PDFs for Higgs Physics

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ISMD 2013

First some history: PDF4LHC

- In 2010, we carried out an exercise to which all PDF groups were invited to participate
- A comparison of NLO predictions for benchmark cross sections at the LHC (7 TeV) using MCFM with prescribed input files
- Benchmarks included
  - W/Z production/rapidity distributions
  - ttbar production
  - Higgs production through gg fusion
    - masses of 120, 180 and 240 GeV
- PDFs used include CTEQ6.6, MSTW08, NNPDF2.0, HERAPDF1.0 ABKM09, GJR08

The PDF4LHC Working Group Interim Report

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All of the benchmark processes were to be calculated with the following settings:

1. at NLO in the $\overline{MS}$ scheme
2. all calculation done in a the 5-flavor quark ZM-VFNS scheme, though each group uses a different treatment of heavy quarks
3. at a center-of-mass energy of 7 TeV
4. for the central value predictions, and for $\pm 68\%$ and $\pm 90\%$ c.l. PDF uncertainties
5. with and without the α_s uncertainties, with the prescription for combining the PDF and α_s errors to be specified
6. repeating the calculation with a central value of $\alpha_s(m_Z)$ of 0.119.

PDF4LHC recommendations(arXiv:1101.0538)

So the prescription for NLO is as follows:

- For the calculation of uncertainties at the LHC, use the envelope provided by the central values and PDF+α_s errors from the MSTW08, CTEQ6.6 and NNPDF2.0 PDFs, using each group's prescriptions for combining the two types of errors. We propose this definition of an envelope because the deviations between the predictions are as large as their uncertainties. As a central value, use the midpoint of this envelope. We recommend that a 68%c.l. uncertainty envelope be calculated and the α_s variation suggested is consistent with this. Note that the CTEQ6.6 set has uncertainties and α_s variations provided only at 90%c.l. and thus their uncertainties should be reduced by a factor of 1.645 for 68%c.l.. Within the quadratic approximation, this procedure is completely correct.

So the prescription at NNLO is:

- As a central value, use the MSTW08 prediction. As an uncertainty, take the same percentage uncertainty on this NNLO prediction as found using the NLO uncertainty prescription given above.

So basically, this is a factor of 2.

At the time of this prescription, neither CTEQ nor NNPDF had NNLO PDFs.

More benchmarking

2 studies in 2011 Les Houches proceedings(1203.6803)

- Benchmarking for inclusive DIS cross sections
  - with S. Alekhin, A. Glazov, A. Guffanti, P. Nadolsky, and J. Rojo
  - excellent agreement observed
- Benchmark comparison of NLO jet cross sections
  - J. Gao, Z. Liang, H.-L. Lai, P. Nadolsky, D. Soper, C.-P. Yuan
  - compare EKS results with FastNLO (NLOJET++)
  - excellent agreement between the two if care is taken on settings for jet algorithm, recombination scheme, QCD scale choices

Higgs Yellow Reports

CERN–2011–002
17 February 2011

arXiv:1101.0593v3 [hep-ph] 20 May 2011

ORGANISATION EUROPÉENNE POUR LA RECHERCHE NUCLÉAIRE
CERN EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Handbook of LHC Higgs cross sections:
1. Inclusive observables

Report of the LHC Higgs Cross Section Working Group

Editors: S. Dittmaier
C. Mariotti
G. Passarino
R. Tanaka

GENEVA
2011

paralleled 2010 PDF4LHC report

arXiv:1201.3084v1 [hep-ph] 15 Jan 2012

Handbook of LHC Higgs cross sections:
2. Differential Distributions

Report of the LHC Higgs Cross Section Working Group

Editors: S. Dittmaier
C. Mariotti
G. Passarino
R. Tanaka

more extensive use of PDF and cross section correlations

- Correlations differ between PDFs more than I would have originally suspected
- Again, MSTW, CTEQ and NNPDF correlations tend to be similar

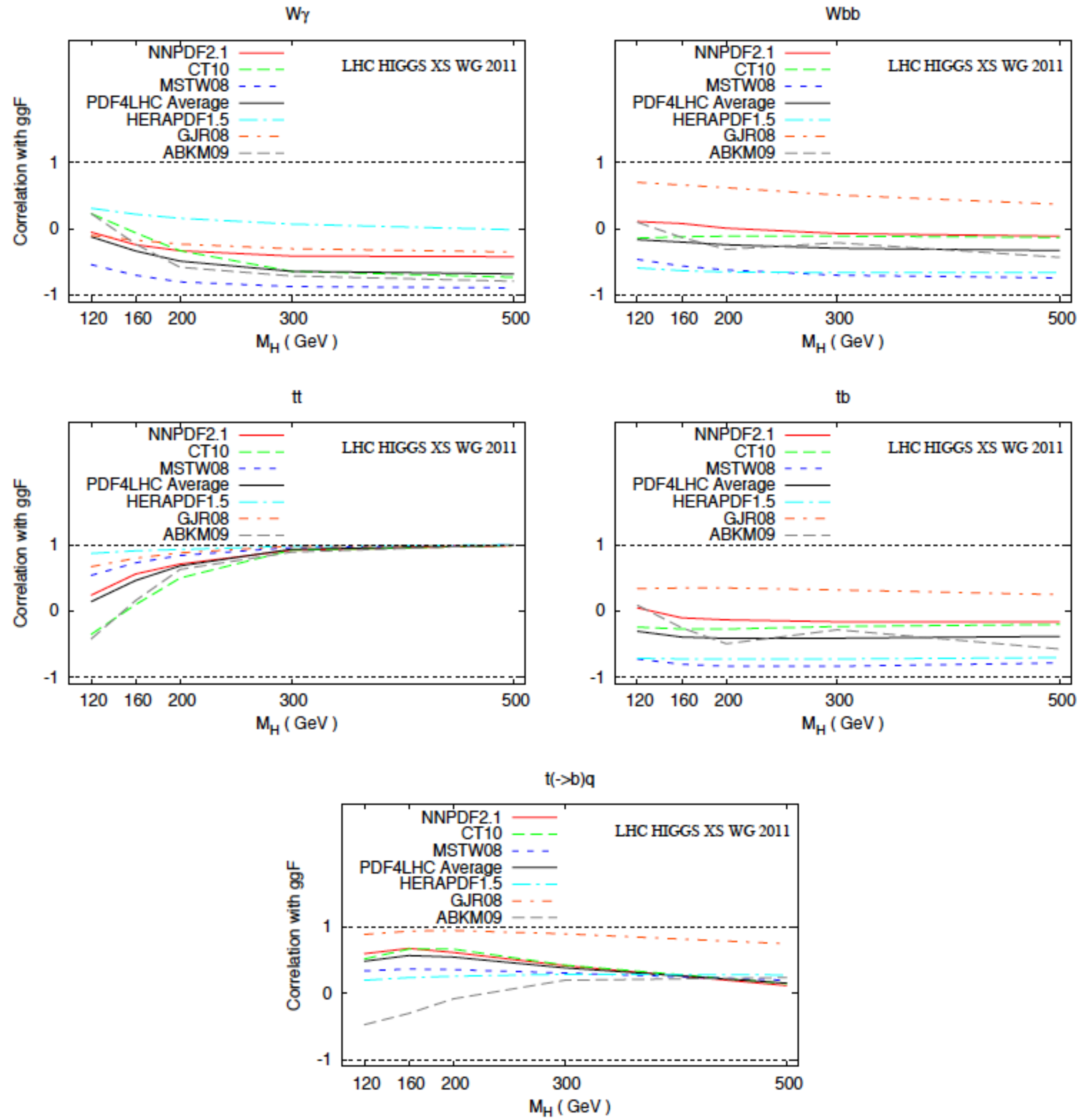

Fig. 15: Correlation between the gluon fusion gg $\rightarrow$ H process and other signal and background processes as a function of $M_{\rm H}$. We show the results for the individual PDF sets as well as the up-to-date PDF4LHC average.

Followup

- Study of NNLO PDFs from 5 PDF groups (no new updates for JR)
  - drawing from what Graeme Watt had done, but now including CT10 NNLO, and NNPDF2.3 NNLO
    - HERAPDF has upgraded to HERAPDF1.5; ABM09->ABM11
  - using a common values of α_s (0.118) as a baseline; varying in range from 0.117 to 0.119)
  - including a detailed comparisons to LHC data which have provided detailed correlated systematic error information, keeping track of required systematic error shifts, normalizations, etc
    - ATLAS 2010 W/Z rapidity distributions
    - ATLAS 2010 inclusive jet cross section data
    - CMS 2011 W lepton asymmetry
    - LHCb 2010 W lepton rapidity distributions in forward region
- The effort was led by Juan Rojo and Pavel Nadolsky and has resulted in an independent publication
- The results from this paper will be utilized in a subsequent PDF4LHC document(s)
- …and are now in YR3

Benchmark paper

- Not officially a PDF4LHC document but will be used as input to future recommendations
- Comparisons only at NNLO, but NLO comparisons available at http://nnpdf.hepforge.org/html/pdfbench/catalog

CERN-PH-TH/2012-263
Edinburgh 2012/21
SMU-HEP-12-16
LCTS/2012-26
IFUM-1003-FT

Parton distribution benchmarking with LHC data

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Abstract:

We present a detailed comparison of the most recent sets of NNLO PDFs from the ABM, CT, HERAPDF, MSTW and NNPDF collaborations. We compare parton distributions at low and high scales and parton luminosities relevant for LHC phenomenology. We study the PDF dependence of LHC benchmark inclusive cross sections and differential distributions for electroweak boson and jet production in the cases in which the experimental covariance matrix is available. We quantify the agreement between data and theory by computing the χ^2 for each data set with all the various PDFs. PDF com-

PDFs used in the comparison

PDF set	Reference	$\alpha_s^{(0)}$ (NLO)	α_s range (NLO)	$\alpha_s^{(0)}$ (NNLO)	α_s range (NNLO)
ABM11 $N_f = 5$	[3]	0.1181	$[0.110, 0.130]$	0.1134	$[0.104, 0.120]$
CT10	[6]	0.118	$[0.112, 0.127]$	0.118	$[0.112, 0.127]$
HERAPDF1.5	[9, 10]	0.1176	$[0.114, 0.122]$	0.1176	$[0.114, 0.122]$
MSTW08	[15]	0.1202	$[0.110, 0.130]$	0.1171	$[0.107, 0.127]$
NNPDF2.3	[13]	all	$[0.114, 0.124]$	all	$[0.114, 0.124]$

Table 1: PDF sets used in this paper. We quote the value $\alpha_s^{(0)}$ for which PDF uncertainties are provided, and the range in α_s in which PDF central values are available (in steps of 0.001). For ABM11 the α_s varying PDF sets are only available for the $N_f = 5$ PDF set.

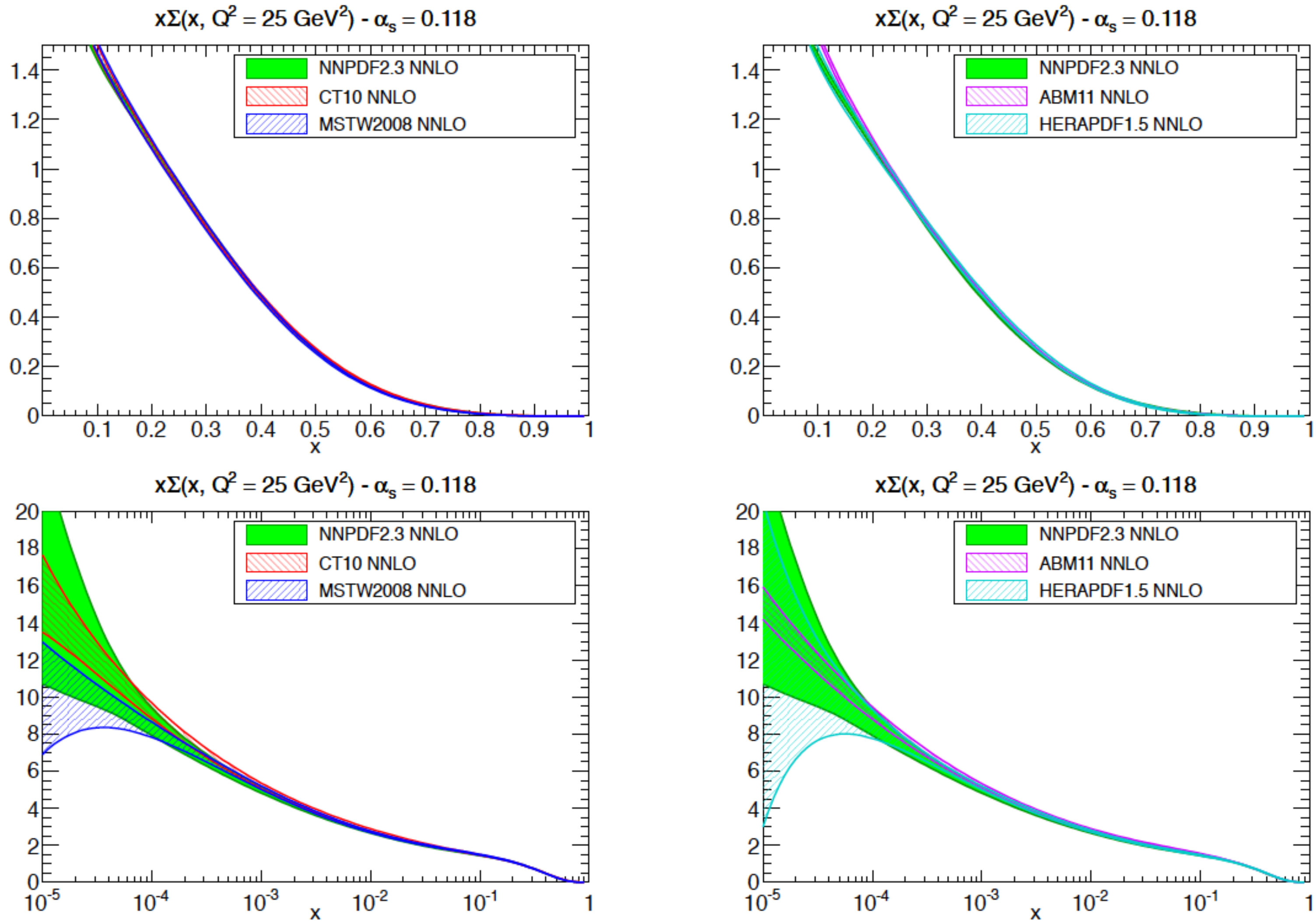
No updates of JR since 2009.

PDF comparisons

…results for other values of α_s and at NLO available on the HEPFORGE website

good agreement for all sets for quark singlet distribution

quark singlet PDFs



Comparison of PDFs

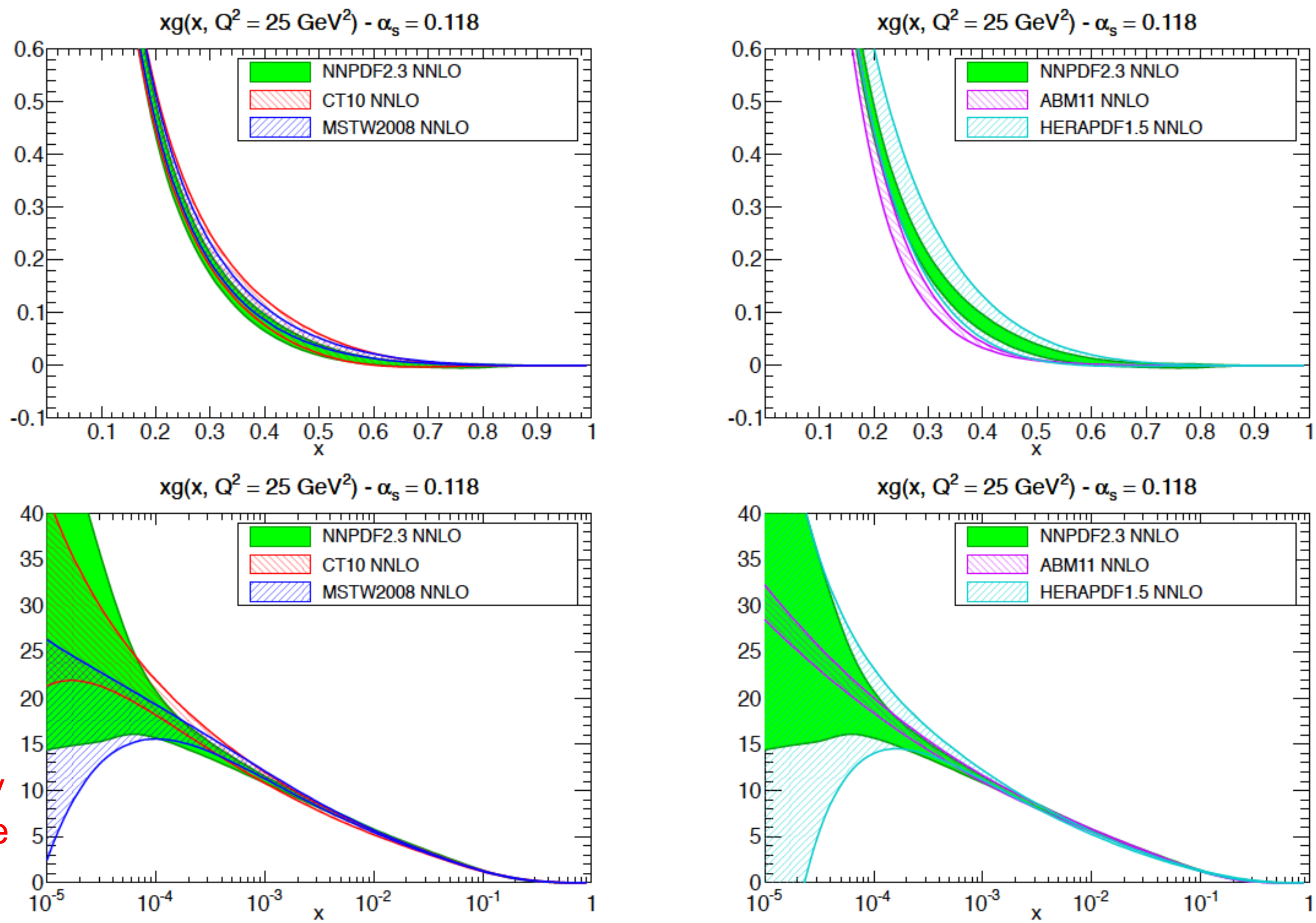
CT10, MSTW08 and NNPDF2.3 gluon distributions all in reasonable agreement

The 1-sigma uncertainty bands overlap for all values of x

Differences are larger for ABM11

HERAPDF uncertainties somewhat larger at low x; noticeably larger at high x due to lack of collider jet data

gluon PDF



PDF luminosities

gluon-gluon and gluon-quark luminosities in reasonable agreement for CT10, MSTW08 and NNPDF2.3 for full range of invariant masses

HERAPDF1.5 uncertainties larger in general

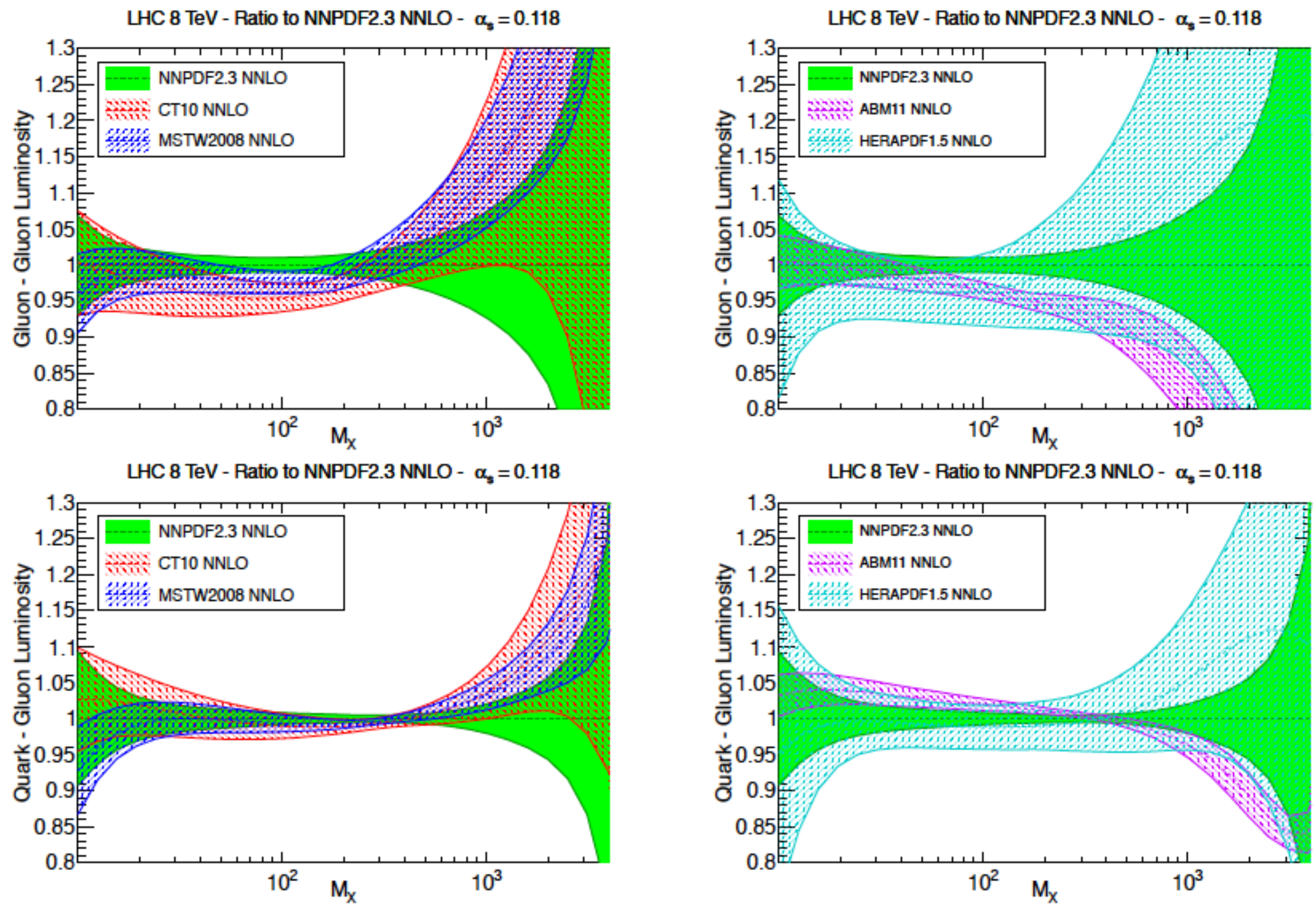


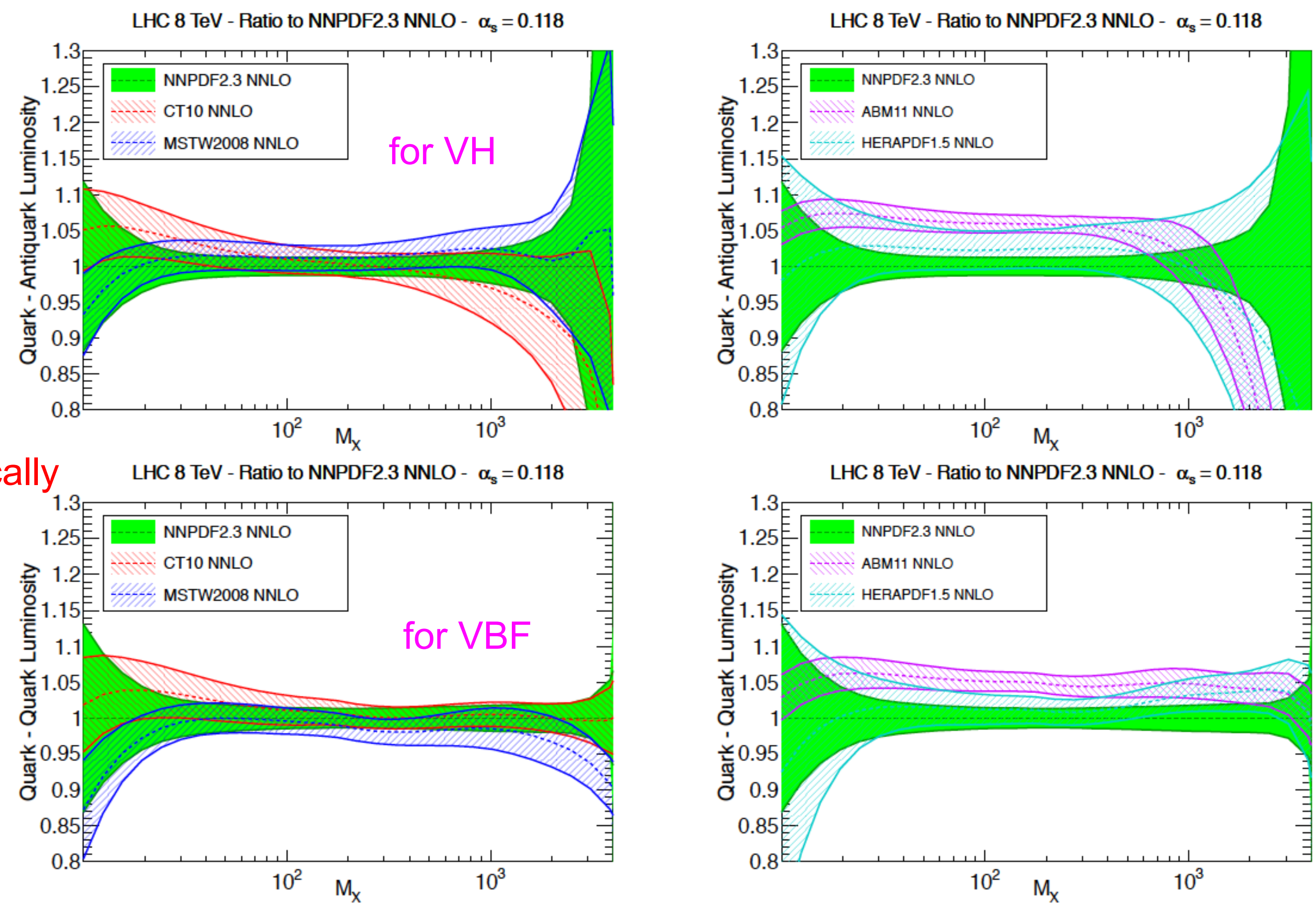
Figure 6: The gluon-gluon (upper plots) and quark-gluon (lower plots) luminosities, Eq. (2), for the production of a final state of invariant mass M_X (in GeV) at LHC 8 TeV. The left plots show the comparison between NNPDF2.3, CT10 and MSTW08, while in the right plots we compare NNPDF2.3, HERAPDF1.5 and MSTW08. All luminosities are computed at a common value of $\alpha_s = 0.118$.

PDF luminosities

quark-quark and quark-antiquark

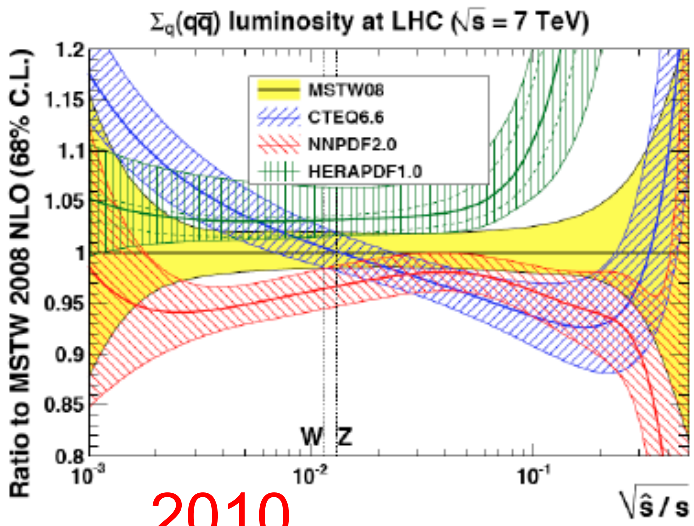
quark-antiquark luminosities for CT10, MSTW08 and NNPDF2.3 overlap almost 100% in W/Z range

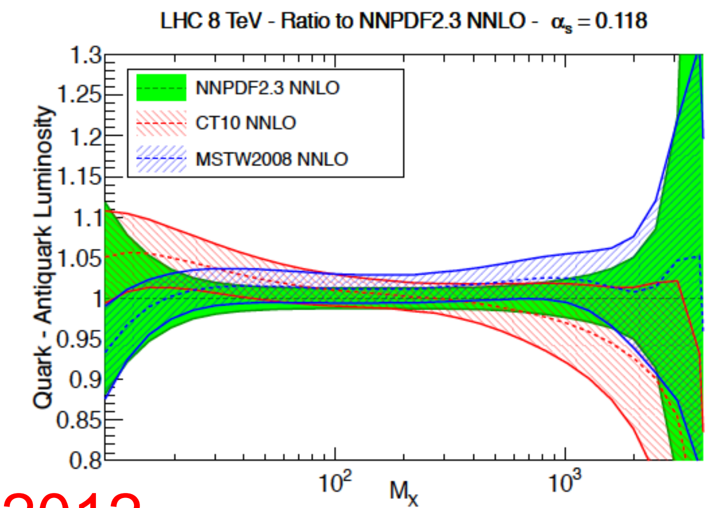
ABM11 systematically larger at small mass, then falls off more rapidly at high mass



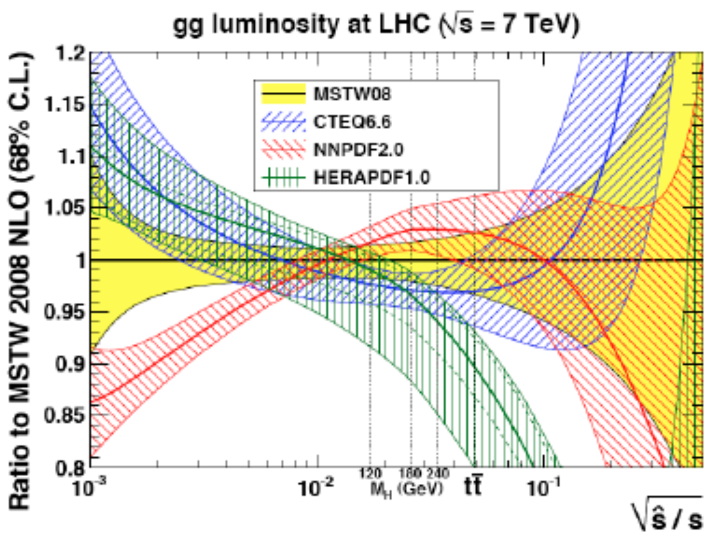
Uncertainties have improved

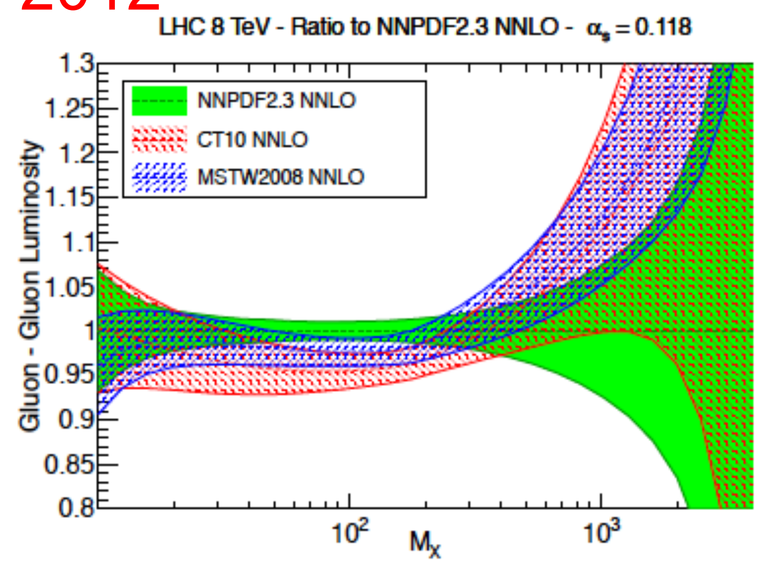
- …with additional data and in going from NLO to NNLO





2010 → 2012





Compare relative luminosity uncertainties

good agreement in size of uncertainties between the 3 global PDFs

larger uncertainties of HERAPDF1.5 apparent

ABM11 uncertainties smaller at high mass

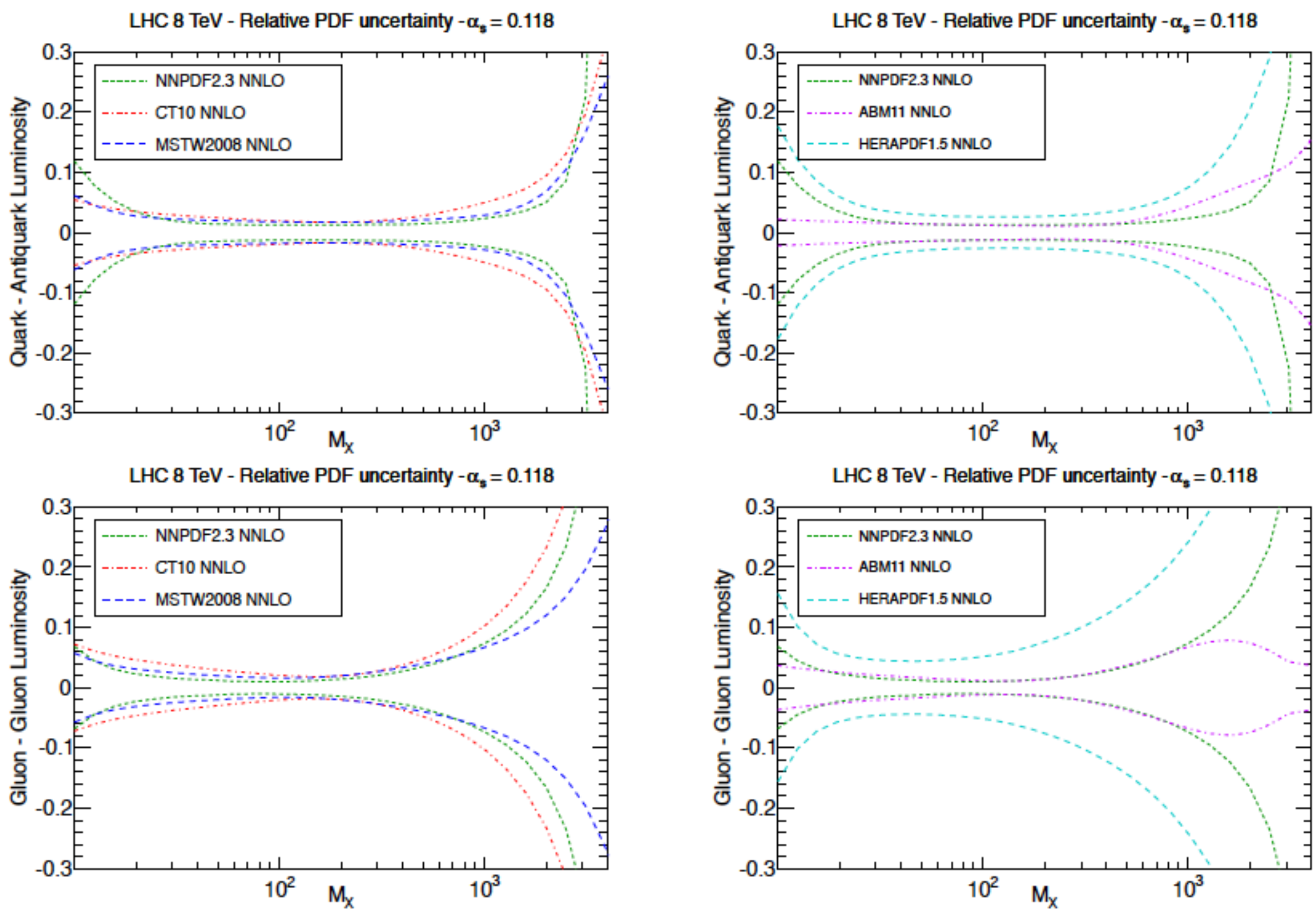
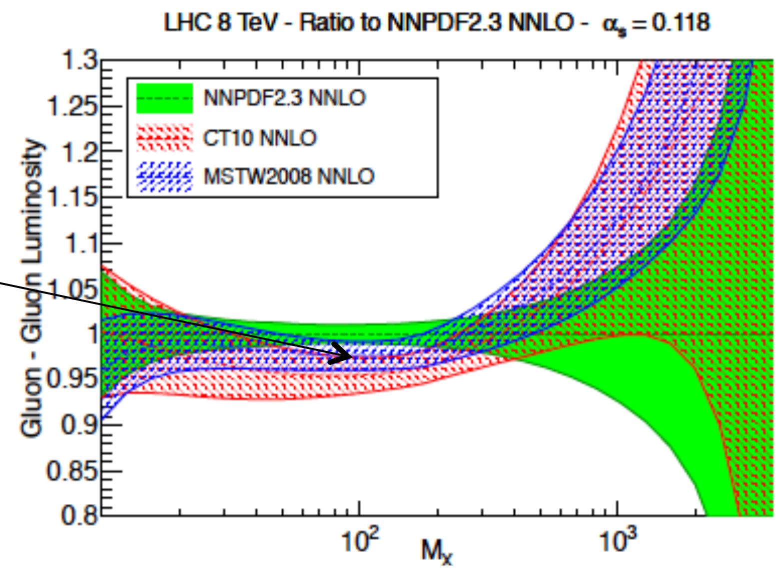
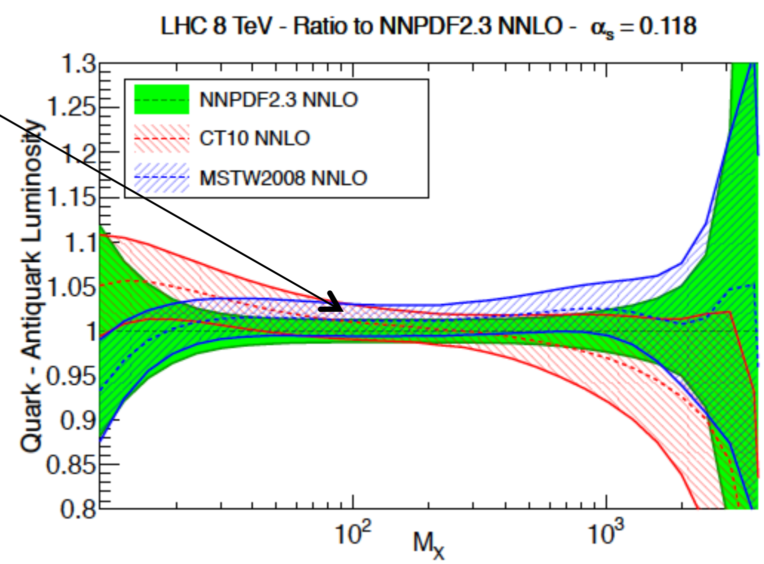


Figure 8: The relative PDF uncertainties in the quark-antiquark luminosity (upper plots) and in the gluon-gluon luminosity (lower plots), for the production of a final state of invariant mass M_X (in GeV) at the LHC 8 TeV. All luminosities are computed at a common value of $\alpha_s = 0.118$.

NNLO PDF uncertainties

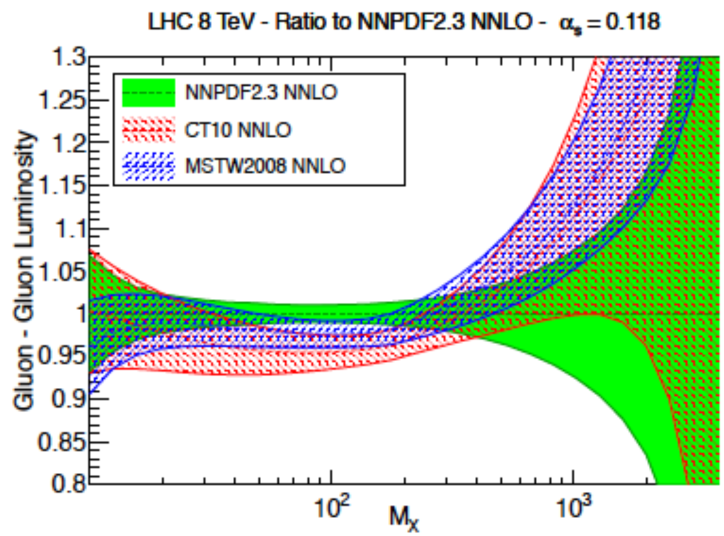
- Factor of 2 expansion of MSTW2008 error basically works for gg initial states (like 125 Higgs)
- …but maybe an overestimate for qQ initial states

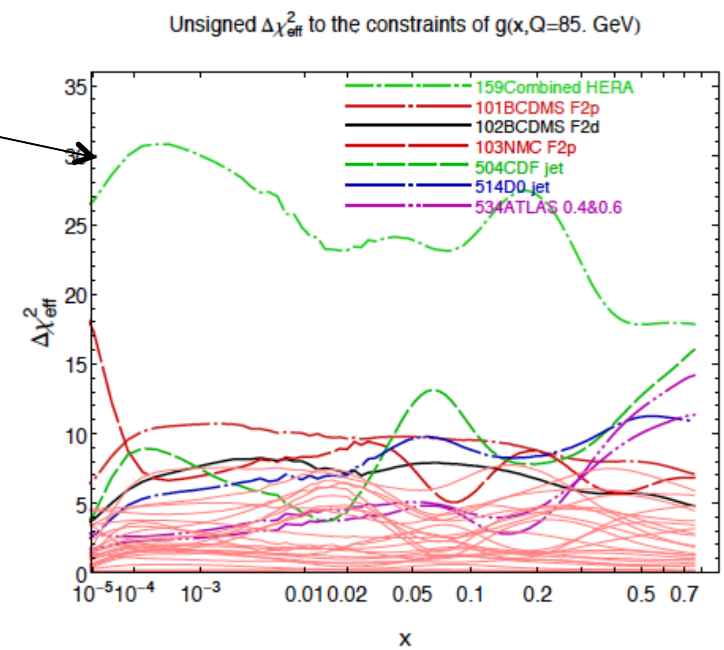




…but are they good enough?

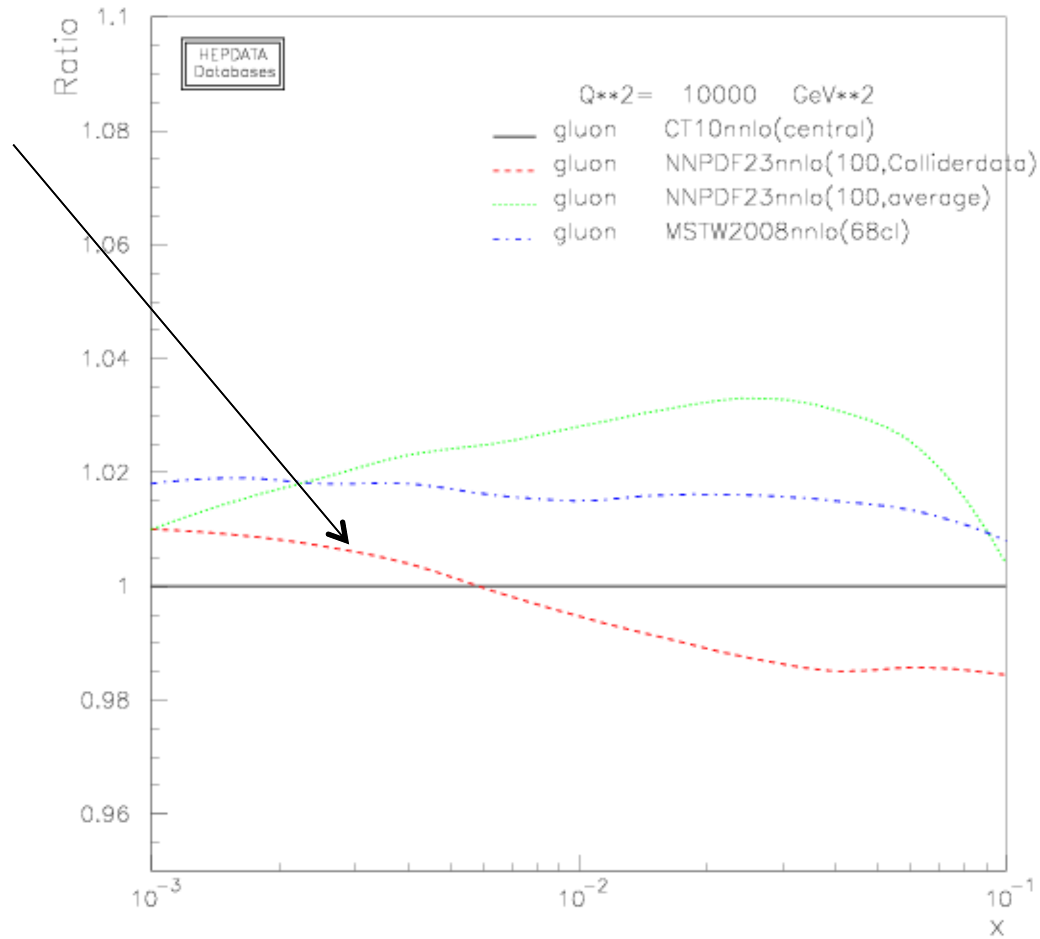
- Can we further improve the gg PDF luminosity uncertainty in the Higgs mass region?
  - PDF+α_s error is now the dominant theory error for ggF
- NNPDF2.3 marks the high edge and CT10 the low edge
  - full gg uncertainty is ~ factor of 2 more than any of the individual group uncertainties
- The gluon in this region is determined largely by the HERA combined Run 1 data set, but fixed target (NMC and BCDMS) have big impact as well
- There may be issues relating to specific heavy quark schemes/ charm quark masses
- This was a project that started at Les Houches





PDF Higgs Projects

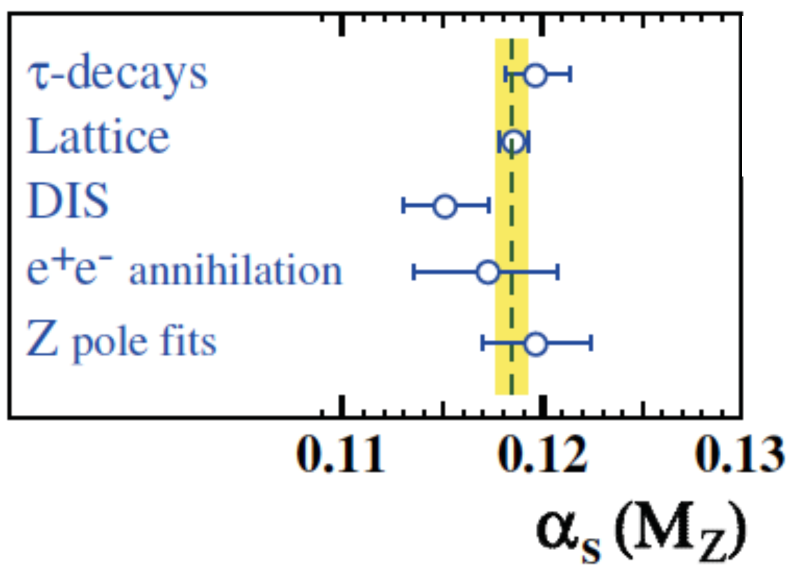
- NNPDF2.3 fit only to collider data leads to a slightly different gluon and a prediction for the gg->Higgs cross section at 8 TeV in better agreement with CT10 and MSTW08
  - but factor of 2 larger uncertainties; we need BCDMS and NMC
- We will re-investigate the impact of BCDMS and NMC data on Higgs cross section predictions
  - impact is on the order of a few percent, but this is one place where that order of magnitude is critical



so we may be able to improve the PDF uncertainty but there is still a strong $\alpha_s(m_Z)$ dependence

$\alpha_s(m_Z)$

- Right now the Higgs Cross Section Working Group is using a mean value for $\alpha_s(m_Z)$ of 0.118 with 90% CL error of 0.002 (68%CL error of 0.012), or an inflation of the world average uncertainties; the α_s error is added in quadrature with the PDF error
- The world average is dominated by lattice results
- I was reasonably convinced at Snowmass that the lattice results are robust enough, so that an uncertainty of 0.012 (at 68% CL) may not be fair
- So I may try to reduce the Higgs Working Group uncertainty, especially if we're successful in reducing the PDF uncertainty



variety of different calculations/groups results in very compatible results

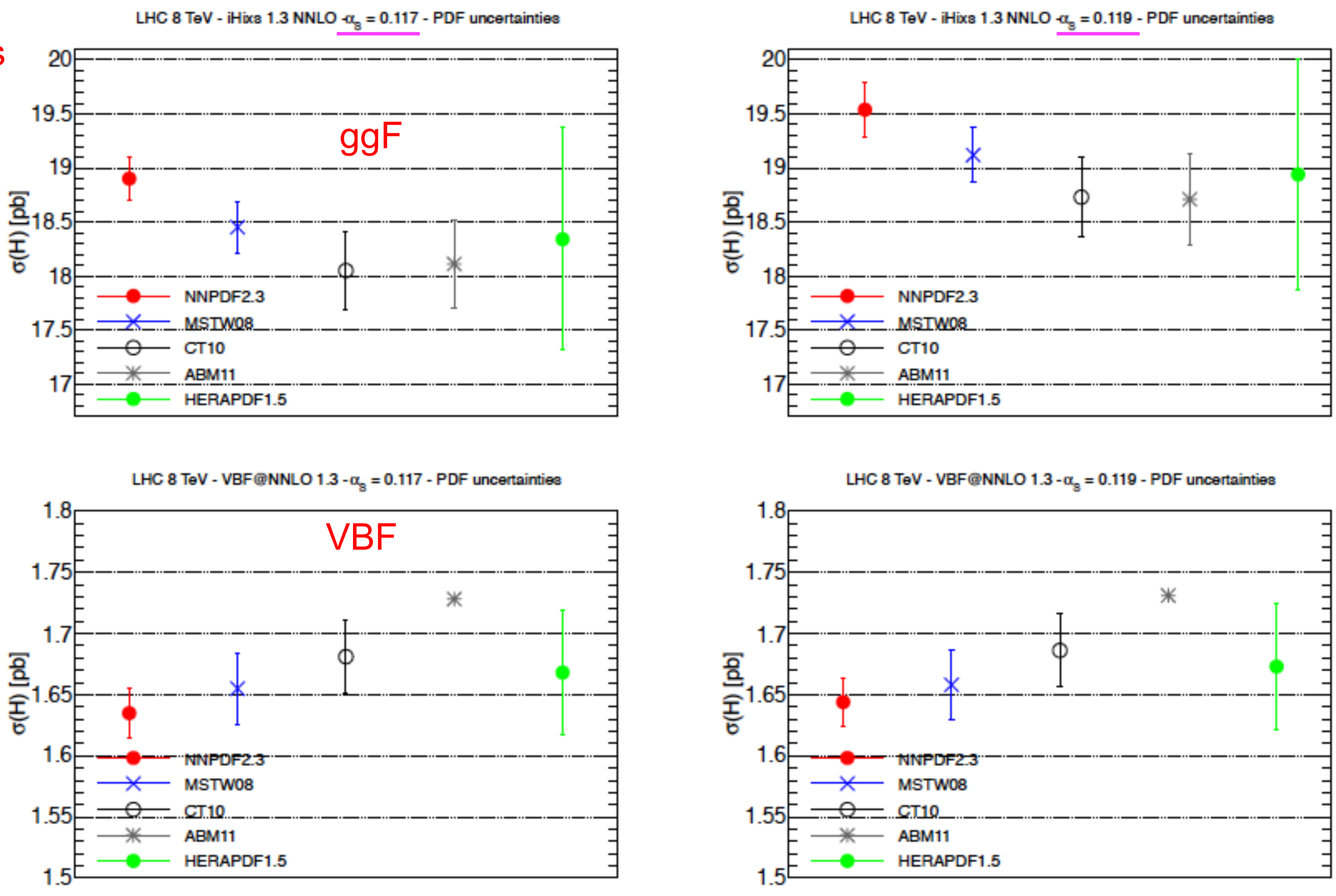
Figure 1-1. *Summary of values of $\alpha_s(M_Z^2)$ obtained for various sub-classes of measurements. The world average value of $\alpha_s(M_Z^2) = 0.1184 \pm 0.0007$ is indicated by the dashed line and the shaded band. Figure taken from [1].*

8 TeV Higgs cross section predictions

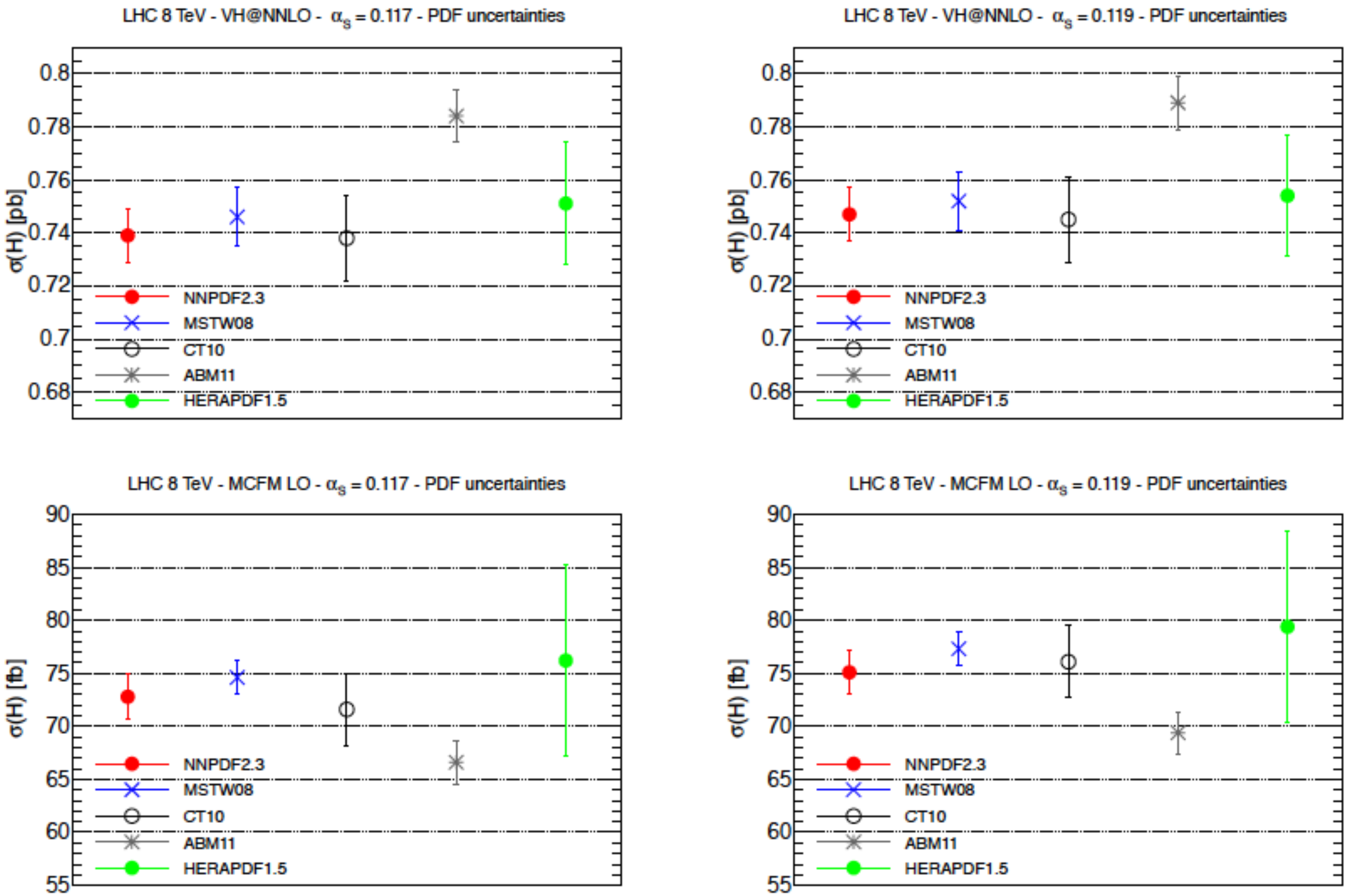
cross sections calculated at NNLO using a scale of m_H

ABM11 and HERAPDF1.5 predictions within error envelope

NB: ABM11 cross section would be lower if native value of α_s (0.1134) used



More 8 TeV Higgs cross section predictions



8 TeV NNLO Higgs Cross Section Predictions

Gluon Fusion (pb)					
$\alpha_S(M_Z)$	NNPDF2.3	MSTW08	CT10	ABM11	HERAPDF1.5
0.117	18.90 ± 0.20	18.45 ± 0.24	18.05 ± 0.36	18.11 ± 0.41	18.34 ± 1.03
0.119	19.54 ± 0.25	19.12 ± 0.25	18.73 ± 0.37	18.71 ± 0.42	18.94 ± 1.07

Vector Boson Fusion (pb)					
$\alpha_S(M_Z)$	NNPDF2.3	MSTW08	CT10	ABM11	HERAPDF1.5
0.117	1.635 ± 0.020	1.655 ± 0.029	1.681 ± 0.030	1.728 ± 0.020	1.668 ± 0.051
0.119	1.644 ± 0.020	1.658 ± 0.029	1.686 ± 0.030	1.731 ± 0.020	1.673 ± 0.051

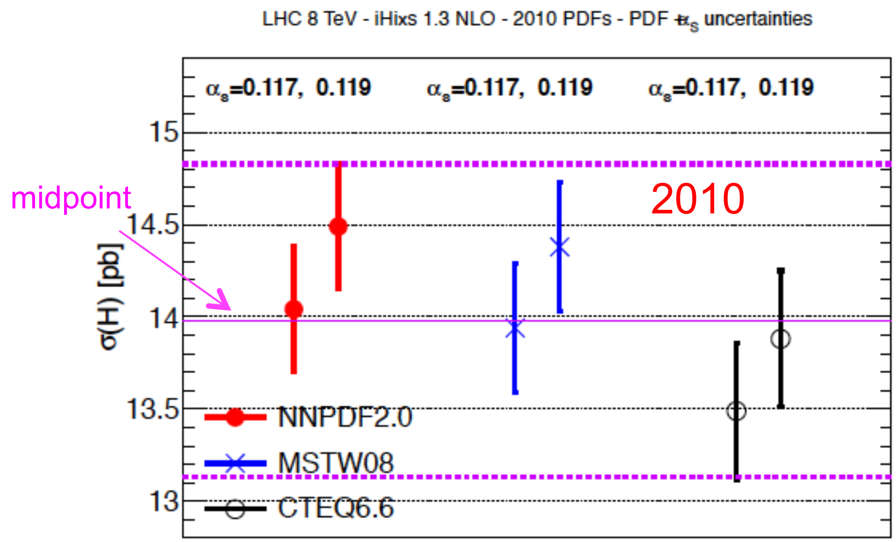
WH production (pb)					
$\alpha_S(M_Z)$	NNPDF2.3	MSTW08	CT10	ABM11	HERAPDF1.5
0.117	0.739 ± 0.010	0.746 ± 0.011	0.738 ± 0.016	0.784 ± 0.010	0.751 ± 0.023
0.119	0.747 ± 0.010	0.752 ± 0.011	0.745 ± 0.016	0.789 ± 0.010	0.754 ± 0.023

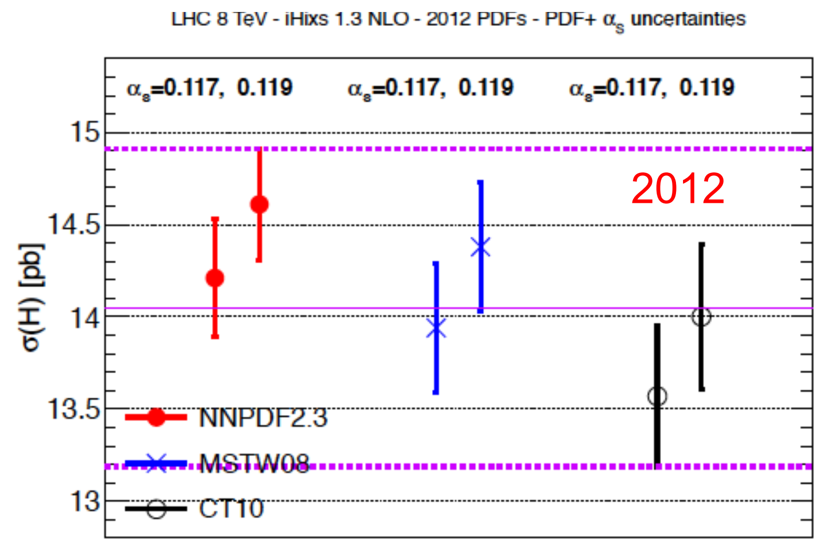
$t\bar{t}H$ associated production (fb)					
$\alpha_S(M_Z)$	NNPDF2.3	MSTW08	CT10	ABM11	HERAPDF1.5
0.117	72.8 ± 2.1	74.6 ± 1.6	71.6 ± 3.4	66.6 ± 2.0	76.2 ± 9.0
0.119	75.1 ± 2.0	77.3 ± 1.6	76.1 ± 3.4	69.4 ± 2.0	79.4 ± 9.0

Table 3: The cross sections for Higgs production at 8 TeV in various channels using the settings described in the text. From top to bottom: gluon fusion, vector boson fusion, WH production and $t\bar{t}H$ production. We have assumed a Standard Model Higgs boson with mass $m_H = 125$ GeV. We show the results for two different values of $\alpha_S(M_Z)$, 0.117 and 0.119.

Revisit prescriptions (for 8 TeV cross sections)

$\sigma_H^{\rm NLO} = 13.98 \pm 0.85 \text{ pb}, \qquad (\pm 6.1\% \text{ "PDF} + \alpha_s\text{"}) \rightarrow \sigma_H^{\rm NLO} = 14.05 \pm 0.86 \text{ pb}, \qquad (\pm 6.1\% \text{ "PDF} + \alpha_s\text{"})$





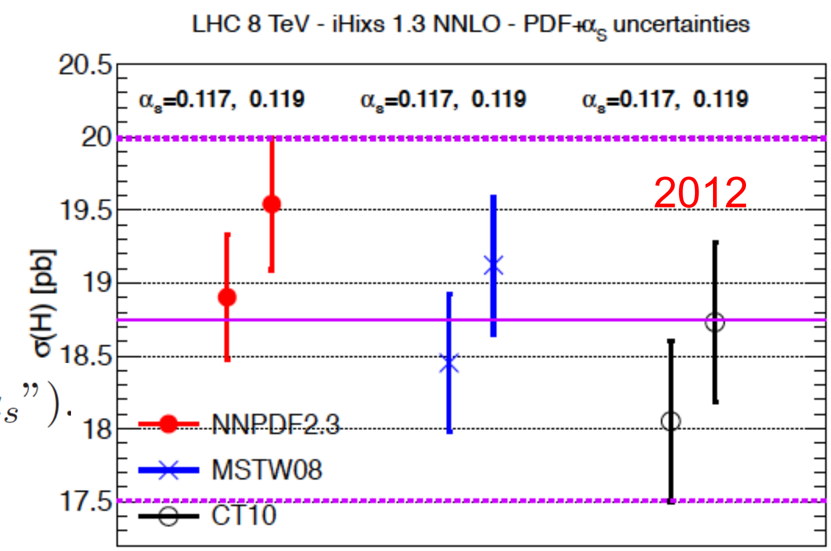
$\sigma_H^{NNLO} = 18.75 \pm 1.24 \text{ pb}, \qquad (6.6\% \text{ "PDF} + \alpha_s\text{"}).$

Compare to MSTW08 NNLO value of 18.45 pb (2010 prescription)

HXSWG 8 TeV NNLO cross section

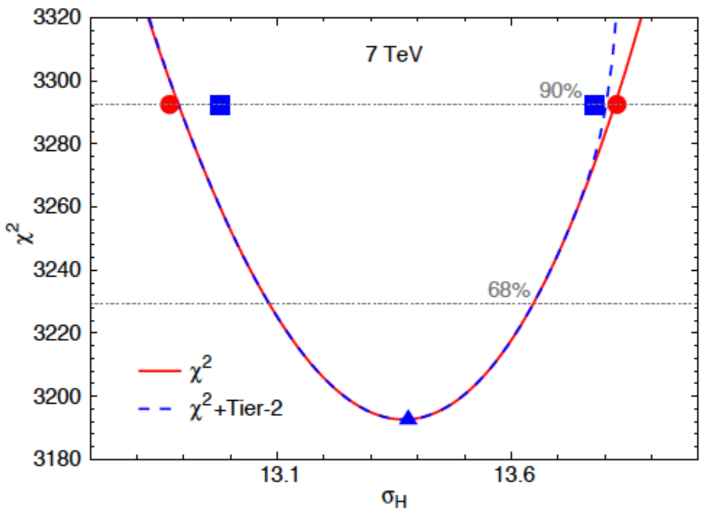
$\sigma_H^{\rm NNLO} = 19.52 \pm 1.41 \text{ pb}, \qquad (\pm 7.2\% \text{ "PDF} + \alpha_s\text{"}).$

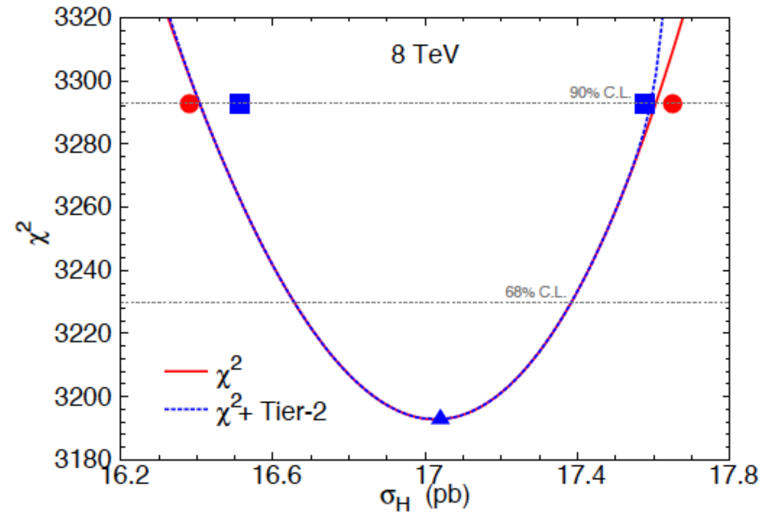
NNLO+NNLL



Scaling issues: 90%CL->68%CL

- New CT paper dealing with PDF and α_s uncertainties for gg->Higgs production, comparing Hessian and Lagrange Multiplier Techniques

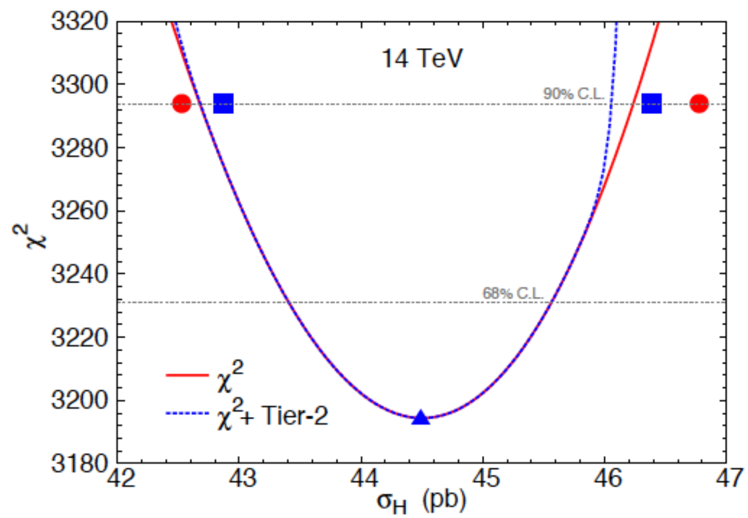




LM technique not dependent on assumption of quadratic χ^2 behavior, so more robust than Hessian

Tier 2 penalty prevents the fit to any one experiment from degrading too Much

all predictions at NNLO using μ=m_H



curves are LM calculations of global fit χ^2 vs Higgs σ with (blue) and without (red) 'Tier 2 penalty'

The blue (red) points are the Hessian determination of the of the PDF uncertainty with (without) the Tier 2 penalty

PDF+α_s uncertainties

- LM estimates of PDF(+α_s) uncertainties slightly larger than Hessian determinations, but close, especially for the combined PDF+α_s errors

Method	7 TeV	8 TeV	14 TeV
LM (PDF-only)	+3.2/-3.7	+3.2/-3.7	+3.5/-4.1
Hessian (PDF-only)	+3.0/-3.0	+3.2/-3.1	+4.3/-3.6
LM (PDF + α_S)	+4.8/-5.0	+4.6/-4.6	+5.2/-5.2
Hessian (PDF + α_S)	+4.7/-4.6	+4.8/-4.6	+5.4/-5.0

Note that validates the prescription of adding the PDF and α_s errors in quadrature

TABLE V: Uncertainties of $\sigma_H(gg \to H)$ computed by the LM method and by the Hessian method, with Tier-2 penalty included. The 90% CL errors are given as percentage of the central value, and the PDF-only uncertainties are for $\alpha_s = 0.118$.

- Scaling the 90%CL error from the CT10 eigenvector set by a factor of 1.645 agrees well with the LM more exact determination

LHC	7 TeV	8 TeV	14 TeV
$\sigma_H(gg \to H)$ (pb) with 90% CL errors	$13.4^{+4.8\%}_{-5.0\%}$	$17.0^{+4.6\%}_{-4.6\%}$	$44.5^{+5.2\%}_{-5.2\%}$
with 68% CL errors	$13.4^{+2.9\%}_{-3.2\%}$	$17.0^{+2.8\%}_{-2.9\%}$	$44.5^{+3.4\%}_{-3.2\%}$

e.g. 4.7%/1.645 =2.85%

TABLE IV: Higgs boson production cross sections through the gluon fusion process at the LHC, with 7, 8 and 14 TeV. The combined PDF and α_S uncertainties at the 90% CL have been calculated by the Lagrange Multiplier method with the CT10H NNLO error PDFs. The errors are expressed as the percentage of the central value.

Summary

- (Relatively) new NLO (and NNLO) PDFs are available: CT10, NNPDF2.3, HERAPDF1.5, ABM11, in addition to MSTW2008
  - expect new updates for all in the near future
- Higgs cross section predictions have been updated using the new NLO and NNLO PDFs
- A new prescription based on the same families of PDFs would lead to a central prediction (and uncertainties) similar to what was used in 2010
  - note that quark-quark luminosity uncertainties have been reduced; gluon-gluon luminosity uncertainties (at least in the 125 GeV range) have not
  - HERAPDF1.5 NNLO predictions consistent with those of CT10, NNPDF2.3 and MSTW2008 but with larger uncertainties
  - larger differences with ABM11; may be due to use FFN scheme
- Ongoing work on trying to understand the differences among CT10, NNPDF2.3, MSTW08 and HERAPDF1.5 for gg PDF luminosities
- A new prescription (somewhat more sophisticated) is being developed; more powerful tools (such as meta-PDFs) will also be used in the near future

Nota bene

- For the PDFs to be fully NNLO, we need to use NNLO matrix elements for inclusive jet production, crucial to the determination of the high x gluon
- So far, we have them for the gg channel
  - corrections are sizeable; I would expect them to be smaller for the gq and qQ channels, following the Dixon conjecture

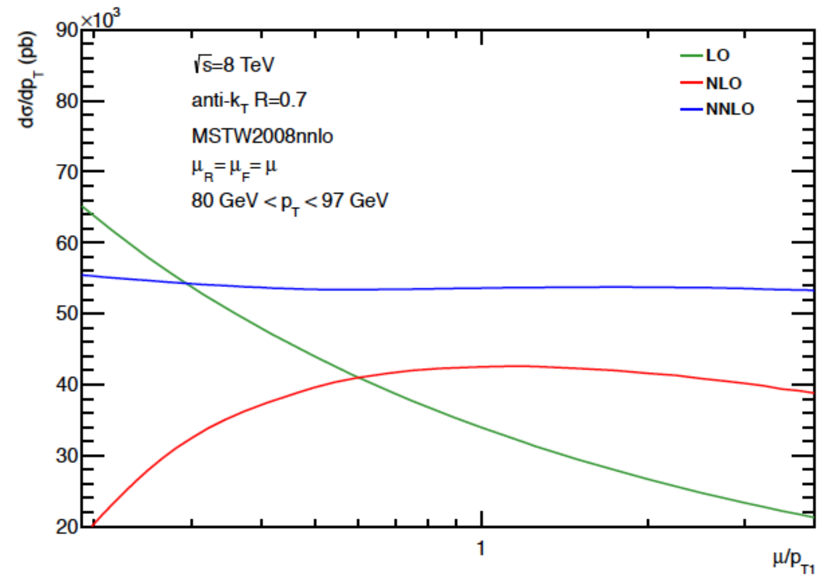
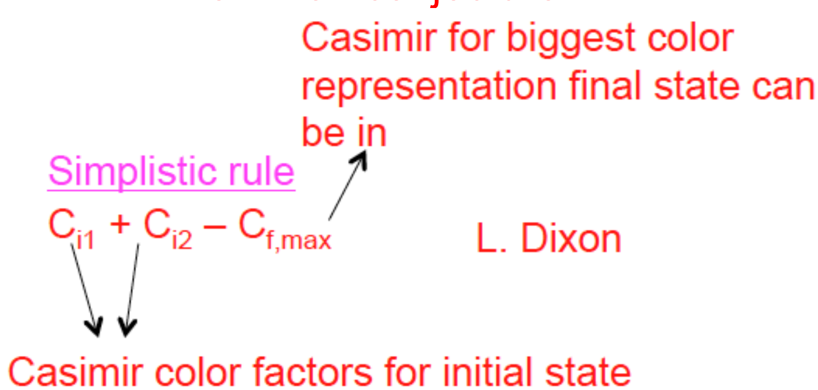


FIG. 2: Scale dependence of the inclusive jet cross section for pp collisions at $\sqrt{s} = 8$ TeV for the anti-k_T algorithm with $R = 0.7$ and with $|y| < 4.4$ and 80 GeV $< p_T < 97$ GeV at NNLO (blue), NLO (red) and LO (green).



Completion this year? Nigel won't take bets any more