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Proton isovector helicity PDF at NNLO and the twist-3 moment $\tilde{d}_2$ from lattice QCD at physical quark masses

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We present a lattice quantum chromodynamics calculation of the x -dependent isovector quark helicity parton distribution function (PDF) of the proton in the large momentum effective theory (LaMET) framework. Through operator product expansion (OPE) we also extract the $\tilde{d}_2$ moment of the twist-3 PDF $g_T(x)$ for the first time in the $\overline{\text{MS}}$ scheme, which is proportional to the average color Lorentz force experienced by the quark in the proton. This calculation is performed on a lattice of spacing $a = 0.076$ fm at physical quark masses. The quasi-PDF matrix elements are measured in proton states boosted to momenta $P_z = \{0, 0.25, 1.02, 1.53\}$ GeV. We first extract the lowest few helicity PDF moments from the renormalization-group (RG) invariant ratios of the matrix elements with OPE. Combined with the matrix elements relevant for $g_T(x)$, we obtain $\tilde{d}_2^{u-d}(2 \text{ GeV}) = 0.0024(46)$ at next-to-leading order in $\overline{\text{MS}}$.

Then, the helicity quasi-PDF matrix elements are renormalized in the hybrid scheme with linear renormalon resummation and Fourier transformed to the x -space after an asymptotic extrapolation. The quasi-PDF is perturbatively matched to the $\overline{\text{MS}}$ PDF with RG and threshold resummations at next-to-leading power and next-to-next-to-leading logarithmic accuracies.

After resummations, we determine the PDF in the region $x \in [0.25, 0.75]$. The end-point regions are then parameterized, combined with the LaMET prediction at moderate x , and fitted to the short-distance matrix elements in coordinate space.

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