

F_2^{CC} measurements at HERA



Marcello Bindi

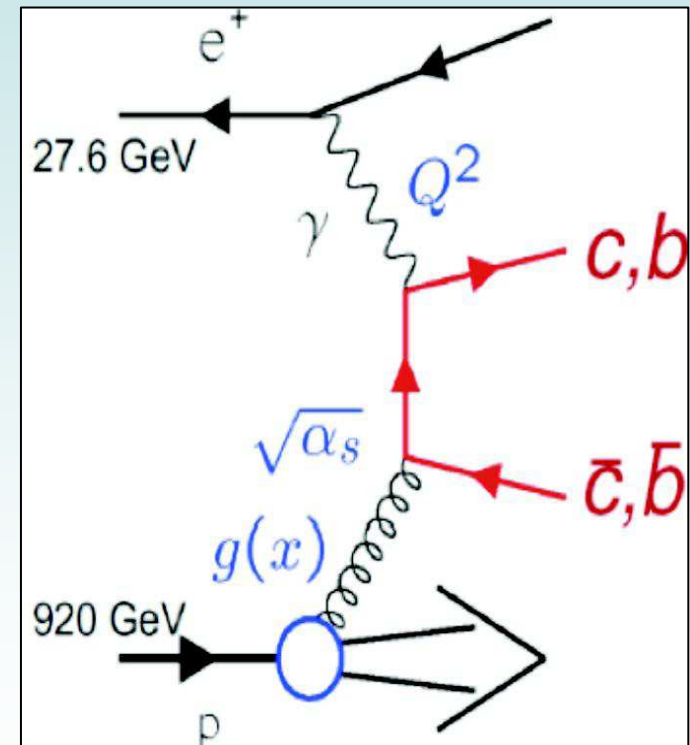
University of Bologna

on behalf of the ZEUS and H1 Collaborations

**DIS 2008, 7-11 April 2008, University College London
XVI International Workshop on Deep-Inelastic Scattering and Related
Subjects**

Motivations


- Heavy flavour production at HERA can be studied for different kinematic regions, from Photoproduction to DIS and for different values of transverse momentum of the heavy quark.
- In DIS regime the heavy quarks are produced mainly by the Boson-Gluon-Fusion process.
- This process is directly sensitive to gluon content inside the proton.
- Factorisation in pQCD:
 $\sigma = \text{parton distr.} \otimes \text{hard scatt.} \otimes \text{fragm./hadron.}$
- Important test of pQCD at different scales (M_Q, p^T_Q, Q^2).



Theoretical models at NLO

Massive approach (**Fixed Flavour Number Scheme**):

- c & b massive \rightarrow full massive matrix elements; *PhP* : Frixione et al., FMNR
- scale M_Q ; *DIS* : Harris & Smith, HVQDIS
- appropriate for $Q^2 \sim M_Q^2$ *fully differential NLO program*

 **c & b produced dynamically in the hard subprocess**
(not part of the proton or photon; 3 active flavours in proton: u, d, s)

Massless approach (**Zero Mass Variable Flavour Number Scheme**):

- c & b massless \rightarrow resums $[\alpha_S \ln (Q^2/M_Q^2)]^n$; *PhP* : Kniehl et al.
- scale Q_2, pT_Q ; *DIS* : only inclusive calculation
- appropriate for $Q^2 \gg M_Q^2$ *of F_2^{cc} available*

 **c & b present in proton and photon**

Combined approach (**Generalized Mass Variable Flavour Number Scheme**):

- massive at small Q^2 *PhP*: Cacciari et al.
- massless at high Q^2 *DIS* : only F_2^{cc} available

Charm tagging

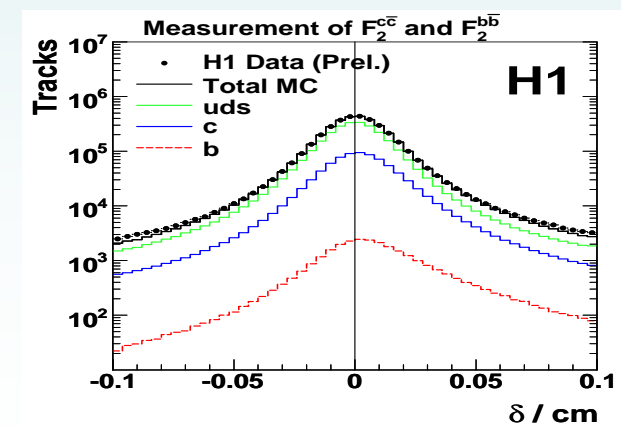
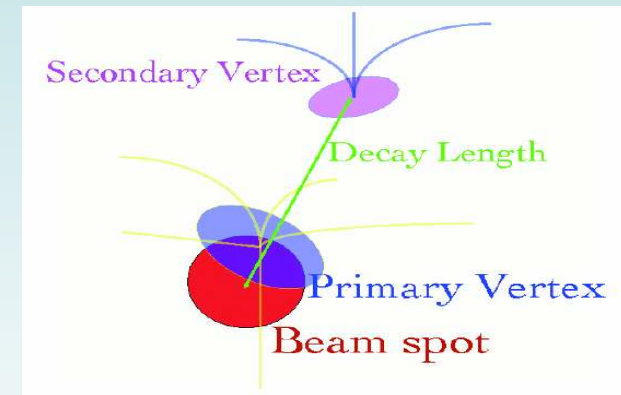
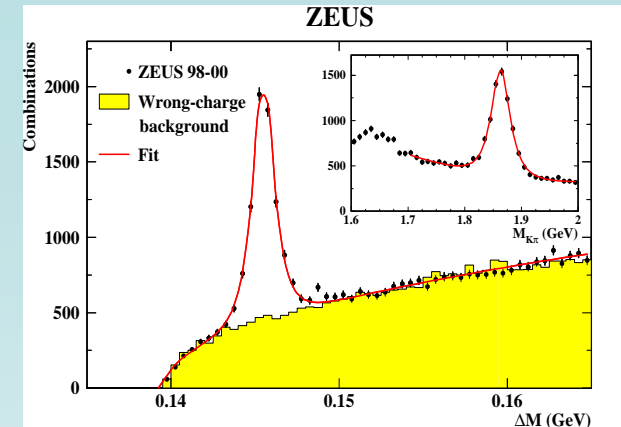
D mesons reconstruction in the final state

- D^* , D^0 mesons: tagged by invariant mass $M(K\pi)$ and $\Delta M = M(K\pi\pi) - M(K\pi)$.
- D^+ meson: being a long lived particle, the secondary vertex of the decay can be reconstructed and used for a better discrimination of the signal.

Both these cases, need an extrapolation factor to the full space phase to obtain the $F_2^{c\bar{c}}$

Inclusive Impact Parameter tagging

- Measure of the impact parameter with respect to primary vertex (beamspot)



D* production in DIS



Golden mode : can be double tagged by the slow pion and the D^0 in the final state.

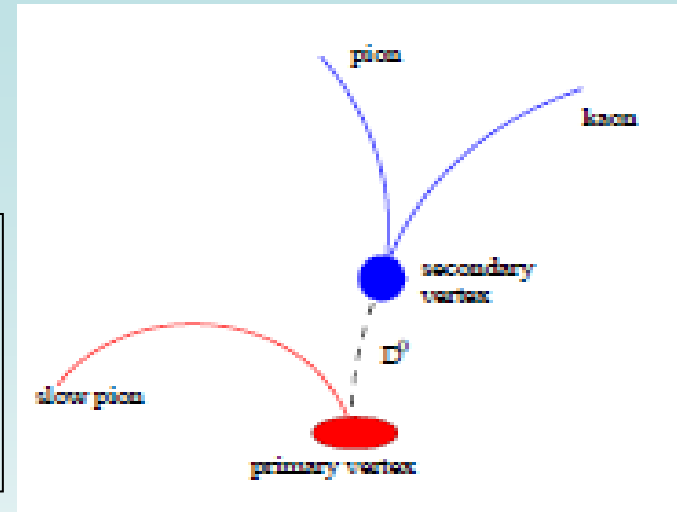
Kinematic Region

- $5 < Q^2 < 1000 \text{ GeV}^2$
- $0.02 < y < 0.7$
- $|\eta (D^*)| < 1.5$
- $1.5 < p_T (D^*) < 15 \text{ GeV}$

HERA II

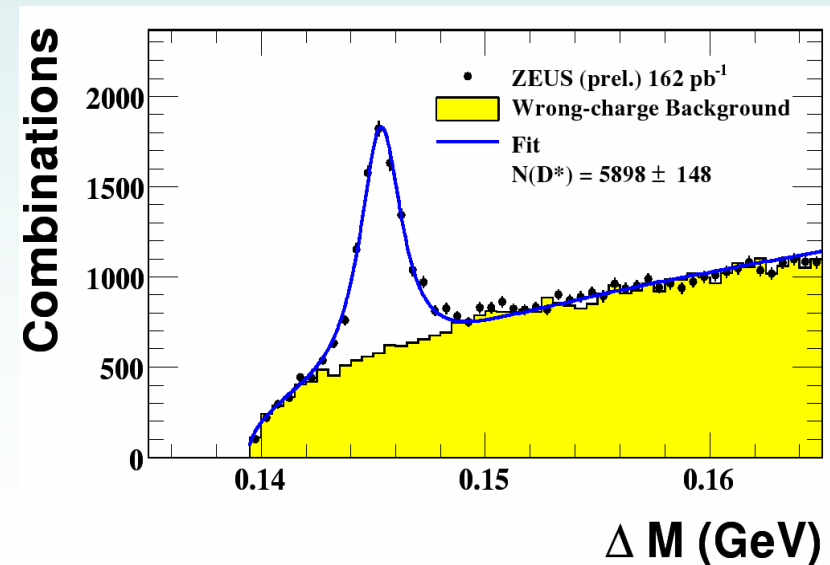
2003-2005

162 pb^{-1}



Selection of D* candidates

- $D^{*\pm} (2010) \rightarrow D^0 \pi^\pm_{\text{slow}}$ (BR: 67.7 %) with $D^0 \rightarrow K^\pm \pi^\pm$ (BR: 3.8 %)
- $|\eta| < 1.75$ (candidate tracks)
- $p_T > 0.4 \text{ GeV}$ (tracks from D^0)
- $p_T > 0.12 \text{ GeV}$ (slow pion from D^*)



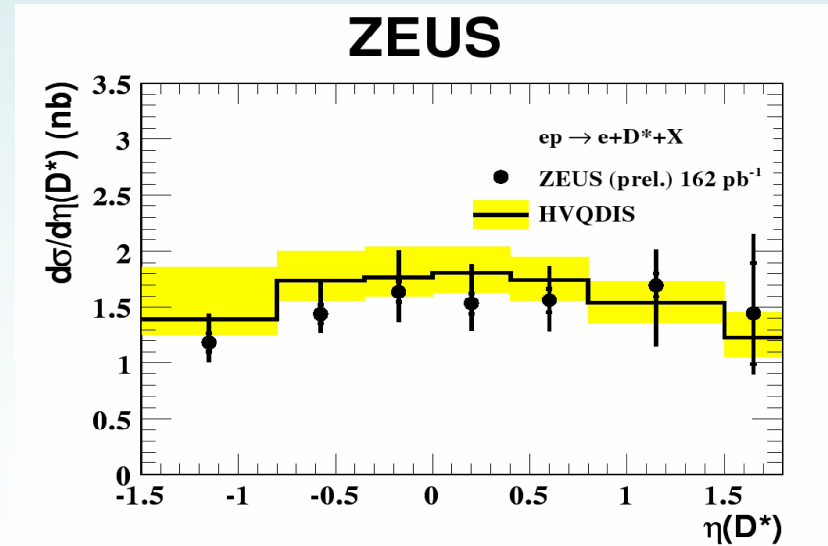
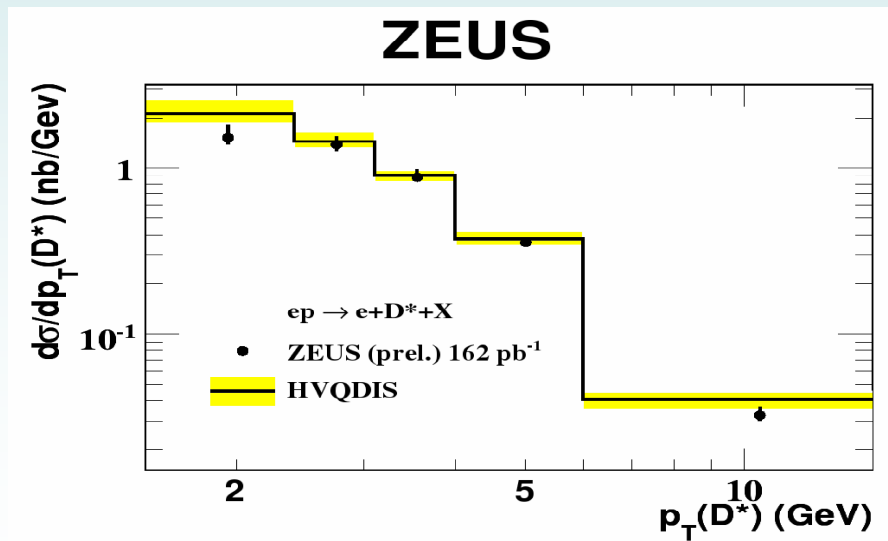
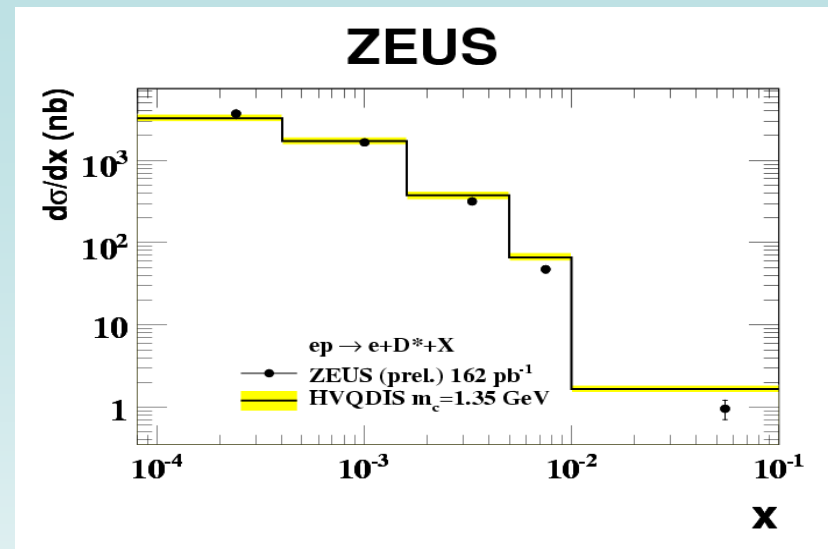
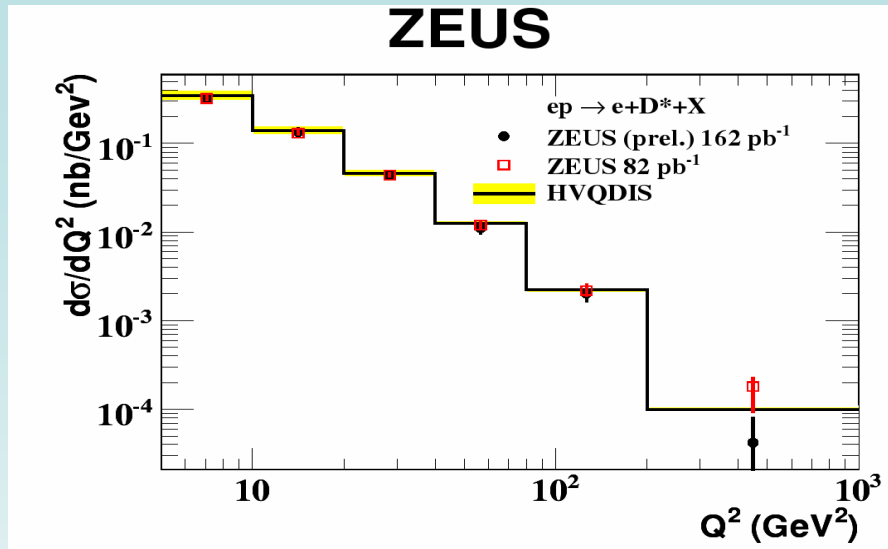
ZEUS: NLO QCD predictions

- The HVQDIS program has been used, which evaluates cross sections for heavy quark production at NLO in the Fixed Flavour Number Scheme.

Quantity	Value	Variation
Renormalisation & Factorisation scale (μ_R, μ_F)	$\mu_R = \mu_F = \sqrt{Q^2 + 4M_c^2}$	$2\sqrt{Q^2 + 4M_c^2}$ Larger of: $\frac{1}{2}\sqrt{Q^2 + 4M_c^2}$ and $2M_c$.
Peterson Parameter (ϵ)	0.035	± 0.015
Charm Mass (M_c)	1.35 GeV	± 0.15 GeV
Input PDF	ZEUS NLO PDF	Upper and lower predictions of ZEUS NLO PDF.

- Biggest uncertainty from Charm mass $\sim 10-20$ %

D* differential cross sections in DIS



D[±] production in DIS

- D[±] long lifetime → displaced secondary vertex (MVD).
- Signed 2-D decay length significance (S_{DL}) with respect to the beamspot
- Better S/N ratio by cutting on the S_{DL} of the decay products.

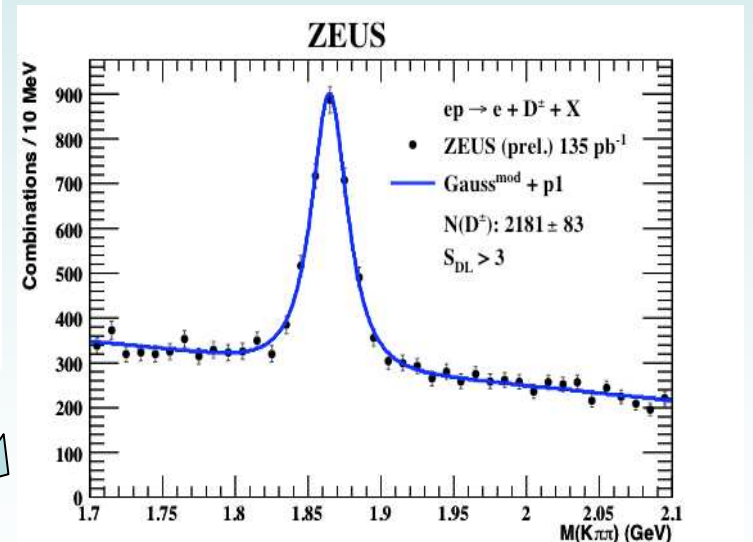
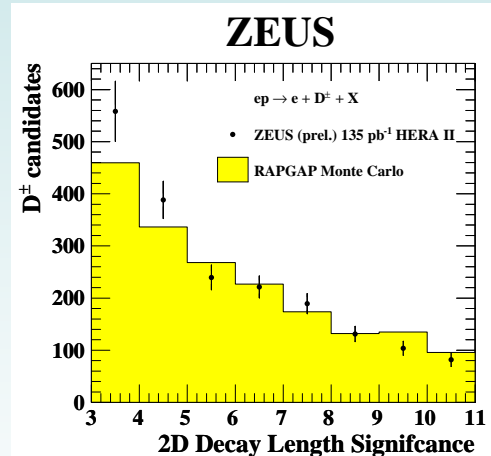
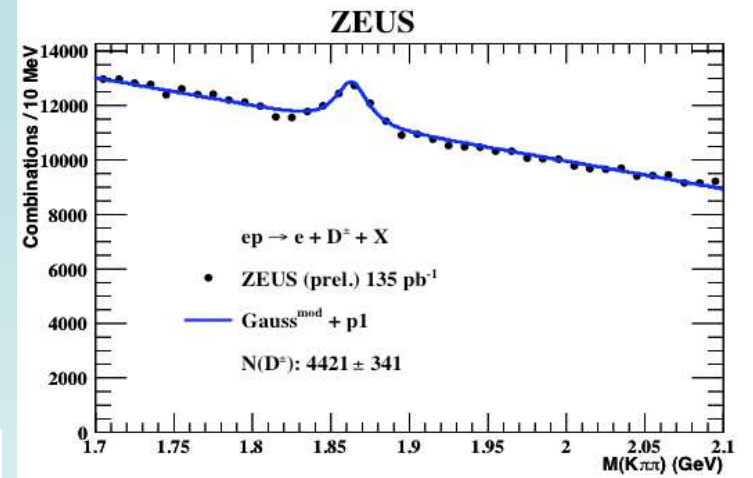
1/3 HERA II:
2005 data
135 pb⁻¹

Kinematic Region

- $5 < Q^2 < 1000 \text{ GeV}^2$
- $0.02 < y < 0.7$
- $|\eta(D^\pm)| < 1.6$
- $3 < PT(D^\pm) < 20 \text{ GeV}$

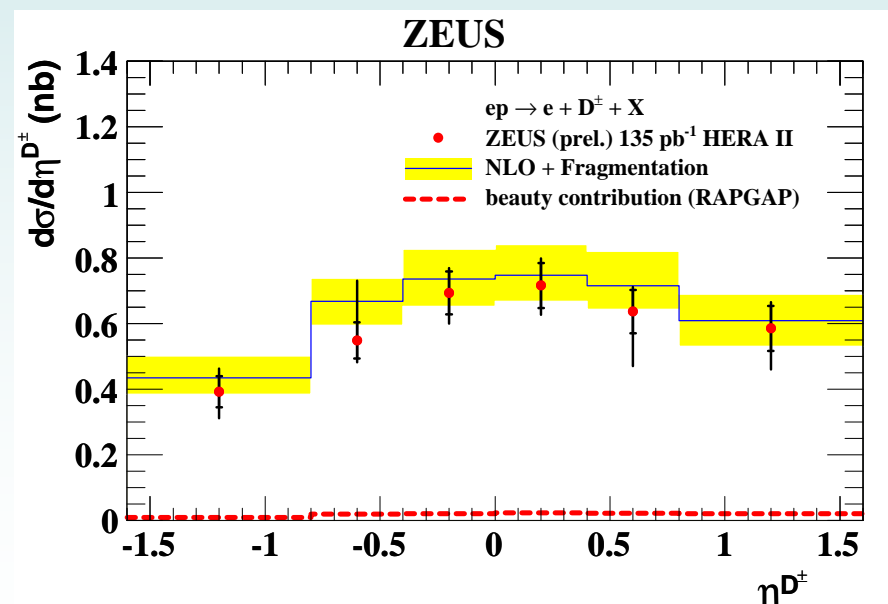
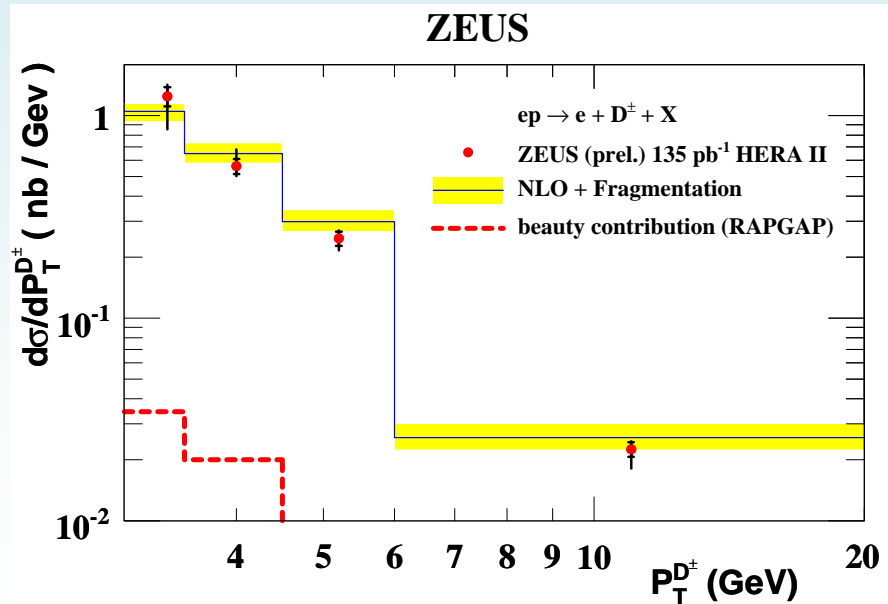
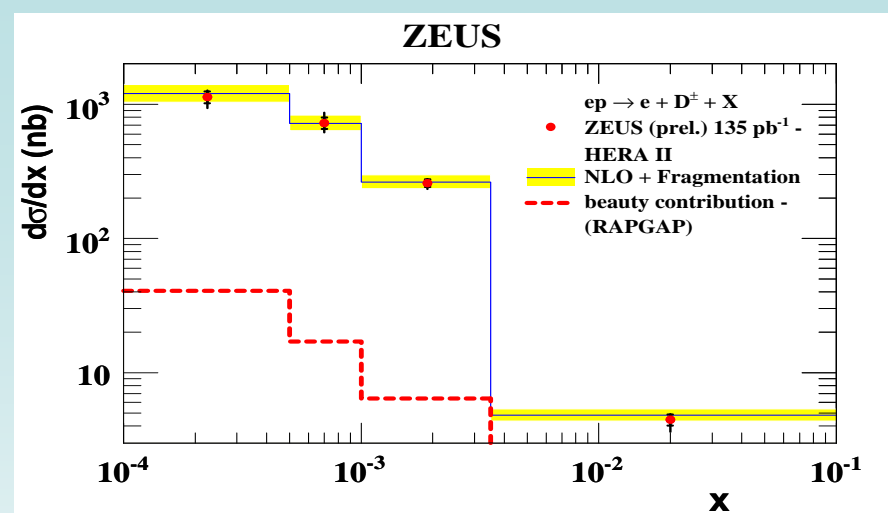
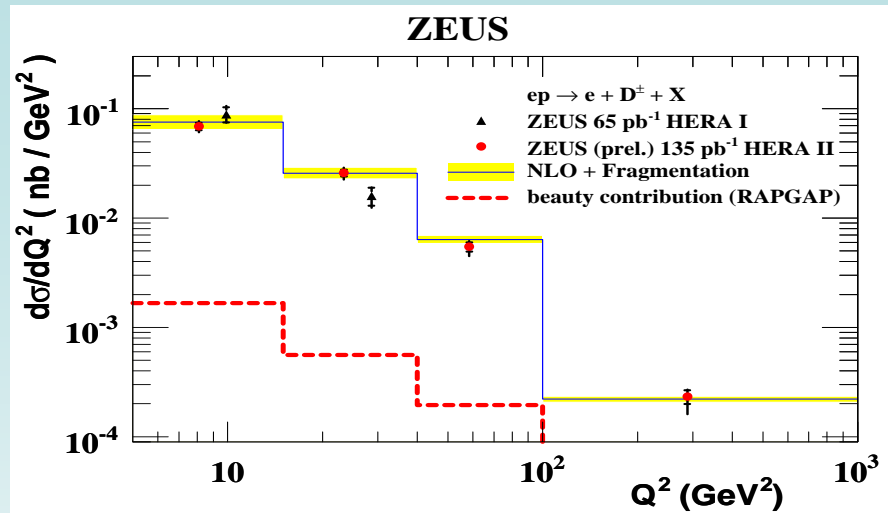
D[±] Selection Cuts

- $PT(K) > 0.7 \text{ GeV}$
- $PT(\pi, \pi) > 0.5 \text{ GeV}$
- $|\eta(K, \pi, \pi)| < 1.6$
- D* and Ds reflections subtracted.



With S_{DL} > 3, statistical error 7.7% → 3.8%

D[±] cross sections



D⁰ production in DIS

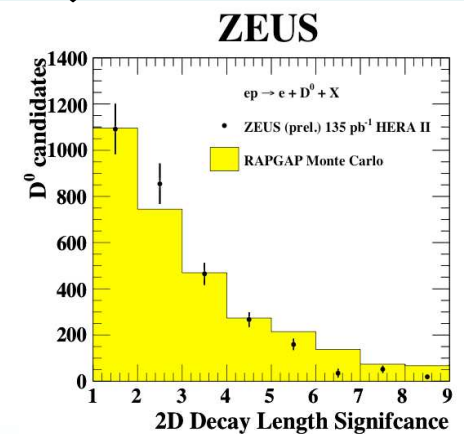
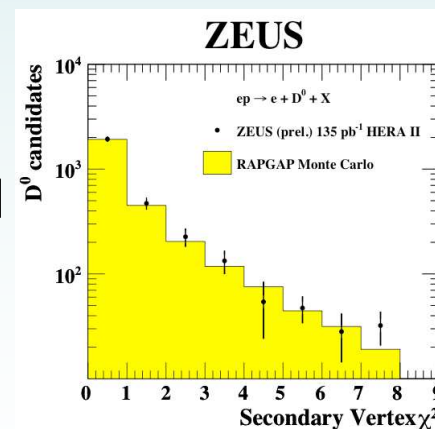
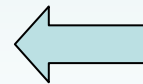
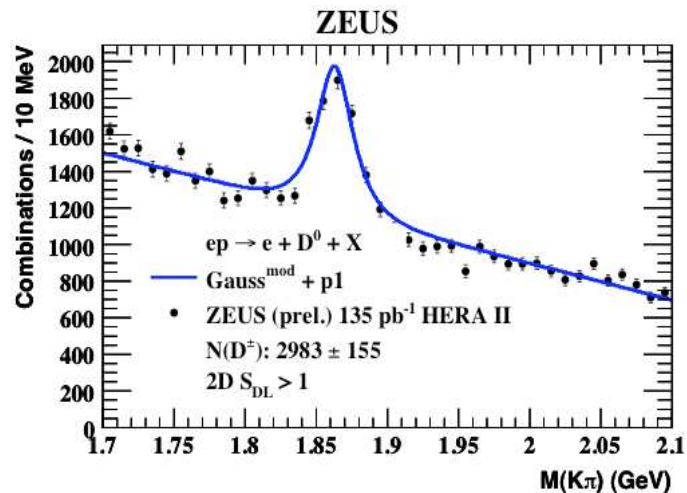
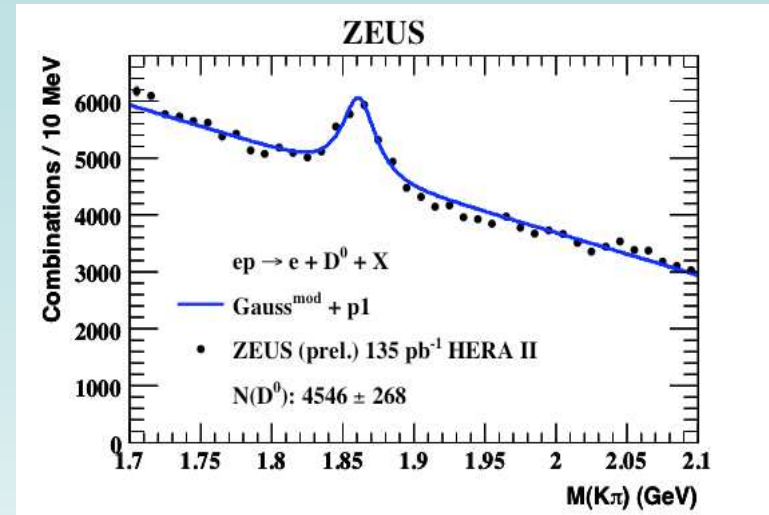
Kinematic Region

- $5 < Q^2 < 1000 \text{ GeV}^2$
- $0.02 < y < 0.7$
- $|\eta(D)| < 1.6$
- $3 < p_T(D) < 20 \text{ GeV}$

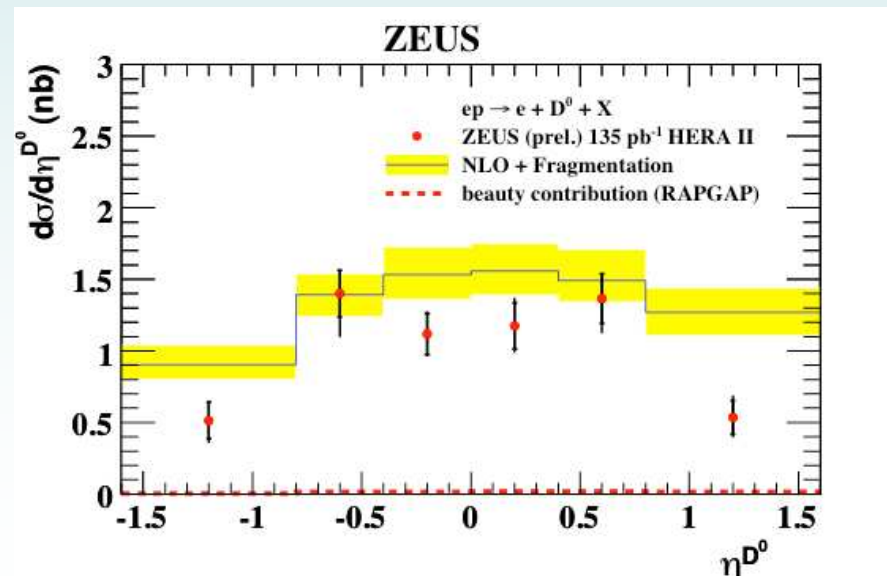
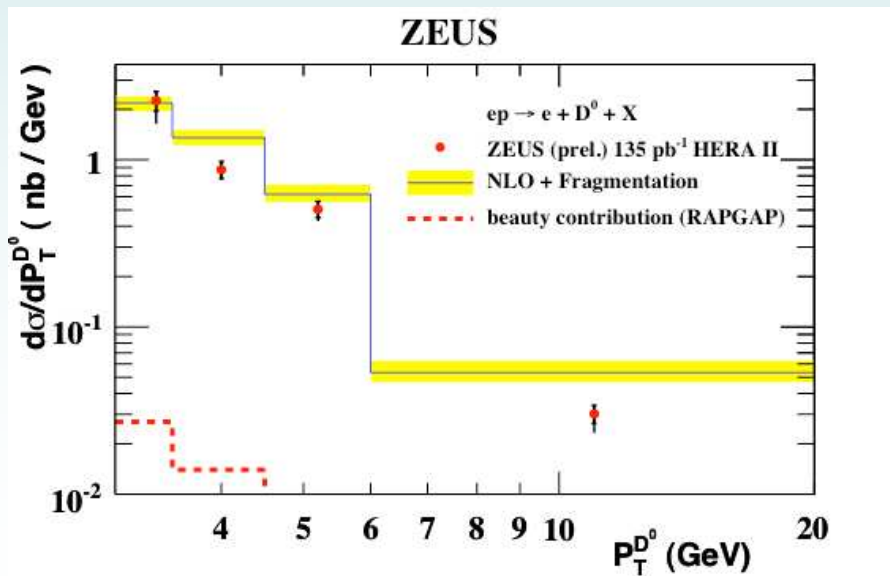
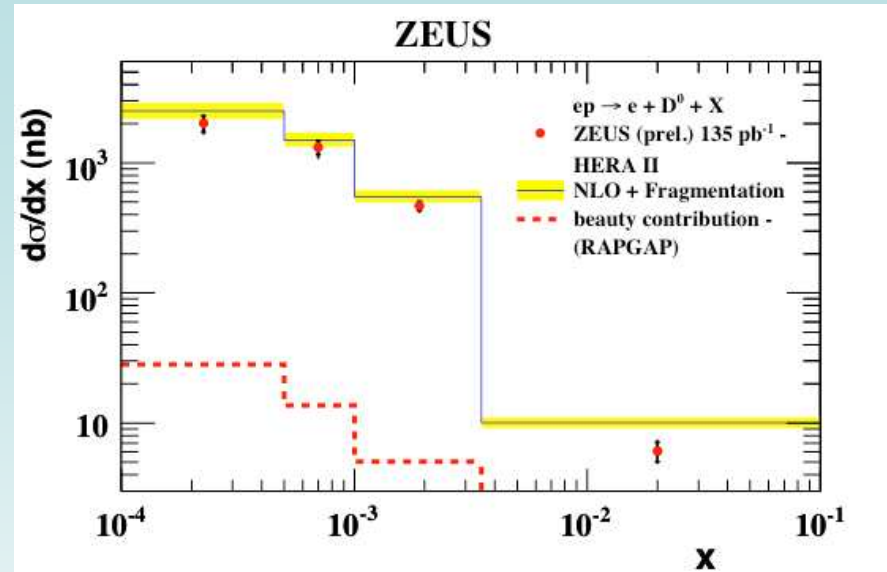
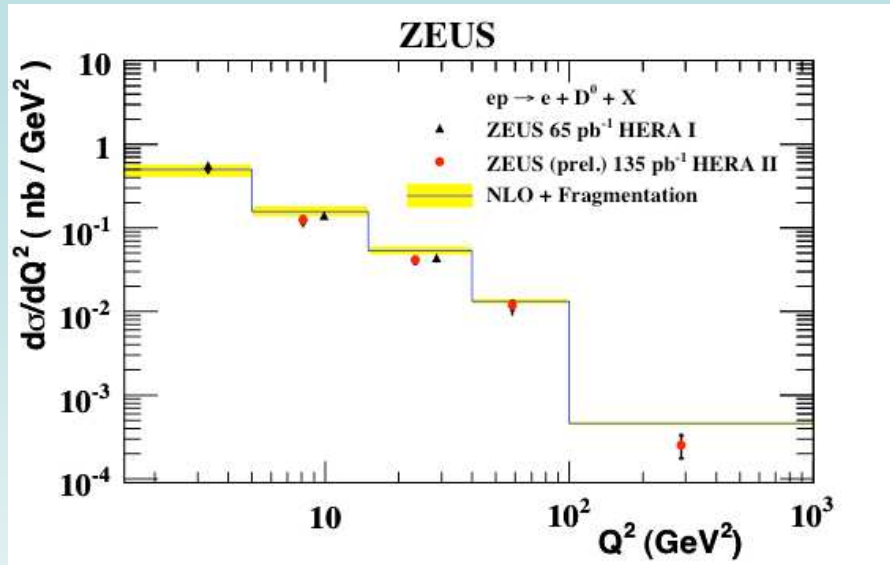
1/3 HERA II:
2005 data
135 pb⁻¹

Selection of D⁰ candidates

- $|\eta(K, \pi)| < 1.6$
- $p_T(K) > 0.7 \text{ GeV}$; $p_T(\pi) > 0.3 \text{ GeV}$
- $S_L > 1$, $\chi^2_{DvtX} < 8$
- ΔM tagged and untagged D⁰ signals are fitted simultaneously



D⁰ cross sections in DIS



F_2^{cc} extraction: ZEUS

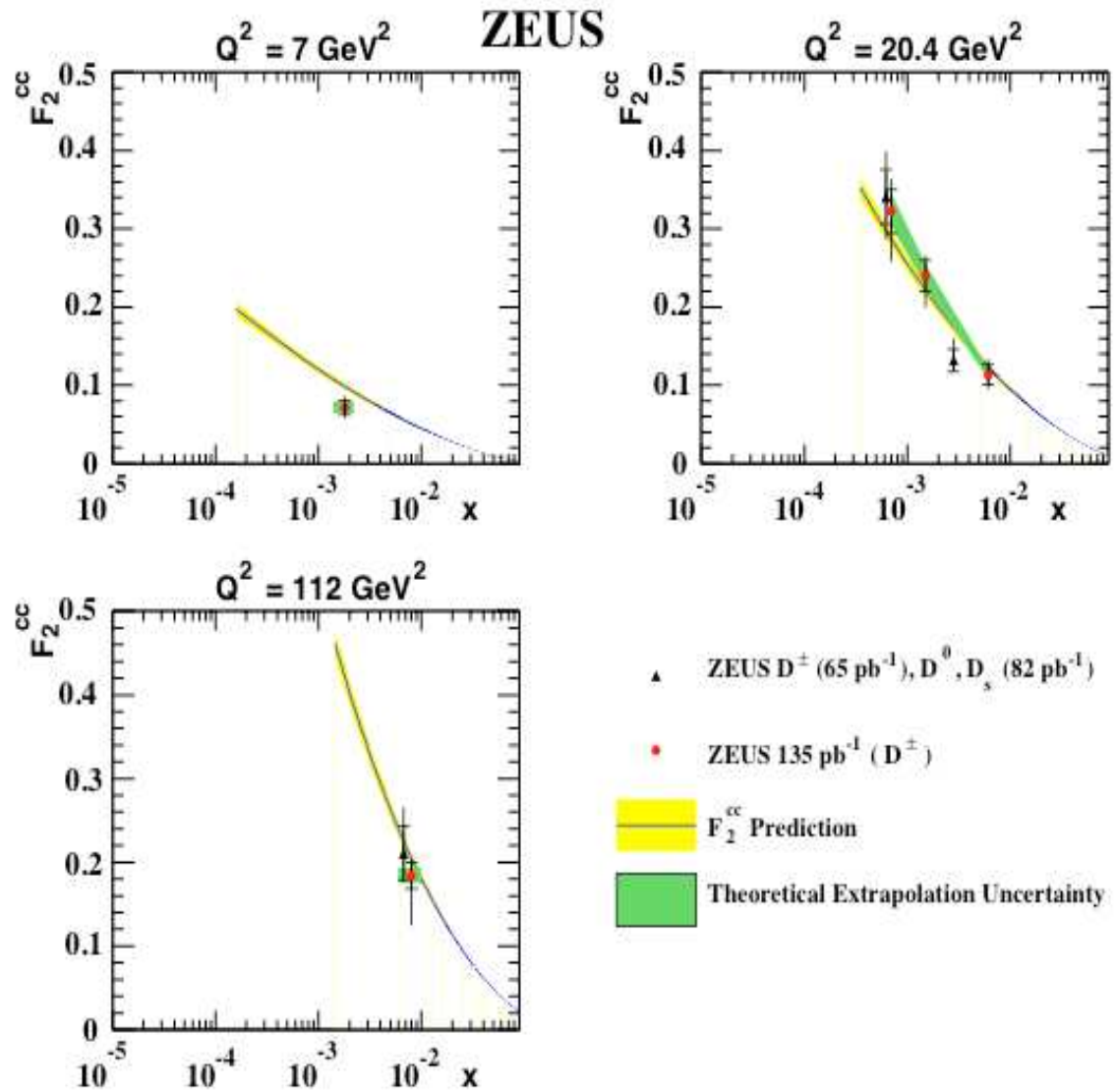
$$\frac{d^2\sigma^{c\bar{c}}(x, Q^2)}{dx dQ^2} = \frac{2\pi\alpha^2}{xQ^4} \{ [1 + (1 - y)^2] F_2^{c\bar{c}}(x, Q^2) - y^2 F_L^{c\bar{c}}(x, Q^2) \}$$

- Subtraction of the beauty contribution by using the RAPGAP MC predictions for each bin.
- ZEUS extracts F_2^{cc} from D meson cross sections using HVQDIS to extrapolate to the full meson phase space:

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

- The extrapolation is performed at the centre of gravity of the bin.
- ZEUS-S PDF were used throughout.

F_2^{CC} with D_{\pm}



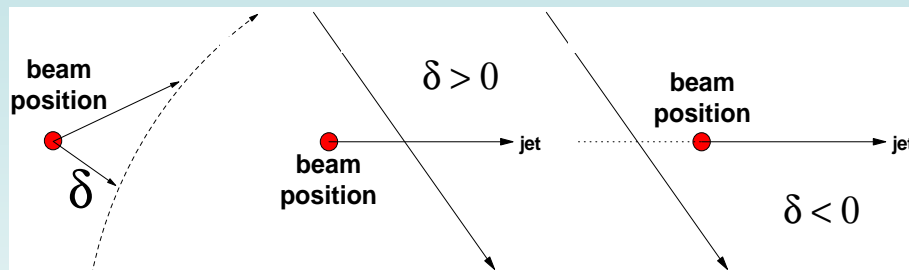
- Previous results combined measurements of F_2^{CC} from 3 mesons to reduce uncertainty.

- F_2^{CC} determined with D_{\pm} at HERA II (1/3 lumi) has comparable precision to that of the whole HERA I measurement with $D0, D_{\pm}$ and D_s mesons.

Inclusive Impact Parameter tagging

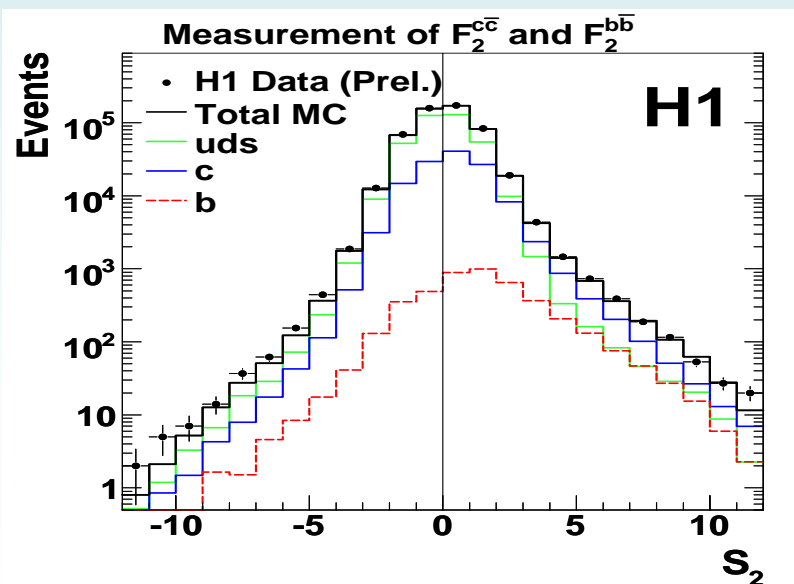


- A powerful tool to separate beauty, charm and background is the significance of the (signed) impact parameter parameter $\mathbf{S} = \delta / \sigma(\delta)$



Kinematic Region

- $12 < Q^2 < 650 \text{ GeV}^2$
- $0.0002 < x < 0.032$
- $0.07 < y < 0.65$



HERA II:
2006 e-
54 pb-1

see talk A. Metha for technical details...

F_2^{cc} extraction: H1

H1 measures charm inclusively

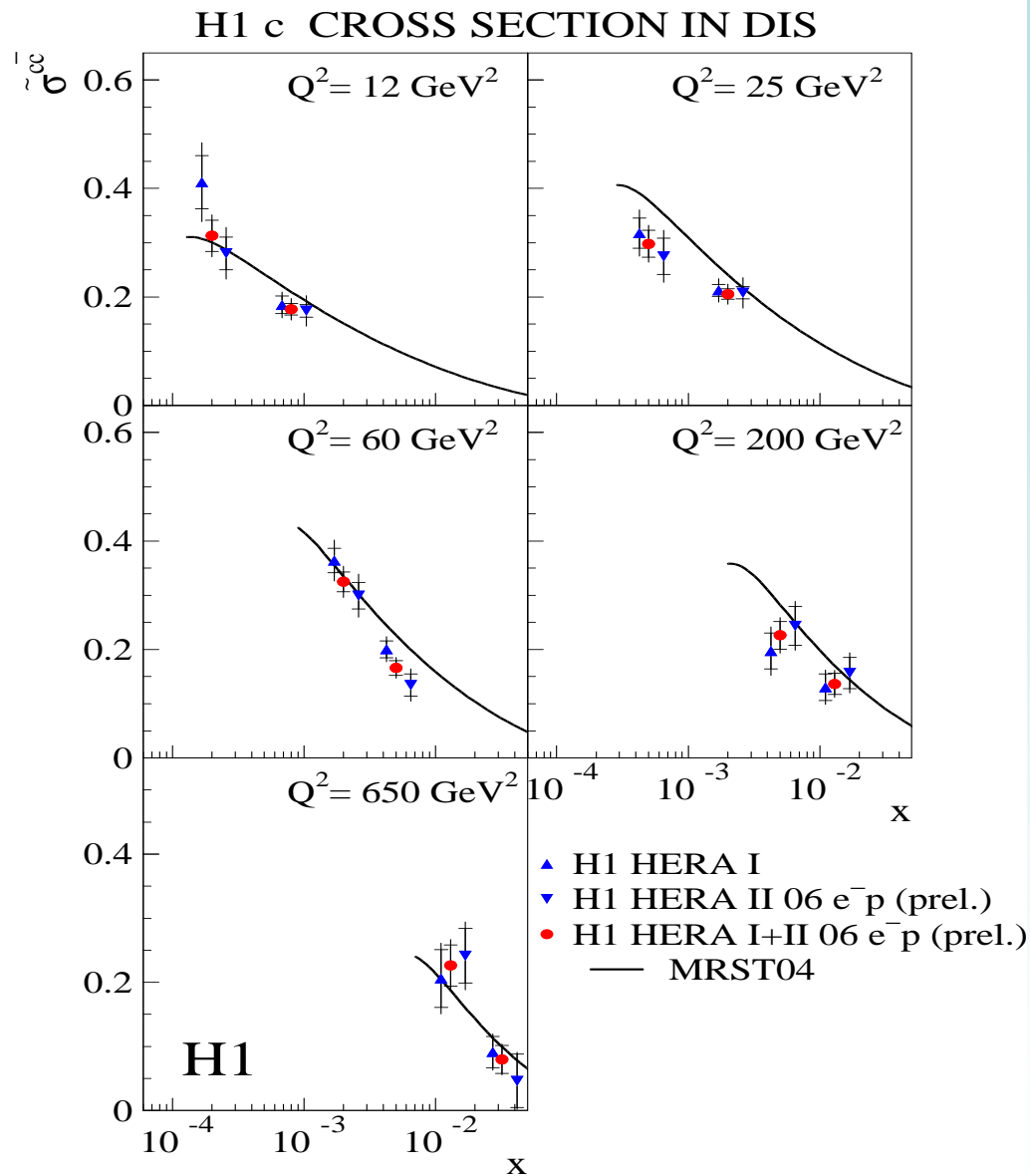
$$\tilde{\sigma}^{c\bar{c}}(x, Q^2) = \tilde{\sigma}(x, Q^2) \frac{P_c N_c^{\text{MCgen}}}{P_c N_c^{\text{MCgen}} + P_b N_b^{\text{MCgen}} + P_l N_l^{\text{MCgen}}} \delta_{\text{BCC}}$$

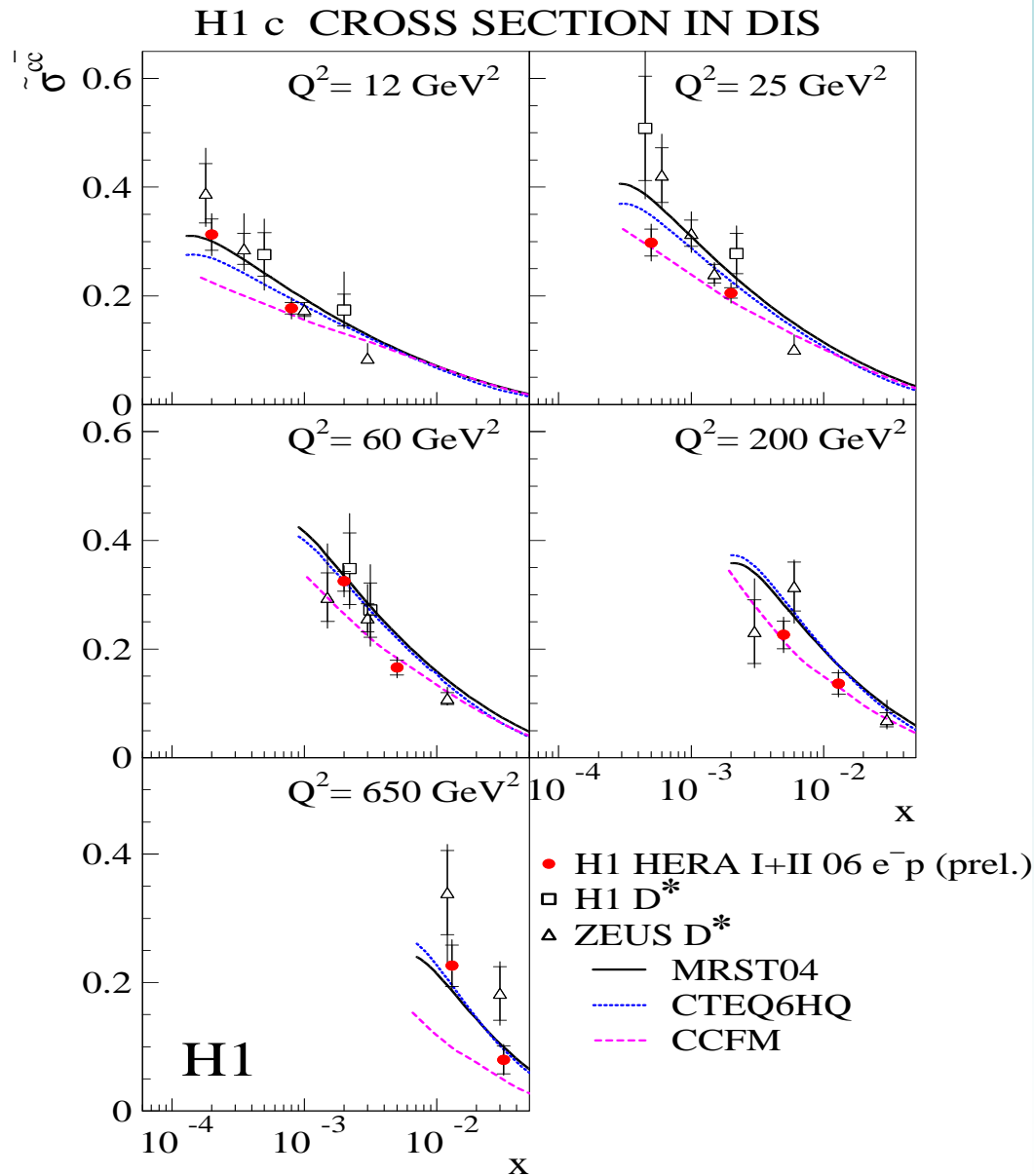
$P_{c,b,l}$ are the fractions of charm, beauty and light flavour from the fit and $\tilde{\sigma}$ is the inclusive reduced cross section.

Structure function evaluated after small corrections for the longitudinal structure functions F_L^{cc}

H1 inclusive charm reduced cross sections

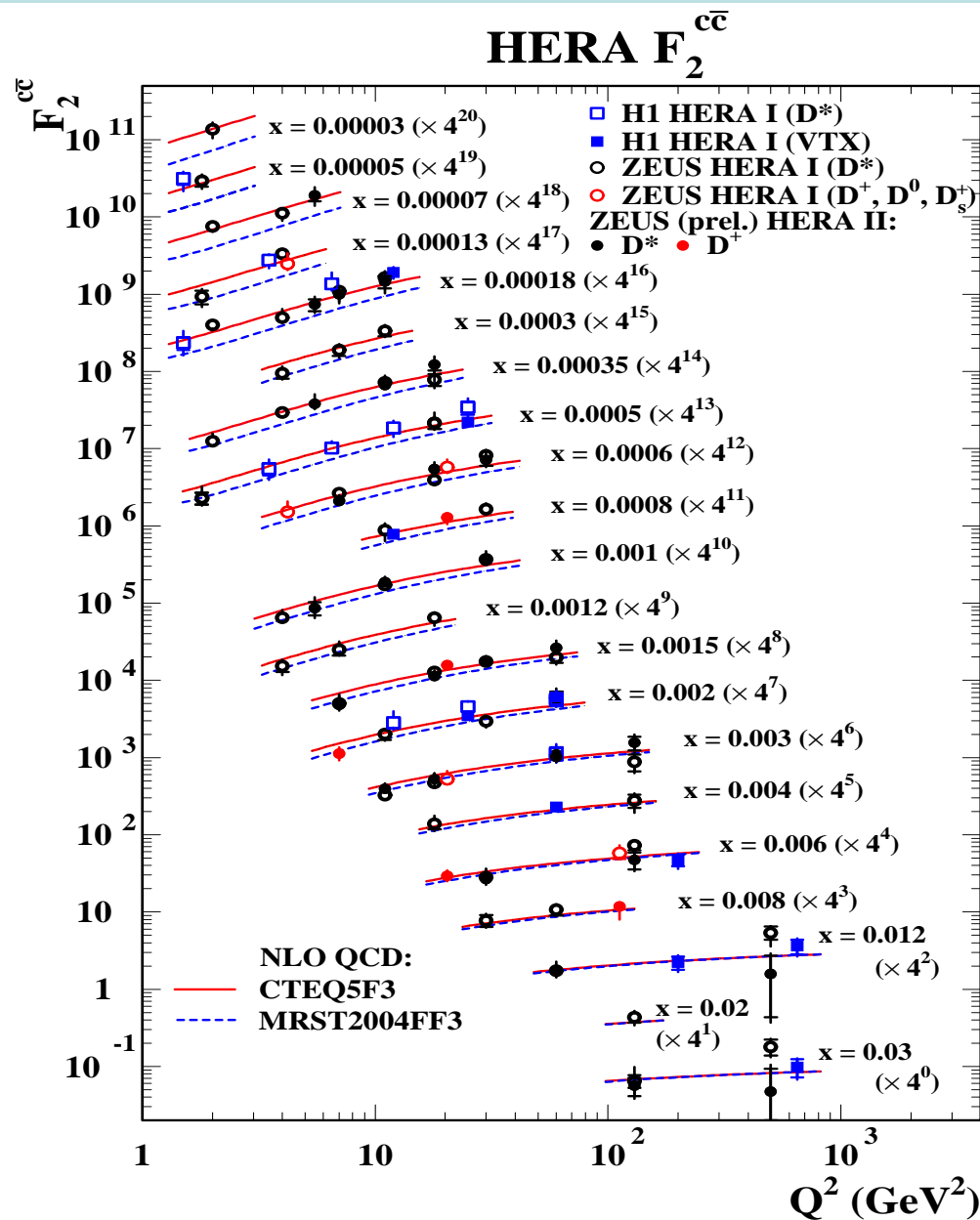
- HERA I and II agree
- Combined results agree with NLO theoretical expectation
- GM-VFNS & MRST04





Inclusive measurements vs D mesons

- Good agreement between different techniques
- Agreement with NLO QCD within the spread of different theoretical approaches
- GM-VFNS MRST04
CTEQ6HQ
- FFNS CCFM

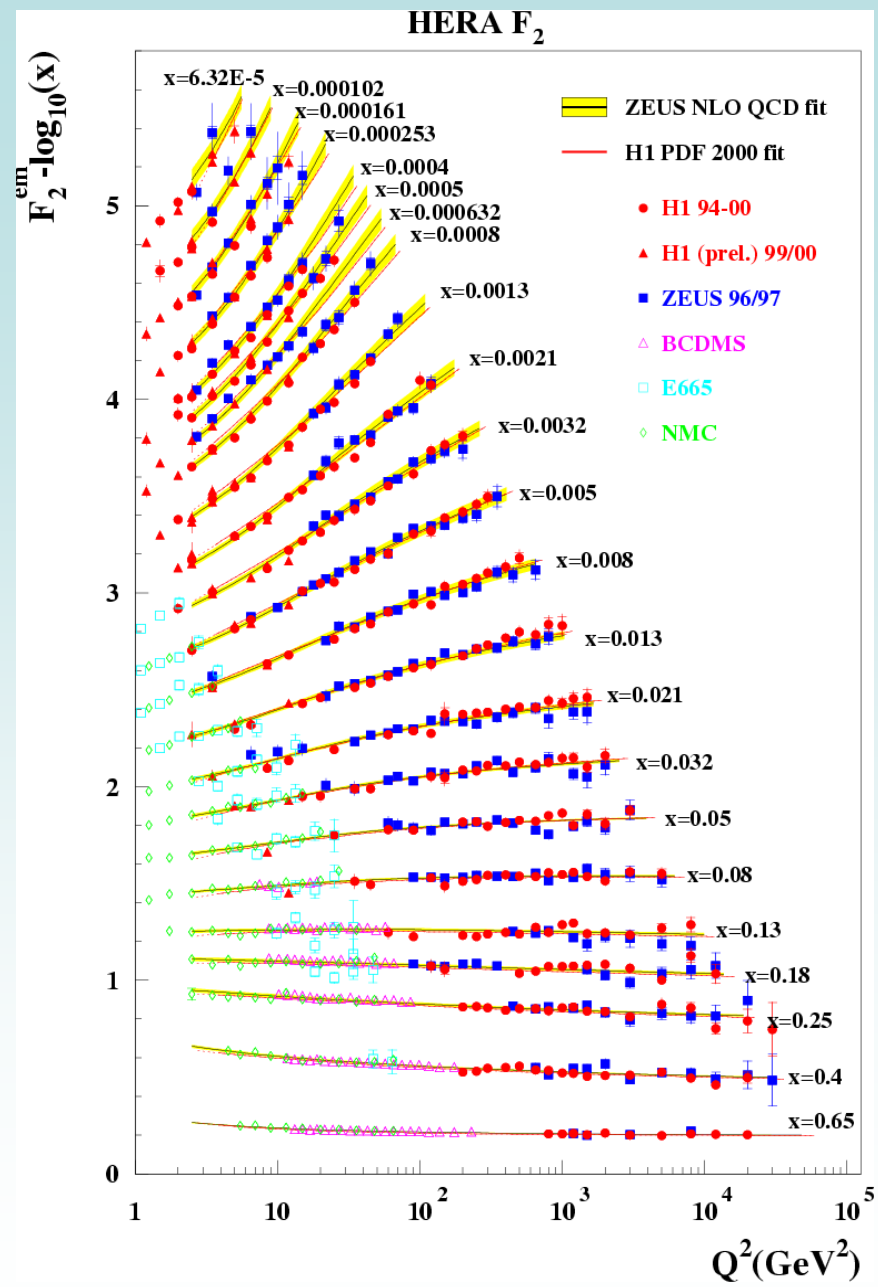


$F_2^{c\bar{c}}$ at HERA

- The measurements can distinguish between different gluon parameterizations.
- ZEUS and H1 measurements are in good agreement.

Conclusions and outlook

- The charm contribution to the proton structure functions, F_2 , is measured at HERA using different techniques, based on D meson tagging and lifetime measurements.
- The two collaborations, ZEUS and H1, using very different methods for the analysis, implying different extrapolations factors, agree on the results.
- The precision of the measurement is improving, and the measurement appears to be able to distinguish between the different gluon parameterizations provided by theorists.
- The use of the whole HERA data sample can help in constraining the gluon parameterization in the proton



ZEUS

