~~ROBERTS~~ ROBERTS

Theory/Phenomenology of DIS

Update on DIS '96 - Rome

Global analyses, parton distbns, $\alpha_s(M_Z)$, ...

A) Updated precision DIS data

NMC - final data $F_2^{\mu p}$, $F_2^{\mu D}$, D/p

$p_{lab} = 90, 120, 200 + 280$ GeV

CCFR - re-analysis of $F_2^{\nu N}$, $xF_3^{\nu N}$

$\Rightarrow$ suggest higher values of $\alpha_s(M_Z)$

B) Improved theoretical treatment of charm, bottom production

Important? Yes, because

(i) To describe very low x $\Rightarrow$ go to low Q^2
= region of charm threshold

Conclusions on BFKL vs. DGLAP may be sensitive to charm component.

(ii) F_2^c appears to be large fraction of F_2 -

need consistent description of HERA + EMC charm data.

C) Large x

How certain is the DIS 'background' to new physics .... ?

D) Resummation of $\ln(\frac{1}{x})$ terms.

Should they be included ?

Do the DIS data favour / disfavour DGLAP+BFK ?

Factorisation scheme dependence ?

F_L ....

Not discussing new theoretical developments

→ Yuri Dokshitzer

or polarised DIS data

→ Richard Milner

New Global Analyses

CTEQ Lai + Tung CTEQ4 HQ

extends CTEQ4 analysis

- proper description of heavy quark prod according to ACOT (Aivazis, Collins, Olness + Tung) Variable Flavour Number scheme (VFN)

MRS + Ryskin

- alternative description of heavy quark prod.
  - used in updated analyses of latest datasets with varying α_s values.

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1) Discussion of results - comparison with data etc.
   - varying α_s

2) Discussion of treatment of heavy quark prod.

Latest CTEQ4 Analysis - talk by H-L Lai
WG1 Tues.

Lai + Tung CTEQ-622 emphasis on effect of improved HQ treatment

Fig. 1

$\Rightarrow$ Only a small change in resulting F_2 fit
for CTEQ4M $\rightarrow$ CTEQ4HQ
more noticeable at low x

Proper description of F_2^c reduces F_2, compensated by increased light quark distbns.

$\Rightarrow$ Fig. 2

Also improved description of F_2

e.g. HERA NVX data χ^2 362/351 $\rightarrow$ 350/351
4M $\rightarrow$ HQ

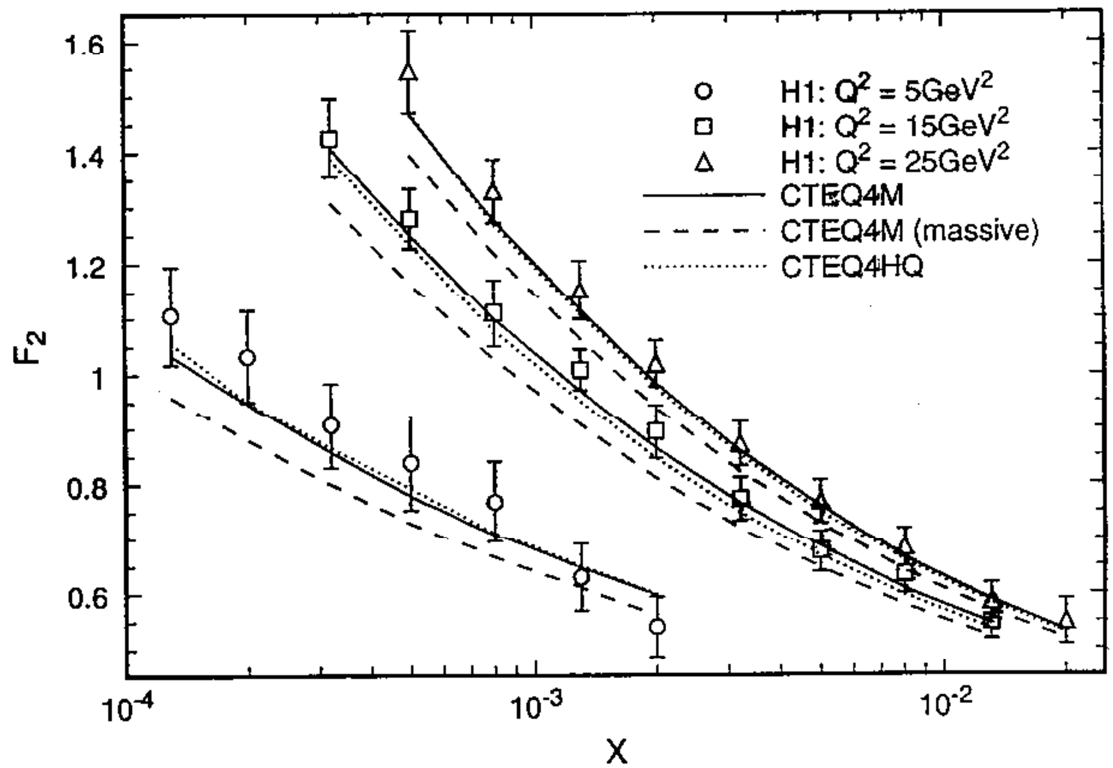
Latest MRS Analysis

a) Uses HQ treatment of MRRS

b) New NMC, CCFR data

deuteron F_2 corrected for shadowing using Badalek + Kwiesinski formula (important at low x, low Q^2)

c) Parton Distbns for $\alpha_S(M_Z) = 0.105 \longrightarrow 0.128$



H1: $Q^2 = 5\mathrm{GeV}^2$
H1: $Q^2 = 15\mathrm{GeV}^2$
H1: $Q^2 = 25\mathrm{GeV}^2$
CTEQ4M
CTEQ4M (massive)
CTEQ4HQ
F_2
X
1.6
1.4
1.2
1
0.8
0.6
10^{-4}
10^{-3}
10^{-2}

Fig. 1

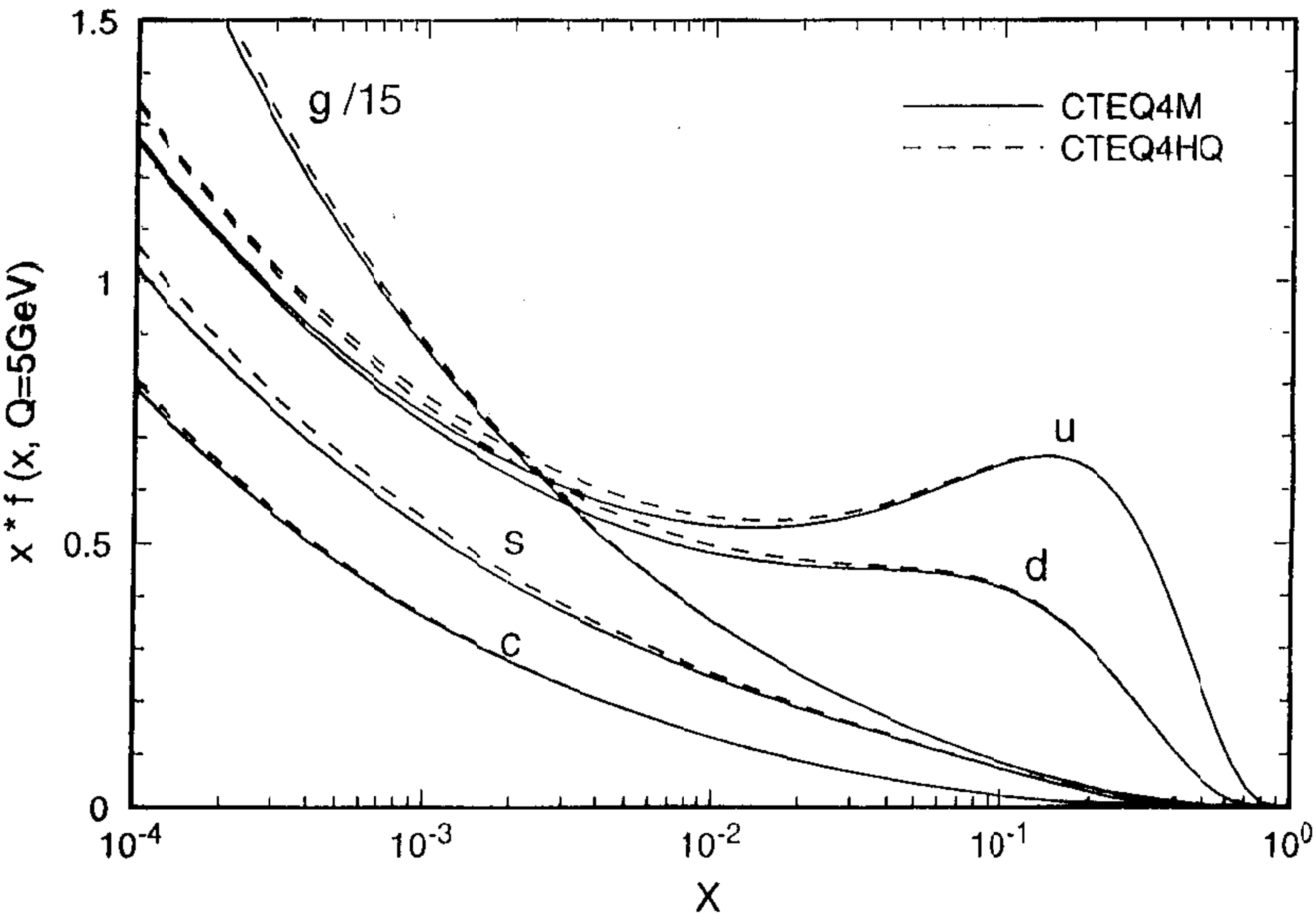


Fig.

Figure 4: Comparison of CTEQ4M and CTEQ4HQ parton distributions.

$Q_0^2 = 1\ GeV^2$ chosen (same as MRS R1 → R4)

Why?

Want to include very low x data of HERA
e.g. SVX data

GRV suggest DGLAP may work down at low Q^2.

Kinematic $x - Q^2$ range of data used Fig. 3

Light Parton Distbns. parametrised in usual way at Q_0^2.

Fits performed at fixed values of $\Lambda_{\overline{MS}}$ ($n_f = 4$)
ie " " " " $\alpha_s(M_Z)$

χ^2 values for each experiment computed Fig. 4

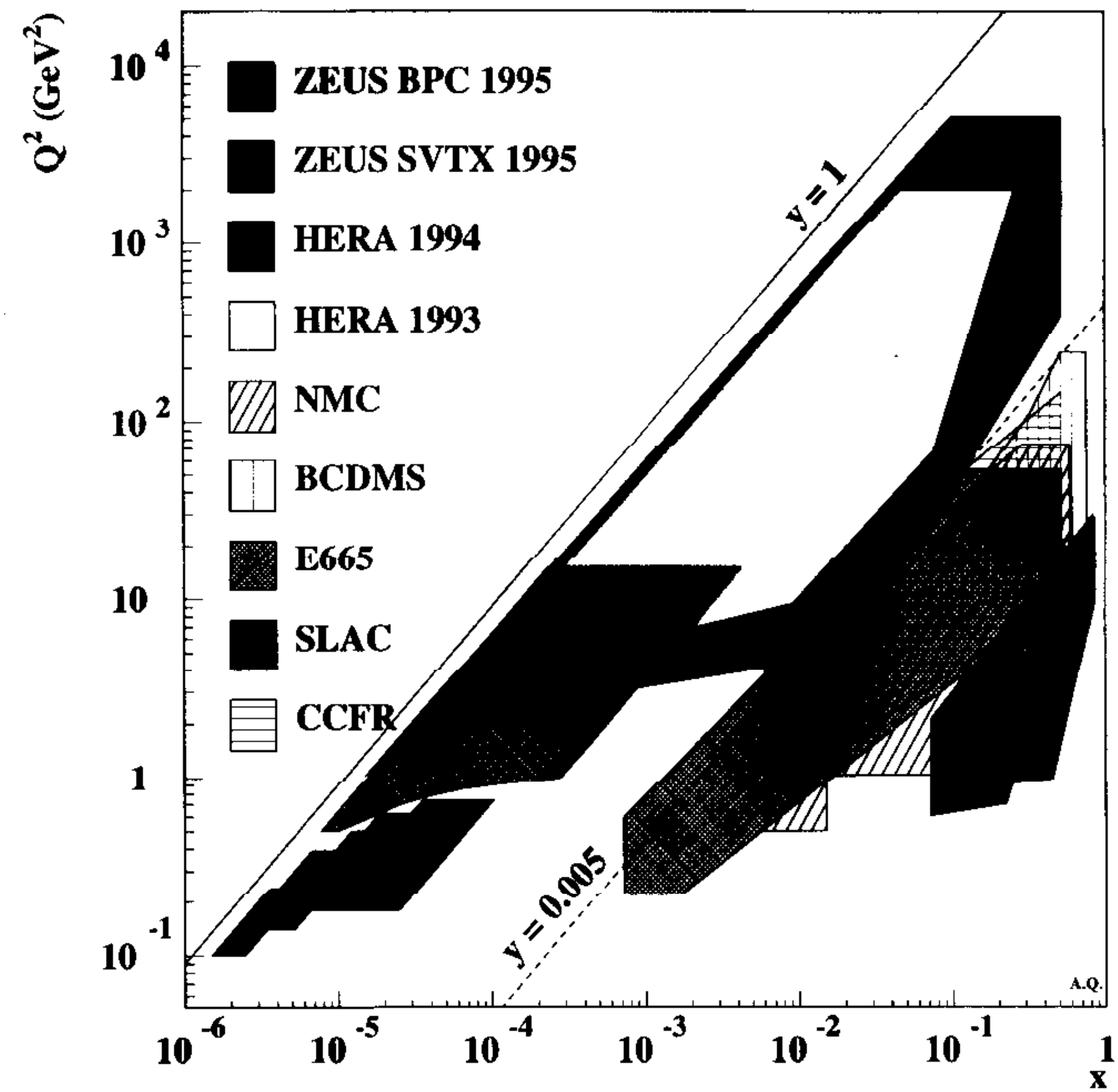
Note:

HERA data prefer $\alpha_s \sim 0.120 - 0.125$ BF

Final NMC data also like 'large' α_s

Re-analysed CCFR F_2 strongly favour α_s large

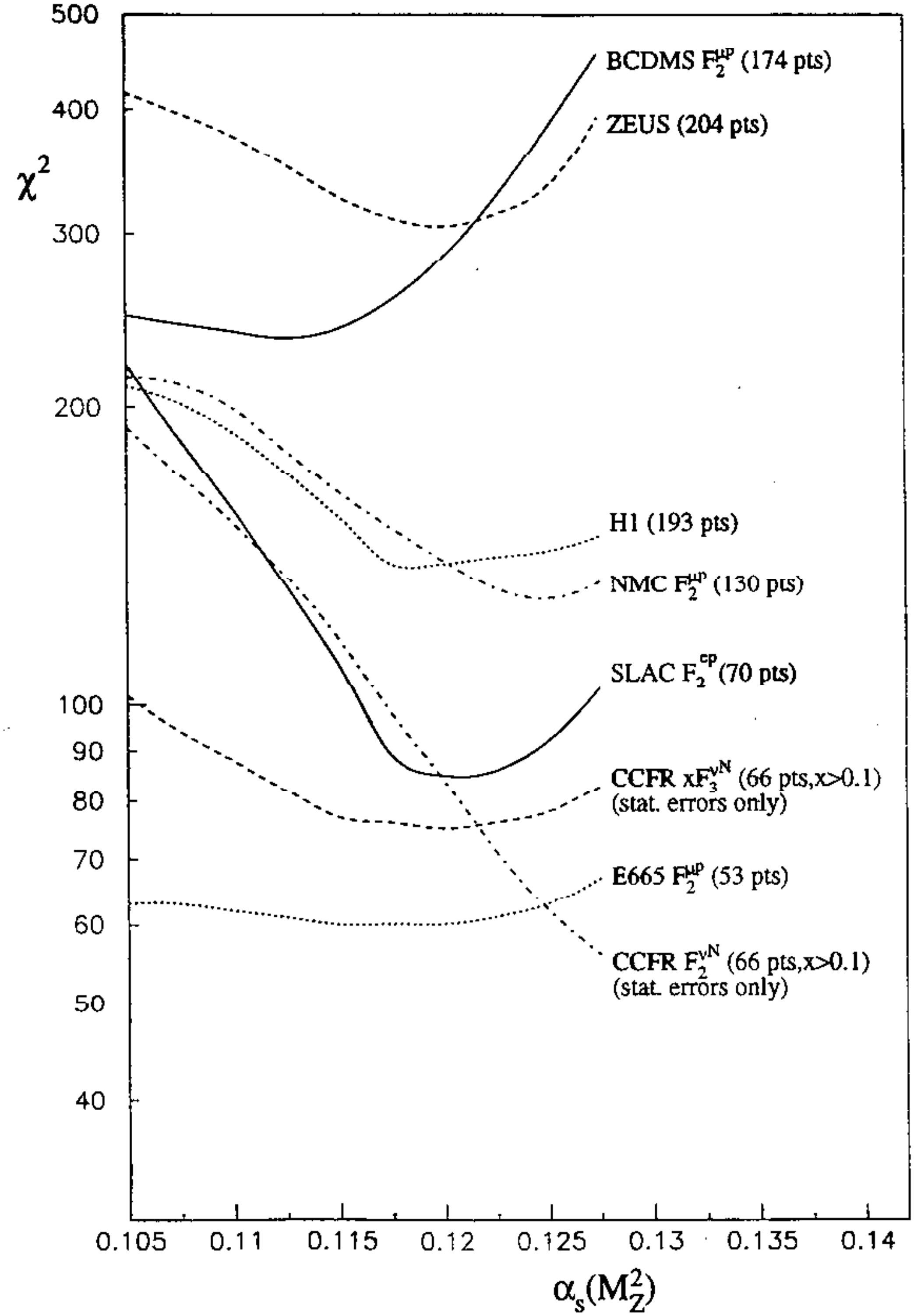
Only BCDMS now favour 'low' $\alpha_s \sim 0.113$



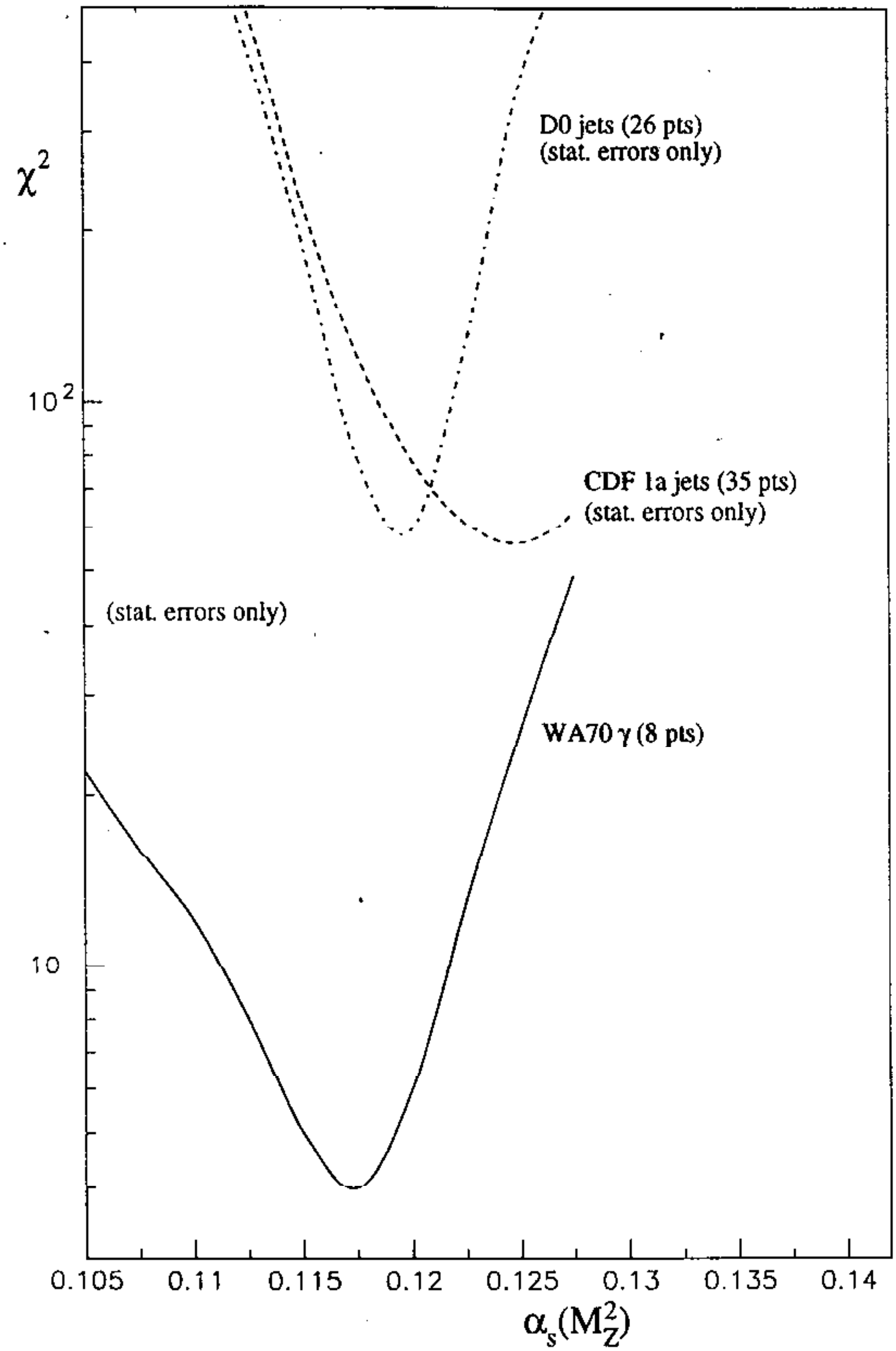
Q^2 (GeV^2)
ZEUS BPC 1995
ZEUS SVTX 1995
HERA 1994
HERA 1993
NMC
BCDMS
E665
SLAC
CCFR
y = 1
y = 0.005
A.Q.
10^{4}
10^{3}
10^{2}
10
1
10^{-1}
10^{-6}
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
1
x

Fig..

Deep Inelastic Data



Other data

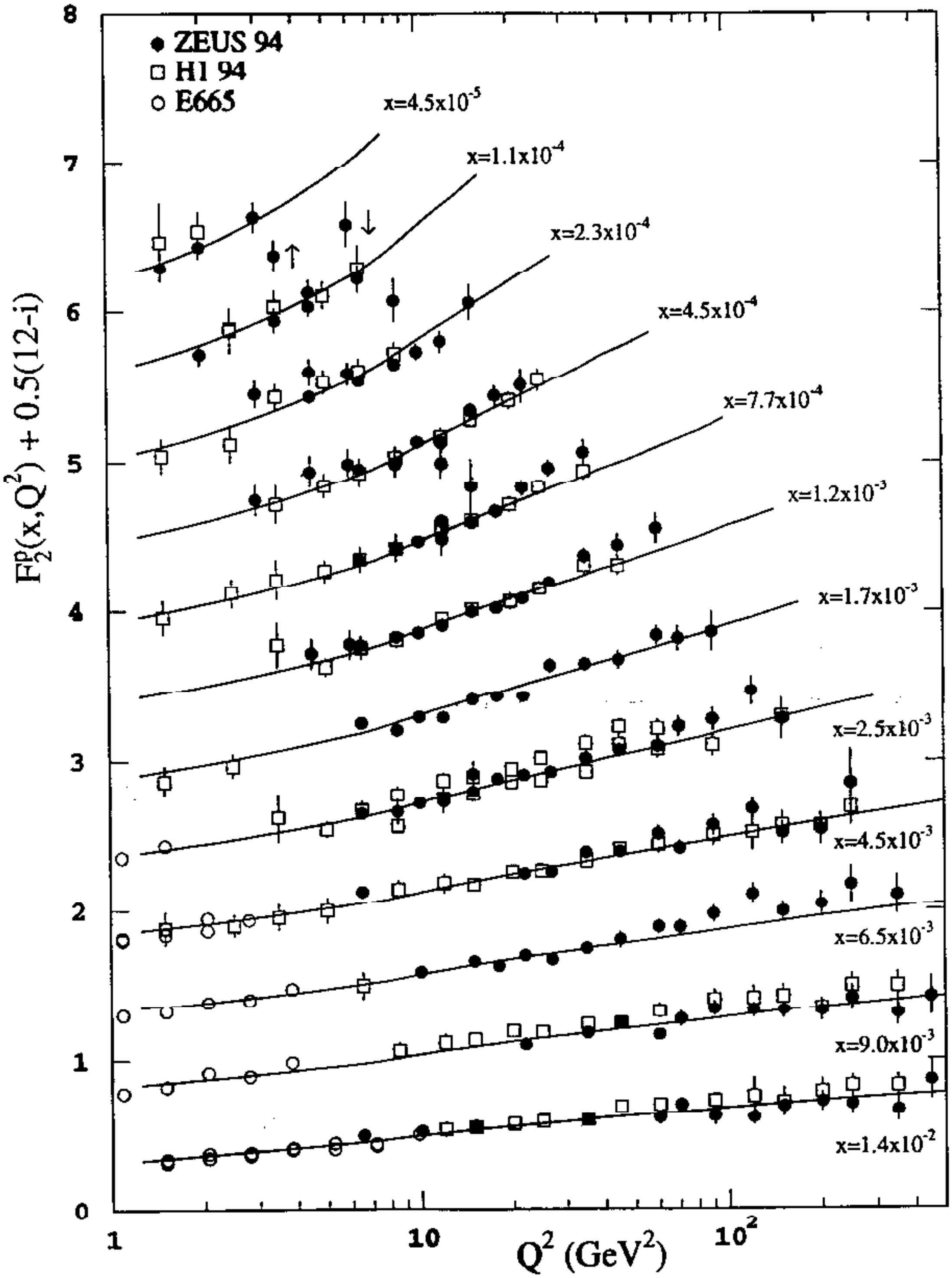


χ^2
10^2
10
D0 jets (26 pts)
(stat. errors only)
CDF 1a jets (35 pts)
(stat. errors only)
(stat. errors only)
WA70 γ (8 pts)
0.105
0.11
0.115
0.12
0.125
0.13
0.135
0.14
$\alpha_s(M_Z^2)$

3

$\alpha_s = .1175$

small x data



Cuts on data: $Q^2 \geq 2\ GeV^2$

except for HERA, $Q^2 \geq 1.5\ GeV^2$

For CCFR $x > 0.1$

Comparison with data – using 'best' α_s value

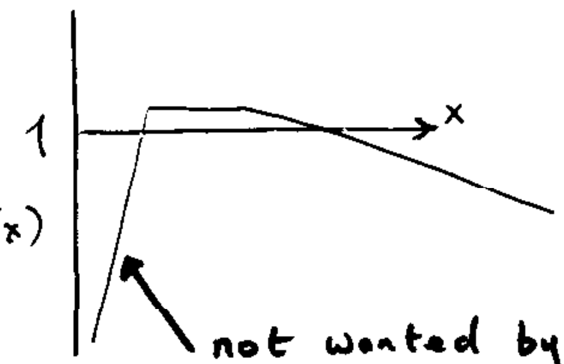
$\alpha_s(M_z) = 0.118$

Fig. 5 comparison with small x

" 6 new NMC data }
" 7 new CCFR data } data like large α_s

Correct for heavy target – divide by Q^2 indep. function $r(x)$

$$\frac{F_2^{Fe}(x)}{F_2^{D}(x)} = r(x)$$



not wanted by F_2 CCFR data!

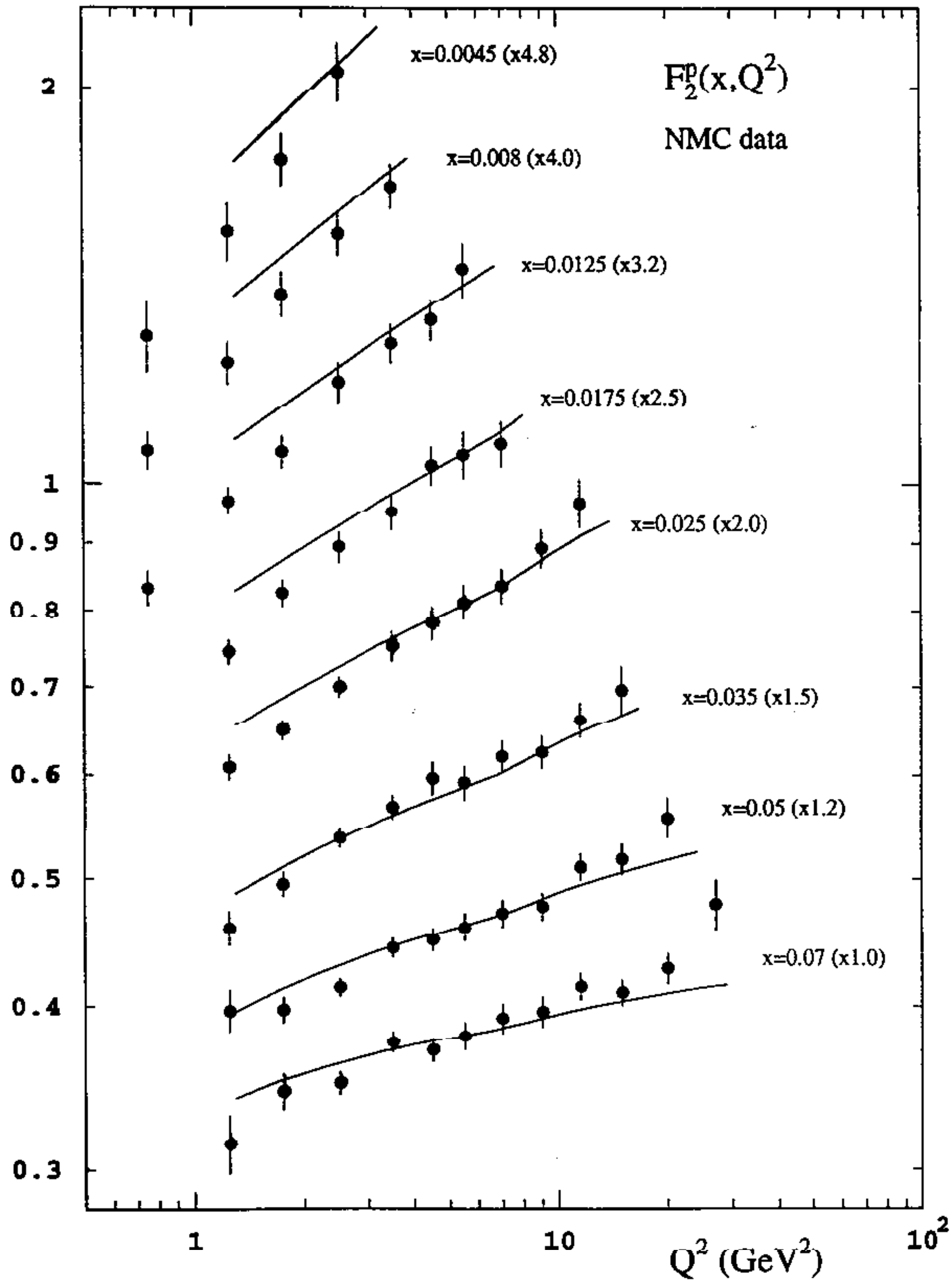
Partons at $Q_0^2 = 1\ GeV^2$

$$x\,S(x) \sim x^{-\lambda_s}(1-x)^{\eta_s}(\ldots\ldots)$$

$$x\,g(x) \sim x^{-\lambda_g}(1-x)^{\eta_g}(\ldots\ldots)$$

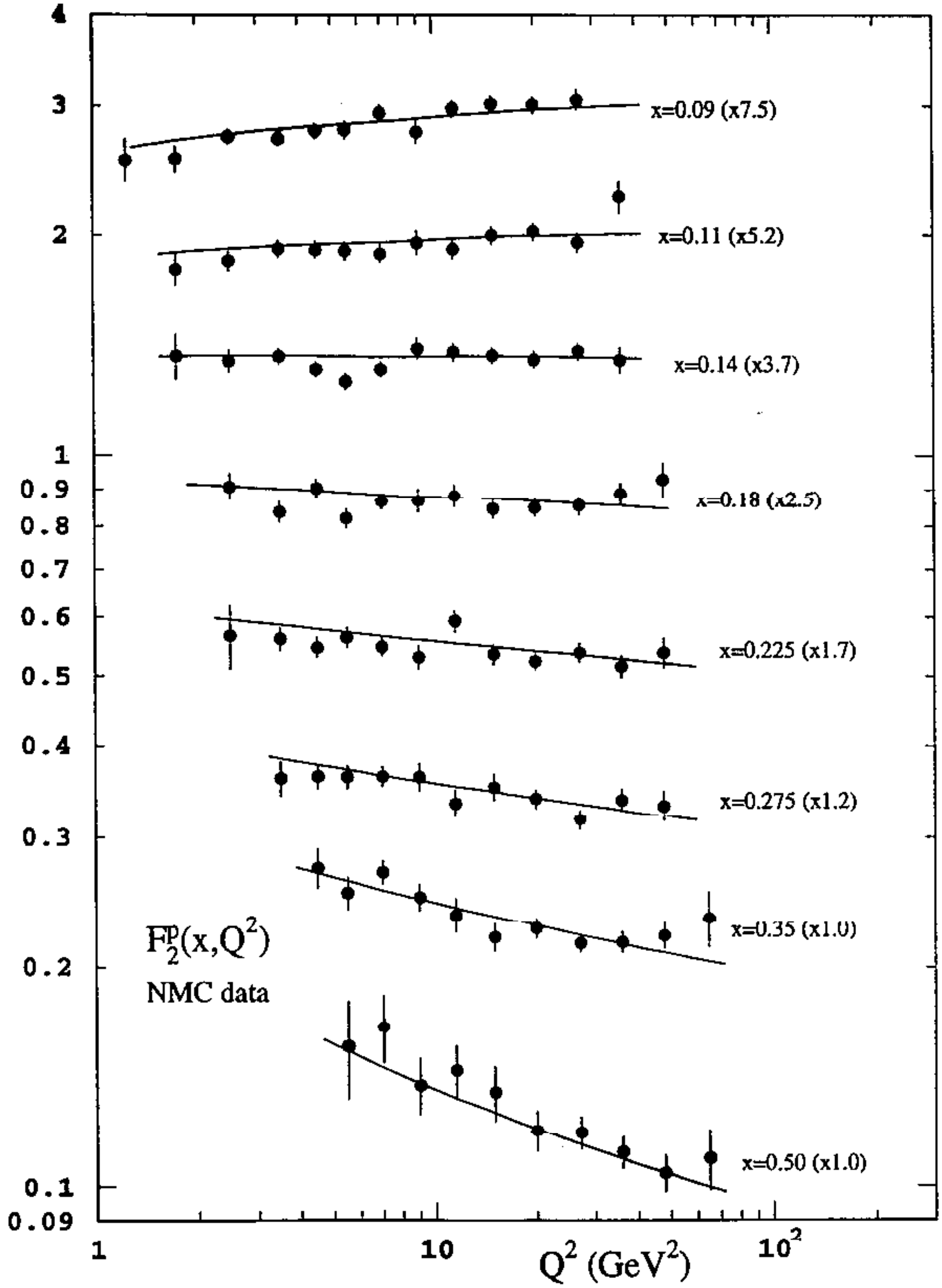
These vary with choice of α_s

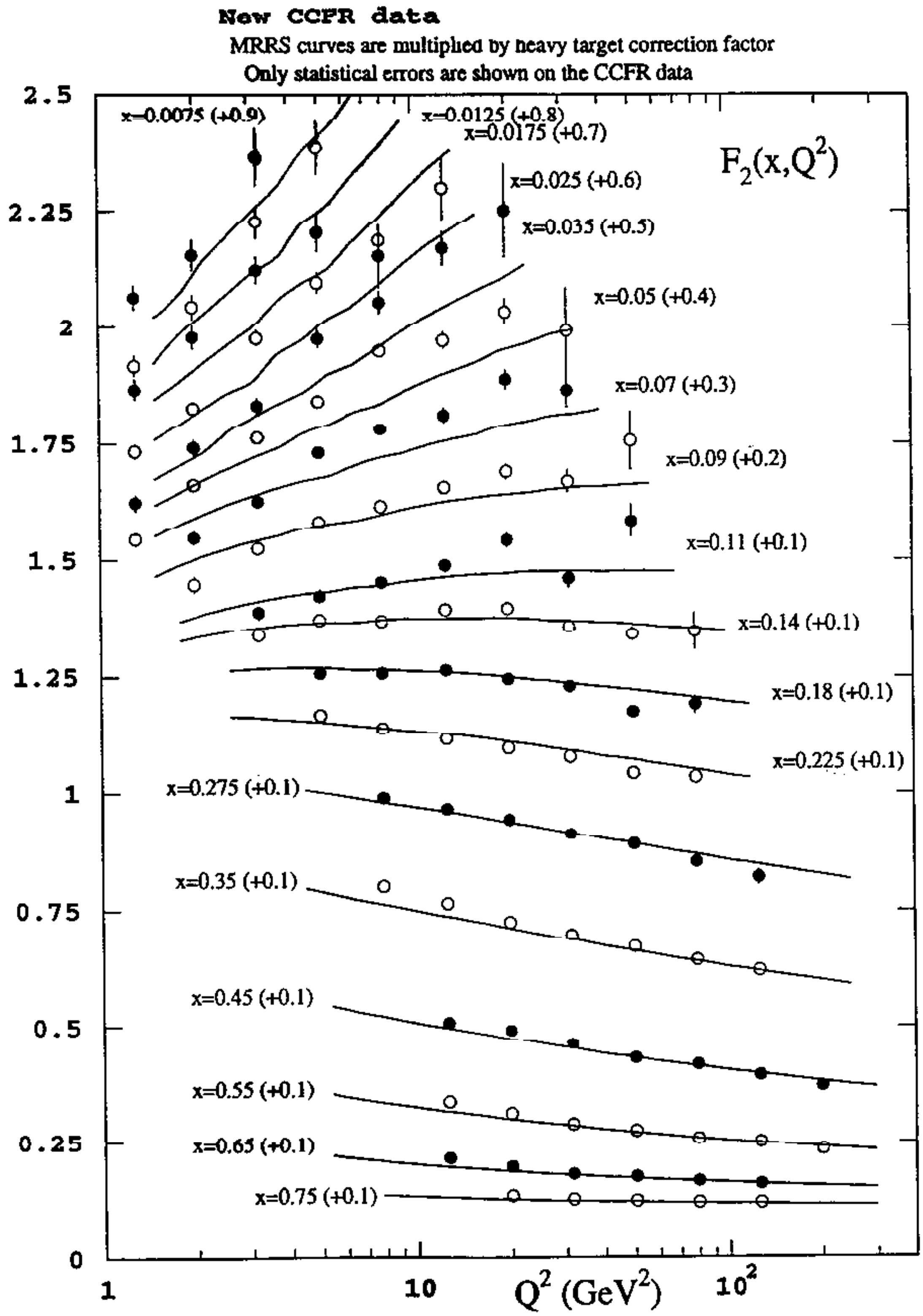
new NMC data



6a

new NMC data

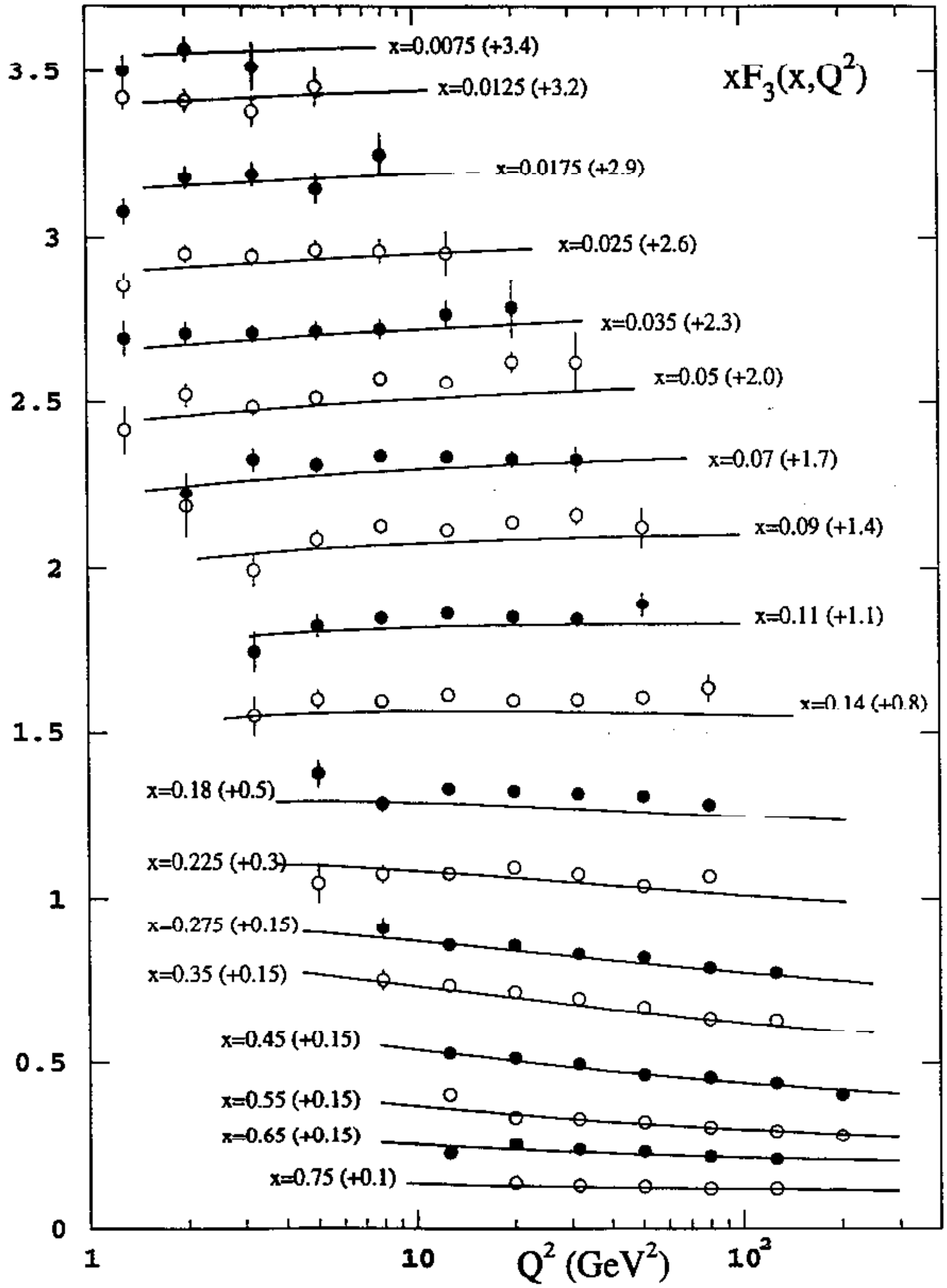

4
3
2
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.09
x=0.09 (x7.5)
x=0.11 (x5.2)
x=0.14 (x3.7)
x=0.18 (x2.5)
x=0.225 (x1.7)
x=0.275 (x1.2)
x=0.35 (x1.0)
x=0.50 (x1.0)
$F_2^p(x,Q^2)$
NMC data
1
10
10^2
Q^2 (GeV^2)


New CCFR data
MRRS curves are multiplied by heavy target correction factor
Only statistical errors are shown on the CCFR data
$F_2(x,Q^2)$
x=0.0075 (+0.9)
x=0.0125 (+0.8)
x=0.0175 (+0.7)
x=0.025 (+0.6)
x=0.035 (+0.5)
x=0.05 (+0.4)
x=0.07 (+0.3)
x=0.09 (+0.2)
x=0.11 (+0.1)
x=0.14 (+0.1)
x=0.18 (+0.1)
x=0.225 (+0.1)
x=0.275 (+0.1)
x=0.35 (+0.1)
x=0.45 (+0.1)
x=0.55 (+0.1)
x=0.65 (+0.1)
x=0.75 (+0.1)
2.5
2.25
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
1
10
10^2
Q^2 (GeV^2)

New CCFR data

MRRS curves are multiplied by heavy target correction factor

Only statistical errors are shown on the CCFR data



λ_s always > 0 $\Rightarrow$ Singular sea-quark
0.15 $\longrightarrow$ 0.21

λ_g always < 0 $\Rightarrow$ 'Valence-like' glue
- very sensitive to α_s
- penalty for taking Q_0^2 so low.

Evolve to $Q^2 = 2$, all gluons fairly 'flat

Fig. 8
Fig. 9 gluons at low Q^2

Partons at higher Q^2 – Fig. 10
$Q^2 = 25$ very similar to CTEQ4HQ

Jet prod. in $\bar{p}p$

$\sqrt{s} = 1800$ GeV

Adequate description using pdf's from global analyses. Figs to CDF 1A, DØ 1B data.

$\sqrt{s} = 630$ GeV

CDF appear to confirm the 'old' discrepancy from $\sqrt{s} = 56$C GeV
- wrong E_T dependence of data/theory

DØ – shape OK, $\frac{\text{data}}{\text{theory}}$ 20% c

What is going on?

Gluons at Q_0^2

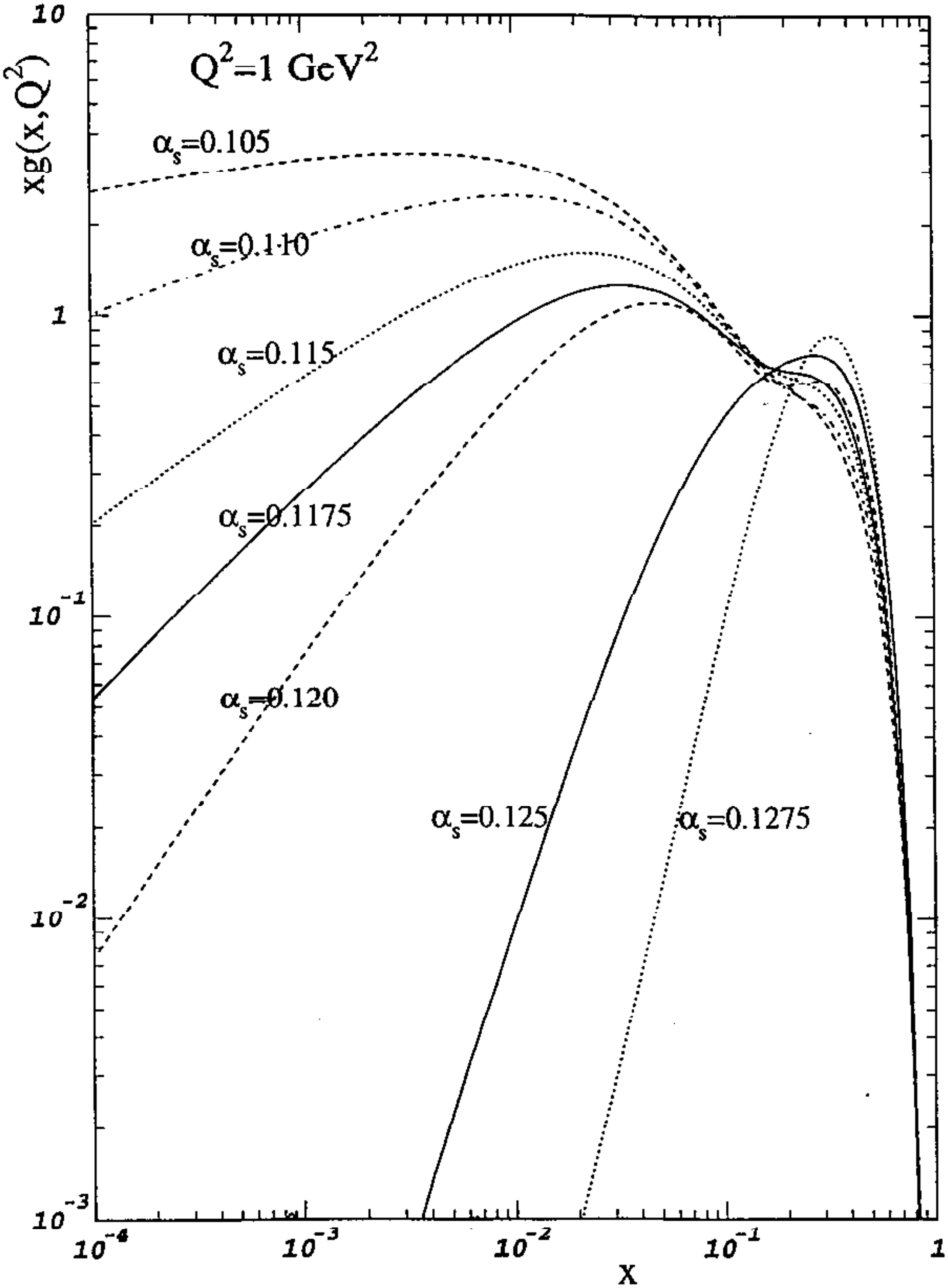
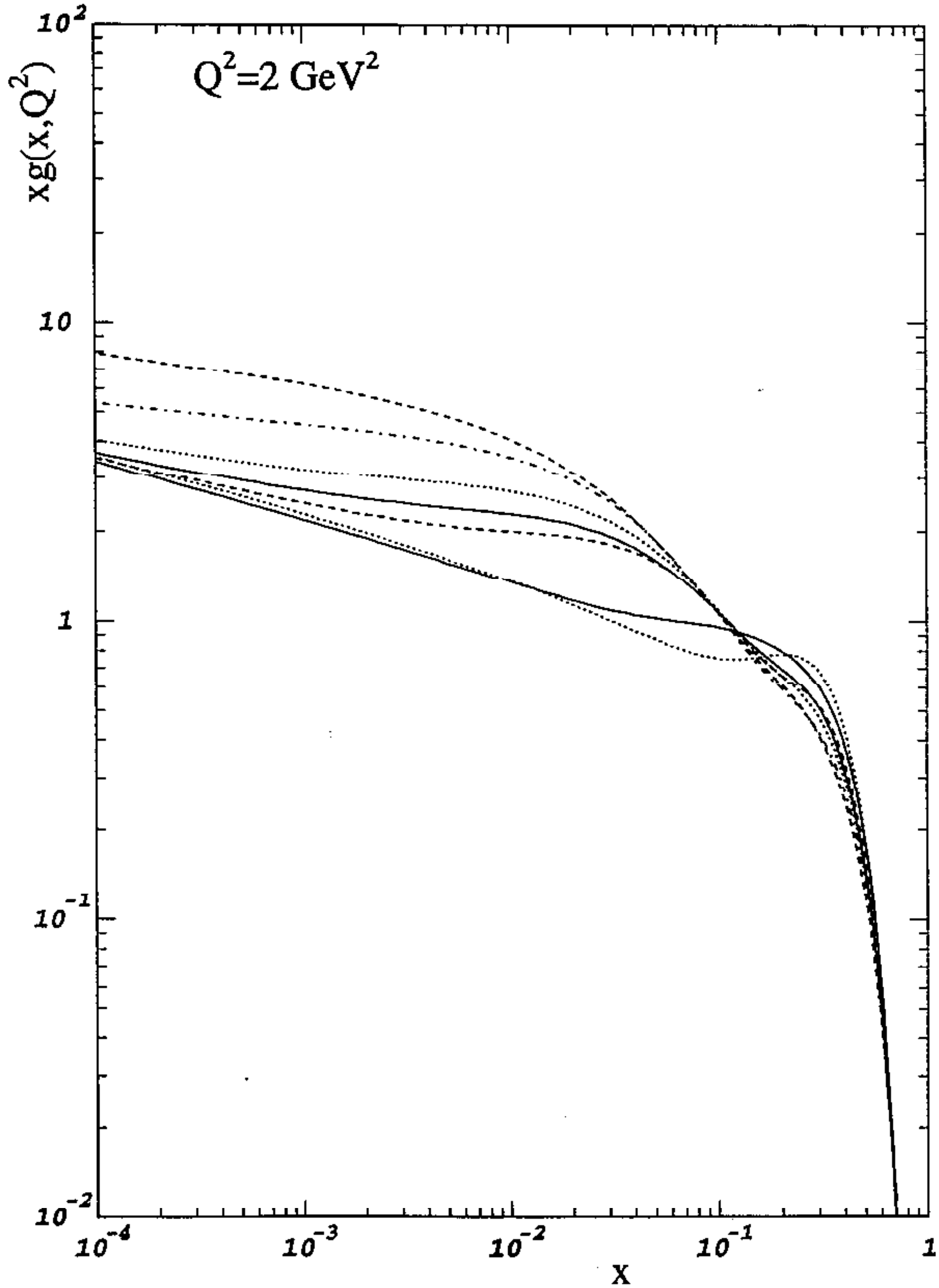
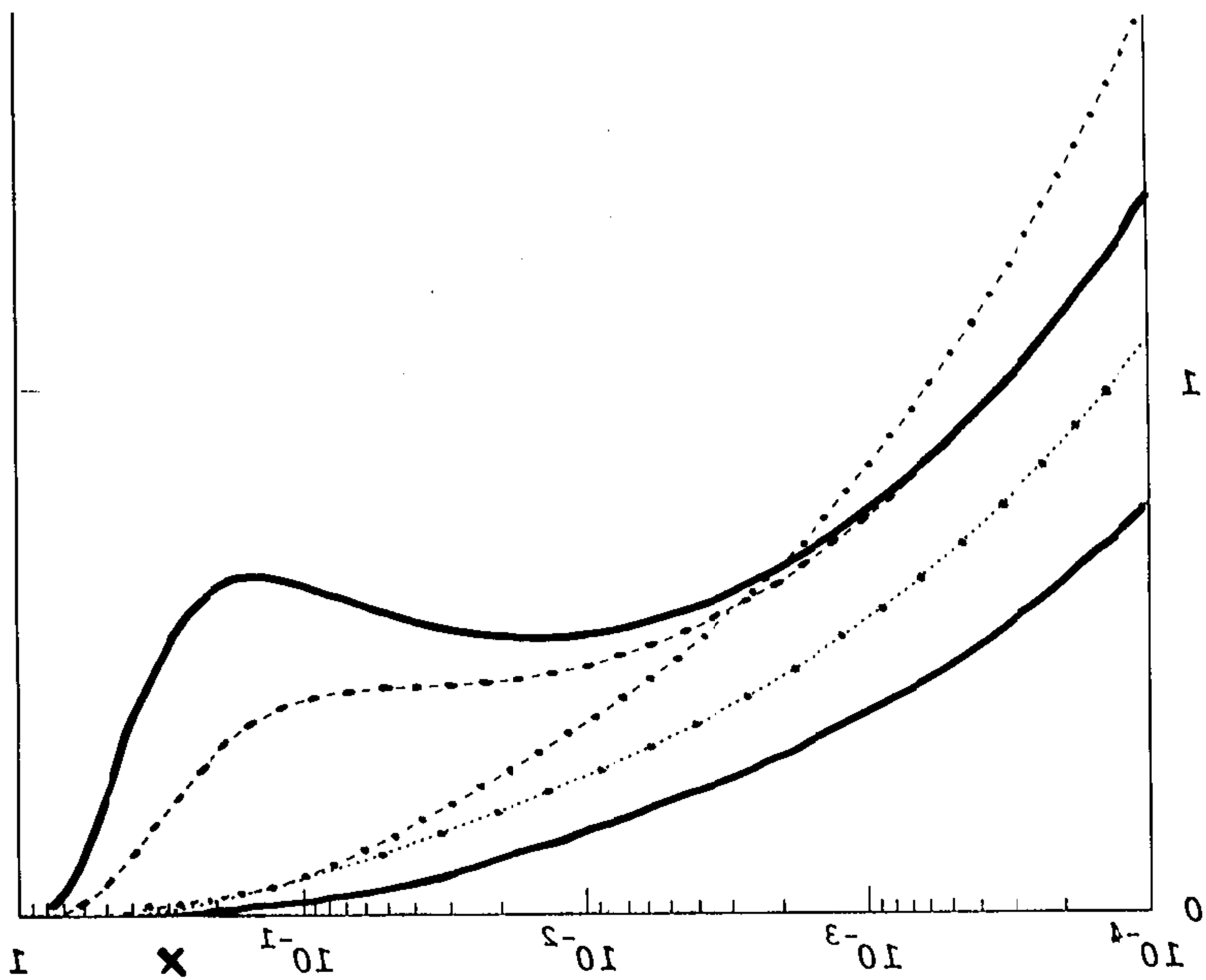


Fig.



Q²=2 GeV²
xg(x,Q²)
10²
10
1
10⁻¹
10⁻²
10⁻⁴
10⁻³
10⁻²
10⁻¹
1
X



1
x
10^{-1}
10^{-2}
10^{-3}
10^{-4}
0
1

'Proper' treatment of heavy quark prod. in DIS

In the past, global analyses offered a 'simplified' treatment of charm, bottom production.

E.g. Take $m_c = 0$ and work with $n_f = 4$ and choose $c(x, Q_0^2) = \bar{c}(x, Q_0^2) = 0$ at Q_0^2 and let $c(x, Q^2)$ evolve according to DGLAP. $Q_0^2 = 4$

<u>Now</u> we have taken $Q_0^2 \simeq 1\ \mathrm{GeV}^2$ (below charm) and want to have 'correct' threshold behaviour as Q^2 increases.

Alternatively e.g. Gluck, Reya, Stratmann

work with $n_f = 3$, $xc(x, Q^2) \equiv 0$

but F_2^{ch} generated by  (BGF).

but we need the concept of a charm parton to calculate other QCD processes, eg. jet prod. at Fermilab

and as $Q^2 \to$ large, BGF has $\ln \frac{Q^2}{M_c^2}$ terms which should be re-summed.

In terms of coeff. functions,

$$F_2^{ch}(x,Q^2) = e_c^2 \int_x^1 dz \left\{ C_q(z,Q^2) \frac{x}{z} c\left(\frac{x}{z},Q^2\right) + C_g(z,Q^2) \frac{x}{z} g\left(\frac{x}{z},Q^2\right) \right\}$$

1) Working with $n_f = 3$, only second line appears with

$$C_g(z,Q^2) = C_g^{BGF}(z,Q^2,m_c^2) \xrightarrow[m_c^2 \to 0]{} \frac{\alpha_s}{4\pi} P_{qg}^{(0)}(z) \ln\left[\frac{Q^2}{m_c^2} \cdot \frac{(1-z)}{z}\right] + \ldots$$

2) Working with $n_f = 4$ and $m_c = 0$, both lines

and $$C_g(z,Q^2) = \frac{\alpha_s}{4\pi} P_{qg}^{(0)}(z) \ln \frac{(1-z)}{z} + \ldots$$

DGLAP evolution of $c(x,Q^2)$ effectively re-sums the potentially large logs

The NLO corrections to the fixed order pert. theory of 1) calculated in recent years. Laenen Riemersma Smith van Neerven
(FOPT) – stabalise variations of choice of scale

A way of generating a consistent $c(x,Q^2)$ which takes $m_c \neq 0$, consistent with 1) and with $Q^2 \to \infty$ massless charm parton in $\overline{MS}$ scheme is the VFN scheme of ACOT

Variable Flavour Number

Aivazis Olness Collins Tung

OPE in FFN or FOPT - 1
scheme

$n_f = 3$

$$F = C_{FFN}\left(\frac{Q^2}{\mu^2}, \frac{m^2}{\mu^2}, \alpha_s(\mu^2)\right) \hat{O}\left(\alpha_s(\mu^2), \epsilon\right) + O\left(\frac{\Lambda^2}{Q^2}\right) \quad (A$$

operators
~ light pdf's

OPE in VFN scheme

$n_f = 4$

$$F = C_{VFN}\left(\frac{Q^2}{\mu^2}, \alpha_s\right) \hat{A}\left(\frac{m^2}{\mu^2}, \alpha_s, \epsilon\right) + O\left(\frac{m^2}{Q^2}\right) \quad (B$$

↑ depends on m^2

but evolves according
to $m=0$ RGE.
(assume only C.F.'s
depend on m^2)

If (A) and (B) consistent

$$O\left(\frac{m^2}{Q^2}\right) \text{ of } (B) \longrightarrow c\left(\frac{m^2}{\mu^2}\right) \hat{O}\left(\alpha_s(\mu^2), \epsilon\right) + O\left(\frac{\Lambda^2}{Q^2}\right)$$

and if we write

$$\underset{\uparrow VFN}{\hat{A}} = A \underset{\uparrow FFN}{\hat{O}} \quad \oplus \qquad A \sim \ln\frac{Q^2}{m^2}$$

then

$$F = \left[C_{VFN}\left(\frac{Q^2}{\mu^2}\dots\right) + c\left(\frac{m^2}{\mu^2}\right) A^{-1}\right] \hat{A}(\dots) + O\left(\frac{\Lambda^2}{Q^2}\right) \quad ($$

Eqn. $\oplus$ establishes relation between light pdf's at $n_f = 3$ and $n_f = 4$ and charm pdf in terms of light pdf's - principally $g(x)$.

From (A) and (C)

$$C_{VFN} + \underbrace{c\left(\frac{m^2}{Q^2}\right) A^{-1}}_{\text{asym.} \to 0} = C_{FFN} A^{-1} \quad *$$

Buza
Matiounin
Smith
van Neerven

BMSvN examine when asymtotic value of lhs = rhs
$Q^2 \sim 20 \text{ GeV}^2$

A^{-1} contains subtraction to avoid double counting

ACOT retain the second term in $*$ and
Q^2 allowed to go down to threshold
$\Rightarrow x c(x, Q^2) > 0$ for $Q^2 > m_c^2$

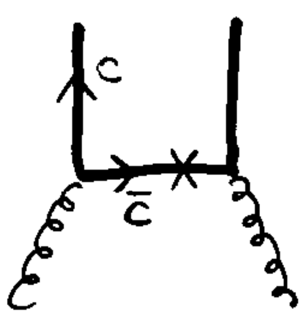
Low Q^2 : $F_2^c \sim$ PGF alone
High Q^2 : $F_2^c \sim$ charm excitation

see Wu-Ki Tung's talk
WG5 Thursday

An alternative procedure

MRRS develop formalism based
$\uparrow$
Ryskin

leading $\log Q^2$ decomposition
of Feynman diagrams



$$\underset{m_c \neq 0}{\Longrightarrow} P_{cg}^{(0)}(z, m_c^2)$$

i.e. splitting fns (an. dims)
depend on m^2

$$\Rightarrow \quad P_{cg}^{(0)}(z) = \left[(z^2+(1-z)^2) + \frac{2m_c^2}{Q^2} z(1-z) \right] \Theta(Q^2 - m_c^2)$$

not kinematics !

need $Q^2 \sim m_c^2$ to resolve $c, \bar{c}$ in proton.

Even if $W^2 = Q^2/x$ large but $Q^2 < m_c^2$ — can't resolve $c\bar{c}$ pair.

$$P_{cg}^{(0)}(z, m_c^2) \xrightarrow[m_c \to 0]{} \text{standard } m_c = 0 \text{ expression}$$

To conserve momentum across charm threshold, $P_{gg}^{(0)}(z)$ adjusted to change by $-\frac{2}{3} T_R \, \delta(1-z) \frac{m_c^2}{2Q^2} \Theta(Q^2 - m$

Main change to coeff. functions is to C_g for F_2^c

$$C_g^{(1)} = C_g^{BGF} - \Delta C_g \qquad \text{to avoid double counting}$$

$$\sim \int d\ln Q^2 \, P_{cg}(z, Q^2)$$

As $m_c \to 0$ $\quad \Delta C_g = P_{qg}^{(0)}(z) \ln\left(\frac{Q^2}{m_c^2}\right) + \ldots\ldots$

$$\Rightarrow C_g(z, m_c^2, Q^2) \xrightarrow[m_c^2 \to 0]{} P_{qg}^{(0)}(z) \ln\frac{(1-z)}{z} + \ldots$$

ie the $\overline{MS}$ $m_c = 0$ coeff. fn.

$\therefore$ At large Q^2, charm production consistent with massless quark in $\overline{MS}$ schem

Calculated F_2^{c} depends on exact choice of m_c

$m_c = 1.35$ GeV consistent with measured F_2^c.

Fig. 11 $F_2^c / F_2 \sim 0.22$ in HERA range

Fig. 12 F_2^c H1 and EMC $m_c = 1.35 \pm 0.15$

For $Q^2 \gtrsim 20\ \mathrm{GeV}^2$, generated F_2^c > BGF F_2^c

$Q^2 = 100\ \mathrm{GeV}^2$
$x = 0.005$ 30% bigger

Further details WG5 session Wednesday.

c) Large x, high Q^2

How precise is $\dfrac{d\sigma^{e^+p \to e^+X}}{dx\,dy}$?

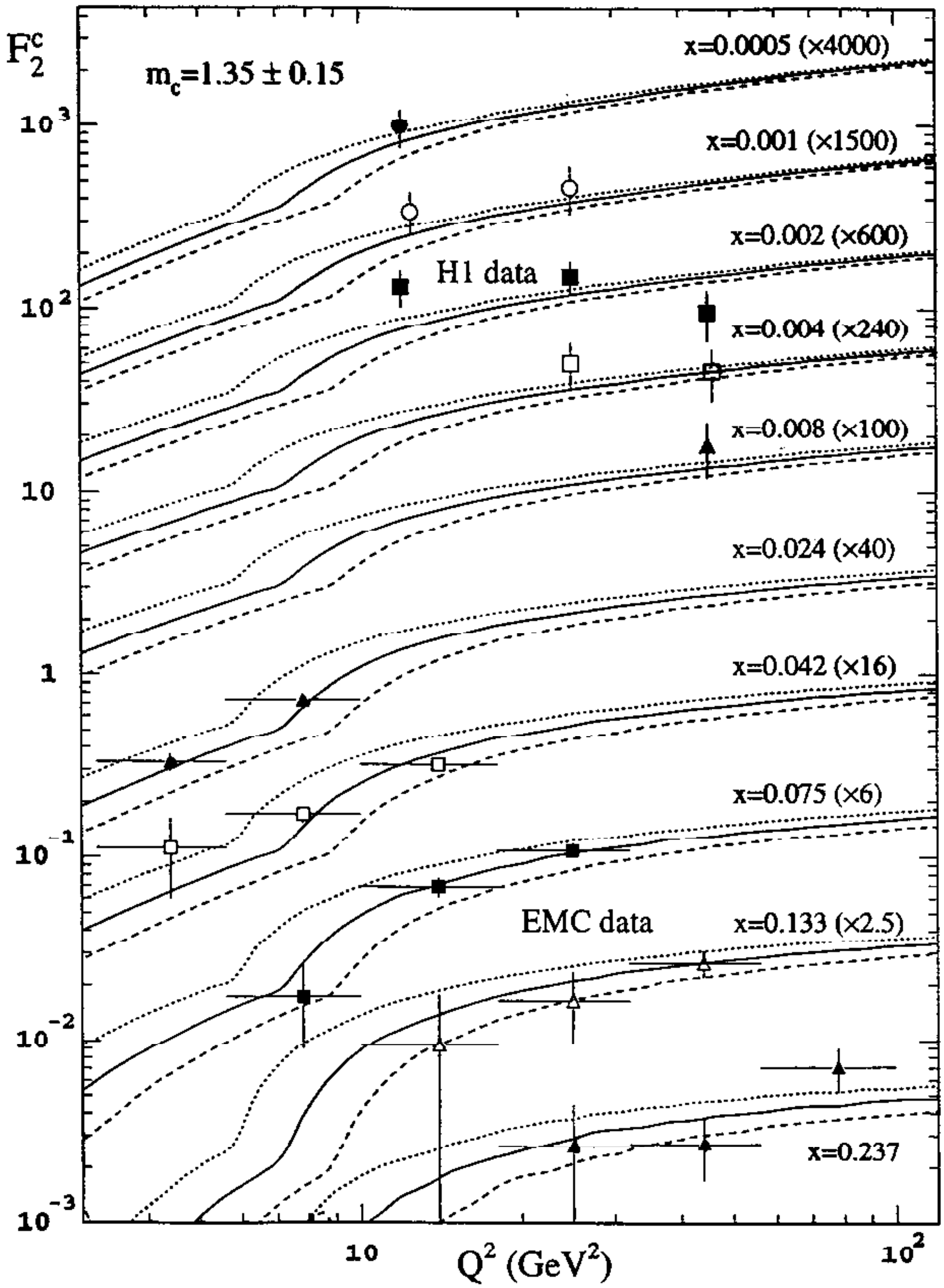
Take $x = 0.45$, $\alpha_s(M_Z) = 0.118 \pm 0.008$

over conservative

$F_2^{\gamma p}(x, Q^2)$ at low Q^2 – 2-3% uncertainty

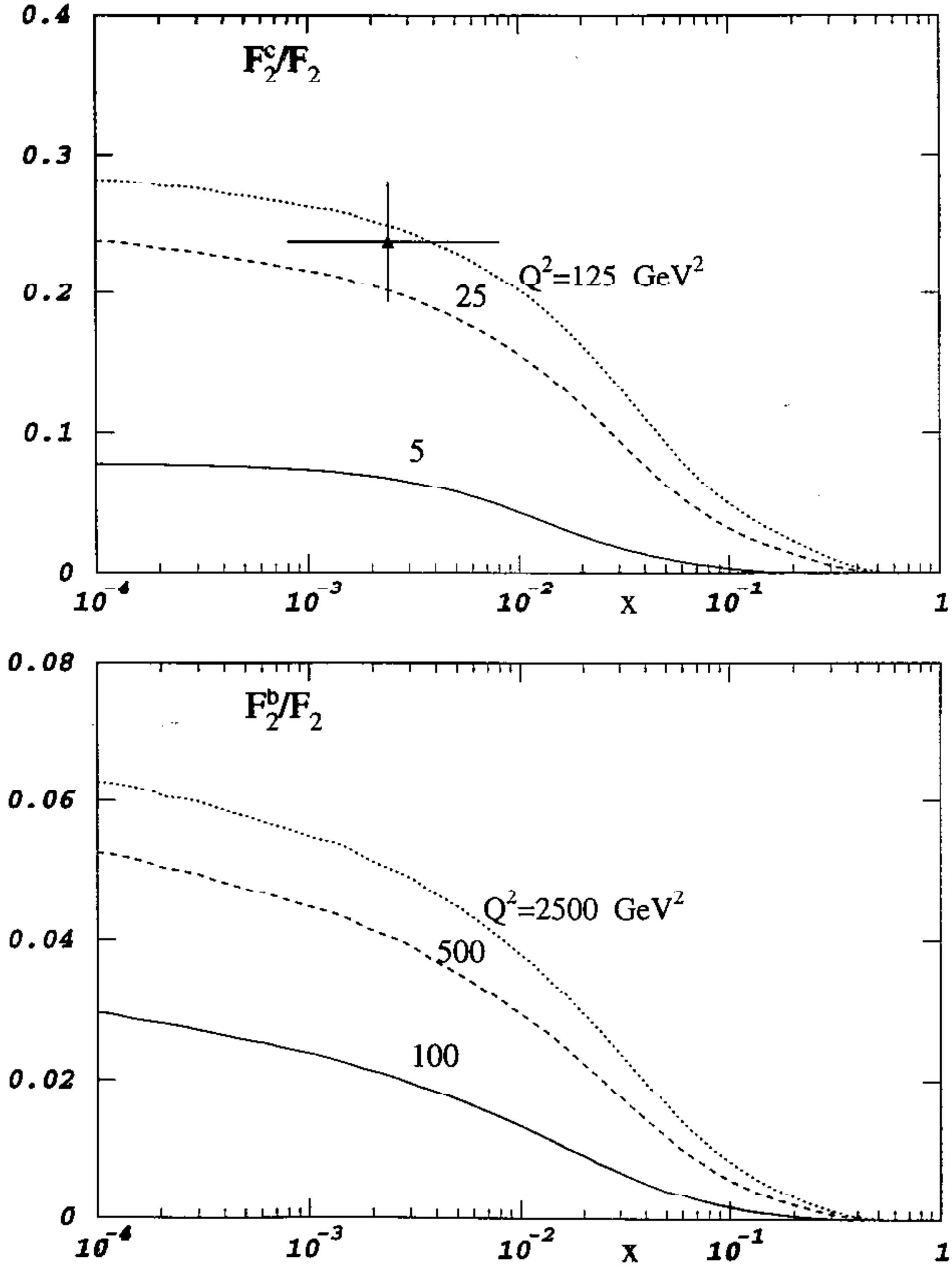
Variation of $\alpha_s \Rightarrow$ 7% uncertainty

$\Rightarrow$ uncertainty on pdf's at large x
$\lesssim 10\%$



F_2^c
m_c=1.35 ± 0.15
x=0.0005 (×4000)
x=0.001 (×1500)
x=0.002 (×600)
x=0.004 (×240)
x=0.008 (×100)
x=0.024 (×40)
x=0.042 (×16)
x=0.075 (×6)
x=0.133 (×2.5)
x=0.237
H1 data
EMC data
10^3
10^2
10
1
10^{-1}
10^{-2}
10^{-3}
10
10^2
Q^2 (GeV^2)

Fig. 7

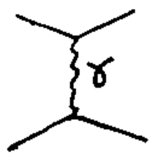


F_2^c/F_2
Q^2=125 GeV^2
25
5
0.4
0.3
0.2
0.1
0
10^{-4}
10^{-3}
10^{-2}
x
10^{-1}
1
F_2^b/F_2
Q^2=2500 GeV^2
500
100
0.08
0.06
0.04
0.02
0

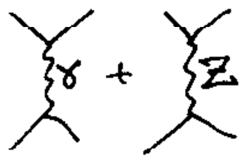
Fig. 8

Weak current + E.M. current at high Q^2

$$\frac{d^2\sigma}{dx\,dQ^2} = \frac{2\pi\alpha^2}{x\,Q^4}\left\{\left[1+(1-y)^2\right]F_2 - \left[1-(1-y)^2\right]xF_3\right\}$$

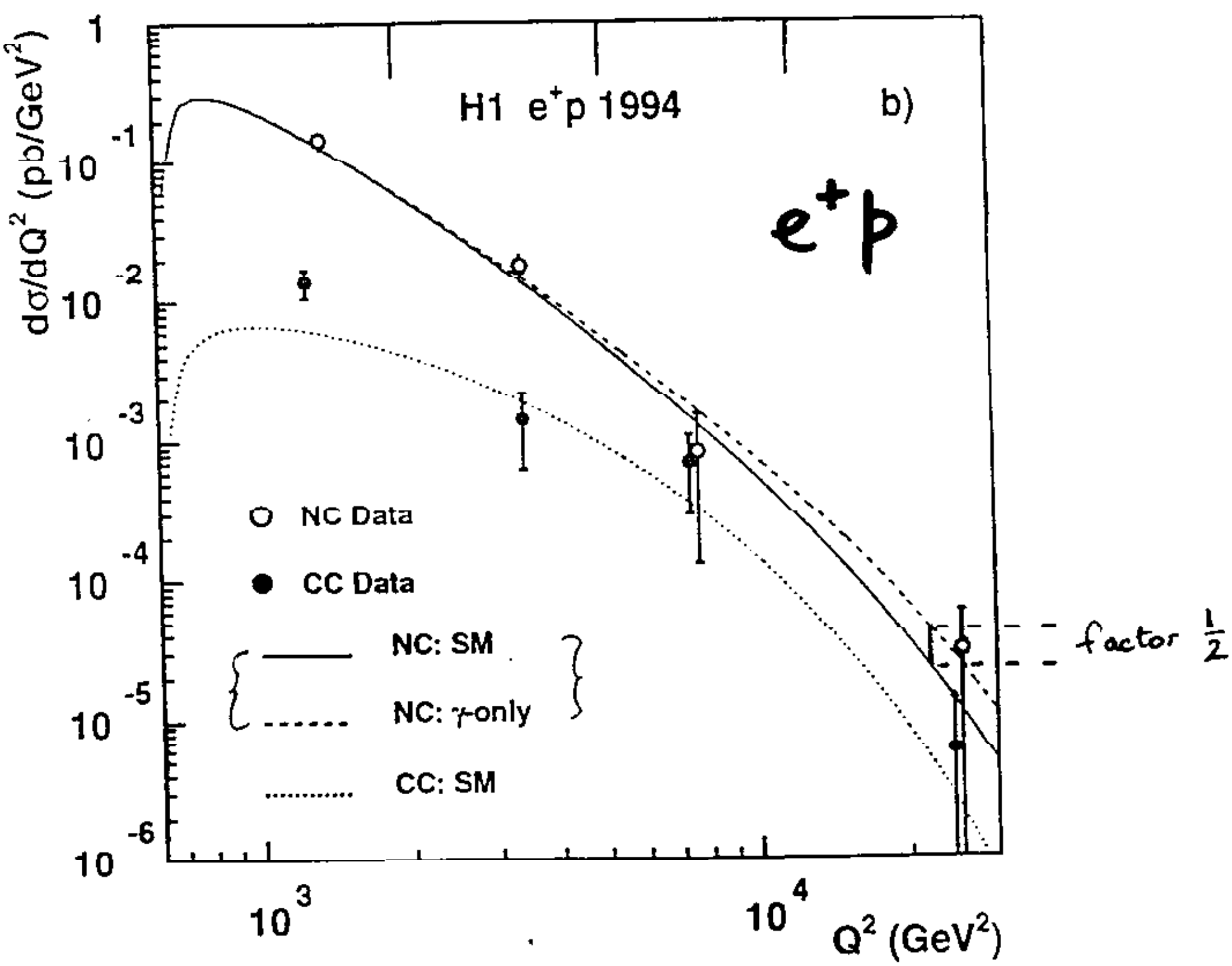


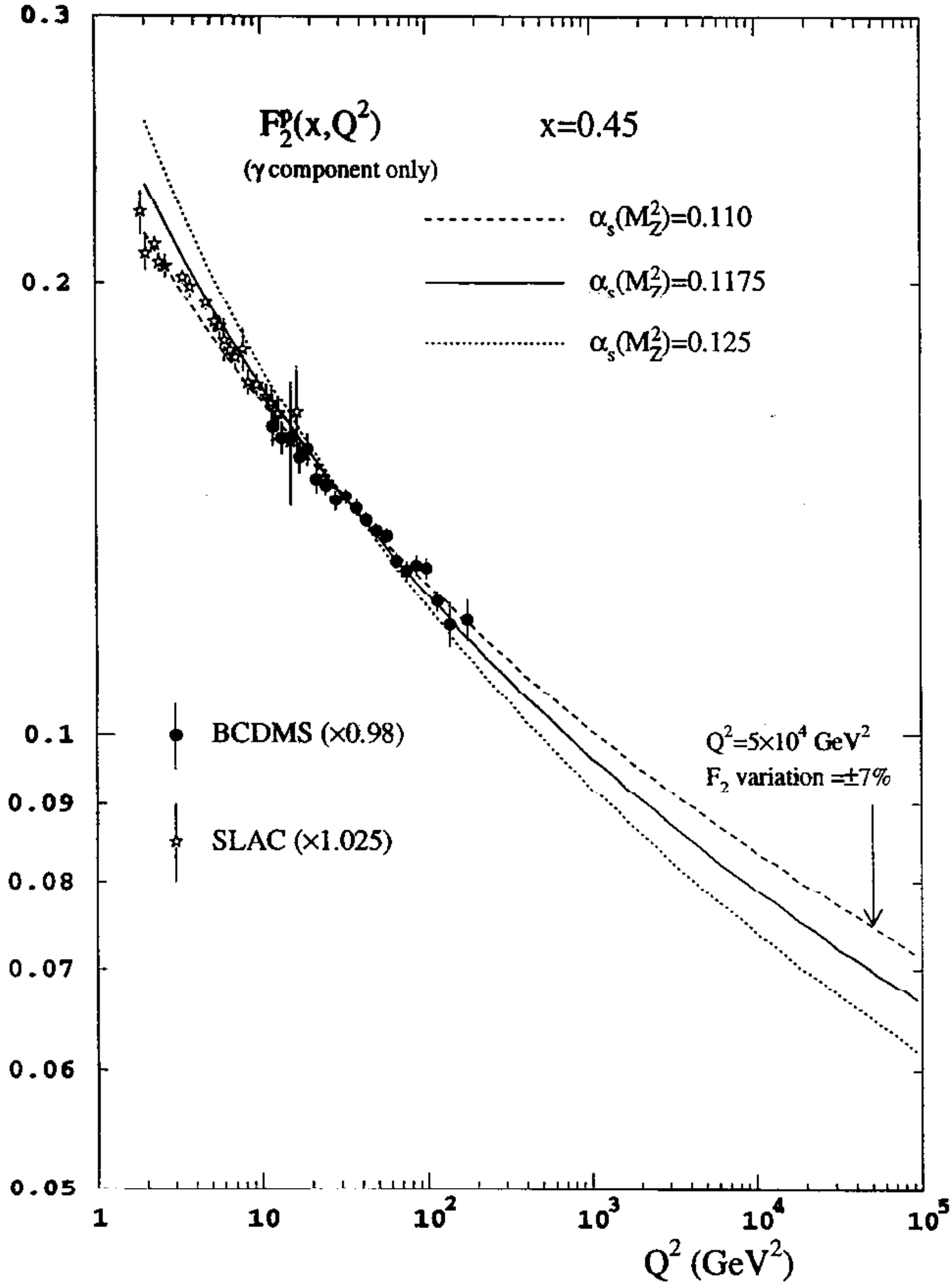
$$\Rightarrow \qquad e_q^2 \qquad\qquad 0$$



$$\Rightarrow \qquad e_q^2 - 2e_q v_e v_q \chi \qquad\qquad -2e_q a_e a_q \chi$$

$$\chi = \frac{1}{\left[2\sin 2\theta_W\right]^2}\;\frac{Q^2}{M_Z^2+Q^2}$$





$F_2^p(x,Q^2)$
(γ component only)
x=0.45
$\alpha_s(M_Z^2)$=0.110
$\alpha_s(M_Z^2)$=0.1175
$\alpha_s(M_Z^2)$=0.125
BCDMS (×0.98)
SLAC (×1.025)
$Q^2=5\times10^4$ GeV^2
F_2 variation =±7%
0.3
0.2
0.1
0.09
0.08
0.07
0.06
0.05
1
10
10^2
10^3
10^4
10^5
Q^2 (GeV^2)

Fig. 13

Re-summed $\ln\left(\frac{1}{x}\right)$ terms :

So far – discussed fits using L.O.+N.L.O
resummation of large $\ln Q^2$
ie $\sum \alpha_s^n (\ln Q^2)^n$ L.O.

Is this sufficient ?

At HERA x down to 10^{-4}, $\ln \frac{1}{x} > 9$

$\therefore$ Should include (BFKL) re-summation of $\ln\frac{1}{x}$
ie $\sum \alpha_s^n \left(\ln \frac{1}{x}\right)^m$

Moment space $F(N) = \int_0^1 dx\, x^{N-1} F(x)$

$\omega = N-1$ eg. exp. of an. dims

1 loop			$\frac{\alpha}{\omega}$	α	$\alpha\omega$	$\alpha\omega^2$	...
2 loop		$\frac{\alpha^2}{\omega^2}$	$\frac{\alpha^2}{\omega}$	α^2	$\alpha^2\omega$	$\alpha^2\omega^2$	...
3 loop	$\frac{\alpha^3}{\omega^3}$	$\frac{\alpha^3}{\omega^2}$	$\frac{\alpha^3}{\omega}$	α^3	$\alpha^3\omega$	....	
	LO BFKL	NLO BFKL					

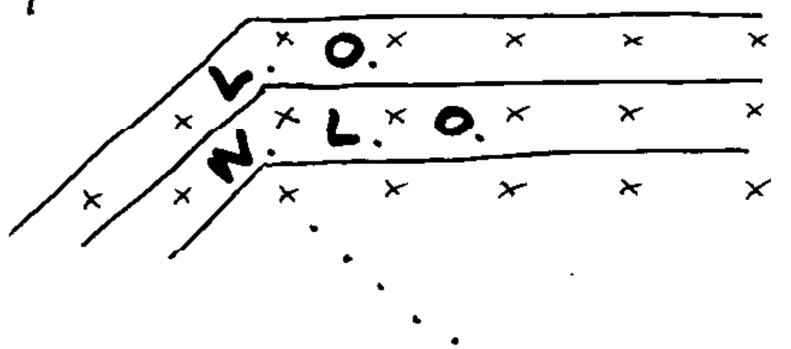
Naive approach : simply add extra terms in the expansions of the an. dims etc.

Just worsens fit to data
– F increases too steeply with decreasing

What is the correct way to include the $\ln(\frac{1}{x})$ terms in the collinear factorisation approach

Answer: Include the terms in both expansions in a systematic expansion in the 'envelopes'

Robert Thorne
WG1 session
Tuesday



$\Rightarrow$ Unambiguous way to get a 'well-ordered' expansion in a renormalisation-scheme-consistent way.

What results:

- No factorisation scheme dependence

- 'Physical' an. dims. of Catani emerge naturally

$$\frac{\partial F_2}{\partial t} = \Gamma_{22} F_2 + \Gamma_{2L} F_L$$

$t = \ln($

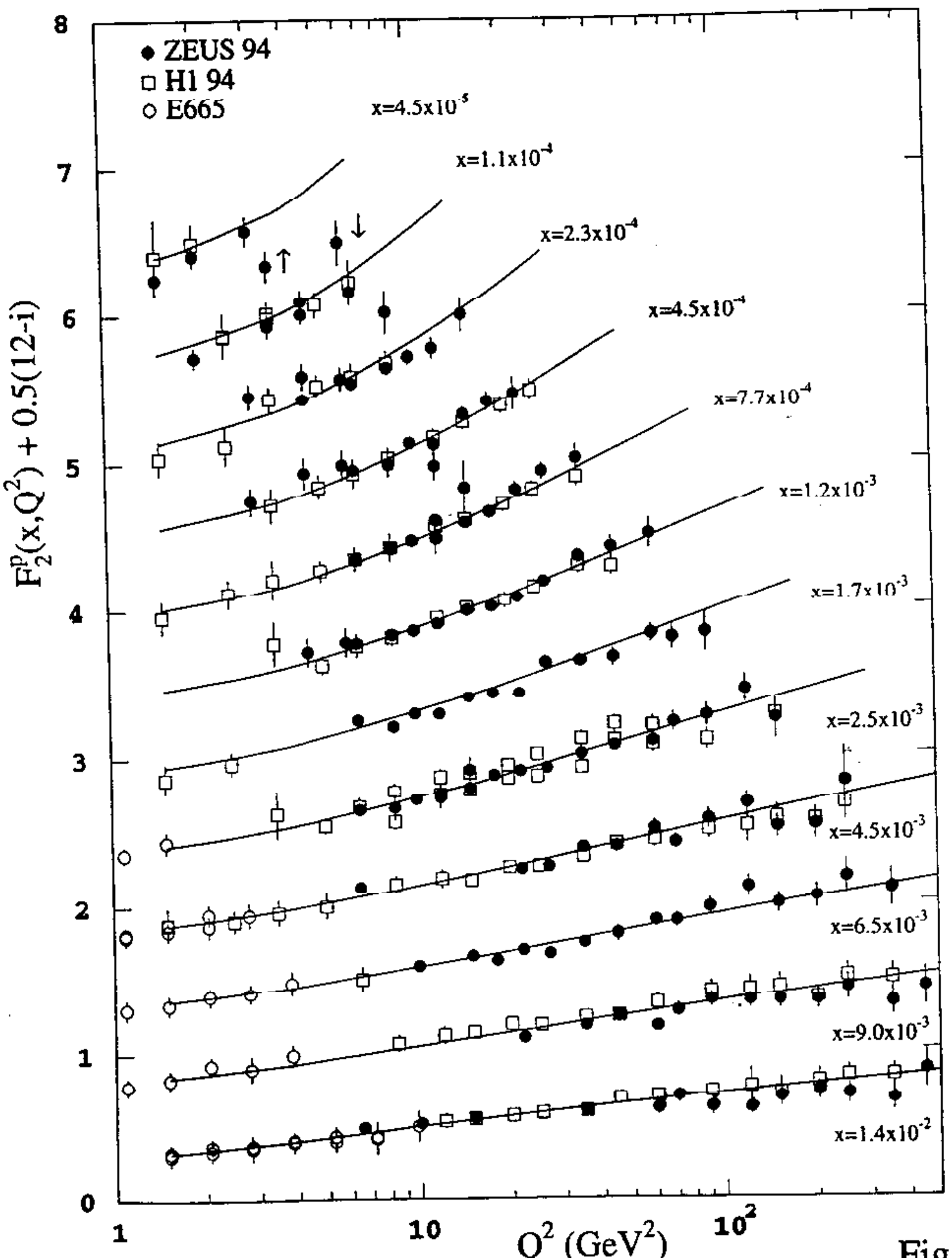
$$\frac{\partial F_L}{\partial t} = \Gamma_{L2} F_2 + \Gamma_{LL} F_L$$

- At starting scale Q_0^2 Input distns F_2 F_L

- Not sensitive to precise choice of Q_0^2
  Both inputs 'flat' (at small x) for non-pert. part

- Resulting fits actually improve on 2-loop fits — Fig. 14

- F_L at small x predicted to differ from 2-loop prediction



ZEUS 94
H1 94
E665
x=4.5x10^-5
x=1.1x10^-4
x=2.3x10^-4
x=4.5x10^-4
x=7.7x10^-4
x=1.2x10^-3
x=1.7x10^-3
x=2.5x10^-3
x=4.5x10^-3
x=6.5x10^-3
x=9.0x10^-3
x=1.4x10^-2
$F_2^p(x,Q^2) + 0.5(12\text{-}i)$
Q^2 (GeV^2)

Fig. 2

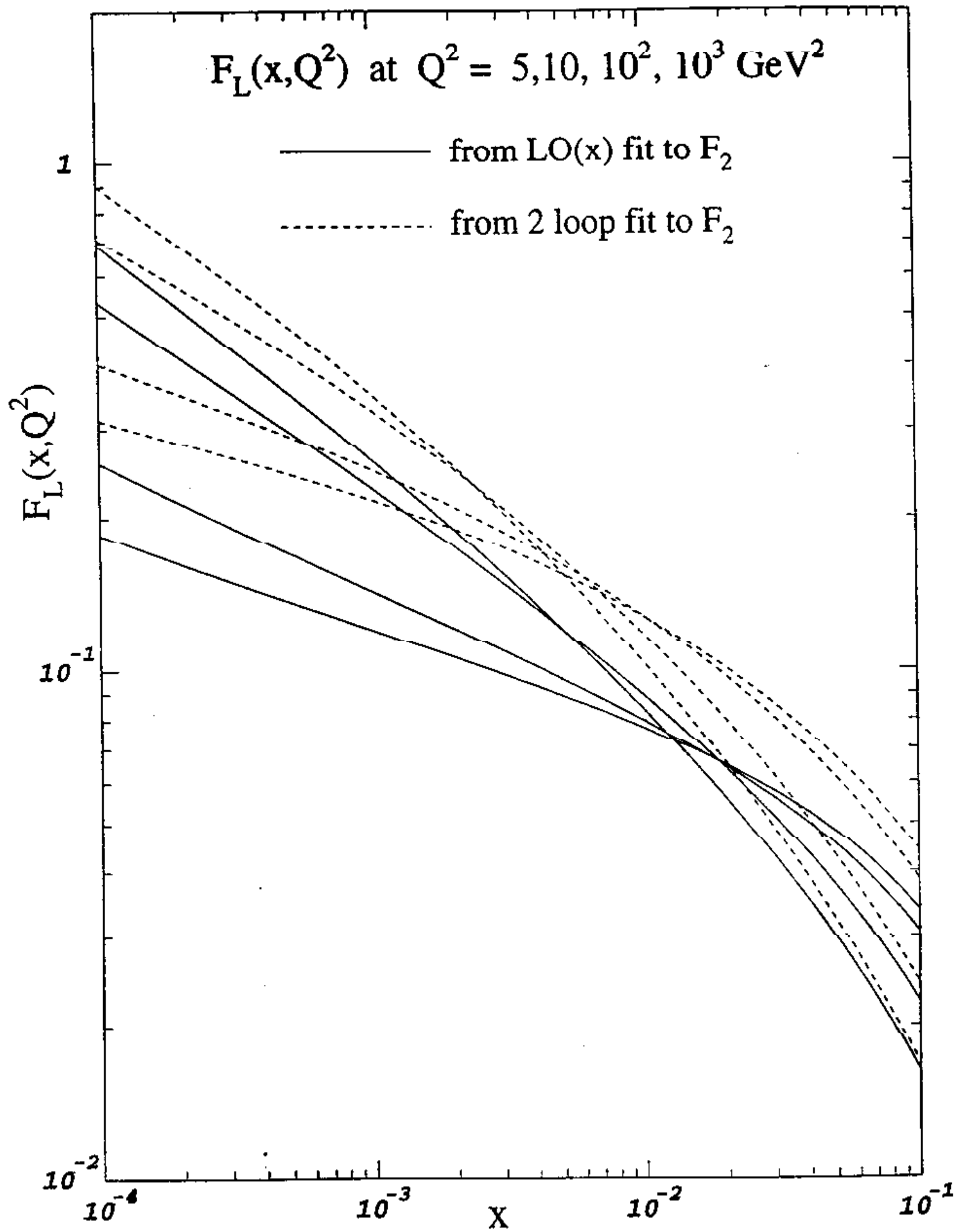

$F_L(x,Q^2)$ at $Q^2 = 5, 10, 10^2, 10^3$ GeV^2
from LO(x) fit to F_2
from 2 loop fit to F_2
$F_L(x,Q^2)$
1
10^{-1}
10^{-2}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
X

Fig. 4

Conclusions

Precision in the DIS data and the resulting pdf's continue to improve.

Description of charm, bottom pdf's put on a firmer theoretical basis

$\alpha_s(M_Z)$ emerging from DIS has increased, $\alpha_s(M_Z) \to 0.118 \pm 0.00\underset{\sim 3}{\uparrow}$

Even with generous uncertainty on $\alpha_s(M_Z)$ our precision on $\frac{d\sigma}{dx\,dQ^2}$ at large x is $< 10\%$

Inclusion of re-summed $\ln\left(\frac{1}{x}\right)$ terms has to be performed in a careful well-ordered manner — still important to measure F_L at HERA.