CHARM PHOTOPRODUCTION AT LARGE TRANSVERSE MOMENTUM AND THE CHARM CONTENT OF THE PHOTON

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Abstract

The charm quark photoproduction at large transverse momentum in the resolved photon interaction via partonic subprocess $c(\gamma)g \to cg$ is studied. It is shown that at HERA energies the contribution of the charm quark excitation in the photon in the inclusive charm production at $p_\perp > 5$ GeV/c dominates over the other resolved photon contribution via the gluon content of the photon and it is about 30% of the contribution of the $c\bar{c}$-pair production via the photon-gluon fusion mechanism.

The study of the charm quark photoproduction on protons at high energies is a clean test of QCD as well as our knowledge of the gluon distribution in the proton [1]-[6]. Recent experiment at HERA ep-collider have shown that the resolved photon interaction, which probes the photon structure, also can be very important in the charm quark photoproduction process [7].

It is well known that the pure perturbative QCD calculations are not adequate to describe the observed charm photoproduction data for $p_\perp$ and x_F distributions. There are strong dependence on the value of the c-quark mass, $k_\perp$-smearing and other nonperturbative effects. In the region of large transverse momentum $p_\perp >> m_c$ the results based on the perturbative QCD must be more reliable. Previous calculations of the c-quark inclusive photoproduction at large $p_\perp$ have included LO and NLO direct charm production via photon-gluon fusion [1]-[6], including the semihard approach calculations [2, 8, 9, 10], the resolved photon contribution via subprocess $g(\gamma)g \to c\bar{c}$ [5, 11] and the diffractive-like photoproduction in the vector-meson-dominance (VMD) model [12]. Recently we have shown the important role of the c-quark photon structure function (PSF) in the J/ψ [13] and B_c-meson [14] photoproduction at large transverse momentum via partonic subprocesses $c(\gamma)g \to J/\psi c$ and $c(\gamma)\gamma \to B_c b$. It is obviously that the similar mechanism also plays a crucial role in the open charm photoproduction at large $p_\perp$ via subprocess $c(\gamma)g \to cg$. Note, that early the charm quark hadroproduction via subprocess $cg \to cg$ [15] as well as J/ψ hadroproduction via subprocess $cg \to J/\psi c$ [16] have been studied, based on charm quark excitation model.

The conception of the intrinsic charm quark in the photon or the proton is theoretically justified in the processes, where the charm quark in the initial parton state receives sufficient transfer momentum $\hat{t}$, which is necessary to excite $c\bar{c}$ pair. This condition takes place for charm quark photoproduction at the large $p_\perp$, where the relevant scale is $Q^2 \sim M_\perp^2 = p_\perp^2 + m_c^2 >> m_c^2$.

In the parton model the measurable cross section for the charm quark photoproduction is defined by the parton level QCD cross section $\hat{\sigma}(cg \to cg)$ and the respective parton distribution functions:

$$\frac{d\sigma}{dp_\perp^2 dy^\star}(\gamma p \to cX) =$$

$$\int_{x_{1,min}}^{1} dx_1 \frac{C_\gamma(x_1,Q^2)G_p(x_2,Q^2)}{x_1 - \frac{M_\perp}{\sqrt{s}}e^{y^\star}} \frac{d\hat{\sigma}}{d\hat{t}}(cg \to cg), \qquad (1)$$

where

$$x_2 = \frac{x_1\sqrt{s}M_\perp e^{-y^\star} - 2m_c^2}{x_1 s - \sqrt{s}M_\perp e^{y^\star}}, \qquad x_{1,min} = \frac{\sqrt{s}M_\perp e^{y^\star} - 2m_c^2}{s - \sqrt{s}M_\perp e^{-y^\star}},$$

$\hat{t} = 2M_\perp^2 - x_1\sqrt{s}M_\perp e^{-y^\star}$, $\hat{u} = M_\perp^2 - x_2\sqrt{s}M_\perp e^{y^\star}$, $\hat{s} = m_c^2 + x_1 x_2 s$, $y^\star$ and $p_\perp$ are the c-quark rapidity and transverse momentum, s is the square of a total energy in γp center of mass reference frame. The explicit formula for the differential cross section $\frac{d\hat{\sigma}}{d\hat{t}}(gc \to gc)$ is taken from [15]. All our calculations are based on the LO-GRV gluon distribution in the proton $G_p(x,Q^2)$ [17] evaluated at the scale $Q^2 = M_\perp^2$. For c-quark PSF we use phenomenological parameterization based on the VMD model [12] as well as QCD motivated LO-GRV parameterization [18]. In the Fig.1 the x-dependence of the c-quark PSF at the scale $Q^2 = 4m_c^2$ is presented for both parameterizations. In spite of the different x-dependence, both parameterization gives the approximately equal values for the mean value of the photon momentum, which is carried by charm quarks: $\sim 0.7 \cdot 10^{-3}$.

The results of the calculation of the $p_\perp-$spectra for c-quark photoproduction at $\sqrt{s} =$ 200 GeV are shown in Fig.2. The curve 1 is the contribution of the photon-gluon mechanism. The curves 2 and 3 are contributions of the c-quark PSF at the different values of the dynamical cutoff [15]: curve 2 corresponds to $|\hat{t}_{min}| = m_c$ and curve 3 – $|\hat{t}_{min}| = 4m_c^2$. One has strong suppression for the c-quark PSF contribution at small $p_\perp$ versus $|\hat{t}_{min}|$. Howere, the results of the calculation are independent of $|\hat{t}_{min}|$ at the large $p_\perp > 5$ GeV/c, where the condition $Q^2 = p_\perp^2 + m_c^2 >> m_c^2$ is satisfied. The curve 4 in Fig.2 is the contribution of the gluon PSF via subprocess $g(\gamma)g \to c\bar{c}$. We can see that the contribution of the gluon PSF is large smaller than the contribution of the c-quark PSF at all $p_\perp > 5$ GeV/c. This conclusion is independent of the c-quark PSF parameterization.

Fig.3 shows the $y^\star$-spectra for c-quark photoproduction at $\sqrt{s} = 200$ GeV and $p_\perp > 5$ GeV/c. The curves 1 and 4 are the same as in Fig.2. The curves 2 and 3 are the contributions of the c-quark PSF at the different parameterization of the PSF: 2 is GRV parameterization [18], 3 is VMD parameterization [12]. The sufficient difference between curve 2 and 3 gives us opportunity to check experimentally the nature of the charm content of the photon in the c-quark photoproduction at the large $p_\perp$. The region of $y^\star < 0$ is also sensitive to the gluon PSF contribution. At $y^\star < 0$ the total contribution of the resolved photon interaction (gluon plus c-quark PSF) becomes larger than the contribution of the direct photon-gluon fusion mechanism (curve 1).

In the Fig.4 the results of the calculation for the total cross section of the charm quark photoproduction at $p_\perp > 5$ GeV/c and all $y^\star$ are presented. The notation as in Fig.3. The contribution of the gluon PSF is strongly suppressed to compare with the c-quark PSF contribution. The last one is about 30% from the dominant photon-gluon fusion contribution at $\sqrt{s} = 200$ GeV and beyond. The both parameterizations of the c-quark PSF gives the equal contributions, which speedily growth versus energy beginning with $\sqrt{s} = 50$ GeV.

In conclusion we want note that our analyze shows the important role of the charm content in the photon for large $p_\perp$ charm quark photoproduction at HERA energy and beyond, independently on the choice of the c-quark PSF parameterization. Our calculation, based on PSF approach, sums up the large logarithmic terms $log(p_\perp^2/m^2)$ and gives more reliable predictions for large $p_\perp$ charm photoproduction than the pure NLO perturbative QCD calculations of the $2 \to 3$ subprocesses. When our work was near to completion, a related study appeared in ref.[19]. Taking into account that we use different sets of the parton densities in the proton and the photon, our conclusions in general is the same as in [19].

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Figure captions

1. The charm quark distribution in the photon at the scale $Q^2 = 4m_c^2$. The curve 1 corresponds to the parameterization [12], the curve 2 - [18].
2. The $p_\perp$ distribution for c-quark photoproduction at $\sqrt{s} = 200$ GeV and all $y^\star$. The curve 1 is the direct photon-gluon fusion contribution. The curve 4 is the resolved photon contribution via the $g(\gamma)g \to c\bar{c}$ subprocess. The short-dashed curves are the contribution of the charm quark excitation in the photon, the curve 2 corresponds to $|\hat{t}|_{min} = m_c^2$ and the curve 3 corresponds to $|\hat{t}|_{min} = 4m_c^2$.
3. The $y^\star$-distribution for the c-quark photoproduction at $\sqrt{s} = 200$ GeV and $p_\perp > 5$ GeV/c. The curve 1 is the direct photon-gluon fusion contribution. The curve 4 is the resolved photon contribution via the $g(\gamma)g \to c\bar{c}$ subprocess. The short-dashed curves are the contributions of the c-quark PSF, the curve 2 corresponds to VMD parameterization [12] and the curve 3 corresponds to GRV parameterization [18] of the c-quark PSF.
4. The total cross section for the c-quark photoproduction at all $y^\star$ and $p_\perp > 5$ GeV/c versus $\sqrt{s}$. Notation as in Fig.3.