

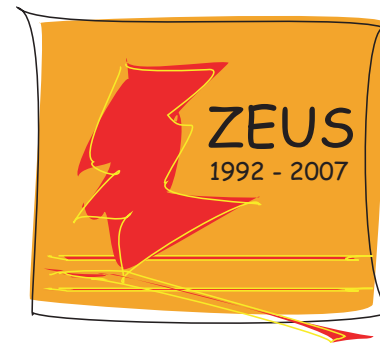
ICHEP 2010, Paris, July 22

Combined measurement of $F_2^{c\bar{c}}$ and effect on PDF fits

Massimo Corradi

INFN Bologna

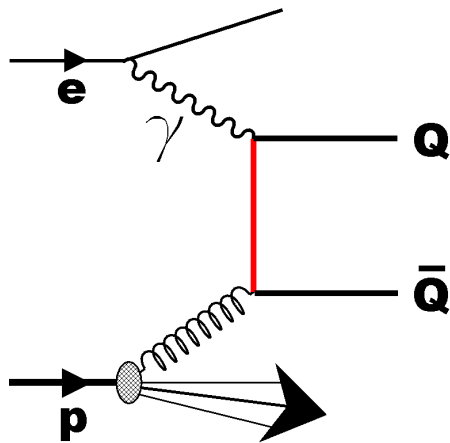
on behalf of the H1 and ZEUS and collaborations



Heavy Quark production in DIS

Fixed Flavour–Number Scheme (FFNS)

c (b) only from hard scattering,
3 (4) active flavours in p



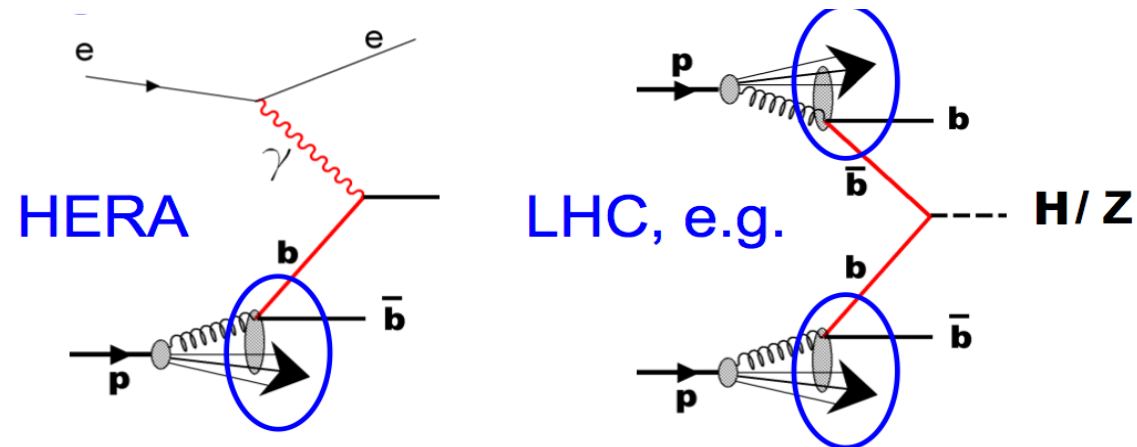
leading order: boson-gluon fusion

Direct access to $g(x)$

FFNS spoiled when $Q^2, p_T \gg m_Q$
e.g. large $\log(Q^2/m_Q^2)$

Zero Mass Variable Flavour–Number Scheme (ZM-VFNS)

c, b active flavours in p



resums $\log(Q^2/m^2)$

c, b : massless partons:
ZM-VFNS fails at $Q^2 \leq \mathcal{O}(m_Q^2)$

needed at high-energy colliders

c, b PDFs can be directly tested in DIS

PDF fits and charm threshold, GM-VFNS

HERA DIS data are in a Q^2 range where the charm mass effects are relevant:
ZM-VFNS can not be used

Generalised Mass-VFNS (GM-VFNS):

interpolates between FFNS at $Q^2 < m_c^2$ and ZM-VFNS at $Q^2 \gg m_c^2$
different HQ schemes developed recently

GM-VFNS PDFs have a significant dependence on

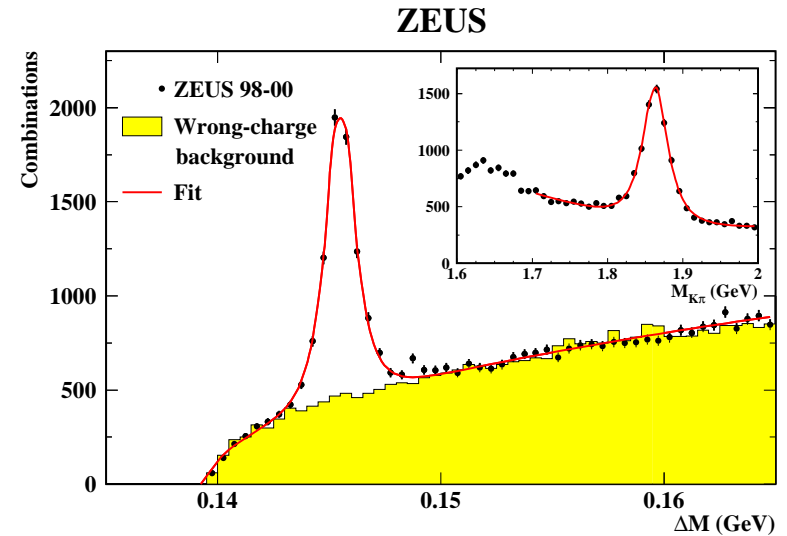
- the HQ scheme
- the charm mass

Impact of different GM-VFNS schemes on W/Z cross section at LHC
up to 3% at NLO

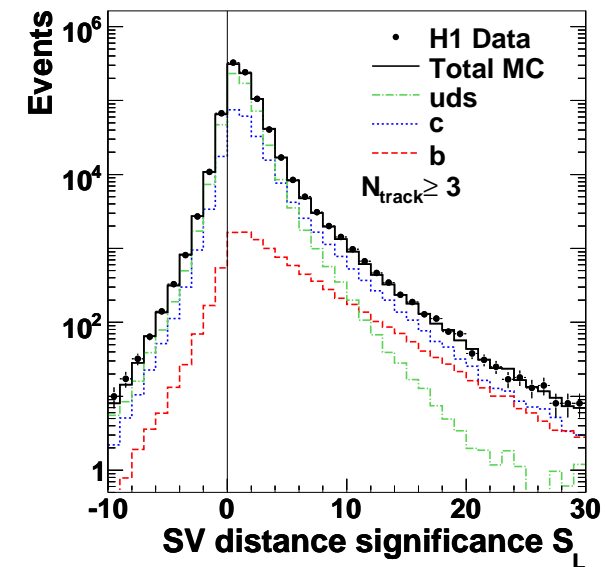
Precise charm DIS data expected to test/constrain these GM-VFN schemes

Data sets used in the prel. H1-ZEUS combination

- ZEUS, D^{*+} , HERA I, $L=82+37 \text{ pb}^{-1}$
(hep-ex/9908012, hep-ex/0308068)
- H1, D^{*+} , HERA I, $L=47 \text{ pb}^{-1}$
(hep-ex/0608042)
- H1, D^{*+} , HERA II prel., $L=340 \text{ pb}^{-1}$
(high- Q^2 part: arXiv:0911.3989)
- ZEUS, D^+ , D^0 , 2005 data, $L=134 \text{ pb}^{-1}$
(arXiv:0704.3562 [hep-ex])
- ZEUS, μ , 2005 data, $L=121 \text{ pb}^{-1}$
(arXiv:0904.3487 [hep-ex])
- H1, lifetime tag, HERA I, $L=57 \text{ pb}^{-1}$
(hep-ex/0411046, hep-ex/0507081)
- H1 lifetime tag, HERA II prel, $L=189 \text{ pb}^{-1}$
(now in arXiv:0907.2643)



D^{*+} signal (ZEUS HERA-I 98-00)



Secondary vertex significance
(H1 lifetime tag)

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

$F_2^{c\bar{c}}$ is the part of the F_2 structure function with a $c\bar{c}$ in the final state:

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

$$Y_+ = 1 + (1 - y)^2$$

(note: definition may differ from that used by theorists, see Forte et al. arXiv:1001.2312)

D mesons (or μ) production measured in “visible” phase space
typically $|\eta(D^*)| < 1.5$, $p_T(D^*) > 1.5$ GeV

$F_2^{c\bar{c}}$ extracted using theory-based correction:

$$F_2^{c\bar{c}}(x, Q^2) = \sigma_{\text{vis,bin}} \frac{F_2^{c\bar{c},\text{theo.}}(x, Q^2)}{\sigma_{\text{vis,bin}}^{\text{theo.}}}$$

Similarly for inclusive lifetime tagging:
experiments mostly sensitive to events with several central high- p_T tracks

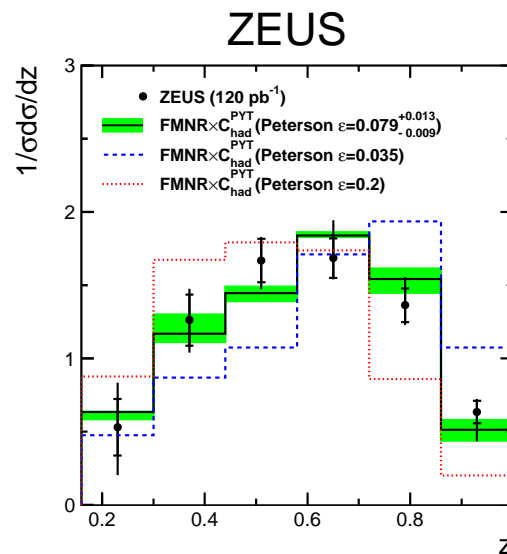
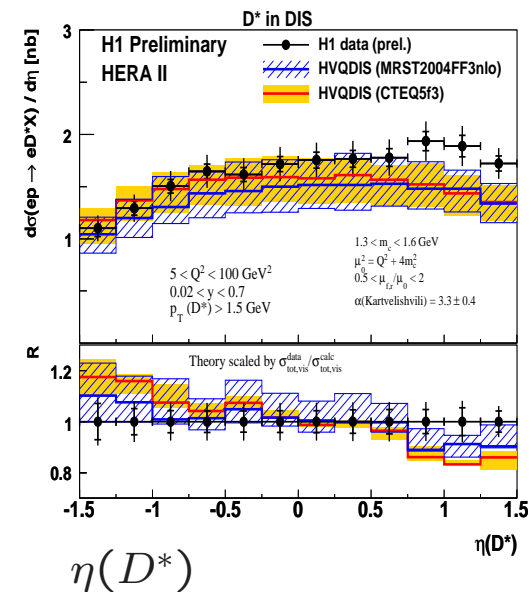
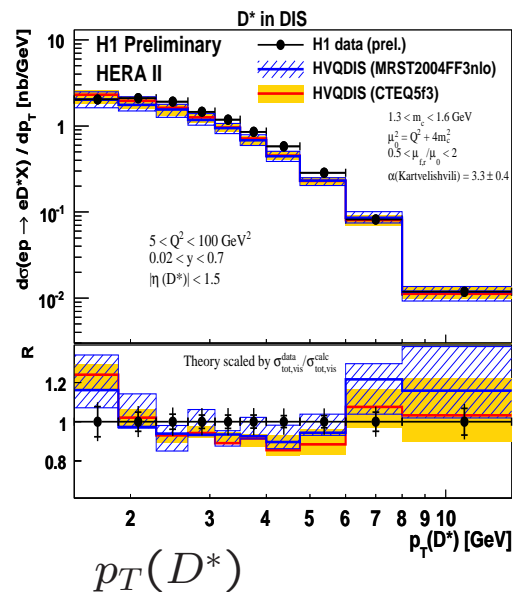
extraction of $F_2^{c\bar{c}}$

- $F_2^{c\bar{c}}$ re-calculated consistently for D , μ data starting from σ_{vis}
- HVQDIS NLO program used (Harris, Smith). good description of $\eta(D)$, $p_T(D)$
- non-perturbative quantities taken from e^+e^- and ep data:
 - fragm. functions
 - fragm. fractions

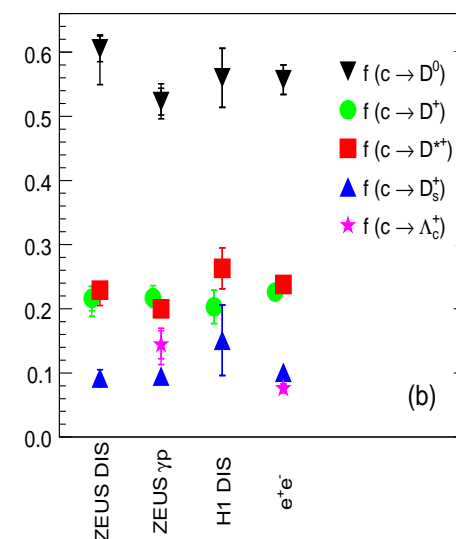
- Typical kin. acceptances: $\mathcal{A} = \sigma_{\text{vis}}/\sigma_{\text{tot}}$

D^* : $0.25 < \mathcal{A} < 0.70$
for $2 < Q^2 < 200 \text{ GeV}^2$

μ : $0.25 < \mathcal{A} < 0.40$
for $30 < Q^2 < 1000 \text{ GeV}^2$



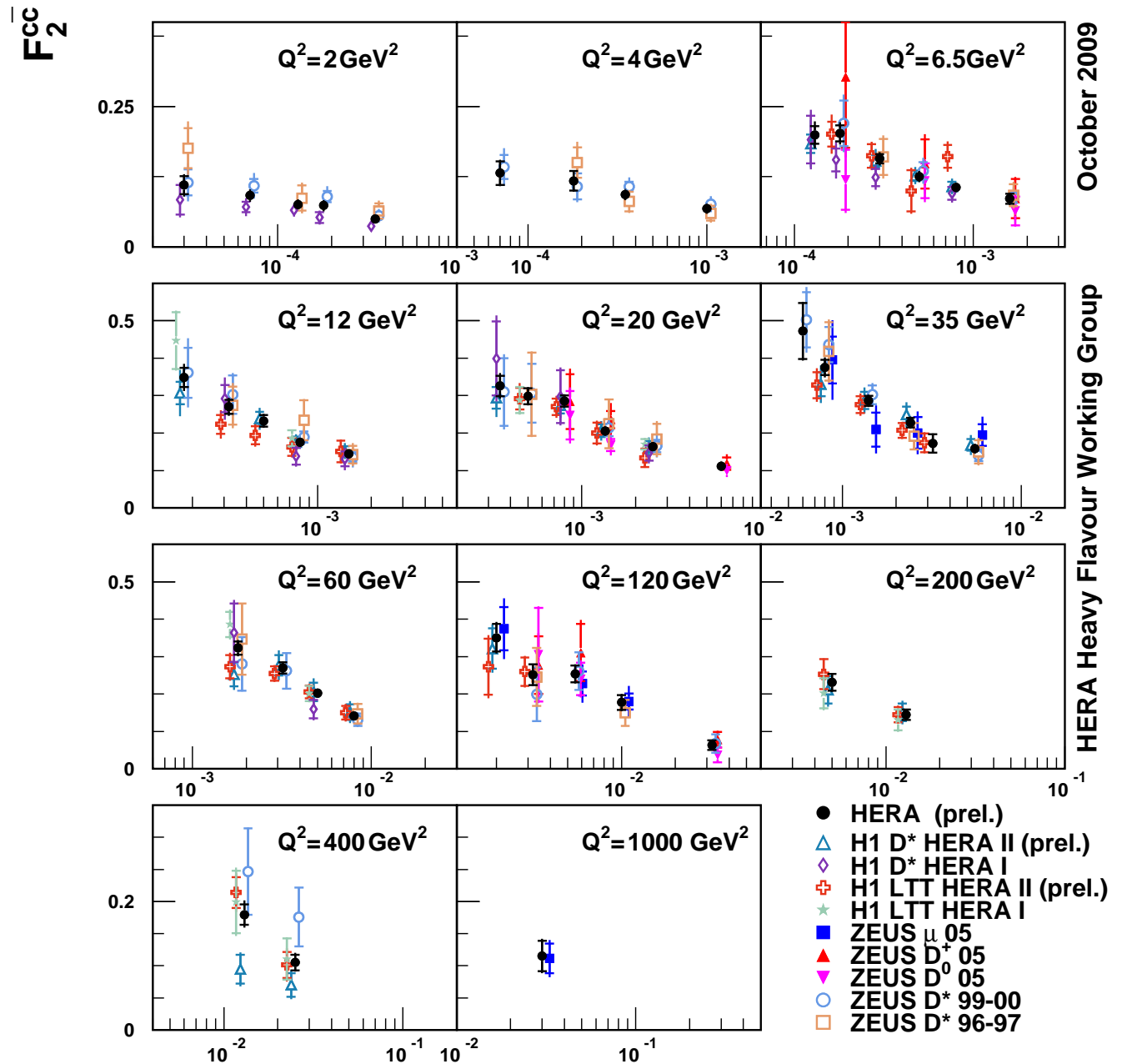
frag. function



frag. fractions

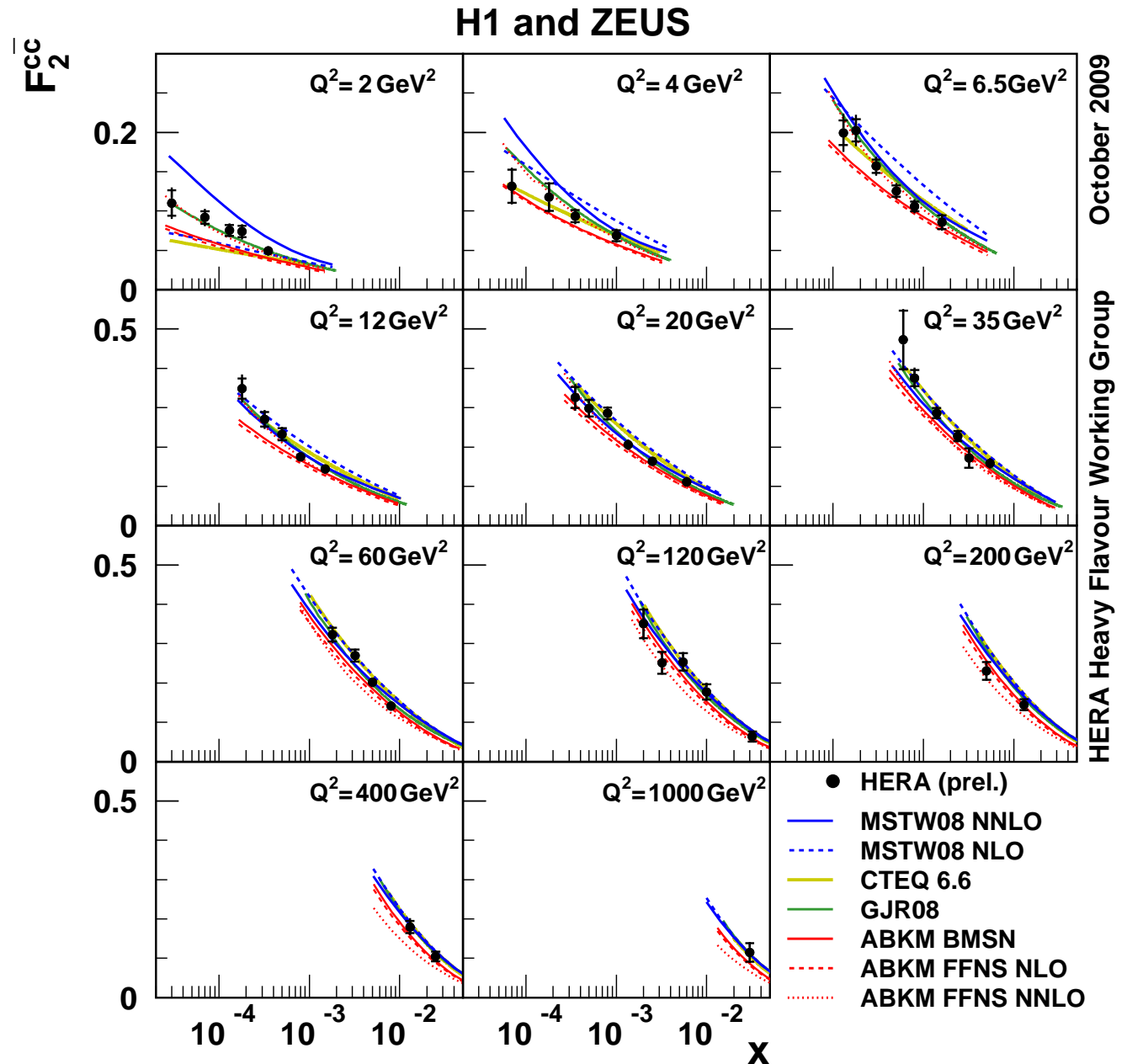
Combined $F_2^{cc\bar{c}}$ compared to single measurements

- method similar to inclusive combination
arxiv:0911.0884
- 156 measurements + 54 correl. syst.
⇒ 46 combined points
- data are compatible
 $\chi^2/\text{ndof} = 88/110$
- precision 7 – 10% for
 $6.5 \leq Q^2 \leq 60 \text{ GeV}^2$
- $Q^2 \leq 4 \text{ GeV}^2$
 D^* HERA-I data
- $Q^2 \leq 20 \text{ GeV}^2$
sizeable correlated
theoretical uncertainty



H1-ZEUS combined $F_2^{cc\bar{c}}$ compared to NLO and NNLO calculations

- data can distinguish between different theoretical predictions
- FFNS:
 - GJR08
 - ABKM FFNS
- GM-VFNS:
 - MSTW08
 - CTEQ6.6
 - ABKM BMSN



H1-ZEUS combined $F_2^{c\bar{c}}$ compared to HERAPDF1.0

- HERAPDF 1.0 fit to inclusive HERA I data

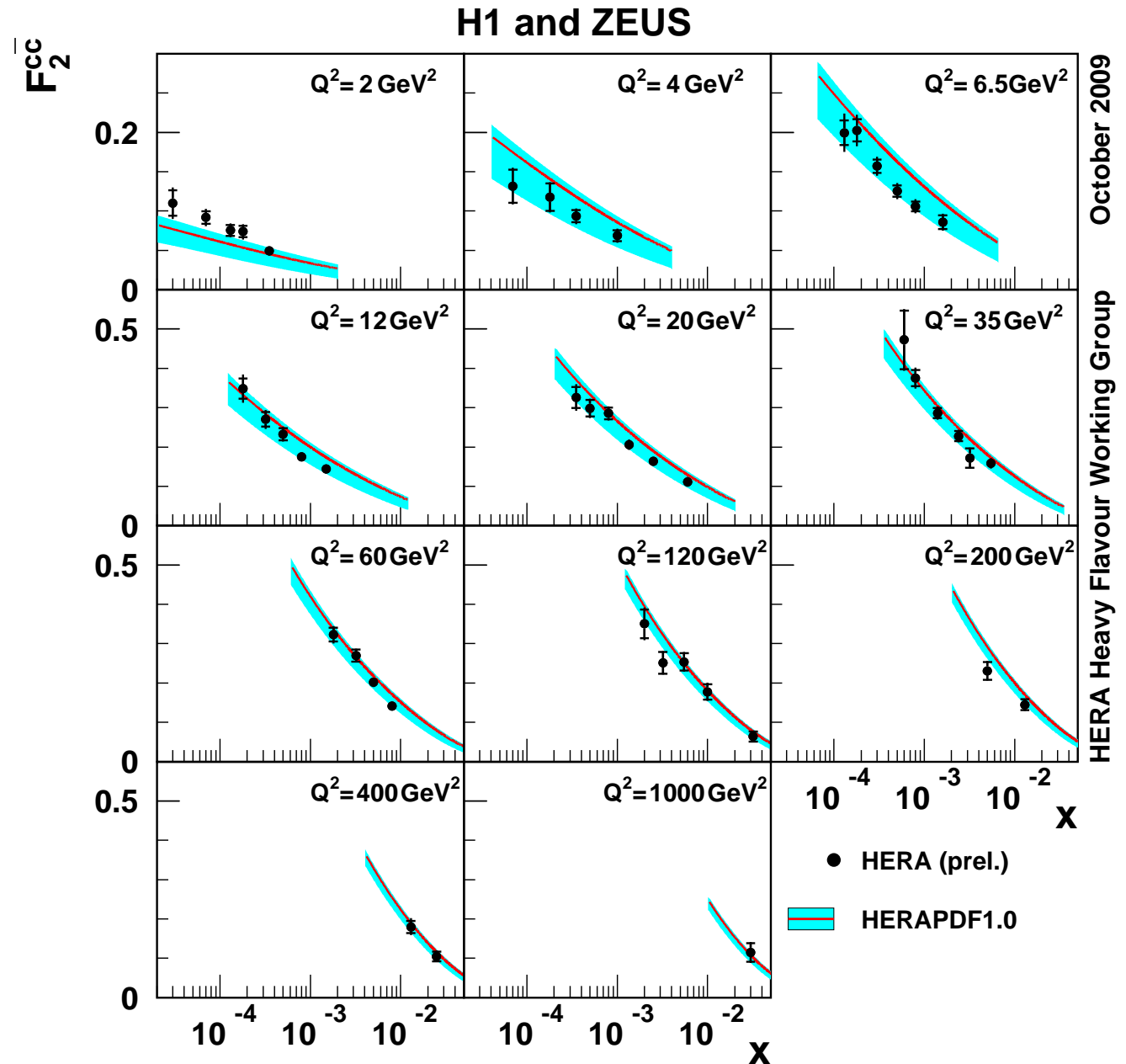
- RT GM-VFNS (as MSTW08)

- **Central curve:**
 $m_c = 1.4 \text{ GeV}$

band:

$m_c = 1.3 \text{ GeV}$ (upper)
 $m_c = 1.65 \text{ GeV}$ (lower)

[pole mass (PDG):
1.47 – 1.83 GeV]



Adding combined $F_2^{c\bar{c}}$ to HERAPDF1.0 Fit

- Fit HERA I + $F_2^{c\bar{c}}$

$Q^2 > 3.5 \text{ GeV}^2$
($Q^2 = 2 \text{ GeV}^2$ bin excluded)

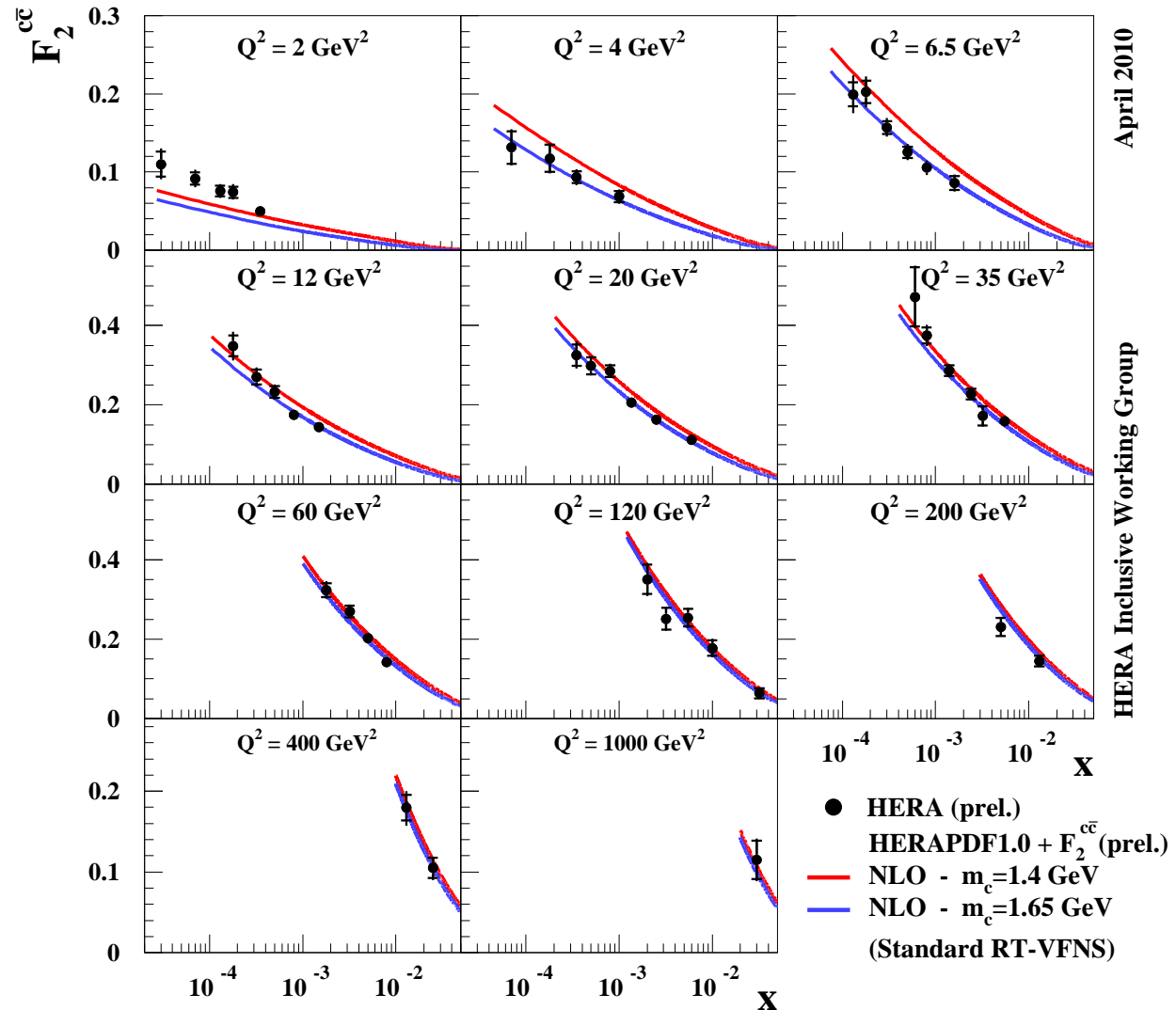
41 charm points

- RT GM-VFNS

- $m_c = 1.4 \text{ GeV}$
 $\chi_{\text{charm}}^2 = 134.5/41$

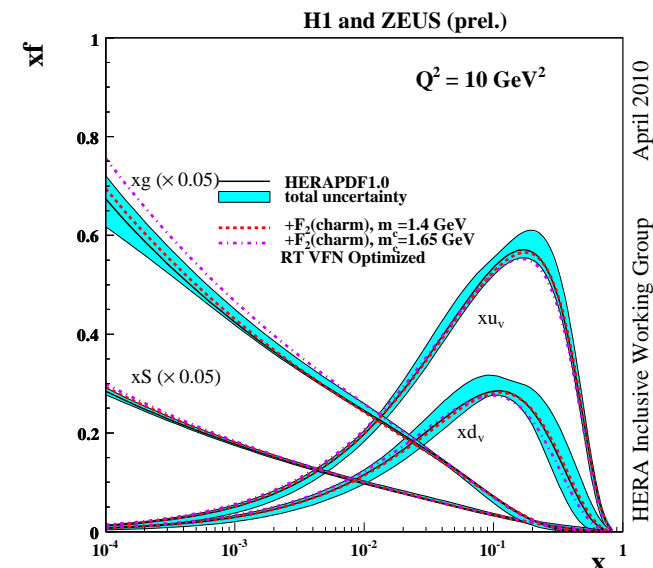
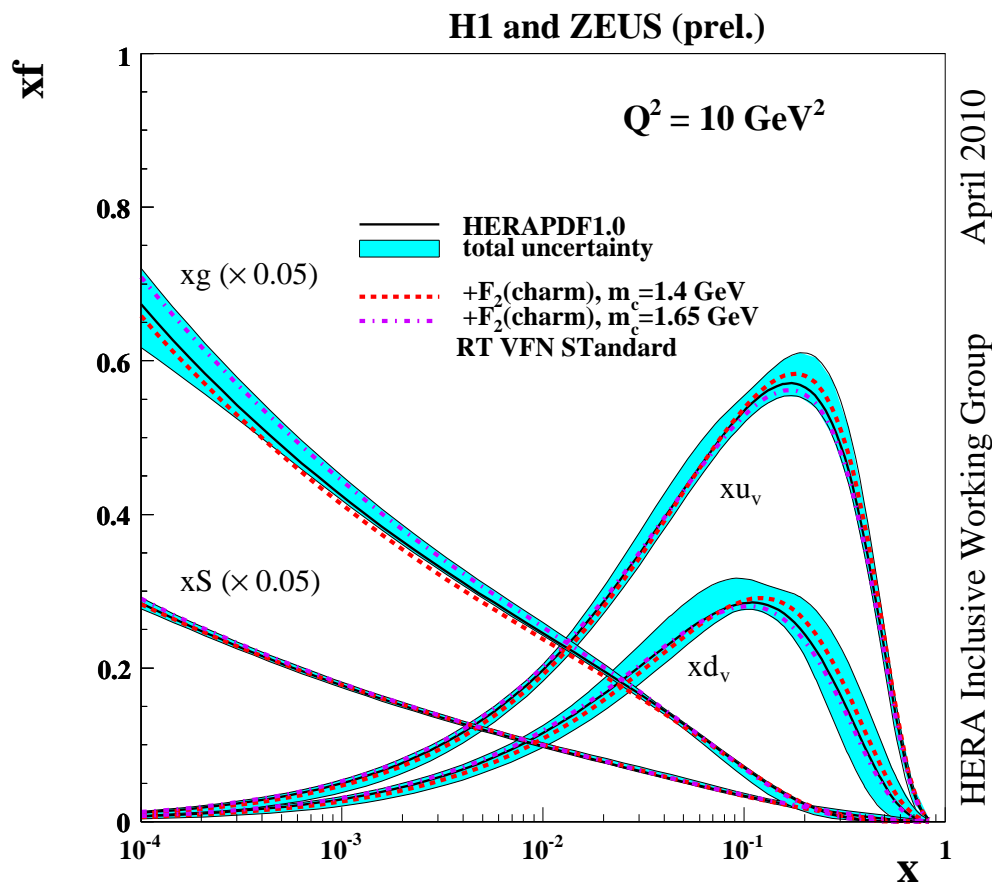
$m_c = 1.65 \text{ GeV}$
 $\chi_{\text{charm}}^2 = 43.5/41$

H1 and ZEUS



Effect on PDFs

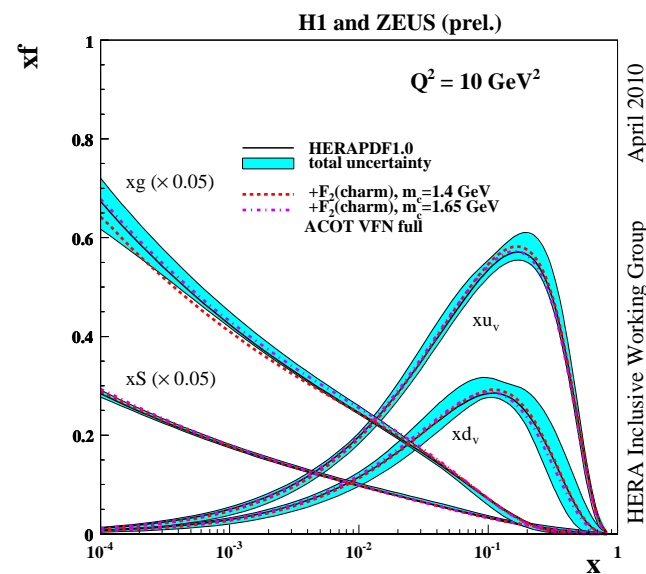
Alternative HQ schemes



Optimized RT (smoother at $Q^2 = m_c^2$, Thorne DIS2010)

RT Standard (MSTW)

- small change in $g(x)$
- dependence on m_c and HQ scheme of the same size of PDF uncertainty



ACOT (as in CTEQ6.6)

NNLO Fit

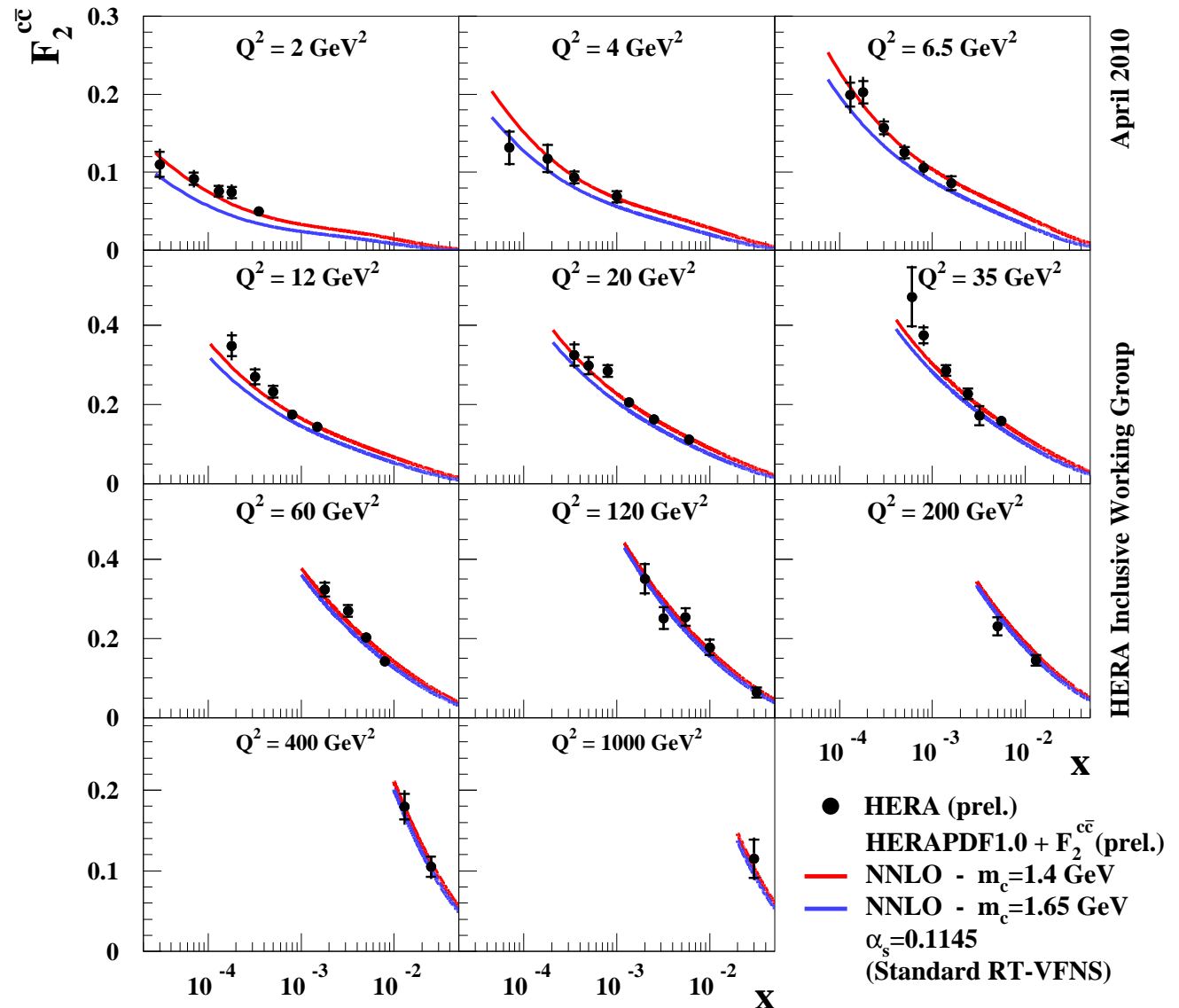
H1 and ZEUS

- “approximated” NNLO RT GM-VFNS (MSWT)
- expected to be less dependent on HQ scheme
- better agreement at $Q^2 = 2 \text{ GeV}^2$

Overall agreement similar to NLO

- $m_c = 1.4 \text{ GeV}$
 $\chi_{\text{charm}}^2 = 54/41$

$m_c = 1.65 \text{ GeV}$
 $\chi_{\text{charm}}^2 = 186/41$



April 2010

Conclusions

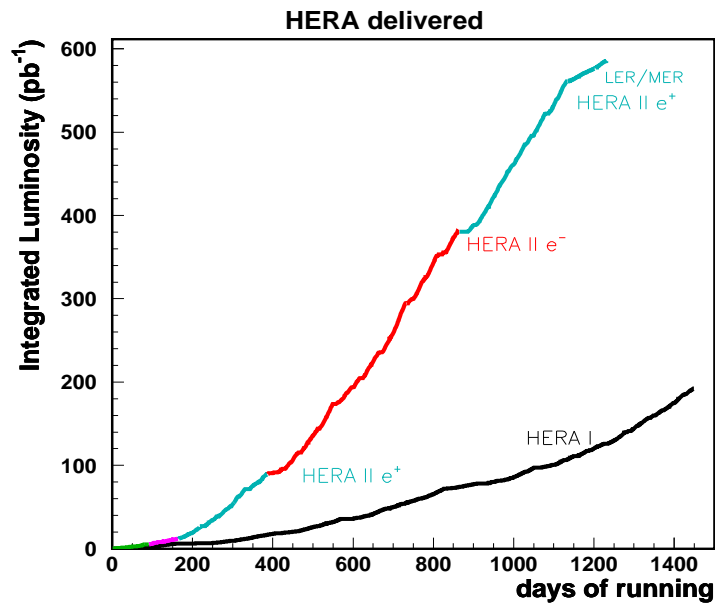
- Preliminary combination of H1 and ZEUS $F_2^{c\bar{c}}$ data
- data from $Q^2 = 2 \text{ GeV}^2$ to 1000 GeV^2
- precision of 7 – 10% on a wide kinematic range
- data more precise than spread between different theor. predictions
- $F_2^{c\bar{c}}$ fits well with inclusive HERA data
- significant dependence of the fit on m_c and HQ scheme.

BACKUPS

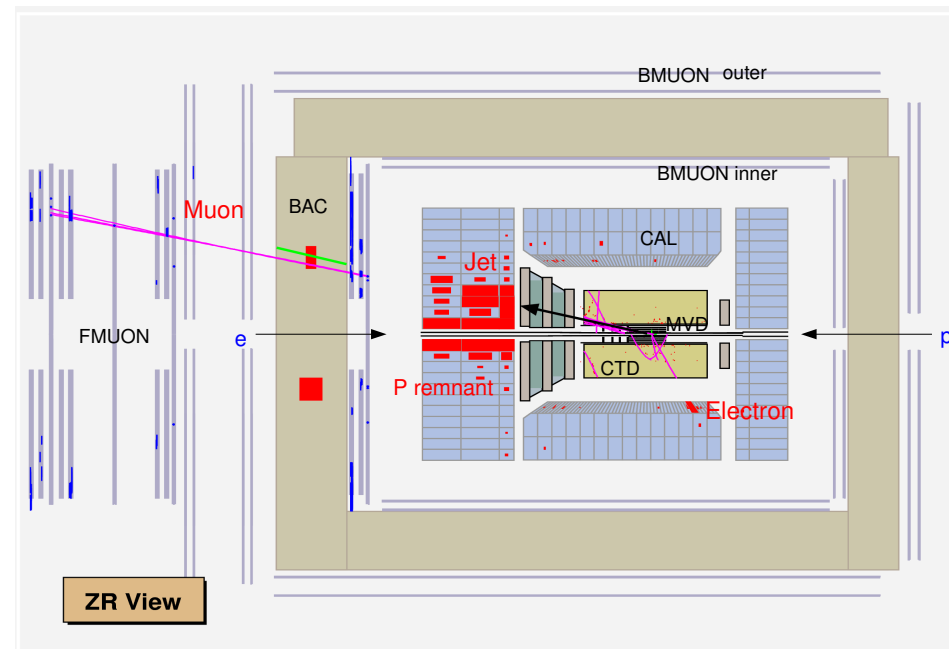
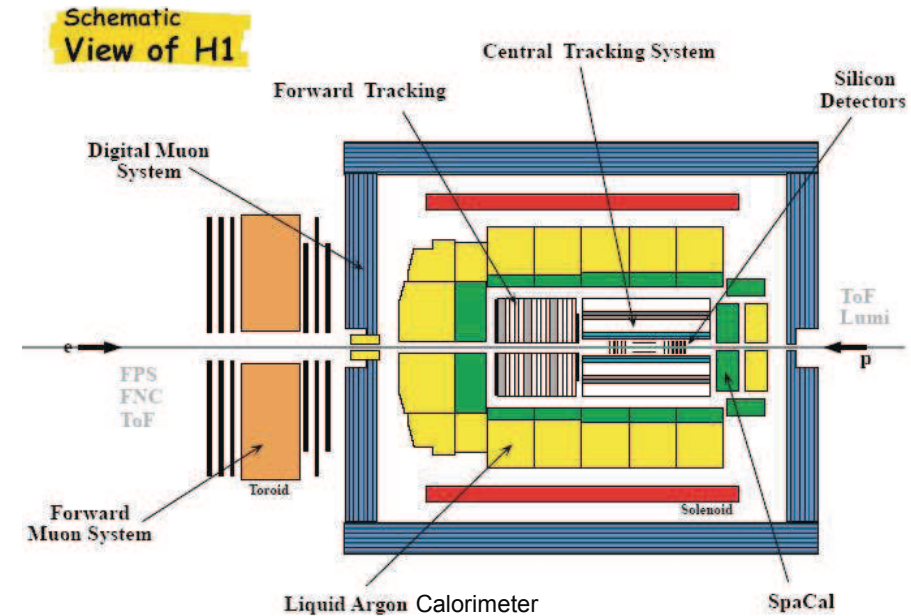
HERA, H1 and ZEUS

HERA

- $E(e^\pm) = 27.5\text{GeV}$
 $E(p) = 920\text{GeV}$
- HERA-I: 1992-2000
HERA-II: 2003-2007



- $\mathcal{L} \simeq 0.5\text{fb}^{-1}$ (per experiment)



Combination method

Combination done taking into account correlated exp. and theo. uncertainties

Similar method as for inclusive combination: find the values of the “true” $F_2^{c\bar{c}}$ (m^i) and of the “systematic shifts” (b_j) that minimize the function

correlated systematic errors

$$\chi^2(\vec{m}, \vec{b}) = \sum_i \frac{\left(m^i - \sum_j \gamma_j^i m^i b_j - \mu^i\right)^2}{(\delta_{i,stat} \mu^i)^2 + (\delta_{i,unc} m^i)^2} + \sum_j b_j^2$$

statistical errors

uncorrelated systematic errors

(where $\mu^i = i^{\text{th}}$ measurement)

MC experiments show that this is an unbiased estimator

Exp. syst. independent between H1 and ZEUS

156 original measurements

54 correlated uncertainties

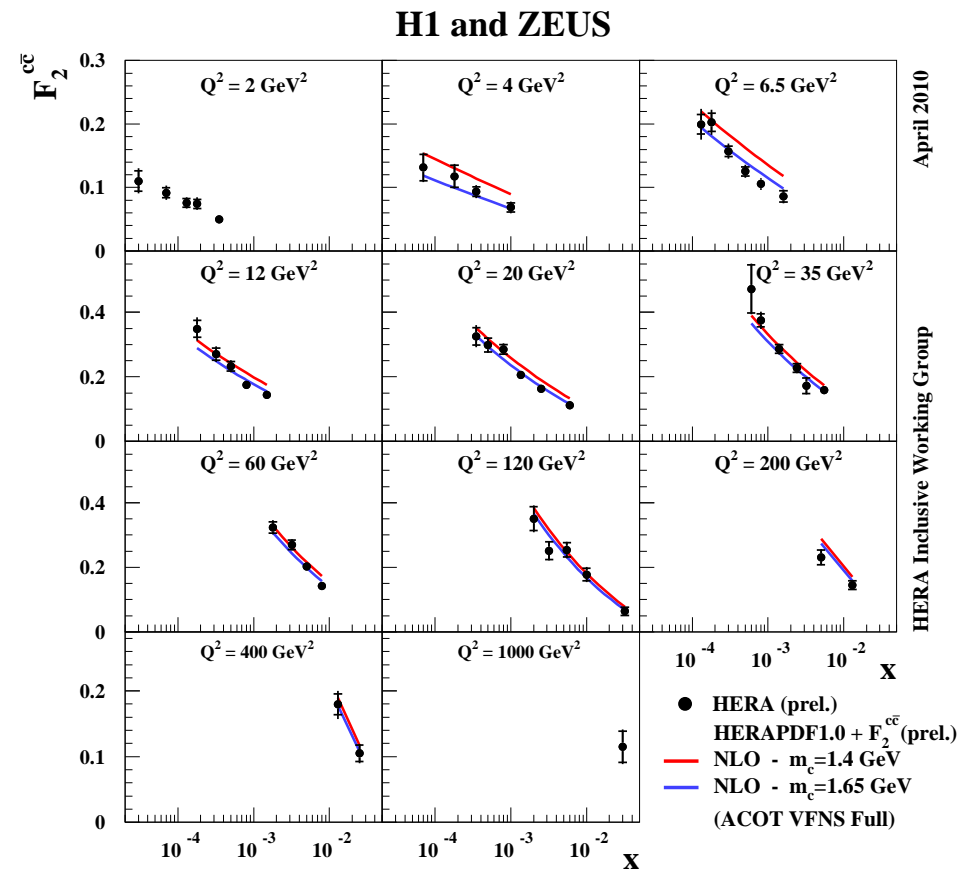
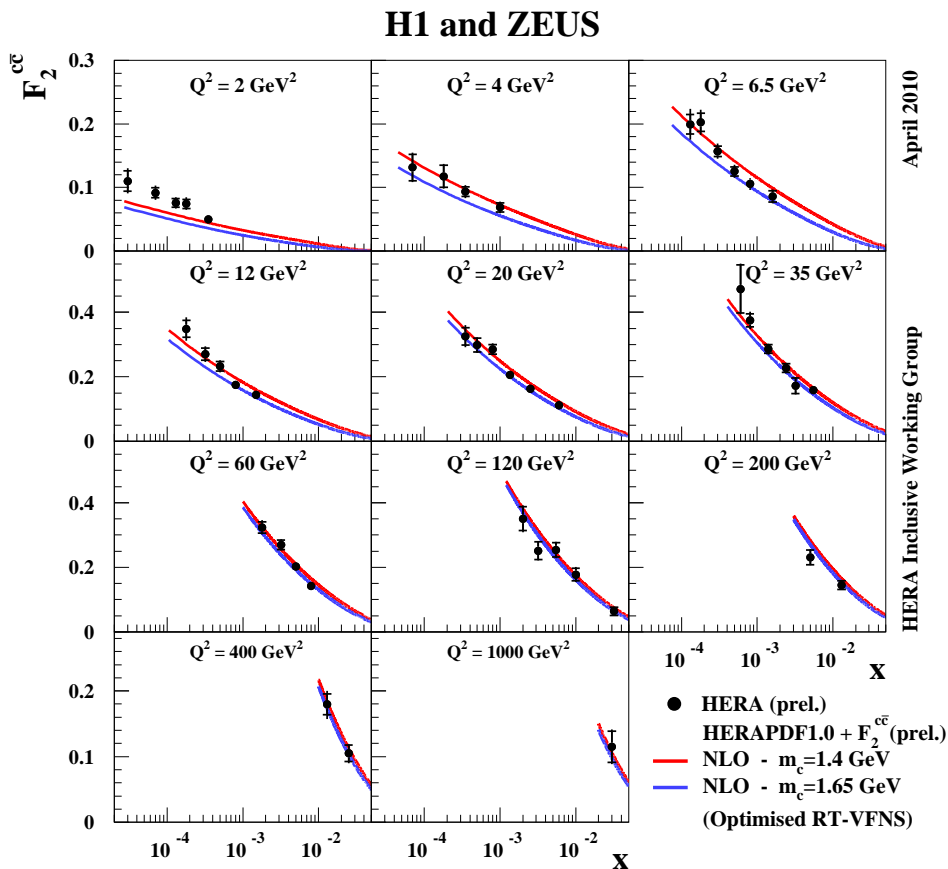
46 combined $F_2^{c\bar{c}}$ points

Theor. unc. correlated between data sets:

- fragmentation function
- fragmentation fractions
- HVQDIS: $\mu_f = \mu_r = \sqrt{Q^2 + m_c^2}$ varied by fact. 2, m_c , PDFs

Procedural unc. on the χ^2 function form

Fits With Different HQ schemes: RT-Optimized, ACOT



RT-optimized: smoother FFNS-VFNS transition (see R. Thorne, DIS 2010)

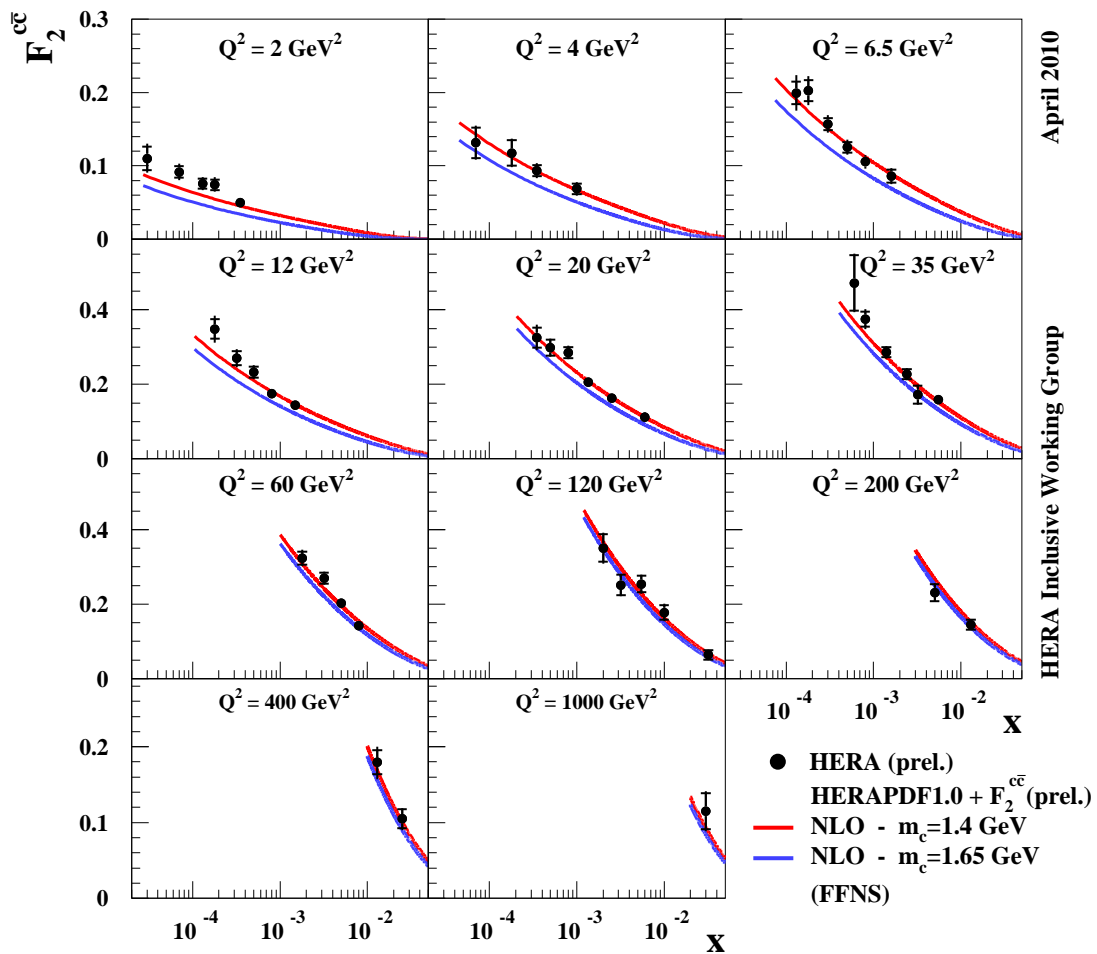
- $m_c = 1.4$ GeV : $\chi_{\text{charm}}^2 = 64/41$
- $m_c = 1.65$ GeV : $\chi_{\text{charm}}^2 = 100/41$

ACOT-full (as used by CTEQ)

- $m_c = 1.4$ GeV: $\chi_{\text{charm}}^2 = 89/41$
- $m_c = 1.65$ GeV: $\chi_{\text{charm}}^2 = 41/41$

HERAPDF1.0 + $F_2^{c\bar{c}}$ FFNS FIT

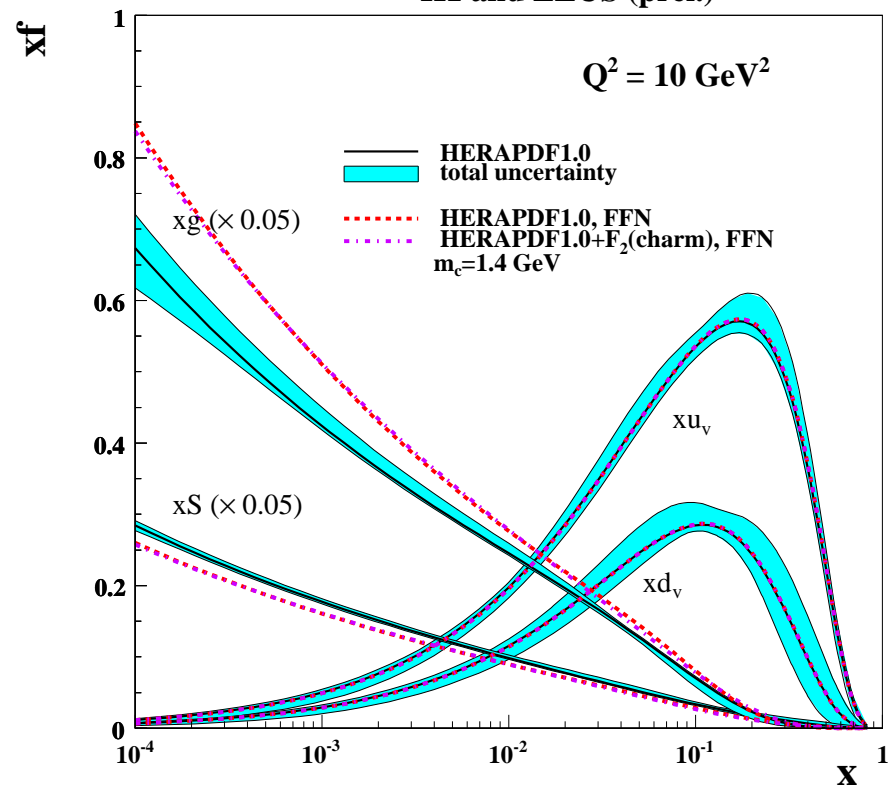
H1 and ZEUS



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H1 and ZEUS (prel.)



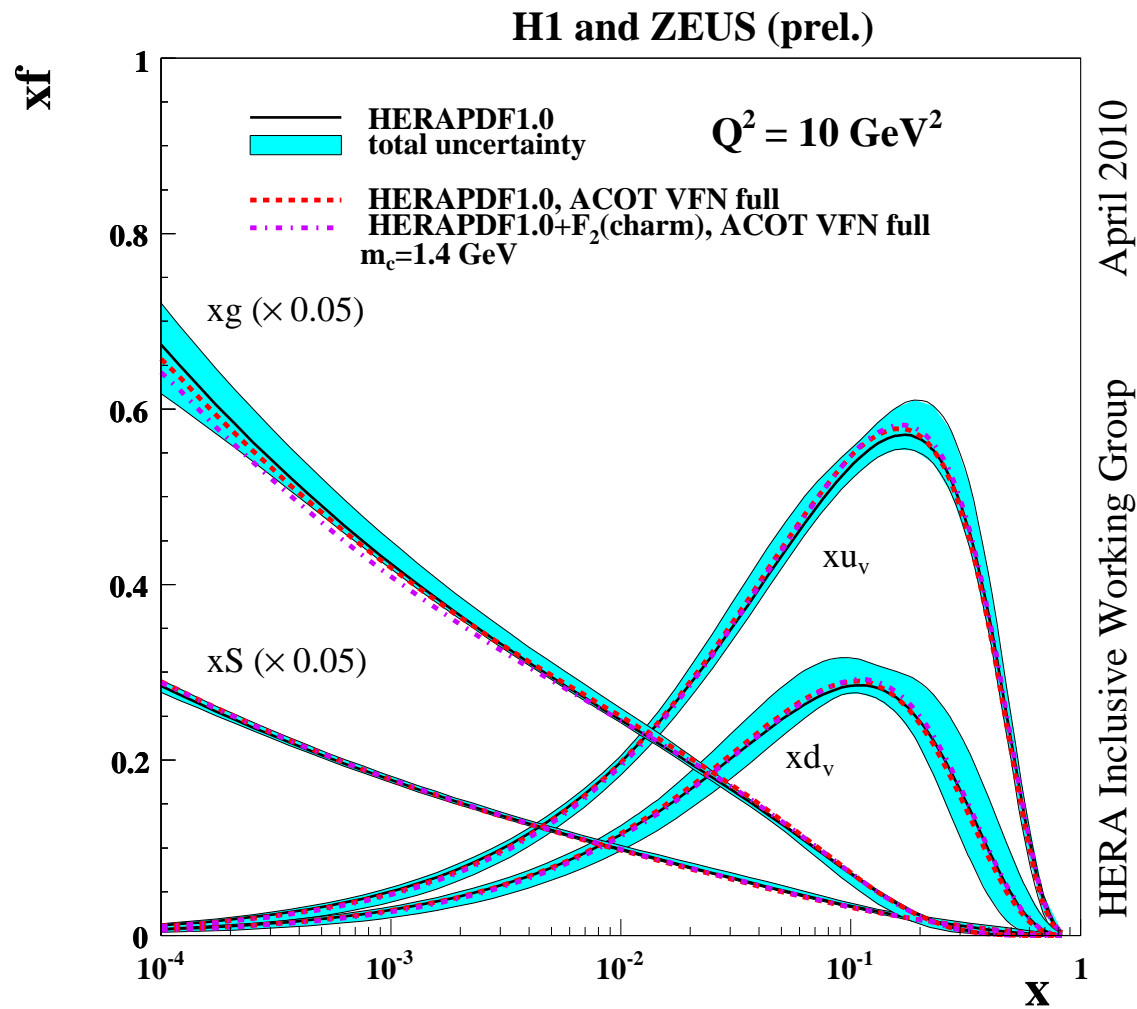
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χ^2 of fits with different HQ schemes:

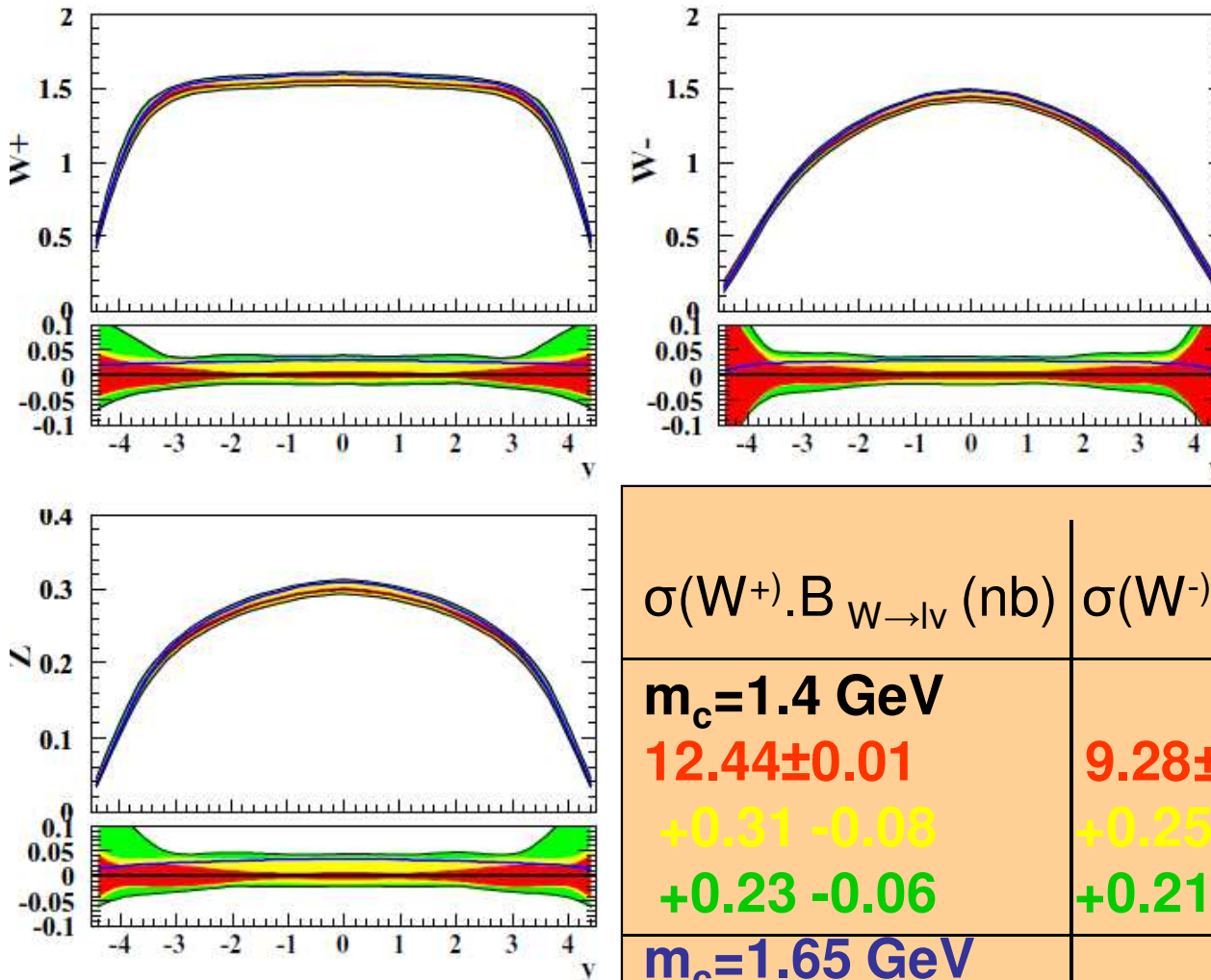
HQ scheme	$m_c = 1.4$ GeV	$m_c = 1.65$ GeV
NLO:		
RT STandard	$\chi_{\text{charm}}^2 = 134/41$	$\chi_{\text{charm}}^2 = 43/41$
RT Optimized	$\chi_{\text{charm}}^2 = 64/41$	$\chi_{\text{charm}}^2 = 100/41$
ACOT	$\chi_{\text{charm}}^2 = 89/41$	$\chi_{\text{charm}}^2 = 41/41$
FFNS	$\chi_{\text{charm}}^2 = 52/41$	$\chi_{\text{charm}}^2 = 249/41$
NNLO:		
RT STandard	$\chi_{\text{charm}}^2 = 54/41$	$\chi_{\text{charm}}^2 = 186/41$

ACOT scheme with/without $F_2^{c\bar{c}}$ data



Thanks to Amanda Cooper Sarkar

W and Z rapidity distributions

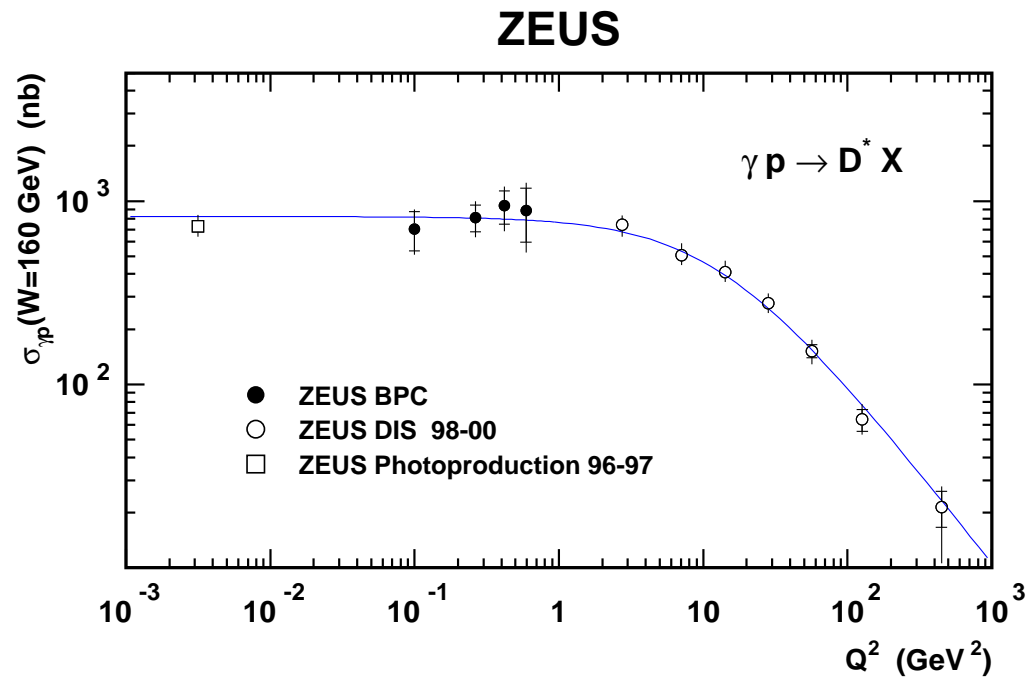


Predictions from HERAPDF1.0 for W^+ W^- and Z rapidity distributions at the LHC 14 TeV ($m_c=1.4\text{GeV}$)

The blue line shows the shift for $m_c=1.65\text{ GeV}$

$\sigma(W^+) \cdot B_{W \rightarrow l\nu}$ (nb)	$\sigma(W^-) \cdot B_{W \rightarrow l\nu}$ (nb)	$\sigma(Z) \cdot B_{Z \rightarrow ll}$ (nb)
$m_c=1.4\text{ GeV}$		
12.44 ± 0.01	9.28 ± 0.05	2.076 ± 0.014
$+0.31 -0.08$	$+0.25 -0.07$	$+0.059 -0.015$
$+0.23 -0.06$	$+0.21 -0.04$	$+0.045 -0.009$
$m_c=1.65\text{ GeV}$		
12.76	9.52	2.13

Charm production from $Q^2 \sim 0$ to 400 GeV^2



$$\sigma(\gamma^* p \rightarrow D^{*\pm} X)$$

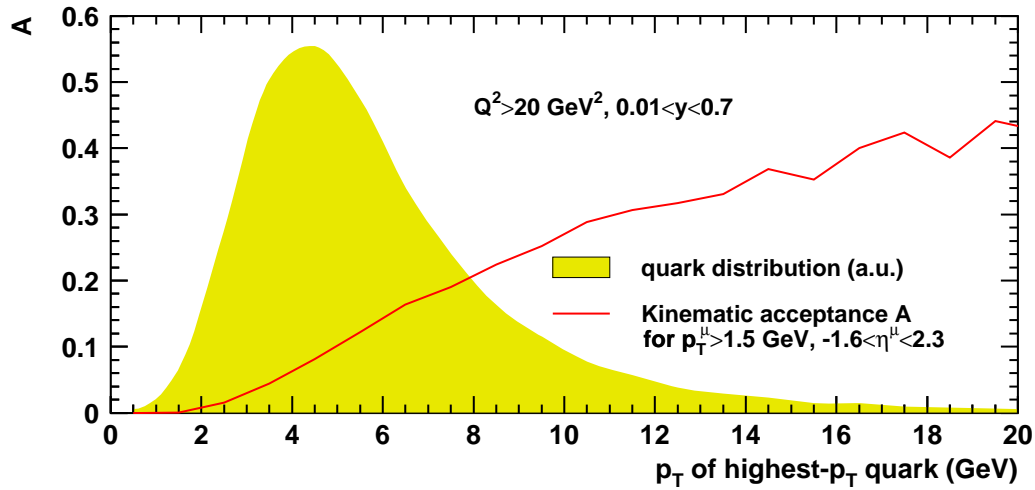
for $p_T(D^*) > 1.5 \text{ GeV}^2$, $|\eta(D^*)| < 1.5$

$$d\sigma(ep \rightarrow D^* X)/dQ^2 \propto 1/Q^2 \text{ for } Q^2 \ll m_c^2$$

$$d\sigma(ep \rightarrow D^* X)/dQ^2 \propto 1/Q^4 \text{ for } Q^2 \gg m_c^2$$

Acceptance of ZEUS muon analysis

Charm NLO



$$A = \frac{N(\mu; p_T > 1.5, -1.6 < \eta < 2.3)}{N(\mu)}$$

versus p_T or y
of the highest- p_T c/\bar{c} quark

