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A set of generalized parton distributions

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Summary. — The information about generalized parton distributions (GPDs) extracted from exclusive meson leptoproduction (DVMP) within the handbag approach is summarized. Details are only discussed for the GPD E and the transversity ones. It is also commented on results for deep virtual Compton scattering (DVCS) evaluated from these GPDs.

PACS `13.60.Le` – Meson production.
PACS `13.60.Fz` – Elastic and Compton scattering.
PACS `12.39.St` – Factorization.

1. – Introduction

The handbag approach to hard exclusive leptoproduction of photons and mesons off protons has extensively been studied during the last fifteen years. This approach is based on factorization of the process amplitudes in hard subprocesses, *e.g.* $\gamma^* q \to \gamma(M)q$, and soft hadronic matrix elements parametrized in terms of GPDs. This factorization property has been shown to hold rigorously in the generalized Bjorken regime of large photon virtuality, Q, and large energy W but fixed x_B. Since most of the data, in particular those from the present Jlab, are not measured in this kinematical regime one has to be aware of power corrections from various sources. Which kind of power correction is the most important one and is to be taken into account is still under debate. Nevertheless progress has been made in the understanding of the DVCS and DVMP data. In this talk, presented at QCD'N12 and SPIN12 (see [1]), I am going to report on an extraction of the GPDs from DVMP [2]. In this analysis the GPDs are constructed from double distributions (DDs) [3,4] where the latter are parametrized as zero-skewness GPDs times weight functions which generate their skewness dependence. The ansätze for the zero-skewness GPDs consist of their corresponding forward limits multiplied by exponentials in Mandelstam t with profile functions parametrized in a Regge-like manner with slopes of appropriate Regge trajectories and constants for the t dependence of their residues. These profile functions are simplified versions of more complicated ones proposed in [5]. At small momentum fractions, x, they fall together with the ones used in [5]. Because of a strong $x-t$ correlation observed in [5] the Regge-like profile functions can only be applied at small $-t$. The forward limits of the zero-skewness GPDs are in some cases (H, $\widetilde{H}$, H_T) given by the usual parton densities, in other cases (for the E-type ones) they are parametrized like the parton densities with a number of free parameters adjusted to experiment.

In sect. **2** some details on the extraction of the GPDs are presented. In sect. **3** E is discussed and in sect. **4** the transversity GPDs. A summary is given in sect. **5**.

2. – Extraction of the GPDs from hard meson leptoproduction

As an example we quote the convolution formula for the production of longitudinally polarized vector mesons:

$$\mathcal{F}_{\rm V}(\xi,t,Q^2)=\sum_{i,\lambda}\int_{x_i}^{1}\mathrm{d}x\mathcal{A}^i_{0\lambda,0\lambda}(x,\xi,Q^2,t=0)\,F^i(x,\xi,t), \tag{1}$$

where $i=g,q$, $x_g=0$, $x_q=-1$ and F either H or E. Similar convolution formulas hold for transversely polarized vector mesons and for pseudoscalar mesons. The subprocess amplitude $\mathcal{A}$ for partonic helicity λ is to be calculated perturbatively using $k_\perp$-factorization. This means that in the subprocess quark transverse degrees of freedom as well as Sudakov suppression [6] are taken into account. The emission and reabsorption of the partons by the protons are treated collinearly. This approach also allows to calculate the amplitudes for transversely polarized photons and like-wise polarized vector mesons which are infrared singular in collinear factorization. The transverse photon amplitudes are rather strong for $Q^2\leq 10\,\mathrm{GeV}^2$ as is known from the ratio of longitudinal and transverse cross sections for ρ^0 and ϕ production [7]. The approach used in [2] bears similarity to the color dipole model [8].

There is another problem with vector meson production: In collinear factorization the cross section for the production of ρ^0 drops as $1/Q^6(\log Q^2)^n$ with increasing Q^2 while experimentally [7] it approximately falls as $1/Q^4$. In the above sketched approach the required suppression of the amplitudes at low Q^2 is generated by the evolution of the GPDs and by $k_\perp/Q$ effects. In [9] however GPDs are proposed which have a much stronger evolution than those used in [2]. At least for HERA kinematics the GPDs advocated for in [9] lead to fair fits of the HERA data on DVMP in collinear factorization.

In [2] parameters of the DDs are fitted to the available data on ρ^0, ϕ and π^+ production from HERMES, COMPASS, E665, H1 and ZEUS. The data cover a large kinematical range: $3\,\mathrm{GeV}^2\leq Q^2\leq 100\,\mathrm{GeV}^2$, $4\,\mathrm{GeV}\leq W\leq 180\,\mathrm{GeV}$, *i.e.* Bjorken-$x$ and, hence, skewness, is small. Data from the present Jlab (characterized by large x_B and small W) are not taken into account in these fits because they are likely affected by strong power corrections at least in some cases (*e.g.* ρ^0 production). Constraints from nucleon form factors and from positivity bounds [5] are taken into account. The analysis is strongly simplified by the fact that, for small x_B, the ρ^0 and ϕ cross sections are under control of contributions from the GPD H, other GPDs can be ignored. Since H is rather well fixed by many constraints (PDFs, nucleon form factors) the vector meson cross sections allow to pin down the remaining few free parameters of H. All other GPDs are much less well known than H. Their extraction requires polarization observables or hard leptoproduction of pseudoscalar mesons. The latter process is however complicated to

Table I. – *Status of small-skewness GPDs as extracted DVMP. No information is presently available on GPDs not appearing in the table. Except of H for gluons and sea quarks all GPDs are only probed for scales of about* $4\,\mathrm{GeV}^2$. *For comparison five stars are assigned to PDFs.*

GPD	Probed by	Constraints	Status
H(val)	ρ^0, ϕ cross sections	PDFs, Dirac ff	***
H(g,sea)	ρ^0, ϕ cross sections	PDFs	***
E(val)	$A_{UT}(\rho^0,\phi)$	Pauli ff	**
E(g,sea)	-	sum rule for 2nd moments	-
$\widetilde{H}$ (val)	π^+ data	pol. PDFs, axial ff	**
$\widetilde{H}$(g,sea)	$A_{LL}(\rho^0)$	polarized PDFs	*
$\widetilde{E}$ (val)	π^+ data	pseudoscalar ff	*
$H_T, \bar{E}_T$(val)	π^+ data	transversity PDFs	*

analyze since many GPDs contribute at the same level. The analysis performed in [2] leads to a fair description of all the mentioned data. What has been learned about the GPDs from this analysis is summarized in table I. For details of the parametrization and values of the parameters it is referred to [2, 10, 11].

In [11] the GPDs extracted in [2] have been exploited to compute DVCS to leading-twist accuracy and leading-order of pQCD while the Bethe-Heitler contribution is worked out without any approximation. It should be realized that, to this level of accuracy, collinear emission and reabsorption of the partons from the protons forces the partonic subprocess of DVCS to be collinear as well. A detailed comparison of this theoretical approach with experiment performed in [11], reveals reasonable agreement with HERMES, H1 and ZEUS data and a less satisfactory description of the large-skewness, small W Jlab data (see talk by F. Sabatie this conference). Note that the GPDs extracted in [2] are not optimized for the latter kinematical region. It should also be mentioned that in the same spirit a DVCS analysis is performed in [9, 12].

3. – The GPD E

Let me now discuss the GPD E in some detail. The analysis of the nucleon form factors carried through in [5] provided the zero-skewness GPDs for valence quarks which can be used to construct the DDs. Since in 2004 data on the neutron form factors were only available for $-t \le 2\,\mathrm{GeV}^2$ the parameters of the zero-skewness GPD E_v^q were not well fixed; a wide range of values were allowed for the powers β_e^u and β_e^d which control the large-x behavior of the forward limits of E_v^q. In the recent reanalysis of the form factors [13] making use of all new data which for the neutron now extend to much larger values of t, similar results for the valence-quark GPDs are obtained but the powers β_e^q are now better determined.

Not much is known about E^g and E^{sea}. There is only a sum rule for the second moments of E [14] at $t = \xi = 0$

$$\int_0^1 \mathrm{d}x E^g(x, \xi = 0, t = 0) = e_{20}^g = -\sum e_{20}^{q_v} - 2\sum e_{20}^{\bar{q}}. \tag{2}$$

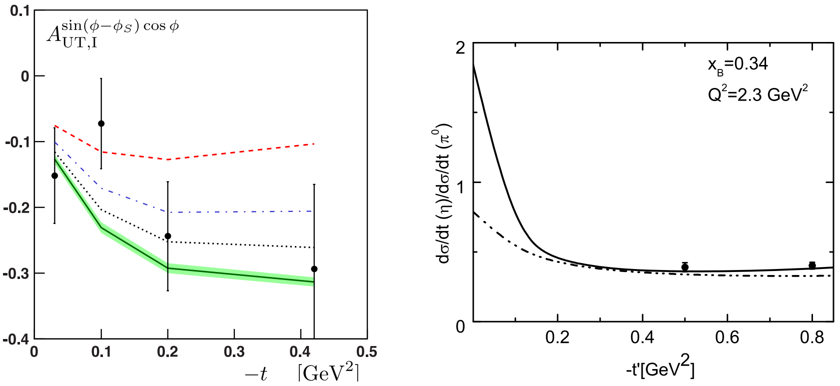

Fig. 1. – Left: The BH-DVCS interference. Data are taken from [18], theoretical results from [11]. Right: The ratio of the η and π^0 cross sections *versus* t'. Preliminary data are taken from [29].

It turns out that the valence contribution to the sum rule is very small [5,13]. Hence, the second moments of the gluon and sea-quark GPD E cancel each other almost completely. For parametrizations of the forward limits of E which do not have nodes except at the end-points (see, *e.g.*, [15]) this property approximately holds of other moments as well and even for convolutions like (1). For E^s there is also a positivity bound for its Fourier transform with respect to the momentum transfer [5,14,15] which forbids a large strange quark contribution and, assuming a flavor-symmetric sea, a large gluon contribution too. Determining the normalization of E^s by assuming that the bound for it is saturated for some values of x (note the bound is quadratic in e_s), one can subsequently fix the normalization of E^g from the sum rule (2) [15].

For given H, as for instance extracted from the DVMP cross sections [2], the GPD E is probed by the transverse target asymmetry

$$A_{UT} \sim \mathrm{Im}\Big[\mathcal{E}^*\mathcal{H}\Big]. \tag{3}$$

The data on ρ^0 production from HERMES [16] and COMPASS [17] are well fitted by the described parametrization of E. However, only E for valence quarks matters for $A_{UT}(\rho^0)$ since the sea and gluon contribution to E cancel to a large extent as remarked above. Fortunately the analysis of DVCS data [11] provides additional although not very precise information on E^{sea}. To leading-order of pQCD there is no gluon contribution in DVCS and therefore E^{sea} becomes visible. The HERMES Collaboration has measured the transverse target asymmetries for DVCS and for the BH-DVCS interference term [18]. Despite the large experimental errors it seems that a negative E^{sea} is favored. As an example the data on the BH-DVCS interference are shown in fig. 1 and compared to the results obtained in [11]. Independent information on E^g would be of interest. This may be obtained from a measurement of the transverse target polarization in J/Ψ photoproduction [19].

The knowledge of E which is admittedly poor, allows for an estimate of the angular momenta the partons inside the proton carry. At $\xi = t = 0$ they are given by the second moments of H and E

$$2J^a = \Big[q_{20} + e^q_{20}\Big], \qquad 2J^g = \Big[g_{20} + e^g_{20}\Big]. \tag{4}$$

The values of the H-moments can be evaluated from the PDFs, for instance from [20]. Since a negative E^s is favored as we learned from the combined analysis of DVMP and DVCS, E^g is positive (remember the no node assumption). Therefore, the second moment of the latter, e^g_{20}, is positive and adds to g_{20} which is large and positive as is known for a long time (it represents the fraction of the proton momentum carried by gluons). From these considerations it follows that the total angular momentum carried by the gluons is large as well. According to [15], it amounts to $J^g = 0.21$–0.29.

4. – The transversity GPDs

There is a second set of four GPDs, the transversity ones which are characterized by opposite helicities of the emitted and reabsorbed partons. In general they play a minor role in exclusive reactions and not many phenomenological studies are devoted to them (an example is [21]). However, it became evident recently that the transversity GPDs contribute strongly to leptoproduction of pseudoscalar mesons [10, 22, 23]. The first experimental evidence for transversity came from the $\sin\phi_s$ harmonics of the π^+ production cross section measured with a transversely polarized target [24]. From these data we learned that this observable is large and does not seem to vanish for forward scattering. Such a behavior requires a strong helicity non-flip amplitude for transversely polarized virtual photons. Within the handbag approach this amplitude is under control of the transversity GPD H_T in combination with a twist-3 pion wave function [22]. This amplitude is parametrically suppressed by μ_π/Q as compared to the asymptotically dominant amplitude for longitudinal polarized photons. Here, $\mu_\pi = m_\pi^2/(m_u + m_d) \simeq 2\,\text{GeV}$ at the scale of $2\,\text{GeV}$ where m_q is a current quark mass. Hence, this twist-3 effect is quite large for experimentally accessible values of Q. Moreover lattice QCD [25] provides some evidence of a large GPD $\bar{E}_T = 2\widetilde{H}_T + E_T$ with the same sign and almost the same size for $\bar{E}^u_T$ and $\bar{E}^d_T$. Both the GPDs, H_T and $\bar{E}_T$ are parametrized in an analog fashion than the other GPDs and their parameters are fixed by fits to the HERMES π^+ data [24, 26] and by taking recourse to the lattice-QCD results. With the GPDs determined this way, the behavior of the transverse target asymmetry can be understood quantitatively and predictions for the productions of the π^0 and other pseudoscalar mesons have been given [10]. It turns out that the π^0 cross section is dominated by the contributions from the transversity GPDs except in the near forward region; the ratio of the longitudinal and transverse cross sections is much smaller than 1 for $Q^2 \leq 10\,\text{GeV}^2$. The results for π^0 production are in fair agreement with the large Bjorken-x (small W) data from CLAS [27]. Another interesting prediction is that the ratio of the η and π^0 cross sections is much smaller than 1 (except in the near forward region) in sharp contrast to expectations [28]. Also this result which is shown in fig. 1, is in reasonable agreement with preliminary CLAS data [29].

5. – Summary

I have briefly summarized the recent progress in the analysis for hard exclusive leptoproduction of mesons and photons within the handbag approach. We learned that the data on both reactions are consistent with each other in so far as they can be described with a common set of GPDs. In fact the GPDs constructed from double distributions and with parameters adjusted to the meson data allow for a parameter-free calculation of DVCS.

Of course the GPDs are not perfect, they are an approximation. Improvements are required for which the future COMPASS and Jlab12 will be of help. Possible improvements may include the use of more recent versions of the PDFs, eventual modifications of the parametrizations of the GPDs, in particular of the profile functions of the corresponding double distributions, and allowance for a non-zero D-term. Updated zero-skewness GPDs H and E for valence quarks have already been obtained from the recent analysis of the nucleon form factors [13]. These result are not yet used in evaluations of the DVCS and meson leptoproduction observables.

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