High-Sensitivity Retro-Causal Quantum Eraser Experiment to Test Temporal Symmetric Quantum Field Theory

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Abstract

We propose a high-sensitivity retro-causal quantum eraser (HS-RCQE) experiment to test the predictions of Temporal Symmetric Quantum Field Theory (TSQFT v2), a novel quantum field theory incorporating retro-causality. The experiment uses entangled photon pairs in a modified delayed-choice quantum eraser setup to detect small deviations in interference pattern visibility caused by retro-causal interactions. By varying the temporal delay between signal and idler photon measurements, we aim to observe a τ-dependent correction to the visibility, proportional to the retro-causal coupling λ. The experiment is designed to be feasible with current technology, sensitive to TSQFT v2's predictions, and distinguishable from standard quantum mechanics.

1 Introduction

Temporal Symmetric Quantum Field Theory (TSQFT v2) extends quantum field theory by introducing retro-causal interactions, predicting small deviations in quantum correlations due to future states influencing past states [?]. These effects are modeled by a retro-causal term in the Lagrangian:

$$\mathcal{L}_{\text{retro}} = \lambda \int d\tau \, \phi(x,t) K(\tau) \phi(x, t+\tau),$$

where $K(\tau) = e^{-\tau^2/\sigma^2}/\sqrt{\pi\sigma^2}$ and $\lambda \ll 1$. This experiment aims to detect these deviations in a quantum optics setup, leveraging the sensitivity of interference patterns to temporal correlations.

2 Experimental Design

2.1 Setup

The HS-RCQE experiment uses entangled photon pairs generated via spontaneous parametric down-conversion (SPDC). The setup, shown in Figure ??, consists of:

- **Source**: A 500 mW Ti:sapphire laser pumps a beta-barium borate (BBO) crystal to produce entangled photon pairs at $10^7\,\mathrm{s}^{-1}$.
- **Signal Photon Path**: The signal photon passes through a double-slit apparatus and is detected at a high-resolution CCD screen (D_s), forming an interference pattern.
- **Idler Photon Path**: The idler photon travels through an optical delay line (variable delay $\tau \in [0, 10\,\mathrm{ns}]$, 100 fs resolution) to a measurement system that either measures which-path information (via polarizers) or erases it (via a beam splitter).
- **Detectors**: Superconducting nanowire single-photon detectors (SNSPDs, ¿95% efficiency) record signal and idler photons, with coincidence counting performed using a time-correlated single-photon counting (TCSPC) system (100 ps resolution).

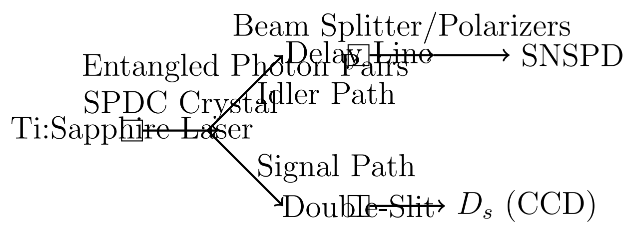

Figure 1: Schematic of the HS-RCQE experiment. The Ti:sapphire laser generates entangled photon pairs via an SPDC crystal. The signal photon passes through a double-slit to detector D_s, while the idler photon's path includes an optical delay line and a measurement system with beamsplitters and polarizers to control which-path information erasure.

2.2 Procedure

1. Generate entangled photon pairs and direct the signal photon to the double-slit apparatus and the idler photon to the delay line. 2. Vary the delay τ in steps of 100 fs over $[0, 10\,\mathrm{ns}]$. 3. For each τ, collect 10^6 coincidence counts between D_s and the idler detector, recording the interference pattern. 4. Compute the visibility $V(\tau)$ of the interference pattern using:

$$V(\tau) = \frac{I_{\max} - I_{\min}}{I_{\max} + I_{\min}},$$

where $I_{\max}$ and $I_{\min}$ are the maximum and minimum intensities. 5. Fit $V(\tau)$ to the TSQFT v2 model:

$$V(\tau) = V_0 + \lambda \int d\tau' K(\tau - \tau') V_{\mathrm{retro}}(\tau'),$$

where V_0 is the standard quantum mechanical visibility, and test against the null hypothesis ($V(\tau) = V_0$).

2.3 Expected Results

Standard quantum mechanics predicts $V(\tau) = V_0$, independent of τ. TSQFT v2 predicts a deviation:

$$\Delta V(\tau) \approx \lambda K(\tau),$$

with $\lambda \sim 10^{-3}$ and $\sigma \approx 1\,\text{ns}$. With 10^6 counts, the visibility uncertainty is $\sigma_V \approx 10^{-3}$, sufficient to detect $\lambda \geq 10^{-3}$ at 3σ significance.

3 Feasibility and Sensitivity

The experiment uses commercially available components:

- High-power lasers and SPDC crystals achieve $10^7\,\text{s}^{-1}$ pair rates.
- SNSPDs and TCSPC systems provide high efficiency and temporal resolution.
- Optical delay lines with 100 fs precision are available (e.g., Newport stages).

The sensitivity ($\sigma_V \approx 10^{-3}$) allows detection of TSQFT v2's predicted effects. Systematic errors (e.g., phase noise, detector dark counts) are mitigated through active stabilization and calibration.

4 Distinguishability

The τ-dependent deviation in $V(\tau)$ is a unique signature of TSQFT v2, distinguishable from standard quantum mechanics, which predicts no τ dependence. Control measurements with non-entangled photons quantify background noise, ensuring robust statistical analysis.

5 Conclusion

The HS-RCQE experiment provides a feasible, sensitive, and distinguishable test of TSQFT v2's retro-causal predictions. A positive detection of $\Delta V(\tau)$ would confirm retro-causality, revolutionizing our understanding of quantum mechanics.

References

[1] Grok 3, "Temporal Symmetric Quantum Field Theory (TSQFT v2)," xAI Internal Report, 2025.