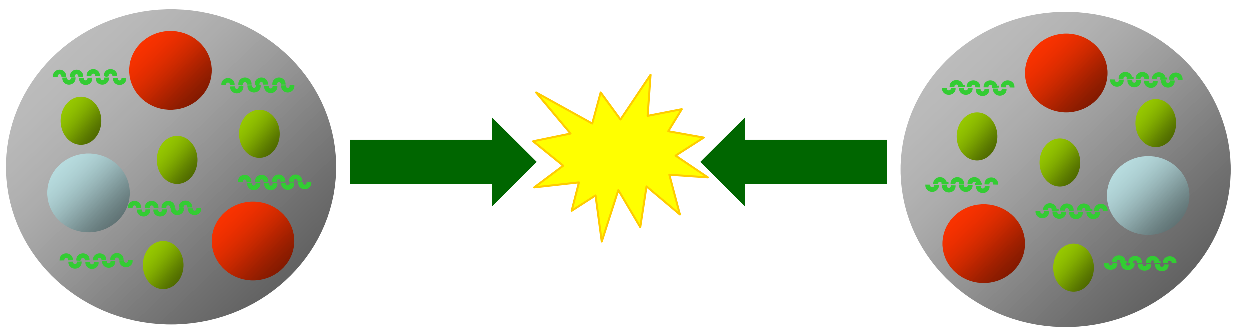
Mini-Workshop on PDFs and Standard Candles at the LHC
Karlsruhe, 19 March 2012

News From MSTW



James Stirling

Cambridge University

with

Alan Martin, Robert Thorne, Graeme Watt

and

Helen Vryonidou, Arnold Mathijssen

recent MSTW -related publications

- arXiv:0901.0002 "Parton distributions for the LHC" [MSTW2008 sets]
- arXiv:0905.3531 "Uncertainties on α_S in global PDF analyses and implications for predicted hadronic cross sections"
- arXiv:1006.2753 "The effects of combined HERA and recent Tevatron W $\rightarrow l\nu$ charge asymmetry data on the MSTW PDFs"
- arXiv:1007.2624 "Heavy-quark mass dependence in global PDF analyses and 3- and 4-flavour parton distributions"
- arXiv:1106.5788 Graeme Watt, "Parton distribution function dependence of benchmark Standard Model cross sections at the 7 TeV LHC"
- arXiv:1106.5789 Robert Thorne and Graeme Watt "PDF dependence of Higgs cross sections at the Tevatron and LHC: Response to recent criticism"
- arXiv:1201.1295 Graeme Watt, "MSTW PDFs and impact of PDFs on cross sections at Tevatron and LHC"
- arXiv:1201.6180 Robert Thorne "The Effect of Changes of Variable Flavour Number Scheme on PDFs and Predicted Cross Sections"

→ no new published global fit since MSTW2008, but plenty of ongoing studies - comment on plans for new global fit at end

data sets used in MSTW fit

Data set	$N_{\text{pts.}}$
H1 MB 99 e^+p NC	8
H1 MB 97 e^+p NC	64
H1 low Q^2 96–97 e^+p NC	80
H1 high Q^2 98–99 e^-p NC	126
H1 high Q^2 99–00 e^+p NC	147
ZEUS SVX 95 e^+p NC	30
ZEUS 96–97 e^+p NC	144
ZEUS 98–99 e^-p NC	92
ZEUS 99–00 e^+p NC	90
H1 99–00 e^+p CC	28
ZEUS 99–00 e^+p CC	30
H1/ZEUS $e^\pm p$ F_2^{charm}	83
H1 99–00 e^+p incl. jets	24
ZEUS 96–97 e^+p incl. jets	30
ZEUS 98–00 $e^\pm p$ incl. jets	30
DØ II $p\bar{p}$ incl. jets	110
CDF II $p\bar{p}$ incl. jets	76
CDF II $W \to l\nu$ asym.	22
DØ II $W \to l\nu$ asym.	10
DØ II Z rap.	28
CDF II Z rap.	29

Data set	$N_{\text{pts.}}$
BCDMS μp F_2	163
BCDMS μd F_2	151
NMC μp F_2	123
NMC μd F_2	123
NMC $\mu n/\mu p$	148
E665 μp F_2	53
E665 μd F_2	53
SLAC ep F_2	37
SLAC ed F_2	38
NMC/BCDMS/SLAC F_L	31
E866/NuSea pp DY	184
E866/NuSea pd/pp DY	15
NuTeV νN F_2	53
CHORUS νN F_2	42
NuTeV νN xF_3	45
CHORUS νN xF_3	33
CCFR $\nu N \to \mu\mu X$	86
NuTeV $\nu N \to \mu\mu X$	84
All data sets	**2743**

- Red = New w.r.t. MRST 2006 fit.

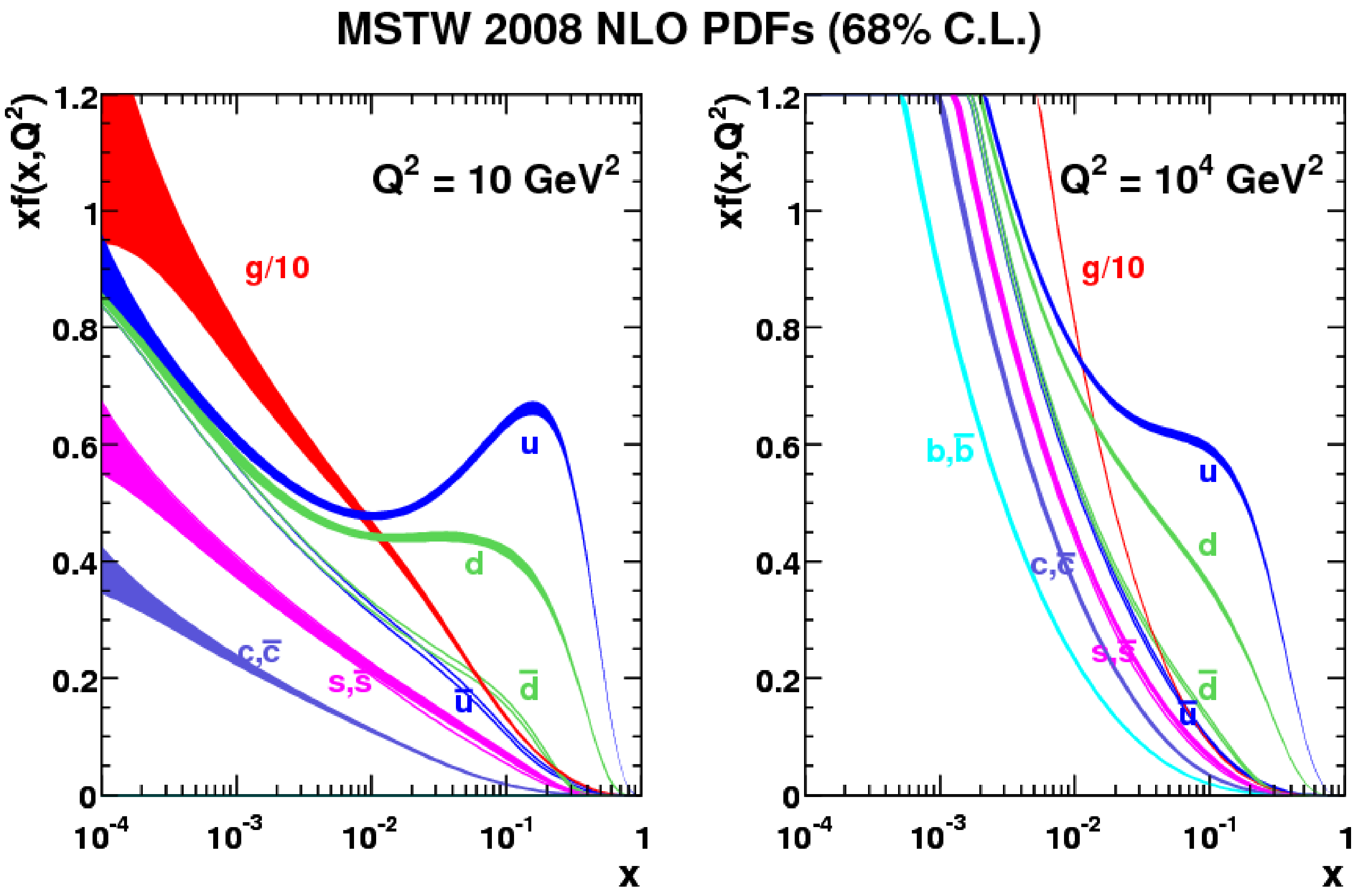
MSTW input parametrisation

At input scale $Q_0^2 = 1\ \mathrm{GeV}^2$:

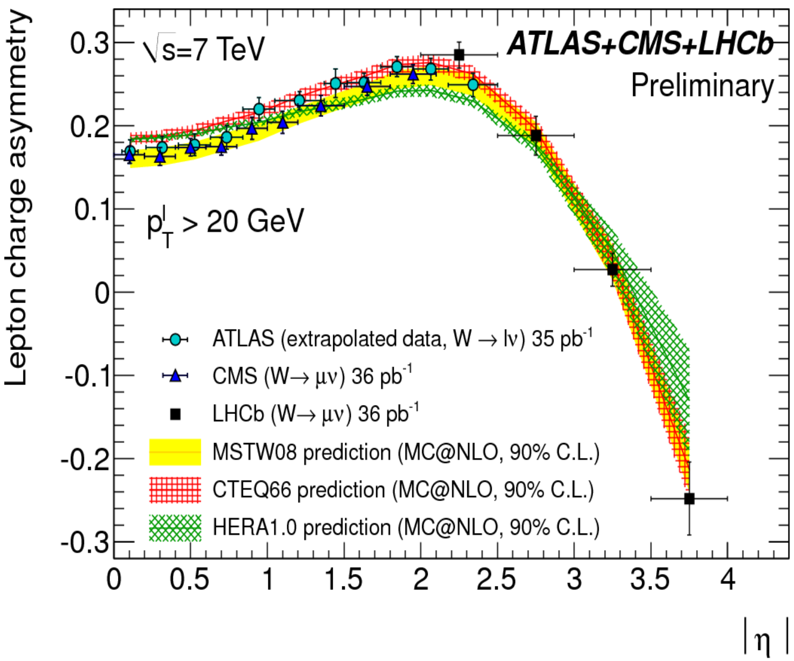
$$
\begin{aligned}
xu_v &= A_u\, x^{\eta_1}(1-x)^{\eta_2}(1+\epsilon_u\sqrt{x}+\gamma_u\, x)\\
xd_v &= A_d\, x^{\eta_3}(1-x)^{\eta_4}(1+\epsilon_d\sqrt{x}+\gamma_d\, x)\\
xS &= A_S\, x^{\delta_S}(1-x)^{\eta_S}(1+\epsilon_S\sqrt{x}+\gamma_S\, x)\\
x\bar{d}-x\bar{u} &= A_\Delta\, x^{\eta_\Delta}(1-x)^{\eta_S+2}(1+\gamma_\Delta\, x+\delta_\Delta\, x^2)\\
xg &= A_g\, x^{\delta_g}(1-x)^{\eta_g}(1+\epsilon_g\sqrt{x}+\gamma_g\, x)+A_{g'}\, x^{\delta_{g'}}(1-x)^{\eta_{g'}}\\
xs+x\bar{s} &= A_+\, x^{\delta_S}\,(1-x)^{\eta_+}(1+\epsilon_S\sqrt{x}+\gamma_S\, x)\\
xs-x\bar{s} &= A_-\, x^{\delta_-}(1-x)^{\eta_-}\,(1-x/x_0)
\end{aligned}
$$

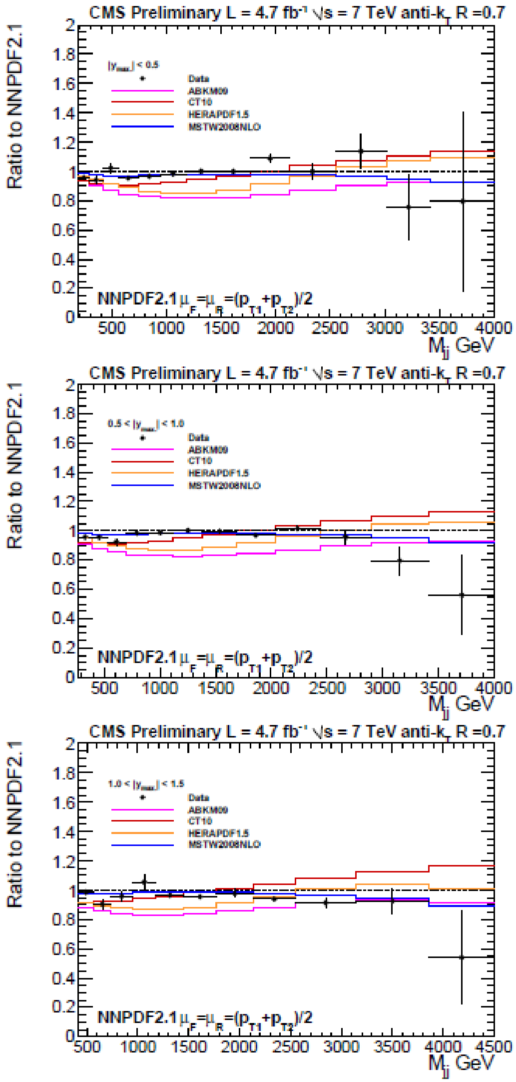
<u>Note:</u> 20 parameters allowed to go free for eigenvector PDF sets

And this is what the PDFs look like ...



Many comparisons with experimental data over past three years ...





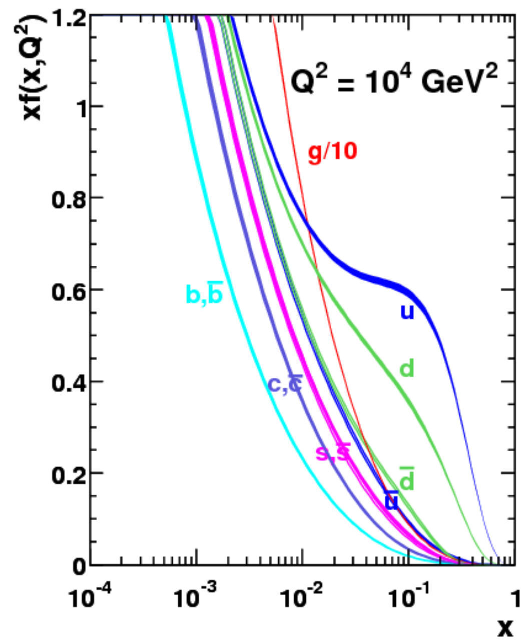
etc etc

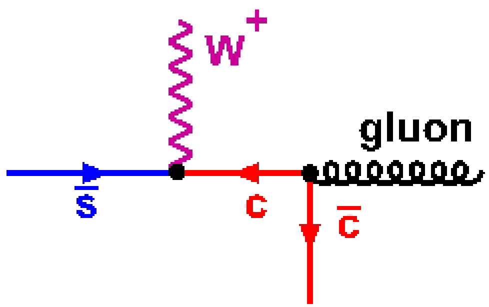
In this talk...

- Charm and strange from LHC W,Z + jets data (WJS and Helen Vryonidou)
- Experimental error propagation: Hessian vs. MC (Graeme Watt, presented at PDF4LHC, November 2011)
- Exploring valence quark parameterisations (Robert Thorne and Arnold Mathijssen)

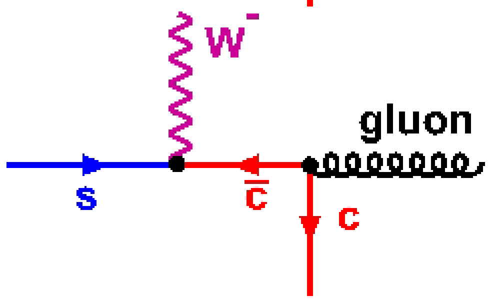
probing heavy quark pdfs at LHC?

take advantage of (a) qg dominates W,Z + jet production, (b) heavy quark suppression becomes weaker at high Q^2, small x, (c) ability to tag c,b jets





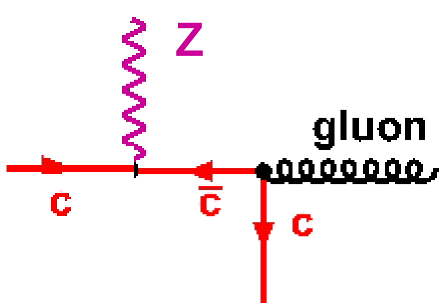
CMS: "W production in association with c jets" (CMS-PAS-EWK-11-013)



$$R_c^{\pm} \equiv \sigma(W^+\bar{c})/\sigma(W^-c) \text{ and } R_c \equiv \sigma(W+c)/\sigma(W+jets)$$

$$R_c^{\pm} = 0.92 \pm 0.19\,(stat.) \pm 0.04\,(syst.)$$ ← sbar / s

$$R_c = 0.143 \pm 0.015\,(stat.) \pm 0.024\,(syst.)$$ ← sbar + s



Ratio	MCFM (CT10)	MCFM (MSTW08)	MCFM (NNPDF21)
$R_c^{\pm}$	$0.915^{+0.006}_{-0.006}$	$0.881^{+0.022}_{-0.032}$	0.902 ± 0.008
R_c	$0.125^{+0.013}_{-0.007}$	$0.118^{+0.002}_{-0.002}$	0.103 ± 0.005

differences at level of exptl. systematic error!

Also: Z + c as a measure of charm pdf?

anatomy of W+c at LHC (with Helen Vryonidou)

- slight disagreement with CMS theory predictions for $R_c^{\pm}$ - using MCFM@NLO (numerical error?). Our predictions are systematically 3% higher

$$R_c \approx \frac{(s+\bar{s}+\epsilon_{dc}(d+\bar{d}))g+\ldots}{\sum_q (q+\bar{q})g+\ldots}$$

- not true that s = sbar → $R_c^{\pm}$ = 1, because of CKM-suppressed asymmetric d-quark contribution

$$R_c^{\pm} \approx \frac{(\bar{s}+\epsilon_{dc}\bar{d})g+\ldots}{(s+\epsilon_{dc}d)g+\ldots} \qquad \epsilon_{dc} \approx 0.05$$

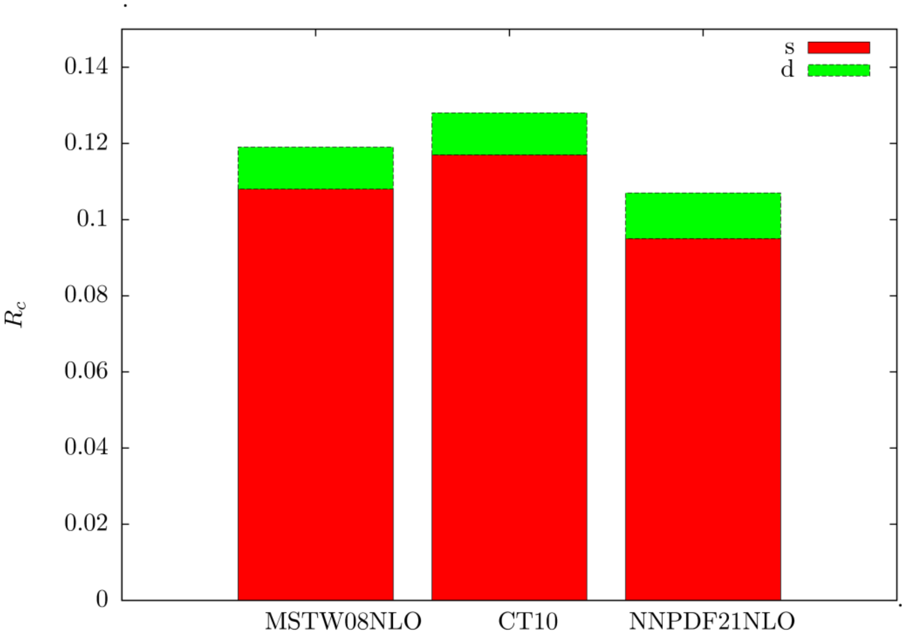
$$R_c^{\pm}(\mathrm{MSTW}) \approx_{\mathrm{LO}} \frac{37.1\ [\bar{s}]+2.9\ [\bar{d}]}{38.4\ [s]+5.2\ [d]}$$

cross sections in pb

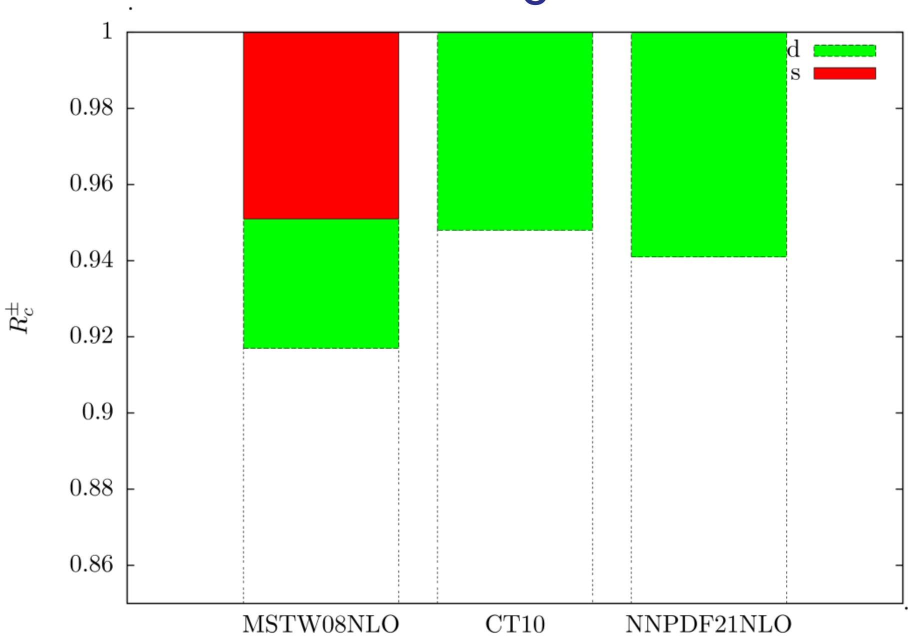
*We use MCFM applying the CMS cuts $(p_T^j > 20$ GeV, $|\eta^j| < 2.1$, $p_T^l > 25$ GeV, $|\eta^l| < 2.1$, $R = 0.5$, $R^{lj} = 0.3)$

Ratio	CT10	MSTW2008	NNPDF21
$R_c^{\pm}$	$0.953^{+0.009}_{-0.007}$	$0.921^{+0.022}_{-0.033}$	0.944 ± 0.008
R_c	$0.125^{+0.013}_{-0.014}$	$0.116^{+0.002}_{-0.002}$	0.104 ± 0.005
$R^{\pm}$	$1.39^{+0.03}_{+0.03}$	$1.34^{+0.01}_{-0.01}$	1.39 ± 0.02

R_c

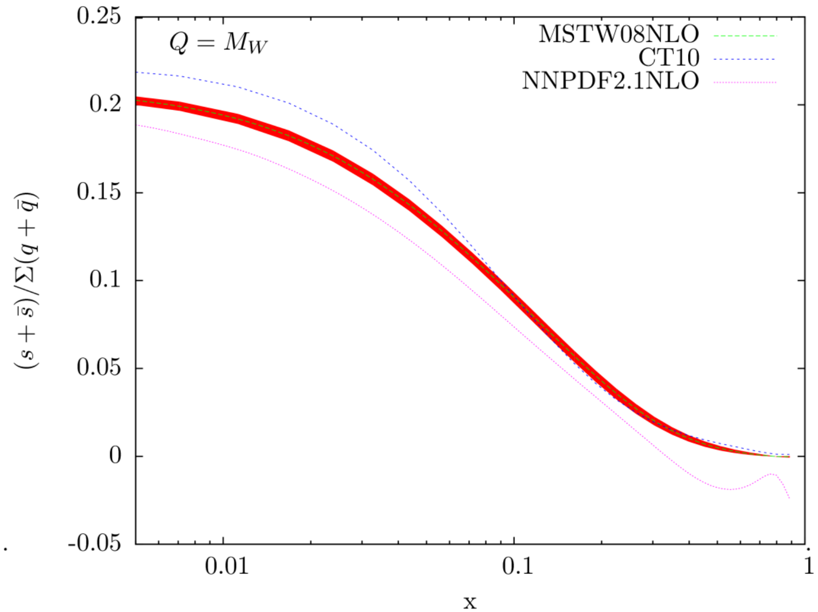


$R_c^{\pm}$

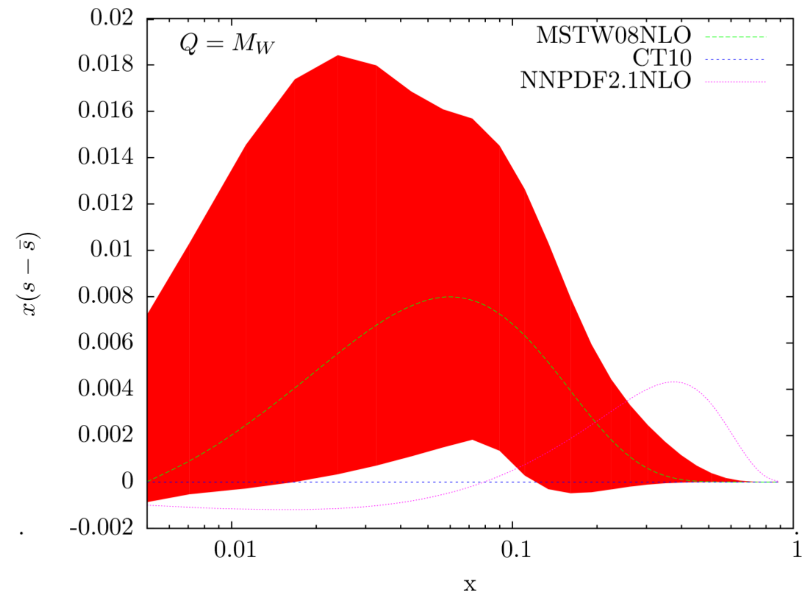


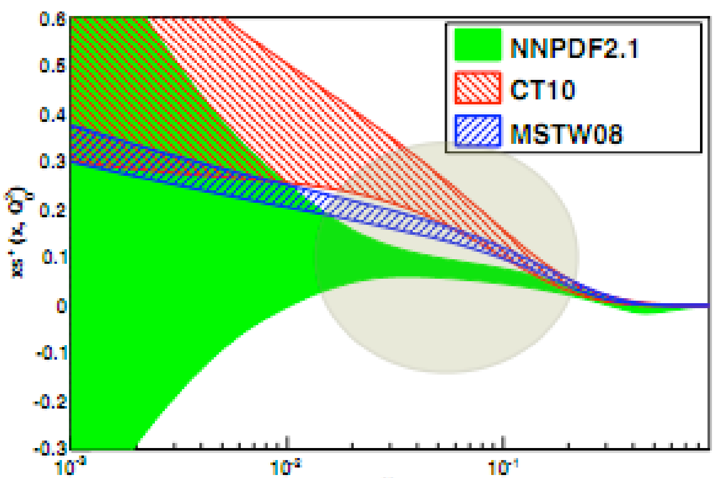
- differences between the three sets easily understood by comparing the corresponding s,d pdfs.

$$\frac{s+\bar{s}}{\sum_q (q+\bar{q})}$$



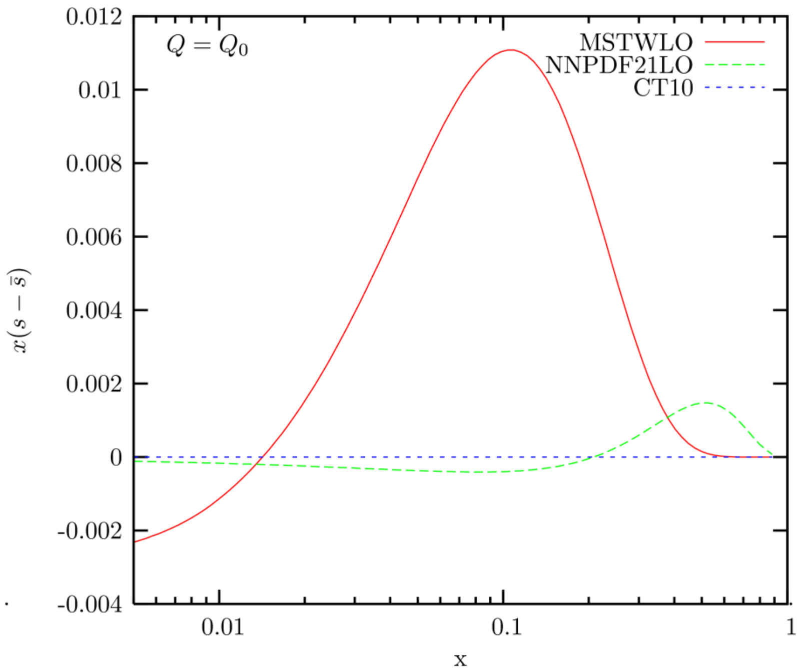
$$x(s-\bar{s})$$

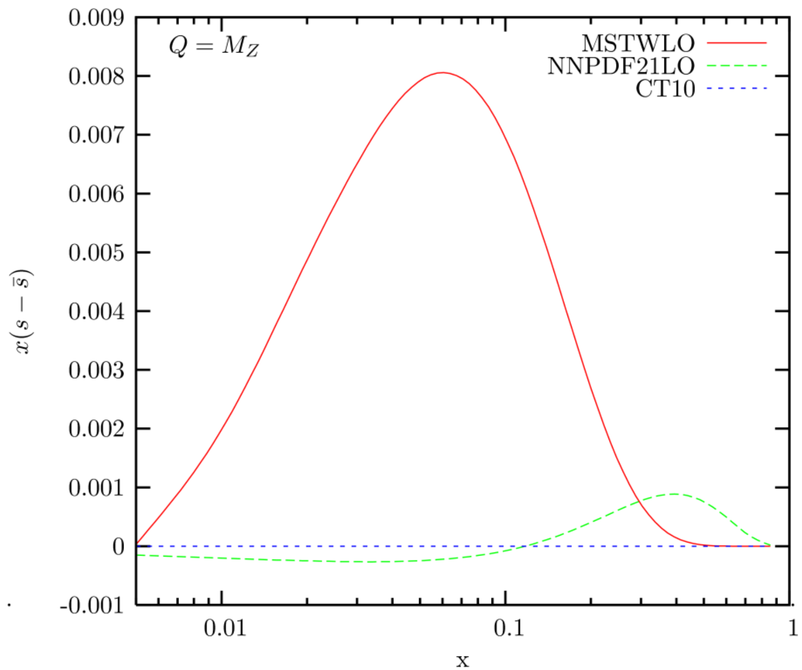




Note:

MSTW assume u,d,s quarks have *same* x^δ behaviour as $x \rightarrow 0$, hence much tighter constraint





MSTW parametrisation:

1 $xu_v(x,Q_0^2) = A_u x^{\eta_1}(1-x)^{\eta_2}\left(1+\epsilon_u\sqrt{x}+\gamma_u x\right)$

2 $xd_v(x,Q_0^2) = A_d x^{\eta_3}(1-x)^{\eta_4}\left(1+\epsilon_d\sqrt{x}+\gamma_d x\right)$

3 $xS(x,Q_0^2) = A_S x^{\delta_S}(1-x)^{\eta_S}(1+\epsilon_S\sqrt{x}+\gamma_S x)$

4 $x\Delta(x,Q_0^2) = A_\Delta x^{\eta_\Delta}(1-x)^{\eta_S+2}(1+\gamma_\Delta x+\delta_\Delta x^2)$

5 $x(s+\bar{s})(x,Q_0^2) = A_+ x^{\delta_S}(1-x)^{\eta_+}(1+\epsilon_S\sqrt{x}+\gamma_S x)$

6 $\boxed{x(s-\bar{s})(x,Q_0^2) = A_- x^{\delta_-}(1-x)^{\eta_-}(1-x/x_0)}$

7 $$xg(x,Q_0^2) = A_g x^{\delta_g}(1-x)^{\eta_g}\left(1+\epsilon_g\sqrt{x}+\gamma_g x\right) + A_{g'} x^{\delta_{g'}}(1-x)^{\eta_{g'}}$$

Where:

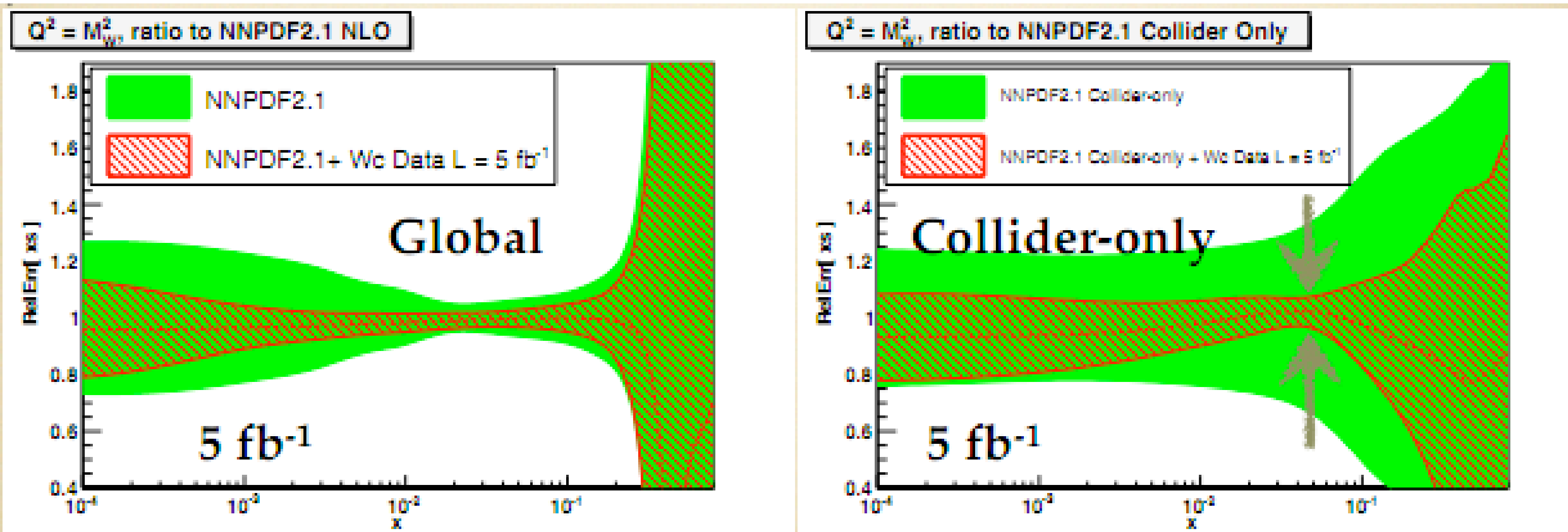
$\Delta = \bar{d} - \bar{u}$,

$q_v = q - \bar{q}$,

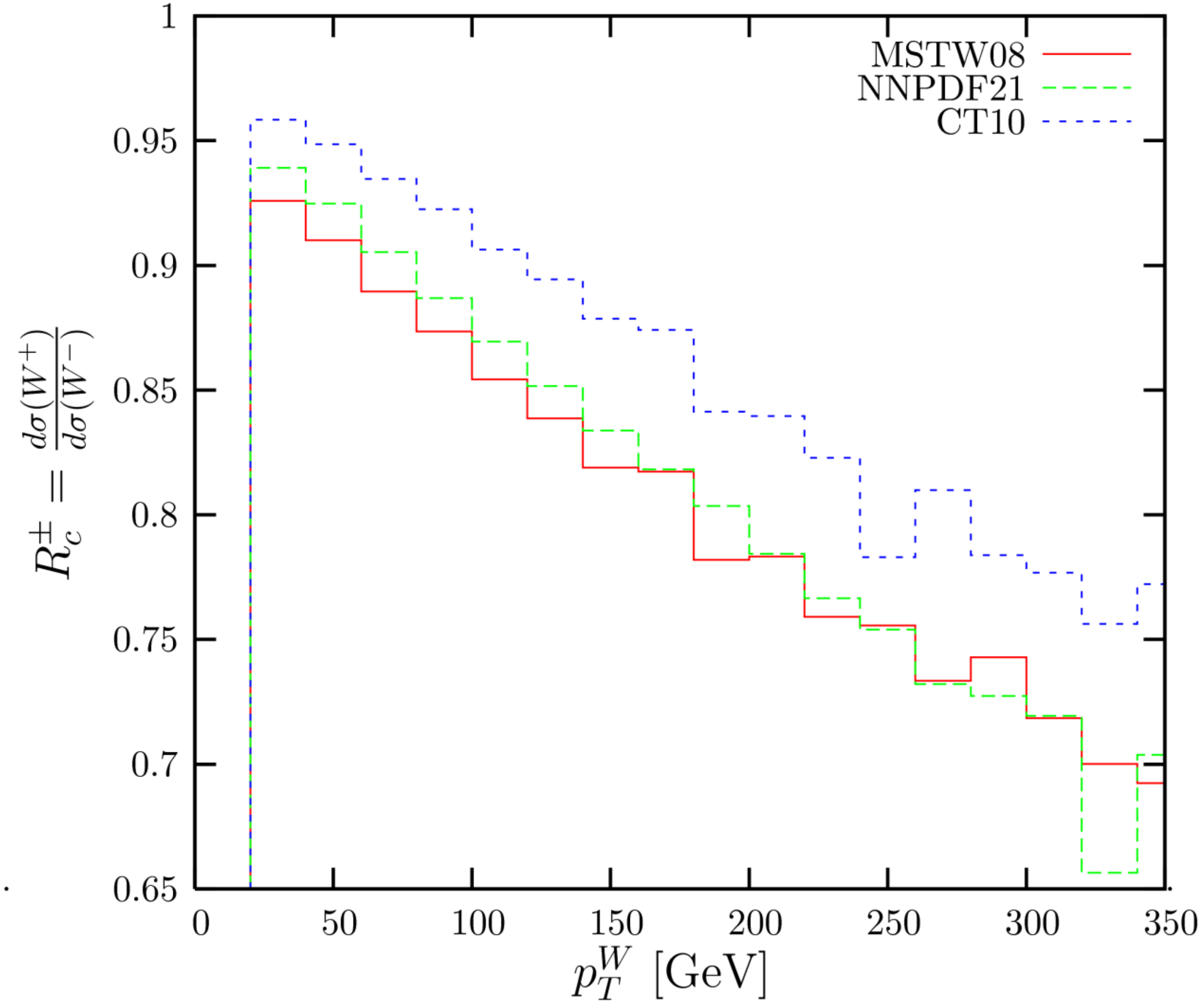
$\Sigma = u + \bar{u} + d + \bar{d} + s + \bar{s}$

$S = \Sigma - u_v - u_v = 2\left(\bar{u} + \bar{d}\right) + s + \bar{s}$

impact of W+c at LHC: NNPDF study



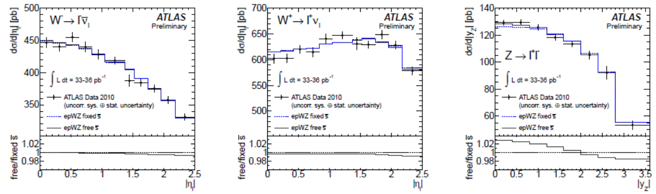
- for high p_T W/jet, $R_c \rightarrow 0$, $R_c^{\pm} \rightarrow 0$ because of light quark dominance, $s/q \rightarrow 0$



S. Glazov (ATLAS) La Thuile 2012

of course, strange also contributes differently to the total **W** and **Z** cross sections ('linear vs. quadratic'), and the ratio **σ(W)/σ(Z)** has some sensitivity

Determination of the strange sea density



A QCD analysis of HERA+ATLAS data, using HERAFitter.

Perform two NNLO fits: with fixed strangeness fraction $r_s = 0.5(s+\bar{s})/\bar{d}$, $r_s = 0.5$ and free strange density parametrized as

$$x\bar{s}(x) = A_s x^{B_{\bar{d}}}(1-x)^{C_s}$$

For $x = 0.023$ and $Q^2 = 1.9\ \mathrm{GeV}^2$, corresponding to the maximum of ATLAS data sensitivity extrapolated to low Q^2

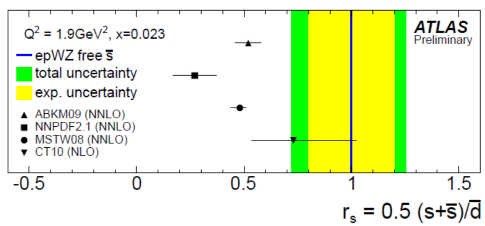
$$r_s = 1.00 \pm 0.20_{\mathrm{exp}} \pm 0.07_{\mathrm{mod}}{}^{+0.10}_{-0.15}{}_{\mathrm{par}}{}^{+0.06}_{-0.07}{}_{\alpha_S} \pm 0.08_{\mathrm{th}}.$$

consistent with sea quark flavour democracy at low x.

10

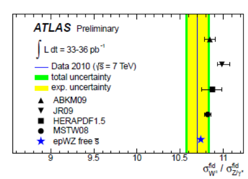
!

ATLAS strange sea determination results

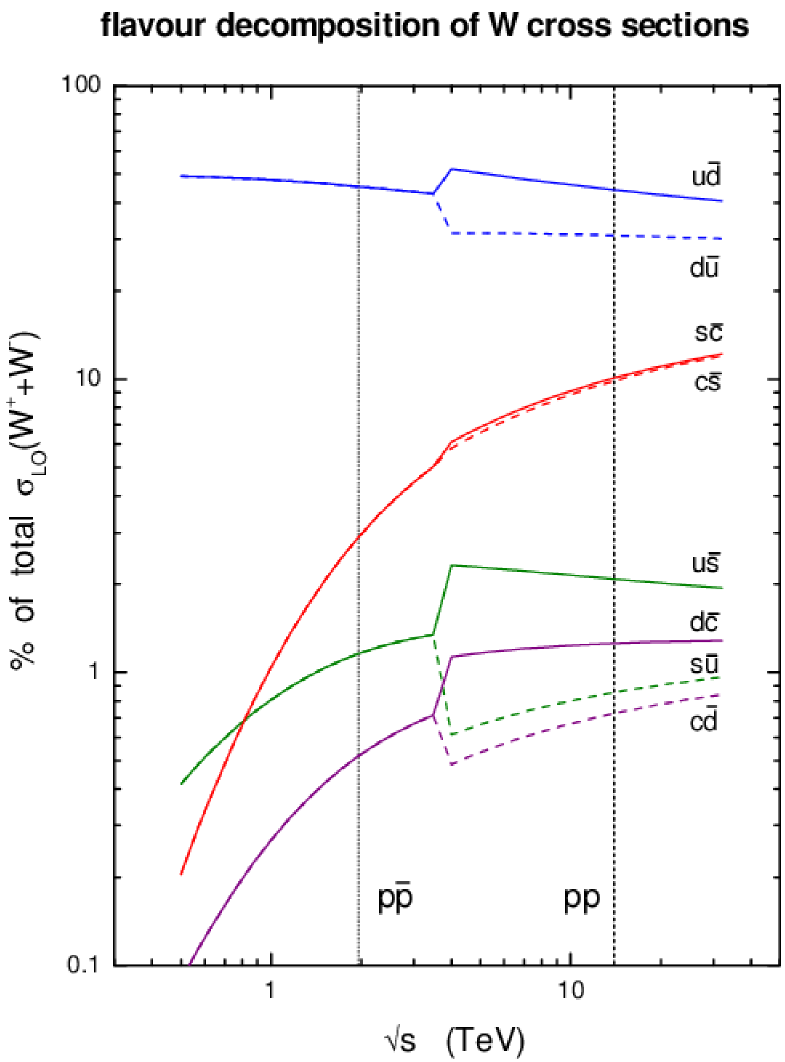


ATLAS result is consistent with CTEQ6.6 (NLO) and is above MSTW08, ABKM09 and NNPDF2.1 determinations.

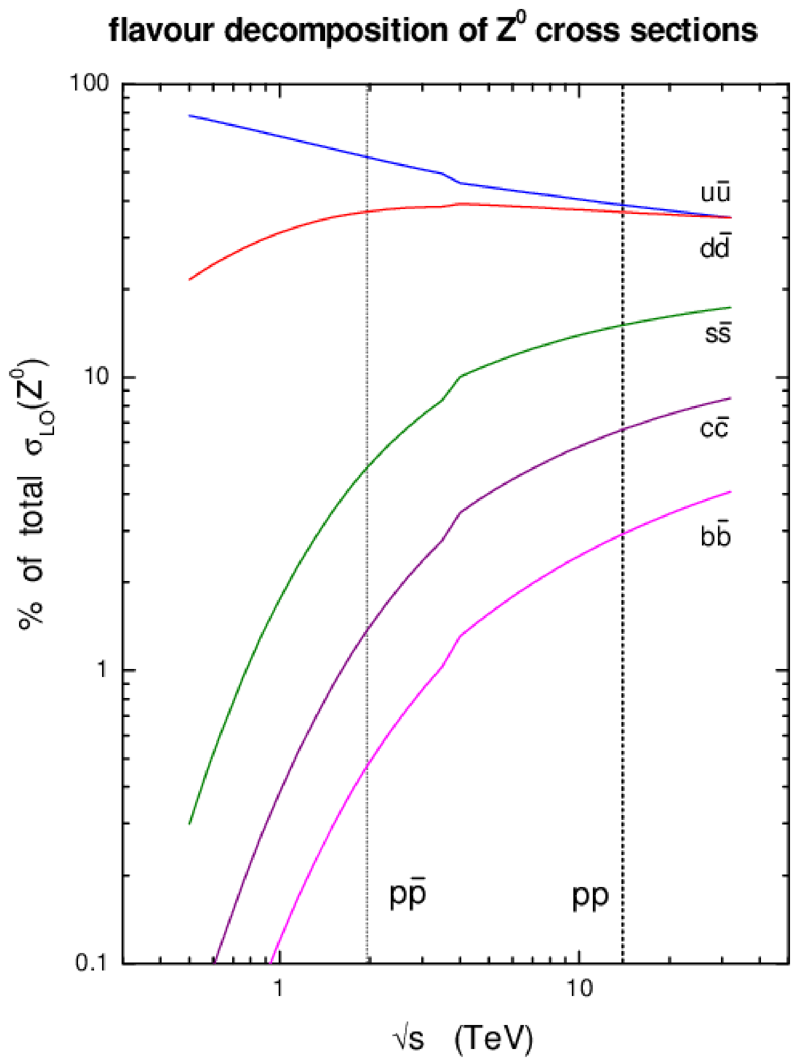
The free $\bar{s}$ fit provides the best description of the measured W/Z cross sections ratio.



11

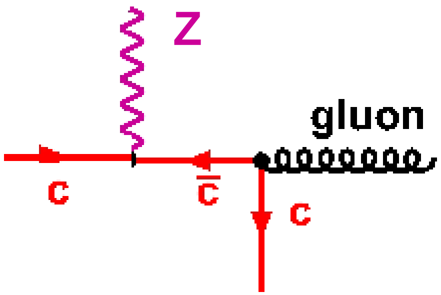


flavour decomposition of W cross sections
% of total σLO(W⁺+W⁻)
√s (TeV)
ud̄
dū
sc̄
cs̄
us̄
dc̄
sū
cd̄
pp̄
pp
100
10
1
0.1
1
10



flavour decomposition of Z⁰ cross sections
% of total σLO(Z⁰)
√s (TeV)
uū
dd̄
ss̄
cc̄
bb̄
pp̄
pp
100
10
1
0.1
1
10

charm from Z+c at LHC

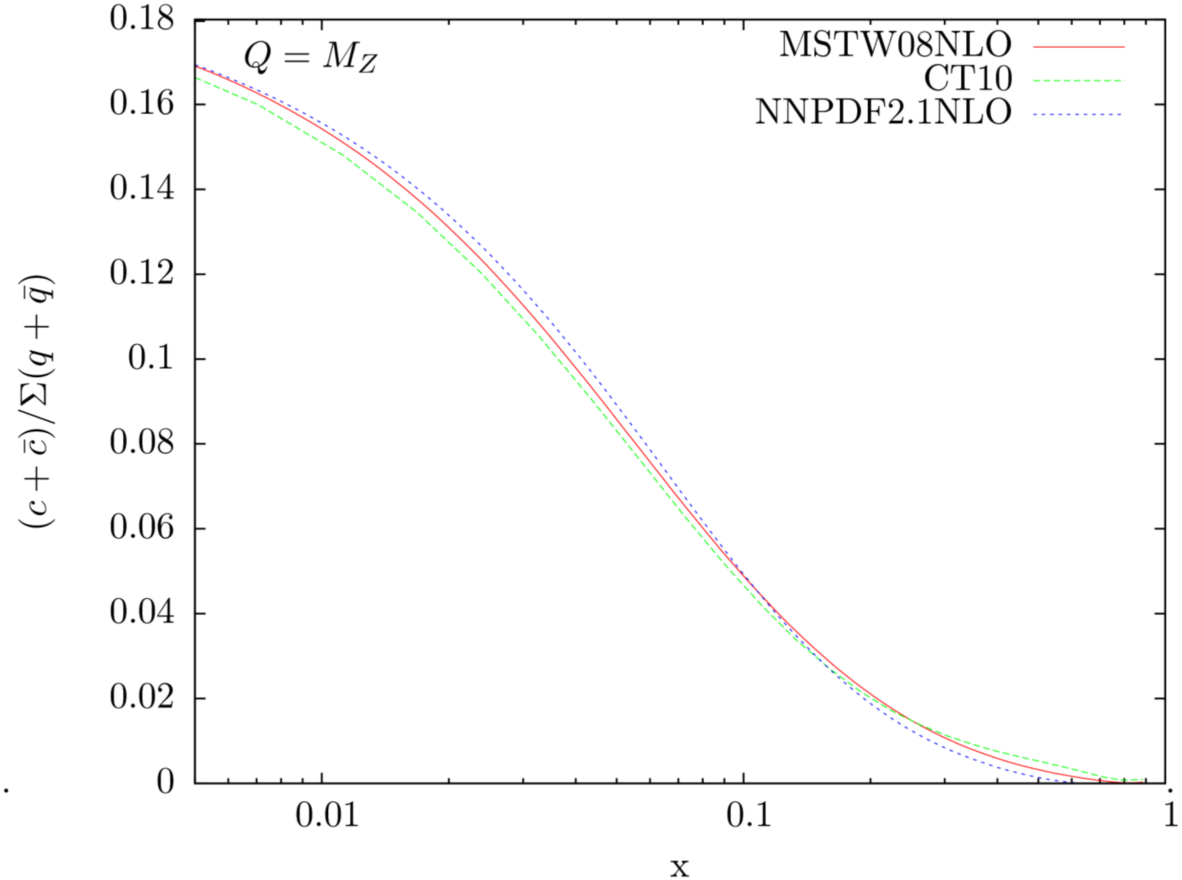


$$R_c^Z = \frac{\sigma(Z\ +\ c - \text{jet})}{\sigma(Z\ +\ \text{jet})}$$

$$R_c^Z \approx \frac{\kappa_u(c+\bar{c})g + \ldots}{[\kappa_u(u+\bar{u}+c+\bar{c}) + \kappa_d(d+\bar{d}+s+\bar{s})]g + \ldots}$$

Ratio	CT10	MSTW2008NLO	NNPDF21NLO
R_c^Z	$0.0623^{+0.0032}_{-0.0032}$	$0.0640^{+0.0014}_{-0.0016}$	0.0662 ± 0.0013

$$\frac{c+\bar{c}}{\sum_q (q+\bar{q})}$$



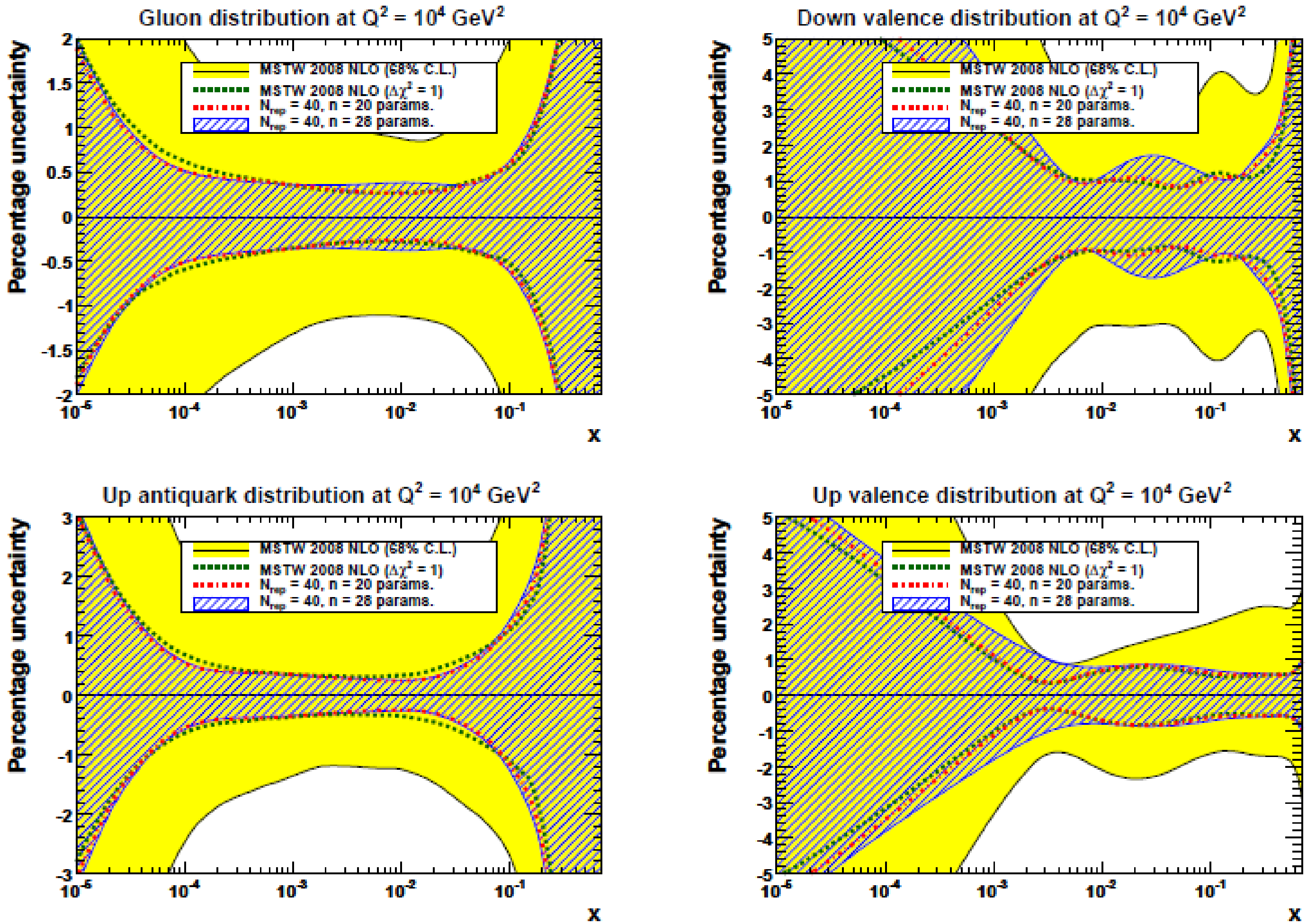
Experimental error propagation: Hessian vs. MC
(study by Graeme Watt*)

- first implementation of Monte Carlo sampling in MSTW fit.
- parameterisation bias is likely to be small (except perhaps s, sbar)
- studies of fitting restricted data sets and consistent or inconsistent pseudodata suggest need MSTW-style tolerance ($\chi^2 > 1$)
- new method of generating random PDFs in parameter space using basis of eigenvectors including dynamic tolerance
- random PDFs can be used for Bayesian reweighting

(contact Graeme.Watt@cern.ch)

*presented at PDF4LHC Meeting, November 2011

Parameterisation bias for PDFs evolved to Q = 100 GeV



Graeme Watt 2011

→ no significant overall bias, small effect in u_V at $x \sim 0.001 - 0.01$

Extended valence quark parameterisations using Chebyshev polynomials (Thorne, Mathijssen)

- MSTW fits use (q=u,d):

$$xq_V(x, Q_0^2) = A_q x^{\eta_{1q}} (1-x)^{\eta_{2q}} \times [1 + \epsilon_q \sqrt{x} + \gamma_q x]$$

- quite restrictive, particularly in important mid-x range relevant for LHC electroweak physics, so try ....

$$xq_V(x, Q_0^2) = A_q x^{\eta_{1q}} (1-x)^{\eta_{2q}} \times [1 + \sum_{i=1}^{n} \alpha_i T_i(y(x) = 1 - 2x^{\beta})]$$

with e.g. n = 4 and β = 0.25 or 0.5

- study:
  - quality of overall global NLO fit
  - comparison of best-fit shape with MSTW08NLO

quality of new fits w.r.t. MSTW08

Parameterisation	χ^2	$\Delta\chi^2$	n_{add}	$\chi^2_{reduced}$	Improvement	$xu_v(x,Q_0^2) = A_u x^{\eta_1}(1-x)^{\eta_2} \times$
MSTW08	2543.0	0	0	0.954580	0.00E+00	$(1+\epsilon_u\sqrt{x}+\gamma_u x)$
c4m025v	2542.5	-0.5	4	0.955827	-1.25E-03	$\left(1+\sum_i^4 \alpha_i T_i(y=1-2x^{\frac{1}{4}})\right)$
MSTW08+$x^{1/4}$	2542.3	-0.65	2	0.955034	-4.54E-04	$(1+\epsilon_u\sqrt{x}+\gamma_u x+\gamma 2_u x^{\frac{1}{4}})$
c4m05v	2539.0	-4.3	4	0.954511	6.83E-05	$\left(1+\sum_i^4 \alpha_i T_i(y=1-2\sqrt{x})\right)$
MSTW08+x^2	2537.0	-6.0	2	0.953043	1.54E-03	$\left(1+\epsilon_u\sqrt{x}+\gamma_u x+\gamma 2_u x^2\right)$

where

χ^2	Chi-squared value of global fit to MSTW08 data sets (N = 2699 data points)
n	Number of parameters fitted = 34 + n_{add}
n_{add}	Number of additional parameters compared to default MSTW08
$\chi^2_{reduced} = \frac{\chi^2}{\nu} = \frac{\chi^2}{N-n-1}$	Chi-squared per degree of freedom
Improvement	$\chi^2_{reduced}$ compared to MSTW08 value; Positive for better = lower $\chi^2_{reduced}$

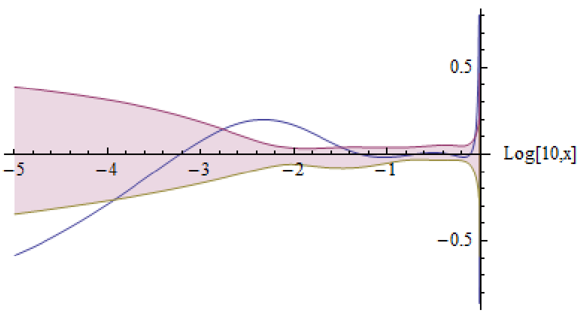
Mattijssen, Thorne

new c4m05v fit vs. MSTW08 (90% c.l. uncertainty)

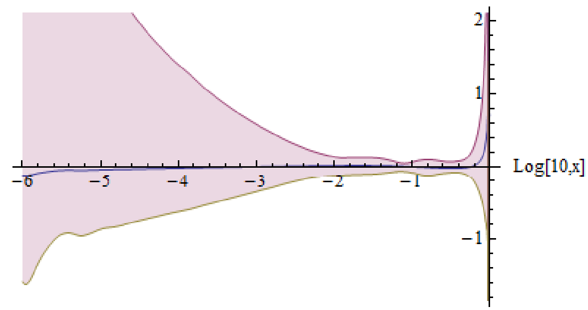
u_V

d_V

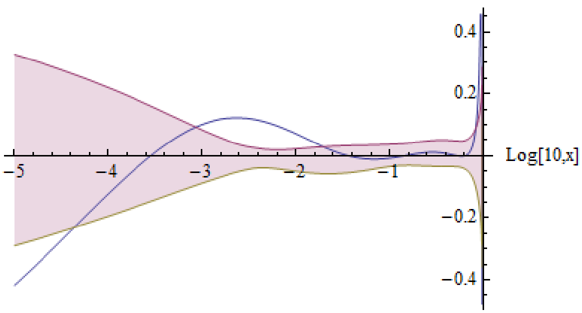
Fractional difference and Fractional uncertainty at 90% confidence level in xu_V at 1 GeV



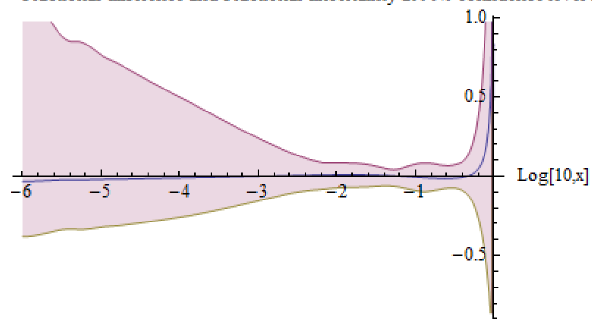
Fractional difference and Fractional uncertainty at 90% confidence level in xd_V at 1 GeV



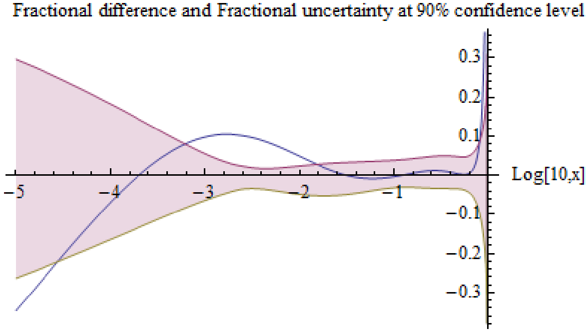
Fractional difference and Fractional uncertainty at 90% confidence level in xu_V at 10 GeV



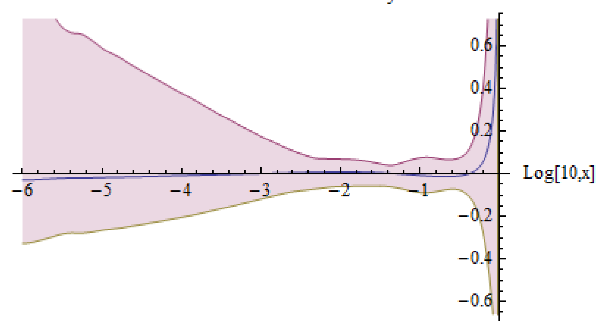
Fractional difference and Fractional uncertainty at 90% confidence level in xd_V at 10 GeV



Fractional difference and Fractional uncertainty at 90% confidence level in xu_V at 100 GeV



Fractional difference and Fractional uncertainty at 90% confidence level in xd_V at 100 GeV



Mattijssen, Thorne

Summary

- W,Z + c-jet measurements at LHC can provide important complementary (e.g. high Q^2, low x) information on strange and charm. Consistency between tagged-jet and total cross section measurements?

- MC studies of MSTW-style fits confirm size of uncertainty bands and generally weak parametrisation dependence

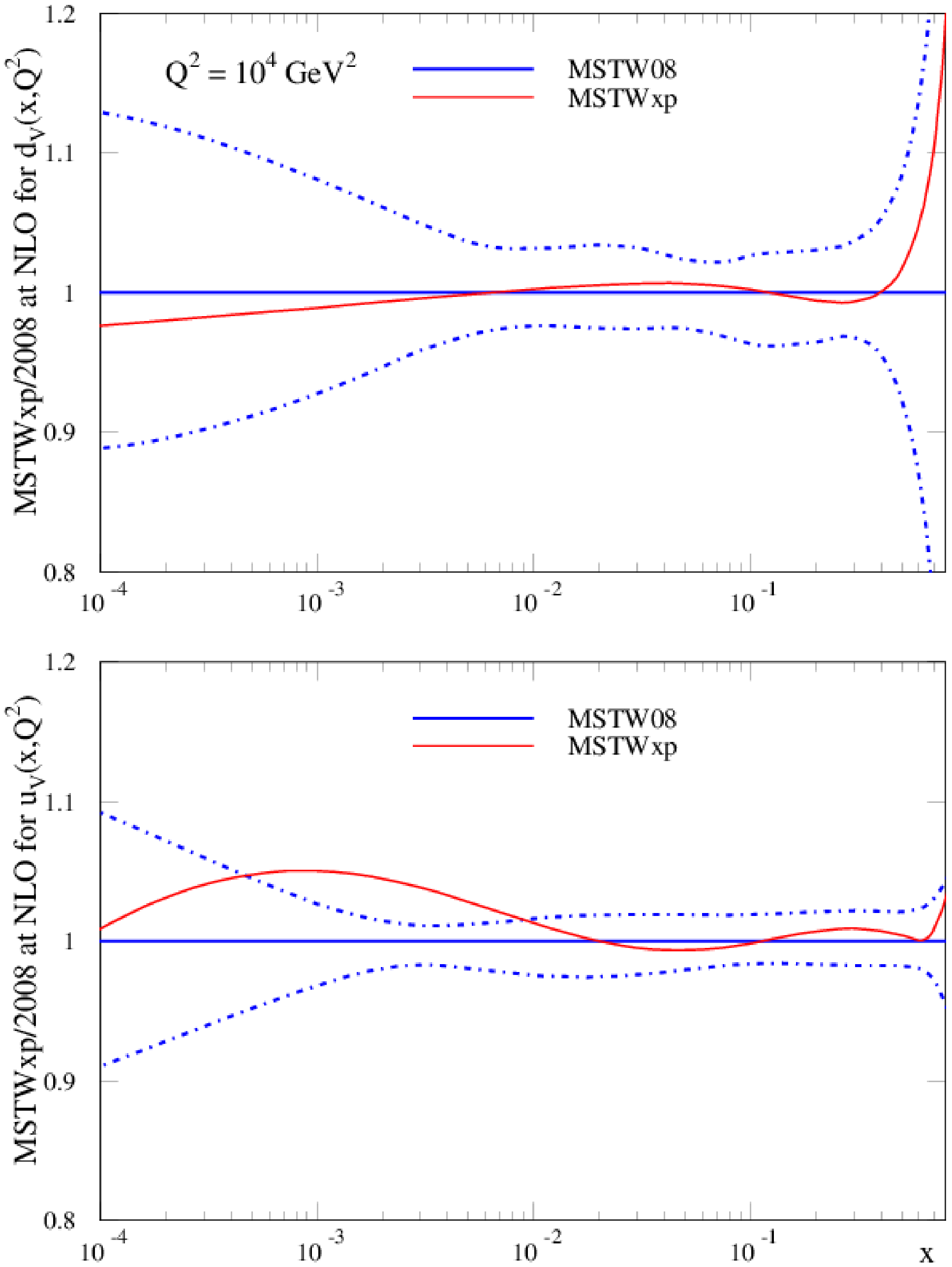
- Preliminary study of alternative Chebyshev parametrisations of valence distributions: little change in quality of global fit, and changes in PDFs mostly stay well within previous c.l. Bands (u_V a possible exception)

Summary contd.

- 2008 MSTW fit(s) still agree remarkably well with more recent Tevatron and LHC data

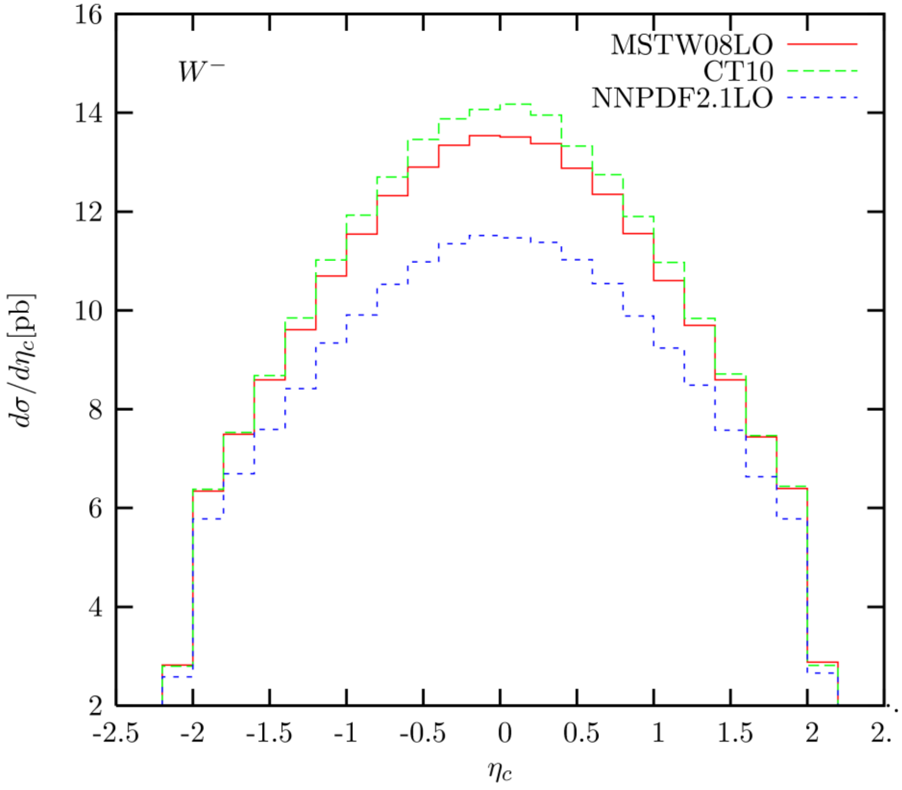
- there are a number of obvious upgrades, e.g. combined HERA data, retune of valence u,d distributions at small x, revisit nuclear corrections, etc. – these have already been extensively studied internally

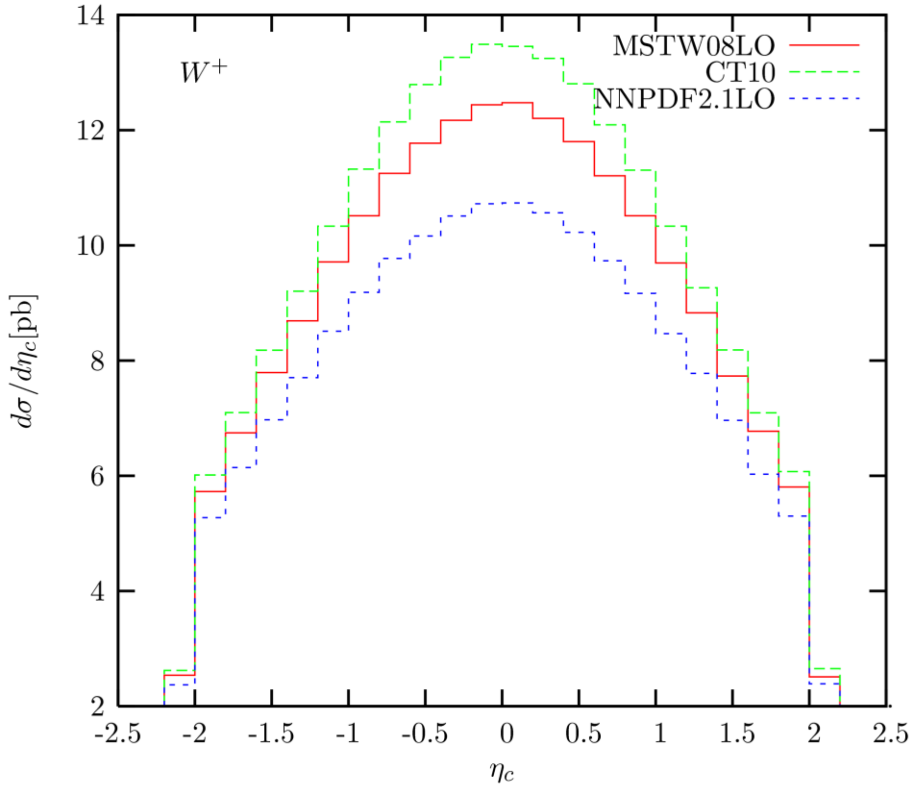
- we will wait for a more complete set of 7 TeV LHC and Tevatron data before performing and releasing a new global fit; likely to be MSTW2012 extra slides



$Q^2 = 10^4\ GeV^2$
MSTW08
MSTWxp
MSTWxp/2008 at NLO for $d_V(x,Q^2)$
MSTW08
MSTWxp
MSTWxp/2008 at NLO for $u_V(x,Q^2)$
1.2
1.1
1
0.9
0.8
10^{-4}
10^{-3}
10^{-2}
10^{-1}
x

Thorne


W^-
MSTW08LO
CT10
NNPDF2.1LO
$d\sigma/d\eta_c$[pb]
η_c


W^+
MSTW08LO
CT10
NNPDF2.1LO
$d\sigma/d\eta_c$[pb]
η_c

Vryonidou