CHARM CONTENT OF A PROTON IN THE COLLINEAR PARTON MODEL AND K_T–FACTORIZATION APPROACH

*V.A.Saleev** and *D.V.Vasin*
Samara State University, Samara, 443011, Russia

Table of contents

*Email: saleev@ssu.samara.ru

Introduction

The result of a study the internal structure of a proton in the process of the lepton deep inelastic scattering (DIS) can be presented in terms of the proton structure function (SF) $F_2^p(x_B, Q^2)$ as a function of $Q^2 = -q^2$ and $x_B = Q^2/2(pq)$, where q is the exchange photon 4-momentum and p is the proton 4-momentum. In a process of the charmed quark leptoproduction the charmed content of the proton structure function $F_{2c}^p(x_B, Q^2)$ is probed. The recent measurings by the H1 [1] and the ZEUS [2] Collaborations at the HERA ep-collider include the following cinematic region: $1.8 < Q^2 < 130$ GeV^2 and $5 \cdot 10^{-5} < x_B < 2 \cdot 10^{-2}$.

[1] C.Adloff et al. (H1 Coll.), Nucl.Phys. **B545** (1999) 21; DESY 01-100, 2001.

[2] J.Breitweg et al. (ZEUS Coll.), Eur.Phys.J. **C12** (2000) 35.

Theoretically, the charmed quark SF has been studied in the framework of DGLAP [3] and BFKL [4] dynamics. In the case of a one-photon exchange approximation the hadron part of the DIS spin-average lepton-hadron cross section can be represented in the form

$$F^p_{\mu\nu} = e_{\mu\nu}(q)F^p_L(x_B, Q^2) + d_{\mu\nu}(q,p)F^p_2(x_B, Q^2), \quad (1)$$

where

$$e_{\mu\nu}(q) = g_{\mu\nu} - \frac{q_\mu q_\nu}{q^2}$$

and

$$d_{\mu\nu}(q,p) = -\left(g_{\mu\nu} + 2x_B\frac{(p_\mu q_\nu + p_\nu q_\mu)}{q^2} + p_\mu p_\nu \frac{4x_B^2}{q^2}\right).$$

[3] V.N. Gribov and L.N. Lipatov, Sov. J. Nucl. Phys. **15** (1972) 438 ; Yu.A. Dokshitser, Sov. Phys. JETP. **46** (1977) 641 ; G. Altarelli and G. Parisi, Nucl. Phys. **B126** (1977) 298.
[4] E.Kuraev, L.Lipatov, V.Fadin, Sov. Phys. JETP **44** (1976) 443; Y.Balitskii and L.Lipatov, Sov. J. Nucl. Phys. **28** (1978) 822.

The tenzor $F^p_{\mu\nu}$ is connected via the optical theorem with the amplitude of elastic forward scattering of a virtual photon on a proton $T^p_{\mu\nu}(q,p)$. Within the framework of the parton model or the k_T-factorization approach the amplitude $T^p_{\mu\nu}(q,p)$ can be written via the amplitude of elastic forward scattering of a photon on a gluon $T^g_{\mu\nu}(q,k)$, where k is the gluon 4-momentum. This amplitude is described by the quark box diagrams in the LO approximation for the running constant α_s. For example, in the k_T-factorization approach the SF $F^p_{2c}(x_B,Q^2)$ is written in the following way:

$$F^p_{2c}(x_B,Q^2) = \int_{x_B}^1 \frac{dx}{x}\int d\vec{k}_T^2 C_2^g(x,Q^2,m_c^2,\vec{k}_T^2) \Phi(\frac{x_B}{x},\vec{k}_T^2,Q^2), \qquad (2)$$

where $\Phi(x,\vec{k}_T^2,Q^2)$ is the unintegrated gluon distribution function in a proton, $k^\mu = xp^\mu + k_T^\mu$,

$$C_2^g(x,Q^2,m_c^2,\vec{k}_T^2)$$

is the universal coefficient function which can be calculated in the perturbative QCD. This type calculation of the $F^p_{2c}(x_B,Q^2)$ will be presented in the talk by A.Kotikov [5].

[5]A.Kotikov et al., hep-ph/ 0107135.

Here we will discussed another **method based on direct calculation of a total $c\bar{c}-$production cross section** in DIS $ep-$scattering. In such a way, we will obtained c-quark distribution function $C_p(x_B, Q^2)$ using the collinear parton model and k_T-factorization approach. It is supposed that charmed quark SF $F_{2c}^p(x_B, Q^2)$ and the distribution function $C_p(x_B, Q^2)$ are connected as follows

$$F_{2c}^p(x_B, Q^2) = 2e_c^2 x_B C_p(x_B, Q^2). \qquad (3)$$

The main aims

1. *To compare predictions obtained in the PM and KT* for $F_{2c}^p(x_B, Q^2)$

2. *To compare different methods of a calculation the c-quark SF*

3. *To test different parameterizations of an unintegrated gluon SF*

4. *To obtain the c-quark SF which can be used in calculations within framework of the charm excitation model*

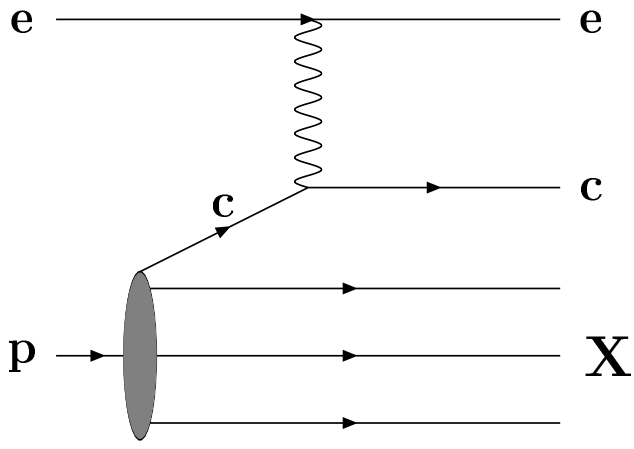
[A] D.Gunter, V.Saleev, Phys.Rev. **D64** (2001) 034006
[B] C.Qiao, J.Phys. **G29** (2003) 1

Electron DIS on the charm quark in a proton

In the framework of the parton picture of a proton and the one photon exchange approximation the charmed quark production cross section in the electron DIS can be considered as a convoluting of the c-quark distribution function in the proton and the electron – c-quark partonic cross section:

$$d\sigma(ep \to ecX) = \int dx_B C_p(x_B, Q^2) d\hat{\sigma}(ec \to ec). \quad (4)$$

The diagram of the relevant process is shown in Fig.1.



For the doubly differential cross section we can write

$$\frac{d\sigma}{dx_B dQ^2}(ep \to e'cX) = C_p(x_B, Q^2)\frac{\overline{|M(ec \to ec)|^2}}{16\pi(x_B s)^2}, \tag{5}$$

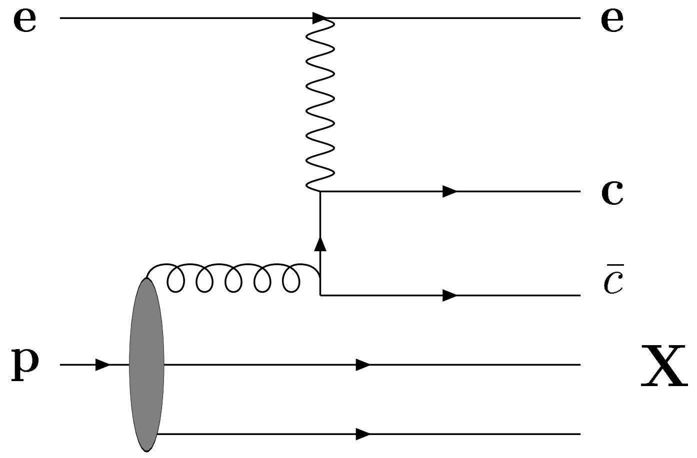
where $s = (p_e + p)^2$, p_e is the initial electron 4-momentum. The amplitude of an elastic $ec-$scattering has the following form

$$\overline{|M(ec \to ec)|^2} = 2\frac{e^4 e_c^2}{Q^4}(x_B s)^2 \left(y^2 - 2y + 2 - \frac{2m_c^2 y^2}{Q^2}\right), \tag{6}$$

where $y = Q^2/(x_B s)$. Such a way we have obtained the master formula

$$C_p(x_B, Q^2) = \frac{Q^4 \frac{d\sigma}{dx_B dQ^2}(ep \to ecX)}{2\pi\alpha^2 e_c^2 (y^2 - 2y + 2 - \frac{2m_c^2 y^2}{Q^2})}. \tag{7}$$

Electro-production cross section in the PM and KT



At the high energy the dominant mechanism of a c-quark electroproduction on a proton is the photon-gluon fusion. In the leading order approximation for the QCD running constant α_s one has the following subprocess

$$\gamma^* + g \to c + \bar{c}. \tag{8}$$

However, we don't reduce here the eg scattering amplitude to the $\gamma^* g$ amplitude and calculate the squared amplitude for the subprocess

$$e + g \to e + c + \bar{c}, \tag{9}$$

which is described by the two Feynman diagrams.

In the conventional collinear parton model it is suggested that hadronic cross section, in our case, $\sigma(ep \to ecX, s)$, and the relevant partonic cross section $\hat{\sigma}(eg \to ec\bar{c}, \hat{s})$ are connected as follows

$$\sigma^{PM}(ep \to ecX, s) = \int dx G(x, \mu^2) \hat{\sigma}(eg \to ec\bar{c}, \hat{s}), \tag{10}$$

where $\widehat{s} = xs$, $G(x, \mu^2)$ is the collinear gluon distribution function in a proton, x is the gluon fraction of a proton momentum, μ^2 is the typical scale of a hard process. The μ^2 evolution of the gluon distribution $G(x, \mu^2)$ is described by DGLAP evolution equation [3]. In the k_T-factorization approach hadronic and partonic cross sections are related by the following condition [6]:

$$\sigma^{KT}(ep \;\to\; ecX) = \int \frac{dx}{x} \int d\vec{k}_T^2 \int \frac{d\phi}{2\pi} \Phi(x, \vec{k}_T^2, \mu^2) \widehat{\sigma}(eg^* \to ec\bar{c}, \widehat{s}) \quad (11)$$

where $\widehat{\sigma}(eg^* \to ec\bar{c}, \widehat{s})$ is the c-quark production cross section on off mass-shell gluons, $k^2 = -\vec{k}_T^2$, $\widehat{s} = xs - \vec{k}_T^2$, ϕ is the azimuthal angle in the transverse XOY plane between vectors $\vec{k}_T$ and the fixed OX axis ($\vec{p}_e$ and $\vec{p}_e^{\,\prime} \in XOZ$).

[6] L.V.Gribov, E.M.Levin, M.G.Ryskin, Phys.Rep. **100** (1983) 1; J.C.Collins and R.K.Ellis, Nucl.Phys. **360** (1991) 3; S.Catani, M.Ciafoloni, F.Hautmann, Nucl.Phys. **B366** (1991) 135.

The unintegrated gluon distribution function $\Phi(x, \vec{k}_T^2, \mu^2)$ satisfies the BFKL evolution equation [4]. At the $x \ll 1$ the off mass-shell gluon has dominant longitudinal polarization along a proton momentum and the gluon polarization four-vector can be written in the two forms:

$$\varepsilon^\mu(k) = \frac{k_T^\mu}{|\vec{k}_T|} \text{ or } \varepsilon^\mu(k) = -\frac{xp^\mu}{|\vec{k}_T|}. \qquad (12)$$

Our calculation in the parton model is down using the GRV LO [7] and CTEQ5L [8] parameterizations for a collinear gluon distribution function $G(x, \mu^2)$. In the case of the k_T-factorization approach we use the following parameterizations for an unintegrated gluon distribution function $\Phi(x, \vec{k}_T^2, \mu^2)$: JB by Bluemlein [9], JS by Jung and Salam [10], KMR by Kimber, Martin and Ryskin [11].

[7] M.Gluck, E.Reya, A.Vogt, Z.Phys. **C67** (1995) 433.

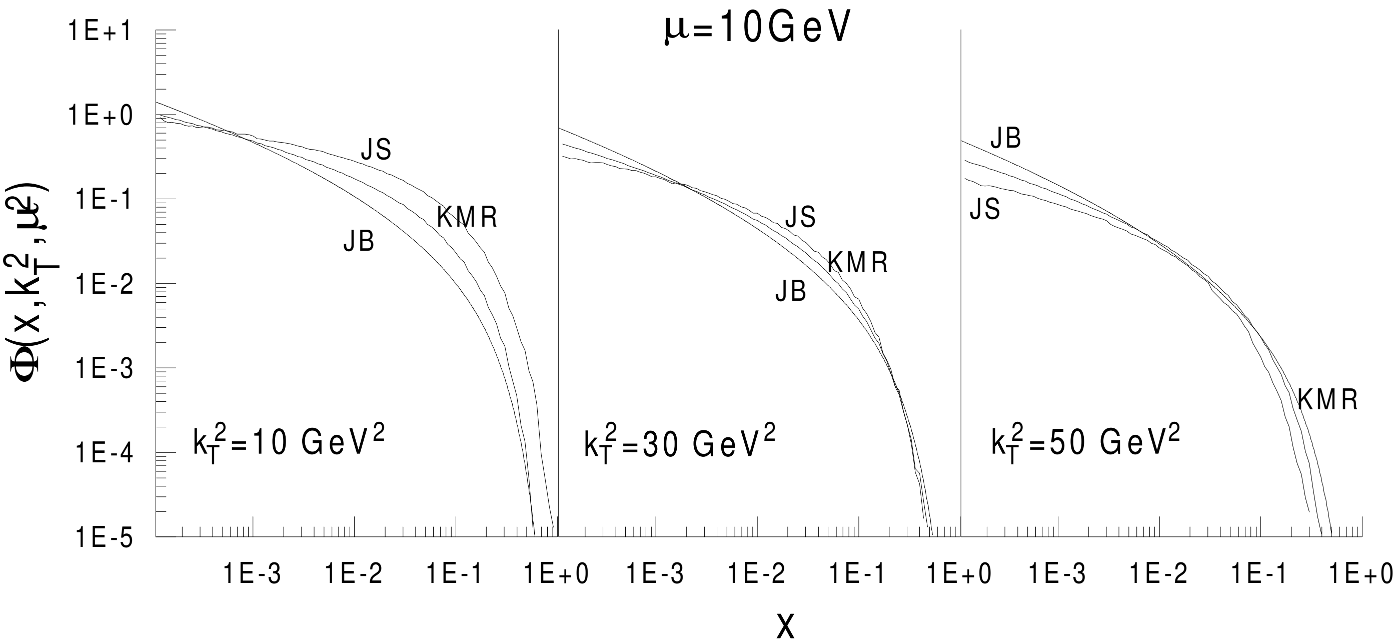
[8] CTEQ Coll., H.L.Lai et al. Eur.Phys.J **C12** (2000) 375.

[9] J.Blumlein, DESY **95-121**, (1995).

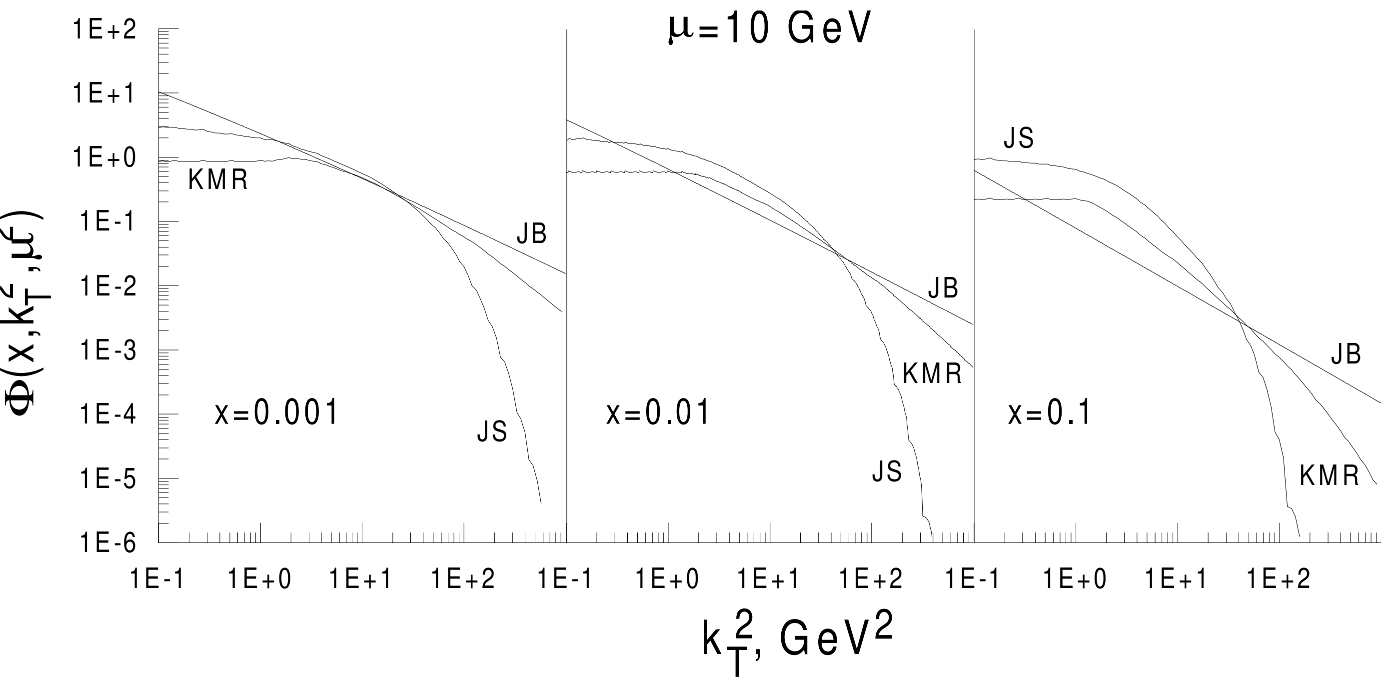
[10] H.Jung, G.Salam, Eur. Phys. J. **C19** (2001) 351.

[11] M.A.Kimber, A.D.Martin and M.G.Ryskin, Phys. Rev. **D63** (2001) 114027.

To compare different parameterizations we have plotted their as a function of x at the fixed $\vec{k}_T^2$ and μ^2 in Fig.2 and as a function of $\vec{k}_T^2$ at the fixed x and μ^2 in Fig.3.



The unintegrated gluon distribution function $\Phi(x, \vec{k}_T^2, \mu^2)$ versus x at the fixed values of μ and k_T^2.



The unintegrated gluon distribution function $\Phi(x, \vec{k}_T^2, \mu^2)$ versus k_T^2 at the fixed values of μ and x.

Finally, in the k_T-factorization formalism the doubly differential cross section for the process $ep \to ecX$ can be written as follows:

$$\frac{d\sigma^{KT}}{dx_B dQ^2}(ep \to ecX) = \frac{y}{x_B}\int dp_{cT}d\phi_c d\eta_c d\vec{k}_T^2 \frac{d\phi}{2\pi}\left(\frac{p_c p_{cT}}{E_c}\right) \frac{\overline{|M(eg \to ec\bar{c})|^2}}{256\pi^4(y-a_1)(xs)^2}\Phi(x,\vec{k}_T^2,\mu^2), \quad (13)$$

where $p_c = (E_c, \vec{p}_c)$ is the c-quark 4-momentum, η_c is the c-quark pseudorapidity, ϕ_c is the azimuthal angle between OX axis and vector $\vec{p}_{cT}$, $a_1 = 2(pp_c)/s$, $b_1 = 2(p_e p_c)/s$ and

$$x = \frac{\vec{k}_T^2 + Q^2 + yb_1 s + 2(\vec{q}_T\vec{k}_T) - 2(\vec{p}_{cT}\vec{k}_T) - 2(\vec{q}_T\vec{p}_{cT})}{(y-a_1)s}. \quad (14)$$

We use the following approximations for the gluon and photon 4-momenta:

$$k^\mu = xp^\mu + k_T^\mu, \quad (15)$$

and

$$q^\mu = yp_e^\mu + q_T^\mu, \quad (16)$$

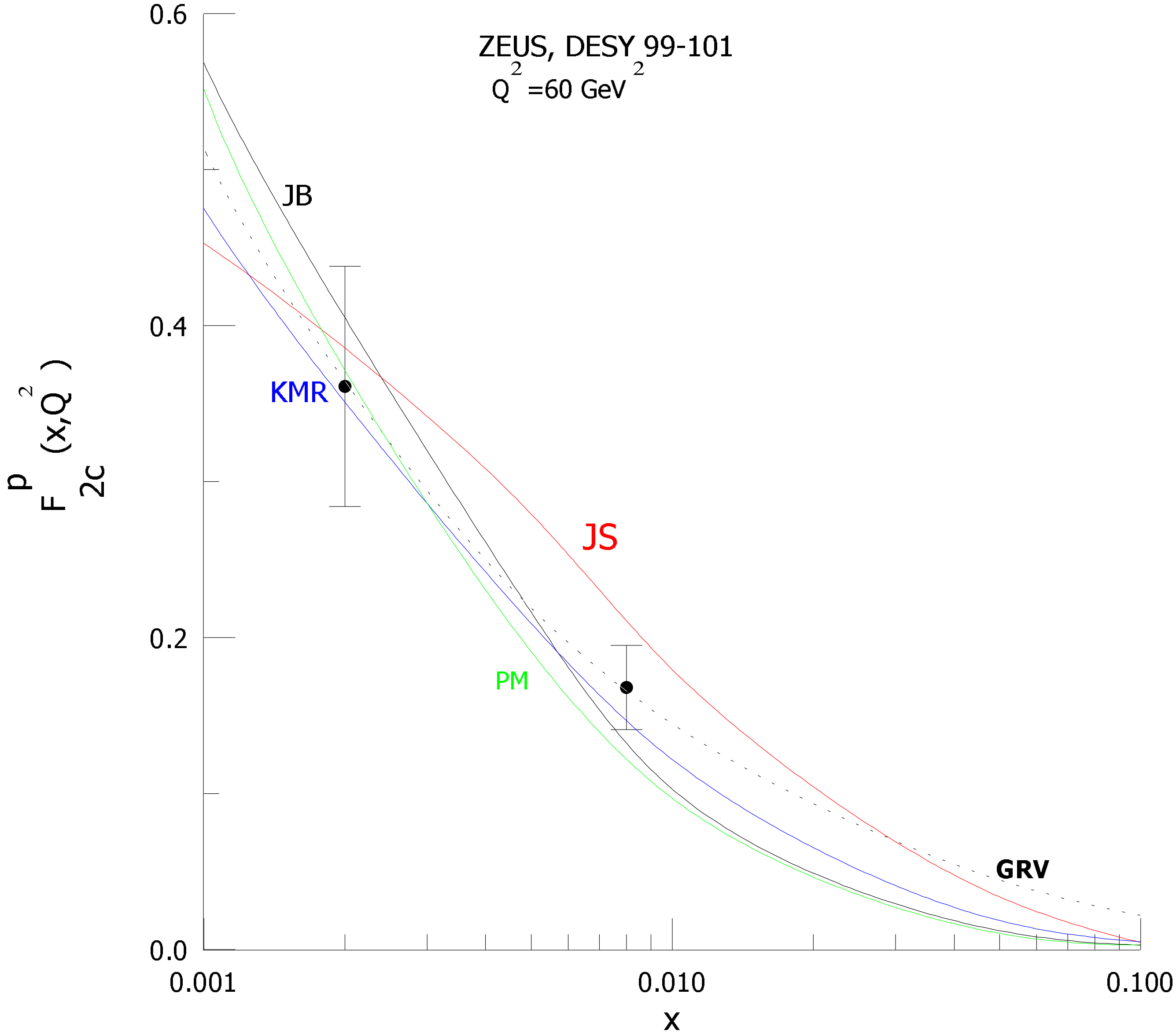
where $k^\mu = (0, \vec{k}_T, 0)$, $q_T^\mu = (0, \vec{q}_T, 0)$.

In the parton model one has $\vec{k}_T = 0$ and

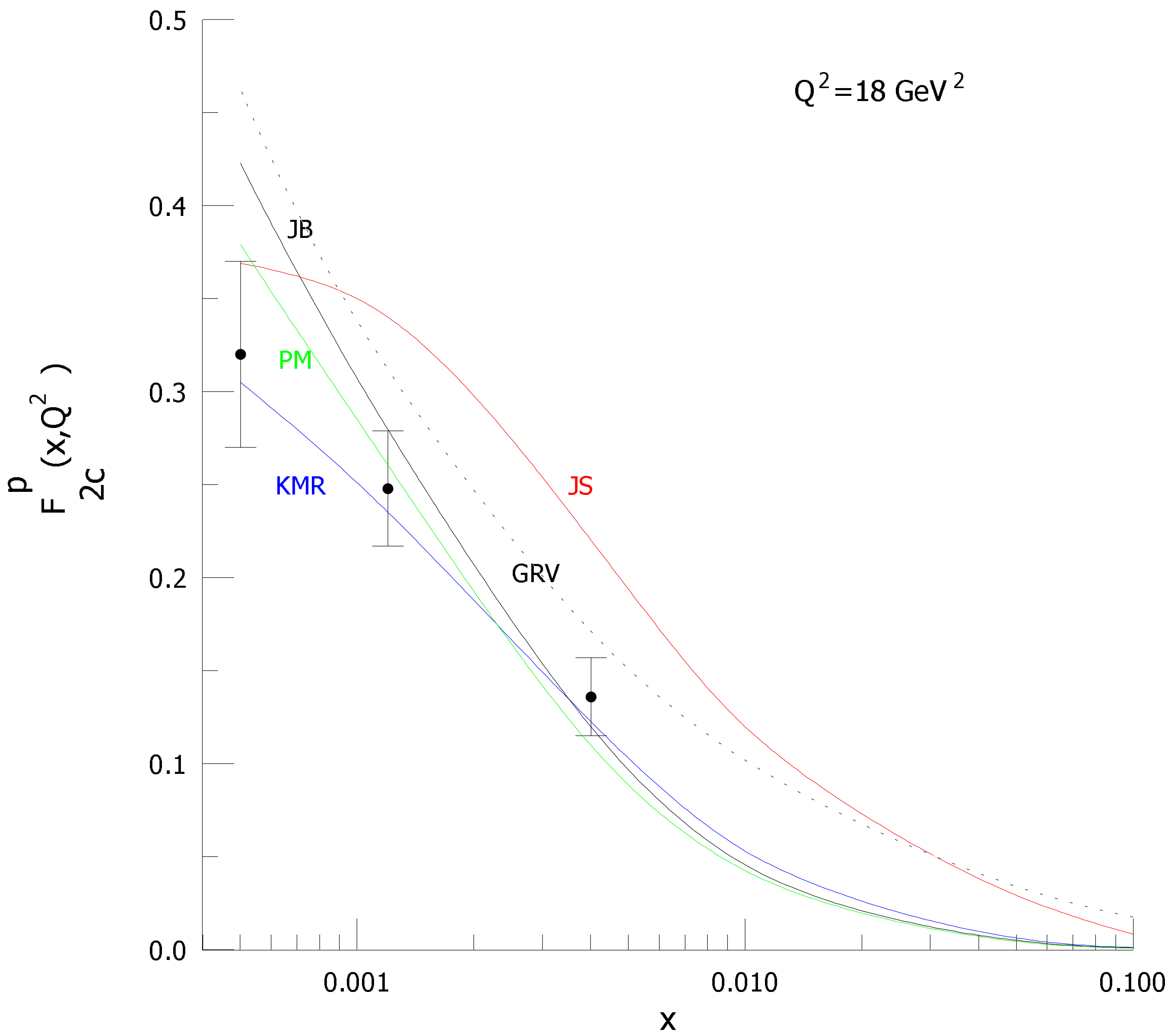
$$\frac{d\sigma^{PM}}{dx_B dQ^2}(ep \to ecX) = \frac{y}{x_B}\int dp_{cT} d\phi_c d\eta_c \left(\frac{p_c p_{cT}}{E_c}\right) \frac{\overline{|M(eg \to ec\bar{c})|^2}}{256\pi^4 (y-a_1)(xs)^2} xG(x,\mu^2), \tag{17}$$

where

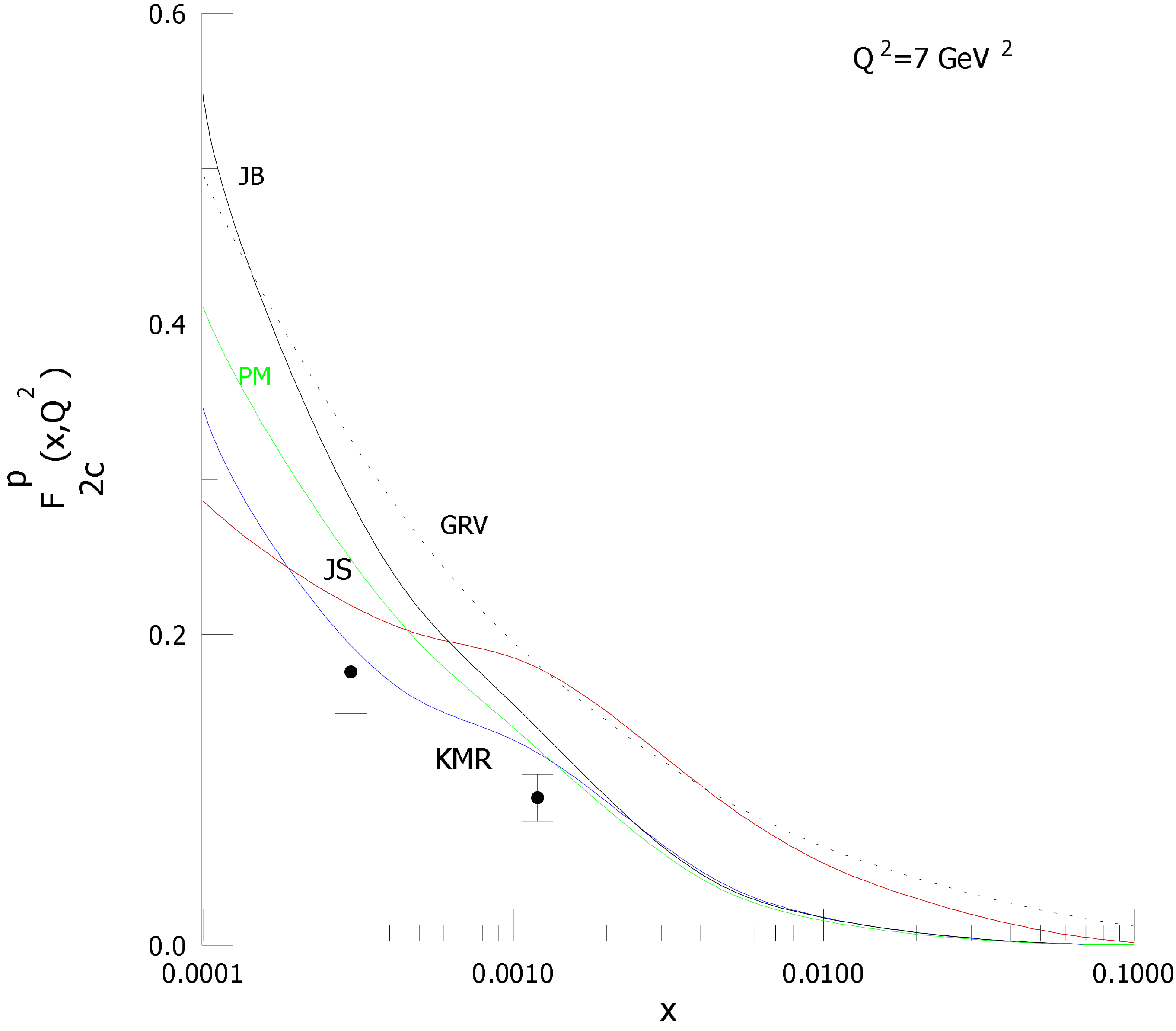
$$x = \frac{Q^2 + y b_1 s - 2(\vec{q}_T \vec{p}_{cT})}{(y-a_1)s}. \tag{18}$$



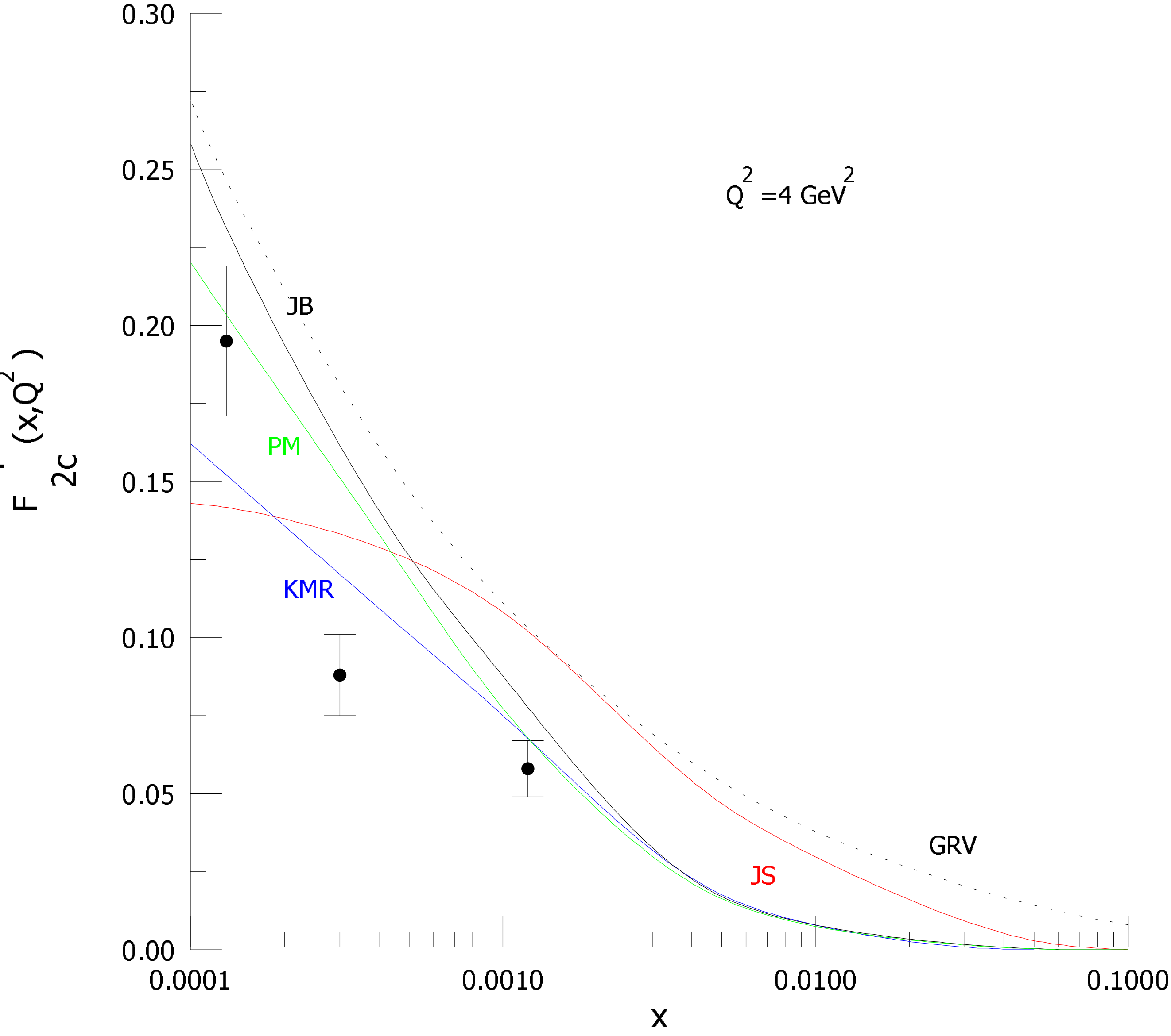
The SF $F^p_{2c}(x_B, Q^2)$ as a function of x_B at the Q^2=60 GeV^2 compared to ZEUS data.



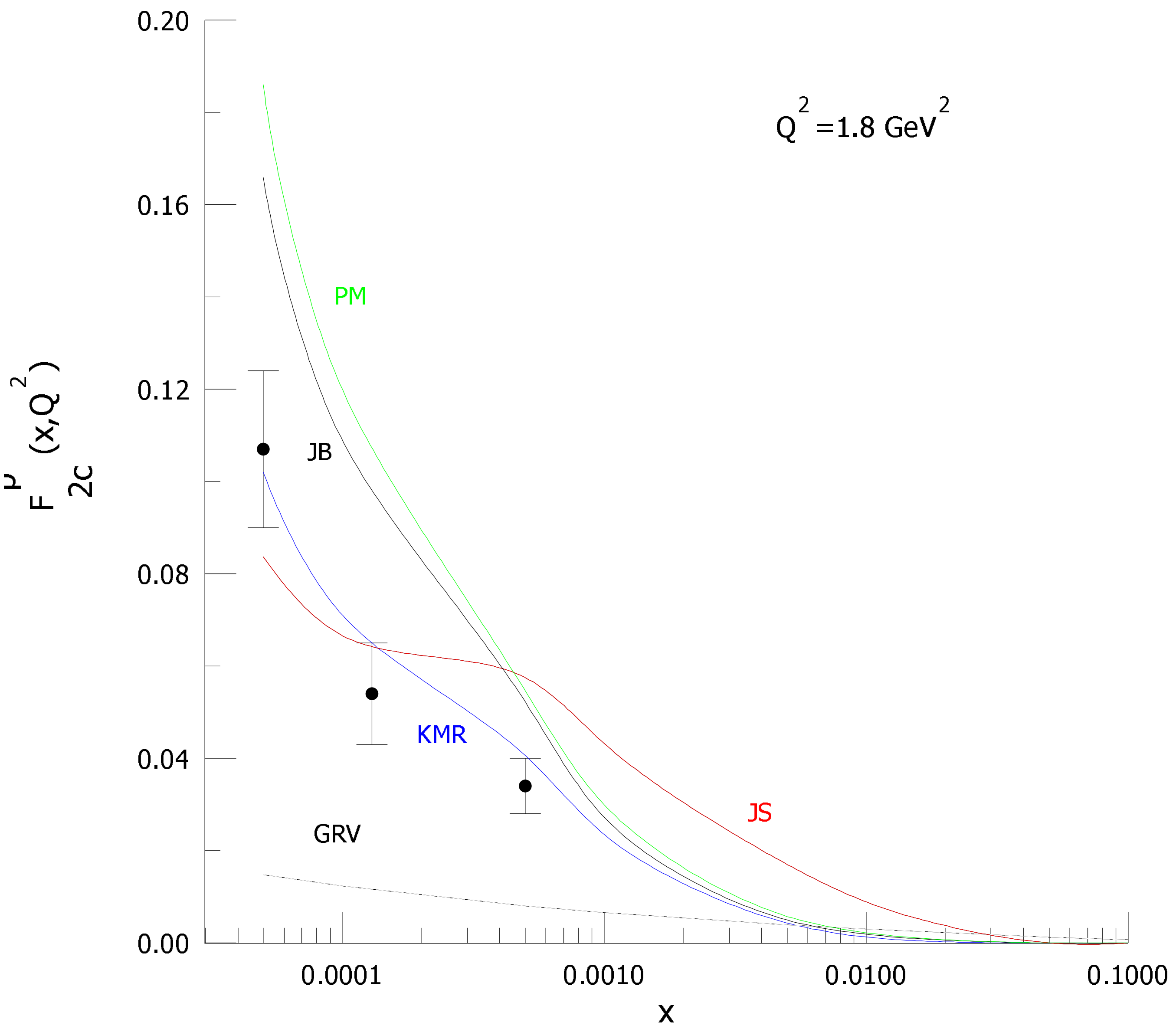
The SF $F_{2c}^{p}(x_B, Q^2)$ as a function of x_B at the Q^2=18 GeV^2 compared to ZEUS data.



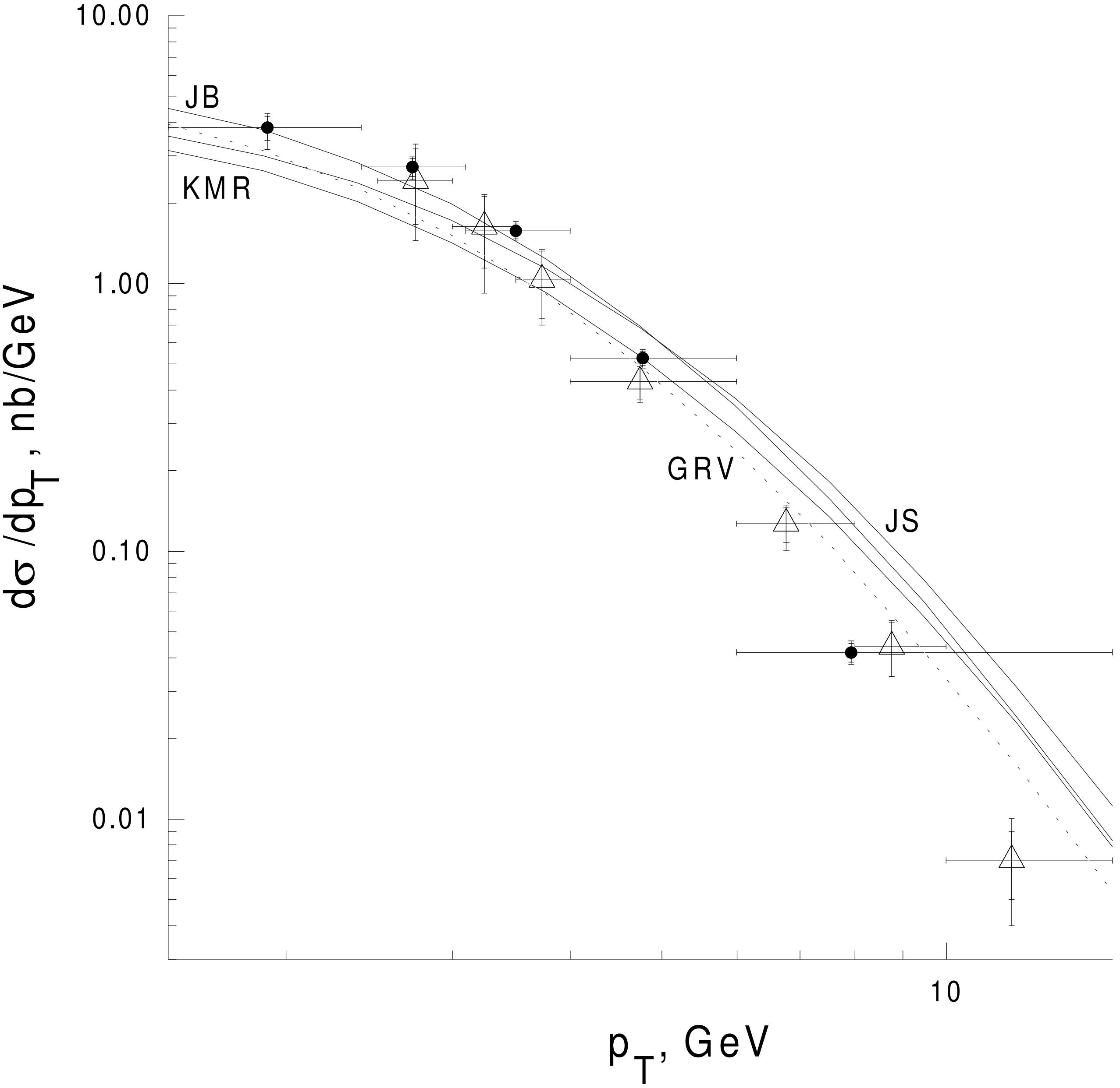
The SF $F^p_{2c}(x_B, Q^2)$ as a function of x_B at the Q^2=7 GeV^2 compared to ZEUS data.



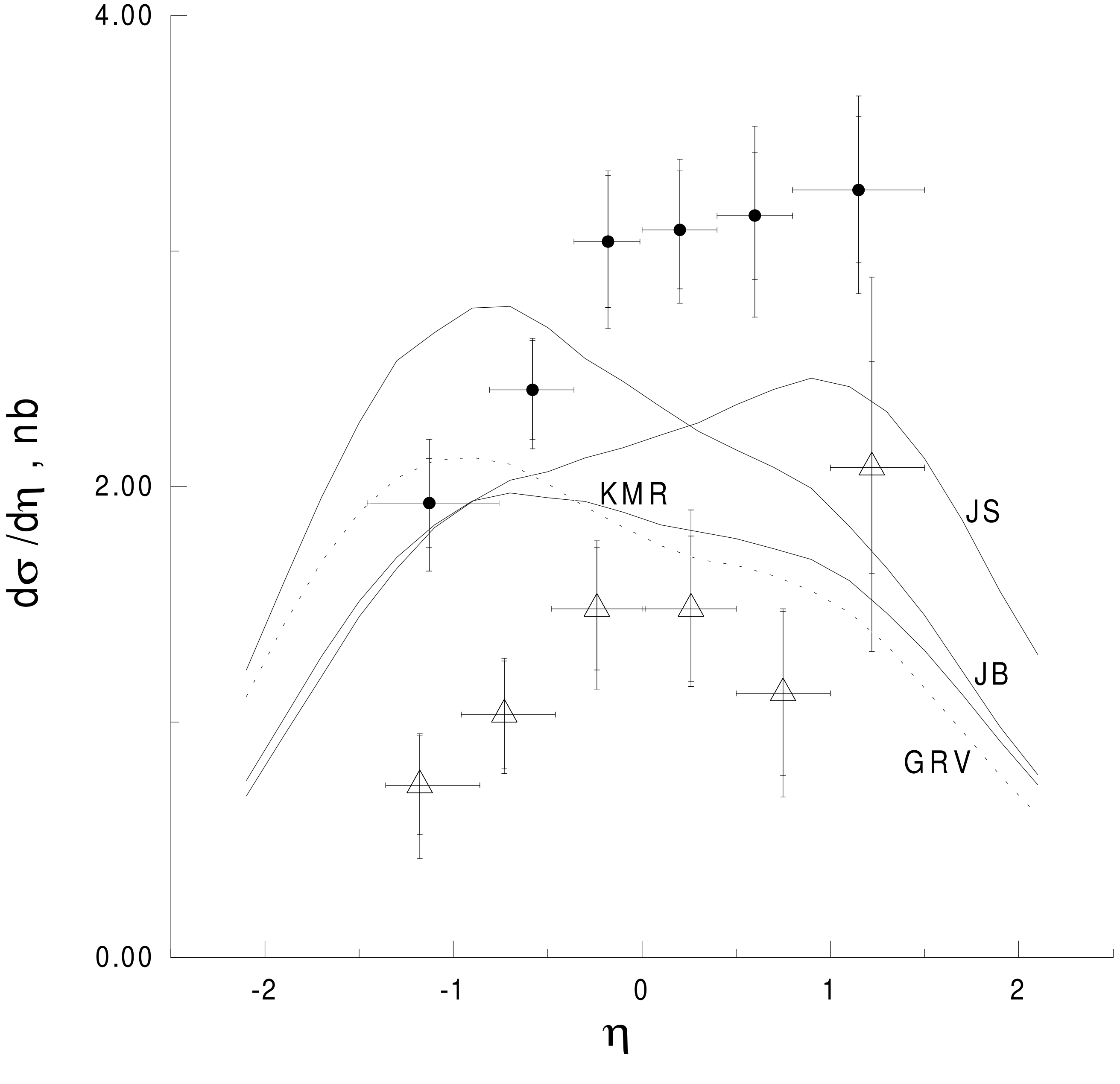
The SF $F_{2c}^{p}(x_B, Q^2)$ as a function of x_B at the Q^2=4 GeV^2 compared to ZEUS data.



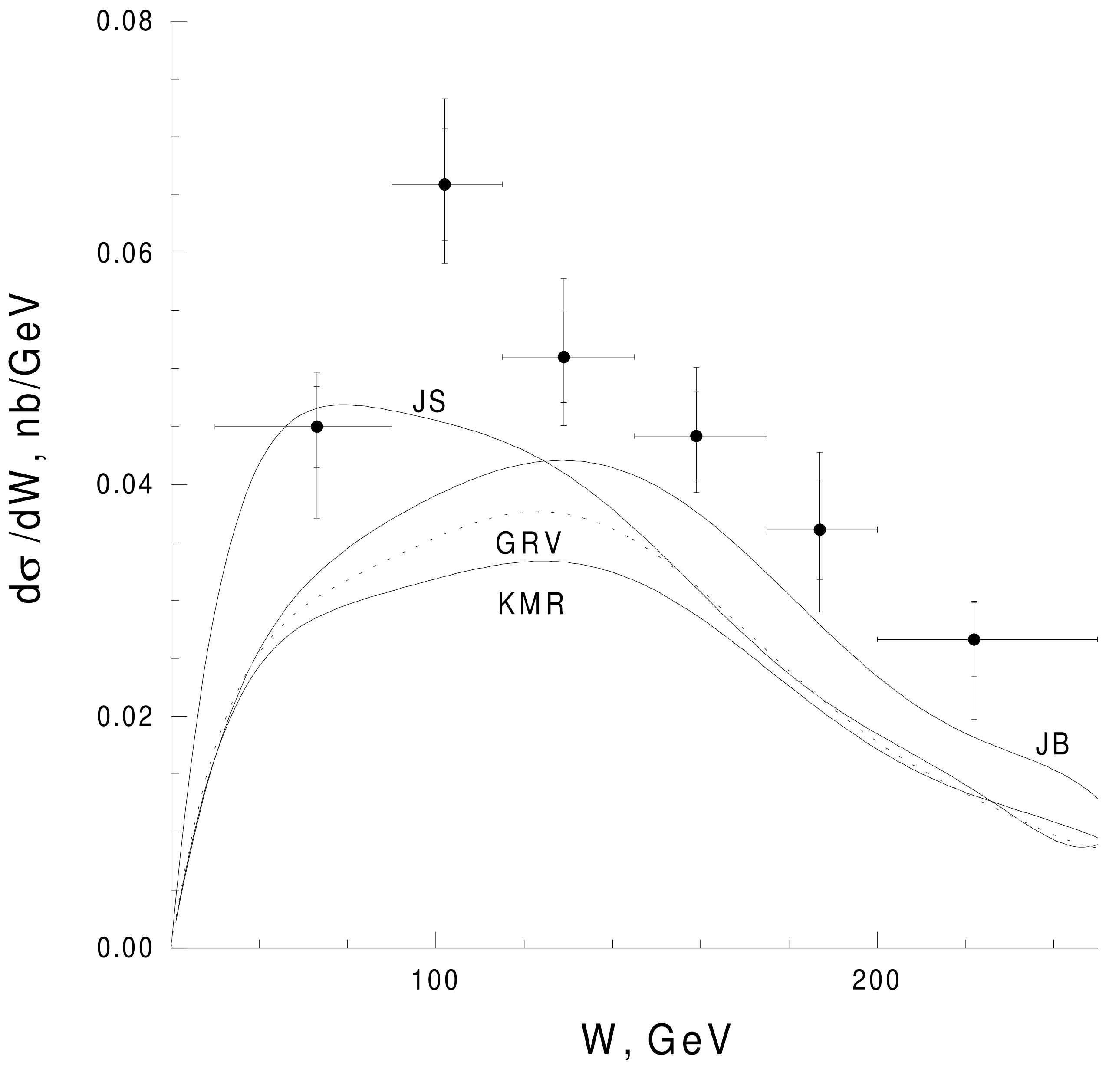
The SF $F^p_{2c}(x_B, Q^2)$ as a function of x_B at the Q^2=1.8 GeV^2 compared to ZEUS data.



The all spectra of D^* mesons have been obtained using Peterson FF with $\varepsilon = 0.06$.



The data are from the following kinematic region: $1 < Q^2 < 100$ GeV^2, $0.05 < y < 0.7$, $p_T > 1.5$ GeV, $|\eta| < 1.5$


0.08
0.06
0.04
0.02
0.00
100
200
dσ /dW, nb/GeV
W, GeV
JS
GRV
KMR
JB

Conclusions

- We have calculated the perturbative part of the c-quark distribution function in a proton within the framework of the **collinear parton model** and k_T-**factorization approach**.

- The basis of our model is **the direct calculation of the total cross section** for the process $ep \to c\bar{c}X$ with the leading order partonic amplitude $M(eg \to ec\bar{c})$.

- We have **described the recent data** for the $F_{2c}^p(x_B, Q^2)$ from HERA ep-collider.

- We have obtained that **difference** between predictions of the discussed here approaches **is smaller** than difference connected with a choice of the gluon SF parameterizations.

- We have found that **KMR** parameterization by Kimber, Martin and Ryskin for an unintegrated gluon distribution function describes data better that other in the relevant range of x_B and Q^2.

- At the small Q^2 our results disagree with the predictions by Kotikov et al. [5], which were obtained in the k_T-factorization approach but using method based on the calculation of the amplitude $\gamma\gamma^*$ elastic forward scattering via the box diagrams.

Our result for D^* photoproduction at HERA was published in

[C] V.A.Saleev, D.V.Vasin, Phys.Lett. **B548** (2002) 161.

The XVIIth International Workshop

High Energy Physics and Quantum Field Theory

4-11 September 2003,

Samara-Saratov-Volgograd-Samara

The Workshop continues a series of workshops started by the Skobeltsyn Institute of Nuclear Physics (SINP MSU) in 1985 and conceived with the purpose of presenting topics of current interest and providing a stimulating environment for scientific discussion on new developments in theoretical and experimental high energy physics and physical programs for future colliders. Traditionally the list of workshop attendees includes a great number of active young scientists from Russia and other countries. **The Workshop QFTHEP'2003 will take place on 4-11 September 2003 on a special Conference Boat "Estoniya" during the round sailing Samara-Saratov-Volgograd-Samara by the Volga river.**

Organizers: D.V. Skobeltsyn Institute of Nuclear Physics of the Moscow State University (SINP MSU), Samara State University, Saratov State University and the SSU Research and Educational Center "Nonlinear Dynamics and Biophysics".

http://www.qfthep.sinp.msu.ru/