Charm production at ZEUS

Matthew Wing (Bristol University)

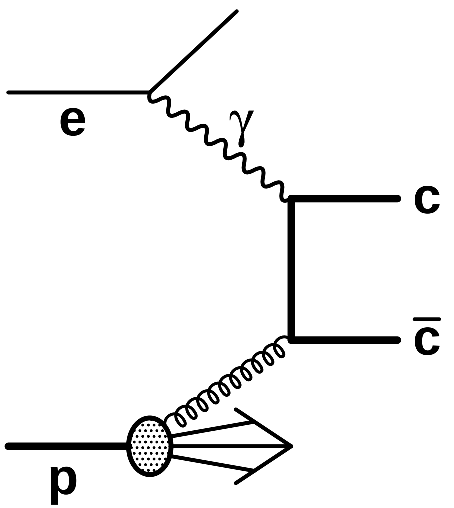
- Introduction and motivation
- Charm production in deep inelastic scattering
- Charm in photoproduction
- Summary and outlook

Introduction and motivation

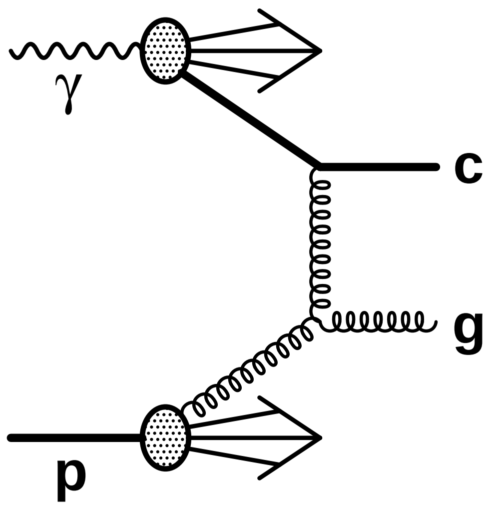
To understand and probe QCD in as much detail as possible

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

QCD-production rate should be accurately understood which can be a significant background to "new" physics



DIS/PHP



PHP

- **gluon density in the proton**
- **charm and gluon density in the photon**
- **schemes and hard scatter**

Introduction and motivation

Three aspects of predicting heavy-quark production:

- **parton densities**
- **hard scatter matrix elements**
- **fragmentation**

Charm mass large enough for reliable perturbative expansion in m_c. Calculations need to treat the mass consistently

Will compare measurements to next-to-leading order predictions:

Fixed order ("Massive") scheme - $p_T^2 < m_c^2$, no heavy quarks in hadron ($gg \to Q\bar{Q}$)

Next-to-leading log ("Massless") scheme - $p_T^2 > m_c^2$, active heavy quarks in hadron (also $gQ \to gQ$)

A combination of the two, FONLL

Analysis

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

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

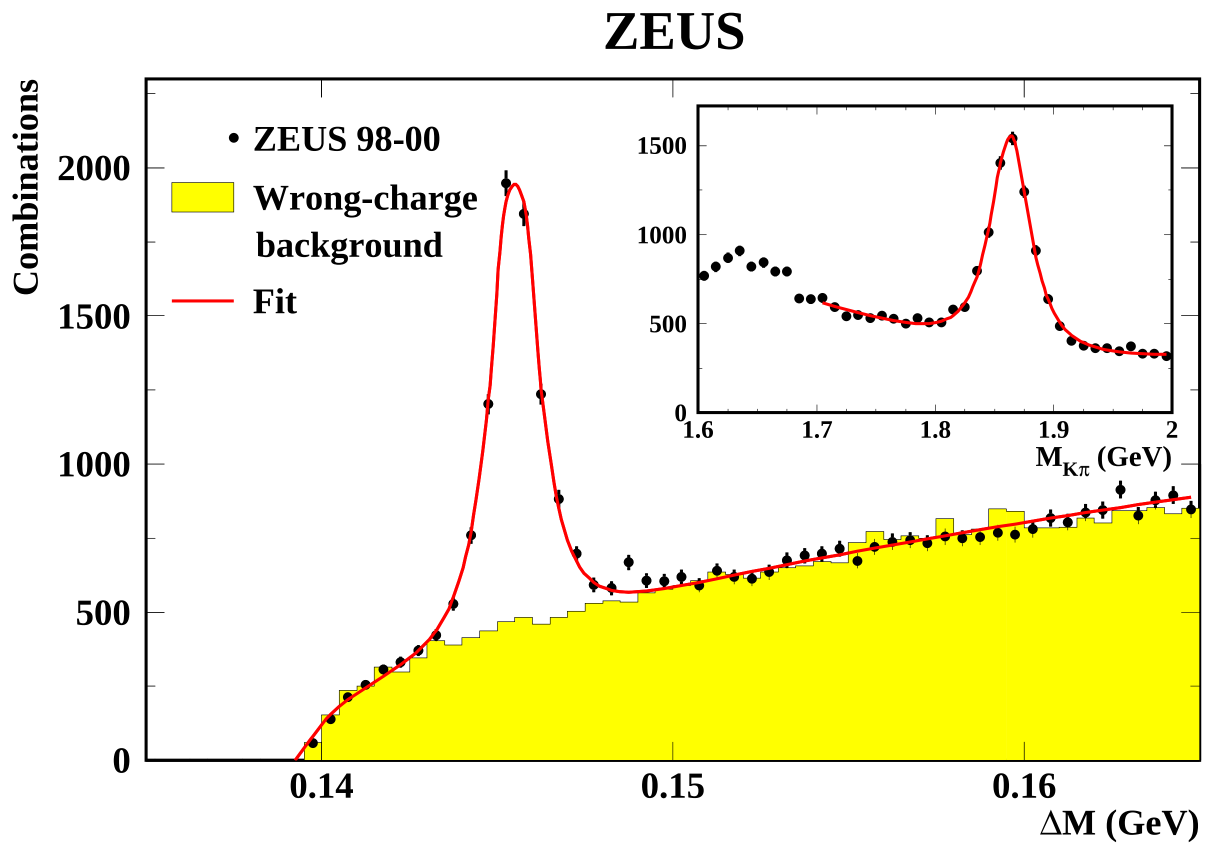
$$|\eta(D^*)| < 1.5$$

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 section

For the production rate, $r = N/\mathcal{L}$

$r^{e^-p}/r^{e^+p} =$ **1.12±0.06 for 1.5**$<Q^2<$**1000 GeV**^{2}

and

$r^{e^-p}/r^{e^+p} =$ **1.67** $\pm$ **0.21 for 40** $< Q^2 <$ **1000 GeV**^{2}

Difference between $\sigma(e^-p)$ **and** $\sigma(e^+p)$ **data**

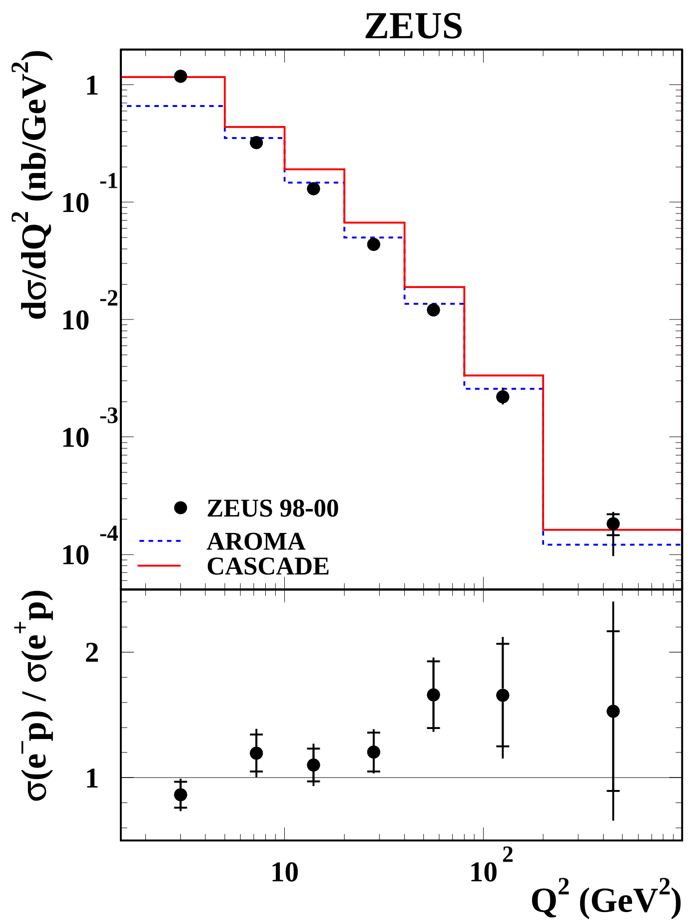
$\sigma(e^-p \to e^-D^*X) = 9.37 \pm 0.44$(**stat.**)$^{+0.59}_{-0.52}$(**syst.**) **nb**

$\sigma(e^+p \to e^+D^*X) = 8.20 \pm 0.22$(**stat.**)$^{+0.39}_{-0.36}$(**syst.**) **nb**

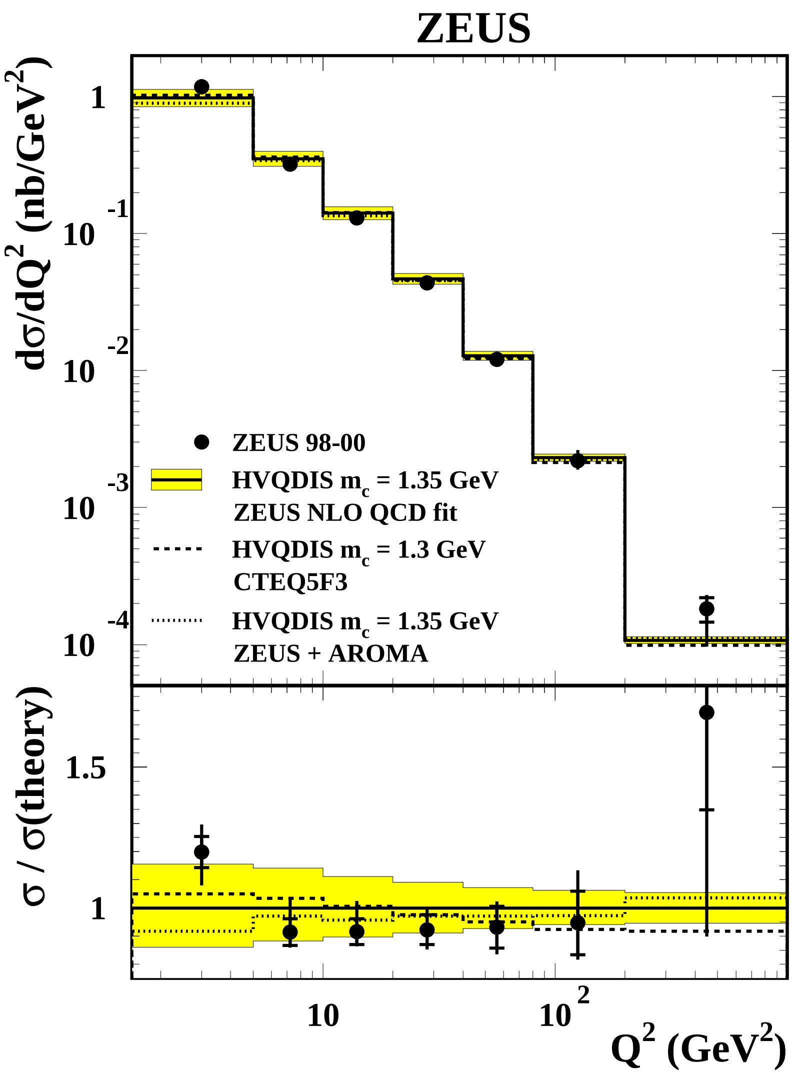
$\sigma(e^-p) > \sigma(e^+p)$ **increasing with** Q^2

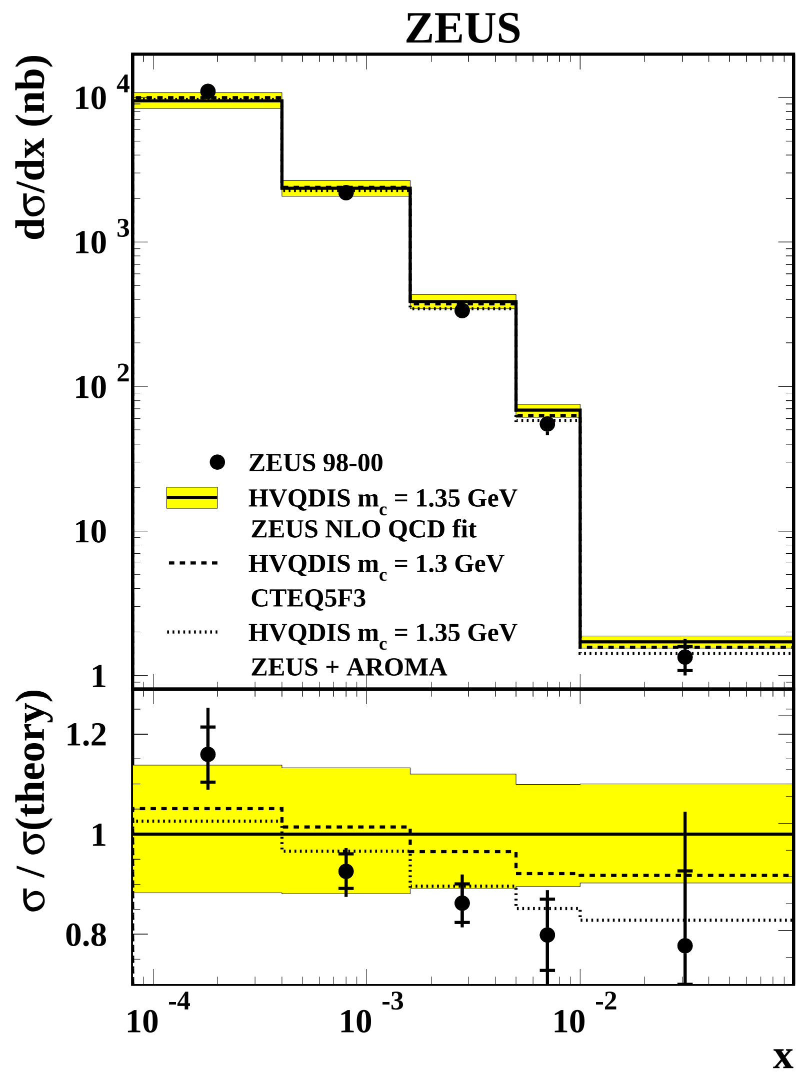
No obvious reason why, assume statistical fluctuation.

Can be solved with more e^-p **data...**



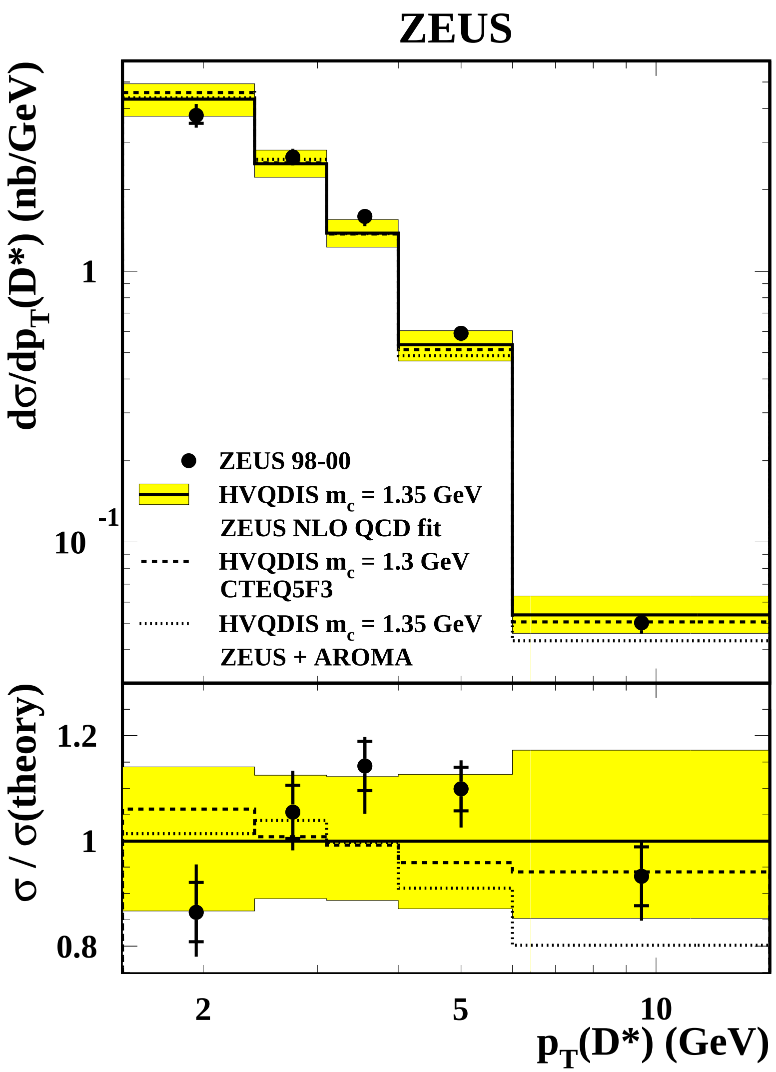
Event cross sections

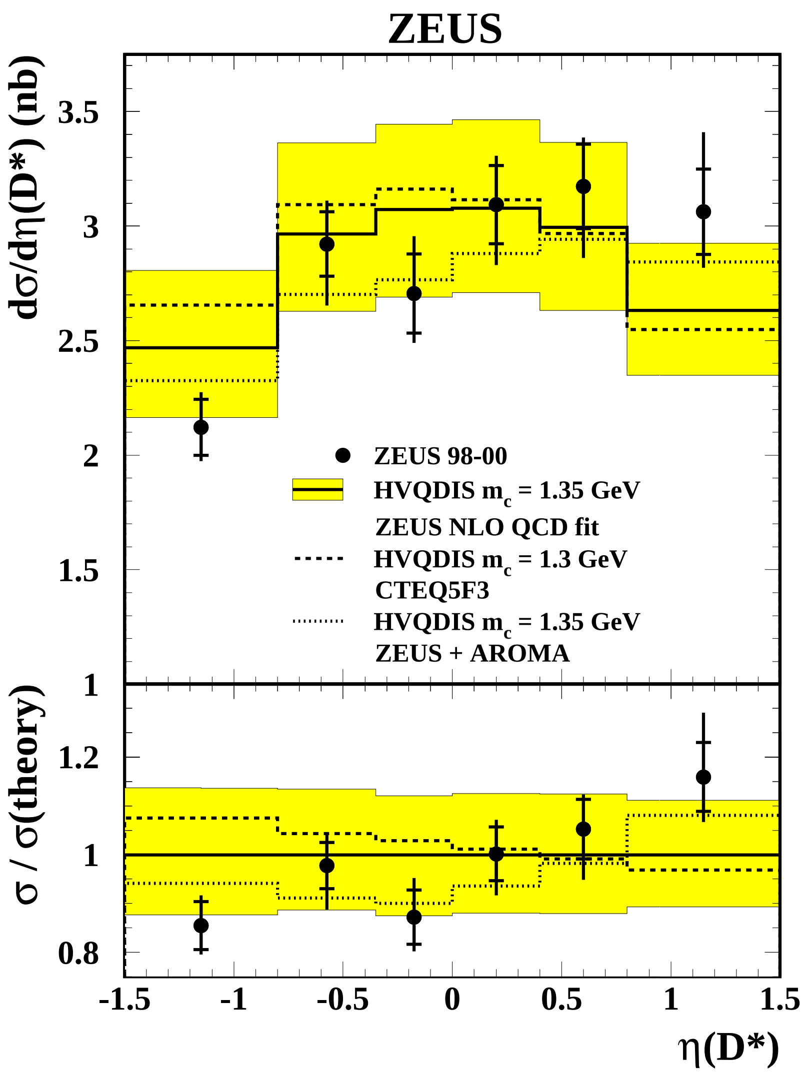




Generally good description of the data over four orders of magnitude

D^* cross sections





Again generally good description of cross sections

Some differences in shape; can the PDF be fitted to describe these?

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

Extraction of $F_2^{c\bar{c}}$ performed in fully consistent way

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

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

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

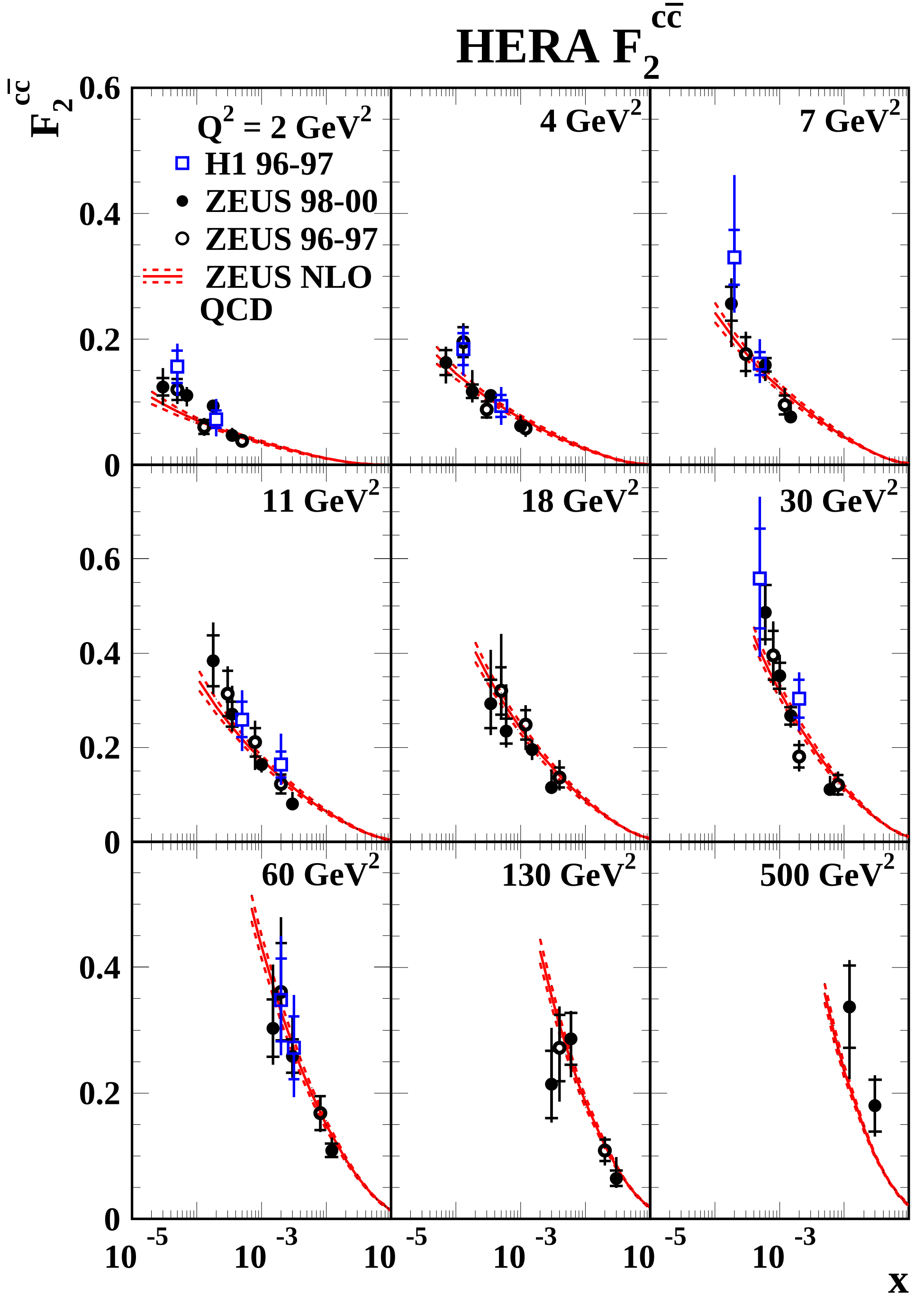
Recently added extra 31 points, extending up to $Q^2 = 500$ GeV^2

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

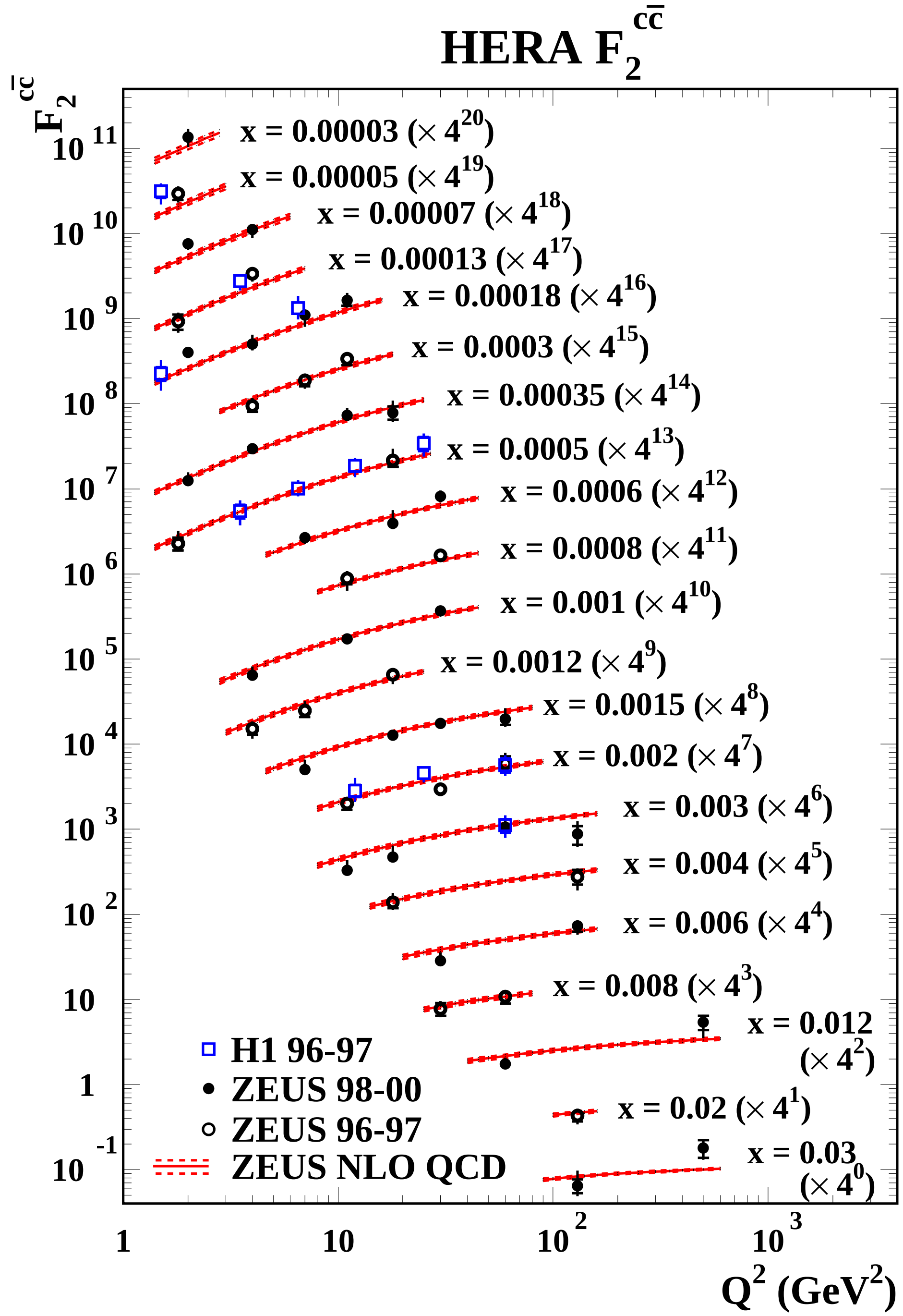


HERA measurements of $F_2^{c\bar{c}}$

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

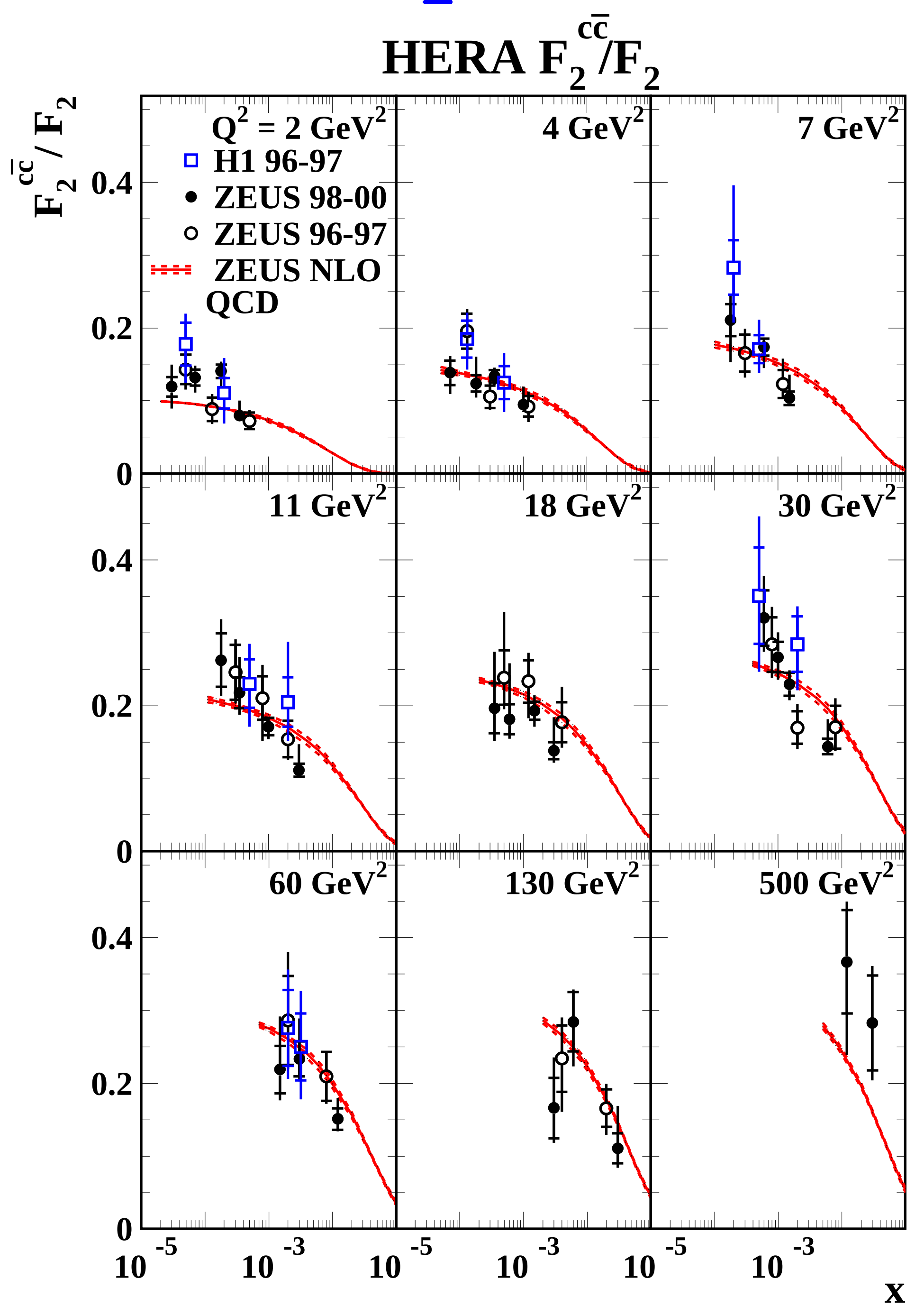
Charm production represents up to 30% of the inclusive cross section

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

Both differential cross sections and $F_2^{c\bar{c}}$

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

In particular D^+ can become more effective

With improved tagging, can use a vertex tag and forward tracking to goto lower p_T and more forward $\eta \Rightarrow$ greatly reduce extrapolation to $F_2^{c\bar{c}}$

A calculation performed in the variable flavour number scheme?

Charm in photoproduction

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

$$1.9 < p_T(D^*) > 20\text{GeV},$$

$$|\eta(D^*)| < 1.6$$

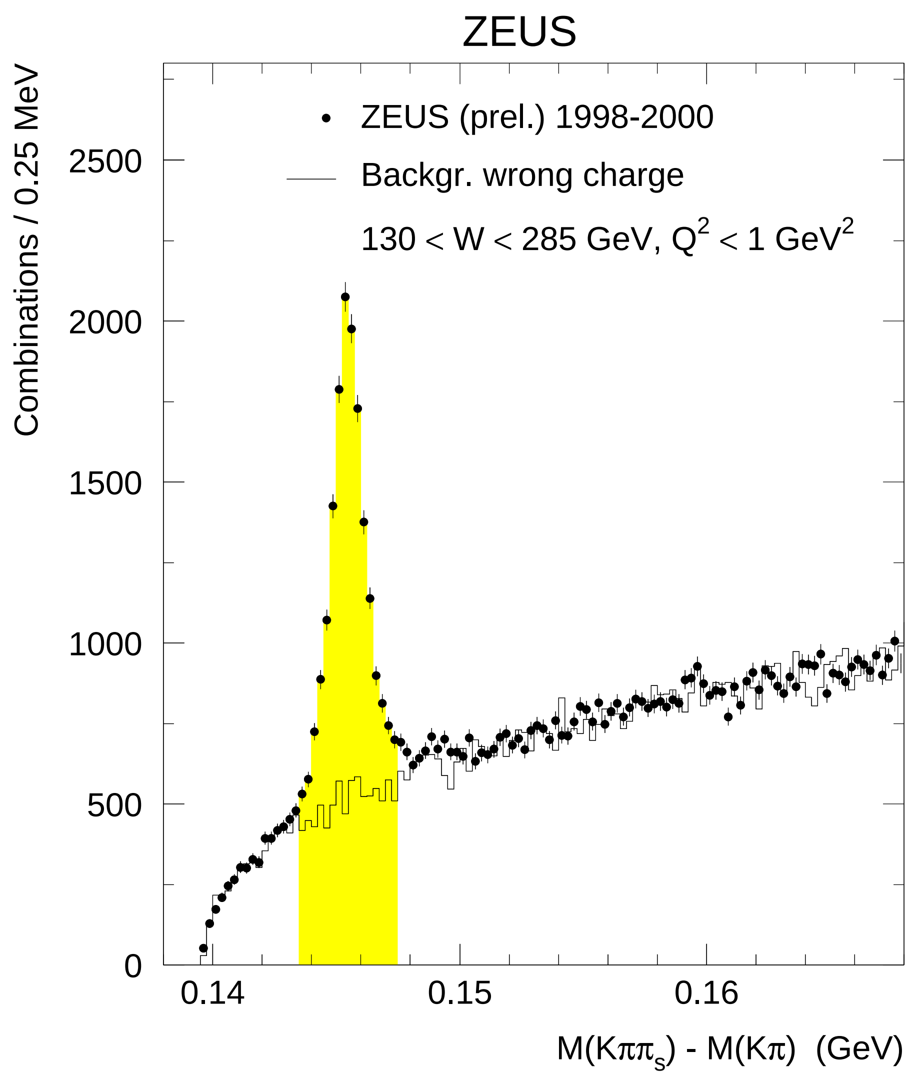
And the absence of a scattered electron

$$Q^2 < 1\text{GeV}^2,$$

$$130 < W_{\gamma p} < 280\text{GeV}$$

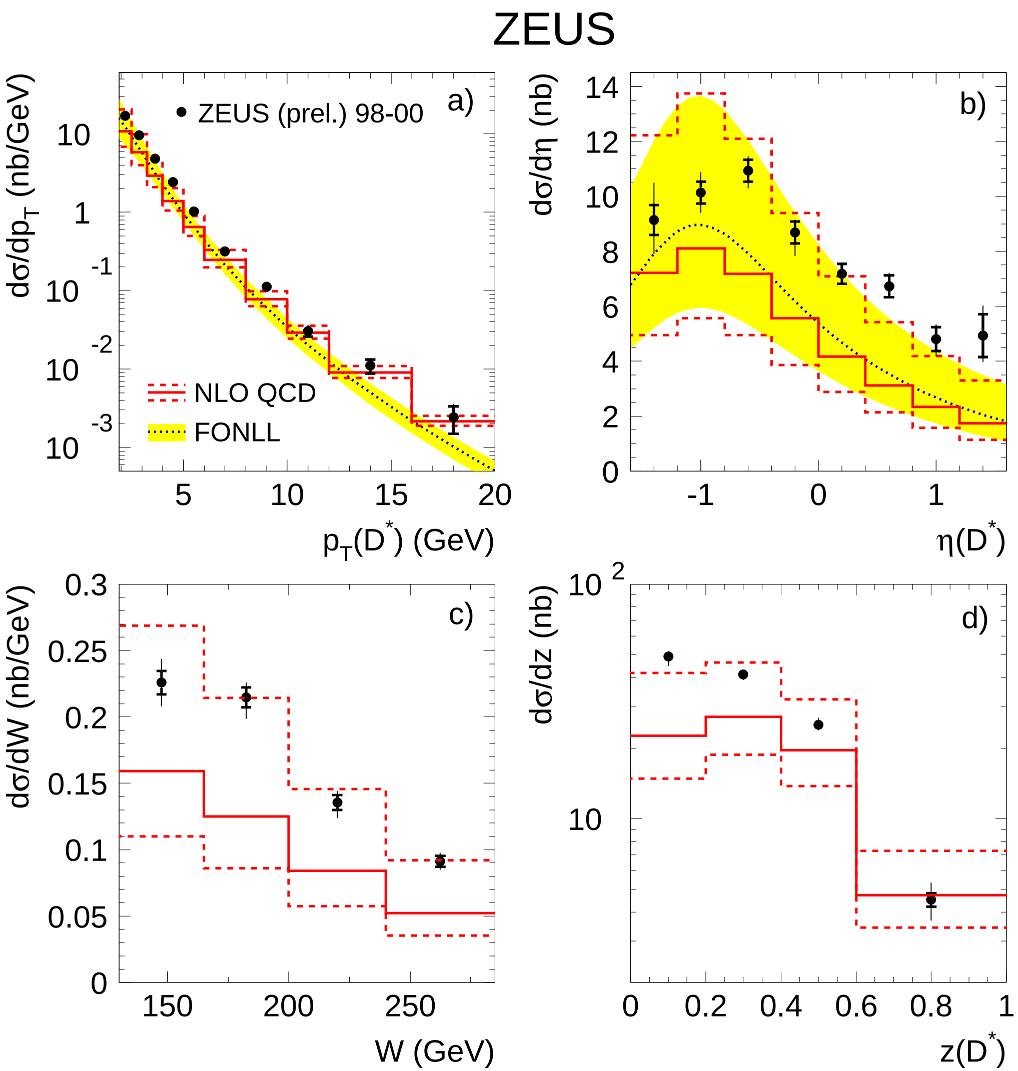
Analysis of 98-00 data, $\sim$ 79 pb^{-1}, in addition to $\sim$ 37 pb^{-1} from 96-97.

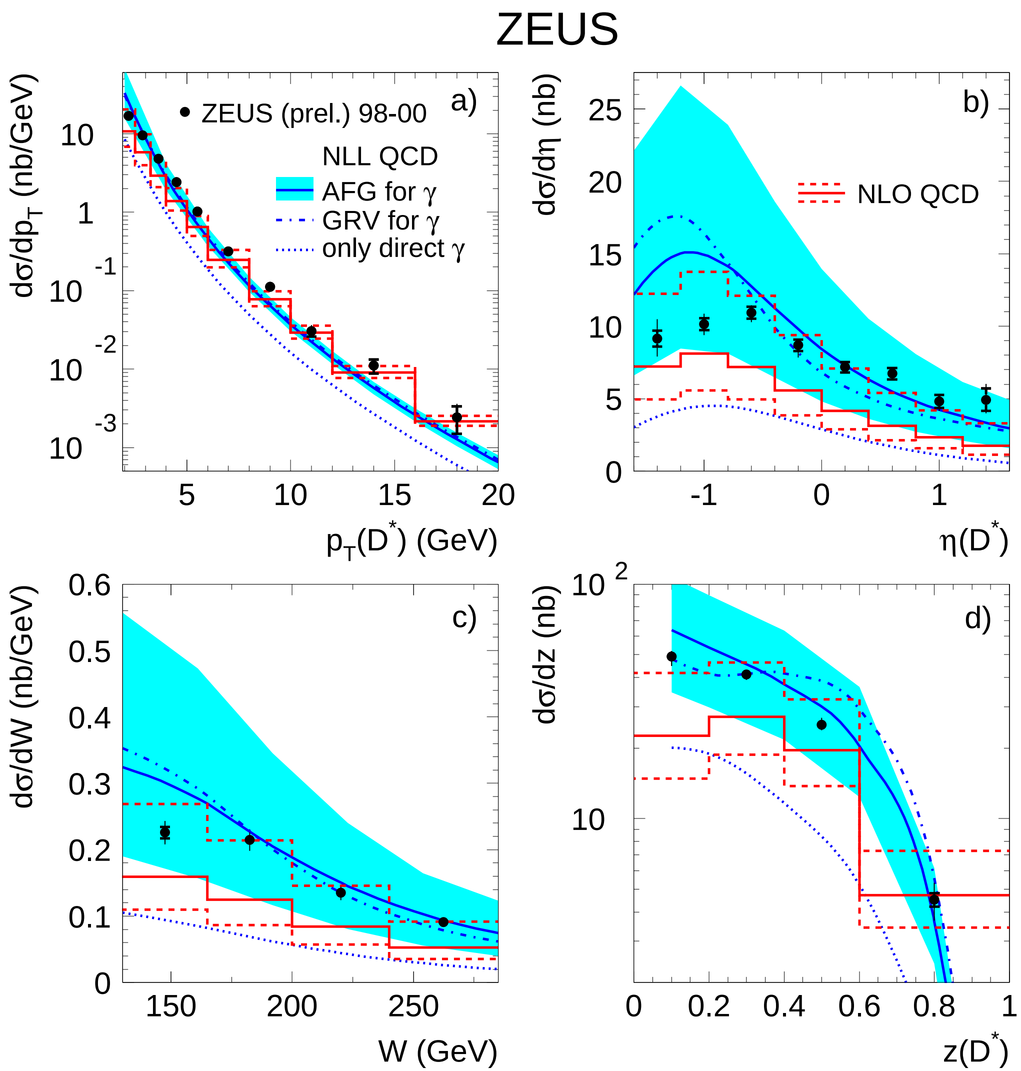
Measure detailed differential cross sections $\to$



Measured 10350 $\pm$ 190 D^* mesons

Single differential cross sections





FONLL certainly not better and is worse at high p_T

NLL describes data within (large) uncertainties

Relook at old results

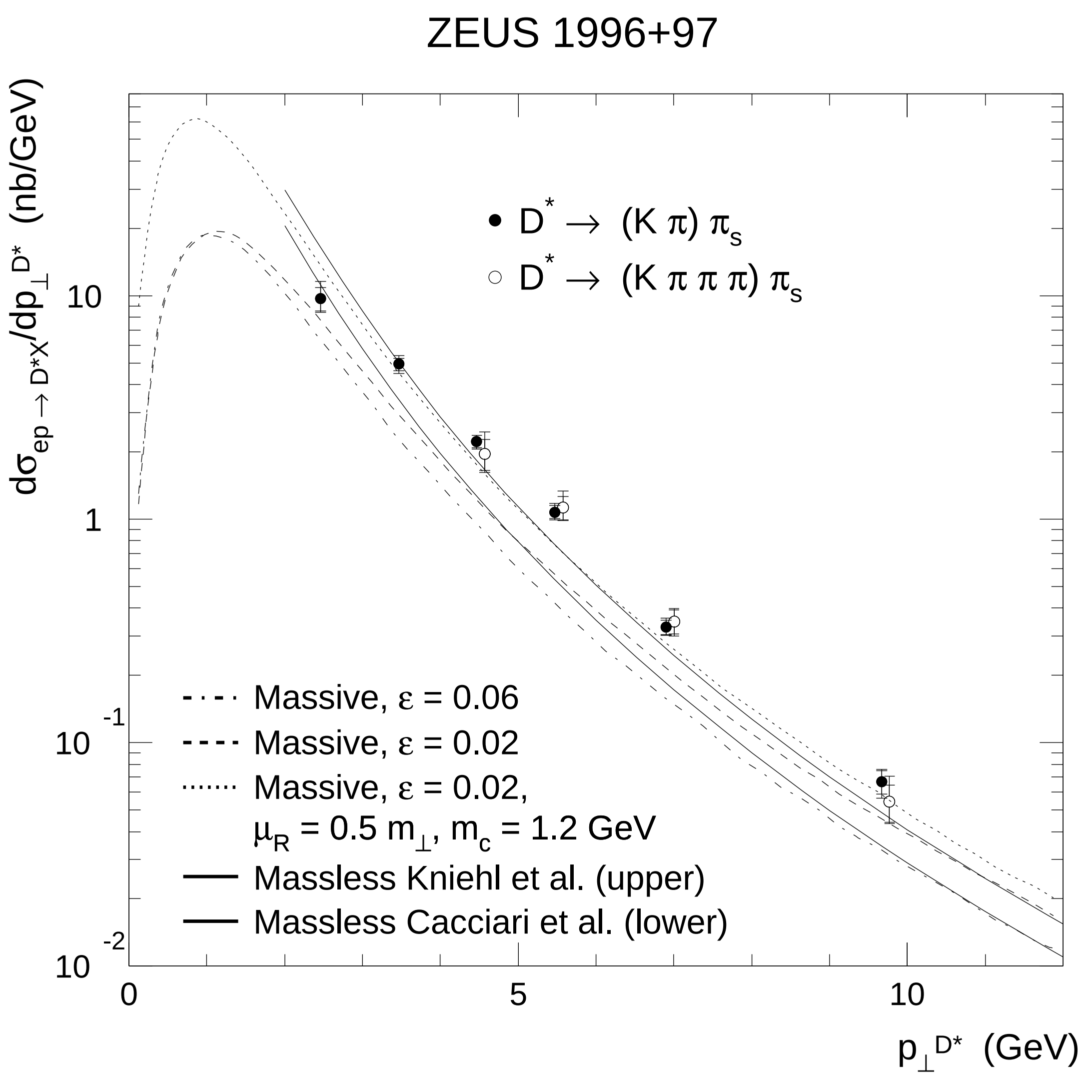
Same message seen in old data (data consistent)

FONLL is NLO (Frixione et al.) at low $p_T(D^*)$ and NLL (Cacciari et al.) at high $p_T(D^*)$

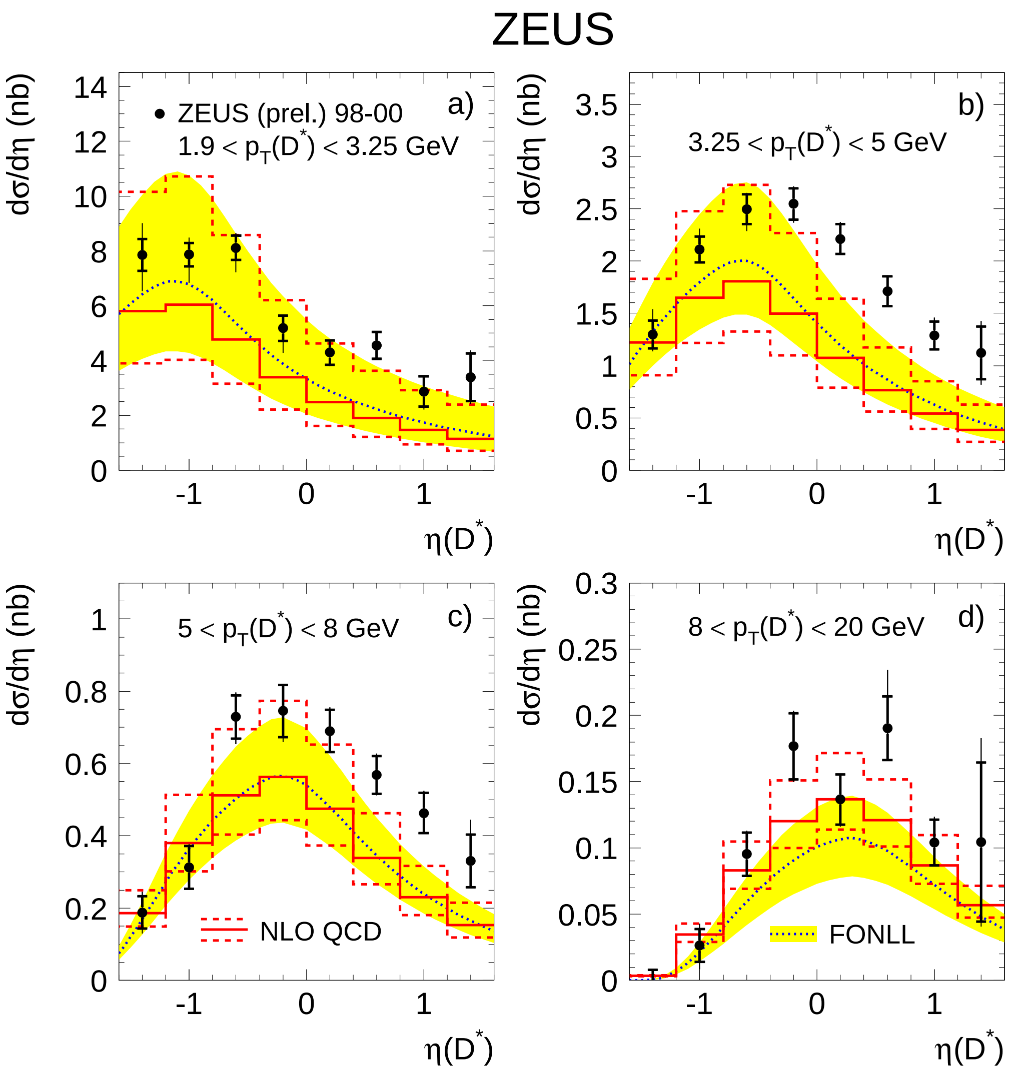
This is why at high $p_T(D^*)$, FONLL is worse than NLO

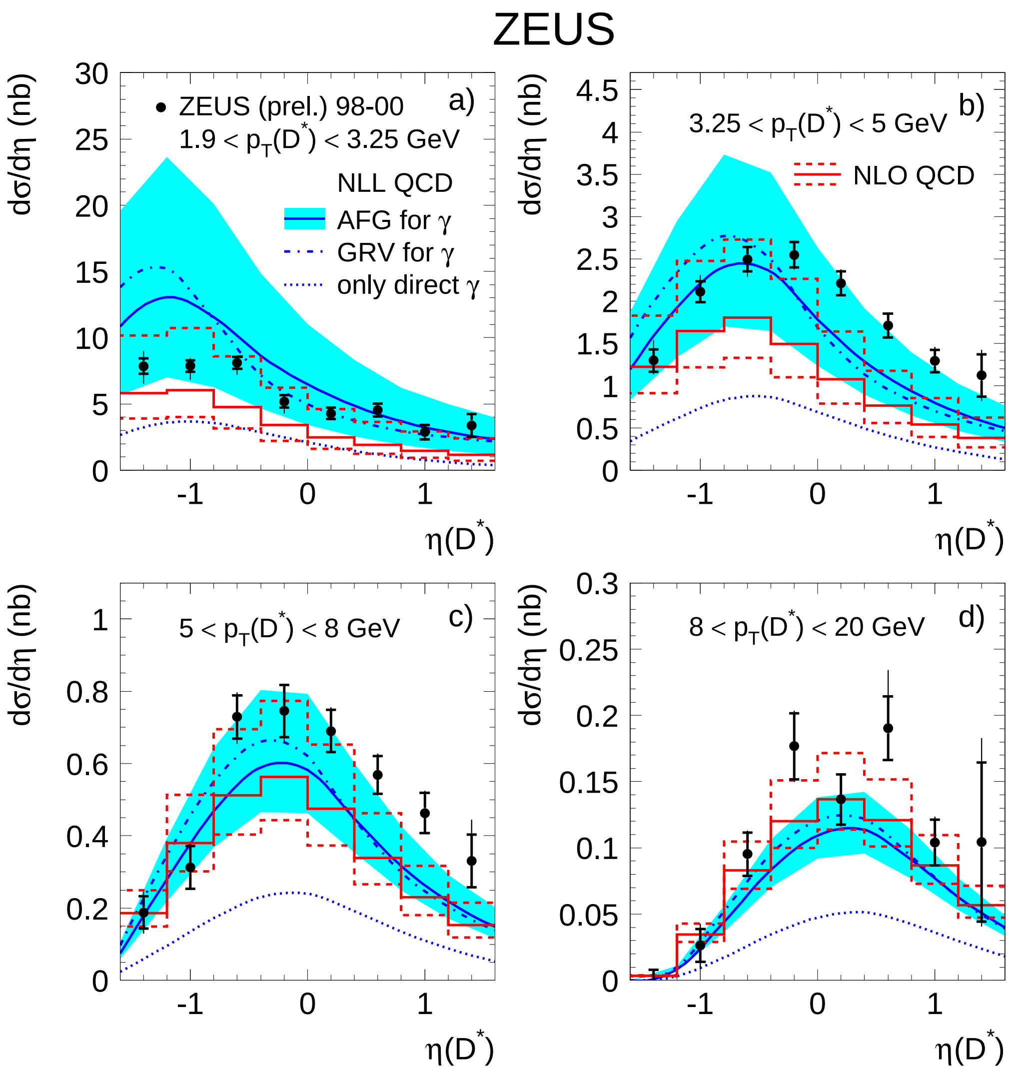
Why are Kniehl et al. and Cacciari et al. so different? A rigorous comparison would be useful

How would NLO (Frixione et al.) at low $p_T(D^*)$ and NLL (Kniehl et al.) at high $p_T(D^*)$ as FONLL work?



More detailed differential cross sections I

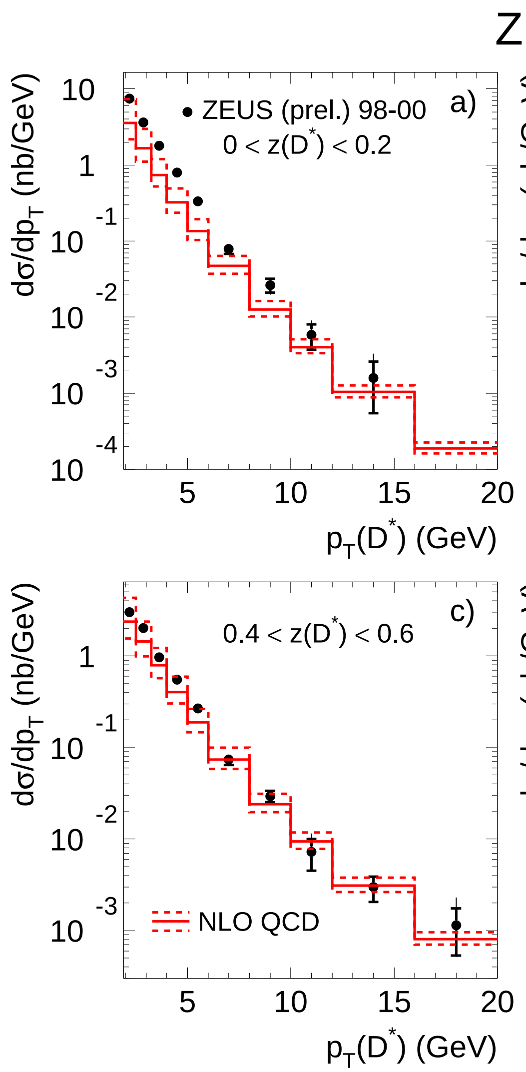


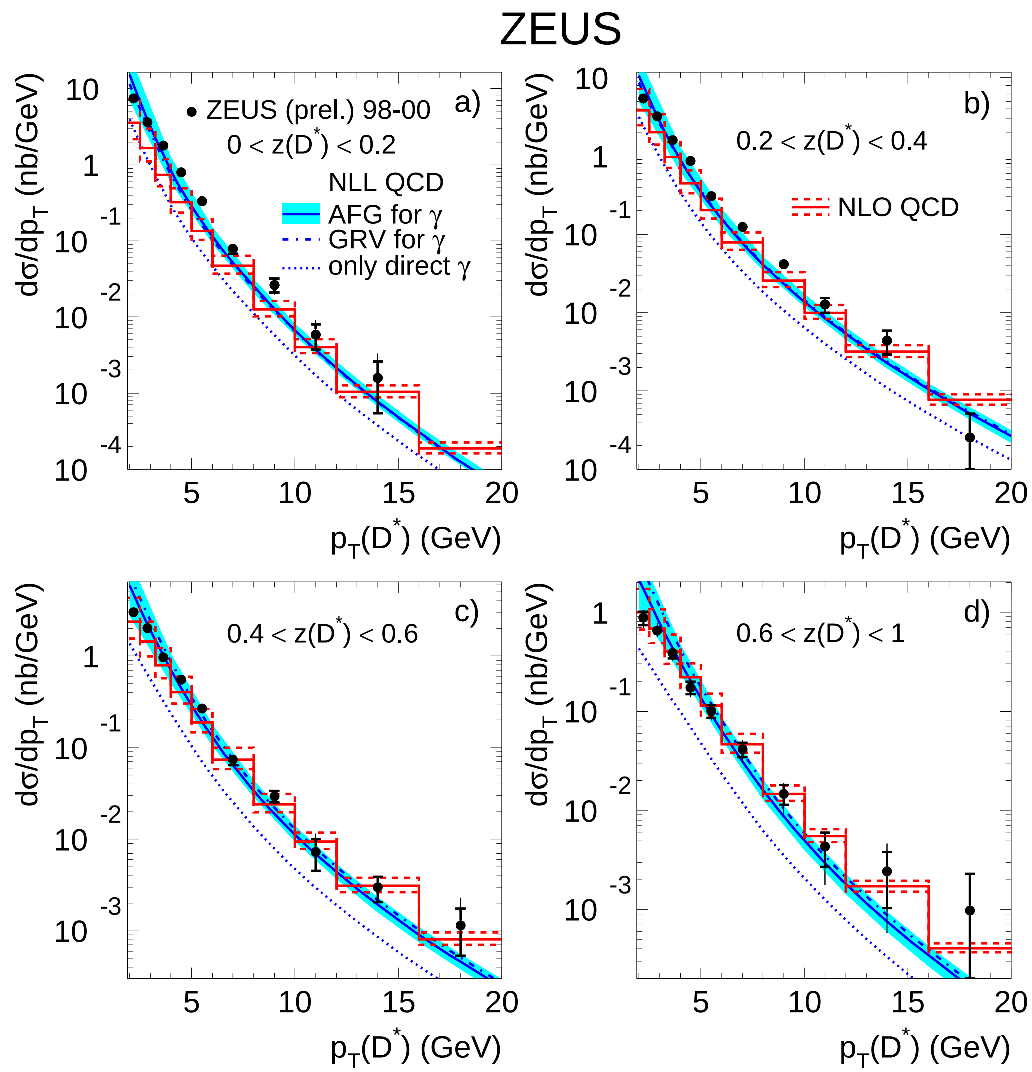


Largest differences at medium $p_T(D^*)$ and forward $\eta(D^*)$

Theory does not describe the details of the measurements

More detailed differential cross sections II

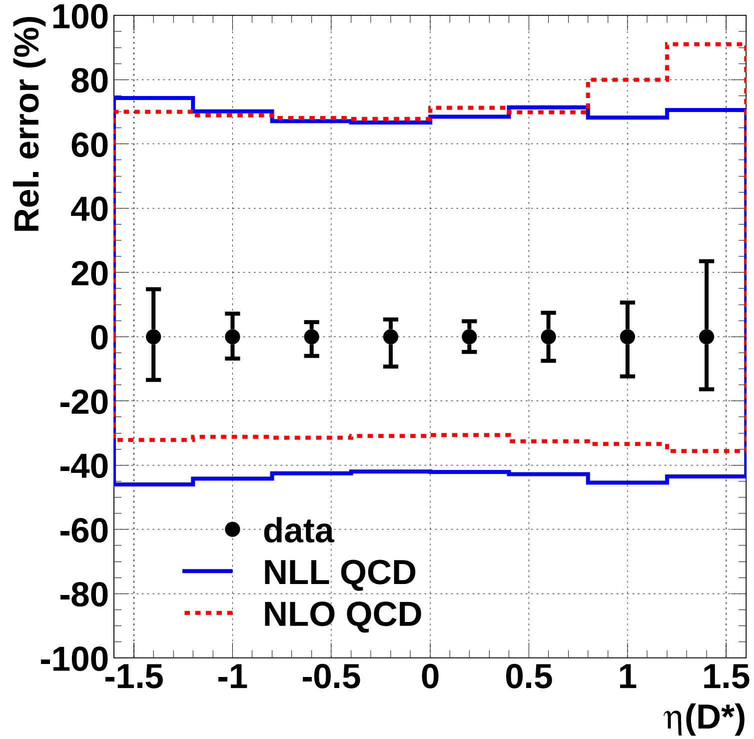




Difference with NLO (and NLL) at low z

Data-theory comparison

Is QCD really predictive? Relative uncertainty on prediction is much larger than for data



Data uncertainties will be reduced...

Are the QCD calculations correct? *cf* difference Cacciari et al. and Kniehl et al.

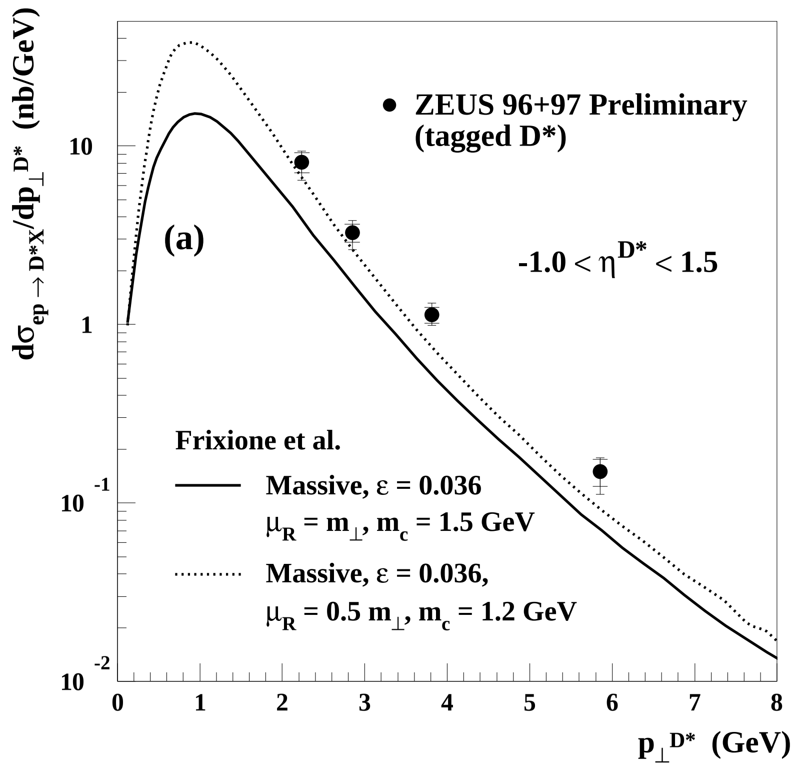
What is the charm mass? Description of DIS with mass 1.3 GeV. This would give a better description of photoproduction data.

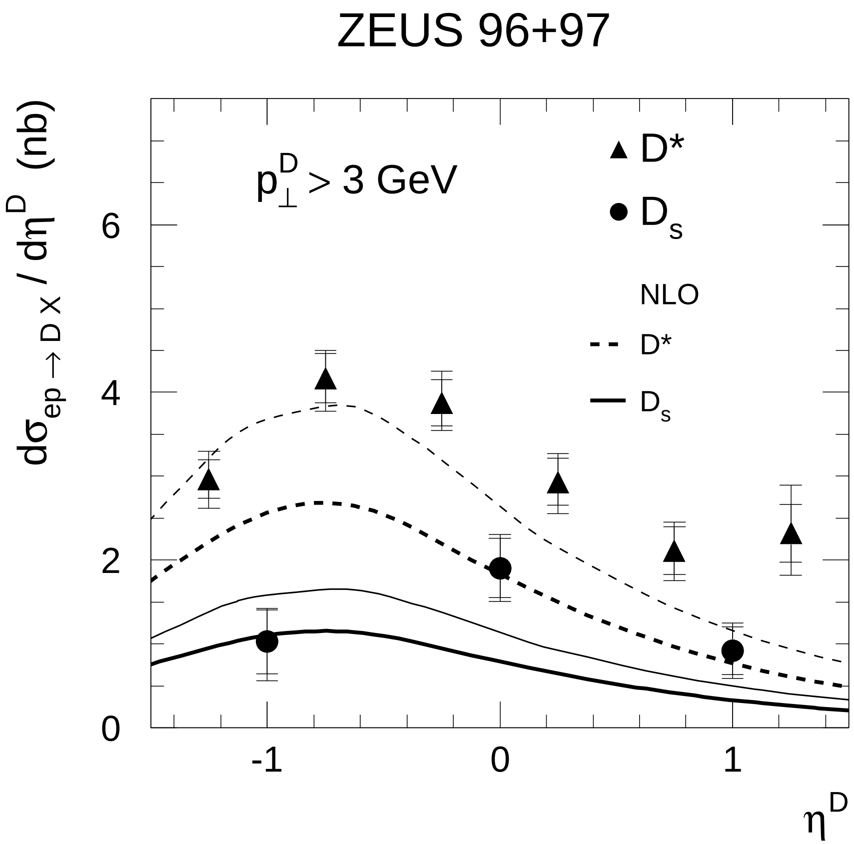
Unlikely to be proton PDF

An effect of the photon PDF? Could use new parametrisation CJK when NLO complete (with uncertainties)

How is the fragmentation? (See L. Gladilin for some details)

Other data





Measurements of D_s production and D^* production for 80 $< W <$ 120 GeV

Similar conclusions from other measurements; theory on the low side particularly at medium $p_T(D^*)$ and forward $\eta(D^*)$

Summary

Now have very precise measurements of charm both in DIS and particularly photoproduction

Measurements in DIS reasonably well described with $m_c \sim$ 1.3 GeV

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

Precise photoproduction data not described in detail by predictions

More measurements and improvements to come

Outlook

Again stress the importance of a vertex tag and improved forward tracking for:

- **a more complete coverage of the kinematic region, $p_T(D) \sim 0$ and $\eta(D) \sim 2-3$**
- **reconstruction and reduction of background for D^+ mesons**
- **large reduction of background for $c \to e$ channel**
- **achieve a more complete picture of QCD and the production of heavy quarks**