On large mass $\gamma - \gamma$ and $\gamma -$ meson photoproduction

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Enlarging the set of hard exclusive reactions to be studied in the framework of QCD collinear factorization opens new possibilities to access generalized parton distributions (GPDs). We studied the photoproduction of a large invariant mass photon-photon or photon-meson pair in the generalized Bjorken regime which may be accessible both at JLab and at the EIC.

Keywords: GPD, transversity, EIC

1. Introduction

Deeply virtual Compton scattering (DVCS) has proven to be a promising tool to study the three dimensional arrangement of quarks and gluons in the nucleon\[1\]. The crossed reaction, the photoproduction of a timelike highly virtual photon which materializes in a large invariant mass lepton pair (dubbed TCS for timelike Compton scattering) is under study at JLab. Its amplitude shares many features with the DVCS amplitude\[2\] but with significant and interesting differences\[3,4\] due to the analytic behavior in the large scale $Q^2$ measuring the virtuality of the incoming ($q^2 = -Q^2$) or outgoing ($q^2 = +Q^2$) photon. In order to enlarge the set of experimental data allowing the extraction of GPDs, we studied the generalization of TCS to the case of the photoproduction of large invariant mass photon- photon and photon-meson pairs. Although factorization of GPDs from a perturbatively calculable coefficient function has not yet been proven for these processes, they are a natural extension of the current picture in the framework of collinear QCD factorization.

2. $\gamma N \rightarrow \gamma\gamma N'$

The photoproduction of a photon pair\[5\] shares with DVCS and TCS the nice feature to be a purely electromagnetic amplitude at the Born level. Charge parity however selects a complementary set of GPDs, namely the charge parity - odd GPDs related
to the valence part of quark PDFs, with no contribution from the gluon GPDs. The analytic form of the Born amplitude calculated from the graphs shown on Fig. 1 is very peculiar since the coefficient function turns out to be proportional to $\delta(x \pm \xi)$ leading through the usual momentum fraction integration to a scattering amplitude proportional to the GPDs taken at the border values $x = \pm \xi$. For illustration, Fig. 2 displays the diphoton invariant squared mass dependence of the unpolarized differential cross section on a proton at $t = t_{min}$ and $s_{\gamma N} = 20$ (resp. $100, 10^6$) GeV$^2$ (full, resp. dashed, dash-dotted multiplied by $10^5$).

3. $\gamma N \to \gamma \rho N'$ : the quest for transversity GPDs

The photoproduction of a $\gamma \rho$ pair has the rare feature of being sensitive to chiral-odd transversity quark GPDs at the leading twist level, because of the leading twist chiral-odd distribution amplitude of the transversely polarized vector meson. Indeed, except for higher twist amplitudes which suffer from end-point divergences and heavy meson neutrino production amplitudes which may be difficult to measure, one needs exclusive processes with more particles in the final state to access transversity GPDs.

We show on Fig. 3 the cross section for the production of a transversely polarized...
ρ in conjunction with a photon, on a proton or a neutron target. The curves show the sensitivity to the transversity GPD parametrization. Cross sections are sufficiently high for the process to be measurable at JLab.

Fig. 3. Energy dependence of the integrated cross section for a photon and a transversely polarized ρ meson production, on a proton (left panel) or neutron (right panel) target. The γρ pair is required to have an invariant mass squared larger than 2 GeV^2. The solid red and dashed blue curves correspond to different parametrization of the transversity GPDs.

4. γN → γπN'

Fig. 4. Left panel: the differential cross section for γπ^+ production on a proton target at s_{γN} = 20 GeV^2, t = t_{min}, and M_{γπ}^2 = 3 (resp. 4, 5, 6) GeV^2 for the black (resp. red, blue, green) curves. The solid and dashed curves correspond to two different parametrization of the axial GPDs. Right panel: the same curves for γπ^- production on a neutron target.

Since deep electroproduction of a π meson has been shown to resist at moderate Q^2 to leading twist dominance in the factorization framework, it has been tempting to put the blame on the peculiar chiral behavior of the higher twist (chiral-odd) pion DA as compared with the leading twist (chiral even) pion DA. However, the dominance of higher twist contributions may not be a common feature of all exclusive amplitudes involving the pion DA. To check this idea, we propose to study
the related process $\gamma N \to \gamma \pi N'$ where the same pion DAs appear. It turns out that the axial nature of the pion leading twist DA infers a high sensitivity of the amplitudes to the axial GPDs $\tilde{H}(x, \xi, t)$ as shown on Fig. 4 where the cross sections for the reaction $\gamma p \to \gamma \pi^+ n$ and $\gamma n \to \gamma \pi^- p$ are displayed for two different sets of axial GPDs. The rates are of the same order as for the $\gamma p$ case and we thus expect these reactions to be measurable at JLab.

5. Conclusions

The processes discussed here, because of the absence of gluon and sea quark contributions are not enhanced at high photon energy (or small skewness $\xi$) and they are thus more accessible at JLab than at EIC. However, since a high energy electron beam is also an intense source of medium energy quasi real photons ($q^2 \approx 0$), with fractions of energy $y = \frac{q \cdot p}{k \cdot p} = 0(10^{-3})$, ($k$ and $p$ being the initial electron and nucleon momenta), one may expect the $\gamma \gamma$ and $\gamma \rho$ channels to be accessible at moderate values of $s_{\gamma N}$. Prospects at higher values of $s_{\gamma N}$ (and smaller values of the skewness $\xi$) are brighter for the $\gamma \pi^0$ channel which benefits from the contributions of small $\xi$ sea-quark and gluon GPDs.

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