MMHT2014 PDFs- Published sets and Updates

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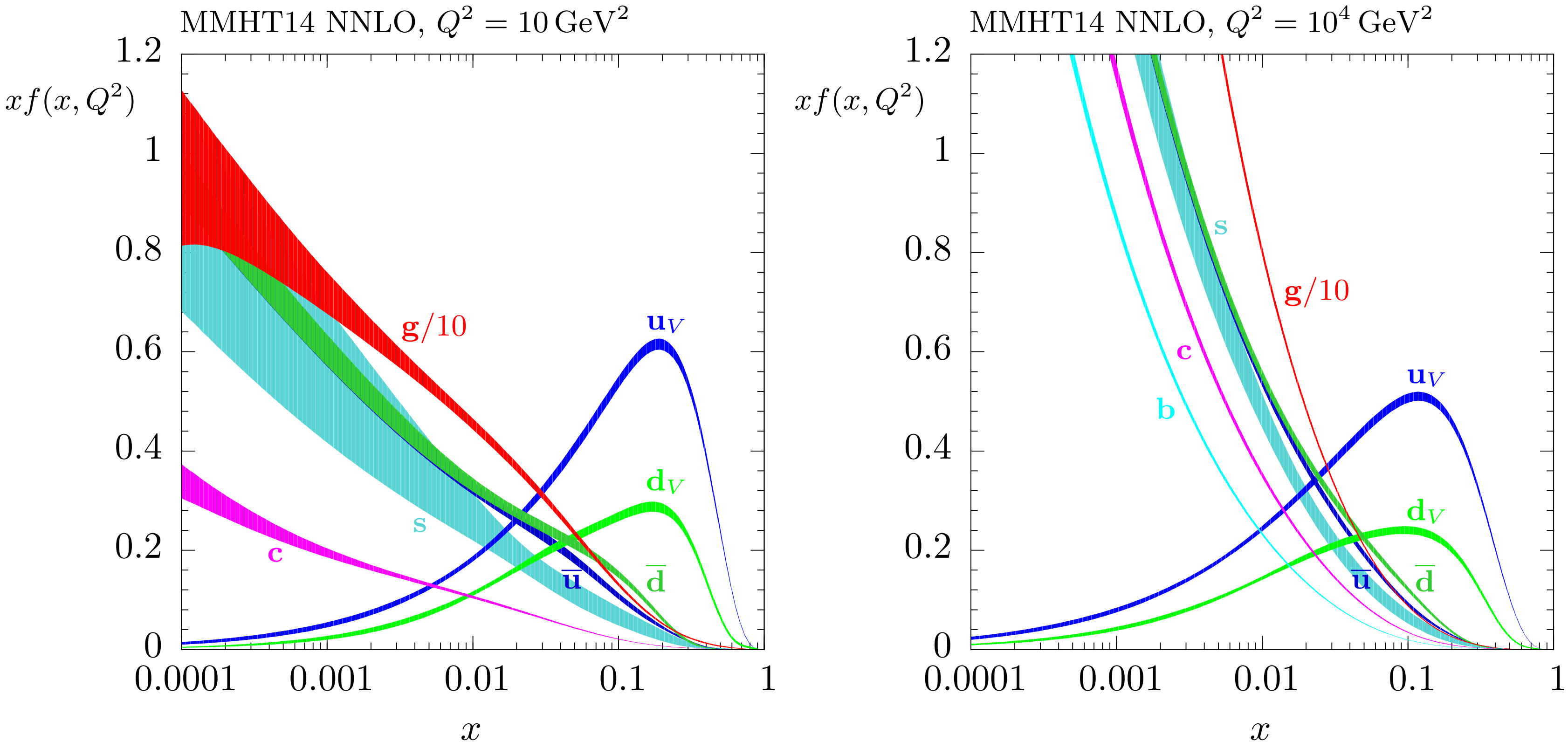
and thanks to Ben Watt, Graeme Watt and James Stirling

Updates in PDF Fits – the MMHT 2014 PDFs.

I will present results on the update in PDFs within the general MSTW framework due to some theory improvements and a variety of new data sets, including most of the up-to-date LHC data. The release of a new set of MMHT PDFs (http://arxiv.org/abs/arXiv:1412.3989 – now accepted for publication in EPJ C) is summarised, and some subsequent results and future plans are discussed.

MMHT 2014 PDFs



Available in LHAPDF5 and LHAPDF6.

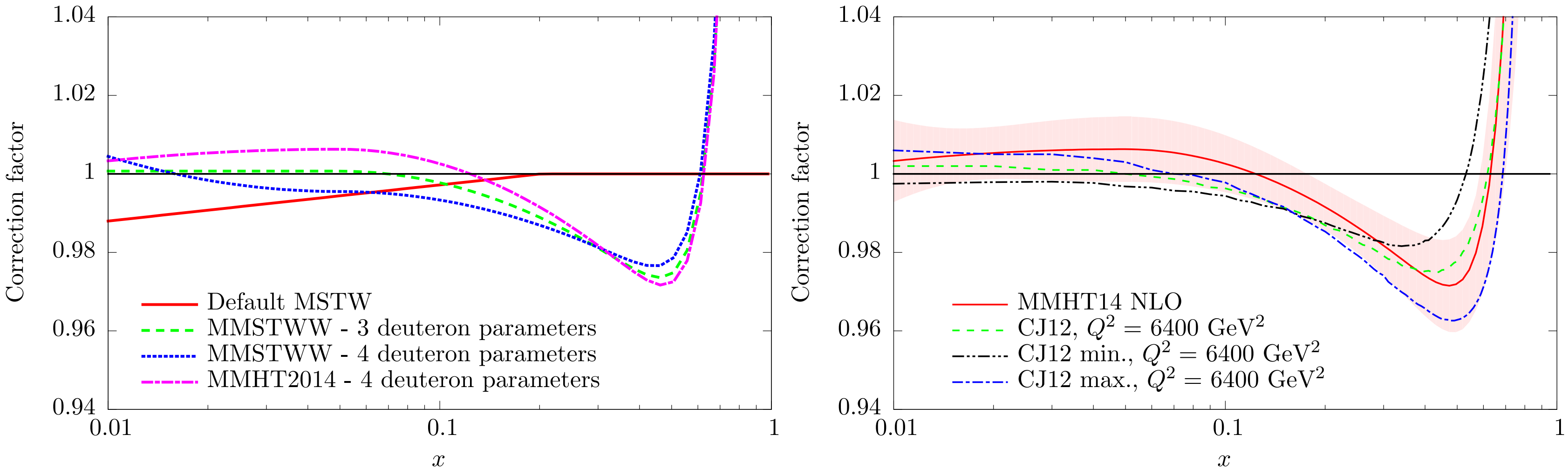
Also at `http://www.hep.ucl.ac.uk/mmht` where there is stand-alone Fortran code, a C++ wrapper and Mathematica implementations as well as grids in LHAPDF5 and LHAPDF6 format.

MMHT2014 – Changes in theoretical treatment or procedures.

Continue to use extended parameterisation with Chebyshev polynomials, and freedom in deuteron nuclear corrections (and heavy nuclear corrections), as in recent MSTWCPdeut study (Eur.Phys.J. C73 (2013) 2318) – change in $u_V - d_V$ distribution.

Now use "optimal" GM-VFNS choice (Phys.Rev. D86 (2012) 074017) which is smoother near to heavy flavour transition points (more so at NLO).

Correct dimuon cross-sections for missing small contribution, i.e. where charm is produced away from the interaction point. Previously assumed this was accounted for by acceptance corrections. Previous checks showed correction is a small effect on strange distribution.



Result for fitted deuteron correction.

Previously big improvement in fit for MMSTWW, but not exactly as expected at lower x.

Now more like that expected, and 4 parameters left free. Good comparison to CJ12mid model (Accardi). Uncertainty of about $0.5-1\%$. Feeds into PDF uncertainty.

Errors multiplicative not additive. Using χ^2 definition

$$\chi^2 = \sum_{i=1}^{N_{pts}} \left(\frac{D_i + \sum_{k=1}^{N_{corr}} r_k \sigma_{k,i}^{corr} - T_i}{\sigma_i^{uncorr}} \right)^2 + \sum_{k=1}^{N_{corr}} r_k^2,$$

where $\sigma_{k,i}^{corr} = \beta_{k,i}^{corr} T_i$ and $\beta_{k,i}^{corr}$ are the percentage error. Additive would use $\sigma_{k,i}^{corr} = \beta_{k,i}^{corr} D_i$. Previously did this for all but normalisation uncertainty.

Strange branching ratio. Now avoid those determined by fits to dimuon data relying on PDF input. Also apply error which feeds into PDFs. Use $B_\mu = 0.092 \pm 10\%$ from hep-ex/9708014. Fits prefer $B_\mu = 0.085 - 0.091 \pm 15\%$.

Have been using de Florian, Sassot nuclear corrections. Update to more recent version, de Florian, Sassot, Stratmann, Zurita, Phys.Rev. D85 (2012) 074028.

Changes in data sets.

Replacement of HERA run I neutral and charged current data from HERA and ZEUS with combined data set with full treatment of correlated errors. Fit to data very good. Slightly better fit at NNLO.

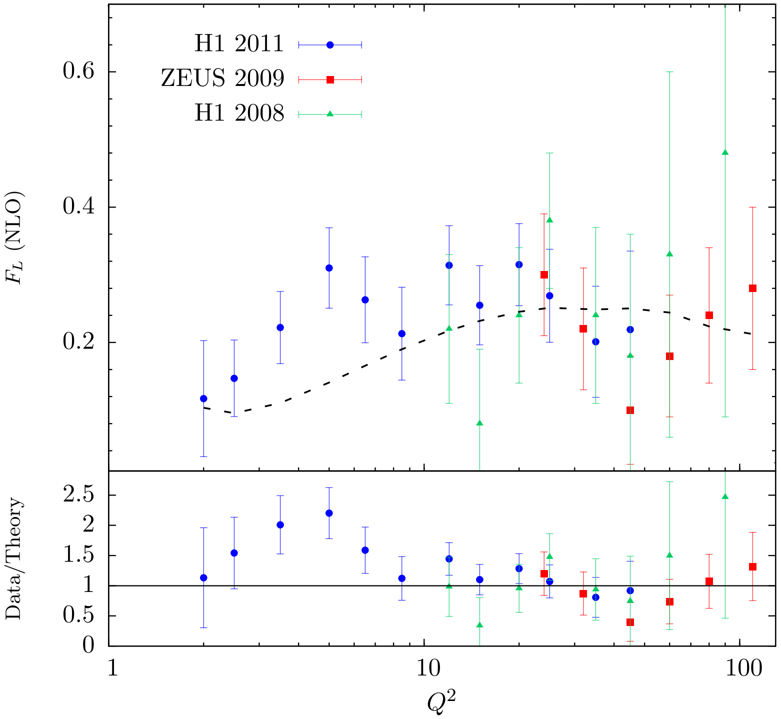
Inclusion of HERA combined data on $F_2^c(x,Q^2)$. Fit quality $\sim$ 60-80 for 52 points.

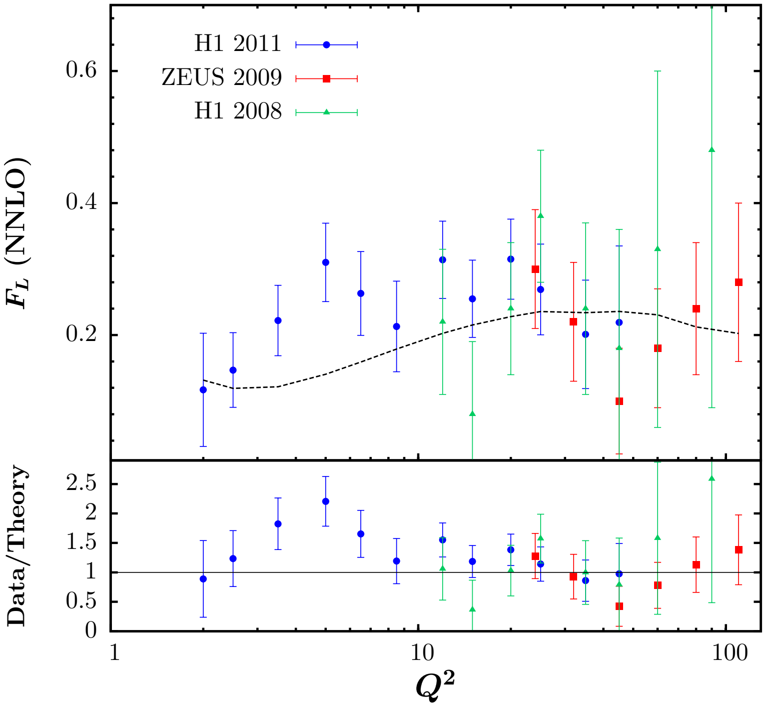
Inclusion of all direct published HERA $F_L(x,Q^2)$ measurements. Undershoot data a little at lower Q^2, but χ^2 not much more than one per point.

No inclusion of separate run II H1 and ZEUS data yet. Wait for Run II combination.

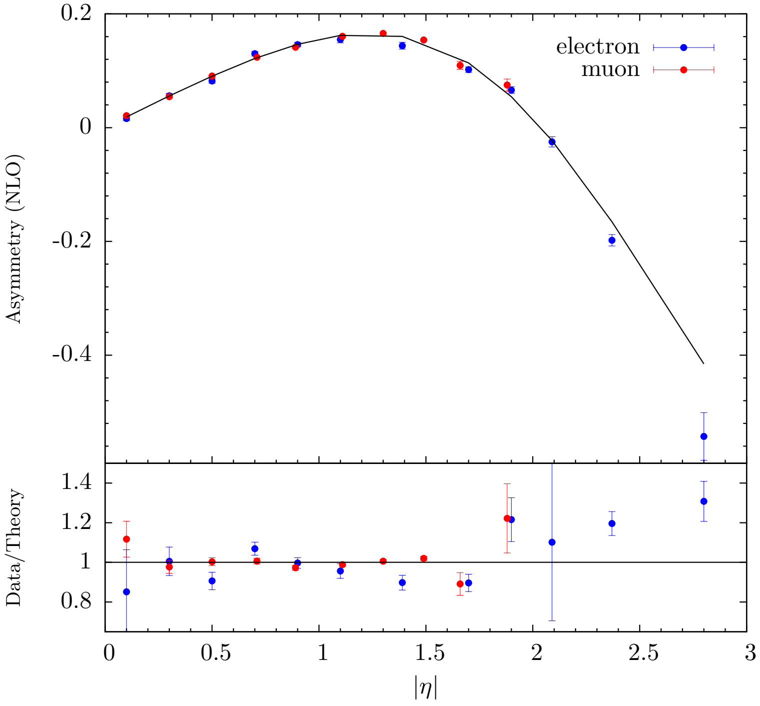
Inclusion of the CDF W-asymmetry data, the D0 electron asymmetry data $p_T > 25\mathrm{GeV}$ based on 0.75 fb^{-1} and new D0 muon asymmetry data for $p_T > 25\mathrm{GeV}$ based on 7.3 fb^{-1}.

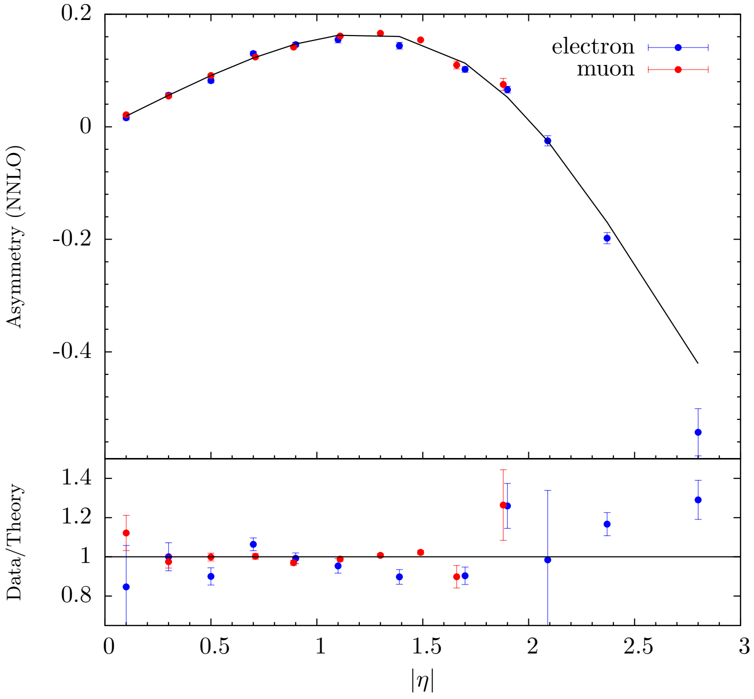
Fit quality at NLO and NNLO for $F_L(x, Q^2)$ data





Fit quality at NLO and NNLO for D0 asymmetry data





LHC data on W,Z

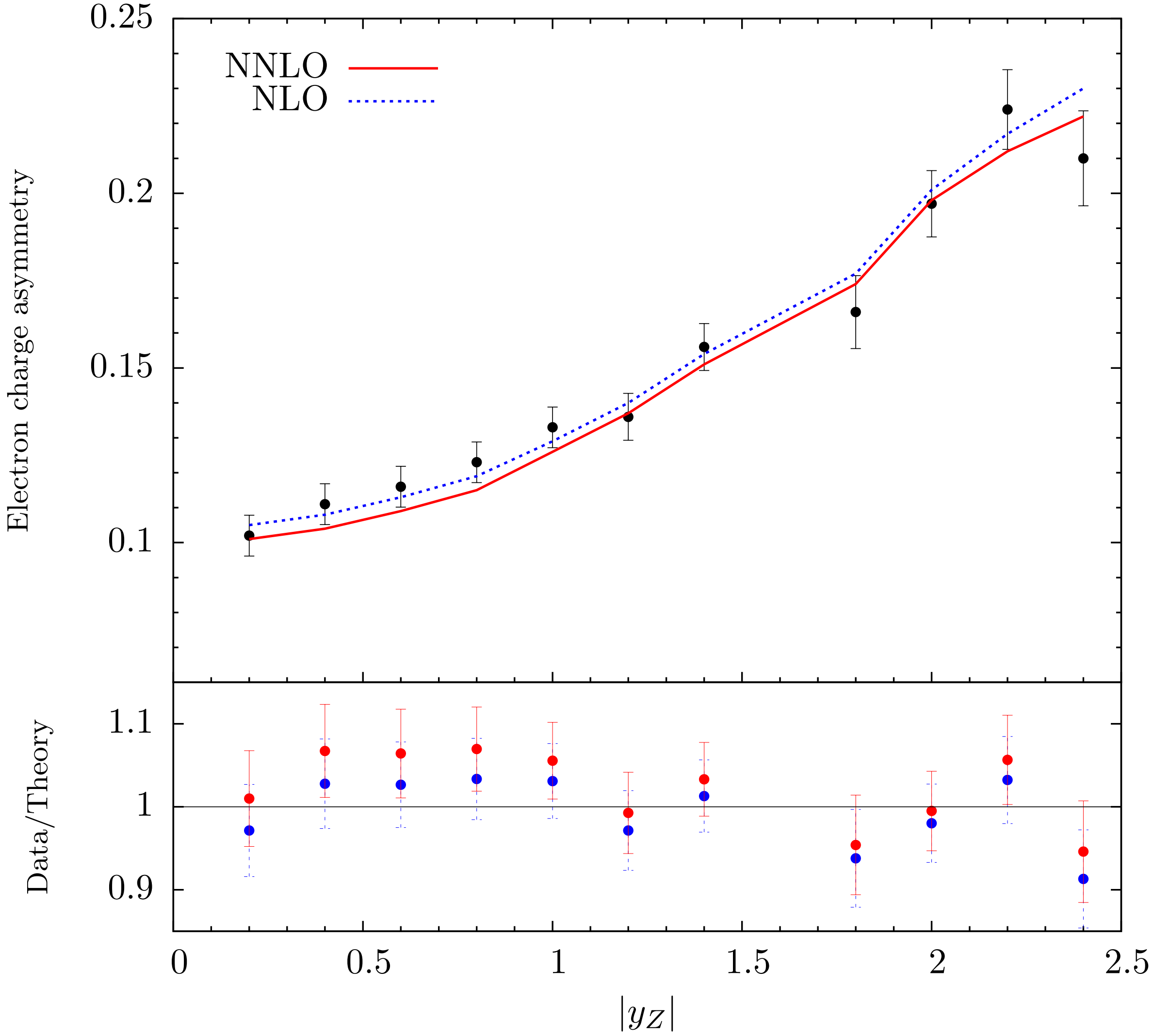
Now using APPLGrid – MCFM and DYNNLO/FEWZ include the ATLAS W,Z rapidity data directly in the fit. $\rightarrow$ slight change is in the strange quark.

$W^+ - W^-$ asymmetry no longer an issue at all both for ATLAS and CMS asymmetry data. Slightly better at NLO.

Include LHCb data on W^+, W^-, and $Z \rightarrow e^+e^-$. Both predicted/fit well at NLO.

Include CMS data on $Z \rightarrow e^+e^-$, and ATLAS high mass Drell-Yan data. Again both predicted/fit well.

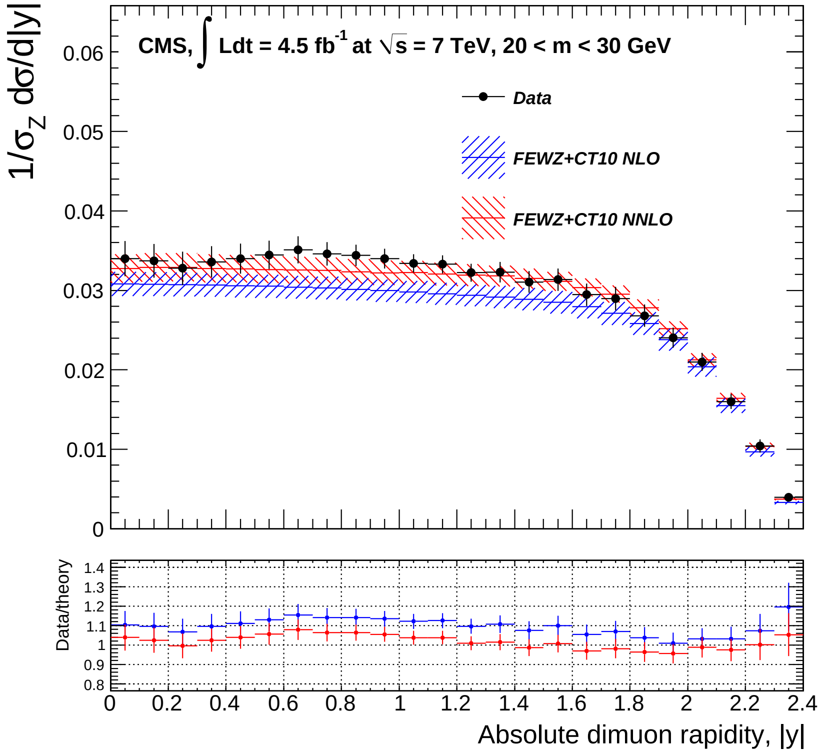
Fit CMS double differential Drell Yan data extending to low mass. NNLO fits enormously better than NLO at lowest mass $\sim 20 - 45\mathrm{GeV}$.

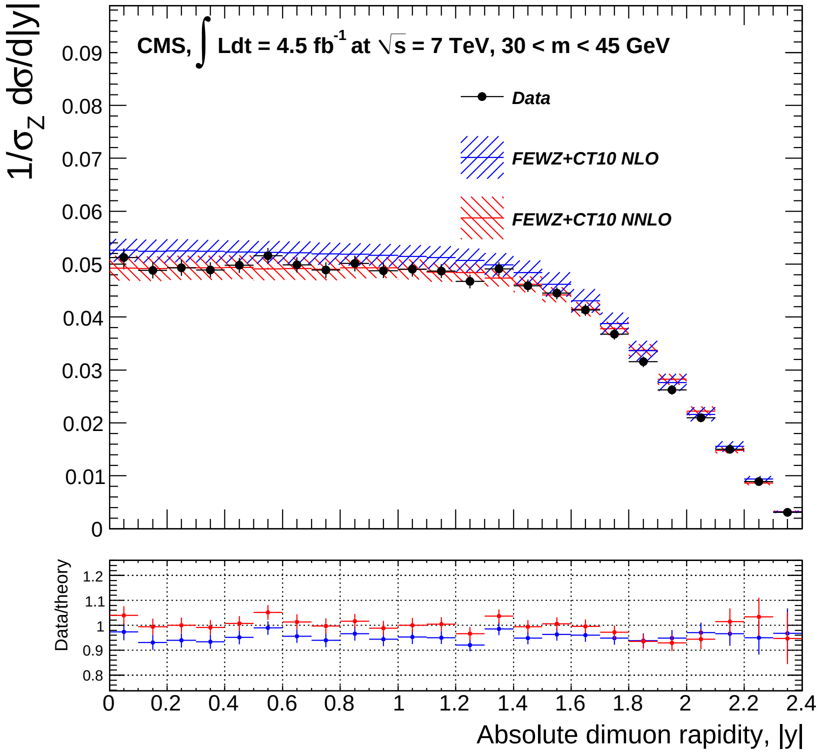


W asymmetry data now fit very well, though a little better at NLO than at NNLO.

CMS Drell Yan data.

Fit very poor at NLO in lowest mass bins (where it is effectively LO), even when data highly weighted.



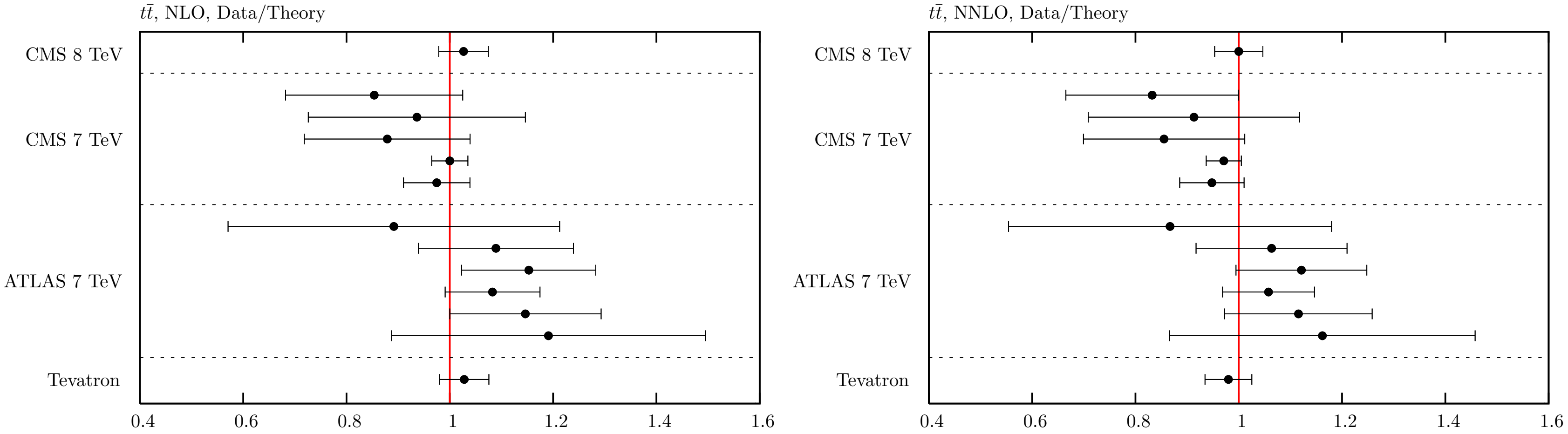


Enormously improved fit quality at NNLO due to improvement in cross-sections.

Sensitivity to strange fraction in quarks, but differs at NLO and NNLO and weak compared to direct constraint from di-muon data.

LHC data on $t\bar{t}$

Include data on $\sigma_{t\bar{t}}$ from Tevatron (combined cross section measurement from D0 and CDF), and all published data from ATLAS and CMS for $7\mathrm{TeV}$ and one point at $8\mathrm{TeV}$. Use $m_t = 172.5\ \mathrm{GeV}$ (value used in Tevatron combination) with an error of $1\ \mathrm{GeV}$, with χ^2 penalty applied. Predictions and fit good, with NLO preferring masses slightly below $m_t = 172.5\ \mathrm{GeV}$ and NNLO masses slightly above.



LHC data on jets

At NLO include CMS data and ATLAS 7 TeV + 2.76 TeV data.ATLAS $\chi^2 = 107/116$ and CMS $\chi^2 = 143/133$ before included directly.

Enormous project of full NNLO calculation (Gehrmann-de-Ridder*et al.*) nearing completion. Some indications of full form.

As default at NNLO still fit Tevatron data which are relatively near to threshold. However, omit LHC data. Investigate inclusion of K-factor.

data set	N_{pts}	MMSTWW	MMHT14 (no LHC)	MMHT14 (with LHC)
NLO				
ATLAS (2.76+7 TeV)	116	107	107	106
CMS (7 TeV)	133	140	143	138
NNLO small				
ATLAS (2.76+7 TeV)	116	(107)	(123)	(122) 115
CMS (7 TeV)	133	(142)	(137)	(138) 137
NNLO large K-factor				
ATLAS (2.76+7 TeV)	116	(117)	(132)	(132) 126
CMS (7 TeV)	133	(145)	(137)	(139) 139

MMHT2014 PDFs compared to MSTW2008 PDFs.

Use same “dynamic tolerance” prescription to determine eigenvectors.

Typical tolerance $T = \Delta\chi^2 \sim 10$.

We now have 25 eigenvector pairs, rather than the 20 in MSTW or even the 23 in MMSTWW.

Eigenvector sets made available for $\alpha_S(M_Z^2) = 0.135$ (LO), $\alpha_S(M_Z^2) = 0.118, 0.120$ (NLO) and $\alpha_S(M_Z^2) = 0.118$ (NNLO)

In addition the central sets are available at

LO	$\alpha_S(M_Z^2) = 0.134, 0.135, 0.136$
NLO	$\alpha_S(M_Z^2) = 0.117, 0.118, 0.119, 0.120, 0.121$
NNLO	$\alpha_S(M_Z^2) = 0.117, 0.118, 0.119$

This allows the PDF $+\ \alpha_S$ uncertainty to be calculated, if using the prescription of adding in quadrature.

NLO

HERA structure – 6 eigenvector directions.

fixed target data DIS data – 13 eigenvector directions

LHC data – 4 eigenvector directions

Tevatron data– 9 eigenvector directions

Dimuon data – 8 eigenvector directions

E866 Drell Yan data – 10 eigenvector directions.

NNLO

HERA structure – 11 eigenvector directions.

fixed target data DIS data – 10 eigenvector directions

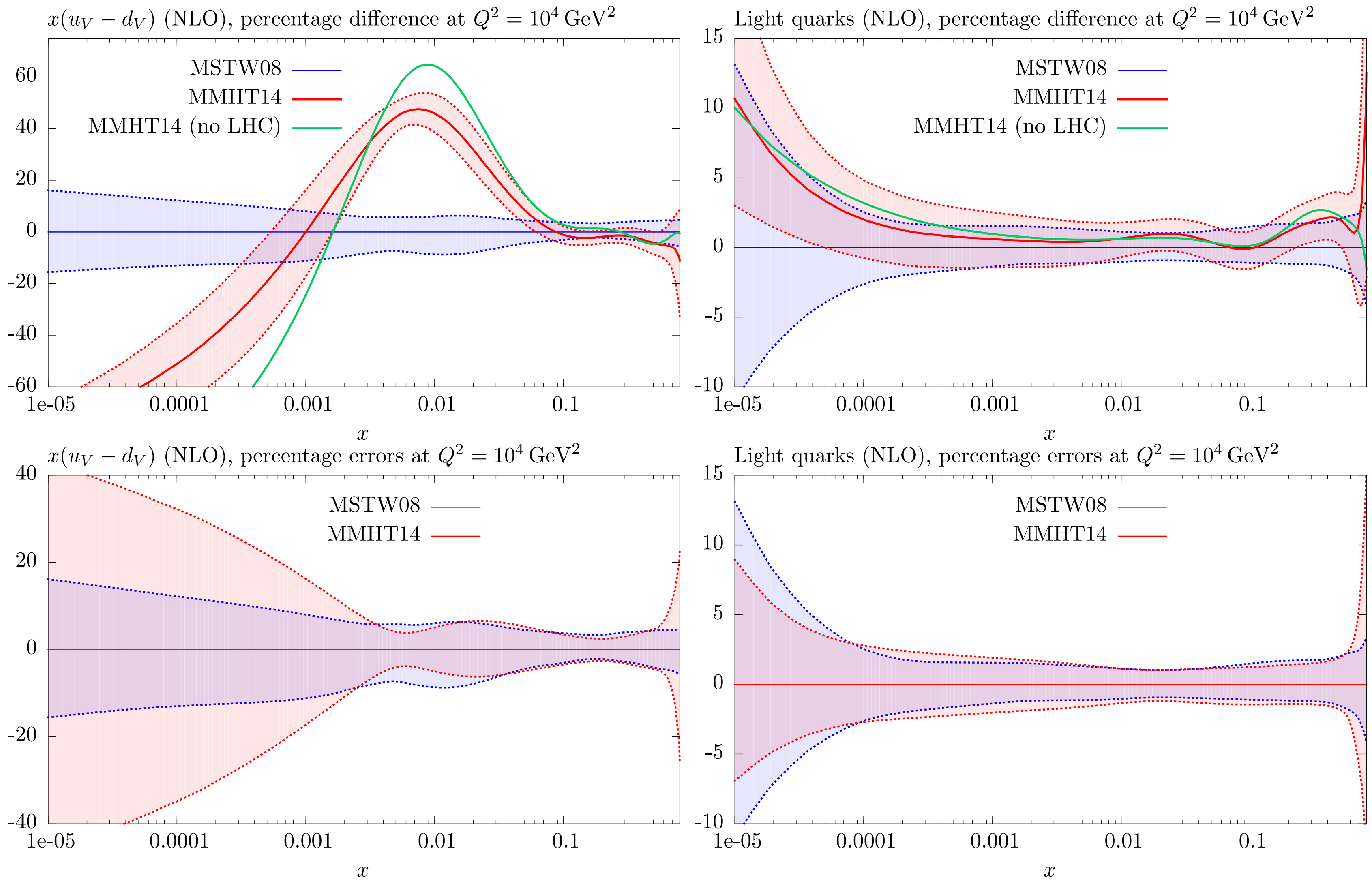
LHC data – 8 eigenvector directions

Tevatron data– 6 eigenvector directions

Dimuon data – 9 eigenvector directions

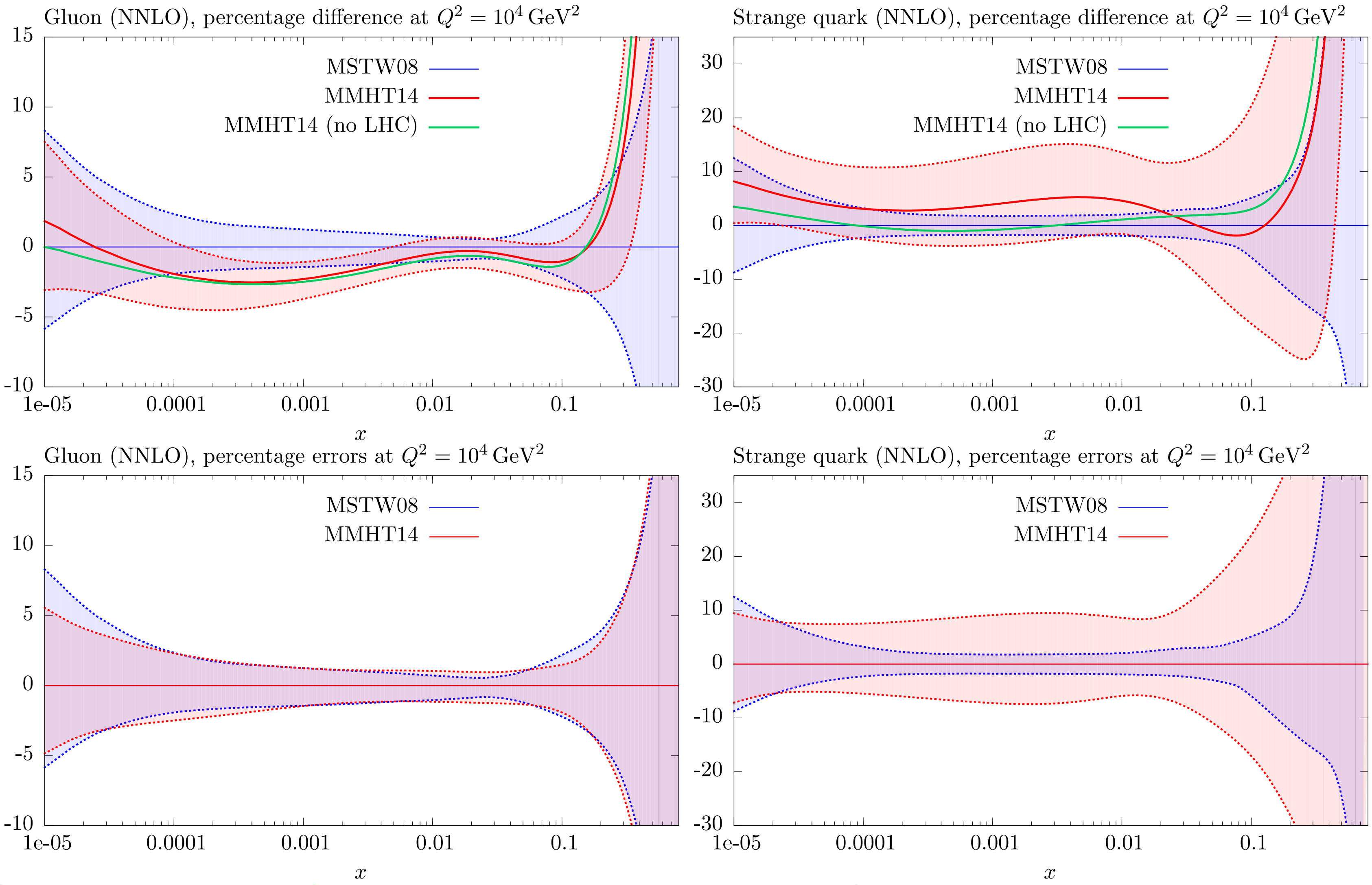
E866 Drell Yan data – 6 eigenvector directions.

Comparison of PDFs at NLO



Change in NLO PDFs from all updates, including LHC data updates.

Comparison of PDFs at NNLO



Gluon (NNLO), percentage difference at $Q^2 = 10^4\ \mathrm{GeV}^2$

Strange quark (NNLO), percentage difference at $Q^2 = 10^4\ \mathrm{GeV}^2$

Gluon (NNLO), percentage errors at $Q^2 = 10^4\ \mathrm{GeV}^2$

Strange quark (NNLO), percentage errors at $Q^2 = 10^4\ \mathrm{GeV}^2$

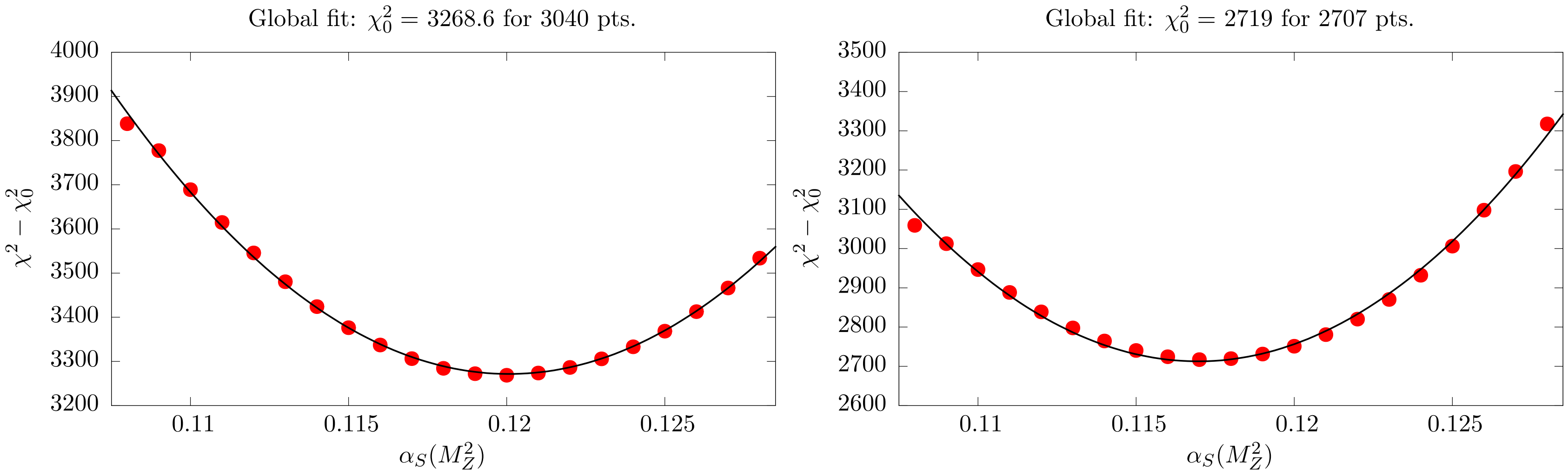
Change in NNLO PDFs from all updates. Gluon uncertainty at high-x slightly greater than at NLO. At NNLO final extracted $\alpha_S(M_Z^2) = 0.11722$, but PDFs presented for $\alpha_S(M_Z^2) = 0.1180$.

$\alpha_S(m_Z^2)$ and PDF sets.

$\alpha_S(m_Z^2)$ coming out similar to 2008 fit. Still a NLO/NNLO difference. Both fairly compatible with global average, i.e.

NLO – $\alpha_S(m_Z^2) = 0.1200$, NNLO – $\alpha_S(m_Z^2) = 0.1172$.

$\alpha_S(m_Z^2)^{\rm world} = 0.1186 \pm 0.0006$. Decide to present MMHT2014 PDFs with eigenvectors at round value of $\alpha_S(m_Z^2) = 0.118$ at NNLO and at NLO also at $\alpha_S(m_Z^2) = 0.120$.

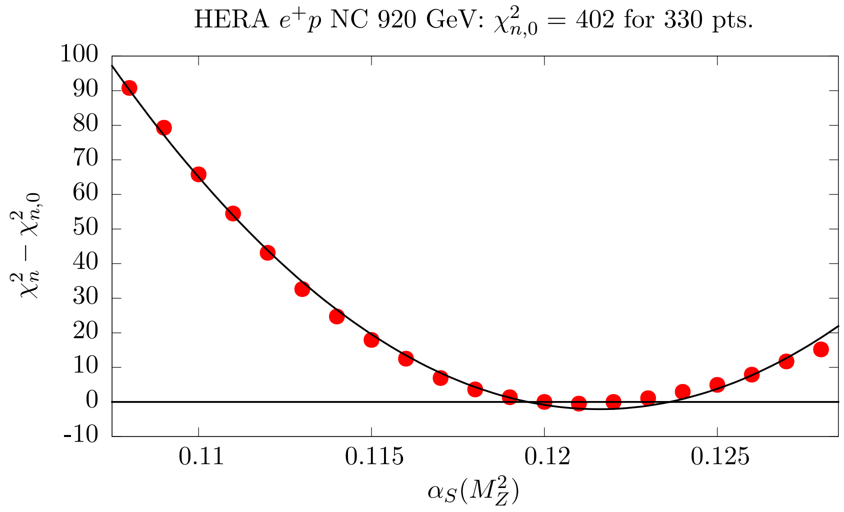


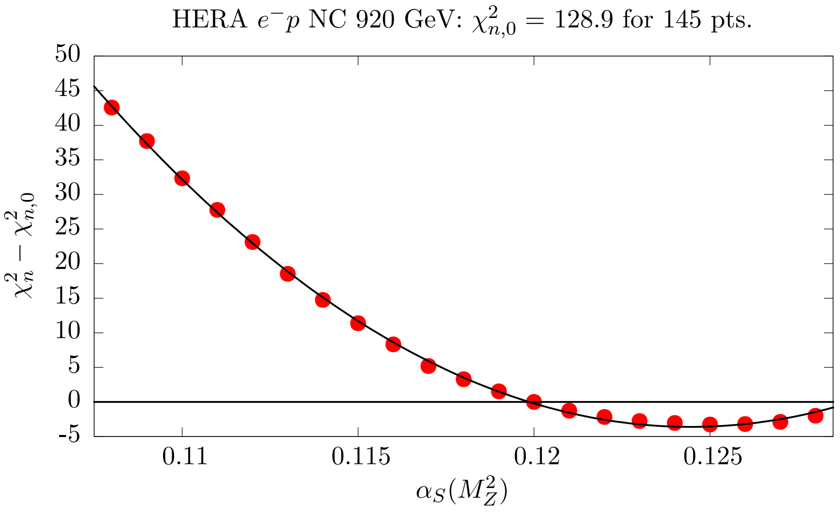
At NNLO forcing 0.118 leads to $\Delta\chi^2 < 2$ and at NLO leads to $\Delta\chi^2 \sim 16$.

Individual Data Sets

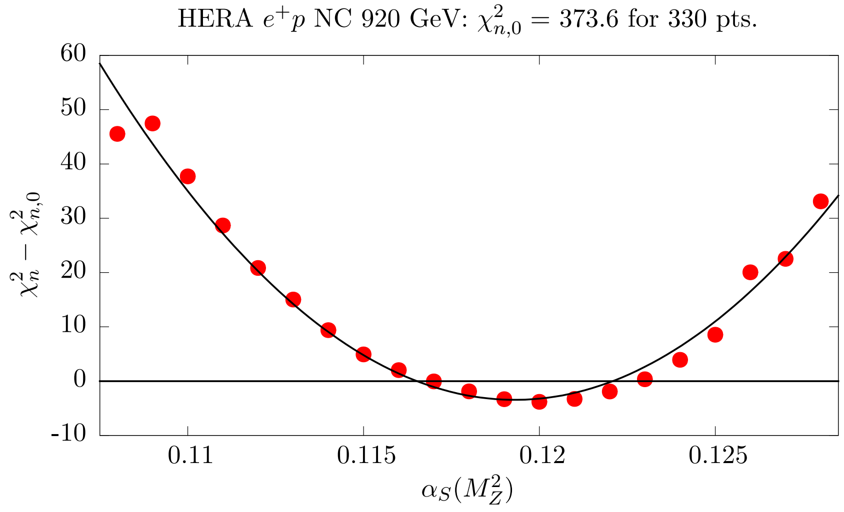
HERA data in global fit prefers higher $\alpha_S(M_Z^2)$.

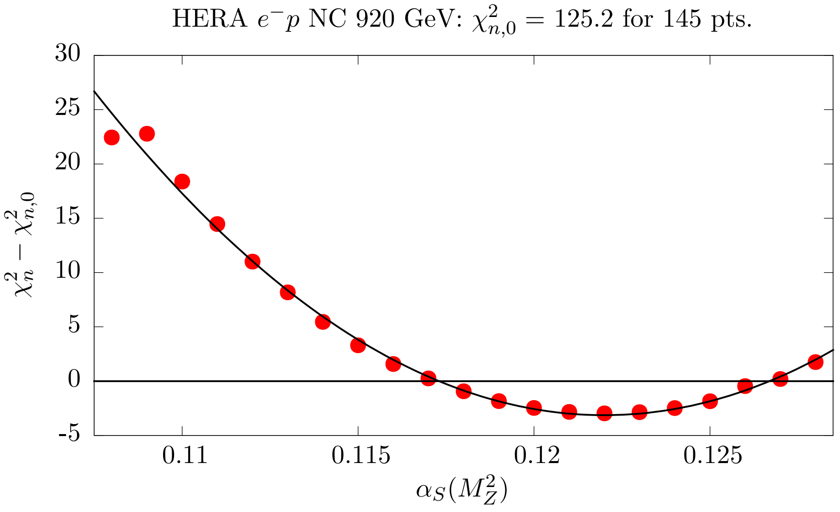
NLO





NLO

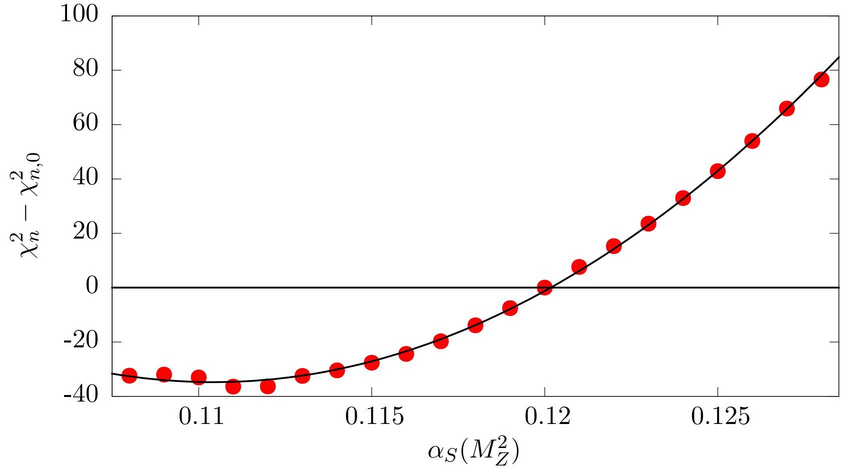




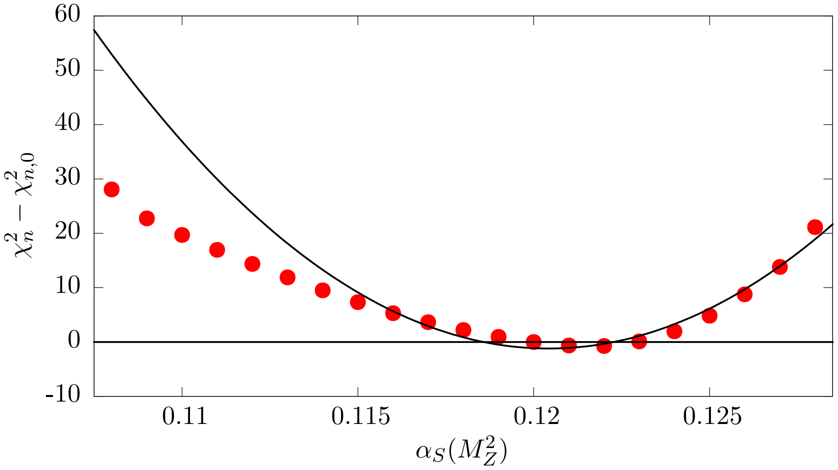
Most constraining Data Sets.

NLO

BCDMS μp F_2: $\chi^2_{n,0} = 176.4$ for 163 pts.

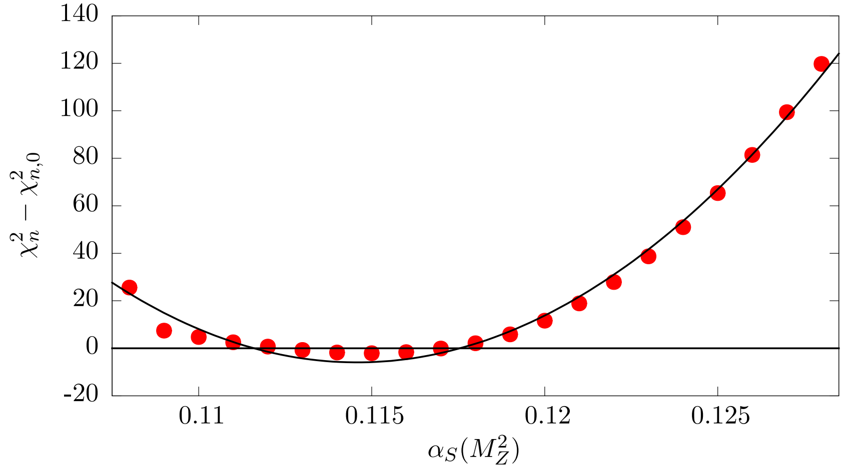


Tevatron, ATLAS, CMS $\sigma_{t\bar{t}}$: $\chi^2_{n,0} = 6.6$ for 13 pts.

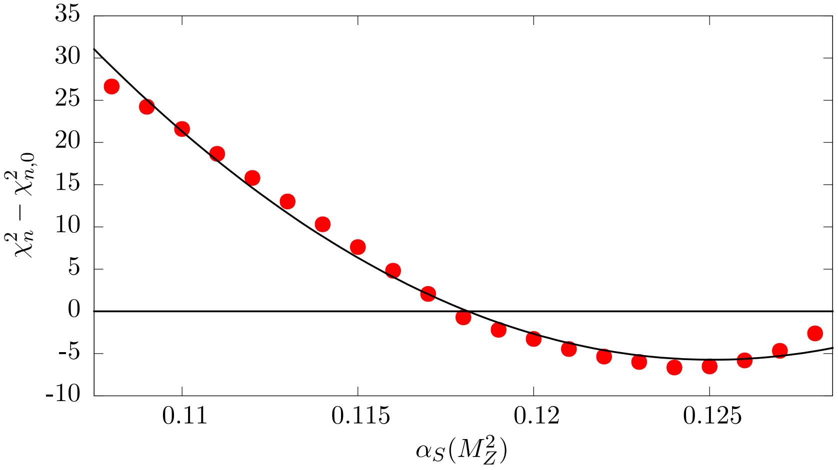


NNLO

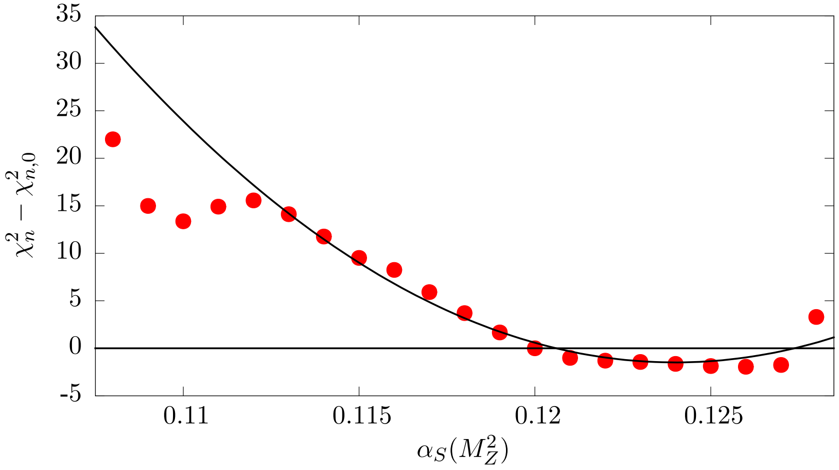
Tevatron, ATLAS, CMS $\sigma_{t\bar{t}}$: $\chi^2_{n,0} = 7.9$ for 13 pts.

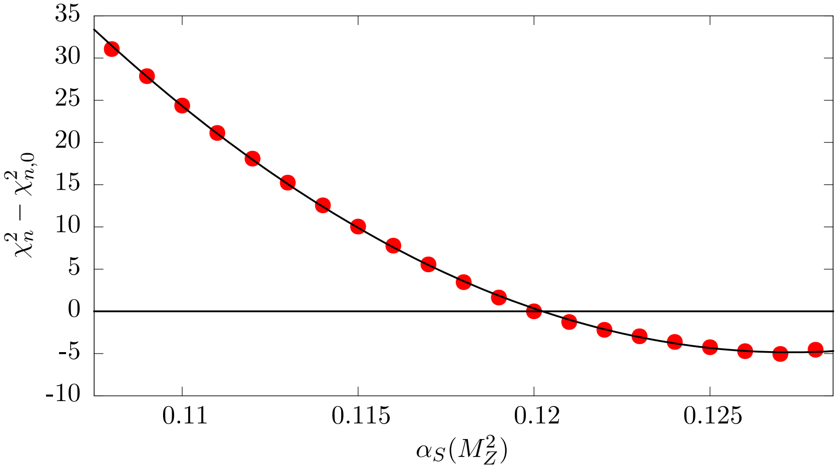


NuTeV νN xF_3: $\chi^2_{n,0} = 31.3$ for 42 pts.

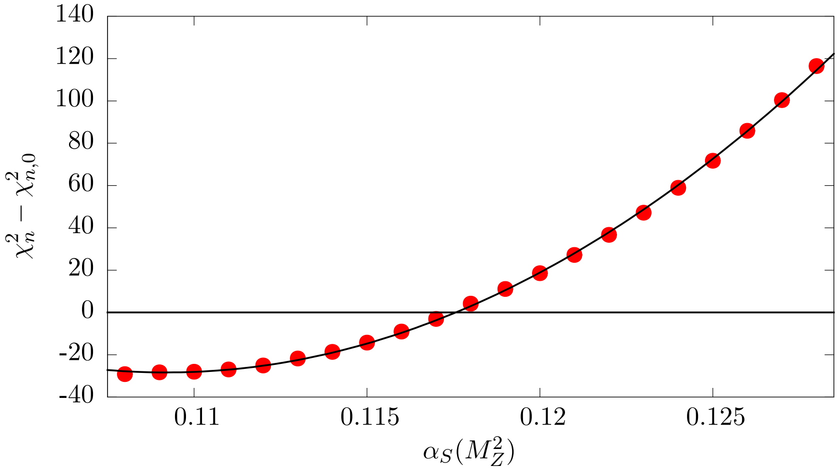


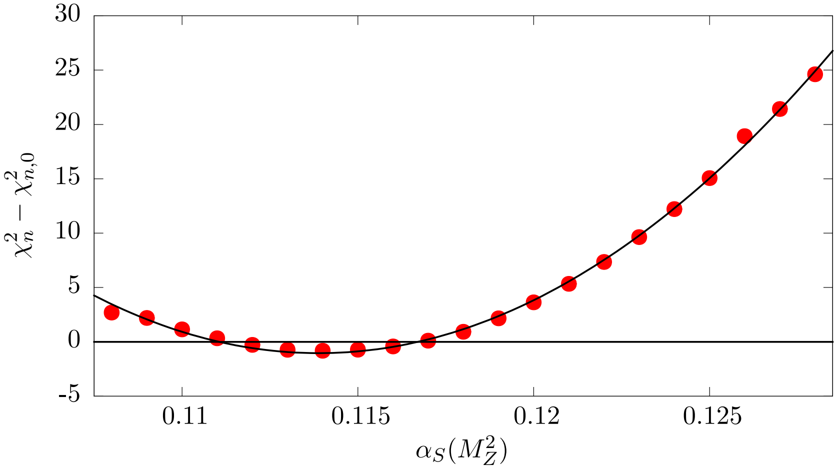
Also constraining lower limit – NLO


NuTeV νN xF_3: $\chi^2_{n,0} = 36$ for 42 pts.

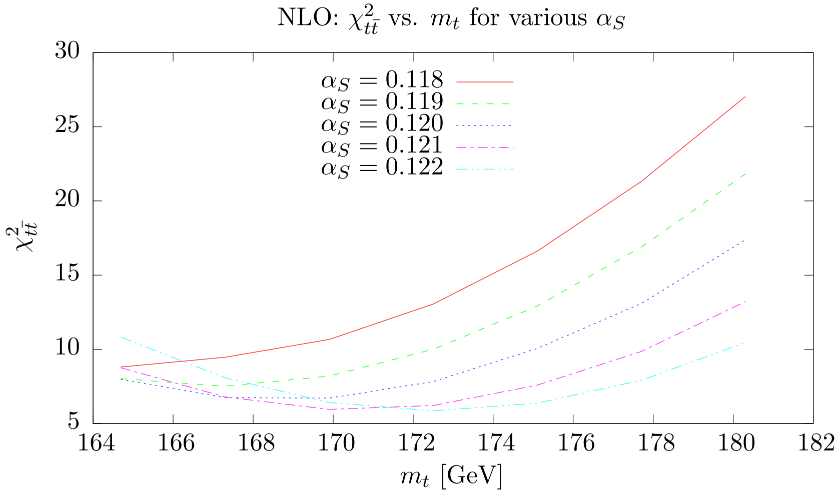

SLAC μd F_2: $\chi^2_{n,0} = 29.4$ for 38 pts.

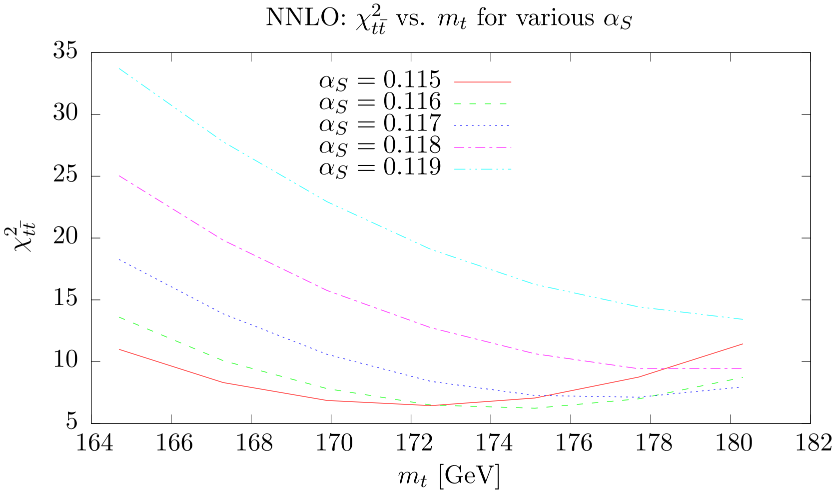
Also constraining upper limit – NNLO


BCDMS μp F_2: $\chi^2_{n,0} = 173$ for 163 pts.


SLAC ep F_2: $\chi^2_{n,0} = 30.4$ for 37 pts.

Global χ^2 depends on m_t but minimises at very similar $\alpha_S(M_Z^2)$ for a rather wide range.





However, fit quality to $\sigma_{\bar{t}t}$ data alone very sensitive to m_t and $\alpha_S(M_Z^2)$ interplay.

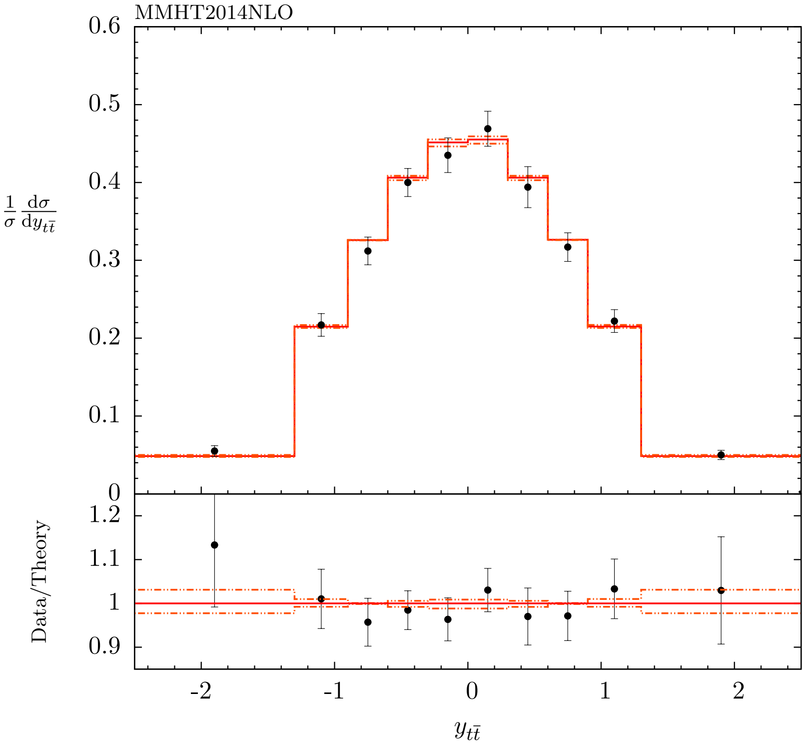
Values determined by free best fit using $m_t = 172.5 \text{ GeV} \pm 1 \text{ GeV}$ are $m_t(\text{NLO}, \text{NNLO}) = 171.7, 174.2 \text{ GeV}$, as opposed to world average of $m_t = 173.34 \pm 0.76 \text{ GeV}$.

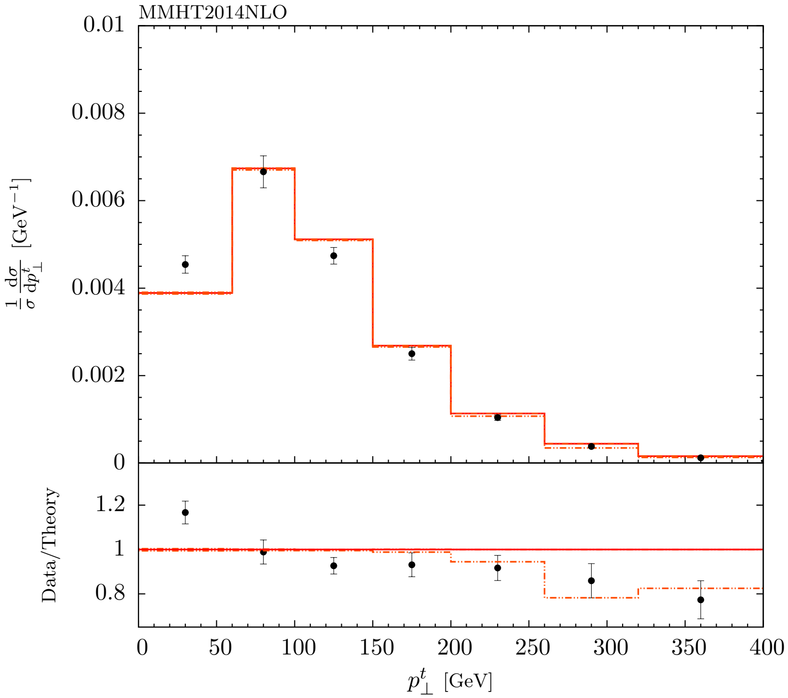
Be conservative on $\alpha_S(M_Z^2)$ constraints direct from $\sigma_{\bar{t}t}$, but similar constraints from other sets.

New data sets for fit – $t\bar{t}$ differential distributions.

Variety of data sets not in PDF determination as they did not meet cut-off date and/or missing NNLO corrections.

For example, differential $\bar{t}t$ production (show CMS below). $y_{\bar{t}t}$ distribution at NLO very good, p_t distribution off in shape ($m_{\bar{t}t}$ somewhere in between).

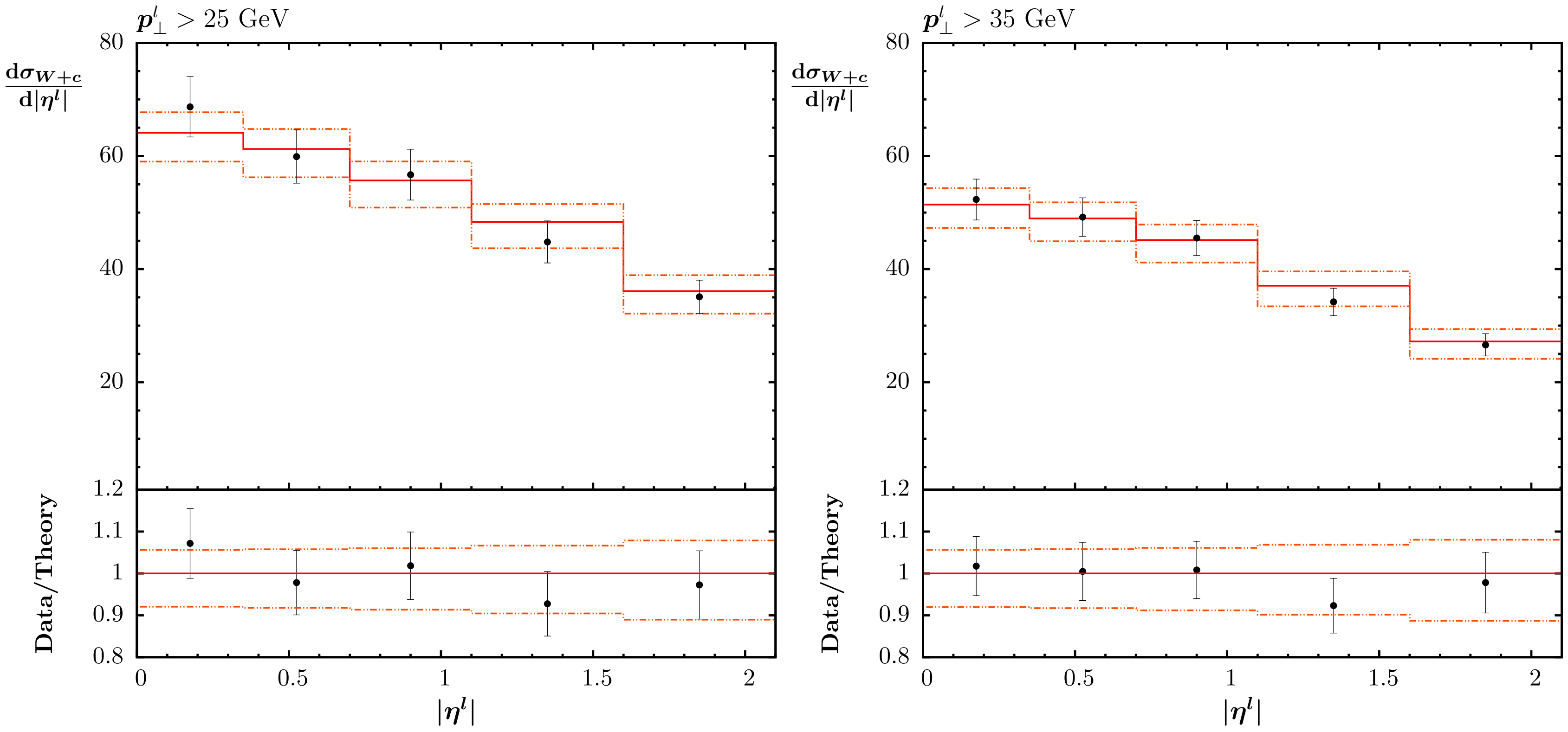




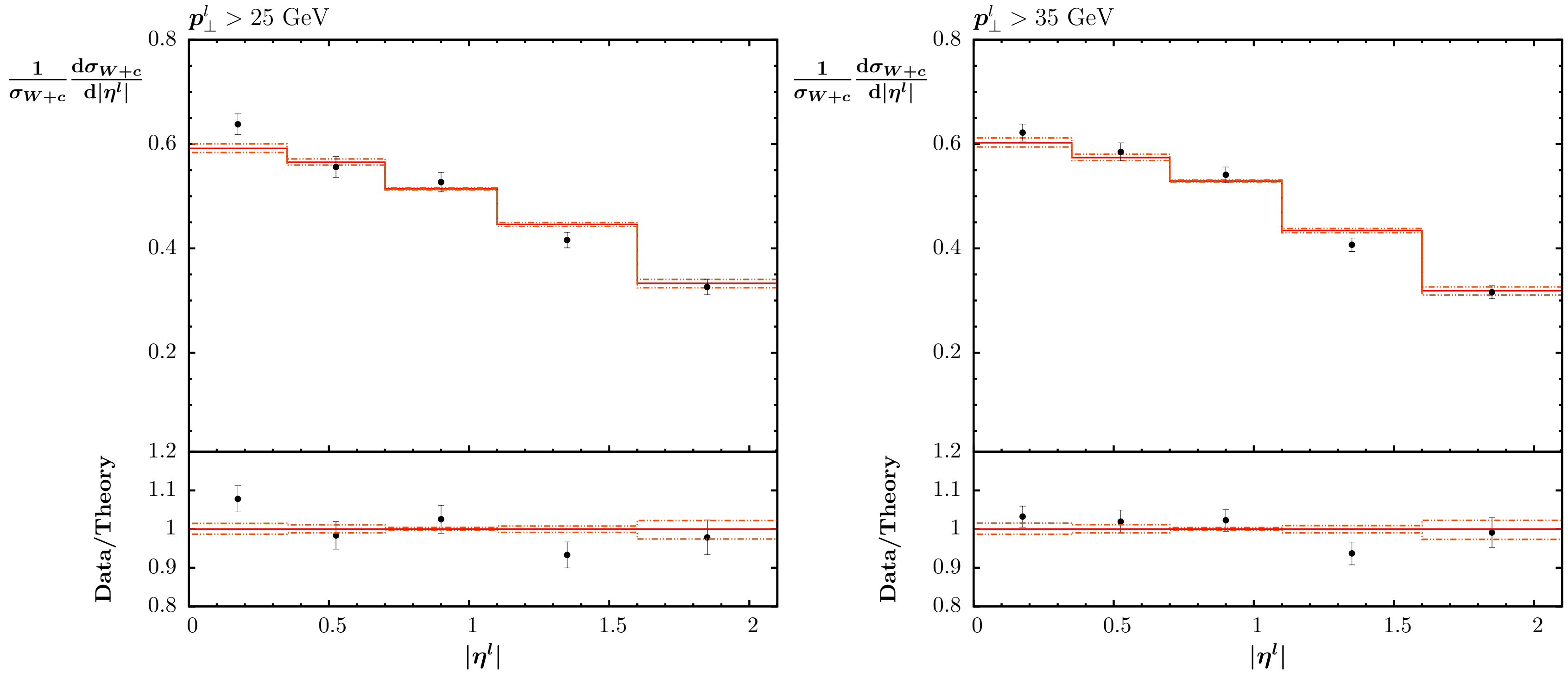
Interesting to see NNLO corrections.

New data sets for fit – $W+c$ differential distributions.

	GeV	data	MSTW2008	MMHT2014
$\sigma(W+c)$	$p_T^{\rm lep} > 25$	$107.7 \pm 3.3({\rm stat.}) \pm 6.9({\rm sys.})$	102.8 ± 1.7	110.2 ± 8.1
$\sigma(W+c)$	$p_T^{\rm lep} > 35$	$84.1 \pm 2.0({\rm stat.}) \pm 4.9({\rm sys.})$	80.4 ± 1.4	86.5 ± 6.5
$R_c^{\pm}$	$p_T^{\rm lep} > 25$	$0.954 \pm 0.025({\rm stat.}) \pm 0.004({\rm sys.})$	0.937 ± 0.029	0.924 ± 0.026
$R_c^{\pm}$	$p_T^{\rm lep} > 35$	$0.938 \pm 0.019({\rm stat.}) \pm 0.006({\rm sys.})$	0.932 ± 0.030	0.904 ± 0.027



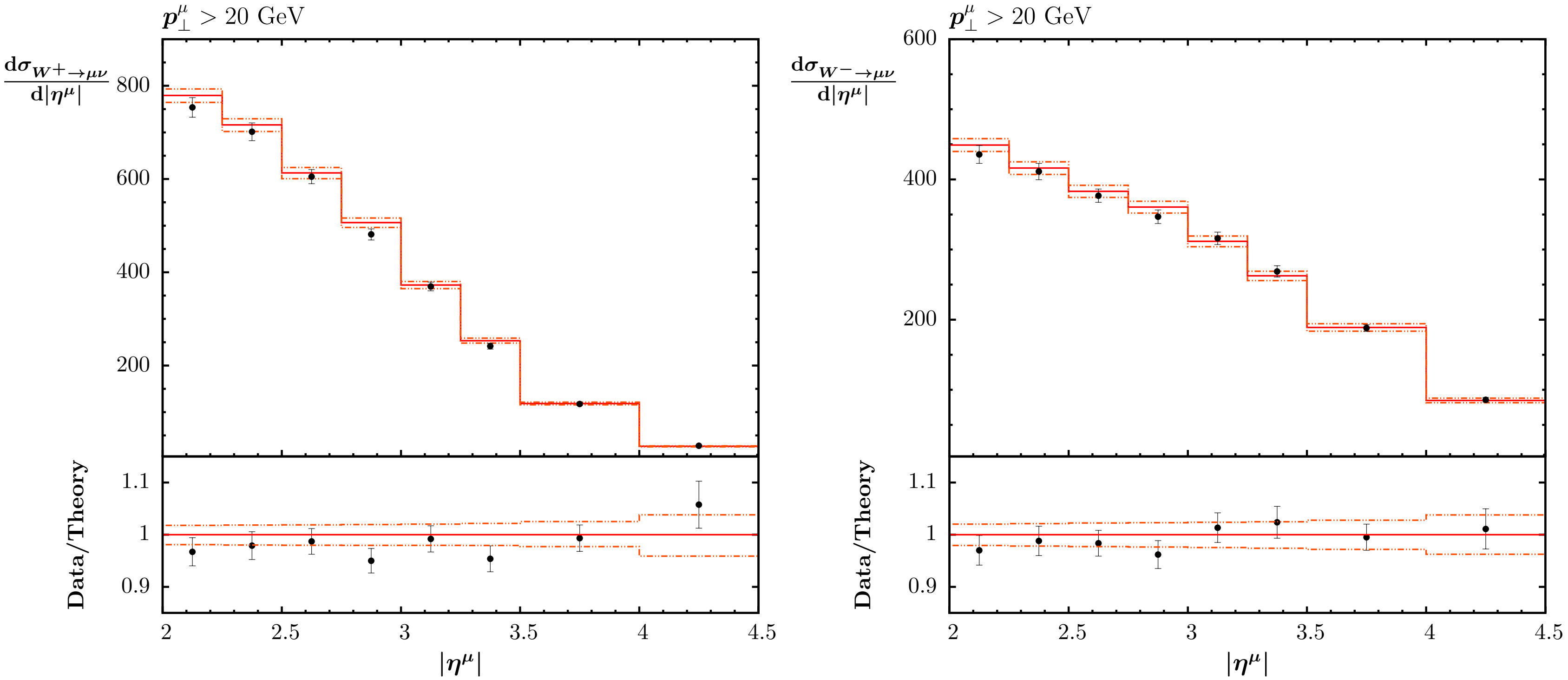
MSTW2008 a bit low (especially for ATLAS), but MMHT2014 seems fine particularly for CMS (shown). Data will add some constraint.



Also fine for normalised distribution.

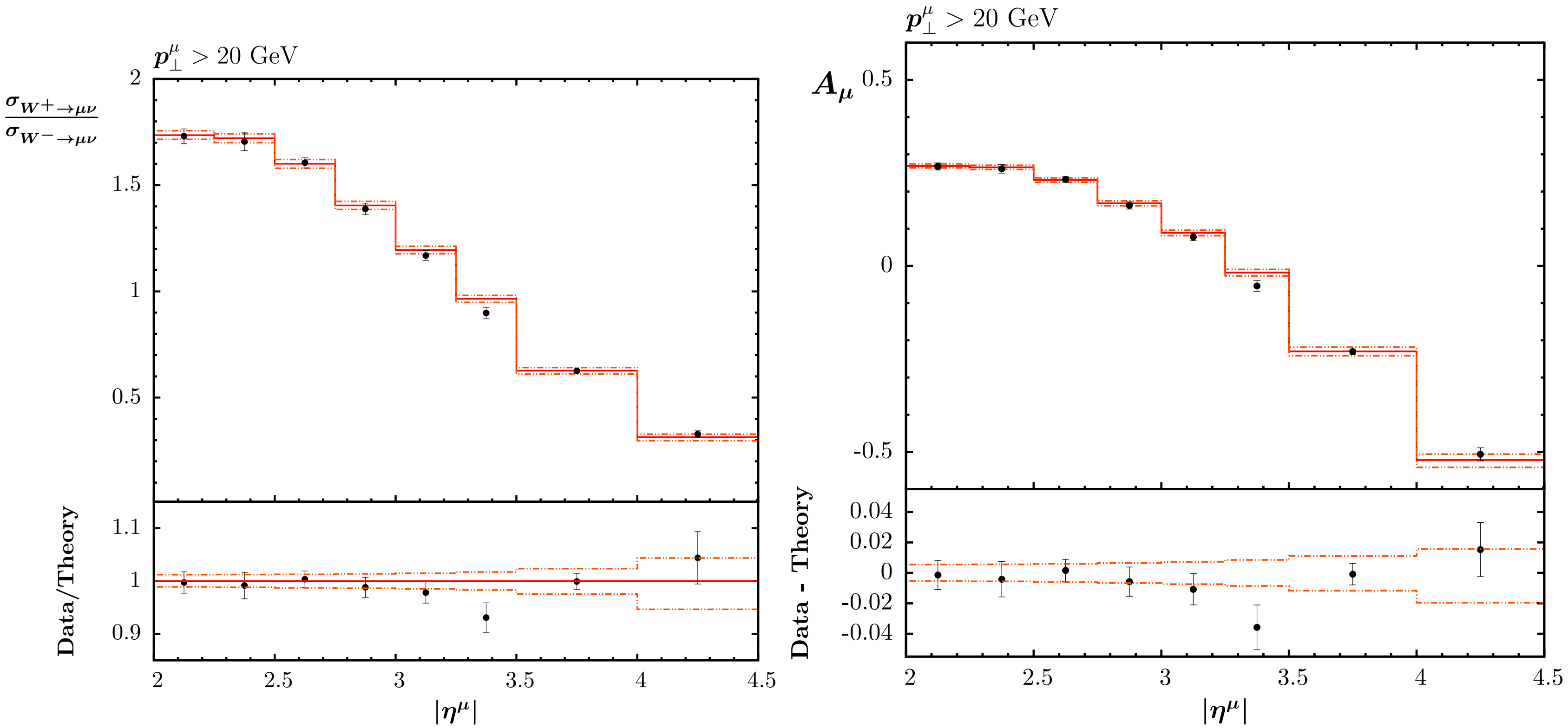
Only at NLO, but possibly less sensitivity to higher order in normalised distribution.

New data on high rapidity W production **LHCb** at 7 TeV.



Generally perfectly good agreement using NNLO.

The same data is also available as a ratio or asymmetry, with a reduction in systematic uncertainty (particularly luminosity).



Again clearly good agreement. PDF uncertainties still a little smaller than data constraints – except maybe highest rapidity (high-x PDF).

PDFs and Heavy Quarks

As before we will make the same PDFs sets (i.e. exactly the same input at $Q_0^2 = 1\ \mathrm{GeV}^2$) available for three flavour and four flavour fixed-flavour number schemes (FFNS).

As default will also fix the number of flavours in α_S, but will probably also provide analogous sets with variable flavour α_S as there were some requests for MSTW2008.

Will also make available sets with fits done for m_c and m_b (defined in pole scheme) varying from default values of $m_c = 1.40\ \mathrm{GeV}$ and $m_b = 4.75\ \mathrm{GeV}$ in steps of $0.05\ \mathrm{GeV}$ and $0.25\ \mathrm{GeV}$ respectively.

Probably not as wide a range as last time – $m_c = 1.05 - 1.75\ \mathrm{GeV}$ and $m_b = 4.00 - 5.50\ \mathrm{GeV}$.

m_b constrained to fairly close to $m_b = 4.75\ \mathrm{GeV}$ from direct $F_2^{\bar{b}b}(x, Q^2)$ data from HERA and m_c also constrained far better than previous range from various sources.

Dependence on m_c (pole mass) at NLO in fits.

m_c (GeV)	χ^2_{global} 2996 pts	$\chi^2_{F_2^c}$ 52 pts	$\alpha_s(M_Z^2)$
1.15	3239	75	0.1190
1.2	3237	73	0.1192
1.25	3239	71	0.1194
1.3	3245	70	0.1195
1.35	3254	70	0.1196
1.4	3268	71	0.1198
1.45	3283	73	0.1200
1.5	3303	76	0.1201
1.55	3327	81	0.1202

Some correlation between m_c and $\alpha_S(M_Z^2)$.

Preference for $m_c \sim 1.20\mathrm{GeV}$.

NMC data prefer lower m_c – quicker threshold evolution respectively.

Slight tension between global fit and charm data.

Dependence on m_c at NLO in fits at fixed $\alpha_s(M_Z^2) = 0.120$.

m_c (GeV)	χ^2_{global} 2996 pts	$\chi^2_{F_2^c}$ 52 pts	$\alpha_s(M_Z^2)$
1.15	3242	76	0.120
1.2	3239	74	0.120
1.25	3240	72	0.120
1.3	3245	71	0.120
1.35	3254	71	0.120
1.4	3267	71	0.120
1.45	3283	73	0.120
1.5	3303	76	0.120
1.55	3327	80	0.120

Similar variation with $m_c$for fixed $\alpha_S(M_Z^2) = 0.120$. For $0.13\ \mathrm{GeV} < m_c < 1.5\ \mathrm{GeV}$ difference compared to free coupling negligible.

Again preference for $m_c \sim 1.20\mathrm{GeV}$, or marginally higher.

For fixed $\alpha_s(M_Z^2) = 0.118$ preference for m_c marginally lower and slightly more tension (and worse fit).

Dependence on m_c at NNLO in m_c fits.

m_c (GeV)	χ^2_{global} 2663 pts	$\chi^2_{F_2^c}$ 52 pts	$\alpha_s(M_Z^2)$
1.15	2703	78	0.1164
1.2	2699	76	0.1166
1.25	2698	75	0.1167
1.3	2701	76	0.1169
1.35	2707	78	0.1171
1.4	2717	82	0.1172
1.45	2729	88	0.1173
1.5	2749	96	0.1173
1.55	2769	105	0.1175

Slightly less correlation between m_c and $\alpha_S(M_Z^2)$.

Less variation in fit quality and much less tension.

Preference for $m_c \sim 1.25\mathrm{GeV}$.

Dependence on m_c at NNLO in fits at fixed $\alpha_s(M_Z^2) = 0.118$.

m_c (GeV)	χ^2_{global} 2663 pts	$\chi^2_{F_2^c}$ 52 pts	$\alpha_s(M_Z^2)$
1.15	2712	79	0.118
1.2	2706	77	0.118
1.25	2705	76	0.118
1.3	2706	77	0.118
1.35	2711	79	0.118
1.4	2720	83	0.118
1.45	2731	88	0.118
1.5	2750	96	0.118
1.55	2770	106	0.118

Similar variation with $m_c$for fixed $\alpha_S(M_Z^2) = 0.118$.

Again preference for $m_c \sim 1.25\mathrm{GeV}$.

Conclusions

MMHT2014 PDFs recently released. Now accepted for publication.

Improvement in parameterisation, heavy flavour treatments, nuclear corrections, and branching ratio for dimuon data.

Inclusion of up-to-date HERA and Tevatron data and most relevant published LHC data. The fit is always good (except low mass Drell-Yan at NLO).

Few dramatic effects on PDFs. In general predictions remain very close to those with MSTW2008 PDFs.

25 eigenvector sets available with $\alpha_S(M_Z^2) = 0.135$ at LO, with $\alpha_S(M_Z^2) = 0.118, 120$ at NLO and with $\alpha_S(M_Z^2) = 0.118$ at NNLO.

Sets at $\Delta\alpha_S(M_Z^2) = \pm 0.001$ available. Sets for $0.108 - 0.128$ produced at NLO and NNLO. Release and study of $\alpha_S(M_Z^2)$ dependence imminent.

Sets in different flavour schemes and different quark masses very soon – study underway.

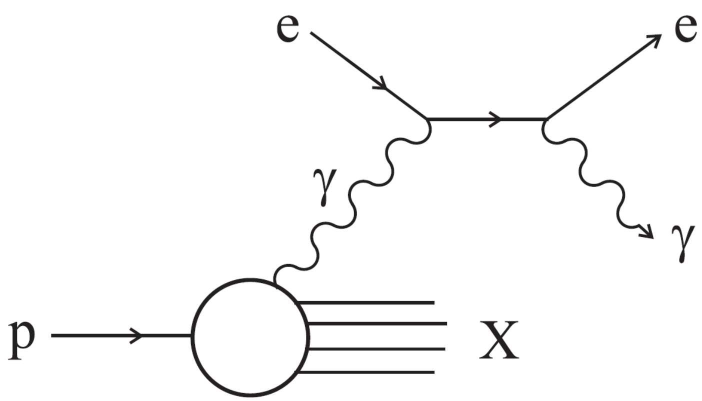
QED corrected set probably next priority.

Back -up

PDFs with QED corrections

At the level of accuracy we are now approaching it is important to account for electroweak corrections. At the LHC this can be important for many processes ($W, Z, WH, ZH, WW, jets\ldots$).

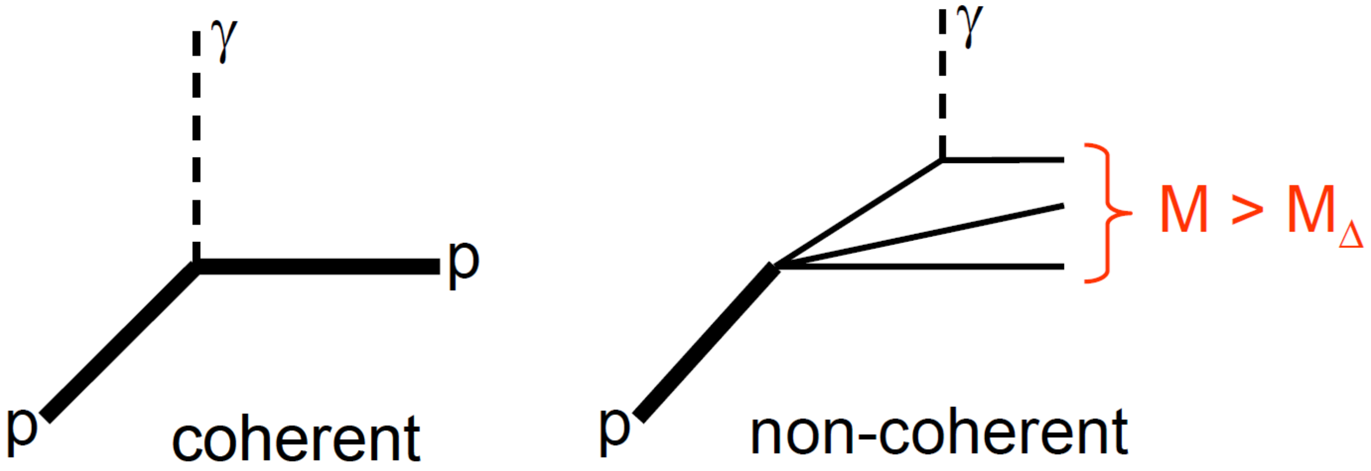
For a consistent treatment need PDFS which incorporate QED into the evolution, i.e. the inclusion of the photon PDF $\gamma(x, Q^2)$. (Set published by NNPDF and studies by CTEQ.)



$$\frac{\partial\gamma(x,Q^2)}{\partial \log Q^2} = \frac{\alpha}{2\pi}\int_x^1 \frac{dy}{y}\left(P_{\gamma\gamma}\otimes\gamma + \sum_1 e_i^2 P_{\gamma q}\otimes q_i\right)$$

Previous sets MRST2004 assumed $\gamma(x, Q^2)$ generated by photon emission off model for valence quarks with QED evolution from $m_q \rightarrow Q_0^2$. Freedom in choice of quark mass, e.g. current mass → constituent mass.

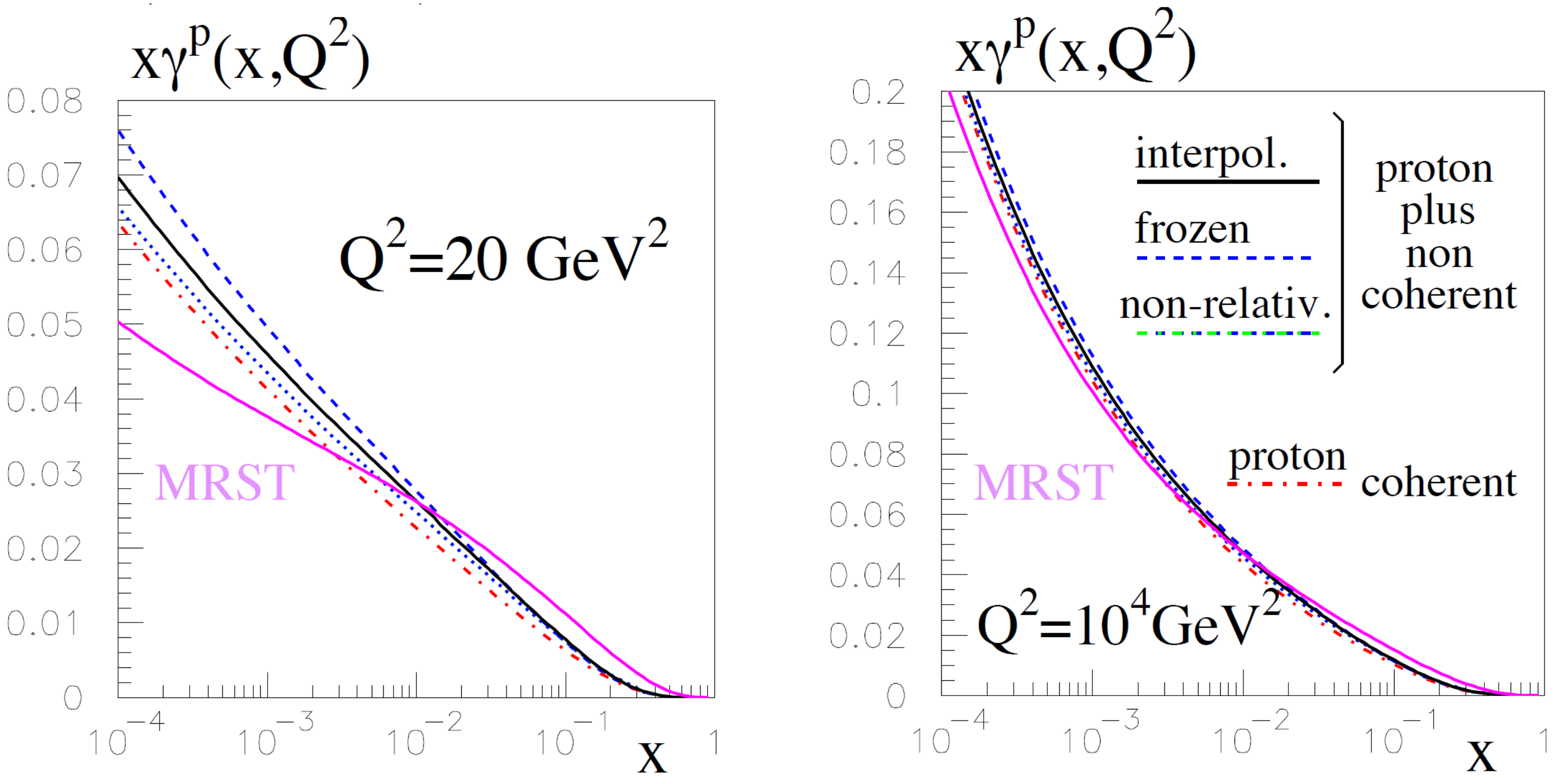
Article by Martin, Ryskin considers separate “coherent” emission and “non-coherent” emission.



$$\gamma^N(x, Q_0^2) = \gamma^N_{\text{coh}} + \gamma^N_{\text{incoh}}$$

Additional possible flexibility in input determination. “Coherent” dies away quickly above Q_0^2, but dominates in input distribution.

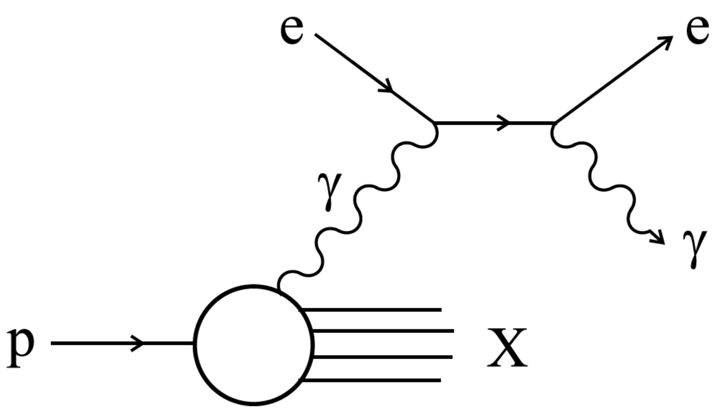
Tends to increase $\gamma(x, Q^2)$ at low x. (MRST2004 larger than NNPDF2.3 for $x < 0.01$).

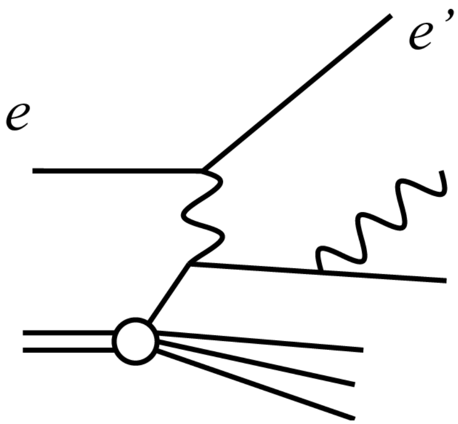


H1 and ZEUS have measurement of isolated photon DIS

$$ep \rightarrow e\gamma + X$$

Important constraint. MRST2004 photon was in good agreement with inclusive ZEUS data for current mass.



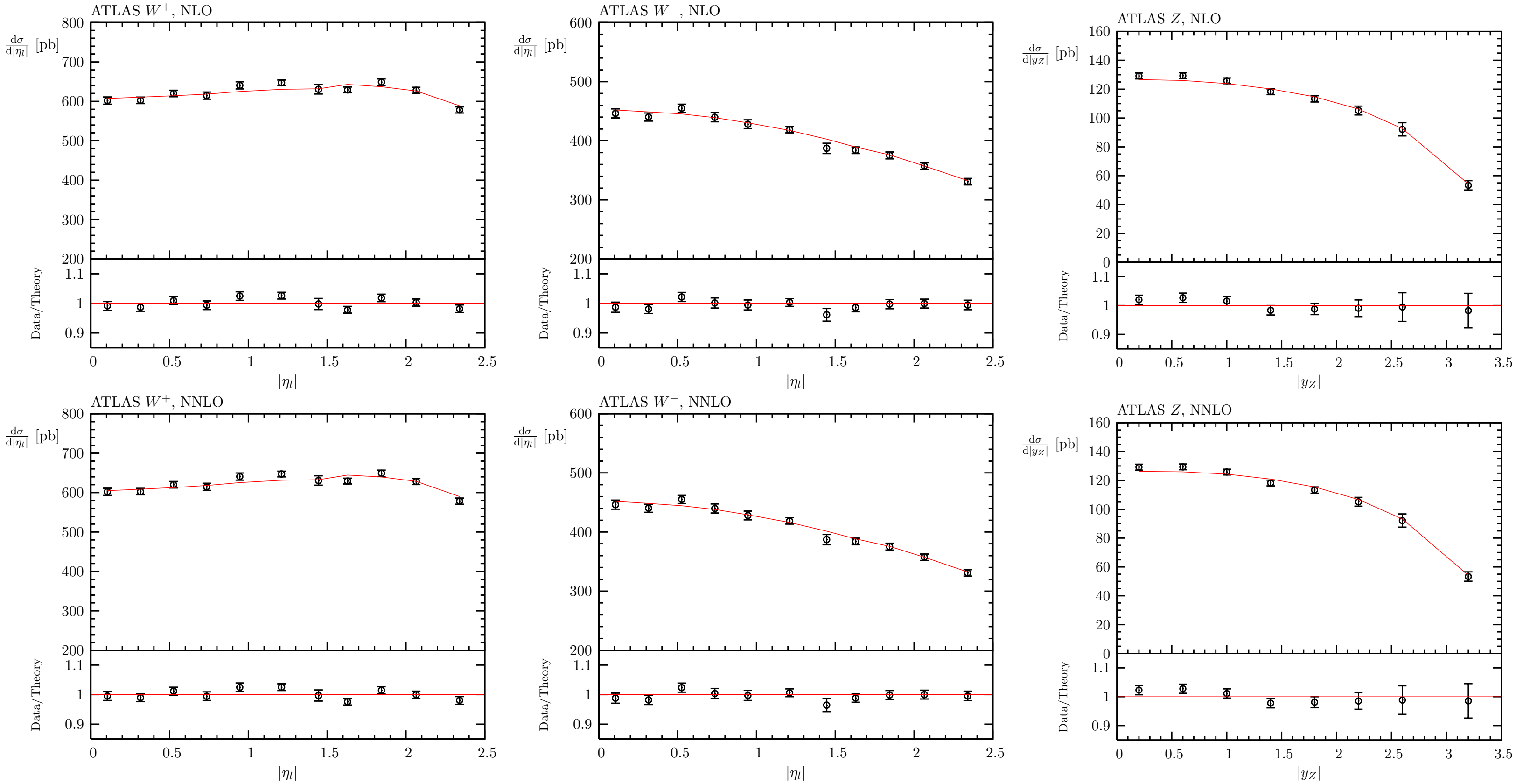


Necessary to consider radiation from quark line also, though at large negative η and high photon E_T the photon-initiated process dominates.

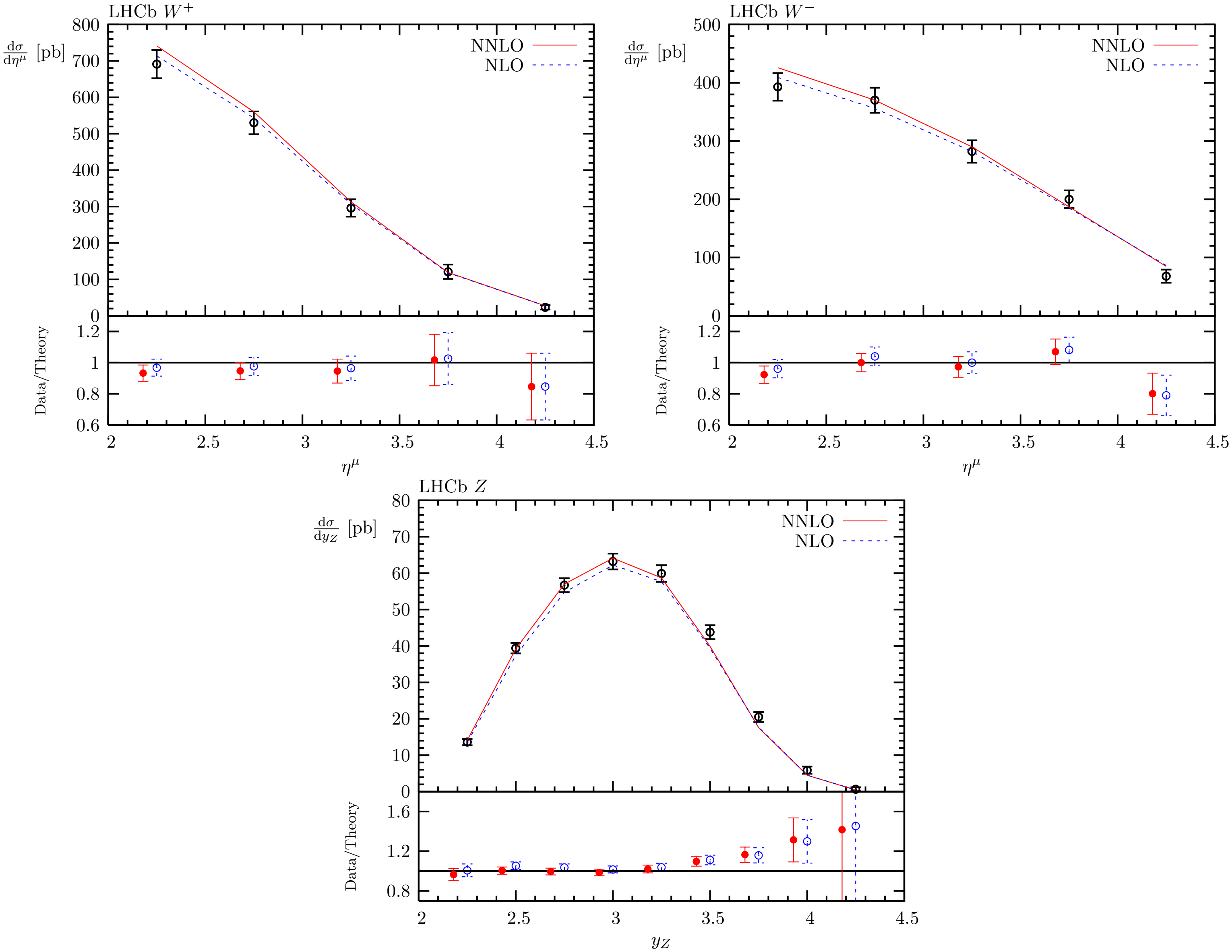
Detailed study a high priority.

data set	$N_{\rm pts}$	MMSTWW	MMHT14 (no LHC)	MMHT14 (LHC)
		NLO		
ATLAS W^+, W^-, Z	30	47	44	38
CMS W asym $p_T > 35$ GeV	11	9	16	7
CMS asym $p_T > 25, 30$ GeV	24	9	17	8
LHCb $Z \to e^+e^-$	9	13	13	13
LHCb W asym $p_T > 20$ GeV	10	12	14	12
CMS $Z \to e^+e^-$	35	21	22	19
ATLAS high-mass Drell-Yan	13	20	20	21
CMS double diff. Drell-Yan	132	385	396	372
		NNLO		
ATLAS W^+, W^-, Z	30	72	53	39
CMS W asym $p_T > 35$ GeV	11	18	15	8
CMS asym $p_T > 25, 30$ GeV	24	18	17	9
LHCb $Z \to e^+e^-$	9	23	22	21
LHCb W asym $p_T > 20$ GeV	10	24	21	18
CMS $Z \to e^+e^-$	35	30	24	22
ATLAS high-mass Drell-Yan	13	18	16	17
CMS double diff. Drell Yan	132	159	151	150

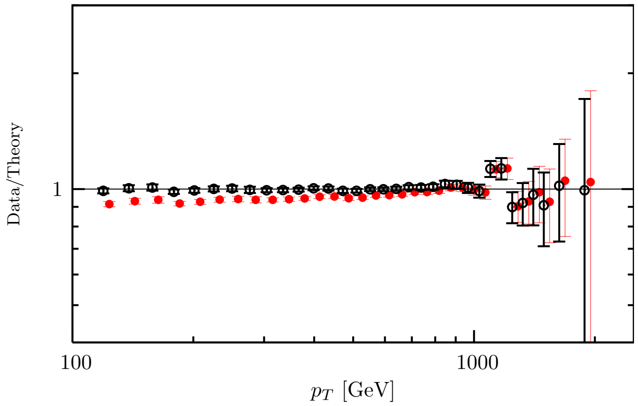
Fit quality at NLO and NNLO for ATLAS W, Z rapidity data

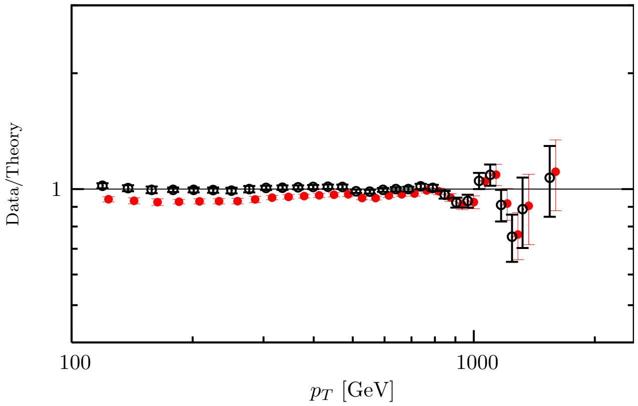


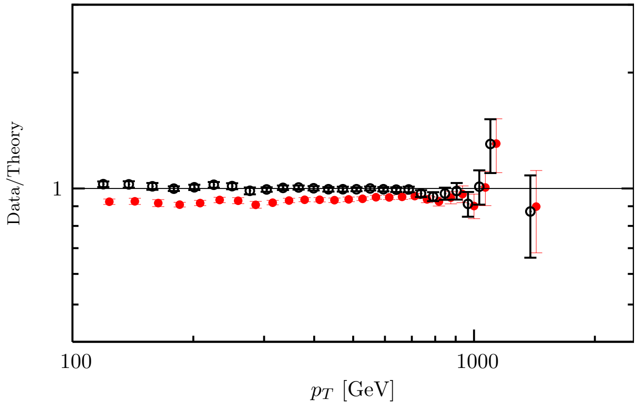
Fit quality at NLO and NNLO for LHCb W, Z rapidity data

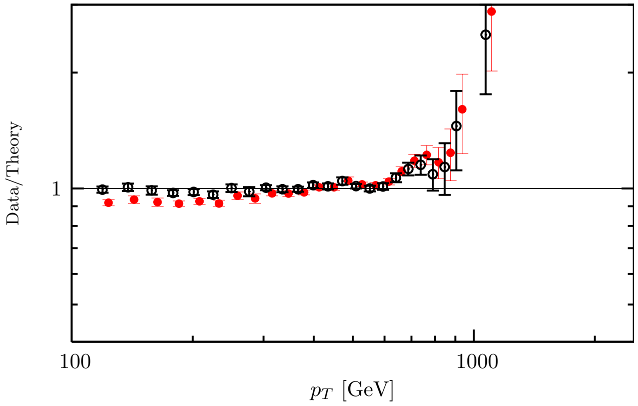


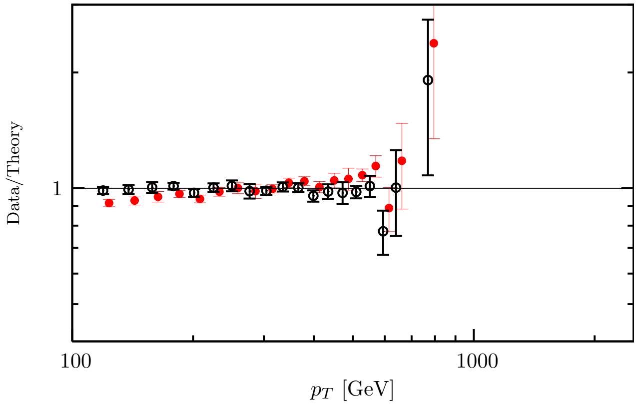
Fit to CMS inclusive jet data.


NLO, CMS jets (7 TeV), $0.0 < |y| < 0.5$

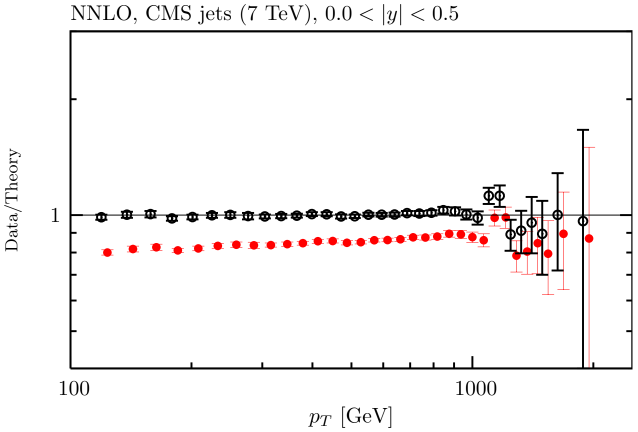

NLO, CMS jets (7 TeV), $0.5 < |y| < 1.0$

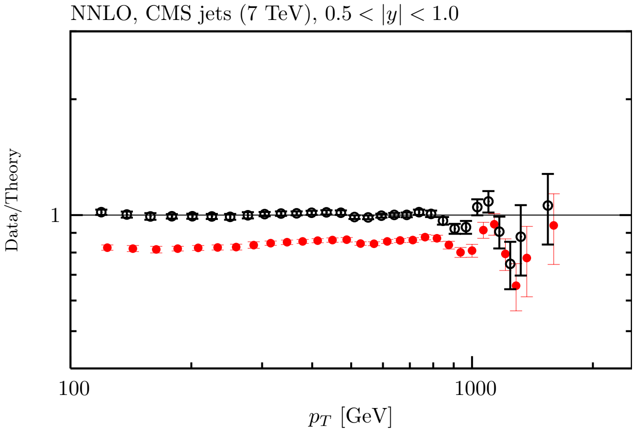

NLO, CMS jets (7 TeV), $1.0 < |y| < 1.5$

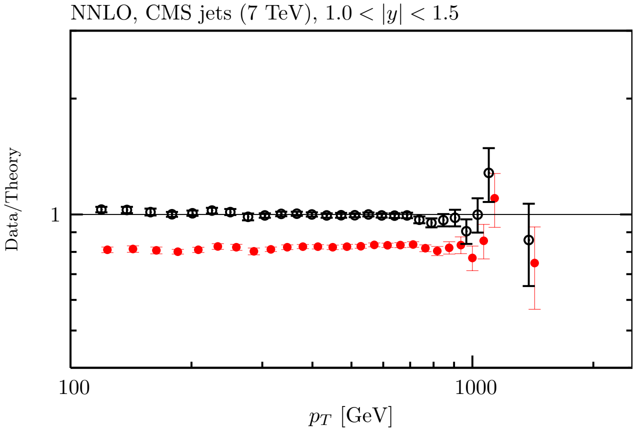

NLO, CMS jets (7 TeV), $1.5 < |y| < 2.0$

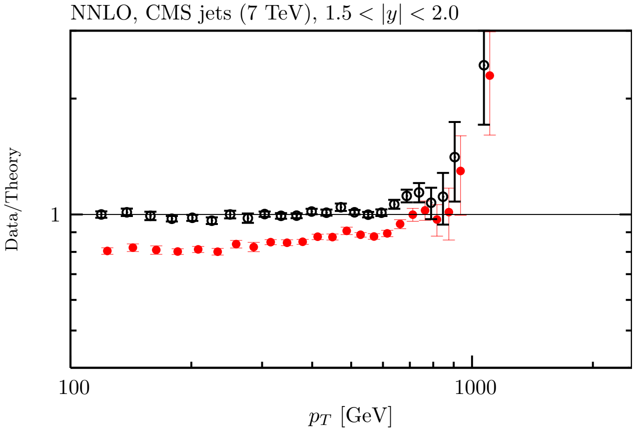

NLO, CMS jets (7 TeV), $1.5 < |y| < 2.0$

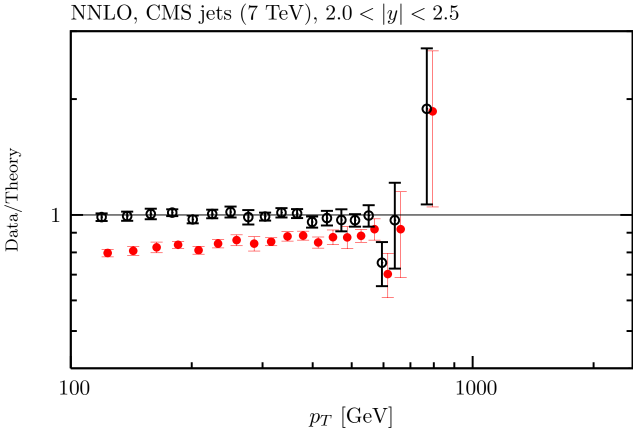
Fit to CMS inclusive jet data at NNLO with large K-factor.


NNLO, CMS jets (7 TeV), $0.0 < |y| < 0.5$


NNLO, CMS jets (7 TeV), $0.5 < |y| < 1.0$

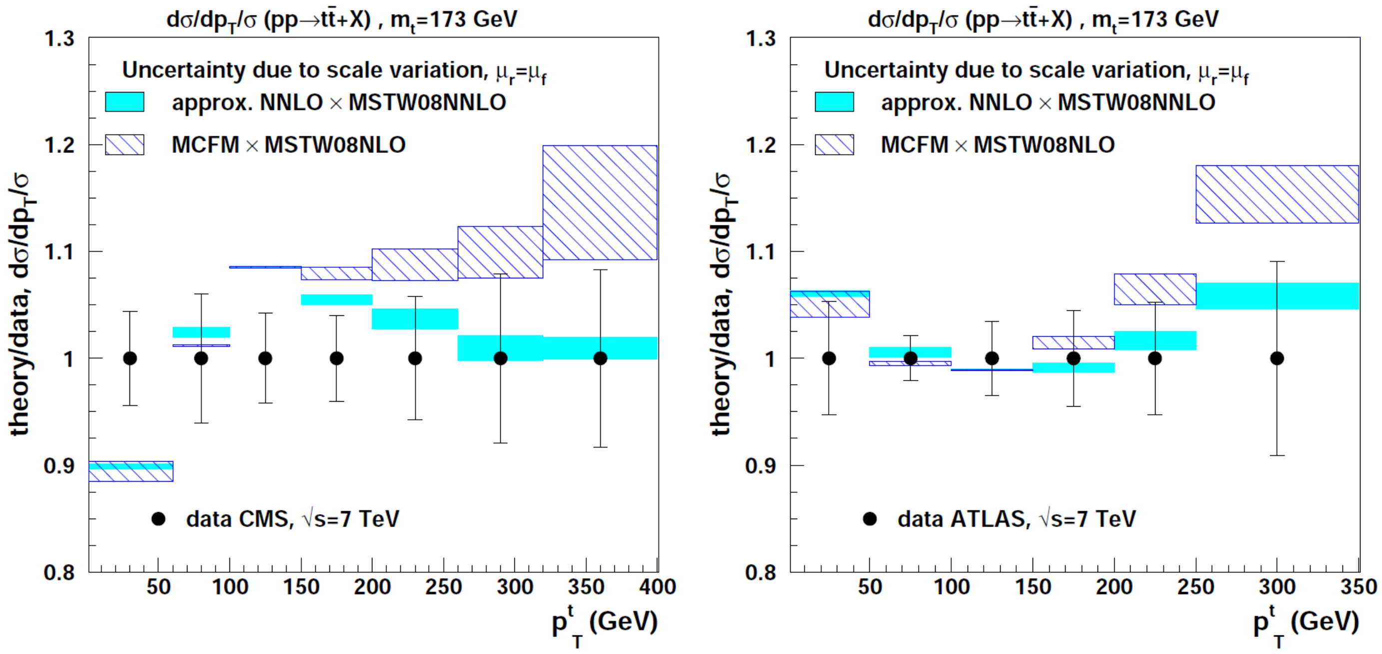

NNLO, CMS jets (7 TeV), $1.0 < |y| < 1.5$


NNLO, CMS jets (7 TeV), $1.5 < |y| < 2.0$


NNLO, CMS jets (7 TeV), $2.0 < |y| < 2.5$

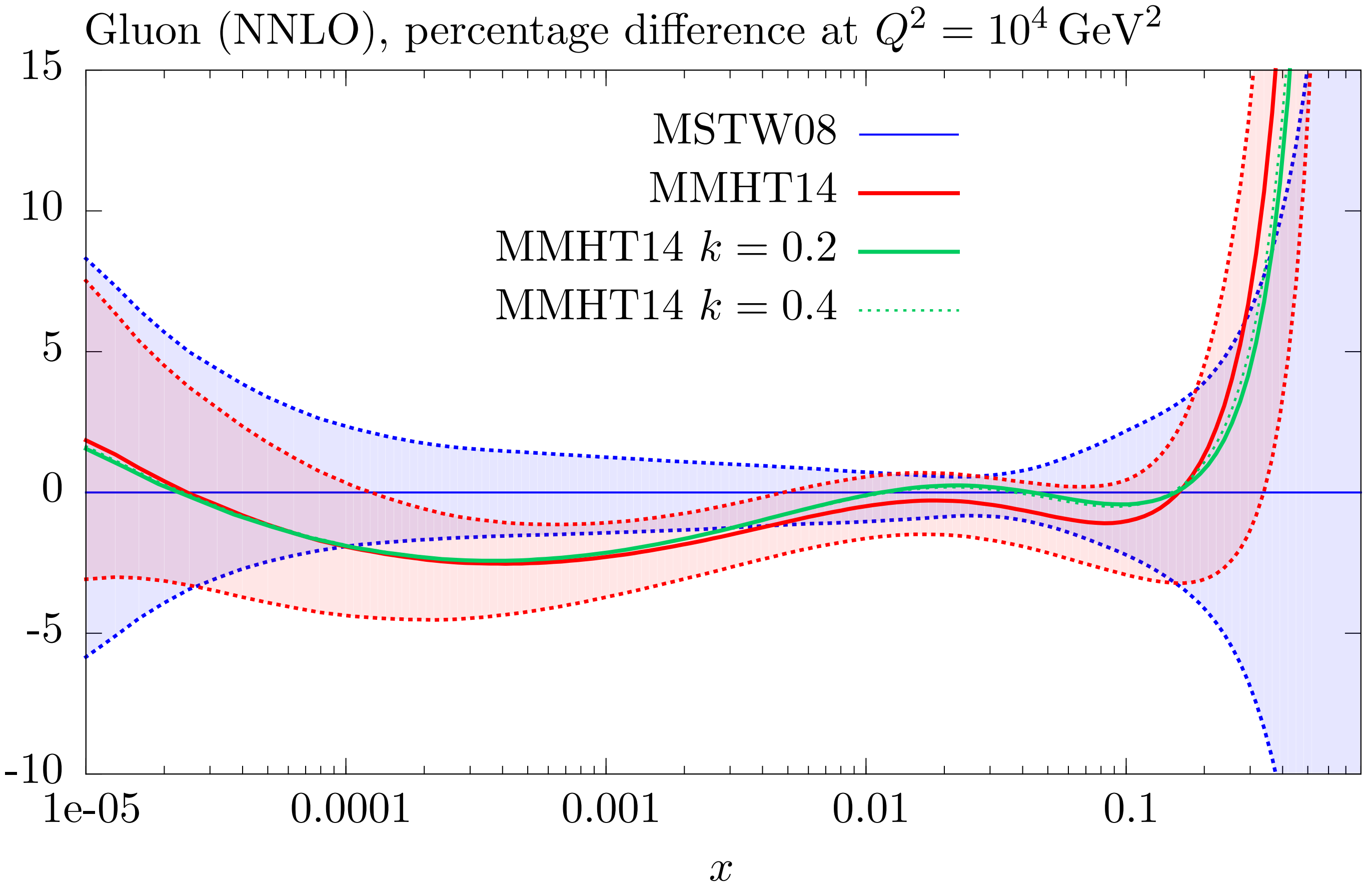
Differential Data

As it improves differential top production data will help constrain the gluon.



However, here potentially inclusion of NNLO is very important as available approximation using threshold resummation (Guzzi, Lipka, Moch) implies. Softer PDF currently preferred at NLO, contrary to requirement of inclusive cross-section, may be misleading.

Comparison of PDFs at NNLO when LHC jet data included



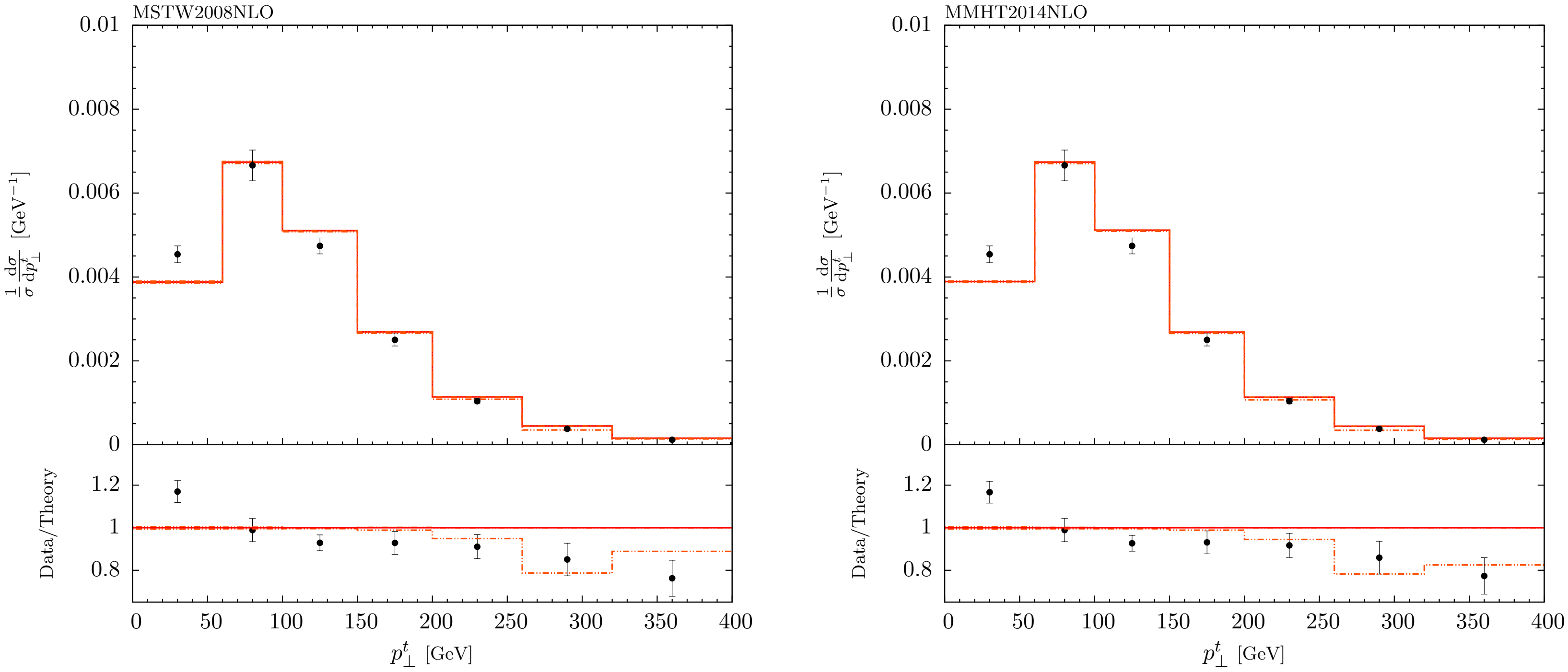
NNLO PDFs with LHC jet data included in fit with both K-factor choices compared to standard NNLO PDFs.

NNLO total cross sections

	MSTW08	MMHT14 no LHC	MMHT14
W Tevatron (1.96 TeV)	$2.746^{+0.049}_{-0.042}$	2.803	$2.782^{+0.056}_{-0.056}$
Z Tevatron (1.96 TeV)	$0.2507^{+0.0048}_{-0.0041}$	0.2574	$0.2559^{+0.0052}_{-0.0046}$
W^+ LHC (7 TeV)	$6.159^{+0.111}_{-0.099}$	6.214	$6.197^{+0.103}_{-0.092}$
W^- LHC (7 TeV)	$4.310^{+0.078}_{-0.069}$	4.355	$4.306^{+0.067}_{-0.076}$
Z LHC (7 TeV)	$0.9586^{+0.020}_{-0.014}$	0.9695	$0.9638^{+0.014}_{-0.013}$
W^+ LHC (14 TeV)	$12.39^{+0.22}_{-0.21}$	12.49	$12.48^{+0.22}_{-0.18}$
W^- LHC (14 TeV)	$9.33^{+0.16}_{-0.16}$	9.39	$9.32^{+0.15}_{-0.14}$
Z LHC (14 TeV)	$2.051^{+0.035}_{-0.033}$	2.069	$2.065^{+0.035}_{-0.030}$
Higgs Tevatron	$0.853^{+0.028}_{-0.029}$	0.877	$0.874^{+0.024}_{-0.030}$
Higgs LHC (7 TeV)	$14.40^{+0.17}_{-0.23}$	14.54	$14.56^{+0.21}_{-0.29}$
Higgs LHC (14 TeV)	$47.50^{+0.47}_{-0.74}$	47.61	$47.69^{+0.63}_{-0.88}$
$t\bar{t}$ Tevatron	$7.19^{+0.17}_{-0.12}$	7.54	$7.51^{+0.21}_{-0.20}$
$t\bar{t}$ LHC (7 TeV)	$171.1^{+4.7}_{-4.8}$	176.5	$175.9^{+3.9}_{-5.5}$
$t\bar{t}$ LHC (14 TeV)	953.3^{+16}_{-18}	969.0	969.9^{+16}_{-20}

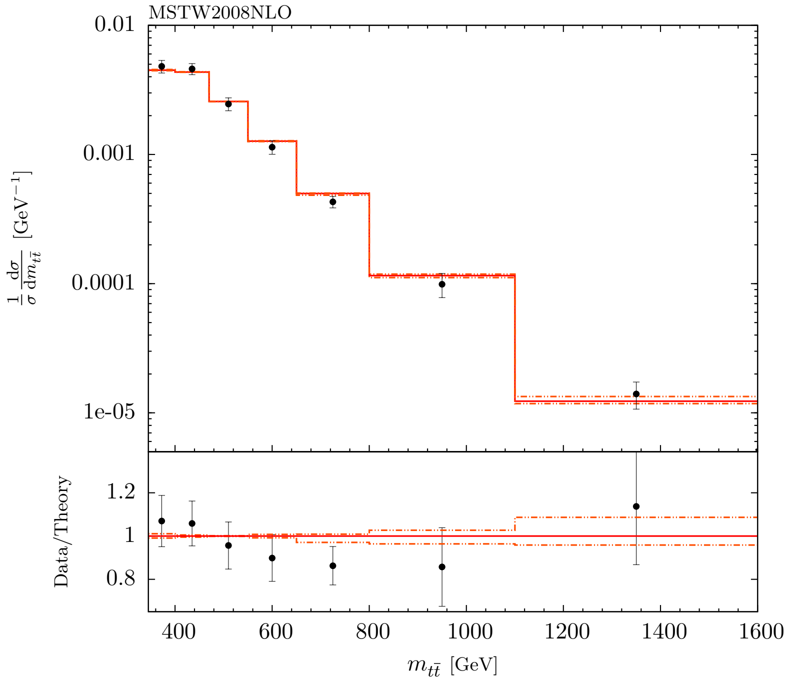
Few changes greater than one sigma (PDF uncertainty only).

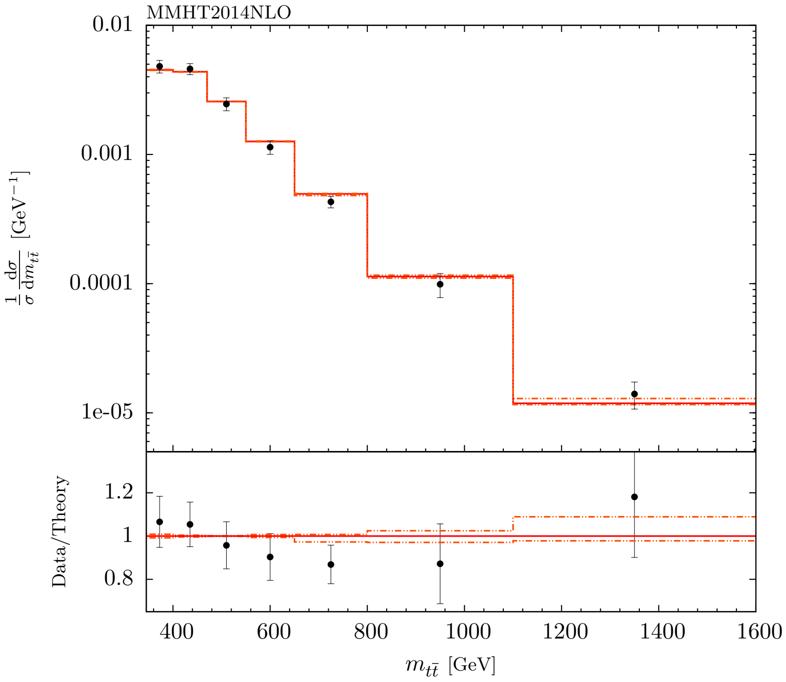
p_T distributions - CMS data



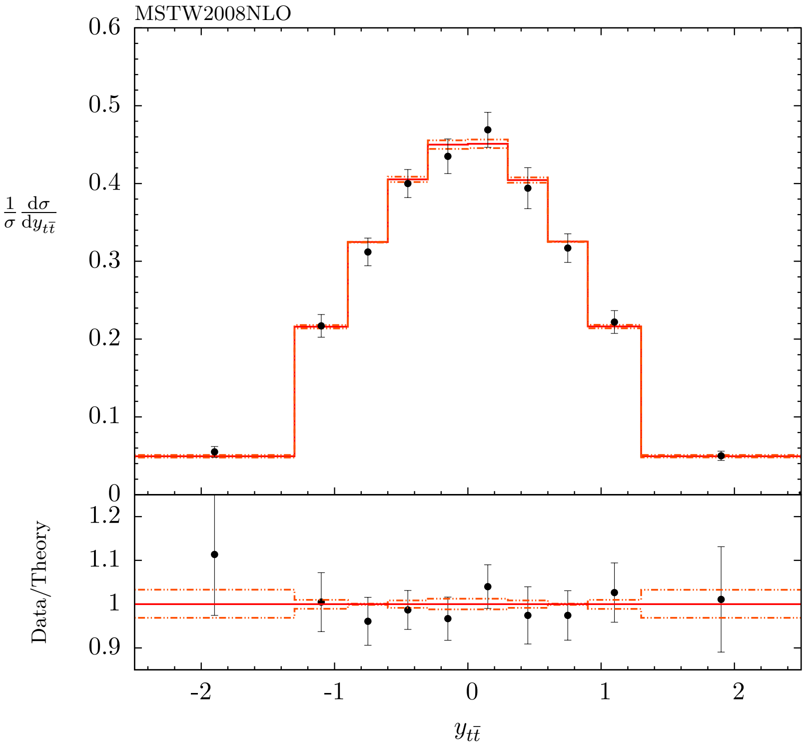
Very little difference between MSTW2008 and MMHT2014 predictions.

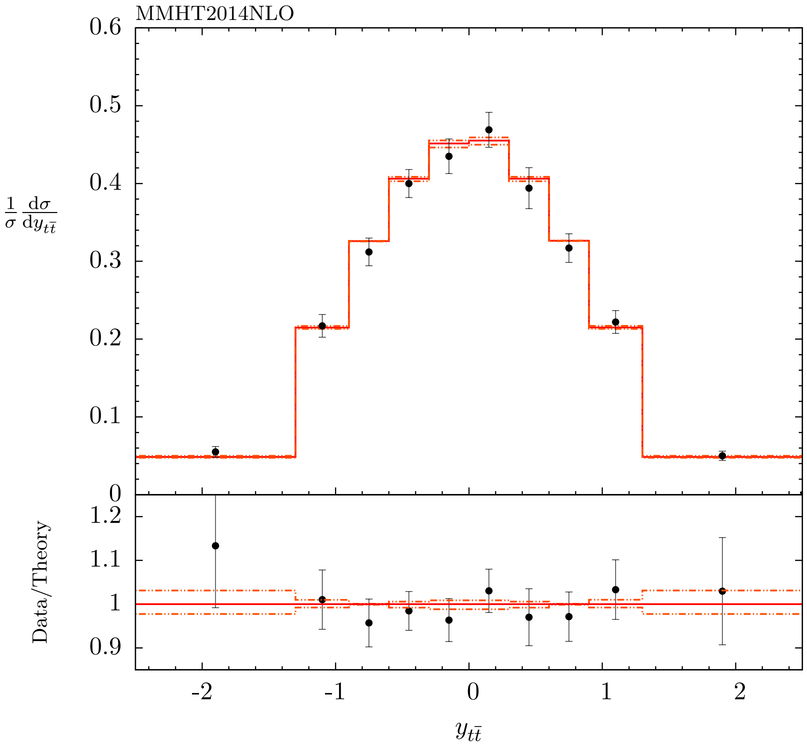
$m_{t\bar{t}}$ **distributions - CMS data**

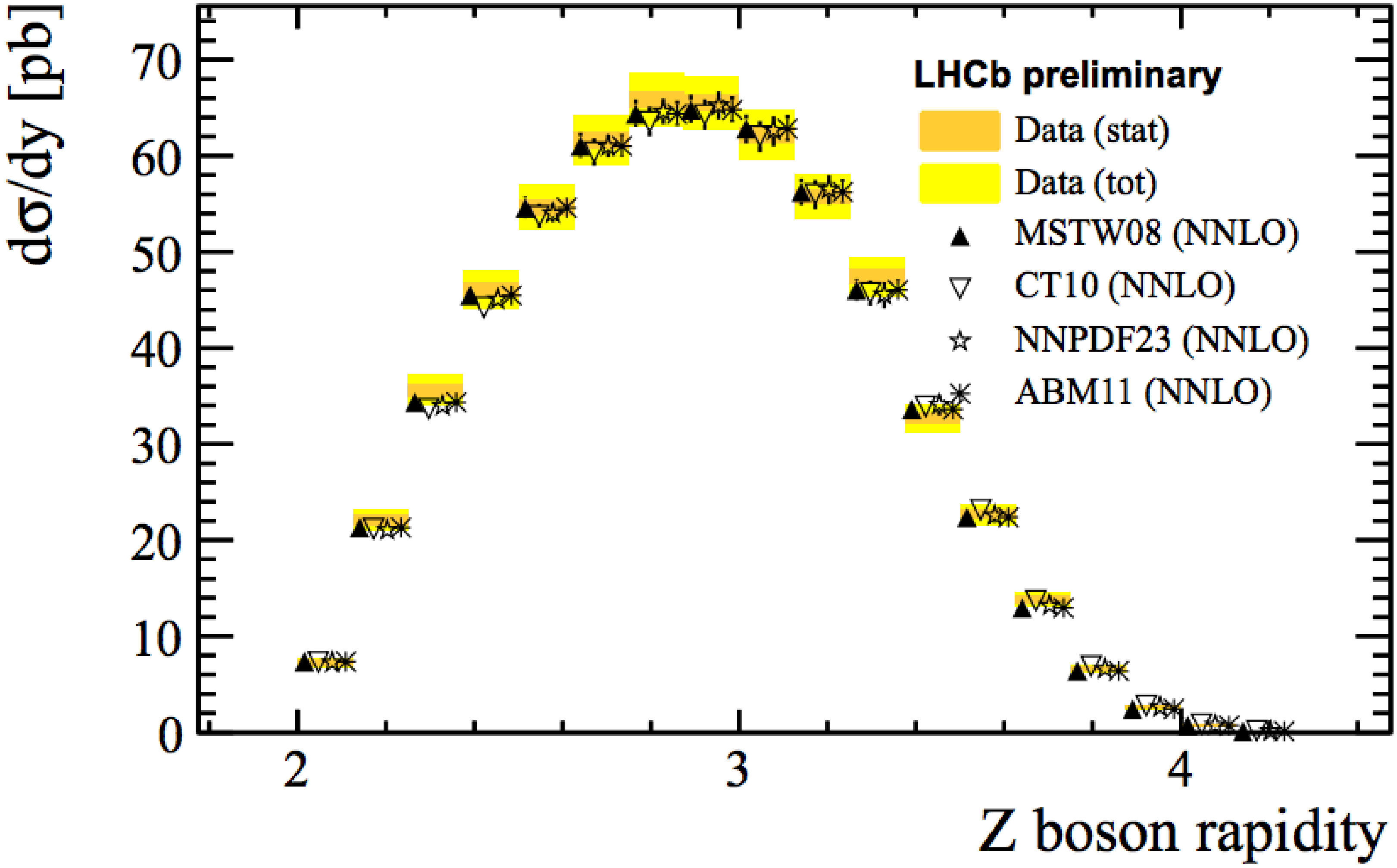




$y_{t\bar{t}}$ distributions - **CMS** data







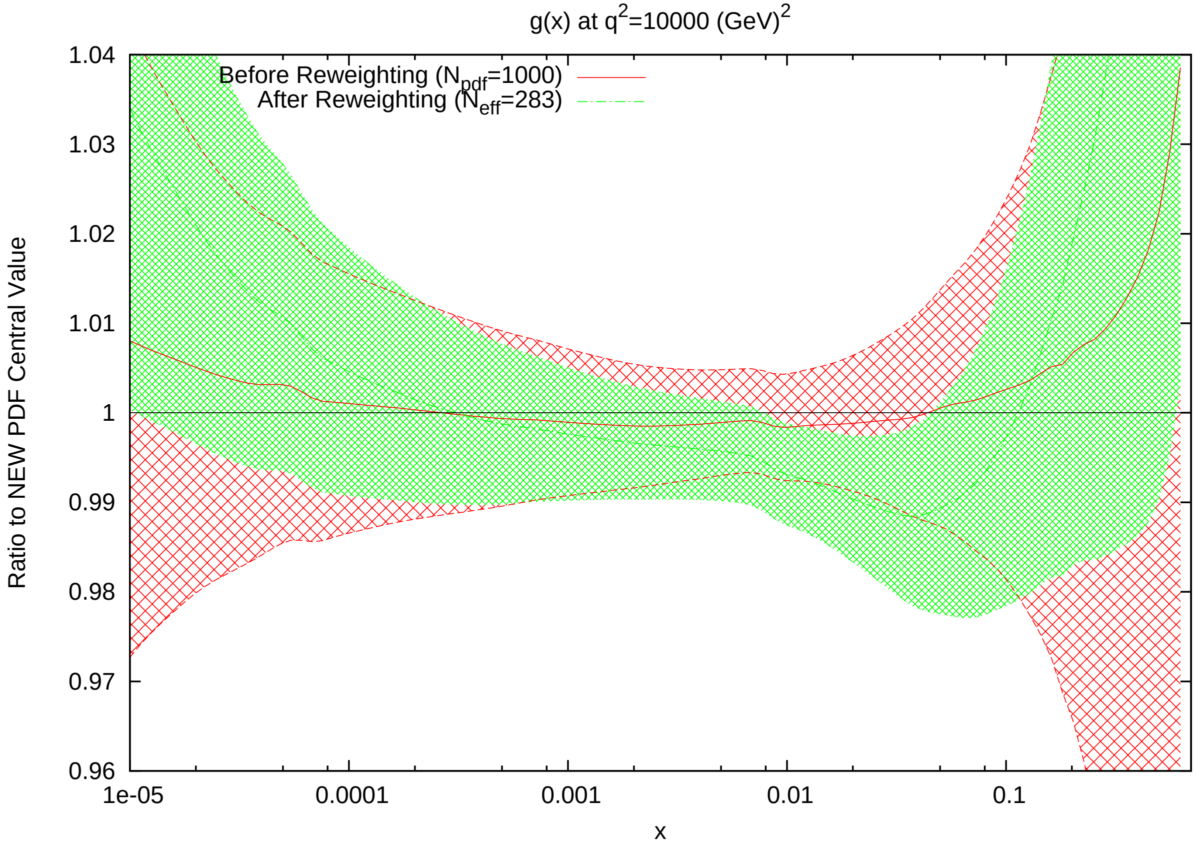
Higher luminosity LHCb $Z \rightarrow \mu^+\mu^-$ data.

Dependence on m_c at NLO in fits at fixed $\alpha_s(M_Z^2) = 0.118$.

m_c (GeV)	χ^2_{global} 2996 pts	$\chi^2_{F_2^c}$ 52 pts	$\alpha_s(M_Z^2)$
1.15	3246	75	0.118
1.2	3245	72	0.118
1.25	3249	70	0.118
1.3	3257	69	0.118
1.35	3269	69	0.118
1.4	3285	69	0.118
1.45	3304	72	0.118
1.5	3326	75	0.118
1.55	3353	80	0.118

Again preference for $m_c \sim 1.20\mathrm{GeV}$, or marginally lower.

Dijets



Using reweighting exercise for CMS dijets results in a rather modified shape of gluon.

Not as high rapidity as other sets – dependence on renormalisation/factorisation scales not so severe.

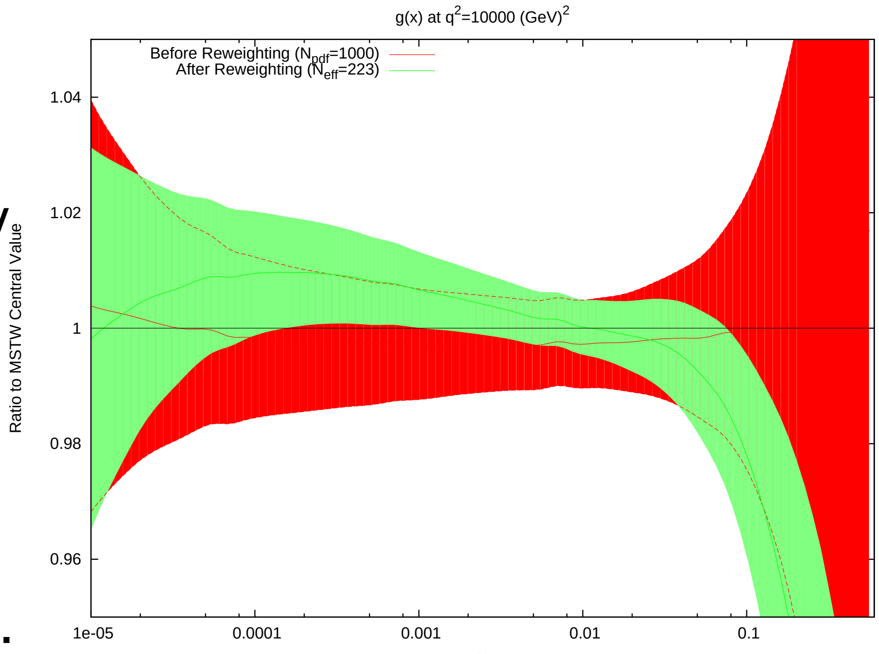
Reflection of different shape of higher order corrections?

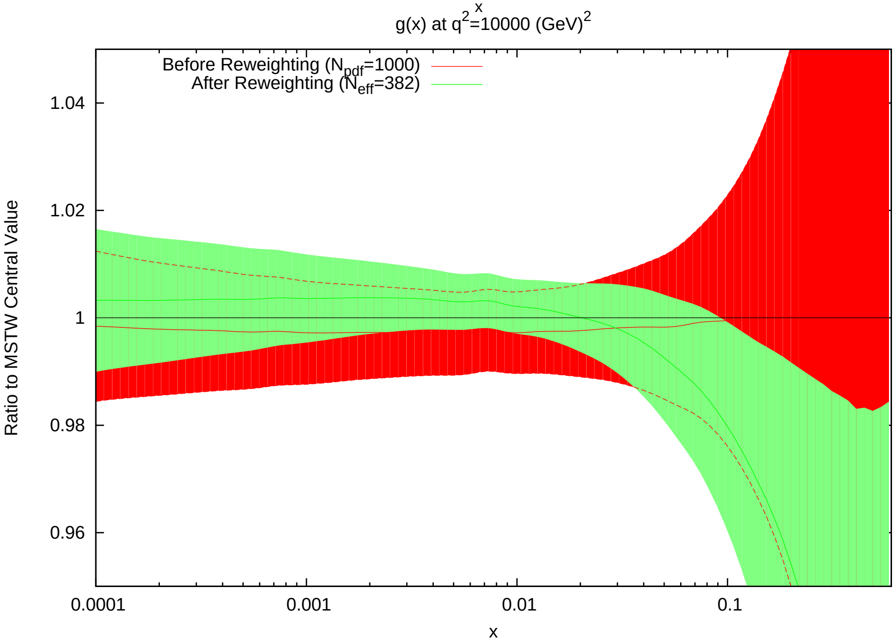
Different conclusions for fits to D0 and ATLAS dijet data, though they are not not necessarily incompatible.

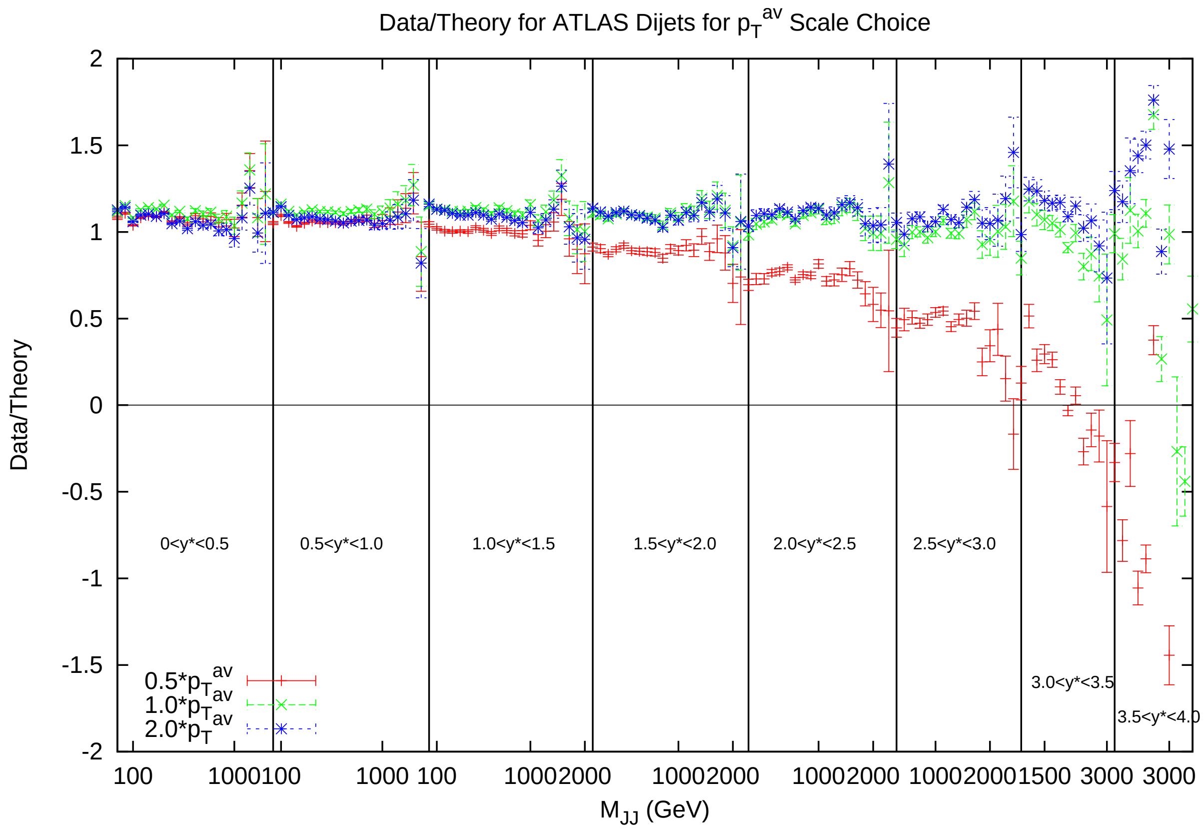
Similar to changes required by LHC inclusive jet data.

Different range of rapidity spanned. Need to use scale other than p_T to get good fits. $\mu = 2p_T$ best for ATLAS and $\mu = M_{JJ}$ best for D0.

For ATLAS rapidity dependent scale choices give results more like that for CMS, but with a worse fit and lower value of N_{eff}.







At high rapidity calculations unstable for scales equal to relativity low multiples of p_T.