential acts as a thermodynamic switch between internal and external geometric domains. When a system transitions from a superposed to a classical state, it moves down an entropy gradient defined by this potential. The result is a unidirectional projection—an emergent arrow of time—not due to fundamental time asymmetry, but due to the requirement that entropic balance be restored globally. In this sense, the global normal distribution (with $dS = 0$) is not merely a statistical artifact but the underlying "vacuum" configuration of a maximally symmetric informational universe.

Revisiting Bell-Type Constraints and Helicity

The conservation framework developed in Section 4 offers a natural resolution to the paradoxes often associated with Bell's theorem and non-local correlations. Instead of invoking hidden variables or many-worlds interpretations, we propose that the EH potential itself encodes a symmetry-preserving channel that enforces matching outcomes across dual projections. Crucially, helicity emerges as a conserved, non-local degree of freedom that links the AdS (quantum) and dS (geometric) projections. It may thereby serve as the entropic "carrier" of correlation across spacelike-separated measurements.

This insight aligns with recent discussions suggesting that certain classes of conserved quantum numbers can function as informational bridges between distant subsystems, circumventing the need for causal signaling without violating relativistic constraints.

Comparison with Classical and Emergent Frameworks

Our model integrates and extends key ideas from Verlinde's entropic gravity approach [1] and Jacobson's thermodynamic derivation of Einstein's equations [3]. However, by introducing the EH field as an active thermodynamic structure, we move beyond both frameworks: the emergent spacetime geometry arises not merely from heat flow, but from an entropy-conserving projection of information that satisfies a deeper symmetry principle.

Whereas Verlinde considered the entropic force as a fundamental mechanism for gravity, we reinterpret it here as a secondary effect of the more primary entropic projection process. Similarly, Jacobson's thermal horizon is generalized into a dynamic field—the EH potential—that governs both geometric emergence and quantum localization.

Consistency with Entropic Quantum Gravity (EQG)

The present work shares philosophical affinities with Bianconi's entropic quantum gravity program [7], particularly in emphasizing the primacy of entropy over geometry. Yet, unlike EQG's micro-network structure, we derive the entropic behavior from a mesoscopic projection potential that bridges quantum fields and spacetime directly.

Both approaches support the idea that spacetime is not fundamental but thermodynamically emergent—though our formalism offers a more explicit description of how projection, conservation symmetry, and entropy interact to stabilize measurement and encode classical outcomes.

In summary, the entropic consistency of the dual projection model manifests at multiple levels:

- The symmetry axis of the EH potential aligns informational and geometric conservation laws.
- Measurement is constrained to occur only at entropy minima that preserve global $dS = 0$.
- Entangled outcomes emerge via conservation matching rather than state collapse or branching.

This establishes a thermodynamically grounded, symmetry-consistent alternative to standard quantum measurement theory—one that reinterprets the classical world not as an approximation, but as an entropic necessity.

6 Conclusion

This work presents a new conceptual framework for understanding quantum measurement, entanglement, and spacetime emergence through the lens of thermodynamic projection. By interpreting quantum systems as dual projections along an entropic symmetry axis defined by the event horizon (EH) potential, we provide a unified view that reconciles gravitational and quantum features.

The key insight is that the EH field acts as an informational event horizon—a thermodynamic interface mediating between two complementary domains: the AdS-like interior associated with quantum spin degrees of freedom, and the dS-like exterior encoding spatial localization. These projections are not simultaneous, but entangled through conserved quantities such as energy, momentum, and helicity. Their co-emergence is constrained by a global requirement of entropy neutrality: $dS = 0$.

We have argued that measurement corresponds to an entropic alignment—a projection from a symmetric superposed configuration into one of two thermodynamically compatible outcomes. This reinterprets the collapse of the wavefunction not as a discontinuous physical process, but as a statistical realization of a global constraint. The familiar features of decoherence, observer-dependence, and probabilistic outcome selection are thereby unified under a single principle: the maintenance of global entropic symmetry.

Furthermore, by introducing the concept of a "gap" within a global normal distribution, we explain why measurement only occurs when a system's entropy matches an available slot in the total configuration space. This suggests that the quantum-to-classical transition is governed not by absolute decoherence thresholds, but by the structure of entropic compatibility across a dynamically evolving EH landscape.

The duality described here builds on recent work in holography, thermodynamic gravity, and entropic quantum geometry. It does not replace existing interpretations, but offers a minimal and physically grounded reinterpretation of quantum measurement as a thermodynamic projection—a consequence of information flow across a curved spacetime interface.

In closing, this model opens a pathway for further investigation into the physical nature of quantum information, the structure of holographic boundaries, and the possible unification of fundamental interactions through entropic symmetry principles.

7 Outlook

The model developed in this work—based on entropic dual projection at the informational event horizon (EH)—raises several important questions and research directions for further exploration.

First, the proposed entropic mechanism underlying quantum measurement invites a deeper connection to Feynman's path integral formulation. The idea that the superposition of paths reflects a thermodynamic weighting over a global entropic distribution suggests a novel perspective on the origin of quantum amplitudes. A reformulation of path integrals as entropic projection functionals could offer a physically intuitive foundation for quantum mechanics, consistent with holographic and thermodynamic principles.

Second, the correlation structure implied by the EH field points toward a hidden variable interpretation of entanglement. In particular, the role of helicity as a non-local, conserved degree of freedom across the AdS/dS interface offers a possible resolution of the Bell inequality paradox. Future work could investigate whether this helicity-based mechanism permits experimental differentiation from standard quantum mechanics—especially in polarization-based setups or asymmetric spacetime geometries.

Third, our model raises new questions about the nature of the Higgs field and its dual counterpart. If mass generation is mediated via projection through an EH potential landscape, the classical concept of inertial mass may need to be reconsidered as a manifestation of thermodynamic coupling. This could offer insight into mass hierarchy, flavor transitions, or even the dimensional stability of spacetime itself.

Finally, the central hypothesis—that reality itself maintains a global state of entropic neutrality ($dS = 0$)—offers a new lens on foundational questions in cosmology and quantum gravity. The global normal distribution employed in this model may act as a symmetry principle, regulating information exchange, guiding projection events, and constraining allowed configurations. Its potential connection to the arrow of time, the emergence of classicality, and even the statistical fabric of spacetime deserves further mathematical development.

We believe that the entropic projection framework introduced here, supported by a thermodynamic symmetry axis and dual boundary encoding, offers a fertile ground for future theoretical and experimental investigations. Its compatibility with existing approaches such as AdS/CFT, dS holography, and thermodynamic gravity invites synthesis rather than replacement—and may provide a missing link between quantum measurement and the structure of spacetime itself.

Appendix: Helicity and Bell-Type Correlations in EH-Projected Systems

Within the dual-projection framework proposed in this work, the helicity of a particle can be interpreted as a conserved projection of spin onto the direction of propagation, mediated by the EH field Φ. Given that the EH defines a thermodynamic boundary between AdS and dS domains, its projective structure imposes constraints on the available degrees of freedom during measurement.

We hypothesize that the helicity acts as a nonlocal hidden variable in the sense of Bell-type experiments. Unlike traditional hidden variable models, which assume pre-existing definite values, this approach maintains quantum indeterminacy while introducing a thermodynamically governed constraint via symmetry conservation. The helicity is not merely preserved—it determines, in conjunction with entropic flow, the projection axis for spin and position.

Proposed Experimental Analogy

Consider an entangled photon-electron pair, where the electron is described by a spin state and the photon by momentum and polarization. According to the model, a dual projection occurs: spin is resolved along the AdS-side (quantum domain), position along the dS-side (spacetime). If helicity is conserved across both projections, then any change or measurement of one observable should correlate with the outcome of the other—without signal exchange—reminiscent of Bell's theorem.

Relevance to Bell's Inequality

In this framework, violations of Bell-type inequalities do not require faster-than-light information transfer. Instead, they arise naturally from a shared projection geometry at the EH. Because both entangled particles share the same projective potential Φ, the outcome of a measurement on one particle reflects a symmetry-preserving collapse that respects the helicity conservation condition. The Bell-type correlations emerge as geometric-entropic constraints, not as paradoxes.

Testable Predictions

- Polarization correlations in entangled photon pairs should exhibit helicity-aligned asymmetries when interacting with structured thermodynamic media.
- Electron spin projections should statistically correlate with momentum-space constraints determined by the entropic gradient across a synthetic or analogue EH (e.g., via graphene membranes or optical lattices).
- Apparent randomness in measurement outcomes may show subtle thermodynamic bias when ensembles are analyzed in terms of helicity-preserving dynamics.

This provides a potential bridge between quantum information theory and classical conservation principles—without abandoning locality in the conventional sense, but reinterpreting it within an entropic, dual-projection framework.

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