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Abstract: We consider the diffractive dissociation production of $c\bar{c}$-pairs at HERA energies and test the sensitivity of this process to the photon and Pomeron structure functions.

1 Introduction

The nature of a Pomeron (or the interpretation of this nature in the framework of QCD [1]-[4]) is still an unresolved problem. The discussion concerning various attempts to describe the diffractive dissociation (DD) processes in terms of QCD and to reveal the Pomeron's nature may be found in the well known review by Gribov, Levin and Ryskin [3] (see also [5]- [8]). Recently the concept of a Pomeron and its structure function is widely discussed in the connection with the forthcoming experiments at the HERA collider [8]- [11].

In the present paper we apply the Pomeron hard scattering model [12] to the diffractive production of $c\bar{c}$ pairs in ep deep inelastic scattering at HERA:

$$e + p \to e + p + c + \bar{c} + X \tag{1}$$

This model is based on the idea of gluon dominance in a Pomeron [12] - [15]. Ingelman and Schlein [12] emphasised the possibility to observe hard scattering effects in DD and calculated the jet production cross section in single dissociation. Fritzsch and Streng [14] demonstrated as well that one may expect relatively high rates for $c\bar{c}$ production in diffractive $p\bar{p}$ collisions. This model was also applied [16], [17] to ep DIS at HERA energies. We follow the same approach and pay a special attention to the "resolved photon" contribution.

As alternative models it is worthwhile to mention [10], [11] , and in particular [18], where Pomeron is assumed to couple directly to quarks, like a "C-even photon". The difference between the models [11]- [13] and [18] is briefly discussed in [9], [11], [18]. In the hard diffractive approach [9], [12] - [17] Pomeron consists primarily of gluons, while in the alternative models [11] , [18] it consists of quarks. In the latter case quarks and antiquarks are estimated to carry about (10-15)% of the Pomeron momentum. Note, that Pomeron is not a real hadron and the momentum sum rules may not apply. Obviously, the Pomeron has quite different structure functions in these approaches. As a consequence, they lead to quite different predictions for the DD cross section, varying from $0.05\mu b$ to $30\mu b$ at HERA energies [19]. Essential differences also take place for the excitation of heavy flavours. As it was found in [11], the excitation of heavy flavours by photons off a Pomeron appears to be much weaker than for a Pomeron treated like a hadronic particle. These facts mean that these models may be distinguished experimentally.

2 The input model

As it was already mentioned above, we favor in our calculations the hard scattering model. This model does not appeal to any physics beyond QCD: the diffractive cross section must not be added to the perturbative cross section but rather is a part of it [13]. In addition the role of gluons in a Pomeron is especially interesting for us since their role in DD processes is not still clear (see, for example, [6]).

The basic formula for the $c\bar{c}$ production cross section corresponds to the diagram of fig.1 and reads as:

$$\frac{d\sigma^{hard\,diff}(ep \to epc\bar{c}X)}{dt\,dz} = P(t,z) \int F_{g/P}(x) W_{\gamma/e}(y)\, \hat{\sigma}_{\gamma g}(c\bar{c})\, dx\, dy \tag{2}$$

Here t is the square of the 4-momentum transfer from the proton to Pomeron, z is the Pomeron momentum fraction with respect to the proton, and $P(t,z)$ may be written in the triple Pomeron limit [13] as:

$$P(z,t) = \frac{1}{16\pi} \mid \beta(t) \mid^2 z^{1-2\alpha(t)} \tag{3}$$

$$\begin{aligned} &\beta(t) = \beta(0)\exp(- \mid t \mid B/2), \quad B = 6.5\ GeV^{-2}, \\ &\beta(0) = \sqrt{40\ mb}, \quad \alpha(0) = 1,\ \alpha' = 0.15\ GeV^{-2}. \end{aligned} \tag{4}$$

Note that additional kinematical cuts have been applied in order to satisfy the "diffractiveness":

$$\mid t \mid \leq 1\ GeV^2, \qquad 0 < z < 0.1 \tag{5}$$

$F_{g/P}(x)$ represents the gluon distribution function in a Pomeron, x being the momentum fraction. In the computations we used the following parametrizations [12] - [14]:

$$\begin{aligned} F_{g/P} &= 6(1-x) && (\text{"}hard\text{"}), && (6)\\ &= 6(1-x)^5/x && (\text{"}soft\text{"}), && (7)\\ &= 2(1-x)/x && (\text{"}semihard\text{"}), && (8)\\ &= (5.46 + 0.18/x)(1-x) && (choice\ of\ [13]) && (9) \end{aligned}$$

The normalization of all these functions assumes that all the Pomeron's momentum is carried by gluons.

For the effective flux of photons from an electron we used the Weizsäcker-Williams approximation [20], which is known to be quite reasonable:

$$W_{\gamma/e}(y) = \frac{\alpha}{2\pi} \ln\frac{\hat{s}}{4m_e^2}(2 - 2y + y^2)/y, \qquad y = p_\gamma/p_e. \tag{10}$$

The last ingredient of our formula is the parton subprocess cross section $\hat{\sigma}$, namely the photon-gluon fusion:

$$\hat{\sigma}(\gamma g \to c\bar{c}) = \frac{8\pi}{9\hat{s}}\alpha\alpha_s[(1 + \gamma - \gamma^2/2)\ln\frac{1+\beta}{1-\beta} - \beta(1+\gamma)], \tag{11}$$

$$\gamma = 4m_c^2/\hat{s}, \quad \beta = \sqrt{1-\gamma}, \quad \hat{s} = xyzs\,.$$

Since we are interested in the investigation of the "resolved" photon structure, we have also to consider the gluon-gluon fusion:

$$\hat{\sigma}(gg \to c\bar{c}) = \frac{\pi\alpha_s^2}{3\hat{s}}[(1 + \gamma + \gamma^2/16)\ln\frac{1+\beta}{1-\beta} - \frac{\beta}{4}(7 + 31\gamma/4)]. \tag{12}$$

The gluon contents of a photon $G_{g/\gamma}(x)$ can also be parametrized in several ways. The first one is to use the Vector Meson Dominance (VMD) model [21]:

$$xG_{g/\gamma}(x) = \frac{4\pi\alpha}{f_\rho^2} \cdot 2(1-x)^3, \tag{13}$$

where $4\pi\alpha/f_\rho^2$ corresponds to the conversion of a photon into a ρ-meson, and $2(1-x)^3$ is the gluon distribution in a ρ -meson (with the proper normalization). Another choice belongs to Duke and Owens [22]:

$$xG_{g/\gamma}(x) = 0.194F \cdot (1-x)/x, \qquad F = \frac{\alpha}{2\pi}\ln\frac{Q^2}{\Lambda^2}, \qquad Q^2 = \hat{s}, \qquad \Lambda = 0.4\ GeV. \tag{14}$$

These distributions provide us with a basis for the comparison of "direct" and "resolved" photon contributions. The parametrizations (13) and (14) are of course too simplified and correspond to two extreme cases in the treatment of resolved photon structure. The account of both these approaches allows us to reveal the most essential observable features of the resolved photon physics, i.e. such features which do not depend on a particular choice of parametrization.

3 The results of calculations and discussion

First of all, let us consider the behaviour of the full cross section for the processe (1). For the HERA energies we obtained the values of $\sigma = 100\ nb$ with soft, and $\sigma = 40\ nb$ with the hard gluon distributions in a Pomeron, both for the case of the direct photon contribution. These values are as high as approximately 10% and 4% with respect to the total cross section of charm electroproduction at HERA ($\sim 1\mu b$ [23]). The resolved photon contribution ranges, depending on the gluon distribution in the photon, from $0.25\ nb$ (for the Duke&Owens choice) to $10\ nb$ (for the VMD-like distribution) for the soft gluon distribution in the Pomeron. In spite of the fact that VMD may lead to too large cross sections, we present this result because such distributions are very popular in phenomenological calculation (see, for example [24]). Fig.2 exhibits the energy dependence of the considered contributions.

Our estimations of the cross section appear to be one order of magnitude lower than those of Bruni, Ingelman, Solano [25]. This discrepancy originates from the difference in the normalization of $P(z,t)$ (3)-(4) and in the value of the quark mass m_c (1.5 GeV vs 1.3 GeV).

Let us draw our attention now to the rapidity distributions of the charmed pairs at fixed invariant mass $M_{c\bar{c}}$ (fig.3). As one can clearly see the direct and the resolved photon interactions contribute to different regions: these are $\eta \geq 1$ for the direct and $\eta \leq 1$ for the resolved cases (positive direction is that of the electron in our notations). Such a separation is valid for almost all kinds of gluon distribution in the photon.

The shape of the $d\sigma/\,dM_X$ distribution (see fig.4) is sensitive to the gluon distribution in the Pomeron, as was pointed out in [17]. Soft gluons lead to a wider distribution over the final hadronic state mass M_X.

The behaviour of the differential cross section $d^2\sigma/\,dM_X^2\,dt$ at fixed M_X versus t is plotted in fig.5. It exhibits the typical diffractive features of the considered process.

The above results may be represented in terms of Pomeron structure function. Following the notations (but not the model) of [11] we write

$$F_{2P}^c(z,Q^2) = \frac{Q^2}{4\pi^2\alpha}\,\frac{16\pi}{\sigma_{tot}(pp)}\,M_X^2\,\frac{d\sigma(DD)}{dt\,dM_X^2}\bigg|_{t=0}, \qquad z = \frac{Q^2}{Q^2 + M_X^2} \tag{15}$$

The dependence of the extracted Pomeron structure function, F_{2P}^{c} on z (fig.6), is different for the soft and hard gluon distributions. As it might be anticipated in the hard scattering model, our estimations of the $c\bar{c}$-pair contribution exceed the estimations of [11].

In conclusion we emphasise that according to our estimates the essential features of diffractive dissociation can really be investigated at HERA energies. This provides us the with possibility to discriminate between the theoretical models and to improve our knowledge of the photon and Pomeron structure functions (as far as the experimental data will allow). Eventually, we hope to reach an adequate description of the Pomeron's nature.

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P.S. The amount of papers devoted to the research of the diffractive dissociation at HERA collider [25]-[30] gives a bright evidence to the enhancement of interest in this topic. The possibility of its experimental study is based on the LPS detector, which is a part of the ZEUS installation [31]. These topics are also disputed in the new projects (see, for example [32]).

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Figure captions

1. General diagram describing diffractive $c\bar{c}$-pair electroproduction in the hard scattering model.

2. The total cross sections of diffractive $c\bar{c}$ -pair electroproduction versus $\sqrt{s}$: (a)-direct photon contribution, (b)-resolved photon contribution in the VMD model parametrization, (c)-resolved photon contribution in the DO parametrization. The four different curves in the figs.2,3,5 correspond to different gluon distributions in a Pomeron (6)-(9).

3. The rapidity distributions for the diffractive $c\bar{c}$-pair electroproduction at $m_{c\bar{c}} = 10\ GeV$ (A) and $m_{c\bar{c}} = 20\ GeV$ (B). (a), (b), (c) - the same as in fig.2.

4. The $d\sigma / dM_X$ distributions for the diffractive $c\bar{c}$-pair elecrtoproduction at $m_{c\bar{c}} = 10\ GeV$ in the cases of the hard and soft gluon distributions in a Pomeron.

5. The differerential cross section $d^2\sigma / dM_X^2\, dt$ versus t at $M_X = 30\ GeV$ for the diffractive $c\bar{c}$-pair electroproduction: (a) - direct photon contribution, (b) - resolved photon contribution in the VMD model.

6. The Pomeron structure function $F_{2P}^c(z, Q^2)$ at HERA energy and $Q^2 = 30\ GeV^2$ in the cases of the hard and soft gluon distributions in a Pomeron (solid curves). The dashed curve is the resolved photon contribution in the VMD model for the hard gluon distributions in a Pomeron.

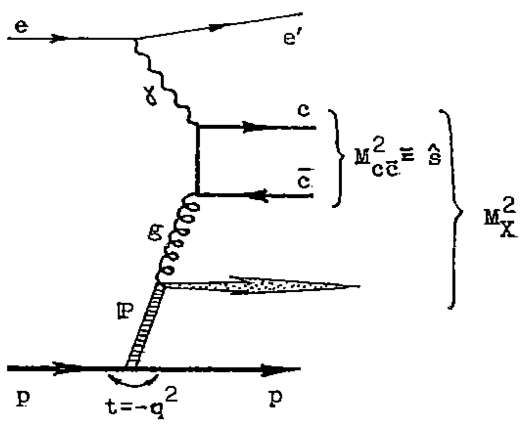
e
e′
γ
c
c̄
$M^2_{c\bar{c}} \equiv \hat{s}$
M^2_X
g
IP
p
$t=-q^2$
p

Fig.1

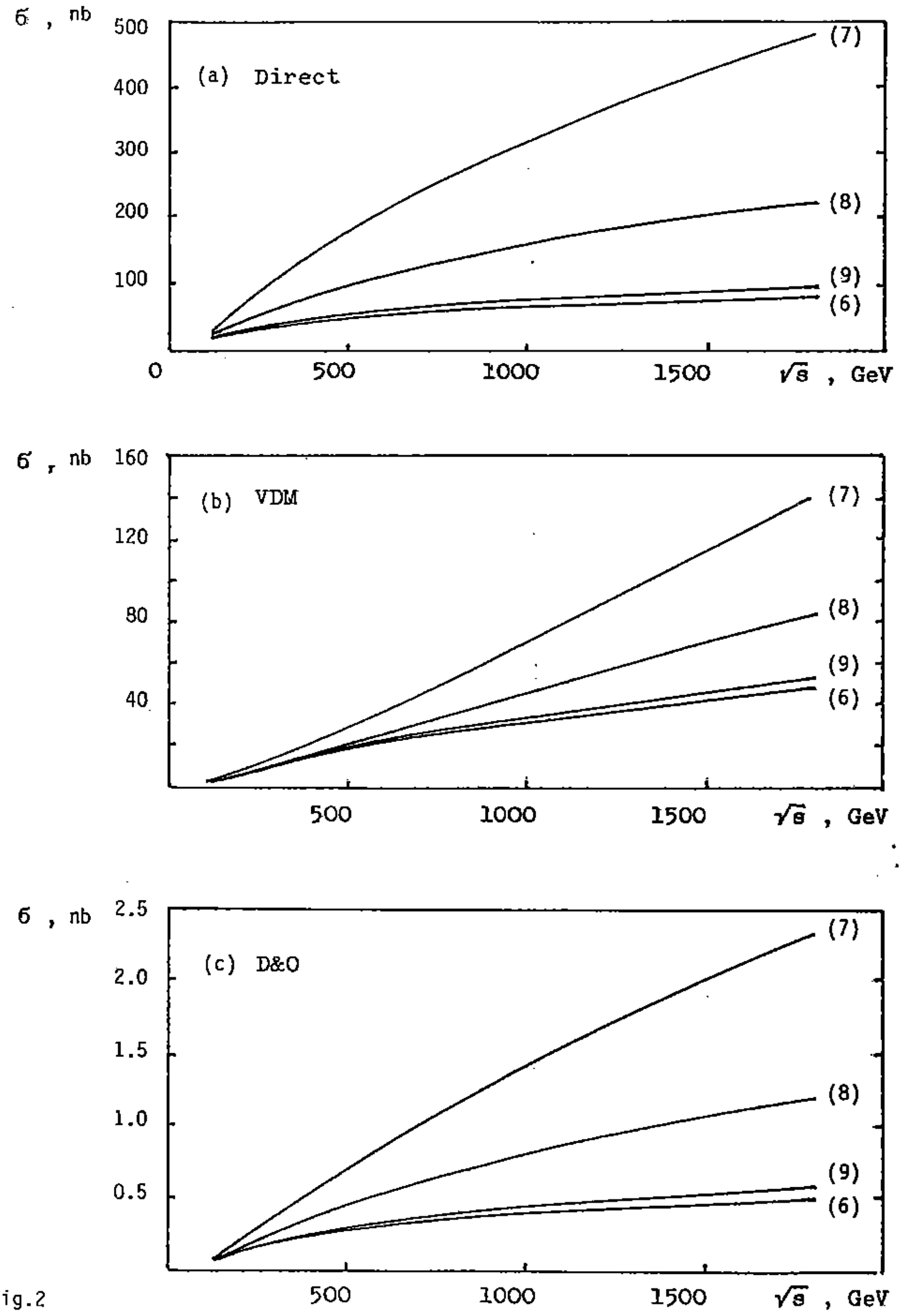
σ , nb
500
400
300
200
100
0
(a) Direct
(7)
(8)
(9)
(6)
500
1000
1500
√s , GeV
σ_r , nb
160
120
80
40
(b) VDM
(7)
(8)
(9)
(6)
500
1000
1500
√s , GeV
σ , nb
2.5
2.0
1.5
1.0
0.5
(c) D&O
(7)
(8)
(9)
(6)
500
1000
1500
√s , GeV

Fig.2

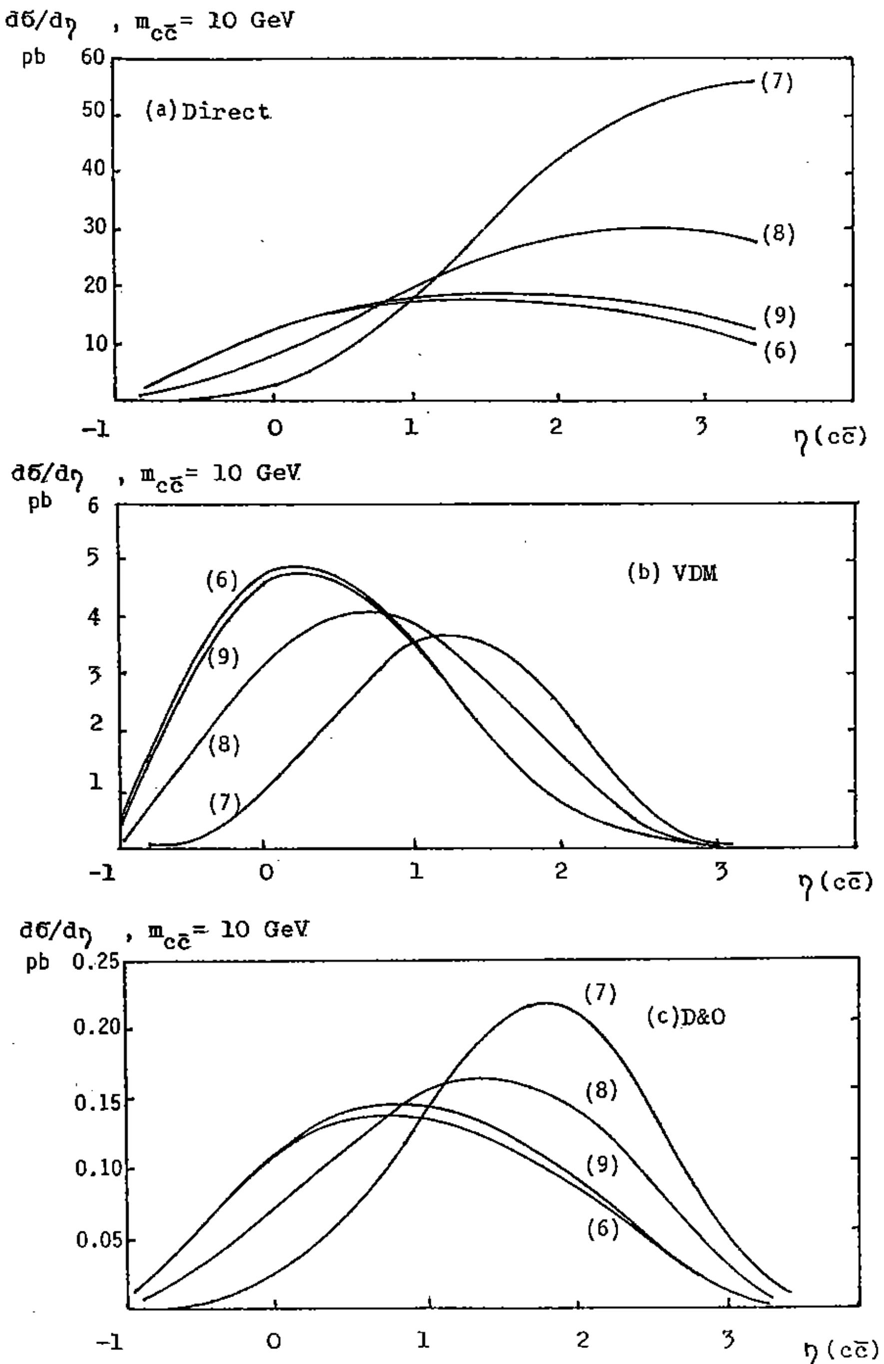
dσ/dη pb, $m_{c\bar{c}}$ = 10 GeV
(a) Direct
60
50
40
30
20
10
-1
0
1
2
3
η(c$\bar{c}$)
(7)
(8)
(9)
(6)
dσ/dη pb, $m_{c\bar{c}}$ = 10 GeV
(b) VDM
6
5
4
3
2
1
(6)
(9)
(8)
(7)
-1
0
1
2
3
η(c$\bar{c}$)
dσ/dη pb, $m_{c\bar{c}}$ = 10 GeV
(c) D&O
0.25
0.20
0.15
0.10
0.05
(7)
(8)
(9)
(6)
-1
0
1
2
3
η(c$\bar{c}$)

Fig.3A

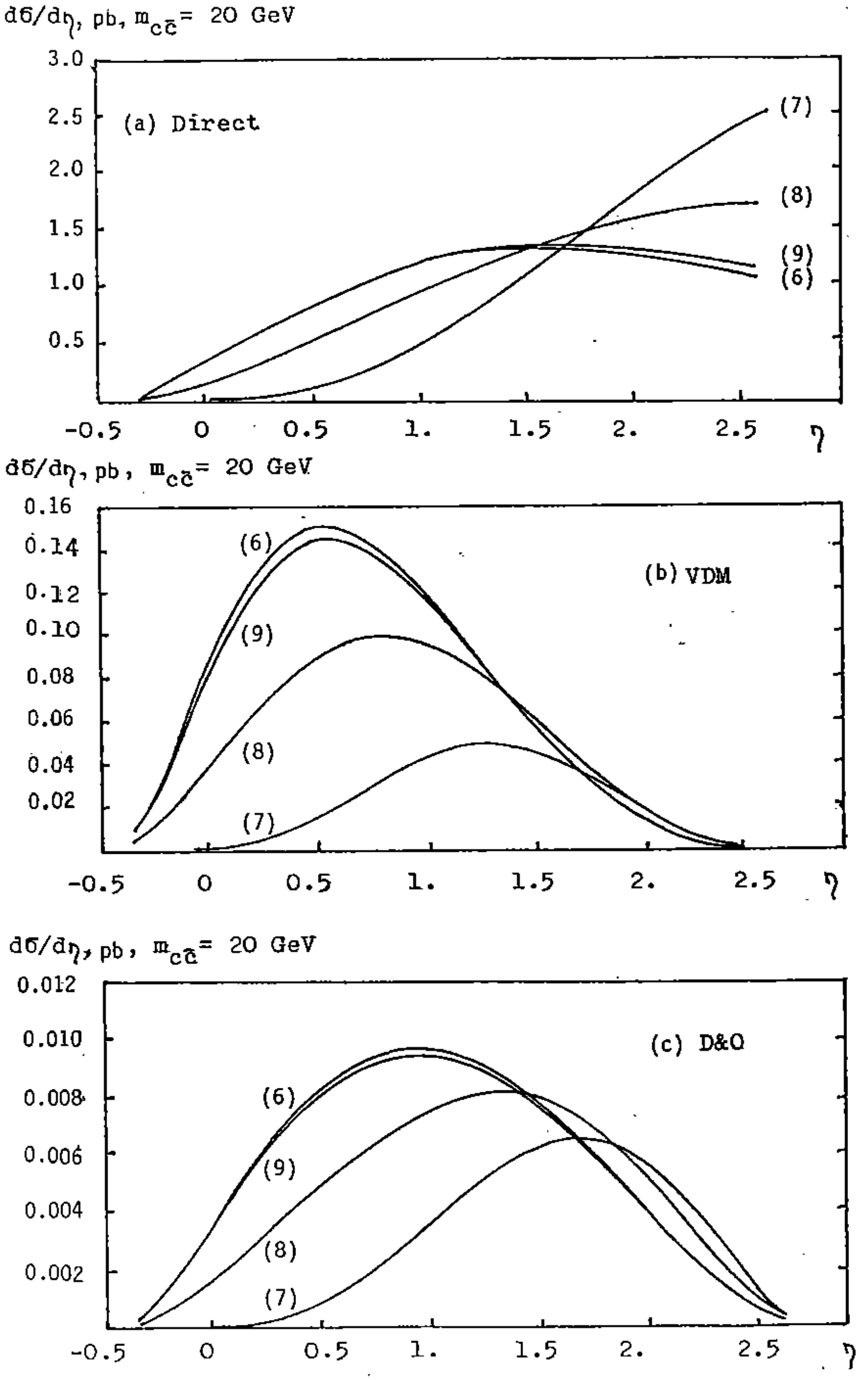
dσ/dη, pb, $m_{c\bar{c}}$ = 20 GeV
(a) Direct
3.0
2.5
2.0
1.5
1.0
0.5
(7)
(8)
(9)
(6)
-0.5
0
0.5
1.
1.5
2.
2.5
η
dσ/dη, pb, $m_{c\bar{c}}$ = 20 GeV
(b) VDM
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
(6)
(9)
(8)
(7)
-0.5
0
0.5
1.
1.5
2.
2.5
η
dσ/dη, pb, $m_{c\bar{c}}$ = 20 GeV
(c) D&O
0.012
0.010
0.008
0.006
0.004
0.002
(6)
(9)
(8)
(7)
-0.5
0
0.5
1.
1.5
2.
2.5
η

Fig.3B

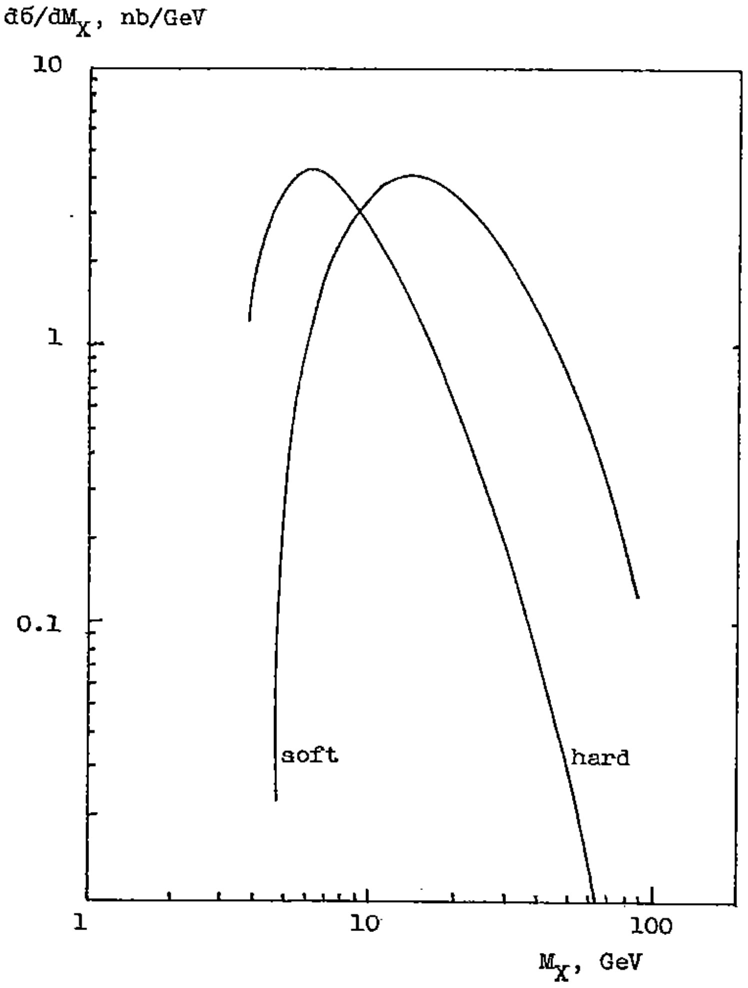
dσ/dM_X, nb/GeV
10
1
0.1
soft
hard
1
10
100
M_X, GeV

Fig.4

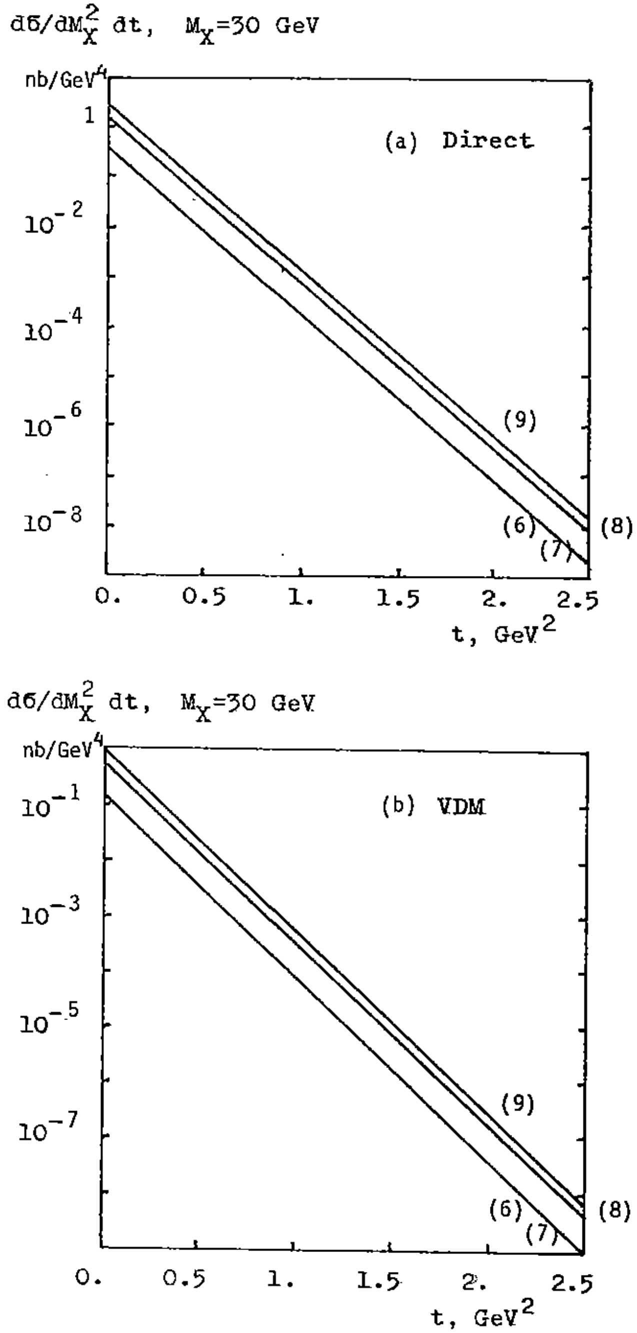
dσ/dM_X^2 dt, M_X=30 GeV
nb/GeV^4
1
10^-2
10^-4
10^-6
10^-8
(a) Direct
(9)
(6)
(7)
(8)
0.
0.5
1.
1.5
2.
2.5
t, GeV^2
dσ/dM_X^2 dt, M_X=30 GeV
nb/GeV^4
10^-1
10^-3
10^-5
10^-7
(b) VDM
(9)
(6)
(7)
(8)
0.
0.5
1.
1.5
2.
2.5
t, GeV^2

Fig.5

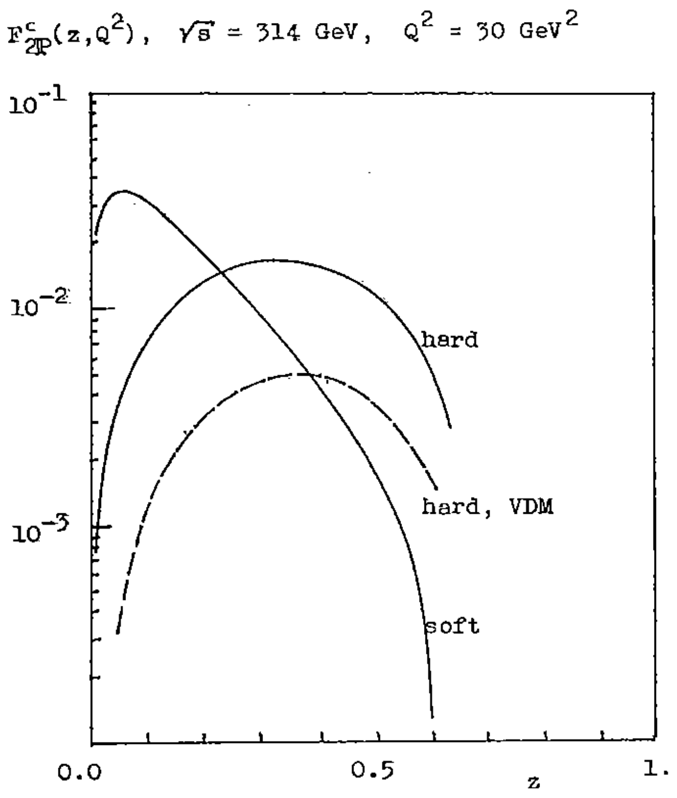
$F^c_{2\mathbb{P}}(z,Q^2)$, $\sqrt{s}$ = 314 GeV, Q^2 = 30 GeV^2
10^{-1}
10^{-2}
10^{-3}
hard
hard, VDM
soft
0.0
0.5
1.
z

Fig.6