PROBING GENERALIZED PARTON DISTRIBUTIONS THROUGH THE PHOTOPRODUCTION OF A $\gamma\pi$ PAIR*

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We study in the framework of collinear QCD factorization the photoproduction of a $\gamma\,\pi$ pair with a large invariant mass and a small transverse momentum, as a new way to access generalized parton distributions (GPDs). In the kinematics of JLab 12 GeV, we demonstrate the feasibility of this measurement and show the extreme sensitivity of the unpolarized cross section to the axial quark GPDs.

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1. Introduction

In order to test the universality of generalized parton distributions in the framework of collinear QCD factorization, it is important to study various

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exclusive reactions which may be accessed at existing and future experimental facilities. We report here on our calculation [1] of the scattering amplitude for the process

$$\gamma^{(*)}(q) + N(p_1) \to \gamma(k) + \pi^{\pm}(p_\pi) + N'(p_2)\,, \tag{1}$$

where $(N, N') = (p, n)$ for the π^+ case and $(N, N') = (n, p)$ for the π^- case, and the $\gamma\pi$ pair has a large invariant mass $M_{\gamma\pi}$. Together with the golden channels, deeply virtual Compton scattering (DVCS) and deeply virtual meson production, this may be looked as an extension of time-like Compton scattering [2–4]. The hard scale $M_{\gamma\pi}$ is related to the large transverse momenta transmitted to the final photon and to the final pion. We require the $\gamma(q\bar{q}) \to \gamma(q\bar{q})$ subprocess to be in the regime of wide angle Compton scattering where collinear QCD factorization is known to apply [5].

The study of such $2 \to 3$ processes was initiated in Refs. [6, 7], where the process under study was the high-energy diffractive photo- (or electro-) production of two vector mesons, the hard probe being the virtual "Pomeron" exchange (and the hard scale being the virtuality of this Pomeron). A similar strategy has also been advocated in Refs. [8, 9] to enlarge the number of processes which could be used to extract information on chiral-even GPDs.

2. Scattering amplitudes

The scattering amplitude of the process (1), in the factorized form shown in Fig. 1, is expressed in terms of form factors $\mathcal{H}_\pi$, $\mathcal{E}_\pi$, $\tilde{\mathcal{H}}_\pi$, $\tilde{\mathcal{E}}_\pi$, analogous to Compton form factors in DVCS, and reads

$$\frac{\bar{u}(p_2)}{n\cdot p}\left[\hat{n}\mathcal{H}_\pi(\xi,t)+\frac{i\,\sigma^{n\,\alpha}\varDelta_\alpha}{2m}\mathcal{E}_\pi(\xi,t)+\hat{n}\gamma^5\tilde{\mathcal{H}}_\pi(\xi,t)+\frac{n\cdot\varDelta}{2m}\,\gamma^5\,\tilde{\mathcal{E}}_\pi(\xi,t)\right]u(p_1)\,,$$

where $\varDelta = p_2 - p_1$, p, n are light-like Sudakov vectors and $p_\perp = \frac{1}{2}(k - p_\pi)_\perp$. The two-photon polarizations enter the amplitude through four tensors

$$\begin{aligned} T_A &= (\varepsilon_{q\perp}\cdot\varepsilon^*_{k\perp})\,, & T_B &= (\varepsilon_{q\perp}\cdot p_\perp)\,(p_\perp\cdot\varepsilon^*_{k\perp})\,,\\ T_{A_5} &= (p_\perp\cdot\varepsilon^*_{k\perp})\;\epsilon^{n\,p\,\varepsilon_{q\perp}\,p_\perp}\,, & T_{B_5} &= -\,(p_\perp\cdot\varepsilon_{q\perp})\;\epsilon^{n\,p\,\varepsilon^*_{k\perp}\,p_\perp}\,, \end{aligned} \tag{2}$$

and the $(\xi,\, t)$ dependence comes from integrated scalar quantities

$$\mathcal{H}_\pi(\xi,t) = \mathcal{H}_{\pi A_5}(\xi,t)T_{A_5} + \mathcal{H}_{\pi B_5}(\xi,t)T_{B_5}\,, \tag{3}$$

$$\tilde{\mathcal{H}}_\pi(\xi,t) = \tilde{\mathcal{H}}_{\pi A}(\xi,t)T_A + \tilde{\mathcal{H}}_{\pi B}(\xi,t)T_B\,. \tag{4}$$

These coefficients can be expressed in terms of the sum over diagrams of the integral of the product of their traces, of GPDs and DAs. We use asymptotical DAs $\phi_\pi(z)$ and models for GPDs $H(x,\xi,t)$ and $\tilde{H}(x,\xi,t)$ based on double distributions and known PDFs. For the axial GPD $\tilde{H}$, our model relies on polarized PDFs, and we use two scenarios [10]: the "standard", *i.e.* with flavor-symmetric light sea quark and antiquark distributions, and the "valence" scenario with a flavor-asymmetric light sea densities.

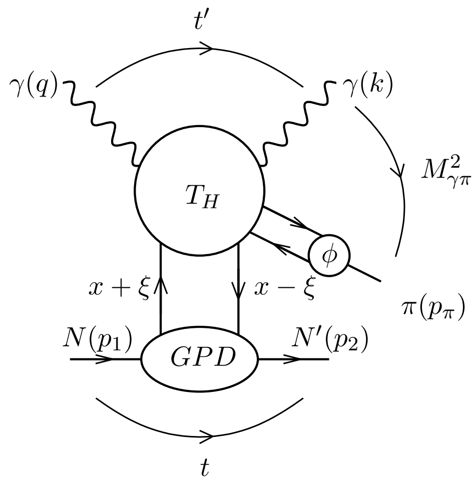

Fig. 1. Factorization of the amplitude for $\gamma + N \to \gamma + \pi + N'$ at large $M^2_{\gamma\pi}$.

3. Cross sections

The differential unpolarized cross section is expressed from the averaged amplitude squared $|\overline{\mathcal{M}}_\pi|^2$

$$\left.\frac{\mathrm{d}\sigma}{\mathrm{d}t\,\mathrm{d}u'\,\mathrm{d}M^2_{\gamma\pi}}\right|_{-t=(-t)_{\min}} = \frac{\left|\overline{\mathcal{M}}_\pi\right|^2}{32 S^2_{\gamma N} M^2_{\gamma\pi}(2\pi)^3}\,. \tag{5}$$

There is no interference between the vector and the axial GPD contributions to the amplitudes. With our models for GPDs, the axial GPD contribution dominates. This turns into a remarkable sensitivity of the unpolarized cross section to the axial GPDs. The root of this result, which is very different from the ρ case [9], is the pseudo-scalar nature of the π meson.

The single differential cross section with respect to $M^2_{\gamma\pi}$ is obtained by integrating over u' and t, taking into account the fact that typical cuts that one should apply to ensure the validity of collinear factorization are $-t', -u' > \Lambda^2$ and $M^2_{\pi N'} = (p_\pi + p_{N'})^2 > M^2_{\mathrm{R}}$, where $\Lambda \gg \Lambda_{\mathrm{QCD}}$ (we take in practice $\Lambda = 1$ GeV) and M_{R} is a typical baryonic resonance mass. We refer to Ref. [1] for a detailed discussion of the integration over the $(-u', -t)$ phase space.

We now show results for unpolarized cross sections, for $\gamma\pi^+$ photoproduction on a proton target and for $\gamma\pi^-$ photoproduction on a neutron target in Fig. 2. In Fig. 3, we show the obtained cross section after integrating over the squared invariant mass $M^2_{\gamma\pi}$, as a function of $S_{\gamma N}$ for the typical range accessible at JLab.

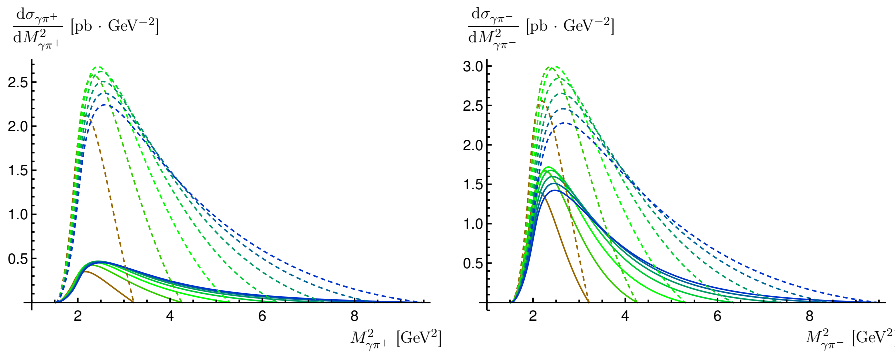

Fig. 2. (Colour on-line) Left: Differential cross section $d\sigma_{\gamma\pi^+}/dM^2_{\gamma\pi^+}$ for the production of a photon and a π^+ meson on a proton target. Right: Differential cross section $d\sigma_{\gamma\pi^-}/dM^2_{\gamma\pi^-}$ for the production of a photon and a π^- meson on a neutron 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. We use here the "valence" (solid) and the "standard" (dashed) scenarios.

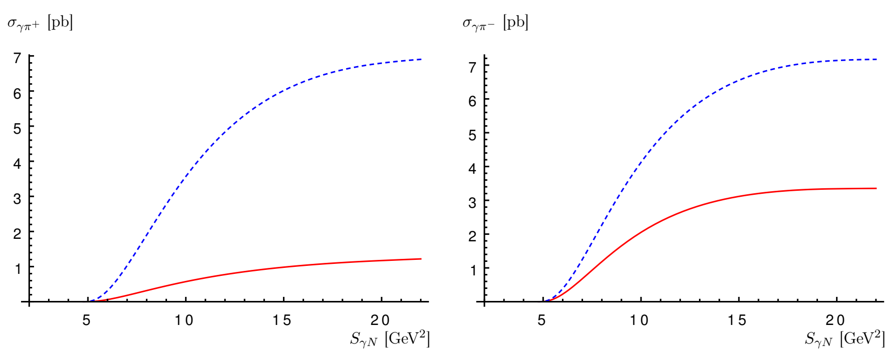

Fig. 3. (Colour on-line) Cross section for the production of a $\gamma\pi^\pm$ pair (conventions as in Fig. 2).

Counting rates in electron mode can be obtained using the Weizsäcker–Williams distribution. With an expected luminosity $\mathcal{L} = 100$ pb^{-1}s^{-1}, we obtain for 100 days of run: between 1.3×10^4 (valence scenario) and 8.0×10^4 $\gamma\pi^+$ pairs (standard scenario), and between 4.4×10^4 (valence scenario) and 8.9×10^4 $\gamma\pi^-$ pairs (standard scenario) in the required kinematical domain.

4. Conclusion

Our analysis of the reaction $\gamma N \to \gamma\pi^\pm N'$ in the generalized Bjorken kinematics has shown that unpolarized cross sections are large enough for the process to be analyzed by near-future experiments at JLab with photon beams originating from the 12 GeV electron beam. It is dominated by the axial generalized parton distribution combination $\tilde{H}_u$–$\tilde{H}_d$ which is up to now not much constrained by any experimental data.

A similar study could be performed at higher values of $S_{\gamma N}$, in the Compass experiment at CERN and at the LHC in ultraperipheral collisions [11], as discussed for the timelike Compton scattering process [12]. Future electron proton collider projects such as EIC [13] and LHeC [14] would offer excellent possibilities for such measurements.

Recent π electroproduction experimental data have questioned the dominance of the twist 2 contribution at moderate Q^2. The problem of collinear factorization at the twist 3 level is not yet fully understood. Despite several successful attempts to include consistently such effects in exclusive amplitudes [15–18], the existing model for explaining pion electroproduction data go beyond standard collinear factorization [19, 20]. Although one may expect sizable contributions to our present process due to the twist 3 pion DA, we are lacking a consistent framework to study this contribution. This is left for future studies.

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