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Three-dimensional Imaging of Transversely Polarized Proton in Momentum Space

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We present a lattice quantum chromodynamics (QCD) calculation of the proton valence-quark transverse-momentum-dependent parton distribution function (TMDPDF) in three polarization channels within the framework of large-momentum effective theory (LaMET). Using correlators fixed in the Coulomb gauge (CG), we computed the quasi-TMD beam function for a proton with the chiral-symmetry-preserving domain wall fermion, the physical valence pion mass, and a lattice spacing of $a = 0.0836$ fm. The intrinsic soft function required in the CG framework is extracted from large-momentum-transfer form factors, and we also determine the associated Collins-Soper (CS) kernel as a direct result. Both the soft function and the CS kernel show agreement with perturbative results at small transverse quark separations ($b_\perp$). At larger values of $b_\perp$, the CS kernel remains compatible with recent findings based on CG and gauge-invariant (GI) TMD correlators in the literature. By applying next-to-leading logarithmic (NLL) factorization to both the quasi-TMD beam function and the soft function, we extract the x dependence of the proton quark TMDPDFs in three polarization channels, extending to transverse separations $b_\perp > 1$ fm.

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