F_2^{CC} measurements at HERA

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on behalf of the ZEUS and H1 Collaborations

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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.

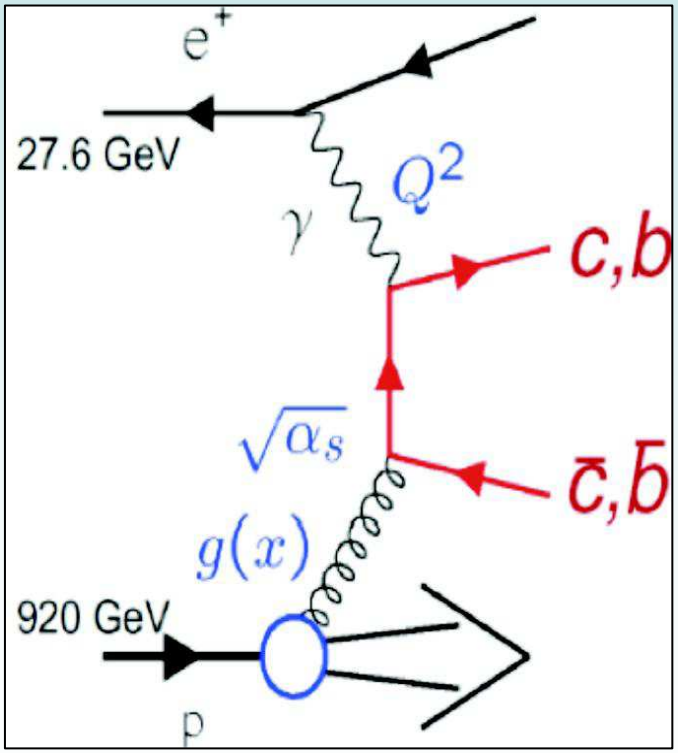
• In DIS regime the heavy quarks are produced mainly by the Boson-Gluon-Fusion process.

• This process is directly sensitive to gluon content inside the proton.

• Factorisation in pQCD:

σ = parton distr.⊗hard scatt.⊗fragm./hadron.

• Important test of pQCD at different scales (M_Q, p^T_Q,Q^2).



Theoretical models at NLO

Massive approach (**F**ixed **F**lavour **N**umber **S**cheme):

- c & b massive →full massive matrix elements;
- scale M_Q ;
- appropriate for $Q^2 \sim M_Q^2$

PhP : Frixione et al., FMNR

DIS : Harris & Smith, HVQDIS fully differential NLO program

→ **c & b produced dinamically in the hard subprocess**

(not part of the proton or photon; 3 active flavours in proton: u, d, s)

Massless approach (**Z**ero **M**ass **V**ariable **F**lavour **N**umber **S**cheme):

- c & b massless → resums $[\alpha_S \ln (Q^2/M^2_Q)]^n$;
- scale Q_2, pT_Q ;
- appropriate for $Q^2 >> M_Q^2$

PhP : Kniehl et al.

DIS : only inclusive calculation of $F2^{cc}$ available

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

Combined approach (**G**eneralized **M**ass **V**ariable **F**lavour **N**umber **S**cheme):

- massive at small Q^2
- massless at high Q^2

PhP: Cacciari et al.

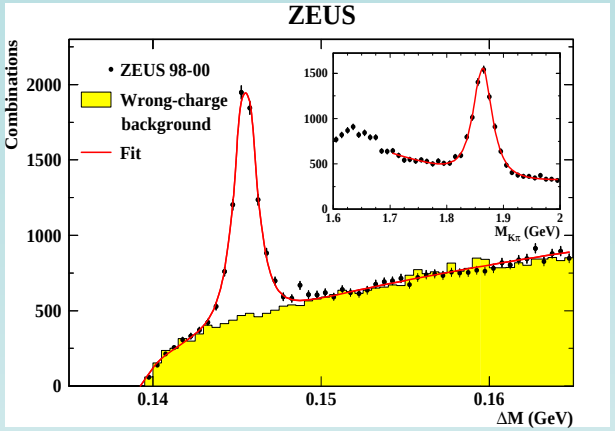
DIS : only F_2^{cc} available

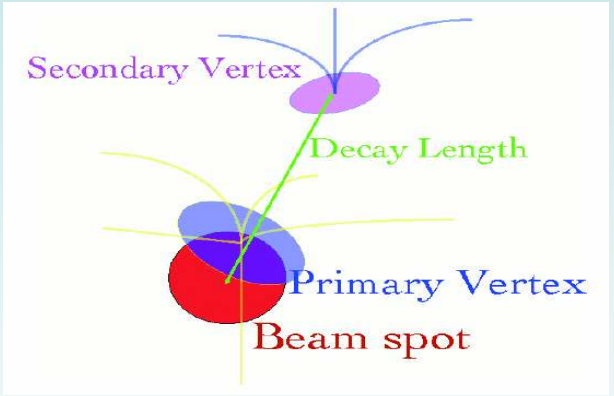
Charm tagging

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.

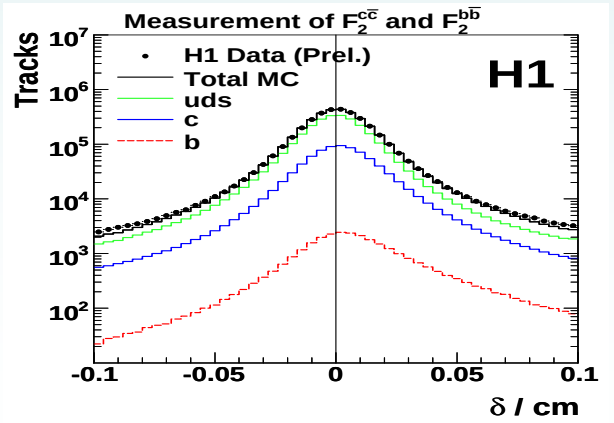
Both these cases, need an extrapolation factor to the full space phase to obtain the F_2^{cc}





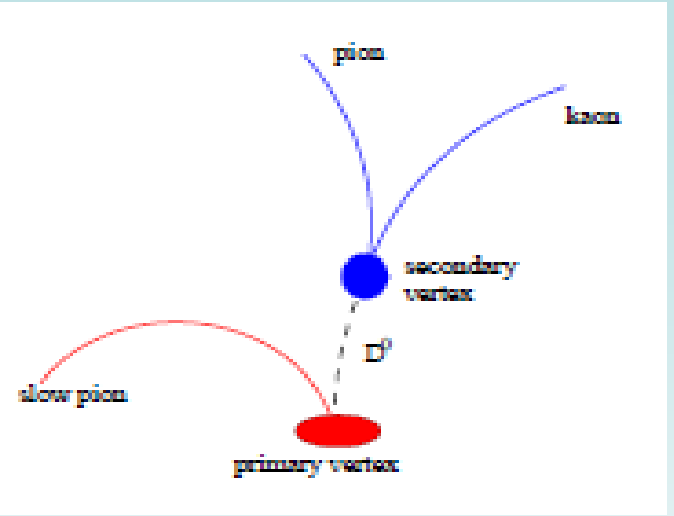
Inclusive Impact Parameter tagging

- 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.



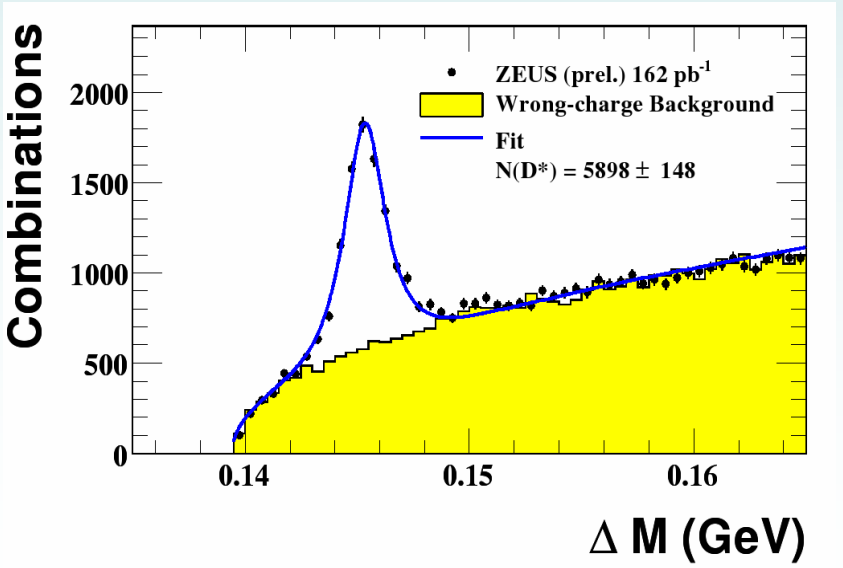
HERA II

2003-2005

162 pb^{-1}

Kinematic Region

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



Selection of D* candidates

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

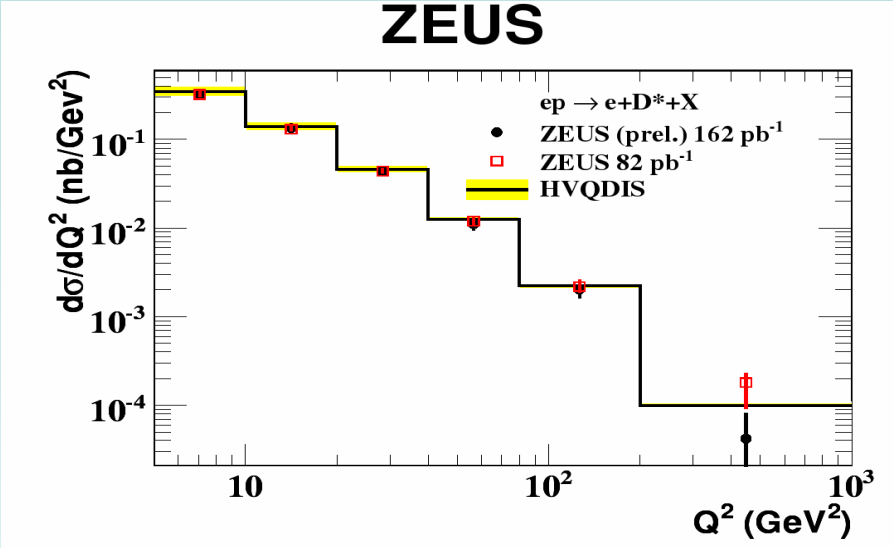
ZEUS: NLO QCD predictions

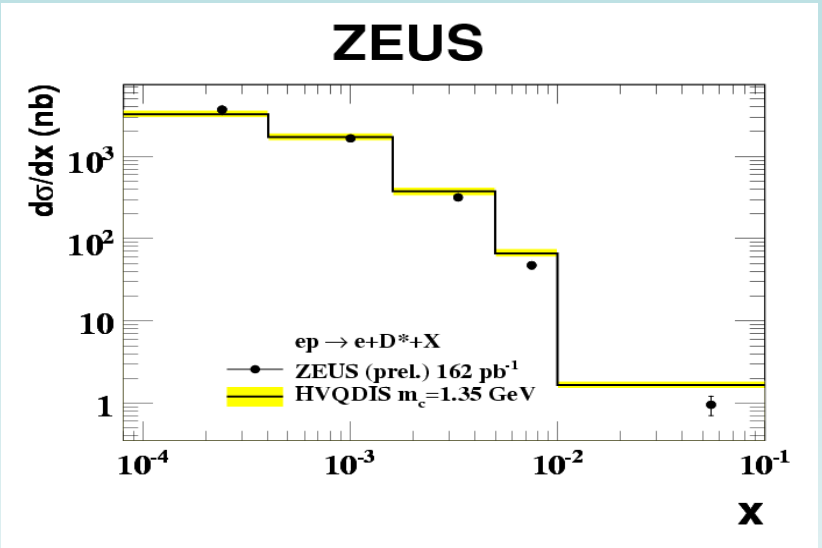
- The HVQDIS program has been used, which evaluates cross sections for heavy quark production at NLO in the Fixed Flavour Number Scheme.

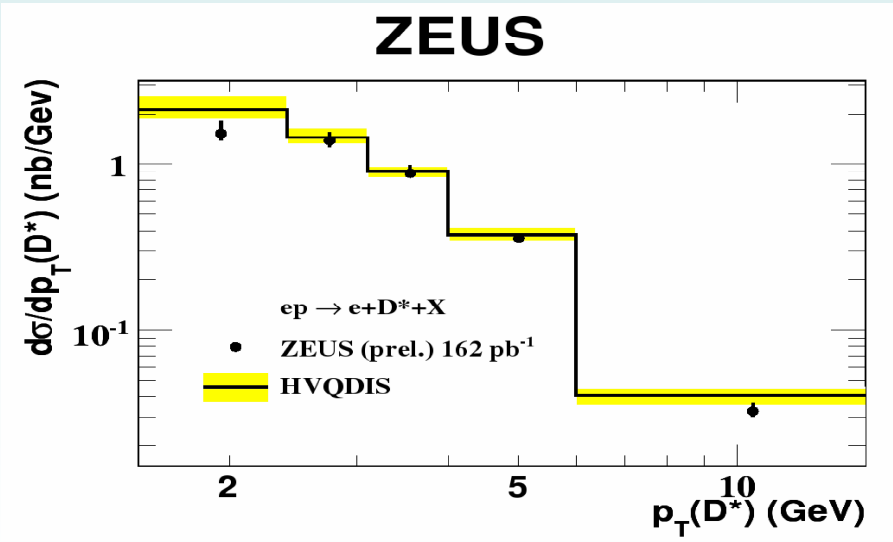
Quantity	Value	Variation
Renormalisation & Factorisation scale (μ_R, μ_F)	$\mu_R=\mu_F=\sqrt{Q^2+4M_c^2}$	$2\sqrt{Q^2+4M_\chi^2}$ Larger of: $\frac{1}{2}\sqrt{Q^2+4M_\chi^2}$ and $2M_c$
Peterson Parameter (ε)	0.035	± 0.015
Charm Mass (M_c)	1.35 GeV	±0.15 GeV
Input PDF	ZEUS NLO PDF	Upper and lower predictions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

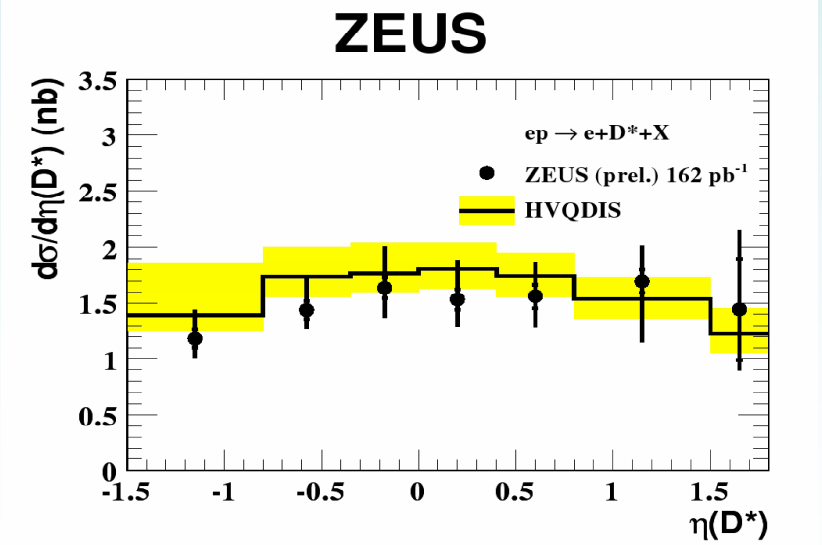
- Biggest uncertainty from Charm mass ~10-20 %

D* differential cross sections in DIS









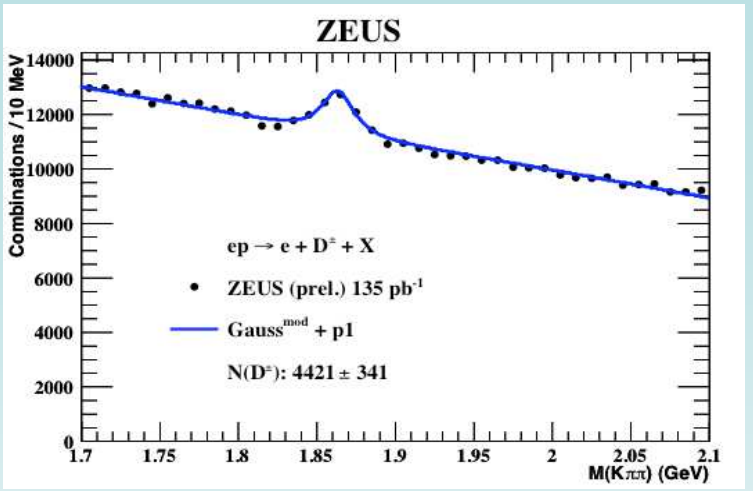
$D^{\pm}$ production in DIS

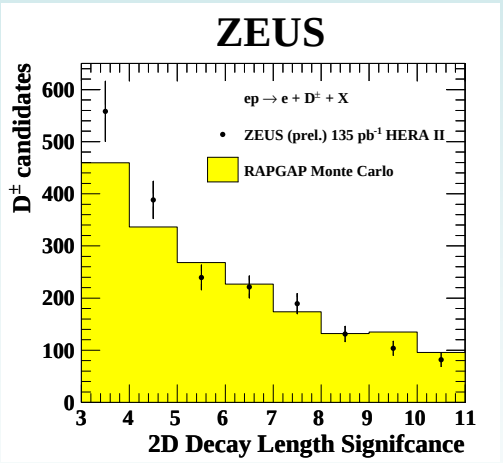
- $D^{\pm}$ long lifetime → displaced secondary vertex (MVD).
- Signed 2-D decay length significance (S_{DL}) with respect to the beamspot
- Better S/N ratio by cutting on the S_{DL} of the decay products.

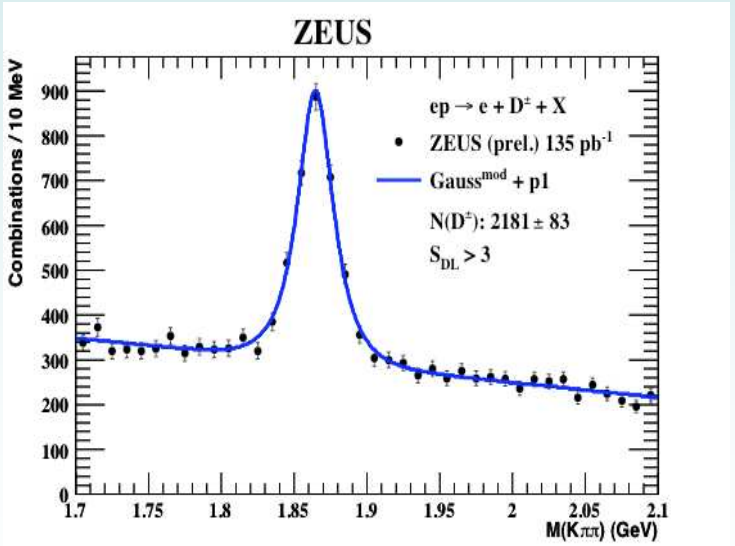
1/3 HERA II:

2005 data

135 pb^{-1}







Kinematic Region

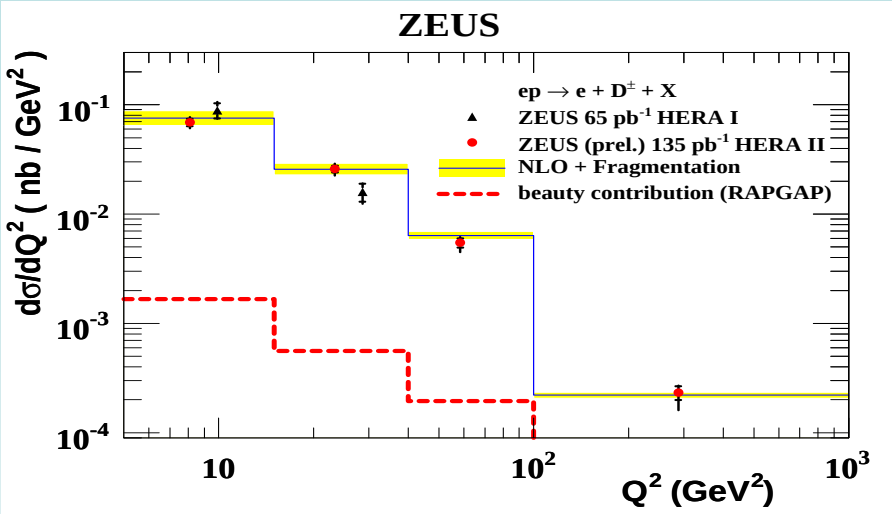
- $5 < Q^2 < 1000$ GeV^2
- $0.02 < y < 0.7$
- $|\eta(D\pm)| < 1.6$
- $3 < PT(D\pm) < 20$ GeV

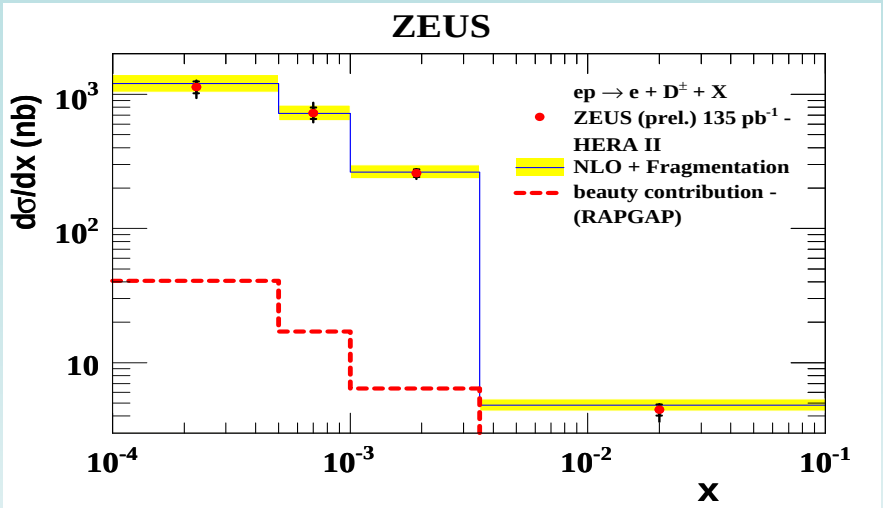
D± Selection Cuts

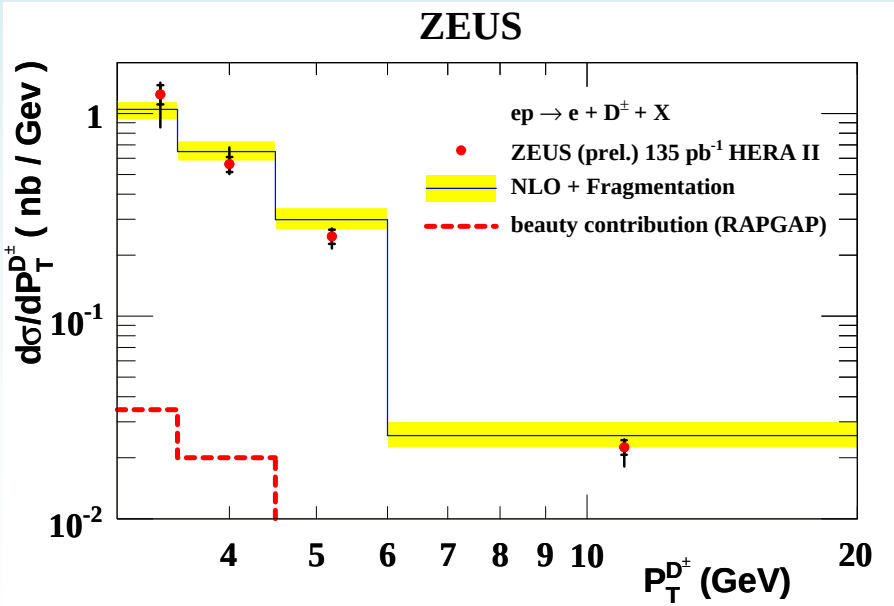
- $PT(K) > 0.7$ GeV
- $PT(\pi,\pi) > 0.5$ GeV
- $|\eta(K,\pi,\pi)| < 1.6$
- D* and Ds reflections subtracted.

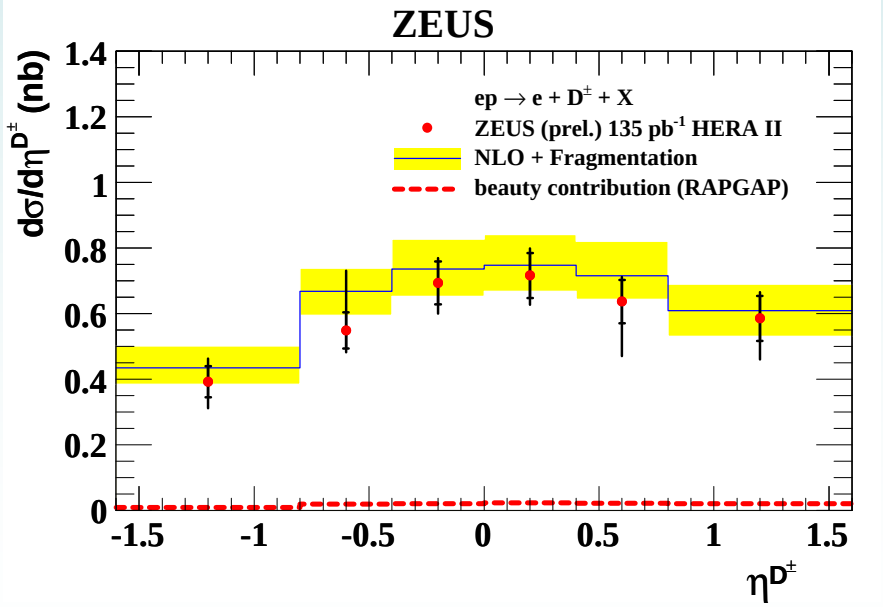
With $S_{DL} > 3$, statistical error 7.7% → 3.8%

$D^{\pm}$ cross sections









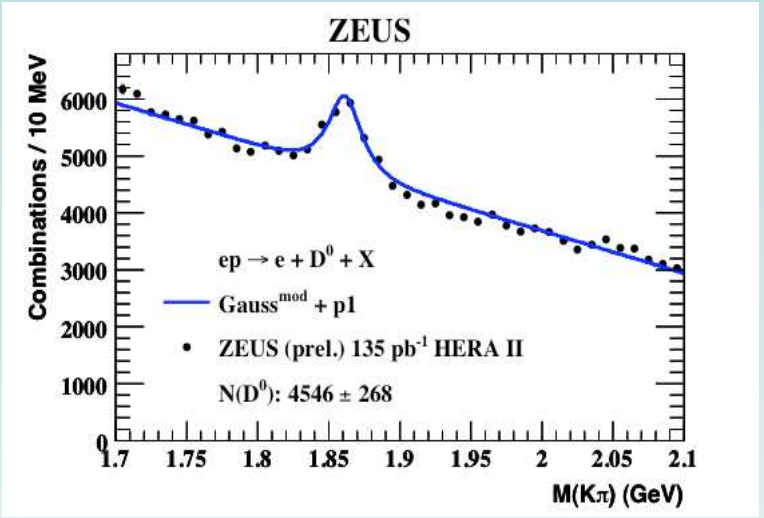
D^0 production in DIS

Kinematic Region
- $5 < Q^2 < 1000\ GeV^2$
- $0.02 < y < 0.7$
- $\eta\ |(D)| < 1.6$
- $3 < pT\ (D) < 20\ GeV$

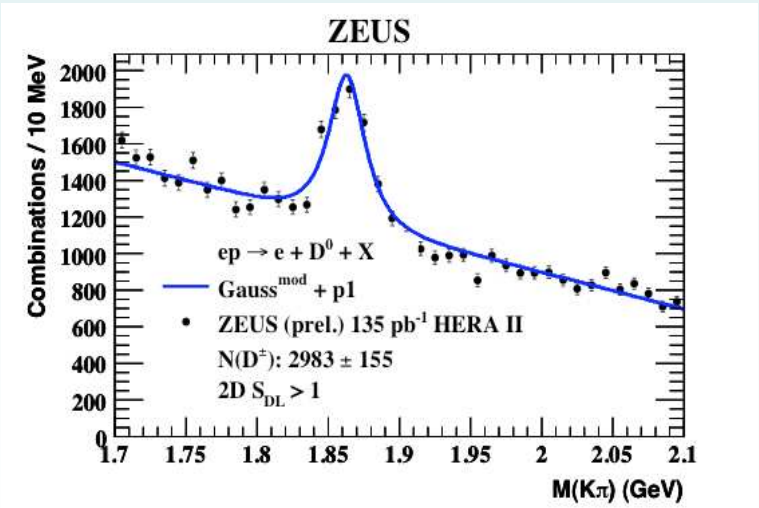
1/3 HERA II:

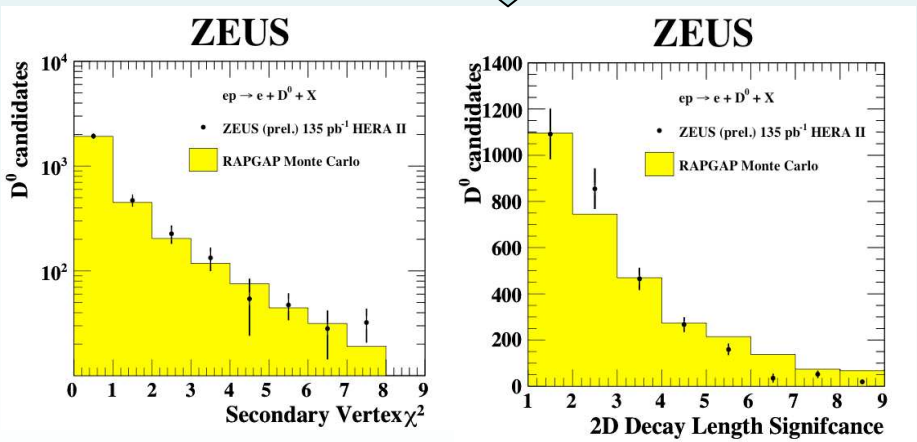
2005 data

135 pb^{-1}

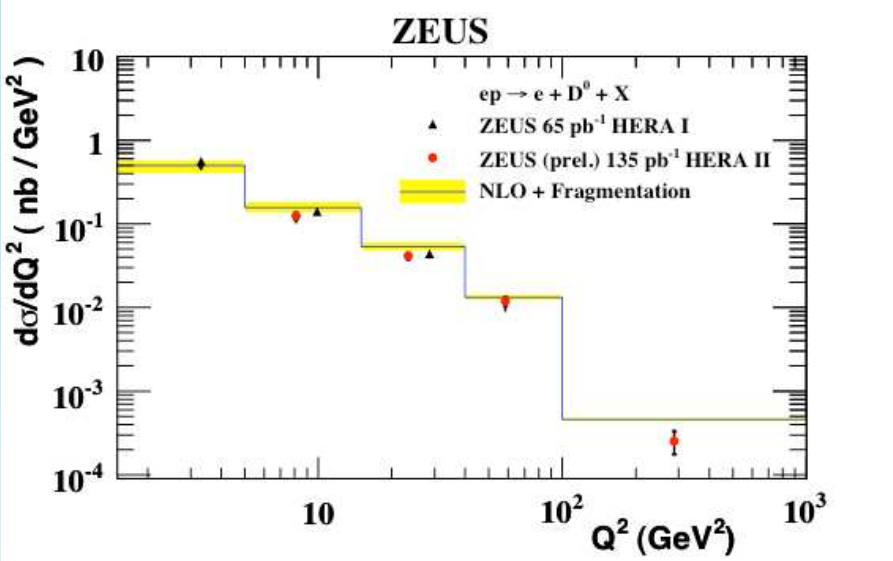


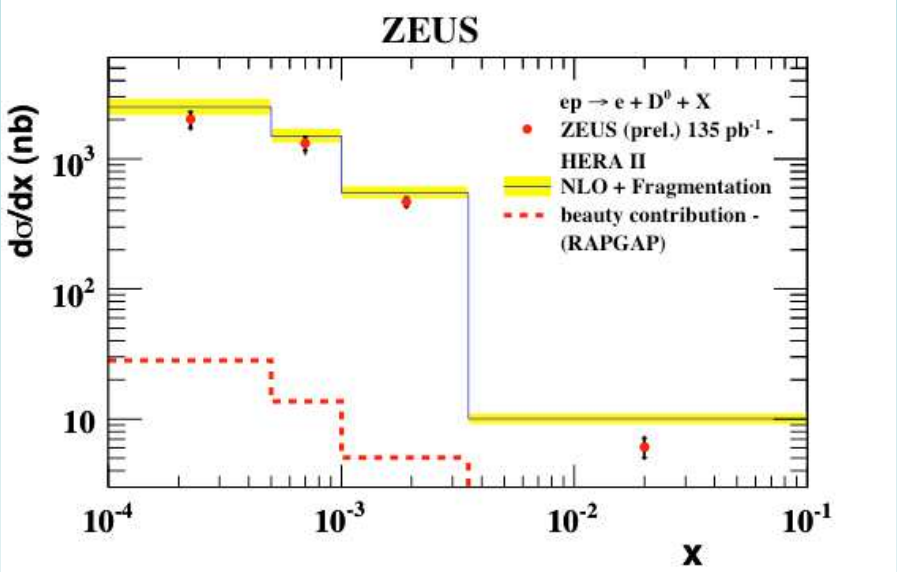
Selection of D^0 candidates
- $|\eta(K,\pi)| < 1.6$
- $p_T\ (K) > 0.7\ GeV\ ;\ p_T\ (\pi) > 0.3\ GeV$
- $S_L > 1,\ \chi^2_{Dvtx} < 8$
- ΔM tagged and untagged D^0 signals are fitted simultaneously

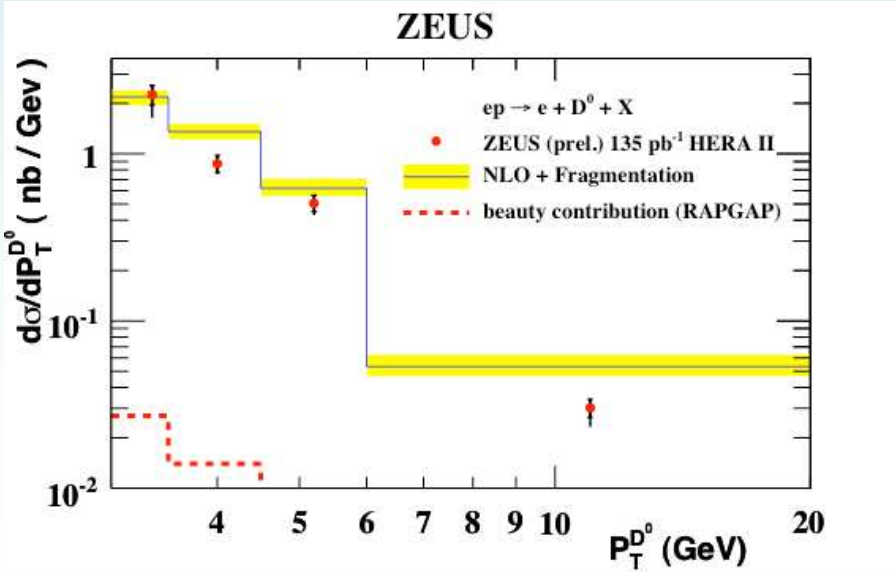


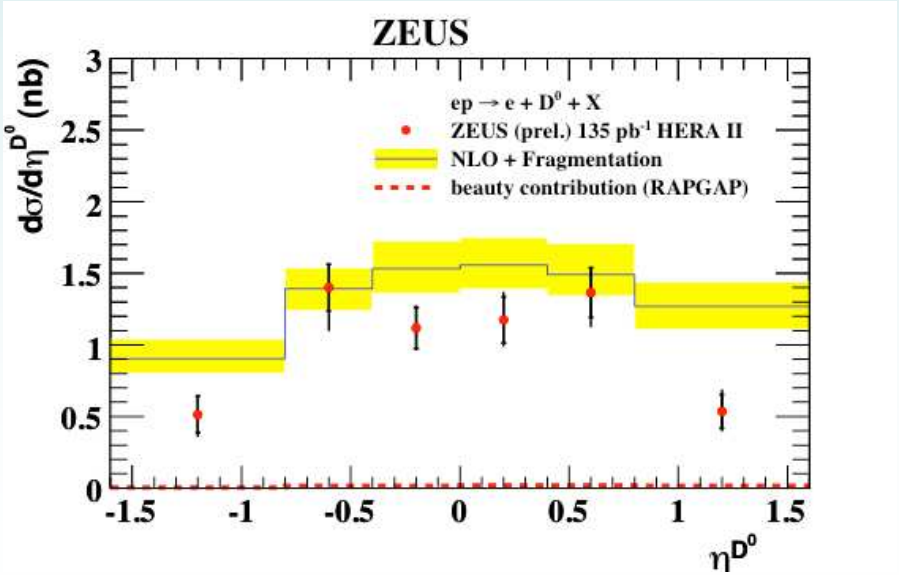


D^0 cross sections in DIS









$F_2^{c\bar{c}}$ extraction: ZEUS

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

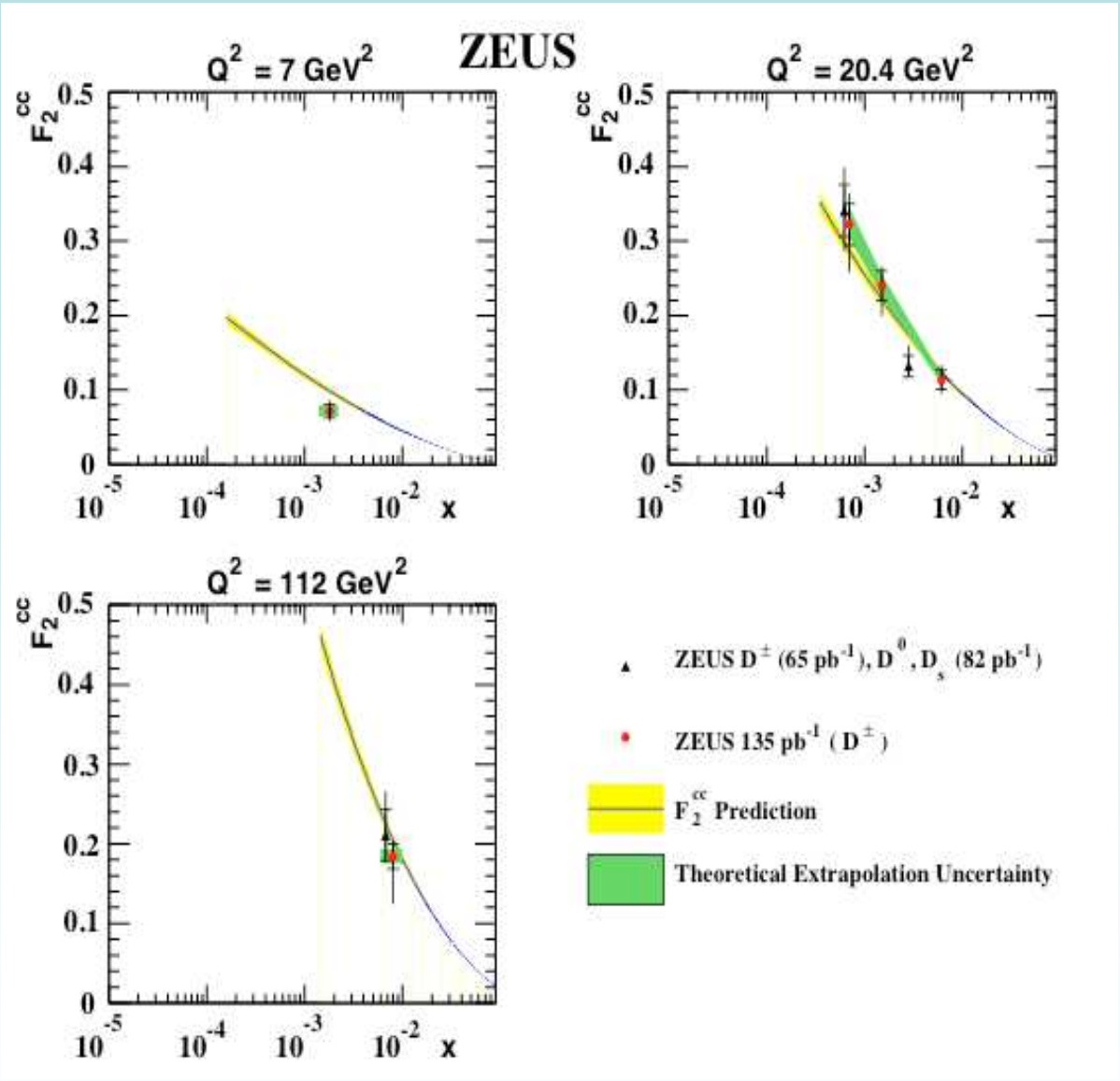
- Subtraction of the beauty contribution by using the RAPGAP MC predictions for each bin.

- ZEUS extracts $F_2^{c\bar{c}}$ from D meson cross sections using HVQDIS to extrapolate to the full meson phase space:

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

- The extrapolation is performed at the centre of gravity of the bin.

- ZEUS-S PDF were used throughout.



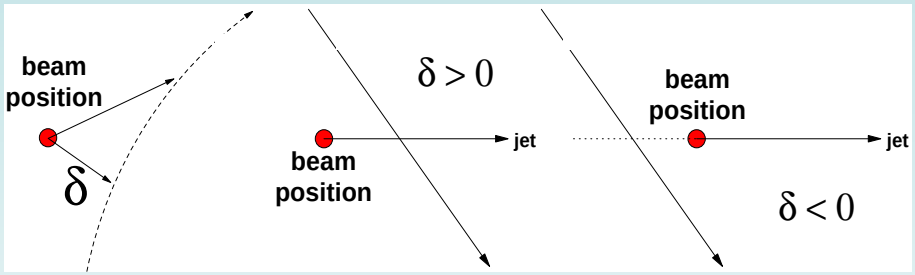
F_2^{cc} with D±

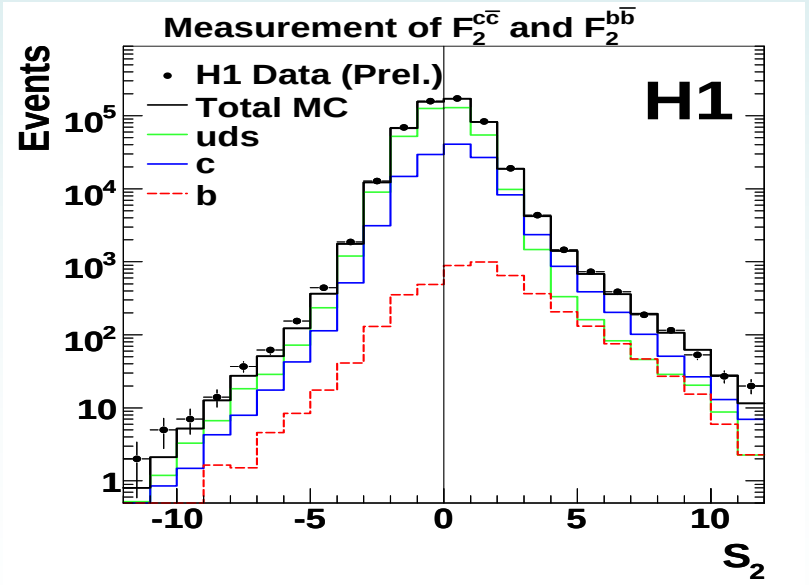
- Previous results combined measurements of F_2^{cc} from 3 mesons to reduce uncertainty.

- F_2^{cc} determined with D± at HERA II (1/3 lumi) has comparable precision to that of the whole HERA I measurement with D0, D± and Ds mesons.

Inclusive Impact Parameter tagging

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





Kinematic Region

- $12 < Q^2 < 650$ 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…

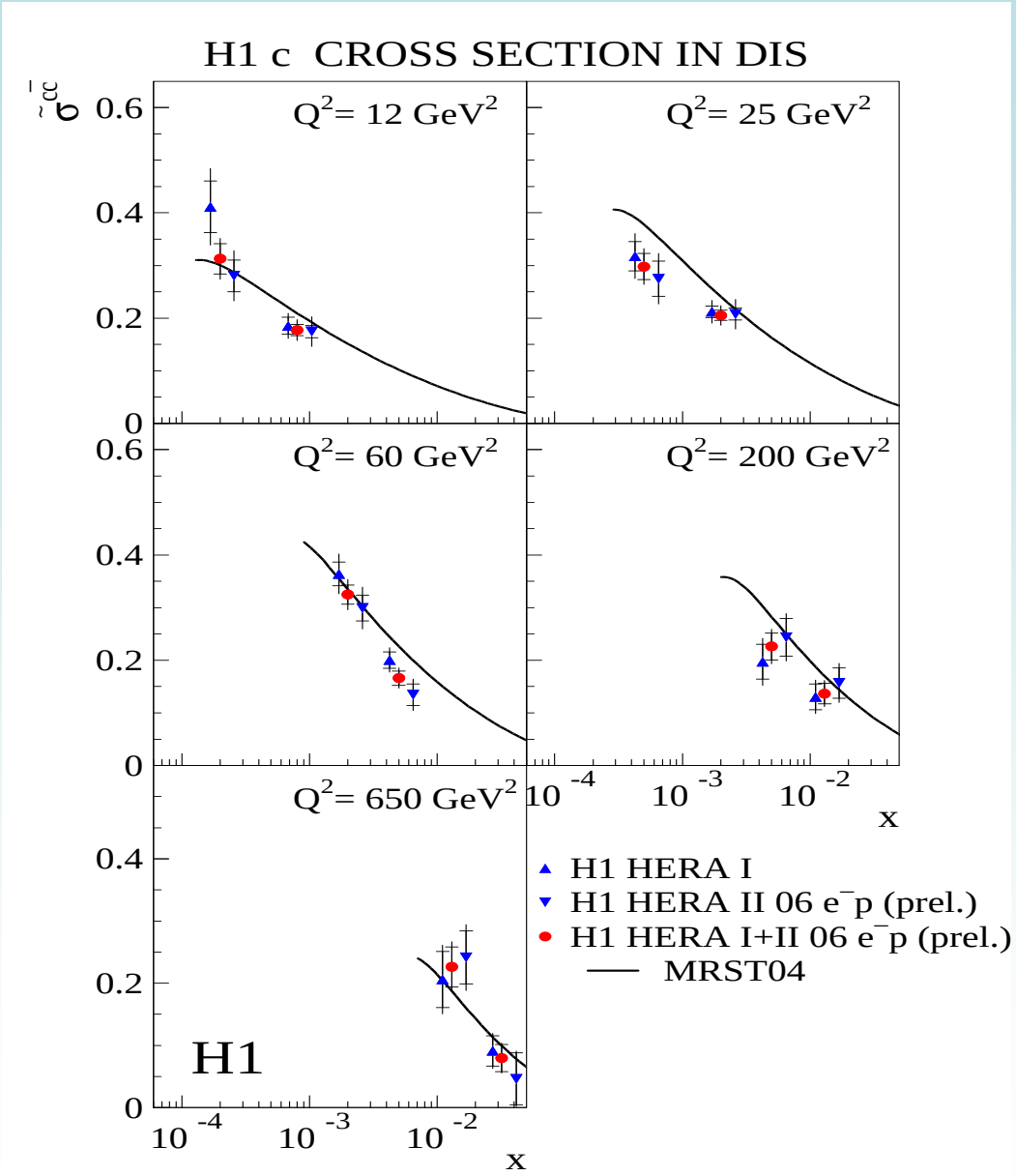
F_2^{cc} extraction: H1

H1 measures charm inclusively

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

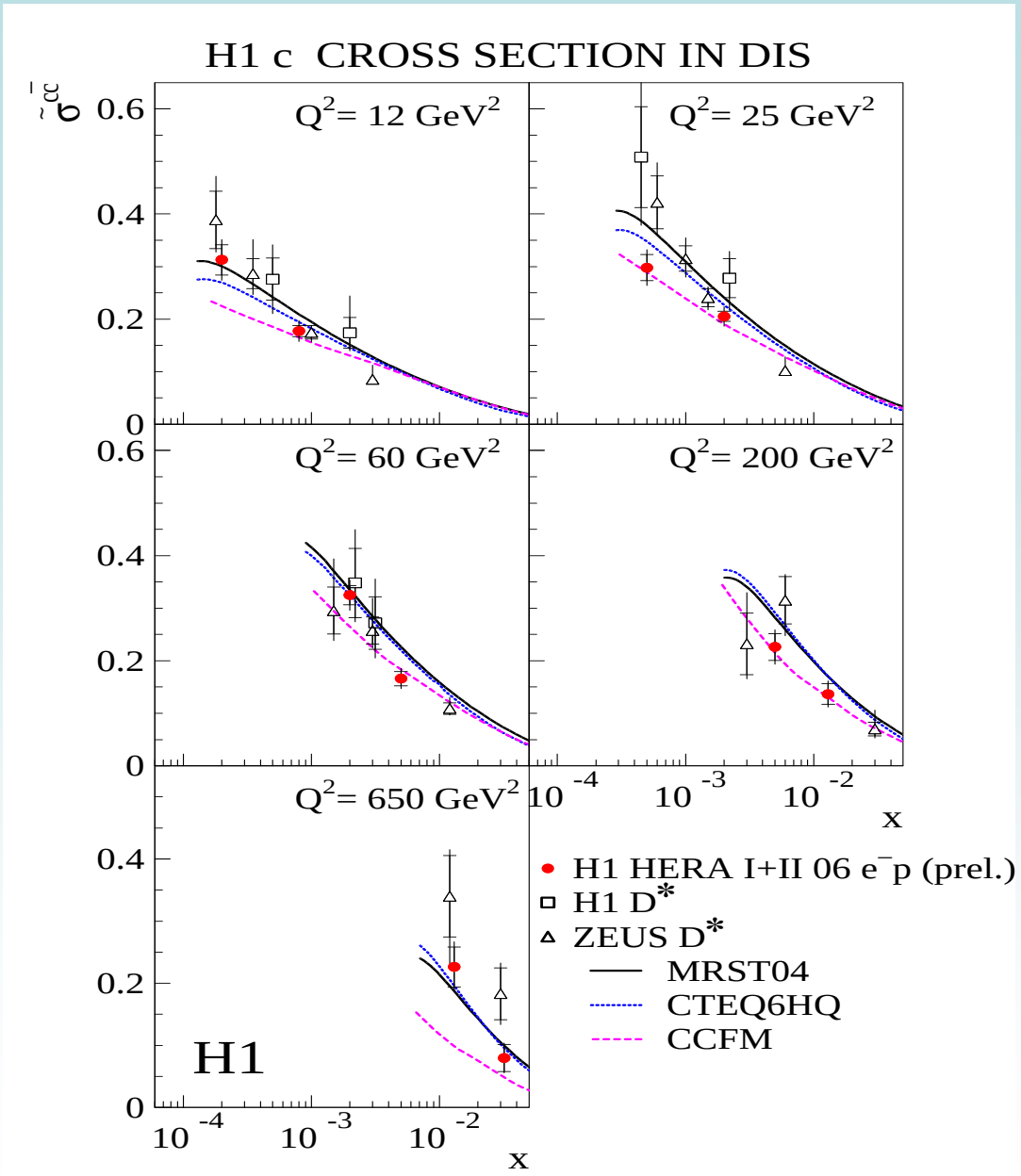
$P_{c,b,l}$ are the fractions of charm, beauty and light flavour from the fit and $\tilde{\sigma}$ is the inclusive reduced cross section.

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



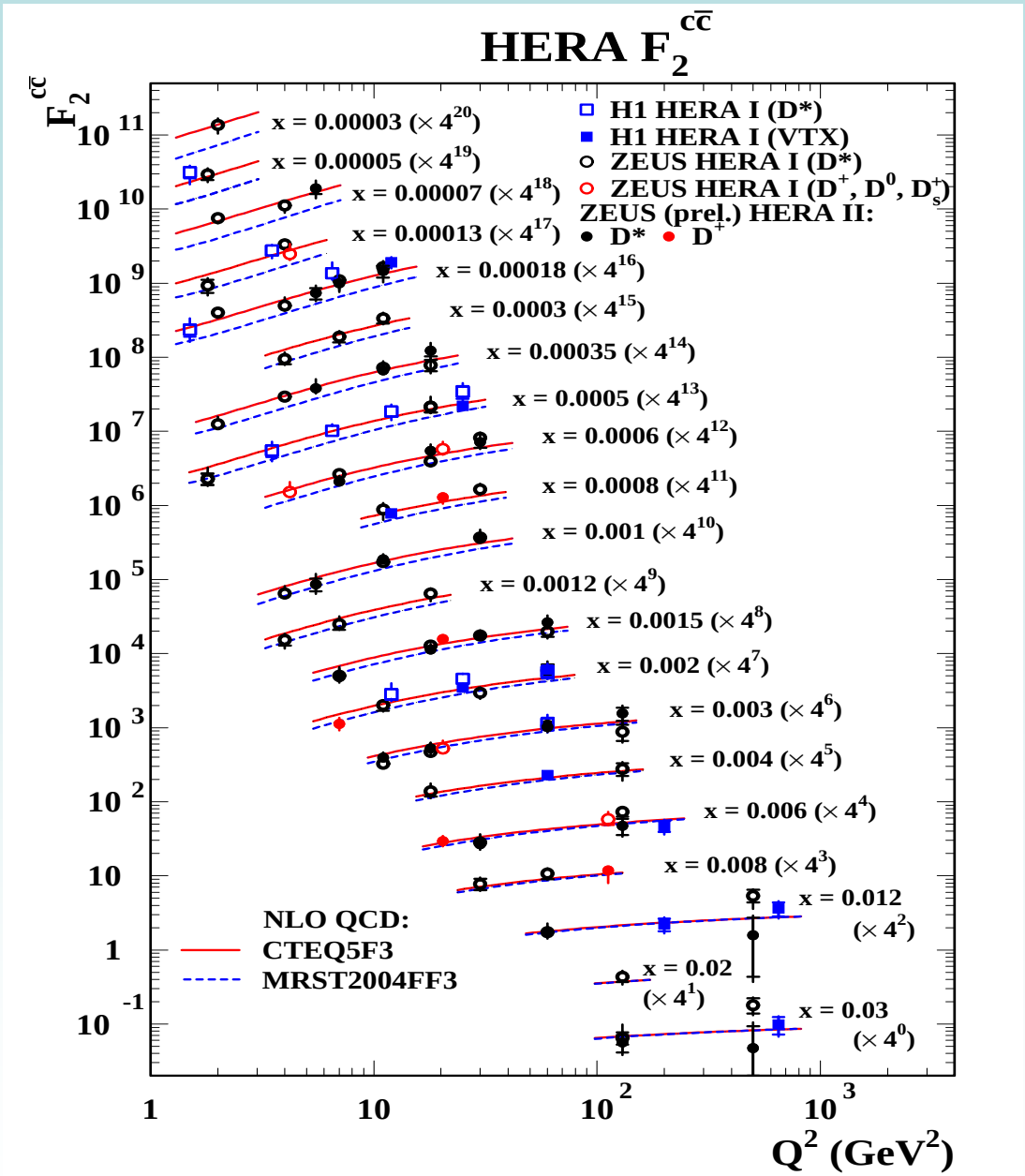
H1 inclusive charm reduced cross sections

- 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^{cc} at HERA

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

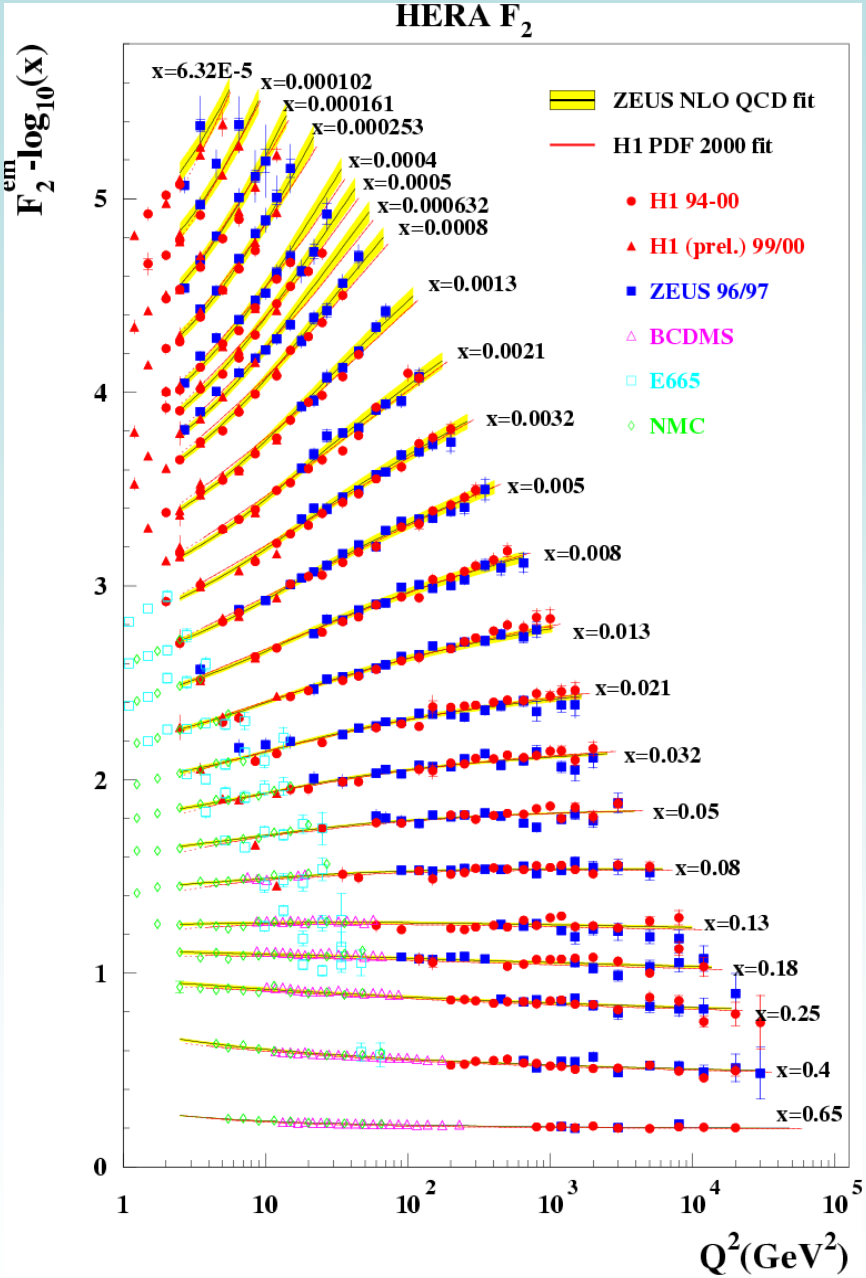
Conclusions and outlook

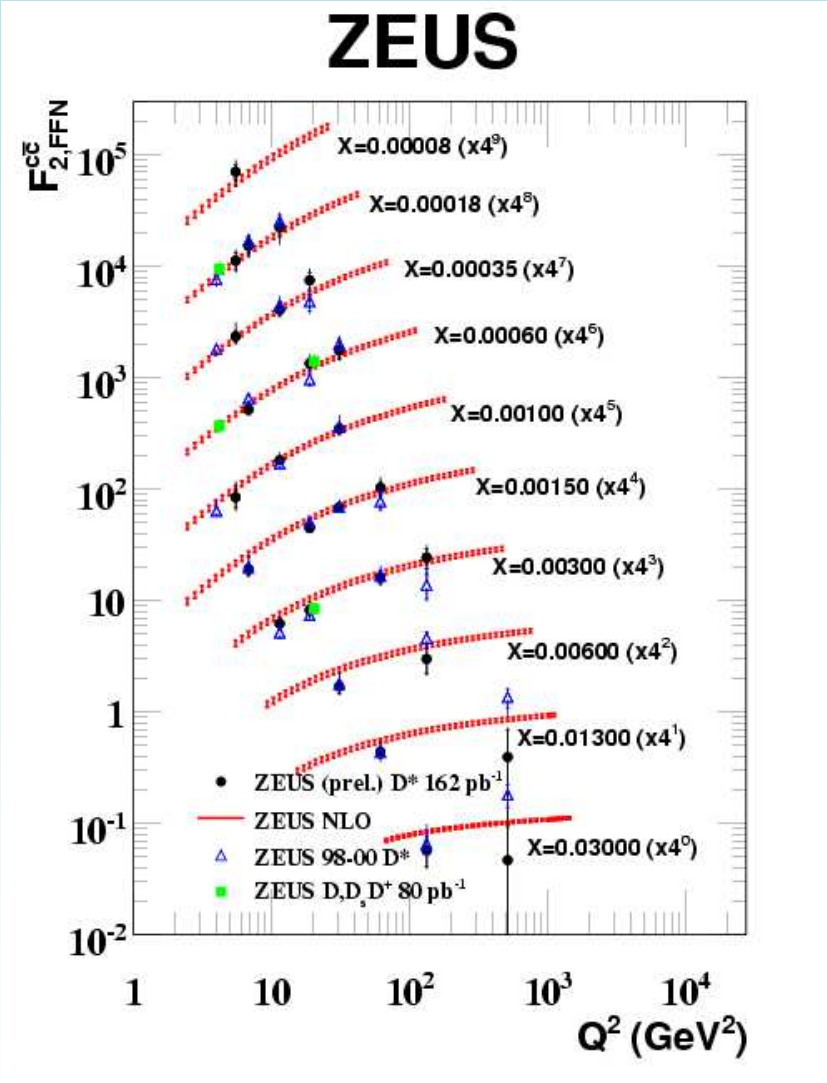
- The charm contribution to the proton structure functions, F_2, is measured at HERA using different techniques, based on D meson tagging and lifetime measurements.

- 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


HERA F_2
F_2^{em}-log$_{10}$(x)
ZEUS NLO QCD fit
H1 PDF 2000 fit
H1 94-00
H1 (prel.) 99/00
ZEUS 96/97
BCDMS
E665
NMC
x=6.32E-5
x=0.000102
x=0.000161
x=0.000253
x=0.0004
x=0.0005
x=0.000632
x=0.0008
x=0.0013
x=0.0021
x=0.0032
x=0.005
x=0.008
x=0.013
x=0.021
x=0.032
x=0.05
x=0.08
x=0.13
x=0.18
x=0.25
x=0.4
x=0.65
Q^2(GeV^2)


ZEUS
$F_{2,FFN}^{c\bar{c}}$
X=0.00008 (x4^9)
X=0.00018 (x4^8)
X=0.00035 (x4^7)
X=0.00060 (x4^6)
X=0.00100 (x4^5)
X=0.00150 (x4^4)
X=0.00300 (x4^3)
X=0.00600 (x4^2)
X=0.01300 (x4^1)
X=0.03000 (x4^0)
ZEUS (prel.) D* 162 pb^-1
ZEUS NLO
ZEUS 98-00 D*
ZEUS D,D_s D+ 80 pb^-1
Q^2 (GeV^2)