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Probing Quark Electromagnetic Properties via Entangled Quark Pairs in Fragmentation Hadrons at Lepton Colliders

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Electromagnetic dipole interactions of light quarks induce distinct spin correlations in quark pairs produced at lepton colliders, favoring entangled spin-triplet state aligned along the $\hat{z}$ axis or spin-singlet state. These correlations lead to unique $\cos(\phi_1 - \phi_2)$ azimuthal asymmetries in inclusive $\pi^+\pi^-$-dihadron pair production and in back-to-back hadron pairs ($\pi\pi$, $K\pi$, KK), which are absent in the SM. By analyzing Belle and BaBar data and using ratios of azimuthal asymmetries, we demonstrate that these measurements provide robust and significant constraints on light-quark dipole couplings, insensitive to nonperturbative fragmentation functions and free from contamination by other new physics effects. This approach offers a clean and novel probe of light-quark dipole interactions in collider experiments.

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