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HIGH TWIST CONTRIBUTIONS, QUANTUM CHROMODYNAMICS, AND INCLUSIVE MESON PHOTOPRODUCTION AT LARGE p_T

F.S.SADYCHOV, C.AYDIN*, A.I.AHMADOV
Institute for Physical Problems
Baku State University
Karadeniz Technical University, Department of Physics, Trabzon (Turkey)

In this article, we investigate the contribution of the high twist Feynman diagrams to the large- p_T single pseudoscalar meson inclusive production cross section in photon-proton collisions and we present the general formulae for the high and leading twist differential cross sections. The pion wave function where two non-trivial Gegenbauer coefficients a_2 and a_4 have been extracted from the CLEO data, Braun-Filyanov pion wave function, the asymptotic and the Chernyak-Zhitnitsky wave functions are used in the calculations. The results of all the calculations reveal that the high twist cross sections, the ratio R, the dependence transverse momentum p_T and the rapidity y of meson in the $\varphi_{GLEO}(x,Q^2)$ wave function case is very close to the $\varphi_{asy}(x)$ asymptotic wave function case. It is shown that the high twist contribution to the cross section depends on the choice of the meson wave functions.

I. INTRODUCTION

During the last few years, a great deal of progress has been made in the investigation of the properties of hadronic wave functions[1-23]. The notion of distribution amplitudes refers to momentum fraction distributions of partons in meson in particular Fock state with fixed number of components. For the minimal number of constituents, the distribution amplitude Φ is related to the Bethe-Salpeter wave function Φ_{BS} by

$$\Phi(x) \sim \int^{|k_\perp|<\mu} d^2k_\perp \Phi_{BS}(x,k_\perp). \quad (1)$$

The standard approach to distribution amplitudes, which is due to Brodsky and Lepage [13], considers the hadron's parton decomposition in the infinite momentum frame. A conceptually different, but mathematically equivalent formalizm is the light-cone quantization [14]. Either way, power suppressed contributions to exclusive processes in QCD, which are commonly refered to as higher twist corrections. The meson wave functions (also called distribution amplitudes -DA) [1] play a key role in the hard-scattering QCD processes because they encapsulate the essential nonperturbative features of the meson's internal structure in terms of the parton's longitudinal momentum fractions x_i. Meson wave functions have been extensively studied by using QCD sum rules. The original suggestion by Chernyak and Zhitnitsky of a "double-humped" wave function of the pion at a low scale, far from the asymptotic form, was based on an extraction of the first few moments from a standard QCD sum rule approach [5], which has been criticized and revised in Refs.[6,7]. Subsequently, a number of authors have proposed and studied the modified versions of meson [7,8] and baryon wave functions [9,10]. Additional arguments in favour of a form of the pion wave functions close to the asymptotic one have come from the analysis of the transition form factor $\gamma\gamma^{*} \to \pi^{0}$ [12]. The measurements of this form factor by the CLEO collaboration are consistent with a near-asymptotic form of the wave function[15]. In [16], the leading-twist wave function of the pion at a low normalization point is calculated in the effective low-energy theory derived from the instanton vacuum. These results for the pion wave function at the low normalization point are close to the asymptotic form and consistent with the CLEO measurements. The authors have obtained a shape substantially different from the Chernyak-Zhitnitsky one because they have chosen a significantly smaller value of the second moment, and, more importantly, they have taken all the moments of the wave function into account. Their results support the conclusions reached previously in Refs.[6,7]. The QCD factorization theorems predict that the hadron-hadron cross section can be obtained by the convolution of parton distribution functions and a cross section of the corresponding hard scattering subprocess. By taking these points into account, it may be asserted that the analysis of the higher twist effects on the dependence of the meson wave function in single pseudoscalar and vector meson production at photon-proton collisions are significant in both theoretical and experimental studies. Another important aspect of this study is the choice of the meson model wave functions. In this respect, the contribution of the high twist Feynman diagrams to a single meson production cross section in photon-proton collisions has been computed by using various meson wave functions. Also, the leading and high twist contributions have been estimated and compared to each other. Within this context, this paper is organized as follows: in section II, we provide some formulae for the calculation of the contribution of the high twist dagrams. In section III, weprovide the formulae for the calculation of the contribution of the leading twist diagrams and in section IV, we present the numerical results for the cross section and discuss the dependence of the cross section on the meson wave functions. We state our conclusions in section V.

II.CONTRIBUTION OF THE HIGH TWIST DIAGRAMS

The high twist subprocess for the meson production in the photon hadron collision is $\gamma q_1 \to (q_1\bar{q}_2)q_2$. Using Brodsky –Lepage formula [24].

$$M(\hat{s},\hat{t}) = \int_0^1\int_0^1 dx_1 dx_2 \delta(1-x_1-x_2) \;\; T_H(\hat{s},\hat{t},x_1,x_2)\phi_\pi(x_1,x_2,Q^2) \quad (2)$$

the amplitude of the process can be estimated. Here, $\hat{s}=(Q+p_1)^2=(p_2+p_\pi)^2$, $\hat{u}=(Q-p_2)^2=(p_\pi-p_1)^2$, $\hat{t}=(Q-p_\pi)^2=(p_2-p_1)^2$ are the kinematic invariants.

In Eq. (1), T_H is the sum of graphs contributing to the subprocess $\gamma q_1 \to (q_1\bar{q}_2)q_2$. Here $(q_1,\bar{q}_2)$ is the colour singlet pseudoscalar meson state. In the ϕ_π pion wave function are all of the nonperturbative and process independent effects of hadronic binding contained. In our investigation we neglect the pion mass. In our work, we have restricted ourselves to considering the lowest Fock state for a meson. Then $x = x_1, x_2$ and $x_1 + x_2 = 1$. This approach can be applied not only to the investigation of exclusive processes [25], but also to the calculation of higher twist corrections to some inclusive processes such as large-p_T dilepton production [26], two-jet+ meson production in the electron-positron annihilation [27], ets. In our calculation, we have also neglected the quark masses. We have aimed to calculate the single meson production cross section and to fix the differences due to the use of various meson wave functions. We have used four different functions: the asymptotic wave function ASY, the Chernyak-Zhitnitsky [2,5] and the wave function in which two non-trivial Gegenbauer coefficients a_2 and a_4 have been extracted from the CLEO data on the $\gamma\gamma^* \to \pi^0$ transition form factor [28] and Braun-Filyanov wave function [7]. In ref.[28], the authors have used the QCD light-cone sum rules approach and have included into their analysis the NLO perturbative and twist-four corrections. The parameters of model wave function have been calculated by using the QCD sum rule method at $\mu_0^2 = 1(GeV)^2$. The pion function $\phi_\pi(x,Q^2)$ can be found for other values of Q as a solution of Beths-Salpeter type equation:

$$\phi_\pi(x,Q^2) = \phi_{ASY}(x)\sum_{n=0}^{\infty} r_n C_n^{3/2}(2x-1)\left[\frac{\alpha_S(Q^2)}{\alpha_S(\mu_0^2)}\right]^{\gamma_n/b_0} \tag{3}$$

Here $\{C_n^{3/2}(2x-1)\}$ is the system of Gegenbauer Polinoms in the pion distributions: $C_0^{3/2}(2x-1)=1$, $C_4^{3/2}(2x-1)=\frac{15}{8}(21(2x-1)^4-14(2x-1)^2+1)$ and γ_n anomalous dimensions. γ_n, b_0 have the following form:

$$\gamma_n = \frac{4}{3}\left[1-\frac{2}{(n+1)(n+2)}+4\sum_{j=2}^{n+1}\frac{1}{j}\right],\ b_0 = 11-\frac{2}{3}N_F, \tag{4}$$

The running QCD coupling constant $\alpha_S(Q^2)$ is defined as

$$\alpha_S(Q^2) = 12\pi/(33-2N_F)\ln\frac{Q^2}{\Lambda^2} \tag{5}$$

N_F is the number of quark flavours and Λ is the QCD scale parameter.
In our calculations we take $N_F = 3$, $\Lambda = 0{,}25GeV$.
The differential cross section of the subprocess $\gamma q_1 \to (q_1\bar{q}_2)q_2$ is given by

$$\frac{d\sigma}{d\hat{t}} = \frac{8\pi^2\alpha C_F}{9}[\Delta(\hat{s},\hat{u})]^2\frac{1}{\hat{s}^2(-\hat{t})}\left[\frac{1}{\hat{s}^2}+\frac{1}{\hat{u}^2}\right] \tag{6}$$

$$\Delta(\hat{s},\hat{t}) = \left[\hat{u}e_1\alpha_s\left[\frac{\hat{s}}{2}\right]I_M\left[\frac{\hat{s}}{2}\right] + \hat{s}e_2\alpha_s\left[-\frac{\hat{u}}{2}\right]I_M\left[-\frac{\hat{u}}{2}\right]\right] \qquad (7)$$

where $\alpha = 1/137$ is the fine structure constant and $C_F = \frac{4}{3}$ is color factor.

Following the usual method, high twist contribution to the cross section can be written as [17]

$$\sum_M^H \equiv E\frac{d\sigma^{HT}}{d^3p}(\gamma p \to \pi x) = \frac{1}{\pi}\int_0^1 dx\delta(\hat{s}+\hat{t}+\hat{u})\hat{s}G_{q/p}(x,-\hat{t})\frac{d\sigma}{dt} \qquad (8)$$

with $\hat{s} = xs$, $\hat{t} = t$, $\hat{u} = xu$, $x = -t/(s+u)$, $G_{q/p}(x,-\hat{t})$ is the parton distribution in hadrons:

$$E\frac{d\sigma^{HT}}{d^3p} = xG_{q/p}\left(\frac{s}{s+u}\right)\frac{1}{\pi}\frac{d\sigma}{d\hat{t}} \qquad E\frac{d\sigma}{d^3p} = \frac{1}{\pi}\frac{d\sigma}{dydP_T^2} \qquad (9)$$

The subprocess invariants are defined as

$$s = (Q+P_p)^2,\ t = (Q-P_p)^2 = -\frac{s}{2}(x_R - x_F),\ u = (P_p - P_\pi)^2 = -\frac{s}{2}(x_R + x_F)$$

with $x_R = (x_F^2 + x_T^2)^{1/2}$, $x_F = 2(p_M)_{//}/\sqrt{s}$, $x_T = 2(p_M)_\perp/\sqrt{s}$.

In terms of X_R and X_F the rapidity can be written as

$$y = \frac{1}{2}\ln\left[(x_R + x_F)/(x_R - x_F)\right]$$

III. CONTRIBUTION OF THE LEADING TWIST DIAGRAMS

Regarding the high twist corrections to the pion production cross section, a comparison of our results with leading twist contribution is crucial.The corresponding cross section is easily verified as

$$\left.\frac{d\sigma}{d\hat{t}}\right|_{\gamma q \to gq}(\hat{s},\hat{t},\hat{u}) = -\frac{8\pi}{3}e_q^2\alpha\frac{1}{\hat{s}^2}\left|\alpha_s(\hat{s})\frac{\hat{t}}{\hat{s}} + \alpha_s(-\hat{t})\frac{\hat{s}}{\hat{t}}\right|. \qquad (10)$$

For the leading –twist (LT) contribution, we find

$$\sum_M^{MT} = E\frac{d\sigma^{MT}}{d^3p}(\gamma p \to MX) = \frac{1}{\pi}\int_0^1 dx\int_0^1\frac{dz}{z^2}\delta(\hat{s}+\hat{t}+\hat{u})\hat{s}G_{q/p}(x,-\hat{t})D_{M/q}(z,-\hat{t})\left.\frac{d\sigma}{d\hat{t}}\right|_{\gamma q\to gq}(\hat{s},\hat{t},\hat{u}), \qquad (11)$$

where

$$\hat{s} = xs,\ \hat{t} = \frac{t}{z},\ u = \frac{xu}{z} \qquad (12)$$

$D_{M/q}(z,-\hat{t})$ represents the quark fragmentation function into a meson containing a quark of the same flavor.In the leading twist subprocess π meson is indirectly emitted from the quark fractional momentum z. The δ function may be expressed in terms of the parton kinematic variables, and the z integration may the be done.

The final form for the cros section is

$$\sum_M^{MT} = E\frac{d\sigma^{MT}}{d^3p}(\gamma p\to MX) = \frac{1}{\pi}\int_0^1 dx\int_0^1 \frac{dz}{z^2}\delta(\hat{s}+\hat{t}+\hat{u})\hat{s}G_{q/p}(x,-\hat{t})D_{M/q}(z,-\hat{t})\frac{d\sigma}{d\hat{t}}\bigg|_{\gamma q\to gq}(\hat{s},\hat{t},\hat{u}) =$$

$$= \frac{1}{\pi}\int_0^1 \frac{dx}{-(t+xu)} sG_{q/p}(x,-\hat{t})D_{M/q}(z,-\hat{t})\frac{d\sigma}{d\hat{t}}\bigg|_{\gamma q\to gq}(\hat{s},\hat{t},\hat{u})$$

IV. NUMERICAL RESULTS AND DISCUSSION

In this section, the numerical results for higher twist effects on the dependence of the chosen meson wave functions in the process $\gamma p\to MX$ are discussed. We have calculated the dependence on the meson wave functions for the high twist contribution to the large-p_T single pseudoscalar π^+ mesons photoproduction cross section in the photon-proton collision. The π^- cross section are, of course, identical. In the calculations, the asymptotic $\phi_{asy}(x,Q^2)$, Chernyak-Zhitnitsky $\phi_{CZ}(x,Q^2)$, Braun-Filyanov wave function $\phi_{BF}(x,Q^2)$ [7], and also, the pion wave function, from which two non-trivial Gegenbauer coefficients a_2 and a_4 have been extracted from the CLEO data on the $\pi^0\gamma$ transition form factor have been used[20]. In the ref.[28], authors have used the QCD light-cone sum rules approach and included into their analysis the NLO perturbative and twist-four corrections. For the high twist subprocess, we take $\gamma q\to Mq$ and we have extracted the following two high twist subprocess $\gamma q_1\to(q_1\bar{q}_2)q_2$, $\gamma\bar{q}_2\to(q_1\bar{q}_2)\bar{q}_2$ contributing to $\gamma p\to MX$ cross sections. Inclusive meson photoproduction represents a significant test case in which higher-twist terms dominate those of leading twist in certain kinematic domains. For the dominant leading twist subprocess for the meson production, we take the photon-quark collisions $\gamma q\to gq$, in which the M meson is indirectly emitted from the gluon. As an example for the quark distribution function inside the proton has been used [29]. The quark fragmentation function has been taken from [30]. The other problems dealth with are the choice of the QCD scale parameter Λ and the number of the active quark flavors n_f. In our calculations below we shal use the following values of the parameters Λ and μ_0: $\Lambda = 0.25GeV$, $\mu_0{}^2 = 1GeV^2$. Also, at the calculations for the Gegenbauer coefficients we use values in the normalization scale $\mu_0{}^2 = 1GeV^2$ from [30].

The high twist subprocesses probe the meson wave functions over a large range of Q^2 squared momentum transfer, carried by the gluon. Therefore, we take $Q_1^2=\hat{s}/2$, $Q_2^2=-\hat{u}/2$ which we have obtained directly from the high twist subprocesses diagrams. The same Q^2 has been used as an argument of $\alpha_s(Q^2)$ in the calculation of each diagram. The results of our numerical calculations are plotted in Figs.1-3. Figs.1-2 show the dependence of the differential cross sections of the high twist Σ_M^{HT},

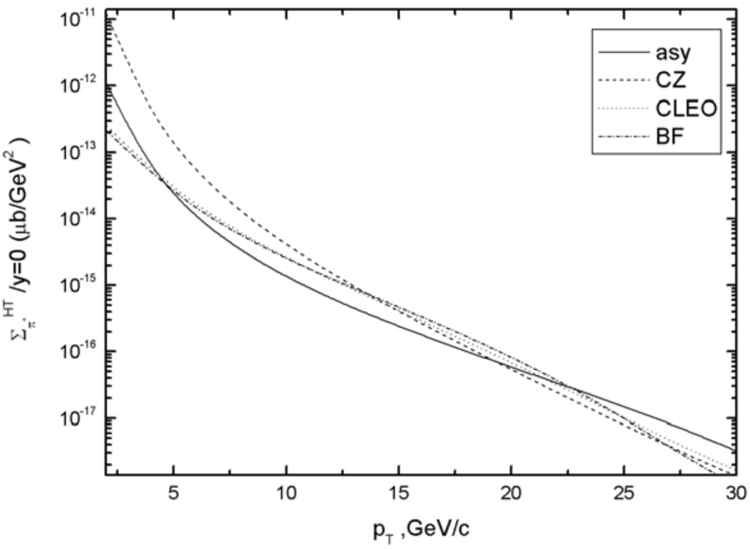

Fig.1. High twist meson M production cross sections as a function of the p_T transverse momentum of the meson at the c.m.energy , $\sqrt{s} = 89 GeV$.

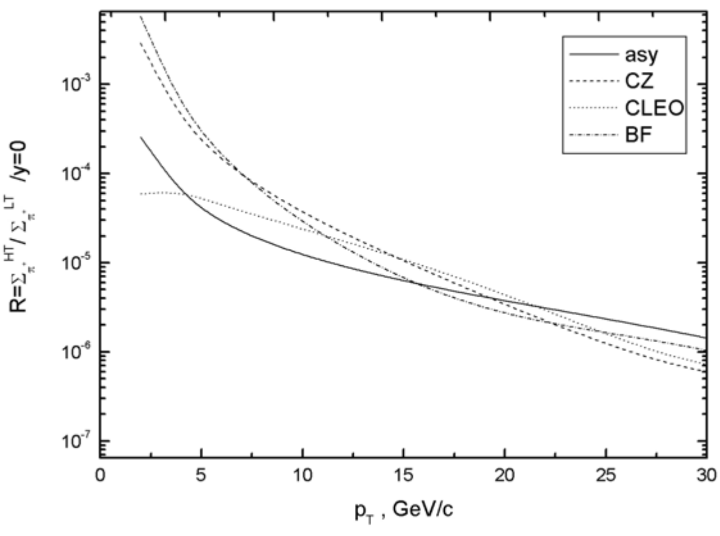

Fig.2. $R = \Sigma_M^{HT} / \Sigma_M^{LT}$, where the leading and the high twist contributions are calculated for the meson rapidity $y = 0$ at the c.m. energy $\sqrt{s} = 89 GeV$, as a function of the meson transverse momentum, p_T .

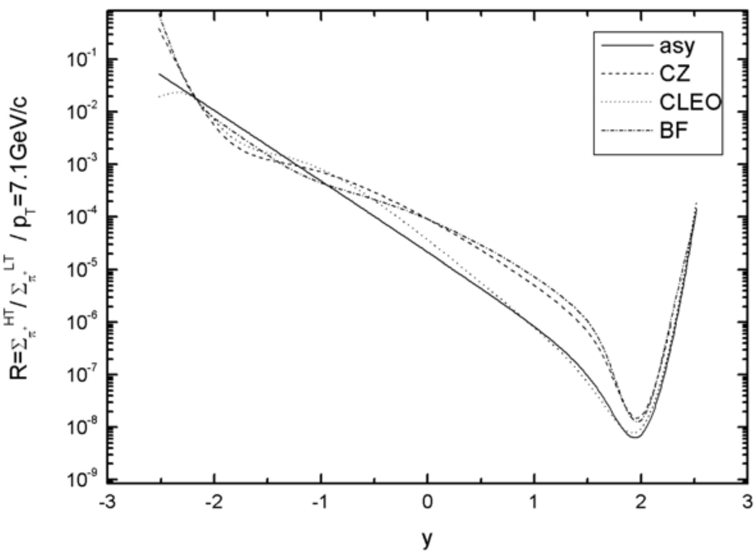

Fig.3. $R = \Sigma_M^{HT} / \Sigma_M^{LT}$, as a function of the y rapidity of the pion at the transverse momentum of the pion $p_T = 7.1 GeV/c$ at the c.m. energy $\sqrt{s} = 89 GeV$.

and ratio $R = \Sigma_M^{HT} / \Sigma_M^{LT}$ as a function of the meson transverse momentum p_T for four different meson wave functions. As shown in Fig.1, the high twist differential cross section is monotonically decreasing with an increase in the transverse momentum of the meson. As seen from Fig.1, in all wave functions of the mesons, the dependencies of the high twist cross sections on the p_T transverse momentum of the meson demonstrate the same behavior. Also, as seen from Fig.1 the leading twist cross section is 2-4 order suppress the high twist cross section in magnitude, on the dependence wave functions of meson, respectively. As seen from Fig.3, the higher twist corrections are very sensitive to the choice of the meson wave function. We should note that the magnitude of the high twist cross section in the pion wave function $\phi_{CLEO}(x,Q^2)$ case is very close to the asymptotic wave function $\phi_{asy}(x)$ case. In Fig.2, the ratio $R = \Sigma_M^{HT} / \Sigma_M^{LT}$ is plotted at $y = 0$ as a function of the meson transverse momentum p_T for the different meson wave functions. First of all, it is seen that the values of R for fixed y and $\sqrt{s}$ depend on the choice of the meson wave function. Also, the distinction betwee $R(\phi_{asy}(x))$ with $R(\phi_{CLEO}(x,Q^2))$, $R(\phi_{CZ}(x,Q^2))$, $R(\phi_{BF}(x,Q^2))$, and have been calculated. We have found that the distinction $R(\phi_{asy}(x))$ and $R(\phi_{CLEO}(x,Q^2))$ is small, whereas a distinction between $R(\phi_{asy}(x))$ with $R(\phi_{CZ}(x,Q^2))$, $R(\phi_{BF}(x,Q^2))$, is significant. In Fig.3, the ratio

$R = \Sigma_M^{HT} / \Sigma_M^{LT}$ is plotted at $p_T = 7.1 GeV/c$ as a function of the rapidity y of the meson for the different meson wave functions. As we are now in the high energy region, the change of the rapidity to determine these relations is given by $-\ln\sqrt{s}/p_T < y < \ln\sqrt{s}/p_T$. At $\sqrt{s} = 89 GeV$ and $p_T = 7.1 GeV/c$, the meson rapidity lies in the region $-2.5 \prec y \prec 2.5$. First of all, it is seen that the values of R for fixed p_T and $\sqrt{s}$ depend on the choice of the meson wave function. As shown in Fig.3 in all wave functions of the mesons, the dependencies of the ratio $R = \Sigma_M^{HT} / \Sigma_M^{LT}$ of the rapidity y of the meson has a minimum approximately at one point $y = 1.75$. After this point, the ratio increases with increasing y.

V. Concluding Remarks

In this work, we have calculated the higher twist contribution to the large-p_T meson production cross section to show the dependence on the chosen meson wave functions in the process $\gamma p \to MX$. In our calculations, we have used the asymptotic $\phi_{asy}(x)$ Chernyak-Zhitnitsky $\phi_{CZ}(x,Q^2)$, $\phi_{CZ}(x,Q^2)$, Braun-Filyanov wave functions and also, the pion wave function, in which the coefficients a_2 and a_4 have been extracted from the CLEO data on the $\pi^0\gamma$ transition form factor used. For the high twist subprocess, we have taken $\gamma q \to Mq$. We have extracted the following two high twist subprocesses $\gamma q_1 \to (q_1\bar{q}_2)q_2$, $\gamma \bar{q}_2 \to (q_1\bar{q}_2)\bar{q}_2$ contributing to $\gamma p \to MX$ cross sections. As the dominant leading twist subprocess for the meson production, we have taken the photon-quark collisions $\gamma q \to gq$, where the M meson is indirectly emitted from the quark. The results of our numerical calculations have been plotted in Figs.1-3. As shown in Figs.1 the high twist differential cross section monotonically decrease when the transverse momentum of the meson increases. As seen from Figs.1 in all wave functions of mesons, the dependencies of the high twist cross sections on the p_T transverse momentum of the meson demonstrate the same behavior. And the higher twist corrections and ratio R are very sensitive to the choice of the meson wave function. It should be noted that the magnitude of the high twist cross section for the pion wave function $\phi_{CLEO}(x,Q^2)$ is very close to the asymptotic wave function $\phi_{asy}(x)$.

Our investigation enables us to conclude that the high twist meson production cross section in the photon-proton collisions depends on the form of the meson model wave functions and may be used for their study. Further investigations are needed in order to clarify the role of high twist effects in QCD. Also we find higher twist contributions to single meson production cross section in the photon -proton collisions have important phenomenological consequences. Further investigations are needed in order to clarify the role of high twist effects in QCD

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KVANT XROMODİNAMİKASINDA YÜKSƏK TVİSTLƏRİN ƏLAVƏSİ VƏ BÖYÜK P_T-DƏ MEZONLARIN FOTOYARANMASI

F.S.SADIQOV, C.AYDIN, A.İ.ƏHMƏDOV

XÜLASƏ

Bu işdə yüksək tvistli Feynman diaqramlarının tək psevdoskalyar mezonların böyük p_T-lərdə inklüziv fotoyaranmasında verdiyi əlavələr tədqiq olunmuşdur. Yüksək və aparıcı tvistin diferensial effektiv kəsikləri təsvir olunmuşdur. Hesablamalarda asimptotik, Çernyak-Jitnitski, Braun–Filyanov və a_2 və a_4 qeyri-trivial Qeqenbauer əmsalları CLEO eksperimentlərindən tapılmış dalğa funksiyalarından istifadə olunmuşdur. Bütün hesablamalardan belə qənaətə gəlirik ki, yüksək tvist effektiv kəsikləri və R -nisbətləri mezonların p_T -eninə impulsundan və y yeyinliyindən asılılıqlarında mezonların $\phi_{CLEO}(x,Q^2)$ -dalğa funksiyası ilə hesablanmış qiymətləri $\phi_{ASY}(x)$ -dalğa funksiyası ilə hesablanmış qiymətinə çox yaxındır. Göstərilmişdir ki, yüksək tvist effektiv kəsikləri mezonların dalğa funksiyalarının seçilməsindən asılıdır.

ВКЛАД ВЫСШЕГО ТВИСТА В КВАНТОВОЙ ХРОМОДИНАМИКЕ И ФОТОРОЖДЕНИЯ МЕЗОНОВ В БОЛЬШИХ P_T

Ф.С.САДЫГОВ, Дж.АЙДЫН, А.И.АХМЕДОВ

РЕЗЮМЕ

В данной работе были исследованы вклады высшего твиста диаграмм Феймана при инклюзивном фоторождении больших p_T единичных псевдоскалярных мезонов. Построены изображения дифференциальных эффективных сечений высшего и ведущего твиста в фотон- протон столкновениях.

В расчетах были использованы асимптотические, нетривиальные коэффициенты a_2 и a_4 Геденбауэра, взятых из CLEO экспериментов волновой функции Браун-Фильянова и Черняк- Житницкого.

В результате вычислений выявлено, что сечения высшего твиста, R - отношение, зависимость поперечного импульса p_T и быстрота мезонов в волновой функции $\phi_{CLEO}(x,Q^2)$ очень близки к асимптотической волновой функции $\phi_{asy}(x)$. Показано, что вклады высшего твиста в эффективные сечения зависят от выбора волновой функции мезонов.