PROCEEDINGS OF SCIENCE

Exploring GPDs through the photoproduction of a $\gamma\rho$ pair

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We describe the process $\gamma N \to \gamma\rho N'$ in the generalized Bjorken regime where the $\gamma\rho$ pair has a large invariant mass. In the collinear QCD factorization framework, the amplitude gives access to both chiral-even and chiral-odd quark generalized parton distributions (GPDs), and is insensitive to gluon GPDs. The separation of longitudinally and transversely polarized ρ meson production allows to distinguish chiral-even and chiral-odd contributions. Production rates are estimated in the kinematics of the near-future JLab 12-GeV experiments.

XXV International Workshop on Deep-Inelastic Scattering and Related Subjects
3-7 April 2017
University of Birmingham, UK

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PoS(DIS2017)241

1. Introduction

We report here on our recent work on exclusive photoproduction of a $\gamma\rho$ pair with a large invariant mass [1]. In specific kinematics, this process may be described in the framework of collinear QCD factorization, where the short distance part of the amplitude is calculated in a perturbative way. For this first study, this is done at first order in the QCD coupling constant α_s with collinear kinematics and the long distance physics is encapsulated in leading twist hadronic matrix elements, namely the ρ meson distribution amplitude (DA) and the nucleon generalized parton distributions (GPDs).

Exploring various exclusive processes in the generalized Bjorken regime is a mandatory step to check the factorization hypothesis which allows to describe their amplitudes in terms of GPDs with the final goal to explore the 3-dimensional structure of the nucleon, including its spin content [2]. Most of the theoretical and experimental effort has been up to now devoted to the analysis of hard leptoproduction processes where a highly virtual photon probes the hadronic system, but the same experimental facilities produce intense real or quasi-real photon beams. Moreover, intense proton or nuclear high energy beams like those of the LHC produce intense photon beams in the so-called ultra-peripheral kinematics [3]. These beams open the way to the study of large invariant mass lepton pair [4] and hadron pair [5] exclusive production.

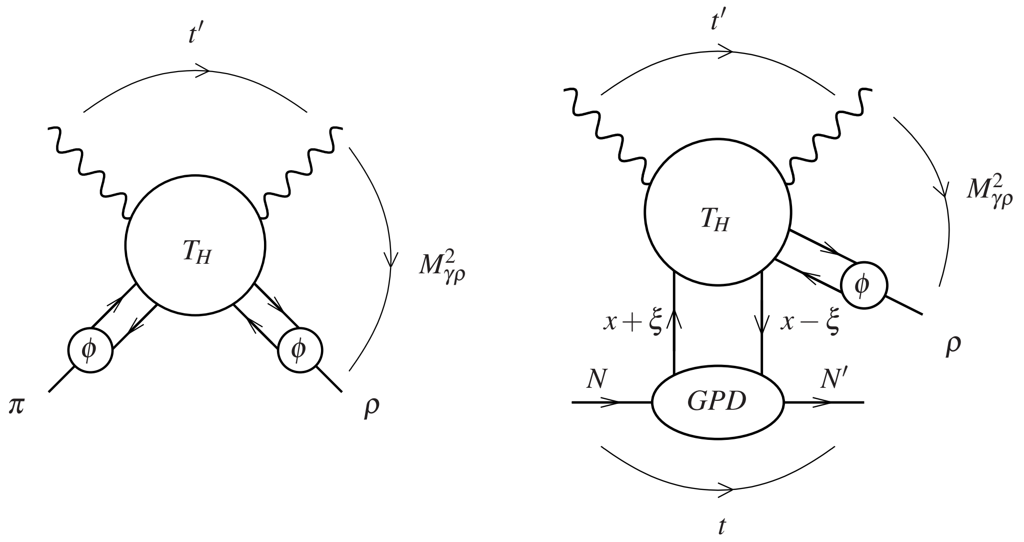

Figure 1: a) Factorization of the amplitude for the process $\gamma+\pi\to\gamma+\rho$ at large s and fixed angle (i.e. fixed ratio t'/s); b) replacing the π meson distribution amplitude by a nucleon generalized parton distribution leads to the factorization of the amplitude for $\gamma+N\to\gamma+\rho+N'$ at large $M^2_{\gamma\rho}$.

2. Kinematics

The process we study here

$$\gamma(q)+N(p_1)\to\gamma(k)+\rho^0(p_\rho,\varepsilon_\rho)+N'(p_2)\,, \tag{2.1}$$

may be described in the framework of collinear QCD by first considering the factorization procedure of the wide angle Compton scattering on a meson [6] which amounts to write the leading twist amplitude for the process $\gamma+\pi\to\gamma+\rho$ shown in Fig. 1a as the convolution of two mesonic DAs and a hard scattering subprocess amplitude $\gamma+(q+\bar{q})\to\gamma+(q+\bar{q})$ with the meson states replaced by a collinear quark-antiquark pair. We then extract from the proof of factorization of exclusive meson electroproduction amplitude near the forward region [7] the right to replace in Fig. 1a the lower left meson DA by a $N\to N'$ GPD, and thus get Fig. 1b. Such a factorization of a partonic amplitude requires to avoid the kinematical regions where a small momentum transfer is exchanged in the upper blob, namely small $t'=(k-q)^2$ or small $u'=(p_\rho-q)^2$, and the region where strong final state interactions between the ρ meson and the nucleon are dominated by resonance effects, namely where the invariant mass $M^2_{\rho N'}=(p_\rho+p_{N'})^2$ is not large enough.

Introducing two light-cone vectors p and n (with $p\cdot n=\frac{s}{2}$), we write the particle momenta as

$$p_1^\mu=(1+\xi)\,p^\mu+\frac{M^2}{s(1+\xi)}n^\mu\ ,\quad p_2^\mu=(1-\xi)\,p^\mu+\frac{M^2+\vec{\Delta}_t^2}{s(1-\xi)}n^\mu+\Delta_\perp^\mu,\quad q^\mu=n^\mu\ ,\qquad (2.2)$$

$$k^\mu=\alpha\,n^\mu+\frac{(\vec{p}_t-\vec{\Delta}_t/2)^2}{\alpha s}\,p^\mu+p_\perp^\mu-\frac{\Delta_\perp^\mu}{2}\ ,\quad p_\rho^\mu=\alpha_\rho\,n^\mu+\frac{(\vec{p}_t+\vec{\Delta}_t/2)^2+m_\rho^2}{\alpha_\rho s}\,p^\mu-p_\perp^\mu-\frac{\Delta_\perp^\mu}{2}\ ,\qquad (2.3)$$

with M, m_ρ the masses of the nucleon and the ρ meson. The squared center-of-mass energy of the γ-N system is then $S_{\gamma N}=(q+p_1)^2=(1+\xi)s+M^2$, while the small squared transferred momentum is $t=(p_2-p_1)^2=-\frac{1+\xi}{1-\xi}\vec{\Delta}_t^2-\frac{4\xi^2M^2}{1-\xi^2}$. The hard scale $M^2_{\gamma\rho}$ is the invariant squared mass of the $\gamma\,\rho$ system. In the generalized Bjorken limit, the approximate kinematics allows to neglect $\vec{\Delta}_t$ in front of $\vec{p}_t$ as well as hadronic masses, leading to

$$M^2_{\gamma\rho}\approx\frac{\vec{p}_t^{\,2}}{\alpha\bar{\alpha}}\ ,\ \alpha_\rho\approx 1-\alpha\equiv\bar{\alpha}\ ,\ \xi=\frac{\tau}{2-\tau}\ ,\ \tau\approx\frac{M^2_{\gamma\rho}}{S_{\gamma N}-M^2}\ ,\ -t'\approx\bar{\alpha}\,M^2_{\gamma\rho}\ ,\ -u'\approx\alpha\,M^2_{\gamma\rho}\,.\qquad (2.4)$$

It is interesting to note the analogy with the kinematics of timelike Compton scattering [4]. However, the more complex momentum flow of the present process leads to the coexistence of both timelike ($M^2_{\gamma\rho}$) and spacelike (u') large scales, allowing a more complex analytic structure of the amplitude [8].

3. Ingredients

One of the peculiar features of our process is its sensitivity to both chiral-even and chiral-odd GPDs due to the chiral-even (resp. chiral-odd) character of the leading twist DA of ρ_L (resp. ρ_T). Indeed, these twist 2 DAs are defined as

$$\langle 0|\bar{u}(0)\gamma^\mu u(x)|\rho^0(p_\rho,\varepsilon_{\rho_L})\rangle\ =\ \frac{1}{\sqrt{2}}p_\rho^\mu f_{\rho^0}\int_0^1 dz\,e^{-izp_\rho\cdot x}\,\phi_\parallel(z),\qquad (3.1)$$

$$\langle 0|\bar{u}(0)\sigma^{\mu\nu}u(x)|\rho^0(p_\rho,\varepsilon_{\rho_\pm})\rangle\ =\ \frac{i}{\sqrt{2}}(\varepsilon^\mu_{\rho\pm}\,p^\nu_\rho-\varepsilon^\nu_{\rho\pm}\,p^\mu_\rho)f_\rho^\perp\int_0^1 dz\,e^{-izp_\rho\cdot x}\,\phi_\perp(z),\qquad (3.2)$$

where $\varepsilon^\mu_{\rho_\pm}$ is the ρ-meson transverse polarization and with f_{ρ^0} = 216 MeV and $f_\rho^\perp$ = 160 MeV.

As for the GPDs, they are defined as usual [2]; in particular the transversity GPD of a quark q is defined by:

$$\langle p(p_2)|\,\bar{q}\left(-\frac{y}{2}\right) i\sigma^{+j} q\left(\frac{y}{2}\right)|p(p_1)\rangle = \int_{-1}^{1} dx\, e^{-\frac{i}{2}x(p_1^+ + p_2^+)y^-}\, \bar{u}(p_2)\, \left[i\sigma^{+j} H_T^q(x,\xi,t) + \ldots\right] u(p_1)\,, \tag{3.3}$$

where $\ldots$ denote the remaining three chiral-odd GPDs which contributions are omitted in the present analysis, in the small ξ limit. We parametrized the GPDs in terms of double distributions without including the quite arbitrary D term.

4. The Scattering Amplitude

The computation of the scattering amplitude of the process is straightforward at leading order in α_s, although the number of Feynman diagrams is quite large. After a tensorial decomposition is applied, the integral with respect to the variable z entering the meson DA is trivially performed in the case of a DA expanded in the basis of Gegenbauer polynomials. The integration with respect to the variable x entering the GPDs is then reduced to the numerical evaluation of a few building block integrals. Details can be found in the appendix of Ref. [1].

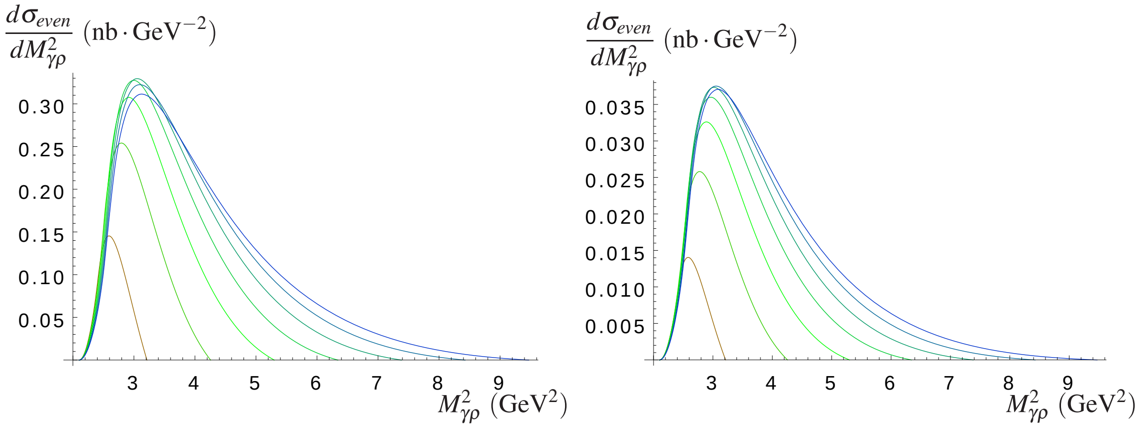

Figure 2: Differential cross section $d\sigma/dM^2_{\gamma\rho}$ for a photon and a longitudinally polarized ρ meson production, on a proton (left) or neutron (right) target. The values of $S_{\gamma N}$ vary in the set 8, 10, 12, 14, 16, 18, 20 GeV^2. (from 8: left, brown to 20: right, blue), covering the JLab energy range.

5. Cross-sections

The differential cross section as a function of t, $M^2_{\gamma\rho}$, $-u'$ reads

$$\left.\frac{d\sigma}{dt\,du'\,dM^2_{\gamma\rho}}\right|_{-t=(-t)_{min}} = \frac{|\overline{\mathscr{M}}|^2}{32 S^2_{\gamma N} M^2_{\gamma\rho}(2\pi)^3}\,. \tag{5.1}$$

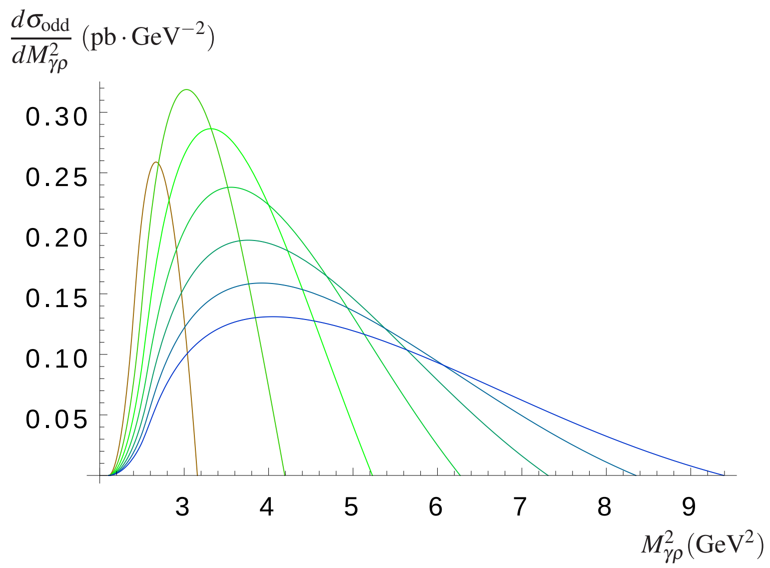

Figure 3: Differential cross section $d\sigma/dM^2_{\gamma\rho}$ for a photon and a transversally polarized ρ meson production, on a proton target. The values of $S_{\gamma N}$ vary in the set 8, 10, 12, 14, 16, 18, 20 GeV^2 (from 8: left, brown to 20: right, blue), covering the JLab energy range.

By lack of space, we refer the interested reader to Ref. [1] for a detailed analysis of this fully differential cross-section. To get an estimate of the total rate of events of interest for our analysis, we restrict here to the $M^2_{\gamma\rho}$ dependence of the differential cross section integrated over u' and t,

$$\frac{d\sigma}{dM^2_{\gamma\rho}} = \int_{(-t)_{min}}^{(-t)_{max}} d(-t) \int_{(-u')_{min}}^{(-u')_{max}} d(-u')\, F_H^2(t) \times \left.\frac{d\sigma}{dt\, du'\, dM^2_{\gamma\rho}}\right|_{-t=(-t)_{min}} . \tag{5.2}$$

The obtained differential cross sections for the longitudinal and transverse polarization cases, $d\sigma/dM^2_{\gamma\rho}$ are shown in Fig. 2 and in Fig. 3 for various values of $S_{\gamma N}$ covering the JLab-12 energy range. These cross sections show a maximum around $M^2_{\gamma\rho} \approx 3$ GeV^2, for most energy values. The order of magnitude of the cross sections are large enough for the measurement to seem feasible at JLab. Longitudinal ρ production clearly dominates over the transverse ρ production, at least with our models of the GPDs. To get a better access to the elusive transversity GPDs [9], one may have to measure the off-diagonal spin matrix components ρ_{10} which is linear in the transversity GPD and measurable through the angular dependence of the ρ meson decay.

Let us note that to confirm the order of magnitude of our present study, the effect of next-to-leading-order corrections, using for example the method of Refs. [10], should be evaluated, as well as the effect of the renormalization/factorization scale fixing (taken here at fixed value) which should be done with care for exclusive processes [11]. This is left for future studies.

Acknowledgements. This work is partly supported by grant No 2015/17/B/ST2/01838 from the National Science Center in Poland, by the French grant ANR PARTONS (Grant No. ANR-12-MONU-0008-01), by the Labex P2IO and by the Polish-French collaboration agreements Polonium and COPIN-IN2P3.

References

[1] R. Boussarie, B. Pire, L. Szymanowski and S. Wallon, *Exclusive photoproduction of a $\gamma\rho$ pair with a large invariant mass,* JHEP **1702** (2017) 054.

[2] M. Diehl, *Generalized parton distributions*, Phys. Rept. **388** (2003) 41–277; A. V. Belitsky and A. V. Radyushkin, *Unraveling hadron structure with generalized parton distributions*, Phys. Rept. **418** (2005) 1–387.

[3] A. J. Baltz *et al.*, *The Physics of Ultraperipheral Collisions at the LHC,* Phys. Rept. **458** (2008) 1; B. Pire, L. Szymanowski and J. Wagner, *Can one measure timelike Compton scattering at LHC?,* Phys. Rev. D **79** (2009) 014010.

[4] E. R. Berger, M. Diehl and B. Pire, *Time - like Compton scattering: Exclusive photoproduction of lepton pairs,* Eur. Phys. J. C **23** (2002) 675; B. Pire, L. Szymanowski and J. Wagner, *NLO corrections to timelike, spacelike and double deeply virtual Compton scattering,* Phys. Rev. D **83** (2011) 034009; H. Moutarde, B. Pire, F. Sabatie, L. Szymanowski and J. Wagner, *Timelike and spacelike deeply virtual Compton scattering at next-to-leading order,* Phys. Rev. D **87** (2013) 054029.

[5] D. Yu. Ivanov, B. Pire, L. Szymanowski and O. V. Teryaev, *Probing chiral-odd GPD's in diffractive electroproduction of two vector mesons,* Phys. Lett. B **550** (2002) 65; R. Enberg *et. al.*, *Transversity GPD in photo- and electroproduction of two vector mesons,* Eur. Phys. J. C **47** (2006) 87 ; M. El Beiyad, B. Pire, M. Segond, L. Szymanowski and S. Wallon, *Photoproduction of a $\pi\rho_T$ pair with a large invariant mass and transversity generalized parton distribution,* Phys. Lett. B **688** (2010) 154; A. Pedrak, B. Pire, L. Szymanowski and J. Wagner, *Hard photoproduction of a diphoton with a large invariant mass*, arXiv:1708.01043 [hep-ph].

[6] G. P. Lepage and S. J. Brodsky, *Exclusive Processes in Perturbative Quantum Chromodynamics*, *Phys. Rev.* **D22** (1980) 2157.

[7] J. C. Collins, L. Frankfurt, and M. Strikman, *Factorization for hard exclusive electroproduction of mesons in QCD*, *Phys. Rev.* **D56** (1997) 2982–3006.

[8] D. Mueller, B. Pire, L. Szymanowski and J. Wagner, *On timelike and spacelike hard exclusive reactions,* Phys. Rev. D **86** (2012) 031502.

[9] M. Diehl, T. Gousset and B. Pire, *Exclusive electroproduction of vector mesons and transversity distributions,* Phys. Rev. D **59** (1999) 034023; J. C. Collins and M. Diehl, *Transversity distribution does not contribute to hard exclusive electroproduction of mesons,* Phys. Rev. D **61** (2000) 114015.

[10] B. Nizic, *Beyond Leading Order Perturbative QCD Corrections To $\gamma\gamma \to M^+M^-$ $(M = \pi, K)$*, Phys. Rev. D **35** (1987) 80; G. Duplancic and B. Nizic, *NLO perturbative QCD predictions for $\gamma\gamma \to M^+M^-$ $(M = \pi, K)$*, Phys. Rev. Lett. **97** (2006) 142003.

[11] I. V. Anikin, B. Pire, L. Szymanowski, O. V. Teryaev and S. Wallon, *On BLM scale fixing in exclusive processes*, Eur. Phys. J. C **42** (2005) 163; S. J. Brodsky and F. J. Llanes-Estrada, *Renormalization scale-fixing for complex scattering amplitudes*, Eur. Phys. J. C **46** (2006) 751.