PROBING THE STRUCTURE OF VIRTUAL PHOTON IN THE DEEP INELASTIC COMPTON PROCESS AT HERA

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The sensitivity of the Deep Inelastic Compton (DIC) scattering at HERA to the structure of the virtual photon is discussed. It is demonstrated that the gluonic content of the virtual photon can be pinned down by measuring the photons with $p_T \sim 5$ GeV in the proton direction.

1 Introduction

The Deep Inelastic Compton (DIC) process provides the opportunity to probe at HERA the structure of the real photon, as was pointed out in \textsuperscript{1}, \textsuperscript{2}, \textsuperscript{3}, \textsuperscript{4}, \textsuperscript{5}. The ability to probe the structure of the photon (and the proton) in the tagged and untagged events at HERA was studied in paper \textsuperscript{3} with the conclusion that in order to separate the contribution arising from the gluonic content of the (real) photon the tagged condition is preferred.

The first attempt to describe the DIC process at HERA using the structure of the virtual photon can be found in \textsuperscript{6}, \textsuperscript{7}, where the EPA approach was compared with the calculation, where the virtual photon interacts directly or by its partonic content. Results obtained for the virtual photon were based on the naive Parton Model formulae only for quarks. The EPA approach leads to the $p_T$ distribution in the resolved photon subprocesses higher by about 20-45\% than one based on the ”exact” approach using the virtual photon structure. For the subprocesses due to the direct photon interaction the EPA works much better.

In the present paper we examine, using the GRS (LO)\textsuperscript{9} parton parametrization for the virtual photon, the usefulness of DIC process to study at HERA the structure of a virtual photon, in particular the gluonic content of virtual photon. The recent study\textsuperscript{a} have showed that the parton distributions of the
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\textsuperscript{b} The sensitivity to the quark fragmentation into the photon in the DIC process has been studied as well, see\textsuperscript{b}.
virtual photon can be tested at HERA via tagged single high $E_T$ jet or $b\bar{b}$ production\cite{3}.

2 Deep Inelastic Compton scattering at HERA collider

We investigate a inclusive DIC process in which photons with large transverse momentum, $p_T \gg \Lambda_{QCD}$, are produced in electron(positron)-proton collision:

$$e p \rightarrow e \gamma X.$$  

(1)

For relatively small momentum transfers between electrons, this reaction proceeds by the exchange of a virtual photon, i.e. the $Z$ exchange can be neglected. We will limit ourselves to events with the tagged electrons, so the energy and (positive) virtuality of the initial photon $-p^2 = P^2$ can be estimated.

Depending on the conditions (untagged, antitagged or tagged events) DIC process may proceed via the (almost) real photon-proton collision:

$$\gamma p \rightarrow \gamma X$$  

(2)

or via the virtual photon-proton scattering:

$$\gamma^* p \rightarrow \gamma X.$$  

(3)

The comparison between these two approaches to DIC process at HERA can be found in\cite{6,7}. The direct photon interaction for both real and virtual photons, corresponding to the following subprocesses

$$\gamma q \rightarrow \gamma q,$$  

(4)

$$\gamma^* q \rightarrow \gamma q,$$  

(5)

where the initial photon interacts with a quark from the proton (the Born approximation), dominates at very large $p_T \sim \sqrt{S_{ep}}/2$.

In the moderate $p_T$ region, $\Lambda_{QCD} \ll p_T \ll \sqrt{S_{ep}}/2$, a resolved photon processes, i.e. where the photon interacts through its partonic constituents, become important. There are three types of subprocesses involving the partonic constituents of the initial and/or final photons in DIC (below we discuss only the virtual initial photons):

- single resolved initial photon

$$g_{\gamma^*} q \rightarrow \gamma q,$$  

(6)

$$q_{\gamma^*} q \rightarrow \gamma q,$$  

(7)

$$q_{\gamma^*} \bar{q} \rightarrow \gamma g$$  

(8)

$$\bar{q}_{\gamma^*} q \rightarrow \gamma g$$  

(9)
• single resolved final photon (fragmentation into the photon)

\[ \gamma^* g_p \rightarrow q\bar{q} \]  
(10)

\[ \gamma^* q_p \rightarrow gq \]  
(11)

• double resolved photons

\[ g\gamma^* g_p \rightarrow gg \]  
(12)

\[ q\gamma^* g_p \rightarrow qg, \text{etc.} \]  
(13)

In this paper we limit ourself to the process involving (single) resolved initial photon, where we expect to see the effect due to the gluonic content in the virtual photon \( P^2 \neq 0 \). The full discussion will be given elsewhere.

3 Calculation of the cross section

The differential cross section for the deep inelastic electron-proton scattering with a photon in the final state, eq. 1, can be written in the following way:

\[ E_e E_\gamma \frac{d\sigma_{ep\rightarrow e\gamma X}}{d^3 p_e d^3 p_\gamma} = \Gamma \left( E_\gamma \frac{d\sigma_{\gamma^* p\rightarrow e\gamma X}}{d^3 p_\gamma} |_T + \epsilon E_\gamma \frac{d\sigma_{\gamma^* p\rightarrow e\gamma X}}{d^3 p_\gamma} |_L \right). \]  
(14)

where \( E_e(E_\gamma) \) and \( p_e(p_\gamma) \) are energy and momentum of the final state electron(photon). Coefficients \( \Gamma \) and \( \epsilon \Gamma \) (functions of energy and momentum of the electron in initial and final states; see also [11]) can be interpreted as the probability of emitting by the initial electron a virtual photon polarized transversely and longitudinally.

Since the cross section for the reaction \( ep \rightarrow e\gamma X \) is dominated by the exchange of photons with small virtuality, one can neglect a contribution due to the longitudinal polarization (see also [6]). Assuming that exchanged photons have only transverse polarization we obtain:

\[ E_e E_\gamma \frac{d\sigma_{ep\rightarrow e\gamma X}}{d^3 p_e d^3 p_\gamma} = \Gamma E_\gamma \frac{d\sigma_{\gamma^* p\rightarrow e\gamma X}}{d^3 p_\gamma} |_T. \]  
(15)

Performing in the above cross section the integration over the 4-momentum of the final electron one obtain the differential cross section \( E_\gamma \frac{d\sigma_{\gamma^* p\rightarrow e\gamma X}}{d^4 p_\gamma} \)

\[ E_\gamma \frac{d\sigma_{\gamma^* p\rightarrow e\gamma X}}{d^4 p_\gamma} = \int \frac{d^3 p_e}{E_e} \Gamma E_\gamma \frac{d\sigma_{\gamma^* p\rightarrow e\gamma X}}{d^3 p_\gamma}. \]  
(16)

where the flux can be found in [3] and the invariant cross section \( E_\gamma \frac{d\sigma_{\gamma^* p\rightarrow e\gamma X}}{d^4 p_\gamma} \) has a form:
\begin{itemize}
  \item for the direct (Born) process:

  \[ \left( E_\gamma \frac{d\sigma^{\gamma^* p \to \gamma X}}{d^3p_\gamma} \right)_{\text{dir}} = \sum_{q,q'} \int_0^1 dx p f_{q/p}(x, \hat{Q}^2) E_\gamma \frac{d\hat{\sigma}^{\gamma^* q \to \gamma q p}}{d^3p_{\gamma}}, \]

  \[ (17) \]

  \item for processes involving the resolved initial photon:

  \[ \left( E_\gamma \frac{d\sigma^{\gamma^* p \to \gamma X}}{d^3p_\gamma} \right)_{\text{res}} = \sum_{i,j} \int_0^1 dx_{\gamma'} f_{i/\gamma'}(x_{\gamma'}, \hat{Q}^2) \int_0^1 dx_p f_{j/p}(x_p, \hat{Q}^2) \left( E_\gamma \frac{d\hat{\sigma}^{ij \to \gamma k}}{d^3p_\gamma} \right), \]

  \[ (18) \]

  \[ f_{i/\gamma'}(x_{\gamma'}, \hat{Q}^2, P^2) \] is a \( (i) \) parton distribution in the virtual photon with a virtuality equal to \( P^2 \) at scale \( \hat{Q}^2 \). The cross sections \( \hat{\sigma} \) correspond to the partonic subprocesses.

  In the calculation we take into consideration the virtuality \(-P^2\) of the photon emitted by the electron as it follows from the kinematics of the process.

\end{itemize}

4 Results

In the calculation we used the GRS (LO) parton parametrizations for the parton distributions in the virtual photon \cite{9} and the GRV (LO) set of the quark and the gluon densities for the proton \cite{12}.

Calculations were performed for the energy of the HERA accelerator: \( S_{ep} = 98400 \text{ GeV}^2 \). We assumed the number of flavours \( f = 4 \), the QCD parameter \( \Lambda_{\text{QCD}} = 0.2 \text{ GeV} \), and the energy scale in Eqs. 18-19 equal to the transverse momentum of the final photon: \( \hat{Q} = p_T \).

We calculated the cross section for the transverse momentum of the final photon equal to 5 GeV and for the fixed energy of the initial photon: \( E_\gamma = 0.5E_e \) (so the \( y \) variable was equal to 0.5). The rapidity dependence was studied for the various values of \( P^2 \) between 0.03 to 2.5 GeV\(^2\). \cite{5}

The results for the \( E_\gamma \frac{d\sigma^{\gamma^* p \to \gamma X}}{d^3p_\gamma} \) for the subprocesses Eqs. 5 and 6 for three values of \( P^2 \) are presented in Fig.1a as a function of the rapidity \( d \) in the

\textsuperscript{c}Note that tagging of the final electron helps to distinguish the direct contribution from the resolved ones.

\textsuperscript{d}The rapidity \( Y \) is equal to \( Y = -\ln \tan \frac{\theta}{2} \), where \( \theta \) is the angle between the momentum of the photon in the final state and the momentum of the electron in the initial state.
electron-proton center of mass system. In Fig.1b the comparison of the different contributions to the considered cross section is plotted for the $P^2 = 0.25$ GeV$^2$.

![Figure 1: a) The cross section $E_\gamma \frac{d^3p}{dp_1 dp_2 dy} \rightarrow e\gamma X$ for subprocesses: direct (5) and $g_p \rightarrow \gamma q$ (6) at the $P^2=0.03, 0.25$ and 2.5 GeV$^2$ (dotted, dashed and solid line). b) The same for subprocesses: (5) and (6) (solid lines), (7) (dashed line) and (8+9) (dotted line) at $P^2=0.25$ GeV$^2$. The clear dominance of the contribution due to gluonic content of the virtual photon in the proton direction is seen for the considered range of virtuality of initial photon. We check that this holds also for smaller $P^2$ values.]

The discussion based on the full set of diagrams, wider $P^2$ range and others parton parametrizations will be given elsewhere. Note that the interference with the Bethe-Heitler process, discussed in [13], seems to be small for $p_T=5$ GeV and in the region of the rapidity where the gluonic content of the virtual photon plays a dominant role.

5 Conclusions

Tagged DIC events at HERA were studied using the GRS and GRV parton parametrizations for the direct and resolved virtual photon subprocesses. The contribution due to gluonic content of the virtual photon was found to dominate in the direction of the proton as compared to others subprocesses. This can have important consequences for the possibility of measuring the gluon content of the virtual photon at HERA.

\footnote{Due to smooth behaviour of the GRS parametrization in the limit $P^2 \rightarrow 0$ we were able to perform the calculation also below $\Lambda_{QCD}^2$.}
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