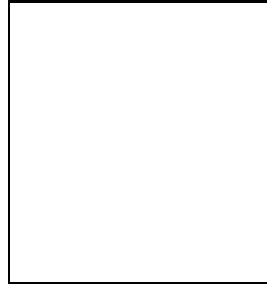


**XIth International Conference on
Elastic and Diffractive Scattering
Château de Blois, France, May 15 - 20, 2005**

ϕ MESON ELECTROPRODUCTION AT SMALL BJORKEN- x

P. Kroll

*Fachbereich Physik, Universität Wuppertal,
D-42097 Wuppertal, Germany*



It is reported on an analysis of ϕ -meson electroproduction at small Bjorken- x (x_{Bj}) within the handbag approach. The amplitudes factorize into generalized parton distributions (GPDs) and a partonic subprocess, electroproduction off gluons. Cross sections and spin density matrix elements (SDMEs) are evaluated for ϕ -meson electroproduction and found to be in fair agreement with recent HERA data.

It has been shown¹ that, at large photon virtuality Q^2 , meson electroproduction factorizes into a partonic subprocess, electroproduction off gluons or quarks, $\gamma^*g(q) \rightarrow Mg(q)$, and GPDs, representing soft proton matrix elements (see Fig. 1). At small x_{Bj} and in particular for ϕ -meson production the quark subprocesses can be ignored and only the gluonic subprocess, $\gamma g \rightarrow \phi g$, contributes. In the following I am going to report on an analysis² of ϕ -meson electroproduction within this handbag approach carried through in the kinematical regime of large Q^2 and large energy W in the photon-proton c.m.s. but small x_{Bj} and Mandelstam t .

The structure of the proton is rather complex. In correspondence to its four form factors there are four gluon GPDs H^g , E^g , \tilde{H}^g and \tilde{E}^g and four for each quark flavour. All GPDs are functions of three variables, t , skewness ξ and the average momentum fraction \bar{x} , the latter two are defined by (see Fig. 1)

$$\xi = \frac{(p - p')^+}{(p + p')^+}, \quad \bar{x} = \bar{k}^+ / \bar{p}^+. \quad (1)$$

The skewness is kinematically fixed to $\xi \simeq x_{Bj}/2$ in a small x_{Bj} approximations and in the γ^*p

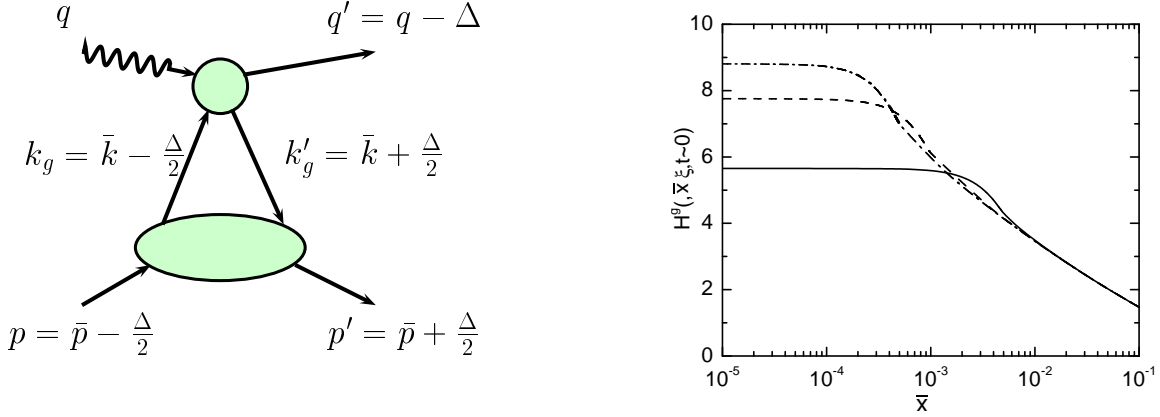


Figure 1: Left: The handbag diagram for meson electroproduction off protons. The large blob represents a GPD while the small one stands for the subprocess. Particle momenta are specified. Right: The GPD H^g at $t \simeq 0$. The solid (dashed, dash-dotted) line represents the GPD at $\xi = 5$ (1, 0.5) $\cdot 10^{-3}$ and at a scale of 2 GeV.

c.m.s. This is to be contrasted with the frequently used leading $\log(1/x_{\text{Bj}})$ approximation³ where $\xi = 0$ and $\bar{x} = x_{\text{Bj}}$ is assumed and the GPD replaced by the usual gluon distribution $g(\bar{x})$.

The handbag approach leads to the following proton helicity non-flip amplitude

$$M_{\mu'+, \mu+}^{\phi} = -\frac{e}{6} \int_0^1 \frac{d\bar{x}}{(\bar{x} + \xi)(\bar{x} - \xi + i\varepsilon)} [H_{\mu'+, \mu+}^{\phi} + H_{\mu'-, \mu-}^{\phi}] H^g(\bar{x}, \xi, t). \quad (2)$$

Contributions from other GPDs can be neglected at small x_{Bj} and for unpolarized protons. The photon and meson helicities are denoted by μ and μ' , respectively. The explicit labels in the full (subprocess) amplitude, M^{ϕ} (H^{ϕ}), refer to the helicities of the protons (gluons).

The GPDs are controlled by non-perturbative QCD. In the absence of a GPD analysis in analogy to those of the usual PDFs (see however Ref.⁴) one has to rely on a model. Following other authors we restrict ourselves to the forward direction and exploit the ansatz for a double distribution proposed in Ref.⁵ ($n = 1, 2$)

$$f(\beta, \alpha, t \simeq 0) = g(\beta) \frac{\Gamma(2n+2)}{2^{2n+1} \Gamma^2(n+1)} \frac{[(1-|\beta|)^2 - \alpha^2]^n}{(1-|\beta|)^{2n+1}}. \quad (3)$$

The GPD is then obtained by an integral over f

$$H^g(\bar{x}, \xi) = \left[\Theta(0 \leq \bar{x} \leq \xi) \int_{x_3}^{x_1} d\beta + \Theta(\xi \leq \bar{x} \leq 1) \int_{x_2}^{x_1} d\beta \right] \frac{\beta}{\xi} f(\beta, \alpha = \frac{\bar{x} - \beta}{\xi}). \quad (4)$$

Using the NLO CTEQ5M⁶ results on the gluon distribution as input one obtains the GPD H^g shown in Fig. 1. While the double-distribution ansatz guarantees polynomiality of the moments of H , positivity is not automatically satisfied. It can however be checked that the positivity bounds are respected by the model (3), (4) in the ξ and \bar{x} range of interest. Inspired by the Regge model one may generalize to non-zero but small t by a factor $\exp[(\alpha' \ln(1/\beta) + b_0)t]$ in (3) where α' is the slope of the Pomeron trajectory. The investigation of this t dependence is left to a forthcoming publication.

The last item of the amplitude (2) to be discussed is the subprocess amplitude. Its treatment is rather standard, it only differs in detail from versions to be found in the literature^{7,8}. In the modified perturbative approach invented by Serman and collaborators⁹, in which quark transverse momenta are retained and gluonic radiative corrections in the form of a Sudakov

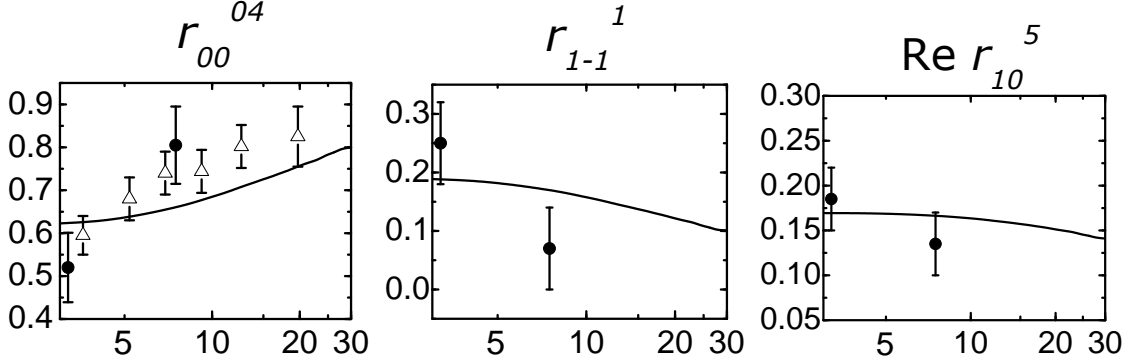


Figure 2: Spin density matrix elements of electroproduced ϕ mesons versus Q^2 at $W \simeq 75$ GeV and $t \simeq -0.15$ GeV². The solid lines are the predictions given in Ref. ². Data taken from Ref. ¹⁰ (●) and ¹² (Δ).

factor are taken into account, it reads

$$\mathcal{H}^\phi = \int \frac{d\tau dk_\perp^2}{\sqrt{2}16\pi^2} \Psi_\phi \text{Tr} \left\{ (\not{d}' + m_\phi) \epsilon_\phi^* T_0 - \frac{k_\perp^2 g_\perp^{\alpha\beta}}{2M_\phi} \{ (\not{d}' + m_\phi) \epsilon_\phi^*, \gamma_\alpha \} \Delta T_\beta \right\}. \quad (5)$$

Higher order terms in this expansion are not shown. Gaussians for the meson wavefunctions, $\Psi_\phi = \Psi_\phi(\tau, k_\perp^2)$, are used which may depend on the polarization of the vector meson. The first term in (5) dominates for ϕ_L while it is approximately zero for transversally polarized vector mesons (ϕ_T). The second term dominates in this case. The soft physics parameter M_ϕ in the second term of Eq. (5) is of order of the vector meson mass m_ϕ . As can be seen from Eq. (5) the $L \rightarrow L$ transition is dominant while the $T \rightarrow T$ one is of relative order $\langle k_\perp^2 \rangle^{1/2}/Q$ and the $T \rightarrow L$ one of order $\sqrt{-t}/Q$. The latter amplitude is tiny and only noticeable in some of the SDMEs. All other transitions are negligible.

Before comparing the results to experiment a comment is in order on the t dependence of the amplitudes. Exponentials in t are assumed with slopes $B_{LL(TT)}^\phi$ taken from experiment. In combination with the calculated forward amplitudes one can thus evaluate the integrated cross sections and the SDME for small t . From (5) one sees that the size of the $T \rightarrow T$ amplitude is controlled by the following product of parameters (f_T^ϕ denotes the corresponding decay constant)

$$|M_{TT}^\phi| \propto \left(\frac{f_T^\phi}{M_\phi} \right)^2 \frac{1}{B_{TT}^\phi}. \quad (6)$$

Since the available data do practically not allow for an independent determination of the slope B_{TT}^ϕ , only this product is probed. Only the SDMEs are slightly sensitive to the value of B_{TT}^ϕ . All values of this slope lying in the range from about $B_{LL}^\phi/2$ up to about B_{LL}^ϕ lead to fair agreement with the present data ^{10,11,12}.

In Fig. 2 a selection of SDMEs is shown and the results obtained in Ref. ² are compared to experiment ^{10,12}. Results for the integrated cross section σ_L are displayed and compared to data in Fig. 3. The GPD approach as detailed in Ref. ², can in principle also be applied to electroproduction of ϕ mesons for COMPASS kinematics where W is much smaller than at HERA. Contributions from the quark GPDs are expected to be very small due to the mismatch of the ϕ and proton valence quarks. Even for HERMES kinematics the quark contribution is likely tiny. As an example the initial state helicity correlation A_{LL} is shown in Fig. 3 which measures an interference term between the contribution from the GPD H^g (see Eq. (5)) and a similar one from the GPD \tilde{H}^g . The latter contribution is negligible in the cross sections and SDMEs, the relative size of \tilde{H}^g and H^g is approximately given by the ratio of the polarized and unpolarized gluon distributions. The smallness of this ratio leads to small values of the

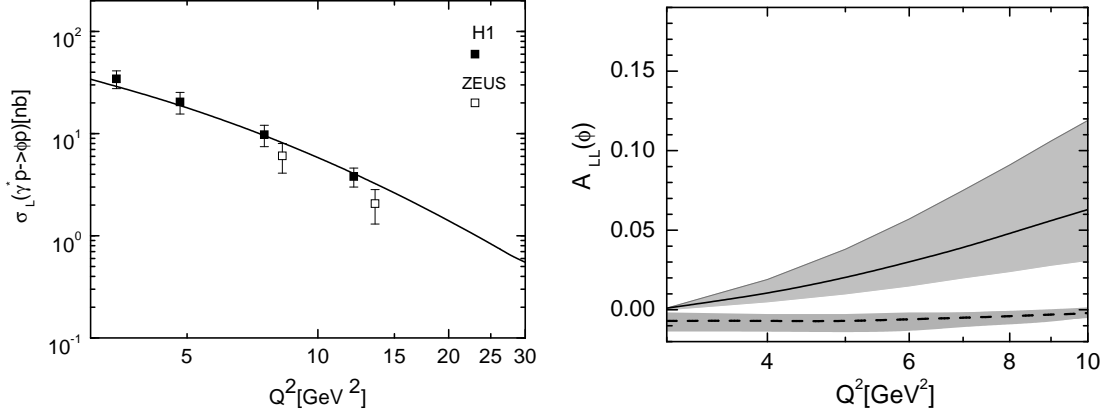


Figure 3: Left: The integrated cross section for $\gamma_{LP} \rightarrow \phi p$ versus Q^2 at $W \simeq 75$ GeV. Data taken from ¹⁰ (filled squares) and ¹¹ (open symbols). The solid line represents the result obtained in Ref. ². Right: Predictions for the helicity correlation A_{LL} for ϕ electroproduction versus Q^2 at $W = 5$ GeV (solid line) and $W = 10$ GeV (dashed line), $t \simeq 0$ and $y \simeq 0.6$. The shaded bands reflect the uncertainties due to the errors of the gluon distributions.

helicity correlation. A detailed investigation of ϕ electroproduction in the GPD framework for COMPASS and HERMES kinematics is in progress.

The approach discussed here applies also to ρ electroproduction for HERA kinematics. Indeed results for this process are given in Ref. ². The analysis of electroproduction of ρ mesons at COMPASS and HERMES kinematics definitely requires the inclusion of the quark contributions.

I summarize: ϕ meson electroproduction off unpolarized protons at small x_{Bj} and small t probes the GPD H^g . Calculating the partonic subprocess within the modified perturbative approach (using gaussian wavefunctions), one achieves fair agreement with HERA data on the integrated cross sections for longitudinally and transversally polarized virtual photons and the SDMEs for electroproduction of ϕ mesons. It is to be stressed that only the forward amplitudes are calculated within the GPD approach as yet. Their t dependencies are assumed to be exponentials with slopes taken from experiment. The present data do, however, not fix the slope of the $T \rightarrow T$ amplitude precisely. This treatment of the t dependence is unsatisfactory and improvements are required. In principle the GPD approach has the potential to do better but the GPDs as a function of t are needed for that. Some results on ϕ production for COMPASS kinematics are already presented in Ref. ².

Acknowledgments: This work has been partially supported by the Integrated Infrastructure Initiative 'Hadron Physics' of the European Union, contract No. 506078.

1. A.V. Radyushkin, *Phys. Lett. B* **385**, 333 (1996) J.C. Collins *et al.*, *Phys. Rev. D* **56**, 2982 (1997).
2. S. V. Goloskokov and P. Kroll, *Eur. Phys. J. C* **42**, 281 (2005).
3. S. J. Brodsky, *et al.*, *PRD* **50**, 3134 (1994).
4. M. Diehl, T. Feldmann, R. Jakob and P. Kroll, *EPJC* **39**, 1 (2005).
5. I. V. Musatov and A. V. Radyushkin, *PRD* **61**, 074027 (2000).
6. J. Pumplin *et al.* *JHEP* **0207**, 012 (2002).
7. A. D. Martin, M. G. Ryskin and T. Teubner, *Phys. Rev. D* **62**, 014022 (2000).
8. L. Frankfurt, W. Koepf and M. Strikman, *PRD* **54**, 3194 (1996)
9. J. Botts and G. Sterman, *Nucl. Phys. B* **325**, 62 (1989).
10. C. Adloff *et al.* [H1 Collaboration], *Phys. Lett. B* **483**, 360 (2000) [hep-ex/0005010].
11. M. Derrick *et al.* [ZEUS Collaboration], *Phys. Lett. B* **380**, 220 (1996) [hep-ex/9604008].
12. S. Chekanov [ZEUS Collaboration], *Nucl. Phys. B* **718**, 3 (2005) [hep-ex/0504010].