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First-Principle Calculation of Collins-Soper Kernel from Quasi-Transverse-Momentum-Dependent Wave Functions

We present a lattice QCD calculation of the Collins-Soper kernel, which governs the rapidity evolution of transverse-momentum-dependent (TMD) distributions, using Large Momentum Effective Theory (LaMET). Quasi-TMD wave functions are computed with three meson momenta on CLQCD configurations (multiple lattice spacings) employing clover quarks and varied hadronic states. HYP smearing is applied to staple-shaped gauge links and Wilson loops to enhance signal-to-noise ratios. Divergences are systematically addressed: linear divergences via Wilson-line renormalization and logarithmic divergences through a self-renormalization-inspired scheme.

By combining two-loop light-cone matching, renormalization group evolution, and leading renormalon resummation, we determine the Collins-Soper kernel for transverse separations up to 1 fm, with extrapolation to large-momentum and continuum limits. This work provides critical inputs for soft functions and precision studies of TMD physics, advancing first-principles QCD in high-energy phenomenology.

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