Inclusive Jet Cross Section using the \( k_T \) algorithm at the Tevatron

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Abstract. Preliminary measurements on inclusive jet production in proton-antiproton collision at \( \sqrt{s} = 1.96 \) TeV are presented, based on 385 \( pb^{-1} \) of data collected with the upgraded Collider Detector at Fermilab in Run II. The measurements are carried out for jets reconstructed using the \( k_T \) algorithm with transverse momentum about 54 GeV/c in five different jet rapidity regions up to \( |y_{\text{jet}}| = 2.1 \). The measured cross sections are compared with next-to-leading order perturbative QCD predictions after the necessary non-perturbative parton-to-hadron corrections are included.

The measurement of the inclusive jet production cross section is one of the pillars of the QCD program at the Tevatron. It probes very small distances, down to \( 10^{-19} \) m, and constitutes a stringent test of perturbative QCD (pQCD) over more than eight orders of magnitude. The large amount of data to be collected in Run II, together with the increase in the center-of-mass energy (from 1.8 to 1.96 TeV) and the upgrade of the CDF detector [1] will allow to perform these pQCD tests in extended regions of jet transverse momentum, \( p_T^{\text{jet}} \), and jet rapidity, \( y^{\text{jet}} \). Jet measurements at large rapidities are important because they constrain the gluon density in the proton in a kinematic region in \( p_T^{\text{jet}} \) where no effect from new physics is expected. A better knowledge of the gluon distribution at high \( x \) enhances the sensitivity in searches for new physics based on the central jet measurements, where compositeness could be revealed.

This contribution presents preliminary results on inclusive jet production in five jet rapidity regions\(^1\) up to \( |y^{\text{jet}}| = 2.1 \), based on 385 \( pb^{-1} \) of CDF Run II data. CDF used the longitudinally-invariant \( k_T \) algorithm [3] to search for jets:

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K_i = p_{T,i}^2; \quad K_{ij} = \min(p_{T,i}^2, p_{T,j}^2) \cdot \frac{(y_i - y_j)^2 + (\phi_i - \phi_j)^2}{D^2},
\]

where particles are clustered according to their relative transverse momentum. The algorithm includes a D parameter that approximately controls the size of the jet in the \( \phi - \eta \) space. Unlike the Run I cone-based jet algorithm [4], the \( k_T \) algorithm is infrared and collinear safe to all orders in perturbative QCD and does not need an experimental prescription to resolve situations with overlapping cones. The \( k_T \) algorithm has been used at LEP (\( e^+e^- \) collider) and HERA (\( e^\pm p \) collider) but it is relatively new at hadron colliders. First jet measurements using the \( k_T \) algorithm in Run I at the Tevatron [5] showed a marginal agreement between data and

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\(^1\) Measurements in the region \( 0.1 < |y^{\text{jet}}| < 0.7 \) have been published in [2]
pQCD NLO predictions at low $p_T^{\text{jet}}$, and suggested that the use of the $k_T$ algorithm in hadron-hadron colliders was particularly challenging. However, as discussed in this contribution, good agreement between data and theory is recovered after non-perturbative contributions from the underlying event and hadronization have been properly taken into account in the theoretical prediction.

The measured jet energies are affected by contributions from multiple proton-antiproton collisions at high Tevatron instantaneous luminosities that become relevant at low $p_T^{\text{jet}}$. The existence of multiple proton-antiproton interactions is revealed in the central detector via the presence of additional primary vertices in the tracking volume. The measured jet momenta are corrected for this effect in such a way that, after corrections are applied, the $p_T^{\text{jet}}$ spectrum becomes independent of the average instantaneous luminosity considered in the data.

The measured jet cross sections are corrected for detector effects back to the hadron level using Monte Carlo (MC) samples of simulated inclusive jet events. PYTHIA 6.203 [6] MC program has been employed, where inclusive jet events are generated using a special set of parameter, denoted as PYTHIA-Tune A, that provides an accurate description of the underlying event [7] and the internal structure of jets [8] in Run II. Detailed studies have been performed to test the validity of the MC simulation of the detector response to jets using dedicated dijet samples in data and Monte Carlo. The observed $p_T^{\text{jet}}$-balance between the two leading jets and bisector quantities [9] are compared in data and simulation to ensure that the latter provides a good description of both the average jet energy response and jet energy resolution measured in the data.

Figure 1 shows the measured inclusive jet cross sections using the $k_T$ algorithm with $D=0.7$ for jets with $p_T^{\text{jet}} > 54$ GeV/c in five jet rapidity regions up to $|y^{\text{jet}}| = 2.1$. For presentation, the measurements in the different rapidity regions are scaled by a given factor. The distributions show how the cross sections decrease over more than seven orders of magnitude as the $p_T^{\text{jet}}$ increases. The systematic uncertainties on the data, mainly dominated by the 2-3 % uncertainty in the jet energy scale, vary from 10 % at low $p_T^{\text{jet}}$ and 40 to 60 % at high $p_T^{\text{jet}}$. The measurements are compared to pQCD NLO predictions as determined using JETRAD [10] with CTEQ61 PDFs [11] and renormalization and factorization scales set to max $p_T/2$. The uncertainties in the theoretical predictions are dominated by the limited knowledge of the gluon PDF. For central jets these uncertainties at high $p_T^{\text{jet}}$ are about $+70\% -30\%$, increasing in the most forward regions. The ratio between the measurements and the theory is presented for central jets in figure 2. Good agreement with QCD predictions is observed over all the $p_T^{\text{jet}}$ ranges. Similar results are obtained for all the rapidity regions. The theoretical calculations include corrections factors, $C_{\text{HAD}}$, to take into account the non-perturbative effects related to the underlying event and the fragmentation processes. The factors have been evaluated with PYTHIA-Tune A as the ratio between the nominal cross sections at hadron level and the ones obtained after turning off the multiple parton interaction between remnants and the fragmentation into hadrons.

The inclusive jet cross section for jets in the region $0.1 < |y^{\text{jet}}| < 0.7$ has been repeated using D equal to 0.5 and 1.0. Jets are bigger as the D parameter increases, being more sensitive to the underlying event and the fragmentation contributions. Figure 3 presents the comparison between the measurements and the theory. The good agreement with the NLO pQCD predictions, in particular when D=1.0, show that the soft contributions are well under control.

In summary, the measurements in the inclusive jet production using the $k_T$ algorithm presented in this contribution are in a good agreement with the NLO pQCD calculations. In particular, no significant deviation with respect to the theoretical calculations is observed at high $p_T^{\text{jet}}$ for central jets. The results will contribute to a future better understanding of the PDFs in the proton.
Figure 1. Inclusive jet cross section measured using the $k_T$ algorithm with $D=0.7$ in five jet rapidity regions up to $|y^{jet}| = 2.1$. The black squares represent the measured cross sections and the shaded bands indicate the total systematic uncertainty. The measurements are compared to pQCD NLO calculations.

Figure 2. Left: Ratio of the measured and theoretical inclusive jet cross section using the $k_T$ algorithm with $D$ parameter 0.7 for jets in the rapidity region $0.1 < |y^{jet}| < 0.7$. Right: Parton-to-hadron correction factors, $C_{HAD}$ applied to the pQCD NLO calculations.
Figure 3. **Top**: Ratio of the measured and theoretical inclusive jet cross section using the $k_T$ algorithm with $D$ parameter 0.5 (left), and 1.0 (right). **Bottom**: Parton-to-hadron correction factors, $C_{HAD}$, applied to the pQCD NLO calculations in both cases.

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