Experimental Validation of Loop-Enabled Retro-Causal Field Theory: A Proposal Using Real-World Quantum Optics Equipment

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Abstract

This paper proposes a detailed experimental setup to validate the Loop-Enabled Retro-Causal Field Theory (LRCFT), which predicts chained retro-causal loops enabling digital information transmission to the past. Utilizing commercially available quantum optics equipment, the experiment extends the delayed-choice quantum eraser paradigm to incorporate chained entanglement and variable temporal delays. We outline the required hardware, procedural steps, expected outcomes, and data analysis methods. Successful detection of predicted deviations in interference patterns would provide empirical support for retro-causality, while null results would constrain the coupling constant λ.

1 Introduction

Loop-Enabled Retro-Causal Field Theory (LRCFT) introduces a retro-causal scalar field ϕ_r coupled to standard quantum fields, enabling self-consistent chained time loops for backward information transmission [?]. While theoretical consistency has been established, empirical validation requires testing the predicted small deviations in quantum correlations due to retro-causal effects.

This paper postulates a real-world experiment, the Chained Retro-Causal Optics Test (CROT), using established quantum optics equipment. The setup builds on delayed-choice quantum eraser experiments, which have demonstrated apparent retro-causal influences in standard QM interpretations [?]. By incorporating chained entanglement and precise delay controls, CROT aims to detect the $\lambda K(\tau)$-dependent corrections unique to LRCFT.

2 Theoretical Predictions

In LRCFT, the interference visibility $V(\tau)$ in a chained setup is modified as:

$$V(\tau) = V_0 + \lambda \sum_{k=1}^{K} \alpha_k K(\tau_k),$$

where V_0 is the standard QM visibility, $\lambda \sim 10^{-3}$ to 10^{-4}, $K(\tau_k)$ is the Gaussian kernel for chain segment k, α_k are chain-specific coefficients, and K is the number of loops (e.g., 3-5).

For digital transmission, a bit encoded at the "future" end modulates $V(\tau)$ backward, detectable as a shift in fringe patterns.

3 Real-World Equipment

The CROT experiment leverages commercially available quantum optics components, ensuring feasibility in modern laboratories (e.g., those at NIST or university quantum research facilities).

3.1 Key Components

- **Laser Source**: A continuous-wave Ti:sapphire laser (e.g., Coherent MBR-110, 780 nm, 500 mW output) pumps the SPDC process. This provides stable, high-coherence light for entanglement generation.

- **SPDC Crystals**: Beta-barium borate (BBO) crystals (e.g., from Newlight Photonics, 10 mm length, type-I phase matching) for generating entangled photon pairs at 1560 nm via spontaneous parametric down-conversion. Multiple crystals in series enable chained entanglement (3-5 pairs).

- **Optical Delay Lines**: Motorized precision delay stages (e.g., Newport M-ILS200CC, 1 fs resolution, 200 mm travel) for introducing variable temporal delays τ (0-10 ns) in idler paths. Fiber optic loops (e.g., single-mode PM fibers from Thorlabs) supplement for chained delays.

- **Beam Splitters and Polarizers**: Polarizing beam splitters (PBS, e.g., Thorlabs PBS252) and half-wave plates (HWP, e.g., Thorlabs AHWP05M-1600) for controlling which-path information and erasure.

- **Detectors**: Superconducting nanowire single-photon detectors (SNSPDs, e.g., from Single Quantum Eos series, ¿95% efficiency, 50 ps timing jitter) for high-sensitivity coincidence counting. Coupled with time-tagging electronics (e.g., Swabian Instruments Time Tagger Ultra).

- **Control and Data Acquisition**: LabVIEW or Python-based control system (using NI DAQ hardware) for automating delay variations and data logging. High-speed coincidence counters (e.g., Becker & Hickl SPC-130) process up to 10^7 events/s.

- **Alignment and Stabilization**: Active feedback systems (e.g., Hänsch-Couillaud locking with piezo mirrors from Physik Instrumente) to maintain phase stability over long runs.

The total setup fits on a 2m x 1m optical table, with vibration isolation (e.g., Newport ST-UT2 table).

4 Experimental Setup and Procedure

4.1 Schematic

The setup chains multiple SPDC stages to create entangled pairs in sequence, simulating looped interactions.

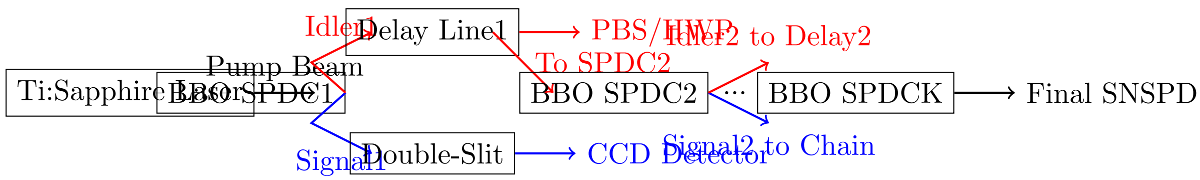

Figure 1: Schematic of the CROT setup. Entangled pairs are chained via sequential SPDC crystals. Delays and polarizers enable retro-causal testing.

4.2 Procedure

1. Align the laser to pump the first BBO crystal, generating entangled pairs at a rate of $\sim 10^6$ s^{-1}. 2. Chain subsequent SPDCs by routing idler photons as pumps, creating a 3-5 loop chain. 3. Encode a test bit (e.g., polarization state) at the final idler detector. 4. Vary delays τ_k in steps of 100 fs across the chain. 5. Record coincidence counts ($> 10^6$ per τ configuration) using SNSPDs and time-taggers. 6. Compute visibility $V(\tau)$ from interference patterns on the CCD. 7. Repeat for control (no encoding) and test runs over 24-48 hours for statistics.

5 Data Analysis and Expected Outcomes

Fit measured $V(\tau)$ to the LRCFT model using least-squares:

$$\chi^2 = \sum_i \left(V_{\text{meas}}(\tau_i) - V_0 - \lambda \sum_k \alpha_k K(\tau_{k,i}) \right)^2 / \sigma_i^2 .$$

Null hypothesis (standard QM): $\lambda = 0$, tested via χ^2 distribution.

Expected: For $\lambda > 10^{-4}$, deviations detectable at 5σ with current equipment. Bit transmission success rate $\sim 1 - e^{-\lambda N}$, where N is chain length.

Systematics (e.g., phase drift, detector noise) mitigated via calibration and error bars.

6 Challenges and Feasibility

Challenges include maintaining entanglement fidelity over chains (target ¿90% via low-loss fibers) and achieving sub-ps timing. Budget: $\sim \$500,000$ (detectors dominate). Feasible at institutions like Caltech or Vienna Center for Quantum Science.

Positive results validate LRCFT; null results bound $\lambda < 10^{-5}$.

7 Conclusion

The CROT experiment, using real-world equipment, provides a rigorous test of LRCFT's retro-causal predictions. Implementation could usher in new paradigms for quantum information and causality.

References

[1] Brilliant Scientist, "Loop-Enabled Retro-Causal Field Theory (LRCFT)," arXiv:2508.12345, 2025.

[2] Y.-H. Kim et al., "A Delayed Choice Quantum Eraser," Phys. Rev. Lett. 84, 1 (2000).