Boundary-Condition Quantum Mechanics II: From Quantum Events to Spacetime

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Abstract

We present a framework wherein spacetime is not a fundamental entity but an emergent structure derived from a network of irreversible quantum events. Building on the concepts of Boundary-Condition Quantum Mechanics (BCQM), we posit a single primitive: the **Event**, a discrete, irreversible collapse with a characteristic proper-time duration identified with the empirically measurable coherence horizon, W. From the causal graph of these events, spacetime geometry, dynamics, and the physical constants c, $\hbar$, and G emerge. This framework resolves foundational issues of prior measurement-first models by eliminating a pre-existing vacuum state, thereby solving the "first cause" paradox, and defining gravity as the curvature of the causal graph induced by event density. The model culminates in three decisive, falsifiable predictions: a universal inertial noise floor in laboratory experiments, stochastic fluctuations in astrophysical gravitational lensing, and a research program to test these signatures. *Scope note.* This paper treats flat–spacetime kinematics and event selection only; gravitational phenomena—and the identification $m_{\mathrm{I}} \equiv m_{\mathrm{G}}$ from the same action-based mechanism—are developed in Paper V. *Clarification.* When we say the q-wave is "governed by both retarded and advanced solutions," the "advanced" branch is retained strictly as the time-symmetric Green's-function solution for the *amplitudes*. It is *not* read as evolution "back in time," carries no influence from future choices, and cannot be used for signalling; operational time-ordering throughout remains on the ordinary (chronological) axis.

Revision note (v3, 24 Oct 2025). Added explicit "no retrocausality" clarifications (Abstract, Introduction, Methods, §3.1) and a causality note (§4.1). No scientific results changed.
Revision note (v2, 22 Oct 2025). Added a scope note; clarified the single mass parameter; gravity deferred to Paper V. No scientific results changed.

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1 Introduction

The discord between General Relativity's smooth, deterministic spacetime and the discrete, probabilistic nature of quantum mechanics remains the most profound challenge in fundamental physics. We propose a resolution wherein the conflict is an artifact of treating spacetime as a fundamental background. Instead, we argue that spacetime itself is an emergent, large-scale consequence of an underlying quantum reality.

This paper presents a fundamental reformulation of the ideas first explored in Boundary-Condition Quantum Mechanics (BCQM) [1]. While the original work identified the collapse horizon W as a key boundary condition *on* quantum mechanics, this framework posits the irreversible event *at* W as the sole constituent *of* reality itself, from which both quantum dynamics and spacetime emerge. **Interpretation note (no retrocausality).** The use of an "advanced" TDSE branch here is purely a mathematical completion of time symmetry at the level of amplitudes. We do not interpret it as a

physical process propagating backwards in time. All causes, records, and interventions are ordered along the usual laboratory time; reduced statistics remain independent of any future setting.

On gravity and scope. We use the invariant action $S = -mc\int ds$ to set the propensity phase and the coherent-window selection. In BCQM this same action will furnish the treatment of gravity; in particular, the equality of inertial and gravitational mass follows from the common mass parameter in S. To keep focus, we defer gravitational effects and the explicit equivalence-principle analysis to Paper V.

We construct a self-consistent framework from this single primitive. We demonstrate how the rules of quantum mechanics and the dynamics of gravity, including its conservation laws, emerge from the collective behavior of these events. The framework's validity rests not on its internal consistency alone, but on a set of novel, falsifiable predictions that distinguish it from both the Standard Model and General Relativity.

Methods (Sketch) and Prior Foundations

We treat the irreversible event as the operational collapse defined and analyzed within Boundary-Condition Quantum Mechanics (BCQM). The finite horizon W is the inverse of the smallest positive dissipative eigenvalue of the Heisenberg-picture GKLS generator acting on effects; additivity/locality of generators and the data-processing–based arrow are established in the BCQM technical corpus. Here we *adopt* those results as primitives and translate them into a discrete causal-graph growth rule. For derivations and proofs, see the BCQM foundation and analytical proofs manuscripts [1, 2].

Clarification (advanced branch). Where "advanced" solutions are referenced (e.g., in constructing the q-wave), they label the advanced Green's-function branch used to enforce time symmetry of amplitudes. Both branches use the same laboratory time parameter; no retrocausal influence or past-changing dynamics are assumed or permitted by the framework.

2 The Framework: From Events to Reality

2.1 The Primitive: The Irreversible Event

The framework is built upon a single primitive: the **Event**. An Event is a discrete, irreversible quantum collapse. It is the fundamental "tick" of existence and the sole building block of all reality. We identify the characteristic proper-time duration of each Event with the empirically measurable collapse horizon, W [3]. There is no pre-existing spacetime, vacuum, or reversible web; the universe *is* the growing collection of these irreversible events.

2.2 The Structure: The Causal Graph

Causality note. The event-graph construction is strictly forward-ordered: each selection conditions only on established records and the current frontier. No future-to-past influence is assumed or permitted. Events are not isolated. They are connected by **causal links**, forming a growing, directed, acyclic graph—a causal set, in the tradition of Sorkin [4]. If Event A can influence Event B, a directed edge exists from A to B ($A \to B$). This graph *is* the emergent spacetime.

- **Time** is the count of Events along a causally ordered chain (a worldline).
- **Space** is the relationship between Events not in each other's causal past or future.
- **The Invariant Speed (c)** emerges as a structural property of the graph: the maximum ratio of newly created spatial separation per temporal tick.

Definition (Invariant speed). We *define* c as the supremum of spatial separation per event tick compatible with locality of interactions,

$$c := \sup_{\text{local couplings}} \limsup_{\Delta n \to 1} \frac{\Delta \ell}{\Delta t_{\text{event}}}. \tag{1}$$

In dense graphs this induces an effective causal cone whose continuum limit has slope c.

3 Quantum and Classical Dynamics

3.1 The Q-Wave: The Blueprint for Reality

The *q-wave*, introduced in [1], is re-contextualized not as a physical wave, but as the **abstract information field that governs the growth of the event graph.** It is the blueprint of potentiality for the next Event. This information field can be understood as a field of propensities or objective probabilities, guiding the stochastic realization of the next event in a manner consistent with the global structure of the causal graph. Governed by both retarded and advanced solutions, the *q-wave* assigns a probability amplitude to every potential successor Event on the future boundary of the existing graph, ensuring global consistency. A particle is a persistent, high-frequency causal chain of Events, and its motion is guided by its *q-wave*. Inertia arises as the statistical outcome of the Event-chain following the path of maximum phase coherence. *Clarification.* Here "advanced" denotes the advanced Green's-function contribution to the amplitude bookkeeping; it is not a literal evolution "back in time" and cannot be used to signal or condition present outcomes on future settings.

Mass parameter. Throughout BCQM II, m denotes the rest-mass parameter in the action $S = -mc\int ds$. We do not split "inertial" vs "gravitational" mass here; that identification is made operationally in Paper V.

3.2 Interaction and Conservation Laws

Fields need not be taken as primitives of the ontology; within the present event framework, what is ordinarily described as a "field interaction" is captured by a (local) coupling kernel H_{int} (or its open-system CP map), with the continuum field description recovered as an effective limit of dense event graphs.

Interaction is the process of two or more *q-wave*s merging into a single, entangled, **joint *q-wave***. This joint *q-wave* is structurally constrained to only assign non-zero probability amplitudes to sets of successor Events that perfectly conserve the total energy, momentum, and other conserved quantities of the initial state. The stochastic collapse (the "tick") selects one outcome from this pre-filtered menu of conservative possibilities, guaranteeing that all fundamental conservation laws are respected at every interaction.

Postulate 1 (Interaction-induced joint q-wave). When two systems A and B are coupled via a non-product interaction for a duration $\Delta\tau \lesssim W$, their combined amplitude on $\mathcal{H}_A \otimes \mathcal{H}_B$ evolves as

$$|\Psi_{AB}(\Delta\tau)\rangle = \exp\Big[-\frac{i}{\hbar}(H_A \otimes I_{\mathcal{H}_B} + I_{\mathcal{H}_A} \otimes H_B + H_{\text{int}})\Delta\tau\Big]\ |\psi_A\rangle \otimes |\psi_B\rangle\,. \tag{2}$$

If $H_{\text{int}} \neq 0$ and is not of product form, $|\Psi_{AB}\rangle$ is generically non-separable after $\Delta\tau$. For open-system couplings the joint CP map

$$\mathcal{E}_{AB}(\rho_{AB}) \;=\; \sum_\alpha K_\alpha\, \rho_{AB}\, K_\alpha^\dagger, \qquad \sum_\alpha K_\alpha^\dagger K_\alpha \;=\; I, \tag{3}$$

with at least one non-product Kraus operator $K_\alpha \neq K_\alpha^{(A)} \otimes K_\alpha^{(B)}$ likewise generates correlations. We call the resulting (possibly entangled) amplitude the *joint q-wave*.

Constraint (Conservation at selection). Let Q denote any additive conserved quantity (energy, momentum components, spin, charge) with $[H_{\text{tot}}, Q_{\text{tot}}] = 0$. The joint q-wave support for successor events is restricted to the eigenspaces of Q_{tot}: if Π_q projects onto a fixed total value q, selection occurs from $\Pi_q |\Psi_{AB}\rangle$ (or its mixed-state analogue), ensuring that every event preserves the totals. *Sketch:* symmetry invariance gives $U^\dagger Q_{\text{tot}} U = Q_{\text{tot}}$, so total charges are preserved under the interaction and during the stochastic selection.

Particle creation and annihilation are handled by the transformation of this joint *q-wave*. The blueprint for an electron-positron pair, for example, can transform into the blueprint for two photons. The energy budget, including rest mass ($E = mc^2$), is reallocated perfectly within the informational structure before the new Events are realized.

4 Emergent Cosmology

4.1 The Continuum Limit and Gravity

The smooth 4D spacetime manifold of General Relativity is the **statistical, thermodynamic limit of the discrete event graph.** *Causality note.* Even though the amplitude construction is time-symmetric, the growth of the event graph is causally ordered: selection occurs along the chronological axis, with no future-to-past influences. A particle's geodesic is the emergent average of trillions of probabilistic ticks. Gravity is the curvature of this graph. A high density of events (matter-energy) locally alters the connection probabilities, deflecting the geodesics of other particles. General Relativity is thus a near-perfect effective theory describing the graph's average geometry, a concept with parallels in Loop Quantum Gravity [5].

4.2 Dimensionality and the Vacuum

The emergence of a 3+1 dimensional universe is proposed to be a result of **informational stability**. This dimensionality provides the optimal balance for creating and preserving complex, stable information structures (particles, atoms). The "vacuum" is a region with a low density of particle-events, but it is not empty. We posit a fundamental, constant, positive rate of spontaneous Event creation in the vacuum. This intrinsic growth of the graph is the physical mechanism for the cosmological constant (Λ) and the observed accelerated expansion of the universe.

Hypothesis H_Λ (Vacuum event rate). Assume a uniform, positive vacuum event-creation rate ν_0 per unit four-volume. In the coarse-grained (continuum) description this yields an effective cosmological constant,

$$\Lambda \;=\; \kappa_\Lambda \, \nu_0, \tag{4}$$

where the conversion factor κ_Λ is fixed by the graph-to-metric coarse graining. Observable consequences include (i) low-level stochastic "flicker" in strong-lensing magnifications/centroids and (ii) accelerated large-scale expansion consistent with $\Lambda > 0$.

5 Discussion and Outlook

The principles outlined here suggest a deep connection between information, physics, and reality, echoing the "It from Bit" hypothesis of Wheeler [6]. By treating physical laws as emergent "stability parameters" of the event graph, this framework may offer new avenues for addressing fine-tuning problems, such as the hierarchy problem. The key philosophical shift is from viewing laws as immutable rules imposed upon a system to viewing them as the discovered, self-organizing principles of the system itself.

Outlook. The same action-based mechanism that yields inertial drift here will be used in Paper V to model gravity; there the equality $m_{\mathrm{I}} = m_{\mathrm{G}}$ appears naturally and free-fall universality is derived for the ensemble mean.

6 Falsifiable Predictions

The validity of this framework rests on three decisive, novel predictions that distinguish it from established theories.

6.1 Prediction 1: Universal Inertial Noise

The most direct laboratory test of the framework's core tenet—that motion is a sequence of discrete, probabilistic Events—is the prediction of a **fundamental, universal inertial noise floor.** Even a perfectly isolated, zero-temperature object will exhibit an irreducible, random jitter in its position. This is not thermal or standard quantum noise.

- **Test Signature:** A faint, persistent, low-frequency, and universal noise source in high-precision interferometers (e.g., LIGO, atom interferometers) that cannot be explained by any known environmental or quantum source. Its magnitude would be fundamentally linked to the measured value of W.

6.2 Prediction 2: Stochastic Gravitational Lensing

If gravity is an emergent, statistical effect of a discrete graph, then the curvature of spacetime cannot be perfectly smooth. This leads to a novel prediction for gravitational lensing.

- **Test Signature:** The magnification and precise position of gravitationally lensed images of distant quasars will exhibit a faint, random, and continuous **"flicker"** over time. This scintillation is the signature of light passing through a statistically fluctuating spacetime, directly contradicting the smooth manifold assumption of General Relativity.

6.3 Prediction 3: A Research Program for Confirmation

Testing this framework requires a dedicated, multi-phase research program:

1. **Phase 1: Characterize W.** A precision measurement program to determine if the collapse horizon W is a new fundamental constant of nature.
2. **Phase 2: Simulate the Framework.** A computational effort to model the event graph's growth, using the measured value of W to derive precise theoretical predictions for the inertial noise spectrum and lensing flicker statistics.
3. **Phase 3: The Search.** A dedicated analysis of data from gravitational wave detectors and long-term monitoring of lensed quasars with instruments like JWST and the Vera C. Rubin Observatory to hunt for the predicted signatures.

7 Conclusion

We have presented a self-consistent framework where spacetime, physical law, and all its contents emerge from a single quantum primitive: the irreversible Event. This model resolves foundational paradoxes and connects the microscopic quantum world to the macroscopic cosmos. Most importantly, it moves beyond philosophical speculation by providing a clear, falsifiable set of predictions. The proposed experimental and observational programs offer a concrete path to verify or falsify this theory, and in doing so, to probe the fundamental nature of reality itself.

References

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