Heavy Flavour Production at HERA

Ringailė Plačakytė

on behalf of the H1 and ZEUS collaborations

- Introduction
- Heavy Flavor production at HERA
- Latest measurements
- Summary

BEACH, Birmingham, 21-26 July, 2014

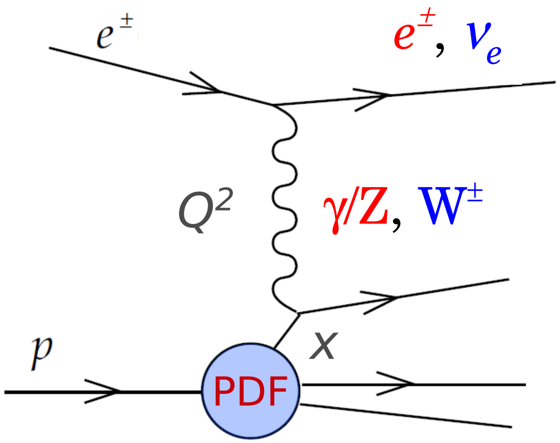
HERA Collider

HERA was the worlds only $e^{\pm}p$ collider

- $e^{\pm}$(27.5 GeV), p(460-920 GeV)
- centre-of-mass energy:
  $\sqrt{s}$ = 225-318 GeV

- Two collider experiments: H1 and ZEUS
- ~0.5 fb^{-1} of luminosity recorded by each experiment

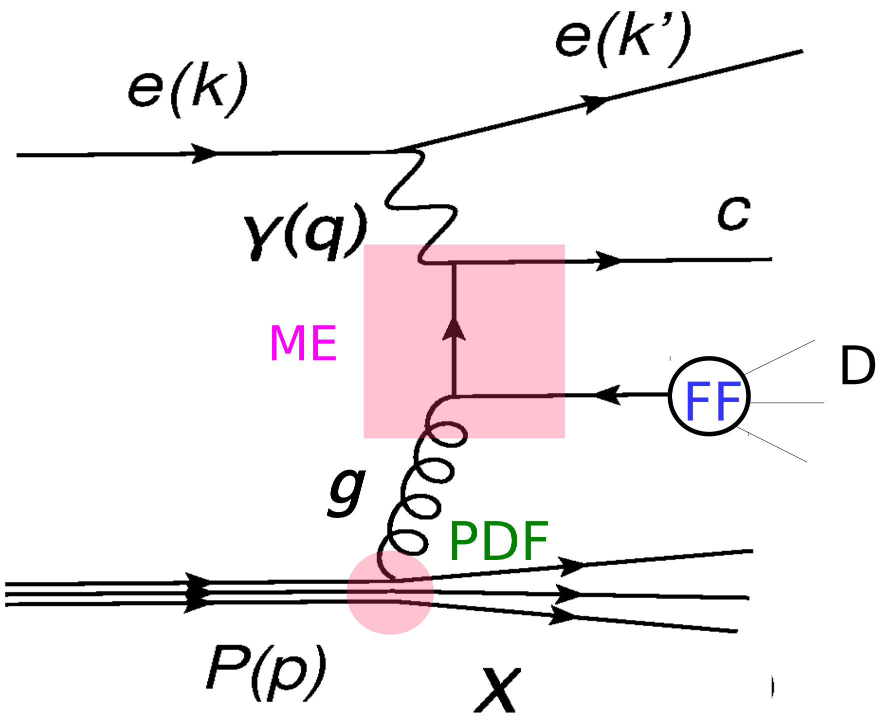
Kinematics:



Neutral Current (NC): $ep \rightarrow eX$
Charged Current (CC): $ep \rightarrow \nu X$

Q^2 - virtuality of exchanged boson
x – Bjorken scaling variable
y – inelasticity
$Q^2 = sxy$ ($\sqrt{s}$ centre-of-mass energy)

Heavy Flavour (HF) Production @ HERA



Heavy flavour production is
dominated by the boson-gluon fusion
→ direct probe of gluon

HF production cross section factorise as:

$$\sigma_{HQ} = \mathrm{PDF} \otimes \mathrm{ME} \otimes \mathrm{FF}$$

Test of pQCD

Multiple scales (Q^2, $m_{c,b}$, p_T^{HF}):

→ massive/fixed-order pQCD calculations: heavy flavours are produced perturbatively

Fragmentation (of the quarks into observable hadrons) model

Heavy Flavour Production Schemes

Fixed Flavour Number Scheme (FFNS)

→ c(b) quarks are massive, only light flavours in the proton
→ valid for $Q^2 \sim m_{c,b}^2$

Zero-Mass Variable Flavour Number Scheme (ZMVFNS)

→ all flavours massless
→ valid at $Q^2 >> m_{c,b}^2$ (breaks at $Q^2 \sim m_{c,b}^2$)

General-Mass Variable Flavour Number Scheme (GM-VFNS)

→ matched scheme
(equivalent to massive at small and massless at large scale)

→ different schemes exist (as used in PDF fits: ACOT, TR', ...)

→ due to differences in the matching schemes between two regions, in the fit charm mass becomes a parameter: M_C^{opt}

Charm Combination: Data

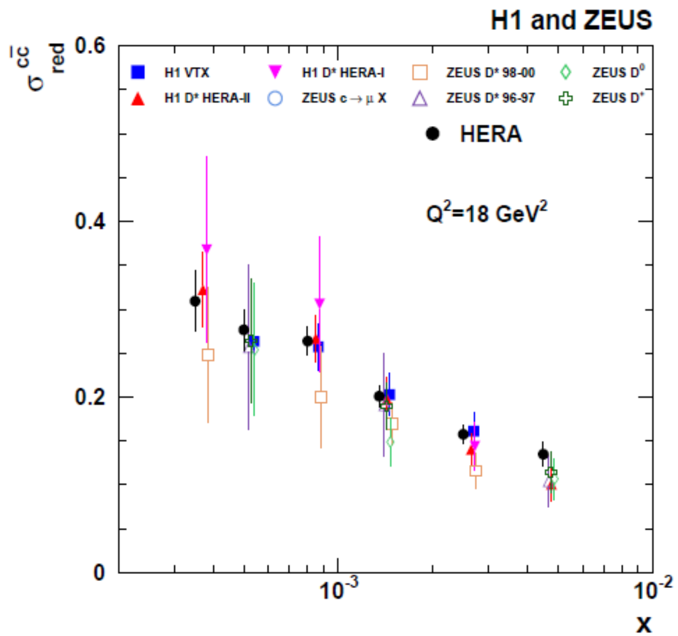
Combined HERA charm measurement

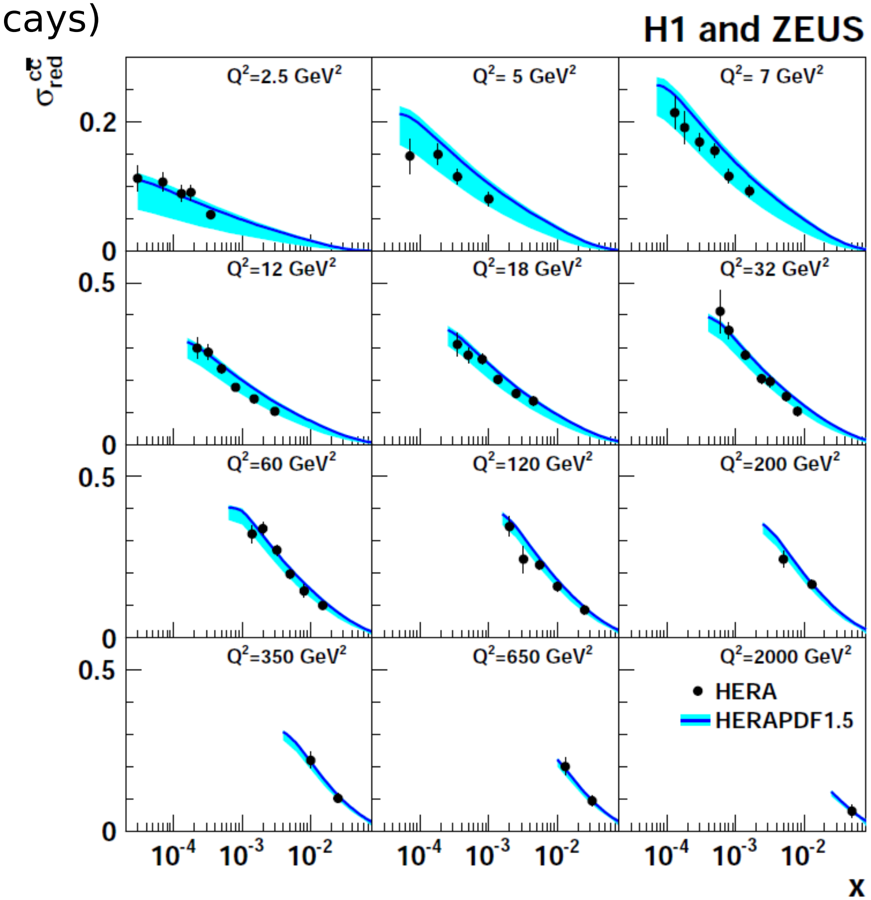
Eur.Phys. J. C73 (2012), 2311

→ combination of 9 H1 and ZEUS measurements

→ different charm tagging methods (full reconstruction of D-mesons, lifetime tagging, semi-leptonic decays)

→ accounting for correlations of systematic uncertainties between data sets





→ full kinematic coverage:
$2.5 < Q^2 < 2000$ GeV^2 and $10^{-5} < x < 10^{-1}$

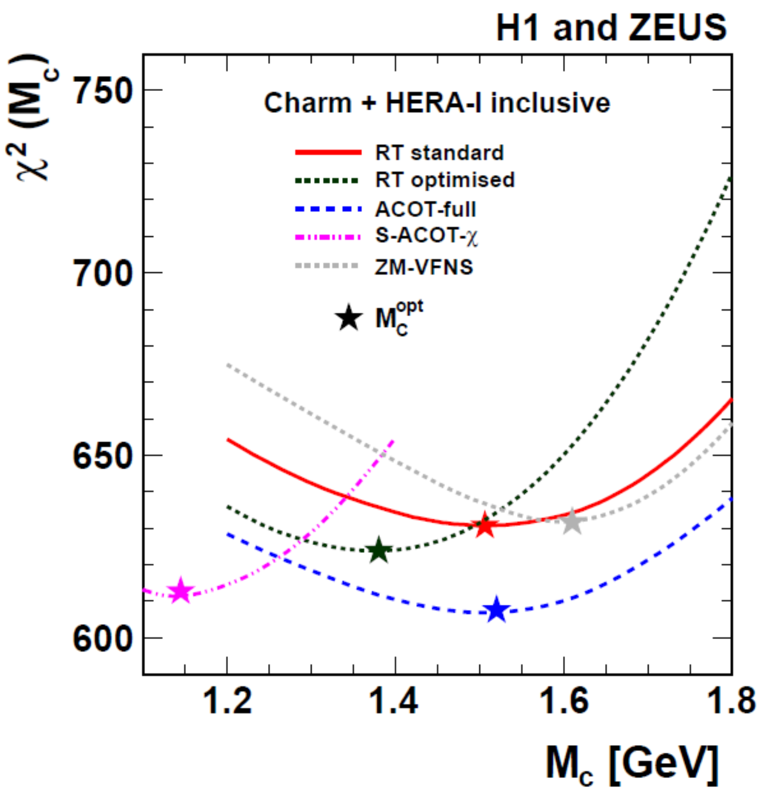
→ 5-10% total uncertainty of combined data
→ combined data well described by the theory predictions (HERAPDF1.5)

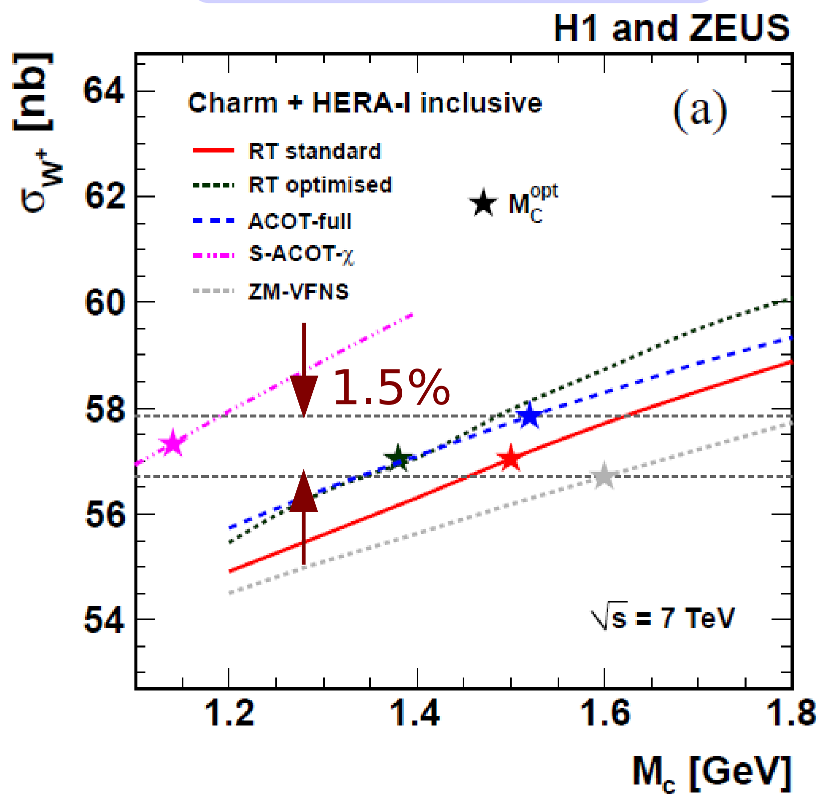
Charm Combination: M_c^{opt}

The combined charm data used in NLO QCD fits using different HF schemes

Eur.Phys. J. C73 (2012), 2311

W^+ cross section@LHC





Different schemes prefer different M_c^{opt}

Variation between schemes ~6%
Significantly reduced at M_c^{opt} (opt) (★)

HERA charm measurements help to reduce uncertainties of predictions for the LHC

Charm Combination: Running $m_c(m_c)$

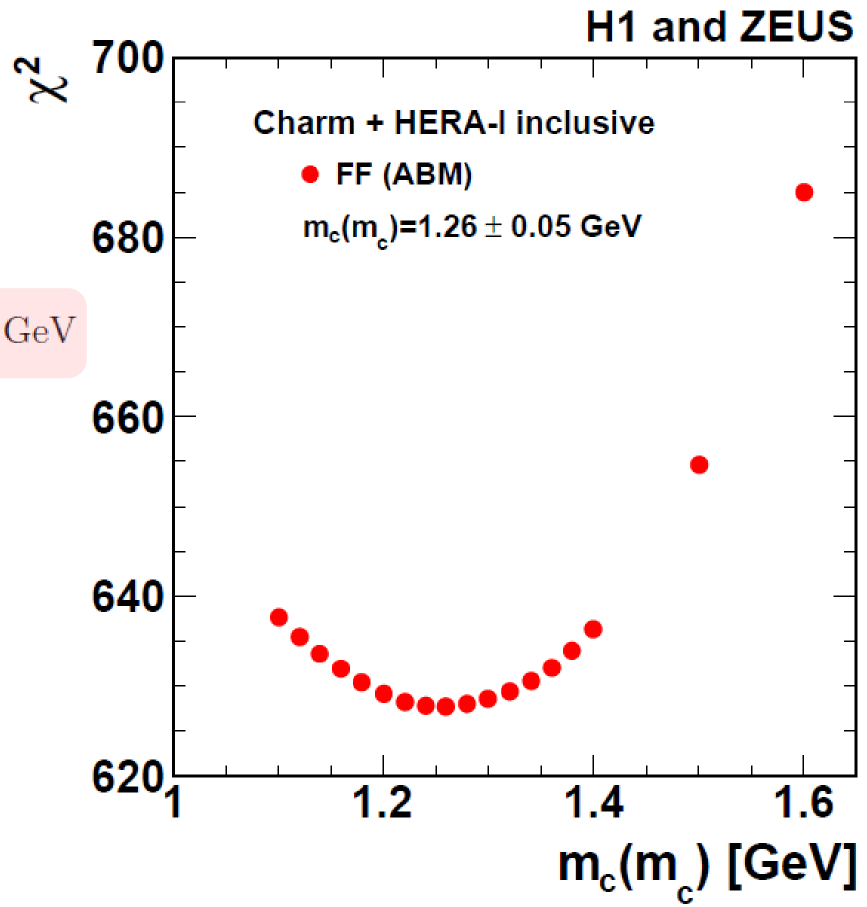
Eur.Phys. J. C73 (2012), 2311

The QCD analysis in Fixed Flavour Number scheme at NLO using the MS running mass definition (arXiv:1011.5790)

→ the running charm-quark mass $m_c(m_c)$ determined:

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

In agreement with the world average of $m_c(m_c) = 1.275 \pm 0.025$ GeV

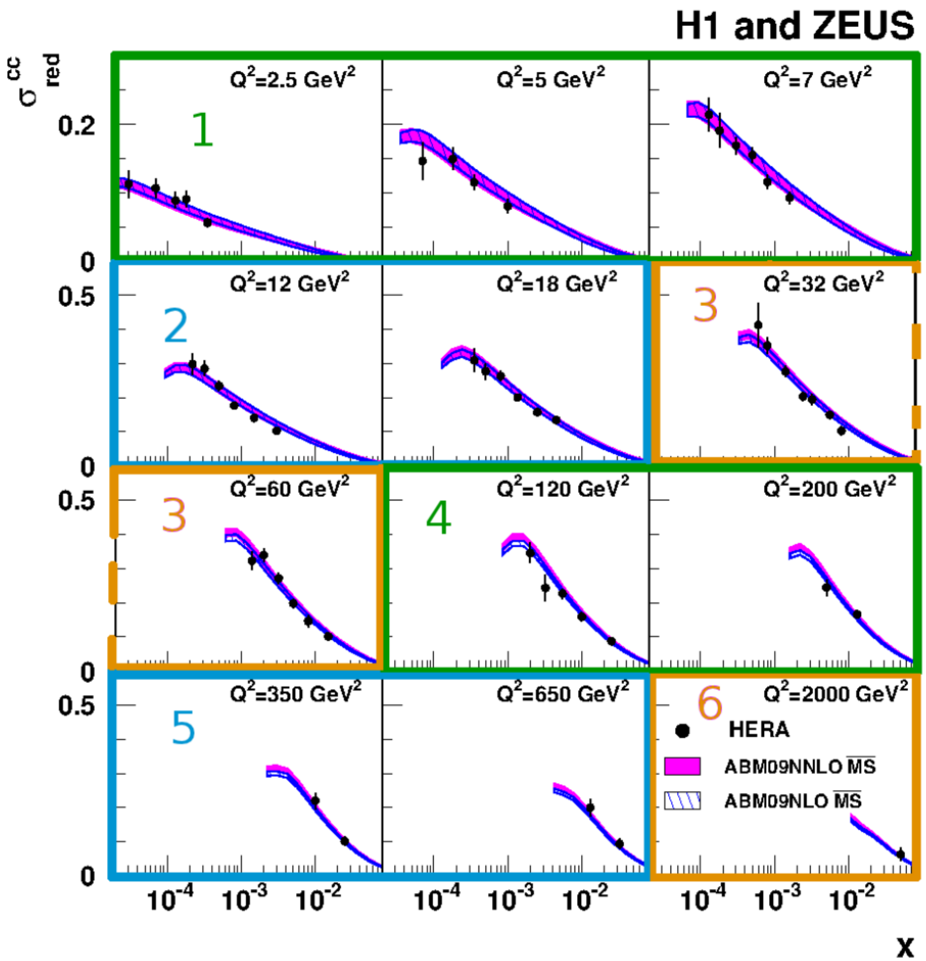


Measurement of Charm Mass Running

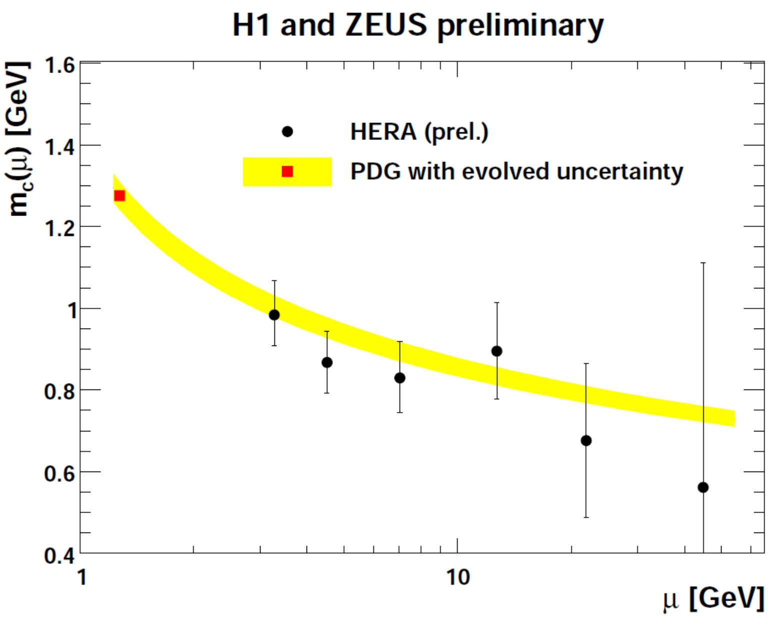
Same data used to determine m_c running:

H1-prelim-14-071
ZEUS-prel-14-006
and 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



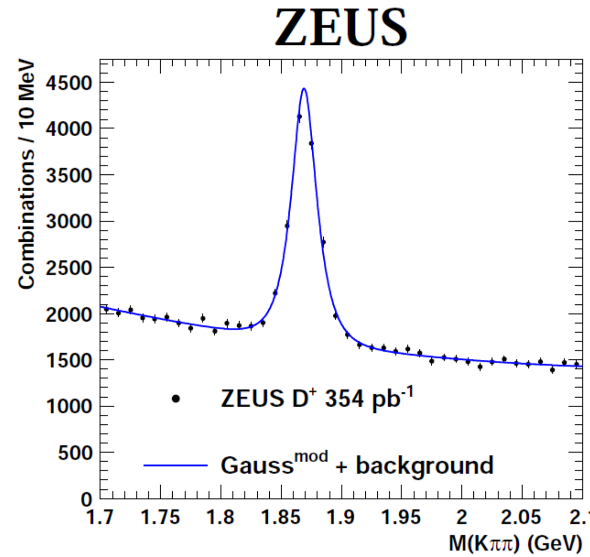
Important QCD consistency check

Recent Heavy Flavour Measurements at HERA

Measurement of $D^{\pm}$ production

JHEP 05 (2013) 023

→ data of 2004-2007 years, L=345pb^{-1}
→ independent from D* data
Identification: D^{+} and secondary vertices + lifetime tag



Data well described by the NLO QCD theory calculations

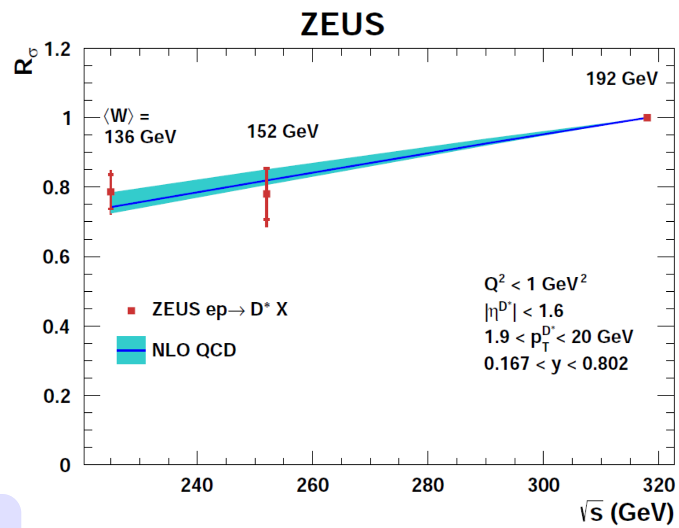
Measurement of D* in photoproduction (Q^2<1GeV^2) at three different centre-of-mass energies

arXiv:1405.5068

→ data of 2006-2007 years

$\sqrt{s}$ = 318 GeV (γ-p c.o.m energy W: 130 <W<285 GeV)
$\sqrt{s}$ = 251 GeV (103 <W<225 GeV)
$\sqrt{s}$ = 225 GeV (92 <W<201 GeV)

→ NLO QCD predictions well describe measured energy dependence



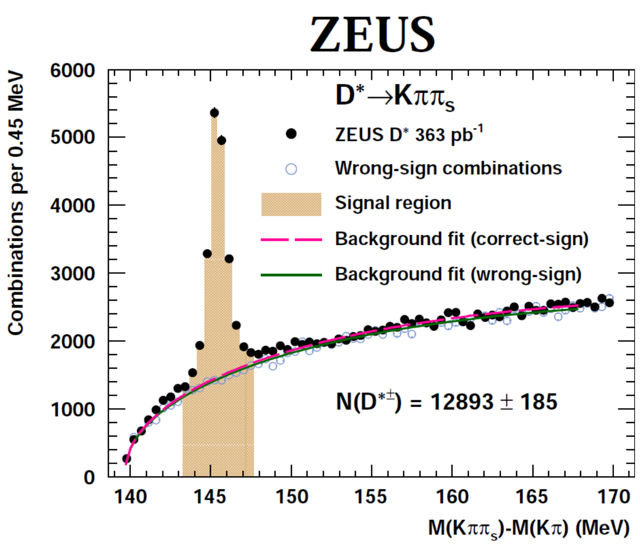
Theory can be used for future *ep* colliders

Recent Measurements and D* Combination

H1-prelim-13-171
ZEUS-prel-13-002

The new, most precise charm (D*) DIS measurement from ZEUS

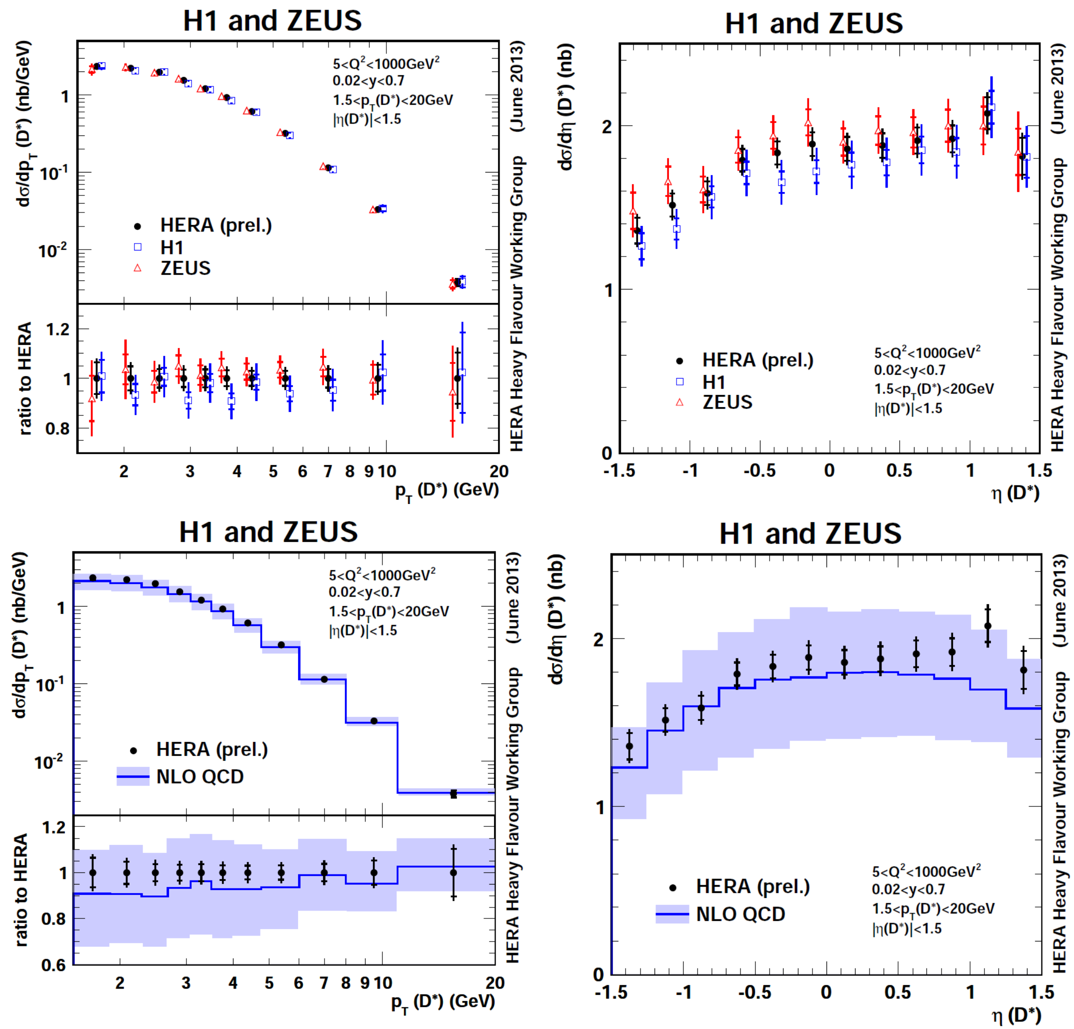
JHEP 05 (2013) 097



Used in the D* (visible cross section combination) together with H1 measurements:

Phys Lett B686 (2010)

Eur Phys J C71 (2011)



→ largest theory uncertainty due to scale variation

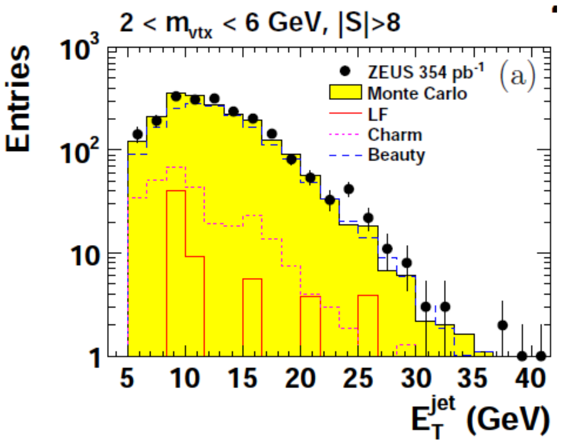
ZEUS Lifetime Tagging: Charm and Beauty

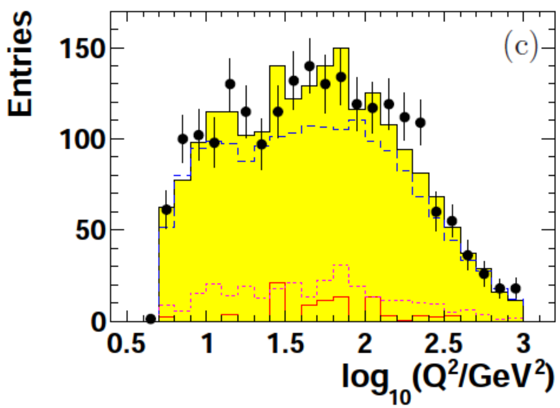
Inclusive jet production containing *b* or *c* quarks

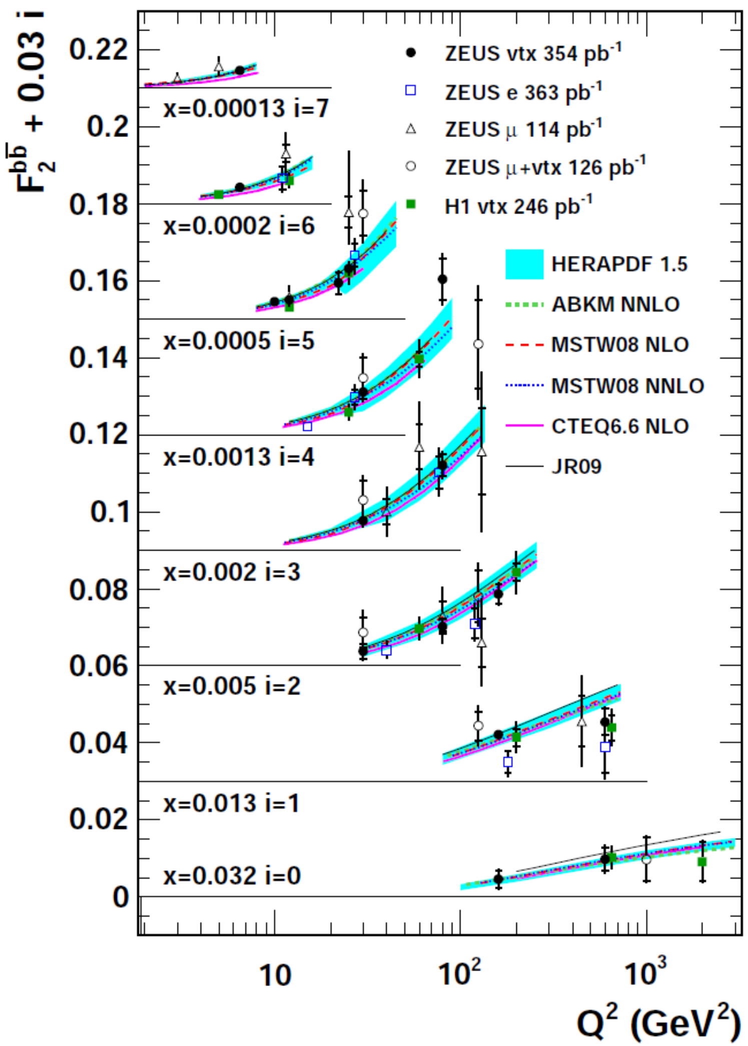
DESY-14-083
arXiv:1405.6915

→ $5 < Q^2 < 1000$ GeV^2, L=345pb^{-1}

→ F_2^{qq} and σ_r^{qq} extracted



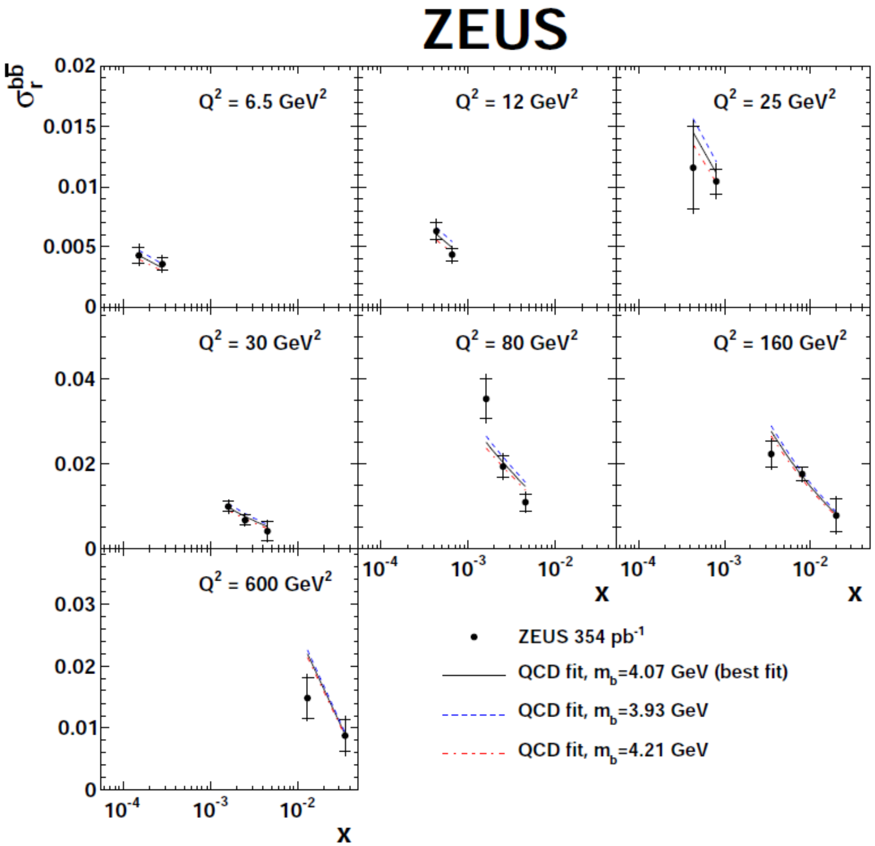




→ additional statistics and cross-calibration of systematics

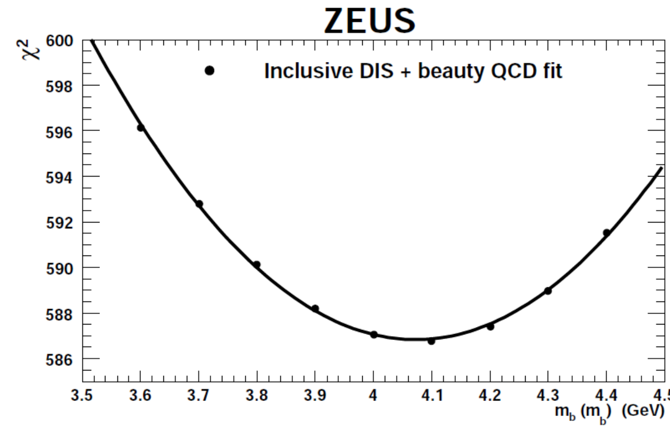
The most precise F_2^{bb} measurement at HERA

ZEUS Lifetime Tagging: Beauty



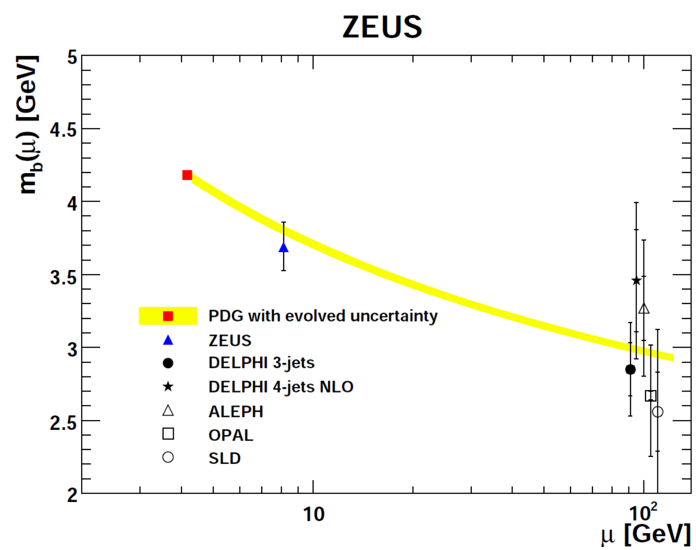
DESY-14-083
arXiv:1405.6915

Measured running mass:



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

PDG 2012 : $m_b(m_b) = 4.18 \pm 0.03$ GeV



→ the extracted beauty mass $m_b(m_b)$ is in agreement with PDG average

→ similar to charm case, the beauty mass running $m_b(\mu)$ extracted

Summary

Heavy Flavour Production in DIS at HERA

Charm combination:

→ the data are well described by fixed-flavour and variable-flavour NLO and NNLO QCD predictions

→ the running charm quark mass determined $m_c(m_c)$

The first measurement of the charm mass running

→ $m_c(\mu)$ provides important QCD consistency check

New heavy flavour measurements

→ provide additional constraints

Combination of D* visible cross section:

→ indicates that more advanced theory is needed

New beauty measurement:

→ one of the most precise beauty measurements at HERA

→ the running beauty quark mass determined $m_b(m_b)$

Back-up slides

Deep Inelastic Scattering (DIS)

Structure function factorisation:

each structure function can be written as a convolution of a hard-scattering coefficient C and non-perturbative parton distributions:

$$F_2^V(x,Q^2) = \sum_{i=q,\bar{q},g} \int_x^1 dz \times C_2^{V,i}(\frac{x}{z}, Q^2, \mu_F, \mu_R, \alpha_S) \times f_i(z, \mu_F, \mu_R)$$

determined using measured cross section

calculable in perturbative QCD

PDFs

PDF scale dependence is calculable in perturbative QCD (DGLAP evolution):

$$\frac{\partial q(x,Q^2)}{\partial lnQ^2} \propto \int_x^1 \frac{dz}{z}\left[q(z,Q^2)P_{qq}\left(\frac{x}{z}\right) + g(z,Q^2)P_{qg}\left(\frac{x}{z}\right)\right]$$

$$\frac{\partial g(x,Q^2)}{\partial lnQ^2} \propto \int_x^1 \frac{dz}{z}\left[q(z,Q^2)P_{gq}\left(\frac{x}{z}\right) + g(z,Q^2)P_{gg}\left(\frac{x}{z}\right)\right]$$

Probability via splitting functions: