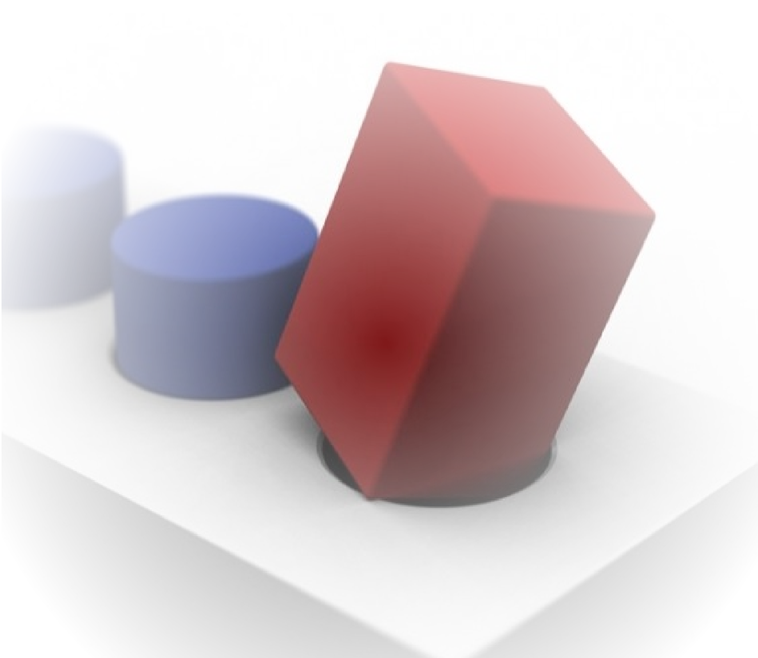
Combined QCD and EW analysis of HERA data



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ZEUS paper presentation
16.12.2015, Hamburg

Analysis setup

- Data used in the analysis (separate datasets, correlations as in HERAPDF2.0):
  - HERAI: H1 + ZEUS;
  - HERAII: H1 unpol. + ZEUS pol.;
  - Reduced E_P runs: H1 + ZEUS;

- $Q_{min}^2 = 3.5$ GeV².
- HF scheme: GM VFNS NLO (RT OPT).
- PDFs parametrised with 13p (HERAPDF2.0 - $D\bar{U}$) at $Q_0^2 = 1.9$ GeV²

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

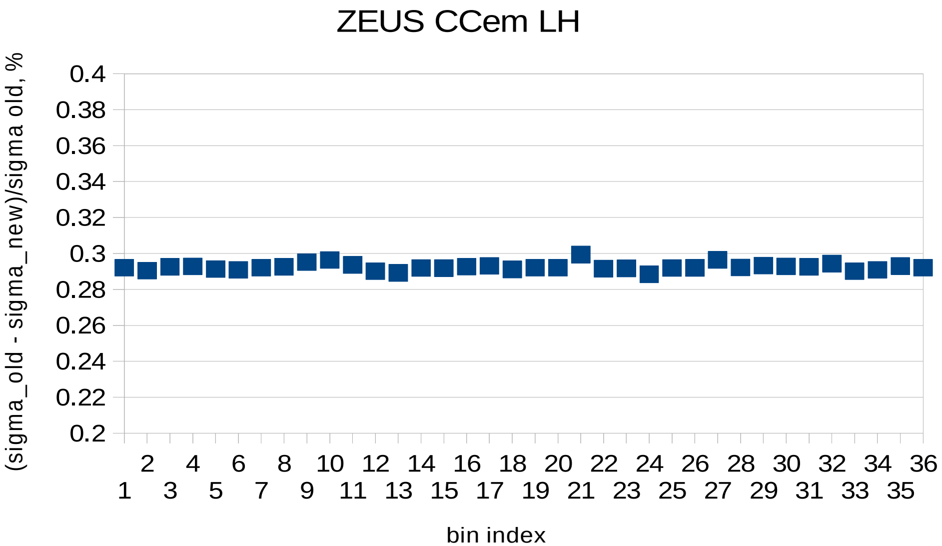
$$xg(x), xu_v(x), xd_v(x), x\bar{U}(x), x\bar{D}(x)$$

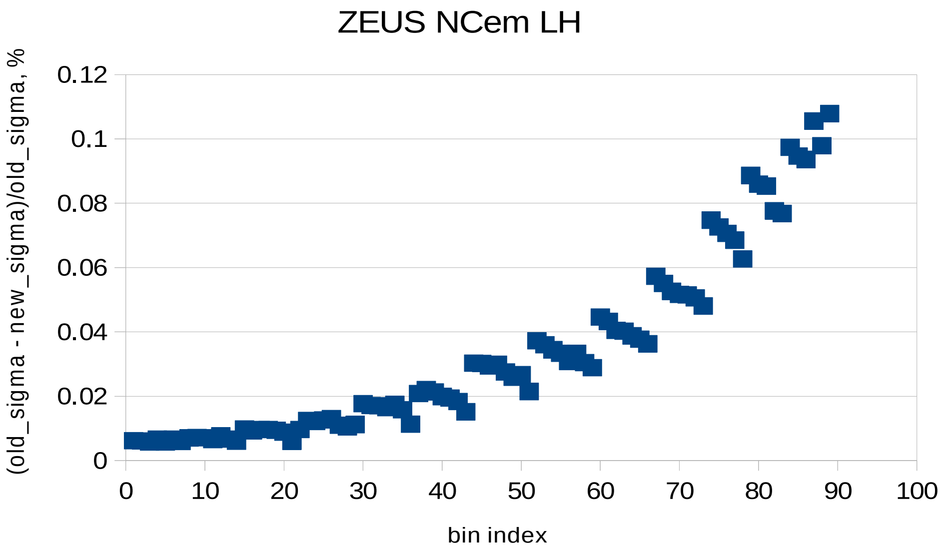
- Free parameters: PDF parameters + couplings of Z^0 to quarks (a_u, a_d, v_u, v_d), or M_W, or $\sin^2\theta_W$ (On-shell scheme).
- Optimal M_c and M_b and α_S are used as for HERAPDF2.0.
- Model and parameterisation uncertainty estimation → HERAPDF2.0 strategy.
- Correction calculated using EPRC code: Δr^{EW}. No QED corrections.

Polarisation update

- Correction from QCD predictions (PDF → HERAPDF2.0)

$$\sigma^{\pm NEW}_{pol} = \frac{\sigma^{pred}_{NEW\,P_e}}{\sigma^{pred}_{OLD\,P_e}} \sigma^{\pm OLD}_{pol}$$





- Very tiny effect on the cross sections.

- Uncertainties due to polarisation were also estimated (treated as correlated in the analysis).

<u>More details in dedicated talk on 07.10.2015</u>

Corrections to the born (QED) level

- All the inclusive DIS cross sections we use were corrected to Born QED level

...we can not be absolutely sure, BUT most likely (we searched hard!)...

- ZEUS corrected for:
  - Init.- final-state radiation from electrons.
- H1 corrected for:
  - Init.- and final-state radiation from electrons;
  - Z self energy;
  - Init.- and final-state quarkonic radiation.

- Zeitschrift für Physik C Particles and Fields Dec.1989, Volume 42, Issue 4, pp 679-692: the difference was traced to be less than 1% of the correction.
- Max. correction @ HERA kin. domain is ~15%
- arXiv:1206.7007: all uncertainties < 2% of correction over complete phase space

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- Assigning 0.3% uncertainty (obvious overestimation) has shown negligible effect on measurements:
  - Totally correlated;
  - Correlated for ZEUS and H1 separately;
  - Uncorrelated.

New since the group presentation

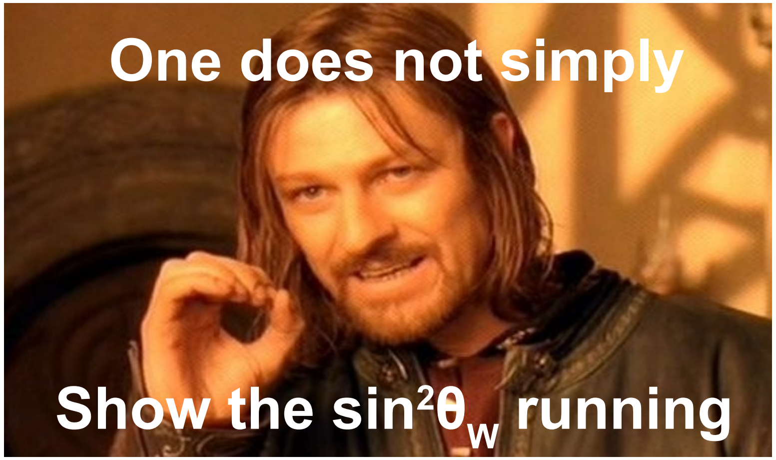
- Before group presentation the $\sin^2\theta_W^{\overline{MS}}$ = 0.23126 was used as an input.

- This was found to be inconsistent with the rest of setup (e.g. calculation of Δr).

- From now on through all the analysis $\sin^2\theta_W^{On\text{-}shell}$ = 0.22333 is used, unless this parameter is set free in the fit => <u>we determine $\sin^2\theta_W$ in On-shell scheme</u>.

- The only noticeable (yet small and within exp. uncertainty) change was observed in the fitted values of couplings. The PDFs almost did not change.

- Did a check of $\sin^2\theta_W$ running. (end of this talk)

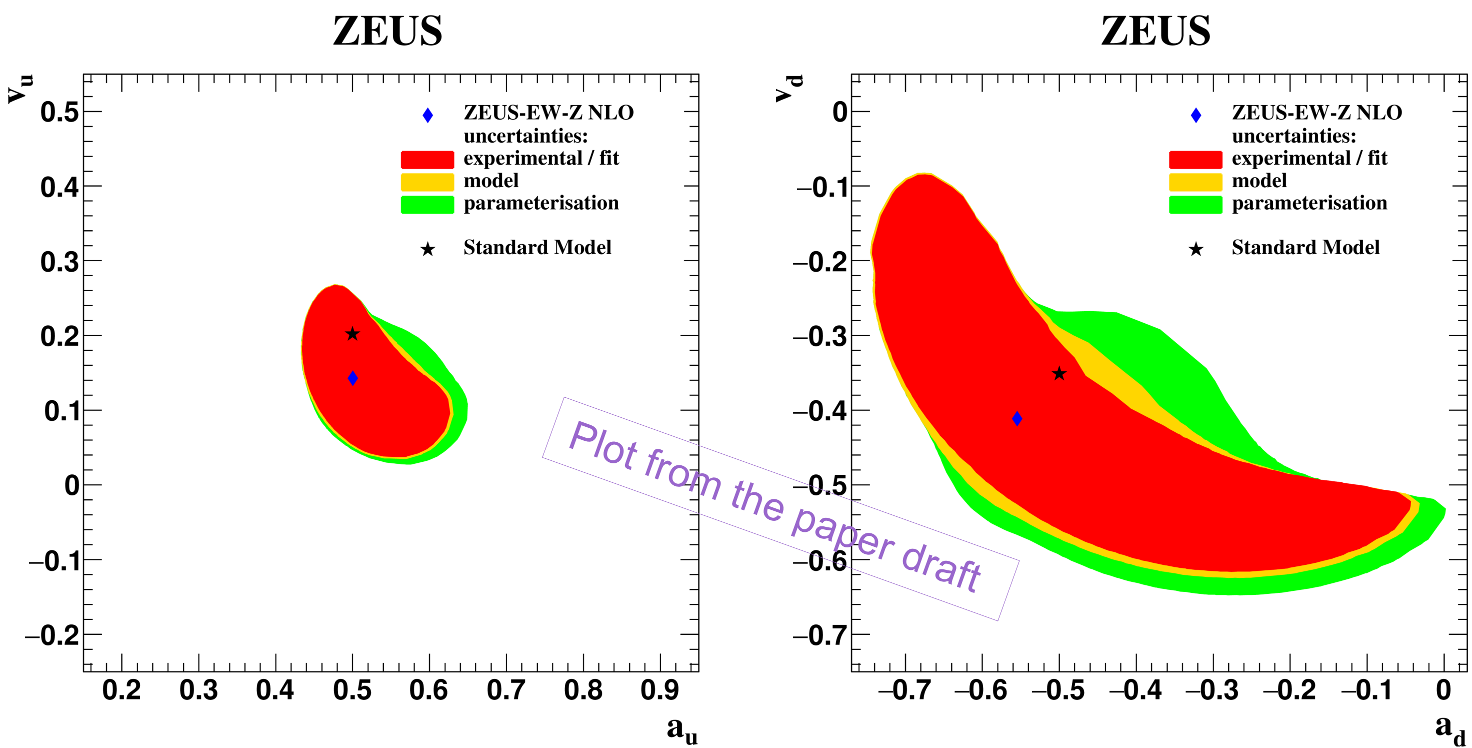


Couplings of quarks to Z boson

- Couplings were determined simultaneously with PDFs (ZEUS-EW-Z)

	SM
$a_u = +0.500 \,^{+0.086}_{-0.047}(\mathrm{exp}) \,^{+0.037}_{-0.016}(\mathrm{model}) \,^{+0.080}_{-0.005}(\mathrm{param})$	**0.5**
$a_d = -0.555 \,^{+0.337}_{-0.144}(\mathrm{exp}) \,^{+0.112}_{-0.048}(\mathrm{model}) \,^{+0.200}_{-0.003}(\mathrm{param})$	**-0.5**
$v_u = +0.143 \,^{+0.084}_{-0.081}(\mathrm{exp}) \,^{+0.014}_{-0.023}(\mathrm{model}) \,^{+0.000}_{-0.027}(\mathrm{param})$	**0.202**
$v_d = -0.411 \,^{+0.243}_{-0.164}(\mathrm{exp}) \,^{+0.041}_{-0.066}(\mathrm{model}) \,^{+0.000}_{-0.082}(\mathrm{param})$	**-0.351**

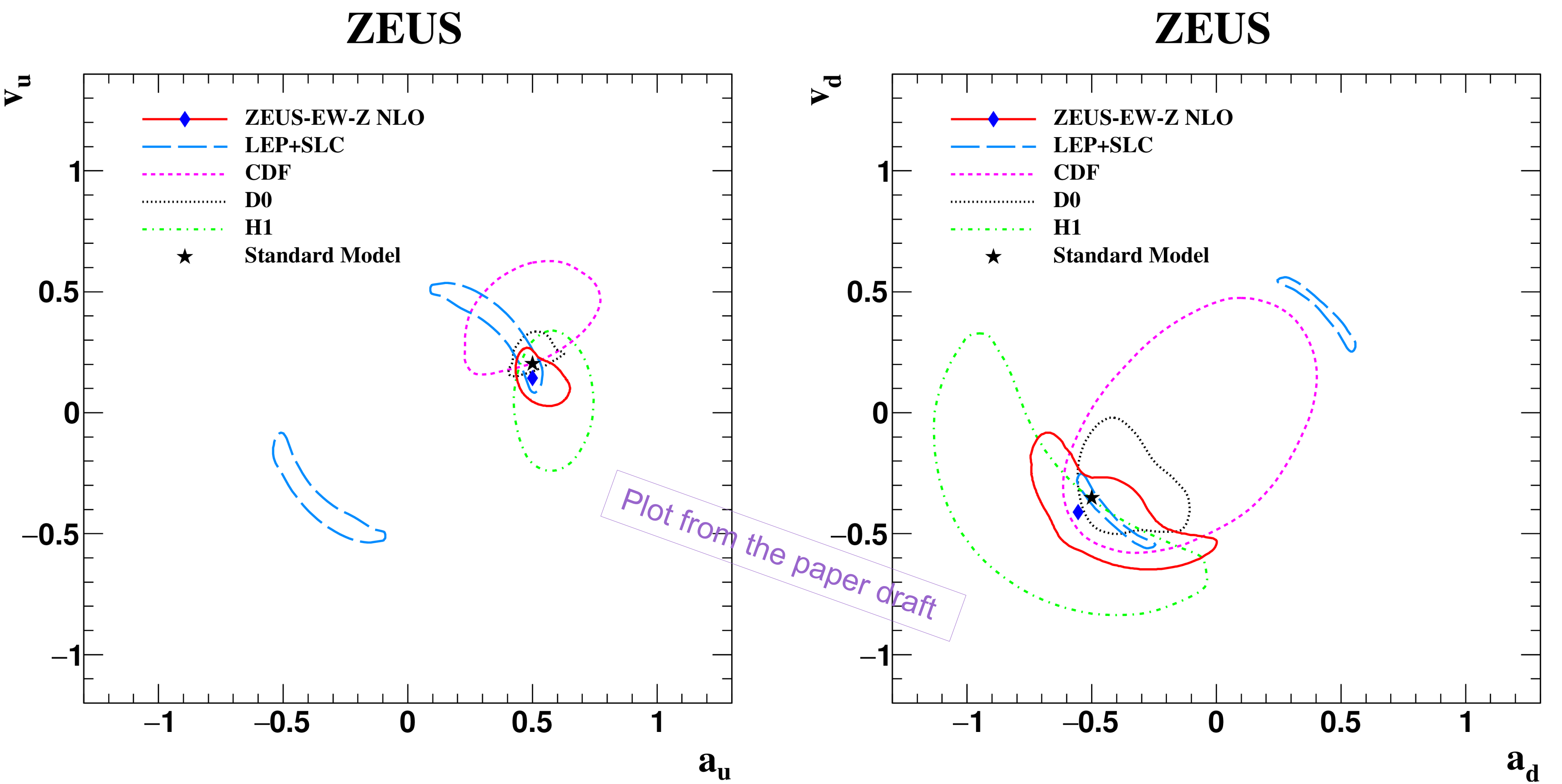
- 2D uncertainties were also evaluated.



Mod/par variations in backup

Couplings of quarks to Z boson

- ZEUS-EW-Z results are compatible with previous measurements

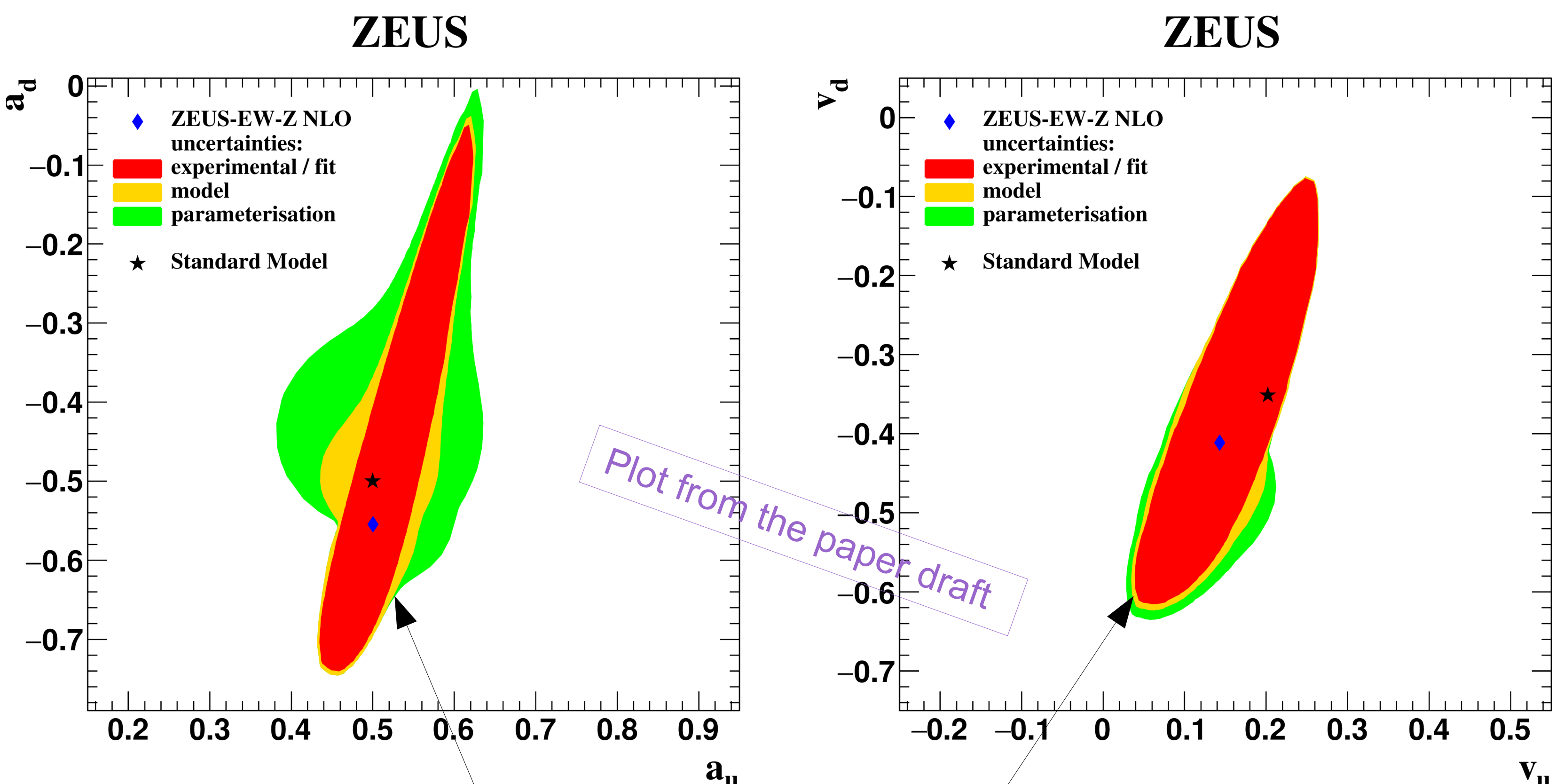


- HERA data shows remarkable sensitivity to the u-type quark couplings.

Comparison of numerical values in backup

Couplings of quarks to Z boson

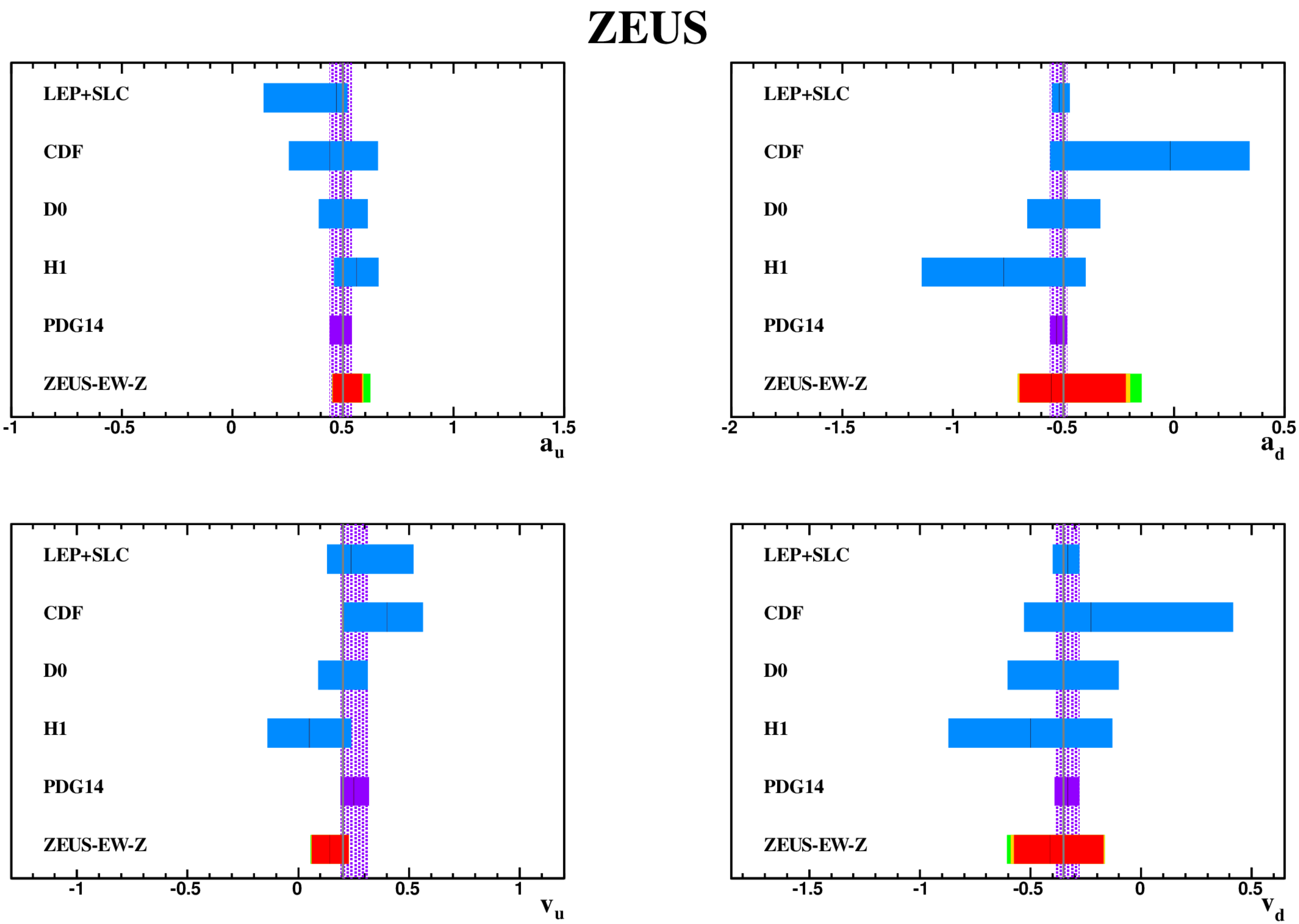
- Couplings in the fit show pretty high correlation
- Correlation of couplings to PDF parameters is weak (see also slides 9 and 10)



	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

Full correlation table in backup

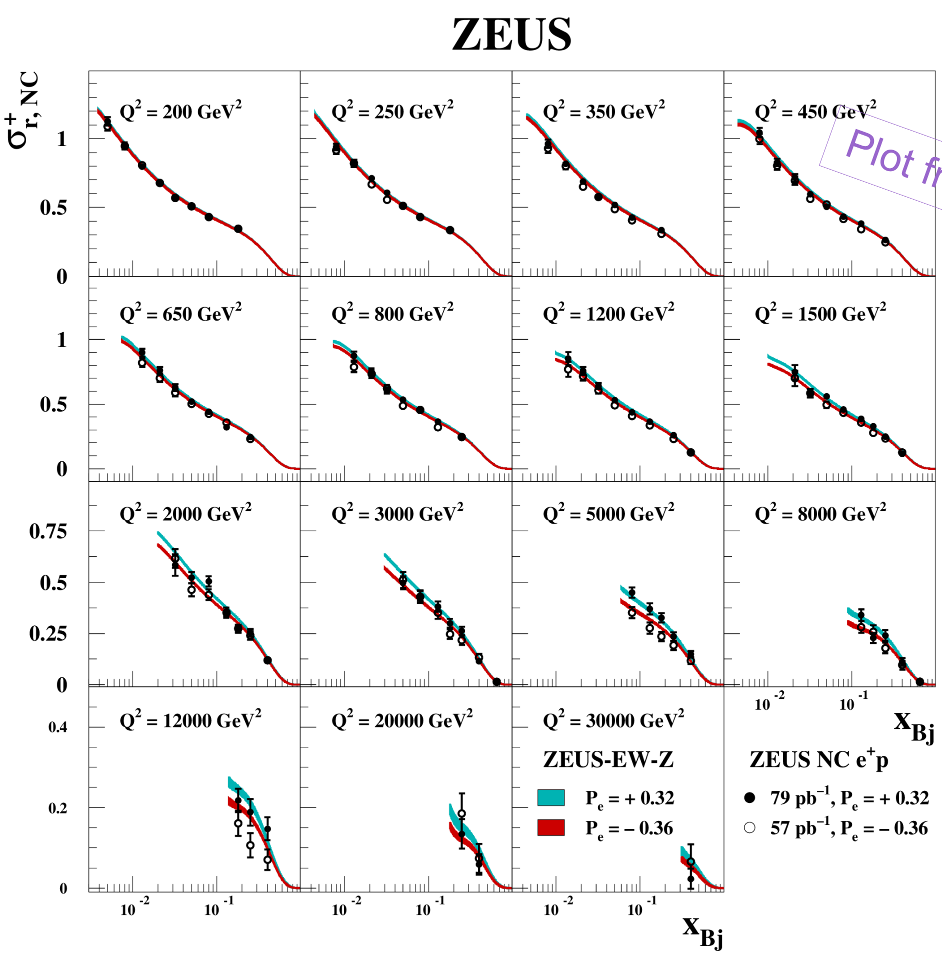
Couplings of quarks to Z boson

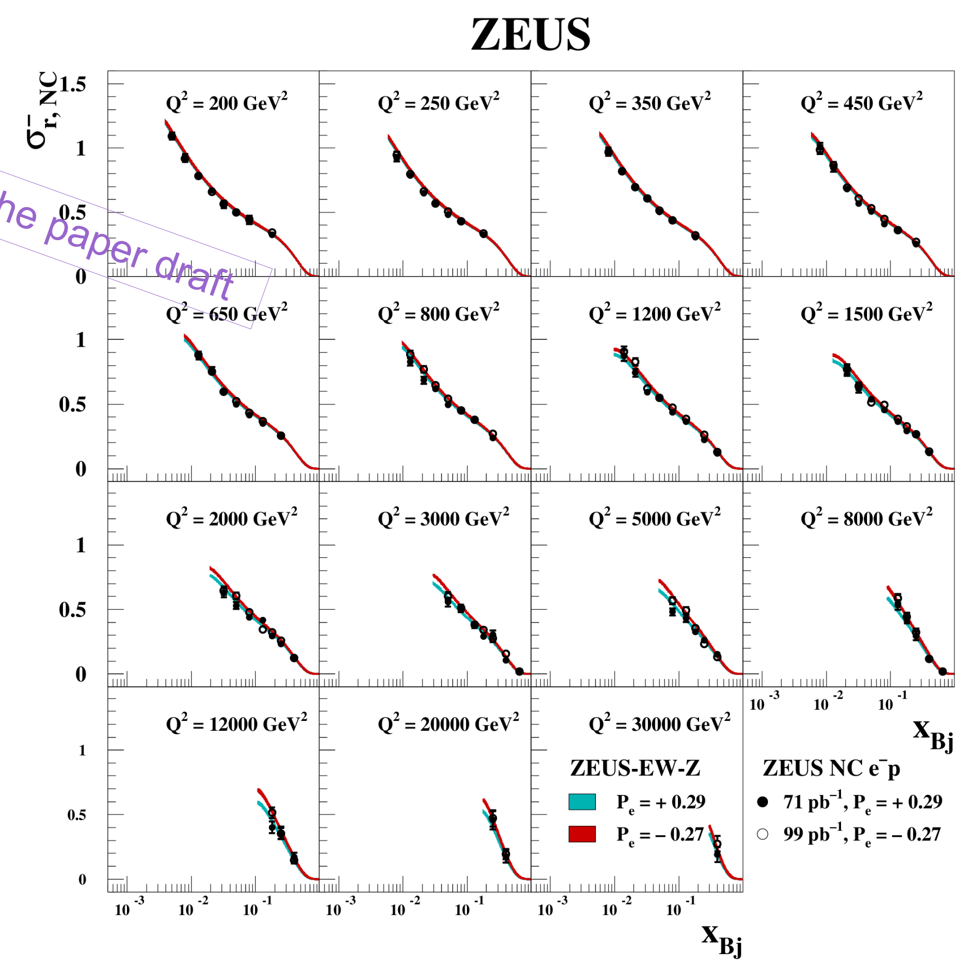


- PDG average values do not include current ZEUS-EW-Z results (red-yellow-green rectangles).
- Results presented here have a potential to decrease uncertainties of average values (u-quark in particular)

Data description (ZEUS-EW-Z)

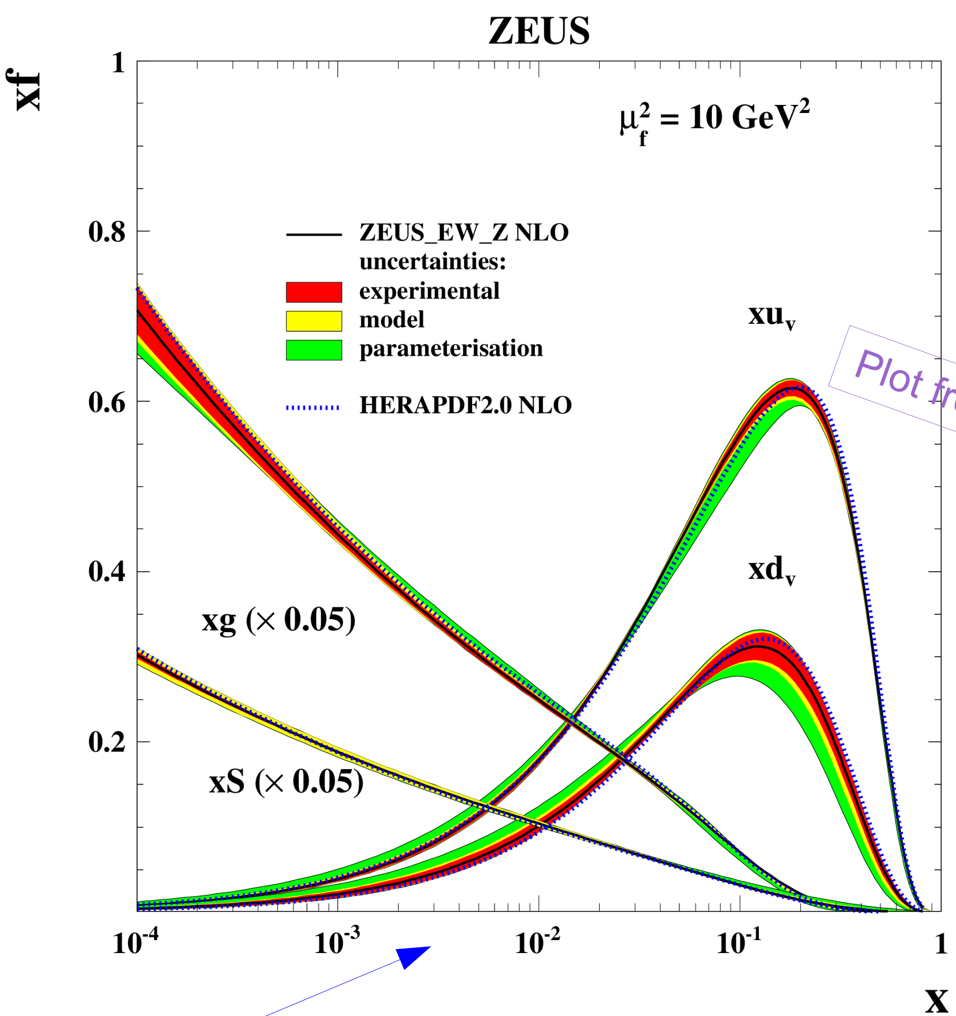
- Fitted predictions describe data well.

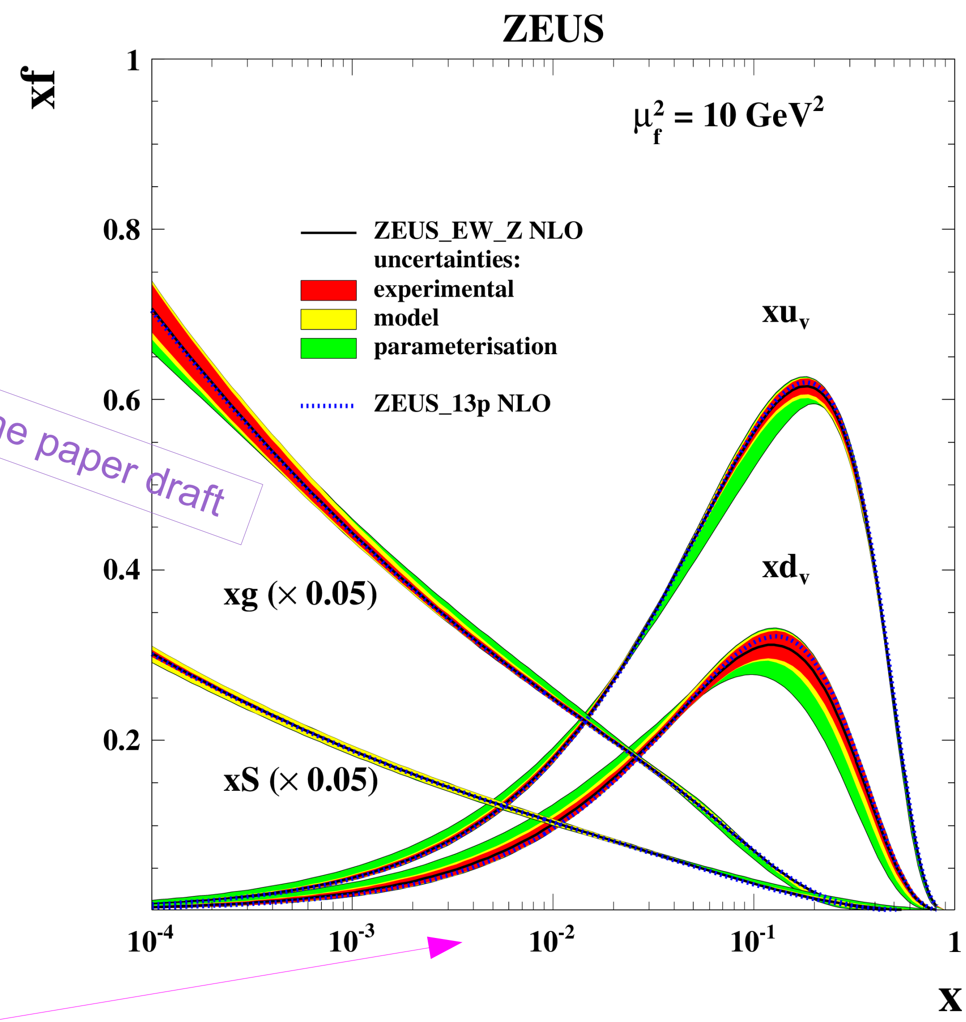




- χ^2 = 3270 / 2925 = 1.118

Effect of coupling determination on PDFs





Plot from the paper draft

- HERAPDF2.0 and ZEUS-13p PDFs with couplings set to SM agree with ZEUS-EW-Z PDFs.
  - Releasing couplings has little effect on PDFs.

Full correlation table in backup

Effect of PDFs determination on couplings

- Couplings, fitted at fixed PDFs are well compatible with those from ZEUS-EW-Z fit.

	a_u	exp	tot	a_d	exp	tot	v_u	exp	tot	v_d	exp	tot
EW-Z	$+.500$	$^{+.086}_{-.047}$	$^{+.122}_{-.050}$	$-.555$	$^{+.337}_{-.144}$	$^{+.407}_{-.152}$	$+.143$	$^{+.084}_{-.081}$	$^{+.085}_{-.088}$	$-.411$	$^{+.243}_{-.164}$	$^{+.246}_{-.195}$
13p	$+.485$	$^{+.073}_{-.038}$		$-.567$	$^{+.295}_{-.130}$		$+.145$	$^{+.079}_{-.076}$		$-.402$	$^{+.216}_{-.171}$	
HPDF1*	$+.474$	$^{+.059}_{-.033}$		$-.619$	$^{+.233}_{-.107}$		$+.156$	$^{+.076}_{-.076}$		$-.353$	$^{+.215}_{-.190}$	
HPDF2*	$+.486$	$^{+.061}_{-.034}$		$-.634$	$^{+.239}_{-.110}$		$+.149$	$^{+.078}_{-.078}$		$-.357$	$^{+.220}_{-.194}$	
SM	$+.500$			$-.500$			$+.202$			$-.351$		

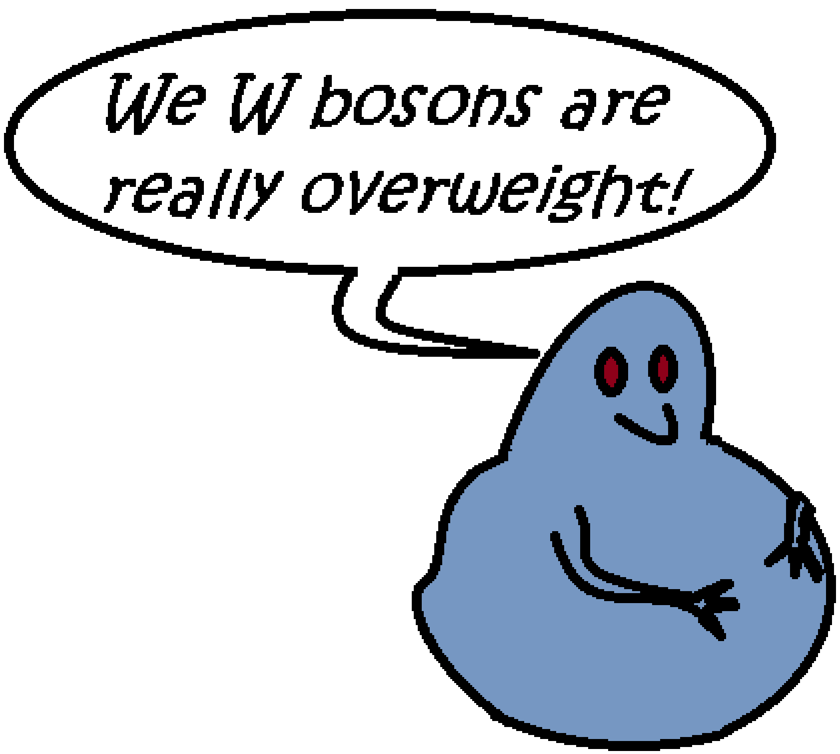
- Differences in the experimental uncertainties can give a rough estimate of PDF uncertainties in the measurement.

* HERAPDF2.0 used $\sin^2\theta_W$ @ $\overline{MS}$ - HPDF2, this analysis uses $\sin^2\theta_W$ @ On-schell - HPDF1.
The influence of $\sin^2\theta_W$ for PDF extraction only is minimal (checked).

Mass of W boson

- Mass of W boson was determined simultaneously with PDFs (ZEUS-EW-W)

$$M_W = 80.68 \pm 0.28(\mathrm{exp})\ ^{+0.12}_{-0.01}(\mathrm{model})\ ^{+0.23}_{-0.01}(\mathrm{param})\ \mathrm{GeV}$$



$$M_W^{World\ average} = 80.385 \pm 0.015\ GeV$$

G_F in CC was re-expressed with:

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

- M_W form ZEUS-EW-W is consistent with current world average.

On $\sin^2\theta_W$(+X) fits to DIS data

- DIS inclusive cross sections depend on $\sin^2\theta_W$ through:
  - Z propagator in NC cross sections;
  - Vector couplings of Z to quarks;

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

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

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

  - W propagator (G_F);

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

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

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

ΔR is an EW correction.

arXiv:hep-ph/9902277

- Re-expressing G_F through $\sin^2\theta_W$ and M_W allows to use both CC and NC for $\sin^2\theta_W$ determination.

- Current analysis exploits all three dependences for $\sin^2\theta_W$ extraction.
- $\sin^2\theta_W$ values extracted in current analysis correspond to On-shell scheme.

Quark couplings to Z

Now consider fits to electroweak NC couplings as well as PDF parameters

The total cross-section : $\sigma = \sigma^0 + P\,\sigma^P$

The unpolarised cross-section is given by $\sigma^0 = Y_+ F_2^0 + Y_- xF_3^0$

$$F_2^0 = \Sigma_i\, A_i^0(Q^2)\, [xq_i(x,Q^2) + x\bar{q}_i(x,Q^2)]$$

$$xF_3^0 = \Sigma_i\, B_i^0(Q^2)\, [xq_i(x,Q^2) - x\bar{q}_i(x,Q^2)]$$

$$A_i^0(Q^2) = e_i^2 - 2 e_i \mathbf{v_i} \mathbf{v_e} P_Z + (v_e^2+a_e^2)(\mathbf{v_i}^2+\mathbf{a_i}^2) P_Z^2$$

$$B_i^0(Q^2) = - 2 e_i \mathbf{a_i} a_e P_Z + 4\mathbf{a_i} a_e \mathbf{v_i} v_e P_Z^2$$

$$P_Z = \frac{1}{\sin^2 2\theta} \frac{Q^2}{(M_Z^2 + Q^2)}$$

The polarised cross-section is given by $\sigma^P = Y_+ F_2^P + Y_- xF_3^P$

$$F_2^P = \Sigma_i\, A_i^P(Q^2)\, [xq_i(x,Q^2) + x\bar{q}_i(x,Q^2)]$$

$$xF_3^P = \Sigma_i\, B_i^P(Q^2)\, [xq_i(x,Q^2) - x\bar{q}_i(x,Q^2)]$$

$$A_i^P(Q2) = 2 e_i \mathbf{v_i} a_e P_Z - 2 v_e a_e (\mathbf{v_i}^2+\mathbf{a_i}^2) P_Z^2$$

$$B_i^P(Q2) = 2 e_i \mathbf{a_i} \mathbf{v_e} P_Z - 2 \mathbf{a_i} \mathbf{v_i} (v_e^2+a_e^2) P_Z^2$$

$P_Z >> P_Z^2$ (γZ interference is dominant)
$\mathbf{v_e}$ is very small (~0.04).

→ unpolarized xF_3 → a_i,
polarized F_2 → v_i

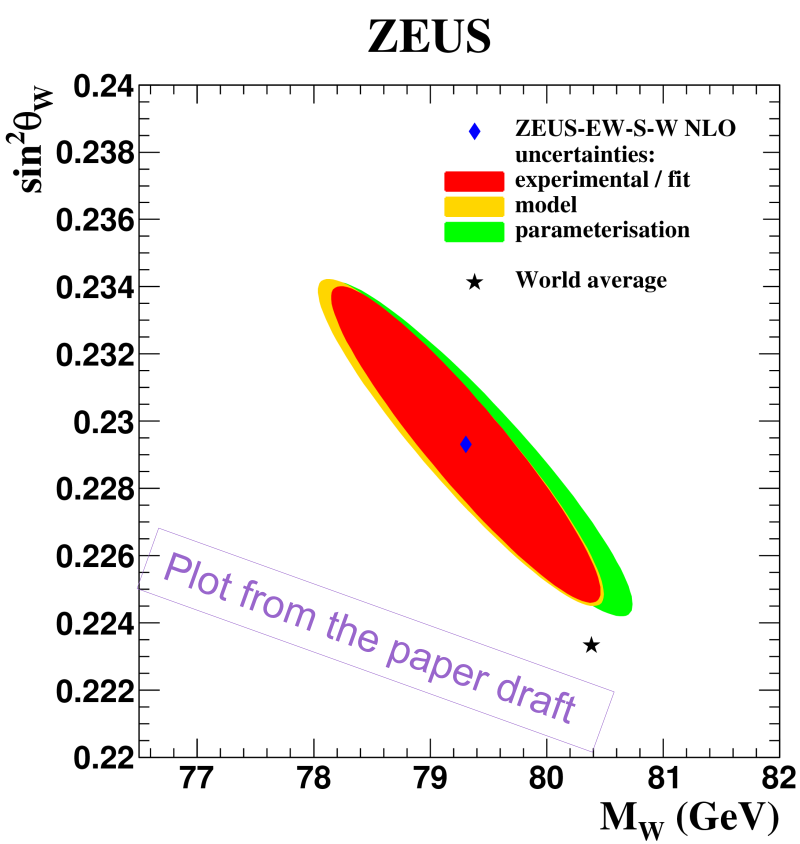
$\sin^2\theta_W$ and mass of W boson

- $\sin^2\theta_W$ was determined simultaneously with PDFs (ZEUS-EW-S)

$$\sin^2\theta_W = 0.2252 \pm 0.0011(\text{exp})\,^{+0.0003}_{-0.0001}(\text{model})\,^{+0.0007}_{-0.0001}(\text{param})$$

$$\sin^2\theta_W^{PDG\,14\,On-shell} = 0.22333 \pm 0.00011$$

- $\sin^2\theta_W$ and M_W were determined simultaneously with PDFs (ZEUS-EW-S-W)



$$\sin^2\theta_W = 0.2293 \pm 0.0031(\text{exp})\,^{+0.0005}_{-0.0001}(\text{model})\,^{+0.0003}_{-0.0001}(\text{param})$$
$$M_W = 79.30 \pm 0.76(\text{exp})\,^{+0.38}_{-0.08}(\text{model})\,^{+0.48}_{-0.10}(\text{param})\ \text{GeV}$$

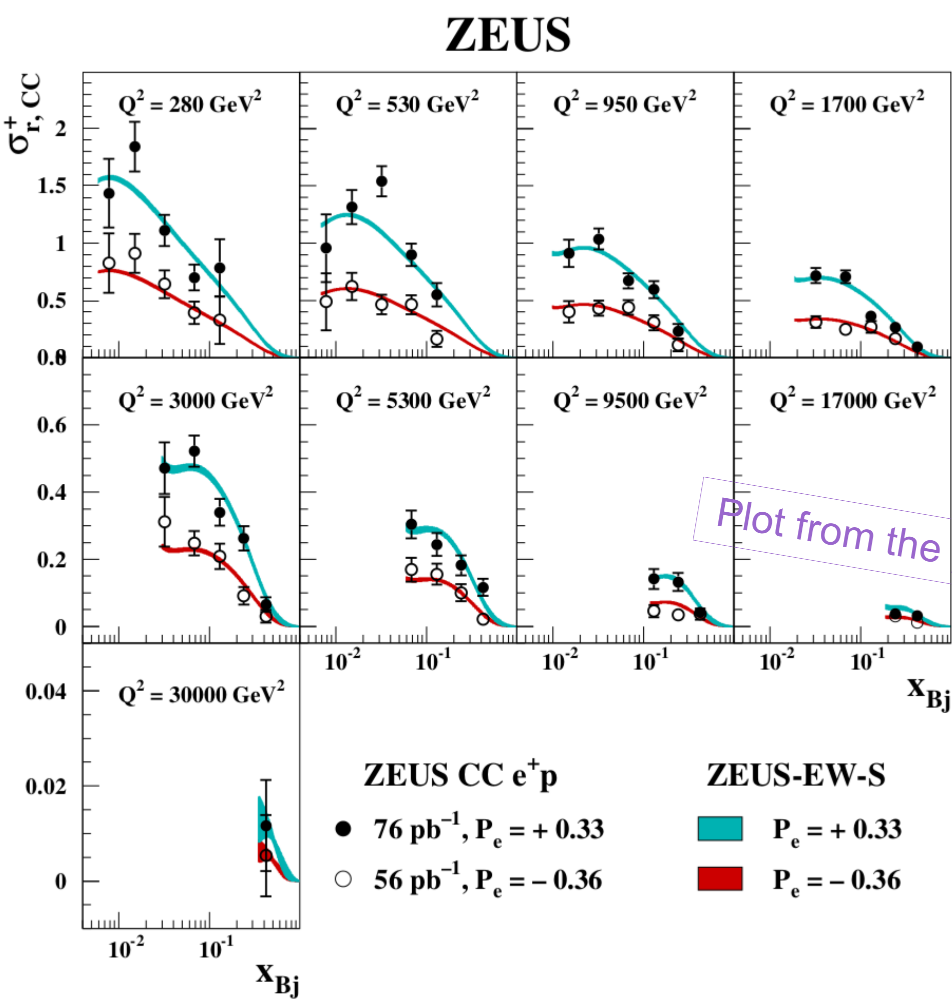
$$corr(M_W, \sin^2\theta_W) = -0.930$$

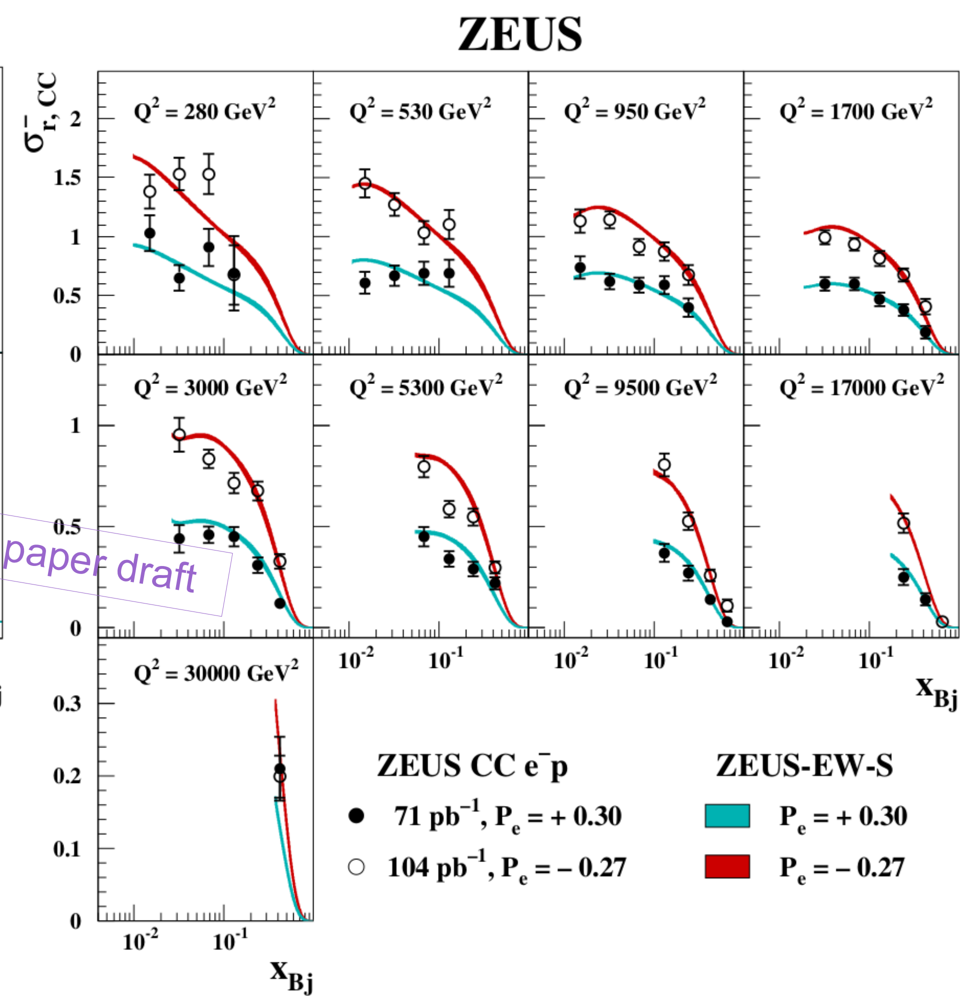
$$M_W^{World\ average} = 80.385 \pm 0.015\ GeV$$

- All extracted quantities demonstrate reasonable agreement with World average values.

Data description (ZEUS-EW-S)

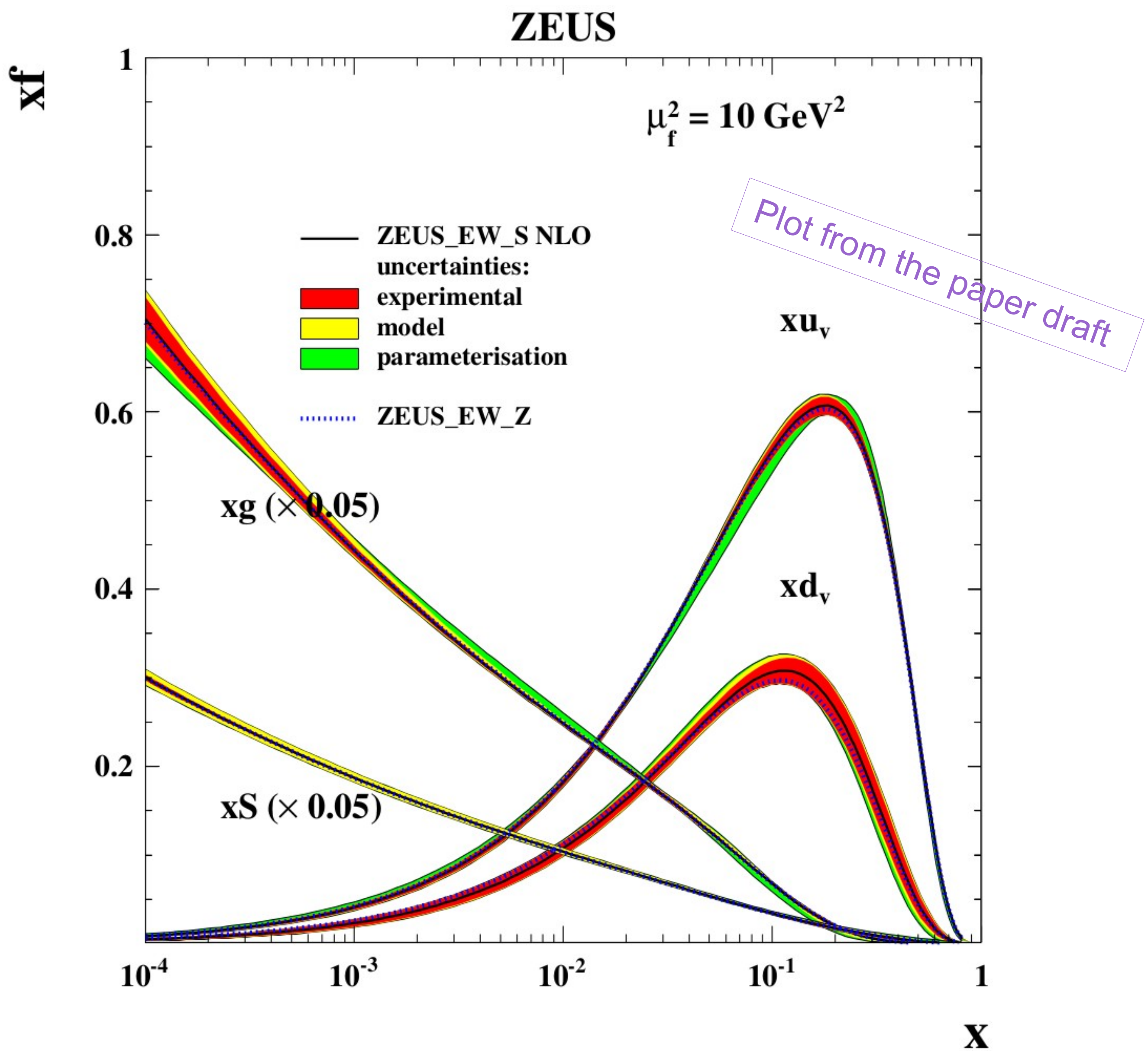
- Fitted predictions describe data reasonably well.





- χ^2 = 3270 / 2928 = 1.118

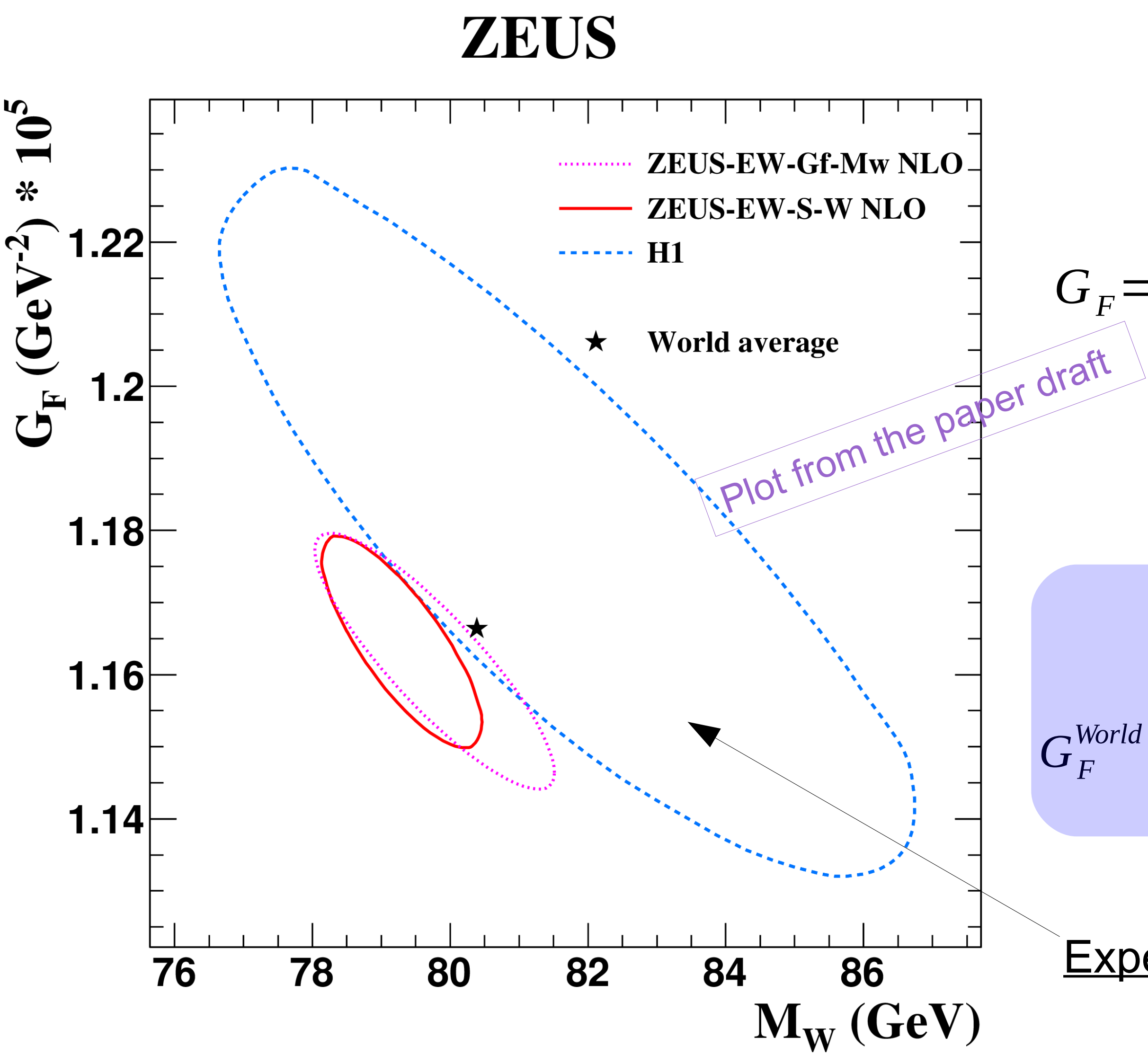
ZEUS-EW-Z vs ZEUS-EW-S



- PDFs from ZEUS-EW-Z and ZEUS-EW-S are very similar.

G_F and mass of W boson

- G_F and M_W were also determined simultaneously with PDFs as a consistency check.



$$M_W = 79.77 \pm 1.15\,(\exp)\,GeV$$

$$G_F = (1.1618 \pm 0.0117) * 10^{-5}\,(\exp)\,GeV^{-2}$$

$$corr\,(M_W, G_F) = -0.87$$

$$M_W^{World\ average} = 80.385 \pm 0.015\,GeV$$

$$G_F^{World\ average} = 1.1663787 * 10^{-5} \pm 6 * 10^{-12}\,GeV^{-2}$$

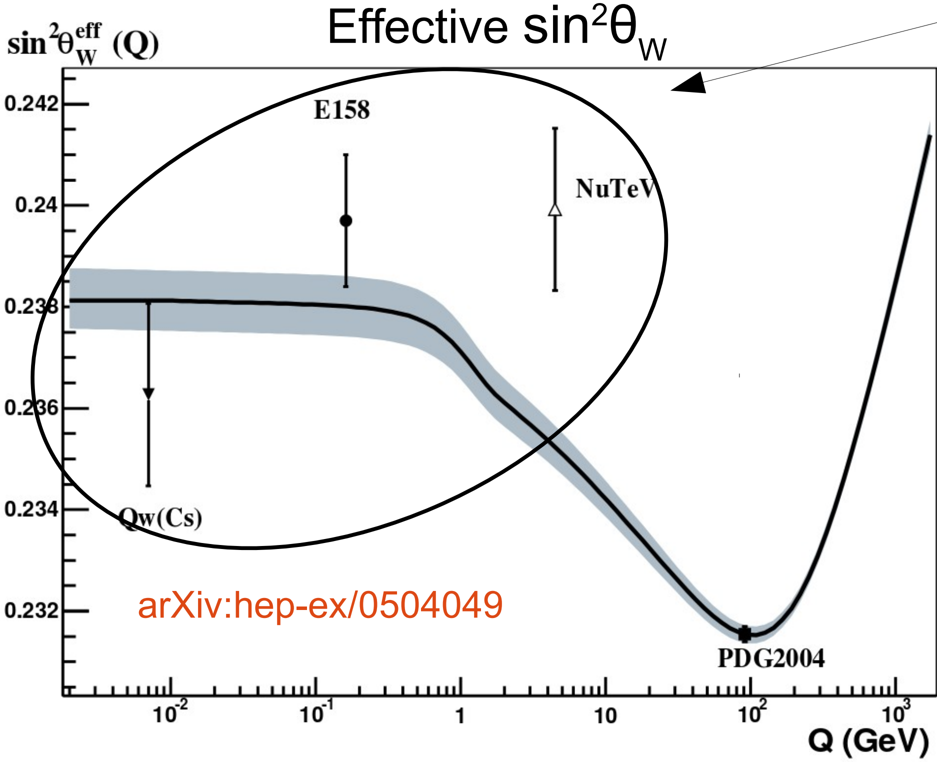
Experimental uncertainties only!!

- Fitter G_F and M_W are consistent with current world average values.

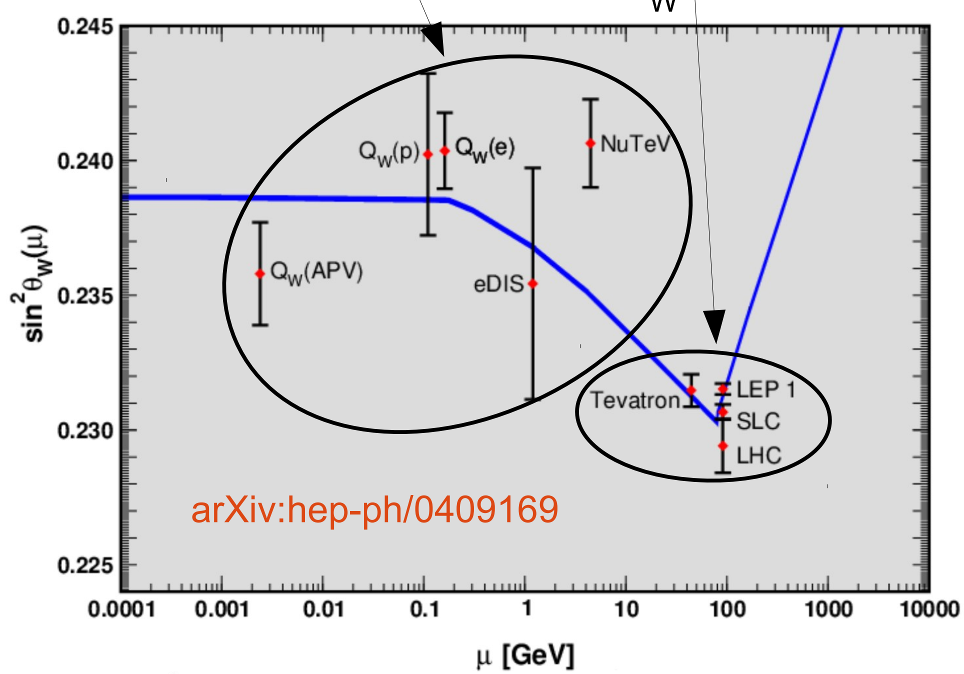
On $\sin^2\theta_W$ running with a scale

- All the measurements were so far done either at the scale μ <≈ 1 GeV or $\mu = M_Z$.

Effective $\sin^2\theta_W$



$\overline{MS}$ $\sin^2\theta_W$



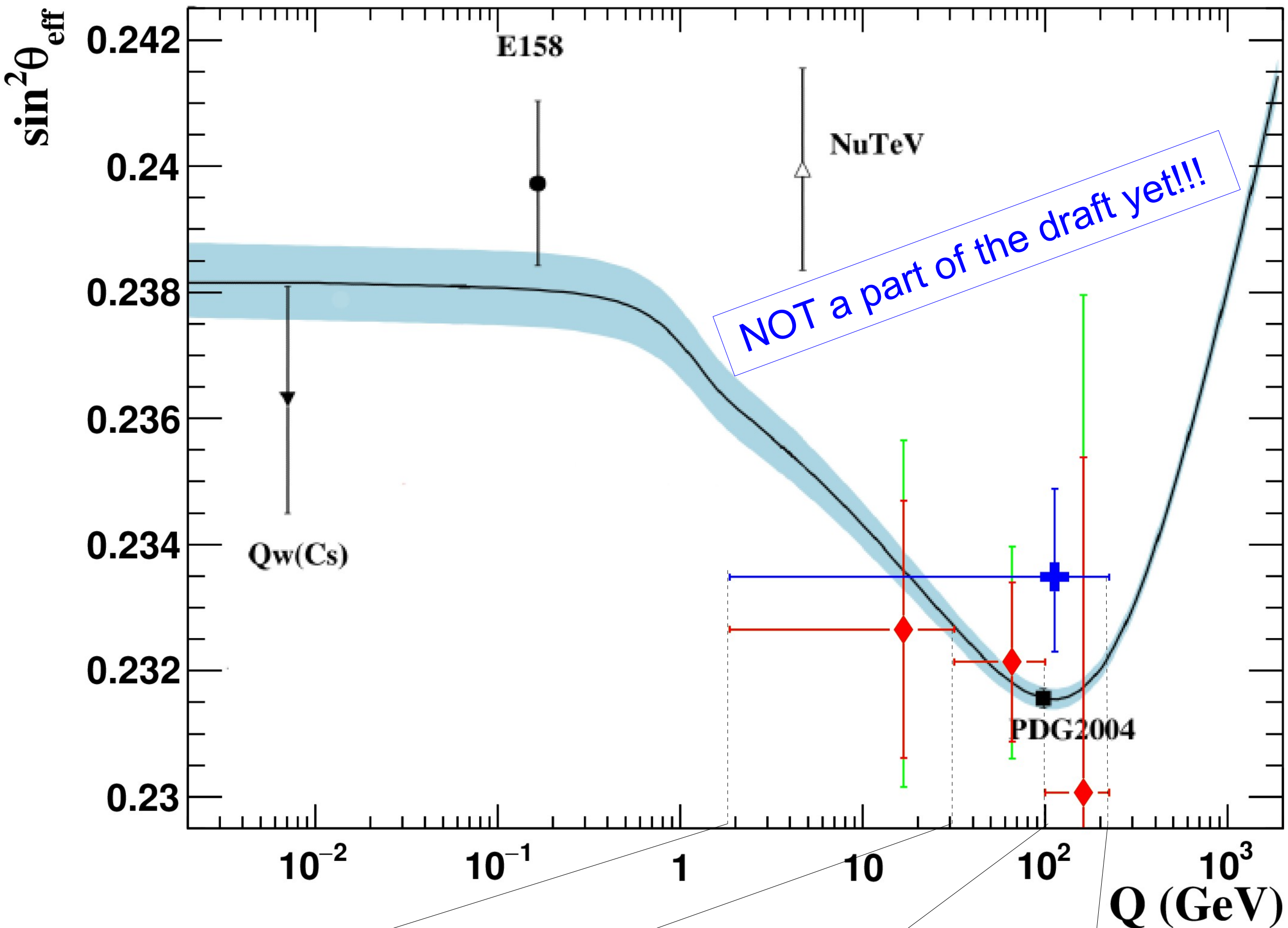
Both of the variants more-or-less follow the same approach:

$$1-4\kappa(Q^2)\sin^2\theta_W(M_Z)=1-4(Q^2)\sin^2\theta_W(Q^2)$$

$$\kappa=\kappa_f(Q^2,\alpha,T_{3f},Q_f,m_f,M_Z)+\kappa_b(Q^2,\alpha,M_W)$$ ← Fermion and boson loop.

Running $\sin^2\theta_W$ from HERA data

- HERA data were divided into 3 intervals to check the $\sin^2\theta_W$ running.
- Our On-shell measurements are translated to $\sin^2\theta_W^{eff}$ using PDG prescription.



Q² = 3.5 GeV² Q² = 1000 GeV² Q² = 10000 GeV² Q² = 50000 GeV²

Number of fitted x-section points: 2065, 759, 118

- Data in the intervals can not constrain PDFs => PDFs were set to ZEUS-13p.

Red error bars — uncertainties from fits with fixed PDFs.

Green error bars — red uncertainties scaled by:

$$\frac{\delta \sin^2\theta_W^{released\ PDFs(full\ uncertainty)}}{\delta \sin^2\theta_W^{ZEUS13p\ PDFs}}$$

$$\sin^2\theta_W^{released\ PDFs} = 0.2252 \pm 0.0011_{exp}$$

$$\sin^2\theta_W^{ZEUS13p\ PDFs} = 0.2241 \pm 0.0009_{exp}$$

Full data, total uncertainty

Other variant of binning is in the backup

Summary

- QCD and EW analysis of HERA data was performed.
- Couplings of u- and d-type quarks to Z boson were determined (ZEUS-EW-Z).
  - Fitted couplings are consistent with SM predictions;
  - Results are compatible with those from other measurements;
  - Couplings of u-quarks are constrained significantly better than those of d-quarks.
- $\sin^2\theta_W$ at On-shell scheme was determined.
  - Fitted value of $\sin^2\theta_W$ is consistent with current world average;
- Mass of W boson was determined.
  - Fitted value of M_W is consistent with current world average;
- Contours of $\sin^2\theta_W$-M_W and G_F-M_W were obtained.
- Running of $\sin^2\theta_W$ with a scale was checked. → addition to the paper?

- Paper draft and supporting materials of the analysis can be found at:

http://www.desy.de/~myronv/ZEUSEW/

Questions / answers (ZEUS presentation)

no comments on the text included

Brian

1) what is the motivation for 0.3% and why is it conservative? (ed.: this is about uncertainty on QED corrections, applied to the used data)

It is 2% of 15% where 2% is the uncertainty of the radiative corrections and 15% is the largest value of a radiative correction.

2) Fig. 12,13 - might it be helpful to put the PDG error bars on the SM point?

The PDG14 uncertainties are invisible on our plots.

Erich

1) We give sin^2thetaw = 0.22333 and we quote ref.17, PDG, but if you look there you find 0.23126(5).

In the summary table the $\overline{\text{MS}}$ value is given. For the On-shell (or anything else) one can look in the Electroweak interaction review.

2) What is fit ZEUS-EW-S? let me guess: G_F is expressed through M-W and sin^th by Eq.11 and inserted into eq.9/10, a fit is made of the data to eq.9/10 and 4/5, keeping M_W and M_Z fixed and variing the 4 EW parameters and the 13 pdfs.

ZEUS-EW-S is a fit with PDF parameters and $\sin^2\theta_W$ are treated as free parameters. G_F is expressed through M_W and $\sin^2\theta_W$. Effectively only vector-couplings are varied as they depend on $\sin^2\theta_W$. In the end there are 14 free parameters: 13 PDF parameters + $\sin^2\theta_W$.

Ewald

1) Have the terms in chi^2_Z and v_e been ignored for the fit of the electromagnetic Z coupling? If yes, this must imply some uncertainties. Have they been taken into account in the fit of the quark couplings?

χ_Z is used according to its formula. $\sin^2\theta_W$ is free in it @ ZEUS-EW-S fit, and it contributes as a factor in ZEUS-EW-Z fit.

v_e is calculated from a_e and $\sin^2\theta_W$, so @ZEUS-EW-S fit it contributes but by a tiny bit (v_e is a very small parameter) and in the rest of the fits it is fixed.

2) That we have a "mininal correlation" is important. But nothing is quantified in the paper. At present we refer to an online supplement which has to be linked still. Where can I find it?

So far only the couplings part of the matrix is in the paper. The full correlation matrix is in the backup of these slides. Do we want it all in the paper?

Achim

1) What does the statement "DeltaR being an EW correction coming from EPRC" mean (sin2theta studies). In particular, what does "EPRC" mean?

DeltaR is a correction-factor calculated by the program EPRC (Electron-Proton Radiative Corrections - code by H. Spiesberger for calculation of QED and EW corrections to the born cross-sections). According to the settings we use in our setup following parts are calculated and included in DeltaR:

photon-Z-mixing, Z and W self-energies, weak box diagrams, *no* QED corrections. This all together we call EW correction through all our paper draft.

2) What is the main cause of the very substantial chi2 improvement (3270 to 2921) which you quote in the context of the 1% uncertainty of the electroweak corrections? (Born correction studies). Whatever it is, would it also make a difference for our standard HERAPDF2.0 fit? (for which 2/3 of the "too bad chi2" originated from the high Q2, i.e. electroweak sensitive, region)

we thought that 1% uncertainty on the radiative corrections was a GROSS overestimate... even 0.3% seems to be very conservative..(it assumes 2% uncertainty on the LARGEST correction which was 15%, but most of the corrections were much smaller) and that 0.3% only gave an improvement of 3270 to 3237. This would of course be worth having, but we only get that improvement if we assume that this 0.3% uncertainty is uncorrelated, whereas it is much more likely to be correlated. We tried two correlated scenarios: correlated for ZEUs and H1 separately and correlated between ZEUS and H1, and both of these gave NO significant decrease in chisq and no significant shift on sin2thetaw.

Achim

3) Presumably it is possible to evaluate an average scale (or at least a range of scales) to which our sin2theta determination is most sensitive. Since you convincingly argue that our measurement is competitive with the one from CCFR, wouldn't it be nice to make a corresponding entry of our result into the famous sin2theta running plot?

(ed.: there was a long thread of emails - not included here)

Done. Needs to be discussed.

Materials in the main part and backup.

Masahiro

1) What happened to H1 HERAII polarized cross sections? Were they thrown away? It was not clear from the text.

Fair answer is: H1 did not allow us to use those.

Probably we need to work out an answer, which could be exceptable for public discussions..?

Plots from paper draft

Fig. 1

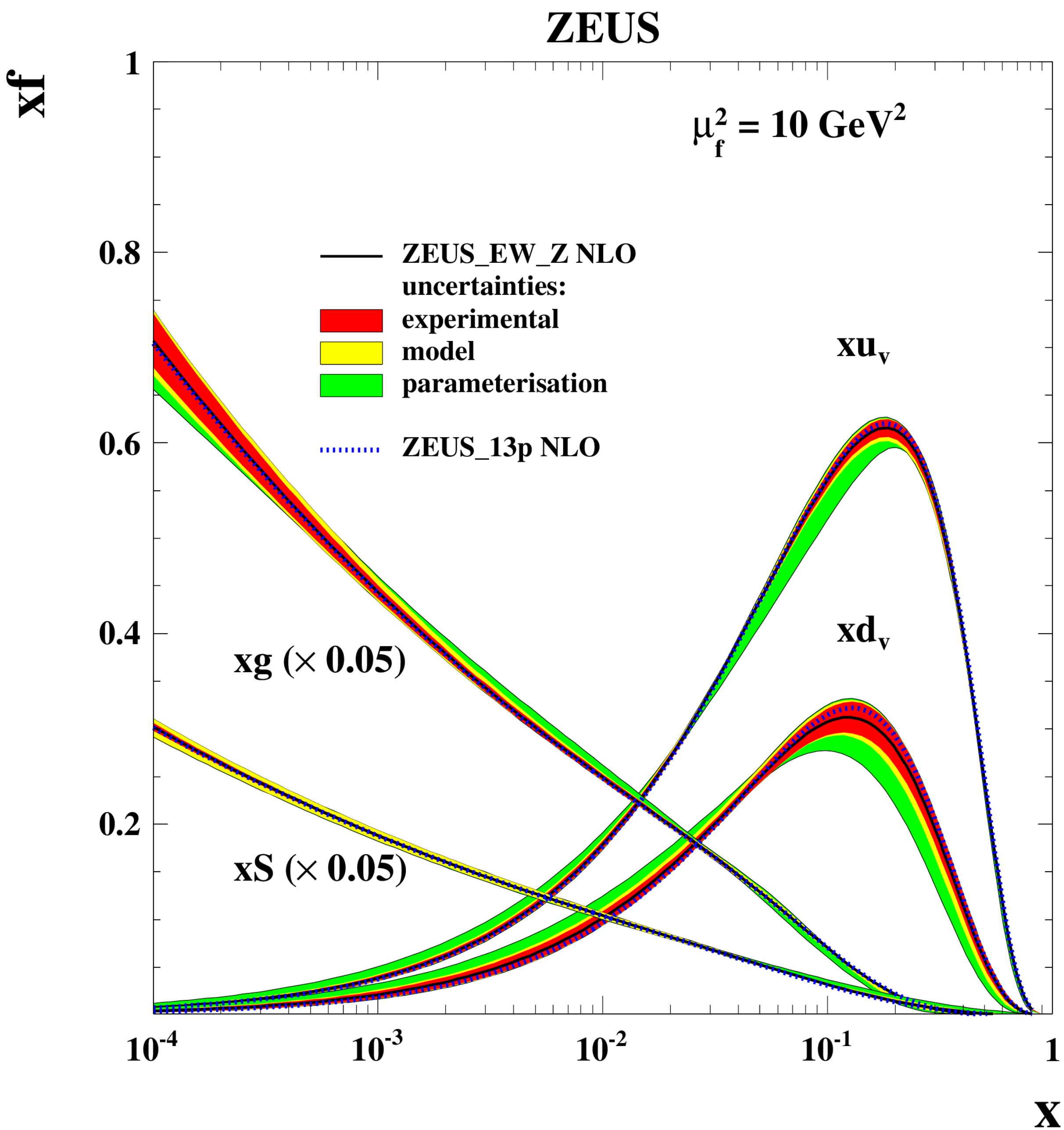
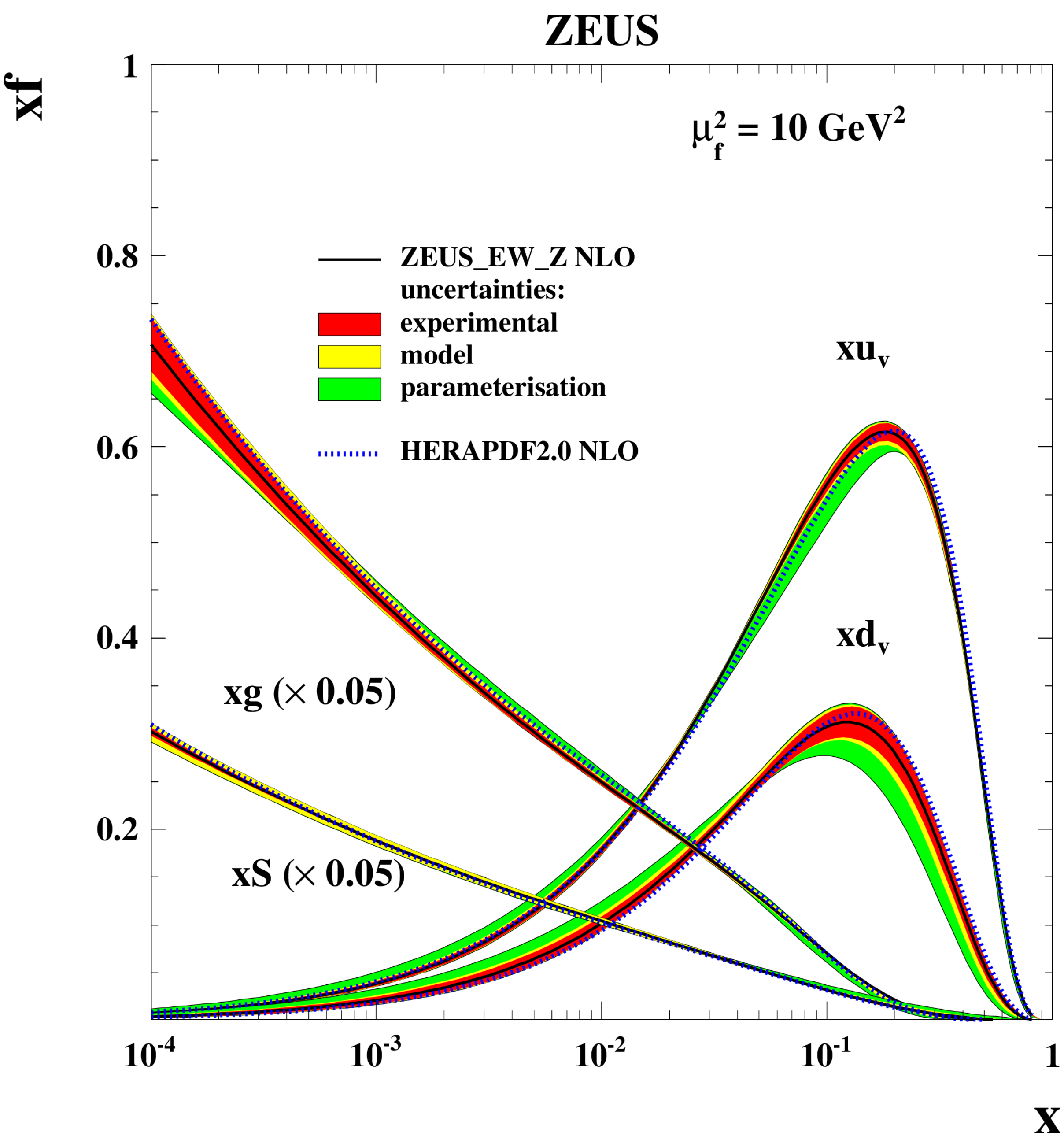

ZEUS
xf
1
0.8
0.6
0.4
0.2
μ_f^2 = 10 GeV^2
ZEUS_EW_Z NLO
uncertainties:
experimental
model
parameterisation
ZEUS_13p NLO
xu_v
xd_v
xg (× 0.05)
xS (× 0.05)
10^{-4}
10^{-3}
10^{-2}
10^{-1}
1
x

Fig. 2



ZEUS
xf
1
0.8
0.6
0.4
0.2
μ_f^2 = 10 GeV^2
ZEUS_EW_Z NLO
uncertainties:
experimental
model
parameterisation
HERAPDF2.0 NLO
xu_v
xd_v
xg (× 0.05)
xS (× 0.05)
10^{-4}
10^{-3}
10^{-2}
10^{-1}
1
x

Fig. 3

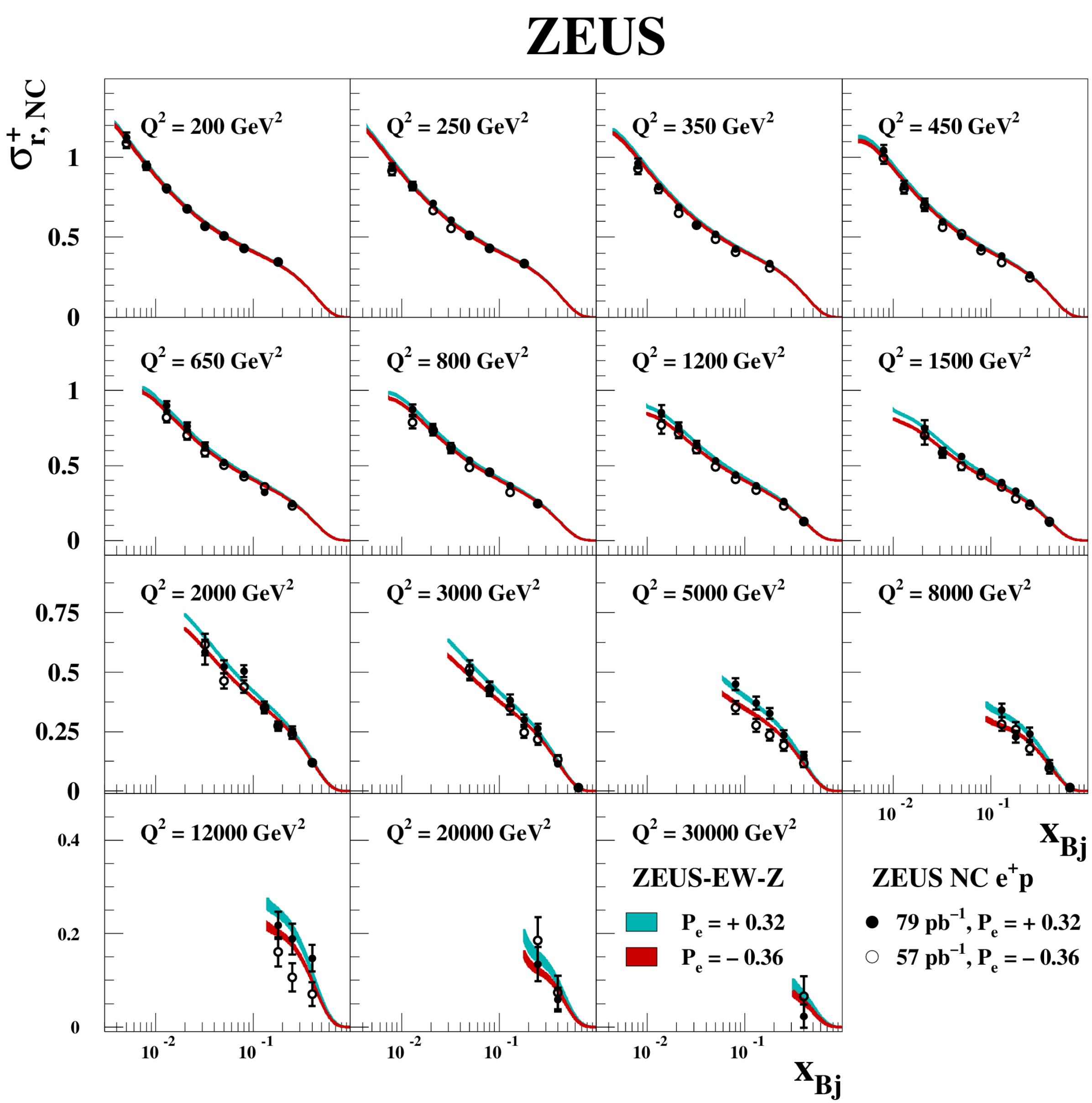

ZEUS
$\sigma^{+}_{r,NC}$
Q^2 = 200 GeV^2
Q^2 = 250 GeV^2
Q^2 = 350 GeV^2
Q^2 = 450 GeV^2
Q^2 = 650 GeV^2
Q^2 = 800 GeV^2
Q^2 = 1200 GeV^2
Q^2 = 1500 GeV^2
Q^2 = 2000 GeV^2
Q^2 = 3000 GeV^2
Q^2 = 5000 GeV^2
Q^2 = 8000 GeV^2
Q^2 = 12000 GeV^2
Q^2 = 20000 GeV^2
Q^2 = 30000 GeV^2
ZEUS-EW-Z
P_e = + 0.32
P_e = – 0.36
ZEUS NC e^+p
79 pb^{-1}, P_e = + 0.32
57 pb^{-1}, P_e = – 0.36
x_{Bj}

Fig. 4

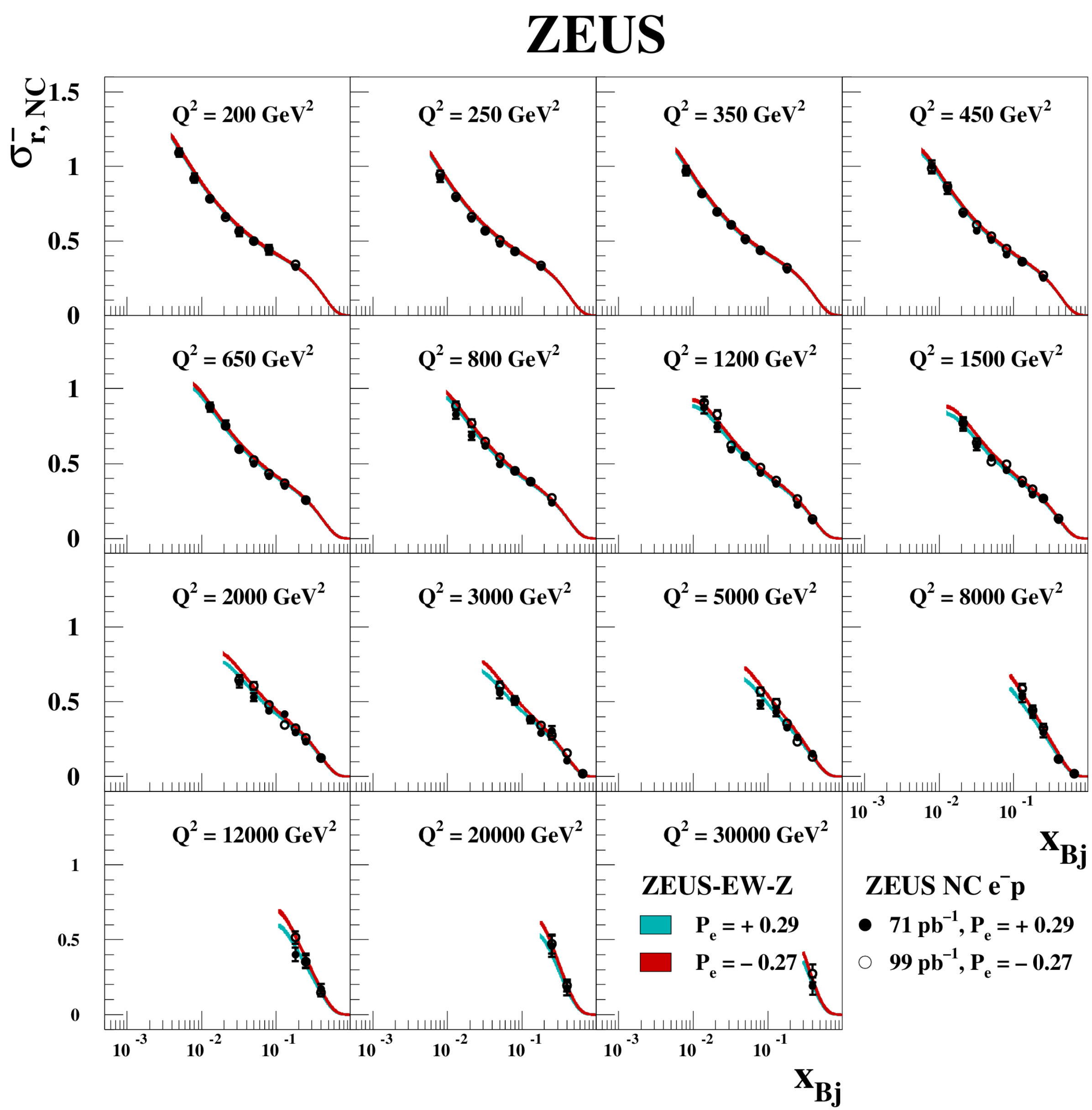
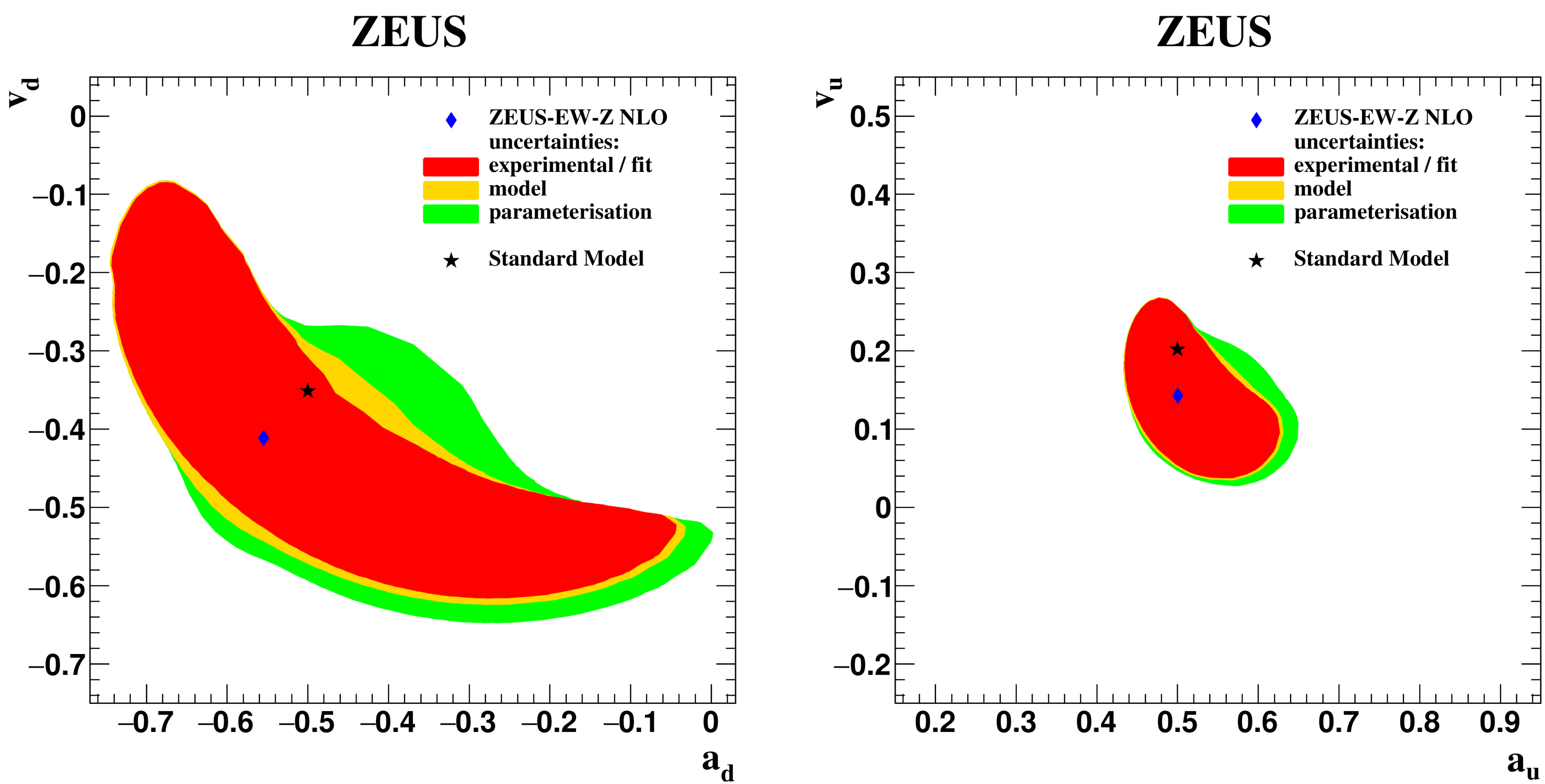
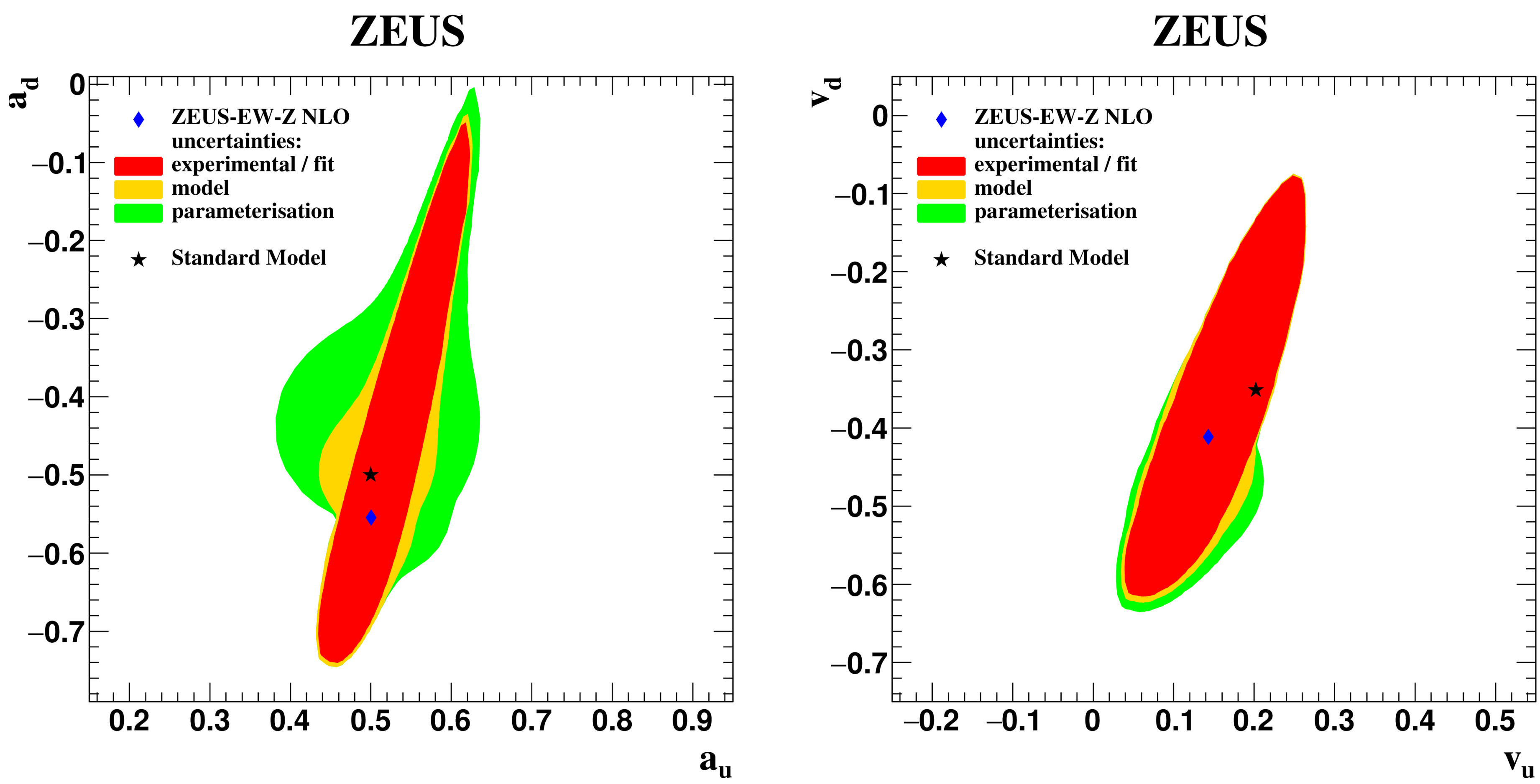

ZEUS
$\sigma^-_{r,NC}$
Q² = 200 GeV²
Q² = 250 GeV²
Q² = 350 GeV²
Q² = 450 GeV²
Q² = 650 GeV²
Q² = 800 GeV²
Q² = 1200 GeV²
Q² = 1500 GeV²
Q² = 2000 GeV²
Q² = 3000 GeV²
Q² = 5000 GeV²
Q² = 8000 GeV²
Q² = 12000 GeV²
Q² = 20000 GeV²
Q² = 30000 GeV²
ZEUS-EW-Z
P_e = + 0.29
P_e = – 0.27
ZEUS NC e⁻p
71 pb⁻¹, P_e = + 0.29
99 pb⁻¹, P_e = – 0.27
x_Bj

Fig. 5



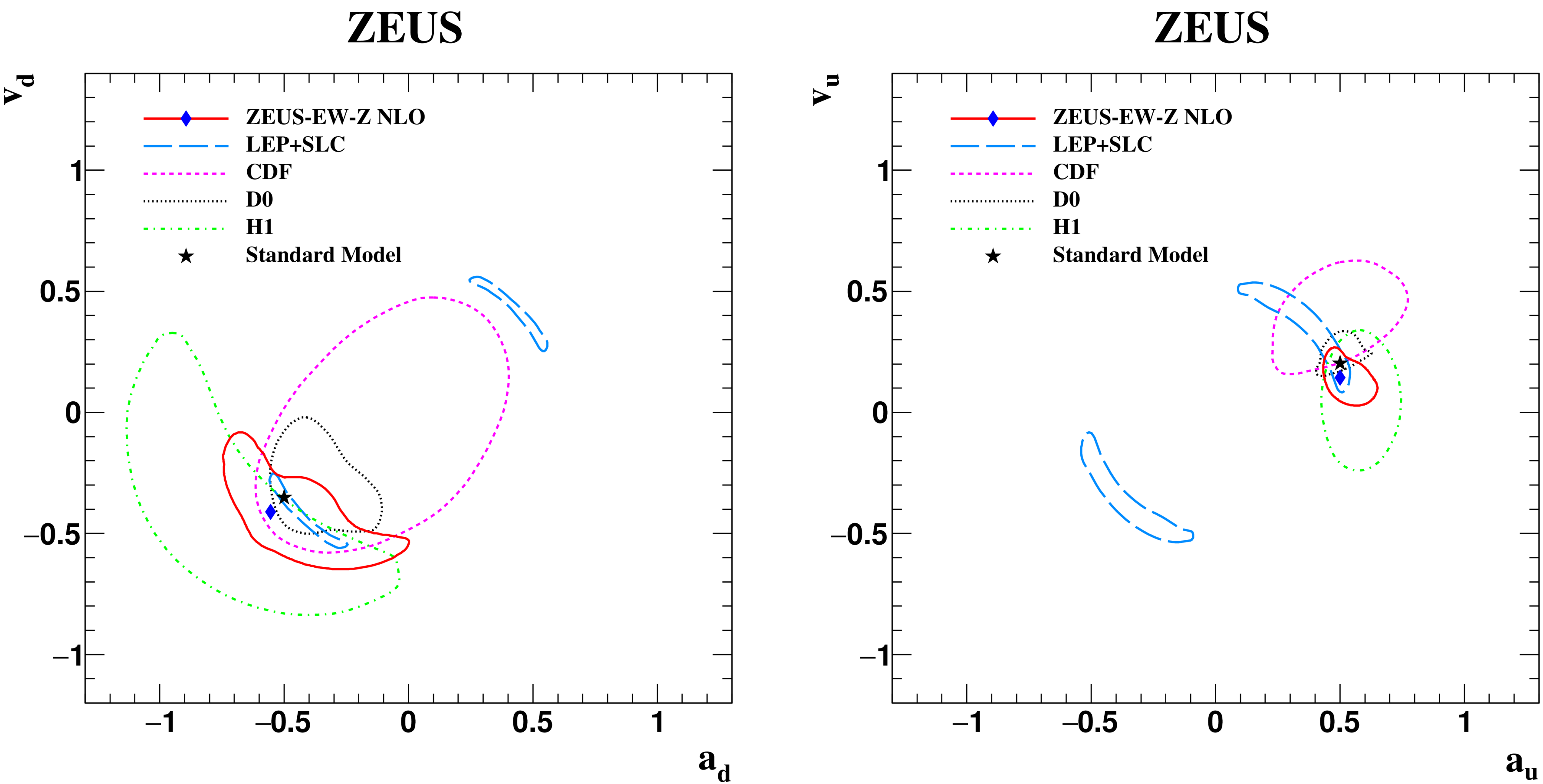
Not yet updated in the paper draft!! This is the latest version.

Fig. 6



Not yet updated in the paper draft!! This is the latest version.

Fig. 7



Not yet updated in the paper draft!! This is the latest version.

Fig. 8

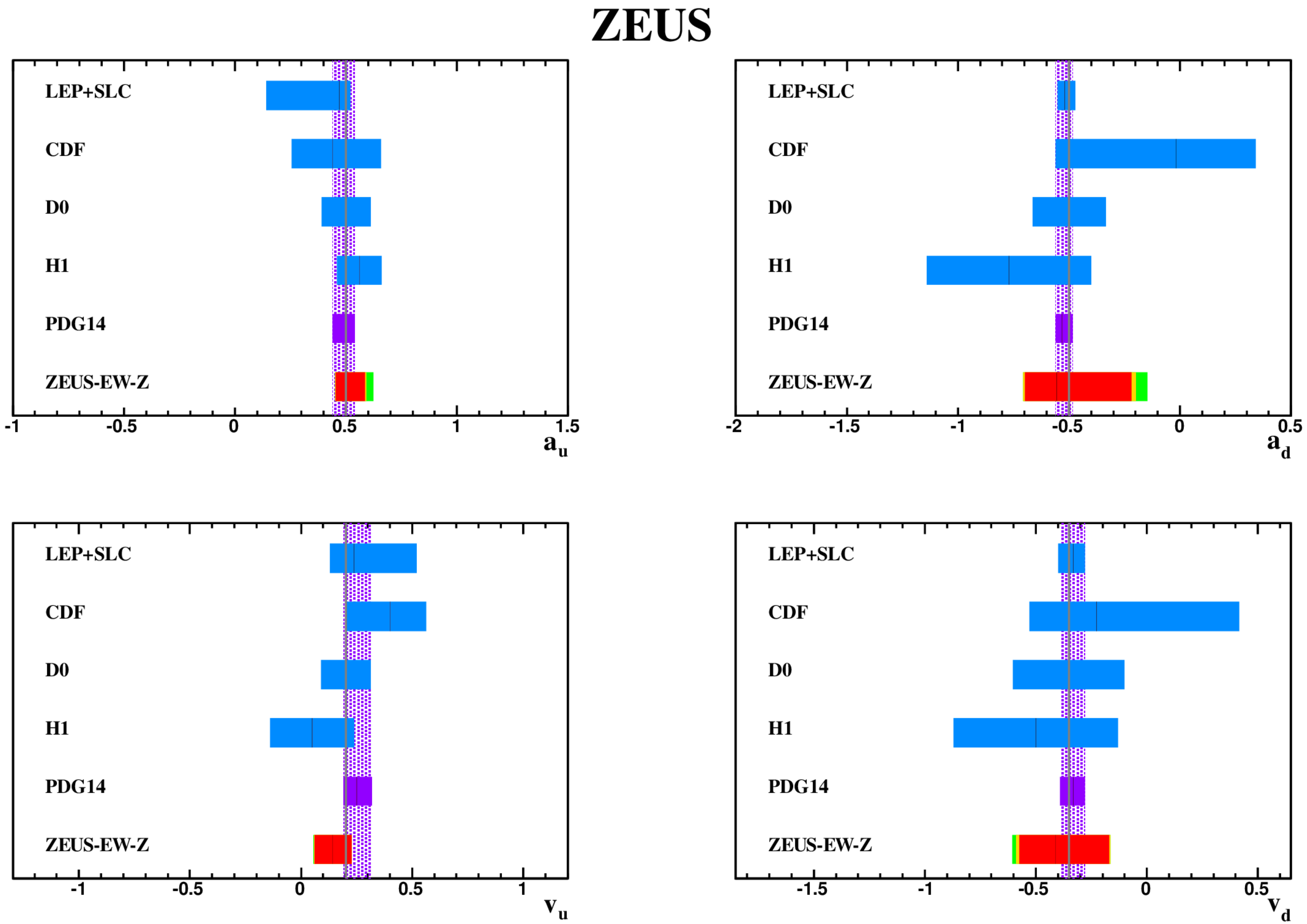
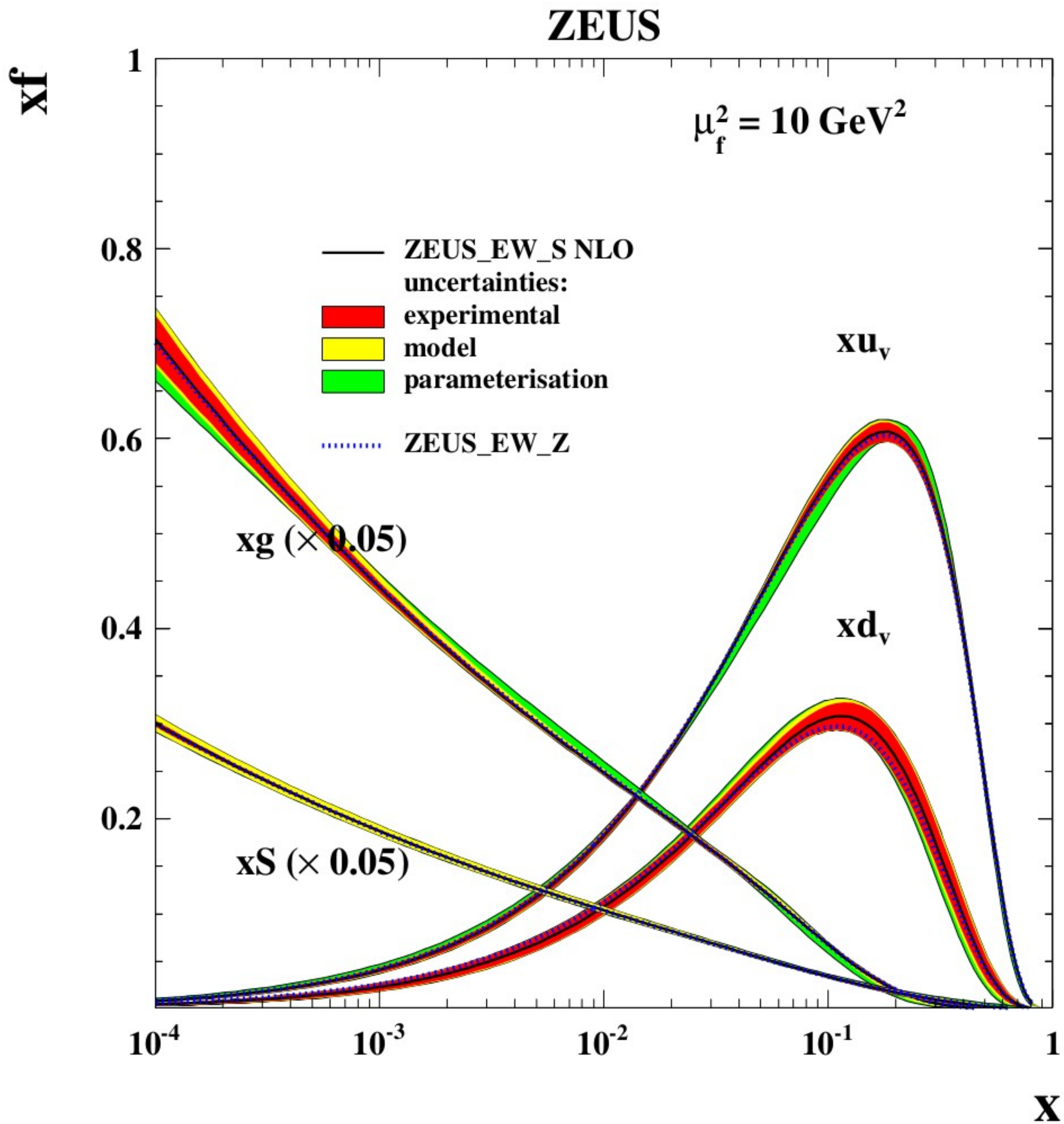
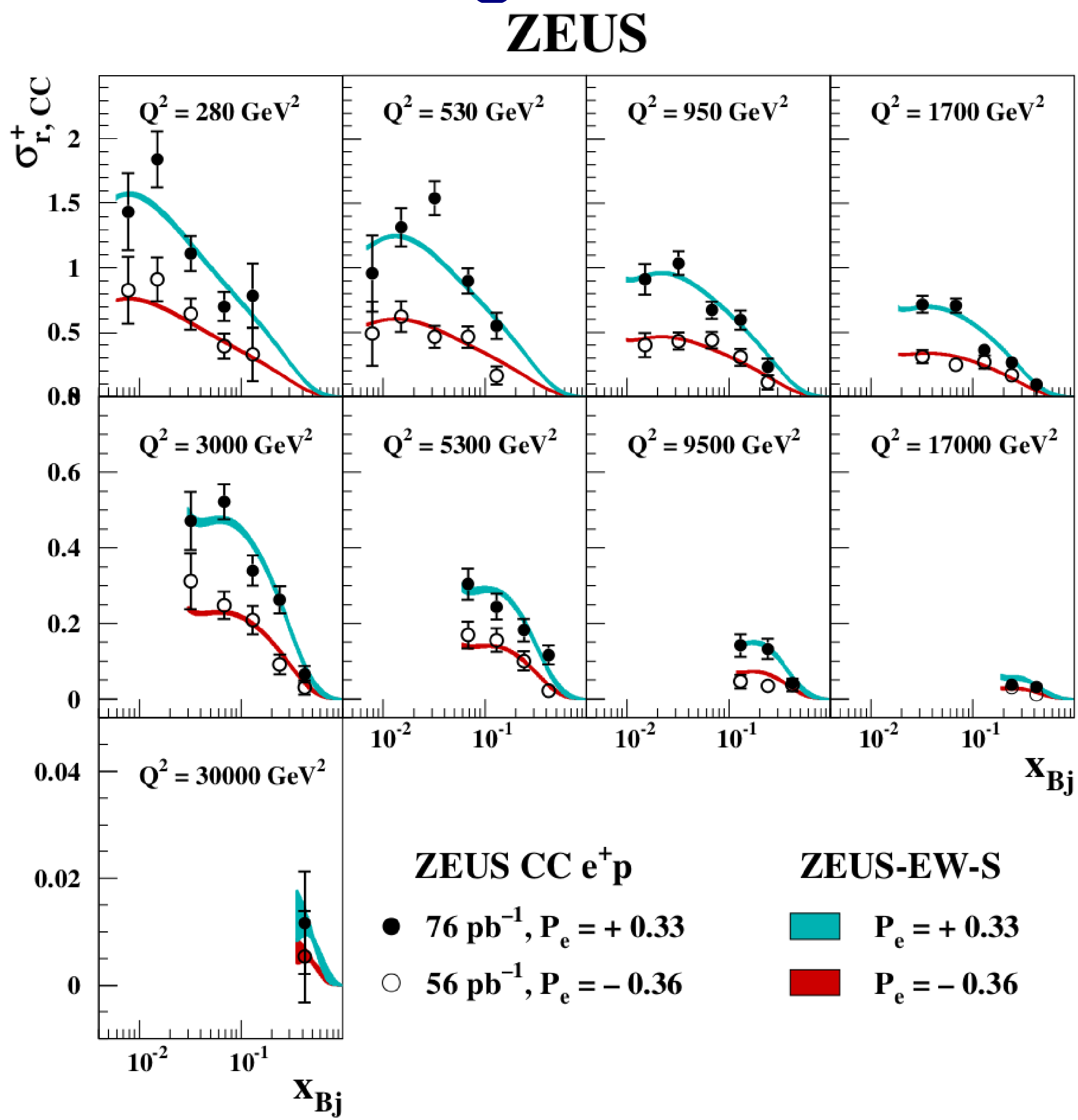

ZEUS
LEP+SLC
CDF
D0
H1
PDG14
ZEUS-EW-Z
-1
-0.5
0
0.5
1
1.5
a_u
-2
-1.5
-1
-0.5
0
0.5
a_d
-1
-0.5
0
0.5
1
v_u
-1.5
-1
-0.5
0
0.5
v_d

Fig. 9



ZEUS
xf
μ_f^2 = 10 GeV^2
ZEUS_EW_S NLO
uncertainties:
experimental
model
parameterisation
ZEUS_EW_Z
xu_v
xd_v
xg (× 0.05)
xS (× 0.05)
1
0.8
0.6
0.4
0.2
10^{-4}
10^{-3}
10^{-2}
10^{-1}
1
x

Fig. 10



ZEUS
$\sigma^+_{r,\,CC}$
Q² = 280 GeV²
Q² = 530 GeV²
Q² = 950 GeV²
Q² = 1700 GeV²
Q² = 3000 GeV²
Q² = 5300 GeV²
Q² = 9500 GeV²
Q² = 17000 GeV²
Q² = 30000 GeV²
x_{Bj}
ZEUS CC e⁺p
76 pb⁻¹, Pₑ = + 0.33
56 pb⁻¹, Pₑ = – 0.36
ZEUS-EW-S
Pₑ = + 0.33
Pₑ = – 0.36

Fig. 11

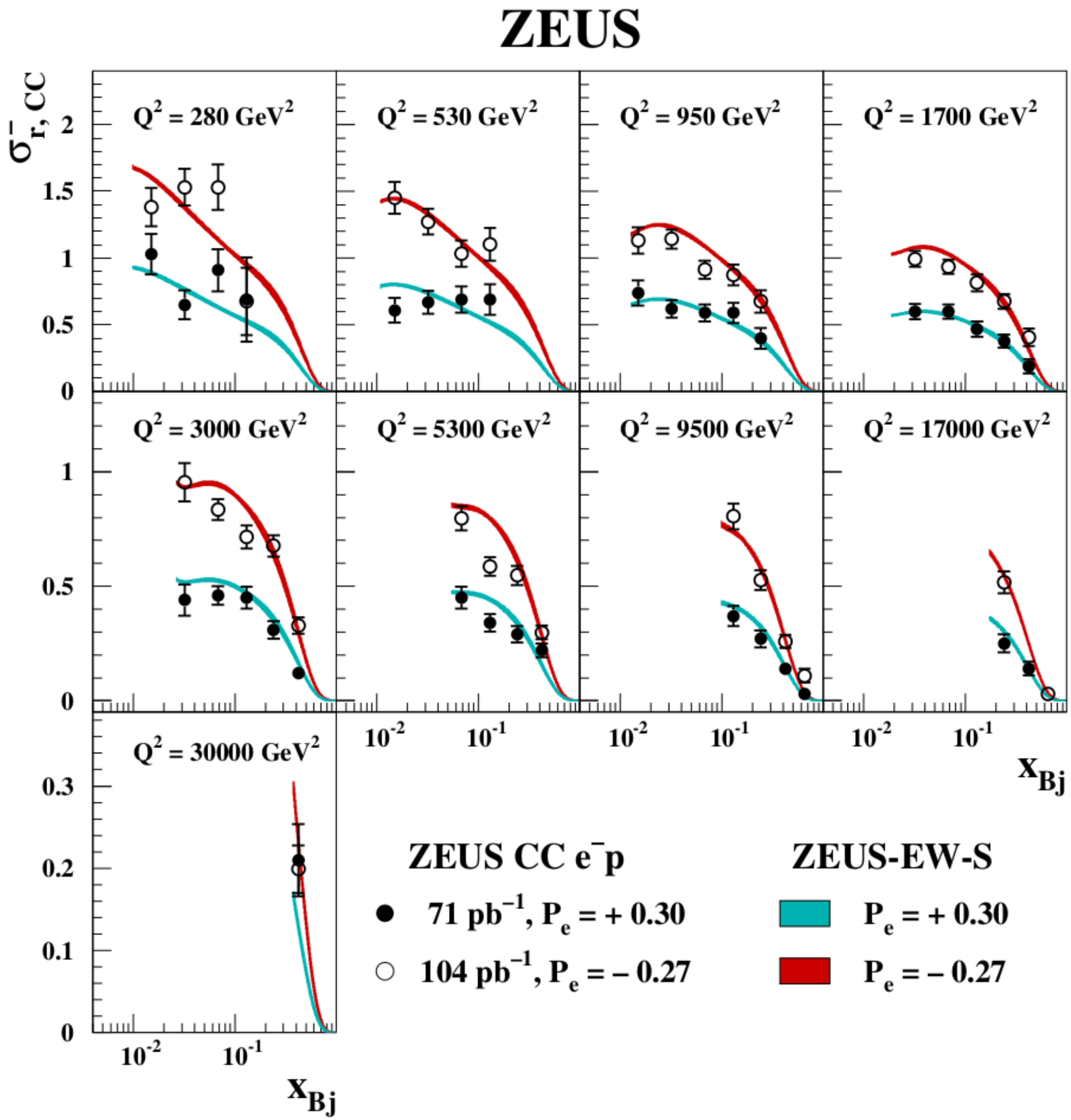

ZEUS
$\sigma^{-}_{r,CC}$
$Q^2 = 280$ GeV^2
$Q^2 = 530$ GeV^2
$Q^2 = 950$ GeV^2
$Q^2 = 1700$ GeV^2
$Q^2 = 3000$ GeV^2
$Q^2 = 5300$ GeV^2
$Q^2 = 9500$ GeV^2
$Q^2 = 17000$ GeV^2
$Q^2 = 30000$ GeV^2
x_{Bj}
ZEUS CC e^-p
71 pb^{-1}, $P_e = +0.30$
104 pb^{-1}, $P_e = -0.27$
ZEUS-EW-S
$P_e = +0.30$
$P_e = -0.27$

Fig. 12

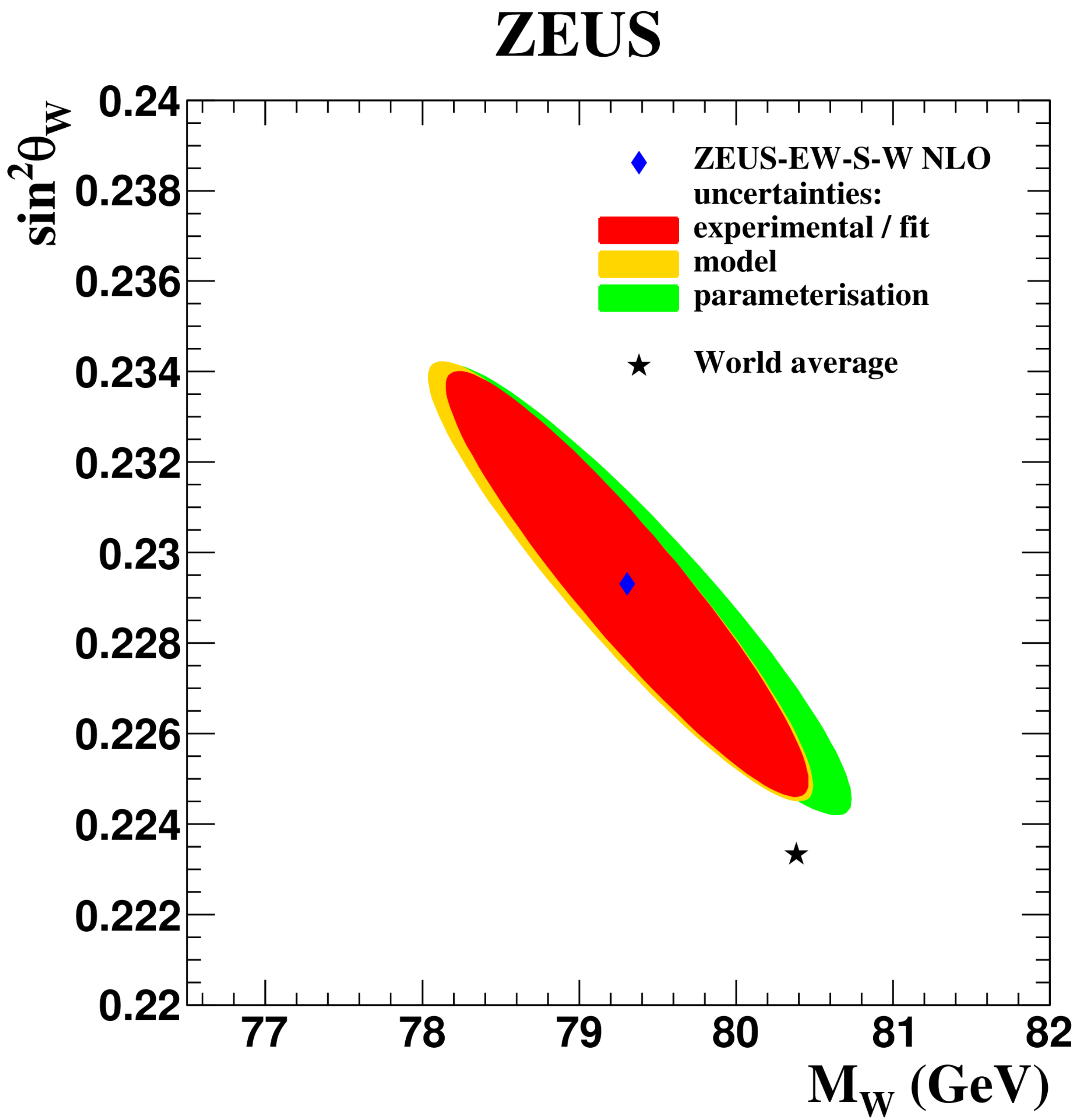
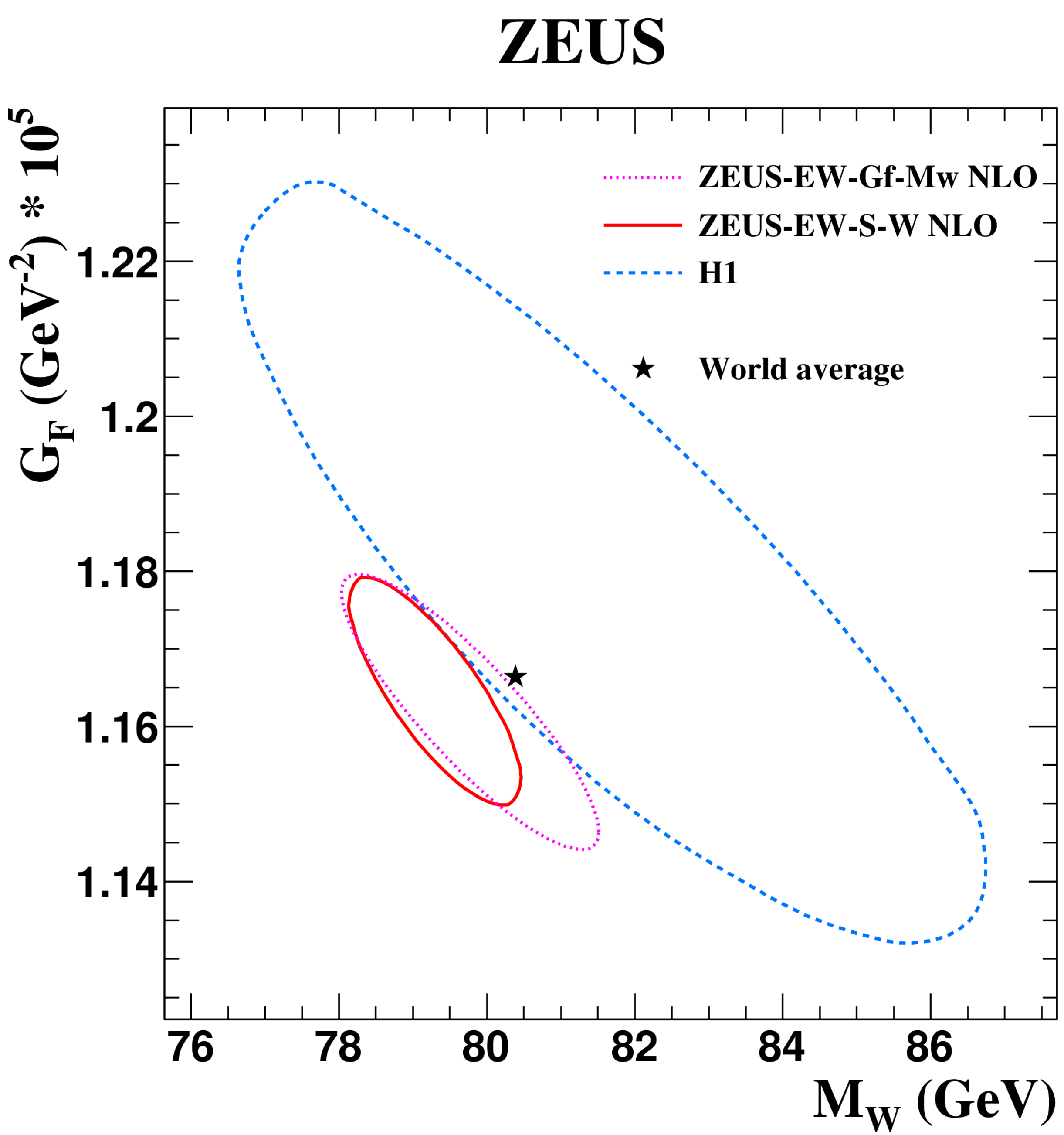
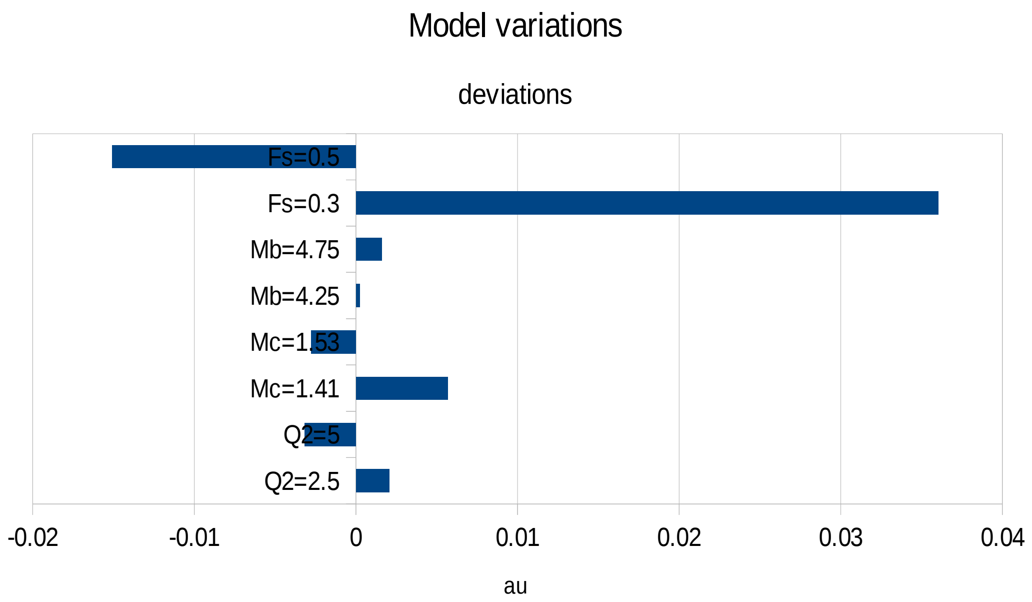

ZEUS
ZEUS-EW-S-W NLO
uncertainties:
experimental / fit
model
parameterisation
World average
$\sin^2\theta_W$
0.24
0.238
0.236
0.234
0.232
0.23
0.228
0.226
0.224
0.222
0.22
77
78
79
80
81
82
M_W (GeV)

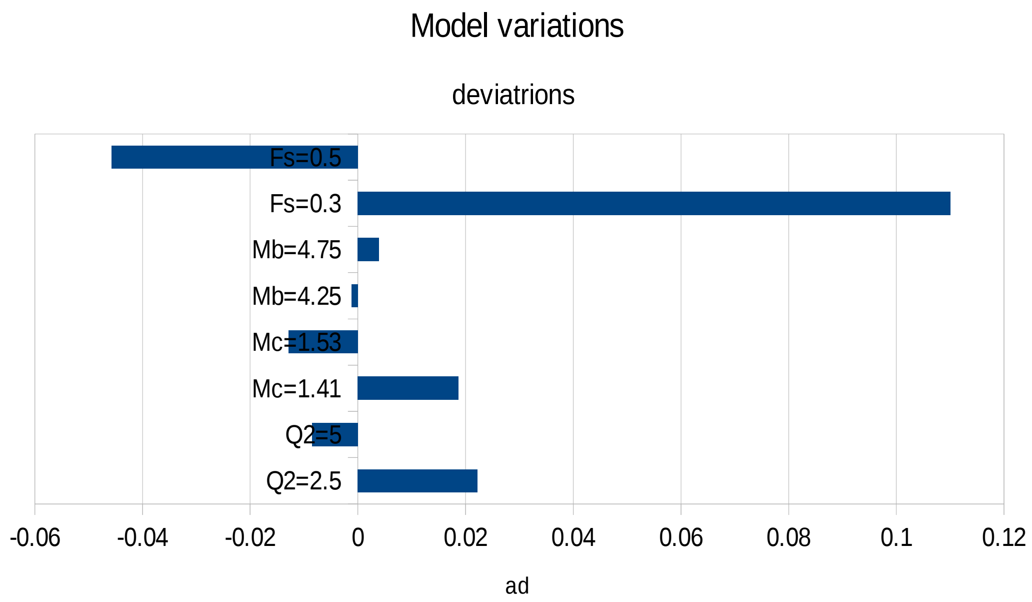
Fig. 13

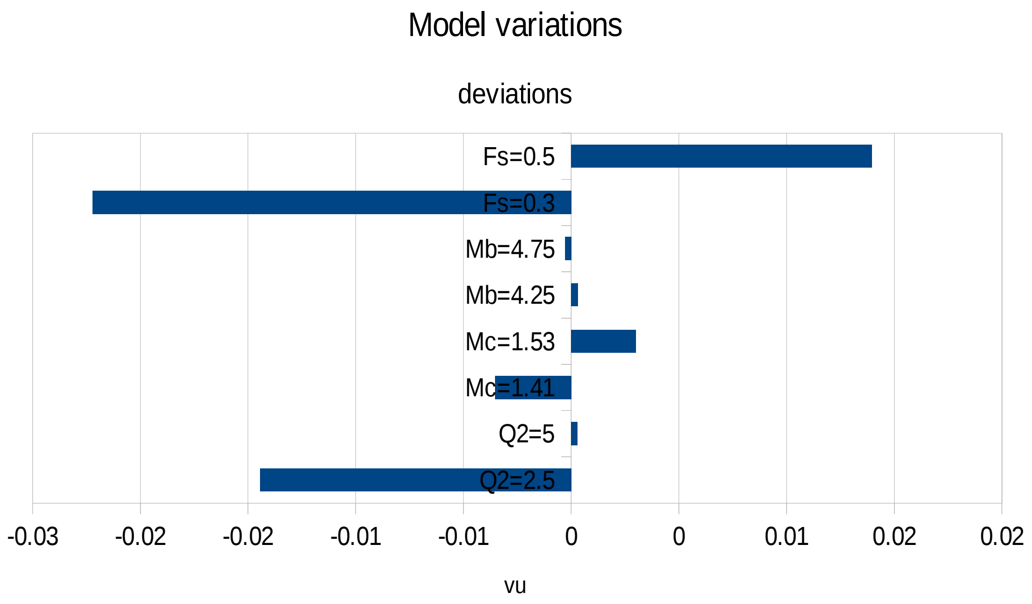

ZEUS
ZEUS-EW-Gf-Mw NLO
ZEUS-EW-S-W NLO
H1
World average
G_F (GeV^{-2}) * 10^5
1.22
1.2
1.18
1.16
1.14
76
78
80
82
84
86
M_W (GeV)

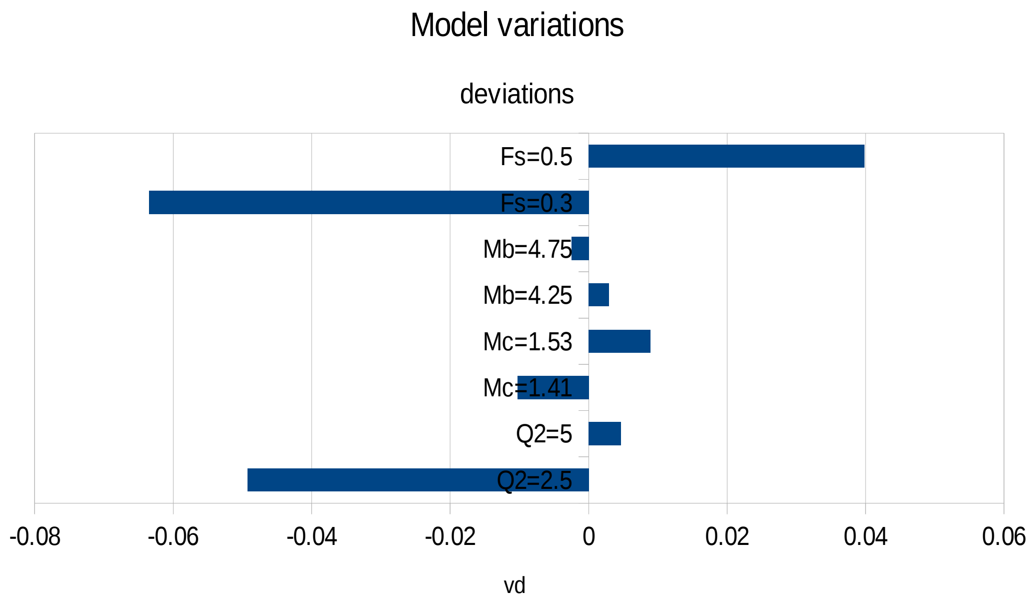
Backup

Model variations

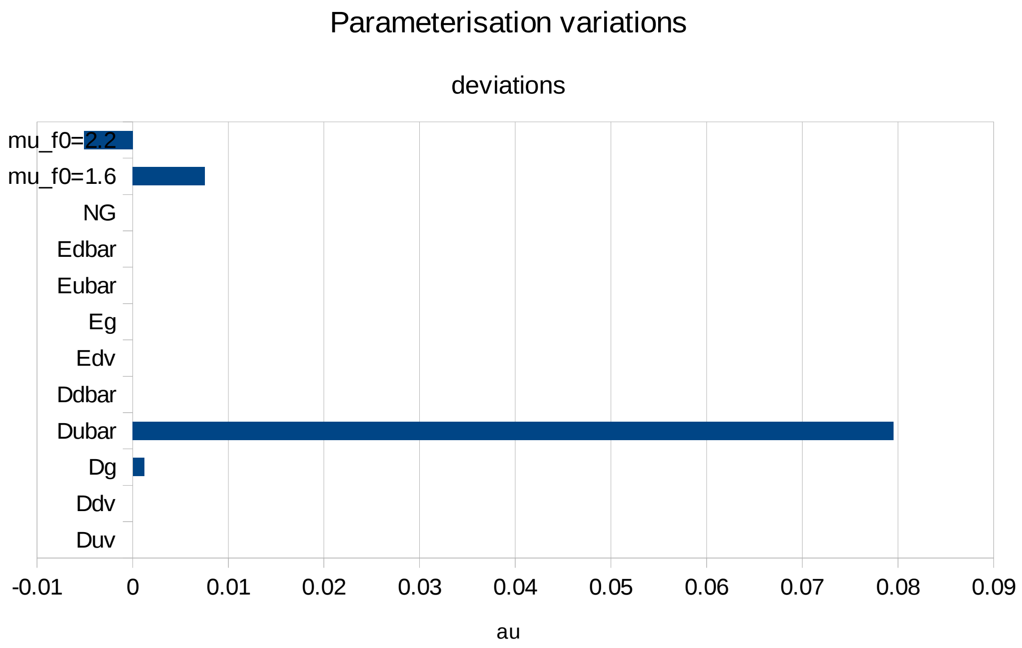


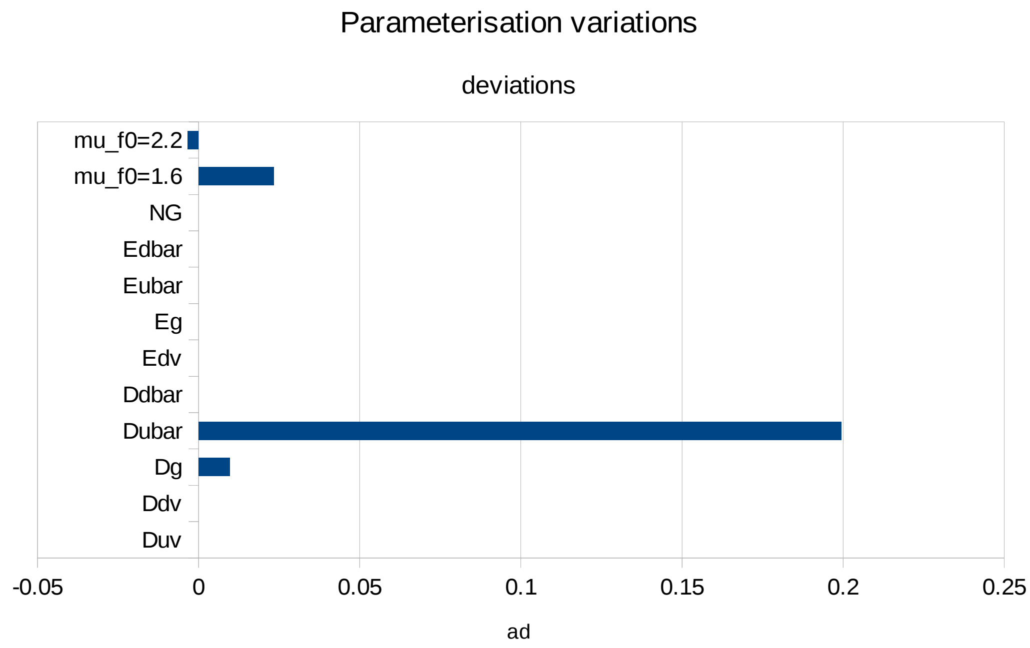


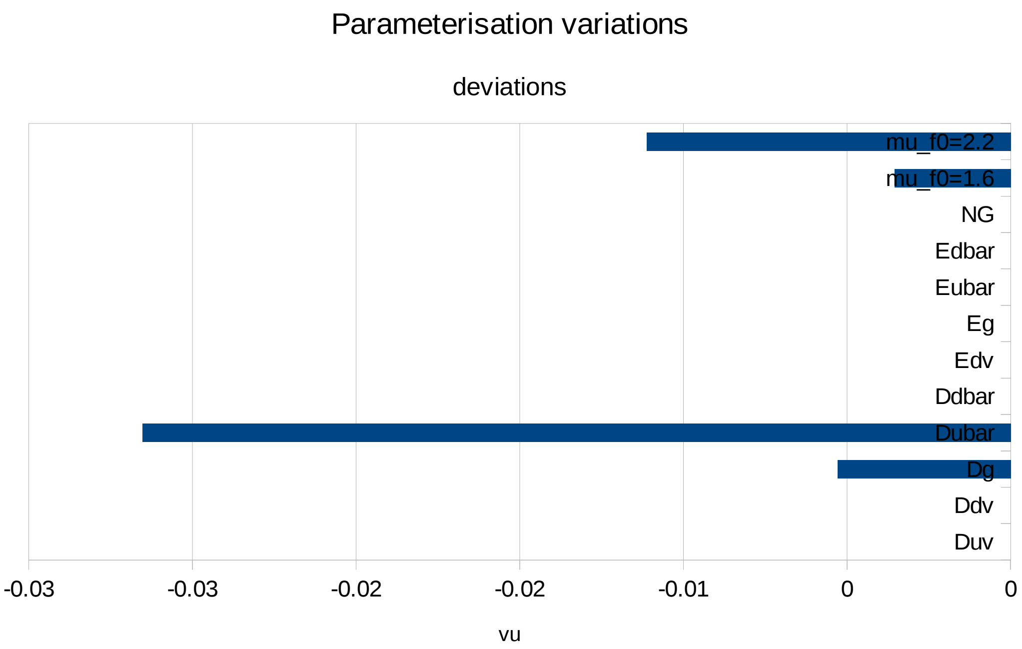


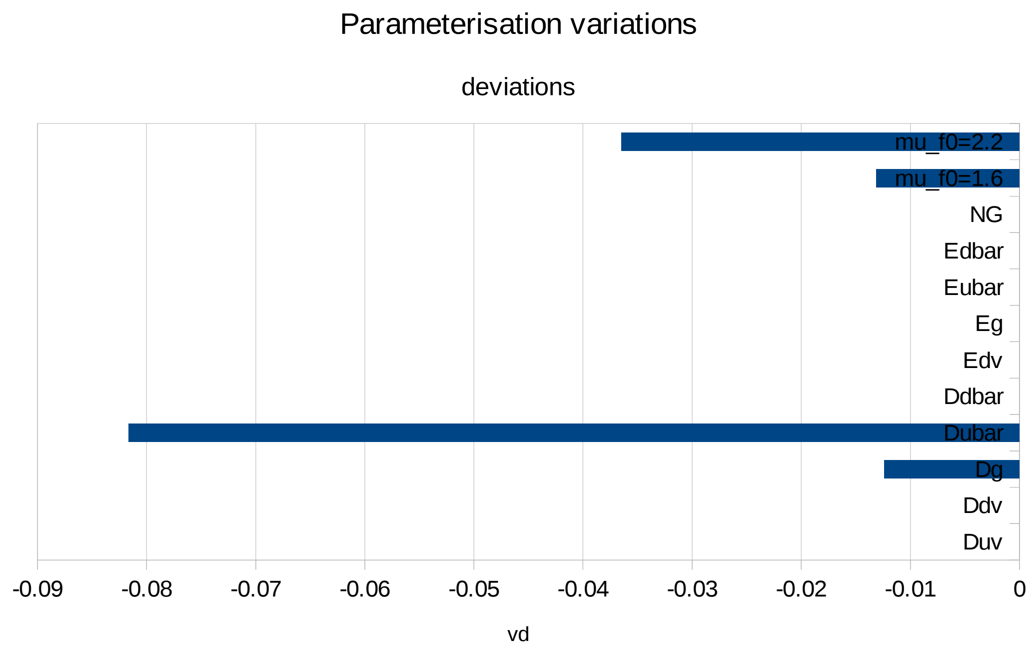


Parametrisation variations variations









World results (full uncertainties)

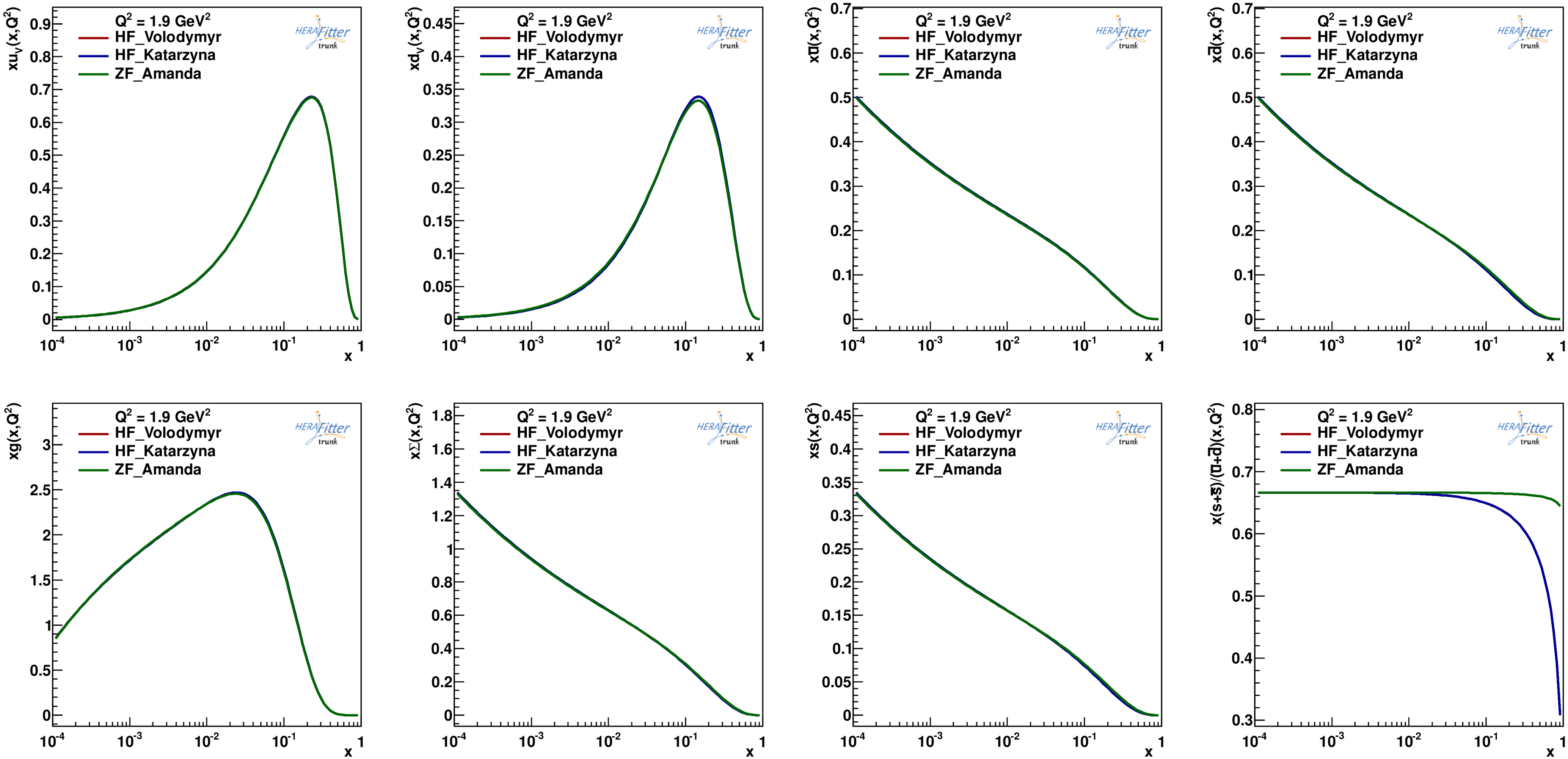
	a_u	a_b	v_u	v_d
LEP	$0.47^{+0.05}_{-0.33}$	$-0.52^{+0.05}_{-0.03}$	$0.24^{+0.28}_{-0.11}$	$-0.33^{+0.05}_{-0.07}$
D0	0.50±0.11	-0.50±0.17	0.20±0.11	0.35±0.25
CDF	$0.44^{+0.22}_{-0.19}$	$-0.02^{+0.36}_{-0.54}$	$0.40^{+0.17}_{-0.20}$	$-0.23^{+0.64}_{-0.30}$
H1: HERA1 (publ.)	0.56±0.10	-0.77±-0.37	0.05±0.19	-0.50±0.37
ZEUS: HERA1+2 (prel.)	0.51±0.20	-0.54±0.37	0.05±0.10	-0.64±0.24
ZEUS-EW-Z	$0.500^{+0.122}_{-0.050}$	$-0.555^{+0.407}_{-0.152}$	$0.143^{+0.085}_{-0.088}$	$-0.411^{+0.246}_{-0.195}$
PDG14	$0.50^{+0.04}_{-0.06}$	$-0.523^{+0.050}_{-0.029}$	$0.25^{+0.07}_{-0.06}$	$-0.33^{+0.05}_{-0.06}$
SM	0.5	-0.5	0.196	-0.346

Cross-checks: HERAFitter vs ZEUSFitter

Parameter	HF Volodymyr	HF Katarzyna	ZF Amanda
'Bg'	-0.068 ± 0.074	-0.068 ± 0.085	-0.07 ± 0.13
'Cg'	8.50 ± 0.84	8.50 ± 0.84	8.5 ± 1.1
'Aprig'	1.41 ± 0.60	1.41 ± 0.62	1.35 ± 0.53
'Bprig'	-0.158 ± 0.058	-0.158 ± 0.064	-0.16 ± 0.12
'Cprig'	25.00	25.00	25.00
'Buv'	0.742 ± 0.026	0.742 ± 0.026	0.737 ± 0.026
'Cuv'	4.698 ± 0.089	4.698 ± 0.089	4.675 ± 0.088
'Euv'	9.2 ± 1.3	9.2 ± 1.3	9.2 ± 1.2
'Bdv'	0.763 ± 0.077	0.763 ± 0.077	0.741 ± 0.076
'Cdv'	4.38 ± 0.33	4.38 ± 0.33	4.34 ± 0.35
'CUbar'	3.56 ± 0.48	3.56 ± 0.48	3.61 ± 0.50
'ADbar'	0.1976 ± 0.0088	0.1976 ± 0.0088	0.1959 ± 0.0091
'BDbar'	-0.1583 ± 0.0054	-0.1583 ± 0.0054	-0.1586 ± 0.0055
'CDbar'	4.1 ± 1.1	4.1 ± 1.1	3.6 ± 1.1
'alphas'	0.1180	0.1180	0.1180
'fs'	0.4000	0.4000	0.4000
'auEW'	0.514 ± 0.057	0.514 ± 0.057	0.520 ± 0.064
'adEW'	-0.57 ± 0.21	-0.57 ± 0.21	-0.55 ± 0.23
'vuEW'	0.136 ± 0.084	0.136 ± 0.084	0.136 ± 0.087
'vdEW'	-0.42 ± 0.21	-0.42 ± 0.21	-0.41 ± 0.23
Fit status	converged	converged	undefined
Uncertainties	migrad-hesse	migrad-hesse	migrad-hesse
Total χ^2 / dof	3270 / 2925	3270 / 2925	3269 / 2925

- Very close results from different codes.

Cross-checks: HERAFitter vs ZEUSFitter

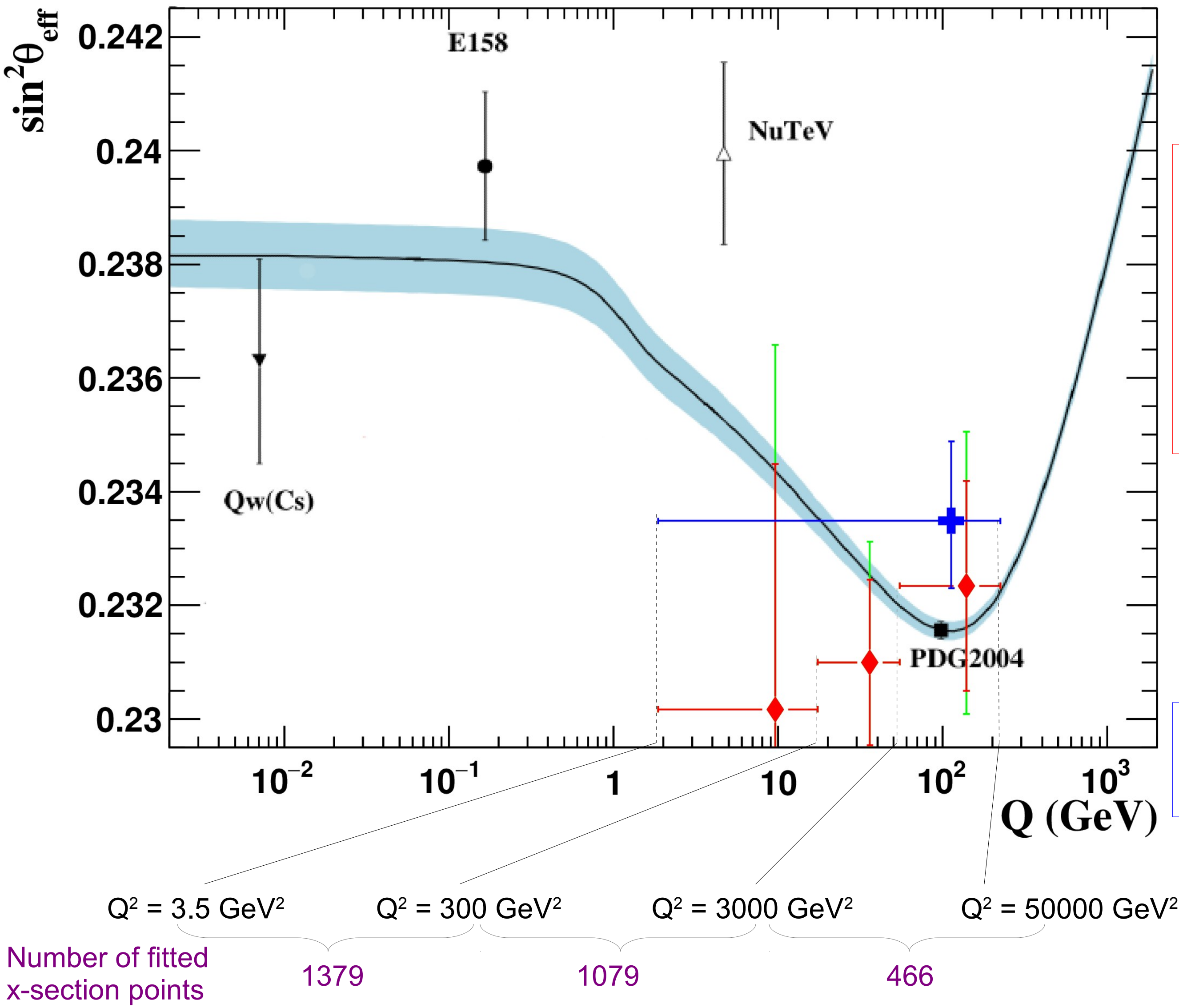


Correlation matrix for the fit parameters

NO.	Bg	Cg	Aprig	Bprig	Buv	Cuv	Euv	Bdv	Cdv	CUbar	ADbar	BDbar	CDbar	auEW	adEW	vuEW	vdEW
Bg	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
Cg	-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
Aprig	-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
Bprig	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
Buv	-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
Cuv	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
Euv	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
Bdv	-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
Cdv	-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
CUbar	-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
ADbar	-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
BDbar	-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
CDbar	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
auEW	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
adEW	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
vuEW	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
vdEW	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

Running $\sin^2\theta_W$ from HERA data (binning 2)

- HERA data were divided into 3 intervals to check the $\sin^2\theta_W$ running.
- Our On-shell measurements are translated to $\sin^2\theta_W^{eff}$ using PDG prescription.



- Data in the intervals can not constrain PDFs => PDFs were set to ZEUS-13p.

Red error bars — uncertainties from fits with fixed PDFs.

Green error bars — red uncertainties scaled by:

$$\frac{\delta \sin^2\theta_W^{released\ PDFs(full\ uncertainty)}}{\delta \sin^2\theta_W^{ZEUS13p\ PDFs}}$$

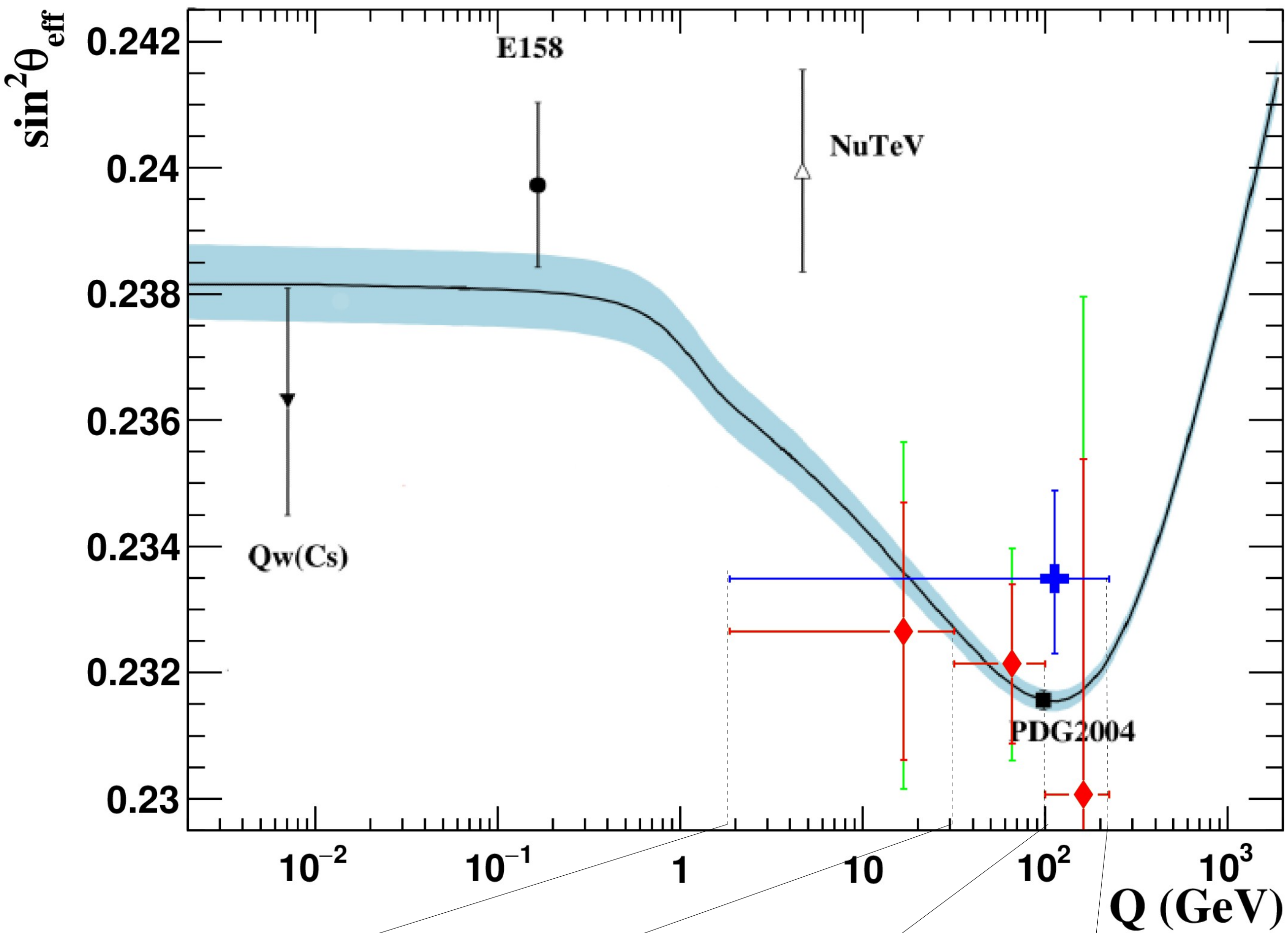
$$\sin^2\theta_W^{released\ PDFs} = 0.2252 \pm 0.0011_{exp}$$

$$\sin^2\theta_W^{ZEUS13p\ PDFs} = 0.2241 \pm 0.0009_{exp}$$

Full data, total uncertainty

Running $\sin^2\theta_W$ from HERA data (binning 1)

- HERA data were divided into 3 intervals to check the $\sin^2\theta_W$ running.
- Our On-shell measurements are translated to $\sin^2\theta_W^{eff}$ using PDG prescription.



Q^2 = 3.5 GeV² — Q^2 = 1000 GeV² — Q^2 = 10000 GeV² — Q^2 = 50000 GeV²

Number of fitted x-section points: 2065, 759, 118

- Data in the intervals can not constrain PDFs => PDFs were set to ZEUS-13p.

Red error bars — uncertainties from fits with fixed PDFs.

Green error bars — red uncertainties scaled by:

$$\frac{\delta \sin^2\theta_W^{released\ PDFs(full\ uncertainty)}}{\delta \sin^2\theta_W^{ZEUS13p\ PDFs}}$$

$$\sin^2\theta_W^{released\ PDFs} = 0.2252 \pm 0.0011_{exp}$$

$$\sin^2\theta_W^{ZEUS13p\ PDFs} = 0.2241 \pm 0.0009_{exp}$$

Full data, total uncertainty

Trying various Q^2_{min} and calc. orders.

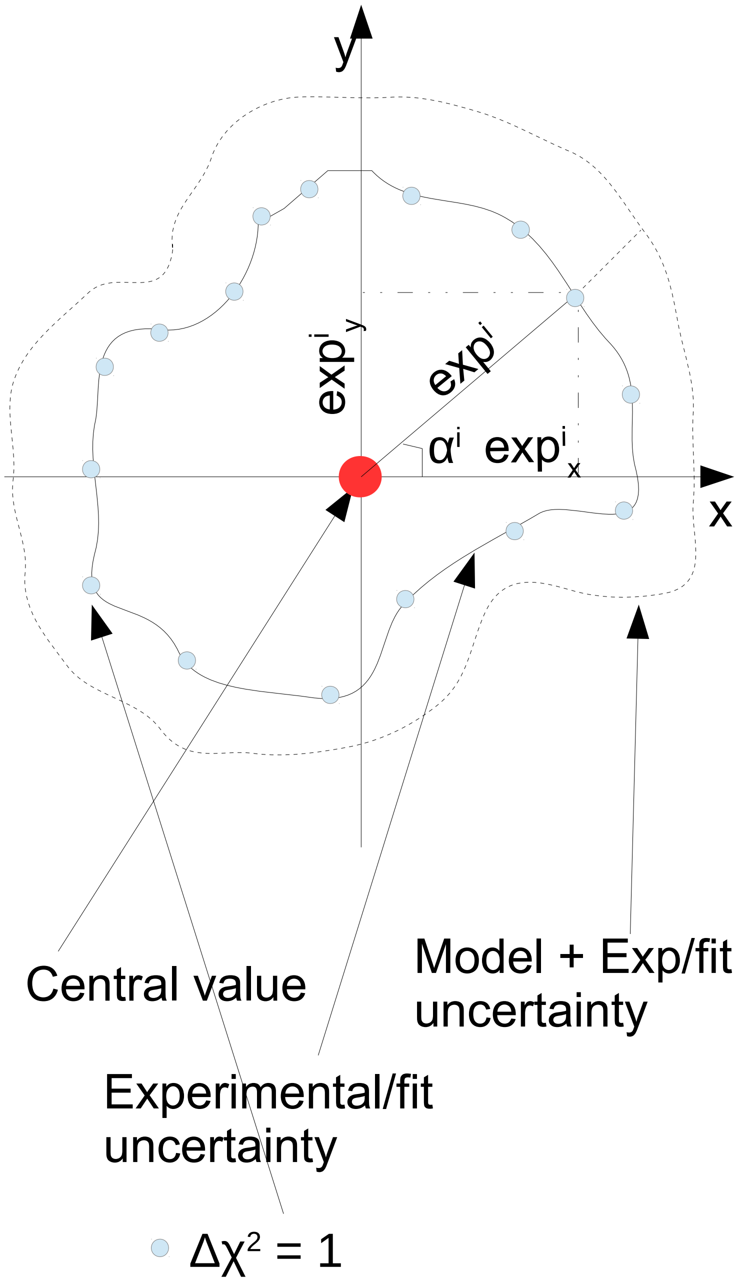
	13p+4EW					14p+4EW					Number of data points
	a_u	a_d	v_u	v_d	χ^2	a_u	a_d	v_u	v_d	χ^2	
NLO 3.5 GeV²	0.516 ±0.062	-0.523 ±0.227	0.148 ±0.071	-0.442 ±0.187	3589	0.601 ±0.061	-0.303 ±0.253	0.102 ±0.049	-0.533 ±0.085	3571	3248
NLO 10 GeV²	0.499 ±0.054	-0.559 ±0.184	0.149 ±0.065	-0.432 ±0.172	3161	0.619 ±0.055	-0.266 ±0.240	0.114 ±0.048	-0.509 ±0.084	3145	3006
NNLO 3.5 GeV²	-	-	-	-	-	-	-	-	-	-	3248
NNLO 10 GeV²	0.501 ±0.051	-0.554 ±0.175	0.146 ±0.061	-0.441 ±0.158	3154	-	-	-	-	-	3006
SM	0.5	-0.5	0.196	-0.346		0.5	-0.5	0.196	-0.346		

Both MIGRAD and HESSE failed

only MIGRAD has converged

- 14p+EW is VERY unstable.
- $Q^2_{min} = 3.5\ GeV^2 \rightarrow Q^2_{min} = 10\ GeV^2$: reduction of uncertainty (but not too stable).

Contours with exp + other uncertainty



$$\exp^i = \sqrt{\exp_x^{i\,2} + \exp_y^{i\,2}}$$

$$mod^i = \sqrt{(\cos\alpha\, mod_x)^2 + (\sin\alpha\, mod_y)^2}$$

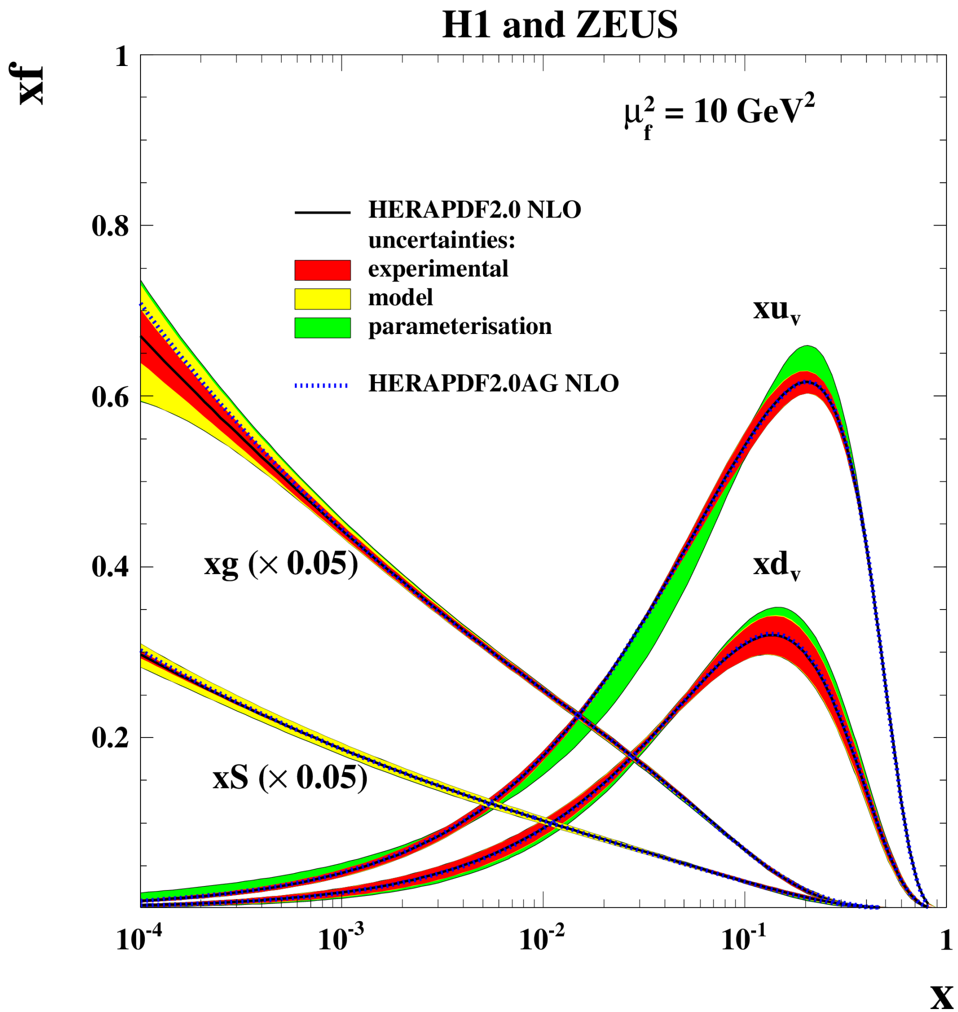
$$\cos\alpha \frac{\exp_x^i}{\exp i} \qquad \sin\alpha \frac{\exp_y^i}{\exp i}$$

$$total^i = \sqrt{\exp^{i\,2} + mod^{i\,2}}$$

$$total_x^i = \cos\alpha\, total^i$$

$$total_y^i = \sin\alpha\, total^i$$

HERAPDF2.0: errors estimation



- **Full systematic correlation treatment.**
- Experimental uncertainties:
  - Hessian method used: full second-derivative matrix calculated
  - Conventional $\Delta\chi^2$ = 1 => 68% CL
- Model uncertainties:
  - All variations are added in quadratures, separately positive and negative.

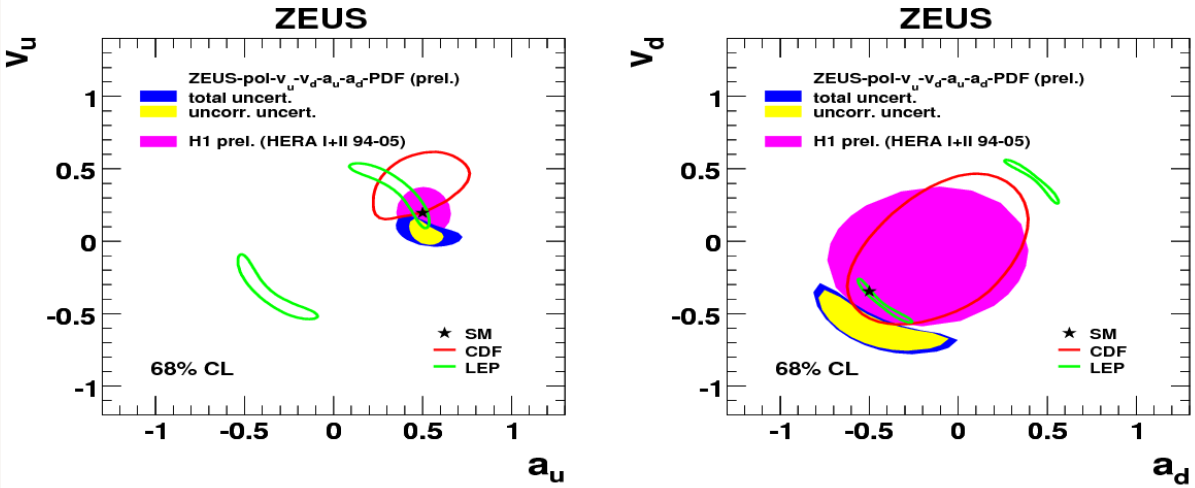
Variation	Standard Value	Lower Limit	Upper Limit
Q^2_{min} [GeV^2]	3.5	2.5	5.0
Q^2_{min} [GeV^2] HiQ2	10.0	7.5	12.5
M_c(NLO) [GeV]	1.47	1.41	1.53
M_c (NNLO) [GeV]	1.43	1.37	1.49
M_b [GeV]	4.5	4.25	4.75
f_s	0.4	0.3	0.5
μ_{f_0} [GeV]	1.9	1.6	2.2

Adding D and E parameters to each PDF

- Parametrisation uncertainties:

- The largest deviation taken.

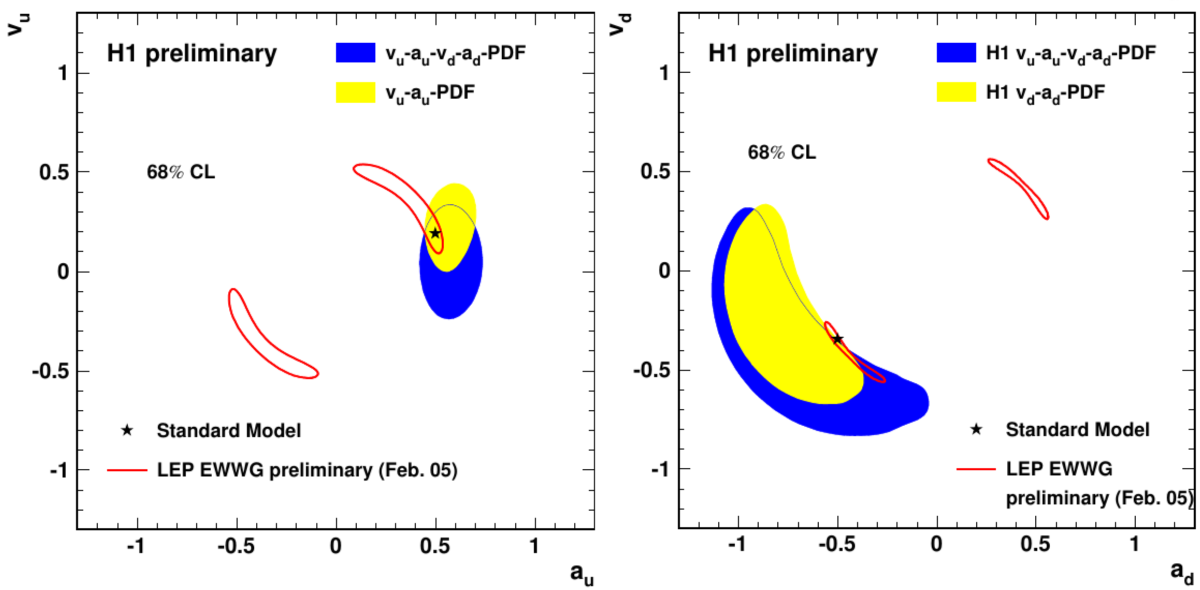
Previous analysis



- Determination of EW par. by ZEUS

  ZEUS HERA I + HERA II e^-p (pol)

- ZEUS-prel-07-027



- Determination of EW par. by H1

  H1 HERA I (unpolarized)

- Phys. Lett. **B632**, 35, (2006)

- All H1 and ZEUS HERA I unpolarized and HERA II polarized data are now available

$$\tilde{F}_2^{\pm} = F_2 + k_Z(-v_e \mp P a_e) \cdot F_2^{\gamma Z} + k_Z^2(v_e^2 + a_e^2 \pm 2P v_e a_e) \cdot F_2^Z$$

$$x\tilde{F}_3^{\pm} = k_Z(\pm a_e + P v_e) \cdot xF_3^{\gamma Z} + k_Z^2(\mp 2 v_e a_e - P(v_e^2 + a_e^2)) \cdot xF_3^Z$$

$$(F_2, F_2^{\gamma Z}, F_2^Z) = x \sum (e_q^2, 2e_q v_q, v_q^2 + a_q^2)(q + \bar{q}) \qquad (xF_3^{\gamma Z}, xF_3^Z) = 2x \sum (e_q a_q, v_q a_q)(q - \bar{q})$$

Questions / answers (group presentation)

Misha

0) l. 67-75 Do I understand correctly, that in fact we measure a_U, v_U and a_D, v_D, as we do to distinguish between flavours in the see?

Yes, we can separate flavours (not in the sea though).

1) why don't we consider NNLO fit? This would be interesting at least as a cross check.

	a_u	a_b	v_u	v_d	chi2
ZEUS-EW-Z (NNLO)	0.454	-0.609	0.128	-0.452	3283
ZEUS-EW-Z	$0.514._{-0.052}^{+0.113}$	$-0.567._{-0.157}^{+0.379}$	$0.136._{-0.091}^{+0.094}$	$-0.416._{-0.193}^{+0.252}$	3269
SM	0.5	-0.5	0.196	-0.346	

NNLO fits are very unstable. In the current cross-check HESSE did not converge.

2) I'm confused about the data sample used in the analysis. From the description it is unclear to me how the polarised ZEUS data samples were usedtogether with the HERAI+II combined data .

Data used: ZEUS and H1 HERAI data + H1 HERAII unpolarised data + ZEUS HERAII polarised data + H1 and ZEUS data from runs with reduced proton energy.

All the correlations are preserved as in the HERAPDF2.0 combination.

Misha

3) l.189: how the 68% CL is defined? Does it cover 68% of the 2D pdf? does it correspond to deltaChi2=1 criteria of the 2D chi2 (what are the values of other 2 couplings? are they frozen?)

> This is basically a MINOS approach: you shift two of your parameters away from the optimal values, fix them and refit all the other parameters in the fit. In such a way one can probe the contour, alone which you have (chi2 - chi2_min) = 2.3 (CL = 68% for 2D case).

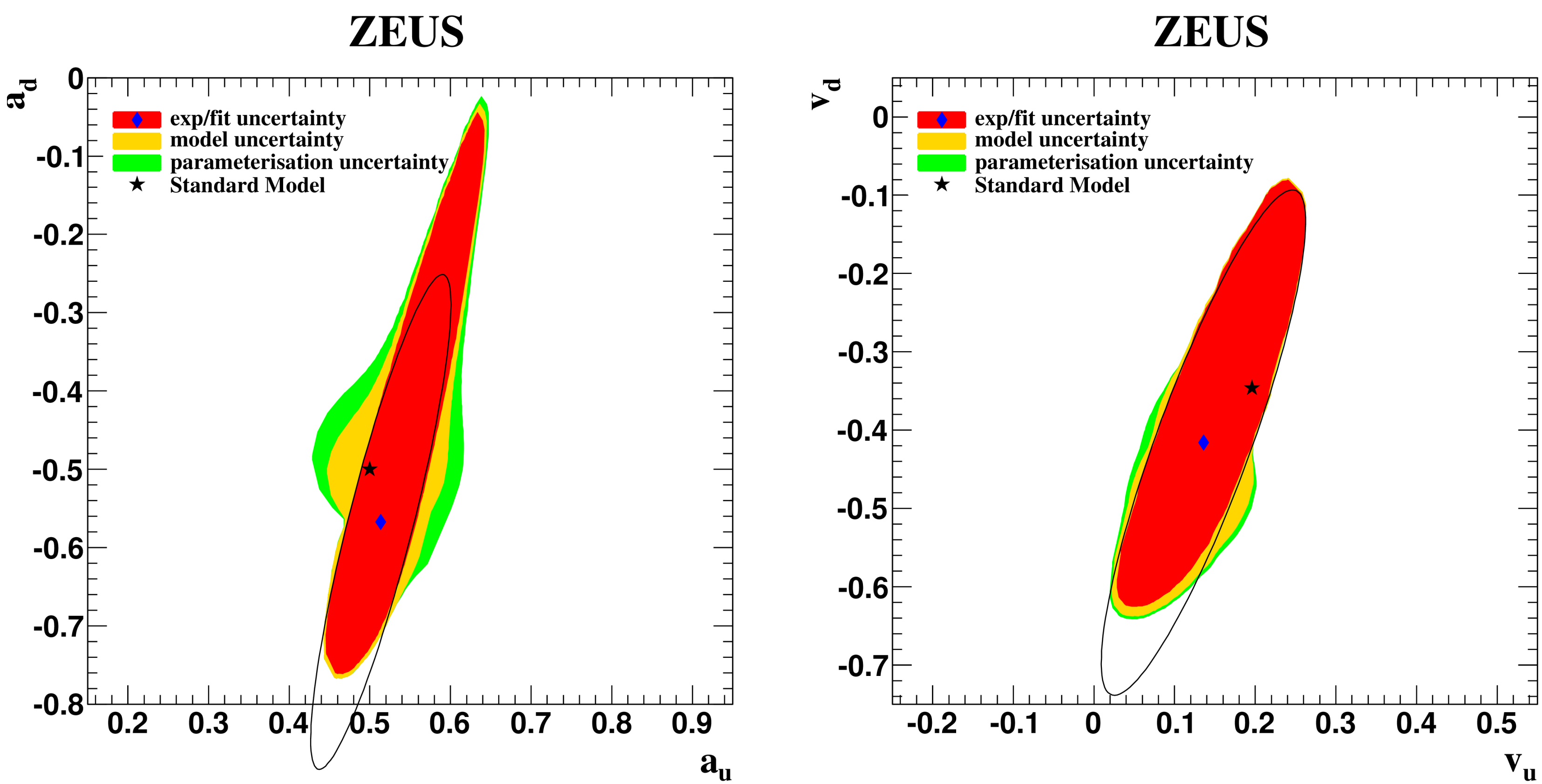
4) Fig. 7: I think we should remove the average. We know the values are correlated with each other within each other and very significantly (for us and LEP at least) and we neglect this significant correlation. We also see that some values have very asymmetric uncertainties (e.g. LEP a_u and v_u) and we had to make some symmetrisation assumptions to use some simple average most likely.

> I symmetrised measurements before averaging. however, for the u-quarks our result, as one can see is not that asummetric, and it strongly dominates the average value. in the d-quark case it is LEP who dominates in the average and there it is also not that asymmetric. So symmetrisation here is not so significant, I guess. In addition, neglecting possible correlations between the experiments means overestimating the uncertainty of average result. This plot has just an illustrative purpose

Misha

5) Fig. 8: please check these plots as the correlation seems to be not very significant on this plots (tilt is far from ~pi/4), whereas the correlation table quotes coefficients ~0.9. Is it due to funny model + param. uncertainties? Can we get stat-only correlation coefficient for a visual check (not to include in the draft)?

Checked. All fine.



Ewald

1) I have a problem with the statement that we improve the precision of a_u and v_u by our results. Of course, as shown in fig. 7, we improve these parameters with respect to other collider experiments. However, having lookedinto the PDG tables I saw that the uncertainties quoted for the world averages of a_uand v_u are by a factor 2 smaller than shown in fig.7. This I would like to understand. I wonder what neutrino experiments contribute.

	a_u	a_b	v_u	v_d
PDG (average)	$0.5\ ^{+0.04}_{-0.06}$	$-0.523\ ^{+0.050}_{-0.029}$	$0.25\ ^{+0.07}_{-0.06}$	$-0.33\ ^{+0.05}_{-0.06}$
ZEUS-EW-Z	$0.514\ ^{+0.113}_{-0.052}$	$-0.567\ ^{+0.379}_{-0.157}$	$0.136\ ^{+0.094}_{-0.091}$	$-0.416\ ^{+0.252}_{-0.193}$
SM	0.5	-0.5	0.196	-0.346

Checked. No neutrino results on this.

PDG does its own FIT using separate measurements. Meaning our current precision CAN contribute significantly to the PDG average.

2) The electroweak coupling constants of u and d on one side and the W mass with the Fermi constant on the other have been fitted on different data sets

Both couplings of light quarks to Z-boson and mass of W-boson were fitted on the same data collection. It was ZEUS and H1 HERAI data + H1 HERAII unpolarised data + ZEUS HERAII polarised data + H1 and ZEUS data from runs with reduced proton energy.

Erich

1)Whereas we contribute something new to the quark ew couplings, this is not the case for the W mass and G. Here our accuracy is far worse than the PDG values and our measurements have more the meaning of a consistency check. I therefore suggest to shorten this chapter fittingly.