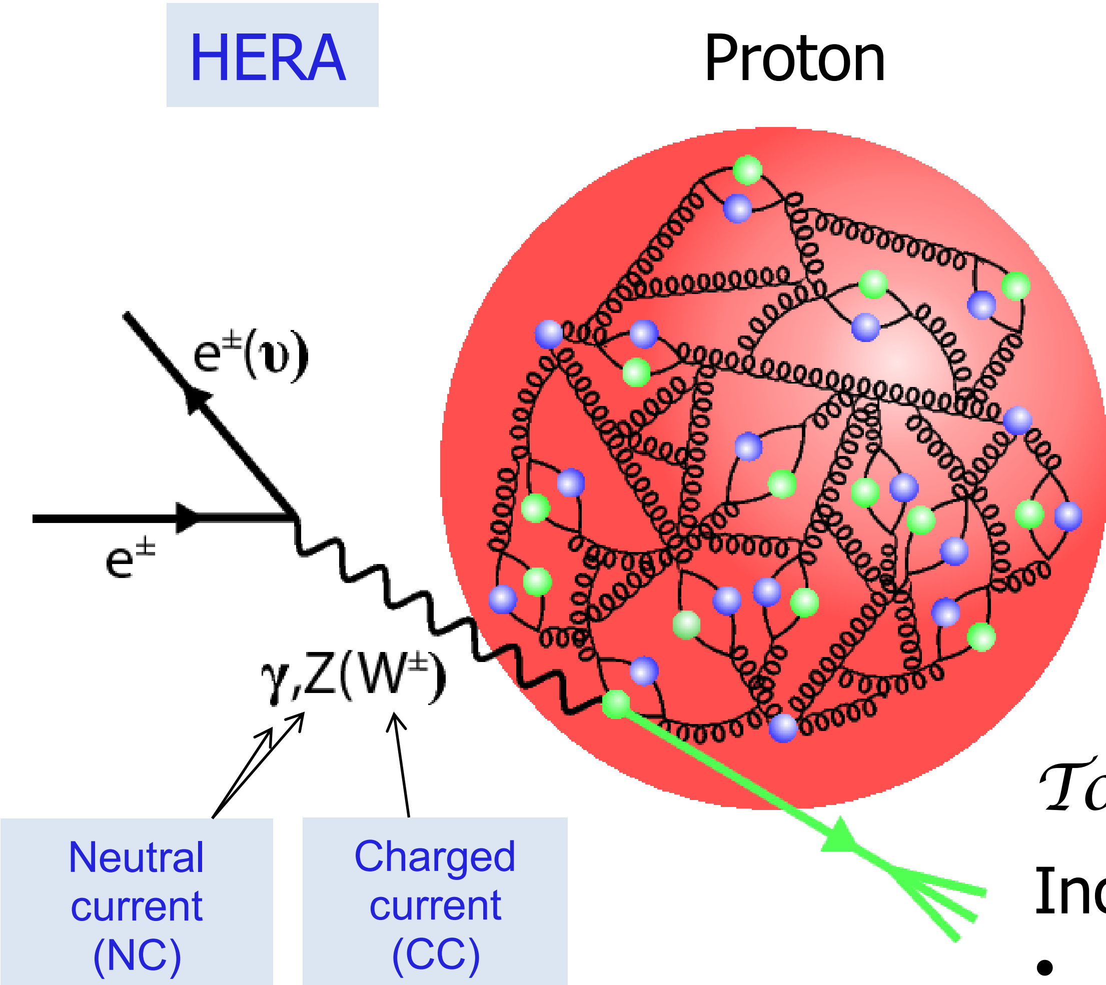
Inclusive measurements at HERA *from low to high x*

ISMD2013, Chicago, USA
17th September 2013

Olaf Behnke (DESY)
on behalf of

Content

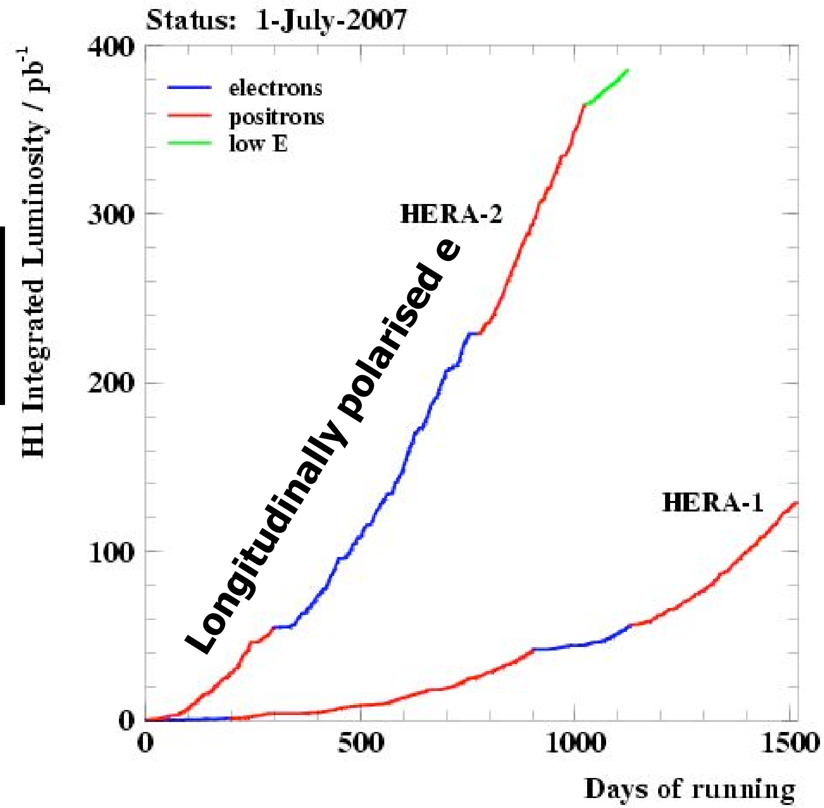


Todays menu:

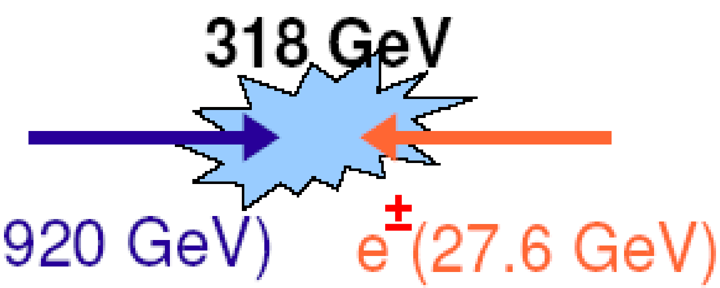
Inclusive measurements:

- Flavour inclusive
- Charm production

The HERA ep collider (1992-2007)



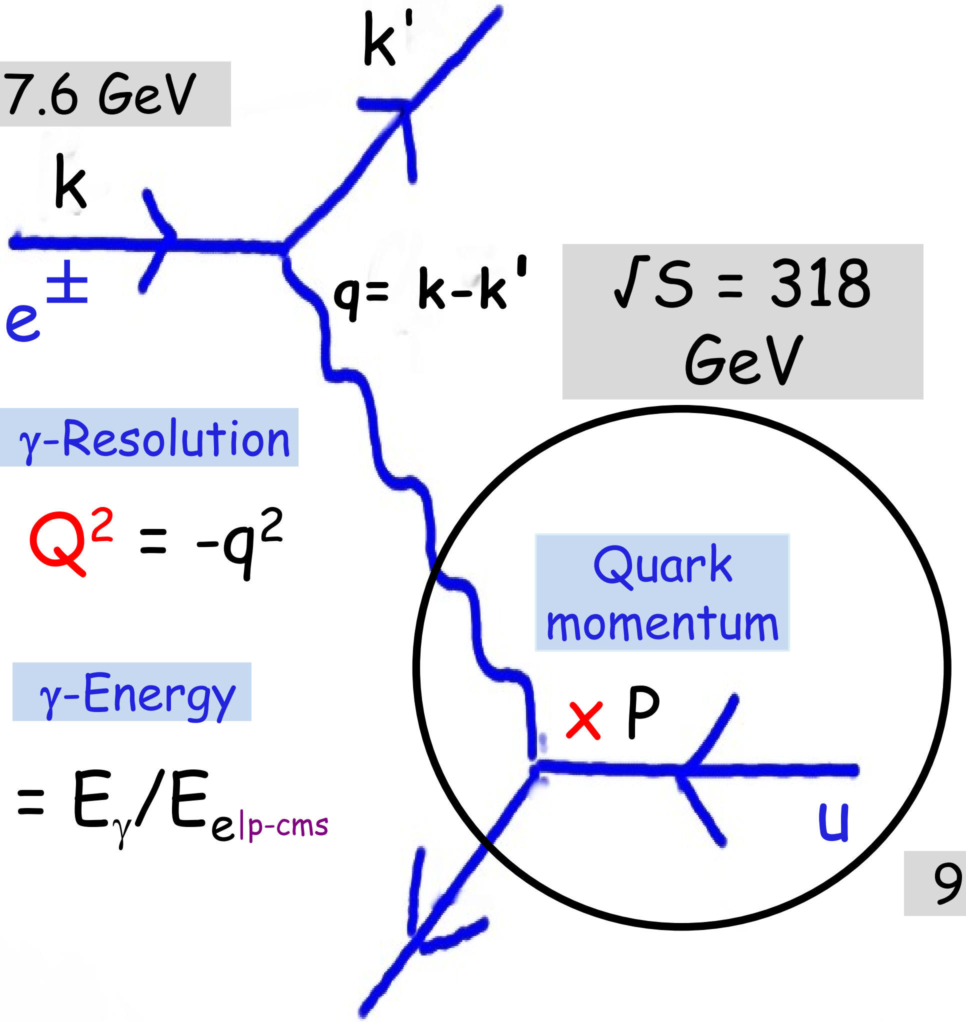
HERA:



~0.5 fb^{-1} per experiment

Deep inelastic scattering at HERA

27.6 GeV



$\sqrt{S} = 318$ GeV

γ-Resolution

$Q^2 = -q^2$

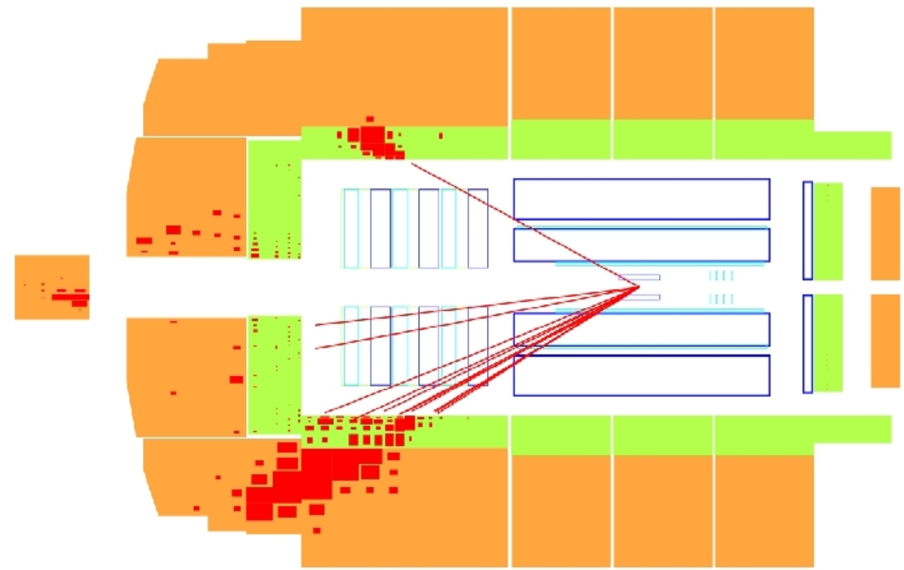
γ-Energy

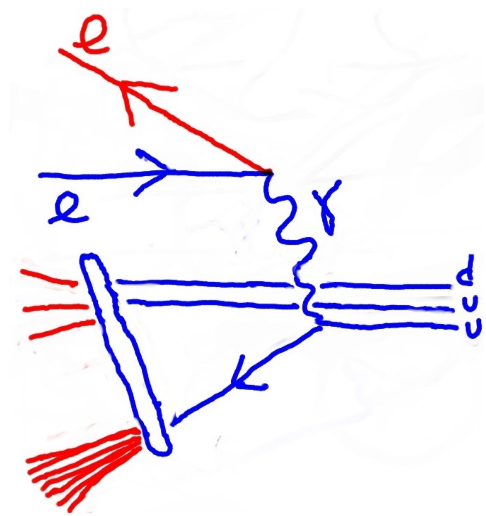
$y = E_\gamma / E_{e|p\text{-cms}}$

920 GeV

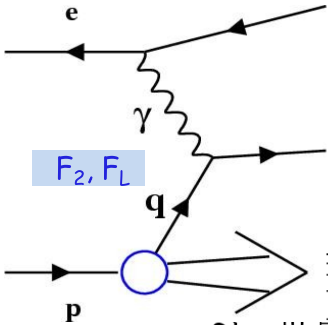
Relation: $Q^2 = Sxy$

NC event in H1 detector:





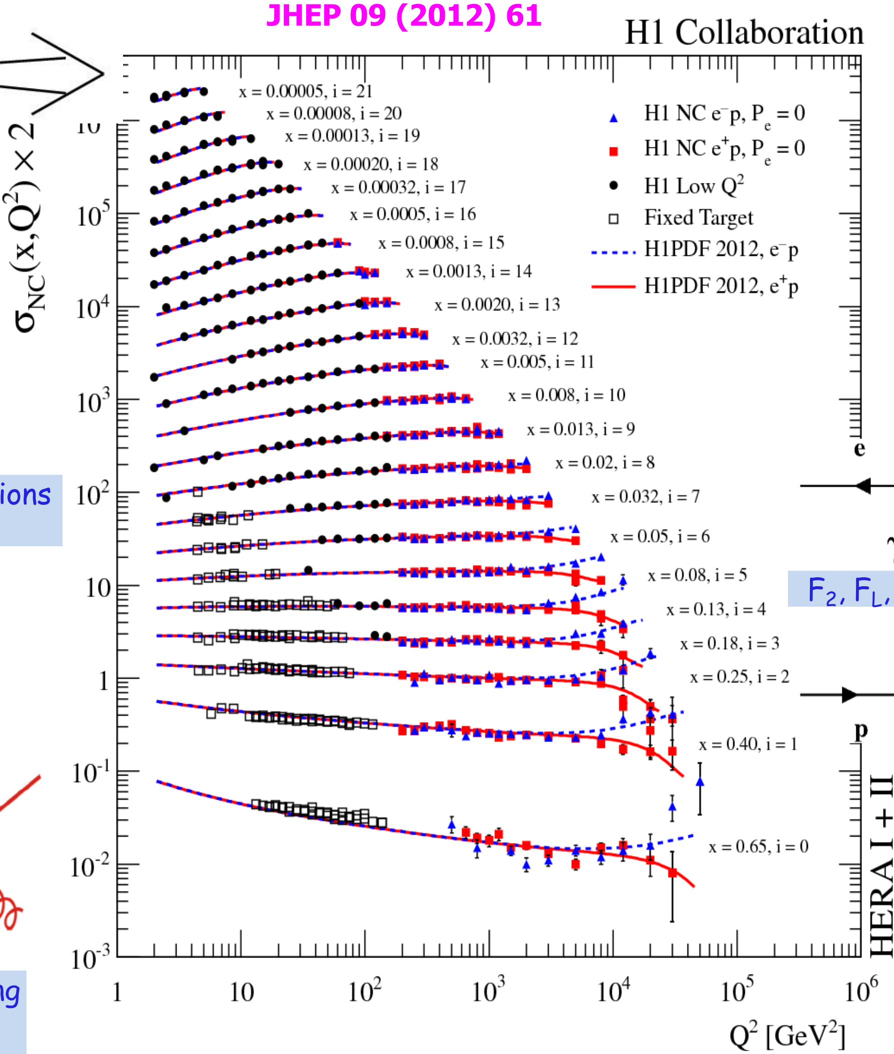
The HERA proton handbook



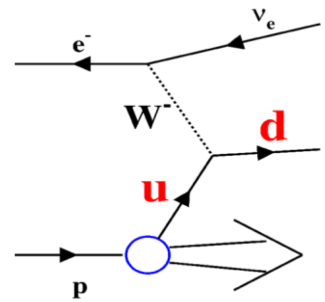
F₂, F_L

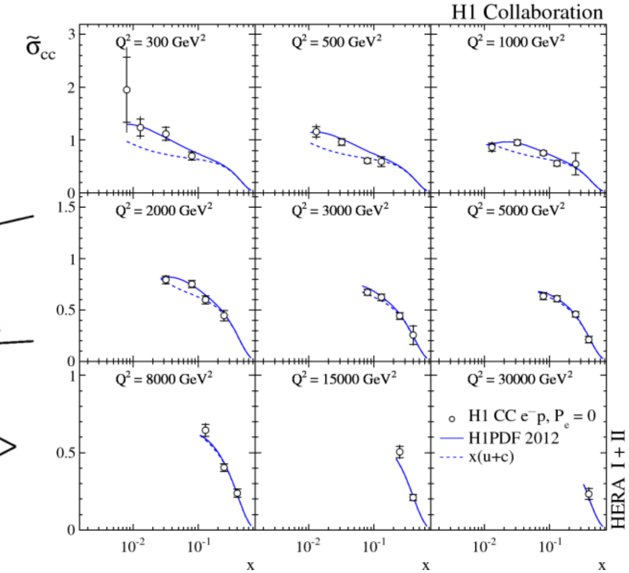
Final H1 results

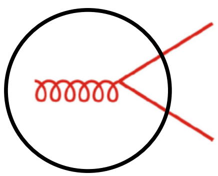
JHEP 09 (2012) 61



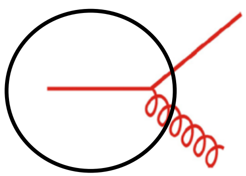
Charged Current



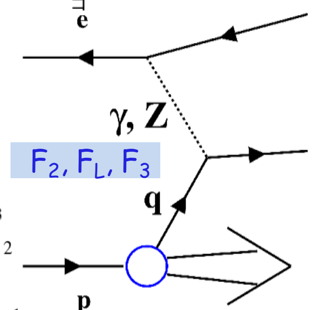




Scaling violations
~ $g(x,Q^2)$



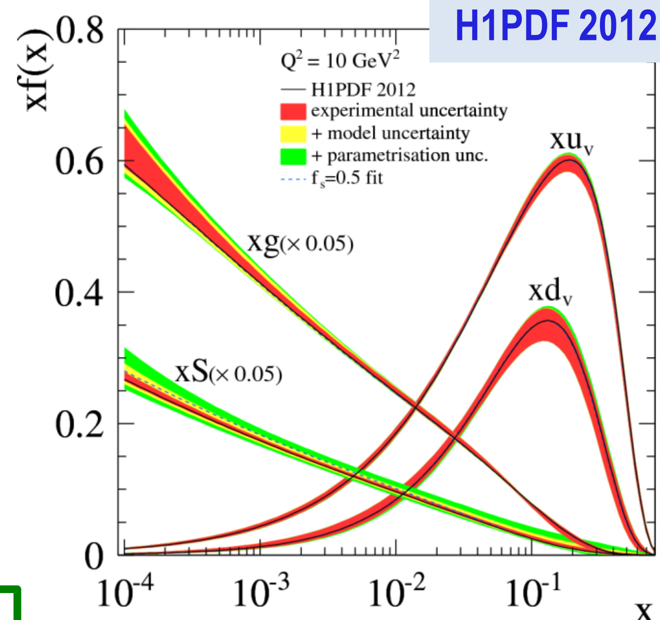
Bremsstrahlung of valence quarks



F_2, F_L, F_3

Using all info in an NLO QCD fit (DGLAP evolution) :

H1PDF 2012



→ Data well described by DGLAP NLO QCD

HERA inclusive data sets

Low Q^2<~150 GeV^2,high Q^2>~150 GeV^2

HERA I		e^+p	e^-p
H1	Low Q^2	NC 22 pb^{-1}	
	High Q^2	NC 100 pb^{-1}	NC 16 pb^{-1}
		CC 100 pb^{-1}	CC 16 pb^{-1}
ZEUS	Low Q^2	NC 30 pb^{-1}	
	High Q^2	NC 108 pb^{-1}	NC 16 pb^{-1}
		CC 108 pb^{-1}	CC 16 pb^{-1}

HERA II		e^+p	e^-p
H1	High Q^2	NC 182 pb^{-1}	NC 150 pb^{-1}
		CC 182 pb^{-1}	CC 150 pb^{-1}
ZEUS	High Q^2	NC 136 pb^{-1}	NC 170 pb^{-1}
		CC 132 pb^{-1}	CC 175 pb^{-1}

+ further data sets from low E_p runs etc.

HERA inclusive data sets

Low $Q^2 <\sim 150$ GeV^2, high $Q^2 >\sim 150$ GeV^2

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HERA II

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H1	High Q^2	NC 182 pb^{-1}	NC 150 pb^{-1}
		CC 182 pb^{-1}	CC 150 pb^{-1}
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		CC 132 pb^{-1}	CC 175 pb^{-1}

H1 HERA I and H1 HERA II data sets → H1PDF 2012

JHEP 09 (2012) 61

+ further data sets from low E_p runs etc.

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} HERAPDF1.0
JHEP 1 (2010) 1

HERA II		e^+p	e^-p
H1	High Q^2	NC 182 pb^{-1} CC 182 pb^{-1}	NC 150 pb^{-1} CC 150 pb^{-1}
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+ further data sets from low E_p runs etc.

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HERA II

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		CC 132 pb^{-1}	CC 175 pb^{-1}

Preliminary data

Not yet available

+ further data sets from low E_p runs etc.

HERAs Best!

HERAPDF1.5

H1prelim-10-141(2)
ZEUS-prel-10-017(8)

Now published

JHEP 09 (2012) 61

Now published

DESY-12-145

Presented @last ISMD

HERA inclusive data sets

Low Q^2<~150 GeV^2, high Q^2>~150 GeV^2

			e^+p	e^-p
HERA I	H1	Low Q^2	NC 22 pb^{-1}	
		High Q^2	NC 100 pb^{-1} CC 100 pb^{-1}	NC 16 pb^{-1} CC 16 pb^{-1}
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		High Q^2	NC 108 pb^{-1} CC 108 pb^{-1}	NC 16 pb^{-1} CC 16 pb^{-1}
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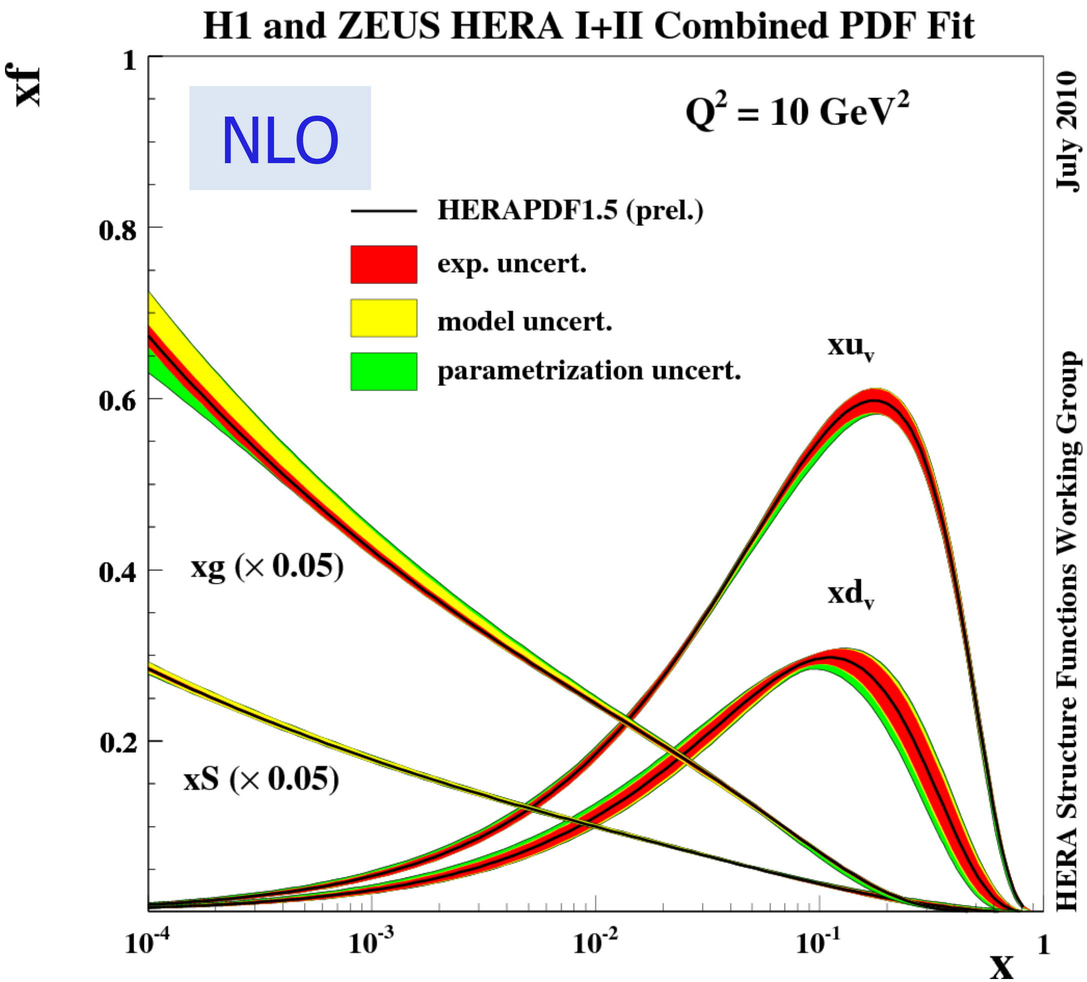
+ further data sets from low E_p runs etc.

➔ Future goal: combination of all the published measurements and PDF fit

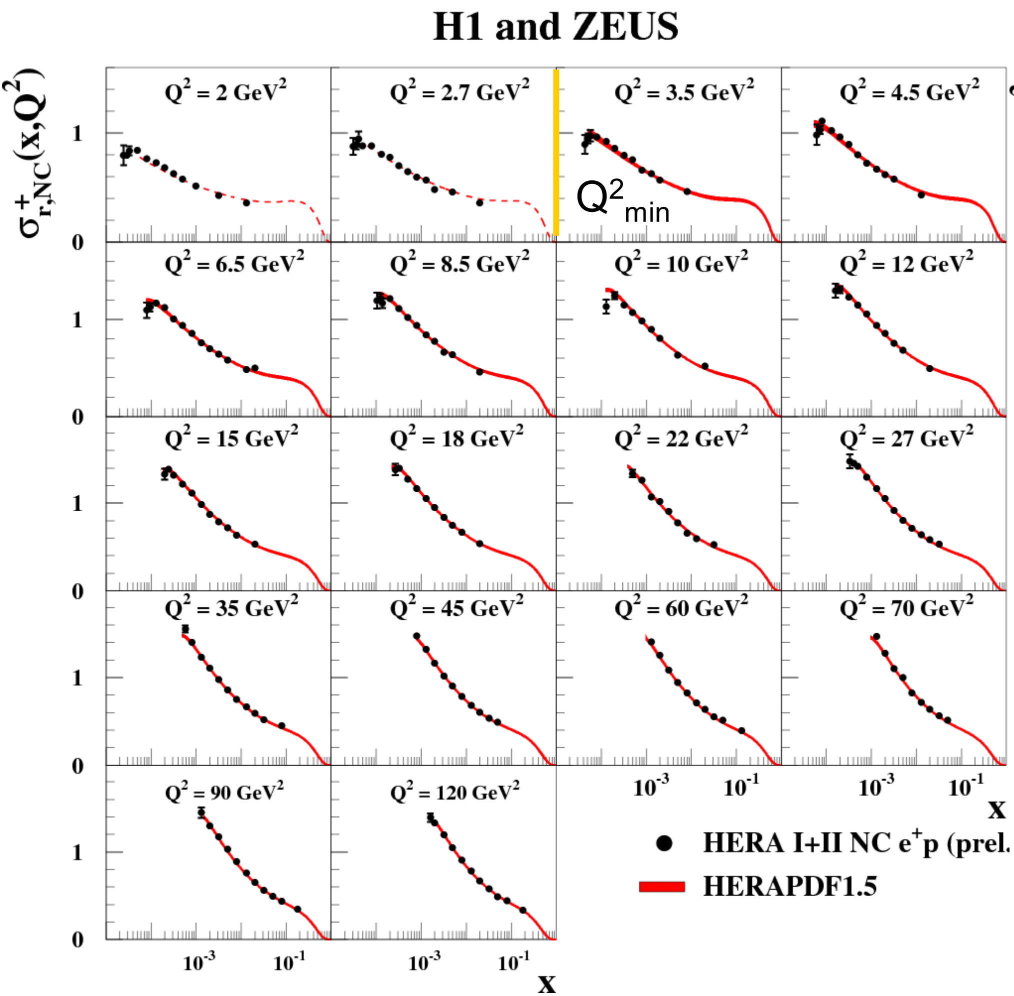
The HERAPDF1.5 family

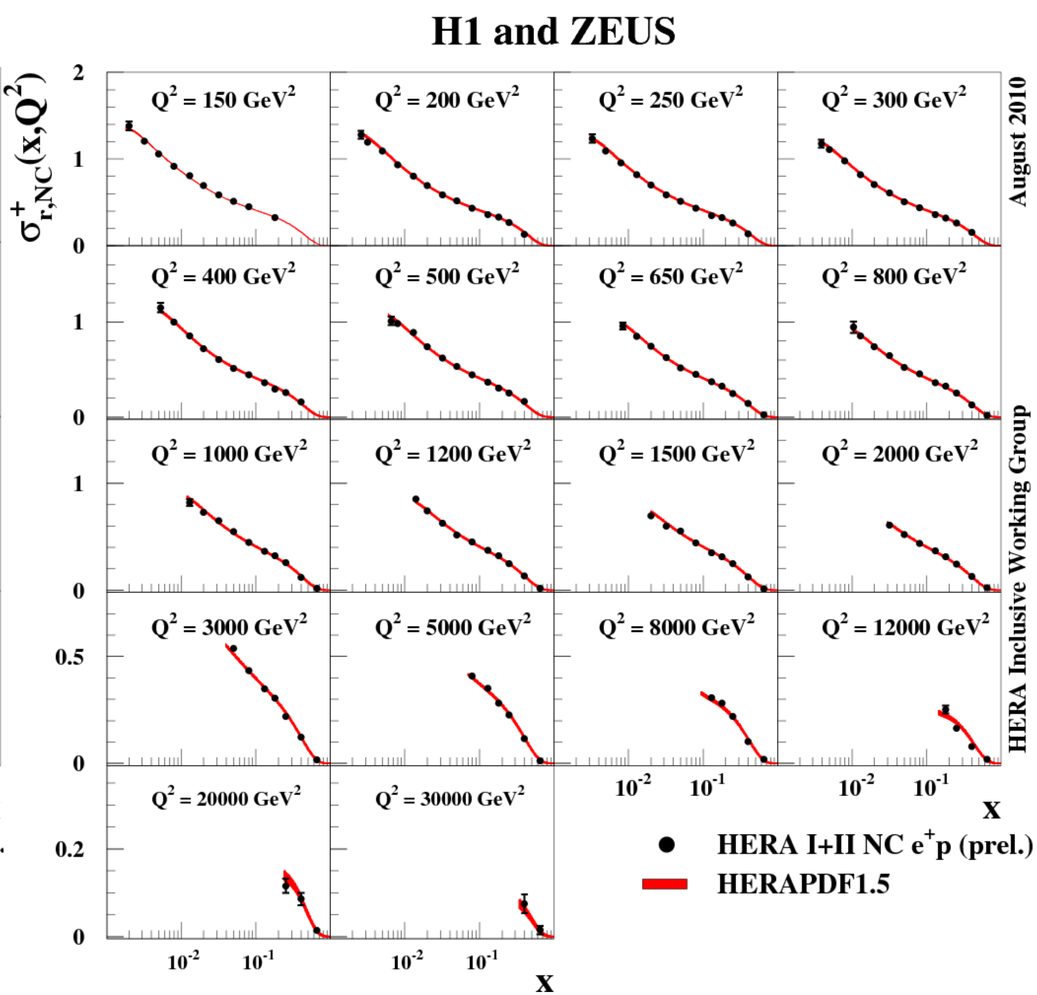


Available at
NLO
NNLO
and now (sep. 2013)
also at
LO

Obtained with the HERAFitter open source QCD fit framework,
see poster by P. Starovoitov

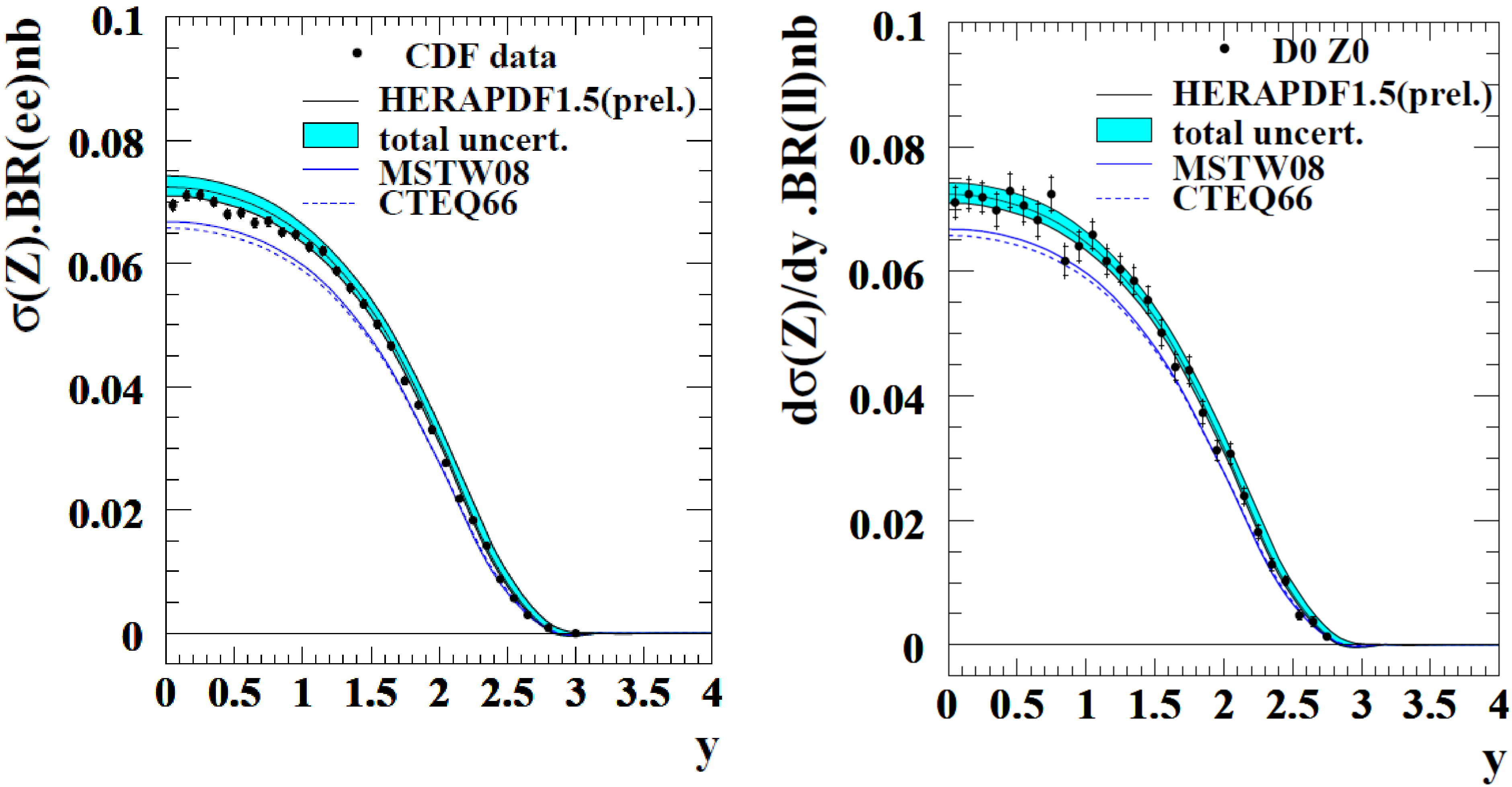
HERAPDF1.5 compared to HERA e^+p NC data





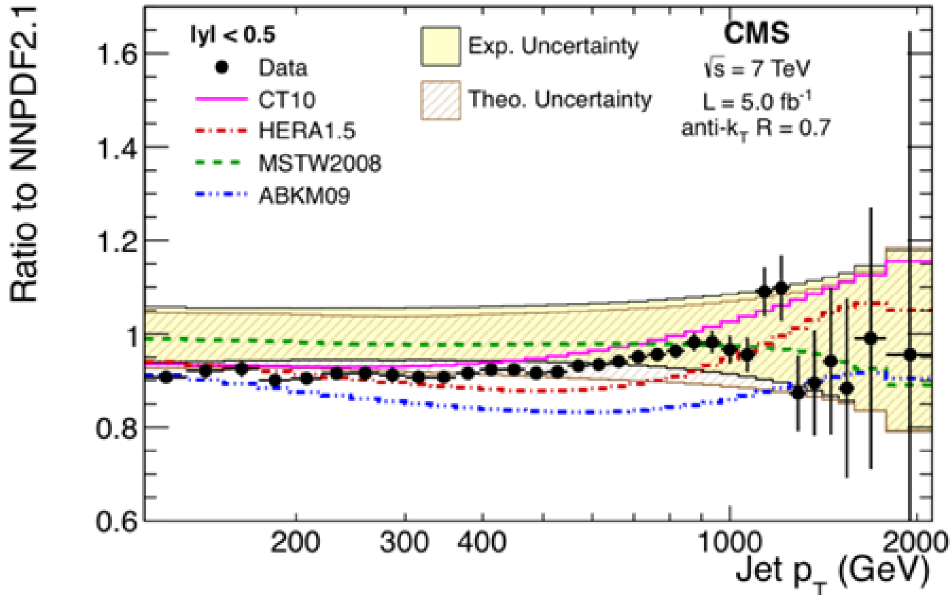
→ Data well described over huge Q^2 and x range by DGLAP NLO QCD

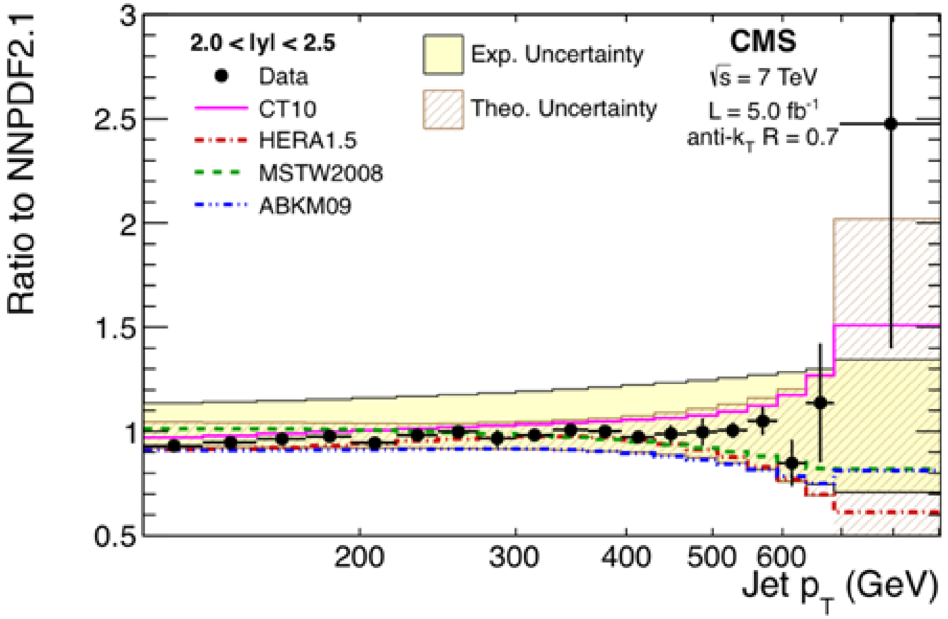
HERAPDF1.5 predictions for Tevatron



→ Data well described by HERAPDF1.5

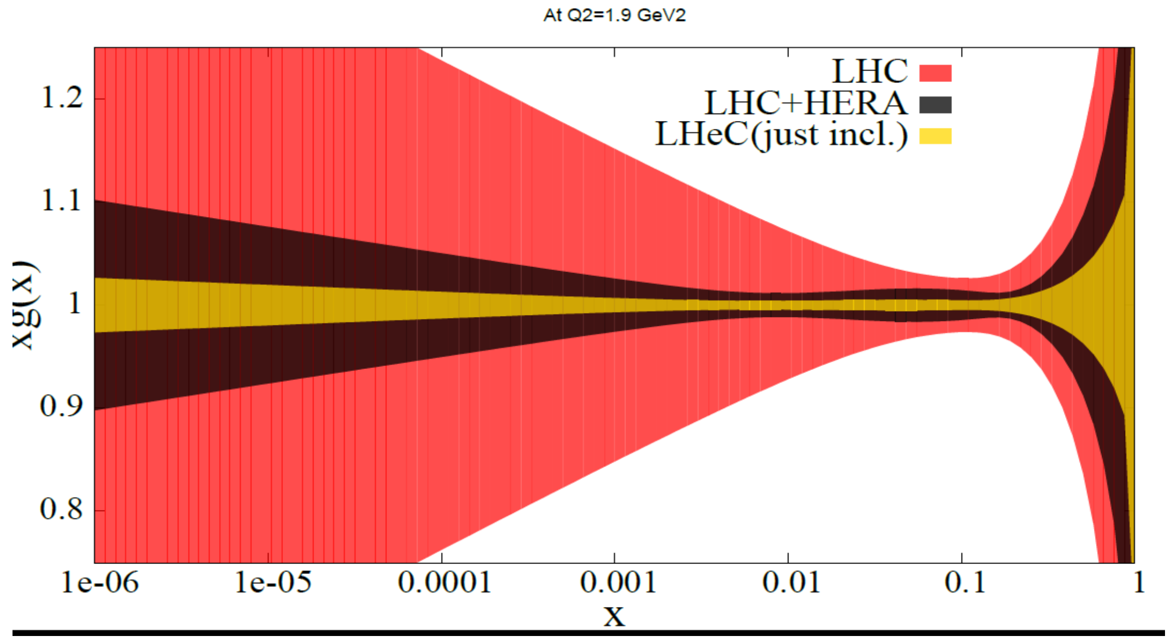
HERAPDF1.5 predictions for (exemplary) LHC jet data

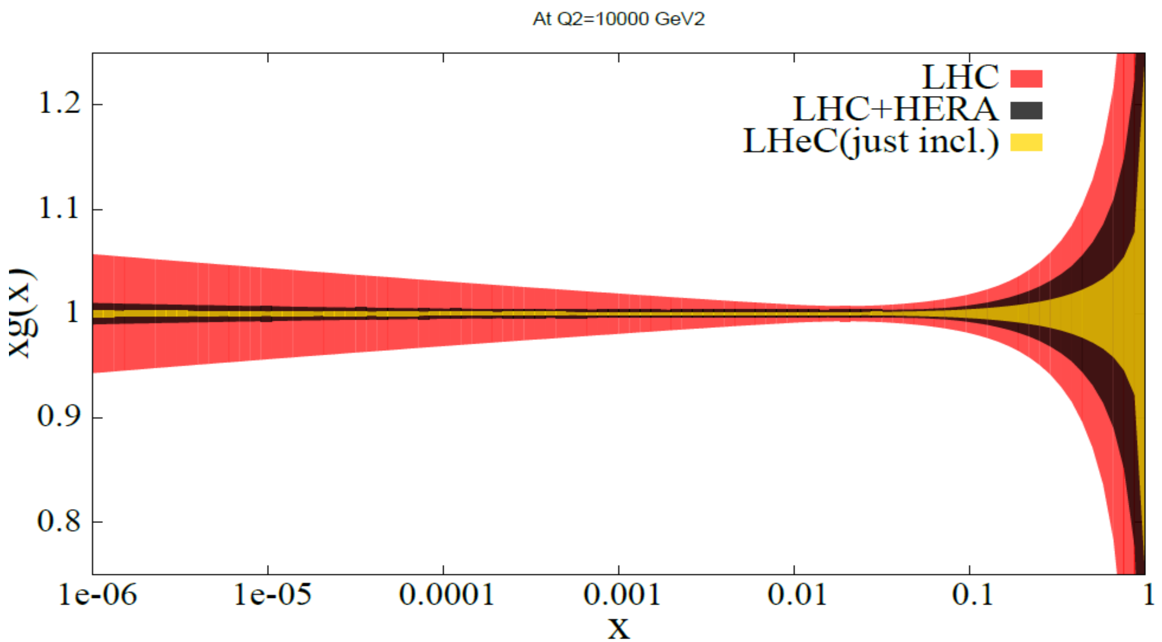




➔ Well described by HERAPDF1.5
➔ These data yet to be used in PDF fit, carry information on high-x gluon

Can we get PDFs just from the LHC?



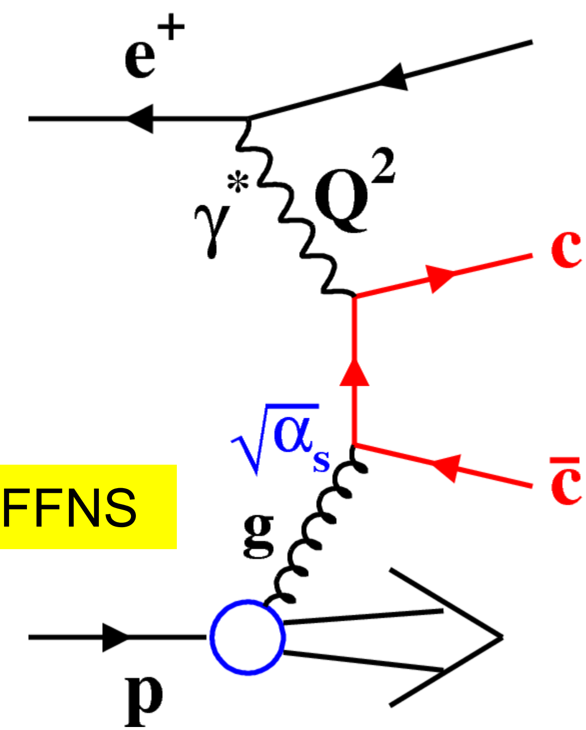


Using simulated LHC W, Z and jet data with ultimate precision estimated from current experience

→ Not with any precision

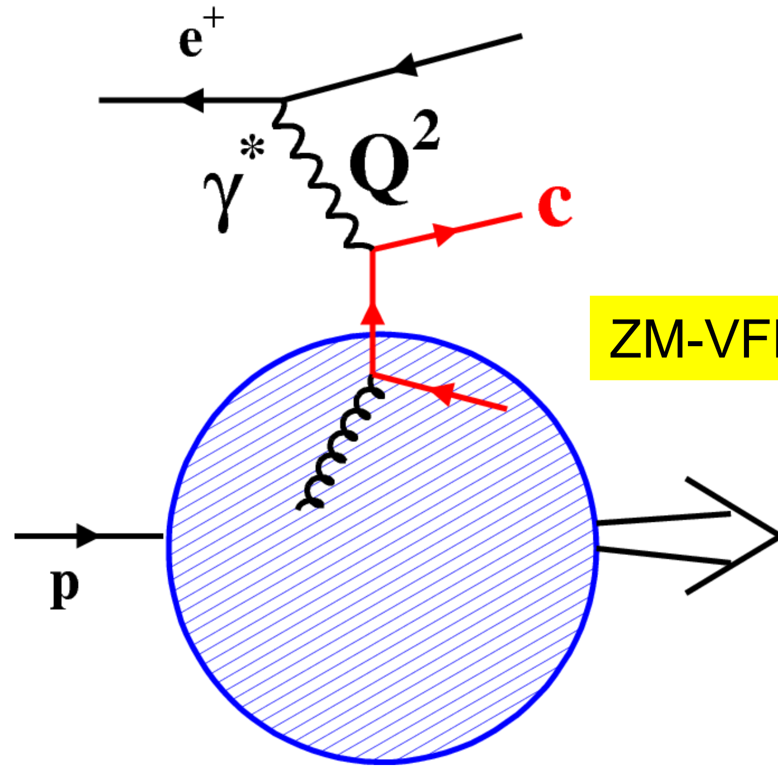
HERA Charm production and schemes

Massive scheme: $Q^2 \sim m_c^2$



FFNS

Massless scheme: $Q^2 >> m_c^2$

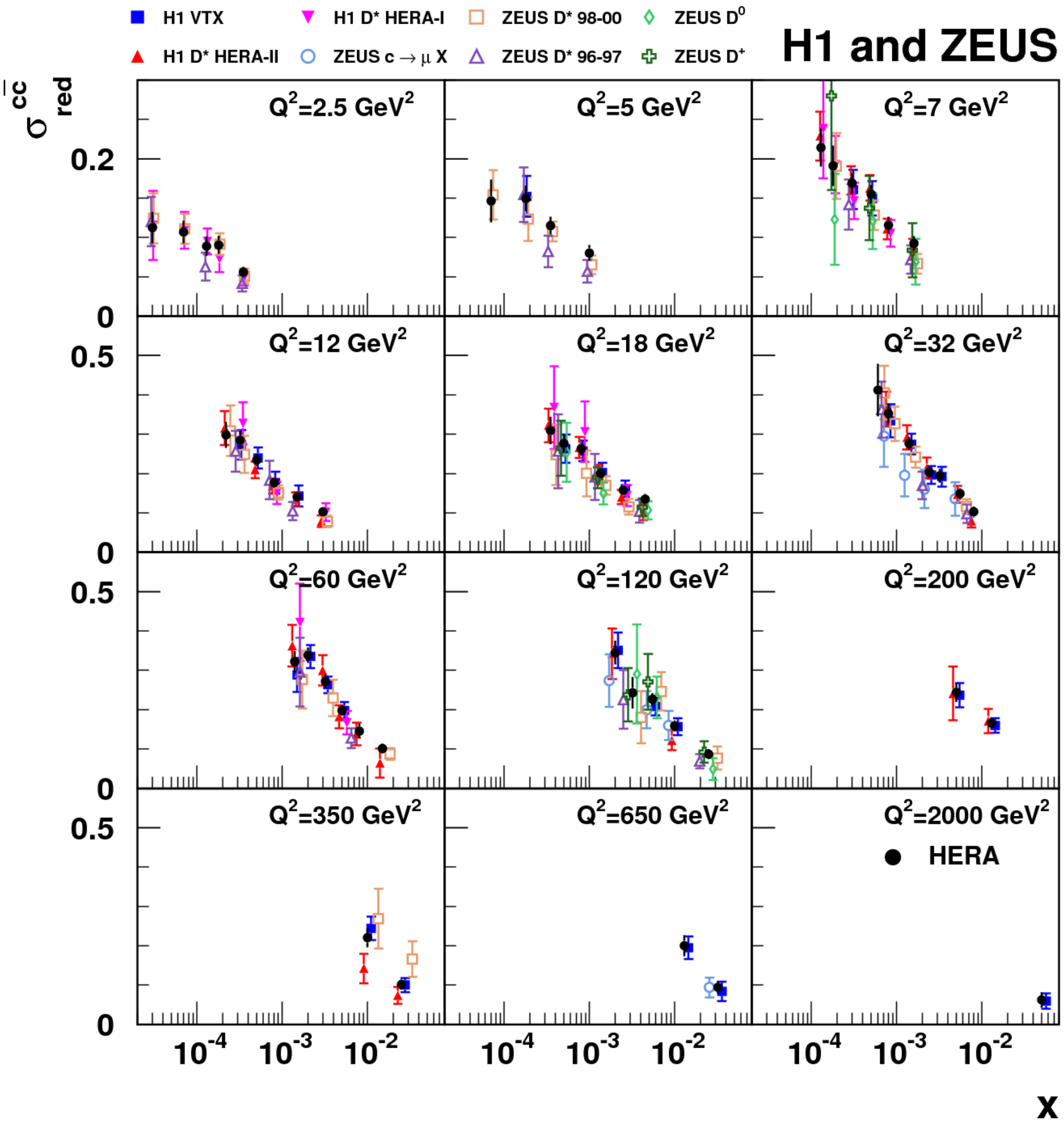


ZM-VFNS

Mixed schemes: interpolate, but how to do transition? → numerous variants GM-VFNS

HERA Charm data combination

- Combine D*, D^+, D^0, μ and lifetime tag data
- take correlated systematics fully into account



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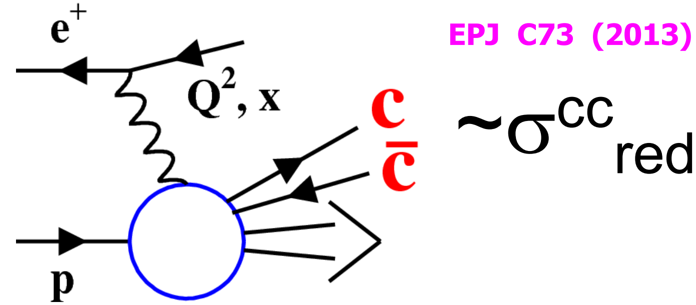

HERA Charm data combination

- Combine D*, D⁺, D⁰, μ and lifetime tag data
- take correlated systematics fully into account

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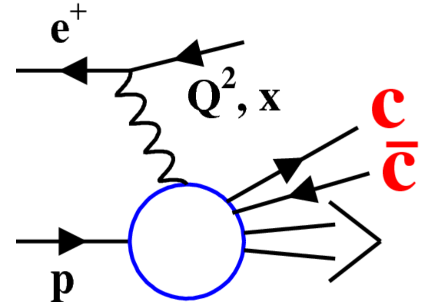
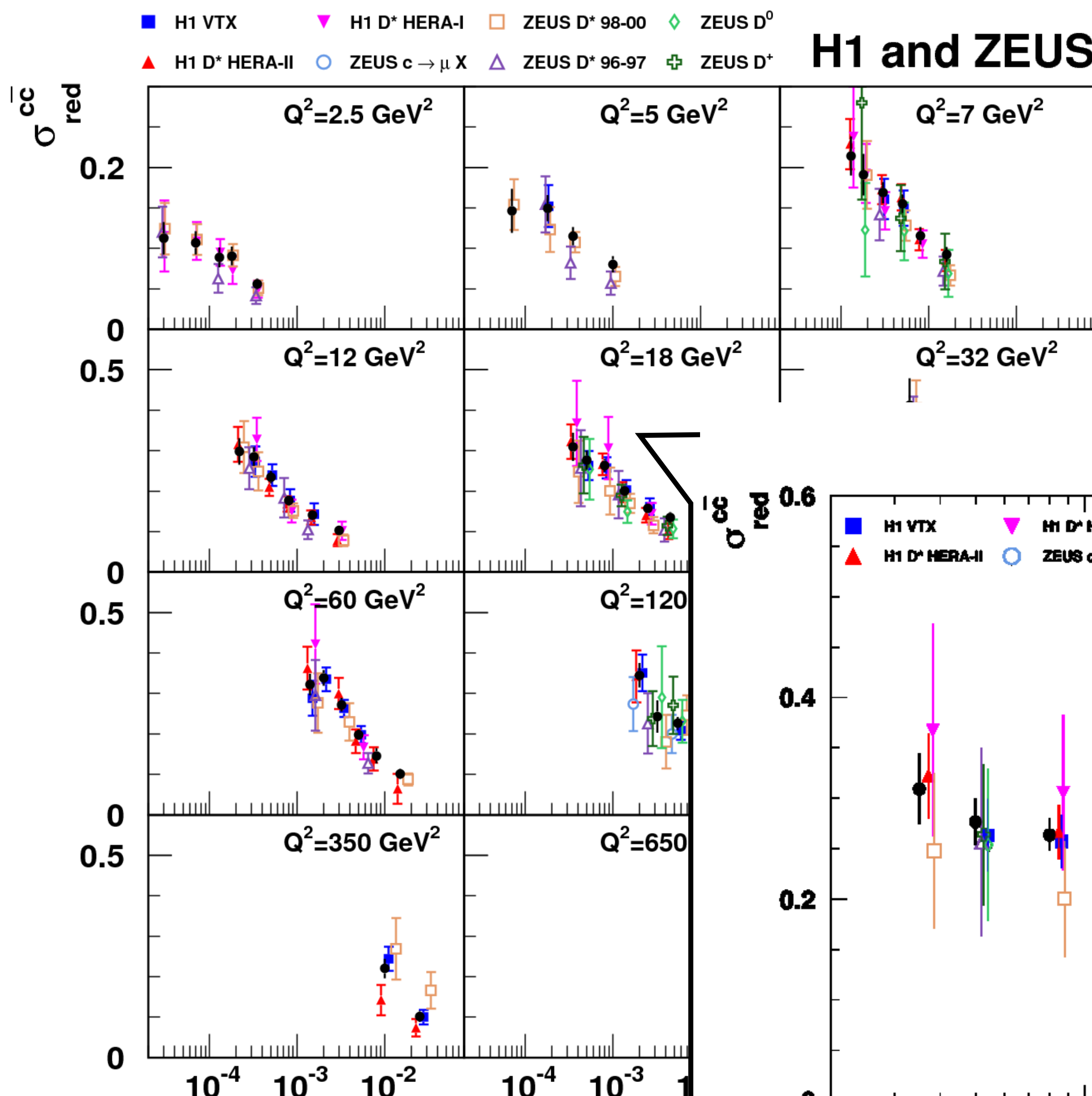
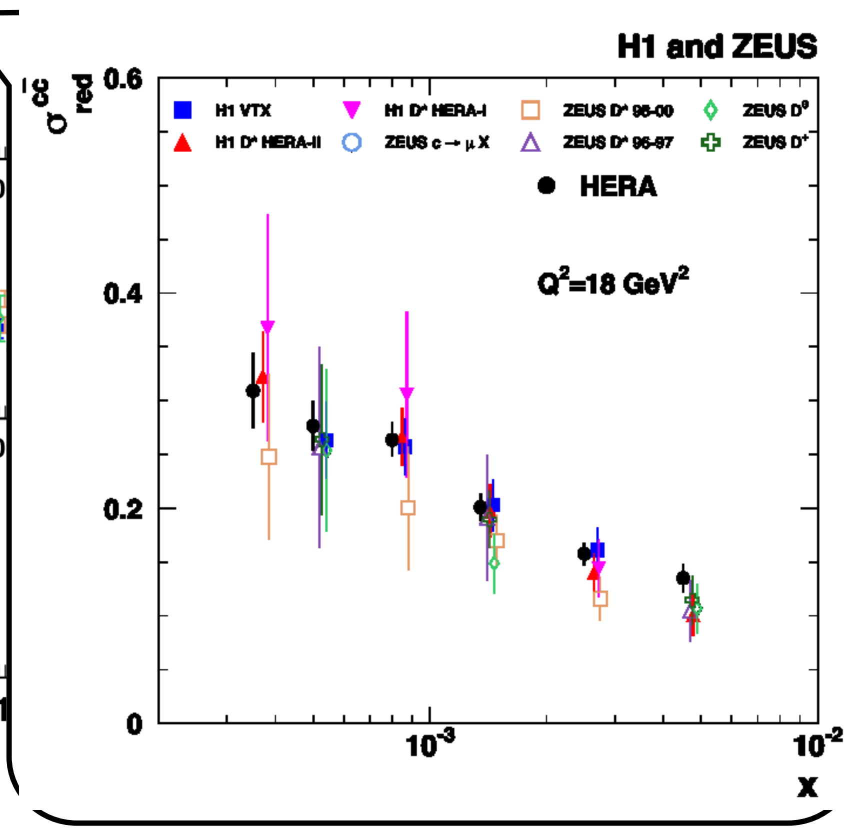


$\sim\sigma^{c\bar{c}}_{red}$





→ Best precision: ~5%

Combined charm data vs NLO GMVFNS

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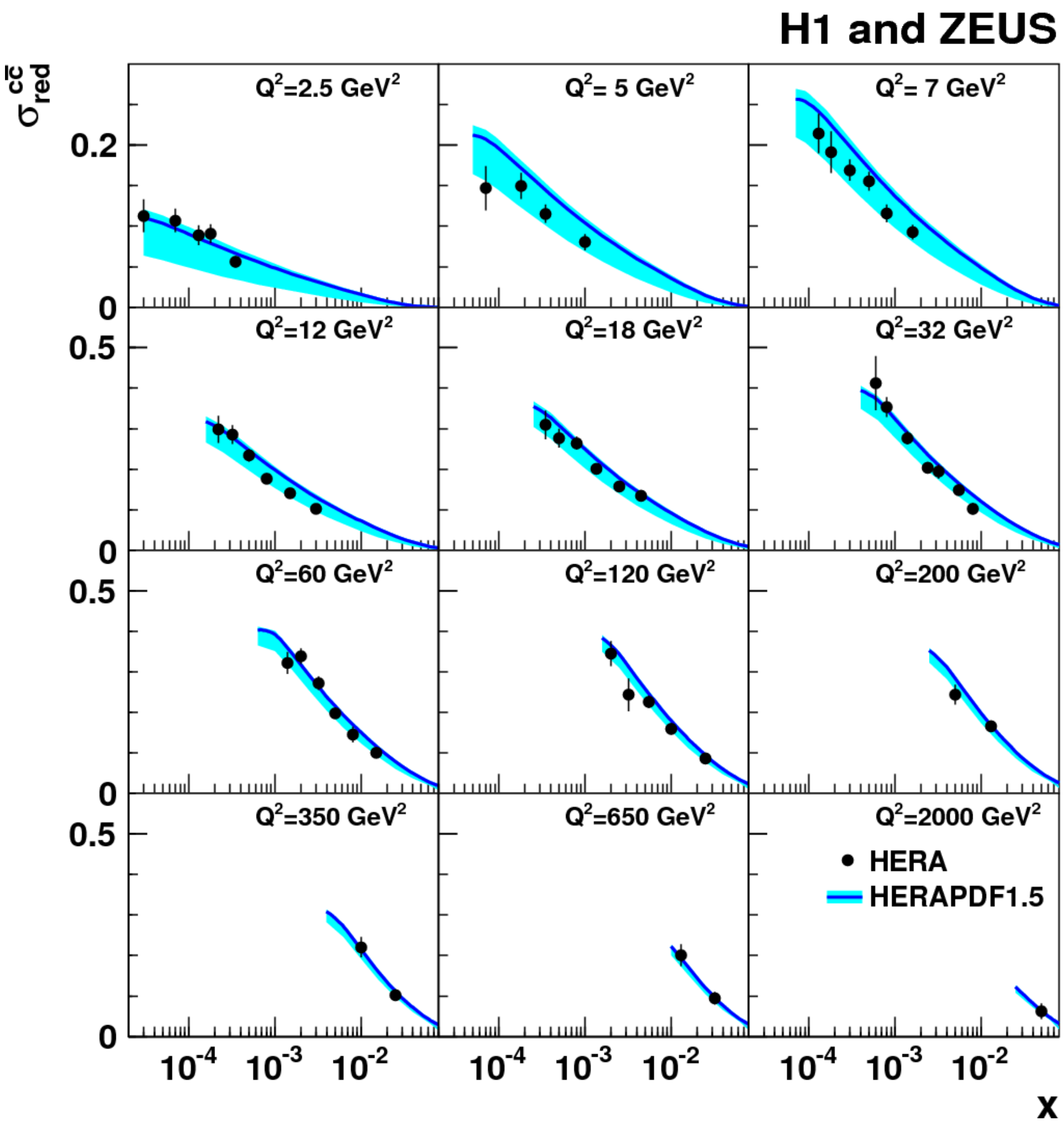

HERAPDF1.5:
- only inclusive DIS data
- RT standard scheme

→ NLO GM-VFNS ok ☺

→large theory uncertainty dominated by m_c variation ☹

PDF plus charm mass parameter fit

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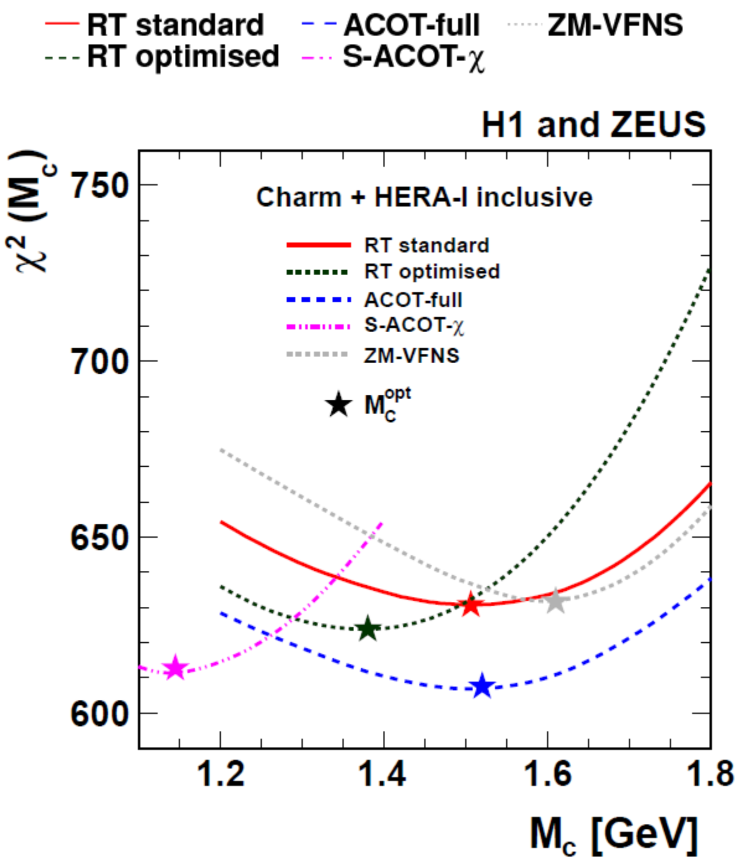
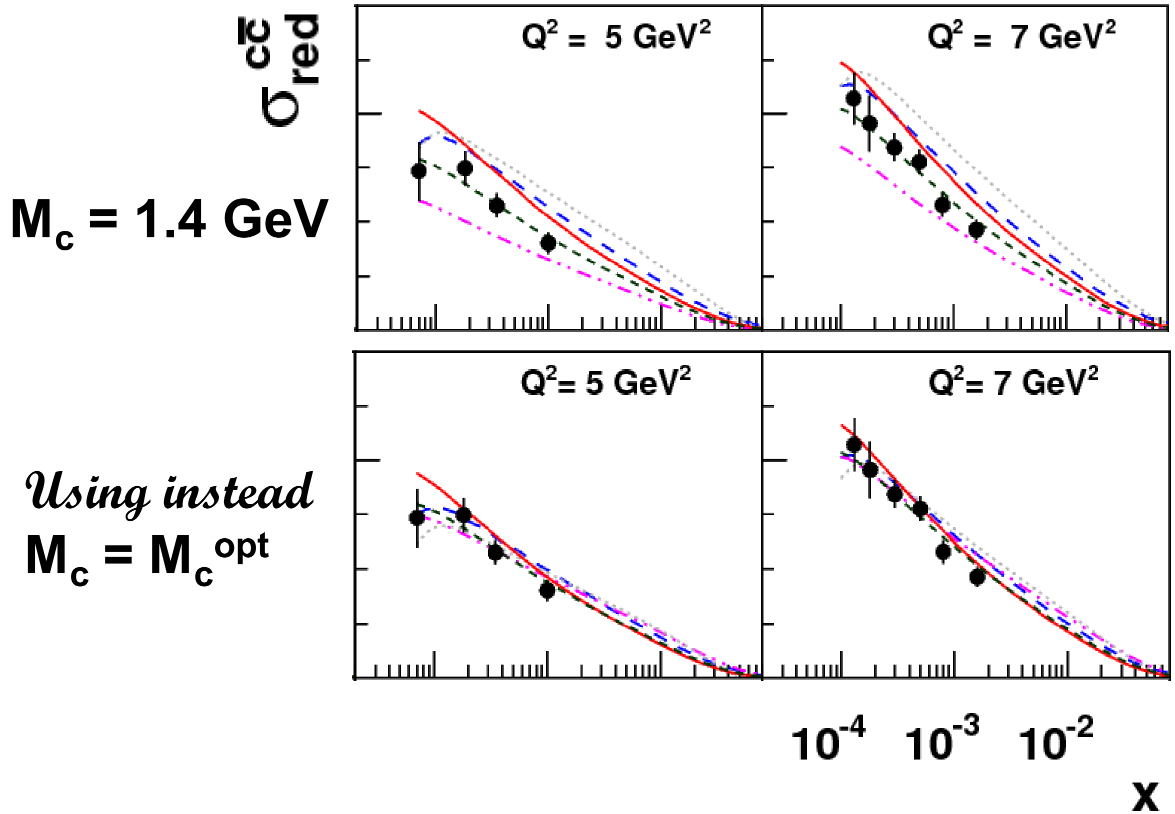
- Fit **combined charm** and inclusive DIS data
- GMVFN-schemes with **charm pole mass M_c**





→ Various GM-VFNS: interpolate differently between massive and massless schemes
→ different quality of charm data description for fixed M_c → compensate by M_c^{opt} values
→ stabilises flavour mixture in PDF → stabilises LHC predictions (W,Z) (see backup)

Impact of charm data on PDF

Example: RT optimal scheme

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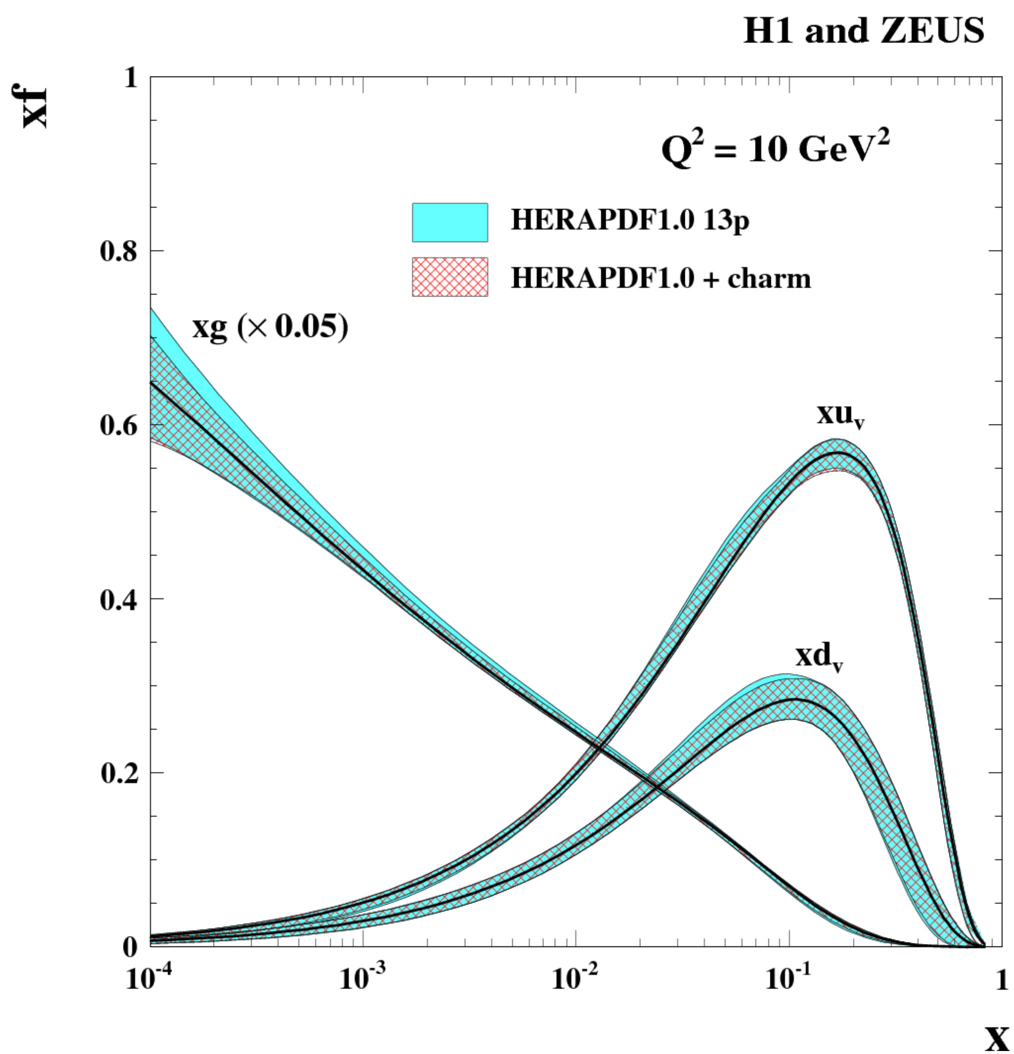
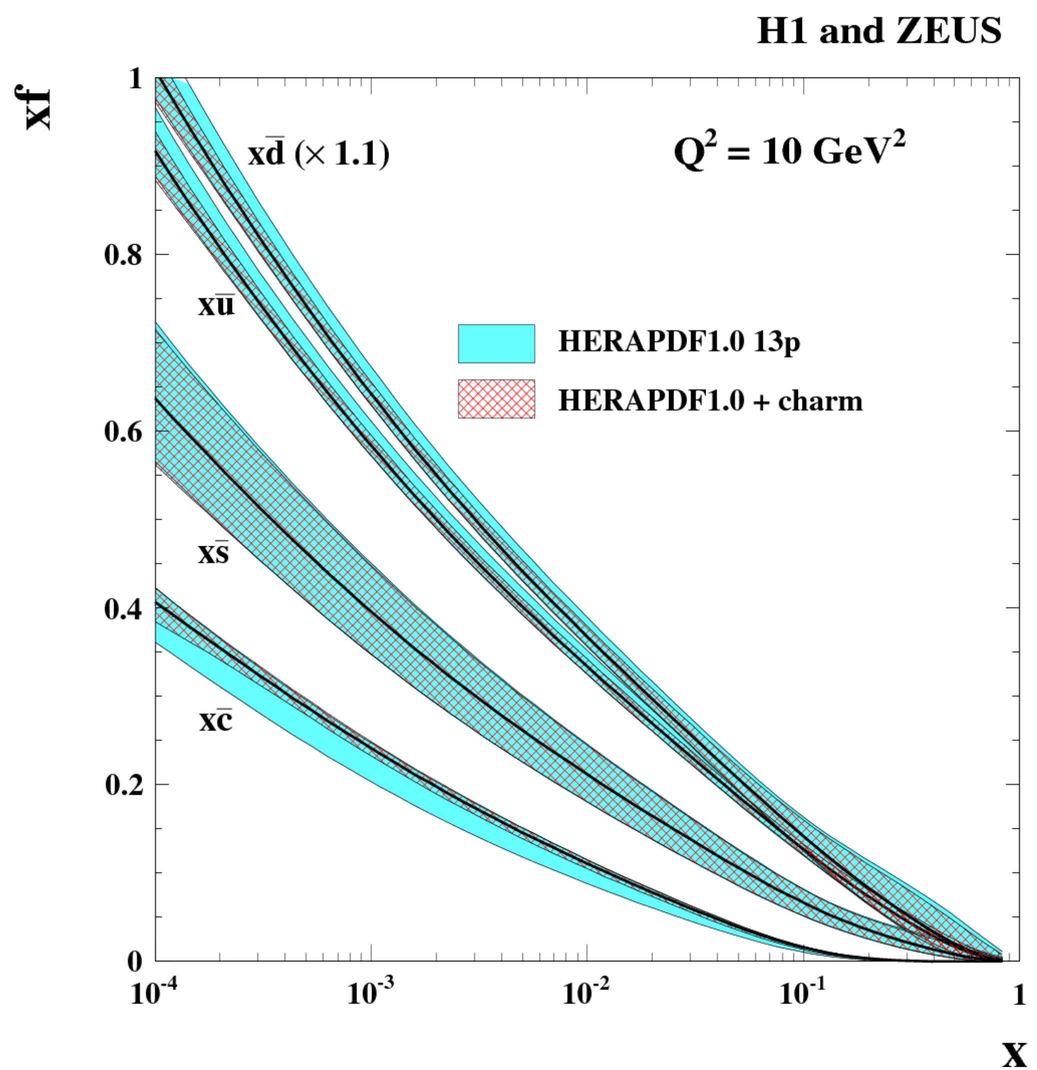




➔ improve sea flavour decomposition

Conclusions

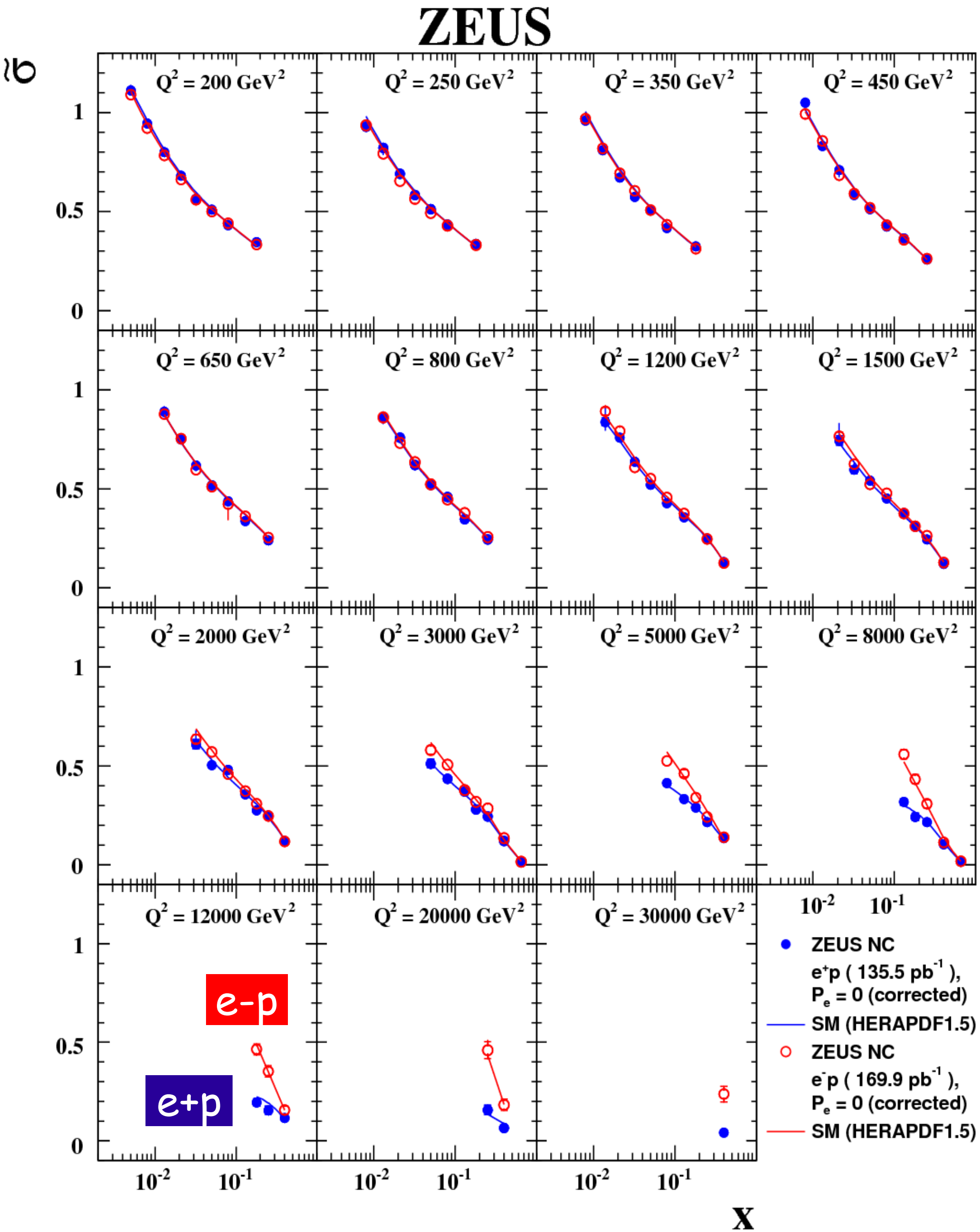
Inclusive DIS

- **Final H1 and ZEUS Neutral and Charged Current bulk data sets available since 2012**
  - Best precisions of ~1.5% for NC data with Q^2 from few to 500 GeV^2
  - Data well described over large Q^2 and x range by NLO QCD
  - Ongoing work on final HERA combination
  - HERA Data based PDFs are essential for **predictions** at the LHC, *we recommend* HERAPDF1.5 (NNLO, NLO, now also @LO)

Charm production

- **Precise combined HERA charm DIS data → test heavy quark mass terms in pQCD:**
  - variable flavour number schemes:
    - Data can separate between them, compensate by M_c^{opt}
    - improve sea flavour decomposition
  - Fixed flavour number scheme **(not shown, see backup) :**
    - Provides the best data description
    - Fit running $m_c(m_c)$= 1.26±0.06 GeV
- **Further new precise ZEUS charm DIS data: D* and D+ (not shown, see backup) :**

Backup slides



Reduced NC cross sections

ZEUS final

high Q^2 HERA II *results*

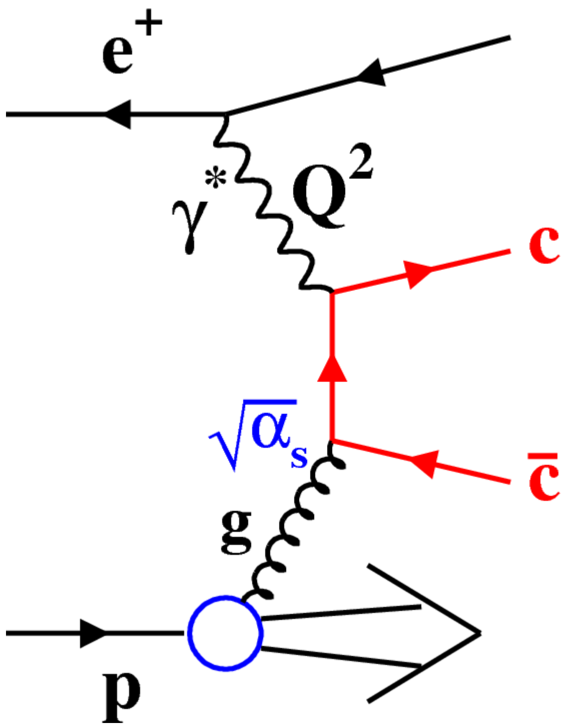
completed by e+p NC data

PRD 87, 052014 (2013)

Best precisions of ~1.5%

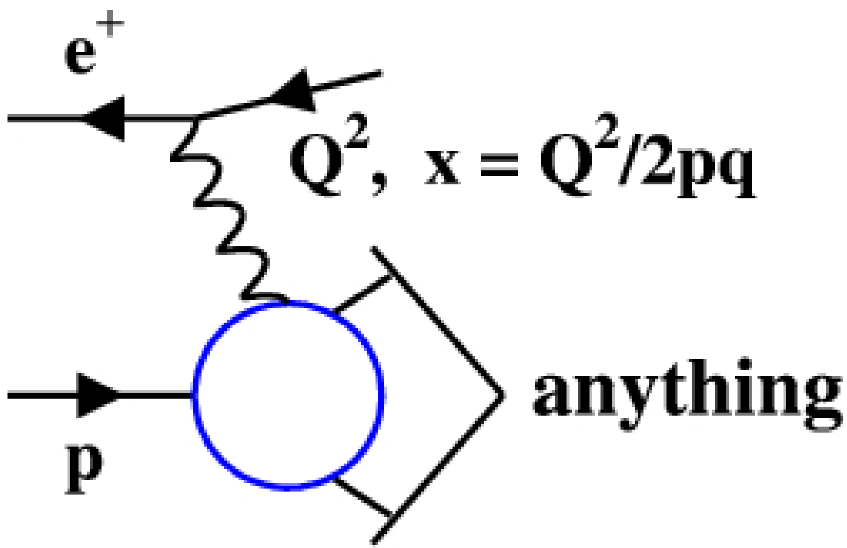
→ Data well described by DGLAP NLO QCD

Charm production at HERA

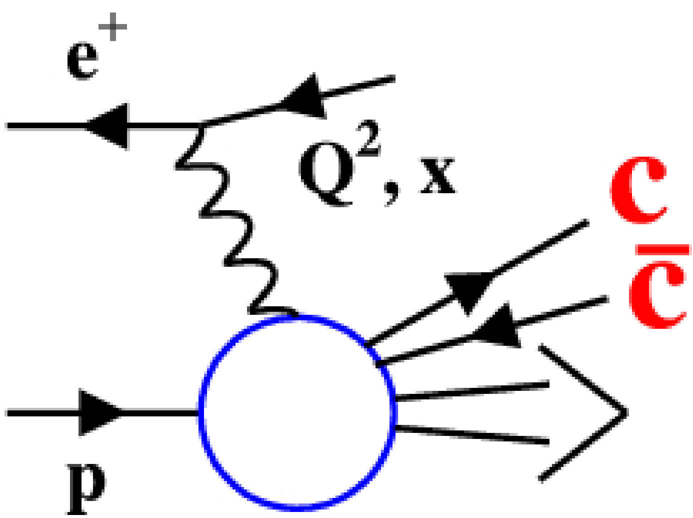


- ❑ Large contributions to incl. DIS
- ❑ Sensitive to g(x)

Charm contribution to DIS: F_2^{cc}



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



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

Z,W cross section predictions for LHC

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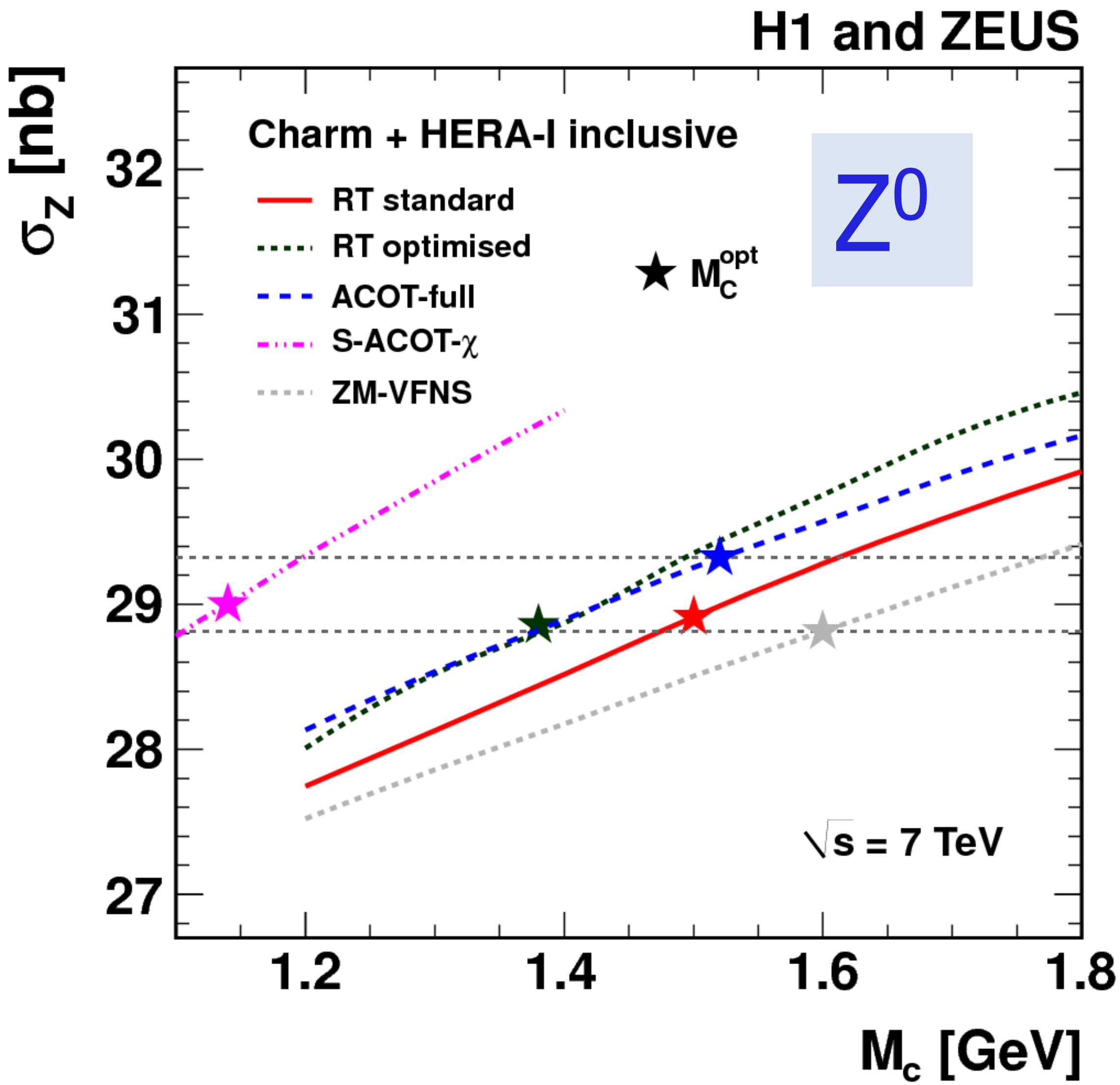

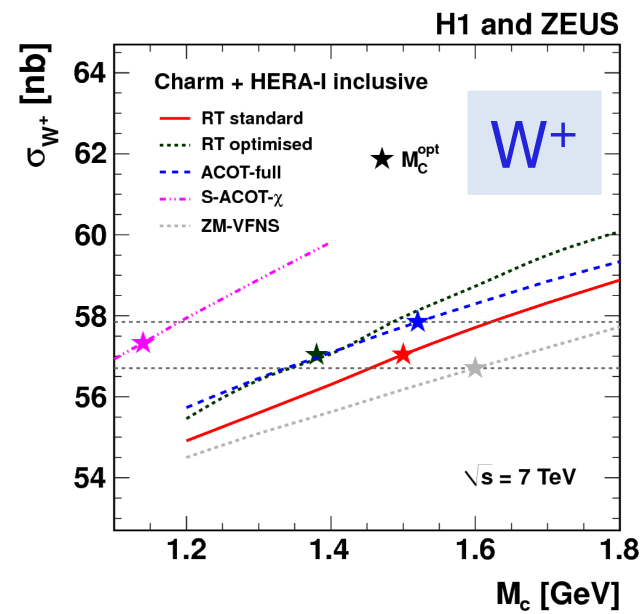

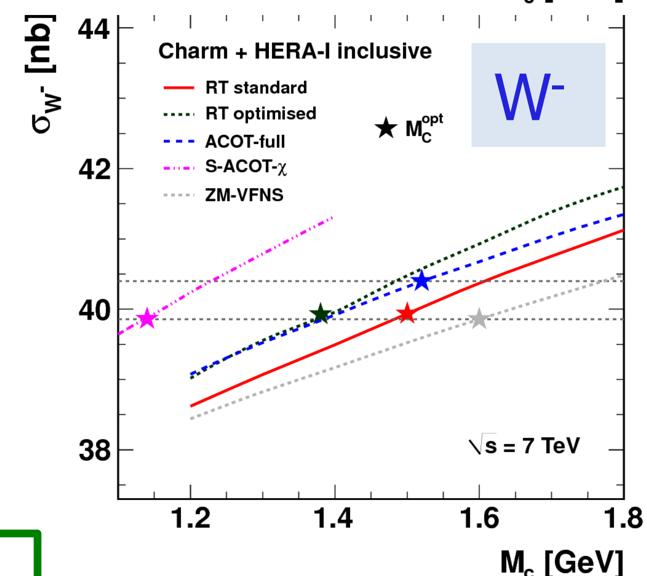

→ optimal M_c reduces significantly uncertainty

Impact of charm data on PDF

Example: RT optimal scheme

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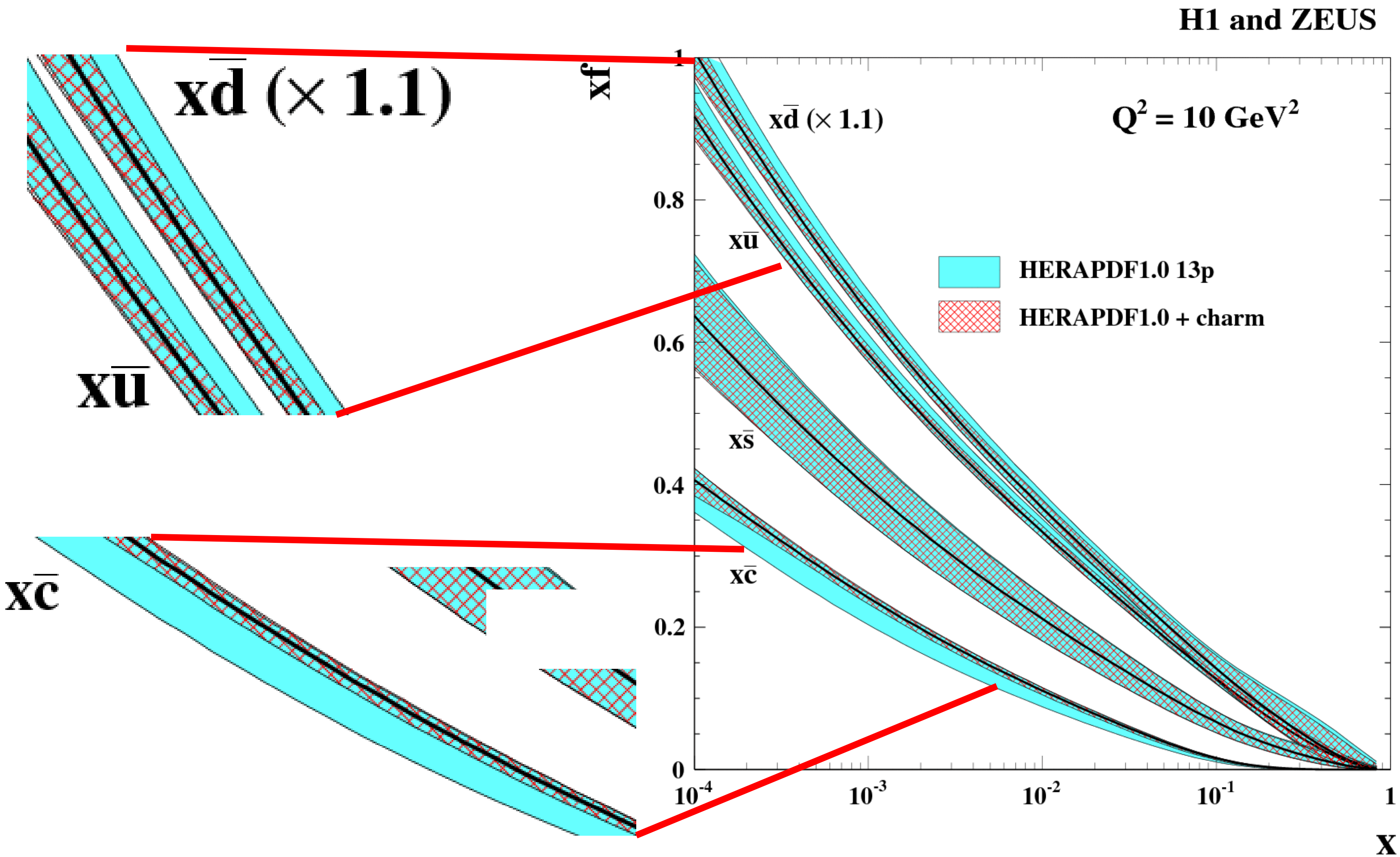

→ stabilise sea flavour composition

Combined charm data vs ABM FFNS prediction

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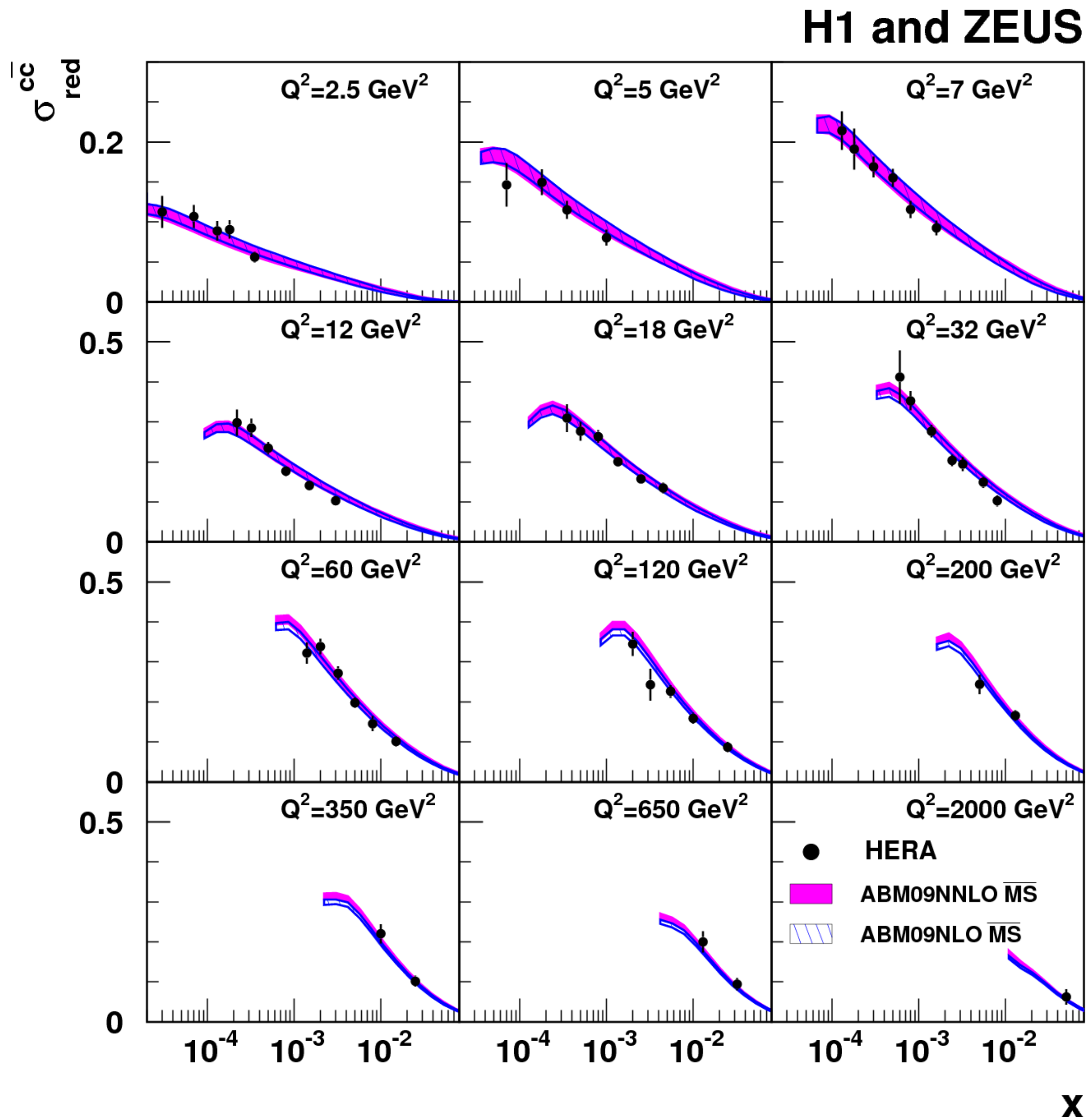

Use $\overline{\text{MS}}$ running mass
NLO+ partial NNLO

→ Very good description everywhere

Fit: PDF plus $\overline{\text{MS}}$ *running* charm mass

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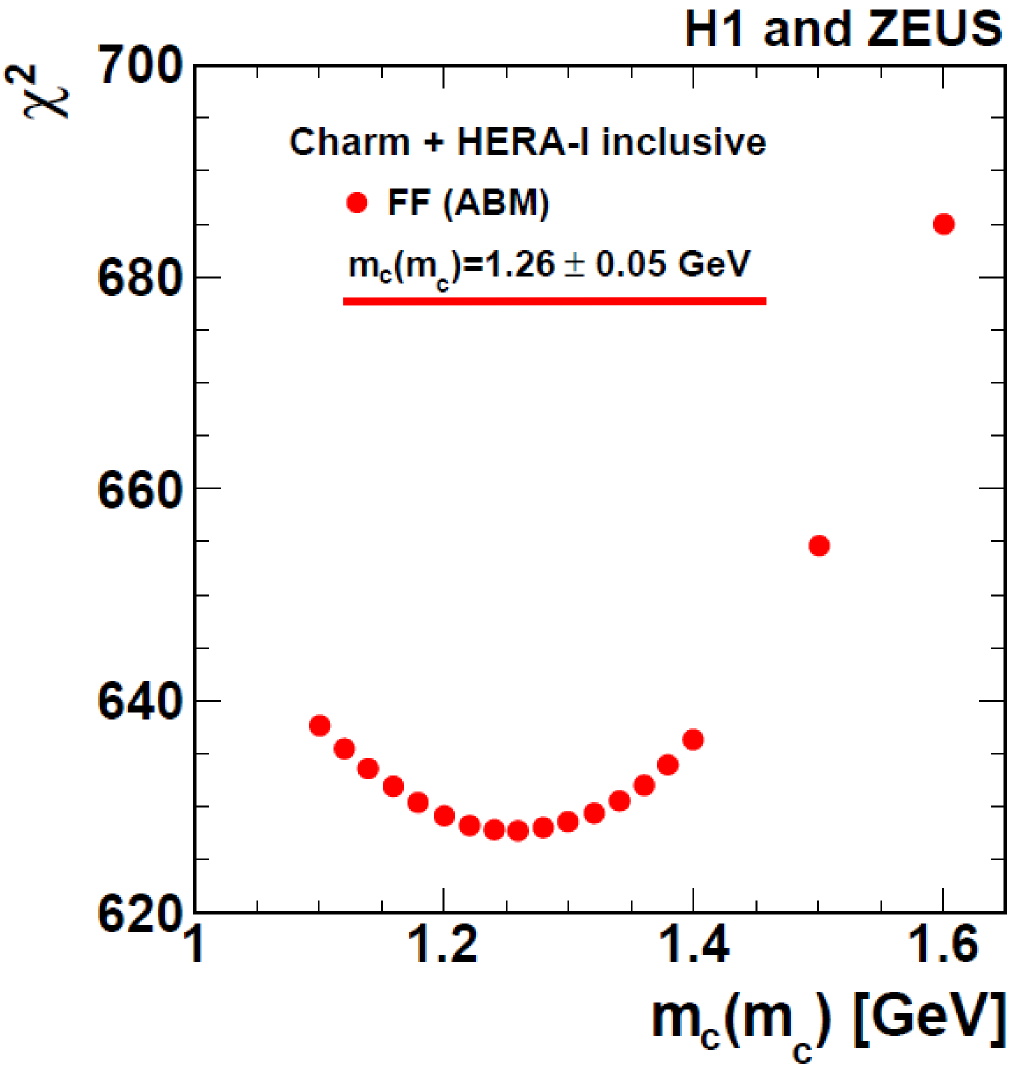


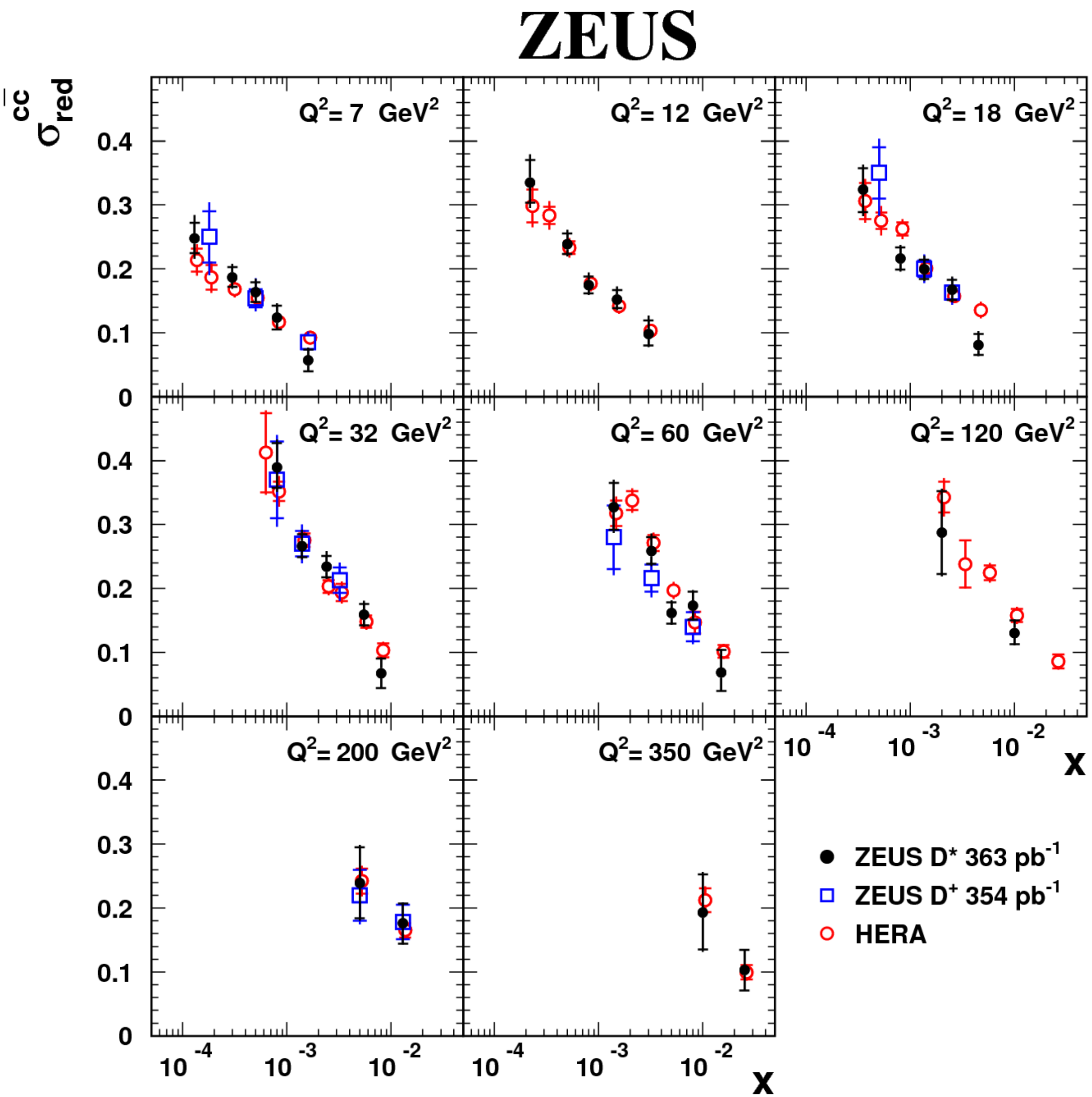
- Fit **combined charm** and inclusive DIS data
- **use ABM FFNS**

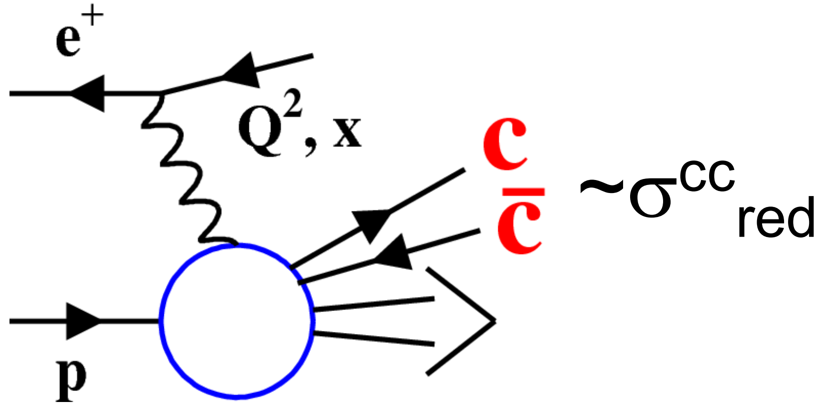
$m_c(m_c)$ = 1.26 $\pm 0.05_{exp}$ $\pm 0.03_{mod}$ $\pm 0.02_{\alpha s}$ GeV
PDG: 1.275 ±0.025 GeV (lattice QCD + time-like processes)

→ nice and consistent result

Brand new charm results in DIS: D* and D+

DESY-13-054
DESY-13-028





→ Consistent findings
→ New ZEUS results will **improve** combination, PDF and m_c fits