# Interpretation-Independent Proof That Decoherence Is Not Collapse

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**Abstract**

This paper presents an interpretation-independent proof that neither detection nor decoherence explains quantum state collapse. The argument is grounded in experimental results from Proietti et al. (2019), which demonstrate the persistence of quantum coherence despite environmental decoherence. By analyzing the logical consequences of entanglement, detection, and decoherence, this work demonstrates the fallacy of equating detection or decoherence with observation in quantum foundations and establishes a necessary condition for viable interpretations.

**Keywords:** Quantum Measurement, Decoherence, Collapse, Entanglement, Interpretation-Independent Proof

## 1 Introduction

In quantum measurement discussions, environmental decoherence is often mistaken for quantum state collapse. Decoherence occurs when a quantum system entangles with its environment, suppressing observable interference patterns. In contrast, collapse-like effects refer to single, definite outcomes upon observation, such as loss of superposition. While collapse-like effects entail loss of interference, loss of interference alone does not guarantee single outcomes or loss of superposition. Hence, despite frequent conflation with collapse-like effects, experimental evidence confirms detection and decoherence are distinct processes. This paper provides a concise, interpretation-neutral proof that decoherence cannot equate to collapse, directly challenging interpretations that rely on decoherence as a sufficient explanation for measurement outcomes in quantum foundations.

This argument is grounded in experimental results from Proietti et al. [2019], where a quantum system entangled with a decohering external system maintains observable coherence. This experimentally-supported result provides a direct counterexample to the assumption that decoherence itself produces global collapse-like effects.

## 2 Experimental Setup

The Proietti et al. [2019] experiment follows a Wigner's friend design with these key elements:

1. **Inside system:**
    - Quantum system (photon polarization)
    - "friend," a detector registering which-way information
2. **Outside system:**

    - Macroscopic detector causing complete decoherence while detecting interference patterns
    - “Wigner,” an external observer finalizing data from the combined system

3. **Key feature:**
    - The inside detector registers which-way information without causing complete system decoherence
    - The internal photon retains interference potential until the outside observer chooses a measurement basis

# 3 Empirical Results

This setup yields three critical features:

1. Proietti et al. [2019] demonstrated persistent quantum coherence in their experimental setup, showing superposition remains intact within the internal system despite external decoherence. Their Bell-like inequality tests revealed interference visibility of $0.98 \pm 0.01$ with a $5\sigma$ statistical significance, strongly reinforcing quantum predictions about coherence preservation.

2. The outside system undergoes decoherence through environmental interaction with a macroscopic detector.

3. The inside and outside systems are described by a single entangled quantum state.

# 4 Logical Argument

Here, “collapse-like effects” refer to the emergence of single, definite outcomes, as opposed to a superposition of multiple possibilities.

## 4.1 Premises:

**P1. Entanglement:** Entangled systems are described by a single global quantum state, with subsystems lacking independent pure states.

**P2. External Decoherence:** The outside system demonstrably undergoes decoherence through environmental coupling.

**P3. Internal Coherence:** Despite external decoherence, the internal system maintains observable quantum coherence.

## 4.2 Assumption:

**Collapse-by-Decoherence Assumption:** If decoherence produced collapse-like effects, then decoherence in any subsystem of an entangled whole would necessarily extend these effects to the entire global system.

## 4.3 Logical Consequence:

**C5:** Given Collapse-by-Decoherence Assumption (together with P1 and P2), external system decoherence should be sufficient to produce collapse-like effects for the entire system.

**C6:** However, P3 shows the internal system maintains coherence despite external decoherence of the entangled system (P2) and entanglement (P1). This directly exposes a contradiction: if decoherence produces collapse-like effects, then coherence should not persist in subsystems entangled with a decohered environment. Yet Proietti et al. [2019] observed precisely this — an empirical refutation of the decoherence-equals-collapse assumption.

### 4.4 Conclusion:

**C7:** Since C5 and C6 contradict, Collapse-by-Decoherence Assumption cannot hold; decoherence does not automatically generate global collapse-like effects.

**C8:** Any interpretation relying on decoherence to produce global collapse-like effects contradicts experimental evidence.

### 4.5 Corollary:

**C9:** Viable interpretations must explain why external decoherence fails to eliminate coherence in the internal system.

## 5 Practical Implications

The distinction between decoherence and collapse has significant consequences for quantum technologies. In quantum computing, understanding that coherence can persist in subsystems despite partial decoherence suggests strategies for error mitigation and quantum memory preservation. Equally important is recognizing what actually triggers collapse—identifying precisely what constitutes "observation" in quantum systems, if not detection or decoherence, could lead to techniques that shield quantum information from collapse-inducing interactions while allowing benign environmental coupling. This combined understanding could inform more robust quantum communication systems that strategically manage both decoherence and collapse mechanisms, potentially extending coherence times in quantum processors and enhancing the fidelity of entanglement-based protocols across noisy channels. These insights directly impact the practical development of fault-tolerant quantum computing and secure quantum networks.

## 6 Conclusion

This experimentally-derived result establishes four conditions for all quantum interpretations:

1. **Detection alone doesn't cause global collapse effects**
   (The inside detector registers information without eliminating photon coherence)

2. **Decoherence alone doesn't explain collapse effects across entangled systems**
   (External decoherence occurs while internal coherence persists in the entangled system)

3. **Definite outcomes require explanation beyond detection and decoherence**
   (The phenomena associated with "collapse" must involve additional factors)

4. **Viable interpretations must address this gap between decoherence and global definite outcomes**
   (Interpretations must explain why external decoherence fails to eliminate internal coherence)

This paper demonstrates that decoherence fails to generate collapse effects across entangled quantum systems. This clarifies a widespread misconception in quantum mechanics that detectors, such as the "friend" in the Proietti experiment, inherently act as observers causing collapse, and underscores the importance of addressing the measurement problem directly, rather than assuming decoherence resolves it.

We would like to note that this distinction between decoherence and collapse is acknowledged by Zurek himself, a pioneer of decoherence theory. In his seminal work "Decoherence, einselection, and the quantum origins of the classical" [Zurek, 2003], Zurek explicitly states that while decoherence explains the absence of observable interference and the selection of preferred basis states, it does not resolve the measurement problem or explain the emergence of unique outcomes. As he notes, "Decoherence transforms entanglements into apparent classical correlations... But it does not remove the 'weirdness' of quantum physics entirely." This admission from the foremost authority on decoherence theory reinforces our central argument: the physical process of decoherence cannot be equated with the emergence of definite measurement outcomes, despite this conflation persisting in quantum discourse.

## References

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