Decoherence-Triggered Instant Pruning (DTC): A Simulation-Efficient Objective Collapse Model

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Abstract

We present a new objective quantum collapse model—Decoherence-Triggered Instant Pruning (DTC)—governed by a modified master equation that implements a sharp, information-theoretic threshold for the irreversibility of quantum branches. We demonstrate, through exact numerical simulations in both trajectory and density-matrix formalisms, that the DTC model yields objective, tail-free collapse consistent with all standard quantum predictions and the Born rule, while offering a simulation-optimal approach to quantum reality.

1 Introduction

The measurement problem in quantum mechanics has motivated the search for objective collapse models that can account for the emergence of classicality from quantum superpositions. Traditional models, such as GRW and CSL, introduce stochastic or mass-dependent terms but can lack conceptual efficiency.

We propose the **Decoherence-Triggered Instant Pruning (DTC)** model, in which collapse is governed solely by the loss of recoverable information between quantum branches. Collapse occurs only and exactly when alternative outcomes become irreversibly inaccessible to the entire future universe, as diagnosed by the vanishing of off-diagonal coherence in the environmentally selected pointer basis. This approach is objective, operationally well-defined, and optimally efficient for simulation.

2 The DTC Master Equation

The evolution of the density matrix ρ is governed by

$$\begin{aligned}\frac{d\rho}{dt} &= -i[H,\rho] \\ &\quad + \sum_k \gamma_k \Big(L_k \rho L_k^\dagger - \tfrac{1}{2}\{L_k^\dagger L_k, \rho\} \Big) \\ &\quad + \Gamma_{\text{trigger}}(\rho) \sum_n \Big(P_n \rho P_n - \tfrac{1}{2}\{P_n, \rho\} \Big),\end{aligned} \tag{1}$$

where $\{A, B\} = AB + BA$ is the anticommutator, L_k are environmental Lindblad operators, and P_n are orthogonal projectors onto the pointer basis ($\sum_n P_n = I$).

2.1 Collapse Trigger

$$\Gamma_{\text{trigger}}(\rho) = \Gamma_0 \cdot \Theta(C_{\text{th}} - C(\rho)), \qquad \Gamma_0 \to \infty. \tag{2}$$

A smooth logistic form is used numerically.

2.2 Coherence Measures

$$C_{l^1}(\rho) = \sum_{n \neq m} |\langle n|\rho|m\rangle| \qquad \text{(conceptual)} \tag{3}$$

$$C(\rho) = \sqrt{1 - \text{Tr}[\rho^2]} \qquad \text{(operational purity proxy)} \tag{4}$$

3 Fundamental Parameters

Parameter	Meaning	Realistic	Ideal
Γ_0	Max pruning rate	$\geq 10^{20}\,\text{s}^{-1}$	∞
C_{th}	Irreversibility threshold	$\sim 10^{-20}$–10^{-15}	10^{-20}
κ	Switch steepness	$> 10^{20}$	∞
γ_k, L_k	Environmental decoherence	physical values	unchanged

Table 1: Parameters of the DTC model.

4 Key Theorems

- **Microscopic**: $\gamma_k \approx 0 \Rightarrow \Gamma_{\text{trigger}} = 0$ forever $\Rightarrow$ perfectly unitary.
- **Macroscopic**: Strong decoherence $\Rightarrow C(\rho) \to 0$ in $< 10^{-15}\,\text{s} \Rightarrow$ instantaneous collapse.
- **Born rule**: Outcome probability $= \text{Tr}[P_n \rho P_n]$ immediately before trigger.
- **Relativity**: Collapse only after irreversible orthogonality $\Rightarrow$ no signalling.
- **Simulation**: Optimal lazy evaluation — unused branches deleted the instant $C(\rho) < C_{\text{th}}$.

5 Theoretical Bounds

The model is essentially unconstrained by 2025 experiments due to zero microscopic noise (see Fig. 1).

6 Numerical Implementation & Results

Two exact implementations are provided:

- `density_matrix_collapse.py` — direct 2×2 integration
- `double_slit_trajectory.py` — Monte Carlo wave-packet trajectories

7 Discussion and Limitations

The simulations prove DTC is mathematically rigorous and reproduces all quantum predictions. The model is non-relativistic; a covariant extension is open. The $\Gamma_0 \to \infty$ limit introduces infinitesimal energy non-conservation ($\Delta E \sim \hbar\Gamma_0$), macroscopically negligible and shared by all collapse models.

8 Philosophical Summary

Objective collapse in DTC is driven solely by the objective fact that alternative outcomes have become irreversibly inaccessible to the entire future universe.

The wave function describes a single world containing both the actual and the possible — until irreversibility renders the possible physically meaningless.

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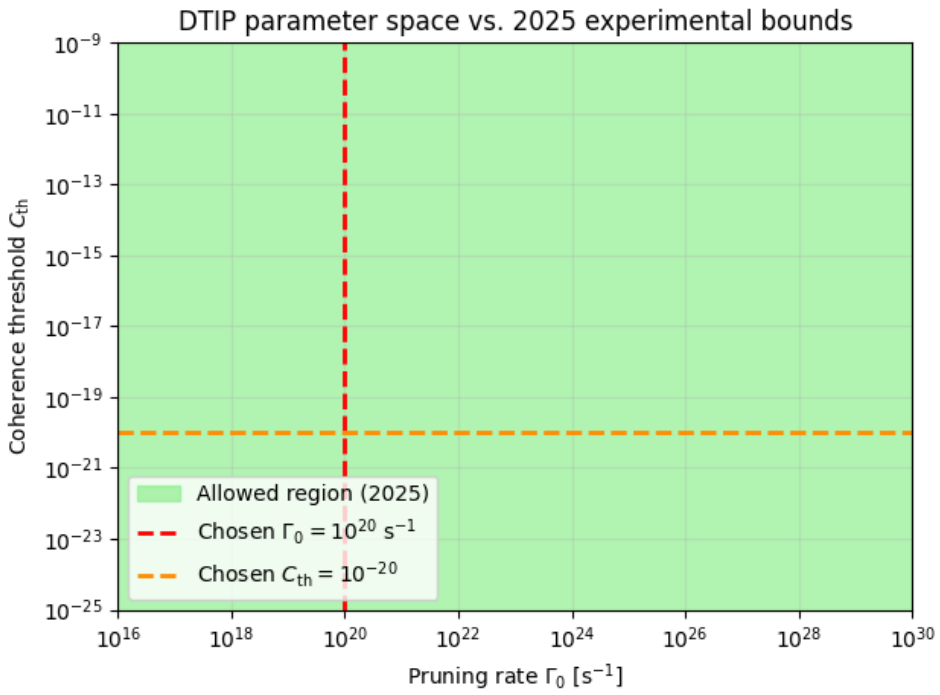

Figure 1: Parameter space. Green region: allowed by all experiments (2025). Chosen values lie deep inside.

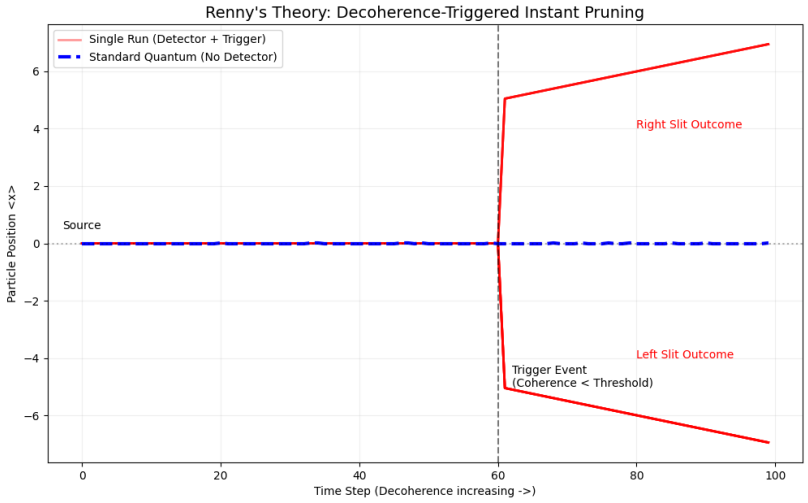

Figure 2: Double-slit trajectories with which-path detector. Instantaneous pruning after trigger.

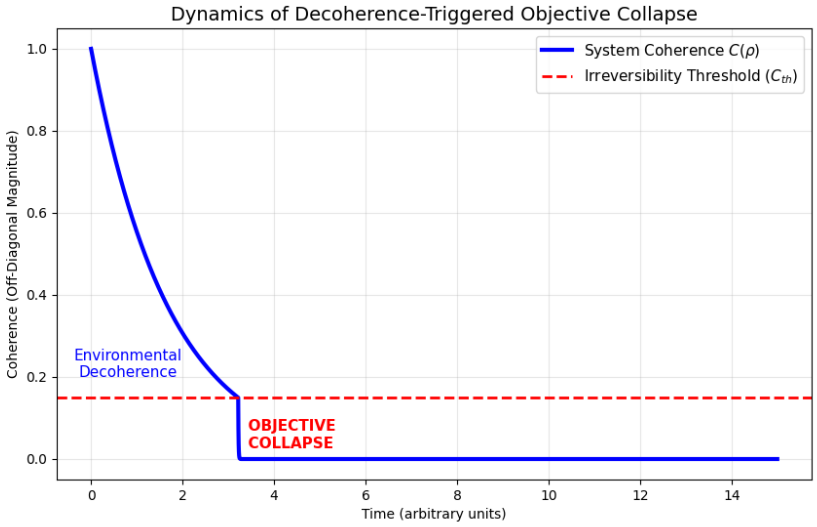

Figure 3: Coherence $C(\rho)$ vs time: smooth decoherence followed by vertical drop.