Heavy Quark Distributions

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(CERN)
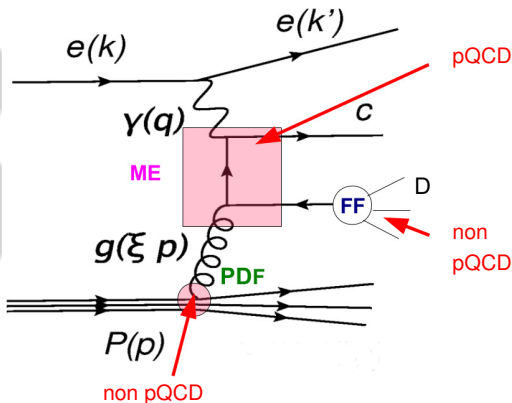
Heavy flavour (HF, charm & beauty) production in NC DIS

Test of pQCD (multiple hard scales: Q^2, $p_T(Q)$, m_Q)

Charm and beauty in DIS are predominantly produced via Boson-Gluon Fusion (BGF)

$$\boldsymbol{\sigma} = \textbf{PDF} \otimes \textbf{ME} \otimes \textbf{FF}$$

Production is directly sensitive to g PDF in the proton and HQ masses

PDF: parton distribution functions
ME: (hard) matrix element
FF: fragmentation function & fraction

pQCD approximation of HF production

Fixed Flavour Number Scheme (FFNS)

- c,b-quarks are massive $\Rightarrow$ not in the proton, produced perturbatively in hard scattering
- appropriate for $Q^2 \sim m_{c,b}^2$, otherwise large logs

Zero Mass Variable Flavour Number Scheme (ZMVFNS)

- c,b-quarks are massless $\Rightarrow$ part of the proton
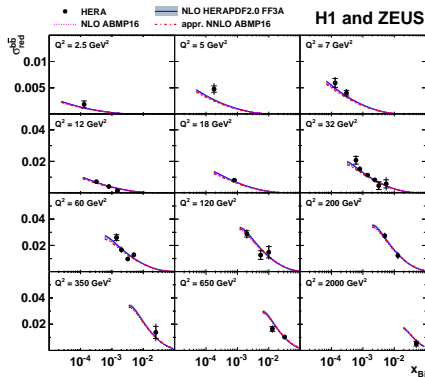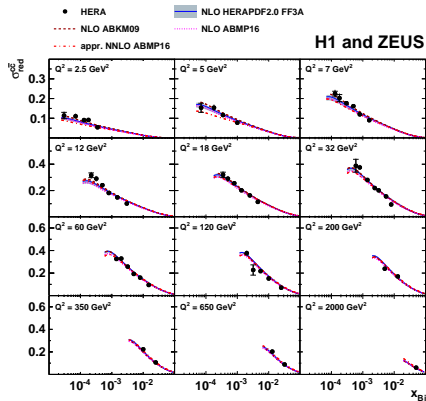- appropriate for $Q^2 \gg m_{c,b}^2$

General Mass Variable Flavour Number Scheme (GMVFNS)

- equivalent to FFNS at low Q^2
- equivalent to ZMVFNS at high Q^2
- not unique (RT, ACOT, FONLL, ...)

Final HERA data on charm and beauty production in NC DIS
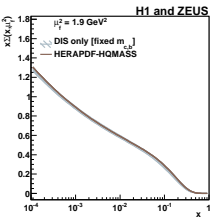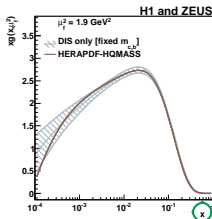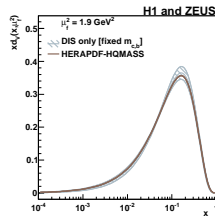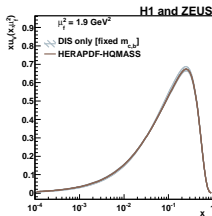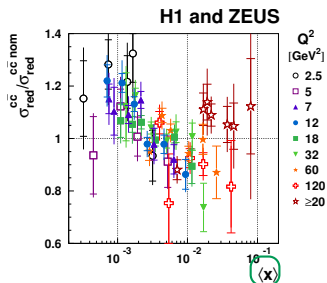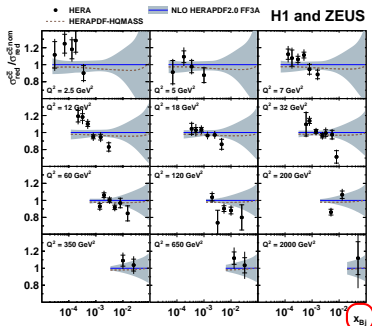

CHARM unc. ~ 5%

BEAUTY unc. ~ 15%

H1 and ZEUS Collaborations [Eur.Phys.J. C78 (2018) 473]

$$m_c(m_c) = 1290^{+46}_{-41}(\text{fit})^{+62}_{-14}(\text{mod})^{+3}_{-31}(\text{par}) \text{ MeV}$$

$$m_b(m_b) = 4049^{+104}_{-109}(\text{fit})^{+90}_{-32}(\text{mod})^{+1}_{-31}(\text{par}) \text{ MeV}$$

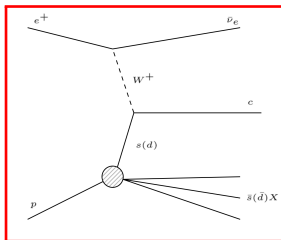⇒ **determined precise HQ masses consistent with world average**

QCD analysis of combined charm and beauty data: PDFs

- $x_{Bj} \neq x$ for BGF!
- small impact of HERA HF data on PDFs (once m_c, m_b are fixed)
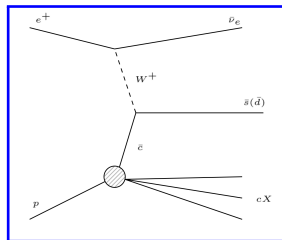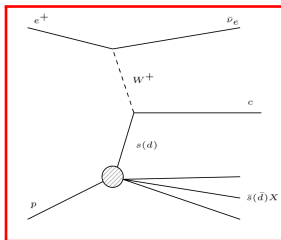- difference in x slope persists after fit

limited precision ($< 3\sigma$) $\Rightarrow$ LHeC will improve

- direct probe of strange PDF

- direct probe of strange PDF
- only in VFNS

Charm production in Charged Current (CC) at HERA
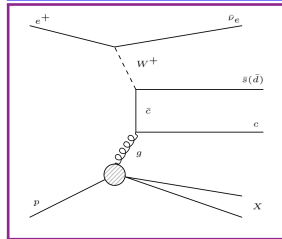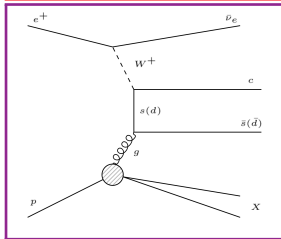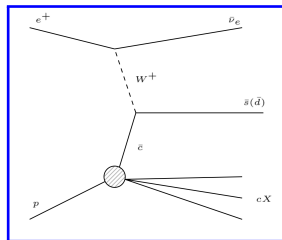
- direct probe of strange PDF
- only in VFNS
- higher-order $O(\alpha_s)$ correction
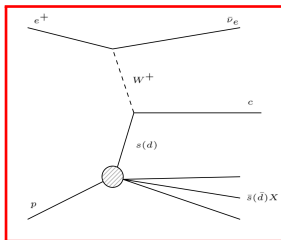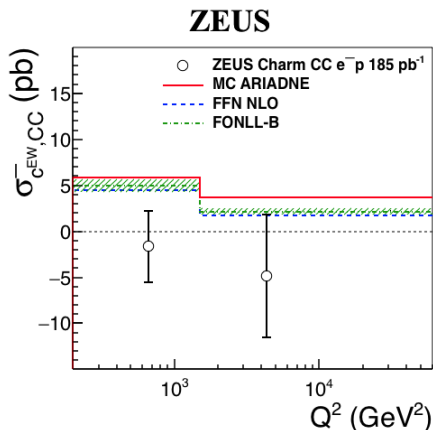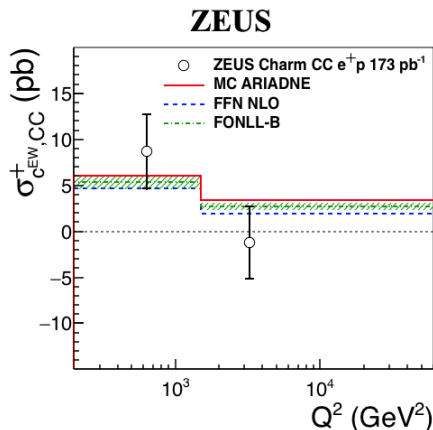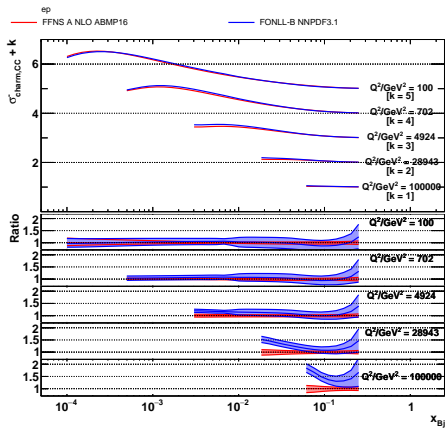
Charm production in Charged Current (CC) at HERA

ZEUS Collaboration [JHEP 1905 (2019) 201]

- Limited statistics does not allow to constrain PDFs or test different HF schemes
- **Can be done at LHeC?**

Charm production in Charged Current (CC) at LHeC
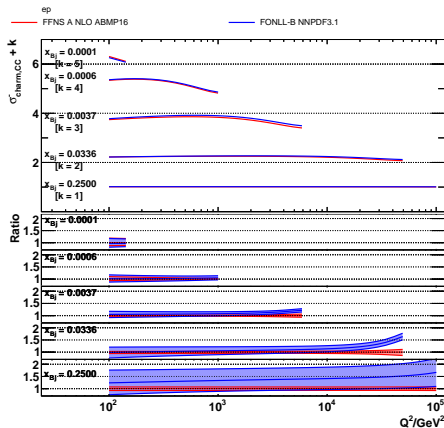
xFitter [arXiv:1907.01014, accepted by EPJ C]

- Compared NLO QCD predictions in different HF schemes
- 'FFNS A' (ABMP16) and 'FONLL-B' (NNPDF3.1) differ at large Q^2, small or large x_{Bj}
- We looked at PDF and scale variation uncertainties separately, also at approximate NNLO

Charm production in Charged Current (CC) at LHeC
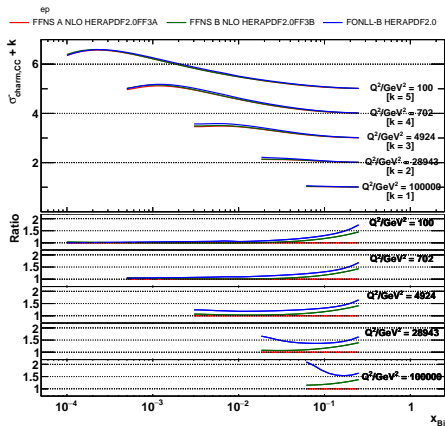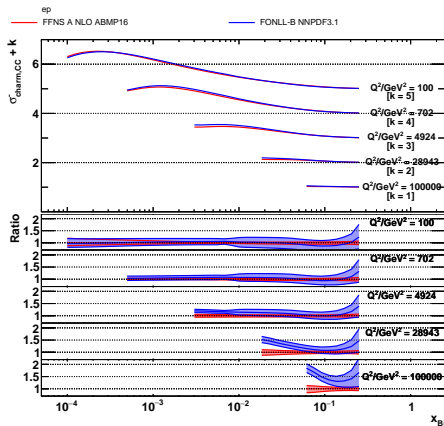

- Part of differences between VFNS and FFNS is captured by variable-flavour α_s running:
  → **hybrid 'FFNS B' scheme** (used in HERAPDF2.0FF3B PDF fit available at LHAPDF)

Partonic subprocesses for charm production in CC
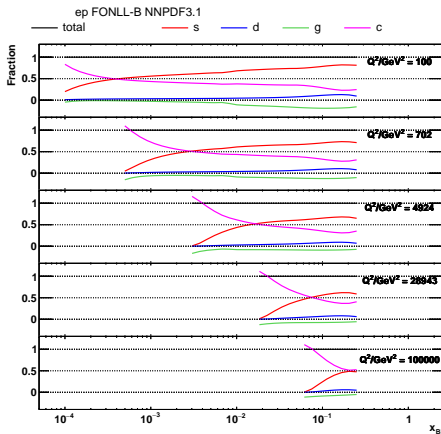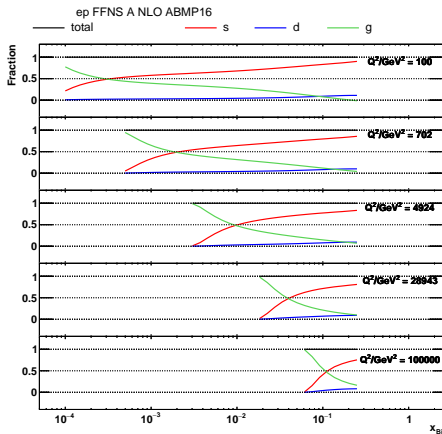
- **gluon** in FFNS $\sim$ **charm** in VFNS
- **strange** contributes only $\sim 50\%$, it is suppressed at low x_{Bj} (large y):

$$y \to 0 : \quad \sigma^{\pm}_{charm,CC} = F_2^{\pm} = xD(x\bar{D}) + x\bar{U}(xU)$$
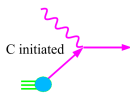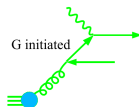$$y \to 1 : \quad \sigma^{\pm}_{charm,CC} = \frac{1}{2}(F_2^{\pm} \mp xF_3^{\pm}) = x\bar{U}(xU)$$

Can we constrain strange PDF by measuring charm CC at LHeC?
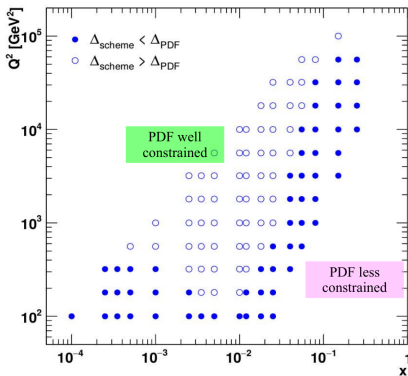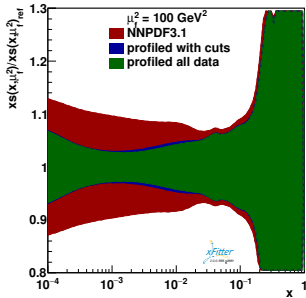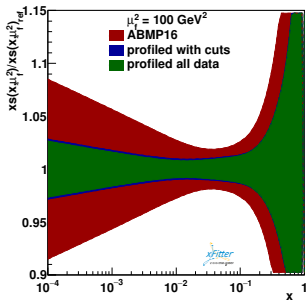
- PDF constraints are estimated using profiling technique in xFitter and two PDF sets: ABMP16 and NNPDF3.1
- strong improvement on strange PDF for both sets, even if reduced phase space is used to exclude points with lare differences between VFNS and FFNS

xFitter [xfitter.org]

- xFitter (HERAfitter before 2016) is open source QCD fit framework ready to extract PDFs, theory parameters, and assess impact of new data
  - various PDF parameterisations, theoretical processes and schemes, and data sets (> 50)
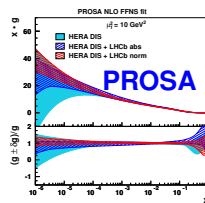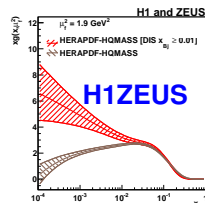   → unique such tool
- ~ 80 publications using xFitter (widely used by LHC community)
- **9** publications by xFitter developers team
- tutorials to get familiar with xFitter
  - presented at CMS Data Analysis School (DESY, September 2018)
- latest stable release xFitter-2.0.1 OldFashioned
  - give it a try www.xfitter.org

xFitter Workshop in Minsk, March 19

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New "PDF set" produced in 2 days using xFitter:

CMSDAS Hamburg 2018
CMS Data Analysis School

Parton Distribution Functions

D. Brzhechko, P. Gianneios, A. Oskin, P. Parygin, M. Schmitz

14 September 2018   CMS DAS 2018, Hamburg

Conclusions

- Determination of strong coupling depends on PDF sets
  - **PDFs are quite important**
- Important to know shape and uncertainties
- Important to include as much data as possible

- Jets improve gluon and allow α_s estimation
- W and Z data constrain u_v, d_v and sea quarks

xFitter Workshop in Minsk, March 19

- Heavy quark production in ep is excellent process to:
  - test different pQCD approaches to treat heavy quark masses ('QCD laboratory')
  - determine proton PDFs and heavy-quark masses
- HERA data on charm and beauty production in NC DIS had great impact on costraining quark masses in PDF fits
- HERA data on charm production in CC DIS is statistically limited to have any impact
- Measuring charm production in CC at **LHeC** would allow determining strange PDFs with great precision and further test different pQCD schemes
- xFitter is an actively developed and widely used tool for phenomenological studies

BACKUP

QCD analysis of combined charm and beauty data: PDFs
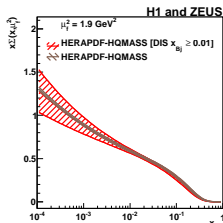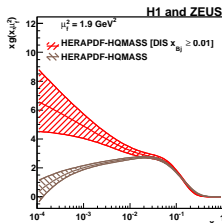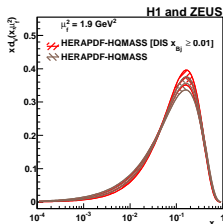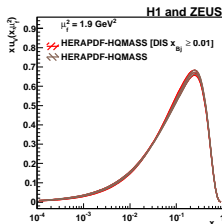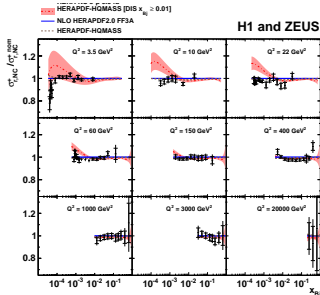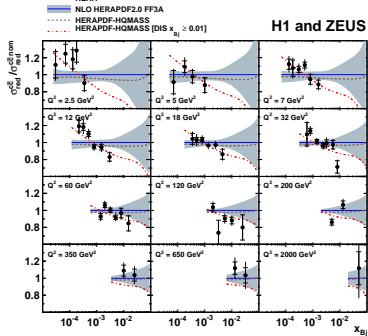
- cut $x_{Bj} > 0.01$ on inclusive data
- observed change for low x gluon:
- $\rightarrow$ better description of HF data
- $\rightarrow$ but worser description of (not fitted) inclus. data

limited precision ($< 3\sigma$) $\Rightarrow$ LHeC will improve