Combination and QCD Analysis of Charm Production Cross Section Measurements in DIS at HERA

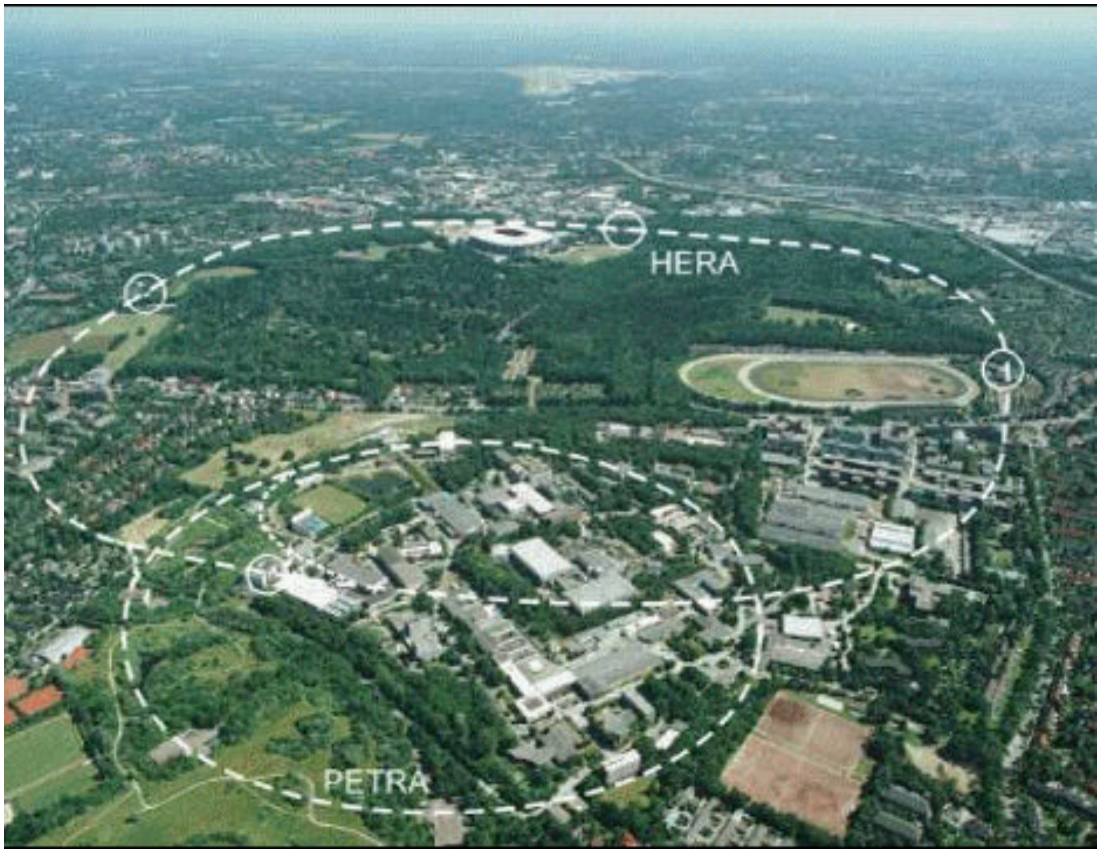
Kenan Mujkic

On behalf of the H1 and ZEUS collaborations

May 16, 2013

Outline

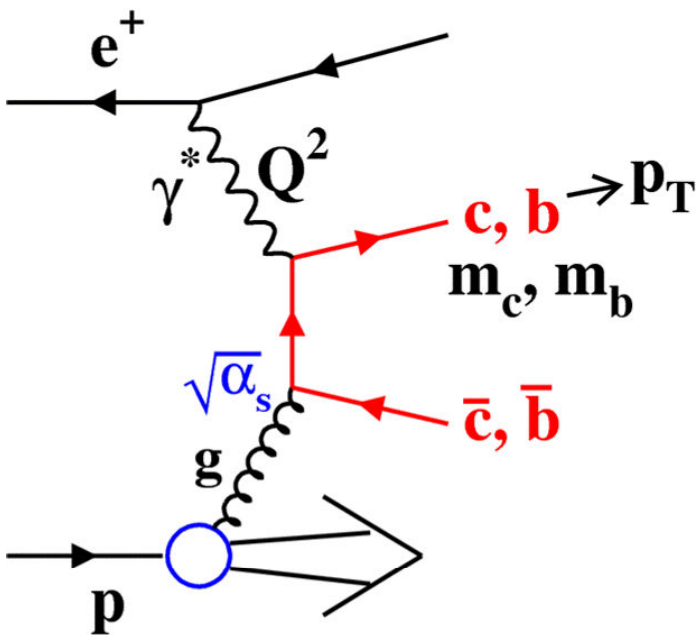
Hadron Elektron Ring Anlage (HERA)



- HERA: world's first and to date only lepton-proton collider
- $\mathrm{e}^{\pm}$ and p were brought to collision at $\sqrt{s} \approx 320$ GeV
- unique facility to resolve the structure of the proton

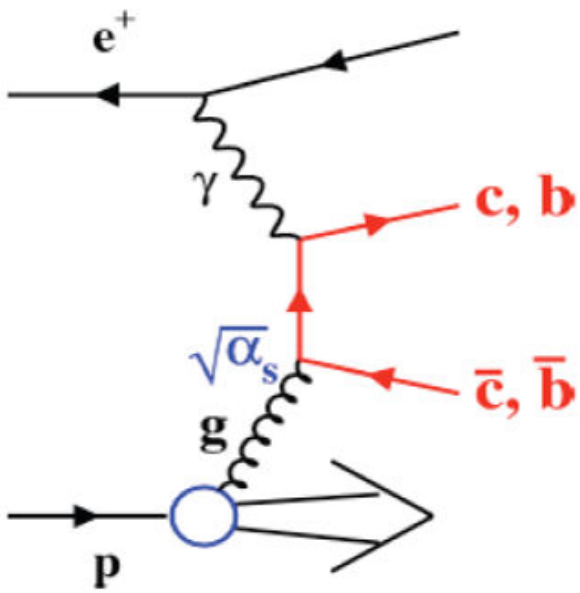
Motivation

Why studying heavy flavour production at HERA?



- Heavy flavours contribute up to 30 % to the structure functions of the proton
- The dominant production mechanism is boson-gluon fusion (BGF)
  $\rightarrow$ sensitivity to the quark and gluon density inside the proton
- Mass effects are relevant for heavy quark production at HERA
  $\rightarrow$ measurements help to distinguish between different theoretical approaches to include mass effects in perturbative QCD calculations

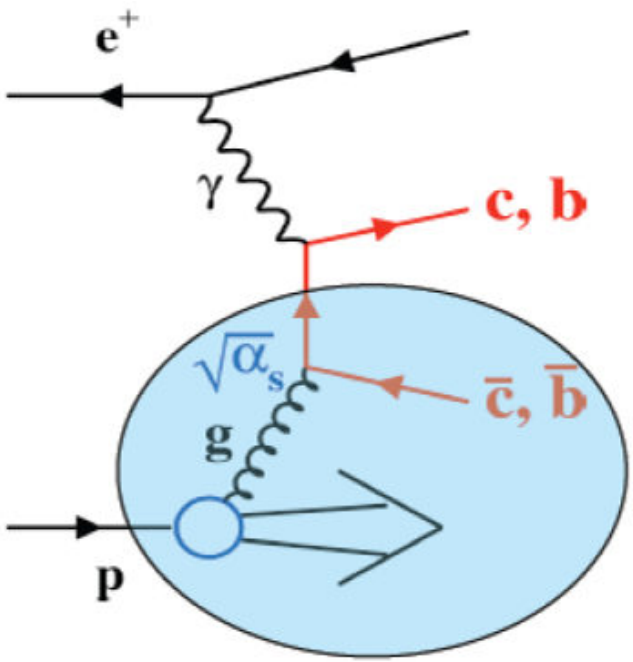
Fixed-Flavour-Number Scheme (FFNS)



+ NLO (and part NNLO) corrections

- $\mathrm{N_f} = 3$ flavours in proton, no charm quarks included in proton
- Heavy flavours produced at LO in boson-gluon fusion in hard scatter
- Mass effects included correctly at threshold
- No resummation of $\log(\mathrm{Q}^2/\mathrm{m}_\mathrm{c}^2)$, $\log(\mathrm{p_T}/\mathrm{m_c})$, ... potentially spoiling the scheme at large Q^2

Variable-Flavour-Number Schemes (VFNS)



+ pQCD corrections at NLO and NNLO

Zero Mass Variable-Flavour-Number Scheme:

- heavy flavours are massless partons
- heavy quark density included for $Q^2 > \mathrm{m}^2_{\mathrm{HQ}}$
- resums large $\log(\mathrm{Q}^2/\mathrm{m}^2_{\mathrm{HQ}})$

General Mass Variable-Flavour-Number Schemes:

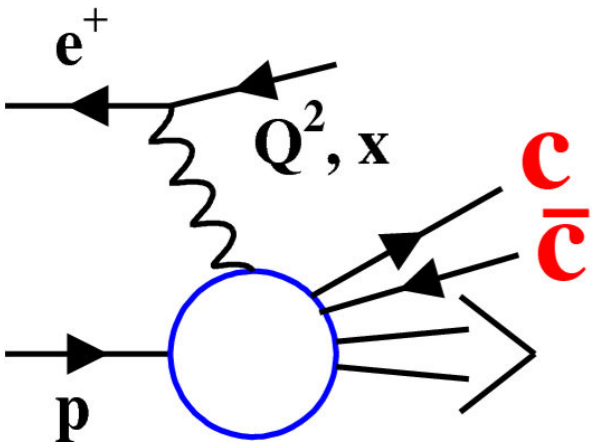
- FFNS for $\mathrm{Q}^2 < \mathrm{m}^2_{\mathrm{HQ}}$
- ZM-VFNS for $\mathrm{Q}^2 \gg \mathrm{m}^2_{\mathrm{HQ}}$
- Interpolation between FFNS and ZM-VFNS introduces ambiguities resulting in different schemes

Definition of Reduced Cross Sections

In analogy to the inclusive case the charm production cross section in neutral current DIS can be written in terms of two structure functions:

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

where $c\bar{c}$ indicates the presence of a charm quark. The cross section is dominated by $F_2^{c\bar{c}}$, as $F_L^{c\bar{c}}$ is small in the kinematic region considered.



The results are then presented in terms of the reduced cross section:

$$\sigma_{\rm red}^{c\bar{c}} = F_2^{c\bar{c}} - \frac{y^2}{1+(1-y)^2}F_L^{c\bar{c}}.$$

Data Samples for the Combination

The present analysis combines HERA charm measurements to extract a combined measurement of $\sigma_{\mathrm{red}}^{c\bar{c}}$. In total 9 data sets are used for 155 points:

Data Set	Reconstruction	Period	$Q^2[GeV]$
H1 VTX	displaced vtx	HERA I + II	5-2000
H1 D^*	D^* decay	HERA I	2-100
H1 D^*	D^* decay	HERA II	5-100
H1 D^*	D^* decay	HERA II	100-1000
ZEUS D^*	D^* decay	96-97	1-200
ZEUS D^*	D^* decay	98-00	1.5-1000
ZEUS D^0	D^0 decay	2005	5-1000
ZEUS D^+	D^+ decay	2005	5-1000
ZEUS μ	semileptonic	2005	20-10000

ZEUS full HERA II D^*, $D+$ and VTX not included yet.

Extrapolation to Full Phase Space

Most measurements are given as visible cross sections with a restricted final state. This is the reason for the extrapolation to the full phase space:

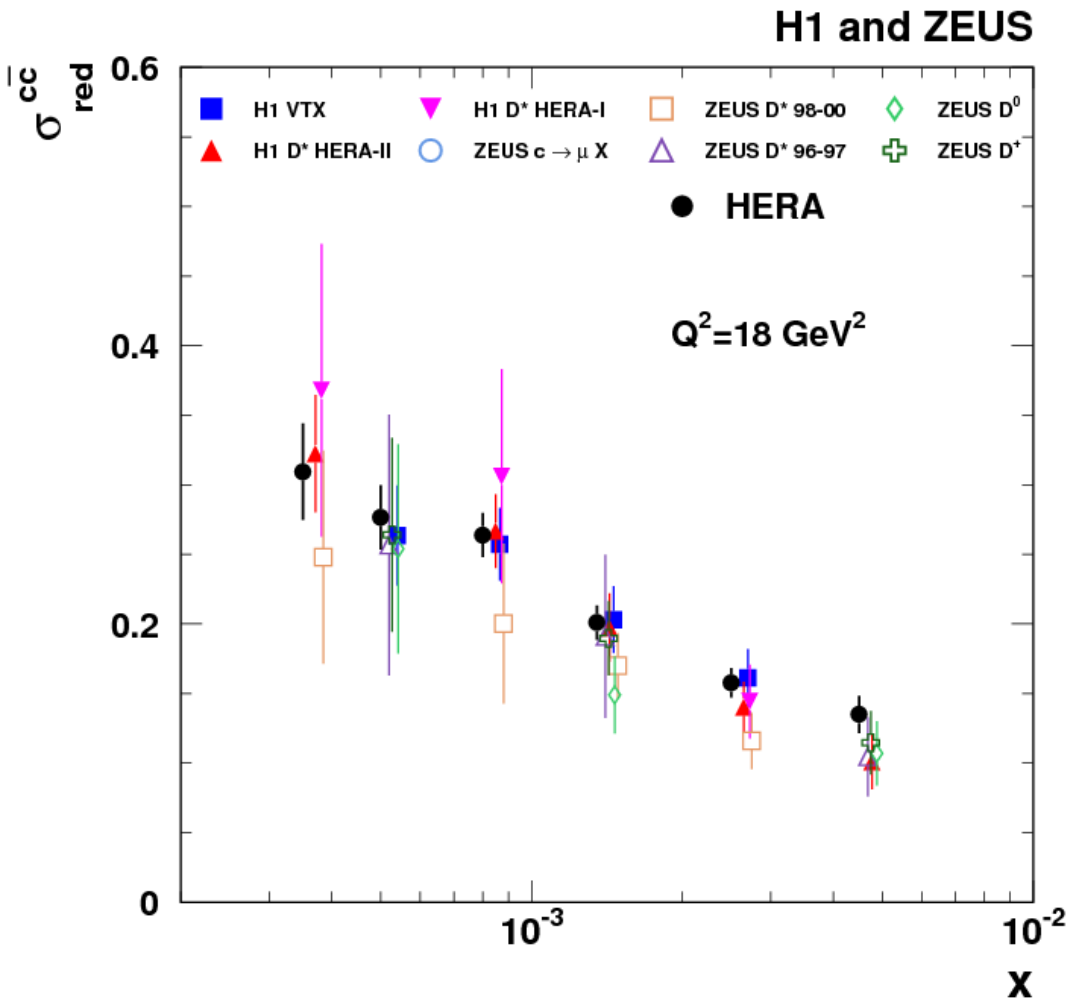
$$\sigma_{\mathrm{red}}^{c\bar{c}}(x, Q^2) = \sigma_{\mathrm{vis,bin}}^{c\bar{c}} \frac{\sigma_{\mathrm{red}}^{c\bar{c},\mathrm{th}}(x, Q^2)}{\sigma_{\mathrm{vis,bin}}^{c\bar{c},\mathrm{th}}} \quad (1)$$

The theoretical predictions for the extrapolation are given by the HVQDIS program in the FFNS at NLO using the following parameters:

- $m_c = 1.5 \pm 0.15$ GeV
- $\mu_f = \mu_r = \sqrt{Q^2 + 4m_c^2}$
- $\alpha_s^{n_f=3}(M_Z) = 0.105 \pm 0.002$

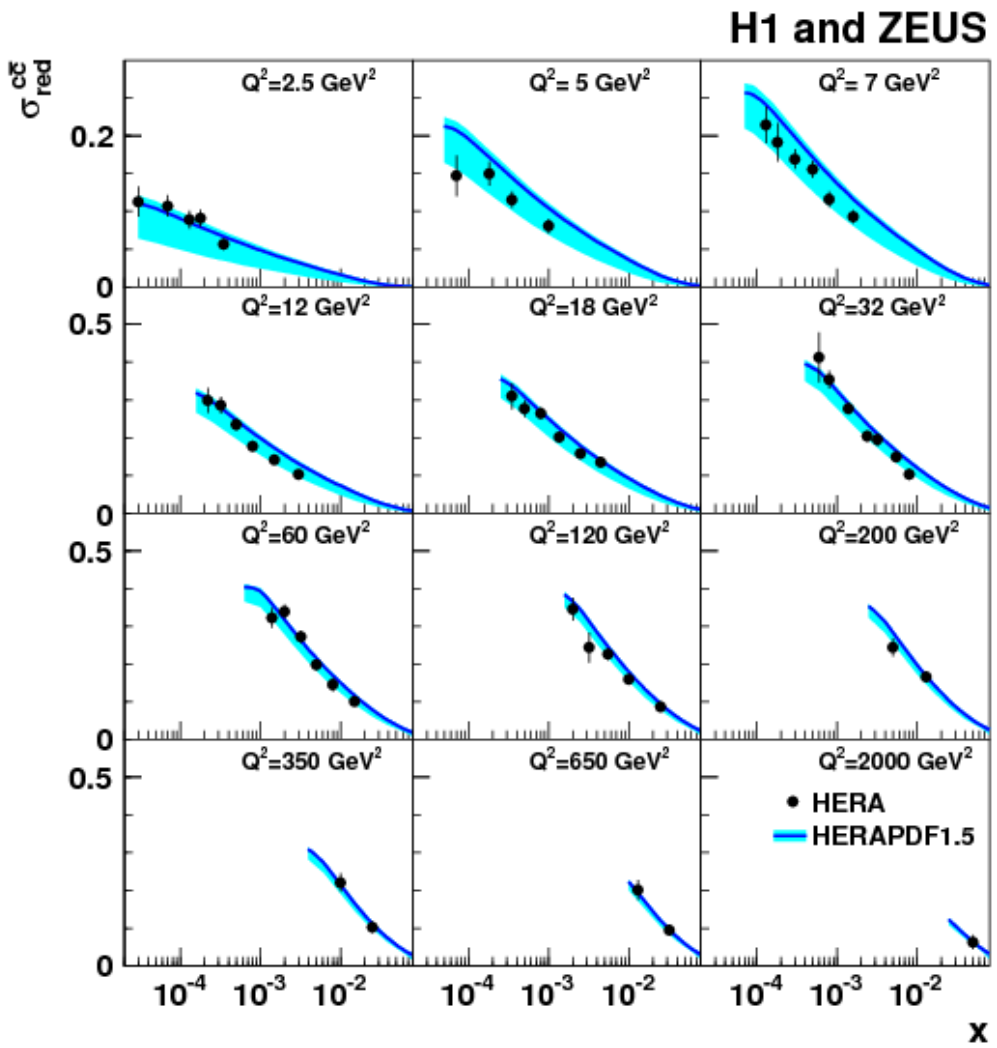
As parton density function HERAPDF1.0 in the FFNS was used.

Combination Results



- combination agrees well with individual measurements from 9 different data sets
- total uncertainty $\approx$ 10 %, about 6 % in middle Q^2 and small x range
- improvement of factor 2 with respect to each of the most precise measurements

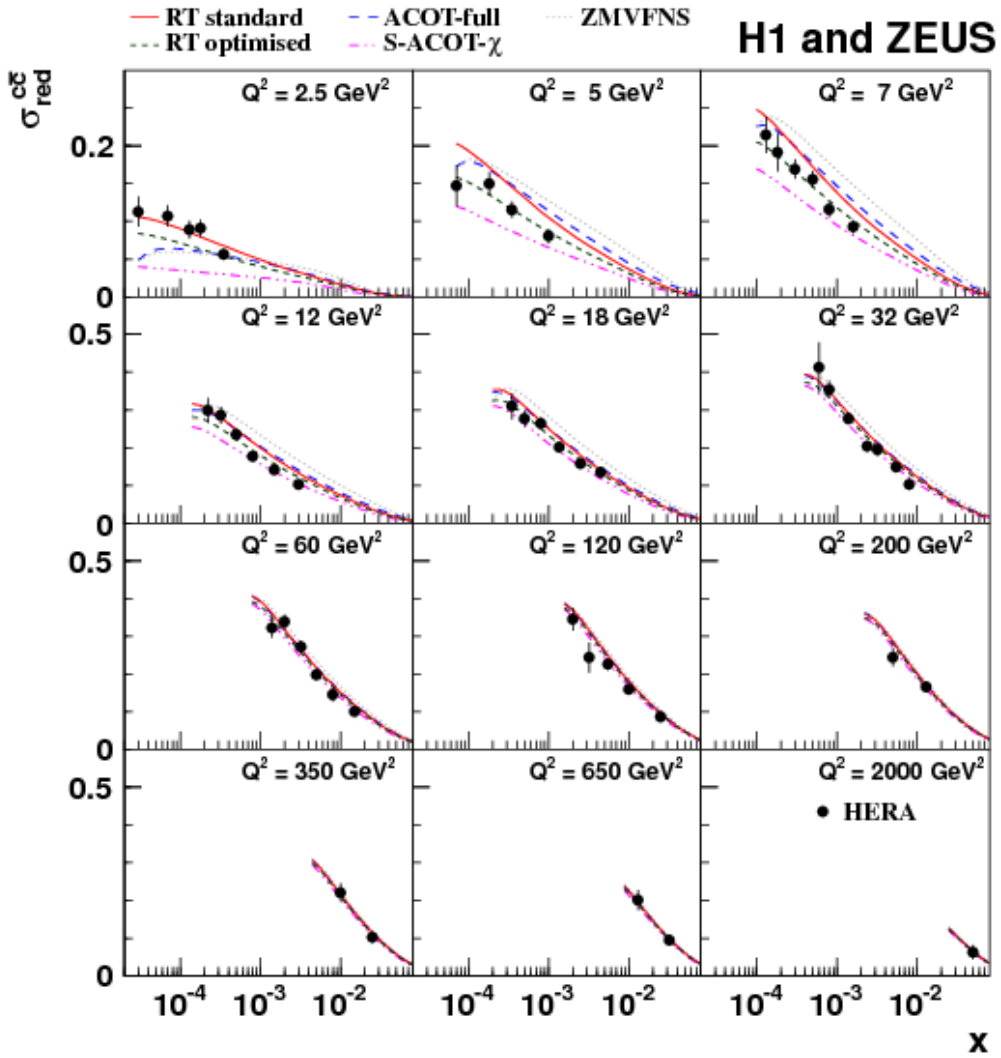
Comparison with GM-VFNS



GM-VFNS, RT-Scheme

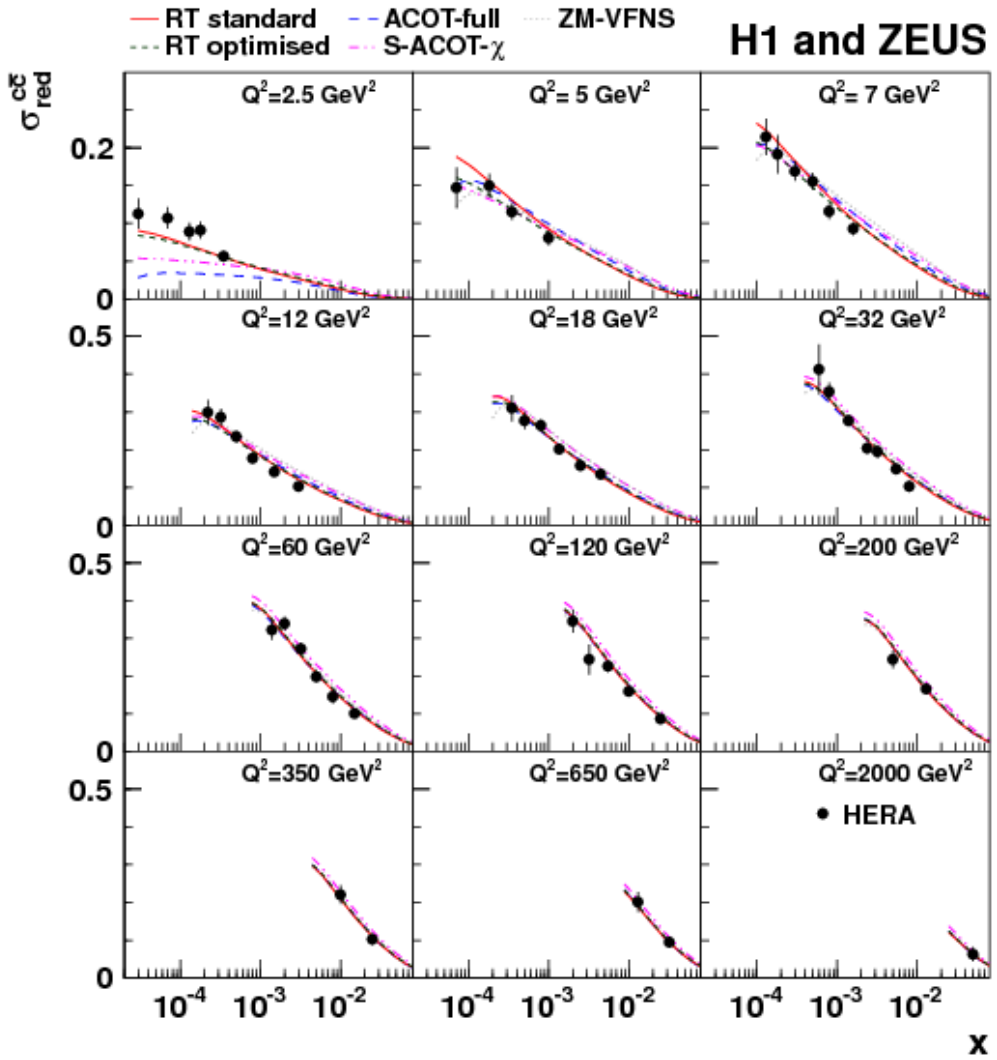
- data well described using HERAPDF1.5 - fitted from inclusive DIS data alone
- blue band represents charm mass variation $1.35 \rightarrow 1.6$ GeV
- strong dependence of theoretical predictions on charm mass $\mathrm{m_c}$ at low Q^2

Comparison with various VFNS



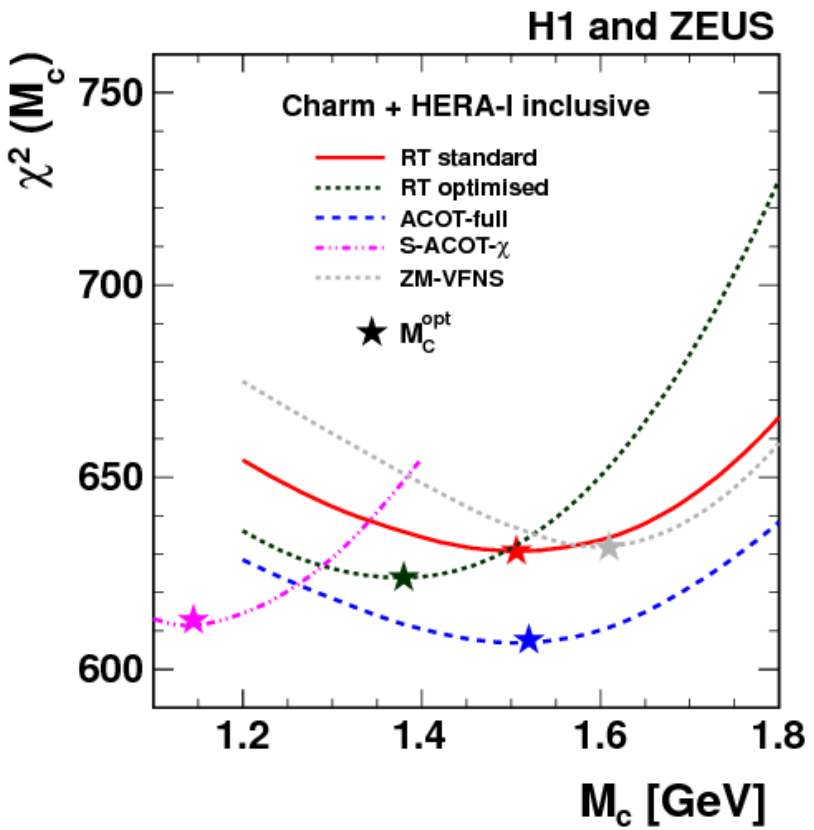
- least χ^2 fit to inclusive DIS data alone
- M_c fixed to 1.4 GeV
- different descriptions due to:
  - different matching schemes of massive and massless parts
  - additional parameters in interpolation terms

Comparison with various VFNS



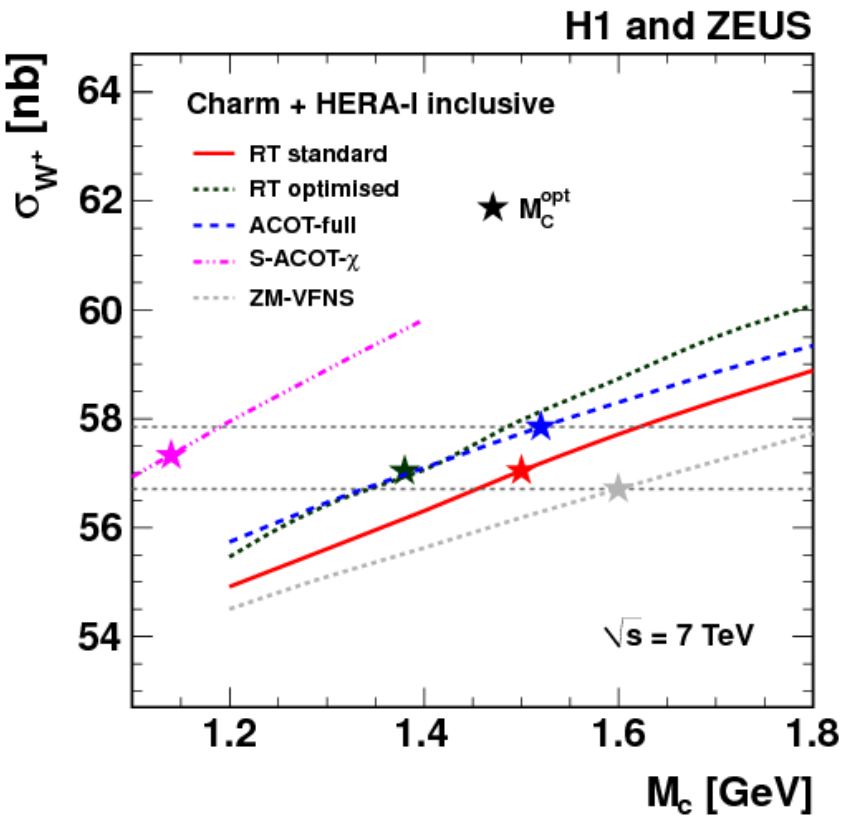
- least χ^2 fit to inclusive DIS and charm data
- $\mathrm{M_c} = \mathrm{M_c^{opt}}$
- improved descriptions albeit:
  - ◇ different matching schemes of massive and massless parts
  - ◇ additional parameters in interpolation terms

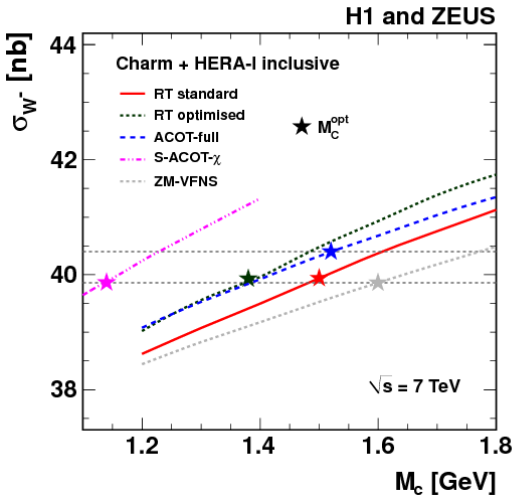
Determination of optimal mass parameter $\mathrm{M_c}$

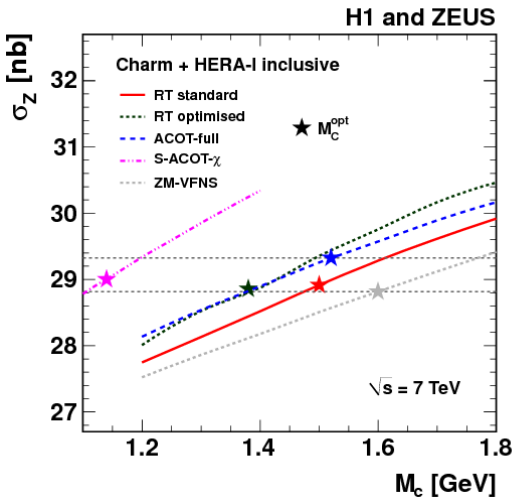


- simultaneous fit of combined charm data and inclusive DIS data to extract PDFs
- fit optimal charm mass parameter $\mathrm{M_c}$ for each varibale flavour number scheme
- optimised charm mass parameter $\mathrm{M_c}$ then used to calculate predictions for $\mathrm{W^{\pm}}$ and Z production at the LHC

Cross Section Predictions at the LHC

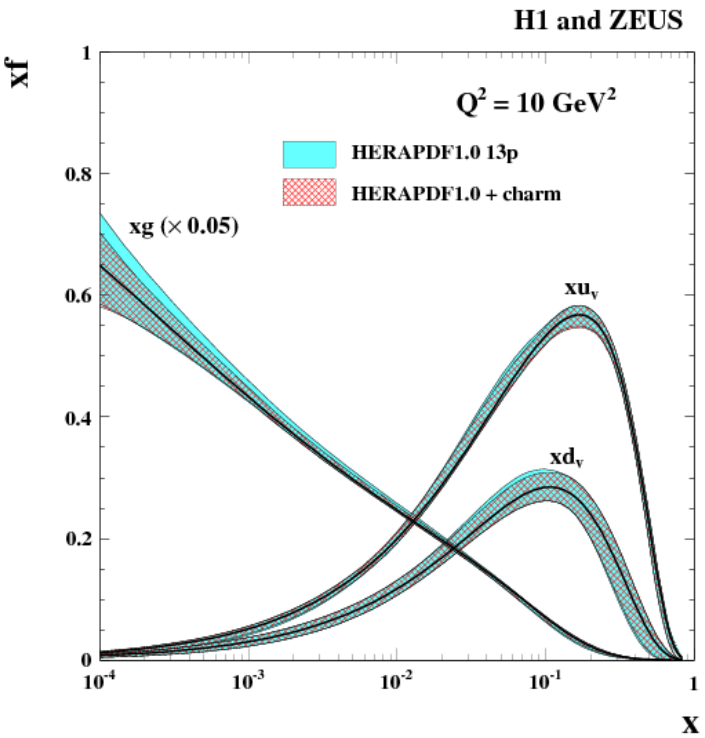


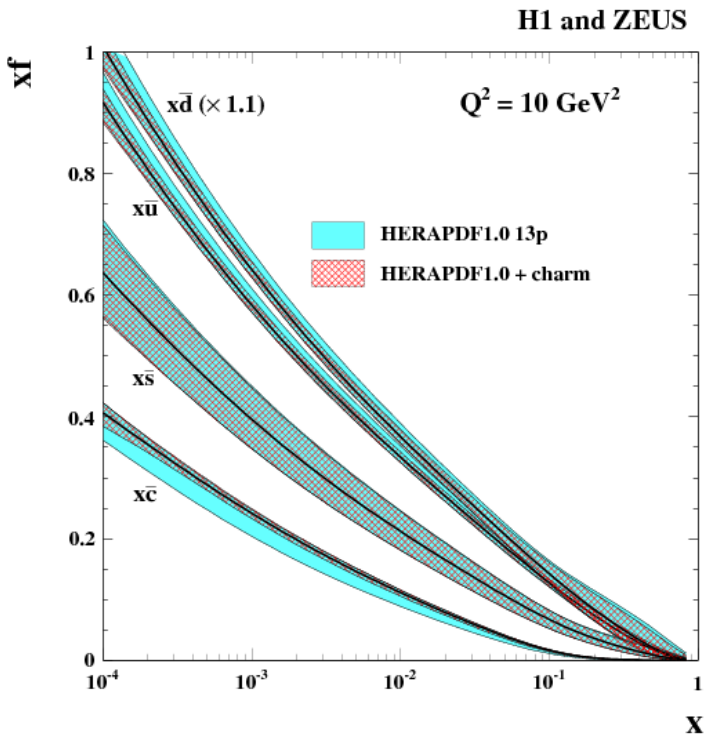




→ Optimal M_c reduces model uncertainty to below 2 %

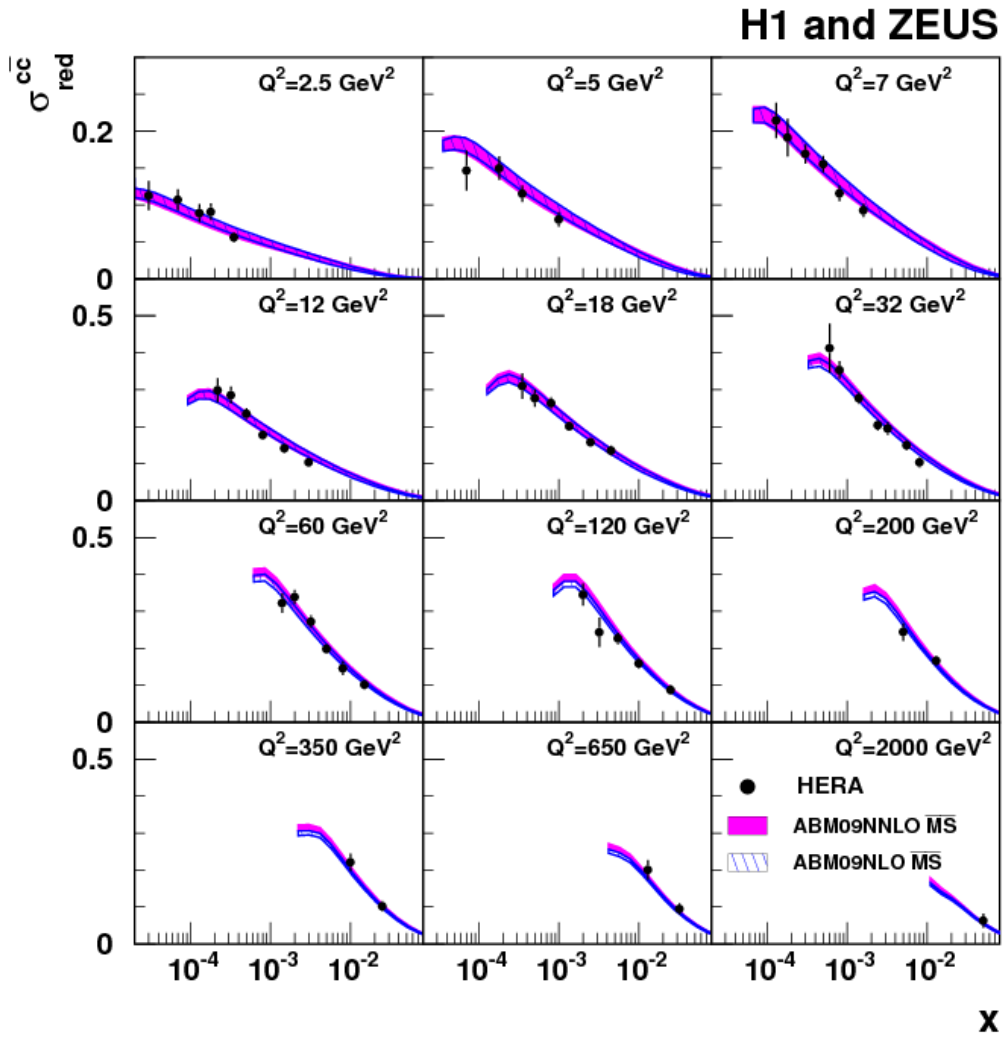
Impact on Parton Density Functions





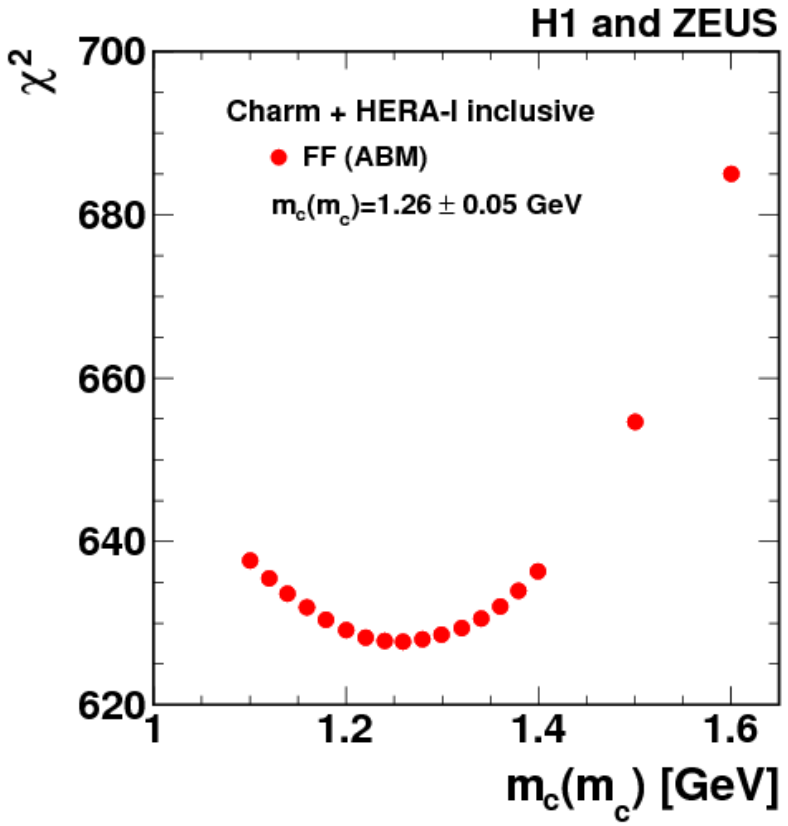
→ charm data stabilises the sea flavour composition and reduces the gluon uncertainty

Comparison with ABM FFNS



- charm data well described by NLO and NNLO calculations
- best description of charm data at low Q^2
- large logarithms do not spoil the description at high Q^2
- unambiguous treatment of running charm mass $\mathrm{m_c}$ in $\overline{\mathrm{MS}}$ scheme in all terms of the calculation

Measurement of $\overline{\mathrm{MS}}$ Running Charm Mass



- simultaneous fit of combined charm data and inclusive DIS data to extract PDFs
- minimisation of χ^2 of the fit as a function of the charm mass
- $\mathrm{m_c(m_c)} = 1.26 \pm 0.05_{\mathrm{exp}} \pm 0.03_{\mathrm{mod}} \pm 0.02_{\alpha_s}$ GeV
- PDG values: $\mathrm{m_c} = 1.275 \pm 0.025_{\mathrm{exp}}$ GeV

Summary and Conclusions

- HERA DIS charm data have been combined, with good consistency and reduced uncertainties.
- Different VFNS prefer different optimal values of the charm mass parameter $\mathrm{M_c}$.
- PDF fits using optimal mass parameter, $\mathrm{M_c^{opt}}$, significantly reduce uncertainties for $W^{\pm}$ and Z production cross sections at LHC and uncertainties on gluon distribution.
- Reduced charm cross sections are well-described by NLO QCD in FFNS confirming the gluon universality.

Thank you very much for your attention!