Inelastic ep Scattering at Low x and Q^2

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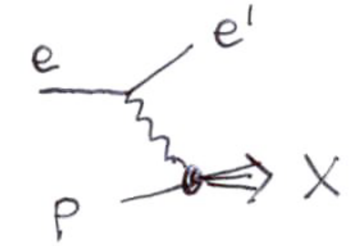
Moriond - 22nd March, 2001



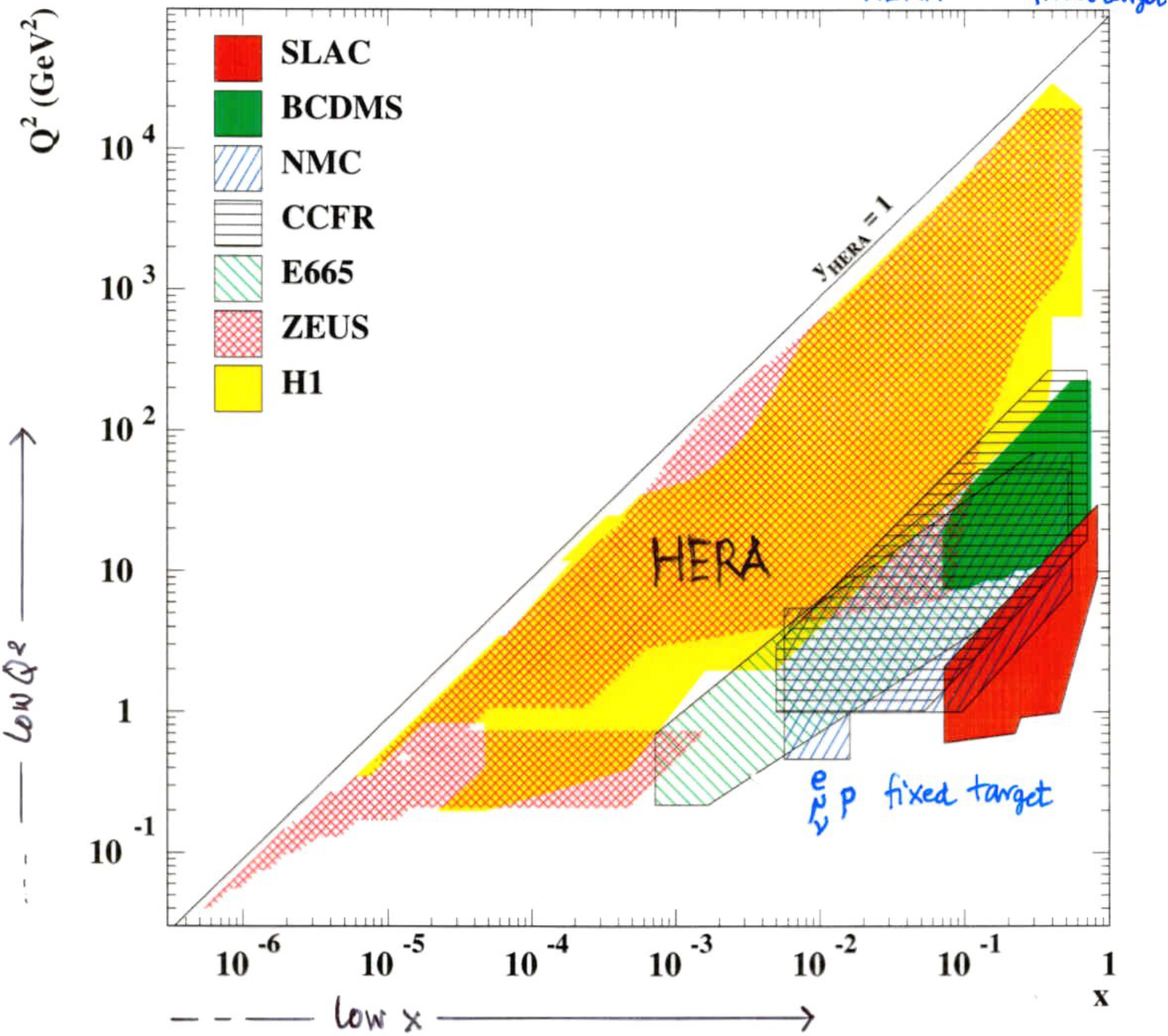
inelastic ep scattering

Q^2 – 4 momentum transfer^2

x momentum fraction of $q(p)$

y inelasticity

$Q^2 = sxy$ $s = 4E_eE_p$ (HERA), $2ME_\ell$ (fixed target)



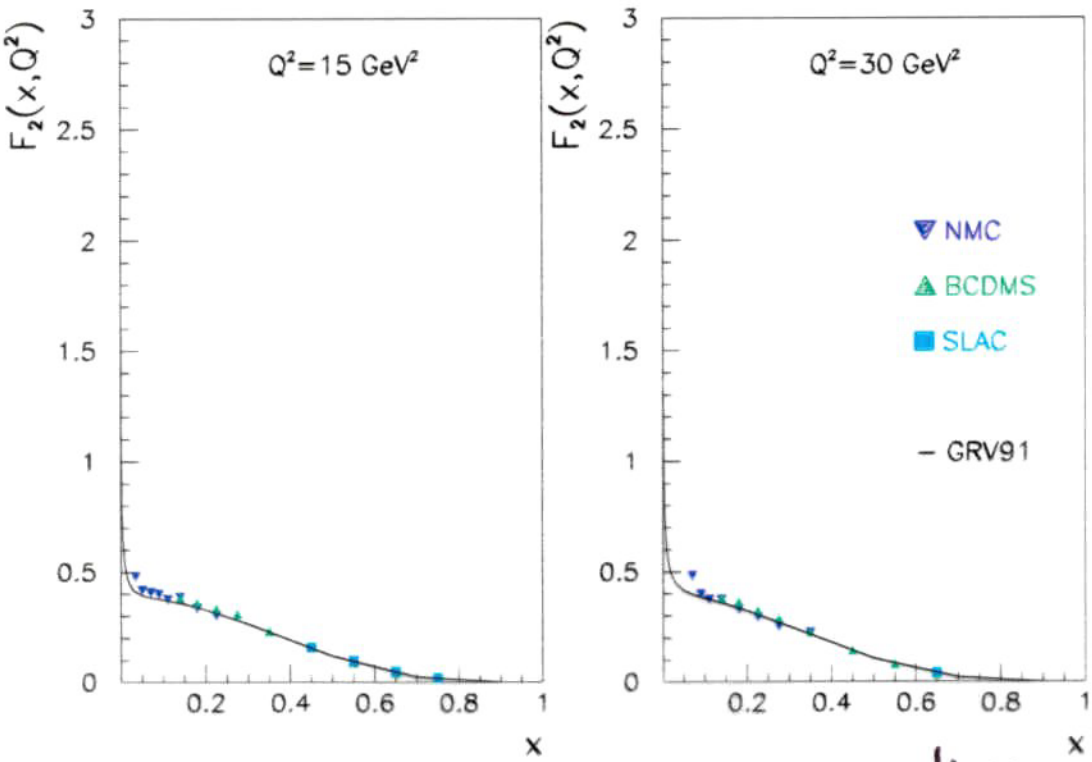
$$\frac{d\sigma}{dQ^2dx} \sim \frac{1}{Q^4} \cdot \underbrace{\left(F_2 - \frac{y^2}{Y_+}F_L\right)}_{\sigma_{reduced}}$$

$Y_+ = 1 + (1-y)^2$

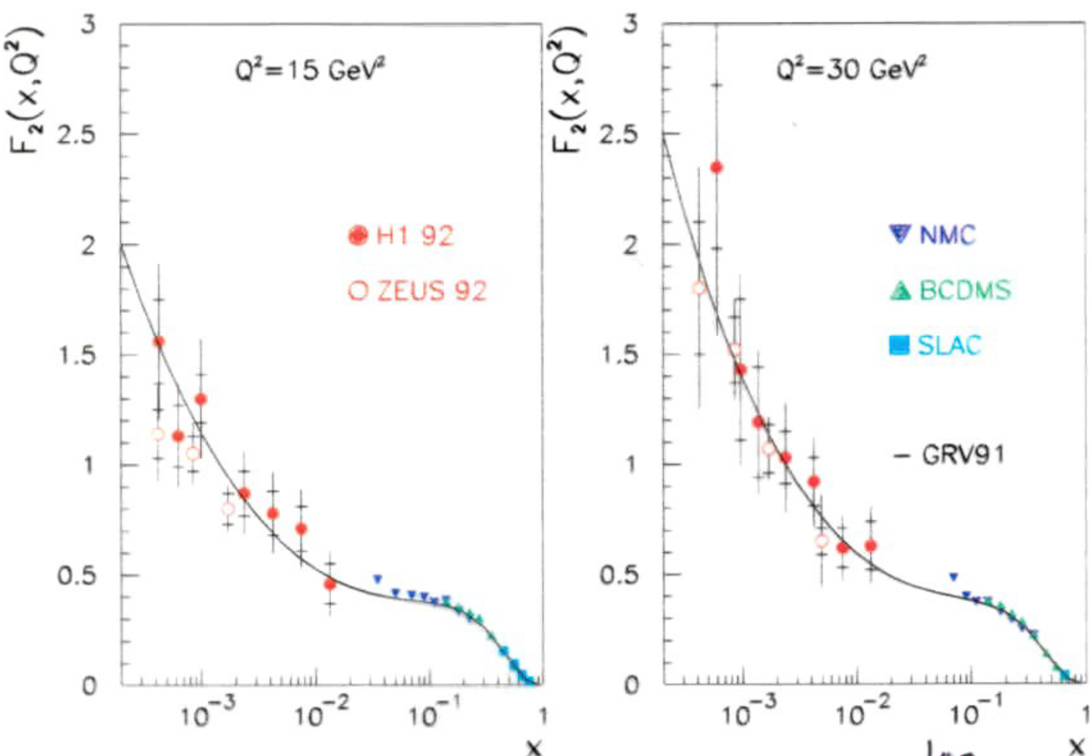
$F_2(x,Q^2) \sim O(Q^2)$, $Q^2 \to 0$ thus

$\sigma_{\gamma^* p} \sim F_2/Q^2 \to$ const.

$F_L(x,Q^2) \sim O(Q^4)$, $Q^2 \to 0$



linear

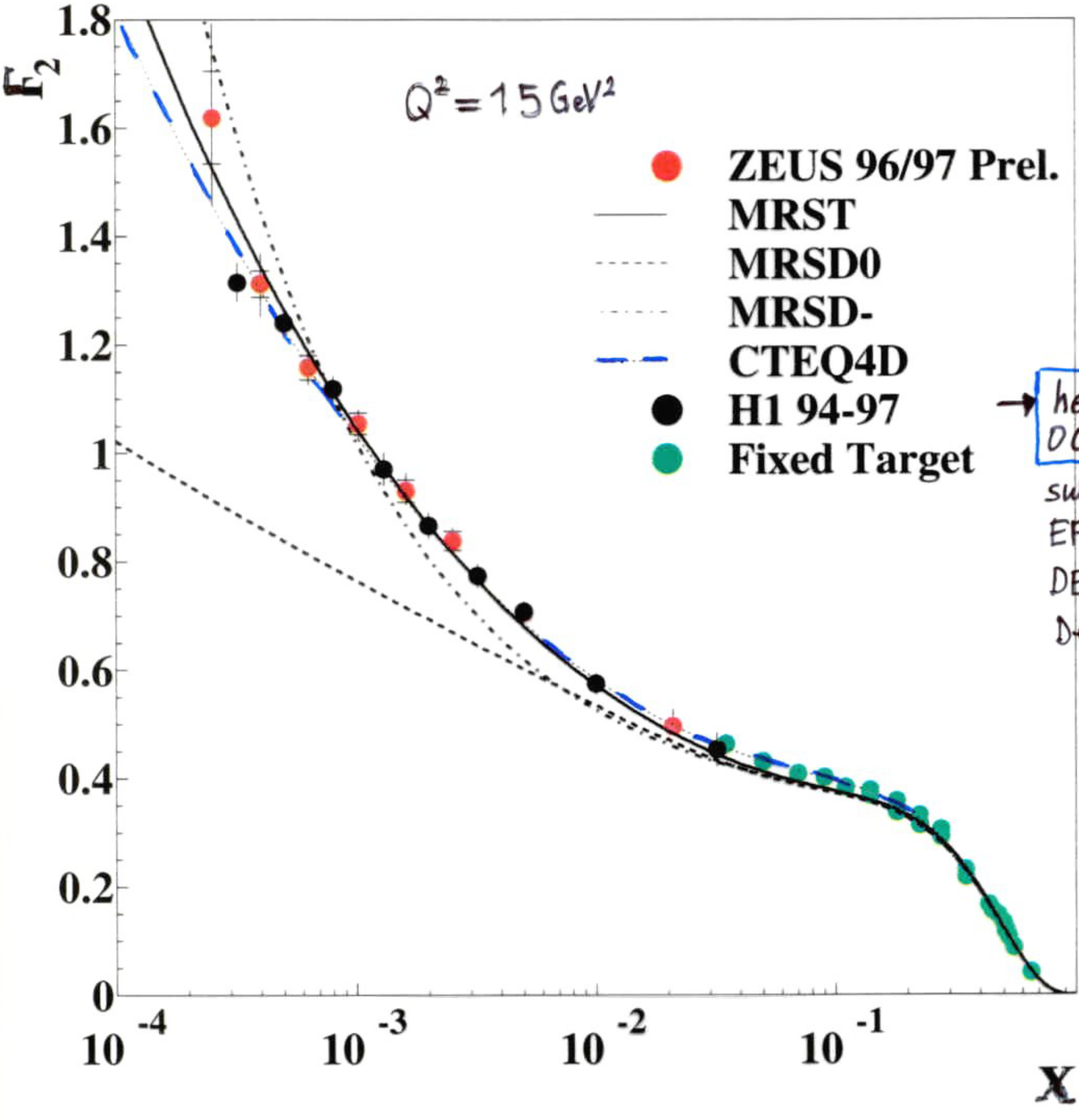


log

the rise of $F_2(x,Q^2)$ towards low x . 92 data

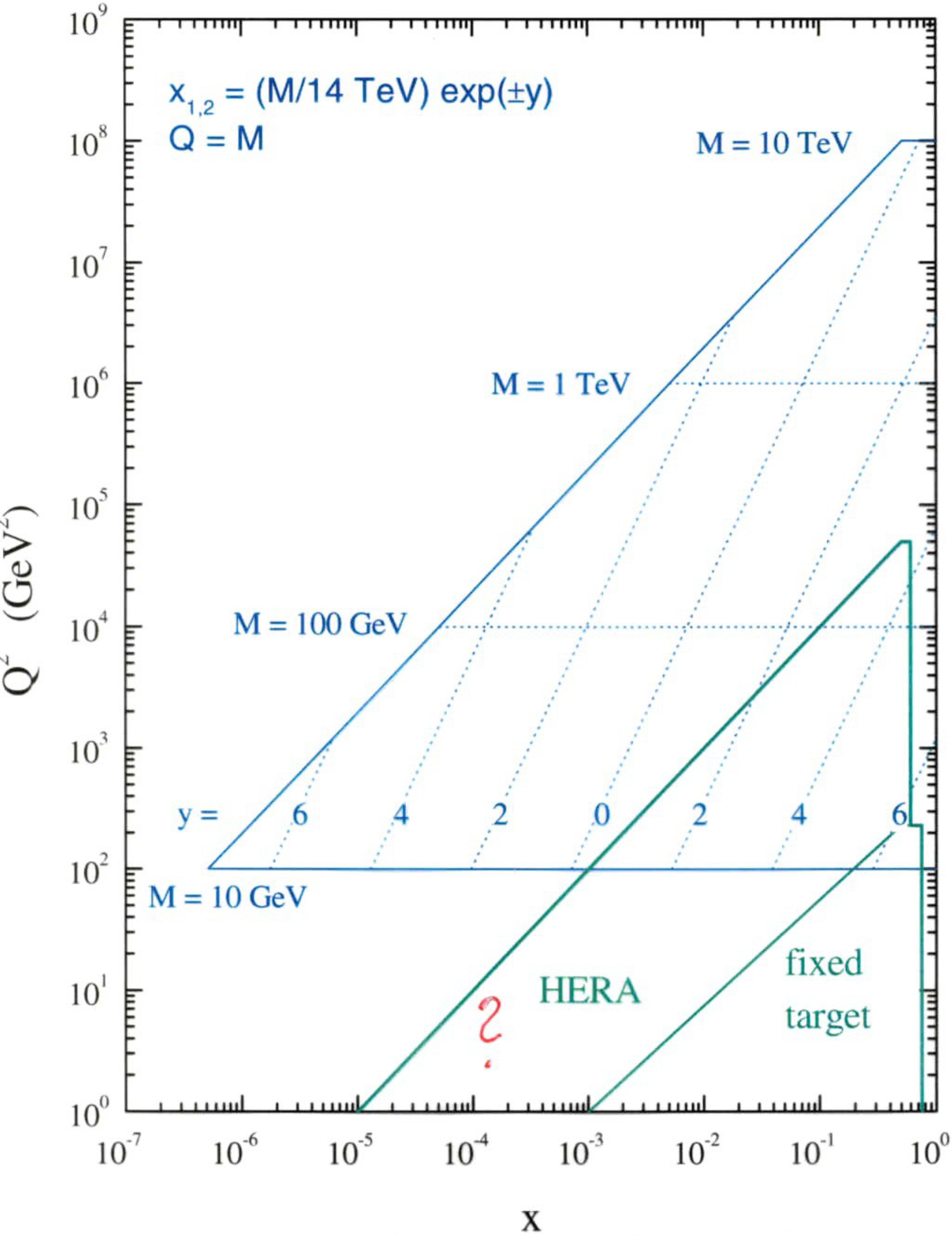
... precision (~3%) measurements of σ_r, F_2.

96/97 data



→ hep-ex/0012053
subm. to EPJ
DESY 00-181
Dec. 2000.

LHC parton kinematics



ultra high $E_\nu \lesssim 10^{12}$ GeV — ν's from AGN's, γray bursts
cf. R. Gandhi hep-ph/0011176 & ref's therein.

strong interaction dynamics @ high parton densities.

- precision tests of DGLAP QCD / limits of application. NNNLO
- $\alpha_s \cdot \ln 1/x \sim 1$: BFKL, CCFM, modified g emission . resummation G. Altarelli R Ball, S Forte

moreover:

- unitarity limits rise of x section : non-linear gluon i.a.'s
  - GLR equation
  - higher twists in DGLAP damp F_2 . J. Blümlein et al. PL (01)
  - Colour Glass Condensate E. Iancu, A. Leonidov, L McLerran hep-ph/0011241

- dipole model $\quad xg \lesssim \frac{1}{\pi N_c \alpha_s} \cdot Q^2 \cdot r_p^2 \simeq Q^2/\alpha_s$

Mueller, Nikolaev-Zakharov ...

factorisation of decay of γ into $q\bar{q}$ and dipole interaction with p. Gribov

$$\sigma_{L,T} \sim \int d^2r\, dz\, |\psi_{L,T}|^2 \cdot \hat{\sigma}_{dipole}$$

M. McDermott review hep-ph/0008260.

F_2, F_L, diffraction, charm production

⇒ rapidly developing field of research !

т.57 ЖЭТФ вып. 4(10).

Литература

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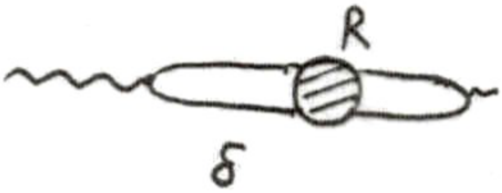
INTERACTION OF HIGH ENERGY γ QUANTA AND ELECTRONS WITH NUCLEI

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, σ_γ, 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.



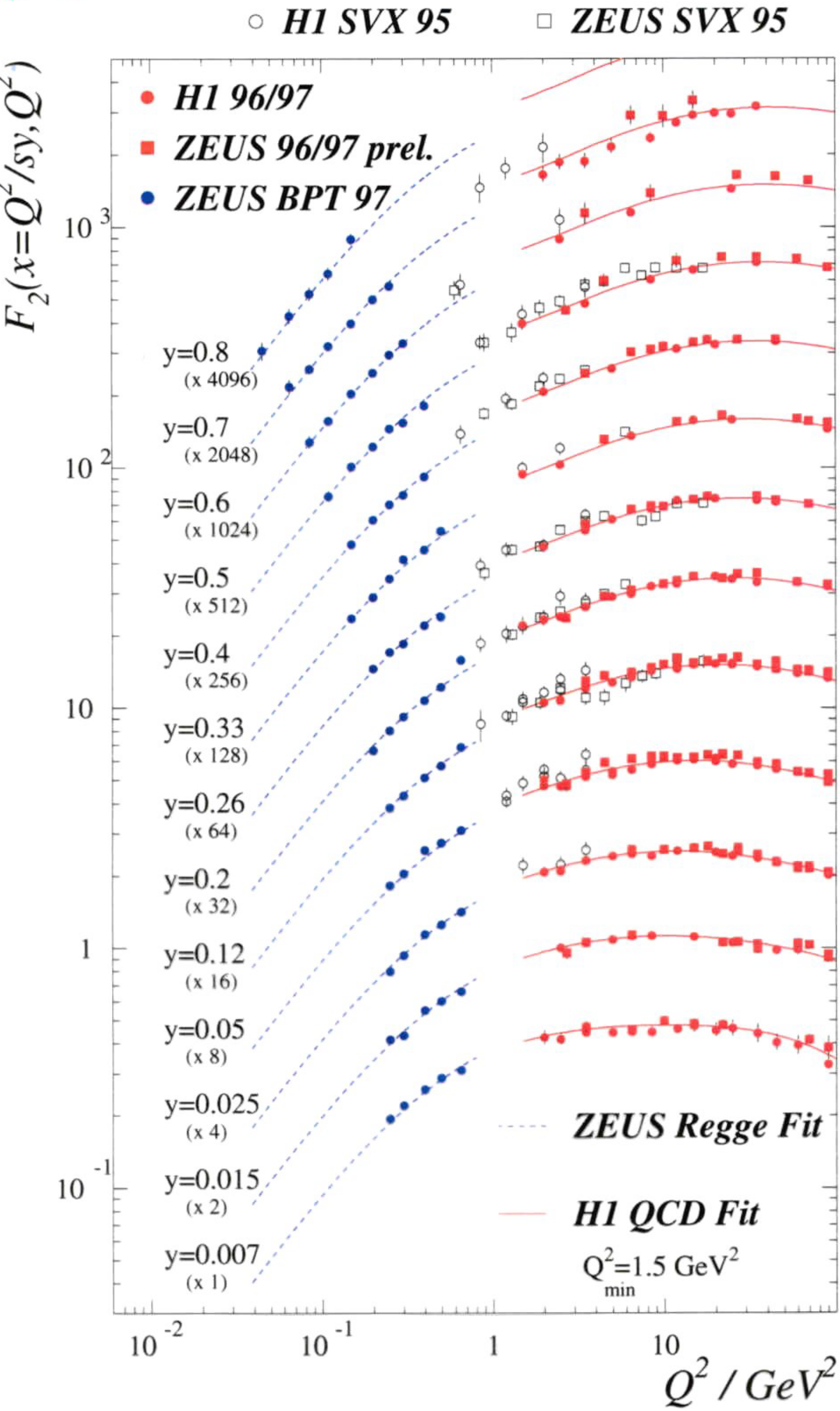
"γ квант сначала виртуально распадается на адроны, а затем адроны взаимодействуют с нуклонами ядра"

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

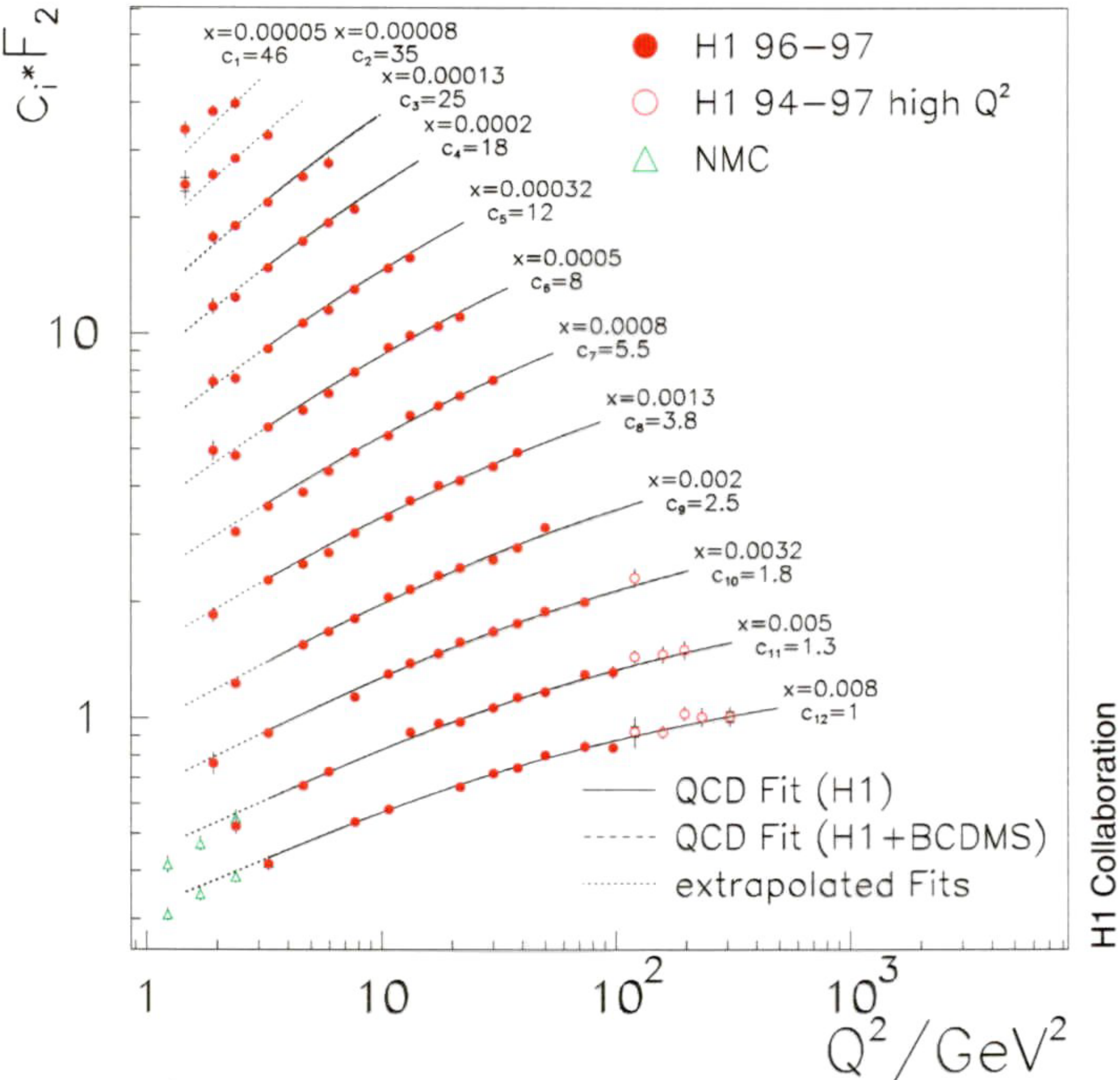
factorisation ansatz

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

$F_2(Q^2$, at fixed $y = W^2/s = Q^2/x)$ – derivative $\partial F_2/\partial \ln Q^2|_W$ changes sign.

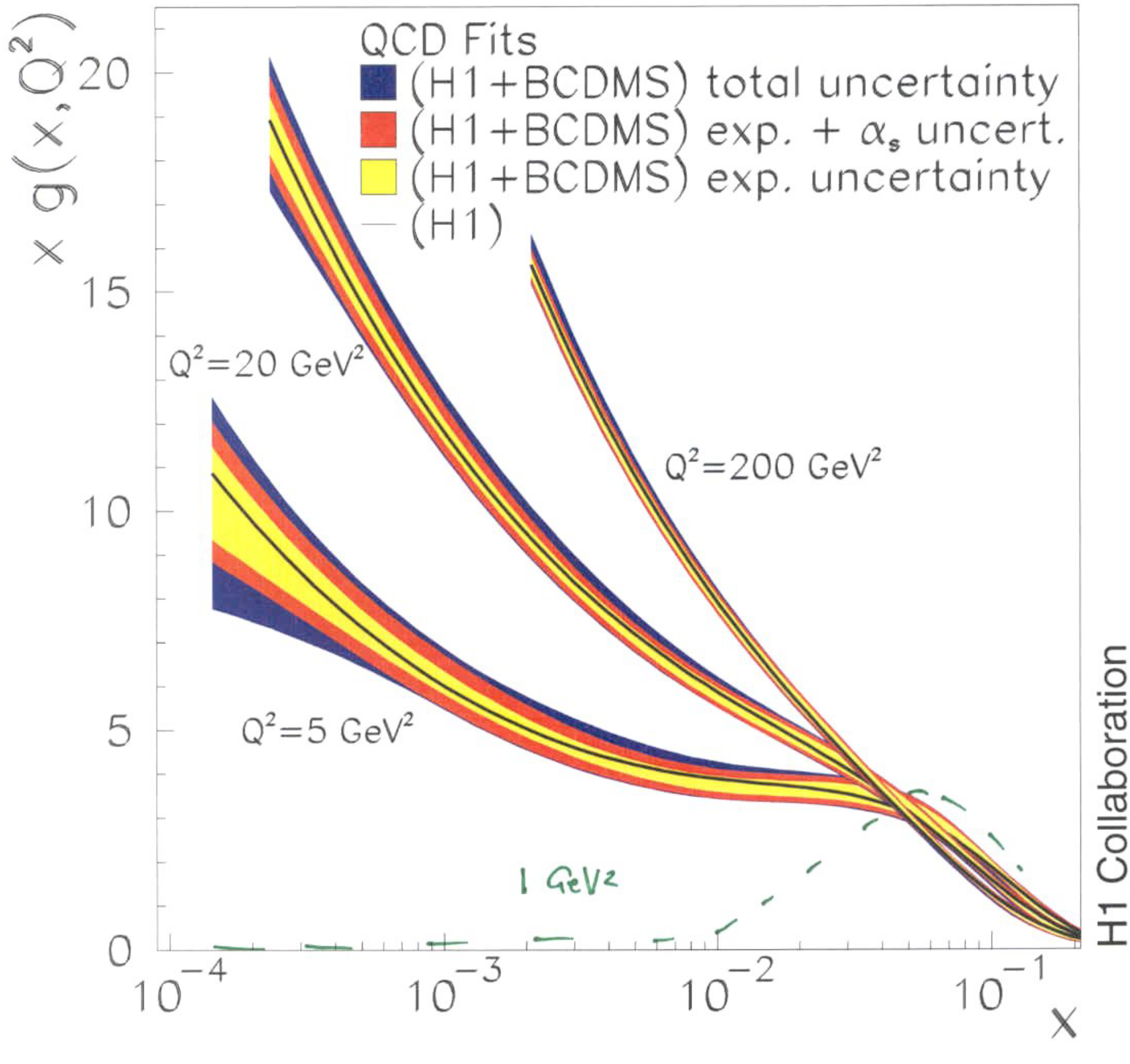


precision measurement of F_2 at low x . published Dec. 2000



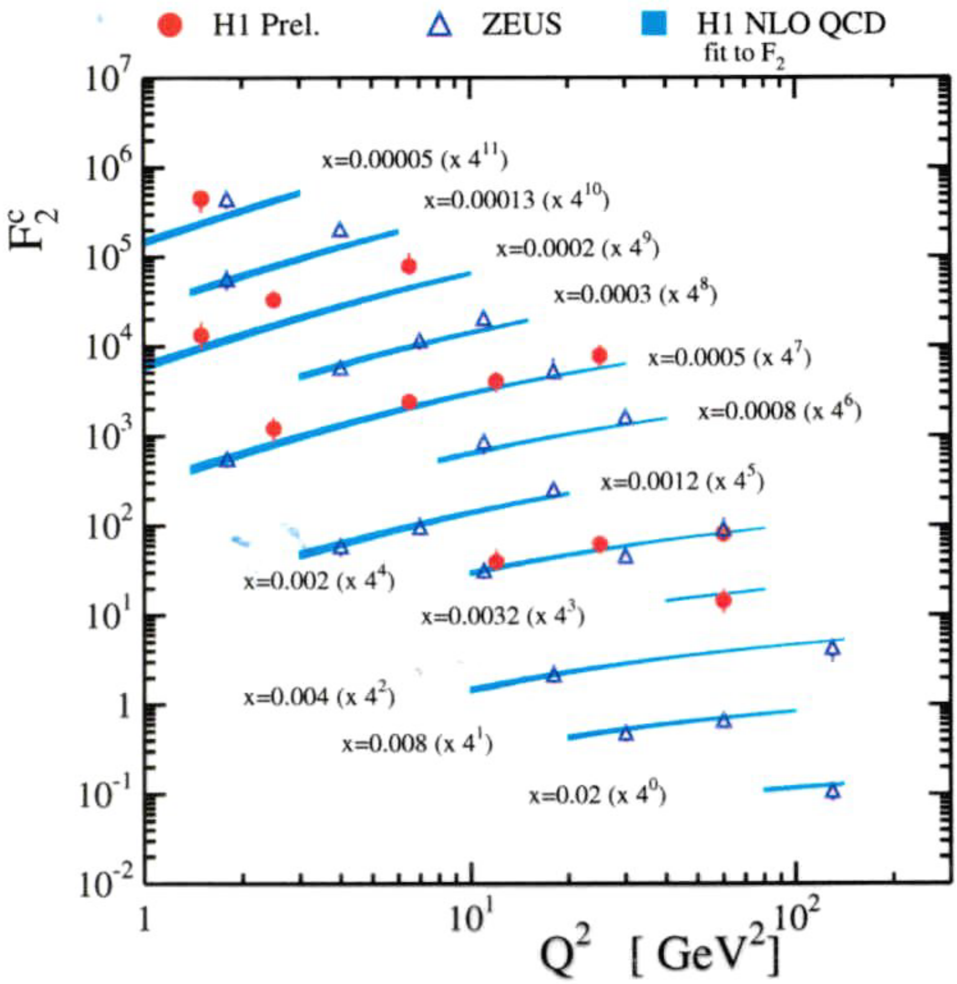
$\left(\partial F_2 / \partial \ln Q^2 \right)_x \sim \alpha_s \, x g(x, Q^2)$ for $Q^2 > 3\ GeV^2$. q negligible

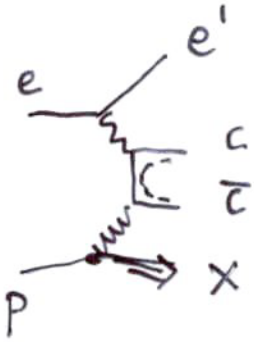
→ gluon distribution rises towards low x



- H1 fixes xg at low x
- correlation of α_s & xg resolved
- xg vanishes at low $x < 10^{-2}$ and $Q^2 \sim 1$ GeV^2 ("valence like")

F_2^c in the NLO DGLAP scheme



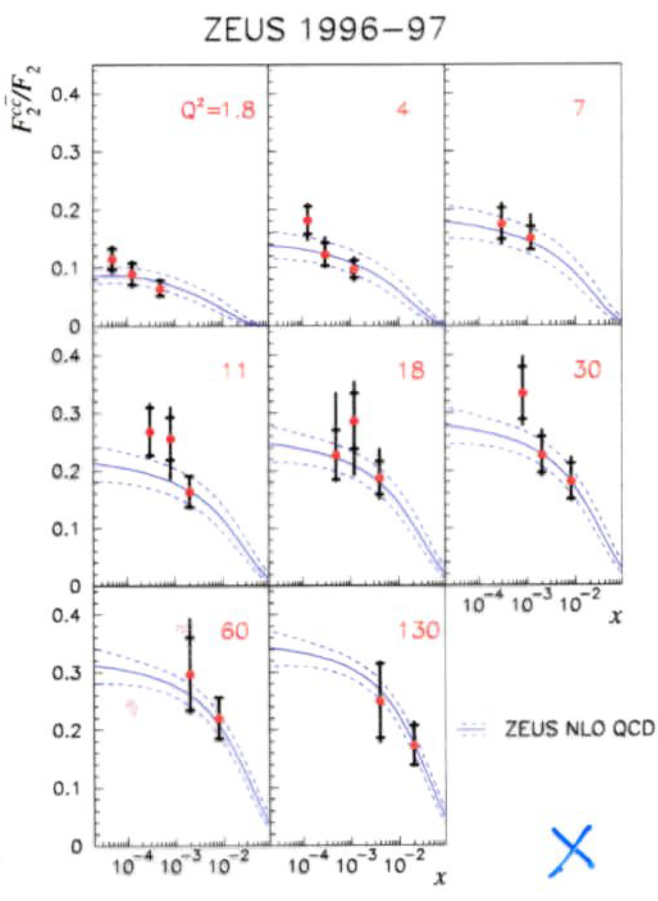


$D^* \to D^0 \pi_s$

$\quad \hookrightarrow K\pi$

photon-gluon fusion

- charm contributes 20-30% to F_2
- heavy flavour theory development
- xg from $\partial F_2 / \partial \ln Q^2$ describes F_2^{cc}
- low x? CCFM? precision!
  ↳ cf T. Sloan in HQ session

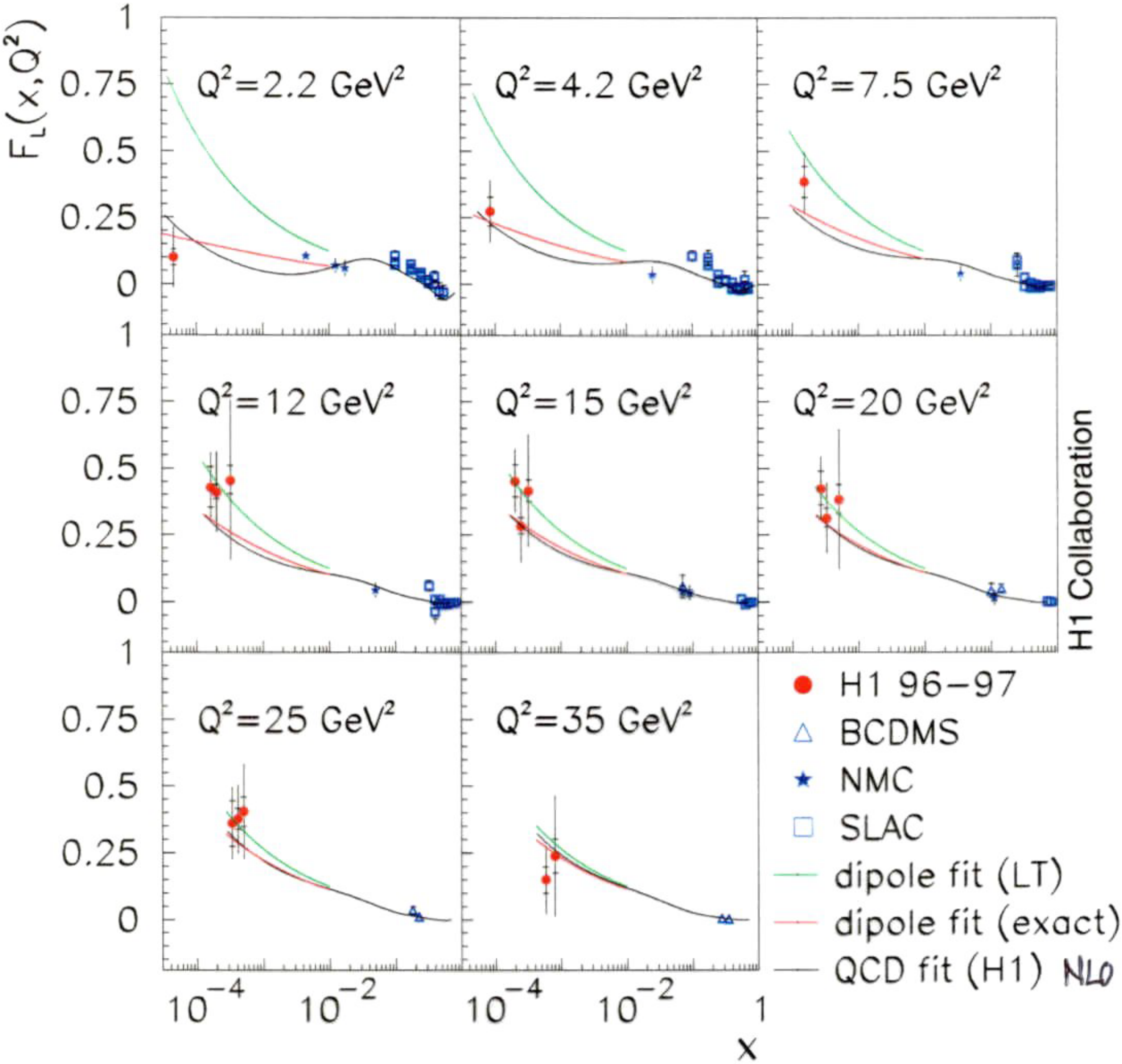


$F_2^{c\bar{c}} / F_2$

x

Longitudinal structure function F_L $\sim \alpha_s xg$ at low x

• — large F_L at low x as calculated in DGLAP using F_2



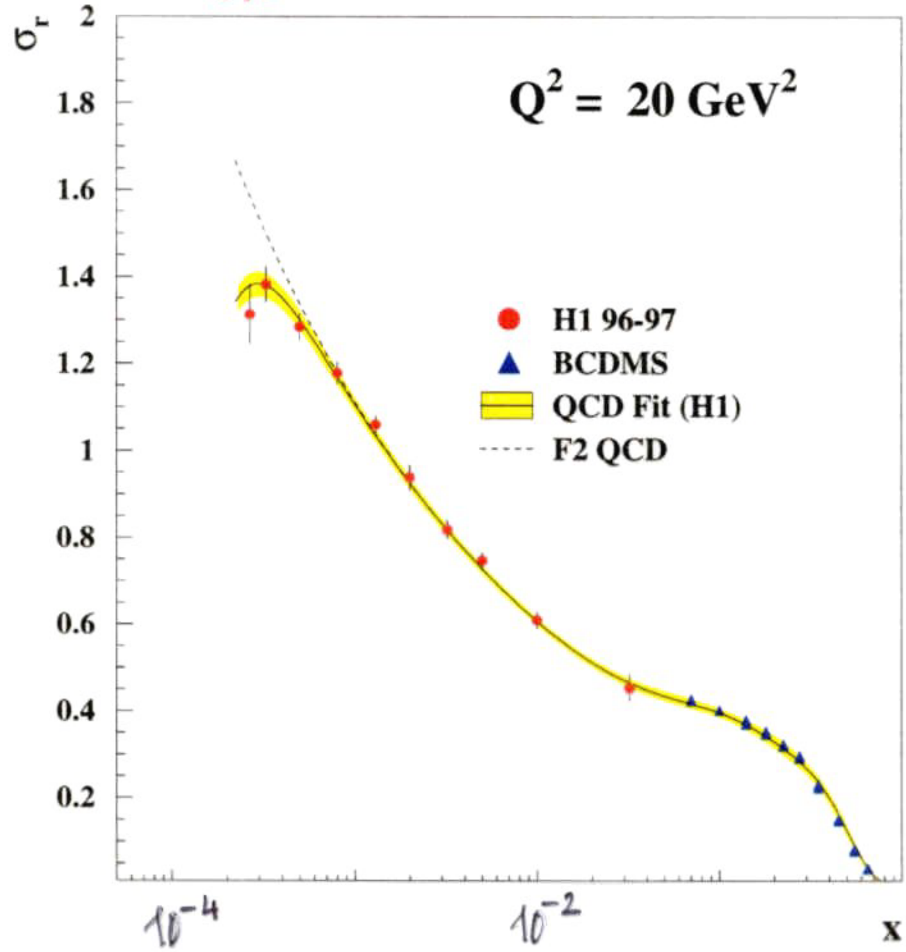
• dipole model: fit to F_2 (3 par's, m_q) Golec-Biernat, Wuesthoff PR D59 (99) 014017

— leading twist: no Q^2 evolution!

— higher twist ~ F_L in DGLAP Bartels, G-B, Peters hep-ph/0003042

Large in F_L, small in F_2

Cross section



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

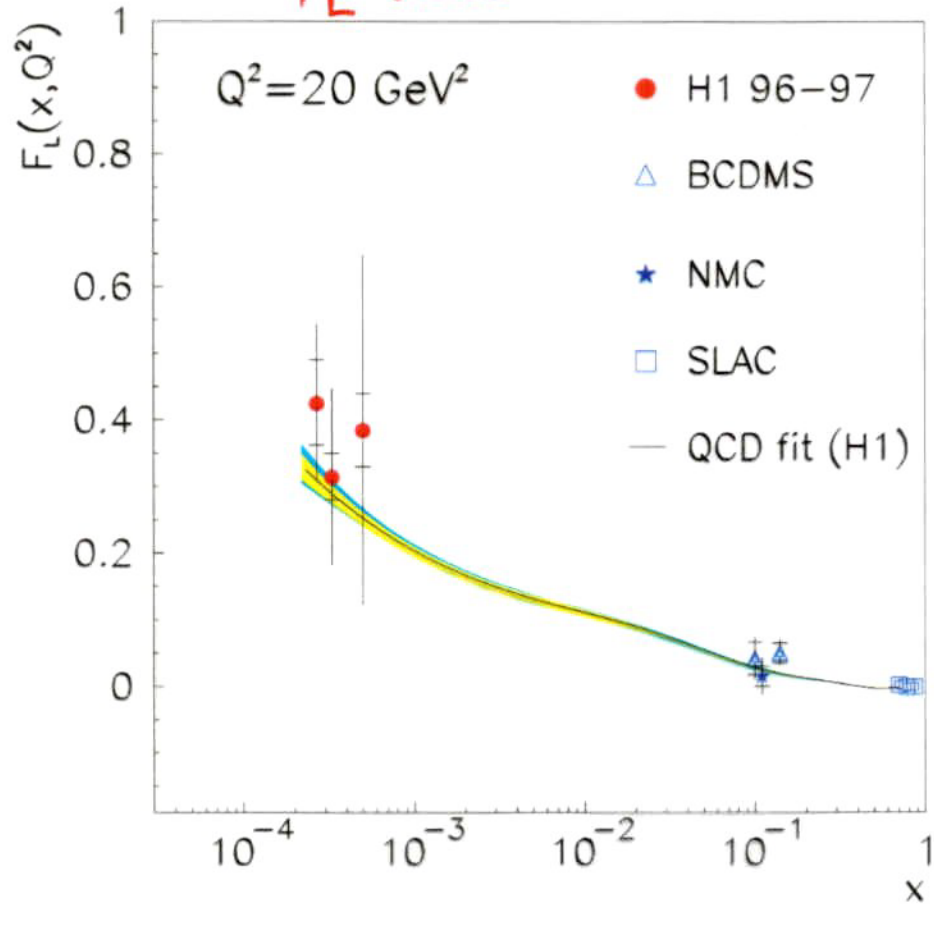
high $y \gtrsim 0.6$
see effect of F_L

$y = Q^2 / s x$
low x only.

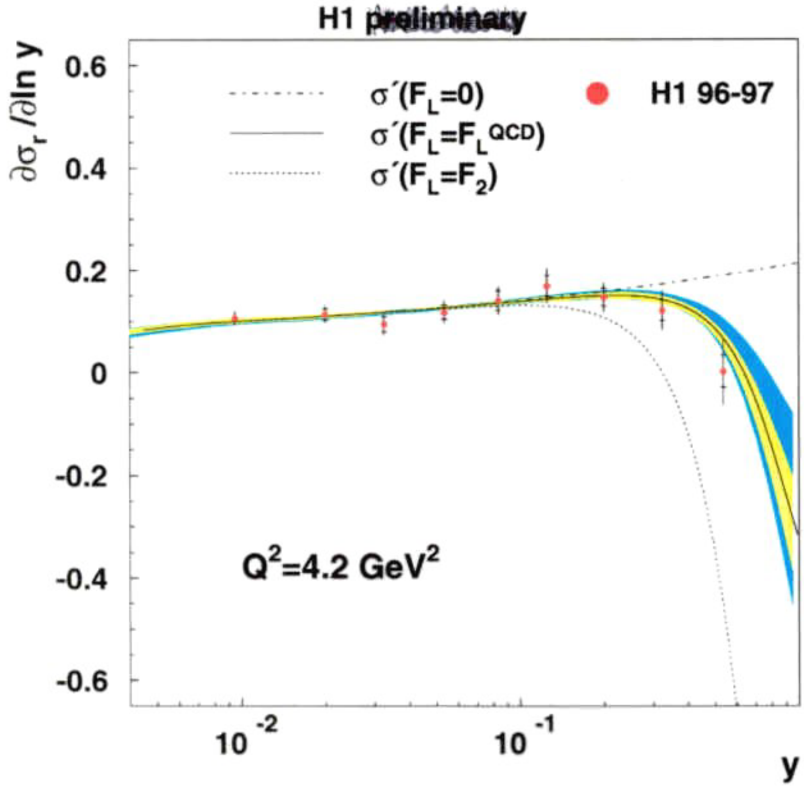
$y \simeq 1 - E_e' / E_e$

- $E_e' \gtrsim 3$ GeV
exp. challenge!
eID, γp bgd.

F_L data



use F_2^{QCD} to
extract F_L.

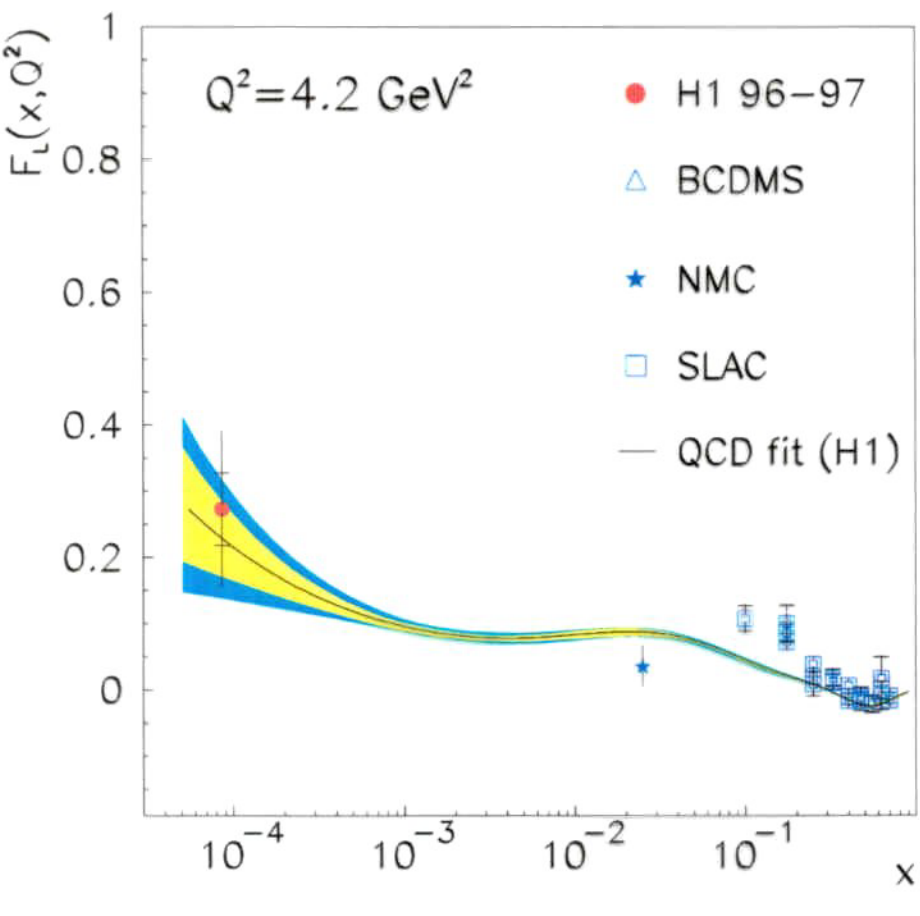


derivative method

low $Q^2 < 10\ GeV^2$

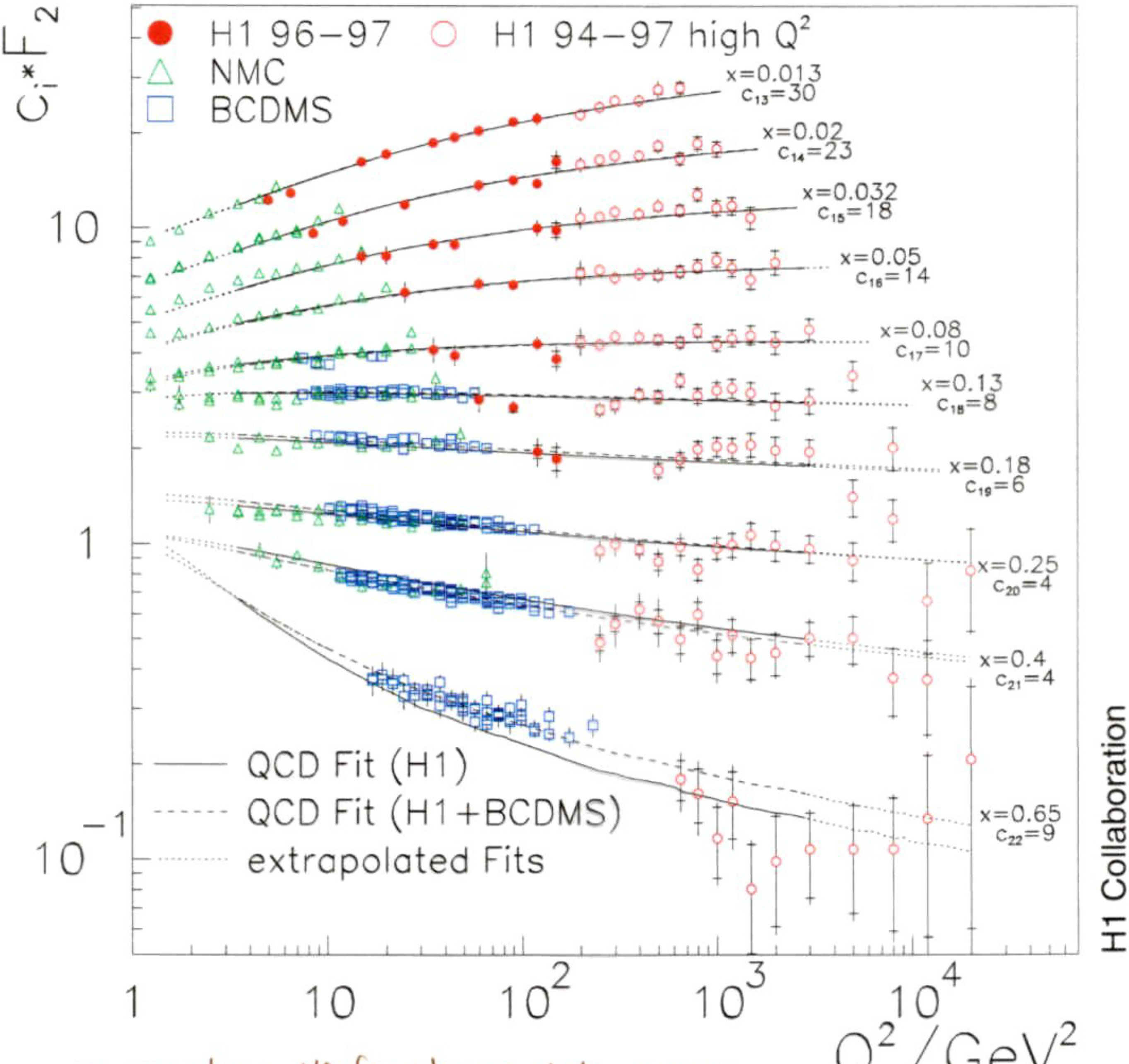
$$\left(\frac{\partial\sigma_r}{\partial \ln y}\right)_{Q^2} = \frac{\partial F_2}{\partial \ln y} - F_L \cdot f(y)$$

$$F_2 \sim x^{-\lambda} \sim y^{\lambda}$$



a precise measurement of α_s from $F_2^{e,\mu p}$ by H1

hep-ex/0012053



- ● overlap with fixed target data $y_e < 0.01$
- ○ high Q^2 access of valence quark region [and el. weak effects]
- □ BCDMS data, cut at $y_\mu = 0.3$, use > 0.3

⇑ HERA $\mathcal{L}$ upgrade! $e^\pm(\lambda)$ to 1 fb^{-1}

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

$$\delta = \int(\overline{u}-\overline{d})dx$$ NuSea $-.118 \pm .011$

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

external constraints

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

NuTeV $\varepsilon = -0.08$

$xg(x,Q^2)$

2+1 parametrizations, ep only, no d

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

momentum conservation

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

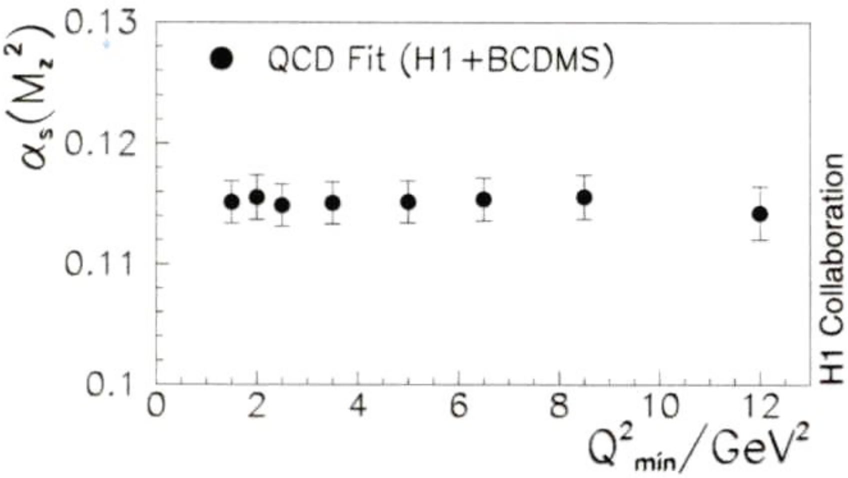
general par'n ansatz, $\chi^2(a, \ldots f)$

sophisticated error treatment

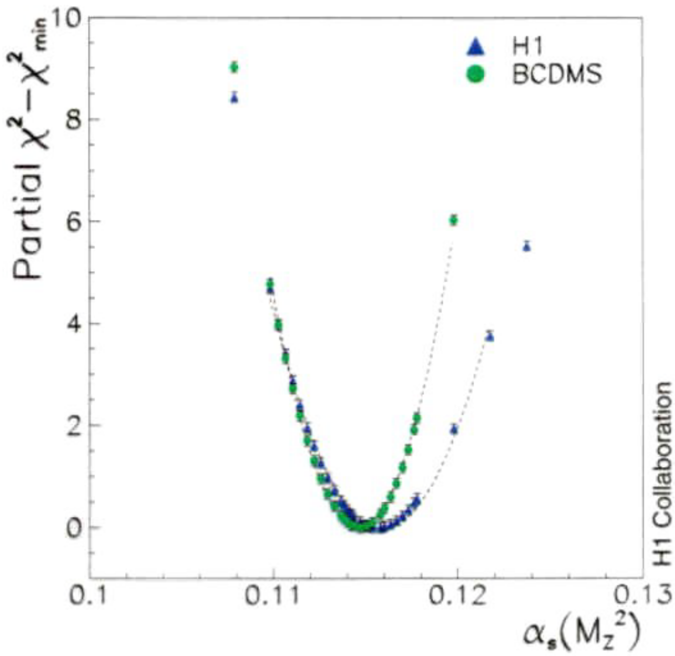
exp. thy norm. corr. syst. errors

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

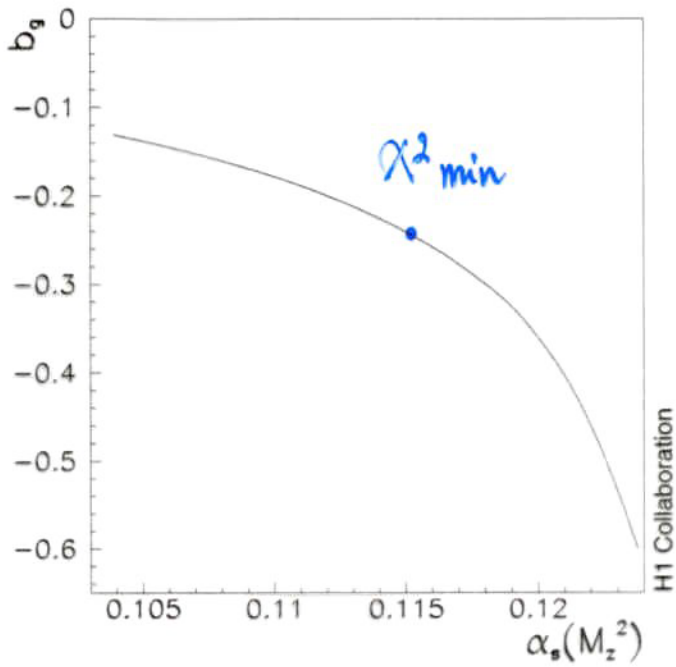
data sets points uncorr. errors penalty



- α_s indep of Q^2_{min}, i.e. indep of x_{min} !



- H1 & BCDMS consistent.



- $\alpha_s \longleftrightarrow b_g$

$xg \sim x^{-b_g}$

$$\alpha_s(M_Z^2) = 0.1150 \pm 0.0017(\text{exp}) \pm 0.00{}^{09}_{05}(\text{model})$$

DGLAP, NLO, proton data H1 $Q^2 \geq 3.5$ GeV^2
BCDMS $Q^2 \geq 6.5$ GeV^2

$\mu_r^2 = m_r \cdot Q^2$, $m_r \in 1/4 \ldots 4$: $\Delta\alpha_s = 0.005$
m_f

↳ requires NNLO

H1 alone : 0.115 ± 0.005 (exp)
high x precision, low E_p for improving δ_{exp}.

H1 + NMC : 0.116 ± 0.003 (exp)
$Q^2 \geq 6.5$
BCDMS leads to superior result

H1+ BCDMS p+d : 0.1158 ± 0.0016 (exp)
consistent with p alone.

H1+BCDMS. $m_Q=0$: 0.1153 ± 0.0017 (exp)
heavy flavour treatment: small influence

⋮

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

Santiago, Yndurain : 0.1163 ± 0.0023

SLAC, BCDMS, E665, HERA94. $b_G = -0.44$ fixed. moments-extended to NNLO.

Σ

- HERA has opened the field of low x physics
  - parton saturation? new state of matter?
  - DGLAP evolution equations applicable down to low $Q^2 > 1\ GeV^2$ and $x \gtrsim 5 \cdot 10^{-5}$
  - $Q^2 < 1\ GeV^2$: Regge theory

- F_2 and $xg|_{DGLAP}$ rise towards low x. don't saturate

- scaling violations of F_2 at low x determine F_L, F_2^c consistent with measurements.

- $\alpha_s = 0.1150 \pm 0.0017_{exp} {}^{+0.0009}_{-0.0005}$ mod.

  with $\delta_{thy} \simeq \pm 0.005$ Nr.

  low x and α_s xg are correlated

- $HERA_{II}$: high $\mathcal{L}$ and increased precision may lead to surprises and will help to establish a "respectable low x theory" PVL.

upgraded detectors

95 - 01 - 07 ?

diffraction
fwd jets.
..

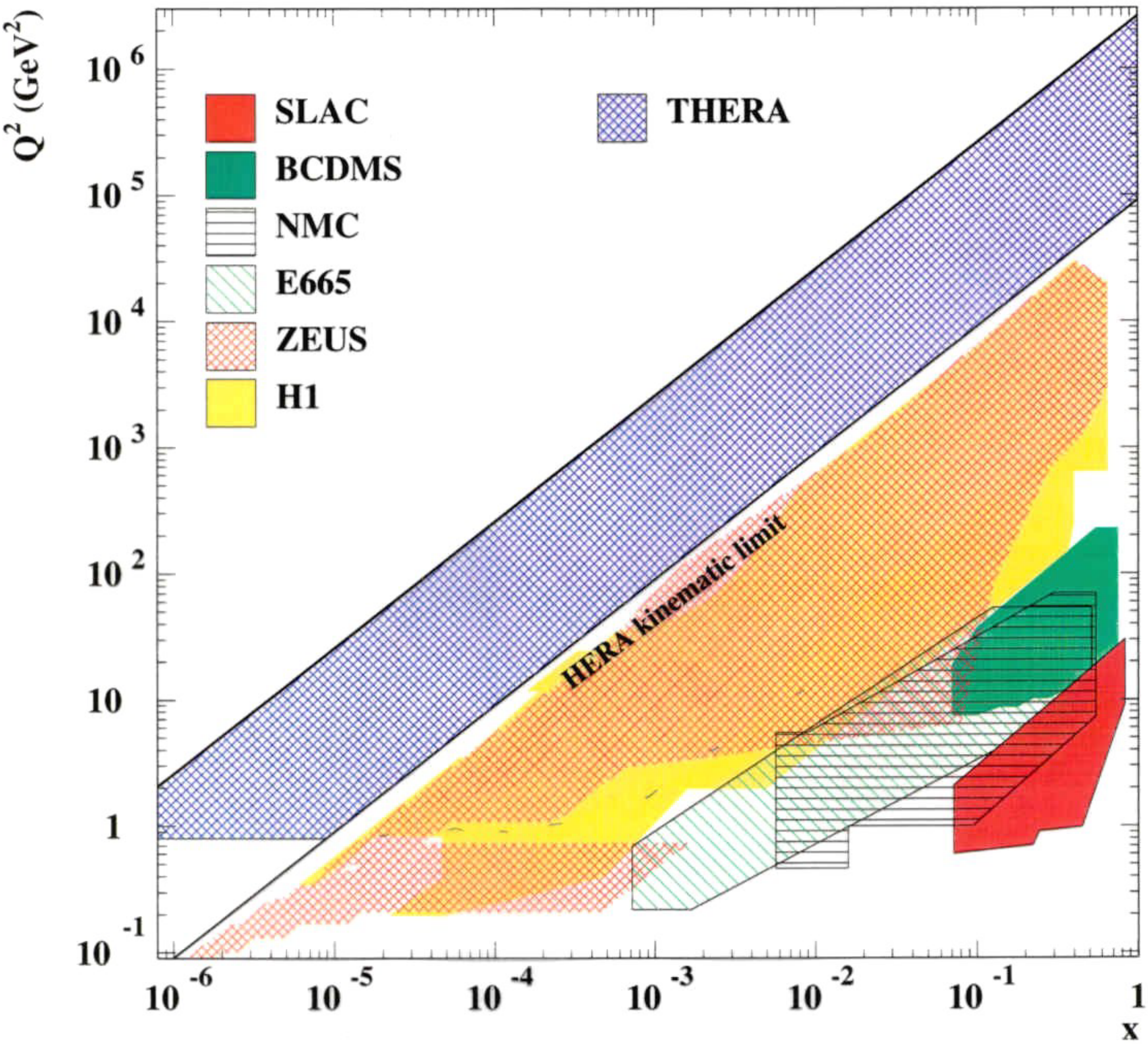
○ tomorrow @ DESY : release of TESLA (e^+e^-) TDR & THERA appendix.

HERA$_p$

$\mathcal{L} \lesssim 2.5 \cdot 10^{31} cm^{-2} s^{-1}$
$\leftrightarrow \lesssim 250 pb^{-1}$/year

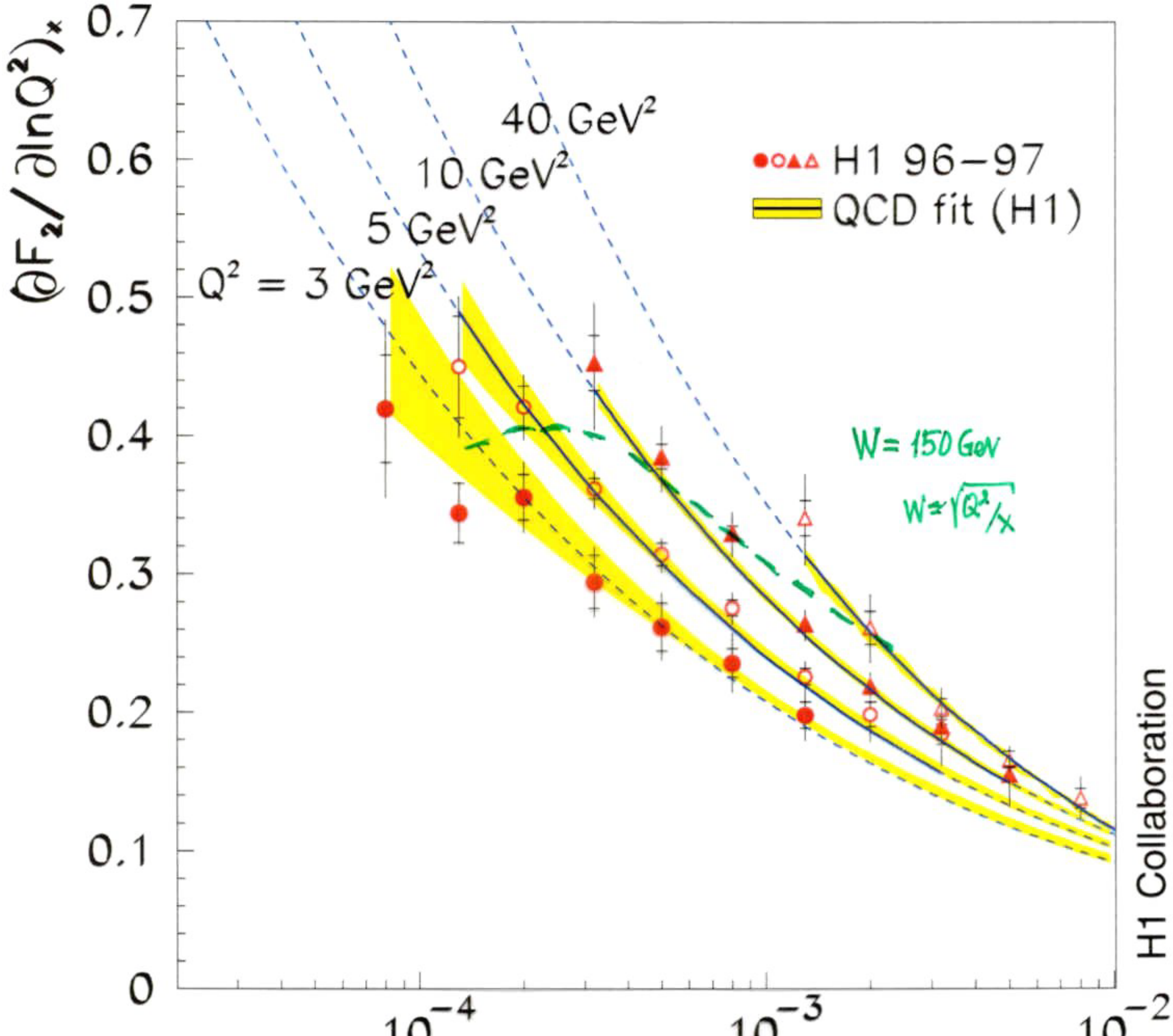
→ E_e : 250 ... 800 GeV * E_p 300 GeV ... 1 TeV

* see TDR and THERA Webp. www.ifh.de/thera



- there is an option for ep to match with e^+e^-, pp accel. developments.
  - low x: saturation in DIS region?
  - p substructure at 10^{-19} m ?

[rich program, see report *
ed. by M. Katz, MK, A. Levy.
~ 120 co-authors of ~40 institutes



$(\partial F_2/\partial \ln Q^2)_x$
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
40 GeV²
10 GeV²
5 GeV²
Q² = 3 GeV²
H1 96–97
QCD fit (H1)
W = 150 GeV
$W \approx \sqrt{Q^2/x}$
10^{-4}
10^{-3}
10^{-2}
x
H1 Collaboration