Update of MRST partons

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We discuss topical issues concerning the MRST parton analysis. We introduce some new parton sets in order to estimate the uncertainty in the cross sections predicted for W and Z production at the Tevatron and the LHC. We compare with CTEQ5 partons.

MRST is a standard next-to-leading order global analysis [1] of deep inelastic and related hard scattering data. The partons were presented at DIS98 and the scheme dependence and higher twist effects studied in a subsequent analysis [2]. Here we concentrate on topical issues.

1. LIGHT QUARK DISTRIBUTIONS u, d, s

u and d are pinned down by DIS data, with the slope of d/u also being constrained for $x \lesssim 0.3$ by the CDF $W^{\pm}$ rapidity asymmetry data. In fact d/u is determined up to $x \sim 0.7$ by the NMC F_2^n/F_2^p data, *provided* that we assume that there are no deuterium binding corrections for $x > 0.3$. Yang and Bodek [3] included such a binding correction and described the data with modified partons which satisfy $d/u \to 0.2$ as $x \to 1$, whereas MRS(T) and CTEQ parametrizations have $d/u \to 0$. We repeated the global analysis, forcing $d/u \to 0.2$ and found an equally good fit, apart from the description of NMC F_2^n/F_2^p for $x \gtrsim 0.5$. To fit these latter (uncorrected) data we require $d/u \to 0$, see also ref. [4]. We note, that as statistics improve, the HERA charge-current DIS data will directly constrain d/u at large x. So far the preliminary data and the MRST prediction are in agreement.

$\bar{d}/\bar{u}$ is determined for $0.05 \lesssim x \lesssim 0.3$ by the E866 $pp, pn \to \mu^+\mu^- X$ data, and also by the HERMES data for $ep, en \to e\pi^{\pm} X$. The MRST partons are in agreement with both the new E866 [5] and HERMES [6] data.

In principle ν and $\bar{\nu}$ DIS data can determine s and $\bar{s}$ separately. However we use the CCFR dimuon data to determine $s + \bar{s}$. To quantify the uncertainty we obtained two new sets of MRST partons, $s \uparrow$ and $s \downarrow$ corresponding to $(s+\bar{s})/(\bar{d}+\bar{u}) = 0.5 \pm 0.06$ at $Q^2 = 1$ GeV^2, which embrace the spread of these data.

2. HEAVY QUARK DISTRIBUTIONS c, b

For a heavy quark, $H = c$ (or b) we should match, at $Q^2 = m_H^2$, the fixed flavour number scheme, describing $\gamma g \to H\bar{H}$ with $n_f = 3(4)$, to the variable flavour number scheme with $n_f + 1$ flavours for $Q^2 > m_H^2$. MRST use the Thorne-Roberts prescription [7] in which F_2^H and $\partial F_2^H/\partial \ln Q^2$ are required to be continuous at $Q^2 = m_H^2$. (CTEQ use an alternative, ACOT, prescription.) In this way the charm distribution is generated perturbatively with the mass of the charm quark m_c as the only free parameter. Not surprisingly, due to the $g \to c\bar{c}$ transition, the charm distribution mirrors the form of the gluon distribution. Again, we have obtained two new MRST sets, $c \uparrow$ and $c \downarrow$, corresponding to $m_c = 1.35 \pm 0.15$ GeV.

3. THE GLUON DISTRIBUTION g

In principle many processes are sensitive to the gluon distribution, *but* it is still difficult to nail down for $x \gtrsim 0.2$ where it becomes increasingly small. In this region MRST used the WA70

prompt photon data to determine the gluon. However this process suffers from scale dependence (reflecting the higher order corrections), effects of intrinsic k_T (needed to describe the E706 prompt photon data) and uncertainties due to fragmentation effects and isolation criteria. To explore an acceptable spread of gluon distributions at large x, MRST presented three sets ($g\uparrow$, default MRST set, $g\downarrow$) corresponding to average intrinsic $k_T = 0,\ 0.4$ and 0.64 GeV respectively for the WA70 data. The arrows indicate the relative sizes of the gluons in the large x region ($x \gtrsim 0.2$). The corresponding $\langle k_T \rangle$ needed to obtain a good description of the E706 prompt photon data is about 1 GeV.

Due to the uncertainties associated with prompt photon production, the recent CTEQ5 analysis [8] omits these data and instead determines the large x behaviour of the gluon using the single jet inclusive E_T distributions measured at the Tevatron. The above three MRST sets of partons describe the shape of the jet E_T distributions, but need to be renormalized upwards by 7%, 13%, 17% respectively to give the correct normalization, with $g\uparrow$ being closest to CTEQ5.

Turning now to the small x domain, the gluon is well constrained by the observed behaviour of $\partial F_2/\partial \log Q^2$. To be precise the H1 and ZEUS data determine the gluon for $x \lesssim 0.01$, and the NMC data for $x \lesssim 0.1$. Inspection of F_2 at low x, low Q^2 shows that the data have flattened out, indicating a smaller value of $\partial F_2/\partial \log Q^2 \simeq \alpha_S(Q^2) P_{qg} \otimes g$. Also α_S increases with decreasing Q^2, and as a consequence g becomes valence-like for $Q^2 \simeq 1$ GeV^2, which is about the lowest value of Q^2 for a satisfactory DGLAP description.

4. W PRODUCTION AT THE TEVATRON AND LHC

The total cross sections for W and Z hadroproduction are known to NNLO [9] and the input electroweak parameters are known to high accuracy. The main uncertainty comes from the input parton distributions and, to a lesser extent, α_S [10]. For example, the results for W production at the Tevatron from the above sets of partons are shown in Fig. 1. In addition we show the cross sections obtained from parton sets

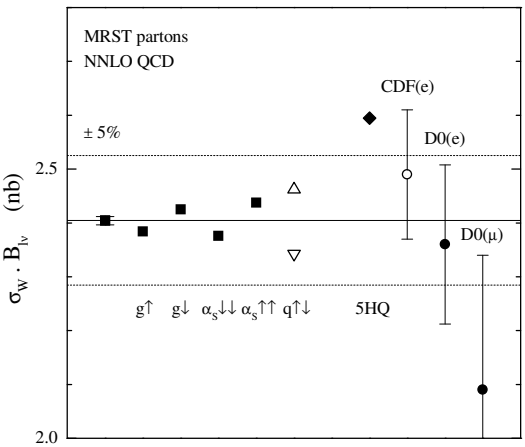

Figure 1. NNLO [9] predictions of the W production cross section at the Tevatron from seven different sets of NLO MRST partons, and from CTEQ5HQ partons. Also shown are the cross sections measured by the CDF and D0 collaborations.

$\alpha_S\uparrow\uparrow$, $\alpha_S\downarrow\downarrow$ corresponding to global analyses with $\alpha_S(M_Z^2) = 0.1175 \pm 0.05$, and from parton sets $q\uparrow, q\downarrow$ corresponding to global fits with the HERA data renormalised up, down by 2.5%. The differences coming from $s\uparrow$, $s\downarrow$ and from $c\uparrow$, $c\downarrow$ are very small (and so the predictions are not shown in Fig. 1), since in the evolution up to $Q^2 = M_W^2$ the transitions $g \to s\bar{s}, c\bar{c}$ wash out the dependence on the s, c input.

We see that the values from all the MRST sets are within about $\pm 2.5\%$ of the MRST default set. The bounds are actually given by the $q\uparrow$ and $q\downarrow$ sets. At first sight we might anticipate these bounds would be $\pm 5\%$ since $q\bar{q}$ initiates W production. However the difference due to using $q\uparrow$ and $q\downarrow$ is diluted by the evolution from Q^2 (HERA data) $\to Q^2 = M_W^2$.

We also show in Fig. 1 the prediction obtained using CTEQ5HQ partons. Surprisingly it differs by about 8% from that of MRST. Since we hope that the rate of W production is accurately predicted at the Tevatron and at the LHC, it is crucial to understand the origin of this difference.

5. COMPARISON OF MRST AND CTEQ5

Differences between the MRST and CTEQ partons can arise from

- the data sets included in the global fit, the $Q^2, W^2 \ldots$ cuts used,
- the normalization of the data sets,
- the treatment of heavy flavors (massless, TR and ACOT schemes),
- differences in the evolution codes.

Inspection of the resulting partons show that CTEQ5 has, first, a larger gluon at large x than MRST (due to the different data fitted), second, a larger charm distribution, and finally a smaller d/u at very large x.

The unexpectedly large difference between the values of the W cross section calculated from the MRST and CTEQ5 partons, seen in Fig. 1, appears to be due to the more rapid evolution of the sea quarks of CTEQ5. A similar effect was found in a comparison of various NLO evolution codes made during the 1996 HERA workshop [11]. Neither CTEQ, nor MRS, agreed completely with the standard code after evolution up to $Q^2 = 100$ GeV^2. The CTEQ sea was some 4% high and the MRS sea was 1% low and the gluon about 1.5% low. A careful check of the MRS code has recently revealed a small error in the NLO contribution to the evolution of the gluon. After this correction the agreement between MRS and the standard evolution code is exact. The corrected code increases the quarks in the relevant x and Q^2 range by typically 1%, and hence the MRST values of the W cross section at the Tevatron shown in Fig. 1 are increased by about 2%, so that

$$B_{W}\sigma_{W} \;=\; 2.45 \pm 0.06 \text{ nb}. \qquad (1)$$

A full discussion will be given in ref. [10].

6. OUTSTANDING PROBLEMS

At present the two major deficiencies in the parton determinations are the absence of a complete NNLO analysis and the need to determine realistic errors on the partons. This last task is especially problematic. Determinations in certain (x, Q^2) domains often rely dominantly on one experiment. Moreover we need some way to quantify the uncertainties due to k_T smearing, heavy target and other nuclear corrections, higher twist cuts etc. However, as evidenced by the contributions at this conference, continued progress is being made in improving our knowledge of partons.

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