Exclusive processes and GPDs

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Abstract. We investigate the exclusive vector meson production (VMP) which is an essential reaction to analyse the General Parton Distributions (GPDs). The possibility to study VMP at NICA is discussed. The other important process is the exclusive Drell-Yan (D-Y) production in the proton-proton reaction, which is determined by two GPDs. These reactions can be studied at NICA and give an additional excess to GPDs.

1. Introduction

In this report, we study what information on GPDs can be extracted from exclusive hadron-hadron reactions, mainly at the NICA collider.

In section 2 we analyse a meson leptoproduction at high photon virtuality Q^2. The amplitude of this process within the handbag approach factorizes into the hard subprocess and GPDs [1, 2, 3]. The handbag approach was successfully applied to the light VMP [4, 5, 6] and the pseudoscalar meson production (PMP) [7, 8]. In this section, we show that VMP can be described properly by using the leading contribution. At the same time, in PMP reactions at intermediate Q^2 the twist-3 transversity effects play an essential role [7, 8].

In section 3, we investigate a possibility to study VMP at hadron accelerators like the NICA collider at Dubna [9]. It is shown that ϕ, ρ, ω and J/Ψ production can be analyzed via a photoproduction mechanism like in lepton-proton reactions.

In section 4, we study the exclusive D-Y process in the proton-proton reaction. It was proposed in [10, 11] and determined by two GPDs contributions. The first preliminary estimations of this reaction at NICA energies were made.

2. Handbag approach. Light meson production

The meson photoproduction mechanism off proton within the handbag approach is shown in Fig. 1. At high Q^2 this amplitude is factorized [1, 2, 3] into a hard subprocess $\mathcal{H}$ and GPDs F. The leading contributions to the proton non-flip amplitude have the form

$$\mathcal{M}_{\mu'+,\mu+} \propto \Sigma_a \int_{-1}^{1} dx \mathcal{H}^a_{\mu'+,\mu+} F^a(x,\xi,t). \tag{1}$$

In the VMP, we have F^a GPDs contributions for gluons, valence and sea quarks. A similar form can be written for the proton spin flip amplitude that is expressed in terms of GPDs E.

The hard subprocess amplitude is calculated within the modified perturbative approach [12]. We consider the power $k_\perp^2/Q^2$ corrections in the propagators of $\mathcal{H}$ together with the

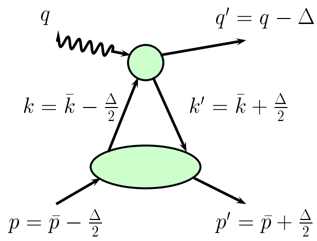

Figure 1. The handbag diagram for the meson photoproduction off proton.

nonperturbative $\mathbf{k}_\perp$-dependent meson wave function [13, 14], see [4, 5, 6] for details. The power $k_\perp^2/Q^2$ corrections can be regarded as an effective consideration of the higher twist effects.

GPDs contain extensive information about the hadron structure. In the forward limit, GPDs are equal to parton distribution functions (PDFs). The GPDs moments are connected with the hadron form factors and contain information on the parton angular momenta (see review [15]).

The model results describe well the energy and Q^2 dependences of the ϕ production cross section from CLAS to HERA energies (see Fig.2, left) [4, 5, 6]. This means that the gluon and sea quark effects, which are essential for ϕ production, are well reproduced. For the ρ production we find good agreement with experiment for $W \geq 5$GeV. One can conclude that we describe properly the valence quark contribution at high energies as well. In Fig.2, right, the W and Q^2 dependences of the ρ production cross section are presented.

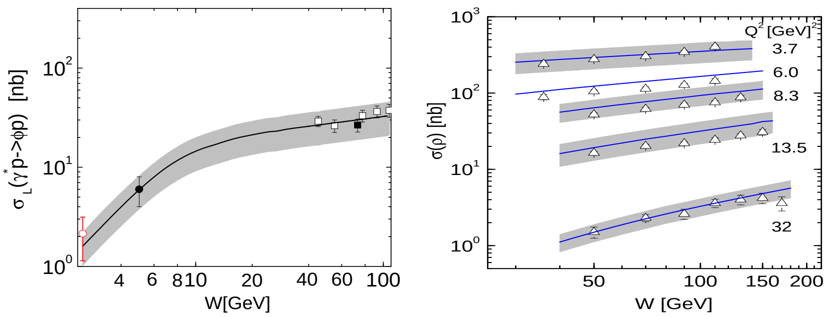

Figure 2. Left: The longitudinal cross section for ϕ at $Q^2 = 3.8\,\mathrm{GeV}^2$. Data: HERMES (solid circle), ZEUS (open square), H1 (solid square), open circle- CLAS data point. Right: The longitudinal cross section for ρ production via W for various Q^2. Data: ZEUS.

In contrast to VMP production, where the leading twist effects are significant, in PMP at intermediate Q^2 the twist-3 transversity effects play an important role [7, 8]. We consider the contributions from the transversity GPDs H_T to the amplitude $M_{0-,++}$ and the $\bar{E}_T$ contribution that determines the $M_{0+,++}$ amplitude. Within the handbag approach the transversity GPDs are accompanied by a twist-3 meson wave function in the hard amplitude $\mathcal{H}$ [7, 8], which is the same for both the $\mathcal{M}^{tw-3}_{0\pm,++}$ amplitudes in (2)

$$\mathcal{M}^{tw-3}_{0-,++} \propto \int_{-1}^{1} d\overline{x}\mathcal{H}_{0-,++}(\overline{x},...)\, H_T(\overline{x},...);\; \mathcal{M}^{tw-3}_{0+,++} \propto \frac{\sqrt{-t'}}{4m}\int_{-1}^{1} d\overline{x}\mathcal{H}_{0-,++}(\overline{x},...)\; \bar{E}_T(\overline{x},...). \tag{2}$$

Details of the calculations and transversity GPDs parameterization can be found in [7, 8, 16]

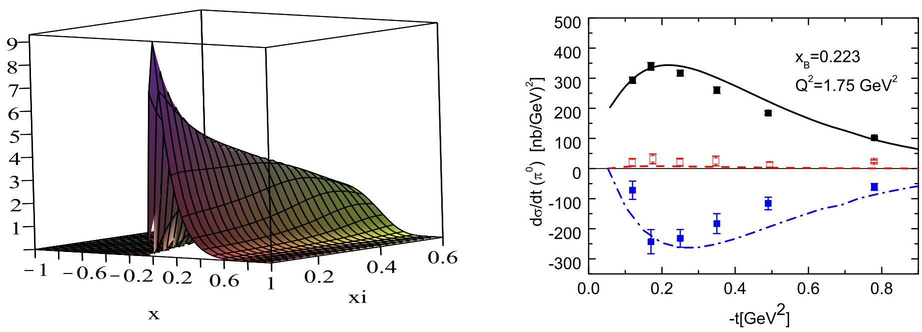

Figure 3. Left: The GPD $\bar{E}_T$ for d quark at $Q^2 \sim 3\,\mathrm{GeV}^2$, $t \sim 0$. Right: π^0 production at CLAS energies together with the data [17]. Full line- $\sigma = \sigma_T + \epsilon\sigma_L$, dashed line-$\sigma_{LT}$, dashed-dotted line- σ_{TT}.

In π^0 production at nonzero momentum transfer at CLAS kinematics the $\bar{E}_T$ contribution is essential. We present an example of this transversity GPD for d quark in Fig. 3, left. In Fig.3, right we show the model results for π^0 cross section together with CLAS data [17], which are well reproduced. Note that at these energies it was shown in [7, 8] that $\sigma_T >> \sigma_L$, which was confirmed by JLAB [18]. The predominant contribution of $\bar{E}_T$ results in the following correlations: $\sigma \sim \sigma_T$ and $\sigma_T \sim -\sigma_{TT}$, which are observed experimentally.

The analyses of the transversity effects in VMP [16] show that they are visible but smaller with respect to the PMP reaction.

3. GPDs in vector meson production at NICA

Let us analyze an opportunity to study meson production at the NICA collider [9]. The NICA detectors should give a possibility to detect an exclusive reaction like $pp \to ppM$ where M is a meson. The meson production mechanism through the photon exchange with virtuality Q^2 is shown in Fig. 4. This contribution is similar to the corresponding process in the lepton-proton reaction shown in Fig. 1.

However, in the proton-proton reaction, a strong interaction contribution should appear in addition to the photon exchange. Estimations show that at NICA the energy $s_1 = (p'_1 + q')^2$ (see Fig. 4) is rather large $s_1 \geq 100\mathrm{GeV}^2$. At such energies the gluon contribution should predominate [4, 5, 6]. Minimum three gluon states can contribute to VMP. Such exchange can be associated with the Odderon contribution. So we have in VMP at NICA the photon contribution and the Odderon effects [19, 20]. Both of these effects are shown in Fig. 4 by the zigzag line. Generally, the Odderon contribution is rather small in most reactions and was not observed experimentally. Thus, the photon channel should dominate in VM production and we can use our estimations for the cross section from section 2.

The usual way to calculate such processes is the decomposition of the $pp \to Vpp$ cross section into the photon flux factor and the $\gamma p \to Vp$ cross section as in the leptoproduction reaction

$$\sigma(pp \to Vpp) = 2\int_{Q_{min}}^{Q_{max}} dQ^2 \Gamma(Q^2)\sigma(\gamma p \to Vp). \tag{3}$$

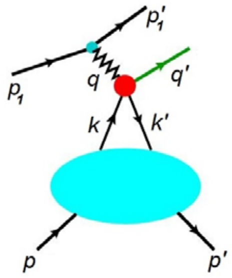

Figure 4. Meson production in hadron reactions. The photon and the strong interaction contributions (Odderon, see the text) are shown by the zigzag line.

Here $\Gamma(Q^2)$ is the known photon flux factor. For the proton- proton reaction it can be found e.g in [21].

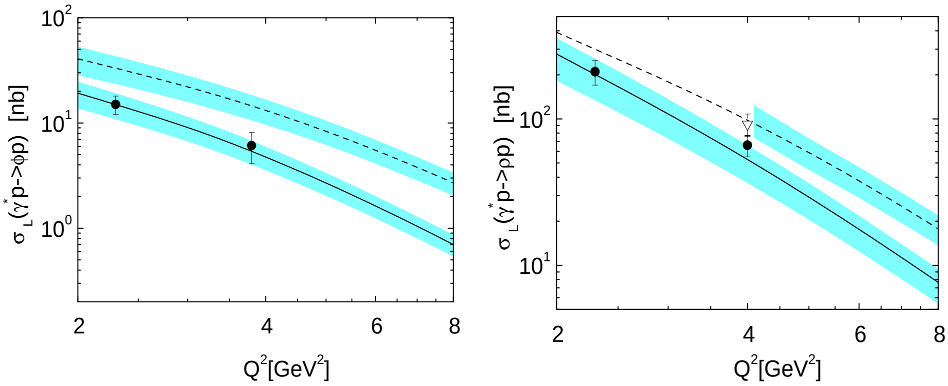

Figure 5. Longitudinal cross section for ϕ (left) and ρ (right). Solid line-$W = 5$GeV, dashed line- $W = 10$GeV. Data from HERMES and E665.

The estimated photon-proton energy $W = \sqrt{s_2 = (q+p)^2}$ at NICA is about $W \sim 5-15$GeV. The longitudinal cross sections for ϕ and ρ production at these energies are shown in Fig. 5. The full cross section will be larger by a factor of ~ 2. For $W \sim 10$GeV the photon channel cross section is about $\sigma_\rho \sim 300$nb and $\sigma_\phi \sim 30$nb [4, 5, 6]. The cross section of ω production, which can be studied at NICA too, is $\sigma_\omega \sim 30$nb [4, 5, 6], similar to σ_ϕ. The VMP cross section is rather large and one can obtain information on GPDs H for gluon, sea and valence quark distributions at the unpolarized NICA. Investigations with longitudinally and transversely proton polarization at the NICA can give information on spin asymmetries in meson production [4, 5, 6]. For a transversely polarized proton beam, the information on GPD E can be obtained from A_{UT} asymmetry

The J/Ψ production can be studied as well. However in this reaction, we are not far from the threshold and the photoproduction cross section at NICA energies is about $\sigma_{J/\Psi} \sim 4$nb.

4. Drell-Yan process with two GPDs contributions

Another possibility to study GPDs in the proton-proton reaction is to study the exclusive Drell-Yan (D-Y) process at the NICA. This process was proposed in [10, 11], where it was shown that the amplitude of the exclusive D-Y reaction is determined by two GPDs. An example of the process that contains the gluon and quark contribution is shown in Fig. 6.

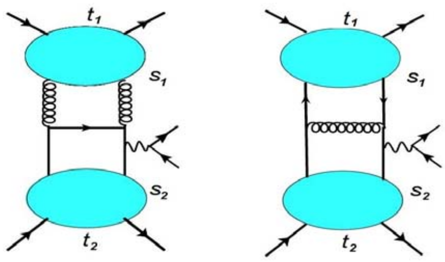

Figure 6. Drell-Yan process with gluon and quark GPDs.

We perform some estimations of the cross section of the exclusive D-Y reaction [22]. It was shown that the gluon and quark sea GPDs lead to the cross section, which does not decrease with energy and this reaction can be studied at high energies. The cross section of the D-Y process decreases rapidly like $(1/Q^2)^3$ with Q^2 growing. As a result, we can study this process at not very high Q^2. Otherwise, to expect the factorization of the exclusive D-Y amplitude into GPDs and a hard subprocess, we should have a sufficiently high Q^2. We chose $Q^2 = 5\mathrm{GeV}^2$ to analyze the exclusive D-Y reaction.

Another serious problem appears in the subprocess amplitude. In some propagators of the amplitude we find a not-integrable double pole [15] like

$$P = \frac{1}{(x_1 - \xi_1)(x_2 - \xi_2) + i\epsilon}. \tag{4}$$

One can regularize it by adding in the denominator the term a^2/Q^2 where a^2 can be an effective mass or transverse momentum correction. Here we use some analytical continuation procedure by replace the P in (4) by

$$P \to \frac{1}{[(x_1 - \xi_1) + i\epsilon][(x_2 - \xi_2) + i\epsilon]}. \tag{5}$$

We estimate the cross section at NICA energies $\sqrt{s} = 24\mathrm{GeV}$ and $Q^2 = 5\mathrm{GeV}^2$ integrated over s_1 and s_2 (see Fig. 7). Both types of regularization give similar results. We have preliminary results for $d\sigma/(dQ^2 dt_1 dt_2)$. It is found that the cross section of the exclusive D-Y process is equal to zero at $t_1 = 0$, $t_2 = 0$. It has a strong maximum at small momentum transfer where the cross section is about $40\mathrm{pb}/\mathrm{GeV}^6$. At higher $-t_1, -t_2$ the cross section decreases exponentially like $\sim \exp(b(t_1 + t_2))$ with $b \sim 5.5\mathrm{GeV}^{-2}$. Integrated over t_1, t_2 the D-Y cross section $d\sigma/dQ^2 \sim 5.5\mathrm{pb}/\mathrm{GeV}^2$. This result is smaller with respect to the cross section of the inclusive D-Y reaction because the investigated contribution is part of the inclusive process. The exclusive D-Y cross section is rather small; however, we hope that it will be possible to observe it at the NICA. This gives a chance to study GPDs at the NICA in the exclusive D-Y production.

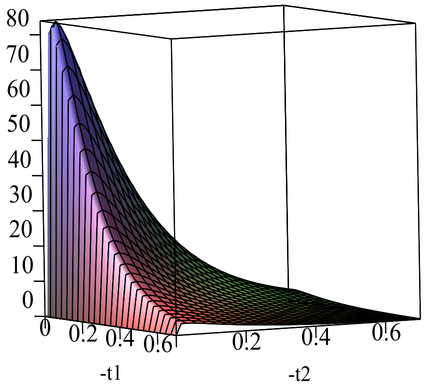

Figure 7. The Drell-Yan cross section $\frac{d\sigma}{dt_1 dt_2 dQ^2}$ with gluon and quark GPDs (in pb/GeV^6).

5. Conclusion

In this report, within the handbag approach we analyze meson photoproduction as an important mechanism to study GPDs in lepton-proton and proton-proton reactions. In the unpolarized case, we can get information on GPDs H from VMP. In the polarized case, we have access to GPDs E from asymmetries.

At NICA enegies we have in VMP the photoproduction mechanism and the Odderon contribution. The last one is expected to be small. In the light VMP at the NICA we can test H and E GPDs contributions. If the J/Ψ production is analysed, it gives information about gluon GPDs.

The exclusive D-Y process with two GPDs contributions is an important test of the GPD model. The D-Y cross section is rather small, but hopefully might be studied at the NICA. Thus, the NICA collider will be a good instrument to study GPDs.

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