

Exclusive emissions of polarized ρ mesons at the EIC and the proton content at low x

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Abstract

We present a new study on helicity amplitudes and cross sections for the exclusive production of ρ mesons at the EIC in high-energy factorization. In this framework the analytic expression of amplitudes takes the form of a convolution between an off-shell impact factor, depicting the $(\gamma^* \rightarrow \rho)$ transition, and a nonperturbative density, known as Unintegrated Gluon Distribution (UGD) that encodes information about the proton structure at low x and evolves according to the BFKL equation. We come out with an evidence that observables sensitive to the polarizations of the incoming virtual photon and of the emitted meson allow us to discriminate among different UGD models and to gather quantitative information on the proton content at high energies.

KEYWORDS:

QCD phenomenology

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1 Hors d'œuvre

Shedding light on the proton structure via a multi-dimensional imaging of their constituents is a frontier research field at new-generation colliding machines. Fundamental questions about the inner dynamics of strong interactions are still far to be answered. We mainly refer to proton mass and spin puzzles, whose resolution key relies upon a viewpoint stretch from the collinear-factorization description to a 3D tomographic vision, elegantly afforded by the *transverse-momentum-dependent* (TMD) formalism (see Refs. [1, 2] and references therein). However, a pure TMD-driven approach may be not enough at low x . Here, large $\ln(1/x)$ -type logarithms enter the perturbative expansion with a power increasing with the order of

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the strong coupling, and they need to be *resummed* by all-order techniques. The Balitsky-Fadin-Kuraev-Lipatov (BFKL) resummation [3–6] allows us to exactly account for these large logarithms both in the leading (LLx) in the next-to-leading ($NLLx$) logarithmic approximation, namely including all contributions proportional to $\alpha_s^n \ln(1/x)^n$ and to $\alpha_s^{n+1} \ln(1/x)^n$, respectively.

A first kind of reactions that serve as probes for BFKL consists in the inclusive *semi-hard* detection [7] of two objects having large transverse momenta and being well separated in rapidity (see Ref. [8] for recent applications). Here, a *hybrid* high-energy and collinear factorization is established [9] (see also Refs. [10–14]) as a convolution of high-energy resummed partonic cross sections and collinear densities (or/and fragmentation functions, when final-state hadrons are identified). Examples of these two-particle configurations include emissions of: light [15–22] and heavy jets [23–27], light [28–30] and heavy hadrons [31–37], Higgs bosons [38–41] and forward Drell-Yan pairs [42–45] in association with a possible tag of backward jets [46].

A second class of BFKL probes is represented by single-forward or single-central detections. Here we access the proton content via the *unintegrated gluon distribution* (UGD), whose evolution at low x is regulated by the BFKL Green's function. As a nonperturbative density, the UGD is not well known and distinct phenomenological models for it have been proposed so far. Starting from the information encoded in the UGD, low- x improved collinear [47, 48] and TMD [49–51] distributions were determined. The UGD has been extensively investigated through the inclusive deep inelastic scattering [52, 53] and the exclusive electro- or photo-production of forward vector mesons at HERA [54–64] and at the Electron-Ion Collider (EIC) [65–68]. Studies of central emissions of quarkonium states [69–78] have the twofold advantages of unraveling the heavy-hadron production mechanisms and of probing kinematic corners at the frontier between TMD and high-energy factorization.

In this work we focus on the exclusive leptoproduction of ρ mesons in high-energy factorization. By investigating polarized cross sections at EIC nominal energies [79–81], we highlight how these observables are able to discriminate among distinct models and parametrizations for the low- x UGD.

2 Theoretical setup

We study the exclusive ρ -meson production at the EIC through the following subprocess

$$\gamma_{\lambda_i}^*(Q^2) p \rightarrow \rho_{\lambda_f} p, \quad (1)$$

where a photon having virtuality Q^2 and polarization λ_i is absorbed by the proton and a ρ -meson with spin λ_f is emitted. The two polarizations $\lambda_{i,f}$ can have values 0 (longitudinal) or ± 1 (transverse). The stringent semi-hard scale hierarchy holds, $W^2 \gg Q^2 \gg \Lambda_{\text{QCD}}^2$, with W being the subprocess center-of-mass energy and Λ_{QCD} the QCD hadronization scale, leads to low- x values, $x = Q^2/W^2$. The BFKL approach affords us a high-energy factorized expression for helicity-dependent amplitudes

$$\mathcal{T}_{\lambda_i \lambda_f}(W^2, Q^2) = \frac{iW^2}{(2\pi)^2} \int \frac{d^2 \mathbf{p}_T}{(\mathbf{p}_T^2)^2} \times \Phi^{\gamma_{\lambda_i}^* \rightarrow \rho_{\lambda_f}}(\mathbf{p}_T^2, Q^2) \mathcal{G}(x, \mathbf{p}_T^2). \quad (2)$$

In Eq. (2) $\Phi^{\gamma_{\lambda_i}^* \rightarrow \rho_{\lambda_f}}(q^2, Q^2)$ stands for the off-shell impact factor that portrays the $\gamma^* \rightarrow \rho$ transition and embodies collinear distribution amplitudes (DAs, for more details see Section 2 of Ref. [65]), whereas $\mathcal{G}(x, \mathbf{p}_T^2)$ is the BFKL UGD. Starting from helicity amplitudes, we build longitudinally (L) and transversally (T) polarized cross sections as

$$\sigma_{L,T}(\gamma^* p \rightarrow \rho p) = \frac{1}{16\pi b(Q^2)} \left| \frac{\mathcal{T}_{00,11}(W^2, Q^2)}{W^2} \right|^2, \quad (3)$$

where $b(Q^2)$ is the *diffraction slope*, for which we employ the following parametrization [82]

$$b(Q^2) = \beta_0 - \beta_1 \log \left(\frac{Q^2 + m_\rho^2}{m_{J/\psi}^2} \right) + \frac{\beta_2}{Q^2 + m_\rho^2}, \quad (4)$$

with $\beta_0 = 6.5 \text{ GeV}^{-2}$, $\beta_1 = 1.2 \text{ GeV}^{-2}$, and $\beta_2 = 1.6$. In our phenomenological analysis we adopt the seven models for the UGD briefly introduced in Section 3 of Ref. [65].

3 Exclusive ρ -meson production at the EIC

Panels of Fig. 1 show the Q^2 -behavior of predictions for the polarized cross sections σ_L (upper), σ_T (central), and their ratio σ_L/σ_T (lower), as obtained with

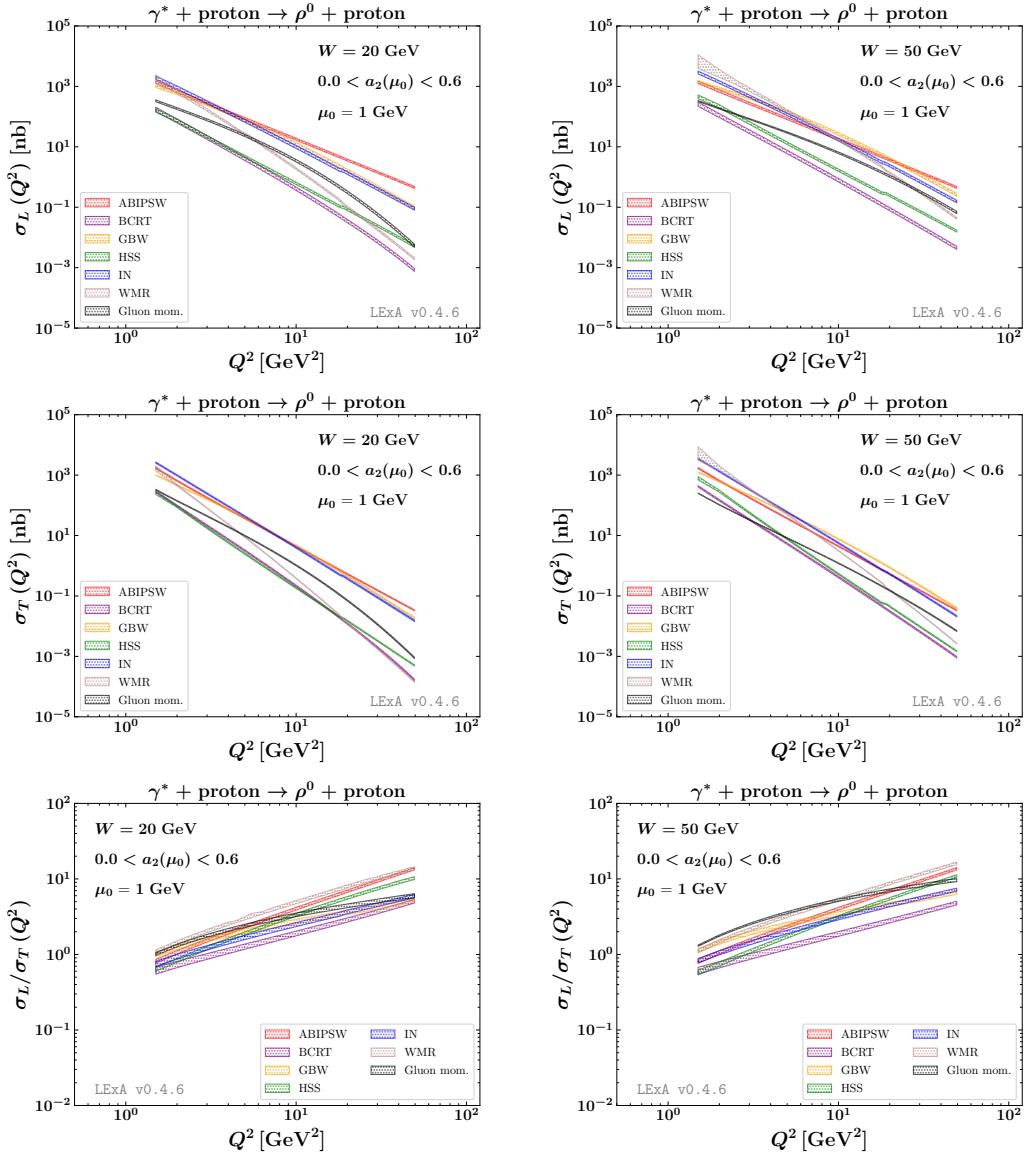


Fig. 1 Q^2 -dependence polarized cross sections σ_L (upper), σ_T (central) and their ratio σ_L/σ_T (lower), for all the considered UGD models, at $W = 20$ GeV (left) and $W = 50$ GeV (right). Shaded bands portray the effect of varying $a_2(\mu_0 = 1 \text{ GeV})$ between 0.0 and 0.6. Figures from Ref. [65].

all the seven UGD at two nominal values of EIC energies, $W = 20$ GeV (left) and $W = 50$ GeV (right). Uncertainty bands are built by accounting for the variation of the Gegenbauer coefficient $a_2(\mu_0)$ entering the definition of DAs (see Section 2.1 of Ref. [65]). We observe that the uncertainty rising from the choice of the UGD is much larger than the one associated to the variation of $a_2(\mu_0)$. The inspection of results

presented in this Section supports the statement that future data collected at the EIC will bring a high potential to constrain the UGD as well as to shed light on the gluon dynamics inside the proton at small x .

4 Summary and Outlook

We computed cross sections for the exclusive diffractive lepton production of ρ mesons in the energy range of forthcoming studies at the EIC. We made use of the high-energy factorization for forward helicity amplitudes [54, 55], adopting an empirical parametrization of the diffraction slope to get relevant polarized cross sections. Impact factors for forward ρ mesons probe the transverse-momentum shape of the UGD in different ways, so that the polarization dependence of ρ -emission can serve as a powerful probe channel of the UGD [57, 58]. New data collected at the EIC have a potential to shed light on the intersection regime between high-energy and TMD factorization. Future studies will extend this analysis at the next-to-leading order and will complement the information on the hadronic structure at low x gathered at the EIC with the one accessible at other new-generation facilities: the Muon-Ion Collider (MuIC) [83], NICA [84], the Forward Physics Facility (FPF) [85–87], and the High-Luminosity LHC [88, 89].

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