Charm (and beauty) structure functions from HERA

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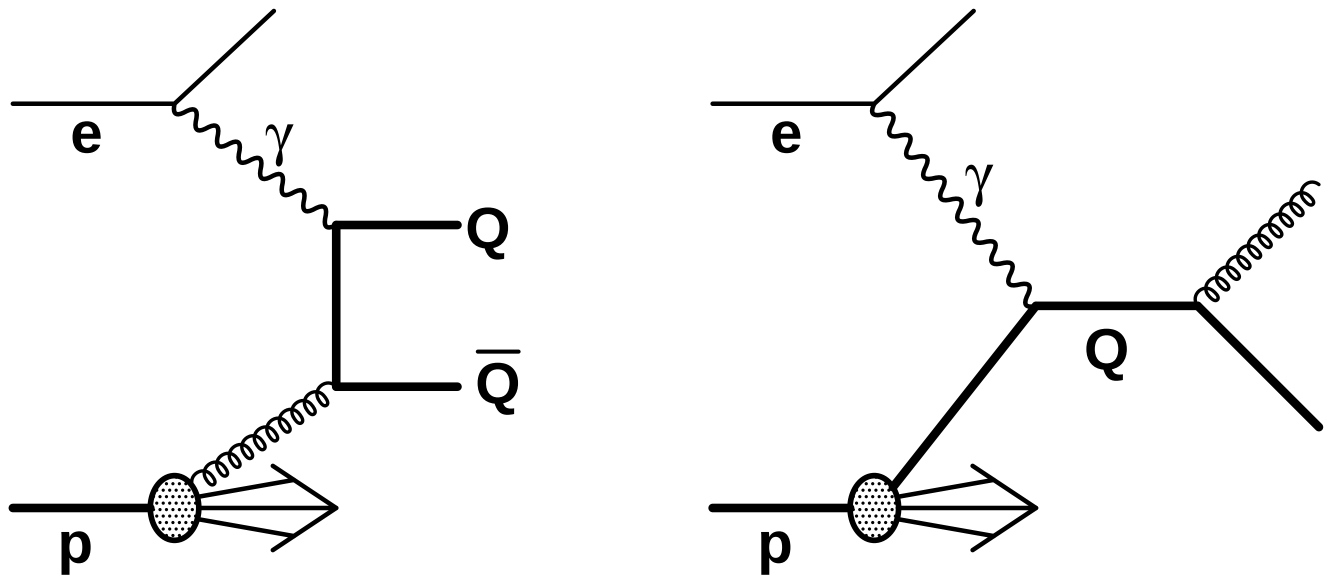
- Introduction
- Deep inelastic scattering and structure functions
- Experimental analysis, techniques and results
- Prospects and summary

Introduction

To understand and probe QCD in as much detail as possible

Parton densities of proton and photon need to be precise. cf **future colliders,** pp, e^+e^- **and** $\gamma\gamma$, **...**



Directly sensitive to:

- **gluon density in the proton**
- **heavy quark density in the proton**

Inclusive deep inelastic scattering

Momentum transfer:

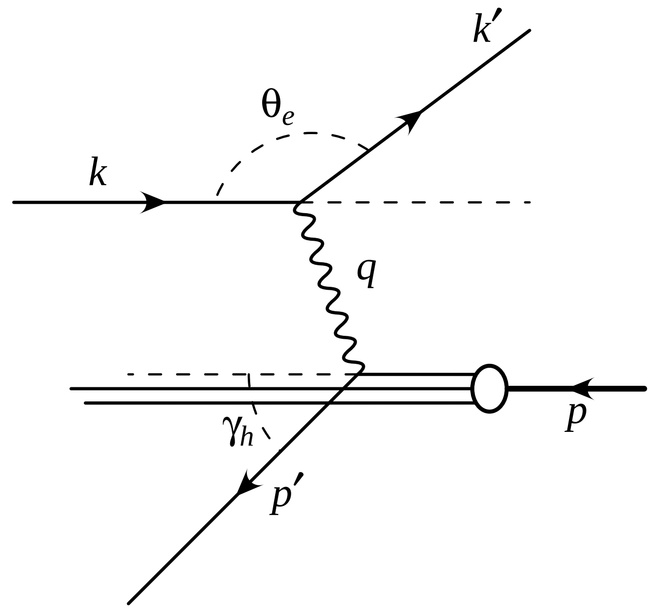
$Q^2 = -q^2 = -(k - k')^2$

Momentum fraction of struck parton:

$x = \frac{Q^2}{2p \cdot q}$

Inelasticity:

$y = \frac{q \cdot p}{k \cdot p}$



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

$F_2 \sim$ **sum of q and $\bar{q}$ densities**

$xF_3 \sim$ **density of valence quarks from Z exchange**

$F_L \sim$ **gluon density**

Charm in deep inelastic scattering

$$\frac{d^2\sigma^{c\bar{c}}\left(x,Q^2\right)}{dxdQ^2} = \frac{2\pi\alpha^2}{xQ^4}\left\{\left[1+(1-y)^2\right] F_2^{c\bar{c}}\left(x,Q^2\right) - y^2 F_L^{c\bar{c}}\left(x,Q^2\right)\right\}$$

$F_2^{c\bar{c}}\left(x,Q^2\right)$ **is the open-charm contribution to the proton structure function** F_2**.**

$F_2 \sim$ **sum of** q **and** $\bar{q}$ **densities only valid for massless scheme,** $Q^2 >> m_Q^2$**.**

Using pQCD

- **Fits performed to inclusive data** $\rightarrow$ **extract parton densities.**
- **Large fraction comes from charm (**$\sim$ **4/11); smaller from** b **(**$\sim$ **1/11).**

Not measuring individual parton densities.

Could use c **(and** b**) data in fits (PDF fitting program interfaced to NLO calculation) to constrain parton densities**

Analysis

Look for $D^* \to D^0\pi_s \to K\pi\pi_s$ channel with

$$1.5 < p_T(D^*) < 15\text{GeV},$$

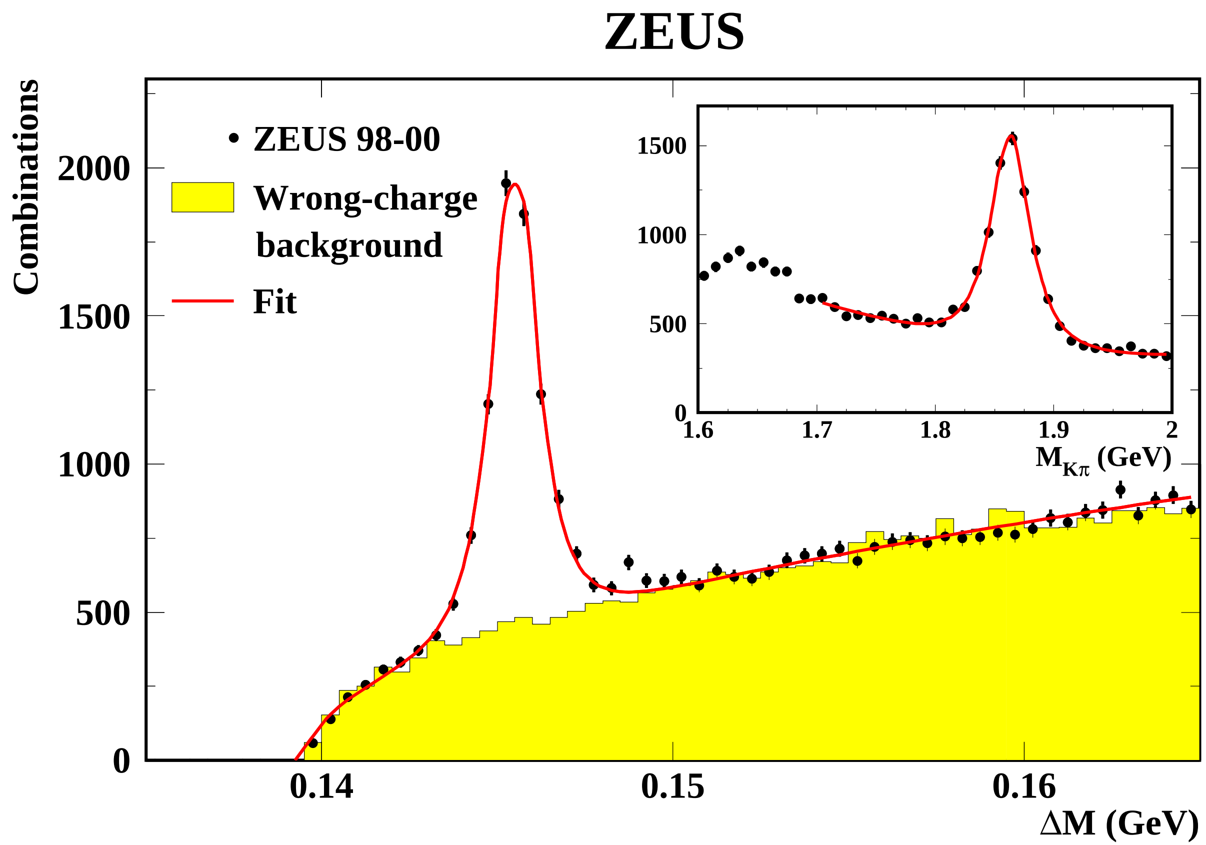
$$|\eta(D^*)| < 1.5$$

And a high energy scattered electron

$$1.5 < Q^2 < 1000\text{GeV}^2,$$

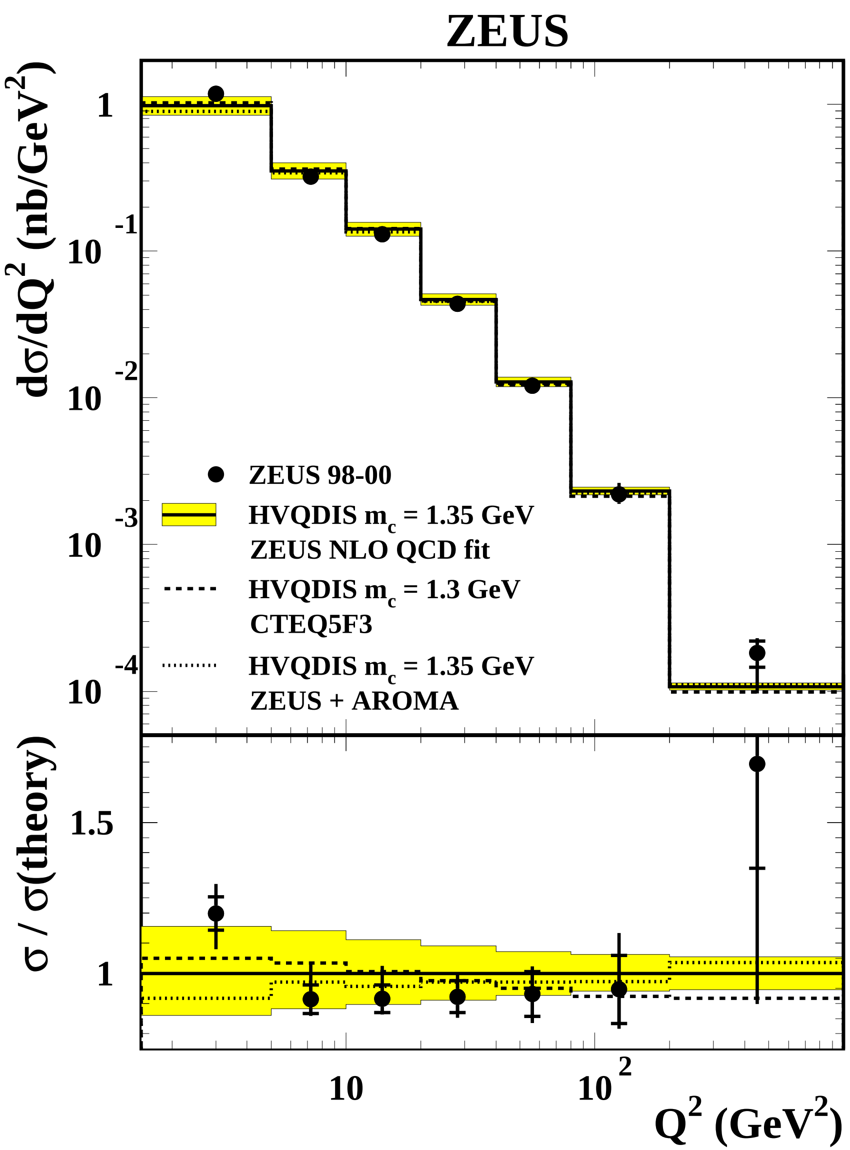
$$0.02 < y < 0.7$$

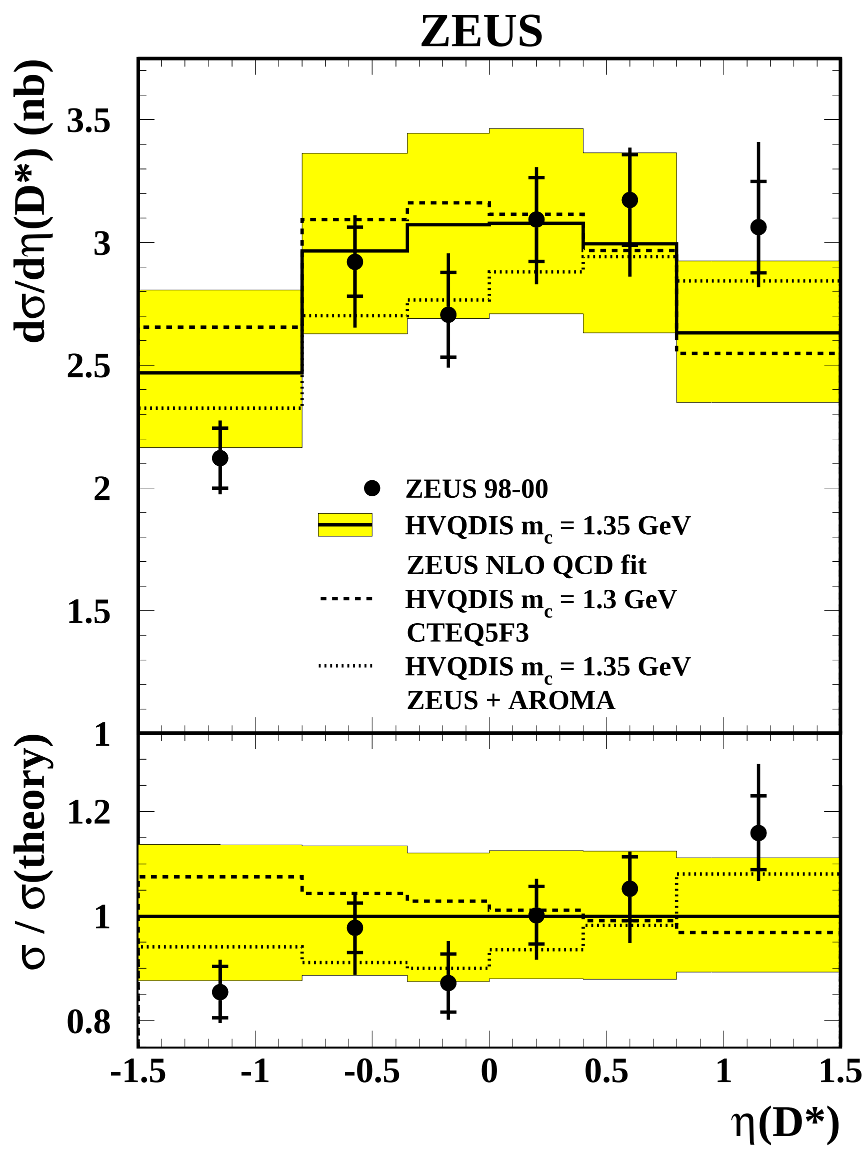
Analysis of 98-00 data, $\sim$ 82 pb^{-1}, in addition to $\sim$ 37 pb^{-1} from 96-97.



Measured 5545 D^* mesons

Measured cross sections





Generally good description of the data; some differences in shape; can the PDF be fitted to describe these?

Extraction of $F_2^{c\bar{c}}$

Extraction of (extrapolation to) $F_2^{c\bar{c}}$ performed in fully consistent way

$$F_{2,\mathrm{meas}}^{c\bar{c}}(x_i, Q_i^2) = \frac{\sigma_{i,\mathrm{meas}}(ep \to D^* X)}{\sigma_{i,\mathrm{theo}}(ep \to D^* X)} F_{2,\mathrm{theo}}^{c\bar{c}}(x_i, Q_i^2)$$

The ZEUS NLO QCD fit was used with:

- **three active quark flavours**
- $m_c =$ **1.35 GeV**
- $\mu = \sqrt{4m_c^2 + Q^2}$

in calculation of $F_2^{c\bar{c}}$ and in HVQDIS for calculation of $\sigma(x, Q^2)$

Peterson function used in HVQDIS calculation

Component expected from b production subtracted from data

Model dependence of unfolding

Extraction of $F_2^{c\bar{c}}\left(x, Q^2\right)$ is dependent on the scheme:

- **"Massive": applicable for low $p_T \sim m_c$, no heavy quarks in hadron ($\gamma g \rightarrow Q\bar{Q}$).**
- **"Massless": applicable for high $p_T >> m_c$, heavy quarks in hadron ($\gamma Q \rightarrow gQ$).**
- **"Matched": a combination of the two.**

QCD parton density fits are available in all schemes. Preferred is the matched version. But only available NLO calculation is massive calculation, HVQDIS.

Uncertainties in extrapolation

Factors for extrapolating to full phase space in $p_T(D^*)$ and $\eta(D^*)$ are 4.7 at low Q^2 and 1.5 at high Q^2

Uncertainties in the extrapolation are:

- using AROMA fragmentation instead of Peterson fragmentation - typically less than 10%, but less than 20%. Most significant at high x for given Q^2
- changing the charm mass by $\pm$ 0.15 GeV - differences of 5% at lower x and negligible elsewhere
- upper and lower predictions from the uncertainty on the ZEUS NLO PDF - typically less than 1%
- varying the b component by factor of 2 - typically less than 1$-$2% and 8% at high Q^2

Using CTEQ5F3 gave uncertainties of less than 10% for low Q^2 and less than 5% for $Q^2 > 11$ GeV^2

HERA measurements of $F_2^{c\bar{c}}$

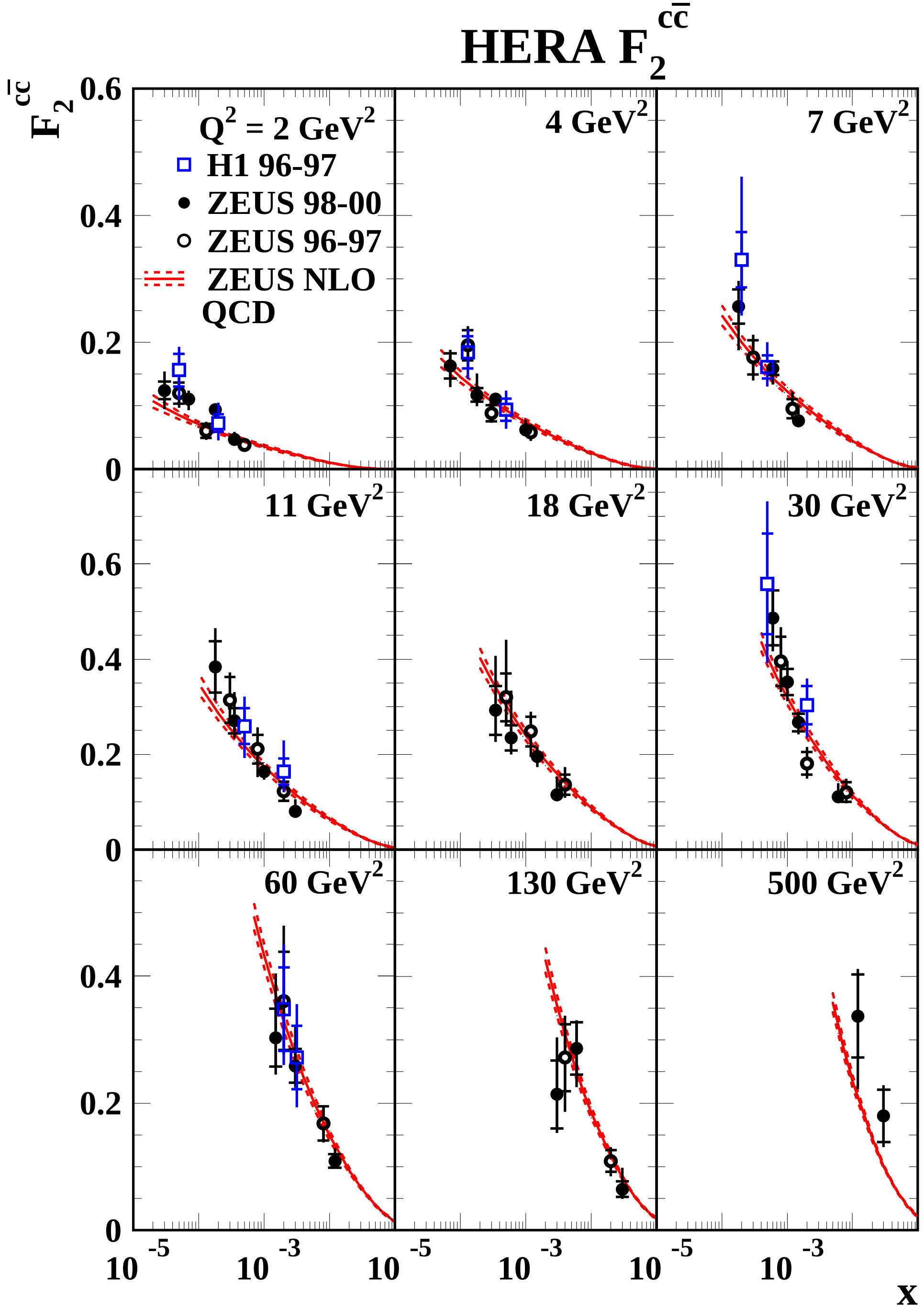
Recently added extra 31 points, extending up to $Q^2 = 500$ GeV^2

Have good(ish) precision up to 30 GeV^2

At lowest Q^2, data and theory uncertainty comparable $\Rightarrow$ data can be used as additional constraint

Steeper rise of data to low x with increasing Q^2 indicative of large density

Reasonable description by NLO QCD fit

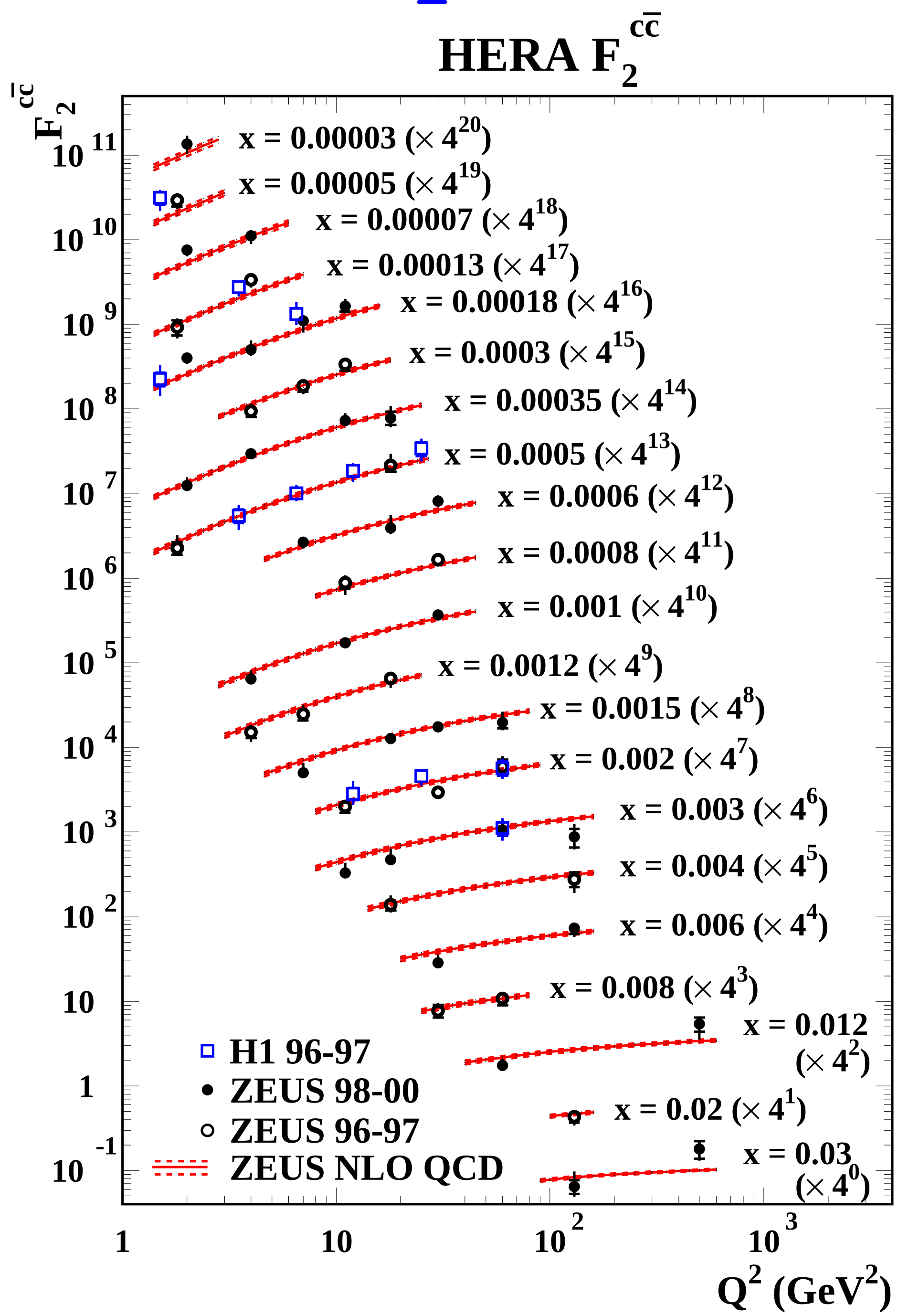


HERA measurements of $F_2^{c\bar{c}}$

Data rise with increasing Q^2, the effect stronger at low x

With extra data, property of scaling violation more clearly seen

The data are well described by the prediction



HERA measurements of $F_2^{c\bar{c}}$

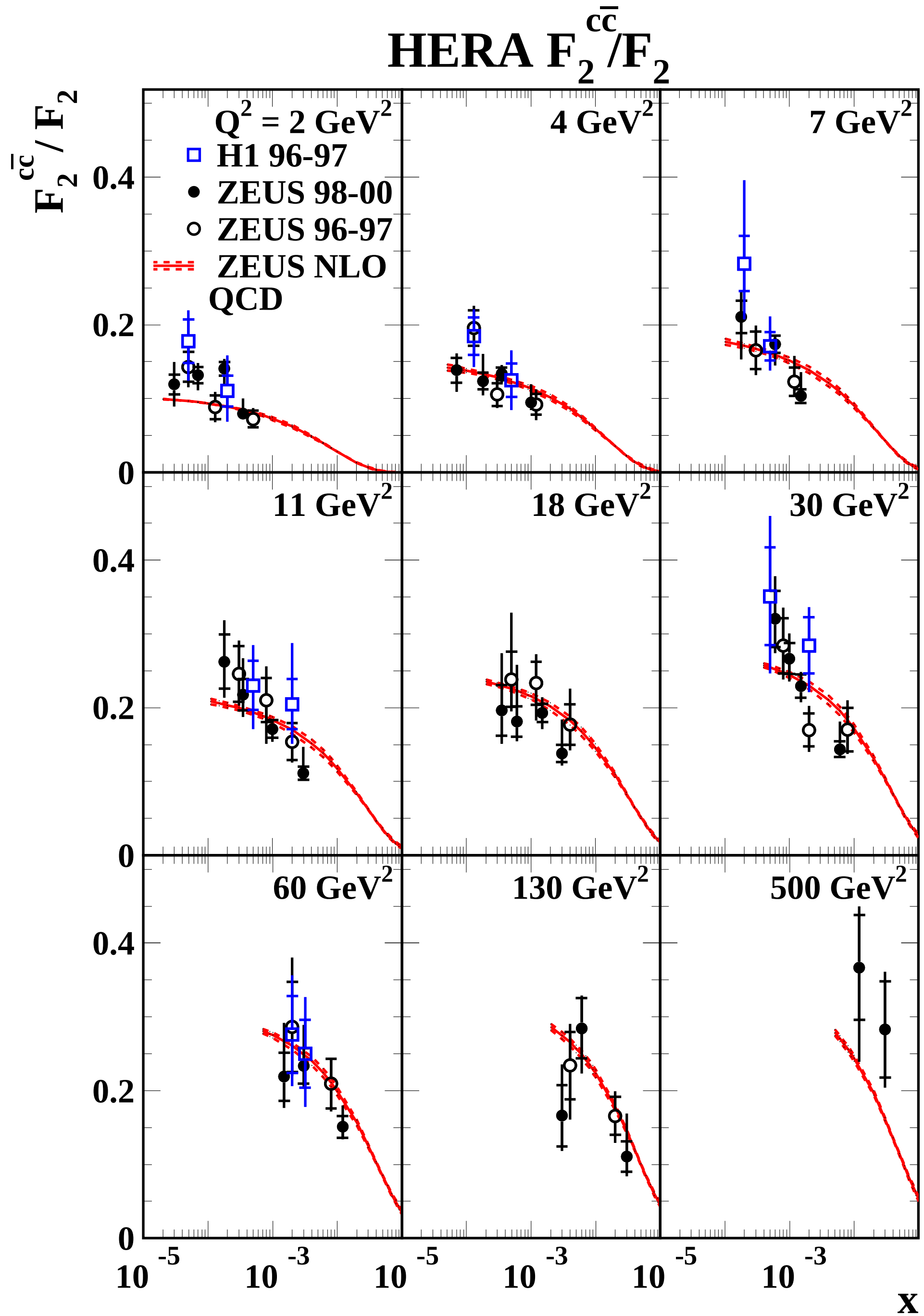
Charm production represents up to 30% of the inclusive cross section

The data are well described by the prediction

Probably best measurements of $F_2^{c\bar{c}}$ made

Cross sections ($\sigma(x, Q^2)$) can be used in future NLO QCD fits

Can they be improved?



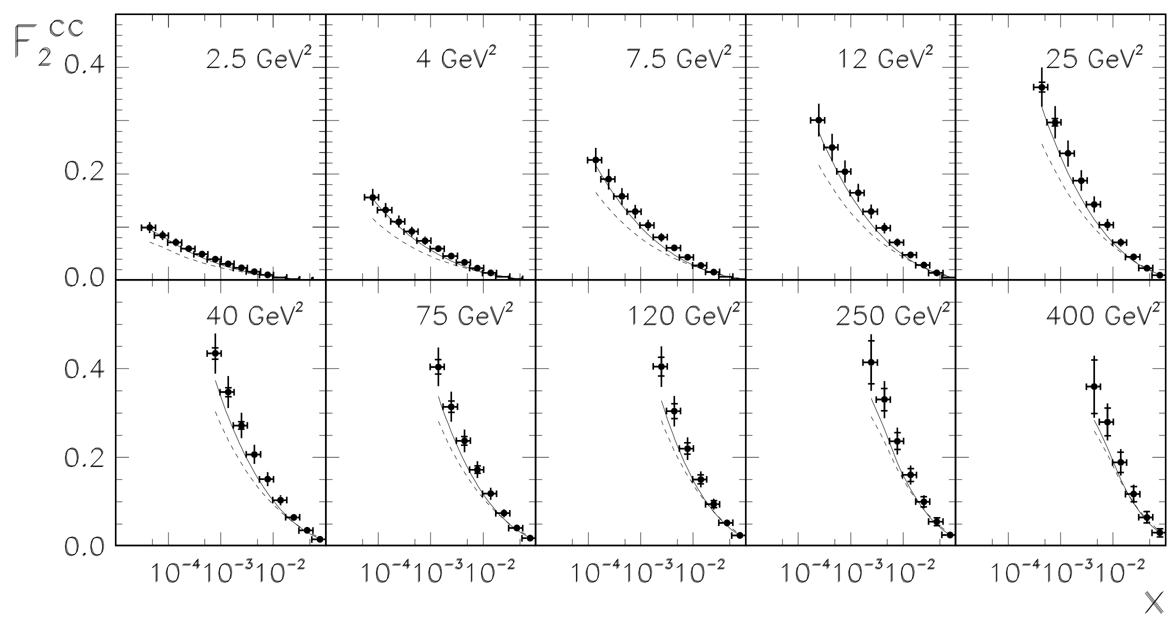
More charm in DIS?

Can use other channels from HERA I data; e.g. $c \to e$ or other D mesons - all together they can be as significant as the D^* measurement

Increased statistics and use of vertex detectors at HERA II can significantly improve things

Improved tagging, 2nd vertex and forward tracking, low p_T and forward η
$\Rightarrow$ greatly reduce extrapolation to $F_2^{c\bar{c}}$
$\Rightarrow$ measurements at higher x

A calculation performed in the variable flavour number scheme?



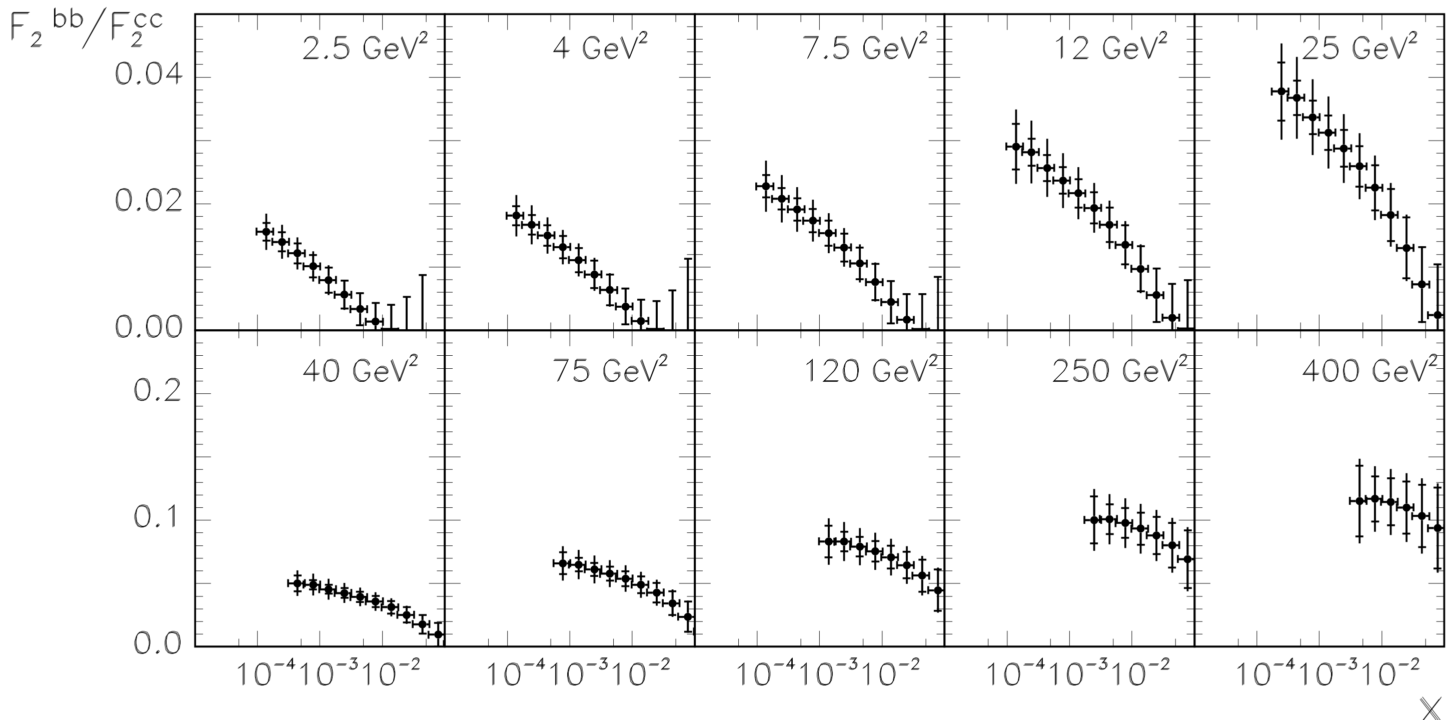
Measuring $F_2^{b\bar{b}}$

$F_2^{b\bar{b}}$ **has not yet been measured**

- **only few hundred events**
- **large extrapolation factors; jets and muons at relatively high p_T and central**
- **good description of measured cross sections?**

Still more challenging; $\sigma^{b\bar{b}} = \sigma^{c\bar{c}}/4$ **at high** Q^2

Could also use photoproduction data (for charm as well)



Summary

Have reasonably precise measurements of charm in DIS

Extracted $F_2^{c\bar{c}}$, but not parton densities; so far no information on Q_p

Double differential cross sections can be used to further constrain the gluon in the proton

More measurements and improvements to come

Measure $F_2^{b\bar{b}}$ at HERA II

What can the LHC expect?

Currently, inclusive DIS and jet measurements constrain the parton densities in the proton

Heavy flavour measurements may do and will increase in importance

Double tagged heavy quarks for g_P

Need matched calculation for Q_p, important at the LHC