Generalised parton distributions and exclusive vector meson production

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Abstract
We briefly review recent developments in the description of exclusive vector meson production in terms of generalised parton distributions. The determination of the gluon distribution at small x from HERA data on diffractive J/ψ production is discussed.

1 Introduction

Contrary to normal DIS, processes like deeply virtual Compton scattering (DVCS) or the diffractive production of (di-) jets, heavy quarks or vector mesons (VMs), cannot be described accurately with the diagonal (normal) parton distribution functions (PDFs). This can be seen from Fig. 1, where the leading order diagram for DVCS (left) and J/ψ vector meson production (right figure) are shown. While DVCS is mainly testing the quark distribution, the amplitude for exclusive vector meson production is, to leading order, directly probing the gluon PDF. The momentum fractions x and x' of the two partons are in general different, resulting in a deviation from the diagonal limit for the distribution function of the respective parton. In this instance, a generalised parton distribution (GPD) must be used to describe the process.

Unlike the diagonal parton distributions, which represent a probability distribution, generalised distributions are defined by matrix elements of quark and gluon light-cone operators $\hat{\mathcal{O}}$ for different initial and final states of the proton, $\langle p'|\hat{\mathcal{O}}|p\rangle$. They encode richer information about the distribution of partons inside the hadron and have no direct probabilistic interpretation. One may express the parton momentum fractions in a GPD in a symmetric manner, with the introduction of a skewing parameter ξ and a symmetric $\tilde{x}$: $x = \tilde{x} - \xi$, $x' = \tilde{x} + \xi$. In the forward limit $\xi, t \to 0$, the generalised partons reduce to the conventional diagonal partons, where t is the square of the momentum transfer between initial and final protons. In the following we will briefly discuss

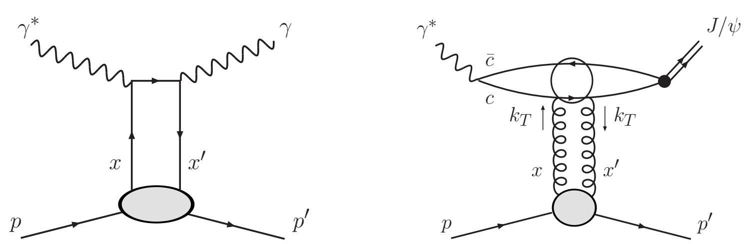

Fig. 1: Left: DVCS $\gamma^* p \to \gamma p'$ and right: elastic J/ψ production $\gamma^* p \to J\psi p'$. The two partons entering the scattering have different momentum fractions x, x'.

selected recent work on the prediction of diffractive production of vector mesons based on generalised parton distributions, both in the framework of collinear and k_T factorisation, and the determination of the small x gluon from diffractive J/ψ data in the latter framework.

2 Predictions for diffractive vector meson production

In the last years a lot of work has been done on dipole and saturation models. For a review of these topics in these proceedings we refer to [1]. Calculations in the framework of dipole cross sections often do not attempt at including the effect of non-forwardness. However, in [2] the skewedness is treated as in [3] discussed below.

2.1 Predictions based on collinear factorisation

Kroll and Goloskokov have described electroproduction of light vector mesons using collinear factorisation on the proton side [4–6]. In the limit of large photon virtuality Q^2 the production amplitude factorises into a perturbatively calculable hard scattering amplitude (coefficient function), a generalised PDF and the wave function of the VM. This is similar to DVCS, where the term 'handbag factorisation' is used which is particularly suitable in the case of initial quarks relevant at lower c.m. energies. The transverse momentum p_T of the quarks forming the vector meson is retained, and a corresponding meson light-cone wave function $\psi_{VM}(\tau, p_T)$ (with p_T the intrinsic transverse momentum and τ the fraction of the light-cone plus component of the meson's momentum carried by the quark) is used. In addition a Sudakov factor $\exp[-S(\tau, p_T, Q^2)]$ is applied at next-to-leading-logarithmic accuracy. This suppresses gluon radiation in the regime between a soft cut-off and a factorisation scale related to the quark-antiquark separation. Softer gluons are included in the VM wave function while harder ones are part of the hard, perturbative scattering amplitude. This so-called 'modified perturbative approach' cures the end-point singularities stemming from configurations with large transverse quark-antiquark separation which otherwise would prevent a prediction of the cross section for transversely polarised mesons. The generalised parton distributions are derived using the ansatz of double distributions following the work of Radyushkin [7] and using global PDFs as input for the diagonal limit.[1] The evolution is approximated by the evolution of the diagonal input. With their approach Kroll and Goloskokov find fair agreement with electroproduction data from COMPASS, HERMES, E665, ZEUS and H1, see [4–6] and Fig. 2 for an example of their longitudinal cross section predictions for ϕ and ρ electroproduction. The extension to contributions from transverse photons is discussed in [6].

While the approach of Kroll and Goloskokov is not restricted by the high energy approximation adopted in other calculations, the hard, perturbative scattering kernel used in [4–6] is leading order (LO) only. Next-to-leading order (NLO) corrections in the framework of collinear factorisation have been calculated by Ivanov et al. [8] and were found to be large generally. In their recent work Diehl and Kugler [9] have made use of these results to further study the impact

[1] Double distributions offer a way to parameterise the hadronic matrix elements defining generalised distributions [7]. They are defined through Fourier transforms of these matrix elements. Such double distributions guarantee the required symmetry properties and the polynomiality (Nth moments of GPDs are Nth degree polynomials in the skewing parameter ξ) of the derived generalised distributions. However their physical interpretation is different (and maybe less apparent) as they are not directly dependent on ξ.

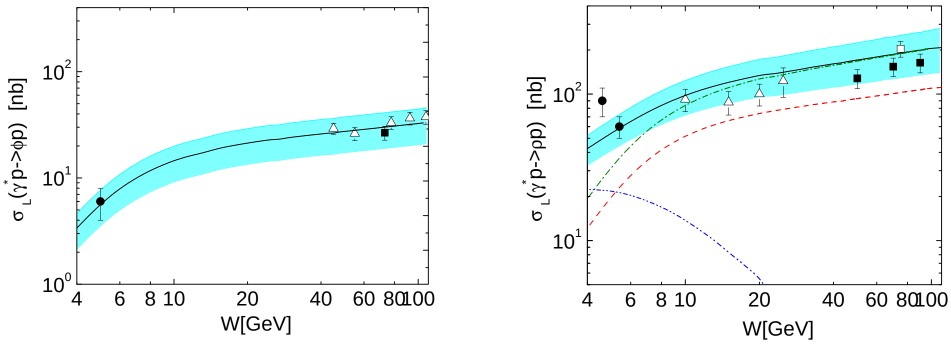

Fig. 2: Predictions from [5] for the longitudinal cross section of ϕ elecroproduction for $Q^2 = 3.8\,\mathrm{GeV}^2$ (left) and ρ electroproduction for $Q^2 = 4\,\mathrm{GeV}^2$ (right). ϕ production data are from HERMES (solid circle), ZEUS (open triangles) and H1 (solid square), and ρ production data are from HERMES (solid circles), E665 (open triangles), ZEUS (open square) and H1 (solid square), see [5] for references. The dashed (dash-dotted) line represents the gluon (gluon+sea) contribution. The dash-dot-dotted line represents the sum of the interference between the valance and (gluon+sea) contributions and the valance contribution. The solid line is the sum of all contributions.

of the NLO corrections to exclusive meson production. They use collinear factorisation, neglecting the transverse momenta of the partons entering the hard scattering both on the proton and on the meson side. For the evolution of the generalised partons they use the leading order evolution code of Vinnikov [10] which uses an optimised fourth order Runge-Kutta method to solve the LO kernels as given in [11]. The input GPDs are again estimated via the double distribution method, and with diagonal input from the global PDF fit CTEQ6M [12]. Diehl and Kugler observe large NLO corrections leading to a strong suppression of the LO result in the small x regime, but no gain from LO to NLO in the stability w.r.t. the scale variation. In Fig. 3 this is shown for the case of ρ electroproduction in different kinematic regimes. Unfortunately such large corrections, which can partly be traced back to BFKL type logarithms (see [13] for first predictions including resummation effects), limit the applicability of the fixed-order collinear approach to describe data for elastic VM production.

2.2 Vector meson production in k_T factorization

Traditionally, k_T (or 'high energy') factorisation has been introduced for the description of heavy quark production in the high energy regime. Recently it has also been applied to various other processes including Higgs production at hadron colliders. Martin et al. have used it for the calculation of diffractive production of light and heavy vector mesons at HERA [14, 15]. The relevant amplitude is shown in Fig. 1 (right diagram). Their predictions involve the integration over the transverse momentum k_T of the exchanged gluons, so the input parton distributions need to be unintegrated w.r.t. k_T. This involves the application of a Sudakov factor, see [15] for details. Additional contributions from the real part of the amplitude are calculated based on dispersive methods. This approach goes beyond the leading $\log Q^2$ approximation while also capturing certain contributions beyond the leading high energy (BFKL) limit. Of course NLO corrections also arise from additional loops, for example gluonic one-loop corrections to the

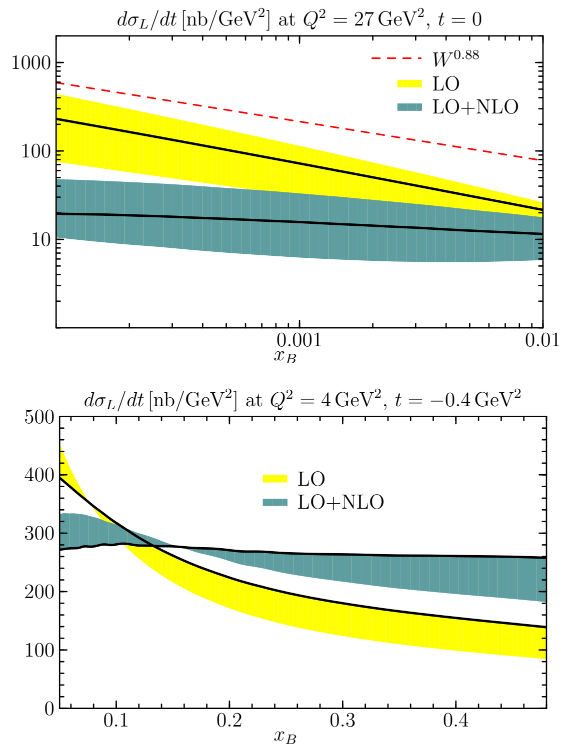

Fig. 3: Longitudinal cross section predictions for ρ electroproduction from [9] for Q^2, t and x as indicated on the plots. The bands are generated from the ranges $Q/2 < \mu < 2Q$ (left) and $2 < \mu < 4\,\mathrm{GeV}^2$ (right), where μ is the renormalisation and factorisation scale. The solid lines correspond to $\mu = Q$. The dashed line in the left panel shows the power-law behaviour $\sigma \propto W^{0.88}$ (with arbitrary normalisation) obtained from a fit by the ZEUS Collaboration to data in the range $x_B = 0.001 \ldots 0.005$.

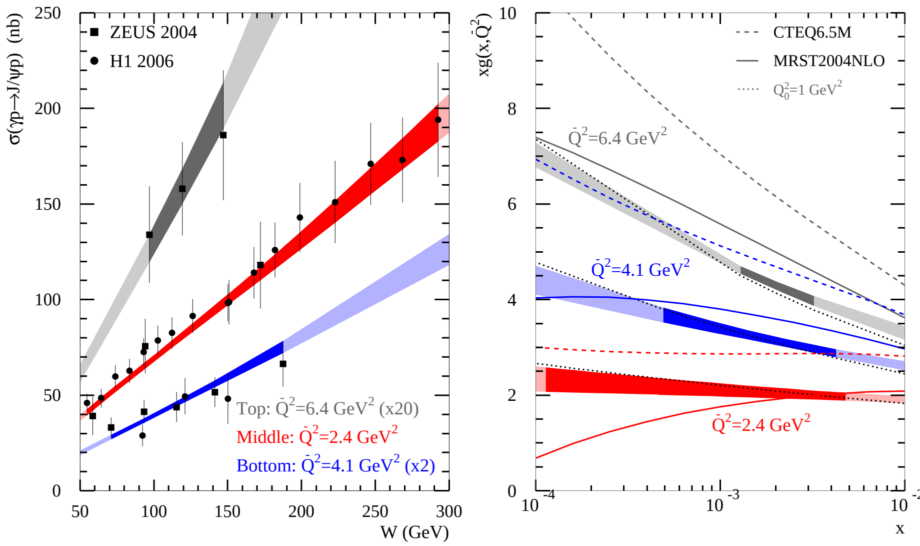

Fig. 4: 'NLO' fit of elastic J/ψ data from HERA [19] as done in [3]. Left: cross section compared to some of the H1 and ZEUS data for three different values of the effective scale $\bar{Q}^2 = (Q^2 + M^2_{J/\psi})/(W^2 + M^2_{J/\psi})$. Right: Fitted diagonal gluon compared to global gluons for scales as indicated. The width of the bands displays the uncertainty of the cross section predictions and the fitted gluon, whereas darker shaded areas indicate the region of available data.

two-gluon quark-antiquark vertex, or when the two gluon system couples via a quark loop to the proton. While such quark contributions are suppressed in the high energy regime, the former class of corrections leads to a genuine K factor which was calculated by Ivanov et al. [8] in collinear factorisation but which is not known in the case of k_T factorisation. Work is in progress to calculate these corrections.

Skewing corrections are taken into account via the Shuvaev transform [16] which, in the case of small x and ξ, allows to calculate the GPDs from the forward PDFs.[2] In this regime, with the assumption of a pure power behaviour of the diagonal PDF $\sim x^{-\lambda}$, the skewing correction is well approximated by a simple factor, $R = \frac{2^{2\lambda+3}}{\sqrt{\pi}} \frac{\Gamma(\lambda+5/2)}{\Gamma(\lambda+3+p)}$ ($p = 1$ for gluons, 0 for quarks), which only depends on the anomalous dimension λ.

3 Determination of the gluon from diffractive J/ψ data

While a good description of many data from HERA and other experiments has been achieved, the predictions show a large dependence on the gluon parametrisations used as input, in the regime of small x and semi-hard scales where they are only poorly known. However, Martin et al. have turned the game around and used their theoretical approach as described above together with exclusive J/ψ data from HERA [19] to determine the gluon distribution in the small x and low-scale regime [3]. Note that whereas in [14, 15] VM production was described via parton-hadron

[2] The use of the Shuvaev transform has become subject of some criticism [17], but see [18] for the justification of its applicability in the regime under consideration here.

duality by integrating over open quark-antiquark production in a suitably chosen mass regime, for the gluon fits in [3] the non-relativistic limit for the J/ψ wave function was adopted. While this is a sufficient approximation w.r.t. the other theoretical and experimental uncertainties, it also allows for the prediction of the normalisation which is not well controlled in the parton-hadron duality approach. With the use of a simple three-parameter ansatz for the gluon, $xg(x,\mu^2) = Nx^{-\lambda}$, with $\lambda = a + b\,\ln\ln(\mu^2/\Lambda^2_{\rm QCD})$, a fit (with $\chi^2_{\rm min}/d.o.f. = 0.8$) gives the results $N = 1.55{\pm}0.18,\ a = -0.50{\pm}0.06,\ b = 0.46{\pm}0.03$. In Fig. 4, both the results for the emerging cross section predictions (left) and the fitted gluon distribution (right panel) are shown for different scales and compared to the gluon PDFs of global fits from CTEQ [20] and MRST [21].

4 Conclusions

We have briefly reviewed recent work on the description of exclusive vector meson production in ep collisions based on generalised parton distributions. While it has been known for a long time that this process is particulary interesting due to its quadratic sensitivity on the input partons, the complexity of the full amplitudes makes systematic higher order predictions difficult. Different approaches as presented above have been discussed at the recent HERA-LHC workshops. Clearly we have gained a much better understanding of exclusive VM production, though the quantitative predictions have not yet achieved the desired accuracy. Nevertheless, a lot of progress has been made in predicting these processes and first results on extracting the gluon at small x from HERA data have been reported. The situation will be even more complicated at the LHC, and with the wider kinematic range accessible, the future will be very interesting.

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