**PDF4LHC Recommendations**

The LHC experiments are currently producing cross sections from the 7 TeV data, and thus need accurate predictions for these cross sections and their uncertainties at NLO and NNLO. Crucial to the predictions and their uncertainties are the parton distribution functions (PDFs) obtained from global fits to data from deep-inelastic scattering, Drell-Yan and jet data. A number of groups have produced publicly available PDFs using different data sets and analysis frameworks. Given the necessity of having an *official* recommendation from the PDF4LHC working available on a short time frame, the prescription outlined below has been adopted. This is not intended to be an ideal or a final prescription, but is considered to be reasonably conservative and reasonably easy to implement. Further improvements and further standardizations are planned for future updates.

A benchmarking exercise was carried out to which all PDF groups were invited to participate. This exercise considered only the most up to date published versions of PDFs from the 6 groups: ABKM09, CTEQ6.6, GJR08, HERAPDF1.0, MSTW08, NNPDF2.0. This exercise was very instructive in understanding many differences in the PDF analyses - different input data, different values of $\alpha_s$, different treatments of heavy quarks, different values of heavy quark masses, different ways of parameterising PDFs, different ways of implementing higher order corrections, different ways of treating experimental systematic errors, different ways of estimating confidence levels-and this is not an exhaustive list. This exercise was very instructive in understanding where the PDFs agree and where they disagree, and it established the broad agreement of all PDF predictions despite these many differences. This was essential in the determination of the recommendation outlined here. The details and results of the benchmarking exercise are described in a note to be available from the PDF4LHC web-site.

**PDF4LHC recommendation for estimates of PDF uncertainties, June 2010:**

At NLO, the recommendation is to use (at least) predictions from the three PDF fits that are truly global, i.e. that use results from the Tevatron and fixed target experiments as well as HERA: CTEQ, MSTW and NNPDF. The PDFs from these three groups to be used are: CTEQ6.6, MSTW2008 and NNPDF2.0. Neither the CTEQ6.6 nor the MSTW2008 PDF sets use the new combined very accurate HERA datasets (future updates of the CTEQ (CT10) and MSTW PDFs will include them- the CTEQ and MSTW presentations at the DIS 2010 workshop can be consulted to assess the effects of these data), but these PDFs are now most commonly used by the LHC experiments and are suggested in the recommendation for this reason. The NNPDF2.0 set does not use a general-mass variable flavor number scheme (the NNPDF2.1 PDF set, which does use a general-mass variable flavor number scheme is currently being finalized), but the alternative method which NNPDF use for determining PDF uncertainties serves as a useful check on the predictions from CTEQ and MSTW.

Other PDF sets, GRJ08, ABKM09 and HERAPDF1.0 are useful for cross checks and specific studies. For example, HERAPDF1.0 allows to study theoretical uncertainties related to the charm mass treatment.

The benchmarking exercises have been particularly useful to understand the $\alpha_s$ dependence of LHC cross sections, and to understand what differences among the PDF groups result from assumptions of different values of $\alpha_s$. It is important to note that different values of $\alpha_s(m_Z^2)$ are used by these three PDF groups. CTEQ6.6 and NNPDF use a fixed value of $\alpha_s$ around the world average (0.118 for CTEQ6.6 and 0.119 for NNPDF) while MSTW2008 uses a value of 0.120, determined from their global fit. The $\alpha_s$ uncertainties (for the PDFs) can be evaluated by taking a range of $\pm 0.0012$ for 68%CL (or $\pm 0.002$ for 90% CL) from the preferred central value for CTEQ and NNPDF. The total PDF+$\alpha_s$ uncertainty can then be evaluated by adding the variations in PDFs due to $\alpha_s$ uncertainty in quadrature with the fixed $\alpha_s$ PDF uncertainty (shown to correctly incorporate correlations in the quadratic error approximation) or, for NNPDF, more efficiently taking a Gaussian distribution of PDF replicas corresponding to different values of $alpha_s$. For MSTW the PDF+$\alpha_s$ uncertainties should be evaluated using their prescription which better accounts for correlations between the PDF and $\alpha_s$ uncertainties when using the MSTW dynamical tolerance procedure for uncertainties. Adding the $\alpha_S$ uncertainty in quadrature for MSTW can be used as a simplification but generally gives slightly smaller uncertainties.

**NLO Summary:**

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 currently greater than their uncertainties would strictly suggest. As a central value, use the midpoint of this envelope*. We recommend that a 68%CL 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%CL and thus their uncertainties should be reduced by a factor of 1.645 for 68%CL.

At NNLO only one PDF set comes from a fully global fit, i.e. MSTW 2008, so this should be used for central predictions. However the uncertainty obtained from MSTW alone should be expanded to some degree. It seems most appropriate to do this by multiplying the MSTW uncertainty at NNLO by the factor obtained by dividing the full PDF + $\alpha_s$ uncertainty obtained from the envelope of MSTW, CTEQ and NNPDF results at NLO by the MSTW PDF+$\alpha_s$ uncertainty at NLO. We note that in most cases so far examined for the LHC running at 7TeV centre of mass energy this factor of the envelope divided by the MSTW uncertainty is quite close to 2, and this factor can be used as a short-hand prescription. Thus for processes which are not dominated by PDF uncertainties the central prediction can be taken from MSTW08 and the uncertainty can be estimated by scaling the MSTW08 error band by a factor of 2.

There are NNLO PDFs obtained from less global fits by the ABKM, GJR and HERAPDF groups and these can be used for cross-checks, bearing in mind that there may be kinematic regions where the absence of data, or in the GJR case the theoretical constraint applied to the input, may lead to PDFs with larger total uncertainties or predictions differing significantly from those in more global fits

**NNLO Summary:**

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. However, if the interest of the user is in the difference of an NLO and NNLO prediction, rather than in the uncertainties, then the same PDF must be used for both evaluations. The current recommendation would be to use the MSTW08 predictions for both.

**Note added, May 2014**

Since the first documented recommendation several more up to date official versions of PDF sets became available and we therefore update the recommendation above to use these data sets, e.g., the use of CT10 instead of CTEQ6.6, NNPDF2.3 instead of NNPDF2.1. We also extend the same recommendation to use these sets for NNLO uncertainty bands.

With the imminent update of a number of PDF sets incorporating significant new data from the LHC and other experiments, and also the advent of more sophisticated and efficient methods of combining different PDF sets, a new recommendation (with the option to include more PDF sets) is under study and will be discussed at future PDF4LHC meetings, with the aim to converge on a prescription by the end of 2014.

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* Take the central value $x = 0.5*(\max(x_1+s_1, x_2+s_2, x_3+s_3)+\min(x_1-s_1, x_2-s_2, x_3-s_3))$ and the symmetric error $s = 0.5*(\max(x_1+s_1, x_2+s_2, x_3+s_3)-\min(x_1-s_1, x_2-s_2, x_3-s_3))$ where $x_1, x_2, x_3$ are the central values of MSTW08, NNPDF2.0, CTEQ6.6 respectively and $s_1, s_2, s_3$ are their 68% CL uncertainties.