Combined measurement of the charm cross sections and their impact for PDFs at LHC

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on behalf of the H1 and ZEUS Collaborations

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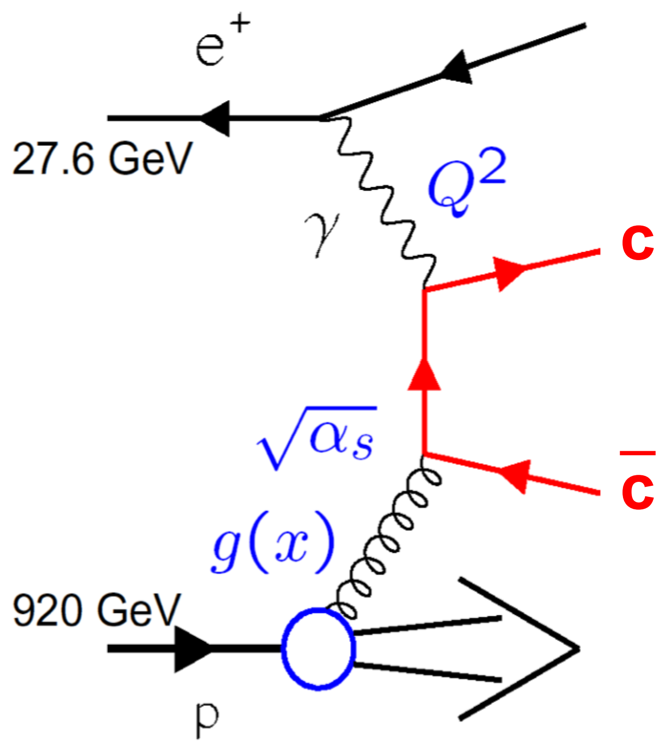
Overview

1.) Combination of $F_2^{c\bar{c}}$ from DIS measurements at HERA
(H1prelim-09-171 / ZEUS-prel-09-015)

2.) QCD analysis using charm data and implications for the LHC
(H1prelim-10-045 / ZEUS-prel-10-009 and H1prelim-10-143 / ZEUS-prel-10-019)

More information: www.desy.de/h1zeus

Introduction



- Dominant process for charm production in DIS (Q^2 > a few GeV^2): Boson-Gluon-Fusion (BGF)

→ Directly sensitive to the gluon density within the proton
→ Test perturbative QCD

- The charm contribution to the inclusive DIS cross section is up to 30%

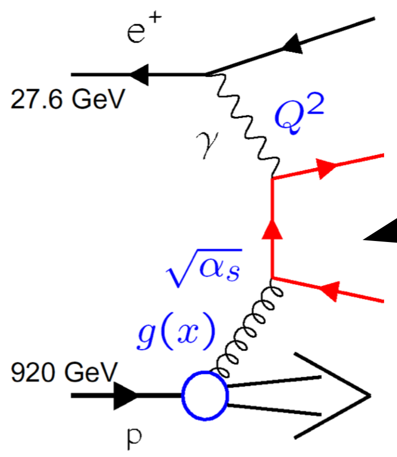
The double differential cross section for the production of open charm can be written as:

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

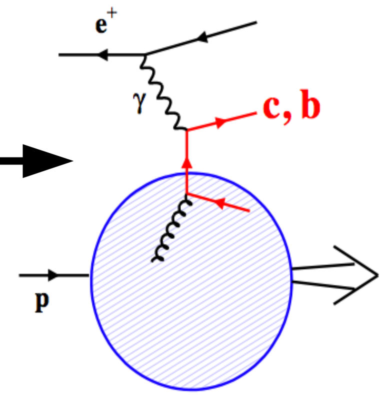
Treatment of charm (and beauty) production in perturbative QCD

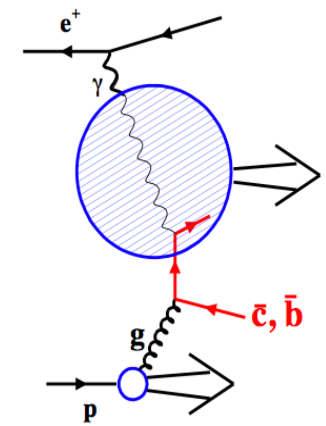
Fixed Flavour Number Scheme, FFNS:
c and b produced dynamically
(not part of proton or photon)
- c, b massive
- Neglects higher order $\log(Q^2/m_{c,b}^2)$ terms
- Valid at threshold

Zero-Mass Variable Flavour Number Scheme, ZM-VFNS:
c and b massless partons in proton and photon
- Valid for $Q^2 \gg m_{c,b}^2$
- Disfavoured by the HERA data



Leading Order (LO)





Variable Flavour Number Scheme, (GM)-VFNS:
Interpolates / matches between both approaches
- Massive at low Q^2, massless at high Q^2
- Different implementations exist

Data sets used in the preliminary H1+ZEUS combination

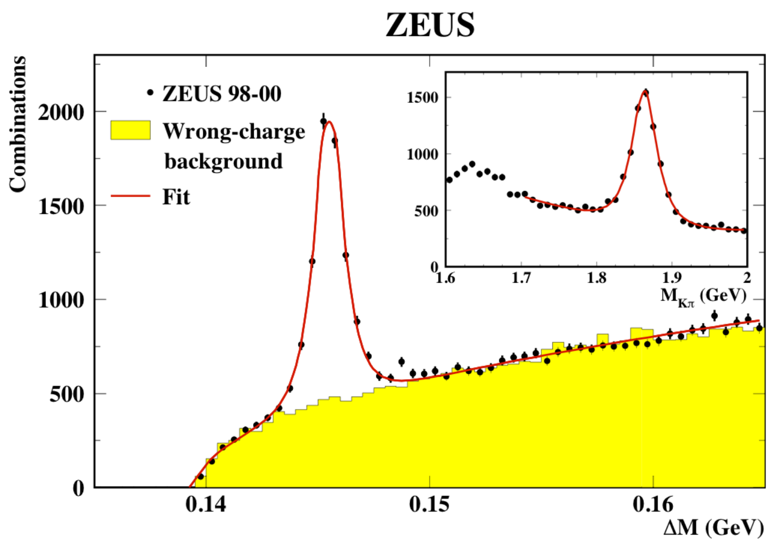
1.) Hadronic D mesons decays:

• ZEUS, D*, HERA I, L = 82+37 pb^{-1}
(Eur. Phys. J. C12, 35, 2000
and Phys. Rev. D69, 012004, 2004)

• H1, D*, HERA I, L = 47 pb^{-1}
(Eur. Phys. J. C50, 251, 2007)

• H1, D*, HERA II prel., L = 340 pb^{-1}
(high-Q^2 part: Phys. Lett. B686, 91, 2010)

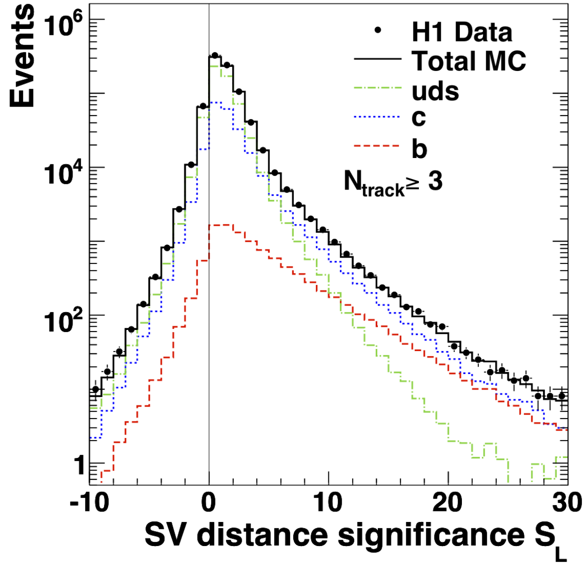
• ZEUS, D^+, D^0, HERA II, L = 134 pb^{-1}
(JHEP 0707, 074, 2007)



2.) Lifetime information:

• H1, HERA I, L = 57 pb^{-1}
(Eur. Phys. J. C40, 349, 2005 and
Eur. Phys. J. C45, 23, 2006)

• H1, HERA II prel., L = 189 pb^{-1}
(now published: Eur. Phys. J. C65, 89, 2010)



3.) Muon + lifetime information:

• ZEUS, HERA II, L = 121 pb^{-1}
(Eur. Phys. J. C65, 65, 2010)

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

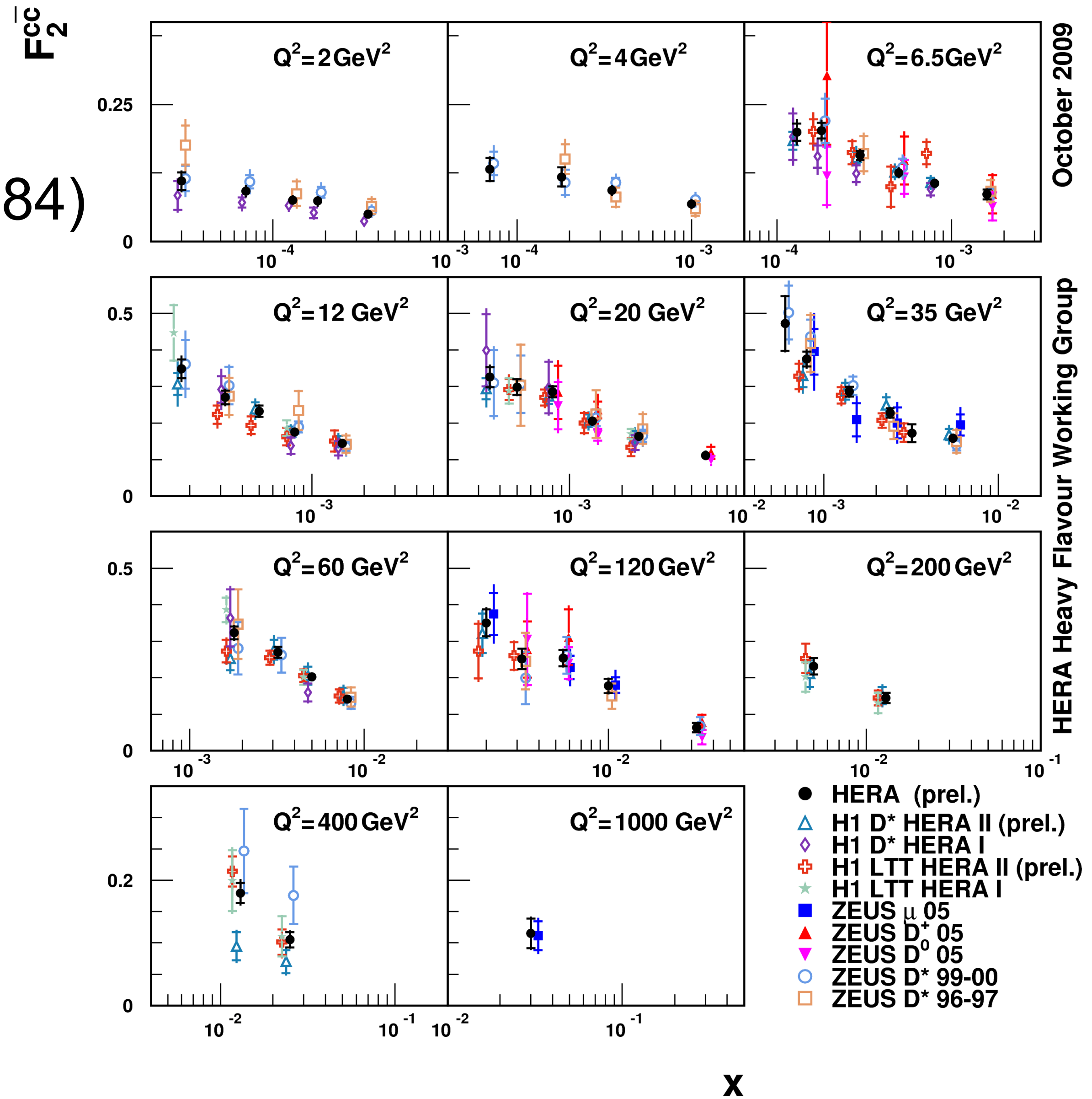
- Method similar to combination of inclusive cross sections (arXiv:0911.0884)

- **Kinematic range:**
2 < Q^2 < 1000 GeV^2 and
$10^{-5} < x < 0.1$

- The data are compatible:
χ^2 / ndof = 88/110

- Precision of the combined result: 5-10%

- $Q^2 \leq 4$ GeV^2:
only HERA I D* data

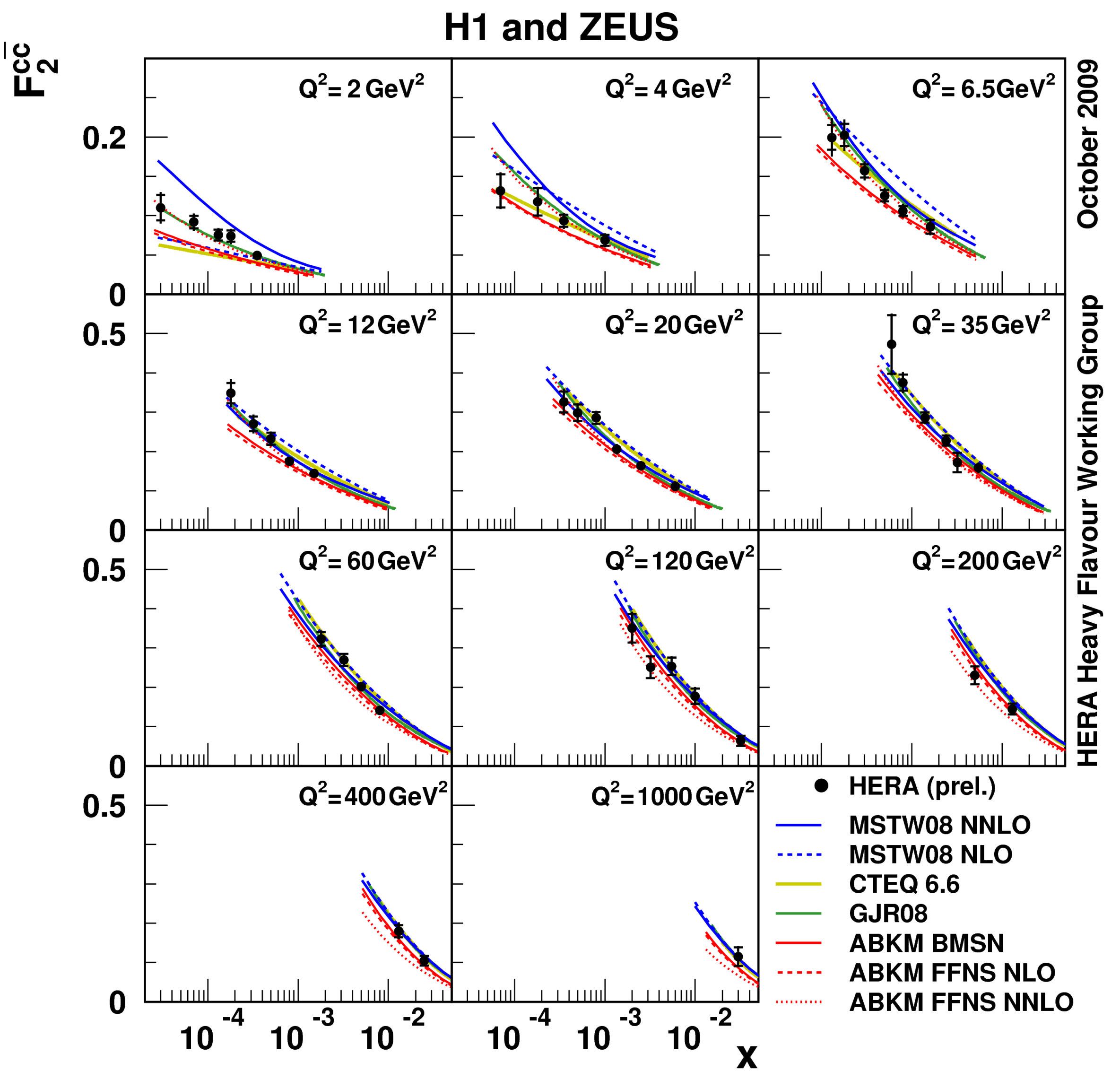


Combined $F_2^{c\bar{c}}$ compared to predictions

FFNS:
GJR08, ABKM FFNS

GM-VFNS:
MSTW08, CTEQ6.6, ABKM BMSN

The uncertainties of the data are smaller than the spread of the theoretical predictions



Combined $F_2^{c\bar{c}}$ compared to HERAPDF1.0

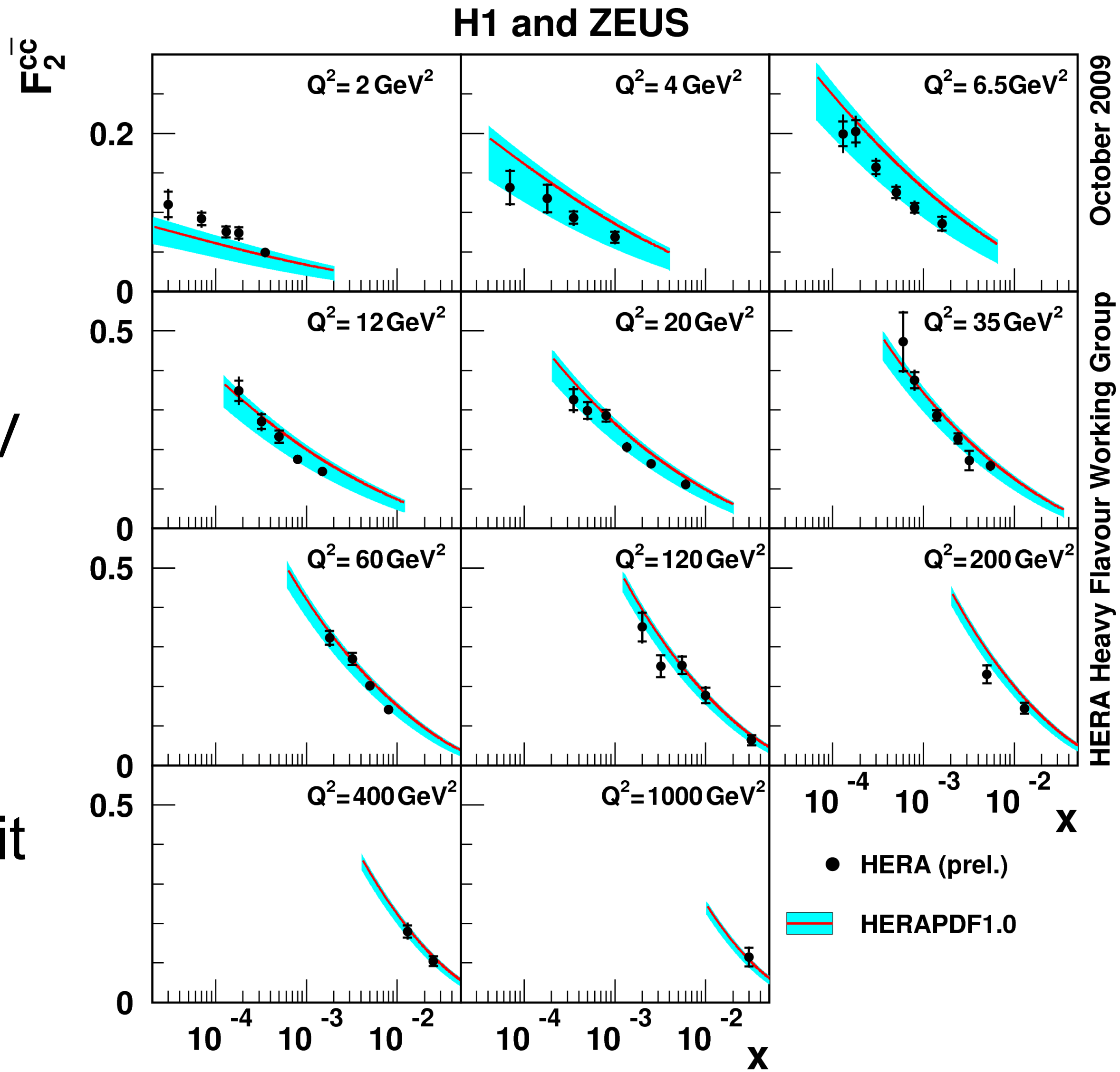
- HERAPDF1.0 fit
to inclusive HERA I data

- Standard RT scheme

- **Charm mass parameter:**
- central curve: m_c = 1.4 GeV
- band: m_c: 1.35 - 1.65 GeV

→ Large dependence of the prediction on m_c

→ Include $F_2^{c\bar{c}}$ data in PDF fit



QCD analysis settings

- NLO QCD fit of published inclusive HERA I data (arXiv:0911.0884) and prel. combined $F_2^{c\bar{c}}$ result

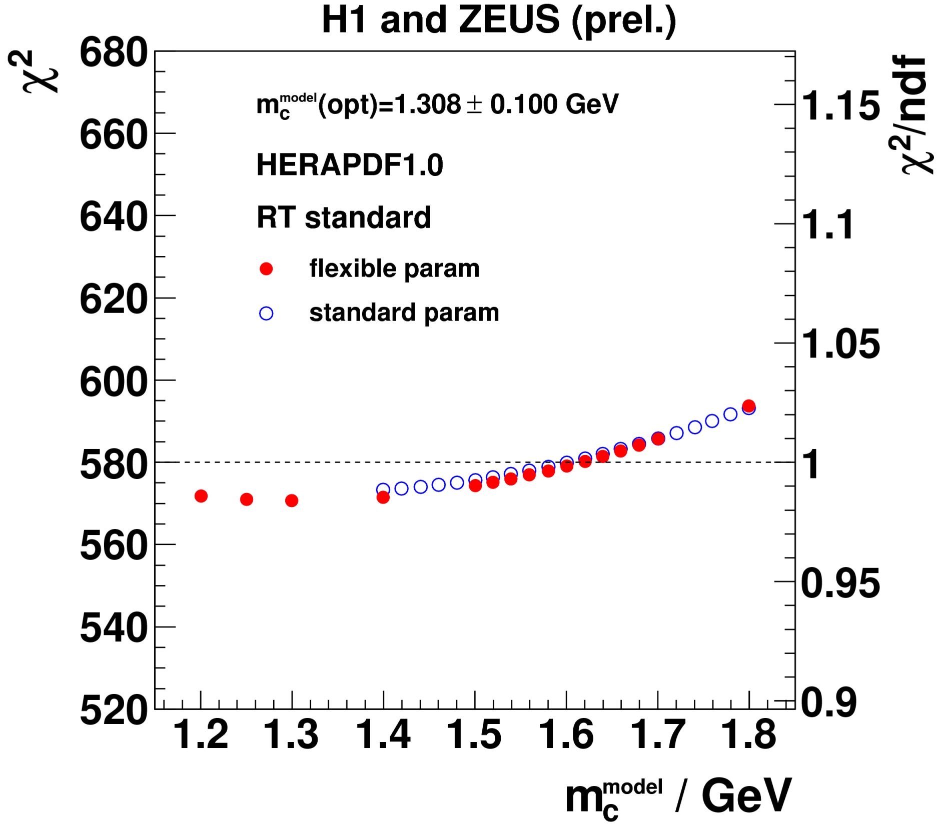
- Settings: $Q^2_{min} = 3.5$ GeV, $\alpha_s(M_Z) = 0.1176$, $\mu_R^2 = \mu_F^2 = Q^2$

- Different heavy flavour schemes:
S-ACOT-χ, ACOT-full, RT, optimised RT (all GM-VFNS) and ZM-VFNS

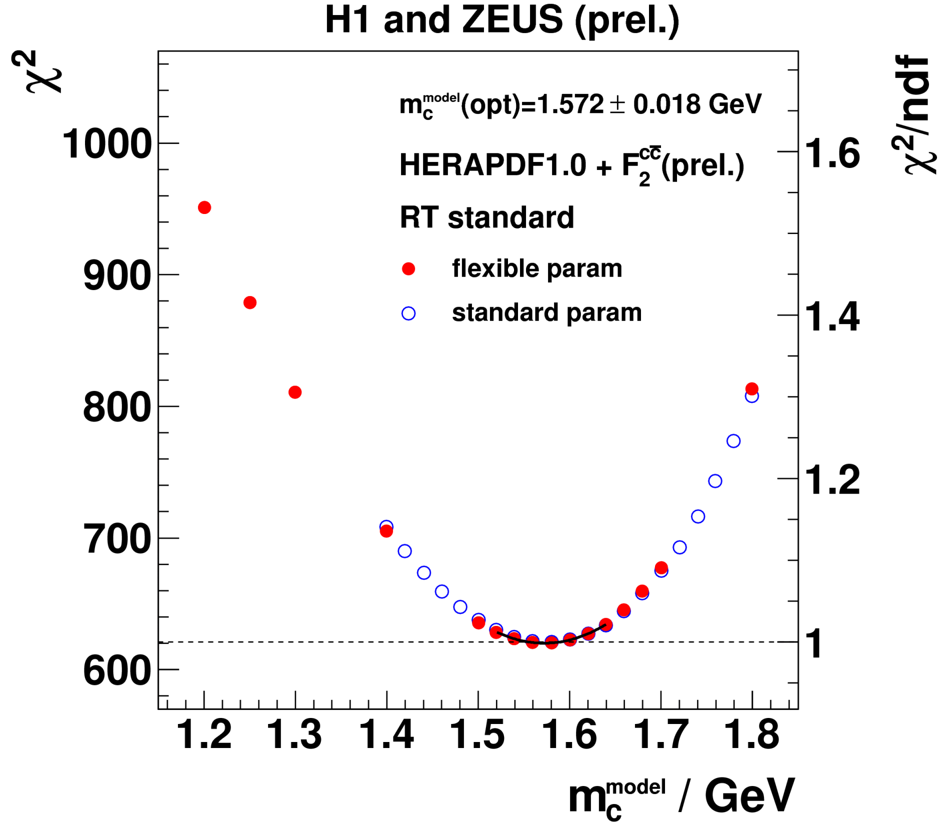
- **PDF parametrisation**:
  - standard: $xf(x) = Ax^B(1-x)^C(1+Ex^2)$, $Q_0^2 = 1.9$ GeV^2,
    $1.4 < m_c^{model} < 1.8$ GeV
  - flexible: $xg(x) = A_g x^{B_g}(1-x)^{C_g} - A'_g x^{B'_g}(1-x)^{25}$, $Q_0^2 = 1.4$ GeV^2,
    allows negative gluon contribution at low x,
    $1.2 < m_c^{model} < 1.8$ GeV

Charm mass parameter scan

Incl. ep data

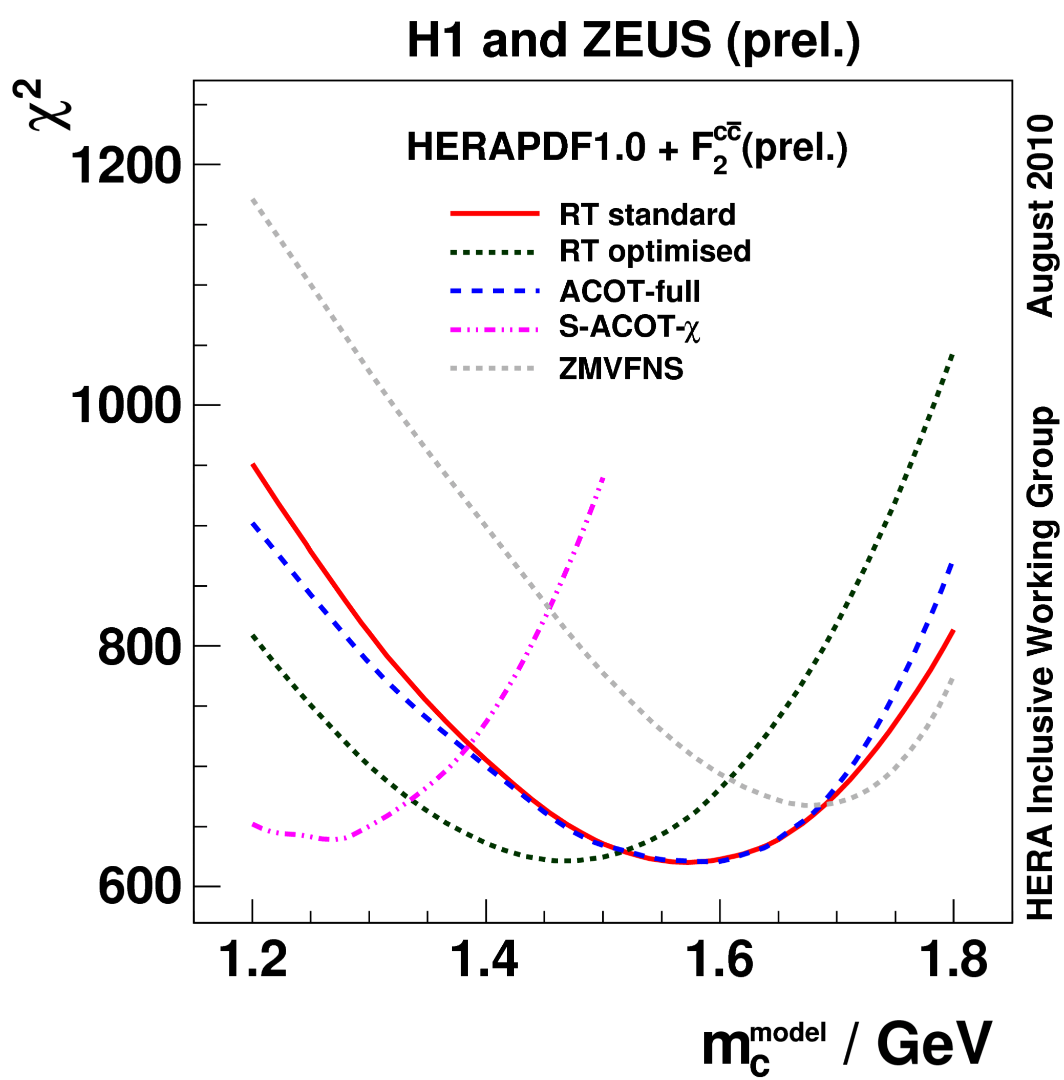


Incl. ep data + $F_2^{c\bar{c}}$



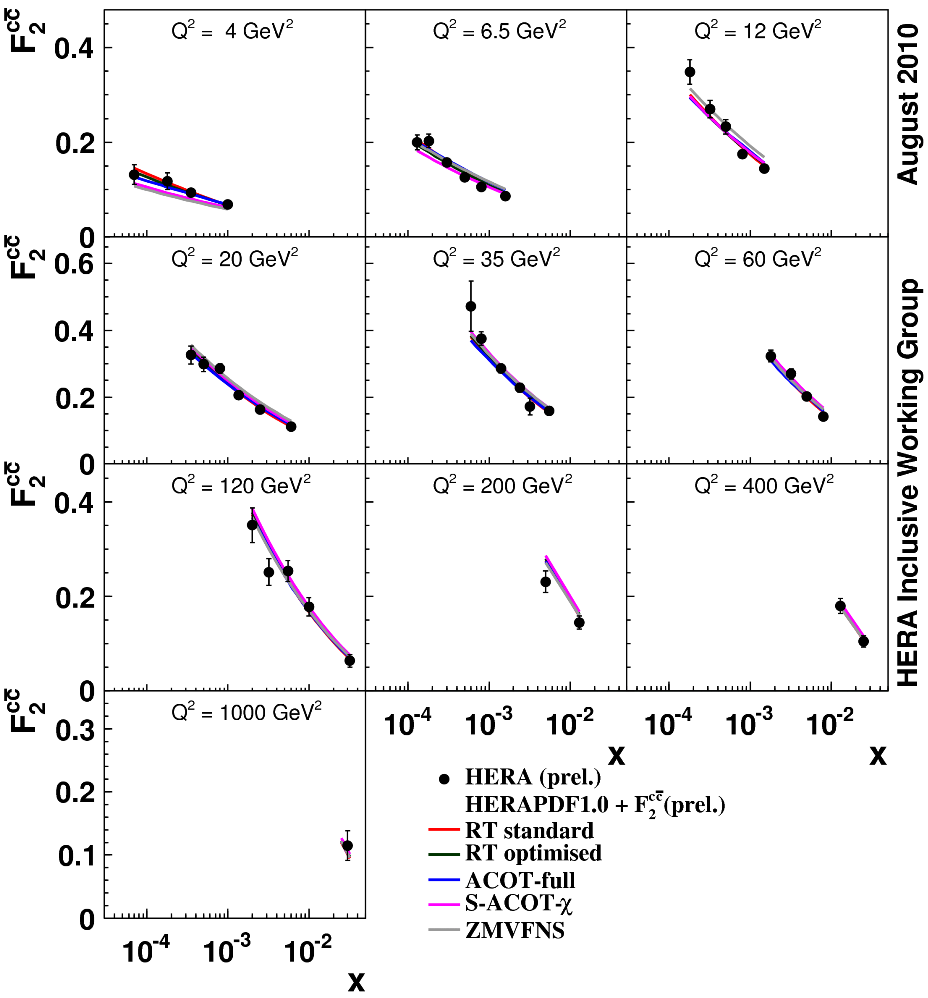
- The charm data allow to constrain m_c^{model}
- Standard and flexible gluon parametrisation very similar

Comparison of different HQ schemes



- Comparable values of χ^2_{min} for all schemes despite different optimal values of m_c^{model}
- The values of χ^2_{min} are almost identical for standard RT, optimised RT and ACOT full
- ZM-VFNS worse by ≈ 50 units

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



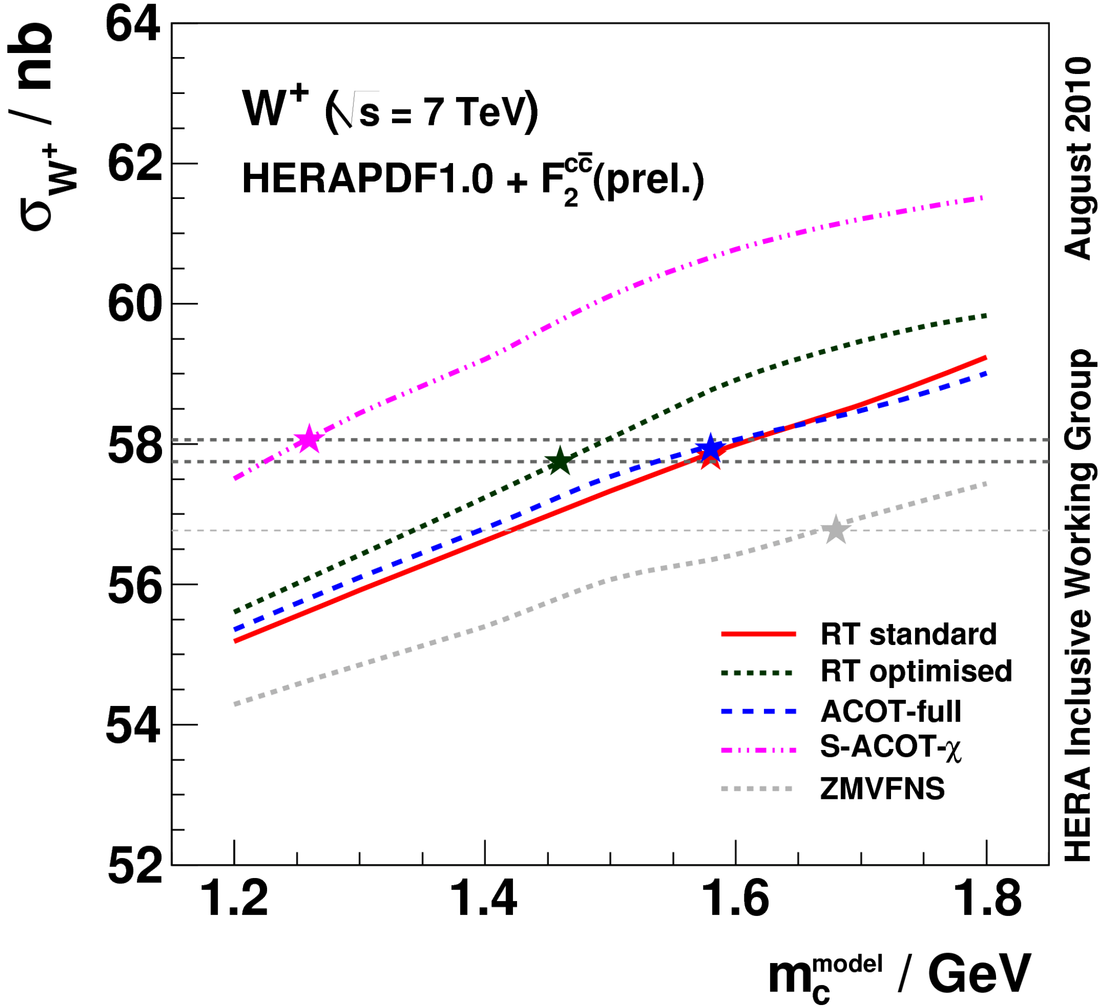
The optimal value of m_c^{model} was used for each scheme:

- All predictions based on the GM-VFNS describe the data well

- The ZM-VFNS fails in the region $Q^2 \leq 12$ GeV^2

Predictions for W^+ cross sections at the LHC

PDFs fitted using different HQ schemes were used to obtain predictions for W^+ production at the LHC:



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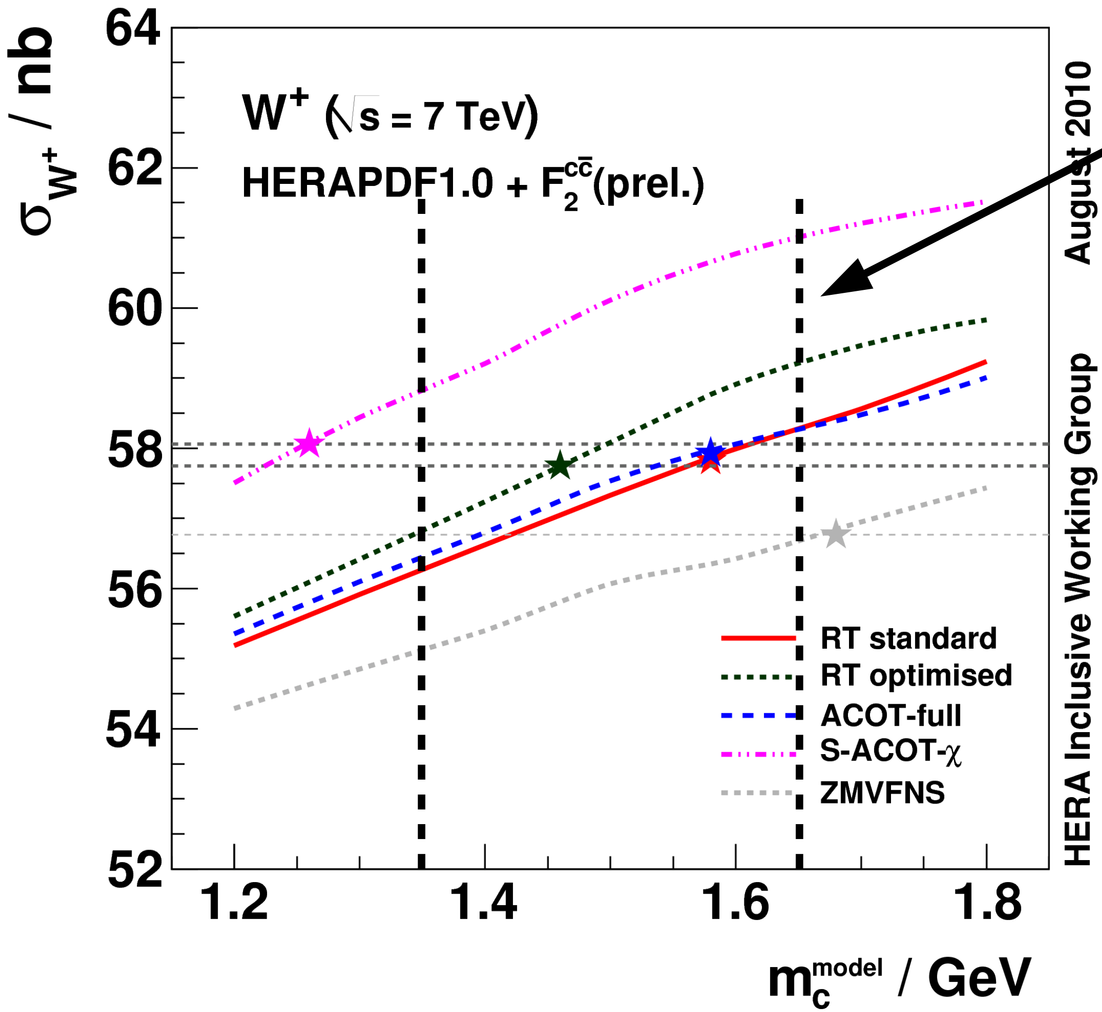

- **Variation of m_c^{model} in PDF fit**

(1.35 - 1.65 GeV):
3% uncertainty within one scheme

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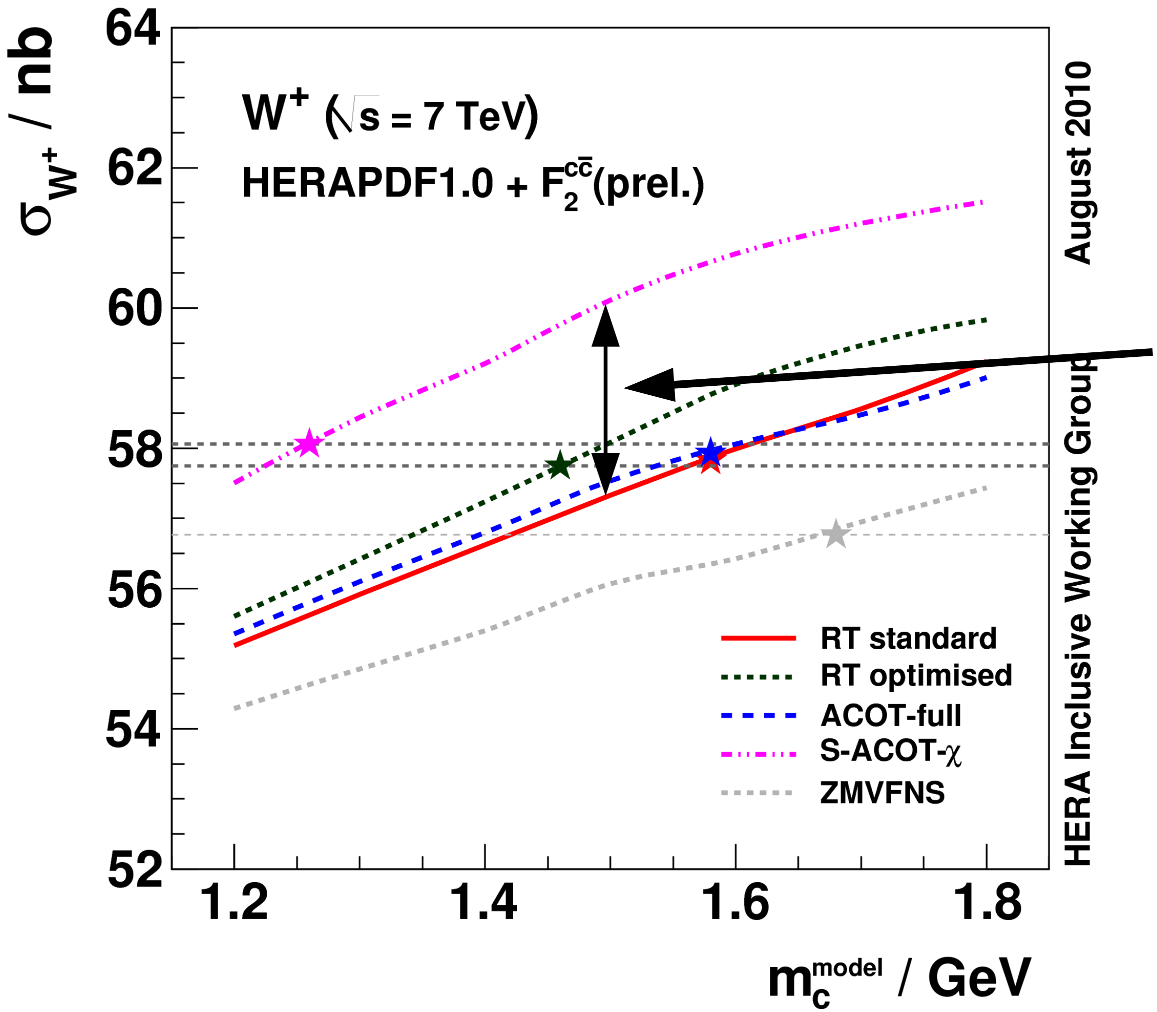

- **Variation of m_c^{model} in PDF fit** (1.35 - 1.65 GeV): 3% uncertainty within one scheme
- **Different HQ schemes:** 5% difference with fixed charm mass

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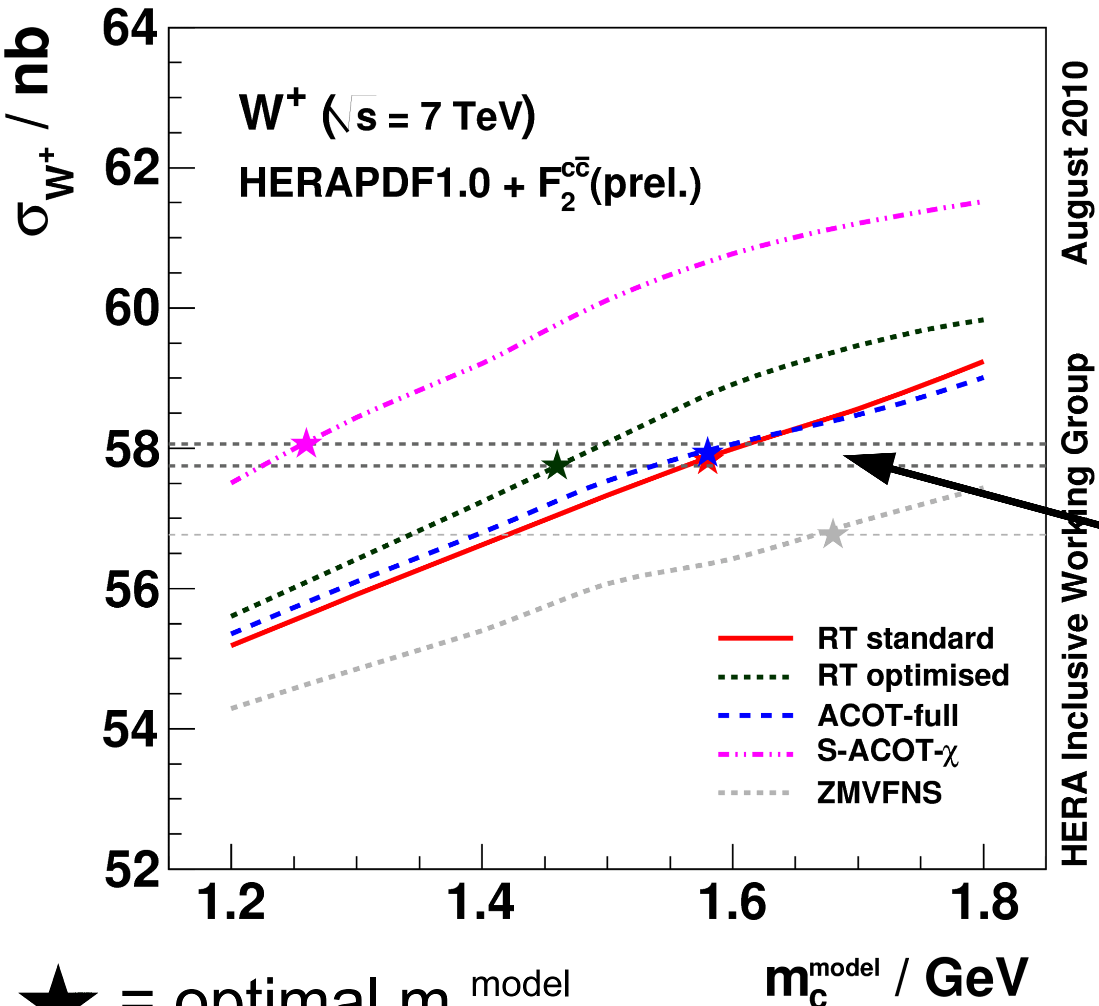


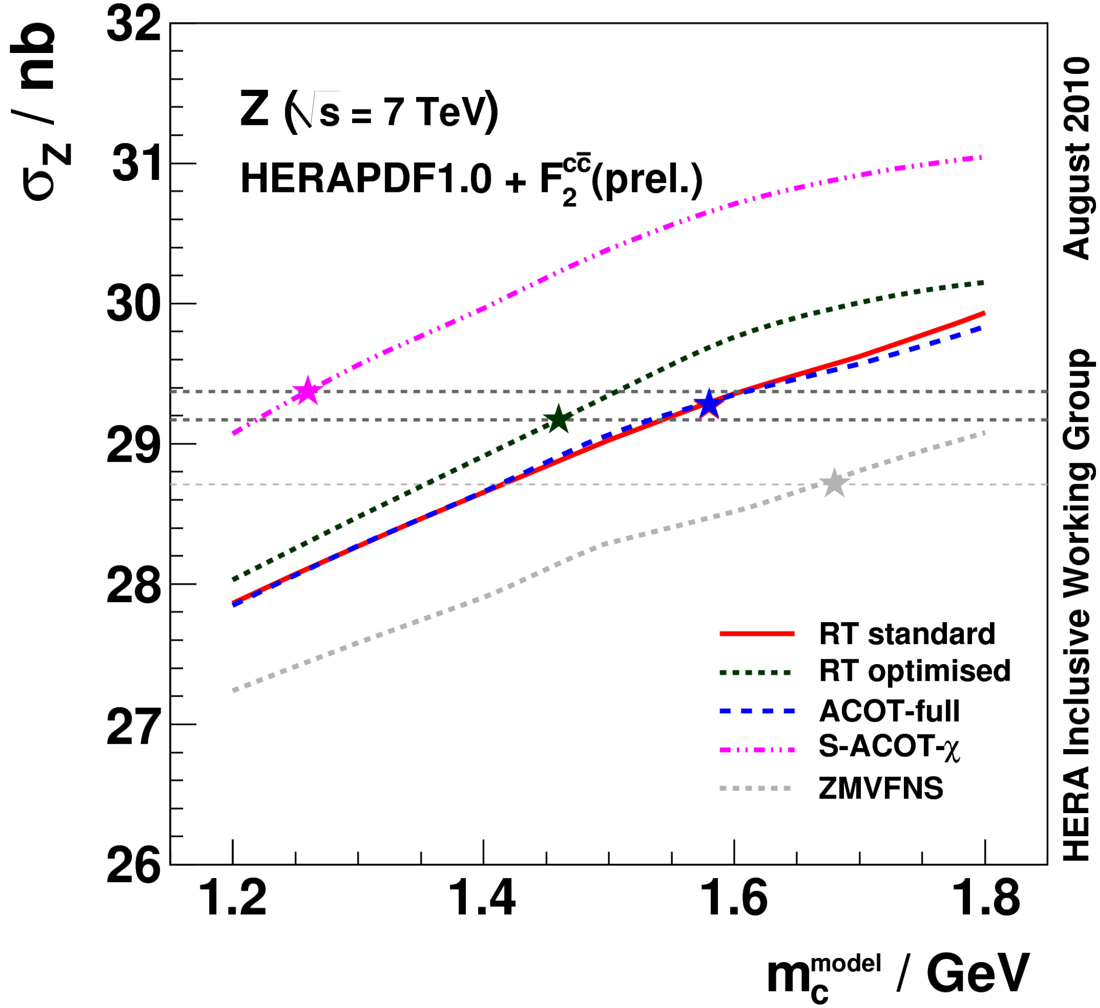
★ = optimal m_c^{model}

- **Variation of m_c^{model} in PDF fit** (1.35 - 1.65 GeV): 3% uncertainty within one scheme
- **Different HQ schemes:** 5% difference with fixed charm mass

Spread of predictions with optimal m_c^{model} for each scheme: < 1%

→ The HERA charm data reduce the uncertainty of the predicted cross sections

Predictions for Z^0 cross sections at the LHC



- **Same conclusion as for W^+ production:**
  Spread of predictions < 1% for optimal m_c^{model}

Summary and conclusions

- Nine independent $F_2^{c\bar{c}}$ measurements from the H1 and ZEUS experiments were combined

  - The precision is 5-10% in a wide kinematic range
  - The combined data are more precise than the spread between different predictions

- An NLO QCD analysis was performed using inclusive and $F_2^{c\bar{c}}$ data

  - Different optimal values for the charm mass parameter were obtained for different HQ schemes
  - The HERA charm data reduce the uncertainty due to the heavy flavour treatment (one of the dominant contributions) of predictions for $W^{\pm}$ and Z^0 production cross sections at the LHC

Backup slides

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

• D mesons (or muons from charmed hadron decays) measured in a "visible" phase space, typically $|\eta(D^*)| < 1.5$, $p_T(D^*) > 1.5$ GeV

→ Extrapolation needed:

Theory:
HVQDIS, CASCADE

$$F_{2,meas}^{c\bar{c}} = \frac{\sigma_{meas,i}}{\sigma_{theo,i}} \cdot F_{2,theo}^{c\bar{c}}(x_i, Q_i^2)$$

Uncertainties: Charm quark mass, renormalisation and factorisation scales and fragmentation model

• Similar for lifetime tagging: mostly sensitive to events with several central tracks with high transverse momentum

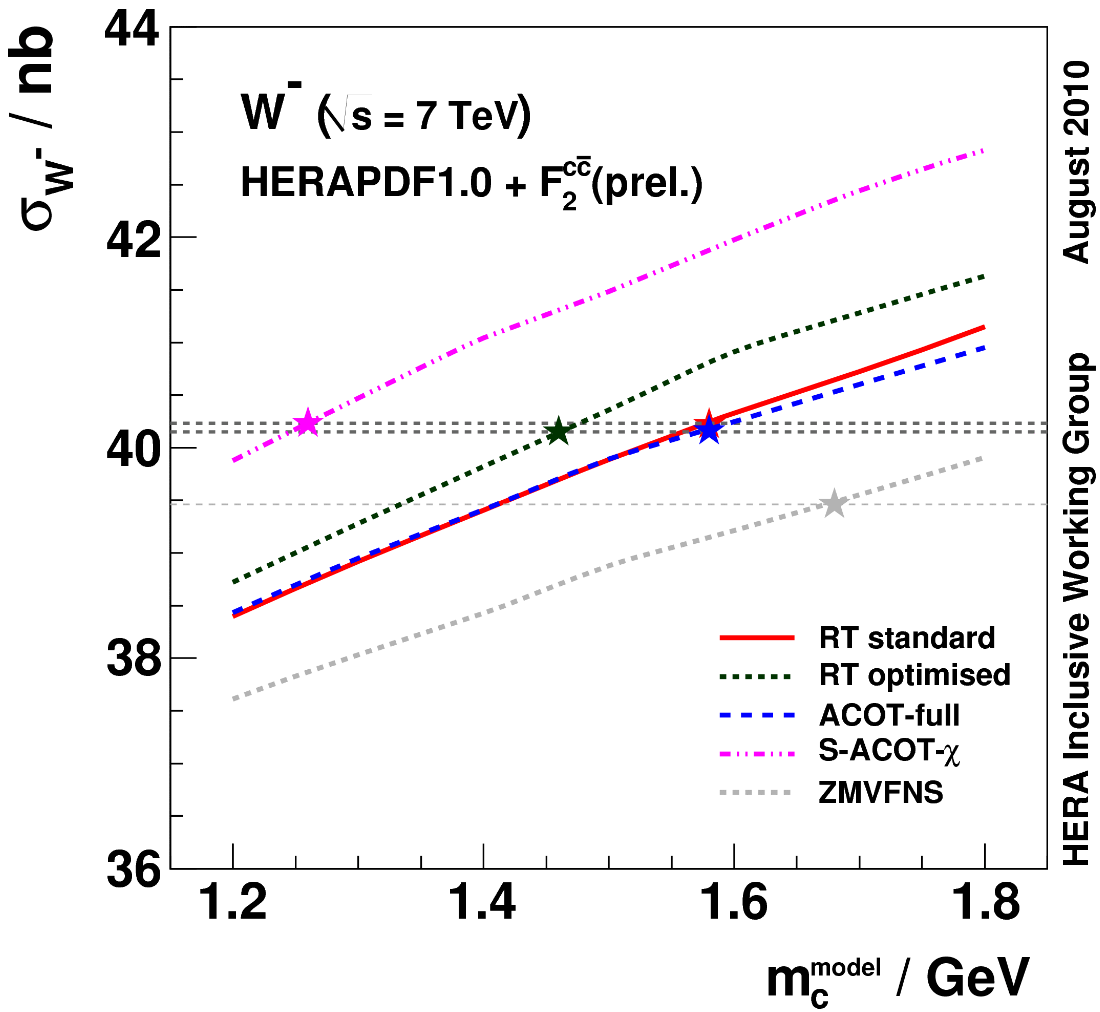
• The measurements were swum to common (x,Q^2) points using FFNS NLO

Combination procedure

$$\chi^2(\boldsymbol{m}, \boldsymbol{b}) = \sum_i \frac{\left(m^i - \sum_j \gamma^i_j m^i b_j - \mu^i\right)^2}{\left(\delta_{i,\mathrm{stat}}\,\mu^i\right)^2 + \left(\delta_{i,\mathrm{uncor}}\,m^i\right)^2} + \sum_j b_j^2$$

μ^i: measured value at point I
δ^i: statistical, uncorrelated systematic error
γ^i_j: correlated systematic error
b_j: shift of correlated systematic error sources
m^i: true value (corresponds to min. χ^2)

Predictions for W^- cross sections at the LHC



- Same conclusion as for W^- production