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Polarization correlations of entangled and classical two-photon states

Quantum entanglement, which is the most fascinating feature of quantum world, is commonly investigated through two-photon maximally entangled states, known as Bell states. Conventionally, entanglement probing relies on measuring polarization correlations between photons. While such correlations are often interpreted as inherently quantum phenomena, theoretical analysis and Monte Carlo simulations of classical systems demonstrate that same polarization correlations can arise in separable photon states. These results are especially important for the study of entangled annihilation photon through Compton scattering.
Experimental setup for measuring polarization correlations was developed at the Institute for Nuclear Research of the Russian Academy of Sciences (INR RAS) [1]. To measure two entangled photons with an energy of 511 keV and mutually orthogonal polarization, two identical arms of Compton polarimeters are employed. Each arm consists of a plastic scintillation scatterer and NaI(Tl) crystal-based detectors that register photons scattered at a 90° angle. An additional GAGG scintillator scatterer is installed in one of the arms to artificially induce decoherence before the photons enter the polarimeters.
Our analytical results, confirmed by experimental data obtained at the said setup, demonstrate that the entangled state never collapses into a separable state, contrary to what was previously assumed [2]. The behavior of quantum entanglement after scattering is identical to that of initially classically correlated photons, up to a constant factor of two. This is consistent with local quantum field theory, and "spooky action at a distance" (nonlocal interaction) is not required to explain the change in the state of entangled qubits when one of them is measured.

1. Abdurashitov, D. et al. Setup of Compton polarimeters for measuring entangled annihilation photons. Journal of Instrumentation vol. 17 P03010 (2022).
2. Tkachev, I. et al. Measuring the evolution of entanglement in Compton scattering. Scientific Reports vol. 15 (2025).

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