HERAPDF0.2 and predictions for W/Z production at LHC

PDF4LHC

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Motivation

Some of the debates about the best way of estimating PDF uncertainties concern the use of many different data sets with varying levels of consistency.

The combination of the HERA data yields a very accurate and consistent data set for 4 different processes: e+p and e-p Neutral and Charged Current reactions.

Whereas the data set does not give information on every possible PDF flavour it does

•Give information on the low-x Sea (NCe+ data)

•Give information on the low-x Gluon via scaling violations (NCe+ data)

•Give information on high-x u (NCe+/e- and CCe-) and d (CCe+ data) valence PDFs

•Give information on u and d-valence shapes down to $x \sim 3\ 10^{-2}$ (from the difference between NCe+ and NCe-)

Furthermore, the kinematic coverage at low-x ensures that these are the most crucial data when extrapolating predictions for W, Z and Higgs cross-sections to the LHC

Correlated systematic uncertainties, $\chi 2$ and $\Delta\chi 2$

The data combination results in a data set which not only has improved statistical uncertainty, but also improved systematic uncertainty.

Even though there are 113 sources of correlated systematic uncertainty on the data points these uncertainties are small. The total systematic uncertainty is significantly smaller than the statistical uncertainty across the the kinematic region used in the QCD fits

This means that the method of treatment of correlated systematic uncertainties in our PDF fits is not crucial. We obtain similar results treating all systematic errors as correlated or as uncorrelated. For our PDF fits we combine 110 sources of systematic uncertainty from the separate experiments in quadrature and OFFSET the 3 procedural systematics which derive from the method of data combination.

The form of the $\chi 2$ that we use for the PDF fit is the same as that used for the data combination- see talk of Sasha Glazov.

We set the uncertainties on our PDFs at 68% CL by the conventional $\chi 2$ tolerance

$$\Delta\chi 2 = 1$$

Theoretical framework

Fits are made at NLO in the DGLAP formalism -using QCDNUM 17.02 (update to 17.04 is consistent) NNLO is work in progress

The Thorne-Roberts massive variable flavour number scheme is used (2008 version)

The starting scale Q^2_0 (= 1.9 GeV^2) is below the charm mass^2 (mc=1,4 GeV) and charm and beauty (mb=4.75) are generated dynamically

A minimum Q^2 cut $Q^2 > 3.5\ GeV^2$ is applied to stay within the supposed region of validity of leading twist pQCD (no data are at low W^2)

Parametrisation and model assumptions (all values in green are varied)

We chose to fit the PDFs for:

gluon, u-valence, d-valence and the Sea u and d-type flavours:

Ubar = ubar, Dbar = dbar+sbar (below the charm threshold)

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

The normalisations of the gluon and valence PDFs are fixed by the momentum and number sum-rules resp.

B(d-valence) = B(u-valence) (can be varied), B(Dbar) = B(Ubar),

A(Ubar) = A(Dbar) (1-fs), where sbar = fs Dbar, so that ubar → dbar as x→ 1 (fs=0.31)

Uncertainties due to model assumptions are evaluated by varying the following inputs

- Variation of the heavy quark thresholds:
  - Mc = 1.4 GeV → 1.35 - 1.50 GeV
    - varied with Q^2_0 (1.77 - 2.19) GeV^2
  - Mb = 4.75 GeV → 4.30 - 5.00 GeV
- Variation of the sea fractions:
  - f_s = s/D = 0.31 → 0.23 - 0.38

Since there is no HERA information on the strange PDF the strange sea fraction is varied by an amount which covers the recent findings of MSTW/CTEQ

- Variation of the starting scale of evolution of PDFs:
  - Q^2_0= 1.9 GeV^2 → 1.5 - 2.5 GeV^2:
    - for Q^2_0= 2.5 GeV^2 vary f_s=0.32 and Mc=1.6 GeV because $Q^2_0 < Mc^2$
    - for Q^2_0= 1.5 GeV^2 vary f_s=0.29
- Variation of the minimum Q^2 cut on data:
  - Q^2_{min}= 3.5 GeV^2 → 2.5 - 5.0 GeV^2

Choice of parametrisation- variations in parametrisation

All fits vary the A,B,C parameters (if not covered by the restrictions on p 3) we then search for good fits with the D and E parameters free $xf(x,Q_0^2) = Ax^B(1-x)^C(1+Dx+Ex^2)$

Our central fit has E(u-valence) free and all other D,E parameters zero (10 parameters)

This is chosen as the central fit not only because of its good $\chi 2$ = 576 for 592 data points but also because: all PDFs are +ve and d-valence > dbar at high-x

However, other possibilities are consider as paramerisation uncertainties

Those which produce significant changes in PDF shapes are 11 parameter fits with:

- •D(u-valence) also free
- •D(Ubar) also free
- •D(Dbar) also free

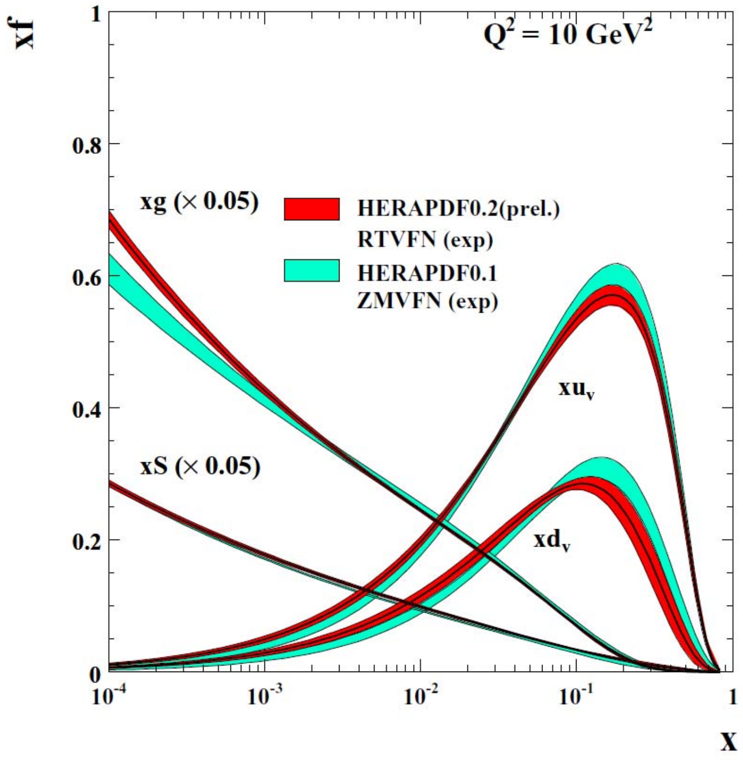
but all other variants with non-zero D and E were tried

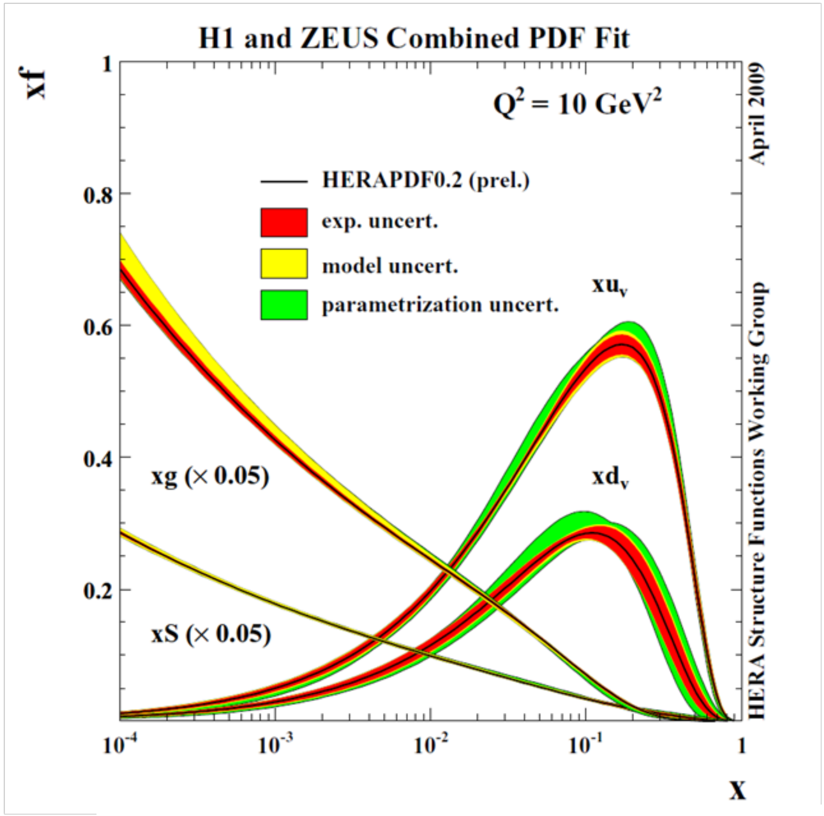
No formal $\chi 2$ requirement was put on these alternative fits -such as requiring, $\Delta\chi 2 < \sqrt{2N} \sim 30$, from our central fit (hypothesis testing criterion) -but in practice they differ from our central fit by $\Delta\chi 2 < 10$.

The envelope of these fits is used as the parametrisation uncertainty.

And we aren't finished yet- work is still in progress

Results





Compare HERAPDF0.1 and 0.2

Experimental uncertainties have decreased- mostly due to newly published H1 data

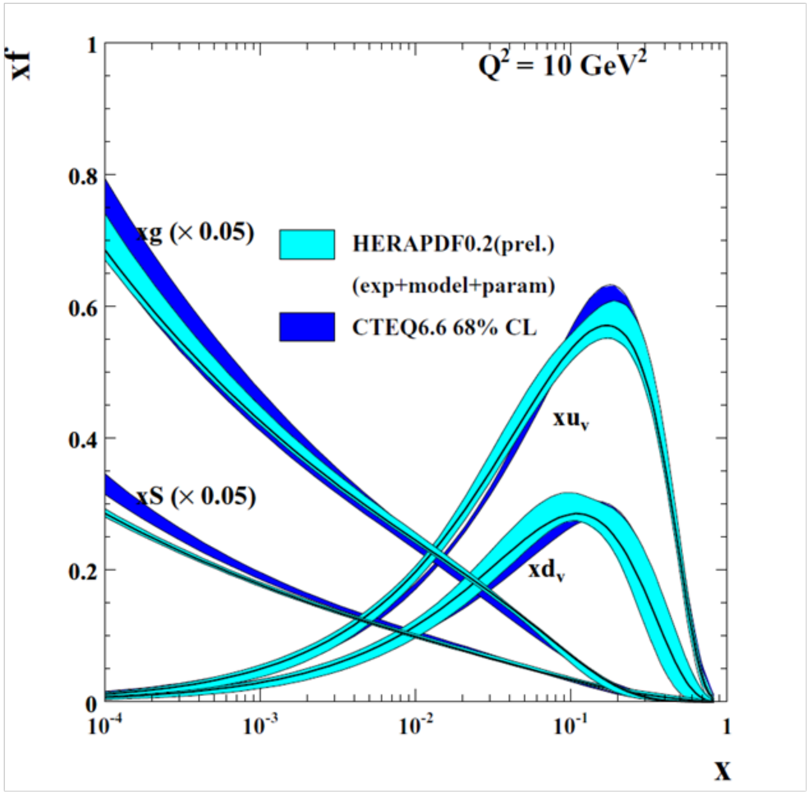
Gluon is steeper- mostly due to massive heavy quark treatment

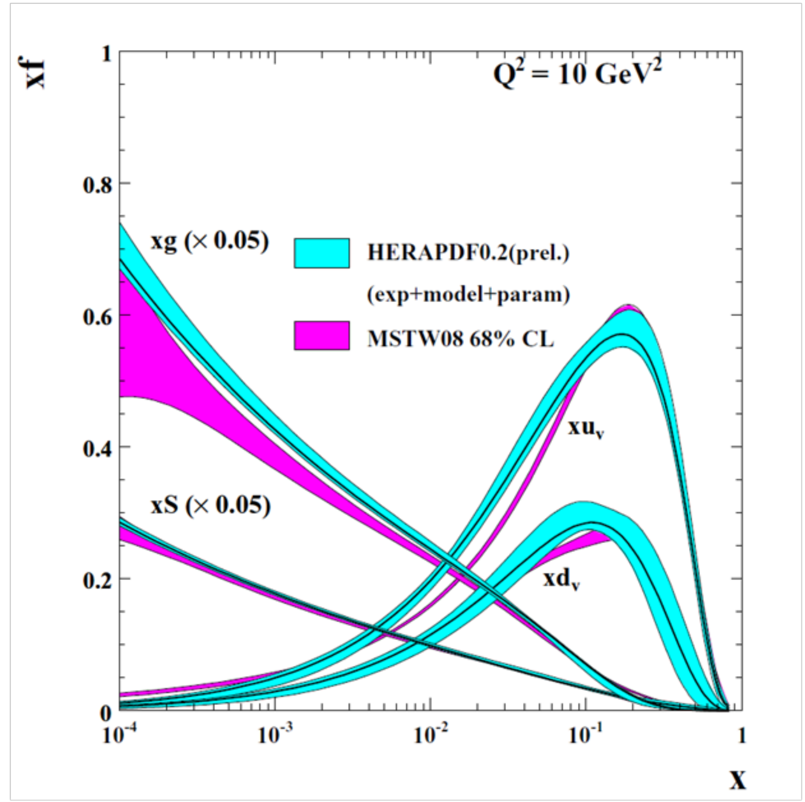
- Red: experimental uncertainties
- Yellow: model uncertainties
- Green: pdf parametrization uncertainties

➡ High-x and valence are mostly affected by the PDF parametrisation

This reflects the limitations of HERA-I data – HERA-II will improve this

Comparison to CTEQ/MSTW

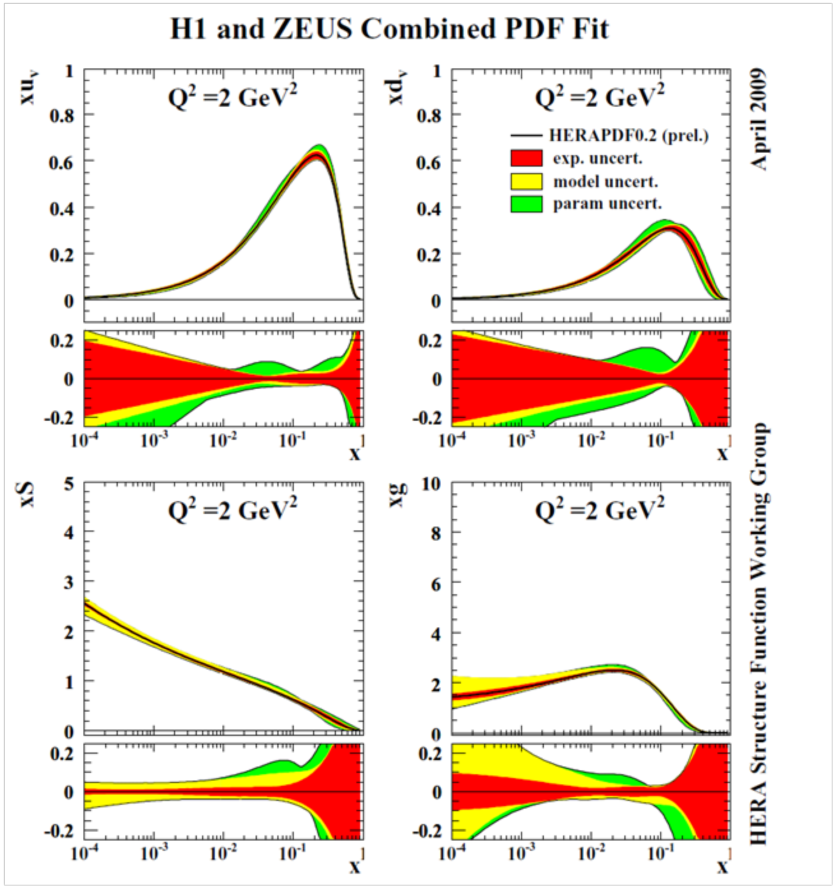


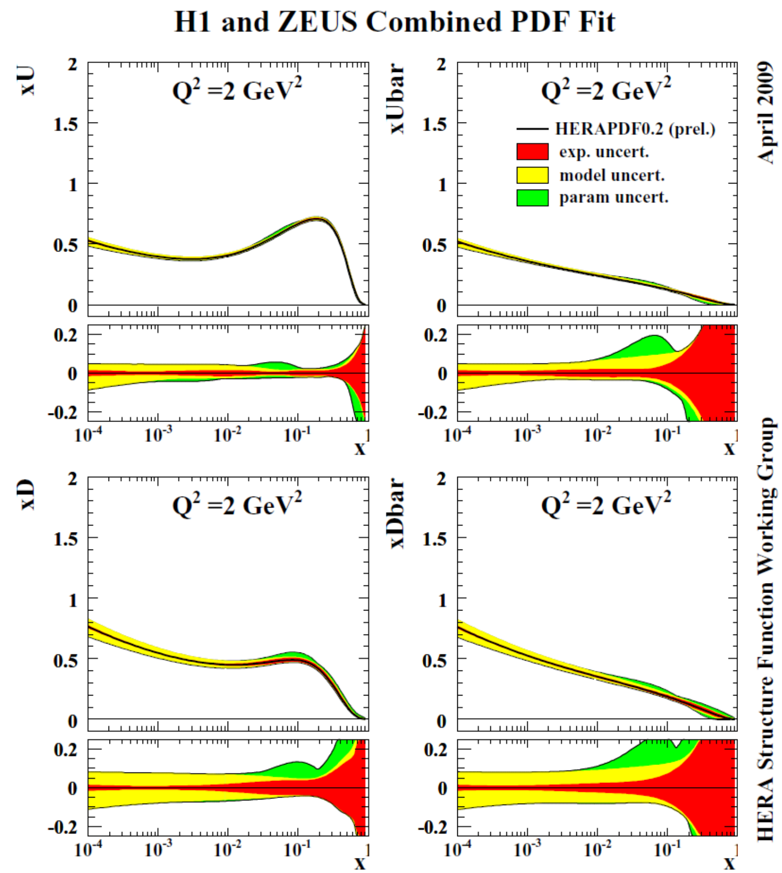


We compare to the global fits using their 68%CL estimates since we use $\Delta\chi2=1$

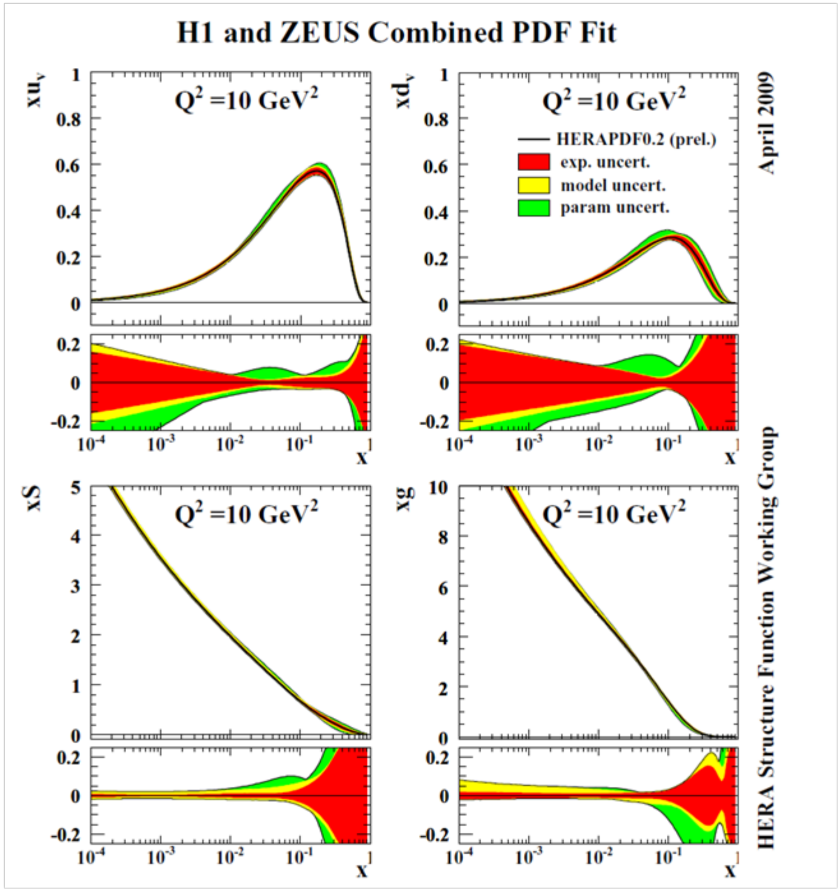
However since we also add model and parametrisation uncertainties this is not completely rigorous

Clearly the combined HERA data give strong constraints on low-x sea and gluon

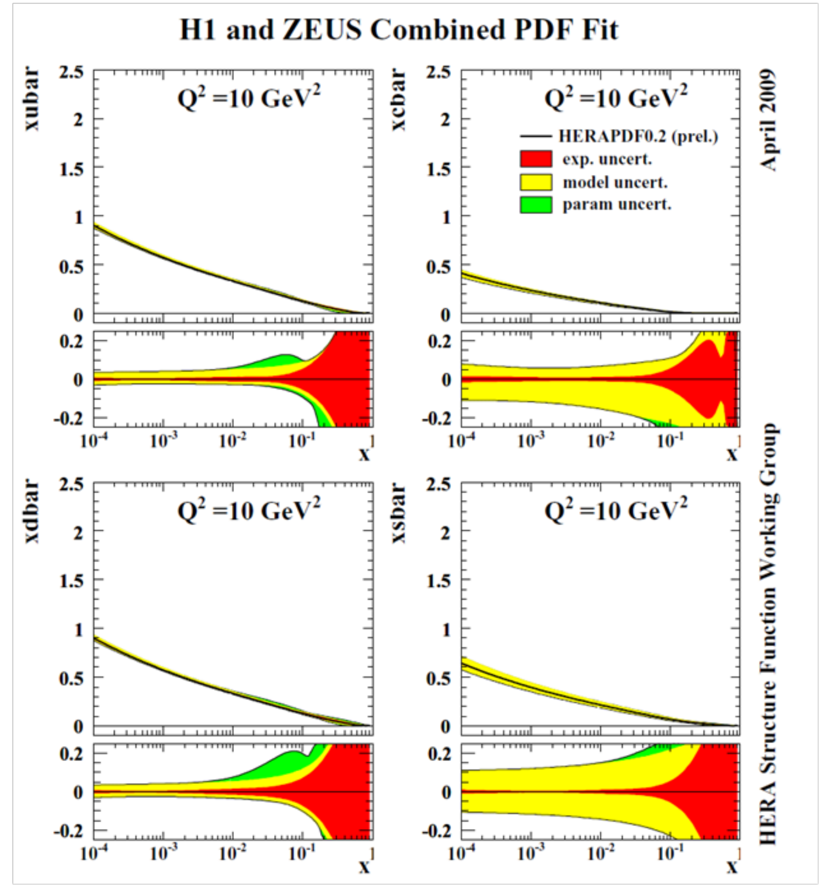




- At the starting scale gluon is valence like
- Q_0^2, Q^2_{min} dominate the model uncertainty of gluon and valence PDFs
- PDF parametrisation uncertainty dominates valence PDFs and high x region



Uncertainties are reduced at higher scale for sea and gluon



Also look at flavour separation in the sea –

for strange this has input model dependence

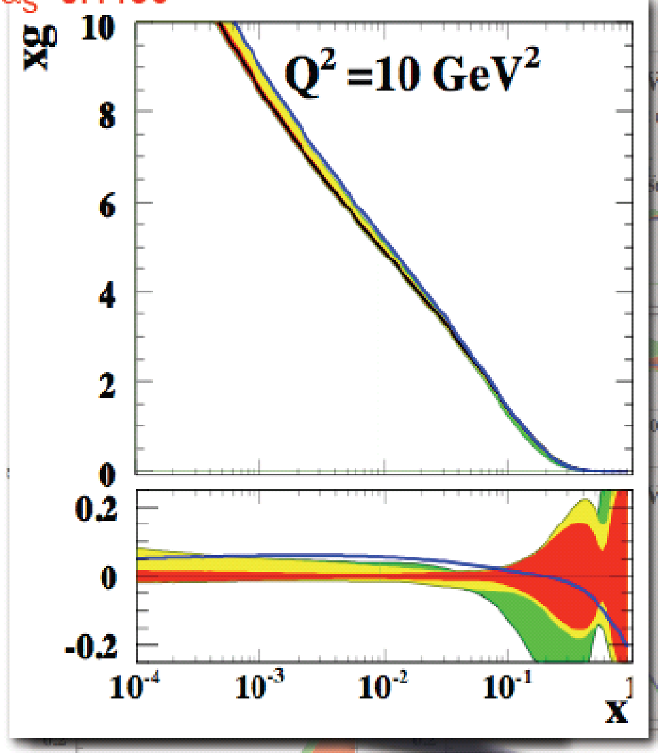
for charm it derives from the gluon

Variation of Strong Coupling

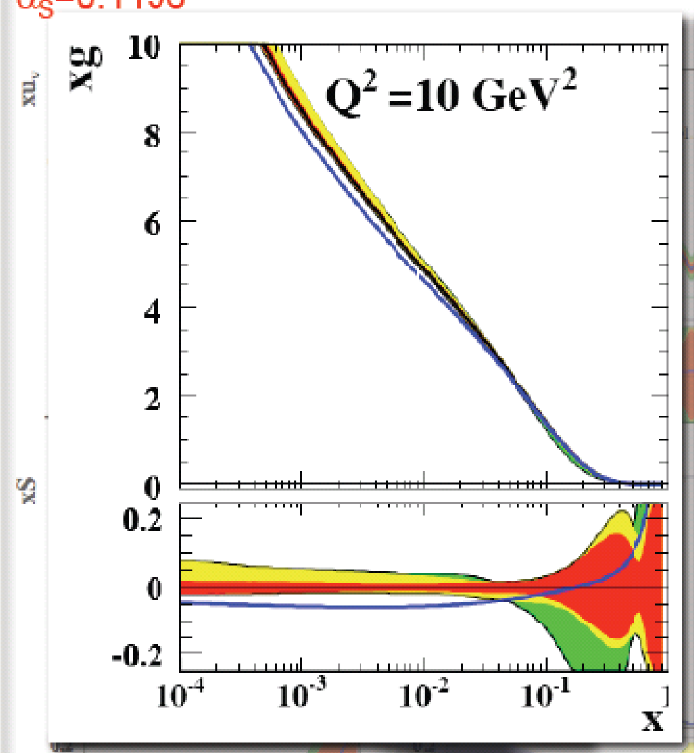
Most pronounced in the gluon distribution (as expected)

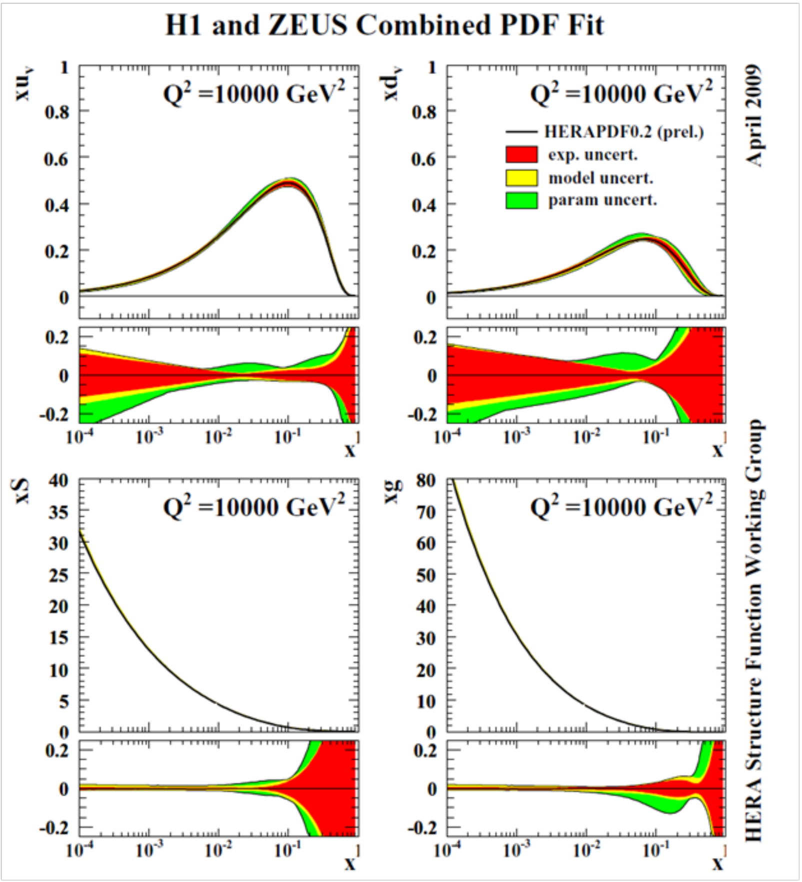
- Shown by the blue line

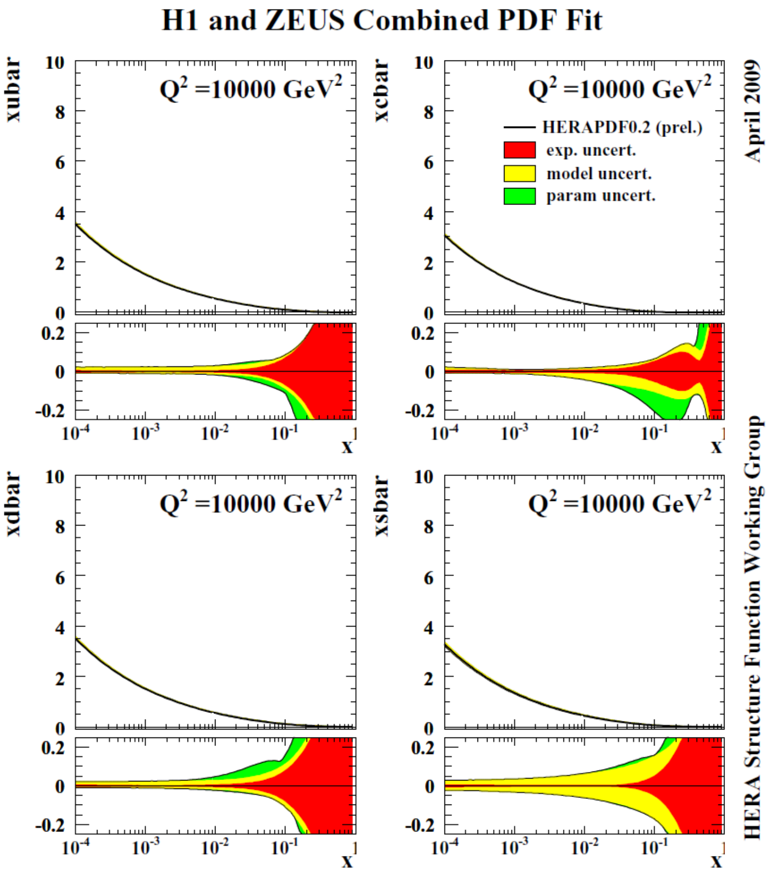
α_S=0.1156



α_S=0.1196





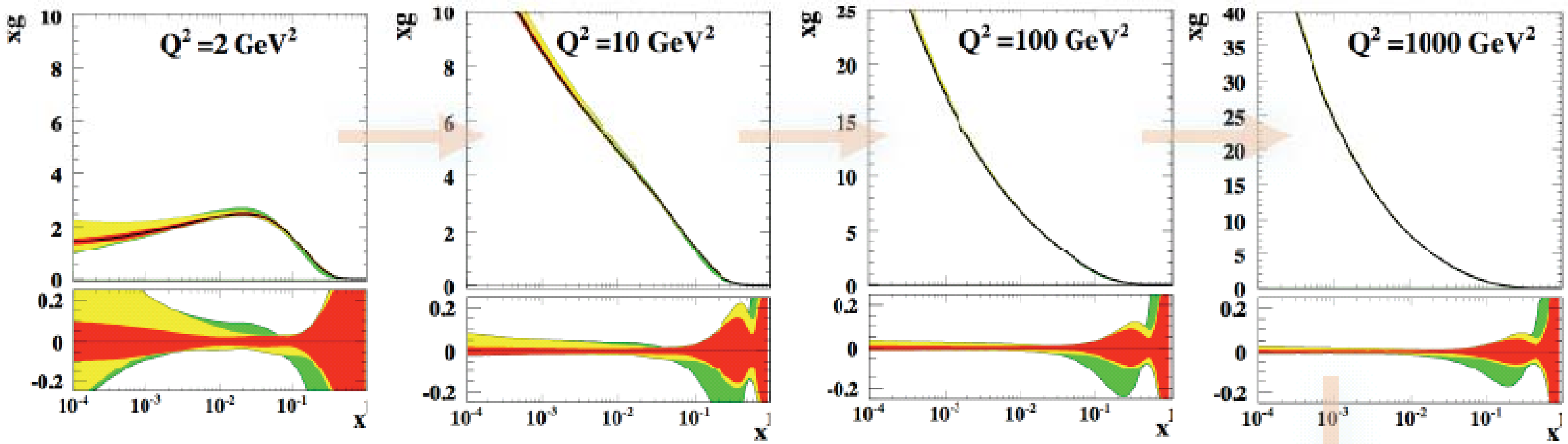


Now look at the scale of the W and Z Q^2~10,000 GeV^2

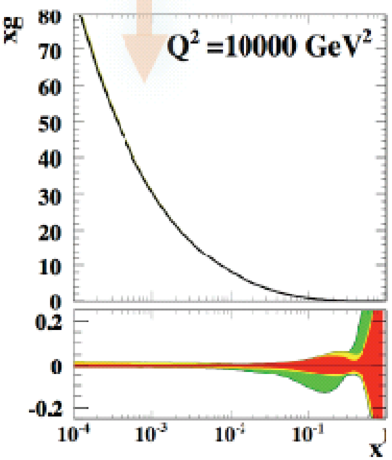
PDF parametrisation uncertainty is still sizeable for valence PDFs and at high-x

But for the gluon and Sea in the low-x region which is relevant for W and Z production at central region there is impressive precision

Evolution of gluon with Q^2



- Near the starting scale gluon is valence like
  - The model uncertainties are large in low x region
    - Mostly due to Q_0^2 variations
  - The PDF param. uncertainty dominates high x



- Impressive precision at higher Q^2

Summary on HERAPDF0.2

Impressive precision on the low-x sea and gluon particularly relevant for W, Z production at LHC

Now let's apply this to predictions for W and Z production at LHC

What changes about W/Z production for LHC running 10 TeV rather than 14 TeV

The central rapidity range for W/Z production AT LHC is still at low-x

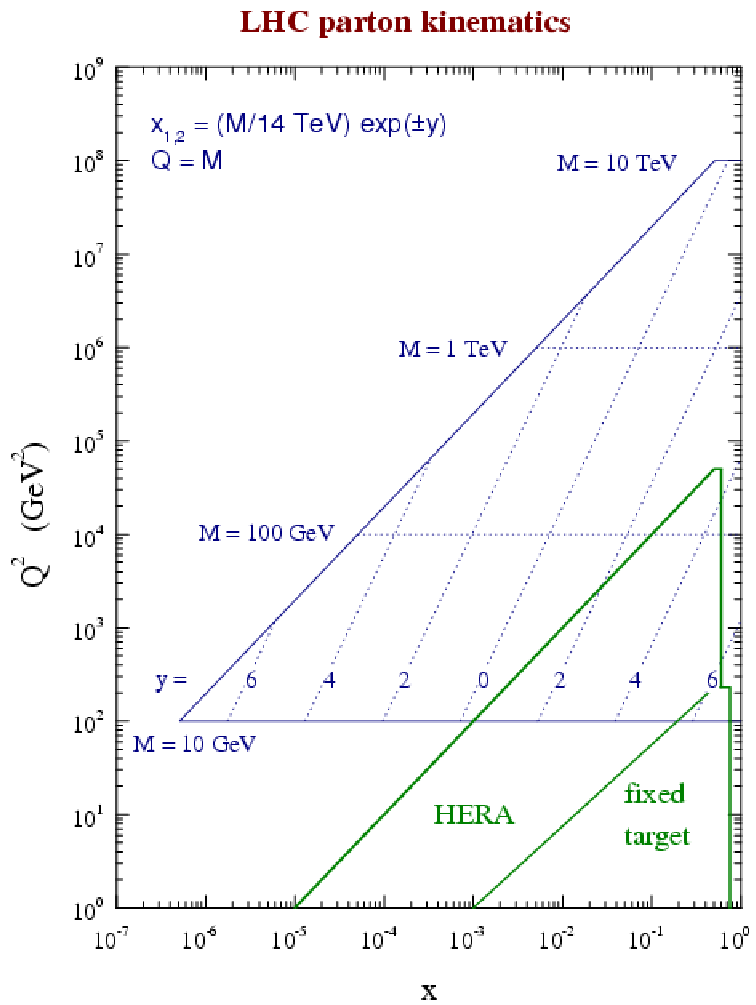
(6×10^{-4} to 6×10^{-2}) at 14 TeV

(8.5×10^{-4} to 8.5×10^{-2}) at 10 TeV

Just slightly higher than before

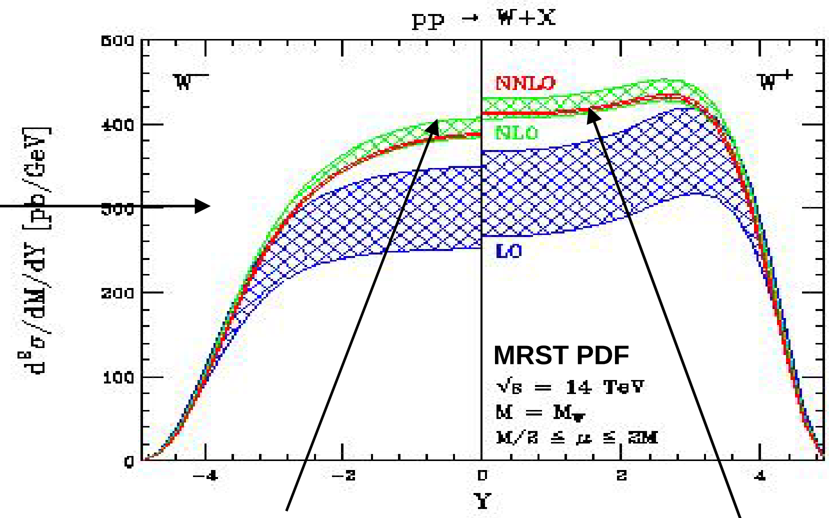
The W and Z cross-sections decrease to ~70% of their values at 14TeV.

This means there will still be millions of events.



W/Z production have been considered as good standard candle processes with small theoretical uncertainty.

PDF uncertainty is THE dominant contribution and most PDF groups quote uncertainties <~3% (at 68%CL)



NNLO corrections small ~ few%
NNLO residual scale dependence < 1%

W Z cross-sections at 10 TeV

PDF set	$\sigma_{W+} B_{W\to l\nu}$ (nb)	$\sigma_{W-} B_{W\to l\nu}$ (nb)	$\sigma_Z B_{Z\to ll}$ (nb)
ZEUS-2005	8.51±0.30	6.08±0.20	1.36±0.04
MSTW08	8.55±0.15	6.25±0.12	1.38±0.025
CTEQ66	8.77±0.18	6.22±0.14	1.40±0.027
HERAPDF02	**8.69±0.07** **±0.16±0.16**	**6.31±0.04** **±0.13±0.13**	**1.40±0.01** **±0.03 ±0.02**
HERAPDF01	**8.64±0.10±0.07**	**6.27±0.11±0.08**	**1.38±0.02±0.02**
CTEQ61	8.29±0.22	5.90±0.17	1.32±0.030

Agreement between PDFs which include massive heavy quark treatment is also to ~3%

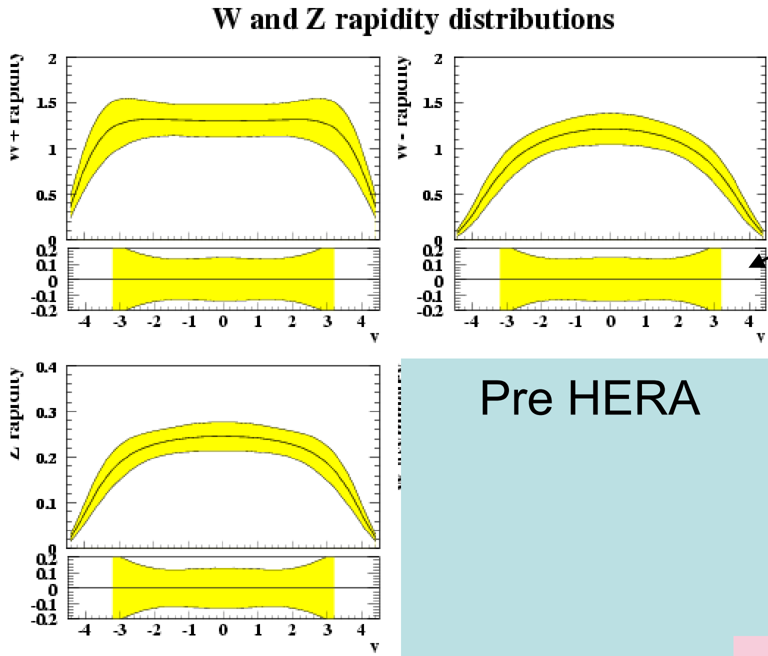
Can be used as a luminosity monitor?

HERAPDF0.2 experimental uncertainties are VERY small

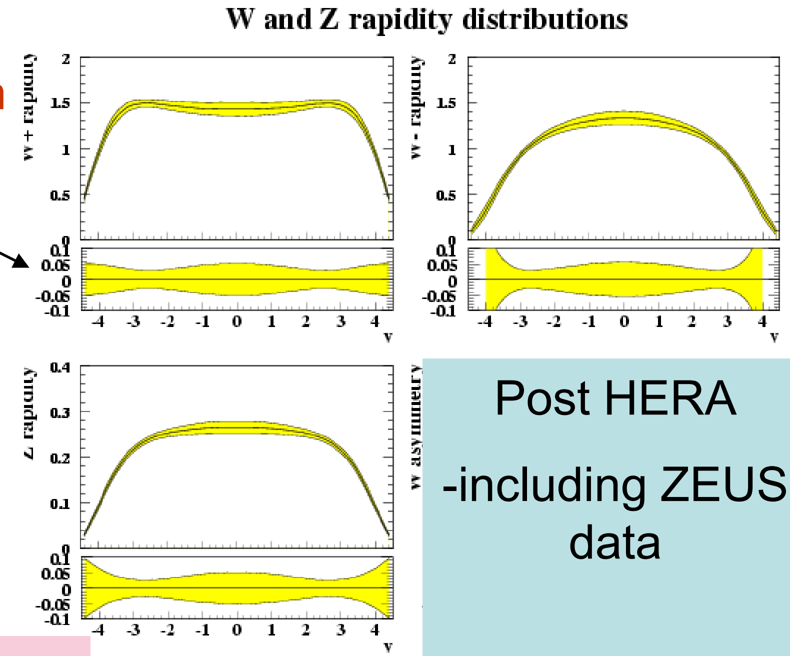
Model/parametrization uncertainties increase this..

But still comparable to CTEQ/MSTW

WHY DO WE KNOW these cross-sections SO WELL? BECAUSE OF HERA.
Look in detail at predictions for W/Z rapidity distributions: Pre- and Post-HERA



Note difference in scale for fractional errors

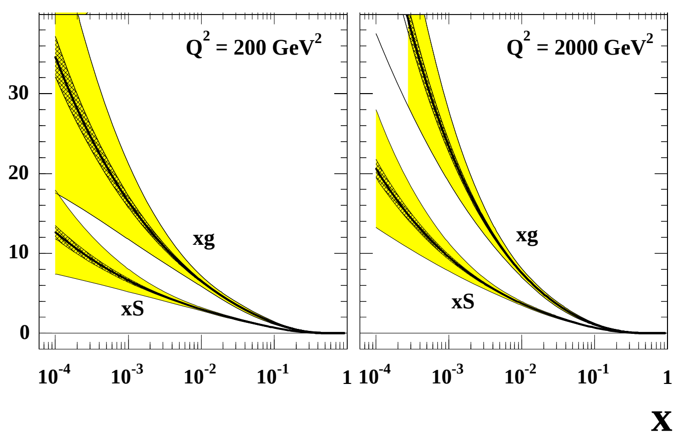


Pre HERA

Why such an improvement ?

Post HERA

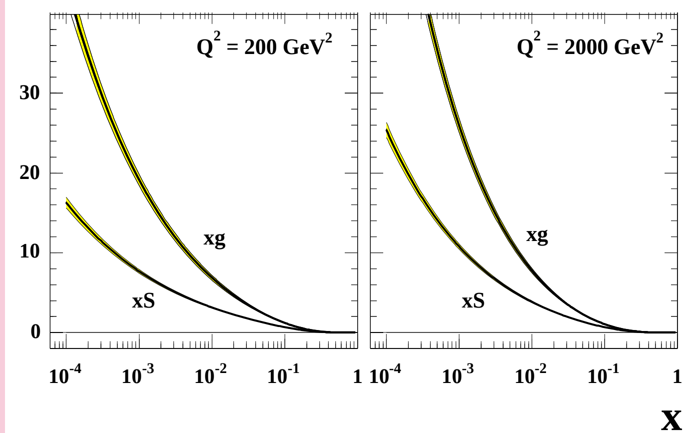
-including ZEUS data



It’s due to the improvement in the low-x sea and gluon

At the LHC the q-qbar which make the boson are mostly sea-sea partons

And at $Q^2 \sim M_Z^2$ **the sea is driven by the gluon**



These illustrations at 14 TeV

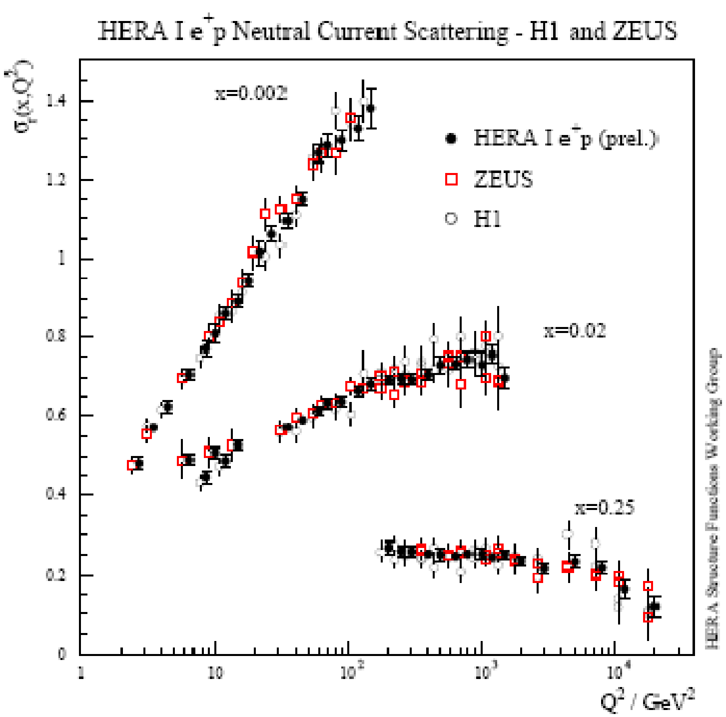
Of course global fits like CTEQ/MSTW include data from BOTH HERA experiments but they don't yet include the HERA combined data

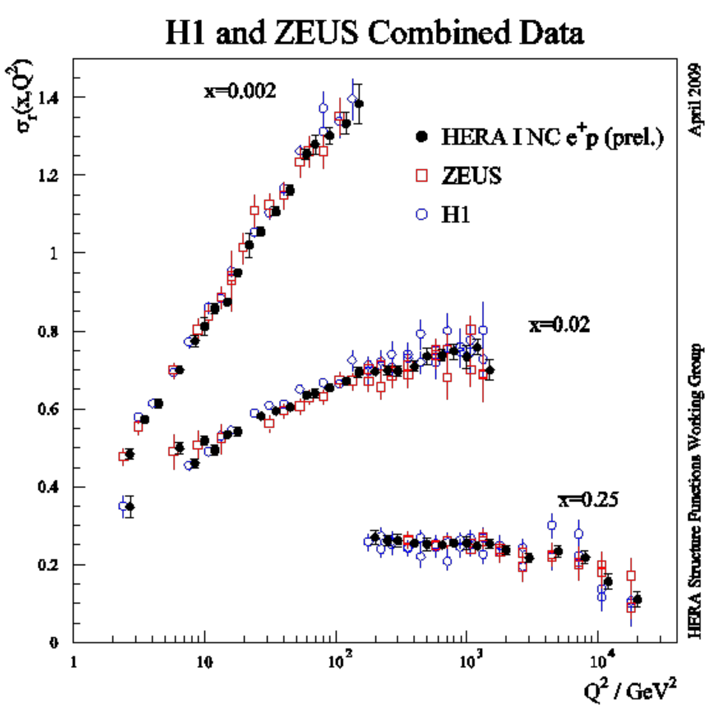
This combination is not just a statistical improvement. Each experiment can be used to calibrate the other since they have rather different sources of experimental systematics

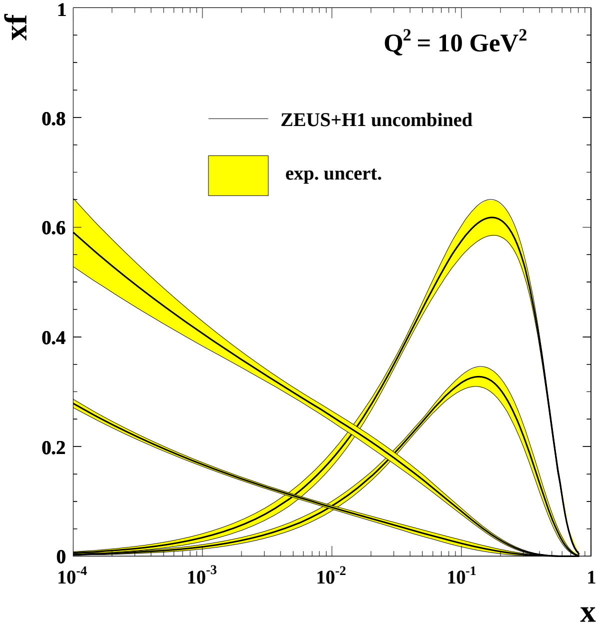
Before combination the systematic errors are ~3 times the statistical for Q2< 100

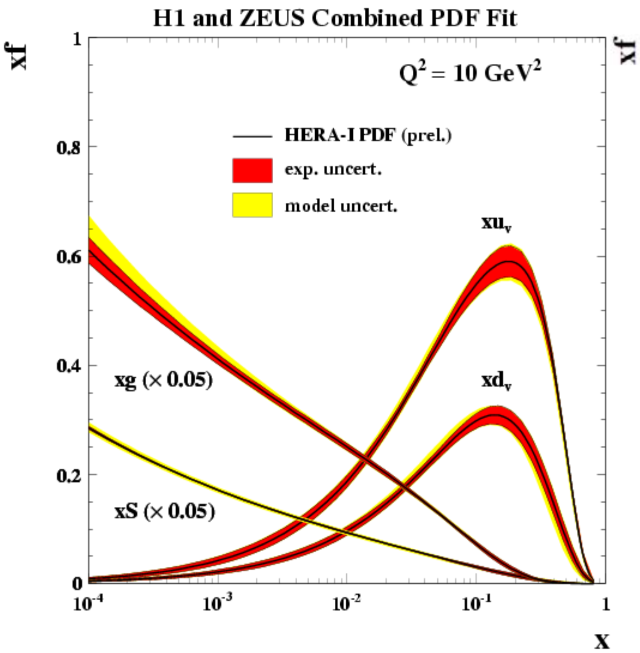
After combination systematic errors are < statistical

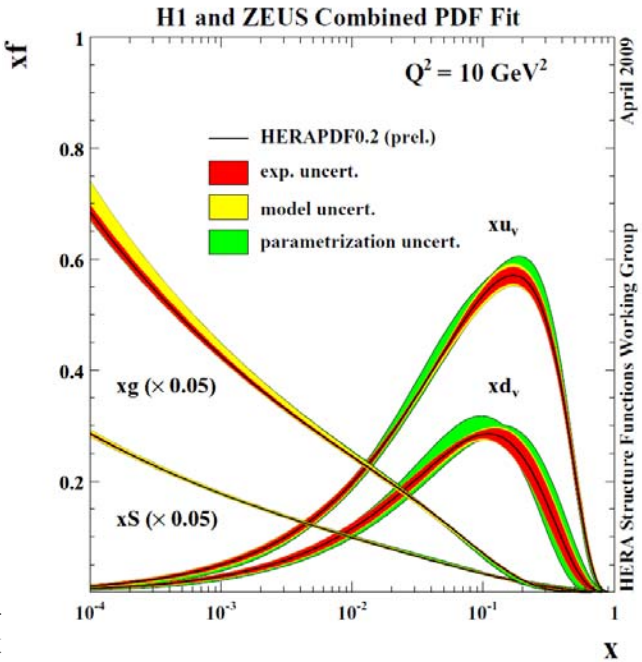
Combination was done in 2008 BUT more very precise H1 data has been added in 2009











PDFs from same QCD analysis of separate ZEUS and H1 data sets - before combination

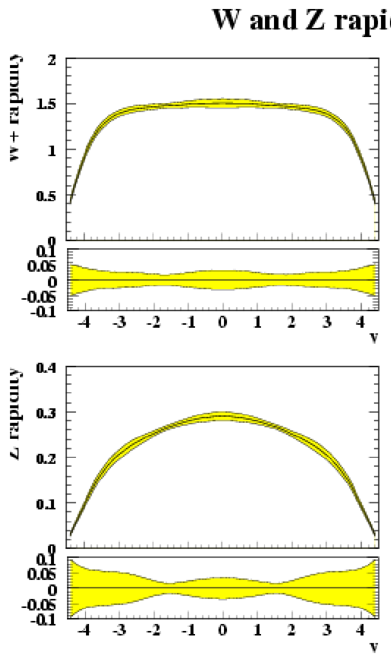
Experimental error only

PDFs from same QCD analysis of combined HERA data - after combination 2008

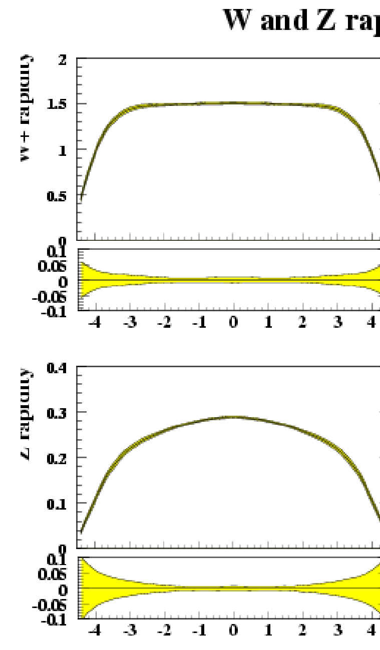
HERAPDF0.1 has very small experimental errors model errors were also added

PDFs from same QCD analysis of combined HERA data - after combination 2009

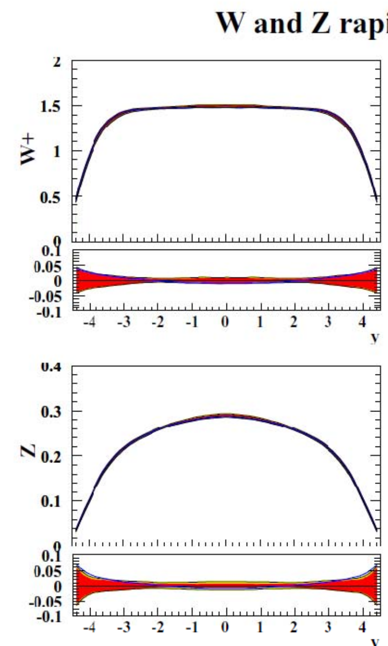
HERAPDF0.2 has even smaller experimental errors model errors and parametrisation errors were added



Predictions for WZ prodn from including HERA data in PDF fit before data combination



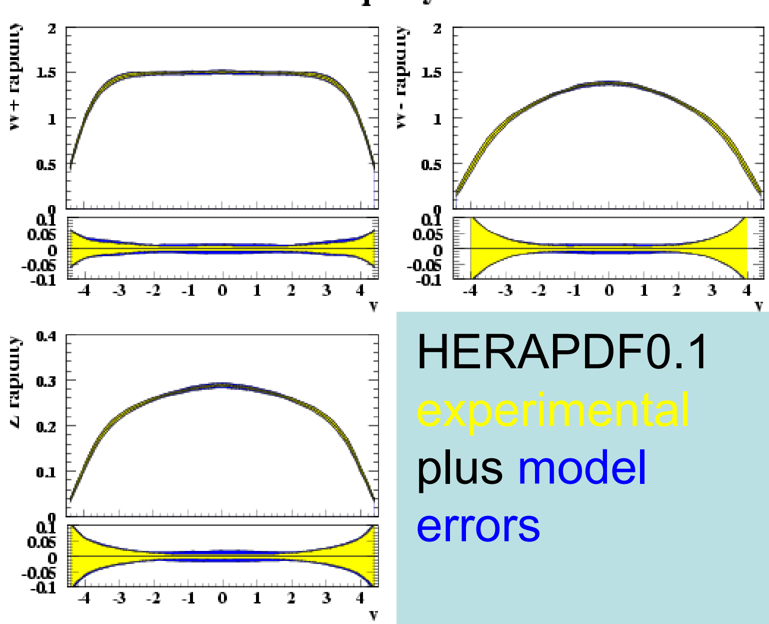
Predictions for WZ prodn from HERAPDF0.1 after data combination



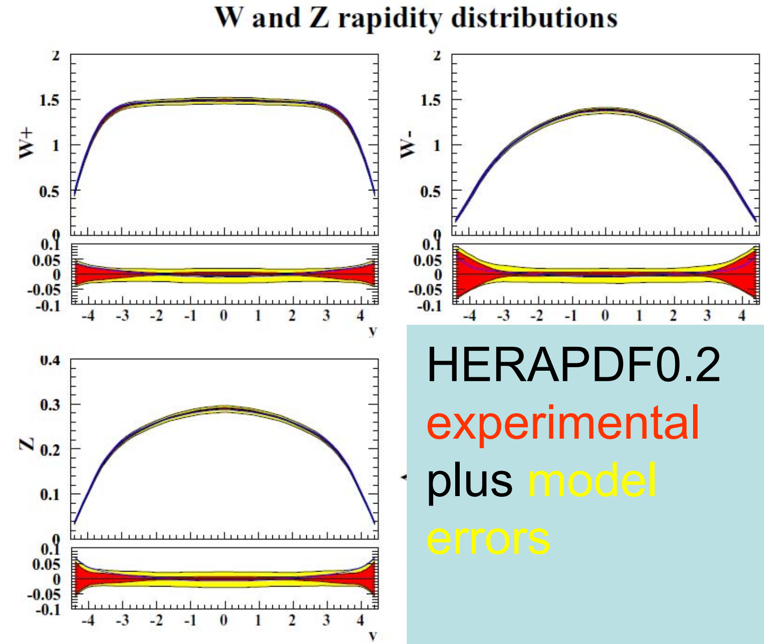
Predictions for WZ prodn from HERAPDF0.2 after new data combination

Using the HERA combined data (2008) and then improving the HERA combined data (2009) leads to smaller and smaller experimental uncertainties on the predictions for W/Z production at central rapidity, because the HERA data improve the low-x sea and gluon PDFs

These illustrations at 14 TeV



HERAPDF0.1
experimental
plus model
errors

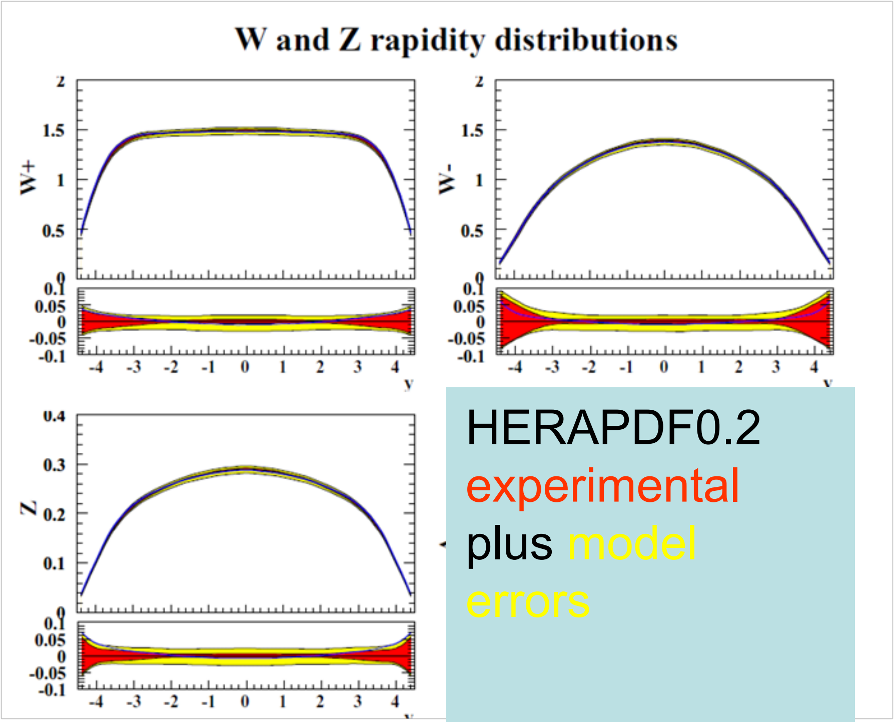


HERAPDF0.2
experimental
plus model
errors

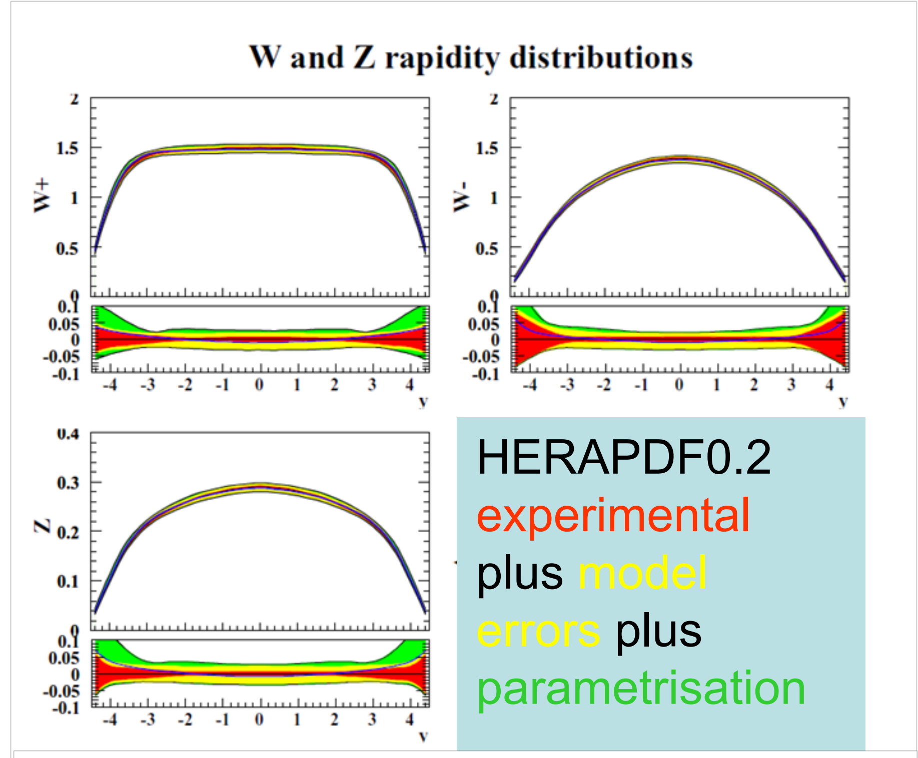
However it is a different story with model uncertainties

Model dependence is larger in HERAPDF0.2. This is mostly because in HERAPDF0.2 we use a general mass variable flavour number scheme rather than a zero-mass scheme and so variation of the charm mass affects the predictions more- smaller mass (closer to zero-mass) lowers the W,Z cross-sections and heavier mass raises them (as observed by CTEQ).

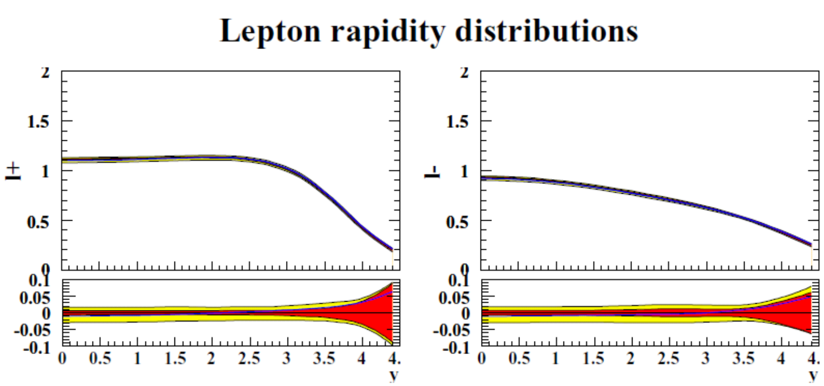
These illustrations at 14 TeV

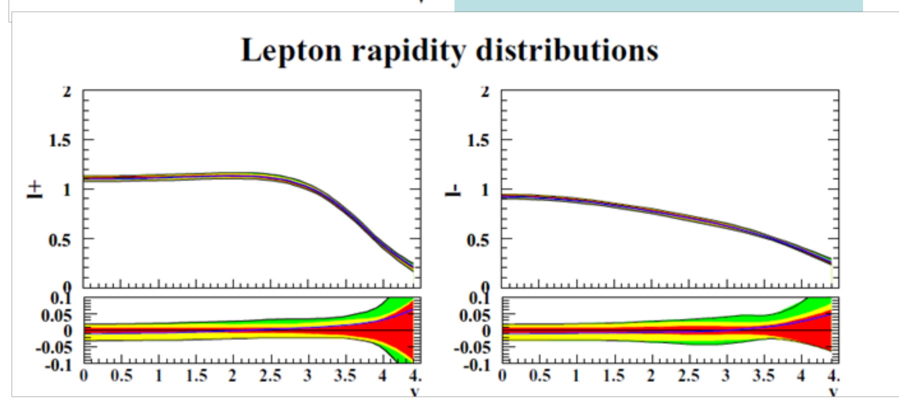


HERAPDF0.2 experimental plus model errors



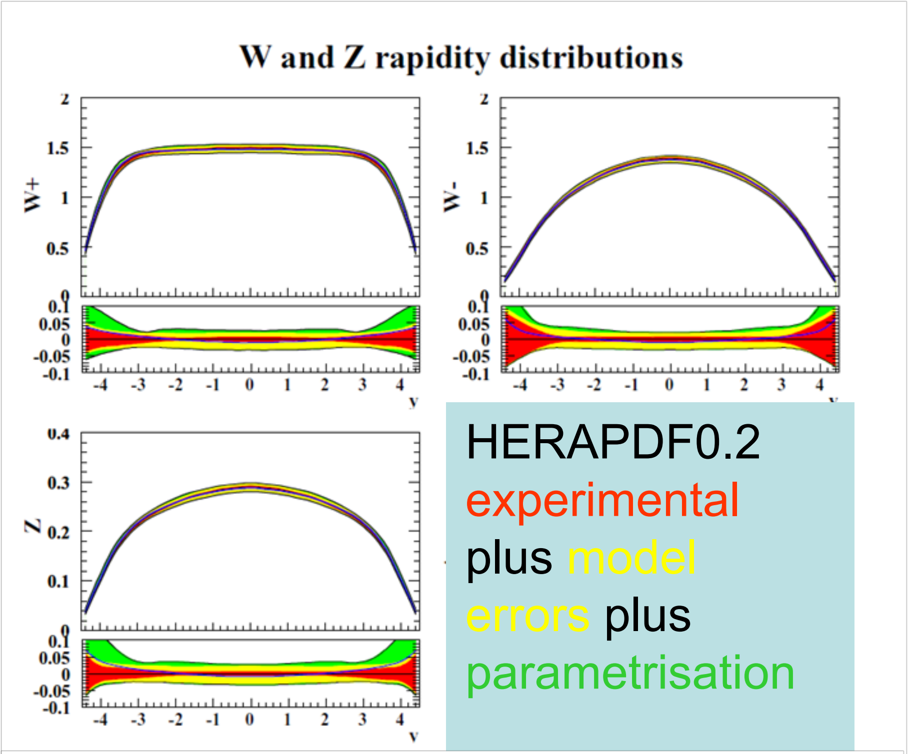
HERAPDF0.2 experimental plus model errors plus parametrisation





Now let's study HERAPDF0.2 parametrisation uncertainty- this affects at larger rapidity (mostly larger x) –will improve with HERA-II data

These illustrations at 14 TeV



HERAPDF0.2
experimental
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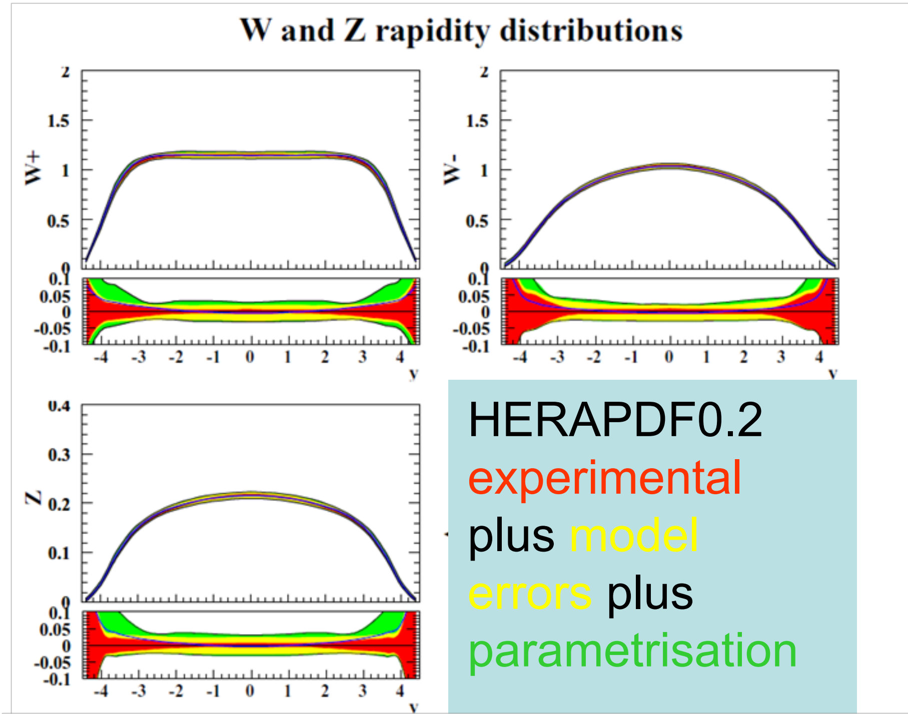

HERAPDF0.2
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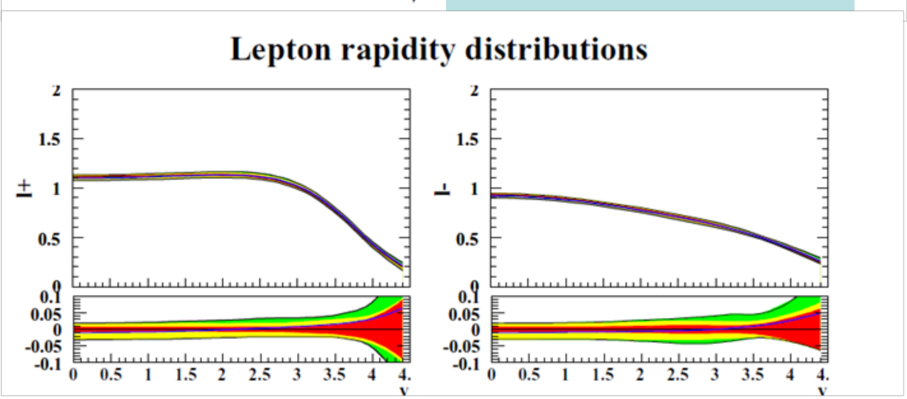
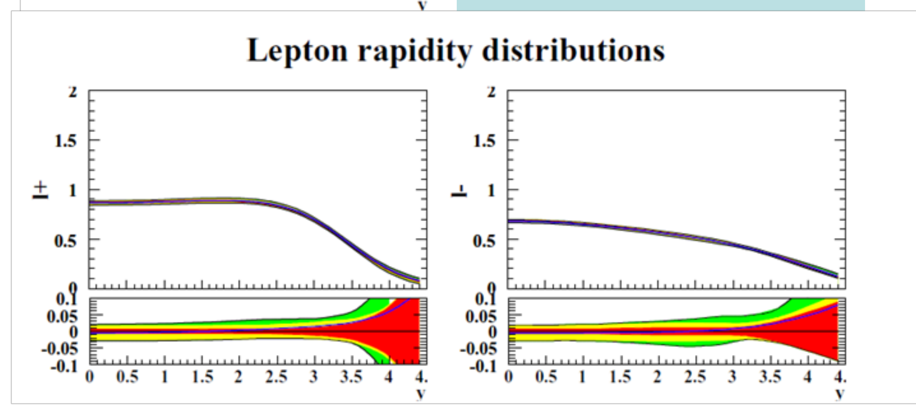
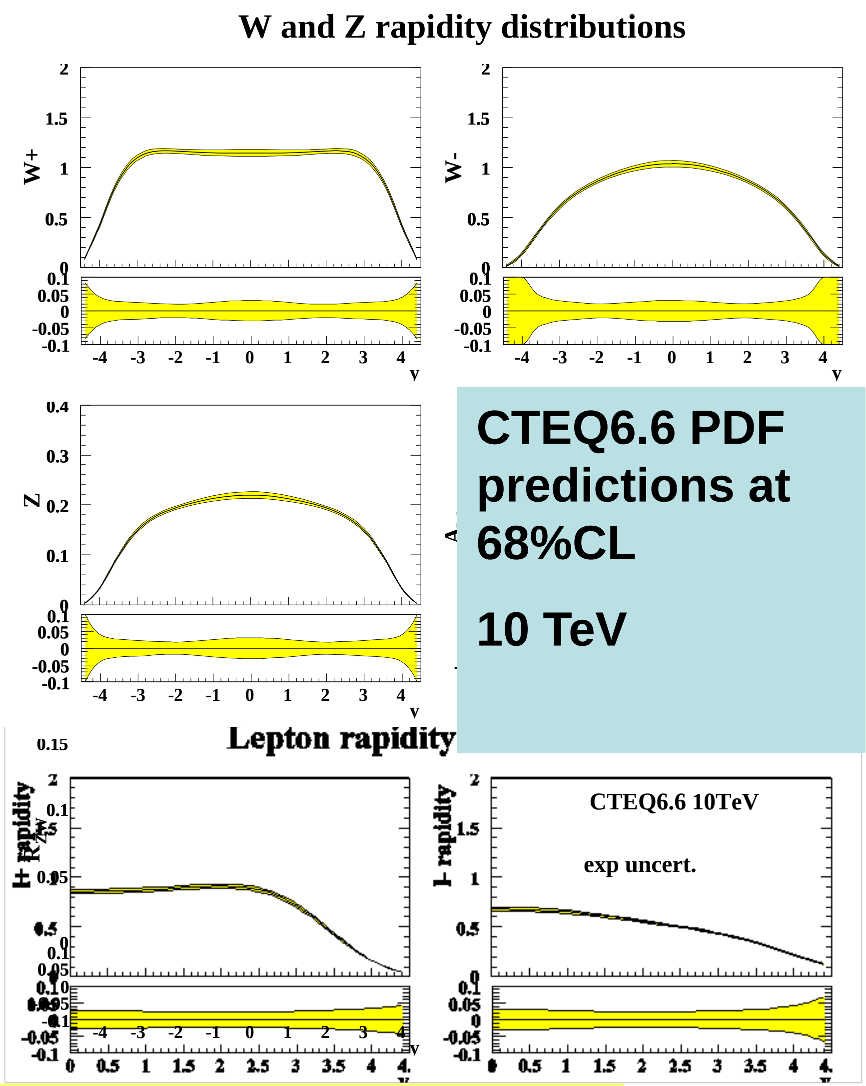




14 TeV

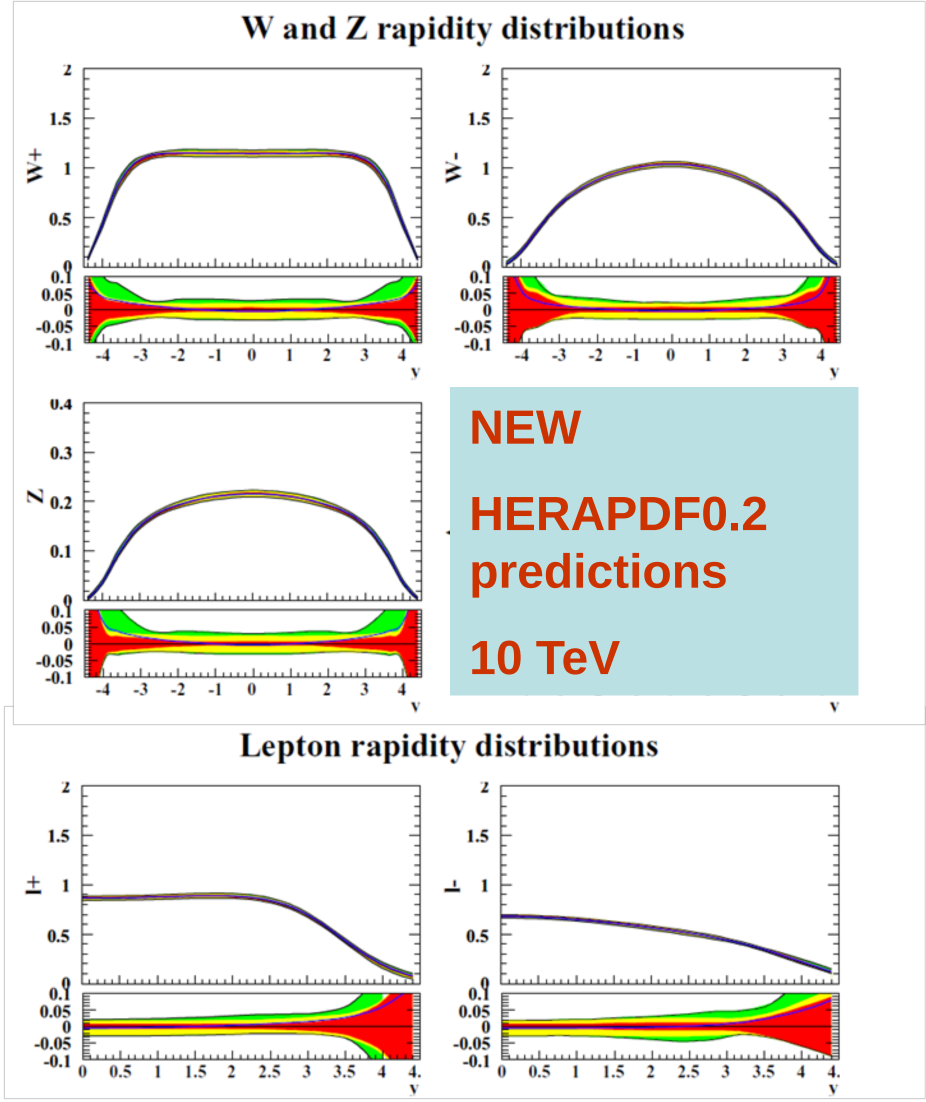
10 TeV

And one further point- the blue line on these plots illustrates the effect of variation of $\alpha_S(M_Z)$ from 0.1176 to 0.1196 .. Not a major source of uncertainty



CTEQ6.6 PDF predictions at 68%CL

10 TeV



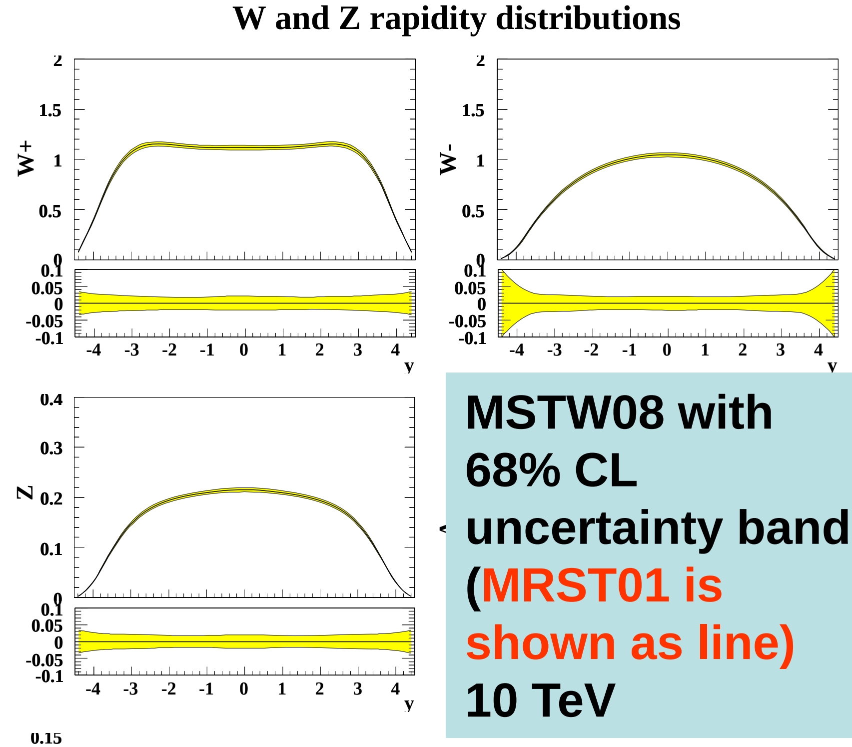
NEW

HERAPDF0.2 predictions

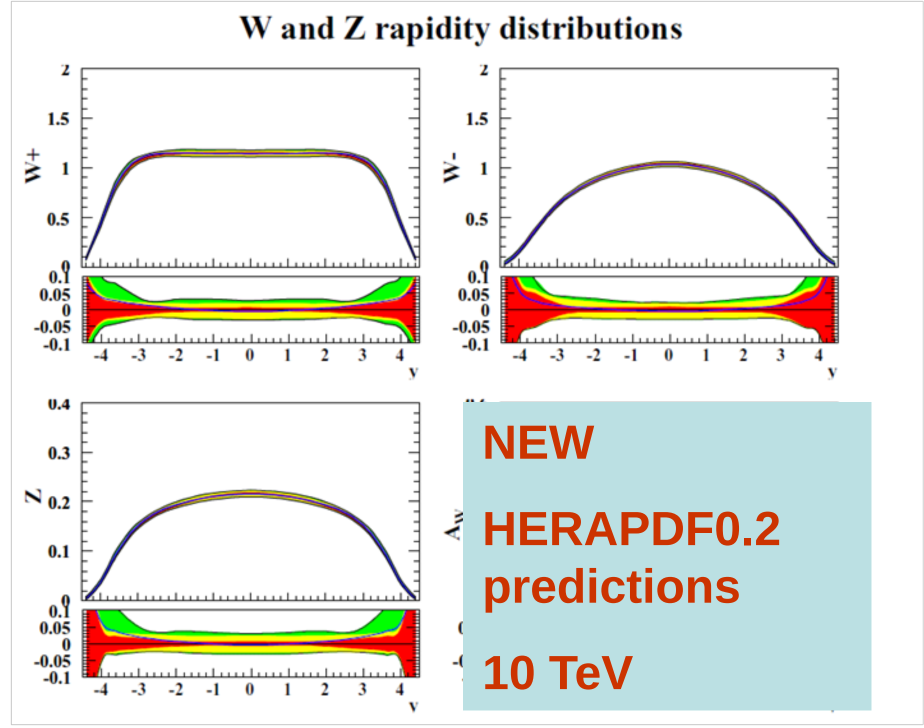
10 TeV

14 TeV plots in EXTRAS

HERAPDF0.2 predictions for W/Z and lepton rapidity spectra are compatible with those of CTEQ66 in central values. HERA experimental uncertainties are VERY small but model uncertainty and parametrisation uncertainty result in a similar overall level of uncertainty at central rapidity.



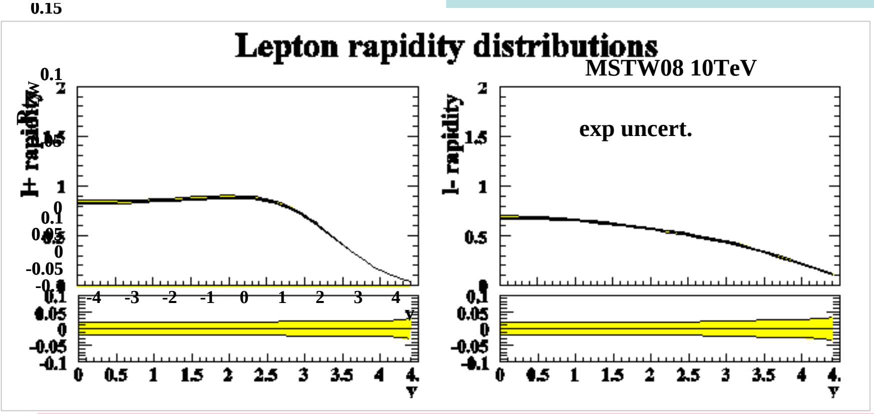
MSTW08 with 68% CL uncertainty bands (MRST01 is shown as line)
10 TeV

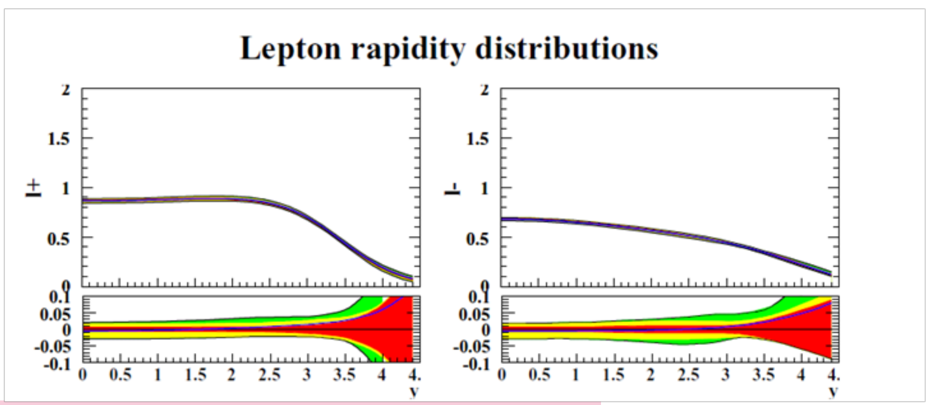


NEW

HERAPDF0.2 predictions

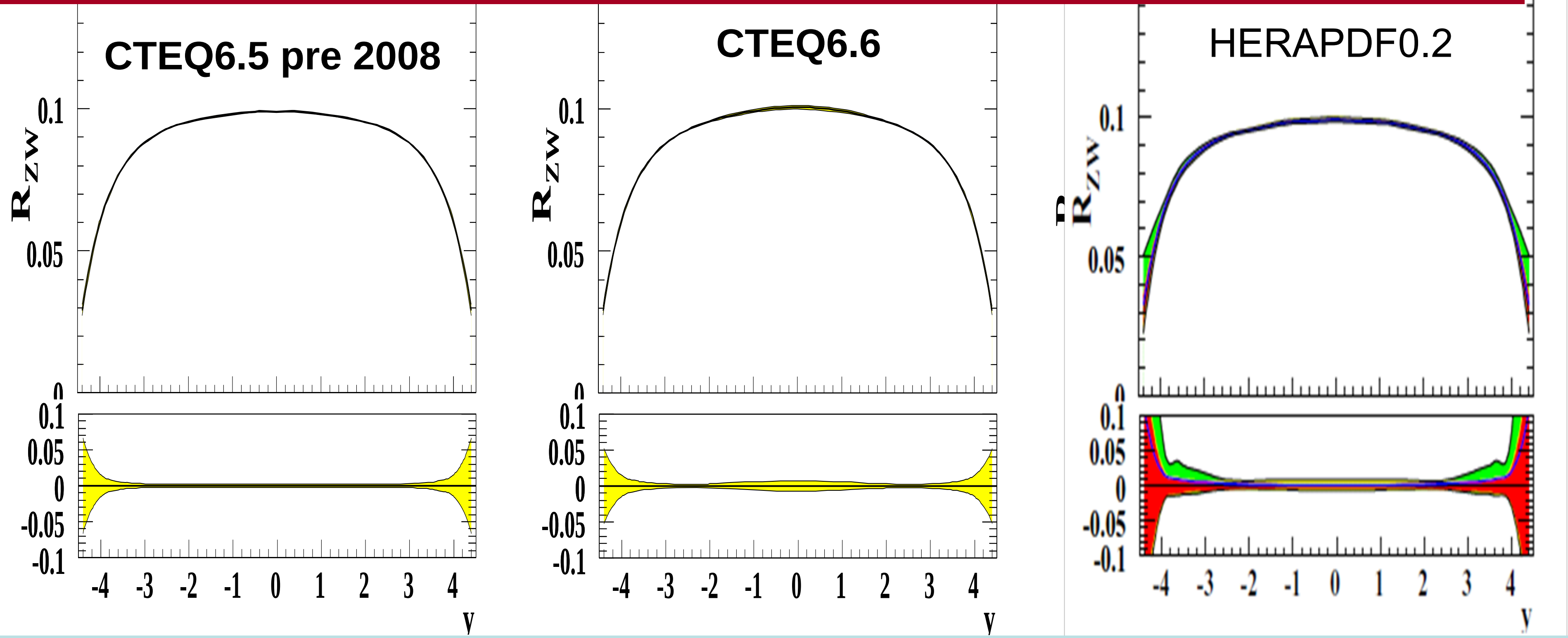
10 TeV





HERAPDF0.2 predictions for W/Z and lepton rapidity spectra are compatible with those of MSTW08 in central values. HERA experimental values are VERY precise but model dependence and parametrisation dependence are important

Now let's look at ratios: Z/W ratio is a golden benchmark measurement - 10TeV



ZOOM in on Z/W ratio – there is fantastic agreement between PDF providers
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YES this does translate to the Z/lepton ratio

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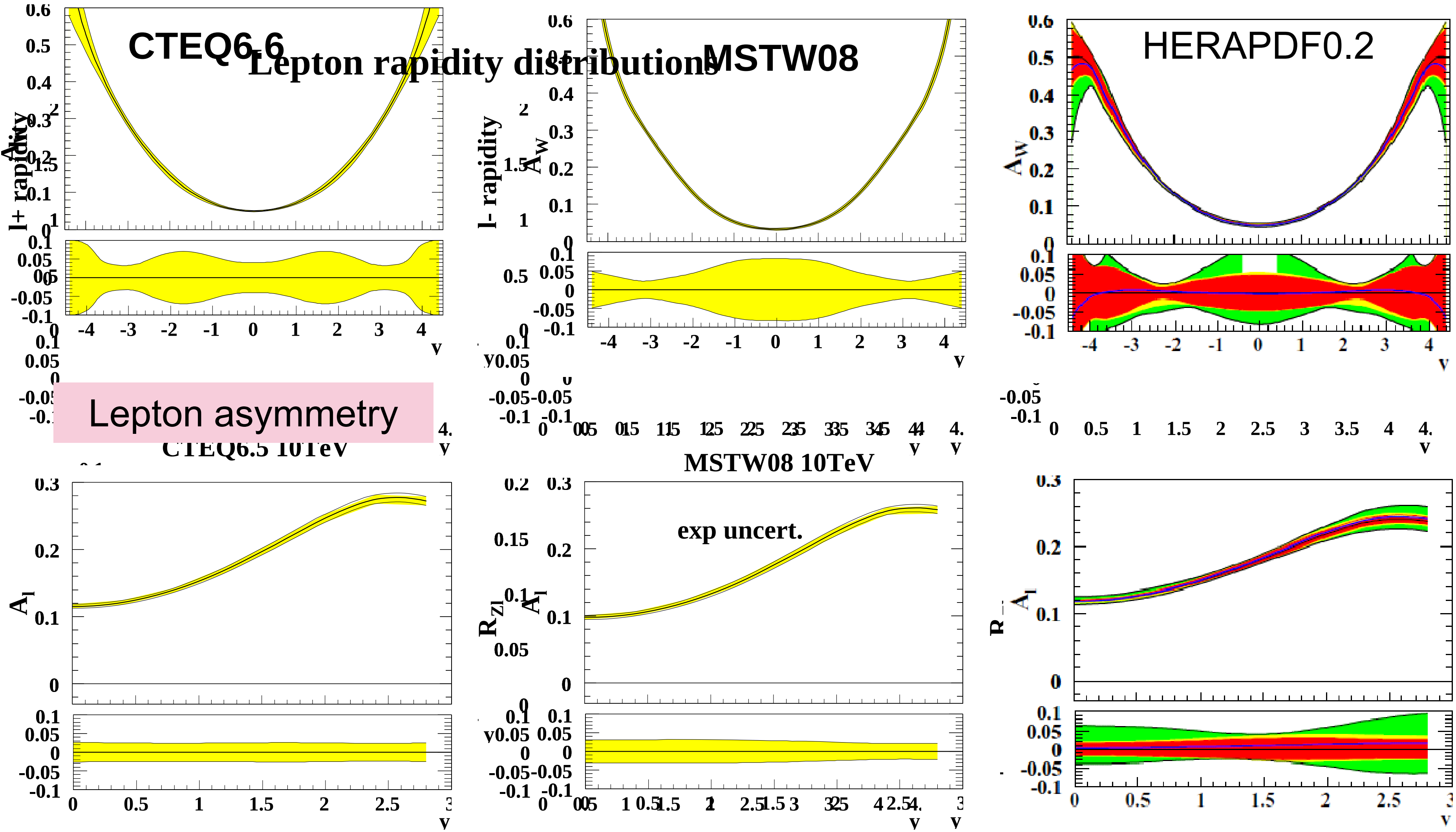


The differences between PDFs at central rapidity are due to different low-x valence behaviour – PDF uncertainties are probably underestimated

(Anyone who doubts this is coming from the valence-sector can look in EXTRAS)

Summary on WZ

Prediction of W/Z at LHC from HERAPDF0.2 based on optimal HERA data combination –sorts out experimental uncertainty from model uncertainty from parametrisation uncertainty

For W, Z and decay lepton rapidity spectra in the central region

1. Very small experimental uncertainty < 1%.
2. Model uncertainty ~2.5% from value of m_c and choice of Q^2_0
3. Parametrisation uncertainty <~2% (But larger at high rapidity)

HERA combination improves our ability to make precision SM predictions for the LHC

For Z/W ratio

1. Very small experimental uncertainty~1% and Very small model/param uncertainty in both Z/W ratio and Z/lepton ratio~1-2

Golden SM benchmark measurement

For W asymmetry

- Experimental uncertainty~5%. Remaining model/parametrisation uncertainty in W and lepton asymmetry can be even larger
- LHC measurements will increase our knowledge of PDFS

extras

Dominantly, at LO y=0

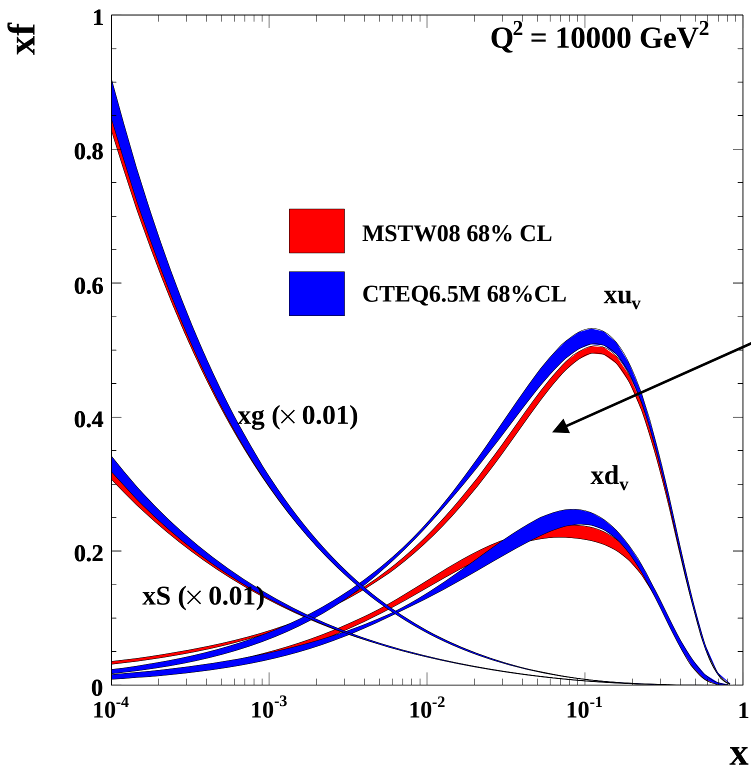
$$A_W = \frac{(u\,\bar{d} - d\,\bar{u})}{(u\,\bar{d} + d\,\bar{u})}$$

Predictions for AW are different in the central region- because predictions for valence distributions at small-x are different

And ubar ~ dbar ~ qbar at small x

$$\text{So } A_W \sim \frac{(u - d)}{(u + d)} = \frac{(u_v - d_v)}{(u_v + d_v + 2\,\bar{q})}$$

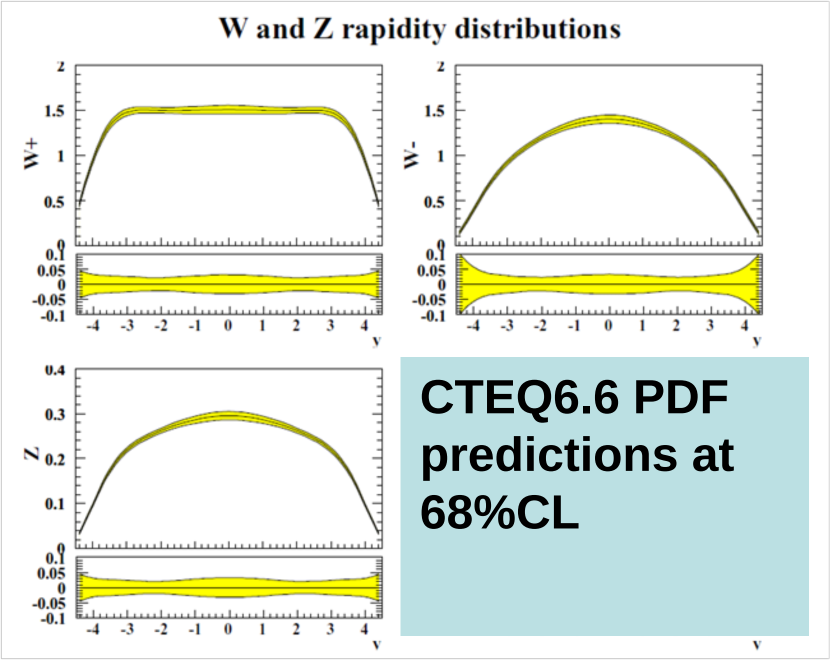
Actually this LO approx. is pretty good even quantitatively
The difference in valence PDFs you see here does explain the difference in A_W between MSTW and CTEQ



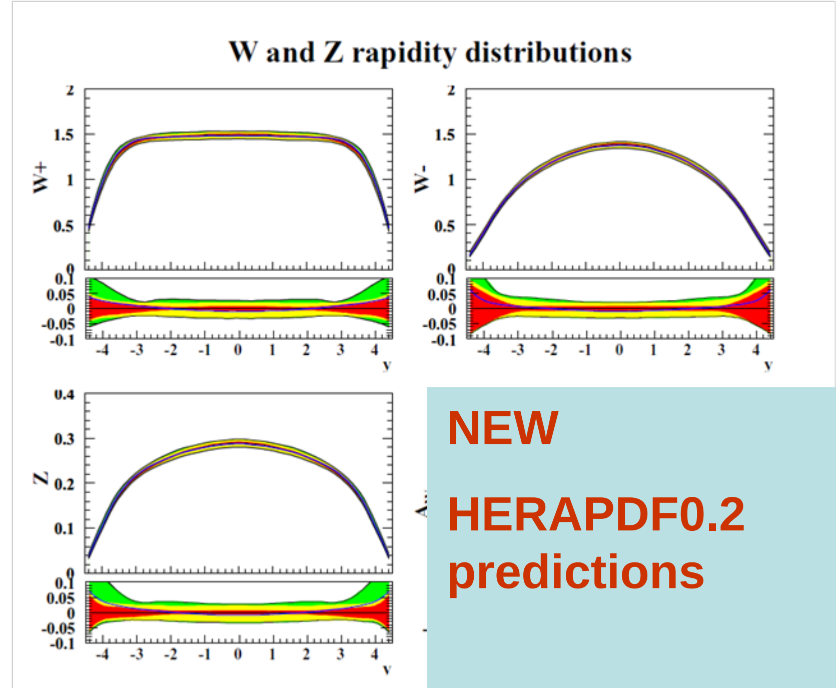
x- range affecting W asymmetry in the measurable rapidity range at ATLAS (10TeV)

14 TeV W,Z xsecn table

PDF set	$\sigma_{W+} B_{W\to l\nu}$ (nb)	$\sigma_{W-} B_{W\to l\nu}$ (nb)	$\sigma_{Z} B_{Z\to ll}$ (nb)
ZEUS-2005	11.87±0.45	8.74±0.31	1.97±0.06
MSTW08	11.97±0.22	9.04±0.16	1.98±0.035
CTEQ66	12.34±0.34	9.06±0.22	2.02±0.04
HERAPDF01	**12.13±0.13**	**9.13±0.15**	**2.01±0.025**
HERAPDF02	**12.11±0.08**	**9.06±0.05**	**2.00±0.012**
CTEQ61	11.61±0.34	8.54±0.26	1.89±0.055
NNPDF1.0	11.83±0.26	8.41±0.20	1.95±0.04

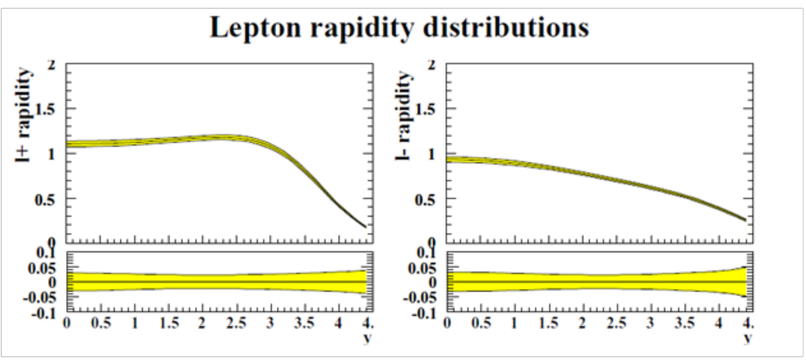


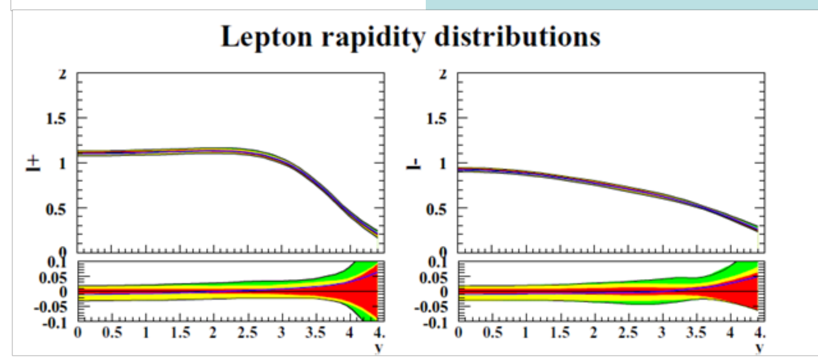
CTEQ6.6 PDF predictions at 68%CL



NEW

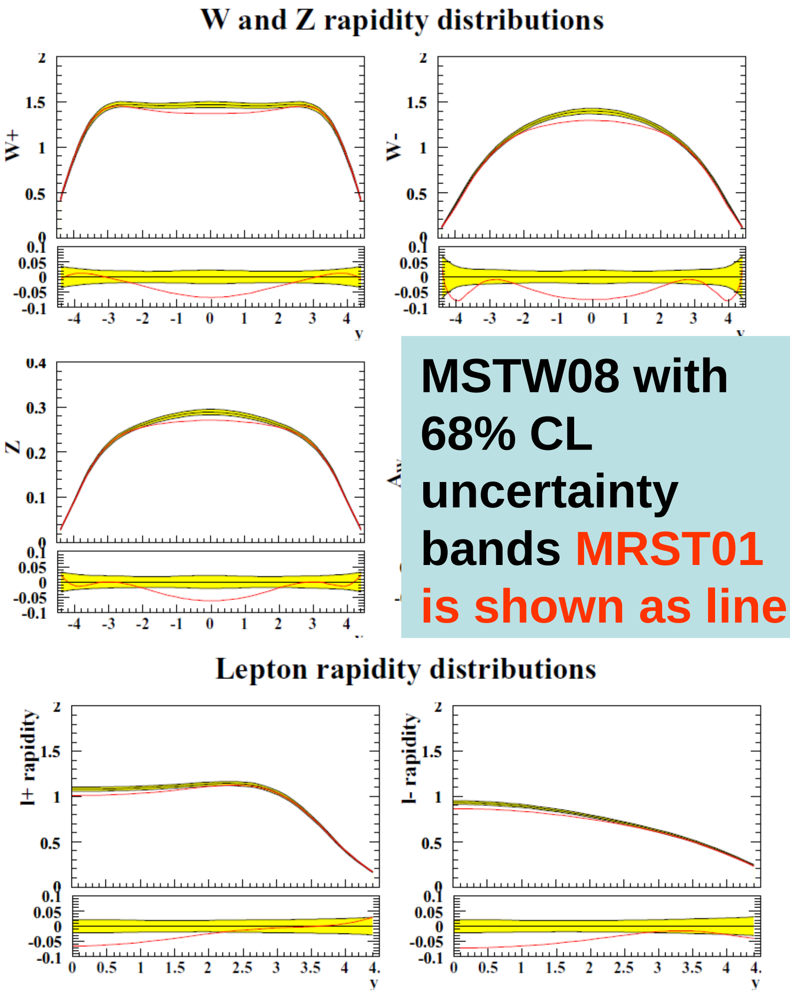
HERAPDF0.2 predictions



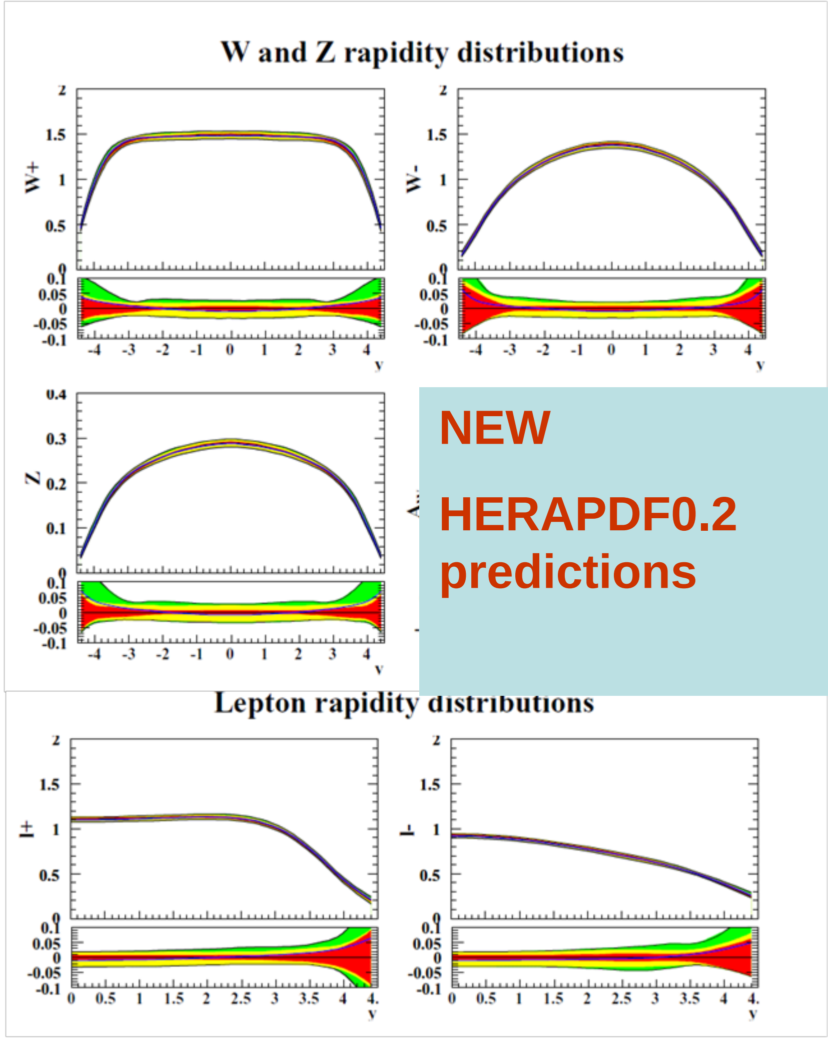


HERAPDF0.2 predictions for W/Z and lepton rapidity spectra are compatible with those of CTEQ66 in central values. HERA experimental values are VERY precise but model dependence and parametrisation dependence result in a similar overall level of uncertainty at central rapidity.

These illustrations at 14 TeV



MSTW08 with 68% CL uncertainty bands MRST01 is shown as line



NEW

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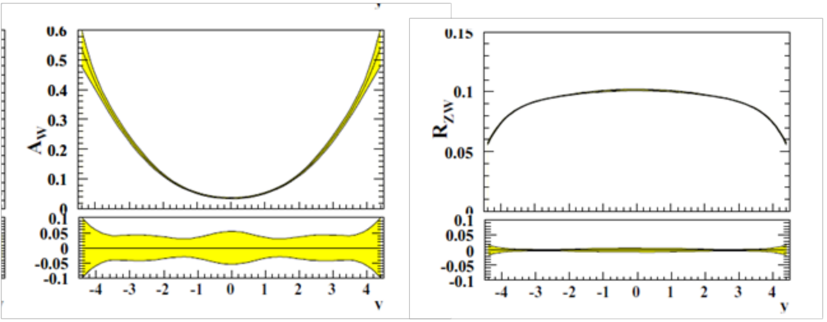
W asymmetry and Z/(W+ + W-) ratio



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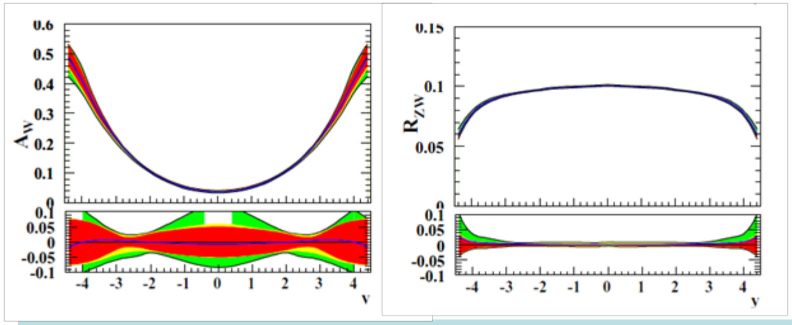
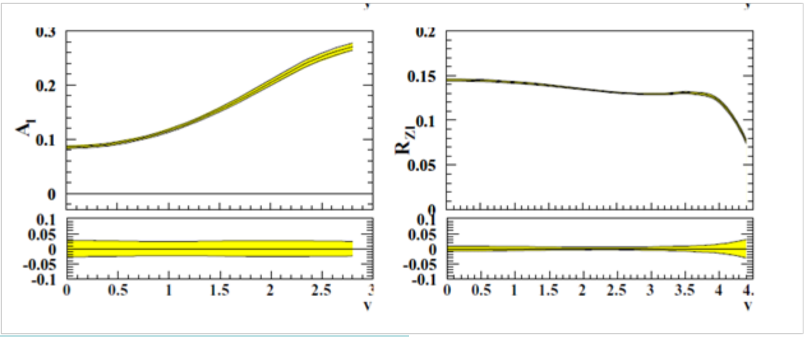


lepton asymmetry and Z/(leptons) ratio



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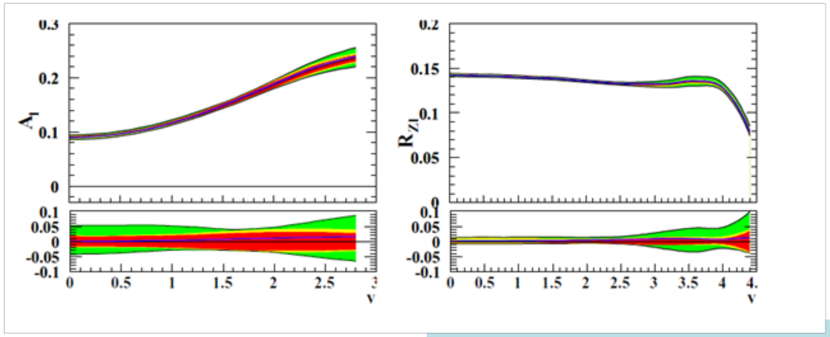

CTEQ6.6PDF predictions 68%CL

NEW

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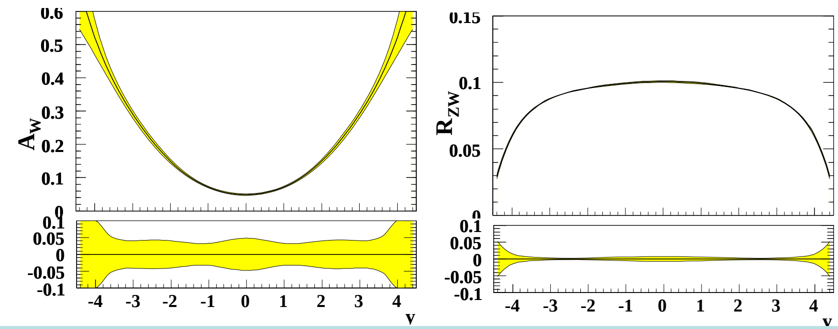

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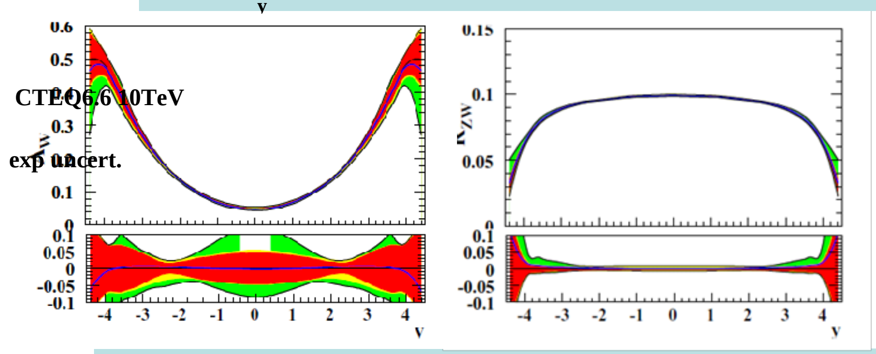

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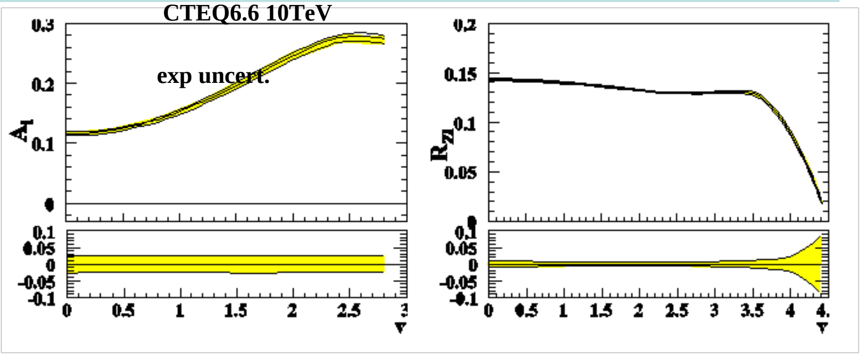

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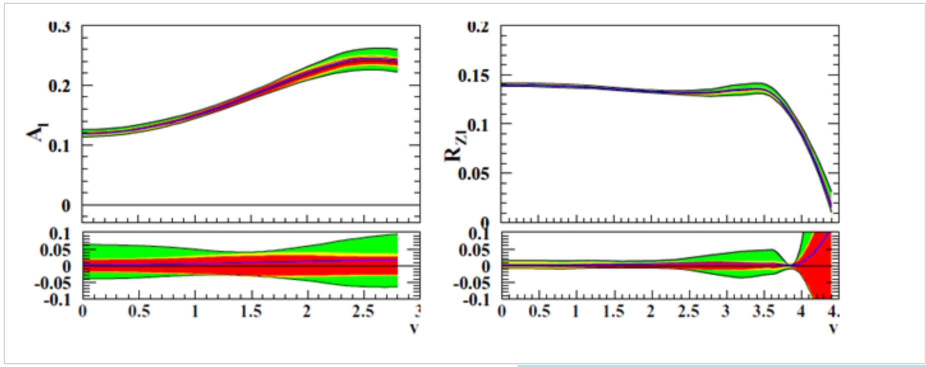

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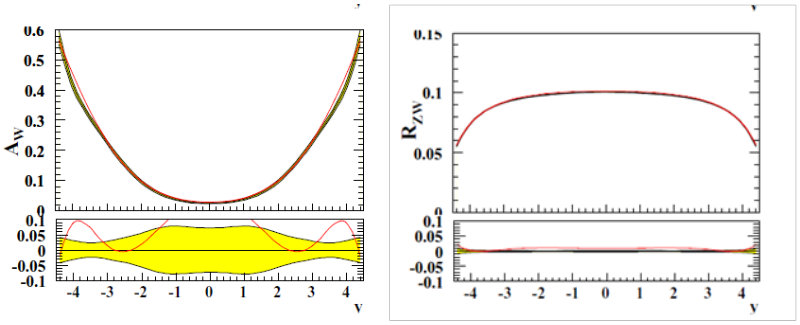

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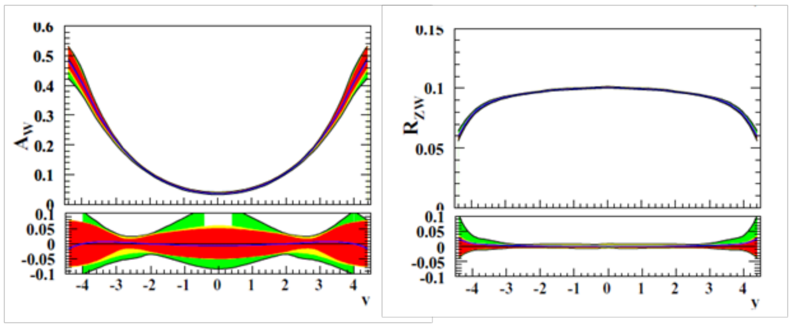

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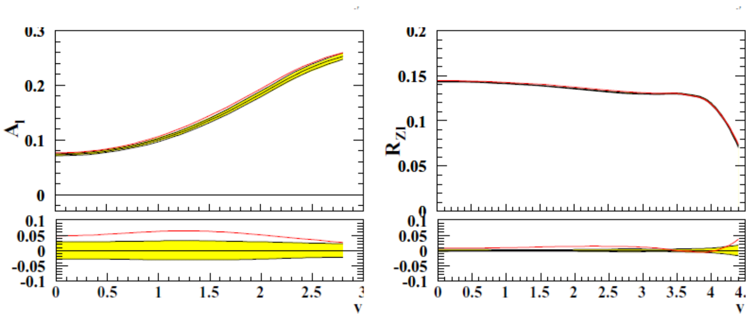

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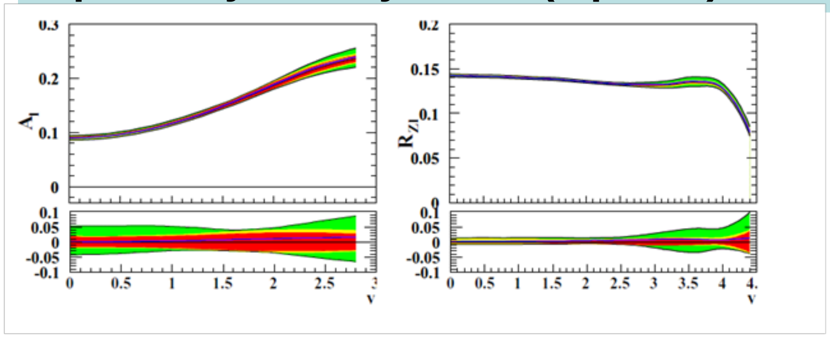

MSTW08 PDF predictions 68%CL

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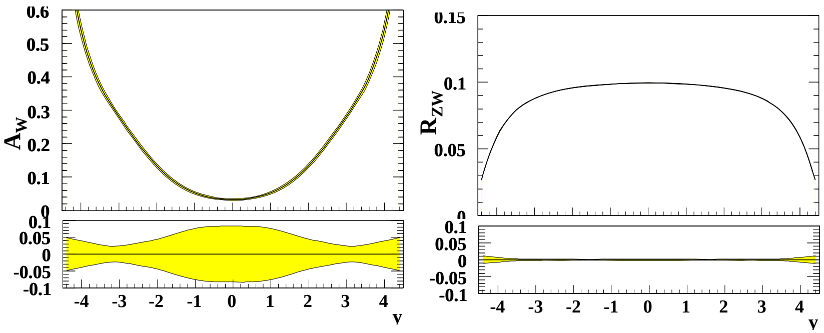

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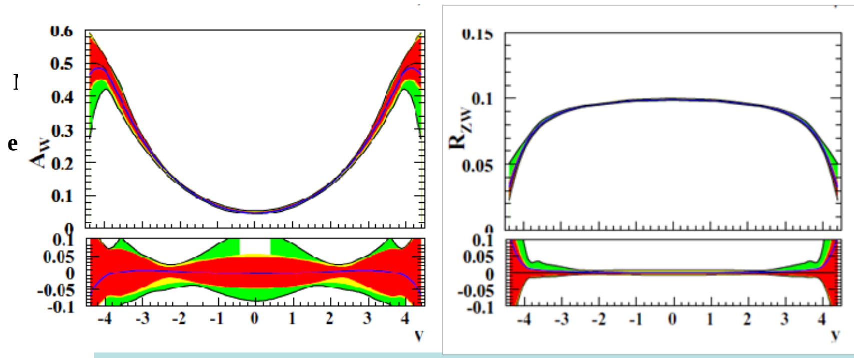

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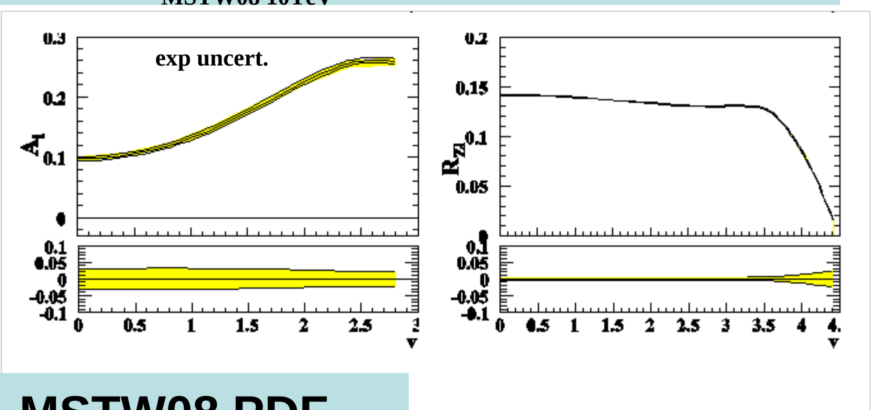

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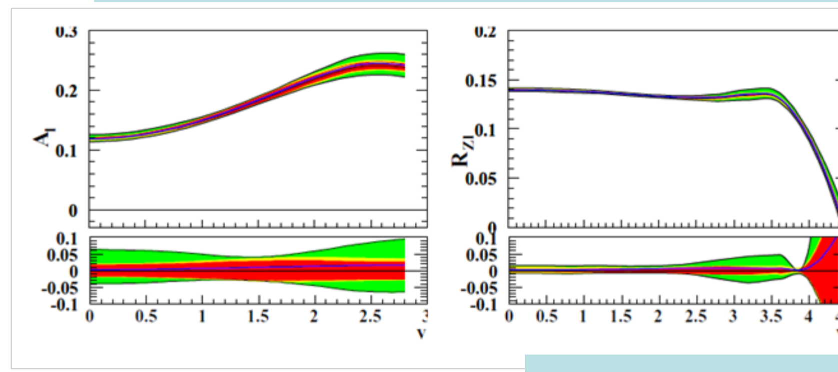

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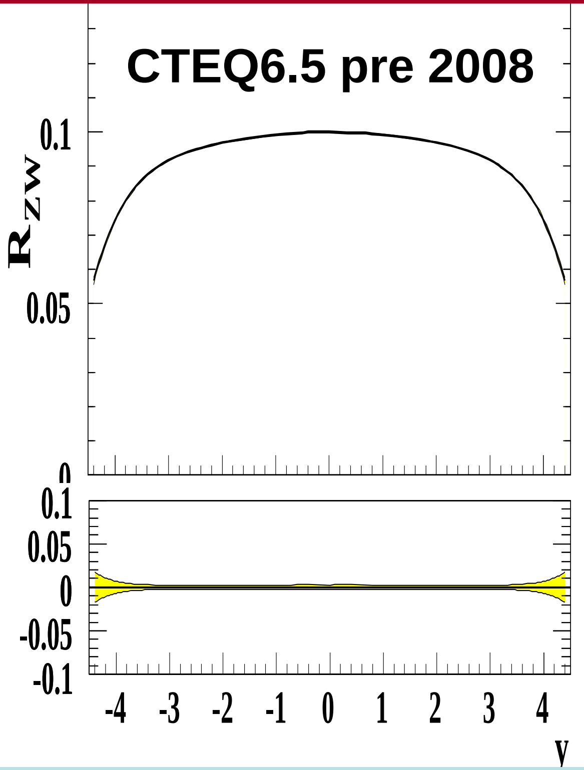

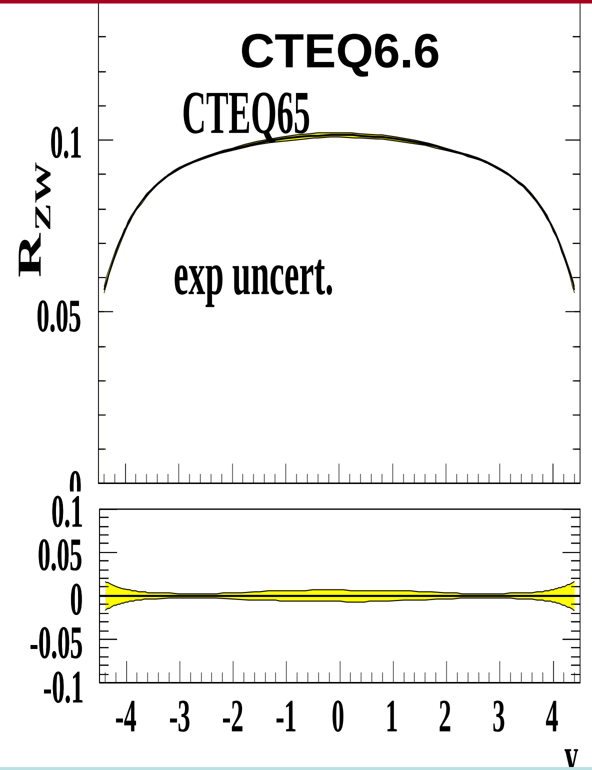

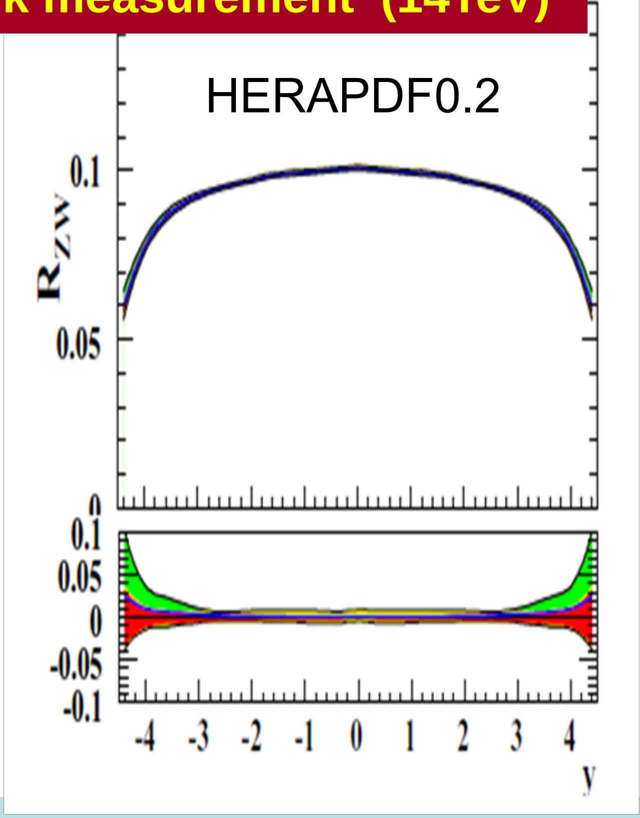

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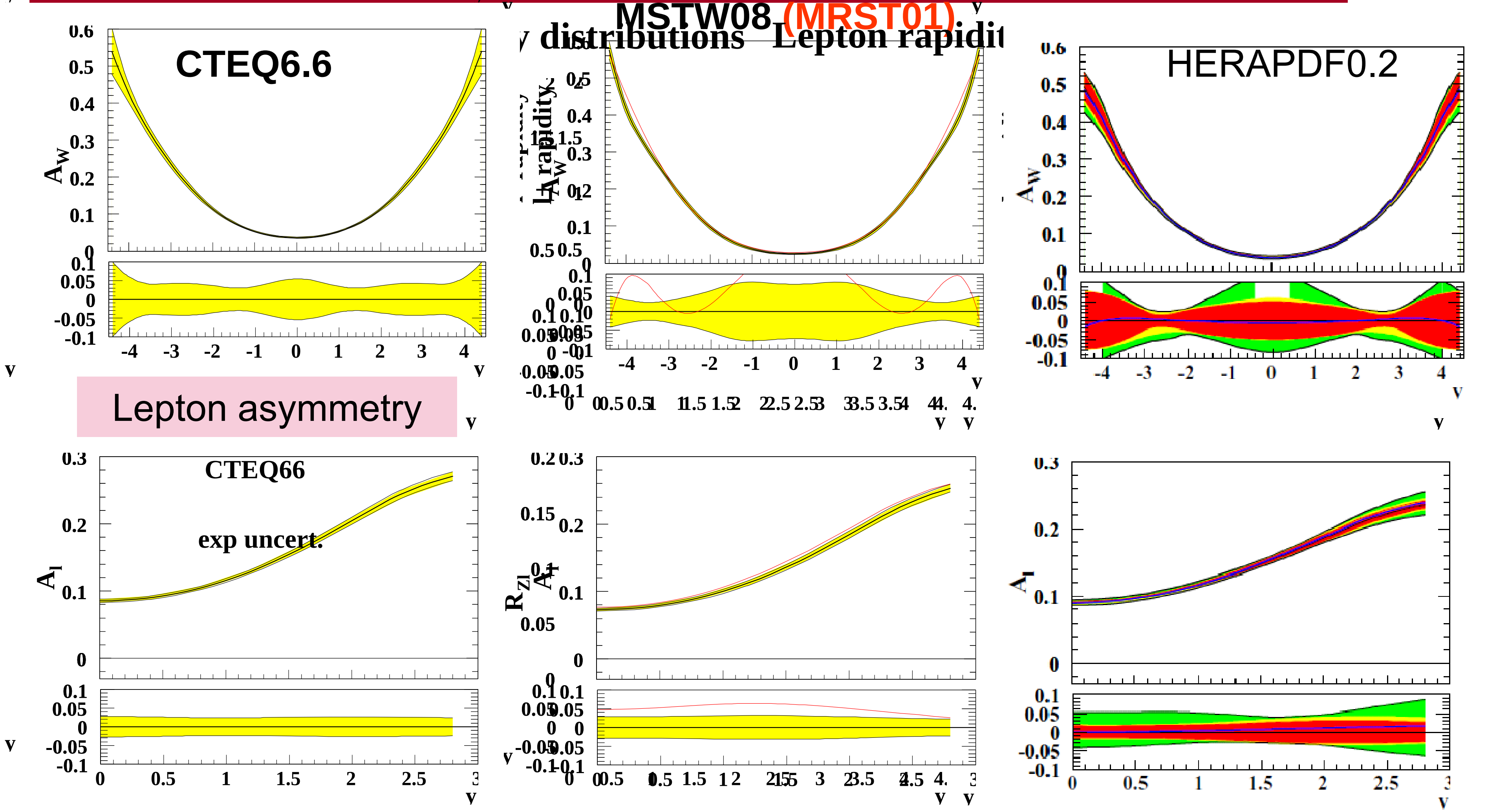

Further sources of PDF uncertainty from the valence sector are revealed.

CTEQ66

exp uncert.

MSTW08

exp uncert.

MRST01