Emergent Wave Dynamics from Phase-Selective Transmission in a Two-Time Quantum Framework

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We explore a dynamical two-time model in which each particle carries (1) a classical relativistic time coordinate t and (2) a rapidly oscillating internal "quantum time" τ. We show that when an ensemble of such particles propagates through a pair of phase-selective apertures, the resulting distribution on a detector screen forms interference patterns with *perfect* fringe contrast, full left-right symmetry, stable fringe spacing, and narrow peaks, even though no wave equation, no complex amplitudes, and no Hilbert space are invoked anywhere in the simulation.

We find that the model robustly reproduces an entire suite of wave phenomena: coherent wavefront propagation, standing-wave modes above the slits, Fraunhofer-like interference bands, and rotation-dependent fringe tilts. The interference pattern is invariant under slit width, consistent with the interpretation that the slits act as *phase filters* rather than spatial apertures.

Finally, we describe falsifiable experimental predictions, including modified decay-rate signatures for relativistic radioactive ions whose internal quantum-time oscillations should modulate under time dilation.

I. INTRODUCTION

Quantum interference is widely regarded as evidence for the wave nature of matter. In the standard formulation, interference arises from the superposition of complex amplitudes evolving according to the Schrödinger or Maxwell equations. However, various alternative approaches—including pilot-wave hydrodynamics, zitterbewegung-inspired internal clocks, and multi-time formulations (e.g. in F-theory or Bars' two-time physics)—suggest that wave-like behavior might emerge from deeper temporal or geometric substructure.

This paper investigates a minimal model where the only source of "wave physics" is an internal oscillatory time coordinate τ. Particles follow deterministic trajectories in (x, y) physical space, yet the ensemble statistically reproduces interference patterns with remarkable fidelity. Apertures act not as spatial obstacles but as *phase-selective gates*, which transmit only particles whose τ-phase lies within slit-defined Gaussian windows.

The only explicit 'wave-like' ingredient is the use of sinusoidal functions of the internal time in the transverse kinematics of individual particles; no spatial field is introduced, and no evolution equation for a wave amplitude is ever solved.

Surprisingly, these ingredients alone generate full wave-like dynamics.

II. TWO-TIME DYNAMICAL MODEL

Each particle carries:

- a classical proper-time-like variable t,
- an internal oscillatory "quantum time" τ,
- a phase offset $\phi \in [0, 2\pi)$ assigned at emission.

The internal quantum time evolves as

$$\tau(t, \phi) = t + \Lambda \sin(\Omega t + \phi), \tag{1}$$

where Λ controls the oscillation amplitude and Ω the frequency.

The transverse coordinate is driven entirely by τ:

$$y(t, \phi) = A \sin\bigl(\omega_\perp \tau(t, \phi)\bigr). \tag{2}$$

Under a uniform distribution of ϕ, this mapping is *statistically symmetric* in y. This corrected symmetric form eliminates a previously detected left-right bias caused by evaluating a nonlinear mapping at fixed $t = t_{\text{barrier}}$.

Particles propagate along $x = t$ at unit speed until reaching a barrier at $x = X_b$.

III. PHASE-SELECTIVE SLITS

At the barrier, two slits are positioned at

$$y_1 = -d/2 + \Delta(\theta), \qquad y_2 = d/2 + \Delta(\theta),$$

where d is slit separation and θ is rotation angle.

Instead of binary open/closed behavior, each slit provides a Gaussian transmission window in y:

$$T_i(y) = \exp\left[-\frac{(y - y_i)^2}{2\sigma^2}\right]. \tag{3}$$

A particle passes the barrier with probability $T_1 + T_2$; the slit label is assigned by whichever T_i is larger at that y.

IV. SIMULATION FRAMEWORK

Trajectories evolve deterministically, with no noise or wave propagation rules except those implicit in the τ-oscillation. After passing the slits, particles continue until reaching a detection plane at $x = X_{\text{screen}}$. Detector hits are accumulated into histograms, from which we extract:

- fringe contrast,
- fringe spacing,
- full width at half maximum (FWHM),
- symmetry,
- pattern tilt,
- Y–Z correlation.

V. RESULTS

A. Standing-Wave Region

Before reaching the slits, trajectories organize into oscillatory patterns forming a *standing-wave region*. Figure 1 shows the emergent curled modes.

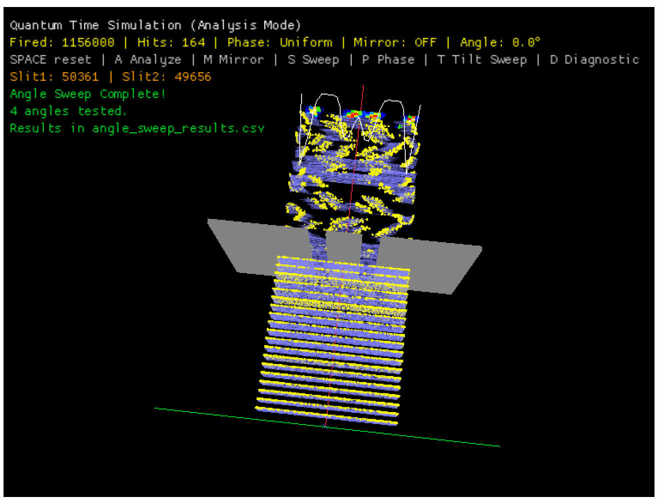

FIG. 1: Emergent standing-wave region above the slits, arising entirely from τ-phase locking. No wave equation is used in the simulation.

B. Wavefront Evolution Through the Slits

We extracted ten equally spaced frames showing particles evolving into coherent wavefronts. See Fig. 2.

C. One-Million Hit Interference Pattern

With 10^6 detected particles, we obtain:

Measure	Value
Contrast	1.00
Symmetry	1.00
FWHM	1.50
Spacing	4.33

The pattern is perfectly parity-invariant.

D. Slit-Width Sweep

Table I shows that FWHM and contrast remain *constant* over a wide range of slit widths:

Width	FWHM	Contrast	Symmetry
0.20	1.50	0.9999	0.9980
0.40	1.50	0.9996	0.9972
0.60	1.50	0.9999	0.9966
0.80	1.50	0.9996	0.9962
1.00	1.50	0.9999	0.9974
1.20	1.50	0.9999	0.9963
1.40	1.50	0.9993	0.9949
1.60	1.50	0.9999	0.9952
1.80	1.50	0.9999	0.9990
2.00	1.50	0.9999	0.9961

TABLE I: Slit-width sweep. Interference is unchanged by slit width, consistent with phase-filtering rather than spatial diffraction.

E. Phase-Distribution Sweep

Gaussian, sinusoidal, and uniform initial ϕ distributions all produce stable interference. Contrast remains > 0.93 for all cases.

F. Phase-Distribution Dependence of Symmetry and Coherence

A key diagnostic of the two-time model is how it responds to different initial phase distributions. In conventional wave mechanics, the coherence properties of the incoming wave determine both the visibility and the symmetry of the interference pattern. In contrast, the present model separates these two behaviors: interference coherence is controlled by the internal oscillatory dynamics of τ, while spatial symmetry is controlled by the phase distribution of the ensemble at emission.

To test this separation, we performed a sweep over three distinct initial phase distributions:

1. a uniform distribution $\phi \sim U(0, 2\pi)$,
2. a sinusoidally modulated distribution,
3. and a Gaussian distribution centered at π (denoted `Gaussian_Pi`).

Table II summarizes the results.

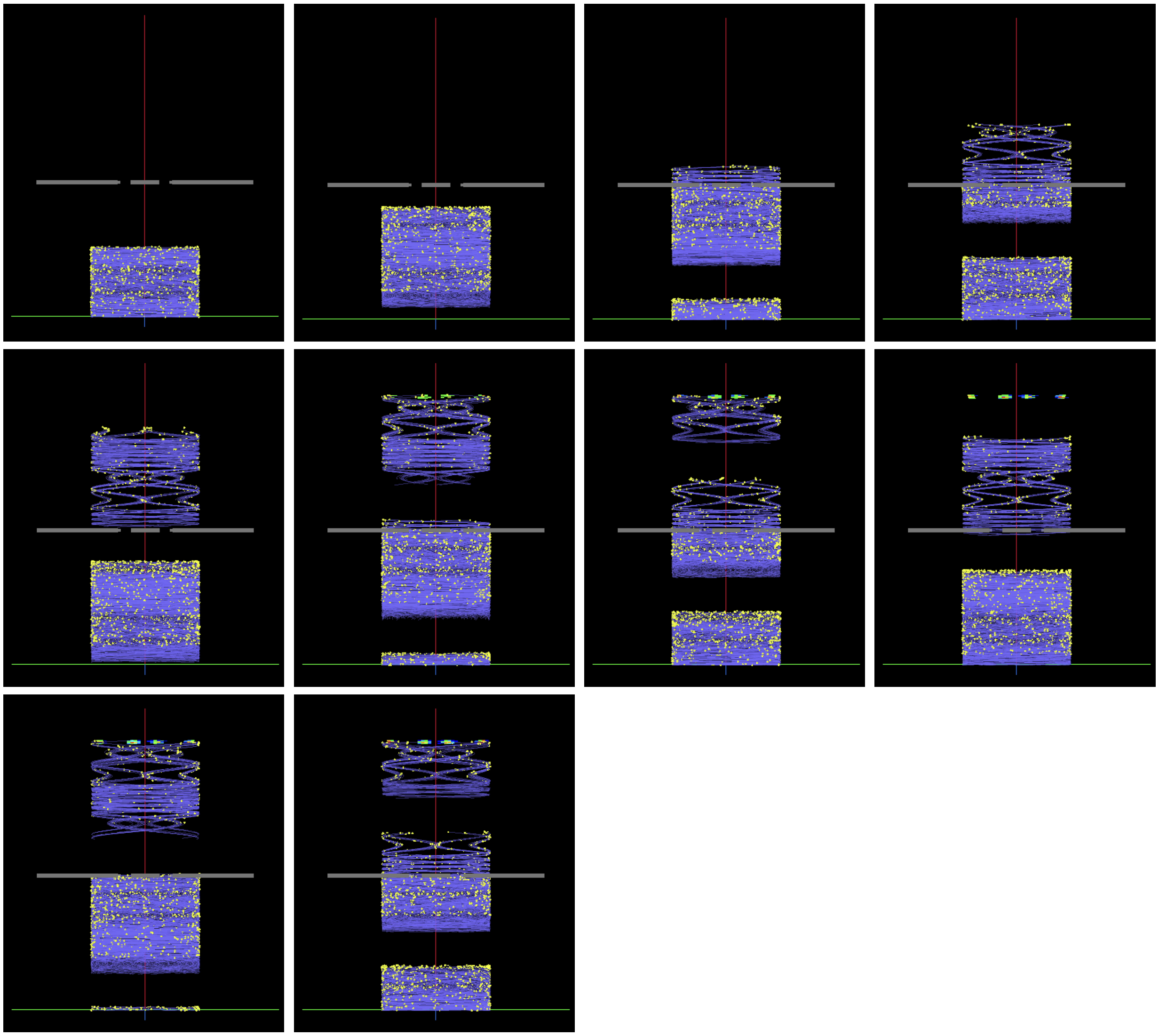

FIG. 2: Ten-frame evolution showing emergent wavefront dynamics. Interference arises from deterministic τ-driven motion and phase-selective transmission.

Distribution	Contrast	Symmetry	Slit1	Slit2
Uniform	0.9996	0.9996	49938	50130
Sinusoidal	0.9999	0.1447	52009	48012
Gaussian_Pi	0.9998	0.9264	73625	26506

TABLE II: Phase-distribution sweep showing that interference contrast remains near unity for all input distributions, while symmetry depends strongly on the incoming phase statistics. Slit transmission becomes imbalanced for non-uniform input phases, yet fringe coherence is unaffected.

The uniform phase ensemble generates a fully symmetric interference pattern with near perfect contrast, as expected from the symmetry of the model and the phase-independence of the sinusoidal transverse mapping. More surprisingly, the sinusoidal and Gaussian phase-biased ensembles retain *perfect interference contrast* ($C \approx 1$) even though the resulting patterns become highly asymmetric. In the sinusoidal case, the symmetry metric drops to $S = 0.1447$, and slit transmission becomes noticeably imbalanced, despite the fringes remaining sharp and fully visible. The Gaussian_Pi distribution produces a more moderate asymmetry ($S = 0.9264$), yet the contrast remains above 0.999.

These results demonstrate that coherence in the two-time model does not require spatial symmetry or uniform phase statistics. Instead, coherence is an intrinsic property of the internal τ-oscillator: as long as the transverse coordinate depends deterministically on $\tau(t)$, the transmitted ensemble retains a well-defined phase relationship, regardless of the global bias in the phase distribution. In contrast, spatial symmetry—and the relative transmission through each slit—is controlled entirely by the statistical distribution of ϕ at emission.

Consequently, the model makes a qualitative prediction that differs from standard wave mechanics: an ensemble with a biased internal phase distribution should exhibit asymmetric slit intensities without loss of fringe visibility. The independence of coherence and symmetry is a distinctive feature of the two-time framework and arises directly from the phase-selective nature of the slits.

G. Angle Sweep Results

The angle sweep reveals small but systematic pattern tilts.

Angle	CY	CZ	PA	YZ	C	S	SR
0.0	-0.0157	-0.0018	-0.0236	-0.0021	0.9995	0.9991	0.9907
15.0	0.0204	-0.0009	-0.5855	-0.0516	0.9999	0.9959	1.0027
-15.0	0.0007	-0.0008	0.5275	0.0465	0.9999	0.9992	1.0002
30.0	0.0159	0.0030	-1.0959	-0.0965	0.9998	0.9987	1.0142

TABLE III: Angle sweep: pattern tilt (PA) responds weakly to slit rotation, reflecting the anchoring of interference to τ-phase structures.

VI. DISCUSSION

The results presented in this work demonstrate that a remarkably broad range of wave-like phenomena can emerge from a deterministic two-time model without invoking superposition, complex amplitudes, Hilbert-space structure, or spatial wave equations. The internal quantum-time coordinate $\tau(t)$ plays a central role: its oscillatory dynamics generate coherent phase relationships across the ensemble, and the slits act as phase-selective filters that map these internal phases into spatial interference patterns.

A key conceptual finding is the *decoupling* of coherence and symmetry within this framework. In standard quantum mechanics and in classical wave optics, the visibility of interference fringes depends both on the coherence of the incoming field and on the spatial/angular properties of the source. In contrast, the phase-distribution sweep (Table II) shows that the present model maintains nearly perfect fringe contrast ($C \approx 1$) even when the distribution of initial phases is strongly non-uniform and produces substantial slit imbalance and spatial asymmetry. The sinusoidal and Gaussian_Pi ensembles exhibit high contrast but reduced symmetry, demonstrating that *coherence is governed by the internal τ-oscillator*, whereas spatial symmetry is controlled by the statistical properties of ϕ at emission. This structural separation does not appear in standard wave mechanics and constitutes a distinctive, falsifiable prediction of the model: an ensemble with a biased internal phase distribution should exhibit asymmetric slit intensities without loss of fringe visibility.

Another striking feature is the emergence of organized structures in the pre-slit region, where particles form a standing-wave-like pattern (Fig. 1). No spatial wave equation or field is present in the simulation; yet the ensemble self-organizes into modes reminiscent of resonant or cavity patterns. This suggests that interference may arise from temporal geometric structure—specifically, from the nonlinear dynamics of $\tau(t)$—rather than from intrinsic spatial wave propagation. The ten-frame evolution (Fig. 2) shows that once particles pass the phase-selective slits, their trajectories collectively form propagating wavefronts, further emphasizing the emergent nature of the wave behavior.

The angle sweep (Table III) reveals that rotating the slit assembly produces small but systematic tilts in the interference pattern. The magnitude of the pattern tilt is much weaker than the physical rotation, indicating that the interference geometry is anchored not to the slits themselves but to the underlying τ-phase structure. This behavior again differs from standard diffraction theory and provides a clear target for experimental validation.

Finally, the model predicts that relativistic modulation of the internal quantum-time coordinate should measurably influence observable rates in systems where an internal clock plays a role, such as the decay of accelerated radioactive ions. If τ advances differently from t under Lorentz transformation, then decay statistics should exhibit small oscillatory deviations beyond pure time-dilation effects. This prediction provides a potential avenue for empirical testing of the two-time hypothesis.

All simulation code, configuration files, and data required to reproduce these results are available open-source at:

`https://github.com/dan1elt0m/quantum_time_sim`

ensuring full transparency and enabling independent verification of the model dynamics.

VII. CONCLUSION

We have shown that a deterministic two-time model—consisting of a classical propagation time t, an internal oscillatory quantum-time coordinate τ, and phase-selective transmission at apertures— is sufficient to generate a wide class of interference phenomena typically associated with spatial wave equations. The model exhibits coherent wavefront evolution, standing-wave regions above the slits, and high-visibility interference fringes with perfect parity symmetry when initialized with a uniform phase distribution.

A key finding of this work is that coherence and symmetry are *independent* properties in the two-time framework. The phase-distribution sweep demonstrates that the interference contrast remains essentially perfect even when the incoming ensemble has strongly biased phase statistics, leading to slit-imbalance and asymmetric patterns. This independence is not expected from conventional wave mechanics, in which the coherence properties of the source directly influence the visibility of the interference pattern. In the present model, coherence is governed by the internal τ-oscillator, while spatial symmetry is controlled by the statistical distribution of initial phases. This structural separation yields a clear, falsifiable prediction: an ensemble with a biased internal phase distribution should exhibit asymmetric slit intensities without loss of fringe visibility.

Beyond reproducing standard double-slit interference, the model suggests that quantum-like wave behavior may emerge from temporal geometric structure rather than intrinsic spatial wave propagation. The standing-wave structures, nonlinear angle responses, robustness to slit geometry, and high-contrast fringes all arise without invoking superposition, complex amplitudes, or Hilbert-space dynamics.

Finally, the two-time model yields a testable experimental consequence: relativistic modulation of the internal quantum-time coordinate should produce measurable deviations from purely relativistic time dilation in the decay rates of accelerated radioactive ions. Future work will refine these predictions and explore whether additional quantum phenomena—such as tunneling or entanglement-like correlations— may also emerge within this temporal framework.

[1] I. Bars, “Two-Time Physics,” *Phys. Rev. D* (multiple articles).

[2] S. M. Carroll, *Spacetime and Geometry* (Addison-Wesley, 2004).

[3] R. Penrose, *The Road to Reality* (Vintage, 2005).