HELMHOLTZ GEMEINSCHAFT

Bundesministerium für Bildung und Forschung

Structure Functions and PDF determination at HERA

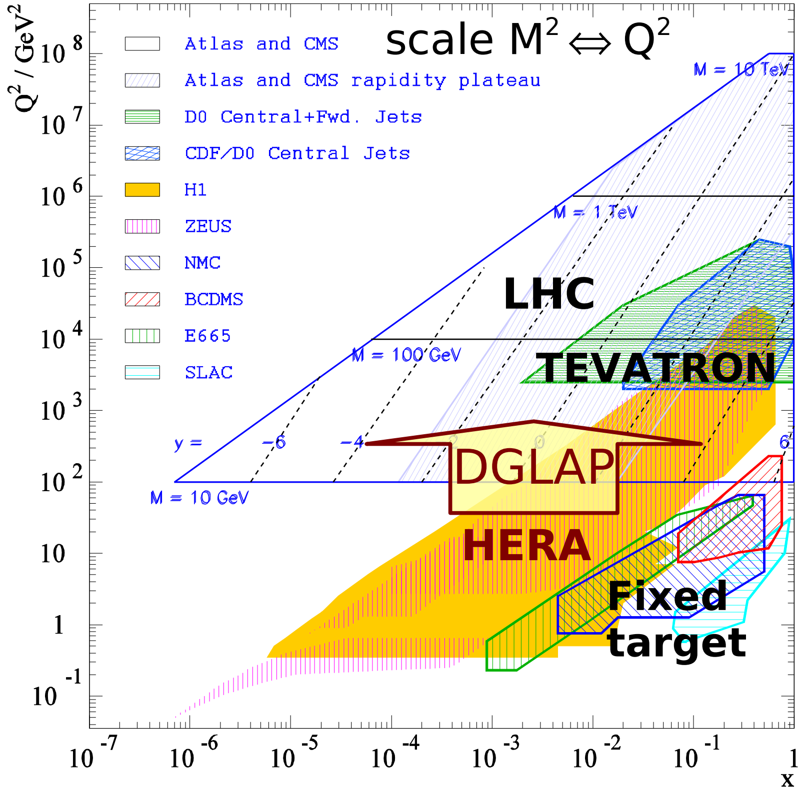
Ringailė Plačakytė
DESY
on behalf of H1 and ZEUS collaborations

- Introduction
- HERA structure function data
- PDF determination at HERA
- HERAFitter project
- Summary

Introduction

HERA is worlds only $e^{\pm}p$ collider
→ provides unique opportunity to study the structure of the proton

HERA covers x range of the LHC
evolution in Q^2 via DGLAP



- $e^{\pm}$(27.5 GeV), p(460-920 GeV)
  $\sqrt{s}$ = 225-318 GeV

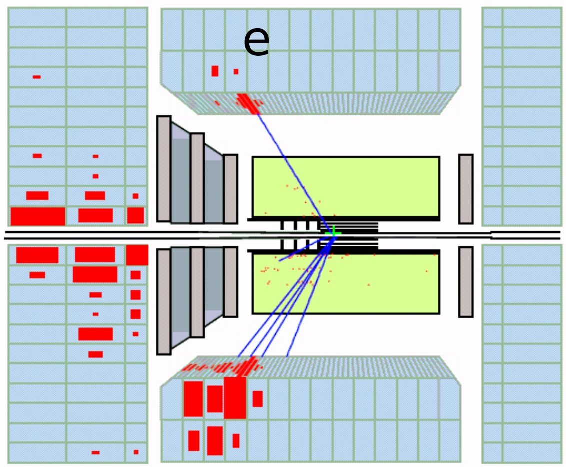
  1994-2000: HERA I data
  2003-2007: HERA II data

- Two collider experiments: H1 and ZEUS
- ~0.5 fb^{-1} of luminosity recorded by each experiment

ep Scattering at HERA

DIS cross sections provide an access to parton distribution functions in proton:

Neutral Currents



$$\frac{d^2\sigma_{NC}^{e^\pm p}}{dx dQ^2} = \frac{2\pi\alpha^2}{xQ^4}\left[Y_+ \tilde{F}_2^\pm \mp Y_- x\tilde{F}_3^\pm - y^2 \tilde{F}_L^\pm\right]$$

dominant contribution

important at high Q^2

sizable at high y

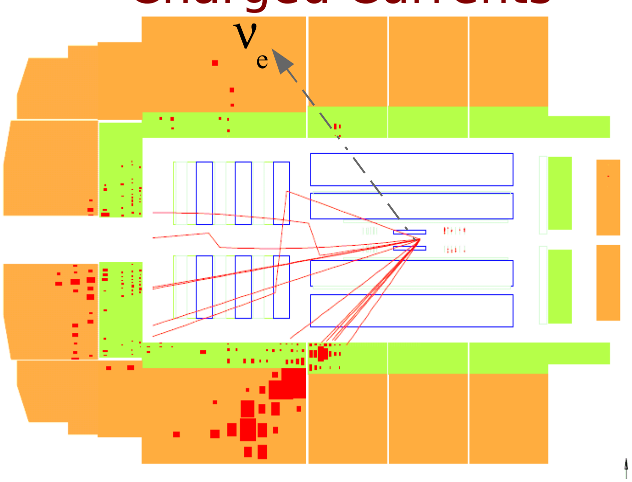
$$Y_\pm = 1 \pm (1-y)^2$$

PDFs

LO: $F_2 \approx x\sum e_q^2 (q+\bar{q})$ (in NLO $(\alpha_s g)$ appears)

$xF_3 \approx x\sum 2e_q a_q (q-\bar{q})$

Charged Currents



In LO e^+/e^- charged current cross sections are sensitive to different quark densities:

$$e^+ : \quad \tilde{\sigma}_{CC}^{e^+p} = x[\overline{u} + \overline{c}] + (1-y)^2 x[d+s]$$

$$e^- : \quad \tilde{\sigma}_{CC}^{e^-p} = x[u + c] + (1-y)^2 x[\overline{d}+\overline{s}]$$

HERA Structure Function Data

arXiv:1208:6138 NEW
EPJC 62 (2009) 625
EPJC 70 (2010) 945
EPJC 61 (2009) 223
JHEP 1209:061 (2012) NEW

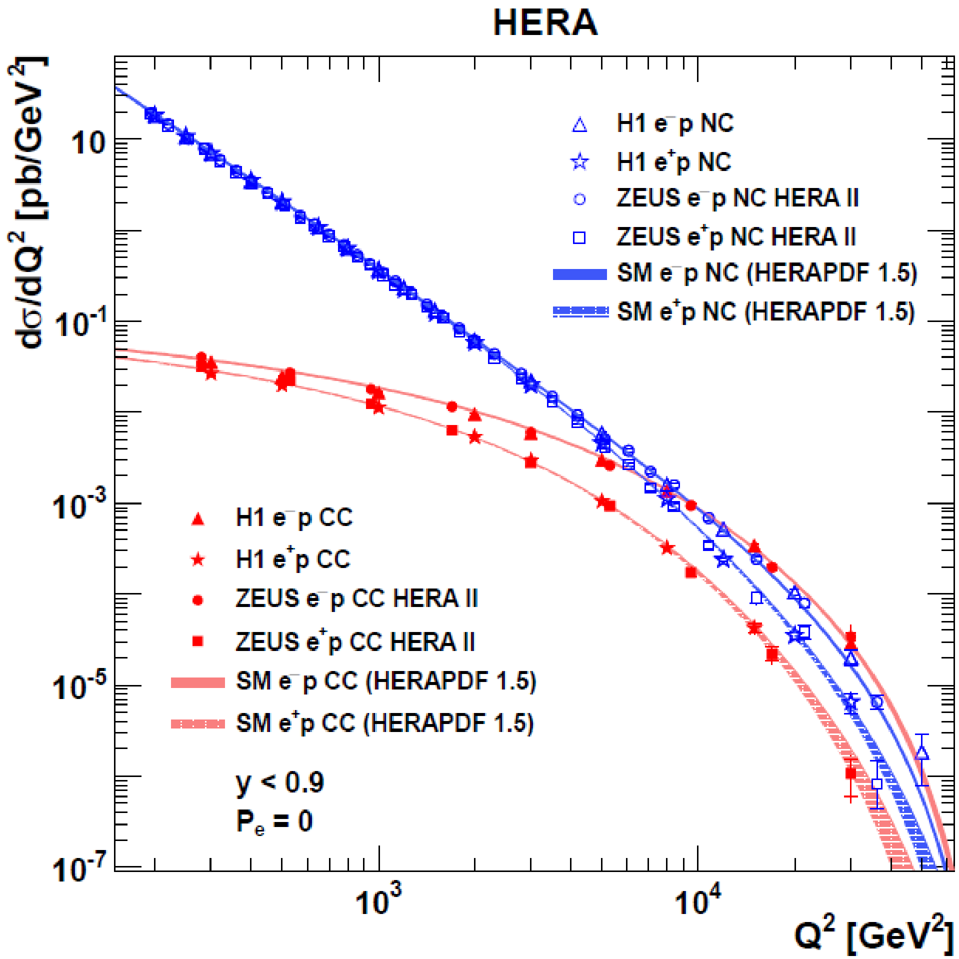
Inclusive HERA I and II data

with typical precision:
NC: ~1.5%
CC: ~4%

neutral (γ/Z)
charged ($W^{\pm}$)
currents cross sections
at $Q^2 \gtrsim M^2_{Z/W}$ scale
get similar:

EW unification

good agreement with
SM (HERAPDF 1.5)



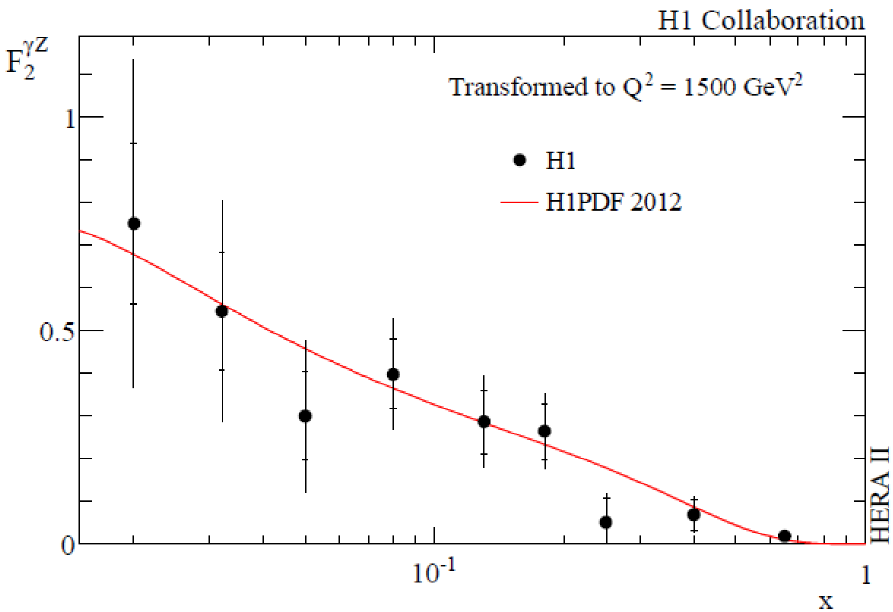
Highlights from High Q^2 NC Measurement

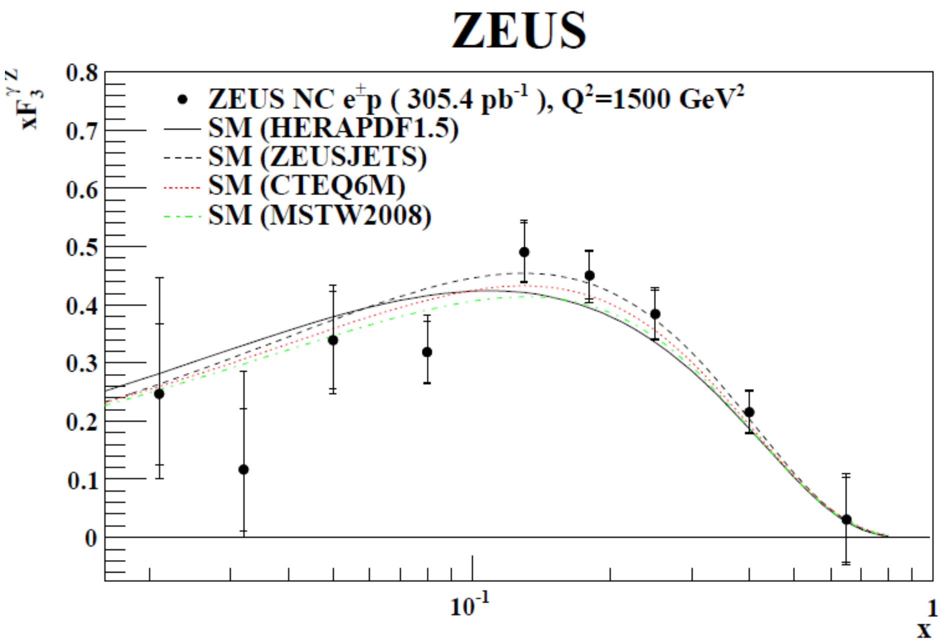
JHEP 1209:061 (2012) NEW

arXiv:1208:6138 NEW

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

Improved $xF_3^{\gamma Z}$ measurement





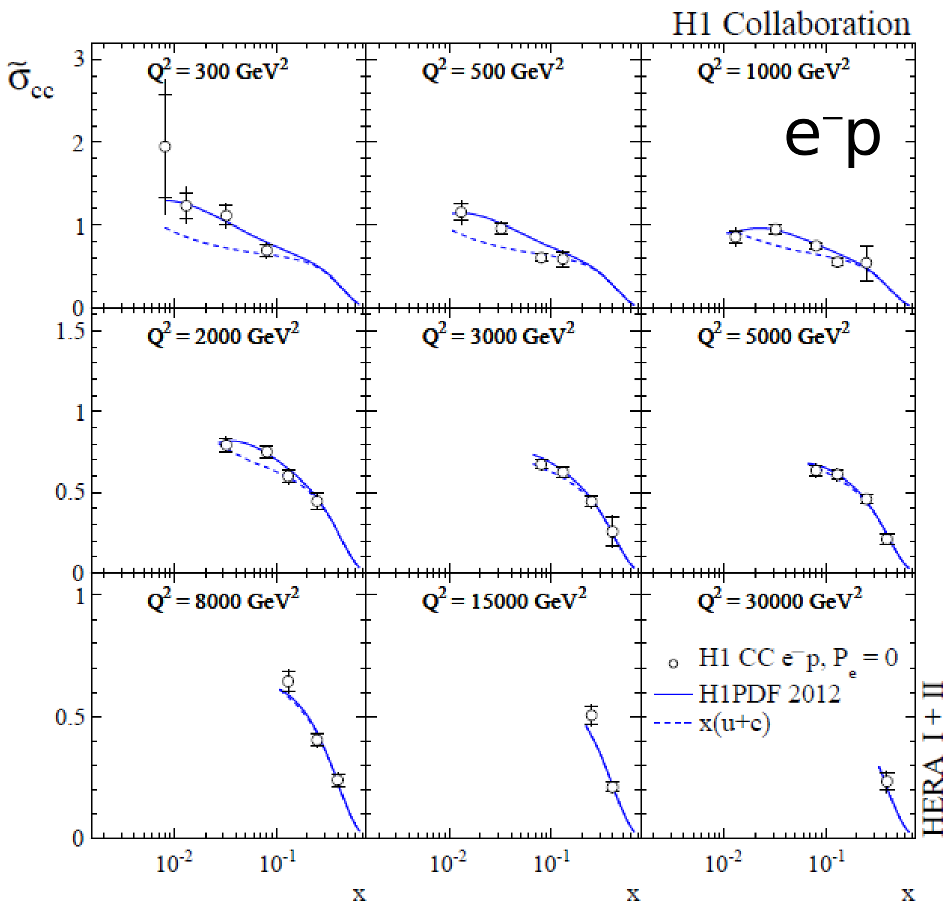
→ provide sensitivity to parton compositions:

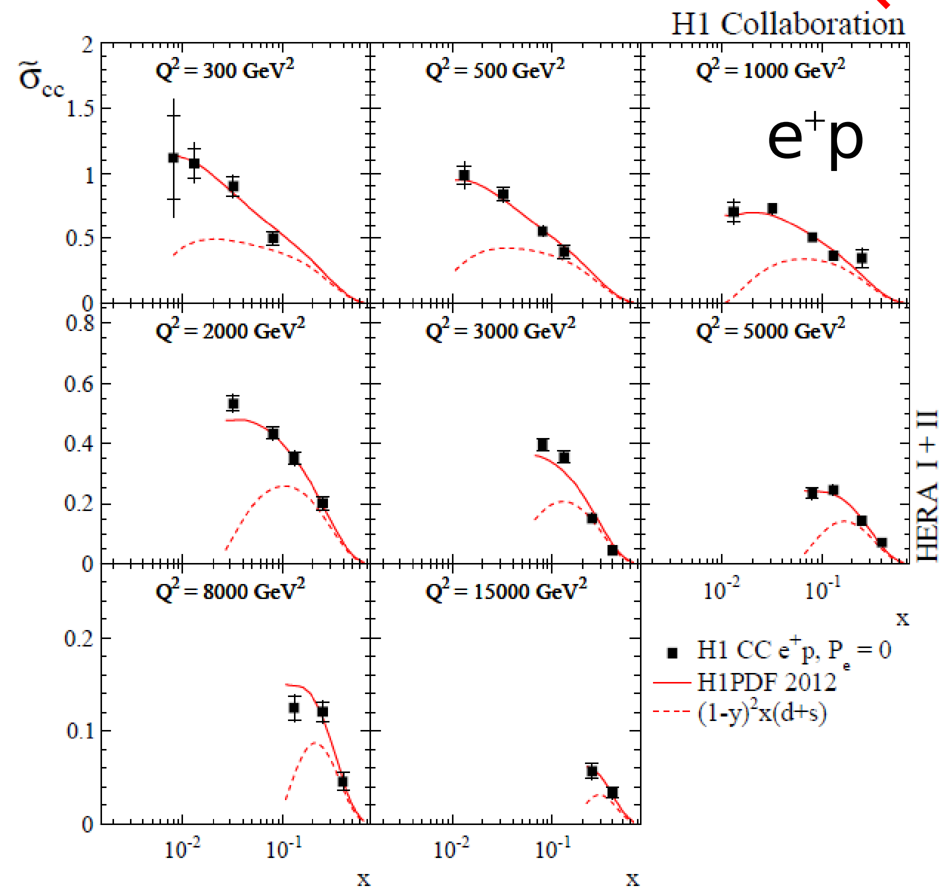
$F_2^{\gamma Z} \sim q+\bar{q}$ $xF_3^{\gamma Z} \sim xq_{val}$

H1PDF2012- fit to final H1 NC, CC data

Highlights from High Q^2 CC Measurement

JHEP 1209:061 (2012) NEW





HERA CC e^+/e^- measurements:

→ sensitivity to quark flavour

→ improvement in precision: *$e^+(e^-)p$* factor of 3(10) luminosity vs HERA I

HERAPDFs: Overview

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

provide NLO and NNLO predictions compatible with other PDF groups

Overview of HERAPDFs:

DATA	PDF set	
H1-ZEUS CC,NC HERAI	HERAPDF1.0 (NLO,NNLO)	
H1-ZEUS CC,NC HERAI+(prel.)II	HERAPDF1.5 (NLO,NNLO)	*recommended*
CC,NC HERAI+(prel.)II +jets	HERAPDF1.6	
CC,NC HERAI +charm	HERAPDF1.0+charm	
All data above	HERAPDF1.7	
Ongoing: H1-ZEUS HERAI+II	HERAPDF2.0 (NLO,NNLO)	

HERAPDF strategy and settings

NLO,NNLO DGLAP evolution (QCDNUM, arXiv:1005.1481)

PDFs parametrised (at starting scale Q^2_0) by:

$$xf(x,Q_0^2) = Ax^B(1-x)^C(1+Dx+Ex^2)$$

A: overall normalisation
B: small x behavior
C: $x \to 1$ shape

- apply quark number and momentum sum rules

Fitted PDFs: xg, xu_v, xd_v, $x\bar{U}=x\bar{u}(+x\bar{c})$, $x\bar{D}=x\bar{d}+x\bar{s}(+x\bar{b})$

The optimal number of parameters chosen when no further improvements in the χ^2 are observed

- more flexible paramerisation than in HERAPDF1.0 used in fits with HERA II data

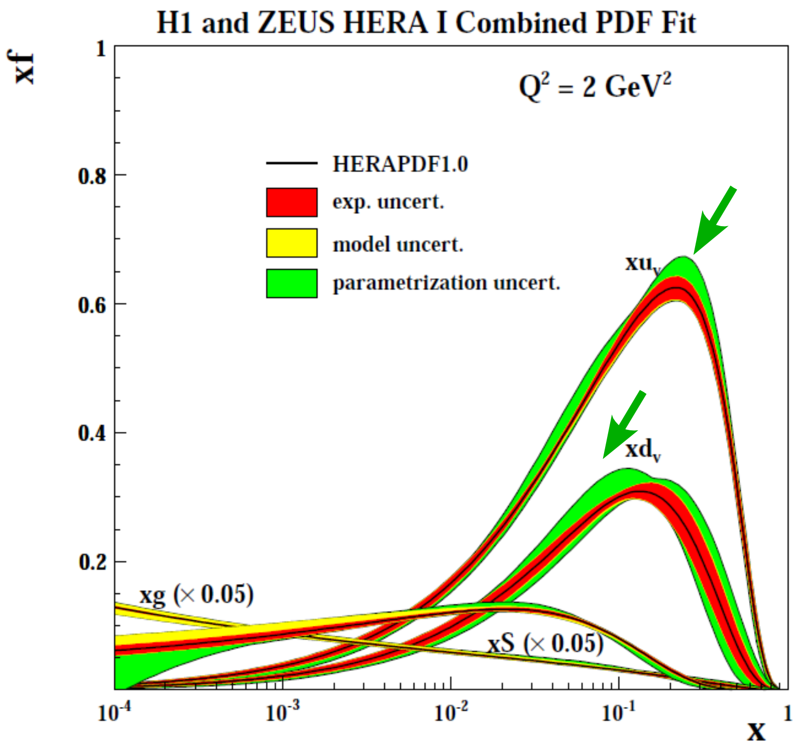
$Q^2_0 = 1.9$ GeV^2, $\alpha_s = 0.1176$, $Q^2_{min} = 3.5$ GeV^2, different HF schemes (RT in HERAPDF1.0)

Uncertainties separated into:

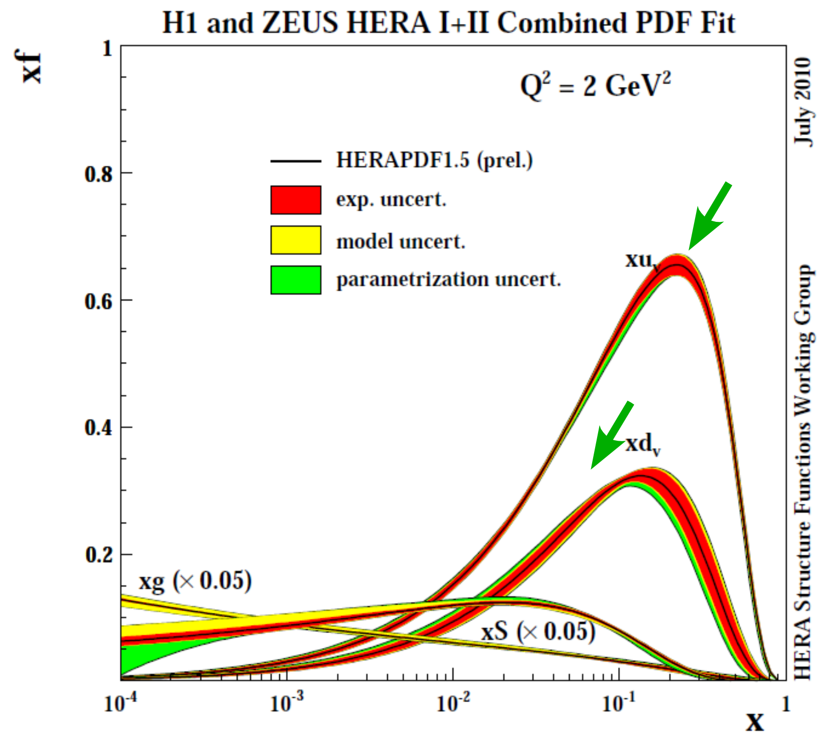
experimental	small uncertainties ($\Delta\chi^2=1$)
model	evaluated from variation of model parameters: Q^2_{min}, f_s, m_C, m_B
parametrisation	results from different parametrisation assumptions

HERAPDF1.0 and 1.5

HERA I



HERA I + II

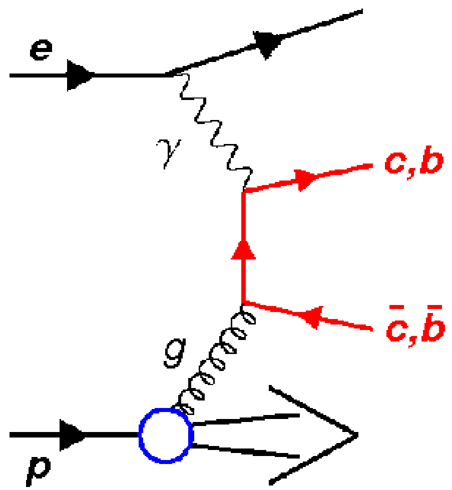


Reduced uncertainties in HERAPDF1.5 (mainly valence quarks)

Inclusion of Charm Data

Eur.Phys. J. C73 (2012), 2311 NEW

LO charm production at DIS (boson-gluon-fusion):



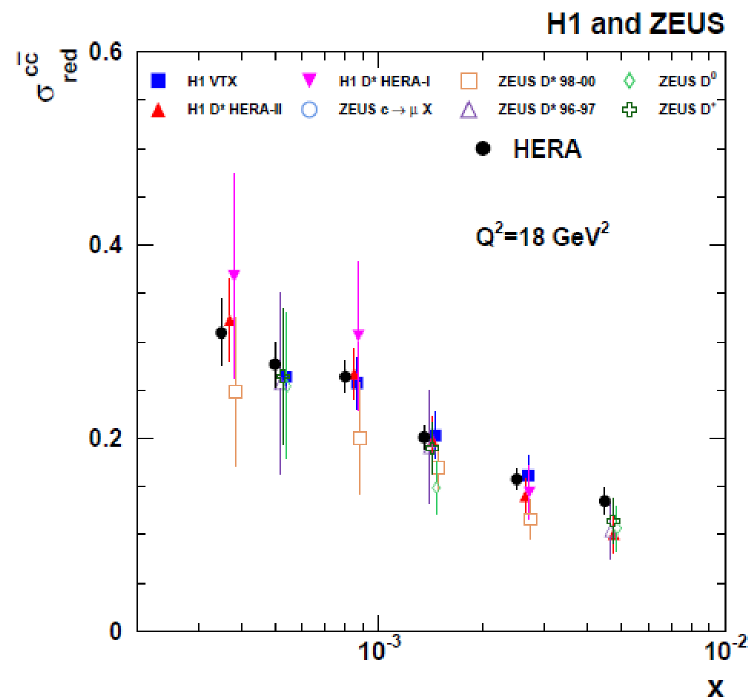
Direct access to the gluon

Heavy quark (HQ) treatment in PDFs is important

Useful to study the influence of different heavy flavour schemes on the PDFs

Combined HERA charm measurement

→ combination of 9 H1 and ZEUS measurements

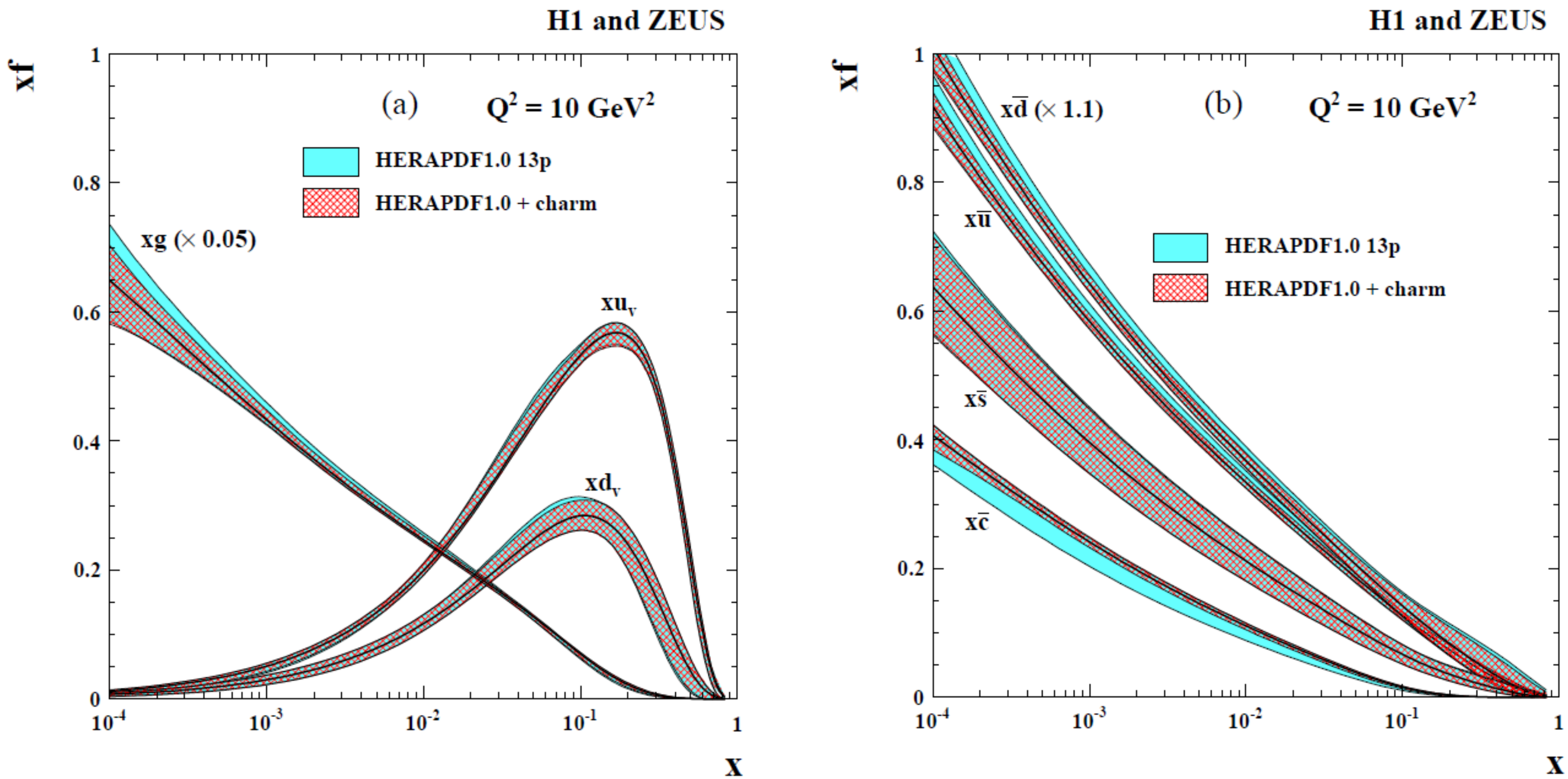


→ covers $2.5 < Q^2 < 2000$ GeV^2 and $10^{-5} < x < 10^{-1}$

→ 5-10% uncertainty

Charm Data: Impact on PDFs

Eur.Phys. J. C73 (2012), 2311 NEW



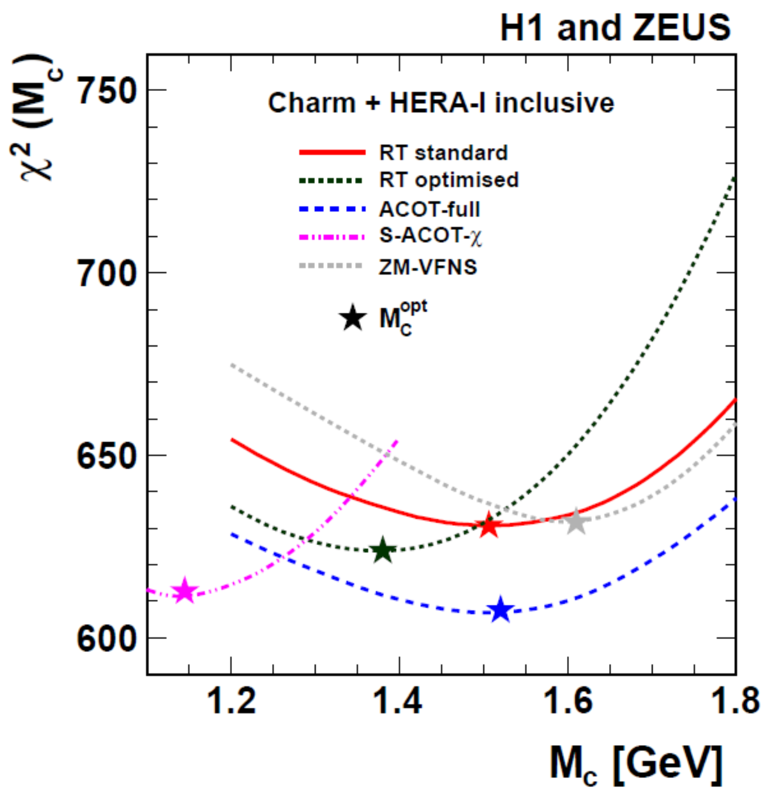
→ uncertainty on g(x), c(x) and light sea reduced

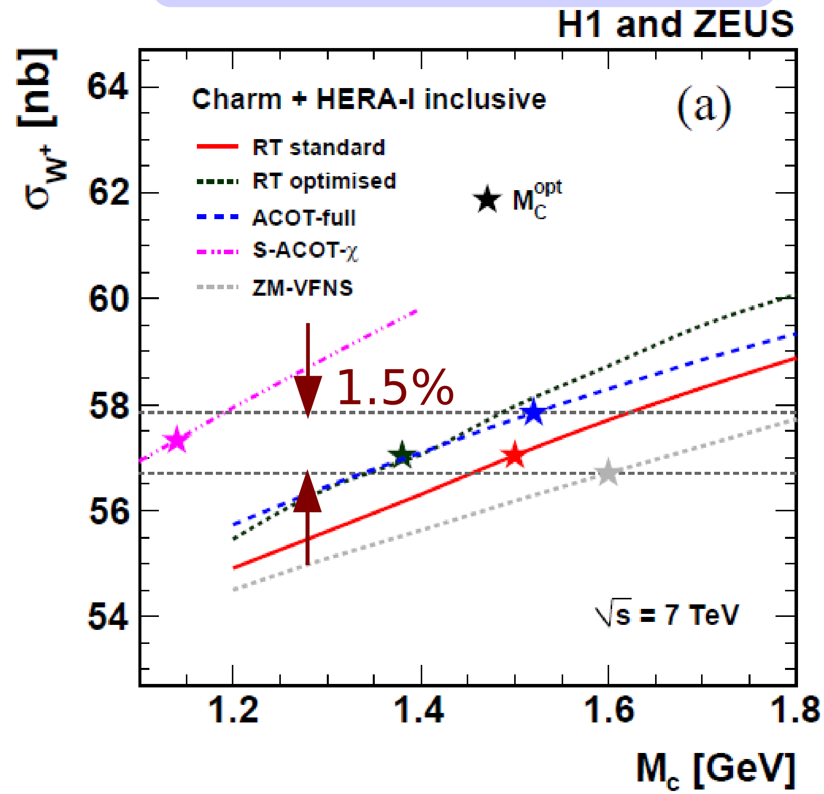
→ impact on Z, W production at LHC (next slide)

QCD Analysis of Charm Data

Eur.Phys. J. C73 (2012), 2311 NEW

W$^+$ cross section@LHC





Different schemes prefer different m_c^{model}

Variation between schemes ~6%
Significantly reduced at m_c^{model} (opt) (★)

HERA charm measurements help to reduce uncertainties of predictions for the LHC

QCD Analysis of Charm Data

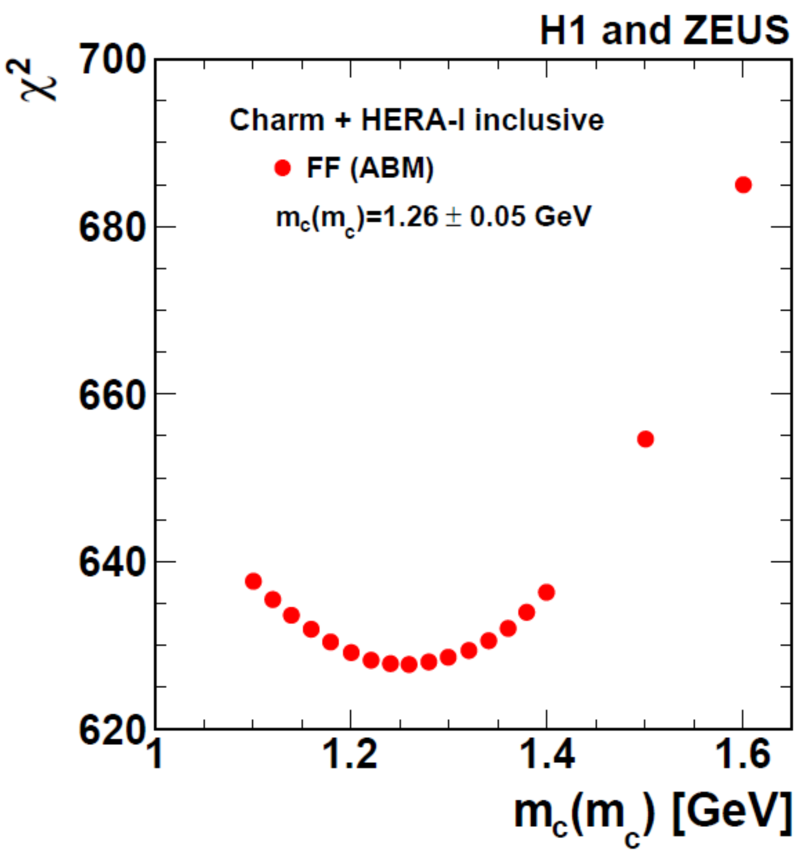
Eur.Phys. J. C73 (2012), 2311 NEW

In VFN schemes the charm quark mass parameter M_c does not correspond directly to a physical mass
→ not the case for Fixed-Flavour Number Scheme (FFNS)

An NLO QCD analysis in the FFNS
(FFNS of ABM, arXiv:1011.5790)
performed to determine the $\overline{\text{MS}}$
running charm quark mass $m_c(m_c)$

$$m_c(m_c) = 1.26 \pm 0.05_{\text{exp}} \pm 0.03_{\text{mod}} \pm 0.02_{\text{param}} \pm 0.02_{\alpha_s} \text{ GeV}$$

In agreement with the world average of
$m_c(m_c) = 1.275 \pm 0.025$ GeV



HERAFitter Project

HERAFitter: a set of PDF fitting tools for determination of the parton distribution functions

→ open source, everyone is free to download and use it

→ developers: H1 and ZEUS, ATLAS, CMS, LHCb, active support by theory groups

HERAFitter-0.1.0: Sept 2011, HERAFitter-0.2.0: May 2012, HERAFitter-0.3.0: March 2013

Search Titles Text

HERAFitter

HERAFitt../../FitForumM.. » HERAFitt../HERAFitterMe.. » HERAFitt../../Meeting20.. » HERAFitt../../Meeting20.. » HERAFitter

Wiki
- WikiPolicy
- RecentChanges
- FindPage
- HelpContents
- HERAFitter

Page
- Edit (Text)
- Edit (GUI)
- Info
- Subscribe
- Add Link
- Attachments
- More Actions:

HERAFitter

Welcome to HERAFitter

HERAFitter is a set of PDF fitting tools initialy developed jointly by the H1 and ZEUS collaborations for determination of the parton density functions and currently extended to LHC experiments and theory groups. Independent developers are also encouraged to add their contribution to the package. The HERAFitter codes were used to obtain the HERAPDF sets.

Downloads of HERAFItter software package

New HERAFitter release is available! The HERAFitter releases can be accessed HERE upon registration. Everyone is free to register.

Registration

To register, please log in (upper right corner) by creating an account (firstnamelastname, example: JohnSmith) and send your request and login name to herafitter-help@desy.de.

HERAFitter Meetings

- User's Meetings: monthly meetings to enhance communication between users and developers (open access)
- Developer's Meeting: technical weekly meetings to ensure communication among developers (restricted access)
- Steering Group's Meeting (restricted access)

Developers Info (restricted to developers)

Internal Developments

Organisation

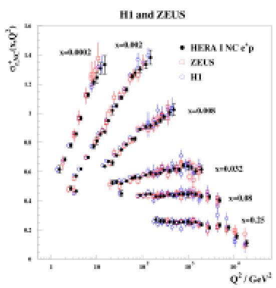
- **Conveners:** Voica Radescu, Ringaile Placakyte, Amanda Cooper-Sarkar
- **Release coordinator:** Sasha Glazov
- **Contact Persons:** Klaus Rabbertz (CMS), Bogdan Malaescu (ATLAS), Olaf Behnke (ZEUS), Cristi Diaconu (H1), Ronan McNulty (LHCb)
- **Steering Group:** Voica Radescu, Ringaile Placakyte, Sasha Glazov, Amanda Cooper-Sarkar, , Gavin Salam (theory), Klaus Rabbertz (CMS), Bogdan Malaescu (ATLAS), Ronan McNulty (LHCb), Olaf Behnke (ZEUS), Cristi Diaconu (H1, chair)
- **Librarians:** authors/developers of individual modules
- **Getting help**: Send email to herafitter-help@desy.de

www.herafitter.org

HERAFitter: Structure

Modular structure of HERAfitter:

experimental data



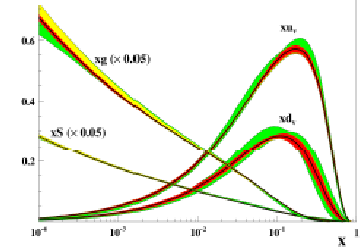
Data: HERA, Tevatron, LHC, fixed target experiments

Processes:
- Inclusive DIS, Jets, Diffraction
- Drell-Yan, Top production
- W and Z production

theory calculations

Heavy Flavour schemes:	MSTW, CTEQ, ABM
Jets, W, Z:	FastNLO, Applgrid
Top:	Hathor
Evolution:	QCDNUM, k_T scheme
Other:	NNPDF reweighing Dipole model

HERAFitter



Parton Density Functions (PDF, DPDF, uPDFS)

$\alpha_s(M_Z)$, m_c, m_b, m_t ...

Theoretical cross sections

Comparisons to other PDFs (lhapdf)

Global benchmarking platform for PDFs and QCD

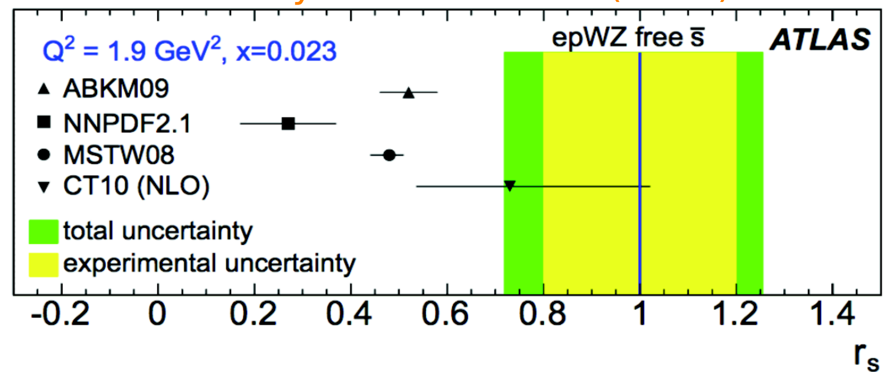
HERAFitter: Usage examples

The differential $W^{\pm}$, Z cross section data of ATLAS (2010, 35/pb) were jointly analysed with $e^{\pm}p$ cross sections from HERA

→ ratio of W/Z cross sections together with y_Z shape provide a constraint on s-quark density

$$r_s = 0.5(s+\bar{s})/\bar{d}$$

Phys.Rev.Lett. 109 (2012) 012001

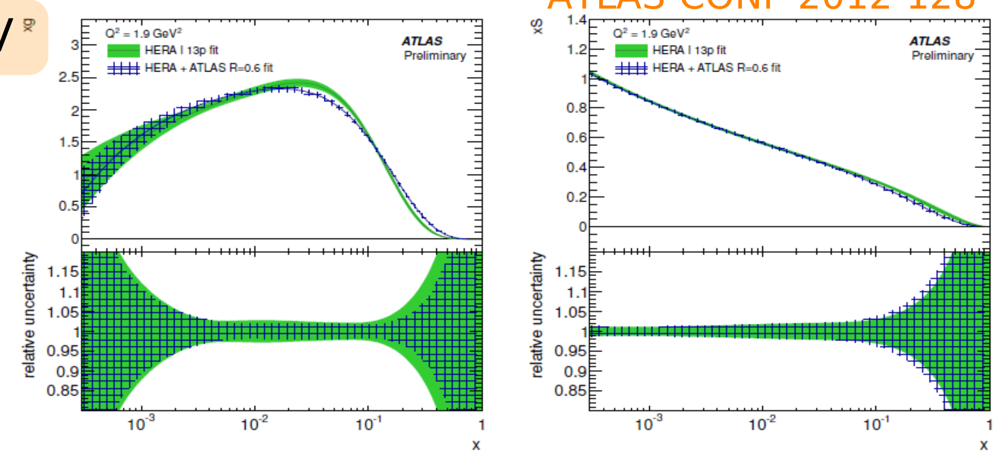


Inclusive jet cross section at 2.76 TeV

- in ratio with inclusive jet cross sections at 7 TeV systematic uncertainties are significantly reduced

→ precise NLO QCD test

ATLAS-CONF-2012-128



(a) xg (b) xS

→ Similar analyses are being performed at CMS

Summary

HERA provides unique determinations of the proton structure and compatible NLO and NNLO predictions with other PDF groups

→ published final HERA II CC,NC data
→ H1-ZEUS combination and HERAPDF2.0 determination ongoing

→ HERA jet and charm data provide additional constrains on gluon density and α_s, charm data help to reduce uncertainties of W,Z predictions at LHC

HERAFitter is open source QCD fit framework supported by many theory and experimental (H1, ZEUS, ATLAS, CMS, LHCb) groups

→ has the potential to increase the scientific output of the LHC data and to provide a flexible environment for theory benchmarking

→ well integrated in the LHC analyses

www.herafitter.org

HERAFitter mail-support: herafitter-help@desy.de
Monthly users' meetings: https://www.herafitter.org/HERAFitter/HERAFitter/HERAFitterMeetings (next meeting: 26.03.2013)

Back-up slides

HERA Structure Function Data

HERA I inclusive data

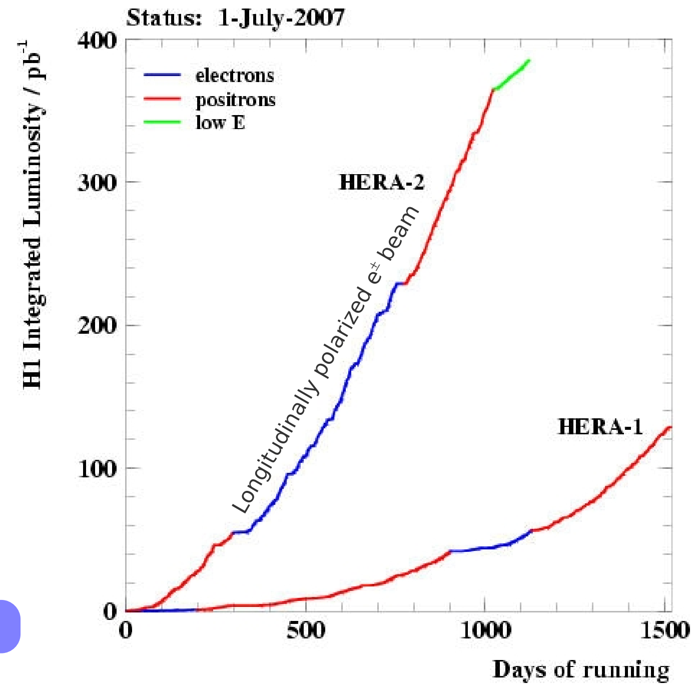
→ combination of H1 and ZEUS sets

JHEP 1001:109 (2010)

HERA II inclusive data

→ combination of preliminary H1 and ZEUS sets

→ new published data



- full HERA II NC and CC data JHEP 1209:061 (2012)
- increase of integrated luminosity by factor of 3(10) for e+(e-)p sets
- significantly improved systematic uncertainties
- integrated luminosity determined with elastic QED Compton events

Eur.Phys. J. C72 (2012), 2163

- last e+p NC period EPJC 12 08 066

→ currently in process of combination (H1 and ZEUS, HERA I and II)

HERA Structure Function Data

Latest H1 and ZEUS publications:

- Inclusive deep inelastic scattering at high Q2 with longitudinal polarised lepton beams at HERA
  JHEP **1209**, 2012, 061, [arXiv:1206.7007]
- Determination of the integrated luminosity at HERA using elastic QED Compton events,
  Eur. Phys. J. C72 (2012) 2163, [arXiv:1205.2448]
- Combination and QCD Analysis of Charm Production Cross Section Measurements in Deep-Inelastic ep Scattering at HERA, DESY-12-172, Eur. Phys. J. C (2013) 73: 2311, [arXiv:1211.1182].
- Measurement of high-Q2 neutral current deep inelastic e+p scattering cross sections with a longitudinally polarised positron beam at HERA, EPJC-12-08-066, [arXiv:1208.6138]

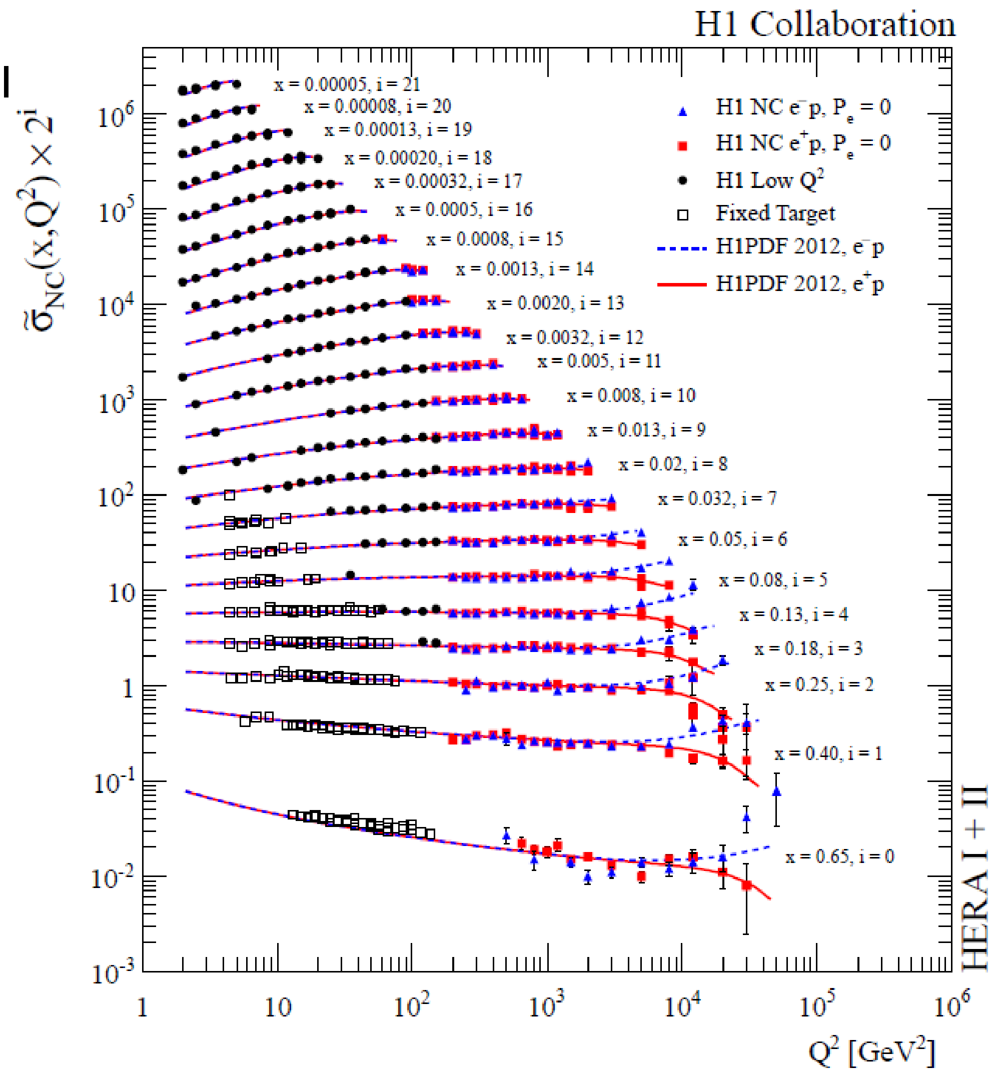
High Q^2 NC Cross Sections

Combination of high Q^2 data HERA-I and HERA-II

H1 precision 1.5% for $Q^2 < 500$ GeV^2
→ factor 2 reduction in error vs HERA-I

At high Q^2 difference between e^- and e^+: xF_3
(sensitive to valence PDFs)

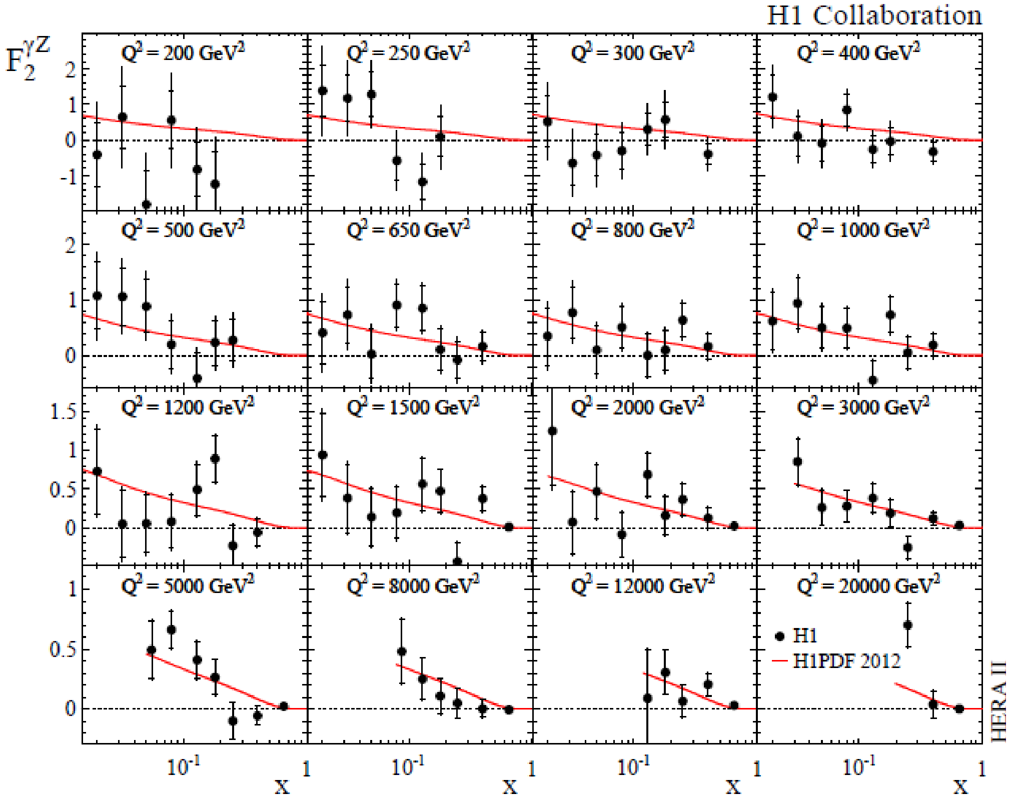
$$x\tilde{F}_3 = \frac{Y_+}{2Y_-}(\tilde{\sigma}^-_{NC} - \tilde{\sigma}^+_{NC})$$

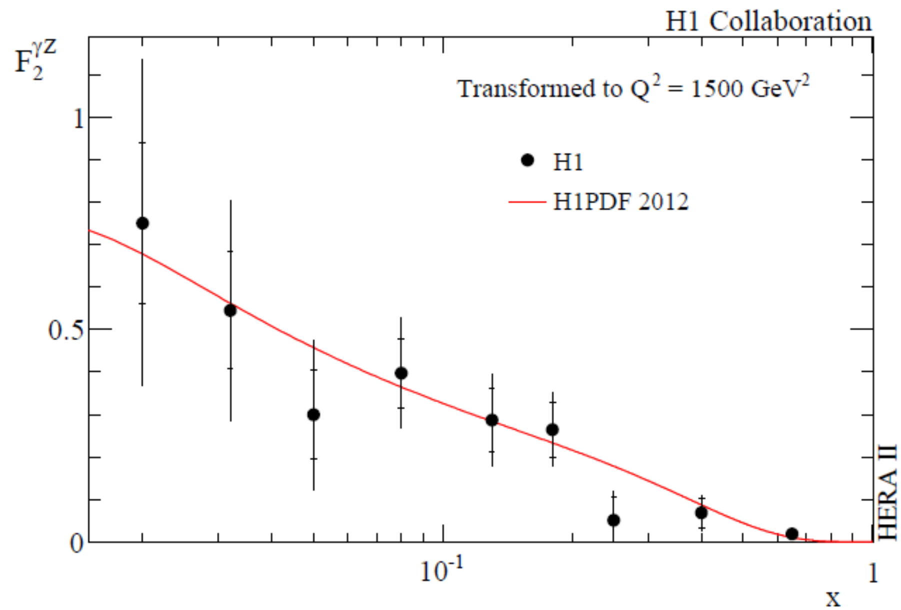


High Q^2 NC Cross Sections

Measuring the difference in NC polarised cross sections $F_2^{\gamma Z}$ can be accessed:

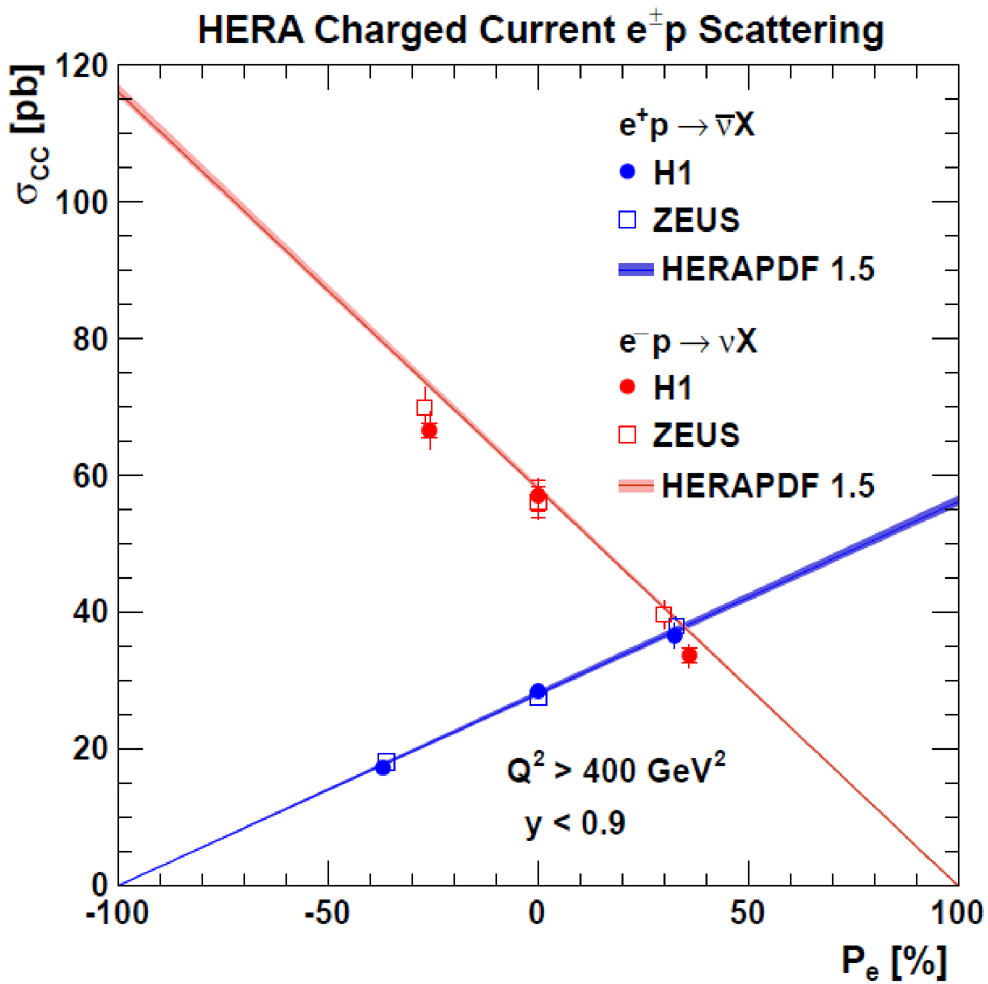
$$\frac{\sigma^{\pm}(P_L^{\pm}) - \sigma^{\pm}(P_R^{\pm})}{P_L^{\pm} - P_R^{\pm}} = \frac{\kappa Q^2}{Q^2 + M_Z^2}\left[\mp a_e F_2^{\gamma Z} + \frac{Y_-}{Y_+} v_e x F_3^{\gamma Z} - \frac{Y_-}{Y_+}\frac{\kappa Q^2}{Q^2 + M_Z^2}(v_e^2 + a_e^2) x F_3^Z\right]$$





High Q^2 CC Cross Sections

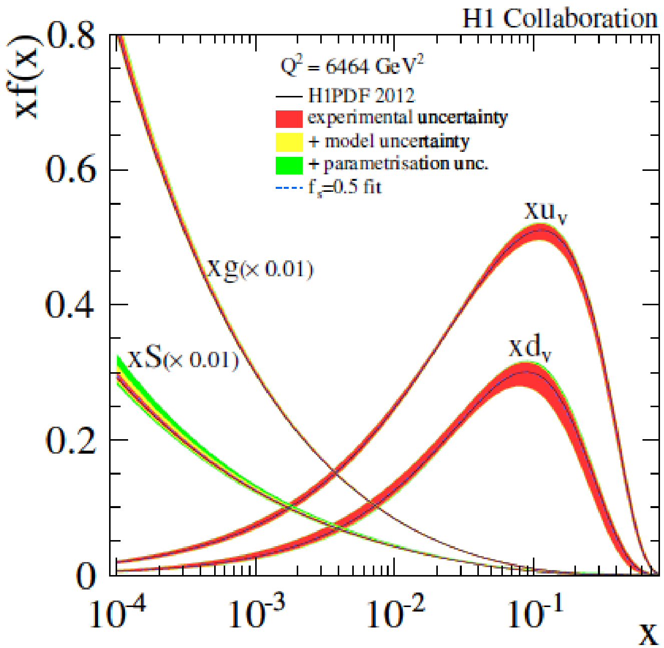
Final measurement of polarisation dependence of CC cross sections from H1 and ZEUS

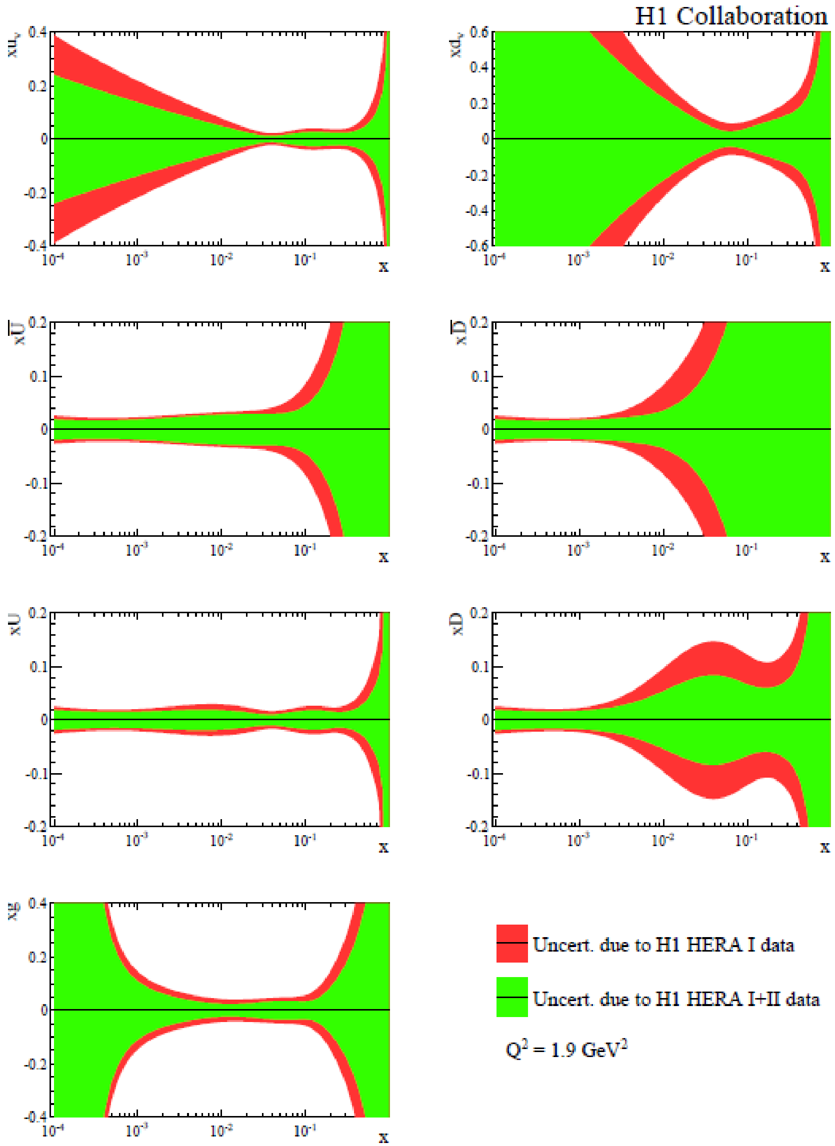


H1PDF2012

QCD analysis of final H1 NC, CC data using HERAFitter

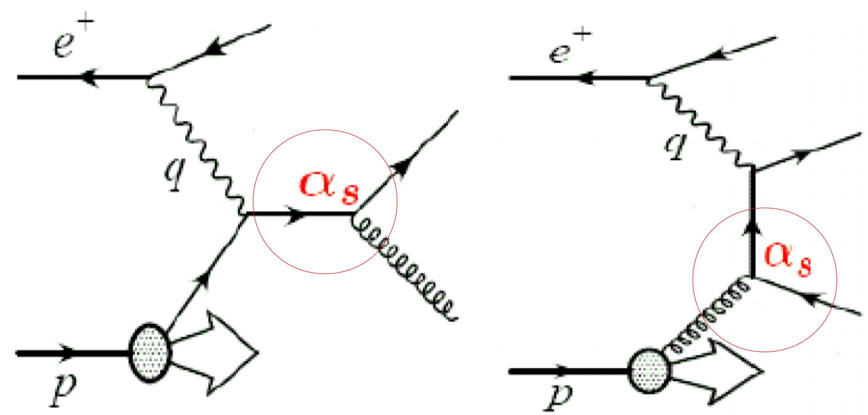
→ improvement in precision for all PDFs in full x range in particular for down-type quarks xD





Inclusion of Jet Data: HERAPDF1.6

LO jet production in DIS:



Direct sensitivity to gluon and strong coupling constant

Reduce correlation of gluon and α_s in PDF fit

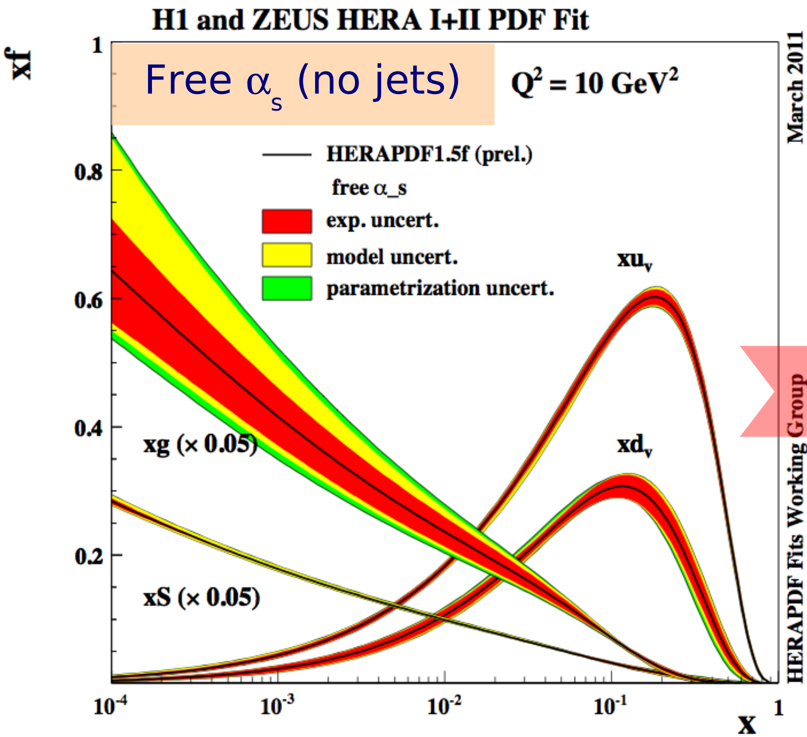
QCD fits with jet data

- allow to constrain simultaneously α_s and gluon

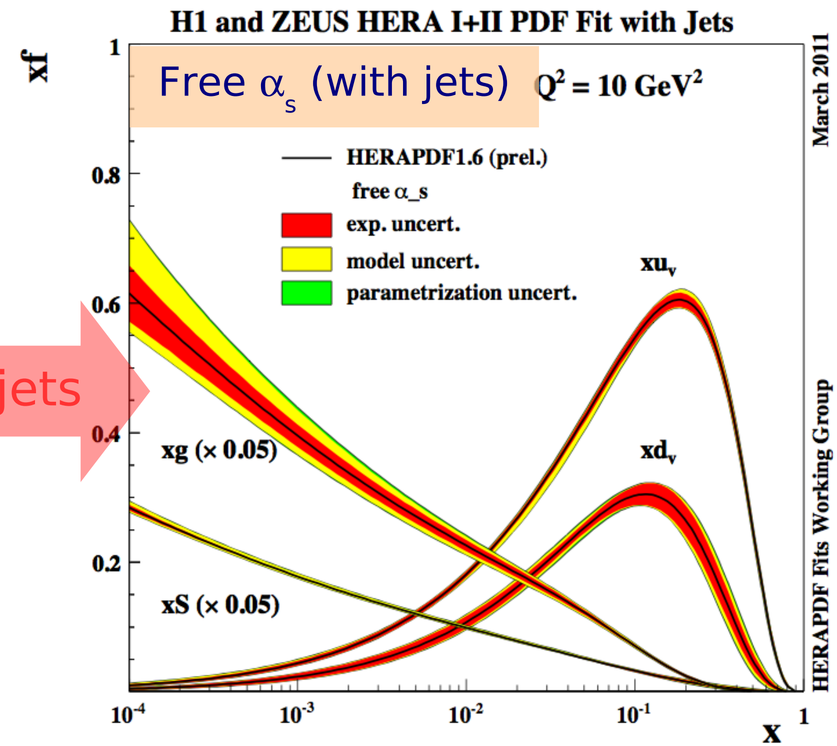
HERAPDF1.6:

CC, NC HERA I+(prel.)II + 4 inclusive jet measurements from H1 and ZEUS

Inclusion of Jet Data: HERAPDF1.6

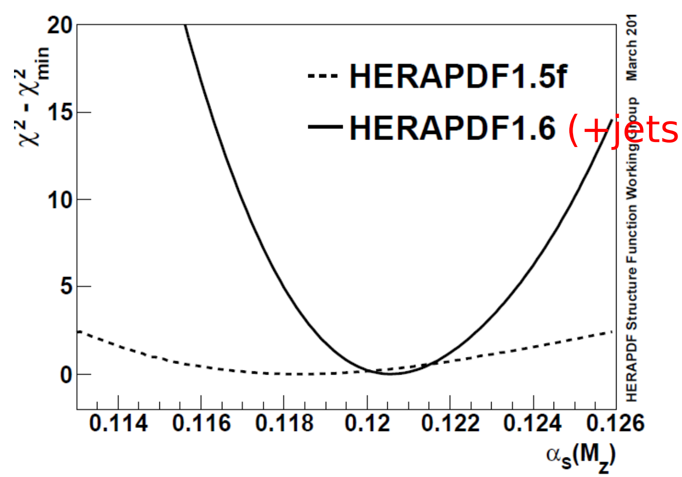


+ jets



HERA jet data allow to constrain simultaneously α_s and gluon

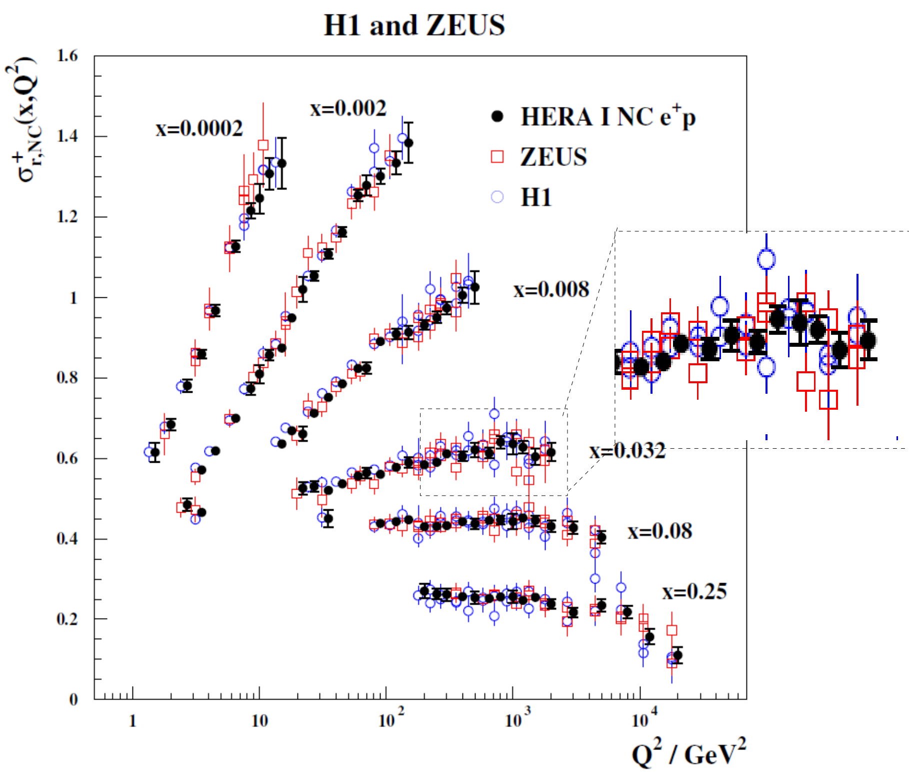
→ $\alpha_s(M_Z)=0.1202 \pm 0.0013(exp) \pm 0.0007(mod) \pm 0.0012(had)\ ^{+0.0045}_{-0.0036}(th)$

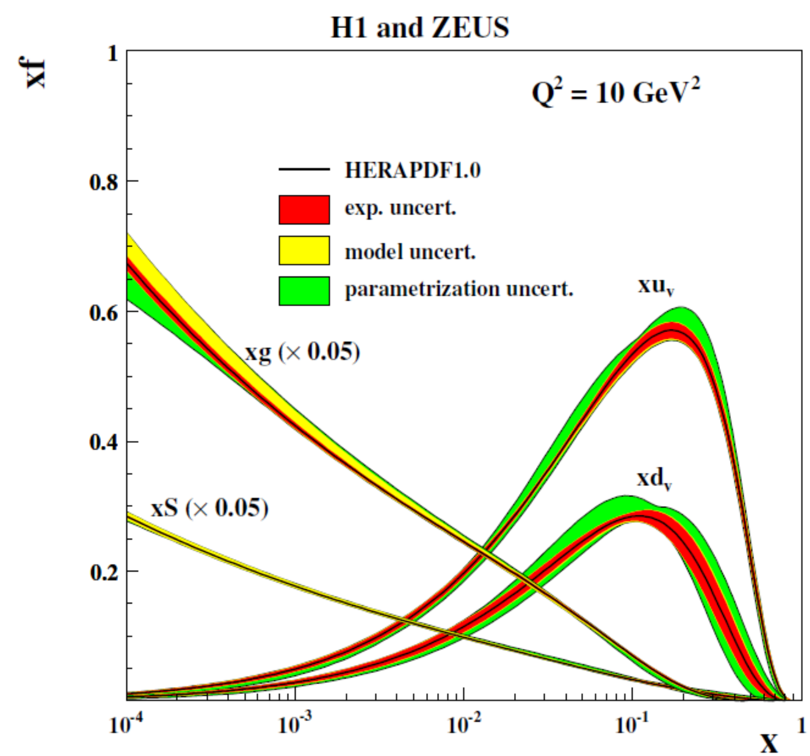


HERAPDF1.0

HERAPDF1.0: QCD fit to combined H1 and ZEUS HERA I CC,NC data

- ultimate precision (experiments cross calibrate each other)





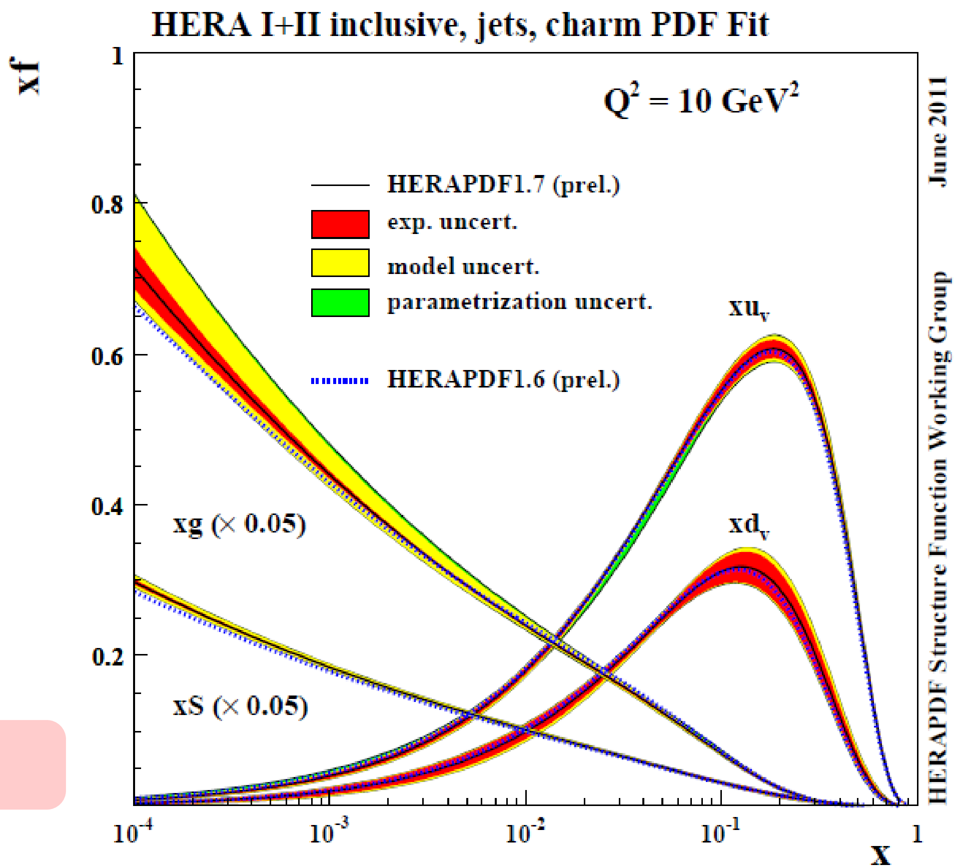
arXiv:0911.0884[hep-ex]   https://www.desy.de/h1zeus/combined_results/index.php

gluon – from F_2 scaling violation, F_L, *quarks* - from CC (flavour separation), NC

Inclusion of All Data: HERAPDF1.7

What if fit all HERA data?
- inclusive + jets + charm + low energy data → **HERAPDF1.7**
→ important consistency check

- flexible parametrisation (as in HERAPDF1.5f)
- heavy flavour treatment as in HERAPDF1.0
  → motivates for RT optimised at m_c^{model}(opt)
- strong coupling constant = 0.119 (as supported by the jet data)



All data sets are very compatible

Deep Inelastic Scattering (DIS)

Structure function factorisation:

each structure function can be written as a convolution of a hard-scattering coefficient C and non-perturbative parton distributions:

$$F_2^V(x,Q^2) = \sum_{i=q,\bar{q},g} \int_x^1 dz \times C_2^{V,i}\left(\frac{x}{z}, Q^2, \mu_F, \mu_R, \alpha_S\right) \times f_i(z, \mu_F, \mu_R)$$

determined using measured cross section

calculable in perturbative QCD

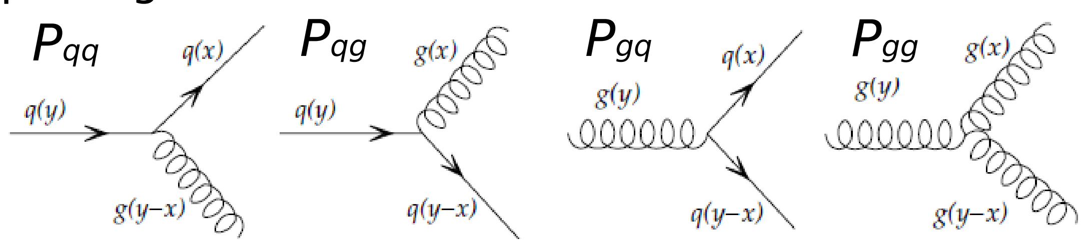
PDFs

PDF scale dependence is calculable in perturbative QCD (DGLAP evolution):

$$\frac{\partial q(x,Q^2)}{\partial lnQ^2} \propto \int_x^1 \frac{dz}{z}\left[q(z,Q^2)P_{qq}\left(\frac{x}{z}\right) + g(z,Q^2)P_{qg}\left(\frac{x}{z}\right)\right]$$

$$\frac{\partial g(x,Q^2)}{\partial lnQ^2} \propto \int_x^1 \frac{dz}{z}\left[q(z,Q^2)P_{gq}\left(\frac{x}{z}\right) + g(z,Q^2)P_{gg}\left(\frac{x}{z}\right)\right]$$

Probability via splitting functions:



PDF Determination

Experimentally measured $\sigma(x,Q^2) \rightarrow F_2(x,Q^2)$

Q^2 dependence of F_2 is given in pQCD (DGLAP evolution equations)

x-dependence of PDFs is not calculable in pQCD

- parametrise PDFs at the starting scale Q^2_0
- evolve PDFs using DGLAP equations to $Q^2 > Q^2_0$
- construct structure functions from PDFs and coefficient functions: predictions for every data point in (x, Q^2) – plane
- χ^2-fit to the experimental data

HERAPDF strategy and settings

DGLAP at NLO $\rightarrow$ QCD predictions

PDFs parametrised (at starting scale Q^2_0) using standard parametrisation form:

$$
\begin{aligned}
xg(x) &= A_g x^{B_g}(1-x)^{C_g}, \\
xu_v(x) &= A_{u_v} x^{B_{uv}}(1-x)^{C_{uv}}\left(1+E_{u_v}x^2\right), \\
xd_v(x) &= A_{d_v} x^{B_{dv}}(1-x)^{C_{dv}}, \\
x\bar{U}(x) &= A_{\bar{U}} x^{B_{\bar{U}}}(1-x)^{C_{\bar{U}}}, \\
x\bar{D}(x) &= A_{\bar{D}} x^{B_{\bar{D}}}(1-x)^{C_{\bar{D}}}.
\end{aligned}
$$

A: overall normalisation

B: small x behavior

C: $x \rightarrow 1$ shape

The optimal number of parameters chosen by saturation of the χ^2
- central fit with:
  10 free parameters for HERA I data
  13 for HERA I+II data

xg, xu_v, xd_v, $x\bar{U}$, $x\bar{D}$

where $x\bar{U}=x\bar{u}$ and $x\bar{D}=x\bar{d}+x\bar{s}$ at the starting scale ($x\bar{s}=f_s x\bar{D}$ with $f_s=0.31$)

A_g, A_{uv}, A_{dv} are fixed by sum rules

extra constrains for small x behavior of d- and u-type quarks:
$B_{uv}=B_{dv}$, $B_{\bar{U}}=B_{\bar{D}}$, $A_{\bar{U}}=A_{\bar{D}}(1-f_s)$ for $\bar{u}=\bar{d}$ as $x\rightarrow 0$

Data in PDF fits

DIS:

ep (HERA) data: quarks and gluon at small *x* (F_L), jets (moderate *x*), CC - flavour separation, heavy quark structure functions

fixed target data: higher *x*

neutrino DIS: flavour decomposition, *x*>0.01

Drell-Yan:

quark-antiquark annihilation – high *x* sea quarks, deuterium target – $\bar{u}/\bar{d}$ asymmetry

High Pt jets at colliders:

high *x* gluon

W/Z production:

different quark contributions

PDF Fit Groups

MSTW

– includes all type of data (not yet most recent HERA data). LO, NLO and NNLO

CTEQ

– includes all type of data (CT10 includes recent combined HERA data and more Tevatron data). NLO

NNPDFs

– includes all type of data (except HERA jets). NLO, recently also LO and NNLO

HERAPDF

– HERA (combined) data. NLO and NNLO

AB(K)M

– DIS and fixed target DY data. NLO and NNLO

GJR

– DIS, fixed target DY data and Tevatron jet data. NLO and NNLO (no jets)

PDF Fit Groups

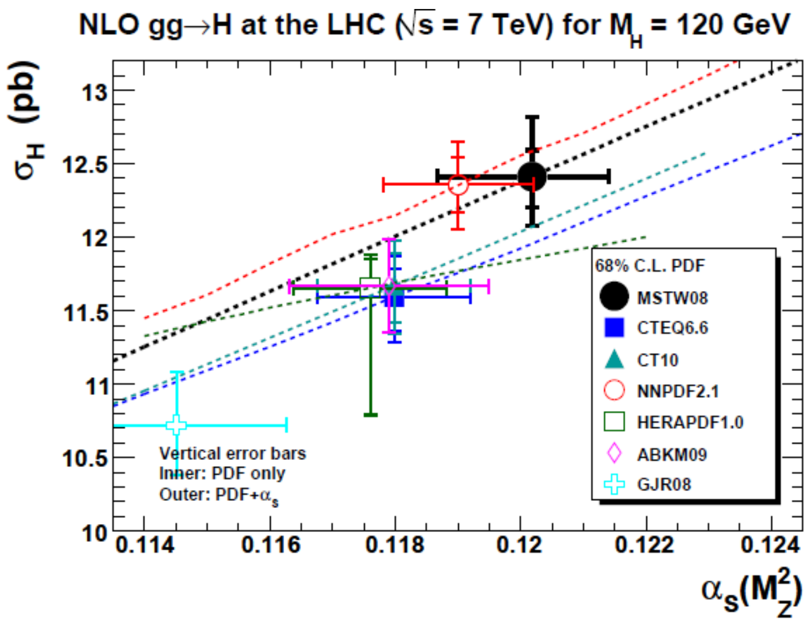
Main sources of difference between different PDFs:

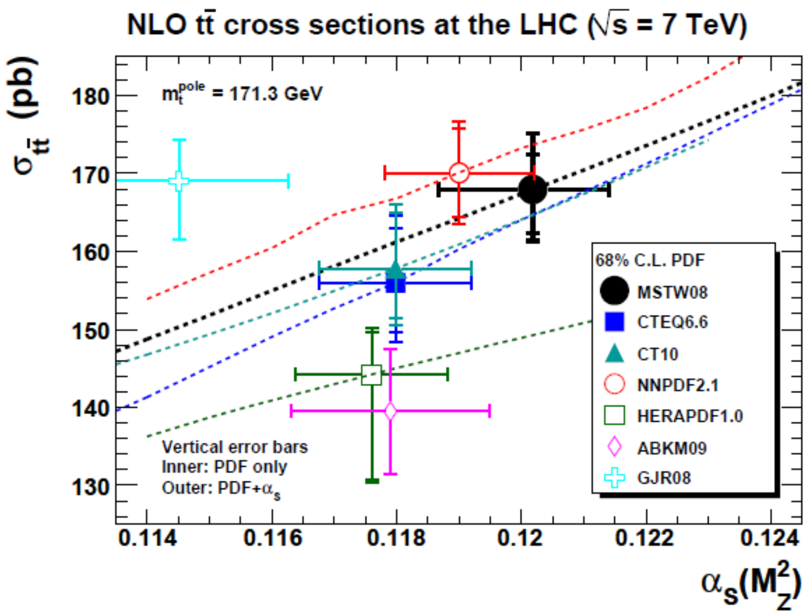
- inclusion of different data
- methods of determining 'best fit'
- uncertainty treatment/sources
- assumptions in procedure (parametrisation)
- heavy flavour treatment
- PDF and α_s correlation

... lead to differences in the cross section predictions

PDF Fit Groups: Benchmarking (PDF4LHC)

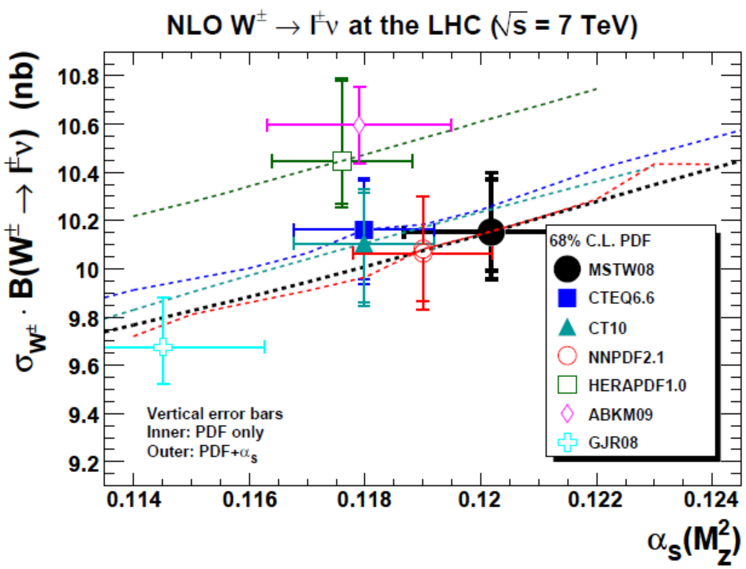
Different PDF lead to differences in cross section predictions

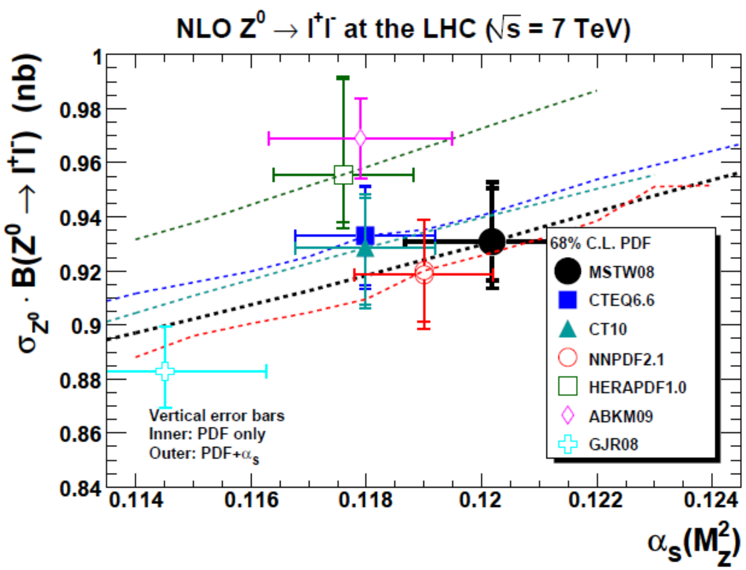




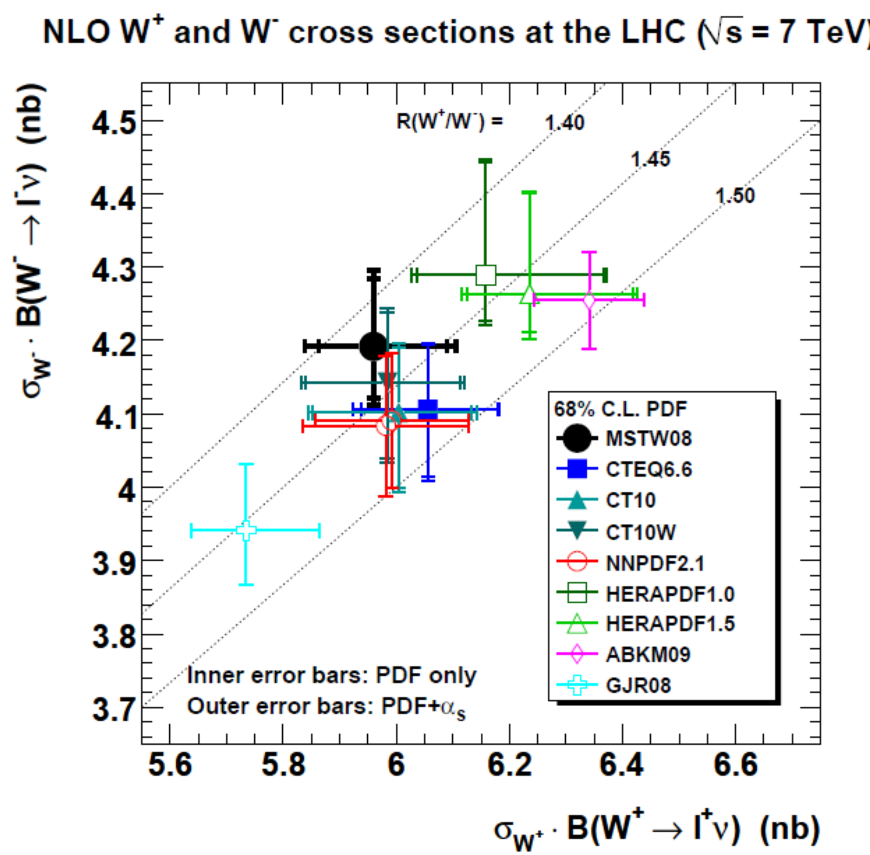
G.Watt
arXiv:1106.5788v1

PDF Fit Groups: Benchmarking (PDF4LHC)





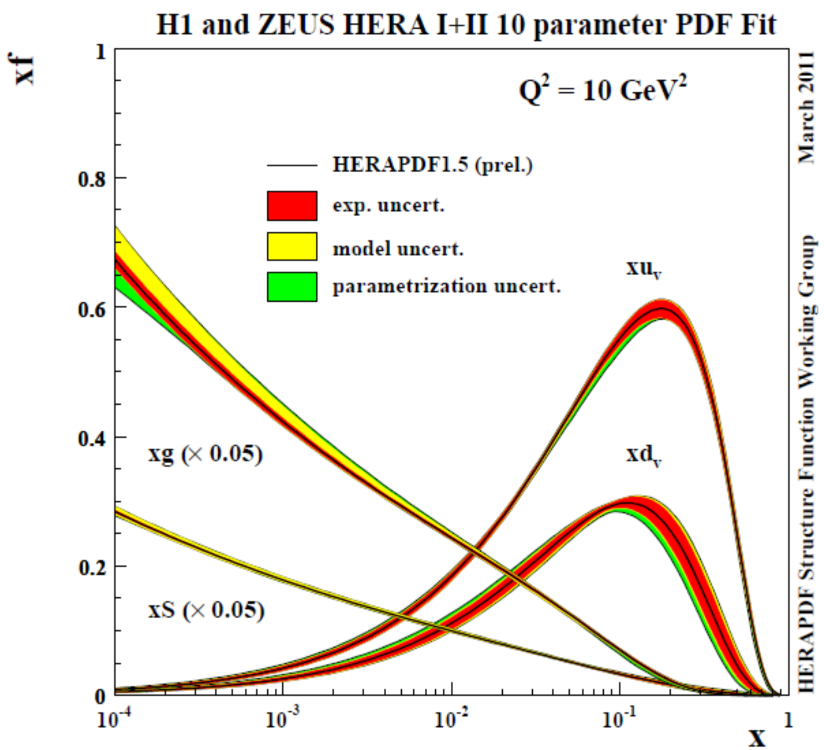
G.Watt



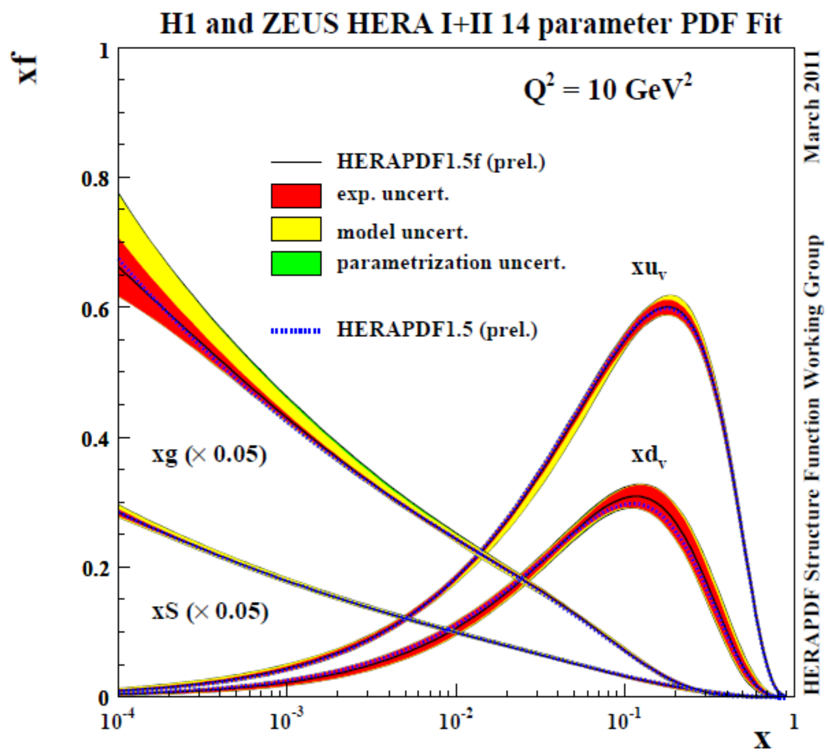
HERAPDF1.5f

HERAPDF1.5f - more flexible parametrisation
→ gluon more flexible and low-*x* *d*-valence is freed from *u*-valence

HERAPDF1.5



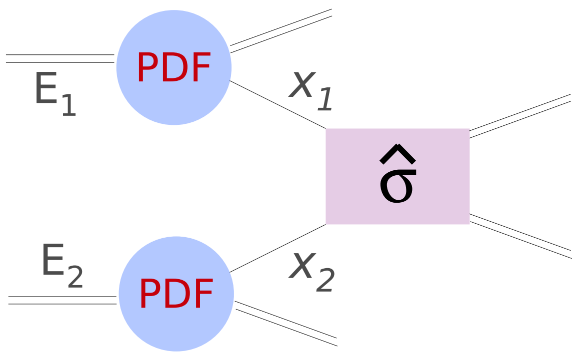
HERAPDF1.5f



Small difference in total uncertainty
→ swap between **parametrisation** and experimental uncertainties

Proton-Proton Collisions

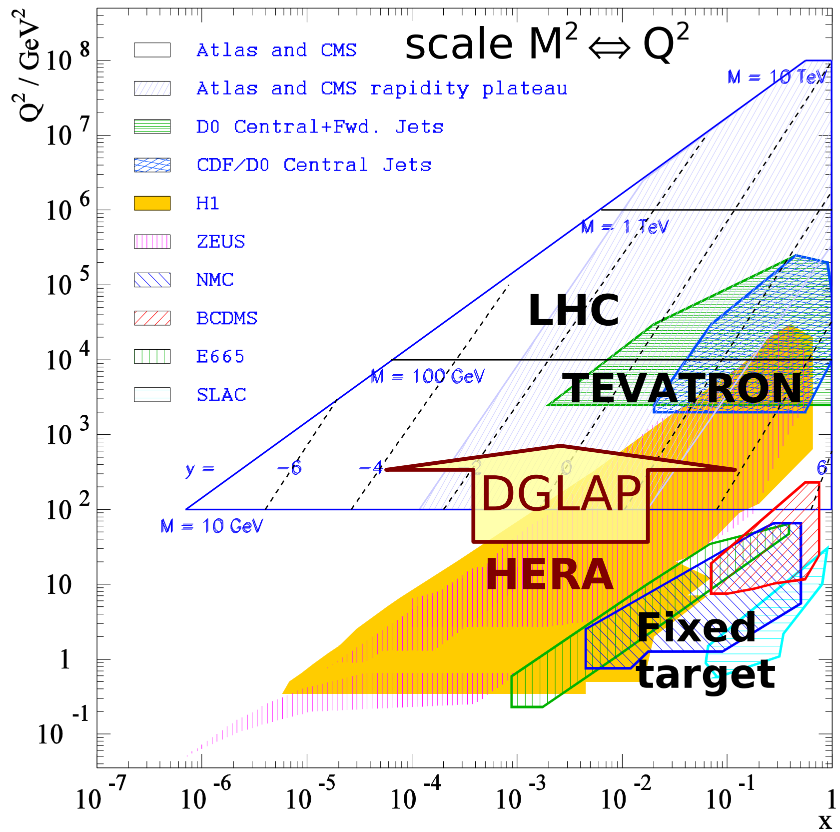
Same PDFs can be used to predict *pp* collisions



$\hat{\sigma}$ – perturbative QCD cross section

Factorisation:

$$\sigma \approx \hat{\sigma} \otimes \text{PDF}$$

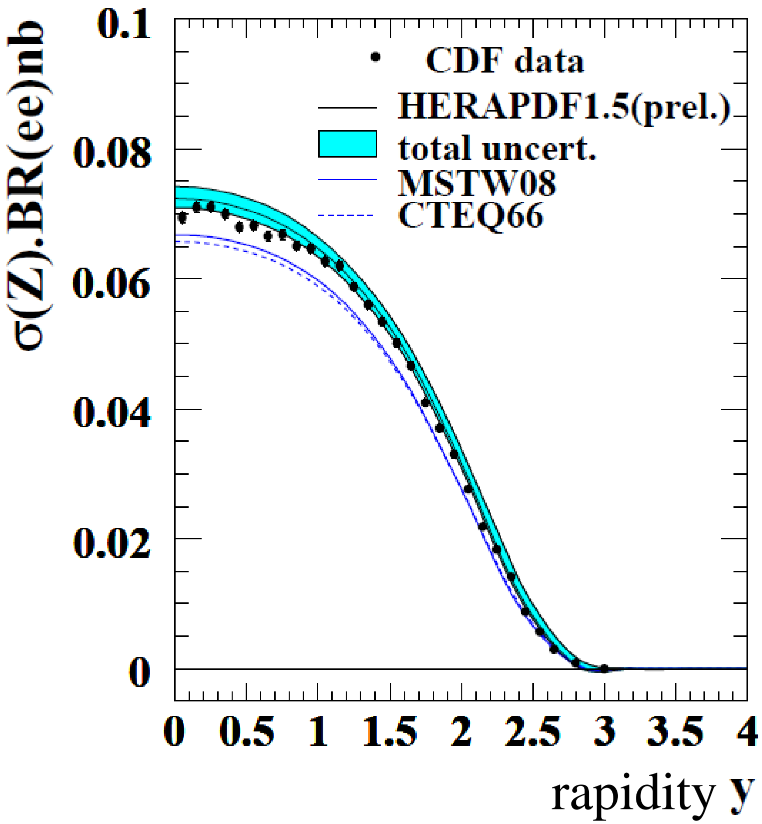


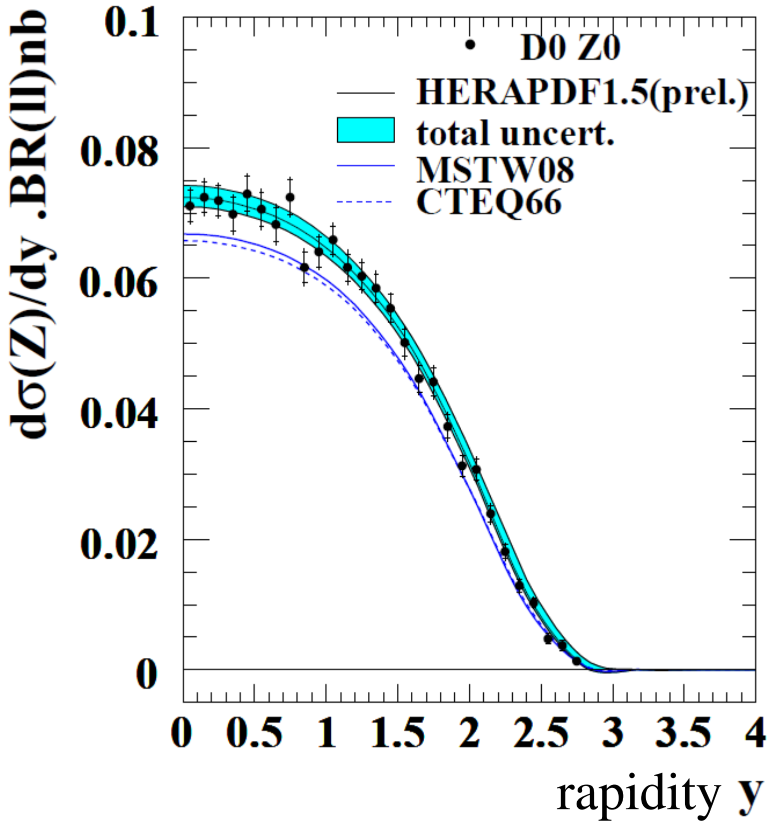
HERA covers *x* range of the LHC
evolution in Q^2 via DGLAP

HERAPDF Predictions for Tevatron

$\sqrt{s}$ = 1.96 TeV

Z rapidity





Predictions based on HERA PDFs describe Tevatron data well

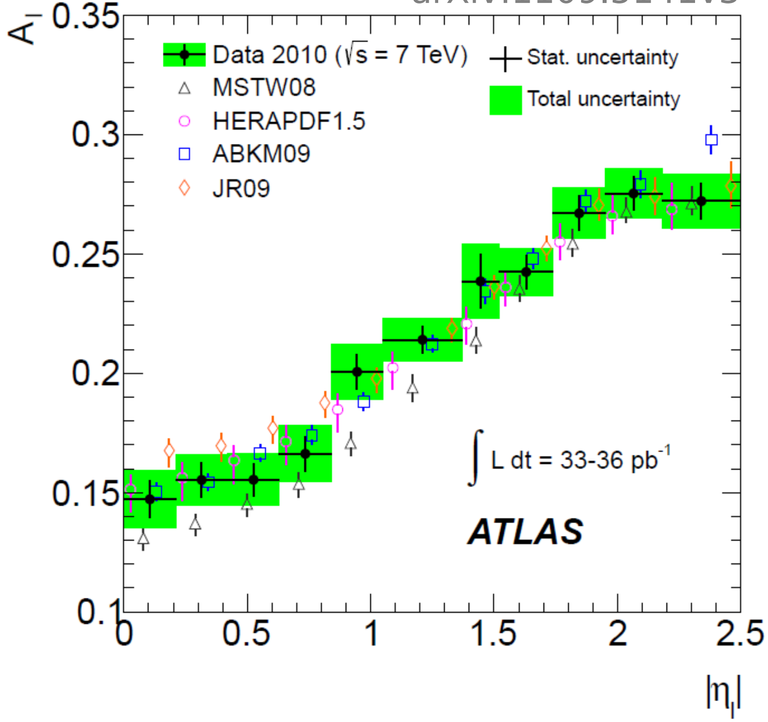
HERAPDF Predictions for Asymmetries at LHC

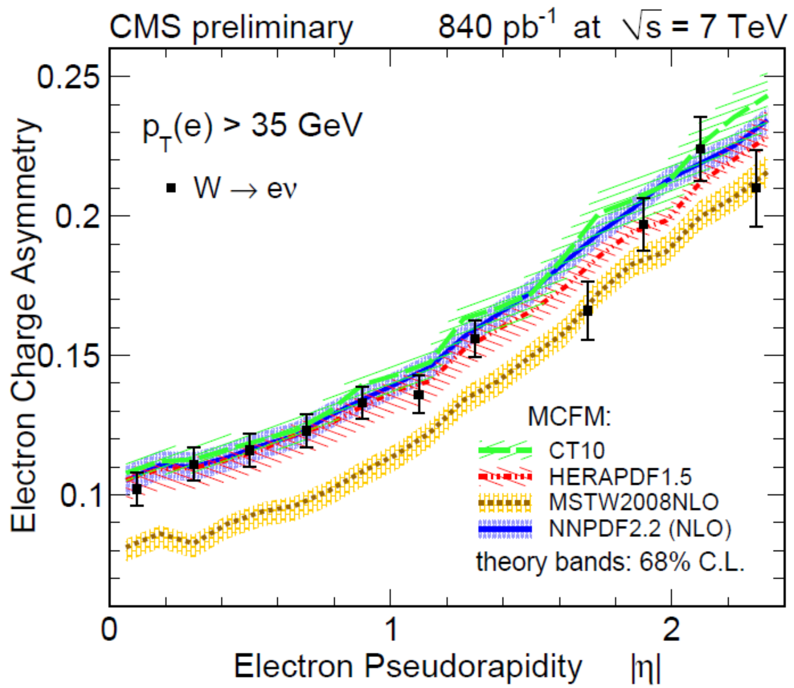
W lepton asymmetry is sensitive to differences between u and d:

$$A_W = \frac{W^+ - W^-}{W^+ + W^-}$$

in terms of valence quarks: $A_W \approx \frac{u_v - d_v}{u_v + d_v + 2u_{sea}}$

arXiv:1109.5141v3





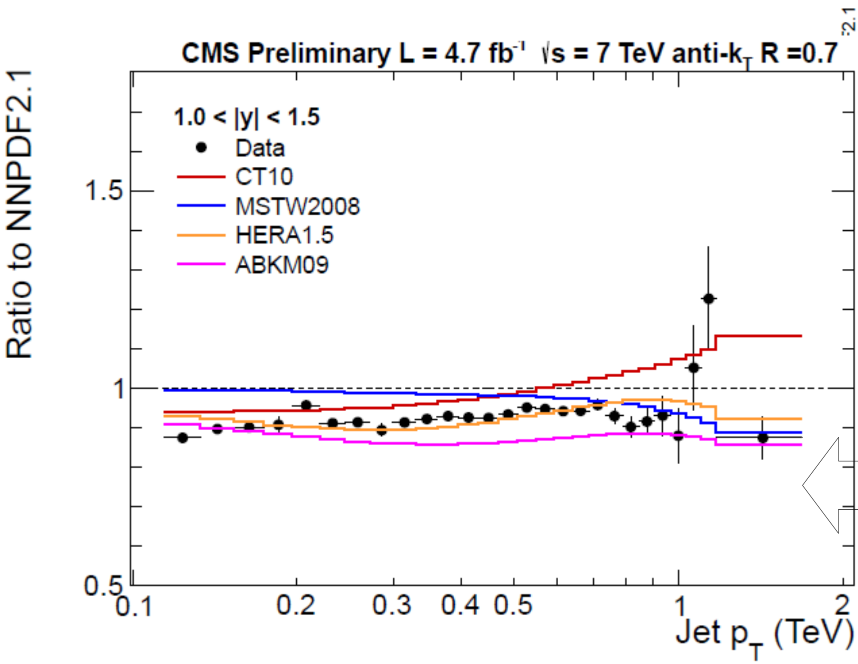
Latest results from ATLAS and CMS

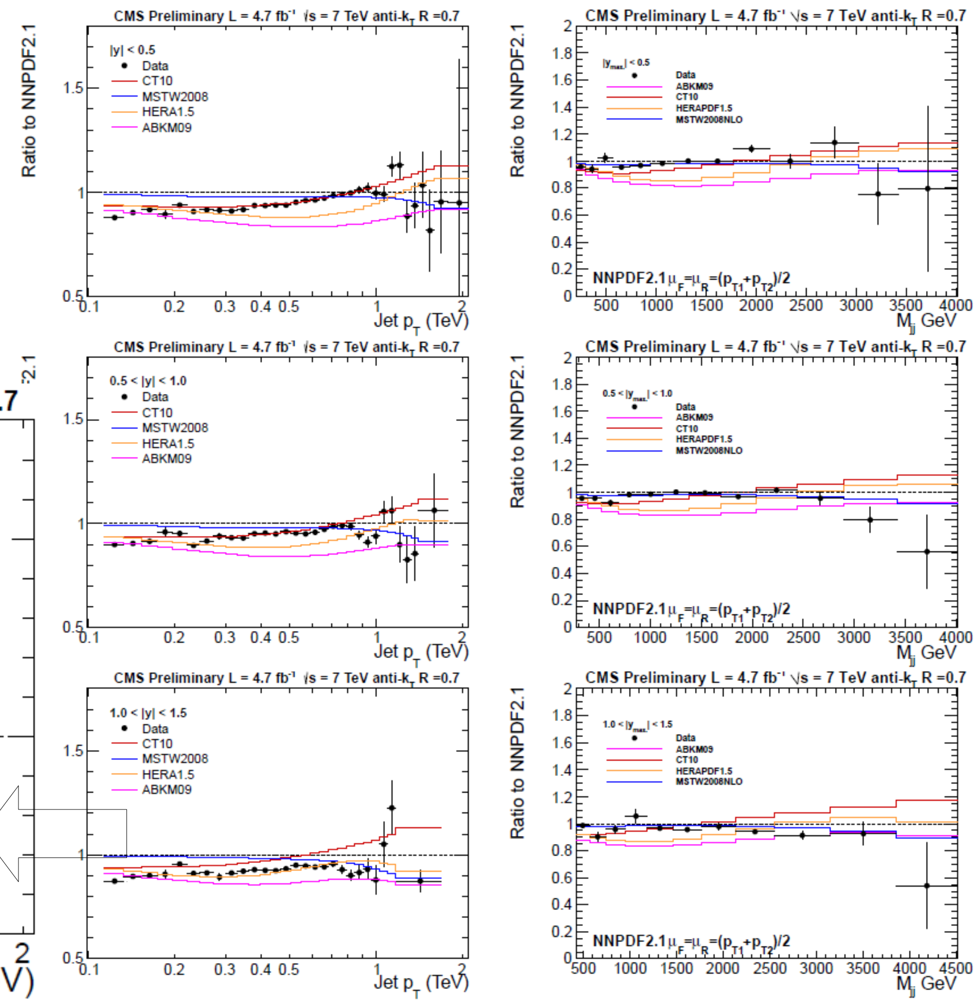
Example: Predictions for Jets at LHC

CMS-PAS-QCD-11-004

Jets have sensitivity to gluon and strong coupling constant

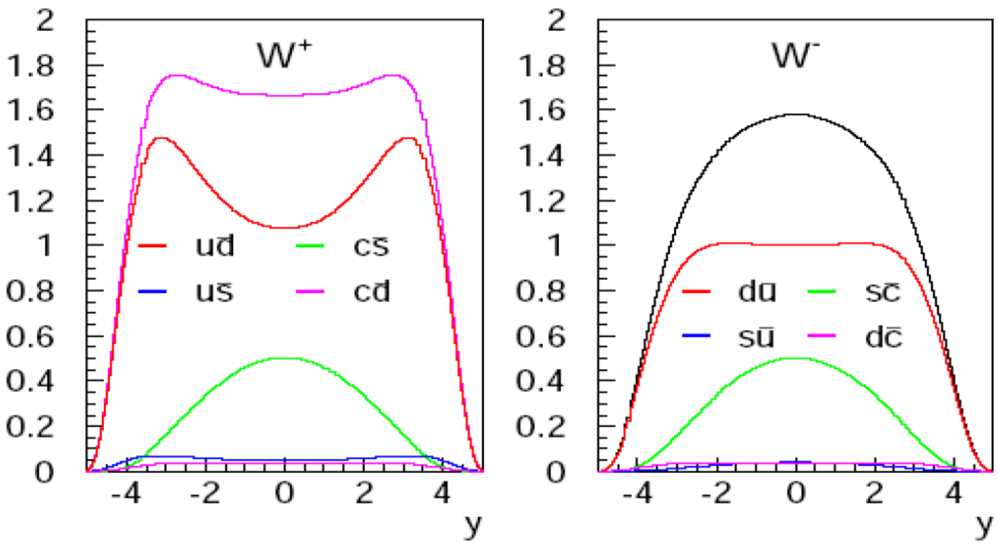
→ can help to understand and constrain gluon PDF at high-x (important for new physics)



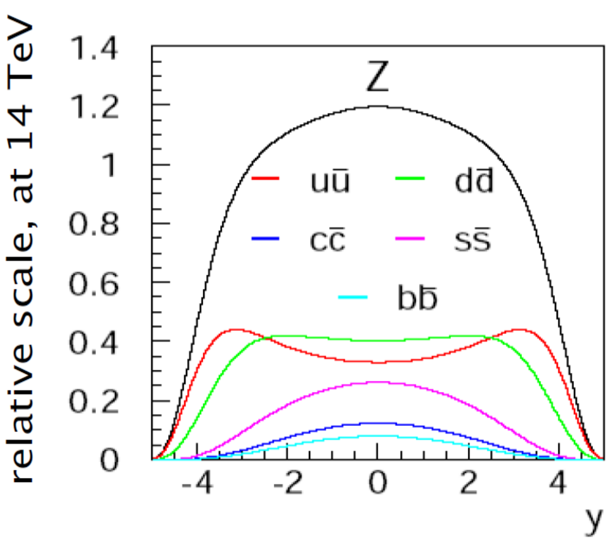


Experimental uncertainties are comparable to theoretical ones
→ using data in QCD fits can improve PDF uncertainties (correlations needed!)

Proton-Proton Collisions: W/Z production



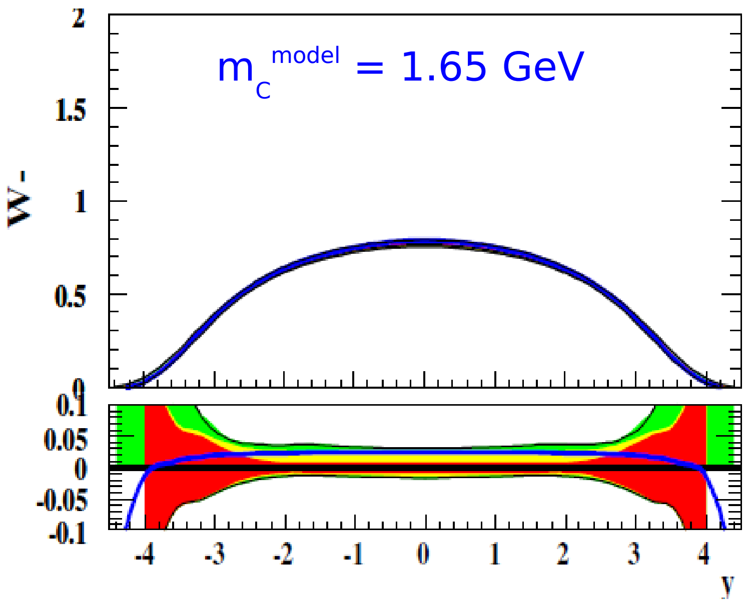
- for W **u** and **d** quarks dominate



- all flavours contribute to Z

Precise parton distributions are needed for LHC analyses

Impact on the LHC predictions



- variation of m_c^{model} changes predictions of Z/W cross sections at LHC by ~3%

A.M.Cooper-Sarkar,
PDF4LHC, March 2010

- sensitivity to charm of the LHC cross section predictions comes from flavour sensitivity of the inclusive DIS data

$$xU = xu + xc \quad x\bar{U} = x\bar{u} + x\bar{c} \quad xD = xd + xs \quad x\bar{D} = x\bar{d} + x\bar{s}$$

- where U is fixed by F_2 data
  larger m_c^{model} $\rightarrow$ less c in sea $\rightarrow$ more u $(= d)$

- important at low Q^2 and low x

Heavy Quark treatment in QCD analysis

Factorisation:

$$F_2^{V,h}(x,Q^2) = \sum_{i=f,\bar{f},g} \int_x^1 dz \cdot C_2^{V,i}\left(\frac{x}{z}, \frac{Q^2}{\mu^2}, \frac{\mu_F^2}{\mu^2} \alpha_S(\mu^2)\right) f_{i/h}(z, \mu_F, \mu^2)$$

i - number of active flavours in the proton m_c=1.5, m_b=4.7 GeV

QCD analysis of the proton structure: treatment of HQ essential

Different prescriptions how to treat heavy quarks in PDF fits (HQ schemes):

Fixed Flavour Number Scheme (FFNS) *i-fixed*

c(b) quarks massive, only light flavours in the proton i=3(4)

General-Mass Variable Flavour Number Scheme (GM-VFNS) *i-variable*

matched scheme, different implementation used by fit groups $\rightarrow m_c^{model}$

Zero-Mass Variable Flavour Number Scheme (ZMVFNS)

all flavours massless (breaks at $Q^2 \sim m_{HQ}^2$)

QCD analysis of F_2^{cc} data

- different implementations of general mass variable flavour number scheme for heavy flavour treatment used in this study:

RT standard	used by MSTW08
RT optimised [arXiv:1006.5925]	
ACOT-full	used by CTEQ4,5,6HQ
S-ACOT-χ	used by CTEQ6.5,6.6,CT10
ZMVFNS	used by NNPDF2.0

- the optimal value of parameter m_c^{model} is determined for each of these schemes (m_c^{model}(opt)), which gives the best description of the HERA data

- PDFs are used in MCFM to calculate $Z/W^{\pm}$ cross-section predictions