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The effects of combined HERA and recent Tevatron $W \to \ell\nu$ charge asymmetry data on the MSTW PDFs

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We examine the effect of including the 'combined' HERA structure function data in the MSTW global fit for parton distribution functions (PDFs). The combined neutral-current HERA data have a significant, if not dramatic, effect, of up to 2–3% at NLO for Z boson and Higgs production at the Tevatron and LHC, and a generally slightly smaller effect, particularly on LHC processes, at NNLO. This is an amount comparable, or less than, the typical PDF uncertainties, and hence we do not intend to release an imminent update to the MSTW 2008 fit. We also investigate the consistency with the recent DØ data on electron and muon charge asymmetry from W decays and the direct CDF measurement of the W charge asymmetry. The DØ lepton charge asymmetry data imply a fairly large change to the down-quark distribution and/or large nuclear corrections to be applied when fitting to deuterium structure function data, while the CDF W charge asymmetry data are more consistent with the existing PDFs. However, it is difficult to reconcile all of the Tevatron $W \to \ell\nu$ charge asymmetry data sets with the fit, and to some extent, with each other.

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1. HERA combined data

The MSTW 2008 global fit [1] for PDFs contains a very large variety of data sets, including a number from H1 and ZEUS on structure functions. These structure function data (along with some newer sets) have recently been combined in [2]. The increase in precision comes about not only from a combination of statistics, but from the fact that one collaboration often controls a source of systematic uncertainty better than the other, so the systematic uncertainties can be greatly reduced by combination. In addition, this treatment of the correlated errors means that the central values are not simply the weighted averages. These data were fit in [2] and differences between previous H1 and ZEUS fits noted. Here we, too, investigate the inclusion of the combined neutral-current (NC) data instead of the component sets, adding the errors in quadrature for the moment (systematics in the combined data set are small). We include the uncombined charged-current data which are statistics dominated. We fit to data with $Q^2 \geq 2$ GeV^2 (553 pts.), but also look at results for $Q^2 \geq 3.5$ GeV^2 (524 pts.) to compare with [2]. All other details of the fit are as in [1].

At NLO the fit quality achieved is $2610/2471$ for the total data. For the HERA NC data it is $600/553$ and $530/524$, compared to $483/524$ in [2]. In order to check if the worse quality is due to the other data in the MSTW fit we also fit *only* to HERA structure function data. This results in $515/553$ and $445/524$, now much better than the HERA fit [2], presumably due to extra parameterisation freedom. Clearly the fit quality is significantly affected by tension with other data sets. The MSTW global fit with HERA combined data requires $\alpha_S(M_Z^2) = 0.1215$, a little higher than the default 0.1202. Keeping at the default value results in a fit quality 10 worse for HERA data and the global fit. Our 'HERA data only' fit gives $\alpha_S(M_Z^2) = 0.123$. The resulting PDFs are shown in Fig. 1 as a ratio to MSTW08 with the 1σ uncertainty. For the global fits the up quark strays outside this uncertainty at $x \sim 0.01$, otherwise there is little change. The predictions for hadron collider processes give 2–3% variations for Z production, but less for Higgs production (from gluon–gluon fusion, with $M_H = 120$ GeV), see Table 1. Our fit to 'HERA data only' gives a similar small-x gluon but for $x > 0.01$ it is far softer, while the up-quark distribution is not well constrained in shape for $x > 0.01$. These PDFs compare very badly to many unfitted data sets. Both the variation and comparison to unfitted data are far worse than for the PDFs in [2], showing that it is implicit constraints on the quark parameterisation rather than a real data constraint that render these PDFs similar to those from global fits at high x.

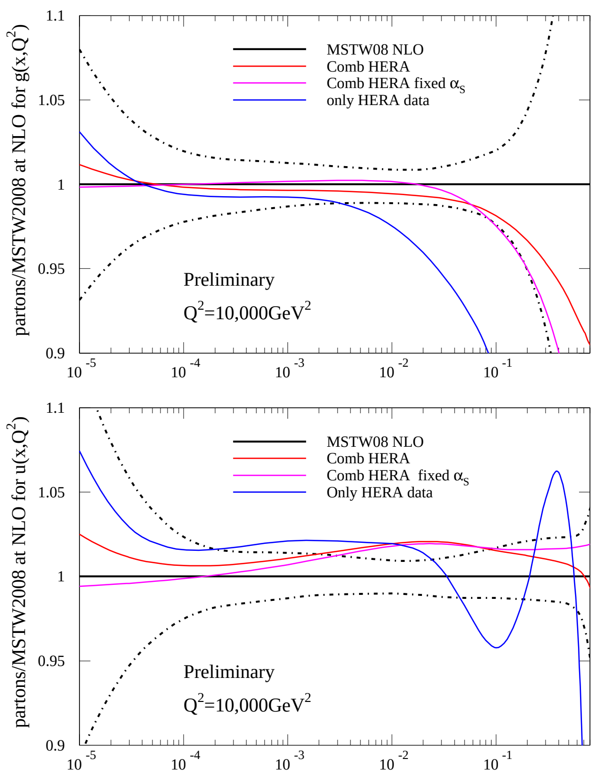

Figure 1: The ratio of NLO PDFs fit to the combined HERA data to the default MSTW08 distributions.

At NNLO the fit quality for the HERA NC data is $575/553$ and $529/524$, better than NLO. $\alpha_S(M_Z^2)$ moves only from 0.1171 to 0.1181, and fixing it leads to $\chi^2 \approx 8$ higher. Fitting only HERA data gives $494/553$ and $467/524$. The change in PDFs is similar to NLO, but with a tendency to dip slightly at $x < 0.001$. The NNLO predictions have generally less variation at the LHC than at NLO, see Table 1. The effect of the combined data is significant, and will be included in an updated set soon, but certainly is not dramatic enough to invalidate the present MSTW 2008 PDFs [1].

PDF set	$B_{l^+l^-}\cdot\sigma_Z$(nb)	σ_H(pb)	$B_{l^+l^-}\cdot\sigma_Z$(nb)	σ_H(pb)
NLO	Tevatron		LHC (14 TeV)	
MSTW08	$0.243^{+2.4\%}_{-2.0\%}$	$0.746^{+5.0\%}_{-4.4\%}$	$2.00^{+2.1\%}_{-1.8\%}$	$40.7^{+3.0\%}_{-2.7\%}$
New HERA	+3.1%	−0.7%	+2.5%	+1.2%
fix $\alpha_S(M_Z^2)$	+3.0%	−4.0%	+1.8%	−0.8%
NNLO	Tevatron		LHC (14 TeV)	
MSTW08	$0.251^{+2.2\%}_{-1.8\%}$	$0.955^{+5.4\%}_{-4.8\%}$	$2.05^{+2.6\%}_{-2.1\%}$	$50.5^{+3.6\%}_{-2.7\%}$
New HERA	+3.0%	+0.2%	+1.8%	+0.8%
fix $\alpha_S(M_Z^2)$	+2.6%	−2.9%	+1.2%	−1.0%

Table 1: The cross sections at the Tevatron and LHC with "PDF+α_S" uncertainties and the changes in fits using the new combined HERA data.

2. Tevatron lepton charge asymmetry from W decays

There are new DØ data on electron [3] and muon [4] charge asymmetry and CDF W charge asymmetry data [5]. These are far more precise than the previous measurements [6, 7], which already give the main constraint on some PDF eigenvectors. These new data should constrain the down quark for $0.01 < x < 0.7$, where the current main constraint is deuterium DIS and is subject to uncertainty from nuclear corrections (a source not included in PDF uncertainties). The current fit to asymmetry data is moderate [1]. At NLO $\chi^2 = 25/10$ (DØ) [7] and $\chi^2 = 29/22$ (CDF) [6].

The new data cause worse problems. Standard MSTW fits give a very poor comparison to both DØ electron and muon data, as seen in Table 2 and Fig. 2. We have tried a variety of alternatives, weighting the asymmetry data and/or making cuts on other data in the fit. The fit quality to DØ e and μ data and other data for these variations is also shown. Here 'cut' means the omission of BCDMS proton and deuterium data and NMC n/p data which are very badly described. NNLO corrections [8, 9, 10] do help the fit, but only marginally.

fit p_T (GeV)	$\chi^2/12\,(e)$ > 25	$\chi^2/12\,(e)$ 25–35	$\chi^2/12\,(e)$ 35–45	$\chi^2/2689$ non- DØ	$\chi^2/16\,(\mu)$ two bins
Standard					
2008 data	116	19	144	2518	542
DØ$_e$	71	**23**	**81**	2551	358
DØ$_e$ (w)	25	**10**	**23**	2942	183
DØ$_\mu$	26	55	58	2640	**119**
DØ$_\mu$ (w)	33	79	88	3131	**10**
DØ$_\mu$ cut	33	52	55	3190	**26**
Deut. Corr.					
2008 data	25	32	42	2455	140
DØ$_e$ (w)	25	**9**	**23**	2551	192
DØ$_\mu$ (w)	38	67	75	2649	**11**
DØ$_{e+\mu}$ (w)	24	**16**	**40**	2848	**42**
DØ$_e$ p_T>25	**23**	38	32	2454	229

Table 2: Description of DØ lepton asymmetry and remaining data, without (upper) and with (lower) deuterium corrections. (w) denotes a high weight. Asymmetry data included in each fit are shown in bold type.

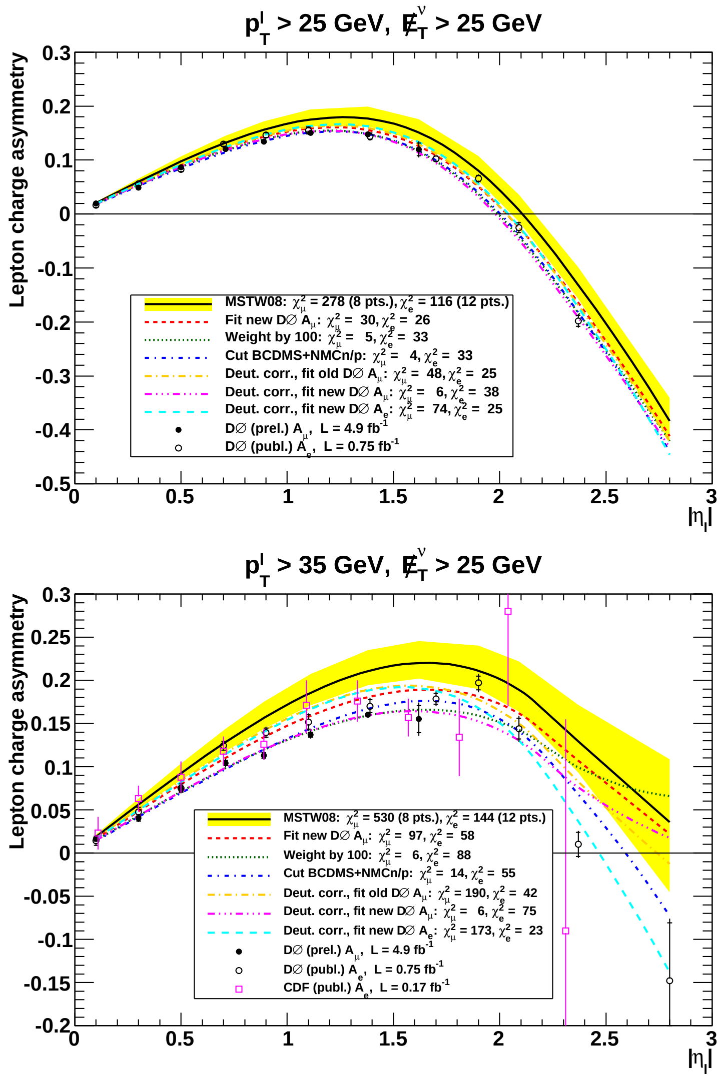

Figure 2: The fit to DØ lepton asymmetry data for all $p_T > 25$ GeV (top) and 35 GeV $< p_T < 45$ GeV (bottom).

In order to try to improve the fit, an extra parameter was added to both the high-x valence quark distributions. This had negligible impact in the fit quality and extracted PDFs. Then variations in the deuterium corrections to the structure function data fit were tried. In the standard MSTW fit these data have small corrections for shadowing at small-x, but none at high-x. Removing these corrections and refitting using the standard MSTW08 data leads to $\chi^2 = 19/10$ (DØ) and $\chi^2 = 25/22$ (CDF), a significant improvement. The up and down quarks change by 1–2% near $x = 0.02$. Given this mild success we also tried a more sophisticated approach to corrections for deuterium data, i.e. Q^2-independent deuterium corrections for all x applied to theory by means of a smooth function with 4 free parameters. This improves the quality of the fit to non-asymmetry data significantly, as seen in the lower half of Table 2, and using the standard MSTW08 data sets gives $\chi^2 = 6/10$ (DØ) and $\chi^2 = 21/22$ (CDF). When fitting to the newer DØ asymmetry data the free deuterium corrections also help a great deal, as seen in Table 2 and Fig. 2. A good fit (given the scatter of data) can be found for the electron data in the combined p_T bin, with no deterioration in fit quality for other data types. However, although very good fits to the electron data in separate-p_T bins, or to the muon data, can be found, they both, especially the latter, result in a deterioration in the fit quality to other data. We also find that the muon data and electron data cannot be fit near their best individual quality simultaneously, see Table 2. The required deuterium corrections are shown in Fig. 3. The general shape is similar to expectations, labelled "simple model", but in all cases, especially when fitting muon data, the correction is low in the region of $x = 0.1$. The main change in the PDFs, when deuterium corrections are applied, is an increase in the $d(x,Q^2)$ for $x > 0.02$, and, in particular, a 10% increase for $x \approx 0.4$ at $Q^2 = 10^4$ GeV^2.

As well as tensions between the two DØ data sets there are also conflicts with the quality of the comparison to CDF W asymmetry data [5]. The MSTW08 PDFs give (an approximate) $\chi^2 \approx 28/13$ which, given the scatter of points, is quite good. The MSTW fit to the standard data with deuterium corrections gives $\chi^2 \approx 24/13$, and as seen this also fits the combined-p_T DØ electron data well.

Good fits to the separate p_T electron data and/or muon data give $\chi^2 > 100$ for comparison to the CDF W asymmetry data, due to too much asymmetry.

We conclude from this study that inclusion of deuterium corrections and an investigation of their uncertainty is important for global fits. The deuterium data can be fit without them, but they improve the comparison even with the older low statistics asymmetry data. An examination of the more recent asymmetry data leads us to conclude that the maximally consistent sets in the fit are the CDF W asymmetry data and the combined-p_T DØ electron data. However, a good fit to the latter, without seriously affecting the rest of the global fit, requires slightly unlikely deuterium corrections. In summary, it seems at present that the difficulties in reconciling the different asymmetry data sets with theory, and with each other, necessitates further study, both of data and the theory to be applied, before the true impact in a global fit can be understood.

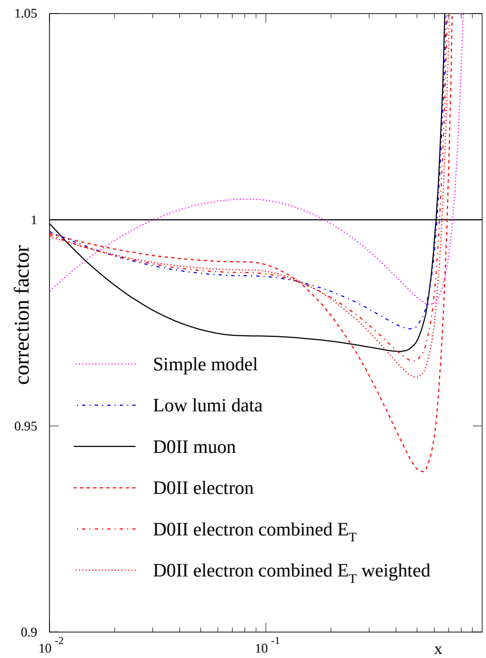

Figure 3: The deuterium corrections.

References

[1] A. D. Martin, W. J. Stirling, R. S. Thorne and G. Watt, *Parton distributions for the LHC, Eur. Phys. J.* C **63** (2009) 189 [`arXiv:0901.0002`].

[2] F. D. Aaron *et al.* [H1 and ZEUS Collaborations], *Combined Measurement and QCD Analysis of the Inclusive ep Scattering Cross Sections at HERA, JHEP* **1001** (2010) 109 [`arXiv:0911.0884`].

[3] V. M. Abazov *et al.* [DØ Collaboration], *Measurement of the electron charge asymmetry in* $p\bar{p} \to W + X \to e\nu + X$ *events at* $\sqrt{s} = 1.96$ *TeV, Phys. Rev. Lett.* **101** (2008) 211801 [`arXiv:0807.3367`].

[4] DØ Collaboration, *Measurement of the muon charge asymmetry in* $p\bar{p} \to W + X \to \mu\nu + X$ *events using the DØ detector*, DØ Note 5976-CONF.

[5] T. Aaltonen *et al.* [CDF Collaboration], *Direct Measurement of the W Production Charge Asymmetry in* $p\bar{p}$ *Collisions at* $\sqrt{s} = 1.96$ *TeV, Phys. Rev. Lett.* **102** (2009) 181801 [`arXiv:0901.2169`].

[6] D. E. Acosta *et al.* [CDF Collaboration], *Measurement of the forward-backward charge asymmetry from* $W \to e\nu$ *production in* $p\bar{p}$ *collisions at* $\sqrt{s} = 1.96$ *TeV, Phys. Rev.* D **71** (2005) 051104 [`hep-ex/0501023`].

[7] V. M. Abazov *et al.* [DØ Collaboration], *Measurement of the muon charge asymmetry from W boson decays, Phys. Rev.* D **77** (2008) 011106 [`arXiv:0709.4254`].

[8] K. Melnikov and F. Petriello, *Electroweak gauge boson production at hadron colliders through* $\mathscr{O}(\alpha_S^2)$, *Phys. Rev.* D **74** (2006) 114017 [`hep-ph/0609070`].

[9] S. Catani *et al.*, *Vector boson production at hadron colliders: a fully exclusive QCD calculation at NNLO, Phys. Rev. Lett.* **103** (2009) 082001 [`arXiv:0903.2120`].

[10] S. Catani, G. Ferrera and M. Grazzini, *W boson production at hadron colliders: the lepton charge asymmetry in NNLO QCD, JHEP* **1005** (2010) 006 [`arXiv:1002.3115`].