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Probing gluon TMDs in J/ψ and Υ production at an EIC

Transverse-momentum dependent parton distribution functions (TMD PDFs, or TMDs for short), are fundamental objects in QCD which describe the parton content of a proton as a function of the parton's longitudinal momentum fraction x w.r.t. the proton, and its transverse momentum k_t. As such, they provide insight in the three-dimensional structure of the proton in terms of quarks and gluons. In recent years, considerable effort has been devoted to the study of gluon TMDs, which are experimentally less known than their quark counterparts.

In this work, we propose to probe gluon TMDs in the deep-inelastic scattering processes $e + p \to [Q\bar{Q}] + X$ and $e + p^{\uparrow} \to [Q\bar{Q}] + X$, with $[Q\bar{Q}]$ being either the J/ψ or Υ heavy quarkonium states. The cross sections for these processes are computed in the TMD framework together with nonrelativistic QCD (NRQCD): an effective theory which allows to factorize the perturbatively calculable heavy-quark pair production from its subsequent nonperturbative hadronization into the quarkonium, which is encoded in so-called long-distance matrix elements (LDMEs). In the kinematical regime in which our TMD formalism is valid, the color octet (CO) production mechanism is expected to be dominant, where the heavy-quark pair is produced in a color state, and only during the hadronization decays to a singlet. The corresponding LDMEs are taken from fits to data from the LHC, RHIC, and TEVATRON, and are the largest source of uncertainty in our work. We show that the cross sections depend on five different gluon TMDs in total, each corresponding to a specific azimuthal modulation which can be used to disentangle them, for instance from measurements at a future Electron-Ion Collider (EIC).

Gluon TMDs are of particular importance in the small-x regime of QCD, which is characterized by such a high gluon density that nonlinear saturation effects are expected to become important. The small-x dynamics of QCD is described by the Color Glass Condensate effective theory (CGC), which allows to calculate the nonlinear evolution of the gluon density in x, given a certain initial condition. In particular, the two gluon TMDs of the unpolarized proton, corresponding to unpolarized and linearly polarized gluons, respectively, can be calculated analytically in the nonperturbative McLerran-Venugopalan (MV) model for the gluon distribution at low-x. Moreover, using an numerical implementation of the JIMWLK equation, their nonlinear evolution in x can be computed. With these results at hand, we show predictions for the $\cos(2\phi_T)$ asymmetry in the $e + p \to [Q\bar{Q}] + X$ cross section, which scales with the ratio of these two TMDs.

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