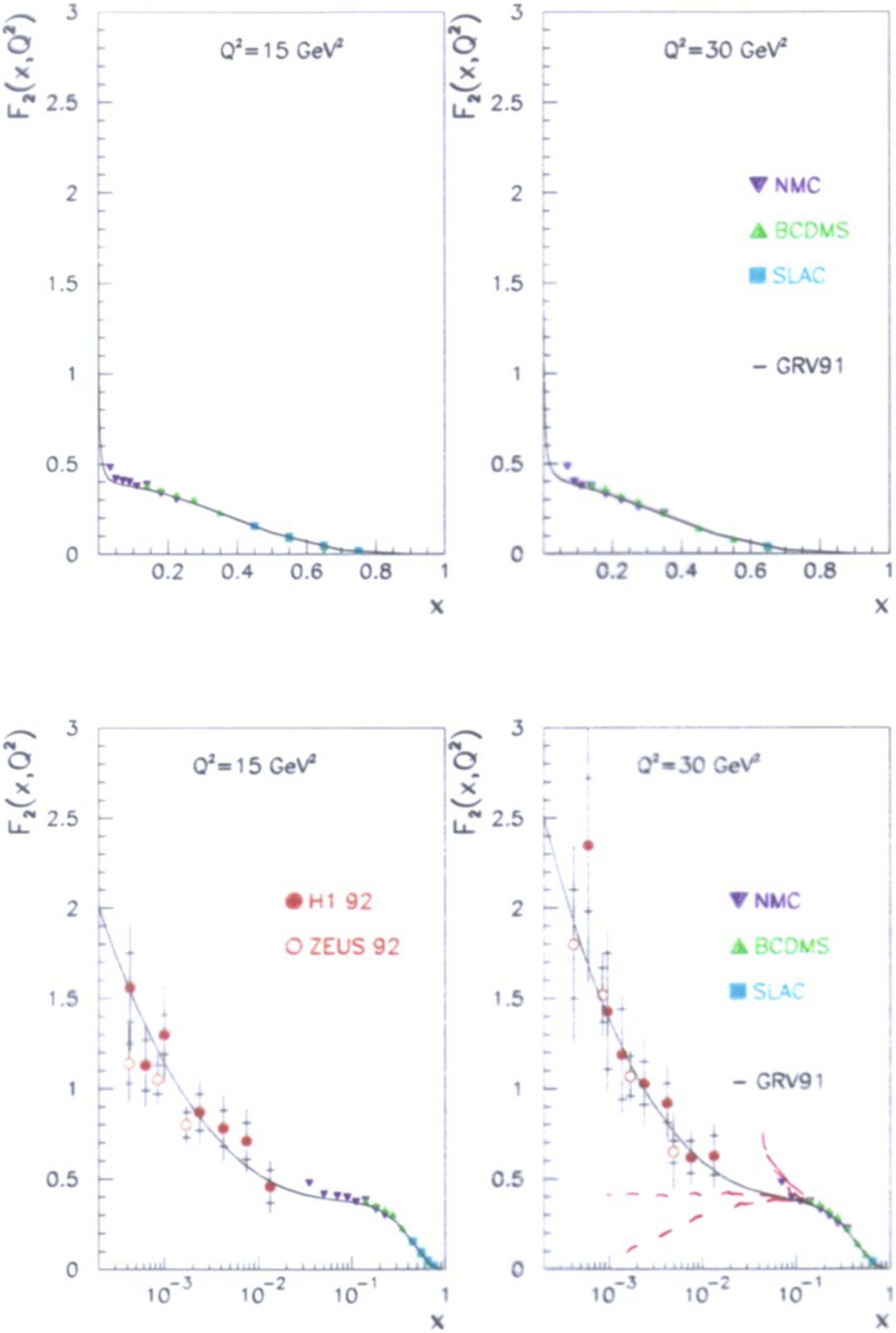
# Low x Physics with H1.

Max Klein
DESY · Zeuthen
for H1.

- low x cross section measurement
- $\alpha_s(M_Z^2)$ and the gluon at low x
- charm
- $F_2(x, Q^2)$ and its derivative $(\partial F_2 / \partial \ln Q^2)_x$
- $F_L(x, Q^2)$
- diffraction

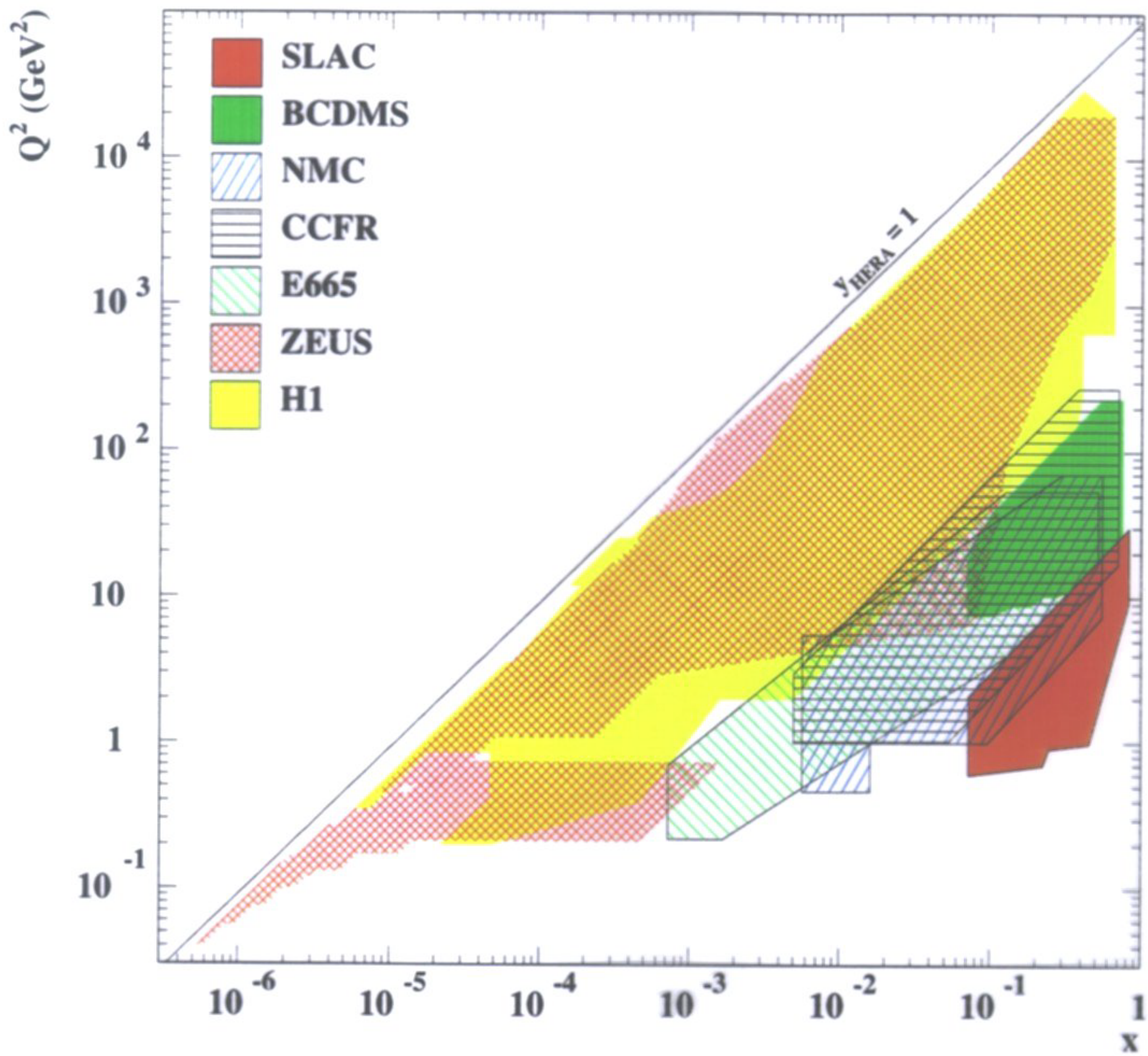
find all H1 results
on H1 webpage,
mostly Osaka 2000.

DESY-Forum on Low x Physics . 30. November 2000. MK




A de Rújula et al
Possible non-Regge behaviour of $F_2$
PR D10 (74) 1649

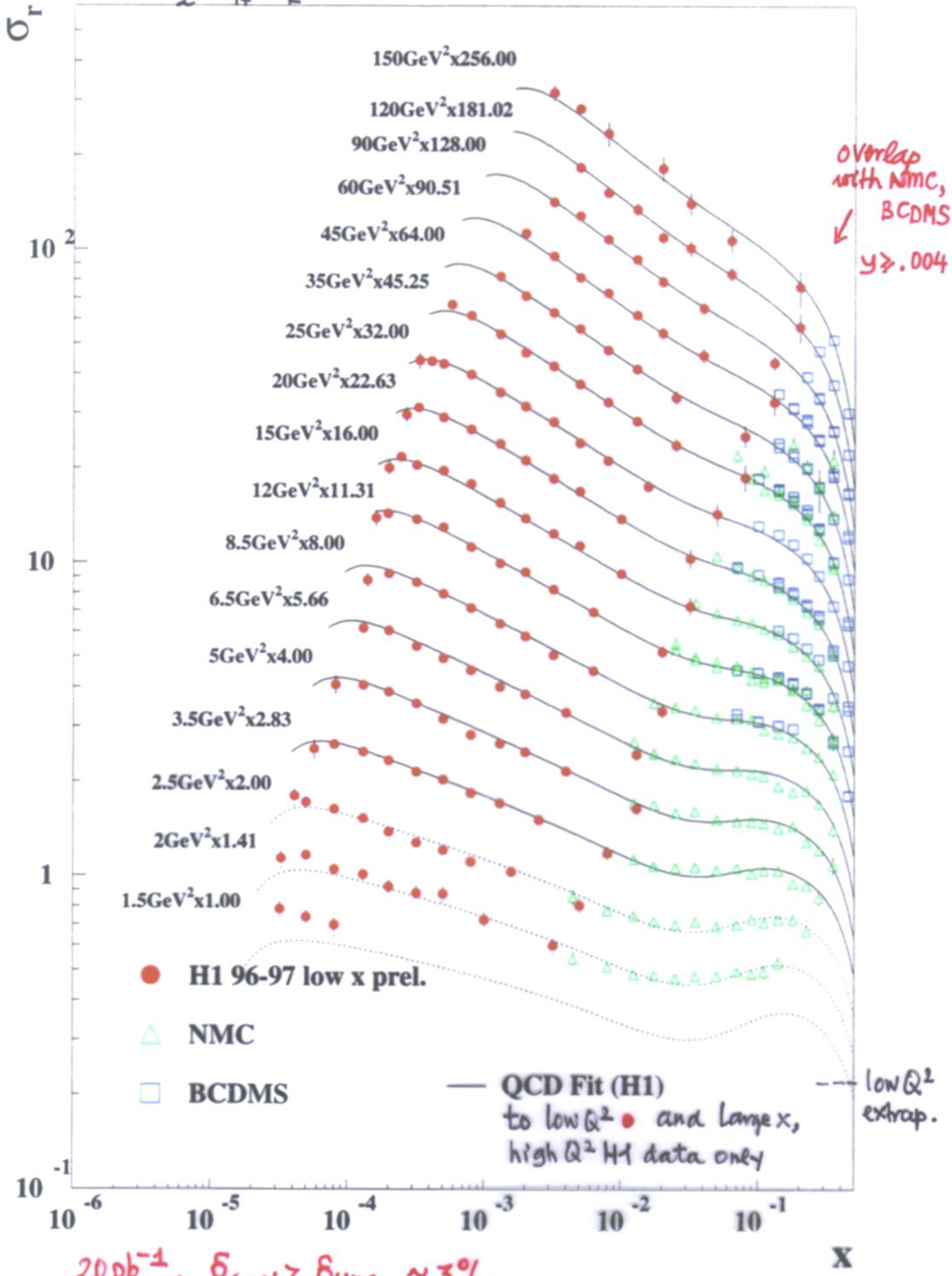
GRV
Z Phys C53 (92) 127
dynamical partons
$Q_0^2 \sim 0.4$ GeV$^2$
Parisi, Petronzio, VTΘΦ, GR. 76



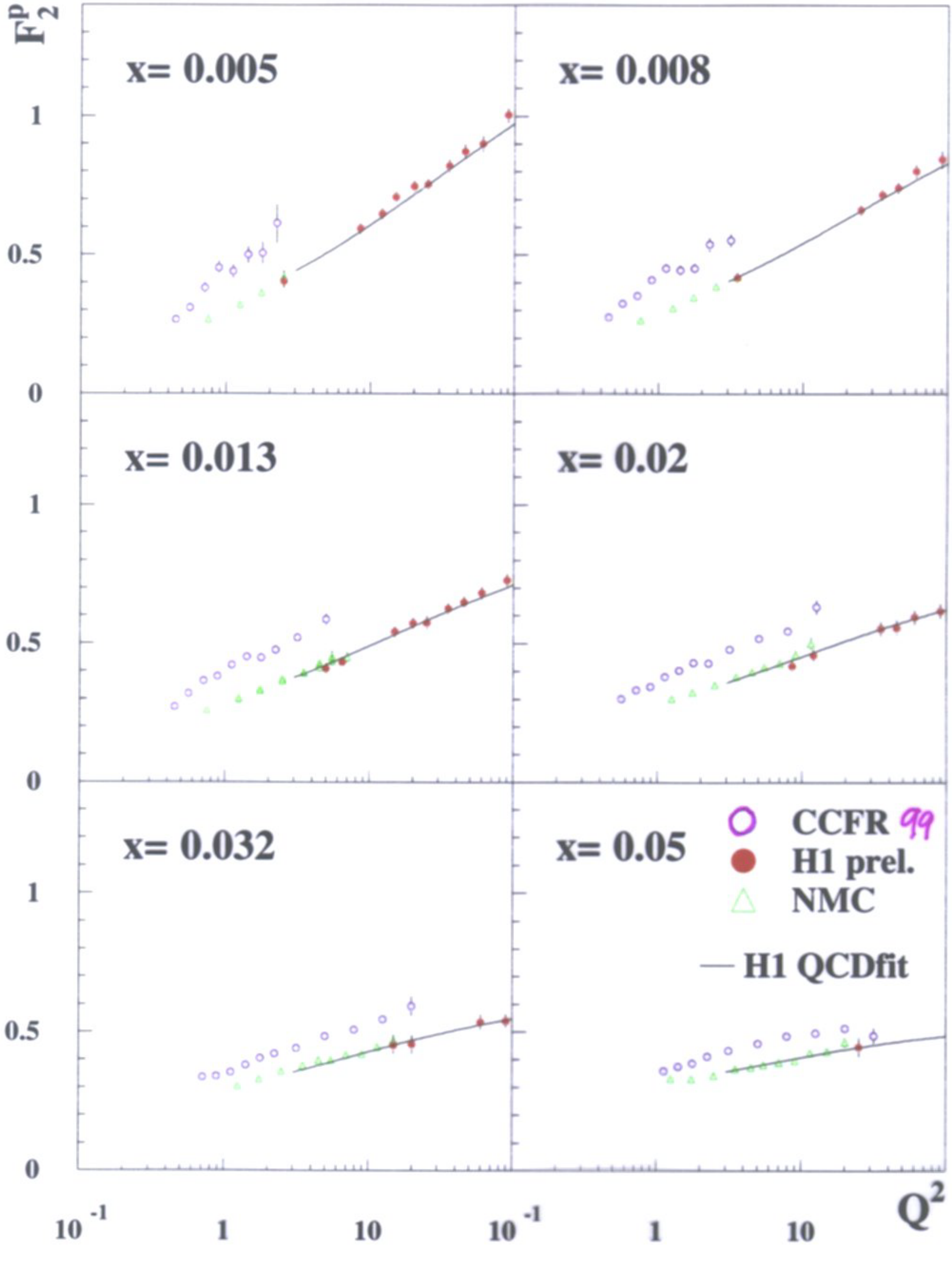

low x is
x lower
than
previously
covered

H1 96-97 preliminary

$\sigma_r = F_2 - \frac{y^2}{Y_+} \cdot F_L$

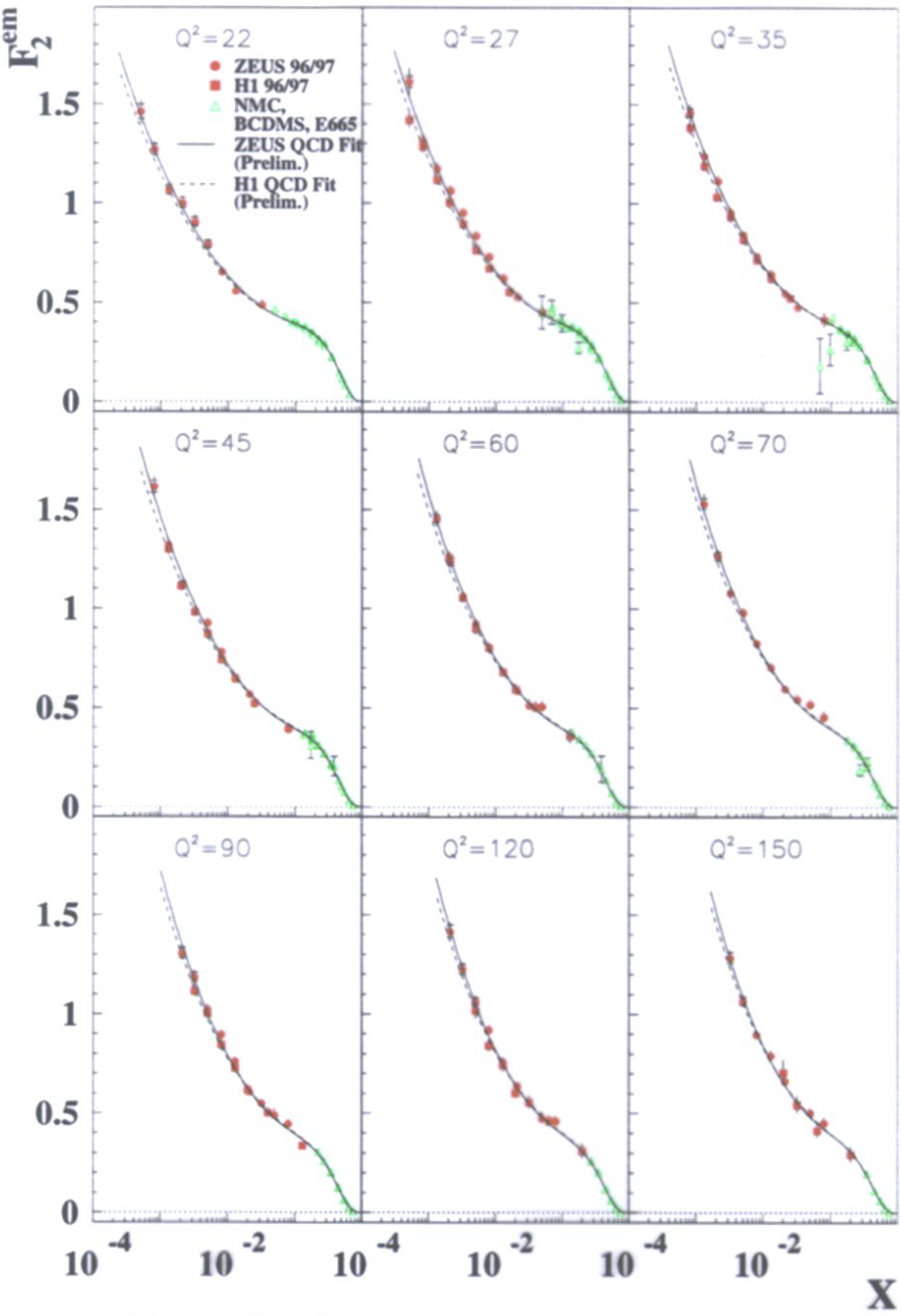



20 pb⁻¹, $\delta_{syst} \gtrsim \delta_{unc} \sim 3\%$




CCFR has re-analyzed their data: $F_2$ , $xF_3$ changed charm!

# ZEUS+H1 Preliminary 96/97

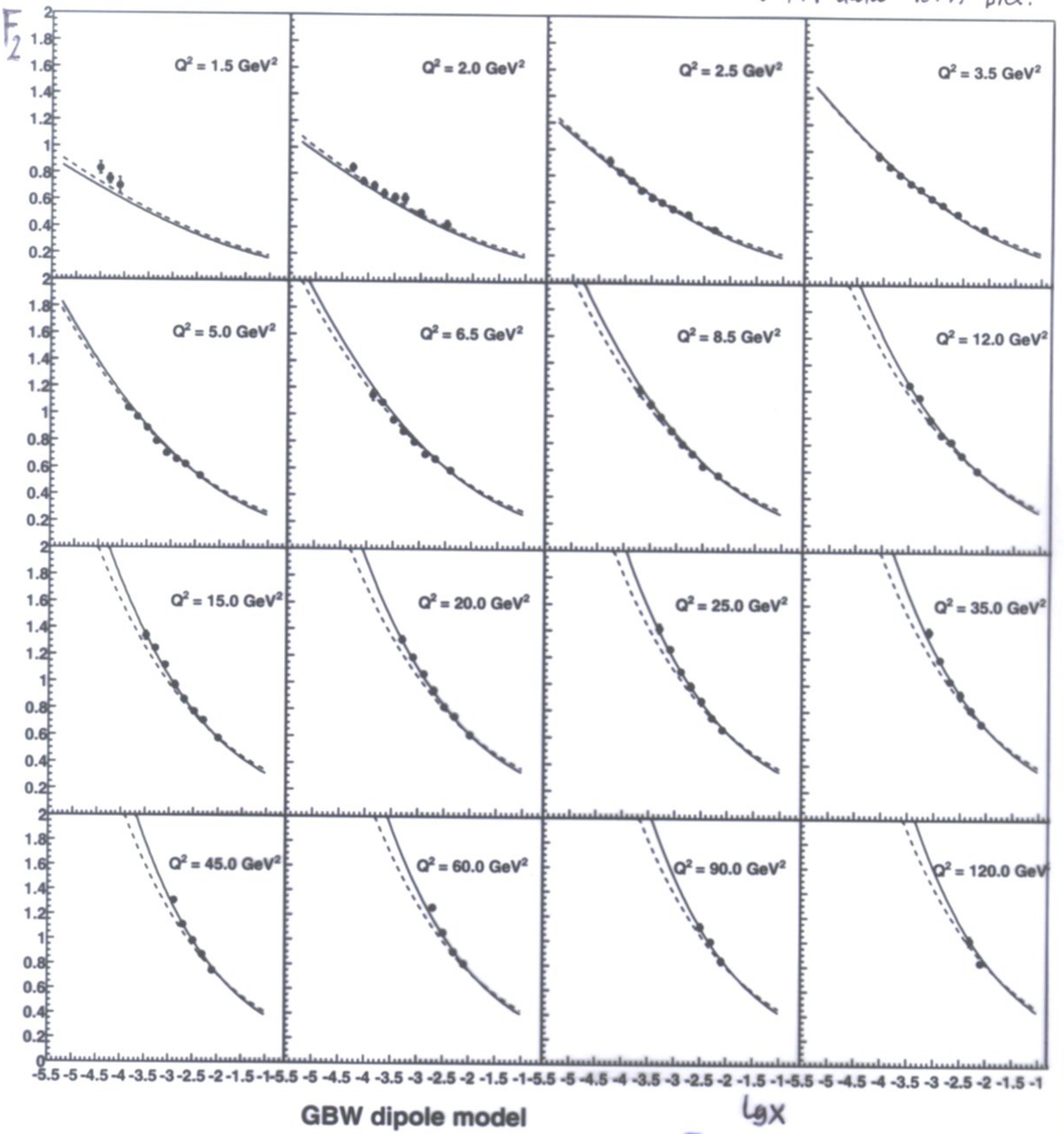



~3% normalization difference of H1 & ZEUS data

SLAC $\ell\gamma$ 1999

DIS00

• H1 data 96/97 prel.




**GBW dipole model**

—— $Q^2 < 150\,\mathrm{GeV}^2$

- - - - $Q^2 < 15\,\mathrm{GeV}^2$

$x < 0.01$

• $\exists$ many few parameter fits to $F_2$
DAS, GVD/CDM,
$a \ln Q^{2\,b}$, $\xi = \log\frac{x_0}{x} \cdot \log(1+\frac{Q^2}{Q_0^2})$
...

$\sigma_{\gamma^* p} \sim \frac{F_2}{Q^2} \to \text{const}$ ; $F_2 \sim x^{-\lambda}$, $\lambda \sim 0.3$ ; ROOT т. 57 ЖЭТФ вып. 4(10).

## Литература


[1] В. Н. Грибов, Б. Л. Иоффе, И. Я. Померанчук. Ядерная физика, 2, 768, 1965.

[2] В. Н. Грибов. Ядерная физика, 5, 399, 1967.

[3] J. S. Bell. Препринт CERN, 68/425|5-TH-88, 1968.

[4] J. D. Bjorken. Phys. Rev., 148, 1966, 1467.

[5] V. N. Gribov, B. L. Ioffe, I. Ya. Pomeranchuk. Phys. Lett., 24B, 1967, 554.

[6] В. Н. Грибов. ЖЭТФ, 56, 892, 1969.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## INTERACTION OF HIGH ENERGY γ QUANTA AND ELECTRONS WITH NUCLEI


$\boxed{\text{V. N. Gribov}}$ 1969



It is shown that if the longitudinal distances which are important in electromagnetic interactions of hadrons linearly grow with the energy then in interactions between high energy γ quanta and nuclei only nucleons on the surface of the nucleus participate and the total cross section for adron processes, $\sigma_\gamma$, involving heavy nuclei is $2\pi R^2(1-Z_3)$, where $Z_3$ is the photon Green function renormalization constant. $1-Z_3$ the probability for virtual transformation of a γ quantum into hadrons. The corrections due to volume absorption of γ quanta and the case when the longitudinal distances increase at a slower rate with increase of energy are discussed in detail.


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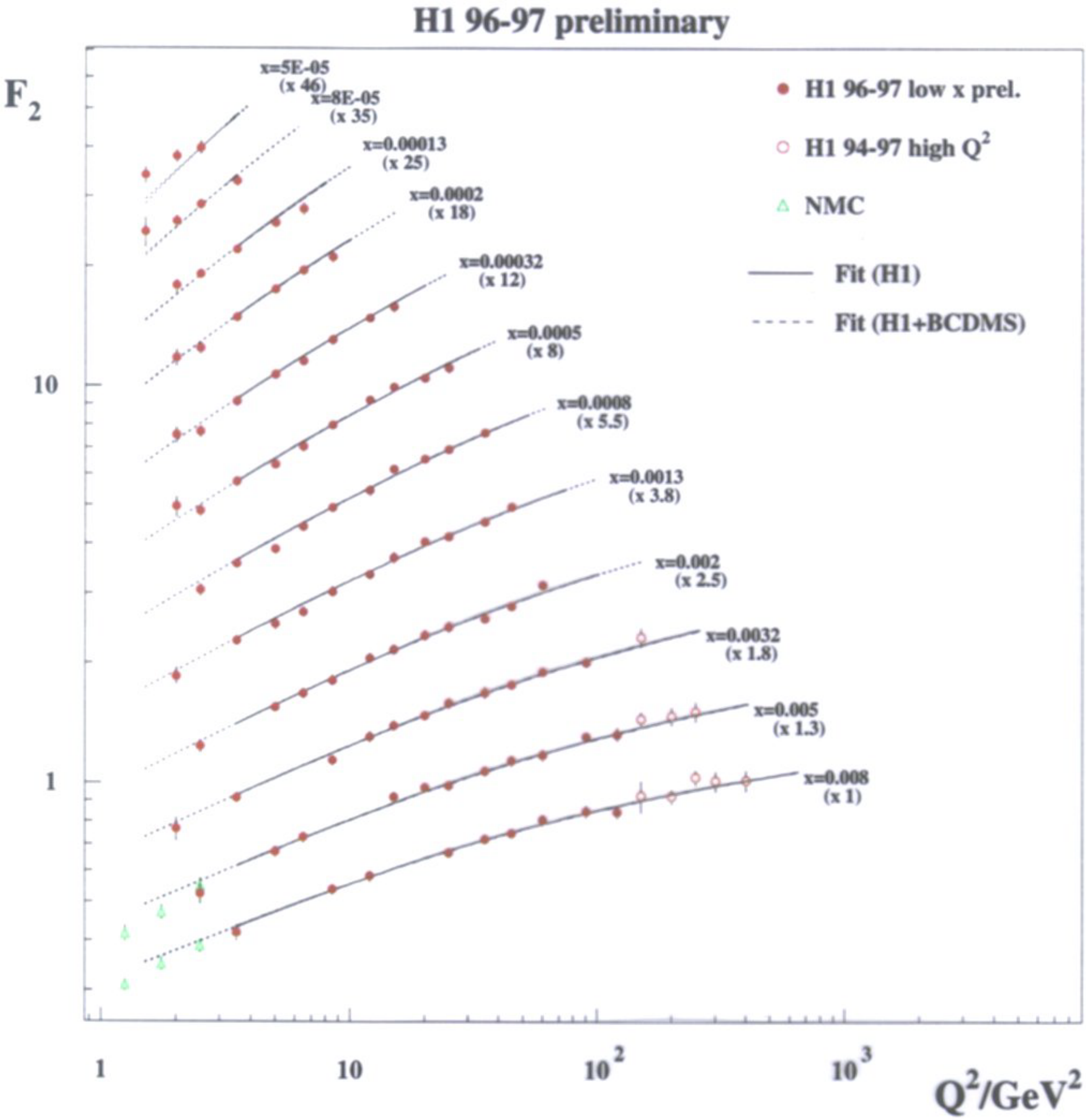
"γ квант сначала виртуально распадается на адроны, а затем адроны взаимодействуют с нуклонами ядра"

$$\sigma = (1-Z_3)\cdot \pi R^2$$

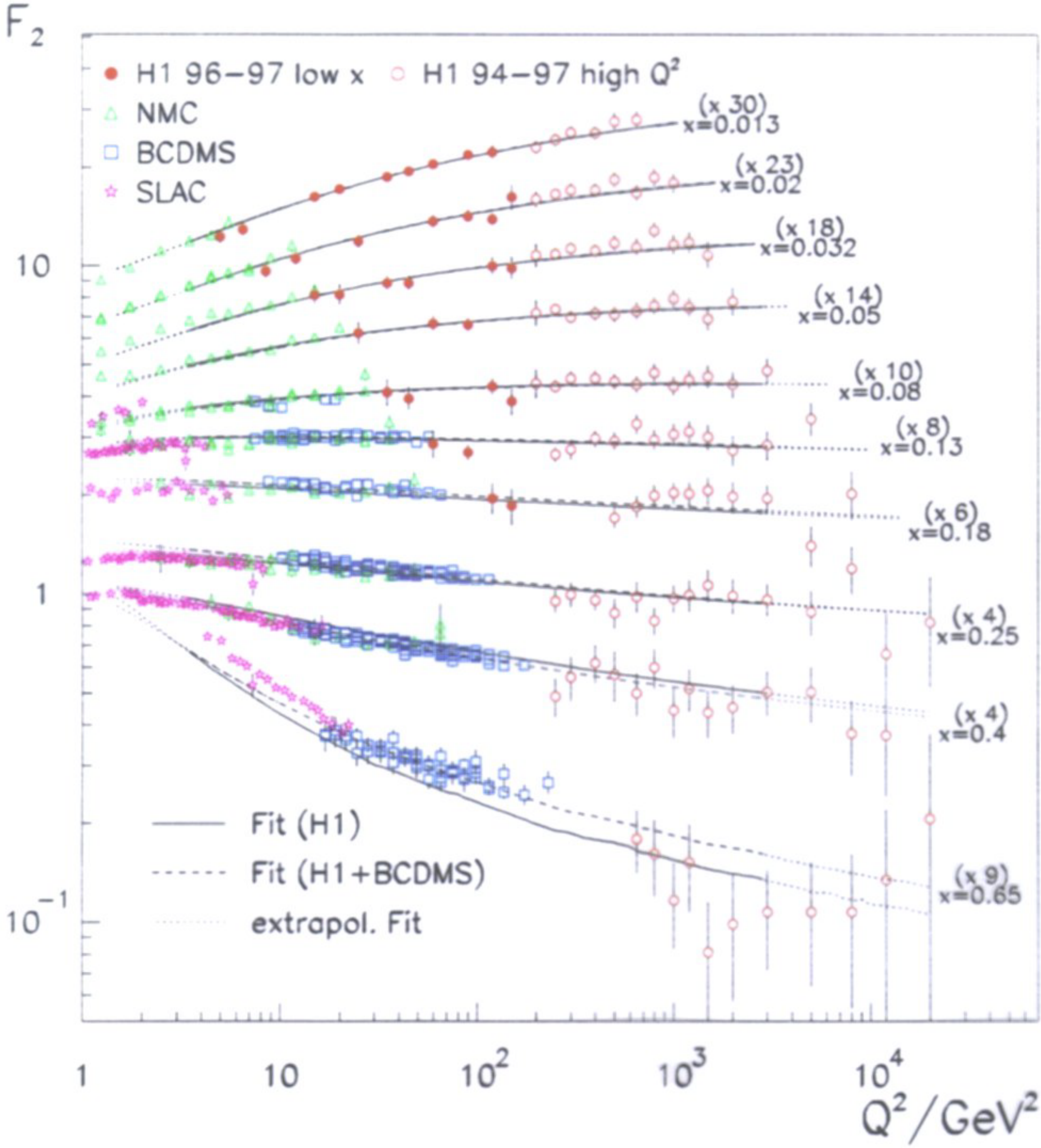
factorisation ansatz

- $\delta \sim \frac{1}{x}$ coherence length. small x.

DGLAP, NLO ($\overline{MS}$), heavy flavour (c,b) QCD analysis of H1 ep (and BCDMS $\mu$p) data.




$$\sigma_r = F_2 - \frac{y^2}{Y_+} F_L$$ use $F_L^{QCD}(\alpha_s^2)$ and $y < 0.6$ to get $F_2$




$Y_{BCDMS} > 0.3$

$Q^2 \leq 3000\ GeV^2$

$$V(x,Q^2) = \frac{3}{4}\cdot\frac{1}{1+\epsilon}[(3+2\epsilon)u_V - 2d_V + (5+2\epsilon)(\overline{u}-\overline{d})], \simeq \frac{3}{2}(u_V\cdot\frac{3}{2} - d_V).\ \int_0^1 V\,dx = 3 + \delta\cdot\frac{3}{4}\cdot\frac{5+2\epsilon}{1+\epsilon} = v(\epsilon,\delta).$$

$\delta = \int(\overline{u}-\overline{d})dx$ NuSea

$$A(x,Q^2) = \overline{u} - \frac{1}{4}(u_V - 2d_V) - 5(\overline{u}-\overline{d}) + 2\epsilon(\overline{u}+\overline{d}). \simeq \overline{u}$$

external constraints $-.118 \pm .011$

$$s + \overline{s} = (\frac{1}{2}+\epsilon)\cdot(\overline{u}+\overline{d})$$

NuTeV $\varepsilon = -0.08$

$xg(x,Q^2)$

2+1 parametrizations, ep only, no d

$\int(\Sigma + xg)dx = 1$

momentum conservation

$$xq(x) = a_q x^{b_q}(1-x)^{c_q}[1 + d_q\sqrt{x} + e_q x + f_q x^2]$$

general par'n ansatz, $\chi^2(a,\dots f)$

sophisticated error treatment

exp. thy norm. corr. syst. errors

$$\chi^2 = \sum_{exp}\sum_{dat}\frac{[\sigma_{r\,exp}^{\;dat} - \sigma_r^{\;fit}\times(1-\nu_{exp}\sigma_{exp} - \sum_k\delta_k^{dat}(s_k^{exp}))]^2}{\sigma^2_{dat,stat}+\sigma^2_{dat,uncor}} + \sum_{exp}\nu^2_{exp} + \sum_{exp}\sum_k(s_k^{exp})^2.$$

data sets points uncorr. errors penalty

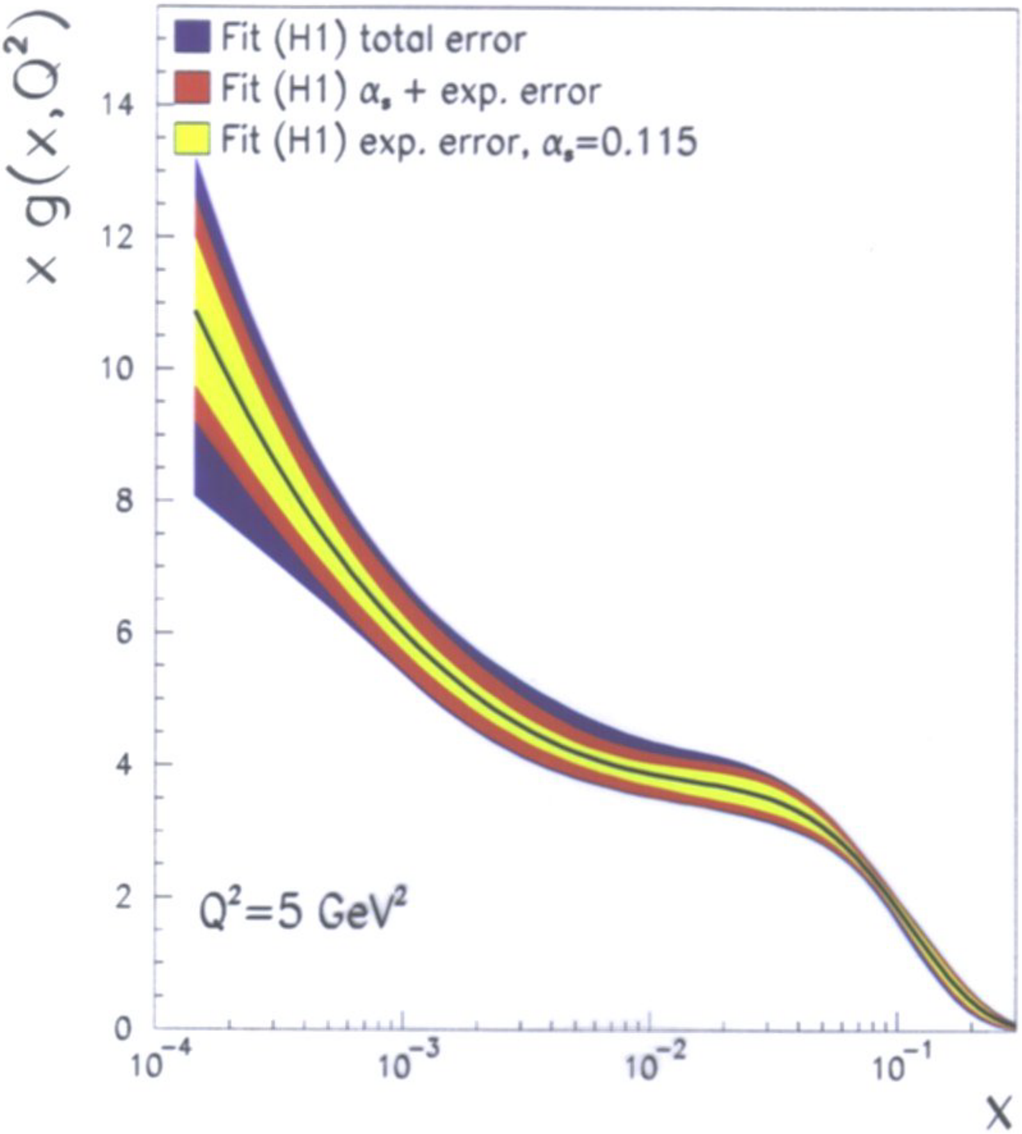
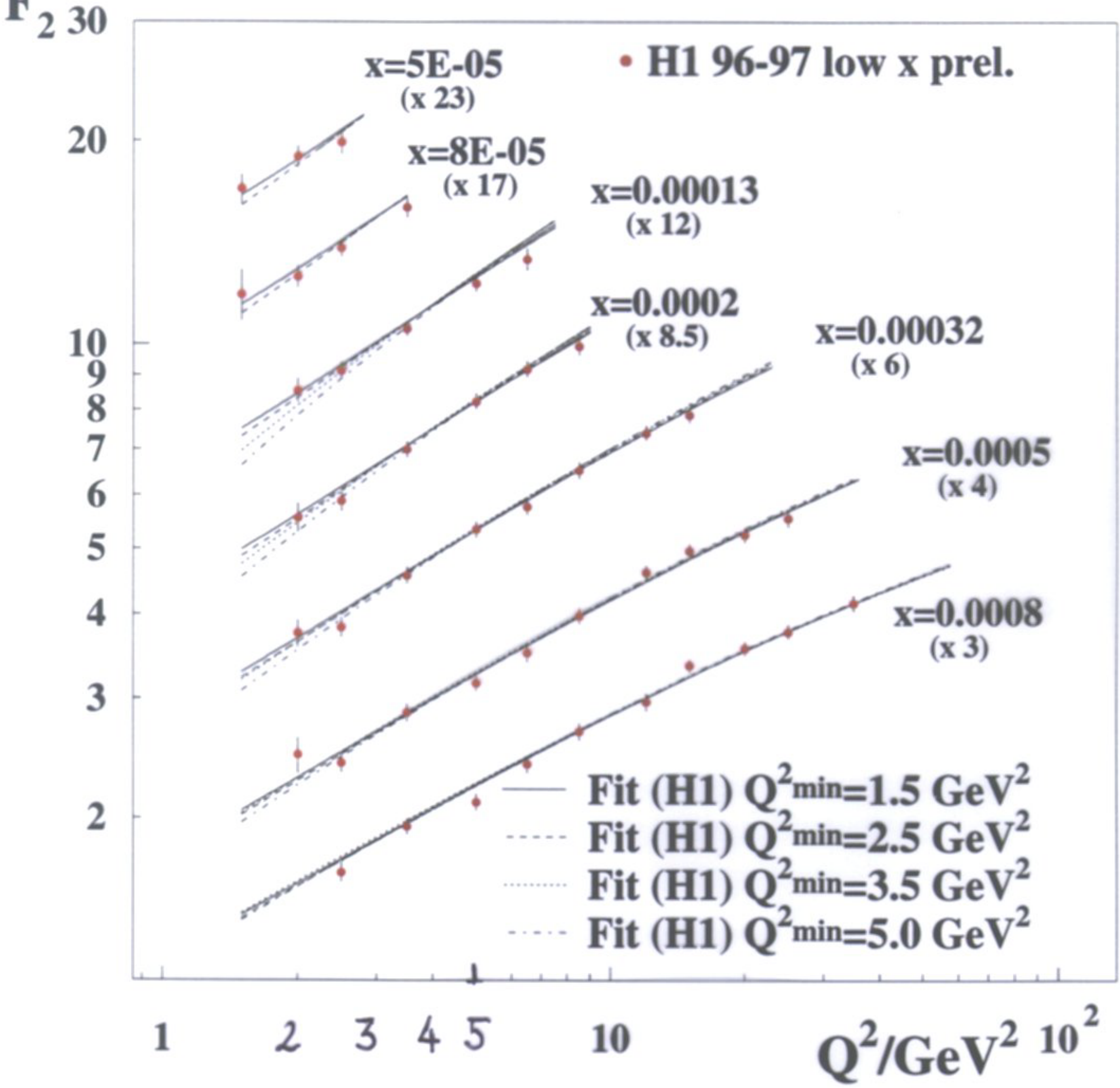



Figure 18: *Gluon distribution at $Q^2 = 5$ GeV$^2$ determined in the DGLAP QCD fit to the H1 data. Inner error band: experimental uncertainty; middle error band: effect of experimental error and of $\alpha_s(M_Z^2)$ uncertainty of $\pm 0.0017$. outer error band: effect of experimental, $\alpha_s$ and model uncertainties.*



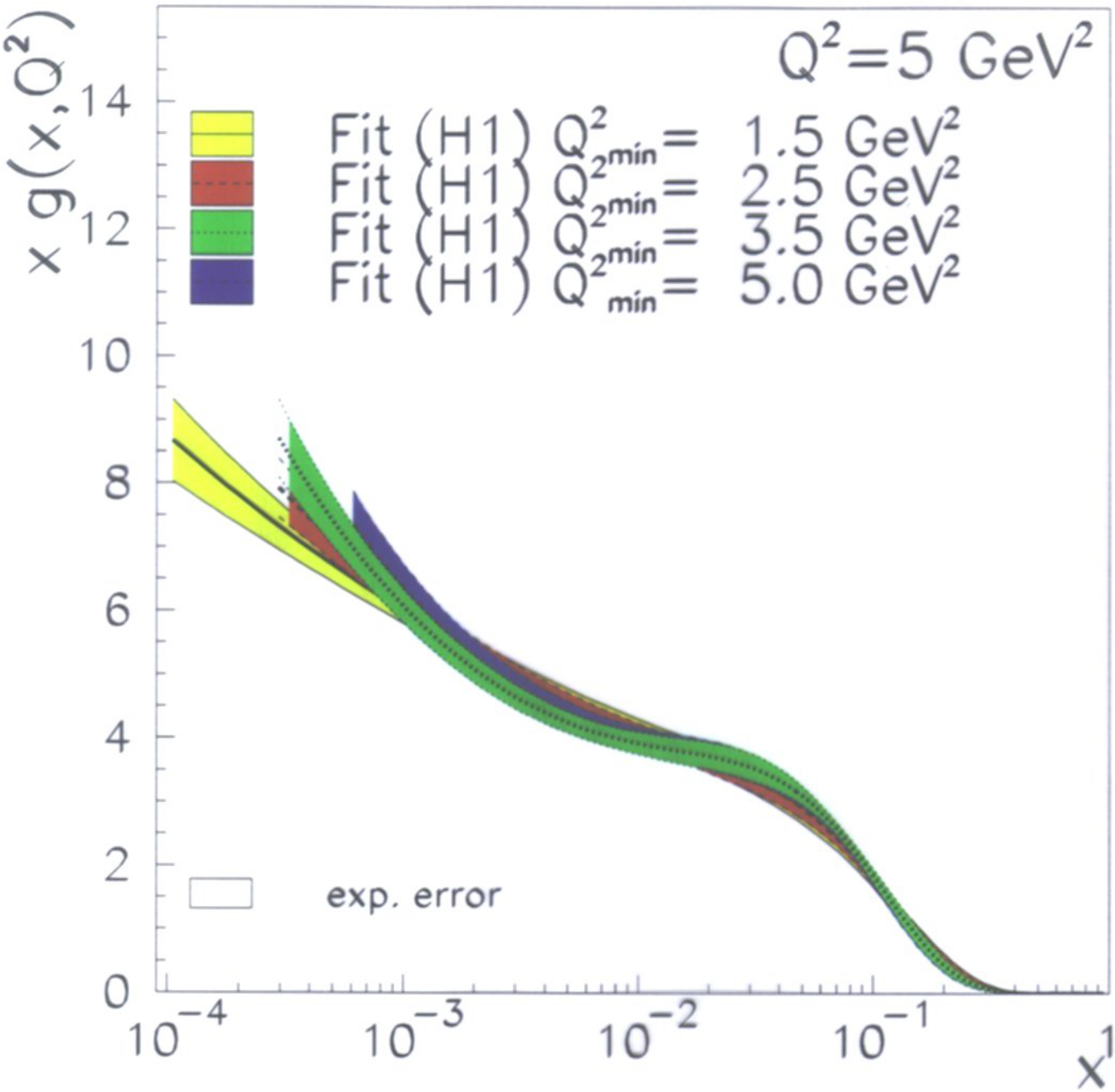
$\alpha_s(M_Z^2) = 0.115 \pm 0.005_{exp.}$
H1 alone

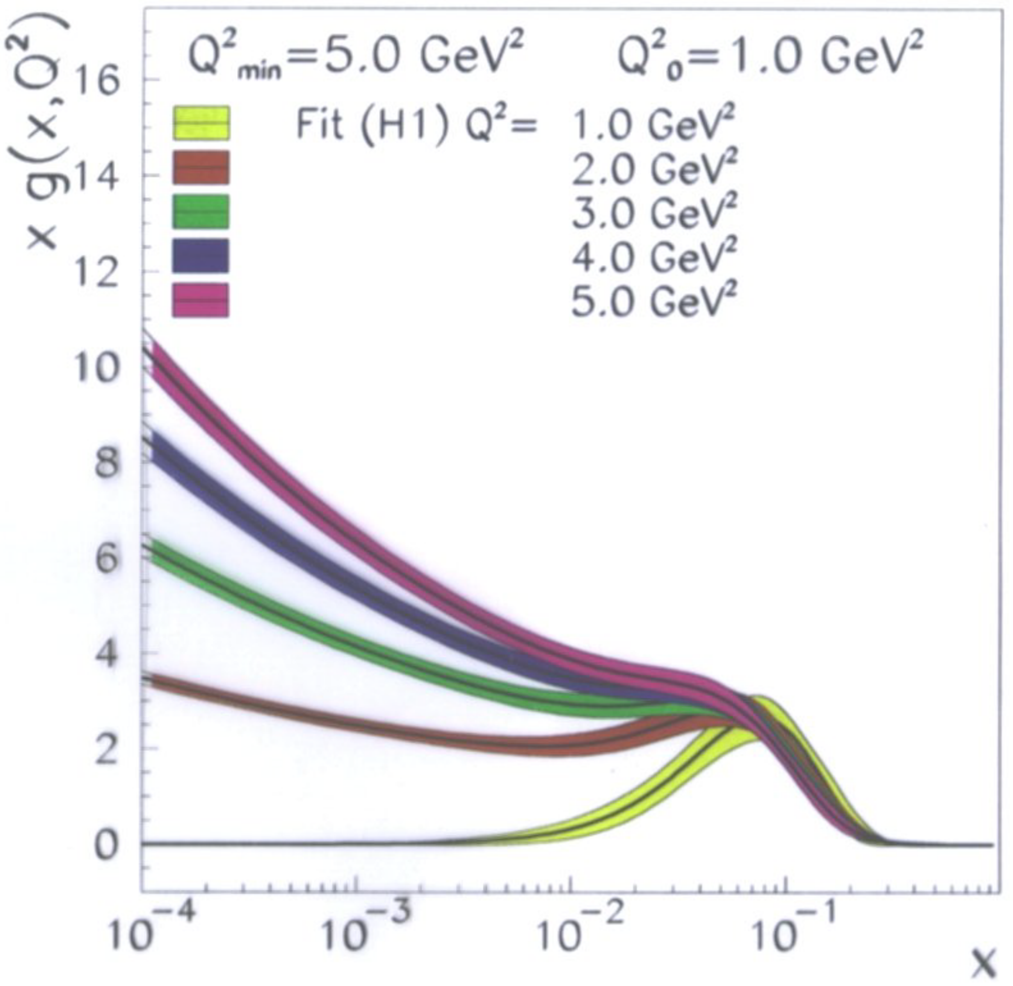
## H1 preliminary




$Q^2_{min} := Q^2 \geqslant Q^2_{min}$

H1 preliminary



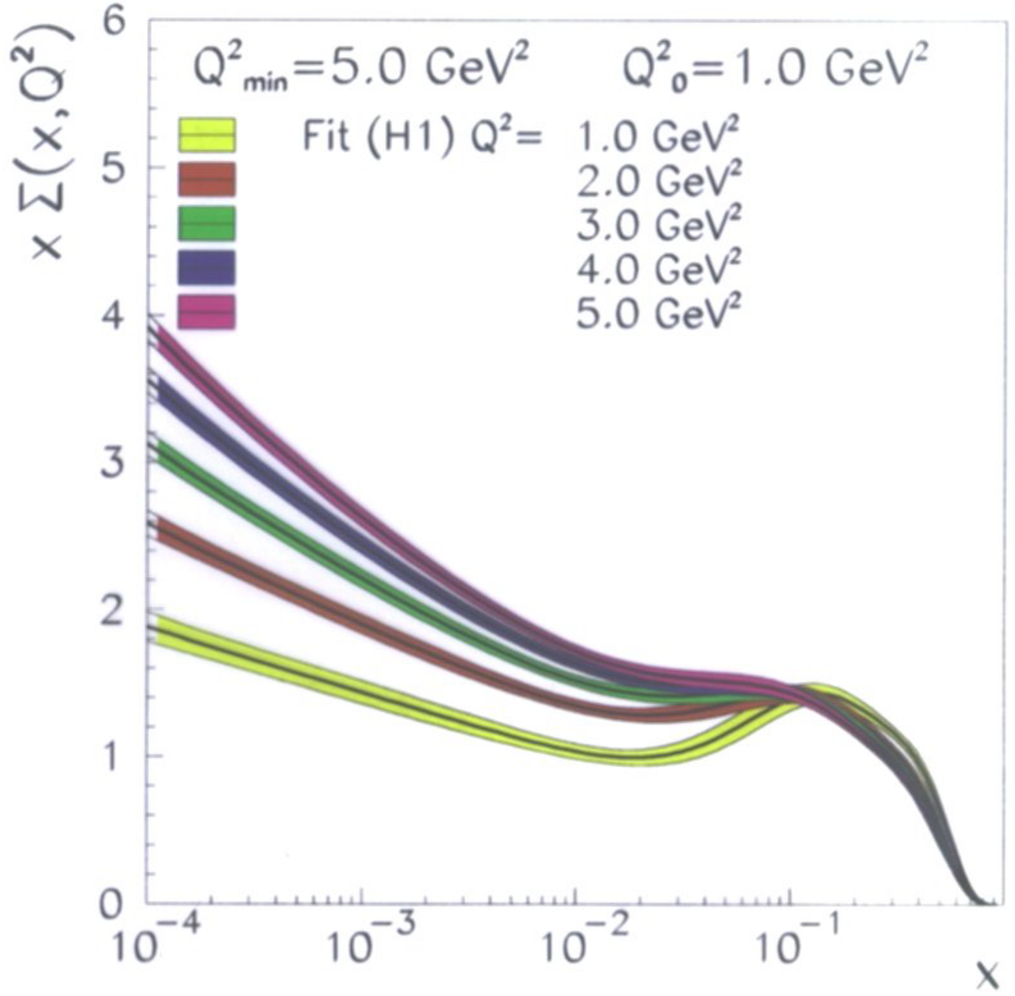



Valence like gluon at $Q^2 \sim 1\,\text{GeV}^2$ !

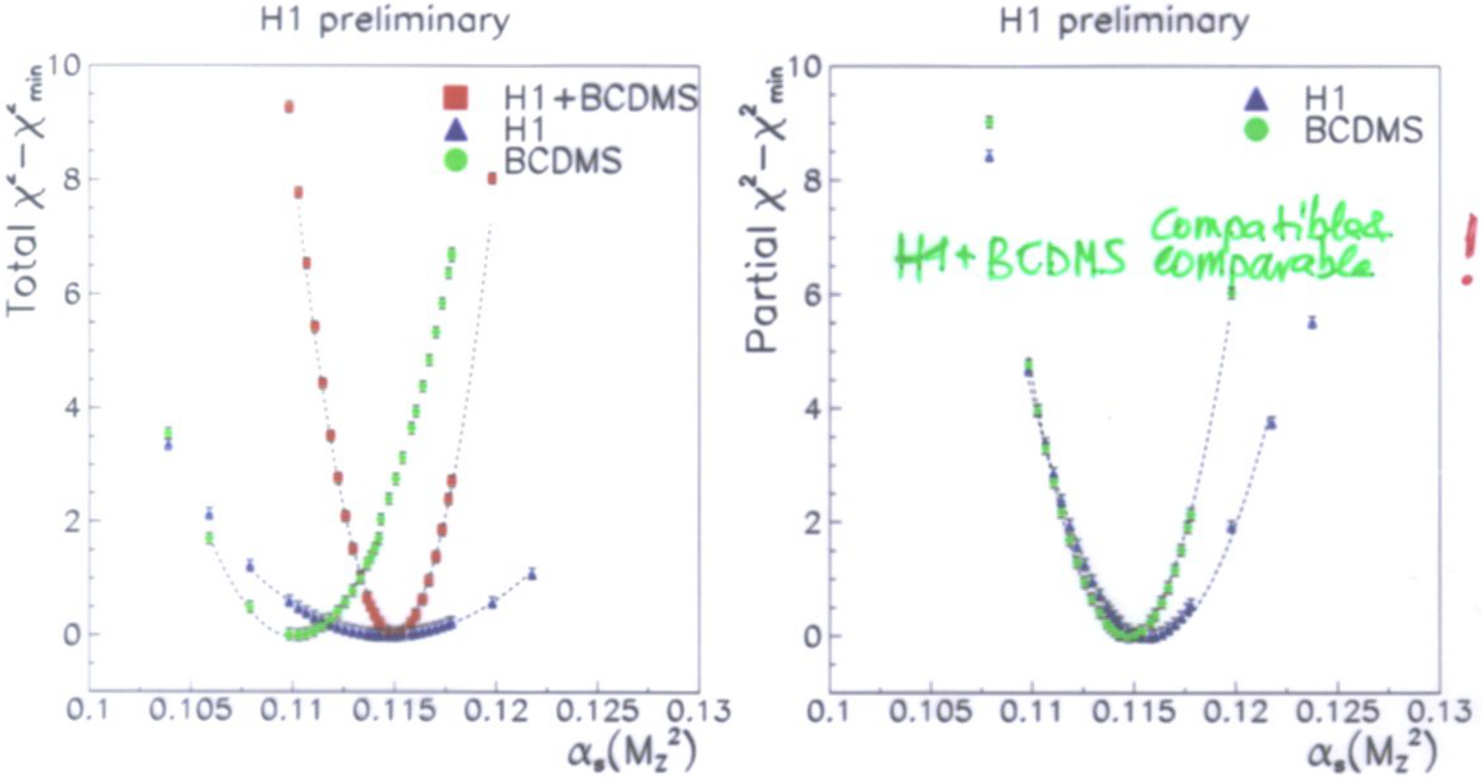
(H1 EPS Jerusalem 97)
ZEUS

$\alpha_s^{LO}(1\,\text{GeV}^2) \sim 0.6$

$\sim 1/\ln Q^2/\Lambda^2$

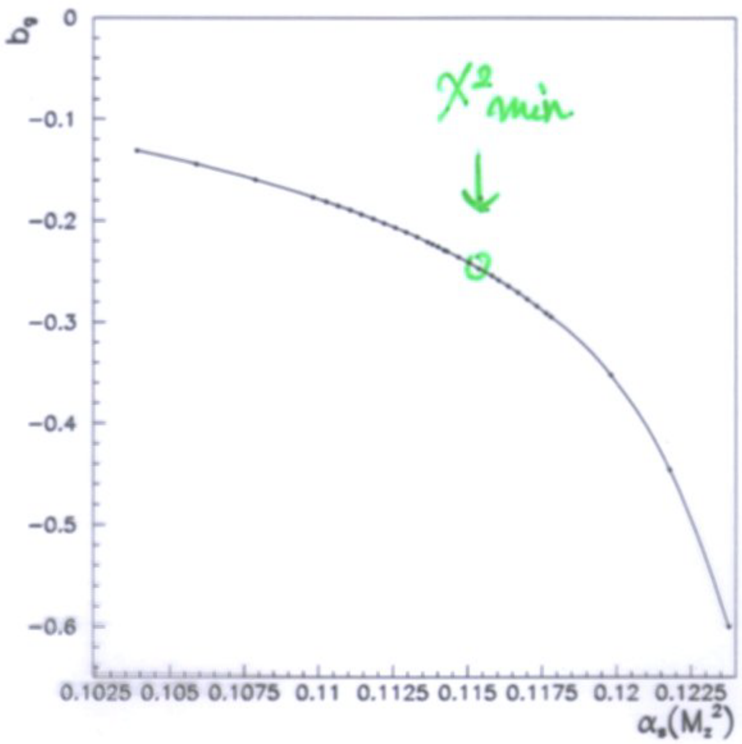



$\Sigma \simeq V + 5A \approx 5\bar{u}$ at small $x$




$xg \sim x^{-b_g}$

$b_g \leftrightarrow \alpha_s$




$y > y_{min}$ and H1 low x data + BCDMS lead to precise, consistent $\alpha_s$ and $xg$.

| analysis uncertainty | $+\delta\ \alpha_s$ | $-\delta\ \alpha_s$ |
|---|---|---|
| $Q^2_{min} = 2\ \mathrm{GeV}^2$ | | 0.00002 |
| $Q^2_{min} = 5\ \mathrm{GeV}^2$ | 0.00016 | |
| parameterisations | 0.00011 | |
| $Q^2_0 = 2.5\ \mathrm{GeV}^2$ | 0.00023 | |
| $Q^2_0 = 6\ \mathrm{GeV}^2$ | | 0.00018 |
| normalisations fixed | 0.00051 | |
| y(H1) $< 0.35$ | 0.00012 | |
| $x < 0.6$ | 0.00033 | |
| y(BCDMS) $> 0.25$ | | 0.00108 |
| $x > 5 \cdot 10^{-4}$ | 0.00053 | |
| systematics fixed | 0.00054 | |
| sea flavour symmetry | | 0.00033 |
| strange quark contribution $\epsilon = 0$ | 0.00010 | |
| $m_c + 0.1$ GeV | 0.00044 | |
| $m_c - 0.1$ GeV | | 0.00042 |
| $m_b + 0.2$ GeV | 0.00010 | |
| $m_b - 0.2$ GeV | | 0.00010 |
| sum | 0.0011 | 0.0012 |

prel.

$$\alpha_S(M_Z^2) = 0.1150 \pm 0.0017\,(\mathrm{exp}) \pm 0.0011\,(\mathrm{model})$$

± 0.005 about
from mainly $\mu_r$

- control analyses:

H1+BCDMS ($\mu p$, $\mu d$): 0.1157 ± 0.0016 (exp)

H1+ BCDMS $\mu p$, light quarks: 0.1153 ± 0.0017 (exp)

H1+ NMC ($\mu p$, $Q^2 \geq 6.5$): 0.115 ± 0.003 (exp)

H1 alone 0.115 ± 0.005 (exp)

- Alekhin hep-ph/0011002 : $0.1165 \pm \underset{(\mathrm{exp})}{0.0017} \pm \underset{(\mathrm{thy})}{{}^{0.0026}_{0.0034}}$
  - all DIS, p, d, higher twist

- Santiago, Yndurain 0.1163 ± 0.0023 (NLO).
  - SLAC, BCDMS, E665, HERA94. $b_g = -0.44$. moments NNLO

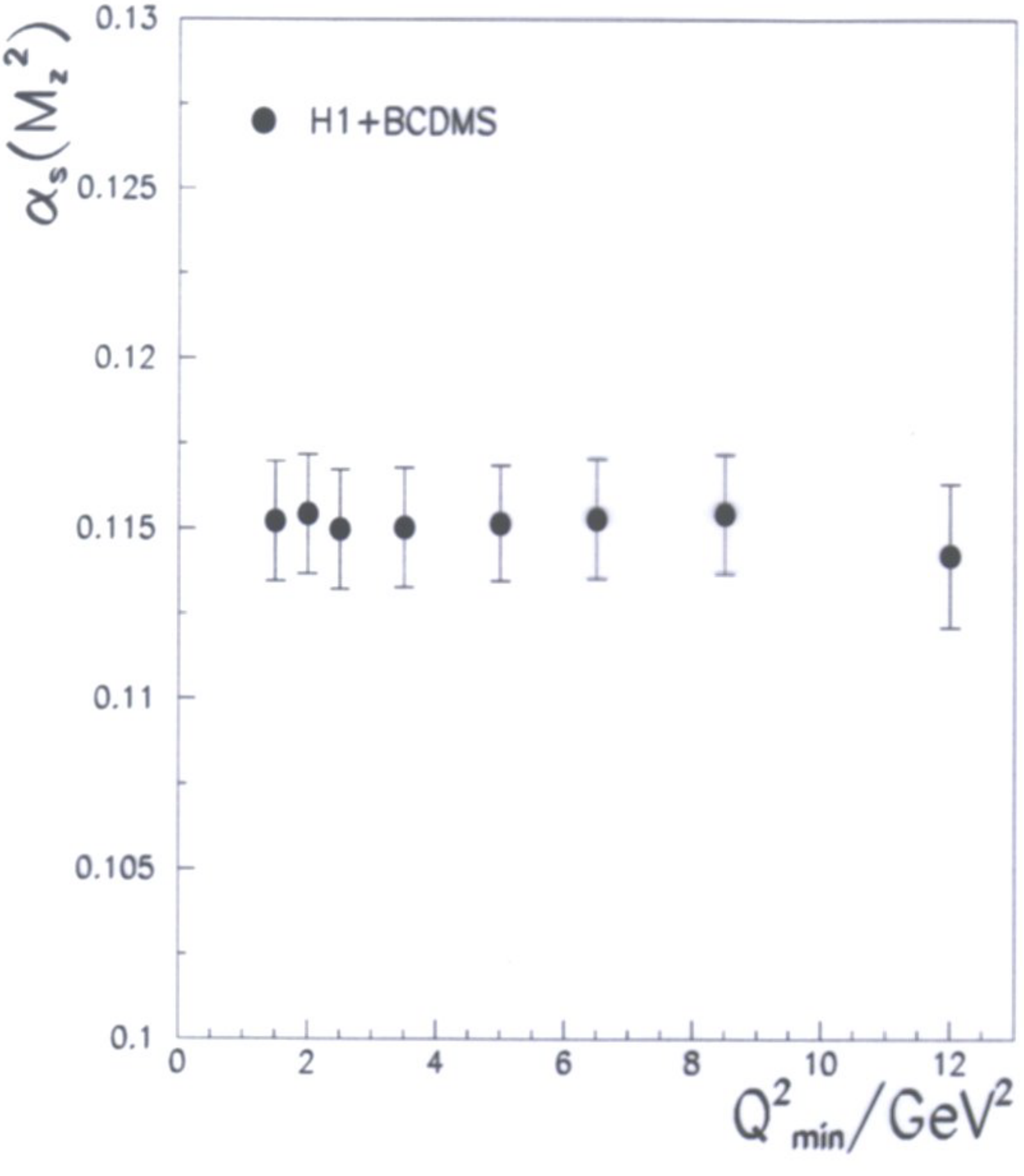
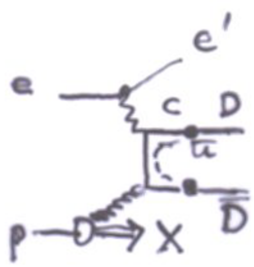


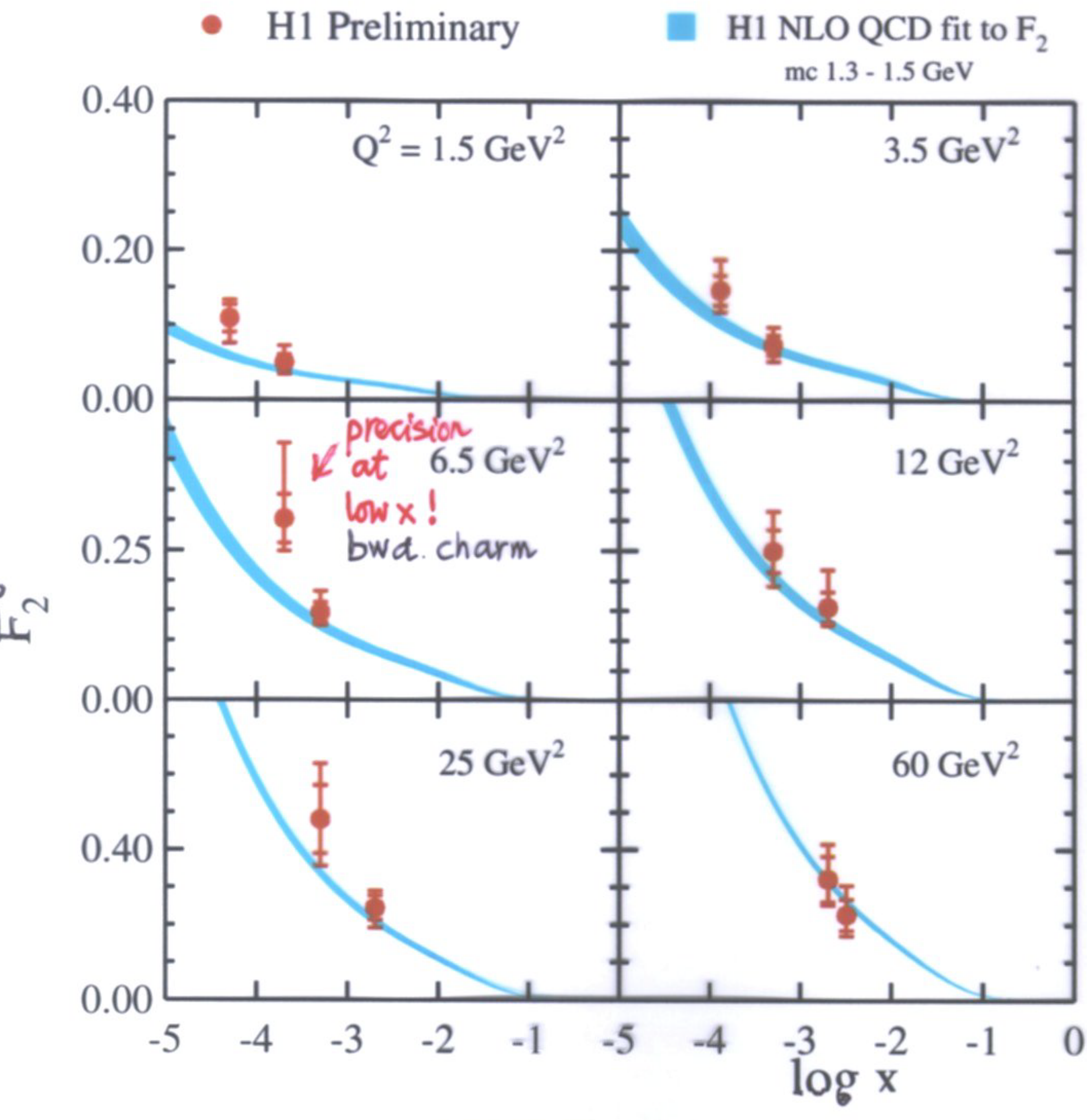

Figure 20: *Dependence of $\alpha_s(M_Z^2)$ obtained in fits to the H1 and BCDMS data on the minimum $Q^2$ value used. The error bars denote the experimental uncertainty of $\alpha_s(M_Z^2)$. Note that the BCDMS data have an intrinsic $Q^2_{min}$ of 7.5 GeV$^2$ and are limited in this analysis to $y \geq 0.3$, see text. Increasing of the $Q^2_{min}$ value implies that the minimum $x$ of data used rises correspondingly, i.e. from $3.2 \cdot 10^{-5}$ at $Q^2_{min} = 1.5\,GeV^2$ to $8 \cdot 10^{-4}$ at $Q^2_{min} = 12\,GeV^2$.*

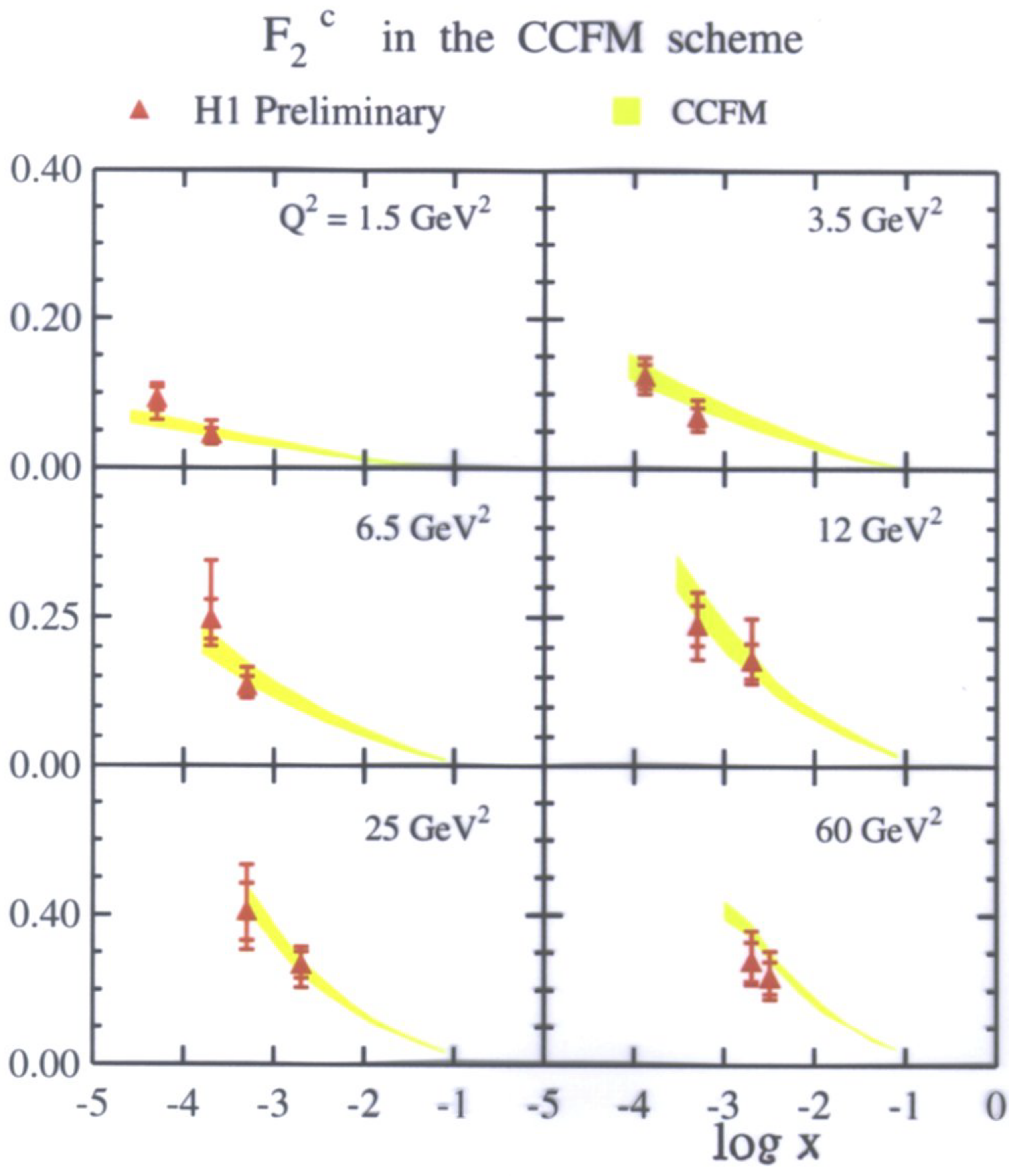



• $F_2^c$ from $D^*$
18.6 pb$^{-1}$, $(973 \pm 40)$ $D^*$'s

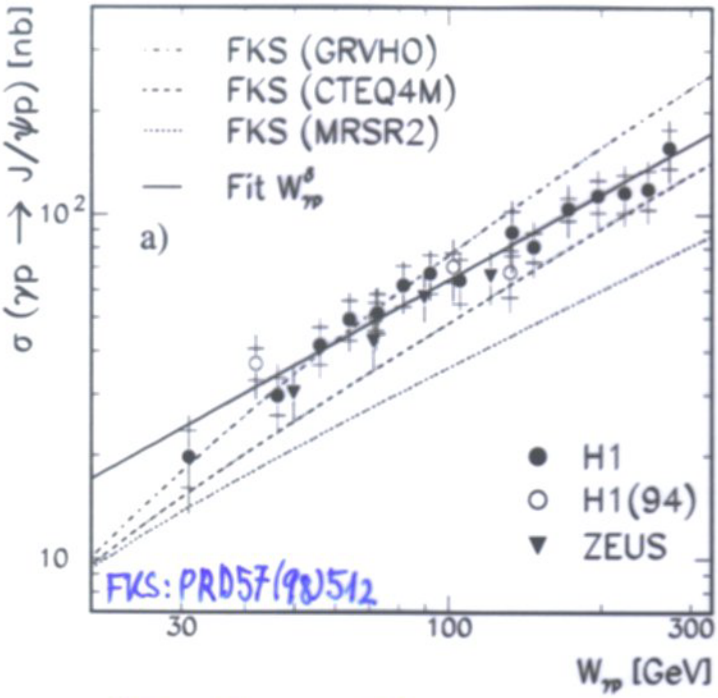
$$F_2^c = Q_c^2 \left[ g \otimes \left\{ H_{2,g}^{(1)} + H_{2,g}^{(2)} \right\} + q\, H_{2,q}^{(2)} \right]$$

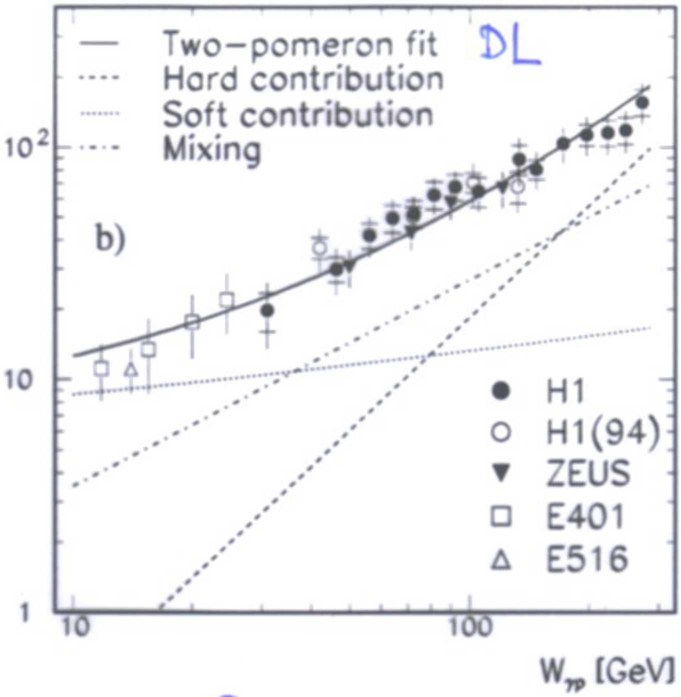
## $F_2^{\,c}$ in the NLO DGLAP scheme





F2 c in the CCFM scheme
H1 Preliminary
CCFM
Q2 = 1.5 GeV2
3.5 GeV2
6.5 GeV2
12 GeV2
25 GeV2
60 GeV2
F2 c exuracted with CASCADE
0.40
0.20
0.00
0.25
0.00
0.40
0.00
-5
-4
-3
-2
-1
-5
-4
-3
-2
-1
0
log x



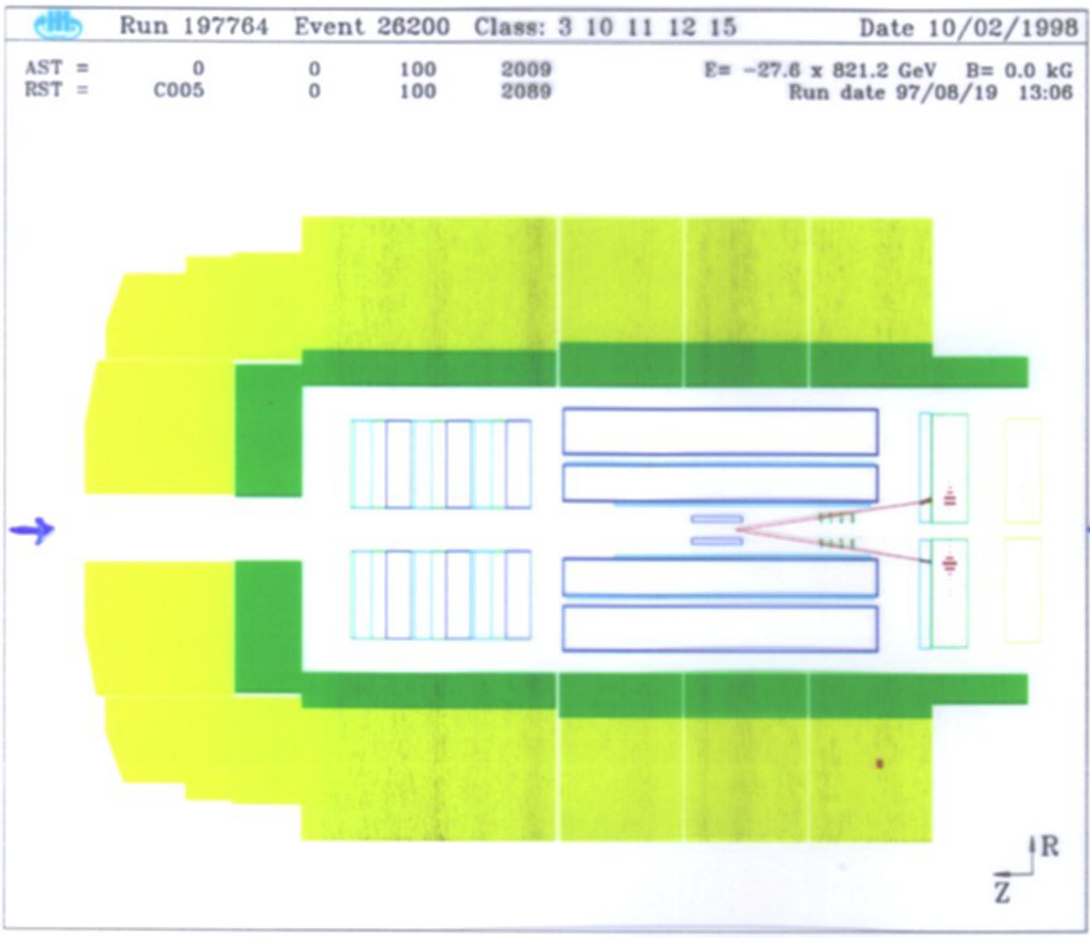




$\frac{d\sigma}{dt} \sim (\alpha_s \cdot xg)^2$ $\quad x = m^2_{J/\psi}/W^2$

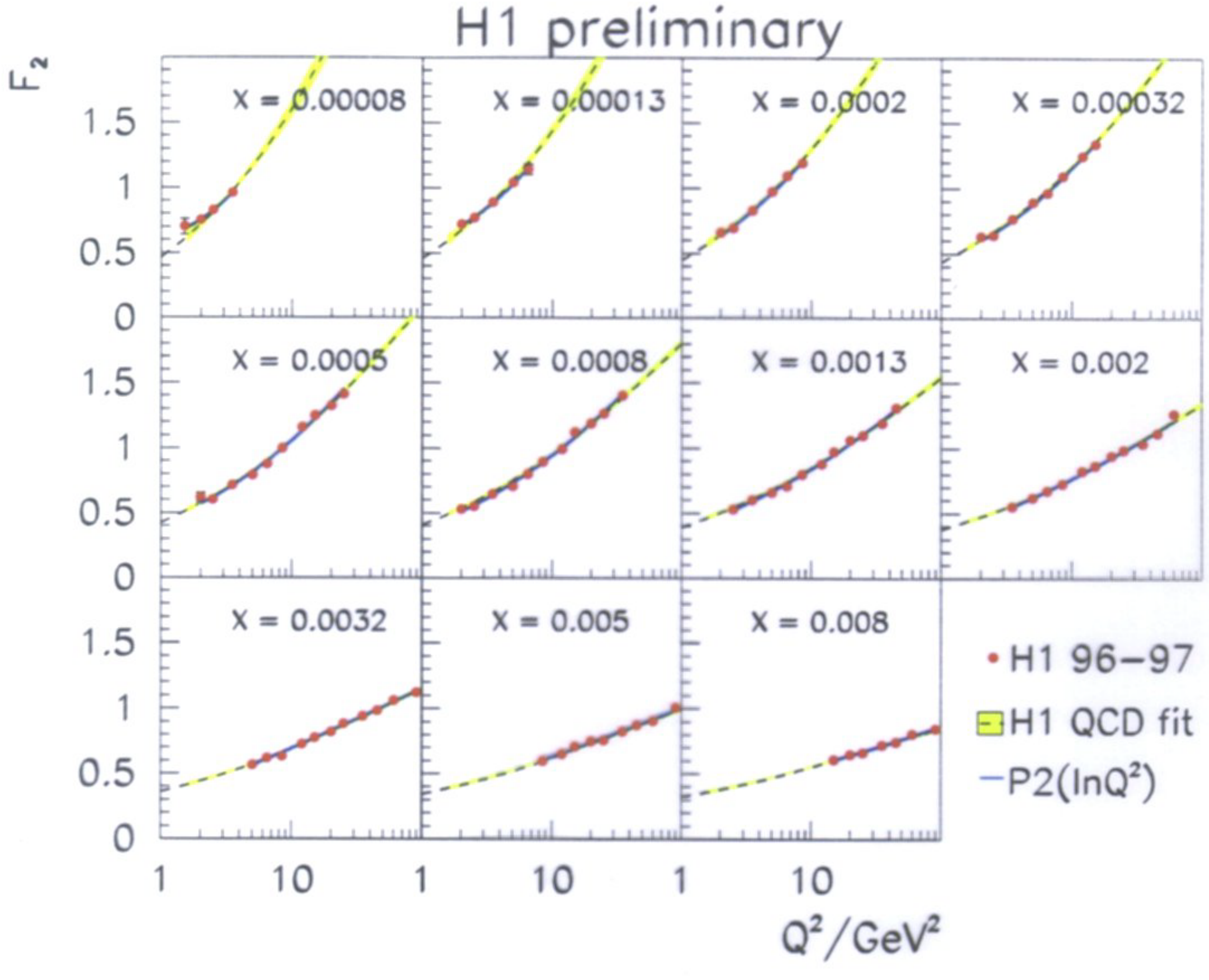
$W^{\delta}$, $\delta = 4(\alpha - 1)$

$\delta = 0.83 \pm 0.07$
H1 data

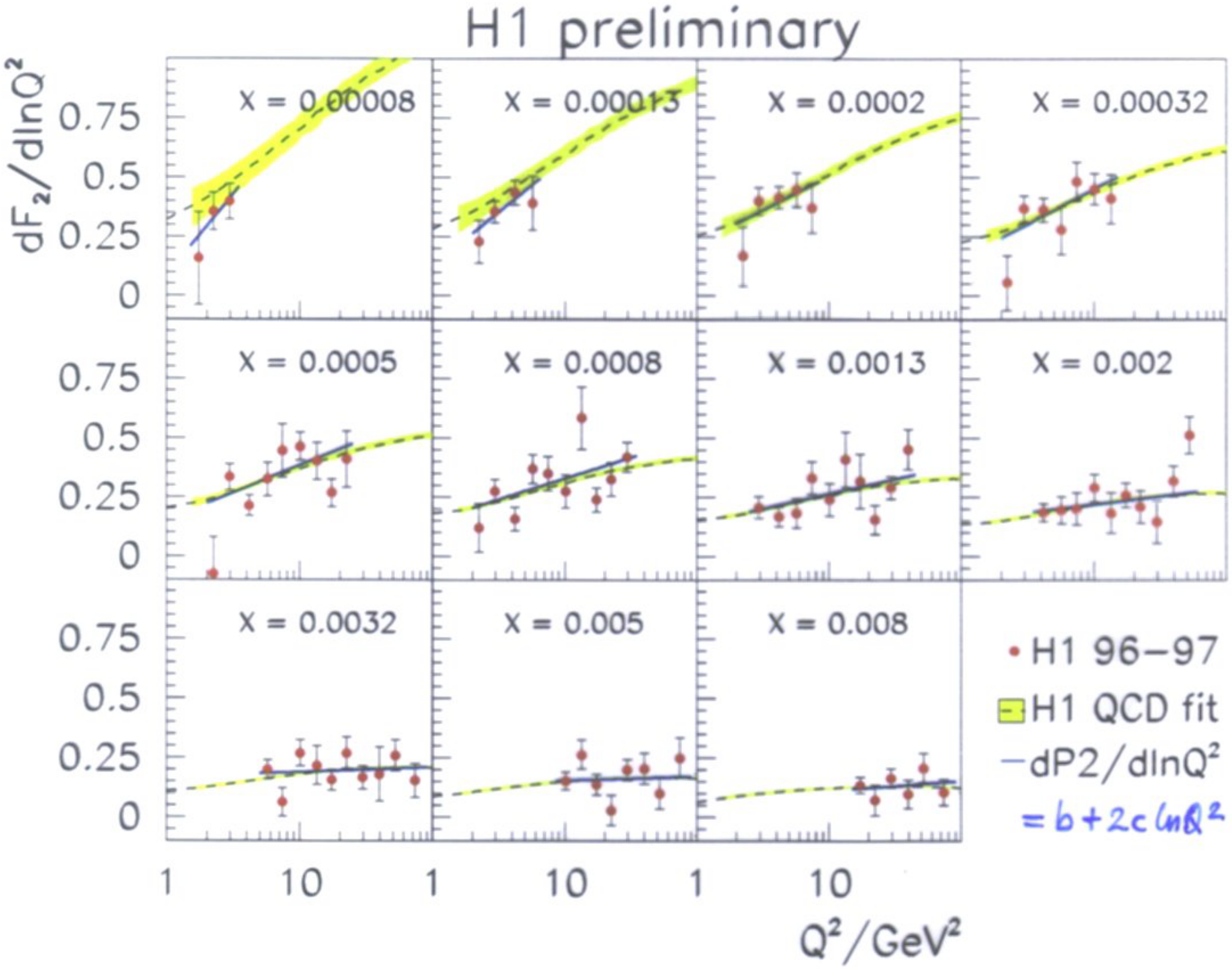
$ep \to e\, J/\psi\, p$
$\quad\quad\hookrightarrow e^+e^-$

e →  ← p

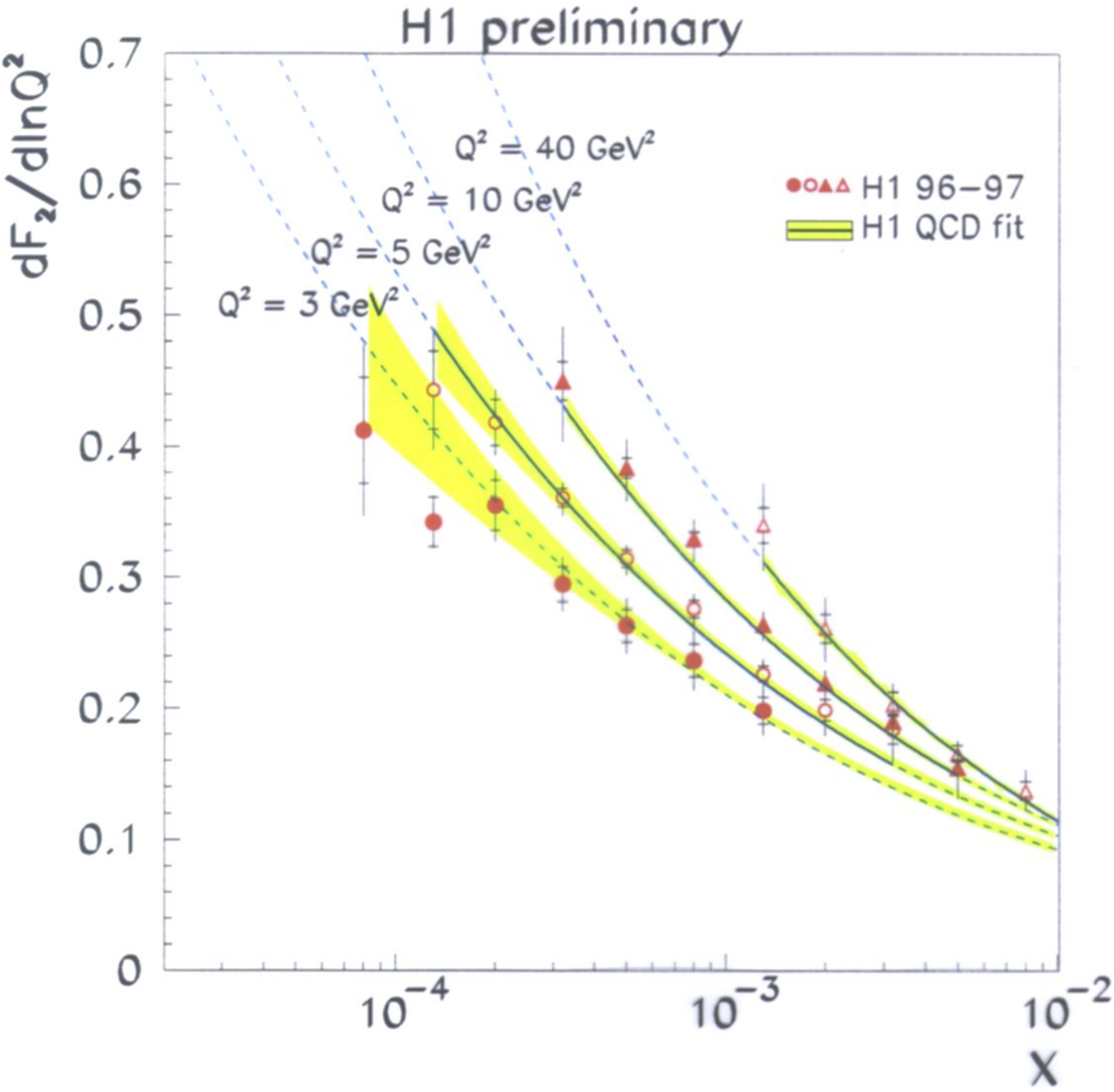

low x:
backward $J/\psi$



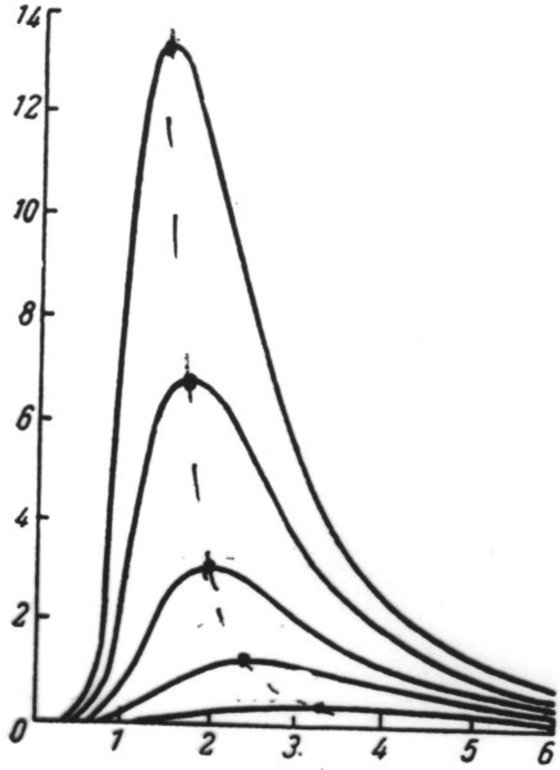

$$P_2 = a(x) + b(x)\ln Q^2 + c(x)(\ln Q^2)^2$$



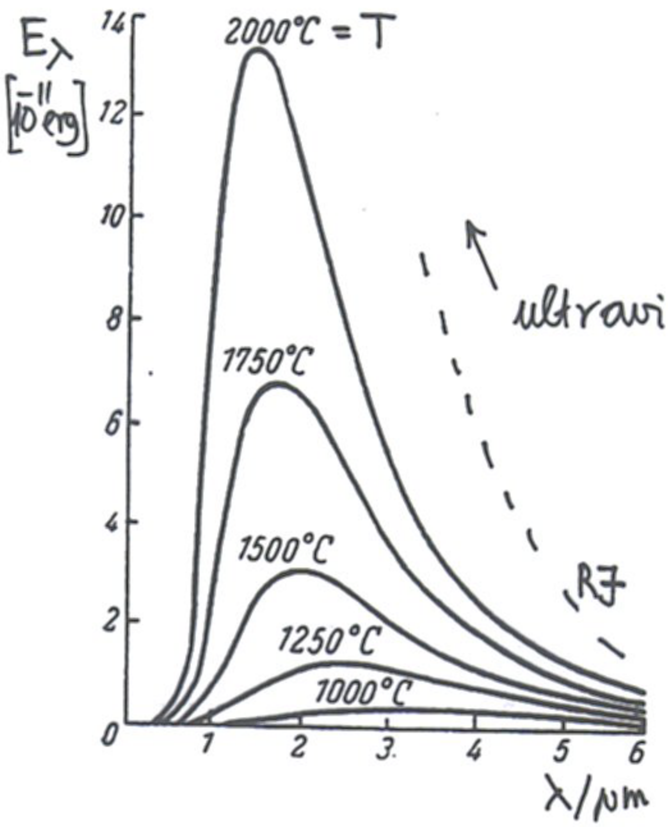
H1 preliminary
dF2/dlnQ²
x = 0.00008
x = 0.00013
x = 0.0002
x = 0.00032
x = 0.0005
x = 0.0008
x = 0.0013
x = 0.002
x = 0.0032
x = 0.005
x = 0.008
H1 96-97
H1 QCD fit
dP2/dlnQ²
= b + 2c lnQ²
Q²/GeV²




$\partial F_2 / \partial \ln Q^2$ : PW Johnson PRD16 (1977) 2769
Wu Ki Tung


14
12
10
8
6
4
2
0
1
2
3.
4
5
6

black body radiation




- Wien

Maxwell distribution of $\rho_\nu$ $(\nu = c/\lambda)$

$$B_\lambda = \frac{c_1}{\lambda^5} e^{-c_2/\lambda T}$$

- Rayleigh / Jeans

equipartition law of statistical mechanics

$$B_\lambda = c \cdot \frac{kT}{\lambda^4}$$

- Planck

14.12.1900

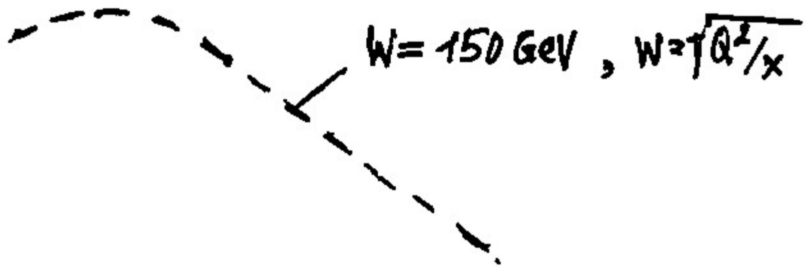
short waves

long waves $\lambda T \gg 1$

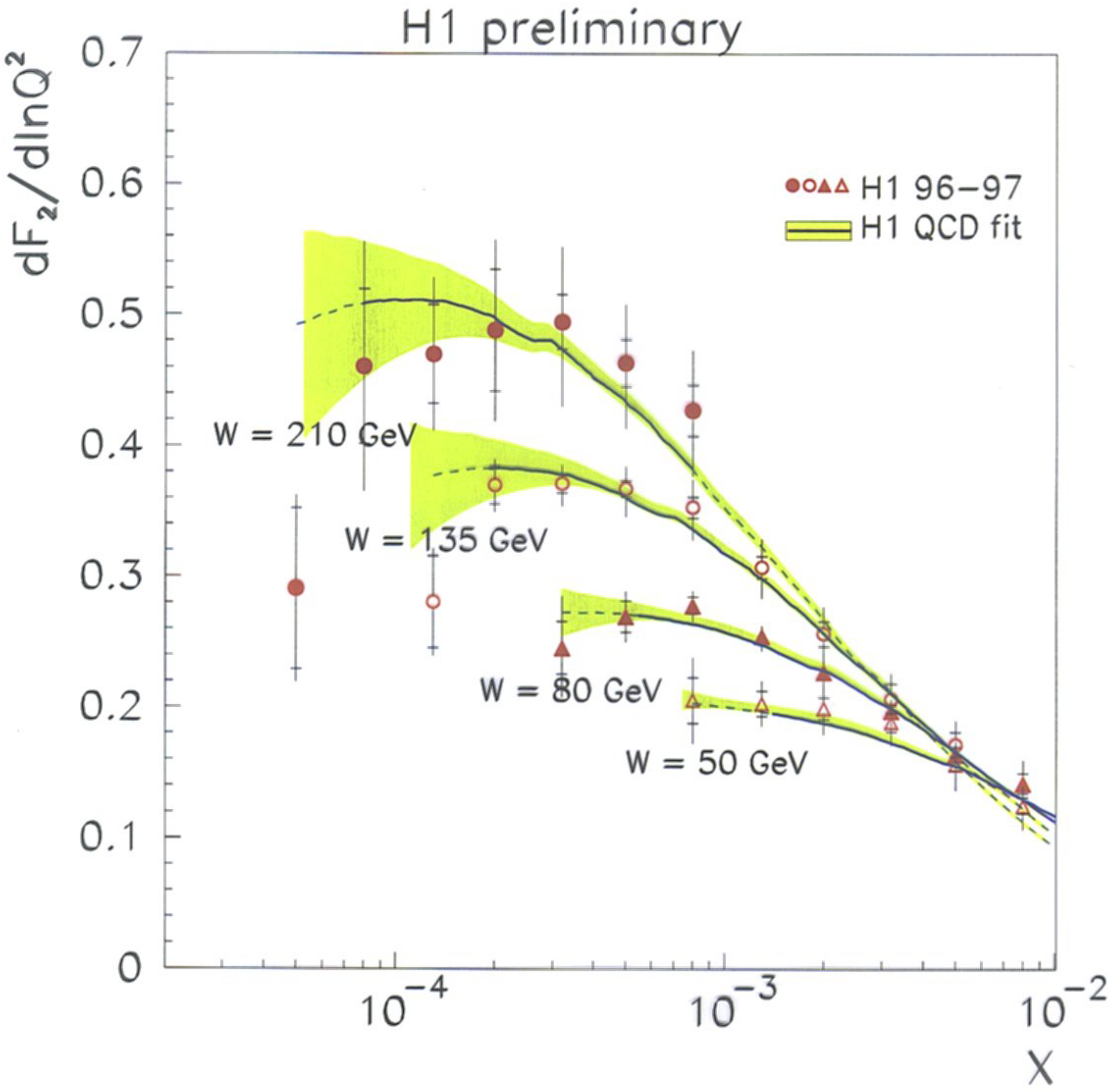
$$\boxed{B_\lambda = \frac{c_1}{\lambda^5} \cdot \frac{1}{e^{c_2/\lambda T} - 1}}$$

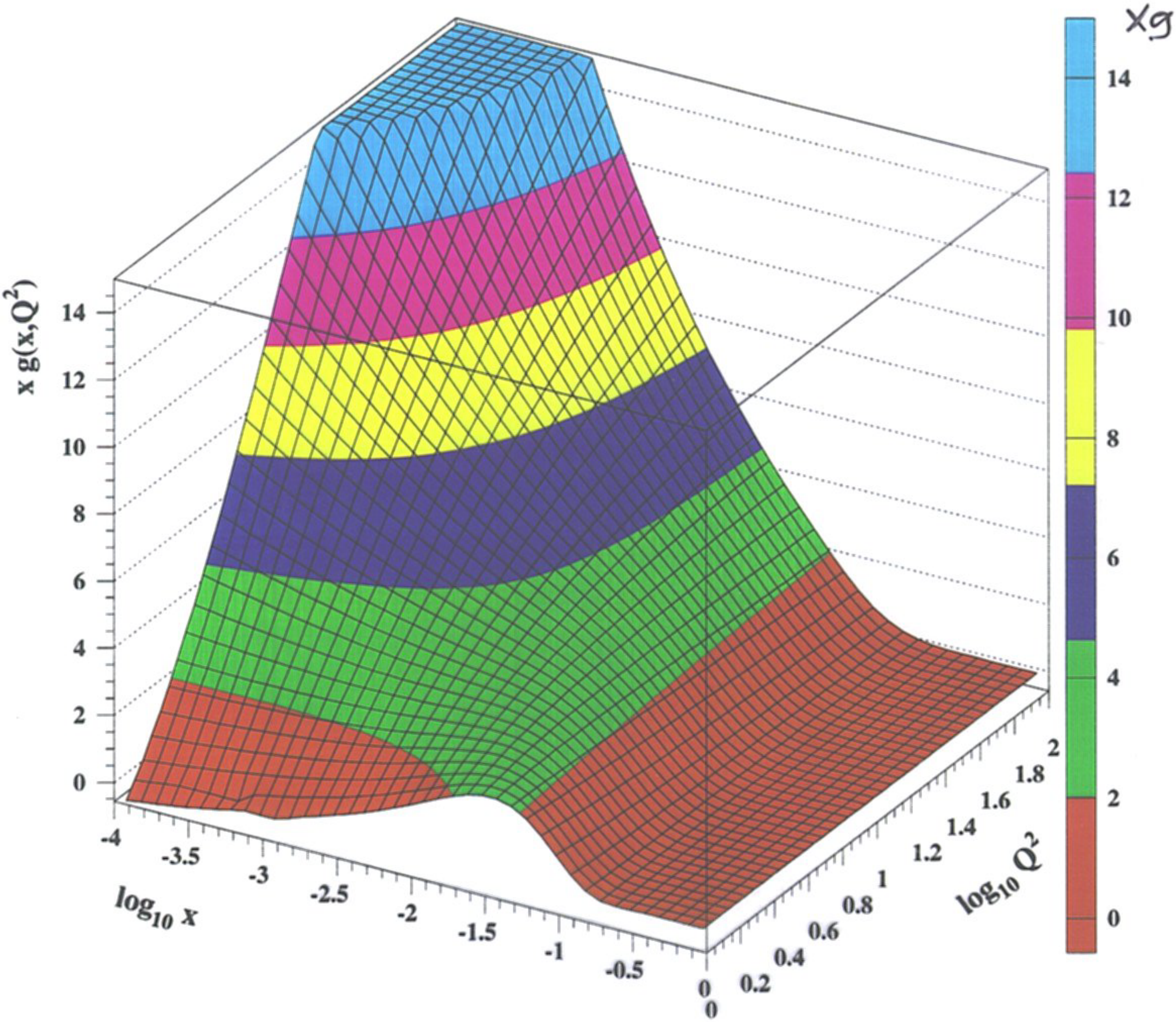
linear harmonic oscillators

$c_2 = c \cdot h / k$ . quantization.


$W = 150\ GeV$ , $W = \sqrt{Q^2/x}$

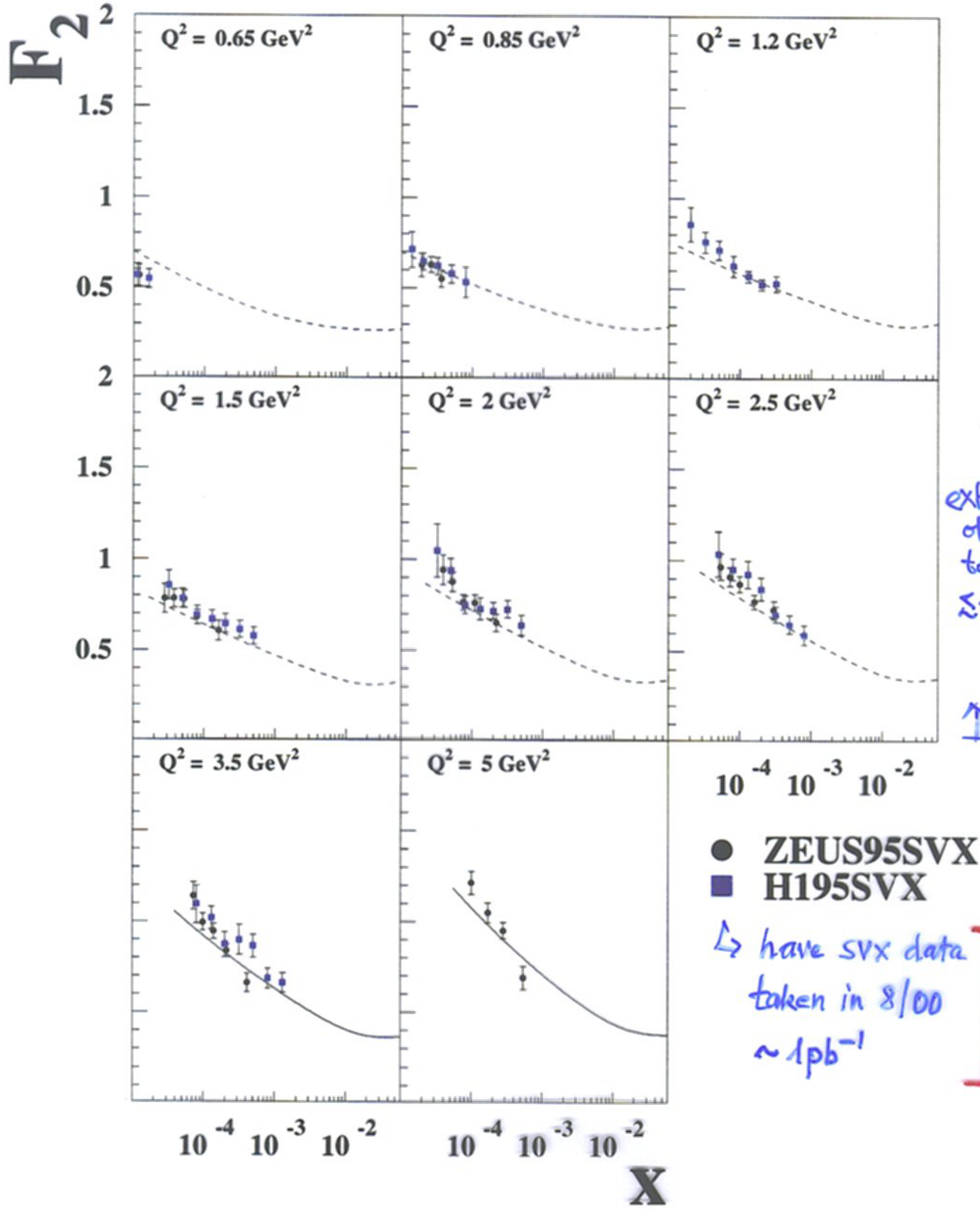
$\left(\partial F_2 / \partial \ln Q^2\right)_x$ plotted at fixed $W \approx \sqrt{Q^2/x} = \sqrt{sy}$





xg
14
12
10
8
6
4
2
0
$x\,g(x,Q^2)$
$\log_{10} x$
-4
-3.5
-3
-2.5
-2
-1.5
-1
-0.5
0
$\log_{10} Q^2$
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2

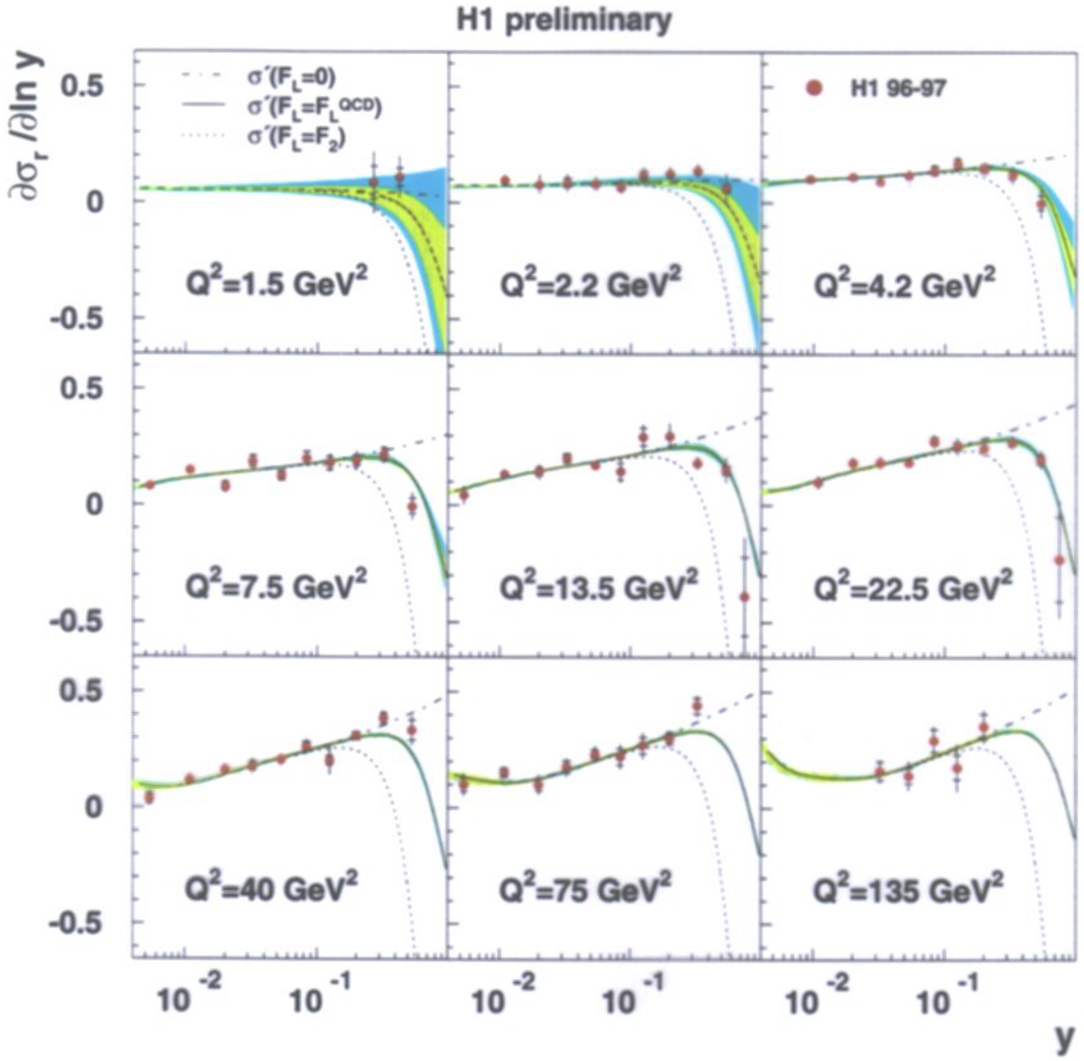
# HERA Low $Q^2$




extrapolation of fit to $Q^2 \lesssim 1$ GeV$^2$

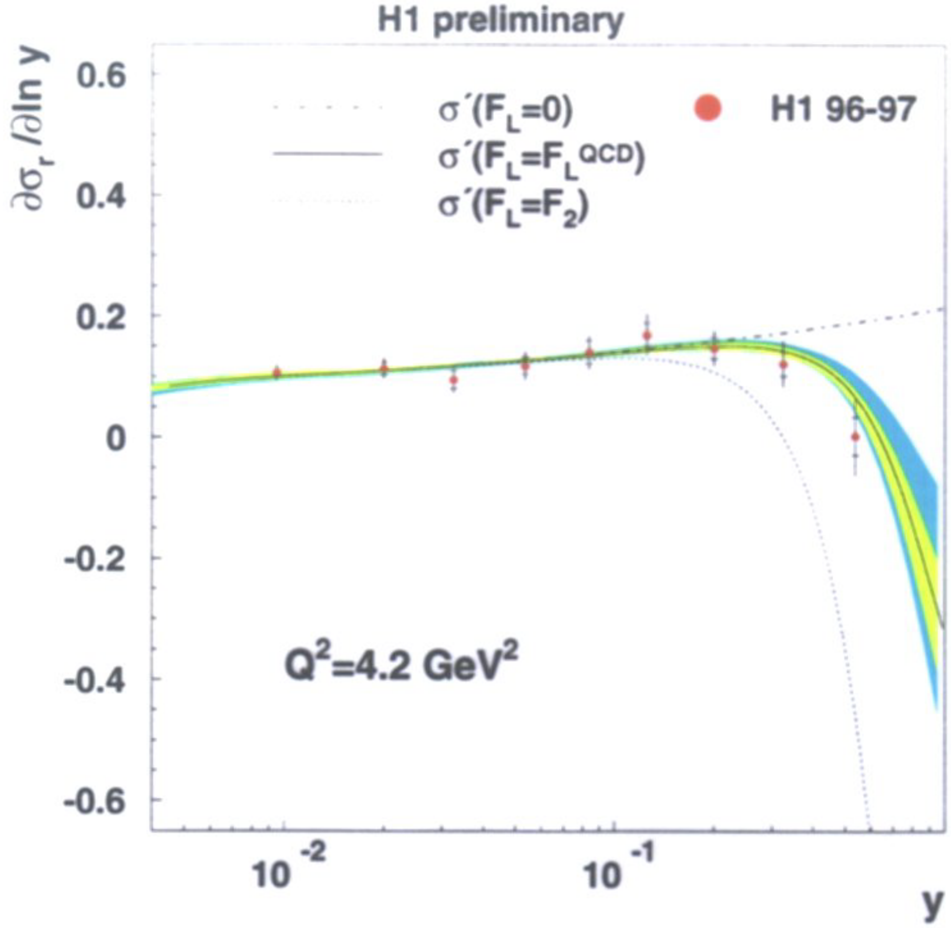
↳ have svx data taken in 8/00 $\sim 1 pb^{-1}$

$$\left.\frac{\partial \sigma_r}{\partial \ln y}\right|_{Q^2} = \frac{\partial F_2}{\partial \ln y} - F_L \cdot 2y^2 \frac{2-y}{Y_+^2} - \frac{\partial F_L}{\partial \ln y} \cdot \frac{y^2}{Y_+}$$

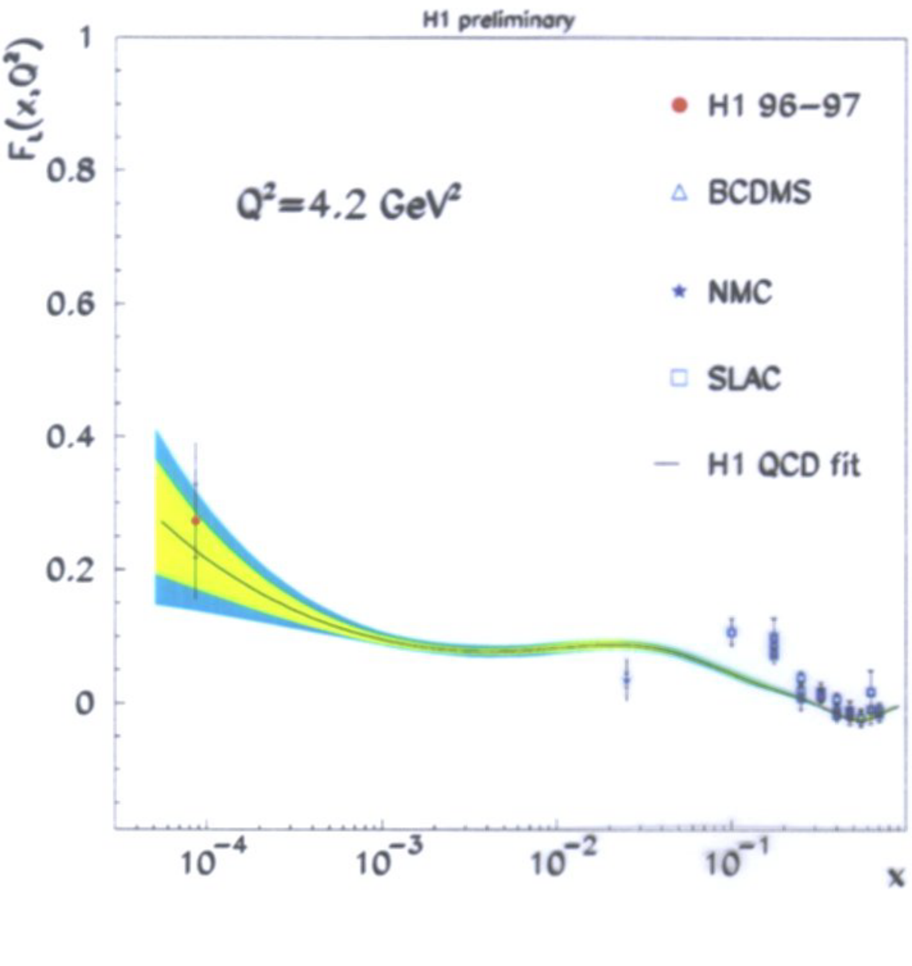


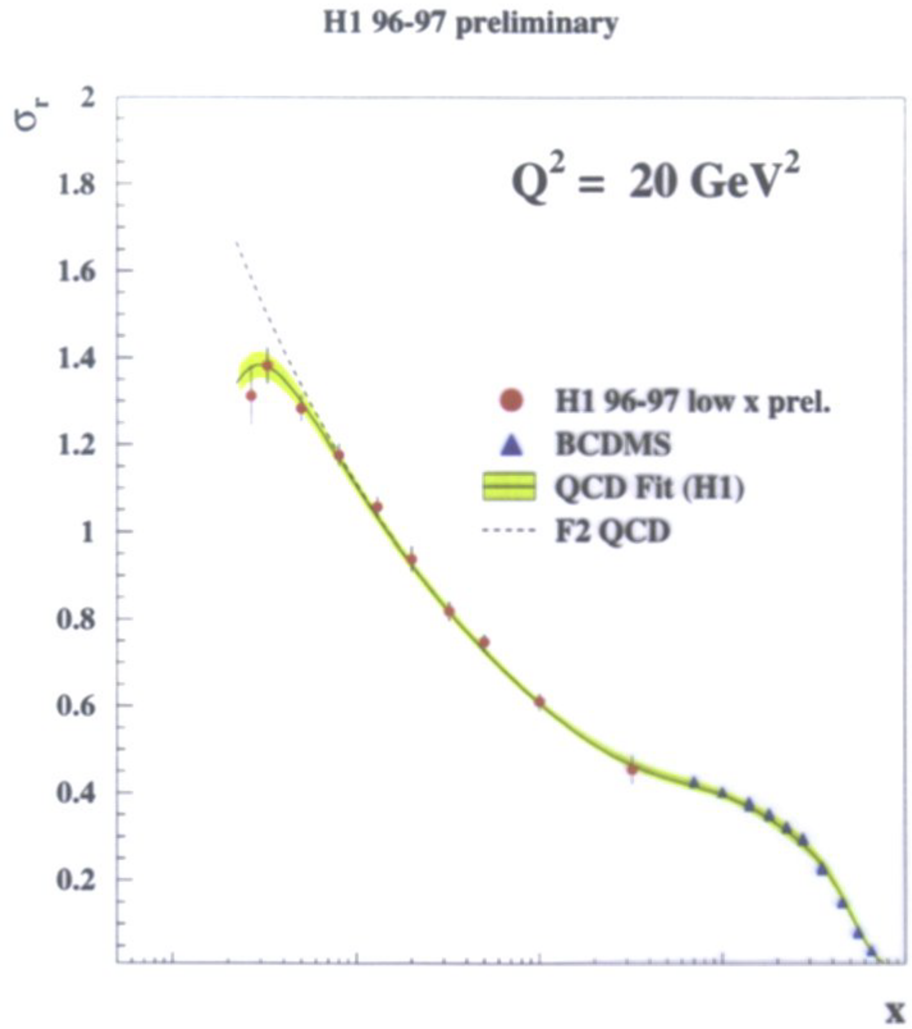

$$F_2(x, Q^2) \sim x^{-\lambda} \sim y^\lambda = \exp(\lambda \cdot \ln y)$$

$$\partial \sigma_r / \partial \ln y \simeq \partial F_2 / \partial \ln y = F_2 \cdot \lambda$$

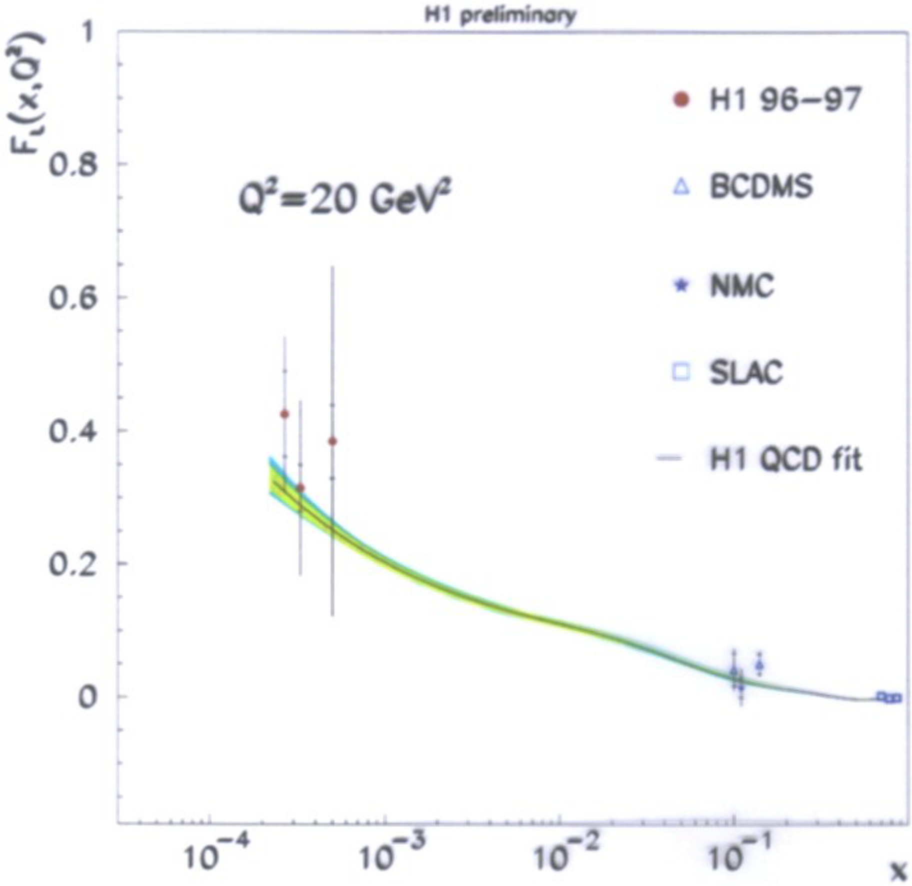


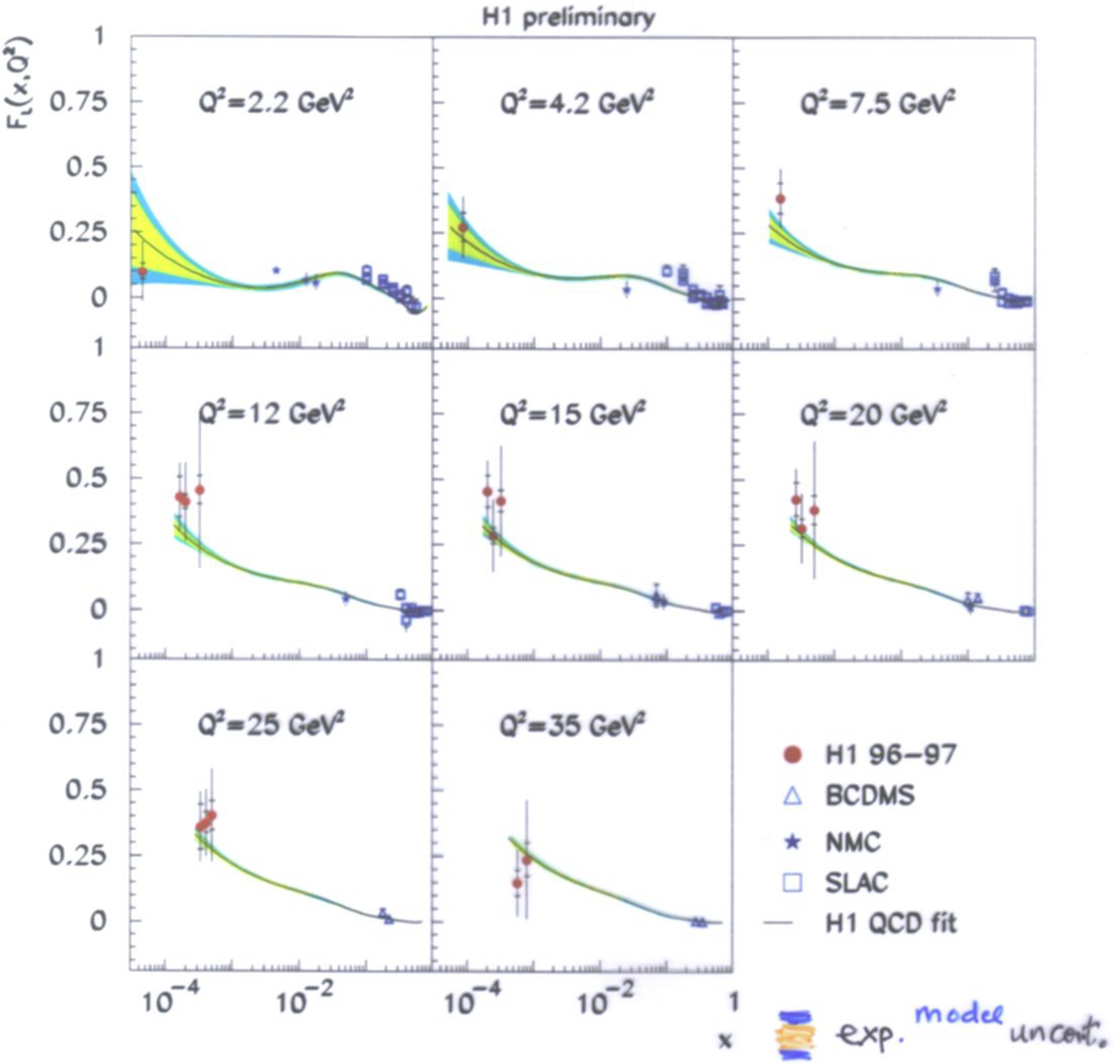

"derivative method"






"extrapolation method"






— fit to $F_2$ only → $xg$ → $F_L$

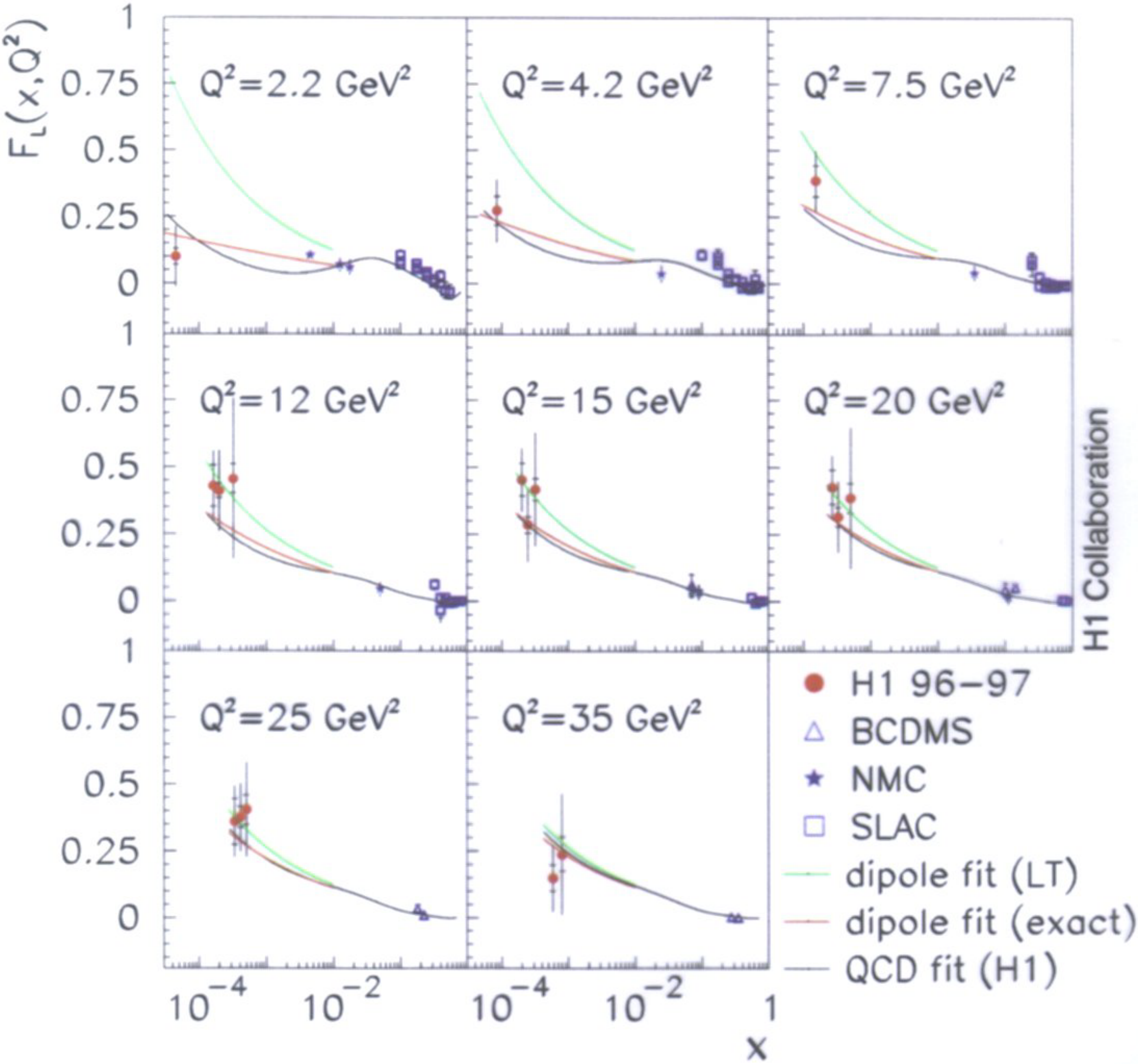
$y < 0.35$

$$\sigma_L = \frac{4\pi^2\alpha}{Q^2} \cdot F_L = \frac{\alpha}{\pi}\sigma_0 \, \xi \sum Q_f^2 \qquad \xi = \frac{Q_0^2}{Q^2}\left(\frac{x_0}{x}\right)^{\lambda}$$

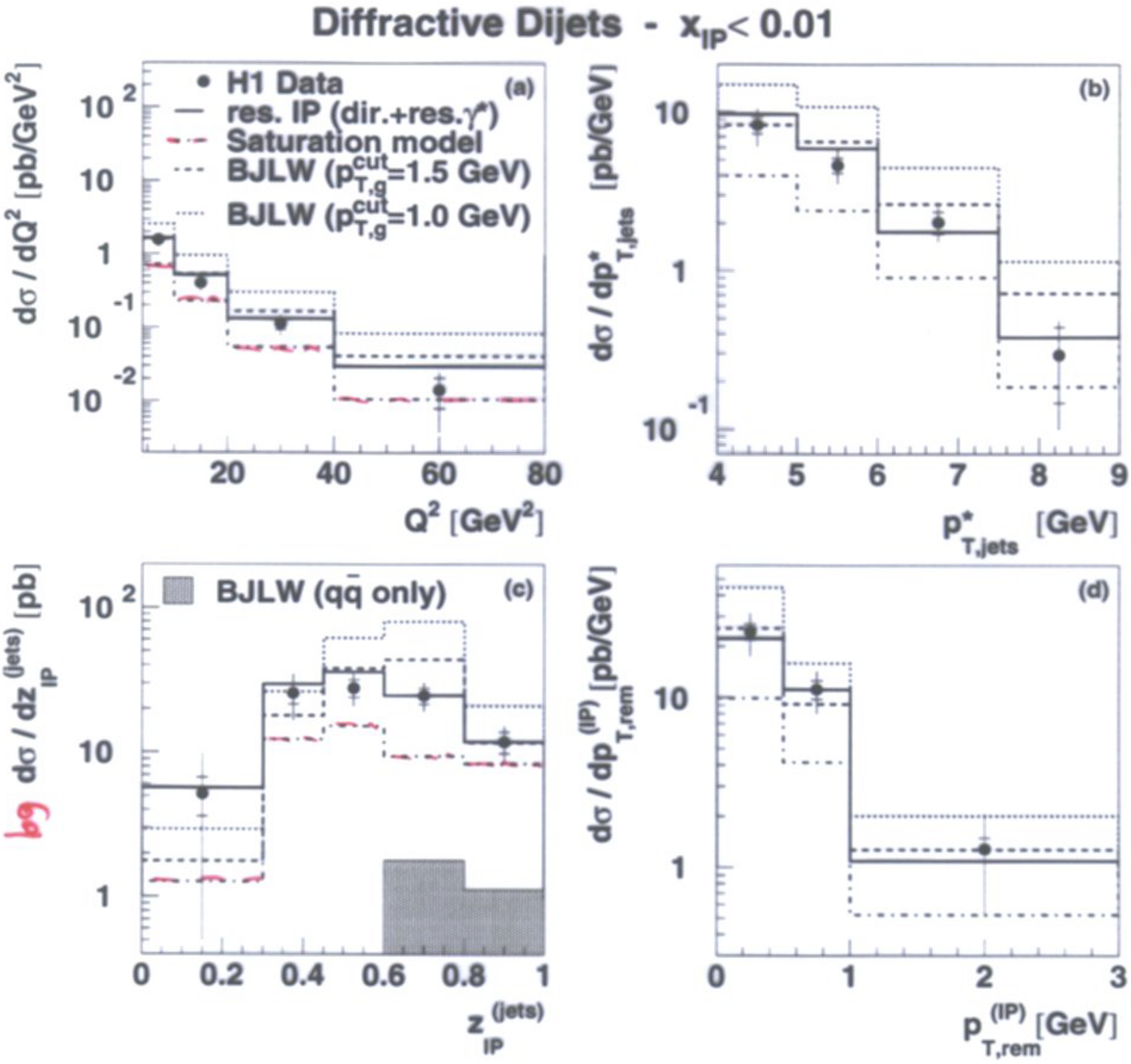
$F_L \sim x^{-\lambda}$, indep. of $Q^2$ — LT

$\sigma_0, x_0, \lambda$ from fit to $F_2$, $m_q$.

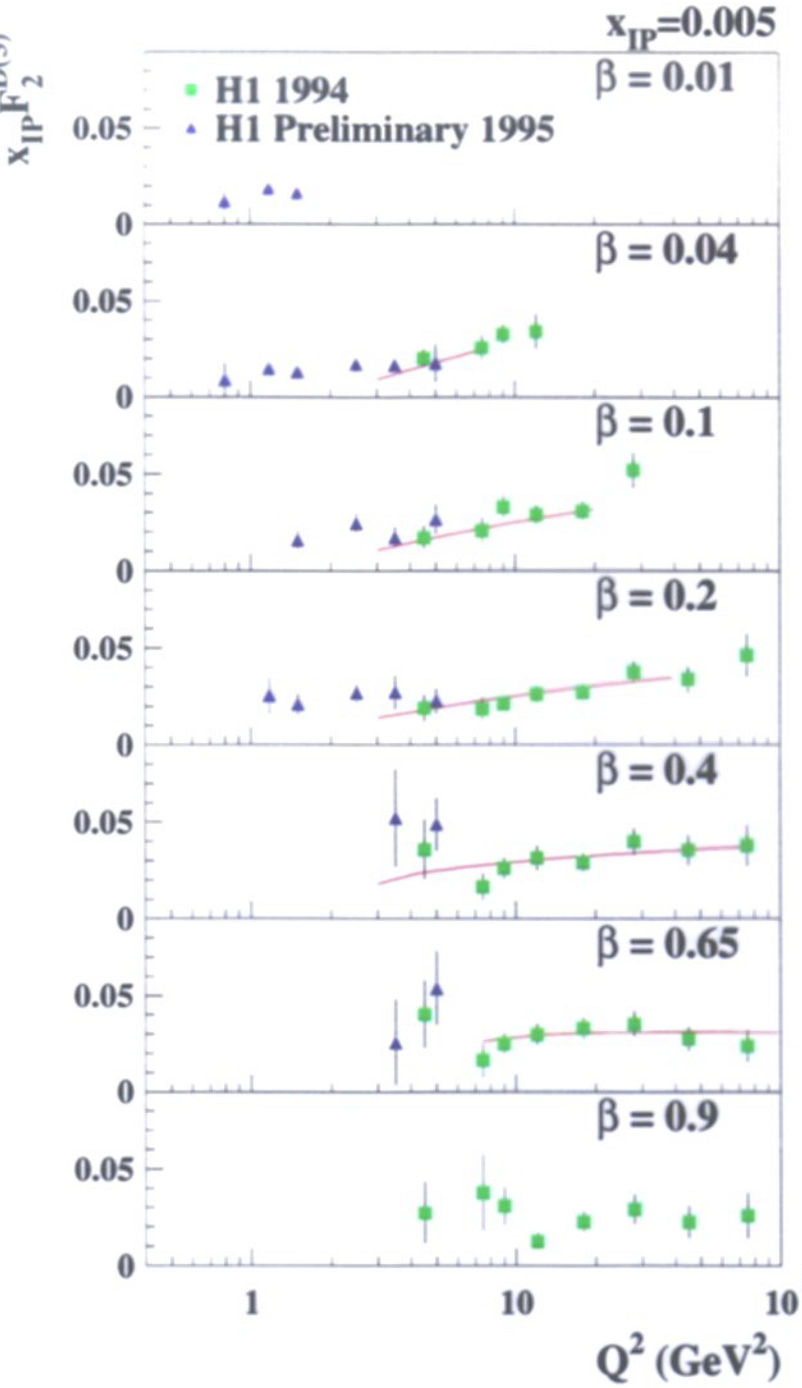
HT see JB, KG-B, KP hep-ph/0003042




- exp. accuracy ↗ : $\mathcal{L}$, tracking (Si)
- x dependence only with variation of $E_p$: 250 ... 1000 GeV.



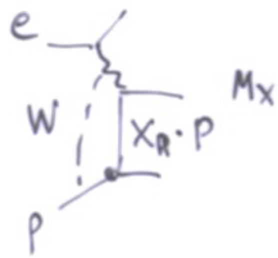

- charm in diffraction : $\mathcal{L} \nearrow$

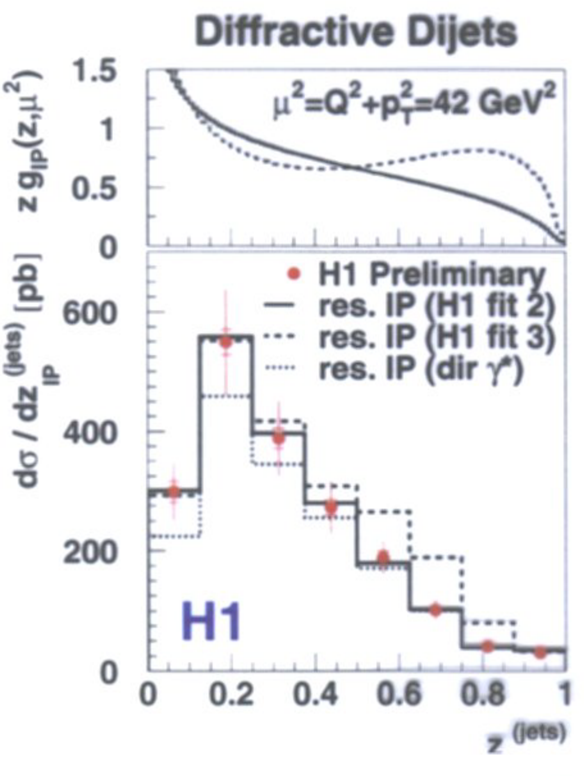



$$F_2^{D(3)}(x_{IP},\beta,Q^2) \sim \frac{1}{x_{IP}^n} \cdot F_2^{IP}(\beta,Q^2)$$

$$\beta = x/x_{IP}$$

$$x_{IP} = \frac{M_X^2 + Q^2}{W^2+Q^2}$$




DGLAP analysis describes $F_2^D$ & dijet data.

"xg 2"

- no departure observed from DGLAP QCD
  $\nexists$ ultraviolet catastrophy

- low x physics demands highest possible precision, achievable with high luminosity, upgraded detectors and dedicated runs at different beam energies

- improvements are required and still possible for all observables like $F_{2,L,c,b,D}$ and the final state (diffraction, forward, .. )

- many years of precision analyses ahead and saturation of this work is not in reach, yet.