STRUCTUREFUNCTIONS, PARTON-DISTRIBUTIONS AND QCD-TESTS AT HERA

FNAL-WS 4/90.
(not presented, no Entrance Visum)

J. BLÜMLEIN, IfH ZEUTHEN

1. INTRODUCTION
2. KINEMATICS, RC's & SYSTEMATIC EFFECTS
3. NC AND CC STRUCTUREFUNCTIONS
4. PARTONDISTRIBUTIONS
5. QCD-TEST : Λ_{QCD} & $\alpha_s(Q^2)$
6. CONCLUSIONS

1. INTRODUCTION

DEEP INELASTIC $\left(\begin{smallmatrix}\overset{(-)}{\nu} \\ \ell^{\pm}\end{smallmatrix}\right) N$ - SCATTERING IS ONE OF THE CLEANEST POSSIBILITIES TO TEST SCALING VIOLATIONS OF STRUCTUREFUNCTIONS.

PAST & PRESENT :

	eN	SLAC-Exp.
	μN	EMC, BCDMS, Exps. at FNAL, NMC, ...
	νN	BEBC, 15 ft., CDHS, CHARM, ...

$1 < Q^2 \lesssim 200\ GeV^2$

$.01 < x < .9$

END OF 1990 : H.E.R.A.

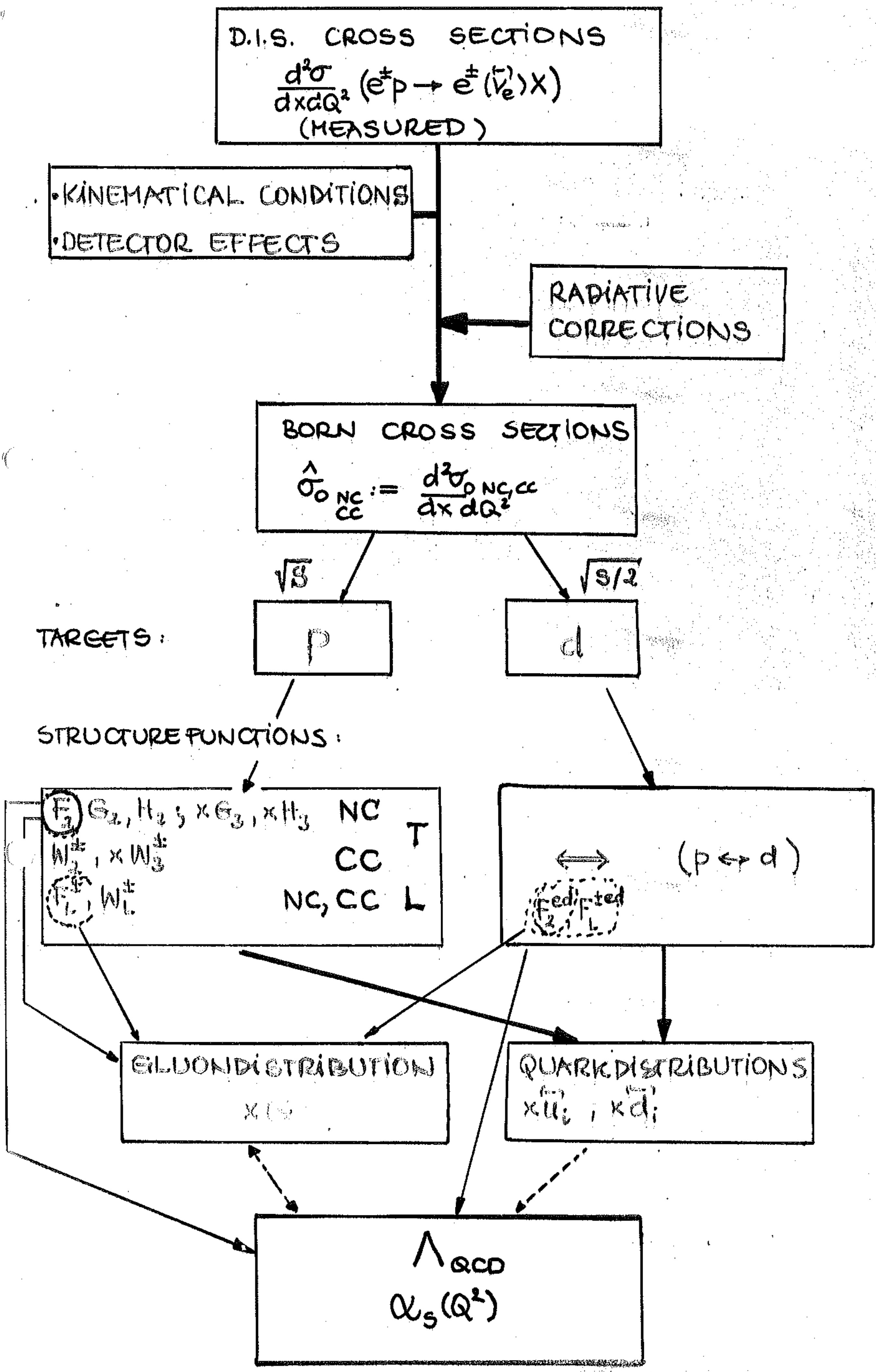
$\longrightarrow\ x \sim 10^{-4}$

$\longrightarrow\ Q^2 \sim O(10^4 GeV^2)$

- WIDE Q^2 RANGE
- PRECISE STRUCTUREFUNCTION-MEASUREMENT AT VERY LOW x

} NEW POSSIBILITIES TO TEST QCD

- $e^{\pm}p \rightarrow \overset{(-)}{\nu}_e X$ MEASURABLE AT HIGH Q^2 – PARTON DISTRIBUTIONS AT HIGH Q^2



D.I.S. CROSS SECTIONS
$\frac{d^2\sigma}{dxdQ^2}(e^{\pm}p \to e^{\pm}(\overset{(-)}{\nu_e})X)$
(MEASURED)
• KINEMATICAL CONDITIONS
• DETECTOR EFFECTS
RADIATIVE CORRECTIONS
BORN CROSS SECTIONS
$\hat{\sigma}_{0\,NC,CC} := \frac{d^2\sigma_{0\,NC,CC}}{dx\,dQ^2}$
$\sqrt{s}$
$\sqrt{s/2}$
TARGETS:
p
d
STRUCTURE FUNCTIONS:
$F_2, G_2, H_2; xG_3, xH_3$ NC
$W_2^{\pm}, xW_3^{\pm}$ CC
T
$F_L, W_L^{\pm}$ NC, CC
L
$\Longleftrightarrow$
$(p \leftrightarrow d)$
F_2^{ed}, F_L^{ed}
GLUONDISTRIBUTION
xG
QUARKDISTRIBUTIONS
$x\overset{(-)}{u}_i, x\overset{(-)}{d}_i$
Λ_{QCD}
$\alpha_s(Q^2)$

2. KINEMATICAL RANGES

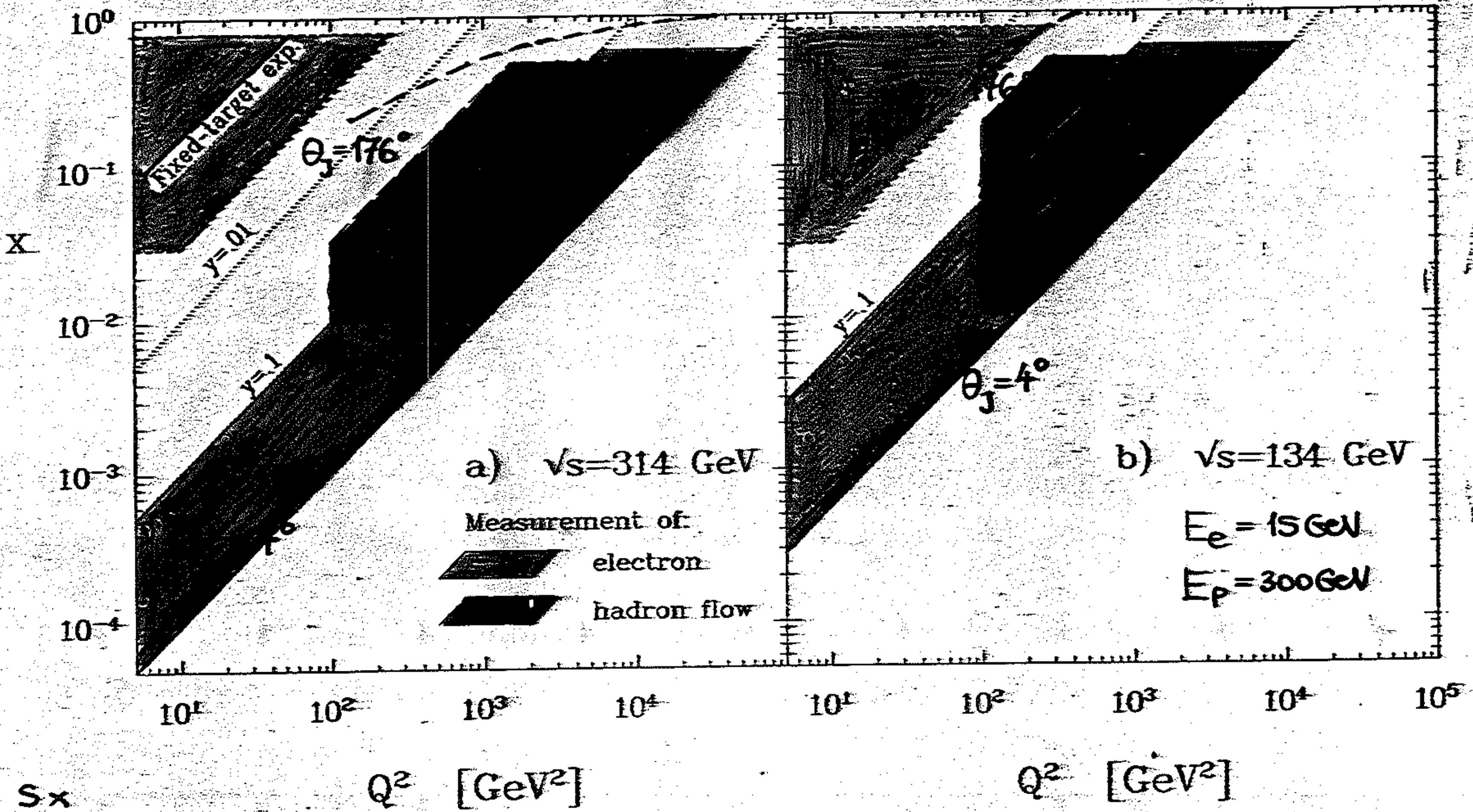


Fig. 1

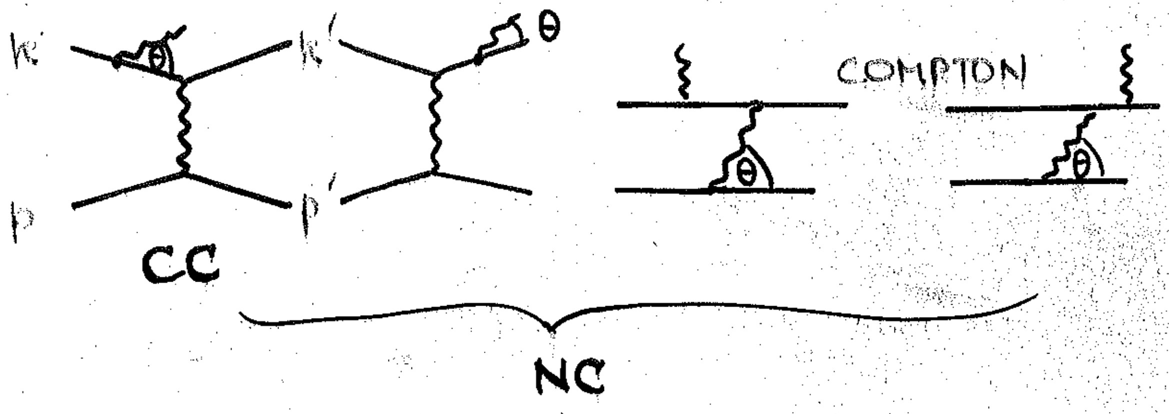
$$Q_e^2 = \frac{sx}{1 + \frac{xE_p}{E_e}\operatorname{ctg}^2\frac{\vartheta_e}{2}}$$

$$Q_J^2 = \frac{sx}{1 + E_e/xE_p \operatorname{ctg}^2 \vartheta_J/2}$$

RADIATIVE CORRECTIONS

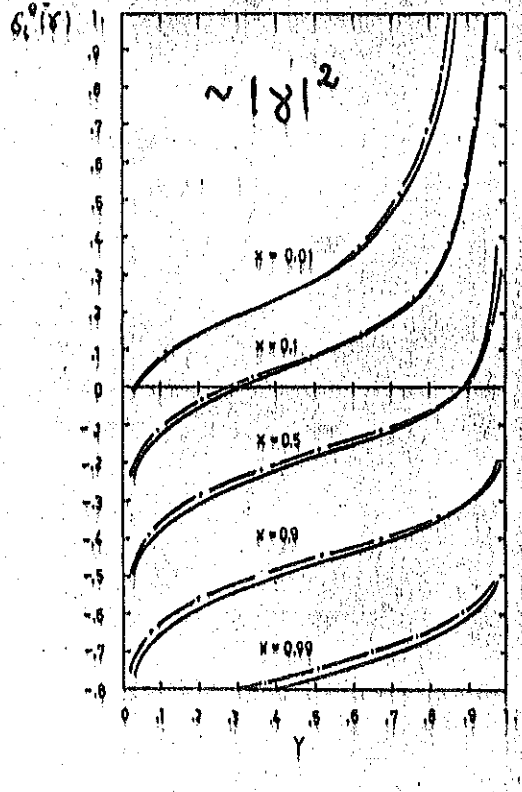
GOOD AGREEMENT BETWEEN EXACT AND LLOG-CALCULATIONS (BARDIN et al., BÖHM/SPIESBERGER; JB, BEHRENDS et al.)

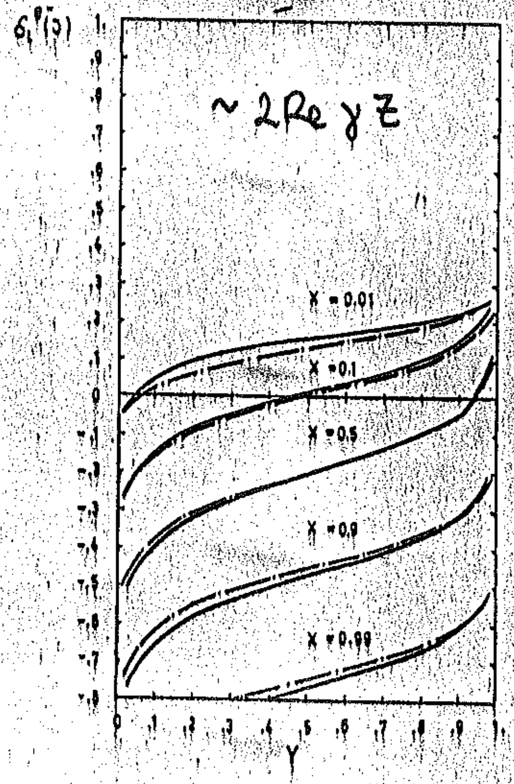
HOW AND WHERE CAN THESE CORRECTIONS BE KEPT AS SMALL AS POSSIBLE ?

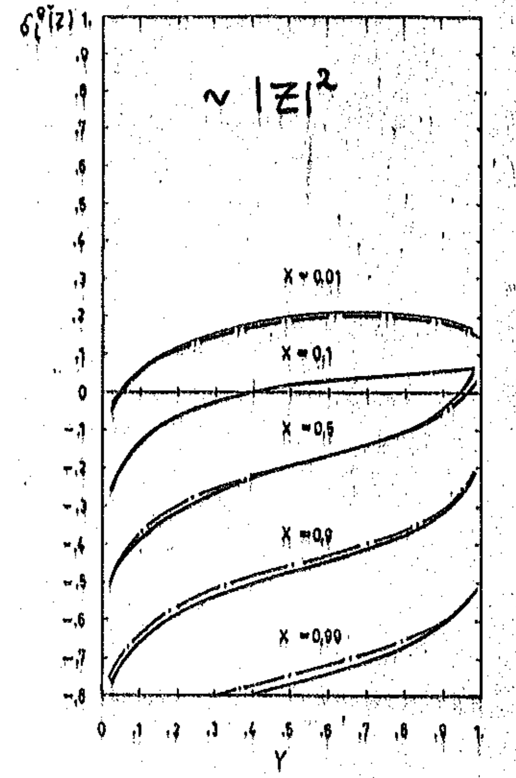


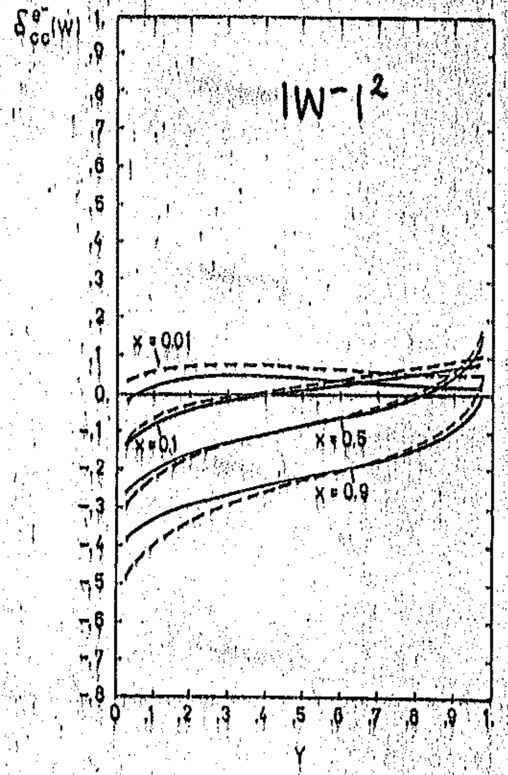
e − e' − MEASUREMENT
e − (e' + $\gamma_{\parallel}$) − MEASUREMENT } $y_{BORN} > .1$ ONLY

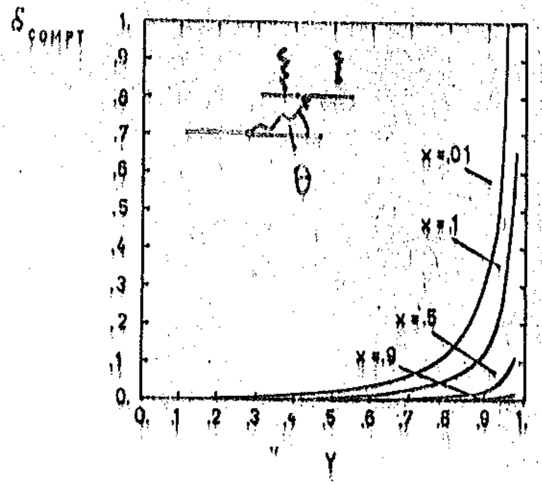
h − h' − MEASUREMENT ($Q^2 > 10^2$ GeV^2, $x > 10^{-2}$ ONLY)
$y_{BORN} > .01 \ldots .03$
(INCLUDE $\gamma \parallel h'$!)

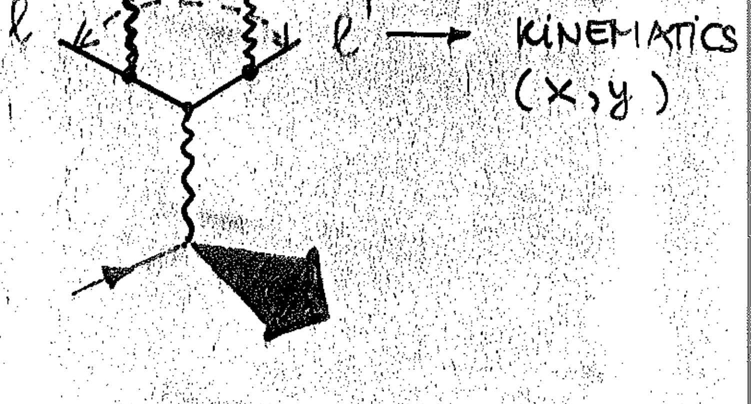

~ |γ|²
X = 0.01
X = 0.1
X = 0.5
X = 0.9
X = 0.99
Y

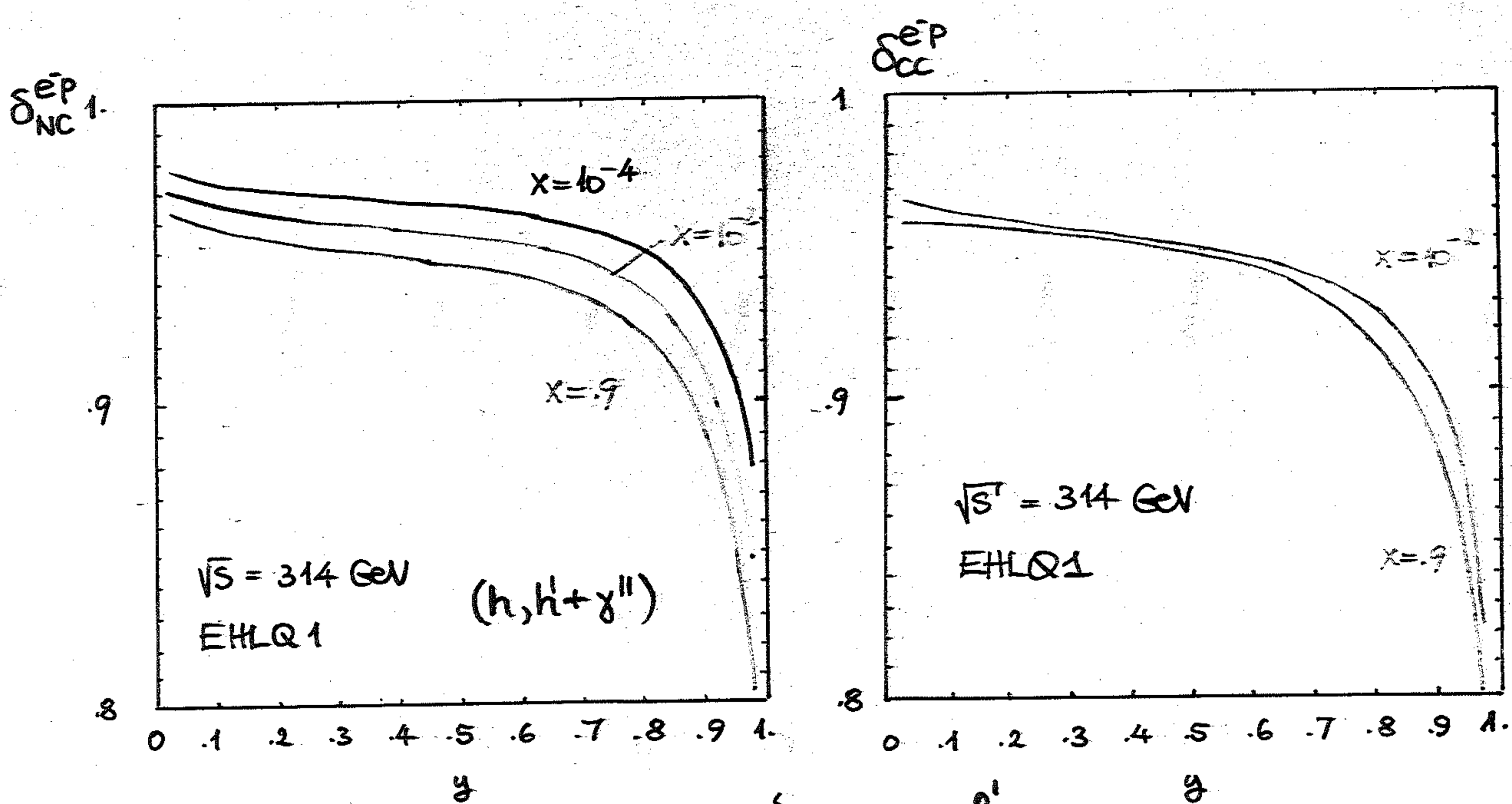

~ 2Re γ Z
X = 0.01
X = 0.1
X = 0.5
X = 0.9
X = 0.99
Y


~ |Z|²
X = 0.01
X = 0.1
X = 0.5
X = 0.9
X = 0.99
Y

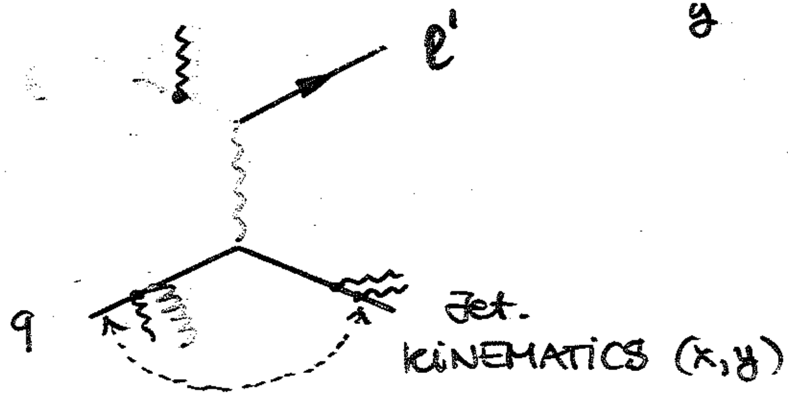

|W⁻|²
X = 0.01
X = 0.1
X = 0.5
X = 0.9
Y


δ COMPT
θ
X = .01
X = .1
X = .5
X = .9
Y


ℓ
ℓ'
KINEMATICS
(x, y)



δ^{ep}_{NC}
1.
.9
.8
0 .1 .2 .3 .4 .5 .6 .7 .8 .9 1.
y
x=10^-4
x=10^-2
x=.9
√S = 314 GeV
EHLQ 1
(h, h' + γ'')
δ^{ep}_{CC}
1
.9
.8
0 .1 .2 .3 .4 .5 .6 .7 .8 .9 1.
y
x=10^-2
x=.9
√S = 314 GeV
EHLQ1

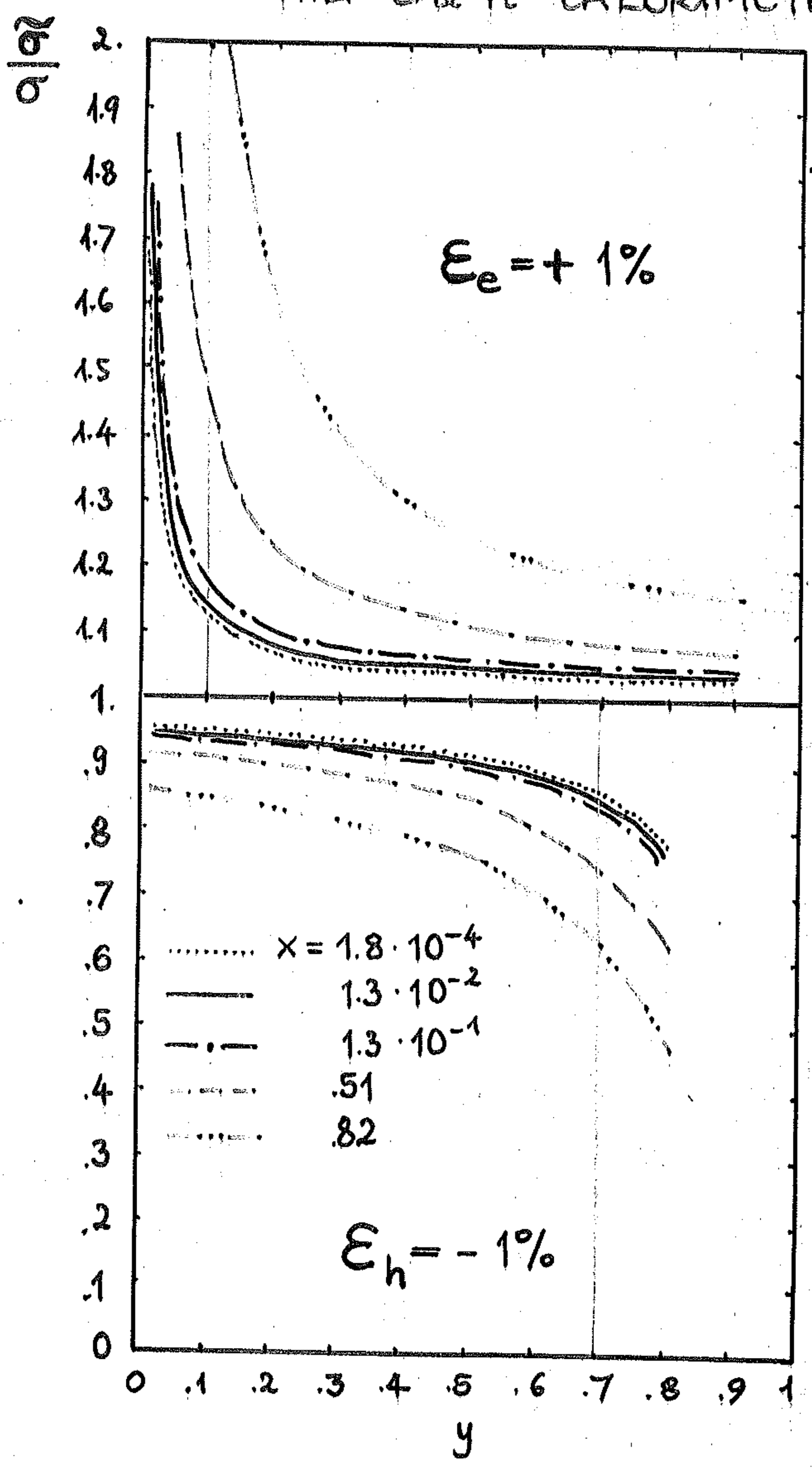


l'
q
Jet.
KINEMATICS (x,y)

JB, PHE 90-6

SYSTEMATIC EFFECTS

- CALIBRATION UNCERTAINTIES OF THE e & h- CALORIMETERS



$-1 + \frac{\tilde{\sigma}}{\sigma} \sim \varepsilon_{e,h}\,,\ \varepsilon_{e,h} \ll 1$

$\frac{\hat{x}}{x} \sim 1 + \frac{\varepsilon}{y}$

$\frac{\hat{y}}{y} \sim 1 + \varepsilon - \frac{\varepsilon}{y}$

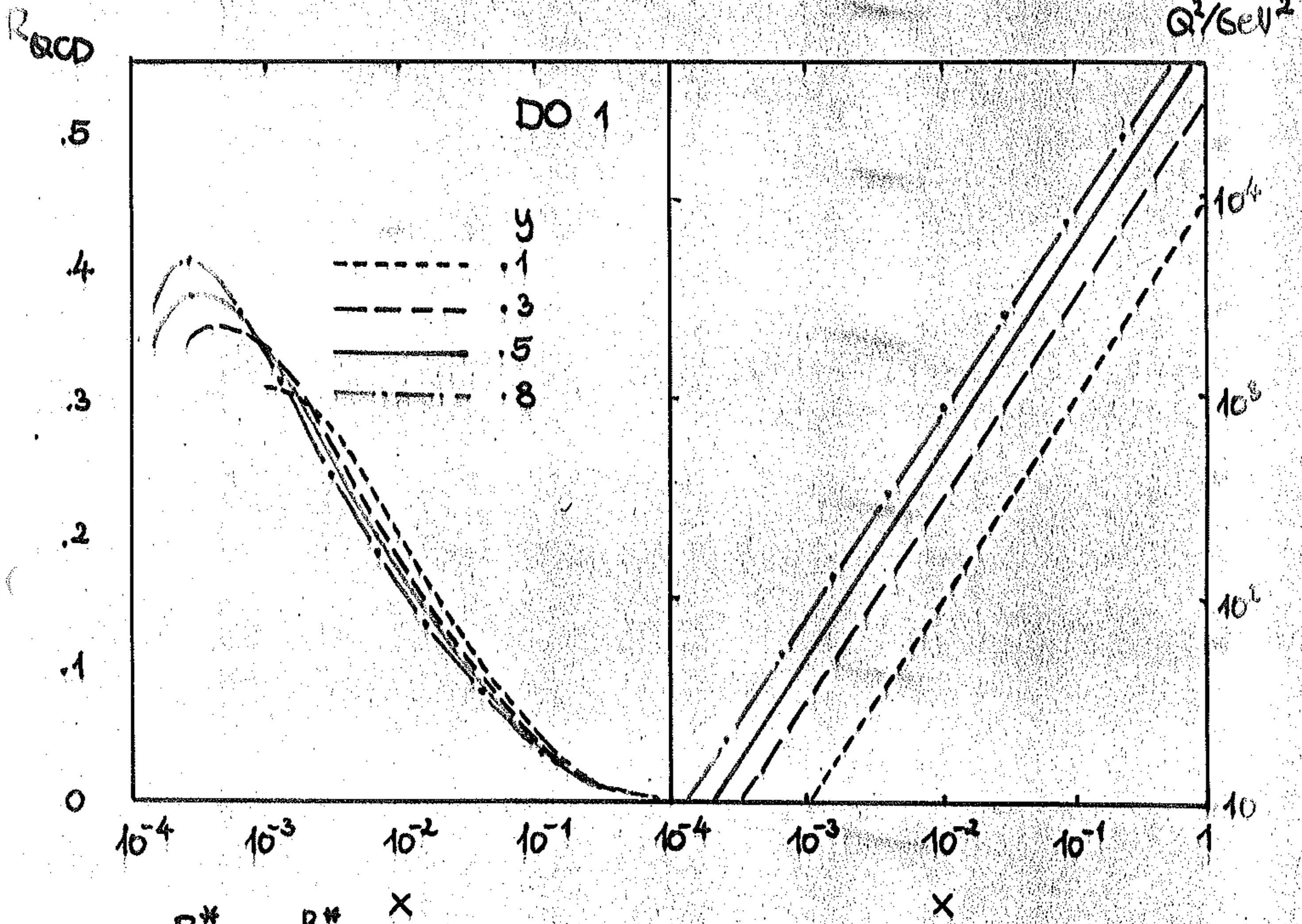
$\frac{\hat{Q}^2}{Q^2} \sim (1+\varepsilon)$

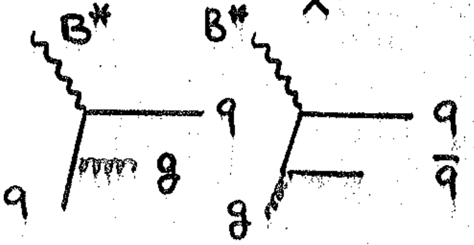
$\frac{\hat{x}}{x} \sim 1 + \frac{\varepsilon}{1-y}$

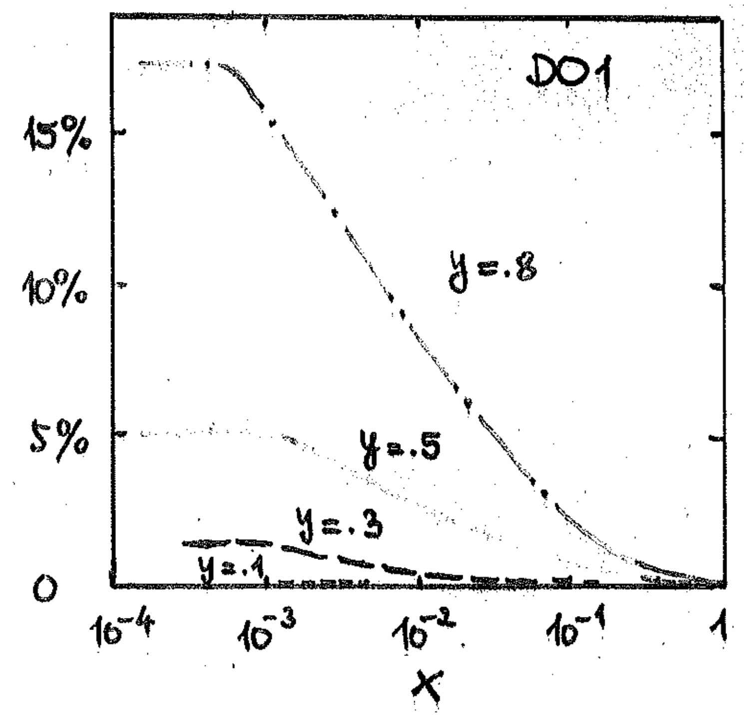
$\frac{\hat{y}}{y} \sim 1 + \varepsilon$

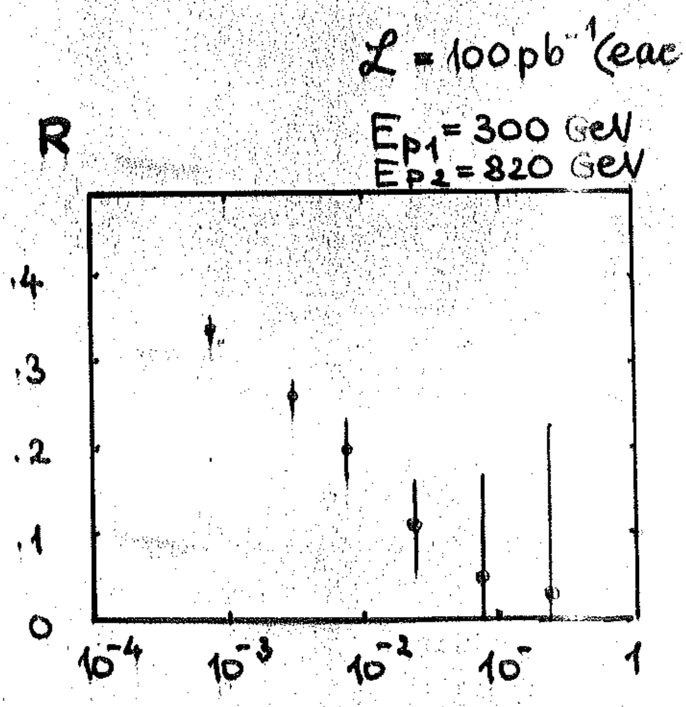
$\frac{\hat{Q}^2}{Q^2} \sim 1 + \varepsilon \frac{2-y}{1-y}$

$R = \sigma_L / \sigma_T$

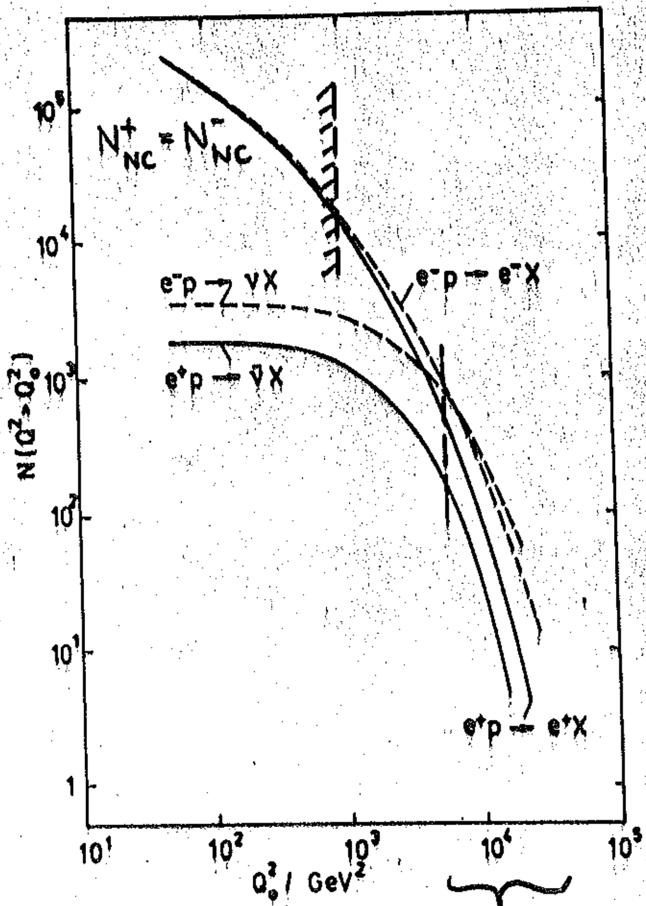








3. STRUCTURE FUNCTIONS



EVENTRATES FOR $Q^2 \geq Q_0^2$:

$x \geq .01$, $y \geq .03$

$\mathcal{L} = 100\ pb^{-1}$

UNFOLDING OF QUARK DISTRIBUTIONS

$N_{CC} \ll N_{NC}$

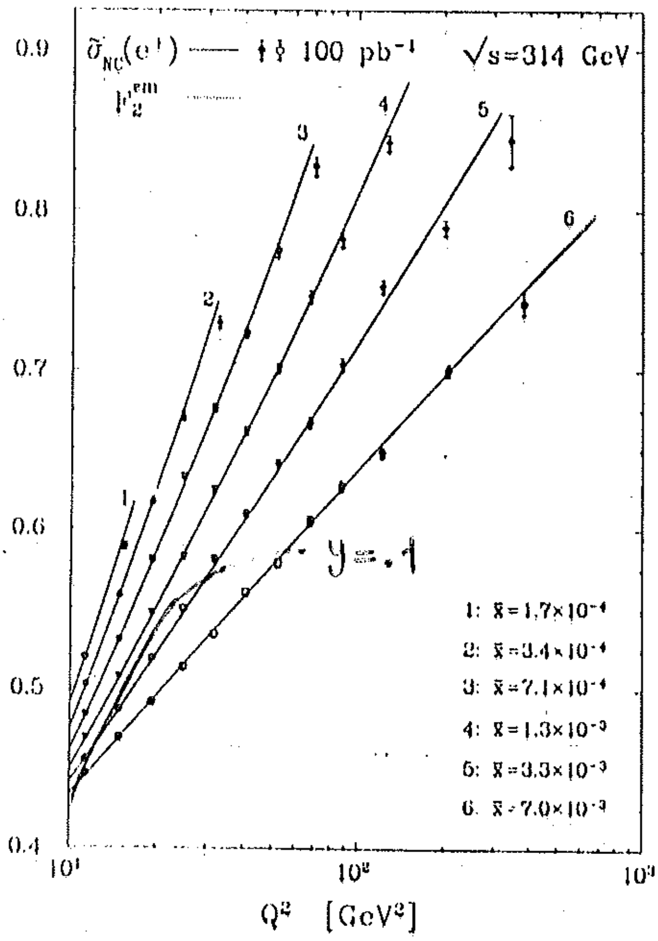
F_2^{em}

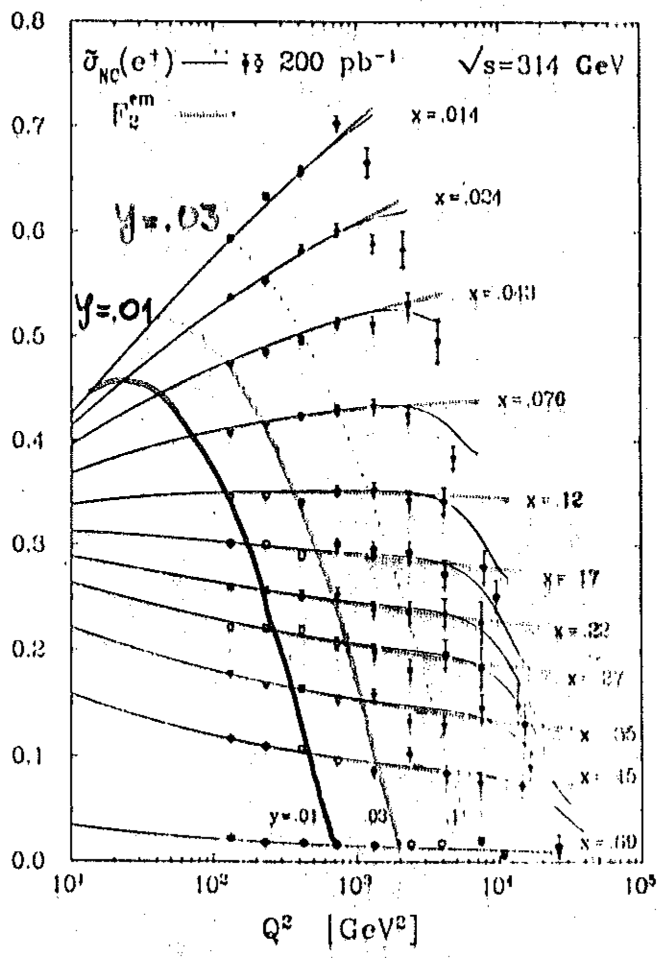
↓

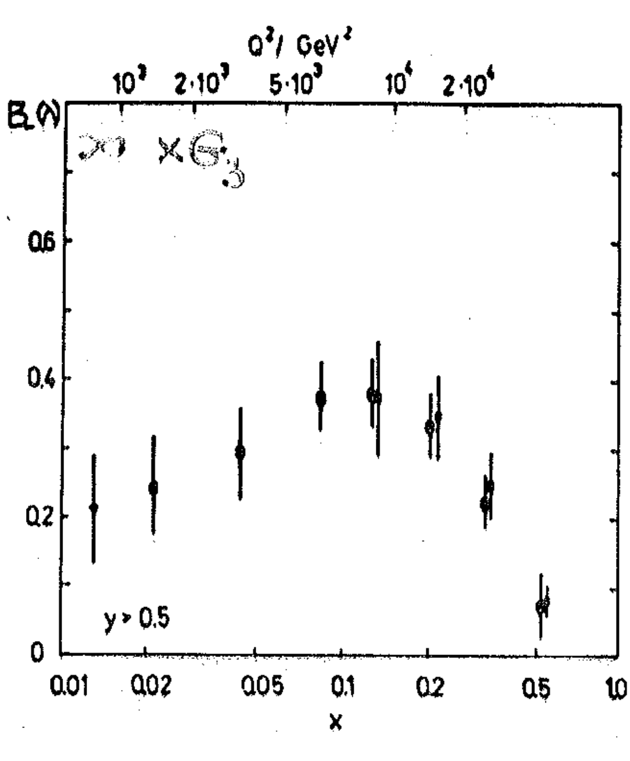
QCD - TESTS

NEUTRAL CURRENT

QUARK DISTRIBUTIONS: DUKE/OWENS 1



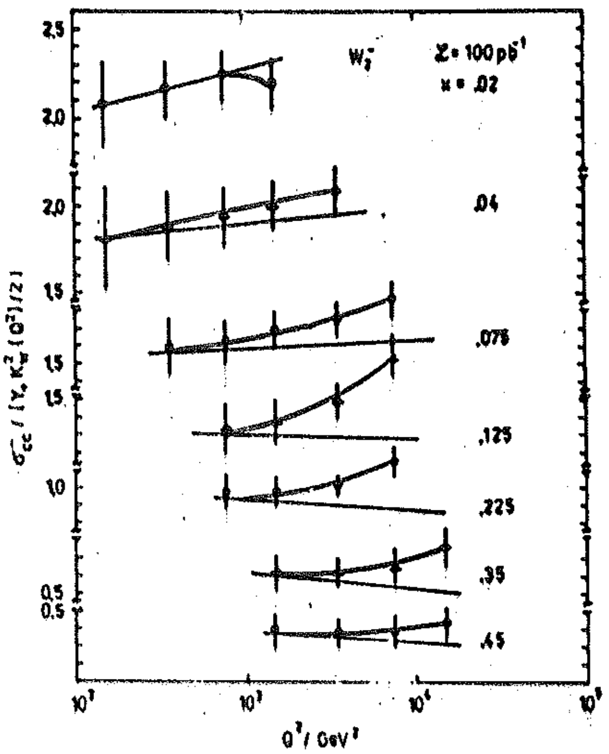




CHARGED CURRENT
$e^{\pm}p$

$$\hat{\sigma}_{\pm} = \frac{d^2\sigma}{dx\,dQ^2}\,\frac{Q^4 x}{2\pi\alpha^2} = \kappa_W^2(Q^2)\,\frac{1\pm\lambda}{2}\left[Y_+ W_2^{\pm} \mp Y_- x W_3^{\pm}\right]$$

$$\kappa_W = Q^2/(Q^2+M_W^2)/4s_\theta^2$$



$\hat{\sigma}_{cc}^- / (Y_+ \kappa_W^2/2)$, $\lambda = 0$,

vs. x & Q^2

—— $W_2^-(x, Q^2)$

$e^{\pm}d$: — DIFFERENT STRUCTURE FUNCTIONS

⟶ $W_2 = \Sigma$ from: $\frac{1}{2}(\hat{\sigma}_{cc}^+ + \hat{\sigma}_{cc}^-)$

— NO SIMPLIFICATION IN THE NC CASE.

COMBINATIONS OF PARTONDENSITIES UNFOLDED FROM DIS CROSS SECTIONS:

- [illegible] NS
- [illegible] S
- [illegible] NS ⊕ S

4. QUARKDISTRIBUTIONS AT HIGH Q^2

FROM 4 CROSS SECTIONS (AT HERA)

$$\frac{d^2\sigma_{NC}^{e^+p}}{dx\,dy} \quad \frac{d^2\sigma_{NC}^{e^-p}}{dx\,dy} \qquad\qquad \frac{d^2\sigma_{CC}^{e^+p}}{dx\,dy} \quad \frac{d^2\sigma_{CC}^{e^-p}}{dx\,dy}$$

4 COMBINATIONS OF QUARK DISTRIBUTIONS CAN BE UNFOLDED IN PRINCIPLE,

- NOTE, HOWEVER, THAT $\sigma_{NC}^{e^+p}$ & $\sigma_{NC}^{e^-p}$ ARE <u>ALMOST IDENTICAL AT LOW Q^2</u> ($Q^2 \lesssim 1000$ GeV^2)
- , THAT A REASONABLE CC-STATISTIC CAN ONLY BE MEASURED AT <u>HIGH Q^2</u> ($Q^2 \gtrsim 500$

<u>TWO METHODS</u>: (J.B., M.Klein, T.Naumann, T. Riemann, HERA proc. I, p.69 ; G.Ingelman, R.Rückl, Z.Phys. C in press DESY 89-25

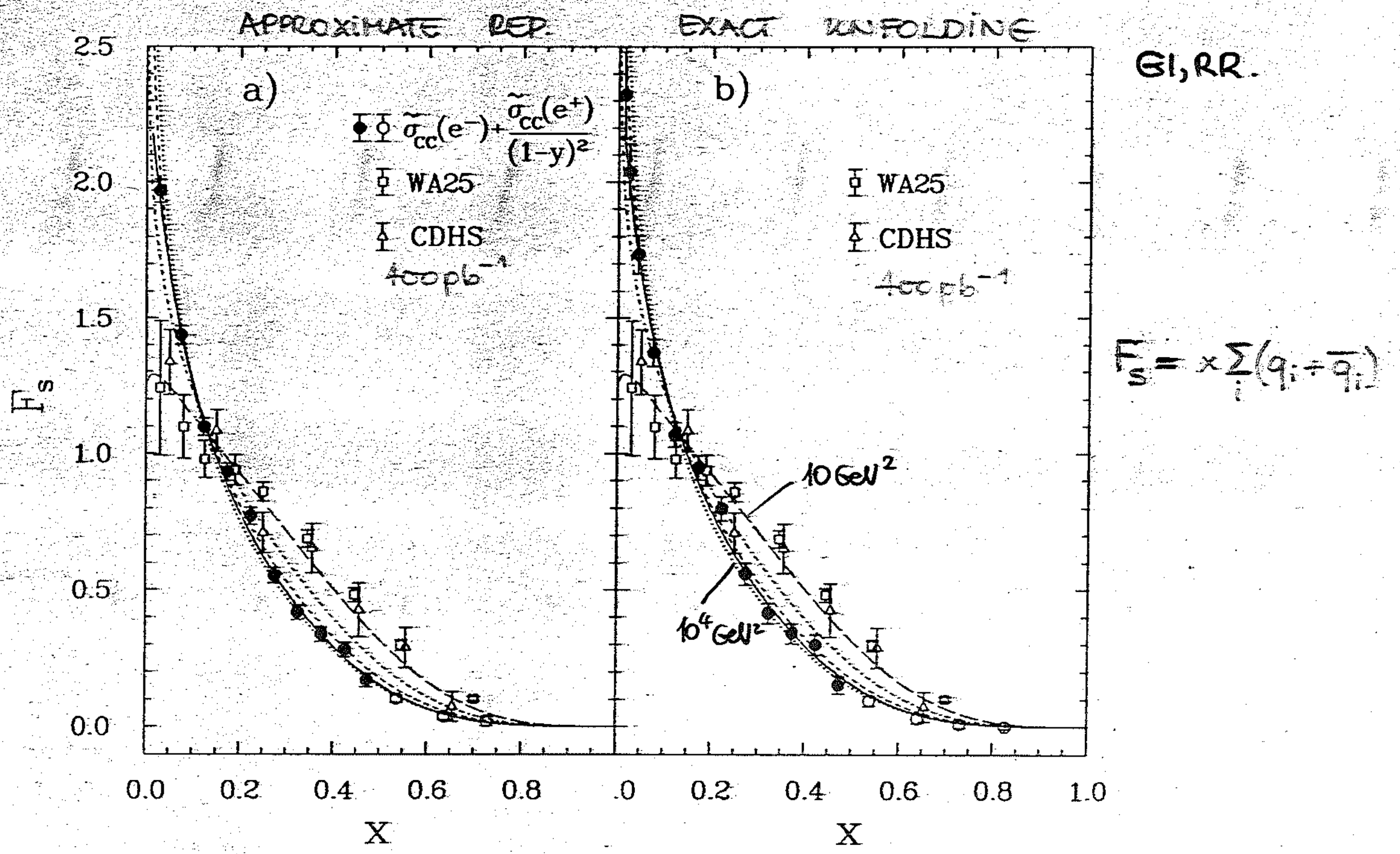
- EXACT UNFOLDING: e.g.

$$\begin{pmatrix} \sigma_{NC}^{e^+p} \\ \sigma_{NC}^{e^-p} \\ \sigma_{CC}^{e^+p} \\ \sigma_{CC}^{e^-p} \end{pmatrix} = \left(A_{ij}(y,Q^2)\right) \begin{pmatrix} u_v \\ d_v \\ \sum_i u_i+\bar{u}_i \\ \sum_i d_i+\bar{d}_i \end{pmatrix}$$

- APPROXIMATE REPRESENTATIONS:

e.g.

$$\sigma_{CC}^{e^-p} \propto x u_v \quad , \quad \sigma_{CC}^{e^+p} \propto x d_v \quad , \quad x \gtrsim .25$$



APPROXIMATE REP.
EXACT UNFOLDING
GI, RR.
a)
b)
$\tilde{\sigma}_{cc}(e^-) + \frac{\tilde{\sigma}_{cc}(e^+)}{(1-y)^2}$
WA25
CDHS
400 pb^{-1}
WA25
CDHS
400 pb^{-1}
10 GeV^2
10^4 GeV^2
F_s
X
X
2.5
2.0
1.5
1.0
0.5
0.0
0.0
0.2
0.4
0.6
0.8
.0
0.2
0.4
0.6
0.8
1.0
$F_s = x \sum_i (q_i + \bar{q}_i)$

Fig. 13

5. QCD ANALYSIS

$$F(x,Q^2) = \sum_i \left[\alpha_i q_i(x,Q^2) + \beta_i \bar{q}_i(x,Q^2)\right] .$$

$$F(x,Q^2) = aF_{NS}(x,Q^2) + bF_S(x,Q^2)$$

$$F_{NS}(x,Q^2) = \sum_{i,j} \alpha_{ij} \left[q_i(x,Q^2) - \bar{q}_j(x,Q^2)\right]$$

$$F_S(x,Q^2) = \sum_i \left[q_i(x,Q^2) + \bar{q}_i(x,Q^2)\right] .$$

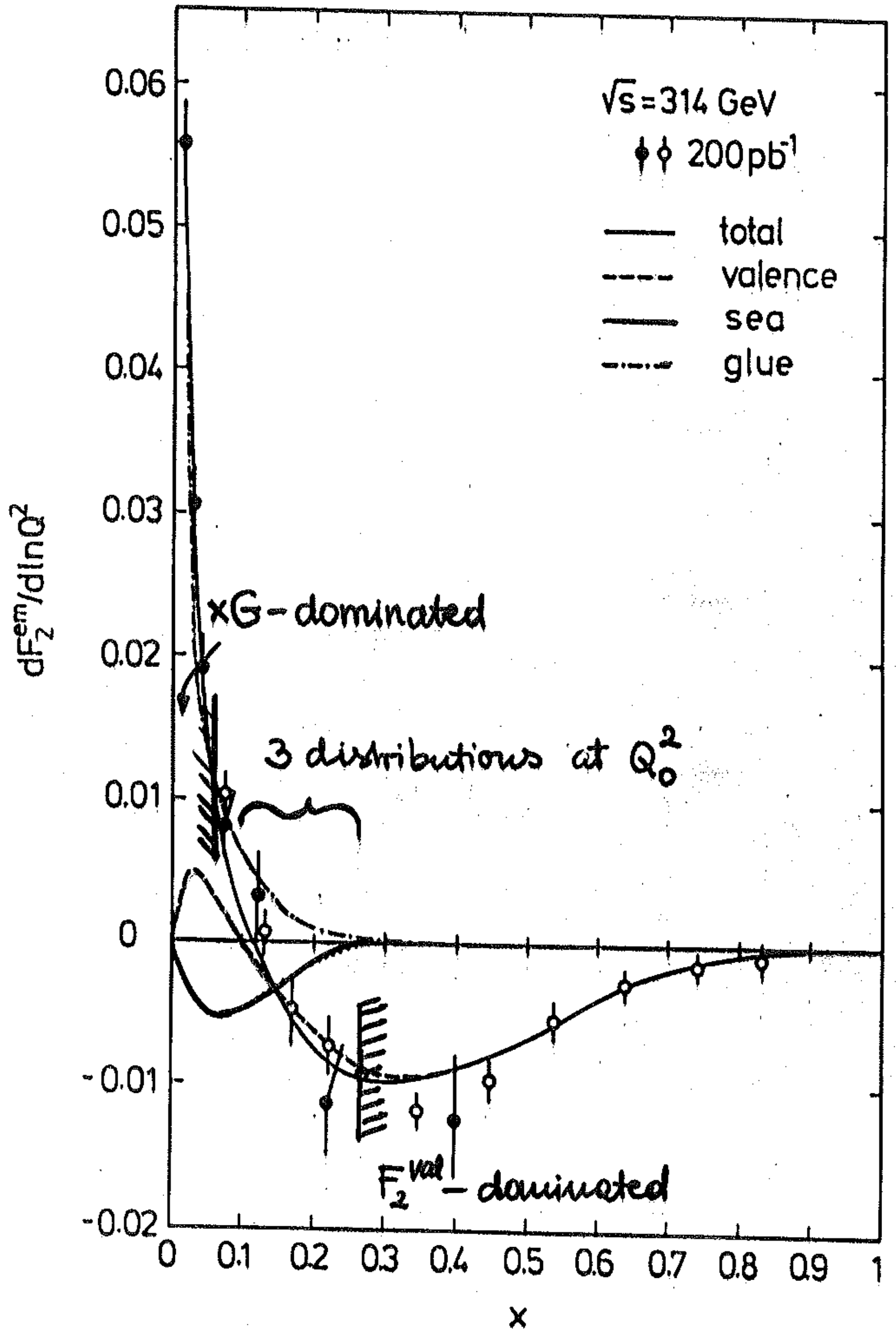
$$\frac{\partial}{\partial t} F_{NS}(x,t) = P_{qq}(x) \otimes F_{NS}(x,t)$$

$$\frac{\partial}{\partial t} \begin{pmatrix} F_S(x,t) \\ G(x,t) \end{pmatrix} = \begin{pmatrix} P_{qq}(x) & 2N_f P_{qG}(x) \\ P_{Gq}(x) & P_{GG}(x) \end{pmatrix} \otimes \begin{pmatrix} F_S(x,t) \\ G(x,t) \end{pmatrix}$$

$$A(x) \otimes B(x) = \int_0^1 dx_1 \int_0^1 dx_2 \, \delta(x - x_1 x_2) A(x_1) B(x_2)$$

$$t = (2/\beta_0) ln[ln(Q^2/\Lambda^2)/ln(Q_0^2/\Lambda^2)]$$

$$\beta_0 = 11 - \tfrac{2}{3} N_f$$

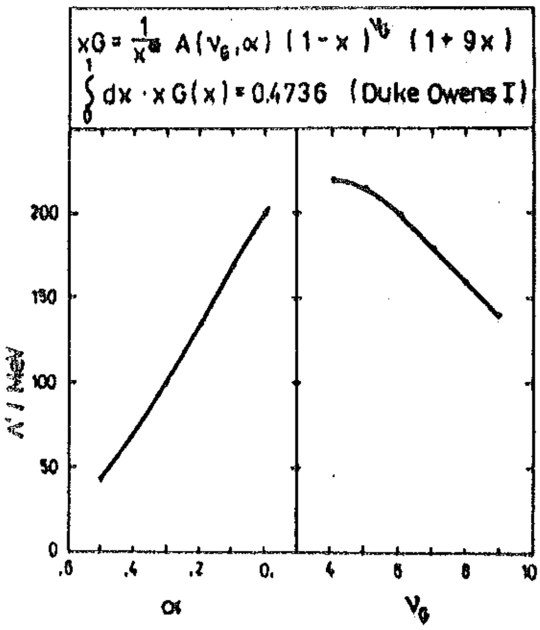


√s = 314 GeV
200 pb⁻¹
total
valence
sea
glue
xG - dominated
3 distributions at Q_0^2
F_2^{val} - dominated
$dF_2^{em}/d\ln Q^2$
0.06
0.05
0.04
0.03
0.02
0.01
0
-0.01
-0.02
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
x

a) **Table 2 Statistical precision on Λ from QCD fits to $\tilde{\sigma}_{NC}(e^+) \approx F_2^{em}$**

x-range	type of fit	full y range $\delta\Lambda$ [MeV]	restrictions according to eqs. (5,6) $\delta\Lambda$ [MeV]
a) $\sqrt{s} = 314$ GeV, $Q^2 \geq 100$ GeV^2, $\int \mathcal{L}\, dt = 200\ pb^{-1}$			
$x \geq 0.25$	non singlet (11)	50	180
$x \geq 10^{-2}$	eqs. (11,12)	80	130
$x \geq 10^{-2}$	eqs. (11,12), xG fix	20	30
b) $\sqrt{s} = 314$ GeV, $Q^2 \geq 10$ GeV^2, $\int \mathcal{L}\, dt = 100\ pb^{-1}$			
$x \geq 10^{-4}$	eqs. (11,12)	5	30
c) $\sqrt{s} = 134$ GeV, $Q^2 \geq 18$ GeV^2, $\int \mathcal{L}\, dt = 100\ pb^{-1}$			
$x \geq 0.25$	non singlet (11)	50	270
$x \geq 10^{-2}$	eqs. (11,12)	30	60

Λ = 200 MeV used as input.



$\delta\Lambda_{Ha} = -20$ MeV $\quad R_{600} \to 0$ $(x \geq 10^{-4})$

b) SYSTEMATIC EFFECTS

- RESTRICTED PHASE SPACE ; SHEARING etc. < 10%
  J. FELTESSE
- CALIBRATION UNCERTAINTY OF THE CALORIMETERS
  e & h

$$\hat{E}_{e'} = E_e(1+\varepsilon_e) \quad ; \quad \hat{E}_h = E_h(1+\varepsilon_h)$$

$$(x, y, Q^2) \rightarrow (\hat{x}_e, \hat{y}_e, \hat{Q}^2_e)$$
$$(x, y, Q^2) \rightarrow (\hat{x}_h, \hat{y}_h, \hat{Q}^2_h)$$

$$\frac{d\hat{\sigma}(\hat{x},\hat{Q}^2)}{d\hat{x}d\hat{Q}^2}\, d\hat{x}d\hat{Q}^2 = \frac{d\sigma(x,Q^2)}{dxdQ^2}\, dxdQ^2,$$

$$\hat{\tilde{\sigma}}(\hat{x},\hat{Q}^2) = \frac{f(x,Q^2)}{f(\hat{x},\ \hat{Q}^2)}\left(\frac{dxdQ^2}{d\hat{x}d\hat{Q}^2}\right)\tilde{\sigma}(x,Q^2),$$

WE CONSIDER : a) $x \geq 10^{-2}$, $Q^2 > 10^2\ \mathrm{GeV}^2$ JET MEASUREMENT

b) $x \leq 10^{-2}$, $Q^2 \leq 10^2\ \mathrm{GeV}^2$ ELECTRON MEASUREMENT

$\varepsilon_{e,h} = \pm 1\%$

↓

a) $\Delta\Lambda = \pm 70$ MeV

b) $\Delta\Lambda = \mp 40$ MeV

SCALES LINEARLY IF $\varepsilon_{e,h} \ll 1$

c) $\alpha_s(Q^2)$

$$\alpha_s(Q^2) = \frac{12\pi}{33-4N_f} \cdot \frac{1}{\ln\left(\frac{Q^2}{\Lambda^2}\right)} \qquad N_f = 4$$

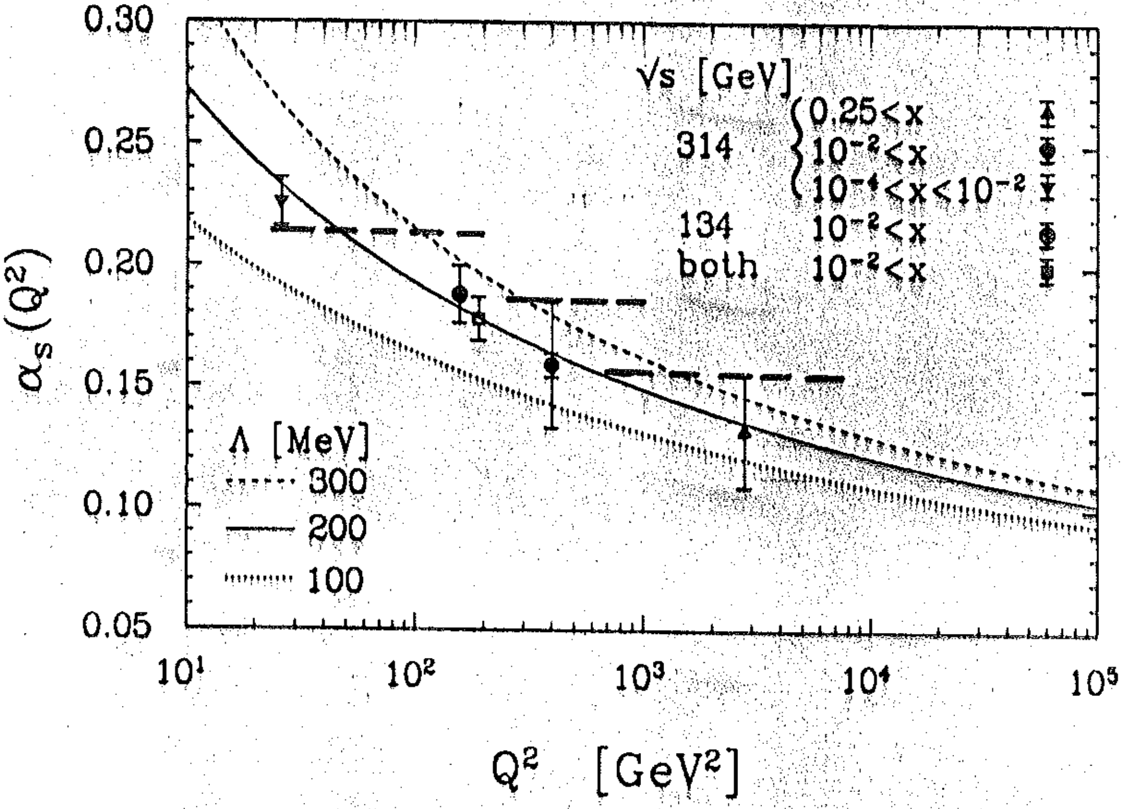


Fig. 8

$xG(x,Q^2)$

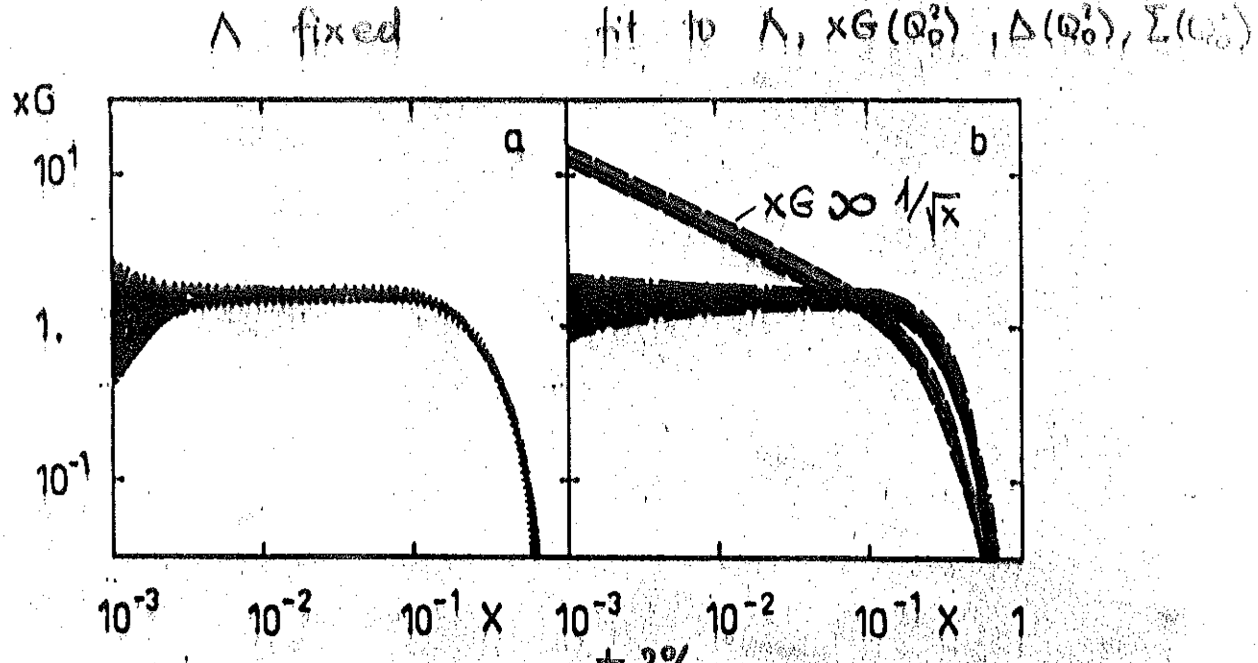
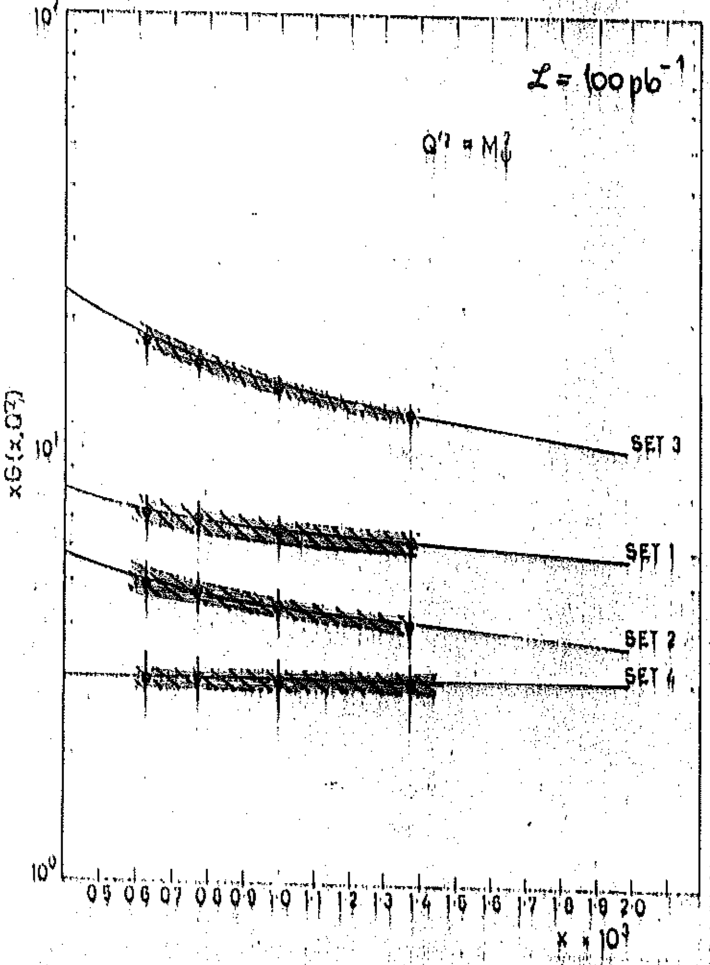
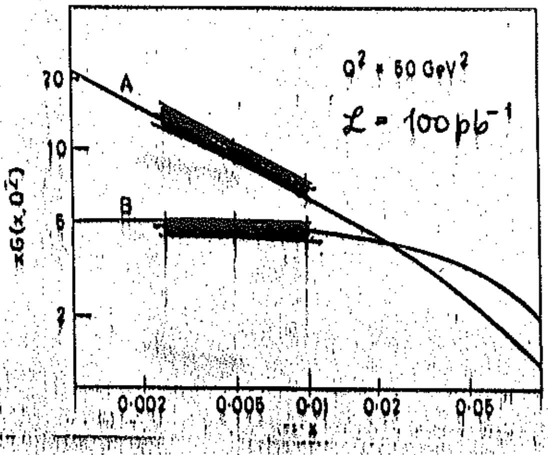


Fig. 4 a) xG(stat) and (stat.⊕ syst.) for $\delta\Lambda = 0$

b) xG(stat) from joint fit of Λ and xG with xG(DO) and $xG \sim 1/\sqrt{x}$.



S.M. THACZYK et al. HERA '88, Vol. 1 p. 265



A.M. COOPER - SARKAR et al.
HERA '88 Vol. 1, p. 231

b) J/ψ - PRODUCTION CROSSECT.

$$\frac{d\sigma^{ep}_{J/\psi}}{dy} = \frac{1.5\,\alpha}{\pi}\,\frac{1}{y}\,Y_+\,\bar{x}\,G(\bar{x}, Q^2 = M_\psi^2) \times \log\frac{Q^2_{max}}{Q^2_{min}}\ \text{nb}$$

$$\bar{x} \sim 3.4\,M_\psi^2 / S_1$$

//// NORMALIZATION UNCERTAINTY (ZEUS)

c) F_L - MEASUREMENT

$$F_L^{QCD}(x, Q^2) = \frac{\alpha_s}{4\pi}\cdot\left(I_1 + I_2\right)$$

$$I_1 = \frac{16}{3}\int_x^1 \frac{dy}{y}\left(\frac{x}{y}\right)^2 F_2(y, Q^2)$$

$$I_2 = 8\sum_i e_i^2 \int_x^1 \frac{dy}{y}\left(\frac{x}{y}\right)^2\left(1-\frac{x}{y}\right)\cdot G(y, Q^2)$$

//// FINITE RESOLUTION & OVERALL NORMALIZ. UNCERTAINTY

d) γ-g FUSION (d'Agostini et al.)

OPEN CHARM (BEAUTY) PRODUCTION

6. CONCLUSIONS

1. HERA WILL PROBE THE PROTON STRUCTURE VIA DEEP INELASTIC SCATTERING

   up to $Q^2 \sim 10^4\ GeV^2$

   down to $x \sim 10^{-4}$

2. THE $O(\alpha)$-EWRC'S ARE CONSISTENTLY KNOWN BY DIFFERENT CALCULATIONS. THE LLA GIVES A GOOD DESCRIPTION. ONE SHOULD USE THE JET ! MEASUREMENT AND THE $(e' + \gamma'')$-MEASUREMENT TO CORRECT FOR THE $O(\alpha, \alpha^2 \ldots)$ TERMS.

3. e' (AND h')-MEASUREMENTS FAIL AT LOW y (HIGH y) DUE TO MISCALIBRATIONS OF CALORIMETERS

4. AMONG THE VARIOUS STRUCTURE FUNCTIONS AND COMBINATIONS OF PARTON DISTRIBUTIONS TO BE MEASURED ONLY F_2^{em} CAN BE DETERMINED WITH SUFFICIENT PRECISION IN x & Q^2.

5. THE x SHAPES OF THE VARIOUS PARTONDISTRIBUTIONS MAY BE MEASURED AT $\sim Q^2 \sim O(10^4\ GeV^2)$. DIFFERENT WAYS TO CONSTRAIN xG EXIST:

   F_L ; $\sigma(J/\psi)$; F_2^{em} ; $\sigma(c\bar{c})$

6. THE STATISTICAL PRECISION ON Λ_{QCD} FOR $\mathbb{L} = 200\,pb^{-1}$, $\sqrt{s} = 314$ GeV, $x > .01$, $Q^2 > 100$ GeV^2, $y > .03$ IS ABOUT 100 MeV.

   IT CAN BE IMPROVED:

   - USING CONSTRAINTS ON $xG(x, Q^2)$
   - INCLUDING DATA AT LOWER y, $y > .01$
   - RUNNING AT LOWER $\sqrt{s}$ ($= 134$ GeV)
   - EXTENDING THE ANALYSIS DOWN TO $x = 10^{-3} \dots 10^{-4}$ (EVOLUTION (Λ, Q_0^2) ?!)

   IT IS EFFECTED BY CALORIMETRIC MIS-CALIBRATIONS.

7. THE LOW x RANGE $10^{-4} < x < 10^{-2}$, $10 < Q^2 < 10^3$ GeV^2 IS A NEW TESTING GROUND FOR QCD (FAN DIAGRAMS, PEGGE…RAT… ?!

THE MEASUREMENTS OF THE ABOVE QUANTITIES ARE LONG TERM TASKS AND REQUIRE THE CONTROL OF SYSTEMATICS AT THE 1 PERCENT LEVEL.

5) MORE STUDIES ARE REQUIRED ON FAN DIAGRAMS:

- HIGHER ORDER CONTRIBUTIONS
- F_L ?!
- BETTER DYNAMICS : 3 LADDER COUPLING
- MORE DETAILED STUDIES OF HIGHER TWIST OPERATORS !

⇓

EVOLUTION PROGRAM ; STILL SOME WAY TO GO.

⟹ LO & NLO TWIST 2 QCD IS BY FAR EASIER : LINEAR EQUATIONS

FAN : NON LINEAR EQUS.

6) SOME NUMERICAL SUCCESS IS ALREADY OBTAINED. WE ARE LEAVING THE QUALITATIVE DISCUSSION OF EARLIER TIMES.

7) THE POSSIBILITY TO MEASURE F_2 AT VERY SMALL x PRECISELY AT HERA HAS ALREADY ATTRACTED THE INTEREST OF VARIOUS THEORETICIANS TO STUDY THIS FIELD.