UPDATE OF MRST PARTON DISTRIBUTIONS*

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We discuss the latest update of the MRST parton distributions in response to the most recent data. We discuss the areas where there are hints of difficulties in the global fit, and compare to some other updated sets of parton distributions, particularly CTEQ6. We briefly discuss the issue of uncertainties associated with partons.

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Over the past couple of years there has been a large amount of updated data both from HERA [1, 2], on small x structure functions, and from the Tevatron, on high-$E_{\rm T}$ jet production [3, 4], which has been more accurate than previous data, and expanded the phase space significantly. This had led to a number of updated sets of parton distributions [5–9]. In this talk we discuss the most recent updates to the MRST set of parton distributions, highlighting the successes and failings, and also compare to other new sets of distributions.

The updated MRST partons were released in 2001 [5]. Compared to previous sets the main improvement was in the accuracy of the determination of the gluon distribution, which was constrained far more strongly at high x due to the new Tevatron jet data. $\alpha_{\rm S}(M_Z^2)$ was left as a free parameter

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in the fit, and found to be $0.119 \pm 0.002(\mathrm{exp}) \pm 0.003(\mathrm{theory})$, where the experimental error was determined by letting the χ^2 for the global fit increase by 20 from the minimum (see [10] for a discussion of the suitable increment in χ^2 to determine the error in a global fit). The fit was of good quality overall, but struggled a little in some regions. It was hard to provide enough high x gluon to fit the jet data very well, and also to have sufficient moderate x gluon to obtain a large enough value of $dF_2(x,Q^2)/d\ln Q^2$ for $x \sim 0.01$. Conversely, the data required the very small x gluon to be small (which also helps the previous shortcomings due to the constraint on the total gluon from the momentum sum rule), and at our input scale $Q_0^2 = 1\mathrm{GeV}^2$ it was found to be necessary to expand our parameterization to allow the very small x gluon to become negative. This latter point led to a dangerously small prediction for $F_{\mathrm{L}}(x,Q^2)$ at small x and Q^2.

Soon afterwards the CTEQ6 set of partons was published [6]. In most ways these are very similar to the MRST01 partons, and produce similar results. However, there are a number of significant differences, particularly concerning the gluon. CTEQ have developed a different type of parameterization for the partons, which allows for a different shape at very high x. Whereas MRST were only able to get a completely satisfactory fit to the Tevatron jet data if the input gluon is allowed to have a definite kink at $x \sim 0.5$ (and with $\alpha_{\mathrm{S}}(M_Z^2) = 0.121$), CTEQ obtain a very good fit with no such modifications.

However, this problem of obtaining a very good fit to the jet data depends on many issues. CTEQ do indeed obtain a much better fit using this new parameterization for the gluon (with same NLO prescription the χ^2 quality is about 50 better) as seen for D0 data in Fig. 1. However, there are many differences in their approach compared to MRST other than the parameterization: CTEQ cut data above $Q^2 = 4\mathrm{GeV}^2$, compared to $Q^2 = 2\mathrm{GeV}^2$; they do not use some data sets used in [5], *i.e.* SLAC and one H1 high-Q^2 set; they use (10%) systematic errors (in quadrature) for Drell–Yan data whereas in [5] only statistical errors are used. Additionally CTEQ have a positive-definite small x gluon at their starting scale of $Q_0^2 = 1.69\,\mathrm{GeV}^2$, they use a massless charm prescription and there are various other minor differences.

In order to investigate which initial choices are most important for the quality of the fit to the jet data, or equivalently, which affect the extracted form of the high-x gluon, we performed various fits changing these choices. We found that we can improve the fits to jets within the global fit by various modifications. Unexpectedly, allowing one of the parameters controlling the negative contribution to our gluon at very small x to vary away from a previously fixed value resulted in $\Delta\chi_J^2 \sim -5$. The fit to the Drell–Yan data actually competes with that to the jets, and using only statistical errors (the systematic errors being defined a little vaguely) presumably over-weights

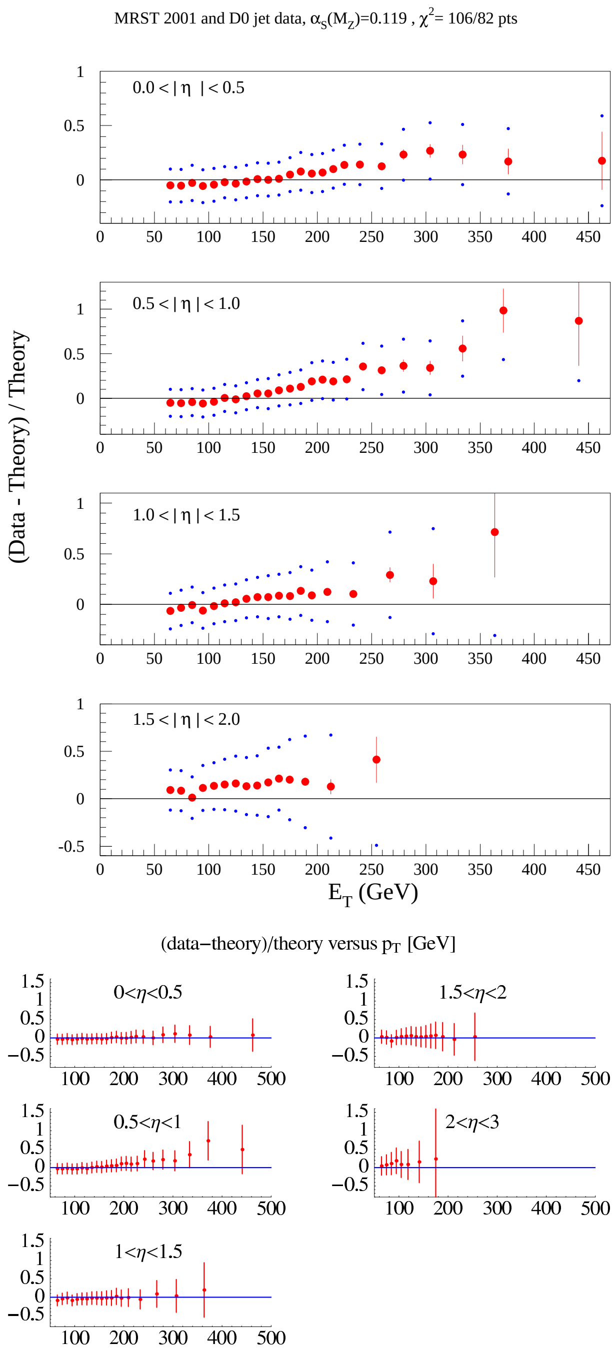

Fig. 1. Comparison of MRST fit to D0 jet data to CTEQ6 fit.

these. Adding 5% systematic errors in quadrature to the statistical errors (which is probably the best approach [11]) leads to $\Delta\chi^2_J \sim -10$. Both these modifications should be performed, and will be implemented in future MRST fits. The resulting partons are currently denoted MRST⋆. The only real change compared to MRST01 is for the high x gluon.

We also discovered that further changes could improve the quality of the jet fit. Changing the Q^2-cut on the data from the MRST value of $Q^2 = 2\text{GeV}^2$ to the CTEQ value of $Q^2 = 4\text{GeV}^2$ leads to $\Delta\chi^2_J \sim -10$. Fitting to the same data as CTEQ, *i.e.* omitting the SLAC data and one H1 high-Q^2 data set and increasing the Drell–Yan systematic errors to 10% leads to $\Delta\chi^2_J \sim -15$. The cumulative effect of all these above steps in a single fit is $\Delta\chi^2_J \sim -40$, which is obtained with a smooth high-x gluon. We denote the resulting partons by MRSTCTQ. We conclude that the remaining improvement of $\Delta\chi^2_J \sim -10$ seen by CTEQ is due mainly to their new parameterization, but that this is only a relatively minor effect. Indeed, we compare the gluons from CTEQ6, MRST01, MRST⋆ and MRSTCTQ in Fig. 2. Clearly MRSTCTQ has a very similar high-x gluon to CTEQ6, and

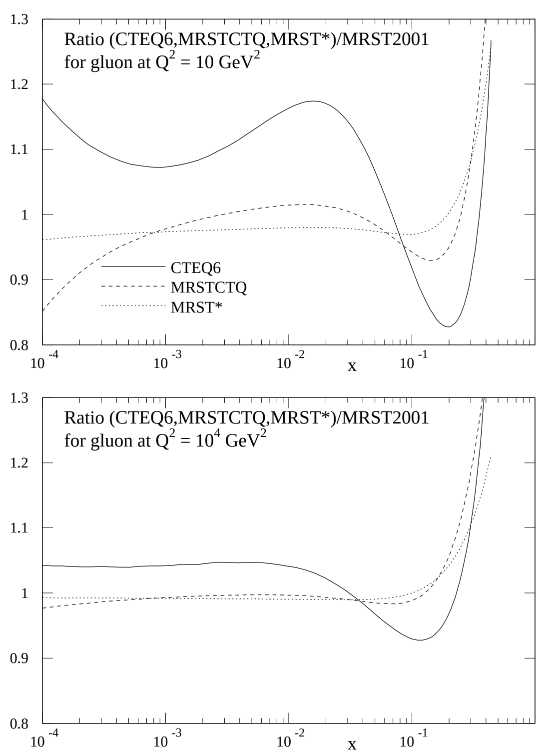

Fig. 2. Comparison of MRST2001 gluon distribution to the other distributions described in the text.

even MRST$\star$ has gone much of the way in the same direction. However, all the MRST gluons are different from the CTEQ6 gluon at smaller x due to their freedom to have a negative input distribution. We also note that although we feel the steps producing the MRST$\star$ partons should be made in future, the further ones leading to MRSTCTQ are a different matter. Although they improve the quality of the jet fit they are not the best fit when including the data sets omitted by CTEQ and the fit is not good at all for data with $Q^2 < 4\text{GeV}^2$. It is certainly true that we should question the nature of our cut on Q^2 (as well as on W^2 and x), but this is a complicated question which will be addressed elsewhere [12].

The comparison to the other sets of parton distributions obtained by fits to mainly structure function data, *e.g.* [7–9], are qualitatively the same as they have been for some time. Since only MRST and CTEQ fit the jet data, it is only these partons which have a direct constraint on the high-x gluon. All other fits always obtain, to varying degrees, a smaller high-x gluon which consequently allows both a larger moderate-x gluon to fit the HERA data and a usually a slightly smaller value of $\alpha_{\rm S}(M_Z^2)$. Hence, the omission of the jet data tends to mask slightly the possible problems encountered in trying to fit the HERA data very well.

Recently, many groups have not only obtained partons from a best fit but, using various methods, have also examined the uncertainty on these partons due to experimental errors. MRST have concentrated on the Lagrange Multiplier technique [13] in order to obtain uncertainties on physical quantities and the corresponding extreme sets of partons. Such uncertainties, and partons, are available for W and Higgs production at the Tevatron and LHC, and for charged current cross-sections at $x = 0.5$ for HERA [14], both for fixed and varying $\alpha_{\rm S}$. However, we have always believed that theory is one of the dominant sources of error. Hence, as well as attempting to determine the areas where the current theory may require corrections by investigating the cuts on data [12], we have also produced approximate NNLO parton distributions and predictions [15] (based on the approximate splitting functions [16] obtained from the known NNLO moments [17]). Indeed, we find, for example, that the NNLO W cross-section at the Tevatron is 4% higher than at NLO, and believe this result is reliable. This change is at least as large as the uncertainty due to experimental errors, and W production is likely to be subject to smaller theoretical uncertainty than many other quantities — particularly those directly related to the gluon. Hence, an understanding of theoretical uncertainties seems to be a priority at present.

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