Update from HERAPDF

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on behalf of the H1 and ZEUS Collaborations

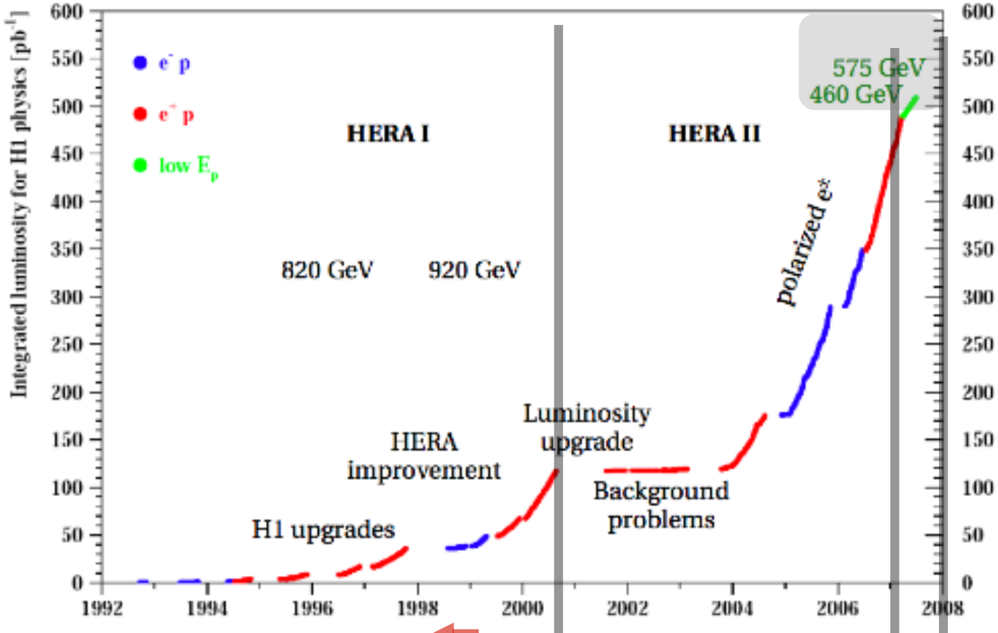
Outline:

- HERAPDF @ NLO series
  - HERAPDF1.0: Based on HERA I data
  - HERAPDF1.5: Based on prelim HERA I+II data
  - HERAPDF1.5f: Using extended parametrisation
  - HERAPDF1.6: Adding HERA Jet data
  - HERAPDF1.7: HERA I+II charm, low energy, jets
- HERAPDF @ NNLO series:
  - HERAPDF1.0 just central fit
  - HERAPDF1.5 with errrors (extended param)
- Predictions based on HERAPDFs
  - Tevatron
  - LHC
- Summary

Input Data from HERA into the HERAPDF fits

- Combined HERA I inclusive data [JHEP01(2010) 109]
  - HERAPDF1.0 NLO (full errors) and NNLO
  - Data used in NNPDF2.0(1), CT10, AB(K)M

- Combined HERA I+high Q^2 HERA II Data [prelim]:
  - Accurate measurements in high Q^2 region
    - Sensitivity to valence quarks
  - HERAPDF1.5*, HERAPDF1.5f (full errors)
    - NLO (full errors)
    - NNLO (full errors)
- HERA I + Combined Charm F_2 data [prelim]:
  - Provides constraints on charm mass
  - Accounts for some differences among PDFs
- Low Energy Data HERA II [EPJ(2011)71]:
  - Accurate measurement in $Q^2 \geq 1.5$ GeV^2 range, sensitive to structure function F_L
  - Investigate the low Q^2 region
- HERA(I+II) +H1 and ZEUS DIS Jet data:
  - HERAPDF1.6 NLO (full errors)
  - Determination of strong coupling



HERAPDF1.0

HERAPDF1.5

HERAPDF1.6 +jets

HERAPDF1.7 +jets+ch+LER

Using all these data sets: HERAPDF1.7

- provides consistency check

* HERAPDF1.5 (NLO and NNLO) in LHAPDF5.8.6

PDF determination at HERA

- HERA PDFs are determined from QCD Fits to solely HERA data of $Q^2 > 3.5$ GeV^2
- The QCD settings are optimised for HERA measurements of proton structure functions (dominated by gamma exchange) $F_2(x,Q^2) = \frac{4}{9}(xU + x\overline{U}) + \frac{1}{9}(xD + x\overline{D})$

  - NLO (and NNLO) DGLAP evolution equations, RT-VFNS (as for MSTW08)
  - PDF parametrised at the starting scale Q_0^2: $xg, xu_{val}, xd_{val}, x\bar{U} = x\bar{u}(+x\bar{c}), x\bar{D} = x\bar{d} + x\bar{s}(+x\bar{b})$

    $Q_0^2 = 1.9$ GeV^2 (below m_c)
  - Simple Functional form: $xf(x, Q_O^2) = Ax^B(1-x)^C(1 + Dx + Ex^2)$
    - It describes the shape of PDFs with few input parameters
    - The number of free parameters is reduced by the physics constraints

  - A - normalisation
  - B - low x behaviour
  - C - high x behaviour
  - D,E - medium x tuning

  - Imposing momentum sum rules:

$$\int_0^1 dx \cdot (xu_v + xd_v + x\bar{U} + x\bar{D} + xg) = 1$$

$$\int_0^1 dx \cdot 2u_v = 2 \qquad \int_0^1 dx \cdot d_v = 1$$

Additional Constraints:

$x\bar{s} = f_s x\bar{D}$ strange sea is a fixed fraction f_s of $\bar{D}$ at Q_0^2

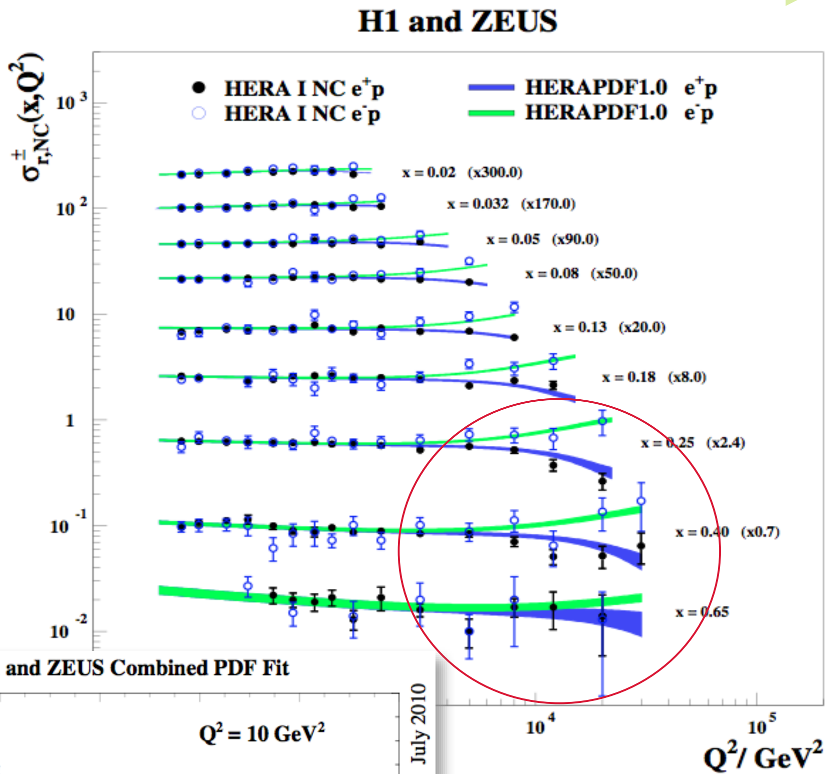
$B_{Ubar} = B_{Dbar}$
sea = 2 x (Ubar +Dbar)
Ubar = Dbar at x=0

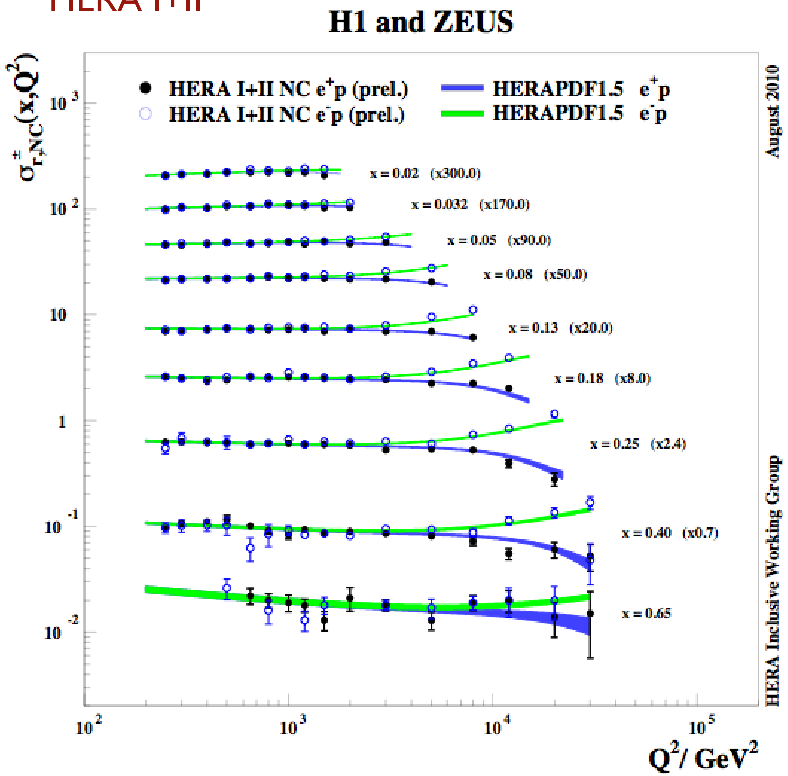
In 10p fit: Buv=Bdv

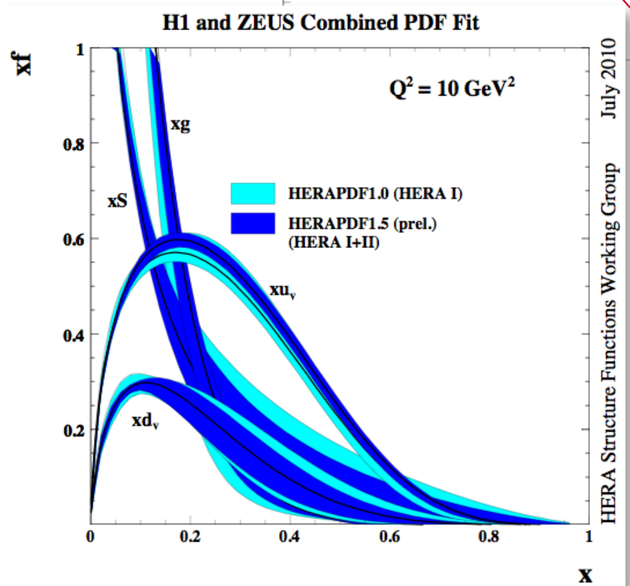
  - The best fit results in:
    - 10 free parameters (for HERA I data)
    - 13 free parameters (for HERA I+II data)

NLO PDFs: HERAPDF1.0 ⇒ HERAPDF1.5

- HERAPDF1.0 at NLO based on HERA I data [JHEP 1001-109]
  - HERA I → HERA I+II







- Larger HERA II luminosity yields in significant improvement in precision at high x, Q^2 reflected in PDFs
  - Valence PDFs more accurate for HERAPDF1.5
  - HERAPDF1.5 has a softer Sea
- Addition of more precise data permits use of more flexible parametrisations and making less assumptions:
  - Allow more flexibility for gluon
  - Free low-x-d-valence from u-valence

PDF parametrisation at HERA

- For HERAPDF1.0 and HERAPDF1.5, 10 free parameters were used for the central fit, however we can test now a more free parametrisation:
  - Additional free parameters for HERAPDF1.5f and higher

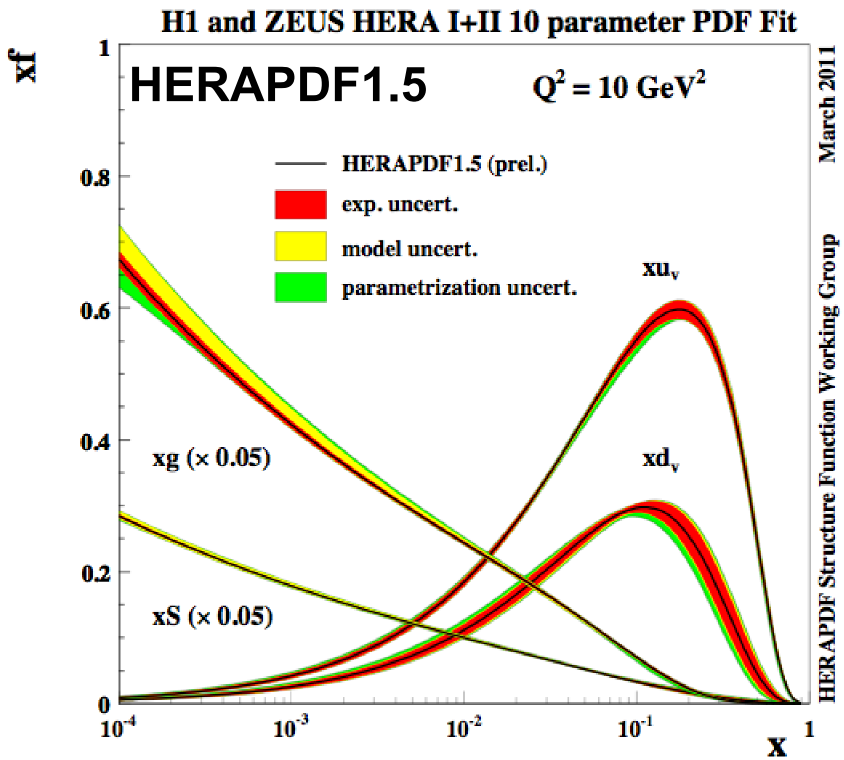
	A	B	C	D	E	ε
uv	Sum rule	free	free	free	free	var
dv	Sum rule	free	free	var	var	var
UBar	=(1-fs)ADbar	=BDbar	free	var	var	var
DBar	free	free	free	var	var	var
glue	Sum rule	free	free	var	var	var

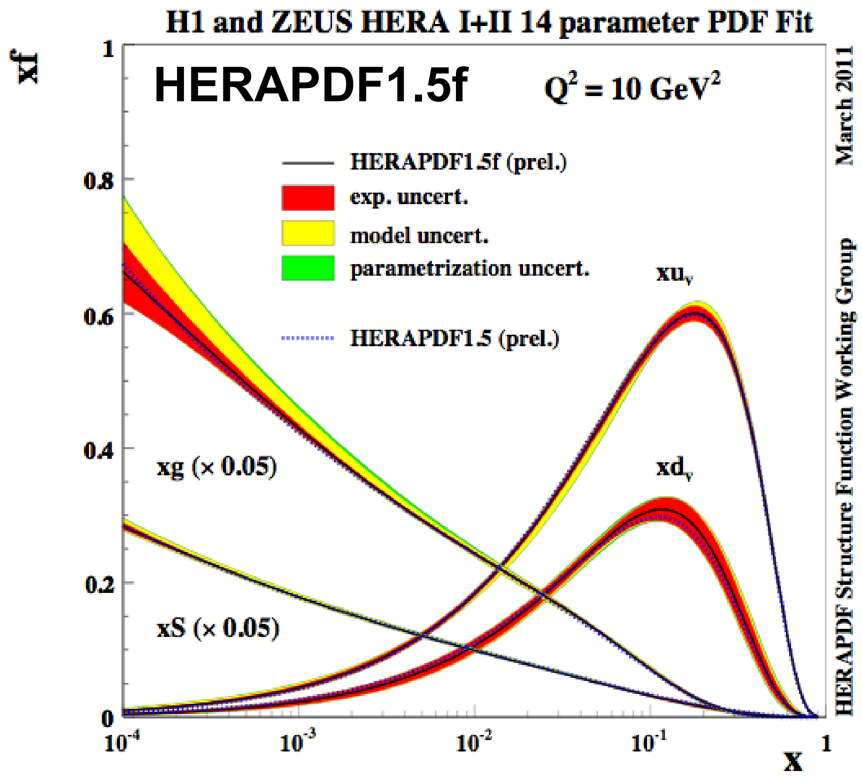
A'g	B'g
free	free

extended gluon parametrisation $A_g x^{B_g} (1-x)^{C_g} (1+Dx+Ex^2) - A'_g x^{B'_g} (1-x)^{C_g}$

- Consider also model uncertainties arising from:
  - Q^2_{min}, f_s, m_c, m_b
- PDFs are also supplied for a range of alphas values

NLO PDFs: HERAPDF1.5 ⇒ HERAPDF1.5f

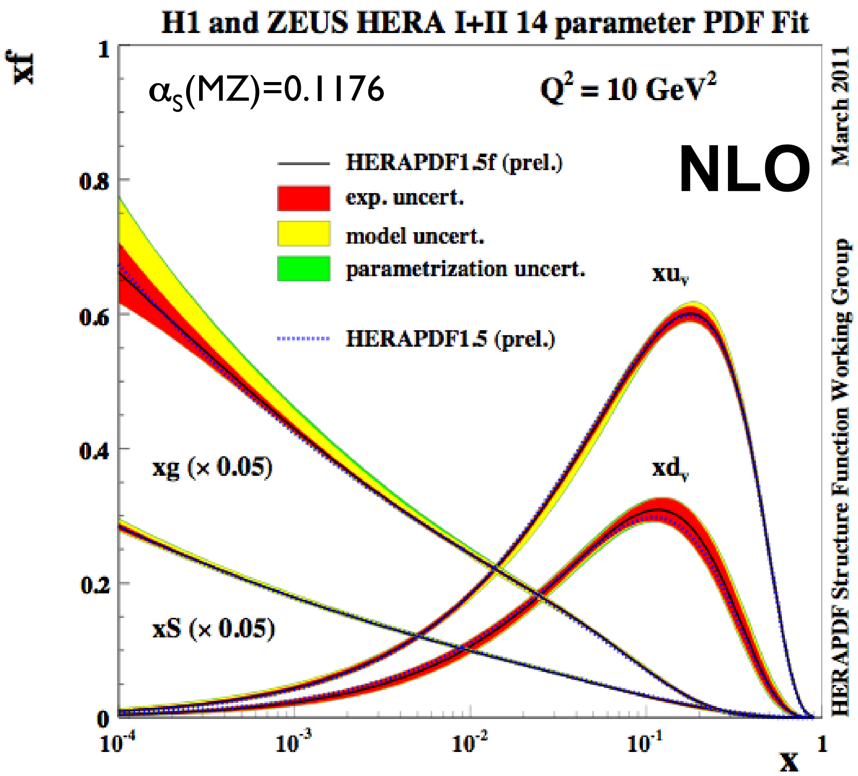


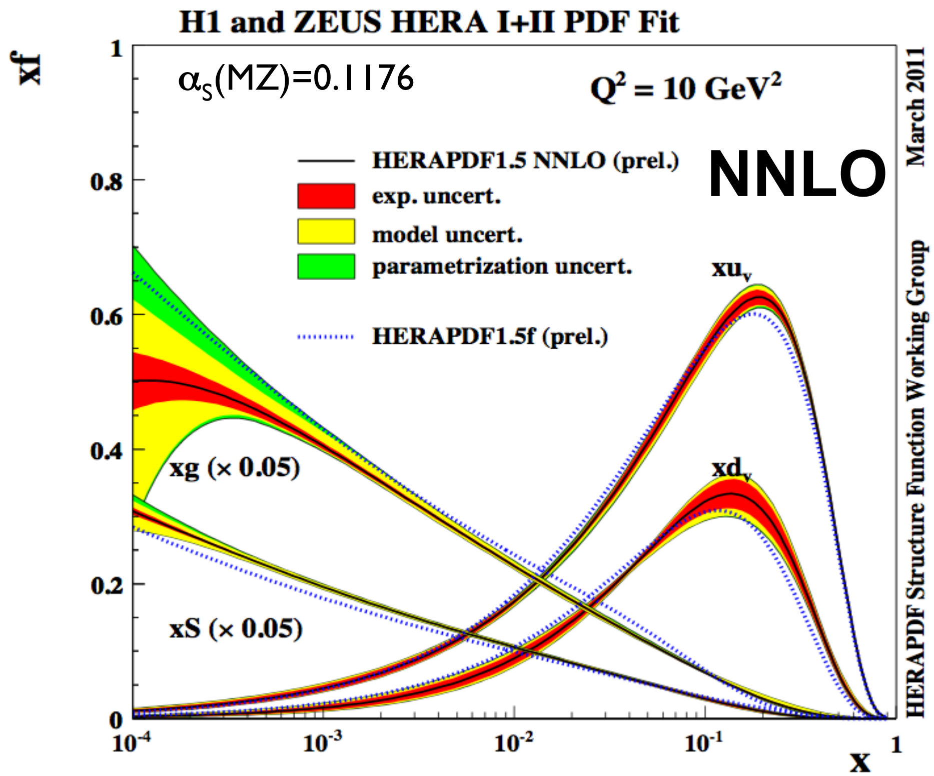


- Little effect is observed for the total uncertainties:
  - Swap between parametrisation (green) and experimental (red) uncertainties
  - Larger uncertainty at low x gluon
- Central fit line got shifted slightly (within experimental error band):
  - A softer high-x Sea
  - A supressed low-x d-valence

HERAPDF1.5 @ NNLO

- First check the effects from NLO to NNLO (same settings: extended parametrisation)

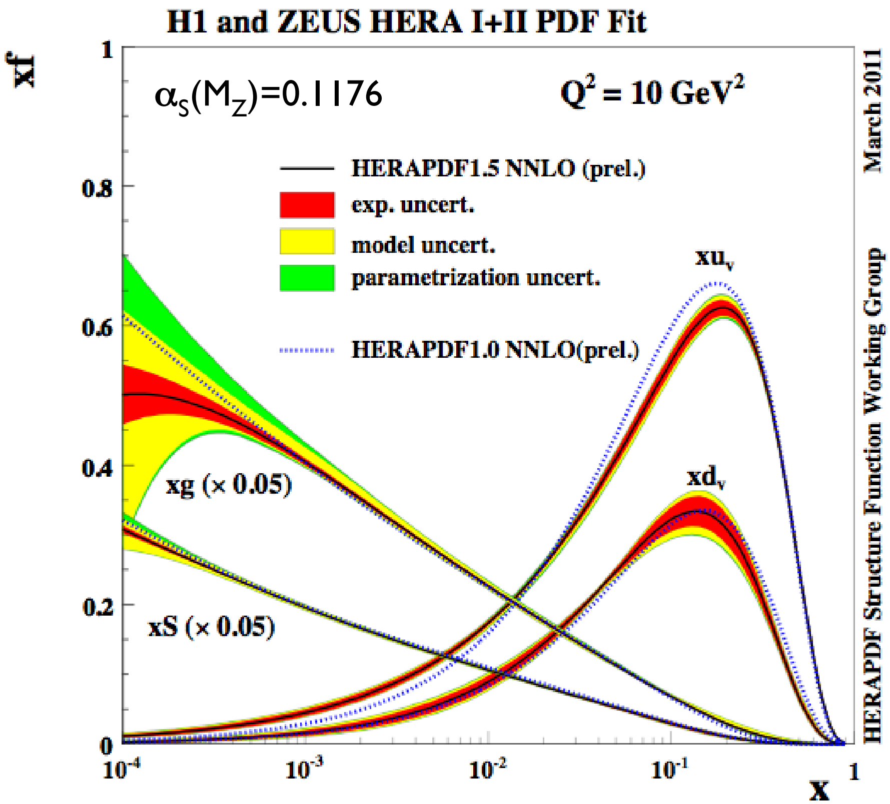


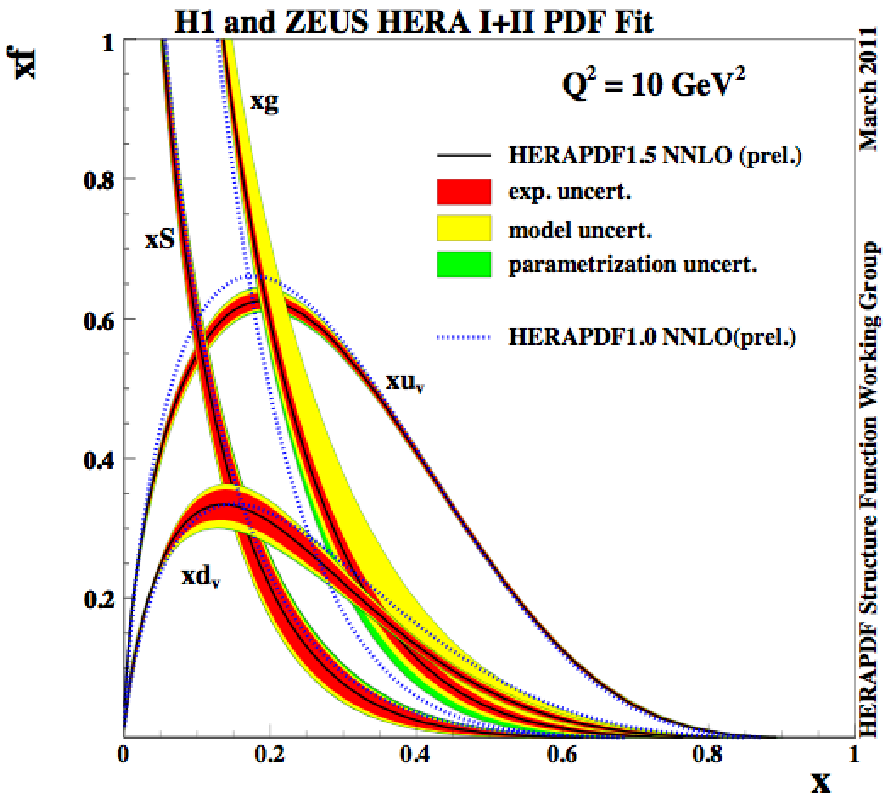


- No much difference for valence PDFs
- Sea is a little steeper
- Gluon more valence like:
  - The low x gluon has larger uncertainty (Q^2min cut)
- NNLO DGLAP not a better fit that NLO to low x, Q^2 data

HERAPDF1.5 vs HERAPDF1.0 @ NNLO

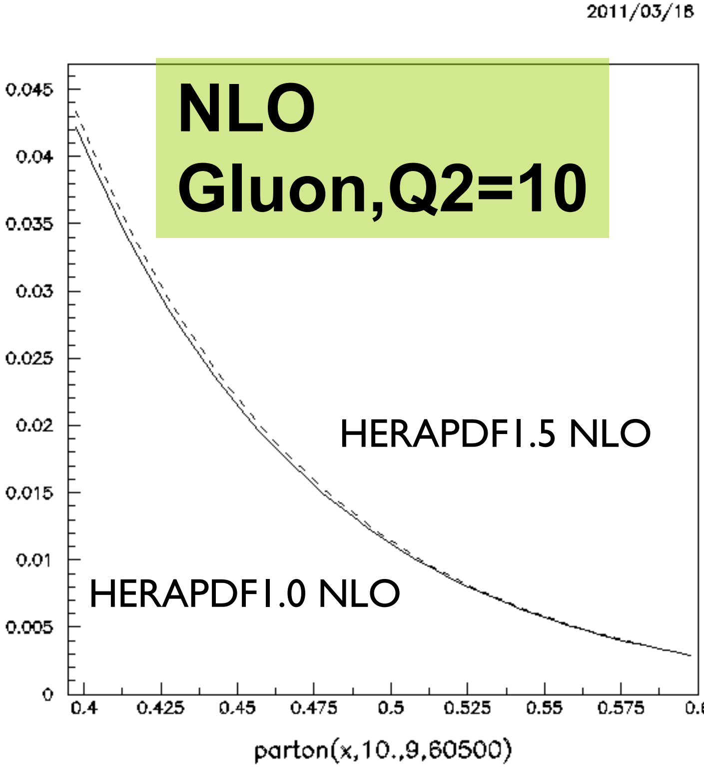
- Previously we have issued HERAPDF1.0 @ NNLO, but without error band

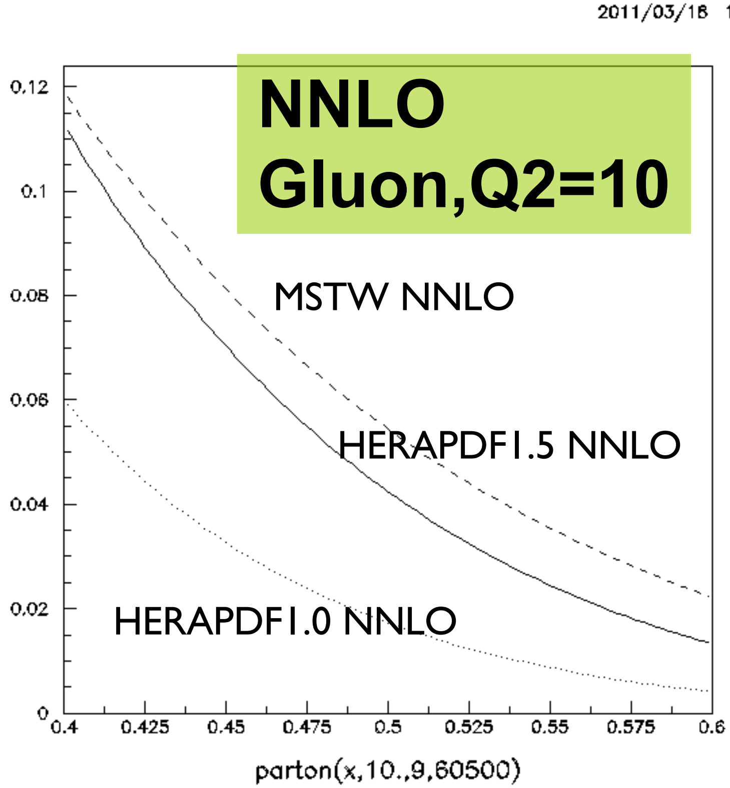




- HERAPDF1.5NNLO has a harder high-x gluon than HERAPDF1.0
  - Hence, would give a better agreement with Tevatron data
- HERAPDF1.5 NNLO (and NLO) is available for a series of $\alpha_S(M_Z)$ values and with experimental, model and parametrisation uncertainties on LHAPDF5.8.6

More on gluon HERAPDF



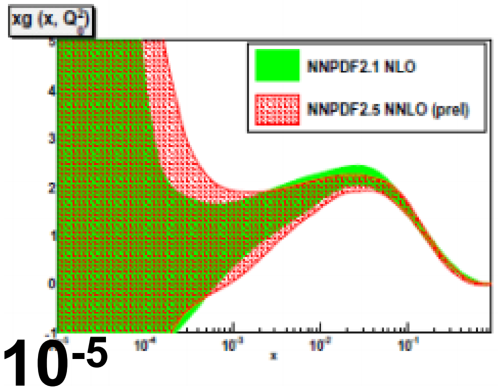


Differences between HERAPDF1.0 and HERAPDF1.5:

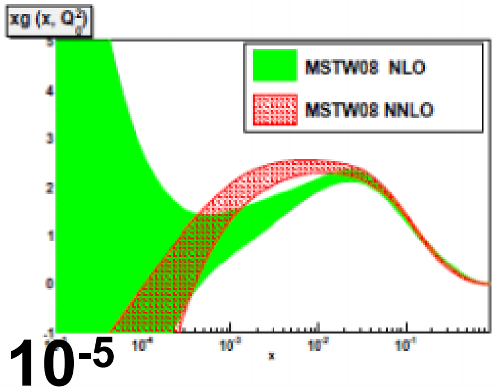
- minimal at NLO
- large at NNLO

HERAPDF1.5 NNLO uncertainties are comparable to NNPDFs

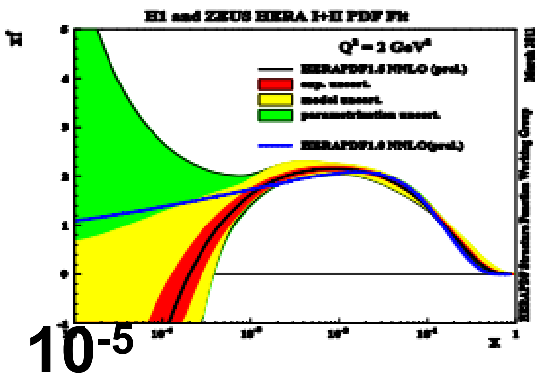
NNLO -- NNPDF2.1



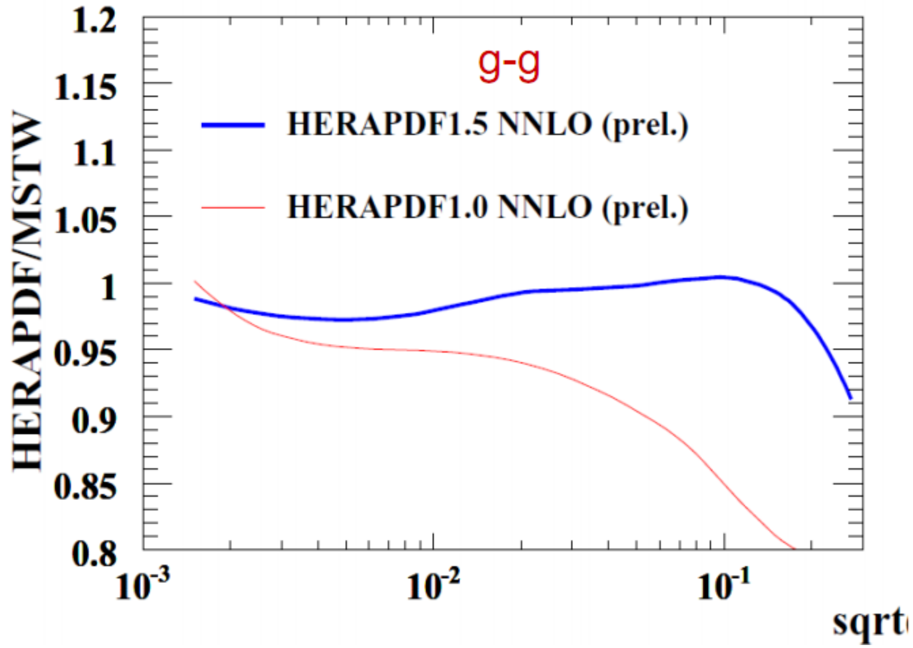
Compare MSTW

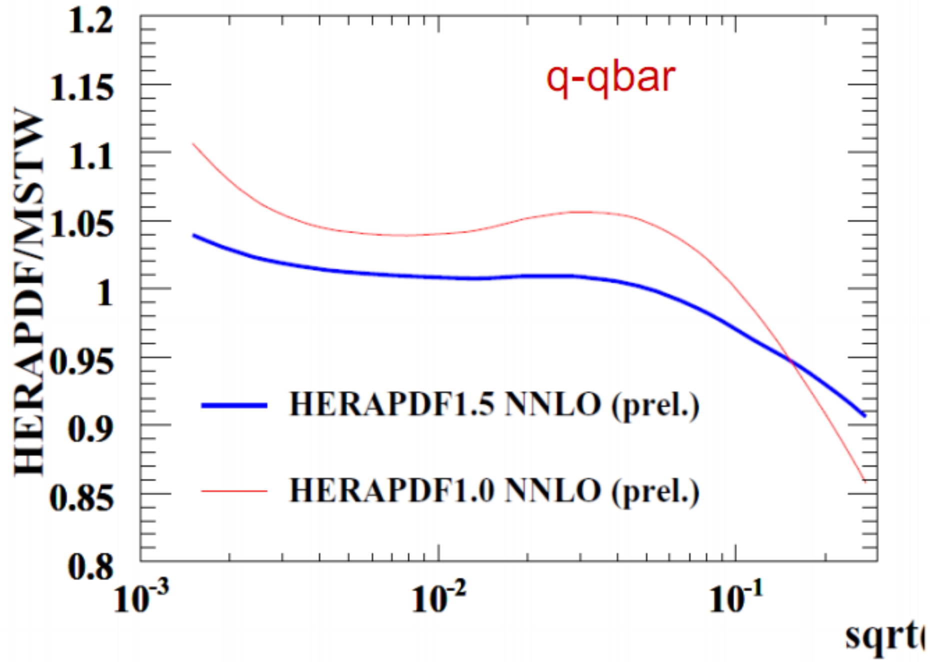


Compare HERAPDF1.5



LHC@7 TeV parton-parton



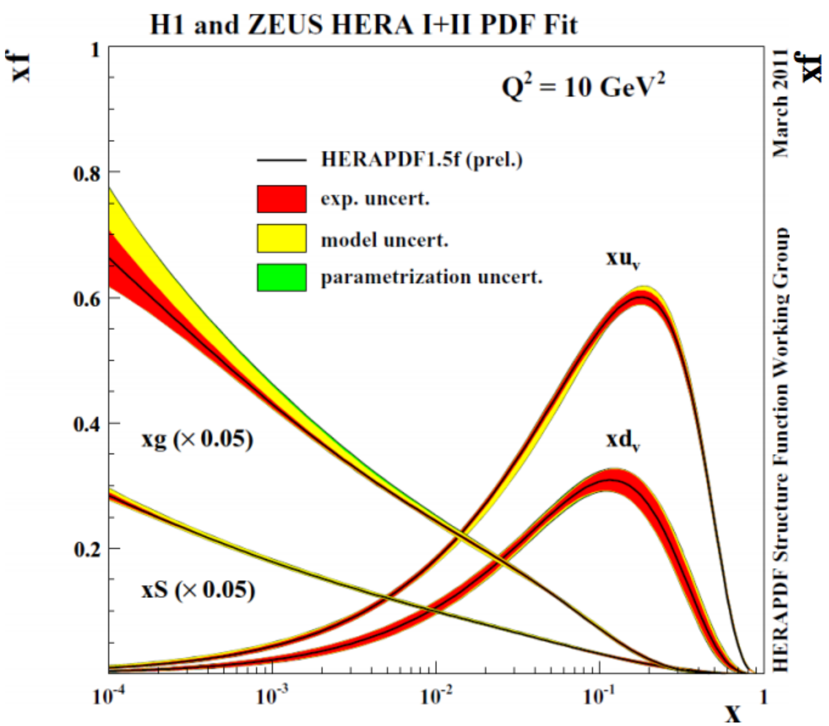


HERAPDF1.5f with free alphas

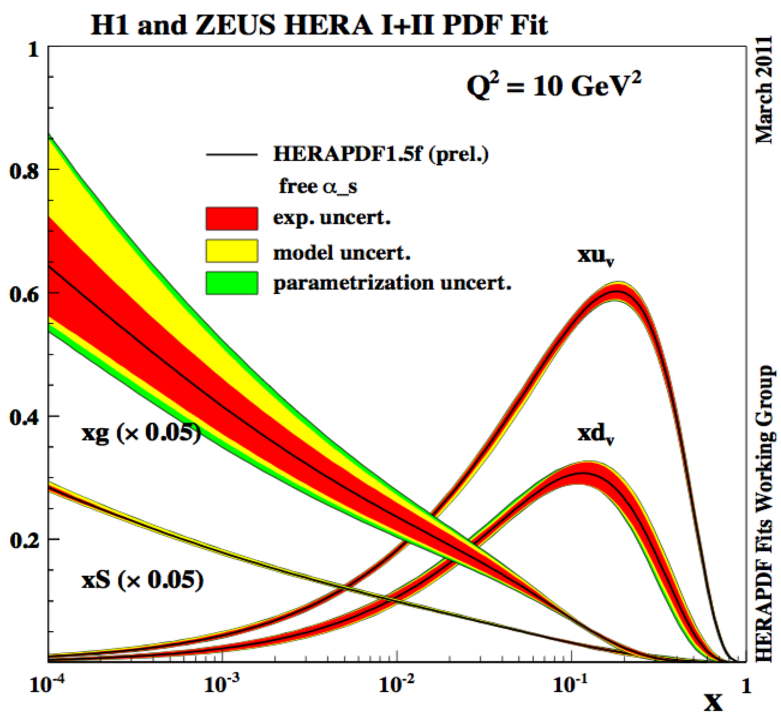
- The strong coupling is tightly correlated to the gluon PDF in fits to inclusive data where gluon is determined from the scaling violations:
  - Comparison of the PDFs (fixed alphas) and PDF+alphas fit using DIS inclusive data only:

NO JETS, HERAPDf1.5f:

Fixed alphas=0.1176 (no jets)



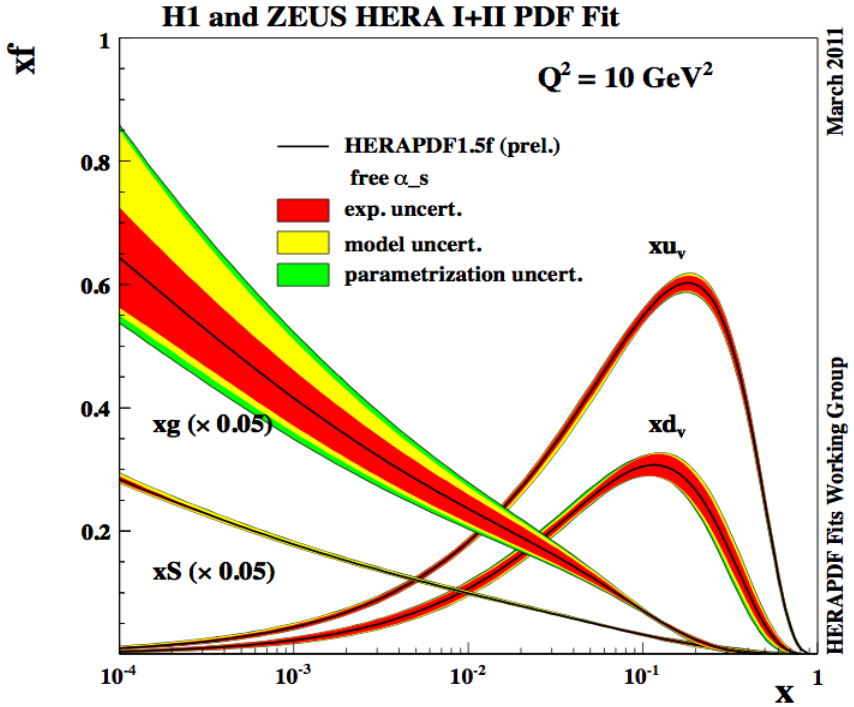
Free alphas (no jets)



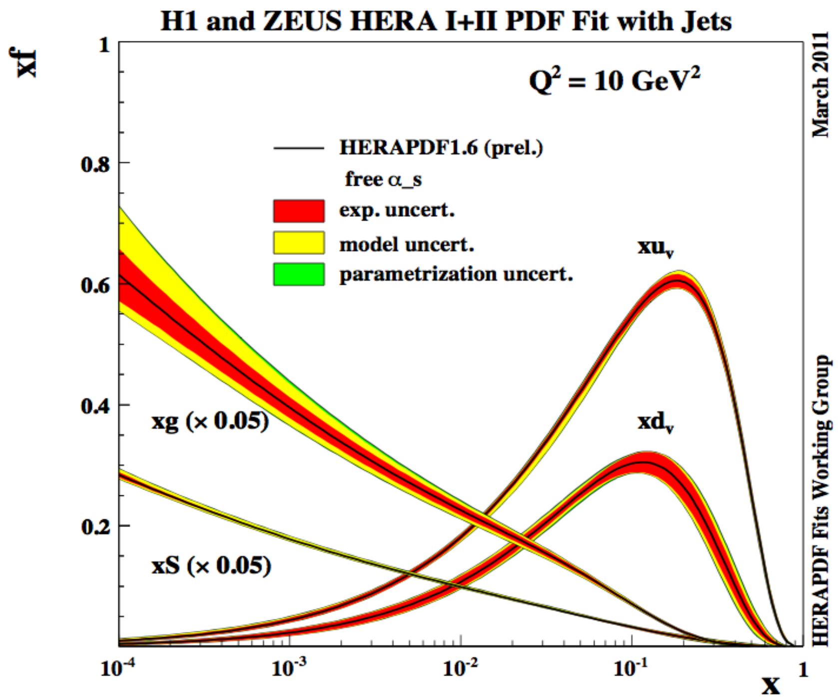
Including Jets: HERAPDF1.6

- The strong coupling is tightly correlated to the gluon PDF in fits to inclusive data where gluon is determined from the scaling violations
- Addition of the HERA Jet cross section data (NLOJet++/fastNLO) into the fits allows to constrain simultaneously alphas and gluon [not yet combined jet data, H1 and ZEUS]
  - Comparison of the PDFs with free alphas fit with and without Jet data

Free alphas (no jets)



Free alphas (with jets)

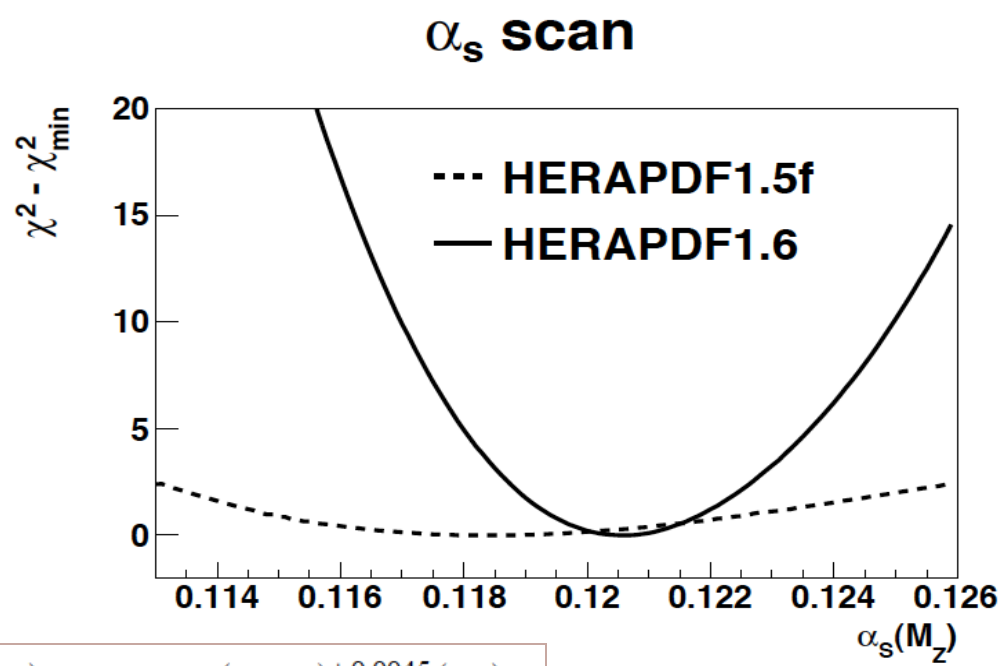


- The uncertainty on the low-x gluon is reduced dramatically once Jet data is included in the fit:

Impact of the jet data on α_S

- Comparison of the chisquare scan versus strong coupling for:
  - HERAPDF1.5f - no jet data
  - HERAPDF1.6 - with jets

- Without jet data the chisquare has only a shallow dependence on strong coupling



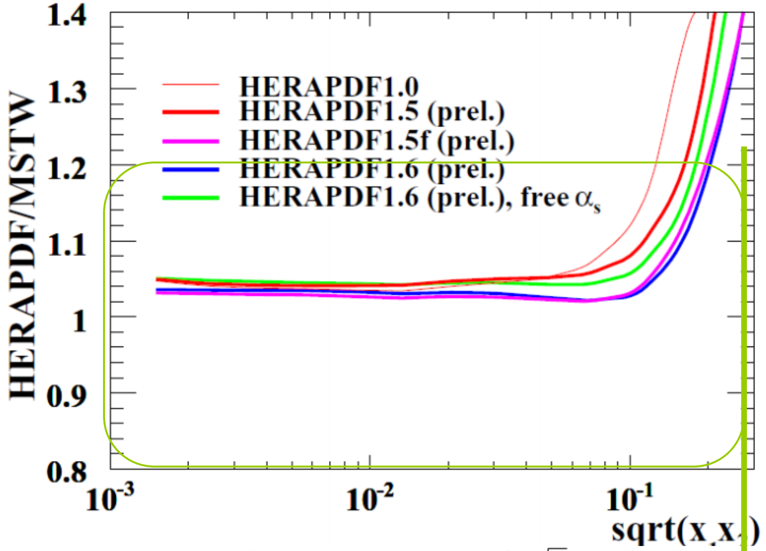
$\alpha_S(M_Z)$ = 0.1202 ± 0.0019 ± scale error

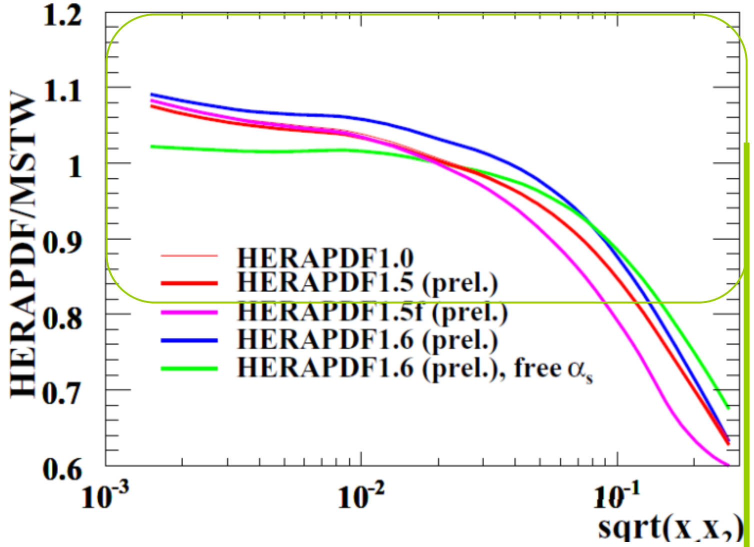
$$\alpha_s = 0.1202 \pm 0.0013\,(\exp) \pm 0.0007\,(mod) \pm 0.0012\,(had)^{+0.0045}_{-0.0036}\,(th)$$

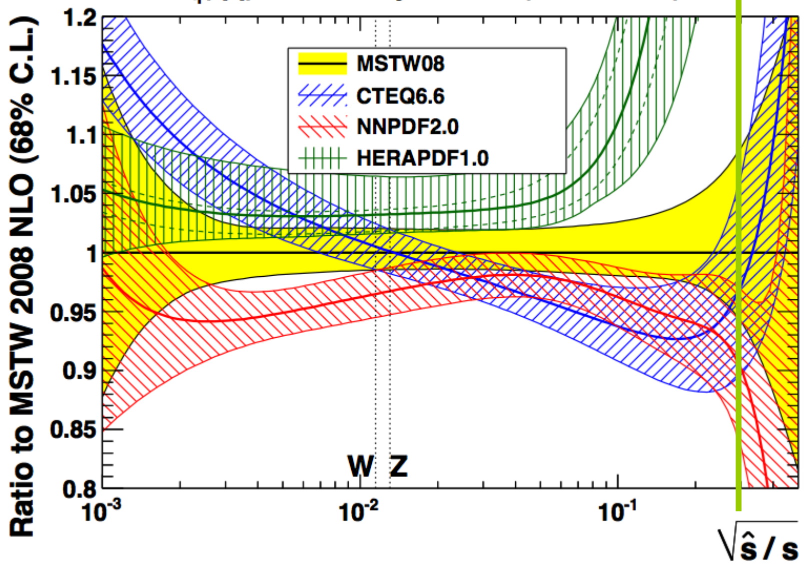
- Jet data have non negligible correlated errors (~5%) which are treated fully correlated
- Predictions for jet cross sections need hadronisation corrections and the uncertainties of the hadronisation corrections are evaluated by OFFSET method (for now)
- The scale error is evaluated by changing the renormalisation and factorisation scales of both the inclusive and jet data by a factor 2:
  - Dominant is the jet renormalisation scale

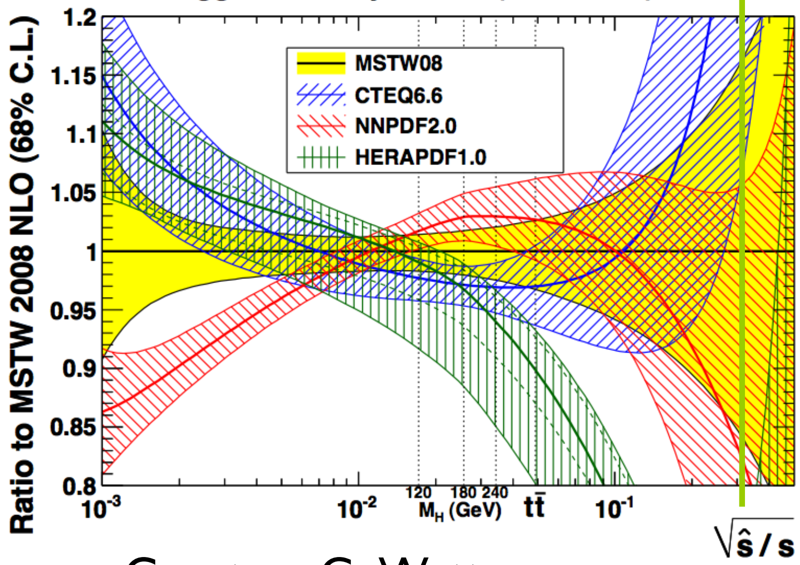
Luminosity plots for 7 TeV

- q-qbar luminosity at NLO (for W,Z) g-g luminosity at NLO (for





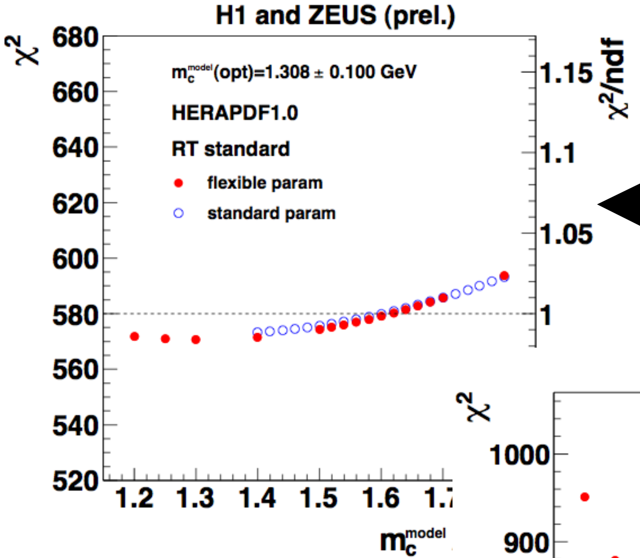




Courtesy G. Watt

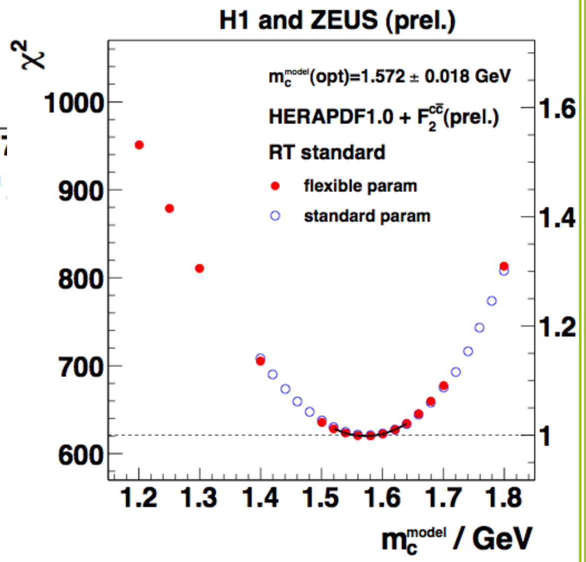
Extra studies at HERA using charm and low energy data

- Addition of the HERA combined F_2 charm data can help reduce model uncertainty of m_c(1.35-1.65):
  - Inclusive data has no sensitivity, while addition of the charm data does.

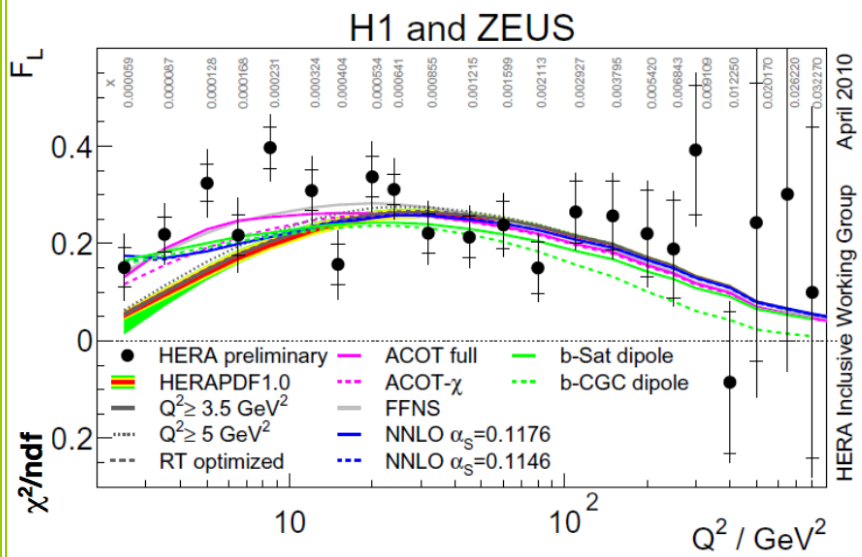


without charm data

Including charm data



- Addition of the HERA combined lower proton energy data provides more sensitivity to the gluon PDFs at low x, low Q^2

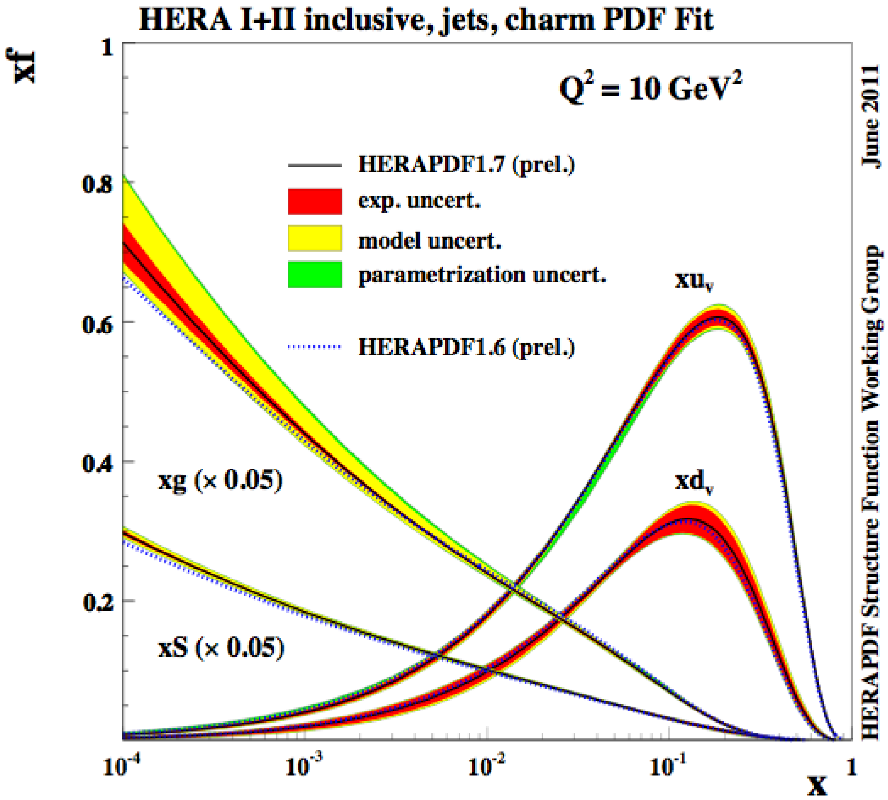


What happens when we put all data together?
DIS inclusive, Jets, Charm, LEN
HERAPDF1.7

HERAPDF1.7 (NLO)

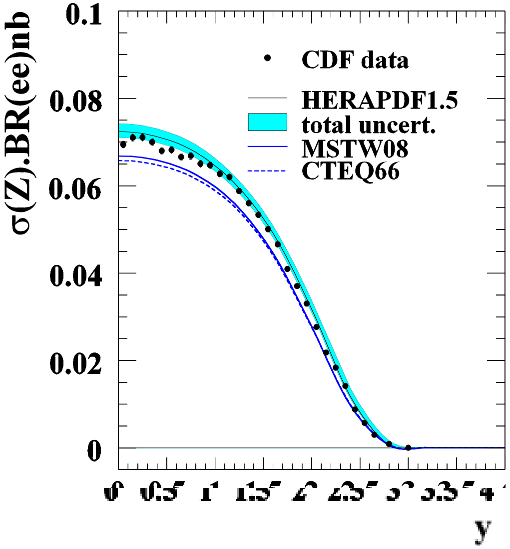
- Data Sets:
  - Combined HERA I+II data (prelim)
  - Combined HERA Charm data (prelim)
  - Combined HERA II low energy data
  - Separate H1 and ZEUS jet data

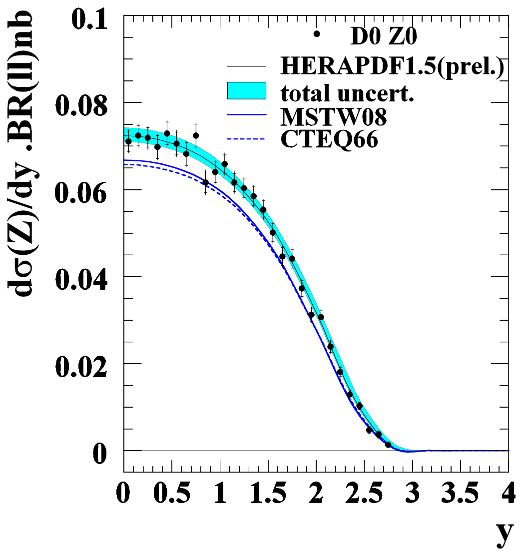
- Adjustments of the settings:
  - Use extended parametrisation
  - Use RT optimised version with its prefered value of mc=1.5 GeV
    - From the studies based using charm data
  - Raise the value of strong coupling from 0.1176 to 0.1190
    - From the studies using jet data



Predictions based on HERAPDFs
to
Tevatron and LHC data

HERAPDF predictions vs Tevatron: Z rapidity



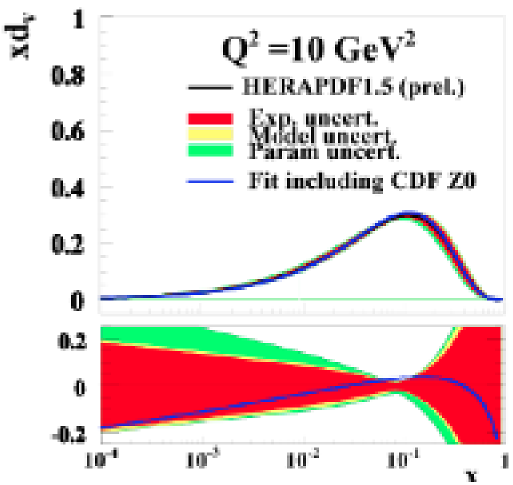


The description of CDF and D0 Z rapidity by HERAPDF1.5 is good:

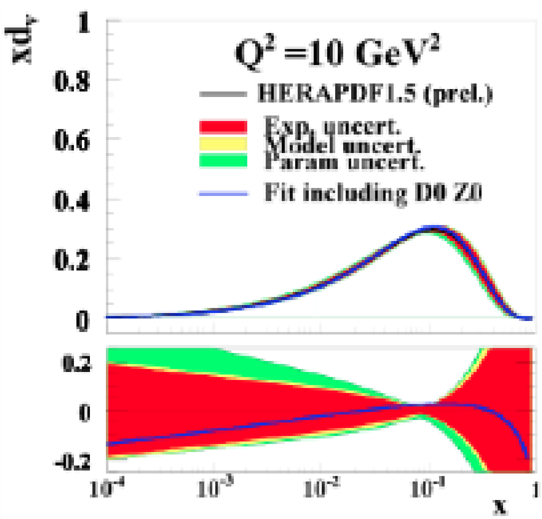
- Without fitting these data (without taking into account PDF uncertainties):
  - $\chi2$/dof=36/28 CDF - more precise data
  - $\chi2$/dof=23/28 D0
- After fitting these data:
  - $\chi2$/dof=27/28 CDF
  - $\chi2$/dof=16/28 D0

Question is: does this fit lies within the uncertainties of HERAPDF1.5?

CDF

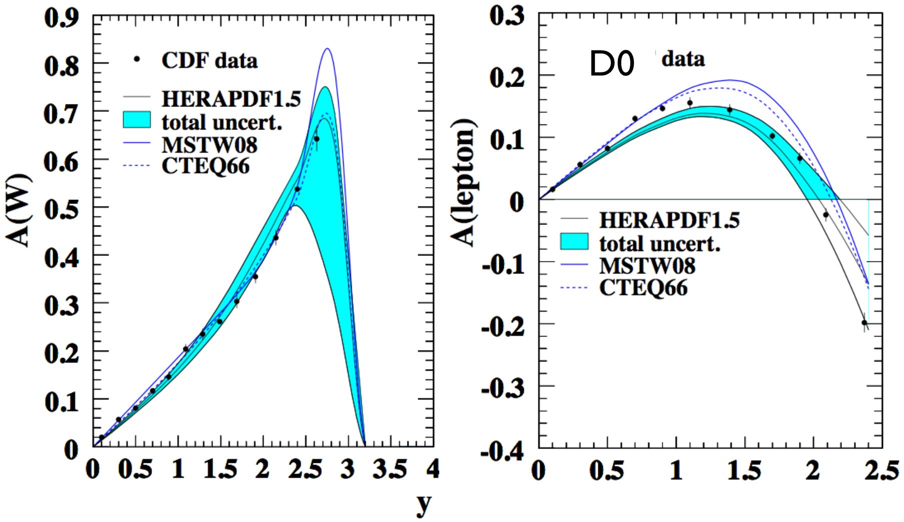


D0



- The blue line is the new fit which includes the Tevatron data :
- The impact of Tevatron Z rapidity data on PDF shape is within uncertainties of HERAPDF

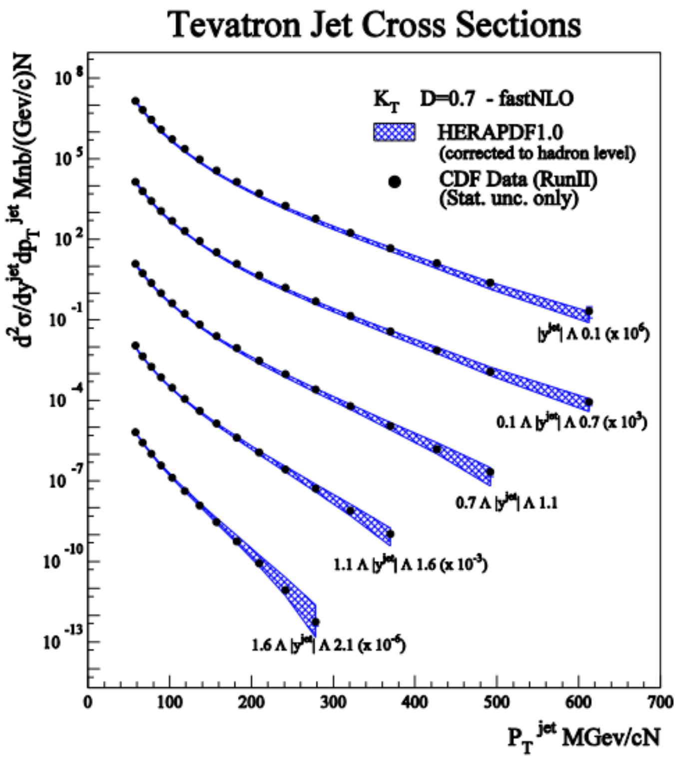
HERAPDF predictions for Tevatron: Asymmetry and jets



Even without fitting the asymmetry data the agreement is pretty ok.

After fit:

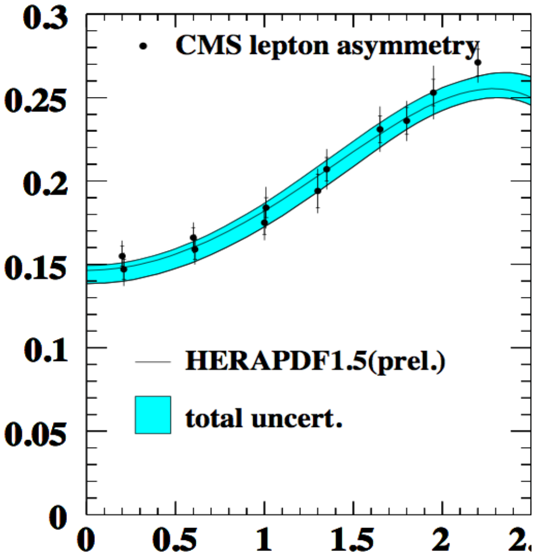
- $\chi 2$/dof=19/13 CDF
- $\chi 2$/dof=25/11 D0
- the resulting PDFs lie within the HERAPDF1.5 error band



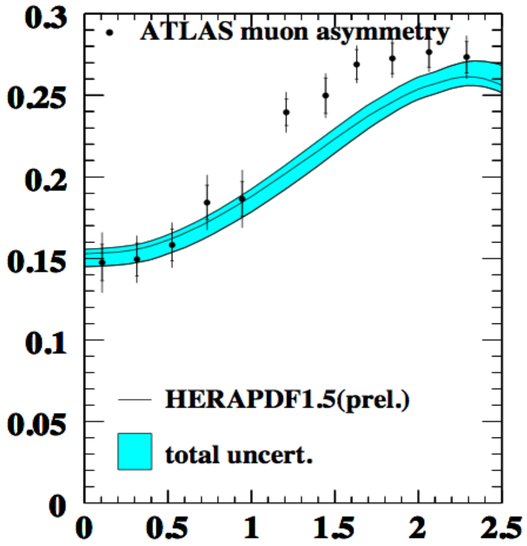
Quantitative description of the Tevatron Jet Data:

- Based on HERAPDF1.5 (NLO):
  - Before fit : 176/76 (central line)
    - Similar to HERAPDF1.0 due to the same high x gluon between 1.0 and 1.5
  - After fit: 113/76
- HERAPDF1.5 NLO describes Tevatron Data within uncertainties!
- HERAPDF1.5 NNLO: NO fit: 72/76

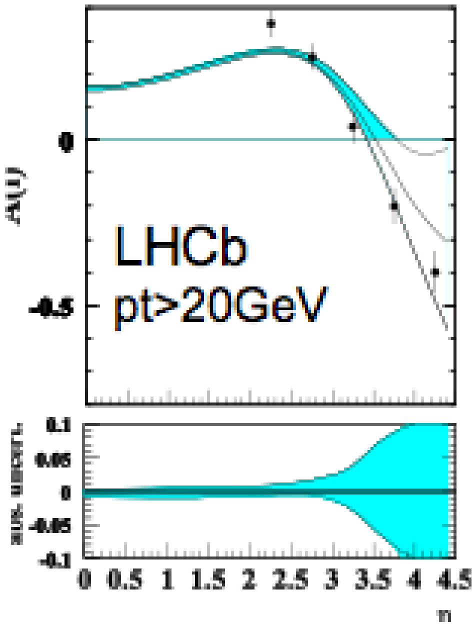
HERAPDF predictions for LHC data



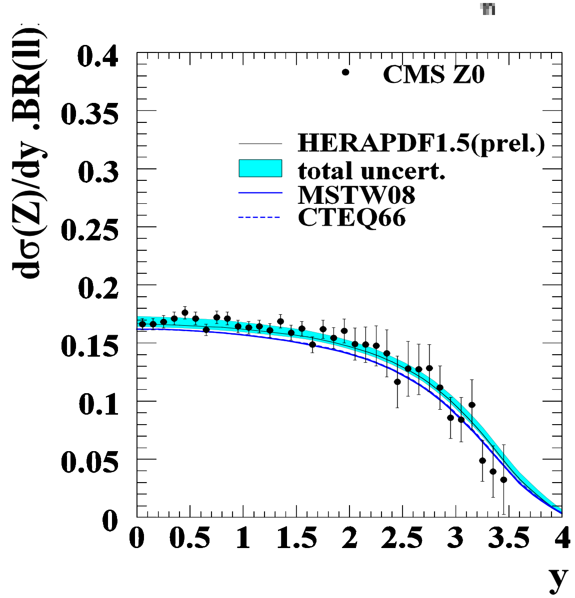
$P_{t,e} > 25$ GeV



$P_{t,e} > 20$ GeV, $P_{t,miss} > 25$ GeV

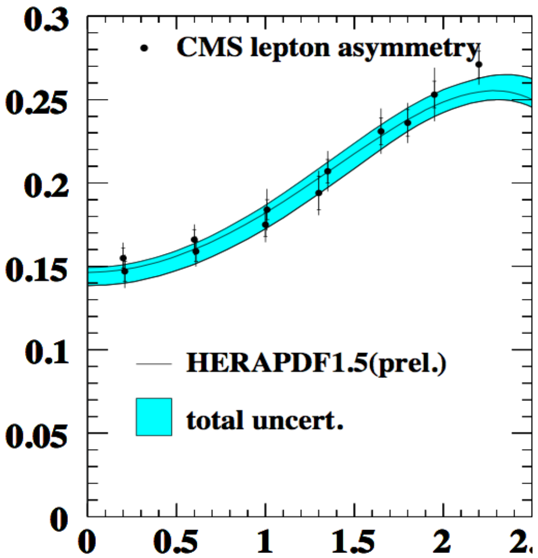


Early LHC data are described fairly well and if these data are fit the PDFs lie within the HERAPDF1.5 error band



	Before fit	After
▪ W asymmetry CMS:	χ^2/dof=6.5/12	3.7/12
▪ W asymmetry ATLAS:	χ^2/dof=30/11	16/11
▪ W asymmetry LHCb:	χ^2/dof=9/5	8/5
▪ Z distribution CMS:	χ^2/dof=35/35	16/35

HERAPDF predictions for LHC data



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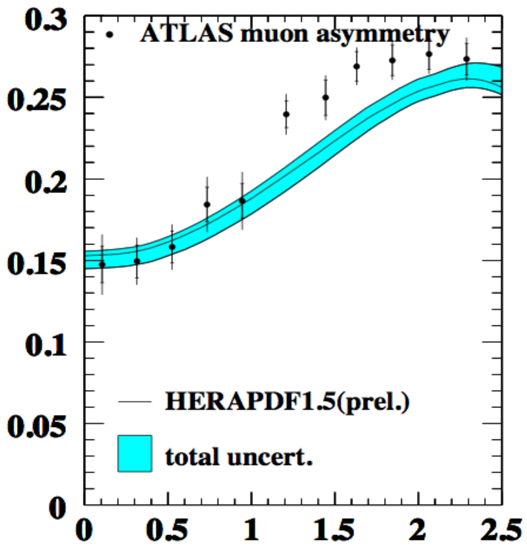
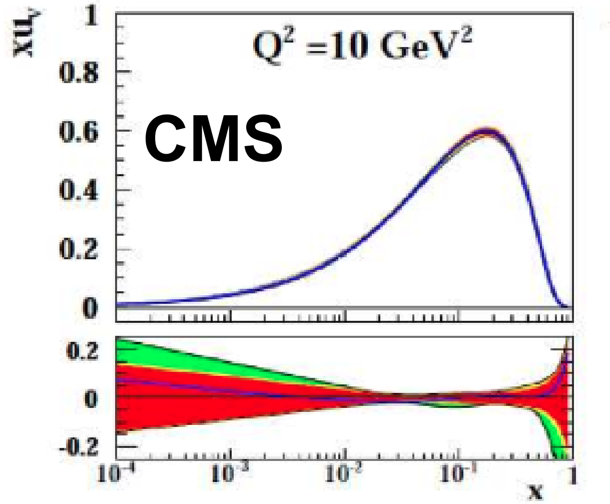
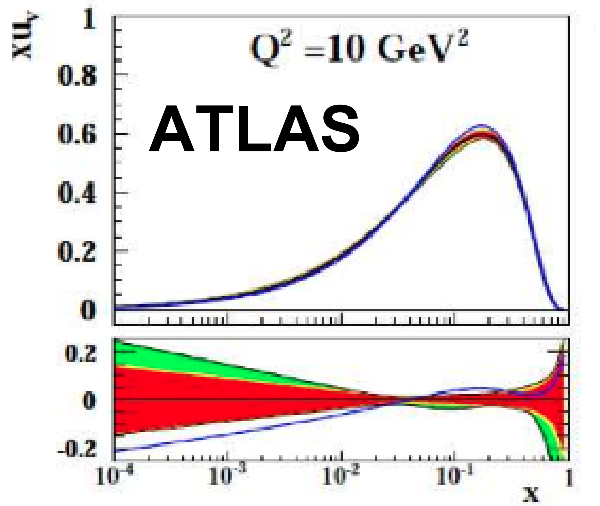


$P_{t,e} > 20$ GeV, $P_{t,miss} > 25$ GeV



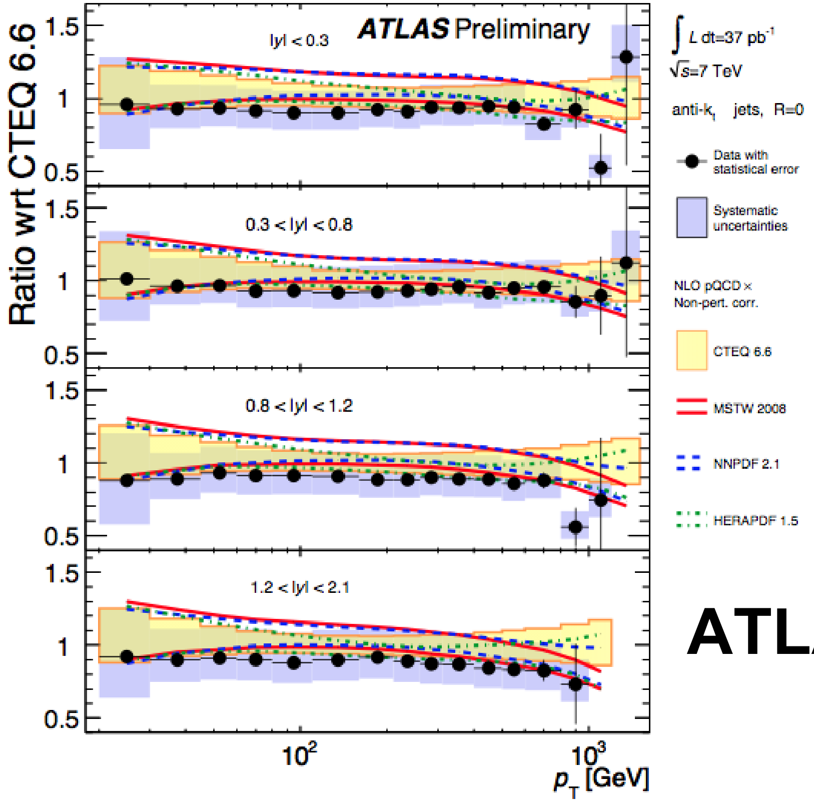


Early LHC data are described fairly well and if these data are fit the PDFs lie within the HERAPDF1.5 error band

	Before fit	After
W asymmetry CMS:	χ^2/dof=6.5/12	3.7/12
W asymmetry ATLAS:	χ^2/dof=30/11	16/11

★ ATLAS and CMS pull u_val in opposite directions

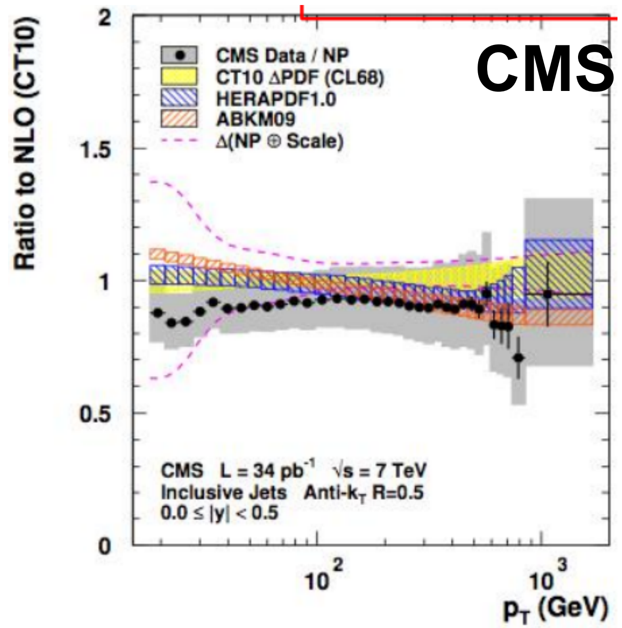
Predictions for LHC Jet Data

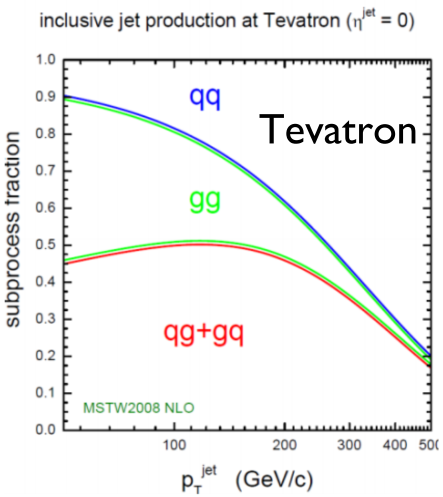


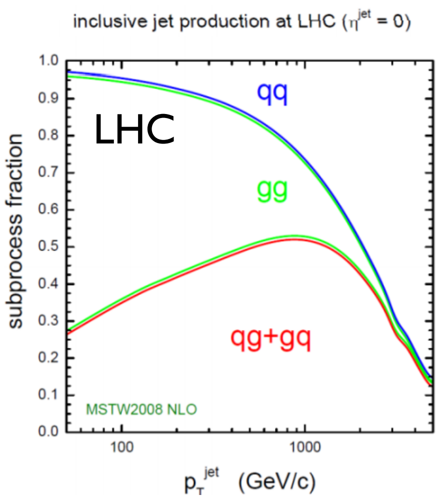
ATLAS

ATLAS and CMS jet measurement based on complete 2010 data;

- Best agreement for ATLAS seems to be with HERAPDF1.5, however experimental/theoretical uncertainties are sizeable
- The PDFs that fit the Tevatron jets best are not necessarily those that fit the LHC ones:
  - The mixture of q-q, q-g, g-g induced jets is different.







Summary

- HERAPDF fits provide basis for QCD analysis with a consistent and high accuracy input data having well understood systematic uncertainties.

- Inclusion of the HERA ep jet data allows for determination of the strong coupling simultaneously with a dramatic reduction in low-x gluon uncertainty for free alphas fit in the PDF fitting.

- DIS scattering at HERA provides good description of Tevatron and LHC results.

Extra

What DIS jet data in HERAPDF1.6?

- High Q^2 (Q^2>125 GeV2) inclusive jet production from ZEUS (HERA I)

[1 PLB547,164(2002), 1 NPB765,1(2007)]

  - Scale of the jet measurement: E_T of the leading jet
  - Experimental uncert: ~15 % uncorr, 5% corr
  - Theoretical error:~5-10%

- Low Q^2 (100>Q^2>5) inclusive jet production from H1 (HERA I)

[EPJC67,1(2010)]

  - Scale of the jet measurement: sqrt(E_T^2+Q^2)
  - Experimental uncert: ~9% uncorr, 8% corr
  - Theoretical uncert:~10-30%

- High Q^2 (Q^2>150) normalised jet cross-sections from H1 (HERA I+II)

[EPJC65,363(2010)]

  - Scale of the jet measurement: sqrt(E_T^2+Q^2)
  - Experimental error ~6% uncorr, 3% corr
  - Theoretical error: ~5-10%

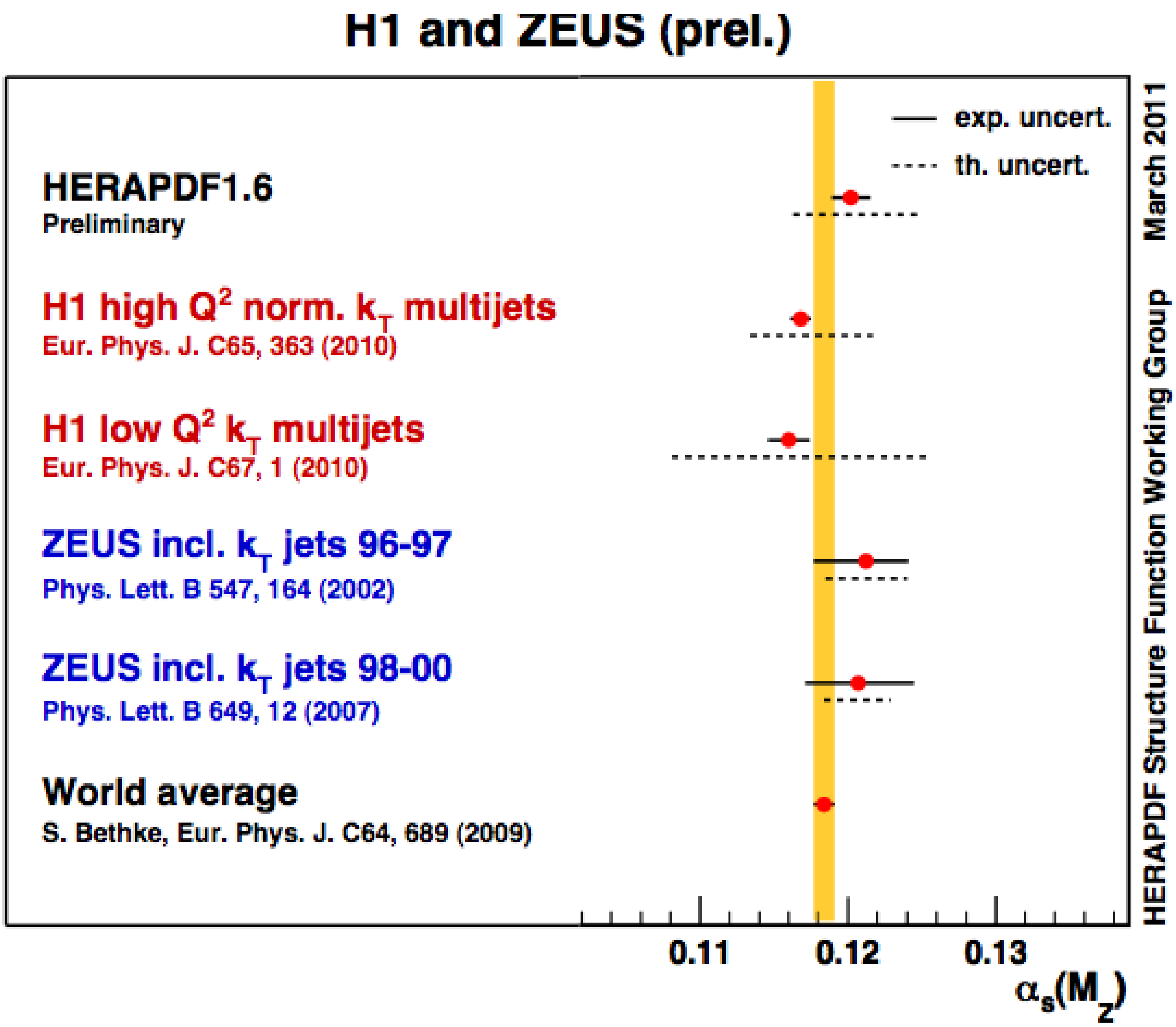
- NLOJet++/FastNLO used for the fast evaluation of the jet cross-sections

Effect of including jets

HERAPDF1.6 $\alpha_S(M_Z)$ =0.1176 fixed	$\chi 2$	ndp
All data	811.5	780
Inclusive cross sections	730.2	674
Jet cross sections	81.3	106

HERAPDF1.6 $\alpha_S(M_Z)$ free	$\chi 2$	ndp
All data	807.6	780
Inclusive cross sections	730.0	674
Jet cross sections	77.6	106 9

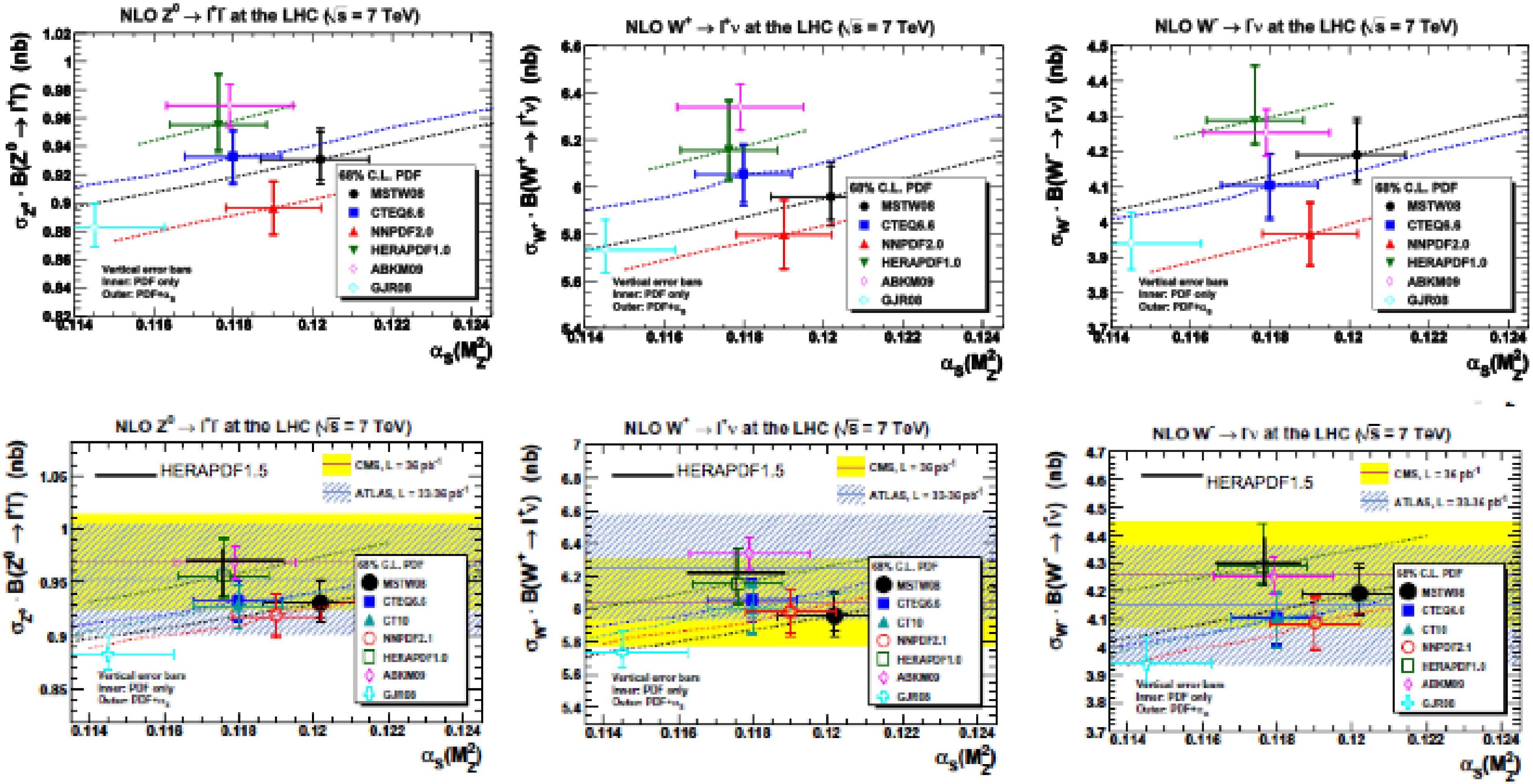
Effect of including jets



- For HERAPDF1.6
  - PDF uncertainty is part of the experimental uncertainty
- For H1:
  - PDF uncertainty is part of the theoretical uncertainty
- For ZEUS:
  - PDF uncertainty is part of the experimental uncertainty

NNPDF2.0 has been updated to NNPDF2.1 using FONLL VFN

CTEQ6.6 to CT10 ABKM09 to ABM11 HERAPDF1.0 to HERAPDF1.5

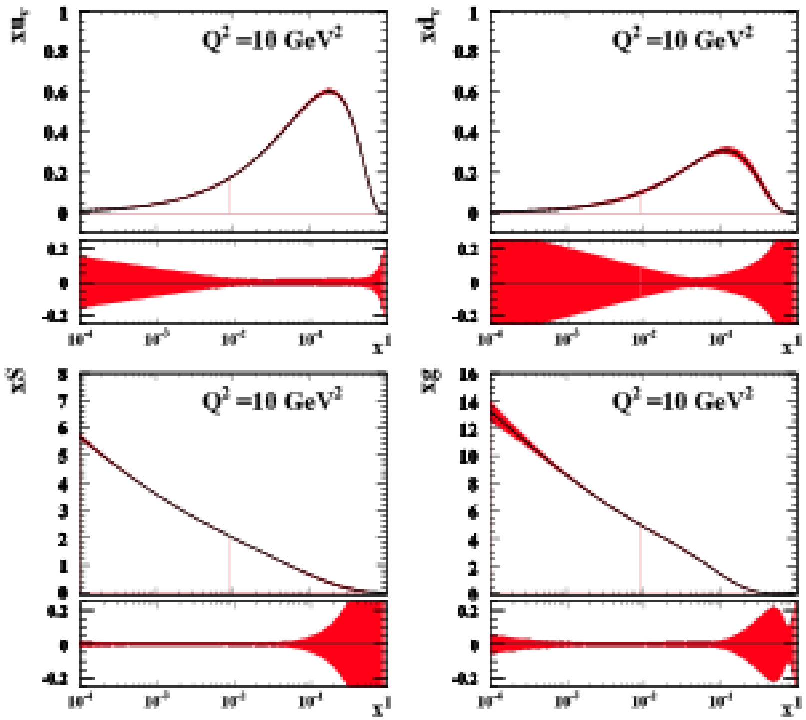


The use of the VFN scheme puts NNPDF2.1 closer to MSTW,

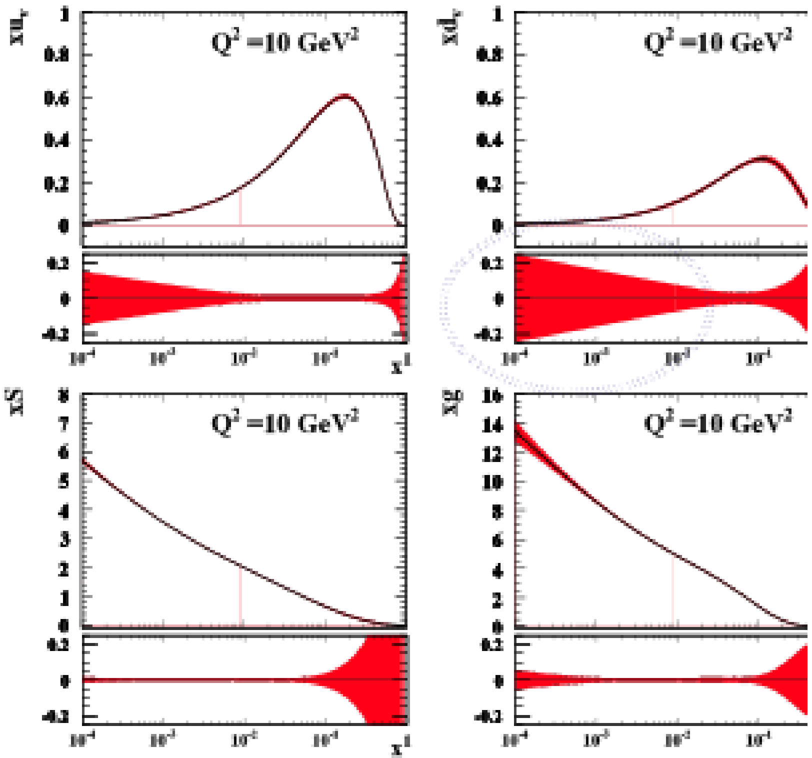
CT10 and CTEQ6.6 are very similar, HERAPDF1.5 is a little higher than 1.0 for W+,Z

Impact of Tevatron Z rapidity on PDF uncertainties

- HERAPDF1.5 (ref)



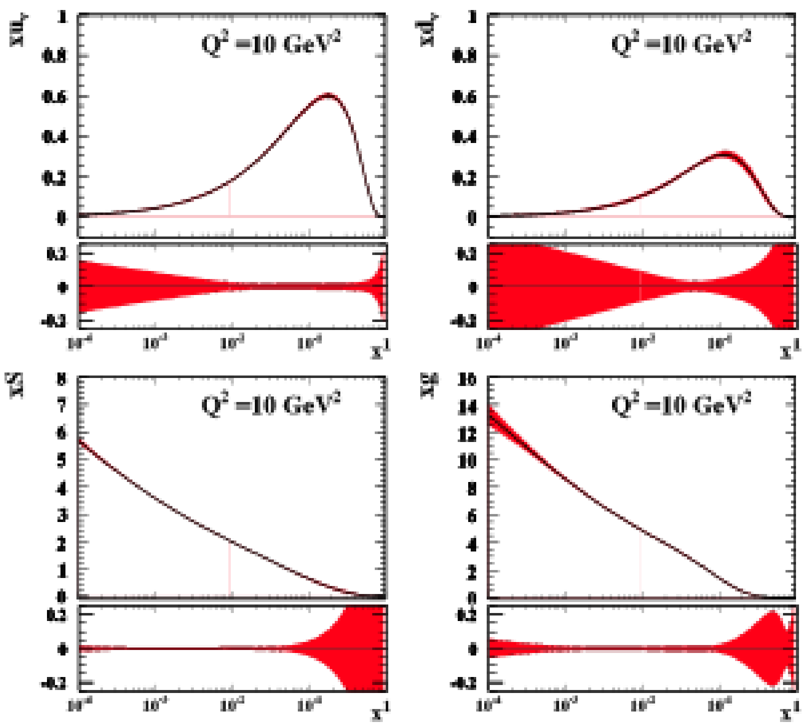
HERA+CDF (Z rapidity data



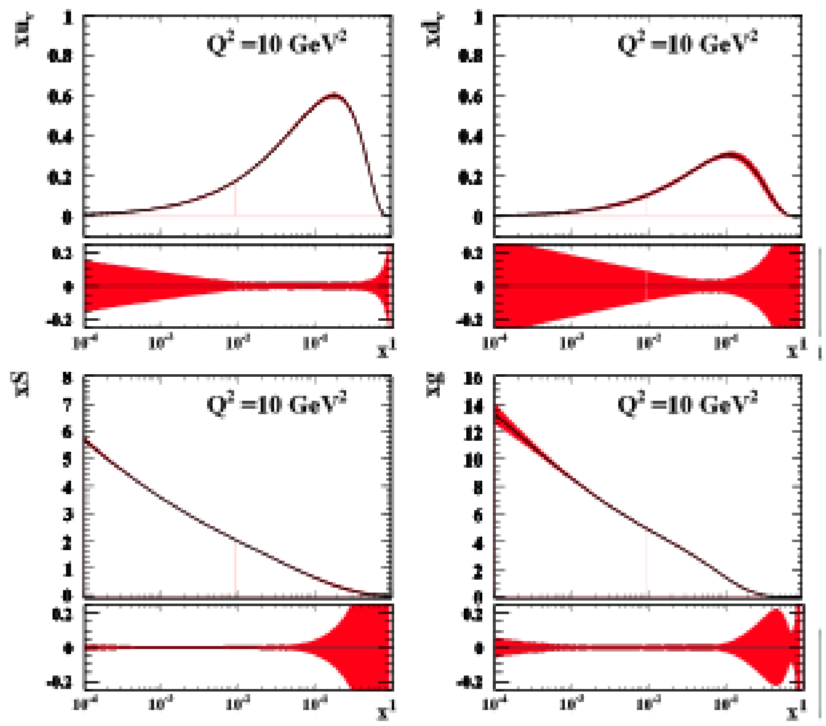
- Based on experimental errors only:
  - Observe some improvement in dvalence once CDF Z rapidity data is added

Impact of Tevatron Z rapidity on PDF uncertainties

- HERAPDF1.5 (ref)



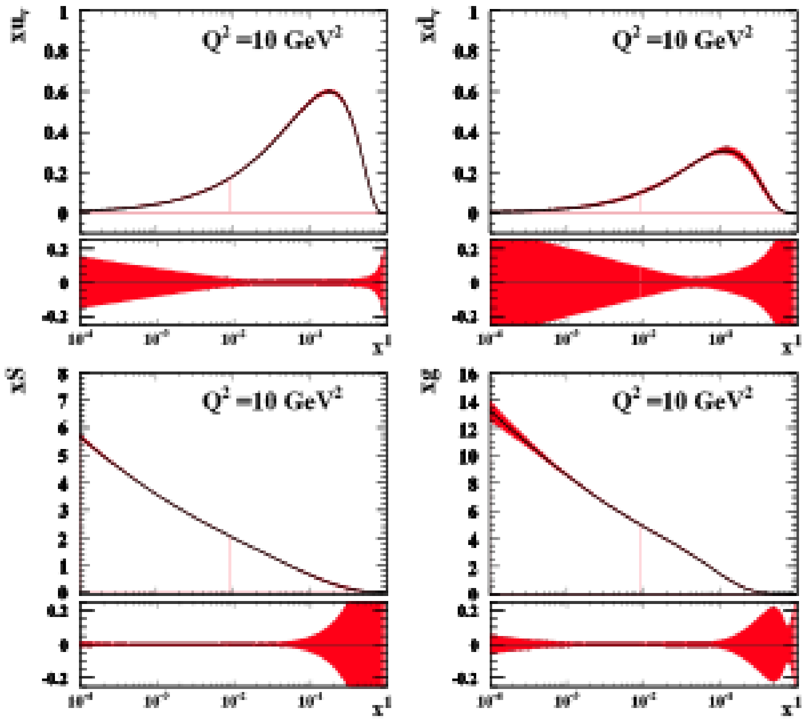
HERA+D0 (Z rapidity data)



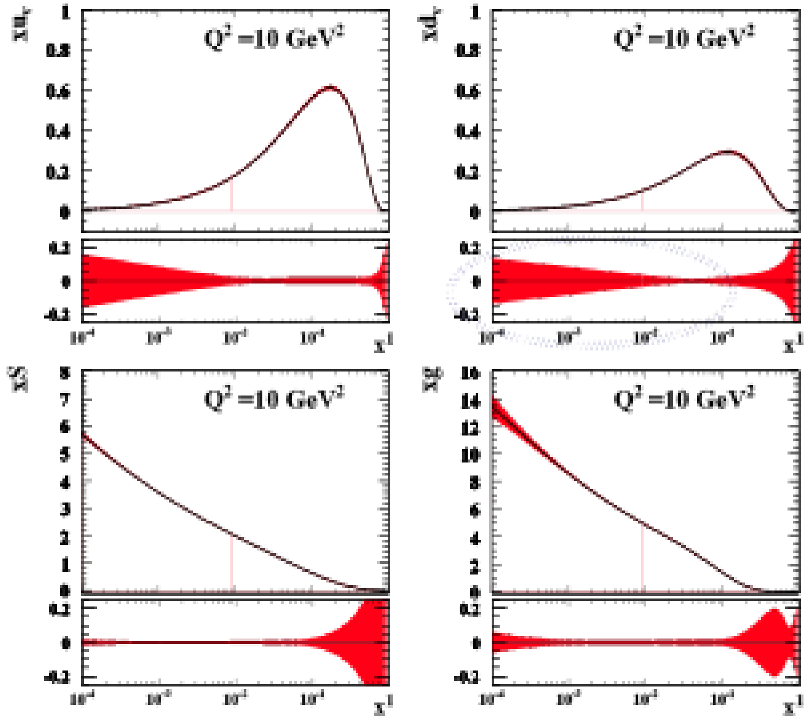
- Based on experimental errors only:
  - Observe some improvement in dvalence once CDF Z rapidity data is added and even less for D0 data (less precise)

Impact of Tevatron W asymmetry on PDF uncertainties

- HERAPDF1.5 (ref)



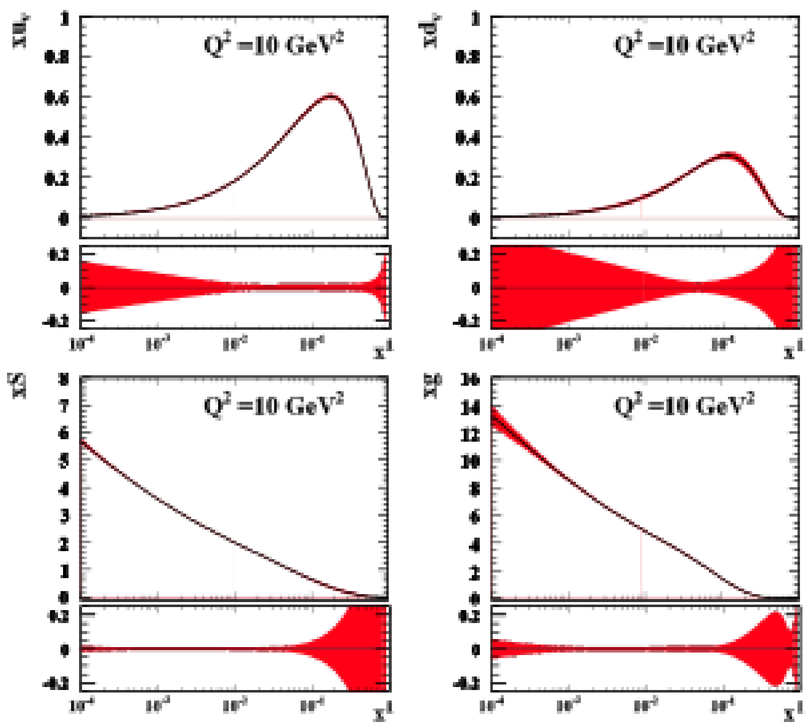
HERA+CDF (W asymmetry data)



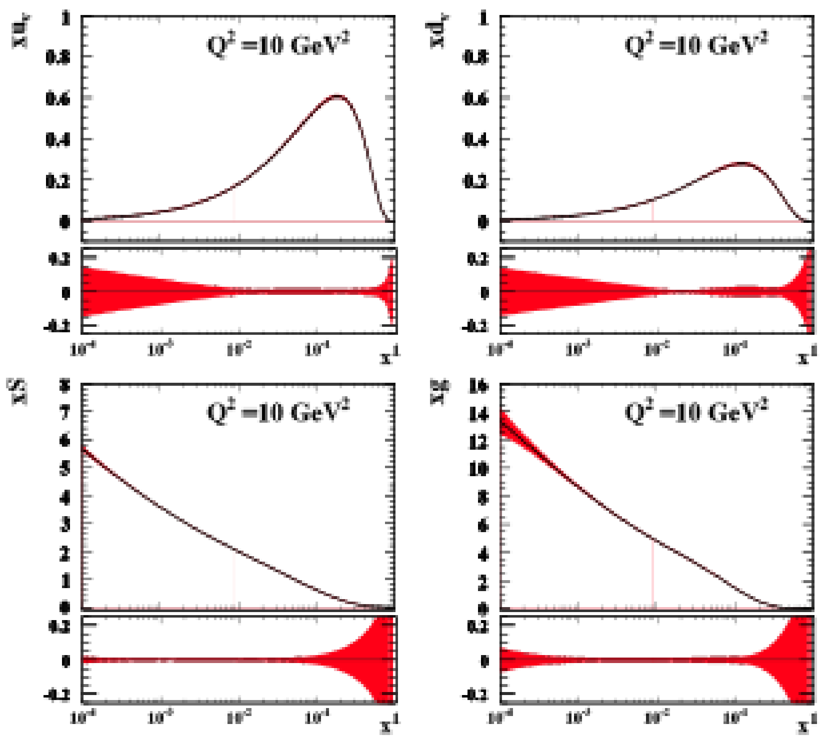
- Based on experimental errors only:
  - Observe large improvement in dvalence once CDF W asymmetry data is added

Impact of Tevatron W asymmetry on PDF uncertainties

- HERAPDF1.5 (ref)



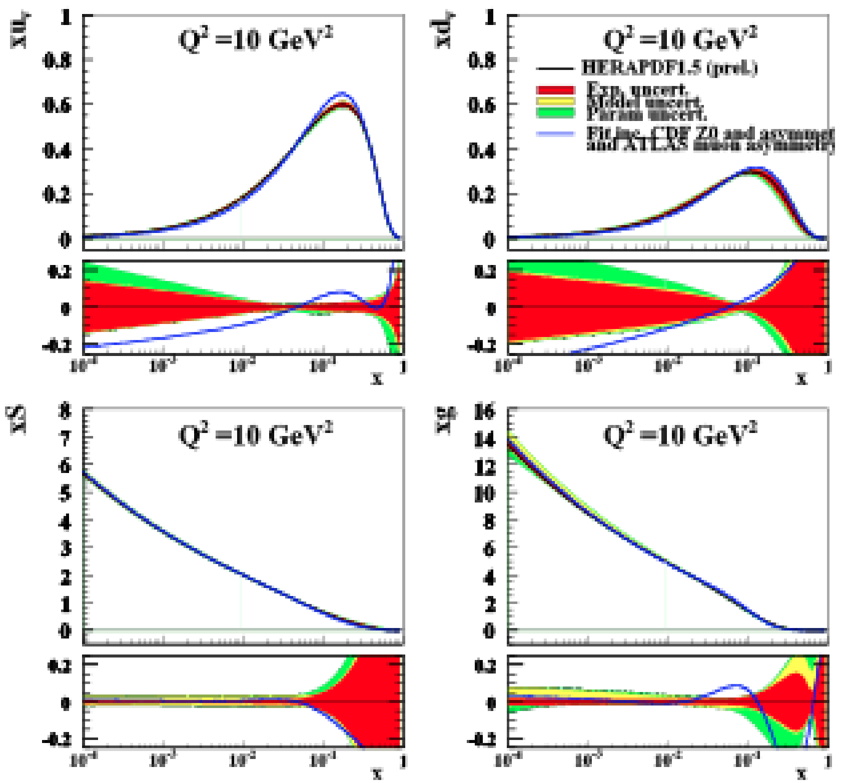
HERA+D0 (W asymmetry data)

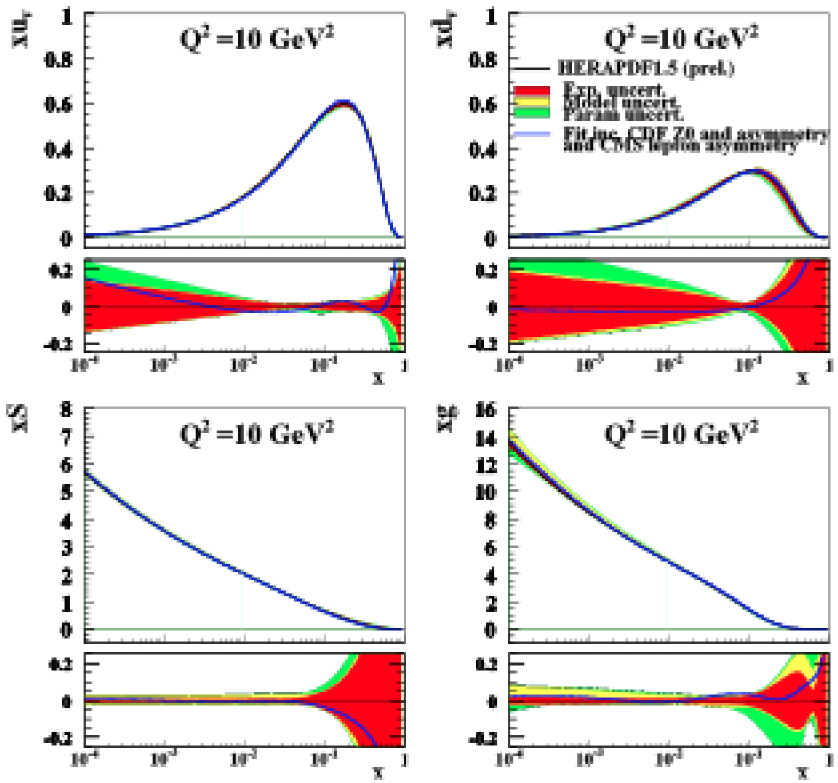


- Based on experimental errors only:
  - Observe large improvement in dvalence once CDF W asymmetry data is added
  - Similar impact from D0 as well.

Fits to HERA and Tevatron and LHC data

- To better assess the impact on the PDF uncertainties of the LHC data best is to use LHC data on top of HERA and Tevatron data:





HERA+CDF yZ+CDF W asymm+ATLAS

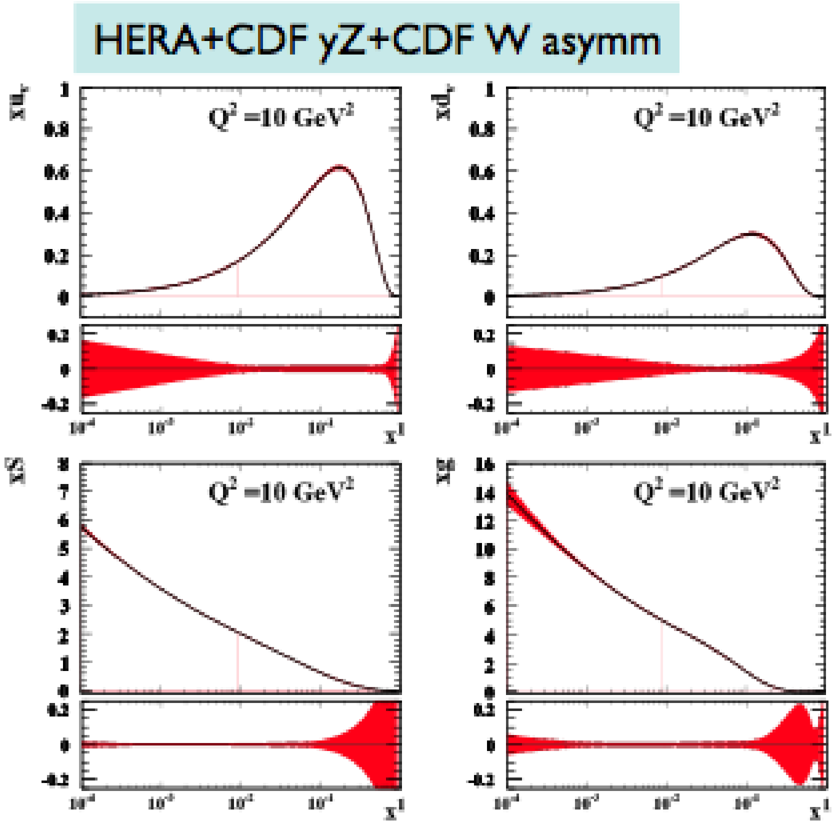
HERA+CDF yZ+CDF W asymm+CMS

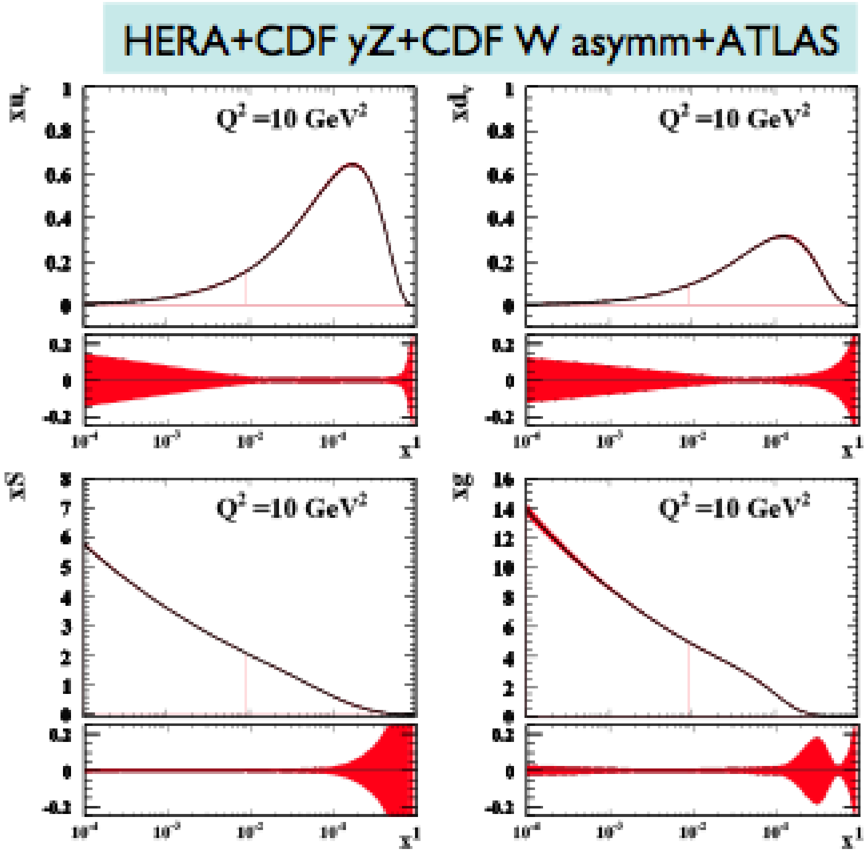
X2/ndp = 27/28, 14.4/13 and 14.2/11

X2/ndp = 26/28, 18.9/13 and 4.5/12

- Shape changes when adding ATLAS   Shape does not changes when adding CMS

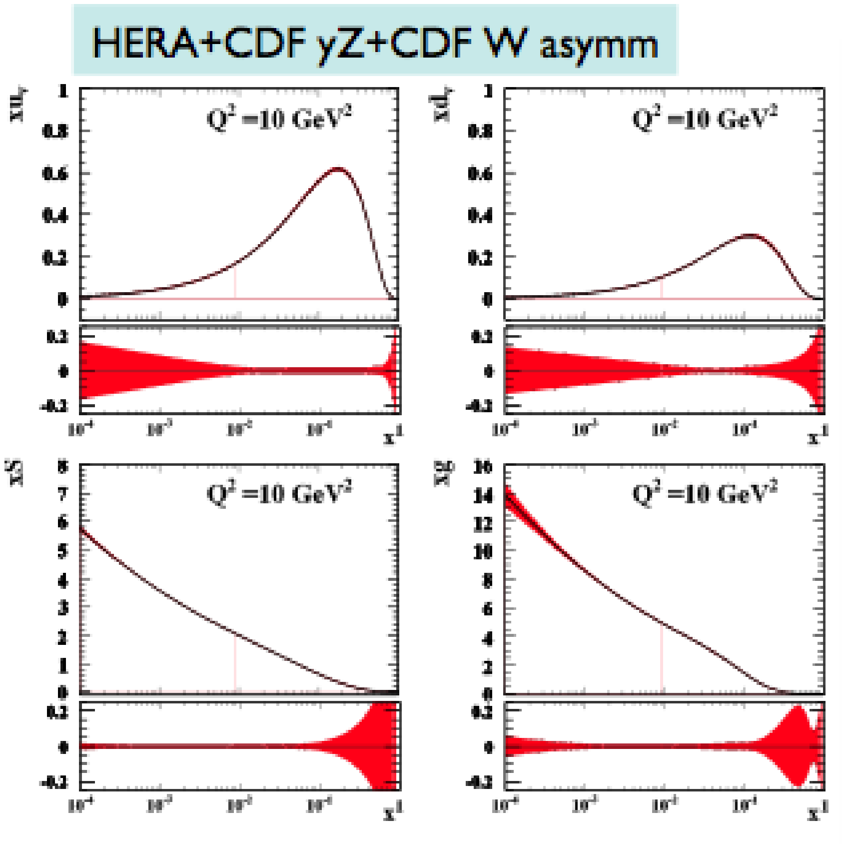
Impact of LHC data on PDF uncertainties

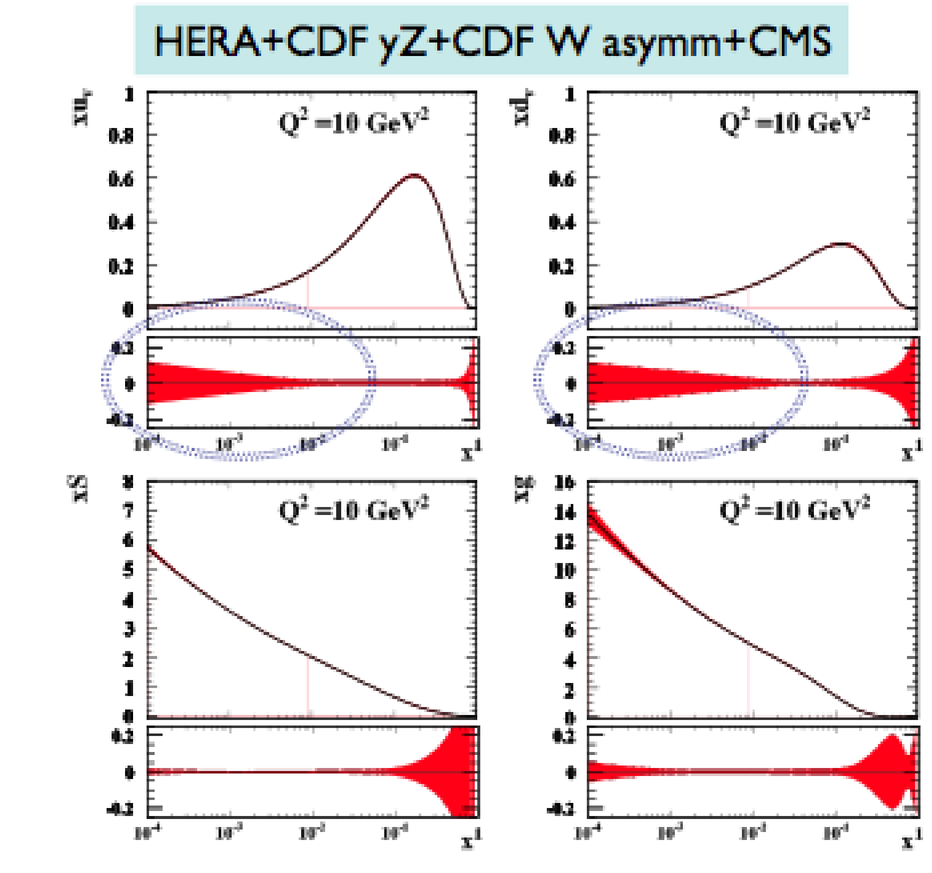




- Hard to see effects including ATLAS W charge asymmetry in the fits on top of HERA+Tevatron data due to differences in the shapes of PDFs

Impact of LHC data on PDF uncertainties





- Hard to see effects including ATLAS W charge asymmetry in the fits on top of HERA+Tevatron data due to differences in the shapes of PDFs
- While we do see impact of the CMS data at low x valence distributions.

HERAPDF predictions for Tevatron Jets

Description of CDF II inclusive jet (k_T) data [hep-ex/0701051]

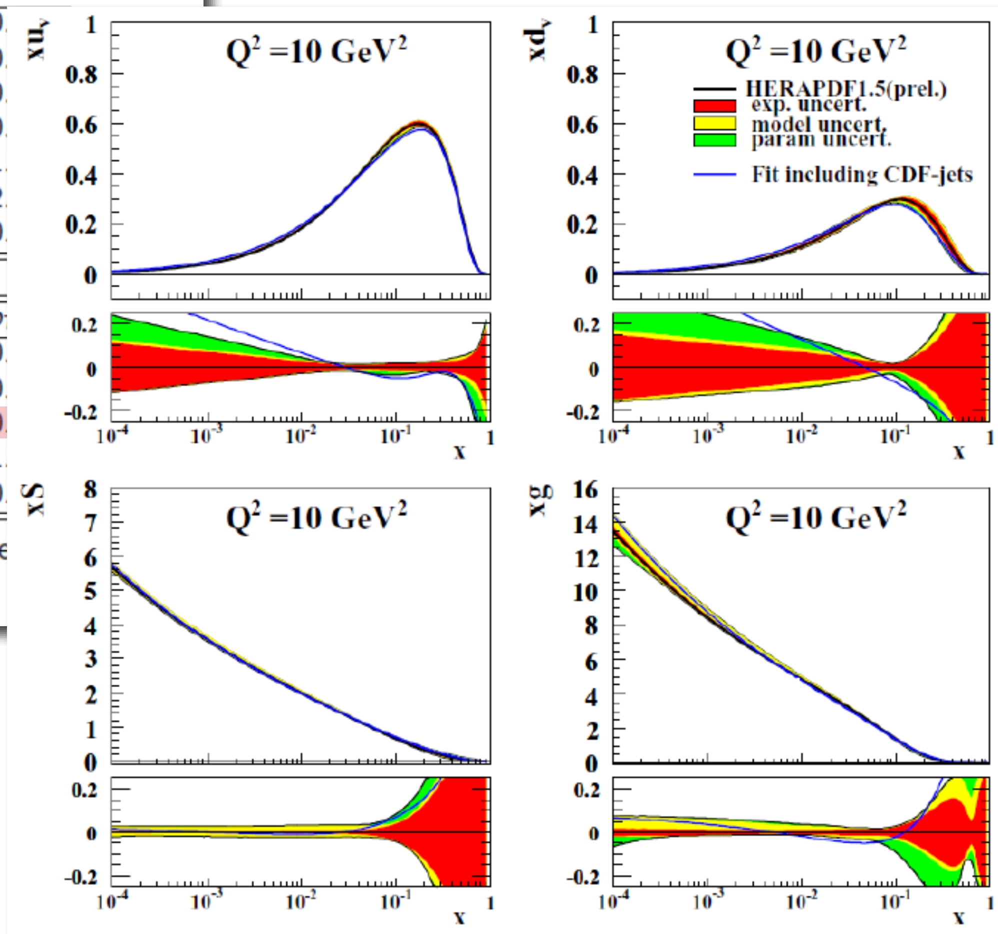
- Values of $\chi^2/N_{\text{pts.}}$ with (without) accounting for correlations:

NLO PDF	$\mu = p_T/2$	$\mu = p_T$	$\mu = 2p_T$
MSTW08	0.75 (0.30)	0.68 (0.28)	0.91 (0.
CTEQ6.6	1.25 (0.14)	1.66 (0.20)	2.38 (0.
CT10	1.03 (0.13)	1.20 (0.19)	1.81 (0.
NNPDF2.1	0.74 (0.29)	0.82 (0.25)	1.23 (0.
HERAPDF1.0 ($\alpha_S = 0.1176$)	2.43 (0.39)	3.26 (0.66)	4.03 (1.
ABKM09	1.62 (0.52)	2.21 (0.85)	3.26 (2.
GJR08	1.36 (0.23)	0.94 (0.13)	0.79 (0.

NNLO PDF	$\mu = p_T/2$	$\mu = p_T$	$\mu = 2p$
MSTW08	1.39 (0.42)	0.69 (0.44)	0.97 (0.
HERAPDF1.0 ($\alpha_S = 0.1145$)	2.64 (0.36)	2.15 (0.36)	2.20 (0.
HERAPDF1.0 ($\alpha_S = 0.1176$)	2.24 (0.35)	1.17 (0.32)	1.23 (0.
ABKM09	2.55 (0.82)	2.76 (0.89)	3.41 (1.
JR09	0.75 (0.37)	1.26 (0.41)	2.21 (0.

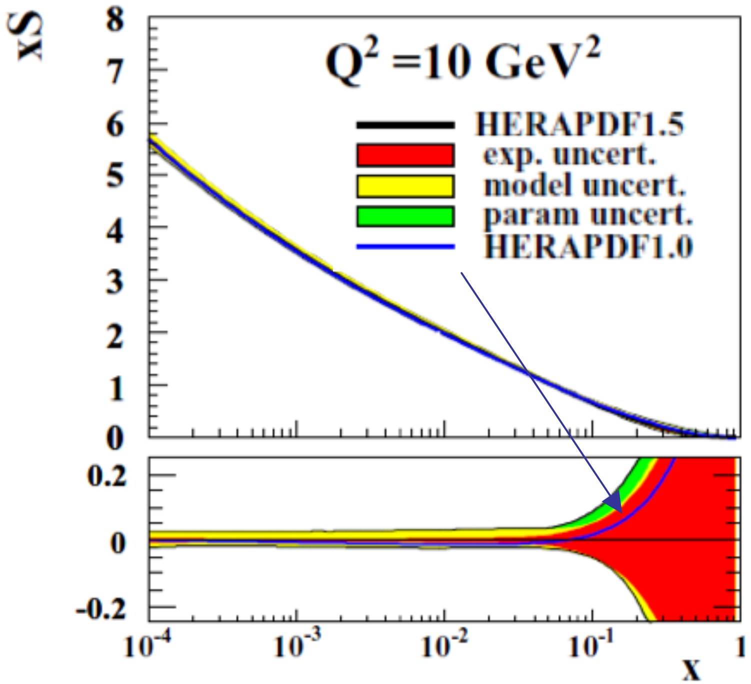
- Similar trends for CDF II (cone) data and DØ II (cone

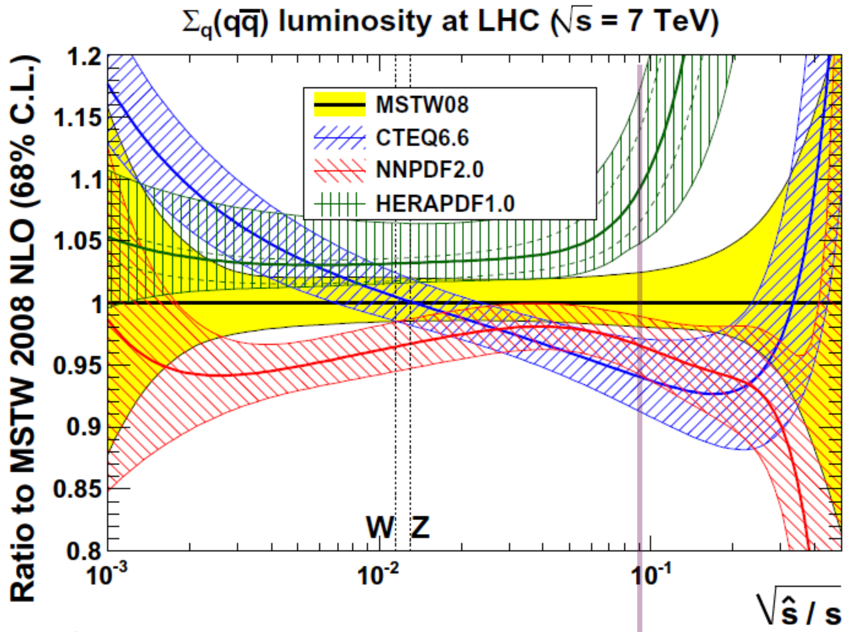
Table from G Watt

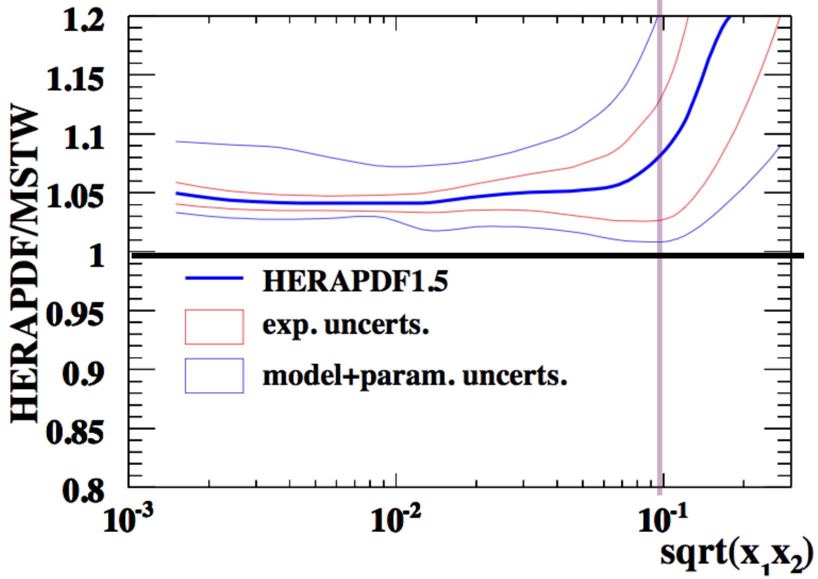


- Based on HERAPDF1.5 (NLO):
  - NO fit : 176/76 (central line)
    - Similar to HERAPDF1.0 due to the same high x gluon between and 1.5
  - After fit: 113/76
- HERAPDF1.5 NLO describes Tevatron Data within uncertainties!
- HERAPDF1.5 NNLO: NO fit: 72/76

Impact on the LHC







- HERAPDF1.0 is high at the large scale because Sea is hard at high x
- HERAPDF1.5 has a softer Sea, hence better agreement with MSTW08