Combination and PDF Fit tools Used in ATLAS.

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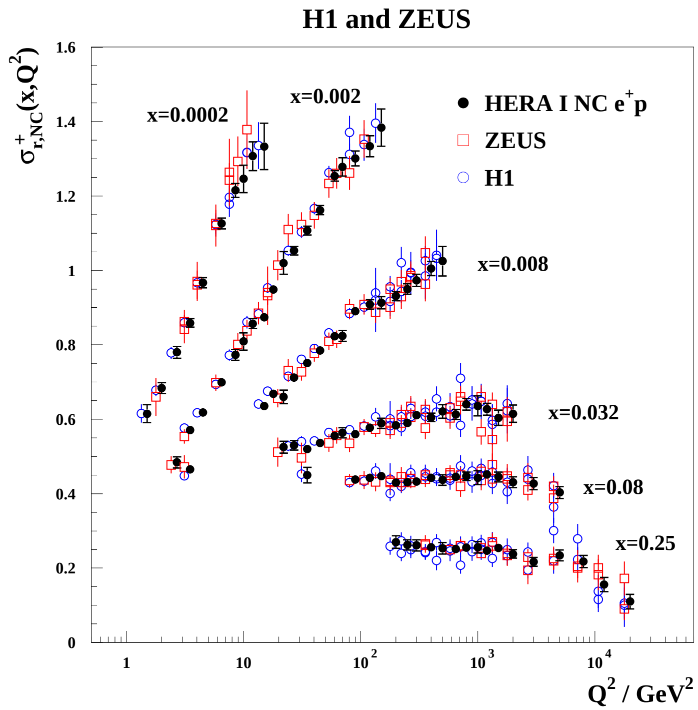
S. Whitehead.

- Data Combination.
- QCD Fit Programs.
- Including LHC data in QCD Fits.

CERN, April 2011

Combination of Data



Several combination tools on the market: BLUE, HERA combination package.

HERA package is being used in ATLAS for *e* and μ channel data combination.

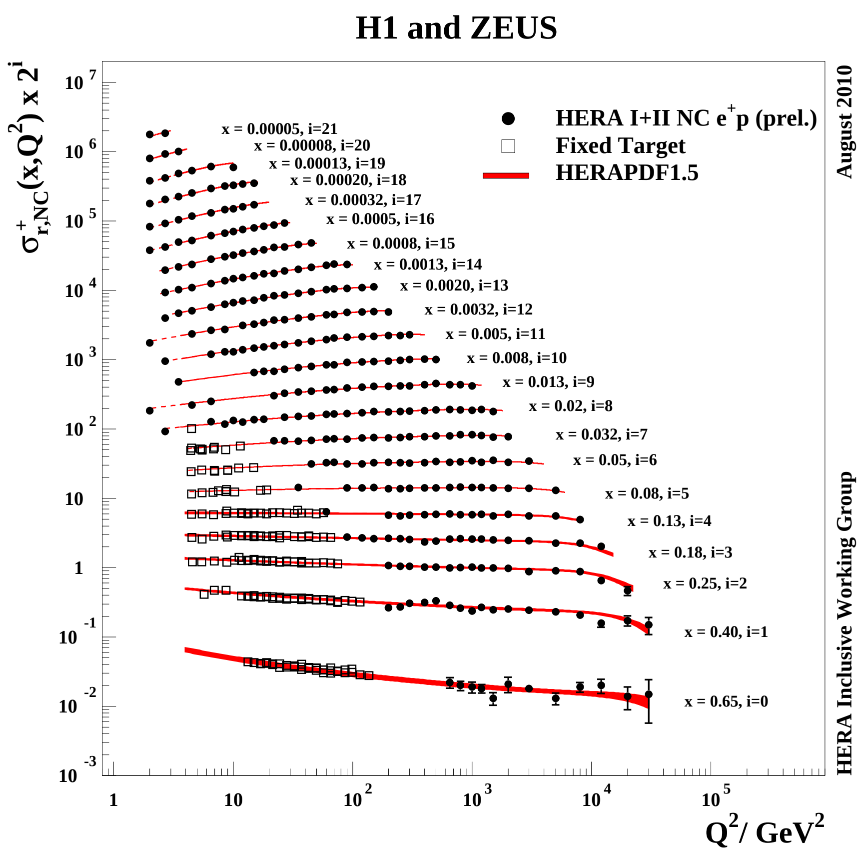
HERA package takes into account correlated systematic errors, corrects for biases due to multiplicative nature of errors.

QCD Fit Packages and Settings

- Evolution code: publicly available QCDNUM package, version 17.00 (`http://www.nikef.nl/h24/qcdnum/index.html`). Active exchange with M. Botje.
- Two independent fitting packages, originated and actively developed within H1 and ZEUS collaborations.
- Different approaches to experimental uncertainties: Hessian, offset, adding in quadrature.
- Error propagation for PDFs: Hessian and MC method.
- NLO and NNLO evolution.
- FastNLO and APPLGRID interfaces.
- Different codes for heavy flavor treatment: RT from R. Thorne, flavours of ACOT from F. Olness.
- Fits to DIS, jet and DY data.

HERA tools are more used in ATLAS, but some developers, e.g. original developer of the `H1 fitter` E. Perez, are in CMS.

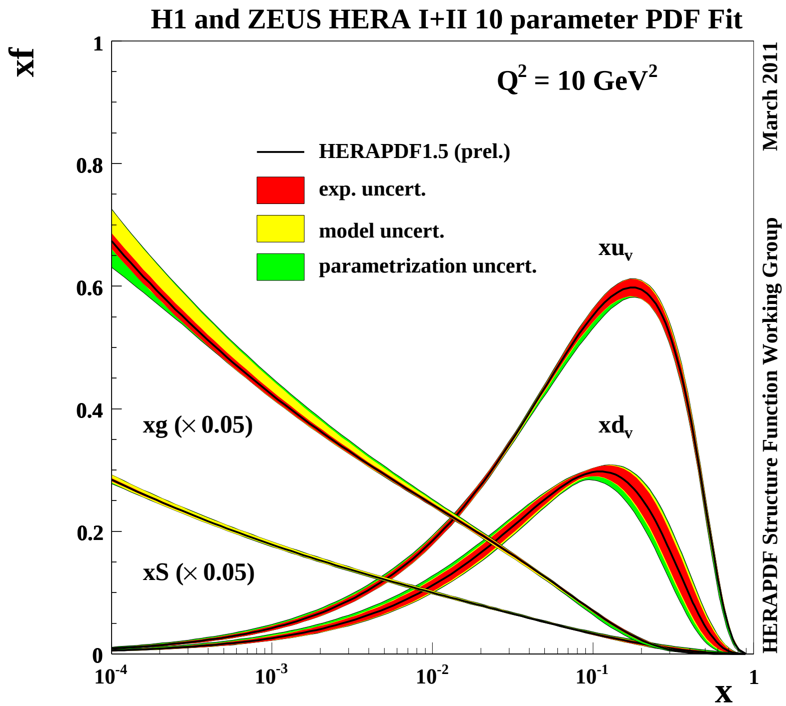
Refernce: HERAPDF1.5 fit

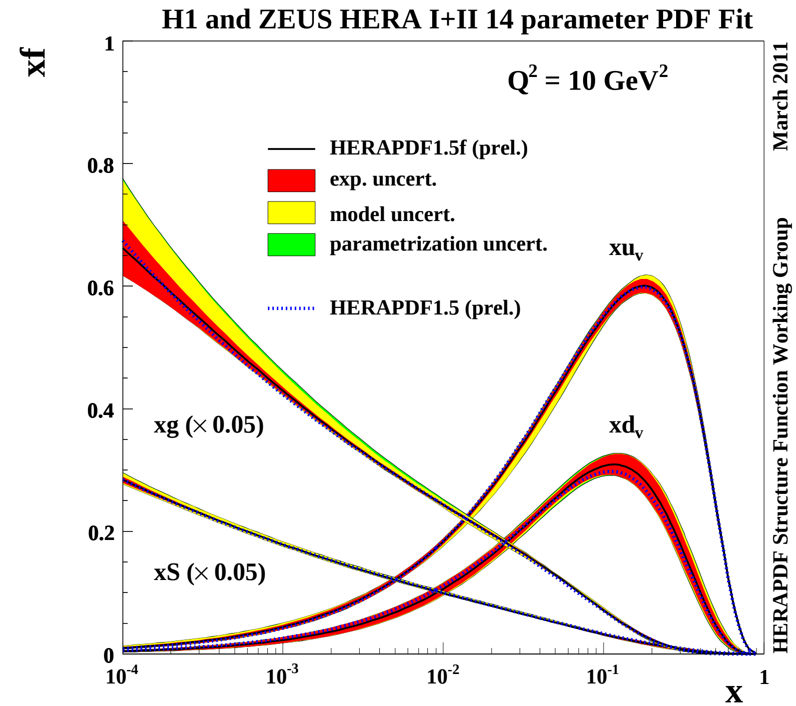


- Fit to the combined preliminary inclusive HERA data, complete dataset.
- Good agreement between data and NLO QCD.

How HERA PDFs compare to *pp* observables and how they can be improved by them ?

HERAPDF1.5f fit





- Fits parameterise $x\bar{U}$, $x\bar{D}$, xu_v, xd_v and xg using $xf(x) = Ax^B(1-x)^C(1 + Dx + Ex^2)$ form.
- Recently fits were extended from 10 to 14 parameters, by relaxing assumptions that $B_{u_v} = B_{d_v}$, using extra term for u_v and flexible parameterisation for the gluon: $xg(x) = Ax^B(1-x)^C - A'x^{B'}(1-x)^{25}$.

$\rightarrow$ similar overall errors, more flexible shapes (important for NNLO).

Tevatron y_Z data

How good or bad is the HERAPDF description of the Tevatron data?.

We usually just show you plots. Let's calculate χ2- and then FIT the data.

Can the error bands of HERAPDF!.5 cover the variation due to input of new data?

The description of the CDF Z0 rapidity LOOKS OK but what is the χ2 for these data points to HERAPDF1.5 central values?

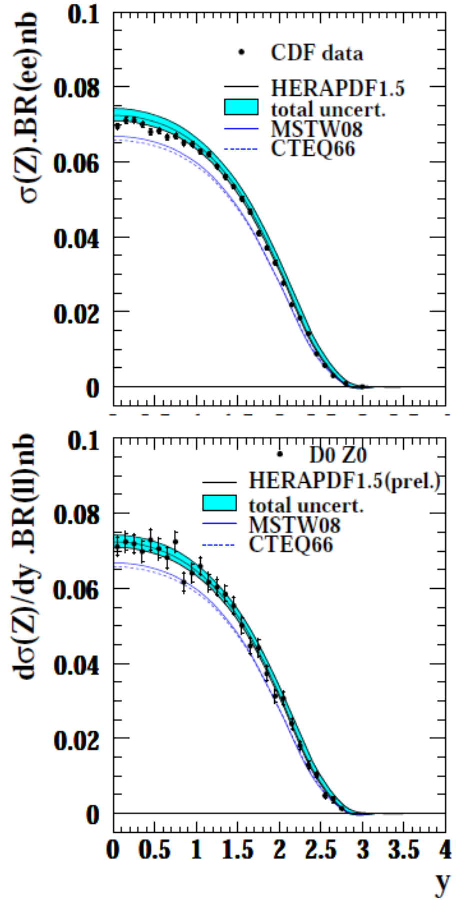
36/28 -acceptable

The D0 Z0 rapidity spectrum LOOKS OK but what is the χ2 for these data points to HERAPDF1.5 central values?

23/28 -acceptable

Obviously the CDF data will be more discriminating..

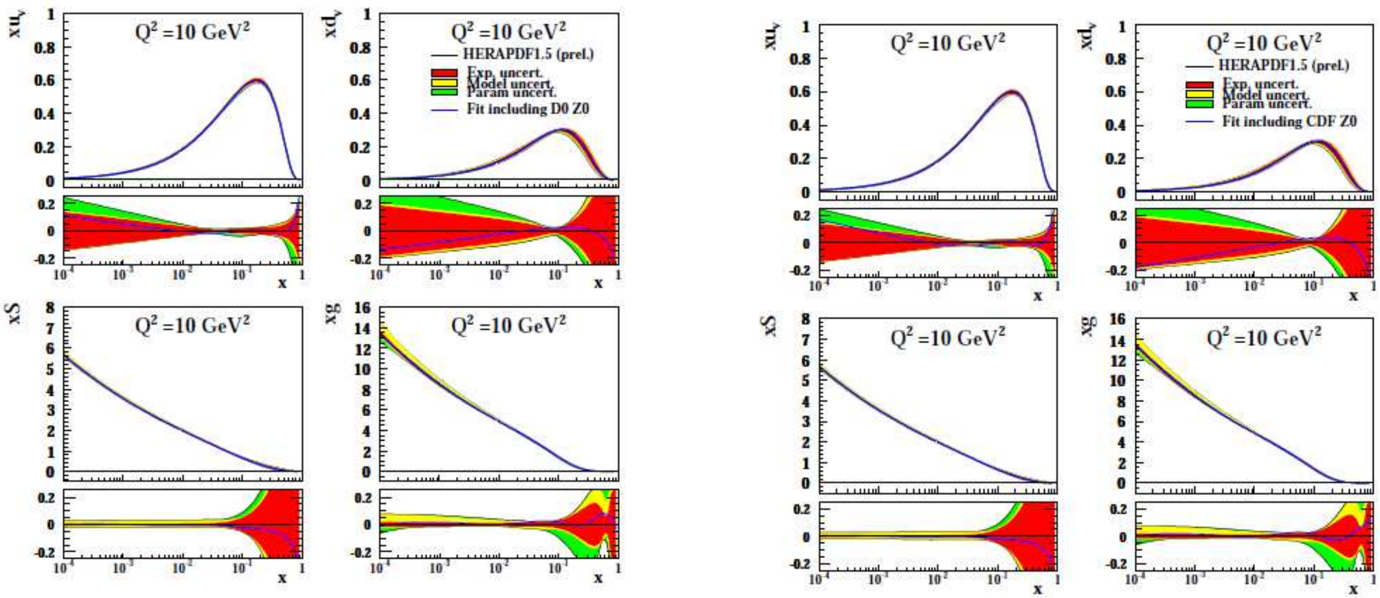
But these χ2 do NOT account for the error band of the HERAPDF fit



Fit including tevatron y_Z data

So FIT the D0 Z0 rapidity data: χ2/ndp =16/28 OR FIT the CDF Z0 rapidity data: χ2/ndp =26.8/28

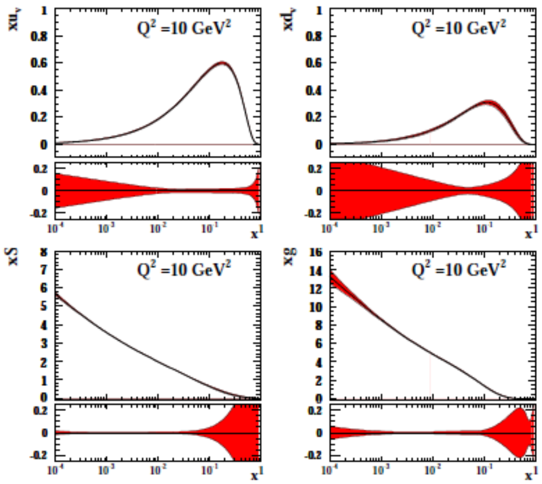
And look to see if the resulting PDF has shifted outside error bands. Here the HERADF+ Z0 rapidity fits are the blue lines– they does NOT move outside the HERAPDF1.5 error bands



The fits are done with HERAPDF1.5f flexible parametrisation

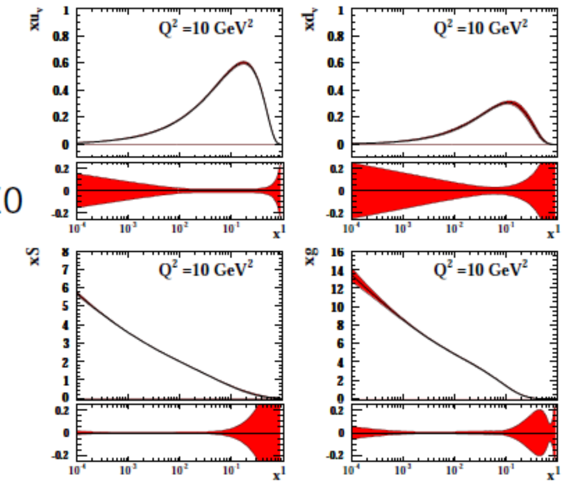
The CDF and D0 Z0 data do similar things to the shape of the PDFs- (ie not much – a slightly softer high-x d-valence-- see next slide) 3

Tevatron y_Z data impact on PDF errors

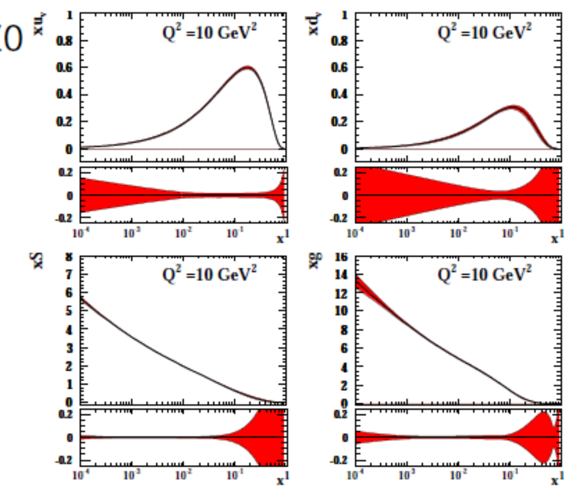


HERAPDF1.5f

+ CDF Z0



+ D0 Z0



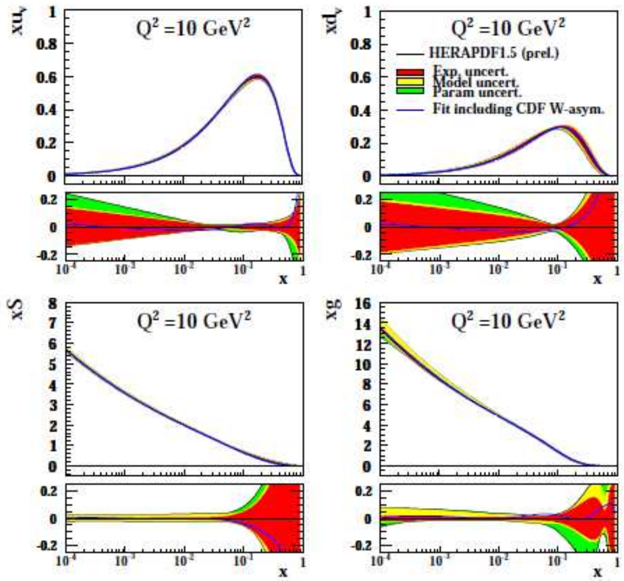
What do the D0 and CDF Z0 spectra do for the PDf uncertainties?- some marginal improvement CDf more so than D0

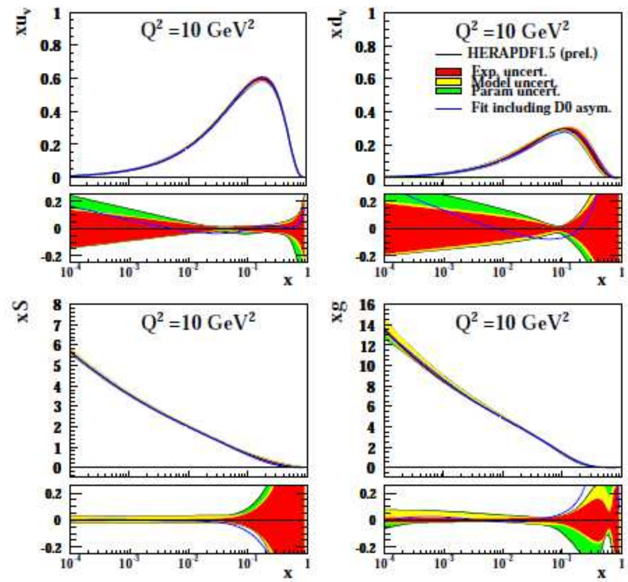
(Just considering experimental uncertainty but using 14 parameter HERAPDF1.5f)

Fit Including Tevatron *W* data

So FIT the CDF W-asymmetry data: $\chi2$ = 19/13 OR the D0 electron asymmetry data $\chi2$ = 25/11

And look to see if the resulting PDF has shifted outside our error bands. Here the HERADF+ asymmetry fits are the blue line– they do NOT move (much) outside the HERAPDF1.5 error bands

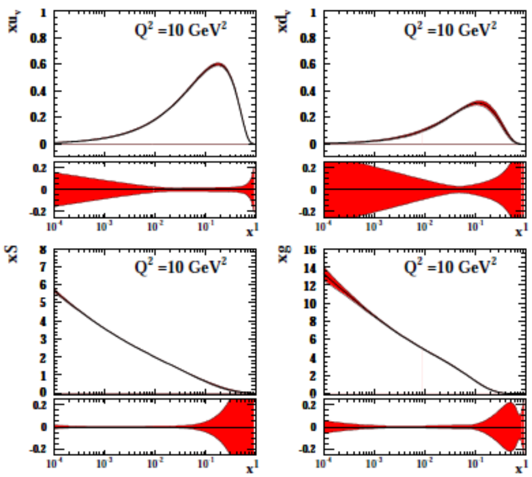




The fits are done with HERAPDF1.5f flexible parametrisation

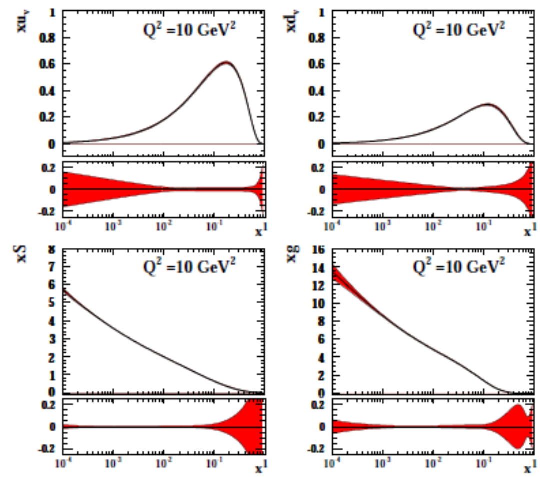
The CDF and D0 asymmetry data do similar things to the shape of the PDFs- harder high-x d-valence

Tevatron *W* data impact on PDF errors

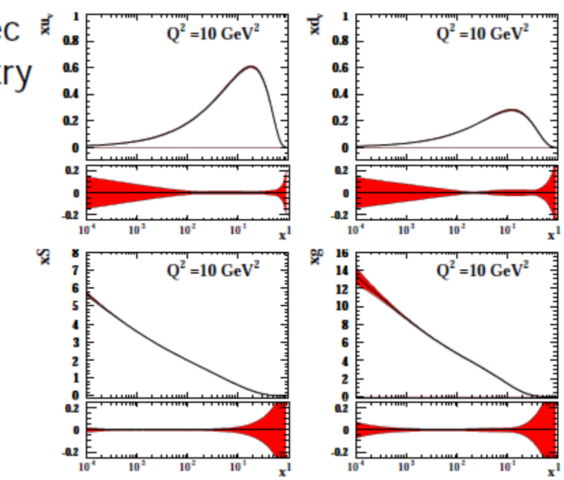


HERAPDF1.5f

+ CDF W-asymmetry



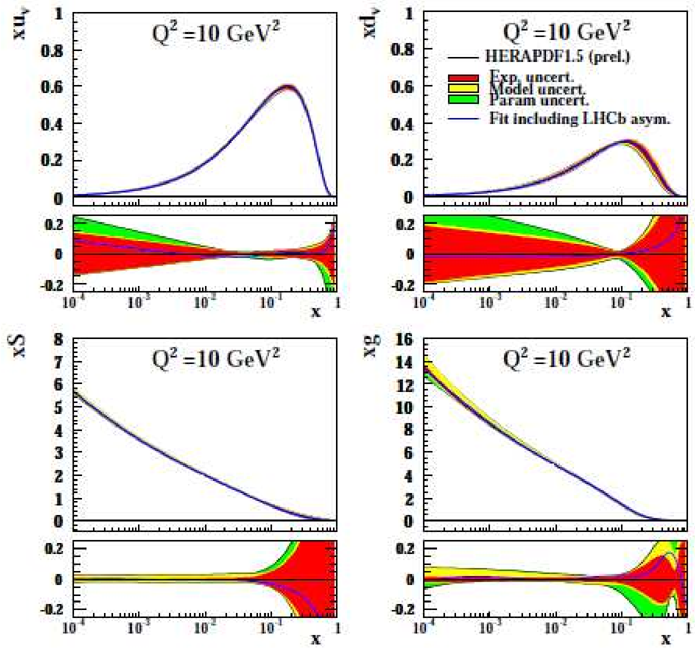
+ D0 elec asymmetry



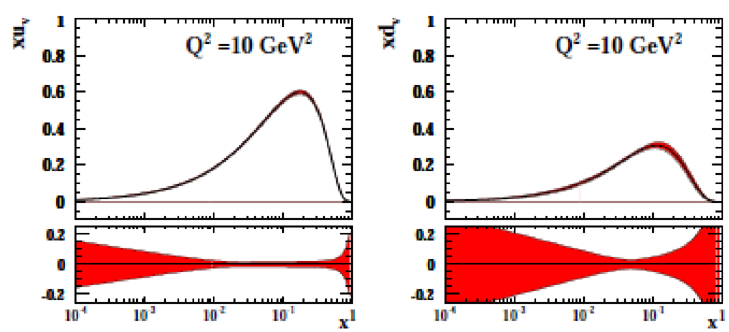
What do the D0 and CDF asymmetry data do for the PDF uncertainties?- quite impressive improvements and quite similar for CDf and D0

(Just considering experimental uncertainty but using 14 parameter HERAPDF1.5f)

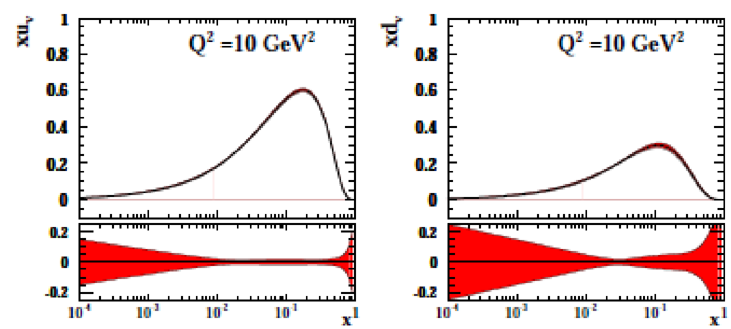
LHCb W data in the fit



Fit including LHCb lepton asymmetry data gives $\chi^2/dof = 7.9/5$. Fit stays within HERAPDF error bands.



HERAPDF1.5 (exp)



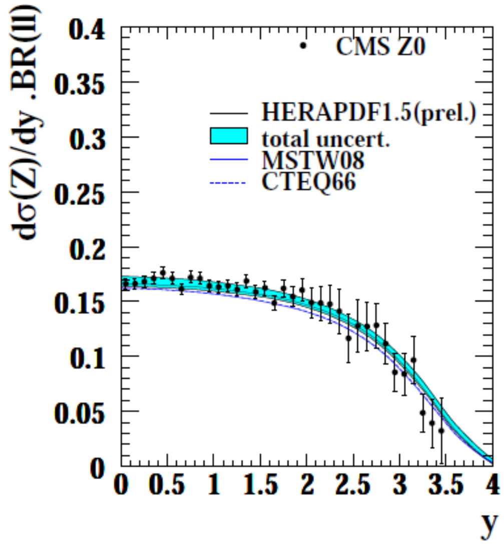
HERAPDF1.5+LHCb (exp)

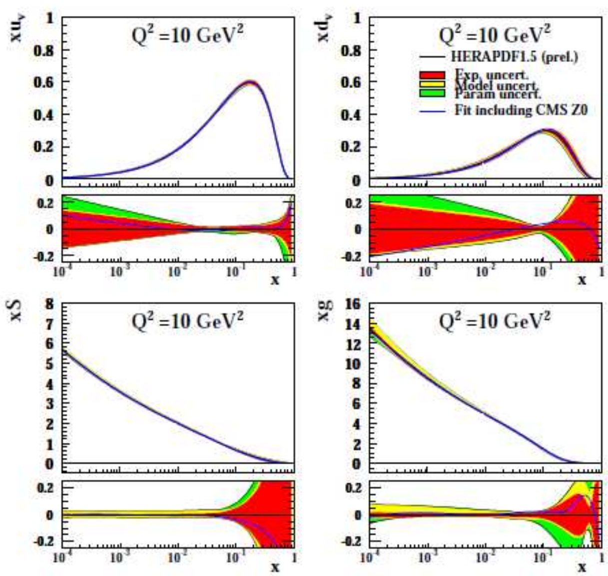
$\rightarrow$ some improvement for d_v at low x.

CMS y_Z data

The description of the CMS Z0 spectrum LOOKS OK but what is the χ2 for these data points to HERAPDF 1.5 central values?
35/35

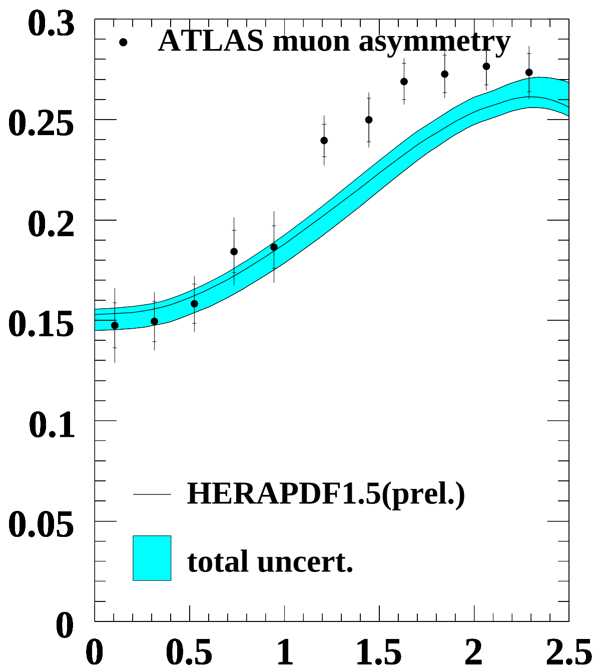
Data is supplied as 1/σ dσ/dy
But the figure shows dσ/dy



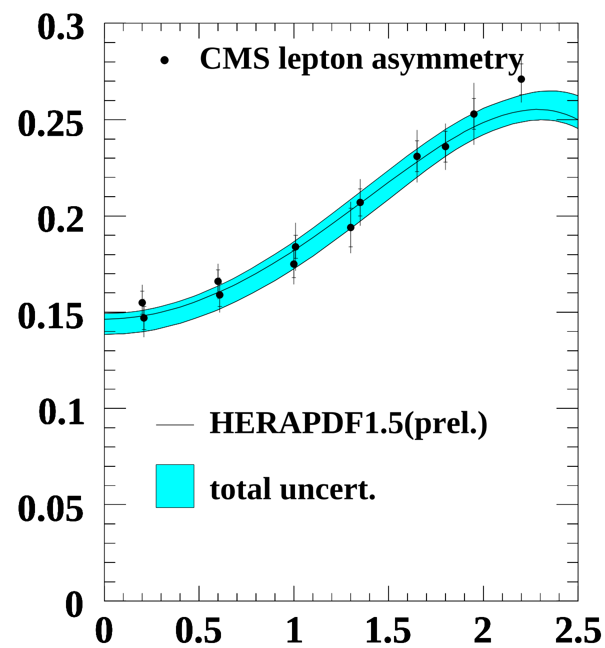


CMS data does not shift fit outside HERAPDF1.5 error band, but does behave as Tevatron data. The reduction of PDF uncertainties is marginal.

ATLAS and CMS W Lepton Asymmetry



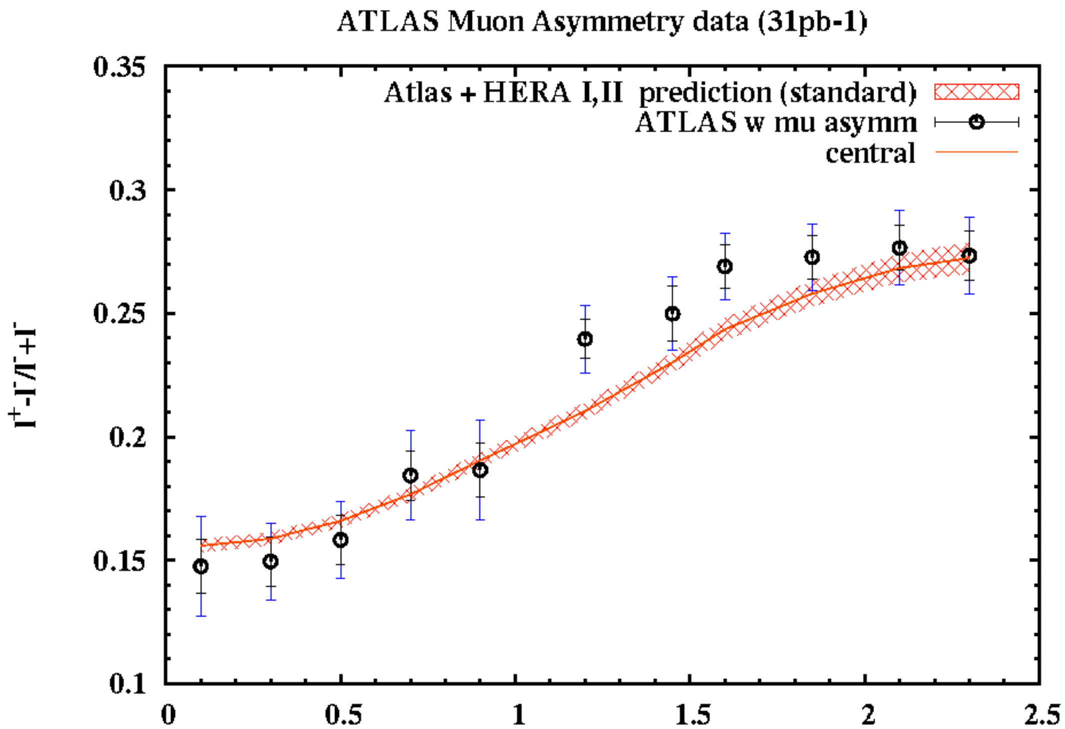
$P_{t,e} > 20$ GeV, $P_{t,miss} > 25$ GeV



$P_{t,e} > 25$ GeV

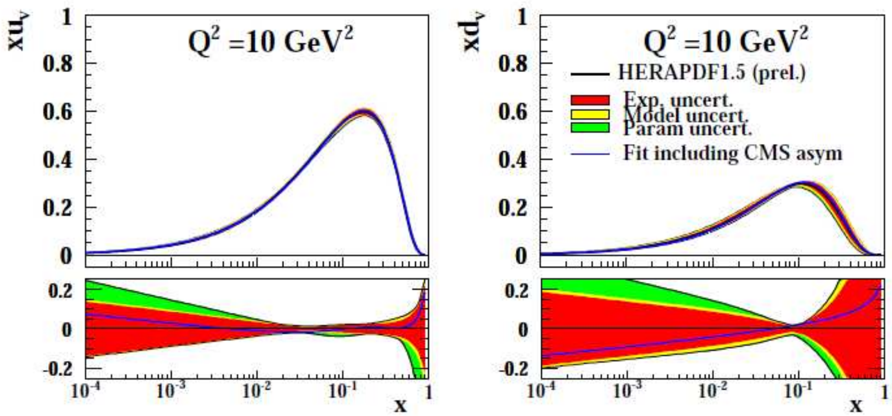
- LO fits with k-factors calculated using MCFM, taking into account different cuts.
- HERAPDF1.5 provides good description of the CMS data with $\chi^2/dof = 6.5/12$ and not so good of ATLAS with $\chi^2/dof = 30/11$.

Fit to ATLAS W asymmetry data



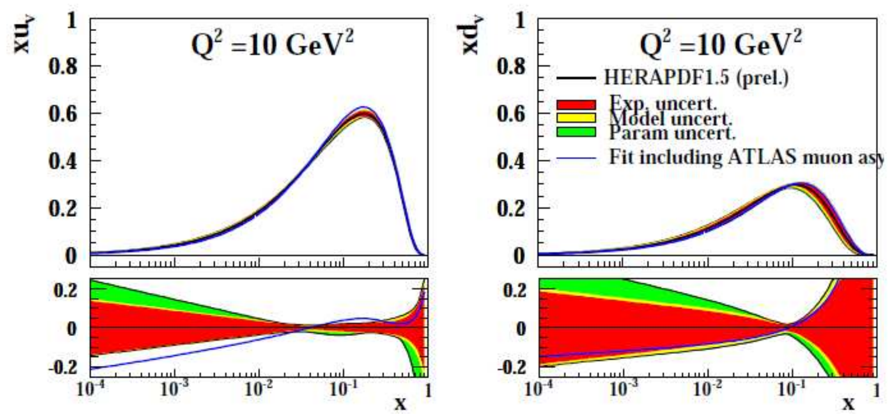
- 14 parameters fit, 6 free parameters for valence quarks, reasonable description of ATLAS asymmetry shape, partial $\chi^2/dof = 16/11$.
- Uncertainty estimated using MC method.

Fits with LHC W asymmetry data



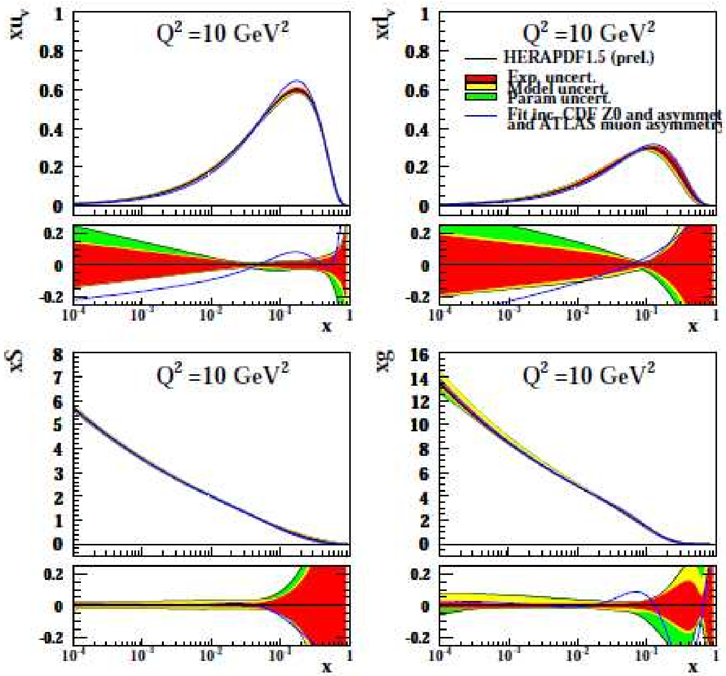
CMS data keep the central line within HERAPDF1.5 error band, $\chi^2/dof = 3.7/12$ is extremely good.

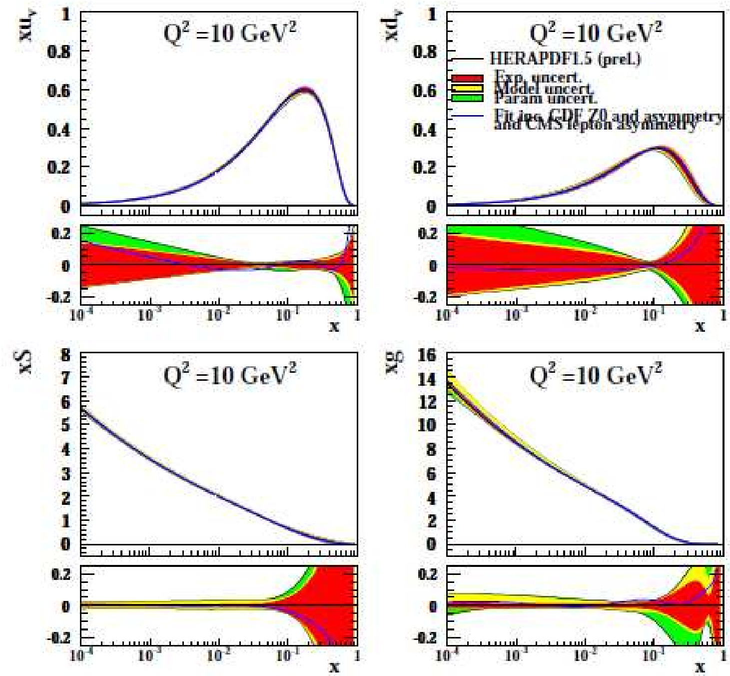
For ATLAS data fit is pulled somewhat outside the bands, the $\chi^2/dof = 16/11$ is Ok.



ATLAS and CMS pull u_v in opposite direction.

Fit to HERA+Tevatron+LHC data





This is then HERAPDf1.5f +CDF Z0 and W-asym PLUS ATLAS muon asymmetry

And the ATLAS data does change the fit!

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

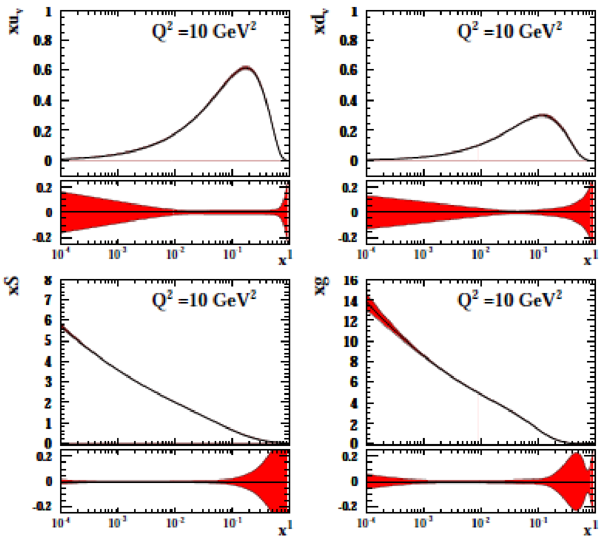
It starts to go outside error bands

This is then HERAPDF1.5f + CDF Z0 and W-asym PLUS CMS lepton asymmetry

And it there is hardly any effect from adding the CMS asymmetry

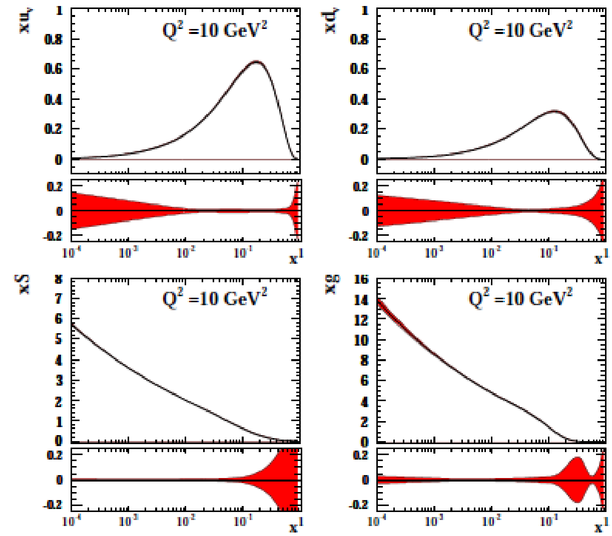
X2/ndp = 18.9/13, 26/28 and 4.5/12

Impact of LHC data on PDF errors

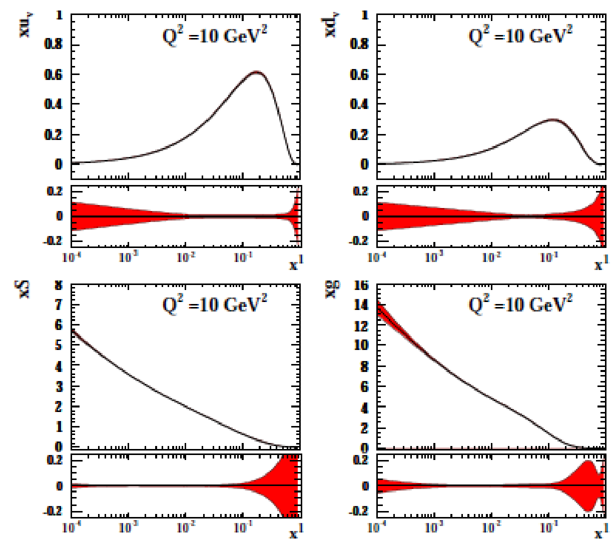


HERAPDF1.5f + CDF Z0
+ CDF W-asymmetry

+ ATLAS asymmetry



+ CMS asymmetry

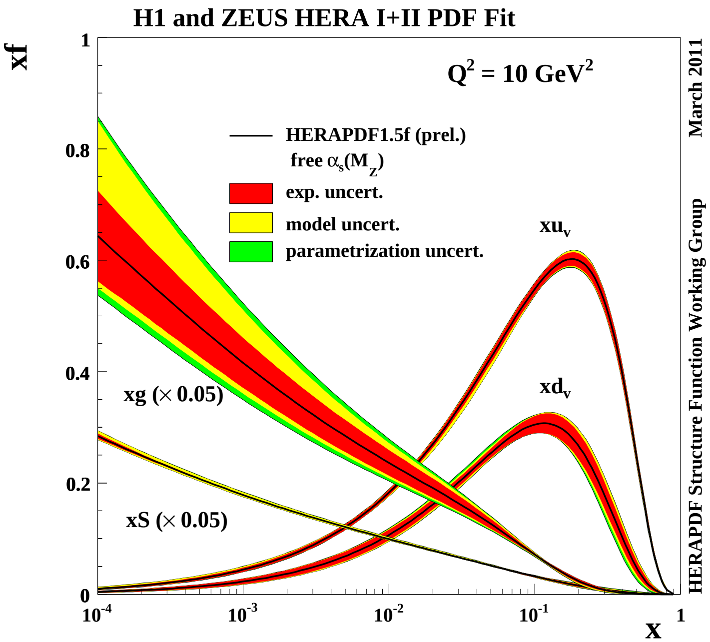


What more do the CMS and ATLAS asymmetry data do for the PDf uncertainties?

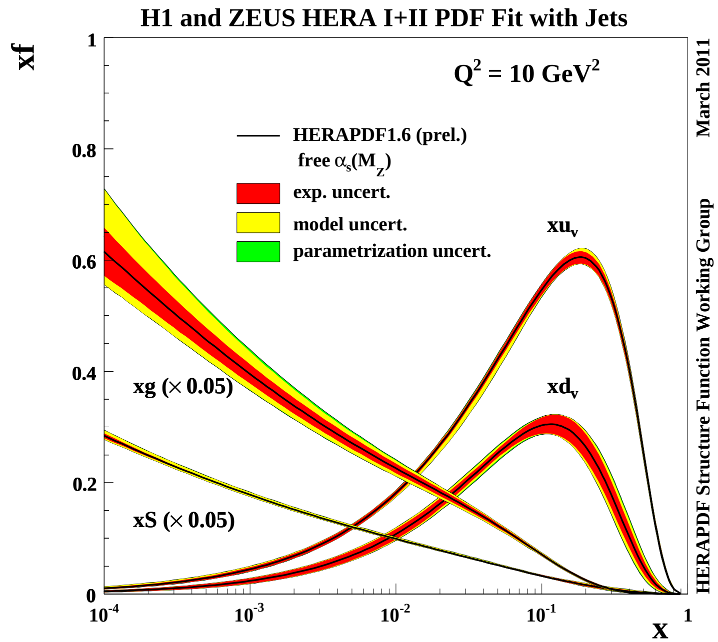
Not much but for CMS one can see a marginal effect at low-x since we are accessing a new kinematic region. For ATLAS you don't see this so obviously because of the shape change

(Just considering experimental uncertainty but using 14 parameter HERAPDF1.5f)

Including HERA Jets

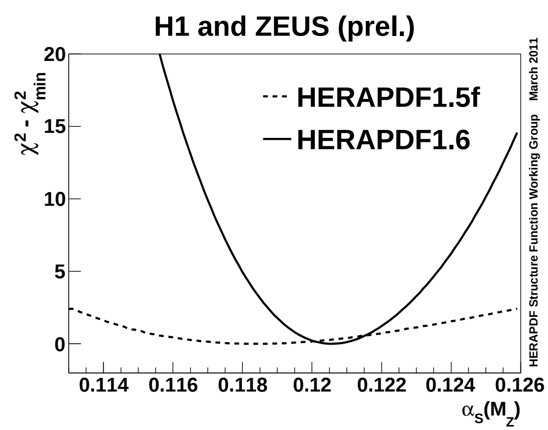


Free α_S, inclusive



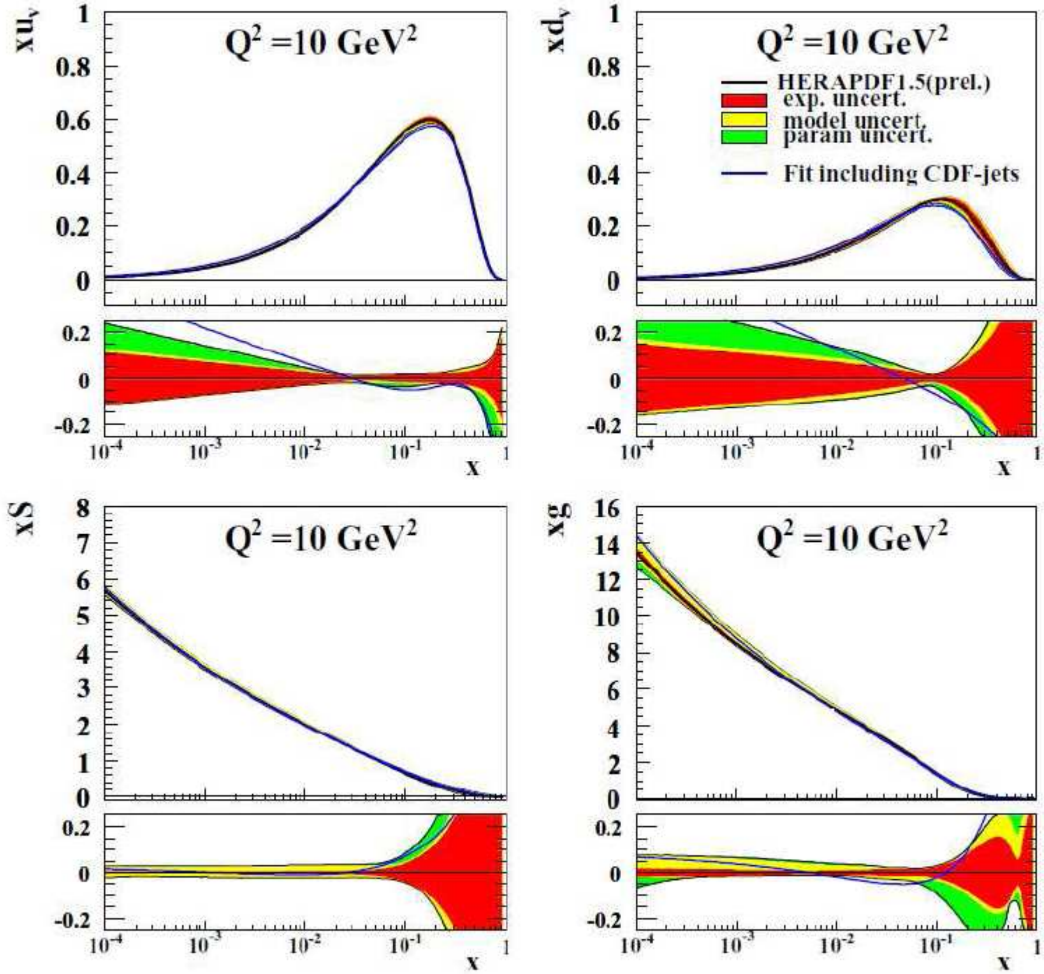
Free α_S, + jets

- Freeing α_S in fits increases $xg(x)$ uncertainty at low x.
- Inclusing jets allows to reduce uncertainty back.
- $\alpha_S(M_Z) = 0.1202 \pm 0.0013(\text{exp}) \pm 0.0007(\text{mod}) \pm 0.0012(\text{had})^{+0.0045}_{-0.0036}(\text{th})$.

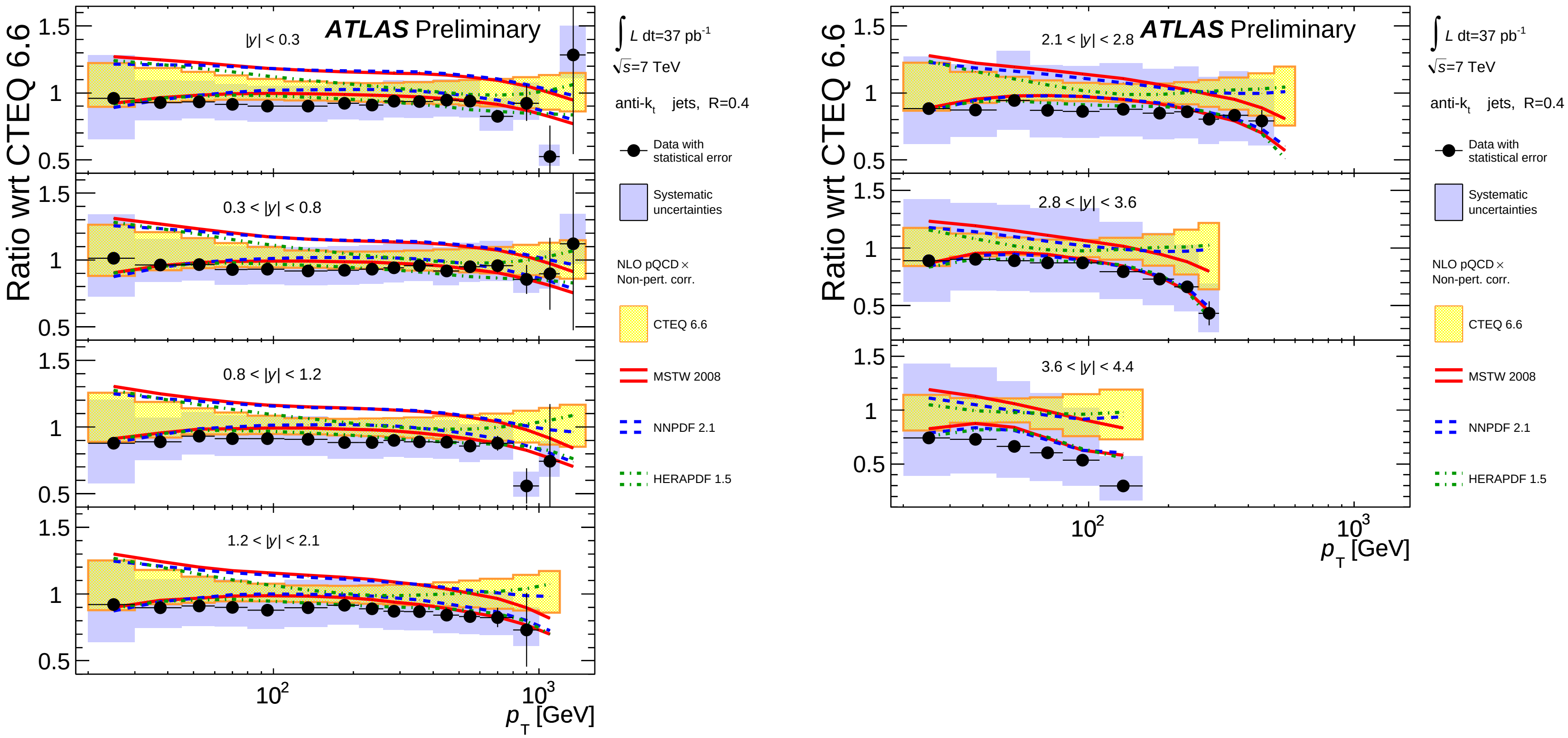


Tevatron jets

- Tevatron jet data provides additional constraints on gluon at high x.
- HERAPDF1.5 provides "reasonable" description of the data.
- Putting the data in the fit gives $\chi^2/dof = 113/76$.



ATLAS jet data



- New ATLAS measurement based on complete 2010 data set, extending to forward and lower p_t regions, with improved JES uncertainty.
- Data tend to be below CTEQ6.6 prediction, best agreement with HERAPDF1.5, however theory/experimental errors are sizable.

Summary

- HERAPDF fits provide basis for QCD analysis with consistent, high accuracy input data having well understood systematic uncertainties and minimal theoretical assumptions.
- The set of tools within the framework, from various methods of PDF error estimates to production of LHAPDF grid files are available for fast feedback to data analysers.
- Extending dataset to $p\bar{p}$ data from Tevatron is important to improve accuracy for d-type quarks. W asymmetry data provide stronger constraints, however Z data are needed to separate light sea/valence quark effects.
- Early LHC data already have some impact on PDF uncertainties at small x. However, inclusion of ATLAS compared to CMS W lepton asymmetry data pulls PDFs in opposite direction.
- ATLAS and CMS jet data should provide additional constraints for the gluon density at high x.

Extras

χ^2 definition

Combination and QCD analysis are based on $\Delta\chi^2$ minimization, taking into account stat. and systematic biases.

Definition of χ^2:

$$\chi^2_{\exp}(\boldsymbol{m}, \boldsymbol{b}) = \sum_i \frac{\left[m^i - \sum_j \gamma^i_j m^i b_j - \mu^i\right]^2}{\delta^2_{i,\text{stat}}\, \mu^i \left(m^i - \sum_j \gamma^i_j m^i b_j\right) + \left(\delta_{i,\text{uncor}}\, m^i\right)^2} + \sum_j b_j^2.$$

- Correlated error can be treated using Hessian, offset methods and be added in quadrature.
- For Hessian fits, correlated errors nuisance parameters b_j modify predicted values m^i.
- Statistical error is re-calculated using expected number of events, uncorrelated systematic errors re-calculated using expected cross sections.

HERAPDF Fit Settings

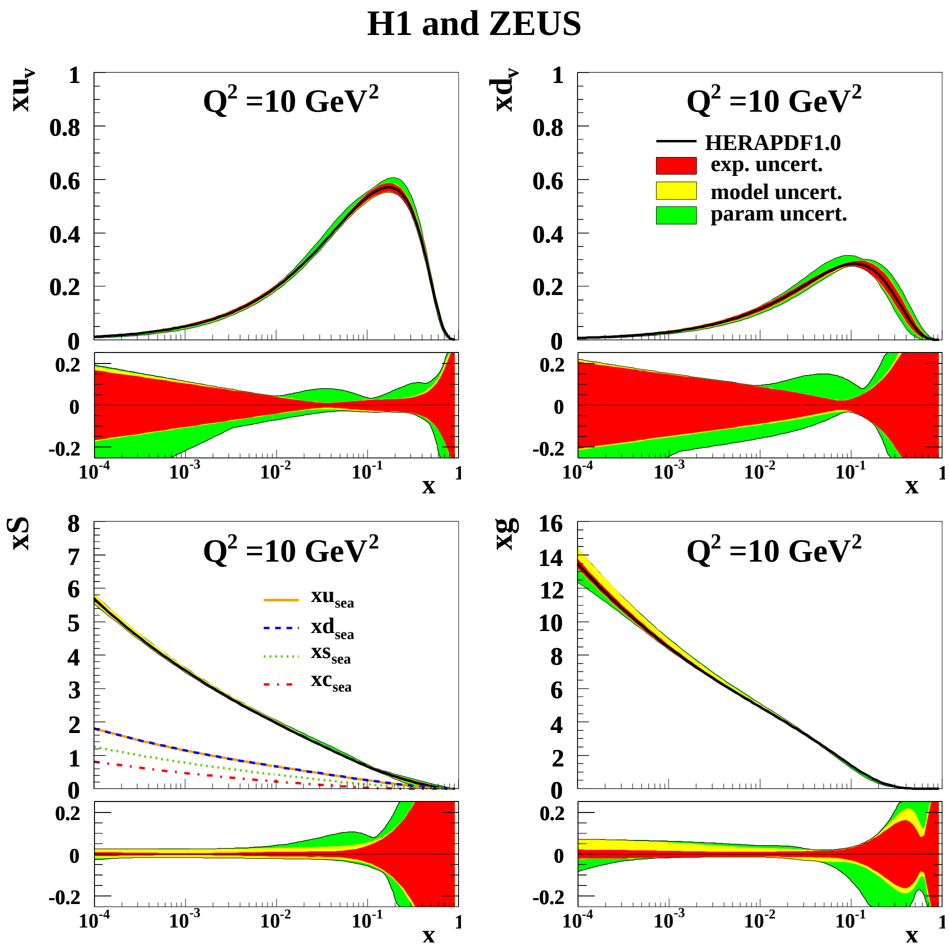
- Input: combined HERA-I data for $e^{\pm}p$ NC and CC scattering.
- $\Delta\chi^2 = 1$, treat experimental errors as uncorrelated, 3 procedural uncertainties with offset method.
- NLO evolution, RT-VFNS for charm and bottom, $\alpha_S = 0.1176$.
- Evolution starting scale $Q^2 = 1.9$ GeV^2, below $m_c^{\rm model} = 1.4$ GeV. Start fitting data at $Q^2_{min} = 3.5$ GeV^2.
- Fitted PDFs are xg, xu_v, $xd_v(x)$, $x\bar{U}$, $x\bar{D}$ where $x\bar{U} = x\bar{u}$ and $x\bar{D} = x\bar{d} + x\bar{s}$ at the starting scale. For the strange, $x\bar{s} = f_s x\bar{D}$ with $f_s = 0.31$ is assumed.
- Standard parameterisation form

$$xf(x) = Ax^B(1-x)^C(1+\epsilon\sqrt{x} + Dx + Ex^2)$$

with only significant ϵ, D and E terms kept.

- A_g, A_{u_v}, A_{d_v} fixed by sum rules. Extra constraints for small x behaviour of d and u-type quarks: $B_{u_v} = B_{d_v}$, $B_{\bar{U}} = B_{\bar{D}}$, $A_{\bar{U}} = A_{\bar{D}}(1-f_s)$

PDF uncertainties



HERAPDF1.0 — NLO QCD analysis of the combined HERA data.

Separation of experimental, model and parameterisation uncertainties.

Accurate xS and xg at low x due to precise measurement of F_2.

Model and Parameterisation variations

Model variations are:

- Change in strangeness fraction from $f_s = 0.31$ to 0.23 and 0.38.
- Change of Q^2_{min} cut from $Q^2_{min} = 3.5$ GeV^2 to 2.5 GeV^2 and 5.0 GeV^2.
- Change of m_c^{model} from 1.4 GeV to 1.35 and 1.6 GeV.
- Change of m_b^{model} from 4.75 GeV to 4.3 and 5.0 GeV.

they are evaluated as by adding in quadrature + and − deviations from the central fit.

Parameterisation variations are:

- Change of the evolution starting scale to $Q^2_0 = 1.5$ GeV^2 using flexible gluon parameterisation term, $xg(x) = A_g x^{B_g}(1-x)^{C_g} - A'_g x^{B'_g}(1-x)^{25}$.
- Change of Q^2_0 to 2.5 GeV^2 with increase of $m_c^{\text{model}} = 1.6$ GeV.
- Extra parameters D_{u_v}, $D_{\bar{U}}$ and $D_{\bar{D}}$.

they are evaluated by building envelope of maximal deviations.