HERA-LHC w/shop 2008
PDF4LHC session

A M Cooper-Sarkar and Emmanuelle Perez

The PDF fit to the HERA combined data set (see talk of G.Li) is to be released and called HERAPDF0.1

In this talk we look at predictions for W/Z production at the LHC from this HERAPDF0.1

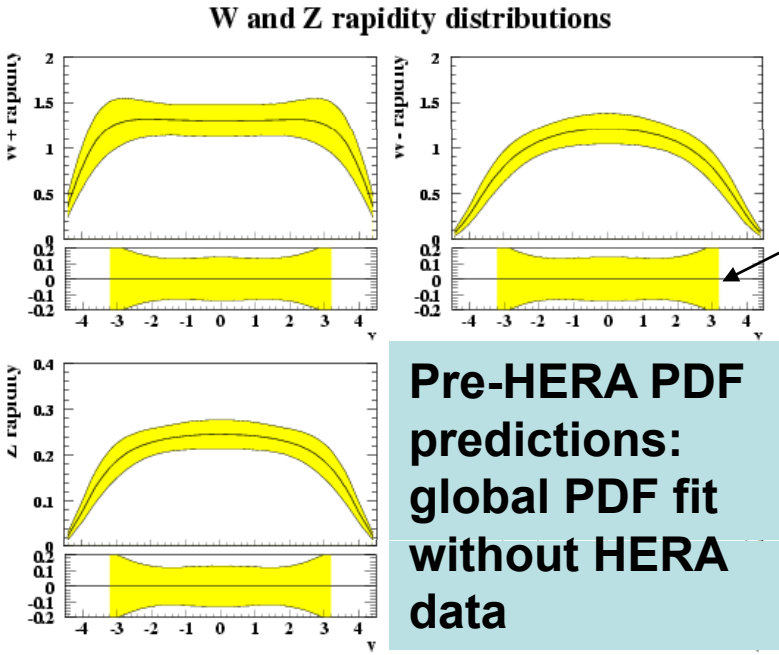
AMCS predictions are done analytically using code of James Stirling for the NLO corrections and the W → lepton decays.

Compare to E. Perez predictions for lepton spectra using MCFM

- W/Z and lepton rapidity spectra
- W asymmetry AW = (W+ - W-)/(W+ + W-), lepton asymmetry
- Z/(W+ + W-) ratio and Z/(leptons) ratio

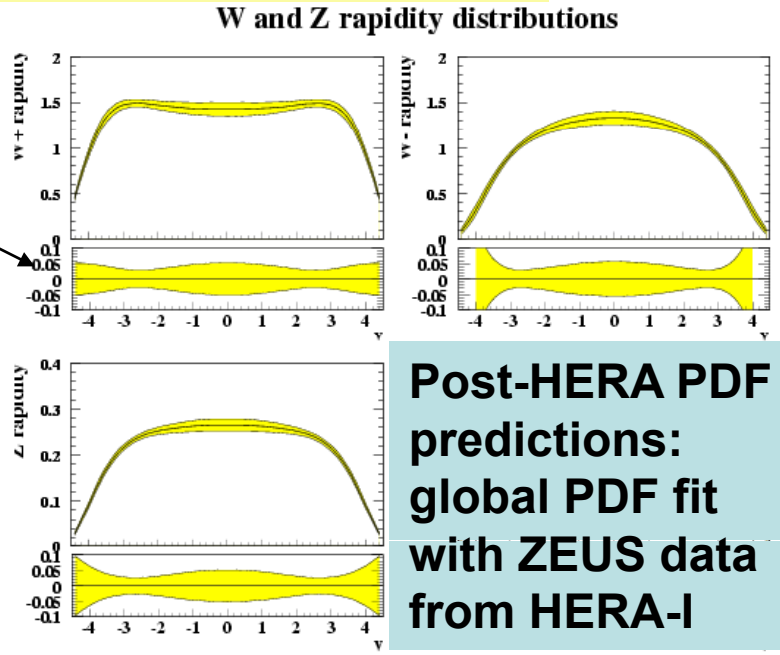
Compare to other PDFs CTEQ, MRST

What has HERA data ever done for us? A little history…

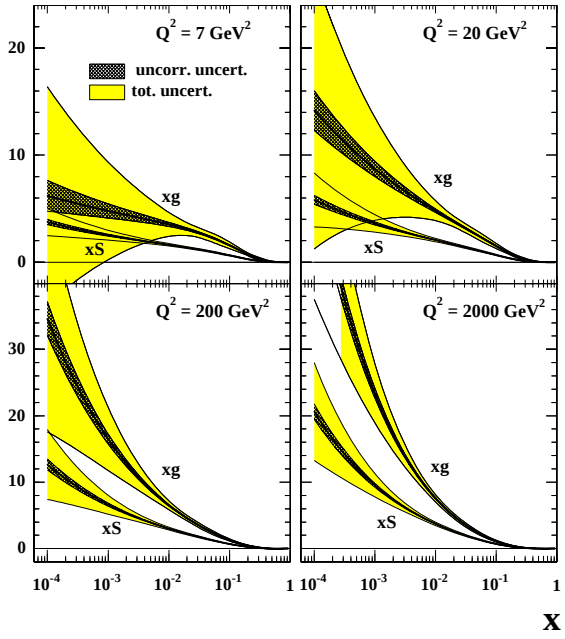


Note difference in scale for fractional errors

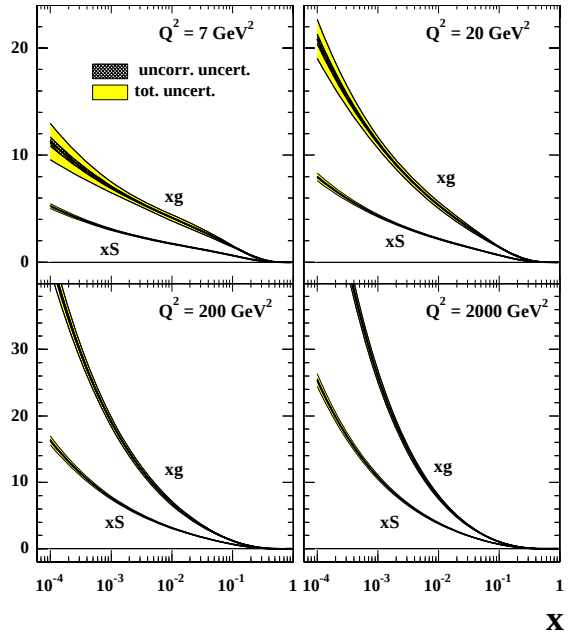
Pre-HERA PDF predictions: global PDF fit without HERA data



Post-HERA PDF predictions: global PDF fit with ZEUS data from HERA-I

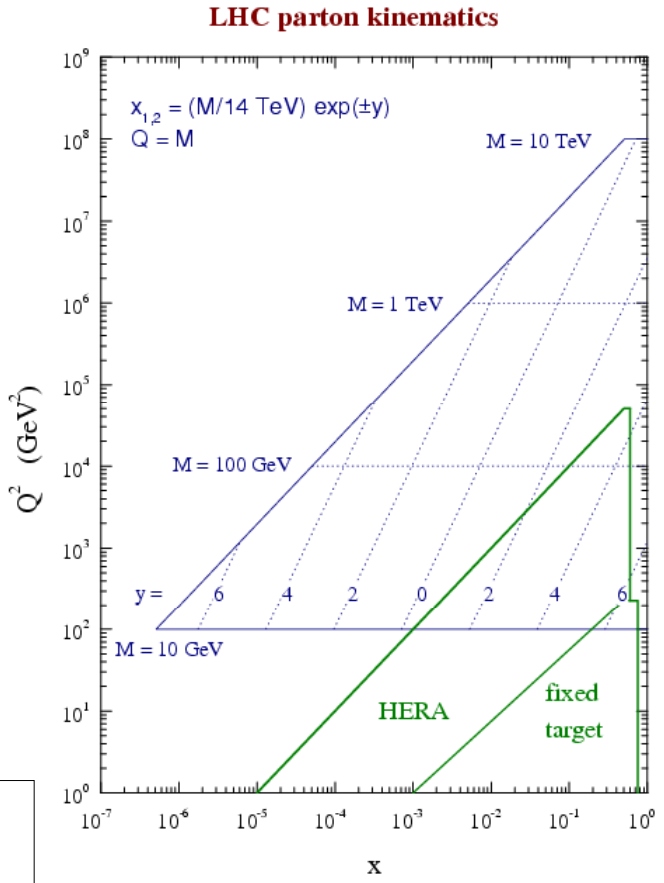


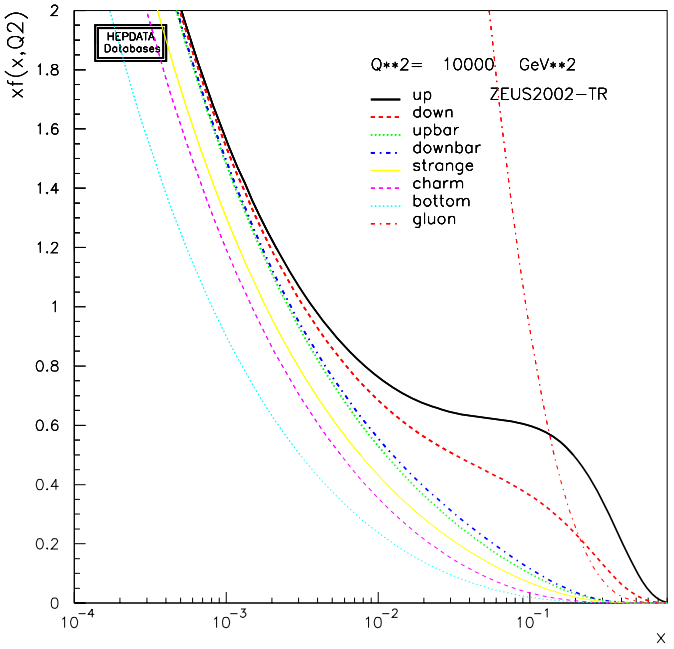
WHY? Because of the tremendous improvement in our knowledge of the gluon at low scale



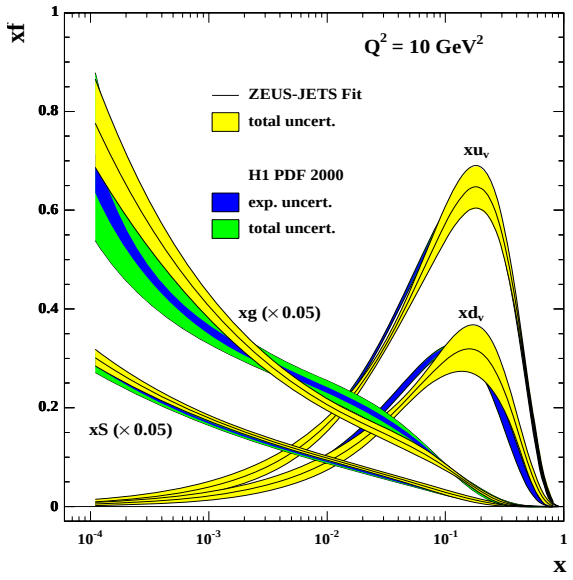
HERA data brings a HUGE improvement to the predictions of the W, Z cross-sections because of the improvement in knowledge of the low-x gluon

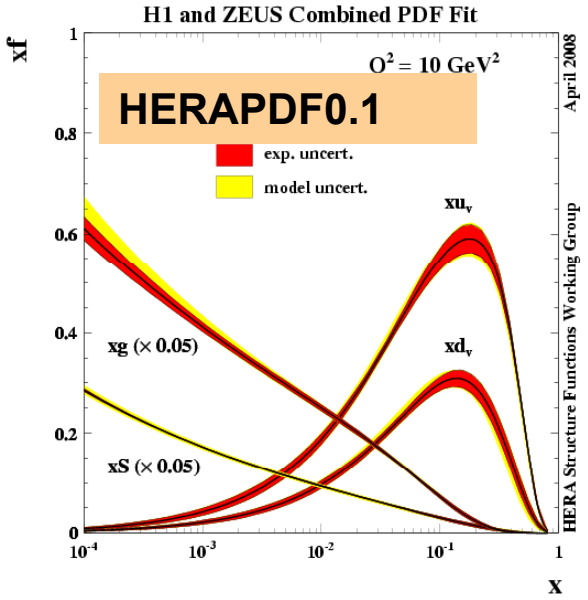
At high scale ($Q^2=M_W^2$), in the central rapidity region, the W+ (and W-, Z) are mostly produced by low-x sea q-qbar collisons. These q-qbar are produced from the gluon by g→qqbar splitting as PDFs evolve. Hence it is the uncertainty on the gluon at low-scale ($Q^2=Q_0^2$) which feeds into the uncertainty on these cross-sections.

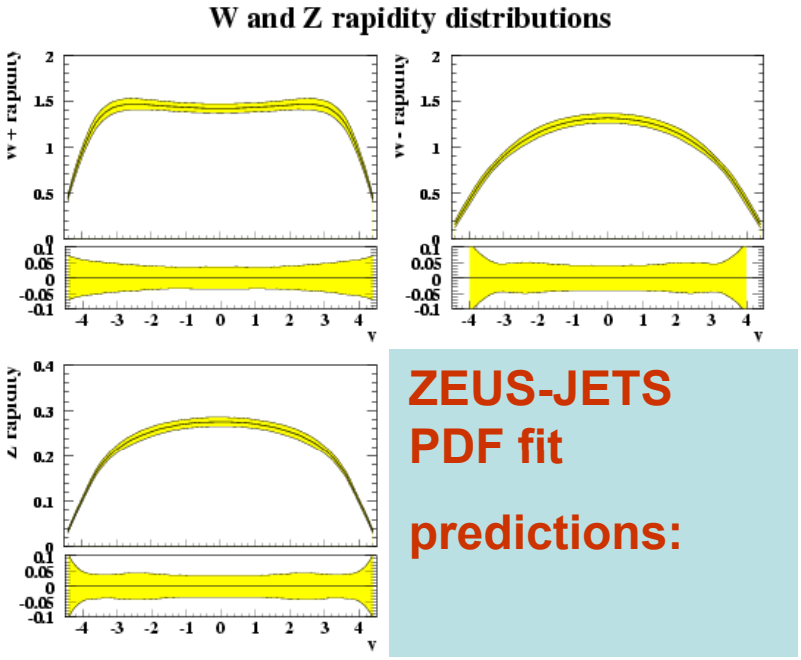




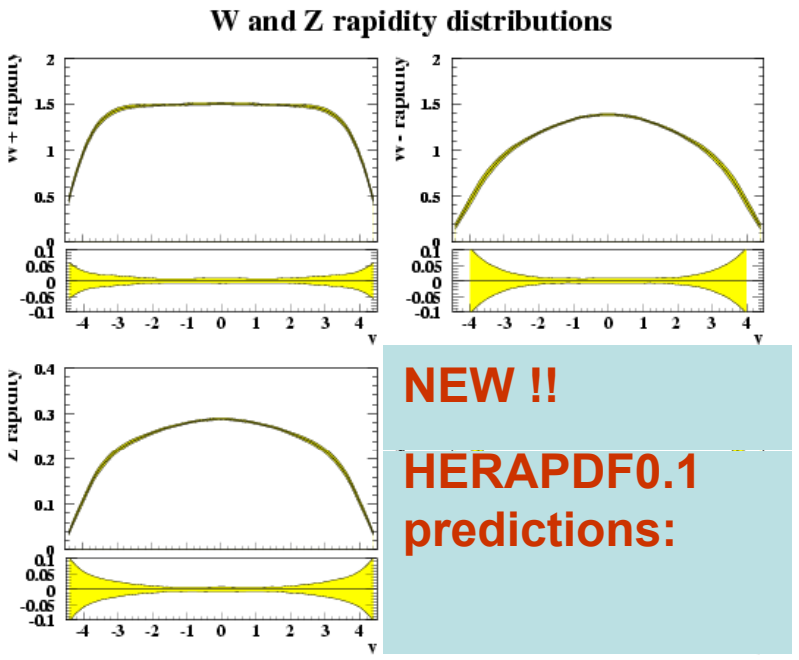
And we have just seen another dramatic improvement in our knowledge of the low-x gluon from the combined HERAPDF0.1







ZEUS-JETS PDF fit predictions:

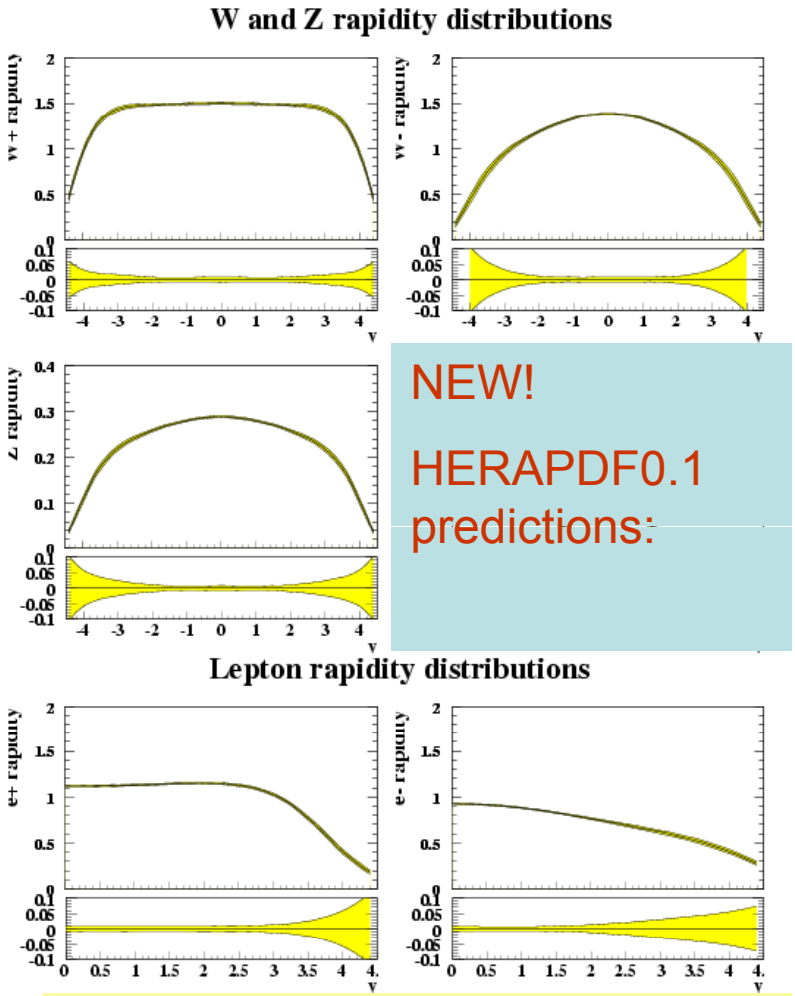


NEW !!

HERAPDF0.1 predictions:

Compare to other PDF predictions for W/Z production at the LHC

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
MRST01	11.61±0.23	8.62±0.16	1.95±0.04
HERA-I	**12.13±0.13**	**9.13±0.15**	**2.01±0.025**
CTEQ65	12.47±0.47	9.14±0.36	2.03±0.07
CTEQ61	11.61±0.56	8.54±0.43	1.89±0.09



NEW!

HERAPDF0.1 predictions:

The new predictions are very precise ~1.5% error in the central region

But wait.. this does NOT have model dependence

Remember we will actually measure lepton spectra not W.
Lepton +, lepton- spectra retain similar features to the W+, W-
(lepton pt cut > 25 GeV)

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)
HERA-I	**12.13±0.13**	**9.13±0.15**	**2.01±0.025**
fs=0.25	12.12	9.09	2.00
fs=0.4	12.15	9.16	2.02
fc=0.10	12.26	9.23	2.04
fc=0.20	12.00	9.03	1.99
Q^2_{min}=2.5	12.13	9.12	2.01
Q^2_{min}=5.0	12.17	9.17	2.01
Q^2_0=2	11.77	8.85	1.95
Q^2_0=6	12.37	9.29	2.06
α_s=0.1156	12.02	9.01	1.98
α_s=0.1196	12.26	9.19	2.04
Humpy param	11.95	9.00	1.98
Zeus param	12.45	9.36	2.07

Model dependences

Varying mc and mb (not shown) gives results well within errors, similarly for fs

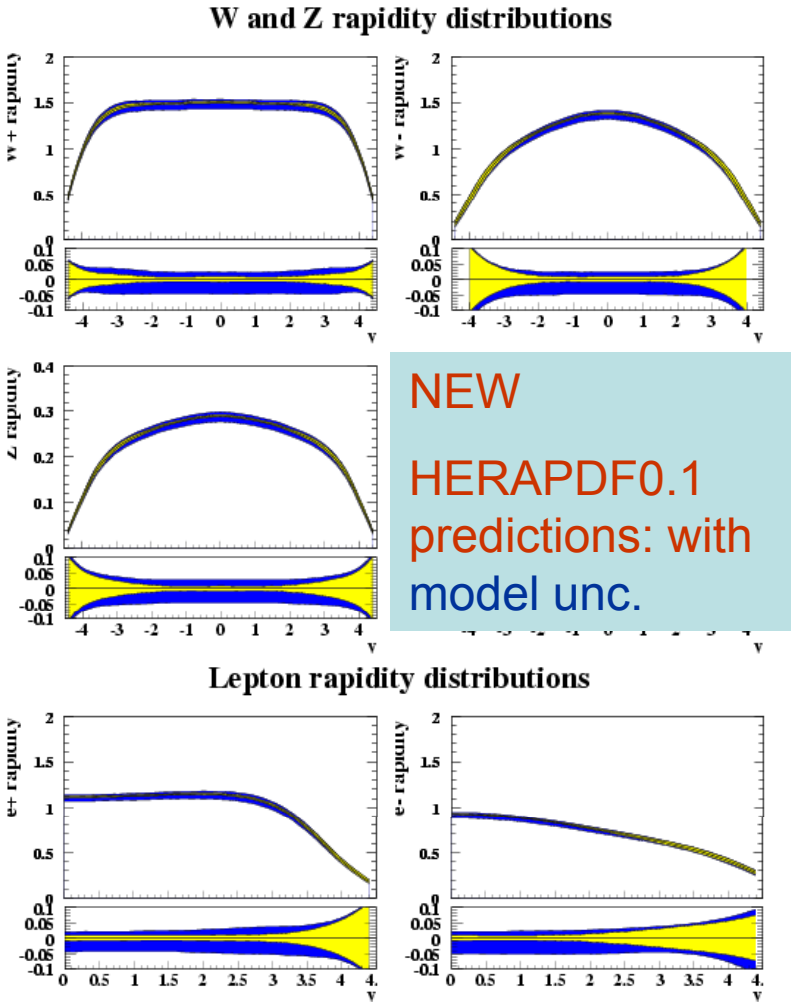
fc variation is just within errors

Q2min variation is well within errors

Q2_0 variation is the biggest effect

Varying αs is just within errors

Varying the parametrization is also significant



NEW

HERAPDF0.1 predictions: with model unc.

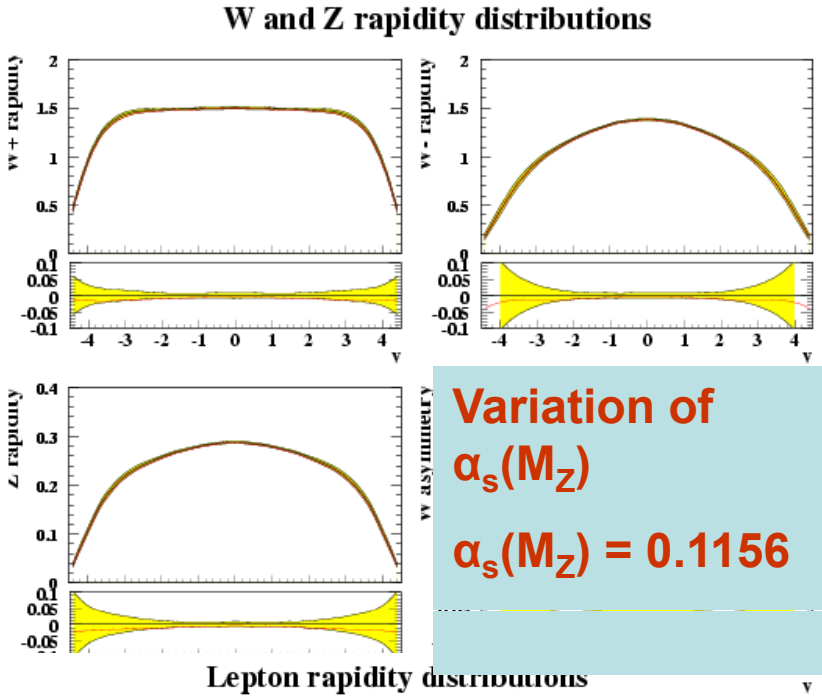
Let's look at model dependence as a function of y:

Experimental uncertainty in yellow

Model uncertainty in blue from:

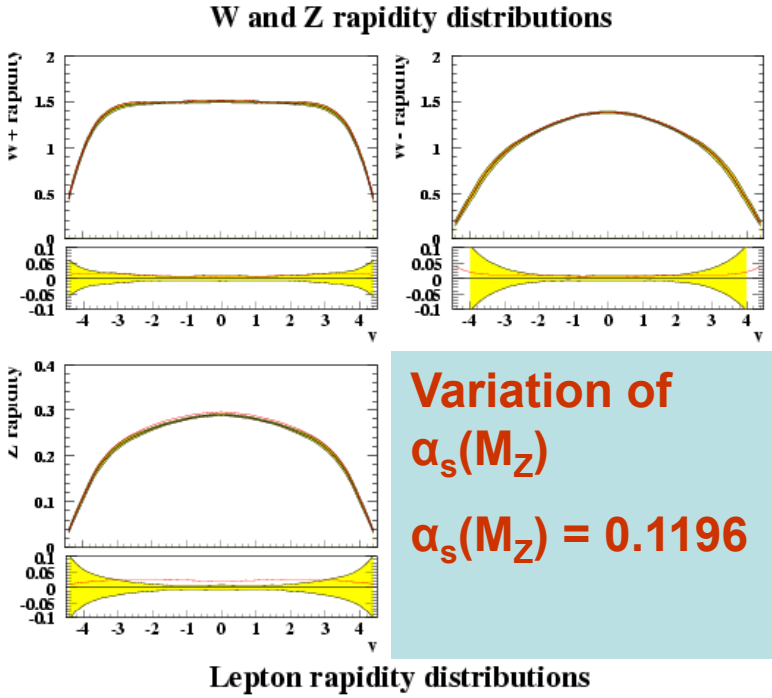
Q^2_0, Q^2_{min}, fs, fc, mb, mc

Variation of Q^2_0 is the most significant model uncertainty in the measurable range



Variation of $\alpha_s(M_Z)$

$\alpha_s(M_Z) = 0.1156$



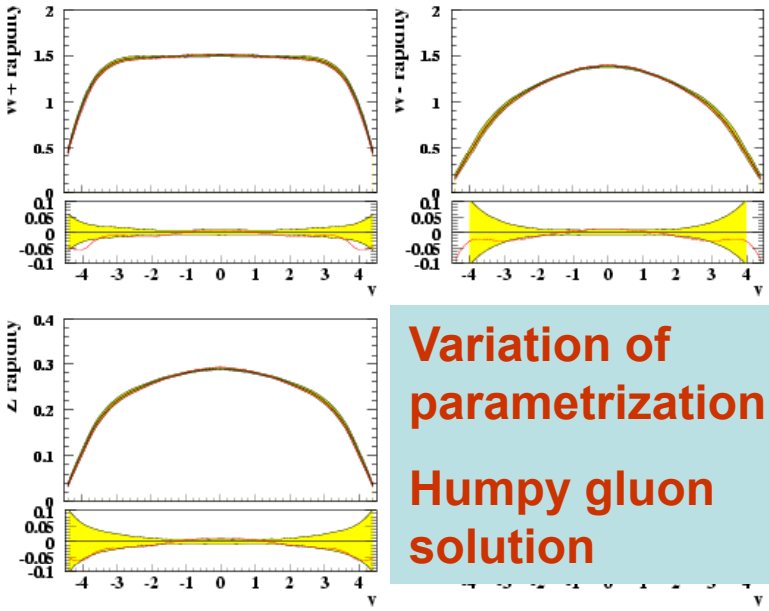
Variation of $\alpha_s(M_Z)$

$\alpha_s(M_Z) = 0.1196$

Consider other variations:

Variation of $\alpha_s(M_Z)$ from central value $\alpha_s(M_Z) = 0.1176$ is not a big effect, but can see seen in Z

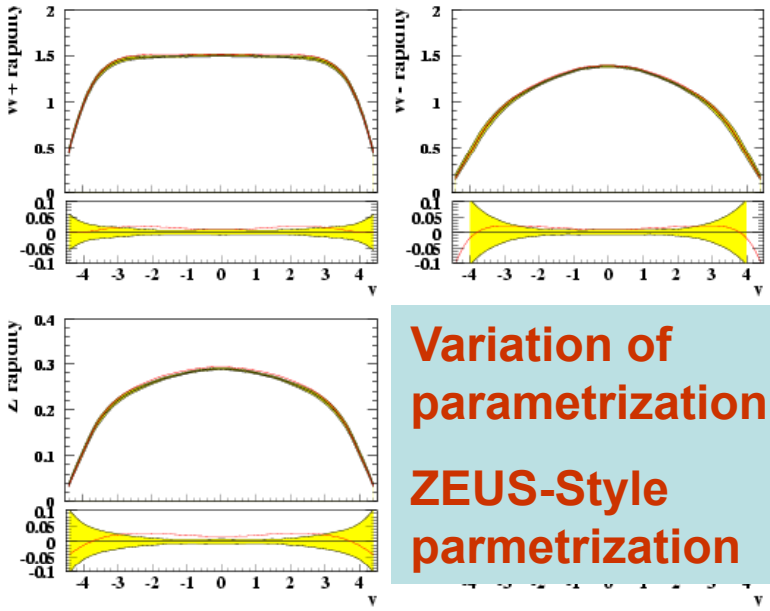
W and Z rapidity distributions



Variation of parametrization

Humpy gluon solution

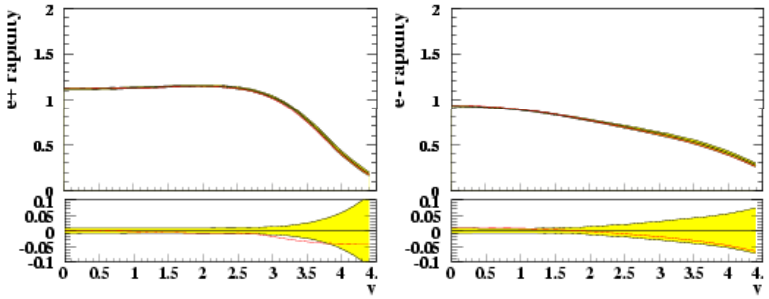
W and Z rapidity distributions



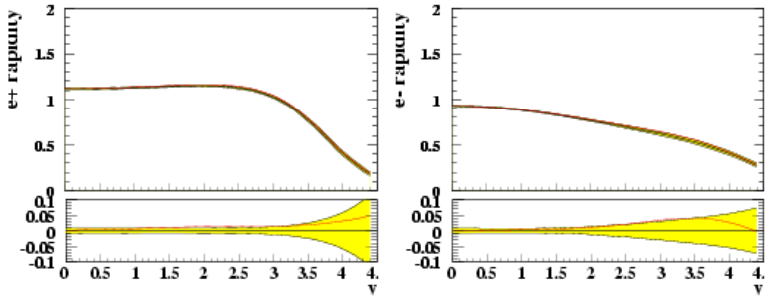
Variation of parametrization

ZEUS-Style parmetrization

Lepton rapidity distributions



Lepton rapidity distributions

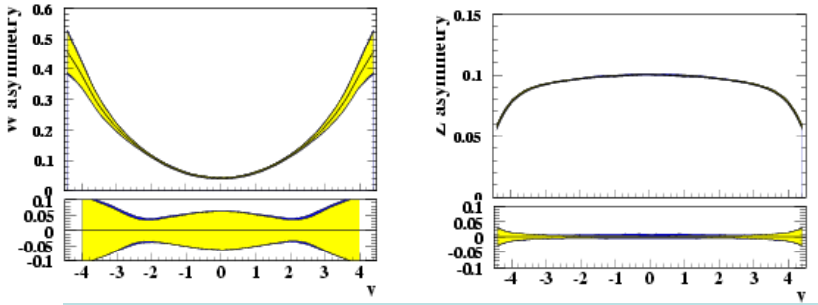


Variation of parametrization is also not large but can be seen- mostly outside central region

Overall conclusion for the W/Z and lepton rapidity spectra: there is ~3% model dependence from choice of parametrization at Q^2_0 and choice of Q^2_0 .

Now let's look at ratios

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



Much smaller model uncertainty in ratios

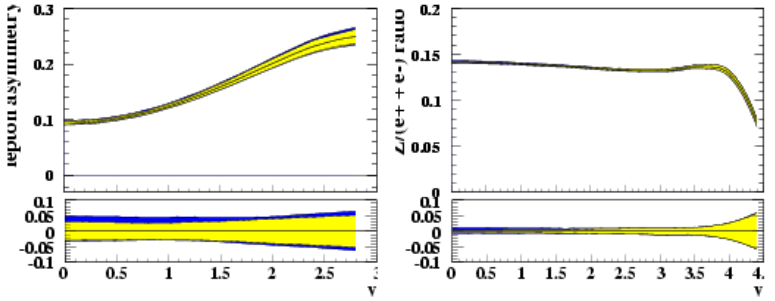
The Z/W ratio is the most reliably predicted quantity of all, PDF Uncertainties from experimental input and from model choices almost cancel out of this ratio.

The W asymmetry has a larger PDF uncertainty from experimental input, but little model uncertainty in the central region.

Experimental uncertainty in yellow

Model uncertainty in blue from:Q20, Q2min, fs, fc, mb, mc

lepton asymmetry and Z/(leptons) ratio



For the lepton ratios the wash out of model uncertainty in the measurable region is not quite so perfect as for the W but it is still quite impressive

Now let's look at ratios

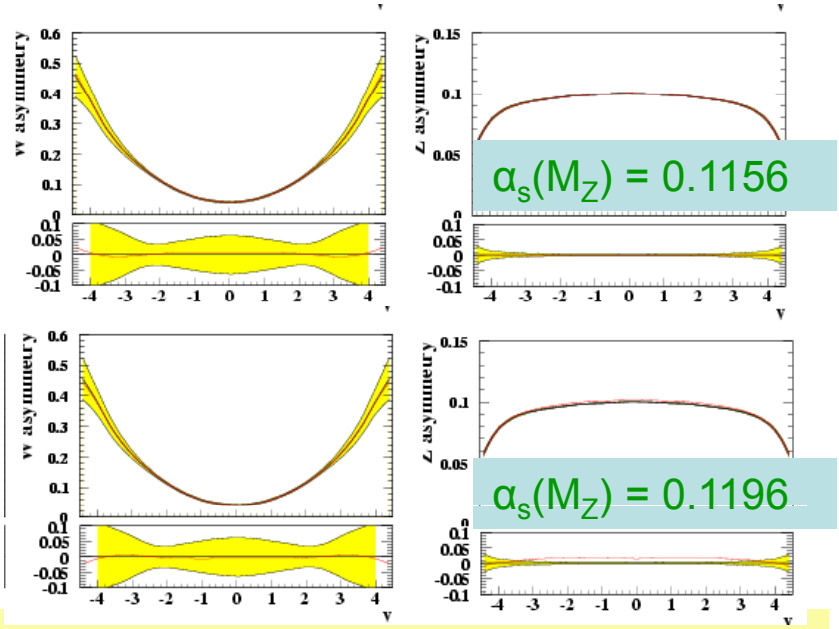
Let's look at model uncertainty in ratios in more detail

The model dependence from choice of $\alpha_s(M_Z^2)$ cancels out in W asymmetry at central rapidity

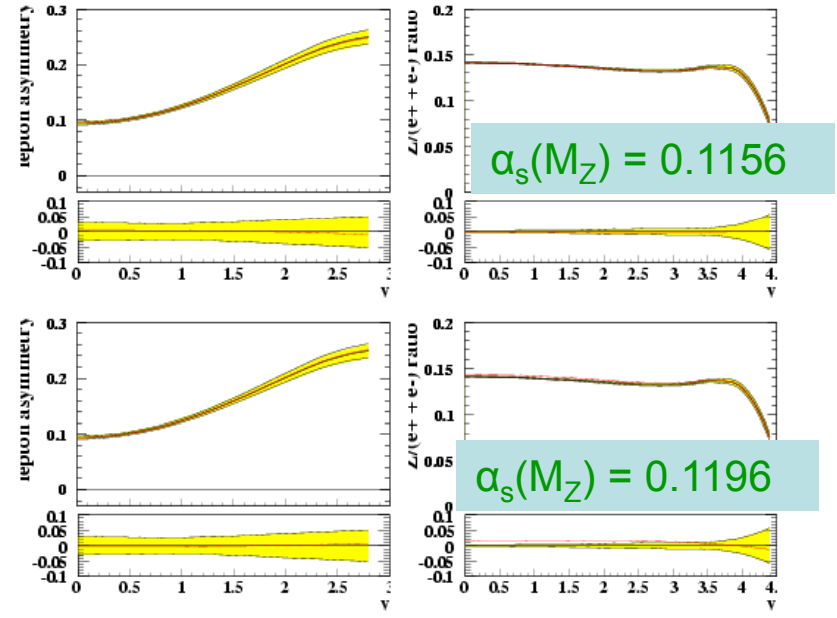
but is just visible in the Z/W ratio

These features are preserved in the lepton ratios.

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



lepton asymmetry and Z/(leptons) ratio



Now let's look at ratios

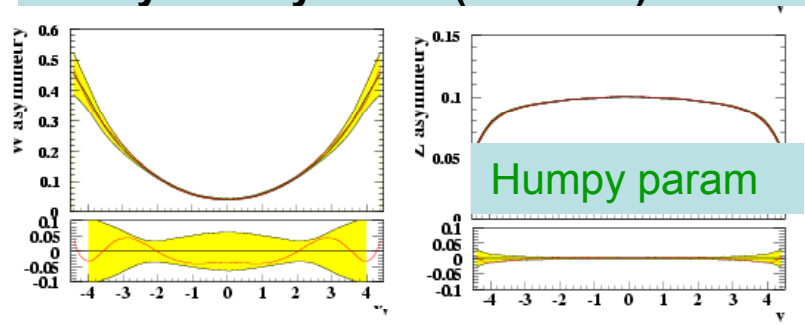
Let's look at model uncertainty in ratios in more detail

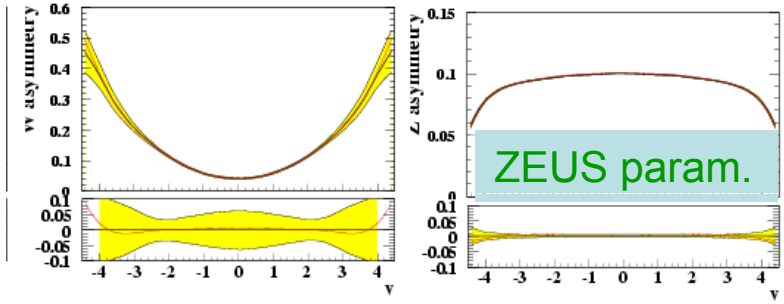
The model dependence from choice of parametrization is visible in W asymmetry in the central region. The Z/W ratio is not affected

These features are preserved in the lrpton ratios - parametrization uncertainty affects the lepton asymmetry in the central rapidity region

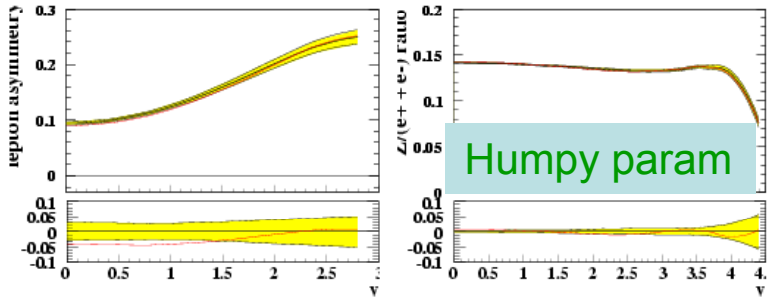
The W asymmetry is related to uv-dv PDFs at small x, rather than to the gluon, and there are differences in predictions from different PDFs due to parametrization differences, see later- a measurement at LHC would be useful

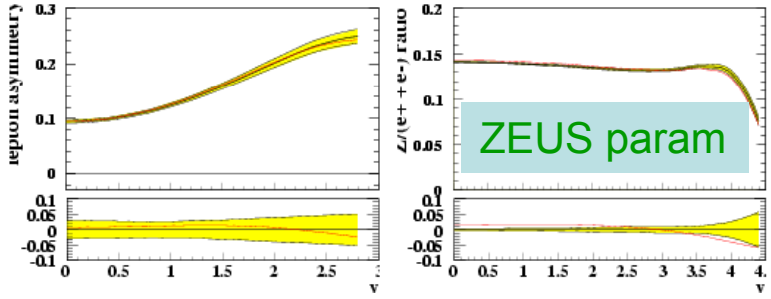
W asymmetry and Z/(W+ + W-) ratio





lepton asymmetry and Z/(leptons) ratio



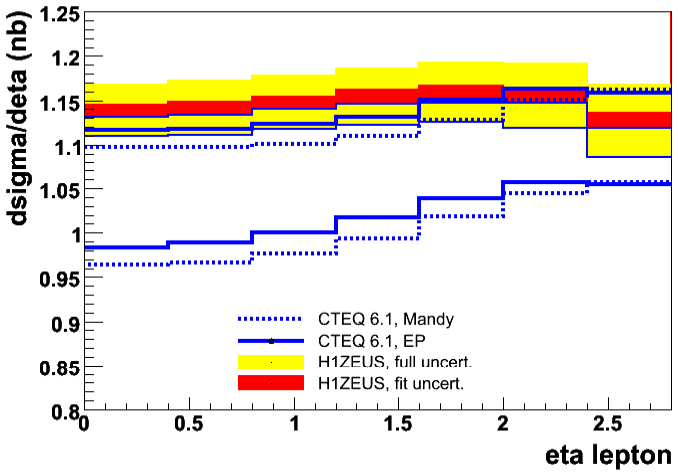


Comparsion to other PDFs

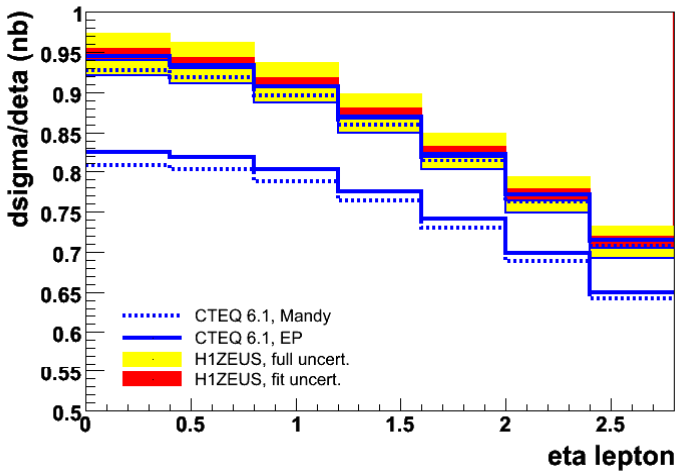
CTEQ6.6, 6.5 and 6.1 and MRST04 with MRST01 errors

- **Compare with work of E Perez using MCFM**
- **Compare W,Z, lepton rapidity spectra from HERAPDF0.1 with CTEQ6.1, 6.5**
- **Compare W asymmetry, Z/W ratio and lepton equivalents from HERAPDF0.1 with CTEQ6.1,6.5**
- **Look more closely at differences in the W and lepton asymmetries, HERAPDF0.1, CTEQ6.5, MRST04(1)**
- **Look more closely at model uncertainty in the Z/W and Z/lepton ratios,**
- **HERAPDF0.1, CTEQ6.5,6.6 and MRST04(1)**

W+ production



W- production

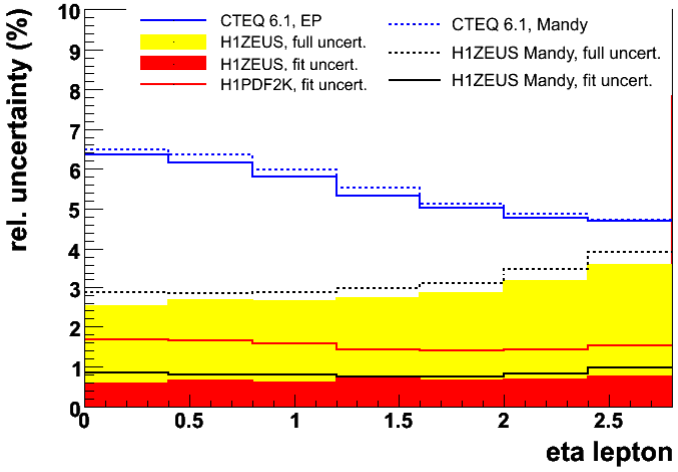


Comparison of lepton spectra and uncertainties between AMCS and E.Perez

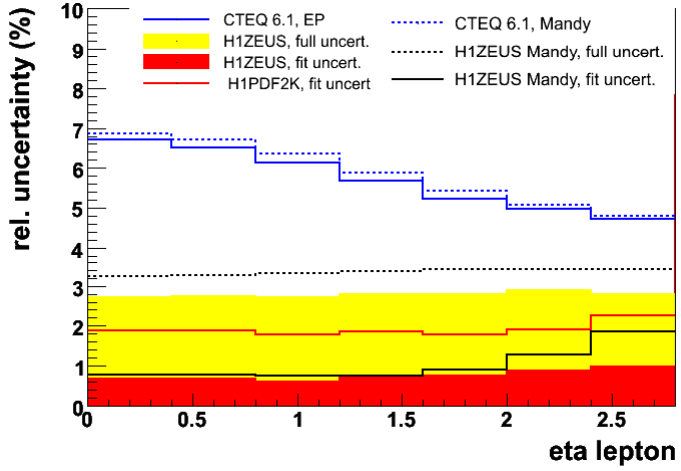
Perez uses MCFM for NLO calculation, AMCS uses analytic code of Stirling. Very different methods give very similar results.

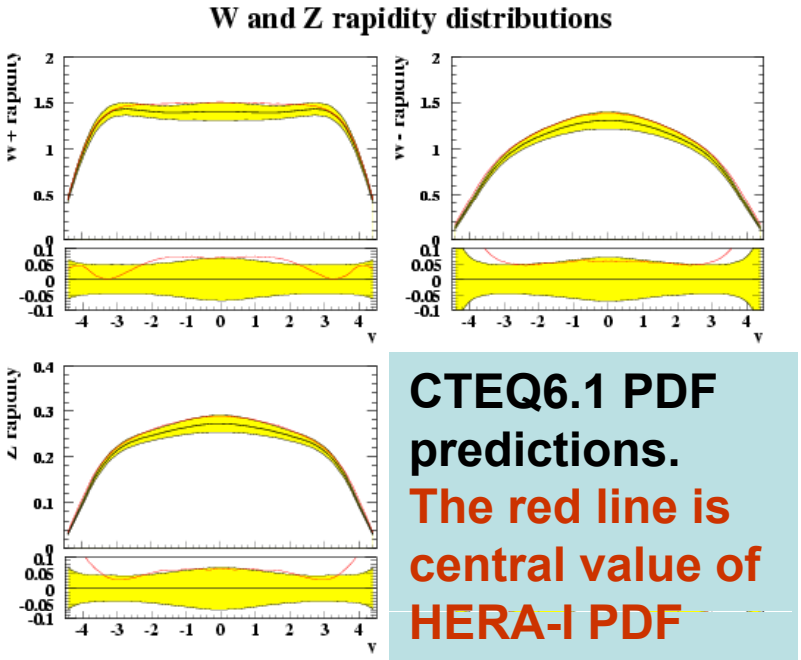
Perez uses Hessian error treatment, AMCS uses OFFSET. There is no longer any big difference for the combined HERAPDF

Wplus

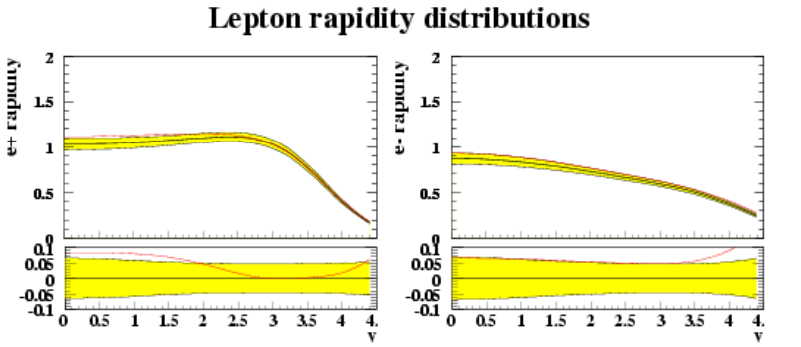


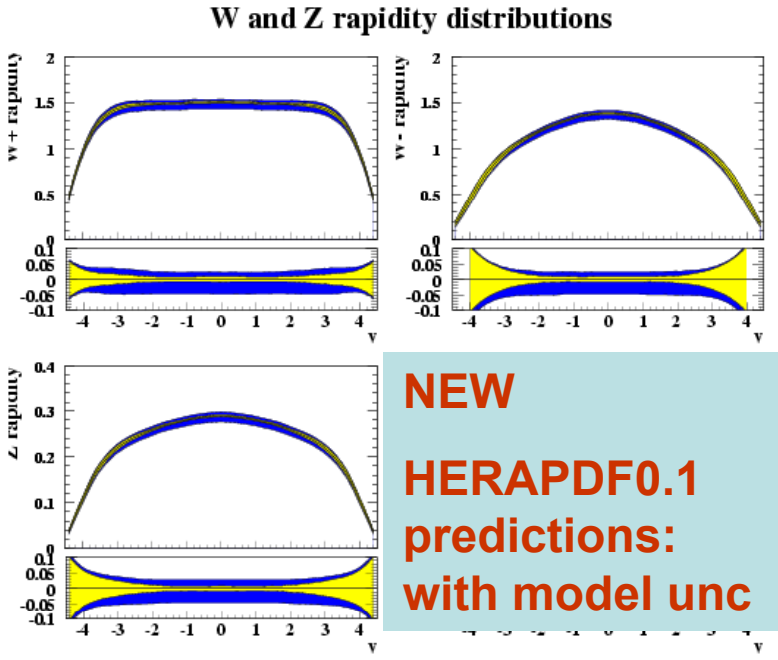
Wminus





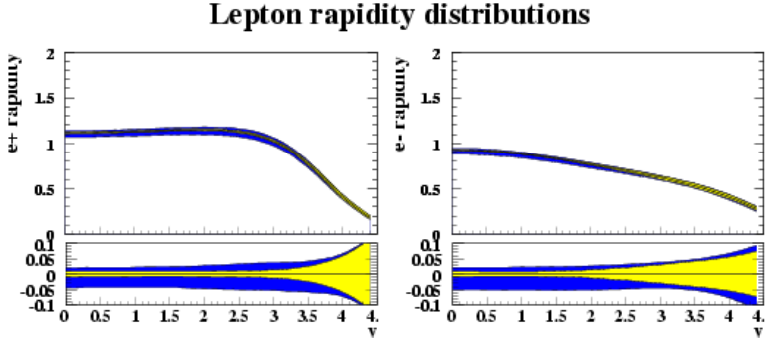
CTEQ6.1 PDF predictions.
The red line is central value of HERA-I PDF





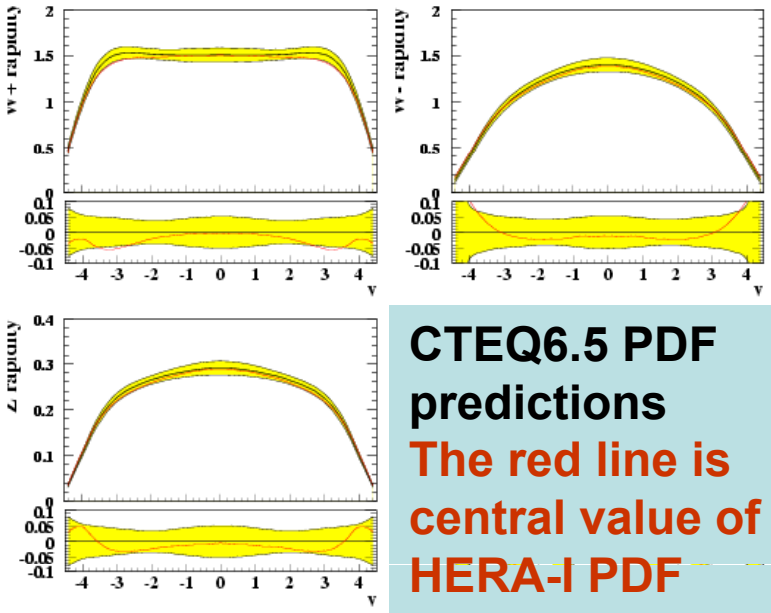
NEW

HERAPDF0.1 predictions: with model unc



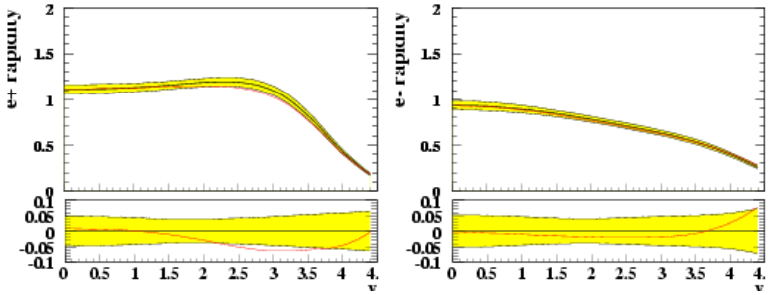
HERAPDF0.1 predictions for W/Z and lepton rapidity spectra are consistently higher than those of CTEQ6.1 in central values (despite using a similar zero-mass scheme). HERAPDFs are more precise even after model uncertainty is accounted (~3% vs 5-6%). See previous slide.

W and Z rapidity distributions

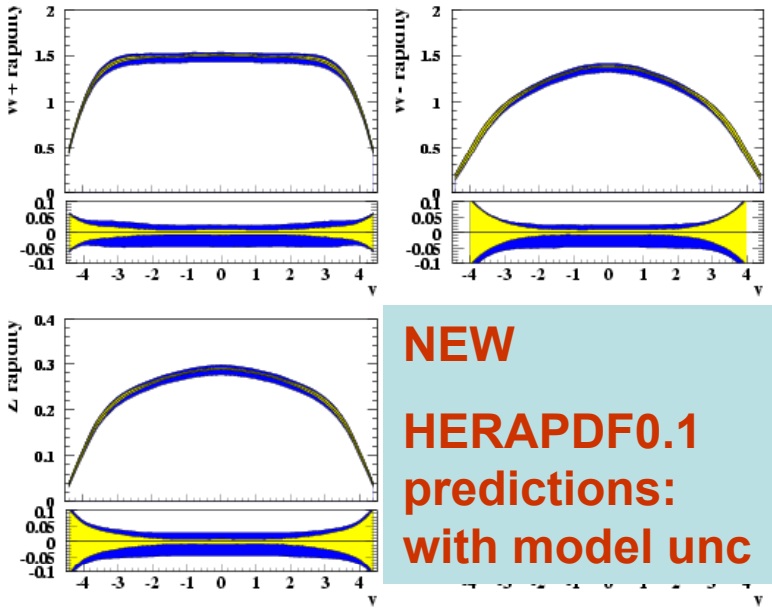


CTEQ6.5 PDF predictions
The red line is central value of HERA-I PDF

Lepton rapidity distributions



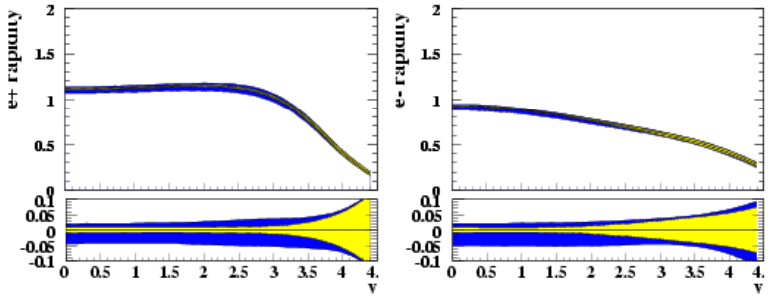
W and Z rapidity distributions



NEW

HERAPDF0.1 predictions: with model unc

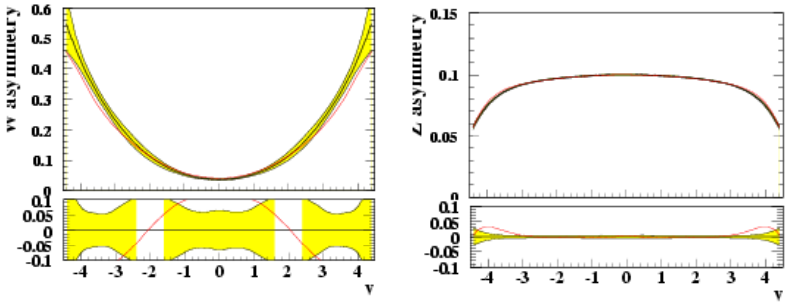
Lepton rapidity distributions



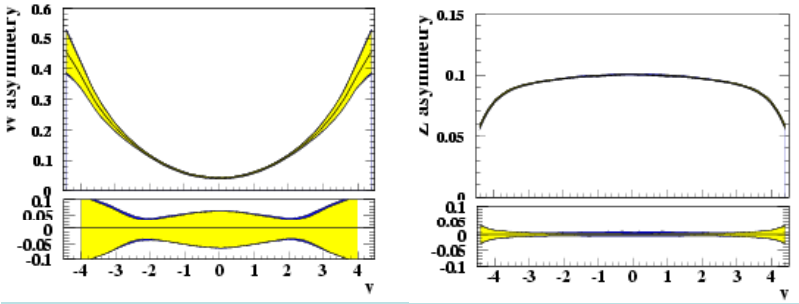
HERA-I PDF predictions for W/Z and lepton rapididty spectra are in agreement with those of CTEQ6.5

Now let's look at ratios

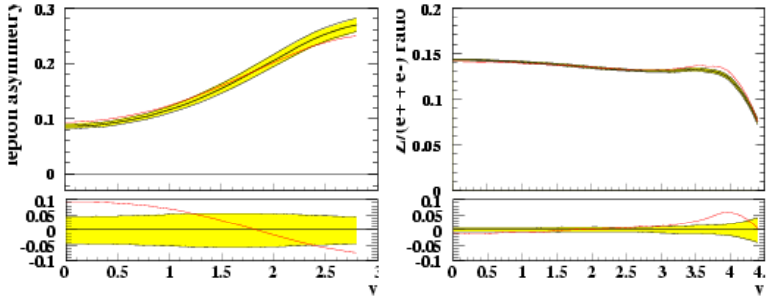
W asymmetry and Z/(W+ + W-) ratio



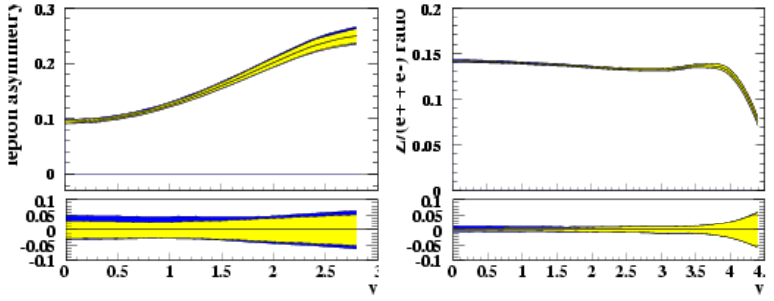
W asymmetry and Z/(W+ + W-) ratio



lepton asymmetry and Z/(leptons) ratio



lepton asymmetry and Z/(leptons) ratio



CTEQ6.1 PDF predictions.
The red line is central value of HERA-I PDF

The Z/W ratio and the Z/lepton ratio are predicted very consistently between different PDF providers.

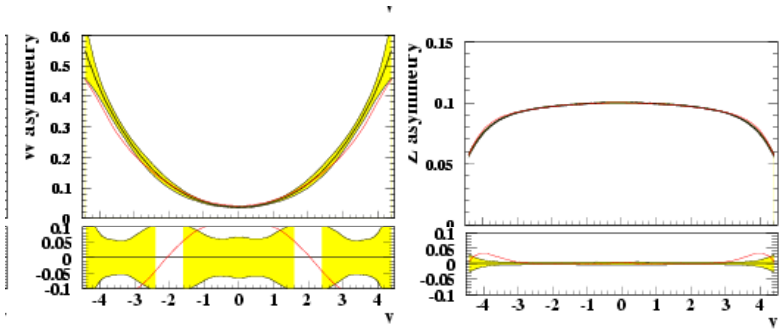
The W asymmetry and lepton asymmetries are not so consistent. This is due to differences in the uv-dv PDF

NEW

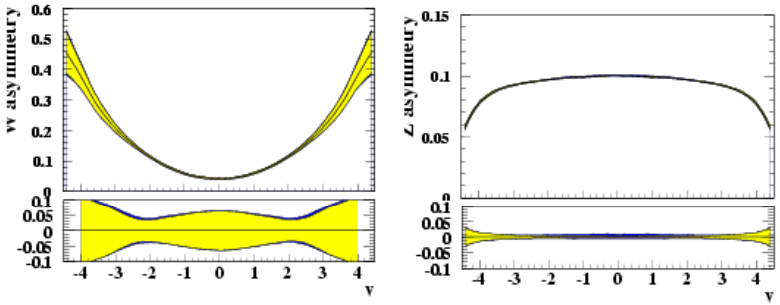
HERAPDF0.1 predictions: with model unc

Now let's look at ratios

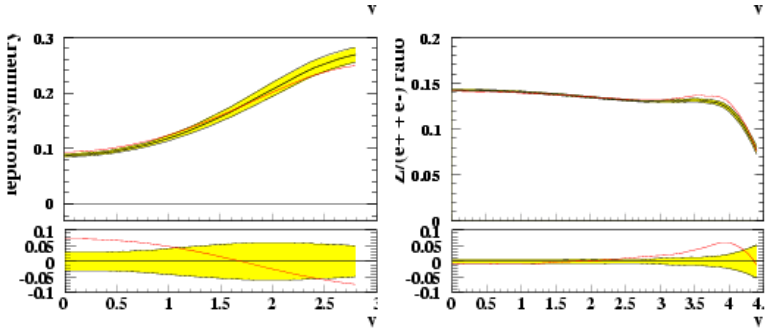
W asymmetry and Z/(W+ + W-) ratio



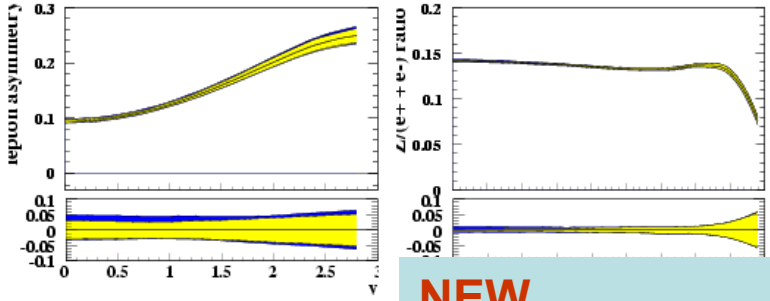
W asymmetry and Z/(W+ + W-) ratio



lepton asymmetry and Z/(leptons) ratio



lepton asymmetry and Z/(leptons) ratio



CTEQ6.5 PDF predictions.
The red line is central value of HERA-I PDF

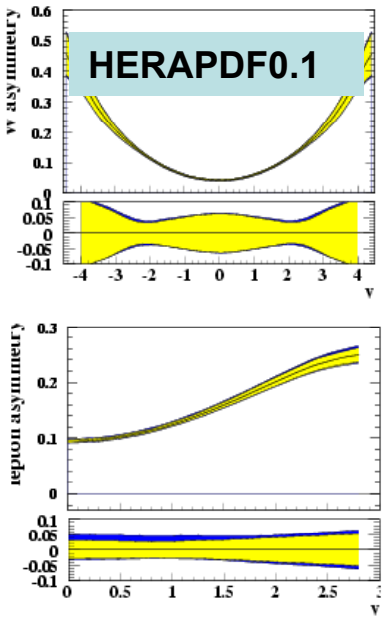
The Z/W ratio and the Z/lepton ratio are predicted very consistently between different PDF providers.

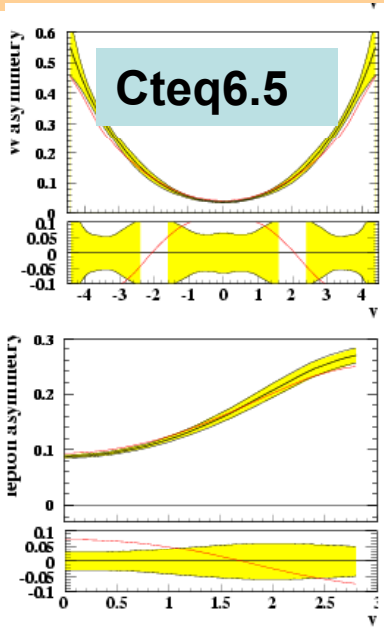
The W asymmetry and lepton asymmetry are not so consistent. This is due to differences in the uv-dv PDF

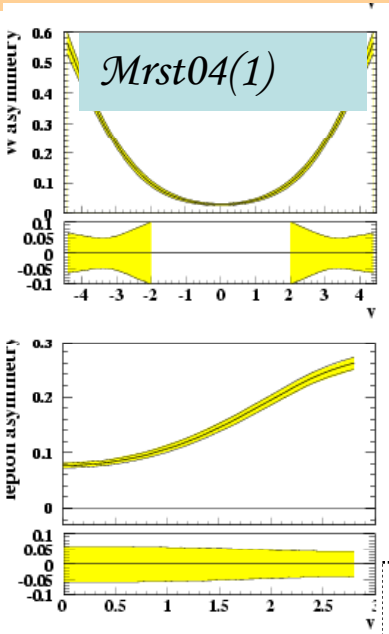
NEW

HERAPDF0.1 predictions: with model unc

Look more closely at AW and lepton asymmetry to see that they relate to uv-dv







Predictions for AW are different in the central region- this persists in the lepton asymmetry

MRST04 ----------

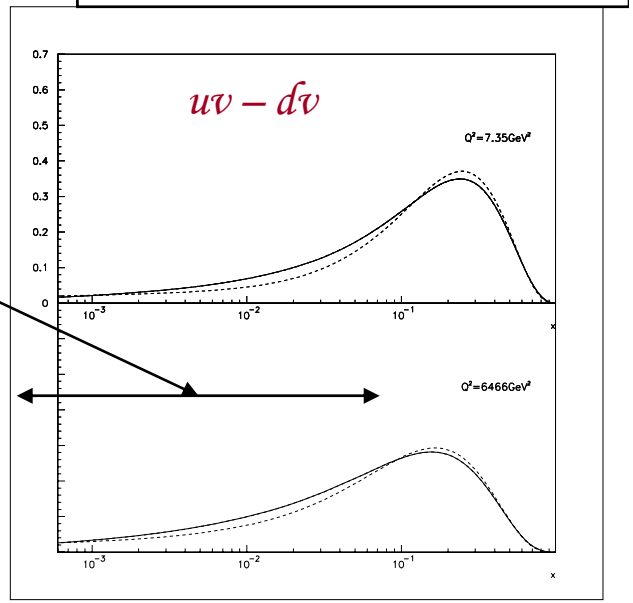
CTEQ6.1 ——————

Dominantly, at LO $A_W = \dfrac{(u\,\bar{d} - d\,\bar{u})}{(u\,\bar{d} + d\,\bar{u})}$

And $\bar{u} \sim \bar{d} \sim \bar{q}$ at small x

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

x- range affecting W asymmetry in the measurable rapidity range

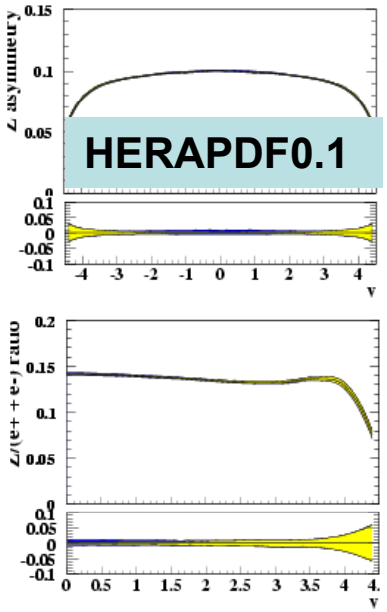


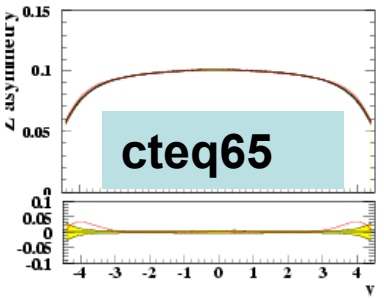
Actually this pretty good even quantitatively

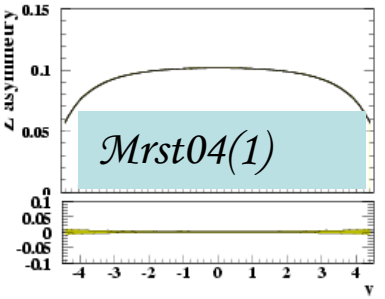
The difference in valence PDFs you see here does explain the difference in A_W between MRST and CTEQ

Look more closely at Z/W and Z/(leptons): very similar from all PDFs

But there are small differences in uncertainty estimates

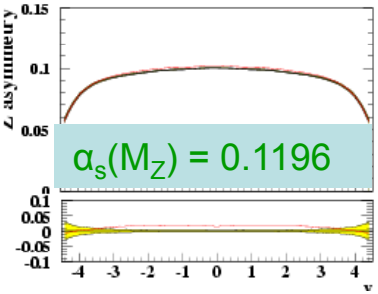


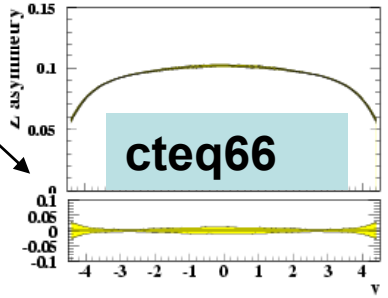




HERAPDF0.1 has some small model uncertainty from strangeness fraction

CTEQ6.6 also shows this extra uncertainty





HERAPDF0.1 also indicates some small model uncertainty from choice of $\alpha_s(M_Z)$

Summary

Prediction of W/Z at LHC from HERAPDF0.1 based on optimal HERA data combination –sorts out experimental uncertainty from model uncertainty

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

1. Very small experimental uncertainty~1.5%.
2. Model uncertainty ~3% from choice of parametrization at Q^2_0 and choice of Q^2_0

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

For Z/W ratio

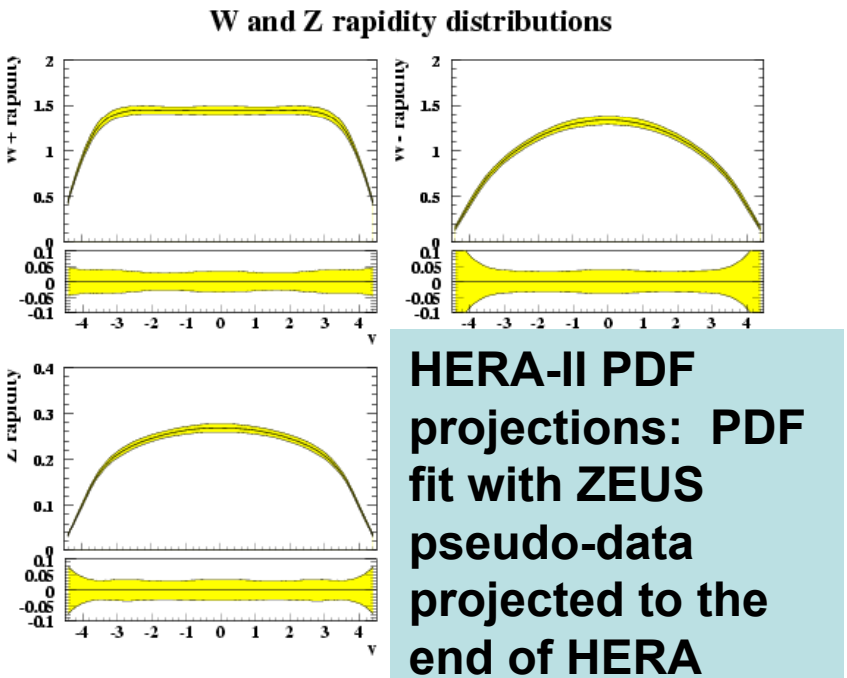
1. Very small experimental uncertainty~1% and Very small model uncertainty in both Z/W ratio and Z/lepton ratio~1-2%:- coming from alphas and strangeness uncertainty- Golden SM benchmark measurement

For W asymmetry

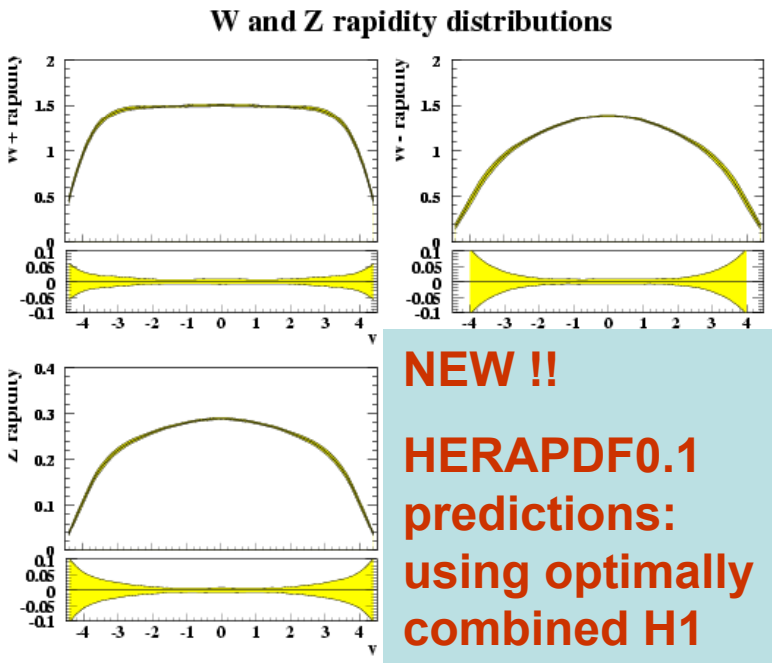
- Experimental uncertainty~5%. Remaining model uncertainty in W and lepton asymmetry can be larger:- comes from choice of parametrization.

LHC measurements will increase our knowledge of PDFS

extras



HERA-II PDF projections: PDF fit with ZEUS pseudo-data projected to the end of HERA



NEW !!

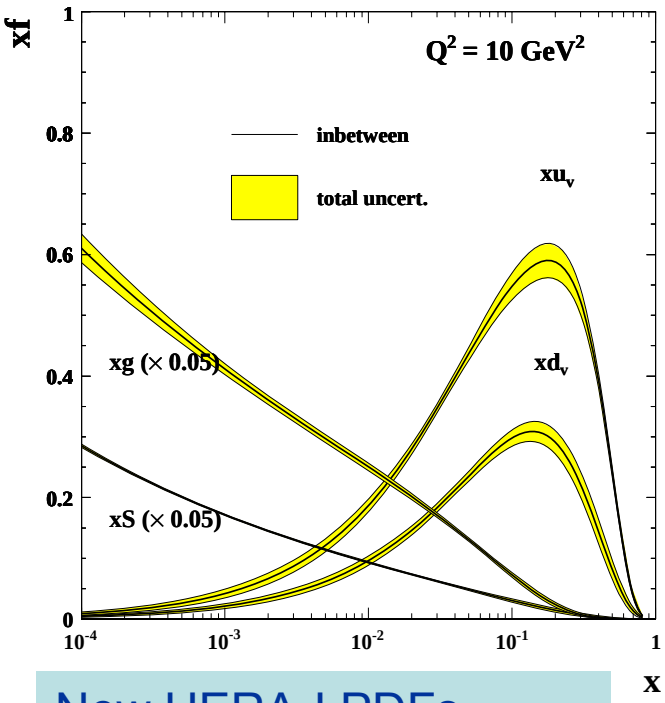
HERAPDF0.1 predictions: using optimally combined H1 and ZEUS data

For previous HERALHC workshops we even made a projections of how good it could get with final HERA-II data.

But we were pessimistic

We were not expecting the improvement in systematic error that the 2008 H1/ZEUS combination has made.

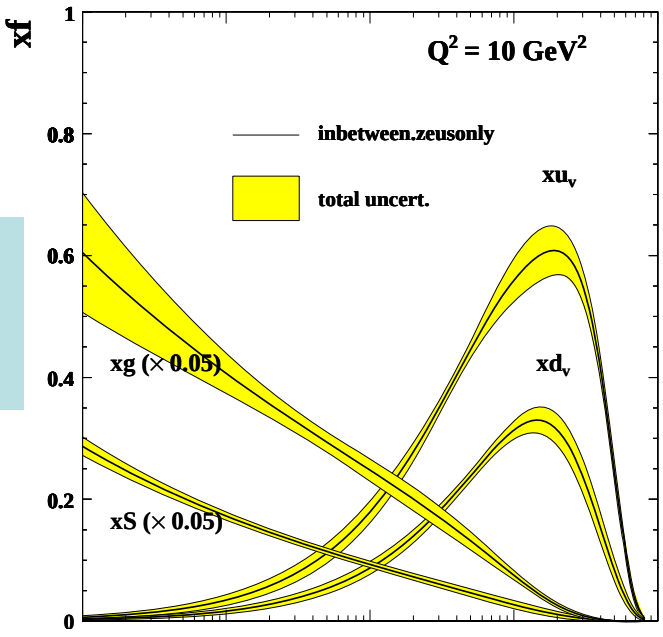
The new predictions are very precise ~1.5% error in the central region



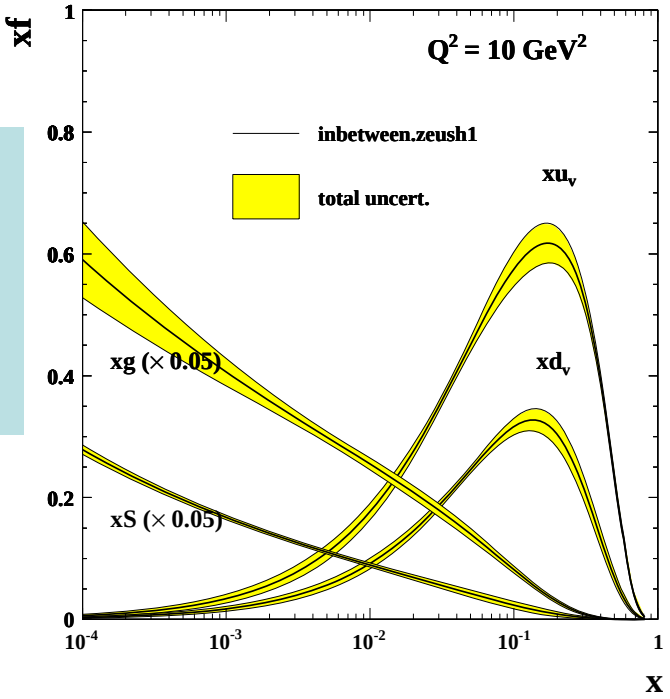
New HERA-I PDFs experimental error only

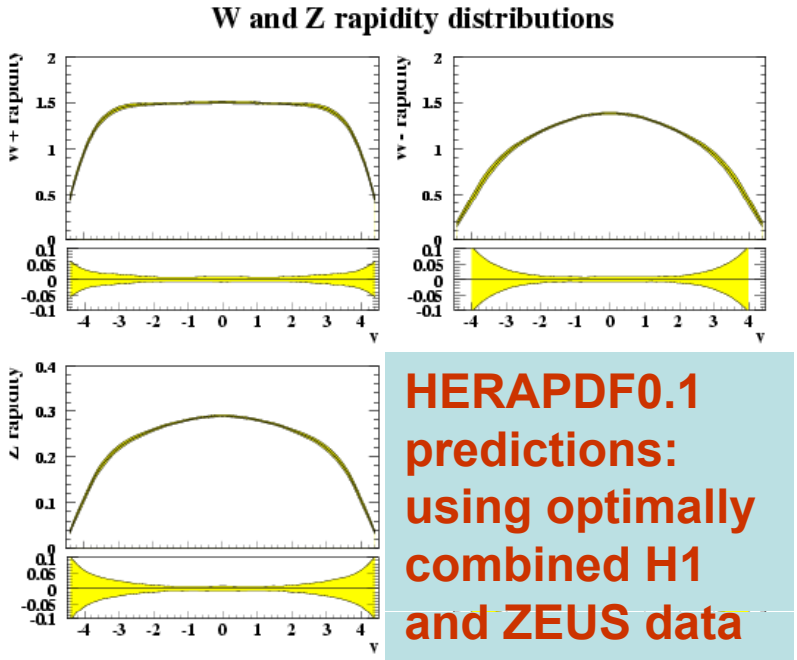
The improvement comes from the data combination NOT from the fit formalism

Fit to ZEUS data with the same parametrization.



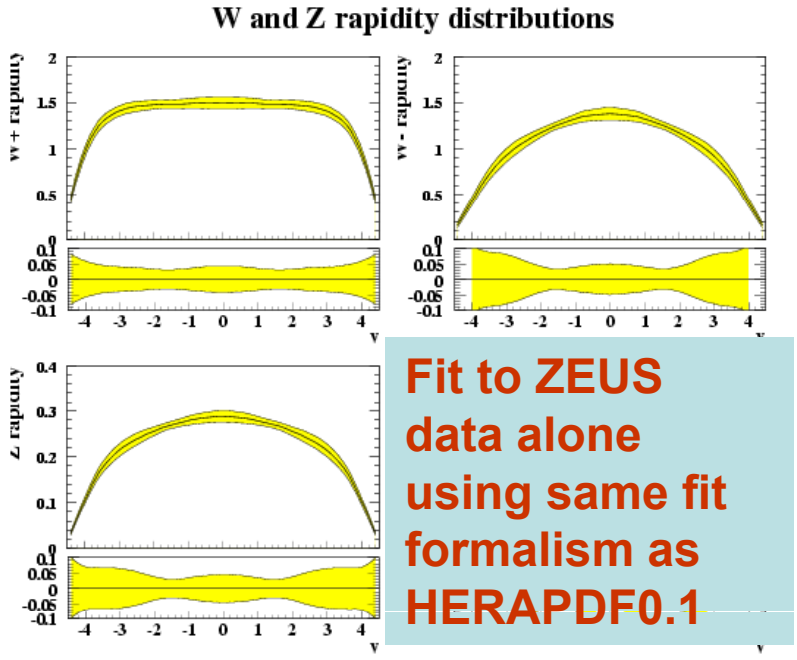
Fit to ZEUS and H1 data as two separate data sets, using the same parametrization



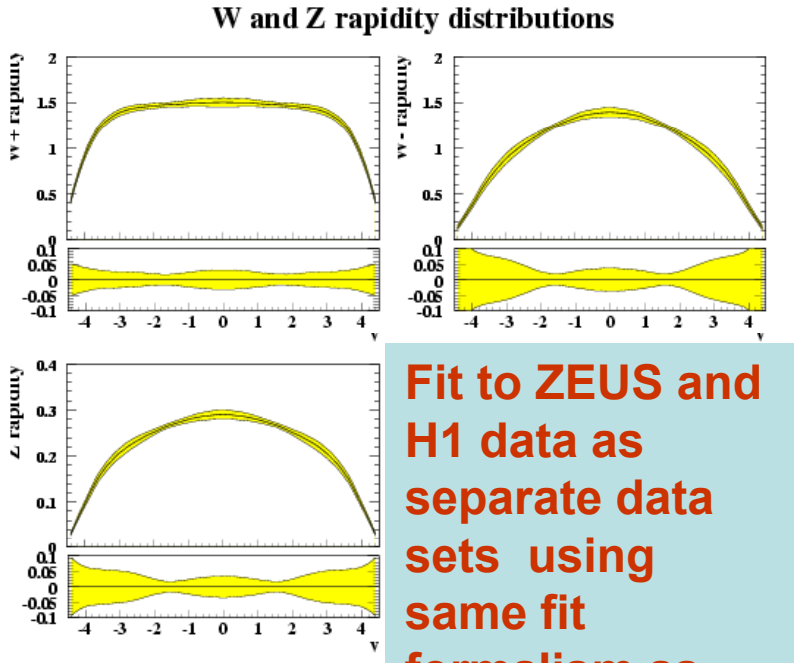


HERAPDF0.1 predictions: using optimally combined H1 and ZEUS data

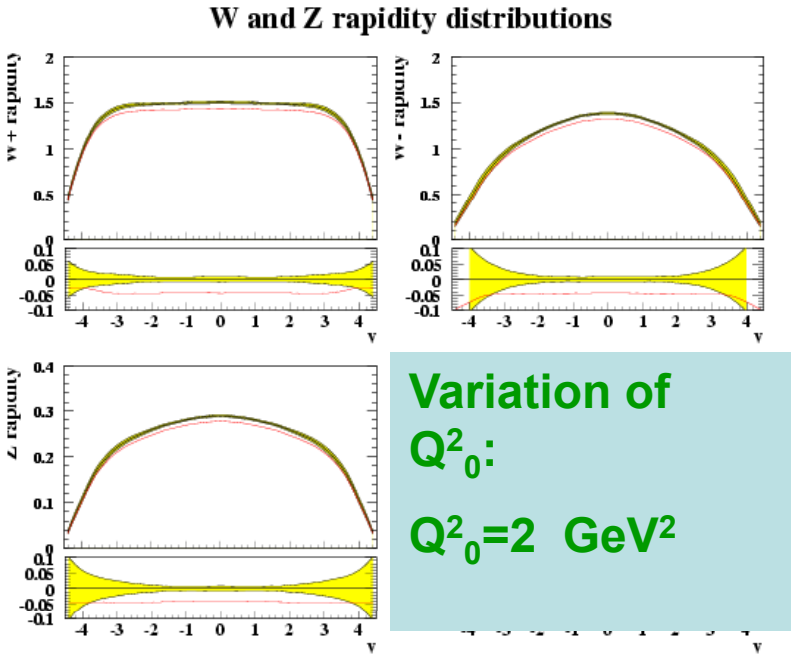
The improvement comes from the data combination NOT from the fit formalism



Fit to ZEUS data alone using same fit formalism as HERAPDF0.1

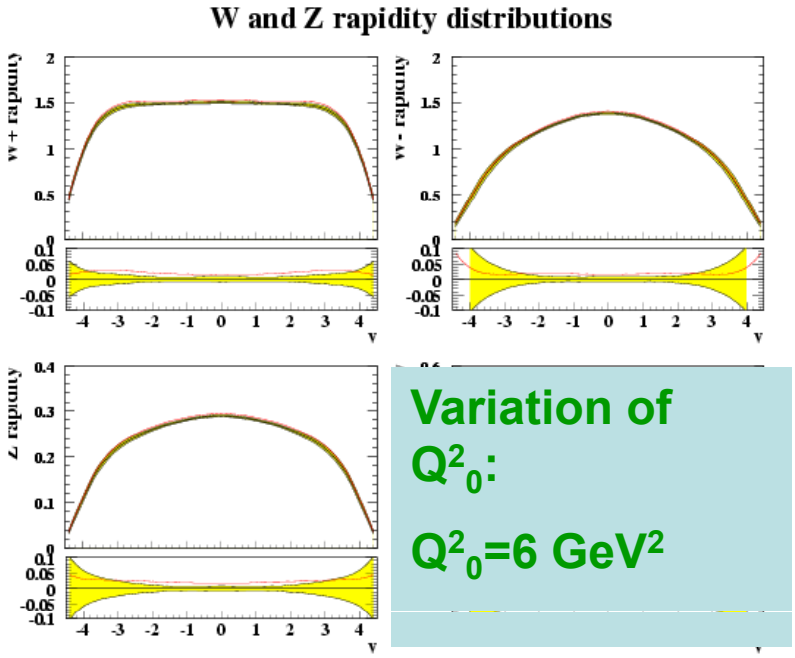


Fit to ZEUS and H1 data as separate data sets using same fit formalism as HERAPDF0.1



Variation of Q^2_0:

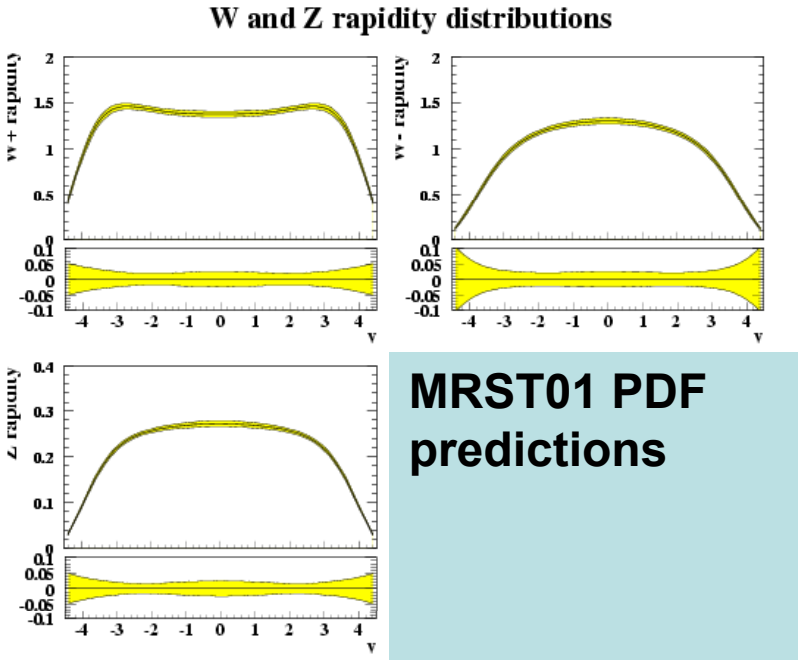
Q^2_0=2 GeV^2



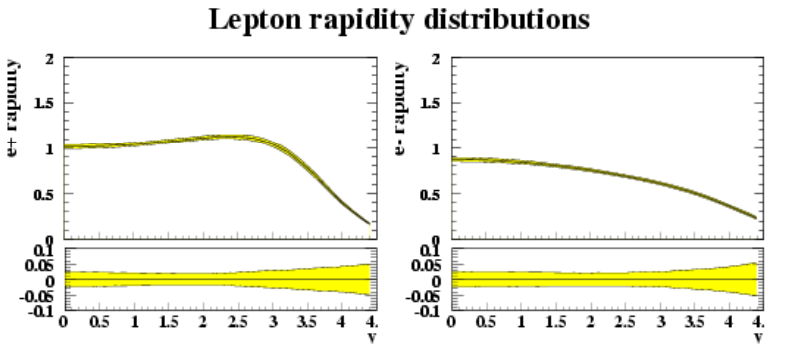
Variation of Q^2_0:

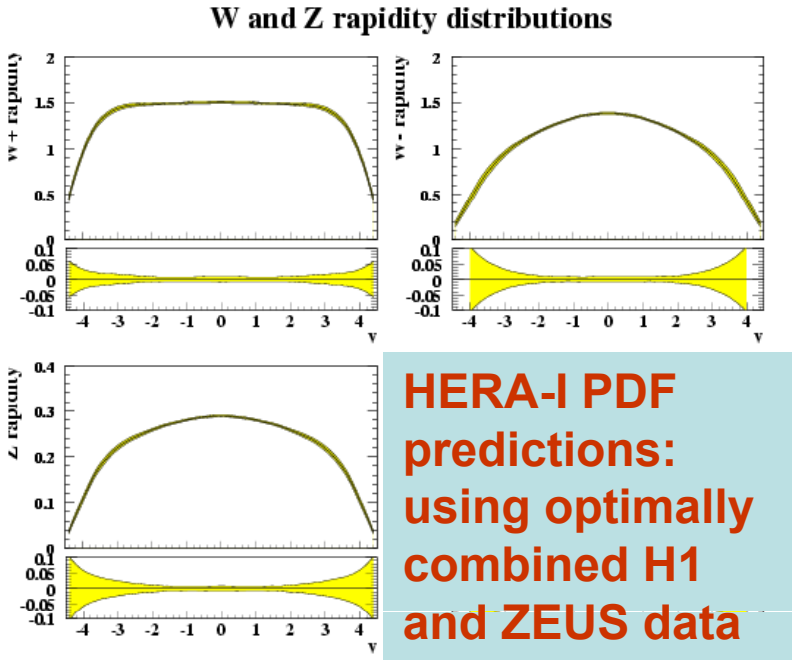
Q^2_0=6 GeV^2

Let's look at model dependence as a function of y: Variation of Q^2_0 is the most significant model error in the measurable range

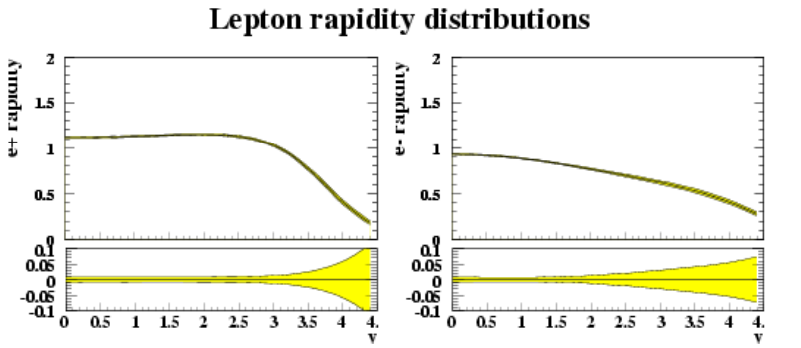


MRST01 PDF predictions





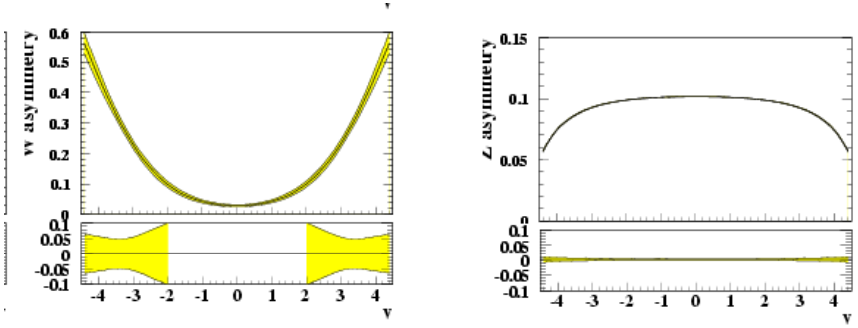
HERA-I PDF predictions: using optimally combined H1 and ZEUS data



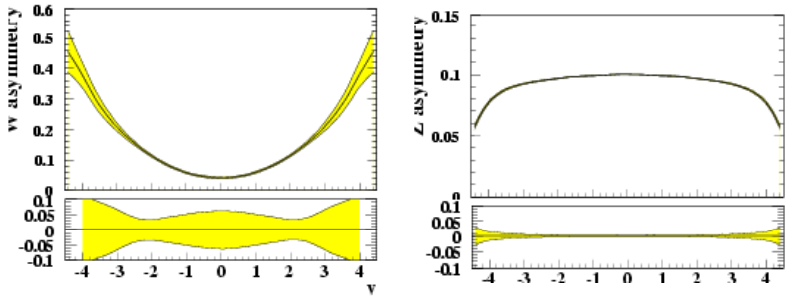
Comparison to other PDFS

Now let's look at ratios

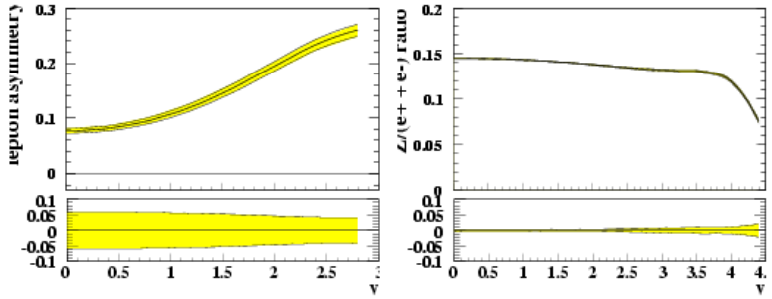
W asymmetry and Z/(W+ + W-) ratio



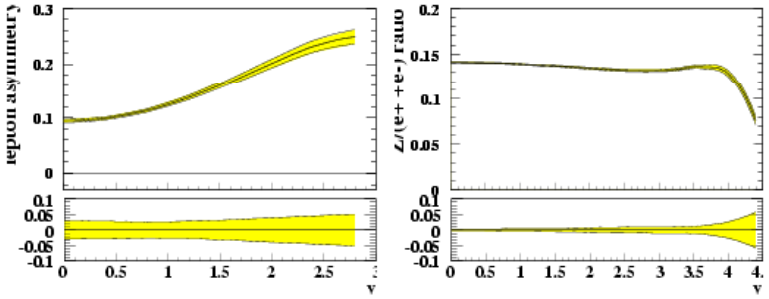
W asymmetry and Z/(W+ + W-) ratio



lepton asymmetry and Z/(leptons) ratio



lepton asymmetry and Z/(leptons) ratio



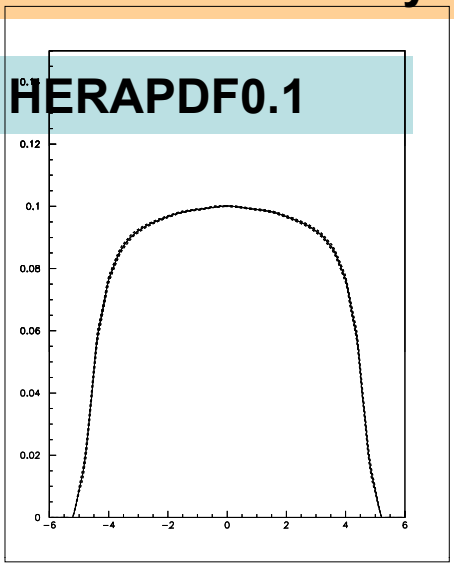
MRST01 PDF predictions

Comparison to other PDFS

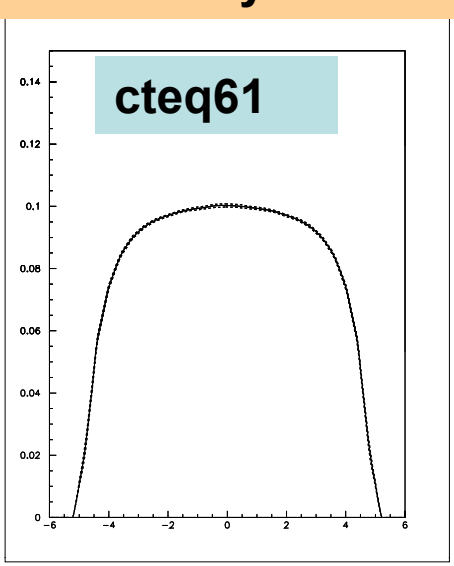
HERA-I PDF predictions: using optimally combined H1 and ZEUS data

Look more closely at Z/W: very similar from all PDFs

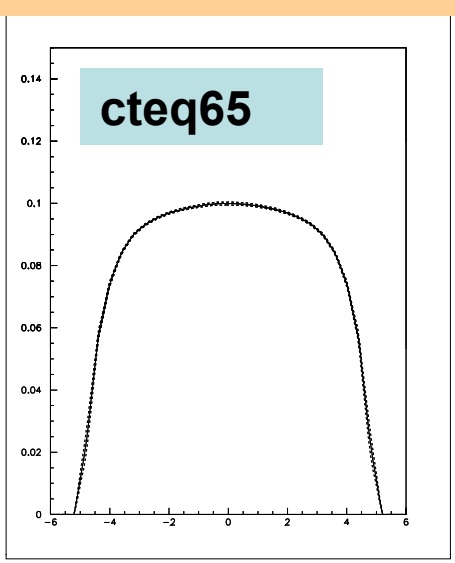
HERAPDF0.1



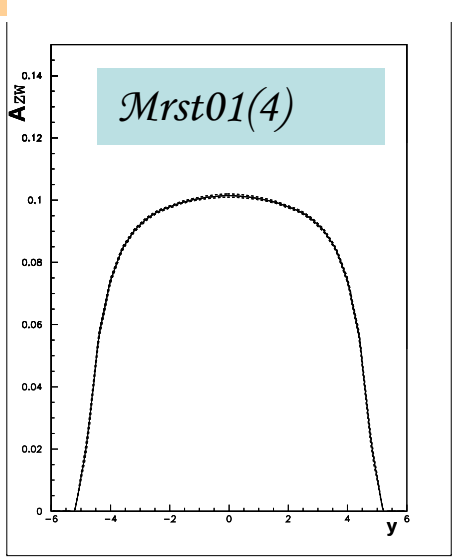
cteq61



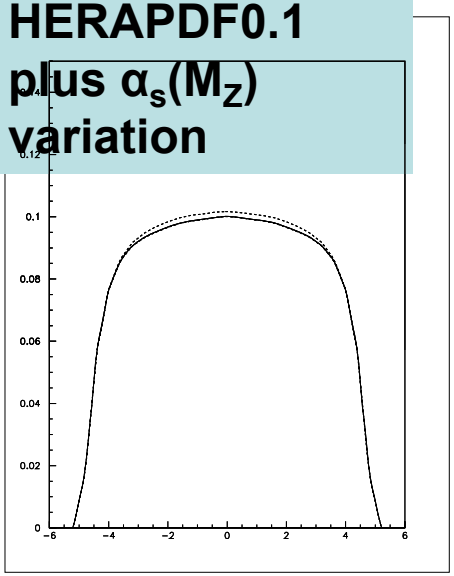
cteq65



Mrst01(4)

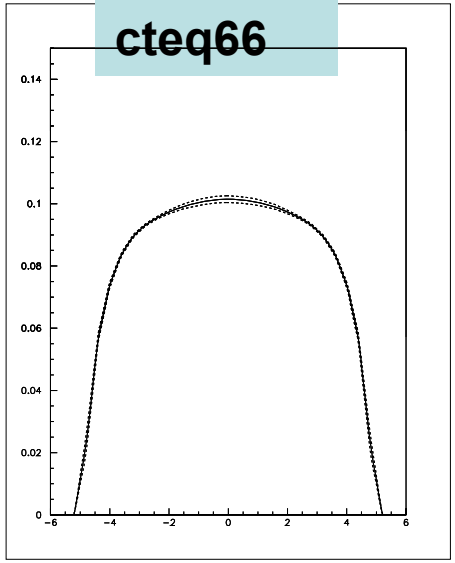


HERAPDF0.1 plus $\alpha_s(M_Z)$ variation



But the choice of $\alpha_s(M_Z)$ affects it a little.

cteq66



And recently strangeness uncertainty has been introduced and this affects it- but it is NOT a big deal, see CTEQ66