Recent results on heavy quark production at HERA

Oleksandr Zenaiev (DESY)
on behalf of H1 and ZEUS collaborations

- Preliminary results:

  https://www.desy.de/h1zeus/combined_results/index.php?do=heavy_flavours

  H1prelim-17-071, ZEUS-prel-17-01

  H1prelim-18-071, ZEUS-prel-17-01-extension

- Paper about to be released on arXiv

Rencontres de Moriond, QCD and High Energy Interactions
La Thuile, 17-24 March 2018

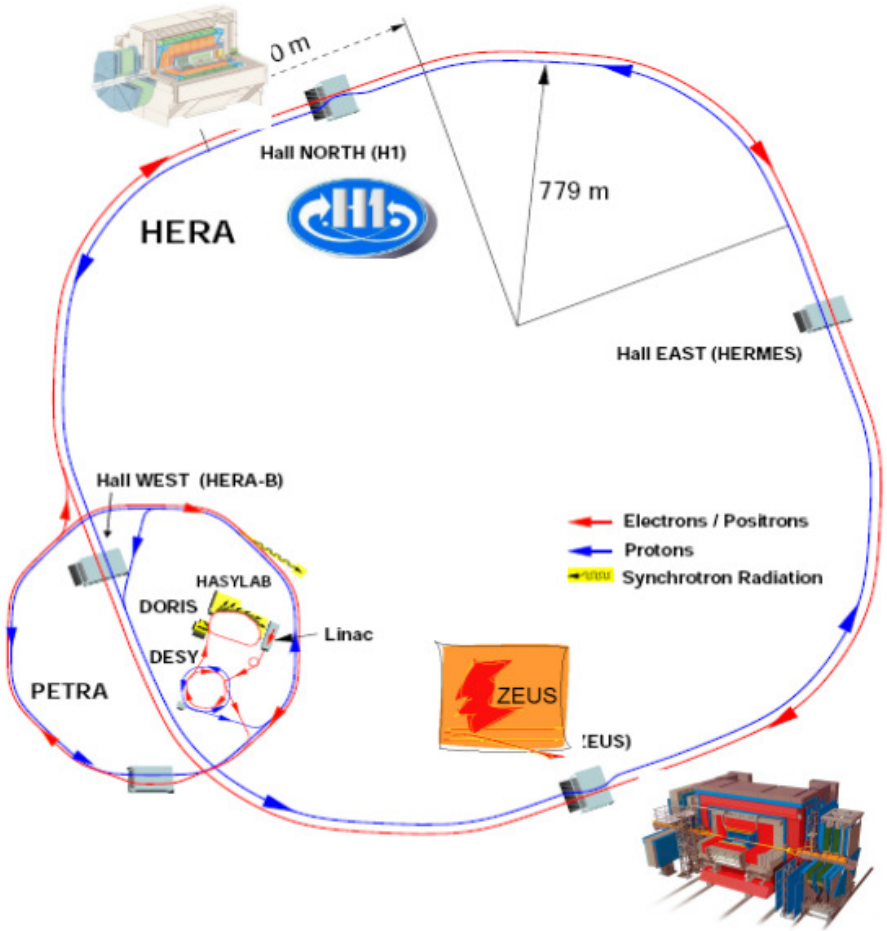
Experimental set-up

HERA Collider

- *ep* collisions
- $\sqrt{s} = 300 \ldots 318$ GeV and lower energy runs

H1 and ZEUS:

- 4π multipurpose detectors
- $\mathcal{L} \sim 500\ \mathrm{pb}^{-1}$ per each experiment



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

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

Kinematics

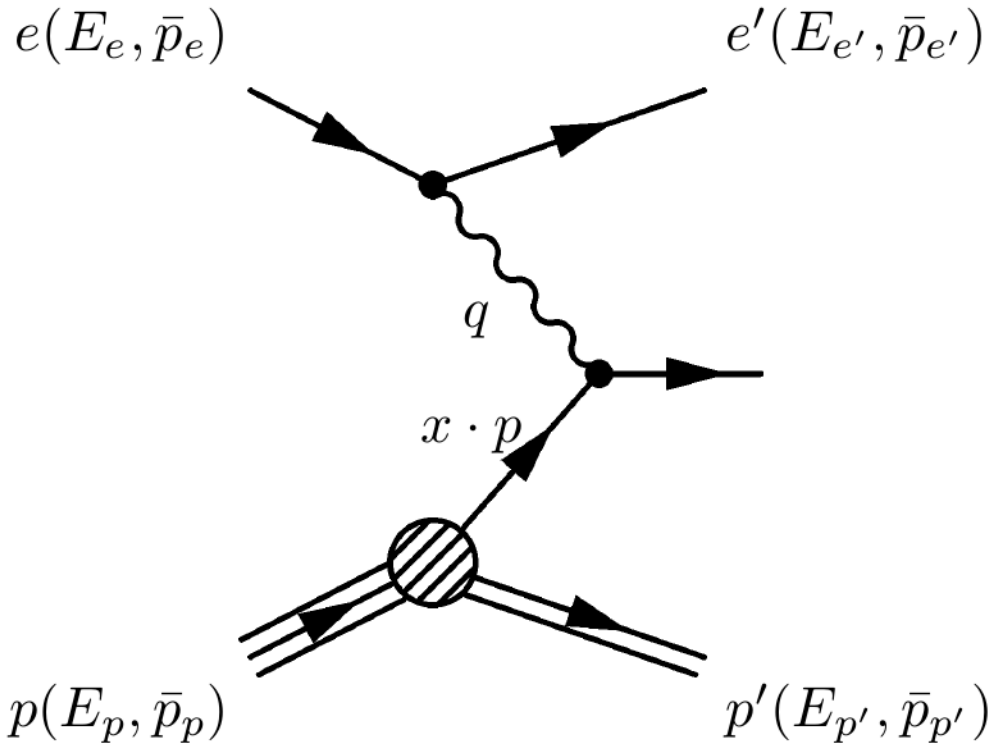
$$Q^2 = -q^2 = -(e - e')^2$$

$$x_{Bj} = \frac{Q^2}{2q \cdot p} \quad (= x \text{ in QPM})$$

$$y = \frac{q \cdot p}{q \cdot e}$$

$$s = (e + p)^2$$

$$Q^2 = s x_{Bj} y$$

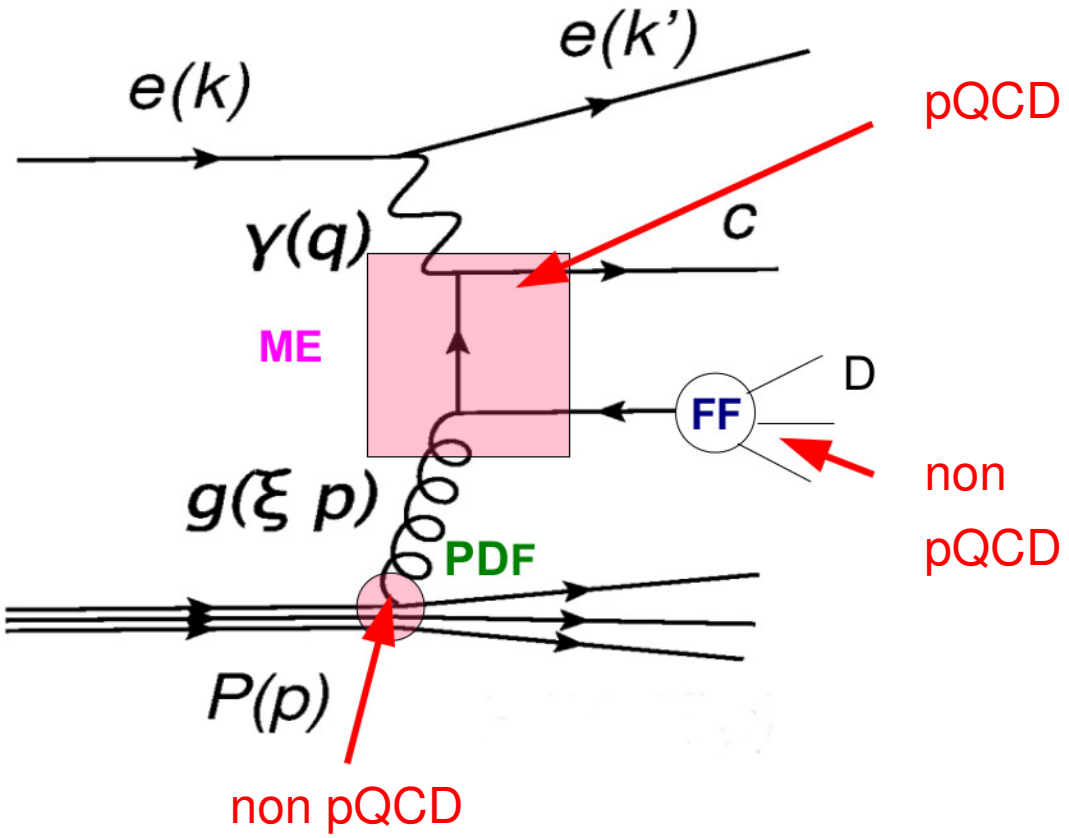


- Any two of the variables (Q^2, x_{Bj}, y) define kinematics
- $Q^2 > 1\ GeV^2$ — deep inelastic scattering (DIS)
- $Q^2 < 1\ GeV^2$ — photoproduction processes (PHP)

Heavy flavour (HF) production in 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)



$$\sigma = \mathbf{PDF} \otimes \mathbf{ME} \otimes \mathbf{FF}$$

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 heavy flavour production

Fixed Flavour Number Scheme (FFNS)

- c,b-quarks are massive $\Rightarrow$ not a part of the proton, produced perturbatively in hard scattering
- valid for $Q^2 \sim m^2_{c,b}$

Zero Mass Variable Flavour Number Scheme (ZMVFNS)

- c,b-quarks are massless $\Rightarrow$ a part of the proton
- valid for $Q^2 >> m^2_{c,b}$

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, ...)

detailed discussion in [EPJ C73 (2013) 2311]

Input data

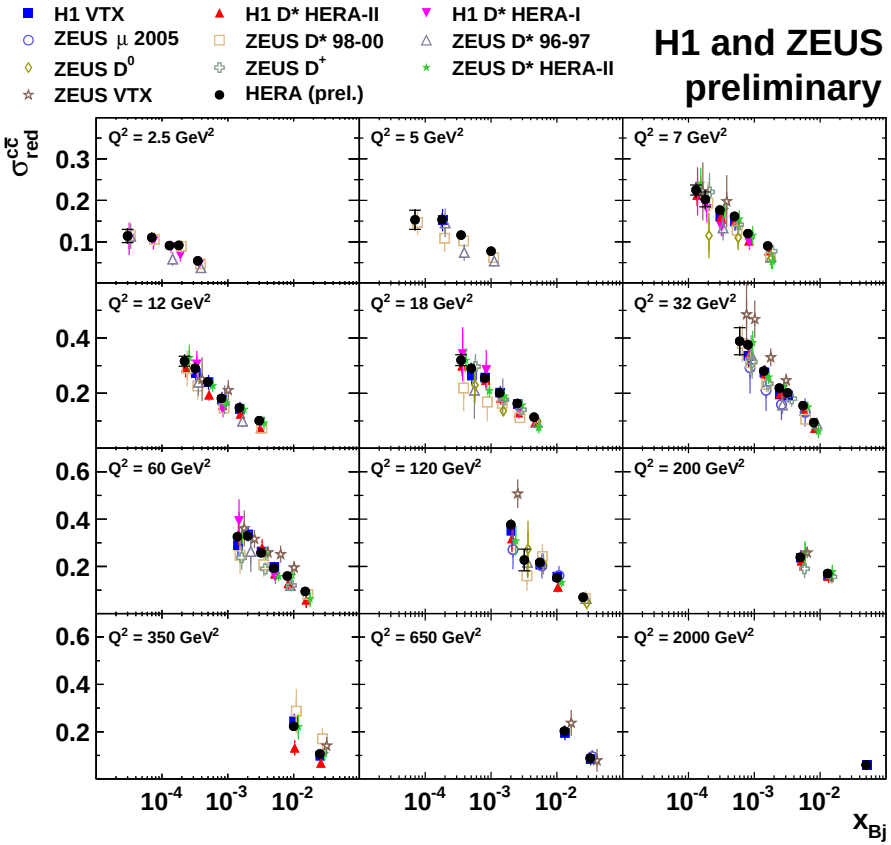
	Data set	Tagging	Q^2 range [GeV^2]	N_c	$\mathscr{L}$ [pb^{-1}]	$\sqrt{s}$ [GeV]	N_b
1	H1 VTX [8]	VTX	5 – 2000	29	245	318	12
2	H1 D^{*+} HERA-I [9]	D^{*+}	2 – 100	17	47	318	
3	H1 D^{*+} HERA-II (medium Q^2) [10]	D^{*+}	5 – 100	25	348	318	
4	H1 D^{*+} HERA-II (high Q^2) [11]	D^{*+}	100 – 1000	6	351	318	
5	ZEUS D^{*+} 96-97 [12]	D^{*+}	1 – 200	21	37	300	
6	ZEUS D^{*+} 98-00 [13]	D^{*+}	1.5 – 1000	31	82	318	
7	ZEUS D^0 2005 [14]	D^0	5 – 1000	9	134	318	
8	ZEUS μ 2005 [7]	μ	20 – 10000	8	126	318	8
9	ZEUS D^+ HERA-II [2]	D^+	5 – 1000	14	354	318	
10	ZEUS D^{*+} HERA-II [3]	D^{*+}	5 – 1000	31	363	318	
11	ZEUS VTX HERA-II [4]	VTX	5 – 1000	18	354	318	17
12	ZEUS e HERA-II [5]	e	10 – 1000		363	318	9
13	ZEUS μ + jet HERA-I [6]	μ	2 – 3000		114	318	11

(corresponding references can be found in backup)

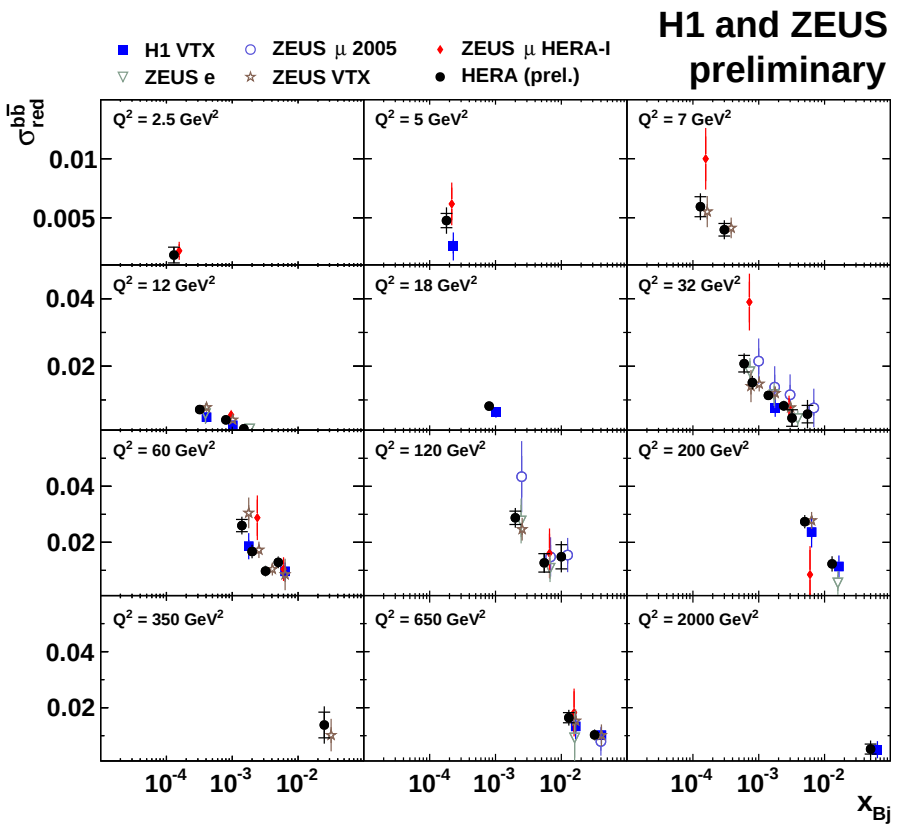
- Combined reduced cross sections: $\sigma_{\mathrm{red}}^{Q\bar{Q}} = \frac{\mathrm{d}^2\sigma^{Q\bar{Q}}}{\mathrm{d}x_{\mathrm{Bj}}\mathrm{d}Q^2} \cdot \frac{x_{\mathrm{Bj}}Q^4}{2\pi\alpha^2\,(1+(1-y)^2)}$
- $2.5 \leq Q^2 \leq 2000$ GeV^2, $3 \times 10^{-5} \leq x_{\mathrm{Bj}} \leq 5 \times 10^{-2}$
- Input 209 *c*, 52 *b* data points $\Rightarrow$ combined 52 *c*, 27 *b* points
- **Extends previous HERA charm combination with 3 new *c* data sets and 5 new *b*: first combination of HERA *b* data**

Combined data

CHARM [9%]



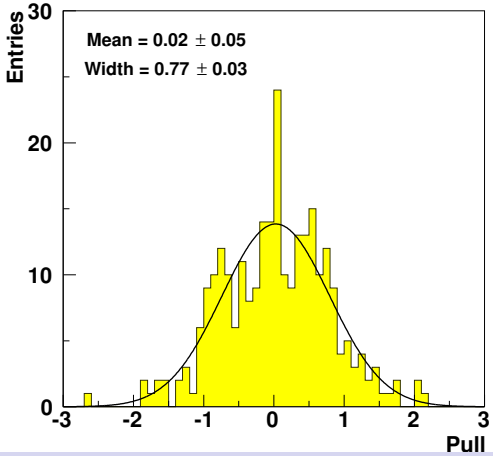
BEAUTY [25%]



$\chi^2/\mathrm{dof} = 149/187$

$\rightarrow$ input data are consistent

$\rightarrow$ significantly reduced uncertainties as compared to the individual measurements



Theoretical predictions (FFNS) compared to combined data

Predictions obtained with OPENQCDRAD interfaced in xFitter

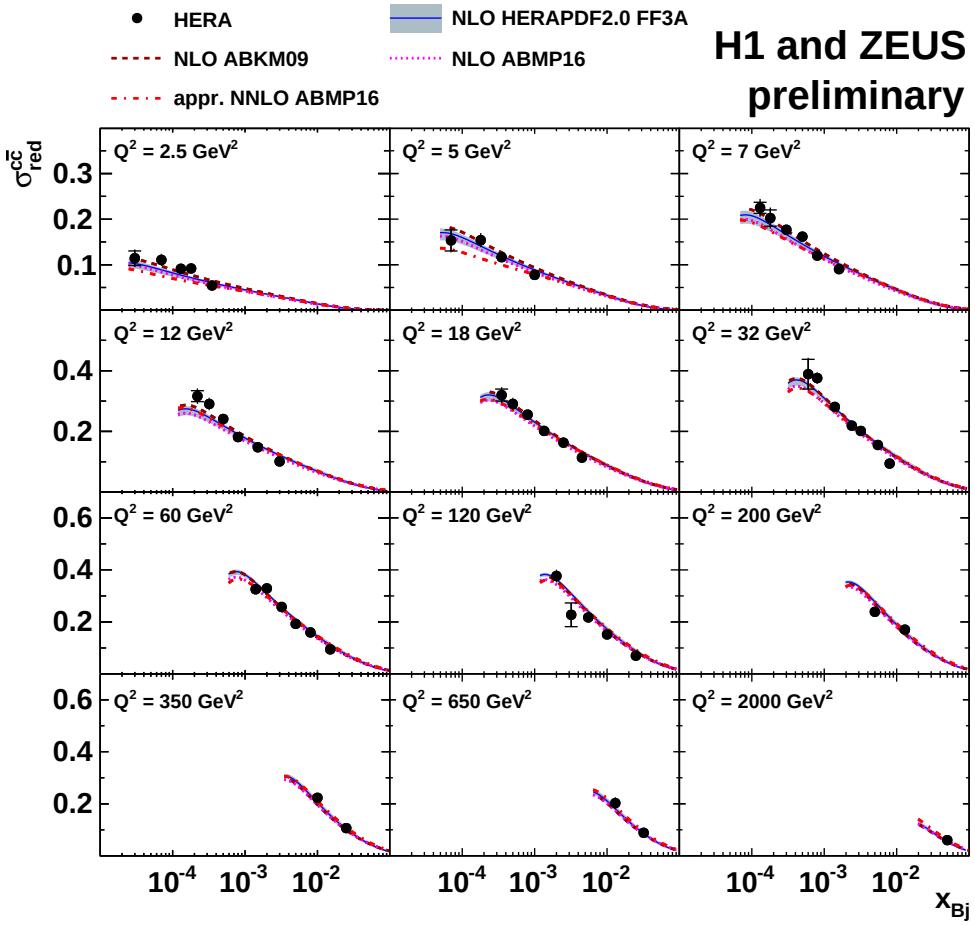
www-zeuthen.desy.de/∼alekhin/OPENQCDRAD

`www.xfitter.org`

- input PDFs: HERAPDF2.0FF3A, ABM11, ABKM09, ABMP16
- $\mu_f = \mu_r = \sqrt{Q^2 + 4m_Q^2}$, varied by factor 2 (dominant unc.)
- $m_c(m_c) = 1.27 \pm 0.03$ GeV, $m_b(m_b) = 4.18 \pm 0.03$ GeV [PDG2016]

FFNS, $n_f = 3$: reliable in this kinematic range

FFNS, CHARM (beauty in BACKUP)



FFNS predictions compared to data: ratio to HERAPDF2.0FF3A

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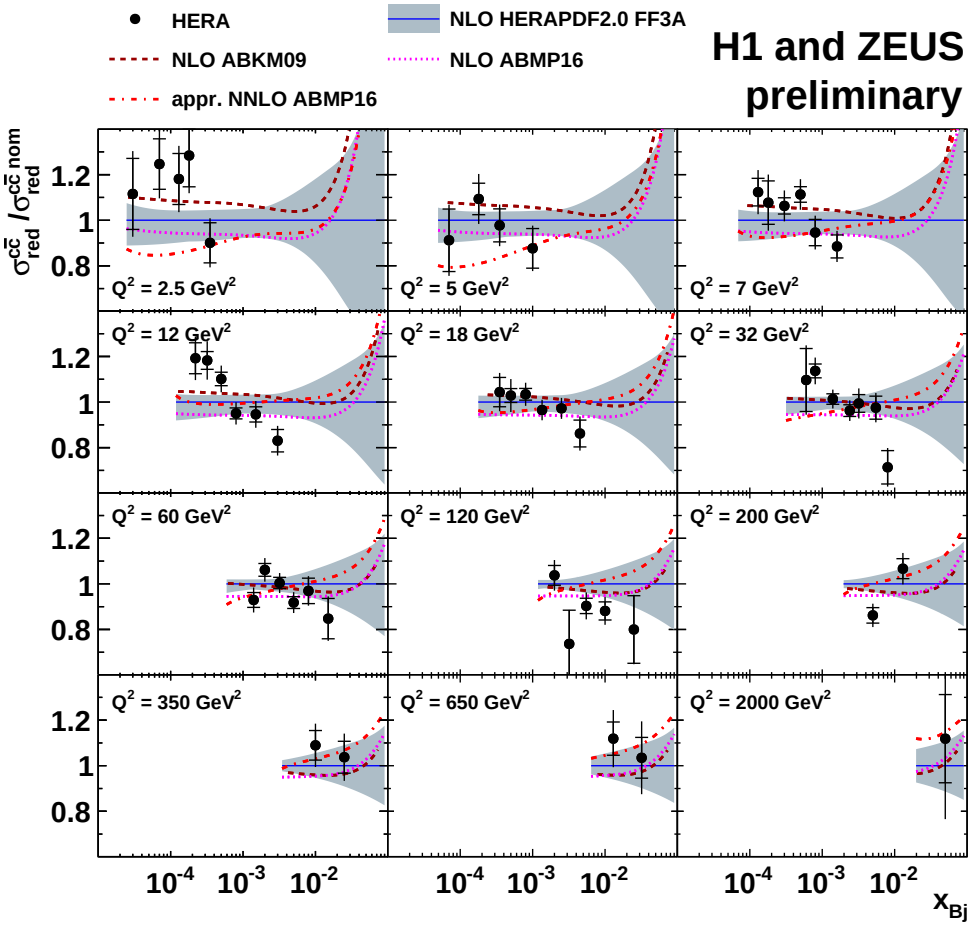
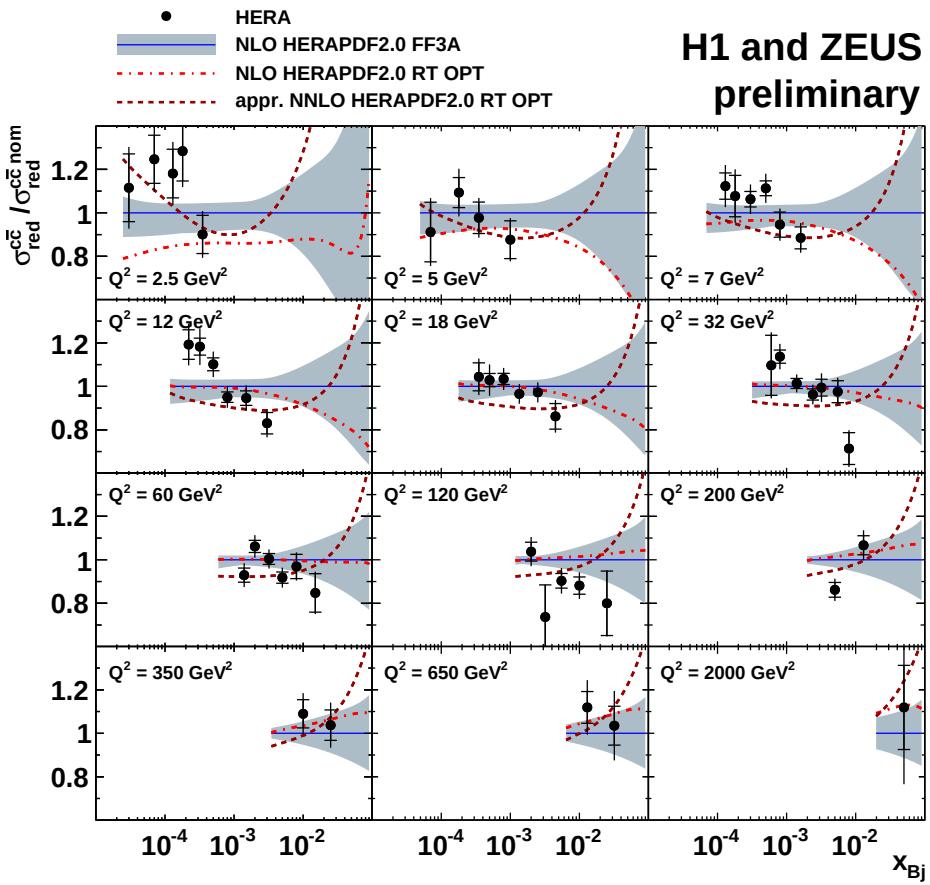


→ **overall fair description, somewhat different *x* slope**

→ **description not improved at approximate NNLO**

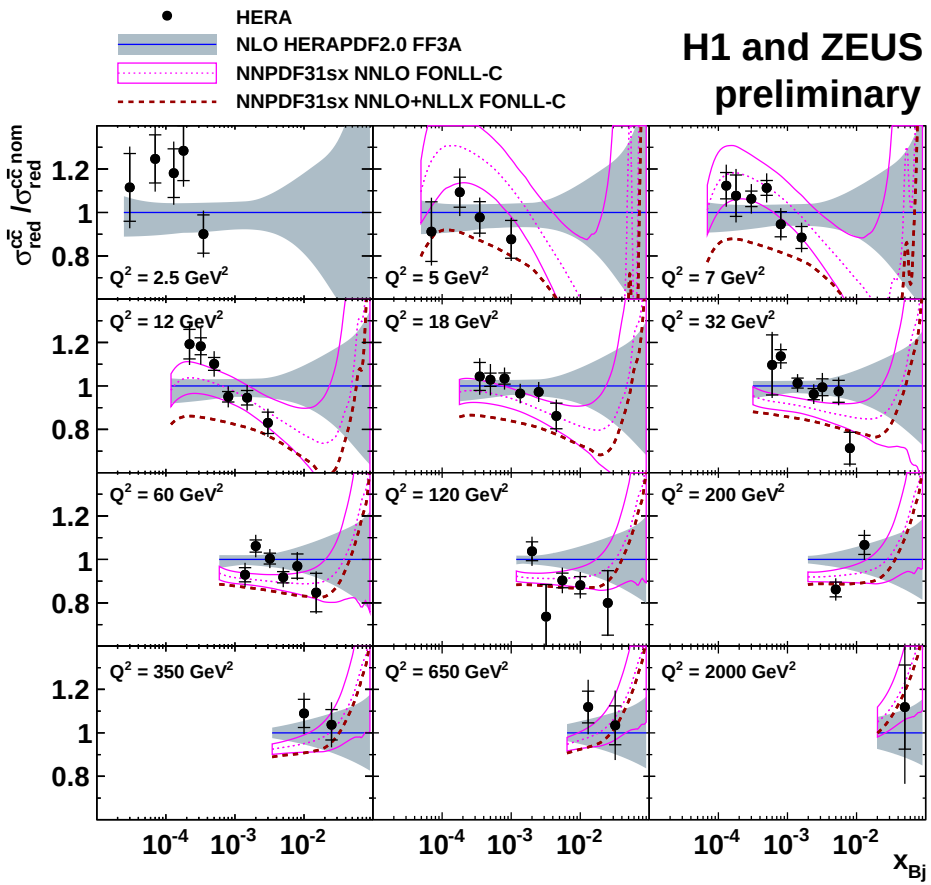
Theoretical predictions (VFNS) compared to combined data

RTOPT [default HERAPDF2.0]



NNPDF3.1 w/ and w/o small-x resummation [1710.05935]

→ **F. Giuli, Wed 18:00**, "Recent QCD results from xFitter"



→ **considered VFNS predictions do not give better data description**

→ **NNPDF3.1: better x_{Bj} slope, but worse normalisation and Q^2**

Similar to HERAPDF2.0 FF:

- performed using xFitter [www.xfitter.org]
- inclusive HERA data + **new combined *c*&*b* data**
- NLO DGLAP [QCDNUM] and matrix elements [OPENQCDRAD], $n_f = 3$
- $\mu_f = \mu_r = \sqrt{Q^2 + 4m_Q^2}$ varied by factor 2 (model unc.)
- **free $m_c(m_c)$, $m_b(m_b)$**
- $\alpha_s(M_Z)^{n_f=3} = 0.106$ ($\rightarrow \alpha_s(M_Z)^{n_f=5} = 0.118$)
- HERAPDF parametrisation, 14p
- fit uncertainty using $\Delta\chi^2 = 1$, model and parametrisation uncertainties

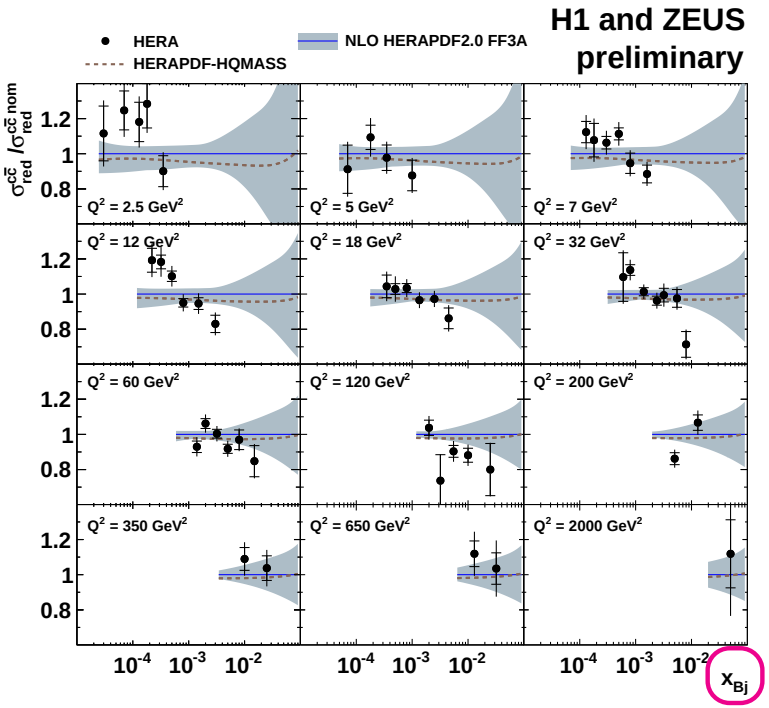
$$m_c(m_c) = 1290^{+46}_{-41}(\text{fit})^{+62}_{-14}(\text{mod})^{+3}_{-31}(\text{par})\ \text{MeV}$$

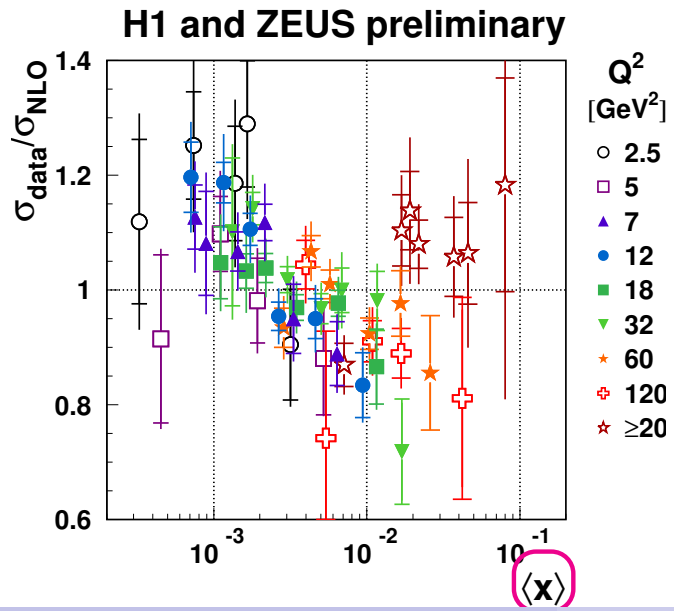
$$m_b(m_b) = 4049^{+104}_{-109}(\text{fit})^{+90}_{-32}(\text{mod})^{+1}_{-31}(\text{par})\ \text{MeV}$$

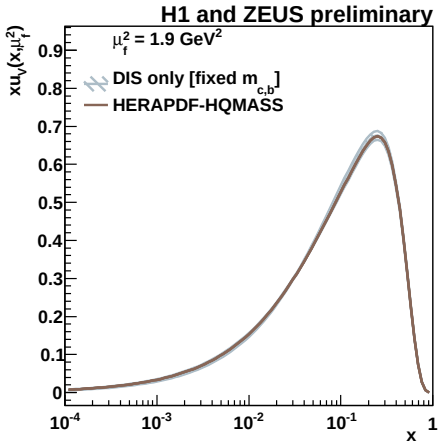
$\Rightarrow$ determined precise HQ masses consistent with world average

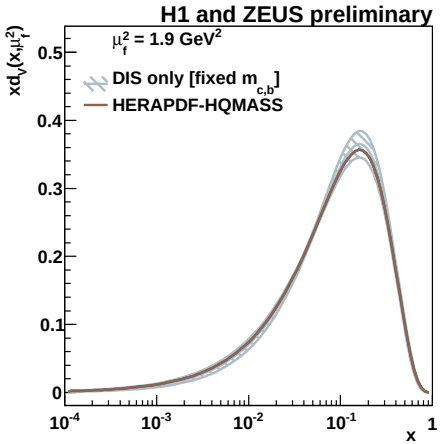
PDG2016: $m_c(m_c) = 1270 \pm 30$ MeV, $m_b(m_b) = 4180^{+40}_{-30}$ MeV

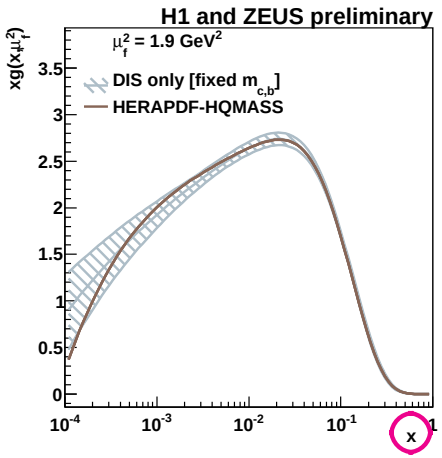
QCD analysis of combined charm and beauty data: PDFs

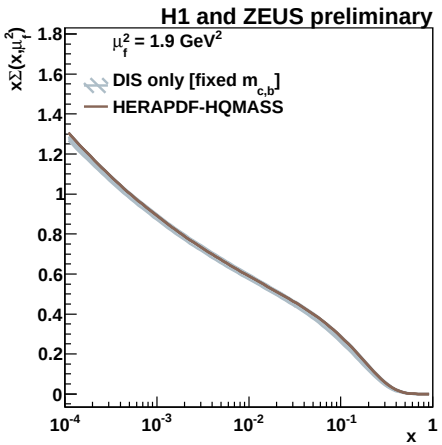






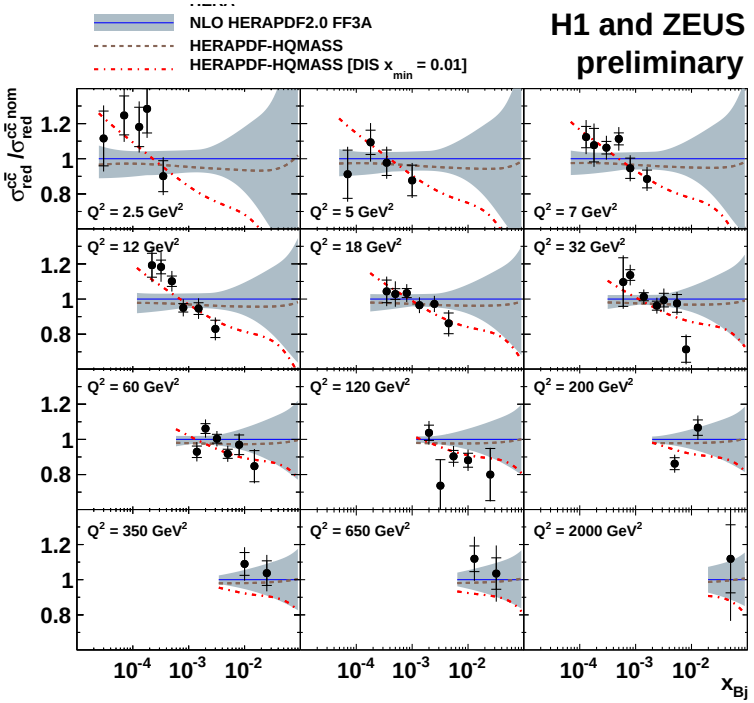


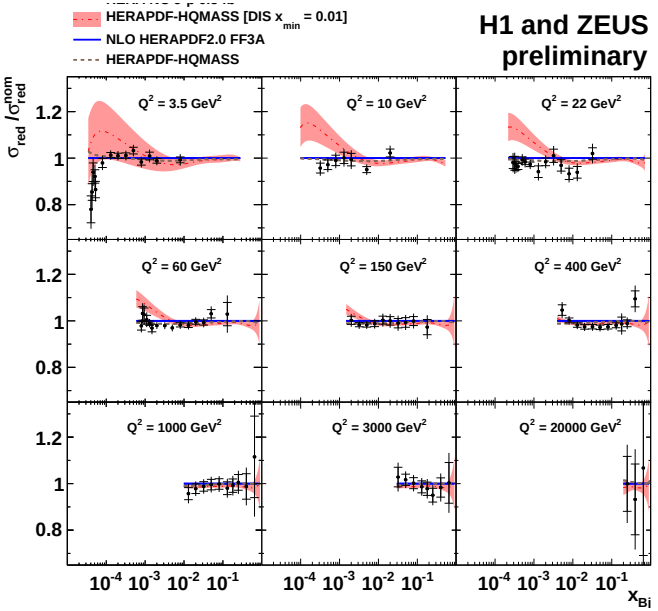


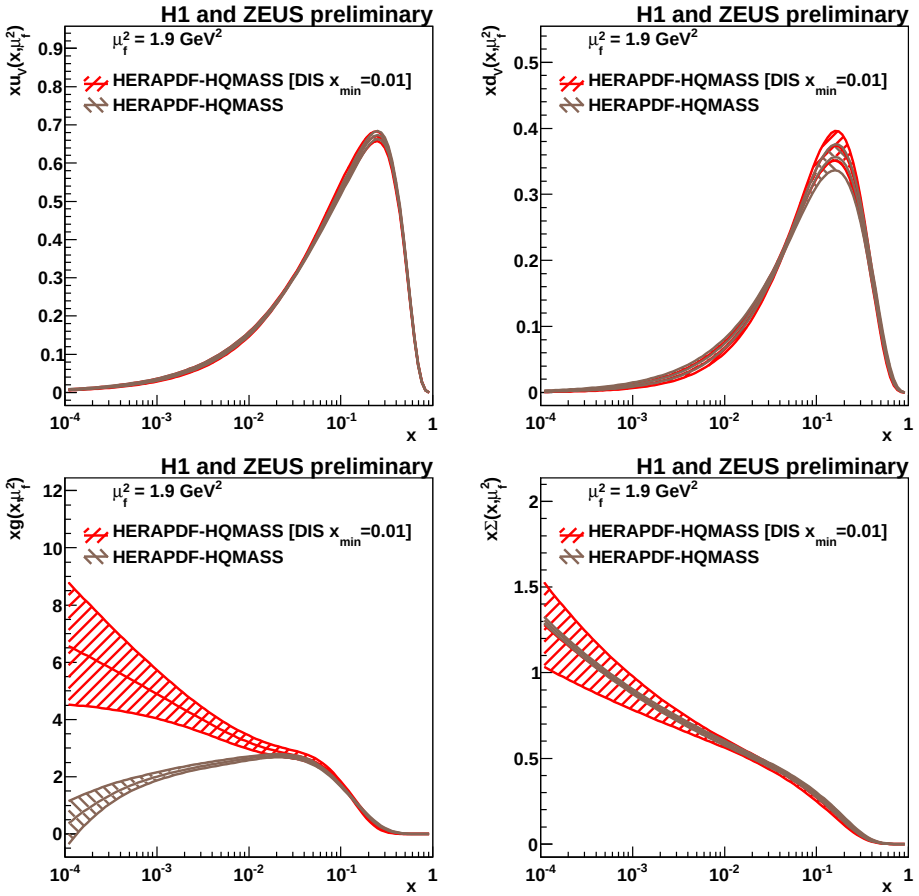


- $x \neq x_{\mathrm{Bj}}$ for BGF!
- small impact of HF data on PDFs
- difference in x slope persists after fit

QCD analysis of combined charm and beauty data: PDFs







- cut $x_{\mathrm{Bj}} > 0.01$ on inclusive data
- observed change for low x gluon:

→ better description of HF data

→ but worser of (not fitted) inclusive data

Summary

New combined HERA charm and beauty data:

- improvement in precision w.r.t previous HERA results for charm
- first combined HERA results for beauty
- enable precise determination of charm and beauty masses
- reveal tension in describing simultaneously HF and inclusive HERA data
- paper and public release of data in a few days

[H1prelim-17-071, ZEUS-prel-17-01] [H1prelim-18-071, ZEUS-prel-17-01-extension]

https://www.desy.de/h1zeus/combined_results/index.php?do=heavy_flavours

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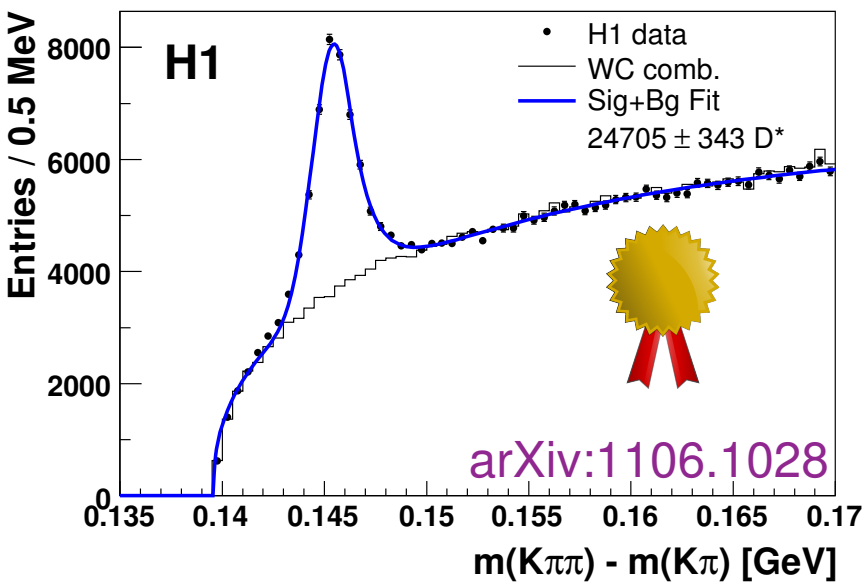
https://www.desy.de/h1zeus/combined_results/index.php?do=heavy_flavours

H1 and ZEUS continue producing valuable QCD results after $>$ **10** *years of HERA shutdown!*

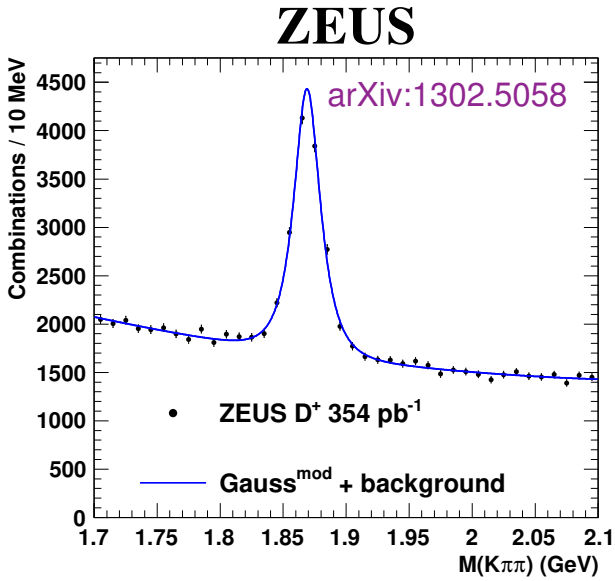
BACKUP

BACKUP. Measurement of charm production at HERA

"Golden" decay channel $D^* \to D^0(K\pi)\pi_s$



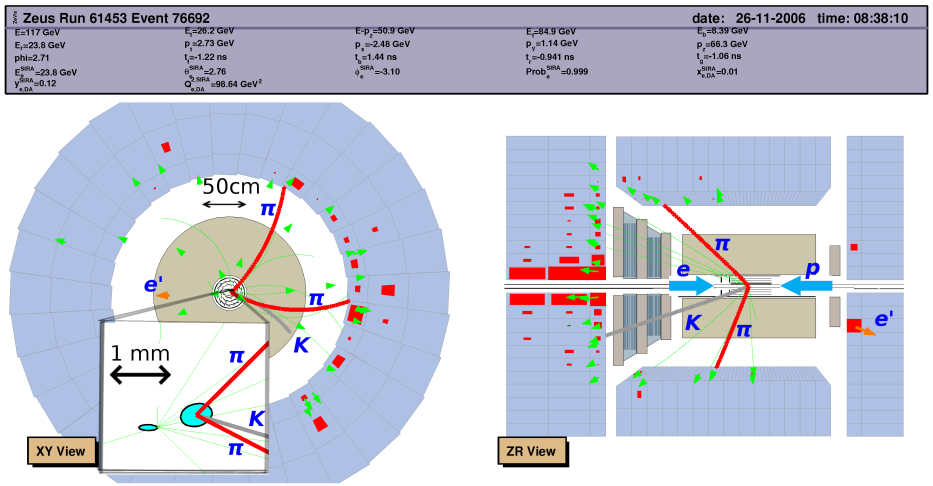
Weakly decaying charm hadrons



Dedicated H1ZEUS combination:

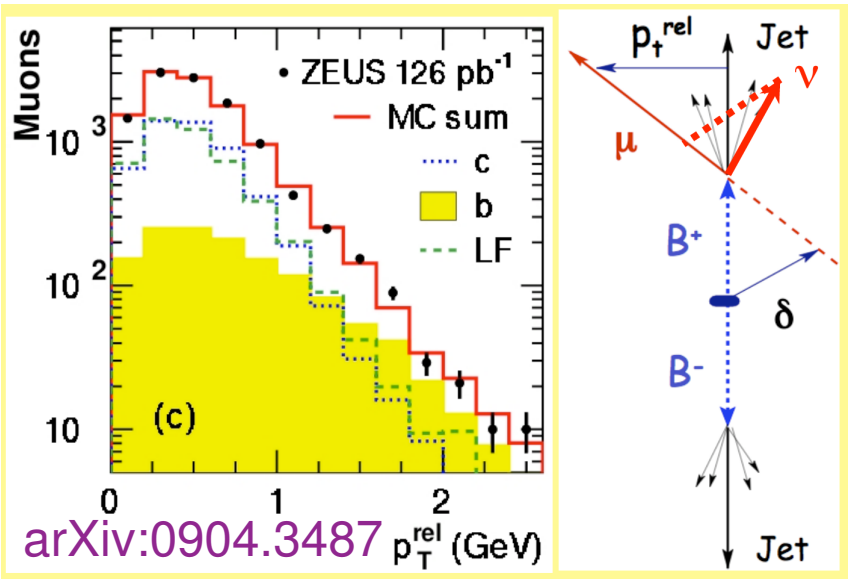
"Combination of differential $D^{*\pm}$ cross-section measurements in deep-inelastic ep scattering at HERA"

[JHEP09 (2015) 149]

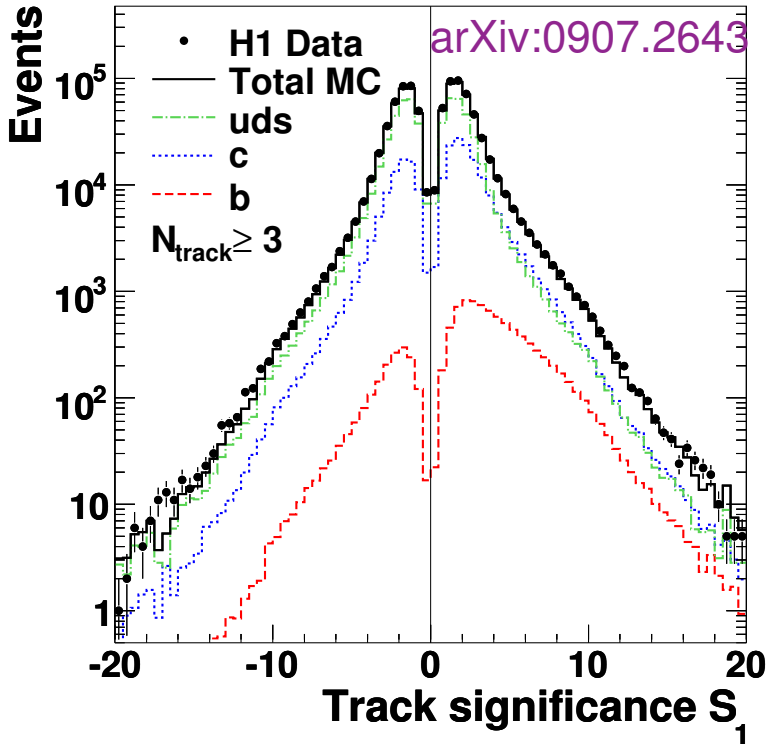


BACKUP. Measurement of *c* and *b* production at HERA

Semi-leptonic (SL) HQ decays



Inclusive lifetime tagging



Recent reviews of HF production at HERA:

- O. Behnke, A. Geiser, M. Lisovyi, “Charm, Beauty and Top at HERA”, Prog. Part. Nucl. Phys. 84 (2015) 1
- O.Z., “Charm Production and QCD Analysis at HERA and LHC ”, Eur. Phys. J. C77 (2017) 151

BACKUP. Combination procedure

- fiducial cross sections extrapolated to full phase space using consistent NLO predictions [HVQDIS], account for relevant unc.
- combined at the level of **reduced cross sections** $\sigma_{\rm red}^{c\bar{c}}$, $\sigma_{\rm red}^{b\bar{b}}$
  $\sigma_{\rm red}^{Q\bar{Q}} = \frac{{\rm d}^2\sigma^{Q\bar{Q}}}{{\rm d}x_{\rm Bj}{\rm d}Q^2} \cdot \frac{x_{\rm Bj}Q^4}{2\pi\alpha^2\,(1+(1-y)^2)}$ (full phase space)
  ($Q\bar{Q}$ stands either for $c\bar{c}$ or $b\bar{b}$)
- combination accounts for correlation of systematic uncertainties, as well as correlation of c and b from same measurements
- $\Rightarrow$ **significant improvement in precision** via cross calibration of different measurement techniques and c/b

Combined using HERAverager program

[https://wiki-zeuthen.desy.de/HERAverager]

well established combination method used in:

- previous HERA charm combination [EPJ C73 (2013) 2311]
- HERAPDF2.0 [EPJ C75 (2015) 580]
- ATLAS papers [1603.09222, 1512.02192, 1606.01736, 1612.03016]

BACKUP. Input data

[2] H. Abramowicz *et al.* [ZEUS Collaboration], "Measurement of $D^{\pm}$ Production in Deep Inelastic ep Scattering with the ZEUS detector at HERA", JHEP **05**, (2013) 023 [arXiv:1302.5058].

[3] H. Abramowicz *et al.* [ZEUS Collaboration], "Measurement of $D^{*\pm}$ Production in Deep Inelastic Scattering at HERA", JHEP **05**, (2013) 097 [arXiv:1303.6578]. Erratum-ibid JHEP **02**, (2014) 106.

[4] H. Abramowicz *et al.* [ZEUS Collaboration], "Measurement of beauty and charm production in deep inelastic scattering at HERA and measurement of the beauty-quark mass", JHEP **09**, (2014) 127 [arXiv:1405.6915].

[5] H. Abramowicz *et al.* [ZEUS Collaboration], "Measurement of beauty production in deep inelastic scattering at HERA using decays into electrons", Eur. Phys. J. **C71**, (2011) 1573 [arXiv:1101.3692].

[6] H. Abramowicz *et al.* [ZEUS Collaboration], "Measurement of beauty production in DIS and F2bb extraction at ZEUS", Eur. Phys. J. **C69**, (2010) 347 [arXiv:1005.3396].

[7] S. Chekanov *et al.* [ZEUS Collaboration], "Measurement of charm and beauty production in deep inelastic ep scattering from decays into muons at HERA", Eur. Phys. J. **C65**, (2010) 65 [arXiv:0904.3487].

[8] F. D. Aaron *et al.* [H1 Collaboration], "Measurement of the Charm and Beauty Structure Functions using the H1 Vertex Detector at HERA", Eur. Phys. J. **C65**, (2010) 89 [arXiv:0907.2643].

[9] A. Aktas *et al.* [H1 Collaboration], "Production of D*+- Mesons with Dijets in Deep-Inelastic Scattering at HERA", Eur. Phys. J. **C51**, (2007) 271 [hep-ex/0701023].

[10] F. D. Aaron *et al.* [H1 Collaboration], "Measurement of $D^{*\pm}$ Meson Production and Determination of F_2^{ccbar} at low Q2 in Deep-Inelastic" Eur. Phys. J. **C71**, (2011) 1769 [arXiv:1106.1028].

[11] F. D. Aaron *et al.* [H1 Collaboration], "Measurement of the D*+- Meson Production Cross Section and F(2)**(c c-bar), at High Q**2, in ep Scattering at HERA", Phys. Lett. **B686**, (2010) 91 [arXiv:0911.3989].

[12] J. Breitweg *et al.* [ZEUS Collaboration], "Measurement of D*+- production and the charm contribution to F2 in deep inelastic scattering at HERA", Eur. Phys. J. **C12**, (2000) 35 [hep-ex/9908012].

[13] S. Chekanov *et al.* [ZEUS Collaboration], "Measurement of D*+- production in deep inelastic e+- p scattering at HERA", Phys. Rev. **D69**, (2004) 012004 [hep-ex/0308068].

[14] S. Chekanov *et al.* [ZEUS Collaboration], "Measurement of D+- and D0 production in deep inelastic scattering using a lifetime tag at HERA", Eur. Phys. J. **C63**, (2009) 171 [arXiv:0812.3775].

BACKUP. Combination procedure

→ Take measured visible x-section $\sigma_{\rm vis}$ and extrapolate to full phase space $\sigma_{\rm red}$ using consistent NLO setup: $\sigma_{\rm red} = \sigma_{\rm vis} \frac{\sigma_{\rm red}^{\rm NLO}}{\sigma_{\rm vis}^{\rm NLO}}$ [HVQDIS]

→ Combine $\sigma_{\rm red}$ accounting for bin-to-bin correlations [HERAverager]

NLO setup for extrapolation as in [DESY-12-172]

- pole masses $m_c = 1.5 \pm 0.15$ GeV, $m_b = 4.5 \pm 0.25$ GeV
  consistent with extracted from data: $m_c = 1.43 \pm 0.04$ GeV, $m_b = 4.35 \pm 0.11$ GeV
  and consistent with PDG: $m_c = 1.67 \pm 0.07$ GeV, $m_b = 4.78 \pm 0.06$ GeV
- $\mu_R = \mu_F = \sqrt{Q^2 + 4m_Q^2}$, varied simultaneously by factor 2
- $\alpha_s^{n_f=3}(M_Z) = 0.105 \pm 0.002$ [$\alpha_s^{n_f=5}(M_Z) = 0.116 \pm 0.002$]
- HERAPDF1.0 FFNS, $n_f = 3$, assign 2% uncor. unc.
  (checked vs HERAPDF2.0: see backup)
- *c* fragmentation: Kartvelishvili frag. function parametrised as step function with k_T kink (H1, ZEUS meas. [DESY-08-080, DESY-08-209])
- *b* fragmentation: Peterson $\epsilon_b = 0.0035 \pm 0.0020$ [NP B565 (2000) 245]
- charm fragmentation fractions [EPJ C76 (2016) 397]
- branching ratios PDG2016
- hadronisation uncertainties for data with jets in the final state

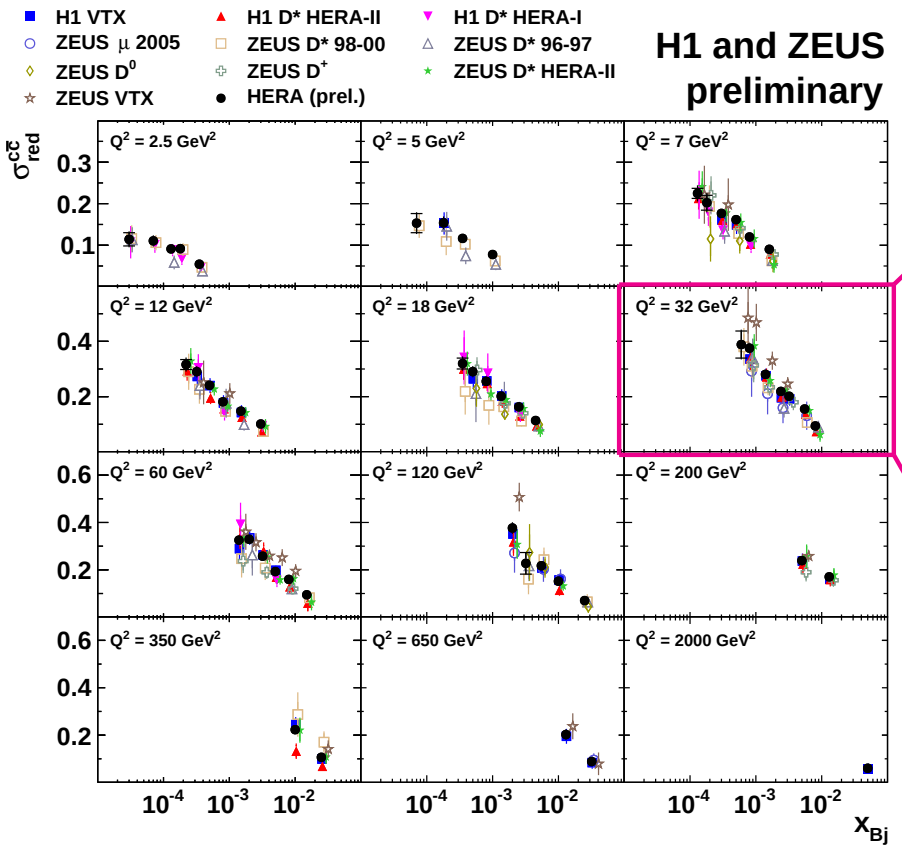
BACKUP. Data combination

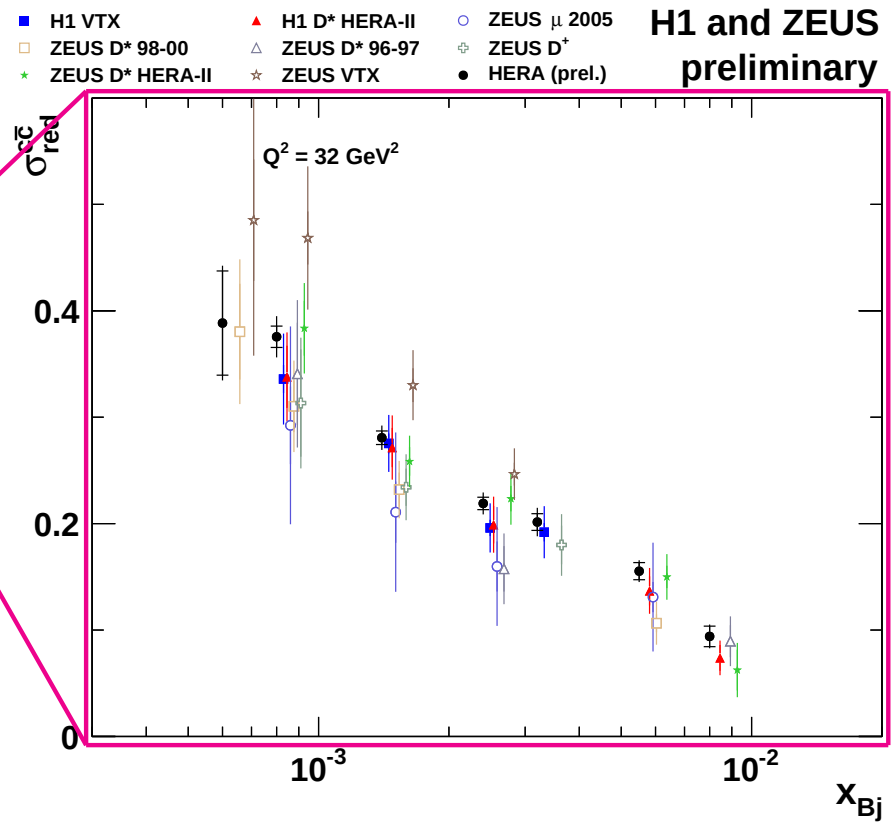
$$\chi^2(\mathbf{m},\mathbf{b}) = \sum_{e=1}^{N_e}\sum_{i=1}^{N_m}\frac{\left(m_i - \sum_{j=1}^{N_s}\Gamma_i^{e,j}b^{e,j} - \mu_i^e\right)^2}{\sigma_i^{e\,2}} + \sum_{j=1}^{N_s} b^{e,j\,2}$$

Minimised in iterative procedure

BACKUP. Combined data: charm

CHARM

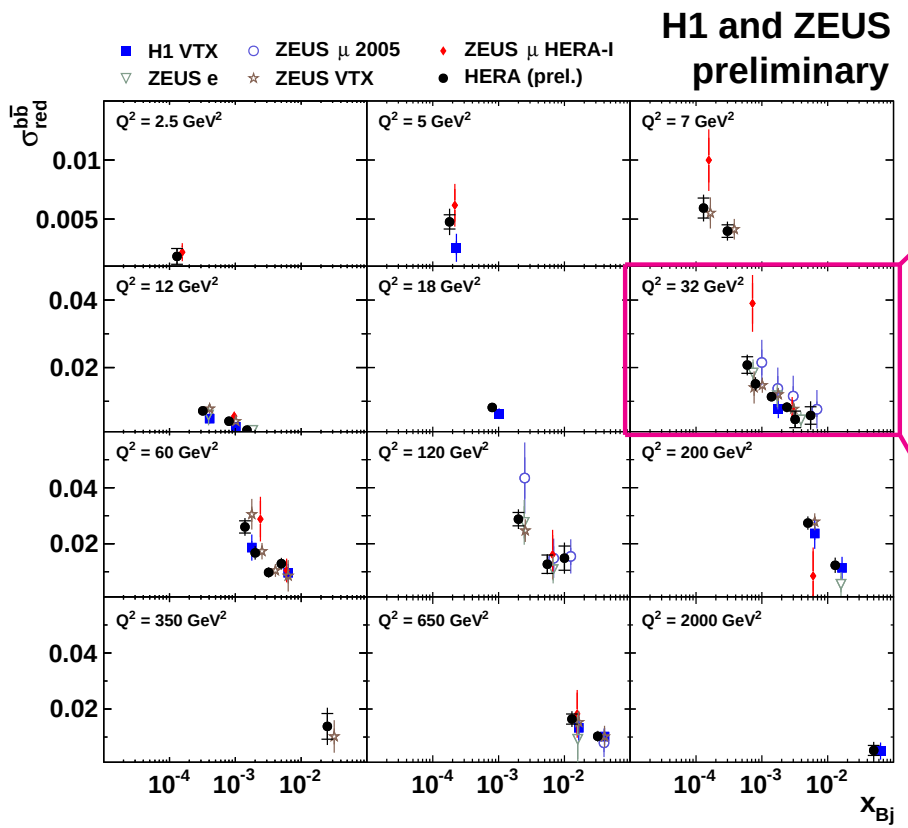


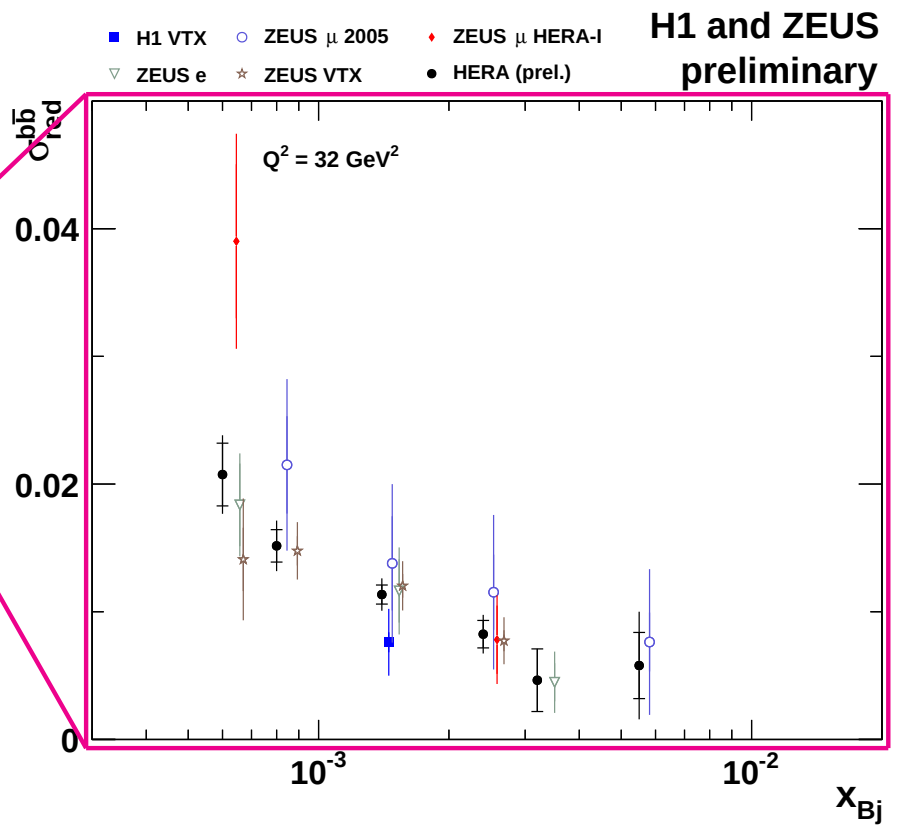


→ **Significantly improved precision compared to input measurements**

BACKUP. Combined data: beauty

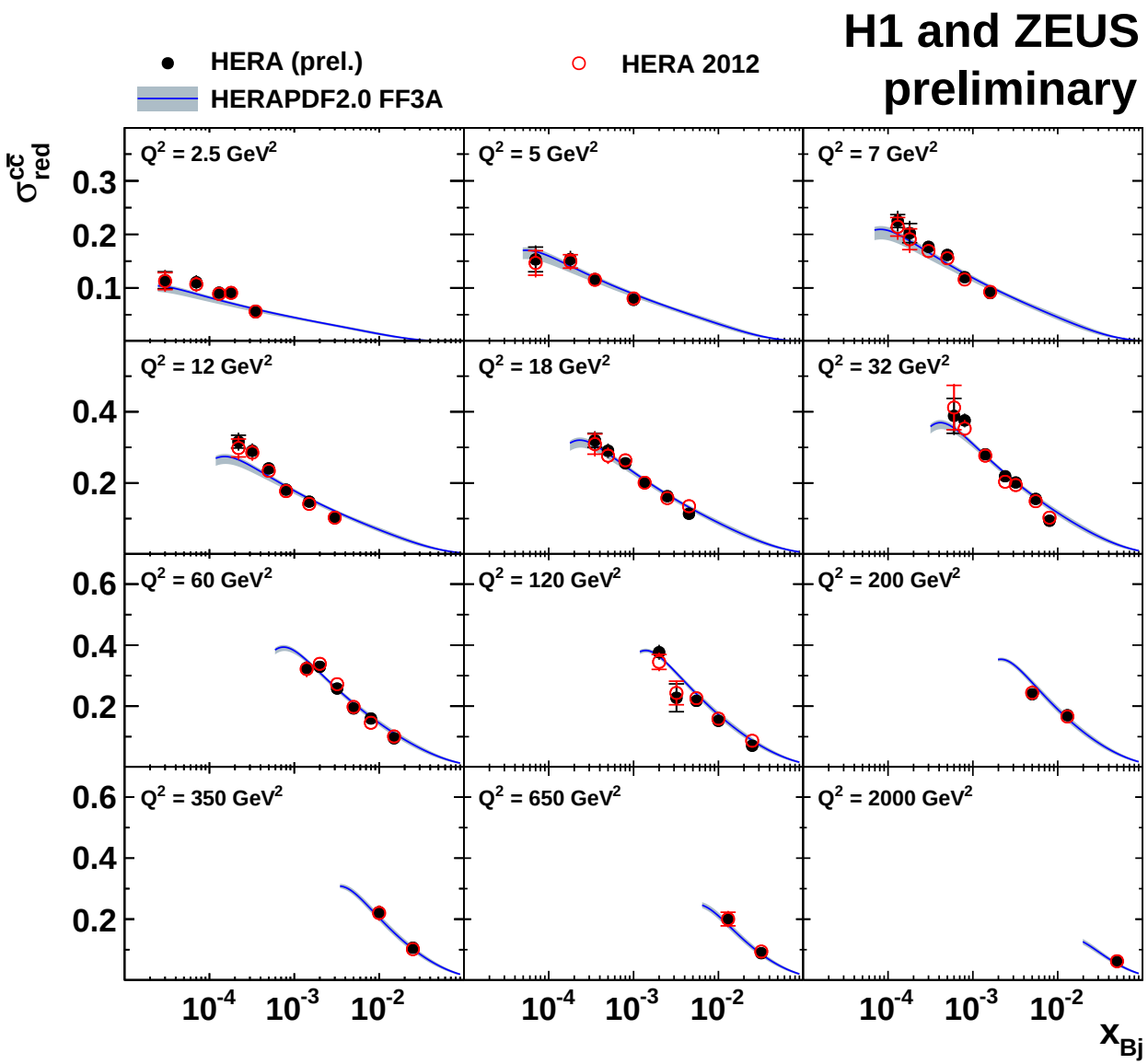
BEAUTY





→ **Significantly improved precision compared to input measurements**

BACKUP. New charm data compared to previous HERA results



BACKUP. FFNS predictions compared to beauty data

Predictions obtained with OPENQCDRAD interfaced in xFitter

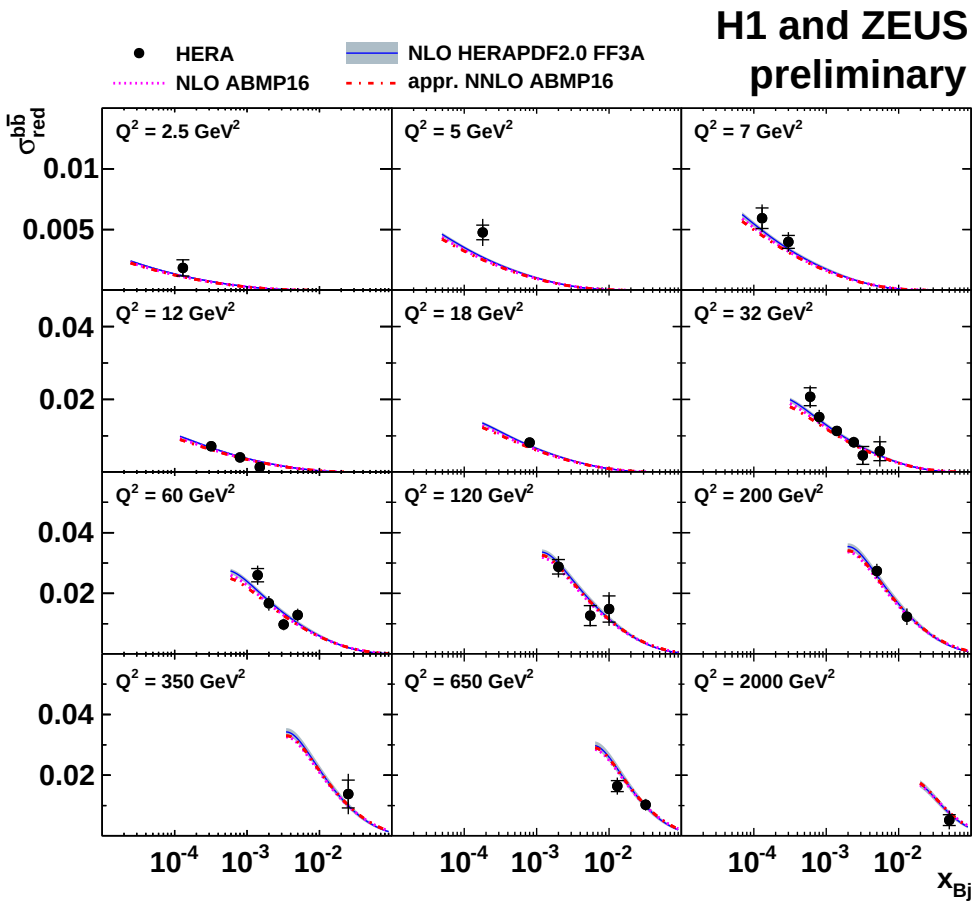
www-zeuthen.desy.de/∼alekhin/OPENQCDRAD

`www.xfitter.org`

- input PDFs: HERAPDF2.0FF3A, ABM11, ABKM09, ABMP16
- $\mu_f = \mu_r = \sqrt{Q^2 + 4m_Q^2}$, varied by factor 2 (dominant unc.)
- $m_c(m_c) = 1.27 \pm 0.03$ GeV, $m_b(m_b) = 4.18 \pm 0.03$ GeV [PDG2016]

FFNS, $n_f = 3$: reliable in this kinematic range

FFNS, BEAUTY



→ **overall fair description, somewhat different *x* slope**

→ **description not improved at approximate NNLO**

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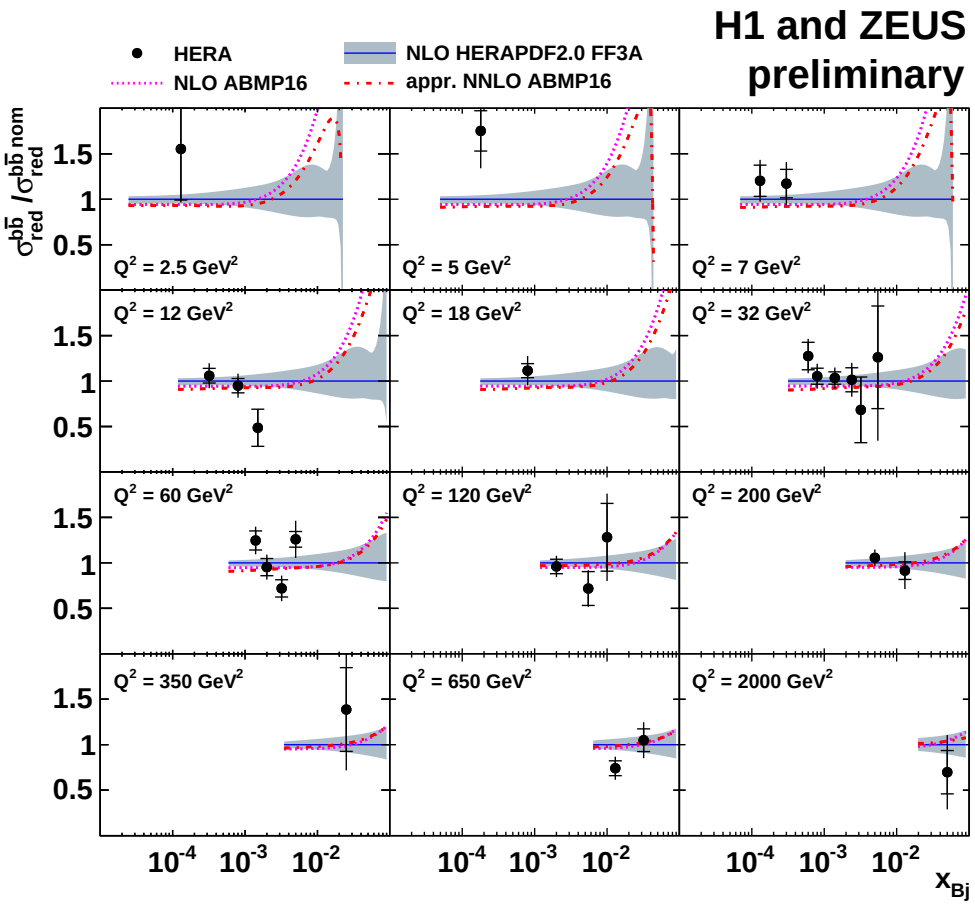


→ **overall fair description, somewhat different *x* slope**

→ **description not improved at approximate NNLO**

BACKUP. QCD analysis settings

Similar to HERAPDF2.0 FF, using running HQ mass definition:

- xFitter-1.2.0
- Input data:
  - HERA $e^{\pm}p$ inclusive data, $Q^2_{\rm min} > 3.5$ GeV^2 [1506.06042]
  - new HERA c and b combined
- FFNS $n_f = 3$ ('FF ABM RUNM'), $(\alpha_s(F_L) = \alpha_s(F_2))$
- $\alpha_s^{n_f=3}(M_Z) = 0.106$
- free $m_c(m_c)$, $m_b(m_b)$, or PDG $m_c(m_c) = 1.27$ GeV, $m_c(m_c) = 4.18$ GeV
- DGLAP NLO [QCDNUM]
- PDF parametrisation: 14p HERAPDF at $\mu^2_{f0} = 1.9$ GeV^2, $f_s = 0.4$:

$$xg(x) = A_g x^{B_g}(1-x)^{C_g} - A'_g x^{B'_g}(1-x)^{C'_g}$$
$$xu_v(x) = A_{u_v} x^{B_{u_v}}(1-x)^{C_{u_v}}(1+E_{u_v}x^2)$$
$$xd_v(x) = A_{d_v} x^{B_{d_v}}(1-x)^{C_{d_v}}$$
$$x\bar{U}(x) = A_{\bar{U}} x^{B_{\bar{U}}}(1-x)^{C_{\bar{U}}}(1+D_{\bar{U}}x)$$
$$x\bar{D}(x) = A_{\bar{D}} x^{B_{\bar{D}}}(1-x)^{C_{\bar{D}}}$$

Additional constrains:

$$A_{\bar{U}} = A_{\bar{D}}(1-f_s),\ B_{\bar{U}} = B_{\bar{D}},\ C'_g = 25$$
$$\int_0^1 [\sum_i (q_i(x) + \bar{q}_i(x)) + g(x)]xdx = 1$$
$$\int_0^1 [u(x) - \bar{u}(x)]dx = 2,$$
$$\int_0^1 [d(x) - \bar{d}(x)]dx = 1$$

- fit ($\Delta\chi^2 = 1$), model (scales, α_s, f_s, $Q^2_{\rm min}$) and par. (μ_{f0}, $E_{u_v} = 0$) unc.

BACKUP. Discussion of HQ mass extraction

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

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

Results have sizable model and parametrisation uncertainty:

- *model uncertainties dominated by scale variations*
- *parametrisation uncertainties dominated by reduced 13p form: closely related to inclusive HERA data in the fit*

Using inclusive HERA data only:

$m_c(m_c) = 1798^{+144}_{-134}(\text{fit})\ \text{MeV}$

$m_b(m_b) = 8450^{+2280}_{-1810}(\text{fit})\ \text{MeV}$

No full uncertainty evaluation, but observed large sensitivity to PDF parametrisation ($\rightarrow$ 13p):

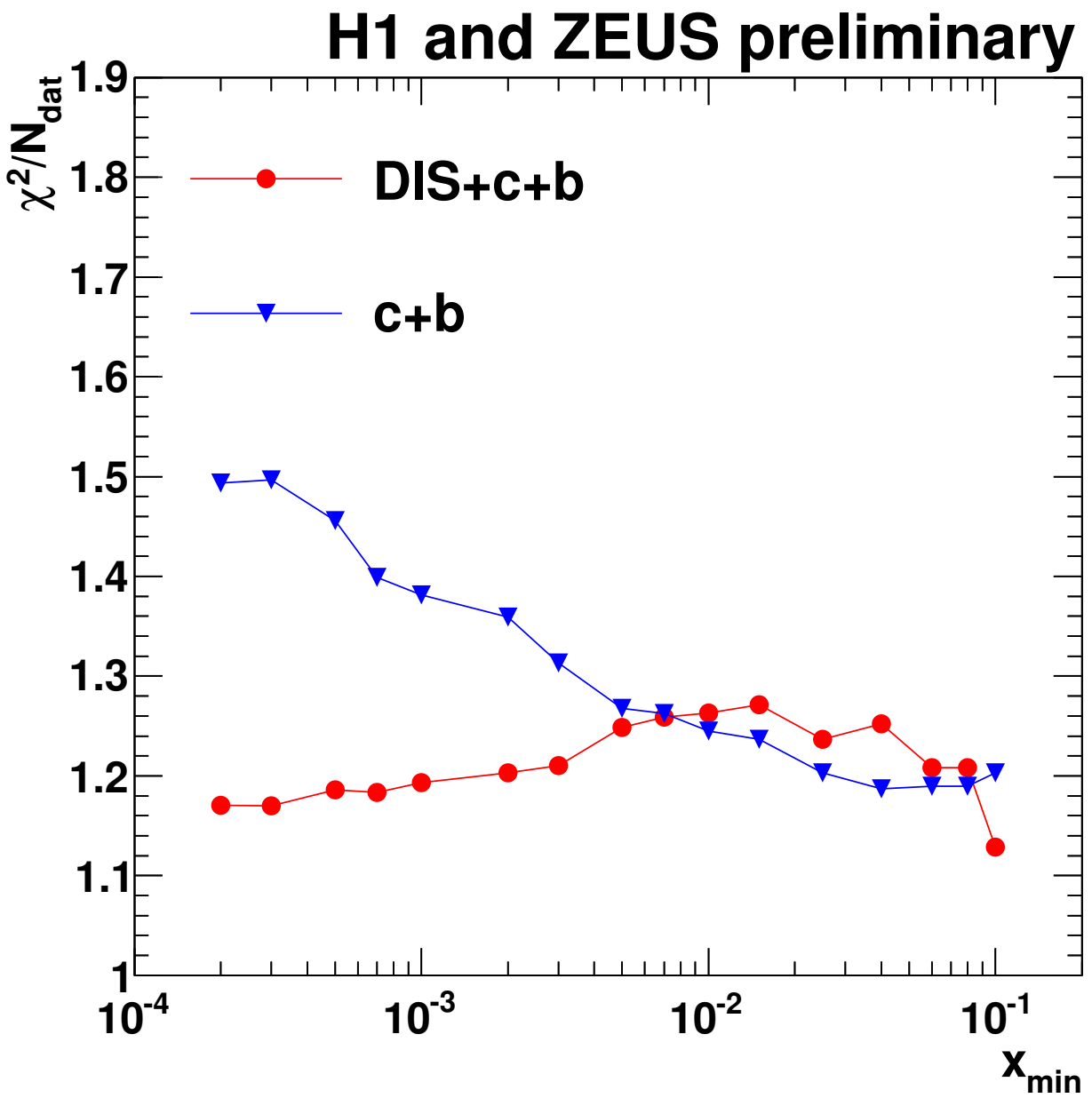
$m_c(m_c) = 1798 \rightarrow 1450\ \text{MeV}$,
$m_b(m_b) = 8450 \rightarrow 3995\ \text{MeV}$

$$xg(x) = A_g x^{B_g}(1-x)^{C_g} - A'_g x^{B'_g}(1-x)^{C'_g}$$
$$xu_v(x) = A_{u_v} x^{B_{u_v}}(1-x)^{C_{u_v}}(1+E_{u_v}x^2)$$
$$xd_v(x) = A_{d_v} x^{B_{d_v}}(1-x)^{C_{d_v}}$$
$$x\bar{U}(x) = A_{\bar{U}} x^{B_{\bar{U}}}(1-x)^{C_{\bar{U}}}(1+D_{\bar{U}}x)$$
$$x\bar{D}(x) = A_{\bar{D}} x^{B_{\bar{D}}}(1-x)^{C_{\bar{D}}}$$

13p: $E_{u_v} = 0$

$\Rightarrow$ inclusive HERA data alone cannot constrain HQ masses reliably
$\Rightarrow$ interplay of PDFs and HQ masses needs carefull treatment

Increasing impact of HF data on gluon: $x_{\mathrm{Bj,min}}$ χ^2 scan



BACKUP. $m_c(m_c)$ extraction in FFNS and VFNS

JHEP 1608 (2016) 050

variation	FONLL-C	FFN
central	1.335 ± 0.043	1.318 ± 0.054
$Q_0^2 = 1.5$	1.354 [+0.019]	1.329 [+0.011]
D_{uv} non-zero	1.340 [+0.005]	1.308 [−0.010]
$f_s = 0.3$	1.338 [+0.003]	1.320 [+0.002]
$f_s = 0.5$	1.332 [−0.003]	1.315 [−0.003]
$m_b(m_b) = 3.93$ GeV	1.330 [−0.005]	1.312 [−0.006]
$m_b(m_b) = 4.43$ GeV	1.343 [+0.008]	1.324 [+0.006]
$\alpha_s(M_Z) = 0.1165$	1.342 [+0.007]	1.332 [+0.014]
$\alpha_s(M_Z) = 0.1195$	1.329 [−0.006]	1.300 [−0.018]
$\mu_F^2 = \mu_R^2 = 2 \cdot Q^2$	1.347 [+0.012]	1.314 [−0.004]
$\mu_F^2 = \mu_R^2 = Q^2/2$	1.361 [+0.026]	1.363 [+0.045]
FONLL Damping power = 1	1.352 [+0.017]	–
FONLL Damping power = 4	1.327 [−0.008]	–

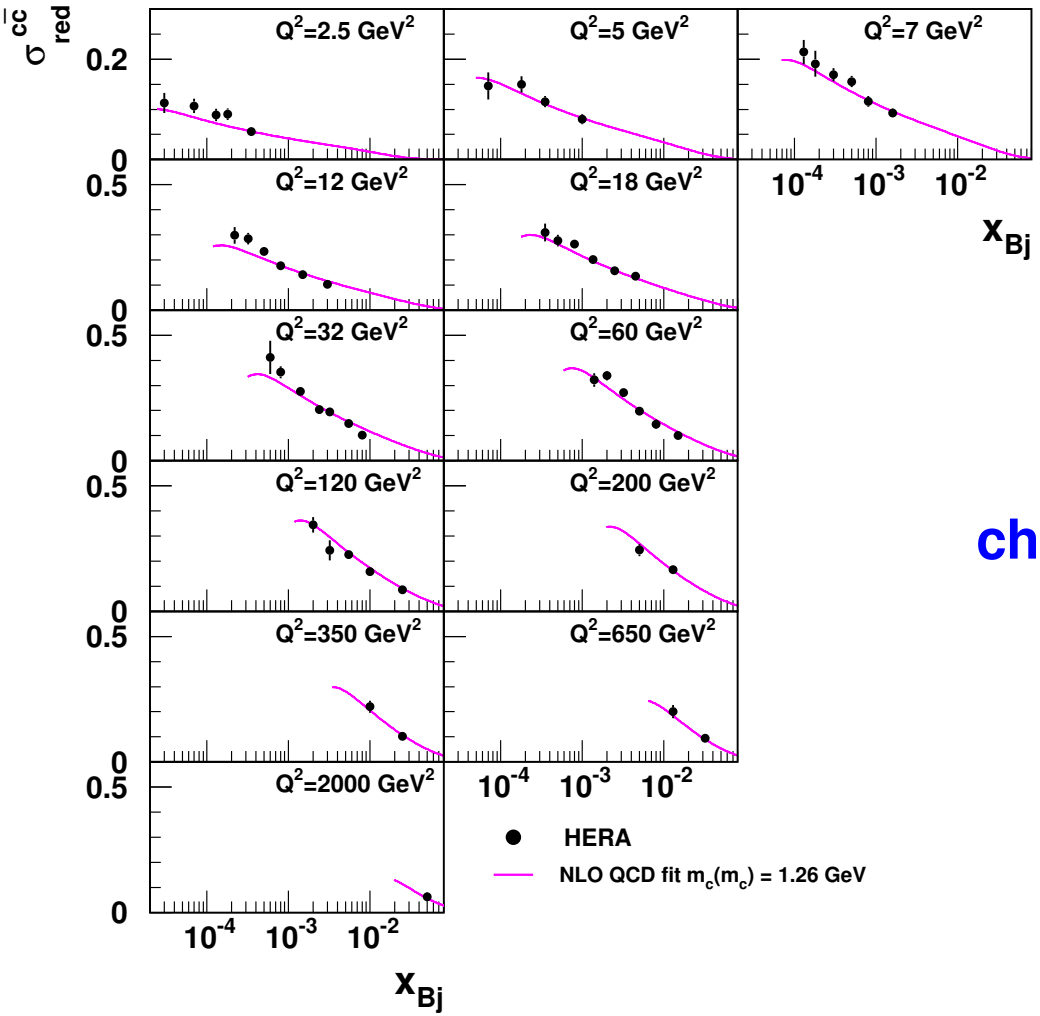
A determination of $m_c(m_c)$ from HERA data using a matched heavy-flavor scheme

---

- consistent results obtained in FFNS and FONLL, with somewhat different decomposition of uncertainties
- $\Rightarrow$ VFNS can be used for $\overline{\rm MS}$ mass extraction, if all uncertainties from extra parameters are considered

BACKUP. Running of charm mass from HERA DIS data

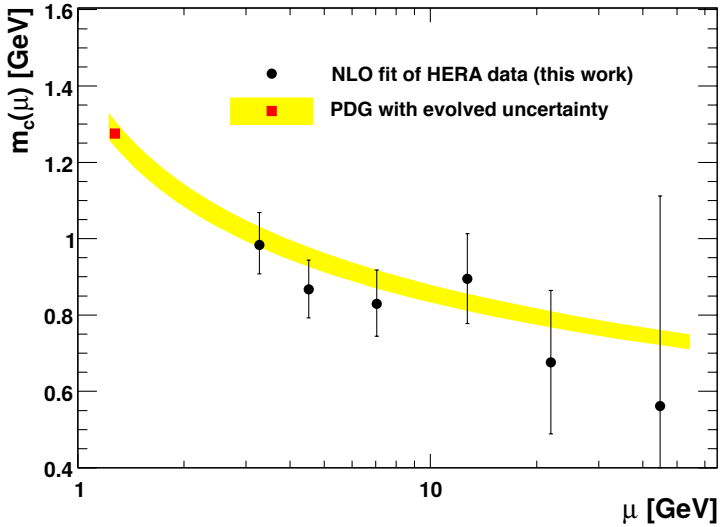
Gizsko et al., PLB775 (2017) 233 (work partially done within scope of PROSA, ZEUS and H1 coll.)



- Determined using earlier published HERA charm data [EPJ C73 (2013) 2311]
- $\overline{\text{MS}}$ charm mass $m_c(m_c)$ extracted in regions of Q^2 and translated to appropriate scale μ

$\Downarrow$

check of QCD running mass concept



New combined HERA charm and beauty data

[H1prelim-17-071, ZEUS-prel-17-01] [H1prelim-18-071, ZEUS-prel-17-01-extension]
https://www.desy.de/h1zeus/combined_results/index.php?do=heavy_flavours

- improvement in precision w.r.t previous HERA results for charm
- first combined HERA results for beauty
- enable precise determination of charm and beauty masses
- reveal tension in describing simultaneously HF and inclusive HERA data

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

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