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Linearly Polarized Photon Fusion as a Precision Probe of the Tau Lepton Dipole Moments at Lepton Colliders

We present a comprehensive investigation into the anomalous magnetic dipole moment (a_τ) and electric dipole moment (d_τ) of the τ lepton using the $\gamma\gamma \to \tau^+\tau^-$ process at future lepton colliders, with the Super Tau-Charm Facility serving as a benchmark. By employing transverse-momentum-dependent factorization, we introduce novel observables derived from $\cos 2\phi$, $\sin 2\phi$, and $\cos 4\phi$ azimuthal asymmetries to precisely probe the τ lepton's electromagnetic structure. Our analysis significantly enhances the precision of a_τ constraints within the photon-photon fusion process, yielding $\mathrm{Re}(a_\tau) \in [-4.5, 6.9] \times 10^{-3}$ at the 2σ confidence level, which approaches the precision of the Standard Model prediction. These findings highlight the considerable potential of azimuthal asymmetry measurements for high-precision determinations of fundamental particle properties at future lepton colliders.

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