# PDF4LHC benchmarking update

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PDF4LHC meeting
Sep 26, 2012

# PDF4LHC report

- 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 $\alpha_s$ uncertainties, with the prescription for combining the PDF and $\alpha_s$ errors to be specified
6. repeating the calculation with a central value of $\alpha_s(m_Z)$ of 0.119.

# 2010 PDF luminosities

- Define and to compare PDF luminosities from the different PDF groups

$$\frac{dL_{ij}}{d\hat{s}\,dy} = \frac{1}{s}\,\frac{1}{1+\delta_{ij}}\left[f_i(x_1,\mu)f_j(x_2,\mu) + (1 \leftrightarrow 2)\right]. \tag{27}$$

The prefactor with the Kronecker delta avoids double-counting in case the partons are identical. The generic parton-model formula

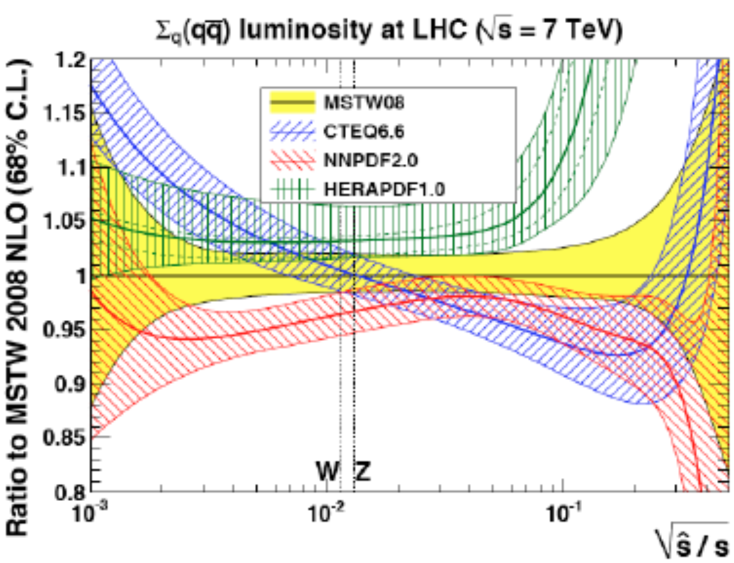
$$\sigma = \sum_{i,j}\int_0^1 dx_1\,dx_2\,f_i(x_1,\mu)\,f_j(x_2,\mu)\,\hat{\sigma}_{ij} \tag{28}$$

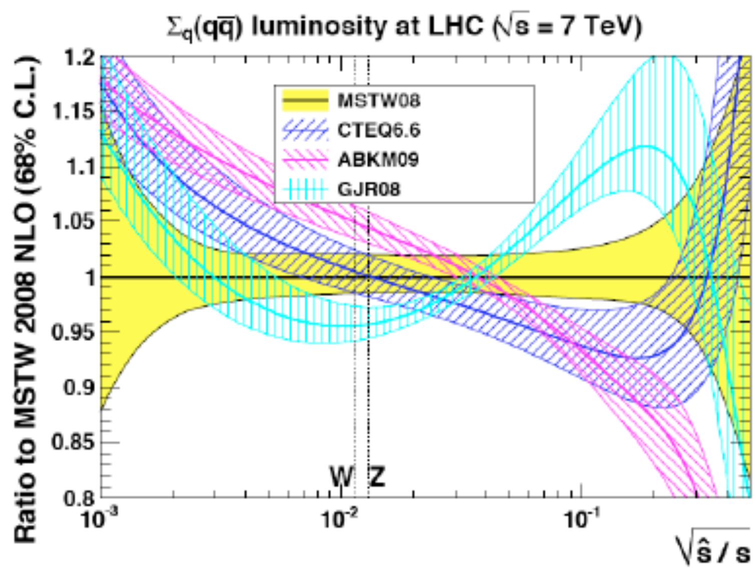
can then be written as

$$\sigma = \sum_{i,j}\int\left(\frac{d\hat{s}}{\hat{s}}\right)\left(\frac{dL_{ij}}{d\hat{s}}\right)\left(\hat{s}\,\hat{\sigma}_{ij}\right). \tag{29}$$

# 2010 PDF luminosities

- The qQ luminosities for the groups tend to have different behaviors at low mass and at high mass
- The reasons can often be understood
  - NNPDF2.0 does not use a heavy quark flavor scheme; this suppresses the low x quark and anti-quark distributions (NNPDF2.1 does use such a scheme)
  - HERAPDF uses the HERA combined Run 1 dataset that prefers a higher normalization
- The agreement tends to be much better in the W/Z region

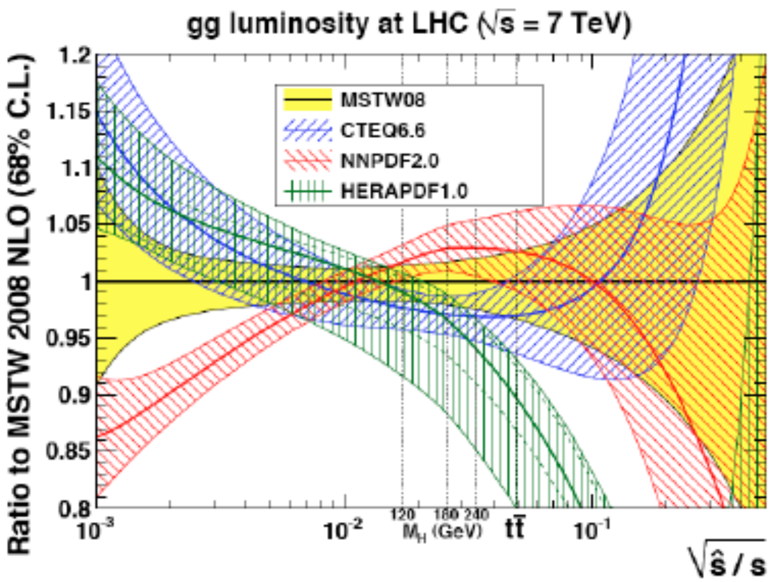


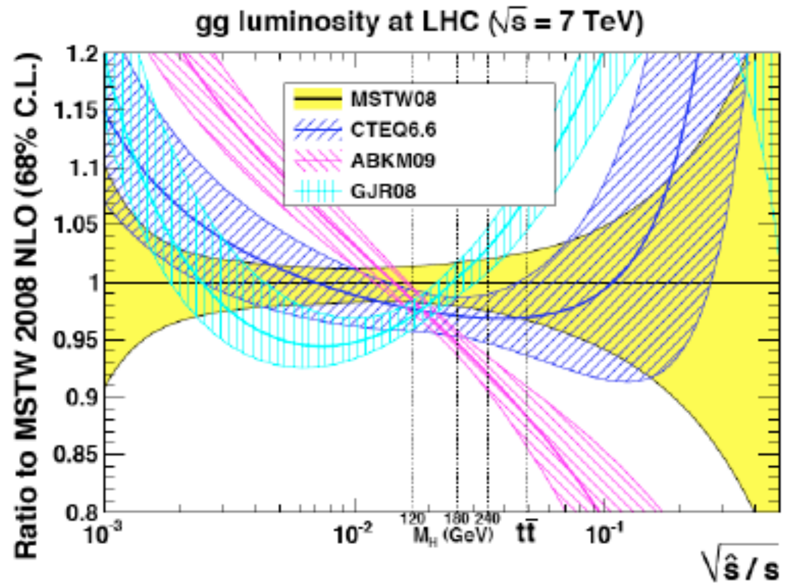




Plots by G. Watt arXiv: 1106.5788

# 2010 PDFs

- Larger differences are observed for gg luminosities, especially at high mass
  - critically depends on whether Tevatron inclusive jet data have been used or not

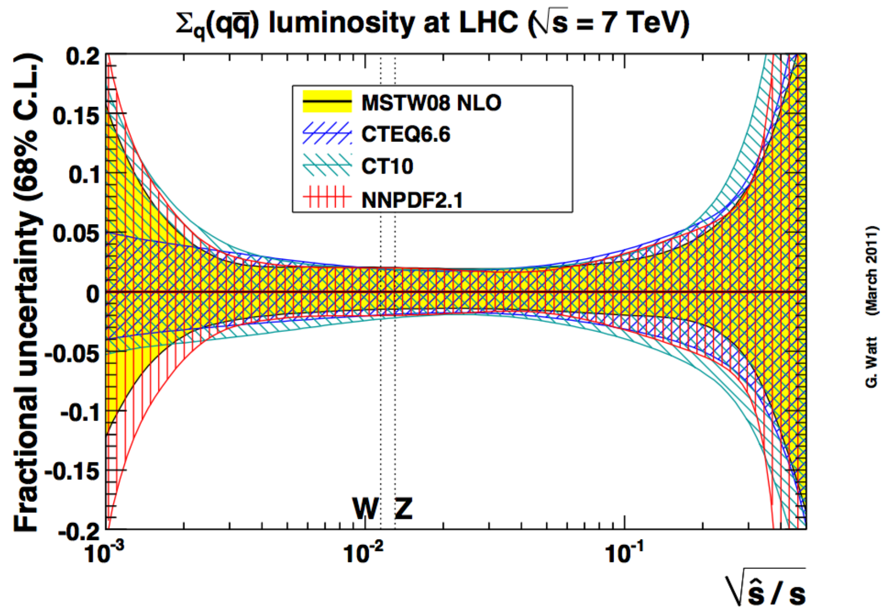


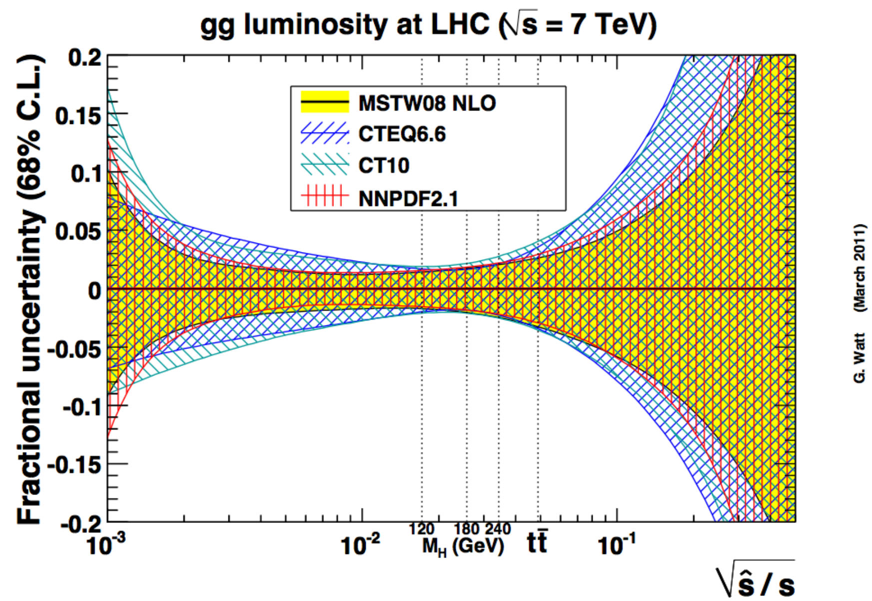




Plots by
G. Watt
arXiv:
1106.5788

# 2010 uncertainties

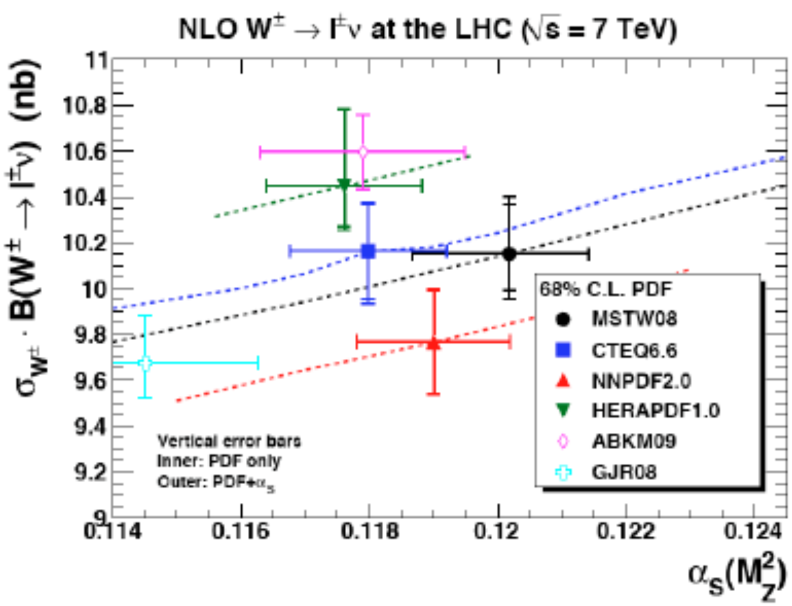
- Uncertainties, at least among the global PDF groups, agree amazingly well for qqbar, especially given different approaches/assumptions
- A bit larger spread for gg
- Unless otherwise stated, all PDF uncertainties are at 68% CL
  - some PDF groups produce uncertainties for both 68% and 90%CL
  - for others, a scaling of 1.645 is used (which works well)

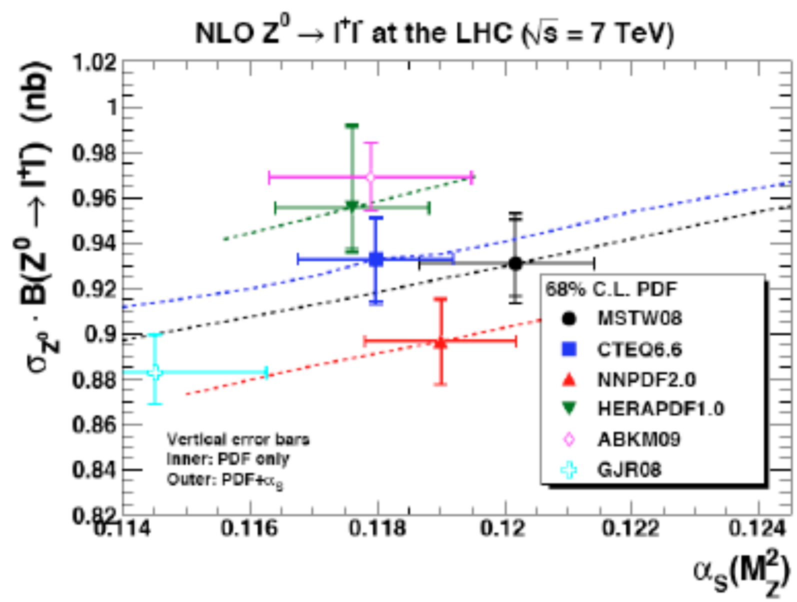


# 2010 cross section comparisons

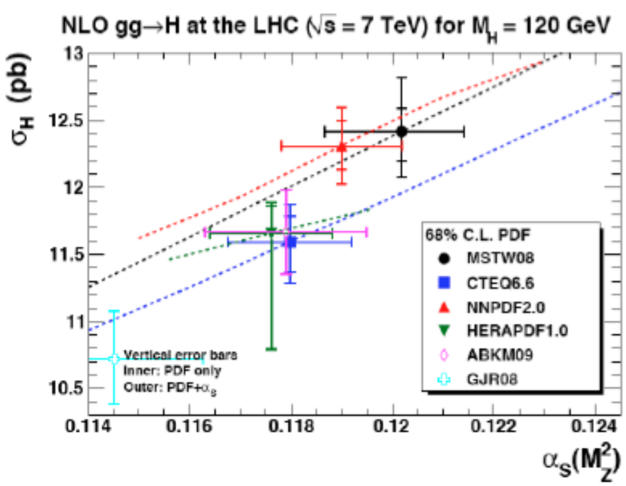
- Notice that the CTEQ and MSTW predictions for W/Z production are very close to each other
- Also, in general, there is very little dependence of the cross sections on the value of $\alpha_s(m_Z)$ (as expected)
- And of course, the higher qQ luminosities observed earlier lead to higher predictions for W/Z cross sections for HERAPDF

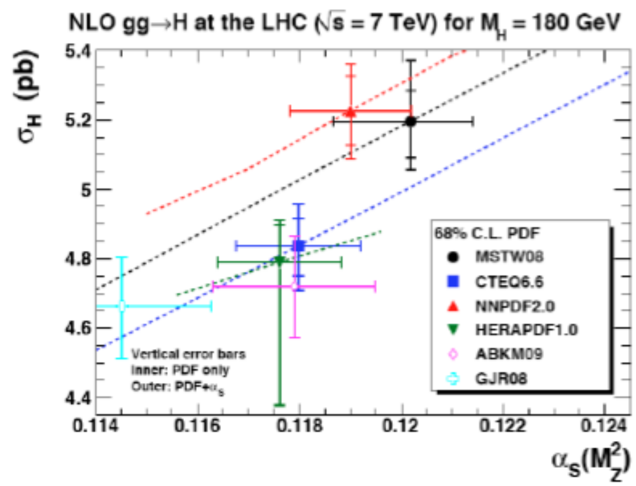


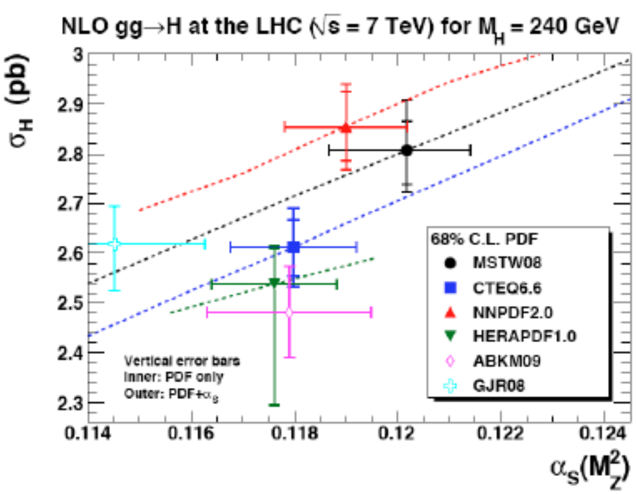
# 2010 cross section comparisons

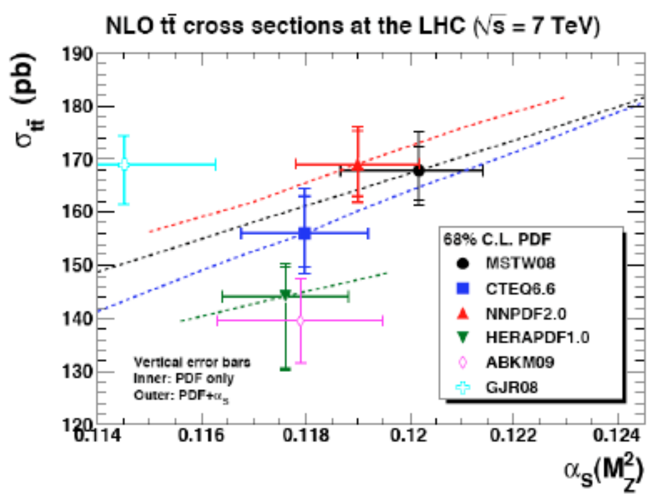
- Larger gg differences and greater dependence on $\alpha_s$ lead to larger differences in Higgs/tT cross section




Note that there tends to be two groupings

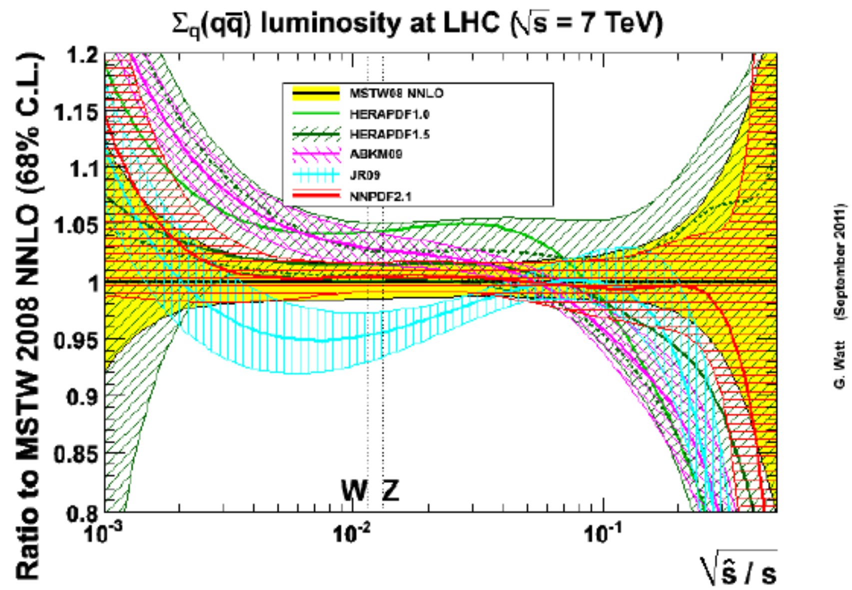


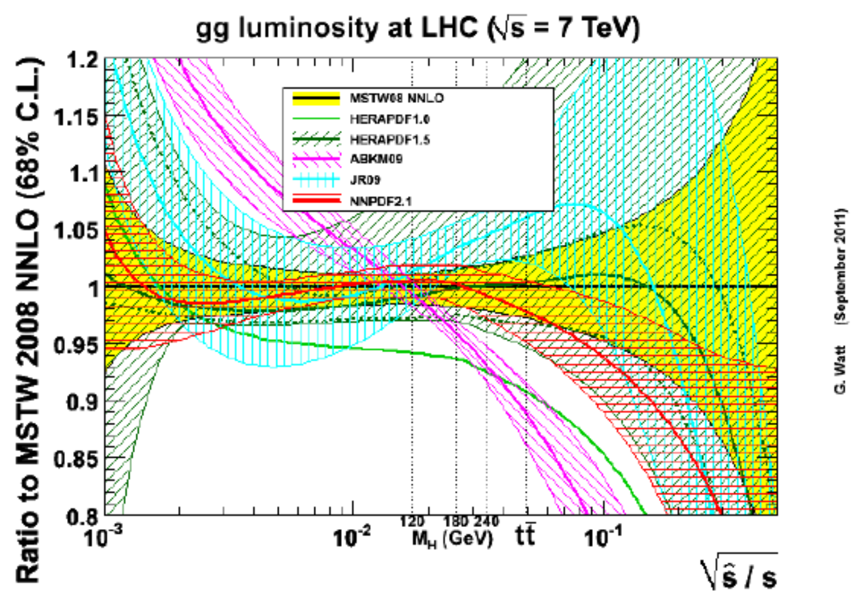




Plots by G. Watt arXiv: 1106.5788

# Comparison of NNLO PDF luminosity functions

- NNLO trends are similar to those observed at NLO

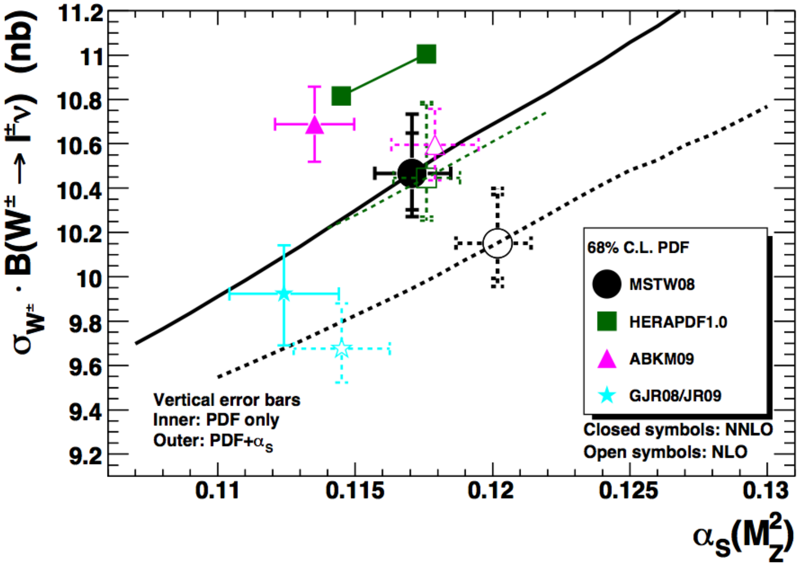


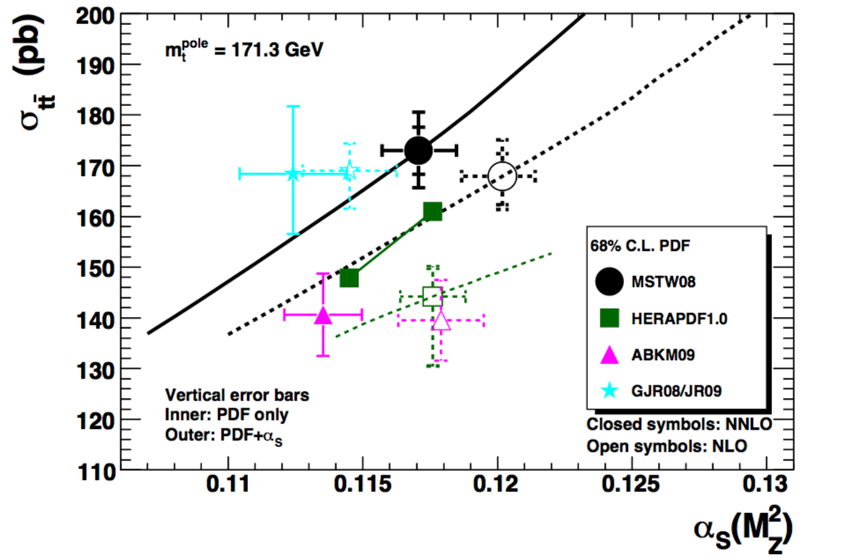

Plots by G. Watt arXiv: 1106.5788

# Comparison of NNLO predictions

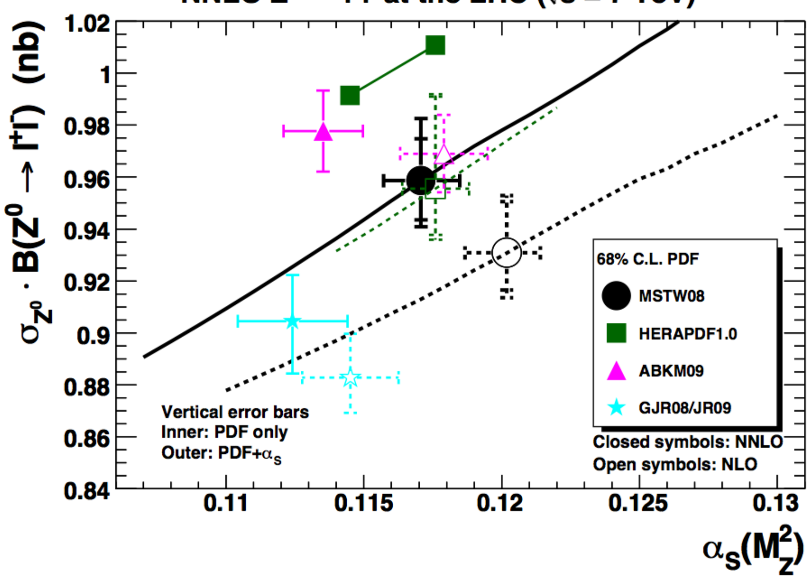
NNLO $W^{\pm} \to l^{\pm}\nu$ at the LHC ($\sqrt{s}$ = 7 TeV)



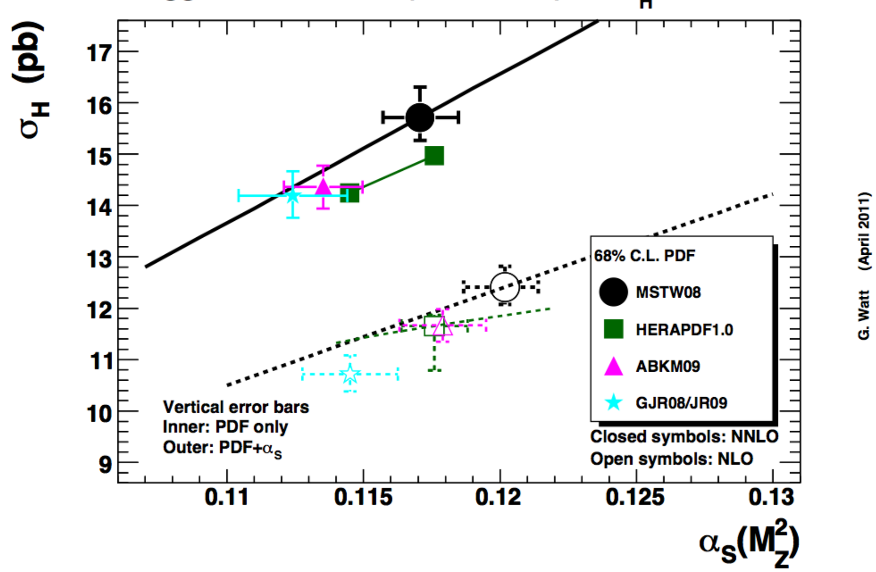

NNLO (approx.) $t\bar{t}$ cross sections at the LHC ($\sqrt{s}$ = 7 TeV)




NNLO $Z^0 \to l^+l^-$ at the LHC ($\sqrt{s}$ = 7 TeV)




NNLO gg→H at the LHC ($\sqrt{s}$ = 7 TeV) for $M_H$ = 120 GeV



# PDF4LHC recommendations

## 2. The PDF4LHC recommendation

Before the recommendation is presented, it is useful to highlight the differences between two use cases: (1) cross sections which have not yet been measured (such as, for example, Higgs production) and (2) comparisons to existing cross sections. For the latter, the most useful comparisons should be to the predictions using individual PDFs (and their uncertainty bands). Such cross sections have the potential, for example, to provide information useful for modification of those PDFs. For the former, in particular the cross section predictions in this report, we would like to provide a reliable estimate of the true uncertainty, taking into account possible differences between the central values of predictions using different PDFs [1]. From the results seen it is clear that this uncertainty will be larger than that from any single PDF set, but we feel it should not lose all connection to the individual PDF uncertainties (which would happen for many processes if the full spread of all PDFs were used), so some compromise is proposed.

# 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+$\alpha_s$ 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 $\alpha_s$ variation suggested is consistent with this. Note that the CTEQ6.6 set has uncertainties and $\alpha_s$ 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.

Of course, there is the freedom/encouragement to use any individual PDF desired for comparison to measured cross sections. This has been the norm for the 2010 LHC results.

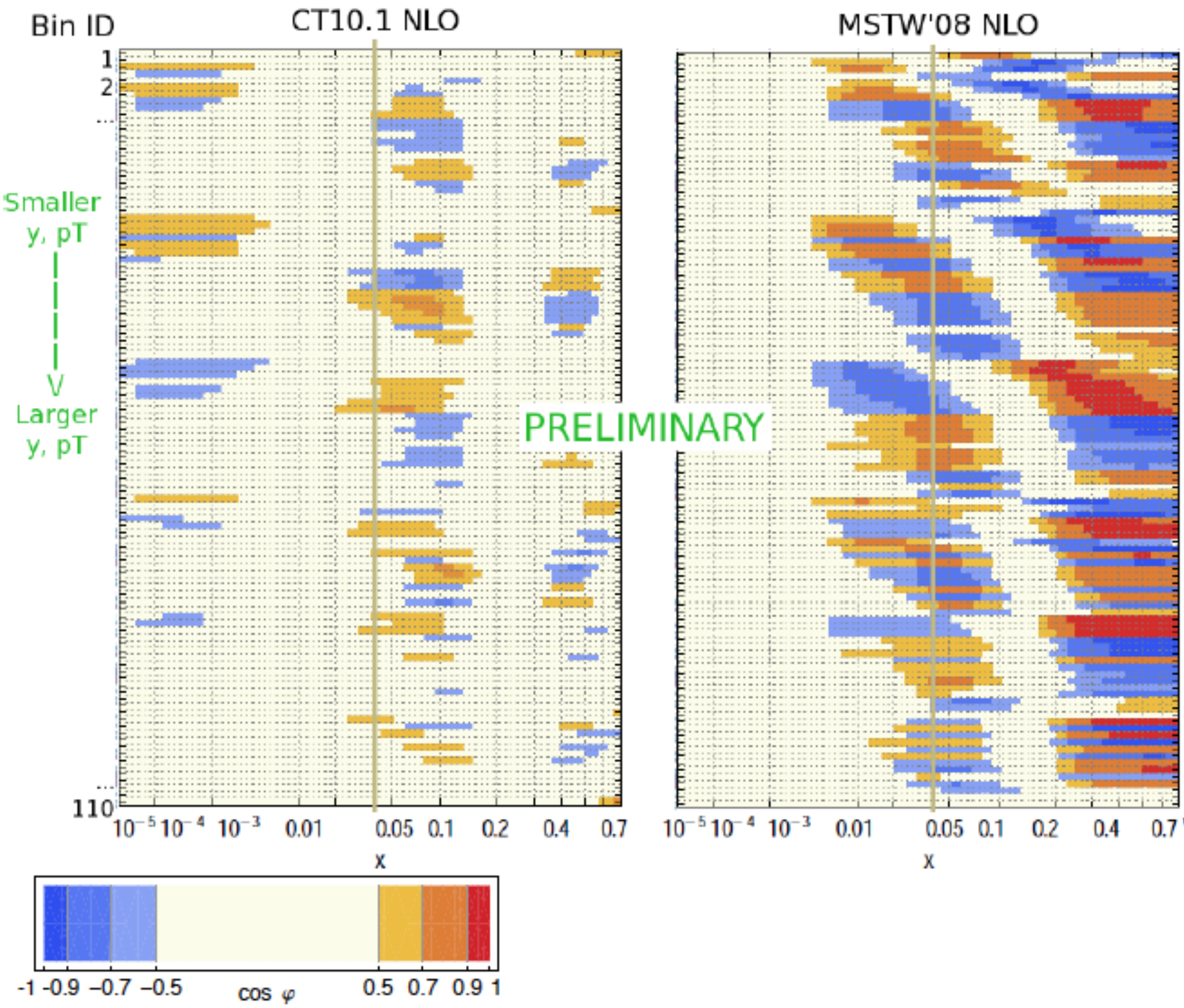
# More benchmarking

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 between CTEQ code with alternative DIS calculation provided by A. Guffanti
- 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

## Correlations between D0 Run-2 inc. jet data and gluon PDF

Z. Liang, P. Nadolsky, in 2011 Les Houches Proceedings




Correlation between $g(x, Q = 3.163 \text{ GeV})$ and $\chi_i^2$ in jet $p_T$ bins (with syst. shifts)...

...is more pronounced for the MSTW'08 sets (right) than for CT10 sets (left)

# Higgs Yellow Reports

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

CERN–2011–002
17 February 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

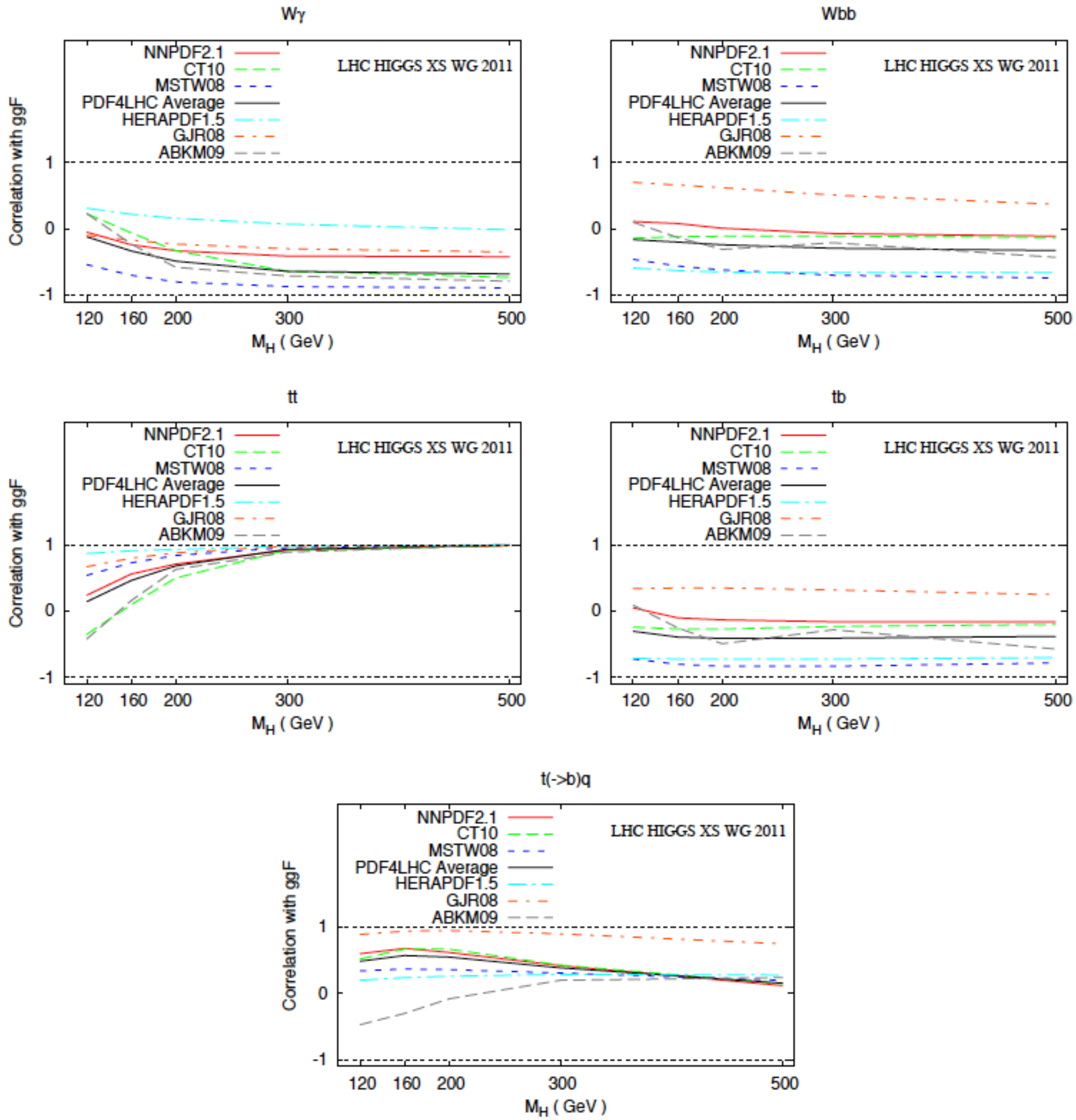



**Fig. 15:** Correlation between the gluon fusion gg → H process and other signal and background processes as a function of $M_H$. We show the results for the individual PDF sets as well as the up-to-date PDF4LHC average.

# Followup for PDF4LHC

- Study of NNLO PDFs from 5 PDF groups (no new updates for JR)
  - drawing from what Graeme Watt has done, but now including CT10 NNLO, and NNPDF2.3
  - using common values of $\alpha_s$ (0.117 and 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 is being led by Juan Rojo and Pavel Nadolsky and will result in an independent publication
  - with Stefano Carrazza, Jun Gao, Stefano Forte, JH, and Robert Thorne
- The results from this paper will be utilized in a subsequent PDF4LHC document(s)

# PDFs used in the comparison

| PDF set | Reference | $\alpha_s^{(0)}$ (NLO) | $\alpha_s$ range (NLO) | $\alpha_s^{(0)}$ (NNLO) | $\alpha_s$ range (NNLO) |
|---|---|---|---|---|---|
| NNPDF2.3 | [3] | all | $[0.114, 0.124]$ | all | $[0.114, 0.124]$ |
| MSTW08 | [4] | 0.1202 | $[0.110, 0.130]$ | 0.1171 | $[0.107, 0.127]$ |
| CT10 | [7] | 0.118 | $[0.112, 0.127]$ | 0.118 | $[0.112, 0.127]$ |
| ABM11 $N_f = 5$ | [9] | 0.1181 | $[0.110, 0.130]$ | 0.1134 | $[0.104, 0.120]$ |
| HERAPDF1.5 | | 0.1176 | $[0.114, 0.122]$ | 0.1176 | $[0.114, 0.122]$ |

Table 1: PDF sets used in this paper. All PDF sets are provided both at NLO and NNLO. In both cases, we quote the value $\alpha_s^{(0)}$ for which PDF errors are provided in all sets but NNPDF2.3, and the range in $\alpha_s$ in which PDF central values are provided. For ABM11 the $\alpha_s$ varying PDF sets are not available in the $N_F = 3$ PDF set.

# PDF comparisons

…so from the document

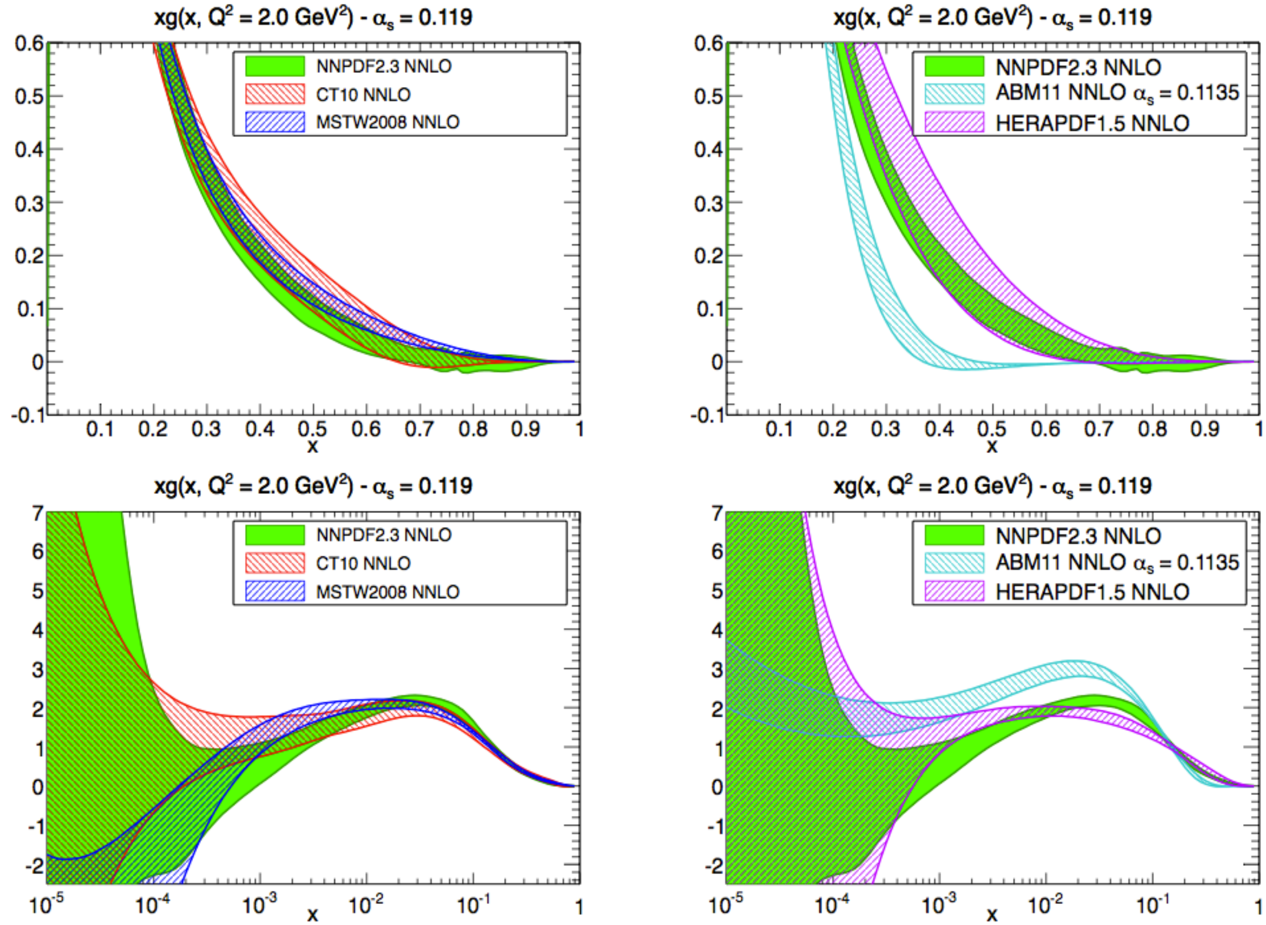



Figure 1: Comparison of the gluon PDF at $Q^2 = 2$ GeV$^2$ between different NNLO PDF sets, in a linear scale (upper plots) and in a logarithmic scale (lower plots). The left plots show the comparison between NNPDF2.3, CT10 and MSTW08, while in the right plots we compare NNPDF2.3, HERAPDF1.5 and MSTW08.

# Comparison of PDFs

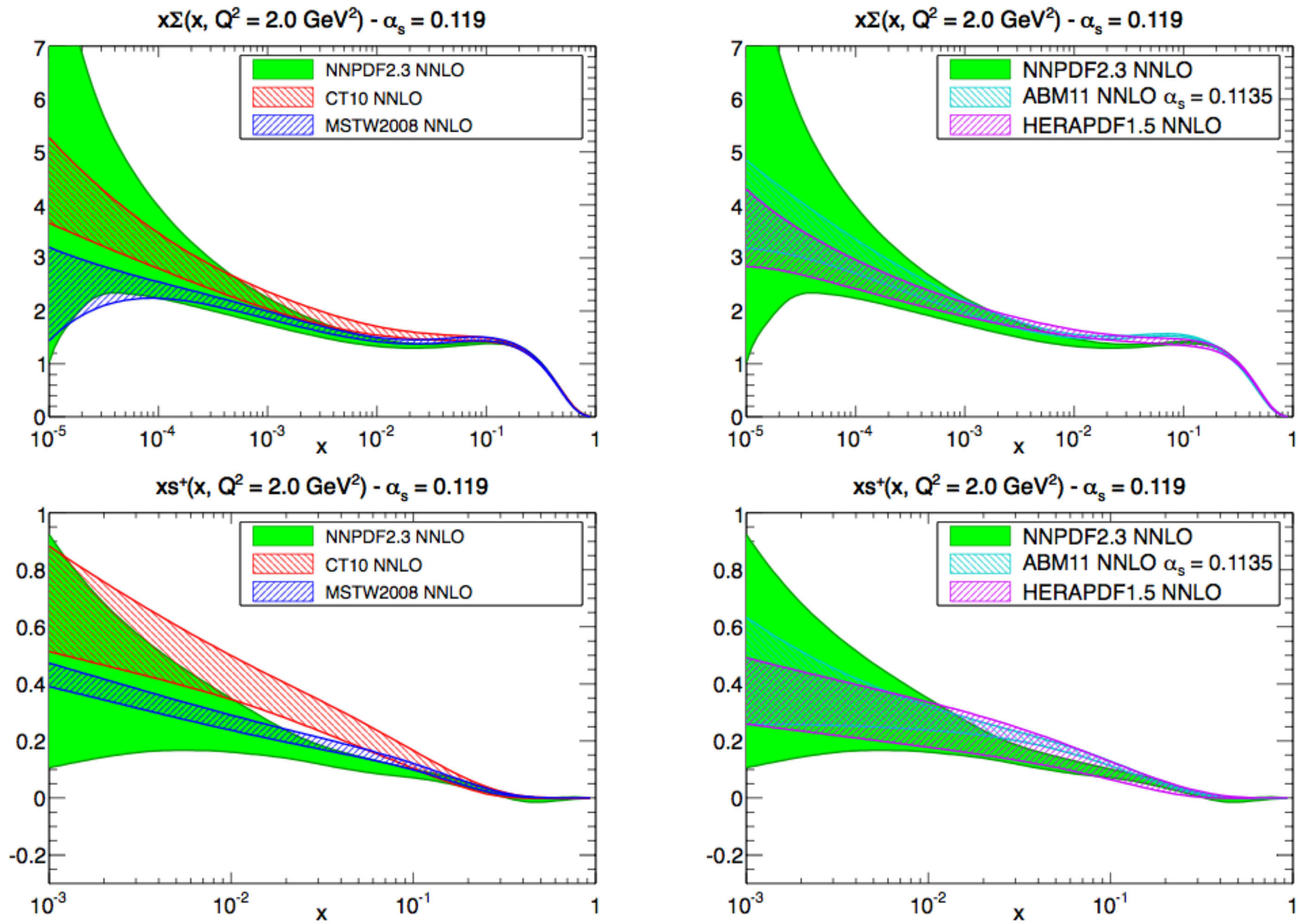



Figure 2: Same as Fig. 1 for the total quark singlet and the total strangeness PDFs.

# Comparison of PDFs

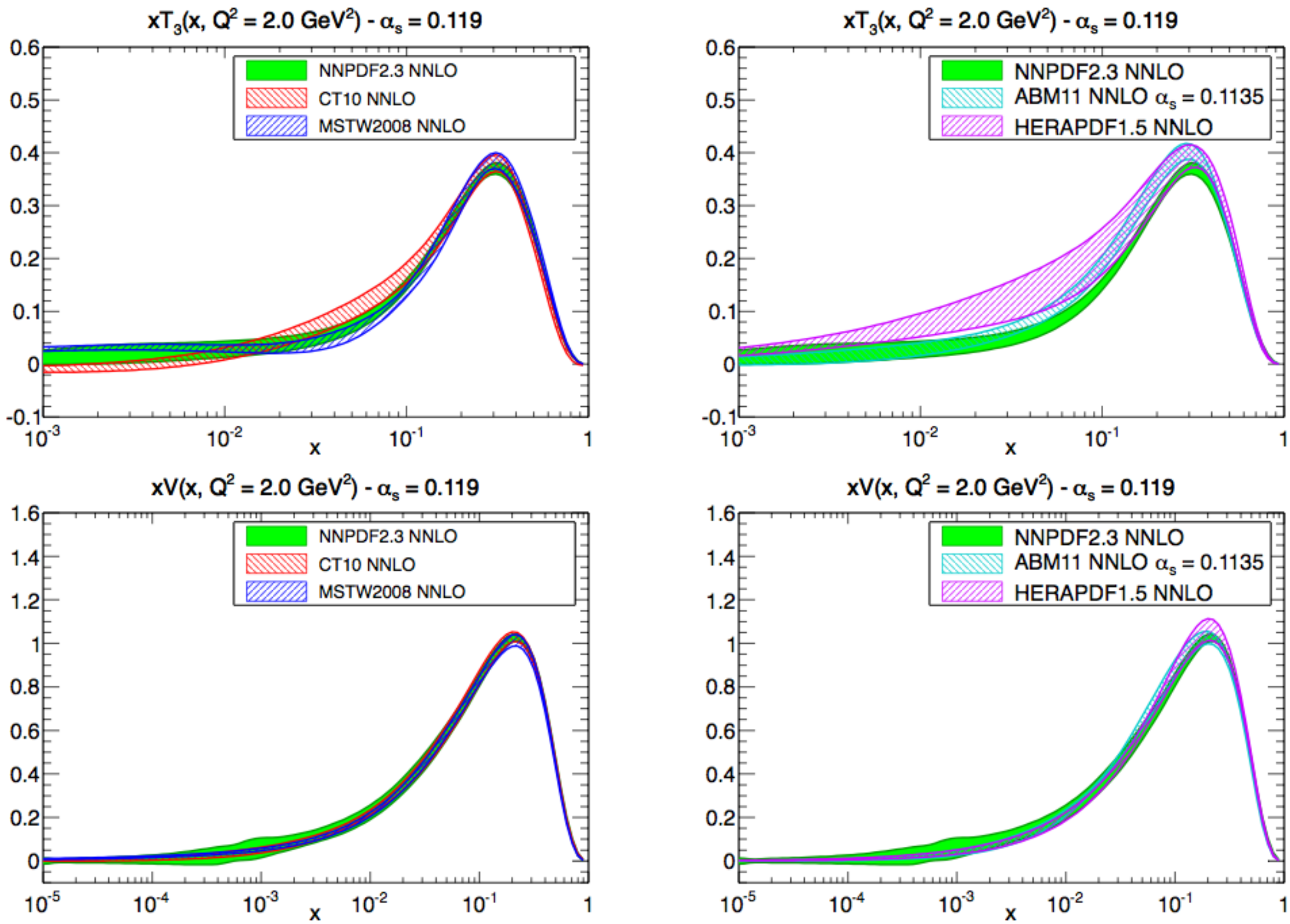



Figure 3: Same as Fig. 1 for the non-singlet triplet and total valence PDFs.

# PDF luminosities

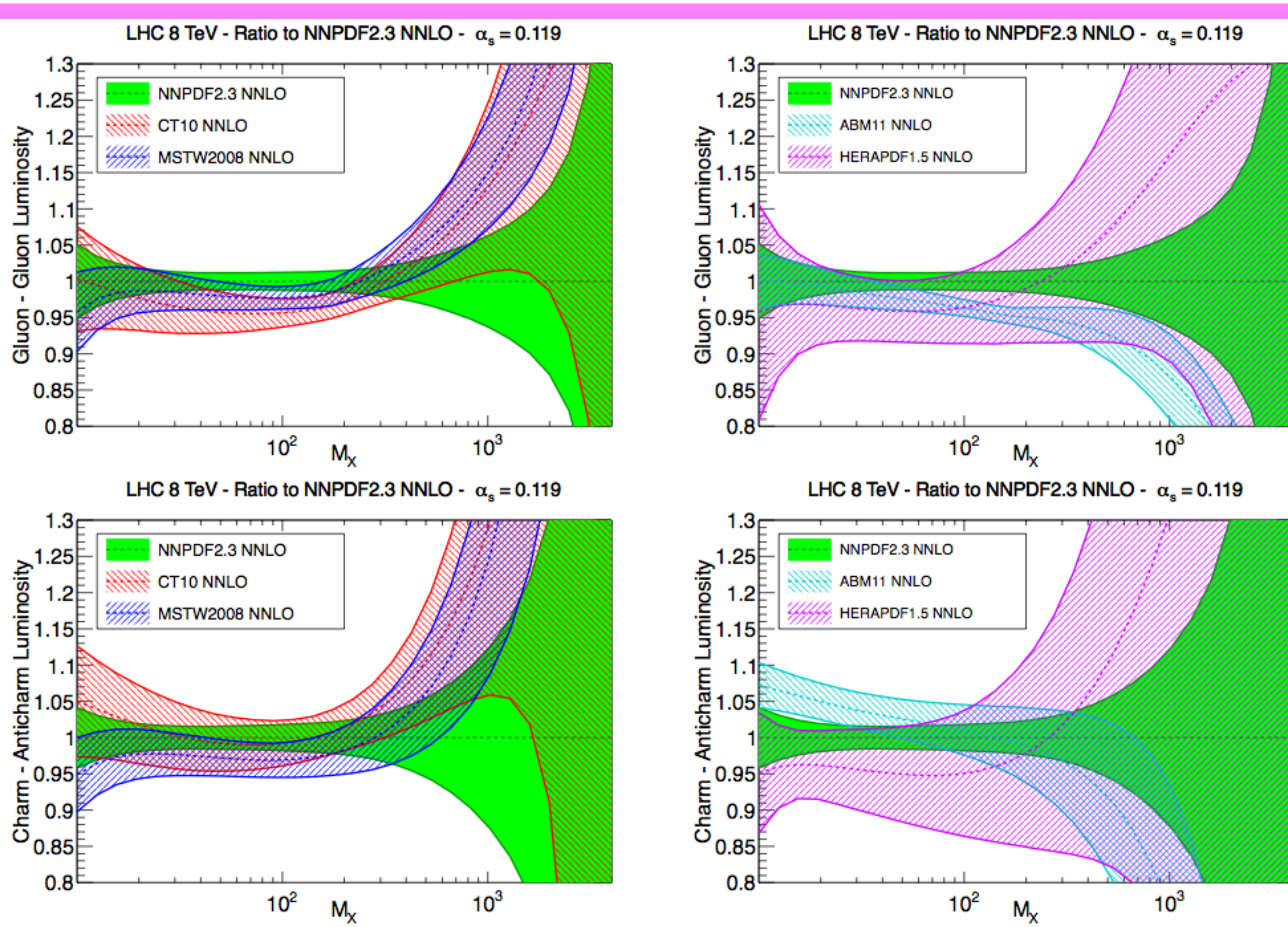



Figure 5: The gluon–gluon parton (upper plots) and charm-charm (lower plots) luminosities, Eq. 1, for the production of a final state of invariant mass $M_X$ at LHC 8 TeV. The left plots show the comparison between NNPDF2.3, CT10 and MSTW08, while in the right plots we compare NNPDF2.3, HERAPDF1.5 and MSTW08. All PDF luminosities are computed at a common value of $\alpha_s = 0.119$.

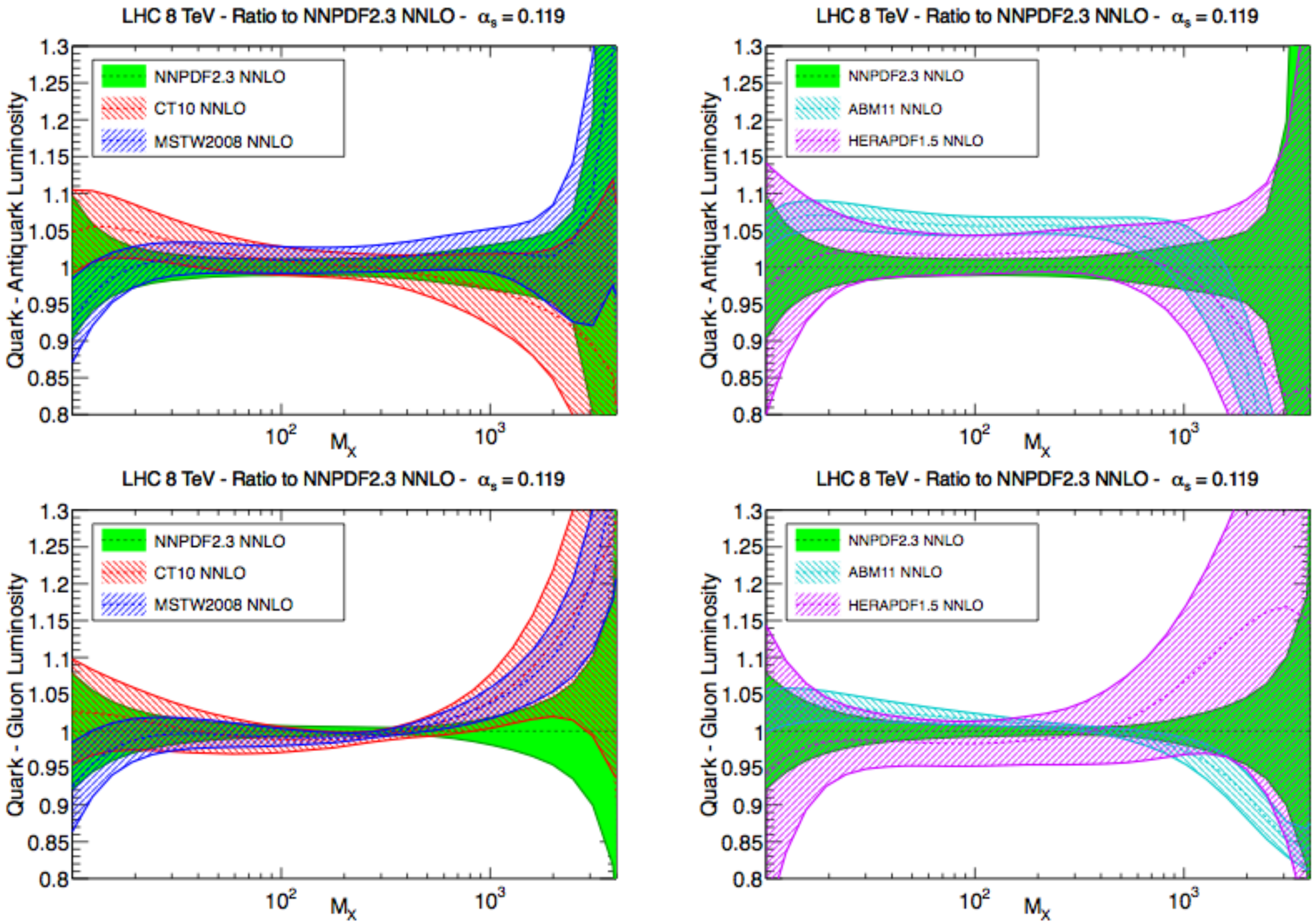
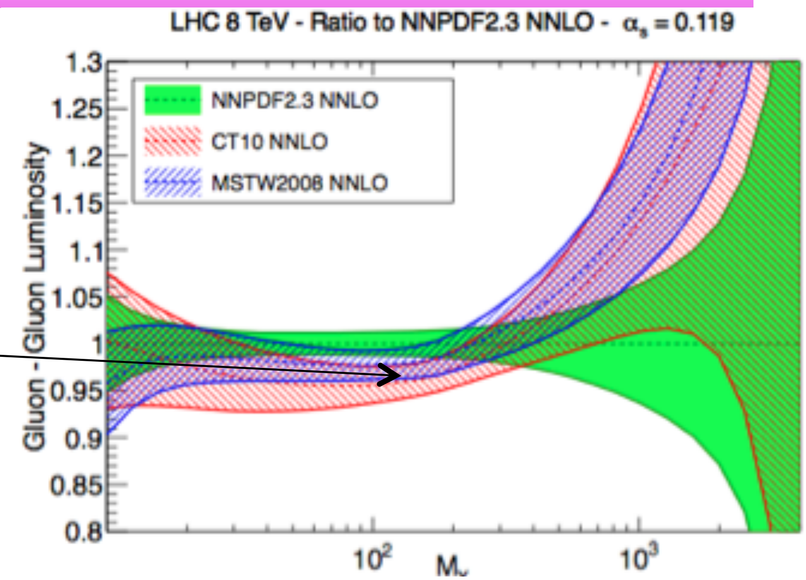
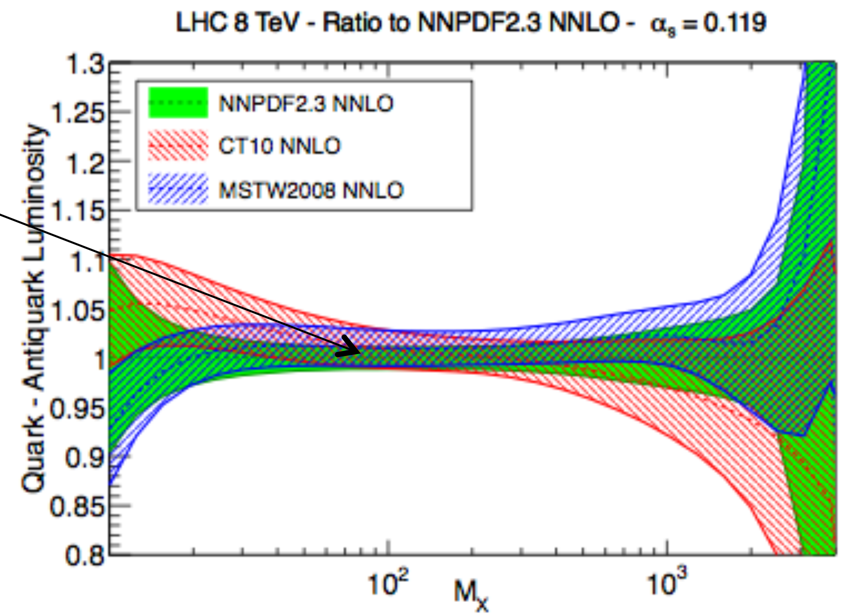



Figure 6: The quark-quark parton (upper plots) and quark-gluon (lower plots) luminosities, Eq. 1, for the production of a final state of invariant mass $M_X$ at LHC 8 TeV. The left plots show the comparison between NNPDF2.3, CT10 and MSTW08, while in the right plots we compare NNPDF2.3, HERAPDF1.5 and MSTW08. All PDF luminosities are computed at a common value of $\alpha_s = 0.119$.

# 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



- Comparisons to ATLAS 2010 W/Z rapidity data

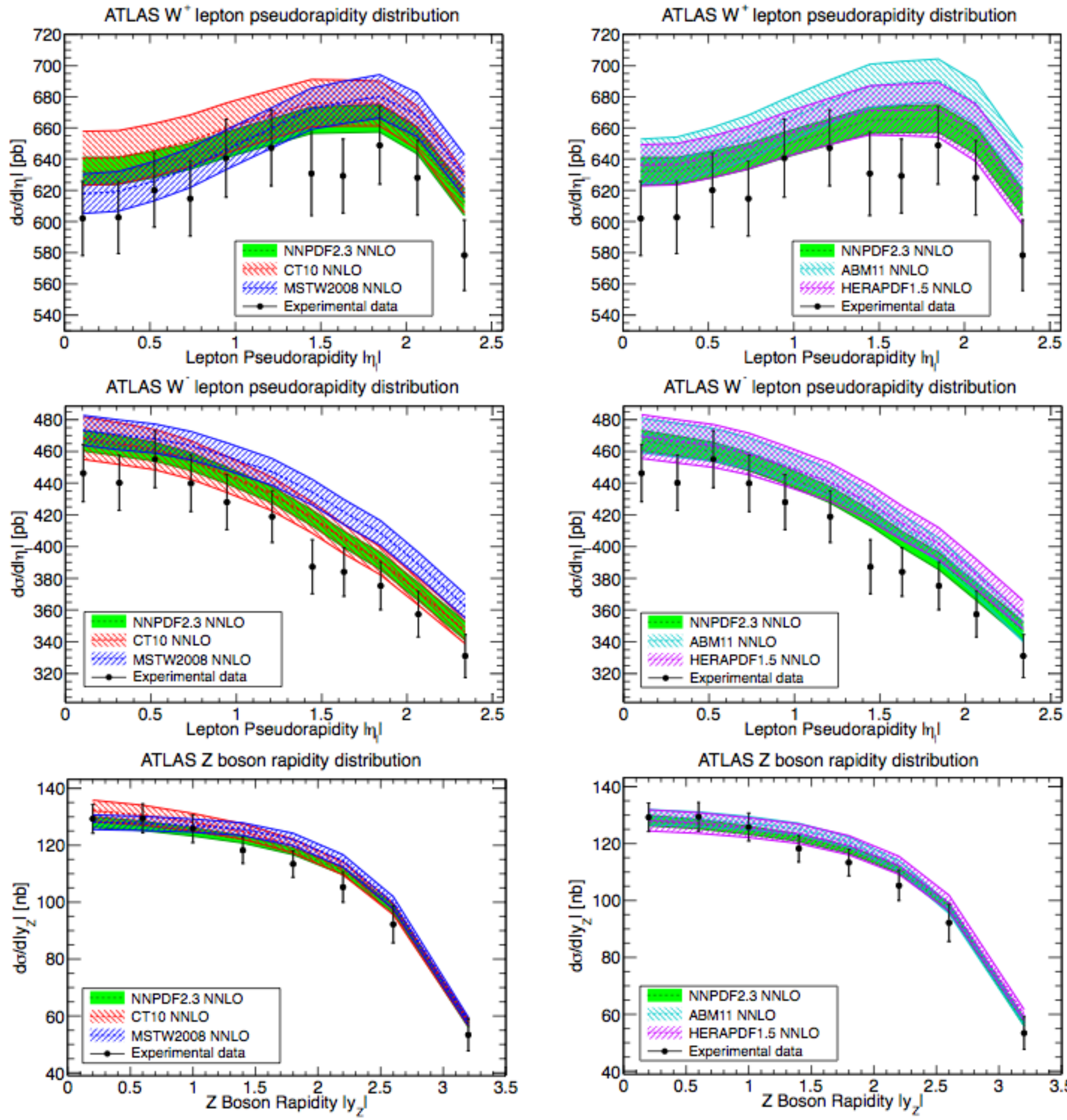



Figure 10: Comparison of the ATLAS electroweak vector production data with the NNPDF2.3, CT10 and MSTW2008 (left plots) predictions with $\alpha_s = 0.119$. The experimental error band is obtained adding in quadrature all experimental systematics including normalization errors.

# LHC data

- CMS 2011 lepton asymmetry and LHCb 2010 lepton rapidity distributions

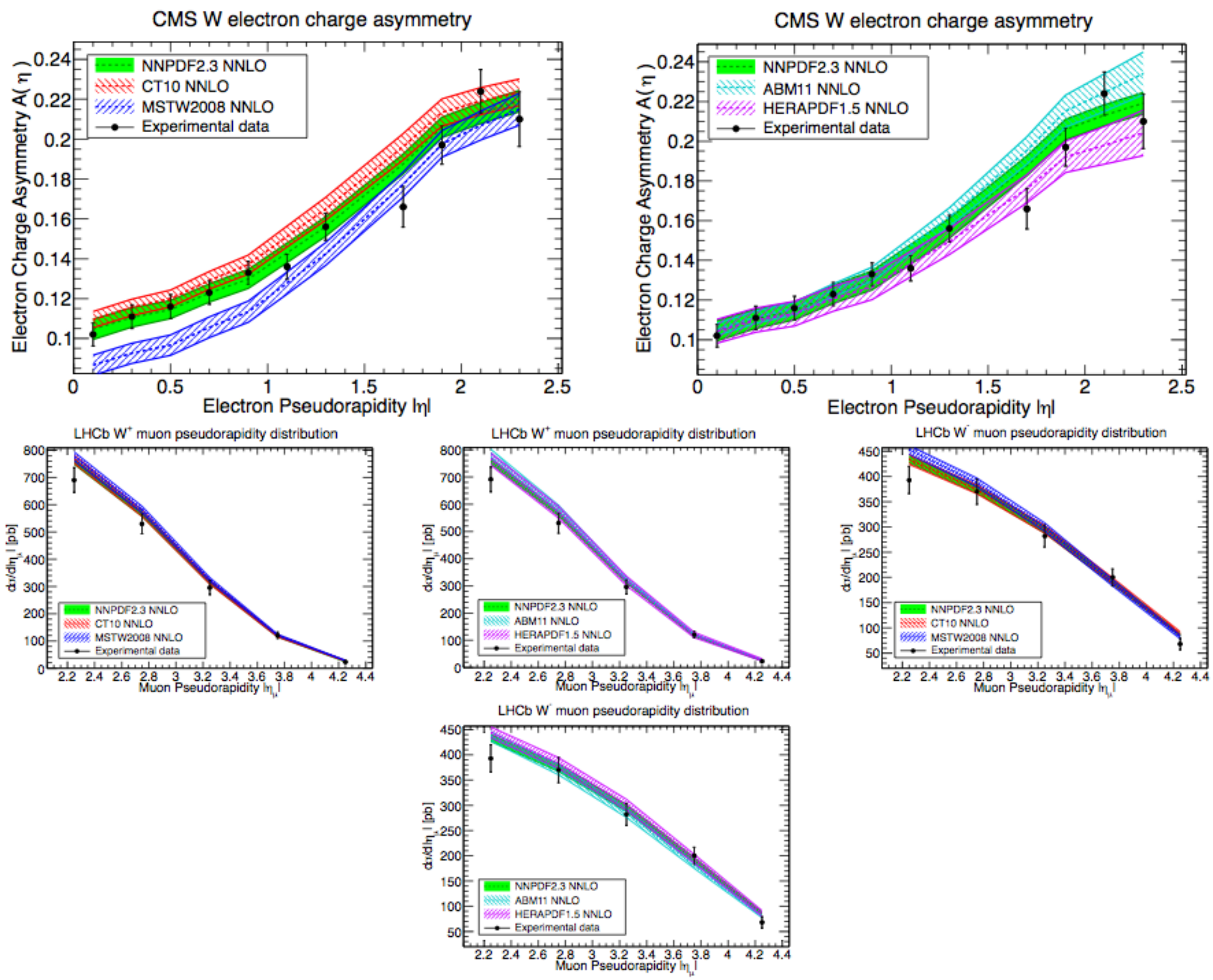



Figure 11: Comparison of the CMS LHCb electroweak vector production data with the NNPDF2.3 NNLO, CT10 NNLO and MSTW2008 NNLO predictions with $\alpha_S = 0.119$. The experimental error band is obtained adding in quadrature all experimental systematics including normalization errors.

- ATLAS 2010 inclusive jet cross section (antikT 0.4)

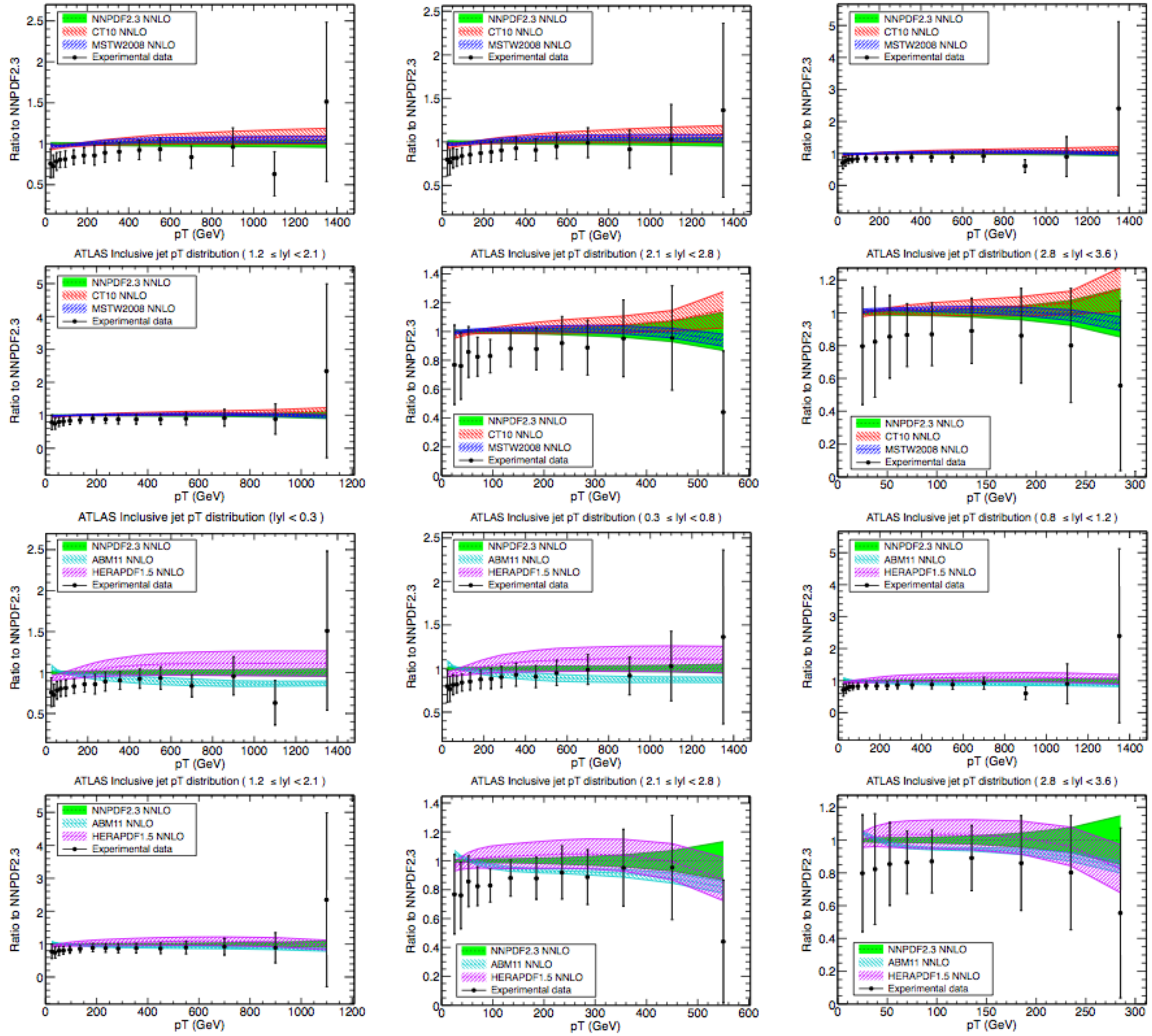



Figure 12: Comparison of the ATLAS $R = 0.4$ inclusive jet production data from the 2010 dataset with the NNPDF2.3 NNLO, CT10 NNLO and MSTW2008 NNLO predictions with $\alpha_S = 0.119$. The experimental error band is obtained adding in quadrature all experimental systematics including normalization errors.

# Comparison of jet predictions

agreement at high $p_T$, some differences for APPLGRID at low $p_T$

larger differences at low $p_T$ if scale of $p_T^{jet,max}$ is used

note unshifted data has poor agreement with theory

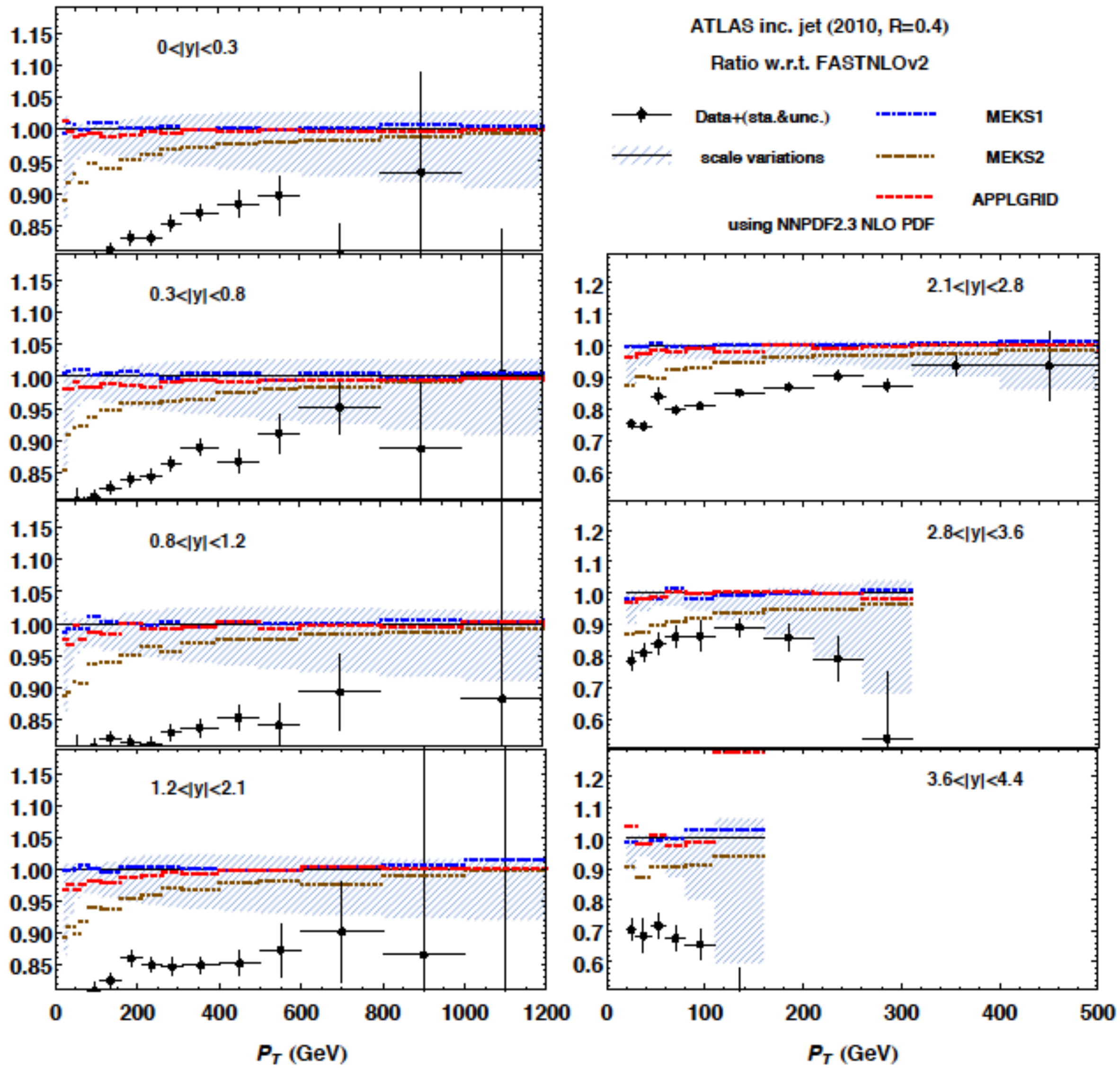



Figure 1: Comparisons of NLO theoretical predictions for 2010 ATLAS single-inclusive jet production ($R = 0.4$) from various numerical programs. NNPDF2.3 NLO PDFs are used with $\alpha_s(M_Z) = 0.119$.

scale $=p_Tj^{et}$

scale $=p_Tj^{et,max}$

scale $=p_Tj^{et,max}$ in each rapidity bin

ATLAS choice

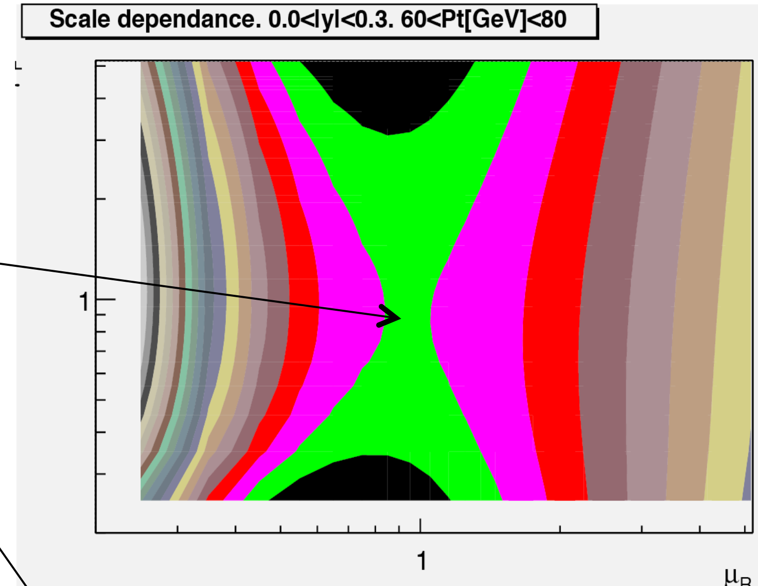
hatched is FASTNLO uncertainty band for $p_T/2$ to $2p_T$

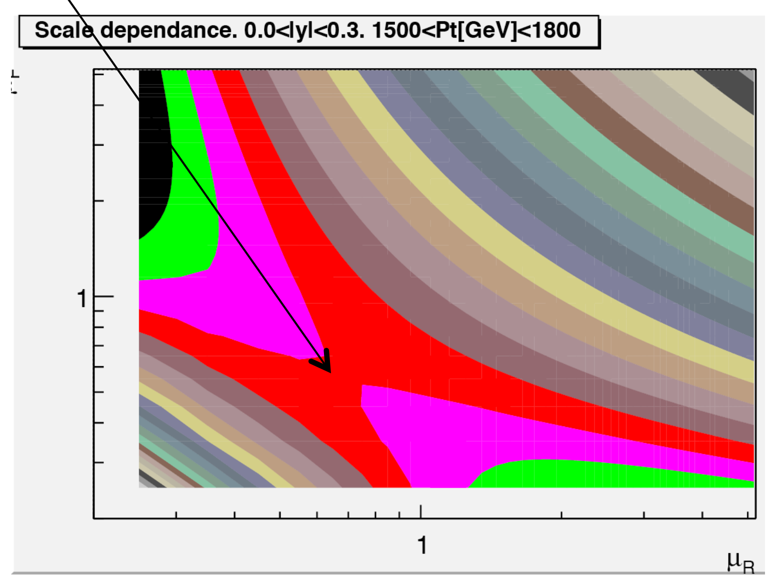
could we agree on a common scale, like $p_T^{jet}$?

# Aside: Scale choices

- Take inclusive jet production at the LHC
- Canonical scale choice at the LHC is $\mu_r=\mu_f=1.0{*}p_T$
  - CDF used $0.5p_T$
  - CTEQ6.6/CT10 used this scale for determination of PDFs
  - new CT PDFs use $p_T$
- Close to saddle point for low $p_T$
- But saddle point moves down for higher $p_T$ (and the saddle region rotates)
- Our typical scale choices don't work for all LHC kinematics; more extreme movements for some of measured cross sections
- Rather than look for some magic formula, we should try to understand what is going on the kinematic/scale point-of-view

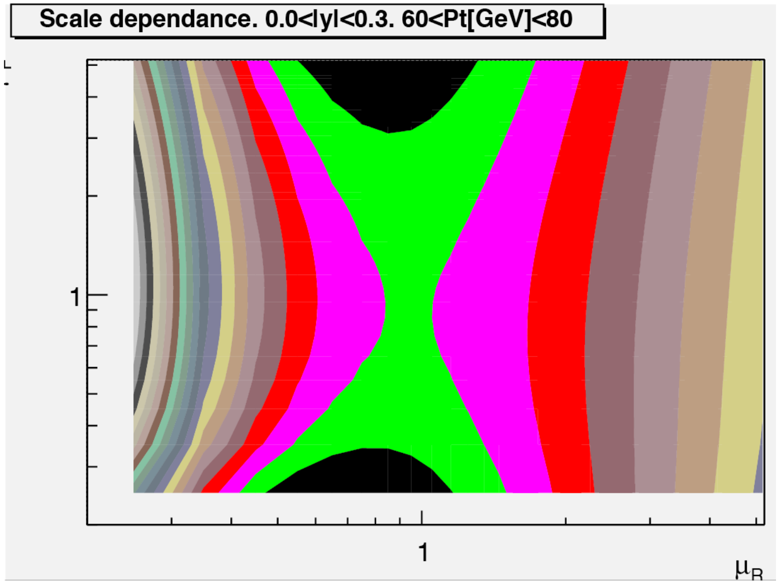
R=0.4
antikT

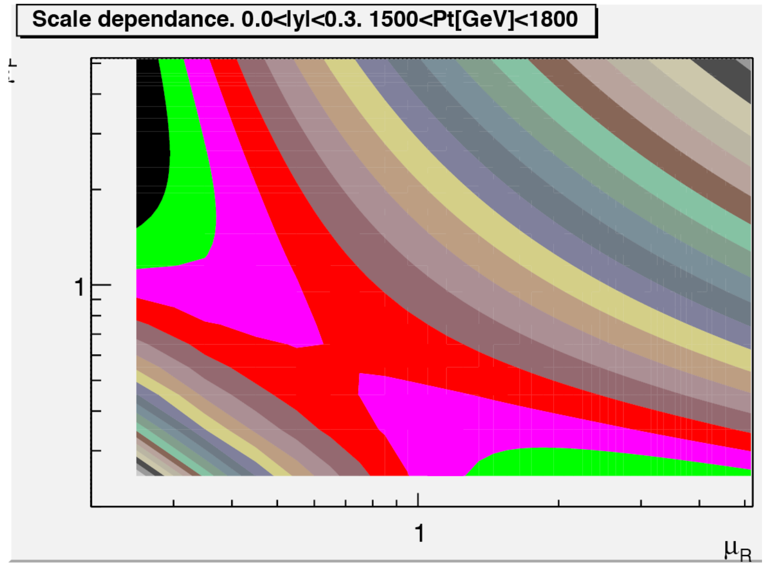


# Scale dependence also depends on jet size;

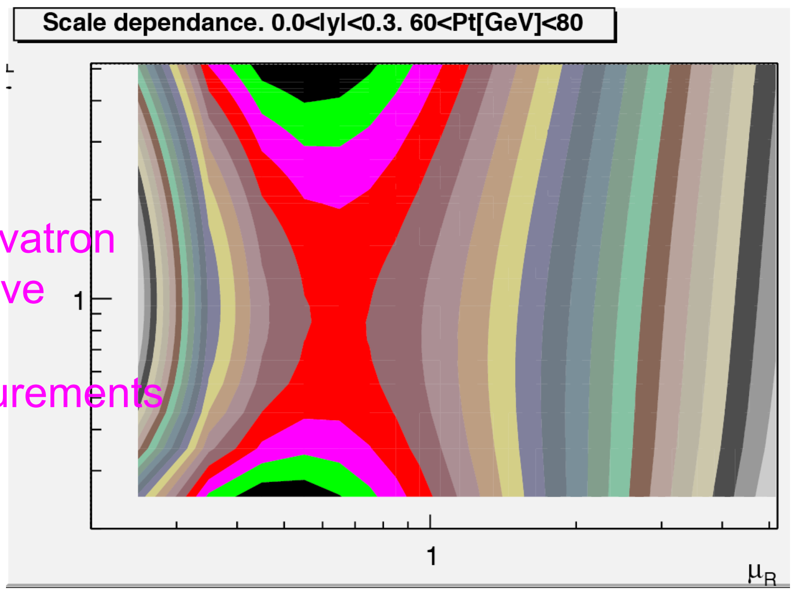
R=0.4
antikT

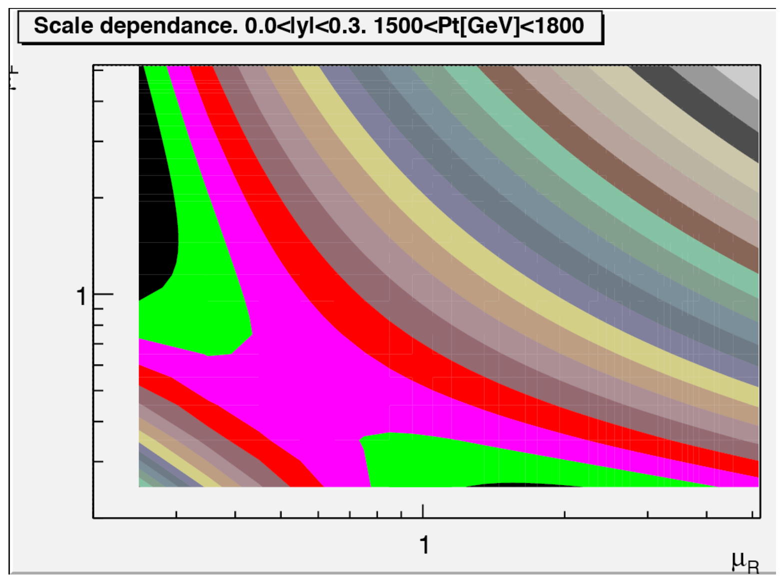



R=0.6
antikT

NB:Tevatron inclusive jet measurements with R=0.7



# Calculation of $\chi^2$

Given the knowledge of the statistical, systematic and normalization uncertainties for a given experiment, we define the experimental covariance matrix used to quantify the data/theory quality as follows:

$$(\mathrm{cov})_{IJ} = \left( \sum_{l=1}^{N_c} \sigma_{I,l}\sigma_{J,l} + \delta_{IJ}\sigma_{I,s}^2 \right) F_I F_J + \left( \sum_{n=1}^{N_a} \sigma_{I,n}\sigma_{J,n} + \sum_{n=1}^{N_r} \sigma_{I,n}\sigma_{J,n} \right) F_I F_J \qquad (2)$$

where $I$ and $J$ run over the experimental points, $F_I$ and $F_J$ are the measured central values for the observables $I$ and $J$. The uncertainties, given as relative values, are: $\sigma_{I,l}$, the $N_c$ correlated systematic uncertainties; $\sigma_{I,n}$, the $N_a$ ($N_r$) absolute (relative) normalization uncertainties; $\sigma_{I,s}$ the statistical uncertainties (which includes uncorrelated systematic uncertainties). Note that Eq. (2) cannot be used in an actual PDF fit since it is affected by the D'Agostini bias for the treatment of normalization errors [21], but it is suitable to compare predictions from different PDF sets.

Other definitions of the covariance matrix rather than Eq. (2) will lead to somewhat different results, as well as different treatments of systematic and luminosity uncertainties, can lead to somewhat different results. We will study in the appendix the impact of different definitions of the covariance matrix in the context of the ATLAS 2010 inclusive jet measurements.

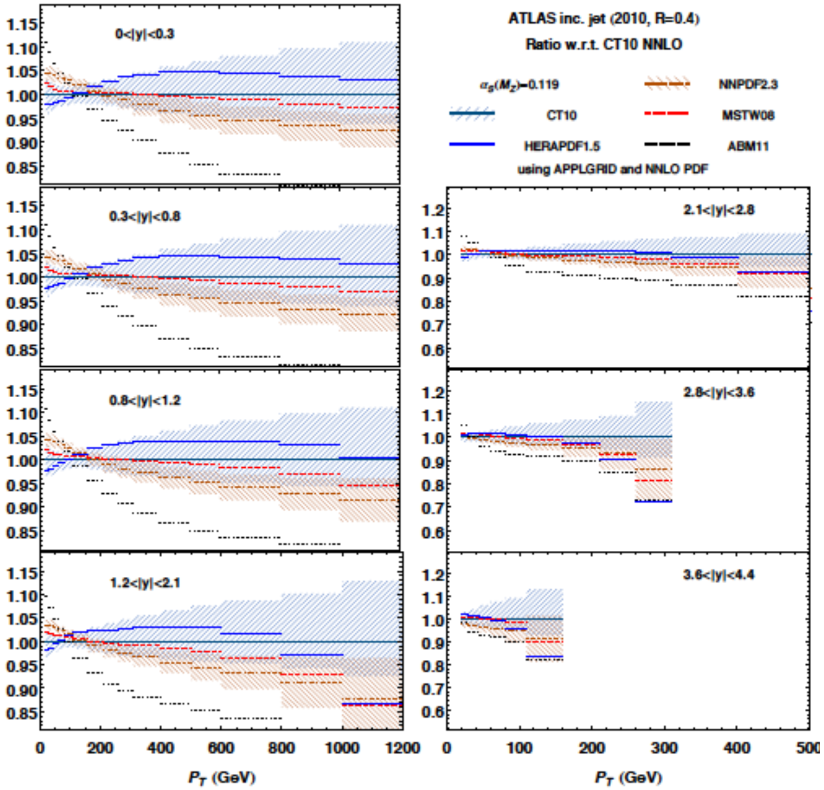
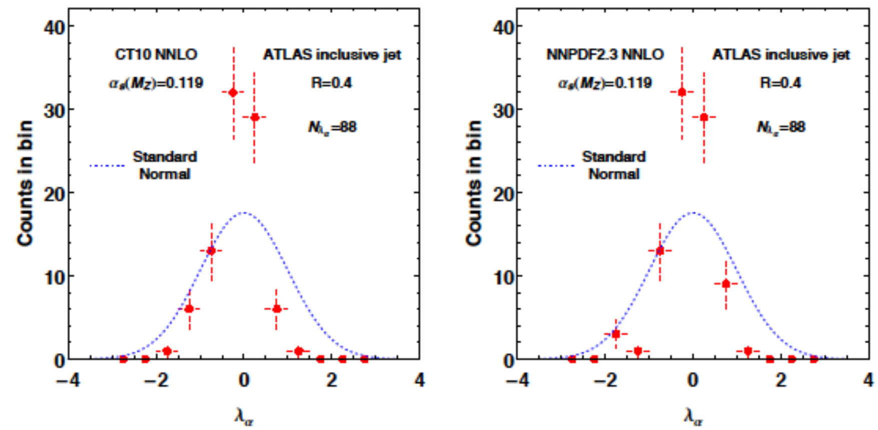



Figure 2: Comparisons of NLO theoretical predictions for 2010 ATLAS single-inclusive jet production ($R = 0.4$) from APPLGRID using various NNLO PDFs with $\alpha_s(M_Z) = 0.119$.

Systematic error shifts for ATLAS jet data for CT10 and NNPDF2.3 NNLO




also important to check that no major systematic errors need large shift

$\chi^2$ for all PDFs are good (too good?) 2010 data not constraining for PDF fits?

| PDFset($\alpha_s(M_Z) = 0.119$) | $\chi^2/d.o.f$ | $\chi^2$(res.) | $\chi^2$(sys.) | $\lambda_{\alpha,lum.}$ |
|---|---|---|---|---|
| ABM11 NNLO | 0.81 | 44.4 | 28.5 | -1.12 |
| CT10 NNLO | 0.81 | 47.4 | 25.5 | -1.76 |
| CT10 NLO | 0.94 | 54.0 | 30.6 | -1.18 |
| HERA1.5 NNLO | 0.85 | 50.7 | 25.8 | -2.36 |
| MSTW08 NNLO | 0.79 | 45.7 | 25.1 | -2.00 |
| NNPDF2.3 NNLO | 0.79 | 42.4 | 29.1 | -1.88 |

Table I: Fit of 2010 ATLAS single-inclusive jet data ($R = 0.4$), including reduced $\chi^2$, luminosity systematic shift, and the separate contributions to the total $\chi^2$ from residuals and systematic shifts, using NLO theoretical predictions from FASTNLOv2 for various PDFs with $\alpha_s(M_Z) = 0.119$.

# Which $\chi^2$?

- There are a number of $\chi^2$ values being quoted that can differ greatly depending on the details of the definition

| | | $\chi^2$ definition | | | |
|---|---|---|---|---|---|
| PDF | Code | Eq. (A1), $\sigma_k = D_k$ | Eq. (A4), $\sigma_k = D_k$ | Eq. (A1), $\sigma_k = T_k$(CT10) | Eq. (A1), $\sigma_k = T_k$(NN2.3) |
| CT10 | FNLO | 0.95 | 0.95 | 0.55 | 0.60 |
| CT10 | MEKS1 | 1.11 | 1.11 | 0.67 | 0.71 |
| CT10 | MEKS2 | 1.00 | 1.00 | 0.65 | 0.68 |
| NN2.3 | FNLO | 0.86 | 0.87 | 0.60 | 0.57 |
| NN2.3 | MEKS1 | 1.11 | 1.12 | 0.80 | 0.82 |
| NN2.3 | MEKS2 | 0.90 | 0.90 | 0.65 | 0.62 |
| NN2.3 | APPLGRID | 1.00 | 1.00 | 0.64 | 0.58 |

Table II: $\chi^2/N_{pt}$ values for the ATLAS inclusive jet production data ($\sqrt{s} = 7$ TeV, $R = 0.4$) obtained with various NLO PDFs, computer codes, and definitions of the $\chi^2$ function. The cross sections are computed at NLO using FASTNLO (FNLO), MEKS with $\mu_{F,R}$ equal to the individual jet $p_T$ (MEKS1) or $p_T$ of the hardest jet (MEKS2), and APPLGRID. The correlation matrix is obtained from the raw experimental matrix as the percentage of the central experimental value (columns 1 and 2), CT10 theoretical prediction (column 3) and NNPDF2.3 theoretical prediction (column 4).

$$\chi^2(\{a\},\{\lambda\}) = \sum_{k=1}^{N_{pt}} \frac{1}{s_k^2}\left(D_k - T_k(\{a\}) - \sum_{\alpha=1}^{N_\lambda} \beta_{k\alpha}\lambda_\alpha\right)^2 + \sum_{\alpha=1}^{N_\lambda} \lambda_\alpha^2, \tag{A1}$$

$$\tilde{\chi}^2(\{a\},\{\lambda_0(a)\}) = \sum_{i,j=1}^{N_{pt}} (D_i - T_i)\, C_{ij}^{-1}\, (D_j - T_j) \qquad C_{ij}^{-1} = \left[\frac{\delta_{ij}}{s_i^2} - \sum_{\alpha,\beta=1}^{N_\lambda} \frac{\beta_{i\alpha}}{s_i^2} \mathcal{A}_{\alpha\beta}^{-1} \frac{\beta_{j\beta}}{s_j^2}\right]$$

# 8 TeV cross section predictions

- The horizontal lines indicate the error range as given by CT10, MSTW2008 and NNPDF2.3

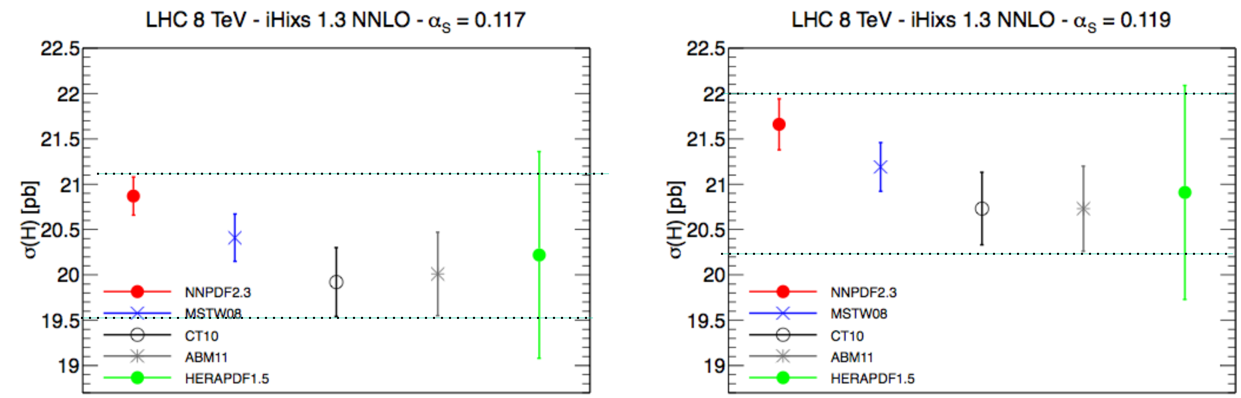



Figure 7: Comparison of the predictions for the LHC Standard Model Higgs boson cross section in gluon fusion at 8 TeV between various NNLO PDF sets. Left plot: results for $\alpha_S(M_Z) = 0.117$. Right plot: results for $\alpha_S(M_Z) = 0.119$.

| $\alpha_S(M_Z)$ | NNPDF2.3 | MSTW08 | CT10 | ABM11 | HERAPDF1.5 |
|---|---|---|---|---|---|
| 0.114 | $19.74 \pm 0.25$ | $19.17 \pm 0.24$ | $18.76 \pm 0.36$ | $18.77 \pm 0.43$ | $19.22 \pm 1.08$ |
| 0.117 | $20.87 \pm 0.21$ | $20.41 \pm 0.26$ | $19.92 \pm 0.38$ | $20.01 \pm 0.46$ | $20.22 \pm 1.14$ |
| 0.118 | $21.29 \pm 0.23$ | $20.78 \pm 0.26$ | $20.31 \pm 0.40$ | $20.36 \pm 0.47$ | $20.42 \pm 1.15$ |
| 0.119 | $21.66 \pm 0.28$ | $21.19 \pm 0.27$ | $20.73 \pm 0.40$ | $20.73 \pm 0.47$ | $20.91 \pm 1.18$ |

Table 3: The cross sections for Higgs production at 8 TeV in the gluon fusion channel at NNLO, using the settings described in the text. The cross sections are given in pb. We have assumed a Higgs boson of $m_H = 125$ GeV. We show the results for different values of $\alpha_S(M_Z)$.

# 8 TeV cross section predictions

- The horizontal lines indicate the error range as given by CT10, MSTW2008 and NNPDF2.3

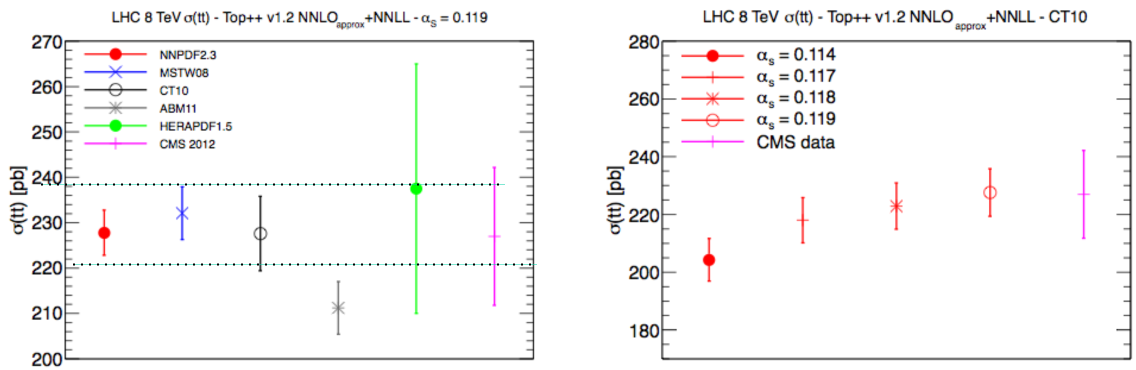
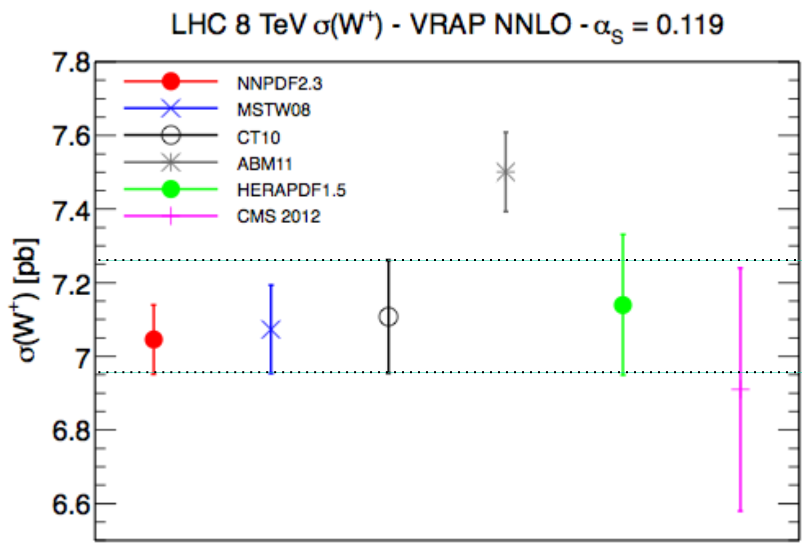


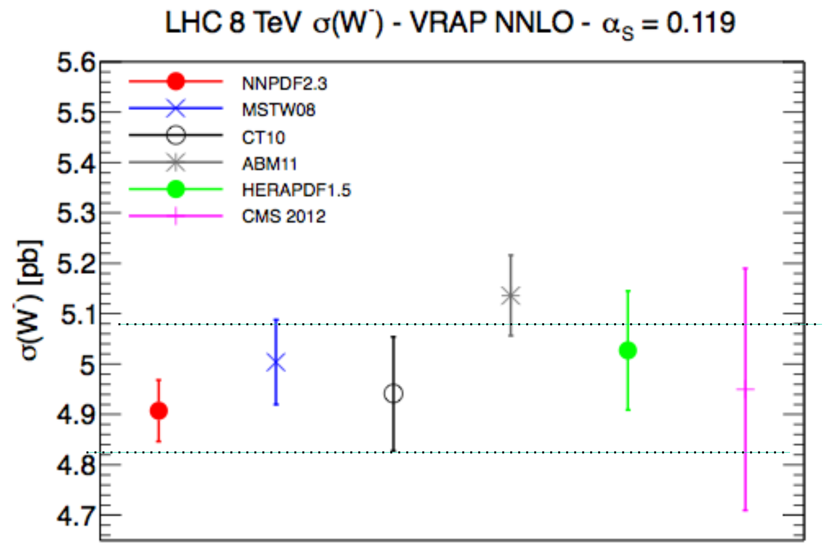

Figure 8: Comparison of the predictions for the top quark pair production at LHC 8 TeV between various NNLO PDF sets. Left plot: results for $\alpha_S(M_Z) = 0.119$. Right plot: the dependence on $\alpha_S(M_Z) = 0.119$ for the CT10 results. In both cases we also show the recent CMS 8 TeV measurement.

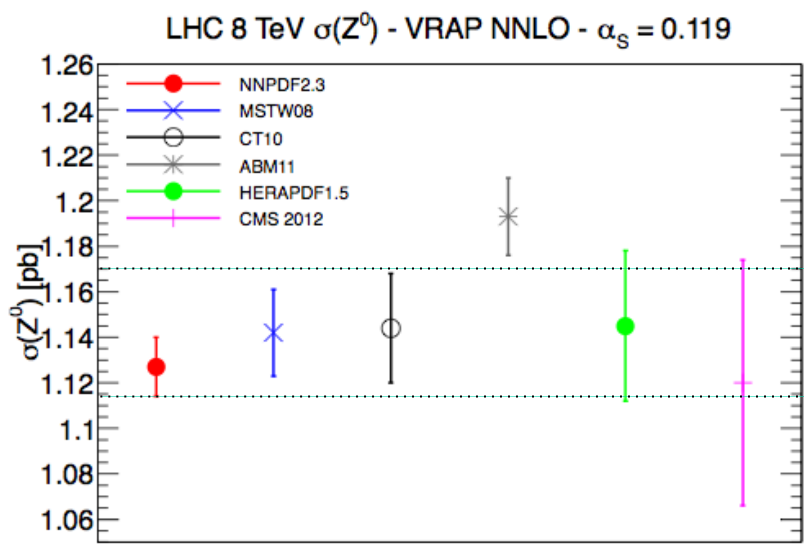
| $\alpha_S(M_Z)$ | NNPDF2.3 | MSTW08 | CT10 | ABM11 | HERAPDF1.5 |
|---|---|---|---|---|---|
| 0.114 | $206.35 \pm 4.5$ | $208.8 \pm 5.2$ | $204.3 \pm 7.4$ | $181.4 \pm 5.0$ | $207.2 \pm 24.0$ |
| 0.117 | $\pm$ | $222.5 \pm 5.5$ | $218.0 \pm 7.8$ | $199.7 \pm 5.5$ | $225.1 \pm 26.1$ |
| 0.118 | $\pm$ | $227.1 \pm 5.7$ | $222.9 \pm 8.0$ | $205.4 \pm 5.6$ | $228.8 \pm 26.5$ |
| 0.119 | $227.8 \pm 5.0$ | $232.1 \pm 5.8$ | $227.6 \pm 8.2$ | $211.2 \pm 5.8$ | $237.5 \pm 27.5$ |

Table 4: Same as Tab. 3 for the cross sections for top quark pair production at 8 TeV at NLO+NNL, using the settings described in the text. The cross sections are given in pb. We have assumed a top quark mass of $m_H = 173.3$ GeV.

# 8 TeV cross sections



# 8 TeV cross section ratios

Here the uncertainty is closer to a factor of 2, even though mostly qQ initial states.

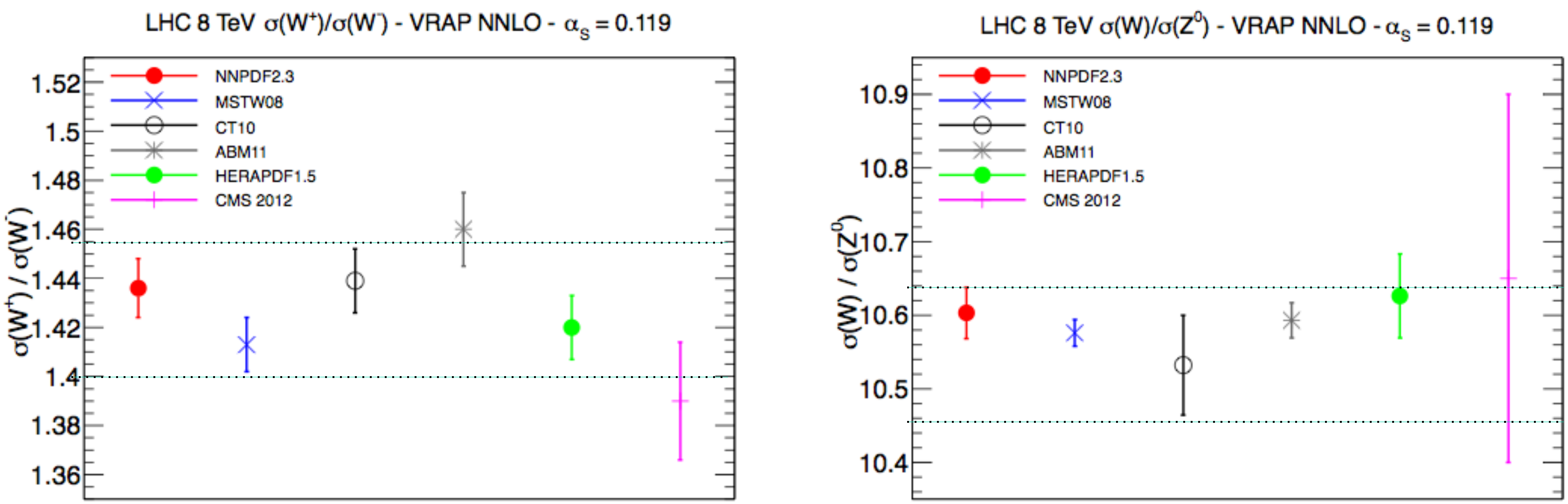



Figure 9: Comparison of the predictions for inclusive cross sections for electroweak gauge boson production between different PDF sets at LHC 8 TeV. In all cases the branching ratios to leptons have already been taken into account. From top to bottom and from left to right we show the $W+$, $W-$ and $Z$ inclusive cross sections and then the $W^+/W^-$ and $W/Z$ ratios. All cross sections are compared at a common value of $\alpha_S(M_Z) = 0.119$.

# Summary

- The plan is to put the paper on the archive before the CERN PDF4LHC (mini)meeting
  - where Juan will present the results
  - and then submit the paper to a journal
- And then to derive a PDF4LHC update from this document, which will include a new recommendation for NNLO predictions where it is necessary to calculate an uncertainty band beyond the use of one PDF error set alone
  - my suggestion would be to use the envelope of CT10, MSTW2008 and NNPDF2.3, similar to what is now done at NLO

# EWK workshop

## Monday 24 September 2012

top

**09:30->*10:45* Experimental issues I**

09:30 Properties of the W and Z boson (45'+30') (1h15') ( Slides ) — J. Kretzschmar

10:45 Coffee break

**11:00->*12:15* Experimental issues II**

11:00 Diboson production (45'+30') (1h15') — L. Marx

12:15 Sandwich lunch

**13:45->*15:15* Theory I**

13:45 Review of electroweak corrections and electroweak Sudakov effects (60'+30') (1h30') — J. Kuehn

15:15 Coffee break

**15:45->*17:30* Theory II**

15:45 W boson properties and EW and QCD corrections to Drell Yan in the Powheg Box (45'+15') (1h00') — F Piccinini

16:45 QED corrections in Monte Carlo tools (25'+5') (30') ( Slides ) — M Schoenherr

17:45 Conference dinner (5h00')
Surprise venue with a maritime flair

## Tuesday 25 September 2012

top

**09:45->*11:00* Experimental issues III**

09:45 Inclusive jet and dijet production (45'+30') (1h15') ( Slides ) — F Mueller

11:00 Coffee break

**11:15->*12:45* Theory III**

11:15 Electroweak radiative corrections for W-Pair Production at the LHC (25'+5') (30') ( Slides ) — A Bierweiler

11:45 Corrections to Vj production (25'+5') (30') ( Slides ) — T Kasprzik

12:15 EW Corrections to Higgs production (25'+5') (30') ( Slides ) — A Mueck

12:45 Sandwich lunch

**14:15->*15:30* Experimental issues IV**

14:15 Electroweak measurements at CMS (45'+15') (1h15') ( Slides ) — Kalanand Mishra

15:30 Coffee break

**16:00->*17:30* Theory IV**

15:45 EW corrections in jet production (25'+5') (30') ( Slides ) — A Huss

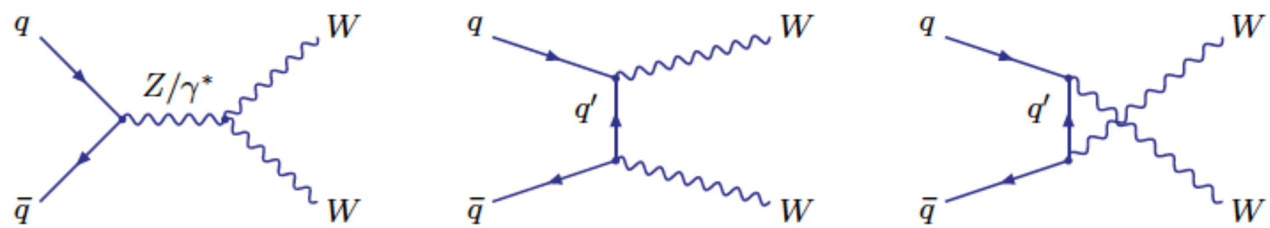
16:15 EW corrections to single-top processes (25'+5') (30') ( Slides ) — E Mirabella

16:45 Estimating EW corrections (25'+5') (30') ( Slides ) — E Vryonidou

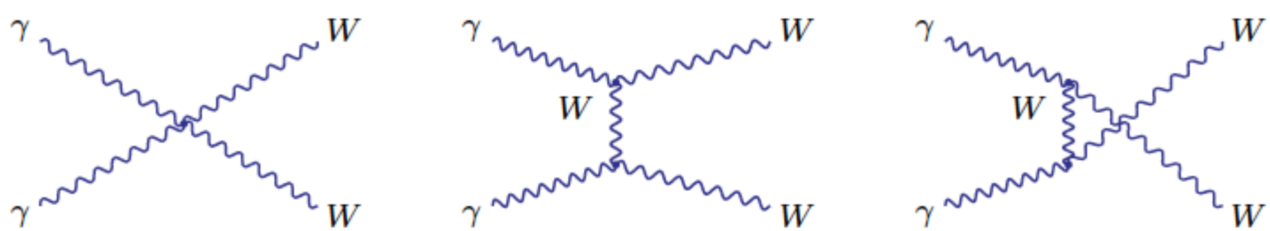
**17:30->*18:30* Final discussion**

# Maritime flair dinner

- **Partonic leading order contributions at $\mathcal{O}(\alpha^2)$:**




- **Photon-induced contributions at $\mathcal{O}(\alpha^2)$:**

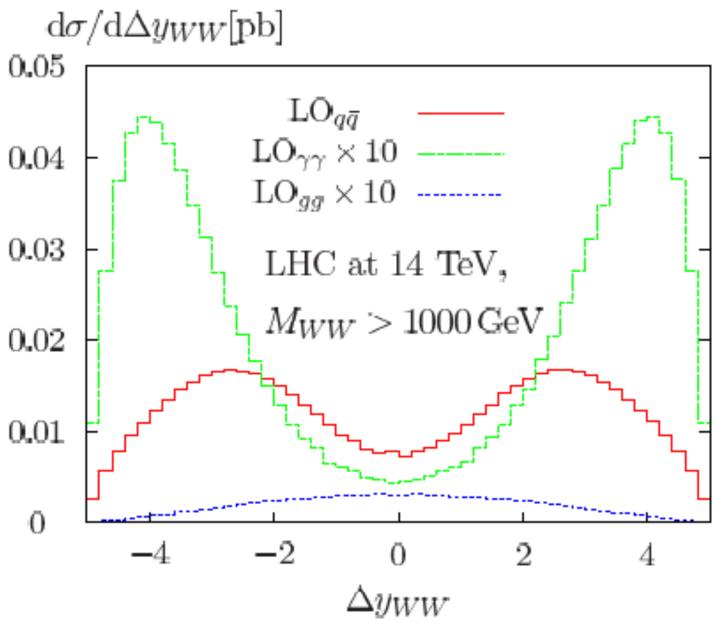


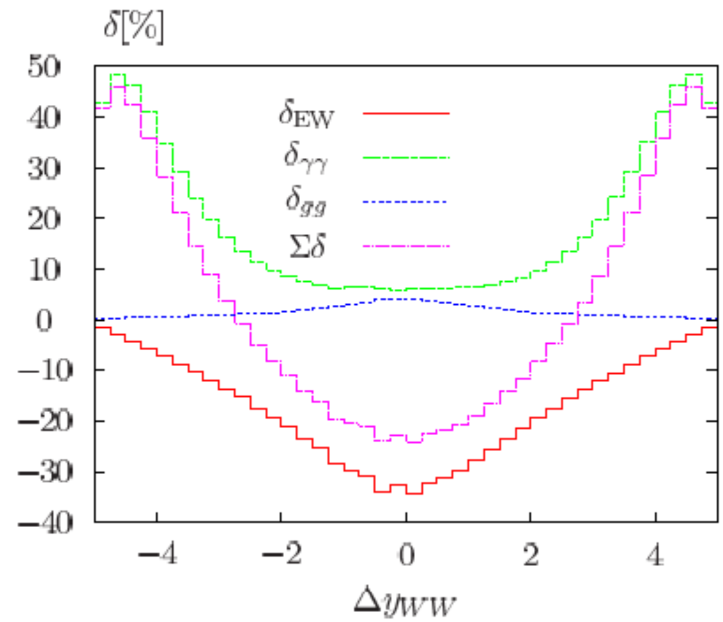

$\rightarrow$ MSTW2004qed PDF set is adopted [Martin et al. 2005]

$\rightarrow$ Potentially large contribution at large invariant masses

**High energy cuts:** $p_{T,W^\pm} > 15$ GeV, $|y_{W^\pm}| < 2.5$ GeV, $M_{WW} > 1$ TeV

MSTW2008LO PDFs [Martin et al. 2009]




- WW production dominated by small scattering angles
- drastic forward-backward peaking of $\gamma\gamma \to WW$
- drastic distortion of angular distribution
- $\Sigma\delta$ varies from $-30\%$ and $+45\%$ for $M_{WW} > 1$ TeV

# The leading jet $k_{T,1}$ ($y^*$ binning)