Inclusive charm production in DIS at HERA

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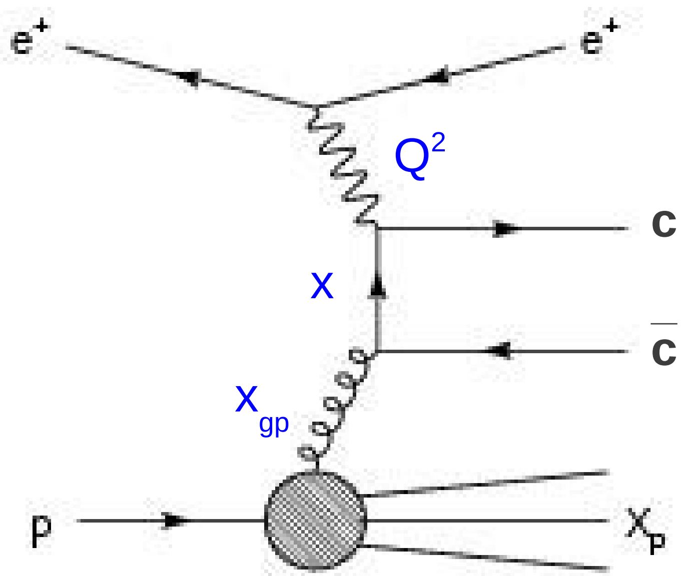
On behalf of the **H1** and **ZEUS** Collaborations

Overview

- Theory introduction
- HERA combination results:
  - Combined data
  - Test of different GM VFNS
    - Optimizing c mass
    - W and Z production @ LHC predictions
    - PDFs
  - Test of FFNS
- Recent results

Charm production at HERA



Heavy flavour production in DIS @ HERA
up to
~30% charm
~ 3% beauty
of total DIS cross section

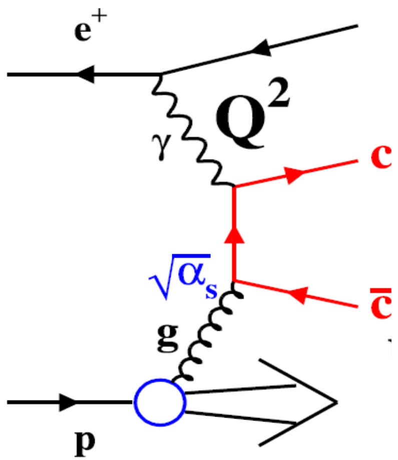
Dominant process of charm production @ HERA – **Boson-Gluon Fusion** (*BGF*)

↓

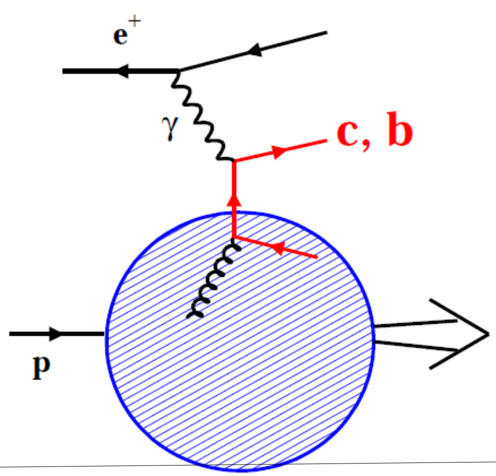
sensitive to gluon density in proton

Heavy quark schemes

- **Fixed Flavour Number Scheme**
  - *Charm is massive, produced only in hard scattering process*
  - $Q^2 \sim m_c^2$



- **Zero Mass Variable Flavour number scheme**
  - *Charm is massless parton in proton*
  - $Q^2 >> m_c^2$



General Mass Variable Number Scheme

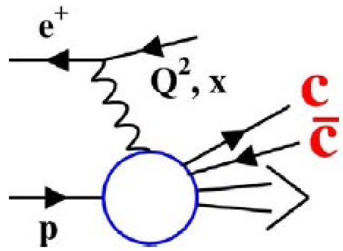
Combination of FFNS & ZM VFNS with some interpolation "in between"

Charm structure functions in inclusive DIS measurements

$$\frac{d\sigma^{c\bar{c}}}{dx\,dQ^2} = \frac{2\pi\alpha^2}{xQ^4}\sigma_{red}^{c\bar{c}}$$

Inclusive charm cross section

Reduced cross section



$\sim\sigma^{cc}{}_{red}$, $\sigma_{red}^{c\bar{c}} \sim F_2^{c\bar{c}}$ → *Structure function F_2*

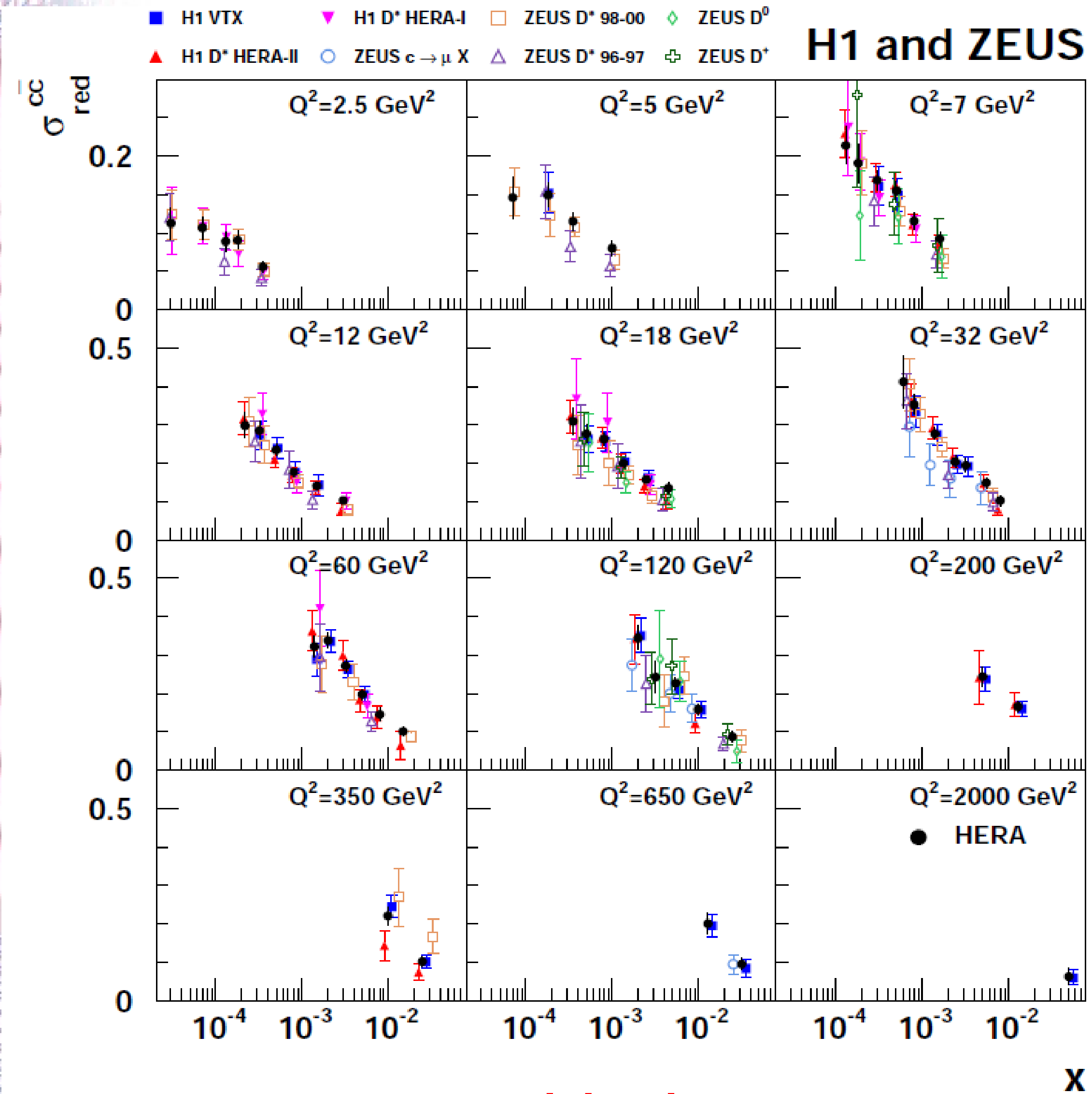
To measure σ_{red}: $\sigma_{red}^{c\bar{c}}(x_i, Q_i^2) \sim \sigma_{i,meas} \frac{\sigma_{red,theo}^{c\bar{c}}(x_i, Q_i^2)}{\sigma_{i,theo}}$

From massive NLO (HVQDIS)

HERA combination

HERA combined results

DESY-12-172



Factor 2 precision improvement

→ **9** data sets
→ **5** tagging methods (*D**, *D*+, *D*0, *μ*, *lifetime*)
→ **155** measurements
→ **52** cross sections
→ **48** correlated systematic uncertainties

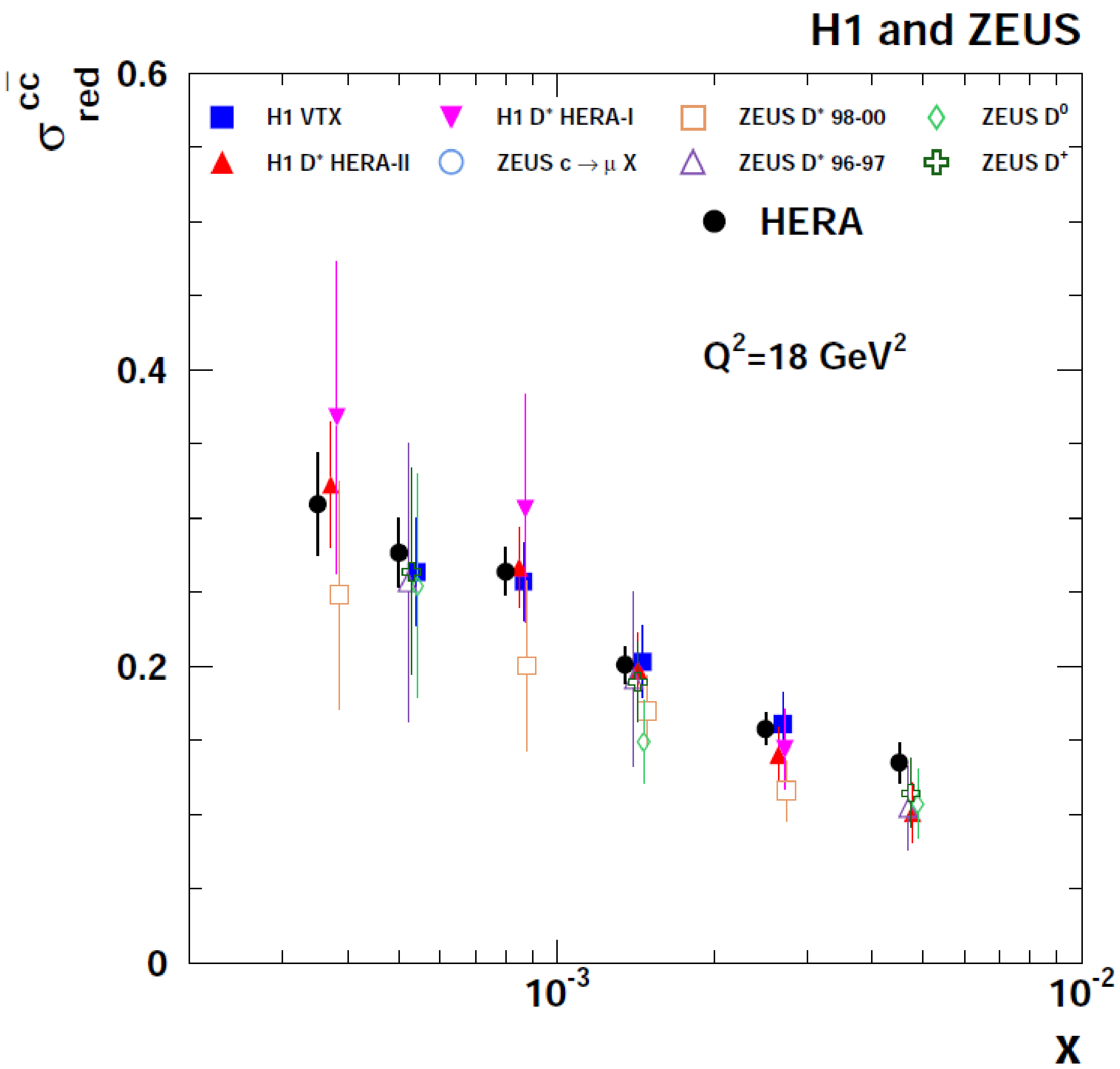
Data consistent

$$\chi^2/ndof = 62/103$$

HERA combined results

DESY-12-172

Uncertainty reaches ~ 6%



- → **9** data sets
- → **5** tagging methods (*D**, *D*⁺, *D*⁰, *μ*, *lifetime*)
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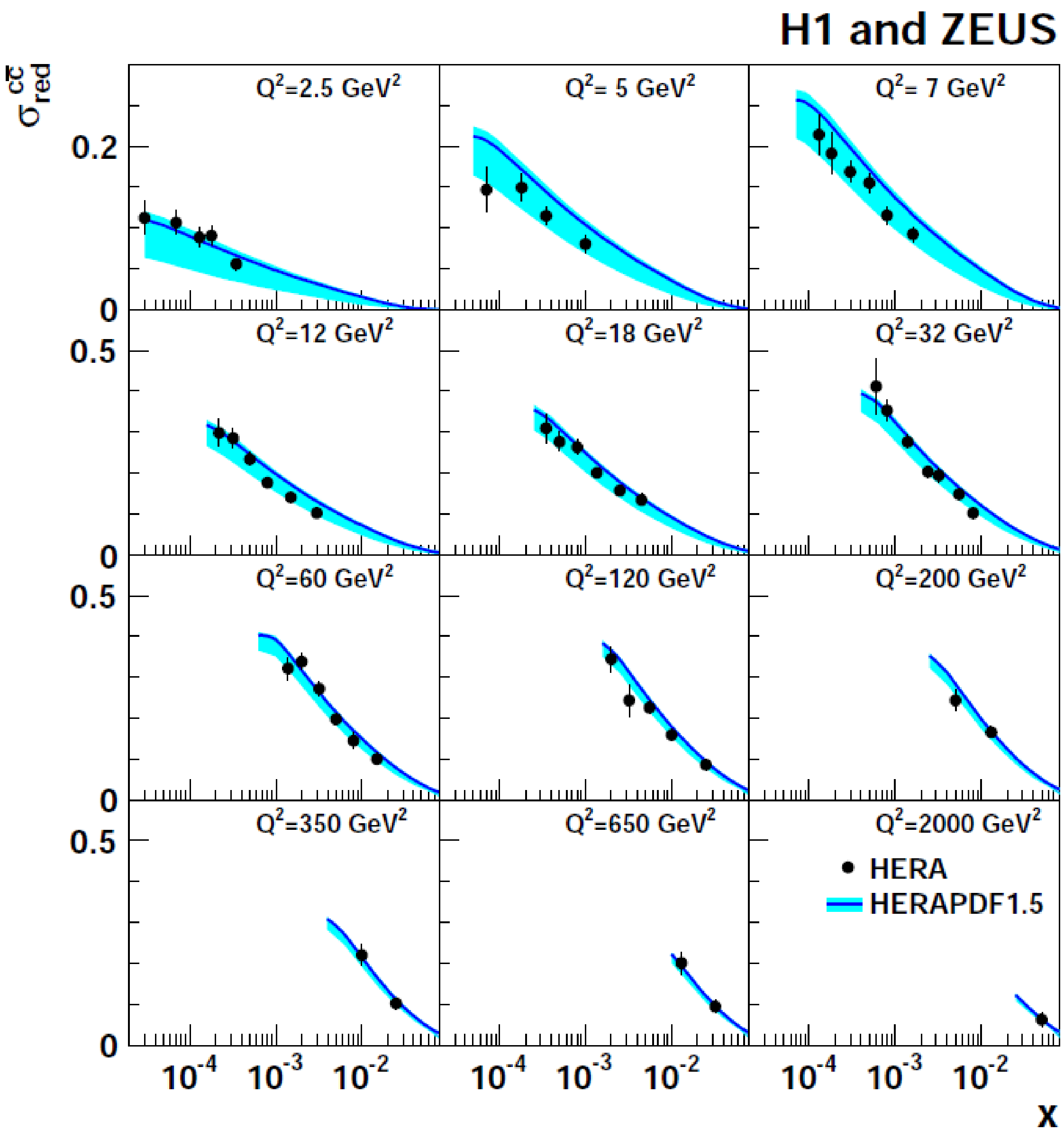
HERA combined results

DESY-12-172



Comparison to GM-VMNS

HERAPDF1.5 provides good description of data → nice!

Big theoretical uncertainty due to charm mass variation

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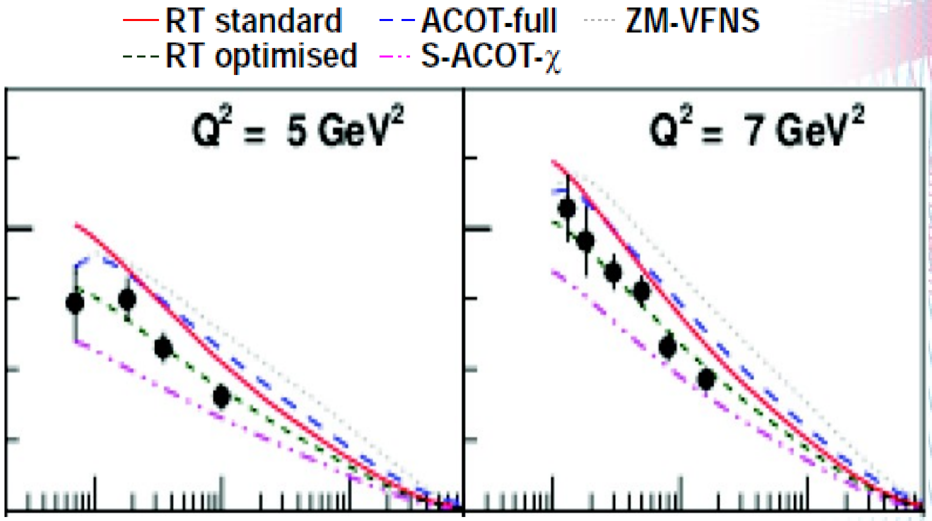
HERA data can help to optimize

Charm mass fit

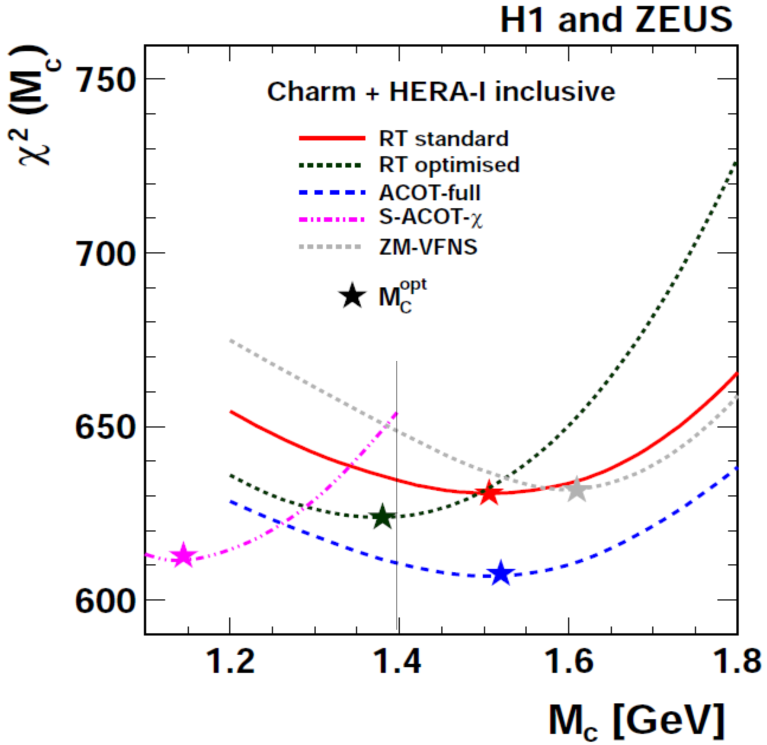
DESY-12-172

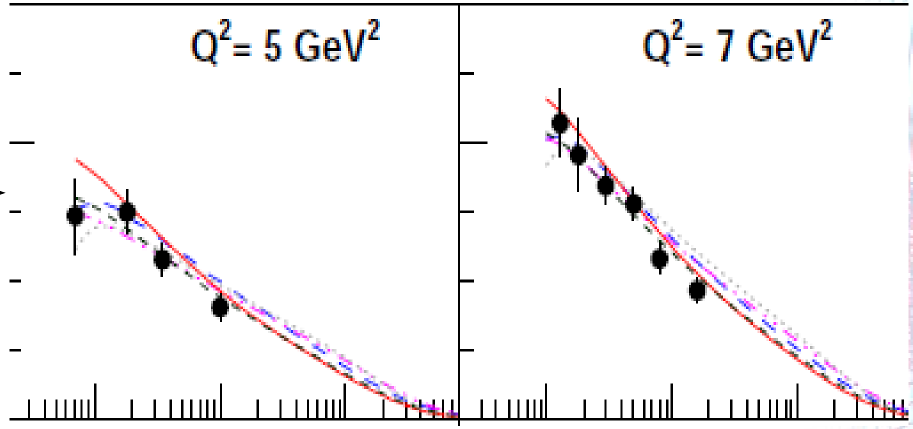
m_c = 1.4 GeV



Some schemes fail with m_c=1.4 GeV

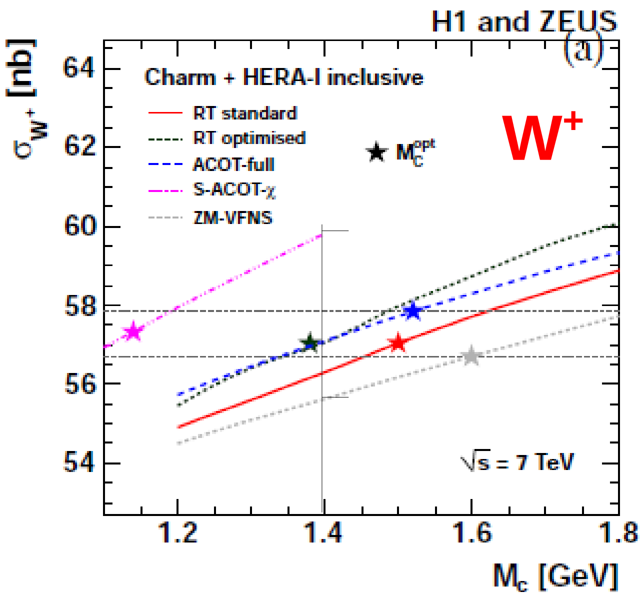
PDF fit to HERA I data

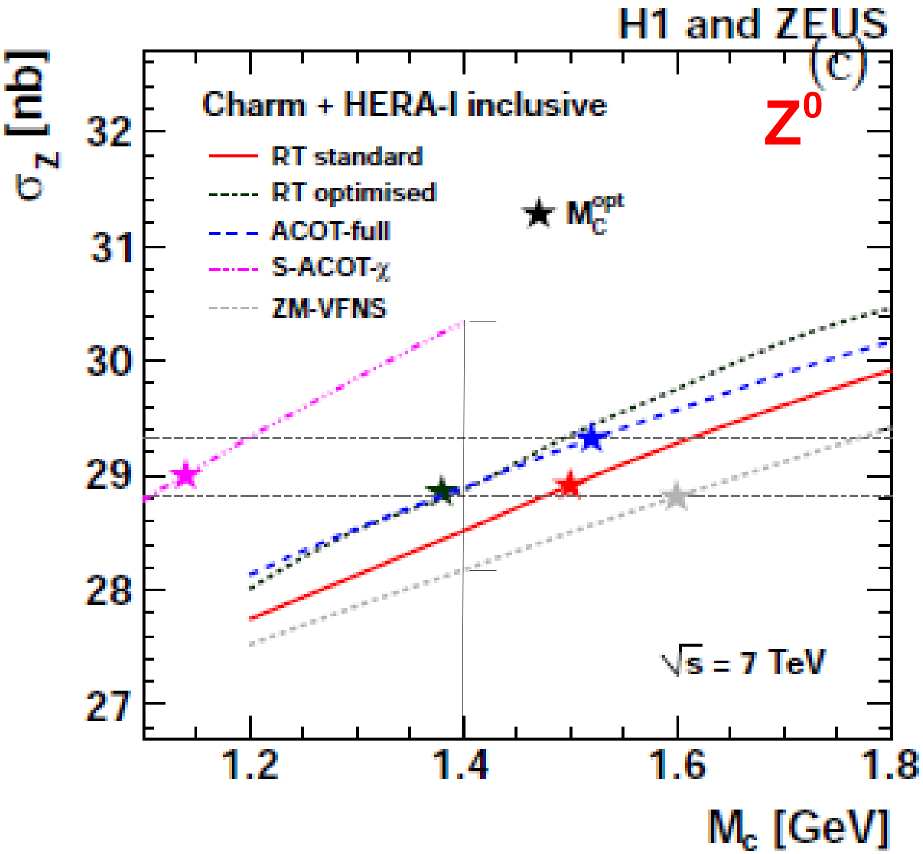


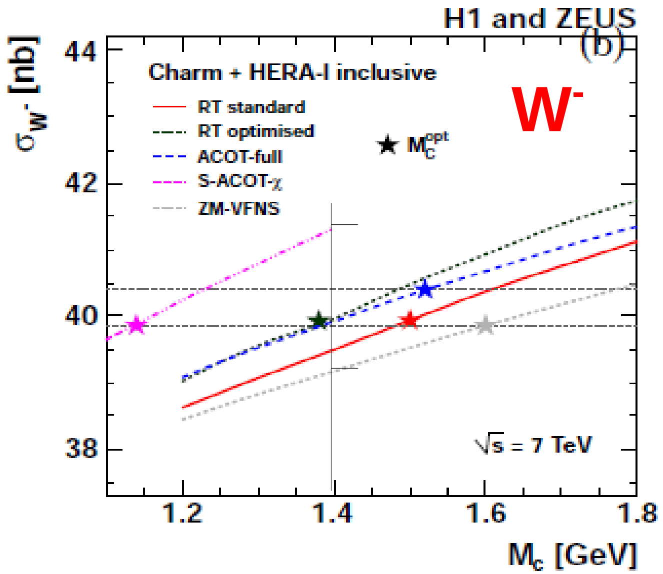


Compensated if using optimal M_c

Z and W predictions for LHC



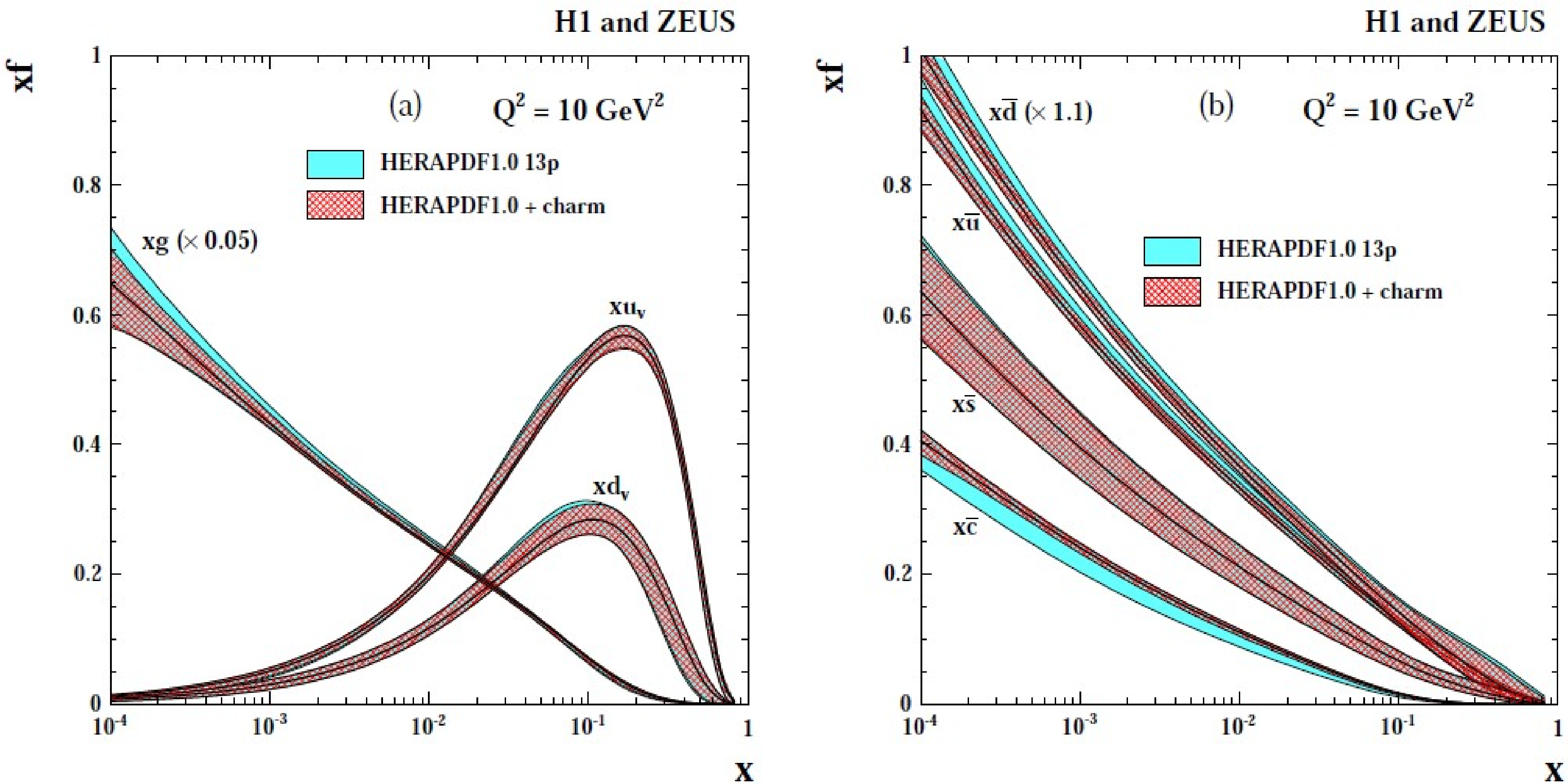




PDFs from HERA → Z & W production cross sections for LHC at 7 TeV

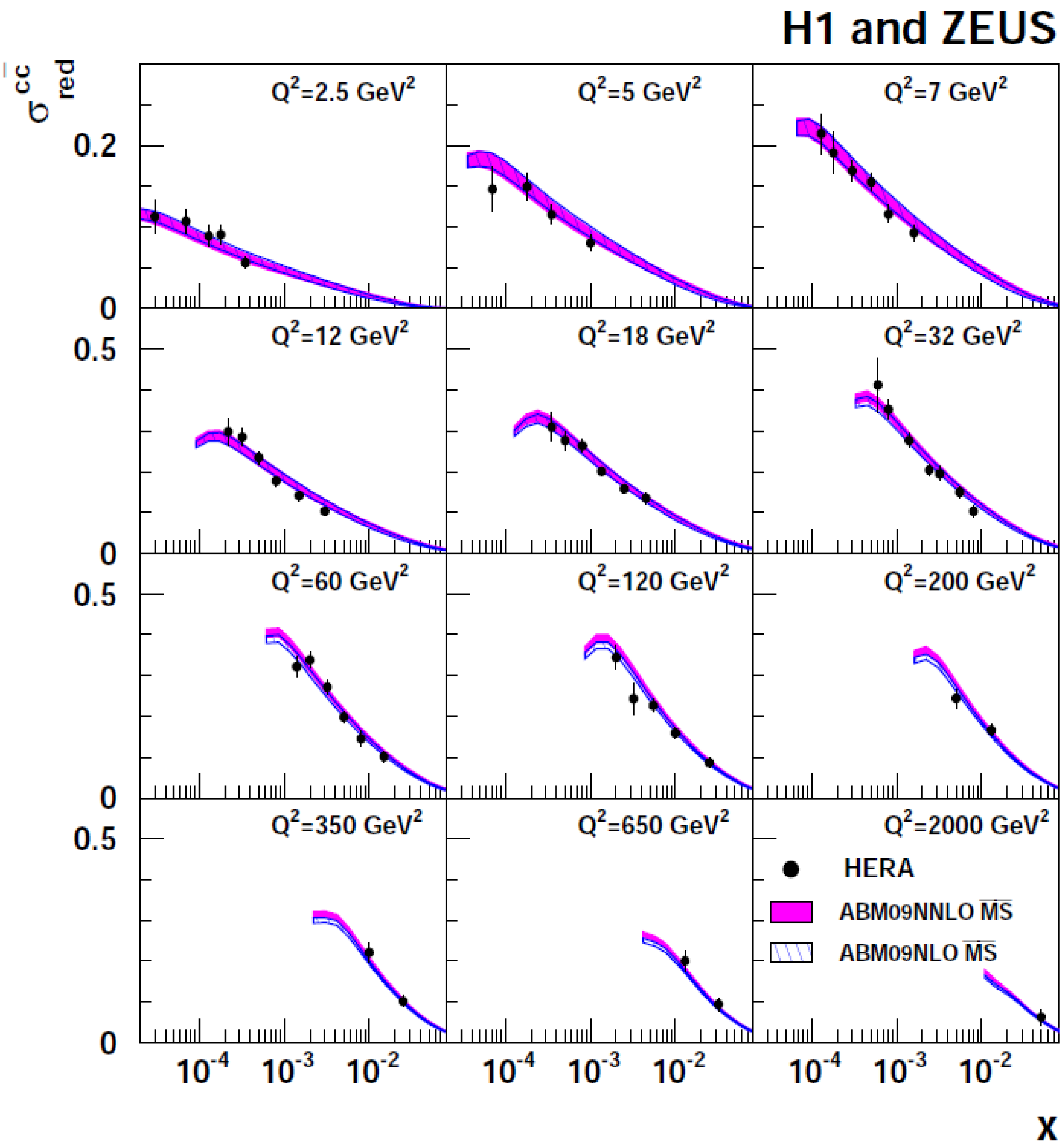
Spread between different theories much smaller, if we use optimized M_c

Impact of charm data on PDF



Inclusion of charm data to the fit decreased the error on sea flavour components

Comparisson to FFNS

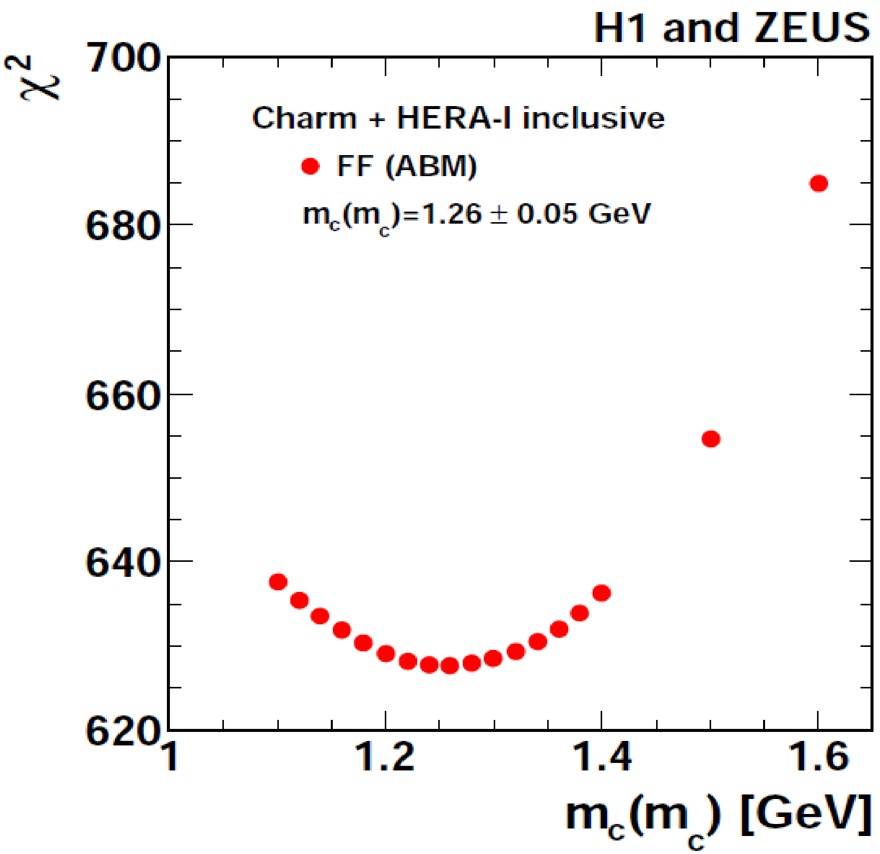


NLO+(partial)NNLO with running mass scheme

Good description in the whole kinematic range of the measurement

Running charm mass

DESY-12-172



Fit used inclusive DIS data and combined charm

$m_c(m_c) = 1.26 \pm 0.05_{\rm exp} \pm 0.03_{\rm mod} \pm 0.02_{\rm param} \pm 0.02_{\alpha_s}$ GeV → **fit result**

$m_c(m_c) = 1.275 \pm 0.025$ GeV → **world average**

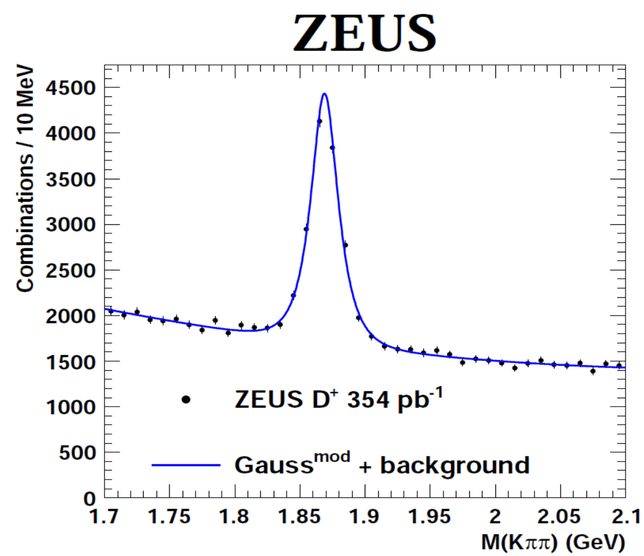
Recent measurements

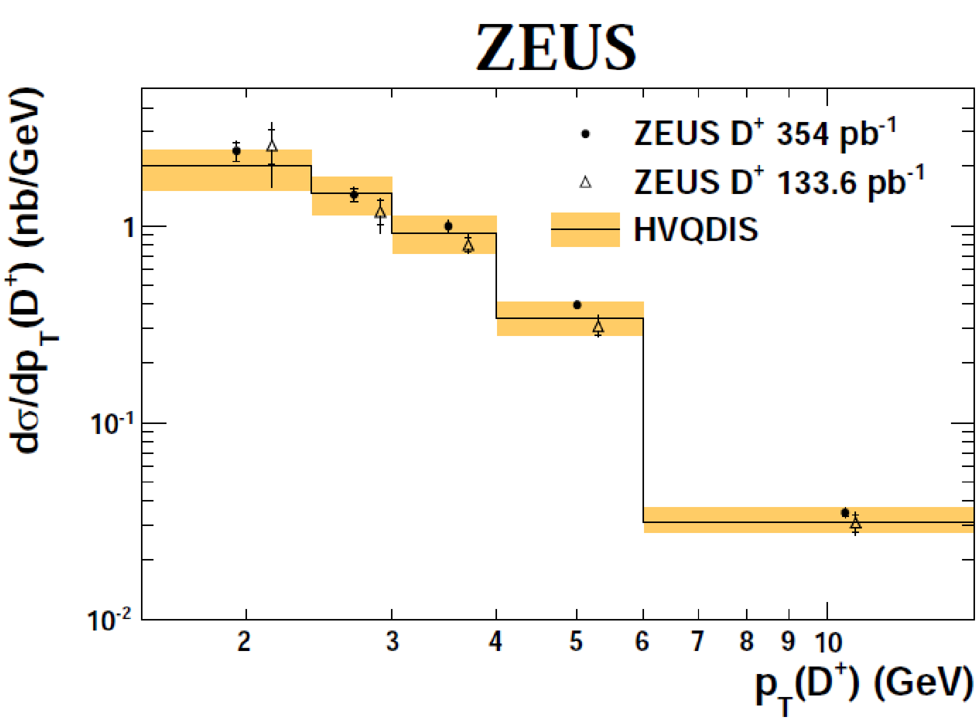
Charm with D+ mesons

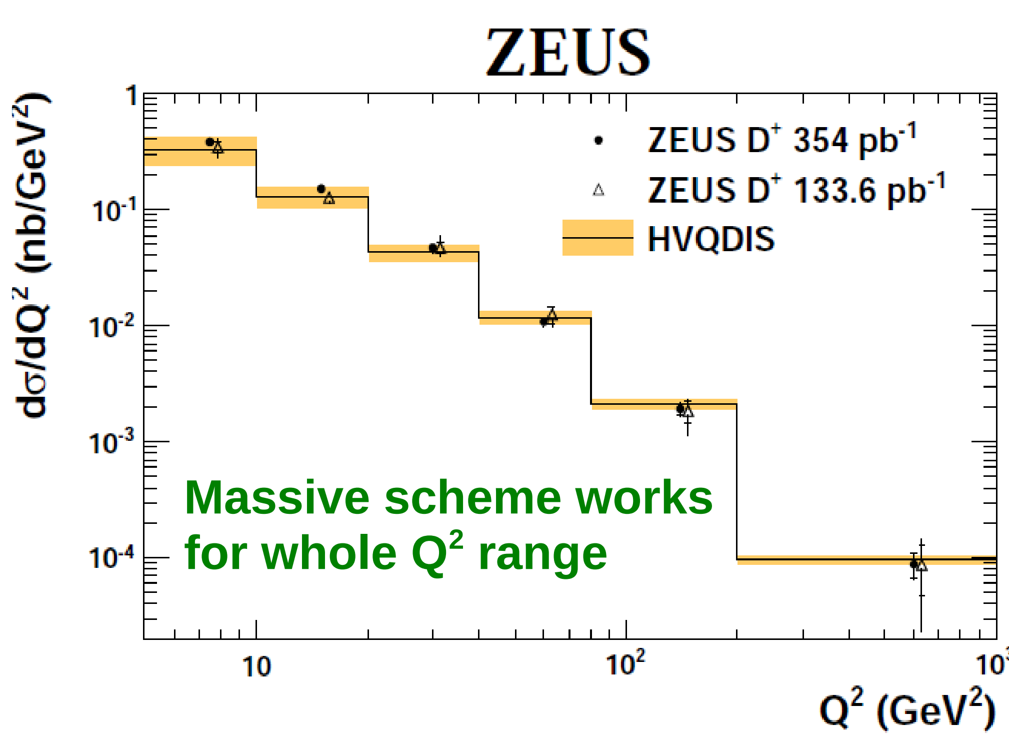
DESY-13-028

Tagging with D+:

- $D^+ \rightarrow K^-\pi^+\pi^+$
- $1.5\ \text{GeV} < p_t(D^+) < 15\ \text{GeV}$
- Secondary vertex used



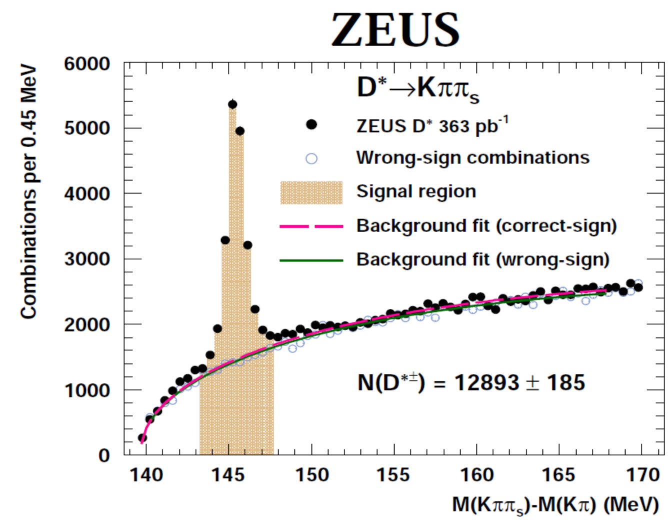


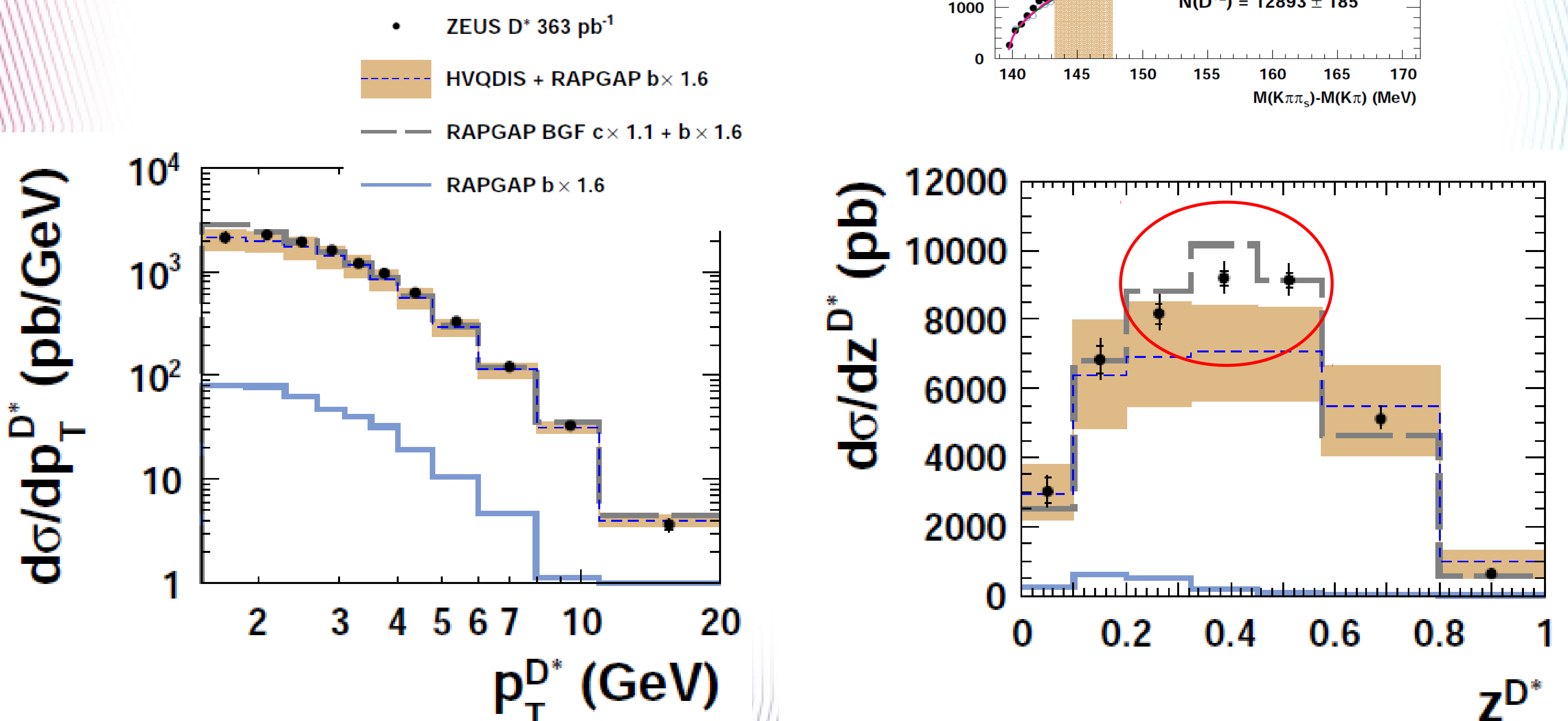


Charm with D* mesons

Tagging with D*:

- $D^{*} \rightarrow D^{0}\pi_{s}^{+} \rightarrow K^{-}\pi^{+}\pi_{s}^{+}$
- $1.5\ \mathrm{GeV} < p_{t}(D^{+}) < 20\ \mathrm{GeV}$

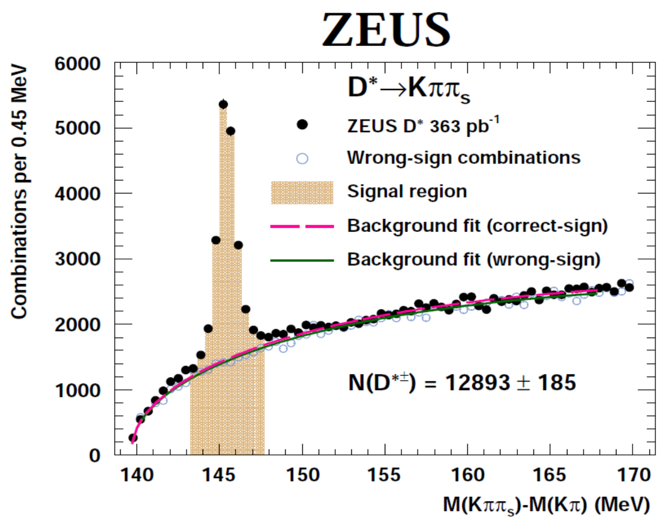


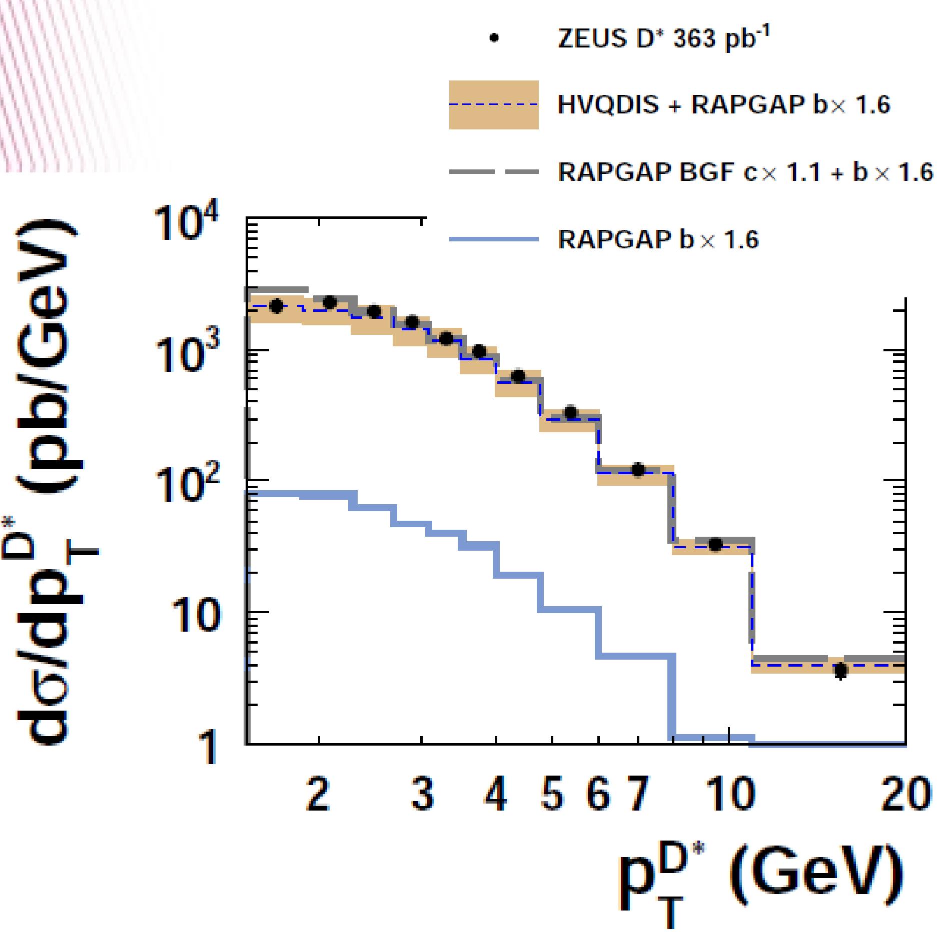


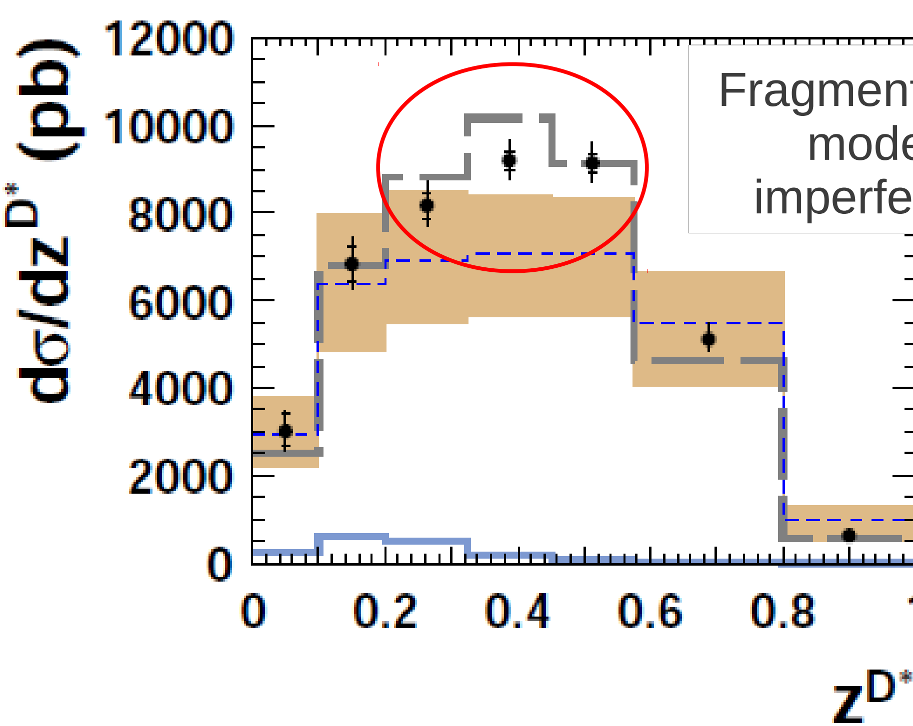
Charm with D* mesons

Tagging with D*:

- $D^* \rightarrow D^0\pi_s^+ \rightarrow K^-\pi^+\pi_s^+$
- $1.5\ \mathrm{GeV} < p_t(D^+) < 20\ \mathrm{GeV}$



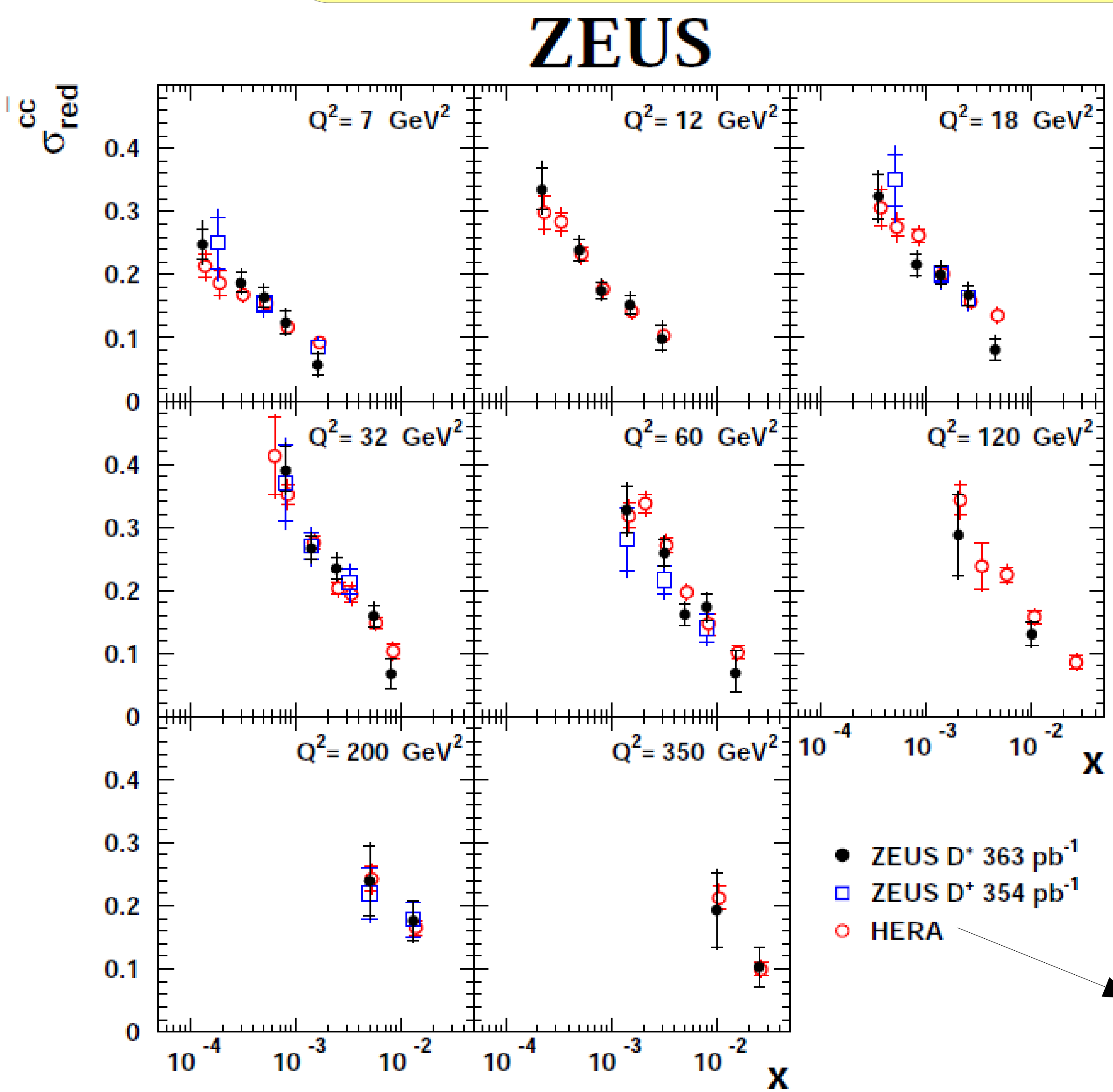




Fragmentation model imperfect ?

Charm with D* mesons

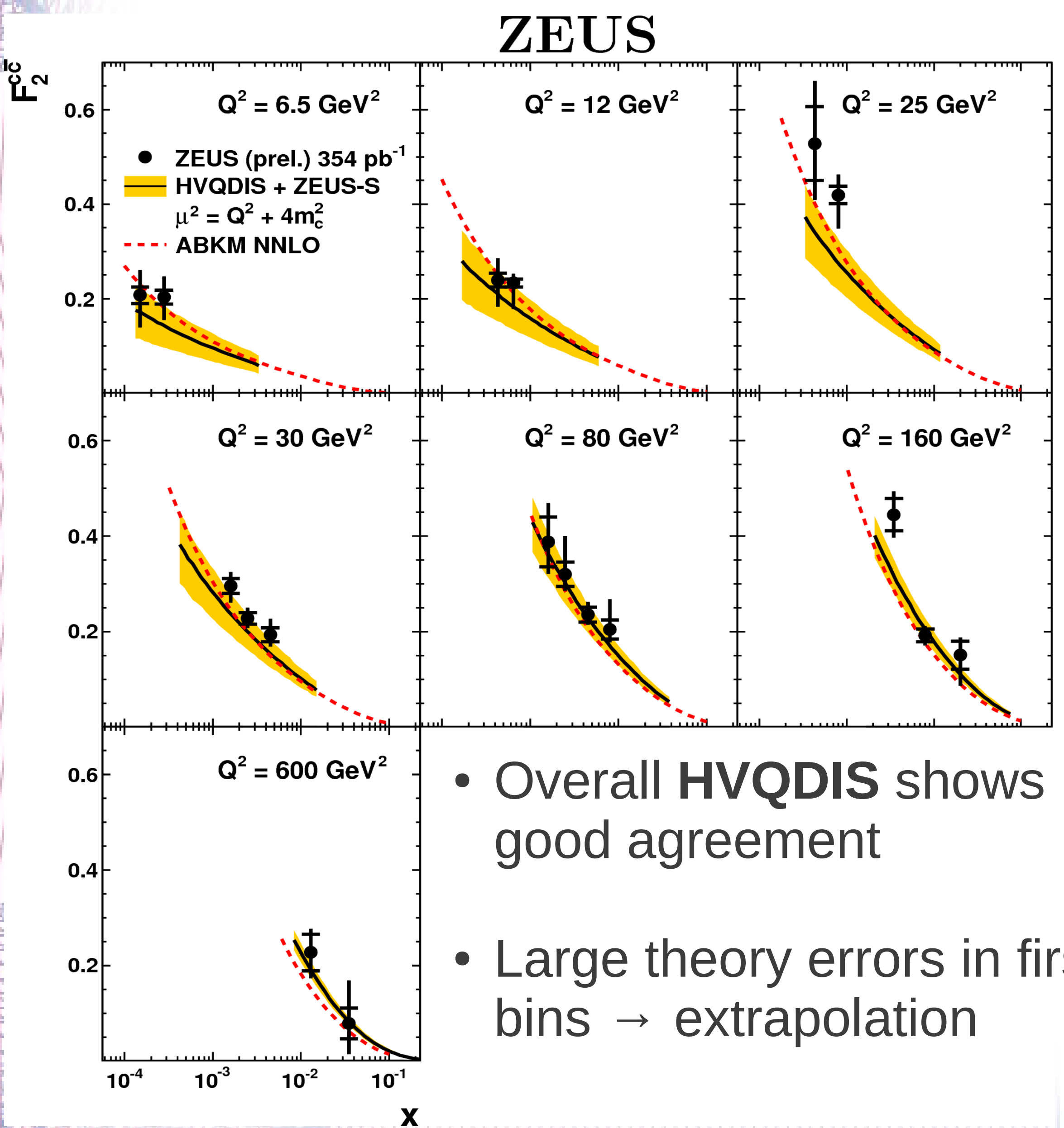
σ^{cc}_{red}



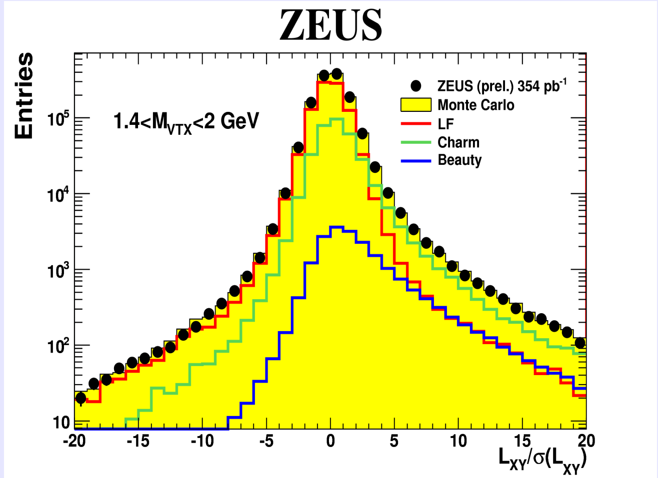
- All results are in a *good agreement*
- **D* measurement** sometimes shows *similar precision to the combination*

Previous HERA data combined

Charm inclusive measurement



- **Lifetime tagging**



- E_t(jet) > 4.2 GeV

- Overall **HVQDIS** shows good agreement
- Large theory errors in first bins → extrapolation

ZEUS-prel-12-002

Conclusions

- **HERA DIS charm data was combined → precise data for testing heavy quark terms in pQCD**

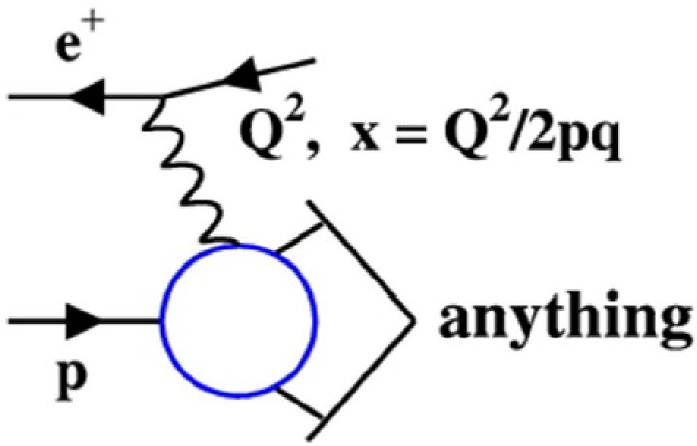
- **Theoretical description is nice:**
  - Different NLO QCD with GM VFNS provide somewhat different results → compensated by optimizing charm mass
  - Addition of charm data improved knowledge of sea flavour decomposition
  - Precise prediction of W and Z production

- **FFNS:**
  - Describes data in the whole kinematic range

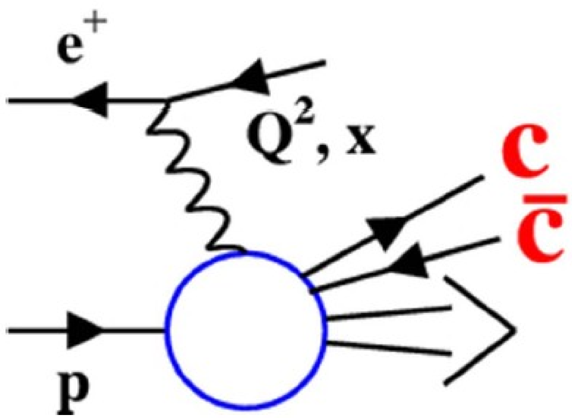
- **New results for D* and D+ measurements, not included to combination:**
  - Precise
  - Possibility of further improvement of HERA charm combination

Backup

F_2^{cc}



$$\frac{d^2\sigma^{ep}}{dQ^2dx} \propto F_2(x, Q^2)$$



$$\frac{d^2\sigma^{ep\to c\bar{c}x}}{dQ^2dx} \propto F_2^{c\bar{c}}(x, Q^2)$$

Different theory calculations

Theory	Scheme	Ref.	$F_{2(L)}$ def.	m_c [GeV]	Massive ($Q^2 \lesssim m_c^2$)	Massless ($Q^2 \gg m_c^2$)	$\alpha_s(m_Z)$ ($n_f = 5$)	Scale	Included charm data
MSTW08 NLO	RT standard	[28]	$F_{2(L)}^c$	1.4 (pole)	$\mathcal{O}(\alpha_s^2)$	$\mathcal{O}(\alpha_s)$	0.12108	Q	[1, 4–6, 8, 9, 11]
MSTW08 NNLO					approx.-$\mathcal{O}(\alpha_s^3)$	$\mathcal{O}(\alpha_s^2)$	0.11707		
MSTW08 NLO (opt.)	RT optimised	[31]			$\mathcal{O}(\alpha_s^2)$	$\mathcal{O}(\alpha_s)$	0.12108		
MSTW08 NNLO (opt.)					approx.-$\mathcal{O}(\alpha_s^3)$	$\mathcal{O}(\alpha_s^2)$	0.11707		
HERAPDF1.5 NLO	RT standard	[55]	$F_{2(L)}^c$	1.4 (pole)	$\mathcal{O}(\alpha_s^2)$	$\mathcal{O}(\alpha_s)$	0.1176	Q	HERA inclusive DIS only
NNPDF2.1 FONLL A	FONLL A	[30]	n.a.	$\sqrt{2}$	$\mathcal{O}(\alpha_s)$	$\mathcal{O}(\alpha_s)$	0.119	Q	[4–6, 12, 13, 15, 18]
NNPDF2.1 FONLL B	FONLL B		$F_{2(L)}^c$	$\sqrt{2}$ (pole)	$\mathcal{O}(\alpha_s^2)$	$\mathcal{O}(\alpha_s)$			
NNPDF2.1 FONLL C	FONLL C		$F_{2(L)}^c$	$\sqrt{2}$ (pole)	$\mathcal{O}(\alpha_s^2)$	$\mathcal{O}(\alpha_s^2)$			
CT10 NLO	S-ACOT-χ	[22]	n.a.	1.3	$\mathcal{O}(\alpha_s)$	$\mathcal{O}(\alpha_s)$	0.118	$\sqrt{Q^2 + m_c^2}$	[4–6, 8, 9]
CT10 NNLO (prel.)		[56]	$F_{2(L)}^{c\bar{c}}$	1.3 (pole)	$\mathcal{O}(\alpha_s^2)$	$\mathcal{O}(\alpha_s^2)$			
ABKM09 NLO	FFNS	[57]	$F_{2(L)}^{c\bar{c}}$	1.18 ($\overline{\text{MS}}$)	$\mathcal{O}(\alpha_s^2)$	-	0.1135	$\sqrt{Q^2 + 4m_c^2}$	for mass optimisation only
ABKM09 NNLO					approx.-$\mathcal{O}(\alpha_s^3)$	-			

Tagging methods