Hard Electroproduction of Vector Mesons

Peter Kroll
Universität Wuppertal - Fachbereich Physik
D-42097 Wuppertal - Germany

It is reported on a global analysis of hard vector-meson electroproduction which is
based on the handbag factorization. The generalized parton distributions are con-
structed from their forward limits with the help of double distributions and the partonic
subprocesses are calculated within the modified perturbative approach.

In this talk I am going to report on an ongoing analysis [1, 2, 3] of hard electroproduction
of light vector mesons within the handbag approach which is based on QCD factorization
into hard subprocesses and generalized parton distributions (GPDs) encoding the soft, non-
perturbative physics. As is well-known the leading-twist contribution (i.e. employing the
collinear approximation) evaluated to leading-order of perturbative QCD, overestimates the
cross section for the processes of interest drastically at photon virtualities, $Q^2$, of about
10 GeV$^2$. This effect diminishes with increasing $Q^2$ but the predictions to leading-twist
accuracy are still larger than experiment [4] at, say, 100 GeV$^2$, see dashed line in Fig. 1.

As shown in Ref. [7] the next-to-leading-order QCD corrections are very large. How-
ever a recent attempt [8] to resum higher orders seems to indicate that the sum of all
higher order corrections is not large. In view of this unsettled situation it seems to be rea-
sonable to simply use the leading order and add power corrections to it. To do so we
calculated in our previous work [1, 2, 3] the quark ($\gamma^* q \rightarrow V q$) and gluon ($\gamma^* g \rightarrow V g$)
subprocess amplitudes within the modified perturbative approach [9] in which quark
transverse degrees of freedom as well as Sudakov suppressions are taken into account.
This approach allows to calculate not only the asymptotically dominant (longitudinal)
amplitude for $\gamma^*_L p \rightarrow V_L p$ but also the one for transversely polarized photons and vec-
tor mesons ($\gamma^*_T p \rightarrow V_T p$). In constrast to the longitudinal amplitude the latter one
cannot be calculated in collinear approxi-

mation since it suffers from infrared singularities [10, 11]. The quark transverse momenta,
k$_T$, provide an admittedly model-dependent regularization scheme of these singularities by
replacements of the type

$$\frac{1}{dQ^2} \rightarrow \frac{1}{dQ^2 + k_T^2}$$

in the parton propagators. Here, $d$ is a momentum fraction or a product of two. The
kinematical region considered in [1, 2, 3] is characterized by small skewness ($\xi \leq 0.1$) and

---

**Figure 1**: The cross section for $\rho^0$ production at $W = 90$ and 75 GeV (the latter is divided
by 10). Data taken from ZEUS [4, 5] (open triangles and squares) and H1 [6] (solid squares).
The shaded bands indicate the uncertainties of the theoretical results.
small invariant momentum transfer \((-t \leq 0.5 \text{GeV}^2)\) but large photon virtuality \((Q^2 \geq 3 \text{GeV}^2)\) and large energy in the photon-proton c.m.s. \((W \geq 5 \text{GeV})\). In this kinematical region the dominant helicity amplitudes for the process \(\gamma^* p \rightarrow V p\) are given by

\[
\mathcal{M}_{\mu^+,\mu^+}^V = \frac{e}{2} \sum_a e_a C_{V}^a \left\{ \langle H \rangle_{V \mu}^a + \langle H \rangle_{\bar{V} \mu}^a + \langle \bar{H} \rangle_{V \mu}^a + \langle \bar{H} \rangle_{\bar{V} \mu}^a \right\},
\]

\[
\mathcal{M}_{\mu^-,\mu^+}^V = -\frac{e}{2} \sqrt{-t} \sum_a e_a C_{V}^a \left\{ \langle E \rangle_{V \mu}^a + \langle E \rangle_{\bar{V} \mu}^a \right\},
\]

in which some simplifications, relevant for the small \(\xi\) region, have been used. Explicit helicity labels refer to the proton while \(\mu\) denotes the helicity of the photon and the vector meson. The quark flavors are denoted by \(a\) and \(e_a\) is the corresponding charge. The non-zero flavor weight factors read for the vector mesons of interest

\[
C^u = -C^d = C^s = \frac{1}{\sqrt{2}}, \quad C^\phi = 1.
\]

The terms \(\langle F \rangle\) denote convolutions of subprocess amplitudes and GPDs \(F = H, E, \bar{H}\). Explicitly they read \((i = g, a, x_g = 0, x_a = -1)\)

\[
\langle F \rangle_{iV}^i = \sum_\lambda \int_{x_1}^1 dx \mathcal{H}_{\mu^+,\mu^+}^i(x, \xi, Q^2, t = 0) F^i(x, \xi, t).
\]

The helicity of the partons participating in the subprocess, is labelled by \(\lambda\). Note that \(\langle \bar{H} \rangle_{V \bar{V}}^0\). The subprocess amplitudes \(\mathcal{H}\) are calculated in the impact parameter space

\[
\mathcal{H}_{\mu^+,\mu^+}^i = \int d\tau d^2b \hat{\Psi}_{V \mu}(\tau, -b) \hat{F}_{\mu^+,\mu^+}^i(x, \xi, \tau, Q^2, b) \alpha_S(\mu_R) \exp[-S(\tau, b, Q^2)].
\]

Its \(t\) dependence is neglected for consistency since it provides corrections of order \(t/Q^2\) which are generally neglected. On the other hand, the \(t\) dependence of the GPDs is taken into account since in them \(t\) is scaled by a soft parameter. The hard scattering kernels \(\hat{F}\), or their respective Fourier transform \(\mathcal{F}\), are calculated to leading-order of perturbative QCD including quark transverse momenta. The explicit expressions can be found in [1 2 3]. Also for the Sudakov factor \(S\) in [4], the renormalization (\(\mu_R\)) and factorization (\(\mu_F\)) scales it is referred to these articles.

For the light-cone wave function \(\Psi\) Gaussians in the quark transverse momenta are used \((\Psi \sim \exp[-a_{Vj}^2 k^2_\perp/(\tau(1 - \tau))]\) with transverse size parameters \(a_{Vj}\) fitted to experiment. Here, \(j\) refers to either longitudinally or transversally polarized vector mesons and \(\tau\) is the momentum fraction of the quark entering the meson.

For the cross sections of \(\gamma^* p \rightarrow V p\) measured with unpolarized protons, only the GPD \(H\) is to be considered, the contributions from the other two GPDs can be neglected. The GPD \(H\) is constructed from the CTEQ6 parton distributions [12] using the familiar double distribution ansatz. Figure 1 compares the predictions for the longitudinal cross section of \(\rho^0\) production with the HERA data [4 5 6]. Satisfactory agreement between theory and experiment is achieved. Another example of results, namely the ratio of longitudinal and transverse cross sections is shown in Fig. 2. Again good agreement is to be seen. For a detailed comparison of the results with the data on \(\rho^0\) and \(\phi\) production from HERA, FNAL, COMPASS and HERMES can be found in [2 3]. The predicted cross section for \(\phi\)
Figure 2: The ratio of longitudinal and transversal cross section for $\rho^0$ production at $W = 90$ (left) and 75(10, 5) GeV (right) shown as solid (dash-dotted, dashed) lines. Preliminary data from HERMES [13] and COMPASS [14] are shown as solid circle and diamond, respectively. For further notation refer to Fig. 1.

production is even in agreement with recent data from CLAS [15] in spite of the fact that $W$ lies outside of our presupposed range of kinematics.

From the results shown in Figs. 1 and 2 it is obvious that the magnitudes of both the longitudinal and transverse amplitudes, are correctly predicted. Their relative phase can be tested by the spin density matrix elements $\text{Re} r_{10}^5$ and $\text{Im} r_{10}^6$. It turns out that the proposed handbag approach predicts a relative phase of about $3^\circ$ while experiment requires a much larger phase although with strong fluctuations ($10^\circ$–$30^\circ$). Whether the model for the transverse amplitude, which represents a power correction to the leading longitudinal one, is inadequate for this detail needs further investigation. However, that the sum $\text{Re} r_{10}^5 + \text{Im} r_{10}^6$ amounts to only $1\%$ of the corresponding difference of these SDME makes it clear that the neglected helicity flip $\gamma^* \rightarrow V$ transitions are not responsible for the observed conflict.

The roles of the GPDs $\tilde{H}$ and $E$ can only be explored with polarization data where interference terms between $H$ and $\tilde{H}$ or $E$ are probed. Analogously to $H$ one may also construct $\tilde{H}$ and $E$ from their forward limits with the double distribution ansatz. In the case of $\tilde{H}$ the forward limit is given by the polarized parton distributions while the forward limit of $E$ has been determined from the data on the Pauli form factor of the nucleon in an analysis of the zero-skewness GPDs [16]. Evaluating these GPDs it turns out that both these GPDs are dominated by the valence quark contributions while the sea and the gluon contributions seem to be small [3, 7]. This feature is to be contrasted with the behavior of $H$ where the gluon plays the most prominent role (except at very large $x$). A consequence of these characteristics is that polarization effects like the initial state helicity correlation $A_{LL}$ or the target asymmetry $A_{UT}$ are generally small and disappear with increasing energy. Particularly small are such observables for $\phi$ production since the valence quarks of the proton do not contribute to this process. Also small but clearly non zero effects are obtained for $\rho^0$ production. As an example the target asymmetry, measuring the imaginary part of the interference between the proton helicity flip and non-flip amplitudes and, hence, between $H$ and $E$ (see Eq. (1)) is shown in Fig. 3. Larger ef-
ffects are found for \( \omega \) production since the sum \( e_u F^u_{\text{val}} + e_d F^d_{\text{val}} \) of the GPDs \( \tilde{H} \) or \( E \) occurs (see Eq. (2)) and not the difference as for \( \rho^0 \) production. Given that \( F^u_{\text{val}} \) and \( F^d_{\text{val}} \) have opposite signs which follows from the known lowest moments of their forward limits (see the discussion in [3]) the mentioned sum of both is much larger than their difference.

A preliminary HERMES result [17] for \( \rho \) production, integrated on the range \( 0 \leq -t \leq 0.4 \text{ GeV}^2 \), is \(-0.033 \pm 0.058\) at \( Q^2 = 3.07 \text{ GeV}^2 \) and \( W = 5 \text{ GeV} \) while a value of \(-0.02 \pm 0.01\) for this kinematical situation is found in [3].

In summary - the handbag approach proposed in [1, 2, 3] which consists of GPDs constructed from double distributions, Gaussian wave functions for the vector meson and power corrections generated from quark transverse momenta in the subprocess describes the data on light vector meson electroproduction measured by HERMES, COMPASS, FNAL and HERA over a wide range of kinematics. While the GPD \( H \) is well fixed by the existing data the other GPDs are not severely constrained as yet. More polarization data are required here.

Figure 3: The asymmetry \( A_{UT} \), scaled by \(-2m/\sqrt{-t}\), for \( \rho^0 \) production versus \( Q^2 \) at \( W = 5 \text{ GeV} \) and evaluated at \( t = 0 \). The dashed line represents the leading-twist contribution.

References

[1] S. V. Goloskokov and P. Kroll, Eur. Phys. J. C42, 281 (2005);
[2] S. V. Goloskokov and P. Kroll, Eur. Phys. J. C50, 829 (2007).
[3] S. V. Goloskokov and P. Kroll, Eur. Phys. J. C53, 367 (2008).
[4] S. Chekanov [ZEUS Collaboration], PMC Phys. A1, 6 (2007).
[5] J. Breitweg et al. [ZEUS Collaboration], Eur. Phys. J. C6, 603 (1999).
[6] C. Adloff et al. [H1 Collaboration], Eur. Phys. J. C13, 371 (2000).
[7] M. Diehl and W. Kugler, Eur. Phys. J. C52, 933 (2007).
[8] D. Yu. Ivanov, Proc. EDS07, Hamburg (2007).
[9] J. Botts and G. Sterman, Nucl. Phys. B 325, 62 (1989).
[10] L. Mankiewicz and G. Piller, Phys. Rev. D 61, 074013 (2000).
[11] I. V. Anikin and O. V. Teryaev, Phys. Lett. B 554, 51 (2003).
[12] J. Pumplin et al., JHEP 0207, 012 (2002).
[13] A. Borissov [HERMES Collaboration], Proc. "Diffraction 06", PoS (DIFF2006) 014.
[14] D. Neyret [COMPASS collaboration] preliminary data presented at SPIN2004, Trieste.
[15] J.P. Santora et al. [arXiv:0803.3537]
[16] M. Diehl, T. Feldmann, R. Jakob and P. Kroll, Eur. Phys. J. C 39, 1 (2005).
[17] A. Rostomyan [HERMES Collab.], Proc. "DIS 2007", World Scientific, Singapore, 2007.