Structure Functions

CIPANP 2000

at high Q^2

Deep Inelastic Scattering
(from low to high x)
at HERA and the Tevatron

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CIPANP 2000 Quebec, May 24th

*supported by PPARC and the Royal Society

Outline

Introduction

Road Maps
Parton Densities

FIXED TARGET RESULTS

NMC d/u
▶ High Energy Predictions
E866 ▶ $\bar{d}/\bar{u}$
▶ Parton Uncertainties

HERA

Low-Q^2 Cross Sections

F_2 Data
Transition Region
Charm Production ▶ F_2^C
F_L Determination
HERA- CCFR-NMC

Tevatron

Jet Production

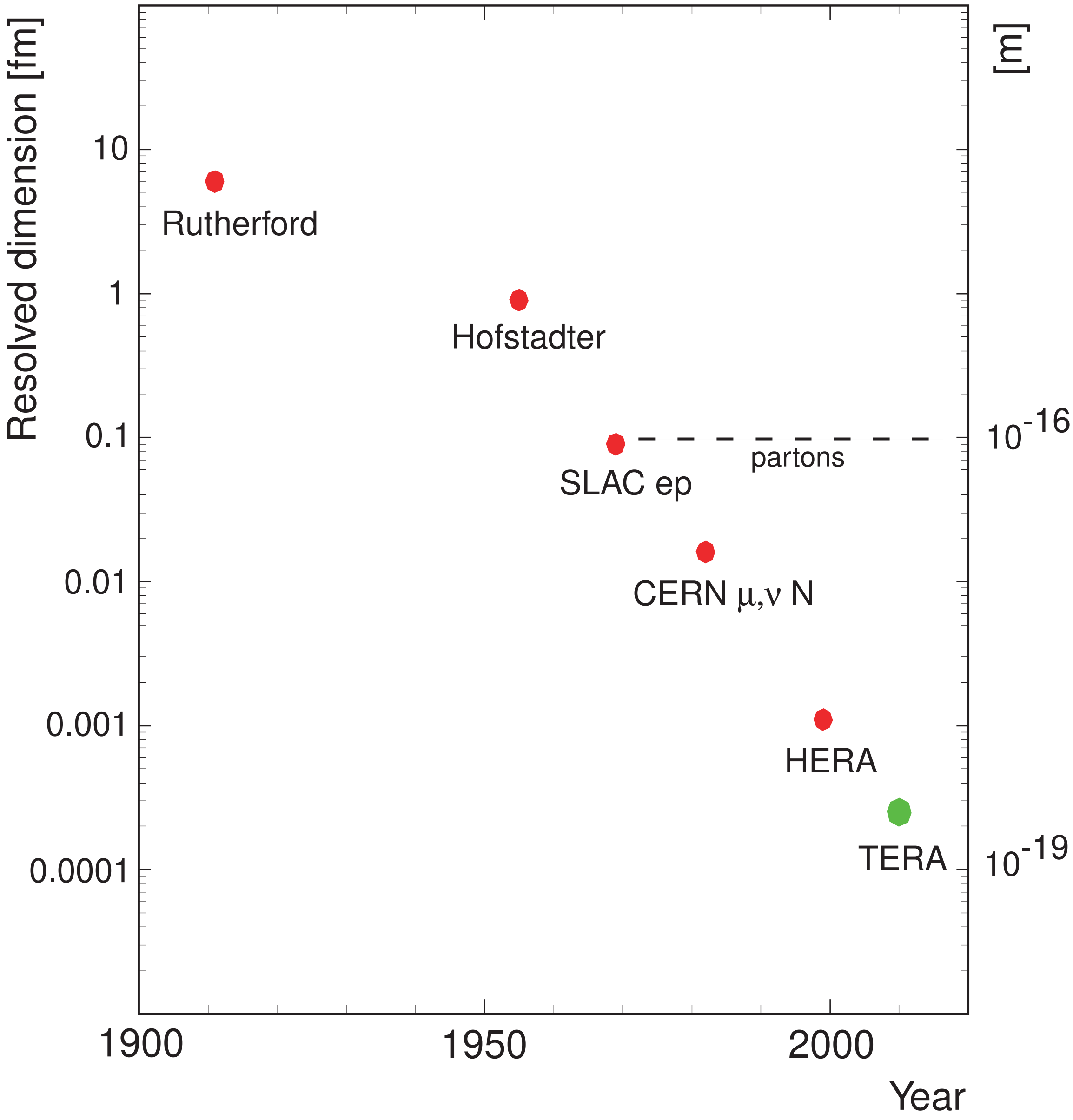
High-Q^2 Cross Sections

HERA Progress
Charged Current
Neutral Current ▶ xF_3

Upgrade and Outlook

Historical Perspective

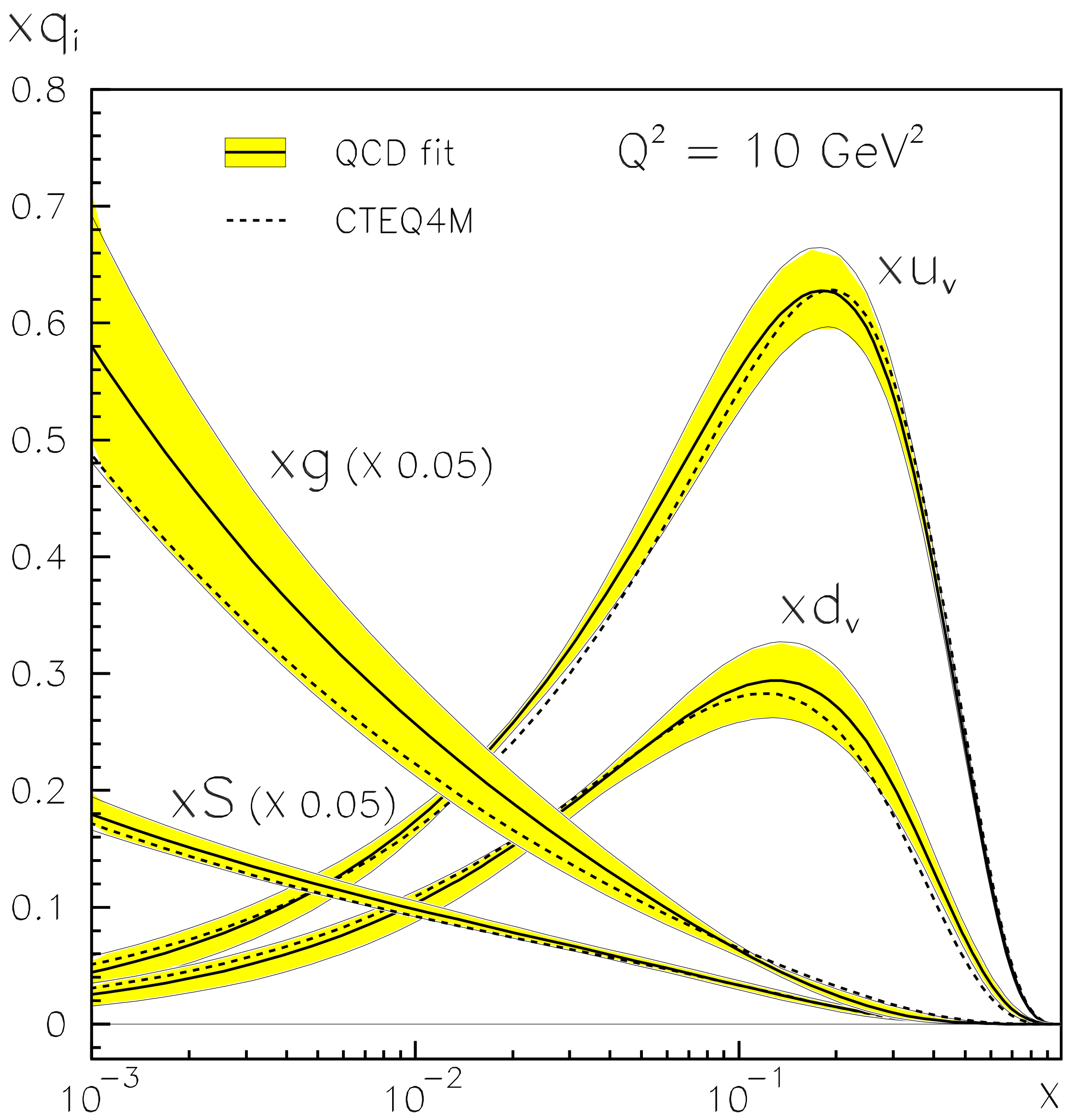
- Future of D.I.S.



- Resolved dimension $= 0.2[\mathrm{GeV.fm}]/Q_{max}$
- TESLA(500 GeV)+HERA(1 TeV)=TERA
- (Proof that Rutherford was 30 years ahead of his time...)

Proton Structure

- Parton Distributions and Uncertainties



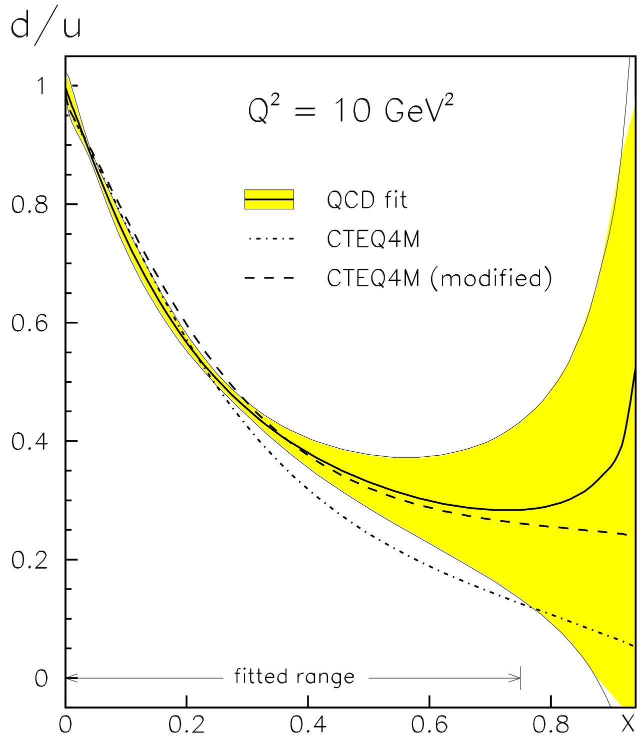
- Not only error bands but correlations
- NLO charm determined from gluon at low x
- Future for MRST, CTEQ and others

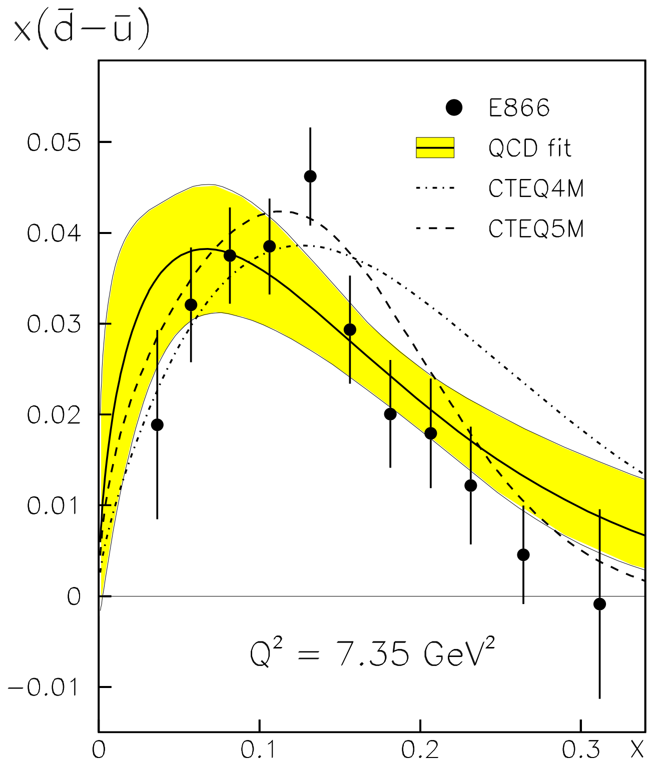
▶ Predictions for HERA, Tevatron and LHC

M. Botje hep-ph/9912439.

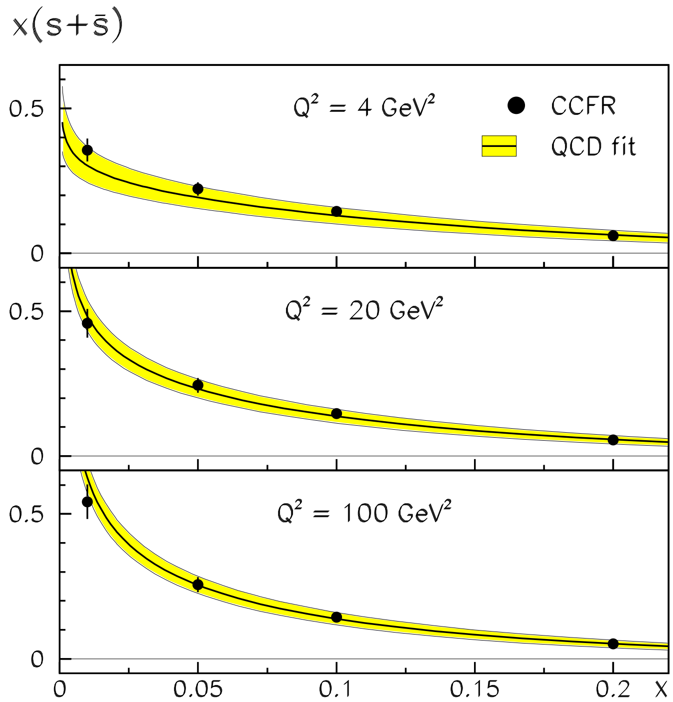
Proton Structure

- d/u, $\bar{d} - \bar{u}$ and $s + \bar{s}$



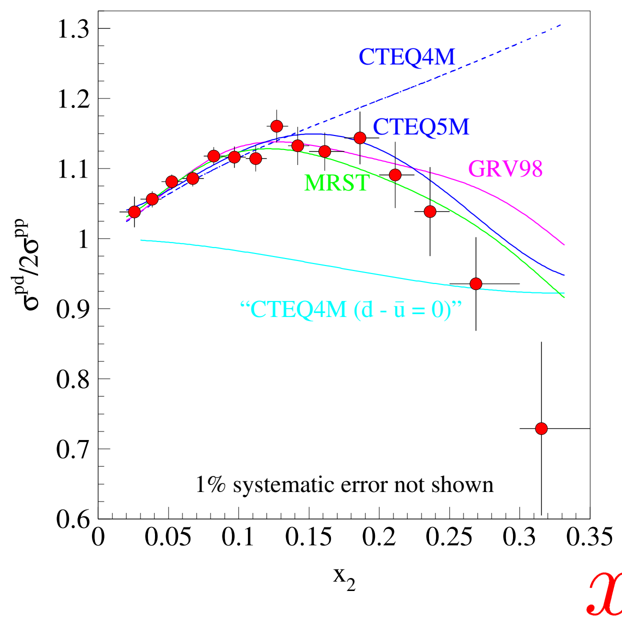


- Large d/u uncertainties at high x
- Reasonable fit to E866 data
- Strange sea from CCFR dimuon data



Sea Quark Distribution

$$\frac{\sigma^{pd}}{2\sigma^{pp}}$$

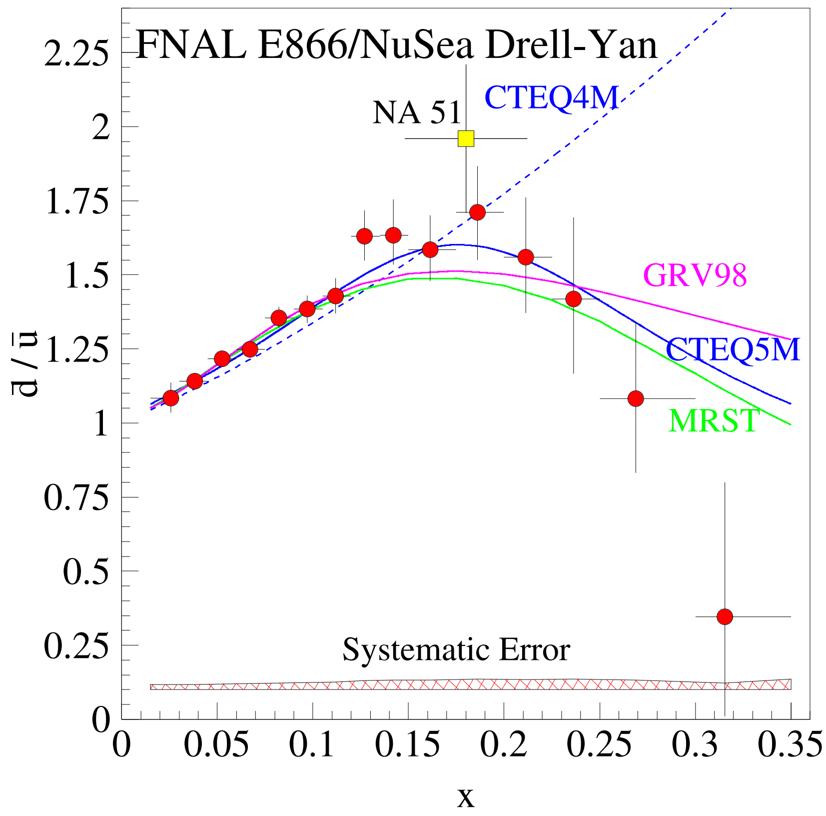


E866 Drell-Yan on proton and deuteron

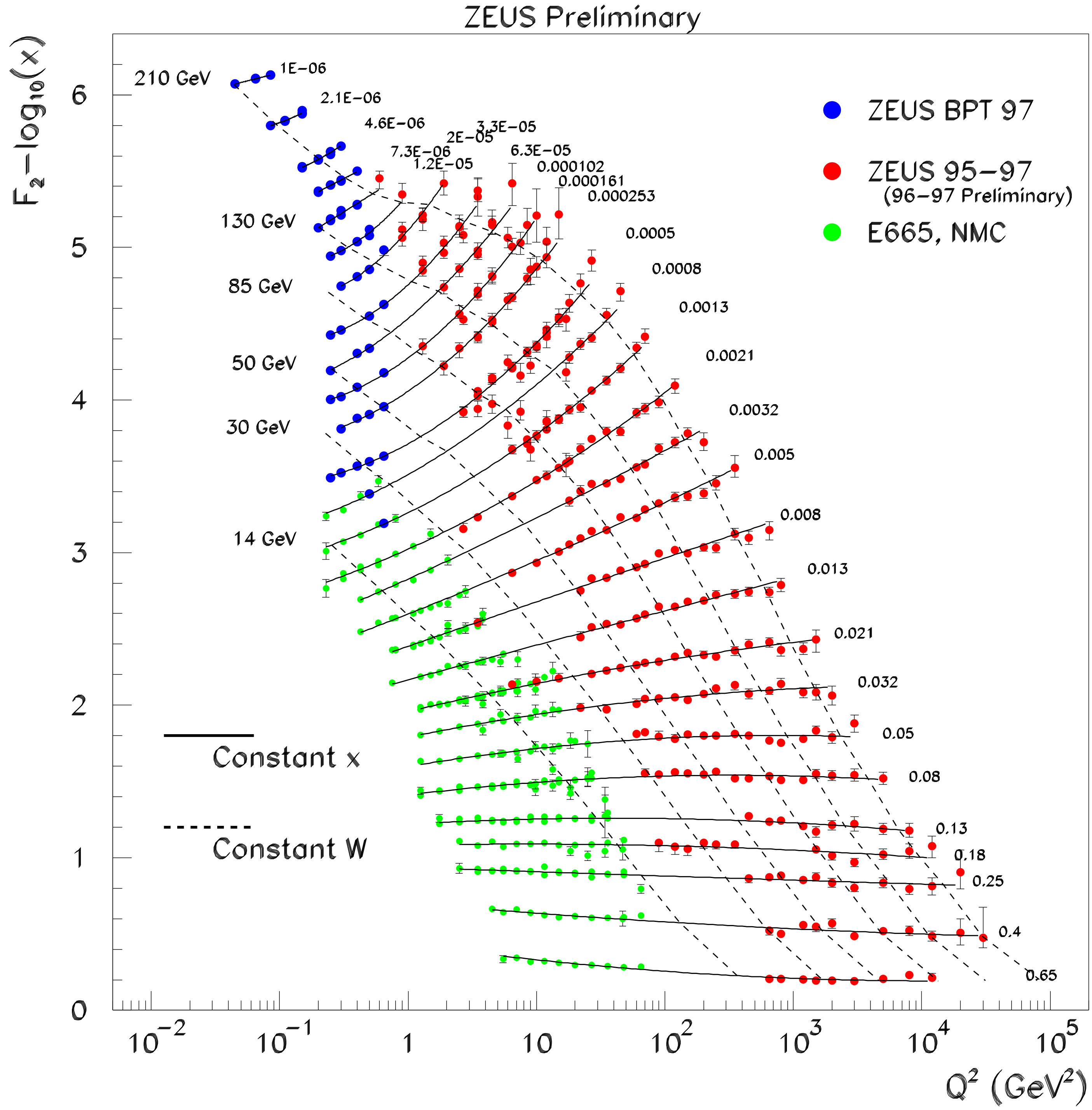
▶ strong constraint on sea quarks

x_2

▶ $\bar{d}/\bar{u}$



F_2 vs Q^2



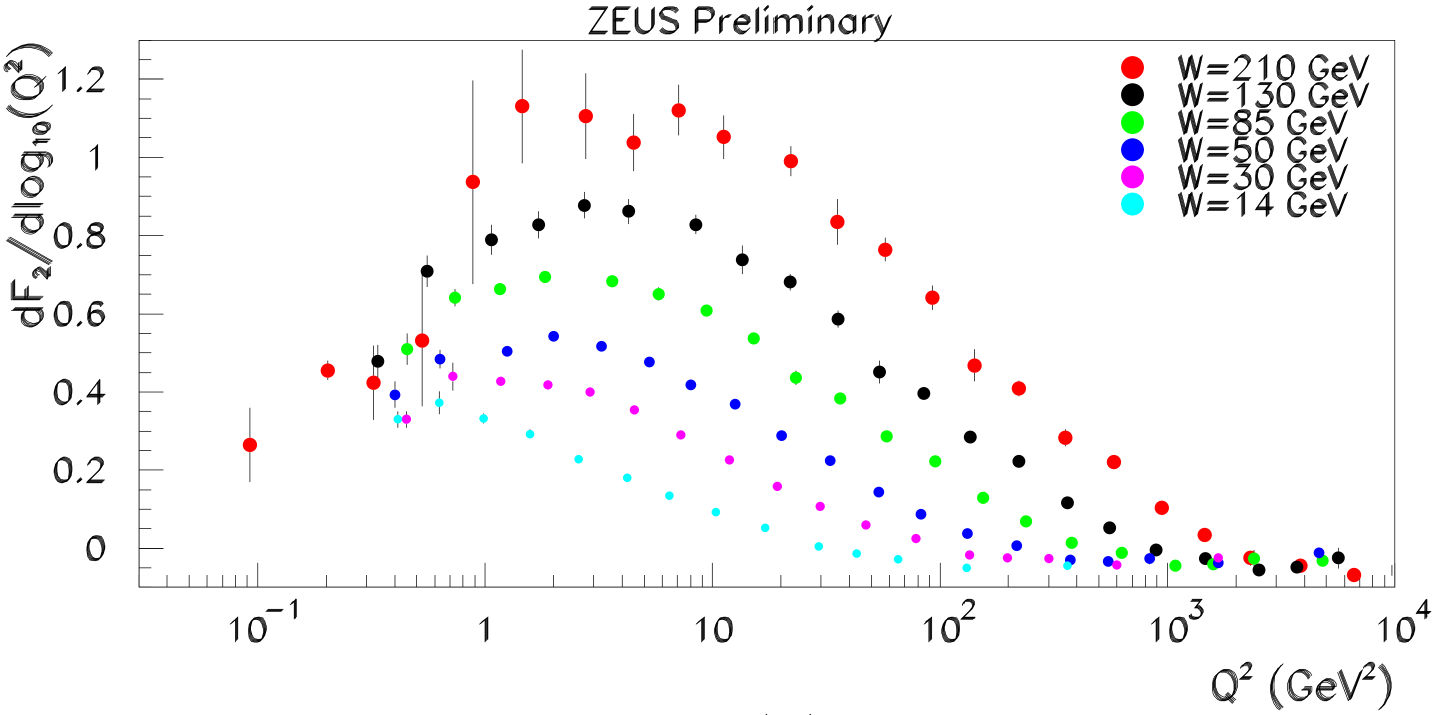
- Rise... and fall of QCD
- Fit to $A + B\log_{10}(Q^2) + C\log_{10}(Q^2)^2$
  - ▶ Saturation effects?

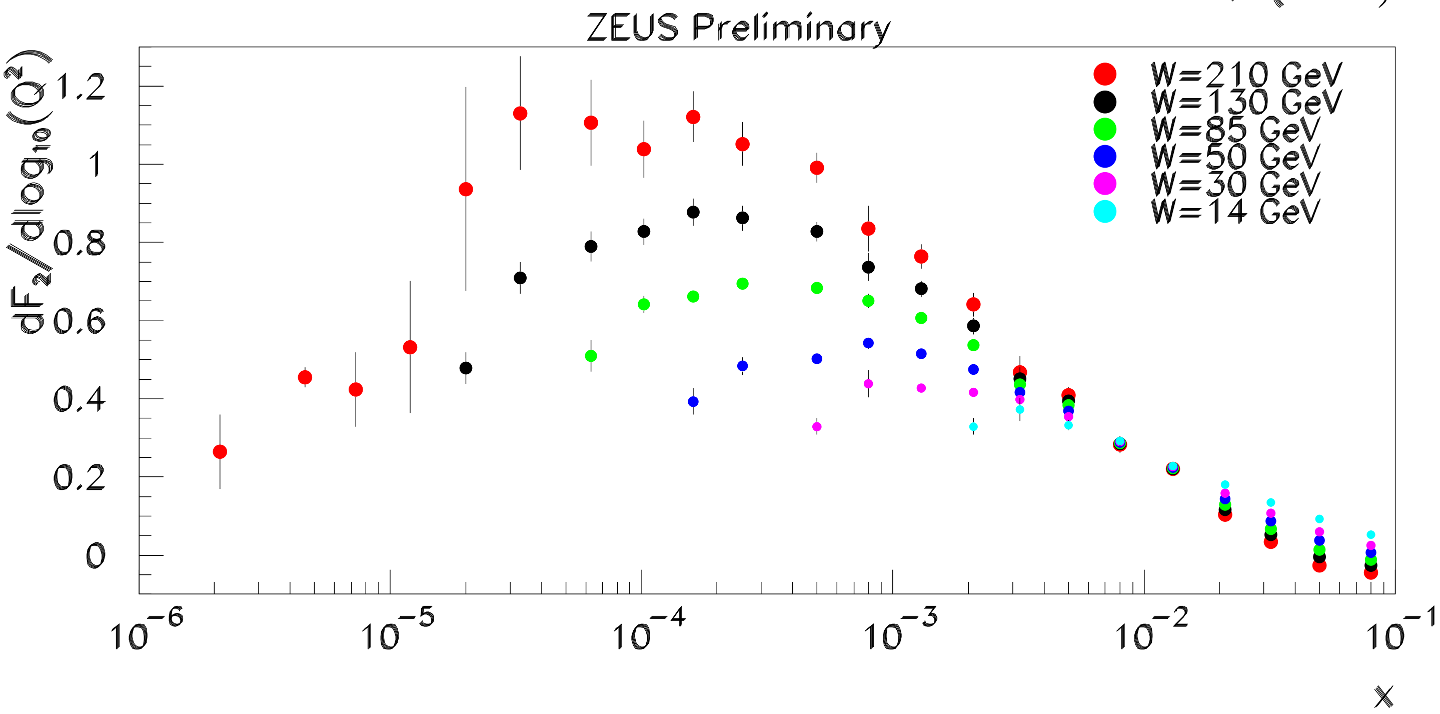
$\mathrm{d}F_2/\mathrm{d}\log_{10}(Q^2)$

$= B + 2C\log_{10}(Q^2)$ at fixed W

- Rise... and fall of QCD

▶ Theoretical interpretation?

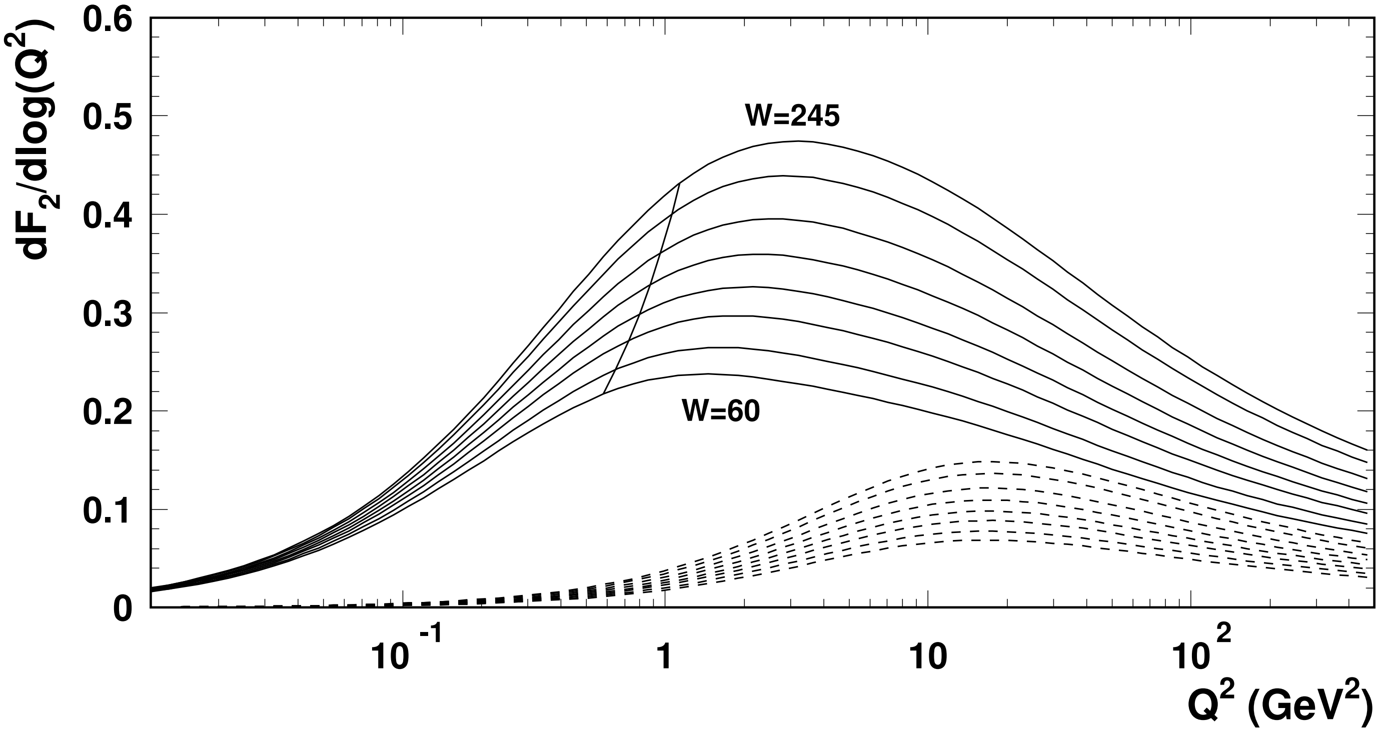


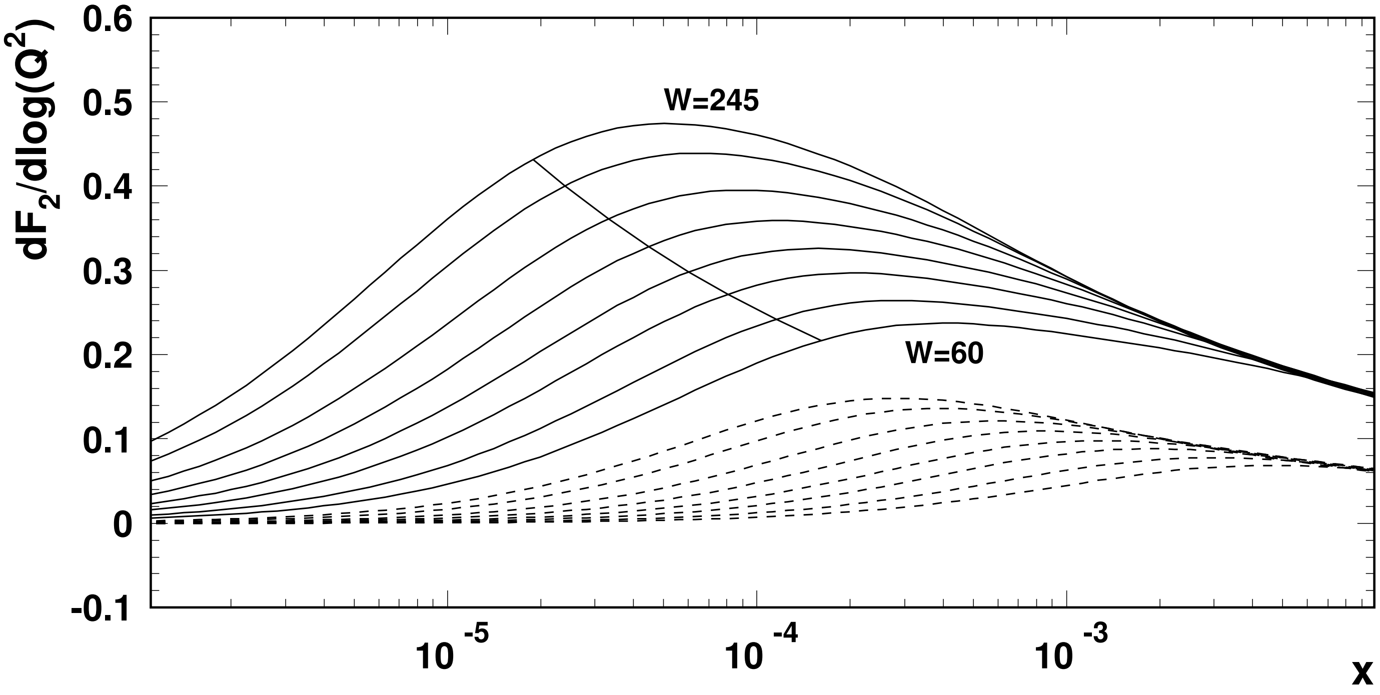


$\mathrm{d}F_2/\mathrm{dlog_e}(Q^2)$

▶ Critical line

N.B. Charm contribution (dashed)



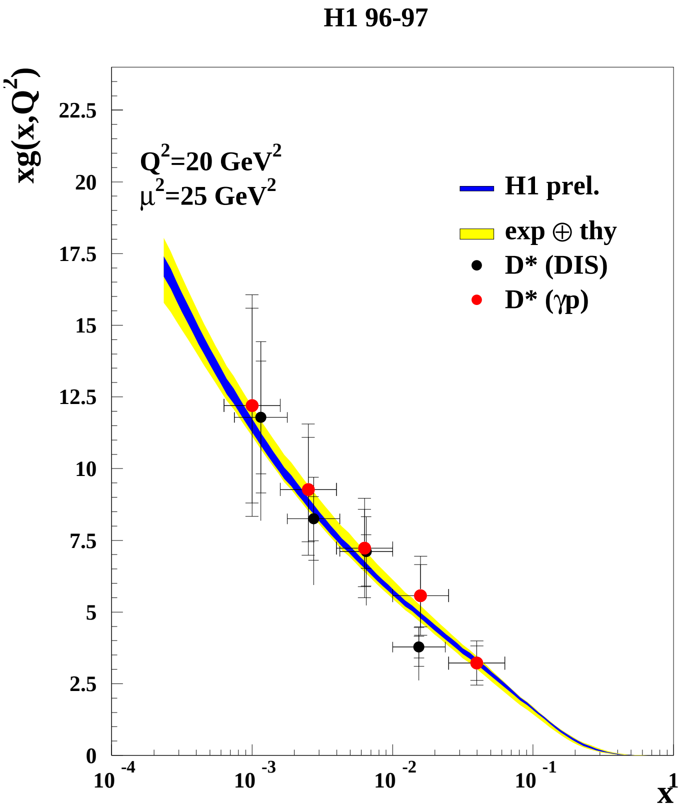


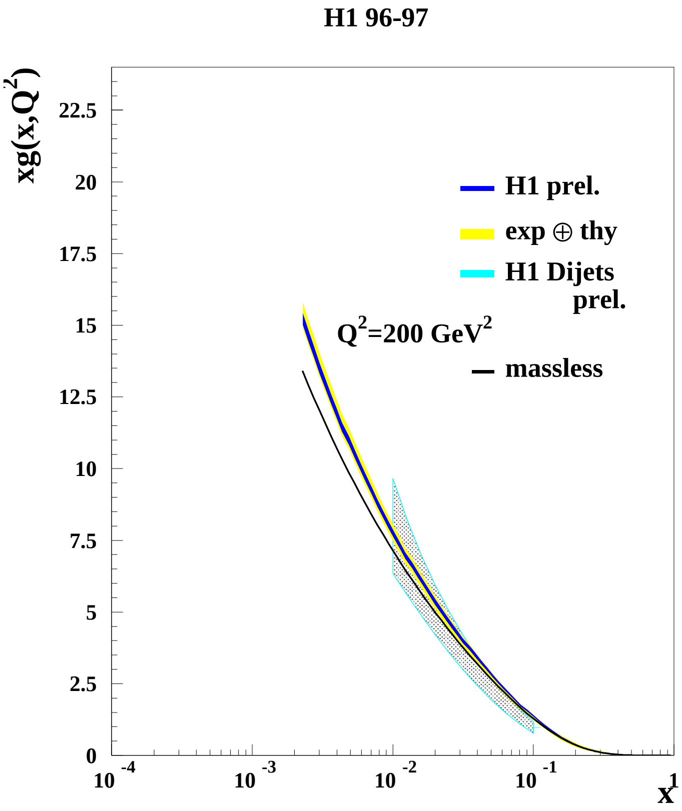
K. Golec-Biernat and M. Wüstoff hep-ph/9807513.

Gluon Density from Charm and Jets

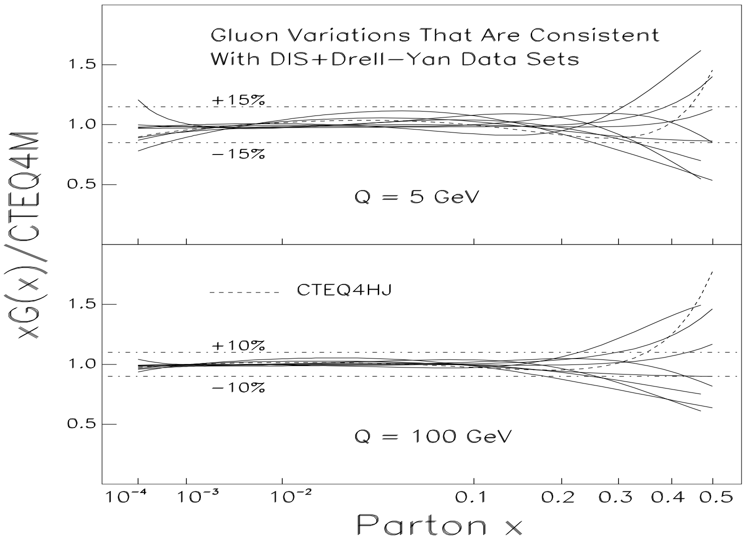
- Most precise extraction – from F_2 scaling violation
- BGF (charm, di-jets) – consistent (larger exp/theor uncertainties)

$\Rightarrow$ **universality**



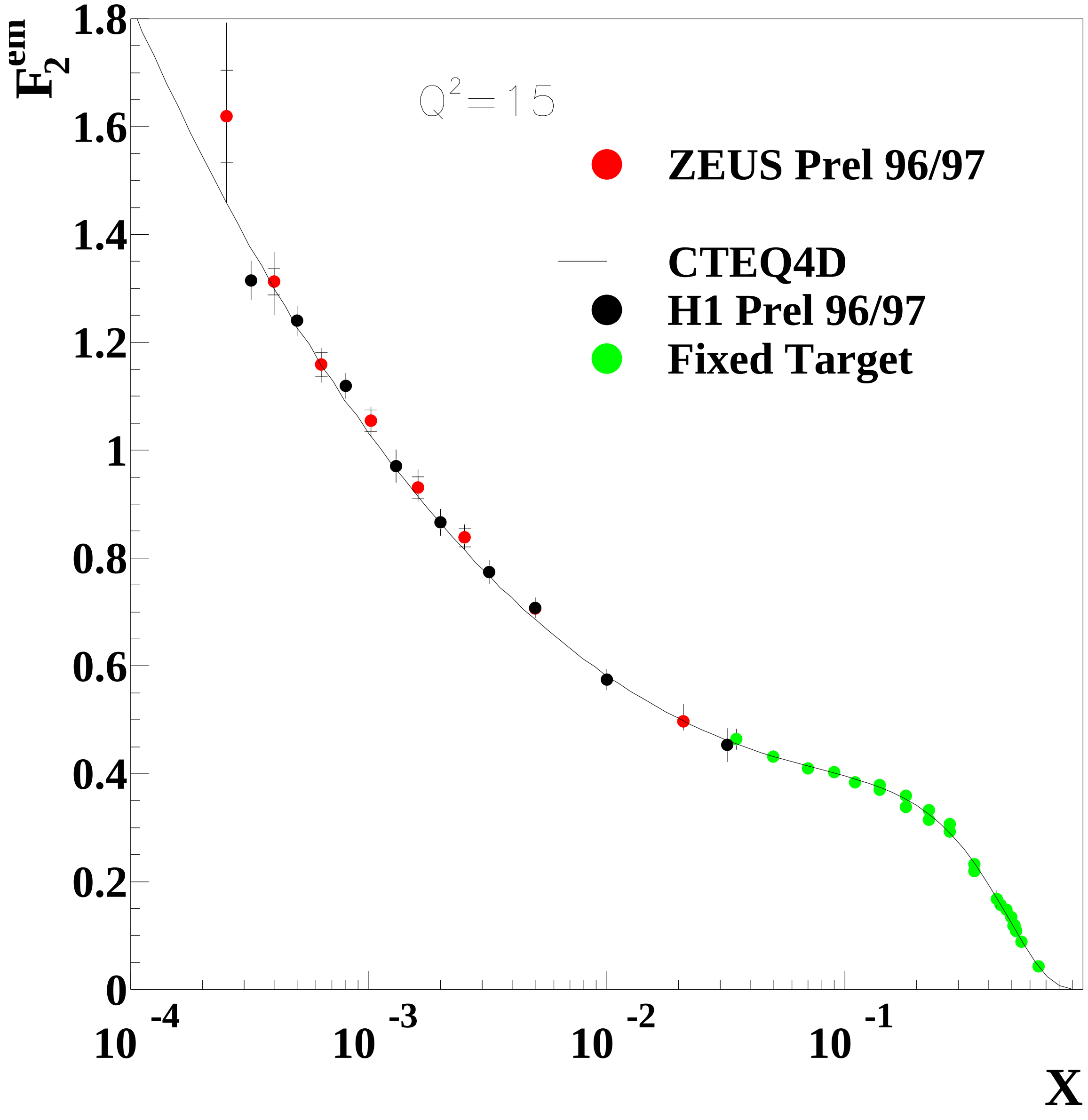


Impact on LHC physics (J.Huston et al.,1999)



★ **Gluon density at low $x < 0.1$ is constrained within 10%**

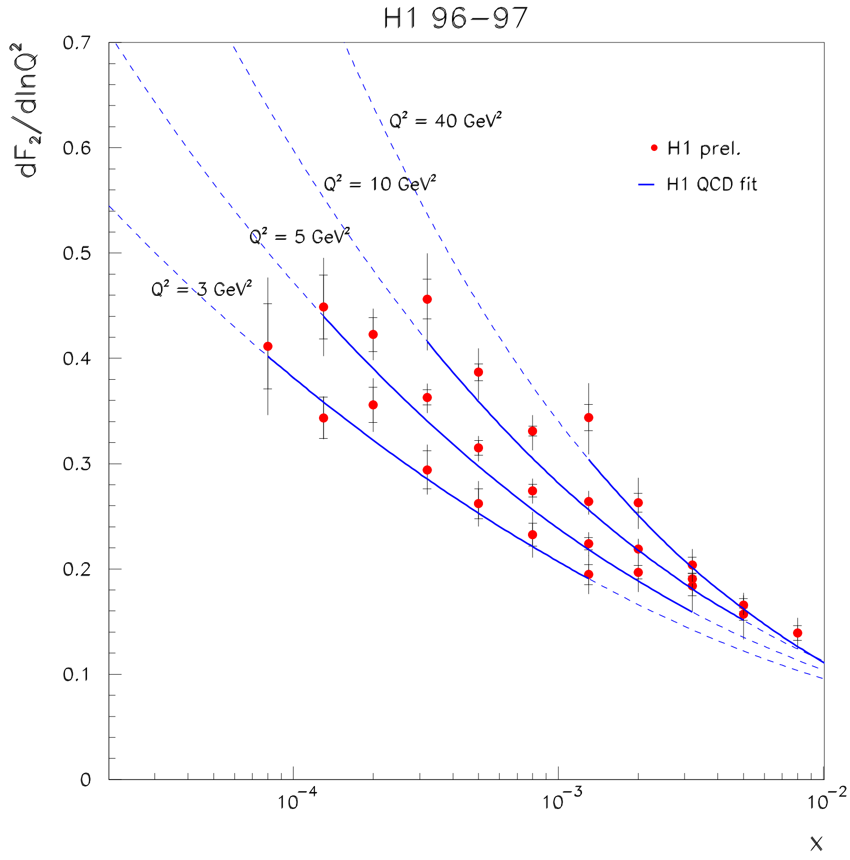
F_2 vs x

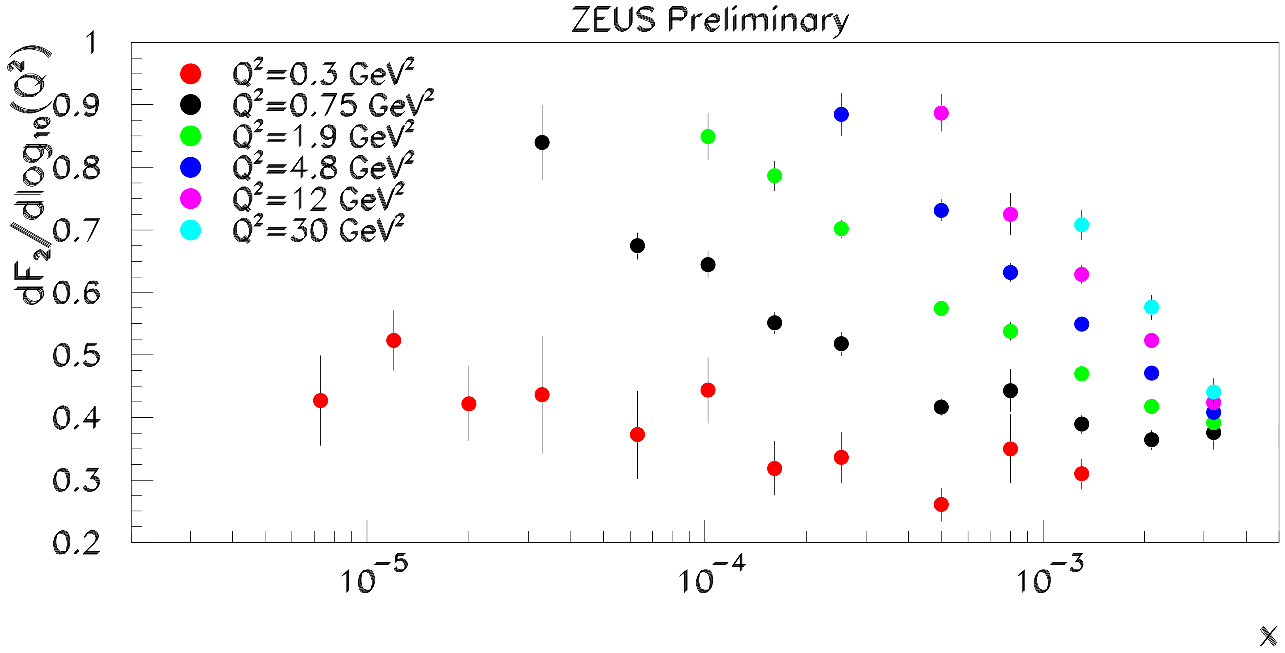


- ★ High precision: 1%(stat) $\oplus$ 2-3%(syst)
- ★ Good agreement between H1 and ZEUS
- ★ Overlap is achieved with fixed target experiments
- ★ **Strong rise at low x ($F_2 \sim x^{-\lambda}$)**

First Discovery at HERA

$\mathrm{d}F_2/\mathrm{dlog}(Q^2)$





Monotonic rise with increasing Q^2

Flattening at lowest accessible Q^2

Saturation?? See e.g. Bartels, Ryskin

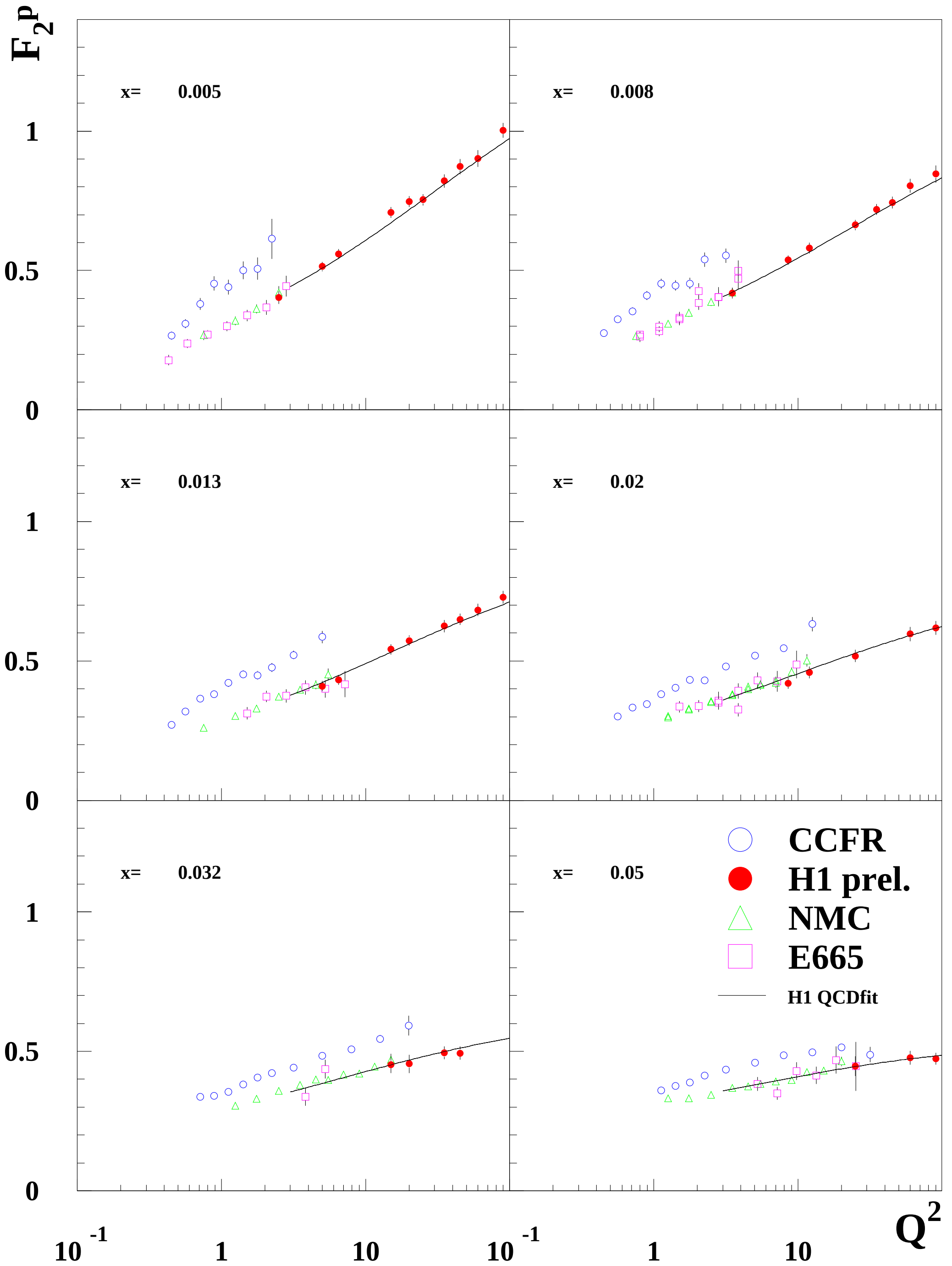
CCFR - NMC Discrepancy

$$F_2^{\mu N} = \frac{5}{18}\left[1 - \frac{3}{5}\frac{xs(x)+x\bar{s}(x)}{xq(x)+x\bar{q}(x)}\right]F_2^{\nu N}$$

5/18 rule OK except at low-x

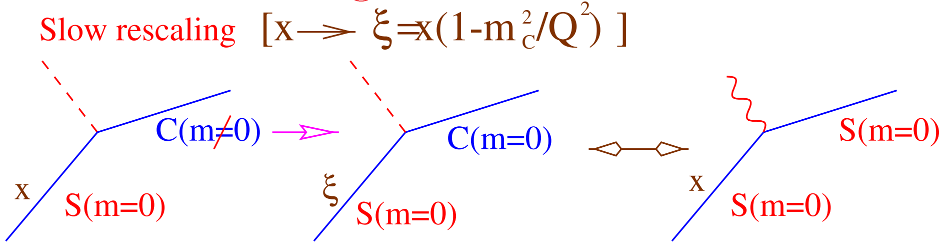
- CCFR heavy target? (5% effect)
- CCFR strange sea → charm production?

- HERA data ▶ CCFR re-analysis required?...



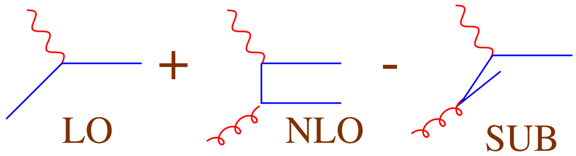
CCFR - Massive Charm

- Previous CCFR F_2 extraction was done with a slow rescaling correction



◁ Such that F_2^ν can be directly compared with F_2^μ

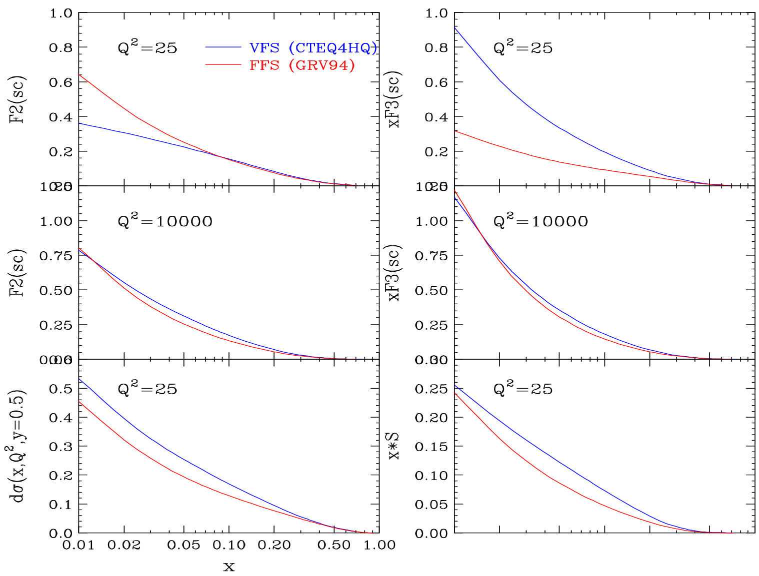
Various NLO heavy quark treatments now available:



▷ Variable Flavor Scheme [VFS]: heavy quark inside proton
LO + NLO - SUB (good for $Q \gg m_h$ region) [$\mu = 2P_t^{max}$]

▷ Fixed Flavor Scheme [FFS]: No heavy quark inside proton
only NLO (good for $Q \approx m_h$) [$\mu = 2m_c$]

▷ Mixed Flavor Scheme [MFS]
FFS($Q \approx m_h$) + VFS($Q > m_h$) [$\mu = Q$]



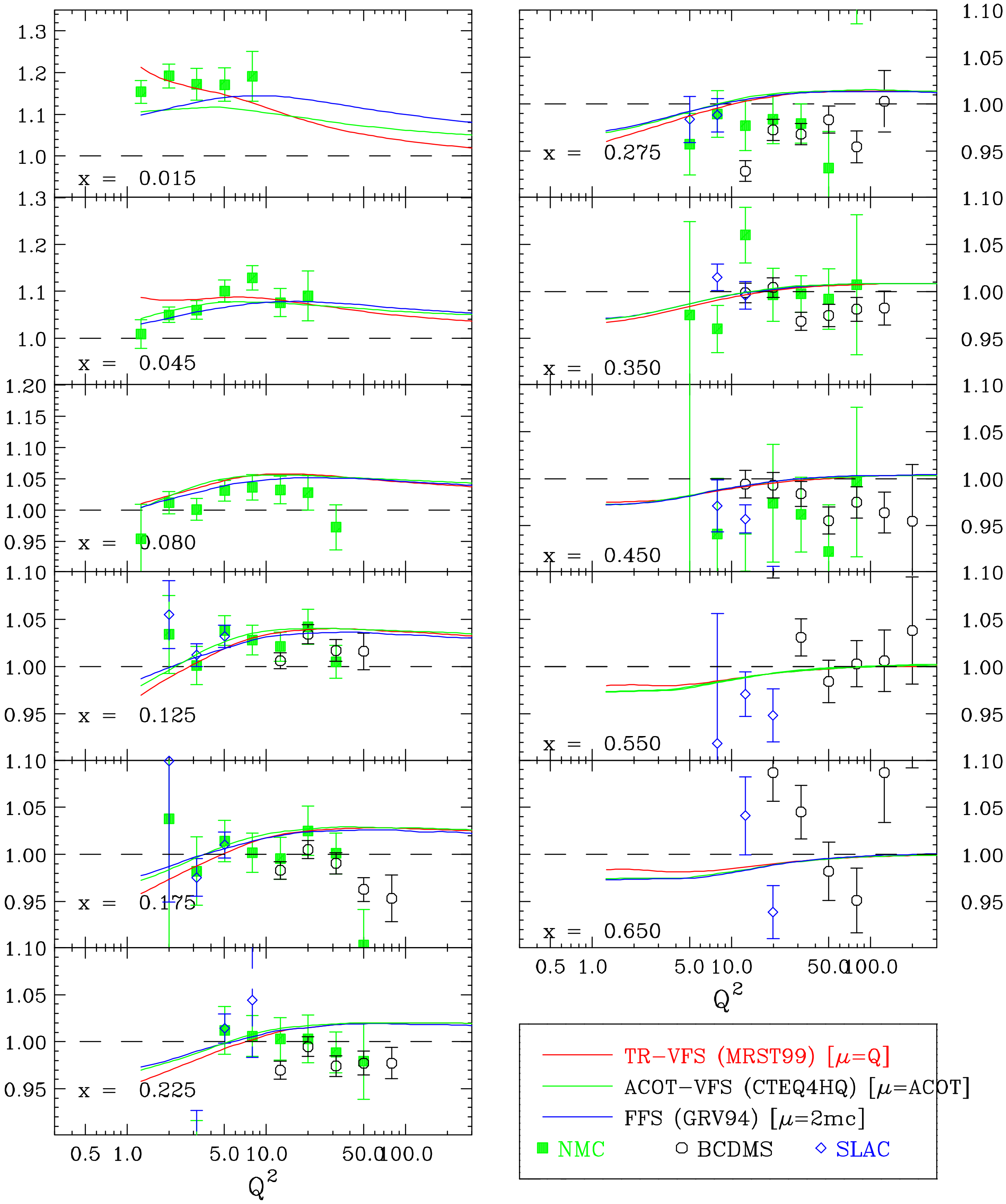
Ref: Z. Phys. C72, 99 (1996) by Kramer, Lampe, and Spiesberger

CCFR - NMC Agreement

$$\text{ratio} = \frac{5}{18}F_2^{\nu N}/F_2^{\mu N}$$

- No massive charm correction made to F_2 (and $\Delta x F_3^{\nu-\bar{\nu}}$)

  ▶ Physics Model Independent approach



- Departure from 5/18 rule due to massive charm

- Described by latest NLO approaches (MRST, CTEQ, GRV)

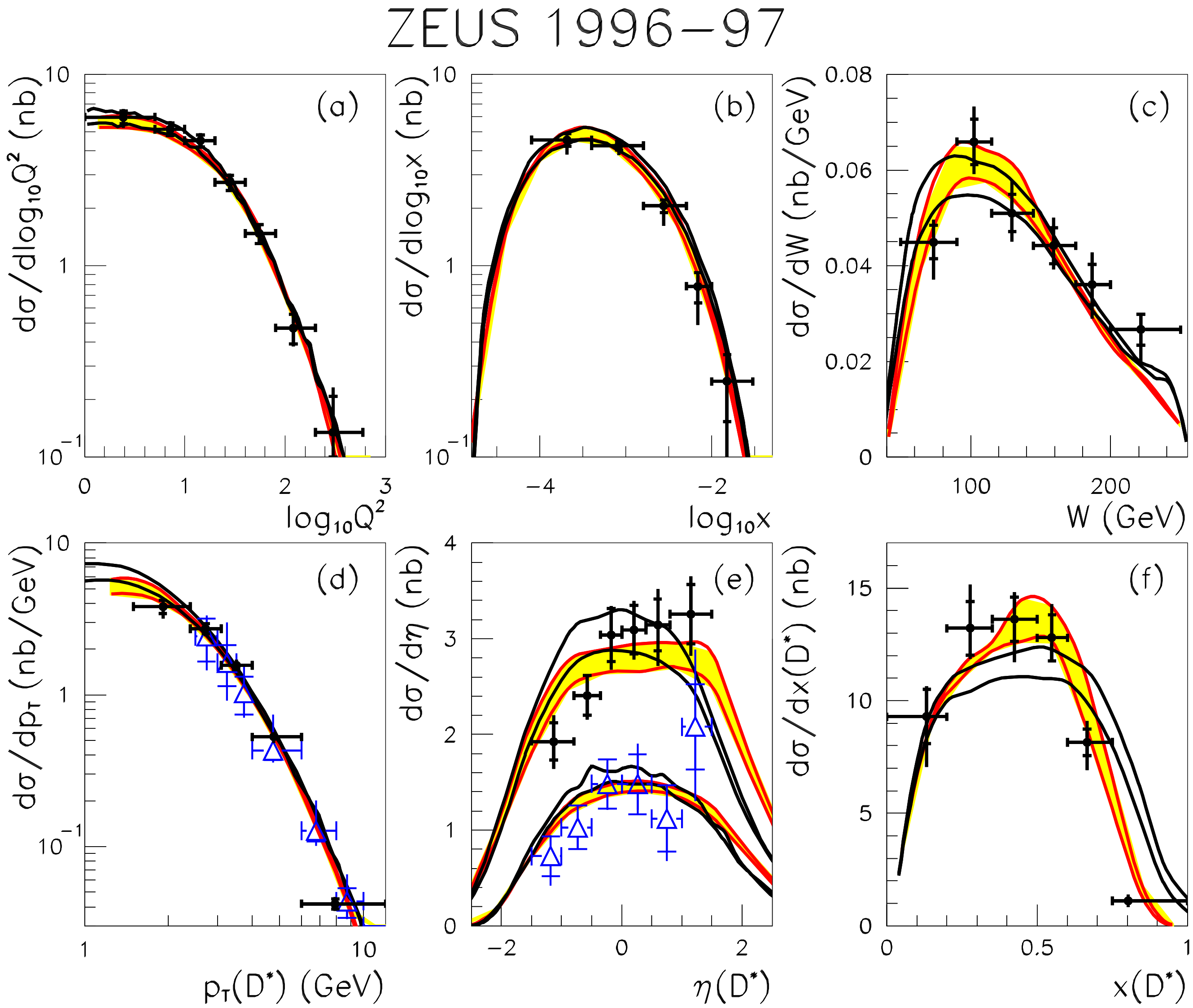
Charm in DIS

- Precision results from HERA

For $1 < Q^2 < 600$ GeV^2, $\quad 0.02 < y < 0.7$,

$1.5 < p_T(D^*) < 15$ GeV, $\quad |\eta(D^*)| < 1.5$

$\Rightarrow \sigma(ep \to eD^*X) = 8.31 \pm 0.31^{+0.30}_{-0.50}$ nb



$K2\pi$ and $K4\pi$ data

$\Rightarrow$ agreement with "massive" NLO pQCD HVQDIS[†]

band: m_c uncertainty (1.3-1.5 GeV)

$f(c \to D^{*+}) = 0.222 \pm 0.014 \pm 0.014$[†]

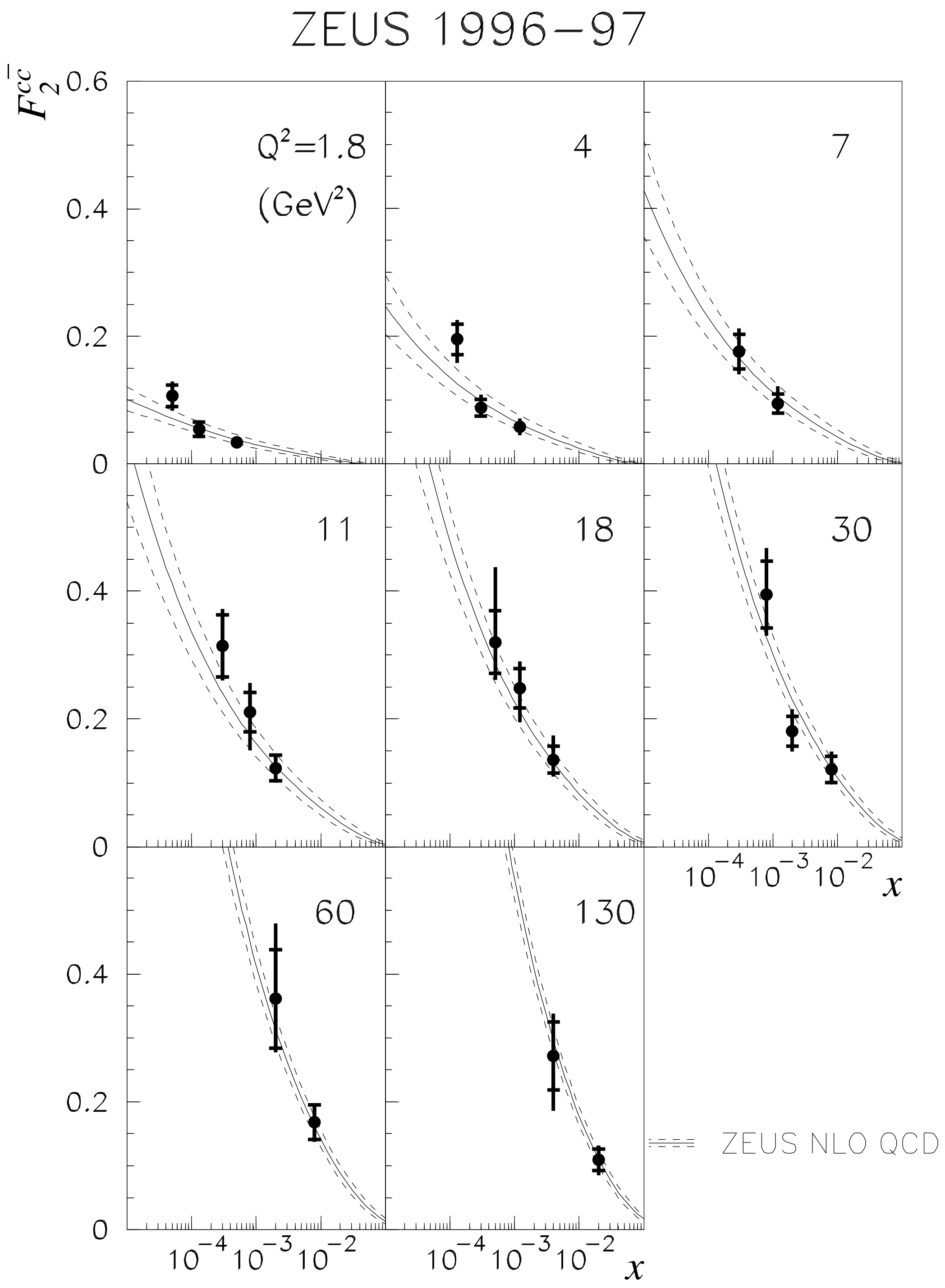
[†] B. W. Harris and J. Smith, hep-ph/9706334

[†] OPAL Collab., Eur. Phys. J C**1**(1998)439

F_2^{charm}

$$\frac{d^2\sigma_{c\bar{c}X}}{dx\,dQ^2} = \frac{2\pi\alpha^2}{xQ^4}[1 + (1-y)^2 F_2^c(x,Q^2) - y^2 F_L^c(x,Q^2)]$$

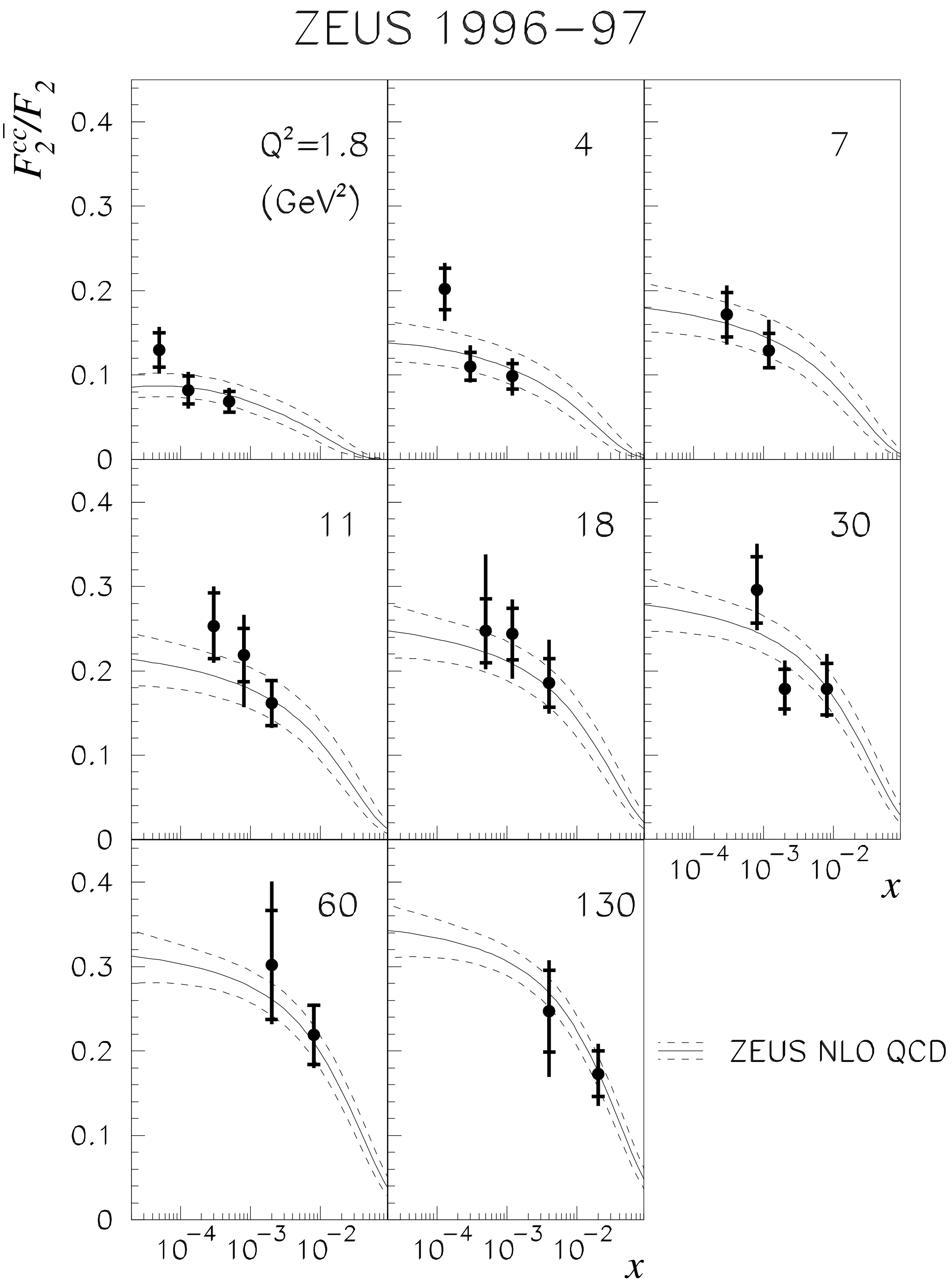
Extraction of F_2^c requires extrapolation to full $\{\eta, p_T\}$ range.



- Precision $\simeq 15 - 20\%$
- Significantly more precise than earlier measurements
- Steep rise towards small $x \to$ gluons

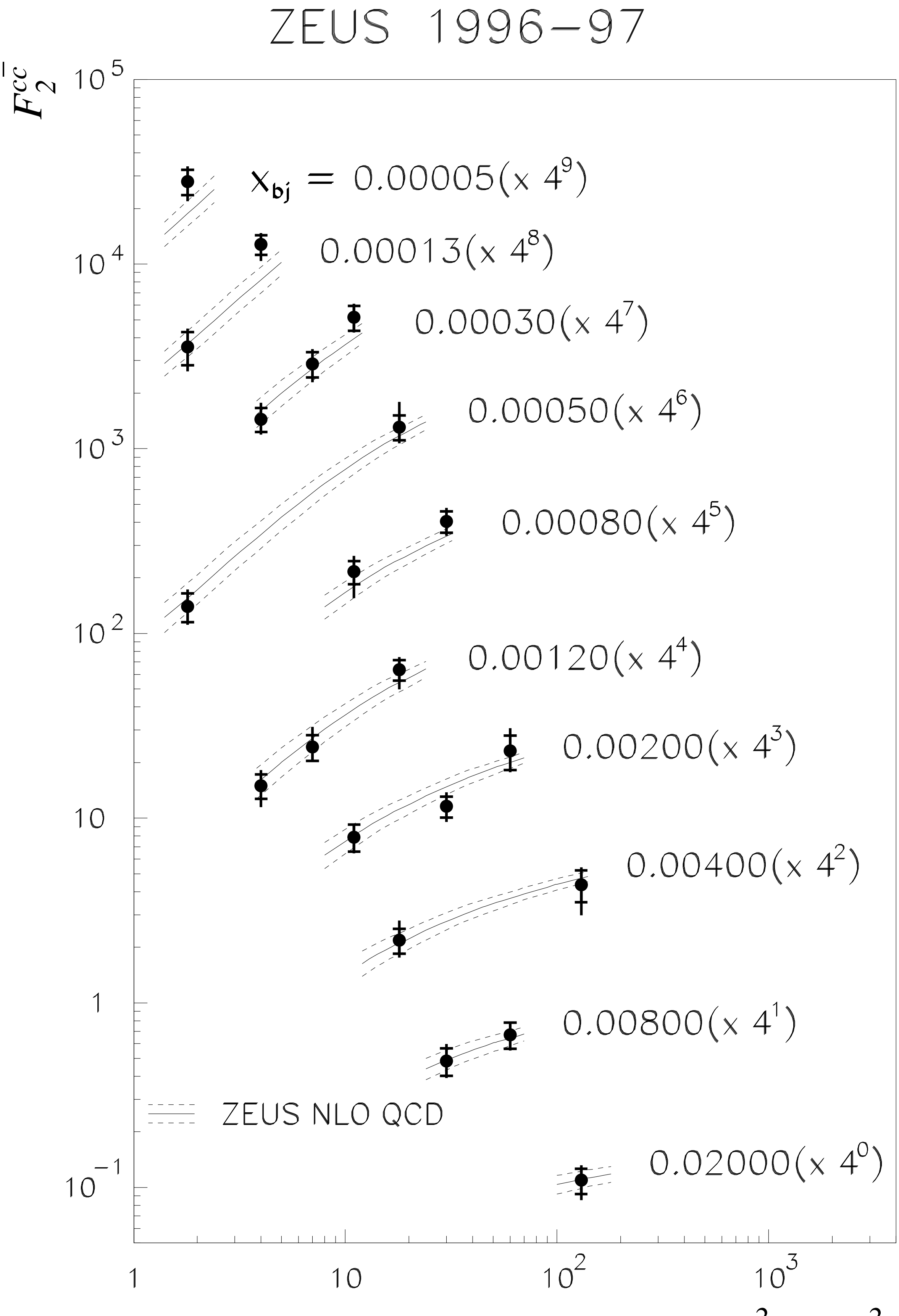
F_2^c / F_2

Significant fraction of inclusive F_2
Comparison with prediction of ZEUS F_2 fit



- F_2^c / F_2 threshold behaviour
- c.f. CCFR massive charm

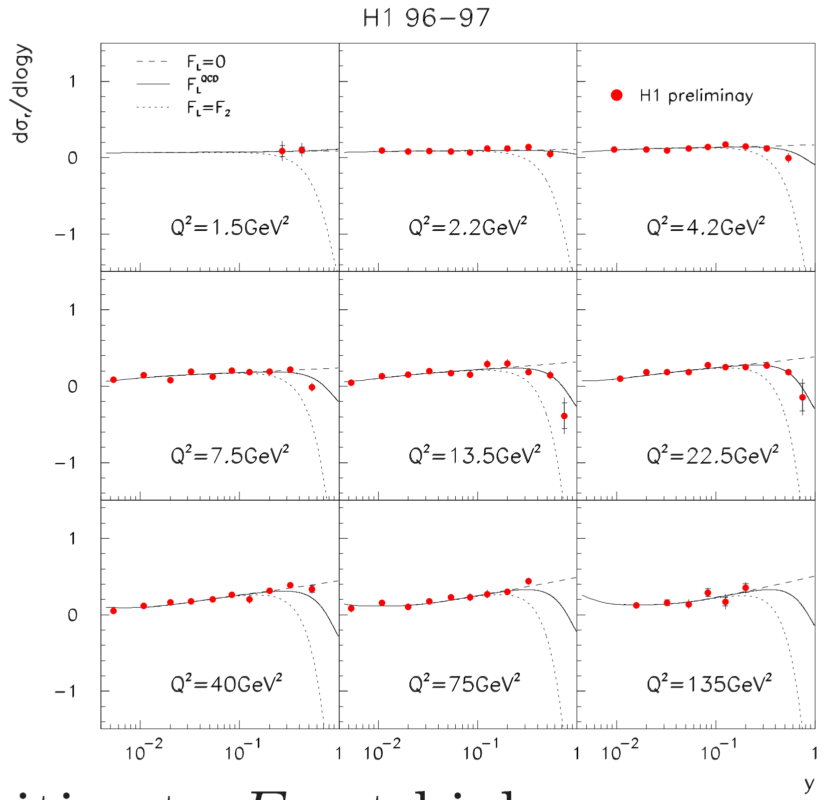
F_2^c Scaling Violations



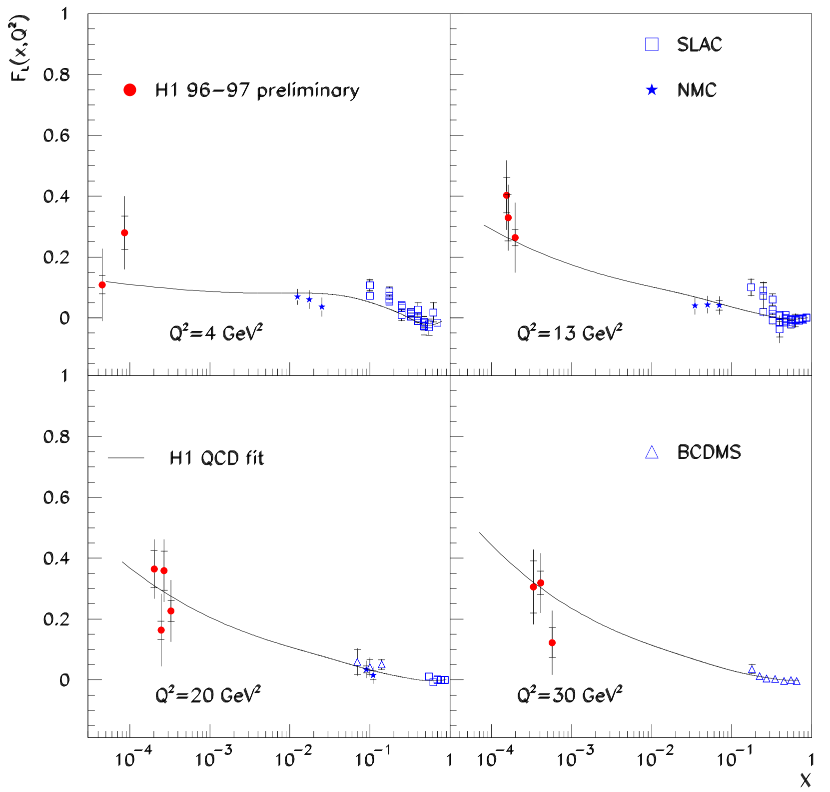
- Large scaling violations

Determination of F_L

- Local derivatives of $\tilde{\sigma} \propto F_2 - f(y) \cdot F_L$



- sensitive to F_L at high y



- consistent with F_L from QCD

Summary

MANY ***Highlights***

PROTON STRUCTURE

- Input on d/u ($\uparrow$'s) [NMC, HERA, Tevatron]

  and $\bar{d}/\bar{u}$ ($\downarrow$'s) [E866 - improved precision]

- HERA rise . . . ▶ gluon determination
- . . . and fall of scaling violations at low x

▶ Parton Saturation?

Phenomenological importance of Charm

◀ [HERA and CCFR]

- data on F_2^c, jets and F_L ▶ calibrated gluon
- High Q^2 Cross Sections [HERA and Tevatron]

▶ Consistent with Standard Model

▶ Importance of PDF uncertainties (inc. correlations)

▶ First extraction of xF_3 on proton target

- Future precision and D.I.S. covery 

▶ HERA and Tevatron luminosity upgrades... ▶ TERA?

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