PROCEEDINGS OF SCIENCE

Unpolarized TMD quark distribution functions at low Q^2 scales

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We calculate the unpolarized transverse momentum dependent (TMD) quark distributions in the modified chiral quark model (χQM). To this end, we use the integrated quark densities which are multiplied by a TMD Gaussian factor. These integrated distributions are computed applying the χQM at low Q^2 value ($Q^2 = 0.35\ GeV^2$). Finally, we compare our results with corresponding ones which were obtained in our previous work via a different approach. It is shown that our results have appropriate treatment which is expected for the TMD quark densities.

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1. Introduction

To get a better understanding of the partonic substructure of the nucleon, it is needed to study the transverse momentum dependent parton distribution functions (TMDs) [1, 2, 3]. These densities have also been called the unintegrated parton distributions [4].
The description of some experimental observations is not possible without a three-dimensional picture of the nucleon including transverse motion. The integrated parton distribution functions (PDFs) can not give such 3-D picture of the nucleons, so the TMD densities are needed for this purpose [5, 6].
We calculated the unpolarized TMD quark distributions inside the proton using the modified chiral quark model in our previous work [7]. This model is valid at low Q^2 values. In Ref.[7], we first formulated the interactions which occur in the χQM at the first approximation in the TMD case and then obtained the TMD quark densities of the proton at $Q^2 = 0.35\ GeV^2$.
In this paper, we compute the TMD quark distributions via a different approach. In this approach, the integrated quark densities which are obtained applying the χQM are multiplied by a TMD Gaussian factor. Finally, we compare the results of this approach with the results of Ref.[7].

2. A relationship between the integrated PDFs and unpolarized TMDs

In this section, we use a phenomenological approach which creates a contact between the integrated quark distribution functions ($q(x)$) and the TMD ones ($q(x, p_T)$). In this approach, the x dependence of the TMD quark densities is factorized and a Gaussian form is used for its p_T dependence [8, 9, 10]. The transverse momentum dependence of these quark distributions is parametrized applying the TMD Gaussian factor (TMD GF) as following [8, 9, 10]:

$$q(x, p_T) = q(x)\frac{1}{\pi\langle p_T^2\rangle}\ \exp(\frac{-p_T^2}{\langle p_T^2\rangle}), \tag{2.1}$$

which [10]

$$\int \frac{1}{\pi\langle p_T^2\rangle}\ \exp(\frac{-p_T^2}{\langle p_T^2\rangle})\, dp_T^2 = 1. \tag{2.2}$$

In above equation $\langle p_T^2\rangle$ is the width of the TMD Gaussian factor which is adopted as $\langle p_T^2\rangle = 0.2\ GeV$ [11]. We also use the results of the modified chiral quark model for the integrated quark distribution functions ($q(x)$) which is appeared in Eq.(1). We explain the method of calculating these integrated densities using the χQM in the next section:

3. Modified chiral quark model

In this section, we calculate the integrated quark distribution functions applying the modified chiral quark model. In this model, proton is considered as a bounded system of bare u and d quarks (u_0, d_0). In this system, the clouds of Goldstone (GS) bosons and gluons surround the bare quarks [12, 13, 14].
At the first approximation, two basic interactions are occurred in the χQM which are represented

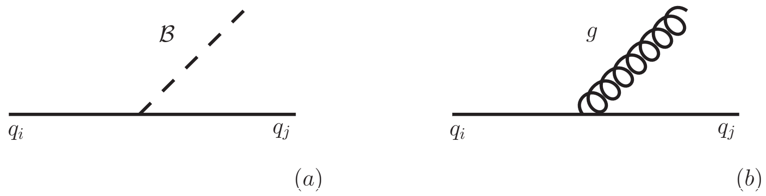

Figure 1: (a) The bare quark fluctuation into a GS boson $\mathcal{B}$ and a struck quark q_j. (b) The bare quark emits a gluon. This picture has quoted from Ref.[7]

in Fig.1. For the interaction of Fig.1(a), the distribution of j quark is written as [12, 13, 14]:

$$q_j(x) = \int_x^1 \frac{\mathrm{d}y}{y} P_{j\mathcal{B}/i}(y) q_{0,i}(\frac{x}{y}). \tag{3.1}$$

$P_{j\mathcal{B}/i}$ is the splitting function of the quark-GS boson vertex [12, 13, 14]:

$$P_{j\mathcal{B}/i}(y) = \frac{1}{8\pi^2} \int (\frac{g_A \bar{m}}{f})^2 \frac{(m_j - m_i y)^2 + k_\perp^2}{y^2(1-y)(m_i^2 - M_{j\mathcal{B}}^2)^2} \mathrm{d}k_\perp^2. \tag{3.2}$$

$M_{j\mathcal{B}}^2$ denotes the squared invariant mass of the final quark-GS boson state [12, 13, 14].
On the other hand, the interaction of Fig.1(b) is formulated as follows [14]:

$$q_j(x) = \int_x^1 \frac{\mathrm{d}y}{y} P_{jg/i}(y) q_{0,i}(\frac{x}{y}) , \tag{3.3}$$

where the quark-gluon vertex splitting function $P_{jg/i}$ is given as [14]:

$$P_{jg/i}(y) \ = \ \int C_f \frac{\alpha_s(Q^2)}{4\pi} \frac{1}{y(1-y)} G_{jg/i}^2 \frac{(y m_i - m_j)^2 + k_\perp^2}{y(m_i^2 - M_{jg}^2)^2} \mathrm{d}k_\perp^2 \ . \tag{3.4}$$

$G_{jg/i}$ is the quark-gluon vertex function [14].
According to above interactions, the quark distribution functions of the proton are obtained [12, 13, 14]:

$$u(x) = Z_u u_0(x) + P_{u\pi^-/d} \otimes d_0 + \frac{1}{2} P_{u\pi^0/u} \otimes u_0 + P_{ug/u} \otimes u_0, \tag{3.5}$$

$$d(x) = Z_d d_0(x) + P_{d\pi^+/u} \otimes u_0 + \frac{1}{2} P_{d\pi^0/d} \otimes d_0 + P_{dg/d} \otimes d_0, \tag{3.6}$$

$$s(x) = P_{sk^+/u} \otimes u_0 + P_{sk^0/d} \otimes d_0. \tag{3.7}$$

Z_u and Z_d are the renormelization constants for u_0 and d_0, respectively. The bare quark distributions are obtained by solving the Dirac equation including a potential with the squared radial symmetry [14, 15, 16].

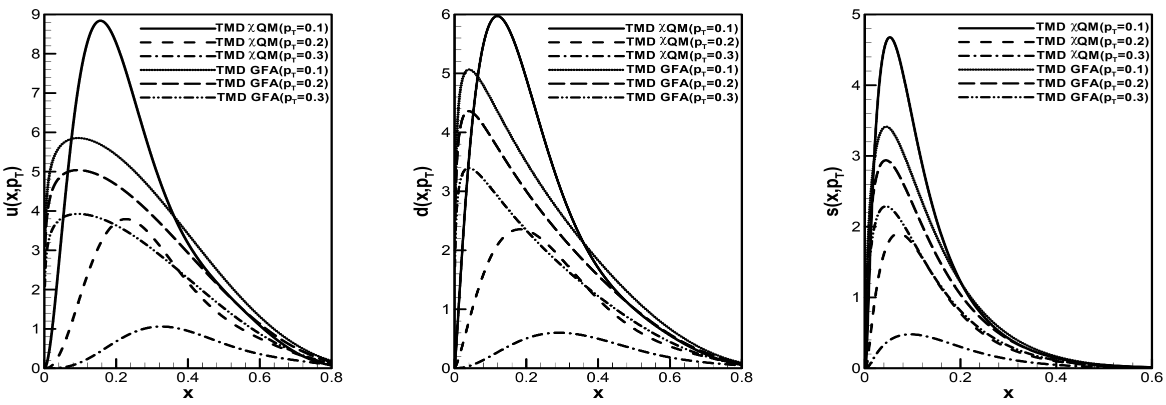

Figure 2: The TMD light quark densities with respect to x at $Q^2 = 0.35\ GeV^2$ for $p_T = 0.1, 0.2$ and $0.3\ GeV$. The results of the TMD Gaussian factor approach (TMD GFA) have been compared with the results of Ref.[7] (TMD χQM).

4. Results and discussion

We have calculated the unpolarized TMD quark distributions using Eq.(1). To this end, we have first obtained the integrated quark densities applying the modified chiral quark model at $Q^2 = 0.35\ GeV^2$. In Fig.2, we have depicted these TMD u, d and s quark distributions with respect to x at different values of transverse momentum p_T ($p_T = 0.1, 0.2$ and $0.3\ GeV$). In this figure, we have compared the result of this approximate approach (TMD GF approach) with the results of TMD χQM approach [7]. In Ref.[7], we extracted the TMD quark densities via the χQM, directly.

As can be seen in Fig.2, the results of both approaches show the same behaviour: the TMD distributions decrease by increasing the p_T value [7, 10, 17, 18]. This means that the probability of finding the quarks with larger p_T value, is lower.

We have also displayed the TMD u, d and s quark distributions with respect to p_T at different x values in Fig.3 and compared the results with the results of our previous work (TMD χQM). It is shown that the Gaussian width of these densities is x dependent [7, 10]. The width of the results of the TMD GF approach is larger than the TMD χQM ones. In the left side of Fig.3, the transverse momentum dependent quark distributions grow by increasing the x value in spite of the behaviour of the TMD quark densities in the right side of this figure [7].

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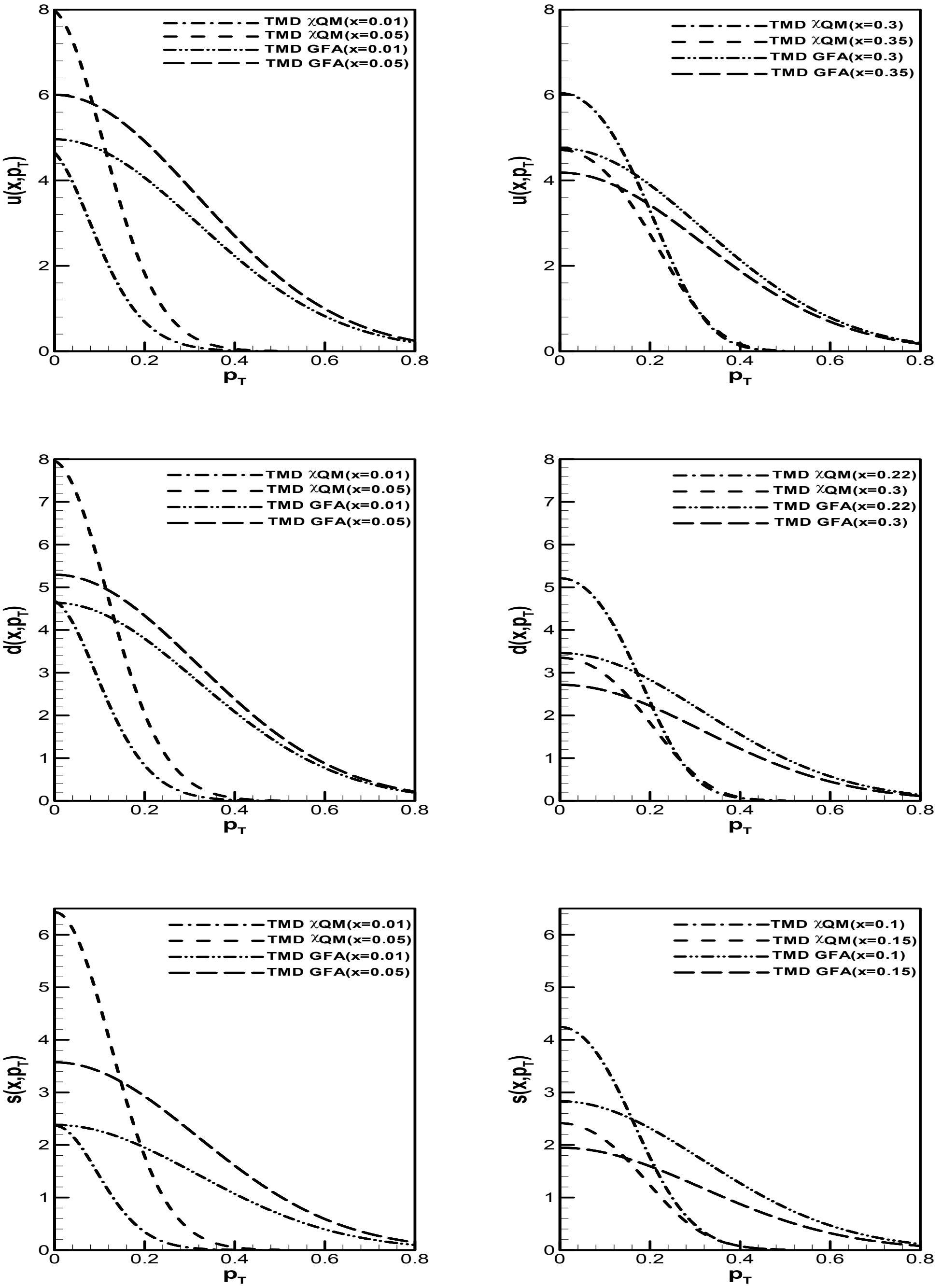

Figure 3: The TMD u, d and s quark distributions with respect to p_T at $Q^2 = 0.35\ GeV^2$. The results of the TMD Gaussian factor approach (TMD GFA) for different x values have been compared with the results of Ref.[7] (TMD χQM).

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