Charm, beauty and top at HERA

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Review

Charm, beauty and top at HERA

CrossMark

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ABSTRACT

Results on open charm and beauty production and on the search for top production in high-energy electron–proton collisions at HERA are reviewed. This includes a discussion of relevant theoretical aspects, a summary of the available measurements and measurement techniques, and their impact on improved understanding of QCD and its parameters, such as parton density functions and charm- and beauty-quark masses. The impact of these results on measurements at the LHC and elsewhere is also addressed.

summary of
~ 60 papers
by
H1 and ZEUS

Introduction to heavy quark theory

schemes
and
diagrams

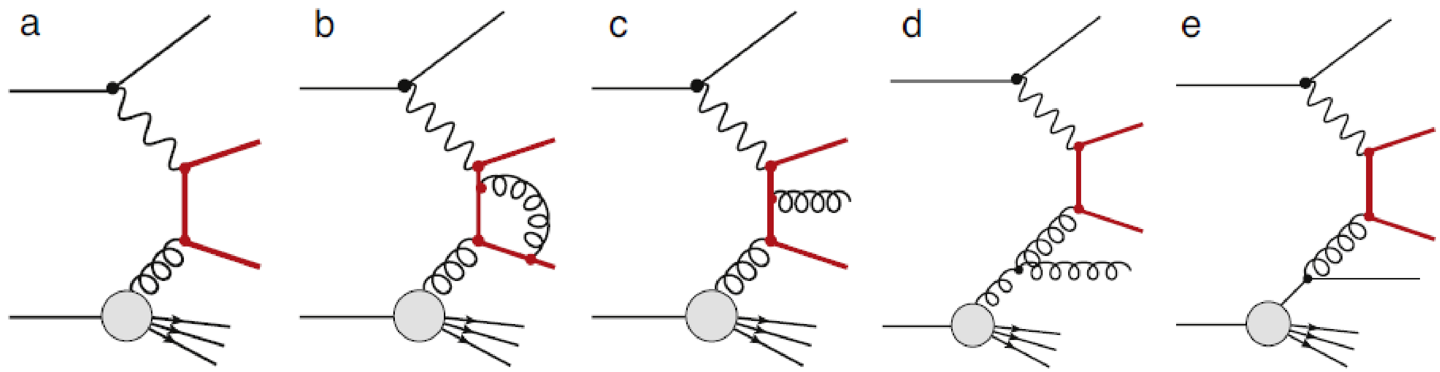


Fig. 8. Leading order (a) and selection of next to leading order (b)–(e) processes for heavy flavour production at HERA in the massive scheme.

Table 1:

Theory	Scheme	Ref.	$F_{2(L)}$ def.	m_c (GeV)	PDF	Massive/F_L ($Q^2 \lesssim m_c^2$)	Massless F_2 ($Q^2 \gg m_c^2$)	$\alpha_s(m_Z)$ ($n_f = 5$)	Scale
MSTW08 NLO	RT standard	[76]	$F_{2(L)}^c$	1.4 (pole)	$\mathcal{O}(\alpha_s^2)$	$\mathcal{O}(\alpha_s^2)$	$\mathcal{O}(\alpha_s)$	0.12108	Q
MSTW08 NNLO					$\mathcal{O}(\alpha_s^3)$	approx.-$\mathcal{O}(\alpha_s^3)$	$\mathcal{O}(\alpha_s^2)$	0.11707	
MSTW08 NLO (opt.)	RT optimised	[77]			$\mathcal{O}(\alpha_s^2)$	$\mathcal{O}(\alpha_s^2)$	$\mathcal{O}(\alpha_s)$	0.12108	
MSTW08 NNLO (opt.)					$\mathcal{O}(\alpha_s^3)$	approx.-$\mathcal{O}(\alpha_s^3)$	$\mathcal{O}(\alpha_s^2)$	0.11707	
HERAPDF1.5 NLO	RT standard	[42]	$F_{2(L)}^c$	1.4 (pole)	$\mathcal{O}(\alpha_s^2)$	$\mathcal{O}(\alpha_s^2)$	$\mathcal{O}(\alpha_s)$	0.1176	Q
NNPDF2.1 FONLL A	FONLL A	[78]	n.a.	$\sqrt{2}$	$\mathcal{O}(\alpha_s^2)$	$\mathcal{O}(\alpha_s)$	$\mathcal{O}(\alpha_s)$	0.119	Q
NNPDF2.1 FONLL B	FONLL B		$F_{2(L)}^c$	$\sqrt{2}$ (pole)	$\mathcal{O}(\alpha_s^2)$	$\mathcal{O}(\alpha_s^2)$ / $\mathcal{O}(\alpha_s)$	$\mathcal{O}(\alpha_s)$		
NNPDF2.1 FONLL C	FONLL C		$F_{2(L)}^c$	$\sqrt{2}$ (pole)	$\mathcal{O}(\alpha_s^3)$	$\mathcal{O}(\alpha_s^2)$	$\mathcal{O}(\alpha_s^2)$		
CT10 NLO	S-ACOT-χ	[55]	n.a.	1.3	$\mathcal{O}(\alpha_s^2)$	$\mathcal{O}(\alpha_s)$	$\mathcal{O}(\alpha_s)$	0.118	$\sqrt{Q^2 + m_c^2}$
CT10 NNLO		[79]	$F_{2(L)}^{c\bar{c}}$	1.3 (pole)	$\mathcal{O}(\alpha_s^2)$	$\mathcal{O}(\alpha_s^2)$	$\mathcal{O}(\alpha_s^2)$		
ABKM09 NLO	FFNS A	[46]	$F_{2(L)}^{c\bar{c}}$	1.18 ($\overline{MS}$)	$\mathcal{O}(\alpha_s^2)$	$\mathcal{O}(\alpha_s^2)$	–	0.1135	$\sqrt{Q^2 + 4m_c^2}$
ABKM09 NNLO					$\mathcal{O}(\alpha_s^3)$	approx.-$\mathcal{O}(\alpha_s^3)$	–		
HVQDIS + ZEUS S	FFNS B	[51]	$F_{2(L)}^c$	1.5 (pole)	$\mathcal{O}(\alpha_s^2)$	$\mathcal{O}(\alpha_s^2)$	–	0.118	$\sqrt{Q^2 + 4m_c^2}$

HERA detectors and tagging methods

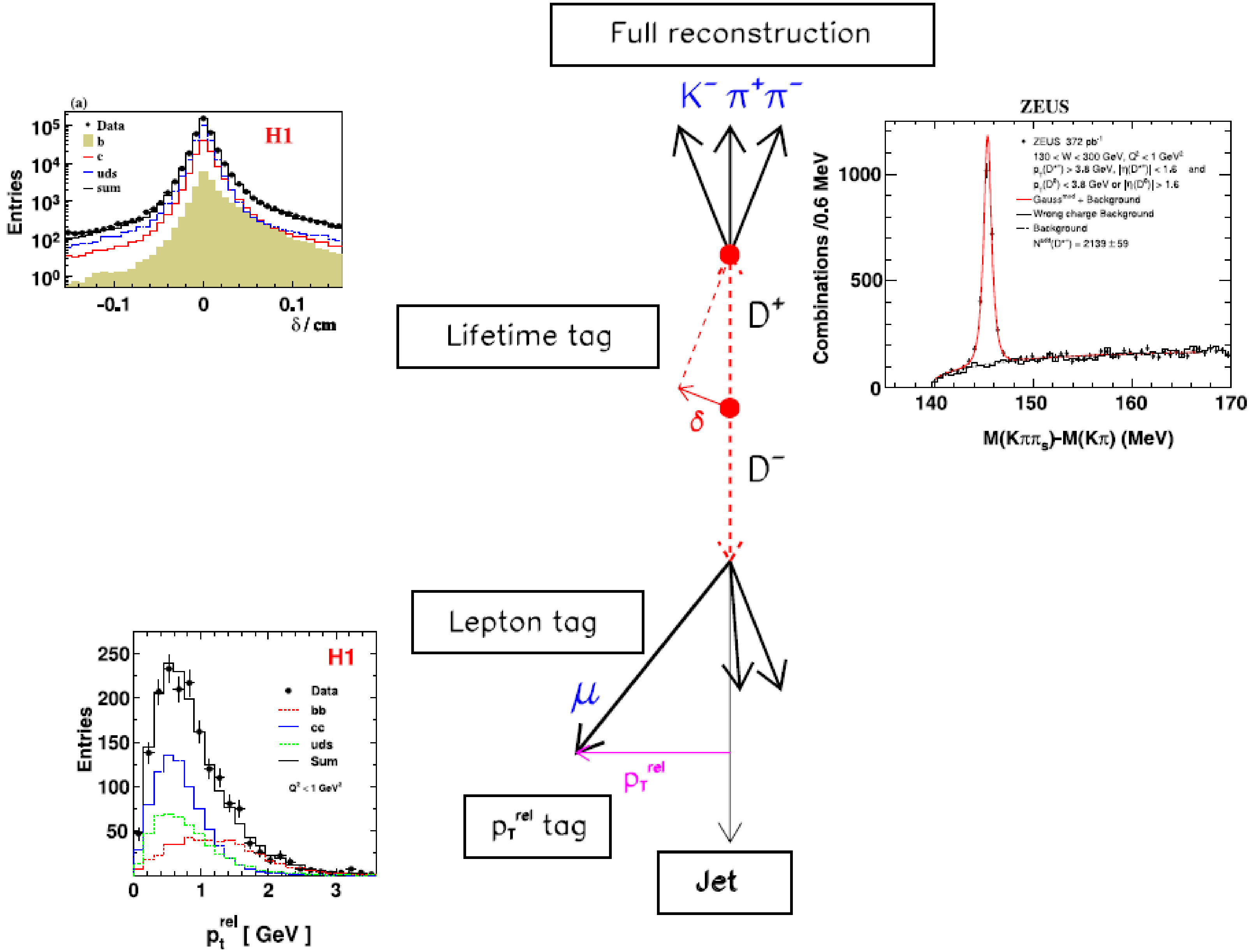


Fig. 17. Overview of tagging methods for heavy-flavour events. Each method is accompanied by an illustrative distribution [142–144].

Search for single top

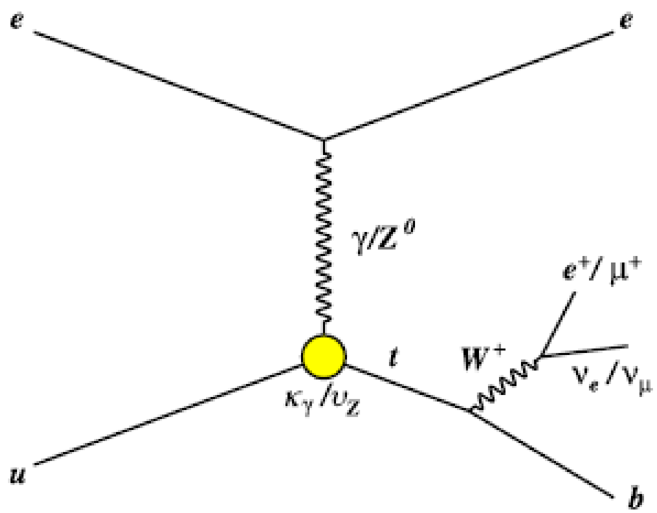


Fig. 25. Feynman graph for anomalous single top production [160].

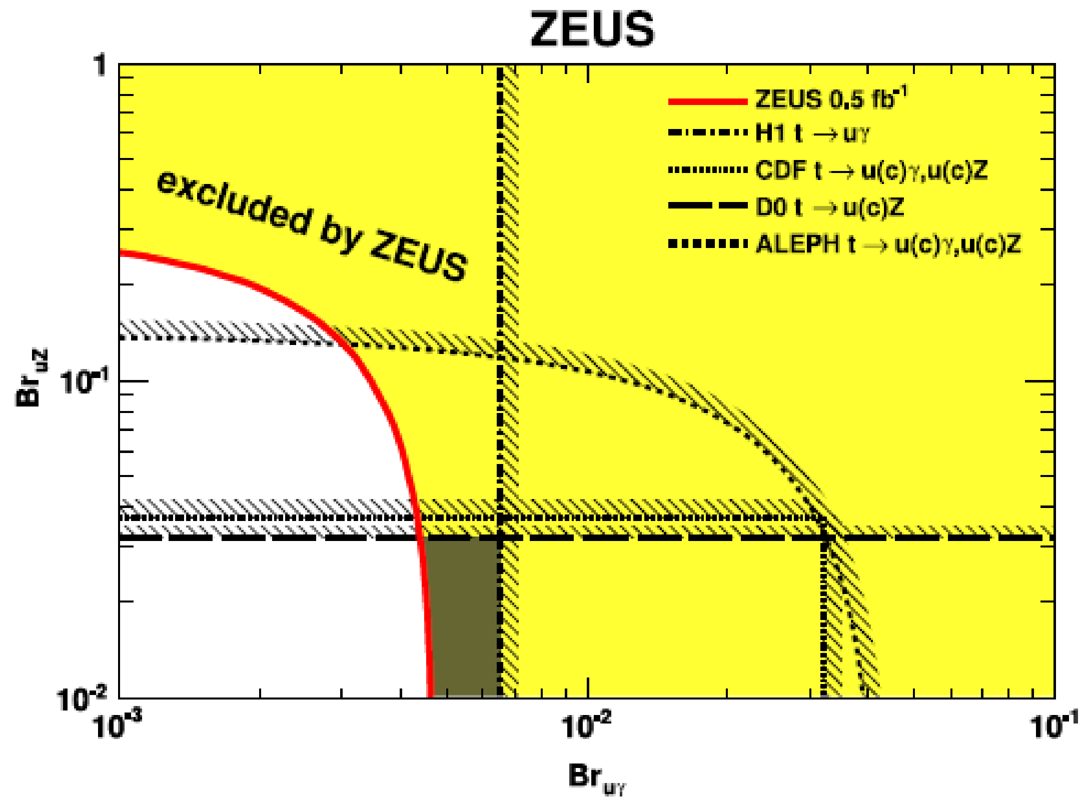


Fig. 26. Limits on anomalous couplings for single top production, translated to branching fractions (Br) for top decay into uZ or $u\gamma$ [160].

still best limit

Charm in photoproduction

total cross sections:

1996 — (data 1993/94)

2014 — (data 2006/7)

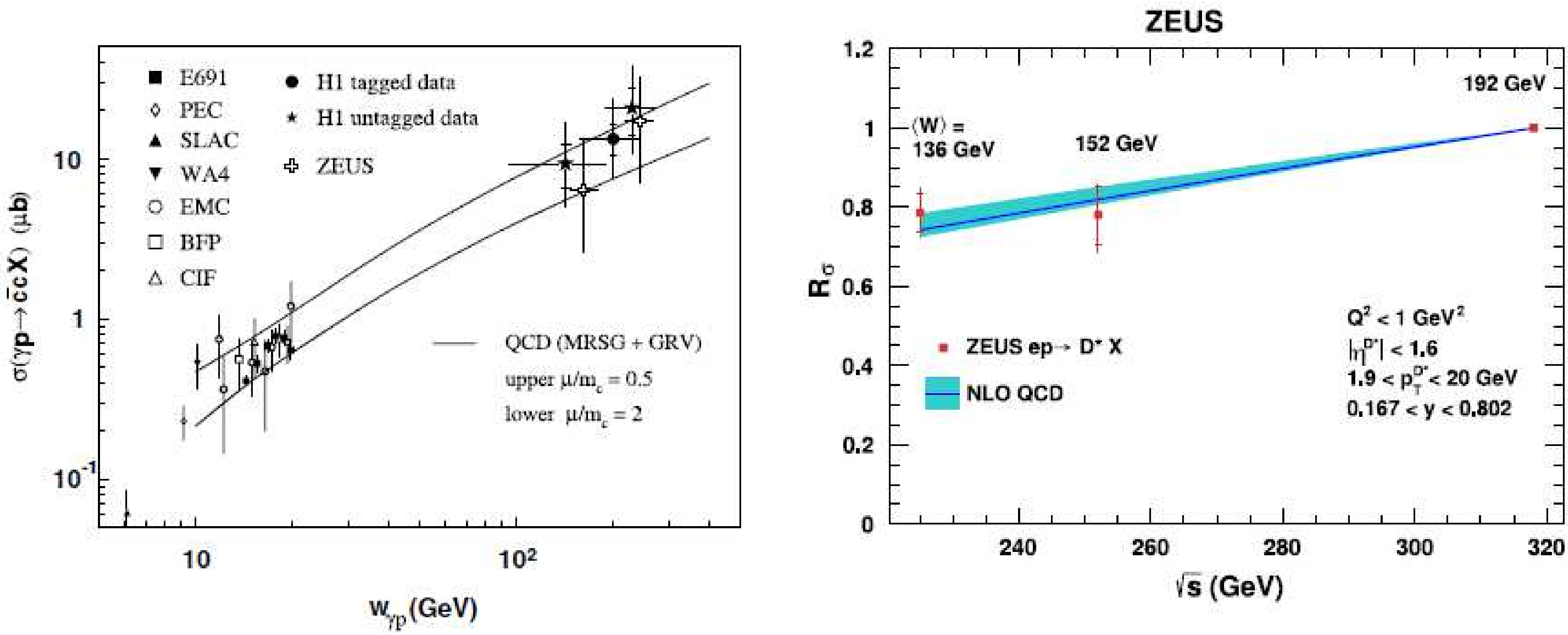


Fig. 27. Left: Total charm-photoproduction cross section as a function of centre-of-mass energy $W_{\gamma p}$ [168]. The data shown are from the first H1 and ZEUS publications on open charm production and from previous fixed-target experiments. Right: Inclusive charm-photoproduction cross section as a function of *ep* centre-of-mass energy [181], normalised to the cross section at 318 GeV.

Charm in photoproduction

D* tagging gives best statistics + signal/background

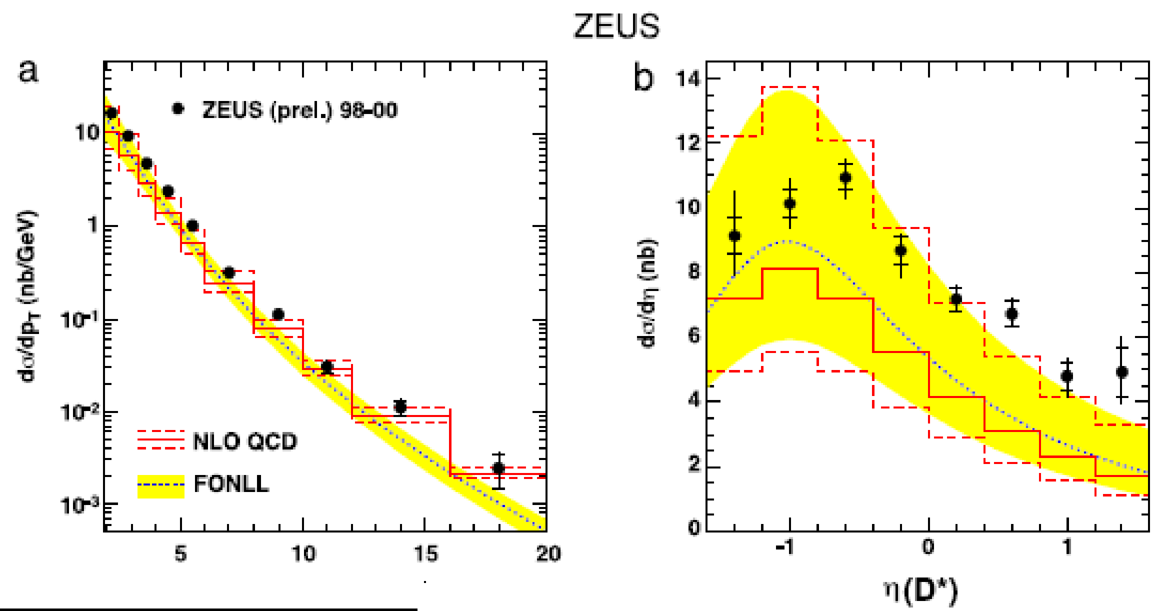
Table 3

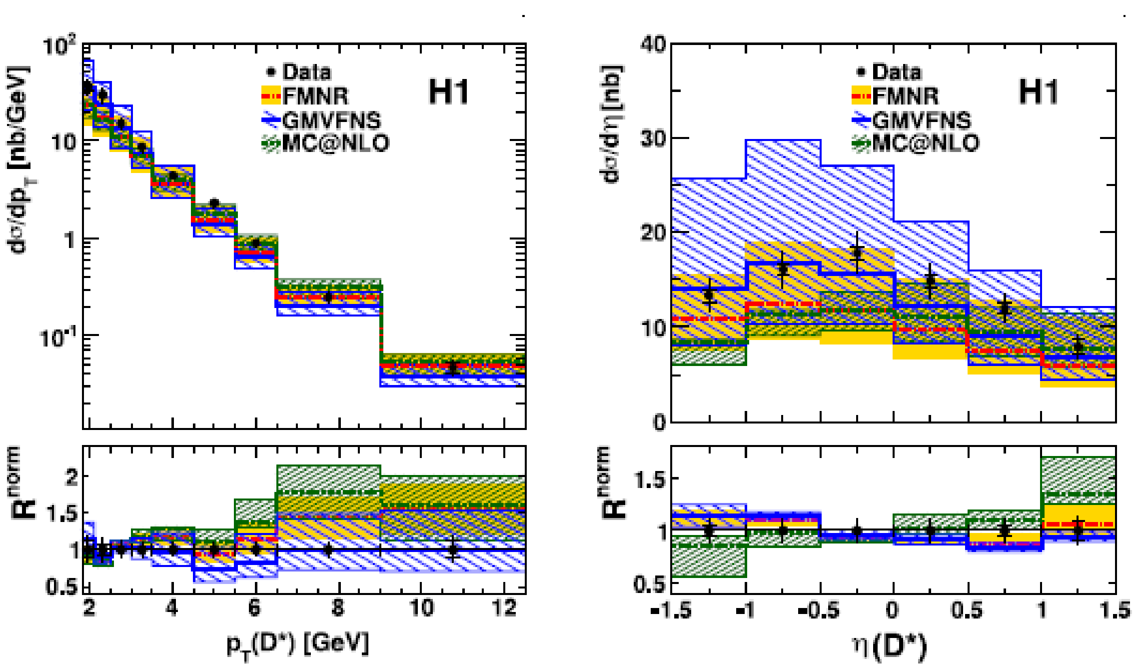
Charm photoproduction cross-section measurements at HERA. Information is given for each analysis on the charm tagging method, the experiment, the data taking period, integrated luminosity, Q^2 and y ranges and the cuts on transverse momenta and pseudorapidities of selected final state particles. The last three columns provide information on the number of tagged charm events, the effective signal-to-background ratio and the equivalent number of background-free events. The centre-of-mass energy of all data taken up to 1997 (6th column) was 300 GeV, while it was 318–319 GeV for all subsequent runs, with the exception of the analyses marked "MER" and "LER" (entry 16), for which the data were taken at 251 and 225 GeV.

No	Analysis	c-Tag	Ref.	Exp.	Data	$\mathcal{L}(pb^{-1})$	Q^2 (GeV^2)	y	Particle	p_T (GeV)	η	Events	effect. s:b	bgfree events
1	D^* incl.	$K\pi\pi_s$	[167]	ZEUS	93	0.5	<4	[0.15, 0.84]	D^*	>1.7	[−1.5, 1.5]	48 ± 11	1 : 1.5	19
2	D^* tagged	$K\pi\pi_s$	[168]	H1	94	2.8	<0.01	[0.28, 0.65]	D^*	>2.5	[−1.5, 1.0]	119 ± 16	1 : 1.2	55
	incl.					1.3	<4	[0.10, 0.80]				97 ± 15	1 : 1.3	42
3	D^* incl.	$K\pi\pi_s$	[169]	ZEUS	94	3.0	<4	[0.15, 0.87]	D^*	>3	[−1.5, 1.0]	152 ± 16	1 : 0.7	90
		$K3\pi\pi_s$										199 ± 29	1 : 3.2	17
4	D^* tagged	$K\pi\pi_s$	[170]	H1	95-96	10.2	<0.009	[0.02, 0.32]	D^*	>2	[−1.5, 1.5]	299 ± 75	n.a.	16
					94-96	10.7	<0.01	[0.29, 0.62]		>2.5	$(\hat{y}(D^*))$	489 ± 92	n.a.	28
5	D^* incl.	$K\pi\pi_s$	[171]	ZEUS	96-97	37	<1	[0.19, 0.87]	D^*	>2	[−1.5, 1.5]	3702 ± 136	1 : 4.0	741
		$K3\pi\pi_s$								>4		1397 ± 108	1 : 7.3	167
									D^*	>3	[−1.5, 1.5]			
	D^* + dijet	$K\pi\pi_s$							Jet 1(2)	>7 (6)	[−2.4, 2.4]	587 ± 41	1 : 1.9	205
6	D^* incl.	$K\pi\pi_s$	[172]	ZEUS	98-00	79	<1	[0.17, 0.77]	D^*	[1.9, 20]	[−1.6, 1.6]	10,350 ± 190	1 : 2.5	2970
7	D^* tagged	$K\pi\pi_s$	[173]	H1	99-00	51	<0.01	[0.29, 0.65]	D^*	>2	[−1.5, 1.5]	1166 ± 82	1 : 4.8	202
	+ jet								Jet	>3	[−1.5, 1.5]	592 ± 57	1 : 4.5	108
	+ dijet								Jet 1(2)	>4(3)	[−1.5, 1.5]	496 ± 53	1 : 4.7	88
									D^*	>3	[−1.5, 1.5]			
8	D^* + dijet	$K\pi\pi_s$	[174]	ZEUS	96-00	120	<1	[0.17, 0.77]	Jet 1(2)	>7(6)	[−1.9, 1.9]	1092 ± 43	1 : 0.7	650
9	D^* + jet	$K\pi\pi_s$	[175]	ZEUS	98-00	79	<1	[0.17, 0.77]	D^*	>3	[−1.5, 1.5]	4891 ± 113	1 : 1.6	1870
	+ dijet								Jet 1(2)	>6(7)	[−1.5, 2.4]	1692 ± 70	1 : 1.6	584
									Track	>0.5	[−1.3, 1.3]			
10	lifet.	imp.par.	[142]	H1	99-00	57	<1	[0.15, 0.80]	Jet 1(2)	>11(8)	[−0.9, 1.3]	4600 ± 460	1 : 45	100
	+ dijet													
		$K\pi\pi_s$							D^*	>1.5	[−1.5, 1.5]			
11	$D^* + \mu$	$+\mu$	[176]	H1	98-00	89	<1	[0.05, 0.75]	μ	$p > 2$	[−1.74, 1.74]	53 ± 13	1 : 2.2	17
									e	>0.9	[−1.5, 1.5]			
12	e + dijet	$e + \not{E}_T$	[177]	ZEUS	96-00	120	<1	[0.2, 0.8]	Jet 1(2)	>7 (6)	[−2.5, 2.5]	~8000	n.a.	70
									tracks	>0.5	[−1.6, 1.4]			
13	lifet.	sec. vtx.	[178]	ZEUS	05	133	<1	[0.2, 0.8]	Jet 1(2)	>7(6)	[−2.5, 2.5]	~20,000	n.a.	2320
	+ dijet													
		μ+							μ	>2.5	[−1.3, 1.5]			
14	μ + dijet	imp.par.	[179]	H1	06-07	179	<2.5	[0.2, 0.8]	Jet 1(2)	>7(6)	[−1.5, 2.5]	3315 ± 170	1 : 7.7	380
15	D^* incl	$K\pi\pi_s$	[180]	H1	06-07	31-93	<2	[0.1, 0.8]	D^*	>1.8	[−1.5, 1.5]	8232 ± 164	1 : 2.3	2520
	+ dijet								Jet 1(2)	>3.5	[−1.5, 2.9]	3937 ± 114	1 : 2.3	1200
16	D^* incl	$K\pi\pi_s$	[181]	ZEUS	06-07	144	<1	[0.167, 0.802]	D^*	[1.9, 20]	[−1.6, 1.6]	12,256 ± 191	1 : 2.0	4120
	MER				07	6.3						417 ± 37	1 : 2.3	127
	LER				07	13.4						859 ± 49	1 : 1.8	307

Charm in photoproduction

differential cross sections:





comparison to various NLO predictions

Charm in photoproduction

double differential cross sections:

(with jets)

reasonably described in general

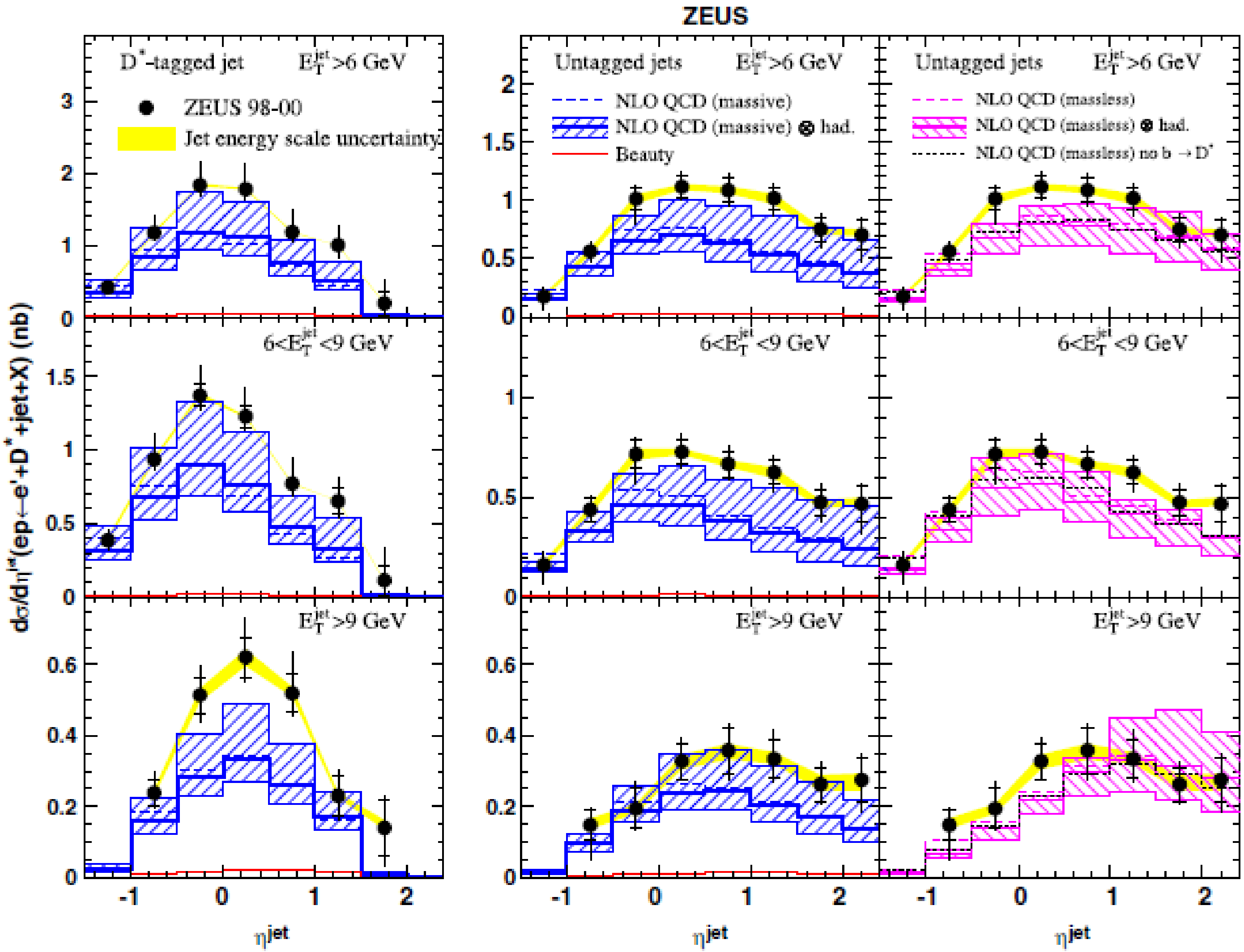
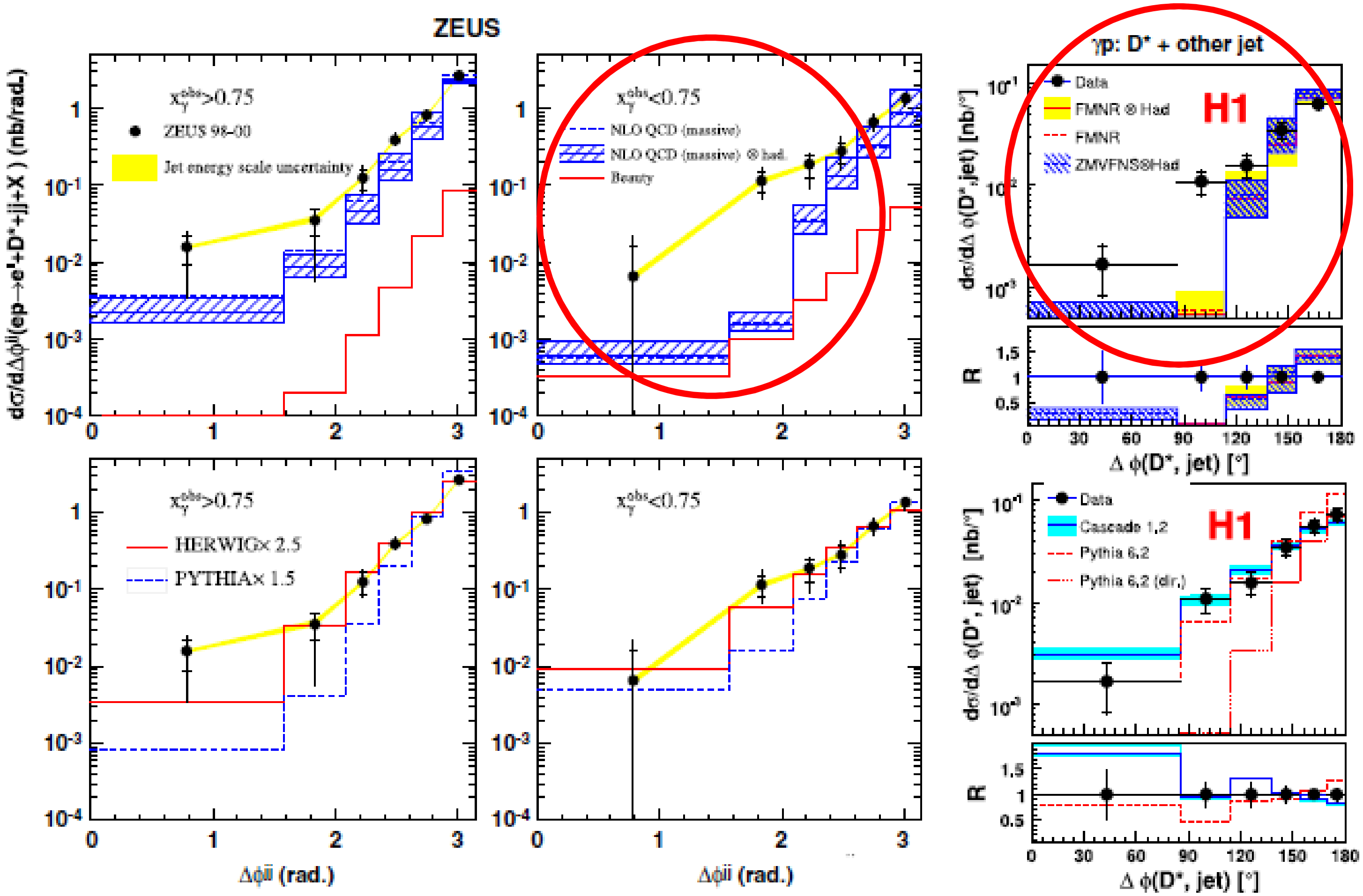


Fig. 32. D^* + jet cross sections as a function of the pseudorapidities of D^*-tagged (left) and untagged (centre and right) jets, from the ZEUS analysis [175]. The measurements are compared to two NLO predictions, the massive scheme calculations from Frixione et al. [58] and the massless scheme predictions from Heinrich and Kniehl [48].

Charm in photoproduction

double differential cross sections:

(with jets)



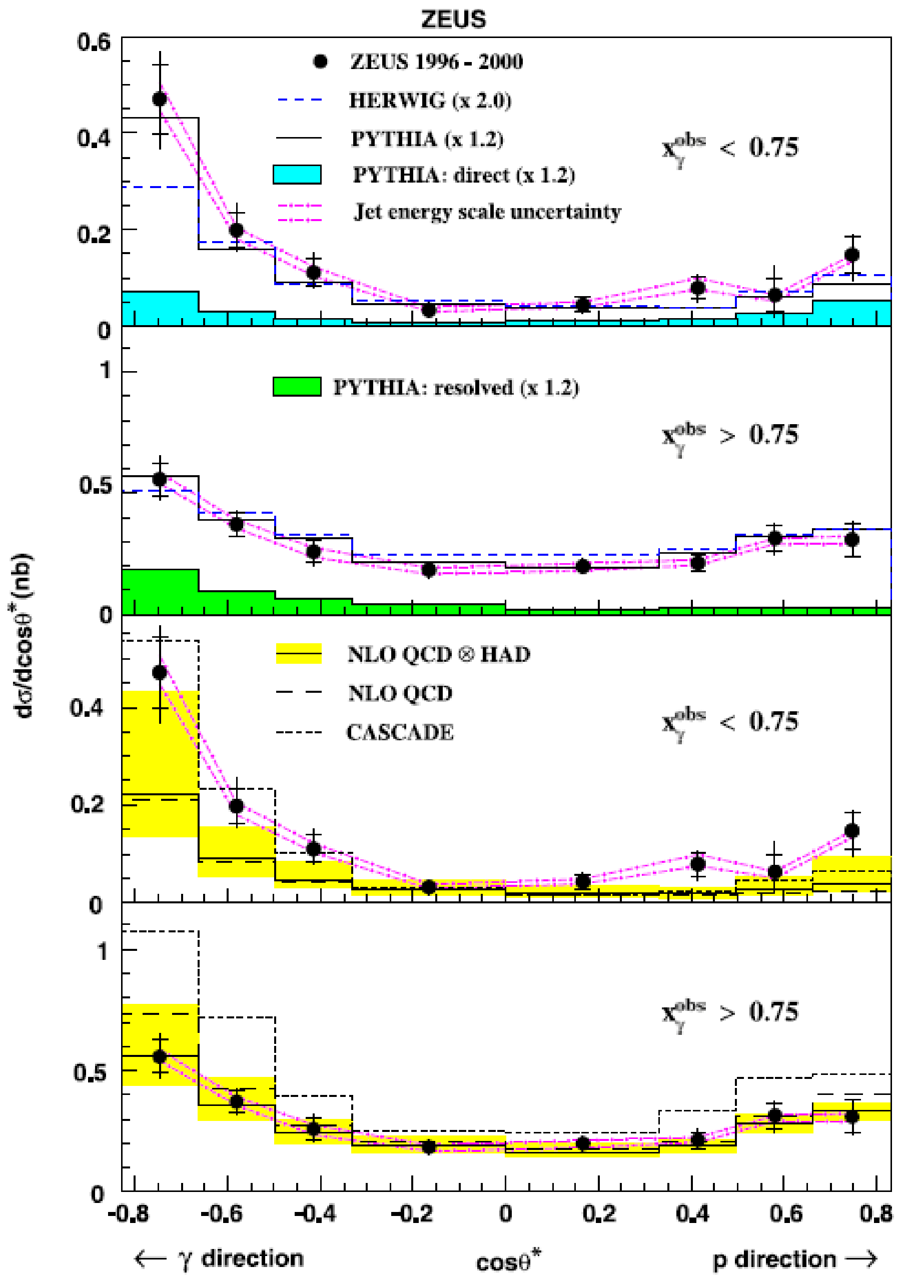
but failure of NLO in kinematic regions where it is expected to fail (not enough final state partons)

Charm in photoproduction

sensitive to
gluon propagator

PYTHIA and
HERWIG
do a reasonable job

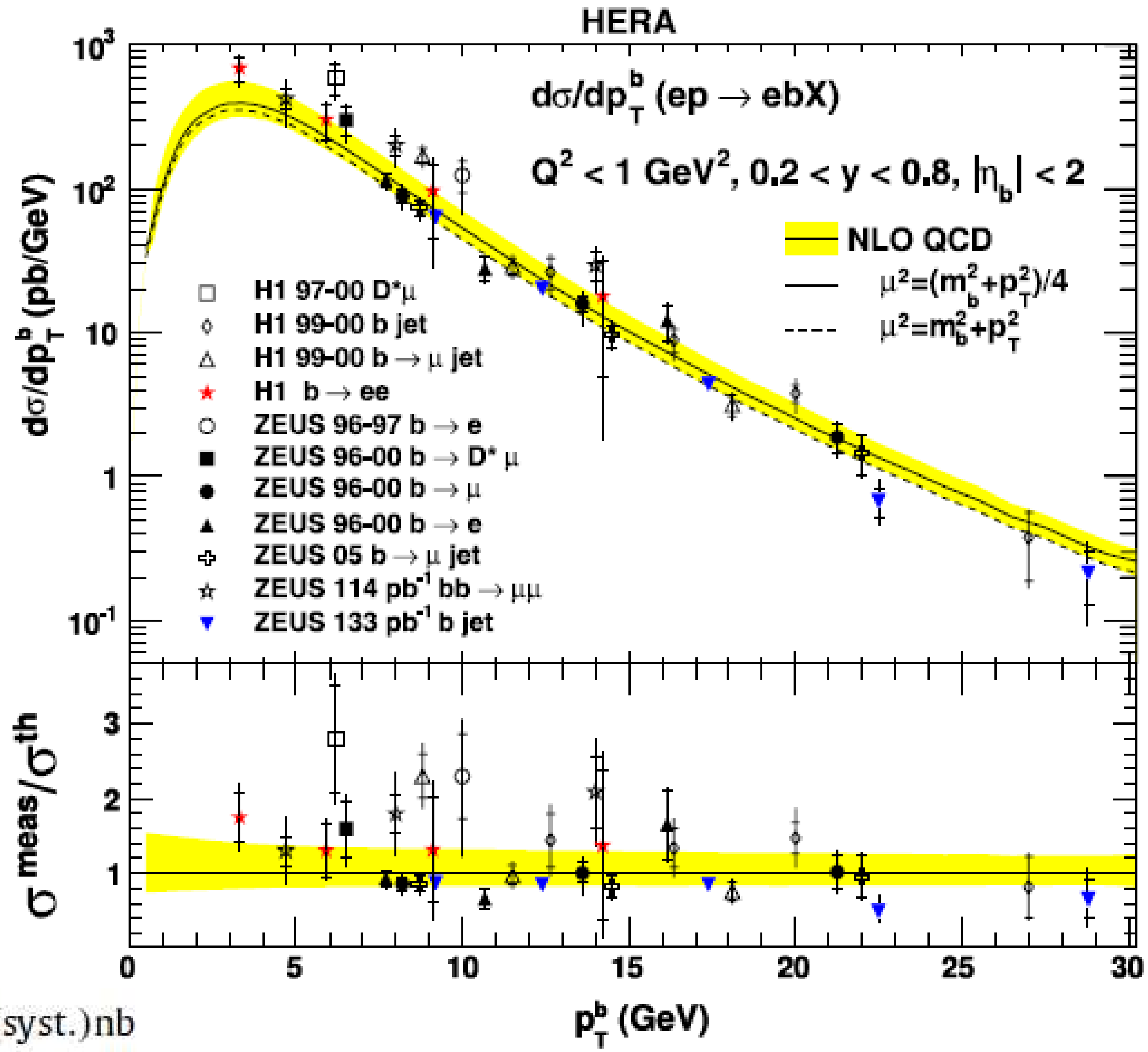
CASCADE
a bit less



Beauty in photoproduction

suppressed relative to charm by mass and charge

coverage of almost full phase space



$$\sigma_{tot}(ep \to b\bar{b}X) = 13.9 \pm 1.5(\text{stat.})^{+4.0}_{-4.3}(\text{syst.})\text{nb}$$

$$\sigma_{tot}^{NLO}(ep \to b\bar{b}X) = 7.5^{+4.5}_{-2.1}\text{nb}$$

Beauty in photoproduction

Table 4

Beauty photoproduction cross-section measurements at HERA. Information is given for each analysis on the beauty tagging method, the experiment, the data taking period, integrated luminosity, Q^2 and y ranges and the cuts on transverse momenta and pseudorapidities of selected final state particles. The last two columns provide information on the number of events in the analysis (number of signal events if an uncertainty is given) and the equivalent number of background-free events. The centre-of-mass energy of all data taken up to 1997 (6th column) was 300 GeV, while it was 318–319 GeV for all subsequent runs.

No.	Analysis	b Tag	Ref.	Exp.	Data	$\mathcal{L}$ (pb^{-1})	Q^2 (GeV^2)	y	Particle	p_T (GeV)	η	Events	bgfree events
1	μ + dijets	$\mu + p_T^{rel}$	[190]	H1	96	6.6	<1	[0.1, 0.8]	μ jet 1(2)	>2 >6(6)	[−0.9, 1.1]	470 ± 43	120
2	e + dijets	$e + p_T^{rel}$	[191]	ZEUS	96-97	38.5	<1	[0.2, 0.8]	e jet 1(2)	>1.6 >7(6)	[−1.1, 1.1] [−2.4, 2.4]	140 ± 35	16
3	μ + dijets	$\mu + p_T^{rel}$	[192]	ZEUS	96-00	110	<1	[0.2, 0.8]	μ jet 1(2)	>2.5 >7(6)	[−1.6, 2.3] [−2.5, 2.5]	834 ± 65	165
4	μ + dijets	$\mu + p_T^{rel} + \delta$	[143]	H1	99-00	50	<1	[0.2, 0.8]	μ jet 1(2)	>2.5 >7(6)	[−0.55, 1.1] [−2.5, 2.5]	1745	128
5	lifet. + dijets	imp. par.	[142]	H1	99-00	57	<1	[0.15, 0.8]	Track Jet 1(2)	>0.5 >11(8)	[−1.3, 1.3] [−0.9, 1.3]	∼80,000	78
6	e + dijets	$e + p_T^{rel} + \not{E}_T$	[177]	ZEUS	96-00	120	<1	[0.2, 0.8]	e Jet 1(2)	>0.9 >7(6)	[−1.5, 1.5] [−2.5, 2.5]	∼6000	129
7	μ + dijets	$\mu + p_T^{rel} + \delta$	[193]	ZEUS	05	126	<1	[0.2, 0.8]	μ Jet 1(2)	>2.5 >7(6)	[−1.6, 1.3] [−2.5, 2.5]	7351	122
8	lifet. + dijets	sec. vtx.	[178]	ZEUS	05	133	<1	[0.2, 0.8]	tracks Jet 1(2)	>0.5 >7(6)	[−1.6, 1.4] [−2.5, 2.5]	∼70,000	1050
9	μ + dijets	μ + imp.par.	[179]	H1	06-07	179	<2.5	[0.2, 0.8]	μ Jet 1(2)	>2.5 >7(6)	[−1.3, 1.5] [−1.5, 2.5]	6807	425
10	$D^* + \mu$	$K\pi\pi_s + \mu$	[176]	H1	98-00	89	<1	[0.05, 0.75]	D^* μ	>1.5 $p > 2$	[−1.5, 1.5] [−1.74, 1.74]	56 ± 17	15
11	$D^* + \mu$	$K\pi\pi_s + \mu$	[194]	ZEUS	96-00	114	<1	[0.05, 0.85]	D^* μ	>1.9 >1.4	[−1.5, 1.5] [−1.8, 1.3]	232	16
12	dimuon	$\mu + \mu$	[195]	ZEUS	96-00	114	all	all	μ 1(2)	>1.5(0.75)	[−2.2, 2.5]	4146	86
13	dielectron	$e + e$	[196]	H1	07	48	<1	[0.05, 0.65]	e	>1	[−1.0, 1.74]	∼1500	51

(semi)inclusive final states only, but useful statistics

(with silicon vertex trackers) not so much smaller than charm

Charm in DIS

charm is mainly produced via boson-gluon fusion:

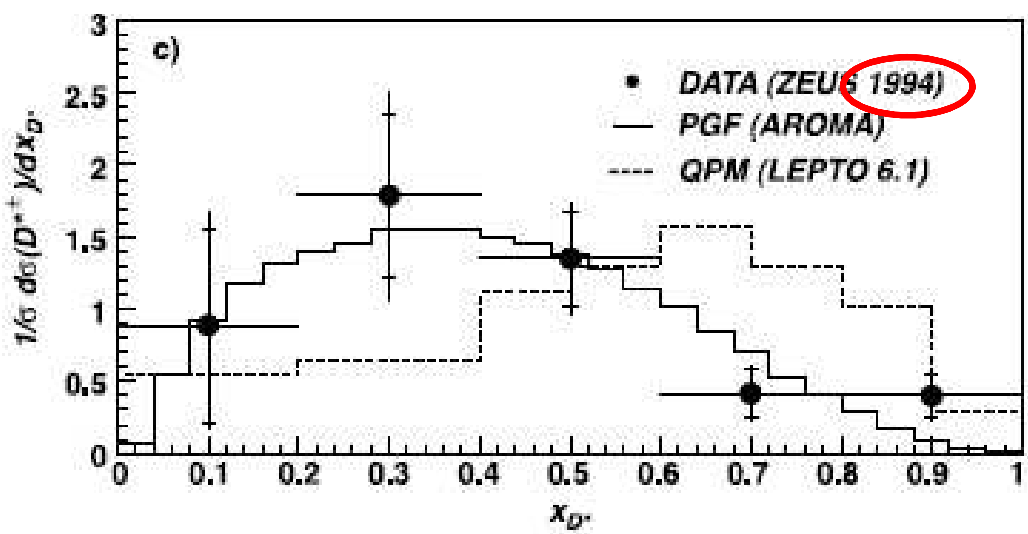
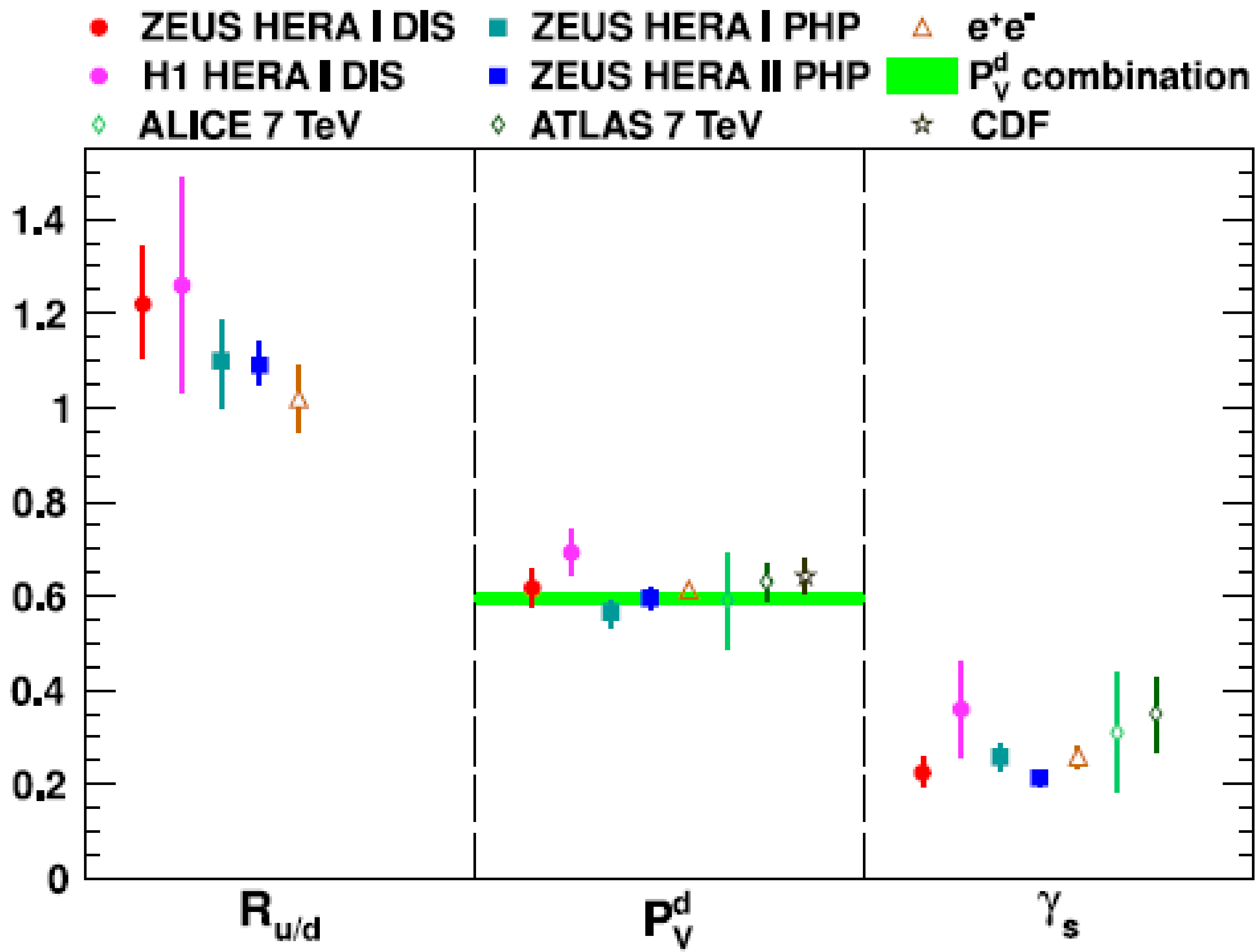


Fig. 40. Normalised differential D^*-production cross section as a function of x^*_D [198]. The measurement was performed for $5 < Q^2 < 100\,\mathrm{GeV}^2$. The points show the data, while solid and dashed lines show the BGF (PGF) and QPM predictions.

Charm fragmentation fractions

HERA competitive with e+e-



(see also talk A. Verbytskyi yesterday)

Charm in DIS

Table 5

Charm DIS measurements at HERA. Information is given for each analysis on the charm tagging method, the experiment, the data taking period, integrated luminosity, Q^2 and y ranges and the cuts on transverse momenta and pseudorapidities of selected final state particles. The last three columns provide information on the number of tagged charm events, the effective signal-to-background ratio and the equivalent number of background-free events. The centre-of-mass energy of all data taken up to 1997 (6th column) was 300 GeV, while it was 318–319 GeV for all subsequent runs.

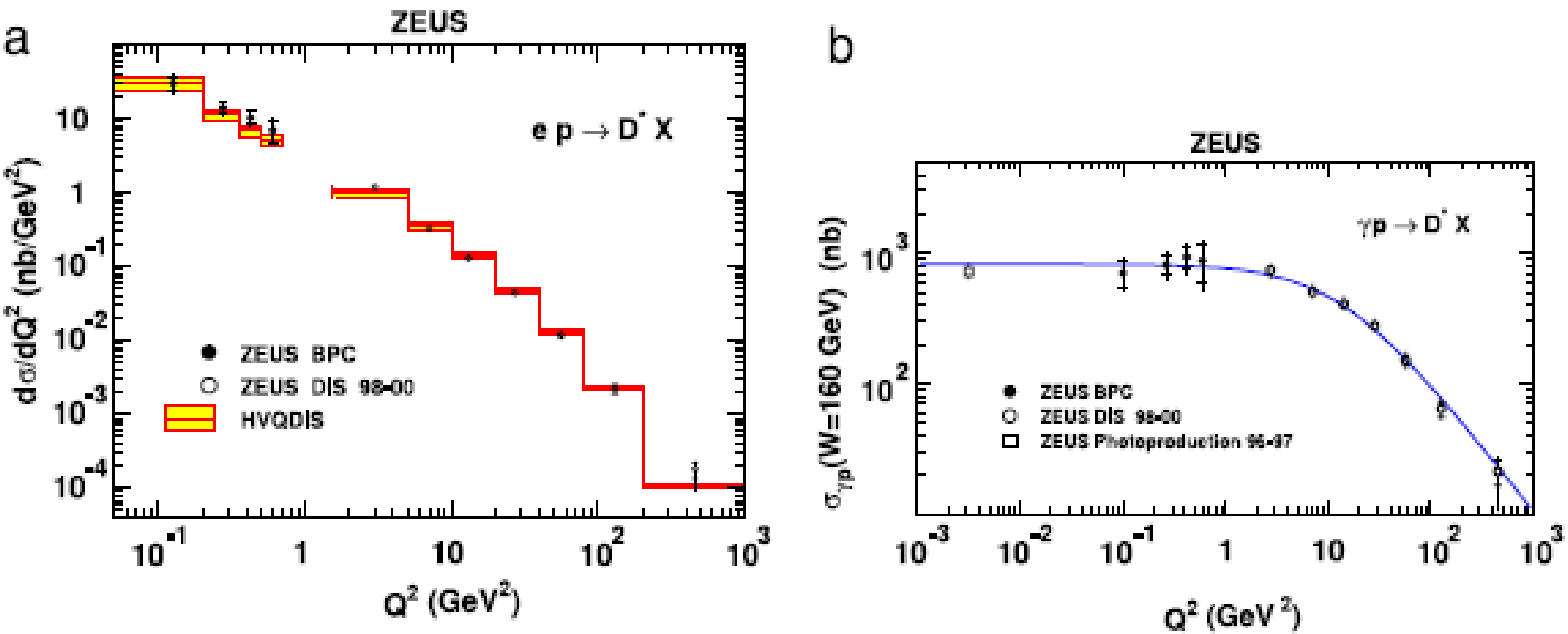
No.	Analysis	c-Tag	Ref.	Exp.	Data	$\mathcal{L}$ (pb^{-1})	Q^2 (GeV^2)	y	Particle	p_T (GeV)	η	Events	effect. s:b	bgfree events
1	D^* incl.	$K\pi\pi_s$	[197]	H1	94	3	[10, 100]	<0.53	D^*	>1.5	[−1.5, 1.5]	103 ± 13	1 : 0.7	64
	D^0 incl.	$K\pi$							D^0	>2.0		144 ± 19	1 : 1.5	57
2	D^* incl.	$K\pi\pi_s$	[198]	ZEUS	94	3	[5, 100]	<0.7	D^*	[1.3, 9.0]	[−1.5, 1.5]	122 ± 17	1 : 1.4	52
3	D^* incl.	$K\pi\pi_s$	[170]	H1	95-96	10	[2, 100]	[0.05, 0.7]	D^*	[1.5, 15]	[−1.5, 1.5]	583 ± 35	1 : 1.1	278
4	D^* incl.	$K\pi\pi_s$	[199]	ZEUS	96-97	37	[1, 600]	[0.02, 0.7]	D^*	[1.5, 15]	[−1.5, 1.5]	2064 ± 72	1 : 1.5	822
		$K\pi\pi\pi\pi_s$								[2.5, 15]		1277 ± 124	1 : 11	106
5	D^* incl.	$K\pi\pi_s$	[200]	H1	97	18	[1, 100]	[0.05, 0.7]	D^*	>1.5	[−1.5, 1.5]	973 ± 40	1 : 0.6	590
6	D^* incl.	$K\pi\pi_s$	[201]	ZEUS	98-00	82	[1.5, 1000]	[0.02, 0.7]	D^*	[1.5, 15]	[−1.5, 1.5]	5545 ± 129	1 : 2	1850
7	D incl.	D mes. + S	[148]	H1	99-00	48	[2, 100]	[0.05, 0.7]	D mesons	>2.5	[−1.5, 1.5]	n.a.	n.a.	263
8	D^* incl.	$K\pi\pi_s$	[202]	H1	99-00	47	[2, 100]	[0.04, 0.7]	D^*	[1.5, 15]	[−1.5, 1.5]	2604 ± 77	1 : 1.3	1140
	+ dijet								Jet1(2)	>4(3)	[−1, 2.5]	668 ± 49	1 : 2.5	186
9	D^* incl.	$K\pi\pi_s$	[203]	ZEUS	98-00	82	[0.05, 0.7]	[0.02, 0.85]	D^*	[1.5, 9]	[−1.5, 1.5]	253 ± 25	1 : 1.5	100
10	D incl.	D mes.	[204]	ZEUS	98-00	82	[1.5, 1000]	[0.02, 0.7]	D mesons	>3	[−1.6, 1.6]	n.a.	n.a.	1100
11	D^+ incl.	$K\pi\pi$	[205]	ZEUS	96-00	120	[1.5, 1000]	[0.02, 0.7]	D^+	[0, 10]	[−1.6, 1.6]	691 ± 107	1 : 16	42
	Λ_c incl.	pK^0_S							Λ_c			79 ± 25	1 : 7	10
		$\Lambda\pi^+$										84 ± 34	1 : 13	6
12	incl. lifet.	imp. par.	[206]	H1	99-00	57	> 150	[0.1, 0.7]	Track	>0.5	[−1.3, 1.3]	∼2300	1 : 22	100
13	incl. lifet.	imp. par.	[207]	H1	99-00	57	[6, 120]	[0.07, 0.7]	Track	>0.5	[−1.3, 1.3]	∼50,000	1 : 48	1024
14	D^0 incl.	$K\pi + S$	[208]	ZEUS	05	134	[5, 1000]	[0.02, 0.7]	D^0	[1.5, 15]	[−1.6, 1.6]	8274 ± 352	1 : 14	550
15	μ + jet	$\mu + p_T^{rel} + \delta + \not{E}_T$	[209]	ZEUS	05	126	> 20	[0.01, 0.7]	μ	>1.5	[−1.6, 2.3]	∼5100	1 : 20	250
16	D^* incl.	$K\pi\pi_s$	[210]	H1	04-07	351	[100, 1000]	[0.02, 0.7]	D^*	[1.5, 15]	[−1.5, 1.5]	∼600	1 : 7	260
17	D^* incl.	$K\pi\pi_s$	[145]	H1	04-07	348	[5, 100]	[0.02, 0.7]	D^*	>1.25	[−1.8, 1.8]	24,705 ± 343	1 : 3.8	5200
18	D^* incl.	$K\pi\pi_s$	[211]	ZEUS	04-07	363	[5, 1000]	[0.02, 0.7]	D^*	[1.5, 20]	[−1.5, 1.5]	12,893 ± 185	1 : 2.7	4860
19	D^+ incl.	$K\pi\pi + S$	[212]	ZEUS	04-07	354	[5, 1000]	[0.02, 0.7]	D^+	[1.5, 15]	[−1.6, 1.6]	8356 ± 198	1 : 3.7	1800
20	incl. lifet.	$\delta + S$	[150]	H1	06-07	189	[5, 2000]	n.a.	Track	>0.3	[−1.3, 1.3]	∼210,000	n.a.	n.a.
21	incl. lifet.	jet + δ + S	[213]	H1	06-07	189	>6	[0.07, 0.625]	Jet	>6	[−1.0, 1.5]	∼85,000	1 : 17	4800
22	incl. lifet.	jet + S	[149]	ZEUS	04-07	354	[5, 1000]	[0.02, 0.7]	Jet	>4.2	[−1.6, 2.2]	∼55,000	1 : 11	4400

lifetime tags competitive with D*

(inclusive DIS trigger!)

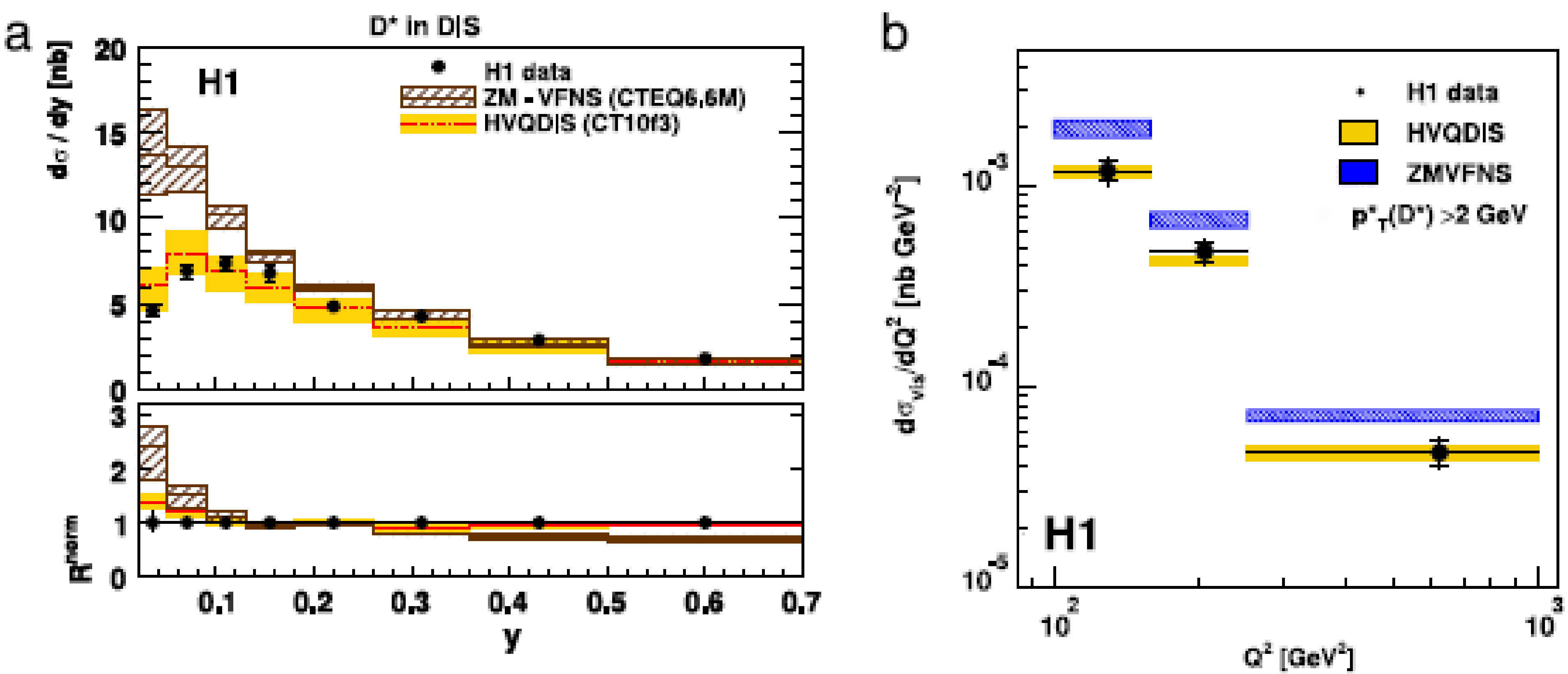
Charm in DIS

at $Q^2 \leq m^2$, DIS behaves like photoproduction



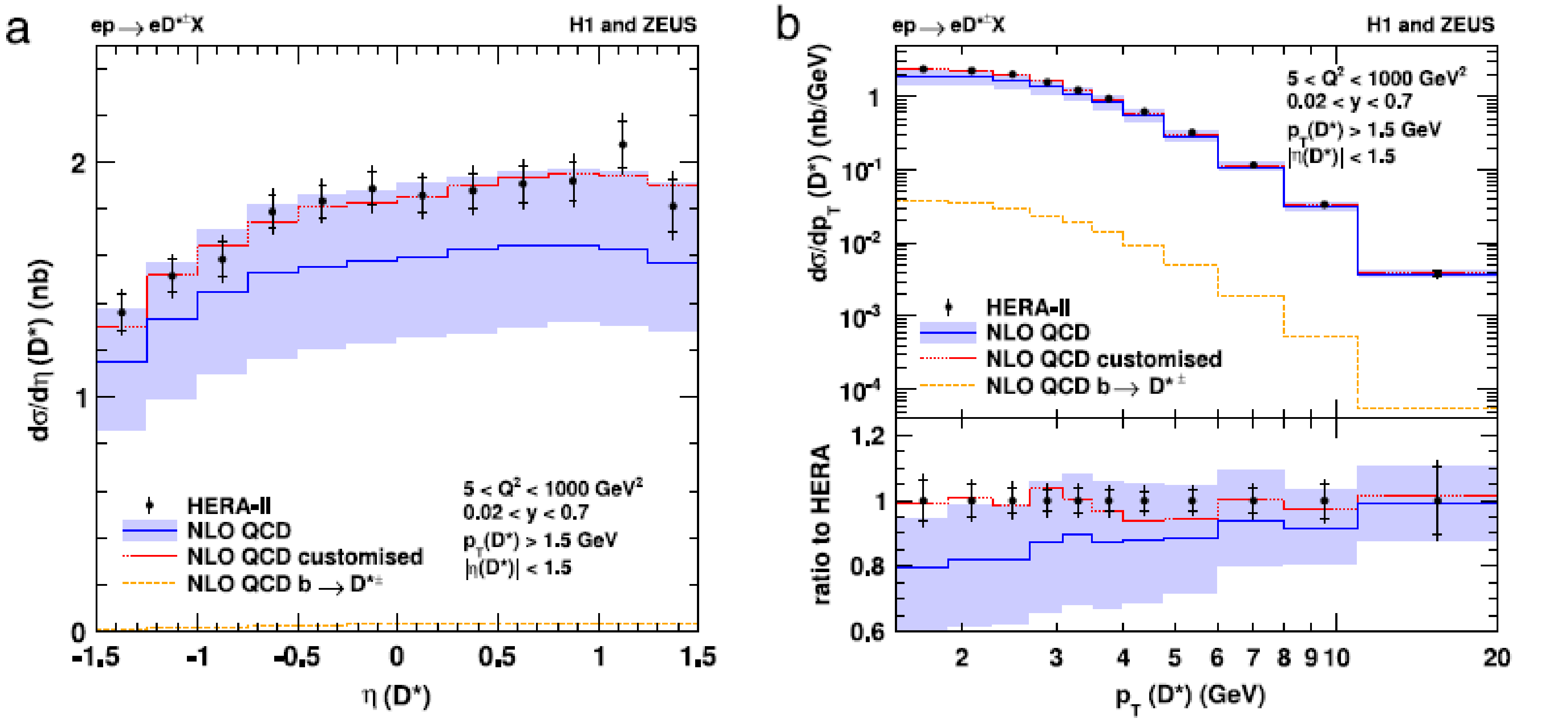
Charm in DIS

zero mass variable flavour number scheme fails in many regions of phase space



Charm in DIS (D* combination)

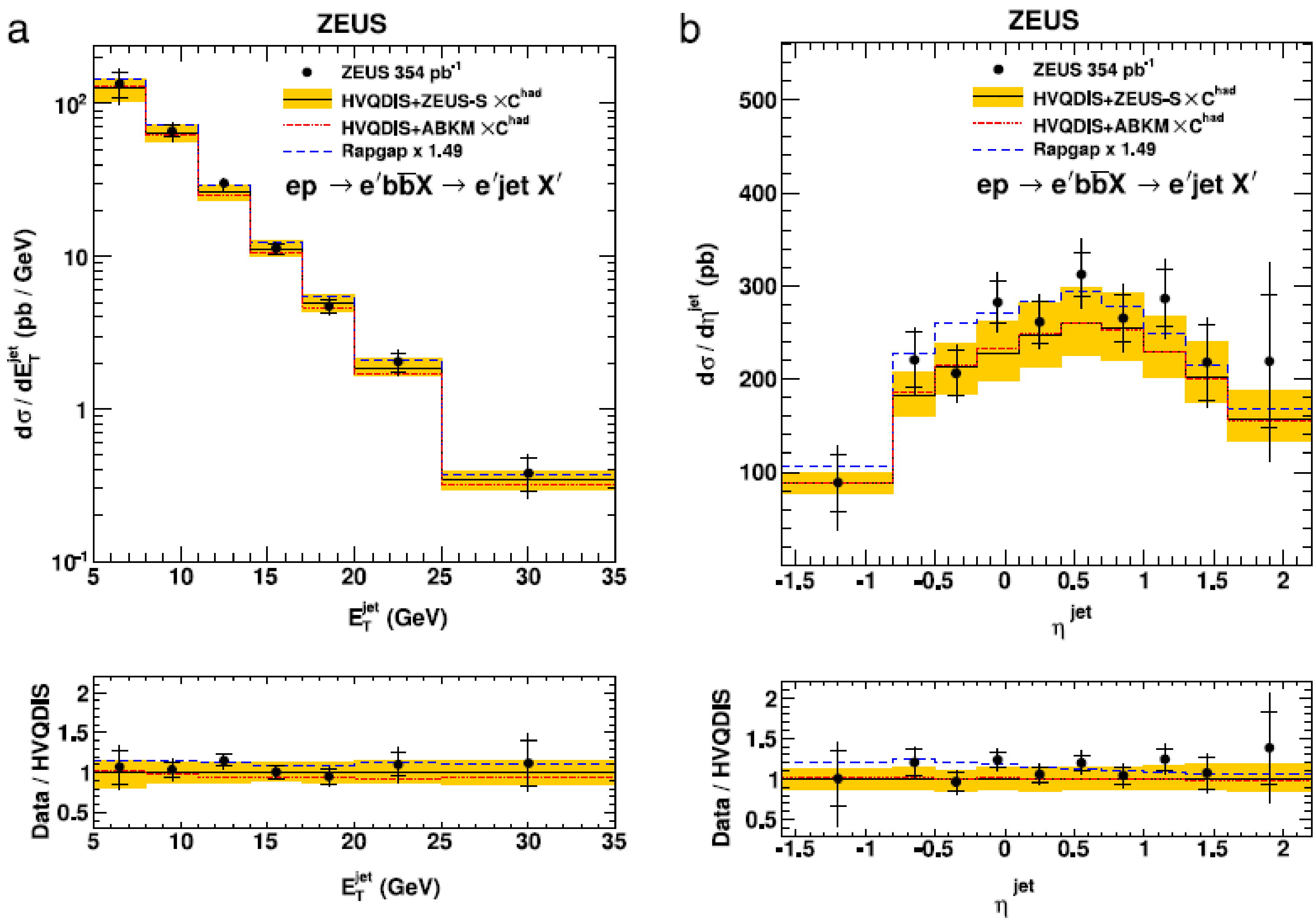
fixed flavour number scheme works well differentially up to highest p_T, Q^2



but theory uncertainties (NLO scale, fragmentation) are large

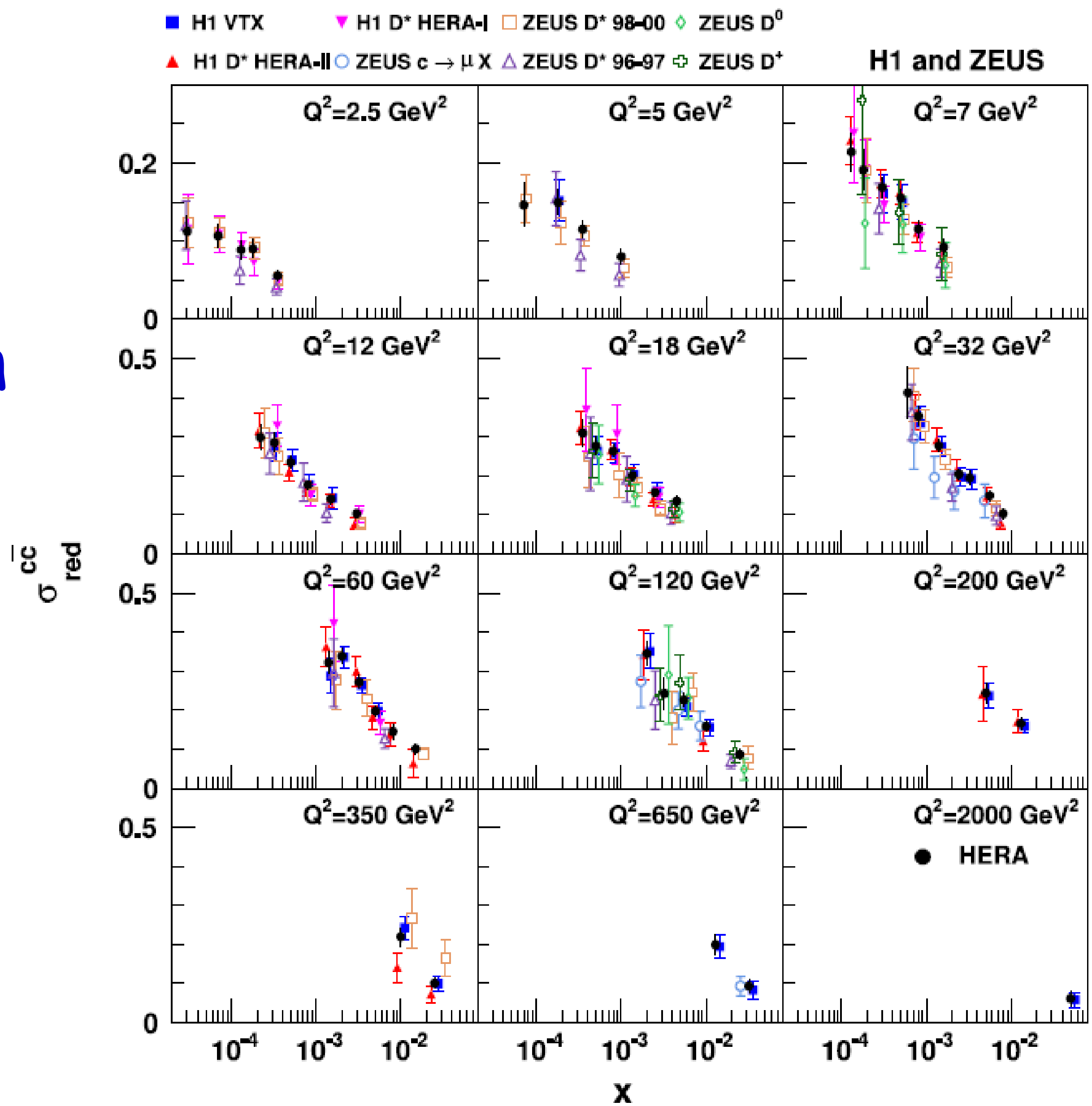
Beauty in DIS

theory uncertainties smaller



Charm in DIS

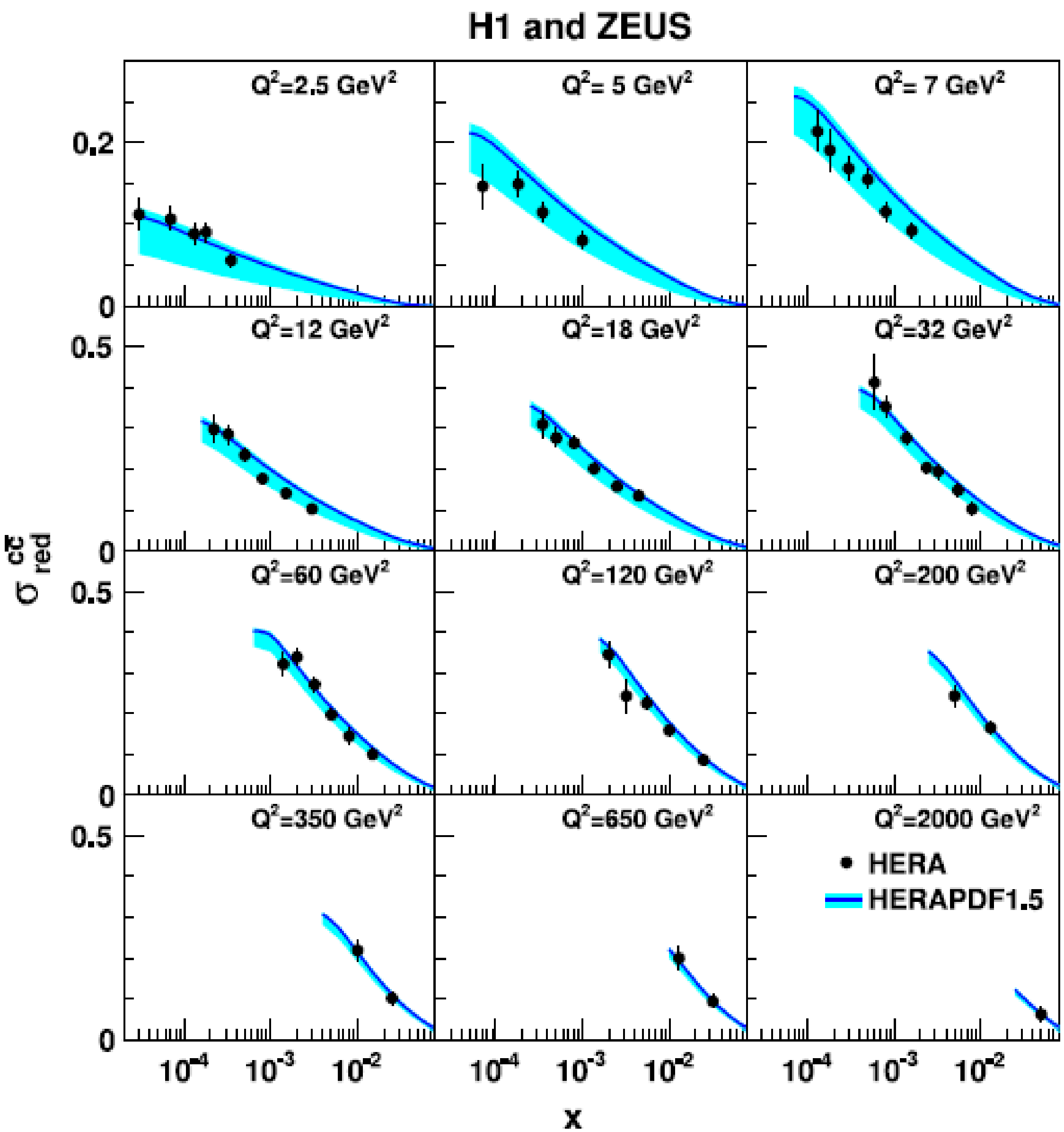
most
charm in DIS
data have been
combined



Charm in DIS

general mass variable flavour schemes work fine, but only available for inclusive quantities

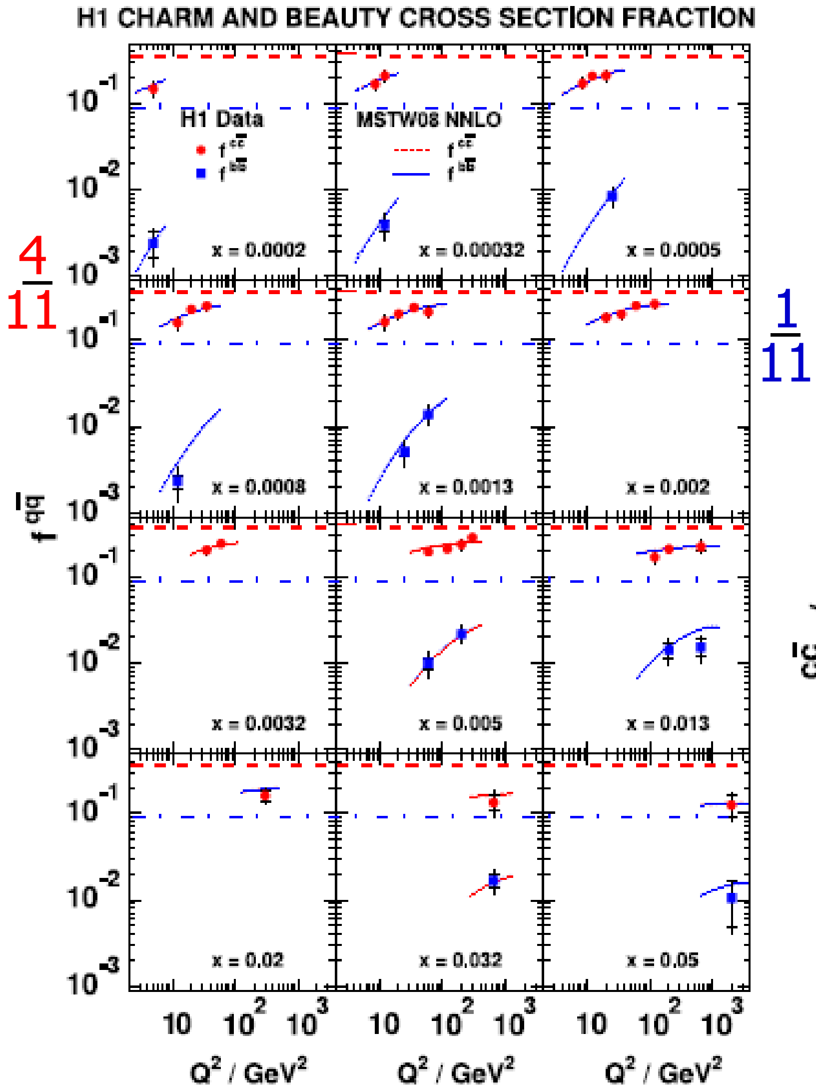
use charm data in PDF fits

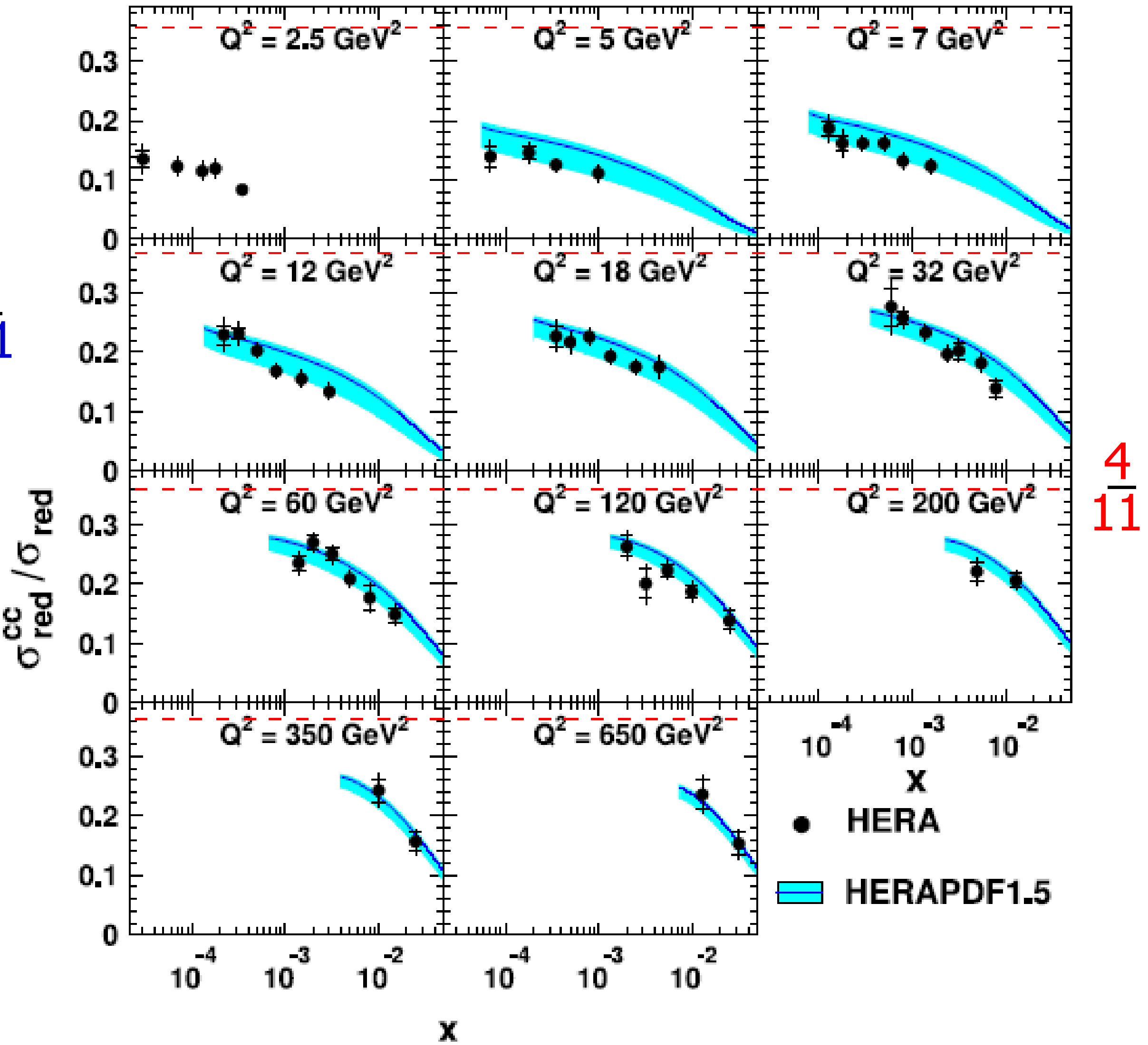


Charm and Beauty in DIS

$$f(c) \sim \frac{Q_c^2}{Q_d^2 + Q_u^2 + Q_s^2 + Q_c^2 + Q_b^2} = \frac{4}{11}$$

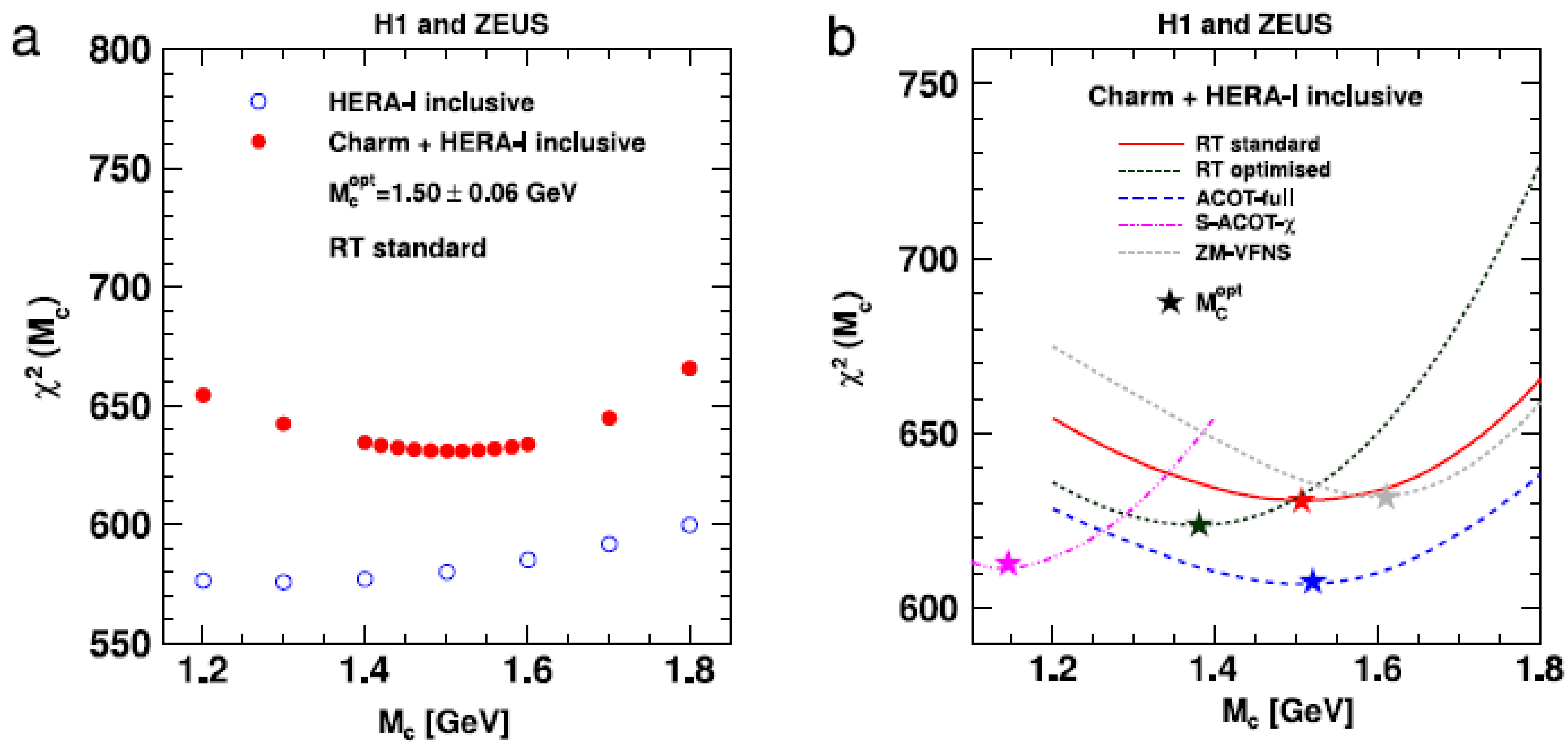
at high Q^2 and low x, data show expected asymptotic behavior





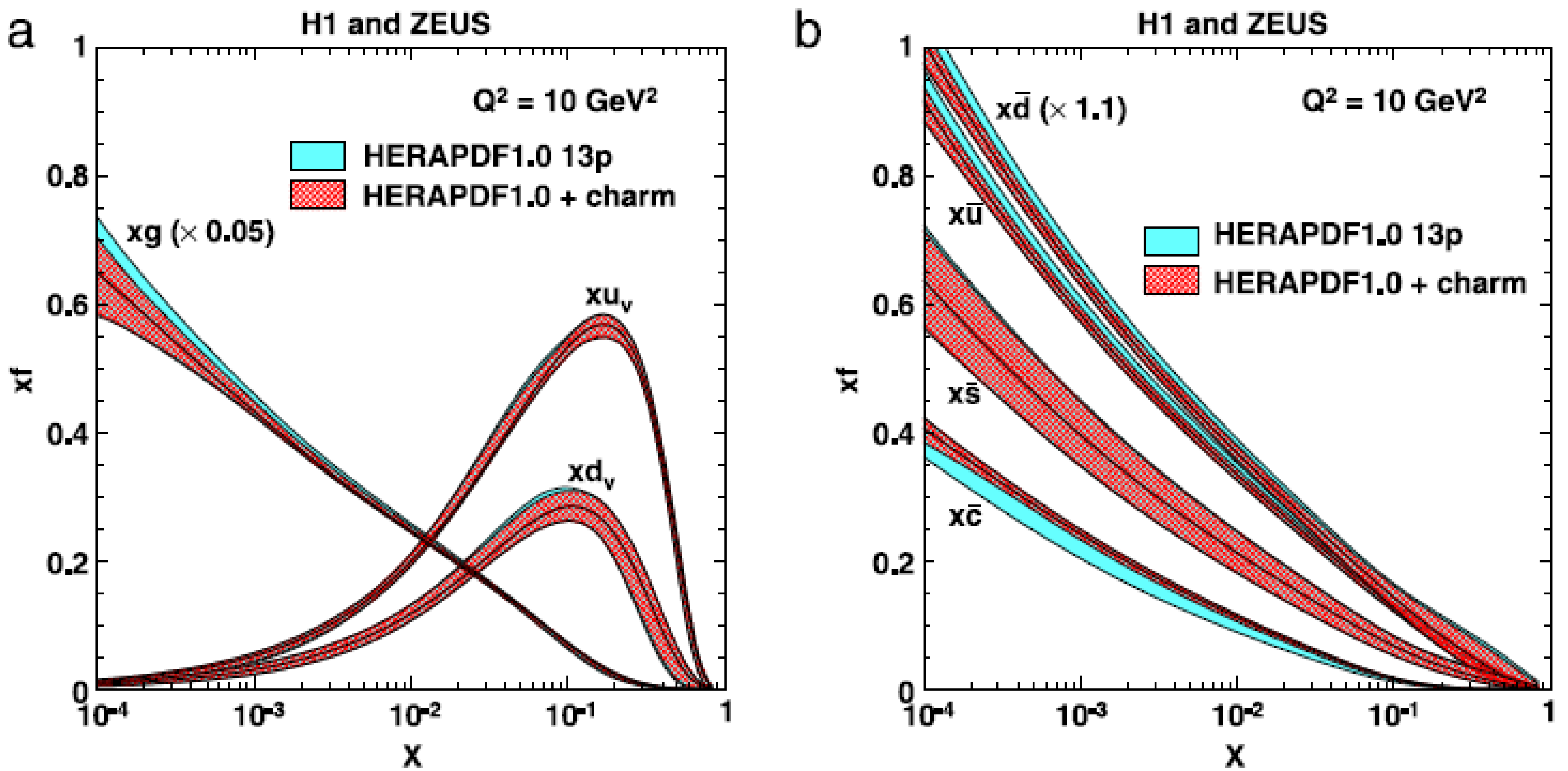
Charm mass fits

charm in DIS data sensitive to charm mass



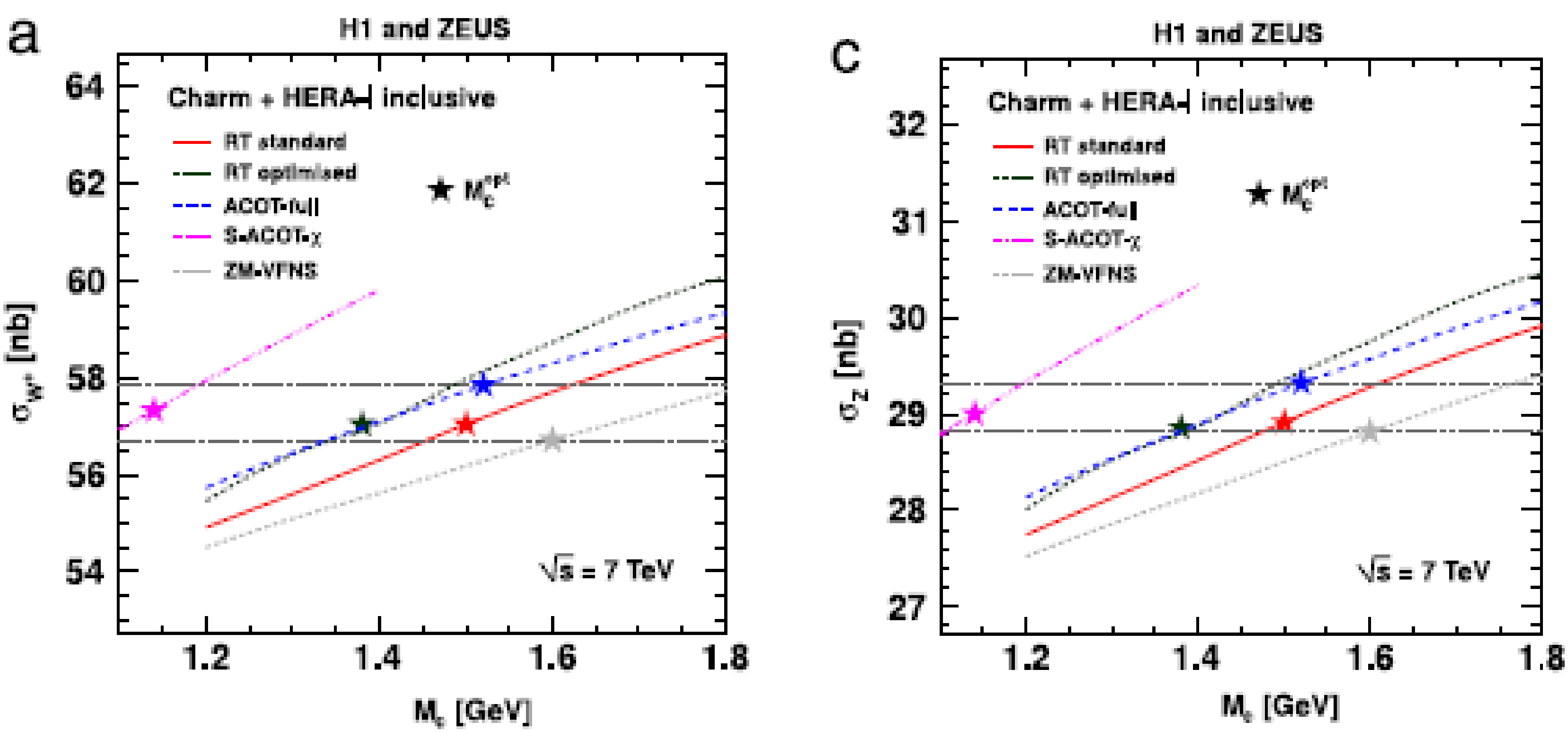
Fit of charm data

better charm mass constraint (tailored for each heavy flavour scheme) reduces PDF uncertainties



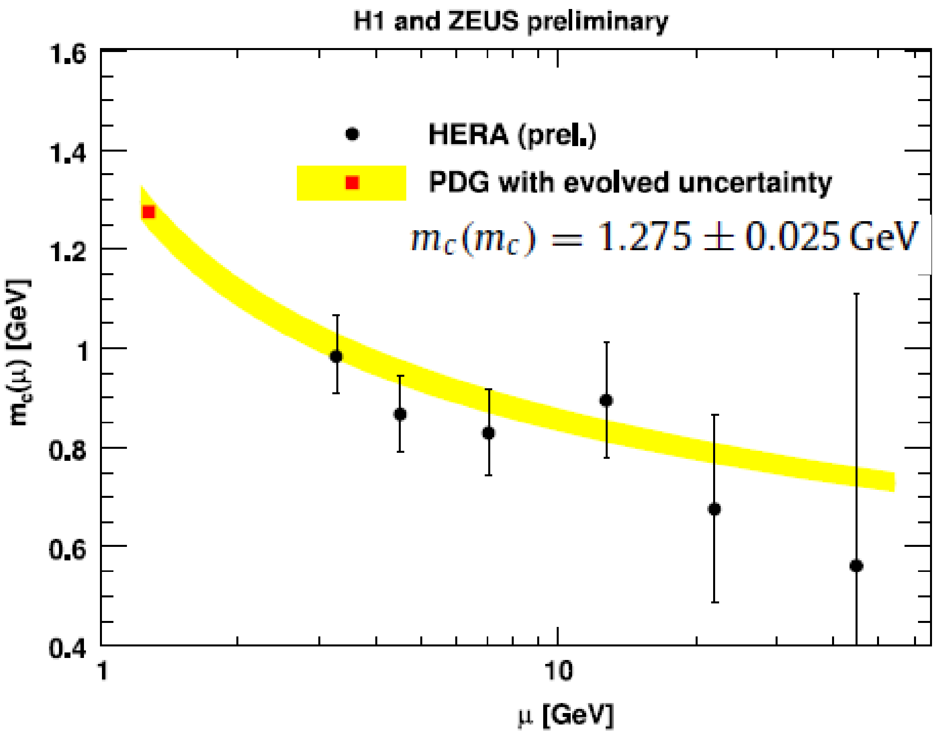
Fit of charm data

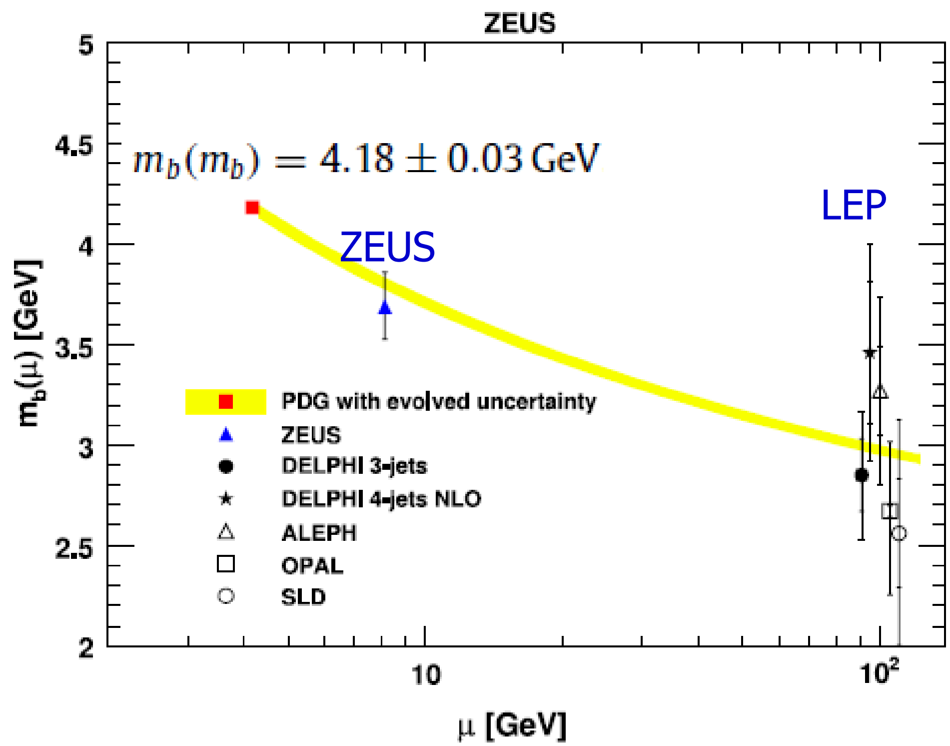
… and reduces uncertainties of cross section predictions for LHC



Charm and beauty mass running

fixed flavour scheme allows measurement of MS mass and mass running





$m_c(m_c) = 1.26 \pm 0.05(\mathrm{exp}) \pm 0.03(\mathrm{mod}) \pm 0.02(\mathrm{param}) \pm 0.02(\alpha_s)\,\mathrm{GeV}$ H1+ZEUS NLO

$m_c(m_c) = 1.36 \pm 0.04(\mathrm{fit})\,^{+0.04}_{-0.00}(\mathrm{scale}) \pm 0.1(\mathrm{theory})\,\mathrm{GeV}$ ABM + friends `NNLO'

$m_b(m_b) = 4.07 \pm 0.14(\mathrm{fit})\,^{+0.01}_{-0.07}(\mathrm{mod})\,^{+0.02}_{-0.00}(\mathrm{param})\,^{+0.08}_{-0.05}(\mathrm{theo})\,\mathrm{GeV}$ ZEUS NLO -> PDG

Conclusions

arXiv:1506.07519

- first review ever dedicated to open charm, beauty and top production at HERA has recently been published (integrating information from previous unpublished review)
- hopefully useful source of information for students and physicists interested in HERA heavy flavour results and their use for non-HERA applications (+ a few aspects not published elsewhere)
- the work is not finished:
  - most results do not yet use the final statistics (PHP: none!)
  - some analyses (e.g. multi-differential production properties) have not even been started
  - large potential for further improved understanding of QCD theory beneficial to particle physics as a whole and LHC in particular