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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 and pion masses) 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 systematically controlling the sources of systematic uncertainties, we determine the Collins–Soper kernel up to transverse separations of 1 fm, followed by extrapolations to the large-momentum limit, the continuum limit, and the physical pion mass. This study delivers essential inputs for soft functions and precision analyses of TMD physics, thereby advancing first-principles QCD in the domain of high-energy phenomenology.

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