Resolving the Proton's Flavour Contents with the LHeC

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DESY

- Introduction
- Strange quark
- Charm and beauty production
- Prospects for the top quark
- Summary

Note: some aspects covered in previous talk

Introduction: *ep* scattering

HERA:

$e^{\pm}$(27.5 GeV), p(460-920 GeV)

$\sqrt{s}$ = 225-318 GeV

~0.5 fb^{-1} luminosity (H1 and ZEUS)

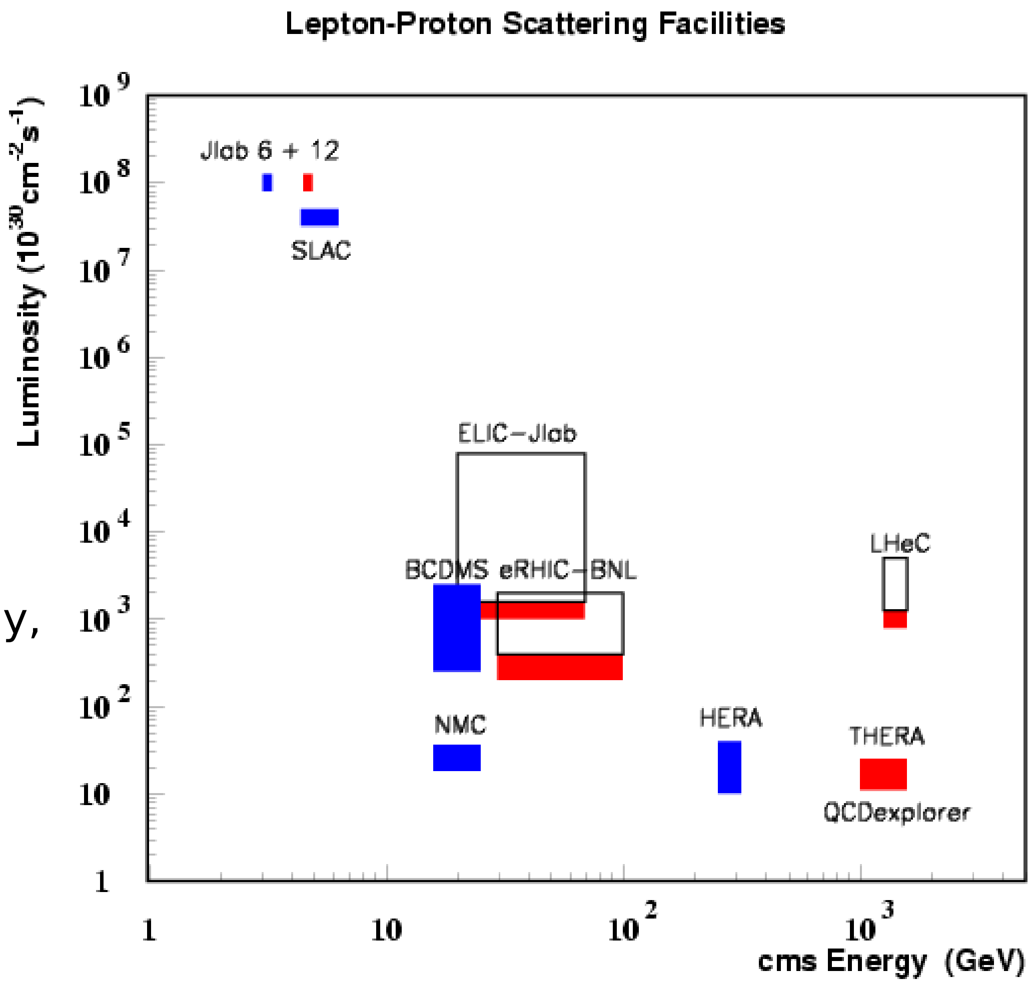
LHeC:

→ highest energy and luminosity

O(100) fb^{-1} luminosity

→ tiny beam spot,
dedicated vertex detector technology,
no pile-up

→ ideal for resolving flavour content and precision pQCD tests



Strange Quark

Strange is one of the least known quarks

→ constraints from fixed target data (NuTeV, CCFR), used in global PDF fits

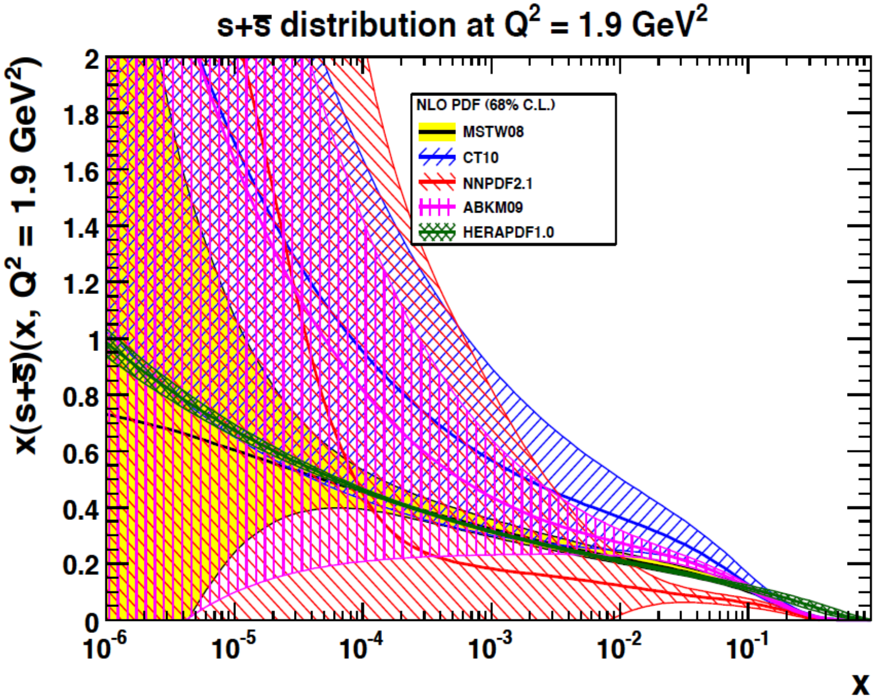
→ with W,Z data Atlas measures $r_s = 0.5(s+\bar{s}/\bar{d}) = 1$, i.e 'unsuppressed' s

→ LHC data will provide further constrains (W+charm, DY)

LHeC:

→ will allow for precision measurements of s quark

→ s and $\bar{s}$ measurement ($W^+ s \rightarrow c$, $W^- \bar{s} \rightarrow \bar{c}$)



Strange Quarks at LHeC

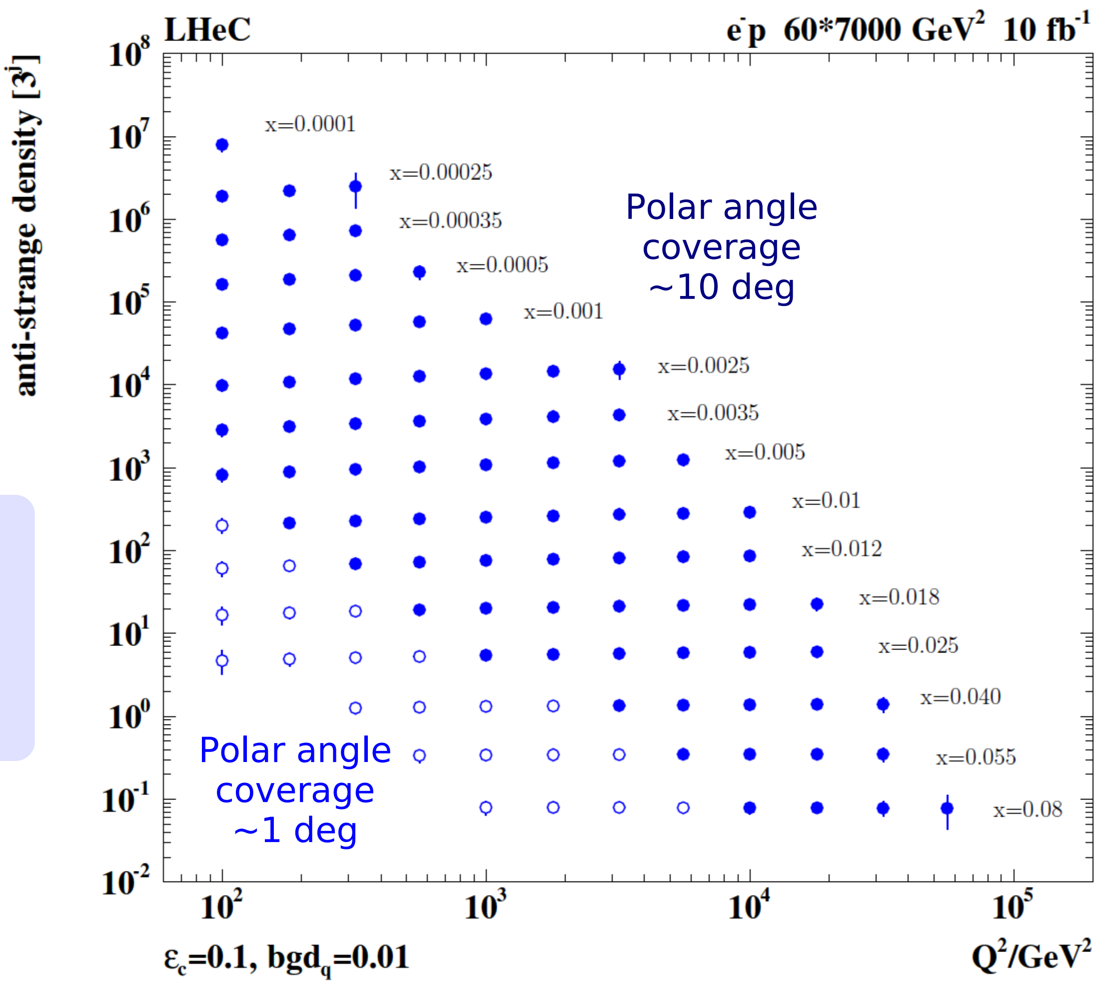
Simulated measurement of the anti-strange quark density in CC e^-p scattering with charm tagging at the LHeC with L = 10 fb^{-1}

→ $\bar{s}$ measurement

$W^- \bar{s} \rightarrow \bar{c}$

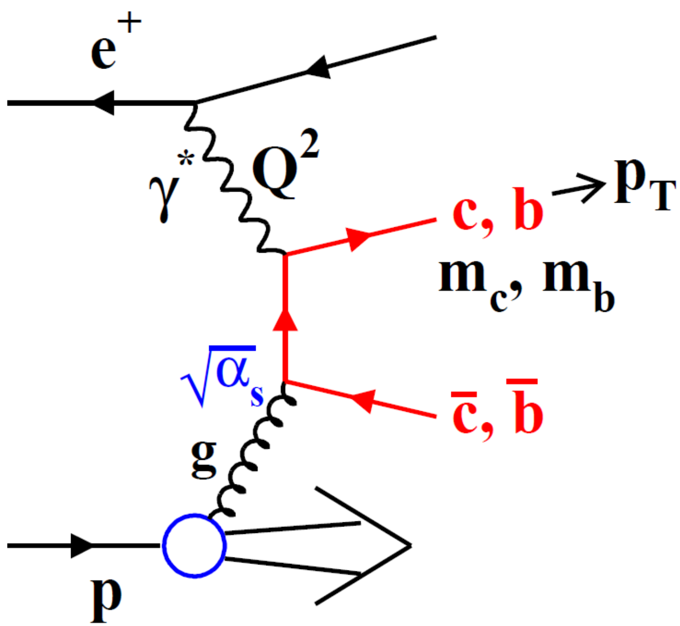
(similar for s)

LHeC provides a possibility for precise s quark density measurements for the first time



Charm and Beauty Production

LO production at DIS
(boson-gluon-fusion BGF):



Direct access to the gluon

Different prescriptions how to treat heavy quarks in *PDF fits* (HQ schemes):

Fixed Flavour Number Scheme (FFNS)

c(b) quarks massive, only light flavours in the proton

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

matched scheme, different implementation used by fit groups

Zero-Mass Variable Flavour Number Scheme (ZMVFNS)

all flavours massless (breaks at $Q^2 \sim m_{HQ}^2$)

Heavy quark treatment in PDFs is important

Heavy Quark treatment in QCD analysis

LHeC heavy flavour data will help:

→ constrain gluon density

→ study heavy quark densities in the proton

(at $Q^2 >> m_c^2, m_b^2$ the F_2^{cc} and F_2^{bb} can be directly related to c, b densities)

→ help to understand VFN schemes

(treatment of heavy quarks in different schemes, m_c and influence on α_s)

→ study intrinsic charm component

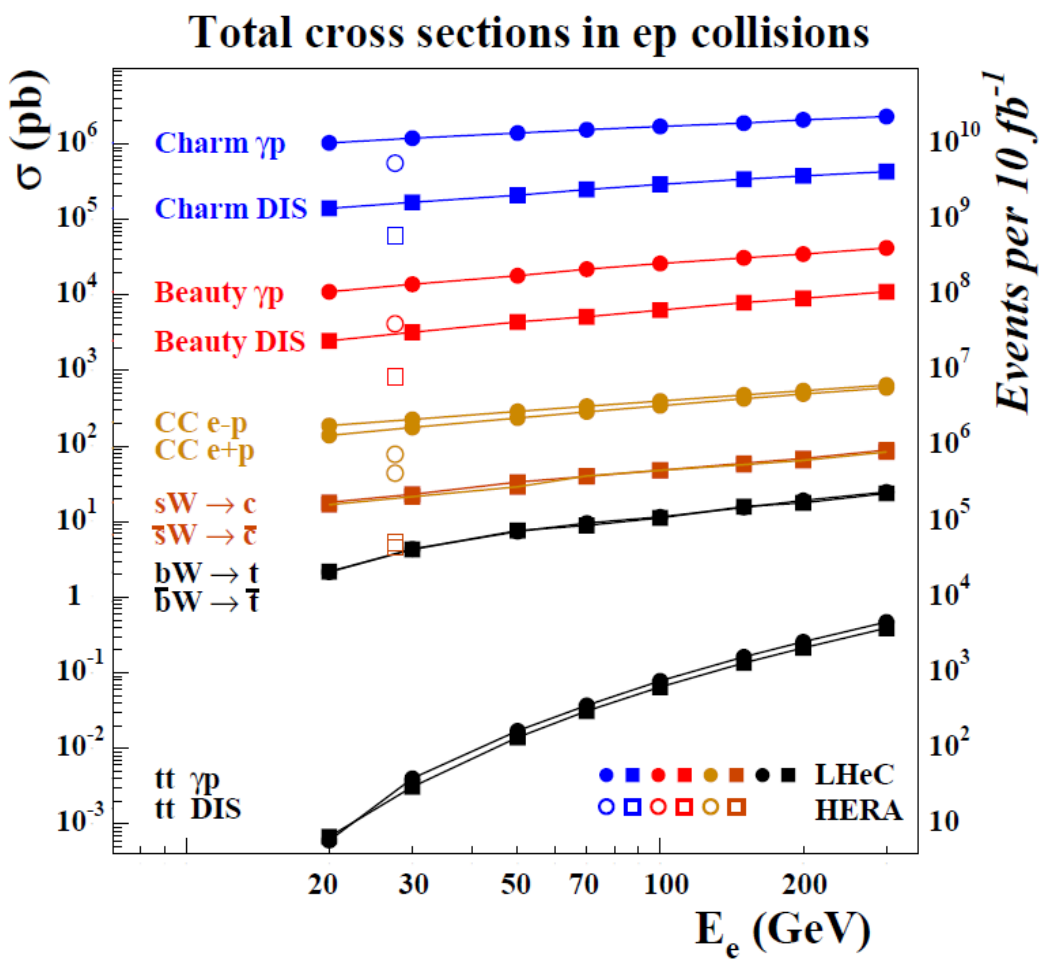
→ measure electroweak parameters

Heavy Quarks

Total production cross section predictions for heavy quark processes at LHeC

simulation:

Process	Monte Carlo	PDF
Charm γp Beauty γp tt γp	PYTHIA6.4 [145]	CTEQ6L [146]
Charm DIS Beauty DIS tt DIS	RAPGAP3.1 [147]	CTEQ5L [148]
CC e^+p CC e^-p $sW \to c$ $\bar{s}W \to \bar{c}$ $bW \to t$ $\bar{b}W \to \bar{t}$	LEPTO6.5 [149]	CTEQ5L
tt DIS	RAPGAP 3.1	CTEQ5L



→ access to all quark flavours with high statistics

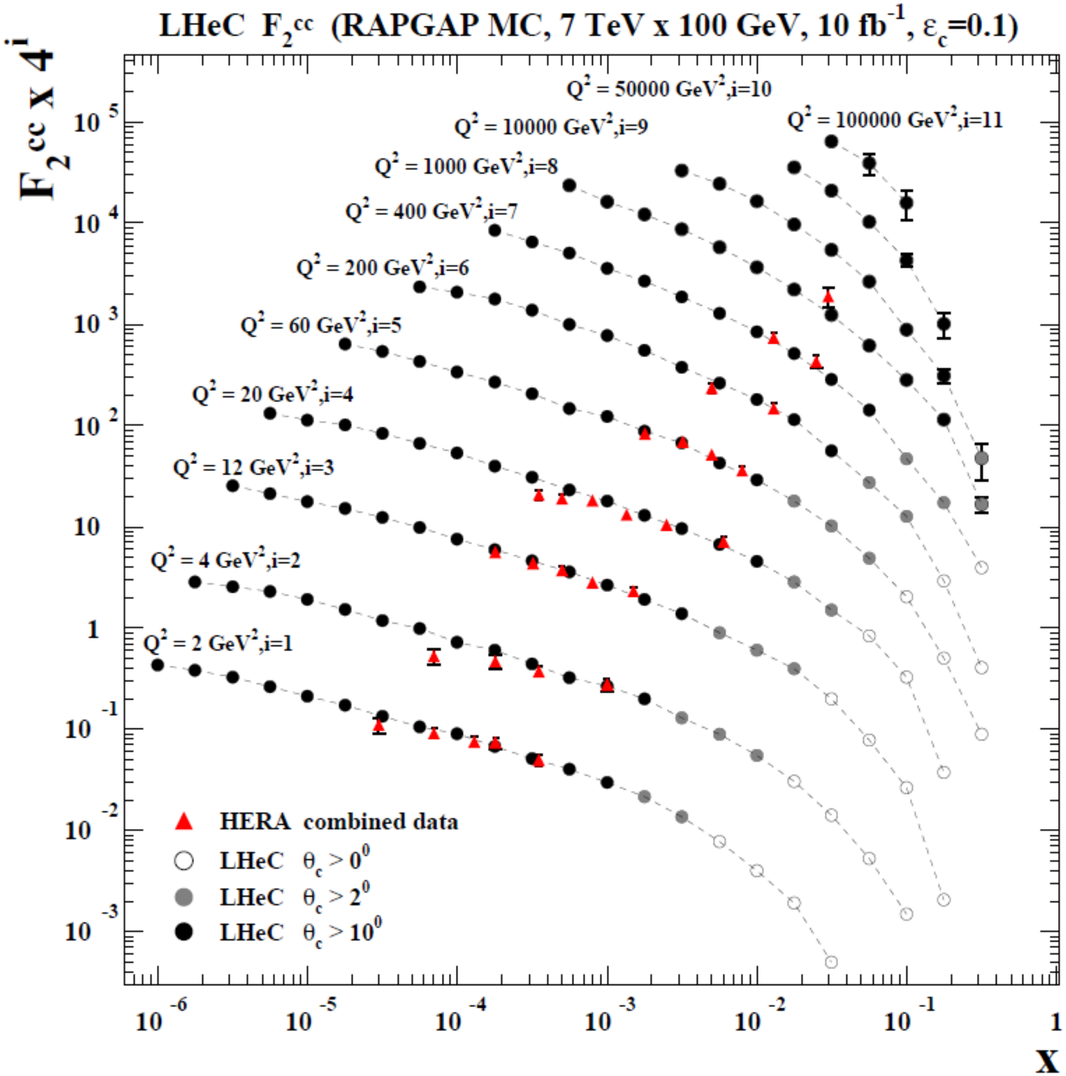
Charm Production

F_2^{cc} simulation obtained with the RAPGAP MC

compared to combined H1-ZEUS charm data (precision 5-10%)

LHeC: significantly improved tagging efficiency, more L

→ hugely extended phase space at LHeC !



PDF fits and m_c

VFNS combines the advantages of FFNS at low Q^2 with ZM-VFNS at high Q^2 range

→ certain arbitrariness in the interpolation region (different implementations exist)

→ charm production data can help to estimate the sensitivity to m_c which enters into QCD fits

→ have significant implications for W and Z cross section predictions at LHC

(see e.g. Eur. Phys. J. C73 (2013) 2311)

Study using:

- HERA inclusive+ F_2^{cc} data
- LHeC inclusive + F_2^{cc} simulation

Data input	Experimental uncertainty on m_c [MeV]
HERA: NC+CC	100
HERA: NC+CC+ F_2^{cc}	60
LHeC: NC+CC	25
LHeC: NC+CC+ F_2^{cc}	3

LHeC data improve the uncertainty from the inclusive HERA data by a factor of 4

→ adding F_2^{cc} reduces uncertainty to 3 MeV !

Potential for similar measurements with b quarks

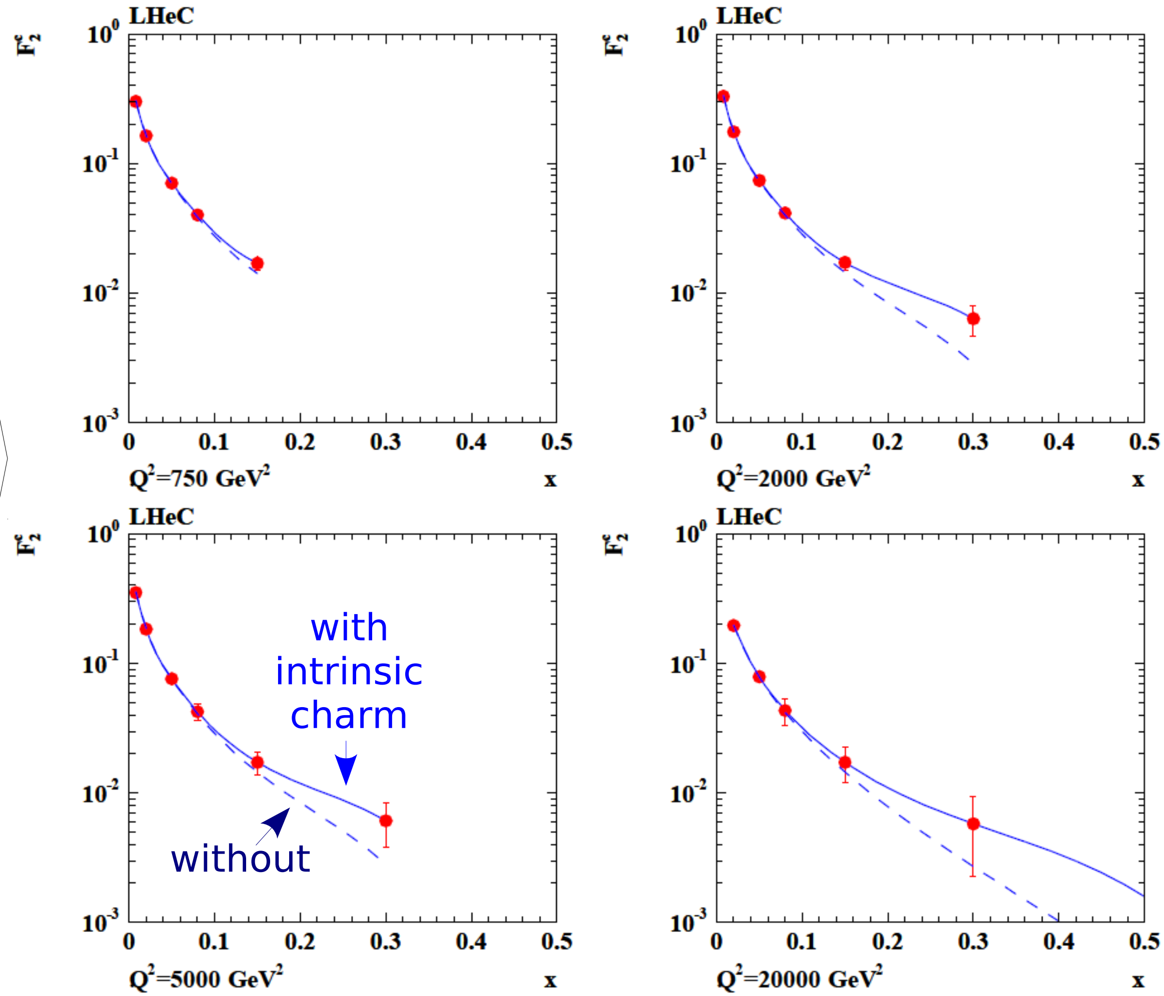
Intrinsic Charm

Intrinsic charm: existence of $c\bar{c}$ pair as non-perturbative component in the bound state nucleon (Fock state components such as $|uudc\bar{c}>$)

→ may explain certain aspects of the charm data and dominate in some regions of the phase space

for large x very good forward tag acceptance needed (possible with reduced E_p)

simulated measurement of the charm structure function (E_p=1 TeV, L=1 fb^{-1}, CTEQ66)



→ reliable detection of an intrinsic heavy charm component challenging but possible

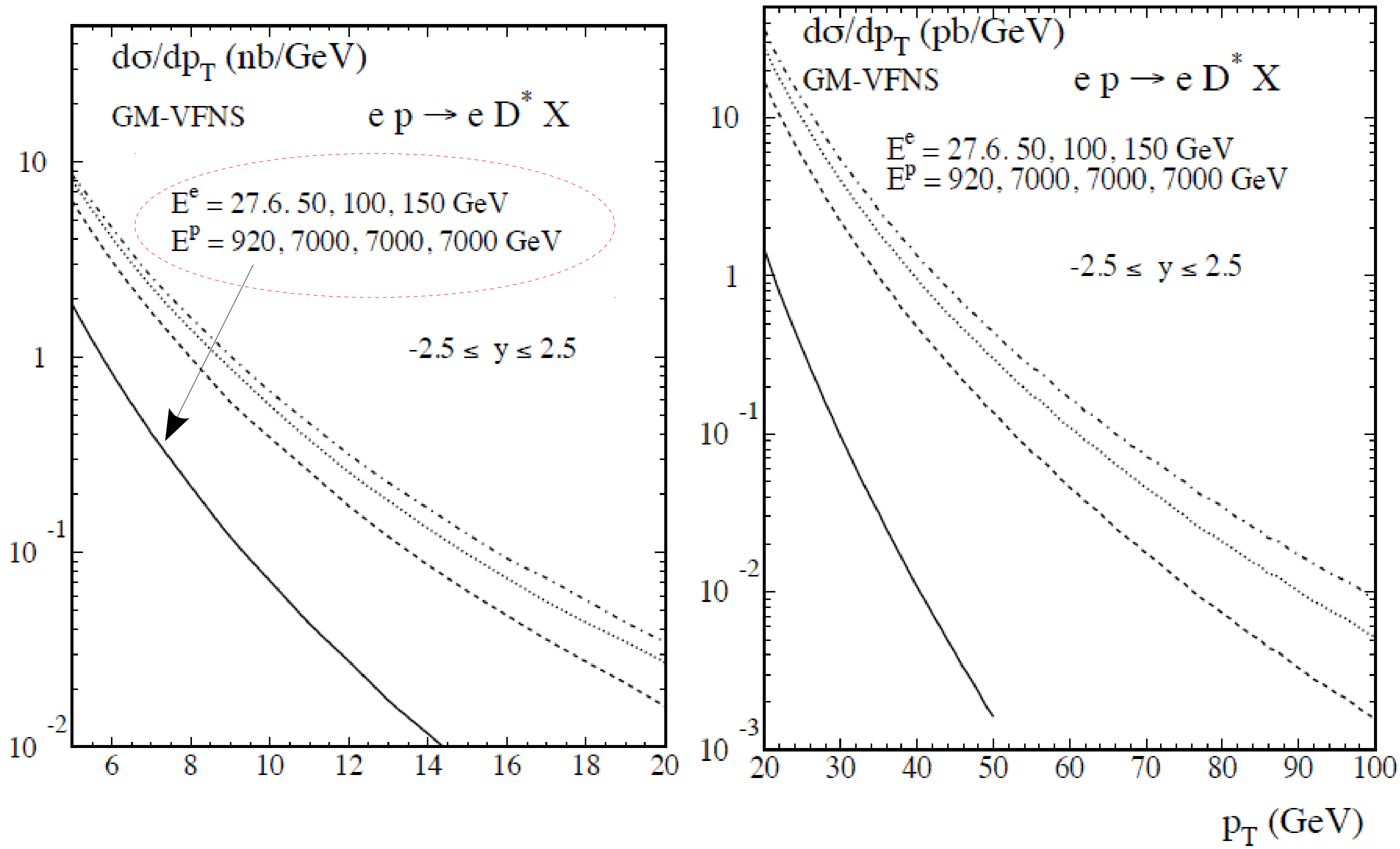
Charm Production

D* meson photoproduction study (based on GM-VFNS)

direct and resolved photon contributions are taken into account

considerable increase of the cross sections as compared to HERA

(much higher charm P_t and η accessible)



Allow stringent tests of the treatment of heavy quark mass dependent terms in pQCD

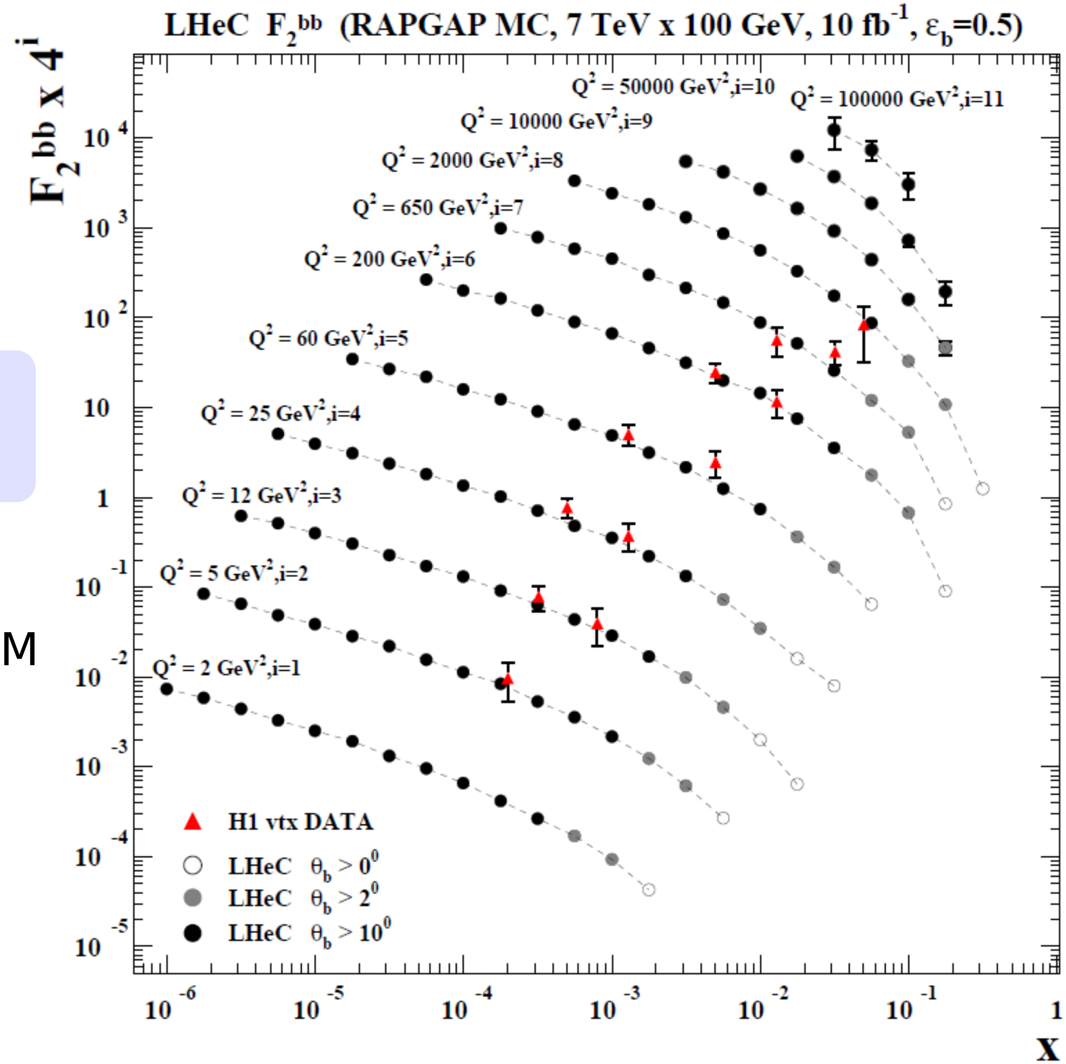
Beauty Production

F_2^{bb} simulation obtained with the RAPGAP MC

compared to combined H1 data (precision 20-50%)

→ precision measurements with hugely extended phase space

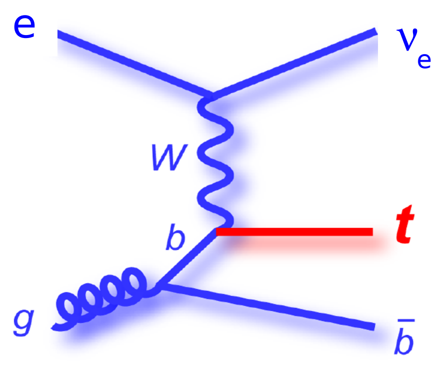
important for e.g. Higgs in MSSM (JHEP 0601:069, 2006)



Top Quarks at LHeC

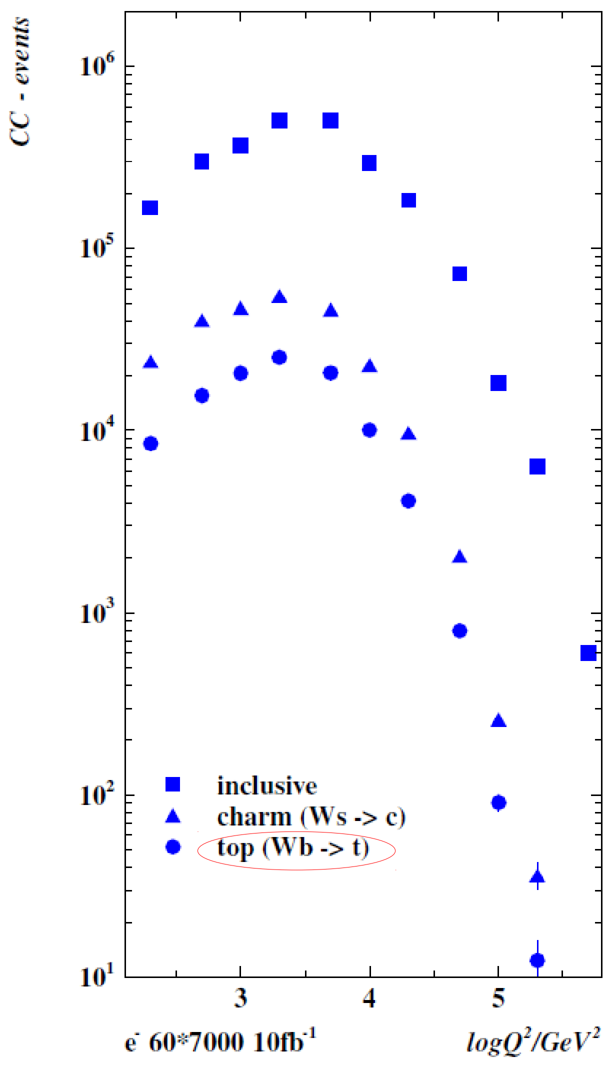
Top quarks can be studied in DIS (negligible cross section at HERA)

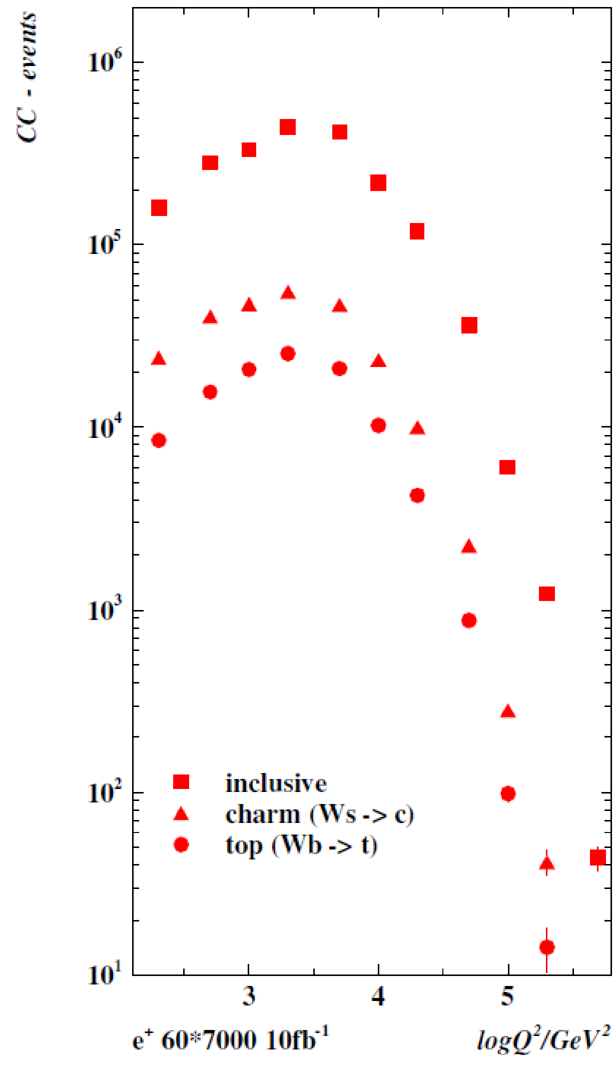
CC: Wb → t production
(cross section O(10pb))



NC: ttbar pair production

t and ttbar physics with LHeC still to be studied: precision measurement of top mass, top PDF, ...





Summary

LHeC is ideal for resolving the flavour content and precision pQCD tests

→ will allow for precision measurements of s and sbar

→ significant extension in kinematics for charm and beauty measurements

allows for pQCD tests, study g and heavy quark densities in the proton, intrinsic charm, study different flavour schemes in PDF and measure electroweak parameters

→ for the first time study top quark in DIS

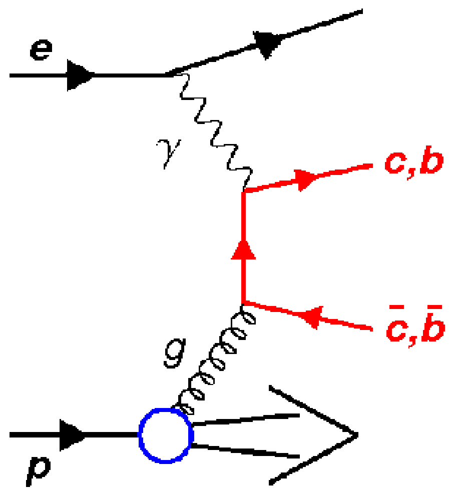
LHeC is a flavour factory

Back-up slides

Inclusion of Charm Data

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

LO charm production at DIS (boson-gluon-fusion):



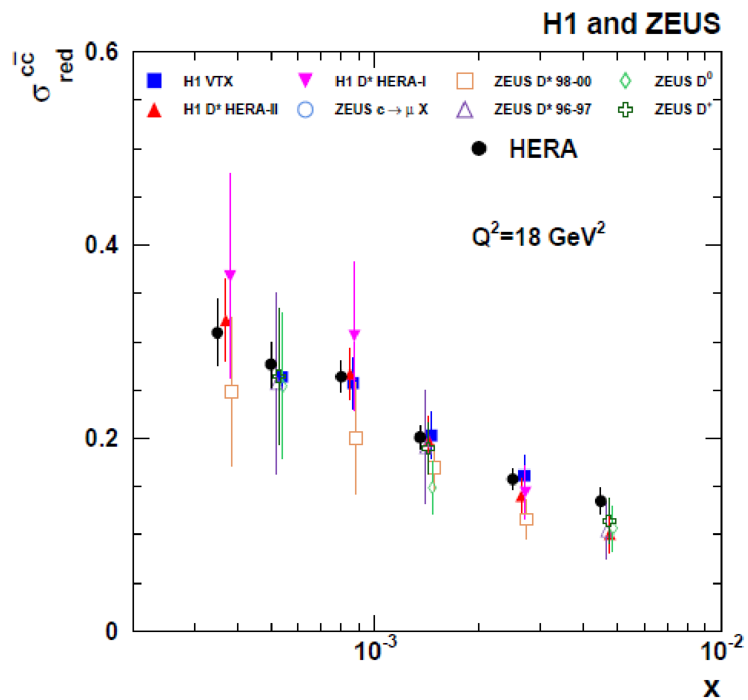
Direct access to the gluon

Heavy quark (HQ) treatment in PDFs is important

Useful to study the influence of different heavy flavour schemes on the PDFs

Combined HERA charm measurement

→ combination of 9 H1 and ZEUS measurements

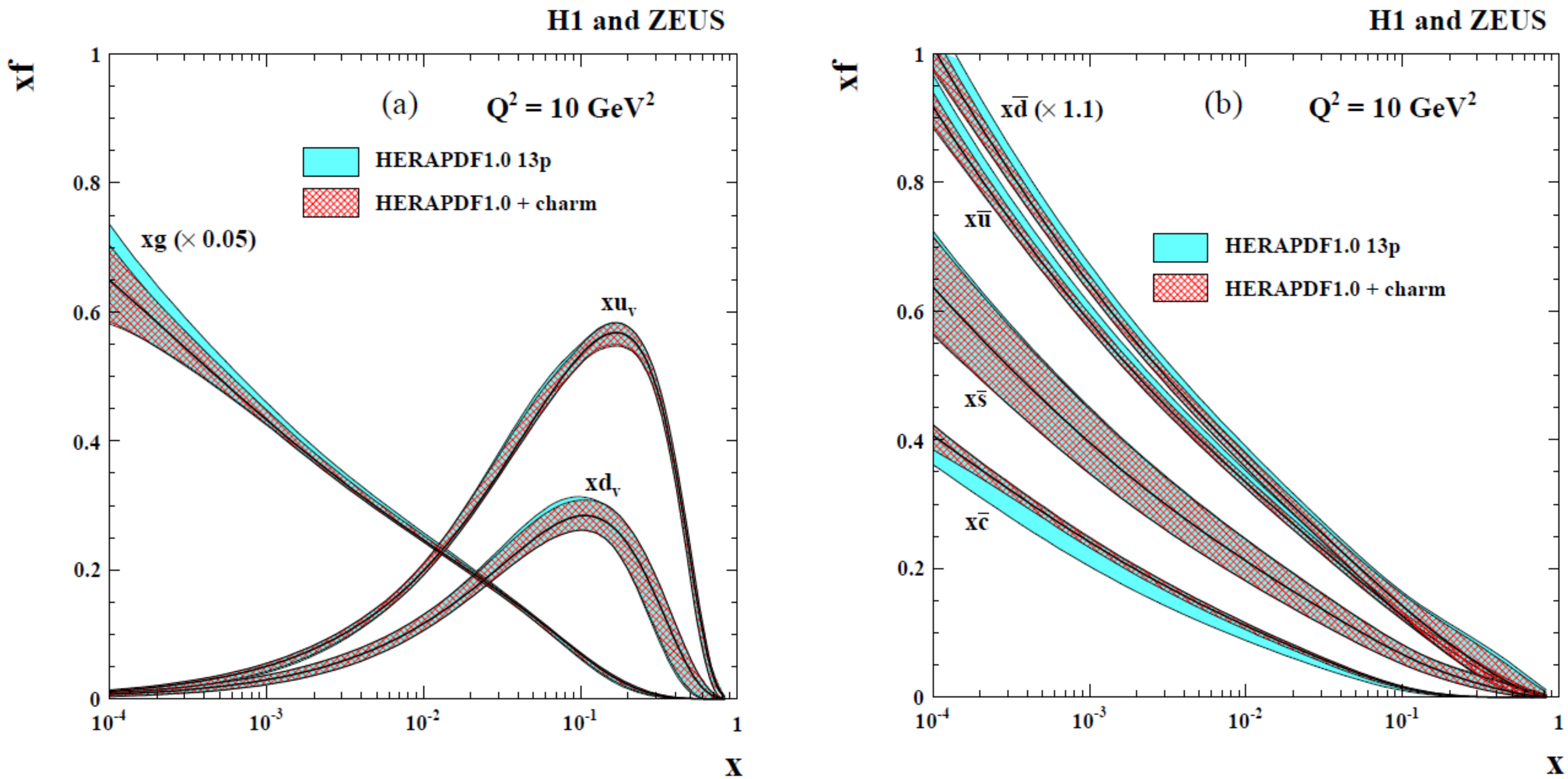


→ covers $2.5 < Q^2 < 2000$ GeV^2 and $10^{-5} < x < 10^{-1}$

→ 5-10% uncertainty

Charm Data: Impact on PDFs

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

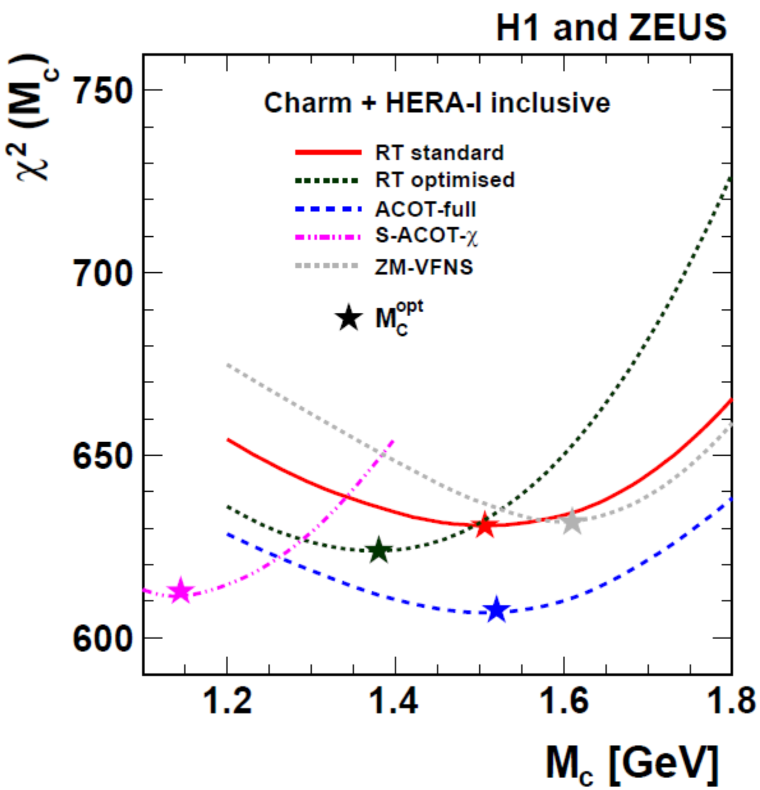


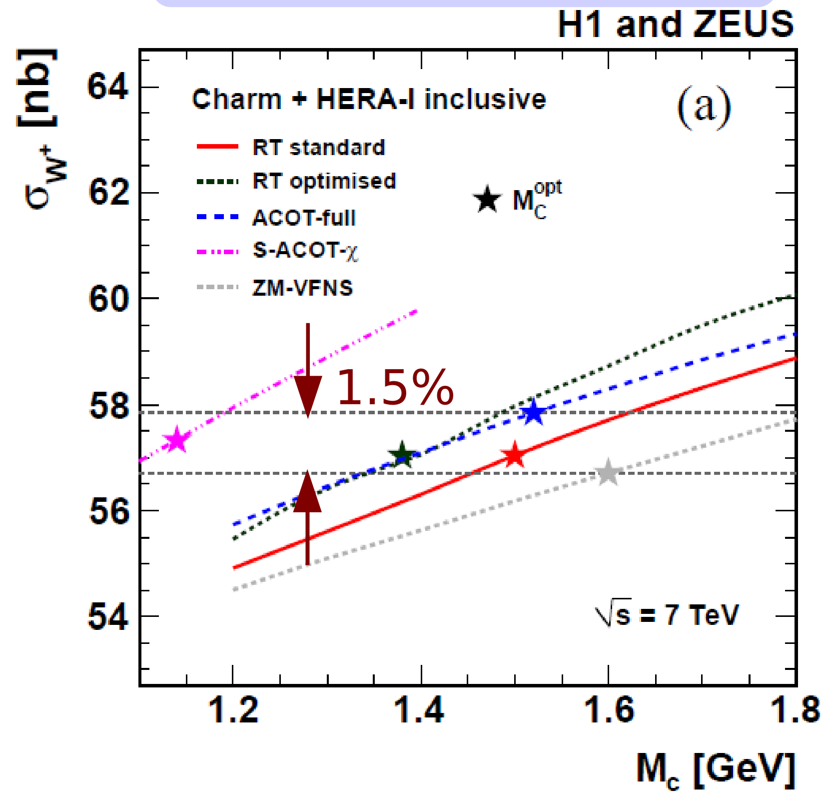
→ uncertainty on g(x), c(x) and light sea reduced
→ impact on Z, W production at LHC (next slide)

QCD Analysis of Charm Data

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

W+ cross section@LHC





Different schemes prefer different m_c^{model}

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

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

QCD Analysis of Charm Data

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

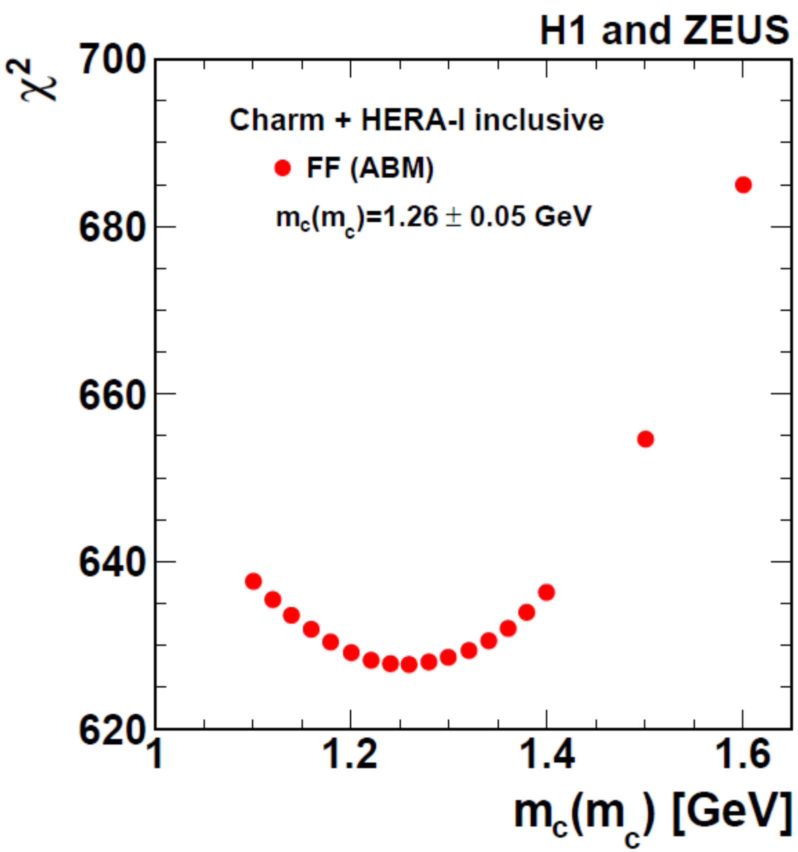
In VFN schemes the charm quark mass parameter M_c does not correspond directly to a physical mass

→ not the case for Fixed-Flavour Number Scheme (FFNS)

An NLO QCD analysis in the FFNS (FFNS of ABM, arXiv:1011.5790) performed to determine the $\overline{\text{MS}}$ running charm quark mass $m_c(m_c)$

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

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



Heavy Quark treatment in QCD analysis

Factorisation:

$$F_2^{V,h}(x,Q^2) = \sum_{i=f,\bar{f},g} \int_x^1 dz \cdot C_2^{V,i}\left(\frac{x}{z}, \frac{Q^2}{\mu^2}, \frac{\mu_F^2}{\mu^2} \alpha_S(\mu^2)\right) f_{i/h}(z, \mu_F, \mu^2)$$

i - number of active flavours in the proton m_c=1.5, m_b=4.7 GeV

QCD analysis of the proton structure: treatment of HQ essential

Different prescriptions how to treat heavy quarks in PDF fits (HQ schemes):

Fixed Flavour Number Scheme (FFNS) *i-fixed*

c(b) quarks massive, only light flavours in the proton i=3(4)

General-Mass Variable Flavour Number Scheme (GM-VFNS) *i-variable*

matched scheme, different implementation used by fit groups $\rightarrow m_c^{model}$

Zero-Mass Variable Flavour Number Scheme (ZMVFNS)

all flavours massless (breaks at $Q^2 \sim m_{HQ}^2$)

Charm and Beauty Production

LO charm production at DIS
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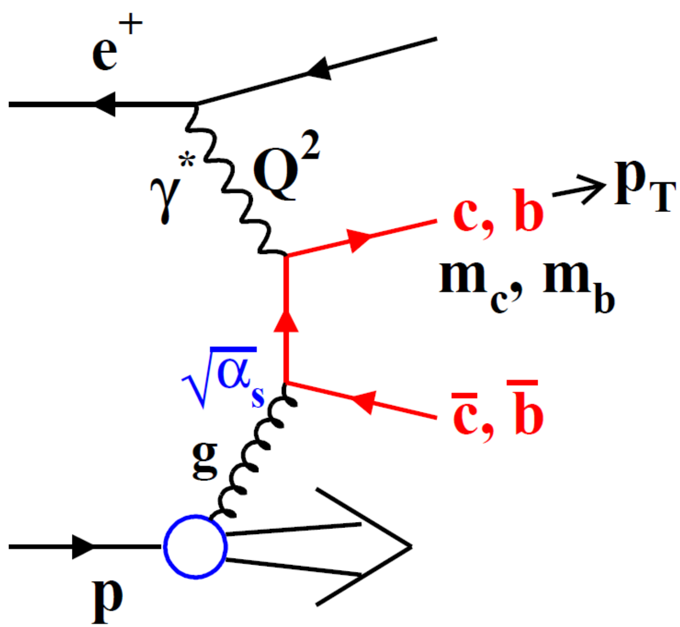
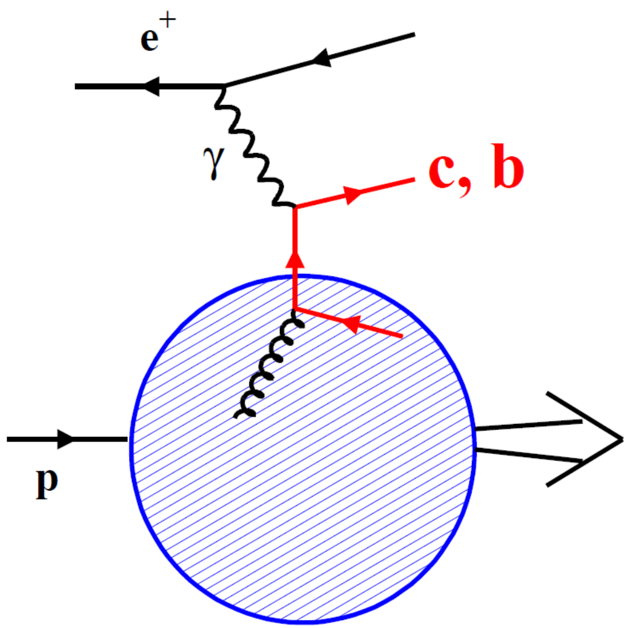


BGF: Massless approach
(ZM-VFNS)



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is important

Useful to study the influence of different heavy flavour schemes on the PDFs