DIFFRACTIVE OPEN CHARM AT HERA

EXPERIMENT VERSUS TWO-GLUON EXCHANGE MODEL

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PLAN OF THE TALK

1. Introduction and interest motivation
2. Theoretical framework
3. Numerical results
4. Conclusions

INTRODUCTION

The Pomeron nature is still a puzzle; many attempts to understand it in terms of QCD. Two-gluon exchange mechanism provides attractive theoretical grounds.

Two versions of Two-Gluon Exchange model:
collinear:
gluons have no transverse momentum;
gluons carry unequal longitudinal momenta.

k_t-factorization:
gluons have transverse momentum;
no difference between longitudinal momenta.

News on the experimental side:
recent **H1** [1] and **ZEUS** [2, 3] data on inclusive diffractive D^* production. Both in real photoproduction and deep-inelastic regimes.

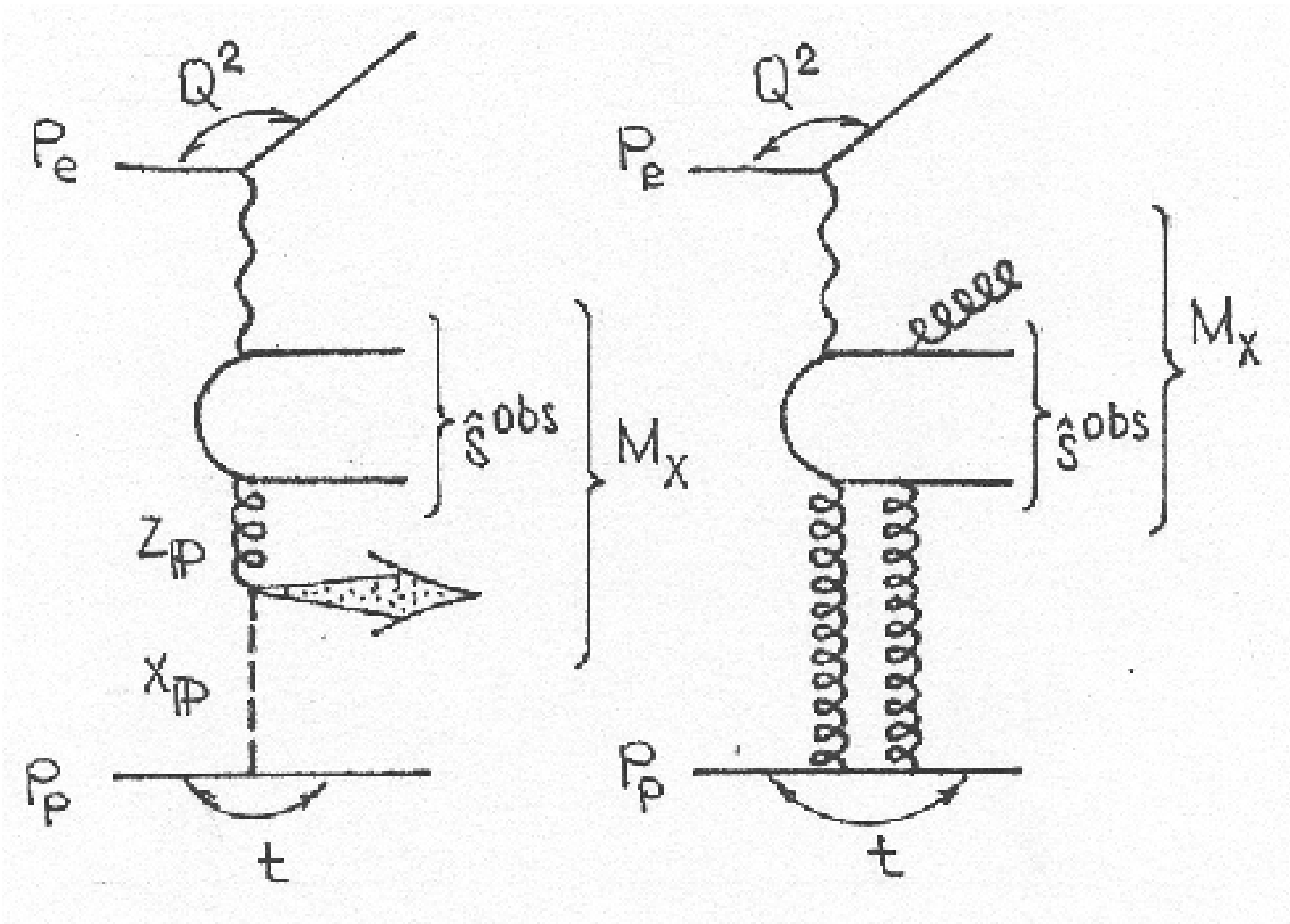
Relevant theoretical calculations
within the k_t-two-gluon exchange model:
massive $Q\bar{Q}$ at LO [4];
massless $q\bar{q}g$ at NLO [5];
massive $Q\bar{Q}g$ at NLO [6];

Yet no collinear calculations, we will try.

THEORETICAL FRAMEWORK

Kinematics

$$e + p \to e' + p' + D^* + X$$



"Constituent" Pomeron

Two-gluon exchange

Kinematic observables

$s = (p_e + p_p)^2$, invariant energy squared;

$Q^2 = -k_\gamma^2$, exchanged photon virtuality;

$y = (k_\gamma p_p)/(p_e p_p)$, photon energy fraction;

$z = (p_D p_p)/(k_\gamma p_p)$, D^* meson/photon energy-momentum fraction;

$p_t(D^*)$, D^* meson transverse momentum;

$\eta(D^*)$, D^* meson rapidity;

$W = (k_\gamma + p_p)^2$, γp c.m.s. energy;

M_X, mass of the final state hadronic system;

$x_{\rm IP} = (Q^2+M_X^2)/sy = (Q^2+M_X^2)/(Q^2+W^2)$, Pomeron momentum fraction;

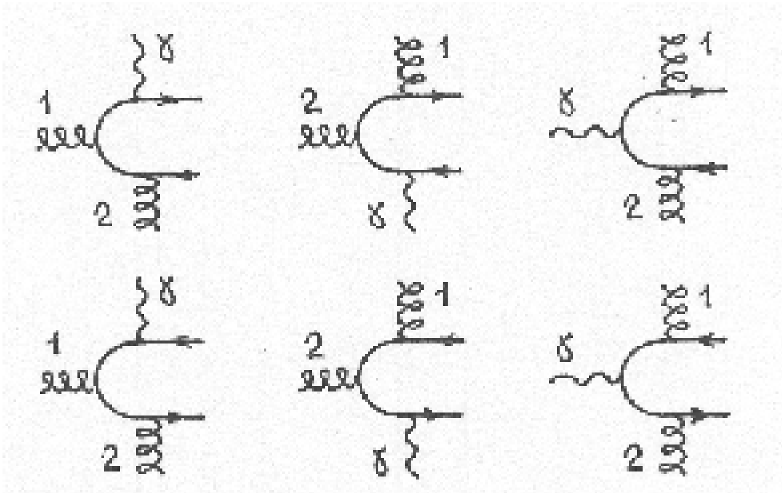
$x = Q^2/2(k_\gamma p_p)$, Bjorken variable;

$\beta = x/x_{\rm IP} = Q^2/(Q^2 + M_X^2)$.

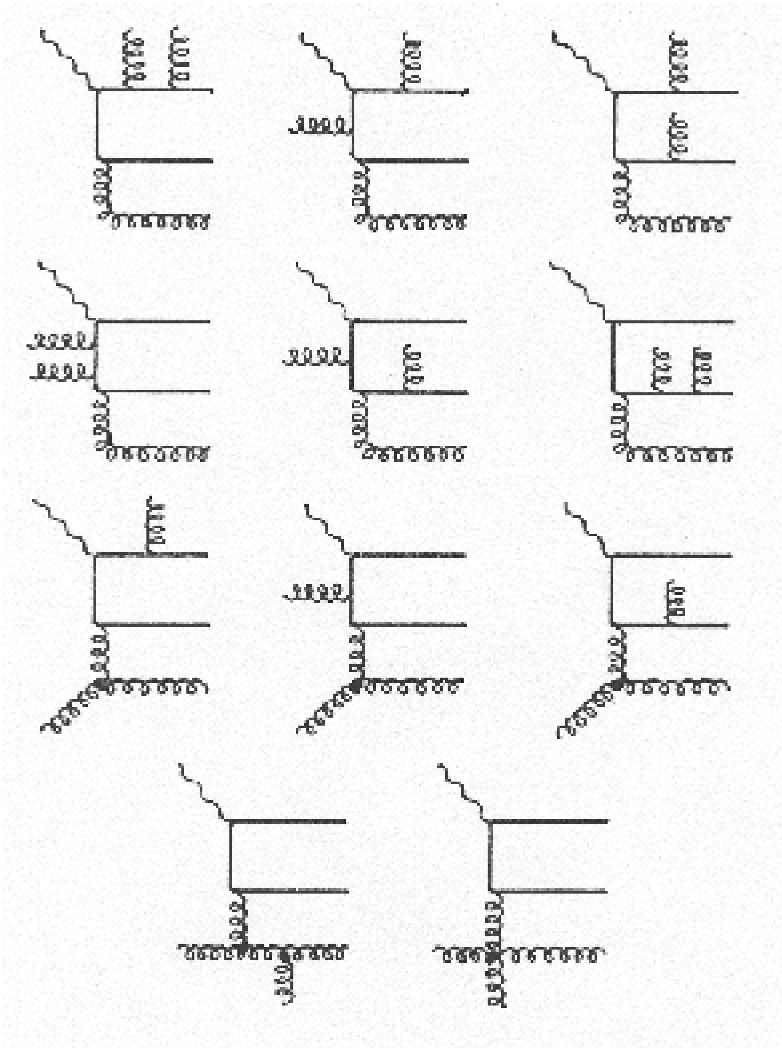
H1 uses also $z_{\rm IP} = (Q^2 + \hat{s}^{\rm obs})/x_p y s$.

Partonic subprocesses

Leading-Order: $\gamma^* + (gg) \to c + \bar{c}$



Next-to-Leading: $\gamma^* + (gg) \to c + \bar{c} + g$



Partonic matrix elements

Computational technique:
method of orthogonal amplitudes [10].

LO ($\gamma^*\mathrm{IP} \to c\bar{c}$): **6** Feynman diagrams,
NLO ($\gamma^*\mathrm{IP} \to c\bar{c}g$): **42** Feynman diagrams.

Photon polarization: full lepton tensor

$$L^{\mu\nu} = 8\, p_e^\mu p_e^\nu - 4(p_e k_\gamma)\, g^{\mu\nu}$$

Gluon polarization vector

$$\epsilon_g^{(x,y,z,t)} = (\cos\chi,\ \sin\chi,\ 0,\ 0)$$

(same for both gluons to get net $J^{PC} = 0^{++}$)

The amplitude of the process

$$\mathcal{A}(ep \to epD^*X) = \int_{-1}^{1} \frac{\mathcal{M}\,\mathcal{H}(v,\xi;\mu^2,t)}{(v+\xi-i\epsilon)(v-\xi+i\epsilon)}\, dv$$

LO: two double poles at $v = \pm\xi$

NLO: two double poles at $v = \pm\xi$
and four single poles at

$$v = \pm\left\{(1+\xi)\left[(p_1 k_\gamma) - k_\gamma^2\right] / \left[(k_\gamma p_p) - (p_1 p_p)\right] - \xi\right\},$$

and $v = \pm\{(1+\xi)(p_1 k_g) / \left[(k_g p_p) + (p_1 p_p)\right] - \xi\}$.

Scewed gluon distributions

The skewed gluon distribution $\mathcal{H}(v,\xi;\mu^2,t)$ related to the double distribution $F_{DD}(x,y;\mu^2,t)$ [12] via the reduction integral reads

$$\mathcal{H}(v,\xi;\mu^2,t) =$$

$$= \int_{-1}^{1} dx' \int_{-1+|x|}^{1-|x|} dy'\, \delta(x'+\xi y'-v)\, F_{DD}(x',y';\mu^2,t)$$

A model for $F_{DD}(x,y;\mu^2,t)$ [13]

$$F_{DD}(x,y;\mu^2,t) = h(x,y)\, G(x,\mu^2)\, r(t)$$

with profile function $h(x,y)$ [14]

$$h(x,y) = \frac{\Gamma(2b+2)}{2^{2b+1}\,\Gamma^2(b+1)} \frac{[(1-|x|)^2 - y^2]}{(1-|x|)^{2b+1}}$$

$$\int_{-1+|x|}^{1-|x|} h(x,y)\, dy = 1, \quad b = 2$$

$G(x,\mu^2)$ taken from Glück-Reya-Vogt [15],

and formfactor $r(t)$ in the form [17]

$$r^2(t) = \exp(-b|t| + ct^2)$$

with $b = 9.5$ GeV^{-2}, $c = 5$ GeV^{-4}

Differential cross sections

Leading-Order:

$$d\sigma_{\rm LO}(ep \to e'p'c\bar{c}) =$$

$$= \frac{\alpha^2\alpha_s^2}{16\pi s^2}\,\frac{1}{Q^4}\,\frac{1}{2}\sum_{\rm spins}\,\frac{1}{64}\sum_{\rm colors}|\mathcal{A}_{\rm LO}(\gamma^*{\rm IP} \to c\bar{c})|^2$$

$$\times\, r^2(t)\,dt\,dp'^2_{eT}\,dp^2_{1T}\,dy_1\,dy_2\,\frac{d\phi_e}{2\pi}\,\frac{d\phi_1}{2\pi}$$

Next-to-Leading Order:

$$d\sigma_{\rm NLO}(ep \to e'p'c\bar{c}g) =$$

$$\frac{\alpha^2\alpha_s^3}{64\pi^2 s^2}\,\frac{1}{Q^4}\,\frac{1}{2}\sum_{\rm spins}\,\frac{1}{64}\sum_{\rm colors}|\mathcal{A}_{\rm NLO}(\gamma^*{\rm IP} \to c\bar{c}g)|^2$$

$$\times\, r^2(t)\,dt\,dp'^2_{eT}\,dp^2_{1T}\,dp^2_{2T}\,dy_1\,dy_2\,dy_g\,\frac{d\phi_e}{2\pi}\,\frac{d\phi_1}{2\pi}\,\frac{d\phi_2}{2\pi}$$

Phase space boundary

$$G(\hat{s}, t_1, s_2, -Q^2, t, 0) \le 0 \quad \text{and} \quad 4m_c^2 \le s_2 \le s$$

Integration by means of the Monte-Carlo technique using VEGAS [19].

Parameter setting in theory

Charmed quark mass, $m_c = m_D = 1.8$ GeV;
Peterson fragmentation, $\epsilon(c \to D^*) = 0.06$;
fragmentation probability, $f(c{\to}D^*){=}0.24$
renormalization and factorization scales:
$\mu_R^2 = \mu_F^2 = \hat{s}/4$;
formfactor $r^2(t) = \exp(-b|t| + ct^2)$
with $b = 9.5$ GeV^{-2}, $c = 5$ GeV^{-4};
Gluck-Reya-Vogt input gluon density.

Cutoffs on the invariant masses of the final state quark-gluon subsystems to regulate the collinear and infrared divergences:
$(p_{1,2} + k_g)^2 > M_{cut}^2$, with $M_{cut} = 2.5$ GeV. Otherwise, the pQCD methods are not applicable. The sensitivity of the results is logarithmic; increasing M_{cut} from 2.5 to 5 GeV has approximately a 25% decreasing effect on the production cross section.

Taken together, all theoretical uncertainties amount to a factor of 3 in the absolute production rate; the shape of the differential distributions remains almost unaffected.

Specific experimental cuts

H1 photoproduction

$Q^2 < 0.01$ GeV^2, $0.3 < y < 0.65$,
$x_{\rm IP} < 0.04$, $|t| < 1$ GeV^2,
$p_T(D^*) > 2$ GeV, $|\eta(D^*)| < 1.5$.

H1 deep-inelastic

$2 < Q^2 < 100$ GeV^2, $0.05 < y < 0.7$,
$x_{\rm IP} < 0.04$, $|t| < 1$ GeV^2,
$p_T(D^*) > 2$ GeV, $|\eta(D^*)| < 1.5$.

ZEUS photoproduction

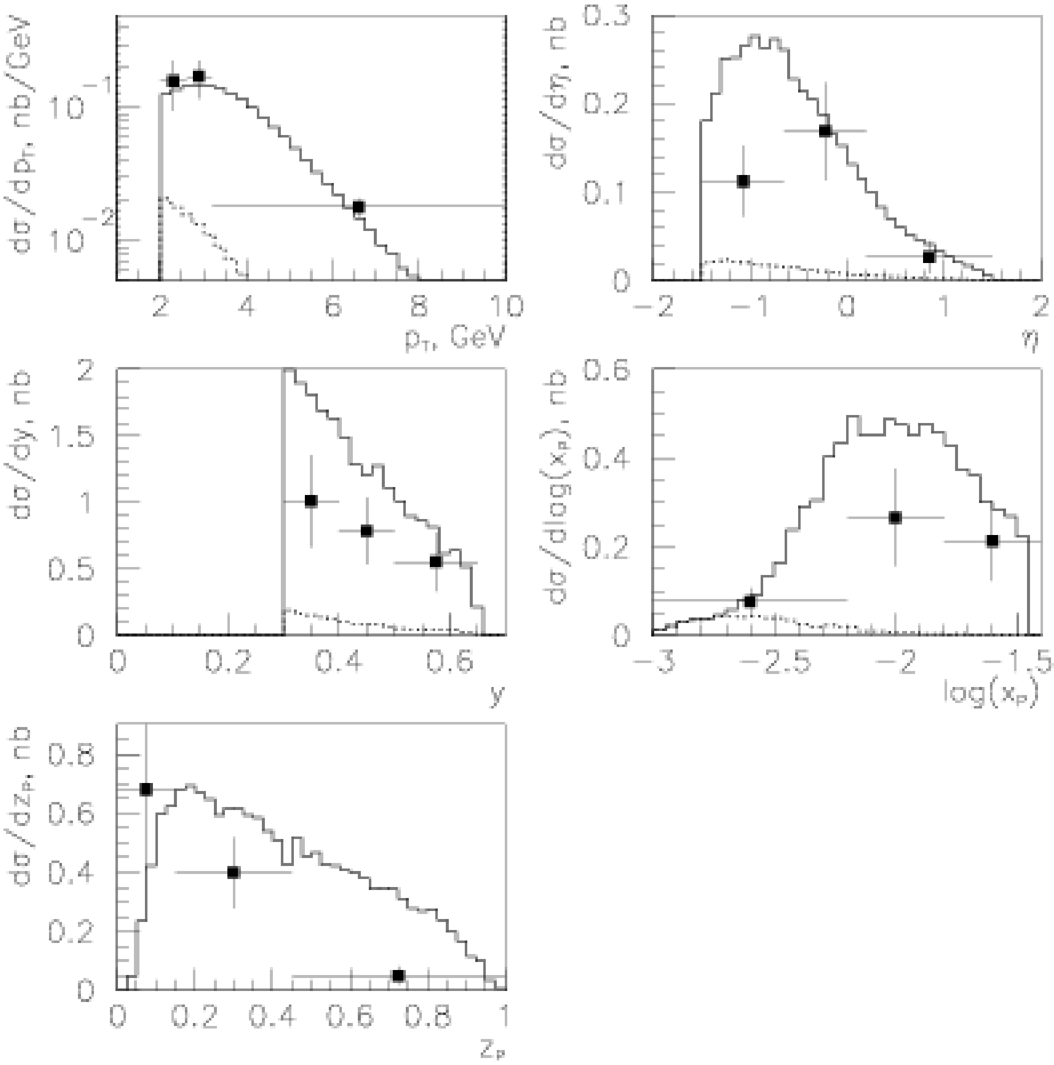
$Q^2 < 1$ GeV^2, $0.17 < y < 0.89$,
$130 < W < 300$ GeV, $x_{\rm IP} < 0.035$,
$p_T(D^*) > 1.9$ GeV, $|\eta(D^*)| < 1.6$.
Events with $x_{\rm IP} < 0.01$ have been considered as a separate subsample.

ZEUS deep-inelastic

$1.5 < Q^2 < 200$ GeV^2, $0.02 < y < 0.7$,
$x_{\rm IP} < 0.035$, $\beta < 0.8$,
$p_T(D^*) > 1.5$ GeV, $|\eta(D^*)| < 1.5$.
Events with $x_{\rm IP} < 0.01$ have been considered as a separate subsample.

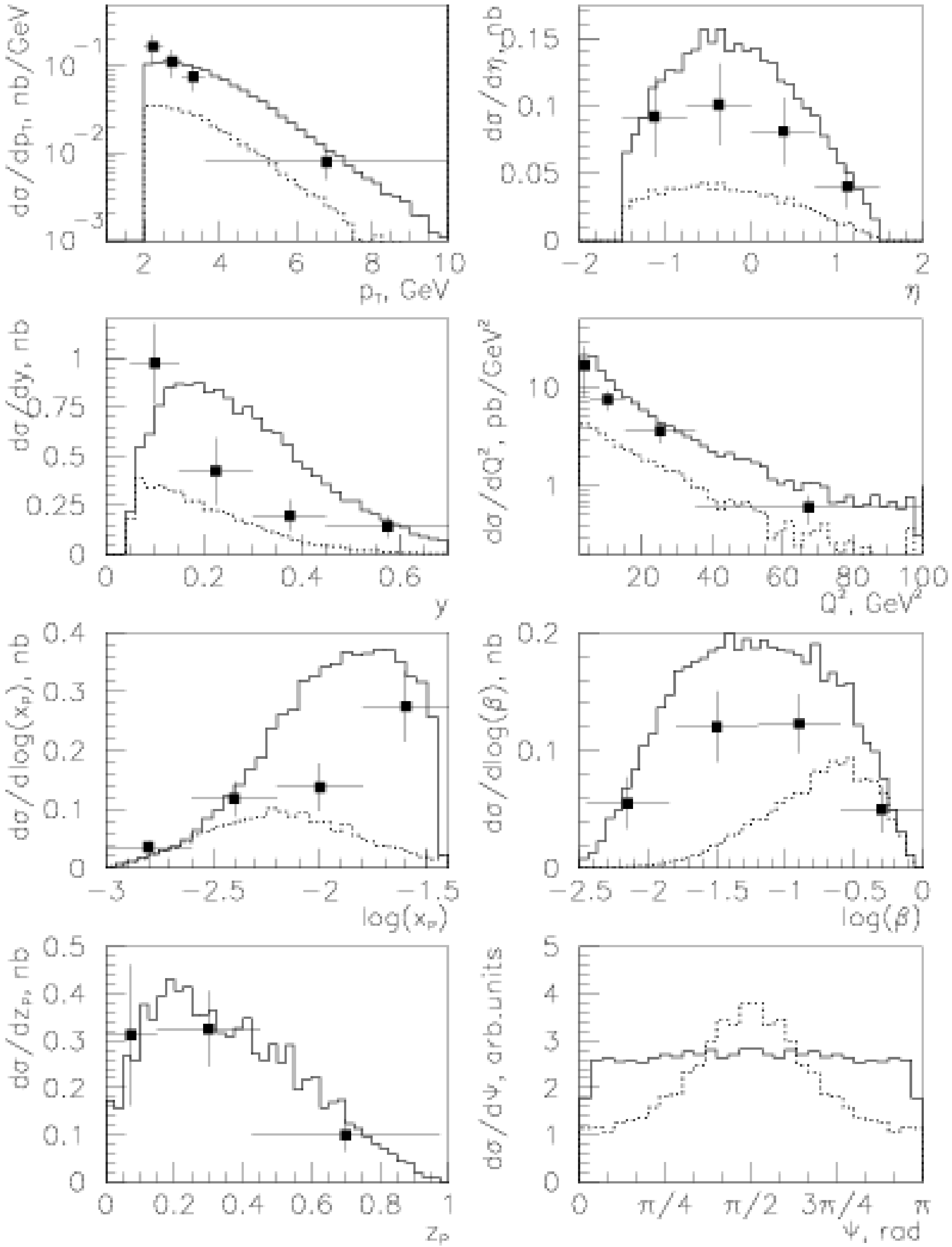
NUMERICAL RESULTS

H1 photoproduction



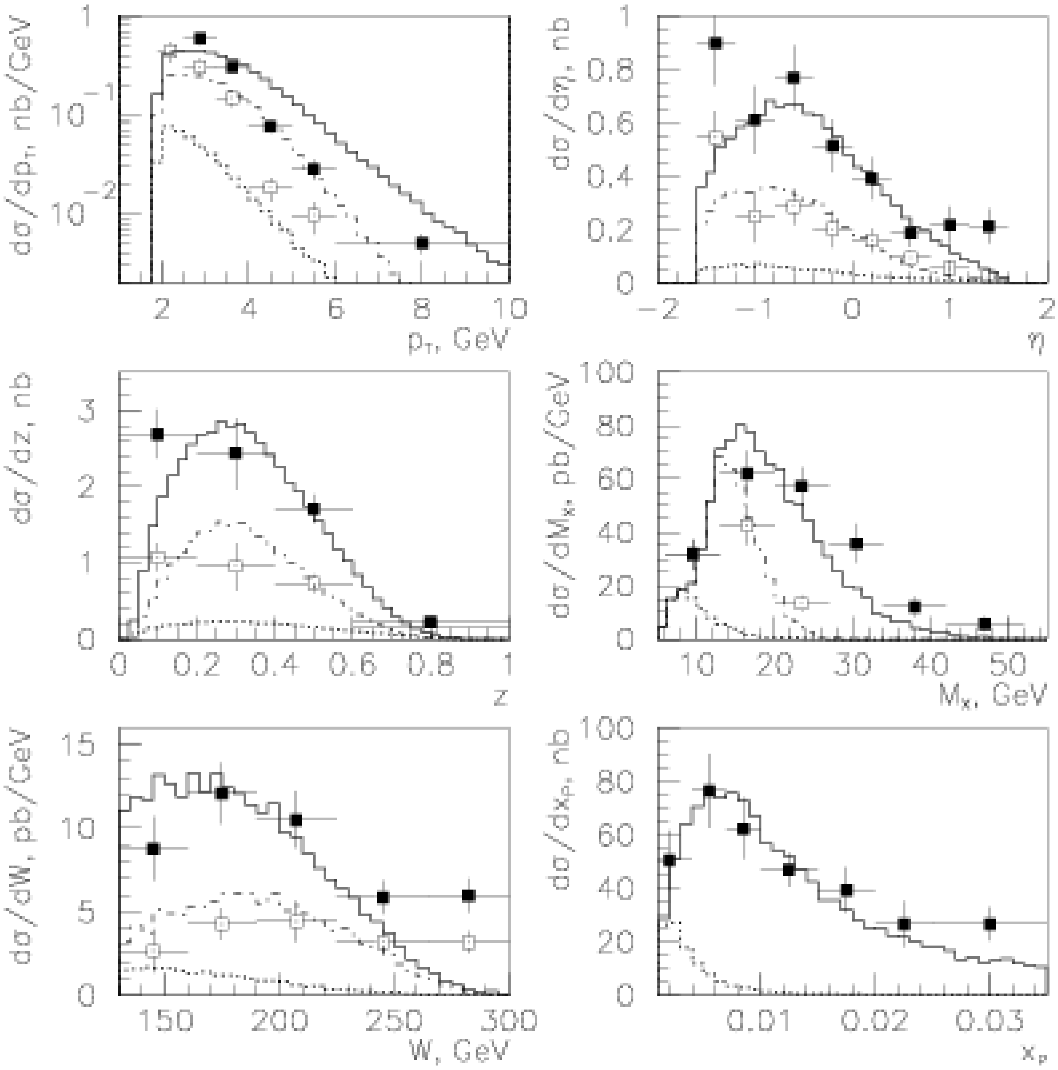
Solid: LO+NLO; dotted: LO alone; ■ H1 data.

H1 deep-inelastic



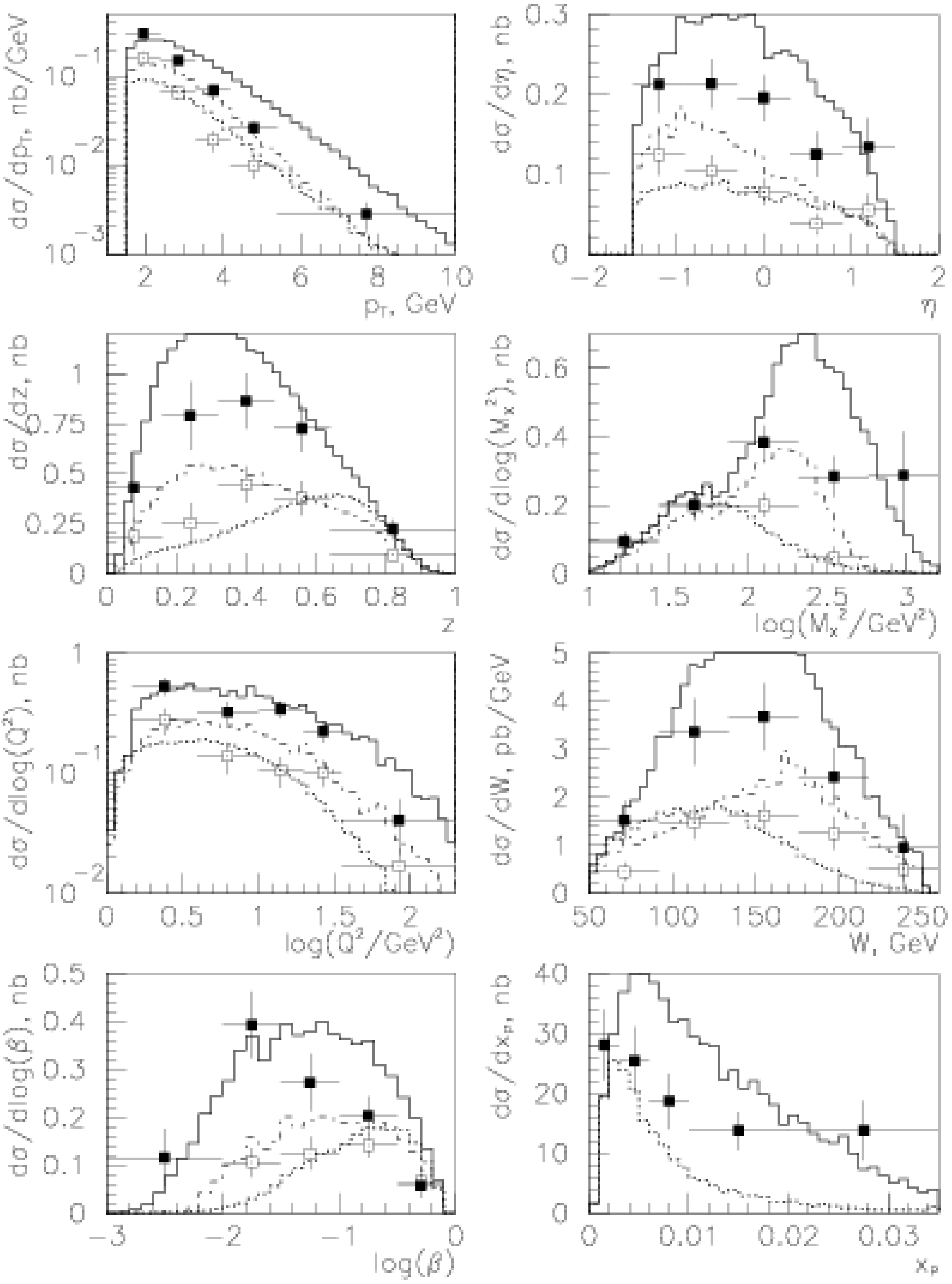
Solid: LO+NLO; dotted: LO alone; ■ H1 data.

ZEUS photoproduction



Solid: LO+NLO, $x_{IP}<0.035$;
dash-dotted: LO+NLO, $x_{IP}<0.01$;
dashed: LO alone, $x_{IP}<0.035$;
ZEUS data: ■ $x_{IP}<0.035$; □ $x_{IP}<0.01$.

ZEUS deep-inelastic



Solid: LO+NLO, $x_{\mathrm{IP}}<0.035$;
dash-dotted: LO+NLO, $x_{\mathrm{IP}}<0.01$;
dashed: LO alone, $x_{\mathrm{IP}}<0.035$;
ZEUS data: ■ $x_{\mathrm{IP}}<0.035$; □ $x_{\mathrm{IP}}<0.01$.

4. CONCLUSIONS

Good quality of experimental data, especially from **ZEUS**

Good agreement between the data and two-gluon exchange model in its both versions.
Many different distributions are nicely described within the same parameter setting.

Hard to make preference between collinear and k_t-factorization schemes.

Maybe, just the consistency of the approach

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