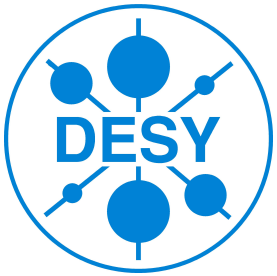


Running of the charm quark mass

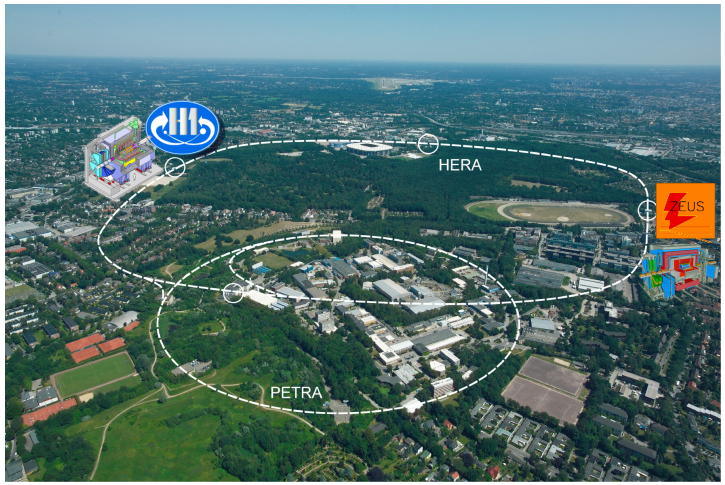
Andrii Gizhko(DESY)
On behalf of the H1 and ZEUS collaborations
and Sven Moch (University of Hamburg)

29.04.2014 DIS 2014 Warsaw, Poland

Outline

- Introduction
- Charm production at HERA
- Heavy quark treatment in pQCD
- HERA charm data combination
- Measurement of the charm quark mass running
- Summary

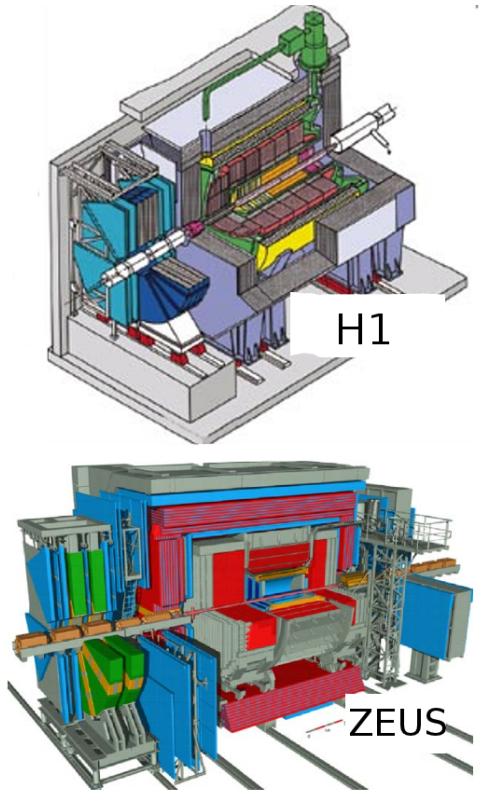
The HERA *ep* collisions experiments



HERA ring

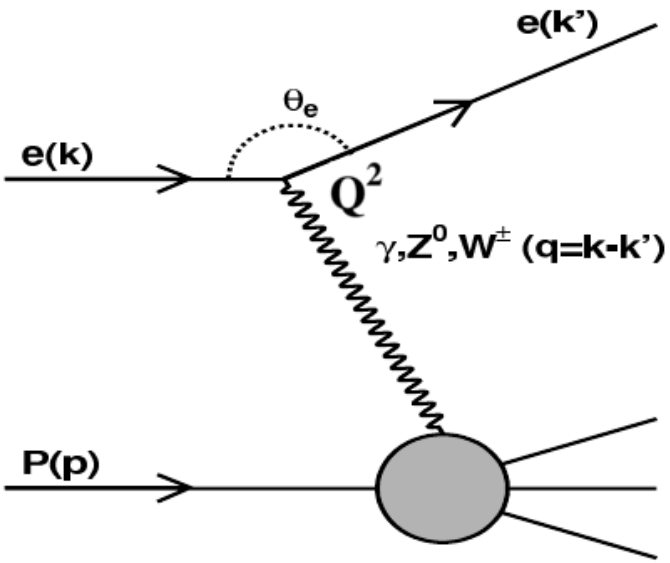
- HERA accelerator was unique lepton-proton collider
- $e^{\pm}$ and p were brought to collision with $\sqrt{s} = 318 GeV$

- H1 and ZEUS experiments collected 0.5 fb^{-1} per experiment



H1 and ZEUS detectors

Deep Inelastic Scattering



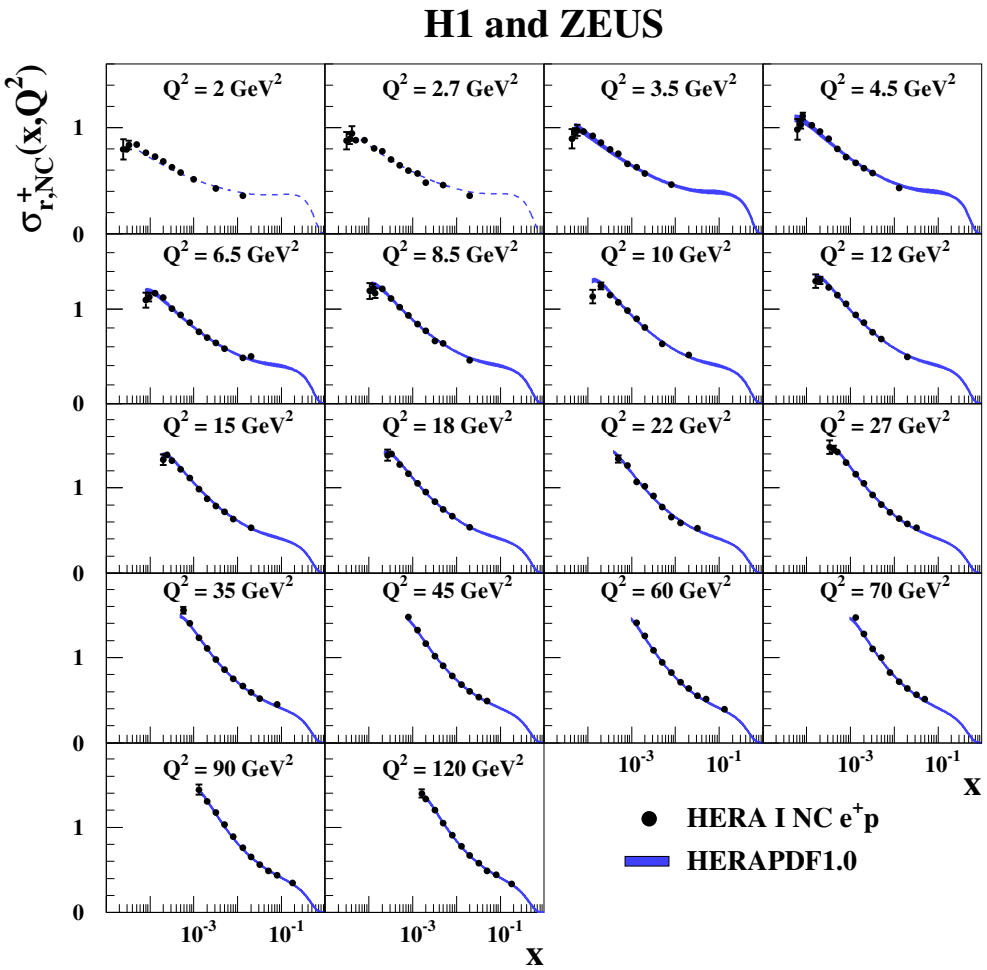
Q^2=-$(k - k')^2$ – boson virtuality,

$x = \frac{Q^2}{2P\cdot(k-k')}$ – Bjorken x

$y = \frac{P\cdot(k-k')}{P\cdot k}$ – inelasticity

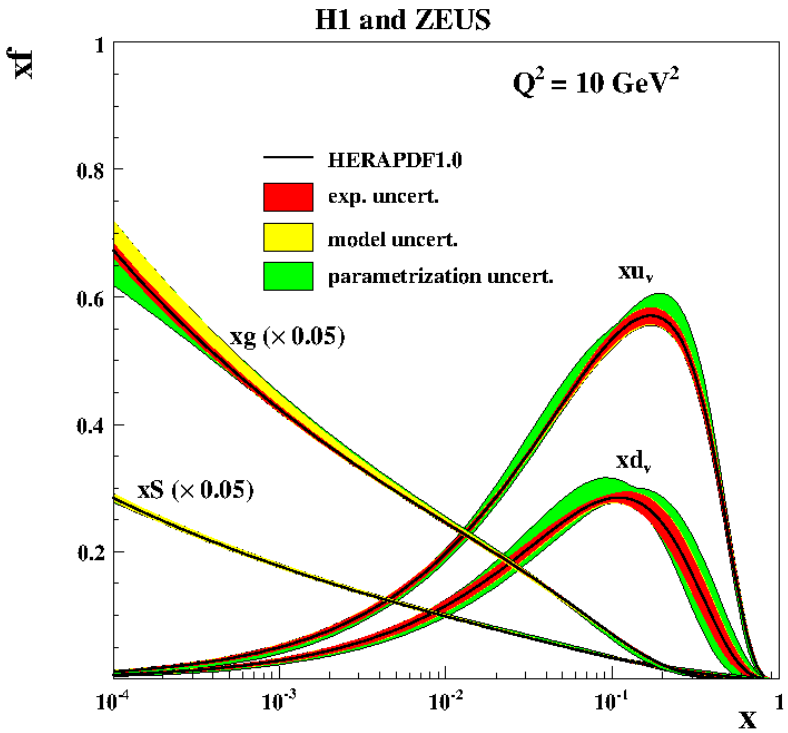
Deep Inelastic Scattering diagram.
$Q^2 > 1 GeV^2$: DIS

Inclusive DIS measurements at HERA



- HERA measurements of DIS cross sections cover wide range of Q^2. Can be used to determine sets of quark and gluon momentum distributions in the proton.

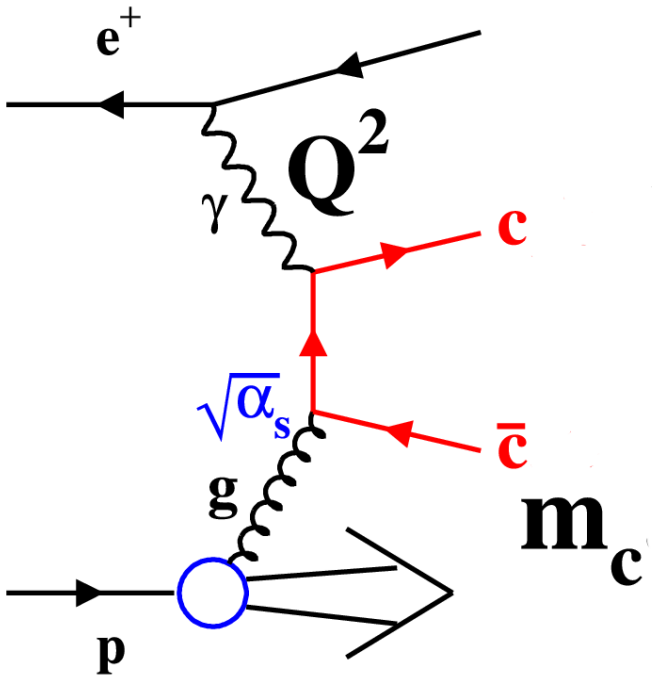
Measurements of parton density functions at HERA



- Previous HERAI inclusive F_2 measurements for neutral current and charged current reactions have been combined and used in global QCD fit of parton density functions (known as PDF).
- PDFs are used in factorization theorem and essential for theoretical predictions

Charm production in *ep* scattering

Charm contribution in DIS $\rightarrow$ 10%-30%.



- At HERA charm mainly produced by boson-gluon fusion (sensitive to the gluon density in the proton)
- Double-differential cross-sections of heavy quarks production can be described in terms of the reduced cross sections $\sigma^{q\bar{q}}_{red.}(Q^2, x)$:

$$\frac{d\sigma^{q\bar{q}}(e^{\pm}p)}{dxdQ^2} = \frac{2\pi\alpha^2}{xQ^4}[1+(1-y)^2]\sigma^{q\bar{q}}_{red.}(Q^2, x)$$

Fixed Flavour Heavy Quark Scheme in QCD Analysis

Heavy Quark Scheme in QCD Analysis defines treatment of heavy flavours in perturbative expansion. Factorisation :

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

where i - number of active flavours in the proton

- Fixed Flavour Number Scheme (FFNS) : heavy quarks are massive, produced in boson-gluon fusion as just they a final-state particle and not as a parton

Quark mass definitions

Pole quark mass

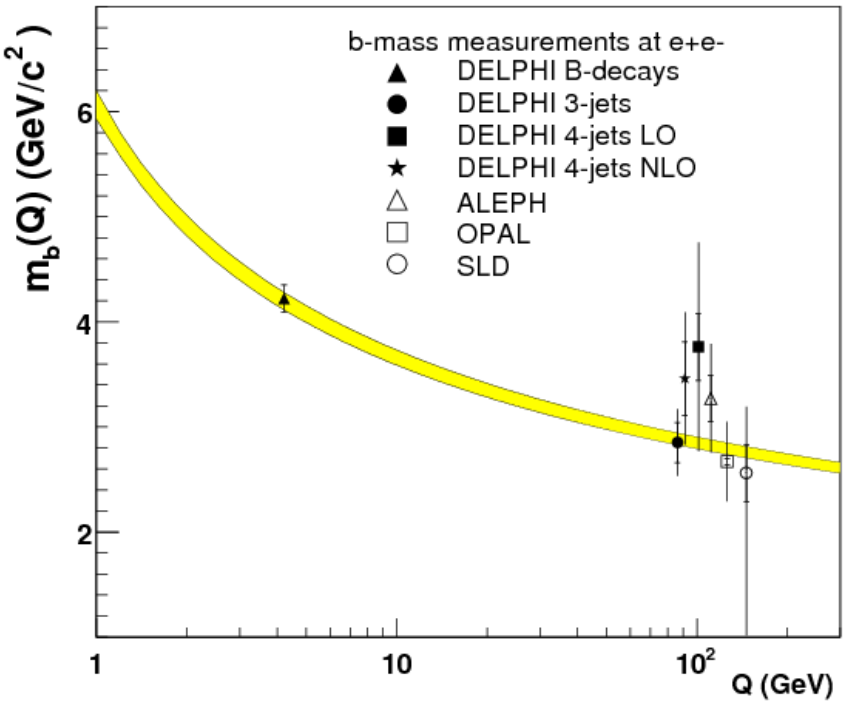
- Based on (unphysical) concept of quark being a free parton
- Pole mass is ambiguous up to corrections of $O(\Lambda_{QCD})$

Running quark mass ($\overline{MS}$)

- $\overline{MS}$ (minimal subtraction scheme) mass definition $m(\mu_R)$ realizes running mass (scale dependence)
- renormalization group equation (mass anomalous dimension γ)

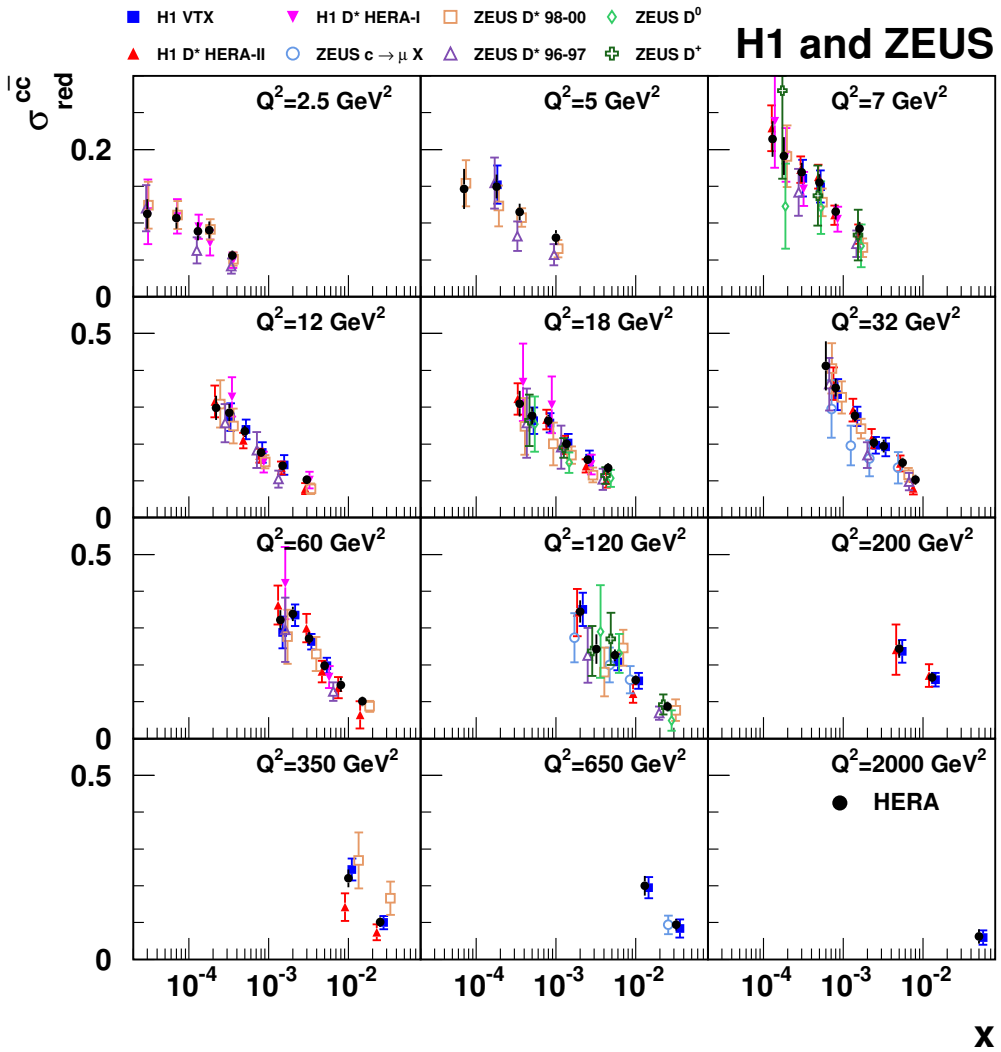
$$\left(\mu_R^2 \frac{\delta}{\delta \mu_R^2} + \beta(\alpha_s) \frac{\delta}{\delta \alpha_s}\right) m(\mu_R) = \gamma(\alpha_s) m(\mu_R)$$

Running quark mass



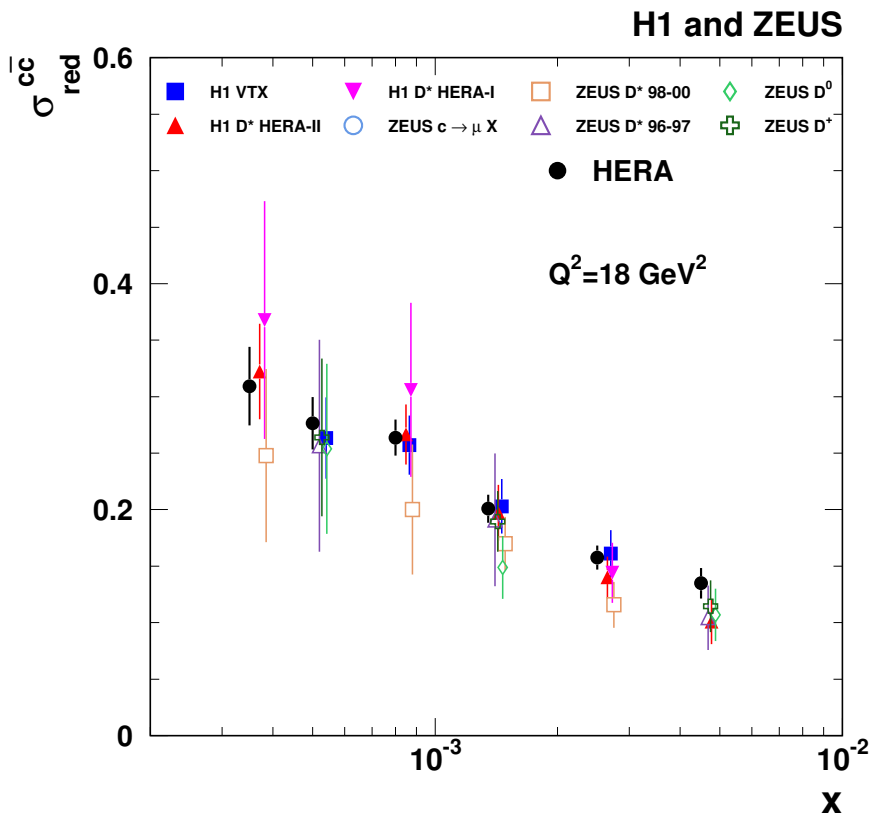
LEP demonstrated **beauty** quark mass running (EPJ C55 (2008) 525).
Can HERA measure **charm** quark mass at different scales?

HERA Charm Data Combination



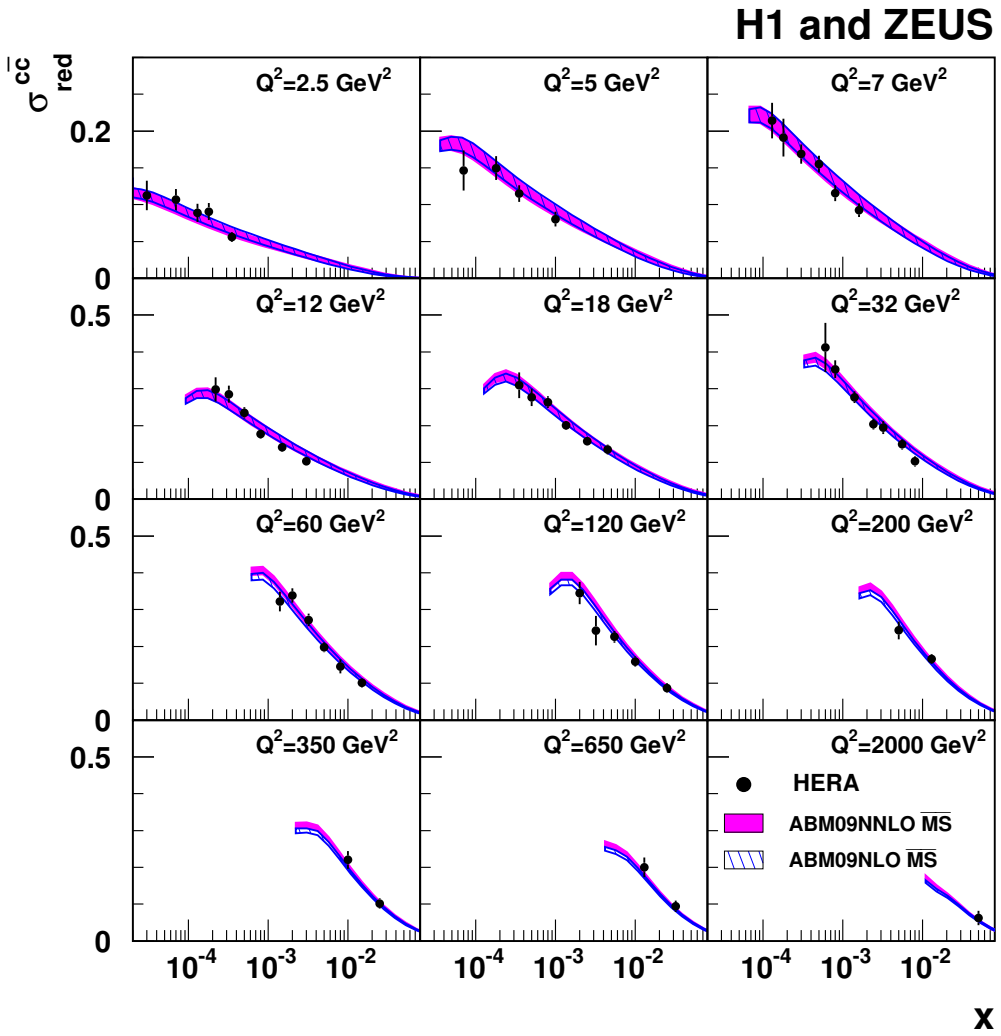
9 different reduced charm cross sections measurements were combined in recent H1/ZEUS paper (Eur. Phys. J. C73 (2013) 2311).
Combination showed good consistency of data with $\frac{\chi^2}{n_{dof}} = 62/103$.

HERA Charm Data Combination - A Close-up



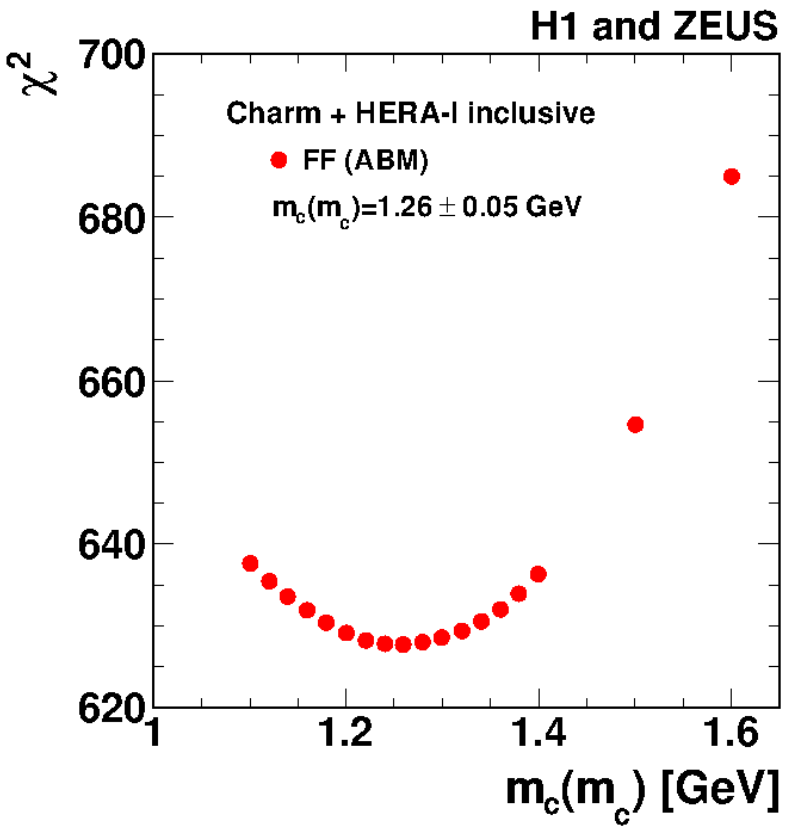
Fully accounts for correlations. Significant reduction of uncertainties.

HERA Charm Data Combination



- Good description of combined data ABM predictions (FFNS using $\overline{MS}$ mass definition.
- We can use it to measure charm quark mass.

QCD analysis of combined charm data



- Charm mass was measured performing mass scan in global QCD fit of NC+CC+charm in FFNS with $\overline{MS}$ charm mass definition.

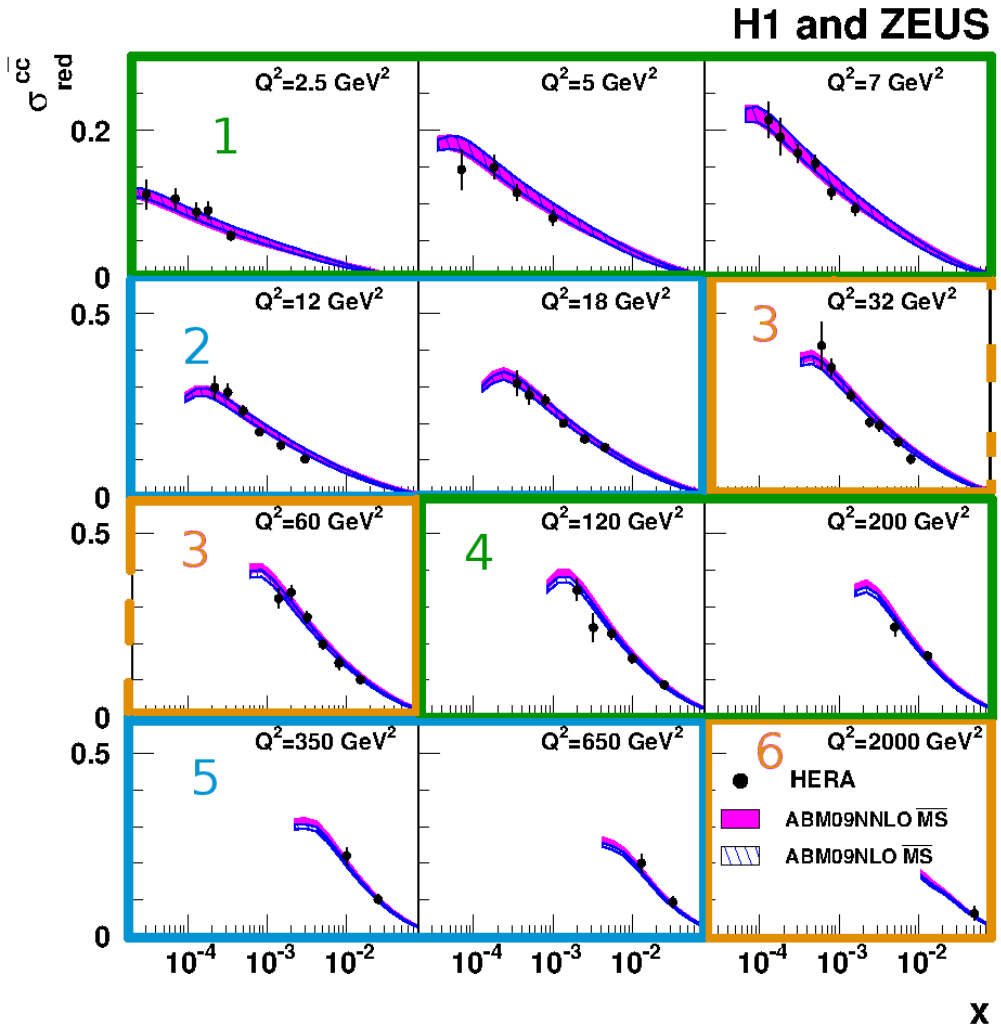
$$m_c^{\overline{MS}}(m_c) = 1.26 \pm 0.05_{exp} \pm 0.03_{mod} \pm 0.02_{param} \pm 0.02_{\alpha_s} \text{ GeV}$$

PDG value : $m_c^{\overline{MS}}(m_c) = 1.275 \pm 0.025$ GeV

Measurement of the charm quark mass running

Charm quark mass running demonstration needs a measurement of m_c at different scales.
$\rightarrow$ use charm data from different Q^2 regions.
Technically OpenQCDRad (code that is used for QCD predictions) returns $m_c(m_c)$ value. However physically we measure m_c at the scale of used data, so translation back from $m_c(m_c)$ to actually measured $m_c(\mu)$ required.

Measurement of the charm quark mass running



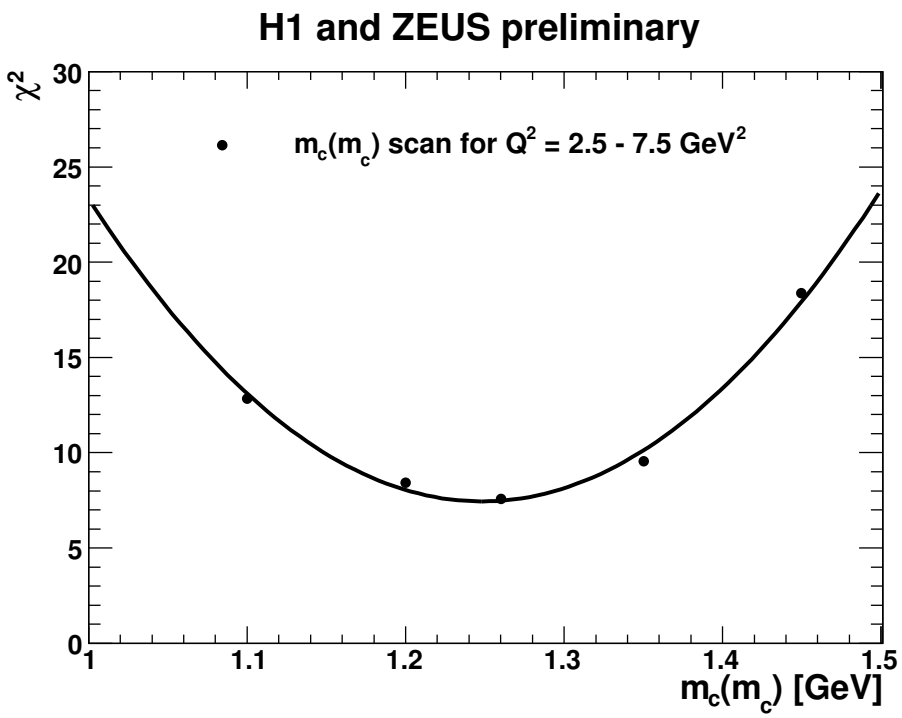
Combined data are grouped into 6 subsets choosing bins close in Q^2

Scale was chosen as :

$\mu = \sqrt{Q^2 + 4m_c^2}$,

Measurement of the charm quark mass running

Procedure is similar to that of [Eur.Phys.J.C73 (2013) 2311] with following modifications:



- 1) PDFs for different $m_c(m_c)$ are extracted using the inclusive HERA-I data only
- 2) Calculate charm cross sections for each of the subsets based on these PDFs for different $m_c(m_c)$
- 3) Perform a χ^2 scan for each of the subsets

Uncertainties of m_c measurement

Fit uncertainty

- Was estimated by taking $\triangle\chi^2 = 1$ (dominant uncertainty)

Parametrisation

- Adding extra parameter in the PDF parametrisation

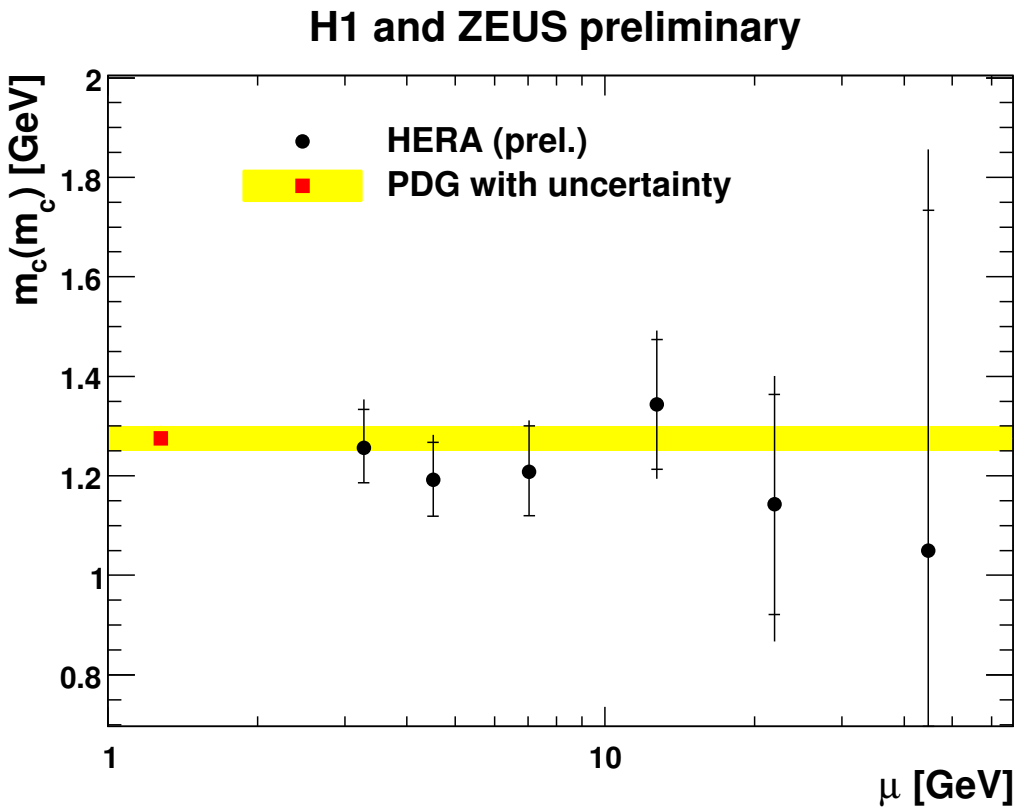
Model uncertainty

- Variation of the strangness supression factor
- Lower cut on Q^2 for inclusive data
- The evolution starting scale
- The b-quark mass

Theory

- Variation of α_s
- Variation of the factorisation and renormalization scales of heavy quarks by factor 2
  (were found to be one of the dominant systematical uncertainty)

Measurement of the charm mass at different scales



Red point - $m_c(m_c)$ PDG value (1.275), its uncert. represented by band, Black points - this measurement $m_c(m_c)(Q^2)$, full uncertanties with scales variation (outer error bars) and without (inner error bars)

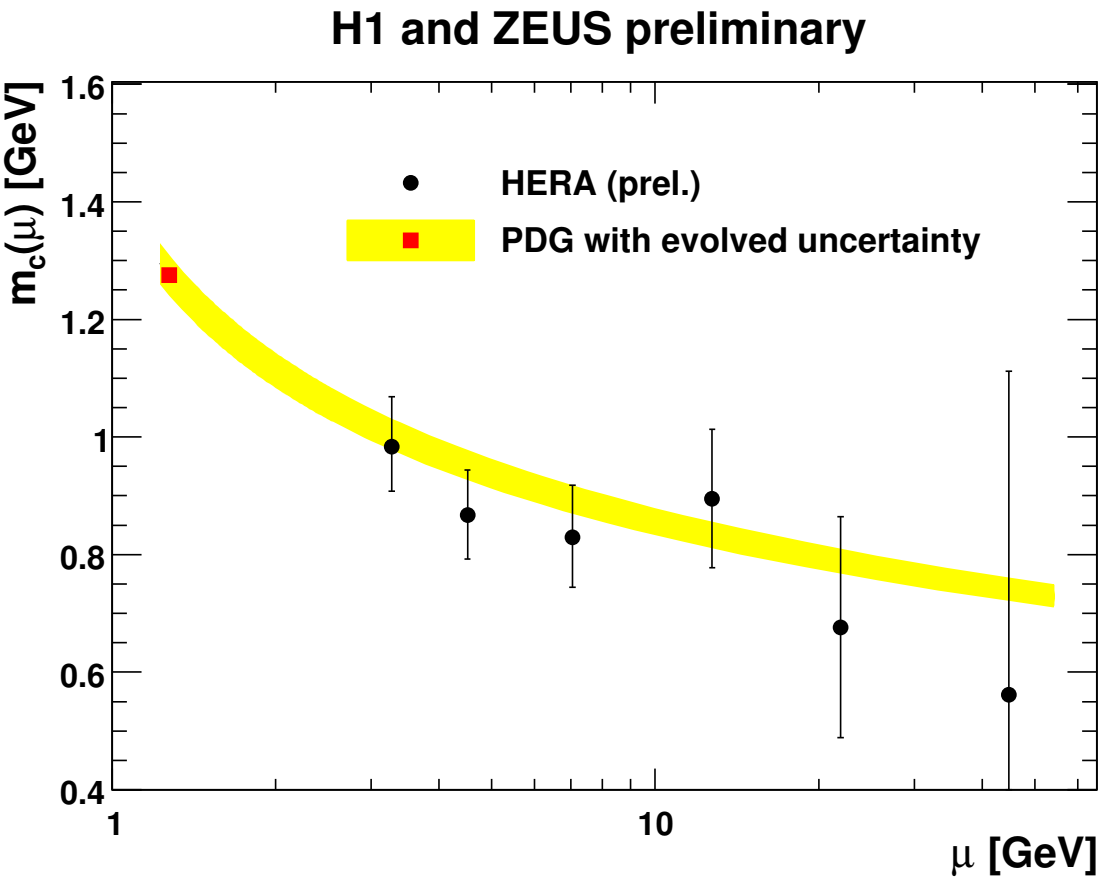
Measurement of the charm quark mass running

From $m_c(m_c)$ it was translated back to $m_c(\mu)$ by 1-loop formula :

$$m_c(\mu) = m_c(m_c) \frac{\left(\frac{\alpha_s(\mu)}{\pi}\right)^{\frac{1}{\beta_0}}}{\left(\frac{\alpha_s(m_c)}{\pi}\right)^{\frac{1}{\beta_0}}}$$

Where β_0 for N_f=3 is $\frac{9}{4}$
$\mu = \sqrt{Q^2 + 4m_c^2}$,
This formula is the same that is used in the QCD fit (OpenQCDRad).
[arXiv:hep-ph/0004189]
Q^2 was chosen to be log average between Q^2 of used bins

Measurement of the charm quark mass running



Red square - $m_c(m_c)$ PDG value (1.275), uncert. represented by band,
Black points - this measurement $m_c(\mu)$, $\mu = \sqrt{Q^2 + 4m_c^2}$

Summary

- **First measurement of the charm quark mass running has been presented based on HERA data**
- Measured charm masses are in good agreement with expected QCD evolution based on the PDG value
- It shows internal consistency of using running mass treatment in QCD

Charm mass measurement

- χ^2 mass scan had been performed by fitting charm data in FFNS ABM($\overline{MS}$) scheme (OPENQCDRAD program) using HeraFitter package with following setup:
  - FFNS ABM (running mass)
  - Evolution starting scale set to Q_0=1.4 GeV^2
  - PDF parametrisation with 13 parameters
  - H12011 χ^2 function definition
  - $\alpha_s(M_z)$=0.105
  - Data below $Q^2 = 3.5$ GeV^2 removed
  - $m_b(m_b)$ was set to 4.75
  - Renormalization and factorization scale was set to $\sqrt{Q^2 + 4m_q^2}$