Structure Functions at Medium Q^2 at HERA

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On Behalf of

- Introduction
- F_2 measurement
- QCD fit
  - ⇒ determination of the gluon density inside the proton
  - ⇒ measurement of α_s
- Determination of F_L

Introduction

- **DIS cross-section** $e^{\pm} + p \to e^{\pm} + X$

$$\frac{d\sigma}{dx dQ^2}\Big|_{Q^2 \ll M_Z^2} = \frac{2\pi\alpha_{em}^2}{xQ^4} Y_+ \left[F_2(x,Q^2) - \frac{y^2}{Y_+} F_L(x,Q^2) \right]$$

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

  $\Rightarrow$ F_2 **determined at small** y

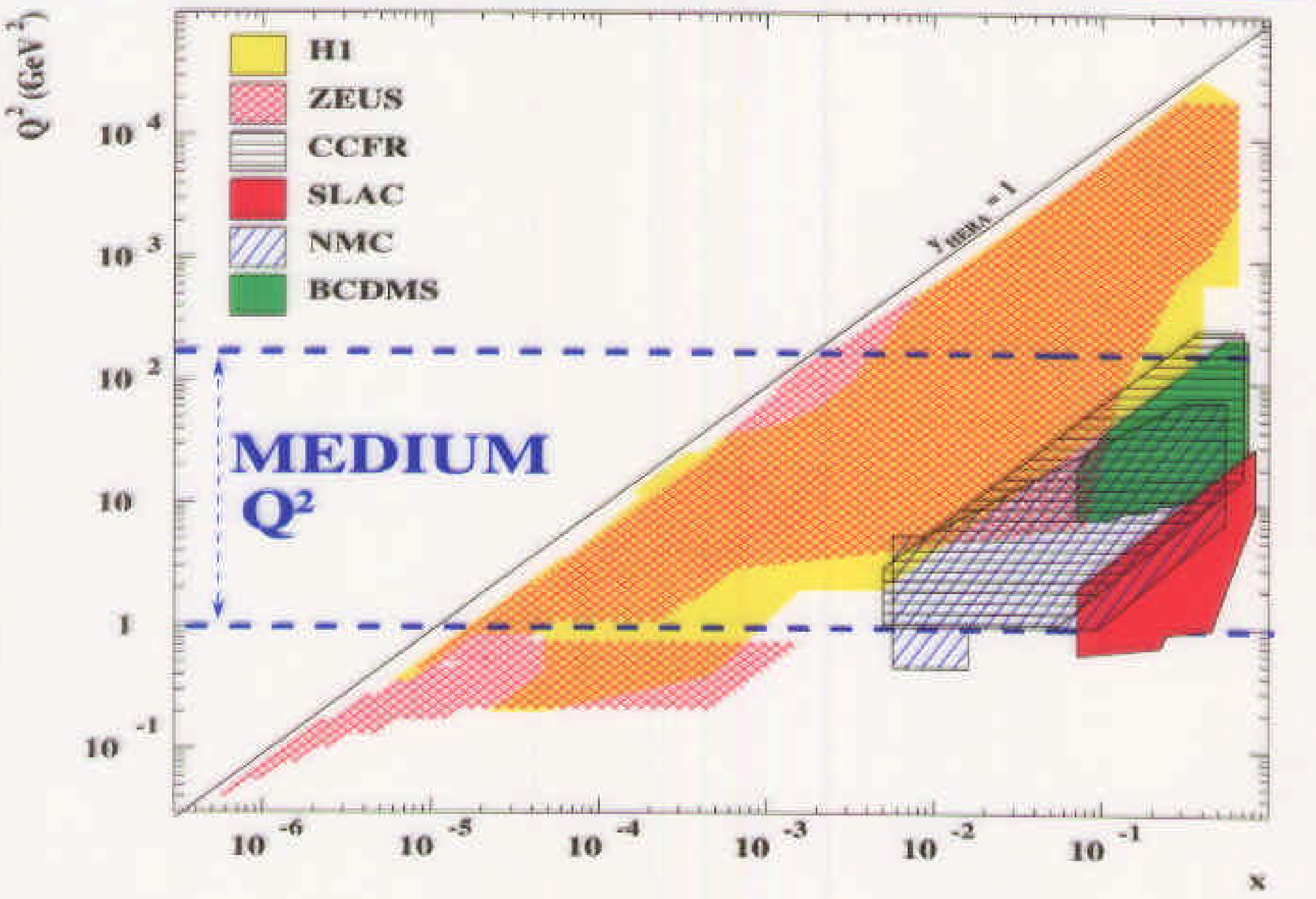
  $\Rightarrow$ F_L **contributes at high** y

- F_2 & F_L **computable with perturbative QCD**

- **Measurements of** $d\sigma/dxdQ^2$ **at** $Q^2 \ll M_Z^2$

  $\Rightarrow$ test of perturbative QCD

Kinematic Domain



Luminosity in 96/97:

ZEUS: 1 **GeV**^{2} < **Q**^{2} < 25 **GeV**^{2}: **2.2 pb**$^{-1}$

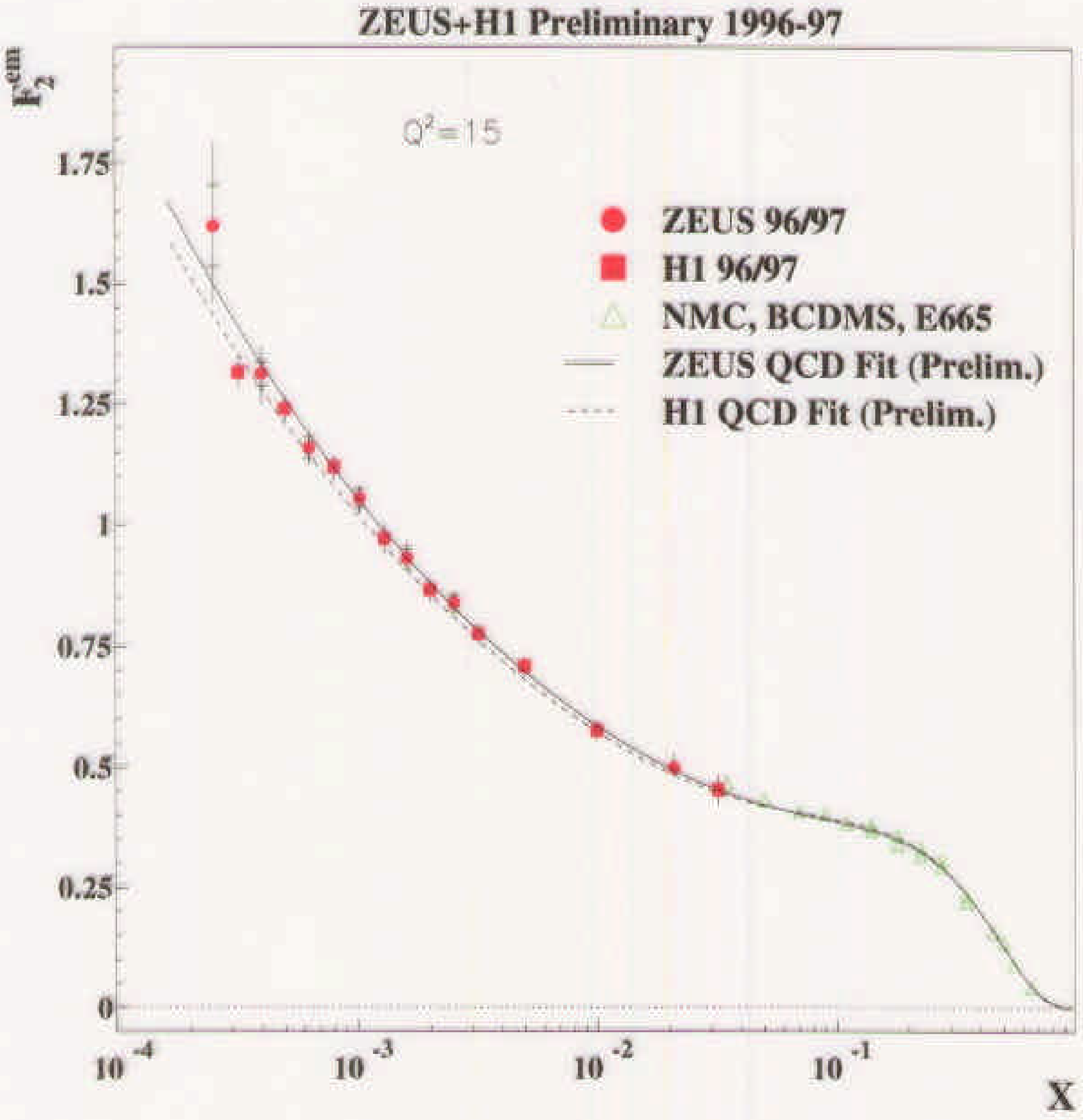
Q^2 > 25 **GeV**^{2}: **30.2 pb**$^{-1}$

H1: 1.5 **GeV**^{2} < **Q**^{2} < 12 **GeV**^{2}: **1.8 pb**$^{-1}$ (dedicated run 97)

12 **GeV**^{2} < **Q**^{2} < 150 **GeV**^{2}: **17.9 pb**$^{-1}$

high y> 0.6: **6.2 pb**$^{-1}$

$F_2(x)$: HERA vs. fixed target



- **High precision** 1%(**stat**)$\oplus$2-3%(**syst**)
- **Good agreement between H1 and ZEUS**
  (≈ 4% rel. normalization)
- **Overlap is achieved with fixed target experiments**
- **Strong rise towards low x** ($F_2 \propto x^{-\lambda}$)

H1 NLO QCD fit

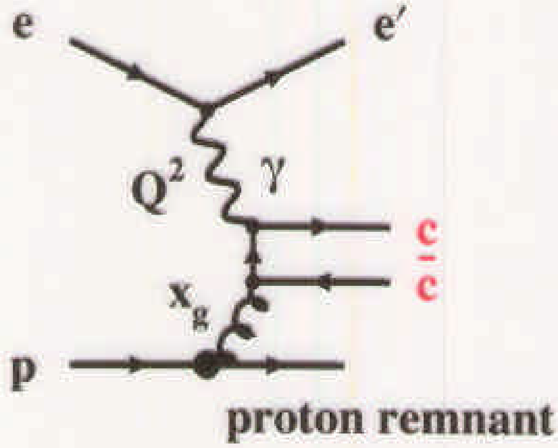
- **'Medium Q^2 fit'**: $\mathcal{O}(1)$ **GeV²** $< Q^2 \leq 3000$ **GeV²**

  ⇒ Light quarks = u,d,s from NLO DGLAP eq.

  [xg and quark densities are coupled by the DGLAP eq.]

  ⇒ c contributions: $m_c \approx 1.4$ GeV

  (γg-fusion process + NLO corrections)



$$\Rightarrow F_2^{LO} = \tfrac{4}{9}(u+\bar{u}) + \tfrac{1}{9}(d+\bar{d}+s+\bar{s}) + F_2^{c\bar{c}}$$

- **Goal**

  – Extract α_s and xg simultaneously using the simplest QCD fit procedure

  ⇒ Proton target data only (D target data avoided)

  (⇒ 1'st step for QCD fits to HERA data alone)

H1 QCD Fit

- **Proton target**

⇒ 2 quark combinations + xg to describe F_2

- Singlet: $\Sigma \equiv u + \bar{u} + d + \bar{d} + s + \bar{s}$
- Non-Singlet: $\Delta \equiv u + \bar{u} - 1/3 \times \Sigma$

$\rightarrow F_2^{u,d,s}(x, Q^2) \equiv 2/9 \times x\Sigma(x, Q^2) + 1/3 \times x\Delta(x, Q^2)$

- Q^2 dependence of xg, Σ & Δ from DGLAP equations, in LO:

$$\frac{\partial \Delta}{\partial \log Q^2} = \frac{\alpha_s}{2\pi} P_{qq} \otimes \Delta$$

$$\frac{\partial}{\partial \log Q^2} \begin{pmatrix} \Sigma \\ g \end{pmatrix} = \frac{\alpha_s}{2\pi} \begin{pmatrix} P_{qq} & n_f P_{qg} \\ P_{gq} & P_{gg} \end{pmatrix} \otimes \begin{pmatrix} \Sigma \\ g \end{pmatrix} \Leftarrow \left\{ \begin{array}{l} \frac{dF_2}{d \log Q^2} \propto \alpha_s \times xg \\ \text{for } x \rightarrow 0 \end{array} \right.$$

⇒ Low-x (HERA) data alone can determine xg for fixed α_s

⇒ Low-x (HERA) + high-x (BCDMS) data required to determine α_s & xg simultaneously

- Constraints:

  Momentum sum-rule &
  Valence counting rule $\Rightarrow$ flavour decomposition of Σ & Δ

- Solution of DGLAP $\rightarrow$ parametrisation of pdf [redacted]

  $$\Rightarrow xq = A_q x^{B_q}(1-x)^{C_q}(1+D_q x + E_q\sqrt{x}),$$

  at $Q_0^2 = 4$ GeV ^{2}, $(A_a, ..., E_q)$ determined by a fit to

  H1 + BCDMS H data SUCH

  $W^2 > 10\,\mathrm{GeV}^2$, $3.5\mathrm{GeV}^2 \leq Q^2 < 3000\,\mathrm{GeV}^2$

  $y_{BCDMS} > 0.3$ (because of systematics)

  $\Leftrightarrow$ Perturbative kinematic domain

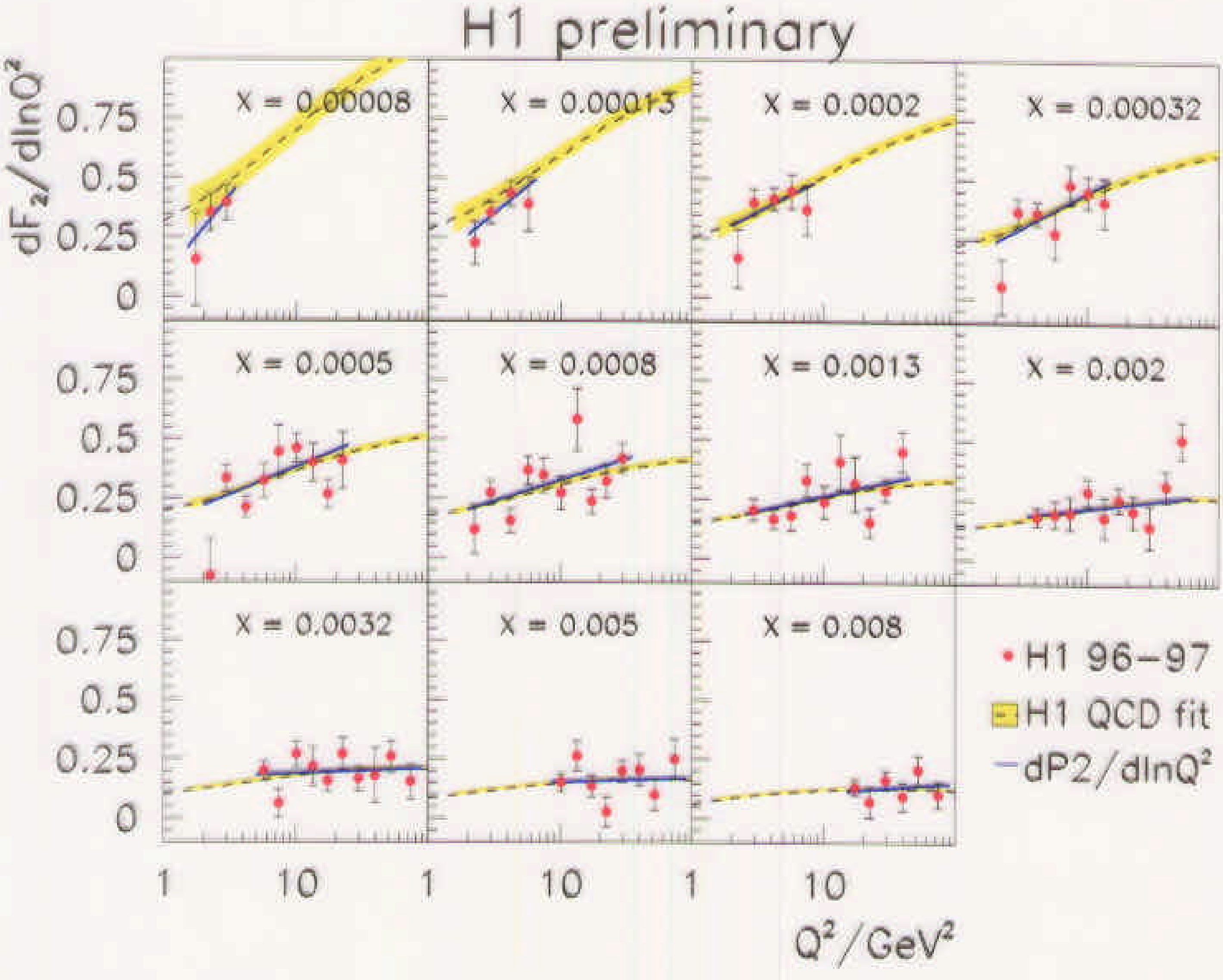
- α_s running and determined by the fit

- $\approx 10^5$ fits performed $\Rightarrow$ search for 'stability region'...
  – Ntuple type of analysis obtained by varying all fit ingredients: Q_0^2, data cuts, systematic & data normalisation treatments, m_c, m_b, parametrisation forms (up to 8 functionals), data samples (BCDMS, H1, NMC) AND α_s.

- Fit results $\Rightarrow \chi^2/dof = 0.9$

Precision F_2 at Low x, Q^2

$$\frac{dF_2}{d\log Q^2} \propto \alpha_s \times xg$$

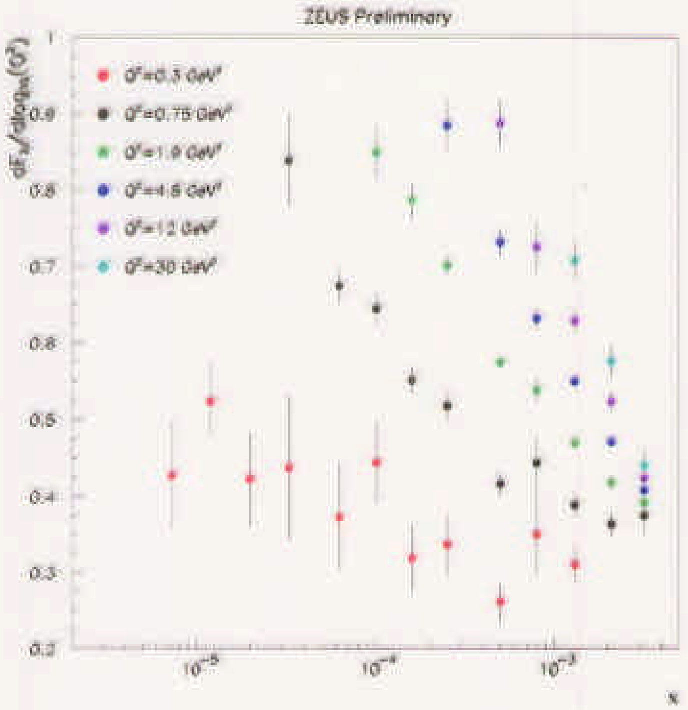


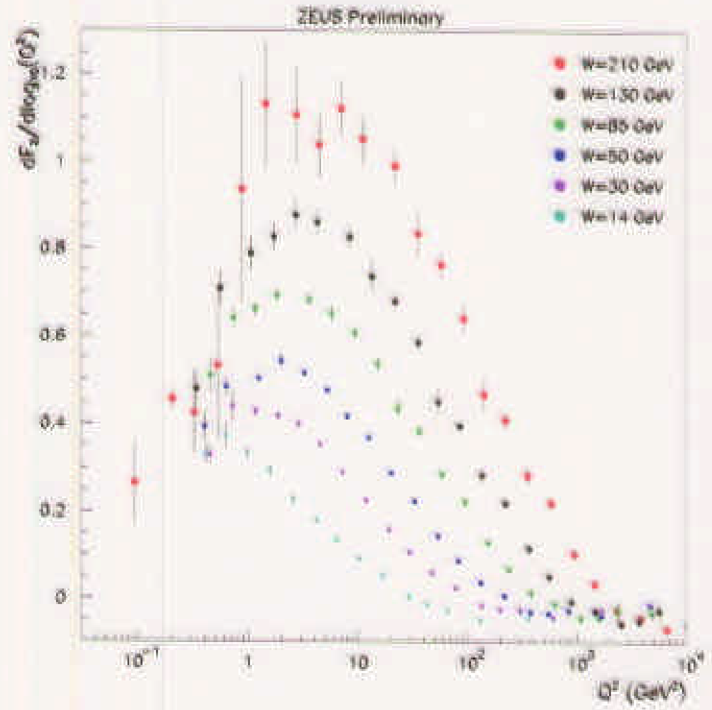
⇒ Local derivatives ⇔ scaling violations

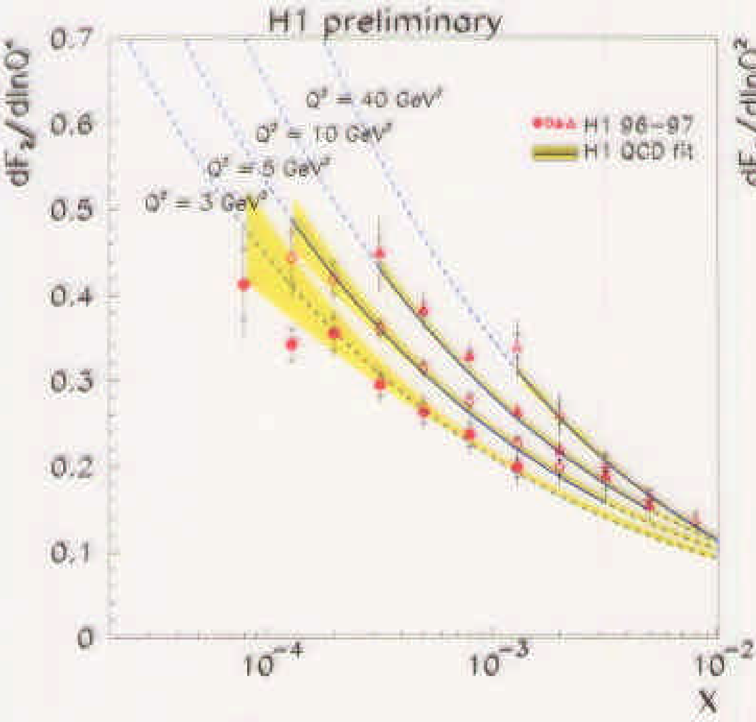
NLO QCD Fit results in good agreement with the data

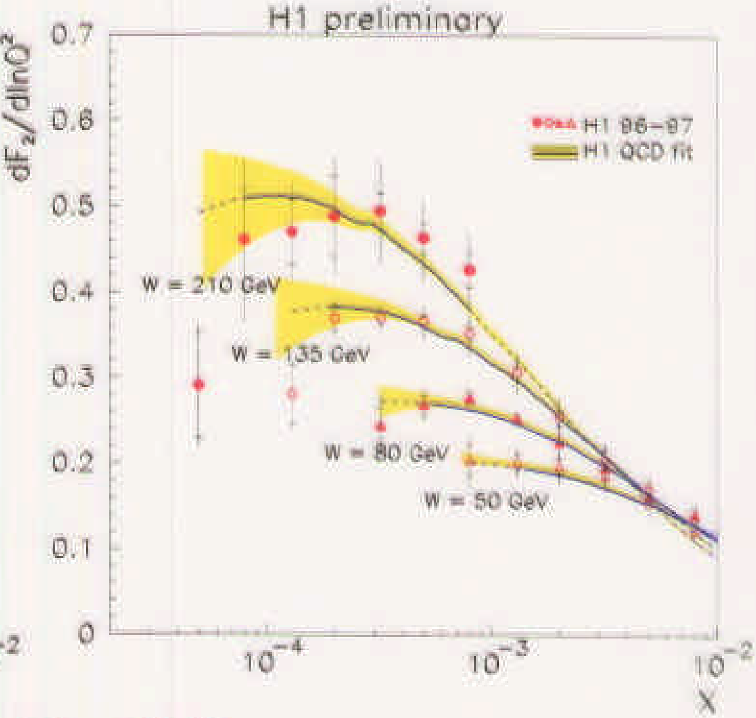
Slopes at fixed x and W^2

- 2 dimensional $\frac{d \log F_2}{d \log Q^2}$







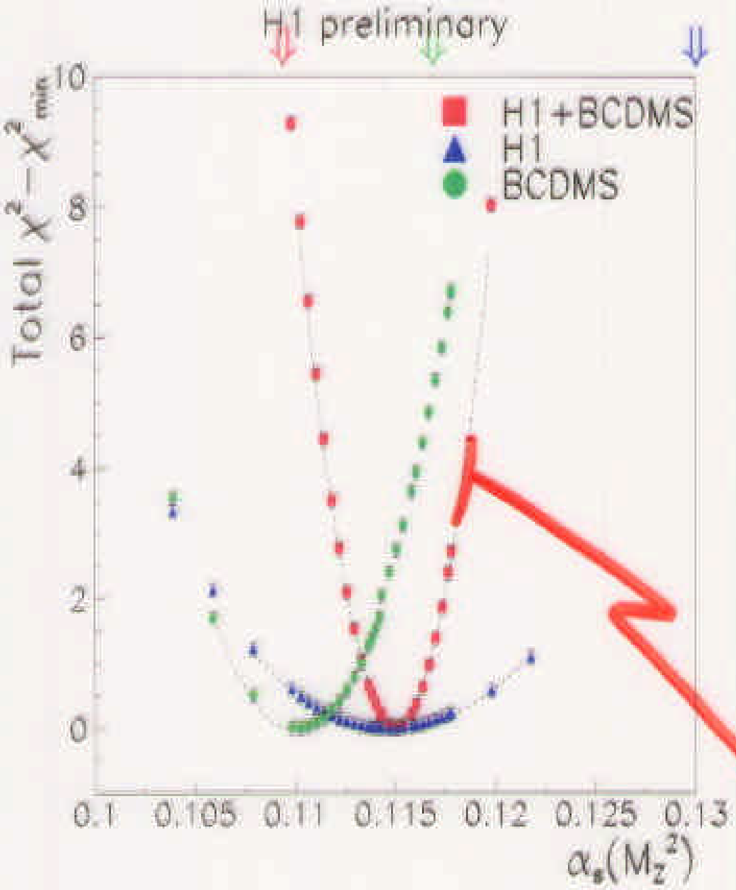


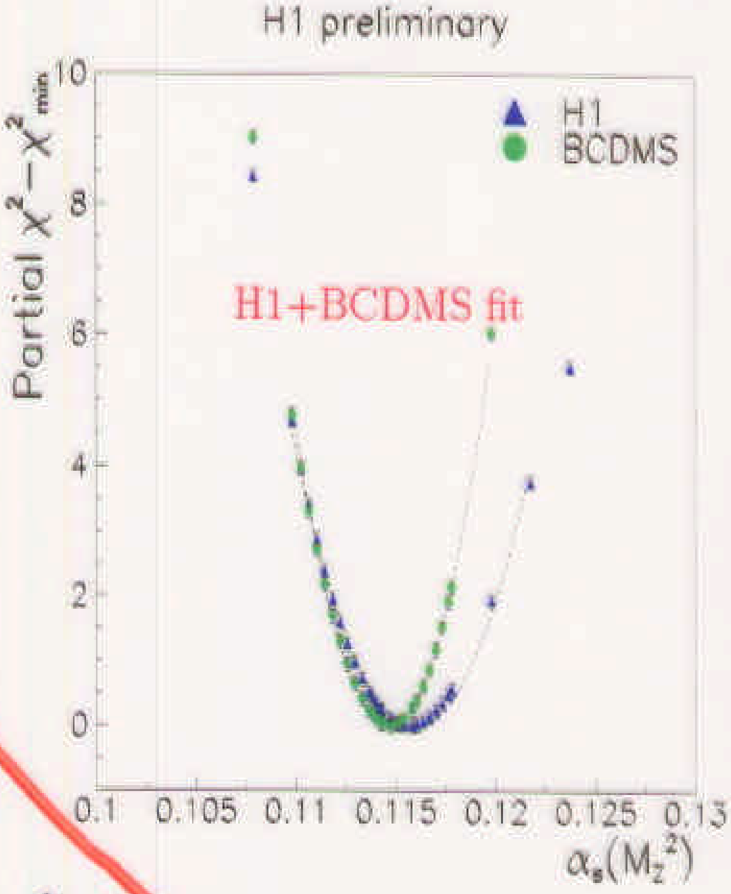
⇒ Turn-over well described by QCD

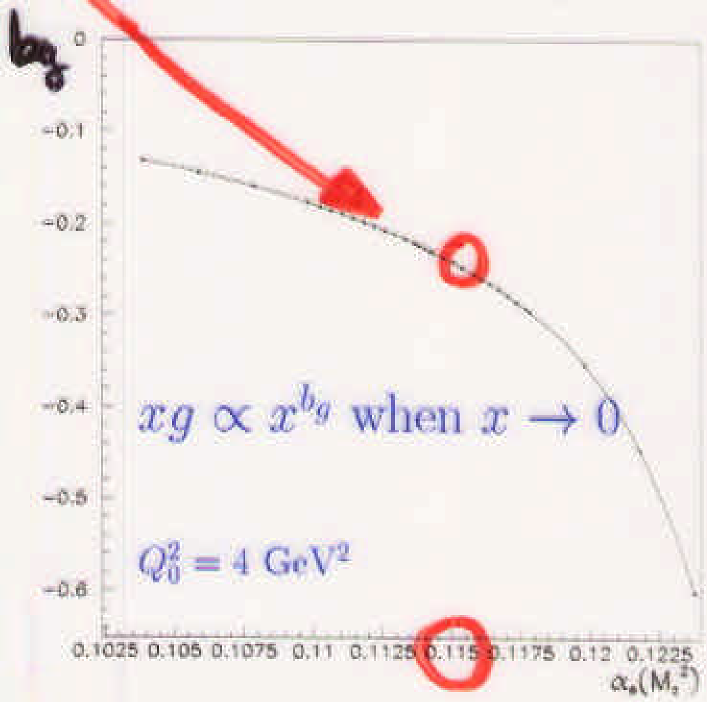
Measurement of α_s

- 3 fits compared:

H1+BCDMS, BCDMS alone , H1 alone







- HERA+BCDMS versus BCDMS:

→ shift of the minimum ⇒

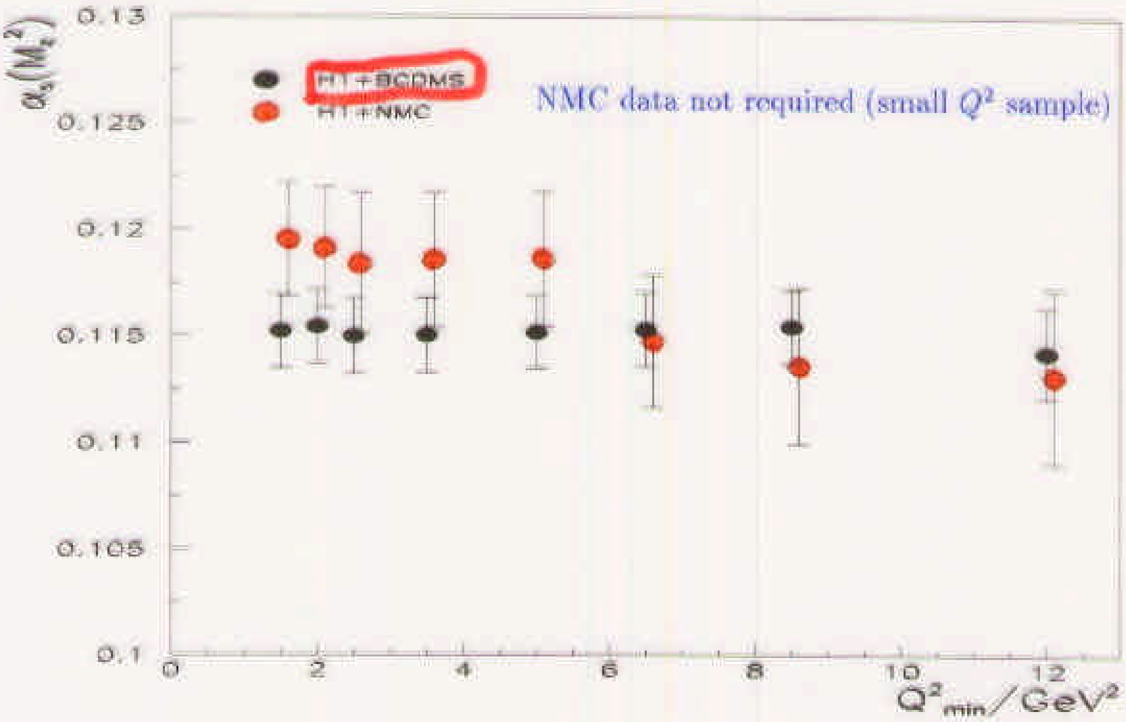
→ decrease of the uncertainty

- Complementarity of low-x & high-x

Measurement of α_s

- Stability criteria of H1+BCDMS fit:

Example : Q^2_{min} variation = Q^2 cut on data in the fit



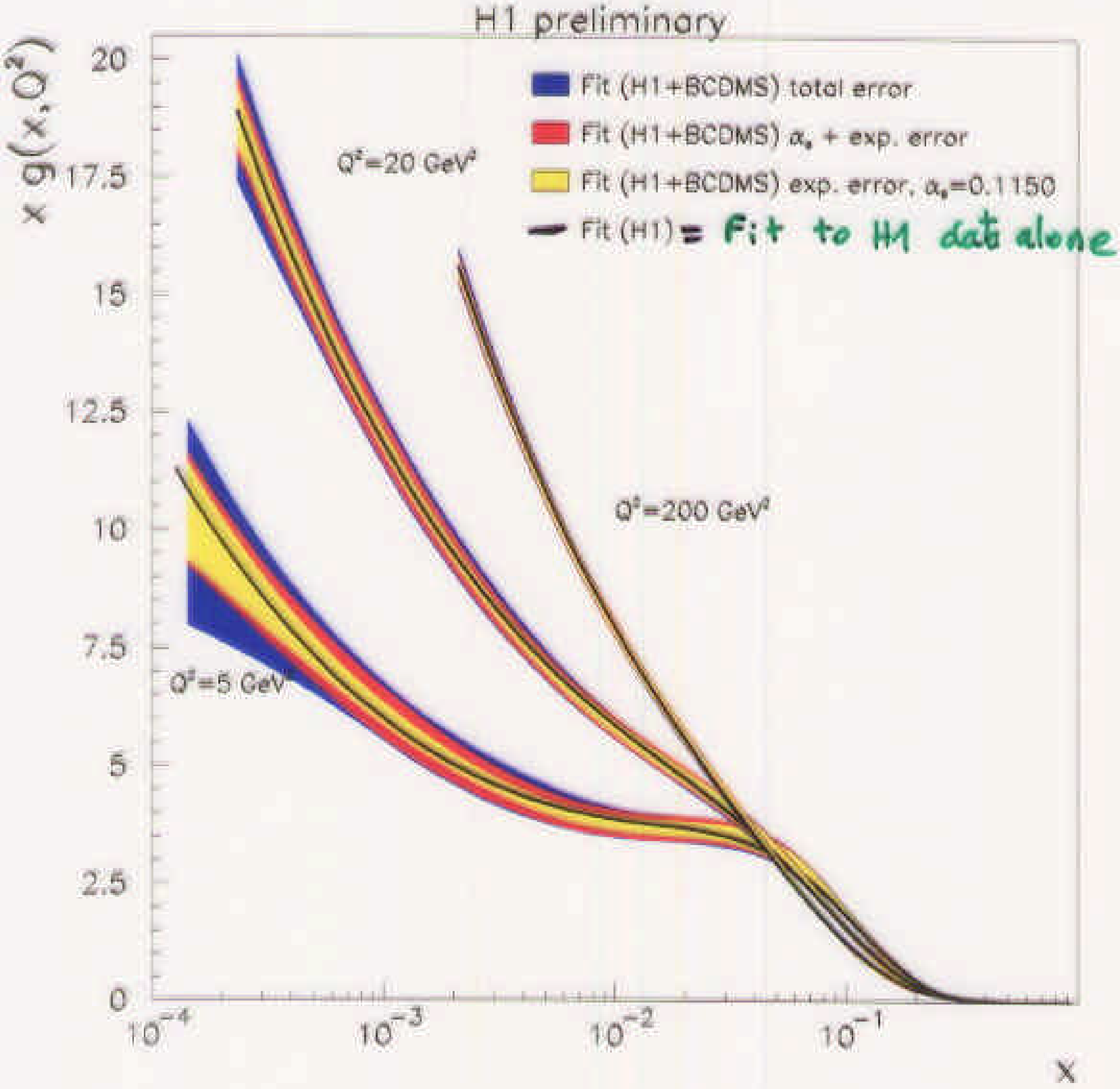
- Result -H1+BCDMS fit (preliminary)

$$\alpha_s(M_Z) = 0.1150 \pm 0.0017(exp)\ ^{+0.0011}_{-0.0012}(model)$$

- Model err. = variation of : Q^2, y and x data rejection cuts, data normalisations & systematics fixed (or not), Q^2_0, param. forms (up to 8 functionals), flavor decomposition, m_c, m_b

- Scale err. $\simeq 0.005$ not included

Gluon Density from inclusive fit



Model uncertainties: $\Delta\alpha_s$ (exp), Δm_c, Q_0^2 variations, input functions ...

⇒ Model uncertainties dominating Δxg ...

Main Differences wrt Global Fits(MRS(T), CTEQ):

Only ep & μp inclusive DIS data used

Correlated syst. errors taken into account → error bands

Emphasis put mainly on xg at low x

Determination of F_L

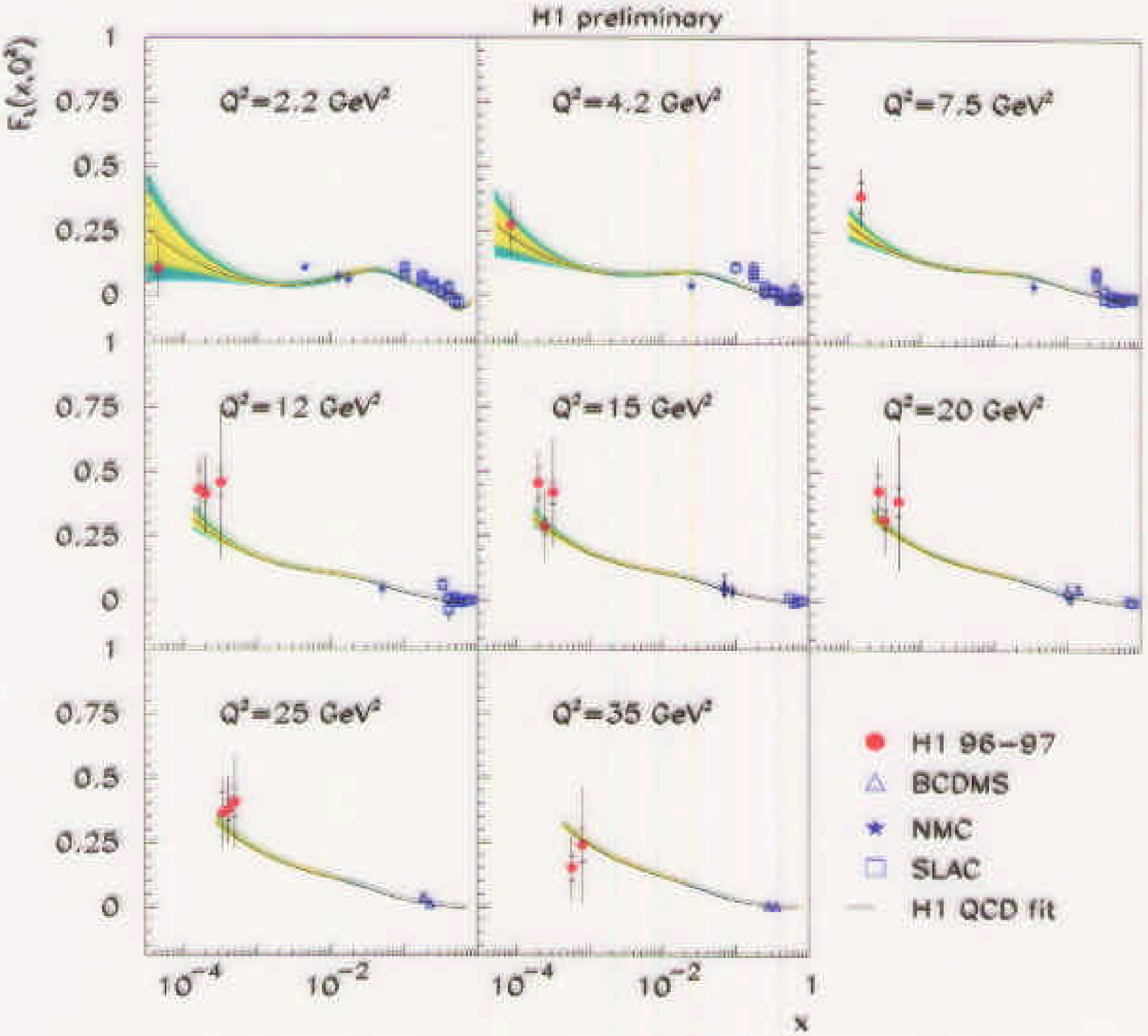
- Previous method $Q^2 > 10$ GeV^2:

$$\sigma_r \equiv \frac{xQ^4}{2\pi\alpha_{em}^2 Y_+}\frac{d^2\sigma}{dx dQ^2} = F_2 - \frac{y^2}{Y_+}F_L \quad \Rightarrow F_L = F_2^{QCD/y<0.35} - \sigma_r$$

- New Method $Q^2 < 10$ GeV^2:

$$\frac{d\sigma_r}{d\log y} = \frac{dF_2}{d\log y} - 2y^2\frac{2-y}{Y_+^2}F_L - \frac{y^2}{Y_+}\frac{dF_L}{d\log y}$$

$$\Rightarrow F_L = \frac{Y_+^2}{2y^2(2-y)}\left(\frac{dF_2}{d\log y} - \frac{d\sigma_r}{d\log y} - \frac{y^2}{Y_+}\frac{dF_L}{d\log y}\right)$$



Summary

F_2 preliminary measurements at medium Q^2:

- $\Delta F_2/F_2 \approx 1\%$ stat & $\approx 3\%$ syst
- Agreement between H1 & ZEUS within overall norm.

DGLAP QCD fit to $d^2\sigma/dx/dQ^2$

- First fit to H1+BCDMS proton data alone
- Extraction of xg and α_s simultaneously
- $\Delta xg/xg \approx 3\%(exp)$ at $Q^2 = 20$ GeV^2 and $x = 10^{-3}$
- $\alpha_s(M_Z) = 0.1150 \pm 0.0017(exp)\,^{+0.0011}_{-0.0012}(model)$
  $\pm 0.005(scale)$
- Account for all correlations due to systematics

Determination of F_L

- 2 methods: σ_r & $d\sigma_r/d\log y$

  $\Rightarrow$ Agreement of methods and results consistent with QCD