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Extracting the partonic structure of colorless exchanges in diffraction at the EIC

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In this talk we analyze the possibility to determine the partonic structure of colorless exchanges, Pomeron and Reggeon, from diffractive measurements in the four diffractive kinematic variables in ep collisions at the EIC. We present the model we use to generate the pseudodata and explain our fitting strategy. We show the results on the uncertainties in the extraction of quark and gluon parton distributions in Pomeron and Reggeon, and analyze the influence of cuts in the different kinematic variables. We consider the possibilities not only at the highest EIC energy, highest luminosity scenario but also for lower luminosities and those in a low energy, first year scenario. The EIC will be able to constrain the partonic structure of the subleading Reggeon exchange, with a similar precision to the leading Pomeron exchange.

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Diffractive events in hadronic collisions are characterized by the presence of large rapidity gap, that is the region of the detector which is void of any particle activity. At the electron-proton collider at HERA it was observed that diffractive events consitute about 10% fraction of total number of events [1, 2]. In order to have the rapidity gap, the color needs to be neutralized so that there will be no radiation into the rapidity gap. Usually this is interpreted as the exchange of the colorless object. There are several fundamental questions: what is the partonic composition of this object, is this one exchange or several exchanges, what is the energy and momentum transfer dependence? The data on inclusive diffraction at HERA collider were very well described within the collinear factorization framework, where the inclusive cross section was computed using a factorized form, which included the hard partonic cross sections, computable in perturbative QCD and the diffractive parton distribution functions (DPDFs). The latter ones contain information about the long distance physics and their hard scale dependence can be obtained through the usual DGLAP evolution equations. The DPDFs were parametrized through the Regge factorized form, as the product of two factors, the parton distributions of the diffractive exchange $f_k^{I\!P,I\!R}$ and the flux factor $\phi_{I\!P,I\!R}$

$$f_k^{D(4)}(z,Q^2,\xi,t) \quad = \quad f_k^{I\!P}(z,Q^2)\,\phi_{I\!P}(\xi,t) \; + f_k^{I\!R}(z,Q^2)\,,\phi_{I\!R}(\xi,t)\;, \tag{1}$$

which separate the dependence on the hard scale Q^2 and longitudinal momentum fraction of the parton with respect to the diffractive exchange z from the momentum transfer t and longitudinal momentum fraction ξ of the proton carried by the diffractive exchange. For the satisfactory description of the experimental data two exchanges were needed, the so called ’Pomeron’ exchange ($I\!P$), dominant for small ξ, and the ’Reggeon’ exchange, ($I\!R$) important for large ξ. The latter one was taken as the parametrization of the pion and could not constrained by the HERA data.

The Electron Ion Collider (EIC) [3] is a facility that will be built at Brookhaven National Laboratory (BNL) using and upgrading the existing accelerator complex for the Relativistic Heavy Ion Collider (RHIC). It will have very high luminosity and excellent forward instrumentation, capable of the tagging of the elastically scattered protons, with very large acceptance in t and ξ. EIC will thus have a unique opportunity to measure the partonic content of the Pomeron and Reggeon exchanges. Here we discuss these opportunities and present a detailed study of the extraction of the DPDFs at EIC focusing on the secondary Reggeon exchange. The details of the study can be found in [4].

Using the ZEUS two-component fit to HERA diffractive data, pseudodata were generated differentially in all 4 variables (Q^2, z, ξ, t) in the kinematic range of EIC. We assumed integrated luminosity of $100\,\mathrm{fb}^{-1}$ for highest energy setup at EIC 275 GeV × 18 GeV (‘high energy’) and $10\,\mathrm{fb}^{-1}$ for lower energy setup 41 GeV × 5 GeV (‘low energy’). The pseudodata were generated according to this framework and smeared with a Gaussian distribution around the central value with a standard deviation given by the addition in quadrature the statistical uncertainties, fixed by luminosity, and the systematic uncertainty of 5%. In addition a 2% normalization uncertainty was considered on top. We impose the cuts on the inleasticity $0.05 < y < 0.96$.

The subset of the generated pseudodata is shown in left plot in Fig. 1 as a function of the Mandelstam variable corresponding to momentum transfer squared t for fixed value of Q^2 and β and several selected values of ξ. We observe the change in slope in t as the value of ξ is increased, which indicates the transition from the Pomeron to the Reggeon dominated regime. This is also illustrated in the middle and right plot in Fig.1 where we show the ratio of the Reggeon to Pomeron contribution in the cross section as a function of $-t$ for two selected values of $\xi = 0.02$ and $\xi = 0.1$. For the small value of ξ the Pomeron contribution dominates, whereas for larger value of $\xi > 0.1$ the Reggeon dominates. The latter region was not accessible at HERA, while it will be possible to explore at the EIC.

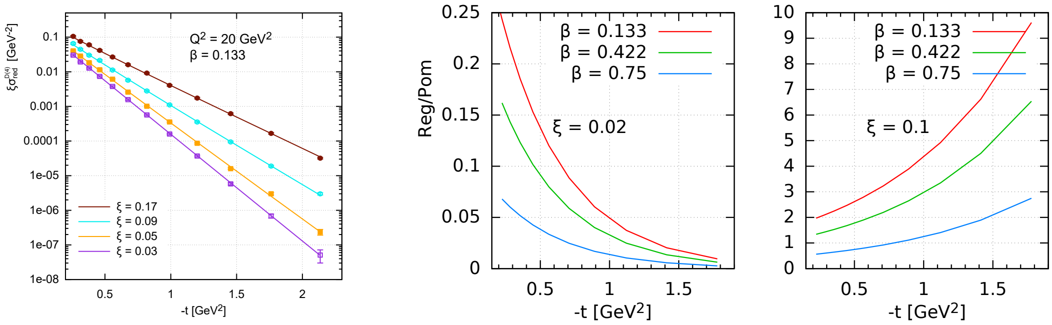

Figure 1: Reduced cross section versus $-t$ (left) for fixed ξ for $Q^2 = 20\,\mathrm{GeV}^2$, $\beta = 0.133$ and selected values of ξ, t, for the top energy setup and integrated luminosity of 100 fb^{-1}. Pseudodata, given by the points with error bars, are compared to the predictions of the model (lines) providing the central values. Middle and right : ratios of the Reggeon to Pomeron contributions to $\sigma_{\mathrm{red}}^{D(4)}$ for the top energy setup and $Q^2 = 20\,\mathrm{GeV}^2$, for selected values of β and $\xi = 0.02$ (middle) $\xi = 0.1$ (right).

Using the generated pseudodata we performed a fit and extracted DPDFs. The parton densities for Pomeron and Reggeon were parametrized at an initial scale $\mu_0^2 = 1.8\,\mathrm{GeV}^2$ with a functional form

$$f_k^{\mathbb{M}}(x, \mu_0^2) = A_k^{\mathbb{M}}\, x^{B_k^{\mathbb{M}}}\, (1-x)^{C_k^{\mathbb{M}}} (1 + D_k^{\mathbb{M}}\, x^{E_k^{\mathbb{M}}}), \tag{2}$$

with $\mathbb{M} = \mathbb{P}, \mathbb{R}$. We use $k = q, g$ with q summed over the light quark and antiquark flavors. No intrinsic charm or bottom is considered, as the heavy flavors are generated radiatively via DGLAP evolution. There are in total 19 parameters to be fitted. We fix $\alpha_s(M_Z) = 0.118$, $m_c = 1.35$ GeV and $m_b = 4.3$ GeV for the fits.

We employed two different fitting strategies depending on the higher or lower energies. Since the Pomeron contribution dominates at large $-t$ and small ξ, see Fig. 1 (middle) a Pomeron-only fit is first performed in the region $-t \in [0.4, 2]\mathrm{GeV}^2$ and $\xi \in [0.0004, 0.007]$ for the case of the higher energy. After that, the parameters extracted from this fit are then taken as initial values for a two-component Pomeron + Reggeon fit over the full accessible kinematic range. At the lower energy, the strategy was different. This is the region where the Reggeon contribution dominates in the full accessible kinematic region, and the Pomeron is smaller, see Fig. 1 (right). Therefore we assume that the Pomeron flux is known from HERA data and the fit was performed for only the Reggeon component. In Figs. 2 and 3 we show the relative uncertainties on the gluon and quark components of the leading (Pomeron) and secondary (Reggeon) exchanges. The uncertainties are extracted from fits including all data up to $-t_{\mathrm{min}} = 1.5\,\mathrm{GeV}^2$ as the statistical errors above that value become rather large. We observe that the uncertainties on the Pomeron gluon and quark are very small, often below the 1% level before taking the normalization uncertainty into account. The normalization uncertainty is dominant throughout the phase space. From Fig. 3 it is clear that the

Reggeon contribution has uncertainties below the 2% level for the quark case except for very large z. The gluon component of the Reggeon has somewhat larger uncertainties, however it should be noted that this component is rather small away from the smallest z values, so the absolute size of the uncertainty is not large. In the Reggeon case, the 2% normalisation uncertainty is dominant for the quark density, but its influence is relatively small for the gluon case.

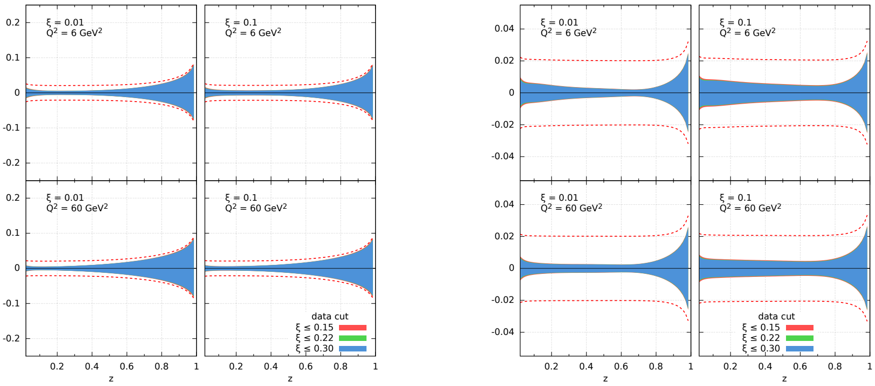

Figure 2: Relative uncertainties for the gluon (left) and quark (right) contributions to the Pomeron PDFs as a function of longitudinal momentum fraction z for fixed values of $\xi = 0.01, 0.1$ and $Q^2 = 6, 60\,\mathrm{GeV}^2$. Results are shown for three different cuts on $\xi < 0.15, 0.22, 0.30$, corresponding to red, green and blue regions respectively. The range in momentum transfer is $-t \leq 1.5\,\mathrm{GeV}^2$. The dashed lines depict error band limits upon including a normalization error of 2% for the case of the lowest ξ cut.

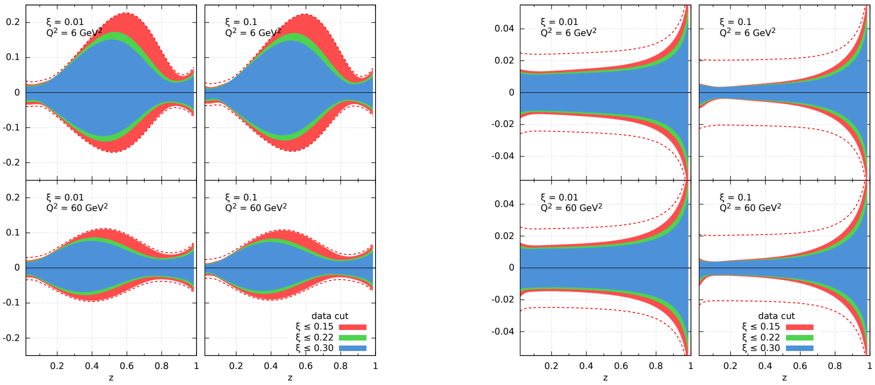

Figure 3: The same as for Fig. 2 but for the Reggeon component.

Dependence on the different cuts on ξ and t was studied. In general, the uncertainties are not very sensitive to different choices of cuts, with some exception for the Reggeon quark component, which shows some moderate sensitivity ot $\xi_{\max}$. We have also checked that the uncertainties are not sensitive to the lower luminosity (for the higher energy beam scenario) and to the binning scheme.

We have also studied a lower EIC beam energy scenario, with $E_e = 5\,\mathrm{GeV} \times E_p = 41$ GeV and a luminosity of $\mathcal{L} = 10\,\mathrm{fb}^{-1}$. As mentioned previously, the sensitivity to ξ is limited to values larger than ~ 0.01, and therefore the fitting strategy is to fix the Pomeron contribution from the HERA data and perform the fit of only Reggeon contribution. In Fig. 4 we show the extracted DPDFs for the quark and gluon contributions to the Reggeon structure at two values of $\xi = 0.01, 0.1$ and two values of $Q^2 = 6, 60$ GeV^2, together with the uncertainties. The results of the fits indicate that a good precision on the quark contribution to the Reggeon is achievable for the low beam energy scenario, particularly if the ξ range extends to at least 0.22.

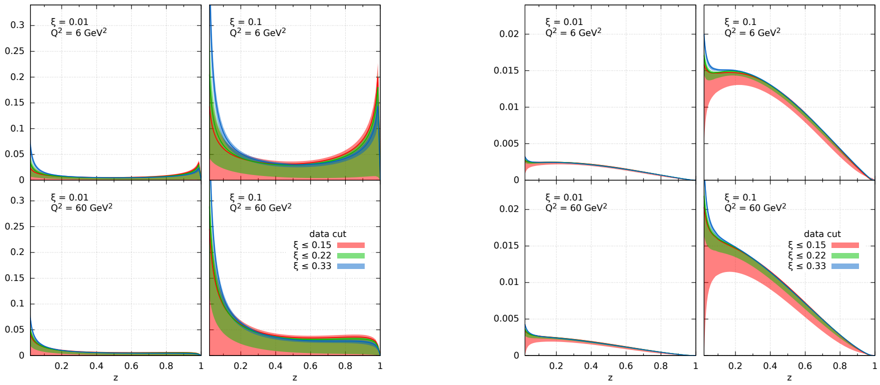

Figure 4: t-integrated DPDFs for the Reggeon versus z for gluons (left plots) and quarks (right plots) at $Q^2 = 6$ (upper plots) and 60 (lower plots) GeV^2, in the lower beam energy configuration, $E_e \times E_p = 5 \times 41$ GeV. The two columns in each panel correspond to $\xi = 0.01$ (left) and $\xi = 0.1$ (right). Uncertainties are shown for three different scenarios with $\xi_{\max} = 0.15$ (orange), 0.22 (green) or 0.33 (blue), with $t_{\min} = -1.2$ GeV^2 in each case.

In conclusion, we have performed a comprehensive study of the feasibility of the simultaneous extraction of the partonic content of the Pomeron and Reggeon contribution in the inclusive diffraction at the EIC. To this aim pseudodata for the diffractive cross section differential in 4-variables were simulated and the fit including both leading and secondary exchange was performed. At the highest EIC energy the partonic content of the Reggeon can be constrained with the precision comparable to that of the Pomeron. At lowest energy Pomeron component has to be fixed by HERA data, but the Reggeon component can already be constrained to quite a good accuracy.

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