



Combination and QCD analysis of beauty and charm production cross section measurements in deep inelastic ep scattering at HERA:
1st preliminary request

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Achim Geiser (for the draft)
(DESY)

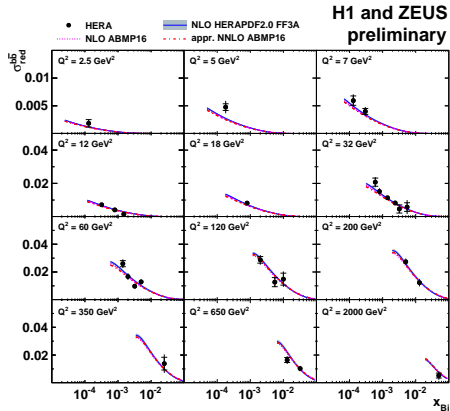
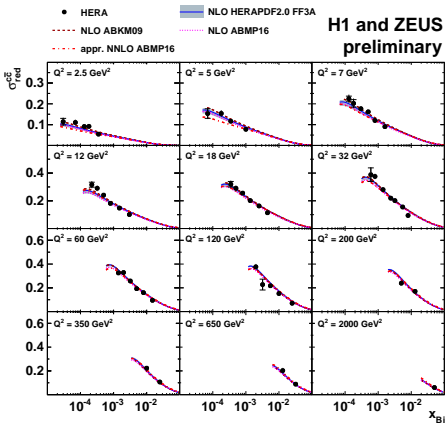
Analysis webpage:

<https://www.desy.de/h1zeus/heavy-flavour/cbcomb2017pre1>

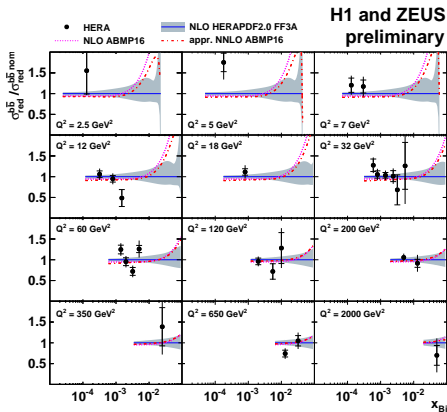
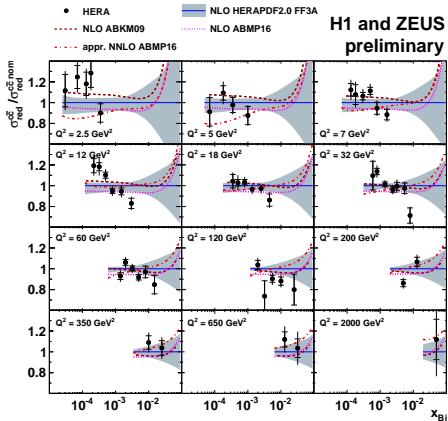
H1ZEUS plenary, 31.01.2018

- Paper draft v2.0 is ready
 - Next steps: circulation and presentation of v2.0 draft, reading, etc.
 - Expect paper submission \sim end of March
 - **Today: request to stamp a few plots as preliminary to be shown at upcoming conferences**
 - preliminary was released in 2017 [H1prelim-17-071, ZEUS-prel-17-01]
 - analysis did not change since that time, but only extended
 - today ask to make preliminary only *new* plots (24)
 - new plots are available at analysis webpage
- <https://www.desy.de/h1zeus/heavy-flavour/cbcomb2017prel/newprelplots2018/>

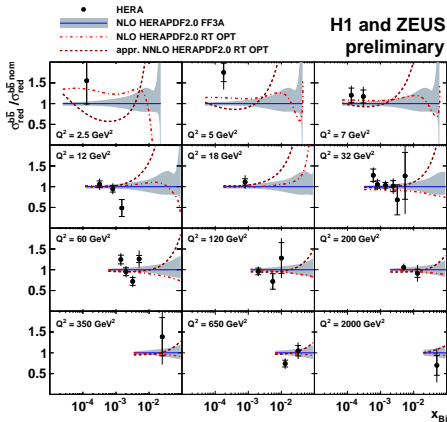
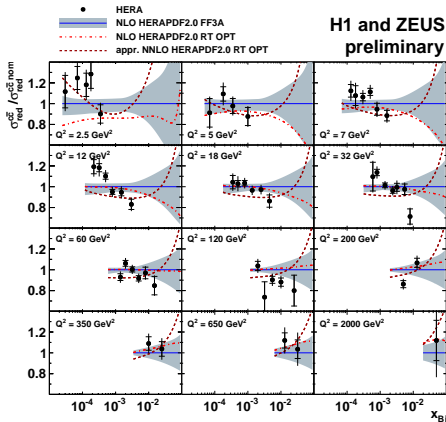
Plots to be made preliminary: comparison to FFNS (fig. 6,7)



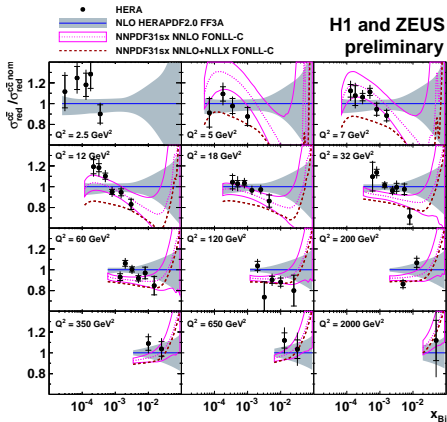
Plots to be made preliminary: comparison to FFNS, ratios (fig. 8,9)



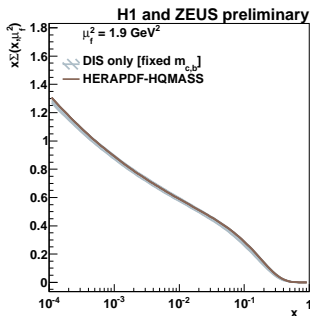
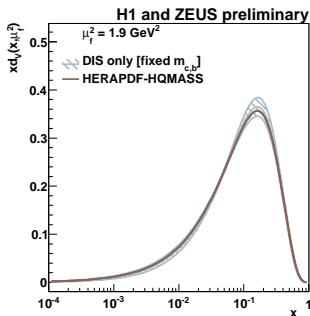
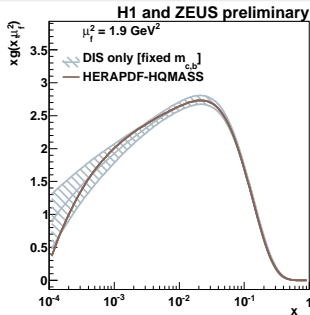
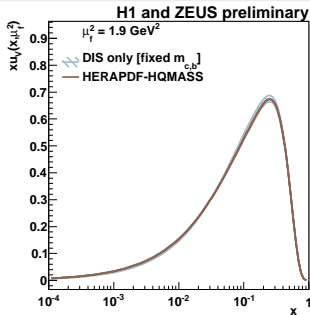
Plots to be made preliminary: comparison to VFNS HERAPDF2.0, ratios (fig. 10,11)



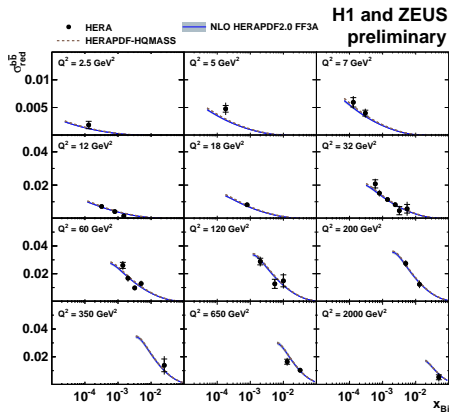
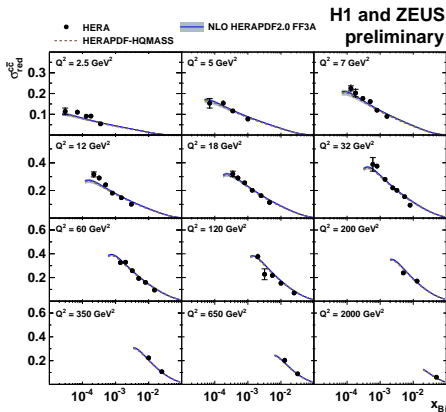
Plots to be made preliminary: comparison to VFNS HERAPDF2.0, ratios (fig. 12)



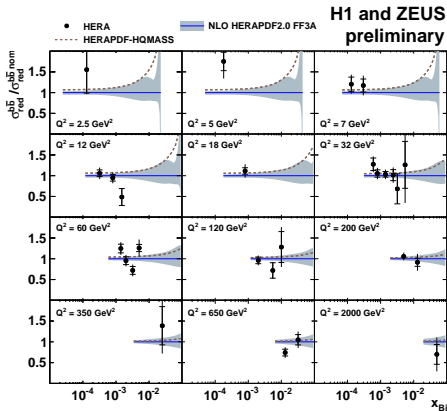
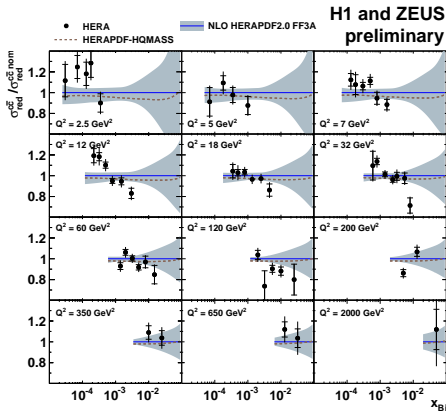
Plots to be made preliminary: PDFs (fig. 13)



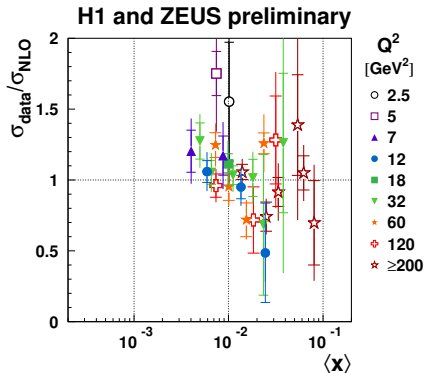
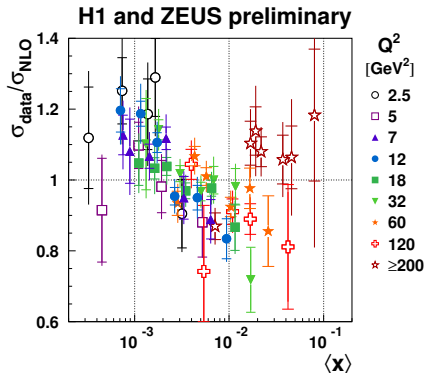
Plots to be made preliminary: comparison to FFNS fit (fig. 14,15)



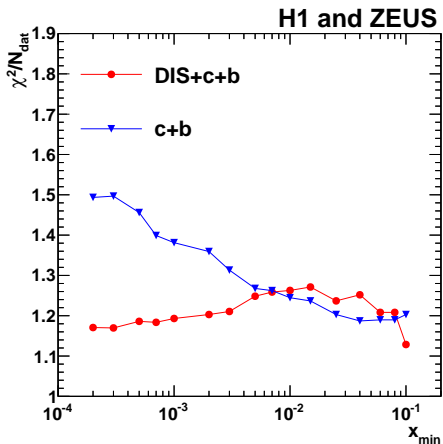
Plots to be made preliminary: comparison to FFNS fit, ratios (fig. 16,17)



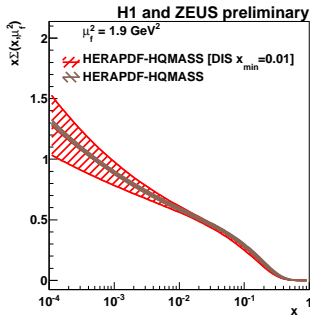
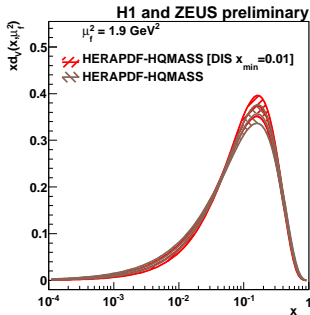
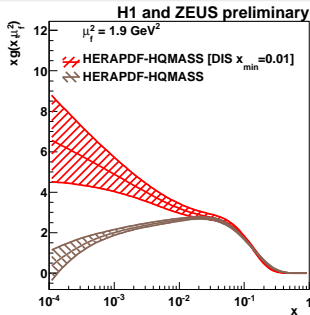
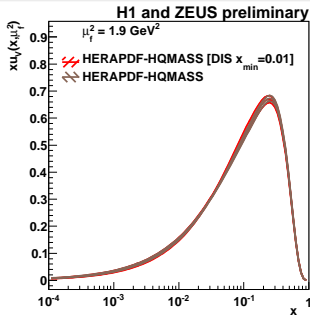
Plots to be made preliminary: partonic x (fig. 18)



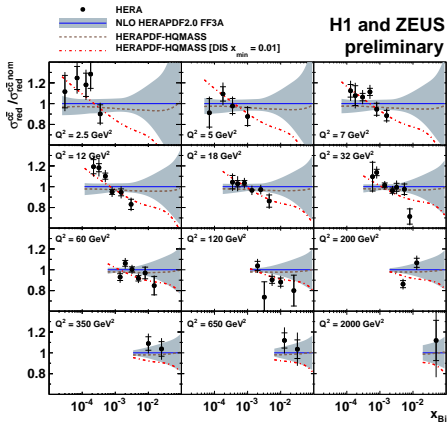
Plots to be made preliminary: χ^2 scan (fig. 19)



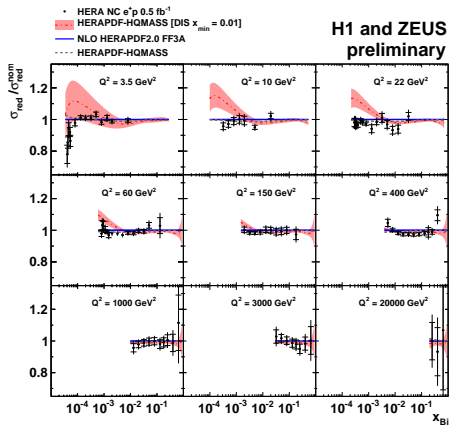
Plots to be made preliminary: PDFs with x_{\min} cut (fig. 20)



Plots to be made preliminary: comparison to FFNS fit with x_{\min} cut, ratio, charm only (fig. 21)



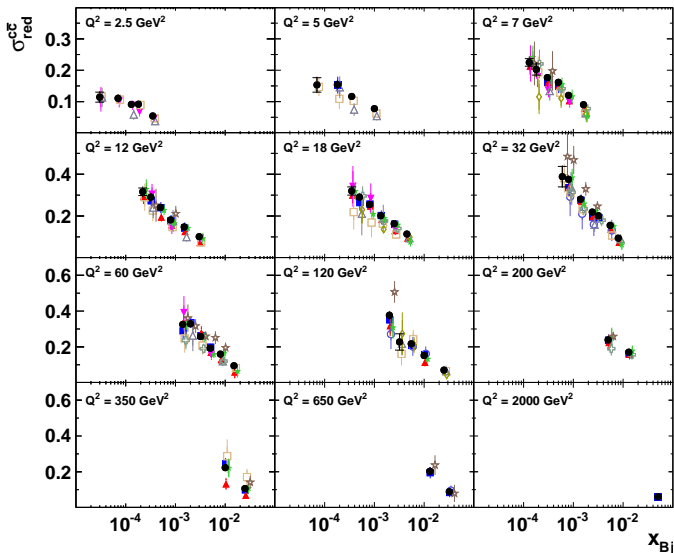
Plots to be made preliminary: comparison to FFNS fit with x_{\min} cut, ratio, inclusive data (fig. 22)



Plots from 2017 preliminary [H1prelim-17-071, ZEUS-prel-17-01])

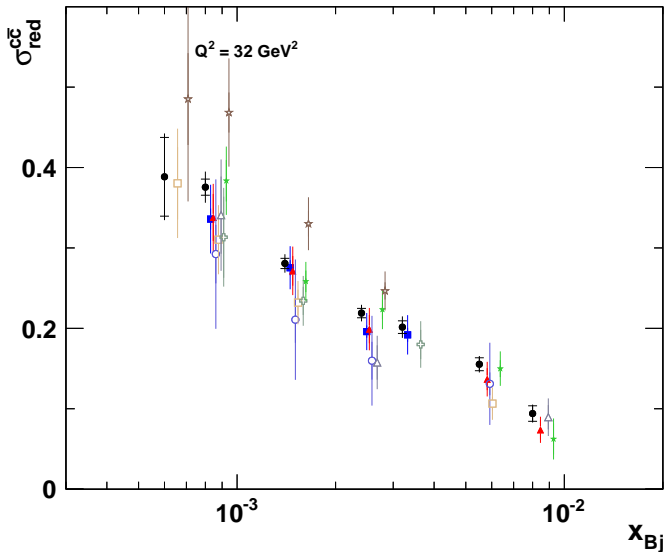
- H1 VTX
- ZEUS μ 2005
- ◇ ZEUS D^0
- ★ ZEUS VTX
- ▲ H1 D^* HERA-II
- ZEUS D^* 98-00
- ⊕ ZEUS D^*
- HERA (prel.)
- ▼ H1 D^* HERA-I
- △ ZEUS D^* 96-97
- ★ ZEUS D^* HERA-II

H1 and ZEUS preliminary

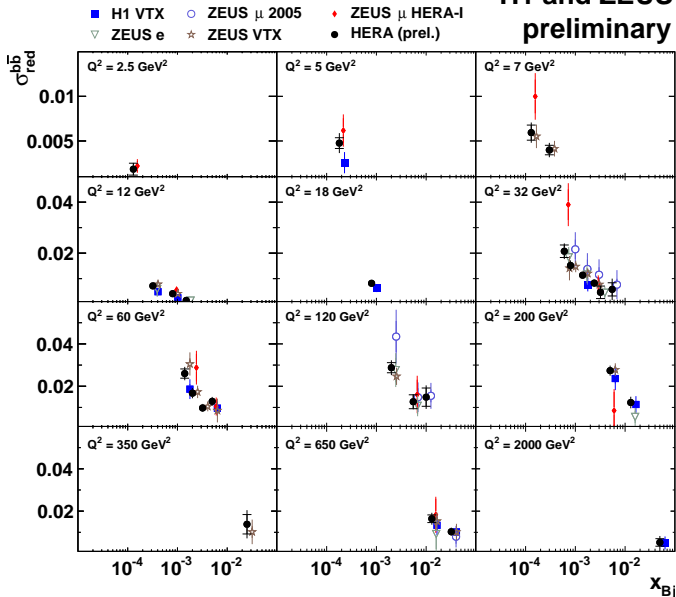


- H1 VTX
- ZEUS D* 98-00
- ★ ZEUS D* HERA-II
- ▲ H1 D* HERA-II
- △ ZEUS D* 96-97
- ☆ ZEUS VTX
- ZEUS μ 2005
- ⊕ ZEUS D*
- HERA (prel.)

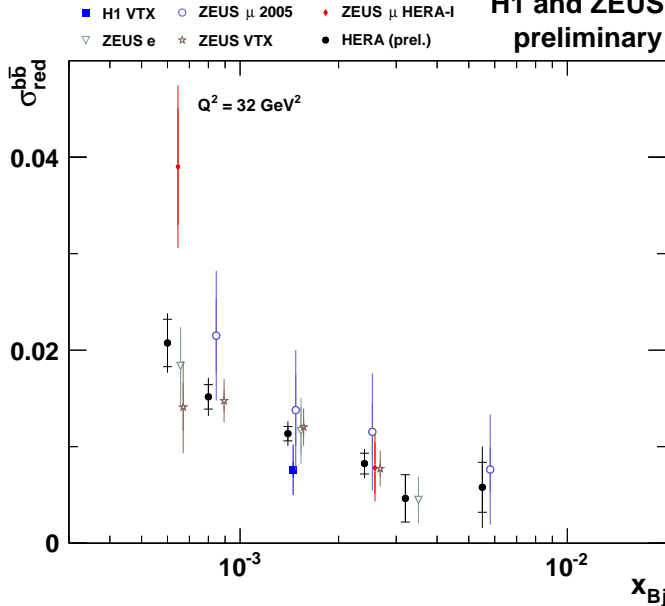
H1 and ZEUS preliminary



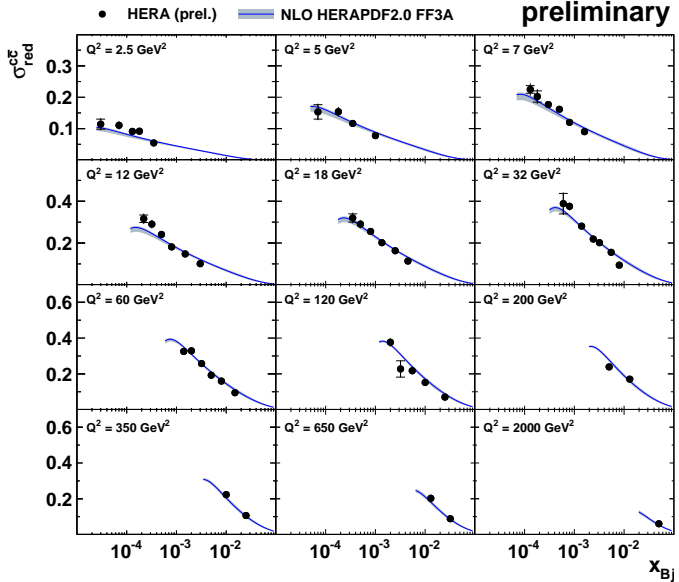
H1 and ZEUS preliminary



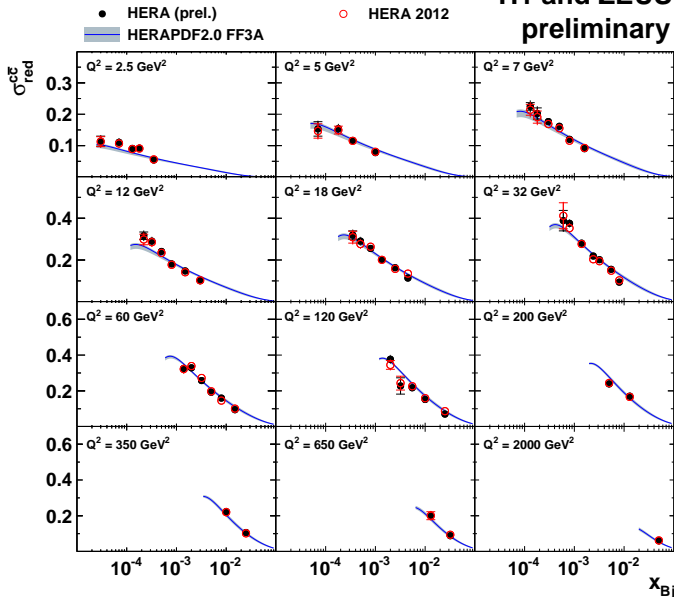
H1 and ZEUS preliminary



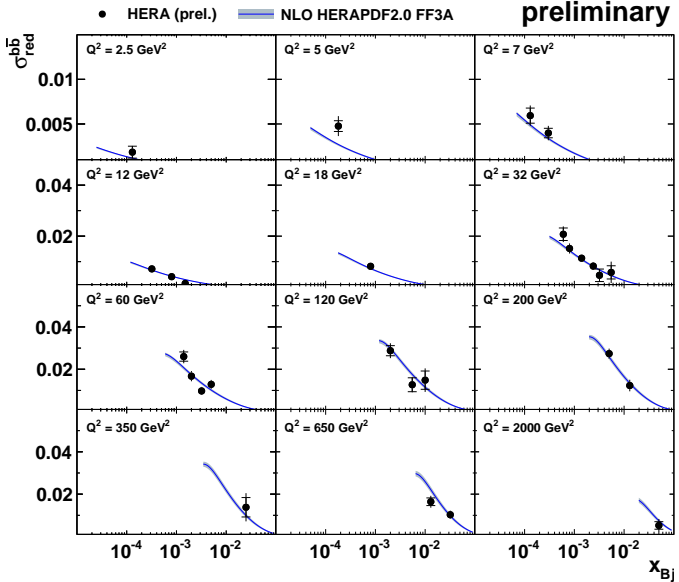
H1 and ZEUS preliminary



H1 and ZEUS preliminary

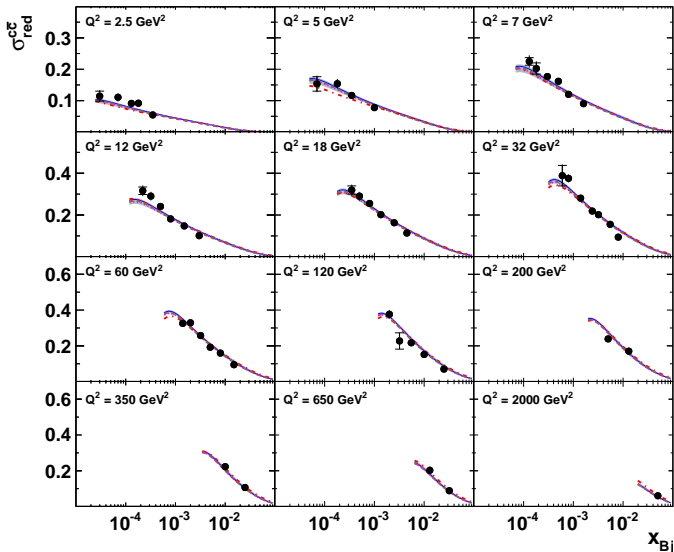


H1 and ZEUS preliminary



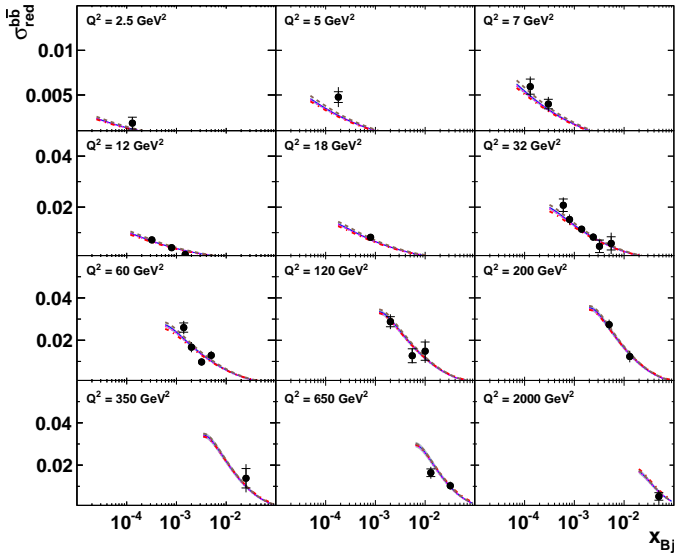
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- NLO HERAPDF2.0 FF3A
- ⋯ NLO ABM11
- - - appr. NNLO ABMP16
- - - NLO fit DIS + c + b

H1 and ZEUS preliminary

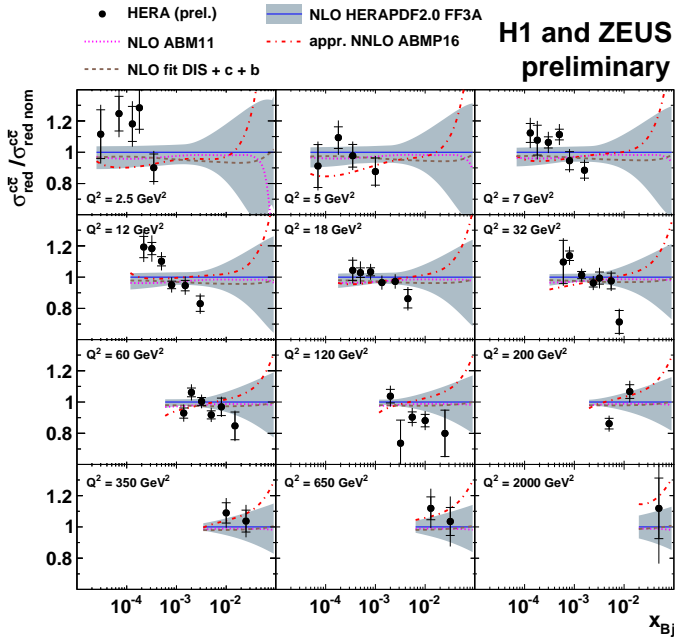


H1 and ZEUS preliminary

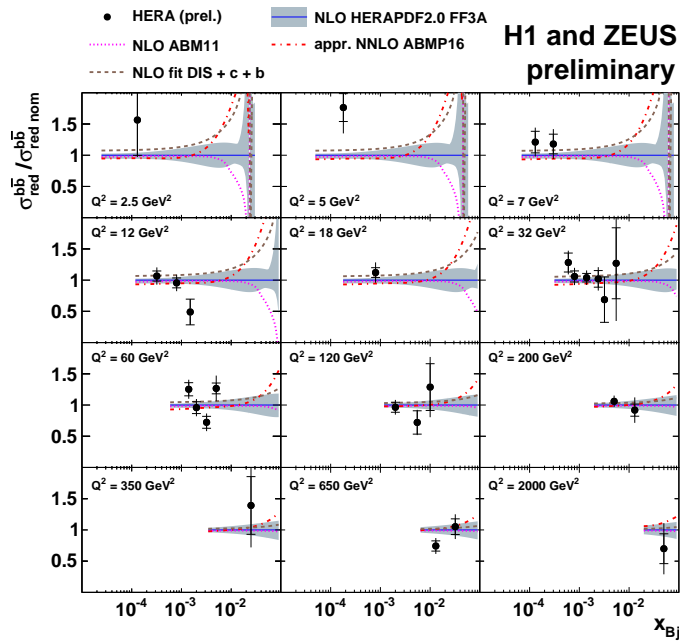
- HERA (prel.)
- NLO HERAPDF2.0 FF3A
- ⋯ NLO ABM11
- - - appr. NNLO ABMP16
- - - NLO fit DIS + c + b



H1 and ZEUS preliminary



H1 and ZEUS preliminary



BACKUP

(slides from paper presentation)

Why combining data?

- Combined data expected to have **ultimate** precision
- **Easy to use**: one dataset, especially if available in open-source package
- **Consistency** is tested in the combination procedure

Why combining charm+beauty simultaneously?

- We have combined large ZEUS+H1 charm subset [DESY-12-172]: **well established procedure**, reference/starting point
- DESY-12-172: ≈ 170 citations, extensively used by most modern PDF groups, referred to as **“unique data for tests of GMVFNS”**, as an arbiter of the quality of the description
- A number of beauty measurements by H1 and ZEUS are less “popular”: less easy to be used in a quantitative analysis
- Most of beauty measurements done together with charm: **accounting for improvement for charm cross sections will automatically improve beauty**, consistent combination of $c+b$ will deliver **ultimately precise results which can be consistently used together**

Combination procedure (same as for preliminary)

- Take measured visible x-section σ_{vis} and extrapolate to full phase space σ_{red} using consistent NLO setup: $\sigma_{\text{red}} = \sigma_{\text{vis}} \frac{\sigma_{\text{red}}^{\text{NLO}}}{\sigma_{\text{vis}}^{\text{NLO}}}$ [HVQDIS]
- Combine σ_{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 effects for data with jets in the final state via corrections from orig. papers

Combination procedure and input measurements

$$\chi_{\text{exp}}^2(\mathbf{m}, \mathbf{b}) = \sum_e \left[\sum_i \frac{\left(m^i - \sum_j \gamma_j^{i,e} m^j b_j - \mu^{i,e} \right)^2}{(\delta_{i,e,\text{stat}} \mu^{i,e})^2 + (\delta_{i,e,\text{uncorr}} m^i)^2} \right] + \sum_j b_j^2$$

Data set	Tagging	Q^2 range [GeV ²]	N_c	\mathcal{L} [pb ⁻¹]	\sqrt{s} [GeV]	N_b	Systematics	Extrapolation
1 H1 VTX DESY-09-096 + b	VTX	5 – 2000	29	245	318	12	DESY-12-172	DESY-12-172 ¹
2 H1 D^* H-I DESY-06-240	D^{*+}	2 – 100	17	47	318		DESY-12-172	DESY-12-172
3 H1 D^* H-II (med. Q^2) DESY-11-066	D^{*+}	5 – 100	25	348	318		DESY-12-172	DESY-12-172
4 H1 D^* H-II (high Q^2) DESY-09-165	D^{*+}	100 – 1000	6	351	318		DESY-12-172	DESY-12-172
5 ZEUS D^* 96-97 DESY-99-101	D^{*+}	1 – 200	21	37	300		DESY-12-172	DESY-12-172
6 ZEUS D^* 98-00 DESY-03-115	D^{*+}	1.5 – 1000	31	82	318		DESY-12-172	DESY-12-172
7 ZEUS D^0 2005 DESY-08-201	D^0	5 – 1000	9	134	318		DESY-12-172	DESY-12-172
8 ZEUS μ 2005 DESY-09-056 + b	μ	20 – 10000	8	126	318	8	DESY-12-172	DESY-12-172
9 ZEUS D^+ H-II DESY-13-028	D^+	5 – 1000	14	354	318		new	new
10 ZEUS D^{*+} HERA-II DESY-13-054	D^*	5 – 1000	31	363	318		new	new
11 ZEUS VTX H-II DESY-14-083 + b	VTX	5 – 1000	18	354	318	17	in the paper	in the paper
12 ZEUS e H-II DESY-11-005 (b only)	e	10 – 1000		363	318	9	new	new
13 ZEUS μ + jet H-I DESY-10-047 (b only)	μ	2 – 3000		114	318	11	new	new

- Same method as for previous H1ZEUS data combinations [HERAverager]
- Q^2 - x grid for charm as in DESY-12-172; for beauty only subset of points
- Correlations taken into account: systematics, statistical c - b correlations and extrapolation (details available in backup)

- **NEW combination:** $\chi^2/\text{ndf} = 149/187$ [+90/93]
- H1ZEUS charm combination: $\chi^2/\text{ndf} = 59/94$ (without D^+ 2005)
- Adding only new charm: $\chi^2/\text{ndf} = 120/157$ [+61/63]
- Adding only beauty: $\chi^2/\text{ndf} = 84/124$ [+25/30]

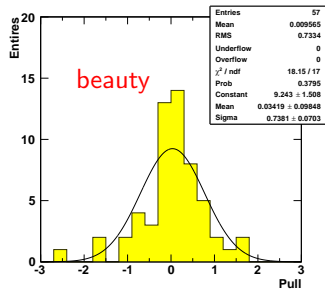
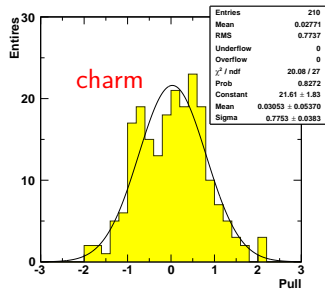
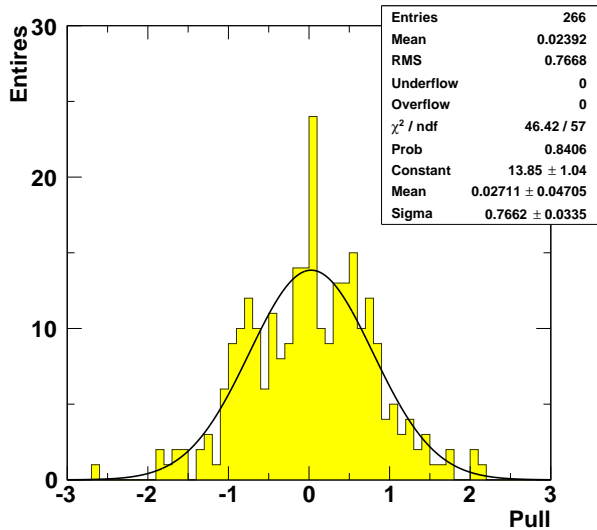
Good consistency!

“Partial” χ^2 of newly included data sets:

ZEUS $D^+ c$	+12/14	H1 vtx b	+8/10
ZEUS $D^* c$	+29/31	ZEUS mu b	+2.9/6
ZEUS VTX c	+22/18	ZEUS el b	+3.3/7
ZEUS VTX b	+14/14	ZEUS mu b HERA-I	+18/10

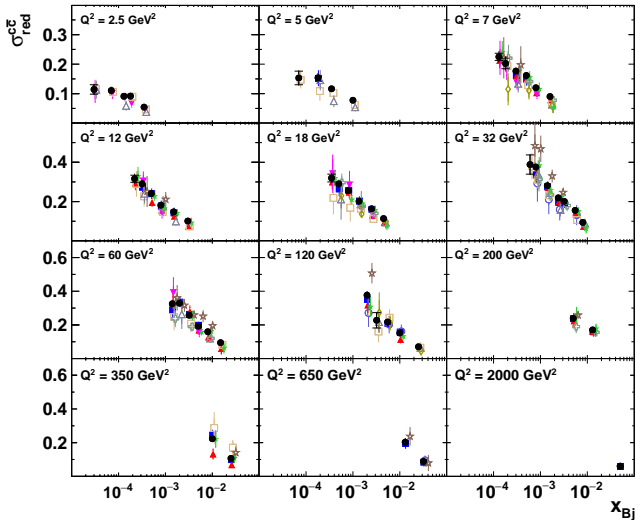
Correlated uncertainties: all shifts within 1.4σ

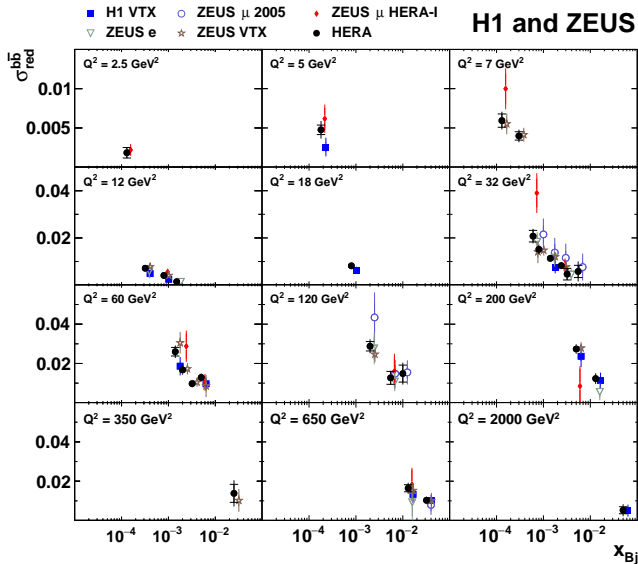
Combined data: pull



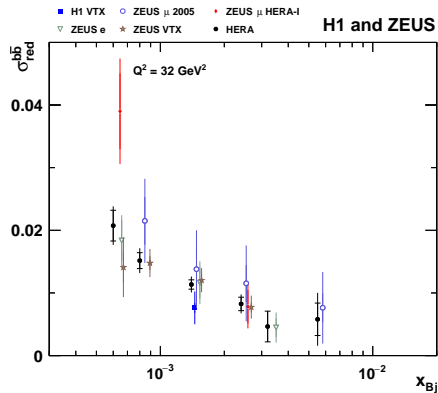
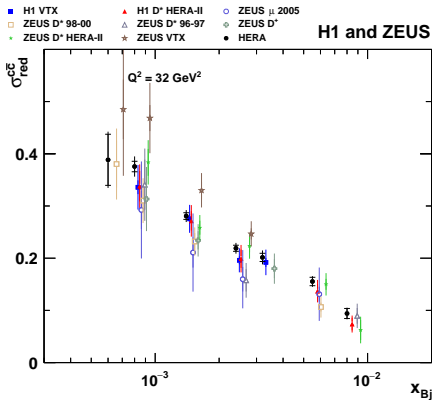
- H1 VTX
- ZEUS μ 2005
- ◇ ZEUS D^0
- ★ ZEUS VTX
- ▲ H1 D^+ HERA-II
- ZEUS D^+ 98-00
- ⊕ ZEUS D^+
- ▼ H1 D^+ HERA-I
- △ ZEUS D^+ 96-97
- ★ ZEUS D^+ HERA-II
- HERA

H1 and ZEUS

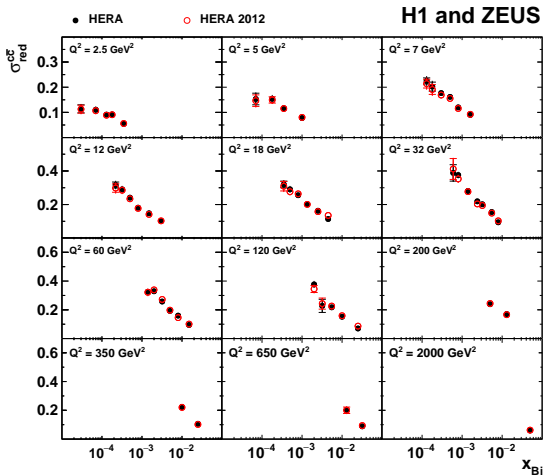




Combined data: charm, beauty $Q^2 = 32 \text{ GeV}^2$



Combined data: charm compared to HERA2012

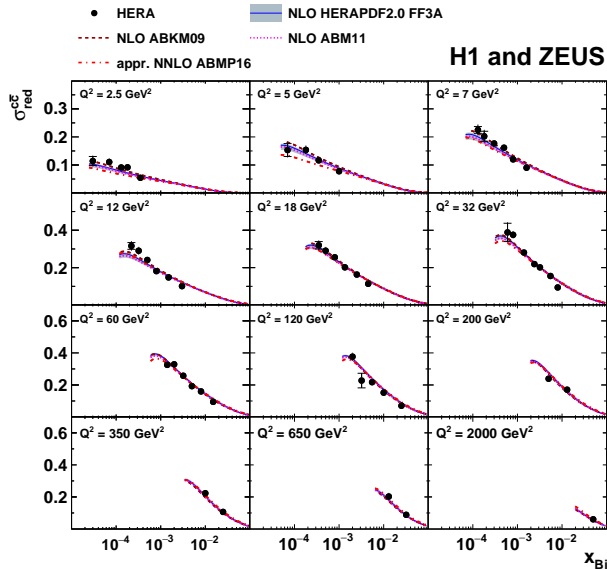


- Consistent with HERA2012 [DESY-12-172], better overall precision
- Marginal improvement at low and very high Q^2 , best at medium Q^2
- Very few points: expanded uncertainties due to removed ZEUS D+ 2005 data set
- Some other points: significant uncor. unc. → corr. (correlation with beauty)

Outline:

- **main focus on FFNS and HERAPDF**
- other FFNS PDFs: ABM, including approximate NNLO
- VFNS:
 - RT OPT: default HF scheme used in HERAPDF
 - FONLL C NNPDF3.1 with and w/out small x resummation: recent calculations aiming to improve description at low x_{Bj} and low Q^2
- summary table with all χ^2 and p -values

Combined data vs FFNS theory: charm

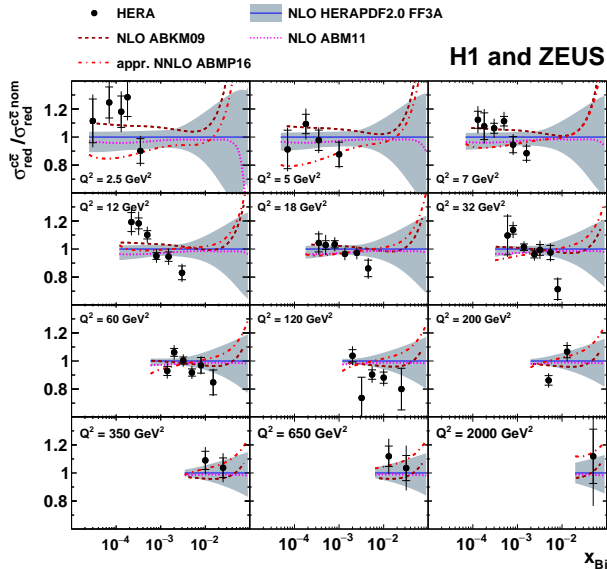


Theory settings:

- * NLO FFNS, running HF masses:
 $m_c(m_c) = 1.27 \pm 0.03 \text{ GeV}$
 $m_b(m_b) = 4.18 \pm 0.03 \text{ GeV}$
- * $\mu_f = \mu_r = \sqrt{Q^2 + 4m_Q^2}$
 (simultaneously varied by factor 2)
- * for HERAPDF2.0 FF3A, EIG only in unc. band
- * ABM09 provided by authors for HERA 2012 charm paper

Reasonable overall description, but tension in x slope at $7 < Q^2 < 32 \text{ GeV}^2$ where data are most precise

Combined data vs FFNS theory: charm



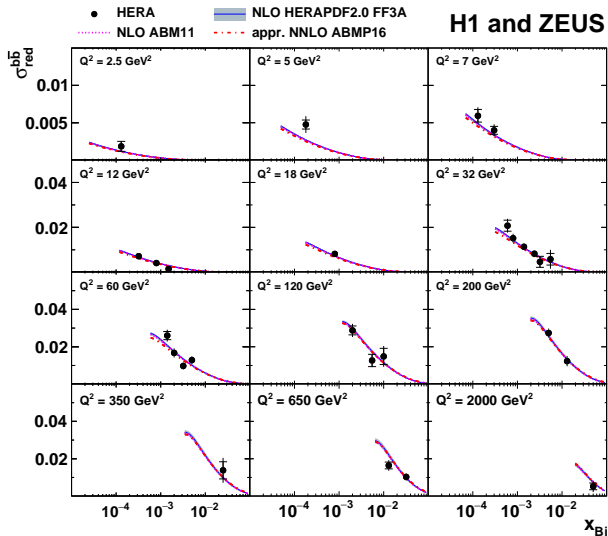
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 $m_b(m_b) = 4.18 \pm 0.03 \text{ GeV}$
- * $\mu_f = \mu_r = \sqrt{Q^2 + 4m_Q^2}$
 (simultaneously varied by factor 2)
- * for HERAPDF2.0 FF3A, EIG only in unc. band

Reasonable overall description, but tension in x slope at $7 < Q^2 < 32 \text{ GeV}^2$ where data are most precise:

- becomes worse with appr. NNLO and latest PDFs

Combined data vs FFNS theory: beauty

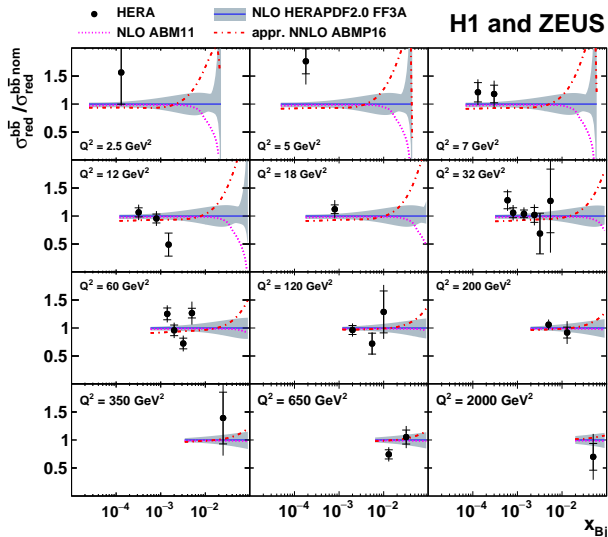


Theory settings:

- * NLO FFNS, running HF masses:
 $m_c(m_c) = 1.27 \pm 0.03 \text{ GeV}$
 $m_b(m_b) = 4.18 \pm 0.03 \text{ GeV}$
- * $\mu_f = \mu_r = \sqrt{Q^2 + 4m_Q^2}$
 (simultaneously varied by factor 2)
- * for HERAPDF2.0 FF3A, EIG only in unc. band

Good overall description

Combined data vs FFNS theory: beauty

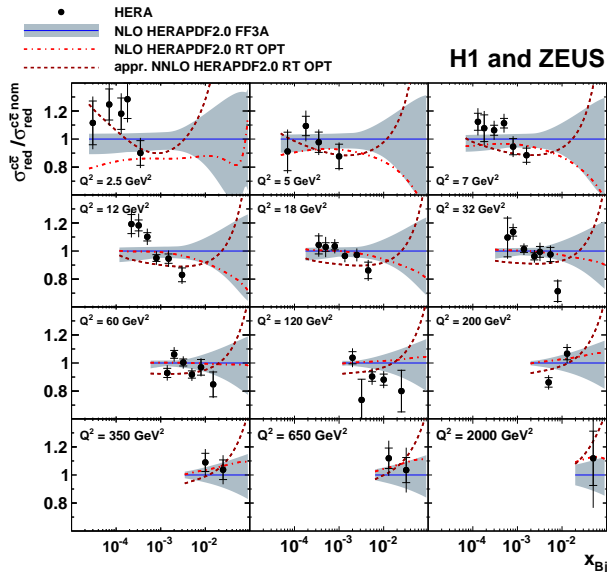


Theory settings:

- * NLO FFNS, running HF masses:
 $m_c(m_c) = 1.27 \pm 0.03 \text{ GeV}$
 $m_b(m_b) = 4.18 \pm 0.03 \text{ GeV}$
- * $\mu_f = \mu_r = \sqrt{Q^2 + 4m_Q^2}$
 (simultaneously varied by factor 2)
- * for HERAPDF2.0 FF3A, EIG only in unc. band

Good overall description

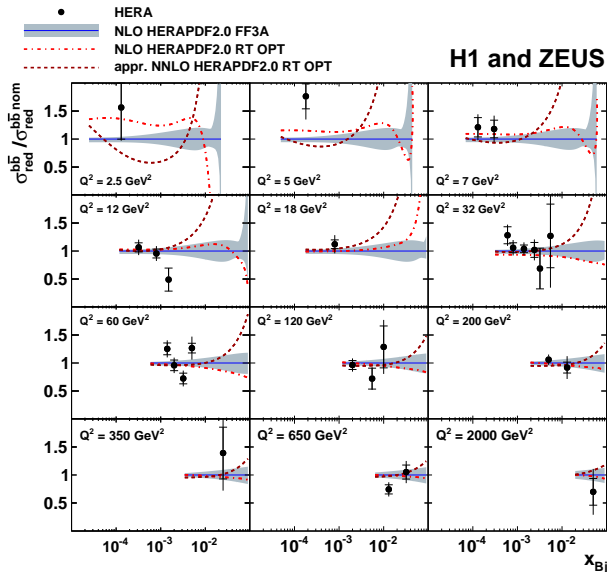
Combined data vs VFNS theory: RT OPT, charm



VFNS:

- * HERAPDF2.0 RT OPT (NLO and appr. NNLO): similar to FF3A, except lowest Q^2
- * NNPDF predictions provided by authors with recommendation not to use 1st Q^2 bin (avail. in backup, also with PDF unc.)
- * NNPDF FONLL C (NNLO for massless, NLO for massive terms): worse data description
- * NNPDF FONLL C with small x resummation: does not improve description in whole phase space
- * however, both NNPDF pred. provide improved description of x slope

Combined data vs VFNS theory: RT OPT, beauty

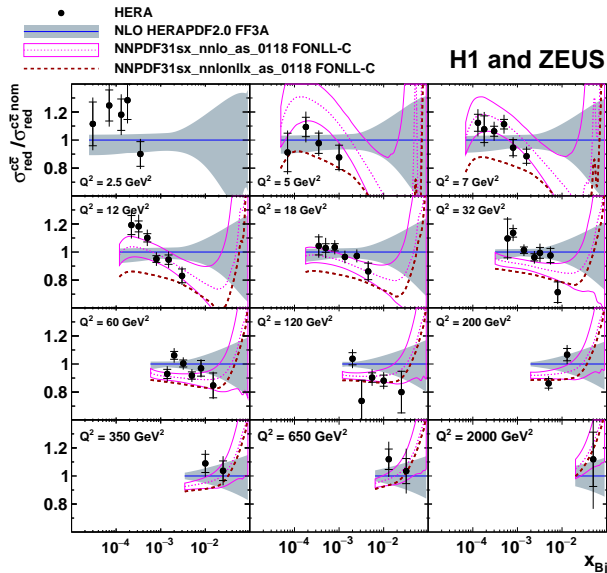


HERAPDF2.0 RT OPT:

- * HERAPDF2.0 RT OPT: similar to FF3A, except lowest Q^2
- * small differences between NLO and appr. NNLO, except lowest Q^2

Good overall descriptions

Combined data vs VFNS theory: FONLL C, charm



NNPDF3.1 FONLL C:

- * NNPDF predictions provided by authors with recommendation not to use 1st Q^2 bin
- * better description of x_{Bj} shape
- * NNPDF FONLL C (NNLO for massless, NLO for massive terms): worse data description
- * NNPDF FONLL C with small x resummation: does not improve description in whole phase space

Combined data vs theory: χ^2

Dataset	PDF	χ^2 [p -value]	χ^2 with PDF unc.
HERA 2012 <i>c</i>	HERAPDF20_NLO_FF3A	59 [0.23]	59
	ABKM09	59 [0.23]	–
	abm11_3n_nlo	62 [0.16]	62
	ABMP16_3_nnlo	70 [0.05]	69
	HERAPDF20_NLO_EIG (RT OPT)	71 [0.04]	70
	HERAPDF20_NNLO_EIG (RT OPT)	66 [0.09]	65
($N_{\text{dat}} = 52$)	-----	-----	-----
(N _{dat} = 47)	NNPDF31sx_nnlo_as_0118 (FONLL-C)	106 [$1.5 \cdot 10^{-6}$]	–
	NNPDF31sx_nnlonllx_as_0118 (FONLL-C)	71 [0.013]	–
New combined <i>c</i>	HERAPDF20_NLO_FF3A	86 [0.002]	85
	ABKM09	82 [0.005]	–
	abm11_3n_nlo	92 [0.0005]	91
	ABMP16_3_nnlo	109 [$6 \cdot 10^{-6}$]	106
	HERAPDF20_NLO_EIG (RT OPT)	99 [$9 \cdot 10^{-5}$]	98
	HERAPDF20_NNLO_EIG (RT OPT)	102 [$4 \cdot 10^{-5}$]	99
($N_{\text{dat}} = 52$)	-----	-----	-----
(N _{dat} = 47)	NNPDF31sx_nnlo_as_0118 (FONLL-C)	140 [$1.5 \cdot 10^{-11}$]	–
	NNPDF31sx_nnlonllx_as_0118 (FONLL-C)	114 [$5 \cdot 10^{-7}$]	–
New combined <i>b</i>	HERAPDF20_NLO_FF3A	33 [0.20]	33
	abm11_3n_nlo	34 [0.17]	34
	ABMP16_3_nnlo	41 [0.04]	41
	HERAPDF20_NLO_EIG (RT OPT)	33 [0.20]	33
	HERAPDF20_NNLO_EIG (RT OPT)	45 [0.016]	45
($N_{\text{dat}} = 27$)	-----	-----	-----

Objective: extract HQ masses (not providing PDFs in this paper)

Setup follows HERAPDF2.0 FF, using running HQ mass definition:

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

$$xg(x) = A_g x^{B_g} (1-x)^{C_g} - A'_g x^{B'_g} (1-x)^{C'_g}$$

$$xu_v(x) = A_{u_v} x^{B_{u_v}} (1-x)^{C_{u_v}} (1 + E_{u_v} x^2)$$

$$xd_v(x) = A_{d_v} x^{B_{d_v}} (1-x)^{C_{d_v}}$$

$$x\bar{U}(x) = A_{\bar{U}} x^{B_{\bar{U}}} (1-x)^{C_{\bar{U}}} (1 + D_{\bar{U}} x)$$

$$x\bar{D}(x) = A_{\bar{D}} x^{B_{\bar{D}}} (1-x)^{C_{\bar{D}}}$$

Additional constrains:

$$A_{\bar{U}} = A_{\bar{D}}(1 - f_s), B_{\bar{U}} = B_{\bar{D}}, C'_g = 25$$

$$\int_0^1 [\sum_i (q_i(x) + \bar{q}_i(x)) + g(x)] x dx = 1$$

$$\int_0^1 [u(x) - \bar{u}(x)] dx = 2,$$

$$\int_0^1 [d(x) - \bar{d}(x)] dx = 1$$

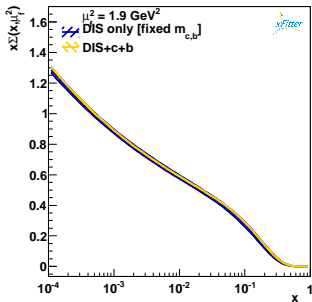
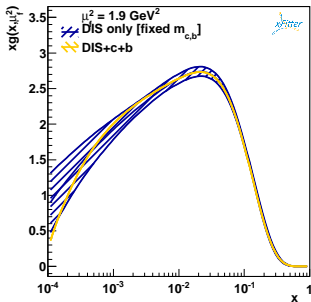
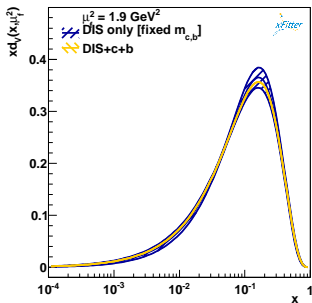
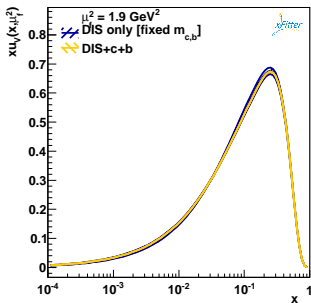
- fit ($\Delta\chi^2 = 1$), model (scales, α_s , f_s , Q_{\min}^2) and par. (μ_{f0} , $E_{u_v} = 0$) unc.

Fit results

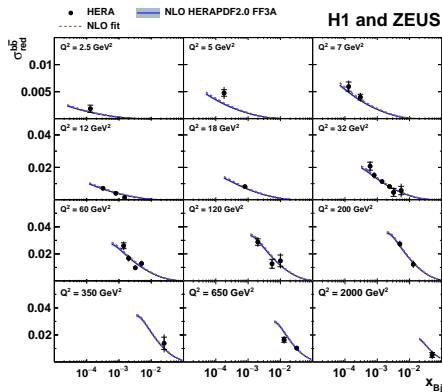
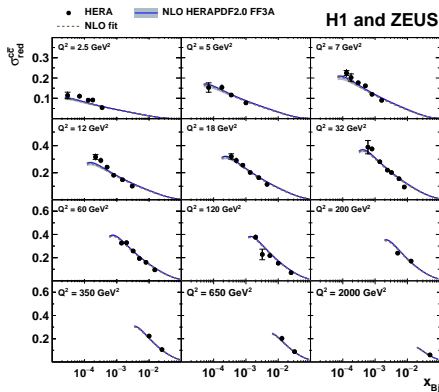
Dataset (uncor. χ^2 only)	DIS free m	DIS PDG m	DIS+c+b free m	DIS+c+b PDG m
HERA1+2 CCep	49 / 39	55 / 39	54 / 39	55 / 39
HERA1+2 CCem	50 / 42	50 / 42	50 / 42	50 / 42
HERA1+2 NCem	225 / 159	221 / 159	221 / 159	221 / 159
HERA1+2 NCep 820	65 / 70	66 / 70	65 / 70	65 / 70
HERA1+2 NCep 920	415 / 377	420 / 377	418 / 377	419 / 377
HERA1+2 NCep 460	223 / 204	221 / 204	221 / 204	220 / 204
HERA1+2 NCep 575	219 / 254	217 / 254	217 / 254	217 / 254
HERA c	-	-	50 / 52	49 / 52
HERA b	-	-	17 / 27	19 / 27
Correlated χ^2	71	75	125	128
Log penalty χ^2	-12	-6	-4	-6
Total χ^2 / dof	1304 / 1129	1319 / 1131	1435 / 1208	1437 / 1210

- DIS PDG masses \approx HERAPDF2.0 FF3A
- DIS+c+b free masses: nominal fit in this paper

Fitted PDFs

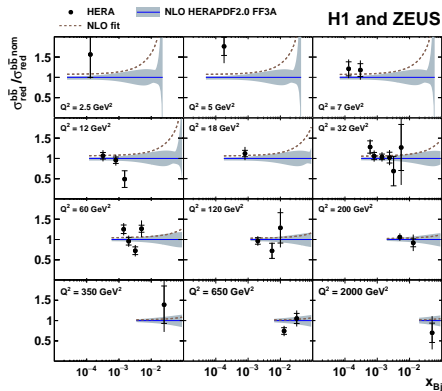
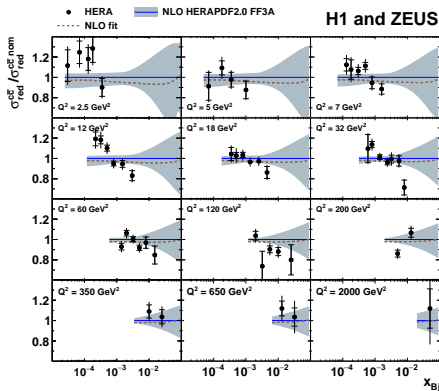


Data to theory comparison in the fit



- Observed almost no impact of HF data on PDFs, **except constraining HQ masses**
- Theory predictions from the fit are consistent with HERAPDF2.0

Data to theory comparison in the fit



- Observed almost no impact of HF data on PDFs, **except constraining HQ masses**
- Theory predictions from the fit are consistent with HERAPDF2.0 (constant offsets are explained by changes in the fitted mass values which are $\approx \pm 1\sigma$ of PDG values)

Variation	DIS			DIS + c + b		
	χ^2/dof	$m_c(m_c)$ [MeV]	$m_b(m_b)$ [MeV]	χ^2/dof	$m_c(m_c)$ [MeV]	$m_b(m_b)$ [MeV]
Nominal	1304/1129	1798^{+144}_{-134}	8450^{+2282}_{-1812}	1435/1208	1290^{+46}_{-41}	4049^{+104}_{-109}
$\mu \times 2$	1307	1752 [-46]	7794 [-656]	1430	1320 [+30]	4017 [-32]
$\mu \times 0.5$	1305	1804 [+6]	8747 [+297]	1435	1350 [+60]	4139 [+90]
$\alpha_s = 0.1075$	1304	1804 [+6]	8720 [+270]	1437	1276 [-14]	4051 [+2]
$\alpha_s = 0.1045$	1305	1780 [-28]	8041 [-409]	1434	1301 [+11]	4044 [-5]
$f_s = 0.50$	1304	1797 [-1]	8375 [-75]	1434	1287 [-3]	4048 [-1]
$f_s = 0.30$	1305	1798 [+0]	8474 [+24]	1436	1294 [+4]	4050 [+1]
$Q_{\min}^2 = 5.0 \text{ GeV}^2$	1237/1087	1932 [+134]	8300 [-150]	1372/1166	1289 [-1]	4044 [-5]
$Q_{\min}^2 = 2.5 \text{ GeV}^2$	1346/1152	1798 [-0]	8509 [+49]	1476/1231	1297 [+7]	4056 [+7]
$\mu_{f0}^2 = 2.2 \text{ GeV}^2$	1305	1798 [+0]	8371 [-79]	1436	1293 [+3]	4048 [-1]
$\mu_{f0}^2 = 1.6 \text{ GeV}^2$	1303	1798 [-0]	8472 [+22]	1434	1289 [-1]	4050 [+1]
$E_{u_v} = 0$	1319	1450 [-348]	3995 [-4455]	1440	1259 [-31]	4018 [-31]

Quote these results as:

DIS (not sensible for HQ mass extraction):

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

$$m_b(m_b) = 8450^{+2282}_{-1812}(\text{fit}) \text{ MeV}$$

' $E_{u_v} = 0$ ': $m_c(m_c) = 1450 \text{ MeV}$, $m_c(m_c) = 3995 \text{ MeV}$ (dominant par. unc.)

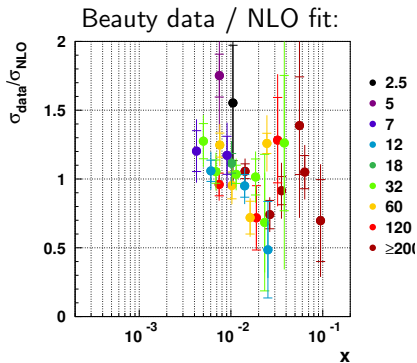
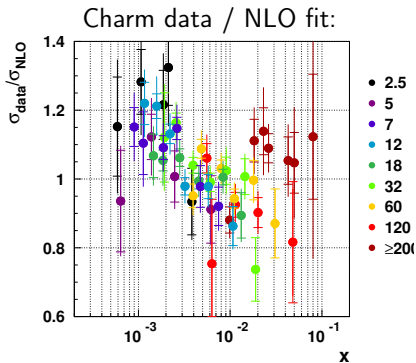
DIS + c + b:

$$m_c(m_c) = 1290^{+46}_{-41}(\text{fit})^{+62}_{-14}(\text{mod})^{+7}_{-31}(\text{par})$$

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

Model unc. are dominated by scale var., par. unc. are dominated by ' $E_{u_v} = 0$ '.

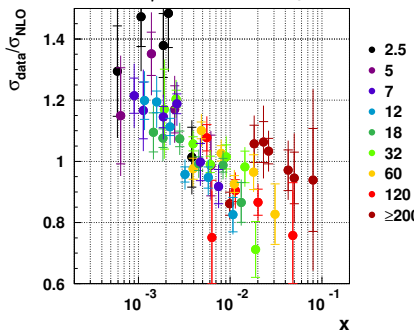
Further studies of data and theory agreement



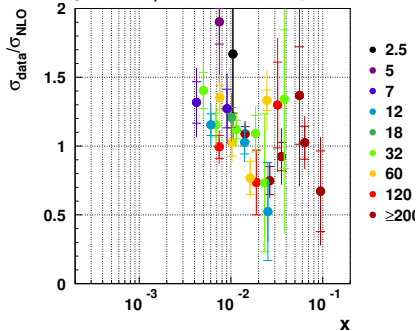
- x is average partonic momentum fraction calculated at NLO
- Charm: apparent x trend in wide Q^2 range for $0.0005 \lesssim x \lesssim 0.01$
- Beauty: similar trend in the same x range within larger uncertainties
- These are paper plots

Further studies of data and theory agreement

Charm data / ABMP16 ap. NNLO:



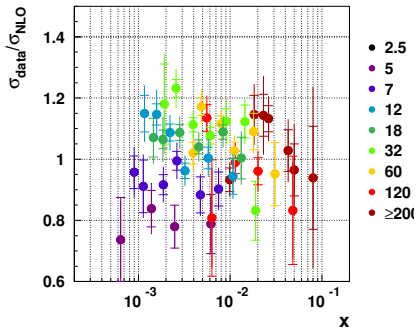
Beauty data / ABMP16 ap. NNLO:



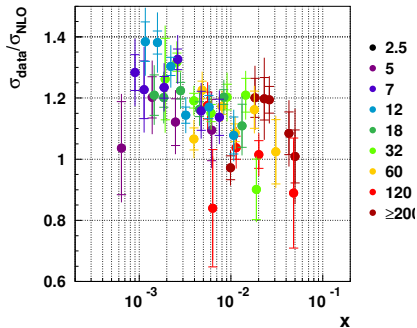
- Worsen description of x at appr. NNLO
- These are **not** paper plots

Further studies of data and theory agreement

Charm data / NNPDF NNLO:



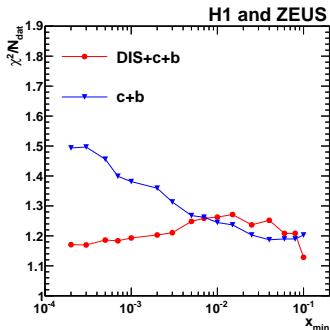
Charm data / NNPDF NNLO NLLx:



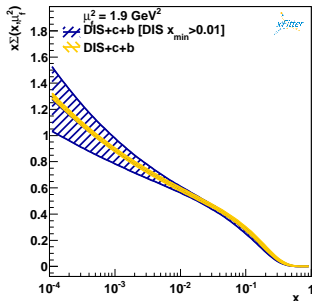
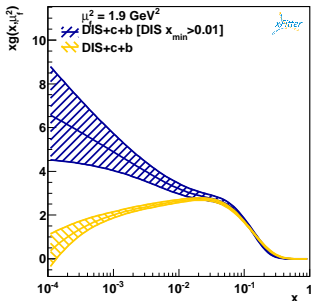
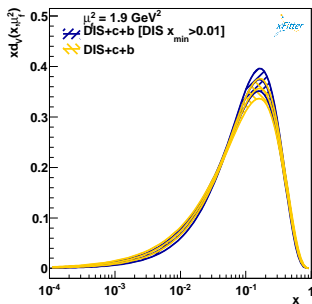
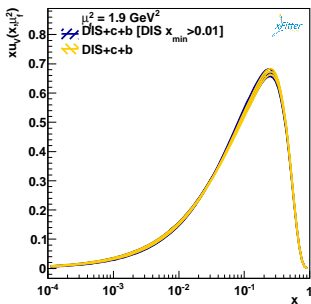
- Better description of x w/out small x resummation, but worsen description of Q^2 shape
- With small x resummation: data above theory
- These are **not** paper plots

Further studies of data and theory agreement

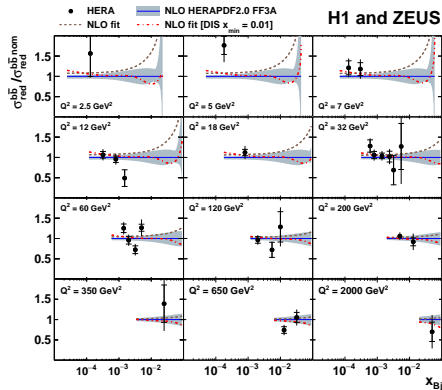
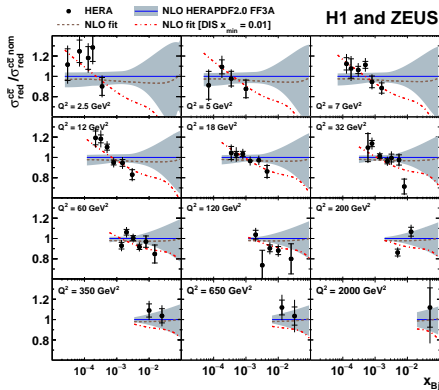
- Apparent difference in x slope suggests that the HF data prefer a steeper low x gluon
- Gluon distribution is **not directly** constrained by inclusive data: relies on many assumptions (parametrisation, sum rules etc.)
- HF data are **directly** sensitive to the gluon distribution, however quantitatively they can not compete with inclusive data and the latter dominate in the fit
- *to increase the weight of HF data*, we apply $x > x_{\min}$ cut on inclusive data in the PDF fit and monitor changes by looking at χ^2 of HF data



PDFs with $x_{\min} = 0.01$ cut on inclusive data



Data to theory comparison in the fit

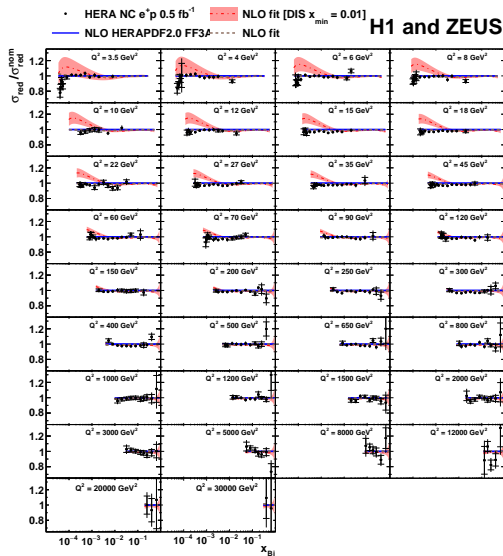


- Fit with $x_{min} = 0.01$ provides a steeper low- x gluon and **better description of HF data:**

- $\chi^2 = 98$ vs 116 in nominal fit per 79 degrees of freedom
- $p = 0.07$ vs $p = 0.004$

- $x_{min} = 0.01$: $m_c(m_c) = 1400_{-51}^{+45}$ MeV, $m_b(m_b) = 4.11_{-0.11}^{+0.10}$ GeV

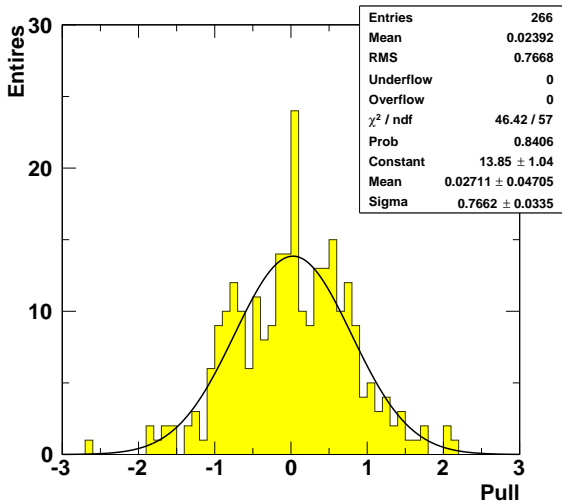
Data to theory comparison in the fit



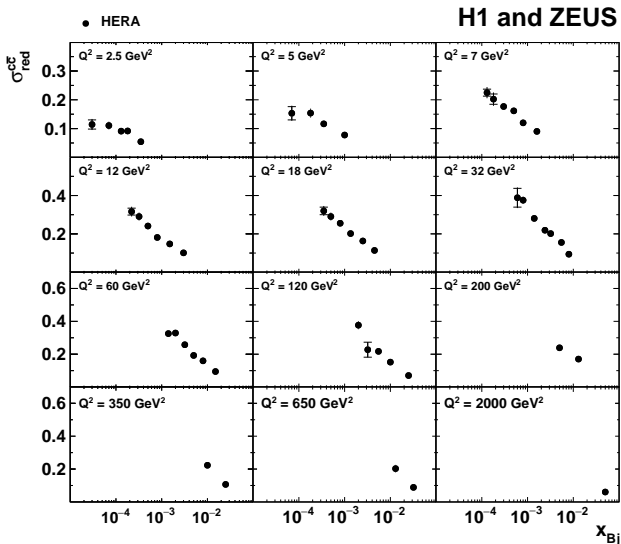
- However as expected, description of inclusive data **excluded from the fit** is worse: $\chi^2 = 2874$ vs 1435 in the nominal fit per 1224 data points

- Combination of charm beauty production measurements:
 - all input measurements are consistent
 - improved precision compared to previously published charm
 - first combination of beauty
- Combined data are compared to FFNS theoretical predictions:
 - overall reasonable description, but revealed tensions in x slope
 - worse description by approximate NNLO
 - worse description by VFNS predictions
 - predictions with small x resummation does not provide good description of data
 - ⇒ revealed tension in data to theory comparison is not due to FFNS
- Extracted HQ masses:
 - attempts to extract from inclusive data only are sensible
 - $m_c(m_c) = 1290_{-41}^{+46}(\text{fit})_{-14}^{+62}(\text{mod})_{-31}^{+7}(\text{par})$ MeV
 - $m_b(m_b) = 4049_{-109}^{+104}(\text{fit})_{-32}^{+90}(\text{mod})_{-31}^{+1}(\text{par})$ MeV
- Further studies revealed that HF data are described better by PDFs with a steeper gluon:
 - in the adopted PDF framework, it appears in tension with the gluon distribution extracted from inclusive HERA data

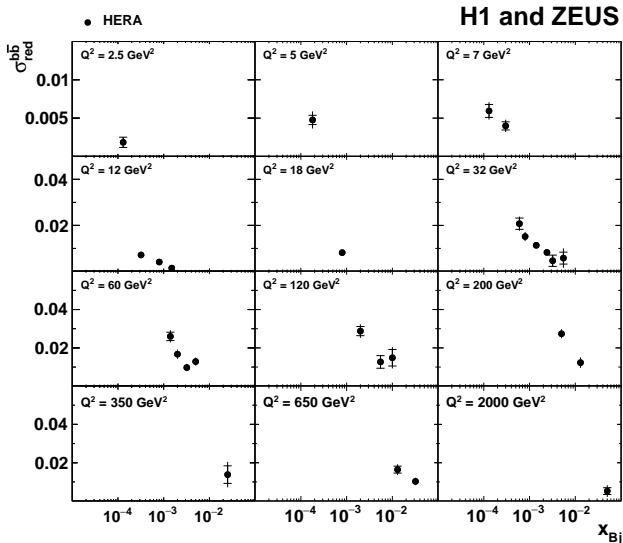
Plots proposed for the paper



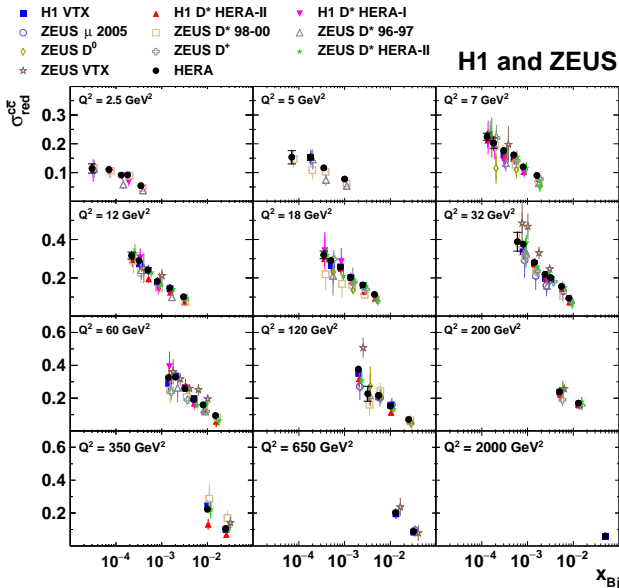
Plots proposed for the paper



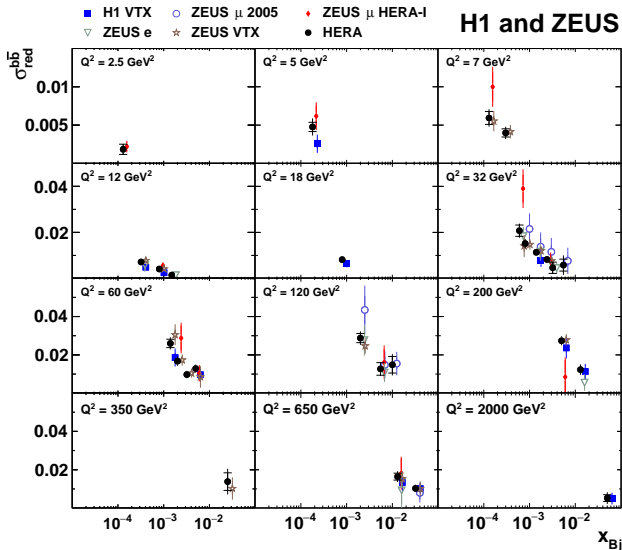
Plots proposed for the paper



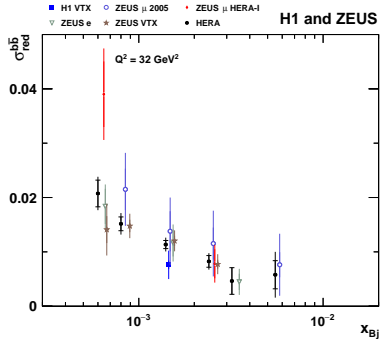
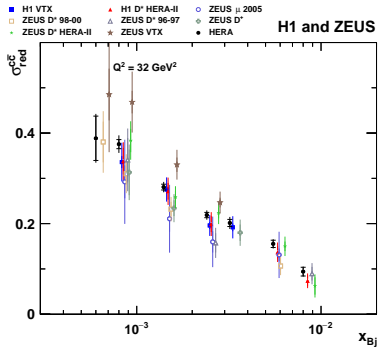
Plots proposed for the paper



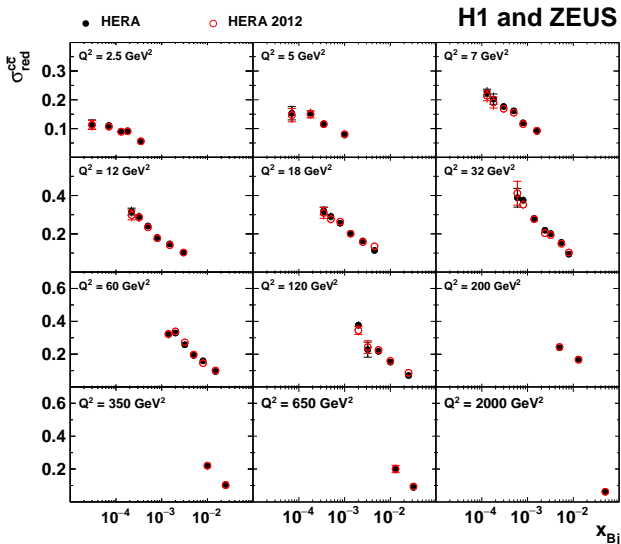
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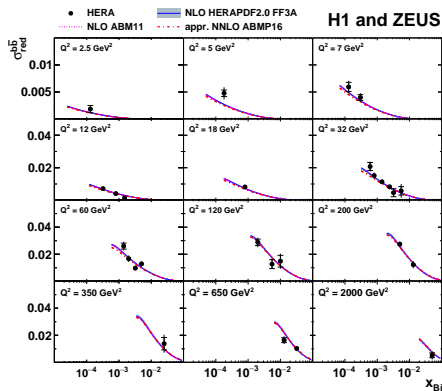
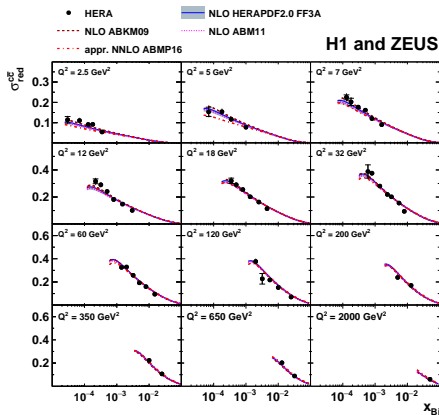
Plots proposed for the paper



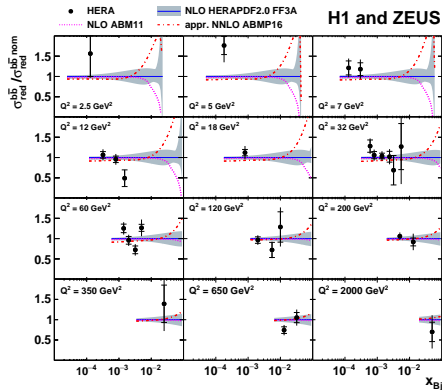
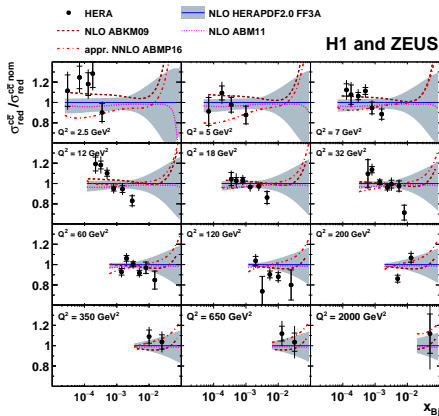
Plots proposed for the paper



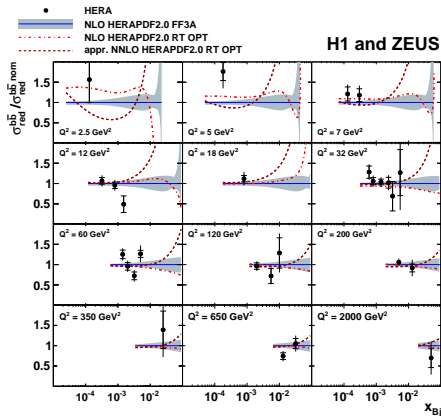
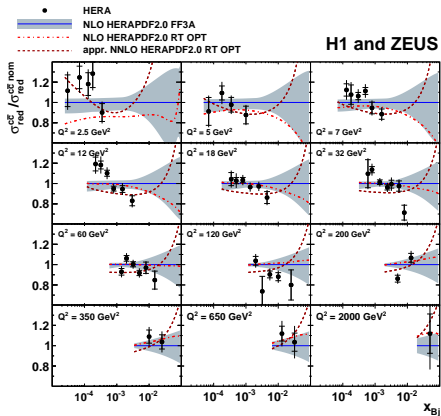
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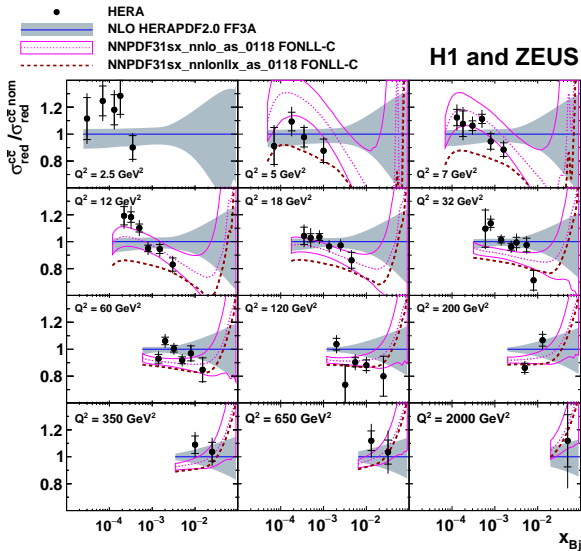
Plots proposed for the paper



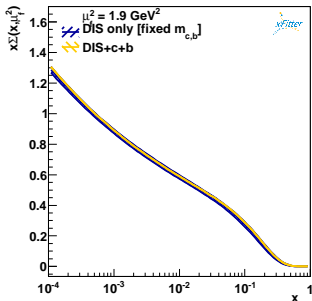
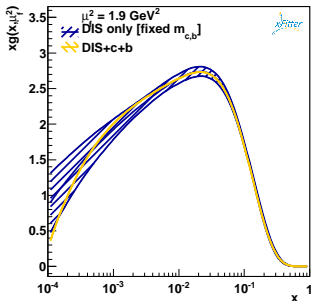
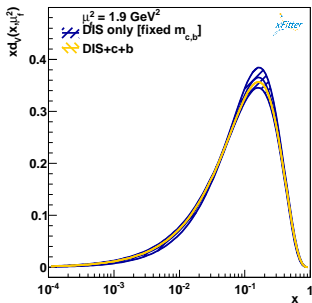
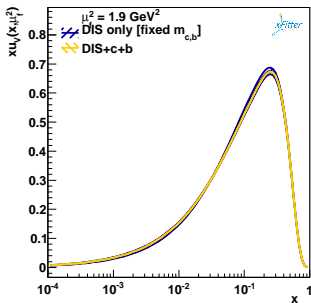
Plots proposed for the paper



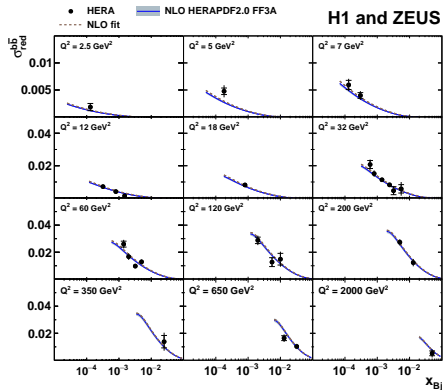
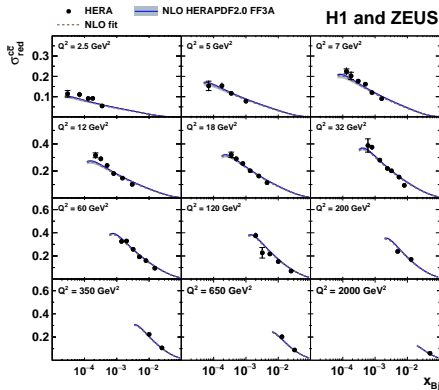
Plots proposed for the paper



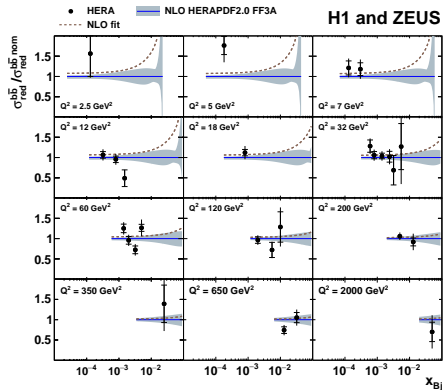
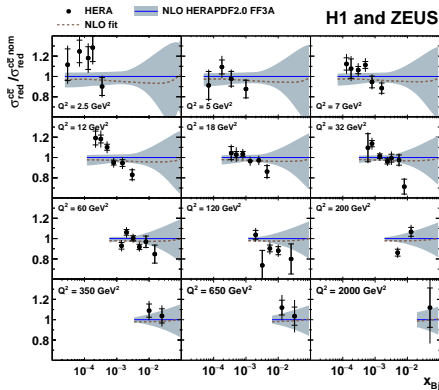
Plots proposed for the paper



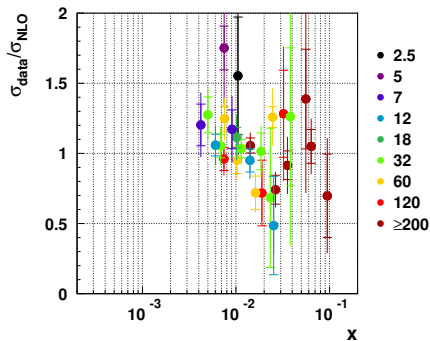
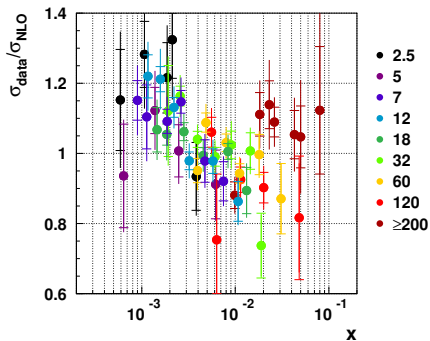
Plots proposed for the paper

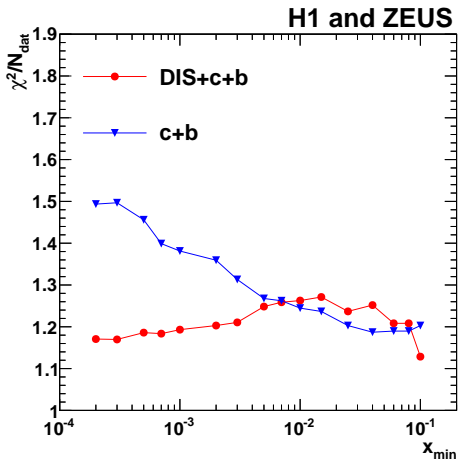


Plots proposed for the paper

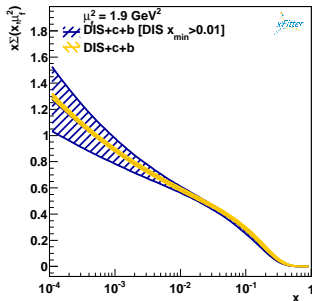
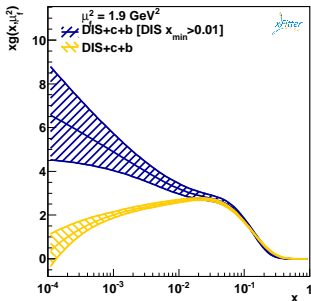
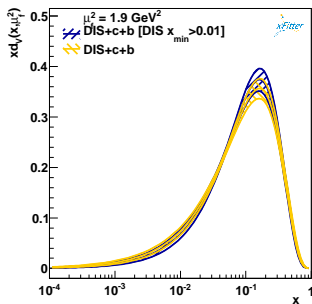
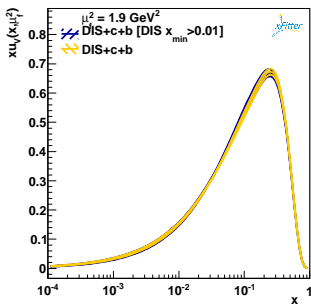


Plots proposed for the paper

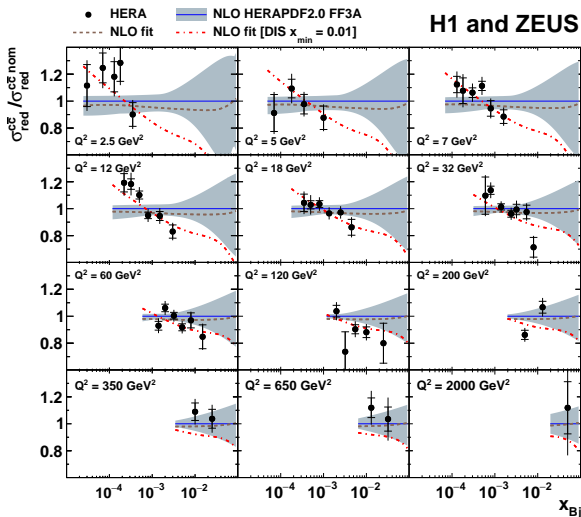




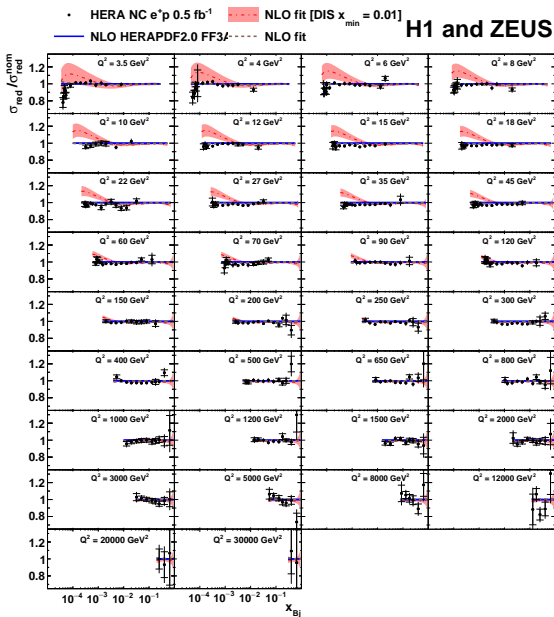
Plots proposed for the paper



Plots proposed for the paper



Plots proposed for the paper



BACKUP

Uncorrelated

- δ_1 Boxcut variation ($\pm 1\%$)
- δ_5, δ_6 Signal extraction procedure ($< \pm 1\%$, $+0.7\%$, -1.5%)

Point-to-point correlated

- δ_2 Electron energy scale ($< \pm 1\%$)
- δ_3 Hadronic energy scale ($< \pm 1\%$)
- δ_4 FLT trigger efficiency ($< \pm 1\%$)
- δ_7 Decay length smearing ($\pm 1\%$)
- δ_8 **Beauty contribution to the cross sections ($\pm 2\%$)**
- δ_9, δ_{10} **MC shape ($\pm 2\%$, $\pm 4\%$)**
- δ_{11} Tracking efficiency ($\pm 1.5\%$)
- δ_{12} MVD hit efficiency ($\pm 0.9\%$)
- δ_{13} $\chi^2_{sec. vtx.}$ **smearing ($+2\%$)**
- δ_{14} $D^+ \rightarrow K^- \pi^+ \pi^+$ **branching ratio ($\pm 2.1\%$)**
- δ_{15} Luminosity ($\pm 1.9\%$)

More details in H1ZEUS HF meeting 19.04.2013

Uncorrelated

- δ_3, δ_4 Boxcut variations ($\pm 1\%$, $\pm 1\%$)
- δ_5, δ_6 Background shape ($< \pm 1\%$, $< \pm 1\%$)
- δ_{11} Acceptance statistical uncertainty ($\pm 1\%$)
- δ_{15} **Resolved photon contribution to the acceptance (+2%)**

Correlated

- δ_1 Hadronic energy scale ($\pm 1\%$)
- δ_2 Electron energy scale ($\pm 1\%$)
- δ_7 $p_T(\pi_s)$ correction ($\pm 1.5\%$)
- δ_8 **Signal outside the $M_{K\pi}$ window (+2%)**
- δ_9 **Tracking efficiency ($\pm 2\%$)**
- δ_{12} Beauty contribution to the acceptance ($< \pm 1\%$)
- δ_{13}, δ_{14} PHP and diffractive MC normalisations ($< \pm 1\%$, $< \pm 1\%$)
- δ_{16}, δ_{17} **MC shape ($\pm 2\%$, $+3\%$, -2%)**
- δ_{18} Luminosity ($\pm 1.9\%$)
- δ_{19} $D^* \rightarrow D^0\pi^+, D^0 \rightarrow K^-\pi^+$ ($\pm 1.9\%$)

More details in H1ZEUS HF meeting 19.04.2013

- Treatment of systematics: as in the original paper for $m_b(m_b)$ extraction

The statistical uncertainties and the uncertainties $\delta_1, \delta_2, \delta_4^{\text{core}}, \delta_5$ and δ_{12} from Tables [12](#) and [13](#) were treated as uncorrelated, while all other uncertainties, including those from luminosity and from Table [18](#) were treated as point-to-point correlated. The

Treated as correlated between ZEUS D^+ , D^* and VTX HERA-II:

- tracking
- e/h energy scales
- lumi (also with beauty ZEUS el)

ZEUS $b \rightarrow \mu$ DESY-09-056, H1 b vertex DESY-09-096

- Charm data were included in previous H1ZEUS combination: treat same sources as correlated for beauty

ZEUS $b \rightarrow e$ DESY-11-005:

- Only lumi treated as correlated

ZEUS $b \rightarrow \mu$ HERA-I DESY-10-047:

- muon detection (7%) and lumi treated as correlated

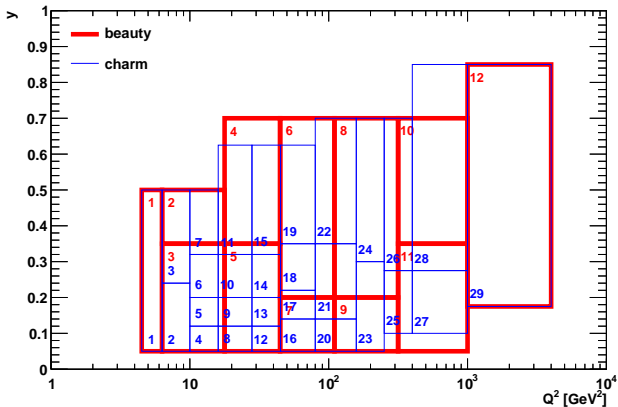
$$\delta_{\text{stat}}^2 = \delta_{\text{uncor}}^2 + \delta_{\text{cor}}^2 \rightarrow \delta_{\text{cor}}^2 = \delta_{\text{stat}}^2 \times |\rho|, \delta_{\text{uncor}}^2 = \delta_{\text{stat}}^2 - \delta_{\text{cor}}^2$$

$\rho < 0 \Rightarrow$ correlated uncertainties are assigned with different \pm signs for c and b

- ZEUS μ 2005: correlation factors ρ are used directly
- $\delta_{\text{stat}}^2 = \delta_{\text{uncor}}^2 + \delta_{\text{cor}}^2 \rightarrow \delta_{\text{cor}}^2 = \delta_{\text{stat}}^2 \times |\rho|, \delta_{\text{uncor}}^2 = \delta_{\text{stat}}^2 - \delta_{\text{cor}}^2$
 $\rho < 0 \Rightarrow$ correlated uncertainties are assigned with different \pm signs for c and b
- ZEUS vertex: to account for different c and b phase space, charm correlation factors are scaled by NLO predictions (see next slides)
- H1 vertex: to account for different c and b binning, split correlations according to NLO predictions (see next slides)

- Charm: $E_T(\text{jet} > 4.2\text{GeV})$, beauty $E_T(\text{jet} > 5\text{GeV})$
- Charm correlation factors are scaled by theory predictions:
 $\sigma(E_T(\text{jet} > 4.2\text{GeV}))/\sigma(E_T(\text{jet} > 5\text{GeV}))$
- This fraction ranges from 0.65 at low Q^2 , high x to 0.95 at high Q^2

H1 vertex, statistical correlations



- 29 c bins, 12 b bins, original Q^2 - y bin boundaries provided by H1
- Found 54 overlays \Rightarrow need 54 correlated uncertainty sources
- Use NLO predictions to split statistical uncertainty into uncorrelated and needed number of correlated parts (number of overlays σ_i):

$$\delta_{\text{stat}}^2 = \delta_{\text{uncor}}^2 + \sum_i \delta_{\text{cor},i}^2, \quad \delta_{\text{cor},i}^2 = \delta_{\text{stat}}^2 \times |\rho| \times \frac{\sigma_i}{\sigma} \text{ small impact: backup}$$

BACKUP. ZEUS μ HERA-I: extrapolation

Q2	x	NLO(pub)	reproduced	hadr	stat
3.0	0.00013	2.40e+00	2.48e+00 [+3.5%]	5.0%	23.8%
5.0	0.00013	2.60e-01	2.66e-01 [+2.4%]	5.0%	20.5%
12.0	0.00020	8.30e-01	8.70e-01 [+4.8%]	5.0%	17.7%
12.0	0.00050	4.80e-01	4.60e-01 [-4.2%]	5.0%	18.8%
25.0	0.00050	1.78e-01	1.84e-01 [+3.2%]	5.0%	14.7%
40.0	0.00200	7.90e-02	7.88e-02 [-0.3%]	5.0%	34.0%
60.0	0.00200	6.70e-02	7.01e-02 [+4.7%]	5.0%	22.0%
80.0	0.00500	3.50e-02	3.44e-02 [-1.6%]	5.0%	31.1%
130.0	0.00200	1.74e-02	1.82e-02 [+4.4%]	5.0%	43.2%
130.0	0.00500	1.35e-02	1.36e-02 [+0.6%]	5.0%	103.7%
450.0	0.01300	7.10e-04	6.94e-04 [-2.2%]	5.0%	41.5%

- visible cross section are reported for μ (from b) + jet final state
- hadronisation corrections are needed for NLO: "...change the NLO QCD predictions by typically 5% or less." [DESY-10-047]
- \Rightarrow apply 5% as uncorrelated uncertainty
- Experimental: treat 7% muon detection and 2% lumi as correlated, all other as uncorrelated (statistical and remaining uncorrelated systematics are much larger)

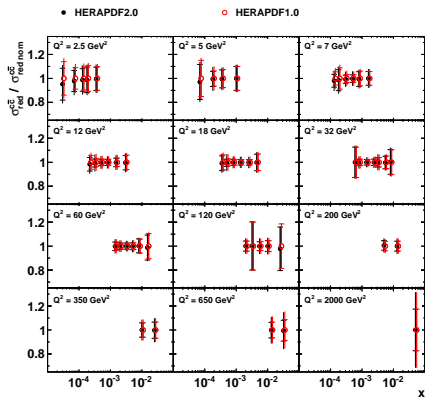
BACKUP. Impact of using HERAPDF2.0 vs HERAPDF1.0 for extrapolation

$$\sigma_{\text{red}} = \sigma_{\text{vis}} \frac{\sigma_{\text{red}}^{\text{NLO}}}{\sigma_{\text{vis}}^{\text{NLO}}}$$

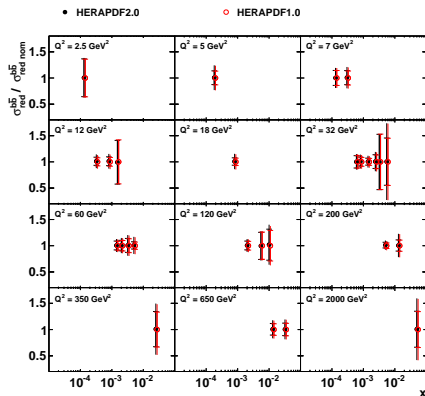
Reminder:

- Need FFNS variant with consistent masses, scales and α_s settings: exists for HERAPDF1.0, does not exist for HERAPDF2.0
- Decision: check HERAPDF2.0 impact on central values

charm



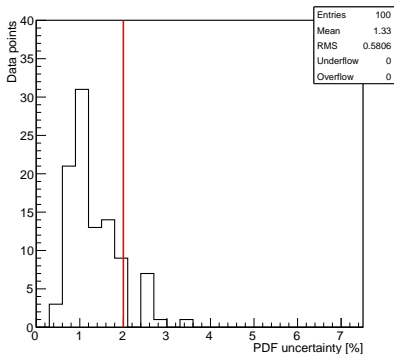
beauty



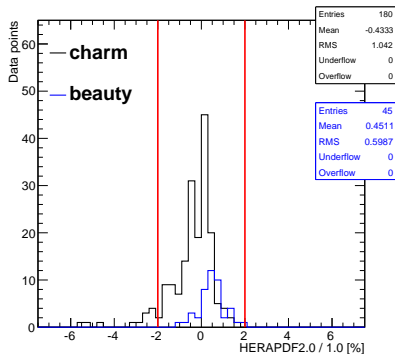
Only small impact on charm at low Q^2 , x , well within uncertainties

Which uncertainty assign to PDFs in extrapolation:

HERAPDF1.0 uncertainty

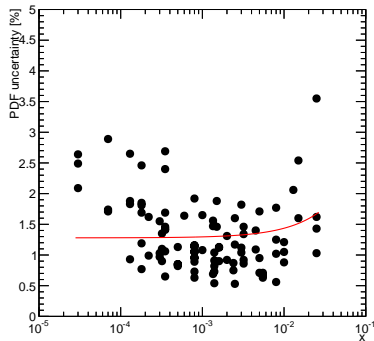
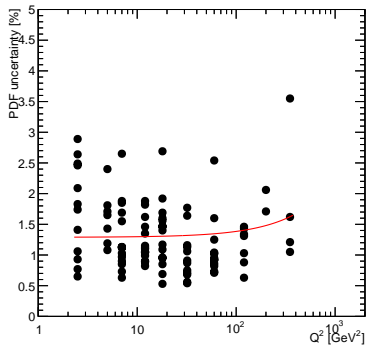


HERAPDF2.0 impact



- $2\% \gtrsim \text{RMS}(\text{HERAPDF1.0 unc.}) \oplus \text{Mean}(\text{HERAPDF2.0/1.0})$
- treat as bin-to-bin uncorrelated (effective sum of many variations)

No substantial Q^2 , x dependence:



- large Q^2 , x points seem to be just more affected by numerical precision
- **Proceed with using HERAPDF1.0 for central values, assign uncorrelated 2% uncertainty for all points: consistent with HERAPDF2.0**

Beauty semileptonic decay spectrum used for extrapolation

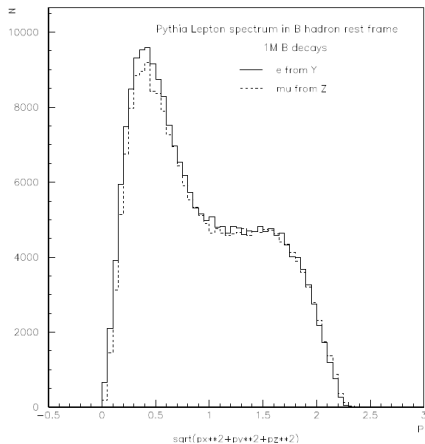
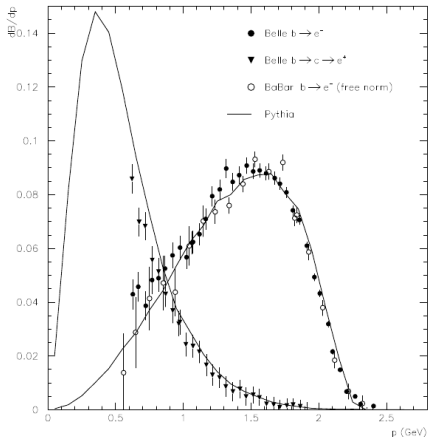
Massimo Corradi, 14 May 2008

HVQDIS for Beauty

The $B \rightarrow \mu X$ spectrum used in FMNR has been plugged in HVQDIS.

It was taken from Pythia and checked with BaBar/Belle data

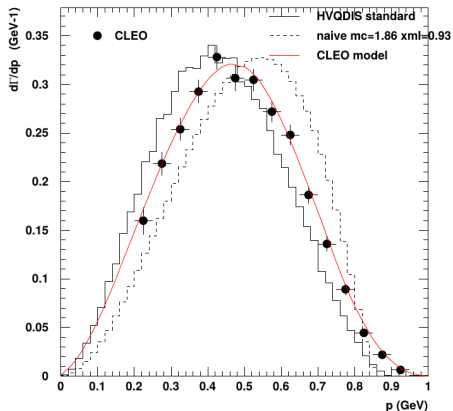
e momentum from $B0/B^+$ decays 2002/12/11 12.35



Massimo Corradi, 19 June 2008

Charm decay, HVQDIS and CLEO data

$$D^+ \rightarrow e \nu X$$



electron momentum in D^+ decay
CLEO data at $\psi(3770)$
 $\simeq D$ rest frame ($E_{\text{kin}} = 16\text{MeV}$)

HVQDIS spectrum from Rappaport (Jetset)
softer than CLEO data

naive free-quark model not so good

CLEO model based on ISGW
parametrisation OK

Data and uncertainties[%]: charm

bin	Q^2 [GeV ²]	x	σ_{red}	stat	uncor	cor	tot	bin	Q^2 [GeV ²]	x	σ_{red}	stat	uncor	cor	tot
1	2.5	0.00003	0.11423	8.9	10.7	9.4	16.9	27	18.0	0.00450	0.11367	5.5	4.1	5.4	8.7
2	2.5	0.00007	0.11054	5.8	6.7	8.2	12.1	28	32.0	0.00060	0.38846	8.5	9.3	5.8	13.9
3	2.5	0.00013	0.09111	7.1	6.2	7.9	12.3	29	32.0	0.00080	0.37557	2.3	1.4	4.4	5.2
4	2.5	0.00018	0.09170	4.8	9.6	7.2	12.9	30	32.0	0.00140	0.28070	2.0	1.1	3.4	4.1
5	2.5	0.00035	0.05437	5.3	8.2	6.9	12.0	31	32.0	0.00240	0.21897	2.3	1.4	3.9	4.7
6	5.0	0.00007	0.15321	11.6	9.6	8.2	17.1	32	32.0	0.00320	0.20149	3.6	1.6	5.4	6.6
7	5.0	0.00018	0.15385	5.3	3.4	7.8	10.0	33	32.0	0.00550	0.15534	4.2	3.0	4.1	6.6
8	5.0	0.00035	0.11642	5.2	5.3	5.7	9.3	34	32.0	0.00800	0.09403	8.7	5.4	6.0	11.9
9	5.0	0.00100	0.07763	4.8	8.7	5.6	11.4	35	60.0	0.00140	0.32542	3.2	1.4	4.8	5.9
10	7.0	0.00013	0.22486	4.3	3.3	6.7	8.6	36	60.0	0.00200	0.32893	2.3	1.2	4.1	4.9
11	7.0	0.00018	0.20231	6.8	5.7	7.2	11.4	37	60.0	0.00320	0.25762	2.2	1.2	3.6	4.4
12	7.0	0.00030	0.17669	2.3	2.4	5.4	6.4	38	60.0	0.00500	0.19250	2.3	1.6	4.1	5.0
13	7.0	0.00050	0.16158	2.5	1.8	5.2	6.0	39	60.0	0.00800	0.15960	4.8	3.1	3.4	6.7
14	7.0	0.00080	0.11994	4.6	4.0	4.9	7.8	40	60.0	0.01500	0.09458	8.1	6.5	4.9	11.5
15	7.0	0.00160	0.09023	4.1	3.9	5.2	7.7	41	120.0	0.00200	0.37661	3.3	2.6	5.0	6.5
16	12.0	0.00022	0.31613	4.9	2.9	5.7	8.0	42	120.0	0.00320	0.22743	14.6	13.7	2.7	20.2
17	12.0	0.00032	0.29041	2.9	1.5	6.3	7.1	43	120.0	0.00550	0.21729	3.3	1.6	5.4	6.5
18	12.0	0.00050	0.24098	2.4	1.3	4.6	5.3	44	120.0	0.01000	0.15186	3.9	2.3	5.2	6.9
19	12.0	0.00080	0.18134	2.1	1.4	4.5	5.1	45	120.0	0.02500	0.07022	13.6	12.6	4.4	19.1
20	12.0	0.00150	0.14761	3.2	1.5	5.1	6.2	46	200.0	0.00500	0.23889	3.1	2.4	4.5	6.0
21	12.0	0.00300	0.10103	4.4	4.0	5.1	7.8	47	200.0	0.01300	0.17035	3.4	2.3	5.0	6.5
22	18.0	0.00035	0.31977	5.2	3.3	5.2	8.1	48	350.0	0.01000	0.22300	5.1	3.0	6.4	8.7
23	18.0	0.00050	0.29049	2.6	1.4	6.4	7.0	49	350.0	0.02500	0.10646	6.1	2.9	7.4	10.0
24	18.0	0.00080	0.25539	2.2	1.2	4.2	4.9	50	650.0	0.01300	0.20260	5.4	3.7	9.1	11.2
25	18.0	0.00135	0.20163	2.0	1.1	4.1	4.7	51	650.0	0.03200	0.08846	7.8	3.8	12.8	15.4
26	18.0	0.00250	0.16300	1.9	1.3	4.2	4.7	52	2000.0	0.05000	0.06026	16.0	6.7	26.4	31.6

Data and uncertainties[%]: beauty

bin	Q^2 [GeV ²]	x	σ_{red}	stat	uncor	cor	tot
1	2.5	0.00013	0.00184	28.4	22.4	11.4	37.9
2	5.0	0.00018	0.00476	10.5	7.1	19.8	23.5
3	7.0	0.00013	0.00593	8.8	11.2	12.7	19.1
4	7.0	0.00030	0.00398	8.5	10.3	15.2	20.2
5	12.0	0.00032	0.00715	4.9	5.8	10.5	13.0
6	12.0	0.00080	0.00409	4.6	6.9	11.1	13.9
7	12.0	0.00150	0.00145	32.2	26.9	3.6	42.1
8	18.0	0.00080	0.00817	4.8	5.0	12.8	14.5
9	32.0	0.00060	0.02074	8.9	7.8	8.9	14.8
10	32.0	0.00080	0.01516	5.8	6.1	10.0	13.1
11	32.0	0.00140	0.01135	3.9	5.3	9.0	11.2
12	32.0	0.00240	0.00824	9.0	9.5	12.9	18.4
13	32.0	0.00320	0.00464	32.2	41.9	3.0	52.9
14	32.0	0.00550	0.00579	39.8	20.4	57.4	72.8
15	60.0	0.00140	0.02599	4.8	6.9	8.8	12.2
16	60.0	0.00200	0.01672	7.5	6.5	10.5	14.4
17	60.0	0.00320	0.00975	10.7	7.7	14.4	19.5
18	60.0	0.00500	0.01287	5.4	4.2	14.7	16.2
19	120.0	0.00200	0.02876	6.3	5.4	9.0	12.2
20	120.0	0.00550	0.01268	21.2	14.9	10.9	28.1
21	120.0	0.01000	0.01485	20.5	20.6	23.6	37.5
22	200.0	0.00500	0.02737	3.8	3.7	6.9	8.7
23	200.0	0.01300	0.01231	9.5	4.8	19.5	22.2
24	350.0	0.02500	0.01381	20.4	26.2	35.0	48.2
25	650.0	0.01300	0.01641	8.1	7.5	13.1	17.1
26	650.0	0.03200	0.01027	8.1	8.7	14.6	18.8
27	2000.0	0.05000	0.00522	30.6	15.2	47.6	58.6

Data correlations[%]: beauty vs charm

bin	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
1	1	0	4	1	3	3	-2	1	1	1	1	-1	-1	1	3	-2	-3	-2	0	-2	0	1	-4	-2	-0	-2	-1
2	1	0	3	1	3	3	-2	1	1	1	2	-1	-1	1	3	-1	-3	-3	0	-2	0	1	-5	-2	-0	-2	-2
3	1	0	2	0	2	1	-1	1	0	0	2	-1	-1	1	2	-0	-3	-3	0	-1	0	-0	-5	-2	-0	-2	-1
4	1	0	2	-0	2	1	-1	1	0	-0	1	-1	-1	1	2	-0	-2	-1	0	-1	0	0	-3	-2	-1	-1	-1
5	0	0	1	-1	2	-0	-0	1	-0	-0	1	-1	-0	1	2	1	-2	0	1	-0	1	1	-2	-1	-1	-1	-1
6	1	0	3	1	3	2	-2	1	1	1	1	-1	-1	1	2	-1	-2	-2	0	-1	0	1	-3	-2	-0	-1	-1
7	-1	-30	1	-0	7	7	-0	4	-0	1	6	-1	-0	1	1	1	-4	1	-1	1	0	-5	-1	-1	1	-1	-2
8	1	0	1	-1	2	1	-0	1	-0	-0	2	-1	-0	1	2	1	-2	-1	1	-0	1	1	-3	-2	-1	-1	-1
9	0	1	-0	-2	1	-2	0	0	-1	-0	0	-1	0	1	1	2	-1	2	1	0	1	1	-0	-0	-1	0	-1
10	1	1	2	2	5	3	-2	1	2	2	2	-3	-1	1	2	-1	-2	-4	0	-2	0	1	-6	-2	-1	-3	-2
11	1	0	3	1	3	3	-1	1	1	1	2	-1	-1	1	3	-1	-3	-4	1	-1	0	-5	-2	-0	-2	-1	-1
12	1	2	2	-1	3	1	-1	4	1	1	3	-3	-0	1	3	2	-1	-4	1	-0	1	0	-6	-1	-2	-3	-2
13	-0	1	0	-2	3	-5	0	2	1	1	4	-4	0	1	2	4	1	0	2	1	1	2	-3	0	-3	-1	-1
14	-0	1	0	-1	2	-2	0	1	0	1	1	-4	0	1	0	3	1	0	1	0	1	0	-2	1	-3	-1	-1
15	-0	1	-1	-3	0	-3	1	0	-1	-0	0	-2	1	1	1	4	0	4	2	1	1	1	0	-1	0	-0	-0
16	1	0	4	1	4	3	-2	1	1	1	2	-2	-1	1	2	-1	-3	-5	0	-2	0	0	-6	-2	-1	-2	-1
17	1	4	3	0	-1	6	-1	7	1	0	3	-2	-1	1	4	1	-2	-5	0	-1	1	0	-5	-2	-1	-4	-2
18	1	1	2	-1	5	1	-0	1	0	0	4	-2	-0	1	3	2	-2	-5	1	0	1	0	-6	-2	-1	-2	-1
19	0	1	1	-2	4	-6	0	2	0	1	2	-3	0	1	3	3	-1	-0	3	0	1	2	-3	-1	-3	-1	-3
20	-0	1	-1	-3	1	-8	1	2	-1	-1	2	-3	1	1	2	3	-1	6	2	1	1	3	2	-1	-2	1	-1
21	-0	1	-2	-3	-0	-3	1	-0	-1	-1	-1	-1	1	1	3	-1	3	2	1	1	1	1	0	-1	1	-0	-1
22	1	0	3	1	4	2	-1	0	1	1	1	-2	-1	0	1	1	-2	-4	0	-1	0	-0	-5	-2	-2	-2	-1
23	1	3	3	0	6	4	-1	-12	1	1	1	-2	-1	0	1	1	-2	-8	0	-1	1	-2	-9	-1	-3	-4	-3
24	0	1	1	-1	4	4	0	0	0	0	0	-2	0	0	3	3	-2	-2	2	0	1	1	-5	-2	-1	-1	-0
25	0	1	-0	-2	2	2	1	0	0	0	0	-2	1	1	3	4	-2	3	3	1	2	2	-1	-2	-1	-0	-1
26	-0	2	-2	-4	-1	-1	1	-0	-1	-1	-3	-2	1	0	1	4	-2	9	3	1	1	2	4	-1	-2	0	-0
27	-0	1	-2	-3	-1	-3	1	-0	-0	-1	-0	-1	1	1	1	2	-1	4	2	1	1	1	2	-1	-0	1	-0
28	1	0	3	2	3	2	-1	1	-10	2	1	-2	-1	0	1	1	1	-2	1	-1	0	0	-2	-0	-1	-2	-1
29	1	1	2	-0	5	4	-1	-9	1	-3	3	-1	-0	-2	2	2	-3	-6	2	-1	1	-0	-7	-3	-1	-2	-2
30	0	1	0	-2	3	2	1	-1	0	1	-5	-2	0	-0	1	5	-1	-2	2	1	0	1	-3	-1	-2	-1	-1
31	-0	1	-1	-3	1	1	1	1	-1	-0	-1	-9	1	1	2	4	-1	-0	3	1	1	2	-2	-1	-1	1	-1
32	0	3	-0	-2	1	1	1	-0	-0	-0	-8	-1	0	0	1	2	-2	10	2	1	0	0	8	-1	-1	1	-0
33	-1	0	-2	-3	-0	-1	2	0	-1	-3	1	2	1	-1	1	2	-2	0	2	2	2	2	-0	-3	1	1	-0
34	-0	1	-1	-2	-0	-1	0	-0	-1	-1	-0	-1	0	0	1	1	-2	4	2	0	0	1	3	-1	-0	0	-0
35	0	1	1	-2	3	0	-0	0	-0	-1	-0	-2	-0	-0	-12	1	-3	-6	1	0	0	-2	-6	-2	-4	-2	-2
36	-1	-1	-1	-3	1	-0	0	-0	-1	-2	1	-2	0	-0	-10	-10	-2	-4	1	0	0	0	-4	-1	-1	-2	-1
37	-0	-0	-1	-3	1	2	1	-2	-1	-1	3	-1	1	0	-0	3	-14	-10	3	1	1	-1	1	-3	-0	0	-0
38	-1	-0	-2	-4	-2	-1	1	-3	-1	1	2	-2	1	0	-1	3	-2	-20	3	1	1	-0	-1	-2	-2	-2	-0
39	-0	0	-1	-3	1	-1	1	0	-1	-1	0	-1	1	0	1	3	-1	1	2	1	1	1	0	-1	-1	0	-0
40	-0	0	-2	-2	-1	-1	1	-0	-1	-1	1	0	1	0	1	2	-0	2	1	1	1	0	1	-1	0	1	-0
41	0	1	0	-1	5	1	0	3	1	1	1	-1	0	-2	2	-1	-4	-16	1	0	-3	-2	-0	1	0	-0	-0
42	0	-0	-0	-0	0	0	0	-0	0	-0	0	0	0	0	1	-0	-0	0	0	0	0	0	-0	-0	-0	-0	-0
43	-1	-0	-2	-2	1	-1	1	0	-1	0	0	-0	1	-1	-4	1	-1	-5	1	-4	2	-5	-6	-2	-1	0	-2
44	-0	1	-1	-2	1	-0	1	-0	0	1	2	0	3	1	2	-2	-8	2	3	-7	-0	-11	-3	1	1	1	-1
45	-0	-0	-1	-1	-0	-1	1	-0	-0	0	-0	1	0	-0	2	1	0	1	0	0	-0	1	0	-0	0	0	0
46	-1	0	-1	-4	1	-3	0	-3	-0	-1	-1	-3	0	-1	-3	2	-1	-5	2	0	0	-27	-2	-2	-3	-1	-2
47	-0	0	-0	-1	2	0	1	0	-0	0	1	0	0	0	2	2	-2	2	2	1	1	-1	-13	-3	2	3	-0
48	-0	-0	-0	-1	2	-0	0	1	-0	0	0	-0	0	-1	1	-2	-5	0	1	0	-3	-0	-2	-6	0	0	0
49	-0	0	-1	-2	-0	-2	1	-1	-0	-0	-0	-1	0	-0	-1	1	-1	2	0	1	-0	-2	-2	-19	-2	-8	-1
50	-1	-2	-1	-3	2	-1	0	-0	-1	-2	-0	0	0	-0	1	0	-3	-7	1	0	0	-0	-0	-3	-30	-2	-2
51	-1	-2	-2	-3	-0	-4	1	-1	-1	2	-1	-2	1	-1	0	2	-1	1	1	1	2	1	3	-1	-1	-25	-2
52	-0	-2	-1	-1	1	-1	0	0	-0	0	-1	0	0	-0	1	1	-1	-5	1	0	0	1	0	-1	1	4	-61

Data correlations[%]: beauty vs beauty

bin	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
1	100	9	10	8	9	10	1	5	7	8	8	6	-0	1	6	7	3	6	4	3	1	4	3	-1	3	2	1
2	9	100	12	11	17	17	1	17	8	11	19	7	-0	1	8	10	5	16	6	3	2	6	9	-0	1	10	1
3	10	12	100	18	19	19	1	12	10	18	17	10	-0	1	14	15	8	9	10	3	2	13	5	-0	3	4	1
4	8	11	18	100	22	21	1	13	10	22	19	13	-0	1	17	16	12	10	11	2	3	14	5	2	7	6	2
5	9	17	19	22	100	26	1	37	11	23	25	12	-0	1	28	18	12	8	13	2	3	22	5	1	9	3	1
6	10	17	19	21	26	100	1	21	11	21	36	16	-0	2	23	16	9	24	13	3	4	19	15	1	11	10	3
7	1	1	1	1	1	1	100	1	1	1	1	1	0	0	1	1	1	1	1	1	0	1	1	-0	0	0	0
8	5	17	12	13	37	21	1	100	7	15	20	9	-0	2	31	11	8	8	8	2	2	26	4	1	9	1	2
9	7	8	10	10	11	11	1	7	100	11	10	6	0	1	8	9	6	6	7	3	2	7	4	2	3	3	1
10	8	11	18	22	23	21	1	15	11	100	21	12	-0	2	18	19	15	11	14	4	7	16	7	4	6	7	2
11	8	19	17	19	25	36	1	20	10	21	100	15	0	3	23	18	10	30	14	3	6	21	18	2	10	16	4
12	6	7	10	13	12	16	1	9	6	12	15	100	0	9	12	9	5	8	9	2	6	12	5	0	9	6	2
13	-0	-0	-0	-0	-0	-0	0	-0	0	-0	0	0	100	0	-0	0	0	0	0	0	1	0	0	0	0	0	0
14	1	1	1	1	1	2	0	2	1	2	3	9	0	100	2	1	1	2	2	3	25	2	1	0	1	3	0
15	6	8	14	17	28	23	1	31	8	18	23	12	-0	2	100	16	9	12	13	2	3	25	8	1	13	6	4
16	7	10	15	16	18	16	1	11	9	19	18	9	0	1	16	100	12	10	13	3	3	15	6	4	4	7	2
17	3	5	8	12	12	9	1	8	6	15	10	5	0	1	9	12	100	8	8	2	2	9	3	5	3	4	1
18	6	16	9	10	8	24	1	8	6	11	30	8	0	2	12	10	8	100	8	3	4	16	32	2	8	25	6
19	4	6	10	11	13	13	1	8	7	14	14	9	0	2	13	13	8	8	100	3	4	13	5	3	4	6	1
20	3	3	3	2	2	3	1	2	3	4	3	2	1	3	2	3	2	3	3	100	4	2	2	0	1	3	0
21	1	2	2	3	3	4	0	2	2	7	6	6	0	25	3	3	2	4	4	4	100	3	4	1	2	5	1
22	4	6	13	14	22	19	1	26	7	16	21	12	0	2	25	15	9	16	13	2	3	100	11	6	12	11	5
23	3	9	5	5	5	15	1	4	4	7	18	5	0	1	8	6	3	32	5	2	4	11	100	2	7	24	5
24	-1	-0	-0	2	1	1	-0	1	2	4	2	0	0	0	1	4	5	2	3	0	1	6	2	100	1	4	1
25	3	1	3	7	9	11	0	9	3	6	10	9	0	1	13	4	3	8	4	1	2	12	7	1	100	7	4
26	2	10	4	6	3	10	0	1	3	7	16	6	0	3	6	7	4	25	6	3	5	11	24	4	7	100	4
27	1	1	1	2	1	3	0	2	1	2	4	2	0	0	4	2	1	6	1	0	1	5	5	1	4	4	100

Parametrisation study

Nominal 14p (HERAPDF2.0):

$$xg(x) = A_g x^{B_g} (1-x)^{C_g} - A'_g x^{B'_g} (1-x)^{C'_g}$$

$$xu_v(x) = A_{u_v} x^{B_{u_v}} (1-x)^{C_{u_v}} (1 + E_{u_v} x^2)$$

$$xd_v(x) = A_{d_v} x^{B_{d_v}} (1-x)^{C_{d_v}}$$

$$x\bar{U}(x) = A_{\bar{U}} x^{B_{\bar{U}}} (1-x)^{C_{\bar{U}}} (1 + D_{\bar{U}} x)$$

$$x\bar{D}(x) = A_{\bar{D}} x^{B_{\bar{D}}} (1-x)^{C_{\bar{D}}}$$

Parametrisation	DIS + c + b			DIS		
	chi2	mc	mb	chi2	mc	mb
14p nominal	1435	1.29	4.05	1304	1.80	8.45
12p Aprig=0	1439	1.29	4.04	1308	1.78	8.03
13p DUBar=0	1459	1.26	3.98	1330	1.45	3.57
13p Euv=0	1441	1.26	4.02	1319	1.45	4.00
15p Cprig	1435	1.29	4.05	1303	1.80	8.49
15p DDbar	1435	1.29	4.05	1304	1.80	8.44
15p Ddv	1435	1.29	4.05	1304	1.80	8.41
15p Dg	1435	1.29	4.06	1303	1.80	8.53
15p Duv	1418	1.29	4.04	1289	1.80	8.18
15p EDbar	1435	1.29	4.05	1304	1.80	8.49
15p Edv	1435	1.29	4.05	1304	1.80	8.44
15p Eg	1435	1.29	4.05	1303	1.80	8.79
15p EUbar	1435	1.29	4.05	1304	1.80	8.43
15p FDbar	1435	1.29	4.05	1304	1.80	8.52
15p Fdv	1435	1.29	4.05	1304	1.80	8.45
15p Fg	1435	1.29	4.05	1303	1.80	8.74
15p FUBar	1429	1.29	4.04	1297	1.80	8.13
15p Fuv	1429	1.29	4.05	1299	1.80	8.33

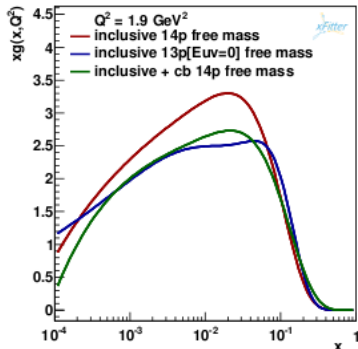
Additional constrains:

$$A_{\bar{U}} = A_{\bar{D}}(1 - f_s), B_{\bar{U}} = B_{\bar{D}}, C'_g = 25$$

$$\int_0^1 [\sum_i (q_i(x) + \bar{q}_i(x)) + g(x)] x dx = 1$$

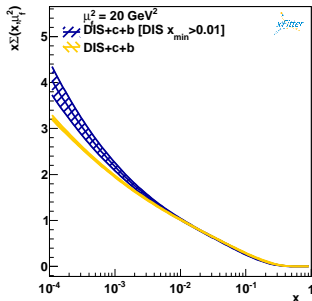
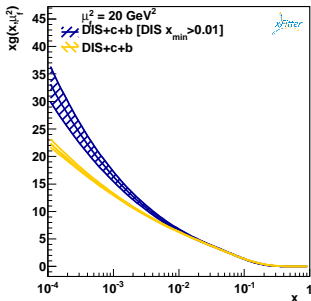
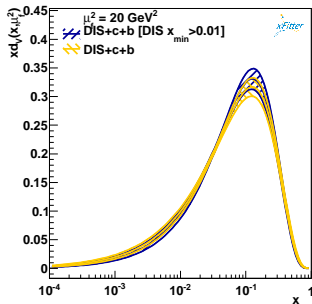
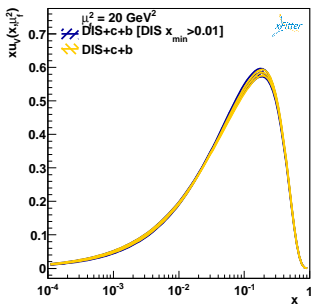
$$\int_0^1 [u(x) - \bar{u}(x)] dx = 2,$$

$$\int_0^1 [d(x) - \bar{d}(x)] dx = 1$$

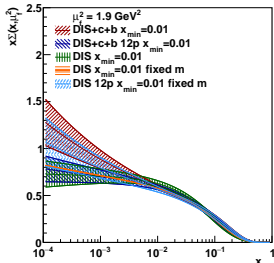
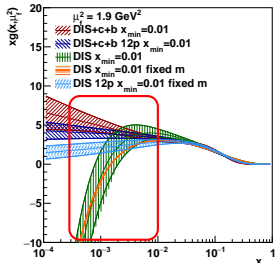
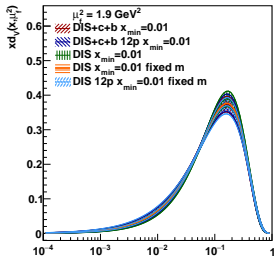
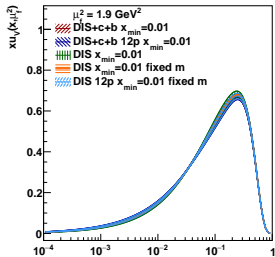


'13p Euv=0' is taken as
parametrisation uncertainty

PDFs with $x_{\min} = 0.01$ cut on inclusive data



Comparison of PDFs

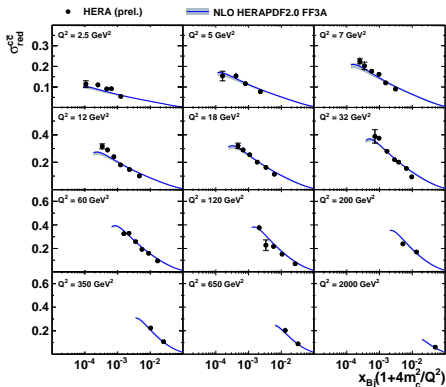
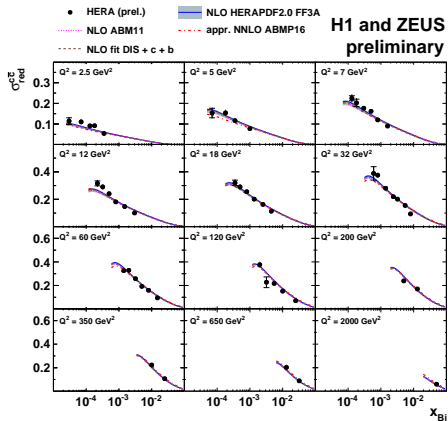


Constraints on low- x gluon are from HF data included in the fit

Cross sections as function of $x(1 + 4m^2/Q^2)$

x_{Bj}

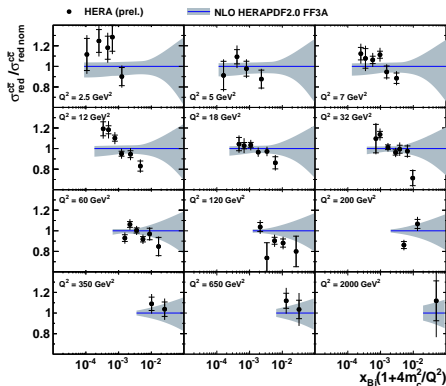
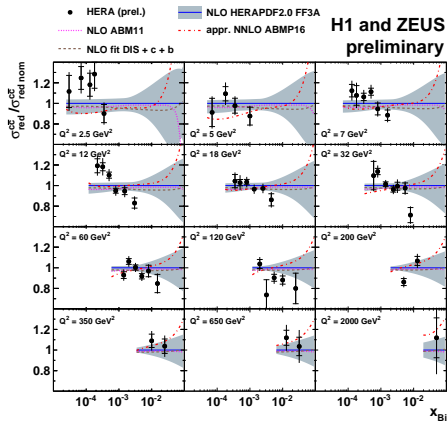
$x_{Bj}(1 + 4m^2/Q^2) \approx \xi$



Cross sections as function of $x(1 + 4m^2/Q^2)$

x_{Bj}

$x_{Bj}(1 + 4m^2/Q^2) \approx \xi$

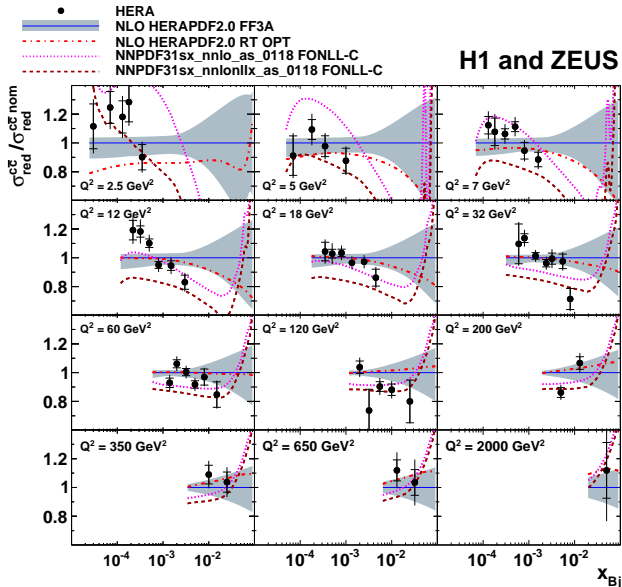


parametrisation scan for $x_{\min} > 0.015$ fit

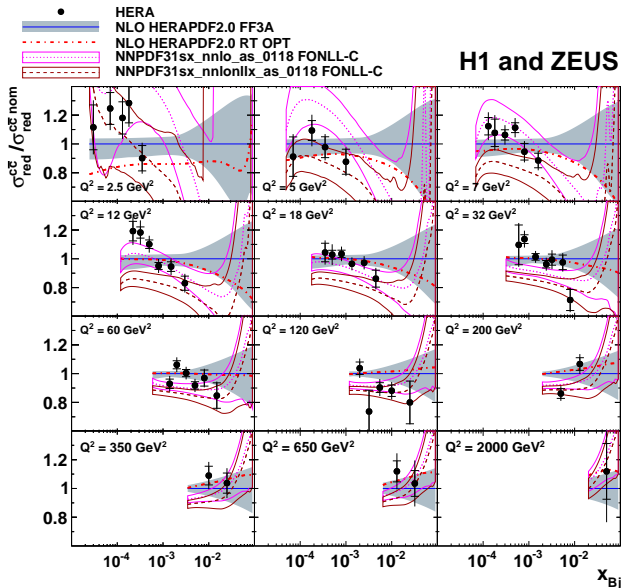
DIS+c+b	DIS
/Cprig/ 737.29	/Cprig/ 632.65
/DDbar/ 737.09	/DDbar/ 632.88
/Ddv/ 737.08	/Ddv/ 632.68
/Dg/ 737.32	/Dg/ 632.50
/Duv/ 718.36	/Duv/ 617.49
/EDbar/ 737.15	/EDbar/ 632.65
/Edv/ 737.10	/Edv/ 632.83
/Eg/ 737.31	/Eg/ 614.64
/EUbar/ 732.00	/EUbar/ 630.99
/FDbar/ 737.07	/FDbar/ 631.39
/Fdv/ 735.79	/Fdv/ 632.33
/Fuv/ 732.10	/Fuv/ 627.69
/nom/ 737.33	/nom/ 632.88

- these are χ^2 values for DIS+c+b and DIS fits with $x_{\min} > 0.015$ cut on inclusive data
- 'nom' is nominal 14p parametrisation
- each other entry is when one parameter released (not all fits converged to physical solutions, e.g. DIS Eg free fit produces negative gluon at $x \sim 1$)
- in general, very similar results to the nominal fit (in particular Duv)

Comparison to NNPDF: lowest Q^2 bin



Comparison to NNPDF: uncertainties



PDF parameters for fits with x_{\min} cuts

Parameter	DIS+c+b x min=0.01	DIS+c+b min=0.01	12p x	DIS x min=0.01	DIS x min=0.01 fixed m	DIS 12p x min=0.01 fixed m
'Bg'	-0.03 ± 0.11	-0.037 ± 0.051		-0.42 ± 0.28	-0.32 ± 0.33	0.16 ± 0.13
'Cg'	11.6 ± 2.8	7.16 ± 0.84		4.3 ± 1.8	4.1 ± 2.1	9.0 ± 1.5
'Aprig'	9 ± 10	-		0.10 ± 0.17	0.09 ± 0.19	-
'Bprig'	0.12 ± 0.19	0.1080		-0.77 ± 0.12	-0.72 ± 0.16	-0.7248
'Cprig'	25.00	25.00		25.00	25.00	25.00
'Buv'	0.693 ± 0.038	0.683 ± 0.042		0.721 ± 0.042	0.708 ± 0.043	0.692 ± 0.042
'Cuv'	4.831 ± 0.085	4.861 ± 0.086		4.844 ± 0.087	4.862 ± 0.086	4.856 ± 0.085
'Euv'	13.0 ± 2.3	13.8 ± 2.7		12.1 ± 2.3	12.9 ± 2.5	13.4 ± 2.5
'Bdv'	0.89 ± 0.10	0.90 ± 0.11		0.95 ± 0.10	0.90 ± 0.11	0.87 ± 0.11
'Cdv'	4.63 ± 0.43	4.67 ± 0.50		4.76 ± 0.47	4.58 ± 0.51	4.51 ± 0.46
'CUbar'	8.00 ± 0.80	7.86 ± 0.99		7.9 ± 1.3	7.8 ± 1.2	8.06 ± 0.88
'DUbar'	12.8 ± 6.7	6.1 ± 4.0		3.3 ± 3.7	4.7 ± 4.6	10.8 ± 6.6
'ADbar'	0.178 ± 0.073	0.321 ± 0.090		0.42 ± 0.13	0.29 ± 0.11	0.200 ± 0.096
'BDbar'	-0.165 ± 0.081	-0.046 ± 0.056		-0.010 ± 0.066	-0.062 ± 0.079	-0.132 ± 0.098
'CDbar'	7.4 ± 2.7	11.6 ± 3.3		14.2 ± 3.9	10.4 ± 3.4	7.5 ± 3.0
'alphas'	0.1060	0.1060		0.1060	0.1060	0.1060
'fs'	0.4000	0.4000		0.4000	0.4000	0.4000
'mc'	1.400 ± 0.014	1.384 ± 0.052		1.924 ± 0.048	1.270	1.270
'mb'	4.10 ± 0.10	4.10 ± 0.11		9.4 ± 3.3	4.170	4.170

$$xg(x) = A_g x^{B_g} (1-x)^{C_g} - A'_g x^{B'_g} (1-x)^{C'_g}$$

$$xu_v(x) = A_{u_v} x^{B_{u_v}} (1-x)^{C_{u_v}} (1 + E_{u_v} x^2)$$

$$xd_v(x) = A_{d_v} x^{B_{d_v}} (1-x)^{C_{d_v}}$$

$$x\bar{U}(x) = A_{\bar{U}} x^{B_{\bar{U}}} (1-x)^{C_{\bar{U}}} (1 + D_{\bar{U}} x)$$

$$x\bar{D}(x) = A_{\bar{D}} x^{B_{\bar{D}}} (1-x)^{C_{\bar{D}}}$$