Update on issues related to MSTW PDFs

Robert Thorne

May 23rd, 2012

University College London

Together with Alan Martin, James Stirling, Graeme Watt

and Arnold Mathijssen and Ben Watt

Variety of topics - related in various ways.

- Brief reminder of results from Monte Carlo approach using MSTW PDFs arXiv:1205.4024.

- Comparison of MSTW PDFs with LHC data and implications.

- Study of strange quark in MSTW2008 fits and source of constraint.

- Investigation of parameterisation extension dependence. Related to deuterium corrections. Implication for LHC data.

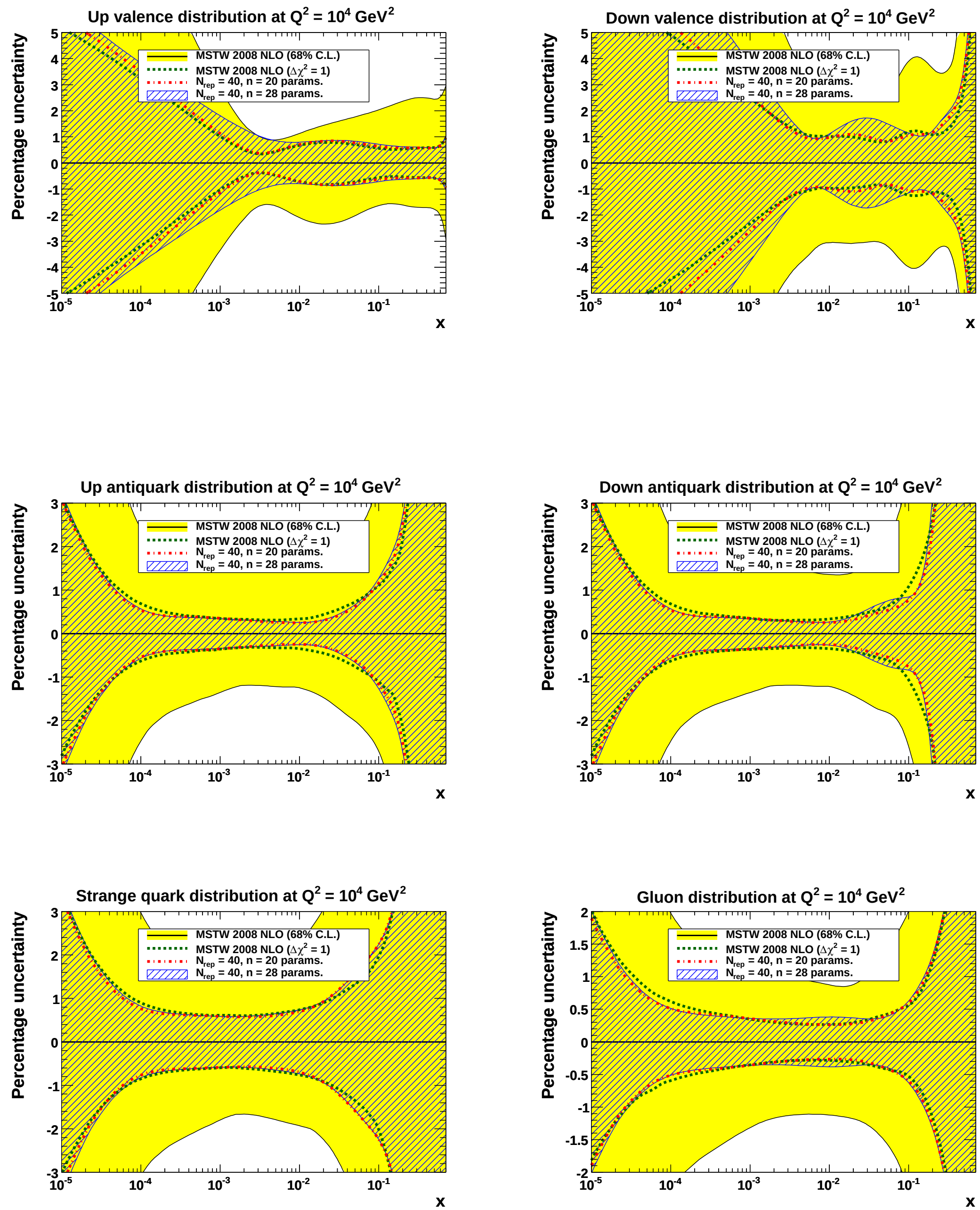
Monte Carlo Approach. (Graeme Watt + RT arXiv:1205.4024)

Generate replica data sets with central values shifted according to size of errors. Similar to NNPDF. Fit using standard technique.

Confirms same result as Hessian approach using $\Delta\chi^2 = 1$ (see previous HERA study).

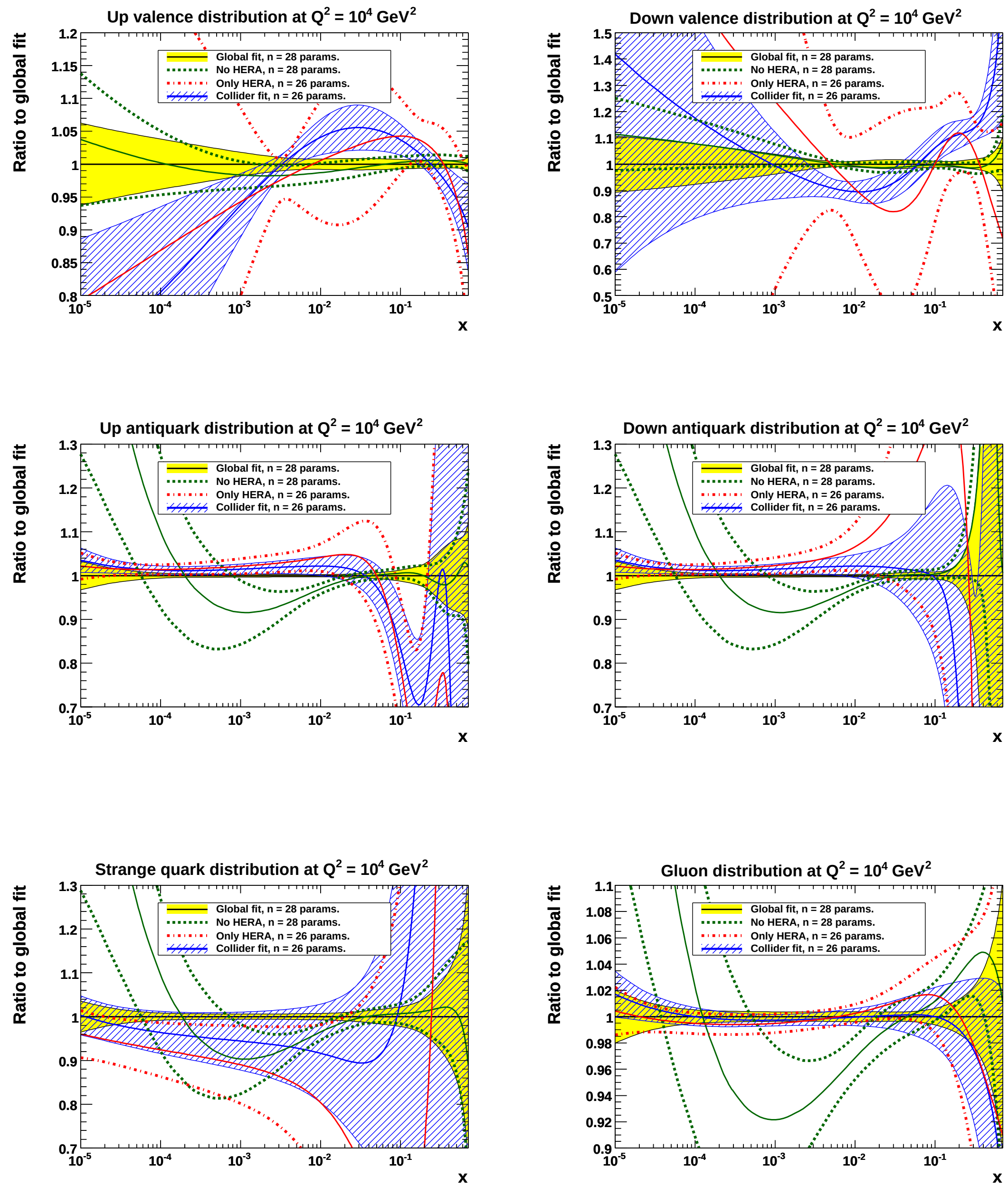
Can vary all 28 parameters rather than just 20 in eigenvectors.

Affects valence quarks at small ($x < 0.01$) mainly.



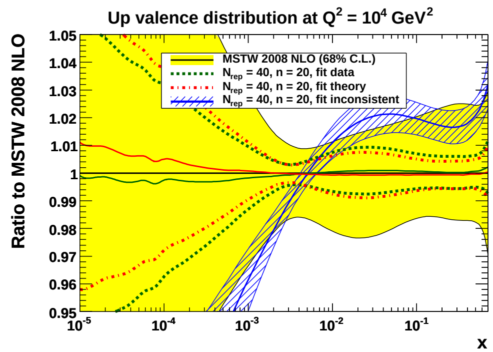
Fit to subsets of data.

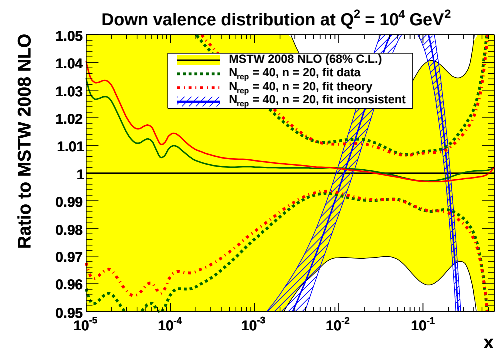
PDFs move by considerably more than $\Delta\chi^2 = 1$ uncertainties in many places.

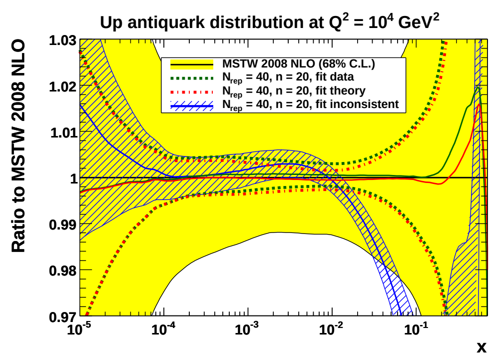


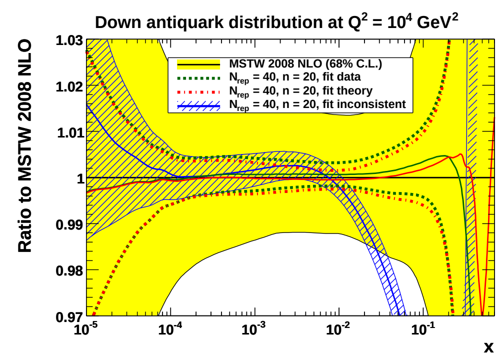
Can construct pseudodata from theory predictions and make "consistent" and "inconsistent" sets.

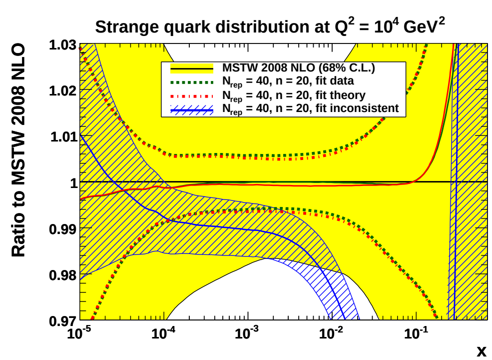
Fit to "inconsistent" sets same uncertainty as "consistent" sets and $\chi^2/N \sim 1$, but PDFs move many $\Delta\chi^2 = 1$ uncertainties.

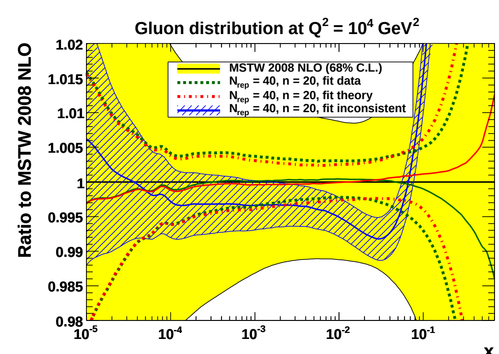




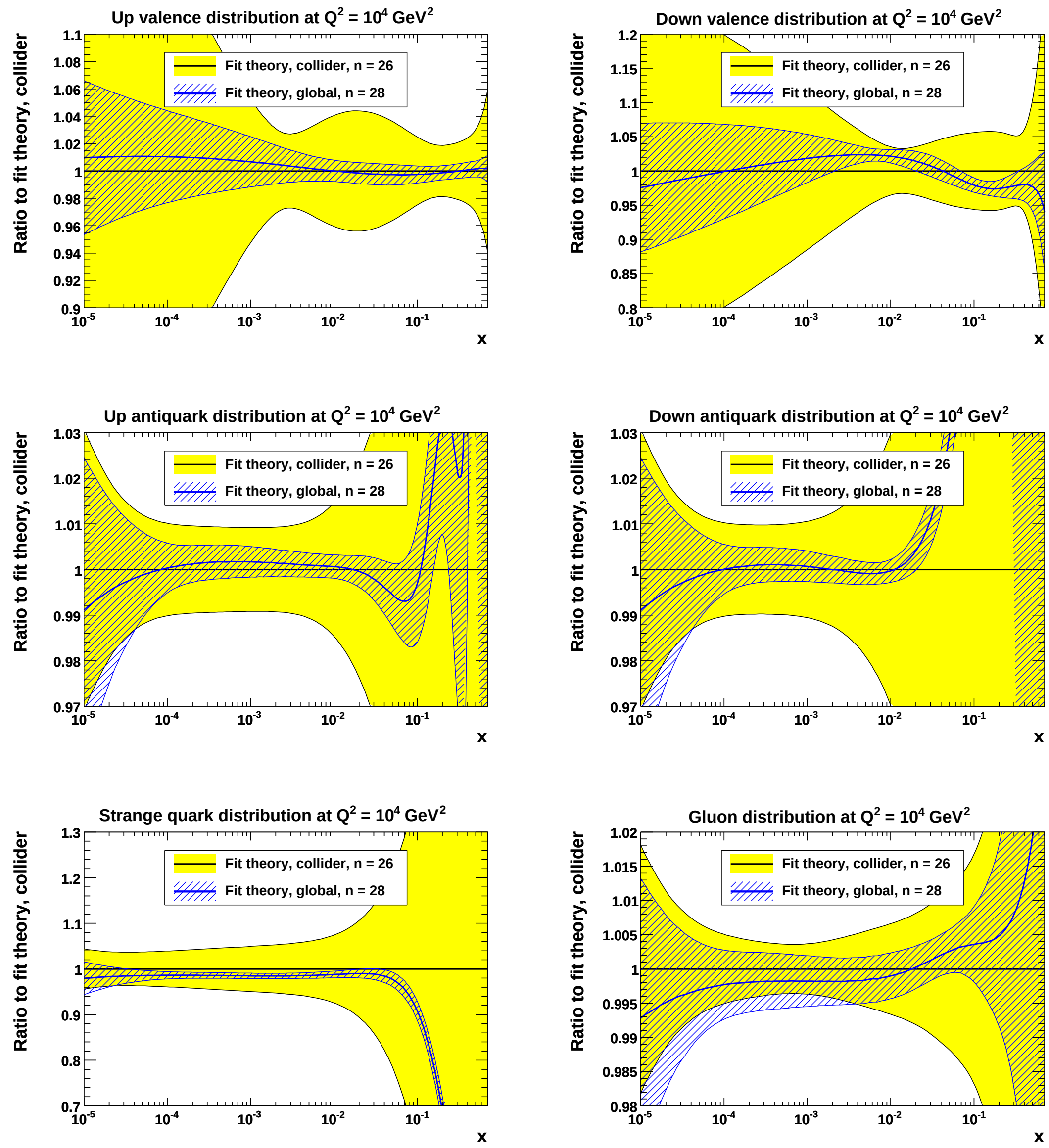






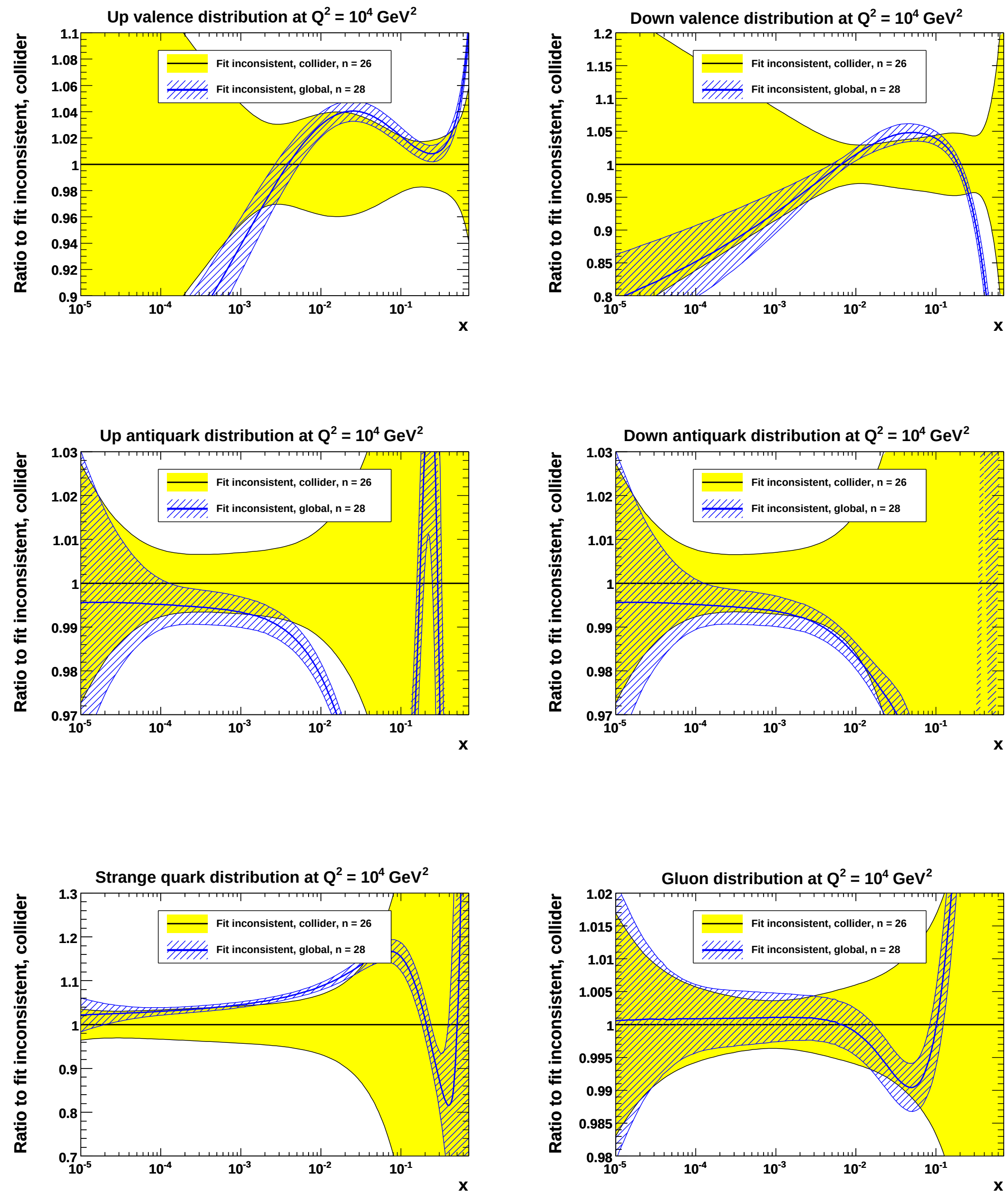


Change fit from "Collider only" to full set for "consistent" set. PDFs consistent but uncertainties much reduced.



For "inconsistent" pseudodata uncertainties reduce in same way but central values move far more than $\Delta\chi^2 = 1$ uncertainty.

Like real situation.



Maintain correctness of "dynamic tolerance" approach. Easiest in Hessian study with eigenvectors.

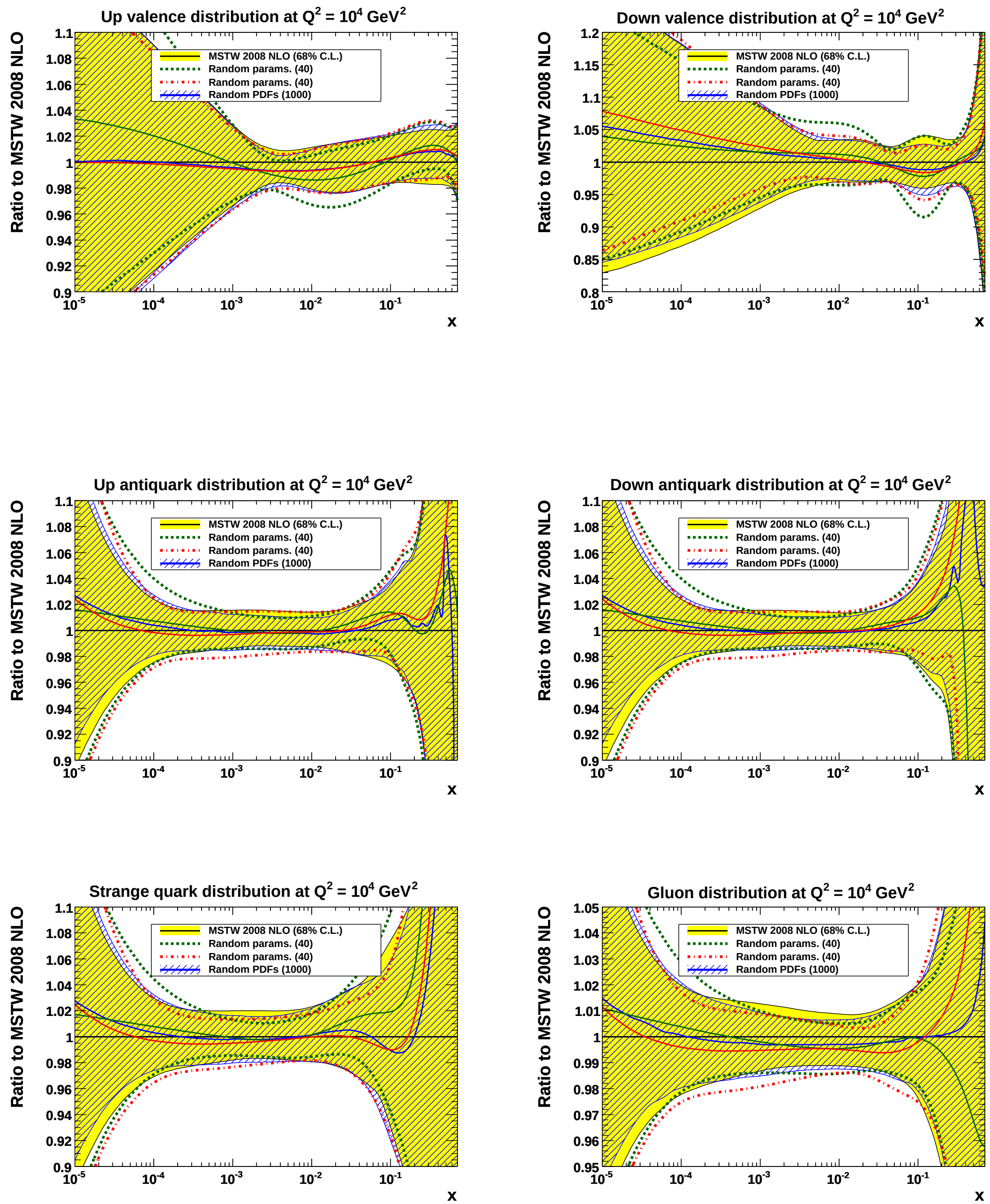
However, can generate "random" PDF sets directly from parameters and variation from eigenvectors.

$$a_i(\mathcal{S}_k) = a_i^0 + \sum_{j=1}^{n} e_{ij}\left(\pm t_j^{\pm}\right)|R_{jk}|$$

$(k = 1, \ldots, N_{\rm pdf})$. Or from eigenvectors directly (see LHCb study and De Lorenzi thesis). Far quicker.

$$F(\mathcal{S}_k) = F(S_0) + \sum_j \left[F(S_j^{\pm}) - F(S_0)\right]|R_{jk}|$$

Use in reweighting studies as NNPDF.



Comparison to LHC data.

Start with ATLAS jets. Use APPLGrid or FastNLO at NLO (Ben Watt) and correlated errors treated as multiplicative, as suggested.

Table 1: χ^2 per point (90 points)

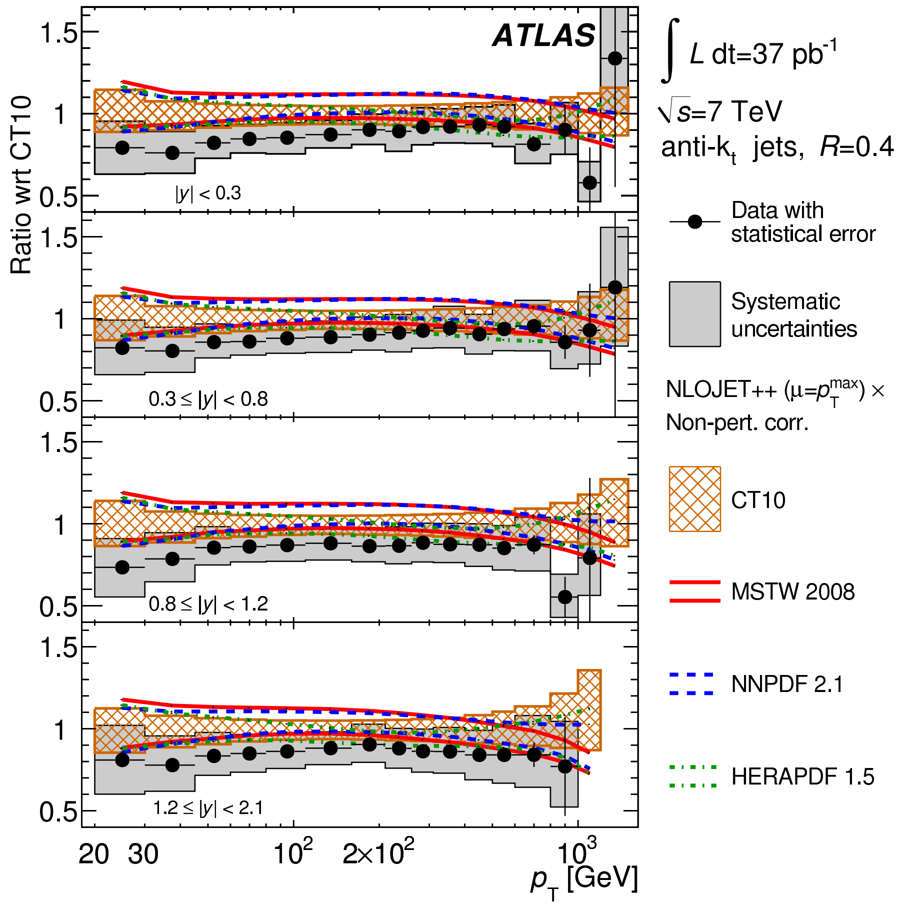
Scale	pT/2	pT	2pT
Inclusive (R=0.4)	0.580	0.548	0.522
Inclusive (R=0.6)	0.630	0.584	0.587
Dijet (R=0.4)	3.76	1.67	1.57
Dijet (R=0.6)	2.91	1.96	1.76

Table 2: Distribution of r_ks (Total 88)

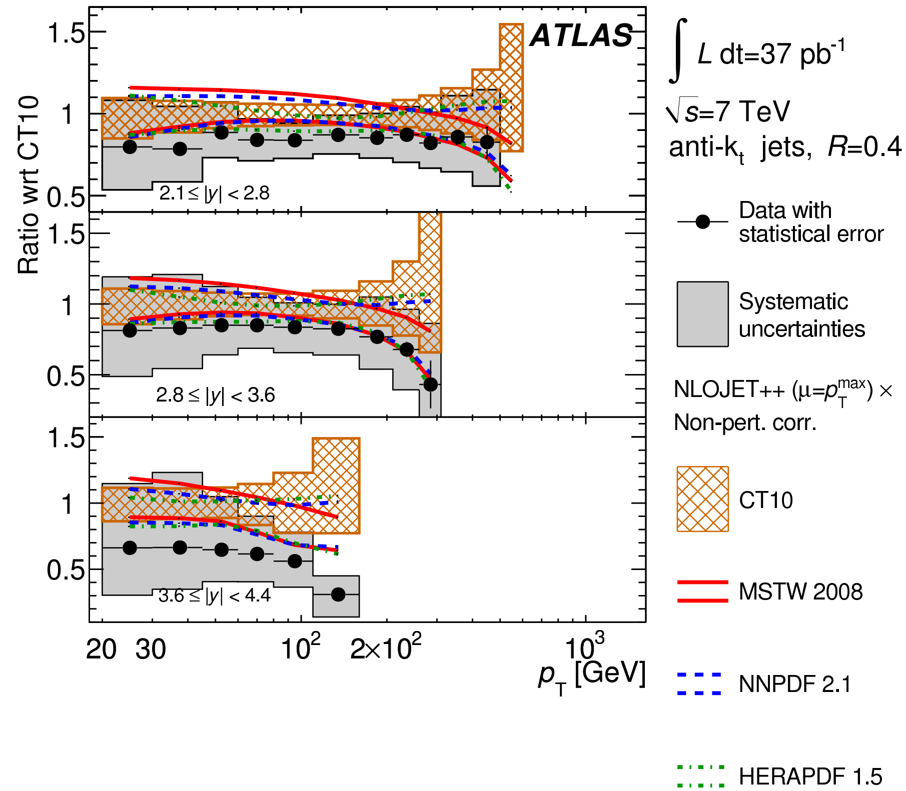
	$\|r_k\| < 1$	$1< \|r_k\| < 2$	$2< \|r_k\| < 3$	$3 < \|r_k\| < 4$
Inclusive (R=0.4)	74	13	1	0
Inclusive (R=0.6)	71	16	1	0
Dijet (R=0.4)	61	25	2	0
Dijet (R=0.6)	55	25	8	0

MSTW fit very good, though numbers lower for inclusive data. Always close to, if not best, particularly for $R = 0.6$. Not huge variation in PDFs though.

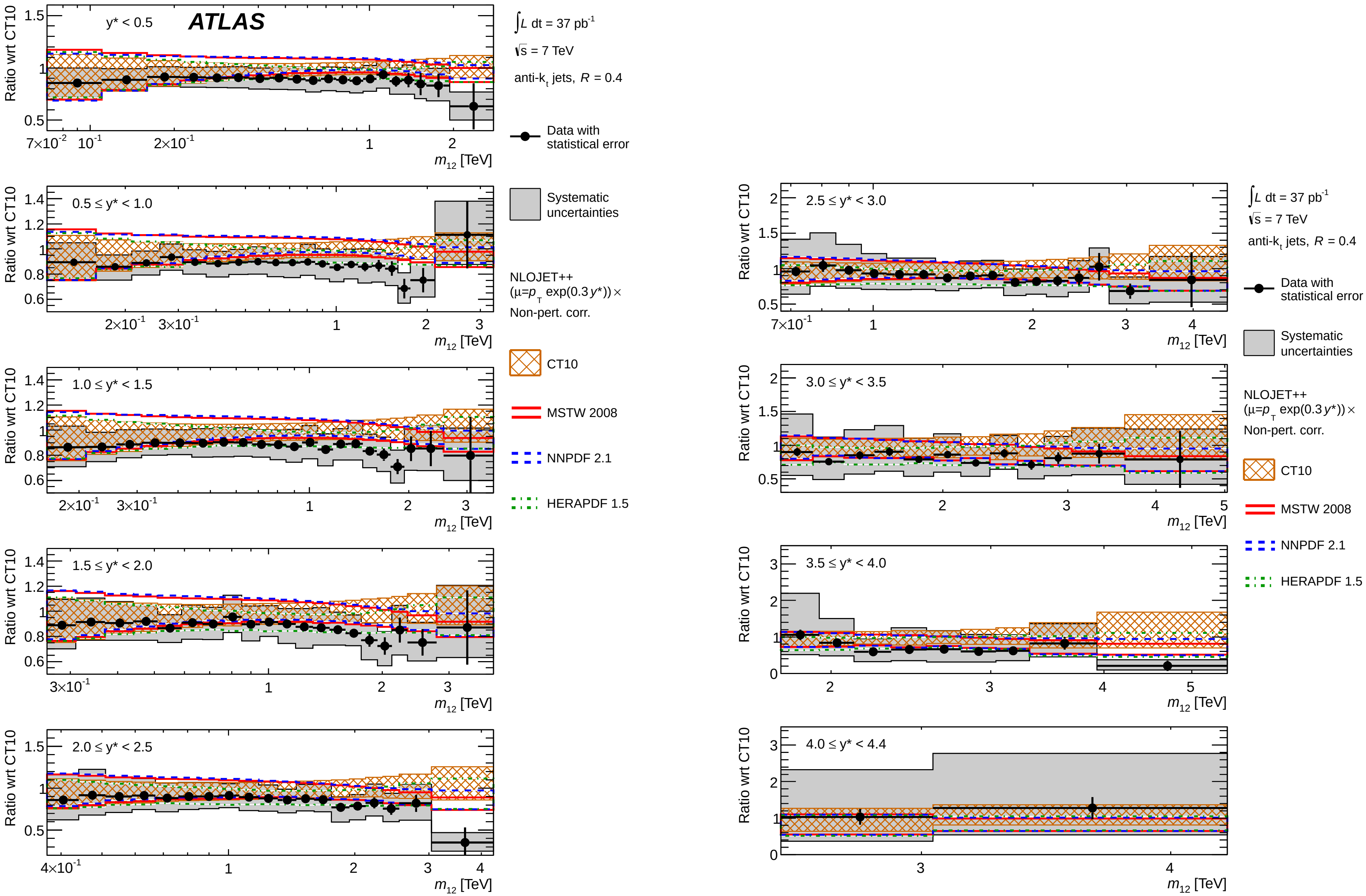
χ^2 per point about $0.7 - 0.8$ lower when multiplicative rather than additive (except $R = 0.6$ dijets) since data scales up relative to theory.



ATLAS
Ratio wrt CT10
|y| < 0.3
0.3 ≤ |y| < 0.8
0.8 ≤ |y| < 1.2
1.2 ≤ |y| < 2.1
p_T [GeV]
∫ L dt=37 pb^-1
√s=7 TeV
anti-k_t jets, R=0.4
Data with statistical error
Systematic uncertainties
NLOJET++ (μ=p_T^max) × Non-pert. corr.
CT10
MSTW 2008
NNPDF 2.1
HERAPDF 1.5

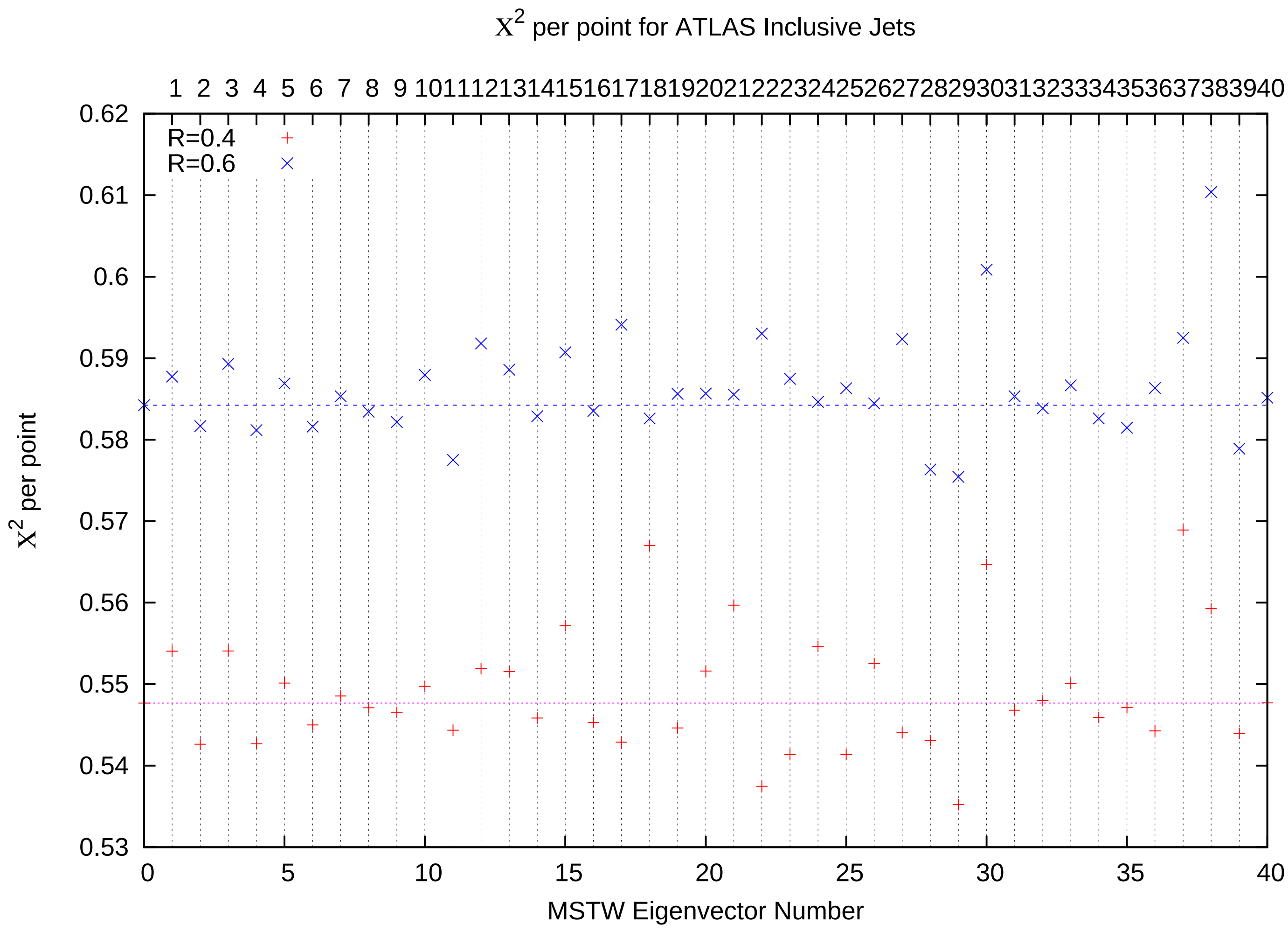


ATLAS
Ratio wrt CT10
2.1 ≤ |y| < 2.8
2.8 ≤ |y| < 3.6
3.6 ≤ |y| < 4.4
p_T [GeV]
∫ L dt=37 pb^-1
√s=7 TeV
anti-k_t jets, R=0.4
Data with statistical error
Systematic uncertainties
NLOJET++ (μ=p_T^max) × Non-pert. corr.
CT10
MSTW 2008
NNPDF 2.1
HERAPDF 1.5


ATLAS
y* < 0.5
0.5 ≤ y* < 1.0
1.0 ≤ y* < 1.5
1.5 ≤ y* < 2.0
2.0 ≤ y* < 2.5
2.5 ≤ y* < 3.0
3.0 ≤ y* < 3.5
3.5 ≤ y* < 4.0
4.0 ≤ y* < 4.4
Ratio wrt CT10
m12 [TeV]
∫L dt = 37 pb-1
√s = 7 TeV
anti-kt jets, R = 0.4
Data with statistical error
Systematic uncertainties
NLOJET++ (μ=pT exp(0.3 y*)) × Non-pert. corr.
CT10
MSTW 2008
NNPDF 2.1
HERAPDF 1.5

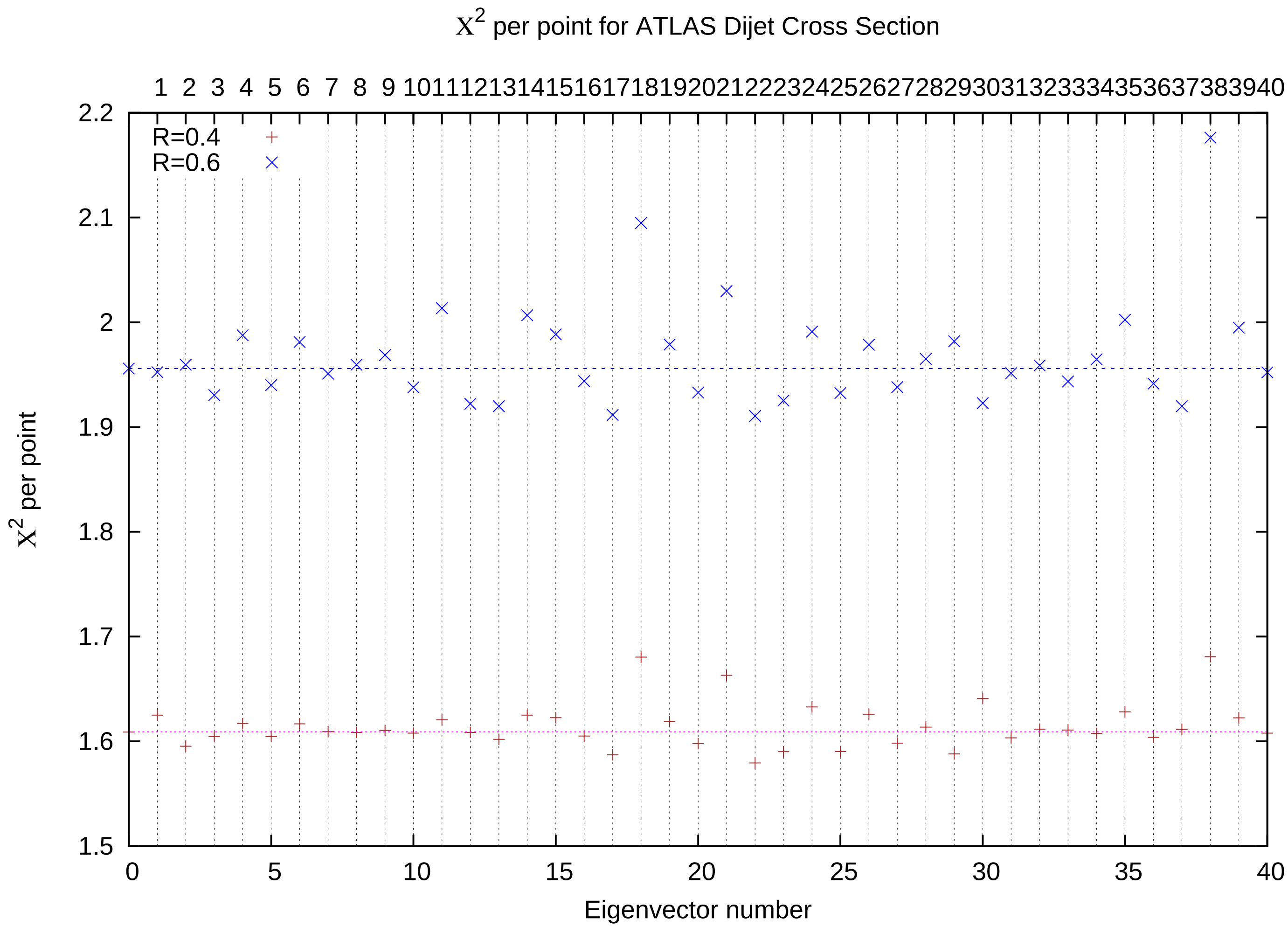
Can see how fit varies across eigenvectors.

Clearly no pull with present data. (Eigenvector χ^2 variation lower than PDF variation.)

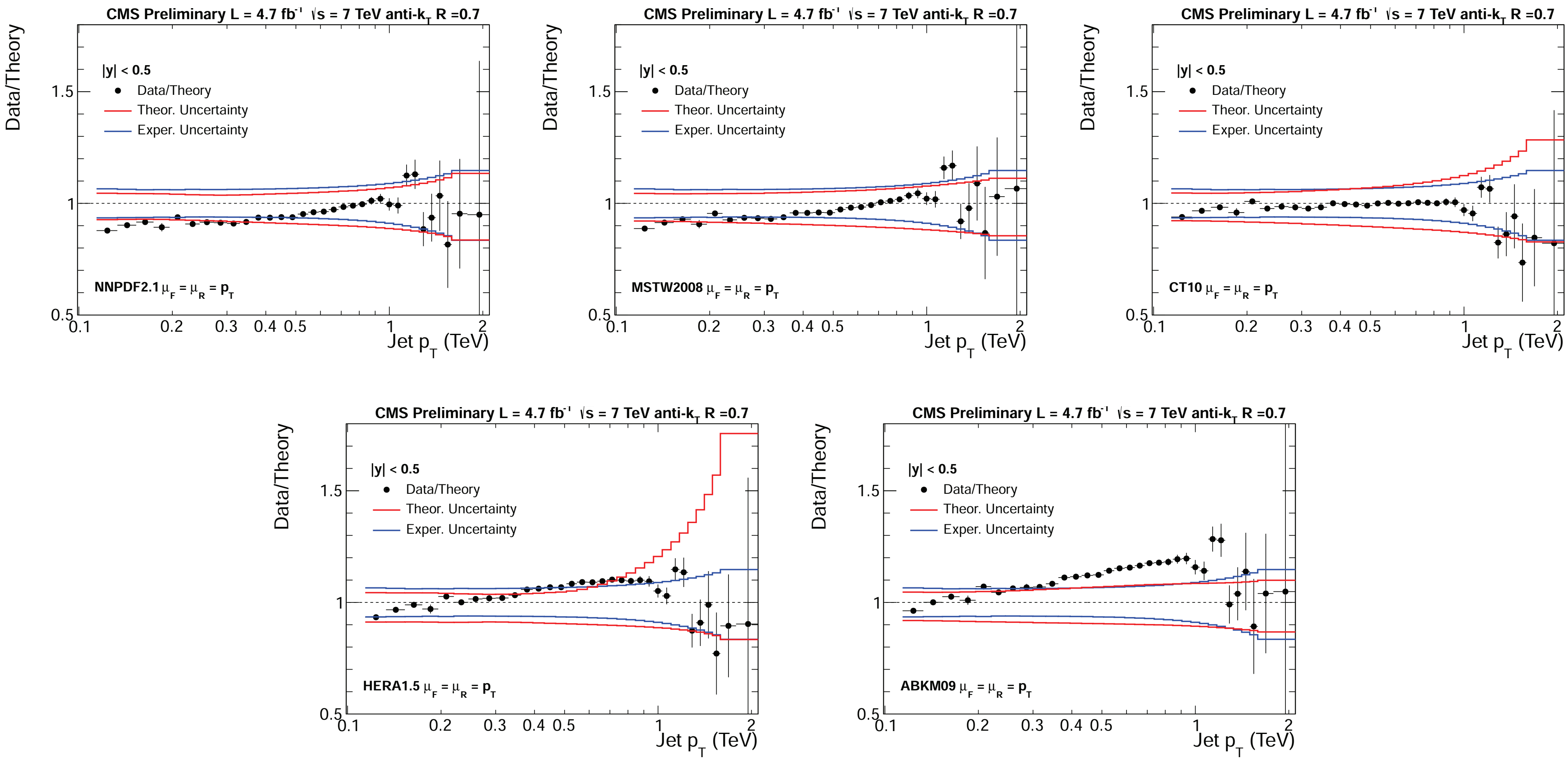


Same conclusion with dijets

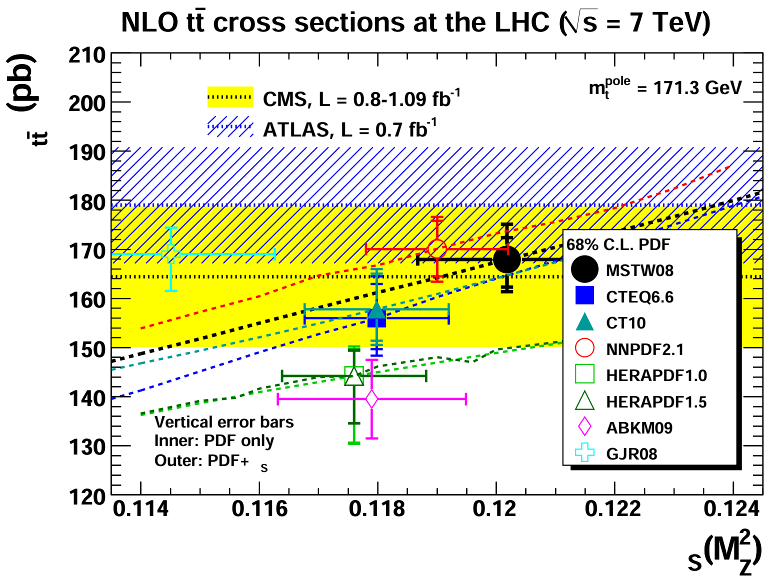
Overall result similar using NNLO PDFs with NLO cross sections. Approx NNLO in FastNLO has unusual features and fit bad (previously noticed).

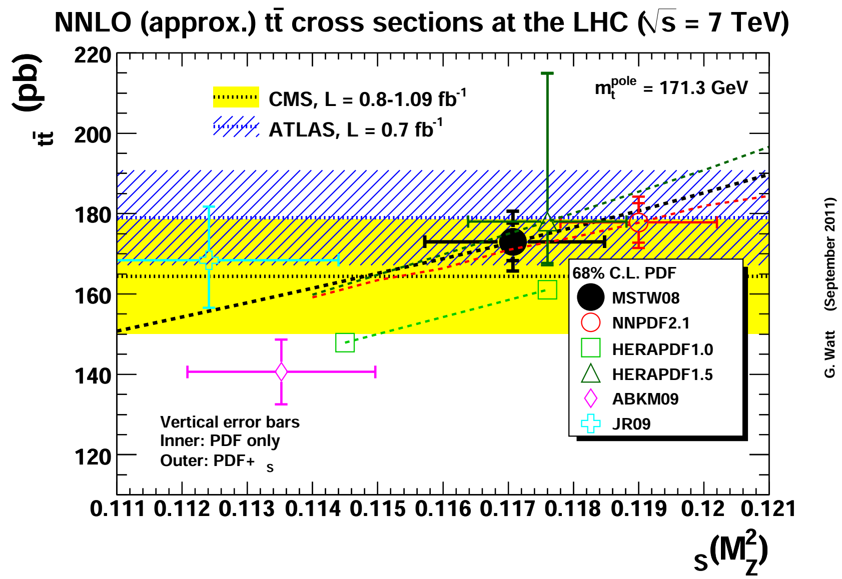


Will be interesting to see results from higher luminosity data. Looks more constraining.

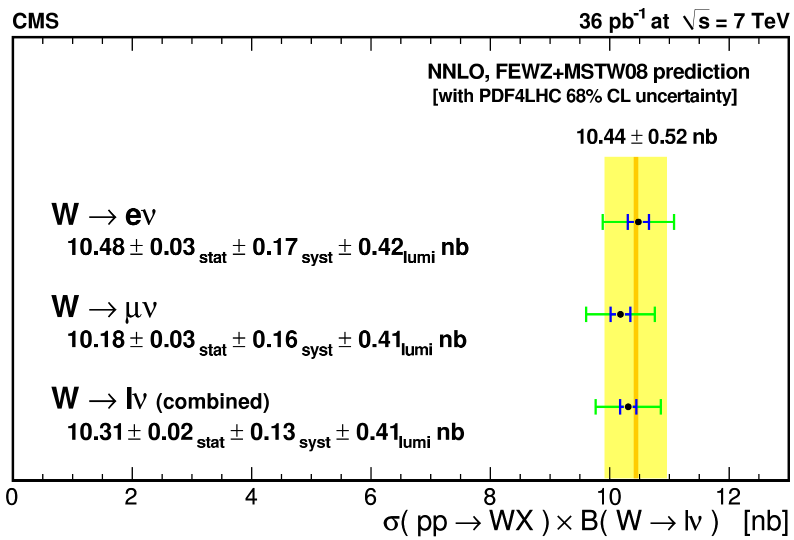


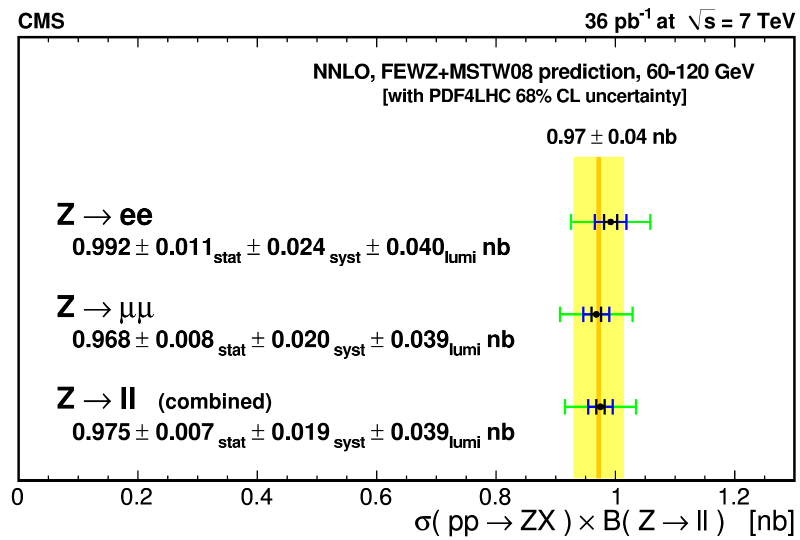
Excellent comparison to top cross section at NLO and approx. NNLO.

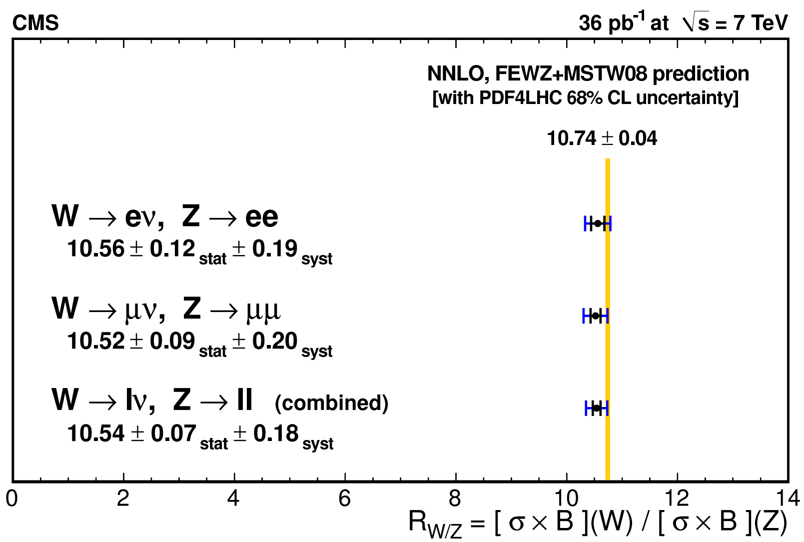


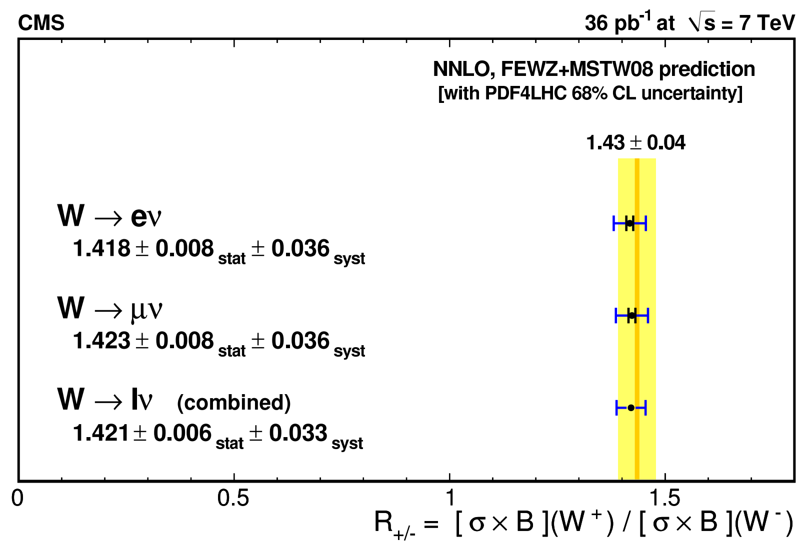


Comparison of MSTW2008 to total W, Z excellent.

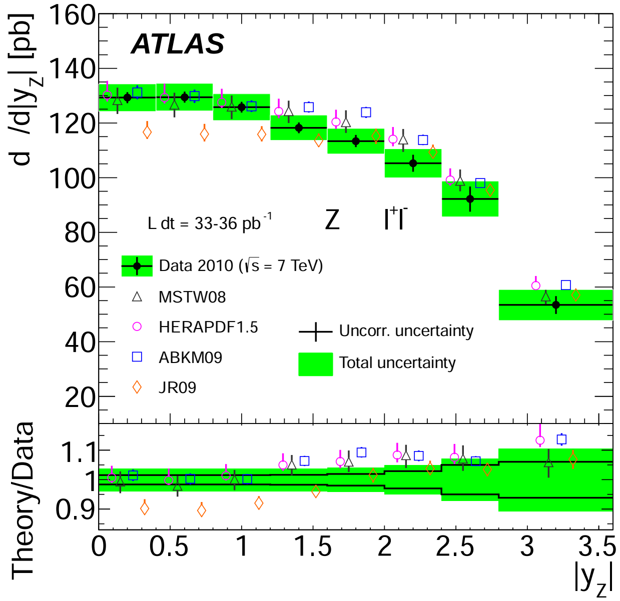


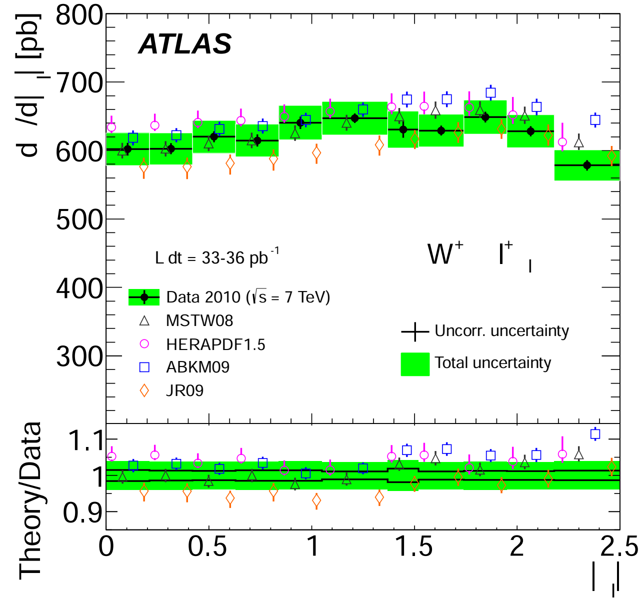


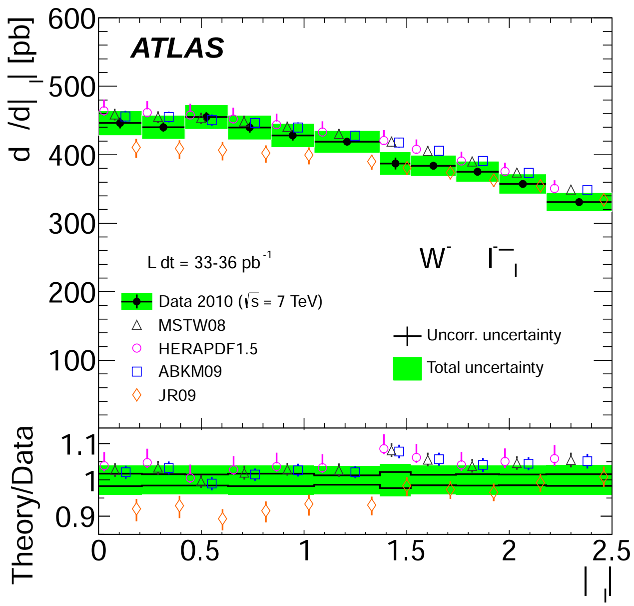


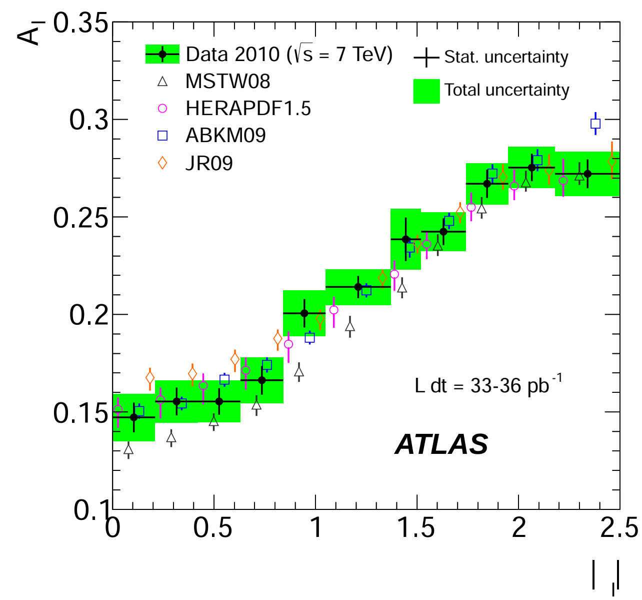


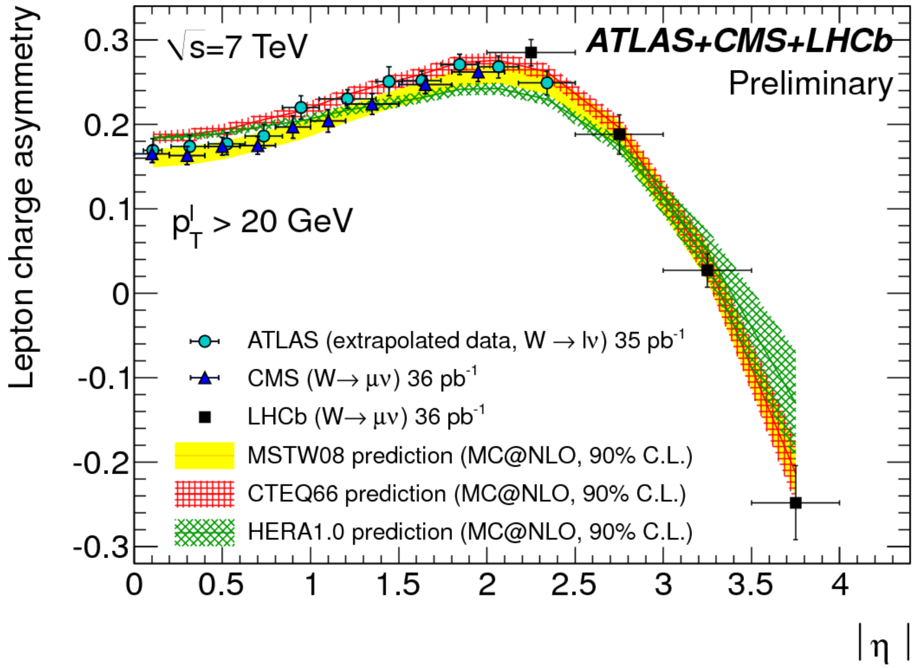
Also pretty good for inclusive distributions. Except some problems with asymmetry.

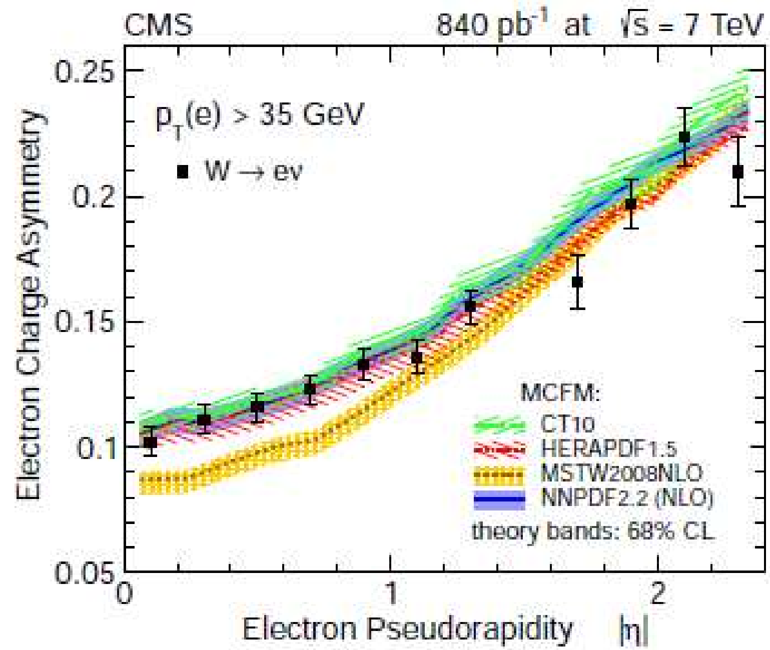




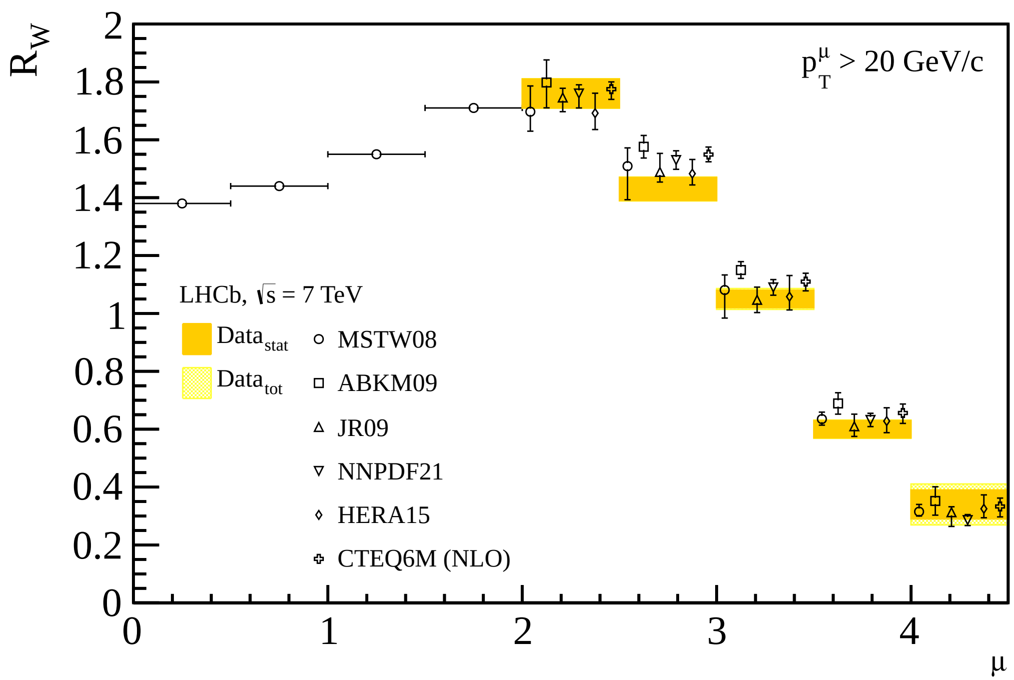






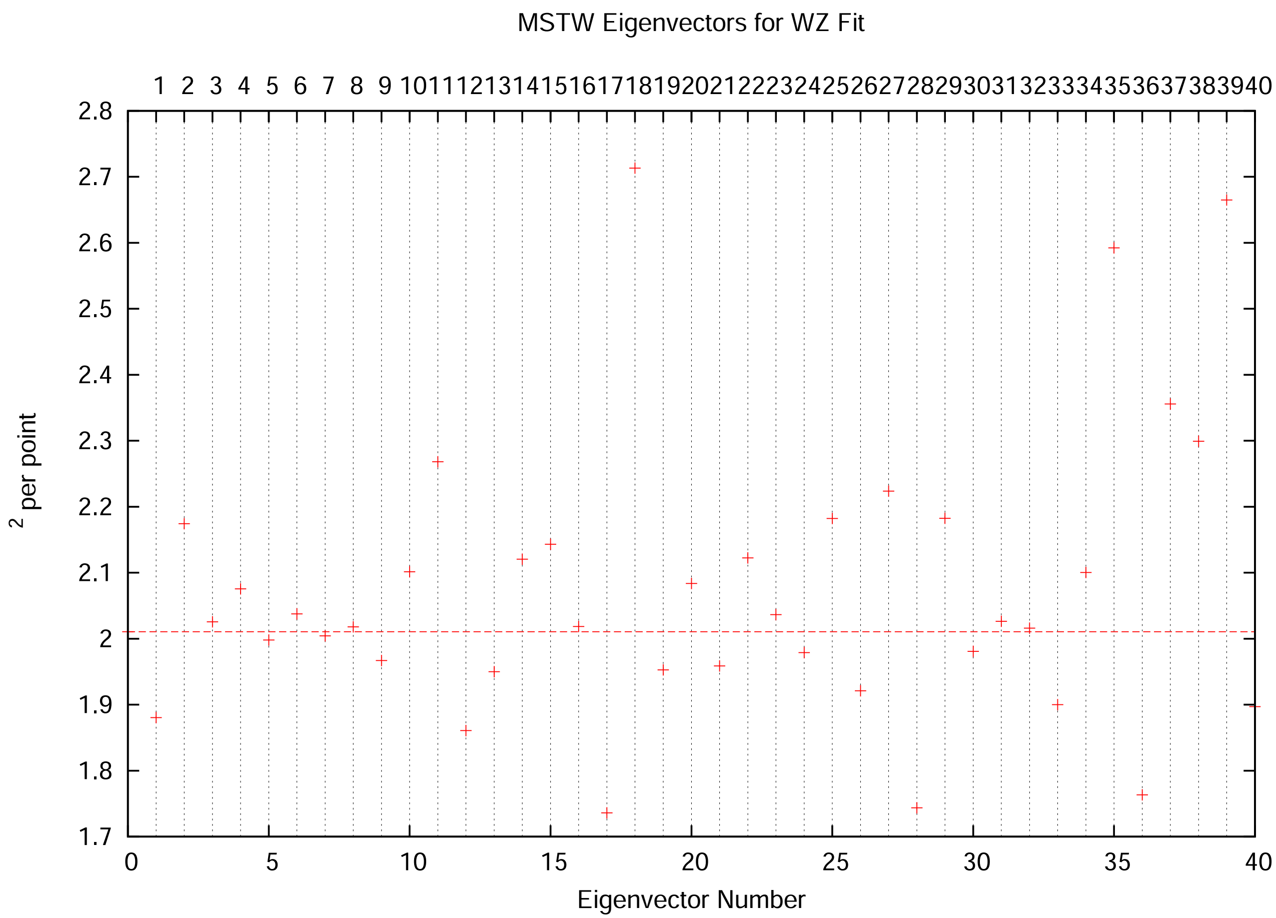


Similar for CMS data, though depends on p_T cut. Generally very good for LHCb.

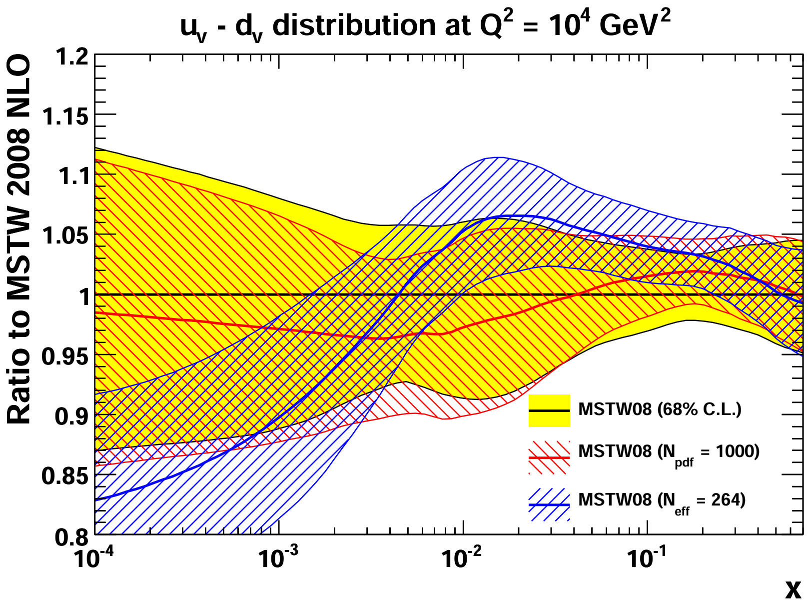


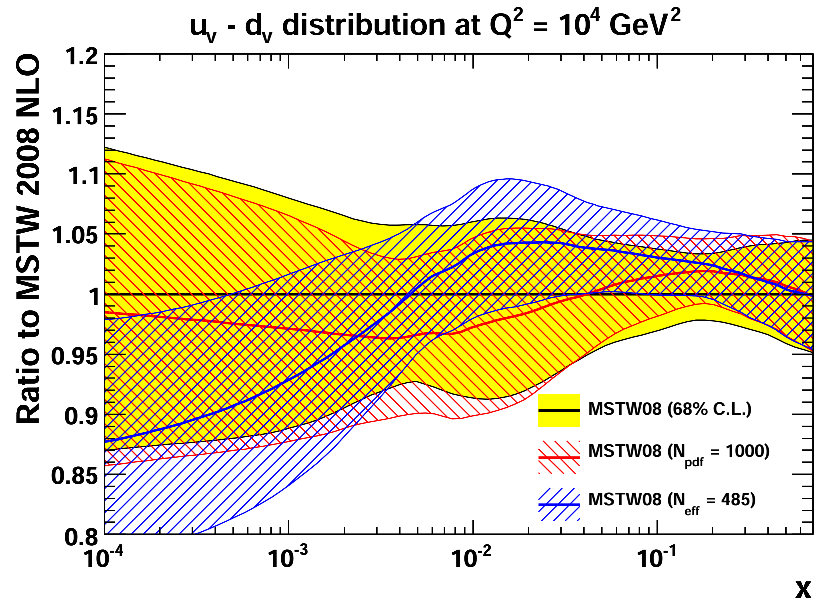
Calculate $\chi^2/N = 60/30$ for ATLAS W, Z data again at NLO using APPLGrid. Not best, but fairly close to any other set except CT10 which is best. Again look at eigenvectors.

Fit improves markedly in one direction with eigenvector 9, gluon, which alters common shape and normalisation, and 14 and 18 which alter d_V and u_V, i.e. affect asymmetry. Not much variation in strange normalisation.

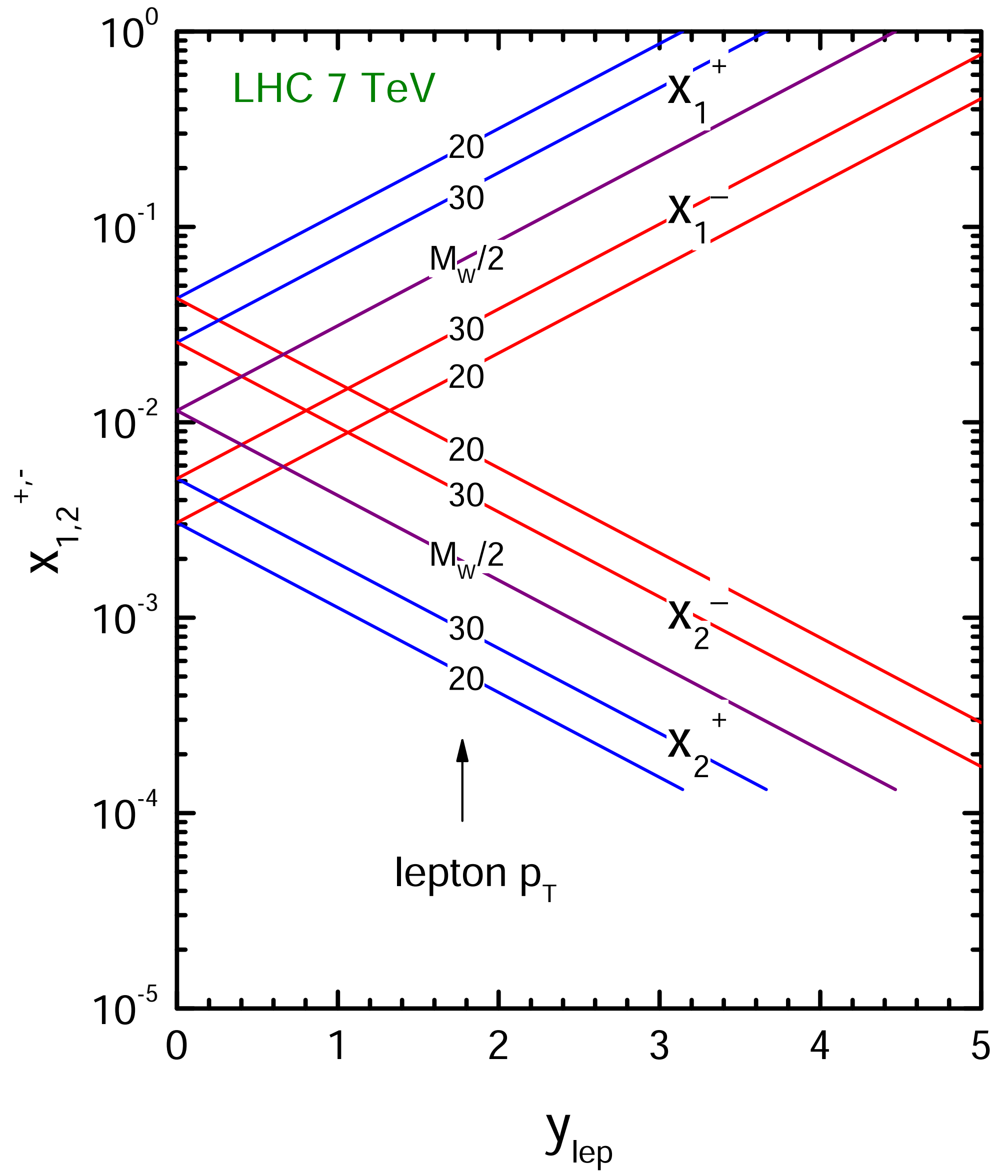


Asymmetry used by Graeme Watt in reweighting, and moves $u_V - d_V$ up around $x = 0.01$ - where parameterisation perhaps underestimates uncertainty. (ATLAS left, CMS $p_T > 25\mathrm{GeV}$ right).



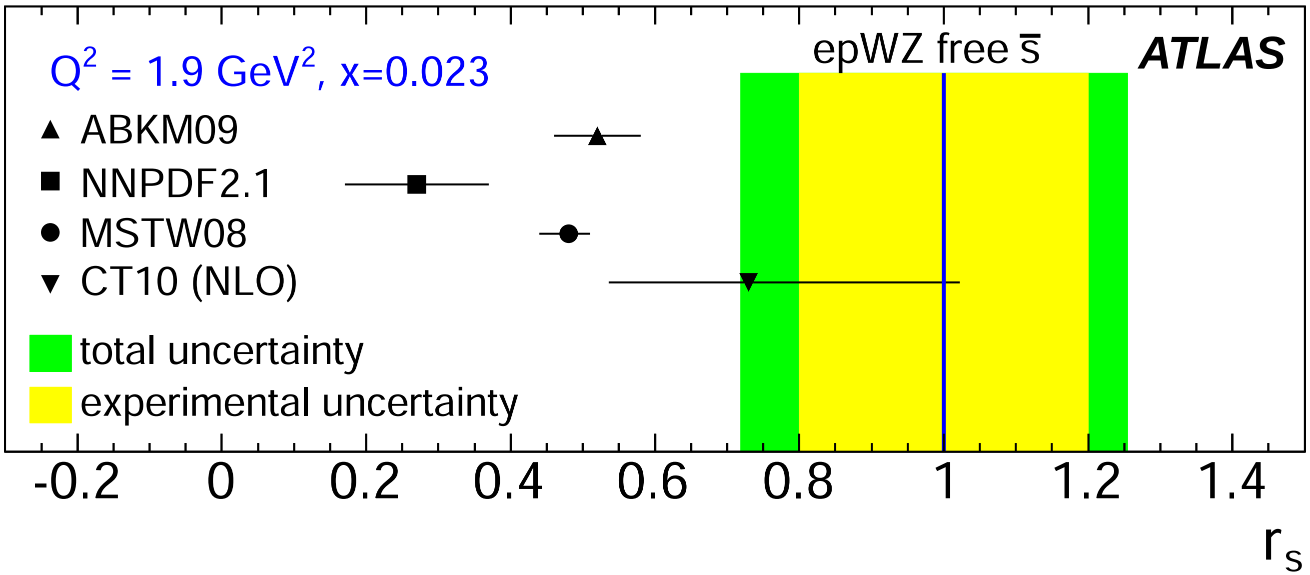


Fits with details of x values probed for different p_T cuts (Stirling).



Strange Quark

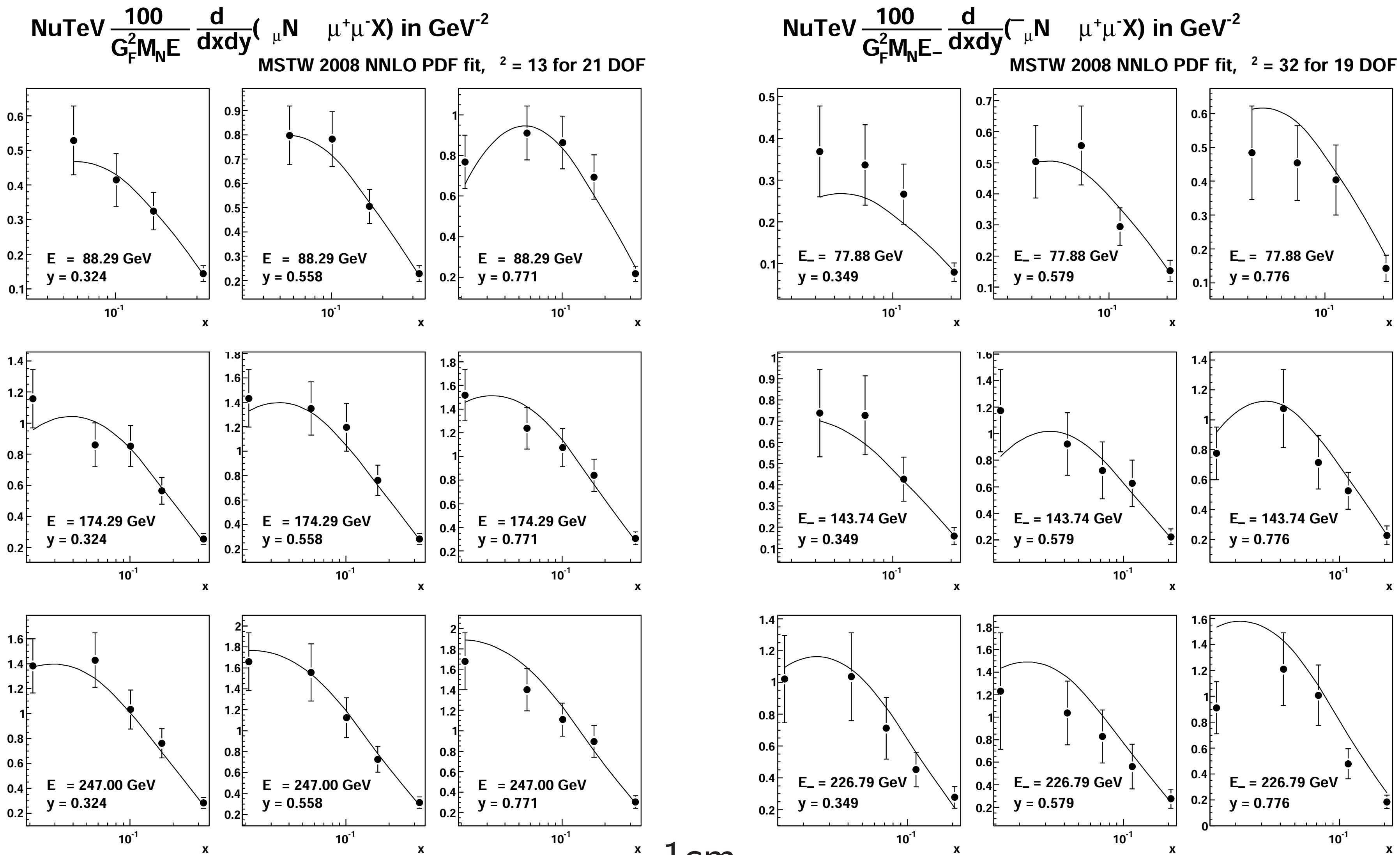
Recently suggested by ATLAS study that strange quark fraction at $x \sim 0.01$ much larger than generally suggested - though there is quite a lot of variation.



Mostly determined in many fits by dimuon data

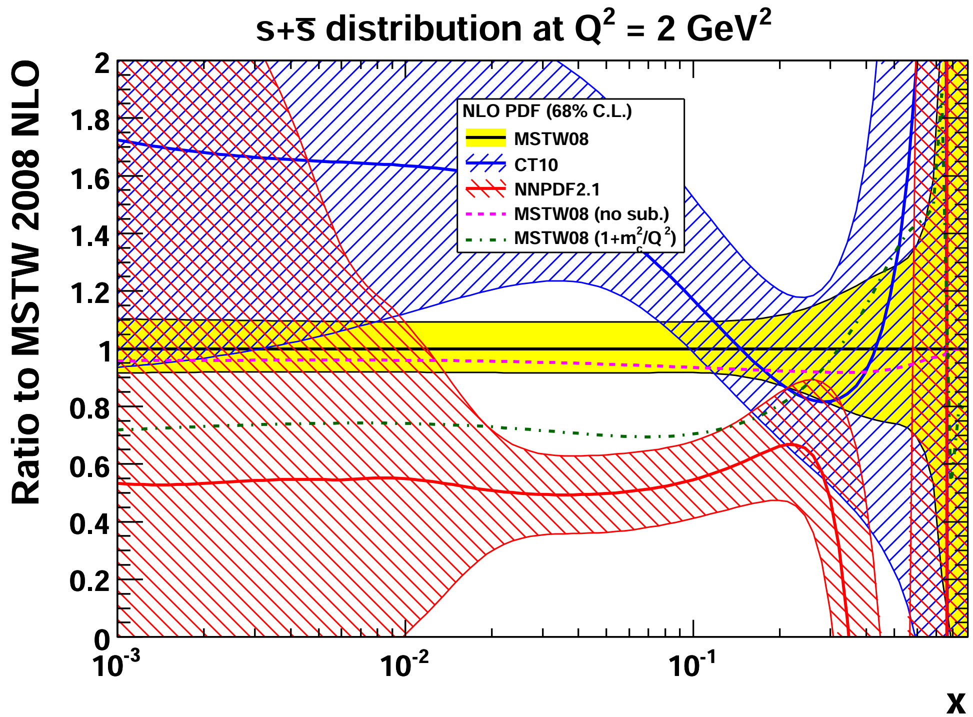
$$\nu_\mu \to \mu^- + W^+, \qquad W^+ + s \to c$$

where the charm meson decays to a muon. From CCFR, NuTeV, the latter being more constraining.



Where $Q^2 = 2m_p x E_\nu$. At $x \sim 0.02$ $Q^2 \sim 2 - 5\text{GeV}^2$. Lowest x bin usually $Q^2 = 2 - 3\text{GeV}^2$.

Significant variation in PDFs (ABM similar to MSTW). Maybe partially explained by Q^2 cuts (MSTW $2\mathrm{GeV}^2$, NNPDF $3\mathrm{GeV}^2$, CT10 $4\mathrm{GeV}^2$). Strange almost unchanged if MSTW cut $5\mathrm{GeV}^2$.



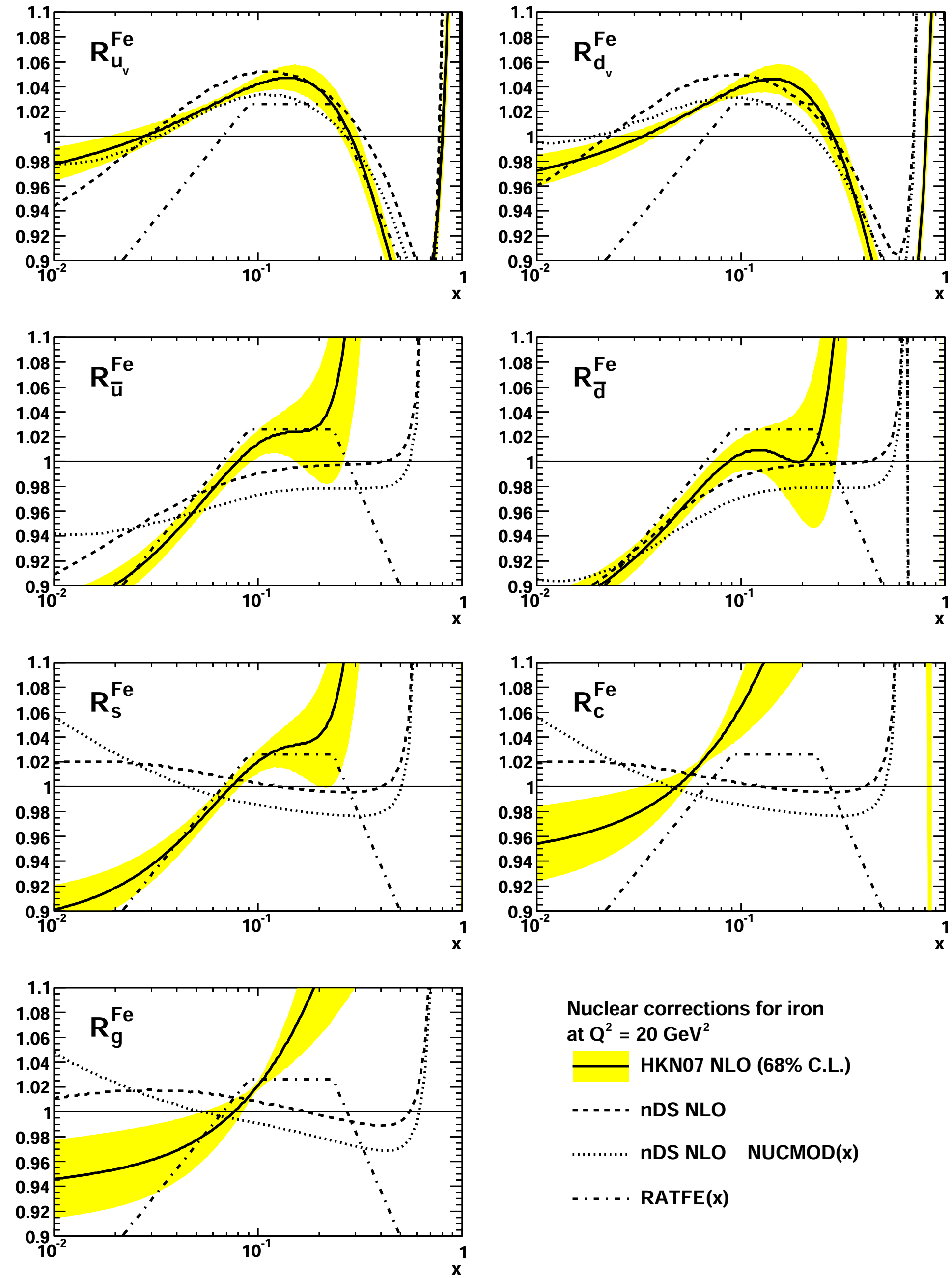
Factor of $(1 + m_c^2/Q^2)$ in NNPDF2.1 lowers MSTW a little - cuts different.

Correction of contribution from initial state charm quarks/subtraction from gluon ($\sigma \propto s + (1-y)^2\bar{c}, y = 0.3 - 0.7$) to be consistent with acceptance corrections moves MSTW down very slightly (smaller $y \rightarrow$ smaller charm). Plot by G. Watt.

Requires use of nuclear corrections.

Can vary by $\sim 10\%$ at $x \sim 0.01$. A little more at low Q^2.

MSTW allow no penalty variation in nuclear corrections with three parameters (normalisation, low x shape and high x shape).



Try various fits changing strange parameterisation. General form

$$s(x, Q_0^2) + \bar{s}(x, Q_0^2) = A(1-x)^\eta (1 + \epsilon x^{0.5} + \gamma x) x^\delta, \qquad Q_0^2 = 1\text{GeV}^2.$$

where δ set equal to light sea. Fix ϵ and γ because the fit finds no improvement if left free. A leads to suppression and η slightly greater than for light sea.

Try raising strange at low x by setting A so that $s(x, Q_0^2) + \bar{s}(x, Q_0^2)$ is a third of the total sea at input at low x. Try 4 variations.

- $k\!=\!1$ where $k = (s + \bar{s})/(\bar{u} + \bar{d})$ - all other parameters fixed. Strange exactly $1/3$ of sea at input. $\Delta\chi^2 = -10$ for ATLAS, W,Z data.
- $k\!=\!1\,1p$ - η free. $\Delta\chi^2 = -11$ for ATLAS, W,Z data.
- $k\!=\!1\,2p$ - η, γ free. $\Delta\chi^2 = -10$ for ATLAS, W,Z data.
- $k\!=\!1\,3p$ - η, γ, ϵ free. $\Delta\chi^2 = -4$ for ATLAS, W,Z data.

$k = 1$ - $\Delta\chi^2 = 1200$. NuTeV dimuon χ^2 25 times worse. All nuclear data and Drell Yan data (E866 and Tevatron) much worse.

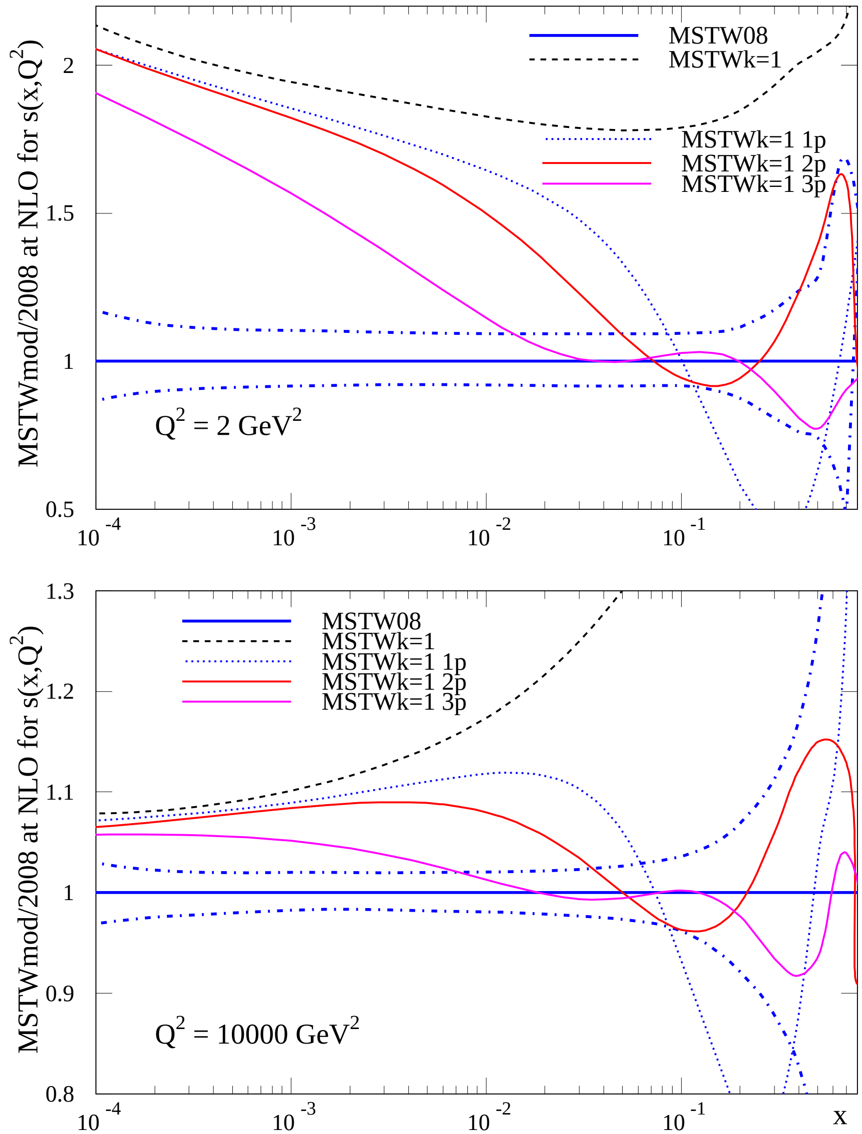
$k = 1\,1p$ - $\Delta\chi^2 = 190$. NuTeV dimuon $\chi^2 120$ worse. Nuclear and Drell Yan data worse. Nuclear correction modified.

$k = 1\,2p$ - $\Delta\chi^2 = 55$. NuTeV dimuon $\chi^2 42$ worse. Nuclear and Drell Yan data slightly worse. (Similar to CT10 strange)

$k = 1\,3p$ - $\Delta\chi^2 = 43$. NuTeV dimuon $\chi^2 17$ worse. Nuclear and Drell Yan data slightly worse.

Does not resolve issues. Some pull from ATLAS data.

Much more from $W + c$ data (see Stirling and Vryonidou study).



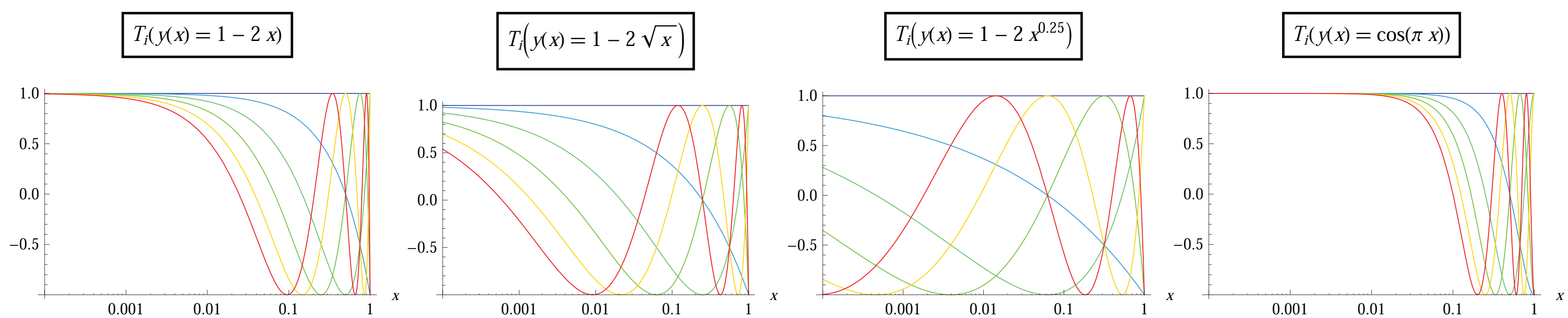
Investigation of Parameterisation Issues - with A. Mathijssen.

In the light of Monte Carlo studies investigate parameterisation dependence, initially concentrating on valence quarks.

Decide to use Chebyshev polynomials (looked at other possibilities)

$$xf(x,Q_0^2) = A(1-x)^{\eta}x^{\delta}(1+\sum_n a_n T_n(y))$$

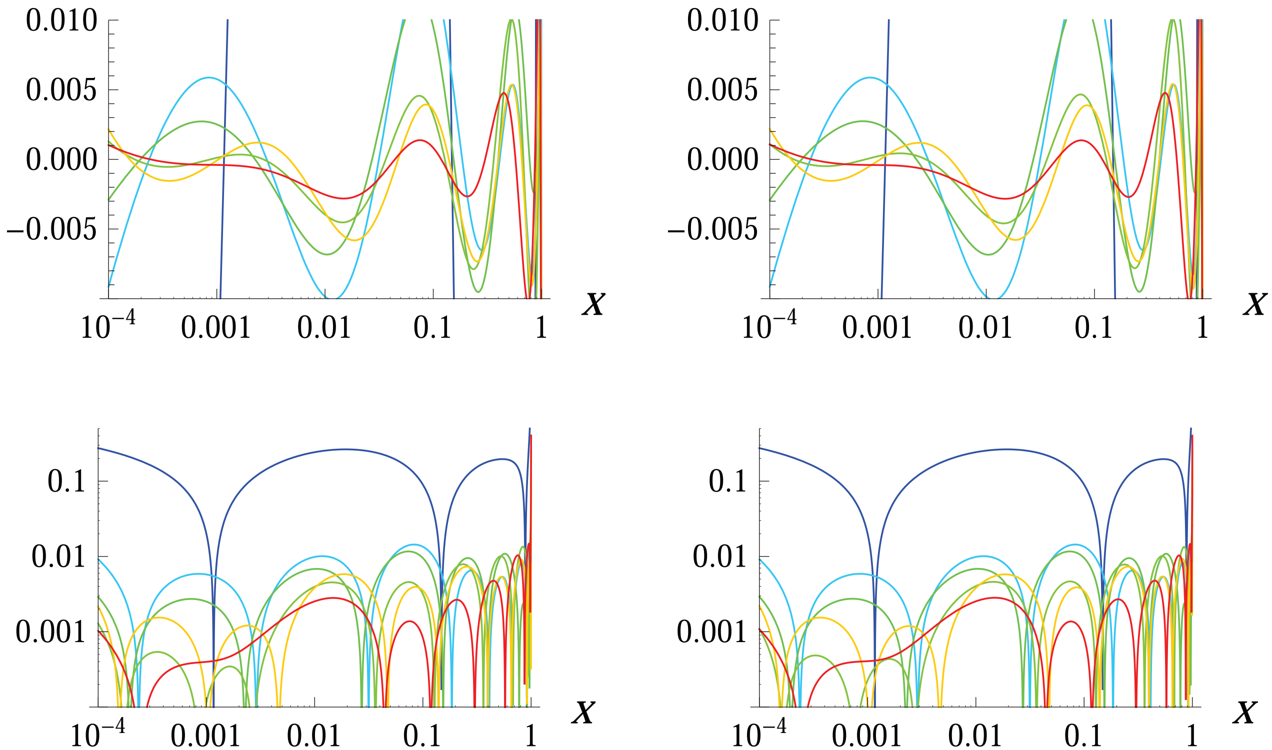
i.e. keep high and low x limits. Choose $y = 1 - 2\sqrt{x}$.



Same choice as in Pumplin study. Slightly different to Glazov, Moch and Radescu.

Fit to pseudodata for valence quark generated from very large order polynomial with smoothness constraints applied.

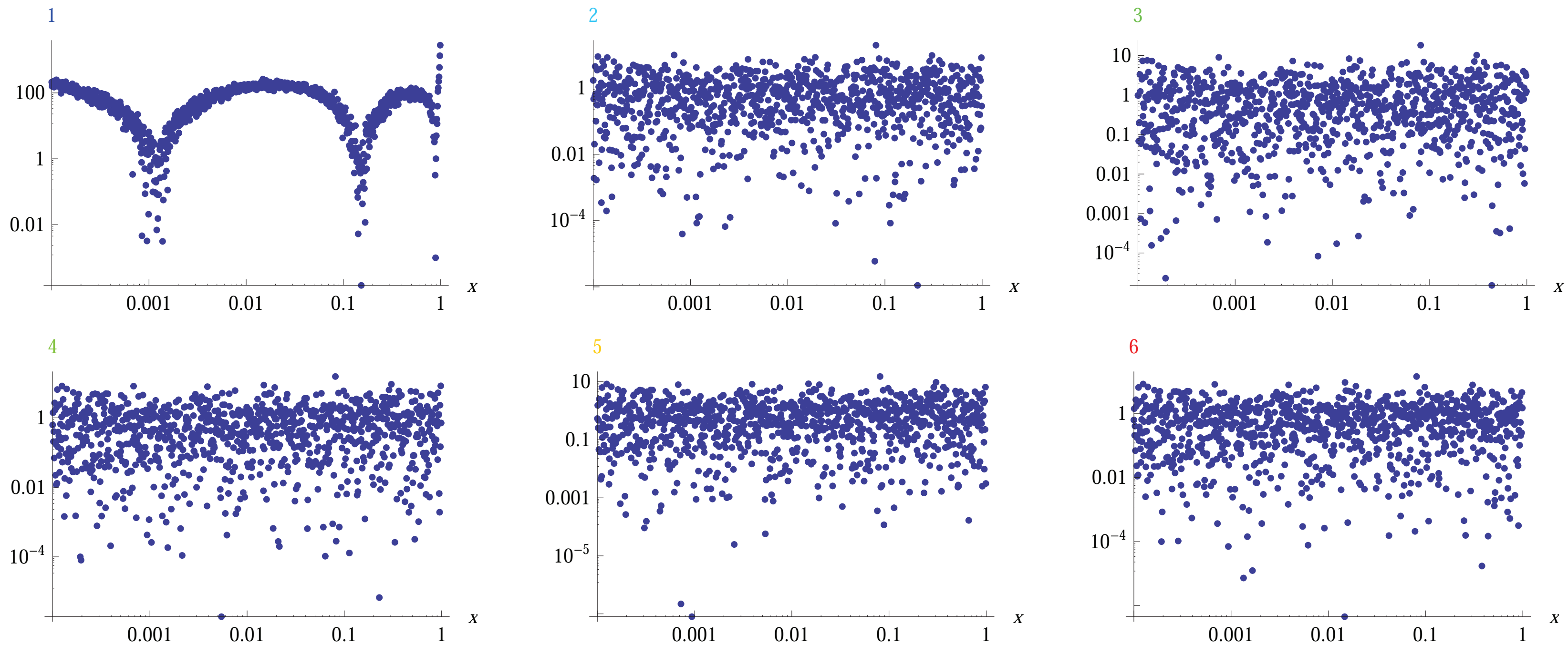
Distributed evenly in $\ln(1/x)$ with percentage error constant.



Percent deviation for full function - Chebyshev result on right. Order increase across the visible spectrum (i.e. dark blue to red).

2 terms in polynomial mainly $\leq 1\%$ deviation. 4 terms in polynomial $\leq 0.5\%$ deviation except high x.

Contributions to χ^2.



After $5 - 6$ polynomials start fitting noise, i.e. χ^2 lower than real function.

Conclude 4 parameters fine. (Note first 2 just re-expression of standard MSTW parameterisation.)

Fits to data

Just applying to valence quarks $\Delta\chi^2 = -4$.

Significant change in $u_V(x), x \leq 0.03$

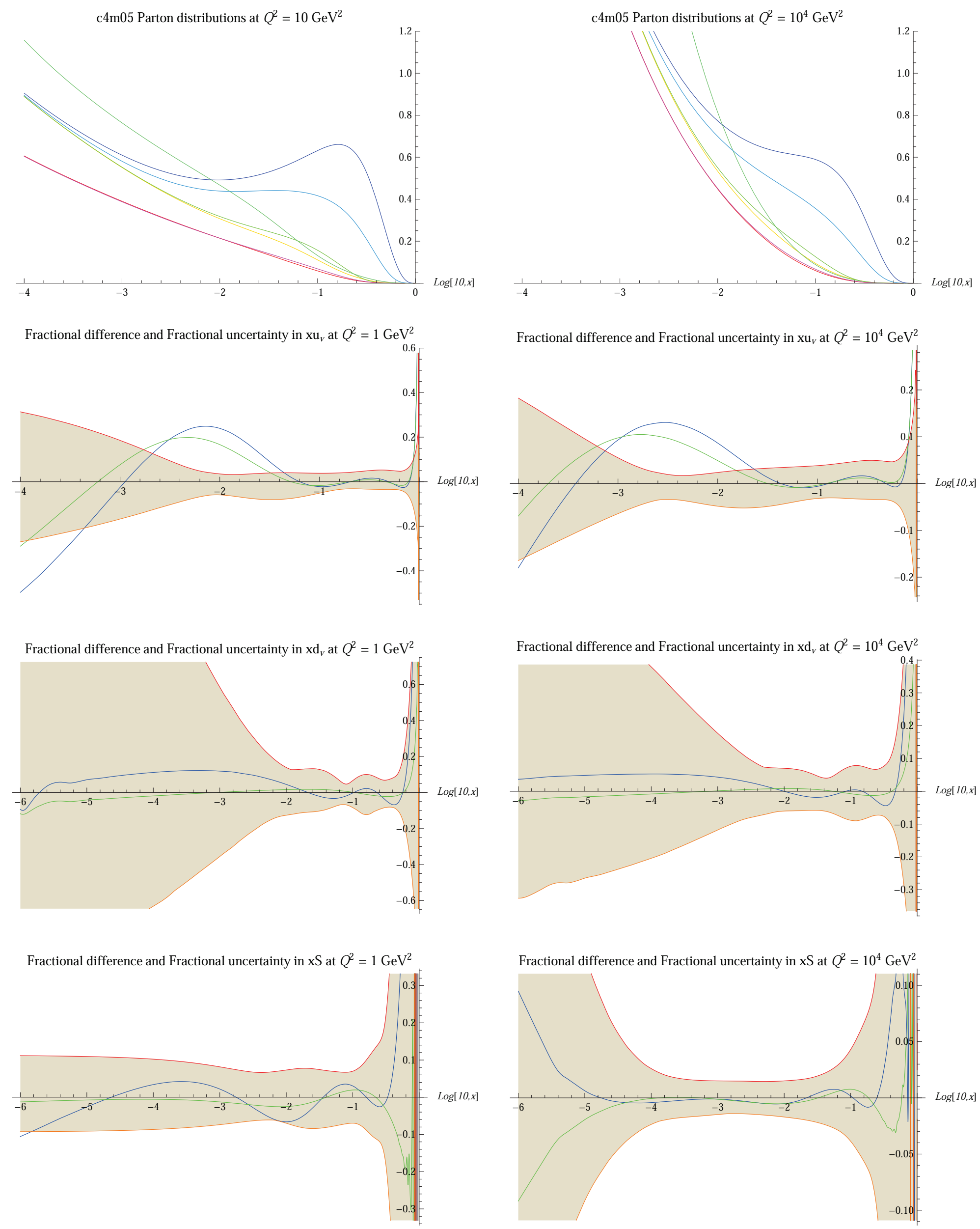
similar to earlier conclusion adding x^2 term to parameterisation.

Applying also to sea and gluon $\Delta\chi^2 = -29$ (mainly BCDMS and Drell Yan data).

Still change significant only for $u_V(x), x \leq 0.03$.

Fits with requirement for fitting lepton asymmetry at LHC.

—— valence, —— valence + sea

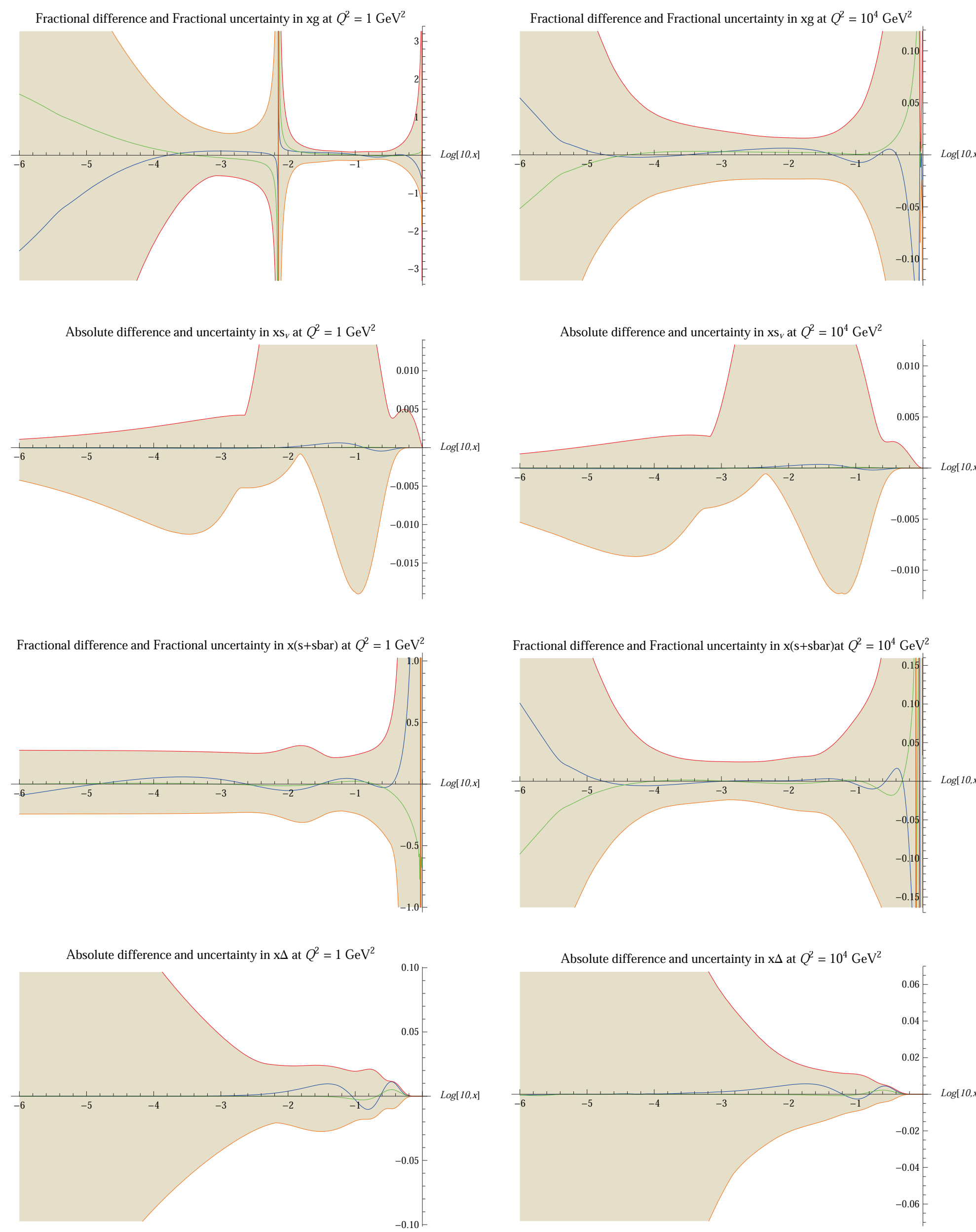


Little change in other PDFs.

Already 7 free parameters in the gluon. Sticking with two terms in Chebyshev polynomial leads to no change.

Take this a default - MSTW2008Cp (preliminary).

Prelim. study of uncertainties with 23 eigenvectors (one extra for valence quarks and sea). Little change except valence for $x \leq 0.03$, where significant increase.

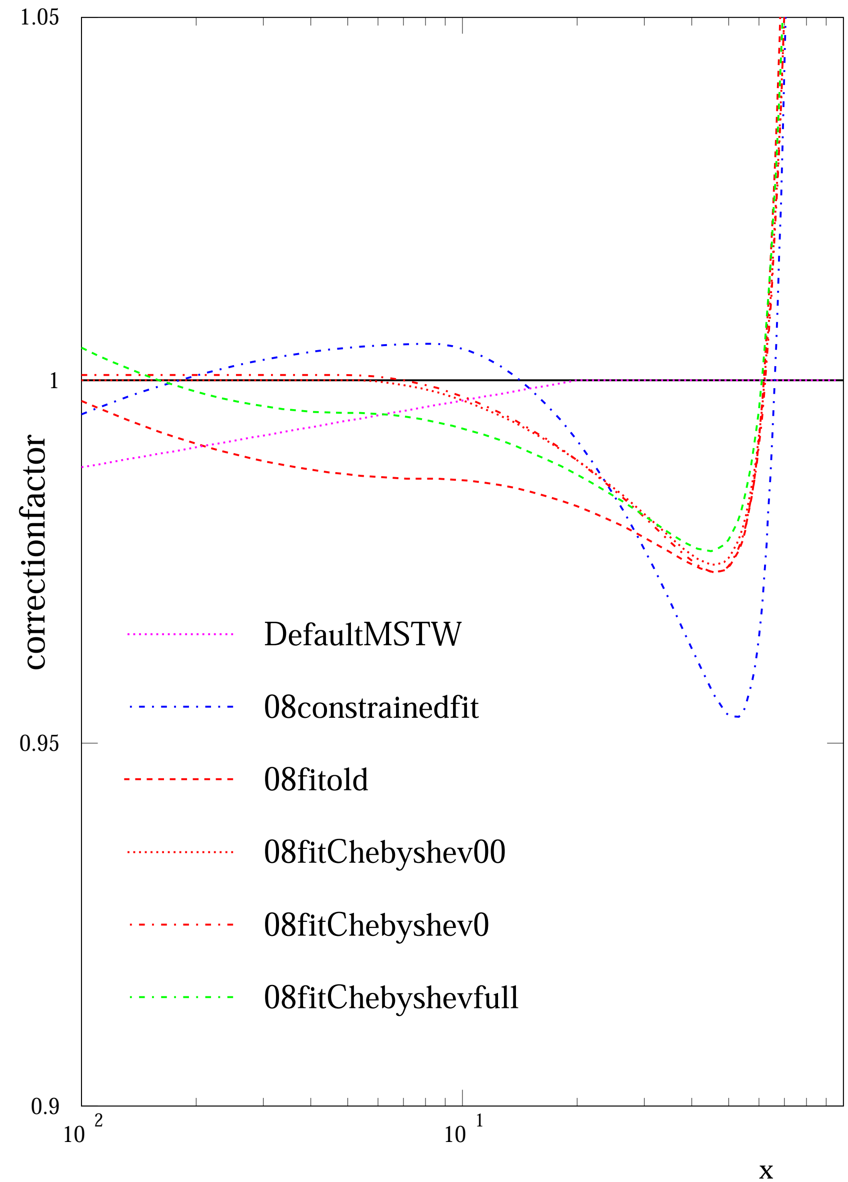


Given previous relationship between Tevatron asymmetry and deuterium corrections where partial success was noted revisit with extended parameterisation.

Default for MSTW some shadowing for $x < 0.01$.

Previously big improvement in fit, but “unusual” corrections.

Now improvement again but much more stable, and sensible for deuterium corrections. (No shadowing favoured though.)

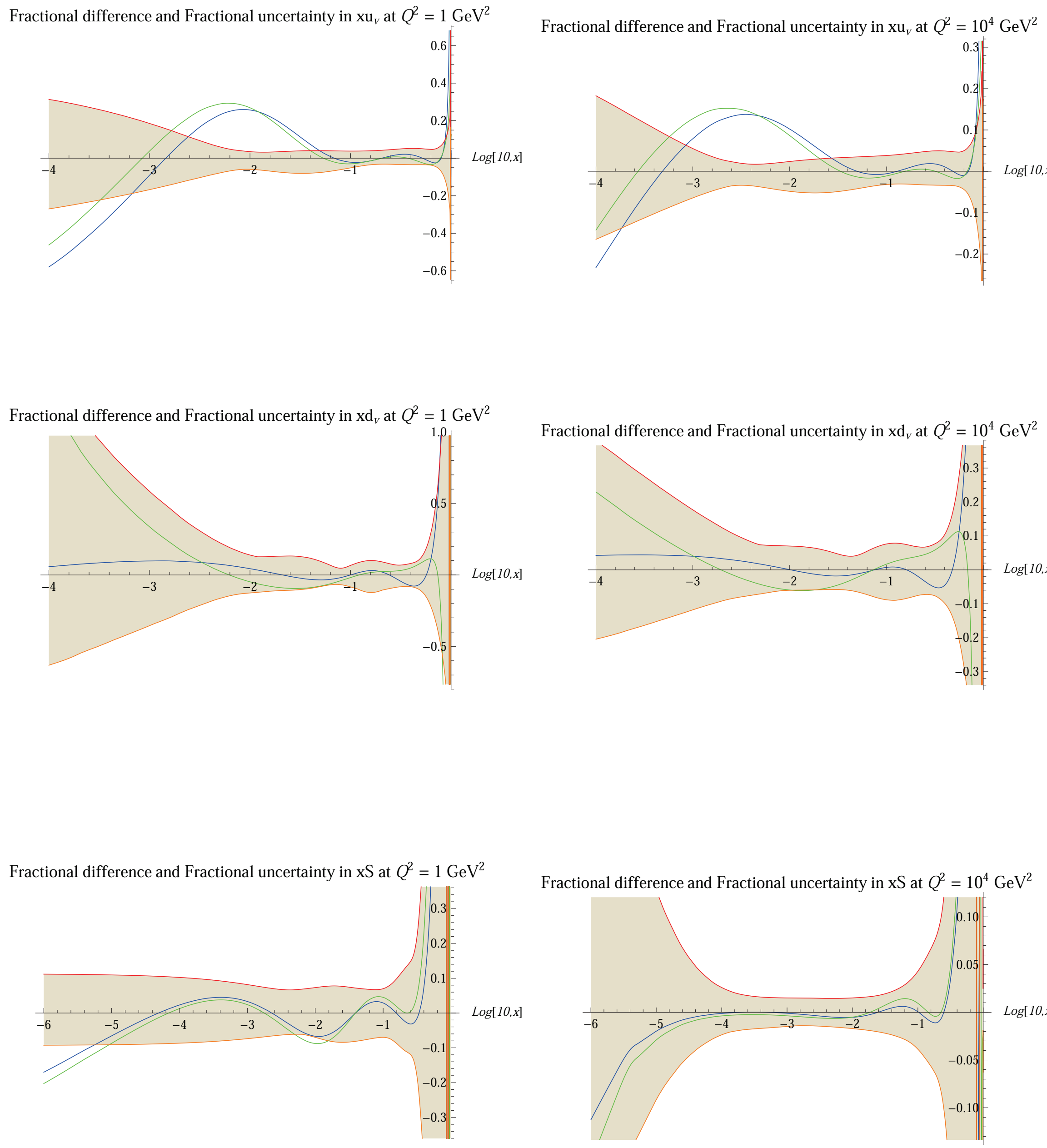


Now also get variation in $d_V(x)$ for higher x due to deuterium correction (seen before) and $x \leq 0.03$ due to parameterization and corrections.

Prelim. MSTW2008Cpdeut PDFs.

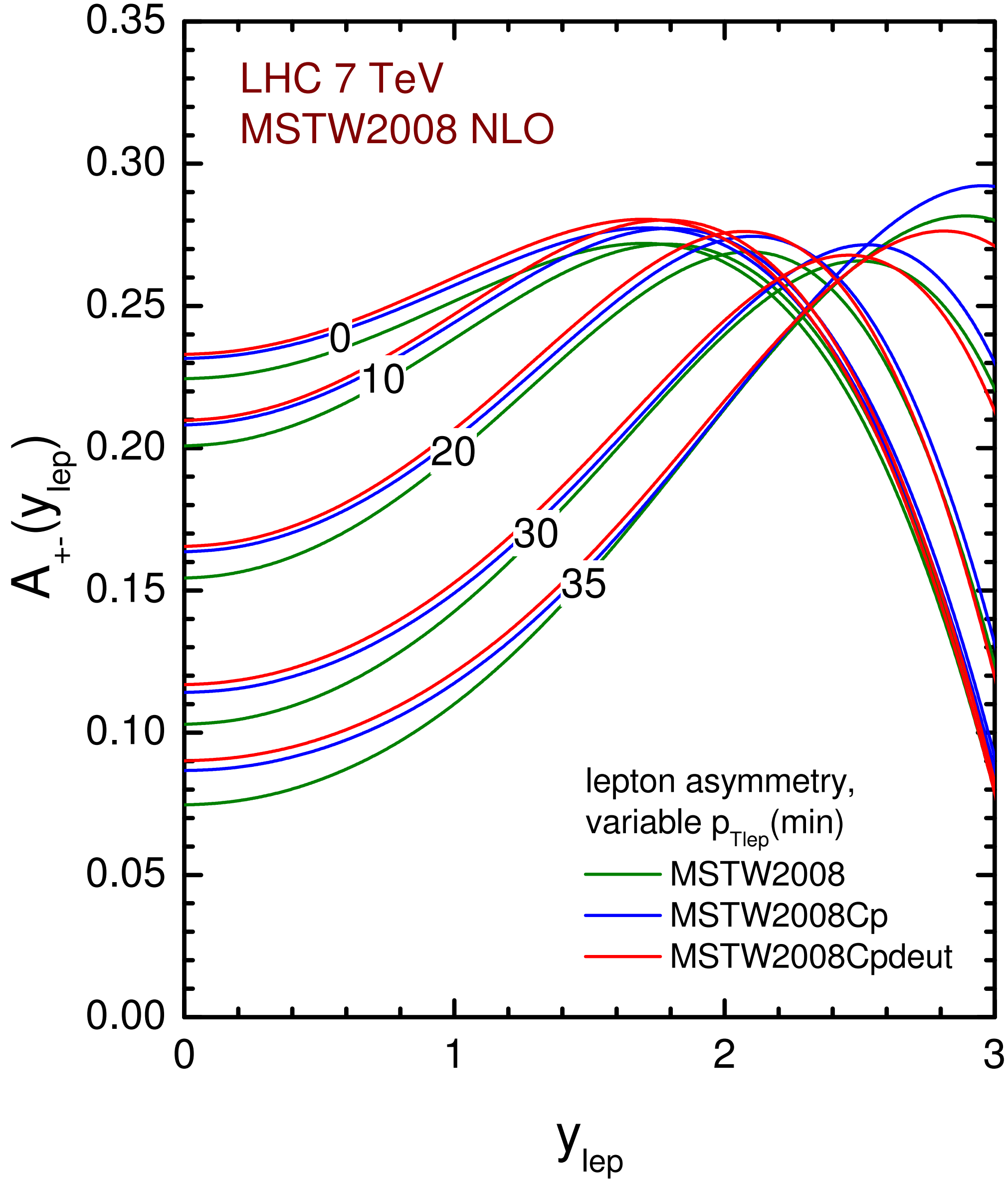
Fit to ATLAS W, Z rapidity data at NLO improves to $48/30$ for MSTWCp and 45/30 for MSTWCpeut.

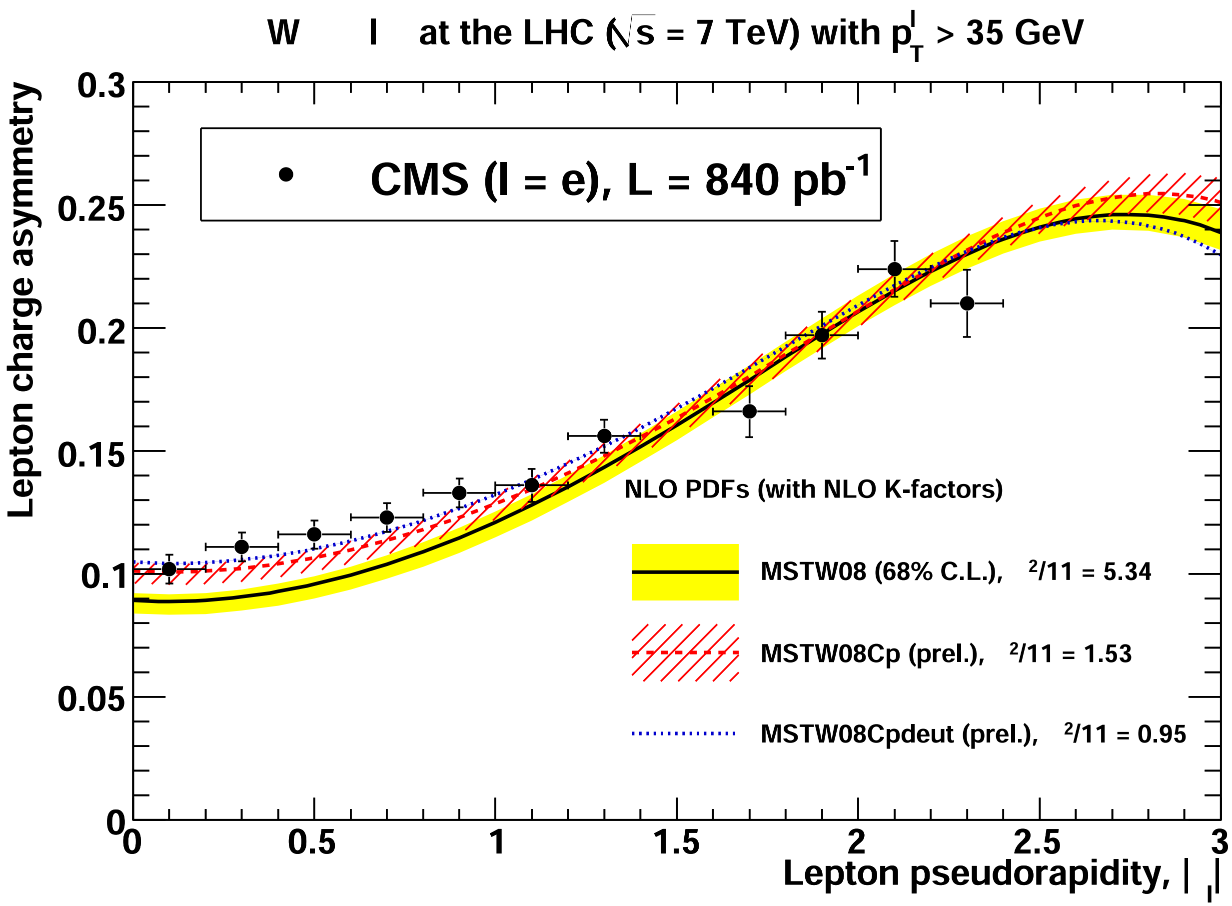
—— CP, —— CPdeut



Increases lepton asymmetry, but very preferentially for high p_T cut. (Curves made here with LO calculations).

Most of the effect already obtained for parameterisation extension, but some from deuterium study.





Prediction for $p_T > 35\mathrm{GeV}$ CMS asymmetry data using MCFM.

Note no change to data fit, just parameterisation and some from deuterium corrections.

Main deuterium effect absence of shadowing in default fit.

Big change in high p_T cut asymmetry, but very specifically sensitive to $u_V(x,Q^2) - d_V(x,Q^2)$. What about other quantities. Other PDFs changed little. α_S free but tiny change. Expect little variation.

The $\%$ change in the cross sections ($M_H = 120\text{GeV}$).

	MSTWCp	MSTWCpdeut
W Tev	+0.6	+0.1
Z Tev	+0.8	+0.7
W^+ LHC (7TeV)	+0.7	+0.3
W^- LHC (7TeV)	-0.7	-0.4
Z LHC (7TeV)	+0.0	-0.1
W^+ LHC (14TeV)	+0.6	+0.3
W^- LHC (14TeV)	-0.6	-0.5
Z LHC (14TeV)	+0.1	-0.1
Higgs TeV	-0.5	-1.8
Higgs LHC (7TeV)	+0.2	-0.1
Higgs LHC (14TeV)	+0.1	+0.1

Extreme stability in total cross sections, all far inside uncertainties. Even $\sigma(W^+)/\sigma(W^-)$ barely more than 1%.

Conclusions

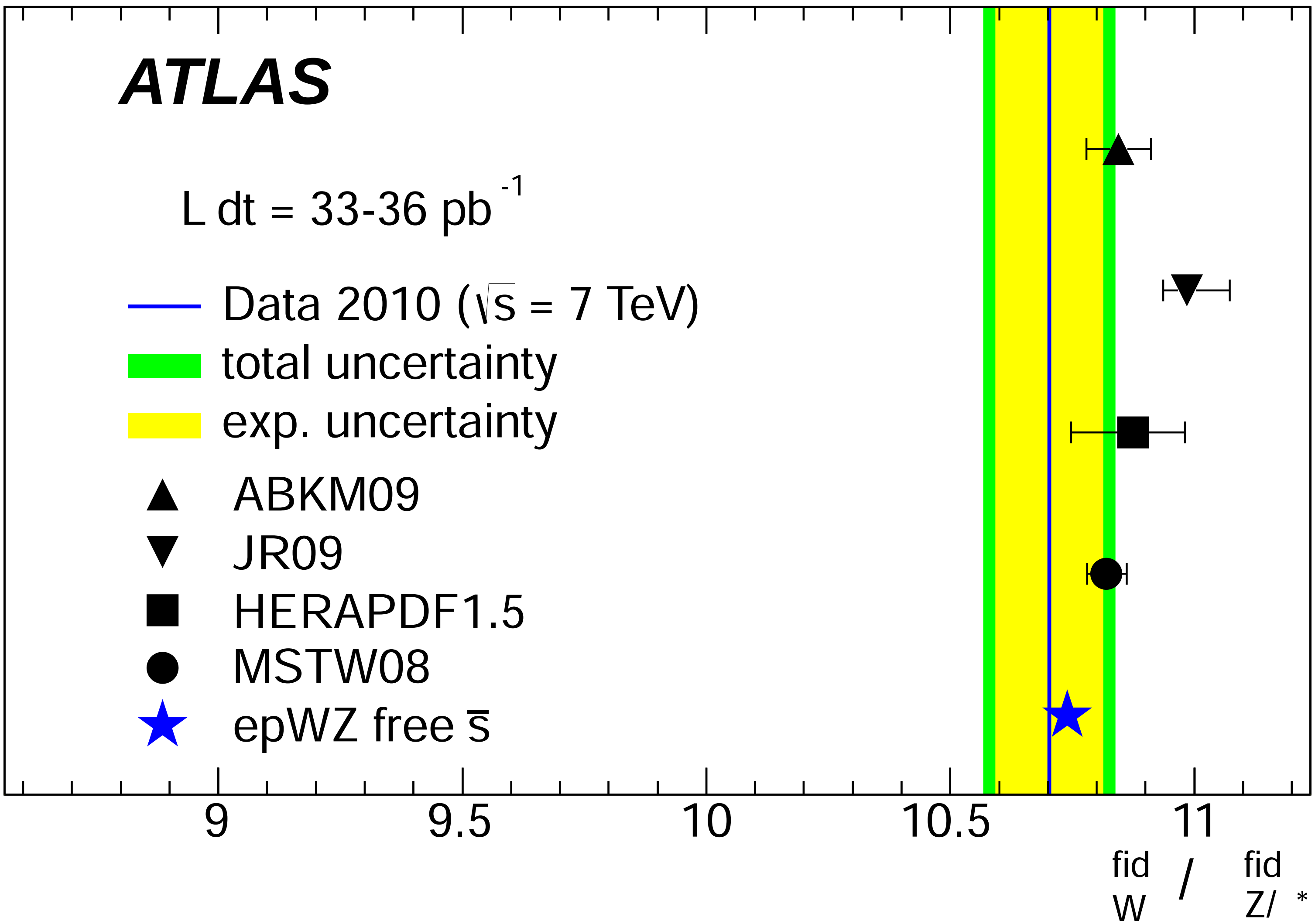
Monte Carlo study shows that fits to real data behave more like those to "inconsistent" than "consistent" pseudodata. Imply parameterisation limitations small except for small-x valence quarks. Maintain Hessian approach with tolerance, but Monte Carlo approach to using PDFs is straightforward. No clear need for a dedicated set.

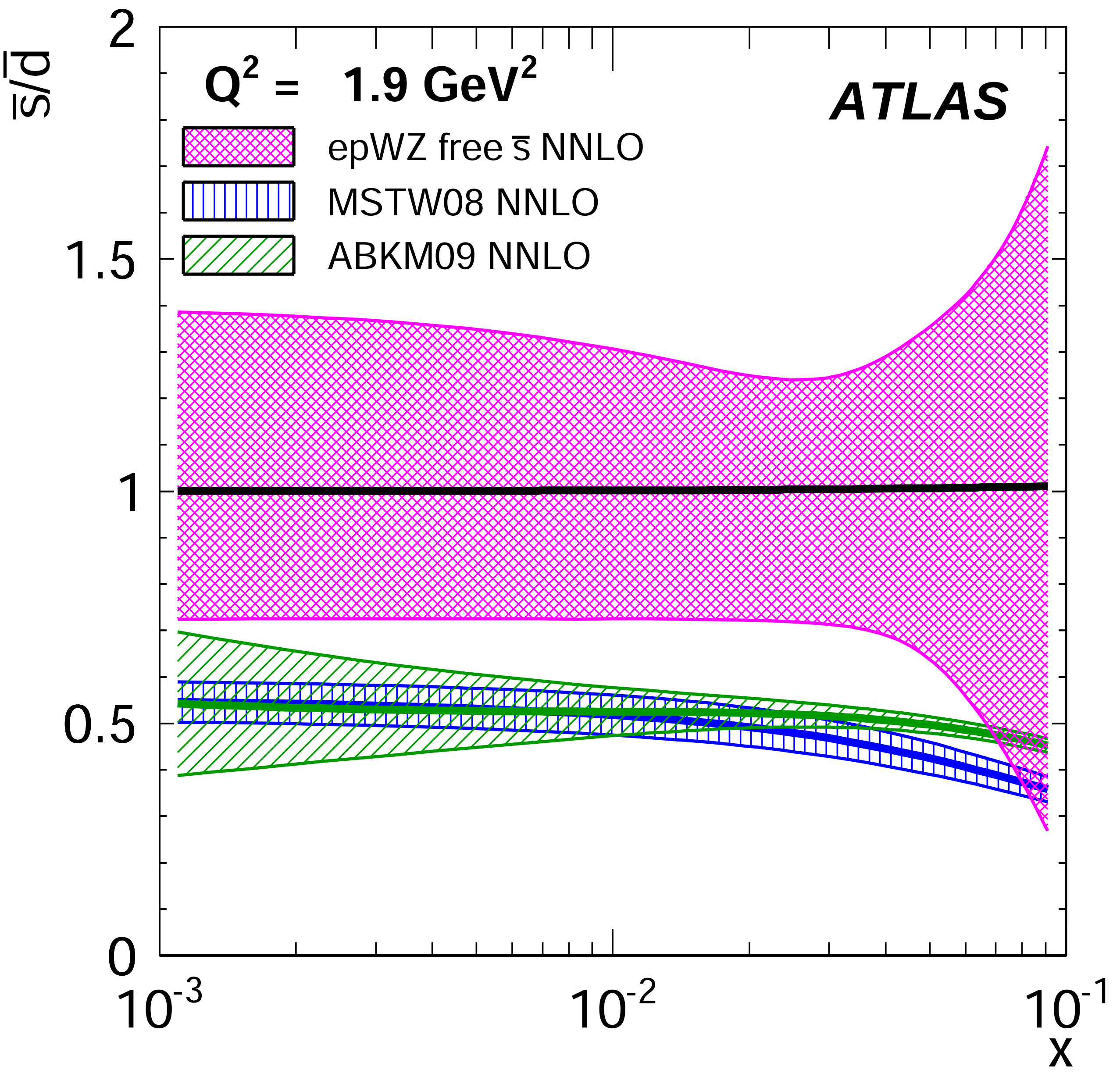
MSTW08 fits current LHC data as well, or better than other sets, with exception of (particularly high-p_T) lepton asymmetry. In the main need more data for constraints.

Studies suggest it is very difficult to raise strange quark fraction at input for $x \sim 0.01$ without spoiling fit. Some, but far from full understanding of differences between groups.

Studies of parameterisation dependence suggest ~ 4 terms in a Chebyshev polynomial about the maximum needed for very high precision. Backs up conclusion that in current MSTW fits the only need for an extended parameterisation is for small-x valence quarks.

Automatically improves comparison to LHC lepton asymmetry data. Makes fit with deuterium corrections much more stable, and these lead to further slight improvements. Total cross sections practically unchanged.


ATLAS
L dt = 33-36 pb -1
Data 2010 (√s = 7 TeV)
total uncertainty
exp. uncertainty
ABKM09
JR09
HERAPDF1.5
MSTW08
epWZ free s̄
9
9.5
10
10.5
11
fid W / fid Z/ *



$\bar{s}/\bar{d}$
$Q^2 = 1.9\ GeV^2$
ATLAS
epWZ free $\bar{s}$ NNLO
MSTW08 NNLO
ABKM09 NNLO
2
1.5
1
0.5
0
10^{-3}
10^{-2}
10^{-1}
x