Tevatron Measurements and PDF Uncertainties

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Abstract. The impact of PDF uncertainties on recent Tevatron measurements is explored. One of the most poorly constrained PDFs is the gluon distribution which is seen to be the dominant source of uncertainty for many interesting calculations. Tevatron measurements that can be used to better constrain PDFs are highlighted. Recent techniques to quantify the error on measured distributions resulting from PDF uncertainties are discussed.

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Parton density functions (PDFs) are essential input in the calculation of production cross sections for many lepton-hadron and hadron-hadron processes. Once the PDFs are specified as a function of the kinematic variable, x, and for a given Q^2, the DGLAP [1] equations can be used to calculate cross sections in any region of phase space. The validity of the extrapolation depends on theoretical assumptions as well as the uncertainties of the PDFs. Refining theory predictions is an iterative process and as new data are incorporated into the global fits, more precise predictions can be made. Calculations have an uncertainty arising from both experiment and theory. Theoretical errors include the choice of parameterization, input parameters such as flavor threshold and α_s and uncertainties on the modeling (scale errors, nonperterbative effects). Experimental errors originate from the statistical and systematic errors of the data that are used in the global fits. PDF errors propagate to the measurement when calculating the acceptance, luminosity, event selection and background estimate.

Recently new methods to estimate PDF uncertainties based on the Hessian and Lagrange multiplier techniques [2] have been developed taking into account the statistical and correlated systematic errors. N_{PDF} eigenvectors are calculated from the error matrix and their upper and lower deviations result in $2 \times N_{PDF}$ new sets of error PDFs. The $\Delta\chi^2$ which best describes the error tolerance is somewhat intuitive and different conventions have been adopted by different groups, for example the CTEQ group uses $\Delta\chi^2 = 100$ while MRST uses $\Delta\chi^2 = 50$. Figure 1 shows the CDF Run I inclusive jet data with the error PDFS determined for the CTEQ6.1M PDF [2]. The dominant error arises from the uncertainty of the gluon distribution. The higher precision Run II data will lead to improved PDF sets with reduced uncertainties. In order to quantify the error arising from PDF uncertainties, the error PDFs have to be available in a form that can be generally used. The Les Houches Accord Parton Density Function Interface (LHAPDF) provides a standard interface enabling PDF error sets to be used with MC generators.

The increased center-of-mass energy available in Run II (1.8 $\rightarrow$ 1.96 TeV) yields a cross section larger by $\sim 2\times$ at 400 GeV and $\sim 5\times$ at 600 GeV compared to Run I. Preliminary measurements are now available based on about $350 pb^{-1}$, already extending

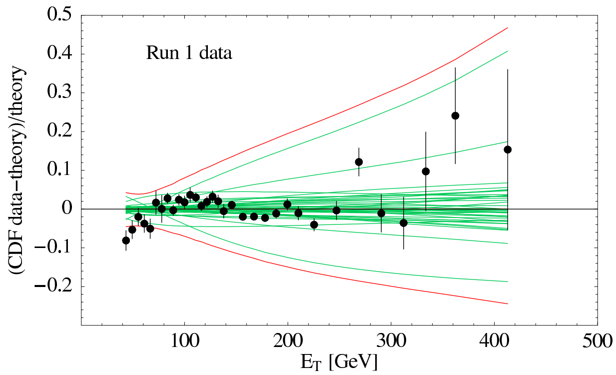

FIGURE 1. The CDF Run I inclusive jet cross section compared to the CTEQ6.1M error PDFs.

the Run I inclusive jet results by ~ 150 GeV as is shown in Figure 2.

In Run I, the measured inclusive jet cross section from the Tevatron was larger than predicted using then current PDFs. New Physics could show up as a deviation from the Standard Model predictions at high E_T. Global PDF fits including the Run I Tevatron jet data were able to accommodate the excess by an enhanced gluon PDF at high x. In order to separate PDF effects from new physics one can study the angular distribution between the leading jets or more generally include measurements of inclusive jet production over a wide rapidity region in global fits [2]. Preliminary Run II results from DØ in two rapidity bins are shown in Figure 2. The dominant systematic error originates from the jet energy scale and can be expected to be improved.

The W cross section has been proposed to determine the luminosity at the LHC since is it theoretically well understood and well measured. Calculation of the cross section depends on the data included in the global PDF fit while the choice of $\Delta\chi^2$ influences the error on calculation. The $\sigma_{\rm NLO}(W)$ at LHC energies was recently calculated using the following PDF sets $\sigma_{\rm NLO}(W) = 204 \pm 4$ (nb) (MRST2002), 205 ± 8 (nb) (CTEQ6),

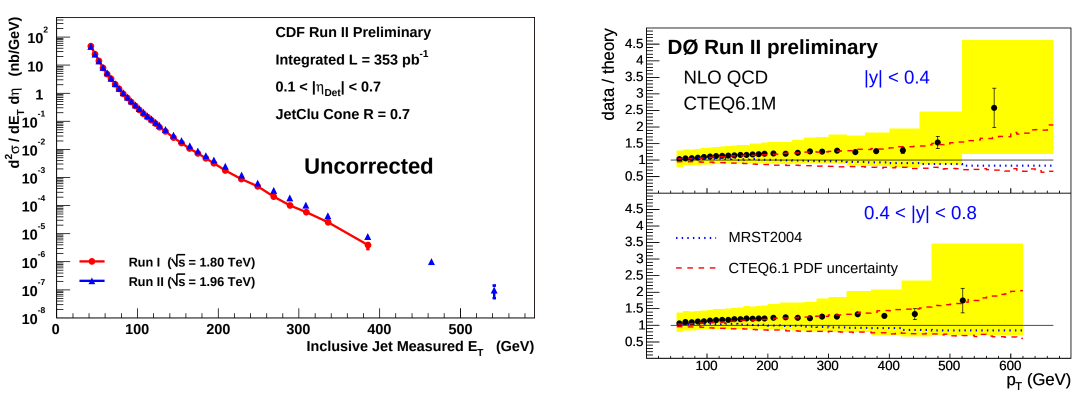

FIGURE 2. Left: Uncorrected inclusive jet distribution showing the extended reach in Run II using $\sim 350 pb^{-1}$ of data. Right: Preliminary DØ results for the inclusive jet cross section in two rapidity bins.

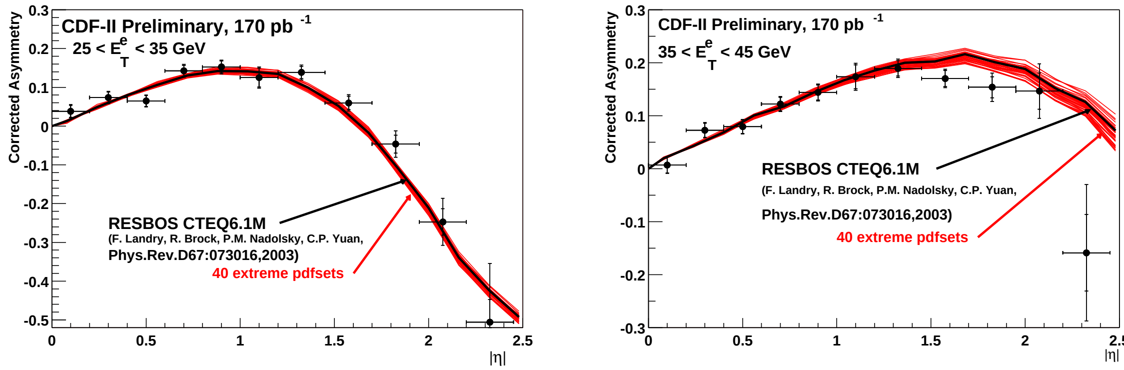

FIGURE 3. W charge asymmetry for two bins in E_T. The 40 PDF error sets from CTEQ6.1M are shown as the band around the central value.

215 ± 6 (nb) (Alekhin02). The error on the luminosity is reflected in any cross section measurement and it is important to understand the source of the error as well as to reduce it. The impact of PDF related uncertainties on the determination of the luminosity can be further reduced to $\sim 1\%$ by using cross section ratios [4].

More data and enhanced detector capabilities allow for the possibility of including new as well as more precise measurements in the PDF fits. Measurement of the W charge asymmetry constrains the ratio $d(x, M_W)/u(x, M_W)$ as $x \rightarrow 1$. Global QCD fits include the W charge asymmetry results from Run I which was averaged over E_T. In Run II we now have two E_T bins allowing us to explore the E_T dependence. Preliminary CDF results are shown in Figure 3 where predictions from the error PDFs are overlayed.

There is very little direct experimental input on the intrinsic heavy flavor of the proton. All c and b distributions in existing PDF sets are radiatively generated. Tevatron measurements with tagged final states $(W/Z/\gamma + c/b)$ probe the sea quark distributions. As more data is collected these measurements may provide insight into the heavy flavor content of the proton which would have a impact on several important production channels including the Higgs and single top.

Inclusion of full PDF systematics leads to a more realistic estimate of the top cross section uncertainty [5]. For $m_t = 175$ GeV, $\sigma = 6.70 \pm 0.45 pb$ (CTEQ6M) and $\sigma = 6.76 \pm 0.21 pb$ (MRST2001). The error on the top cross section is dominated by PDF and α_s uncertainties where the $\pm 3-6\%$ error mainly arises from the uncertainty of large-x gluons. Comparison of the data to the theory is shown in Figure 4 where it can be seen that the measurement error is approaching the magnitude of the error on the prediction. The inclusion of Run II data in PDF fits will help reduce the theoretical uncertainties.

The uncertainty on the Standard Model Higgs cross section was calculated for the main production processes [6]; associate production with W/Z $(q\bar{q} \rightarrow VH)$, massive vector boson fusion $(qq \rightarrow Hqq)$, gluon fusion $(gg \rightarrow H)$ and associate production with top quarks $(gg, q\bar{q} \rightarrow t\bar{t}H)$. The different results obtained when using different PDF sets is attributed to the choice of data used as input to fits and the treatment of errors. For a given PDF set there is $\sim 5\%$ uncertainty while there is $\sim 15\%$ spread between PDF sets at Tevatron and LHC energies.

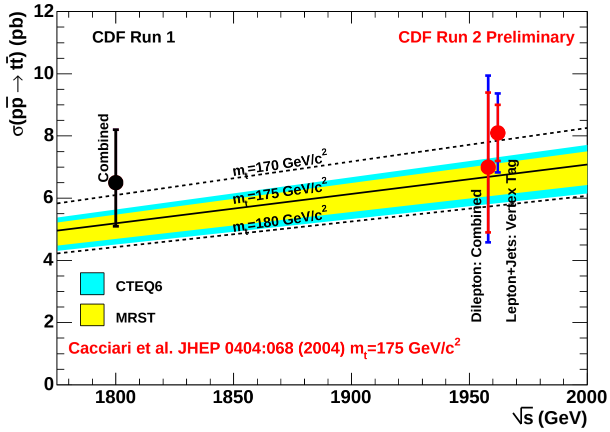

FIGURE 4. The top cross section measured by CDF is shown at different center of mass energies. The predictions determined using two PDF sets are shown as the bands.

CONCLUSION

PDFs are essential input in the calculation of hard scattering lepton-hadron and hadron-hadron cross sections and directly influence the precision of measurements. New techniques to estimate PDF related errors together with a standard interface between PDF sets and MC generators allow possibilities to better understand the impact on measured observables. The increased luminosity of the Tevatron and the upgraded detectors of CDF and DØ greatly extend the kinematic reach and precision of measurements that can be used in global QCD fits. The new data will lead to refined PDF sets with reduced errors. Uncertainty of the gluon distribution at high x is the dominant error on many interesting measurements such as top and Higgs production. Inclusive jet measurements will provide an important constraint on the gluon distribution at high x. Significantly different predictions can be obtained when using different PDF sets which is attributed to the choice of the input data in the fits as well as the treatment of errors. PDFs are universal and efforts should be made to use as much of the available data in the fits as possible.

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