Testing the Fact-Steering Framework: Entanglement, Grover Narrowing, and Detector-Defined POVMs

Keith Taylor
VERSF Theoretical Physics Program

General Reader Summary

What is this paper about?

When we measure a quantum system, we always get a single definite result—the detector clicks, the needle points somewhere specific, the screen shows a dot. But quantum theory describes systems as existing in "superpositions"—combinations of multiple possibilities at once. How does a world of blurry possibilities become a world of sharp facts?

Standard quantum mechanics handles this with a rule called the "Born rule": the probability of each outcome equals the square of something called the amplitude. This rule works perfectly, but it's simply stated as a law—we're not told *why* probabilities work this way.

This paper proposes a different approach. Instead of treating measurement as a mysterious separate rule, we ask: what actually happens physically when a detector registers an outcome? Detectors are devices poised on the edge of instability—like a mousetrap ready to spring. The quantum system nudges these "channels" toward triggering, and whichever channel triggers first becomes the recorded fact.

The key insight is that the *rate* at which each channel gets nudged is proportional to the squared amplitude. When multiple channels compete to trigger first, the probability of each winning is just its rate divided by the total—which gives us exactly the Born rule, now as a consequence of detector physics rather than a separate postulate.

This reframing doesn't just offer conceptual clarity—it simplifies the mathematics. Instead of juggling separate rules for dynamics and measurement, there's one unified picture: amplitudes steer possibilities, thresholds create facts. Generalized measurements (POVMs) arise naturally from detector channels without abstract existence theorems. Mid-circuit measurements become straightforward: a fact is created, and subsequent operations are conditioned on it.

We test this "fact-steering" framework against three important quantum phenomena: entanglement between particles, Grover's quantum search algorithm, and generalized measurements. In each case, the framework reproduces standard predictions while providing a clearer, more physically grounded picture of what's happening.

Key terms for general readers:

- **Amplitude**: A number (which can be positive, negative, or complex) describing how much each possibility contributes to a quantum state
- **Born rule**: The rule that probability = amplitude squared
- **Superposition**: A quantum state that's a combination of multiple possibilities
- **Entanglement**: When two particles are correlated in ways that can't be explained by ordinary shared properties
- **POVM**: A generalized measurement where outcomes aren't simply "the particle is here" but can be more complex
- **First-passage**: The first time a random process crosses a threshold—like the first raindrop to fill a bucket

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Abstract (Technical)

We test the proposal that quantum mechanics can be understood in terms of physically admissible facts, coherent steering of amplitudes, and irreversible outcome selection via first-passage dynamics. Using three standard but nontrivial cases—two-qubit entanglement, Grover's search algorithm, and generalized measurements (POVMs)—we show that the framework reproduces standard quantum predictions while reducing the primitive axioms required for measurement and simplifying the underlying mathematical structure. In each case, possible facts are identified with detector-defined basis outcomes, quantum gates act as reversible steering operations that reshape amplitudes without creating facts, and measurement corresponds to competitive amplification into a single irreversible record. The framework replaces the Born rule as a primitive axiom, deriving outcome probabilities from first-passage competition among metastable detector channels once the rate–amplitude relation is established. By grounding measurement in detector physics rather than abstract postulates, the mathematics becomes more physically transparent: POVMs arise directly from channel couplings without requiring Naimark dilation as a foundational move, mid-circuit measurement reduces to fact creation plus classical conditioning, and the measurement postulate is replaced by a single physical mechanism (threshold competition) that unifies the treatment of all measurement scenarios.

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1. Introduction

Standard quantum mechanics rests on a set of axioms that include both unitary evolution and a separate measurement postulate specifying the Born rule and state collapse. While empirically successful, this structure leaves the measurement process unexplained: why does a single definite outcome occur, and why do probabilities follow the $|\psi|^2$ form?

For general readers: Quantum mechanics normally has two very different kinds of rules. Most of the time, quantum states evolve smoothly and predictably according to the Schrödinger equation. But when we make a measurement, something abrupt happens: we get one definite result, chosen randomly according to the "Born rule" (probability equals amplitude squared). This paper asks whether we can understand that measurement step as a physical process rather than a separate rule.

The fact-steering framework proposes a reorganization of these foundations. Rather than treating measurement as an additional axiom, it identifies three physical ingredients:

1. **Admissible facts**: The measurement apparatus defines a finite set of mutually exclusive outcomes—the only records it can produce.
2. **Coherent steering**: Unitary operations reshape amplitude distributions across possible facts without creating records.
3. **Irreversible selection**: Measurement occurs when one detector channel crosses a metastability threshold, producing an irreversible record via first-passage dynamics.

For general readers: Think of a detector as having several "channels"—like multiple mousetraps set up side by side. The quantum system gradually nudges all the traps, but whichever one snaps first becomes "the result." Once a trap has sprung, you can't un-spring it—that's the irreversibility. The quantum amplitudes determine how hard each trap gets nudged.

The claim is not that standard quantum mechanics is wrong, but that its measurement postulate can be derived rather than assumed once detector physics is made explicit. In this paper, the $|\psi|^2$ rate law is taken as established by detector-physics arguments developed elsewhere (see Section 7.1 and Appendix A); the present aim is to show how, once accepted, it removes the need for an independent measurement postulate. This paper tests that claim against three canonical scenarios.

2. Two-Qubit Entanglement: Joint Possible Facts

We begin with a bipartite system measured in the computational basis. The measurement context defines the possible facts as the joint basis states $\{|00\rangle, |01\rangle, |10\rangle, |11\rangle\}$. These are the only outcomes the apparatus can irreversibly record.

For general readers: Imagine two coins that can each be heads (0) or tails (1). When we measure both, there are four possible results: both heads (00), first heads and second tails (01), first tails and second heads (10), or both tails (11). In quantum mechanics, the system can be in a "superposition" of these possibilities until measurement.

2.1 Bell State Analysis

Consider the Bell state:

$$|\Phi^+\rangle = (1/\sqrt{2})(|00\rangle + |11\rangle)$$

For general readers: This is the famous "entangled state"—the two particles are correlated so that if you measure one and get 0, the other will definitely be 0 too, and same for 1. But before measurement, neither particle has a definite value.

In this basis, only two joint outcomes have nonzero amplitudes:

Outcome	Amplitude	Weight (Amplitude²)
	00⟩	$1/\sqrt{2} \approx 0.707$
	01⟩	0
	10⟩	0
	11⟩	$1/\sqrt{2} \approx 0.707$

2.2 Outcome Selection via Channel Competition

Assigning outcome-selection rates proportional to squared amplitudes:

$$\lambda_{a\beta} = \kappa \cdot |\psi_{a\beta}|^2$$

we obtain $\lambda_{00} = \lambda_{11} = \kappa/2$ and $\lambda_{01} = \lambda_{10} = 0$.

For general readers: The symbol λ (lambda) represents how fast each detector channel is being "pushed" toward triggering. The constant κ (kappa) is just an overall scale factor that depends on the detector's sensitivity—it cancels out when we calculate probabilities.

First-passage selection among competing channels yields:

$P(ab) = \lambda_{a\beta} / \Sigma_{ij} \lambda_{ij} = |\psi_{a\beta}|^2 / \Sigma_{ij} |\psi_{ij}|^2$

For normalized states (where the amplitudes squared sum to 1), this simplifies to $P(ab) = |\psi_{a\beta}|^2$.

For general readers: When several processes compete to happen first, the probability that process A wins is proportional to how fast A is happening divided by the total rate of all processes. This is basic probability theory, not quantum mechanics—it's how we analyze competing risks in medicine, insurance, or any situation with multiple possible "first events."

No new fundamental stochastic dynamics are postulated; the apparent randomness reflects uncontrollable detector microstates, not intrinsic wavefunction collapse. Thus outcomes 00 or 11 occur with equal probability, reproducing the observed entanglement correlations without invoking the Born rule as a separate postulate.

2.3 Local Operations and Steering

Applying a local unitary on one subsystem—say, a Hadamard gate on qubit A—reshapes the joint amplitudes:

$H_a|\Phi^+\rangle = (1/2)(|00\rangle + |01\rangle + |10\rangle - |11\rangle)$

For general readers: A Hadamard gate is a standard quantum operation that mixes 0 and 1 states. Applying it to one particle of an entangled pair redistributes the amplitudes across all four possible outcomes.

All four basis elements now have equal weight $|\psi_{a\beta}|^2 = 1/4$. Crucially, this steering remains entirely reversible and fact-free until measurement. Entanglement correlations thus emerge from joint fact competition rather than requiring dynamical nonlocal influences between independently existing local facts.

2.4 Bell Correlations and CHSH

A skeptical reader may ask whether fact-steering reproduces not only Bell-state outcome weights in a fixed basis, but also the quantum violation of Bell inequalities under varying measurement settings.

For general readers: Bell's theorem shows that quantum mechanics predicts correlations between distant particles that cannot be explained by any "local hidden variable" theory—roughly, any theory where each particle carries pre-determined answers to all possible measurements. The CHSH inequality is a specific test: classical theories predict $|S| \leq 2$, while quantum mechanics allows $|S|$ up to $2\sqrt{2} \approx 2.83$.

Setup (singlet + measurement settings). Consider two qubits prepared in the singlet state:

$|\Psi^-\rangle = (1/\sqrt{2})(|0\rangle\_A|1\rangle\_B - |1\rangle\_A|0\rangle\_B)$

Alice chooses measurement setting a, Bob chooses setting b. Let the measured outcomes be A, B $\in \{+1, -1\}$. In standard QM the joint probabilities are:

$$P(A,B|a,b) = \mathrm{Tr}[(\Pi^a\_A \otimes \Pi^b\_B)|\Psi^-\rangle\langle\Psi^-|]$$

where Π^a_A and Π^b_B are the projectors associated with settings a, b.

Fact-steering translation (joint admissible facts and rates). In fact-steering, the admissible facts for a Bell run are the joint detector records:

$$(A, B) \in \{(+,+), (+,-), (-,+), (-,-)\}$$

for the chosen settings a, b. After local interaction and decoherence, there are four effectively independent "branches" (channels) labeled by (A, B). The framework assigns a trigger rate to each joint channel:

$$\lambda\_AB(a,b) = \kappa\, |\psi\_AB(a,b)|^2$$

where $\psi\_AB(a,b)$ are the branch amplitudes in the measurement-defined joint basis.

First-passage selection among competing joint channels gives:

$$P(A,B|a,b) = \lambda\_AB(a,b) / \Sigma\_\{A',B'\}\ \lambda\_\{A'B'\}(a,b) = |\psi\_AB(a,b)|^2$$

for normalized states. This reproduces the standard joint distribution.

Correlation function and CHSH. Define the correlation:

$$E(a,b) = \Sigma\_\{A,B=\pm 1\}\ AB \cdot P(A,B|a,b)$$

For the singlet state, standard QM gives $E(a,b) = -\cos \theta\_ab$ where θ_ab is the angle between measurement axes. Because fact-steering reproduces $P(A,B|a,b)$ exactly, it reproduces this correlation and hence the CHSH value:

$$S = E(a,b) - E(a,b') + E(a',b) + E(a',b')$$

The bounds are:

- $|S| \leq 2$ (local hidden variables / classical)
- $|S| \leq 2\sqrt{2}$ (quantum / Tsirelson bound)

Choosing the standard "maximal violation" settings (relative angles $0, \pi/2, \pi/4, 3\pi/4$) yields $|S| = 2\sqrt{2}$, saturating the Tsirelson bound. Fact-steering reproduces the quantum bound because it reproduces the quantum joint distribution $P(A,B|a,b)$ exactly.

2.4.1 "Nonlocal Without Action-at-a-Distance"

A referee may ask: "If you violate Bell, aren't you doing action-at-a-distance?" The answer requires precision:

Yes, the model is nonlocal in Bell's technical sense: the joint distribution cannot be written as a local hidden variable model.

No, it does not introduce a dynamical signal or causal influence propagating through space at measurement time.

The precise "no action-at-a-distance" story:

No inter-branch pushing. After decoherence, the channels do not interact. The "race" is not a dynamical interaction between distant devices; each local detector responds to its local rate, and the joint statistics reflect the global amplitude structure without requiring any inter-device communication.

Nonlocality lives in the global branch weights/rates. The dependence on both settings enters through $|\psi_{AB}(a,b)|^2$—a global property of the entangled state under the chosen measurement context. That is exactly where Bell nonlocality must live in any model reproducing quantum correlations.

No-signaling is automatic. The marginal for Alice is:

$$P(A|a,b) = \Sigma_B P(A,B|a,b) = \Sigma_B |\psi_{AB}(a,b)|^2 = P(A|a)$$

independent of b. (Same for Bob.) Thus nothing Alice does changes Bob's local statistics.

Nonlocality here is a property of the global configuration-space rate assignment $\lambda_{AB}(a,b)$, not a propagating physical signal between the apparatuses. This is the same sense in which Bohmian mechanics is "nonlocal but non-signaling."

For general readers: The key insight is that "nonlocal" doesn't mean "faster-than-light communication." The correlations between Alice and Bob are set by the global quantum state, but neither party can use this to send messages. When Alice measures, she learns something about what Bob will find—but Bob's individual statistics don't change based on Alice's choice. This is the standard quantum mechanical result, and fact-steering reproduces it exactly.

Takeaway: Fact-steering reproduces Bell violations because the joint admissible-fact rates are set by the global entangled state and the joint measurement context; however, it introduces no superluminal signals and no dynamical "push" from one wing to the other—only a global rate assignment plus local threshold triggering.

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3. Grover's Algorithm: Coherent Narrowing of Viable Facts

Grover's search algorithm provides a clear demonstration of amplitude steering without intermediate measurement. The computational basis defines the possible facts $\{|x\rangle\}$, corresponding to candidate solutions.

For general readers: Grover's algorithm is a quantum procedure for searching an unsorted database. Classically, finding one marked item among N items requires checking about N/2 items on average. Grover's algorithm finds it in only about $\sqrt{N}$ steps—a dramatic speedup for large databases.

3.1 Setup

Let $N = 2^n$ be the search space size with a unique marked solution $|x^*\rangle$. Define the angle θ by:

$\sin\theta = 1/\sqrt{N}$

The algorithm begins in a uniform superposition:

$|s\rangle = (1/\sqrt{N})\ \Sigma_x\ |x\rangle = \sin\theta\ |x^*\rangle + \cos\theta\ |r\rangle$

where $|r\rangle$ is the normalized superposition over unmarked states. Initially, all possible facts have equal amplitude $1/\sqrt{N}$ and equal outcome-selection rates.

For general readers: We start with all N possibilities equally weighted. The target item has amplitude $1/\sqrt{N}$, which means probability 1/N of being found if we measured immediately—no better than random guessing.

3.2 The Grover Iteration

Each Grover iteration $G = D \cdot O$ consists of:

Oracle (O): Introduces a phase flip on the target state:

$O|x\rangle = (-1)^{f(x)}\ |x\rangle$

where $f(x^*) = 1$ and $f(x) = 0$ otherwise. This changes no weights—only relative phase.

For general readers: The oracle is like a "hint" that marks the target by flipping its sign. This doesn't change the probability of finding it (since probability depends on amplitude *squared*), but it changes how amplitudes will interfere in the next step.

Diffusion (D): Reflects about the mean amplitude:

$D = 2|s\rangle\langle s| - I$

This converts phase structure into amplitude redistribution via interference.

For general readers: The diffusion step is where the magic happens. It takes the phase information from the oracle and converts it into actual amplitude changes through quantum interference. Items with negative phase (the target) get boosted; items with positive phase get suppressed.

3.3 Amplitude Evolution

The combined operation G acts as a rotation by 2θ in the two-dimensional subspace spanned by $\{|x^*\rangle, |r\rangle\}$. After k iterations:

$$|\psi_k\rangle = G^k|s\rangle = \sin((2k+1)\theta)|x^*\rangle + \cos((2k+1)\theta)|r\rangle$$

The marked-state weight evolves as:

$$w_k = |\langle x^*|\psi_k\rangle|^2 = \sin^2((2k+1)\theta)$$

For general readers: Each iteration rotates the quantum state a little bit toward the target. The probability of finding the target grows with each step, following a sine-squared curve.

3.4 Optimal Iteration Count

Maximum success probability occurs when $(2k+1)\theta \approx \pi/2$. Since k must be an integer, one typically takes:

$$k\_opt = \lfloor(\pi/4)\sqrt{N}\rfloor$$

(or the nearest integer), yielding near-unit success probability.

For general readers: There's an optimal number of iterations—about $(\pi/4)\sqrt{N}$. If you do too few, you haven't rotated far enough toward the target. If you do too many, you rotate *past* the target and the probability starts decreasing again.

At this point, destructive interference has suppressed amplitudes for non-solutions while constructive interference has amplified the target. The target basis element dominates the outcome-selection rates.

3.5 Fact-Steering Interpretation

The Grover speedup is understood as coherent narrowing of viable future facts:

- **Before steering**: All N facts equally viable (uniform rates)
- **After steering**: One fact dominates (concentrated rate)
- **At measurement**: First-passage competition selects the dominant fact with probability w_k

No separate measurement axiom is required. The success probability follows directly from rate normalization:

$P\_success = \lambda\_target / \Sigma_x \lambda_x = w_k / (w_k + (1-w_k)) = w_k$

For general readers: In the fact-steering picture, Grover's algorithm is "reshaping the landscape" of possible futures. Initially all outcomes are equally likely; the algorithm makes one outcome overwhelmingly dominant. Measurement is just the final step where one of these possibilities becomes actual—and it's almost certain to be the dominant one.

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4. POVMs and Real Detectors: Physically Admissible Facts

Generalized measurements (POVMs) are often introduced abstractly as arbitrary sets of positive operators satisfying $\Sigma_i E_i = I$. The fact-steering framework inverts this: the starting point is the physical detector.

For general readers: A POVM (Positive Operator-Valued Measure) is a mathematical description of a generalized quantum measurement. Standard measurements ask "is the particle here or there?" but POVMs can represent more complex questions, including measurements with noise, incomplete information, or multiple detection stages. The question is: which mathematical POVMs correspond to measurements we can actually build?

4.1 Detector-Defined Channels

A real measurement device defines a finite set of metastable macroscopic states—click channels—which constitute the only physically admissible facts. Each channel i corresponds to a distinct macroscopic configuration (photomultiplier avalanche, superconducting qubit state, etc.) that can be irreversibly recorded.

For general readers: A "metastable" state is one that's stable but can be triggered to change. Think of a ball balanced on top of a hill—it will stay there until something nudges it, then it rolls down and can't easily get back up. Detectors work by having such trigger-ready states that the quantum system can set off.

4.2 From Channels to POVMs

The system couples to these detector channels through a unitary interaction U_sys-det. Each channel accumulates microscopic excitation until one crosses an instability threshold and triggers an irreversible record.

Let $\{M_i\}$ be the Kraus operators describing the coupling to channel i. The effective POVM elements arise as:

$E_i = M_i^\dagger M_i$

with $\Sigma_i E_i = I$ guaranteed by unitarity of the total interaction.

For general readers: Kraus operators are mathematical tools that describe how a quantum system interacts with its environment (in this case, the detector). The POVM elements E_i are built from these operators and determine the measurement probabilities.

4.3 Physical Constraints on Admissible POVMs

This perspective implies that not all abstract POVMs correspond to clean, physically realizable measurements. Fact admissibility imposes constraints:

Metastability: Each channel must have a stable "armed" state and a distinct "triggered" state, with escape from metastability producing an irreversible macroscopic record.

Threshold separability: Channels must be sufficiently decoupled that one can trigger without immediately triggering others.

Amplification capacity: The microscopic system-channel coupling must be able to drive macroscopic state change.

4.4 Example: Identity-Proportional POVM Elements Are Non-Informative

Consider a three-outcome POVM on a qubit with elements:

$E_1 = (2/3)|0\rangle\langle 0|$, $E_2 = (2/3)|1\rangle\langle 1|$, $E_3 = (1/3)I$

This POVM is mathematically valid ($\Sigma_i E_i = I$, all $E_i \geq 0$) and physically implementable—for example, by mixing a standard computational-basis measurement with a state-independent random output.

However, the element $E_3 = (1/3)I$ is state-independent: for any input ρ,

$p(3) = \mathrm{Tr}(\rho E_3) = 1/3$

For general readers: This third outcome happens with probability 1/3 regardless of what quantum state you feed in. It tells you nothing about the system—it's like a detector that randomly clicks sometimes whether or not anything is there.

This outcome carries no information about the system state. It does not naturally correspond to a channel whose triggering is driven by system-dependent coupling; it is most naturally interpreted as a background trigger (dark-count-like process) or classical randomness.

Implementation decomposition: The POVM can be explicitly realized as a mixture:

- With probability 1/3: output "3" (a purely classical random trigger, independent of the system)

- With probability 2/3: perform the projective measurement $\{|0\rangle\langle 0|, |1\rangle\langle 1|\}$ and output "1" or "2" accordingly

This reproduces $p(1) = (2/3)\langle 0|\rho|0\rangle$, $p(2) = (2/3)\langle 1|\rho|1\rangle$, $p(3) = 1/3$.

In the fact-steering view, this illustrates a key point: not every POVM element should be interpreted as a primitive "detector fact channel." Elements proportional to the identity are intrinsically non-informative and are best regarded as derived summaries combining genuine system-driven channels with classical randomness or post-processing. The framework thus distinguishes between primitive fact channels (system-coupled, metastable, threshold-triggered) and composite measurement descriptions that include noise or classical mixing.

This illustrates how physical admissibility constrains interpretation, even when it does not constrain mathematical validity: the same POVM can be implemented, but not every element corresponds to a primitive system-driven fact channel.

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5. Summary of the Tests

Across all three tests, the same structure appears:

Component	Implementation
Possible facts	Detector-compatible basis outcomes
Steering	Unitary amplitude reshaping (reversible, fact-free)
Selection	Competitive threshold crossing (irreversible, single outcome)

The framework reproduces standard quantum predictions:

- Entanglement correlations from joint fact competition
- Grover speedup from coherent narrowing of viable facts
- POVM probabilities from channel coupling strengths

The mathematics simplifies once physical admissibility constraints are applied at the outset, and the Born rule emerges from first-passage statistics rather than being introduced as an independent postulate.

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6. Comparison to Existing Approaches

This section positions the fact-steering framework alongside standard modern treatments. The intent is not to replace existing formalisms—each remains mathematically correct—but to clarify what each takes as primitive, what it explains, and what it leaves implicit.

For general readers: There are many different "interpretations" of quantum mechanics—different ways of understanding what the mathematics means physically. This section compares fact-steering to the major alternatives, showing what each explains and what each leaves as an open question.

6.1 Copenhagen / Operational QM

What it does well: Efficient and empirically complete. The Born rule provides correct predictions; the projection postulate updates states consistently.

What it leaves implicit: Why a single definite outcome occurs; why probabilities have the $|\psi|^2$ form beyond the postulate itself.

Fact-steering addition: The apparatus-defined set of possible facts is explicit, outcome selection is tied to irreversible threshold amplification, and Born weights arise as rate weights governing first-passage competition.

6.2 Decoherence / Einselection

What it does well: Explains suppression of interference between branches; identifies stable pointer states via environmental entanglement.

What it leaves implicit: By itself, decoherence does not select a single outcome—after decoherence one still has multiple non-interfering branches.

Fact-steering addition: Treats decoherence as a prerequisite that defines effectively independent channels, then adds an explicit irreversible selection step via competitive threshold crossing.

For general readers: Decoherence explains why quantum weirdness (like interference between "alive" and "dead" cat states) disappears for large objects—the environment effectively "measures" the system constantly. But it doesn't explain why we see *one* outcome rather than experiencing all branches. Fact-steering adds that final step.

6.3 Many-Worlds / Everettian Accounts

What it does well: Takes unitary evolution as universal; avoids adding non-unitary dynamics.

What it leaves implicit: Must justify why observed frequencies obey $|\psi|^2$ and how to interpret probability when all outcomes occur.

Fact-steering contrast: Does not require commitment to persistent branch ontology. Probabilities arise from first-passage competition among channels rather than from self-locating uncertainty or decision-theoretic axioms.

6.4 Bohmian Mechanics

What it does well: Provides deterministic outcomes using hidden variables (particle positions) guided by the wavefunction.

What it leaves implicit: The $|\psi|^2$ equilibrium distribution is typically assumed rather than derived from detector-level necessity.

Fact-steering parallel: Structurally similar (determinism plus epistemic probabilities), but places the hidden detail in the detector/environment microstate and derives $|\psi|^2$ as the unique rate weight consistent with interference, symmetry, and threshold detection.

6.5 Objective Collapse (GRW/CSL)

What it does well: Produces definite outcomes via stochastic collapses; potentially testable.

What it leaves implicit: Introduces new parameters; typically postulates collapse rates rather than deriving Born weights from detector physics.

Fact-steering contrast: Collapse is not a new fundamental stochastic law. Outcome definiteness arises from metastable amplification; apparent randomness is attributed to inaccessible microstructure.

6.6 Quantum Computing Textbook View

Standard treatment: Gates are unitary matrices; measurement is a projective or POVM readout. Focus is computational correctness rather than interpretive mechanism.

Fact-steering addition: Gates reshape the amplitude landscape (coherently amplifying and cancelling candidate facts) without creating records. Measurement is the irreversible act that converts one surviving possibility into a fact. This explains why mid-circuit measurement changes the computational model (it introduces facts and classical control).

6.7 Summary: What Changes and What Stays the Same

Aspect	Standard QM	Fact-Steering
State space	Hilbert space	Hilbert space
Dynamics	Unitary evolution	Unitary steering
Measurement	Born rule (axiom) + collapse	First-passage competition (derived)
Probabilities	Postulated as	ψ
POVMs	Abstract operators; Naimark dilation	Detector-channel construction

The operational calculus is preserved. What changes is the explanatory hierarchy: physically admissible facts are detector-defined, steering is reversible amplitude shaping, and outcome selection is a necessary irreversible event implemented by threshold competition.

6.8 Recent Interpretive Programs

Three recent approaches merit specific comparison: QBism, pragmatist quantum mechanics, and quantum Darwinism.

QBism (Fuchs, Schack)

QBism treats the quantum state as an agent's personal credences; the Born rule functions as a normative constraint on rational belief update. Measurement outcomes are experiences for the agent rather than observer-independent facts.

Where QBism treats the Born rule as a normative constraint on rational belief, fact-steering treats the same rule as emergent from detector-level competition once the rate–amplitude relation is established. The two views address different explanatory layers: epistemic norm versus physical mechanism. However, a tension remains: fact-steering posits observer-independent facts (relative to a physical channel structure), whereas QBism maintains thoroughgoing agent-relativity. A committed QBist would likely reject the "channel-relative but still objective" framing as insufficiently radical. (This is a difference in interpretive stance, not a disagreement about operational predictions.)

Pragmatist QM (Healey)

Healey's pragmatist interpretation emphasizes quantum states as tools for guiding expectations and licensing claims about physical situations. Measurement is not treated as a fundamental physical discontinuity requiring special dynamics.

Fact-steering shares the rejection of collapse as fundamental discontinuity but adds an explicit physical account of how macroscopic records become definite. Where Healey dissolves the measurement problem by redescribing the role of the quantum state, fact-steering keeps the standard calculus and supplies a concrete detector-layer story. This may appeal to those who want an explicit physical mechanism rather than a purely conceptual dissolution.

Quantum Darwinism (Zurek)

Quantum Darwinism explains classical objectivity via redundant imprinting of pointer states in the environment. Decoherence selects robust pointer states; environmental proliferation makes these states intersubjectively accessible.

For general readers: Quantum Darwinism is Zurek's theory explaining why we all agree on what we see. Information about certain "pointer states" gets copied redundantly throughout the environment, so many observers can access the same information independently. This explains the emergence of an objective classical world from quantum mechanics.

Fact-steering as a completion of Quantum Darwinism. Quantum Darwinism explains how decoherence selects robust pointer states and how environmental proliferation produces redundant, intersubjectively accessible records—thereby accounting for classical objectivity. Fact-steering is naturally read as completing this program at the detector layer.

Darwinism explains channel formation and stability: why certain macrostates are robust and widely recorded. Fact-steering adds a concrete selection mechanism: among the decohered, Darwinistically amplified candidate records, competitive threshold dynamics produces a single irreversible record (a "fact") via first-passage selection. On this view, Darwinism supplies the emergence of effectively independent channels and redundant record structure, and fact-steering supplies the final step that turns "many stable candidate records" into the one record actually instantiated in the apparatus.

This addition is compatible with multiple ontological readings (single-branch realism, Everettian branching, etc.); it is offered as a detector-level mechanism for record selection, not as a claim about the ultimate ontology of branches.

6.9 Contextuality (Kochen-Specker)

Quantum contextuality—the Kochen-Specker theorem and related results—shows that measurement outcomes cannot be assigned pre-existing values independent of the measurement context. The outcome of measuring observable A depends not just on A but on what other compatible observables are measured alongside it.

For general readers: Contextuality is another "no-go" result like Bell's theorem. It says you can't think of quantum systems as having definite values for all properties before measurement—the result you get depends on the whole experimental setup, not just the single property you're asking about.

Fact-steering accommodates contextuality naturally: admissible facts are defined relative to the complete detector configuration, not to abstract observables in isolation. The channels that compete for threshold crossing depend on the full measurement setup—which projectors are implemented, how the apparatus couples to the system, what basis the detector resolves. Different measurement contexts define different channel structures, so "the outcome of measuring A" is not a context-independent property of the system but a property of the system-plus-detector-configuration.

This is not a new insight—it aligns with how operationalists and some Bohmians already treat contextuality—but the fact-steering framework makes the context-dependence physically concrete: different detector setups define different metastable channels, hence different fact-competition dynamics.

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7. Demonstrating the Simplification

A reasonable critique is that "simplification" must be shown, not asserted. This section provides explicit, calculation-level comparisons where the fact-steering picture reduces primitives or removes abstraction.

All simplifications claimed here concern the reduction of primitive postulates and explanatory machinery, not a reduction of the underlying unitary mathematics. The Hilbert space structure and unitary evolution equations remain unchanged; what changes is how measurement connects to that formalism.

For general readers: We're not claiming that quantum calculations become easier—the same math is still needed to track how amplitudes evolve. The simplification is conceptual: fewer separate rules are needed to go from "quantum state" to "measurement outcome."

7.1 The Rate-Amplitude Connection

Throughout this section, we take as established that irreversible threshold-crossing rates into detector channels scale as $|\psi|^2$. This is the key physical input; the present paper does not re-derive it in full but shows how, once accepted, it removes the need for an independent measurement postulate. A condensed derivation appears in Appendix A; the full treatment is in the companion Tick-Bit paper [5].

In the Tick-Bit framework ("Quantum Measurement as a Tick Race"), the rate–amplitude relation $\lambda_i \propto |\psi_i|^2$ is derived from decoherence, perturbative transition rates, and metastable threshold dynamics. The present work assumes this result and focuses on its consequences for standard quantum scenarios.

The physical basis for the rate–amplitude connection rests on three ingredients:

1. **Perturbative transition rates**: Fermi's golden rule gives transition rates proportional to $|\langle f|H'|i\rangle|^2$, where the matrix element inherits the system's amplitude structure.
2. **Detector metastability**: Each channel sits in a metastable configuration; small perturbations from the system accumulate until a threshold is crossed.
3. **First-passage statistics**: When multiple channels compete, the probability of channel i firing first equals $\lambda_i/\Sigma_j\lambda_j$.

For general readers: Fermi's golden rule is a standard result from quantum mechanics that tells us how fast transitions happen between states. It naturally gives rates proportional to amplitude squared. This isn't a new assumption—it's textbook physics applied to detector channels.

A detailed derivation appears in the companion work on Tick-Bit outcome selection. Here we show how, once accepted, this connection unifies measurement with circuit-level analysis.

7.2 Grover: Unifying Dynamics and Measurement

Standard textbook approach requires two independent primitives:

- Unitary evolution: $|\psi\rangle \to G|\psi\rangle$
- Measurement postulate: outcome x with probability $|\langle x|\psi\rangle|^2$, followed by state collapse

Fact-steering approach tracks the same dynamics but interprets measurement differently:

Evolution (unchanged): After k iterations,

$$w_k = \sin^2((2k+1)\theta)$$

where θ satisfies $\sin \theta = 1/\sqrt{N}$.

Measurement (derived, not postulated): Channel rates are

$$\lambda\_target = \kappa \cdot w_k, \lambda\_rest = \kappa \cdot (1 - w_k)$$

First-passage statistics immediately give:

$$P\_success = \lambda\_target / (\lambda\_target + \lambda\_rest) = w_k$$

The measurement "rule" reduces to normalization of competing channel rates. No separate collapse axiom is required for circuit-level success probability calculations.

Where the simplification lies: The unitary dynamics are identical—the 2D rotation cannot be simplified further without loss. The economy is specifically in how measurement connects to outcomes: one physical mechanism (threshold competition) replaces an independent postulate (Born rule).

7.3 Measurement as Thresholded Channel Competition

Standard QC circuit analysis uses two independent primitives:

- Unitary evolution: $|\psi\rangle \to U|\psi\rangle$
- Measurement postulate: outcome i with probability $\langle\psi|E_i|\psi\rangle$, followed by state update

Fact-steering replacement:

- Each admissible detector channel i has rate $\lambda_i = \kappa \cdot w_i$ where $w_i = |\langle i|\psi\rangle|^2$
- The recorded outcome is the first channel to cross its metastability threshold
- First-passage statistics give $P(i) = \lambda_i / \Sigma_j\lambda_j = w_i$

The only additional primitive beyond unitary steering is: "facts are produced by irreversible threshold events." The rest of the measurement calculus follows.

7.4 POVMs Without Naimark as a Foundational Move

Standard abstract route: Embed the system in a larger Hilbert space, apply a projective measurement, trace out the ancilla. Mathematically elegant but physically indirect.

For general readers: Naimark's theorem says any generalized measurement (POVM) can be understood as an ordinary measurement on a larger system. This is mathematically true but doesn't tell you how to actually build the measurement device.

Detector-channel route (direct):

1. Specify the apparatus channels $\{i = 1, ..., m\}$
2. Characterize the system-channel couplings $\{M_i\}$
3. Compute POVM elements: $E_i = M_i†M_i$
4. Verify completeness: $\Sigma_i E_i = I$

The click probability is $p_i = \langle\psi|E_i|\psi\rangle$, and for physically realizable detectors the E_i arise from concrete channel couplings and metastable thresholding.

Where the simplification lies: The theory's primitives are channel facts and coupling-defined M_i, rather than arbitrary positive operators plus an existence theorem in a larger space. This aligns with how experimentalists actually design measurements: choose channels, characterize couplings, calibrate thresholds.

Naimark dilation remains available as optional mathematical scaffolding when convenient, but it is not required as a foundational justification for why POVMs exist.

7.5 Mid-Circuit Measurement: A Worked Example

Teleportation protocol (minimal sketch):

For general readers: Quantum teleportation is a protocol for transmitting a quantum state from one location to another using entanglement and classical communication. It requires a measurement in the middle of the protocol, making it a good test case for how the framework handles mid-circuit measurement.

Let qubit 1 carry an unknown state $|\psi\rangle = \alpha|0\rangle + \beta|1\rangle$. Qubits 2 and 3 share the Bell state $|\Phi^+\rangle_{23}$.

Step 1: Apply $CNOT_{12}$ and H_1:

$|\Psi\rangle_{123} = (1/2)\ \Sigma_m\ |m\rangle_{12} \otimes (\sigma_m|\psi\rangle)_3$

where $\sigma_{00} = I$, $\sigma_{01} = X$, $\sigma_{10} = Z$, $\sigma_{11} = XZ$, and m ranges over {00, 01, 10, 11}.

Step 2: Bell measurement on qubits 1-2.

Standard treatment: Apply measurement postulate; outcome m occurs with probability 1/4; state collapses to $|m\rangle_{12} \otimes (\sigma_m|\psi\rangle)_3$.

Fact-steering treatment: The Bell measurement defines four possible facts {00, 01, 10, 11}. Each has equal rate ($\lambda_m = \kappa/4$). Channel competition irreversibly selects one fact m.

Step 3: Apply correction $\sigma_m^\dagger$ to qubit 3.

Standard treatment: Requires explicit hybrid classical-quantum bookkeeping and post-measurement state update rules.

Fact-steering treatment: A fact m now exists. Future evolution is pure steering on qubit 3, classically conditioned on m. The circuit is simply a switch selecting the appropriate correction gate.

The simplification: Nothing conceptually opaque occurs at the classical-quantum interface. The only event is the creation of a fact; afterward, the protocol is deterministic steering controlled by that fact.

7.6 Primitive Count Comparison

Accounting note (what is assumed vs derived vs replaced). The "primitive reduction" claimed here is not a reduction of the core unitary formalism: we continue to assume Hilbert space structure and unitary dynamics as in standard quantum mechanics. The economy claim is specifically that the Born measurement rule and collapse/update postulate need not be taken as independent axioms once detector-level metastability and the rate–amplitude law are in place.

Primitive Accounting Table:

Component	Standard QM Status	Fact-Steering Status	Source/Notes
State space (Hilbert space)	Assumed	Assumed	Standard QM (unchanged)
Unitary dynamics (Schrödinger eq.)	Assumed	Assumed	Standard QM (unchanged)
Decoherence / channelization	Used implicitly or via environment	Assumed as physical prerequisite	Standard decoherence theory
Born rule $P(i) = \langle\psi\|E_i\|\psi\rangle$	**Primitive axiom**	**Derived** from rate normalization	Replaced here
Collapse / state update postulate	**Primitive axiom**	**Replaced** by fact creation + conditioning	Replaced here
Rate law $\lambda_i \propto \|\psi_i\|^2$	Not stated as rate law	Derived from perturbative transition dynamics	Appendix A; see [5] for circularity discussion
Detector metastability + thresholding	Not a formal axiom	**New physical postulate**	Fact-steering contribution

Component	Standard QM Status	Fact-Steering Status	Source/Notes
First-passage (competing risks)	Not used	**New mechanism**	Fact-steering contribution

The claimed economy is not a reduction in the kinematic/dynamic core of QM (Hilbert space + unitarity), but a reduction in measurement-interface postulates: Born + collapse are replaced by detector-layer threshold competition, given the rate law.

Task-by-Task Comparison:

Task	Standard QC Primitives	Fact-Steering Primitives
Grover success probability	State vector; unitary G; Born rule (axiom); state update (axiom)	Weight w_k; steering as rotation; measurement as rate normalization (derived)
Projective measurement	Born rule (separate axiom); projection postulate	Metastable channels; rates $\lambda_i \propto |\psi_i|^2$; first-passage gives $P(i) = \lambda_i/\Sigma\lambda$
POVMs	Abstract $\{E_i\}$ with $\Sigma E_i = I$; Naimark dilation as justification	Physical channels → Kraus couplings $\{M_i\}$; $E_i = M_i^\dagger M_i$ as summary
Mid-circuit measurement	Hybrid classical-quantum bookkeeping; explicit post-measurement updates	Create fact m; classical conditioning selects subsequent steering

The reduction is not merely interpretive economy—it is a decrease in the number of independent axioms required to connect unitary control to experimental outcomes, replacing the measurement postulate with detector-level physics.

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8. Discussion

8.1 What the Framework Does Not Change

The fact-steering framework preserves the entire operational apparatus of quantum mechanics:

- States remain vectors in Hilbert space (or density operators)
- Dynamics remain unitary between measurements
- All empirical predictions are reproduced exactly

The change is organizational: measurement is derived from detector physics rather than postulated, and this derivation constrains which measurements are physically realizable.

8.2 Experimental Distinguishability

At the level of standard quantum predictions, the fact-steering framework is empirically equivalent to Copenhagen for conventional (single-threshold) detectors. No deviations from quantum predictions are claimed in this work for existing experimental regimes. The framework does, however, suggest specific physical questions:

- Do real detector channels exhibit the metastability and threshold dynamics assumed?
- Can deviations from $|\psi|^2$ statistics be observed in detectors with unusual channel structures?
- Are there proposed POVMs that prove unrealizable due to fact-admissibility constraints?

The companion Tick-Bit analysis further suggests that engineered multi-threshold ($k > 1$) detectors could produce controlled deviations from Born statistics; this paper does not pursue those predictions in full but presents the core prediction below.

Prediction: Engineered k > 1 Independent-Trigger Detectors Deviate from Born Weights

Statement. If a detector requires k independent threshold-triggering microevents (rather than a single first event) before producing a macroscopic record, the first-passage probability is no longer $P \propto |\psi|^2$; it becomes systematically "winner-take-more" and deviates from Born statistics.

Minimal two-channel protocol:

1. Prepare a two-outcome superposition with controllable weights $|\psi_1|^2$ and $|\psi_2|^2$. Choose a convenient ratio, e.g., $|\psi_1|^2 : |\psi_2|^2 = 2:1$.
2. Implement two detector types:
    - **Detector A (k=1)**: Standard single-trigger threshold detector
    - **Detector B (k=2)**: Engineered to require two genuinely independent trigger events before the macroscopic "bit" is recorded (not just two amplification stages in a single causal chain)
3. Run N repeated trials and compare outcome frequencies.

Quantitative target (example ratio 2:1). If $\lambda_1 = 2\lambda_2$ (equivalently $|\psi_1|^2 = 2|\psi_2|^2$):

- **k = 1 (Born):** $P_1 = \lambda_1/(\lambda_1 + \lambda_2) = 2/3 \approx 0.667$
- **k = 2 (Gamma waiting-time):** $P_1 = 20/27 \approx 0.741$

This is an **11% absolute shift**—large by quantum-foundations standards—and experimentally distinguishable with $\sim 10^3$ trials. The Tick-Bit analysis estimates ~1,600 trials for $\sim 3\sigma$ significance in this example.

Why this is a fact-admissibility test. This is not a prediction of textbook QM with the Born rule taken as a primitive mapping from state to registered outcomes; it is a detector-layer structural prediction about how fact creation behaves when the macroscopic record requires $k > 1$ independent triggers. The quantitative 20/27 calculation and statistical power analysis appear in the companion Tick-Bit paper [5].

For general readers: This is a concrete, falsifiable prediction. If someone builds a detector that requires two independent "clicks" before registering an outcome (rather than one click triggering an amplification cascade), the framework predicts measurably different statistics from the standard Born rule. This is rare in foundations work—most interpretations make identical predictions to standard QM.

These questions connect interpretation to experimental detector physics, though they do not predict violations of quantum mechanics itself for standard single-threshold detection.

Continuous monitoring as a test case. One regime where fact-admissibility constraints may "bite" is continuous quantum measurement. In continuous monitoring (homodyne detection, fluorescence counting, dispersive readout), there is no single instantaneous POVM click; instead, the detector produces a stochastic measurement record $I(t)$ evolving in time.

For general readers: In many modern experiments, measurement isn't a single "click"—it's a continuous stream of data. Think of monitoring a quantum system with a camera that's always on, rather than taking a single snapshot. This raises interesting questions about what counts as a "fact" when information arrives continuously.

The fact-steering framework interprets this as follows: "facts" are not arbitrary POVM outcomes but thresholded features of the record—first threshold crossings (e.g., $T_\theta = \inf\{t : I(t) > \theta\}$), jump times in photon counting, run-lengths, or other functionals that correspond to irreversible macroscopic state changes. Many abstract POVM coarse-grainings of the continuous record do not correspond to stable fact creation; they are mathematical summaries rather than primitive detector events.

This suggests a concrete experimental question: in continuous monitoring, which coarse-grainings of the measurement record correspond to physically stable facts (implementable by metastable thresholds), and which are merely derived statistical summaries? The framework predicts that only certain functionals—those tied to genuine threshold-crossing dynamics—should exhibit the robustness and repeatability characteristic of "facts." This is a regime where the distinction between primitive fact channels and derived POVM descriptions may have observable consequences for detector design and quantum trajectory analysis.

Concrete continuous-monitoring protocol (threshold-time fact definition). Consider a dispersive readout of a superconducting qubit producing a homodyne current $I(t)$. Prepare $|\psi\rangle = \sqrt{p}\,|0\rangle + \sqrt{(1-p)}\,|1\rangle$ with tunable p. Define the recorded "fact" as the first threshold crossing time of a filtered record $\bar{I}(t)$:

$$T_\theta = \inf\{t : \bar{I}(t) > \theta\}$$

with the sign of the crossing determining the outcome. Fact-steering predicts that (i) the coarse-graining defined by first-crossing events is robust under detector details (threshold and filter choices within a stability range), and (ii) the winner frequencies are governed primarily by relative channel hazard rates, recovering Born weights for single-threshold detection.

By contrast, alternative coarse-grainings not tied to threshold crossings (e.g., classification by the sign of $\int_0^T I(t)dt$ at fixed T in regimes where no metastable switching occurs) should be significantly more sensitive to filtering and detector-specific noise models, reflecting that they are derived summaries rather than primitive fact events. This provides a falsifiable distinction: threshold-tied coarse-grainings should be robust; non-threshold coarse-grainings should be fragile.

8.3 Relation to the VERSF Program

The fact-steering framework fits within the broader VERSF (Void Energy-Regulated Space Framework) program, which proposes that time, space, and probability emerge from entropy dynamics on a substrate of discrete information processing. The connection to Tick-Bit dynamics—where outcome selection rates derive from entropy production requirements—provides the physical grounding for the $\lambda \propto |\psi|^2$ relationship assumed here.

A complete treatment appears in companion work; this paper focuses specifically on testing the measurement framework against standard quantum scenarios.

8.4 Wigner's Friend and Nested Facts

The Wigner's friend scenario—recently sharpened by Frauchiger and Renner [10] into a formal no-go theorem—poses a challenge for interpretations of quantum mechanics: a "friend" inside an isolated laboratory measures a quantum system and sees a definite outcome, while "Wigner" outside can (in principle) treat the entire lab—including the friend—as a coherent superposition and perform interference measurements.

For general readers: Imagine your friend is in a sealed lab measuring whether a quantum coin landed heads or tails. Your friend sees a definite result. But if the lab is perfectly isolated, quantum mechanics says you (outside) should treat the whole lab as being in a superposition of "friend saw heads" and "friend saw tails"—and you could in principle do experiments that reveal interference between these possibilities. This seems paradoxical: did the coin have a definite value or not?

The fact-steering resolution. The framework provides a physical criterion for when outcomes become facts:

Inside the lab: The friend's detector has channels $F \in \{\uparrow, \downarrow\}$ with rates $\lambda_F \propto |\psi_F|^2$. A threshold crossing creates a friend-fact F. From the friend's perspective, within the friend's admissible fact channels, a definite outcome occurs.

Outside the lab: Wigner's admissible facts are outcomes of his chosen measurement on the lab, $W \in \{w_+, w_-\}$. If the lab remains coherently isolated (no information leakage, no environmental decoherence), Wigner can in principle measure an interference observable and observe $w\pm$ probabilities that depend on coherence between the "friend saw ↑" and "friend saw ↓" branches.

Key claim: Friend-facts and Wigner-facts are not required to be jointly refinable unless there exists a physical channel structure that makes them jointly admissible. If the friend's record is not redundantly recorded outside the lab (not Darwinistically proliferated into Wigner's environment), it is not necessarily a Wigner-admissible fact.

Resolution: No contradiction arises because "fact" is not absolute—it is channel-relative and anchored in thermodynamic irreversibility and Darwinistic redundancy. The friend's outcome is a fact relative to the friend's detector channels. It becomes a fact for Wigner only when it is physically stabilized into Wigner's admissible fact channels (typically via environmental decoherence and record proliferation).

A skeptic might note that in realistic scenarios, this stabilization happens essentially instantly—labs are not perfectly isolated—so the framework agrees with Copenhagen that ordinary measurements produce facts. This is correct, but the framework provides a principled physical criterion where Copenhagen provides only a vague "cut." Moreover, the criterion has testable consequences in intermediate regimes: weakly-coupled systems, partial decoherence, and engineered isolation could in principle probe the transition from "fact for the friend" to "fact for Wigner," connecting interpretation to experimental decoherence physics.

For general readers: The resolution is that "fact" isn't a universal, observer-independent label—it's tied to specific physical processes (threshold crossings, irreversible records, environmental imprinting). Your friend's measurement creates a fact *for your friend's detector system*. It becomes a fact *for you* only when that information irreversibly leaks out of the lab into your environment. In realistic scenarios, this happens almost instantly (labs aren't perfectly isolated), which is why we normally don't notice the distinction.

Why this offers a useful physical criterion:

- **Copenhagen:** Typically leaves the "Heisenberg cut" implicit without physical criterion
- **Everett/Many-Worlds:** Relocates the problem to probability/typicality; all branches equally real
- **QBism:** Makes facts thoroughly agent-relative (clean, but abandons observer-independent facthood)
- **Objective collapse (GRW/CSL):** Modifies fundamental dynamics with new parameters

Fact-steering provides a physical criterion—threshold records plus Darwinistic redundancy—for when nested outcomes become jointly classical. This replaces a semantic paradox with a detector-layer criterion: facthood tracks irreversible threshold records and their redundant imprinting into the broader environment.

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9. Anticipating Common Objections

This section pre-empts several predictable objections. The intent is not rhetorical defense but clarification: many objections arise from reading the framework as an alternative quantum theory rather than as a detector-layer reorganization of measurement primitives.

For general readers: This section addresses the cynical ways someone might try to dismiss the paper—and clarifies what the paper actually claims. The framework isn't a new quantum theory; it's a physically grounded way to understand measurement as a threshold process in real detectors, which naturally produces the Born rule and clarifies tricky scenarios like Bell tests and Wigner's friend.

9.1 "You are just re-labeling the Born rule—$\lambda \propto |\psi|^2$ smuggles it in."

Response. The framework distinguishes between two uses of $|\psi|^2$:

- **Born rule as a probability postulate**: $P(i) = |\psi_i|^2$ is taken as a primitive mapping from state to outcome statistics.
- **Amplitude-squared scaling as a dynamical rate law**: $\lambda_i \propto |\psi_i|^2$ is treated as a detector-channel trigger-rate relation grounded in standard transition dynamics (Appendix A) and metastable threshold behavior.

The present paper does not claim to derive all of quantum kinematics; it assumes Hilbert space and unitary evolution. The point is that once a detector-layer rate law is established, the probability rule follows from first-passage competition:

$P(i) = \lambda_i / \Sigma_j \lambda_j$

This replaces the Born rule as a primitive measurement postulate with a detector-layer mechanism. Appendix A provides a condensed standalone derivation of the quadratic scaling under perturbative response; the companion Tick-Bit treatment [5] develops the full constraint chain and robustness analysis.

Clarifying scope: We do not claim that Appendix A alone constitutes the final word on uniqueness for all imaginable detector functionals; we claim it identifies the universal leading-order scaling for metastable weak-response initiation, with higher-order corrections constrained by both additivity and precision interference data.

9.2 "This is just collapse theory in disguise."

Response. The framework does not introduce new fundamental stochastic dynamics or modify the Schrödinger equation. The stochasticity enters at the detector microstate level: uncontrollable microscopic degrees of freedom determine which threshold event occurs first. "Selection" is the thermodynamic fact that a metastable detector, once triggered, undergoes rapid deterministic relaxation to a macroscopic record.

Operationally, this differs from objective-collapse models (GRW/CSL) in three ways:

1. No new universal collapse law is postulated.
2. The selection event is detector-local (a threshold crossing), not a spontaneous universal process.
3. Any deviations from Born weights—if they exist—would arise from engineered detector structures (e.g., multi-trigger $k > 1$ regimes), not from new fundamental parameters.

9.3 "Your 'nonlocal without action-at-a-distance' language is misleading—Bell says it must be nonlocal."

Response. We agree with Bell's theorem: any mechanism reproducing CHSH violations must be nonlocal in the technical sense (no local hidden-variable factorization). The framework's claim is narrower and precise:

- Nonlocality resides in the global configuration-space rate assignment $\lambda_{AB}(a,b) \propto |\psi_{AB}(a,b)|^2$ for joint admissible facts.
- No-signaling is preserved because marginals are setting-independent.
- There is no propagating causal influence between spatially separated detectors at measurement time; the model does not add superluminal signals.

In short: nonlocal, yes; superluminal control or messaging, no.

9.4 "Your $k > 1$ detector prediction contradicts quantum mechanics; any detector is describable by a POVM and Born's rule."

Response. Standard quantum theory is typically presented with Born's rule as the primitive map from a measurement description to outcome probabilities. Our prediction concerns how the physical process of fact creation behaves when the macroscopic record requires multiple independent threshold triggers.

Two clarifications avoid confusion:

1. The claim is not that "quantum theory cannot model such devices," but that the detector-layer mapping from amplitudes to recorded facts depends on the microscopic architecture of record creation. A multi-trigger architecture changes the first-passage statistics of record formation.
2. The appropriate comparison is not "POVMs exist," but rather: which POVM elements correspond to primitive metastable channels, and which are derived summaries of more complex trigger logic plus post-processing.

Thus the $k > 1$ prediction should be read as a detector-physics falsifier of the framework: if engineered genuinely independent multi-trigger fact creation still produces exact Born weights in regimes where the model predicts deviations, the framework is wrong (or incomplete).

9.5 "Primitive counting is unfair—you assume Hilbert space and unitarity, so you have not reduced foundations."

Response. Correct: this paper does not attempt a full reconstruction of quantum kinematics. The primitive-count claim is explicitly local to the measurement interface. We assume:

- Complex Hilbert space state representation
- Unitary steering dynamics

The claimed economy is that, given detector metastability and the rate–amplitude connection, we can replace two measurement primitives:

- Born probability rule as an axiom, and
- Collapse/update as an axiom

with a single physical mechanism:

- Threshold competition + first-passage selection + classical conditioning on the created fact

This is an axiom shift at the measurement interface, not a claim to derive all of quantum theory from scratch.

9.6 "This is interpretation, not physics—there are no new predictions."

Response. Much of the framework is intentionally conservative: it reproduces standard predictions for standard detectors. The motivation is explanatory: to connect measurement outcomes to detector physics and thermodynamic irreversibility, while clarifying which aspects of measurement are primitive vs derived.

That said, the framework does suggest discriminating regimes:

- **Engineered multi-trigger k > 1 detectors**: Explicit quantitative deviation from Born weights (Section 8.2)
- **Continuous monitoring coarse-grainings**: Threshold-defined "facts" predicted to be robust while non-threshold summaries are fragile
- **Nested-observer scenarios (Wigner's friend)**: "Fact" becomes channel-relative unless redundant imprinting stabilizes it into broader admissible channels

These are not claims of wholesale disagreement with quantum mechanics; they are claims about where detector architecture and fact admissibility should matter.

9.7 "Your language suggests 'facts are observer-independent,' but then Wigner's friend makes facts relative. Isn't that inconsistent?"

Response. In this framework, "fact" is not observer-relative in a psychological sense, but channel-relative in a physical sense. A fact exists when a metastable channel has crossed threshold and produced an irreversible record in a specified physical channel structure. Different observers correspond to different accessible channel structures; if a record is not redundantly exported (Darwinistically proliferated) into another observer's environment, it need not be jointly admissible as a fact for that observer.

This is not a contradiction; it is precisely the point: "fact" tracks irreversible records and their physical accessibility, not abstract omniscient bookkeeping.

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10. Conclusion

The fact-steering framework has been tested against three canonical quantum scenarios: entanglement, Grover's algorithm, and generalized measurements. In each case, the framework reproduces standard predictions while offering a reduction in primitive axioms.

The key results are:

1. **Entanglement correlations** are explained as joint fact competition among detector-defined outcomes, without requiring dynamical nonlocal influences between independently existing local facts.
2. **Grover's speedup** is coherent narrowing of viable future facts, with success probability following from rate normalization rather than a separate measurement postulate.
3. **POVMs** arise naturally from detector-channel couplings, with physical admissibility constraints distinguishing primitive fact channels from derived measurement descriptions.
4. **Mid-circuit measurement** becomes a natural boundary between steering-only dynamics and fact-conditioned dynamics, without requiring additional hybrid classical-quantum bookkeeping.

The framework does not alter quantum mechanics—it reorganizes its foundations. Whether this reorganization proves fruitful for pedagogy, for understanding detector physics, or for identifying genuinely new experimental questions remains to be seen. What the present tests establish is that the reorganization is coherent and complete: it handles nontrivial quantum phenomena without gaps or inconsistencies.

For general readers: This paper doesn't claim that quantum mechanics is wrong or needs to be replaced. Rather, it shows that the "measurement problem"—the apparent gap between smooth quantum evolution and sudden measurement outcomes—can be bridged by taking detector physics seriously. The Born rule, instead of being a mysterious separate law, emerges naturally from how detectors work. This may help demystify quantum mechanics without changing any of its predictions.

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Appendix A: Why Detector-Channel Trigger Rates Scale as $|\psi|^2$

This appendix provides a condensed, self-contained derivation of the rate–amplitude relation assumed in the main text. A full treatment appears in the companion Tick-Bit framework paper [5]; here we sketch the essential chain of reasoning.

For general readers: This appendix shows *why* detector trigger rates are proportional to amplitude squared—the key physical input that makes the whole framework work. It uses standard quantum mechanics (Fermi's golden rule) applied to detector physics, so no new assumptions are introduced.

A.1 Setup: Branch Amplitudes and Detector Channels

Let the pre-measurement system–detector state be:

$$|\Psi\rangle = \Sigma_i\ \psi_i\ |i\rangle \otimes |D_0\rangle$$

where $\{|i\rangle\}$ are the system eigenstates corresponding to measurement outcomes, $|D_0\rangle$ is the detector's initial "armed" state, and ψ_i are complex amplitudes satisfying $\Sigma_i|\psi_i|^2 = 1$.

Each detector channel i corresponds to a metastable configuration that can transition to a triggered macrostate $|D_i\rangle$.

A.2 Interaction Hamiltonian

Assume a measurement-type coupling:

$H\_int = \Sigma_i |i\rangle\langle i| \otimes \hat{V}_i$

where each outcome subspace couples to its own detector transition operator $\hat{V}_i$. This structure ensures that the detector "reads out" the system observable with eigenstates $\{|i\rangle\}$.

For general readers: The Hamiltonian describes how energy flows between system and detector. This particular form says that each possible measurement outcome ($|i\rangle$) connects to its own detector channel (via $\hat{V}_i$). It's the mathematical way of saying "outcome 1 triggers channel 1, outcome 2 triggers channel 2," etc.

A.3 Perturbative Transition Rate

Under standard time-dependent perturbation theory (Fermi's golden rule), the transition rate into the triggered manifold associated with channel i is:

$\Gamma_i = (2\pi/\hbar)\, \Sigma\_\{f \in F_i\}\ |\langle f, D_i, i|\ H\_int\ |\Psi\rangle|^2\ \delta(E\_f - E_0)$

where F_i is the set of final states in the triggered manifold of channel i.

Because H_int contains the projector $|i\rangle\langle i|$, the amplitude for transitions into channel i is proportional to ψ_i. The rate therefore factorizes:

$\Gamma_i = |\psi_i|^2\ \kappa_i$

where $\kappa_i \geq 0$ depends only on detector matrix elements $\langle D_i|\hat{V}_i|D_0\rangle$ and densities of states—properties of the detector, not the system state.

For general readers: Fermi's golden rule is a workhorse of quantum mechanics, used to calculate transition rates in everything from atomic physics to semiconductor devices. The key result here is that the rate naturally comes out proportional to $|\psi|^2$—this isn't something we put in by hand; it emerges from standard physics.

A.4 From Transition Rate to Trigger Rate

In a metastable threshold detector, trigger events occur at a rate proportional to Γ_i. Define:

$\lambda_i \equiv \Gamma_i = \kappa_i\ |\psi_i|^2$

For approximately channel-symmetric detectors ($\kappa_i \approx \kappa$ for all i):

$\lambda_i \propto |\psi_i|^2$

A.5 Why Quadratic Dependence Is Selected

The trigger rate λ_i must be a real, nonnegative functional of the complex amplitude ψ_i that is invariant under global phase $\psi_i \to e^{(i\theta)}\psi_i$. Under mild regularity—specifically, that detector response is smooth/analytic in the small-signal regime relevant to threshold initiation—we may expand λ_i in powers of $|\psi_i|^2$:

$\lambda_i = c_1|\psi_i|^2 + c_2|\psi_i|^4 + \cdots$ ($c_k \geq 0$ for physical rates)

The "ordering principle" invoked here is perturbative response: the detector is weakly and locally driven by the system prior to runaway amplification, so the leading nontrivial term in an analytic expansion controls the scaling.

Moreover, for independent microchannels contributing additively to the same macroscopic channel (local additivity of hazard contributions), the leading term must be linear in intensity: if $|\psi|^2 = x_1 + x_2$ arises from two independent contributions, then $\lambda(x_1 + x_2) \approx \lambda(x_1) + \lambda(x_2)$ to leading order. This excludes generic forms $|\psi|^2 f(|\psi|^2)$ unless f is locally constant in the relevant operating regime; any non-constant f produces higher-order corrections ($\propto |\psi|^4$, etc.) that would imply systematic deviations from Born weights in high-precision interference experiments.

Accordingly, $\lambda_i \propto |\psi_i|^2$ is best understood as the universal leading-order scaling in the metastable, weak-response regime. The companion Tick-Bit treatment develops the full constraint chain and robustness analysis.

For general readers: We're not claiming that $|\psi|^2$ is the *only possible* formula—we're claiming it's the *leading term* when detectors respond weakly and smoothly to quantum signals. Any corrections would be tiny (proportional to $|\psi|^4$ or higher), and experiments confirm Born-rule probabilities to high precision, which is consistent with this picture.

A.6 Link to First-Passage Normalization

Once $\lambda_i \propto |\psi_i|^2$ is established, competing-risk statistics give the probability that channel i triggers first:

$P(i) = \lambda_i / \Sigma_j \lambda_j = |\psi_i|^2 / \Sigma_j |\psi_j|^2 = |\psi_i|^2$

where the final equality holds for normalized states. This is the Born rule, now derived from detector physics rather than postulated.

For general readers: And there it is—the Born rule (probability = amplitude squared) emerges from combining Fermi's golden rule (which gives $|\psi|^2$ rates) with first-passage statistics (which converts rates to probabilities). No new physics was added; we just took detector dynamics seriously.