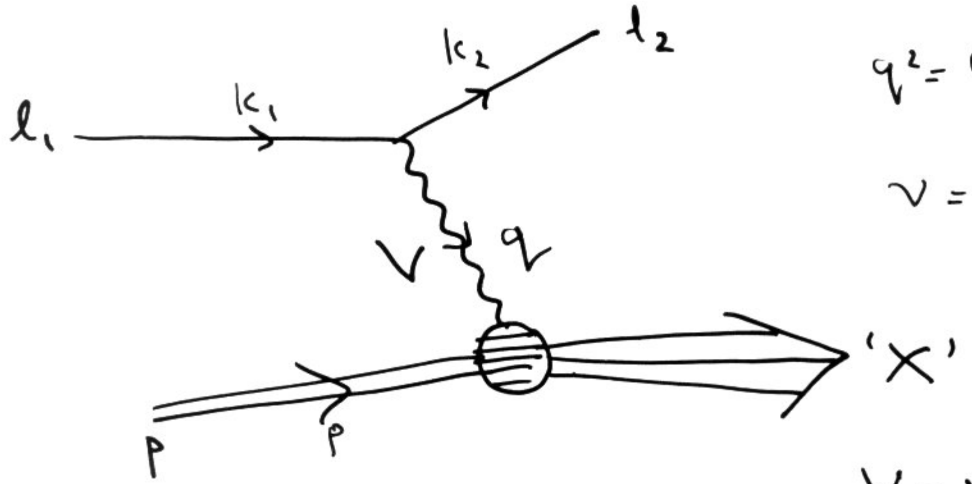
PRECISION TESTS OF PERTURBATIVE QCD AT THERA

1. ACCURATE KNOWLEDGE OF BACKGROUND FOR NEW PHYSICS

2. ACCURATE DETERMINATION OF THE STRONG PARAMETERS (α_s , Λ_{QCD} , QUARK MASS) ANALOGOUS TO ELECTRO-WEAK PARAMETERS AT LEP , SLD

DEEP INELASTIC LEPTON-HADRON SCATTERING

$$\ell_1(k_1) + P(p) \to \ell_2(k_2) + \text{'}X\text{'}$$



$$q^2 = (k_1 - k_2)^2 = -Q^2 < 0$$

$$\nu = \frac{p \cdot q}{M} \qquad x = \frac{Q^2}{2M\nu}$$

$$y = \frac{p \cdot q}{p \cdot k_1}$$

$$V = \gamma, Z, W$$

$$0 < x \leq 1 \qquad 0 < y < 1$$

$$\frac{d^2\sigma}{dx\,dy} \longrightarrow$$

UNPOL STRUCT. FUNC $\quad F_1, F_2$ (OR F_L), F_3
Z, W

POL. STRUCT. FUNC. $\quad g_1, g_2$

g_3, g_4, g_5
Z, W

TWIST 2 : F_1, F_2 (F_L), F_3, g_1, g_4, g_5

TWIST 2 AND 3 : g_2, g_3

IN THE BJORKEN LIMIT ($Q^2 \to \infty$, x = FIXED $\neq 0, \neq 1$) $F(x, Q^2)$ IS DOMINATED BY THE LIGHT CONE

$$F(x, Q^2) = \frac{1}{4\pi M} \int d^4z \, e^{iq\cdot z} \langle p,s | [J(z), J(0)] | p,s \rangle$$

STATIONAIRY PHASE ARGUMENT $\quad q\cdot z$ = CONST

REST FRAME PROTON $\quad p = (M, \vec{0})$

$$q \cdot z \sim \nu(z_0 - z_3) - x M z_3 \qquad (\nu \gg M)$$

$$\rightarrow \quad |z_0 - z_3| < \frac{1}{\nu}, \quad z_0 < \frac{1}{xM} \quad z_3 < \frac{1}{xM}$$

WITH CAUSALITY $\quad [J(z), J(0)] = 0 \quad$ FOR $z^2 < 0$

AND x NOT TOO SMALL

ONE CAN SHOW $\quad z^2 < \frac{1}{Q^2} \quad$ LIGHT CONE REGION

CONCLUSION

Q^2 AND TO SOME EXTENT x IS THE RELEVANT VARIABLE FOR THE

a. OPERATOR PRODUCT EXPANSION (O.P.E.)

b. PARTON MODEL

NOTICE THAT LIGHT CONE DOMINANCE ALSO APPLIES TO

$$\sigma_{tot}(e^+e^- \to \text{'X'}) \sim \int d^4z \, e^{iqz} \langle 0 | [J(z), J(0)] | 0 \rangle$$

FROM CURRENT ALGEBRA WE INFER

E.T.C.

$$[J_a^0(x), J_b^0(y)]_{x_0=y_0} = i\,\delta^{(3)}(\bar{x}-\bar{y})\, f_{abc}\, J_c^0(x)$$

$$[J_a^0(x), J_b^{50}(y)]_{x_0=y_0} = i\,\delta^{(3)}(\bar{x}-\bar{y})\, f_{abc}\, J_c^{50}(x)$$

$$[J_a^{50}(x), J_b^{50}(y)]_{x_0=y_0} = i\,\delta^{(3)}(\bar{x}-\bar{y})\, f_{abc}\, J_c^0(x)$$

$Q_a^{(5),0} = \int d^3\bar{x}\, J_a^{(5),0}$ GENERATORS OF $SU(n_f)$

FLAVOUR.

ONE CAN DERIVE THE SUM RULES

ADLER $\int_0^1 \frac{dx}{x}\left(F_2^{\bar{\nu}p}(x,Q^2) - F_2^{\nu p}(x,Q^2)\right) = 2$ $n_f = 4$

$\int_0^1 \frac{dx}{x}\left(g_4^{\bar{\nu}p}(x,Q^2) - g_4^{\nu p}(x,Q^2)\right) = \left|\frac{G_A}{G_V}\right|$ $n_f = 4$

FOR ARBITRARY Q^2 !!

→ NO POWER CORRECTIONS

NO QCD CORRECTIONS

IS IT POSSIBLE TO MEASURE THESE

SUM RULES AT $\boxed{\text{THERA}}$?

SMALL x $(x \sim 10^{-6})$ LARGE x $(x \sim 0.9)$

IN THE LIMIT $Q^2 \to \infty$ x = FIXED ONE CAN MAKE A LIGHTCONE EXPANSION

O.P.E. $$[J(z), J(0)] \underset{z^2 \sim 0}{=} \sum_{\tau} \sum_{N} C^{N,\tau}(z^2 \mu^2)\, O^{N,\tau}(\mu^2, 0)$$

$\uparrow$ REN SCALE

τ = TWIST $\qquad$ N = SPIN

$$\int_0^1 dx\, x^{N-1} F(x, Q^2) = \sum_{\tau} \left(\frac{M^2}{Q^2}\right)^{\frac{\tau}{2}-1} A^{(N),\tau}(\mu^2)\, \mathbb{C}^{(N),\tau}\left(\frac{Q^2}{\mu^2}\right)$$

$A^{(N),\tau}(\mu^2) = \langle p,s | O^{N,\tau}(\mu^2, 0) | p,s \rangle$ $\qquad$ O.M.E.

$\mathbb{C}^{(N),\tau}\left(\frac{Q^2}{\mu^2}\right) = \int d^4z\, e^{iqz}\, C^{N,\tau}(z^2 \mu^2)$ $\qquad$ COEFF. FUNC.

IF $F(x, Q^2)$ IS KNOWN FOR THE WHOLE x REGION (SMALL EXTRAPOLATIONS ALLOWED) ONE CAN EXTRACT $A^{(N),\tau}$ FOR FINITE N ($N = 1, 2, 3.$)

COMPARE WITH LATTICE CALCULATIONS

NOTICE: $A^{(N),\tau}$ is NON PERTURBATIVE

PARTON MODEL (FOR LEADING TWIST ONLY)

$$A^{(N),\tau}(\mu^2) = \int_0^1 dx\, x^{N-1} f(x,\mu^2)$$

$\uparrow$ PARTON DENSITY

USING LIGHT CONE EXPANSIONS AND $SU(n_f)$

ONE CAN DERIVE FOR $n_f = 4$ AND $\tau = 2$

BJORKEN 2 $$\int_0^1 dx \left(F_1^{\bar{\nu}p}(x,q^2) - F_1^{\nu p}(x,q^2) \right)^{-1}_{n\ \ n} = 1$$

GROSS-LLEWELLYN SMITH $$\int_0^1 dx \left(F_3^{\bar{\nu}p}(x,q^2) + F_3^{\nu p}(x,q^2) \right)^{n\ \ n} = -6$$

BJORKEN 1 $$\int_0^1 dx \left(g_1^{\gamma p}(x,q^2) - g_1^{\gamma n}(x,q^2) \right) = \frac{1}{6} \left| \frac{G_A}{G_V} \right|$$

$$\int_0^1 dx \left(g_5^{\bar{\nu}p}(x,q^2) - g_5^{\nu p}(x,q^2) \right)^{n\ \ n} = \bar{\frac{1}{2}} \left| \frac{G_A}{G_V} \right|$$

THESE SUM RULES ARE ONLY VALID FOR $Q^2 \to \infty$

CONTRARY TO ADLER AND $\int \frac{dx}{x} g_4^{\bar{\nu}p - \nu p}$

HERE WE HAVE HIGHER TWIST $(\tau > 2)$ AND

QCD CORRECTIONS.

$A^{(N),\tau}(\mu^2)$ EVOLUTION W.R.T μ^2 AND THE

COEF. FUNC. $C^{(N),\tau}\left(\frac{Q^2}{\mu^2}\right)$ ARE CALCULABLE

IF ONE HAS A MODEL

FOR LEADING TWIST ($\tau=2$) ONE ADOPTS THE

PARTON MODEL MERGED WITH QCD

$$QCD \to O^{N,\tau}(x) \longrightarrow A^{(N),\tau}(\mu^2)$$

PARTON MODEL $\longrightarrow C^{(N),2}\left(\frac{Q^2}{\mu^2}\right)$

MODIFICATION SUM RULES

$$\int_0^1 dx\, F_{i}^{\bar{\nu}p-\nu p}(x,q^2) = A^{(1),2}\left[1+\frac{\alpha_s(\mu_r^2)}{\pi}c_1+\left(\frac{\alpha_s(\mu_r^2)}{\pi}\right)^2 c_2+\dots\right]$$
$$g_i$$

+ HIGHER TWIST

EXCEPT FOR ADLER AND $\int_0^1 \frac{dx}{x}\, g_4^{\bar{\nu}p-\nu p}$

$$A^{(1),2} \longrightarrow \langle p.s \,|\, J_a^{\mu}(0) \,|\, p.s\rangle = p_\mu \longrightarrow A^{(1),2}=1$$

$$\langle p.s \,|\, J_a^{\mu,5}(0) \,|\, p.s\rangle = s_\mu \left|\frac{G_A}{G_V}\right| \to A^{(1),2} = \left|\frac{G_A}{G_V}\right|$$

$$\partial_\mu J_a^{\mu}=0 \qquad \partial_\mu J^{\mu,5}=0 \text{ if } m\to 0$$

$\to A^{(1),2}$ INDEPENDENT OF μ

NOTICE THAT FOR SOME SUM RULES

PERT SERIES IS KNOWN UP TO $\alpha_s^3(\mu_r^2)$ (N^3LO)

MEASUREMENT OF STRUCTURE FUNCTIONS

AT LARGE Q^2 AND LARGE x

1. DETERMINATION OF α_s AND Λ_{QCD}

2. EXTRACTION OF PARTON DENSITIES f_q, f_g

   $q = u, d, s$

Q^2 EVOLUTION OF $F(x,Q^2)$ DETERMINED BY

1. SPLITTING FUNCTIONS $P_{ij}(x)$ OR

   ANOMALOUS DIMENSIONS $\gamma_{ij}^{(N)} = -\int_0^1 dx\, x^{N-1} P_{ij}(x)$

   KNOWN UP TO $O(\alpha_s^2)$

   FOR α_s^3 $N = 1 \cdots 14$ (SEE TALK A. VOGT)

2. COEFFICIENT FUNCTIONS $\mathbb{C}_{i,q}, \mathbb{C}_{i,g}$

   KNOWN UP TO $O(\alpha_s^2)$

   FOR α_s^3 $N = 1 \cdots 14$

IN NEAR FUTURE $\gamma_{ij}^{(N)}$ AND $\mathbb{C}_{i,k}$ KNOWN

UP TO $O(\alpha_s^3)$ (VERMASEREN)

COMPLETE NNLO ANALYSIS POSSIBLE FOR $F_i(x,Q^2)$

THE SAME HOLDS FOR DRELL-YAN

$\rightarrow$ LUMINOSITY MONITOR $p\bar{p}$, pp COLLISIONS

INTERESTING RELATIONS WHICH HOLDS

FOR NON-SINGLET COEF FUNC UP TO $O(\alpha_s^2)$

ONLY

$$g_{4\Delta} \quad \mathbb{C}^{NS}_{4,q} = \mathbb{C}^{NS\ F_2}_{2,q}$$

$$g_{5\Delta} \quad \mathbb{C}^{NS}_{5,q} = \mathbb{C}^{NS\ F_1}_{1,q}$$

$$g_{1\Delta} \quad \mathbb{C}^{NS}_{1,q} = \mathbb{C}^{NS\ F_3}_{3,q}$$

REMOVAL OF FACTORIZATION SCALE DEPENDENCE

IN $F(x,Q^2)$

$$F^{(N)}(Q^2) = f_q^{(N)}(\mu_f^2, \mu_r^2)\, \mathbb{C}_q^{(N)}\left(\frac{Q^2}{\mu_f^2}, \frac{\mu_f^2}{\mu_r^2}\right)$$

μ_f : FACT. SCALE

μ_r : REN SCALE $\longrightarrow \alpha_s(\mu_r)$

NON-SINGLET CASE

$$\mathcal{C}_q^{(N)} = \Big[1 + a_s(Q^2) \Big\{ C_q^{(1)} + \frac{\gamma_{qq}^{(1)}}{2\beta_0} - \frac{\beta_1 \gamma_{qq}^{(0)}}{2\beta_0^2} \Big\}$$
$$\underbrace{- a_s(\mu_f^2) \Big\{ \frac{\gamma_{qq}^{(1)}}{2\beta_0} - \frac{\beta_1 \gamma_{qq}^{(0)}}{2\beta_0^2} \Big\}}_{\mu_f\text{, SCHEME DEPENDENT}} \Big] \Big[\frac{a_s(Q^2)}{a_s(\mu_f^2)} \Big]^{\frac{\gamma_{qq}^{(0)}}{2\beta_0}}$$

$$f_q^{(N)} = \Big[1 + a_s(\mu_f^2) \underbrace{\Big\{ \frac{\gamma_{qq}^{(1)}}{2\beta_0} - \frac{\beta_1 \gamma_{qq}^{(0)}}{2\beta_0^2} \Big\}}_{\mu_f\text{, SCHEME DEP}} \Big] \Big[\frac{a_s(\mu_f)^2}{a_s(Q_0^2)} \Big]^{\frac{\gamma_{qq}^{(0)}}{2\beta_0}} f^{(N)}(Q_0^2)$$

$$F^{(N)}(Q^2) = f_q^{(N)} \mathcal{C}_q^{(N)} = \Big[1 + a_s(Q^2) \Big\{ C_q^{(1)} + \underbrace{\frac{\gamma_{qq}^{(1)}}{2\beta_0} - \frac{\beta_1 \gamma_{qq}^{(0)}}{2\beta_0^2}}_{\mu_f\text{, SCHEME INDEPENDENT}} \Big\} \Big] \Big[\frac{a_s(Q^2)}{a_s(Q_0^2)} \Big]^{\frac{\gamma_{qq}^{(0)}}{2\beta_0}} f^{(N)}(Q_0^2)$$

$$+ \; a_s^2(\mu_f^2) \Big(\qquad \Big)$$

$\uparrow$ μ_f, SCHEME DEPENDENT

TRUNCATE $\qquad \alpha_s(Q^2) = a_s(\mu_f^2) \Big[1 - a_s(\mu_f^2) \beta_0 \ln \frac{Q^2}{\mu_f^2} \Big]$

THE TRUNCATED PERTURBATION SERIES

IS FACT-SCHEME (μ_f) INDEPENDENT

FOR μ_r DEPENDENCE ONE CAN ESTIMATE

$\sim$ HIGHER ORDER CORRECTIONS

1. EFFECTIVE CHARGE SCHEME (ECH)

2. PMS

3. PADÉ

FOR THAT ONE NEEDS NNLO

SEE $R(e^+e^- \to 'X') = 1 + a_s(\mu_r^2) c_1 + a_s^2(\mu_r^2) \left[-\beta_0 c_1 \ln \frac{Q^2}{\mu_r^2} + c_2 \right] + \dots$

SUMMARY

DEEP INELASTIC STRUCTURE FUNCTIONS PROVIDES US WITH THE BEST TEST OF QCD

1. INCLUSIVE QUANTITIES, NO HADRONIZATION EFFECTS

2. LIGHT CONE DOMINANCE, VALID BEYOND QCD

3. SUM RULES, VALID BEYOND QCD

NOTICE THAT APART FROM $R(e^+e^- \to X)$ AND SOME DECAYS NO OTHER QUANTITIES SATISFY THE ABOVE PROPERTIES

E.G. DRELL-YAN

$$\frac{d\sigma}{dQ^2} = \frac{4\pi\alpha^2}{Q^4}\tau\, W(\tau, Q^2)$$

$$W(\tau, Q^2) = \frac{1}{4\pi}\int d^4z\, e^{iqz} \langle p_1, s_1; p_2, s_2 | J^\mu(z) J_\mu(0) | p_1, s_1; p_2, s_2 \rangle$$

$$\neq [J^\mu(z), J_\mu(0)]$$

NO LIGHTCONE DOMINANCE

THE SAME HOLDS FOR: JET PRODUCTION

HEAVY FLAVOUR PRODUCTION

DIRECT PHOTON PRODUCTION

ETC.

THERFORE THESE PROCESSES ARE THEORETICALLY LESS SUITABLE TO TEST QCD

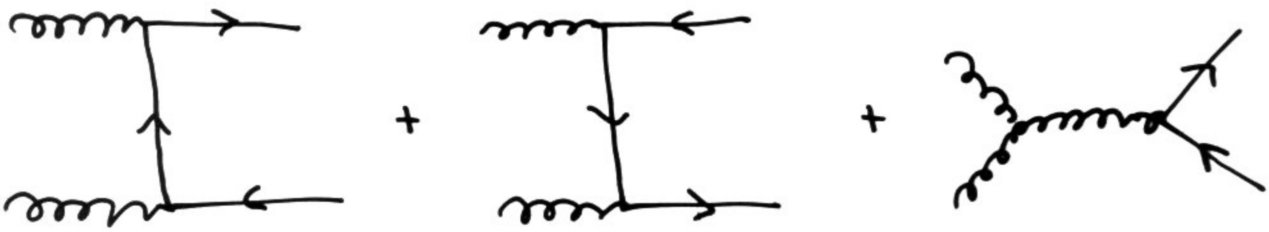
HEAVY FLAVOUR PRODUCTION

I. HADRON-HADRON COLLISIONS

$p\bar{p}$, πN

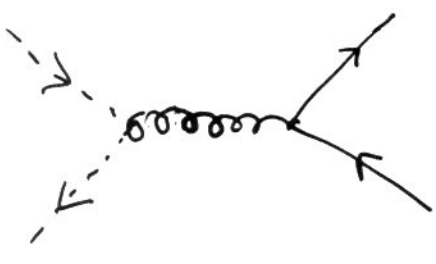
PRODUCTION MECHANISMS

$g + g \rightarrow Q + \bar{Q}$



DOMINATING FOR $c\bar{c}$, $b\bar{b}$ PRODUCTION

$q + \bar{q} \rightarrow Q + \bar{Q}$



ALSO IMPORTANT FOR $t\bar{t}$

$$d\sigma \sim f_i^H \otimes f_j^H \otimes d\sigma_{ij}$$

THEORETICAL STATUS: NLO CORRECTIONS AVAILABLE, RESUMMATION OF SOFT GLUON CONTRIBUTIONS $\rightarrow$ IMPROVEMENT THRESHOLD BEHAVIOUR.

RESUMMATION OF $\ln \frac{p_T}{m}$ IN QUARK $\rightarrow$ HADRON FRAGMENTATION PROCESS.

EXPERIMENTAL STATUS

FIG. 1,2 $\pi + N \rightarrow c + \bar{c} + 'X'$ $E_\pi = 500$ GeV

E791 - DATA

NLO CROSS SECTION HAS EXTREMELY LARGE THEOR. UNCERTAINTIES

HIGHLY SENSITIVE ON FACT/REN SCALE μ

HARD CHARM FRAGM. FUNCTION $D_c^{D^0}(x, \mu^2)$

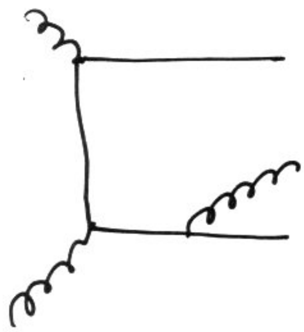
$k_T|_{INTRINSIC} \sim 1$ GeV (INCOMING PARTONS)

AGREEMENT BETWEEN EXP. AND THEOR. FORTUITOUS!!

FIG. 3, 4 $p + \bar{p} \rightarrow b + \bar{b} + 'X'$ $\sqrt{s} = 1.8$ TEV

$$\frac{\dfrac{d\sigma^{EXP}}{dp_T^b}}{\dfrac{d\sigma^{THEOR}}{dp_T^b}} \sim 2$$

RESUMMATION OF $\ln \frac{p_T}{m_b}$ (FRAGMENTATION)



HARDLY CHANGES THE THEOR $\frac{d\sigma}{dp_T}$

NOTICE THAT

$$\frac{d\sigma^{NLO}}{dp_T} \Big/ \frac{d\sigma^{LO}}{dp_T^b} \sim 2 \qquad \text{CORRECTION } 100\,\%$$

$\longrightarrow$ NEED FOR NNLO CORRECTIONS BUT WHAT HAPPENS WITH $\frac{d\sigma}{dp_T^c}$

$p + \bar{p} \longrightarrow t + \bar{t} + 'x'$

$\sigma_{TOT}(t\bar{t})$ AGREES WITH THEOR. PREDICTION

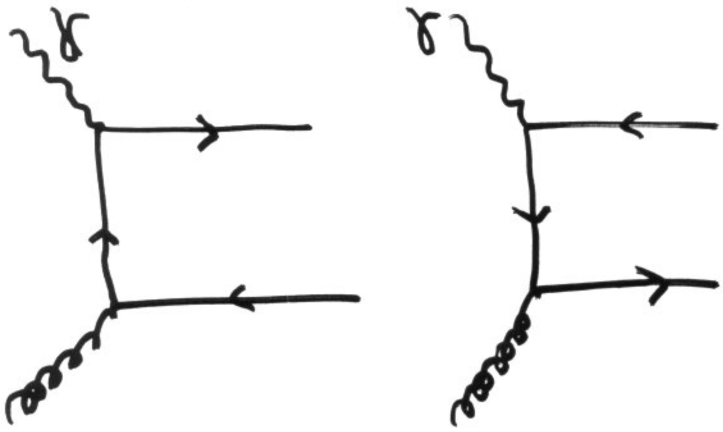
BUT LOW STATISTICS

II PHOTON - HADRON COLLISIONS

γN (EMC), γp (HERA)

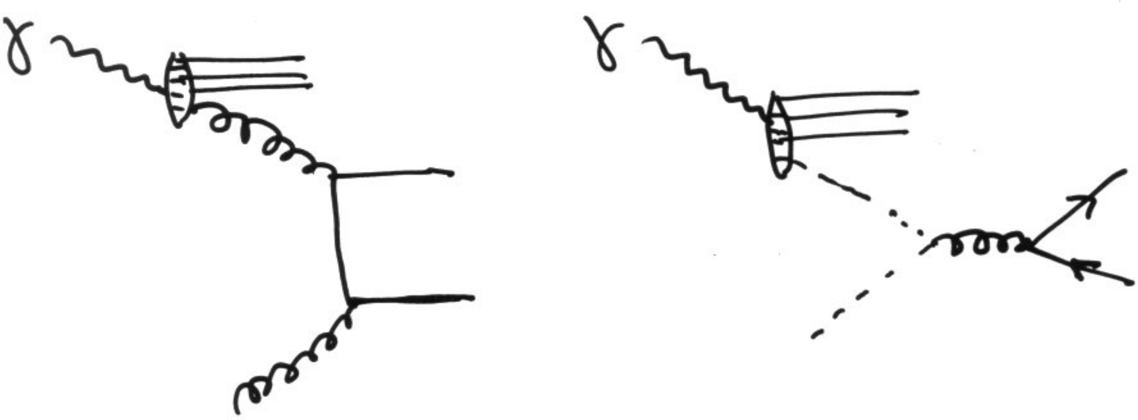
PRODUCTION MECHANISMS

UNRESOLVED PHOTON: $\gamma + g \to Q + \bar{Q}$



PHOTON-GLUON FUSION

RESOLVED PHOTON $g + g \to Q + \bar{Q}$, $q + \bar{q} \to Q + \bar{Q}$



$$d\sigma = e_H^2 f_i^H \otimes d\sigma_i + f_i^H \otimes f_j^\gamma \otimes d\sigma_{ij}$$

$i, j = q, \bar{q}, g$ KNOWN UP TO NLO

SOFT GLUON RESUMMATION (b)

$\to$ IMPROVEMENT THRESHOLD BEHAVIOUR

THE SAME THEORETICAL UNCERTAINTIES

AS IN HADRON-HADRON COLLISSIONS

E.G. μ- DEPENDENCE, $\frac{d\sigma^{NLO}}{d\sigma^{LO}}$

MOREOVER ONE HAS TO DEAL WITH

THE BADLY KNOWN f_i^{γ} $i = q, \bar{q}, g$

EXPERIMENTAL STATUS FIG. 5,6

$\gamma + p \to c + \bar{c} + 'X'$ $\qquad \frac{d\sigma}{dp_T^D} \qquad \frac{d\sigma}{d\eta^D}$

$\quad \hookrightarrow D^*$

$\qquad D_s$

$\eta^D > 0.1 \qquad \frac{d\sigma^{EXP}}{d\eta^D} > \frac{d\sigma^{THEOR}}{d\eta^D}$

$\gamma + p \to b + \bar{b} + 'X'$

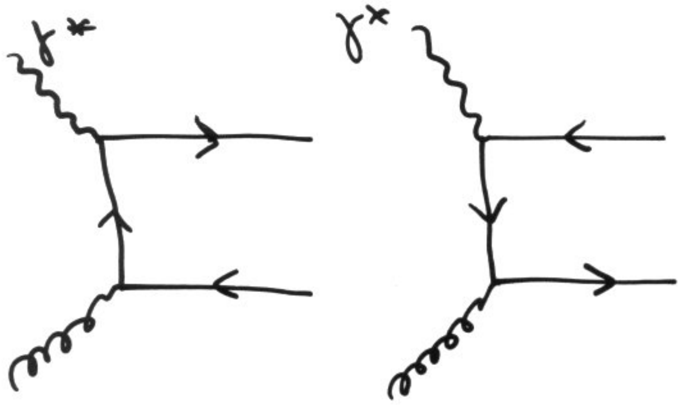
$\frac{\sigma_{TOT}^{EXP}}{\sigma_{TOT}^{THEOR.}} \approx 1.6$

HIGHER ORDER CORRECTIONS IMPORTANT

III ELECTRO-PRODUCTION $\gamma^* N$, $\gamma^* p$

$\gamma^*(Q)$ $\quad Q^2 \gtrsim 4\ \mathrm{GeV}^2$

PRODUCTION MECHANISMS $\quad \gamma^* + g \to Q + \bar{Q}$



PHOTON-GLUON FUSION (GF)

$Q^2 \sim M_Z^2, M_W^2$ ALSO Z, W CONTRIBUTION

$d\sigma \sim F_{i,Q}(x, Q^2, m^2)$

$F_{i,Q} \sim e_H^2\ f_k \otimes H_{i,k} + e_k^2\ f_k \otimes L_{i,k}$

$\uparrow$ GF $\qquad \uparrow$ COMPTON

THEORETICAL STATUS

CORRECTIONS KNOWN UP TO NLO

SOFT GLUON RESUMMATION

EXPERIMENTAL STATUS

$\gamma^* + p \to c + \bar{c} + $ 'X' (ZEUS, H1)

FIG. 7.8

GOOD AGREEMENT FOR $F_{2,c}$ BETWEEN THEOR. AND EXP IN NLO (BUT NOT LO) EXCEPT FOR $x < 2.10^{-4}$ (SMALL x RESUMMATION CCFM)

REASONABLE AGREEMENT FOR $\frac{d\sigma}{dp_t}, \frac{d\sigma}{d\eta}$ (LOW STATISTICS)

NO DATA AVAILABLE FOR

$\gamma^* + p \to b + \bar{b} + $ 'X'

HIGH STATISTICS ONLY POSSIBLE AT $\boxed{\text{THERA}}$

ELECTROPRODUCTION PROVIDES US WITH A BETTER TEST OF PERT. QCD THAN PHOTON-HADRON AND HADRON-HADRON PRODUCTION

THEORETICAL ARGUMENT

LOOK FIRST AT TOTAL CROSS SECTIONS OR STRUCTURE FUNCTIONS.

NO HADRONIZATION $Q \to H$ PROBLEM

THEN $\gamma^* p$ IS A PROCESS DOMINATED BY THE LIGHT-CONE (Q^2 LARGE, x FINITE) WHICH DOES NOT HOLD FOR γp AND pp

$$W^2 = \frac{1-x}{x}\frac{Q^2}{m^2} \quad \to \quad F_{i}(W^2, Q^2, m^2)$$

W : CM ENERGY
pp, γp SYSTEM

3-SCALE QUANTITY

IN γp OR $p\bar{p}$ $\to$ $\sigma_{TOT}(W^2, m^2)$

2-SCALE QUANTITY

WHY IS ELECTROPRODUCTION A BETTER TEST OF QCD THAN PHOTO- OR HADROPRODUCTION?

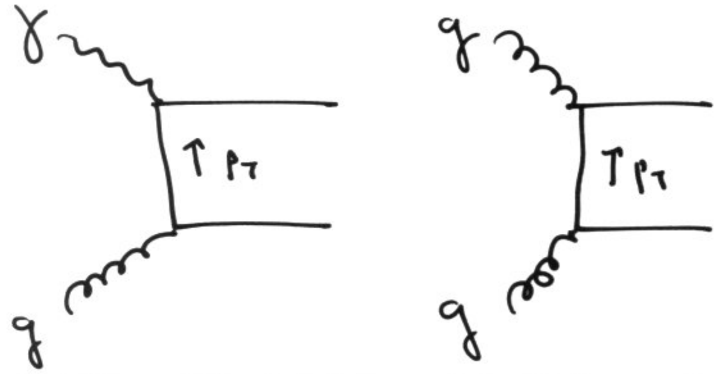
QCD APPLICABLE TO $\sigma_{TOT}^{\gamma p}$, $\sigma_{TOT}^{p\bar{p}}$

WHEN $W^2 \sim O(m^2)$

HOWEVER FOR c, b $W^2 \gg m^2$ EXPERIMENT

$$\sigma_{TOT}^{\gamma p} \sim \alpha\,\alpha_s \ln\frac{W^2}{m^2} + \alpha\,\alpha_s^2 \ln^3\frac{W^2}{m^2}$$

$$\sigma_{TOT}^{p\bar{p}} \sim \alpha_s^2 \ln\frac{W^2}{m^2} + \alpha_s^3 \ln^3\frac{W^2}{m^2}$$



$p_T \sim O(m) \to 0$

THE PROCESS CEASES TO BE HARD WHEN $p_T \to 0$

FURTHER $\ln\frac{W^2}{m^2}$ CANNOT BE RESUMMED

THIS DOES NOT HAPPEN FOR $F_{i,Q}(W^2, Q^2, m^2)$

$(Q = c, b)$

WHEN $W^2 \sim O(Q^2)$ $\quad Q^2 \gg m^2 \to F_{i,Q} \overset{ASYMP}{\sim} \sum_{k=1}^{\infty} \alpha_s^k \ln^k\frac{Q^2}{m^2}$

$\ln\frac{Q^2}{m^2}$ CAN BE RESUMMED USING DGLAP

EXAMPLE CHARM PRODUCTION (3-FLAVOUR SCHEME)

$$F^{ASYMP}_{i,c} \sim f_{g_3} \otimes H^{ASYMP}_{i,g}\left(\frac{Q^2}{m^2}\right) + (u_3+\bar{u}_3+d_3+\bar{d}_3+s_3+\bar{s}_3) \otimes H^{ASYMP}_{i,q}\left(\frac{Q^2}{m^2}\right)$$

$$= (c_4+\bar{c}_4) \otimes C_{i,c} + f_{g_4} \otimes C_{i,g} + (u_4+\bar{u}_4+d_4+\bar{d}_4+s_4+\bar{s}_4) \otimes C_{i,q}$$

FOUR FLAVOUR SCHEME

$$(c+\bar{c})_4 = f_{g_3} \otimes \left(\ln^k \frac{Q^2}{m^2}\right) + (u_3+\bar{u}_3+d_3+\bar{d}_3+s_3+\bar{s}_3) \otimes \left(\ln^k \frac{Q^2}{m^2}\right)$$

TRANSITION FROM 3-FLAVOUR TO 4-FLAVOURS

ALSO POSSIBLE FOR $\frac{d\sigma^{\gamma p}}{dp_T^2}$, $\frac{d\sigma^{pp}}{dp_T^2}$ AT LARGE p_T

BUT NOT FOR $\sigma^{\gamma p}_{TOT}$, σ^{pp}_{TOT}

VARIABLE FLAVOUR NUMBER SCHEME (VFNS)

n_f+1 MASSLESS FLAVOURS

$$F^{VFNS}_{i,q\,n_f} = F^{EXACT}_{i,q\,n_f} - F^{ASYMP}_{i,q\,n_f} + F^{PDF}_{i,q}$$

$W^2 \gg m^2$ $\quad F^{EXACT}_{i,q} \to F^{ASYMP}_{i,q}$: $F^{VFNS}_{i,q} \to F^{PDF}_{i,q}$

$W^2 \sim 4m^2$ $\quad F^{ASYMP}_{i,q} \to F^{PDF}_{i,q}$ (NEED MATCHING CONDITIONS)

(THRESHOLD)

$\quad F^{VFNS}_{i,q} \to F^{EXACT}_{i,q}$

WE EXPECT THAT THE SAME FEATURES OF CHARM PRODUCTION AT HERA WILL PERSIST FOR BOTTOM PRODUCTION AT THERA

CONCLUSIONS

1. ELECTROPRODUCTION OF HEAVY FLAVOURS IS THE BEST TESTING GROUND OF QCD

   THIS PHENOMENON IS DUE TO THE LIGHT CONE DOMINANCE FOR $F_{k,c}$, $F_{k,b}$

2. BECAUSE OF THE NON-RESUMMABLE $\ln \frac{s}{m^2}$ TERMS IN PHOTO AND HADRO PRODUCTION, NNLO CORRECTIONS WILL NOT CLOSE THE GAP BETWEEN PERT QCD AND DATA (TOO LARGE K-FACTORS)

3. STRUCTURE FUNCTIONS AND e^+e^- COLLINEAR SAFE OBSERVABLES ARE THE BEST OBJECTS TO TEST PERT. QCD.

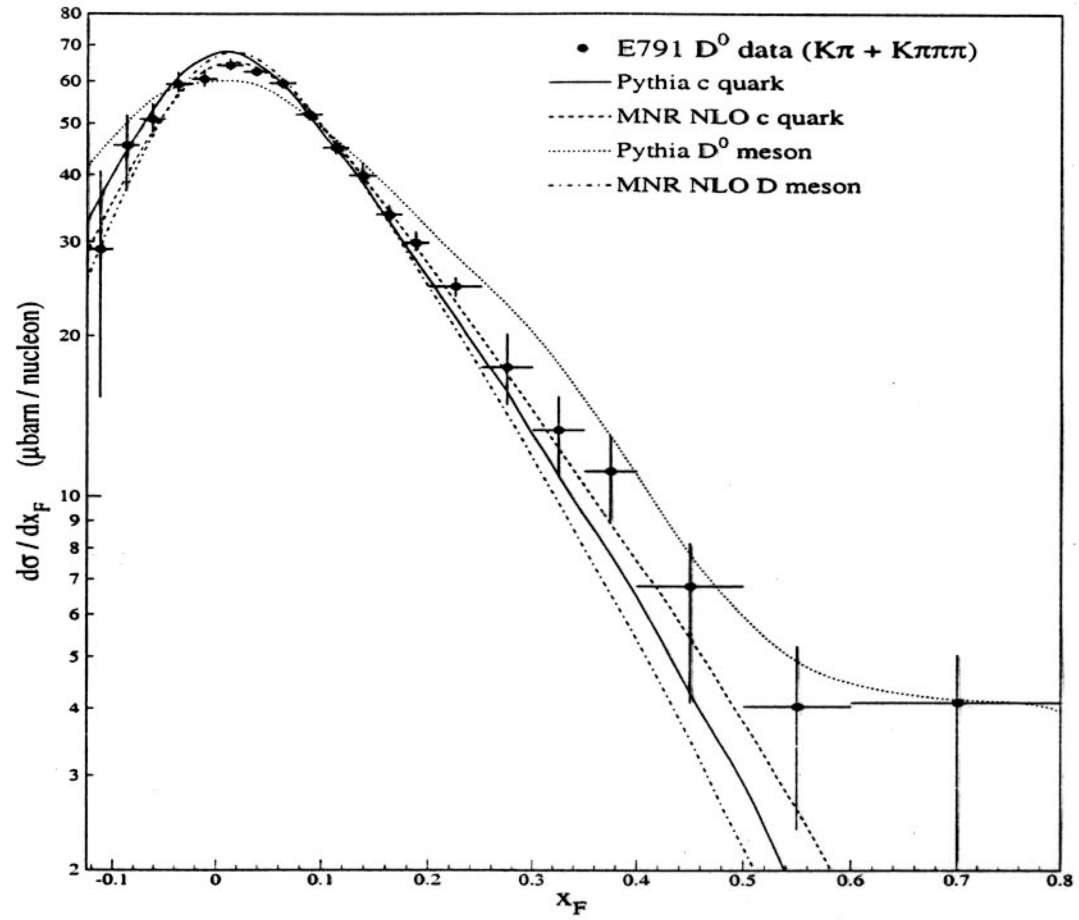


Fig. 5. The $D^0+\overline{D}^0$ x_F differential cross section compared to various theoretical predictions described in the text. The curves are normalized to obtain the best fit to the data in each case. Error bars do not include a $^{+10}_{-11}\%$ normalization uncertainty.

FIG. 1

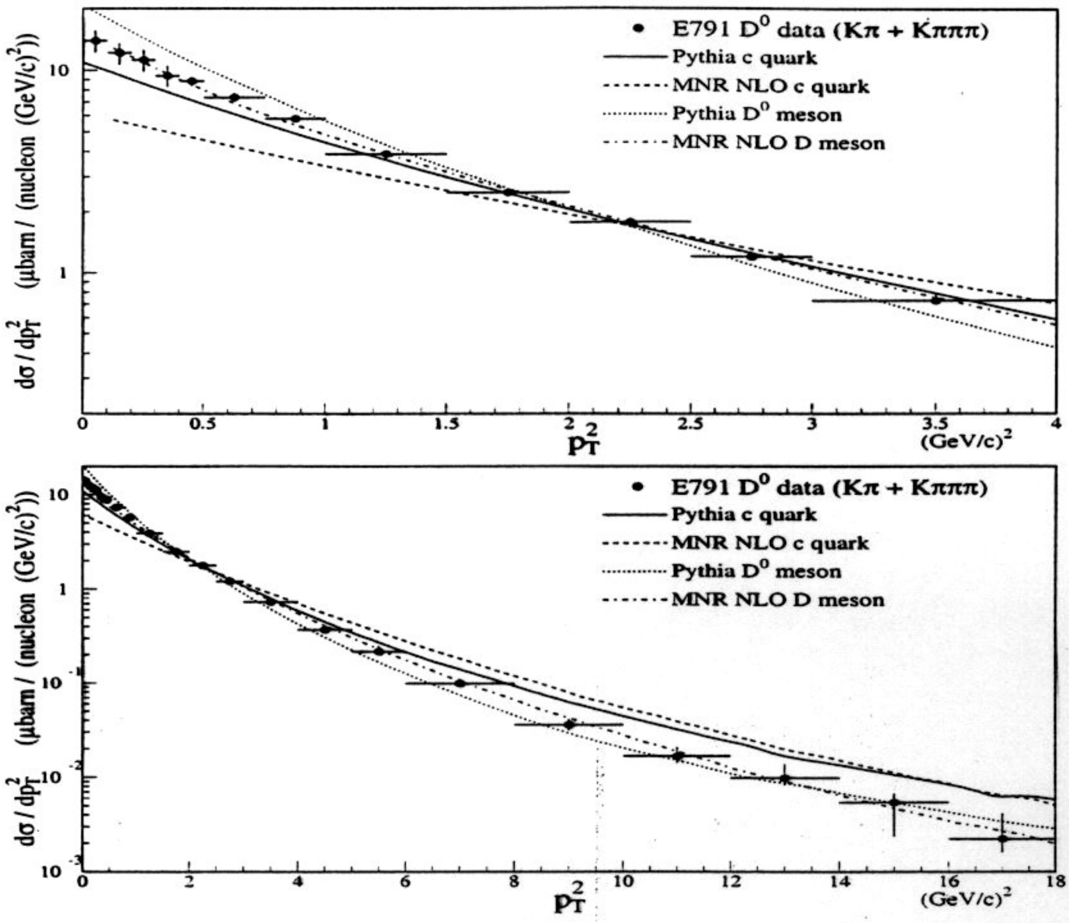


Fig. 6. The $D^0+\overline{D}^0$ p_T^2 differential cross section compared to various theoretical predictions described in the text. The curves are normalized to obtain the best fit to the data in each case. The top plot shows the range $0<p_T^2<4$ $(\mathrm{GeV}/c)^2$ while the bottom plot shows the full range, $0<p_T^2<18$ $(\mathrm{GeV}/c)^2$. Error bars do not include a $^{+11}_{-15}\%$ normalization uncertainty.

FIG. 2

C D F

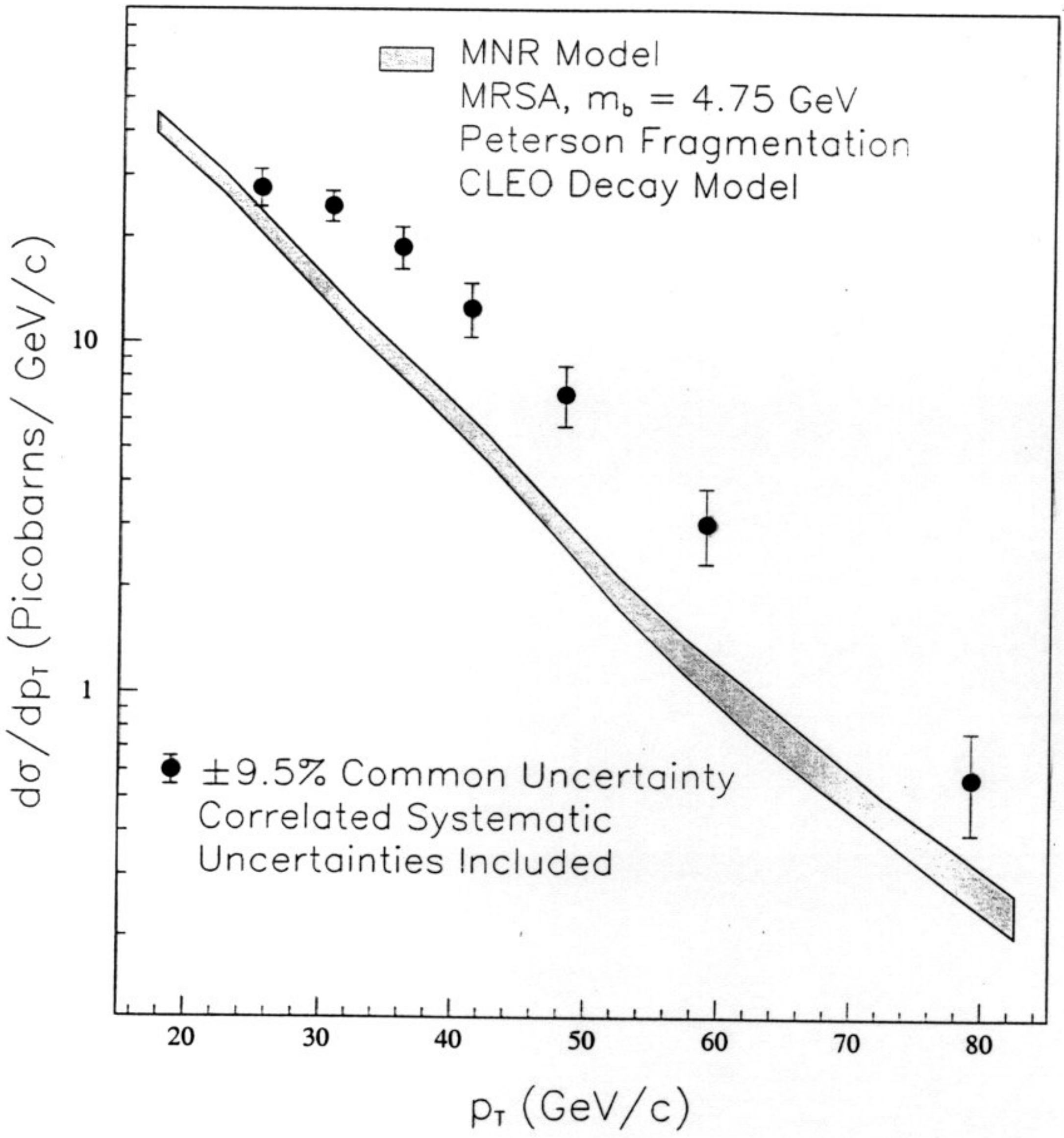


Figure 11: The differential p_t cross section, for $p_T^\mu > 9$ GeV/c, $|\eta^\mu| < 0.6$, $|\eta^{\bar{b}}| < 1.5$, compared to theoretical predictions. The data points have a common systematic of ± 9.5% and there are correlated systematic uncertainties. The uncertainty in the theory curves comes from the muonic branching fraction and fragmentation model.

FIG. 3

DØ

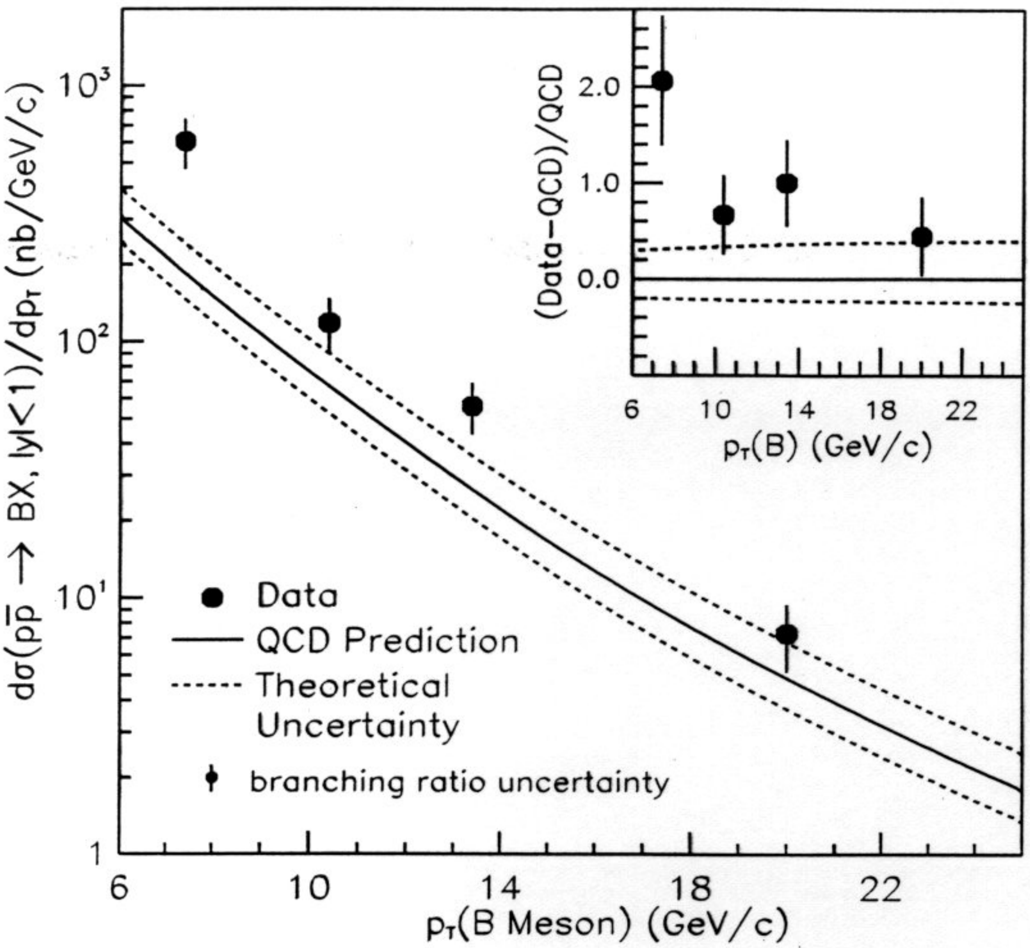


FIG. 2. Average B **meson differential cross section compared to the QCD prediction.** The branching ratio uncertainty, which contributes 11.9% to the cross section uncertainty, is shown separately. The dashed curves indicate the uncertainty in the theoretical prediction. The inset plot shows (data-QCD)/QCD on a linear scale.

FIG. 4

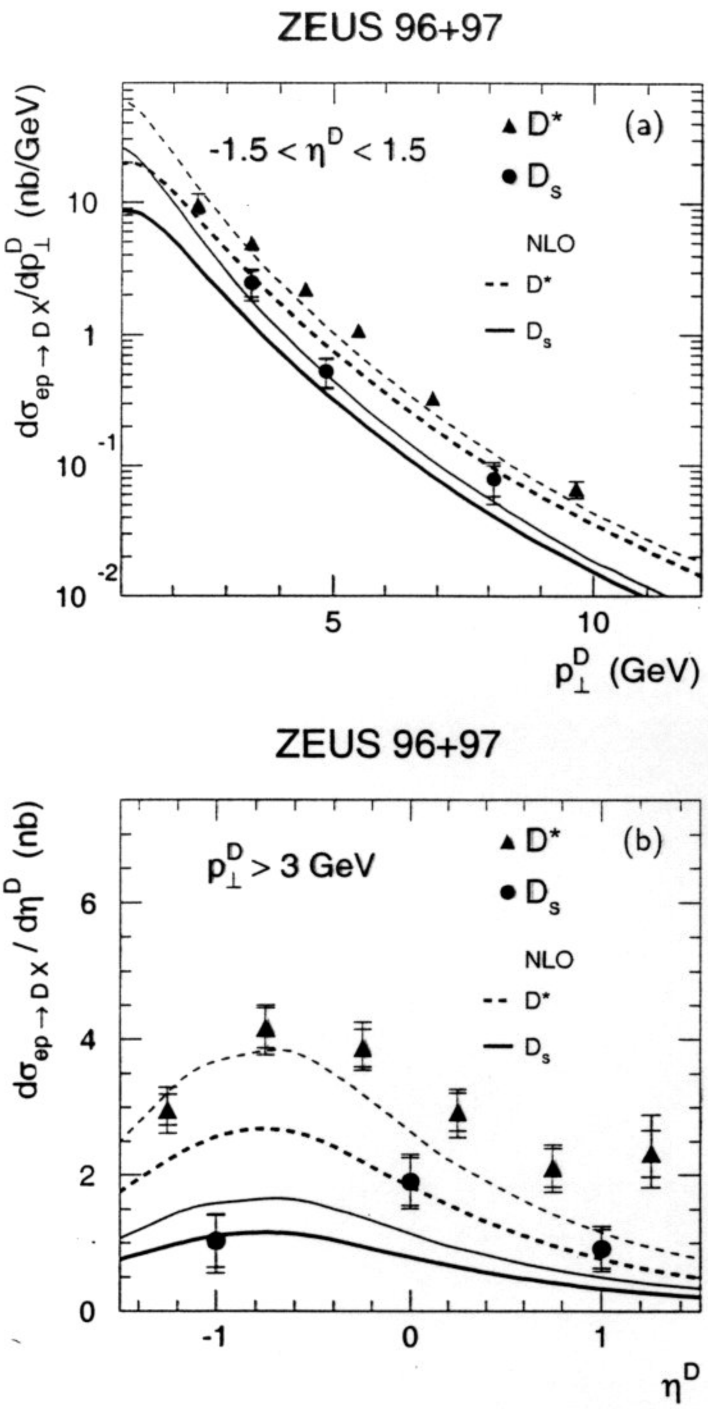


Figure 2: Differential cross sections for the photoproduction reaction $ep \to DX$: (a) $d\sigma/dp_\perp^D$ and (b) $d\sigma/d\eta^D$, where D stands for D^* or D_s. The $p_\perp^D$ points are drawn at the position of the average value of an exponential fit in each bin. The η^D points are drawn at the middle of each bin. The inner error bars show the statistical uncertainty, while the outer ones show the statistical and systematic errors added in quadrature. Normalisation uncertainties due to the $D_s \to \phi\pi$ branching ratio are not included in the systematic errors or in the theoretical calculations. The D_s (dots) and D^* (triangles) data are compared with the NLO predictions for D_s (full curves) and D^* (dashed curves) with two parameter settings: $m_c = 1.5\,\mathrm{GeV}$, $\mu_R = m_\perp$ (thick curves) and $m_c = 1.2\,\mathrm{GeV}$, $\mu_R = 0.5 m_\perp$ (thin curves).

FIG. 5

FIG. 6

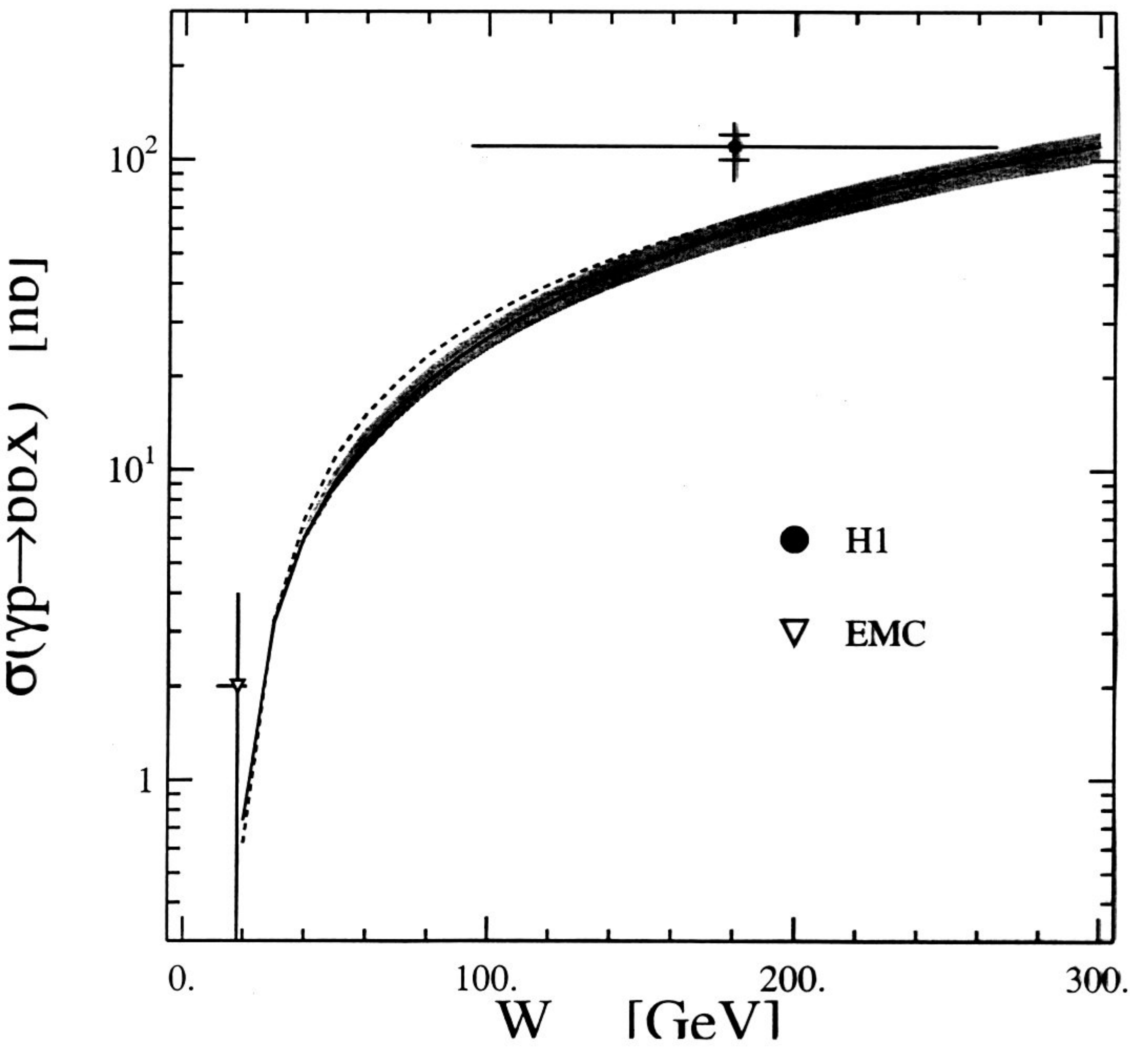
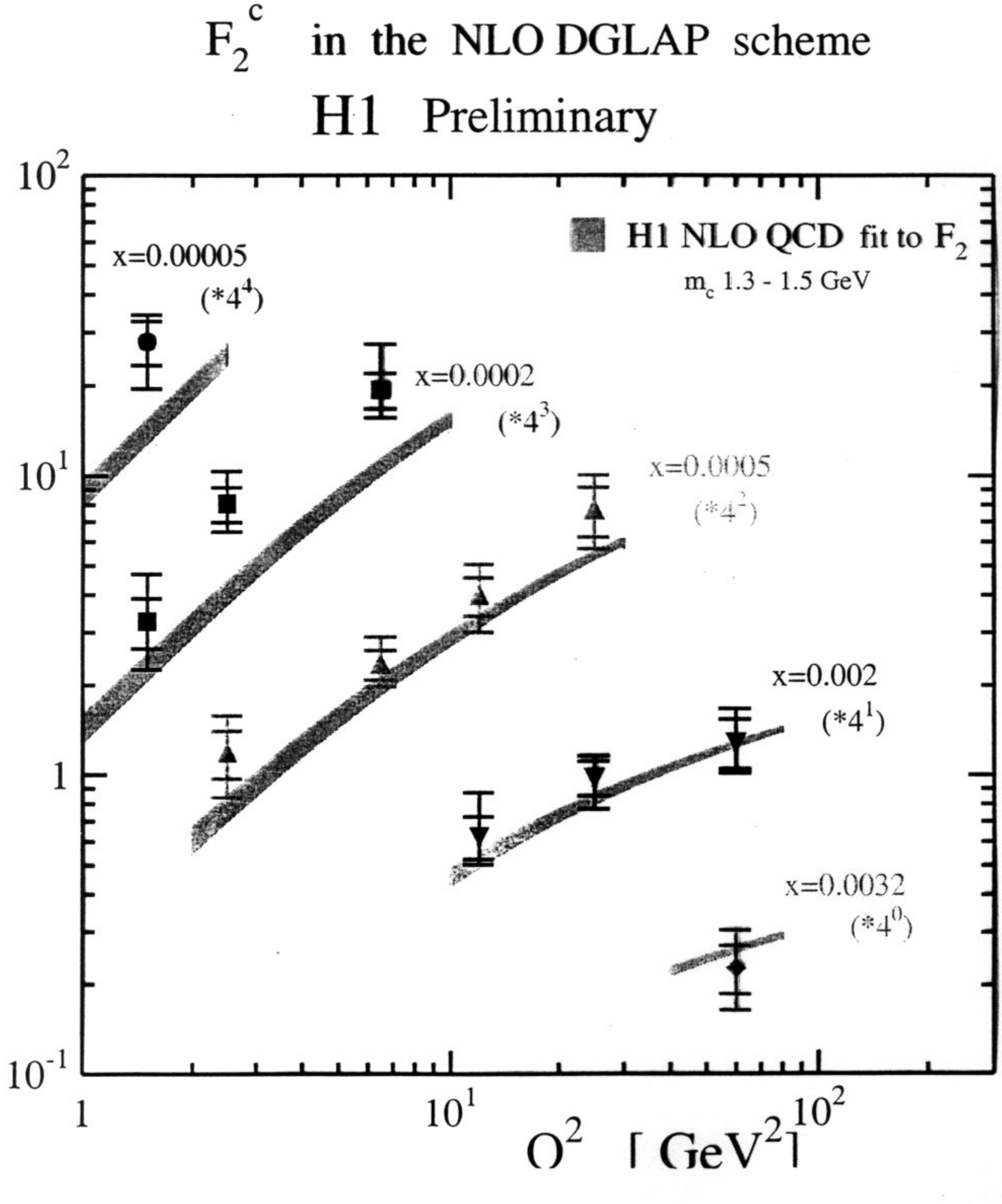
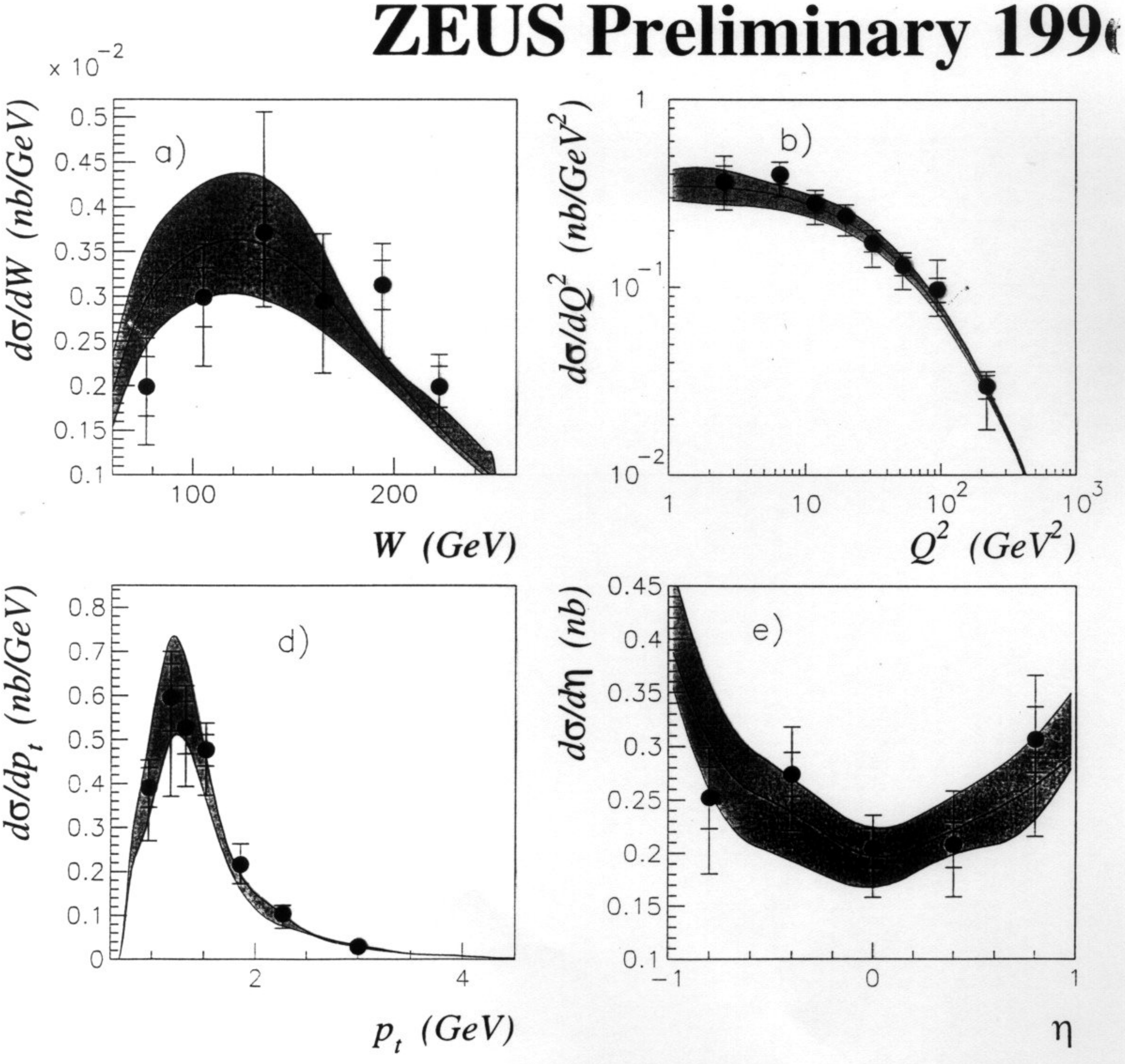


FIG. 7



F2 c in the NLO DGLAP scheme
H1 Preliminary
H1 NLO QCD fit to F2
mc 1.3 - 1.5 GeV
x=0.00005
(*4^4)
x=0.0002
(*4^3)
x=0.0005
(*4^2)
x=0.002
(*4^1)
x=0.0032
(*4^0)
10^2
10^1
1
10^-1
F2
1
10^1
10^2
Q^2 [GeV^2]

FIG. 8



ZEUS Preliminary 199
a)
$\times 10^{-2}$
$d\sigma/dW$ (nb/GeV)
W (GeV)
b)
$d\sigma/dQ^2$ (nb/GeV^2)
Q^2 (GeV^2)
d)
$d\sigma/dp_t$ (nb/GeV)
p_t (GeV)
e)
$d\sigma/d\eta$ (nb)
η