Inclusive DIS at HERA and PDFs

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On Behalf of the H1 and ZEUS Collaborations

Diffraction 2012

Lanzarote - September 10-15, 2012

HERA and the Structure of the Proton

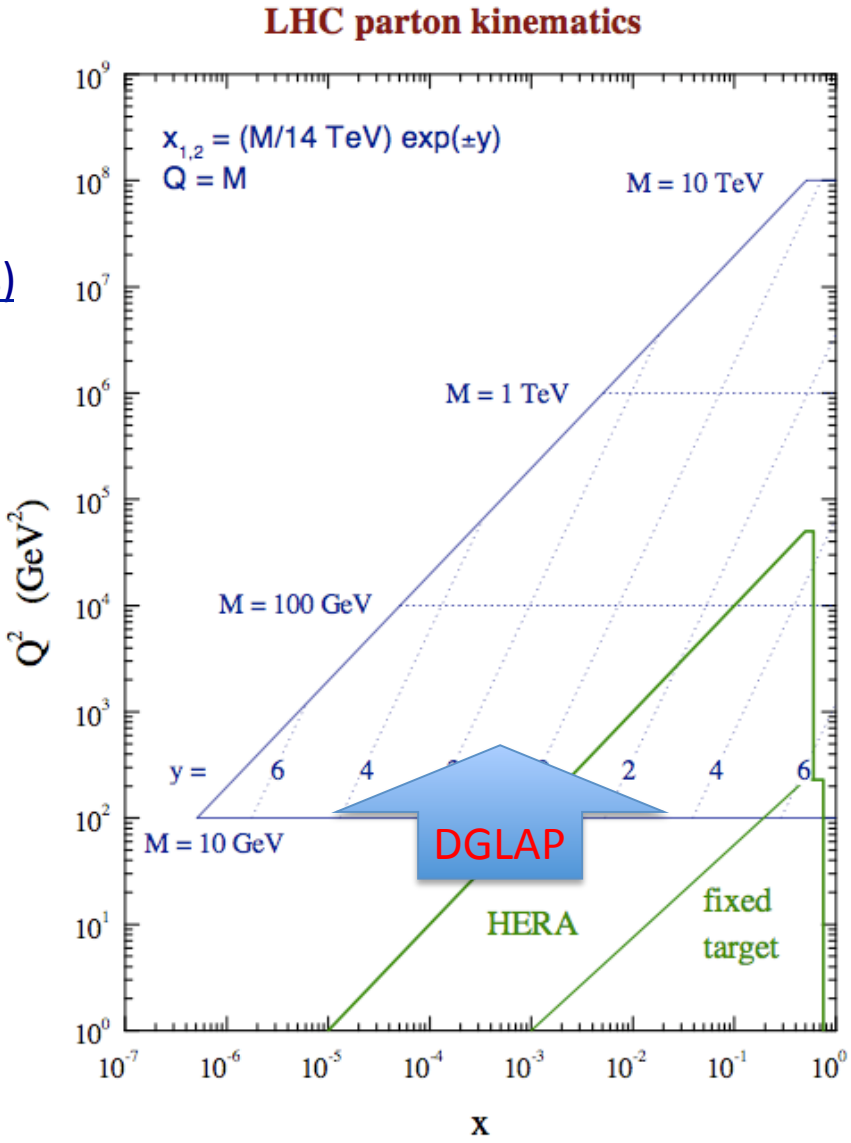
HERA data are our main source of knowledge on proton structure:

➔ proton's parton distribution functions (PDFs)

Combine the H1 and ZEUS data in order to provide the most precise input to DGLAP analyses

Precise knowledge of PDFs crucial to carry out LHC Physics Program:

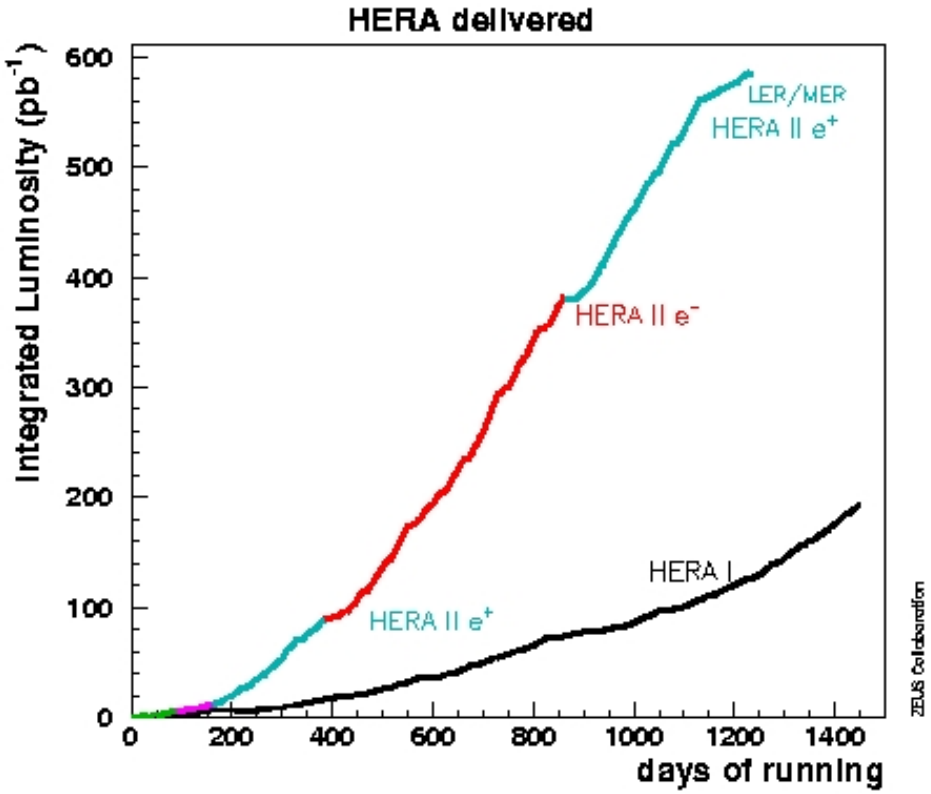
- Very stringent tests of the Standard Model
- Searches of Physics Beyond the SM (need to control QCD Background)



The HERA Collider

World's only ep collider (Desy-Hamburg)
Data taking: Fall 1992 - June 2007

$e^{\pm}$ (27.5 GeV) → ← p (820/920 GeV)

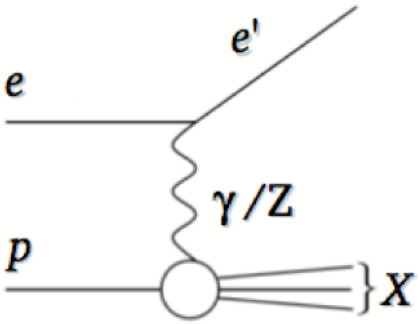


HERA-I (1992-2000)
L ~ 130 pb^{-1}/experiment
Mostly e^+p

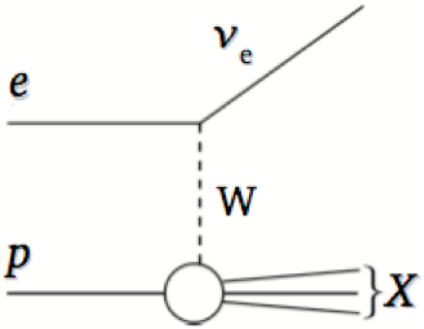
HERA-II (2003-2007)
L~360 pb^{-1}/experiment
Similar amounts of e^+p and e^-p
Long. polarized lepton beams (P~0.35)
Last months: Runs at reduced √s for F_L

DIS processes and cross sections

NC : $e\,p \to e'\,X$



CC : $e\,p \to \nu_e\,X$



Kinematic variables:

- Virtuality exchanged boson

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

- Bjorken scaling variable

$$x = \frac{Q^2}{2p \cdot q}$$

Double differential and "reduced" cross sections:

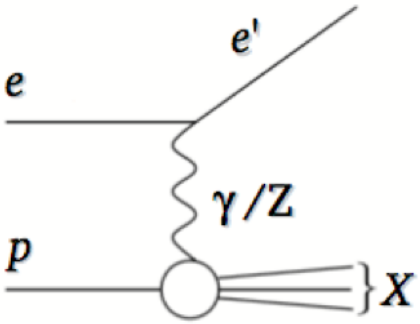
NC: $$\sigma^{\pm}_{r,\mathrm{NC}} = \frac{d^2\sigma^{e^{\pm}p}_{\mathrm{NC}}}{dxdQ^2} \cdot \frac{Q^4 x}{2\pi\alpha^2 Y_+} = F_2 \mp \frac{Y_-}{Y_+} xF_3 - \frac{y^2}{Y_+} F_L$$

CC: $$\sigma^{\pm}_{r,\mathrm{CC}} = \frac{d^2\sigma^{e^{\pm}p}_{\mathrm{CC}}}{dxdQ^2} \cdot \frac{2\pi x}{G_F^2} \left[\frac{M_W^2 + Q^2}{M_W^2}\right]^2 = \frac{1}{2}\left(Y_+ W_2^{\pm} \mp Y_- x W_3^{\pm} - y^2 W_L^{\pm}\right)$$

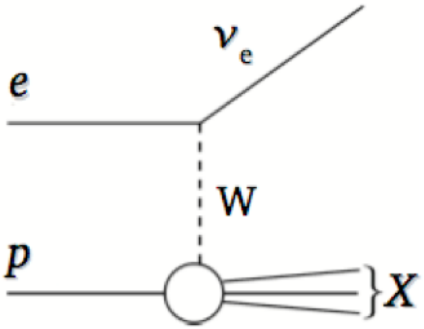
with $$Y_{\pm} = 1 \pm (1-y)^2$$

DIS processes and cross sections

NC : $e\,p \to e'\,X$



CC : $e\,p \to \nu_e\,X$



Kinematic variables:

- Virtuality exchanged boson

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

- Bjorken scaling variable

$$x = \frac{Q^2}{2p \cdot q}$$

Structure Functions, PDFs and DGLAP evolution equations:

$$x^{-1} F_2(x, Q^2) = \sum_{i=q,g} \int_x^1 \frac{d\xi}{\xi} C_{2,i}\left(\frac{x}{\xi}, \alpha_s(\mu^2), \frac{\mu^2}{Q^2}\right) f_i(\xi, \mu^2)$$

$$\frac{d}{d\ln\mu^2} f_i(\xi, \mu^2) = \sum_k \left[P_{ik}(\alpha_s(\mu^2) \otimes f_k(\mu^2))\right](\xi)$$

Results I will Cover

- Combination of the H1 and ZEUS data and DGLAP fits:

  - HERA-I inclusive cross sections: JHEP 1001:109(2010)
    ➔ Precise determination of the sea quarks and gluons at mid- and low-x

  - HERA-I+HERA-II Inclusive cross sections (high-Q^2):
    ➔ Better determination of the valence quarks at high-x

  - HERA-I + charm data:
    ➔ Constraints on the charm mass and study of different heavy quarks schemes

  - HERA-I + jet data:
    ➔ Strong coupling and gluon density

Preliminary

- Final results of the H1 an ZEUS collaborations with HERA-II data

  - H1 NC and CC $e^{\pm}p$ high Q^2 Cross Sections and new QCD analysis
    arXiv:1206.7007 (➔JHEP)

  - ZEUS NC $e^{+}p$ high Q^2 cross sections
    arXiv:1208.6138 (➔EPJC)

HERAPDFs

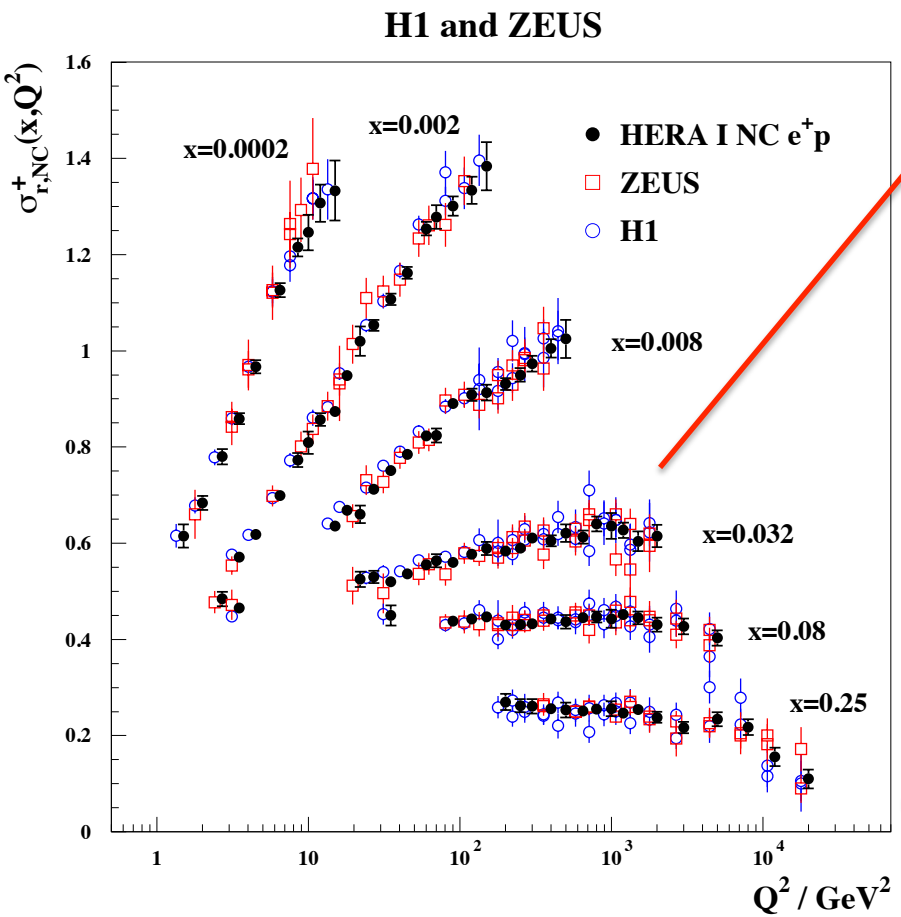
HERAPDF: only HERA data
- uses consistent data with very well understood correlations
- no need for nuclear corrections etc

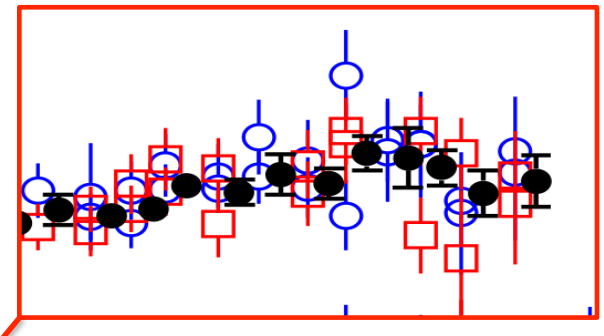
Overview of HERAPDF sets:

Data	PDF Set
H1+ZEUS NC,CC - HERA I	HERAPDF1.0 (NLO,NNLO)
H1+ZEUS NC,CC - HERA I +II (part)	HERAPDF1.5 (NLO,NNLO)
NC,CC HERA I + II (part) + jets	HERAPDF1.6 (NLO)
NC,CC HERA I + II (part) + charm	HERAPDF1.0 + charm
All data above	HERAPDF1.7
Planned: Full HERA data set	HERAPDF2.0 (NLO, NNLO)

Part of the HERAPDF Project: **HERAFitter**
- Open source QCD fitting tool to determine PDFs
  (see http://projects.hepforge.org/herafitter)

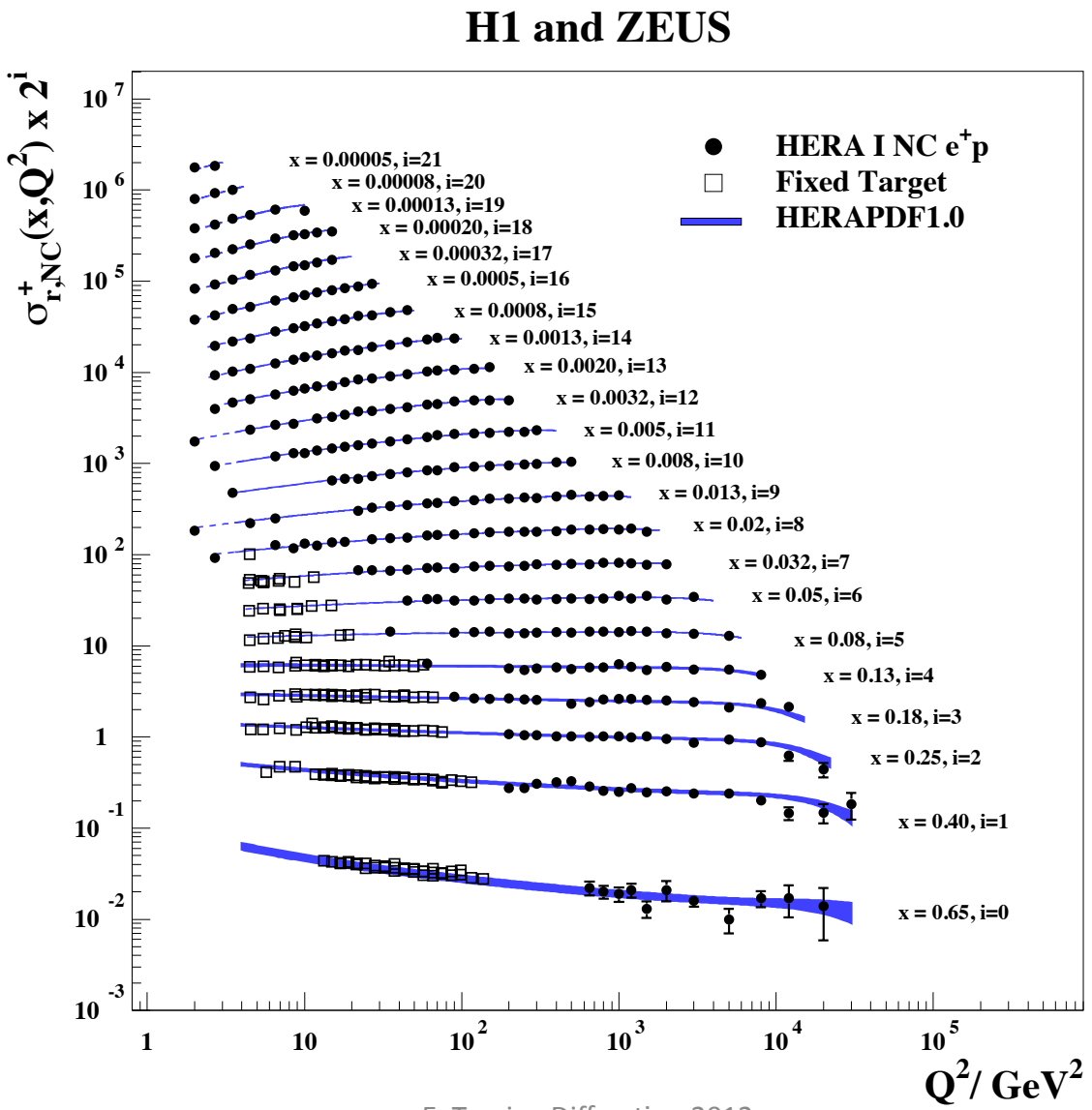
Combination of HERA I data



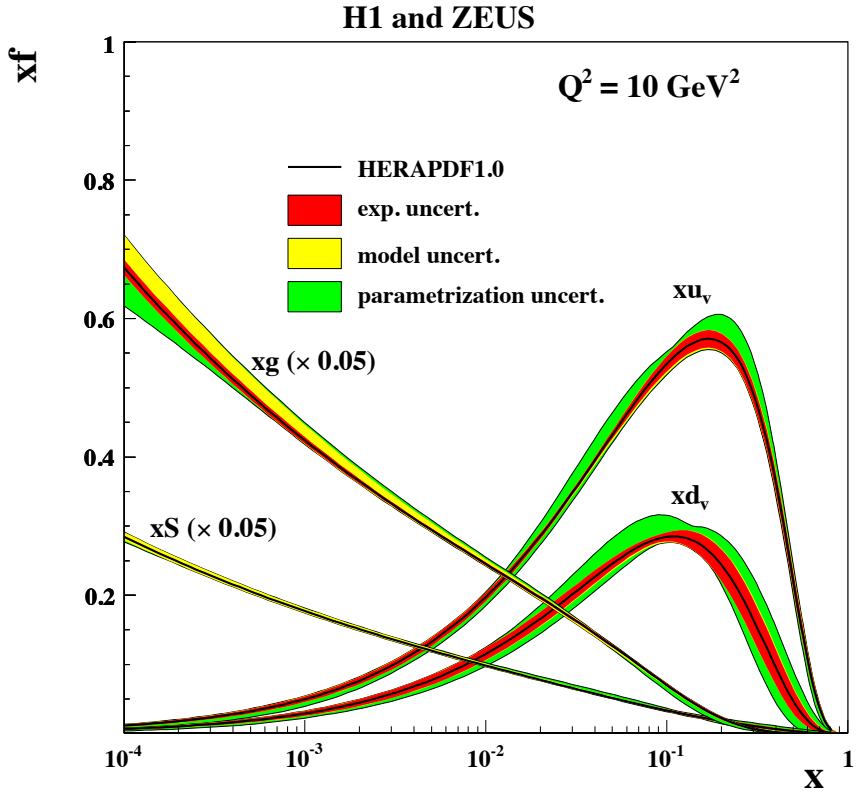


- Combined are all published HERA-I NC,CC $e^{\pm}p$ cross section measurements
  - 1402 data points
  - 110 syst. error sources (and correlations)
  - details on the χ^2 combination method:
    - ➔ see JHEP 1001:109(2010) [arXiv:0904.0929]
- Data show good consistency:
  - χ^2/ndof =637/656
  - small shift of global norms
  - distribution of pulls
- Experiments "cross calibrate" each other
  - 1-2% total uncert. in the low- mid-Q^2 region

Combination of HERA I data



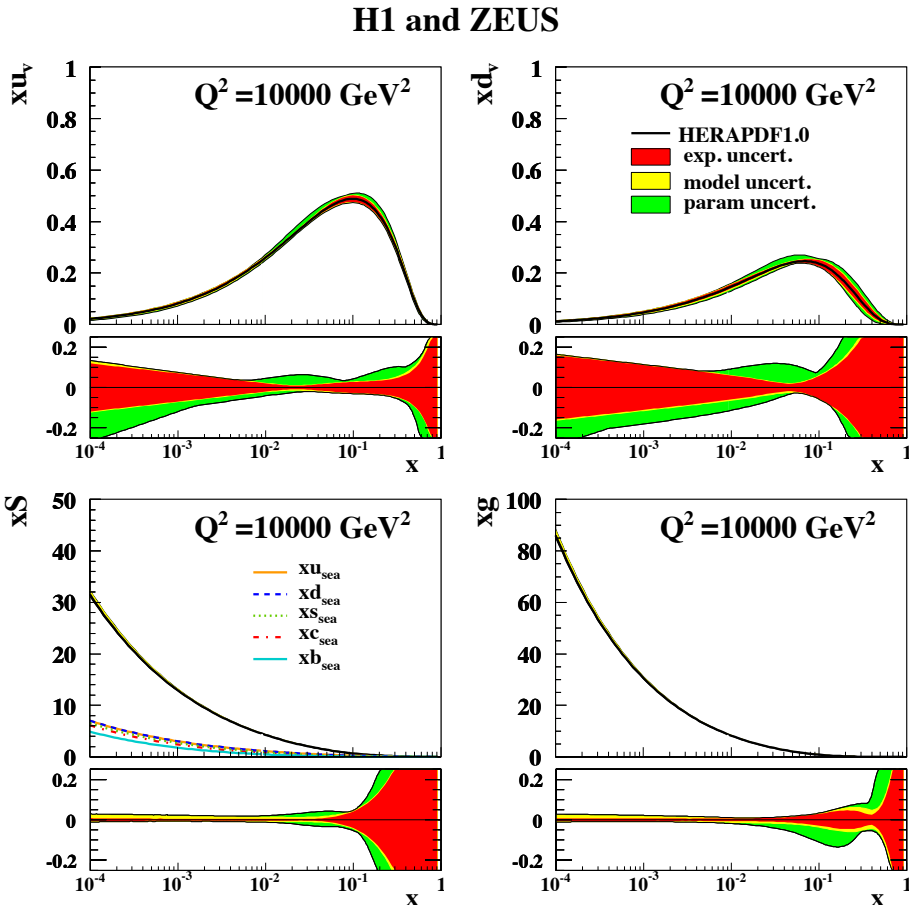
DGLAP Analysis of HERA-I data: HERAPDF 1.0



- NLO DGLAP analysis based only on the HERA-I, fully consistent, combined dataset:
  - no need for heavy target/deuterium corrections or strong isospin assumptions
  - χ^2/ndof = 574/582
- Massive treatment for heavy flavours (RT-VFNS)
- Detailed study of uncertainties:
  - experimental, model and parametrisation

The very precise HERAPDF1.0 set is available in LHAPDF since v5.8.1

DGLAP Analysis of HERA-I data: HERAPDF 1.0



Experimental uncertainty:

Consistent data set ➔ use $\Delta\chi^2 = 1$

Model Uncertainty:

Following variations were considered

Variation	Standard Value	Lower Limit	Upper Limit
f_s	0.31	0.23	0.38
m_c [GeV]	1.4	1.35$^{(a)}$	1.65
m_b [GeV]	4.75	4.3	5.0
Q^2_{min} [GeV^2]	3.5	2.5	5.0
Q^2_0 [GeV^2]	1.9	1.5$^{(b)}$	2.5$^{(c,d)}$

Parametrization uncertainty:

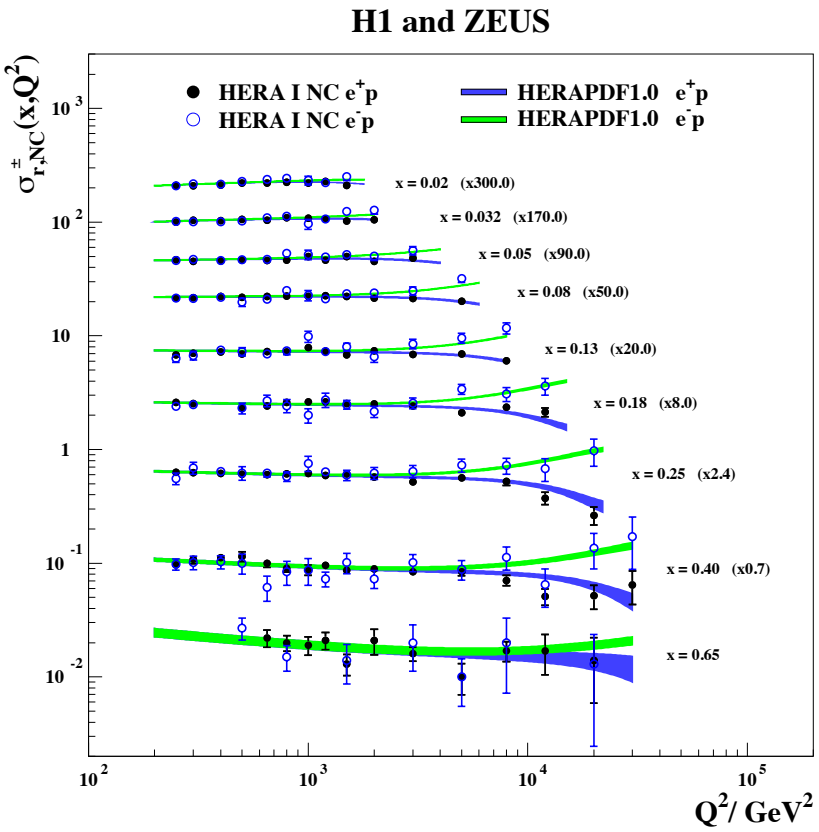
Envelope from DGLAP Fits using variants of the parametrisation form at Q_0^2

$$xf(x) = Ax^B(1-x)^C(1+Dx+Ex^2)$$

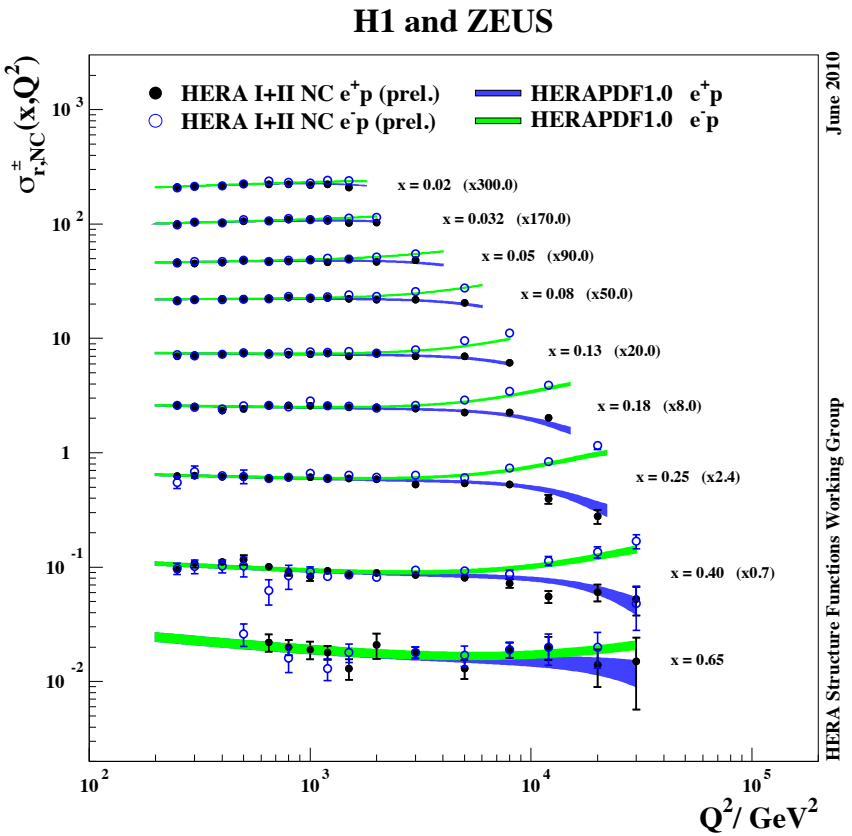
At the scale Q^2=10 000 GeV^2 (relevant to LHC)
the sea and gluon densities are known at the % level for $x \leq 10^{-1}$

HERA-II High-Q^2 Data: NC $e^{\pm}p$

HERA-I combined results



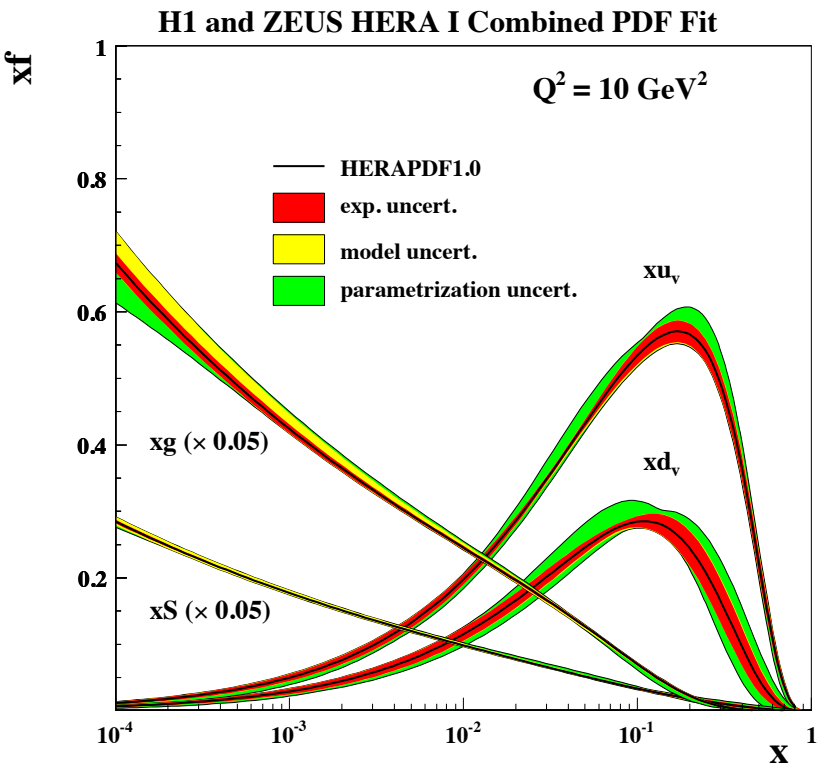
HERA-I + HERA-II combined results



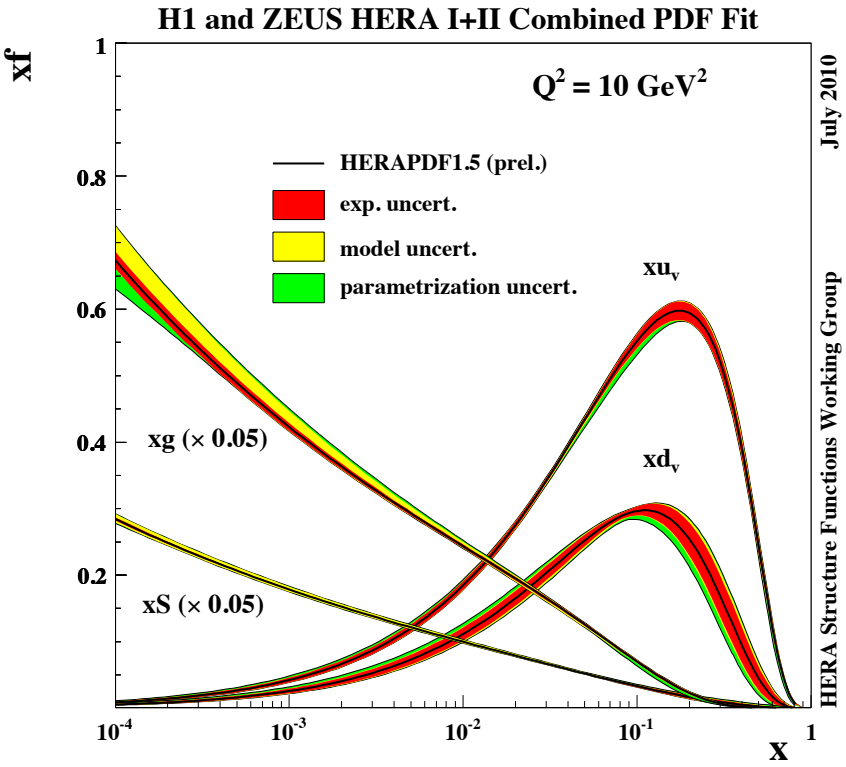
New HERA-II measurements: increased precision at high-Q^2

HERAPDF1.0 vs HERAPDF1.5

HERA-I / HERAPDF1.0

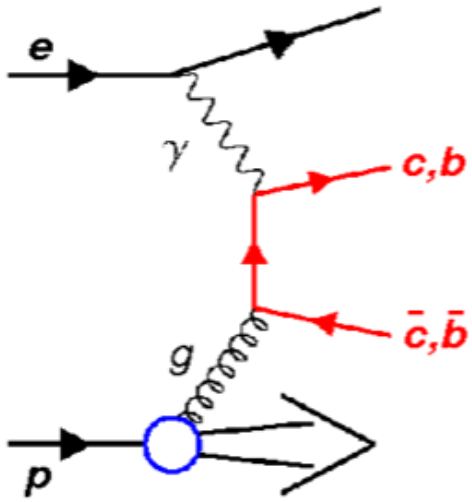


HERA-I+II / HERAPDF1.5



Impact on valence quarks: much better constrained at mid and high-x

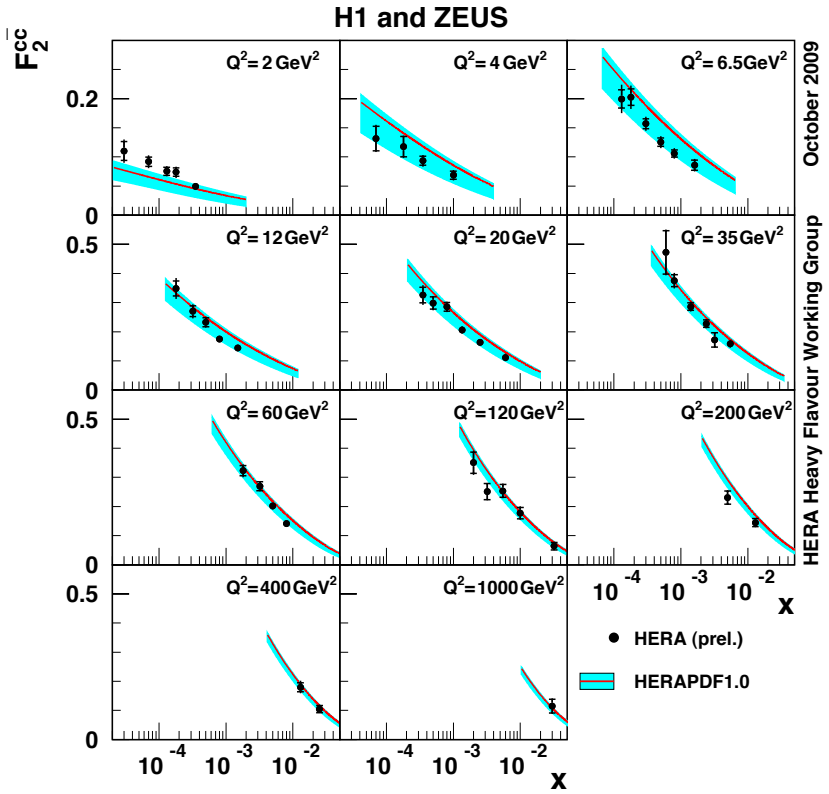
Inclusion of Charm data



Heavy Quarks (HQ) treatment in DGLAP fit is very important.

New HERA combined charm data allow to study different HQ schemes.

Combine H1 and ZEUS charm data: (accuracy 7-10%)

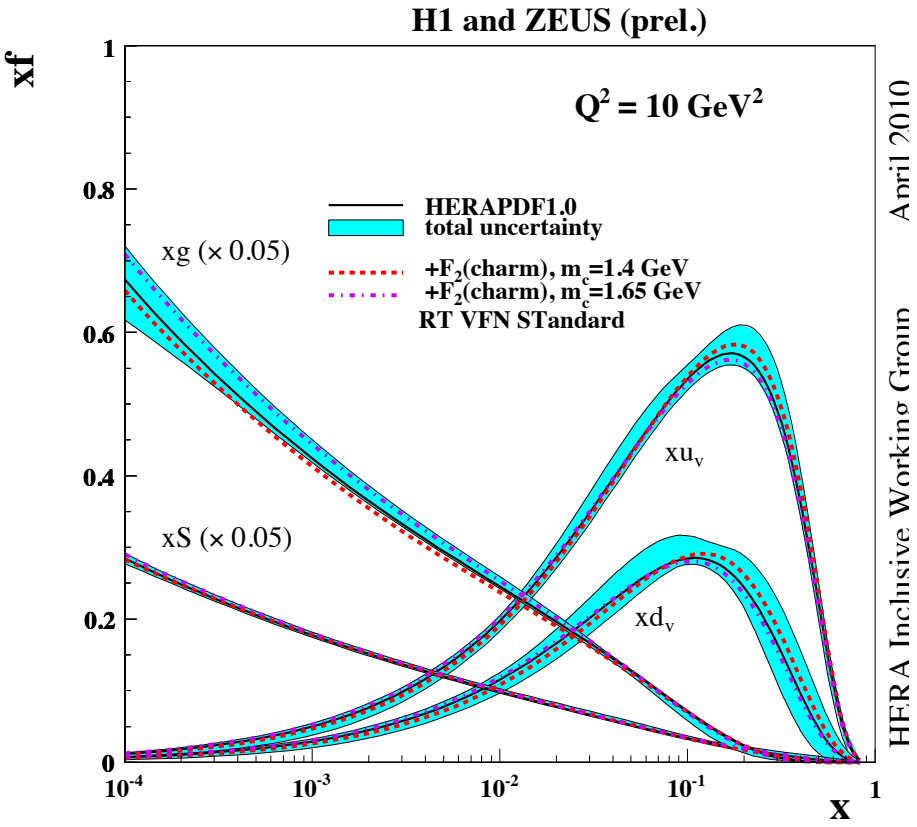


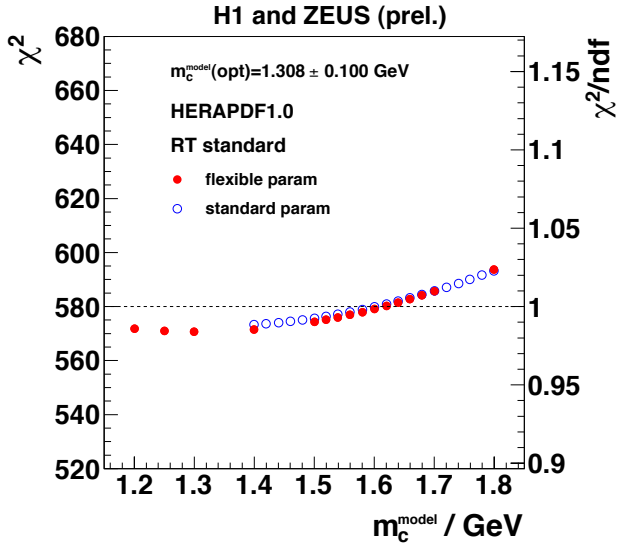
Reasonable agreement with QCD prediction, based on HERAPDF1.0, when accounting for uncertainty on m_c

Uncertainty band: $1.35 < m_c < 1.65$ GeV

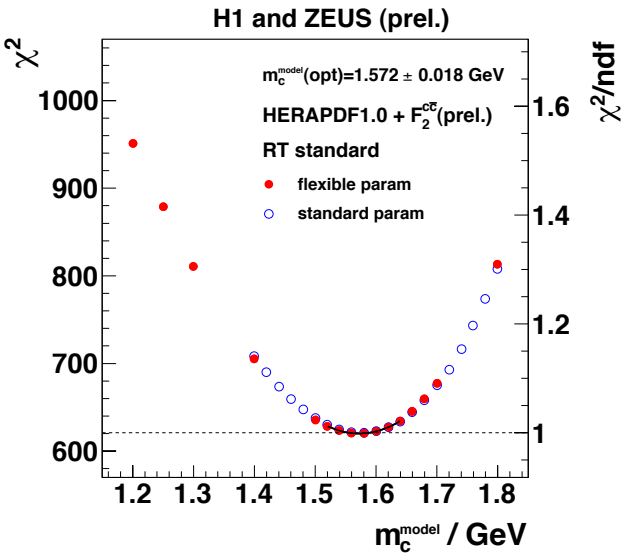
Inclusion of charm data

…does not change PDF significantly
but increases sensitivity to charm mass



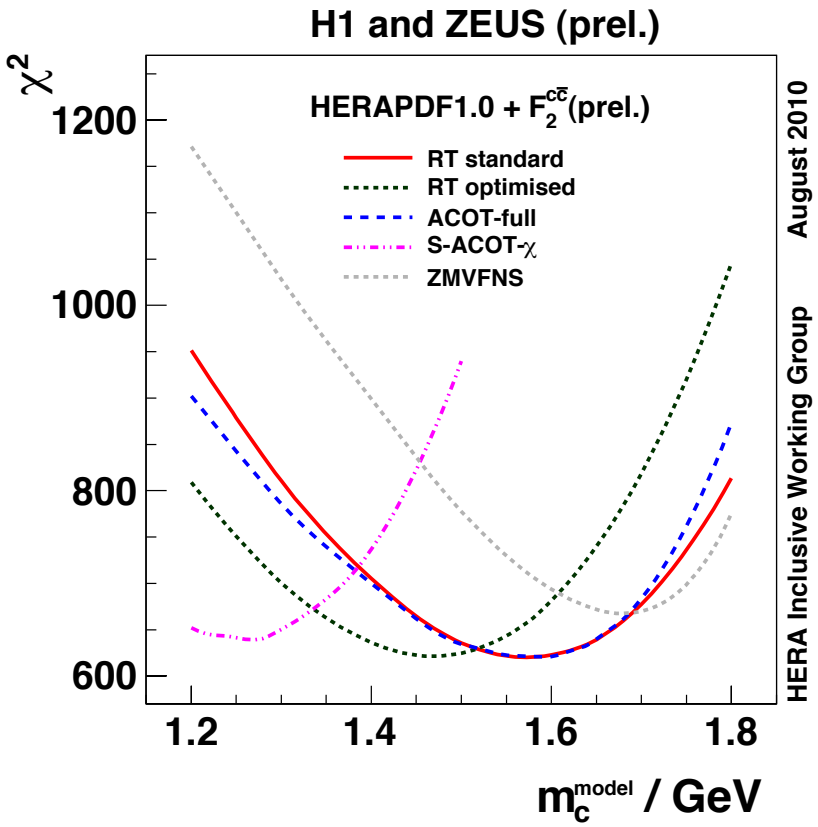


without charm



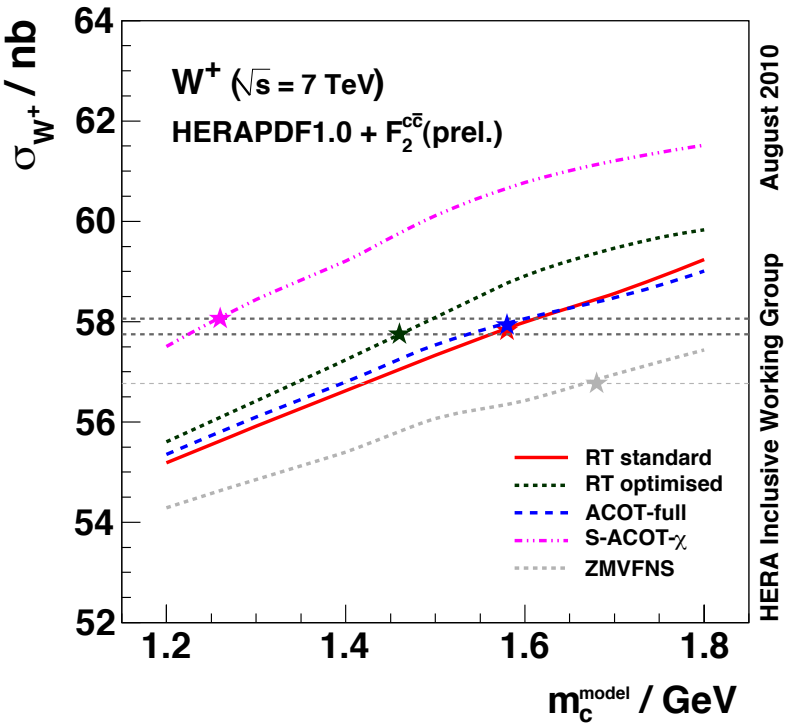
with charm

Charm, VFNS schemes and W predictions at LHC



Different "optimal" effective masses for different GM-VFNS yield very similar fits

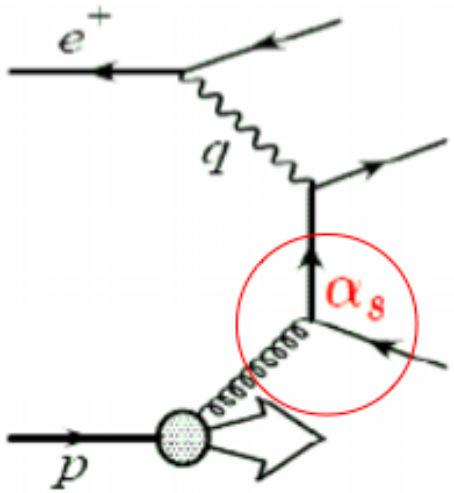
W^+ cross section @ LHC



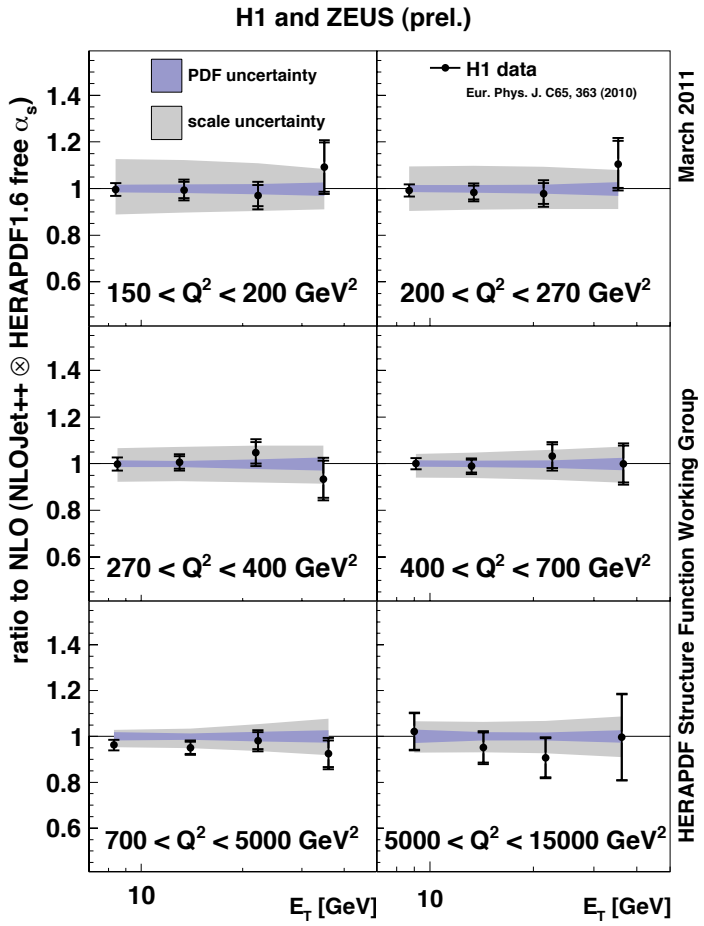
If a fixed "optimal" mass value is considered then the spread is still considerable (~7%) but if each prediction is taken at its own optimal value the spread among predictions is reduced to 1% (2% considering ZM-VFNS)

Inclusion of jets: HERAPDF1.6

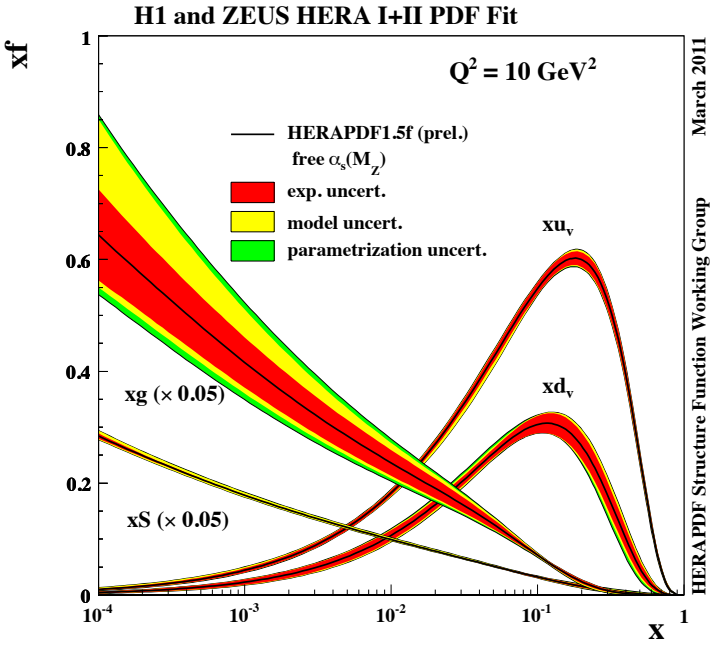
HERAPDF1.6: CC,NC HERA I + II(part) +
4 inclusive jet measurements from H1 and ZEUS



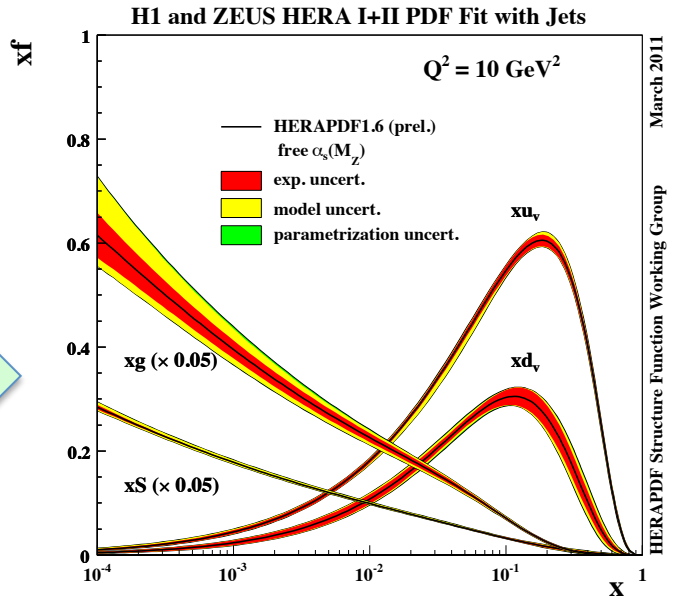
Direct sensitivity to gluon and strong coupling constant

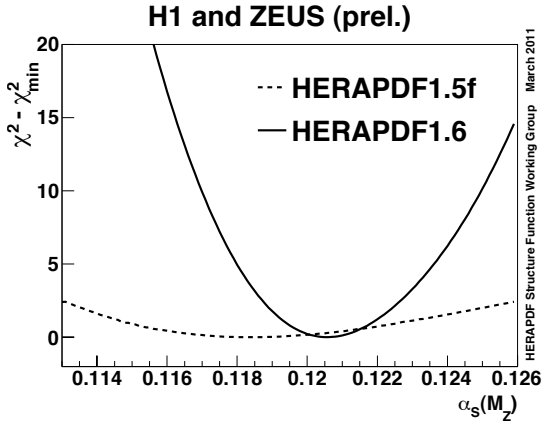


Inclusion of jets: HERAPDF1.6



+ jets



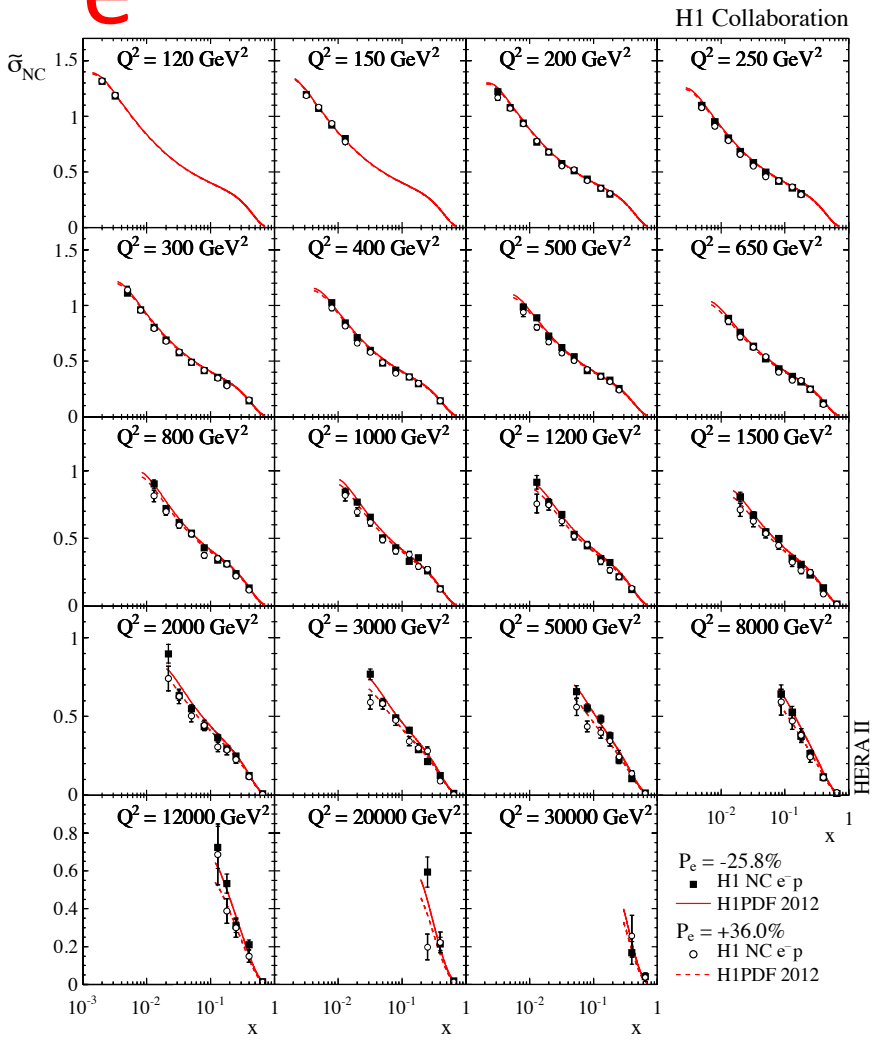


HERA Jet data allow to constrain simultaneously αs and gluon

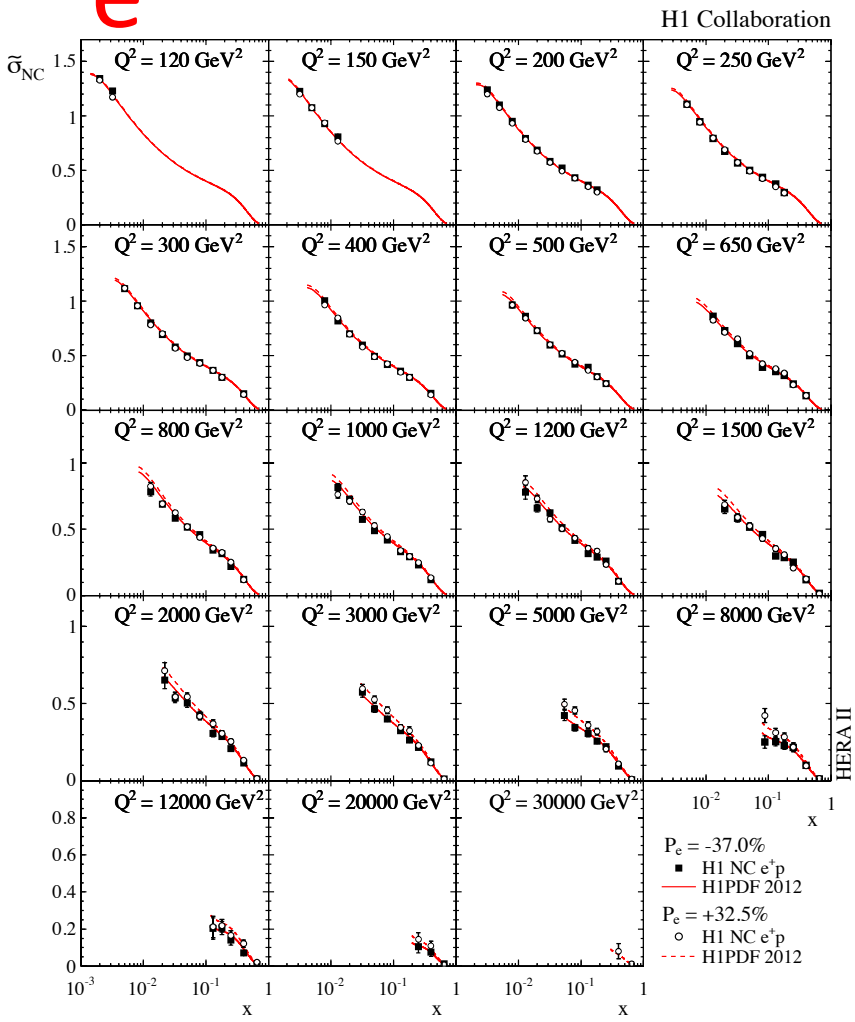
$$\alpha_s(M_Z) = 0.1202 \pm 0.0013(\mathrm{exp}) \pm 0.0007(\mathrm{mod}) \pm 0.0012(\mathrm{had})^{+0.0045}_{-0.0036}(\mathrm{th})$$

Final H1 HERA-II High-Q^2 cross sections

e^-



e^+

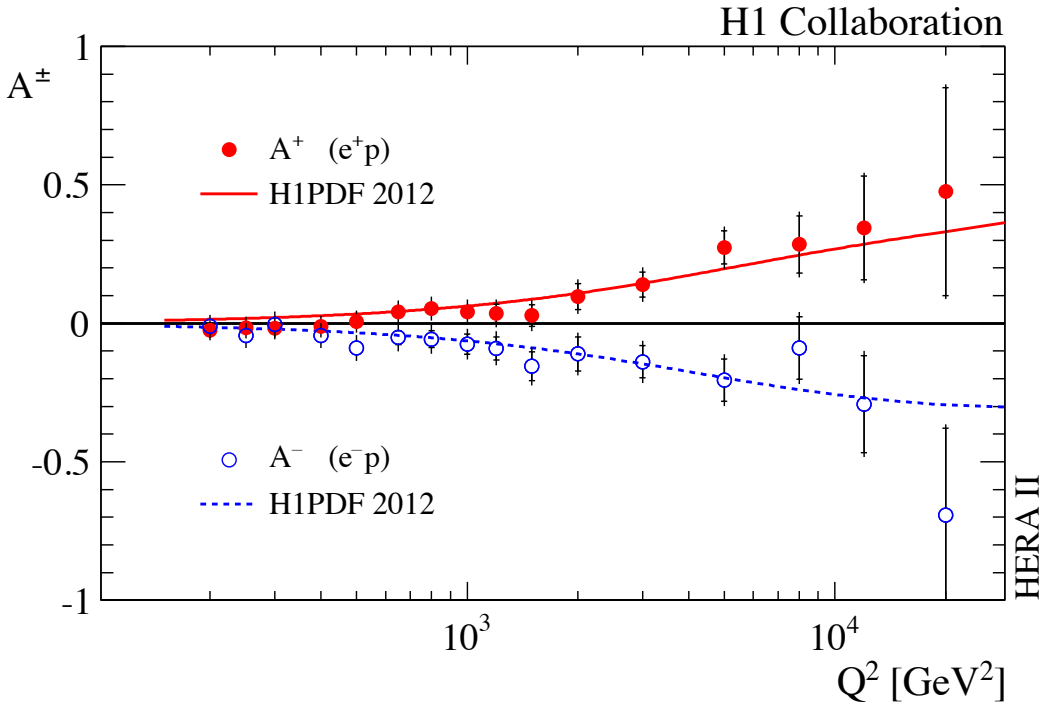


- Show here only NC $e^{\pm}p$ Reduced Cross Sections
- Polarized Cross sections well described by SM predictions (H1PDF 2012)

arXiv:1206.7007 (→JHEP)

NC Polarization Asymmetry

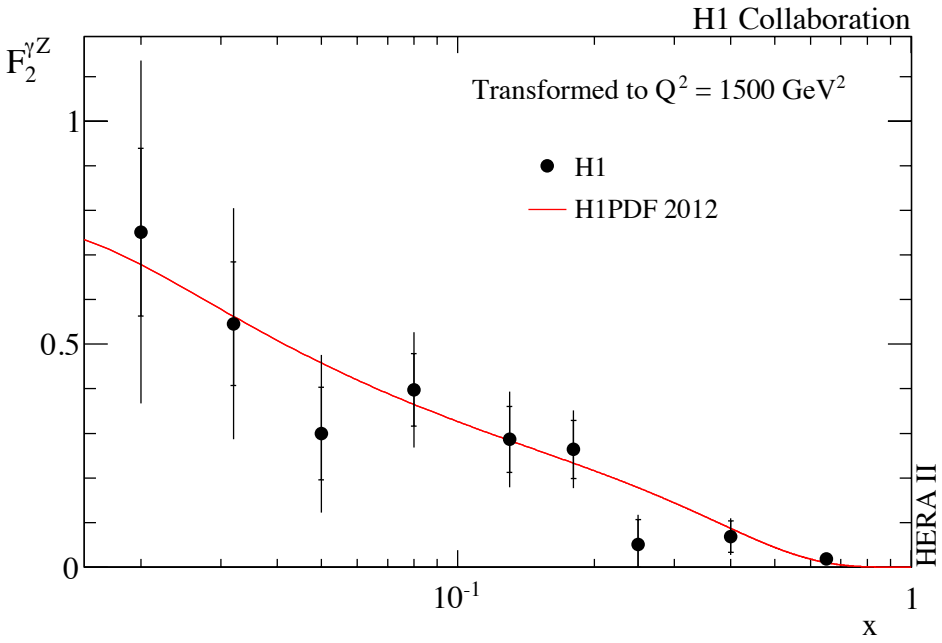
$$A^{\pm} = \frac{2}{P_L^{\pm} - P_R^{\pm}} \cdot \frac{\sigma^{\pm}(P_L^{\pm}) - \sigma^{\pm}(P_R^{\pm})}{\sigma^{\pm}(P_L^{\pm}) + \sigma^{\pm}(P_R^{\pm})}$$



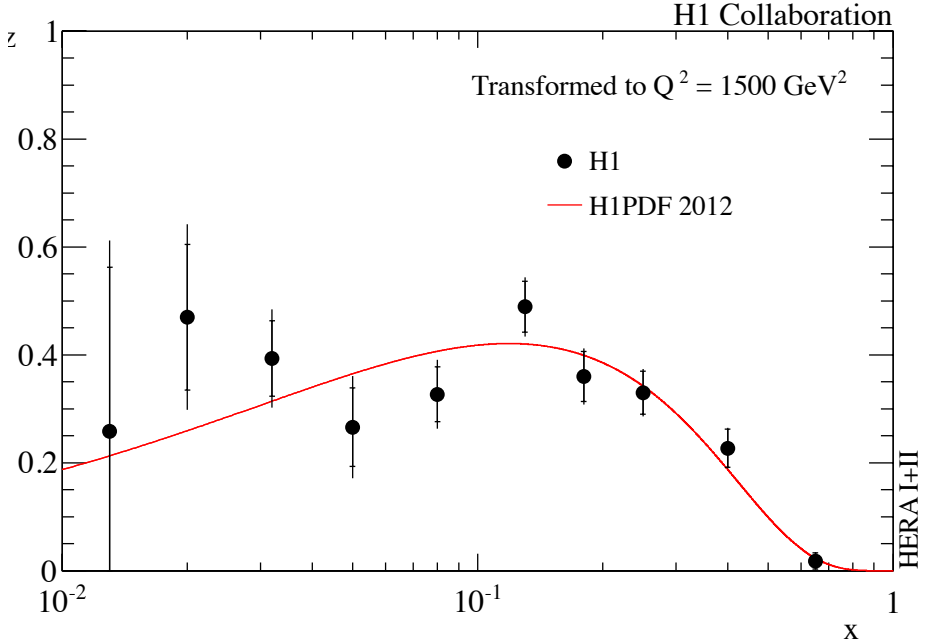
Direct measure of Parity violation effects in NC DIS

Structure Functions $F_2^{\gamma Z}$, $F_3^{\gamma Z}$

First measurement of $F_2^{\gamma Z}$



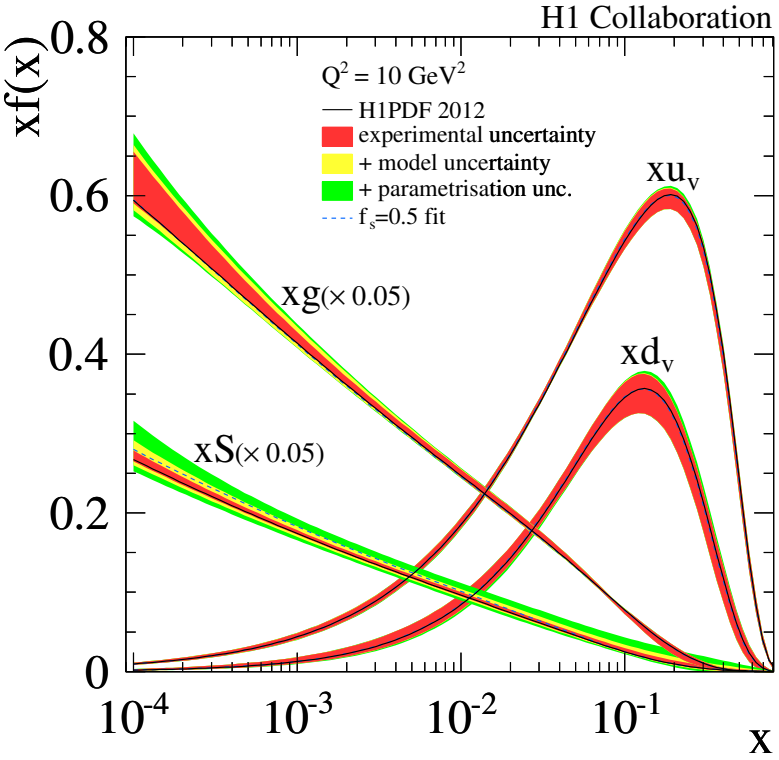
Improved measurement of $F_3^{\gamma Z}$

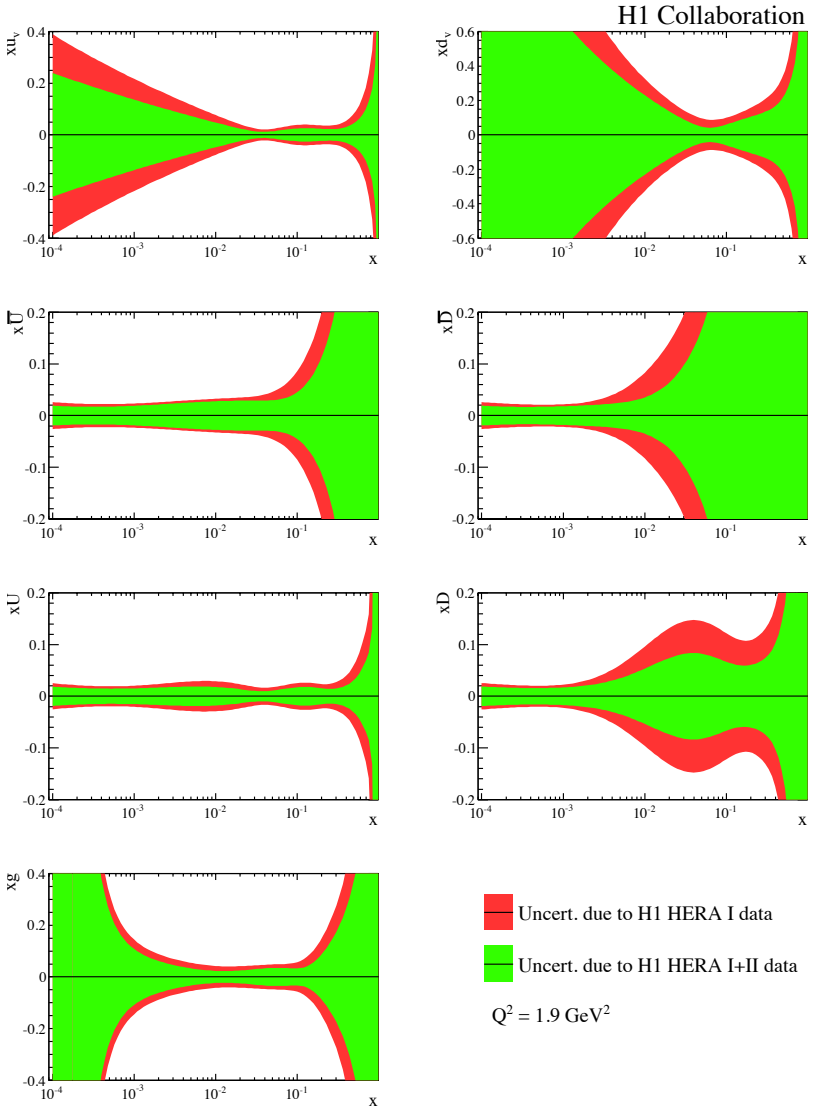


$$F_2^{\gamma Z} \sim q + \bar{q}$$

$$xF_3^{\gamma Z} \sim xq_v$$

H1PDF 2012

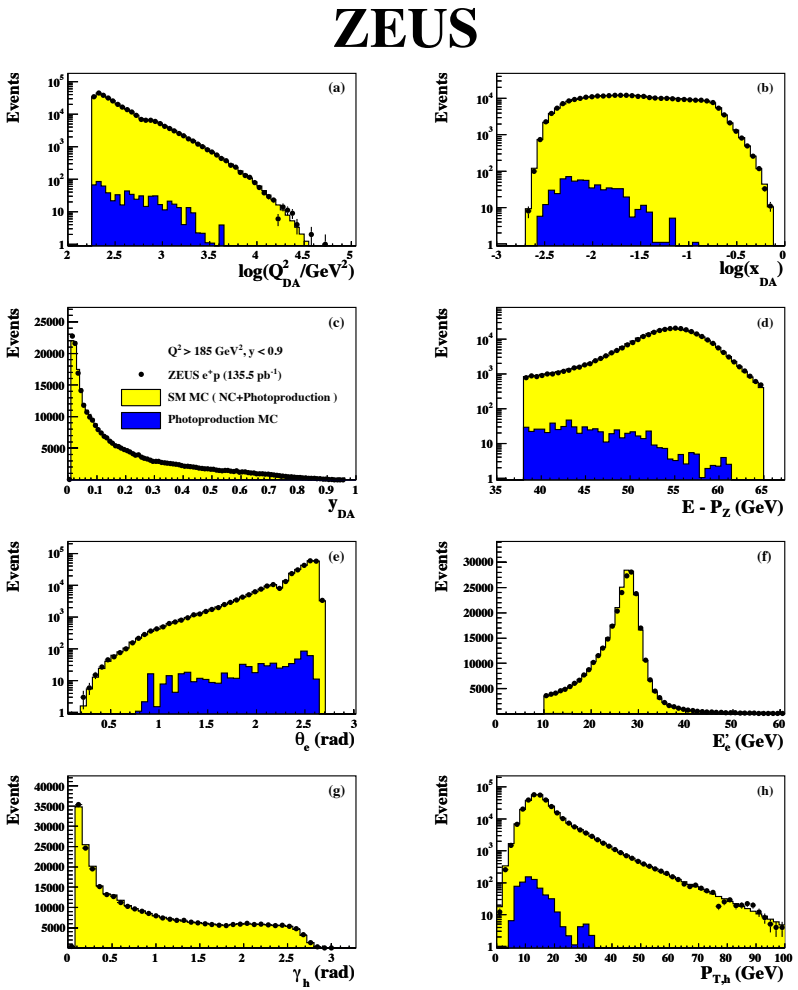


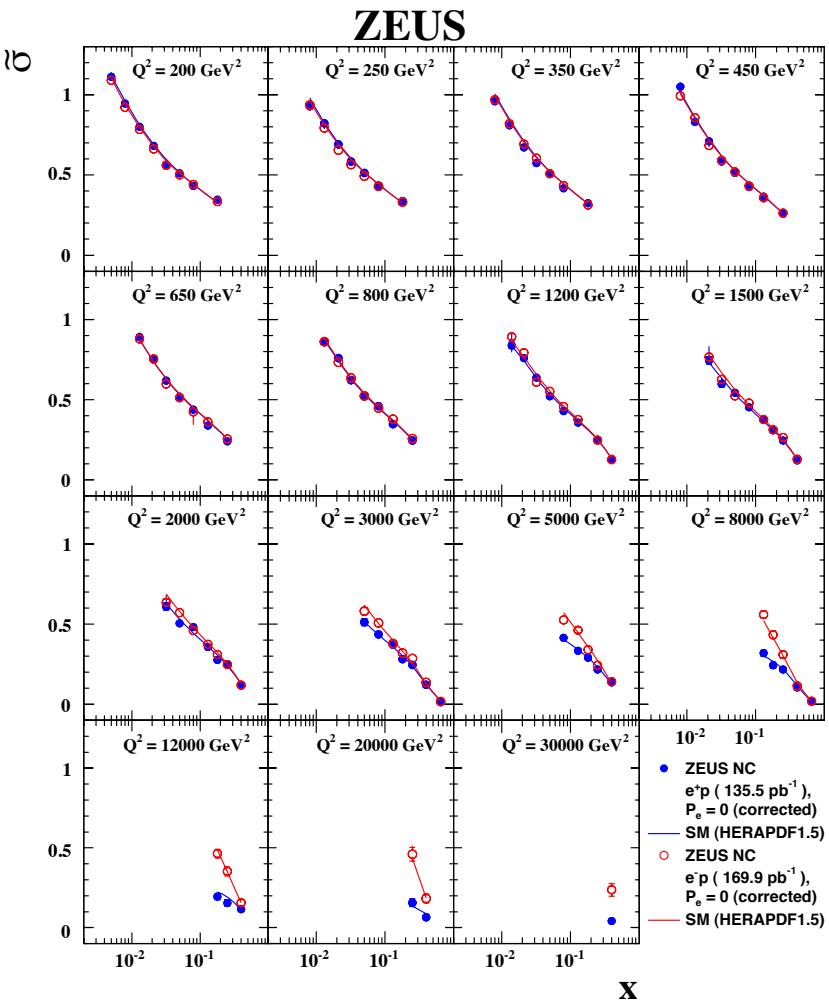


- HERAFitter
- 5 sets of PDFs (with 13 free parameters)

Reduced uncertainties in particular for down-type quarks (xD)

Final ZEUS HERA-II NC e^+p cross sections

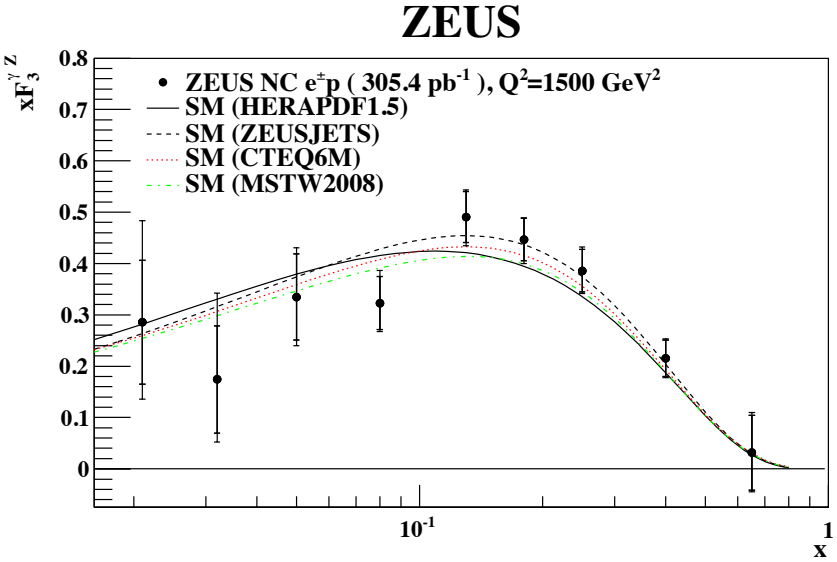


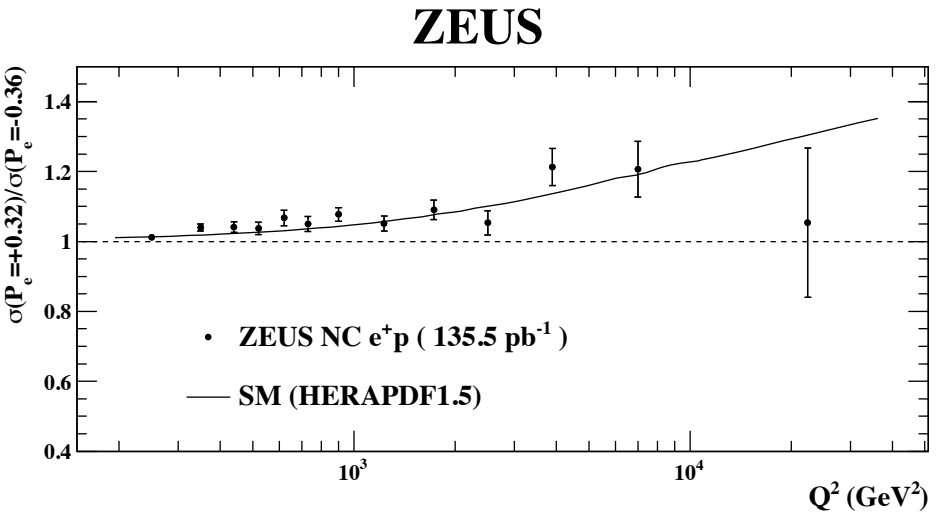


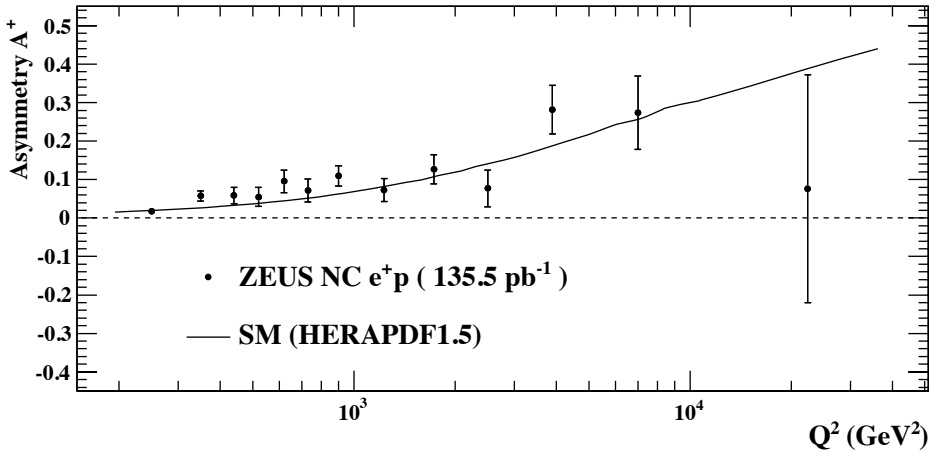
- Very pure signal, good agreement with MC expectations
- Reduced Cross sections (corrected to P=0) well described by SM predictions (HERAPDF1.5)

arXiv:1208.6138 (→EPJC)

Final ZEUS HERA-II NC e^+p cross sections







- Improved determination of $F_3^{\gamma Z}$
- Parity violation demonstrated down to scale 10^{-18} m

Summary

HERA remains our main source of information on proton structure

Recent combined results of the H1 and ZEUS Collaborations have allowed to determine proton's PDFs with an unprecedented precision

Most of the improvements in the understanding of the PDFs, described here, are very relevant for the physics program of the LHC

Final High Q^2 NC and CC HERA II Cross sections now published.
Final HERA combinations and QCD Analysis being worked on.

For additional information and results please refer to:
https://www.desy.de/h1zeus/combined_results/

Measurement of $F_2^{\gamma Z}$, $F_3^{\gamma Z}$

$F_2^{\gamma Z}$:

$$\frac{\sigma^{\pm}(P_L^{\pm}) - \sigma^{\pm}(P_R^{\pm})}{P_L^{\pm} - P_R^{\pm}} = \frac{\kappa Q^2}{Q^2 + M_Z^2}\left[\mp a_e F_2^{\gamma Z} + \frac{Y_-}{Y_+} v_e x F_3^{\gamma Z} - \frac{Y_-}{Y_+}\frac{\kappa Q^2}{Q^2 + M_Z^2}(v_e^2 + a_e^2) x F_3^Z\right]$$

$F_3^{\gamma Z}$:

$$x\tilde{F}_3 = \frac{Y_+}{2Y_-}(\tilde{\sigma}^{e^- p} - \tilde{\sigma}^{e^+ p}). \qquad x\tilde{F}_3 \simeq -a_e \chi_Z x F_3^{\gamma Z}.$$