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CONTRIBUTIONS DUE TO THE LONGITUDINAL VIRTUAL PHOTON IN THE SEMI-INCLUSIVE *ep* COLLISION AT HERA*

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The importance of contributions due to the longitudinally polarised virtual photon, $d\sigma_{\rm L}$ and the interference term $d\tau_{\rm LT}$, in the unpolarised ep collisions is discussed. The numerical calculations for the Compton process $ep \to e\gamma X$ at the HERA collider were performed in the Born approximation. The various distributions in the CM$_{ep}$ and Breit frames are presented. These cross sections are dominated by the transversely polarised intermediate photon, even for large Q^2.

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1. Introduction

In cross sections for semi-inclusive ep processes and collisions with two intermediate photon, the terms coming from the interference between $\gamma^*_{\rm L}$ and $\gamma^*_{\rm T}$ or between two different transverse states of γ^* can appear [2]. The detailed studies of various contributions for the process $e^+e^- \to e^+e^-\mu^+\mu^-$ performed for the kinematical range of the PLUTO and LEP experiments [3] show the importance of interference terms.

Here we study the longitudinal-transverse interference term ($d\tau_{\rm LT}$) and contributions due to exchange of $\gamma^*_{\rm L}$ ($d\sigma_{\rm L}$) and $\gamma^*_{\rm T}$ ($d\sigma_{\rm T}$) in the unpolarised semi-inclusive ep collisions [1]. Assuming one-photon exchange we factorise the cross-section onto the photon emission by the electron and the $\gamma^* p$ collision in a way independent on the reference frame. For this purpose we use the propagator decomposition method and explicit forms of all polarisation vectors of the virtual photon ($q^2 < 0$).

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2. Factorisation formulae for unpolarised *ep* collisions

The cross section for an unpolarised $lN \to lX$ process, for example DIS $ep \to eX$, can be factorised onto the leptonic and hadronic tensors, $d\sigma \sim L^{\mu\nu} W_{\mu\nu}$. Further on, the differential cross section can be decomposed on the parts related to the subprocesses $\gamma^*_{\mathrm{T}} N \to X$ and $\gamma^*_{\mathrm{L}} N \to X$, respectively

$$d\sigma^{ep\to eX} = \Gamma_{\mathrm{T}} \sigma_{\mathrm{T}}^{\gamma^* p \to X} + \Gamma_{\mathrm{L}} \sigma_{\mathrm{L}}^{\gamma^* p \to X} \,. \tag{1}$$

The above factorisation and separation formula can be obtained in various ways. One of them uses the known hadronic tensor and explicit form of the scalar polarisation vector [4]. Another way is the propagator decomposition method [5] in which the cross section is written as follows

$$d\sigma^{ep\to eX} \sim L_e^{\alpha\beta} \frac{g_{\alpha\mu}}{q^2} \, \frac{g_{\nu\beta}}{q^2} W_p^{\mu\nu} \,. \tag{2}$$

Afterwards one decomposes the propagator of the exchanged photon using the completeness relation, what leads directly to Eq. (2). This method is especially useful in analysing of the semi-inclusive processes.

In case of the semi-inclusive process one additional particle in the final state is produced. For example for the Compton process $ep \to e\gamma X$ (Fig. 1) the differential cross section can be decomposed as follows

$$d\sigma^{ep\to e\gamma X} = d\sigma_{\mathrm{T}}^{ep\to e\gamma X} + d\sigma_{\mathrm{L}}^{ep\to e\gamma X} + d\tau_{\mathrm{TT}}^{ep\to e\gamma X} + d\tau_{\mathrm{LT}}^{ep\to e\gamma X} \,. \tag{3}$$

In the above formula two additional contributions, $d\tau_{\mathrm{LT}}$ and $d\tau_{\mathrm{TT}}$, appear. They are related to the interference between γ^*_{L} and γ^*_{T}, and between two different transverse polarisation states of the γ^*, respectively.

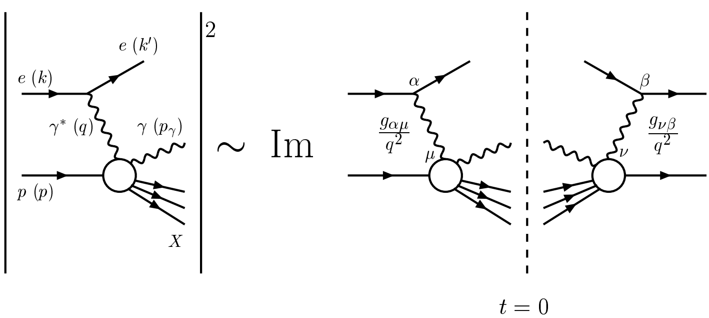

Fig. 1. The optical theorem for the Compton process $ep \to e\gamma X$.

In studies of the interference terms in the semi-inclusive processes $ep \to e\gamma X$ the azimuthal angle ϕ distribution is especially useful. The angle ϕ is defined as the difference of the azimuthal angle of the final electron and of the final photon: $\phi = \phi_e - \phi_\gamma$.

In the Breit frame ϕ is the angle between the electron scattering plane and plane fixed by the momenta of the exchanged γ^* and final photon γ. In this reference frame $d\sigma/d\phi$ is linear in $\cos\phi$, $\cos 2\phi$, $\sin\phi$ and $\sin 2\phi$.

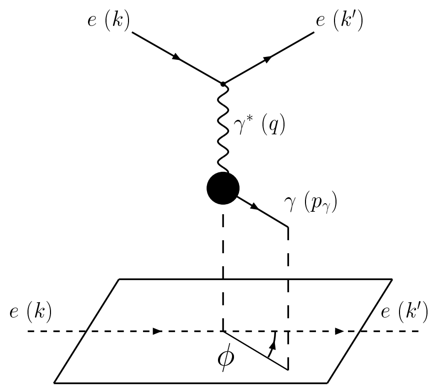

Fig. 2. The azimuthal angle ϕ for the process $ep \to e\gamma X$ in the Breit frame.

For calculations in the Born approximation the terms containing $\sin\phi$ and $\sin 2\phi$ vanish as a consequence of time-reversal invariance, so the azimuthal distribution for the Compton process reduces to the following form [7]:

$$\frac{d\sigma^{ep\to e\gamma X}}{d\phi} = \sigma_0 + \sigma_1 \cos\phi + \sigma_2 \cos 2\phi \,. \tag{4}$$

The coefficients σ_0, σ_1 and σ_2 are related to $d\sigma_{\rm T}/d\phi$, $d\sigma_{\rm L}/d\phi$, $d\tau_{\rm LT}/d\phi$ and $d\tau_{\rm TT}/d\phi$. The third term arises from the interference between two different transverse polarisation states of the exchanged photon ($\sigma_2 \cos 2\phi = d\tau_{\rm TT}/d\phi$). The longitudinal-transverse interference gives rise to the second term ($\sigma_1 \cos\phi = d\tau_{\rm LT}/d\phi$). The σ_0 consists of the sum of the cross sections with the intermediate $\gamma^*_{\rm L}$ and $\gamma^*_{\rm T}(\sigma_0 = d\sigma_{\rm L}/d\phi + d\sigma_{\rm T}/d\phi)$. Therefore, the ϕ distribution in the Breit frame is an excellent tool to identify and study interference terms.

3. Numerical results for Compton process $ep \to e\gamma X$

We calculate various contributions to the cross sections for the unpolarised Compton process $ep \to e\gamma X$ in both the CM_{ep} and Breit frames for the HERA energy $\sqrt{S_{ep}} = 300$ GeV. We consider the emission of the γ from the hadronic vertex at the Born level (*i.e.* the $\gamma^* q \to \gamma q$ subprocess only)[1]. For the proton we have used the CTEQ5L parton parametrisation [8] with $N_f = 4$ and the hard scale equals to $p_{\rm T}$.

[1] The cross section for the Bethe–Heitler process, *i.e.* production of the γ from the electron line, can be neglected for the photon's rapidity range $Y(CM_{ep}) < 0$ [6].

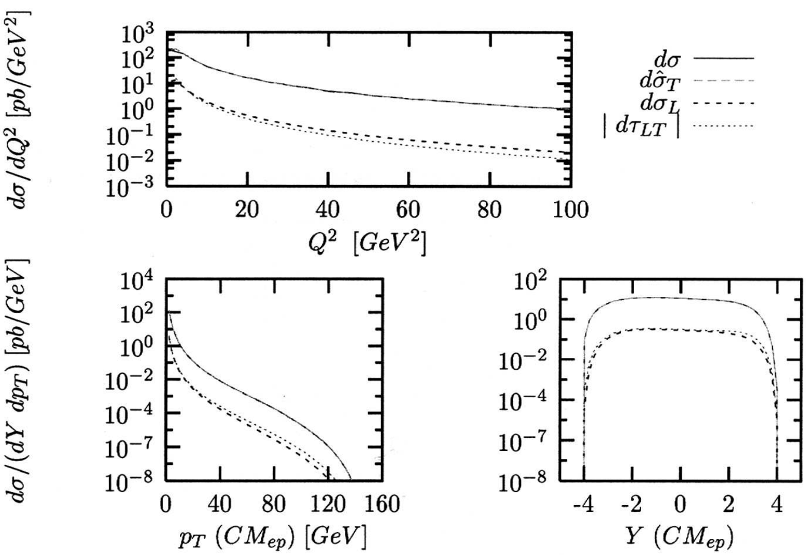

Fig. 3. Contributions to $d\sigma/dQ^2$ (at the top) and to $d\sigma/(dp_{\mathrm{T}}dY)$ (below) as a functions of p_{T} with $Y = 0$ (on left) or Y with $p_{\mathrm{T}} = 5$ GeV (on right), in CM_{ep}.

The cross section $d\sigma/dQ^2$, (Fig. 3, top) is strongly dominated by contribution due to the transversely polarised γ^*, even for large values of virtuality Q^2. Also the cross sections $d\sigma/(dp_{\mathrm{T}}dY)$ (Fig. 3, bottom), as a function of p_{T} or rapidity Y, are very well described by the γ^*_{T} cross section only. Both contributions coming from the γ^*_{L}, $d\sigma_{\mathrm{L}}$ and $d\tau_{\mathrm{LT}}$, are below 10%, moreover due to opposite signs they almost cancel each other.

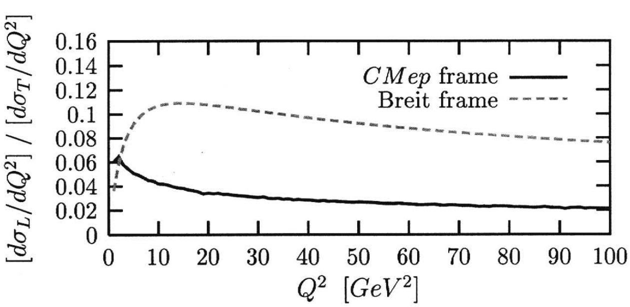

Fig. 4. The ratio $[d\sigma_{\mathrm{L}}/dQ^2]/[d\sigma_{\mathrm{T}}/dQ^2]$ as a function of Q^2, in the CM_{ep} frame (solid line) and in the Breit frame (dashed line).

The ratio $[d\sigma_{\mathrm{L}}/dQ^2]/[d\sigma_{\mathrm{T}}/dQ^2]$ (Fig. 3) shows interesting Q^2 dependence in two reference frames (CM_{ep} and Breit frame). We see that domination of the cross sections by γ^*_{T} is stronger in the CM_{ep} frame in which $d\sigma_{\mathrm{L}}$ and $d\tau_{\mathrm{LT}}$ almost cancel each other.

For the azimuthal angle distribution in Breit frame the relatively large sensitivity to the interference term $d\tau_{\rm LT}$ is found (Fig. 5), while the interference between two different transverse polarisation states of γ is invisible.

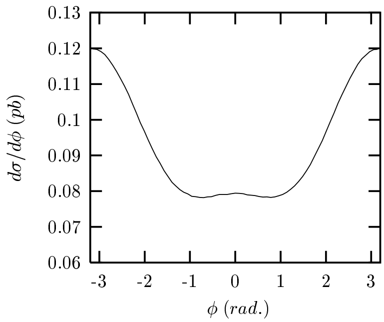

Fig. 5. The $d\sigma/d\phi$ in the Breit frame.

4. Conclusions

Our analysis show that the cross section for the Compton process (the Born level) in CM_{ep} is strongly dominated by $\gamma^*_{\rm T}$. If the contributions due to $\gamma^*_{\rm L}$ are included then interference terms need to be included in a consistent analysis because they both are similar in size but opposite in sign.

The studies of the azimuthal angle dependence, $d\sigma^{ep\to e\gamma X}/d\phi$, in the Breit frame give access to the longitudinal-transverse interference term.

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