PDFs and Top Physics

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September 17th, 2015

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Updates in PDFs relevant to Top Physics.

I will present the results from this recent PDF4LHC study, and the resulting new recommendation for combining PDFs sets for LHC calculations.

In order to put this into context I will summarise continuing updates in PDFs. This includes improvements and recent updates of particular PDF sets due to theory improvements and a variety of new data sets, including most of the up-to-date LHC data.

I will emphasise particular issues relevant for top physics.

Recent PDF Updates - effect and treatment of LHC data

ABM12 PDFs S. Alekhin

The ABM fit ingredients

DATA:
- DIS NC inclusive
- DIS charm production
- DIS μμ CC production (NOMAD data)
- DIS charmed-hadron CC production (CHORUS data)
- fixed-target DY
- LHC DY distributions (CMS 4.7 1/fb)
- W+charm production (CMS and ATLAS data)

QCD:
- NNLO evolution
- NNLO massless DIS and DY coefficient functions
- NLO+ massive DIS coefficient functions (**FFN scheme**)
  - – NLO + NNLO threshold corrections for NC
  - – NNLO CC at Q>> m_c
  - – running mass
- NNLO exclusive DY (DYNNLO 1.3 / FEWZ 3.1)
- NNLO inclusive ttbar production (pole / running mass)

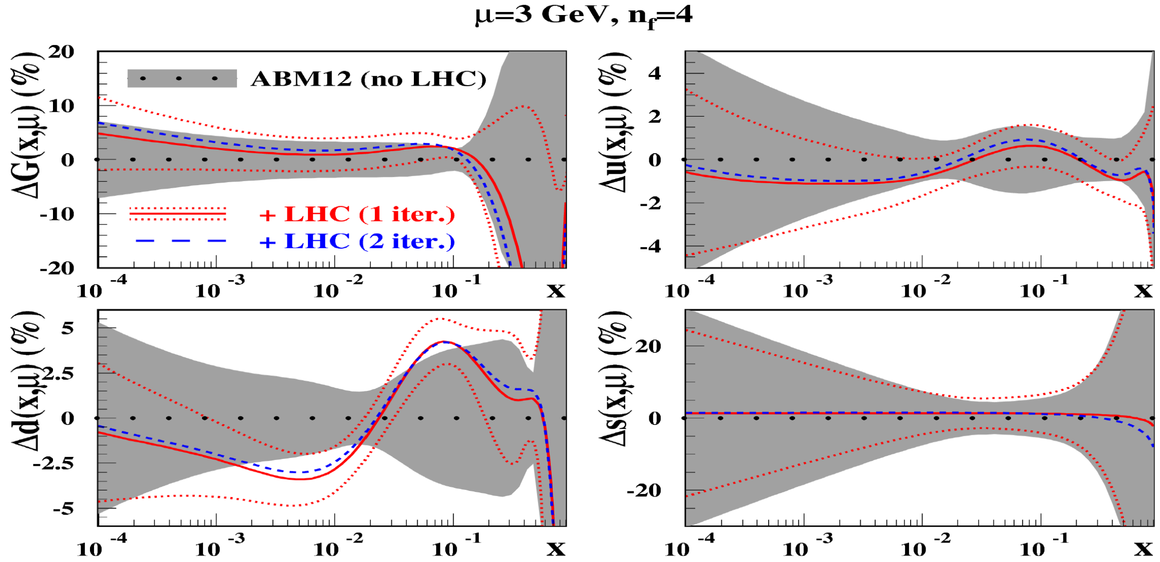
Deuteron corrections in DIS:
- Fermi motion
- off-shell effects

Power corrections in DIS:
- target mass effects
- dynamical twist-4 terms

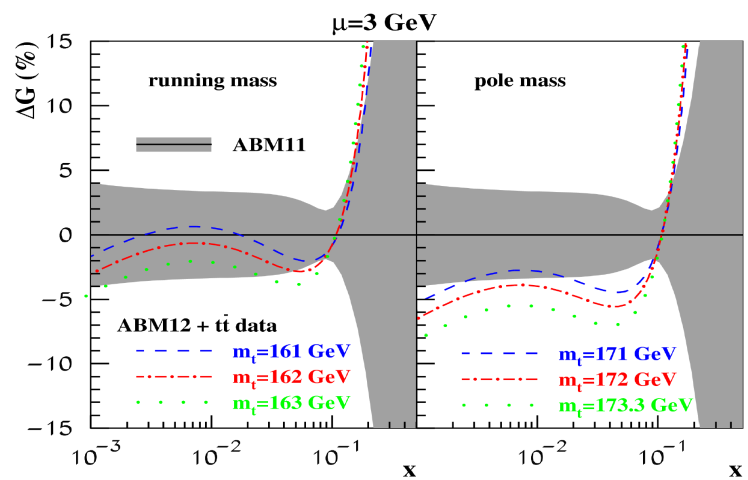
The jet data are still not included: The NNLO corrections may be as big as 15-20%

Gehrmann-De Ridder, Gehrmann, Glover, Pires JHEP 1302, 026 (2013) 2

Impact of the LHC DY data on the PDFs

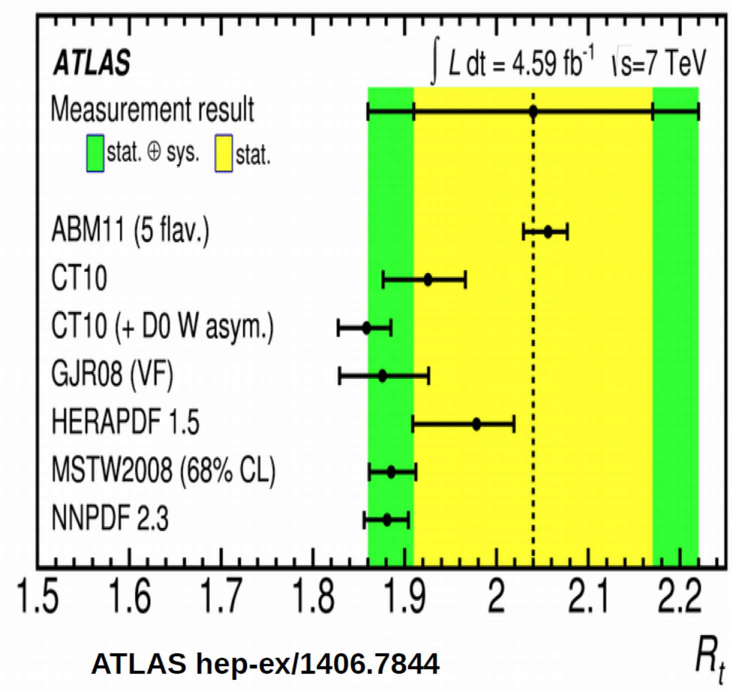


Variation with m_t - $\sigma_{t\bar{t}}$ a constraint on gluon.

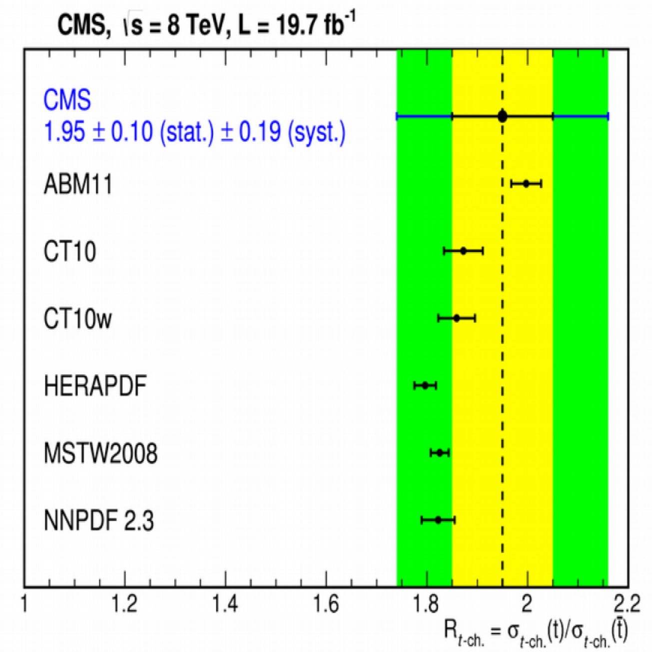


$\alpha_s(M_z)$ 0.1133 – 0.1142 0.1144 – 0.1154

t-channel single-top production



ATLAS hep-ex/1406.7844



CMS hep-ex/1403.7366

- The ratio of t/tbar rates is driven by u/d → suppressed for the "truly global PDFs"

More on this later.

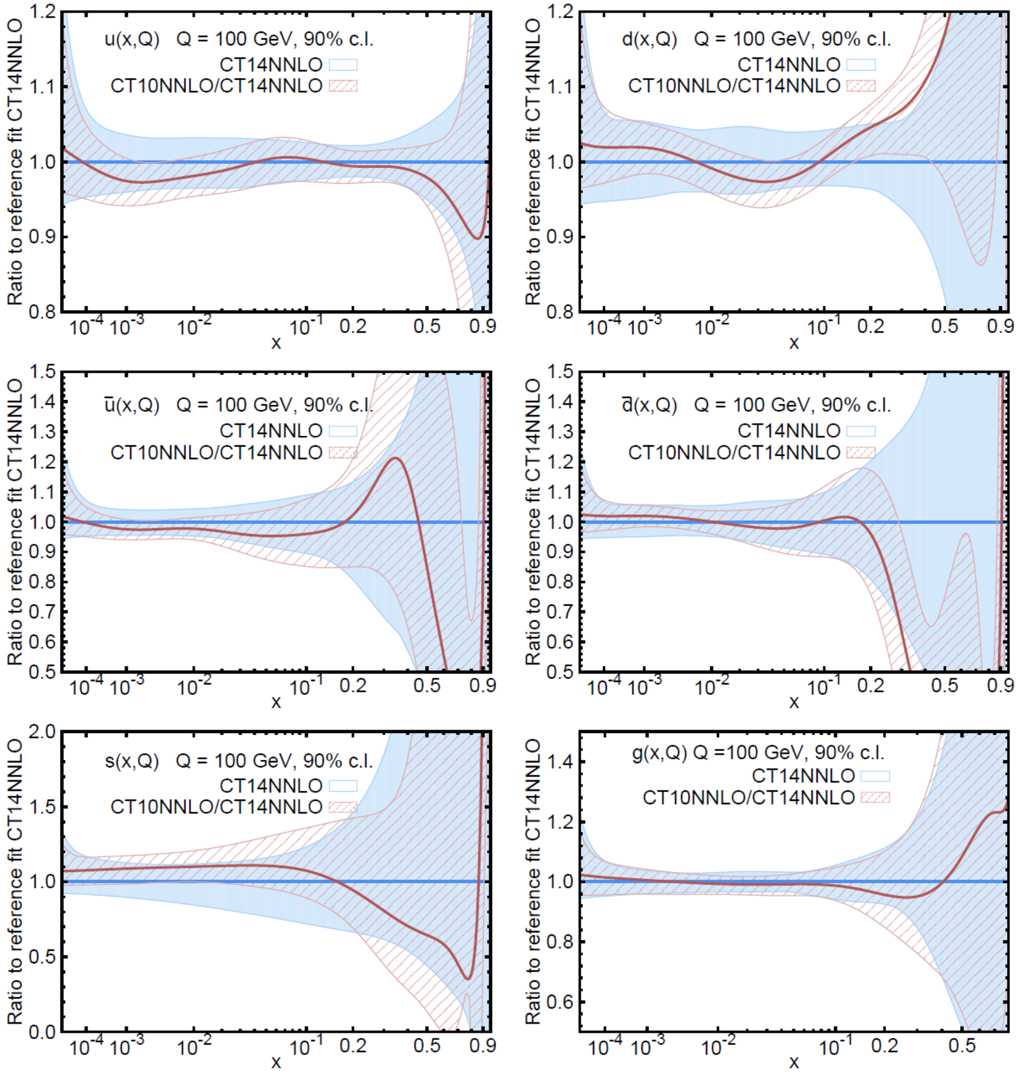
CT14 PDF sets

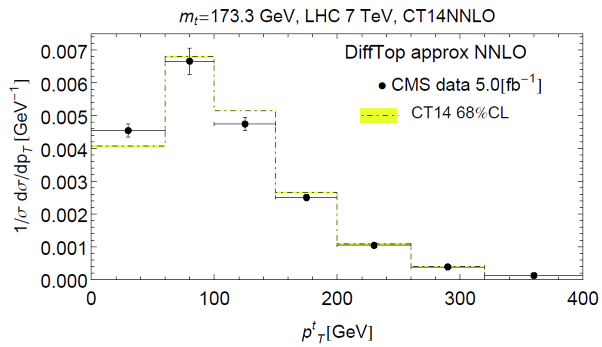
ID#	Experimental data set		N_{pt}	χ_e^2	χ_e^2/N_{pt}	S_n
101	BCDMS F_2^p	[23]	337	384	1.14	1.74
102	BCDMS F_2^d	[24]	250	294	1.18	1.89
104	NMC F_2^d/F_2^p	[25]	123	133	1.08	0.68
106	NMC σ_{red}^p	[25]	201	372	1.85	6.89
108	CDHSW F_2^p	[26]	85	72	0.85	-0.99
109	CDHSW F_3^p	[26]	96	80	0.83	-1.18
110	CCFR F_2^p	[27]	69	70	1.02	0.15
111	CCFR xF_3^p	[28]	86	31	0.36	-5.73
124	NuTeV $\nu\mu\mu$ SIDIS	[29]	38	24	0.62	-1.83
125	NuTeV $\bar{\nu}\mu\mu$ SIDIS	[29]	33	39	1.18	0.78
126	CCFR $\nu\mu\mu$ SIDIS	[30]	40	29	0.72	-1.32
127	CCFR $\bar{\nu}\mu\mu$ SIDIS	[30]	38	20	0.53	-2.46
145	H1 σ_r^b	[31]	10	6.8	0.68	-0.67
147	Combined HERA charm production	[32]	47	59	1.26	1.22
159	HERA1 Combined NC and CC DIS	[33]	579	591	1.02	0.37
169	H1 F_L	[34]	9	17	1.92	1.7

ID#	Experimental data set		N_{pt}	χ_e^2	χ_e^2/N_{pt}	S_n
201	E605 Drell-Yan process	[36]	119	116	0.98	-0.15
203	E866 Drell-Yan process, $\sigma_{pd}/(2\sigma_{pp})$	[37]	15	13	0.87	-0.25
204	E866 Drell-Yan process, $Q^3 d^2\sigma_{pp}/(dQdx_F)$	[38]	184	252	1.37	3.19
225	CDF Run-1 electron A_{ch}, $p_{T\ell} > 25$ GeV	[39]	11	8.9	0.81	-0.32
227	CDF Run-2 electron A_{ch}, $p_{T\ell} > 25$ GeV	[40]	11	14	1.24	0.67
234	DØ Run-2 muon A_{ch}, $p_{T\ell} > 20$ GeV	[41]	9	8.3	0.92	-0.02
240	LHCb 7 TeV 35 pb^{-1} W/Z $d\sigma/dy_\ell$	[42]	14	9.9	0.71	-0.73
241	LHCb 7 TeV 35 pb^{-1} A_{ch}, $p_{T\ell} > 20$ GeV	[42]	5	5.3	1.06	0.30
260	DØ Run-2 Z rapidity	[43]	28	17	0.59	-1.71
261	CDF Run-2 Z rapidity	[44]	29	48	1.64	2.13
266	CMS 7 TeV 4.7 fb^{-1}, muon A_{ch}, $p_{T\ell} > 35$ GeV	[45]	11	12.1	1.10	0.37
267	CMS 7 TeV 840 pb^{-1}, electron A_{ch}, $p_{T\ell} > 35$ GeV	[46]	11	10.1	0.92	-0.06
268	ATLAS 7 TeV 35 pb^{-1} W/Z cross sec., A_{ch}	[47]	41	51	1.25	1.11
281	DØ Run-2 9.7 fb^{-1} electron A_{ch}, $p_{T\ell} > 25$ GeV	[14]	13	35	2.67	3.11
504	CDF Run-2 inclusive jet production	[48]	72	105	1.45	2.45
514	DØ Run-2 inclusive jet production	[49]	110	120	1.09	0.67
535	ATLAS 7 TeV 35 pb^{-1} incl. jet production	[50]	90	50	0.55	-3.59
538	CMS 7 TeV 5 fb^{-1} incl. jet production	[51]	133	177	1.33	2.51

Changes due to new data sets and new parameterisation (Bernstein polynomials - peak at specific x).

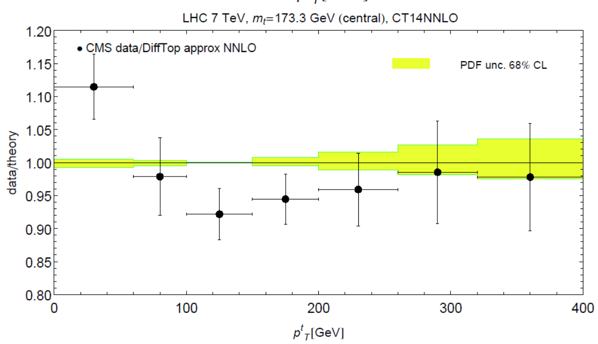
Some significant changes (strange smaller due to correction in charged current cross-section code).

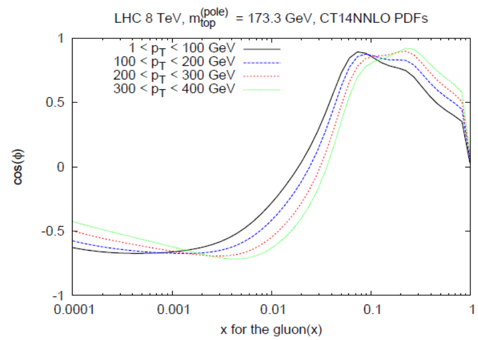


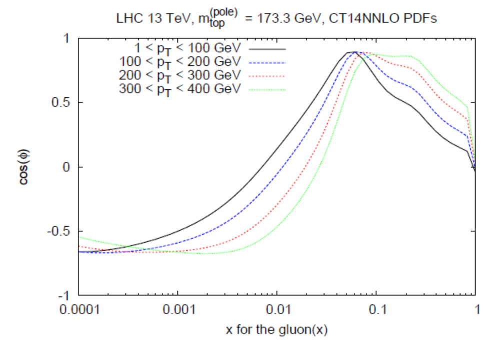


$pp \to t\bar{t}$ (pb), PDF unc., $\alpha_s = 0.118$	7 TeV	8 TeV	13 TeV
68% C.L. (Hessian)	$177 + 4.8\% - 3.9\%$	$250 + 3.9\% - 3.5\%$	$820 + 2.6\% - 2.7\%$
68% C.L. (LM)		$+4.8\% - 4.6\%$	$+2.9\% - 2.9\%$
$pp \to t\bar{t}$ (pb), PDF+α_s	7 TeV	8 TeV	13 TeV
68% C.L. (Hessian)	$+5.5\% - 4.6\%$	$+5.2\% - 4.4\%$	$+3.6\% - 3.5\%$
68% C.L. (LM)		$+5.1\% - 4.7\%$	$+3.6\% - 3.5\%$

3LE V: CT14 NNLO total inclusive cross sections for top-quark pair production at LHC center-of-mass energies of 7, 8, 13 TeV



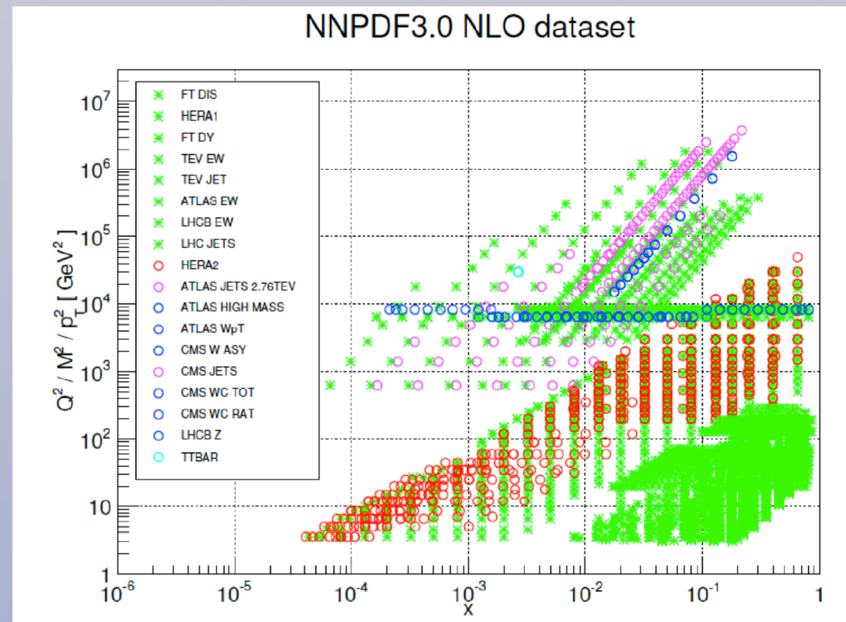




Do not fit top data but make comparisons.

NNPDF3.0 PDFs

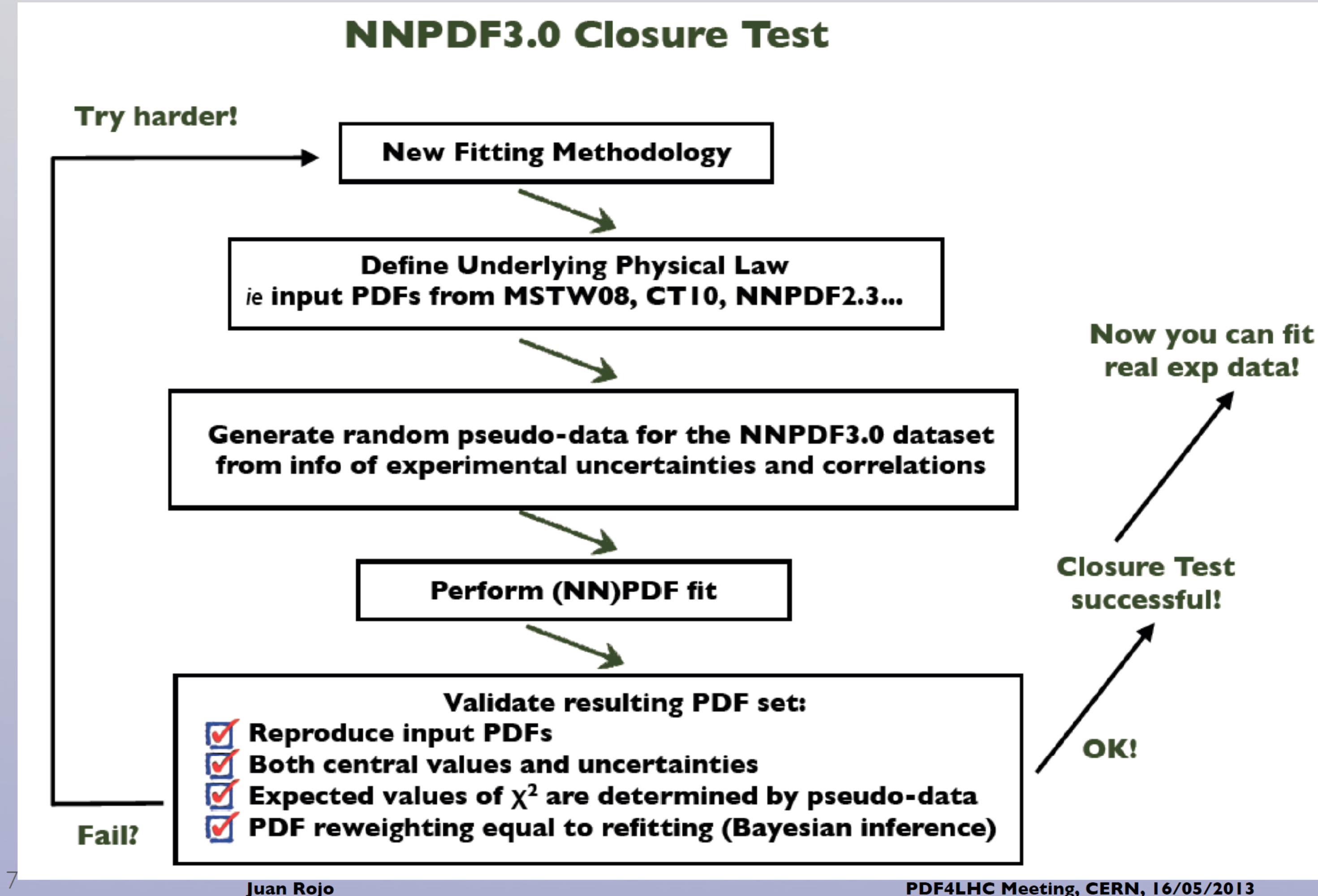
- ☑ **HERA structure function data: HERA-II structure functions from H1 and ZEUS**, combined HERA F_{2c} cross-sections
- ☑ **LHC jet data:** CMS **7 TeV inclusive jets** from 2011, ATLAS **2.76 TeV jets** including their correlation with the 7 TeV jet data
- ☑ **LHC electroweak data:** CMS **muon asymmetries** from 2011, LHCb **Z rapidity distributions** from 2011, CMS **W+charm** production data, ATLAS and CMS **Drell-Yan production**, ATLAS **W p_T** distributions
- ☑ **ATLAS and CMS top quark pair production data**



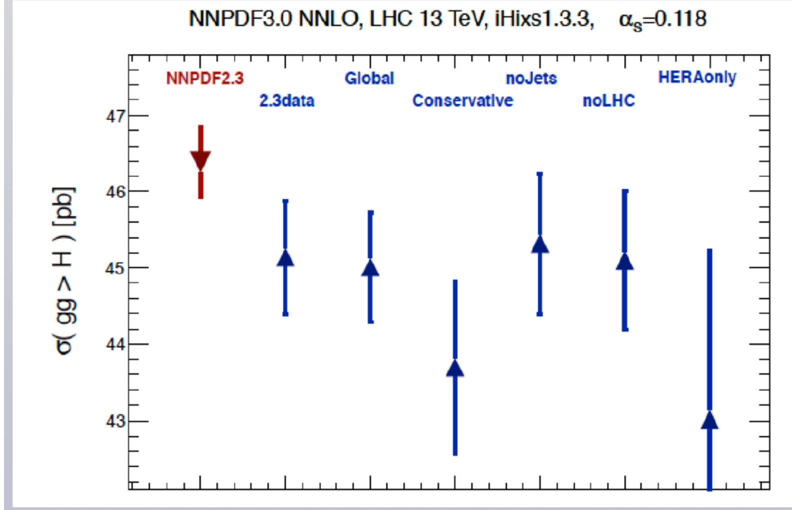
3 **Juan Rojo** **PDF4LHC Meeting, 03/11/2014**

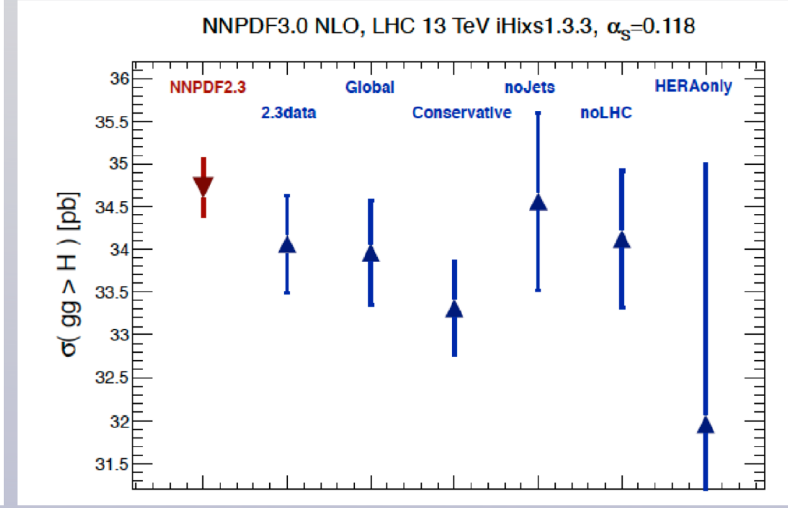
Closure Testing

Validation and optimization of fitting strategy performed on **closure test with known** underlying PDF set



Higgs production in gluon fusion





- The softer **gg luminosity** in NNPDF3.0 leads to a **decrease in the ggH xsec** at the LHC 13 TeV
- The effect is more marked at NLO and NNLO, though even in the latter the pull is only **P ~1.5**
- The ggH process is different from many other LHC xsecs because there are **no direct experimental constraints on the gluon at x ~ 0.01**, and thus predictions for **ggH** are more sensitive to modifications in the methodology or in the choice of dataset (that indirectly affects g(x) for **x ~ 0.01**)
- In NNPDF3.0, the changes in the **ggH xsec arise mostly from** the **improved fitting methodology**, validated on the closure tests

MMHT2014 – Changes in theoretical treatment or procedures.

Continue to use extended parameterisation with Chebyshev polynomials, and freedom in deuteron nuclear corrections – change in $u_V - d_V$ distribution.

Now use "optimal" GM-VFNS choice which is smoother near to heavy flavour transition points (more so at NLO

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 $\sigma_{k,i}^{corr} = \beta_{k,i}^{corr} D_i$.

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.

Update in nuclear corrections (de Florian *et al*).

Changes in data sets.

Replacement of HERA run I neutral and charged current data from HERA and ZEUS with combined data set.

Inclusion of HERA combined data on $F_2^c(x,Q^2)$ and HERA $F_L(x,Q^2)$ measurements.

Inclusion of CDF W-asymmetry data, D0 electron asymmetry and D0 muon asymmetry data.

LHC data on W,Z

LHC jet data at NLO

Data set	LO	NLO	NNLO
BCDMS μp F_2 [125]	162 / 153	176 / 163	173 / 163
BCDMS μd F_2 [19]	140 / 142	143 / 151	143 / 151
NMC μp F_2 [20]	141 / 115	132 / 123	123 / 123
NMC μd F_2 [20]	134 / 115	115 / 123	108 / 123
NMC $\mu n/\mu p$ [21]	122 / 137	131 / 148	127 / 148
E665 μp F_2 [22]	59 / 53	60 / 53	65 / 53
E665 μd F_2 [22]	52 / 53	52 / 53	60 / 53
SLAC ep F_2 [23, 24]	21 / 18	31 / 37	31 / 37
SLAC ed F_2 [23, 24]	13 / 18	30 / 38	26 / 38
NMC/BCDMS/SLAC/HERA F_L [20, 125, 24, 63, 64, 65]	113 / 53	68 / 57	63 / 57
E866/NuSea pp DY [88]	229 / 184	221 / 184	227 / 184
E866/NuSea pd/pp DY [89]	29 / 15	11 / 15	11 / 15
NuTeV νN F_2 [29]	35 / 49	39 / 53	38 / 53
CHORUS νN F_2 [30]	25 / 37	26 / 42	28 / 42
NuTeV νN xF_3 [29]	49 / 42	37 / 42	31 / 42
CHORUS νN xF_3 [30]	35 / 28	22 / 28	19 / 28
CCFR $\nu N \to \mu\mu X$ [31]	65 / 86	71 / 86	76 / 86
NuTeV $\nu N \to \mu\mu X$ [31]	53 / 40	38 / 40	43 / 40
HERA e^+p NC 820 GeV[61]	125 / 78	93 / 78	89 / 78
HERA e^+p NC 920 GeV[61]	479 /330	402 /330	373/ 330
HERA e^-p NC 920 GeV [61]	158/ 145	129/ 145	125 /145
HERA e^+p CC [61]	41 / 34	34 / 34	32 / 34
HERA e^-p CC [61]	29 / 34	23 / 34	21 / 34
HERA ep F_2^{charm} [62]	105 /52	72 / 52	82 / 52
H1 99–00 e^+p incl. jets [126]	77 / 24	14 / 24	—
ZEUS incl. jets [127, 128]	140/60	45 / 60	—
DØ II $p\bar{p}$ incl. jets [119]	125 / 110	116 / 110	119 / 110
CDF II $p\bar{p}$ incl. jets [118]	78 / 76	63 / 76	59 / 76
CDF II W asym. [66]	55 / 13	32 / 13	30 / 13
DØ II $W \to \nu e$ asym. [67]	47 / 12	28 / 12	27 / 12
DØ II $W \to \nu\mu$ asym. [68]	16 / 10	19 / 10	21 / 10
DØ II Z rap. [90]	34 / 28	16 / 28	16 / 28
CDF II Z rap. [70]	95 / 28	36 / 28	40 / 28
ATLAS W^+, W^-, Z [10]	94/30	38/30	39/30
CMS W asymm $p_T > 35$ GeV [9]	10/11	7/11	9/11
CMS asymm $p_T > 25$ GeV, 30 GeV[77]	7/24	8/24	10/24
LHCb $Z \to e^+e^-$[79]	76/9	13/9	20/9
LHCb W asymm $p_T > 20$ GeV[78]	27/10	12/10	16/10
CMS $Z \to e^+e^-$ [84]	46/35	19/35	22/35
ATLAS high-mass Drell-Yan [83]	42/13	21/13	17/13
CMS double diff. Drell-Yan [86]	—	372/132	149/132
Tevatron, ATLAS, CMS $\sigma_{t\bar{t}}$ [91]–[97]	53/13	7/13	8/13
ATLAS jets (2.76 TeV+7 TeV)[108, 107]	162/116	106/116	—
CMS jets (7 TeV) [106]	150/133	138/133	—
All data sets	**3706 / 2763**	**3267 / 2996**	**2717 / 2663**

Table 5: The values of $\chi^2/N_{\mathrm{pts.}}$ for the data sets included in the global fit. For the NuTeV $\nu N \to \mu\mu X$ data, the number of degrees of freedom is quoted instead of $N_{\mathrm{pts.}}$ since smearing effects mean nearby points are highly correlated. The details of corrections to data, kinematic cuts applied and definitions of χ^2 are contained in the text.

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.

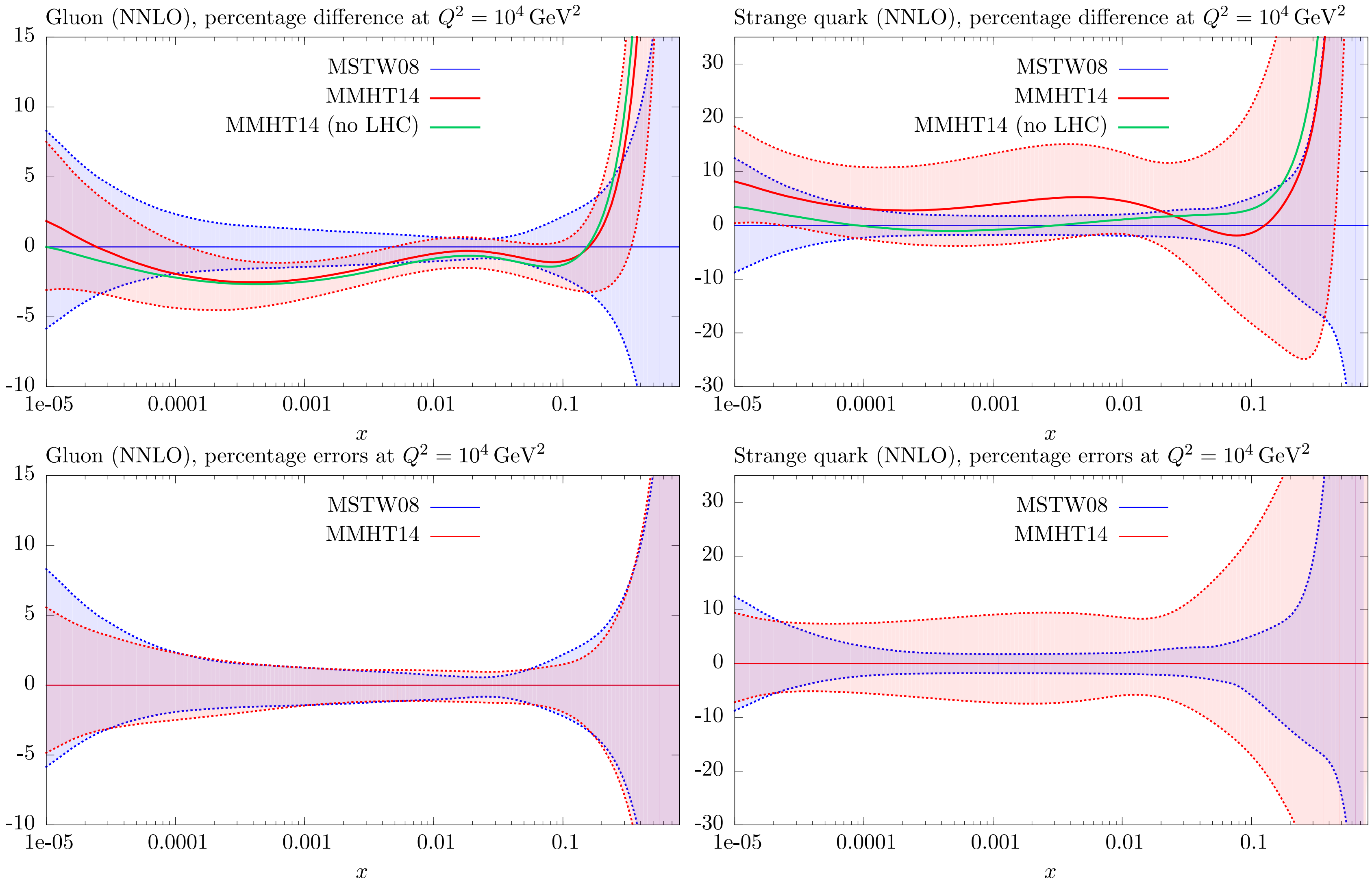
Eigenvector sets made available for $\alpha_S(M_Z^2) = 0.135$ (LO), $\alpha_S(M_Z^2) = 0.118, 0.120$ (NLO) and $\alpha_S(M_Z^2) = 0.118$ (NNLO)

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

NLO – $\alpha_S(m_Z^2) = 0.1201$, 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 $\alpha_S(m_Z^2) = 0.120$.

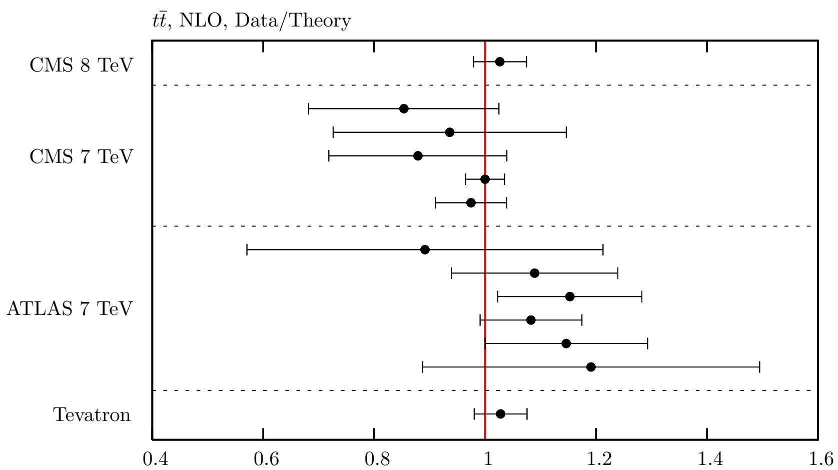
Comparison of PDFs at NNLO

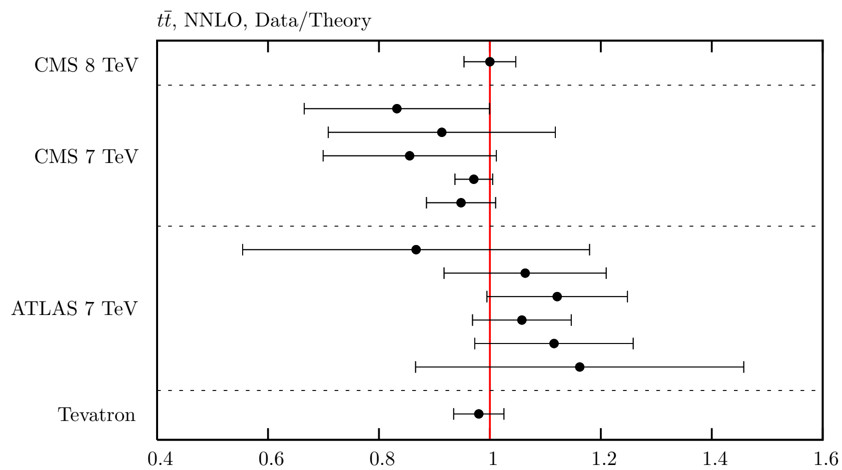


Change in NNLO PDFs from all updates. Almost no change in light sea quarks.

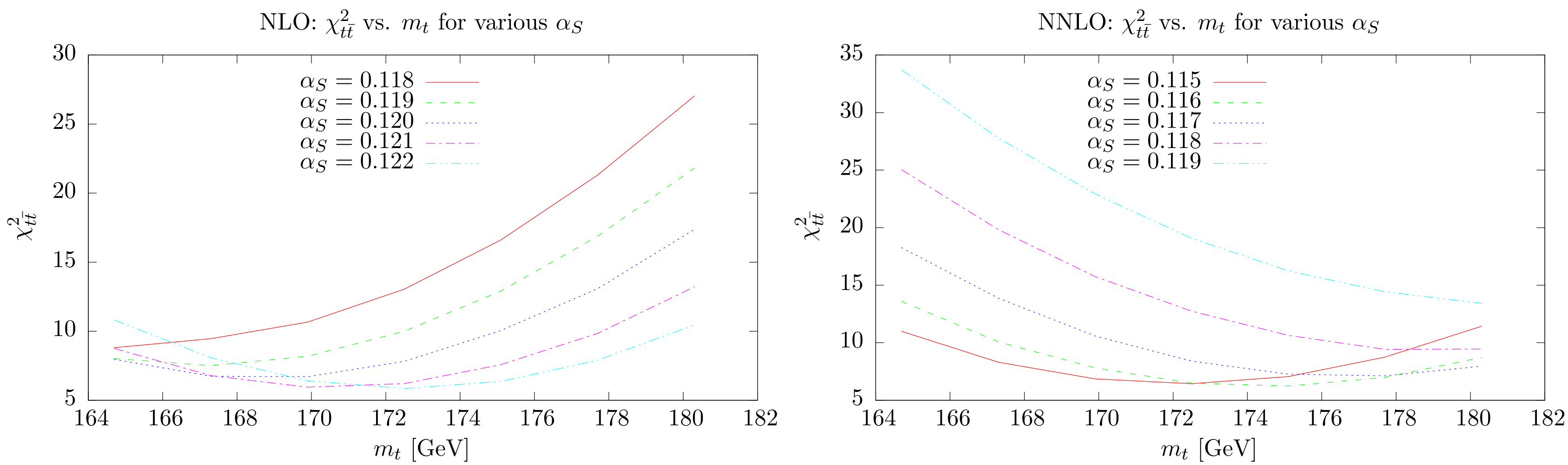
LHC data on $t\bar{t}$

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 7TeV and one point at 8TeV. Use $m_t = 172.5\ \text{GeV}$ (value used in Tevatron combination) with an error of $1\ \text{GeV}$, with χ^2 penalty applied. Predictions and fit good, with NLO preferring masses slightly below $m_t = 172.5\ \text{GeV}$ and NNLO masses slightly above.





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 $m_t = 172.5\ \mathrm{GeV} \pm 1\ \mathrm{GeV}$ are $m_t(\mathrm{NLO}, \mathrm{NNLO}) = 171.7, 174.2\ \mathrm{GeV}$, as opposed to world average of $m_t = 173.34 \pm 0.76\ \mathrm{GeV}$.

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

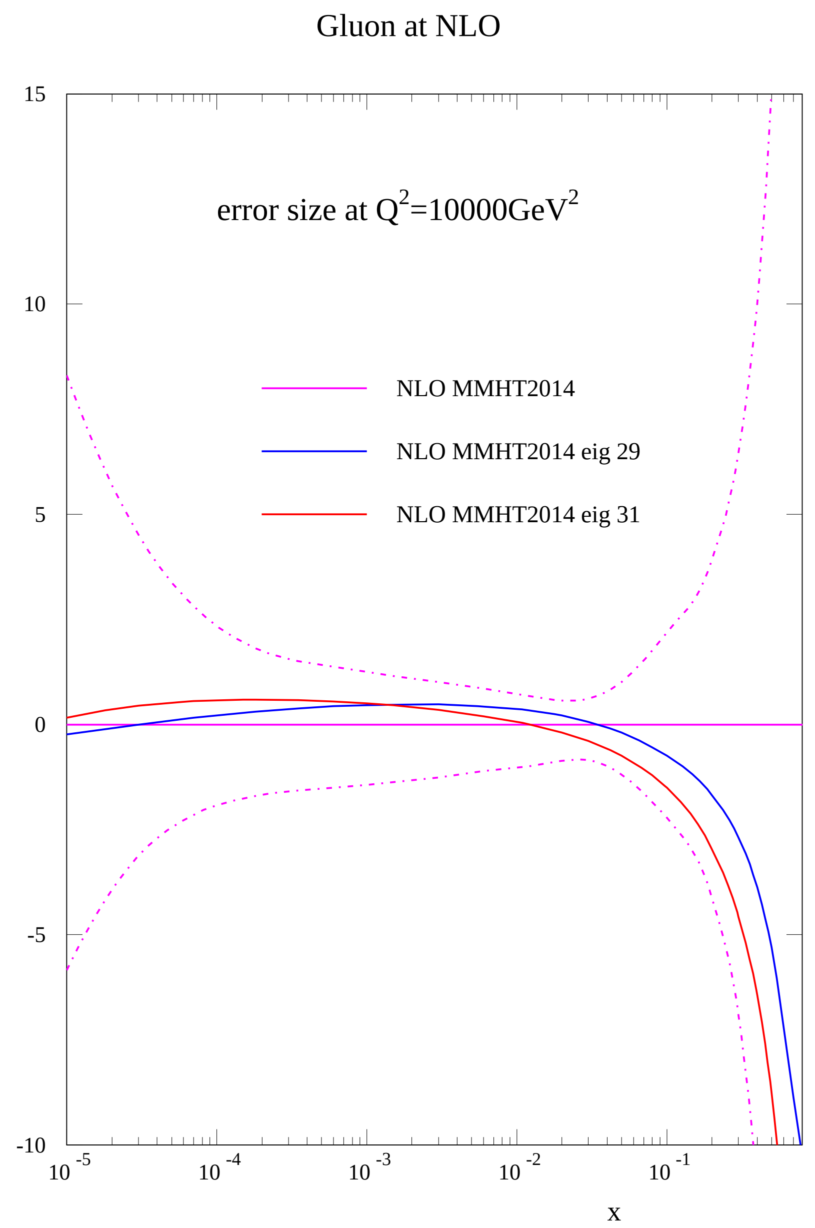
In the NLO fit the inclusive $t\bar{t}$ cross section does not constrain any eigenvectors. Best fit $m_t = 171.7\mathrm{GeV}$ (lower if $\alpha_S(M_Z^2) = 0.118$).

Nearly constrains eigenvector number 29 and 31.

Both correspond to decreased gluon at high x only.

29 also corresponds to lower high-x sea and constrained mainly by NuTeV $F_3(x, Q^2)$ data.

31 primarily constrained by CDF jet data.



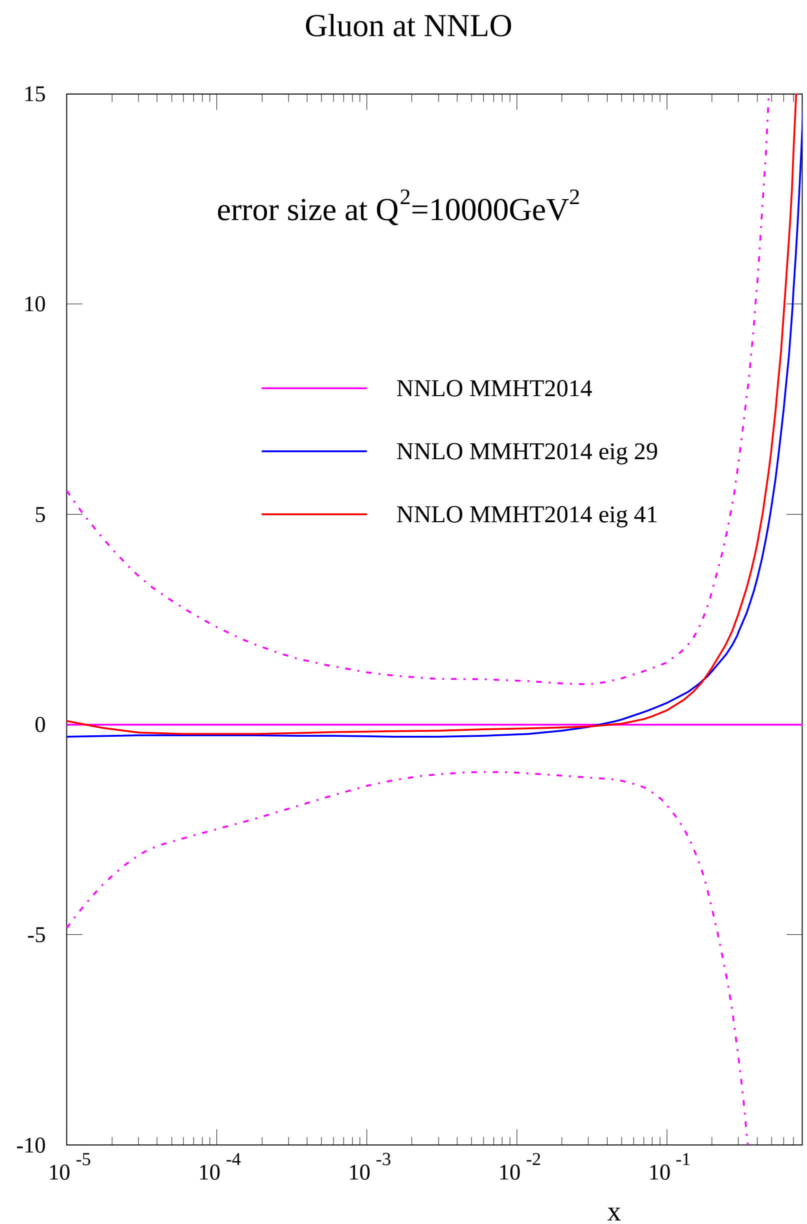
In the NNLO fit the inclusive $t\bar{t}$ cross section constrains one eigenvector.

At NNLO preferred $m_t = 174.1\mathrm{GeV}$.

Constrains eigenvector number 29 and (nearly) 41.

Both correspond to increased gluon at high x only.

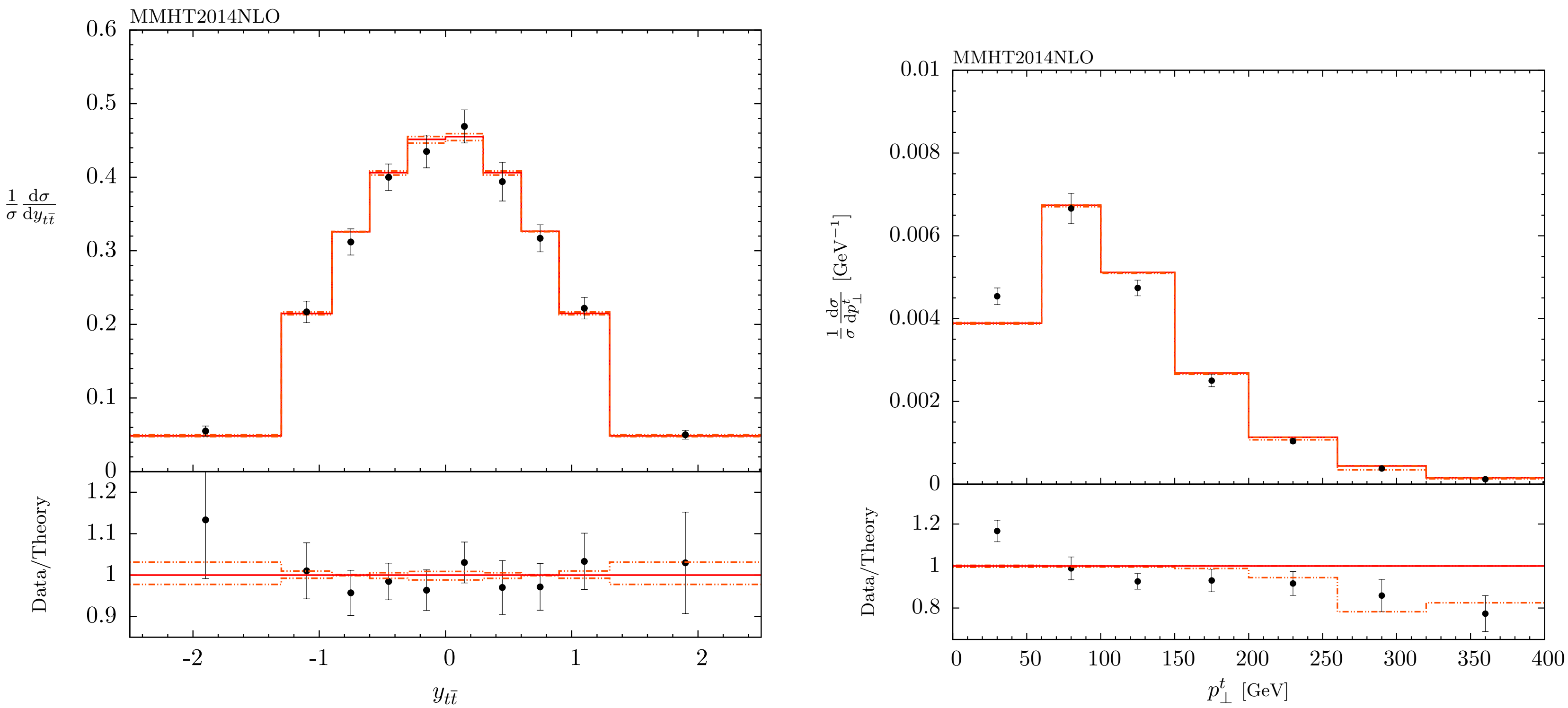
41 also corresponds to strange normalisation and constrained also by ATLAS W, Z data.



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

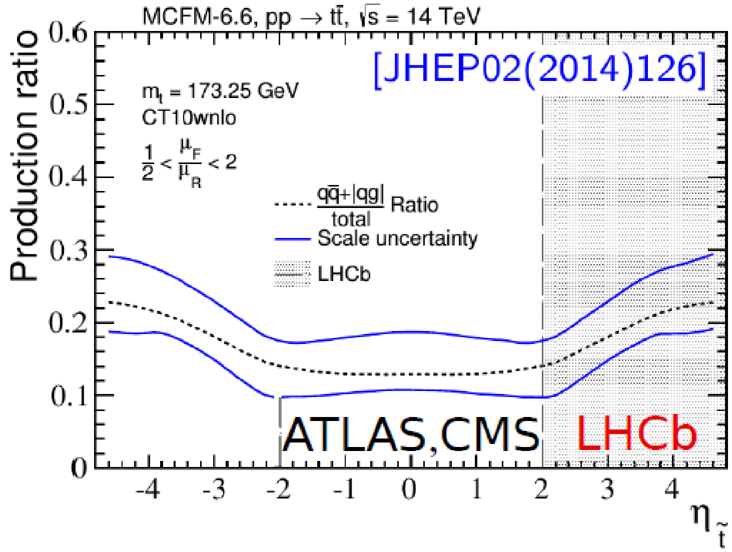
Variety of data sets not in PDF determination as they did not meet cut-off date and/or missing NNLO corrections.

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).



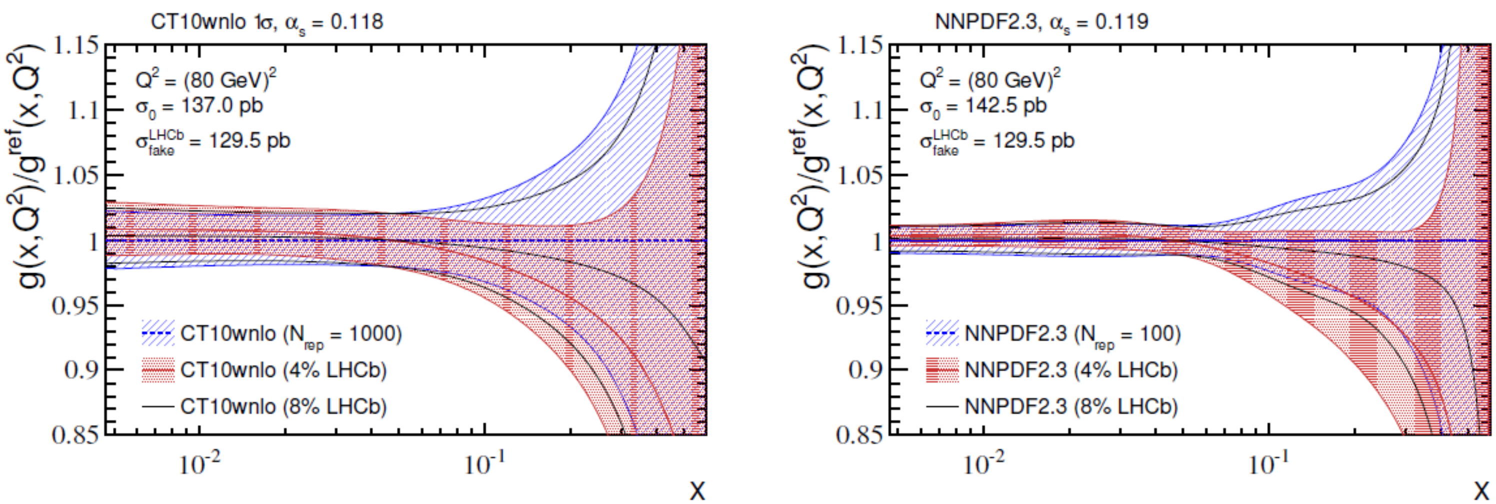
Interesting to see NNLO corrections.

LHCb Measurement.

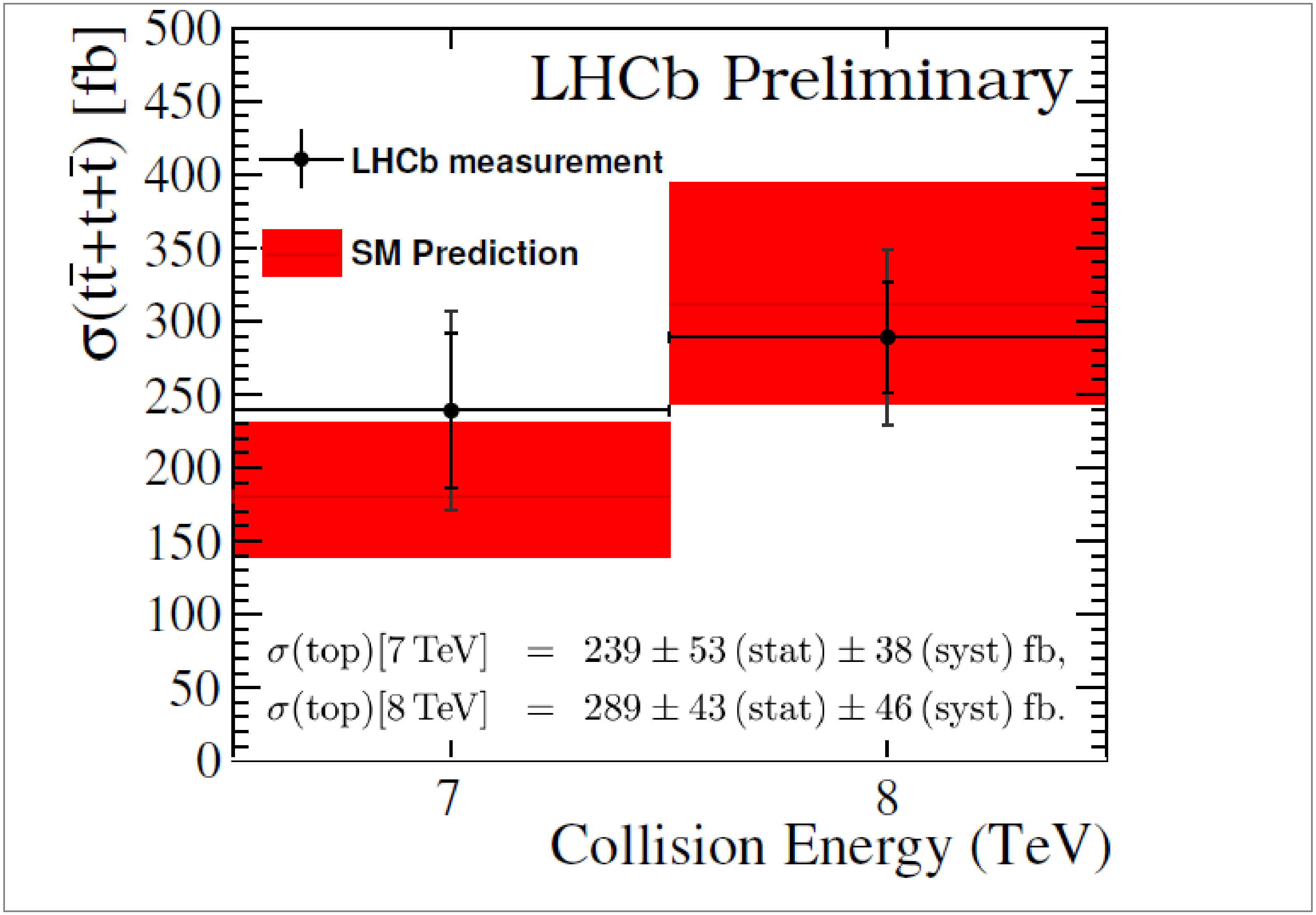


Motivation for studies in the forward region:

- test for the differential predictions.
- reduced g-initiated production.
- probe different momentum fraction of the proton compared to central region.



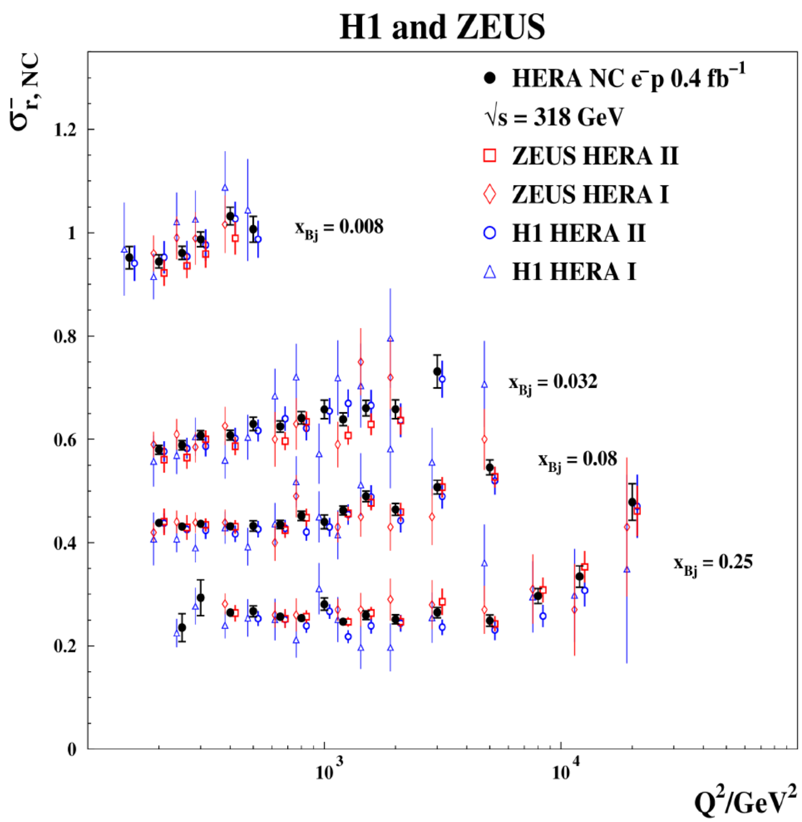
More impact if in some disagreement with expectation. Gauld

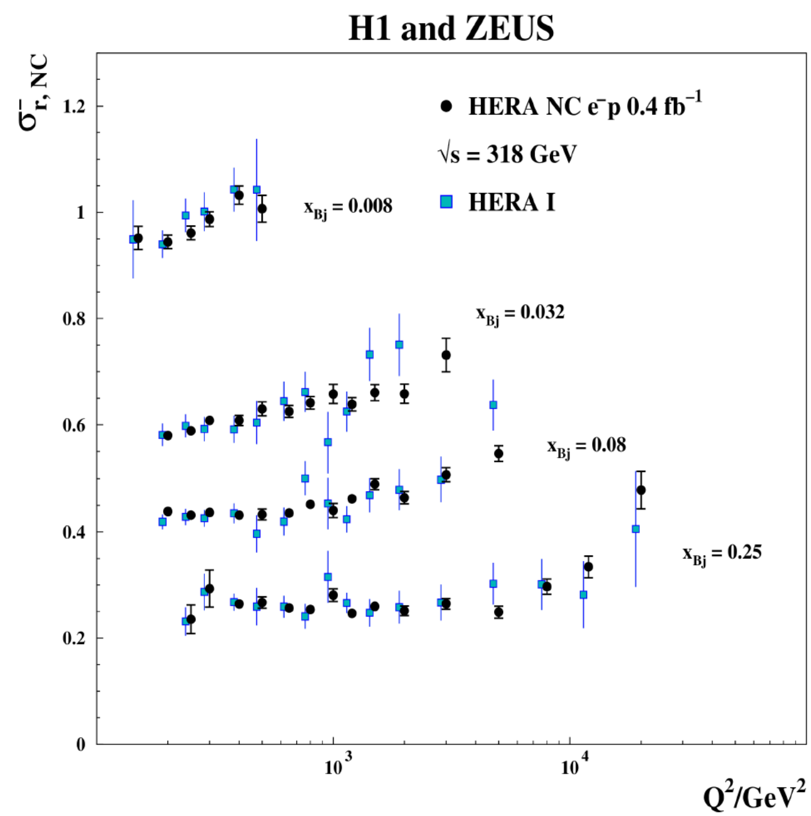


First measurement in good agreement with theory.

HERAI+II combination data.

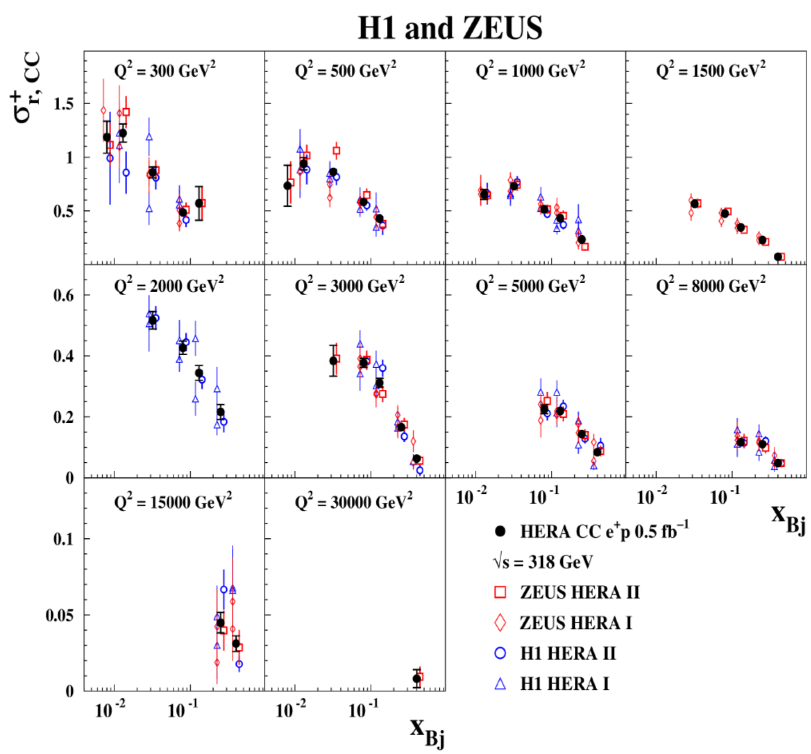
Averaged cross sections: NC e-p



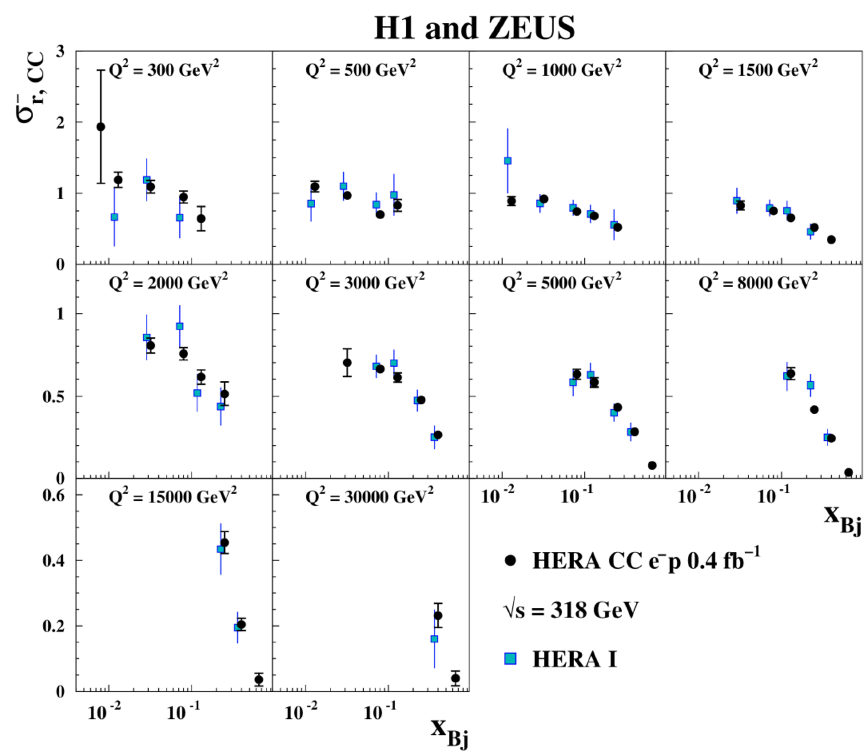


Averaged cross sections: CC e±p

CC e+p

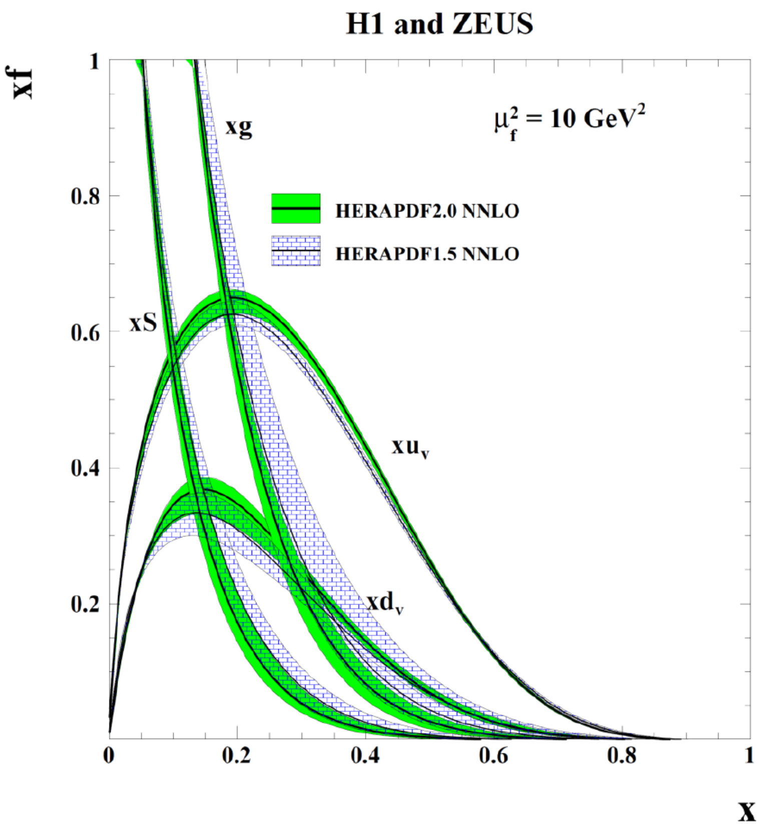


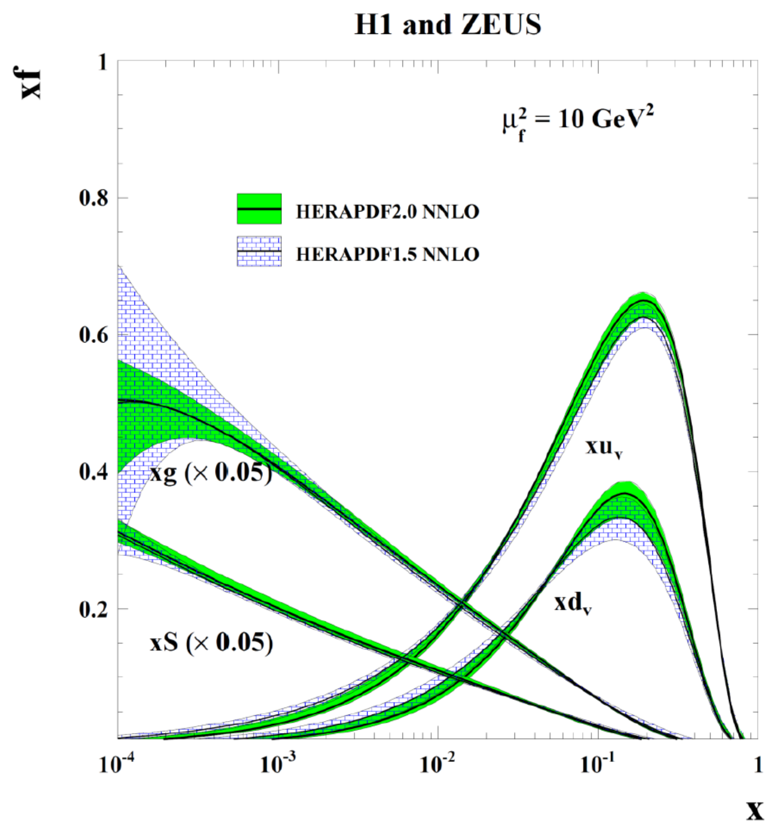
CC e-p



Included in HERAPF2.0 fits. A.M. Cooper-Sarkar

Compare HERAPDF2.0 to HERAPDF1.5 at NNLO

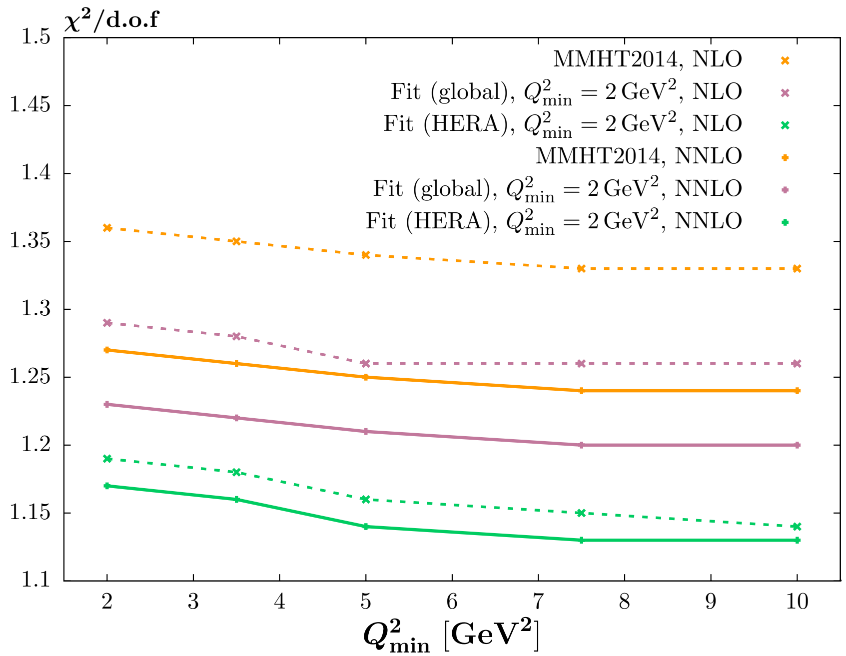


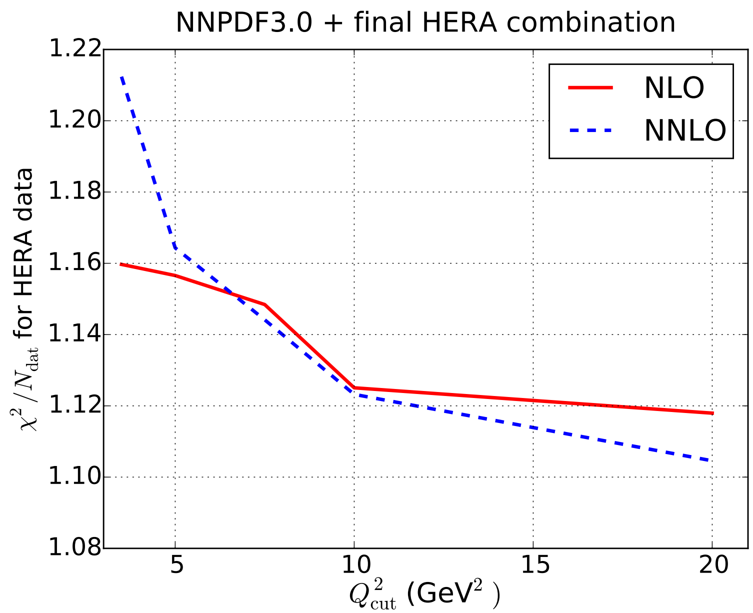


Make HERAPDF PDFS more precise, but in general a bit further from other PDFs in some places, e.g high-x up quark.

HERA II **Combined data in other PDFs**

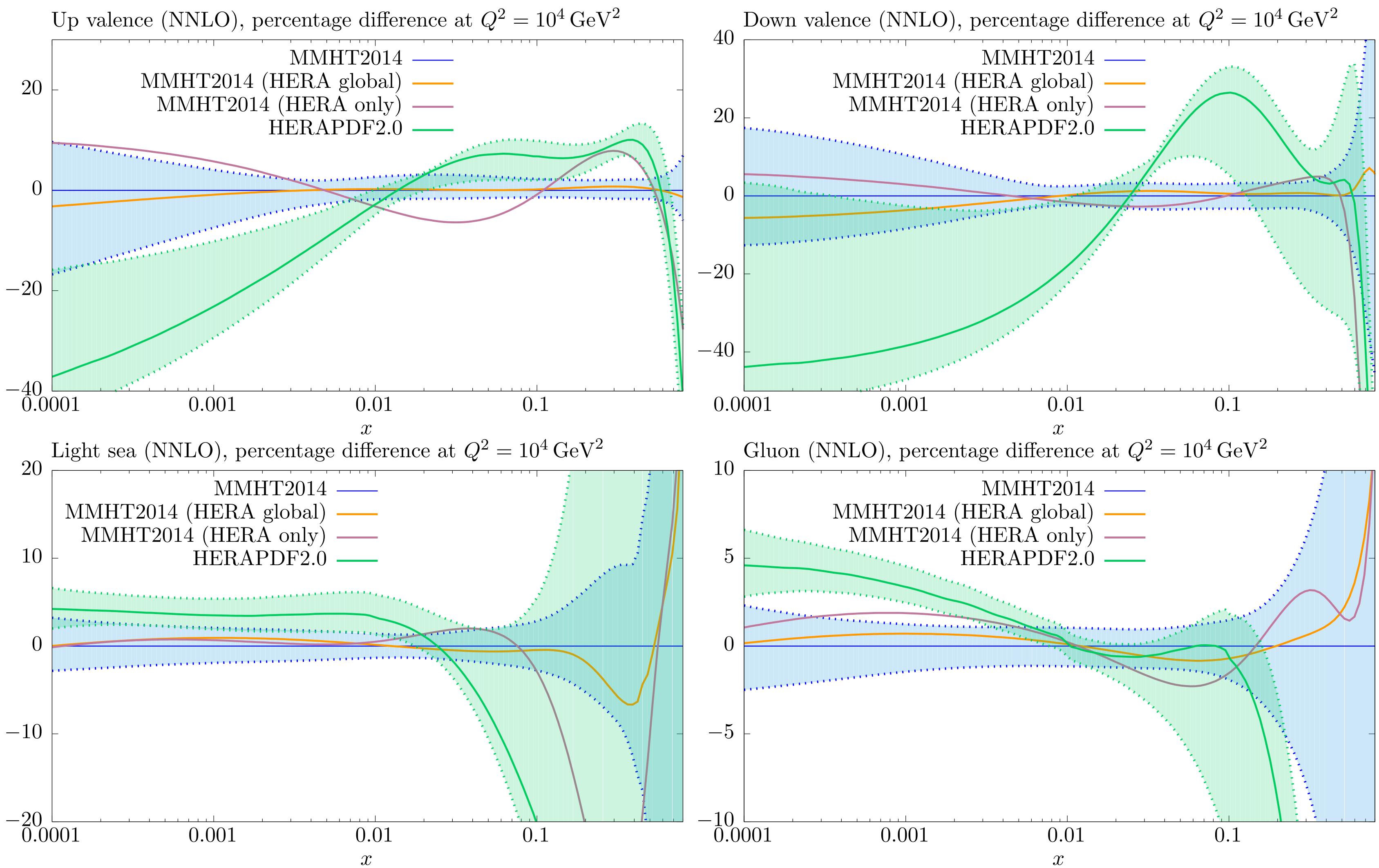
Good fits possible with little deterioration for other data seen for both MSTW and NNPDF





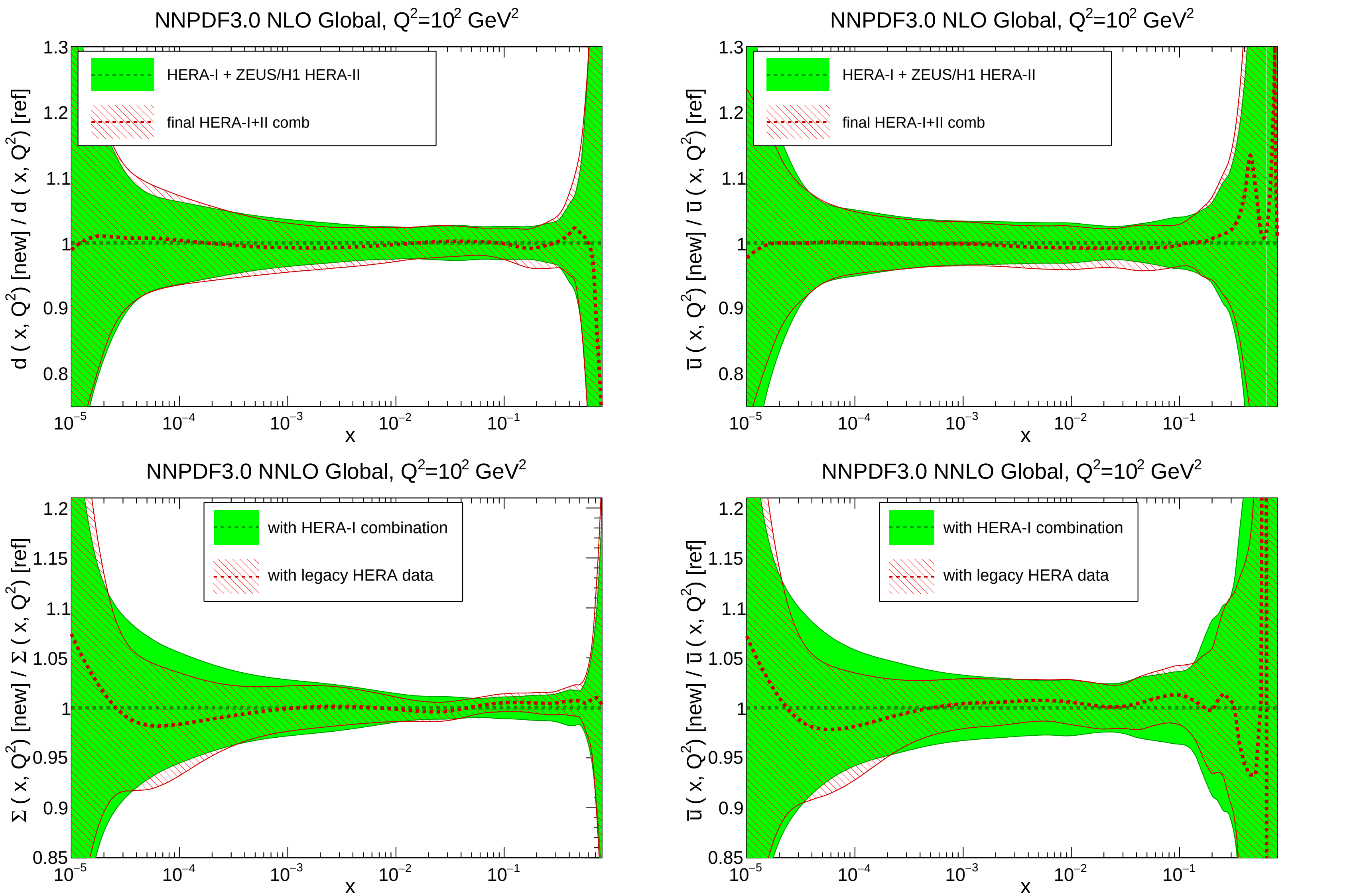
Also look at effect of changing the Q^2 cut, at both NLO and NNLO

Improvement in χ^2 with $Q^2_{\rm min}$, but other than NNPDF at NNLO not dramatic.



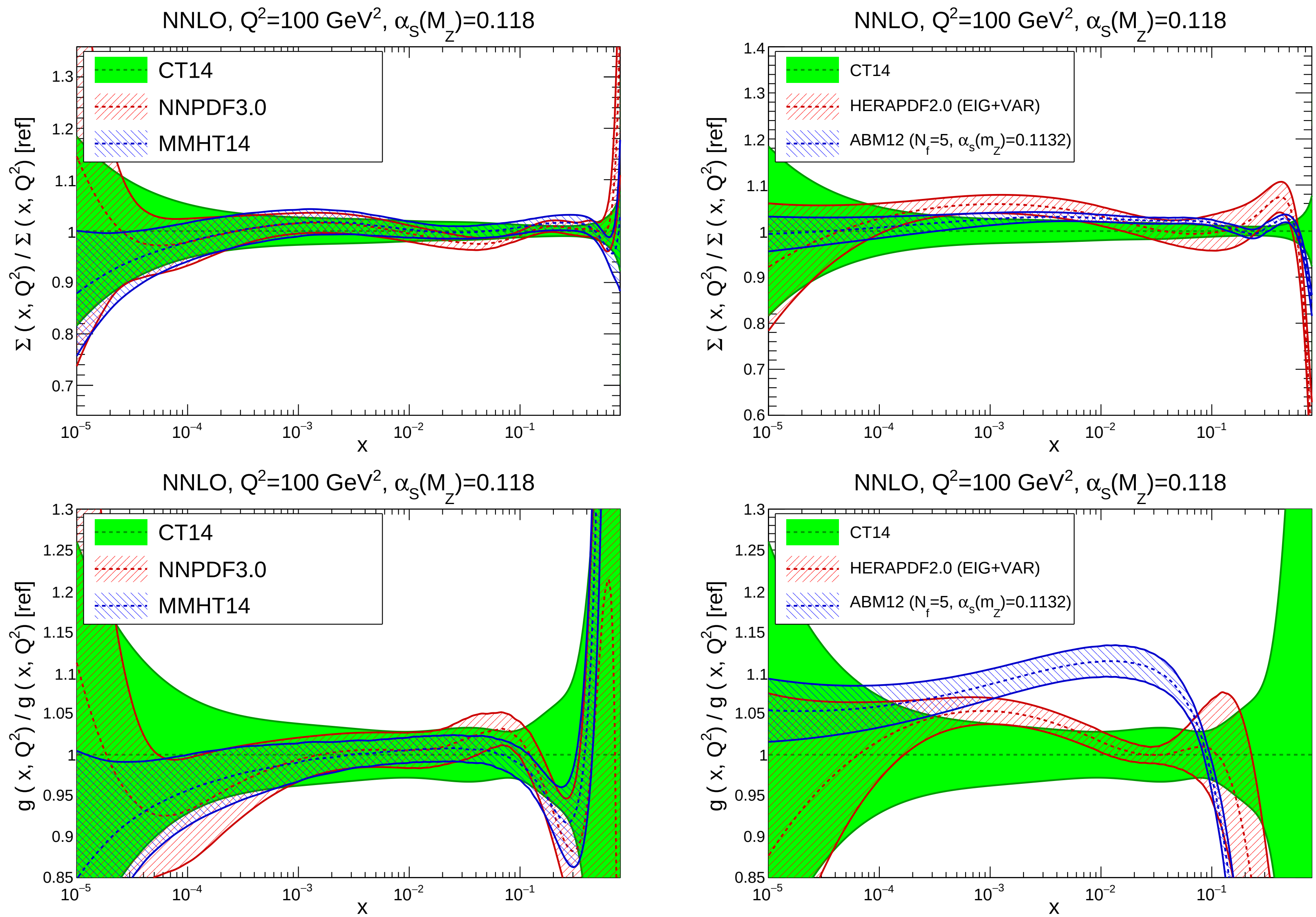
HERA II modified PDFs very well within MMHT2014 uncertainties. PDFs from HERA II data only fit in some ways similar to HERAPDF2.0.

Predictions for e.g. $gg \to H$ change by $< 0.2\%$ for full range of LHC energies.

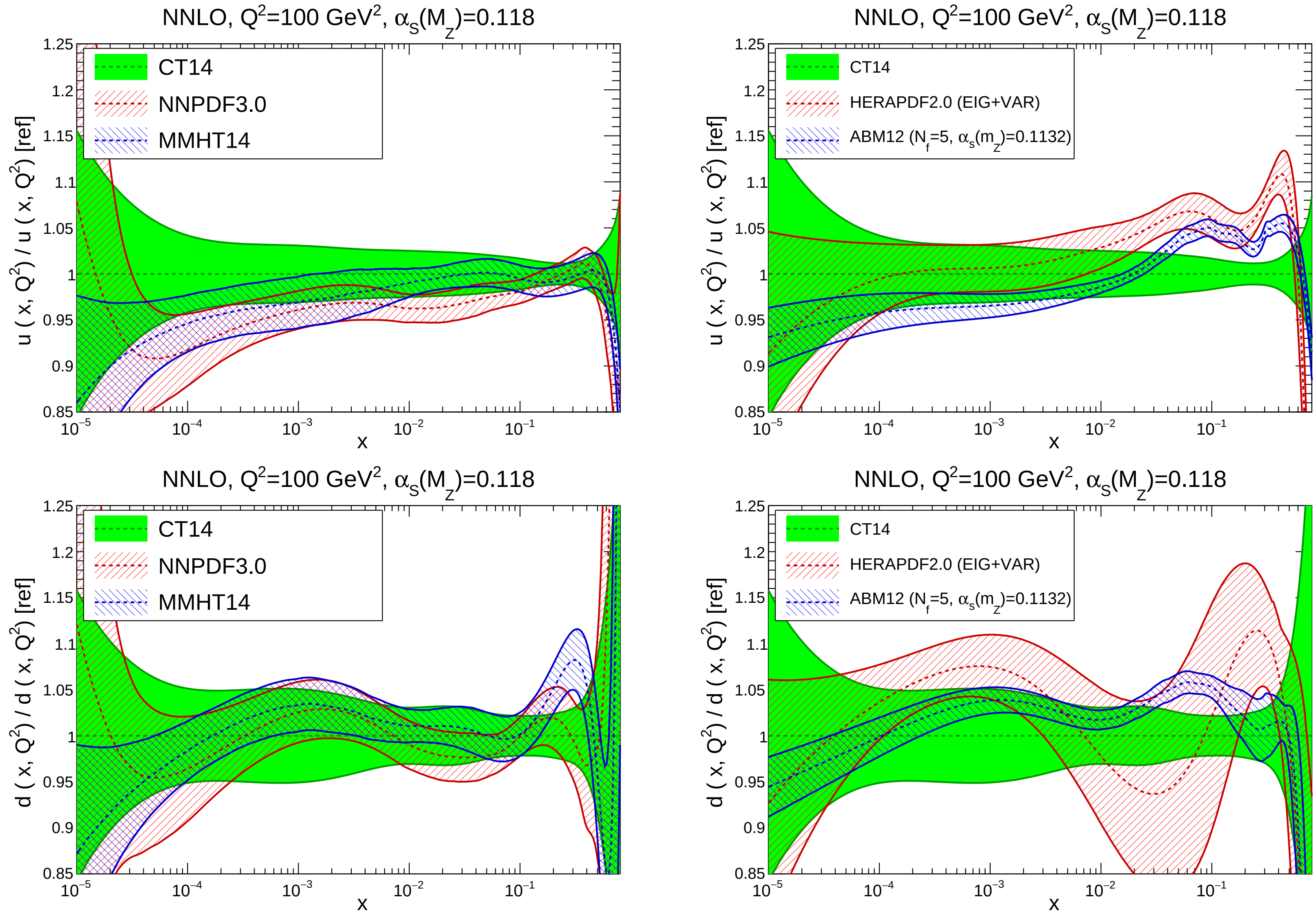


Similar results for NNPDF3.0.

Comparison of state-of-the-art PDFs

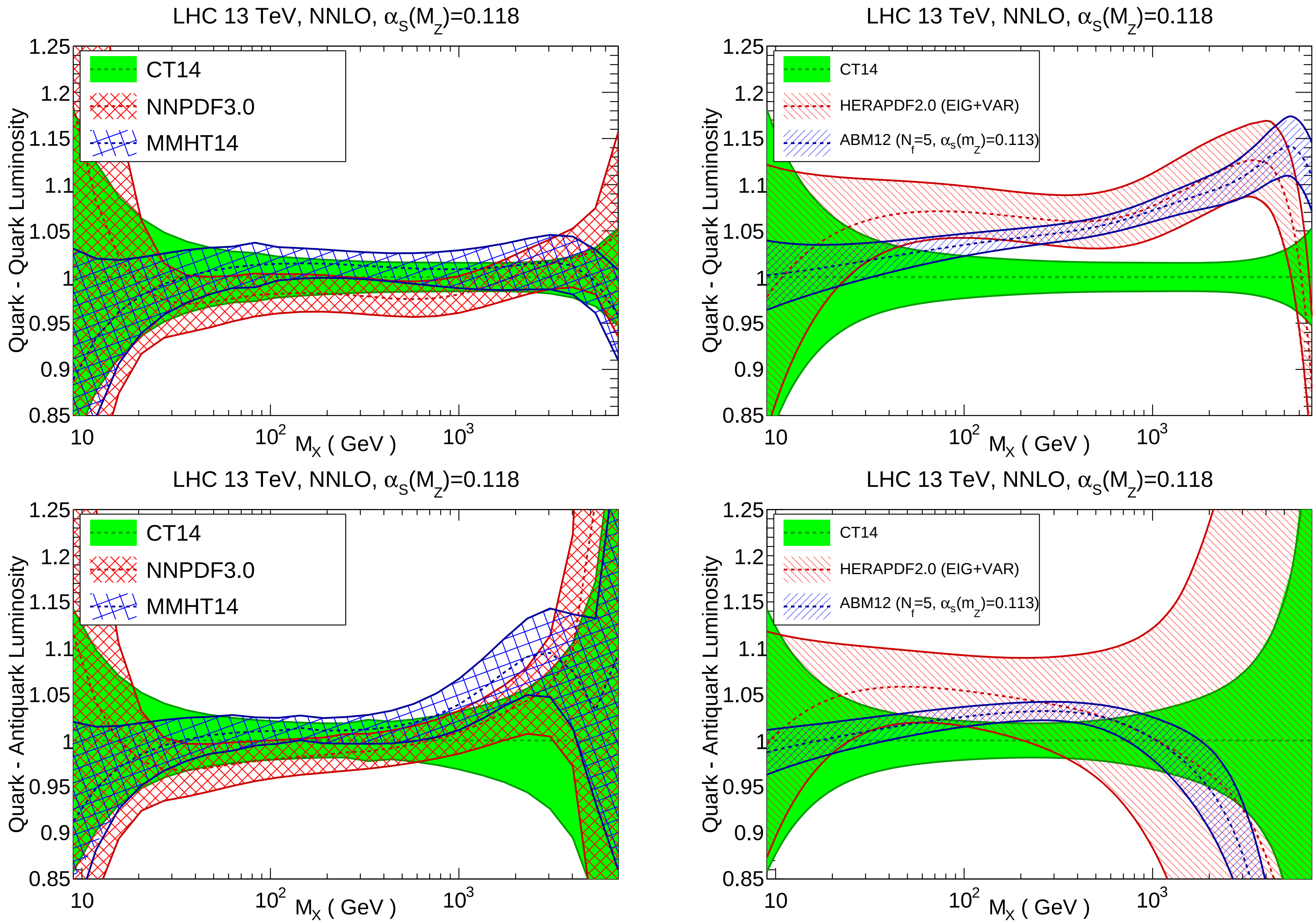


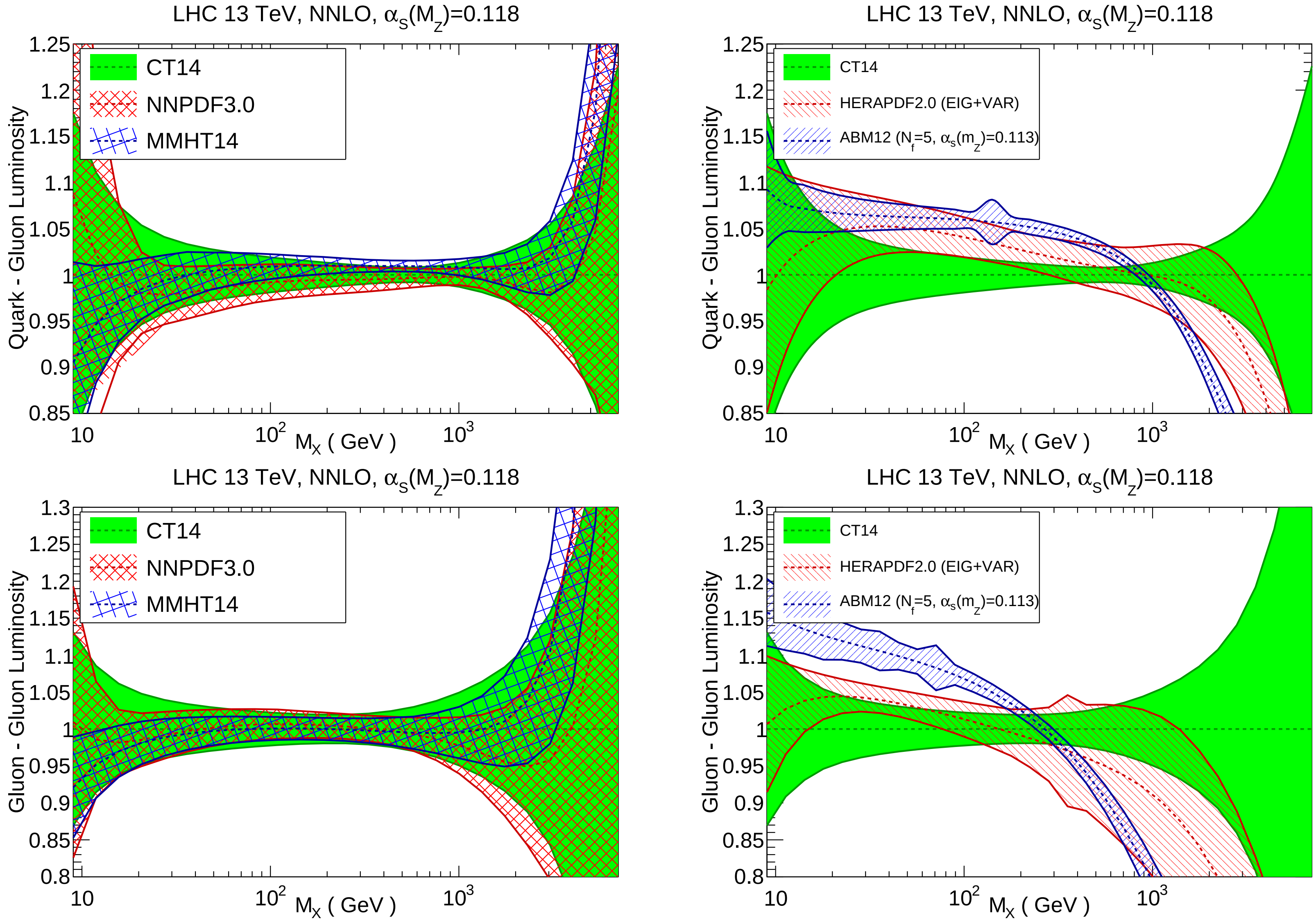
Some excellent agreement between CT14, MMHT2104 and NNPDF3.0.



Some significant differences in some PDF sets in central values and uncertainty.

Comparison of PDF luminosities





gg luminosity now almost perfect agreement for “global” sets.

Randomly distributed "Hessian" PDF sets. G. Watt, RST

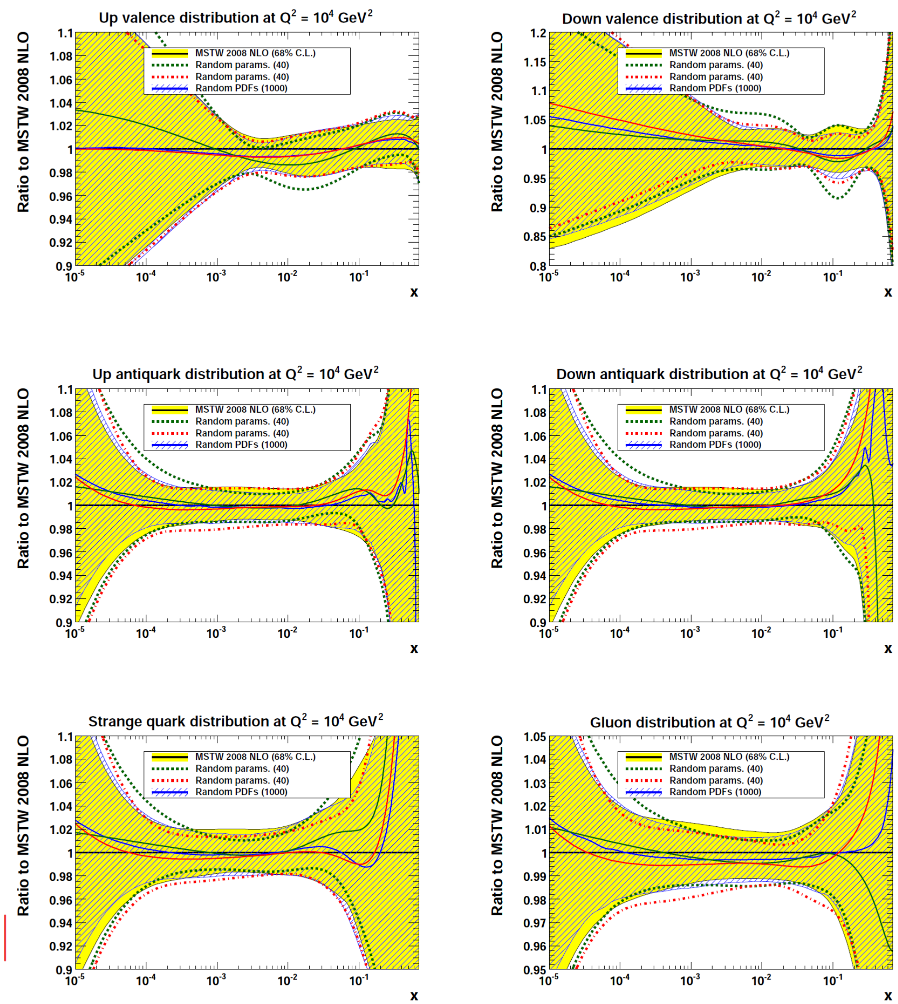
Study supported correctness of "dynamic tolerance" approach. Easiest in Hessian study with eigenvectors.

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

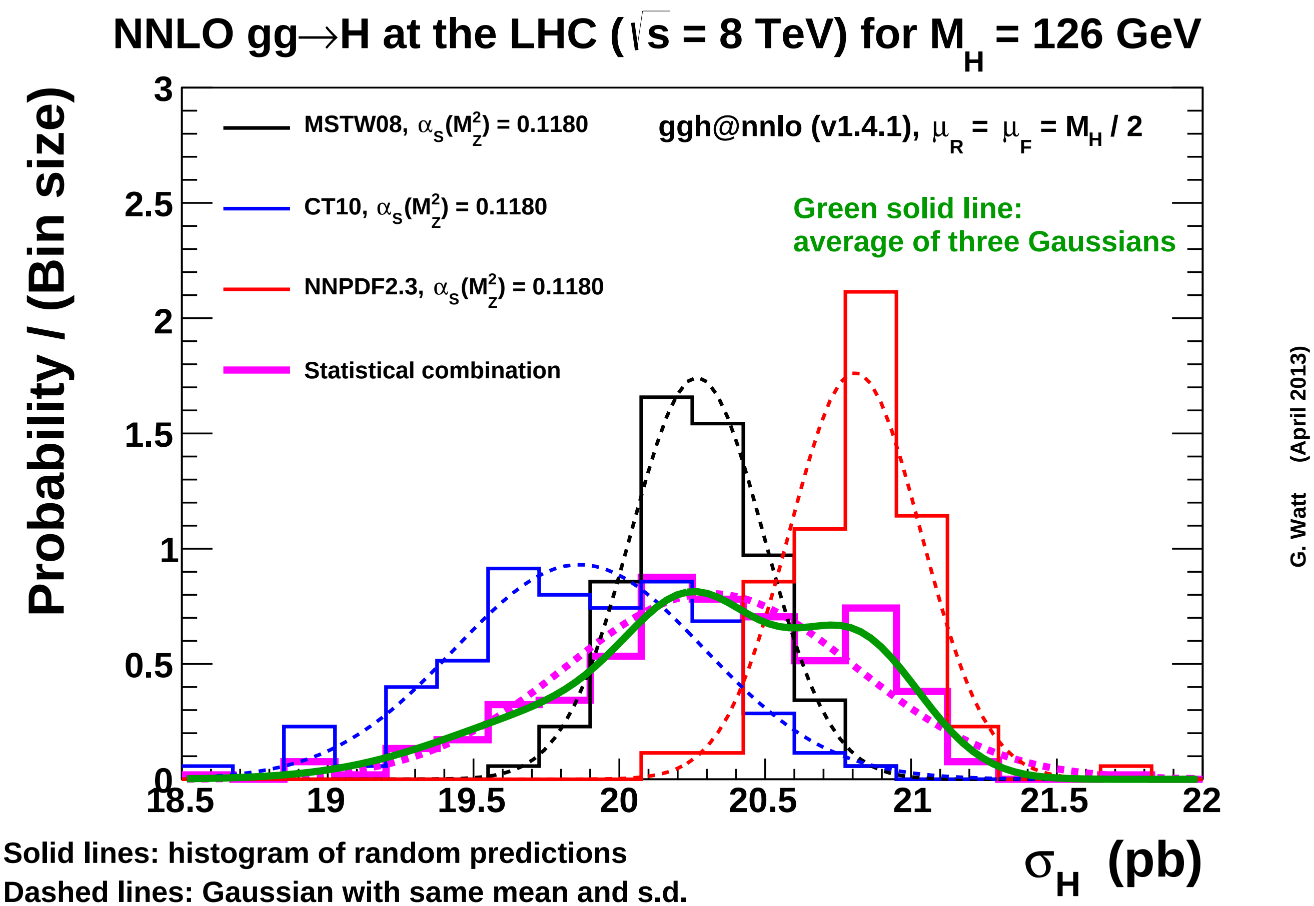
$$a_i(S_k) = a_i^0 + \sum_{j=1}^{n} e_{ij}(\pm t_j^{\pm})|R_{jk}|$$

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

$$F(S_k) = F(S_0) + \sum_j [F(S_j^{\pm}) - F(S_0)]|R_{jk}|$$

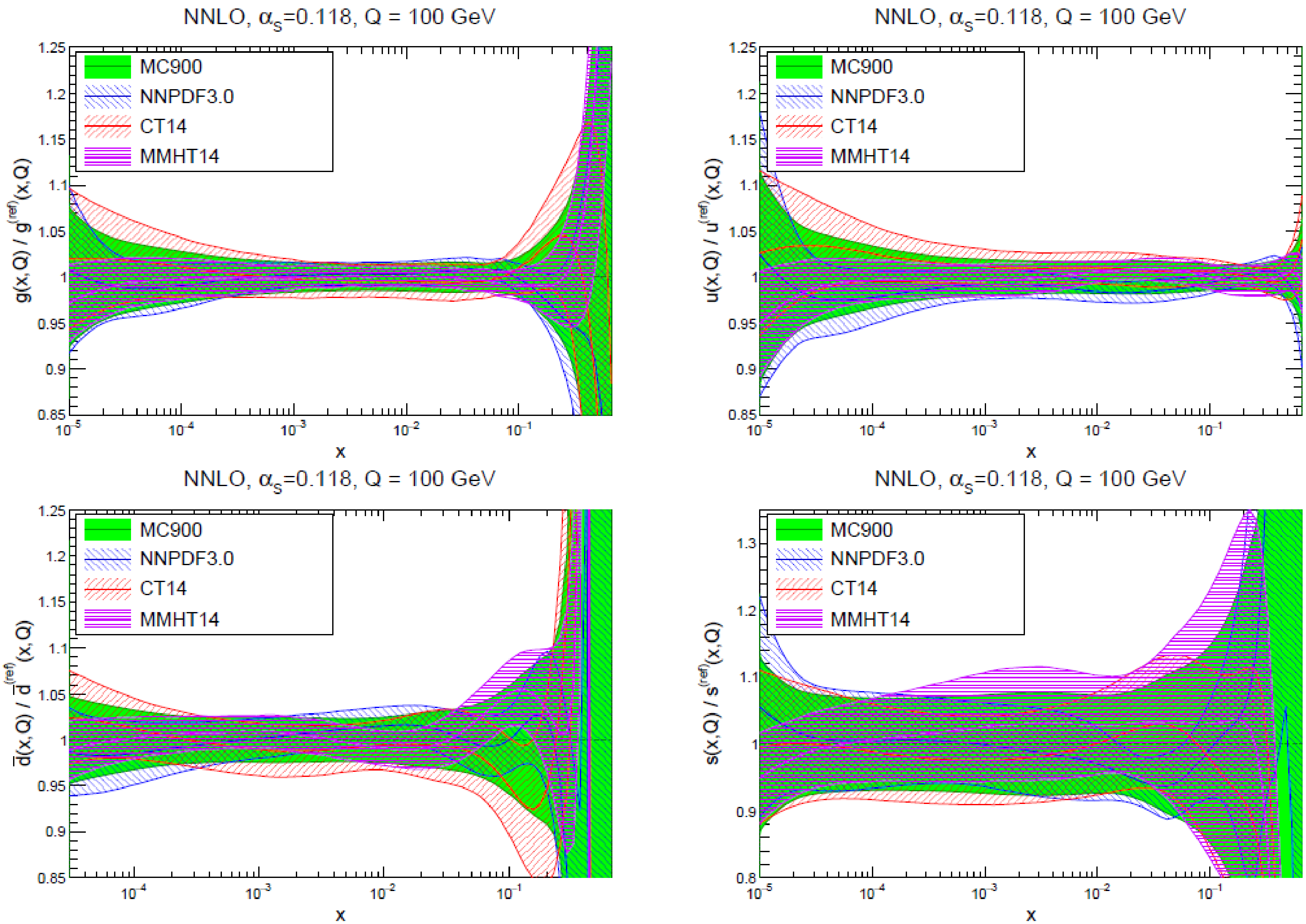


Can combine different PDF sets either at PDF level or predictions, e.g. Higgs cross section (Plot by G. Watt - original example.)



Slightly smaller uncertainty and shifted central value than envelope method if disagreement between individual predictions.

Comparison of Combination to Individual PDFs



Works well if PDFs are fairly compatible - both in central value and uncertainty.

The New PDF4LHC Prescription

Perform a Monte Carlo combination of the included PDf sets.

Sets entering into the combination must satisfy requirements, i.e. be compatible for combination. $\alpha_S(M_Z^2) = 0.118$

Deliver a single combined PDF set - either Monte Carlo or Hessian form for combined PDF.

– Monte Carlo - A set of PDF replicas is delivered. The mean is the central value and the standard deviation the uncertainty.

– Hessian - A central set and eigenvectors representing orthogonal sources of uncertainty are delivered. Uncertainty obtained by summing each uncertainty source in quadrature.

In each case a single combined set at both $\alpha_S(M_Z^2) = 0.1165$ and $\alpha_S(M_Z^2) = 0.1195$ is provided to give $\alpha_S(M_Z^2)$ uncertainty (i.e. $\Delta\alpha_S(M_Z^2) = 0.118$) to be added in quadrature with other uncertainties.

Three Options Provided

PDF4LHC15-mc: A compressed **Monte Carlo** set with $N_{\rm rep} = 100$.

PDF4LHC15-30: A symmetric **Hessian** set with $N_{\rm eig} = 30$. (Meta-PDF approach - refit combination to functional form.)

PDF4LHC15-100: A symmetric **Hessian** set with $N_{\rm eig} = 100$. (MC-H representing eigenvectors on linear basis of replica.)

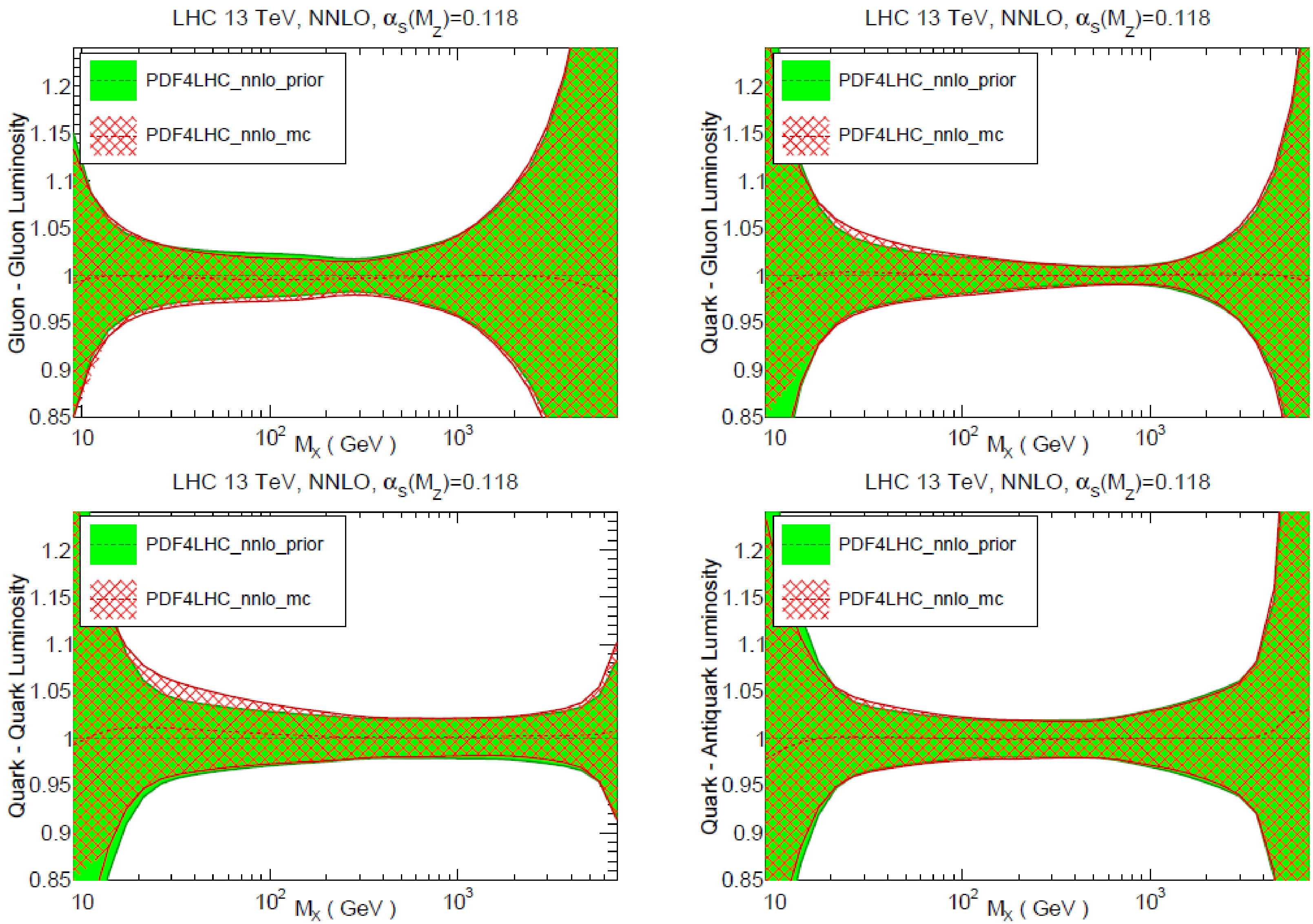
Some suggestions for which ones to use

Monte Carlo contains non-gaussian features – important for searches at high masses (high x).

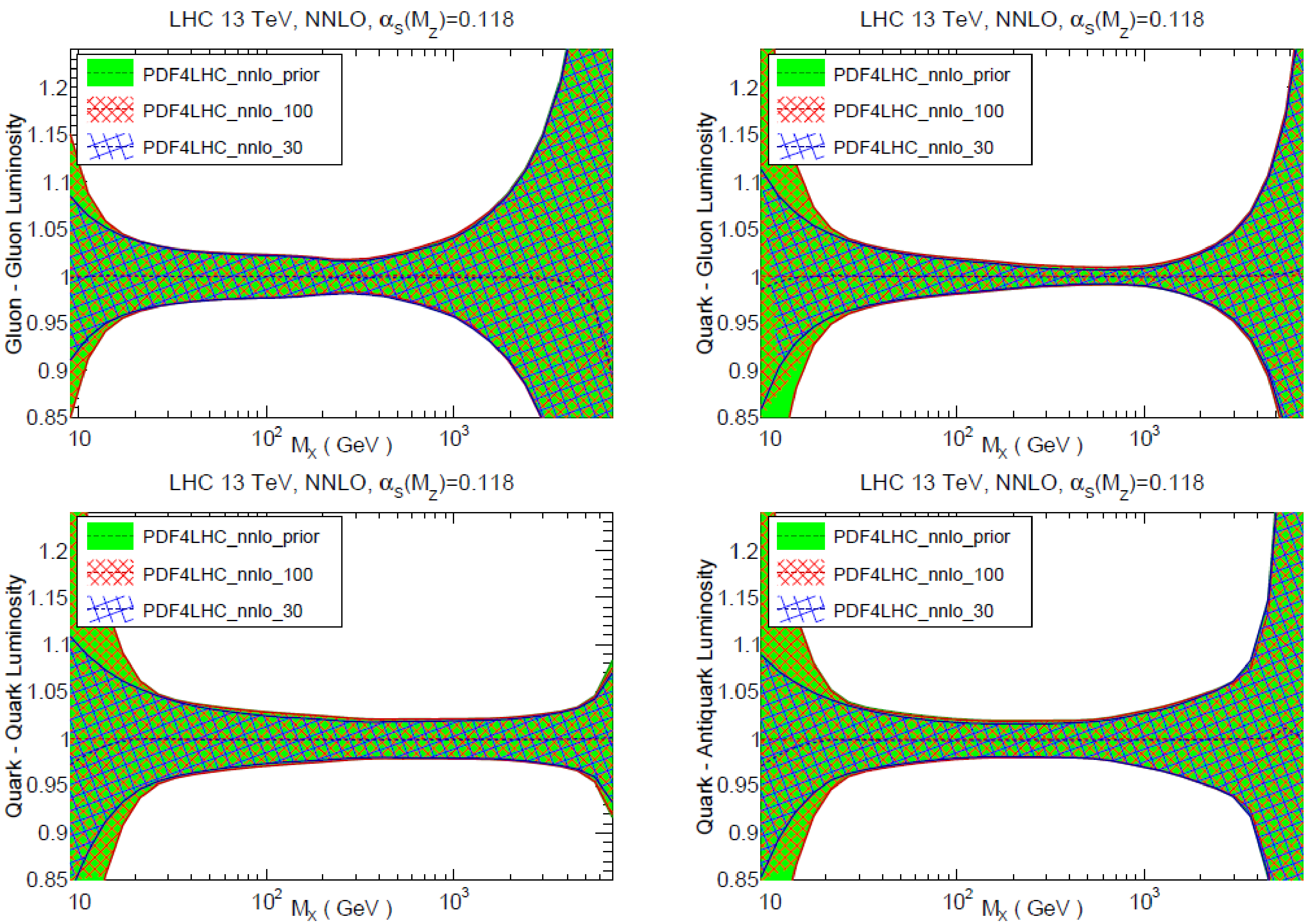
Hessian 30 set has good precision and useful for many experimental needs and when using nuisance parameters.

Hessian 100 set has optimal precision if running time not a problem or extreme accuracy needed.

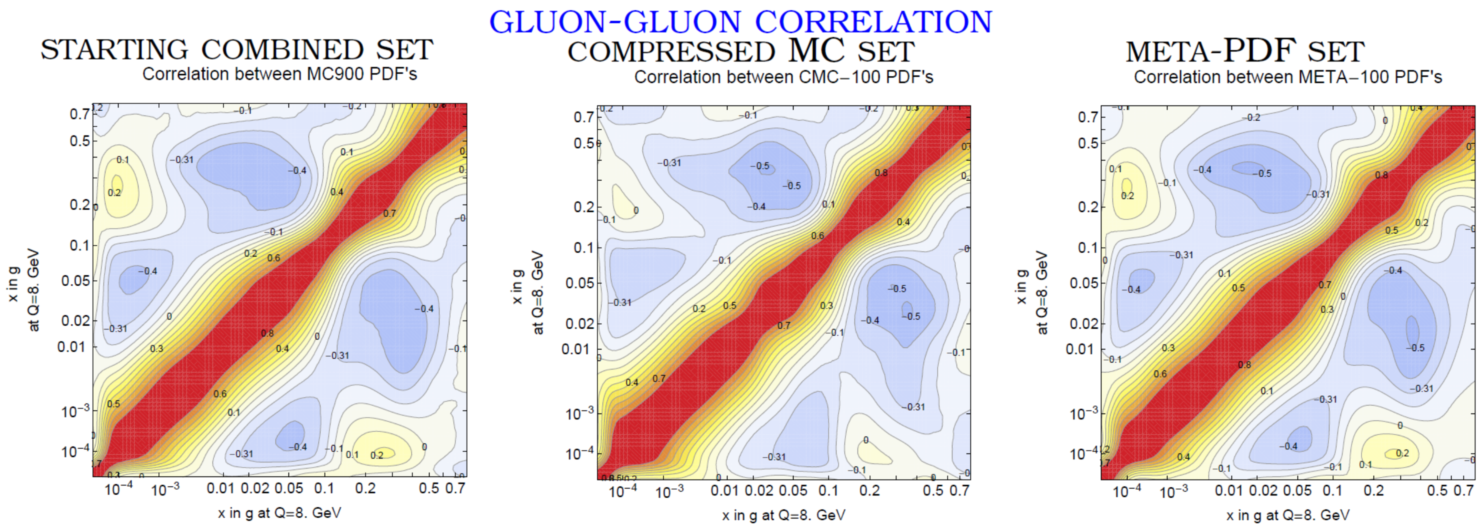
Comparison of PDF luminosities for MC Compression



Comparison of PDF luminosities for Hessian Compression

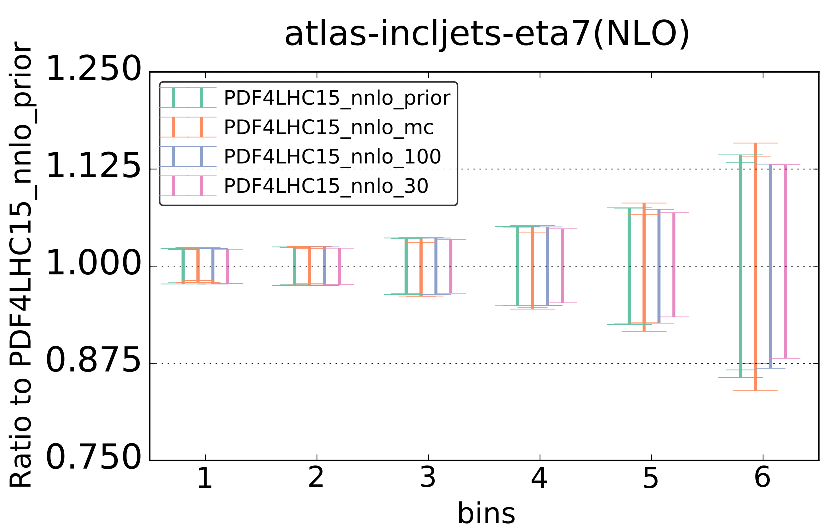


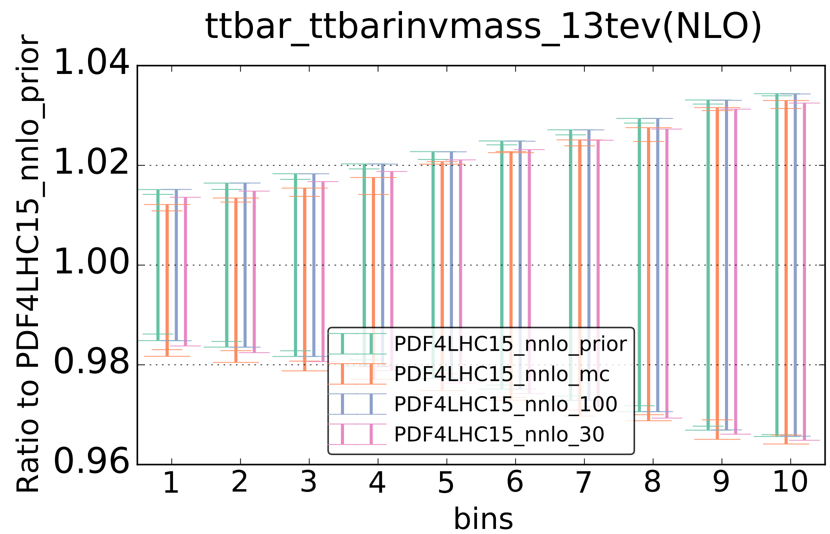
PDF correlations in Compressed sets

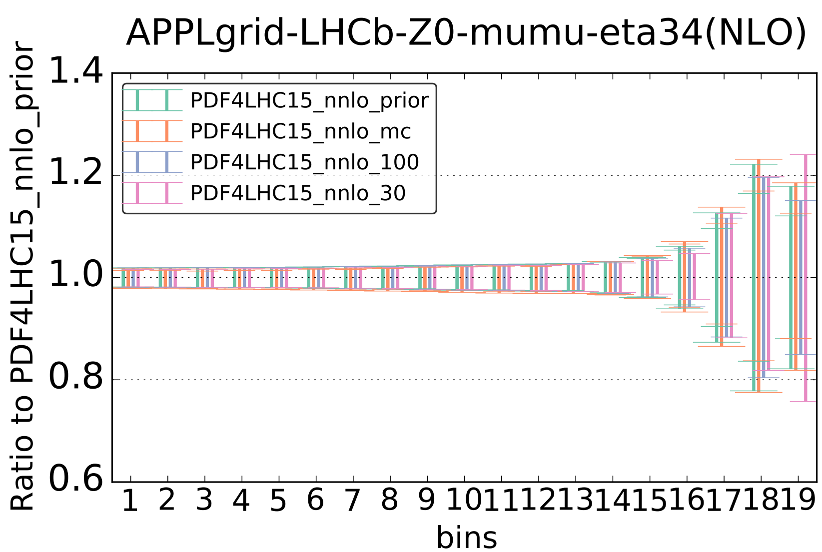


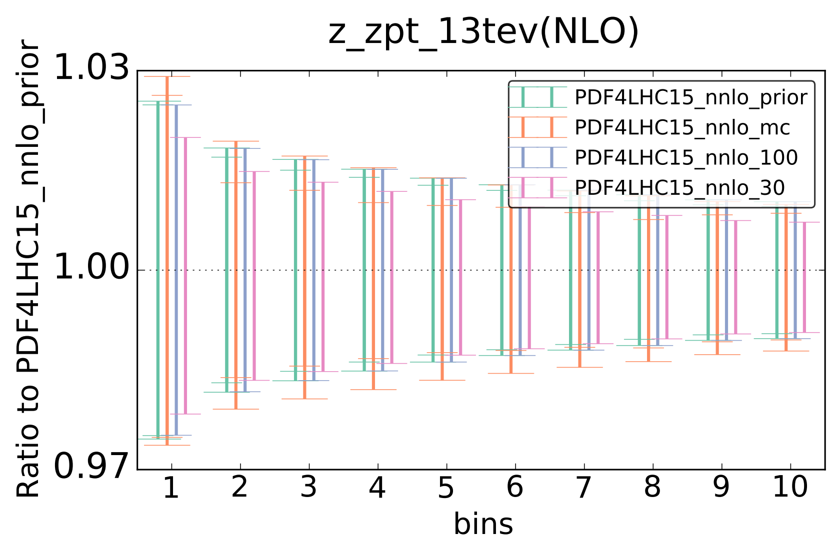
Correlations in PDFs preserved extremely well in compression.

Results using compressed sets for some LHC quantities









Generally all sets work pretty well, even in more extreme regions of kinematics.

There are basically two kinds of situation.

- For assessment of the PDF uncertainty in searches, discovery, acceptance corrections ... (e.g. Higgs, Susy). Use the PDF4LHC prescription.

- When comparing predictions to theory in well-determined standard model processes, e.g. jets, W, Z distributions, top pair cross sections .... Use the individual PDF sets (ABM, CT, HERAPDF, JR, MMHT, NNPDF)

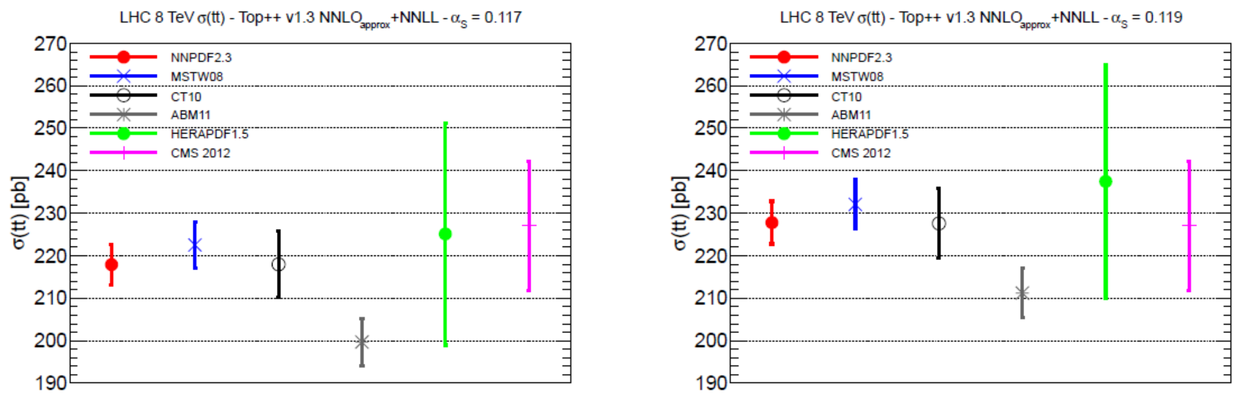


Figure 10: Comparison of the predictions for the top quark pair production at LHC 8 TeV obtained using various NNLO PDF sets. Left plot: results for $\alpha_S(M_Z) = 0.117$. Right plot: results for $\alpha_S(M_Z) = 0.119$. We also show the recent CMS 8 TeV measurements.

Conclusions

All PDF sets have been recently updated with either new data inputs or improvements in methodology, or in many cases both.

Generally good agreement between the sets which fit to global data, both in central values and uncertainties. Improved considerably compared to earlier versions for the gluon.

Some discrepancies with other sets due to different data and/or different procedures (e.g. treatment of heavy quarks). HERA I + II combination does not significantly alter global PDFs.

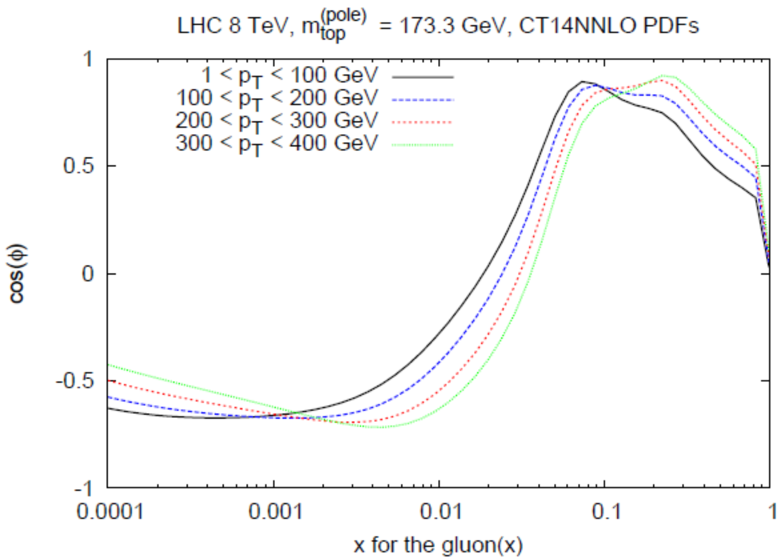
Inclusive top pair production used in some cases and compared to in others. Most PDFs give good predictions, but distinct interplay between $\alpha_S(M_Z^2)$ and m_{top}.

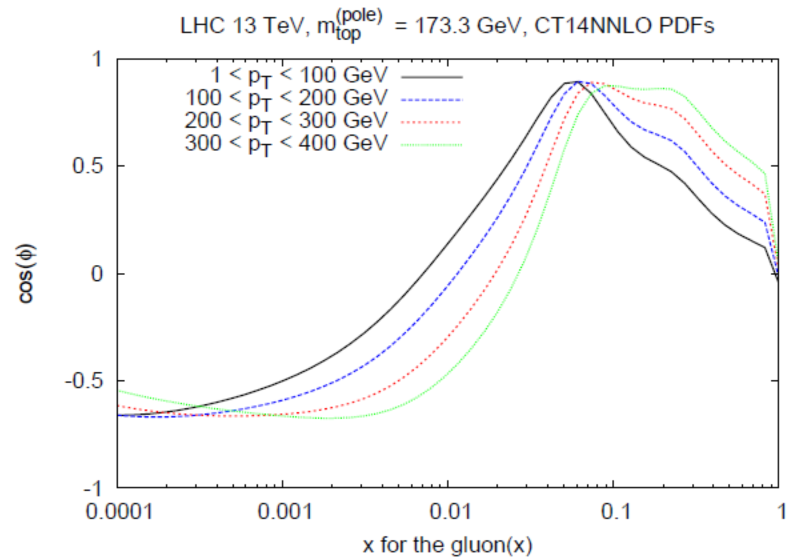
More information will be obtained from differential distributions. Fits at NLO not perfect. Very interesting and useful to see full NNLO.

New ways of combining PDFs $\rightarrow$ PDF4LHC recommendation update.

For many top measurements want to compare and discriminate between PDFs, not check agreement with PDF4LHC prescription value.

BACK-UP


LHC 8 TeV, $m_{top}^{(pole)}$ = 173.3 GeV, CT14NNLO PDFs
1 < p_T < 100 GeV
100 < p_T < 200 GeV
200 < p_T < 300 GeV
300 < p_T < 400 GeV
cos(ϕ)
x for the gluon(x)


LHC 13 TeV, $m_{top}^{(pole)}$ = 173.3 GeV, CT14NNLO PDFs
1 < p_T < 100 GeV
100 < p_T < 200 GeV
200 < p_T < 300 GeV
300 < p_T < 400 GeV
cos(ϕ)
x for the gluon(x)

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

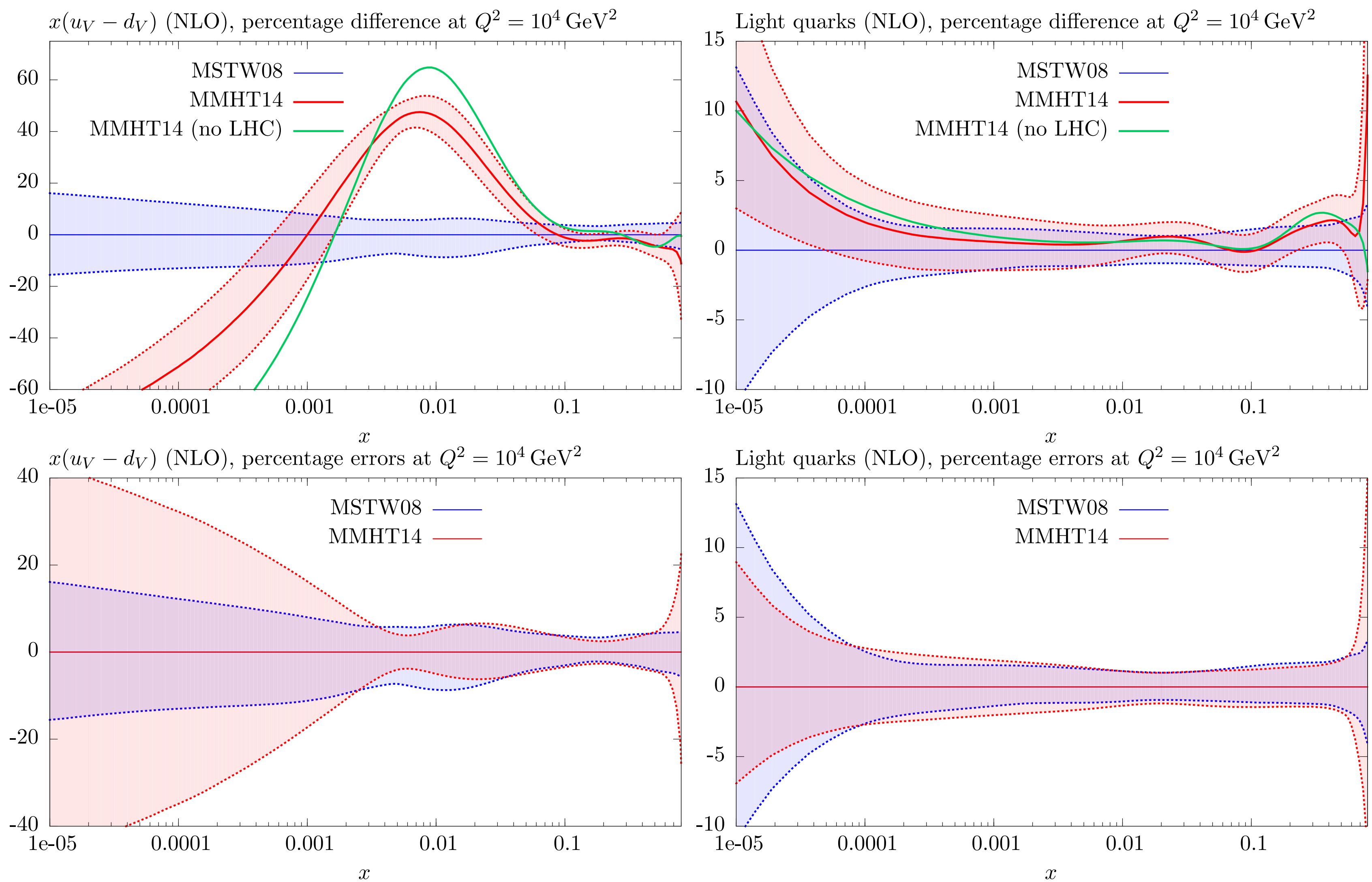
LO $\alpha_S(M_Z^2) = 0.134, 0.135, 0.136$

NLO $\alpha_S(M_Z^2) = 0.117, 0.118, 0.119, 0.120, 0.121$

NNLO $\alpha_S(M_Z^2) = 0.117, 0.118, 0.119$

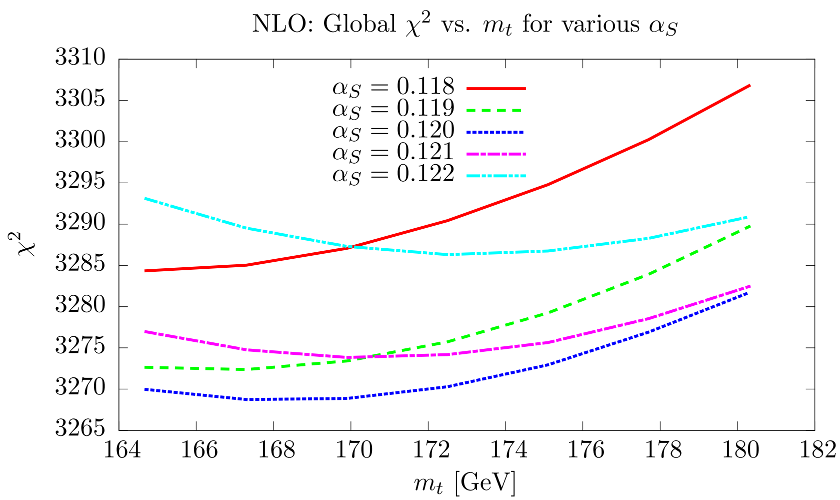
This allows the PDF $+ \alpha_S$ uncertainty to be calculated, if using the prescription of adding in quadrature.

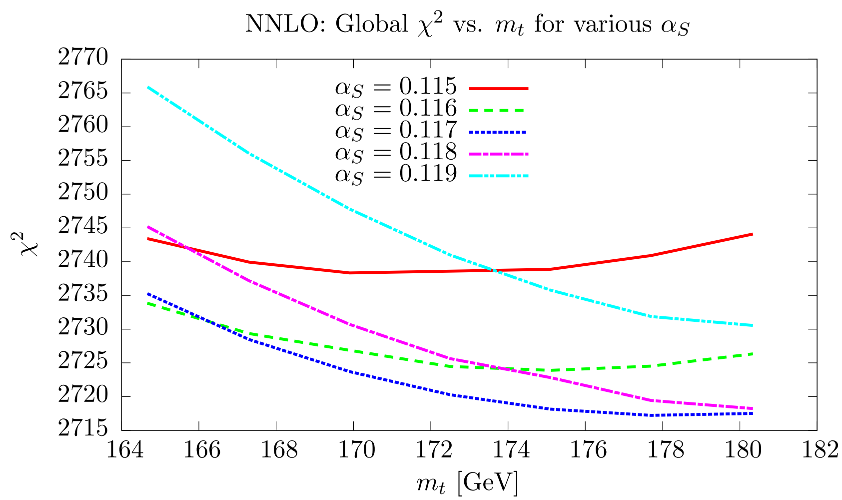
Comparison of PDFs at NLO

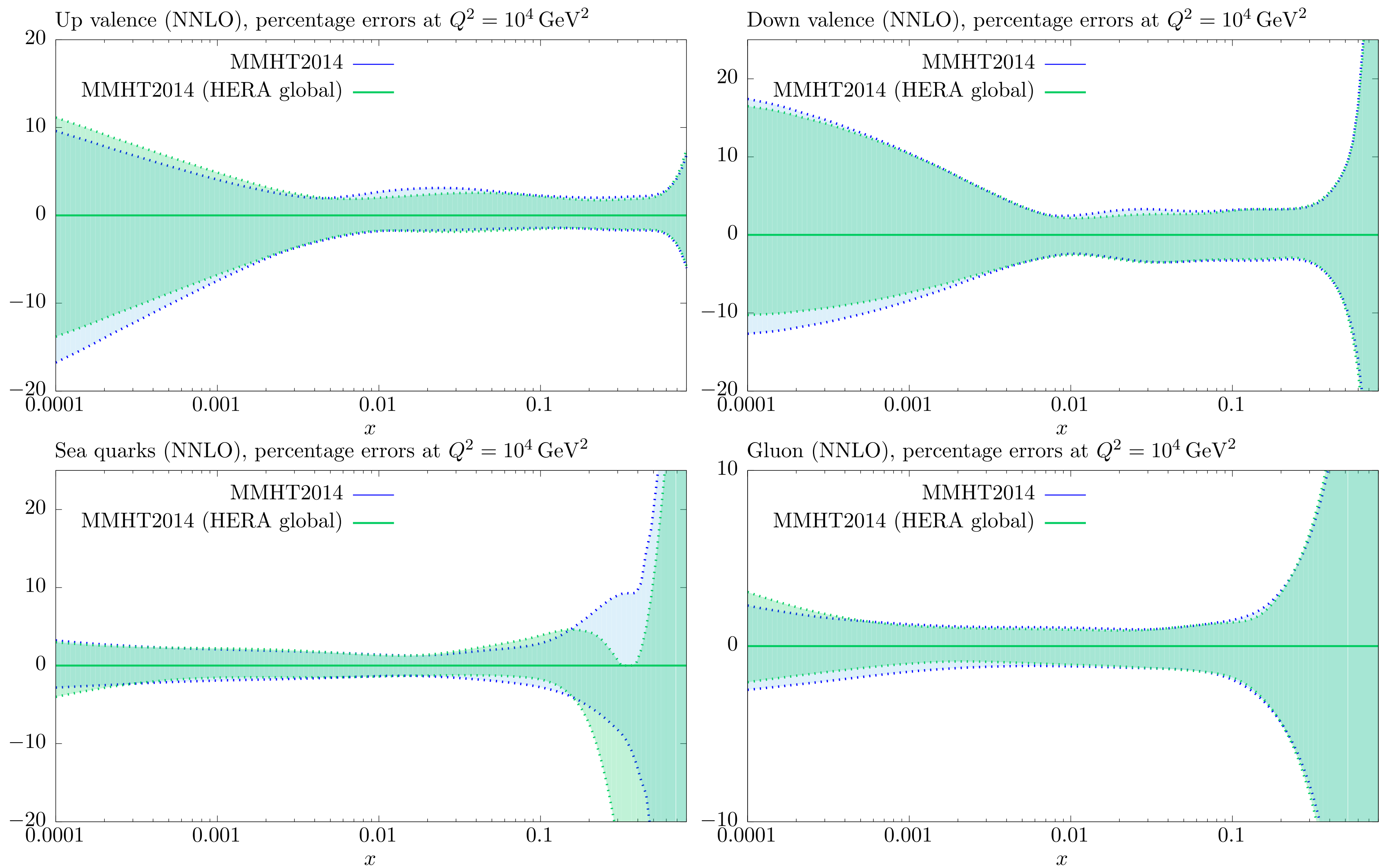


Change in NLO PDFs from all updates, including LHC data updates.

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







Uncertainties (preliminary) quite similar to MMHT2014.

Most obvious improvement in gluon for $x \sim 0.001$.

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.

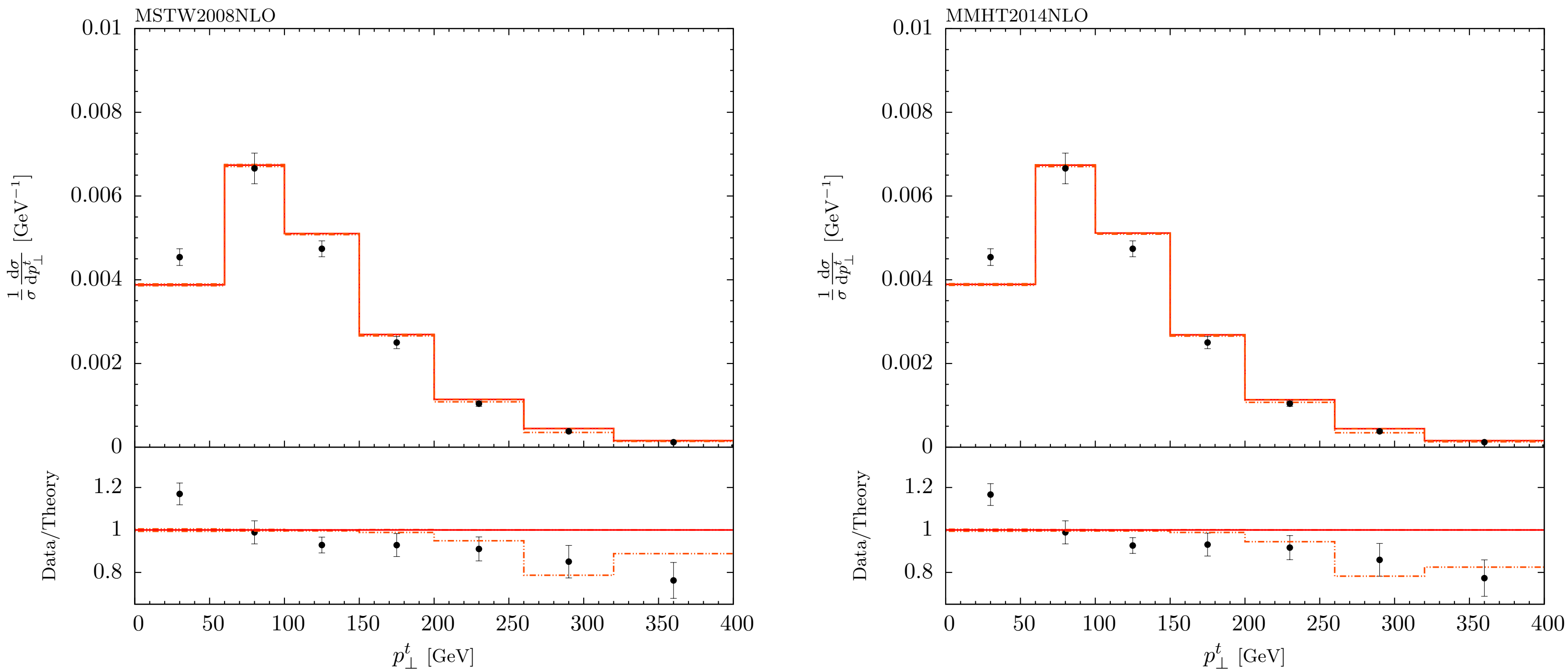
Enormous project of full NNLO calculation (Gehrmann-de-Ridder*et al.*) nearing completion. Some indications of full form.

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

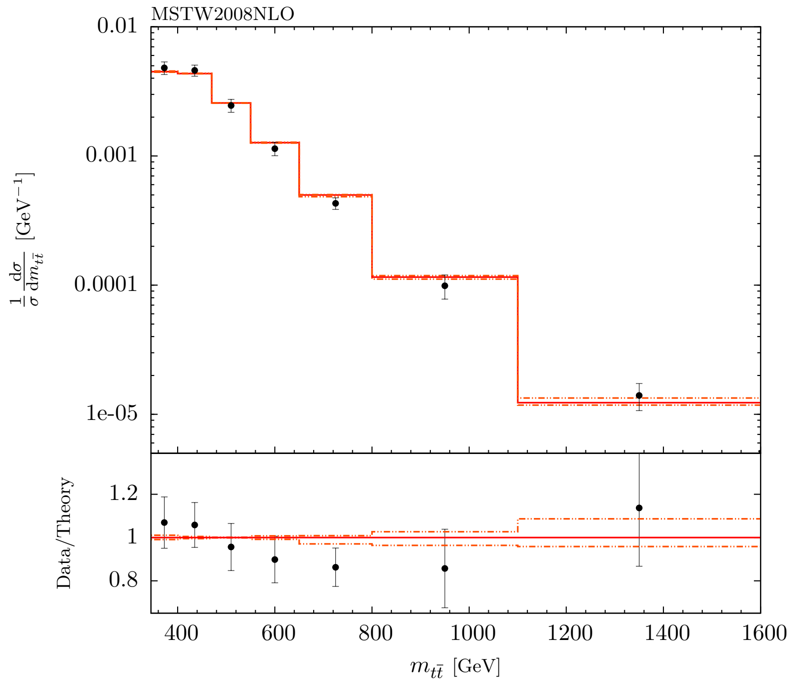
New results – plots by Harland-Lang

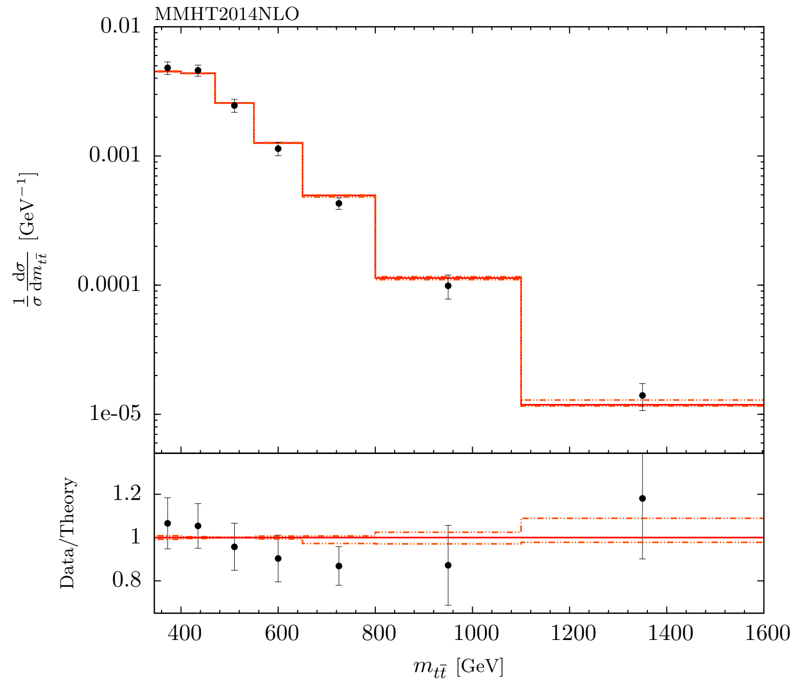
p_T distributions - CMS data



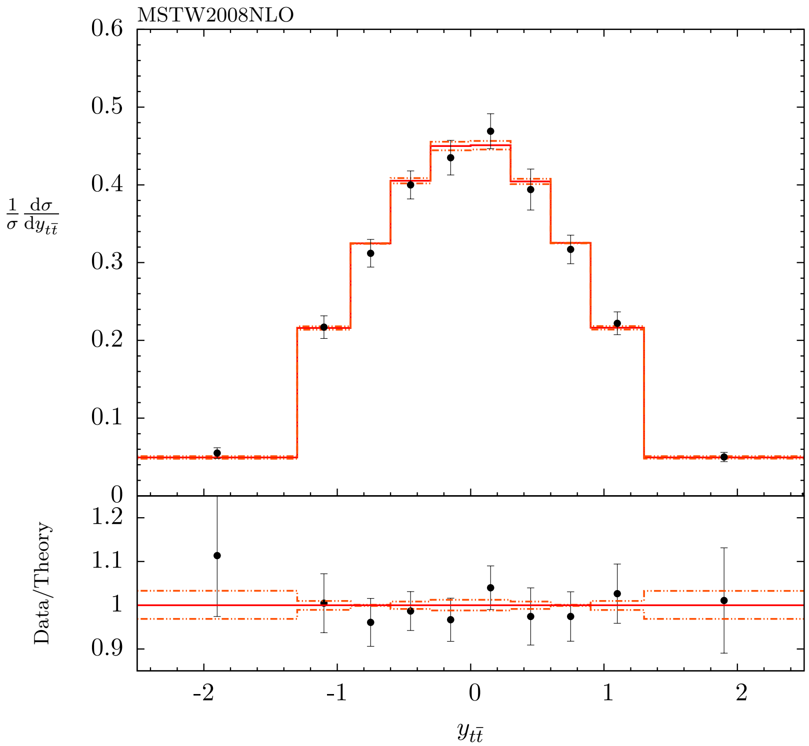
Very little difference between MSTW2008 and MMHT2014 predictions.

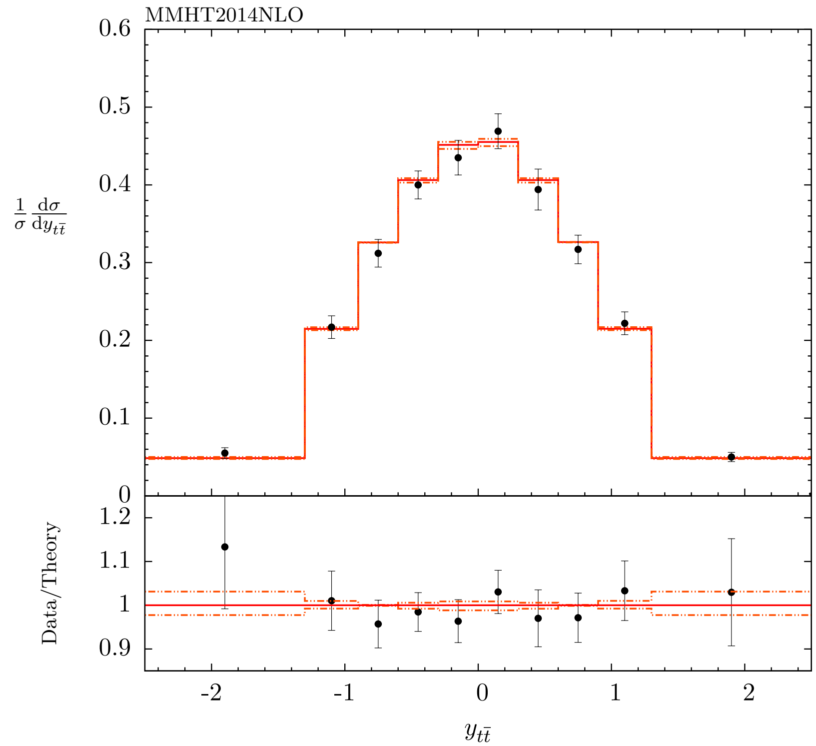
$m_{t\bar{t}}$ distributions - CMS data





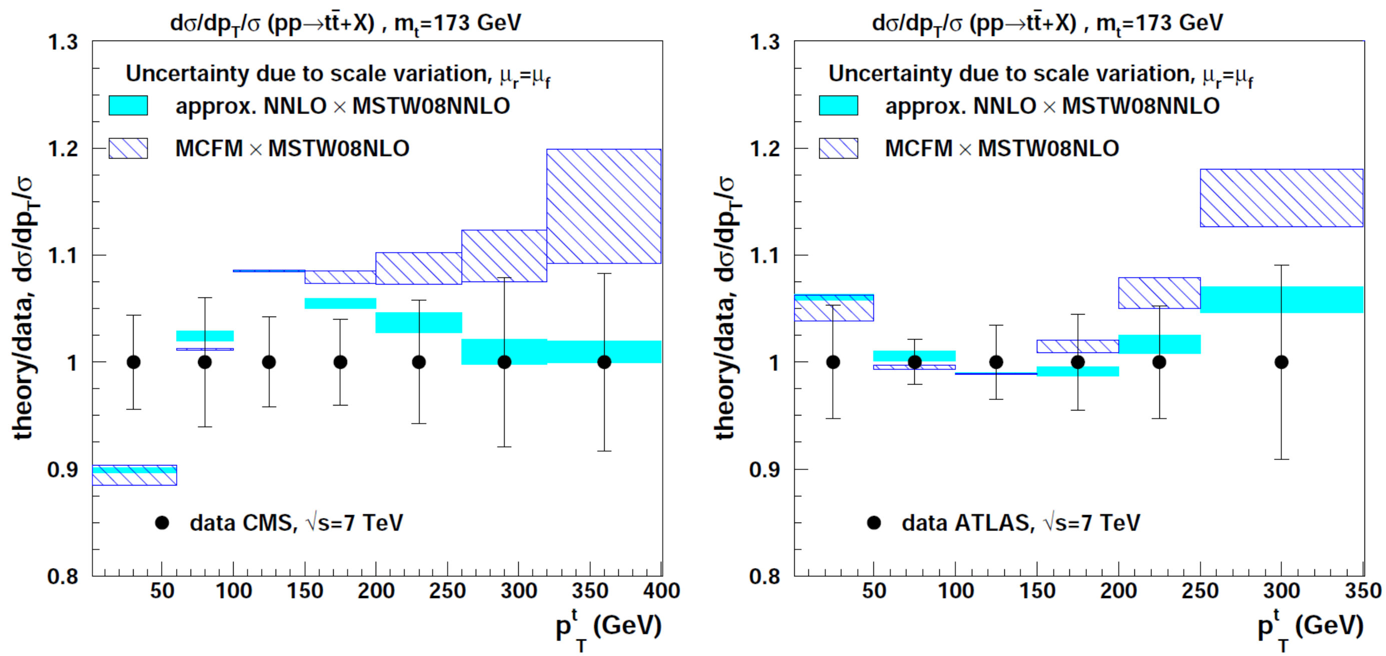
$y_{t\bar{t}}$ distributions - CMS data





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.

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).