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MMHT 2014 Parton Distributions Functions

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I present the MMHT2014 PDFs, an update of the previous major release in the same framework, i.e. MSTW2008. I discuss the changes in both the central values and uncertainties in the PDFs due to changes in theoretical procedures and the impact of new, largely LHC data-sets. I discuss the correlation between the PDFs and the strong coupling constant and the constraint on the latter. I also present some results with varying quark masses.

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I present results on the update in PDFs within the general MSTW framework [1] due to some theory improvements and a variety of new data sets, including most of the up-to-date LHC data. The release of a new set of MMHT 2014 PDFs [2] is summarised, and some subsequent results and future plans are discussed.

There are a number of changes in the theoretical treatment or procedures. We continue to use extended parameterisation with Chebyshev polynomials, and freedom in deuteron nuclear corrections (and heavy nuclear corrections) introduced in [3], which led to a change in the $u_V - d_V$ distribution. We now use the "optimal" GM-VFNS choice [4] which is smoother near to heavy flavour transition points, particularly at NLO. We also correct the cross-sections for charm mesons decaying to muon production from charged current neutrino scattering from nuclear targets [5] for a missing small contribution, i.e. where charm is produced away from the interaction point. We previously assumed this was accounted for by acceptance corrections. Checks show correction is a small effect on strange distribution. Correlated systematic uncertainties are now treated as multiplicative not additive. Relevant for the neutrino on nucleus $\rightarrow$ dimuon data, we have also changed the value of the charm branching ratio to muons used which is not in itself reliant on a PDF input, and now also apply an uncertainty on the branching ratio which feeds into the PDFs. We use $B_\mu = 0.092 \pm 10\%$ from [6]. The fits prefer $B_\mu = 0.085 - 0.091 \pm 15\%$. Finally, we update to a more recent determination of nuclear target corrections [7].

We include relevant data published before the end of 2013. This includes various changes in non-LHC data sets. Most important is the replacement of HERA run I neutral and charged current data separately from H1 and ZEUS with the combined data set [8]. The fit to these data is very good and is slightly better at NNLO than at NLO. We include HERA combined data on $F_2^c(x,Q^2)$ [9], with a fit quality of about $\chi^2 = 1.2$ per data point. We include all direct published HERA $F_L(x,Q^2)$ measurements. We undershoot data a little at lower Q^2, but the χ^2 is about one per point. There is no inclusion of separate run II H1 and ZEUS data sets yet, since we waited instead for the Run II combination data which has very recently appeared [10]. We include some updated Tevatron data sets, i.e. the CDF W-asymmetry data [11], the D0 electron asymmetry data [12] with $p_T > 25$ GeV based on 0.75 fb^{-1} and the new D0 muon asymmetry data [13] for $p_T > 25$GeV based on 7.3 fb^{-1}.

We also now include a variety of different types of LHC data in the PDF determination. A large fraction of this is rapidity-dependent vector boson production. This consists of ATLAS W,Z cross sections differential in rapidity [14], which leads to a slight increase in the strange quark; CMS data on the asymmetry of W bosons decaying to leptons [15, 16]; Z rapidity data [17]; LHCb data on W and Z rapidity distributions [18, 19]; and ATLAS high mass Drell Yan data [20] and CMS double-differential Drell Yan data [21]. The W asymmetry type data was poorly predicted by MSTW2008 PDFs, but these predictions were immensely improved by the modifications of valence quarks in [3], and the fit to asymmetry data is no longer an issue at all. The fit to CMS double differential Drell Yan data extending to low mass shows an interesting feature. NNLO works enormously better than NLO for the lowest mass bins of $\sim 20-45$ GeV. This is partially due to the fact that at the lowest mass the kinematic cuts largely remove the LO contribution to the cross section and NLO is close to being LO in practice. We also include data on $\sigma_{t\bar{t}}$ from the combined cross section measurement from D0 and CDF [22], and all published data from ATLAS and CMS. For calculations we use $m_t^{\rm pole} = 172.5$ GeV (the value used in the Tevatron combination) with an error of 1 GeV and a χ^2 penalty applied. The fit results are good, with NLO preferring masses about 1 GeV below $m_t = 172.5$ GeV and NNLO masses about 1 GeV above.

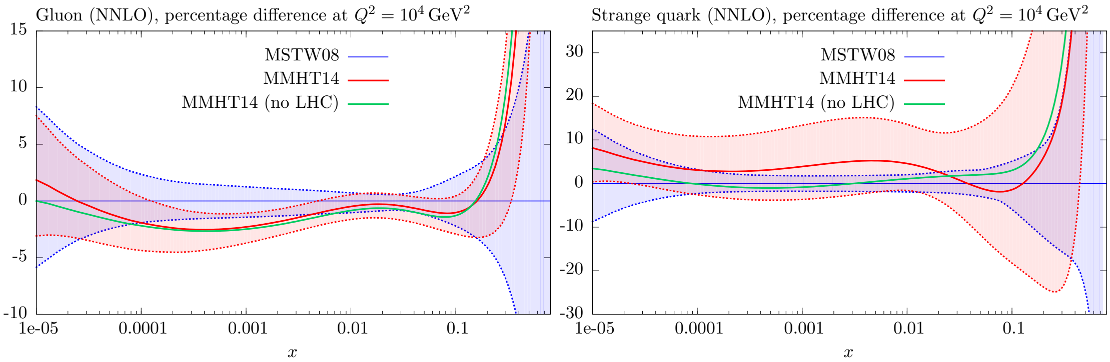

Figure 1: Comparison of the mSTW2008 and MMHT2014 gluon and $s+\bar{s}$ distributions at NNLO.

At NLO we also include CMS inclusive jet data [21] together with ATLAS 7 TeV [24] and 2.76 TeV data [25]. The ATLAS fit quality is $\chi^2/N_{pts} = 106/114$ and for CMS is $\chi^2/N_{pts} = 138/133$ (where the analysis includes the further breakdown of one correlated uncertainty into five recommended in [26]), with very little change on PDFs. We do not include these data at NNLO. Previous analyses have used threshold corrections for Tevatron data, and we continue to include these data, but at the LHC we are often far from threshold. The full NNLO calculation [27, 28] is nearing completion, and gives indications of the full form of the correction. Hence we obtain predictions at NNLO using "smaller" and "larger" approximate NNLO K-factors for the LHC data. In both cases the χ^2 is similar to NLO, but with some preference for a lower K-factor.

In order to determine PDF uncertainties we use the same "dynamic tolerance" prescription to determine eigenvectors as for MSTW2008 [1]. A typical tolerance $T = \Delta\chi^2 \sim 10$. We now have 25 eigenvector pairs, rather than 20. The data sets providing the dominant constraints are spread widely over LHC, HERA, fixed target DIS and Drell Yan data and Tevatron data. Changes in PDFs compared to MSTW2008 are similar at NLO and NNLO. There is an increase in $u_V - d_V$ at small x, as observed in [1]. Most other PDFs are largely unchanged. There are some differences for the gluon and strange quark, and the central values obtained in our updated fit are shown at NNLO as a ratio to MSTW2008 in Fig. 1. The NNLO gluon is slightly larger at high x and slightly smaller at low x, but within uncertainties. For $x \sim 0.01$ where the constraint on Higgs production is maximal, the gluon is almost unchanged. Indeed, the prediction for Higgs production from gluon-gluon fusion cahnged by less than 1%. The strange quark increases slightly in general and the uncertainty is far larger due to a better treatment of the comparison to the dimuon data.

We have also made a study of $\alpha_S(m_Z^2)$ and PDF sets [29]. The best fit vale of $\alpha_S(m_Z^2)$ comes out similar to the 2008 fit still with a NLO/NNLO difference. Both are fairly compatible with the global average [30], i.e. at NLO$\alpha_S(m_Z^2) = 0.1200$, and at NNLO $\alpha_S(m_Z^2) = 0.1172$, whereas $\alpha_S(m_Z^2)^{\text{world}} = 0.1186 \pm 0.0006$. We decide to present MMHT2014 PDFs with eigenvectors at a round values of $\alpha_S(m_Z^2) = 0.118$ at NNLO, close to teh world average, and at NLO also at $\alpha_S(m_Z^2) = 0.120$. The global χ^2 as a function of $\alpha_S(M_Z^2)$ is shown in Fig. 2. At NNLO forcing $\alpha_S(M_Z^2) = 0.118$ leads to $\Delta\chi^2 < 2$ compared to the best fit, but at NLO leads to $\Delta\chi^2 \sim 16$. We also considered the variation of fit quality of individual data sets with $\alpha_S(M_Z^2)$. The single most constraining data sets are for the lower limit on $\alpha_S(M_Z^2)$, $\sigma_{t\bar{t}}$ at NLO and NuTeV $xF_3(x,Q^2)$ [31] at NNLO. For the upper limit on $\alpha_S(M_Z^2)$ it is $\sigma_{t\bar{t}}$ at NLO and SLAC deuteron $F_2(x,Q^2)$ [32] at NNLO.

However, in all cases there are other data sets almost as constraining. For $\sigma_{t\bar{t}}$ there is considerable correlation with the value of m_t, and we relax the constraint from this source a little. Overall we determine an uncertainty of $\Delta\alpha_S(m_Z^2) = \pm 0.0015$(NLO), ± 0.0013(NNLO): the slightly smaller NNLO value because of a little less variation in preferred $\alpha_S(M_Z^2)$ between data sets at NNLO.

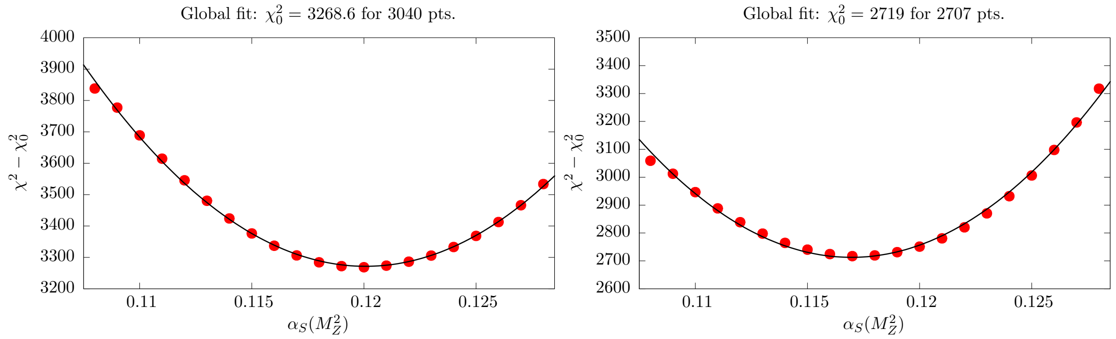

Figure 2: The global χ^2 as a function of $\alpha_S(M_Z^2)$ at NLO (left) and at NNLO (right).

We have made predictions for a number of LHC data not included in the fit due to date of publication. The comparison to $W+c$ production [33, 34] (which probes the strange quark) at NLO is good, while the comparison to differential top pair data at NLO [35, 36] is not ideal for the p_T distribution. Neither of these processes has calculations which are available for use in fits at at NNLO, though the complete results for differential top pairs are known [38] and some results have appeared. We also compare to some updated and more precise $W \to \mu$ data from LHCb [37], as shown in Fig. 3. The prediction is very good, and the data errors are now smaller than the PDF errors in places.

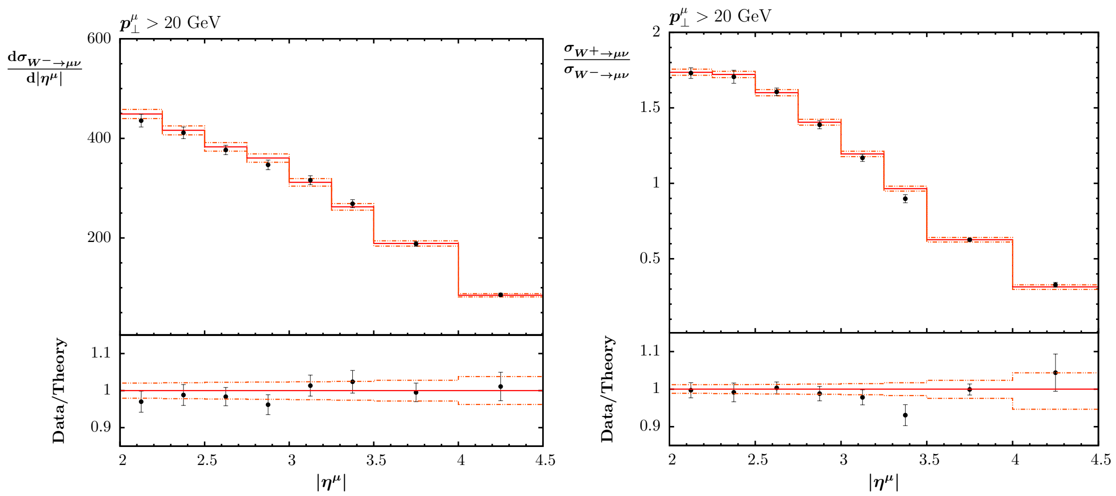

Figure 3: Comparison of the LHCb data on W^- production (left) and the W^-/W^+ ratio to MMHT2014 predictions.

We have also undertaken a study of the dependence of PDFs on heavy quarks masses. As in the mSTW 2008 study [39] we will make the same PDFs sets (i.e. exactly the same input at $Q_0^2 = 1$ GeV^2) available for three flavour and four flavour fixed-flavour number schemes (FFNS). As default we will fix the number of flavours in α_S, but will probably also provide analogous sets with variable flavour α_S since there were some requests for MSTW2008. We will also make available sets with fits done for m_c and m_b (defined in pole scheme) varying from default values of $m_c = 1.40$ GeV and $m_b = 4.75$ GeV in steps of 0.05 GeV and 0.25 GeV respectively. We will probably not make available quite as wide a range as last time, i.e. $m_c = 1.05-1.75$ GeV and $m_b = 4.00-5.50$ GeV. In practice m_b is constrained to fairly close to $m_b = 4.75$ GeV from direct $F_2^{\bar{b}b}(x,Q^2)$ data from HERA, and m_c also constrained to far better accuarcy than the than this previous range from various sources.

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

Table 1: Dependence on m_c (pole mass) at NLO in fits with $\alpha_S(M_Z^2)$ as a free parameter.

In Table 1 we show the variation with m_c of the NLO fit with free $\alpha_S(M_Z^2)$ (there is far less variationj in fit quality with variation in m_b). The global fit prefers $m_c \sim 1.25$ GeV whereas the $F_2^{\bar{c}c}(x,Q^2)$ data prefers a slightly higher value. There is some preference for lower $\alpha_S(M_Z^2)$ with lower mass. If $\alpha_S(M_Z^2)$ is fixed at 0.120 the variation with m_c is similar but the best χ^2 is not quite so low. In Table 2 we show the variation with m_c of the NNLO fit with $\alpha_S(M_Z^2) = 0.118$. Again the global fit prefers $m_c \sim 1.25$ GeV and now the $F_2^{\bar{c}c}(x,Q^2)$ data prefers a similar value. Again the picture is very similar for varying $\alpha_S(M_Z^2) = 0.118$, but with slightly better fit quality. A full publication containing the details of variation with heavy quark mass is in preparation.

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

Table 2: Dependence on m_c (pole mass) at NNLO in fits for fixed $\alpha_S(M_Z^2) = 0.118$.

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