MRST PARTON DISTRIBUTIONS – STATUS 2006.

R.S. THORNE *

Department of Physics and Astronomy
University College London
Gower St, London, WC1E 6BT, UK

A.D. MARTIN AND W.J. STIRLING

Institute for Particle Physics Phenomenology
University of Durham, DH1 3LE, UK

We present the new preliminary MRST parton distributions at NLO and NNLO. The analysis includes some new data and there is an improvement in the theoretical treatment at NNLO. Essentially complete NNLO partons are presented for the first time, together with uncertainties.

There are a number of reasons for an update of the MRST parton distributions. There are new data to be included: NuTeV data[1] on $F_2^{\nu,\bar{\nu}}(x,Q^2)$ and $F_3^{\nu,\bar{\nu}}(x,Q^2)$ replacing CCFR[2]; and we now include direct high-x data on $F_L(x,Q^2)$. There are also major changes in the theory: an implementation of a new heavy flavour VFNS[3], particularly at NNLO; and the inclusion of NNLO corrections[4] to the Drell-Yan cross-sections. This leads to some important changes as NLO → NNLO. The most important change compared to the previous NNLO partons[5], which already used the exact splitting functions[6], is the new VFNS which leads to a significant change in the gluon and heavy quarks. Moreover, due to the NNLO procedure being essentially complete we now examine the uncertainties on the NNLO partons. In general the size of the uncertainties due to experimental errors is similar to that at NLO[7]. There is more work to do in order to estimate the theoretical uncertainty, which is certainly important in some regions[8].

We first consider the new data in the fit. The NuTeV structure function data are not completely compatible with the older CCFR data. The main source of the discrepancy is in the calibration of the magnetic field map of the muon spectrometer, i.e. in the muon energy scale. However, the previous parton distribution fits were perfectly compatible with the CCFR data using an EMC inspired Q^2-independent nuclear correction[9] R. This correction is far too large for the new NuTeV data. The high-x region is completely dominated by the valence quarks for both $F_2^{\nu,\bar{\nu}}(x,Q^2)$ and $F_3^{\nu,\bar{\nu}}(x,Q^2)$. These are well known from fixed target $F_2^{\mu,p}(x,Q^2)$ and $F^{\mu,d}(x,Q^2)$. In order to fit the NuTeV data we try a reduced correection

---

*Royal Society University Research Fellow.

factor $R^{eff} = 1 + A * (R - 1)$. The best fit is for $A = 0.2$ and the previous nuclear correction is clearly ruled out. Hence, the NuTeV data imply a nuclear correction which is different for neutrinos than for charged leptons. However, recent CHORUS[10] data are in much better agreement with the CCFR data than the NuTeV data. Also, the partons in the region of high nuclear correction are already well determined. It may be appropriate to cut the nuclear target data in this region. The important information that neutrino DIS gives on the flavour composition of the proton is in the region $x < 0.3$, where the nuclear corrections are not so large or uncertain. The fit to the fixed target data on $F_L(x, Q^2)$ prefers a larger gluon since the data are generally larger than NLO or NNLO[11], and a large coupling (and/or higher twist contributions) is needed.

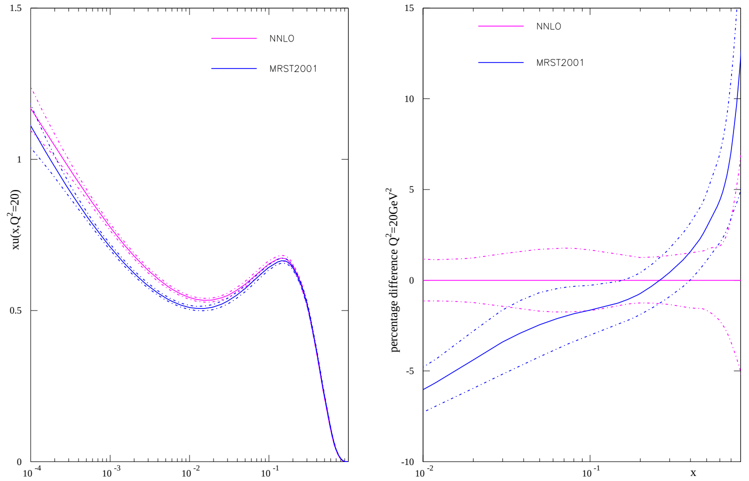

Figure 1. Comparison of the NLO up distribution with the NNLO up distribution, concentrating on small x (left) and high x (right).

The change in the up quark when going from NLO to NNLO is shown in Fig. 1. At small x the coefficient functions, particularly $C_{2,g}(x, Q^2)$, is important and the difference between NLO and NNLO is greater than the uncertainty in each calculated using the Hessian approach[12]. At large x the coefficient functions are important – $C^2_{2,q}(x) \sim (\ln^3(1-x)/(1-x))_+$ and the difference between NLO and NNLO is again larger than the uncertainty in each. There is no real change from the MRST2004NNLO partons for the light quarks. At small x the effect of the splitting functions is important, particularly from $P^2_{qg}(x, Q^2)$, which has a positive $\ln(1/x)/x$ contribution. This affects the NNLO gluon distribution via the fit to $dF_2(x, Q^2)/d\ln Q^2$, it is smaller at very low x than the NLO gluon.

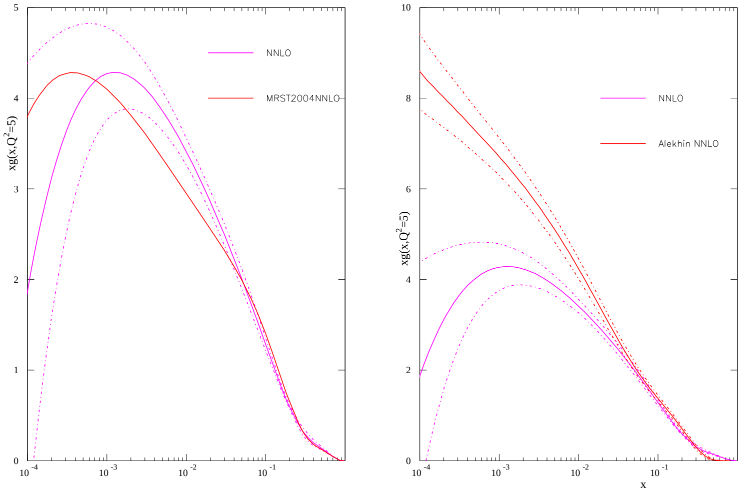

Figure 2. Comparison of the NNLO MRST gluon distribution with the previous approximate NNLO distribution (left) and the NNLO distribution of Alekhin (right).

At NNLO heavy flavour no longer evolves from zero at $\mu^2 = m_c^2$, i.e. $(c+\bar{c})(x, m_c^2) = A^2_{Hg}(m_c^2) \otimes g(m_c^2)$. In practice it starts from a negative value since the matrix element is negative at small x. The increased evolution from the NNLO splitting function allows the charm distribution to catch up partially with respect to that at NLO, which starts from zero at m_c^2 but it always lags a little at higher Q^2. The correct NNLO charm is smaller than the approximate MRST2004 distribution which turned on from zero. This correction in the charm procedure also affects the gluon compared to the MRST2004 NNLO partons, Fig. 2, and the change is greater than the uncertainty in some places. The correct heavy flavour treatment is vital.

At NNLO the Drell-Yan corrections[4] are significant. There is an enhancement at high $x_F = x_1 - x_2$ due to large logarithms. The NLO correction is large and the NNLO corrections are 10% or more. The quality of the fit to E866 Drell-Yan production[13] in proton-proton collisions is $\chi^2 = 223/174$ at NLO and $\chi^2 = 240/174$ at NNLO. The scatter of points is large and a $\chi^2 \sim 220$ is the best possible. The quality of the fit is worse for proton-deuteron data. The correction at NNLO requires the data normalization to be 110% (103% at NLO), there being little freedom since the sea quarks for $x \leq 0.1$ and the valence quarks are well determined by structure function data. The normalization uncertainty on the data is 6.5%, and a change of 10% is a little surprising. The quality of the full fit at NLO is $\chi^2 = 2406/2287$ and at NNLO is $\chi^2 = 2366/2287$. NNLO is fairly consistently better than NLO. There is a tendency for $\alpha_S(M_Z^2)$ to increase with both the new data and the improved theoretical treatment. At NLO

$\alpha_S(M_Z^2) = 0.121$ and at NNLO $\alpha_S(M_Z^2) = 0.119$. Although the fit is generally good, particularly at NNLO, there is some room for improvement, and the data would prefer a little more gluon at high and moderate x.

We compare with the only other NNLO partons available, those of Alekhin[14]. We have a much larger $\alpha_S(M_Z^2)$, i.e. $\alpha_S(M_Z^2) = 0.119$ compared to 0.114. There is not much difference in high-x valence quarks, except that explained by the difference in $\alpha_S(M_Z^2)$. There are differences in the low-x sea quarks but these are dominated by differences in flavour treatments of $\bar{u} - \bar{d}$ and $s(x, Q^2)$. The gluon distribution difference at small x is seen in Fig. 2, and is much bigger than the uncertainties. This is due to the heavy flavour treatments, as well as to differences in the data fit and in $\alpha_S(M_Z^2)$. The gluons also differ a great deal at high x, where they are determined by the Tevatron jet data[15] for MRST, the comparison now being excellent[5]. In the $\overline{\mathrm{MS}}$ scheme the gluon is more important for jets at high x at NNLO than at NLO because the high-x quarks are smaller.

Hence, we have included both new data and new theoretical corrections in our global analysis. The NNLO fit improves on that at NLO. For both the value of $\alpha_S(M_Z^2)$ creeps upwards. The NNLO procedure is essentially complete and we have a preliminary update of parton distributions. There are more new data to be included and some further theoretical fine-tuning, but we will have fully updated NLO and NNLO partons for the LHC complete with uncertainties – both experimental and theoretical.

References

1. NuTeV Collaboration: M. Tzanov *et al.*, Int. J. Mod. Phys. **A20**, 3759 (2005).
2. CCFR Collaboration: W.G. Seligman *et al.*, Phys. Rev. Lett. **79** 1213 (1997); CCFR Collaboration: U.K. Yang *et al.*, Phys. Rev. Lett. **86** 2742 (2001).
3. R.S. Thorne, Phys. Rev. **D73** 054019 (2006).
4. C. Anastasiou *et al.*, Phys. Rev. Lett. **9**1, 182002 (2003); Phys. Rev. **D**69, 094008 (2004).
5. A.D. Martin *et al.*, Phys. Lett. **B604** 61 (2004).
6. S. Moch *et al.*, Nucl. Phys. **B688** 101 (2004); Nucl. Phys. **B691** 129 (2004).
7. A.D. Martin *et al.*, Eur. Phys. J. **C28** 455 (2003).
8. A.D. Martin *et al.*, Eur. Phys. J. **C35** 325 (2004).
9. A. D. Martin *et al.*, Eur. Phys.J. **C4**, 463 (1998).
10. CHORUS Collaboration: G. Onengut *et al.*, Phys. Lett. **B632** 65 (2006).
11. A.D. Martin, W.J. Stirling and R.S. Thorne, Phys. Lett. **B635** 305 (2006).
12. CTEQ Collaboration: J. Pumplin *et al.*, Phys. Rev. **D65** 014013 (2002).
13. NuSea Collaboration: J.C. Webb *et al.*, hep-ex/0302019.
14. S. I. Alekhin, Phys. Rev. **D68** 014002 (2003); JETP Lett. **82** (2005) 628.
15. D0 Collaboration: B. Abbott *et al.*, Phys. Rev. Lett. **86** 1707 (2001); CDF Collaboration: T. Affolder *et al.*, Phys. Rev. **D64** 032001 (2001).