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Inclusive Jet Production at the Tevatron using the CDF experiment

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Abstract. This contribution reports on measurements of the inclusive jet production cross section in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV. Two analyses are presented: one uses the longitudinally invariant k_T algorithm to reconstruct the jets, the other uses the midpoint algorithm. The data samples have been collected at CDF during the Run II of the Tevatron and correspond to integrated luminosities of 1.0 fb^{-1} for the k_T study and 1.13 fb^{-1} for the midpoint one. The inclusive jet cross sections are measured as a function of the jet transverse momentum in five jet rapidity regions for jets in the ranges $54 < p_T^{jet} < 700$ GeV/c and $|y^{jet}| < 2.1$. Next-to-leading order perturbative QCD predictions are in good agreement with the measured cross sections after including the non-perturbative corrections necessary to account for underlying event and hadronization effects.

The measurement of the inclusive jet production cross section at the Tevatron constitutes an important test of perturbative QCD (pQCD) predictions. As a function of the jet transverse momentum (p_T^{jet}), the cross section extends over more than eight orders of magnitude. The high p_T^{jet} tail probes distances down to about 10^{-19} m and is sensitive to new physics [1]. This measurement can also be used to constrain the Parton Distribution Functions (PDFs) at high x and high Q^2. Run I measurements [2, 3] raised a great interest on an apparent excess at high transverse energy. This excess was finally explained within the Standard Model by increasing the gluon PDF at high x as suggested by global PDF analyses [4]. Recent PDF sets, such as CTEQ6 [5] and MRST2004 [6], include Run I jet data in their global fits.

The results presented here use data samples collected at CDF [7] during the Run II of the Tevatron which correspond to integrated luminosities of 1.0 fb^{-1} to 1.13 fb^{-1}, over 10 times more than for the Run I measurements. In addition, the jet production rate at high p_T^{jet} has significantly increased thanks to the increase of the Tevatron center of mass energy, from 1.8 TeV in Run I to 1.96 TeV in Run II. It has been multiplied by a factor five around 600 GeV/c for instance. Therefore, the p_T^{jet} coverage has been considerably extended, by about 150 GeV/c for central jets.

The measurements are here performed in five different jet rapidity regions up to $|y^{jet}| = 2.1$: $|y^{jet}| < 0.1$, $0.1 < |y^{jet}| < 0.7$, $0.7 < |y^{jet}| < 1.1$, $1.1 < |y^{jet}| < 1.6$, and $1.6 < |y^{jet}| < 2.1$. Previous CDF studies [8, 9] were based on 385 pb^{-1} and limited to jets within $0.1 < |y^{jet}| < 0.7$. The extension of the measurement to forward jets is essential to better constrain the PDFs while searching for eventual effects from new physics at higher Q^2 in the central region.

In Run II, new jets algorithms are explored as the cone algorithm used in Run I is not infrared safe and compromises meaningful comparisons with pQCD calculations [10]. Inclusive jet cross section calculations would be affected at next-to-next-to-leading order. The jets are here reconstructed with the longitudinally invariant k_T algorithm [11, 12] or the midpoint algorithm [13].

The latter is still an iterative seed-based cone algorithm but it uses midpoints between pairs of protojets as additional seeds in order to make the clusterization procedure infrared safe. A cone size of $R_{cone} = 0.7$ in the $y - \phi$ plane was used. One may notice that the search cone step used in previous CDF studies was found to introduce some infrared sensitivity [14] and has been removed. A merging fraction of $f_{merge} = 0.75$ was used to decide whether overlapping cones have to be merged. To emulate this experimental merging / splitting feature, the corresponding next-to-leading order (NLO) pQCD calculation merges two partons if they are within $R_{cone} \times R_{sep}$ of each other and within R_{cone} of the resulting jet centroid. The parameter R_{sep} was set to 1.3 according to parton level approximate arguments.

The k_T algorithm merges pairs of nearby protojets in order of increasing relative transverse momentum. Inspired by pQCD gluon emissions, it is infrared and collinear safe to all orders in pQCD. Unlike cone based algorithm, it does not include any merging / splitting prescription and allows a well defined comparison with the theory without introducing any arbitrary parameter. On the other hand, it may be more sensitive than cone algorithms to soft contributions such as the underlying event or multiple $p\bar{p}$ interactions per bunch crossing. The k_T algorithm has a parameter D that approximately controls the size of the jets. The measurements are done using a D parameter of 0.7. To make sure that soft contributions are well understood, they are also carried out with $D = 0.5$ and $D = 1.0$ in the rapidity range $0.1 < |y^{jet}| < 0.7$.

Regardless of the jet algorithm used, proper comparisons with the theory require corrections for non-perturbative contributions. Those contributions come from the underlying event and the hadronization processes and become more and more important as p_T^{jet} decreases: they could explain the marginal agreement obtained in the DØ Run I study of the inclusive jet cross section

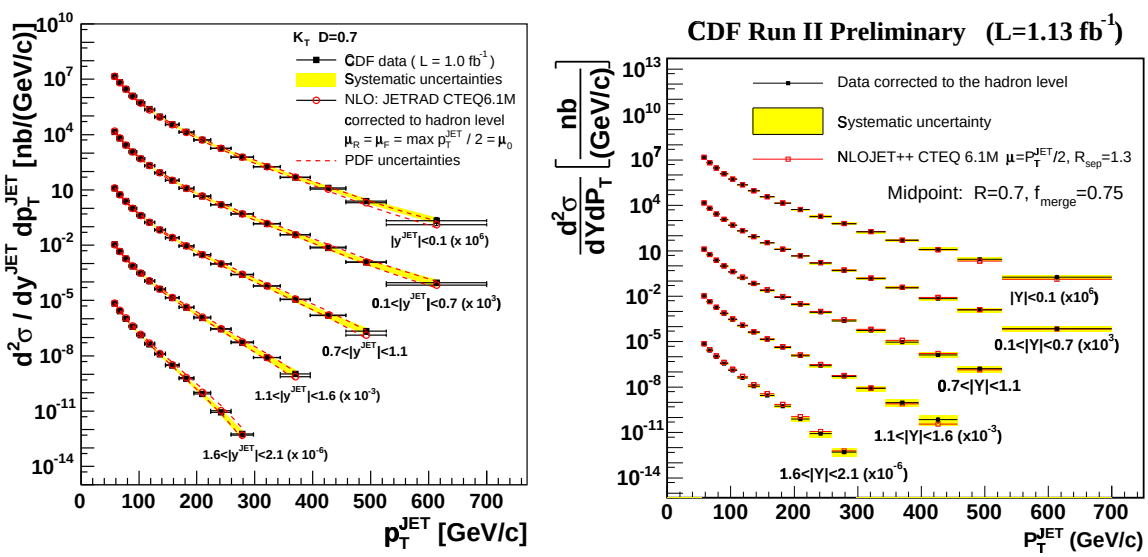

Figure 1. Inclusive jet cross sections as a function of p_T^{jet} measured in five rapidity regions for jets reconstructed using the k_T algorithm (left) and the midpoint algorithm (right).

using the k_T algorithm [15]. The corresponding parton-to-hadron correction was obtained with PYTHIA 6.203 [16] as the ratio of the predicted inclusive jet cross sections at the hadron level [1] on one hand, and at the parton level [2] turning off the interactions between proton and antiproton remnants, on the other hand. A special set of parameters, tuned on Run I CDF data to reproduce the underlying event activity and denoted as PYTHIA-TUNE A [17], was used. TUNE A has been shown to properly describe the jet shapes measured in Run II [18]. The parton-to-hadron level correction was also evaluated with HERWIG 6.4 [19]. The difference between the two Monte Carlos was considered as the systematic uncertainty on the correction. At p_T^{jet} of 54 GeV/c and in the rapidity range $0.1 < |y^{jet}| < 0.7$, the obtained parton-to-hadron correction is about 1.1 ± 0.1 for midpoint with $R_{cone} = 0.7$ and $f_{merge} = 0.75$, and about 1.1 ± 0.1, 1.2 ± 0.1 and 1.4 ± 0.2 for k_T with $D = 0.5$, 0.7 and 1.0 respectively. It has a moderate rapidity dependence and quickly decreases with p_T^{jet}: it is at a level of few percents around 200 GeV/c.

Figure 1 shows the inclusive jet cross sections measured in five rapidity regions and their comparisons to theory. For the k_T algorithm, the NLO pQCD cross section was calculated with JETRAD [20] using CTEQ6.1M PDFs [5] and setting the renormalization and factorization scales to $max(p_T^{jet})/2$. For the midpoint algorithm, it was obtained with NLOJET++ [21, 22] using CTEQ6.1M PDFs and $R_{sep} = 1.3$, setting the renormalization and factorization scales to $p_T^{jet}/2$.

Figures 2 and 3 show the Data/Theory ratios obtained in the five different rapidity regions for the k_T and the midpoint algorithms respectively. The experimental uncertainties are dominated by the uncertainty on the absolute jet energy scale which is known at the level of ± 2 % at low p_T^{jet} and ± 3 % at high p_T^{jet} [23]. An additional ± 5.8 % normalization uncertainty associated with the luminosity measurement is not included on the plots. The main uncertainty on the pQCD prediction comes from the PDFs, especially from the limited knowledge of the gluon PDF at high x. The theoretical predictions are in good agreement with the measured cross sections over the whole transverse momentum and rapidity range [24]. Specifically, no significant deviation from pQCD is observed at high p_T^{jet}. Figure 2 also shows that MRST2004 predictions are well within theoretical and experimental uncertainties. The uncertainty on the measured cross section in the most forward region at high p_T^{jet}, compare to that on the theoretical prediction, indicates that the results reported in this contribution will help to better constrain the gluon PDF at high x.

[1] The hadron level is defined using particles with lifetime above 10^{-11} s.

[2] The parton level is defined using the partons after final state radiations, *i.e.* just before hadronization.

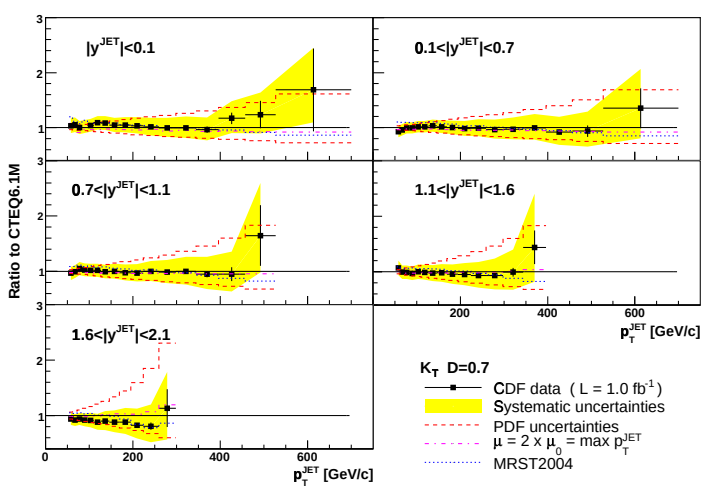

Figure 2. Data/Theory ratios as a function of p_T^{jet} in the different rapidity regions for jets reconstructed using the k_T algorithm.

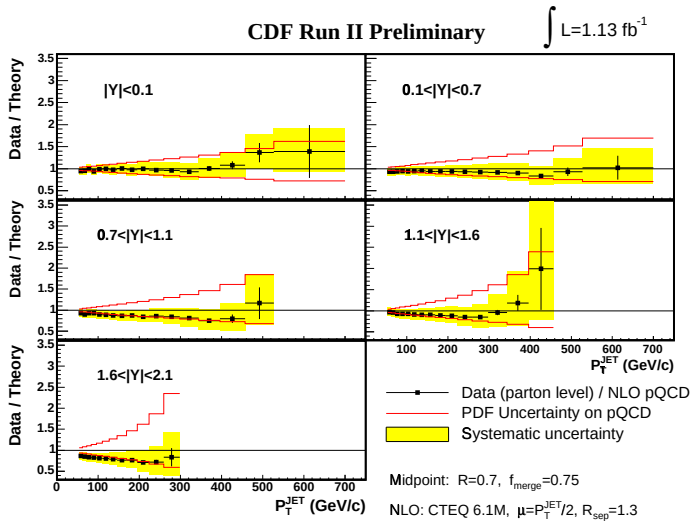

Figure 3. Data/Theory ratios as a function of p_T^{jet} in the different rapidity regions for jets reconstructed using the midpoint algorithm.

In the rapidity region $0.1 < |y^{jet}| < 0.7$, similar good agreements between data and theory are observed using the k_T algorithm with a D parameter of 0.5 and of 1.0, showing that soft contributions are well under control as they depend a lot on the size of the jets.

In conclusion, NLO pQCD predictions are in good agreement with the measured inclusive jet cross sections which extend over more than eight orders of magnitude. This is true both for the midpoint and the k_T algorithms. The presented studies include careful treatments of non-perturbative effects such as the underlying event which are found to be well under control. Those measurements may be used in future PDF global fits to better constrain the gluon PDF at high x, in this respect forward jets appear to be essential.

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