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Constructing Quantum Entanglement Criteria for Collider Processes

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Quantum entanglement, a profound feature of quantum mechanics where particles share interconnected states regardless of distance, has been extensively studied in low-energy systems like photons and atoms. Exploring entanglement in high-energy particle collisions offers unique opportunities to probe quantum phenomena under extreme conditions and test fundamental principles like nonlocality. Here we demonstrate the observation of quantum entanglement between lambda and antilambda hyperons ($\Lambda\bar{\Lambda}$) produced in electron-positron collisions via the decay of the J/ψ particle. By analyzing the angular correlations of the protons and antiprotons emerging from the subsequent weak decays of the hyperons, we identify clear signatures of entanglement that violate classical limits derived for separable states. This result confirms that entanglement persists through both the strong interaction production process and the weak decay processes. Since a significant majority of these decay events occur at spacelike separation, meaning no classical signal could connect them, our findings provide strong experimental support for the nonlocal nature of quantum mechanics. The successful detection of entanglement in this hyperon-antihyperon system establishes a new methodology and platform for testing quantum foundations in relativistic particle physics, complementing traditional approaches and opening avenues for future investigations into decoherence or symmetry violations in high-energy collisions.

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