QCD and electroweak fits to HERA inclusive DIS data

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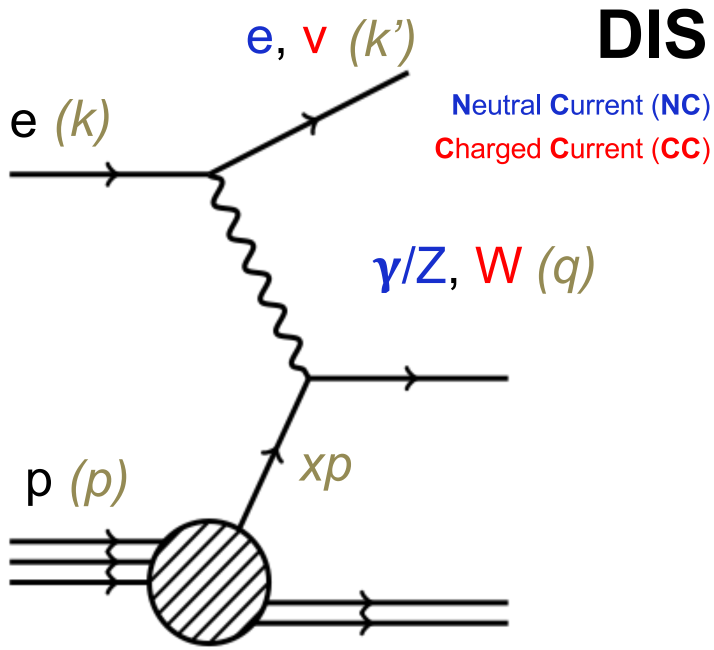
on behalf of the ZEUS Collaboration

Phys Rev D94 (2016) 052007

I. Abt, A.M. Cooper-Sarkar, B. Foster, C. Gwenlan, V. Myronenko, O. Turkot, K. Wichmann

HERA: the world's only ep collider



HERA (1992–2007): √s = 252–**318** GeV

(E_e = 27.5 GeV; E_p = **920**, 820, 575, 460 GeV)

two general purpose detectors, **H1** and **ZEUS**

collected 0.5 fb^{-1} per experiment, equally between e^+ and e^-

HERA-II (02–07): polarised lepton beams;

crucial for electroweak measurements

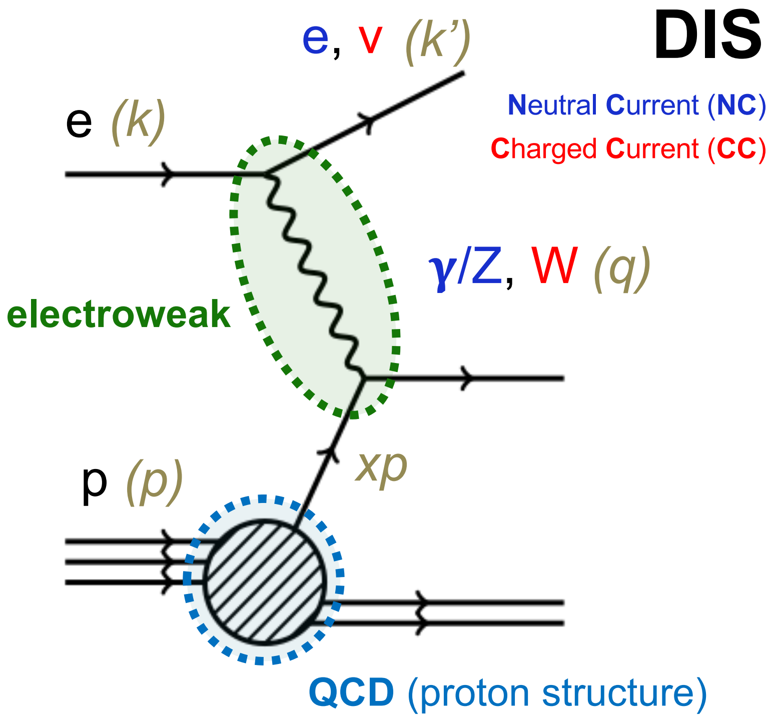
$Q^2 = -q^2 = -(k - k')^2$ Virtuality of the exchanged boson

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

$y = \frac{p \cdot q}{p \cdot k}$ Inelasticity parameter

$s = (k + p)^2 = \frac{Q^2}{xy}$ Invariant c.o.m.

HERA: the world's only ep collider



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(E_e = 27.5 GeV; E_p = **920**, 820, 575, 460 GeV)

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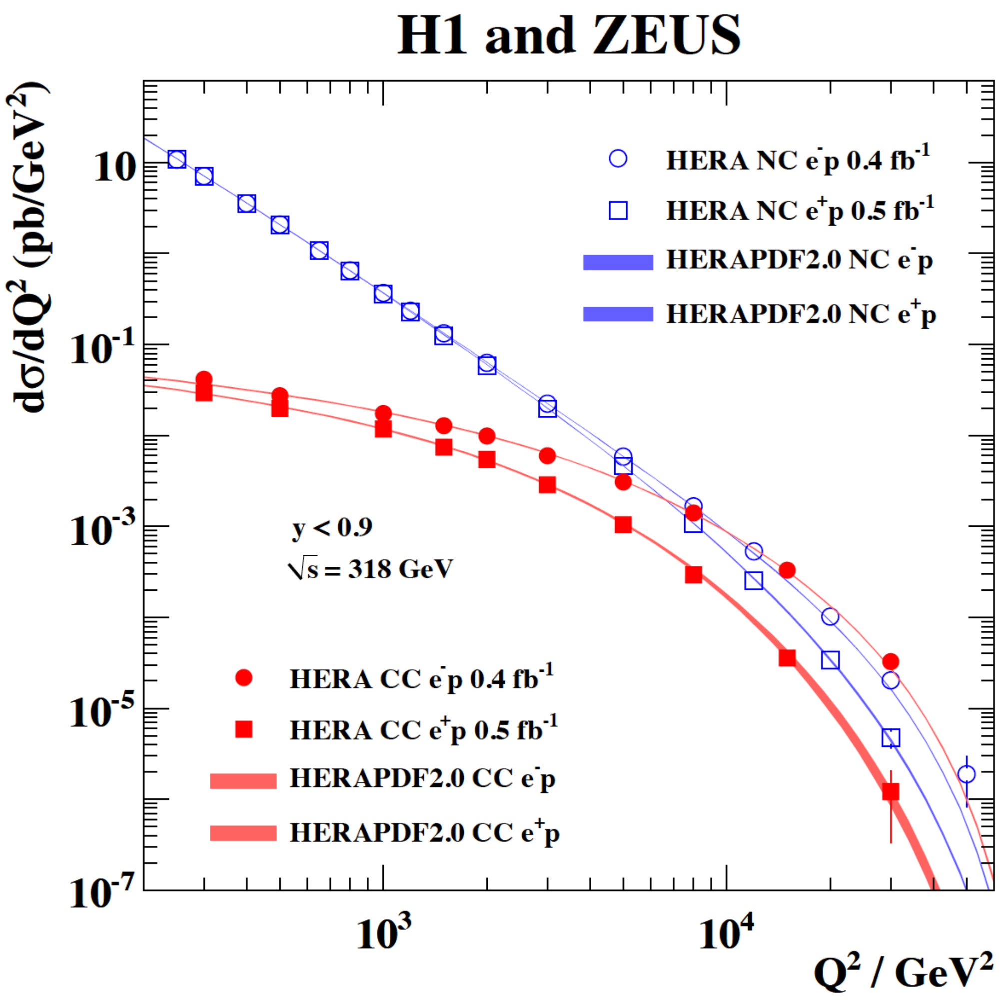
crucial for electroweak measurements

Deep Inelastic Scattering at HERA:

- a super-microscope to study **proton structure** (PDFs)
- sensitive to **EW** via t-channel gauge boson exchange

HERA inclusive NC and CC DIS data



HERA data combination
H1 and ZEUS Colls.,
EPJ C75 (2015), 580

extraordinary **precision** of final HERA measurements!

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

NC: $\sigma_{r,\mathrm{NC}}^{e^\pm p} = \frac{x_{\mathrm{Bj}} Q^4}{2\pi\alpha_0^2} \frac{1}{Y_+} \frac{d^2\sigma(e^\pm p)}{dx_{\mathrm{Bj}} dQ^2} = \tilde{F}_2(x_{\mathrm{Bj}}, Q^2) \mp \frac{Y_-}{Y_+} x\tilde{F}_3(x_{\mathrm{Bj}}, Q^2) - \frac{y^2}{Y_+} F_L(x_{\mathrm{Bj}}, Q^2)$

(similar equation for **CC** cross section)

NC polarised DIS

NC: **γZ** interference and **Z** exchange affected by e-beam polarisation

$$P_e = \frac{N_R - N_L}{N_R + N_L}$$

$$\tilde{F}_2^{\pm} = F_2^{\gamma} - (v_e \pm P_e a_e)\chi_Z F_2^{\gamma Z} + (v_e^2 + a_e^2 \pm 2P_e v_e a_e)\chi_Z^2 F_2^Z$$

$$x\tilde{F}_3^{\pm} = -(a_e \pm P_e v_e)\chi_Z x F_3^{\gamma Z} + (2v_e a_e \pm P_e(v_e^2 + a_e^2))\chi_Z^2 x F_3^Z$$

$$v_e = -1/2 + 2\sin^2\theta_W$$

$$a_e = -1/2$$

NC structure functions in QPM:

sensitive to **EW vector** and **axial-vector couplings** to **light quarks**, and **sin²θw** via

$$[F_2^{\gamma}, F_2^{\gamma Z}, F_2^Z] = \sum_q [e_q^2, 2e_q v_q, v_q^2 + a_q^2] x(q + \bar{q})$$

$$[xF_3^{\gamma Z}, xF_3^Z] = \sum_q [e_q a_q, v_q a_q] 2x(q - \bar{q})$$

$$\chi_Z = \frac{1}{\sin^2 2\theta_W} \frac{Q^2}{M_Z^2 + Q^2} \frac{1}{1 - \Delta R}$$

(where ΔR accounts for radiative corrections)

$$v_u = 1/2 - 4/3\sin^2\theta_W \quad a_u = 1/2 \quad v_d = -1/2 + 2/3\sin^2\theta_W \quad a_d = -1/2$$

on-shell scheme used: $\sin^2\theta_W = 1 - M_W^2/M_Z^2$ = 0.22333 (**PDG14**)

NC polarised DIS

NC: **γZ** interference and **Z** exchange affected by e-beam polarisation

$$P_e = \frac{N_R - N_L}{N_R + N_L}$$

$$\tilde{F}_2^{\pm} = F_2^{\gamma} - (\quad \pm P_e a_e)\chi_Z F_2^{\gamma Z}$$

$$x\tilde{F}_3^{\pm} = -(a_e \qquad)\chi_Z x F_3^{\gamma Z}$$

$\chi_Z \gg \chi_Z^2$ and $v_e \approx 0.04$:
vq from **polarised** $F_2^{\gamma Z}$
aq from unpolarised $xF_3^{\gamma Z}$

NC structure functions in QPM:

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$$[F_2^{\gamma}, F_2^{\gamma Z}, F_2^{Z}] = \sum_q [e_q^2, 2e_q v_q, v_q^2 + a_q^2] x(q + \bar{q})$$

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CC polarised DIS

CC:

$$P_e = \frac{N_R - N_L}{N_R + N_L}$$

$$\frac{d^2\sigma_{\mathrm{CC}}(e^+p)}{dx_{\mathrm{Bj}}dQ^2} = (1+P_e)\frac{G_F^2 M_W^4}{2\pi x_{\mathrm{Bj}}(Q^2+M_W^2)^2}\, x\left[(\bar{u}+\bar{c}) + (1-y)^2(d+s+b)\right]$$

$$\frac{d^2\sigma_{\mathrm{CC}}(e^-p)}{dx_{\mathrm{Bj}}dQ^2} = (1-P_e)\frac{G_F^2 M_W^4}{2\pi x_{\mathrm{Bj}}(Q^2+M_W^2)^2}\, x\left[(u+c) + (1-y)^2(\bar{d}+\bar{s}+\bar{b})\right]$$

$$G_F = \frac{\pi\alpha_0}{\sqrt{2}\,\sin^2\theta_W\, M_W^2}\,\frac{1}{1-\Delta R}$$

CC provides further sensitivity to PDFs (quark flavour separation)

and sensitivity to **$\sin^2\theta_W$**, and **M_W** via G_F and propagator

QCD and electroweak fit to HERA data

simultaneous **NLO QCD** and **LO electroweak** fit of PDF and EW parameters

- HERA **NC** and **CC** inclusive **uncombined** data sets as input:

1. datasets as used in HERA combination (EPJ C75 (2015) 580):
   HERA I H1 and ZEUS; H1 and ZEUS reduced Ep data; HERA II data from H1 (UNPOLARISED)
2. **HERA II data from ZEUS (POLARISED)**

- PDF fit, closely follows HERAPDF2.0 (EPJ C75 (2015) 580):

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

fixed, or from sum rules   set equal

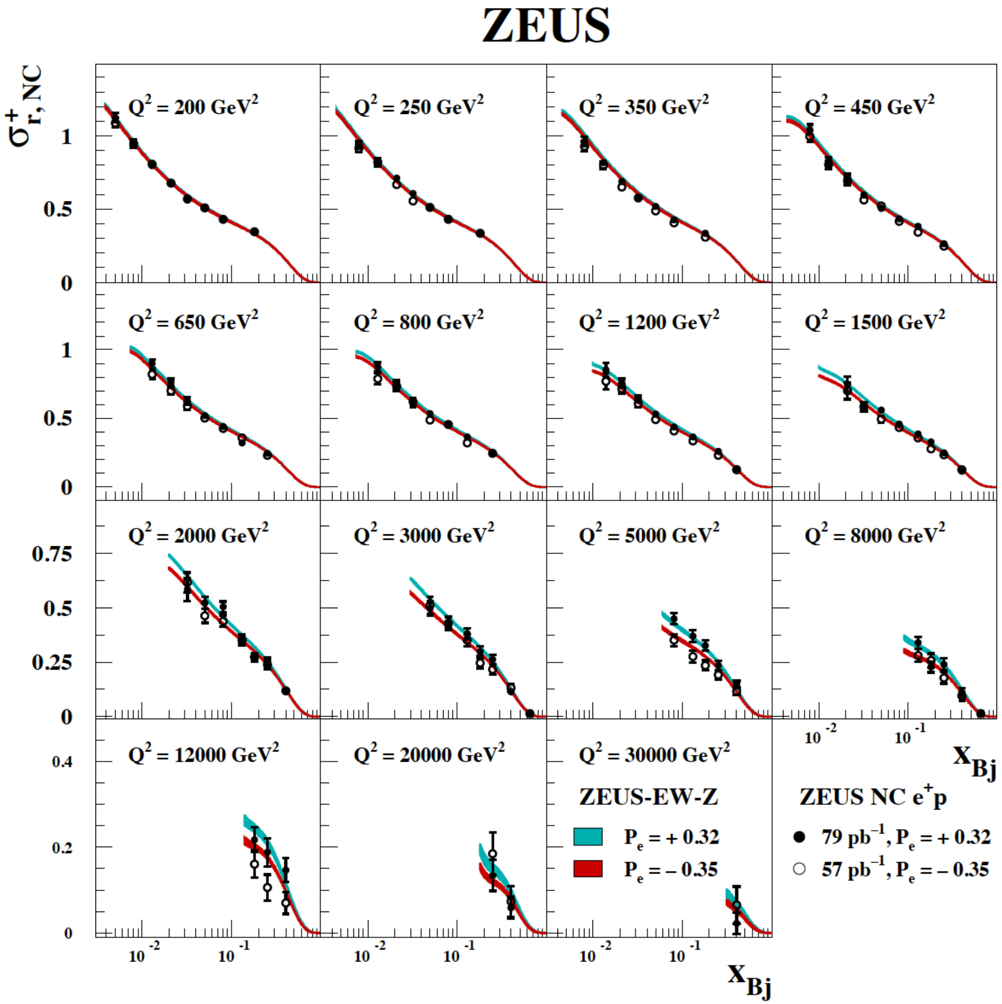
start scale Q_0^2=1.9 GeV^2

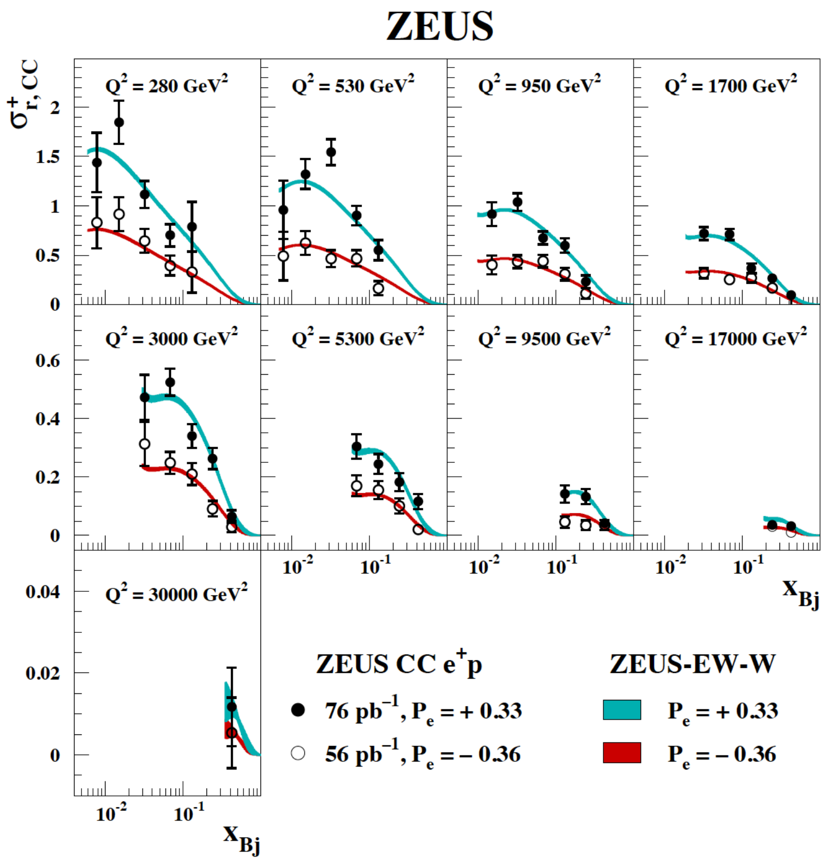
model and parameterisation uncertainties as in HERAPDF2.0

ΔR corrections calculated using EPRC code
(H. Spiesberger, desy.de/~hspiesb/eprc.html)

13 free PDF parameters, and **4** light quark **NC EW couplings** (or free $\sin^2\theta_W$ / M_W)

NC and CC polarised DIS data



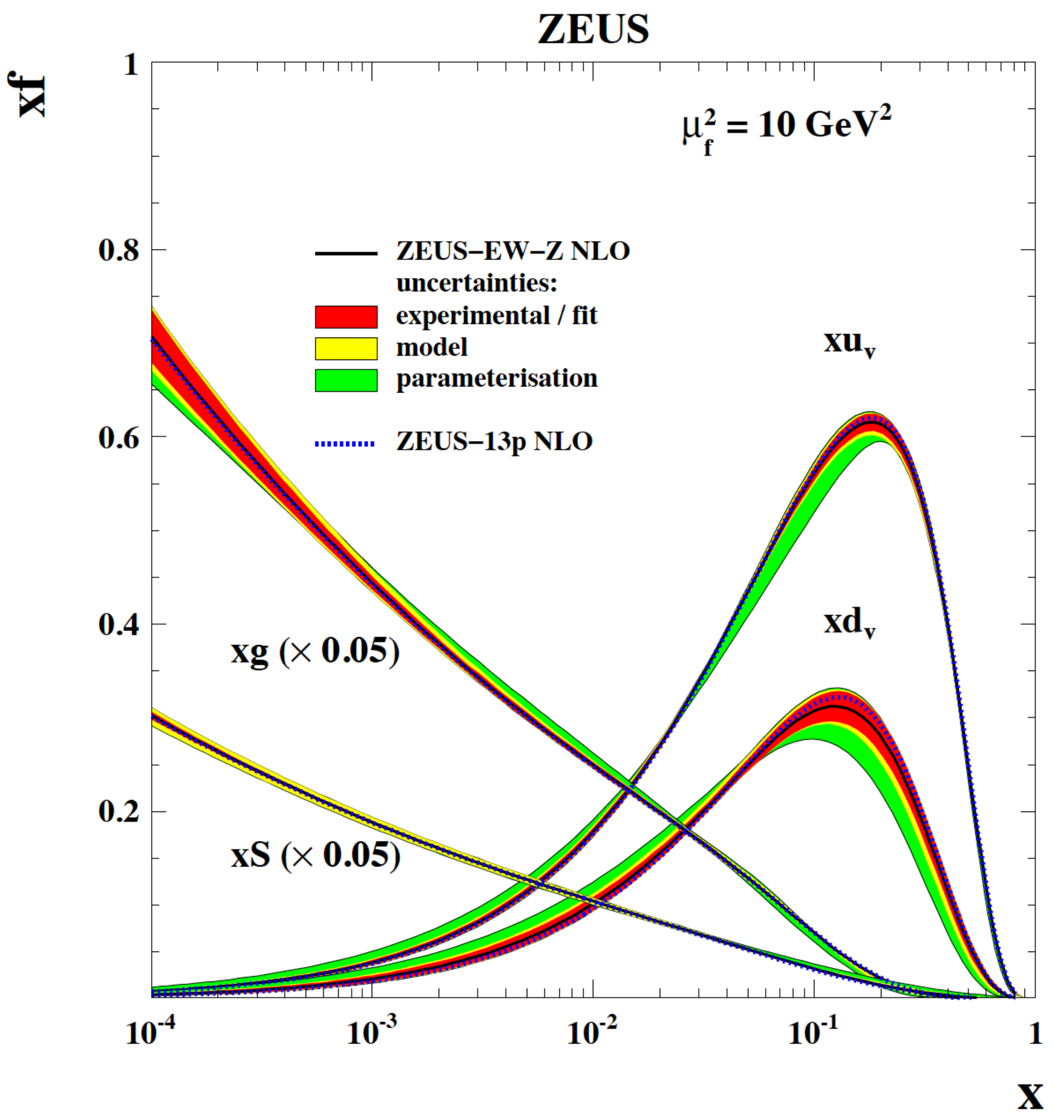


NC and CC polarised **e^+p** shown

ZEUS Coll., PRD 93, 092002 (2016)

Q^2_{min} = 3.5 GeV^2 – number of data points is 2942, of which 501 are polarised
ZEUS cross section data (X^2/NDF = 1.12 for fit with NC couplings free)

PDF results



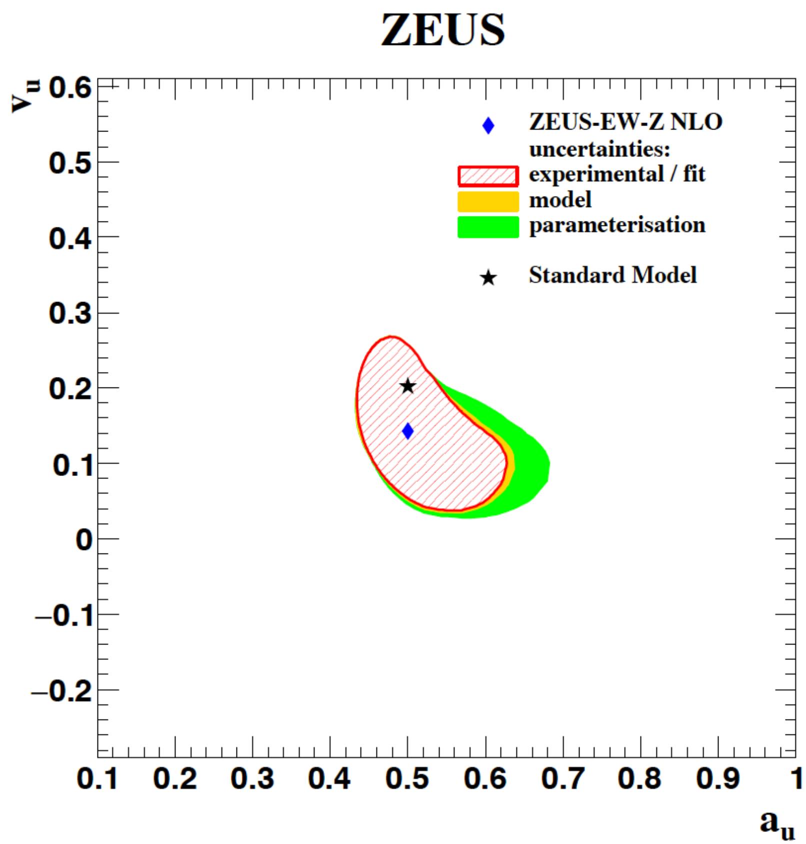
ZEUS Coll., PRD 93, 092002 (2016)

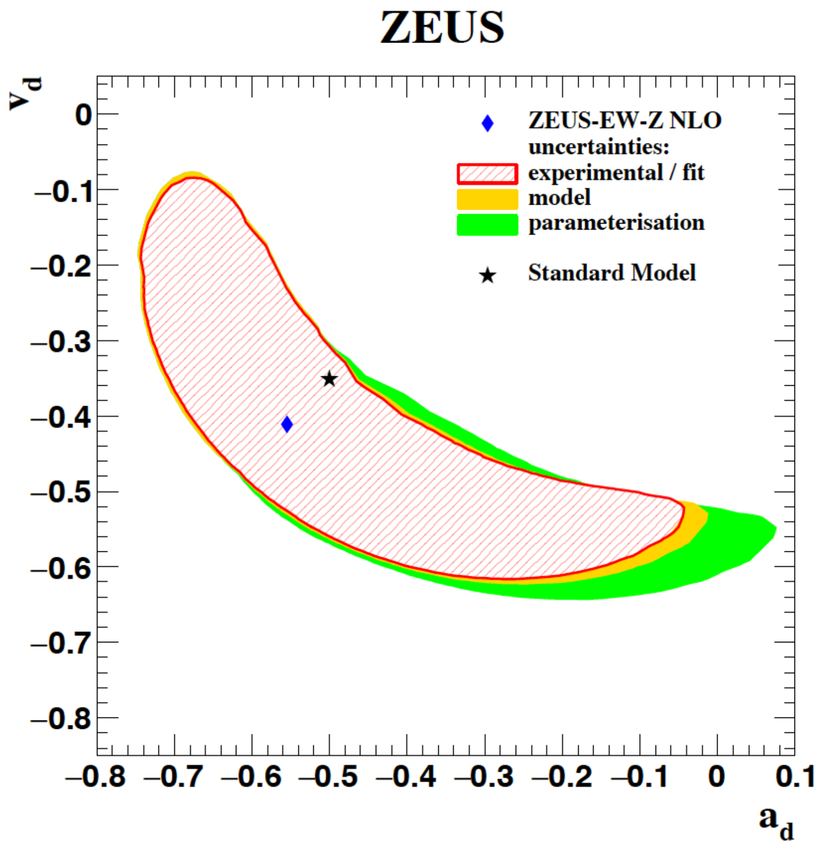
agreement with equivalent (13p) fit with **EW couplings** set to SM values

only weak correlation between **PDF** and **electroweak** parameters (QCD part of fit can be repeated at NNLO with little pull on EW parameters)

(also agrees well with **HERAPDF2.0** EPJ C75 (2015), 580)

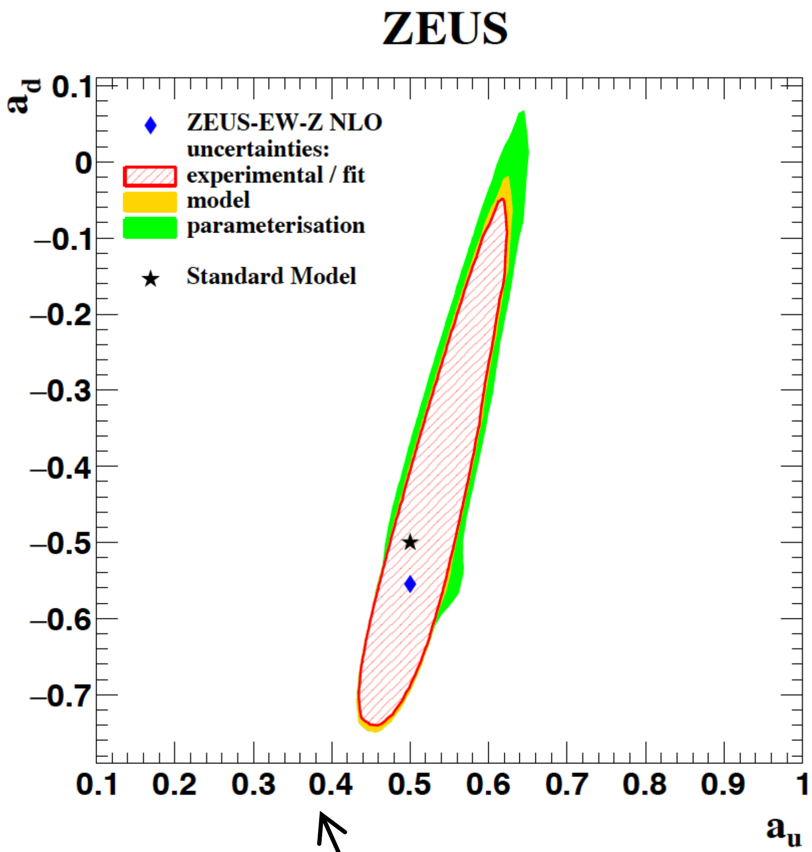
NC electroweak couplings

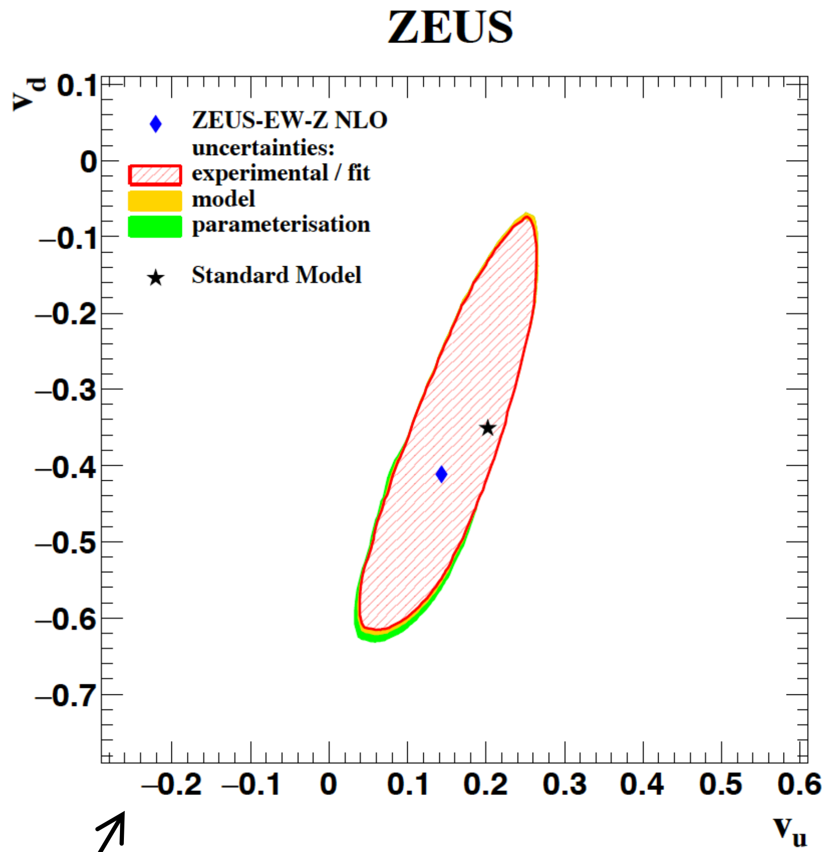




					Standard Model
$a_u = +0.50$		$^{+0.09}_{-0.05}$ (experimental/fit)	$^{+0.04}_{-0.02}$ (model)	$^{+0.08}_{-0.01}$ (parameterisation)	0.5
$a_d = -0.56$		$^{+0.34}_{-0.14}$ (experimental/fit)	$^{+0.11}_{-0.05}$ (model)	$^{+0.20}_{-0.00}$ (parameterisation)	-0.5
$v_u = +0.14$		$^{+0.08}_{-0.08}$ (experimental/fit)	$^{+0.01}_{-0.02}$ (model)	$^{+0.00}_{-0.03}$ (parameterisation)	0.202
$v_d = -0.41$		$^{+0.24}_{-0.16}$ (experimental/fit)	$^{+0.04}_{-0.07}$ (model)	$^{+0.00}_{-0.08}$ (parameterisation)	-0.351

NC electroweak couplings – correlations

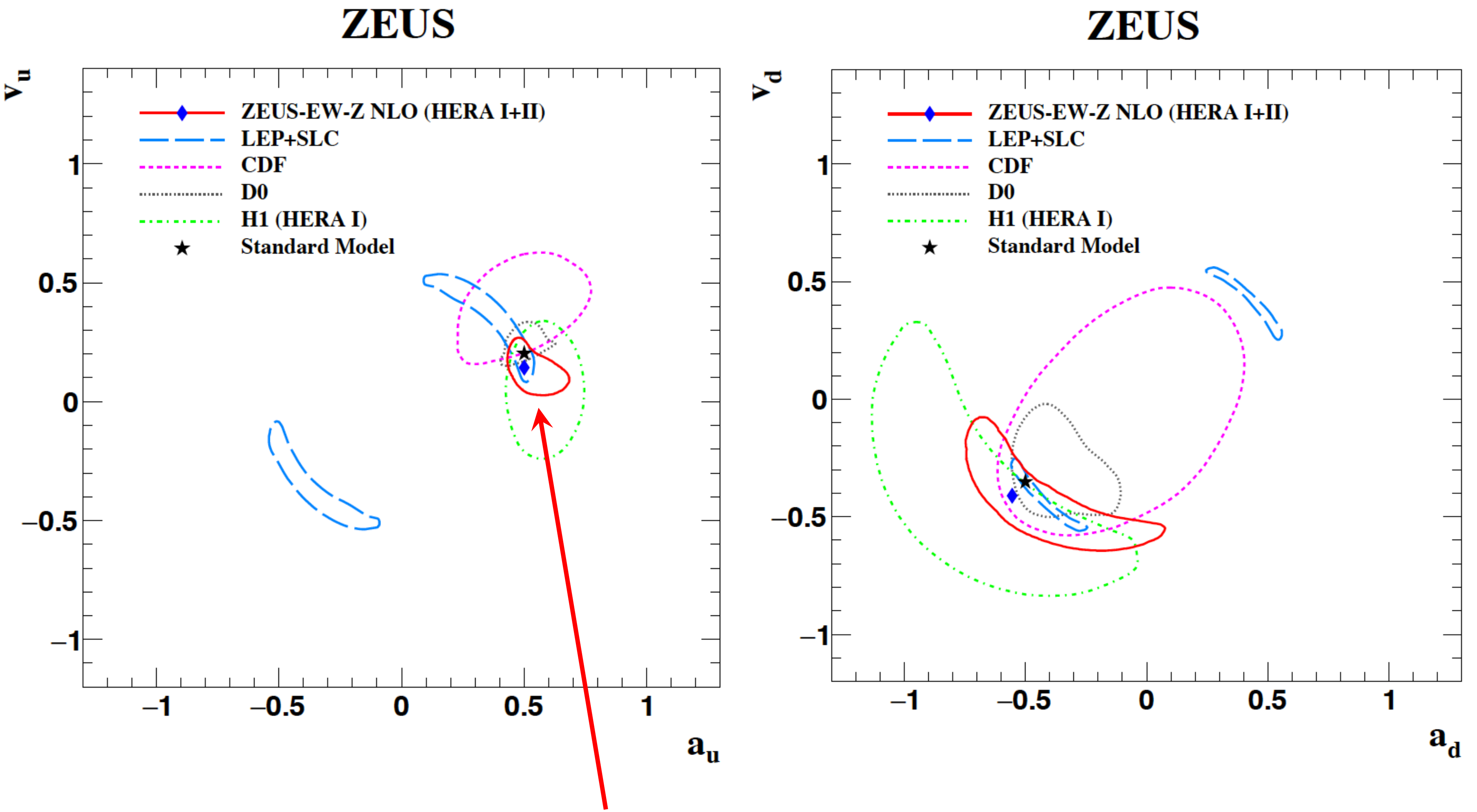




	a_u	a_d	v_u	v_d
a_u	1.000	0.861	−0.555	−0.729
a_d	0.861	1.000	−0.636	−0.880
v_u	−0.555	−0.636	1.000	0.851
v_d	−0.729	−0.880	0.851	1.000

vector and axial vector couplings show strong correlation

comparison with other measurements

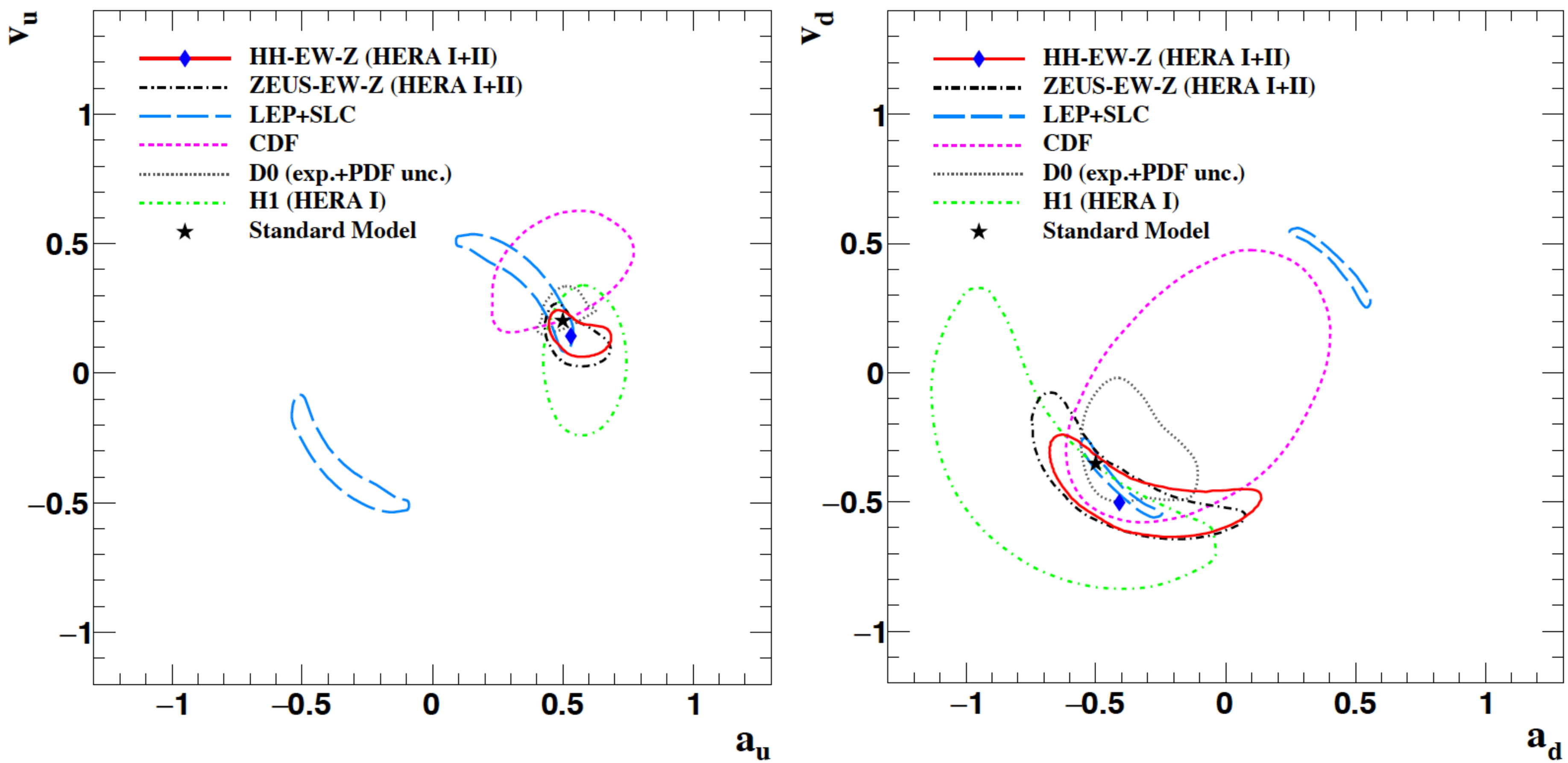


- excellent sensitivity to **u-type** quark couplings
- results compatible with **SM** expectation

improvement from using all HERA polarised data

independent analysis (HH-EW-Z) performed,
using also published **H1 polarised data**
(H1 Coll., JHEP 1209 (2012) 061)

I. Abt et al.,
PRD 94, 052007 (2016)
(arXiv:1604.05083)

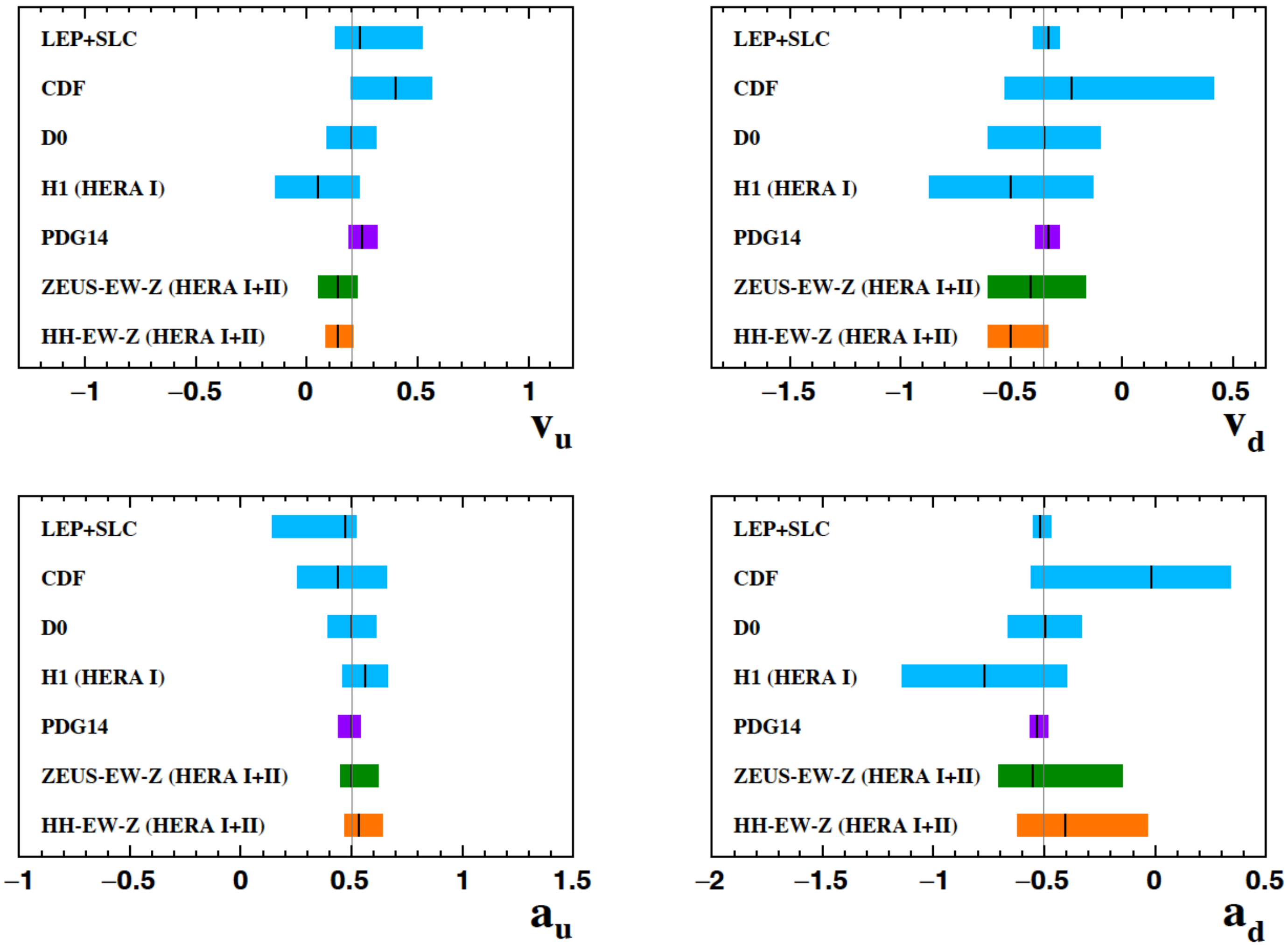


HERA II polarised data especially important for **vector couplings**

comparison with other results

ZEUS Coll., PRD 93, 092002 (2016)
(arXiv:1603.09628)

I. Abt et al., PRD 94, 052007 (2016)
(arXiv:1604.05083)



NC coupling determinations from **I. Abt et al.**, included in **PDG17 world average**

$\sin^2\theta_W$ and M_W

ZEUS Coll., PRD 93, 092002 (2016)

- **$\sin^2\theta_W$** and **M_W** can also be extracted from the HERA inclusive DIS data

σ_{NC} $(\alpha, \sin^2\theta_W, M_Z)$
σ_{CC} $(G_F(\alpha, \sin^2\theta_W, M_W), M_W)$

- **$\sin^2\theta_W$** fitted as parameter, along with PDFs:

$$\sin^2\theta_W = 0.2252 \pm 0.0011\,(\text{experimental/fit})\ ^{+0.0003}_{-0.0001}\,(\text{model})\ ^{+0.0007}_{-0.0001}\,(\text{parameterisation})$$

- **M_W** and PDF parameters fitted simultaneously ($\sin^2\theta_W$=0.22333 fixed):

$$M_W = 80.68 \pm 0.28\,(\text{experimental/fit})\ ^{+0.12}_{-0.01}\,(\text{model})\ ^{+0.23}_{-0.01}\,(\text{parameterisation})\ \text{GeV}$$

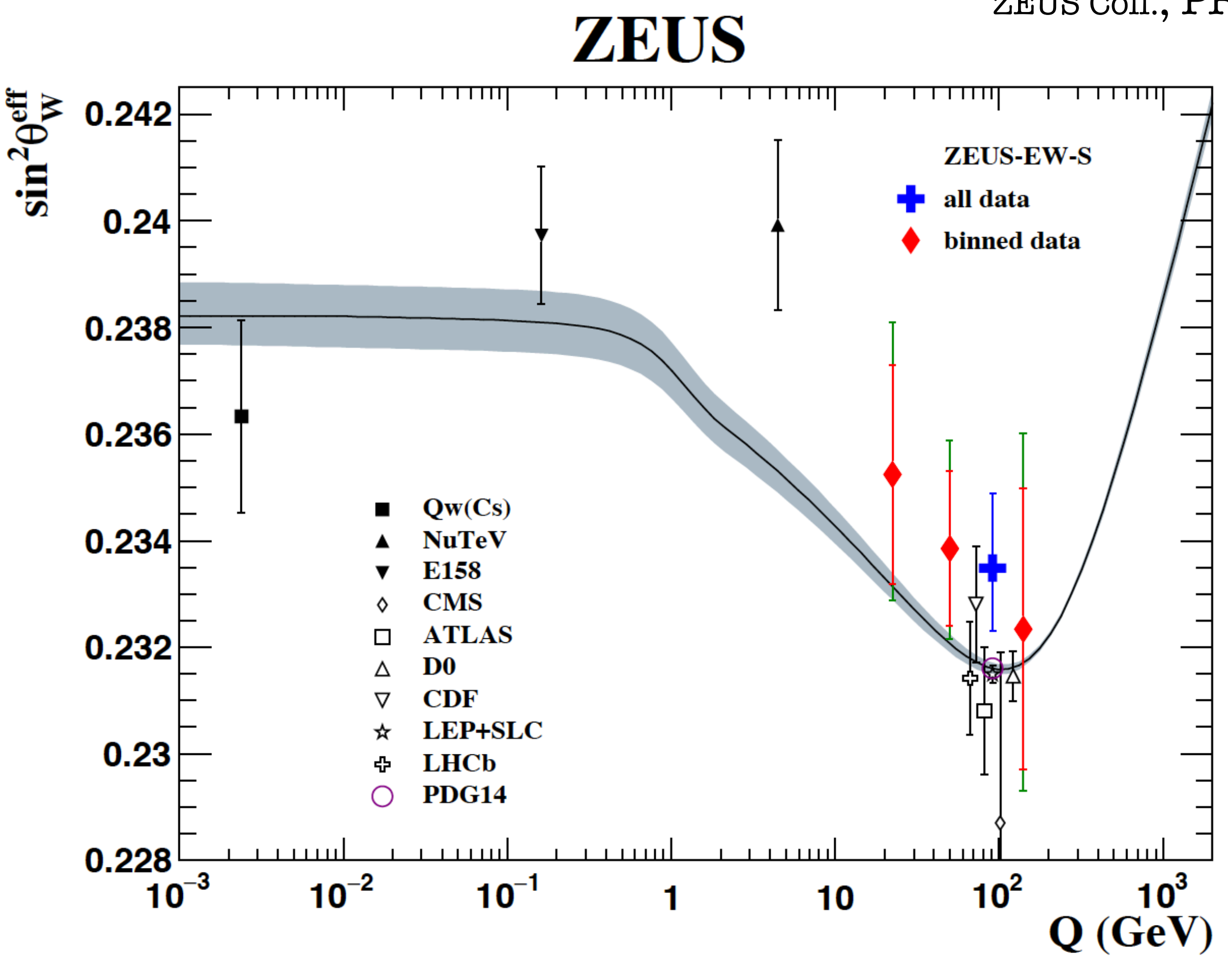
M_W determination from **space-like** process, complementary to other measurements

(simultaneous extraction of $\sin^2\theta_W$ and M_W (and PDFs) also performed as cross check; results consistent with PDG world average – see backups)

effective $\sin^2\theta_W$

- measurements from full dataset, and in **3 bins of Q^2** (PDF parameters fixed) translated † to effective $\sin^2\theta_W$

ZEUS Coll., PRD 93, 092002 (2016)



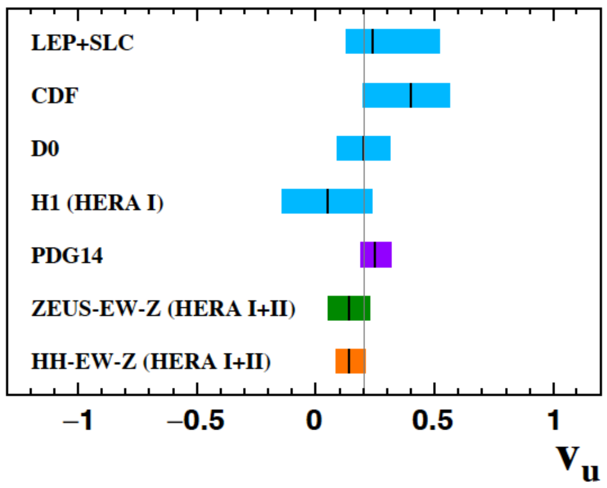
first observation of $\sin^2\theta_W^{eff}$ **running** from **single machine**

† procedure from Czarnecki and Marciano, IJMPA 15 (2000) 2365

summary

- HERA polarised inclusive DIS data sensitive to electroweak parameters
  → **simultaneous PDF and EW fits**

- NC **vector** and **axial-vector couplings** to quarks agree with world average and SM expectation
- measurements of **u-type quark couplings** among most accurate from single collider

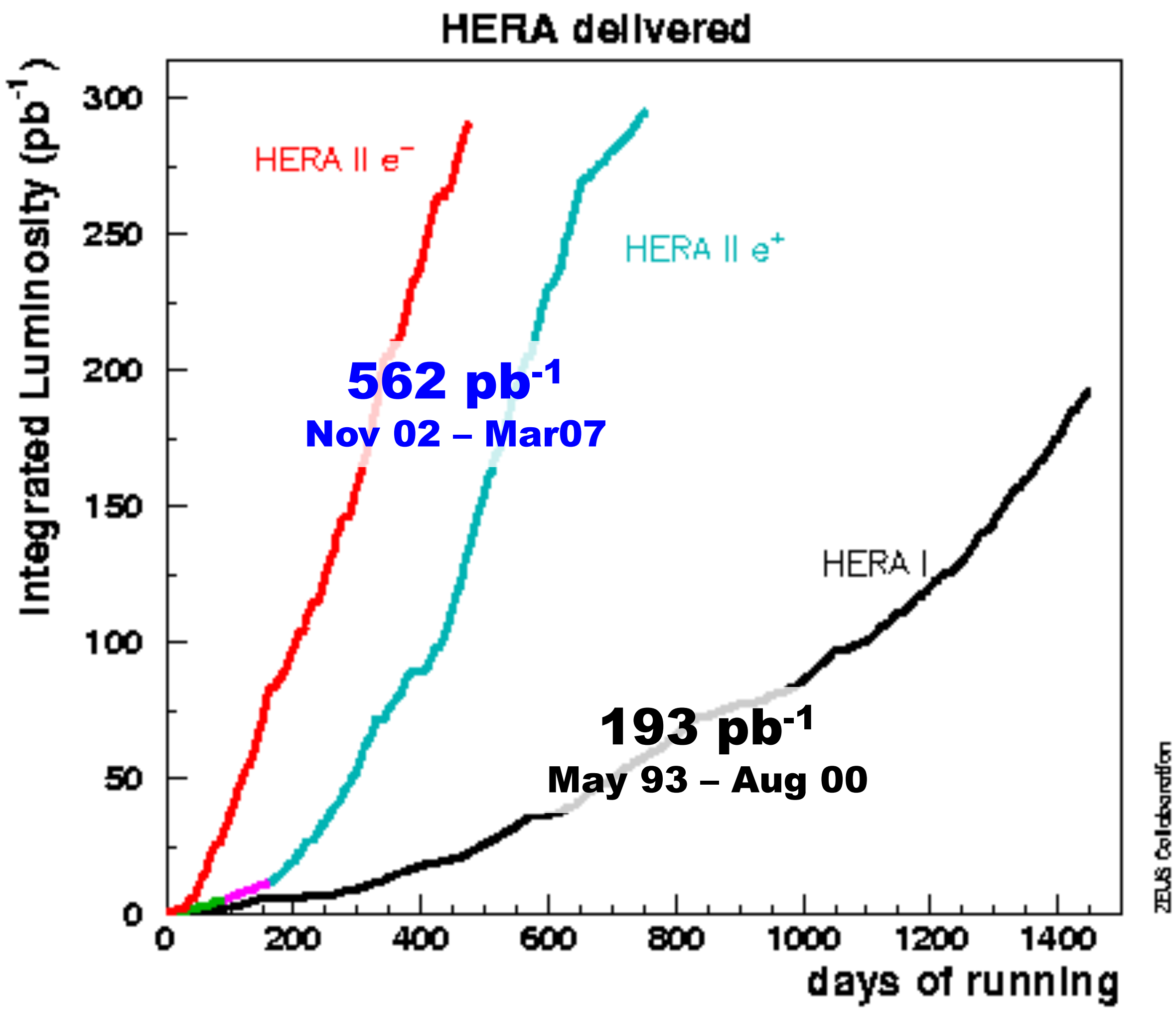


- couplings from I. Abt et al. (HH-EW-Z) included in **PDG17 world average**

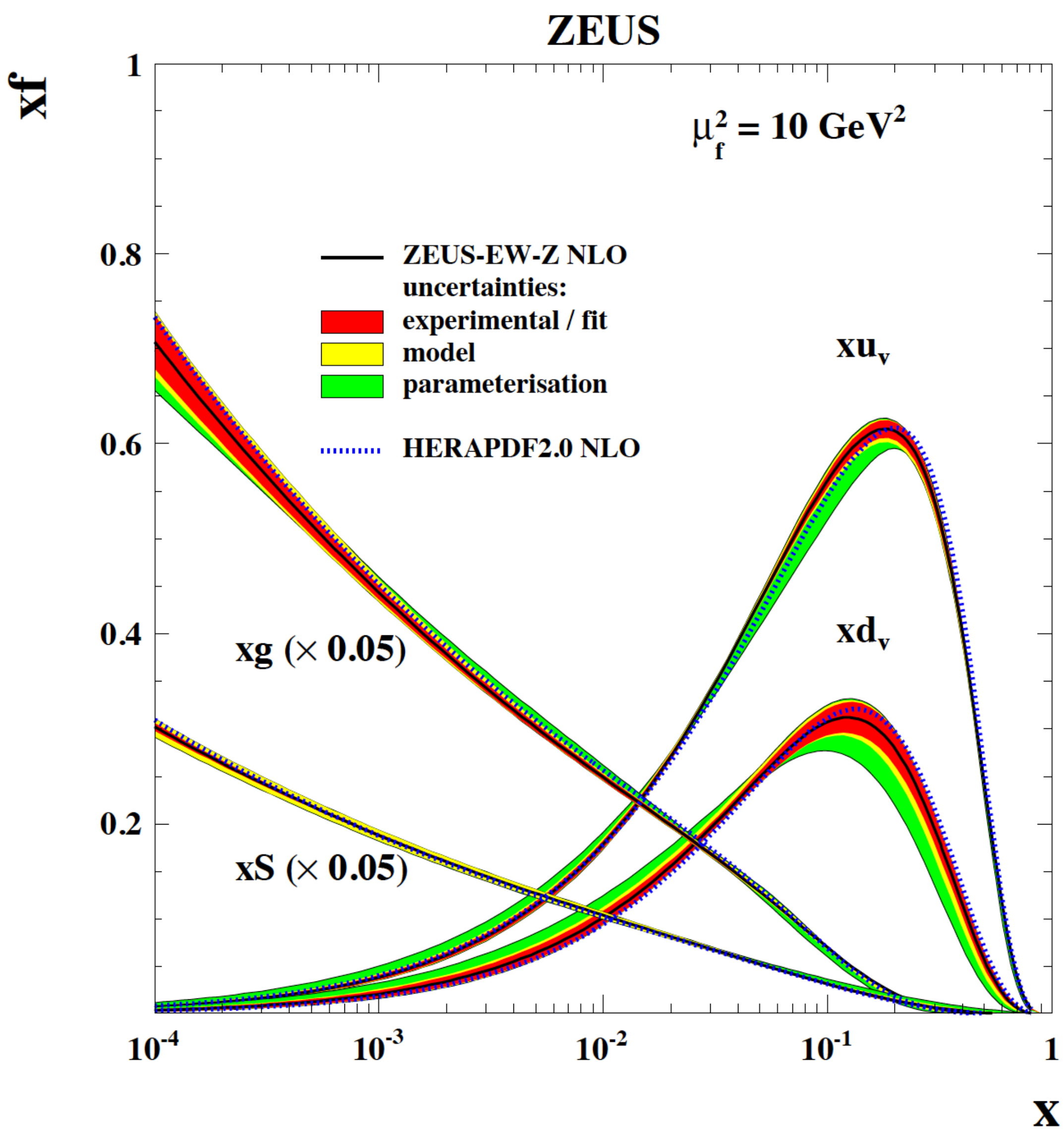
- **$\sin^2\theta_W$** determined; first observation of **$\sin^2\theta_W^{eff}$ running** from single machine
- **mass of W boson** determined in **space-like** momentum transfer process

extras

HERA: world's only ep collider

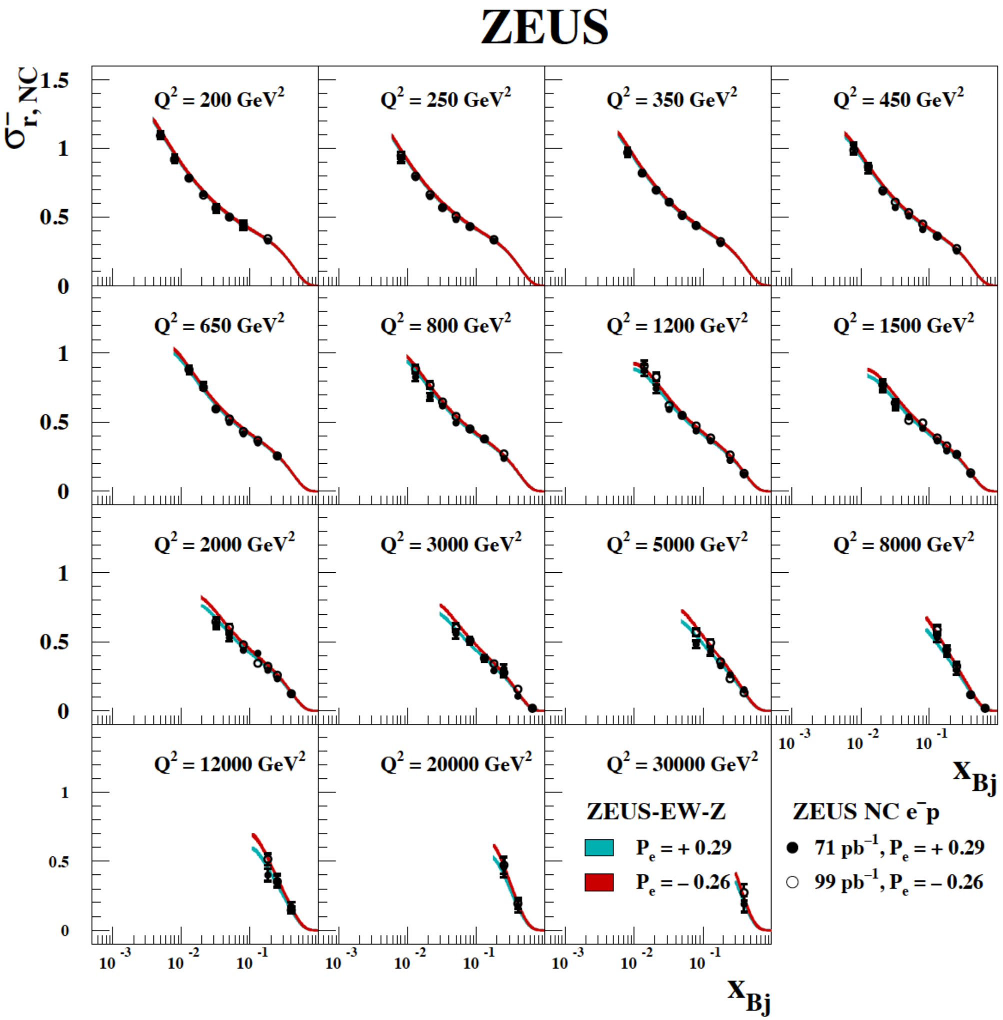


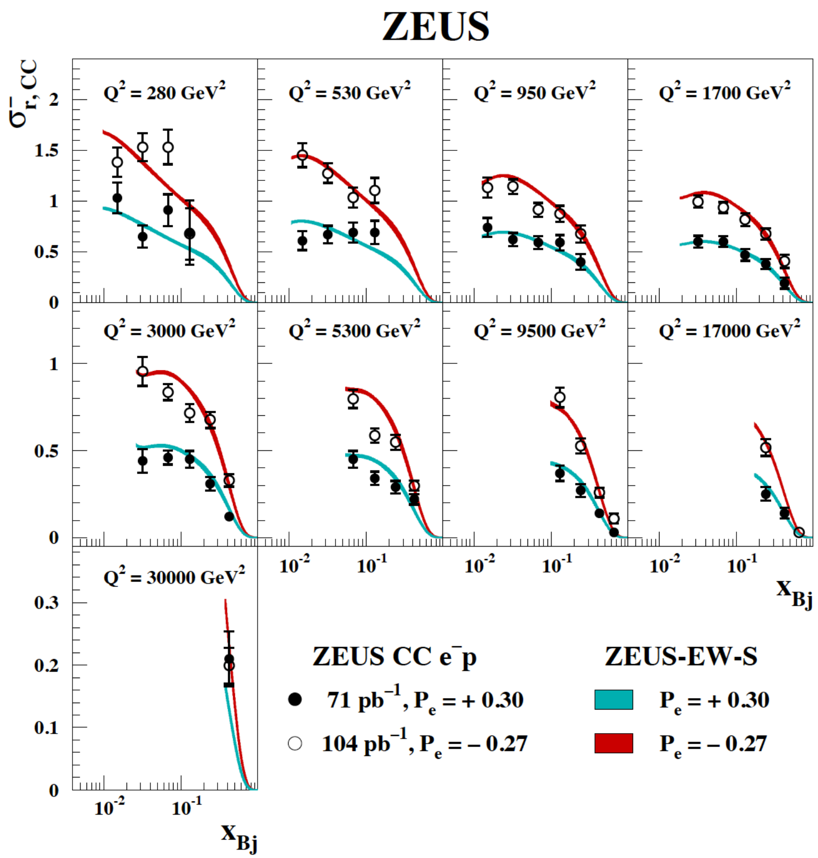
PDF fit results



comparison with HERAPDF2.0 (EPJ C75 (2015), 580)

NC and CC polarised DIS data





polarised **e⁻p**

Q^2_{min} = 3.5 GeV^2 – number of data points is 2942, of which 501 are polarised

ZEUS cross section data (X^2/NDF = 1.12 for fit with NC couplings free)

correlation matrix

ZEUS Coll., PRD 93, 092002 (2016)
(arXiv:1603.09628)

Parameters	xg: B	xg: C	xg: A'	xg: B'	xu_v: B	xu_v: C	xu_v: E	xd_v: B	xd_v: C	$x\bar{U}$: C	$x\bar{D}$: A	$x\bar{D}$: B	$x\bar{D}$: C	a_u	a_d	v_u	v_d
xg: B	1.000	−0.014	−0.449	0.824	−0.216	0.172	0.250	−0.084	−0.085	−0.098	−0.107	−0.136	0.046	0.025	0.003	0.015	0.018
xg: C	−0.014	1.000	0.831	0.457	0.341	−0.373	−0.550	0.010	0.296	−0.018	−0.082	−0.103	−0.434	0.105	0.095	−0.098	−0.111
xg: A'	−0.449	0.831	1.000	0.120	0.548	−0.404	−0.629	0.233	0.274	0.159	0.081	0.072	−0.148	−0.052	0.000	−0.043	−0.054
xg: B'	0.824	0.457	0.120	1.000	0.106	−0.037	−0.082	0.075	0.047	0.043	0.011	−0.014	0.012	−0.029	−0.011	−0.001	−0.002
xu_v: B	−0.216	0.341	0.548	0.106	1.000	−0.409	−0.774	0.465	−0.086	0.690	0.476	0.395	0.439	−0.360	−0.178	0.079	0.070
xu_v: C	0.172	−0.373	−0.404	−0.037	−0.409	1.000	0.828	−0.297	−0.235	−0.188	−0.095	−0.069	−0.040	0.110	0.029	0.040	0.028
xu_v: E	0.250	−0.550	−0.629	−0.082	−0.774	0.828	1.000	−0.296	−0.066	−0.363	−0.170	−0.117	−0.092	0.192	0.087	−0.023	−0.017
xd_v: B	−0.084	0.010	0.233	0.075	0.465	−0.297	−0.296	1.000	0.518	0.405	0.350	0.291	0.673	−0.335	−0.134	0.038	0.021
xd_v: C	−0.085	0.296	0.274	0.047	−0.086	−0.235	−0.066	0.518	1.000	−0.137	−0.186	−0.193	−0.139	0.110	0.128	−0.101	−0.128
$x\bar{U}$: C	−0.098	−0.018	0.159	0.043	0.690	−0.188	−0.363	0.405	−0.137	1.000	0.673	0.635	0.329	−0.320	−0.137	0.055	0.052
$x\bar{D}$: A	−0.107	−0.082	0.081	0.011	0.476	−0.095	−0.170	0.350	−0.186	0.673	1.000	0.959	0.477	−0.272	−0.137	0.056	0.059
$x\bar{D}$: B	−0.136	−0.103	0.072	−0.014	0.395	−0.069	−0.117	0.291	−0.193	0.635	0.959	1.000	0.415	−0.239	−0.120	0.047	0.053
$x\bar{D}$: C	0.046	−0.434	−0.148	0.012	0.439	−0.040	−0.092	0.673	−0.139	0.329	0.477	0.415	1.000	−0.449	−0.271	0.148	0.153
a_u	0.025	0.105	−0.052	−0.029	−0.360	0.110	0.192	−0.335	0.110	−0.320	−0.272	−0.239	−0.449	1.000	0.861	−0.555	−0.729
a_d	0.003	0.095	0.000	−0.011	−0.178	0.029	0.087	−0.134	0.128	−0.137	−0.137	−0.120	−0.271	0.861	1.000	−0.636	−0.880
v_u	0.015	−0.098	−0.043	−0.001	0.079	0.040	−0.023	0.038	−0.101	0.055	0.056	0.047	0.148	−0.555	−0.636	1.000	0.851
v_d	0.018	−0.111	−0.054	−0.002	0.070	0.028	−0.017	0.021	−0.128	0.052	0.059	0.053	0.153	−0.729	−0.880	0.851	1.000

Table 2: *The correlation matrix of all parameters of the ZEUS-EW-Z fit.*

EW parameter cross checks

- studies performed to check stability of EW couplings with respect to various QCD parameters

	a_u	exp	tot	a_d	exp	tot	v_u	exp	tot	v_d	exp	tot
EW-Z	$+0.50$	$^{+0.09}_{-0.05}$	$^{+0.12}_{-0.05}$	-0.56	$^{+0.34}_{-0.14}$	$^{+0.41}_{-0.15}$	$+0.14$	$^{+0.08}_{-0.08}$	$^{+0.09}_{-0.09}$	-0.41	$^{+0.24}_{-0.16}$	$^{+0.25}_{-0.20}$
13p	$+0.49$	$^{+0.07}_{-0.04}$		-0.57	$^{+0.30}_{-0.13}$		$+0.15$	$^{+0.08}_{-0.08}$		-0.40	$^{+0.22}_{-0.17}$	
HPDF1	$+0.47$	$^{+0.06}_{-0.03}$		-0.62	$^{+0.23}_{-0.11}$		$+0.16$	$^{+0.08}_{-0.08}$		-0.35	$^{+0.22}_{-0.19}$	
HPDF2	$+0.49$	$^{+0.06}_{-0.03}$		-0.63	$^{+0.24}_{-0.11}$		$+0.15$	$^{+0.08}_{-0.08}$		-0.36	$^{+0.22}_{-0.19}$	
SM	$+0.50$			-0.50			$+0.20$			-0.35		

Table 3: *The results on the axial-vector and vector couplings of the Z boson to u- and d-type quarks from ZEUS-EW-Z. Given are the experimental/fit (exp) and total (tot) uncertainties. Also listed are results of fits with the PDFs fixed to ZEUS-13p and HERAPDF2.0, HPDF1 and HPDF2, for which only the couplings of the Z were free parameters. The HPDF1 fit was performed with the on-shell value of $\sin^2\theta_W$ used in the fit while HPDF2 was performed with the $\sin^2\theta_W$ value used for the extraction of HERAPDF2.0. Also listed are the predictions of the SM for the a and v couplings in the on-shell scheme.*

$\sin^2\theta_W$ and M_W

DIS inclusive cross sections depend on $\sin^2\theta_W$ through:

Neutral **C**urrent:

- χ_Z term in NC cross section: $$\chi_Z = \frac{1}{\sin^2 2\theta_W} \frac{Q^2}{M_Z^2 + Q^2} \frac{1}{1 - \Delta R}$$
- NC vector couplings to quarks: $$v_u = 1/2 - 4/3 \sin^2\theta_W$$ $$v_d = -1/2 + 2/3 \sin^2\theta_W$$

Charged **C**urrent:

- CC cross sections, via G_F

$$\frac{d^2\sigma_{CC}(e^+p)}{dx_{Bj}dQ^2} = (1+P_e)\frac{G_F^2 M_W^4}{2\pi x_{Bj}(Q^2+M_W^2)^2} x\left[(\bar{u}+\bar{c}) + (1-y)^2(d+s+b)\right]$$

$$G_F = \frac{\pi\alpha_0}{\sqrt{2}\sin^2\theta_W M_W^2}\frac{1}{1-\Delta R}$$

$$\frac{d^2\sigma_{CC}(e^-p)}{dx_{Bj}dQ^2} = (1-P_e)\frac{G_F^2 M_W^4}{2\pi x_{Bj}(Q^2+M_W^2)^2} x\left[(u+c) + (1-y)^2(\bar{d}+\bar{s}+\bar{b})\right]$$

G_F re-expressed through $\sin^2\theta_W$ and M_W meaning both NC and CC used to extract $\sin^2\theta_W$

χ_F and G_F are most important for $\sin^2\theta_W$ determination

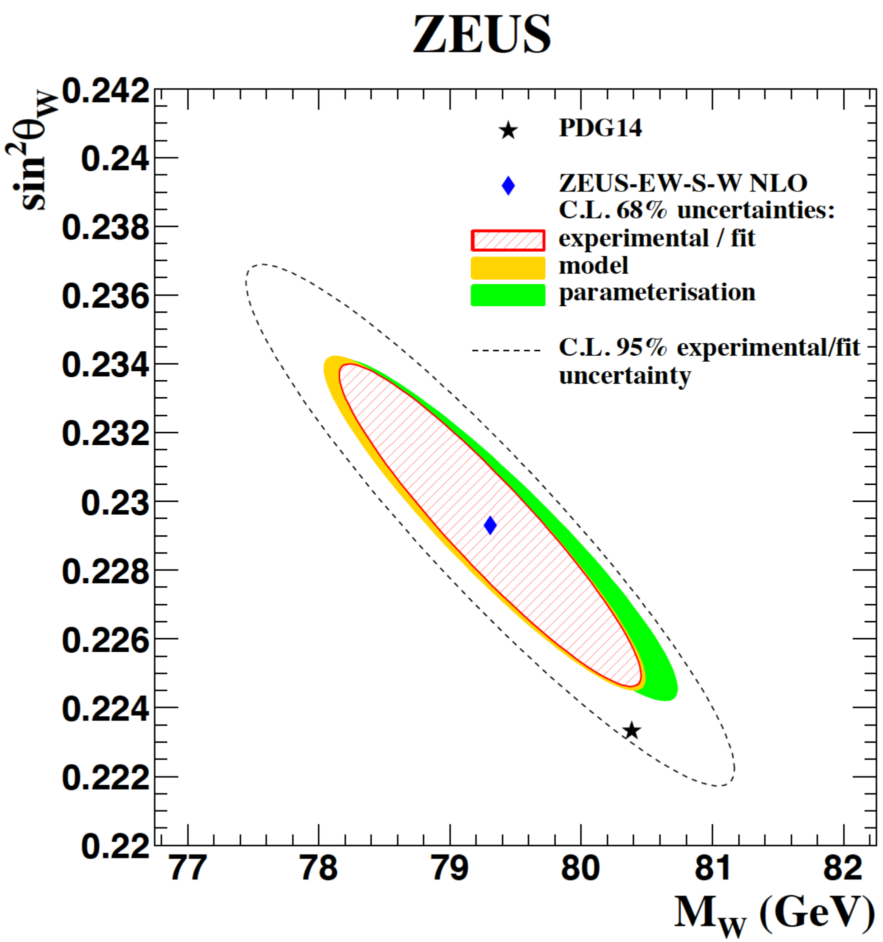
M_W sensitivity comes from G_F and W propagator in CC events

$\sin^2\theta_W$

bin	Q^2_{min} (GeV^2)	Q^2_{max} (GeV^2)	scale (GeV)	$\sin^2\theta_W$ on-shell	exp unc.	$\sin^2\theta_W^{eff}$ effective	exp unc.	PDF unc.
1	200	1000	22.3	0.2254	± 0.0020	0.2352	± 0.0020	$^{+0.0020}_{-0.0012}$
2	1000	5000	49.9	0.2251	± 0.0014	0.2339	± 0.0015	$^{+0.0014}_{-0.0008}$
3	5000	50000	139.8	0.2240	± 0.0026	0.2323	± 0.0026	$^{+0.0025}_{-0.0015}$
All Data			M_Z	0.2252	± 0.0011	0.2335	± 0.0011	$^{+0.0008}_{-0.0004}$

Table 4: *The on-shell and effective values of* $\sin^2\theta_W$ *as determined for three bins in* Q^2 *and for all data. Experimental/fit (exp) uncertainties are given as determined by the one-parameter fits for each bin or ZEUS-EW-S, respectively; model and parameterisation uncertainties as determined by ZEUS-EW-S were added in quadrature and are denoted as PDF uncertainties. They are identical for on-shell and effective values at the accuracy given.*

$\sin^2\theta_W$ and M_W



simultaneous extraction of $\sin^2\theta_W$ and M_W (together with PDFs) also performed as cross-check

PDG14:

$\sin^2\theta_W = 0.22333 \pm 0.00011$ (on-shell)

$M_W = 80.385 \pm 0.015$

$$\sin^2\theta_W = 0.2293 \pm 0.0031 \text{ (experimental/fit) } {}^{+0.0005}_{-0.0001} \text{ (model) } {}^{+0.0003}_{-0.0001} \text{ (parameterisation)}$$

$$M_W = 79.30 \pm 0.76 \text{ (experimental/fit) } {}^{+0.38}_{-0.08} \text{ (model) } {}^{+0.48}_{-0.10} \text{ (parameterisation) GeV} .$$

comparison of NC light quark couplings

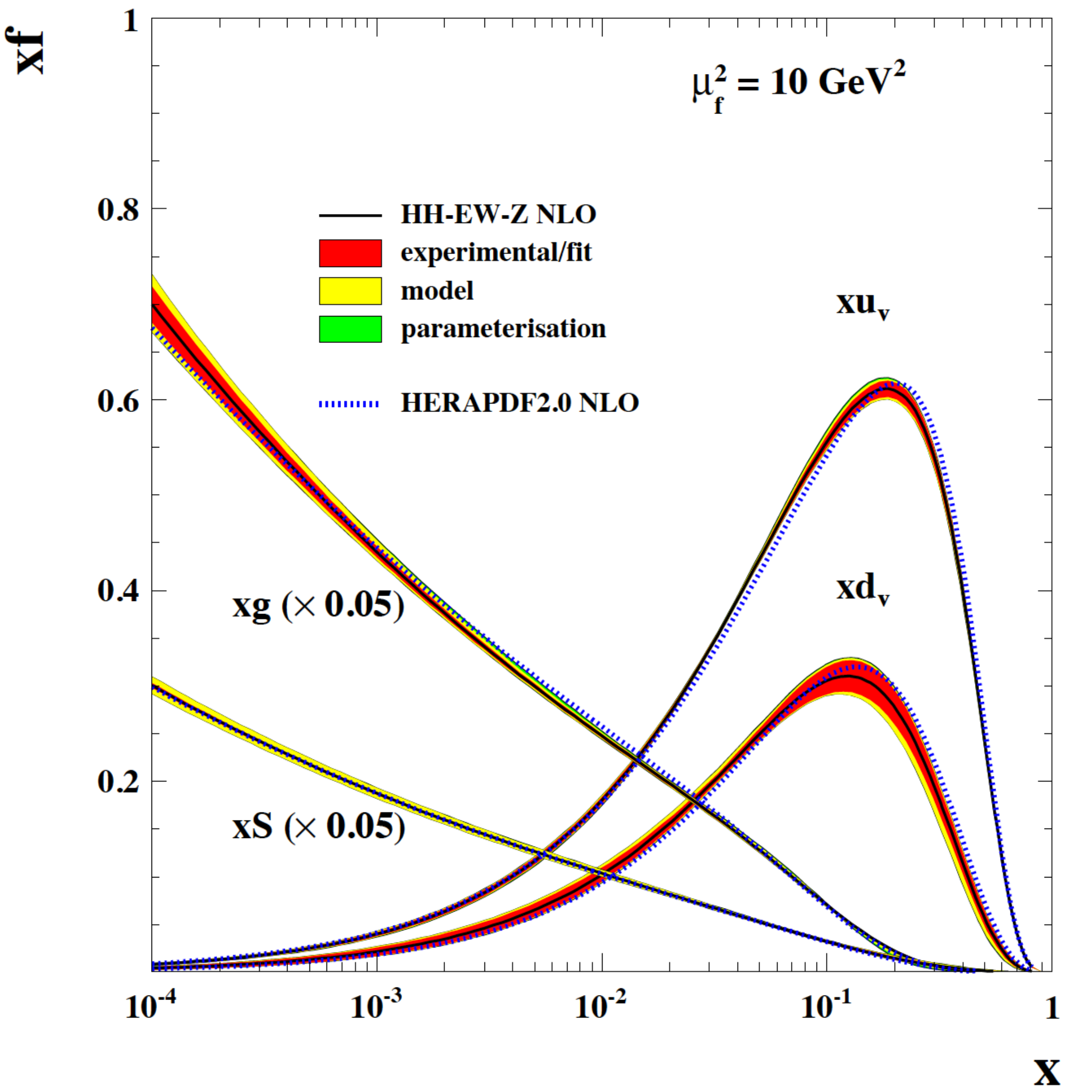
ZEUS Coll., PRD 93, 092002 (2016) (arXiv:1603.09628)

					Standard Model
a_u	$= +0.50$	${}^{+0.09}_{-0.05}$ (experimental/fit)	${}^{+0.04}_{-0.02}$ (model)	${}^{+0.08}_{-0.01}$ (parameterisation)	0.5
a_d	$= -0.56$	${}^{+0.34}_{-0.14}$ (experimental/fit)	${}^{+0.11}_{-0.05}$ (model)	${}^{+0.20}_{-0.00}$ (parameterisation)	-0.5
v_u	$= +0.14$	${}^{+0.08}_{-0.08}$ (experimental/fit)	${}^{+0.01}_{-0.02}$ (model)	${}^{+0.00}_{-0.03}$ (parameterisation)	0.202
v_d	$= -0.41$	${}^{+0.24}_{-0.16}$ (experimental/fit)	${}^{+0.04}_{-0.07}$ (model)	${}^{+0.00}_{-0.08}$ (parameterisation)	-0.351

I. Abt et al., PRD 94, 052007 (2016) (arXiv:1604.05083)

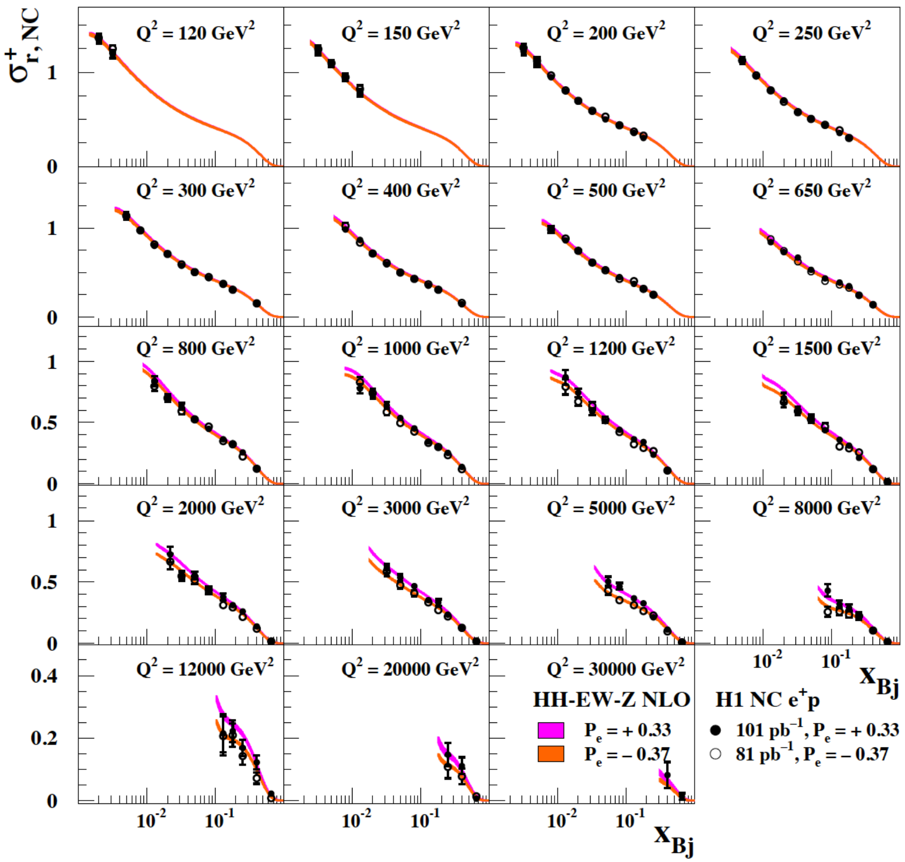
a_u	$= +0.532$	${}^{+0.081}_{-0.058}$ (experimental/fit)	${}^{+0.036}_{-0.022}$ (model)	${}^{+0.060}_{-0.008}$ (parameterisation)
a_d	$= -0.409$	${}^{+0.327}_{-0.199}$ (experimental/fit)	${}^{+0.112}_{-0.071}$ (model)	${}^{+0.140}_{-0.026}$ (parameterisation)
v_u	$= +0.144$	${}^{+0.065}_{-0.050}$ (experimental/fit)	${}^{+0.013}_{-0.014}$ (model)	${}^{+0.002}_{-0.025}$ (parameterisation)
v_d	$= -0.503$	${}^{+0.168}_{-0.093}$ (experimental/fit)	${}^{+0.031}_{-0.028}$ (model)	${}^{+0.006}_{-0.036}$ (parameterisation)

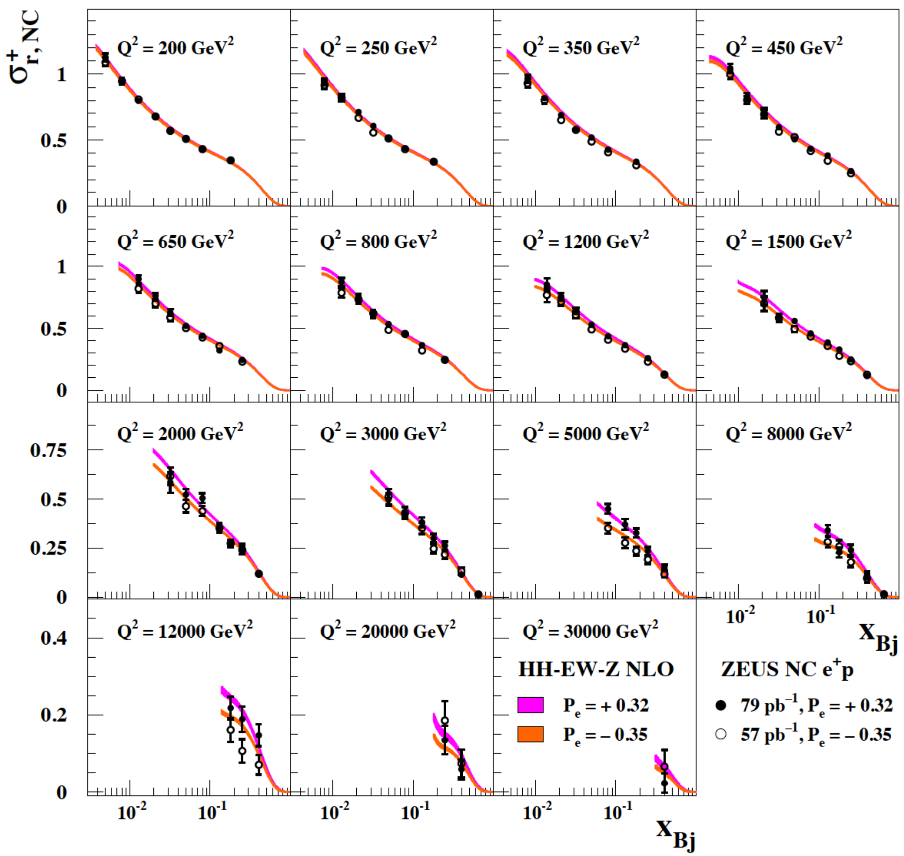
PDF fit results – HH-EW-Z



comparison with HERAPDF2.0 (EPJ C75 (2015), 580)

NC polarised DIS data from H1 and ZEUS





polarised **e⁻p**

Q^2_{min} = 3.5 GeV² – X^2/NDF = 3556/3231=1.10 for fit with NC couplings free

correlation matrix

I. Abt et al.,
PRD 94, 052007 (2016)
(arXiv:1604.05083)

Parameters	xg: B	xg: C	xg: A'	xg: B'	xu_v: B	xu_v: C	xu_v: E	xd_v: B	xd_v: C	$x\bar{U}$: C	$x\bar{D}$: A	$x\bar{D}$: B	$x\bar{D}$: C	a_u	a_d	v_u	v_d
xg: B	1.000	0.491	−0.224	0.935	0.012	0.106	0.044	−0.049	−0.078	−0.049	−0.098	−0.140	0.018	0.057	0.061	−0.039	−0.051
xg: C	0.491	1.000	0.660	0.707	0.287	−0.267	−0.464	−0.054	0.196	−0.047	−0.140	−0.175	−0.369	0.106	0.093	−0.124	−0.114
xg: A'	−0.224	0.660	1.000	0.125	0.513	−0.361	−0.593	0.226	0.254	0.162	0.084	0.072	−0.100	−0.038	0.003	−0.065	−0.070
xg: B'	0.935	0.707	0.125	1.000	0.200	−0.002	−0.144	0.048	−0.008	0.042	−0.017	−0.056	0.018	0.033	0.057	−0.058	−0.074
xu_v: B	0.012	0.287	0.513	0.200	1.000	−0.337	−0.760	0.510	−0.084	0.698	0.498	0.409	0.507	−0.256	−0.095	0.019	−0.032
xu_v: C	0.106	−0.267	−0.361	−0.002	−0.337	1.000	0.796	−0.249	−0.247	−0.140	−0.055	−0.032	−0.013	0.092	0.044	0.026	0.013
xu_v: E	0.044	−0.464	−0.593	−0.144	−0.760	0.796	1.000	−0.298	−0.057	−0.363	−0.165	−0.105	−0.127	0.133	0.045	0.024	0.043
xd_v: B	−0.049	−0.054	0.226	0.048	0.510	−0.249	−0.298	1.000	0.502	0.437	0.406	0.344	0.727	−0.221	−0.056	0.014	−0.056
xd_v: C	−0.078	0.196	0.254	−0.008	−0.084	−0.247	−0.057	0.502	1.000	−0.116	−0.168	−0.175	−0.097	0.107	0.115	−0.092	−0.109
$x\bar{U}$: C	−0.049	−0.047	0.162	0.042	0.698	−0.140	−0.363	0.437	−0.116	1.000	0.685	0.647	0.366	−0.234	−0.082	−0.006	−0.028
$x\bar{D}$: A	−0.098	−0.140	0.084	−0.017	0.498	−0.055	−0.165	0.406	−0.168	0.685	1.000	0.961	0.525	−0.231	−0.114	0.049	0.021
$x\bar{D}$: B	−0.140	−0.175	0.072	−0.056	0.409	−0.032	−0.105	0.344	−0.175	0.647	0.961	1.000	0.460	−0.210	−0.106	0.046	0.026
$x\bar{D}$: C	0.018	−0.369	−0.100	0.018	0.507	−0.013	−0.127	0.727	−0.097	0.366	0.525	0.460	1.000	−0.327	−0.168	0.133	0.056
a_u	0.057	0.106	−0.038	0.033	−0.256	0.092	0.133	−0.221	0.107	−0.234	−0.231	−0.210	−0.327	1.000	0.928	−0.665	−0.779
a_d	0.061	0.093	0.003	0.057	−0.095	0.044	0.045	−0.056	0.115	−0.082	−0.114	−0.106	−0.168	0.928	1.000	−0.714	−0.876
v_u	−0.039	−0.124	−0.065	−0.058	0.019	0.026	0.024	0.014	−0.092	−0.006	0.049	0.046	0.133	−0.665	−0.714	1.000	0.880
v_d	−0.051	−0.114	−0.070	−0.074	−0.032	0.013	0.043	−0.056	−0.109	−0.028	0.021	0.026	0.056	−0.779	−0.876	0.880	1.000

Table 1: The correlation matrix of all parameters of the HH-EW-Z fit.