Charm and beauty structure functions and heavy-quark masses at HERA.

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on behalf of the H1 & ZEUS collaborations

ICHEP2014, Valencia

4/07/2014

HELMHOLTZ GEMEINSCHAFT

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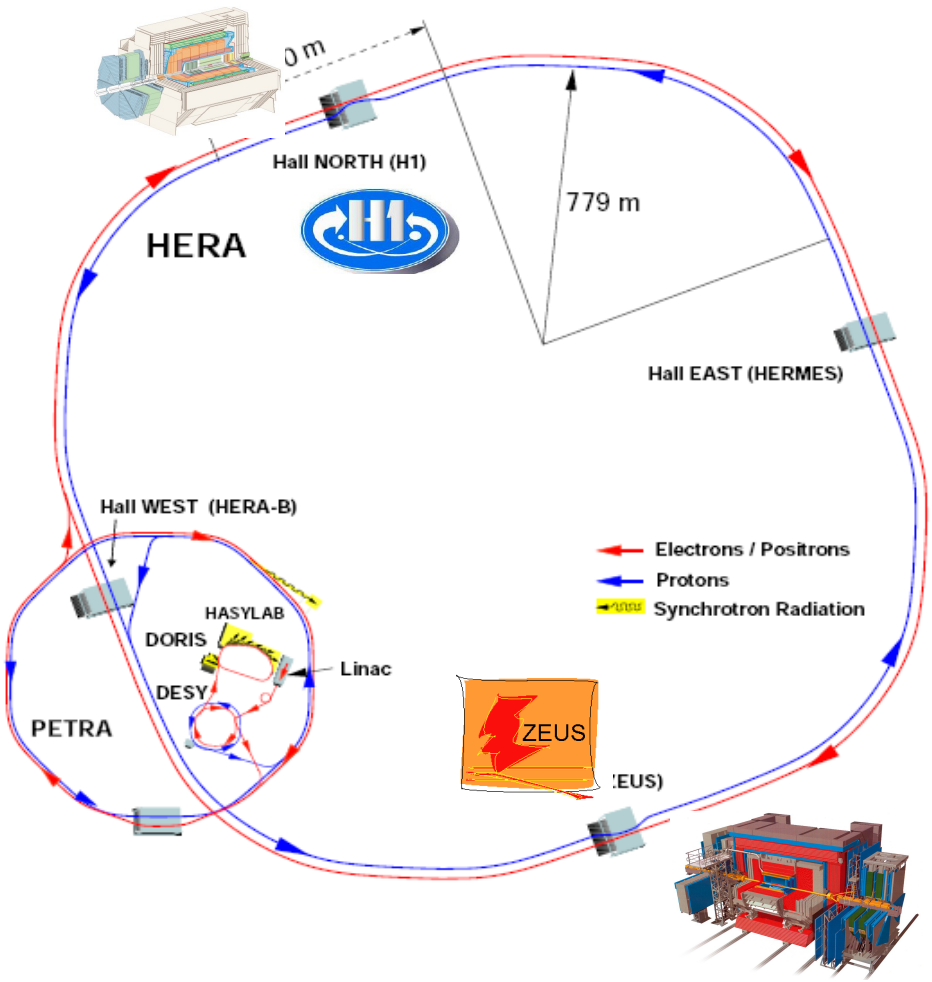
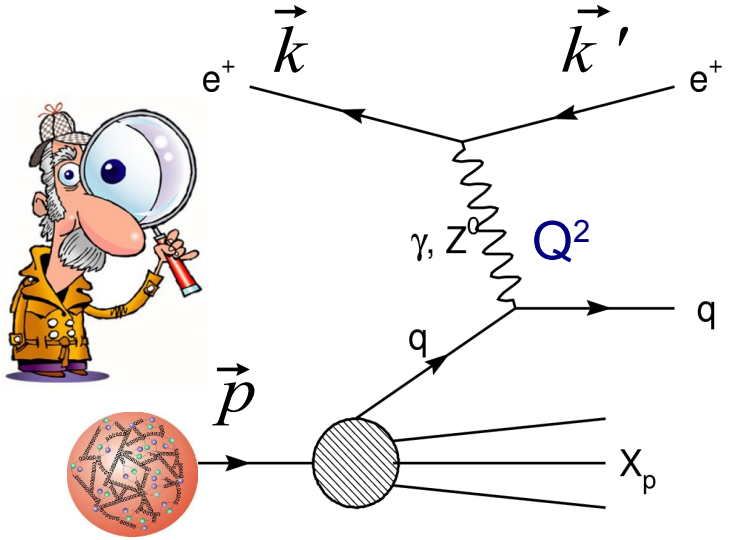
DIS at HERA.





Photon virtuality:

$$Q^2 = -q^2 = -(k - k')^2$$

Inelasticity: $y = \frac{q \cdot p}{k \cdot p}$

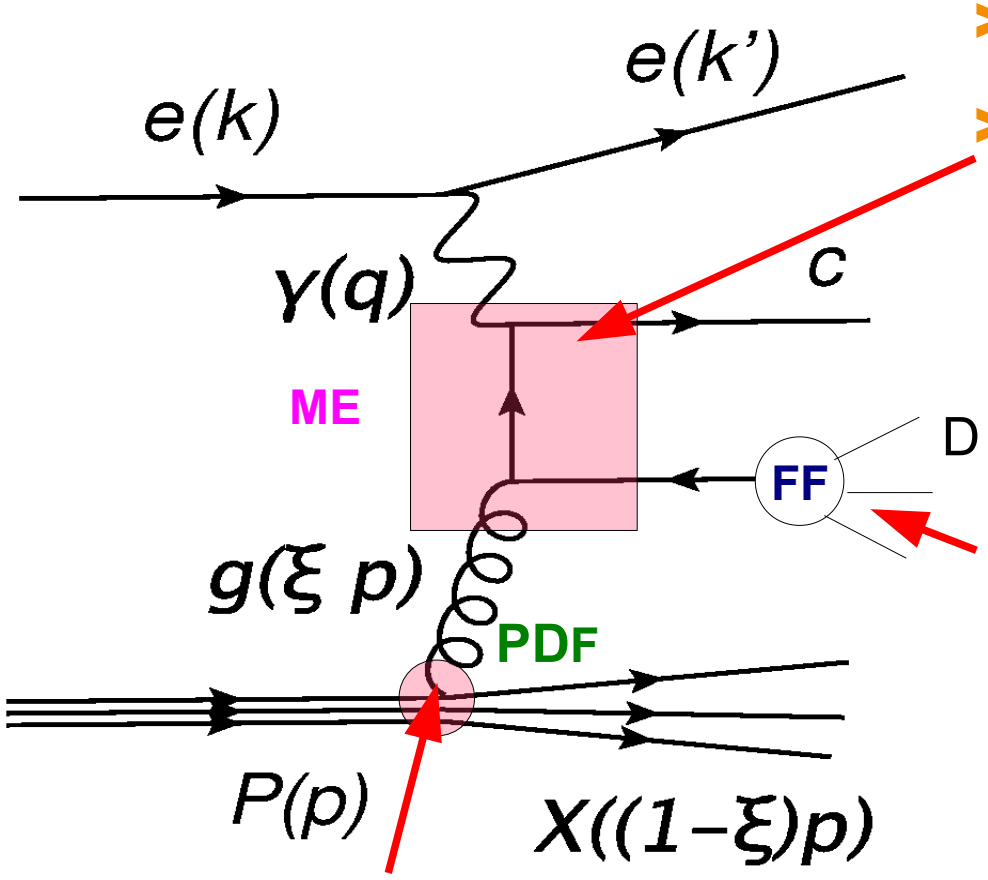
Deep Inelastic Scattering (DIS): $Q^2 > 1\ GeV^2$

$E_p = 920\,GeV$ $E_e = 27.5\,GeV$

$\sqrt{s} = 318\,GeV$

L~2x0.5 fb^{-1}

Introduction to HQ production @ HERA.



- Important test of QCD
- Multiple scales (Q^2, $m_{c,b}$, $p_T(c,b)$): a challenge for pQCD. Massive/fixed-order pQCD calculations: heavy flavours are produced perturbatively
- Fragmentation model c,b → D,B
- Direct probe of the gluon in the proton: predominantly boson-gluon fusion.

$$\sigma^{HQ} = \mathrm{PDF} \otimes \mathrm{ME} \otimes \mathrm{FF}$$

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Heavy-quark production schemes.

Massive scheme (FFNS):

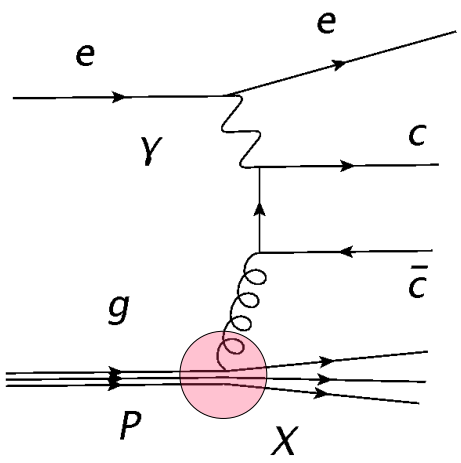
- c,b quarks are massive;
- valid for $Q^2 \sim M^2_{c,b}$;

➔ HQ produced perturbatively

Massless scheme (ZM-VFNS):

- c,b mass neglected;
- valid for $Q^2 \gg M^2_{c,b}$;

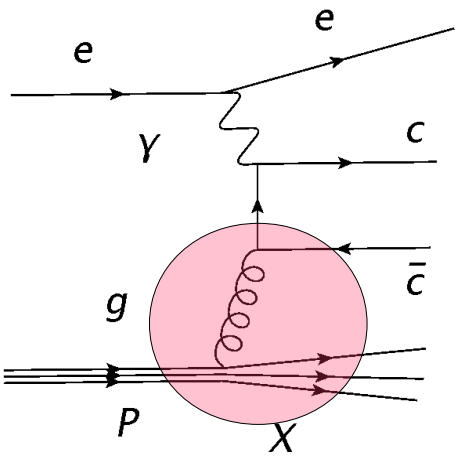
➔ HQ present in proton



Variable FNS (GM-VFNS):

- equivalent to massive at small Q^2;
- equivalent to massless at high Q^2;

➔ HQ present in proton starting from a certain scale



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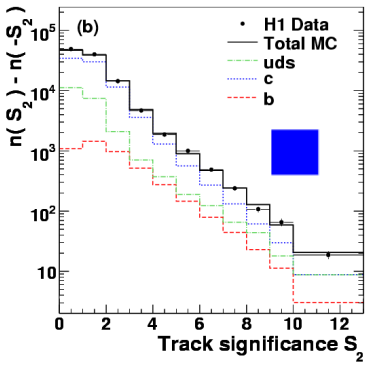
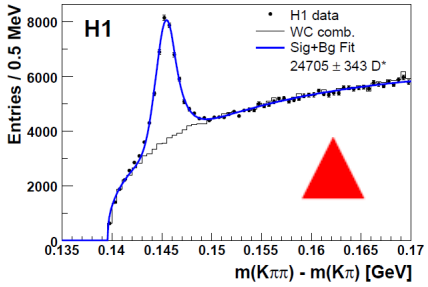
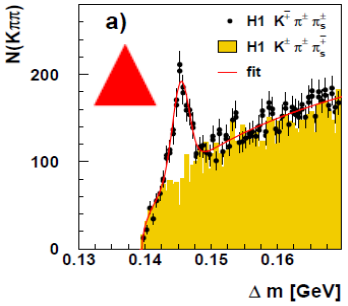
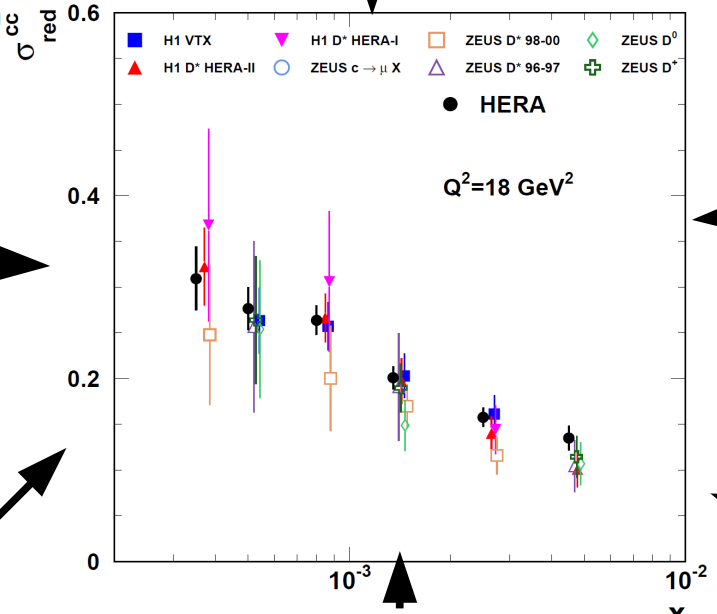
Charm combination.

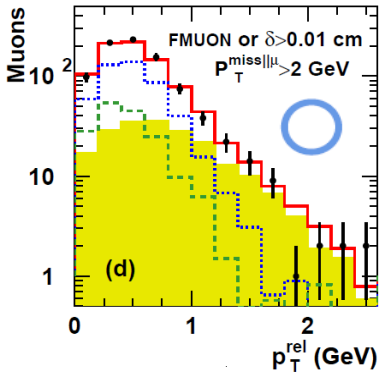
EPJ C73 (2013) 2311

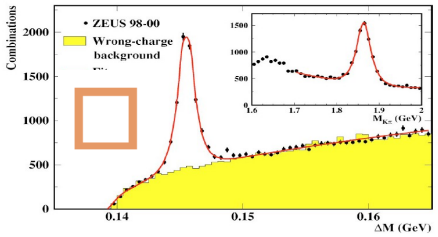


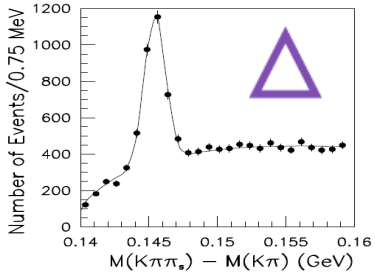


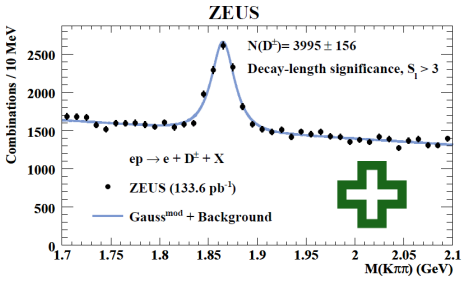


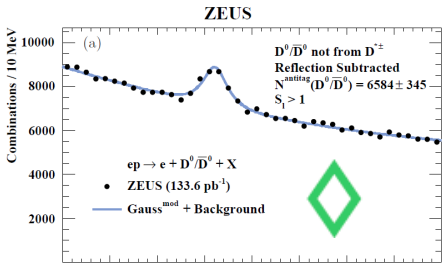










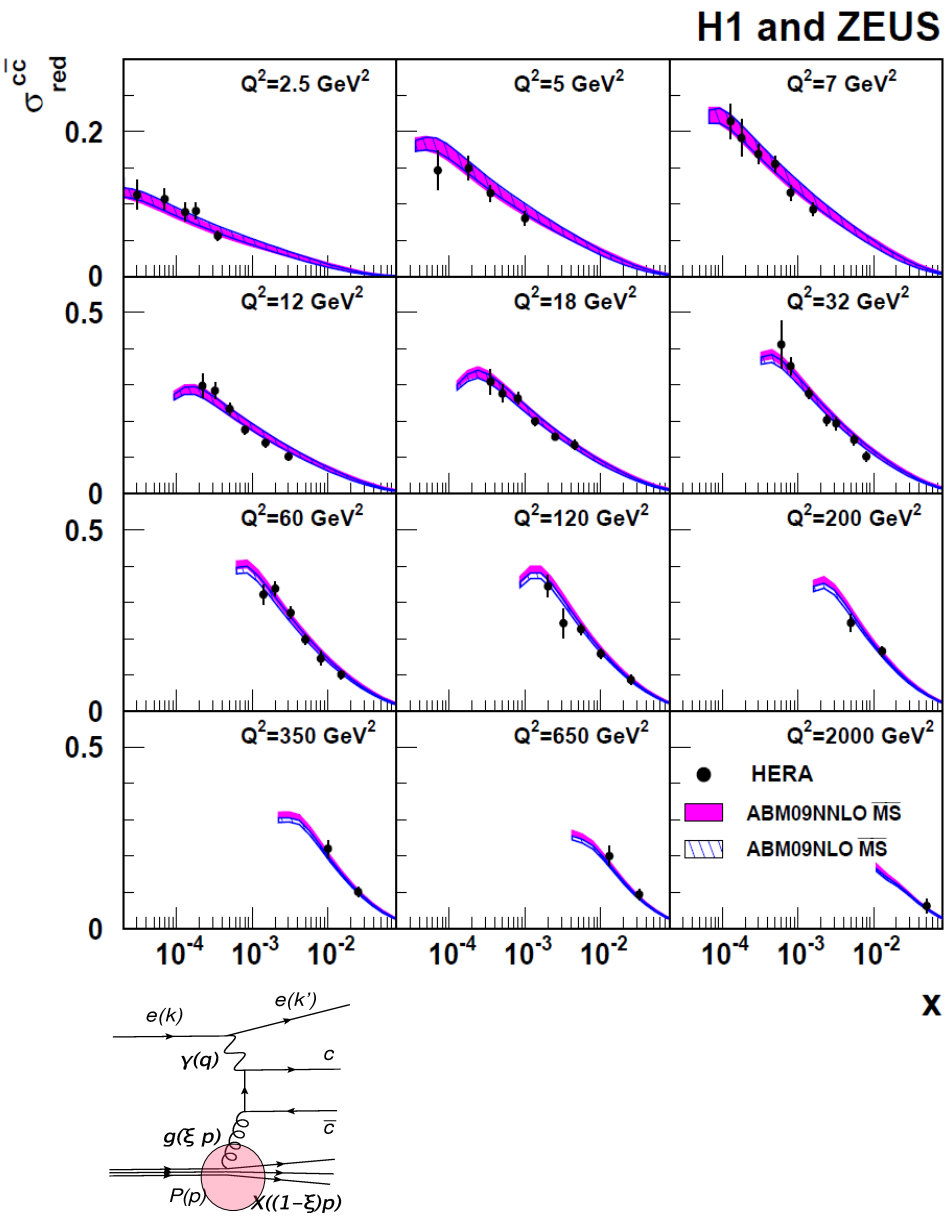


- 55 data points -> 52 combined points.
- χ^2/ndf=62/103.

DESY

Charm combination.

EPJ C73 (2013) 2311



- Extrapolation to the full phase space + related theory uncertainty (see M. Sauter's talk for D^* combination in fiducial region)
- Charm reduced cross sections:

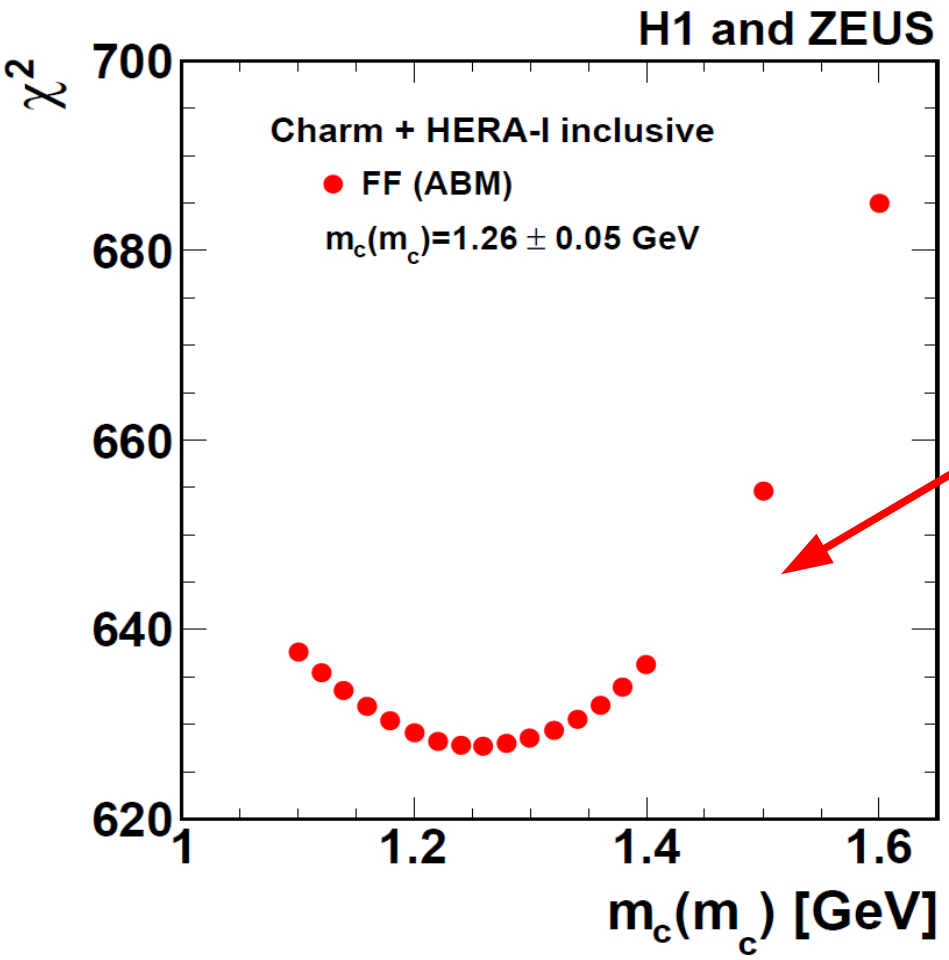
$$\frac{d\sigma^{c\bar{c}}}{dxdQ^2} = \frac{2\pi\alpha^2}{xQ^4}\cdot[1+(1-y)^2]\cdot\sigma_{red}^{c\bar{c}}$$

- Well described by NLO and NNLO massive ABM09 predictions.
- Uncertainty at low Q^2 is dominated by charm mass variation .

DESY

Extraction of $\overline{\text{MS}}$ charm mass.

EPJ C73 (2013) 2311



- Simultaneous analysis of the combined charm and inclusive DIS HERA I data.
- Mass scan.

$$m_c(m_c) = 1.26 \pm 0.05_{\text{exp}} \pm 0.03_{\text{mod}} \pm 0.02_{\text{param}} \pm 0.02_{\alpha_s} \text{ GeV}$$

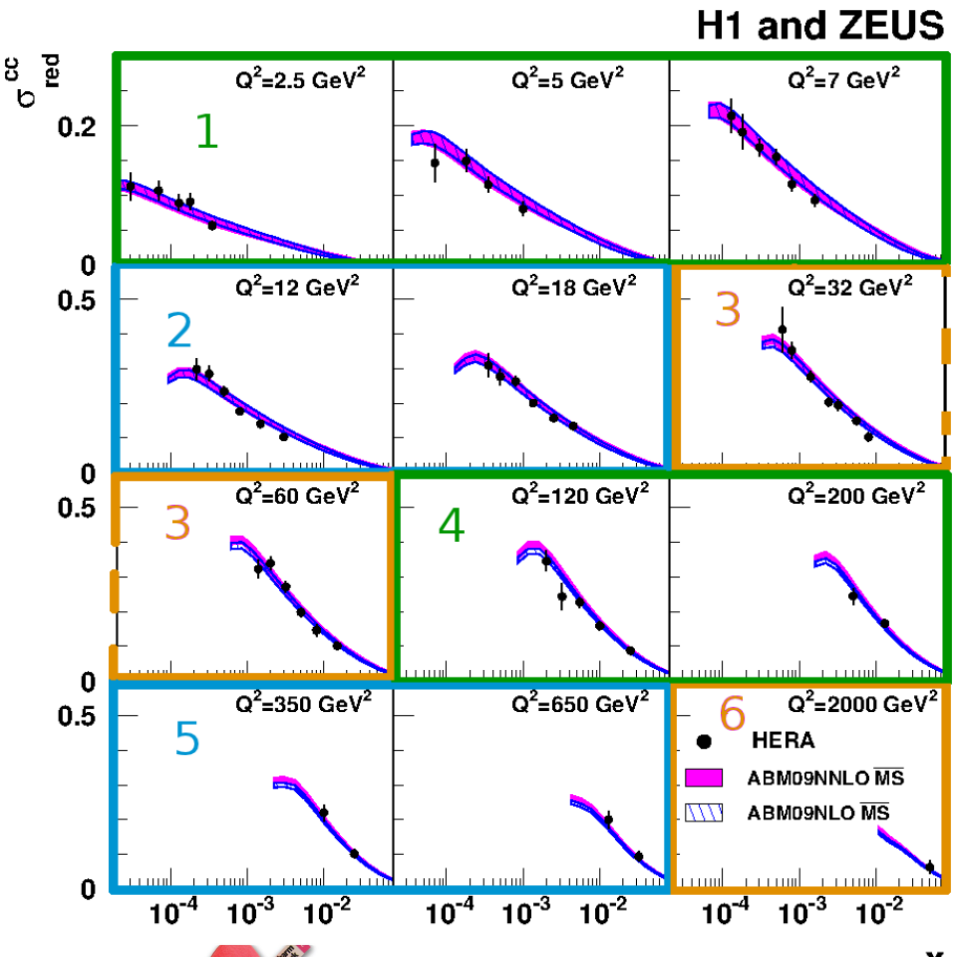
PDG 2012 : $m_c(m_c)$ = 1.275 ± 0.025 GeV

(lattice QCD & time-like processes)

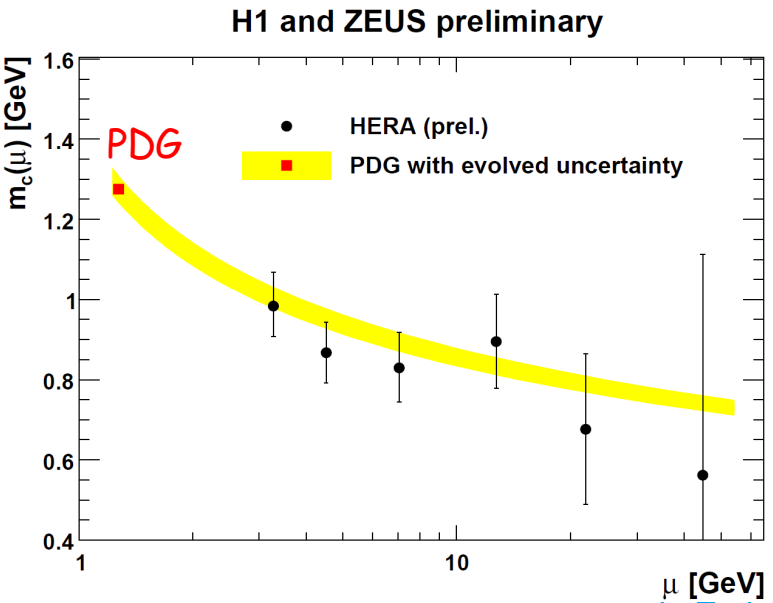
DESY

$\overline{\text{MS}}$ charm mass running.

H1-prelim-14-071, ZEUS-prel-14-006, +S.Moch



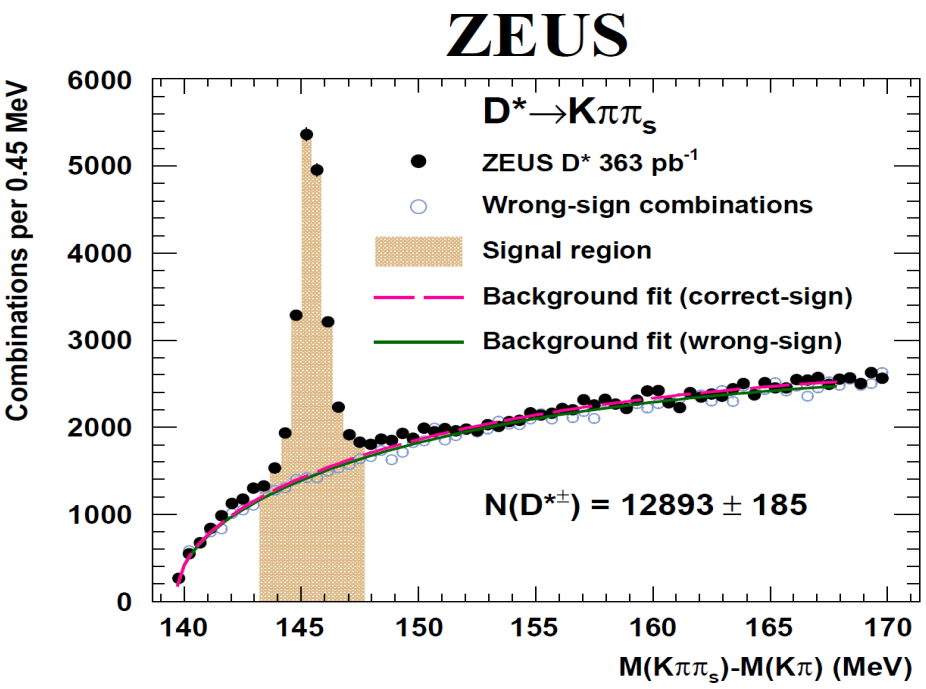
- Extract $m_c(m_c)$ in separate kinematic regions
- Translate back to $m_c(\mu)$ ($\mu^2=Q^2+4m_c^2$) using OpenQCDrad.
- Important QCD consistency check.

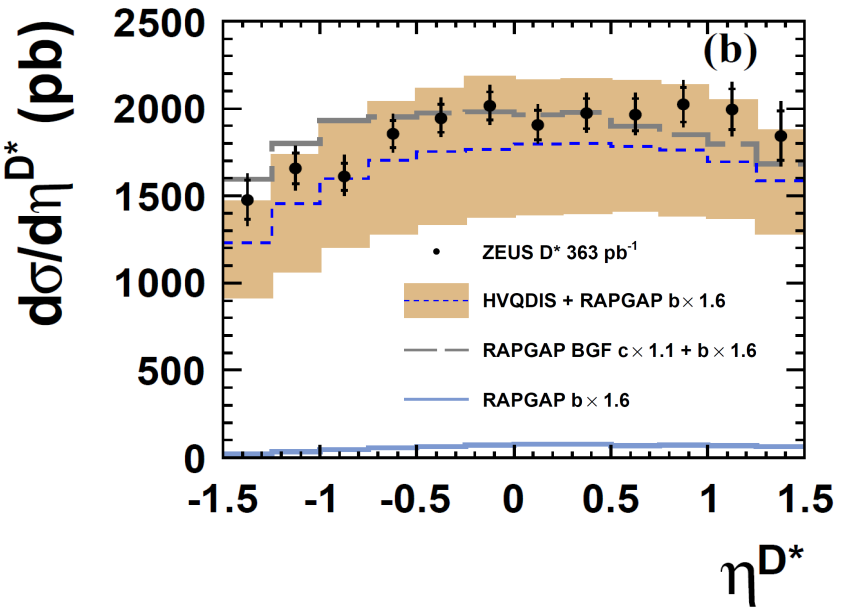


DESY

New charm measurements: D^*.

JHEP 02 (2014) 106





- The most precise charm DIS measurement from ZEUS.
- Well described by massive NLO QCD predictions.

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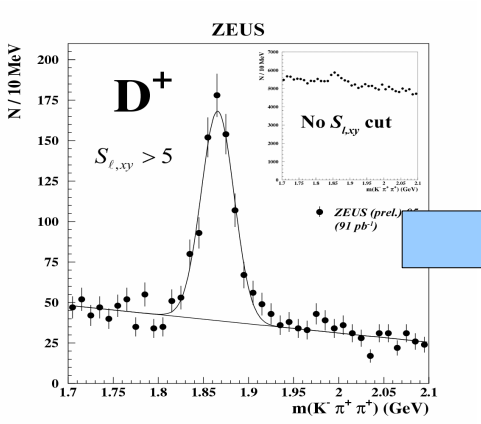
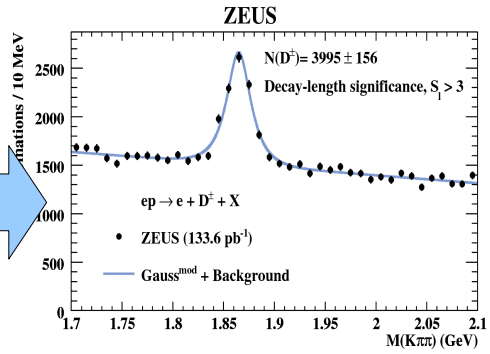
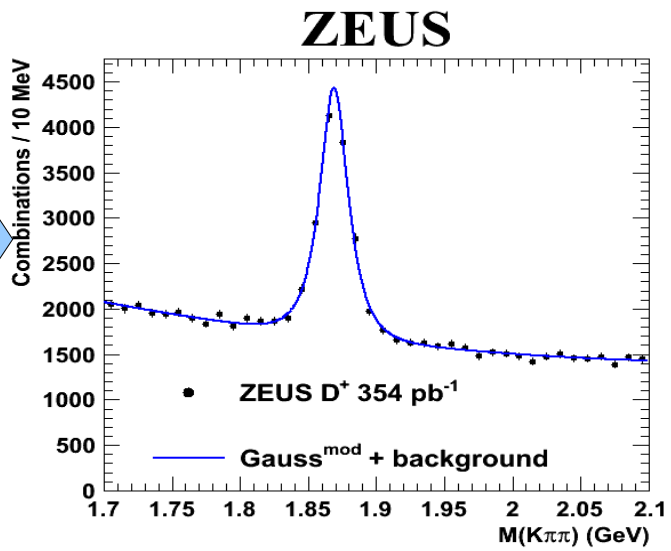
New charm measurements: D^+, sec.vtx.

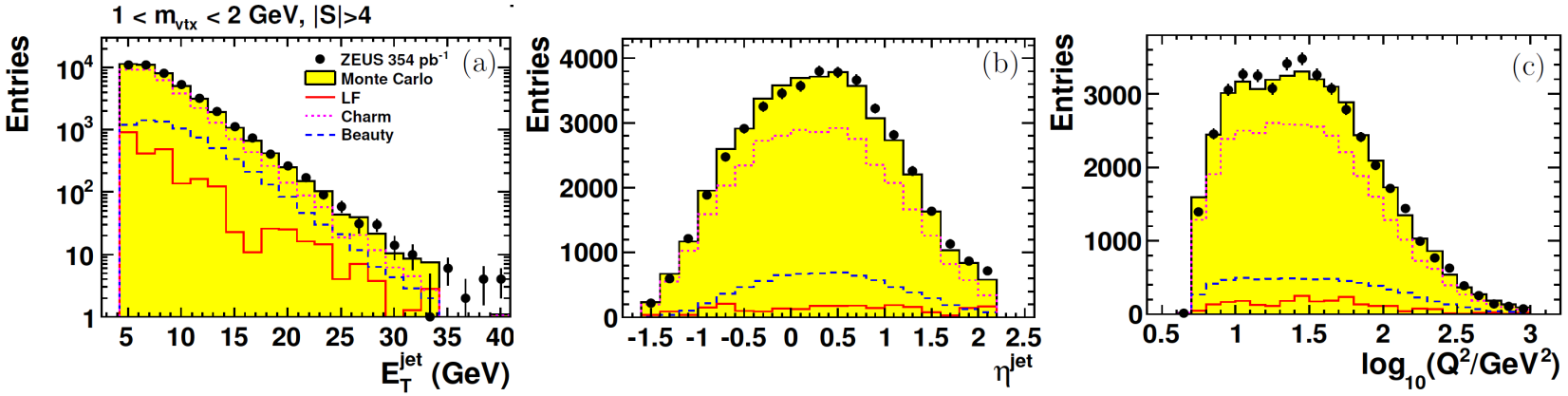
JHEP 05 (2013) 023, arXiv:1405.6915







- Independent from D^* data: D^+ and secondary vertices+lifetime tag.
- Additional statistics and cross-calibration of systematics.



Charm-enriched sample

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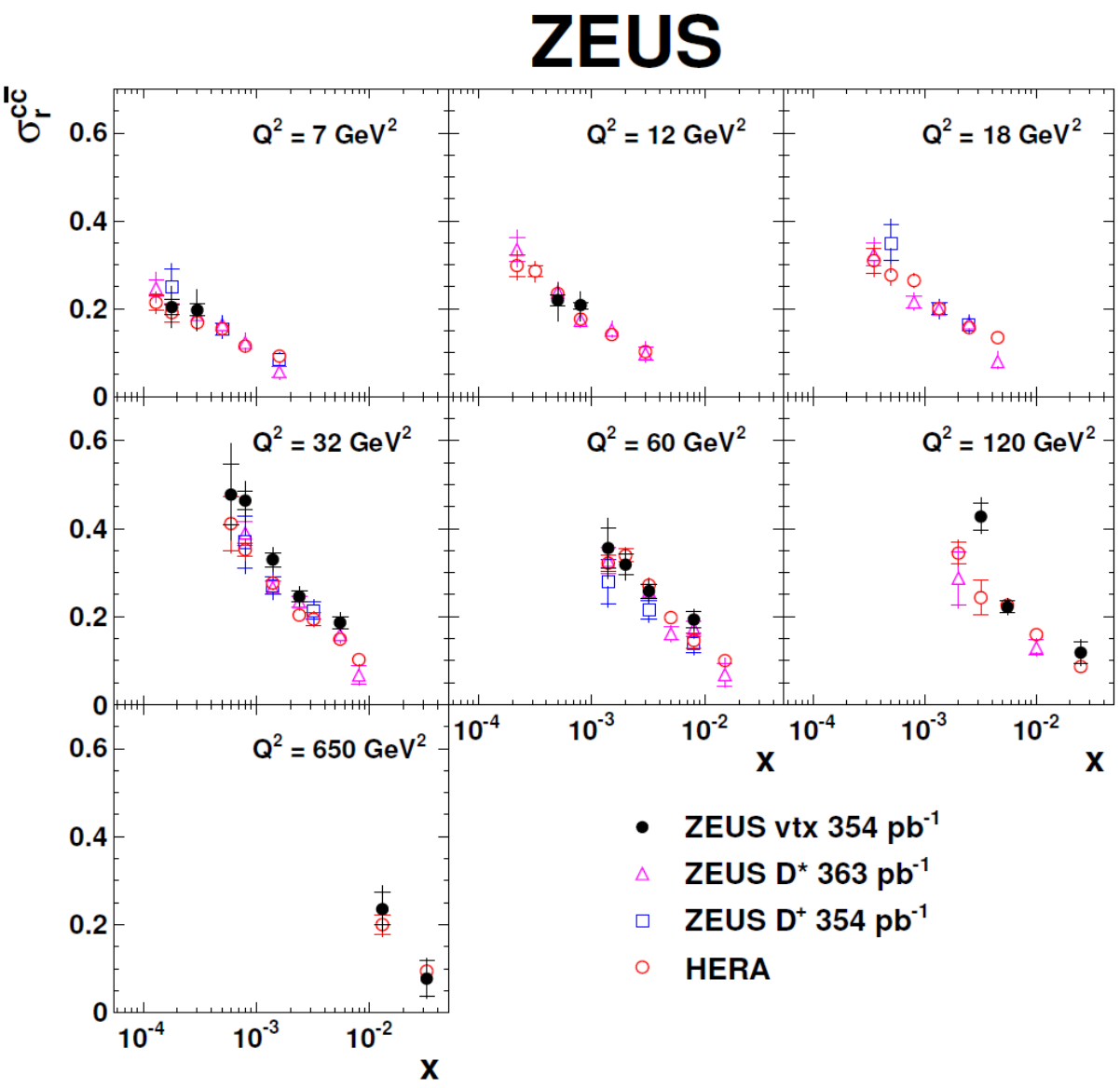
Comparison of charm: D^*, D^+, sec.vtx., combination.



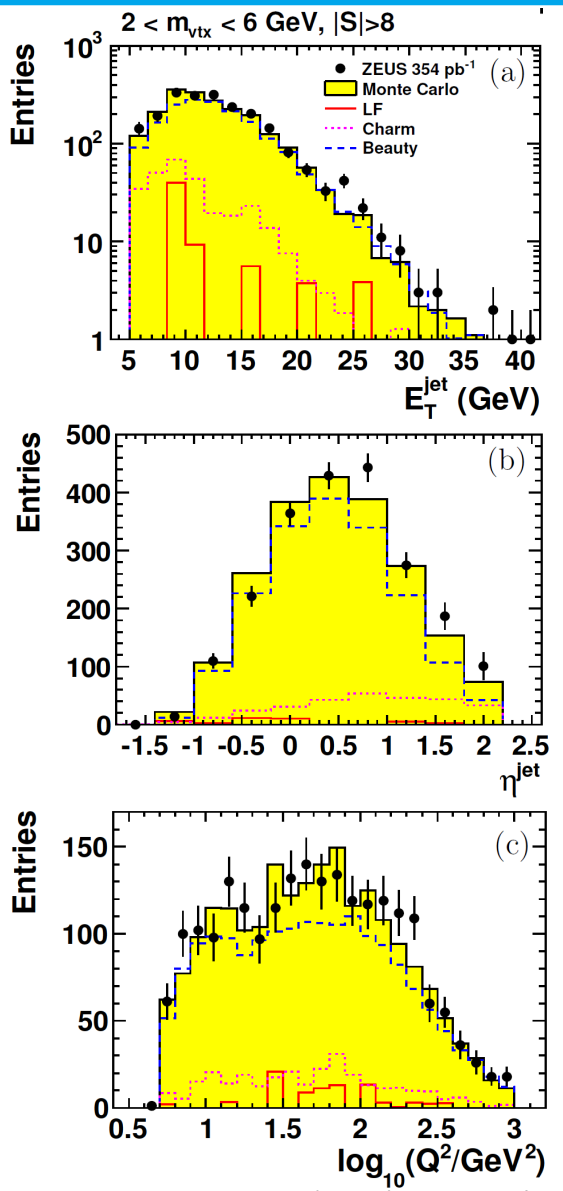
$$\frac{d\sigma^{c\bar{c}}}{dxdQ^2} = \frac{2\pi\alpha^2}{xQ^4}\cdot[1+(1-y)^2]\cdot\sigma_{red}^{c\bar{c}}$$

- The new data are precise and independent from the previous combination.
- All data are consistent

DESY

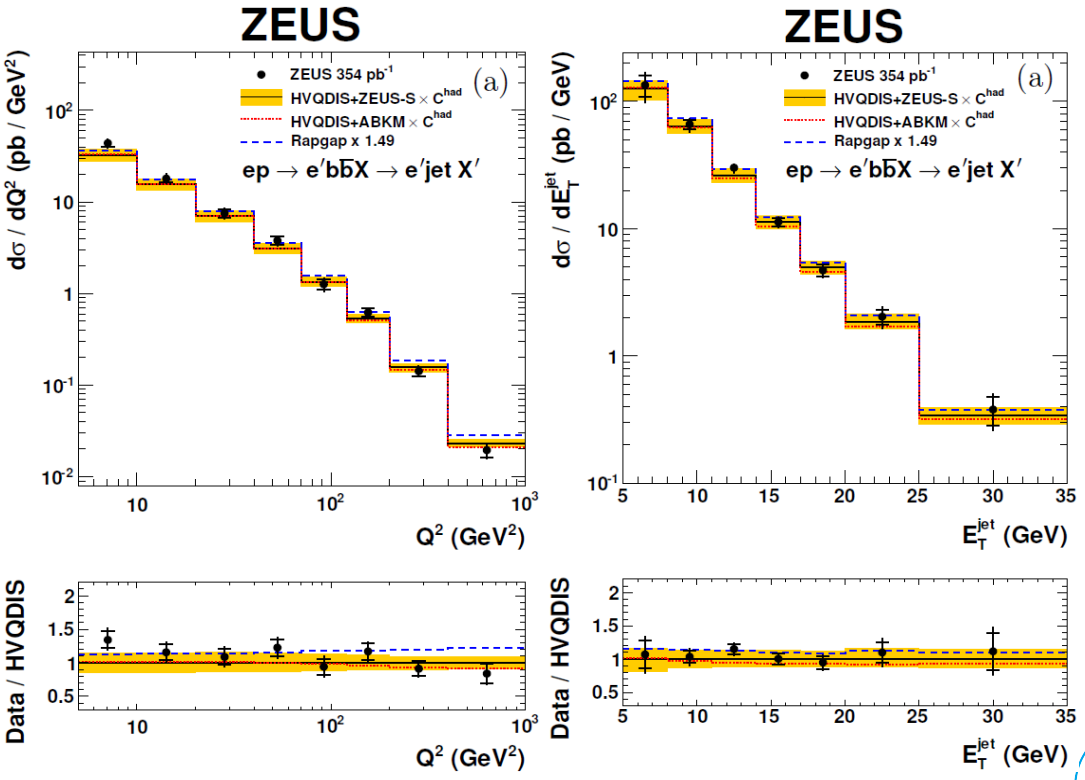
New beauty measurement: sec.vtx.

arXiv:1405.6915



Beauty-enriched sample

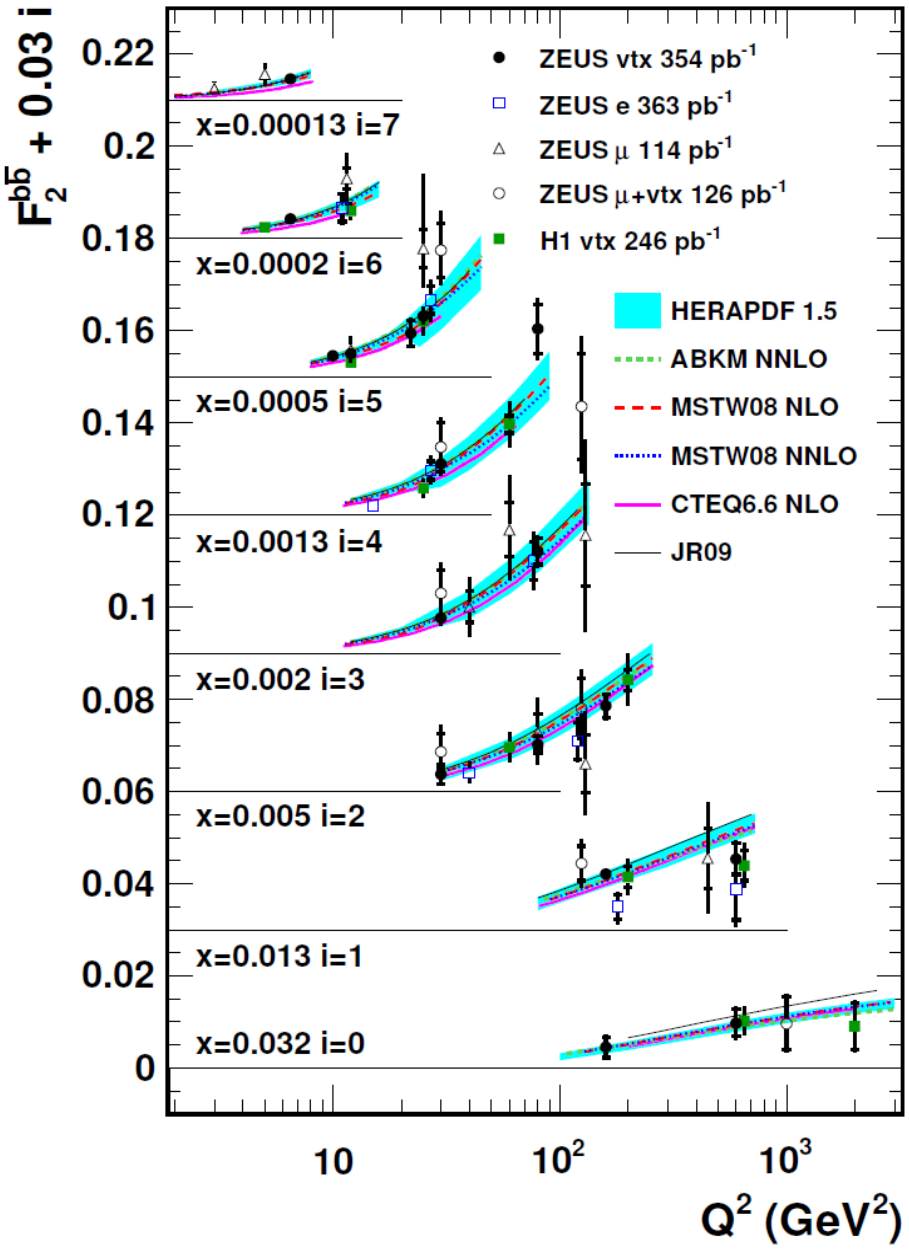
- Measurement of HF jets using secondary vertices + lifetime tag (simultaneous and b measurement).
- Good description of the data by the massive NLO QCD predictions.



DESY

New beauty measurement: sec.vtx.

arXiv:1405.6915



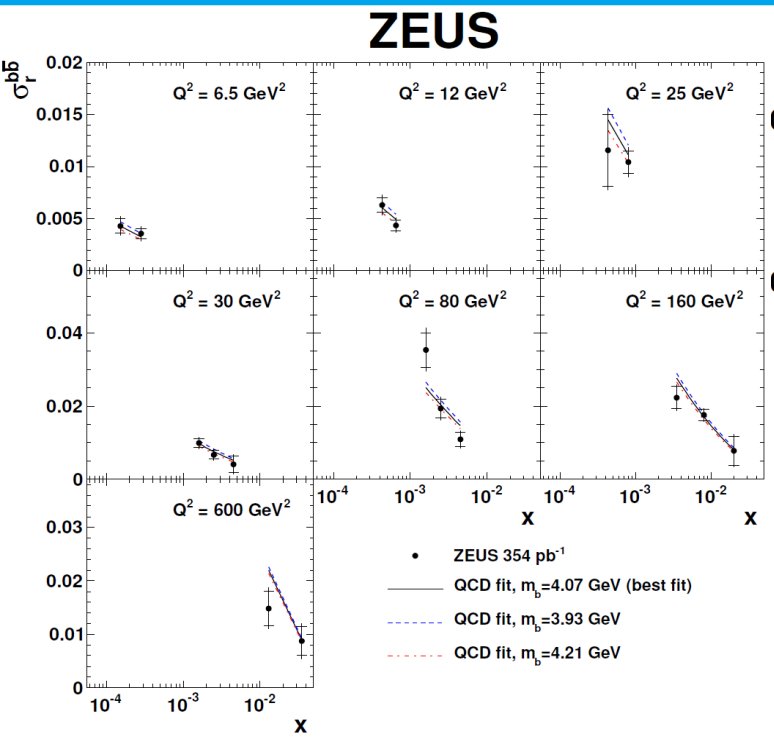
$$\frac{d\sigma^{b\bar{b}}}{dxdQ^2} = \frac{2\pi\alpha^2}{xQ^4}\cdot[(1+(1-y)^2)\cdot F_2^{b\bar{b}} - y^2\cdot F_L^{b\bar{b}}]$$

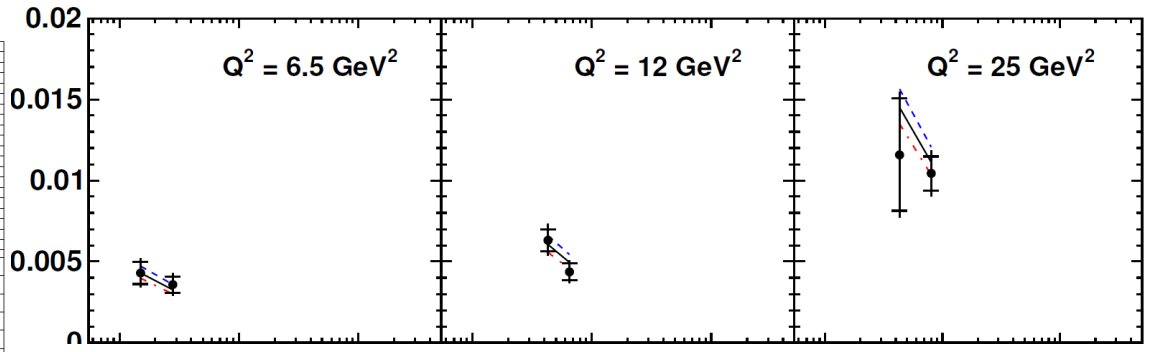
- In a wide range of Q^2, the new measurement is the most precise determination of F_2^b at HERA.
- All beauty data are in good agreement and well described by fixed-order (massive) and variable-flavour (mixed) NLO and NNLO QCD calculations.

DESY

Extraction of $\overline{\text{MS}}$ beauty mass.

arXiv:1405.6915

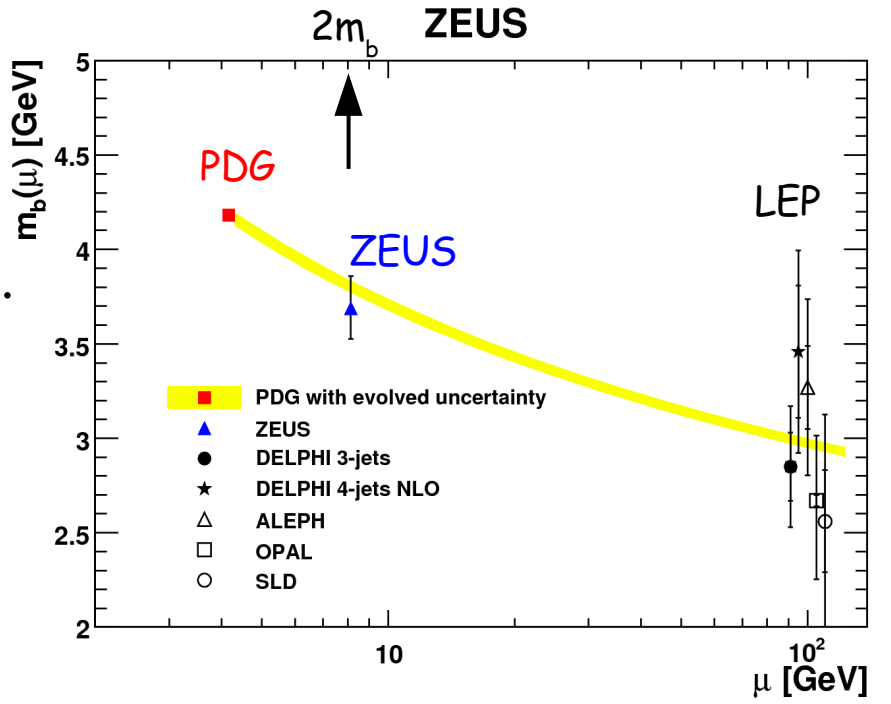




$$m_b(m_b) = 4.07 \pm 0.14\,(\text{fit})^{+0.01}_{-0.07}\,(\text{mod.})^{+0.05}_{-0.00}\,(\text{param.})\,^{+0.08}_{-0.05}\,(\text{theo.})\ \text{GeV}$$

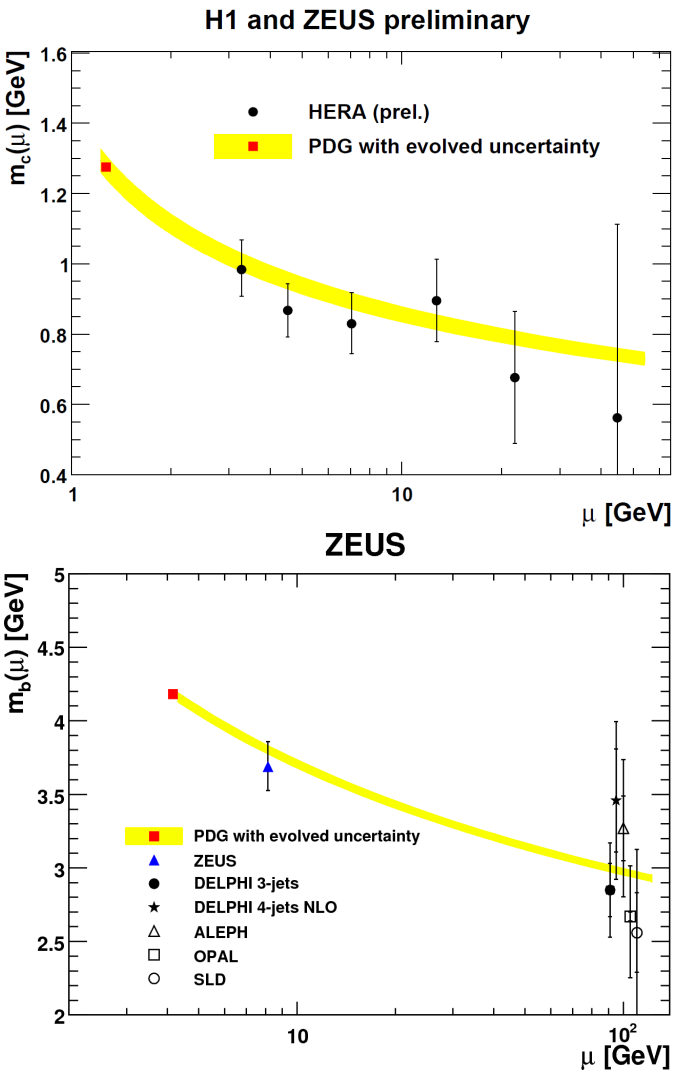
PDG 2012 : $m_c(m_c)$ = 4.18 ± 0.03 GeV

- The largest sensitivity to m_b at low Q^2.
- The extracted $\overline{\text{MS}}$ beauty-quark mass is in agreement with PDG average and LEP results.
- Important QCD consistency check.



Summary.

- Most HERA DIS charm data were combined:
  - the data are well described by fixed-flavour and variable-flavour NLO and NNLO QCD predictions;
  - charm mass measured: $m_c(m_c) = 1.26 \pm 0.06$ GeV;
  - first measurement of the charm-mass running.
- New charm measurements will provide further constraints:
  - D^*, D^+, secondary vertices+lifetime.
- New beauty-jet measurement + lifetime tag in DIS by ZEUS:
  - one of the most precise beauty measurements at HERA;
  - beauty mass measured: $m_b(m_b) = 4.07 \pm 0.17$ GeV.



Backup

NLO QCD predictions.

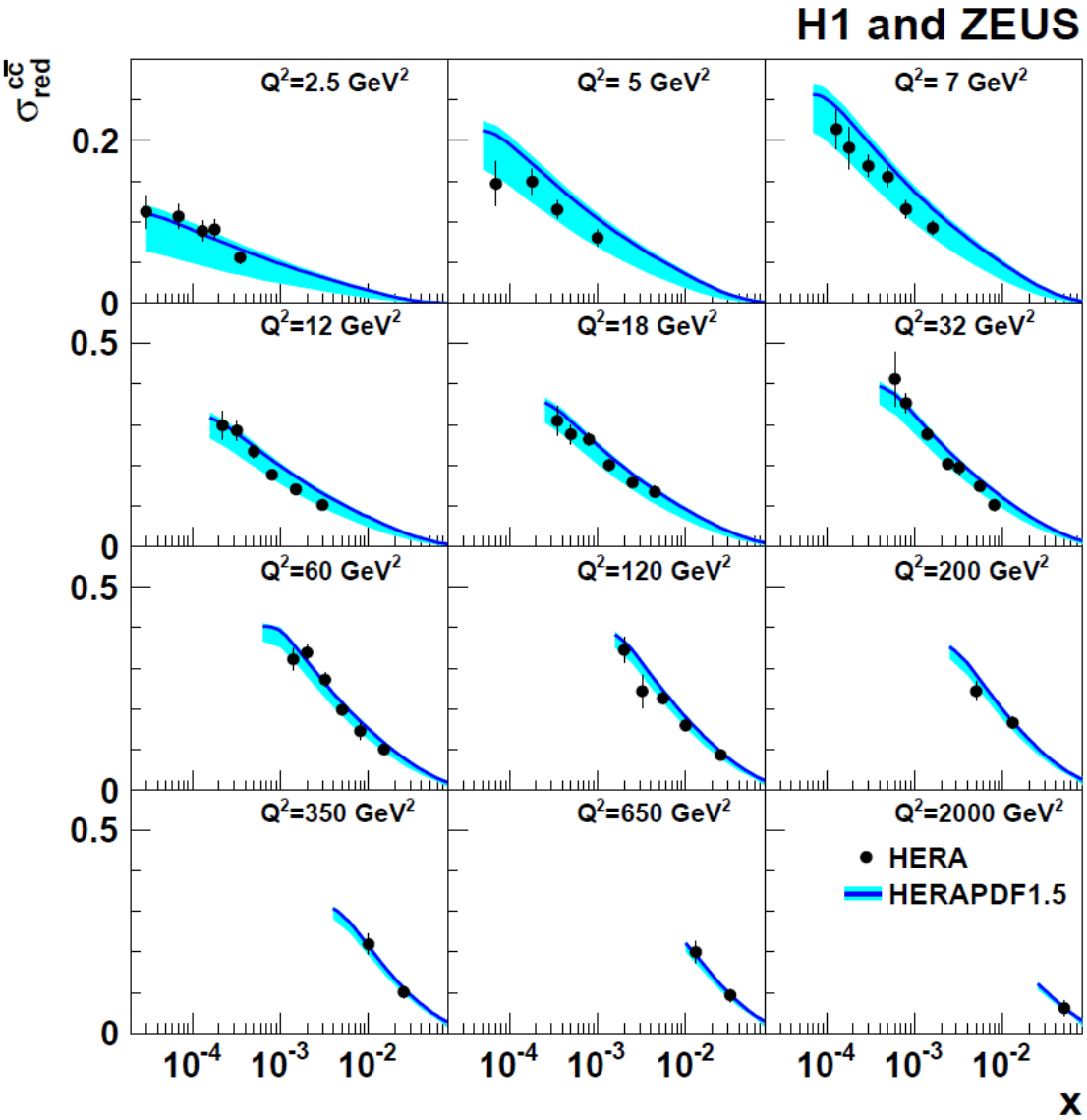
H1prelim-13-171, ZEUS-prel-13-002

- Fixed-order $O(\alpha_s^2)$ calculations using HVQDIS.
- Set-up follows closely the one used in the combination of inclusive charm cross sections (EPJ C73 (2013) 2311) (see back-up). Only μ_R and μ_F are varied independently.
- Small beauty contribution is estimated with RAPGAP and normalised following original analyses.

DESY

Charm combination.

EPJ C73 (2013) 2311



- 155 data points -> 52 combined points.
- Charm reduced cross sections:

$$\frac{d\sigma^{c\bar{c}}}{dxdQ^2} = \frac{xQ^4}{2\pi\alpha^2}\cdot[1+(1-y)^2]\cdot\sigma_{red}^{c\bar{c}}$$

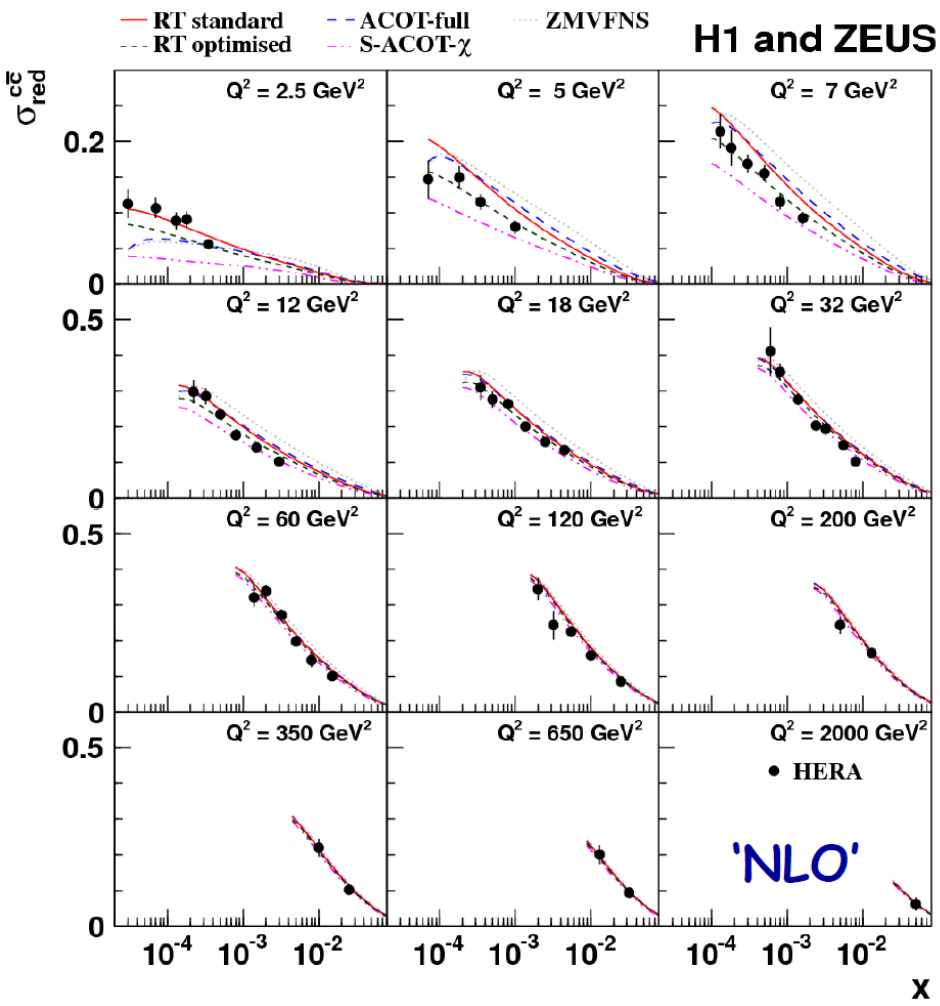
- Good consistency of the input data: χ^2/ndf=62/103.
- Well described by HERAPDF1.5 (from inclusive DIS only).
- Strong charm-mass dependence.

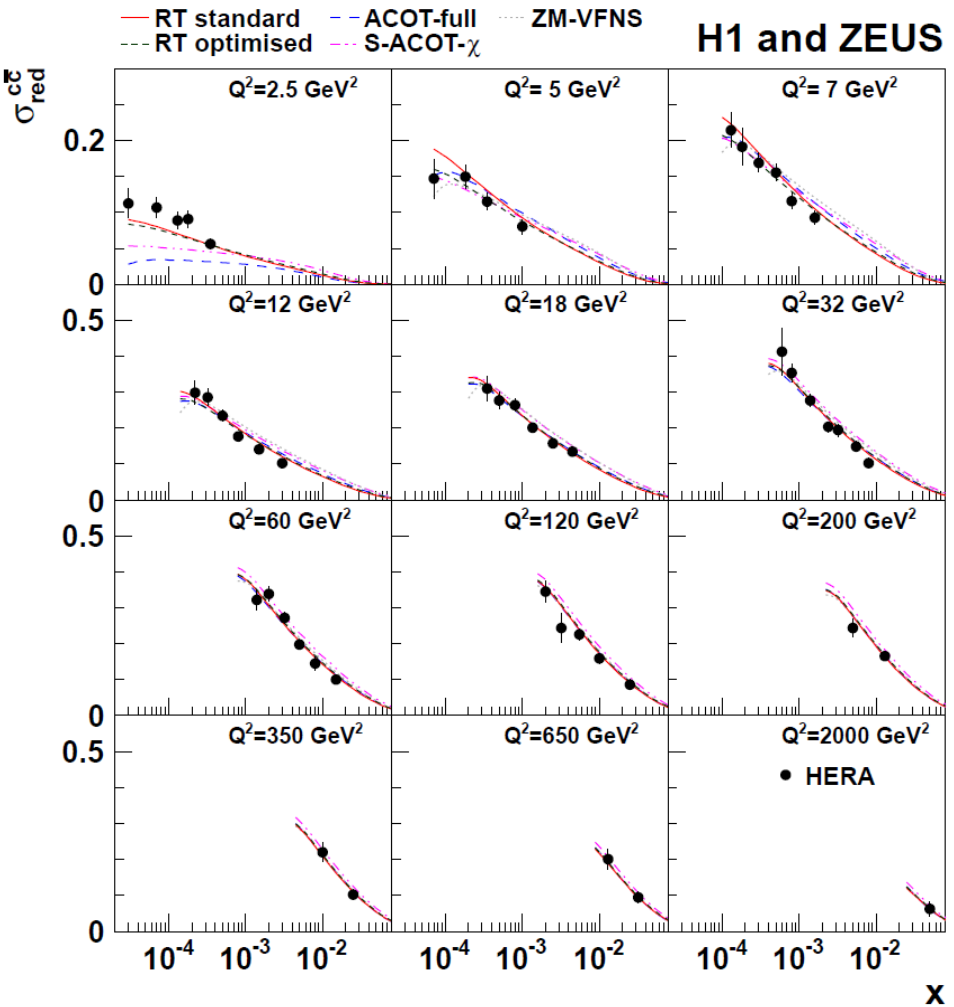
$1.35 < M_c < 1.65$ GeV

DESY

Charm combination.

EPJ C73 (2013) 2311





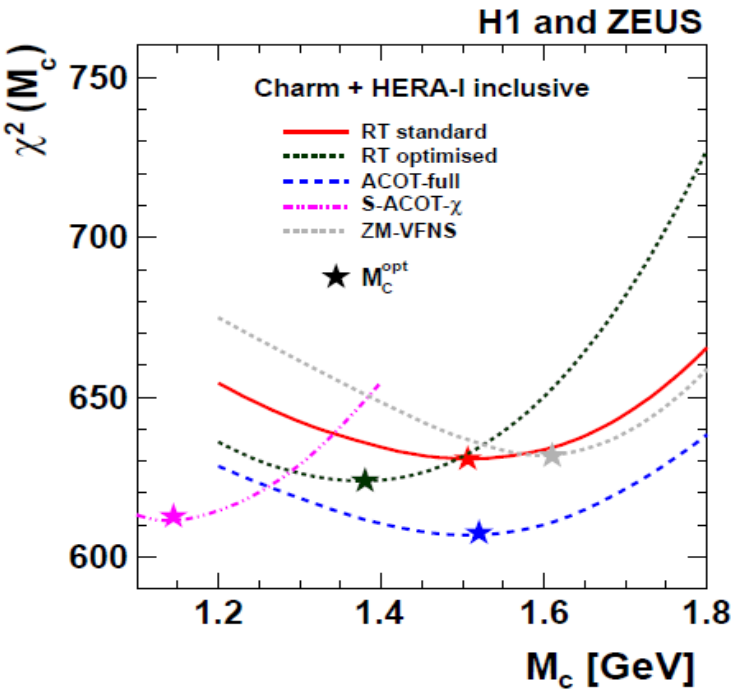
M_c (effective parameter) is fixed to 1.4 GeV.

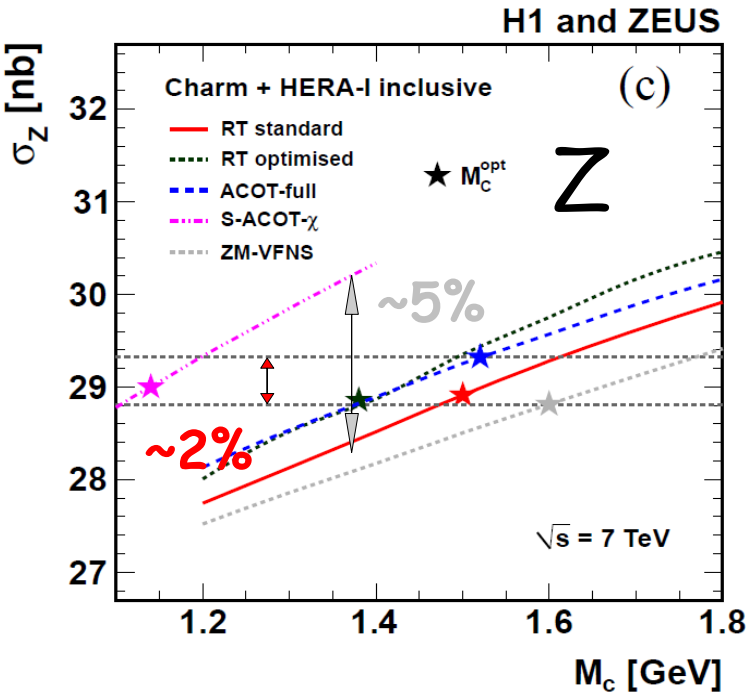
Optimal M_c value for each scheme.

DESY

Charm combination.

EPJ C73 (2013) 2311



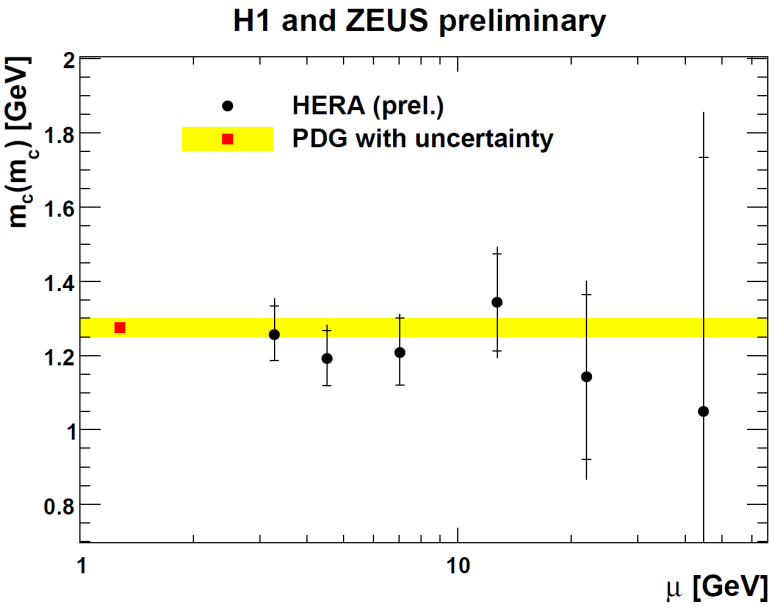


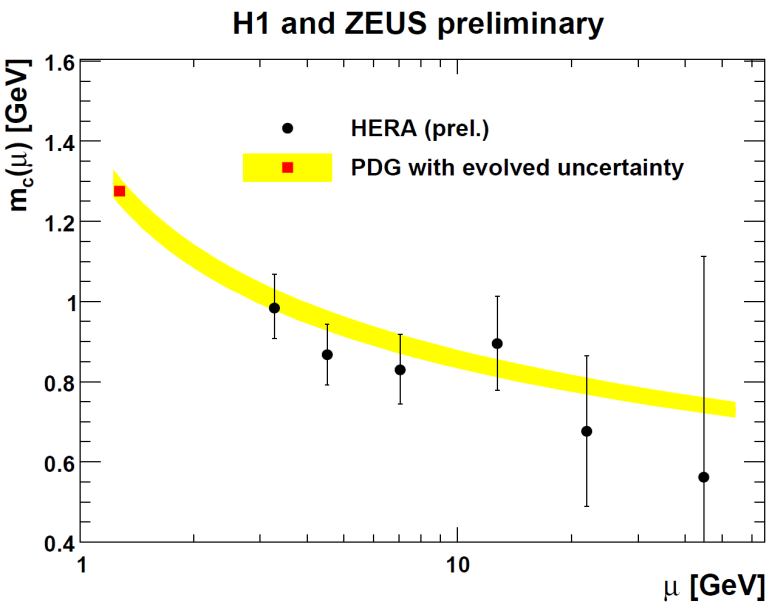
Optimal M_c value for each scheme.

DESY

$\overline{\text{MS}}$ charm mass running.

H1-prelim-14-071,
ZEUS-prel-14-006, +S.Moch





- Left: $m_c(m_c)$. Right: $m_c(\mu)$.