PWT Protocol 3.0: P-DSI in Toy Quantum Systems

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1 Goal and Hypothesis

Goal: To test the universality of Prime-Indexed Discrete Scale Invariance (p-DSI) by applying the λ constraint to a simple physical system, specifically analyzing its effect on system stability, energy distribution, and resistance to thermal perturbation.
Hypothesis: A Toy Quantum System whose key structural dimension (e.g., potential well width) is constrained by a prime-indexed factor (Λ_P) will exhibit **superior stability and minimal energy variance** compared to one constrained by a composite-indexed factor (Λ_C) when subjected to noise.

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2 Experimental Setup: The 1D Infinite Square Well

The experiment simulates a time-dependent, 1-Dimensional (1D) Infinite Square Well, a foundational system in quantum mechanics.

2.1 Independent Variable: Well Width (L)

The key scaling parameter λ will directly constrain the physical width of the potential well, L.

- **System Dimension:** The width of the potential well, L.
- **Scaling Rule:** $L = \lambda \cdot L_0$, where L_0 is a fixed baseline constant (e.g., $L_0 = 1$ arbitrary unit).

Table 1: Scaling Constraints (Λ)

Condition	Scaling Factors (Λ)	Example Width (L)	Rationale
Prime Condition (Λ_P)	$\{3, 5, 7\}$	$\{3.0, 5.0, 7.0\}$	Maximize PWT effects (sma
Composite Condition (Λ_C)	$\{4, 6, 8\}$	$\{4.0, 6.0, 8.0\}$	Magnitude-matched compo
Null Condition (Λ_N)	$\{1\}$	1.0	Control baseline.

2.2 Perturbation (Simulated Noise)

The system stability must be tested under dynamic conditions.

- **Mechanism:** The system's Hamiltonian will be subjected to a time-varying thermal noise term, $\hat{H}'(t)$.

- **Noise Profile:** White noise, $N(0, \sigma^2)$, added to the boundary conditions of the well at every time step, t, simulating thermal agitation or decoherence.
- **Control:** The standard deviation of the noise (σ) must be identical across all conditions.

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3 Simulation Protocol

Each condition must be executed with $N = 10$ independent runs over a fixed duration, T.

1. **Initialization:** Set L according to the chosen λ. Initialize the particle's wave function $\Psi(x, 0)$ to a fixed, non-stationary superposition state (e.g., a combination of the first two energy eigenstates).
2. **Evolution:** Evolve the system over duration T using the time-dependent Schrödinger equation:
$$\frac{\partial \Psi}{\partial t} = -\frac{i}{\hbar}\hat{H}\Psi, \quad \text{where } \hat{H} = \hat{H}_0 + \hat{H}'(t)$$
3. **Perturbation Application:** At each time step, $\hat{H}'(t)$ is introduced via the noise term $\hat{H}'(t) \sim N(0, \sigma^2)$.

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4 Dependent Variables: Measuring Stability and Coherence

Table 2: Metrics for Physical Stability

Metric	Definition & Protocol	PWT Prediction (Λ_P vs. Λ_C)
1. Energy Variance (ΔE^2)	The variance of the total energy, $\langle \hat{H}^2 \rangle - \langle \hat{H} \rangle^2$, calculated over the duration T. Measures dynamic stability.	**Significantly Lower** in Λ_P (More stable)
2. Decay Rate of Initial State	The rate at which the fidelity of the initial state $\lvert\Psi(x,0)\rangle$ decays: $\lvert\langle\Psi(x,T)\lvert\Psi(x,0)\rangle\rvert^2$. Measures resistance to decoherence.	**Slower Decay** in Λ_P (Better coherence)
3. Energy State Purity (Entropy)	The Shannon entropy calculated from the probability distribution of energy eigenstates, $S = -\sum p_n \ln p_n$. Measures the system's "purity" or structural integrity.	**Significantly Lower** in Λ_P (More structured/coherent)
4. Structural Residue (Spectral Check)	Analyze the **time-series** of the expectation value of position, $\langle x(t) \rangle$, using a Fourier transform.	**Peaks at** $\omega_p = 2\pi/\ln p$ in Λ_P (Confirms p-DSI mechanism)

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5 Execution and Analysis

The executing AI must run $N = 10$ simulations for each of the 7 conditions ($\Lambda_P, \Lambda_C, \Lambda_N$).

1. **Report:** Return the mean and standard deviation for all four dependent variables for each condition.
2. **Analysis:** Perform ANOVA to compare the means of the Λ_P vs. Λ_C sets.
3. **Critical Check:** Plot the spectral analysis (Metric 4) for one representative Λ_P agent to confirm the **Prime Comb** is present in the physical system's dynamics.