Fermi National Accelerator Laboratory

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Inclusive Jet Cross Section in $p\bar{p}$ Collisions with the D0 Detector

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The DØ Collaboration[1]
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We report on two preliminary measurements of the central inclusive jet cross section at $\sqrt{s} = 1.8$ TeV. The two data sets with integrated luminosities of 91 $pb^{-1}$and 14 pb^{-1}were collected at the Fermilab Tevatron $p\bar{p}$ Collider with the DØ detector. The cross section, reported as a function of transverse jet energy 35 GeV $\leq E_T \leq$ 470 GeV and in the pseudorapidity interval $|\eta| \leq 0.5$, is in excellent agreement with next–to–leading order QCD.

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I. INTRODUCTION

High transverse momentum jets are predominantly produced in proton–antiproton collisions by two body scattering of a single proton constituent with an antiproton constituent. Predictions for the inclusive jet cross section (1–3) have been made using next–to–leading order Quantum Chromodynamics (NLO QCD). These calculations to third order in the strong coupling constant (α_s^3) reduce theoretical uncertainties to 10-20% . We measure the cross section for the production of jets as a function of the jet energy transverse to the incident beams in the DØ Detector (4) at the Fermilab Tevatron Collider. Previous measurements of inclusive jet production with smaller data sets have been performed by the UA2 (5) and CDF (6) experiments. Most recently, the CDF collaboration has reported excess jet production at large E_T relative to QCD expectations (7).

II. JET DETECTION

Jet detection in the DØ detector primarily requires the uranium–liquid argon calorimeters which cover pseudorapidity $|\eta| \leq 4.1$. Pseudo–rapidity is defined as $\eta = -\ln(\tan(\theta/2))$, where θ is the polar angle of the object relative to the proton beam. The calorimeter has trigger tiles of segmentation $\Delta\eta \times \Delta\phi = 0.8 \times 1.6$ and trigger towers of $\Delta\eta \times \Delta\phi = 0.2 \times 0.2$, where ϕ is the azimuthal angle. For $|\eta| \leq 0.5$ the calorimetric depth exceeds seven nuclear interactions lengths. The DØ detector includes two trigger scintillator hodoscopes located on each side of the interaction region. Timing distributions of particles traversing the two hodoscopes indicate the occurance of single of multiple interactions during a single beam–beam crossing. The event vertex is determined using tracks reconstructed in the central tracking system.

Online event selection occurs in two hardware stages and a final software stage. The initial hardware trigger selected an inelastic particle collision as indicated by the hodoscopes. The next trigger stage required transverse energy above a preset threshold in the calorimeter trigger tiles for 1994–1995 data and towers for the 1992–1993 data. Selected events were digitized and sent to an array of processors. Jet candidates were then reconstructed with a fast cone algorithm and the entire event logged to tape if any jet E_T exceeded a specified threshold. During the 1994–1995 (1992–1993) data run, the software jet thresholds were 30, 50, 85, and 115 (20, 30, 50, 85, 115) GeV with integrated luminosities of 0.355, 4.56, 51.7 and 90.7 (0.00950, 0.0778, 1.02, 7.95, and 13.7) pb^{-1}, respectively.

III. RECONSTRUCTION AND OFFLINE SELECTION

Jets are reconstructed offline using an iterative jet cone algorithm with a cone radius of $\mathcal{R}$=0.7 in η–ϕ space (8). Background jets from isolated noisy calorimeter cells and accelerator losses are eliminated with quality cuts. Background events from cosmic ray bremsstrahlung is eliminated by requiring the missing E_T in an event to be less than 70% of the leading jet E_T. Residual contamination from the backgrounds is estimated to be less than 2% at all $E_T < 500$ GeV based on Monte-Carlo simulations and scanning of all very high jet E_T candidates (9). The overall jet selection efficiency for $|\eta| \leq 0.5$ has been measured as a function of jet E_T and found to be 97±1% below 250 GeV and 94±1% at 400 GeV.

At high instantaneous luminosity more than one interaction in a single beam crossing is probable. The event reconstruction retained, at most, two vertices. The quantity $\mathcal{H}_T$ = $|\Sigma_{\rm jets}\vec{E_T}^{\rm jet}|$ was calculated for both vertices. The vertex with the minimum $\mathcal{H}_T$ was selected as the event vertex and used to calculate jet E_T and η. This reduced the cross section 5% at 100 GeV and 10% at 300 GeV. $\mathcal{H}_T$ was also taken as $\not{E}_T$ for the cosmic ray cut described earlier, when choosing the secondary vertex. This procedure was not required for the 1992–1993 data set as the instantaneous luminosity was much lower. The selected vertex was required to be within 50 cm of the detector center. The z requirement was 90 ± 1% efficient, independent of E_T .

IV. ENERGY CORRECTIONS

The transverse energy of each jet was corrected for offsets due to underlying events and noise/zero suppression, out–of–cone showering, and detector hadronic response. The offset corrections, extracted from minimum bias events, are adjusted according to the average number of interactions expected for the instantaneous luminosity at the time a jet was recorded. The out–of–cone showering correction compensates for energy (from particles emitted within the cone) that leaks outside the cone during calorimeter showering. Similarly, the correction must compensate for particles emitted outside the cone but which deposit some energy inside. Jet simulations combined with test beam data show the correction to be negligible for $\mathcal{R}$=0.7.

The hadronic response correction is based on the E_T balance of photon–jets events after the jets are corrected for the offset. The absolute electromagnetic (or photon) calibration of the calorimeter is determined using dielectron and diphoton decays of the Z, J/ψ, and π^0 resonances. The hadronic response for γ–jets events can then be derived from data using the conservation of momentum: $R = 1 + [\hat{n_{T\gamma}} \cdot \hat{\not{E}_T}]/E_{T\gamma}$, where $\hat{n_{T\gamma}}$ and $E_{T\gamma}$ are the transverse direction vector and energy of the γ and $\hat{\not{E}_T}$ is the missing E_T vector. The photon candidates include direct photons and electromagnetically fragmented jets. The electromagnetic response is equivalent for photons and electromagnetic jets since all photon candidates are required to be isolated and have shower shapes consistent with test beam electrons. For jet energy below 350 GeV the response is directly measured with data and is extended to higher energy using simulated γ–jets events. The simulation is in good agreement with the data. At $\eta = 0$ the mean total jet energy correction is 18% (14%) at 100 GeV (400 GeV). The correction uncertainty is $\approx$ 3% at 100 GeV and $\approx$ 5% at 400 GeV.

The jet energy scale corrects only the average response of a jet, so the steeply falling jet spectrum is distorted by jet energy resolution. At all E_T the resolution, as measured with dijet E_T balance, is well described by a gaussian distribution. The fractional resolution σ_{E_T}/E_T is 7% at 100 GeV. This number includes the correction for additional soft radiation and smearing caused by particles radiated outside the reconstruction cone. The observed E_T spectrum is corrected for resolution smearing by assuming a trial unsmeared spectrum $(A{E_T}^{-B})\cdot(1-2E_T/\sqrt{s})^C$, smearing it with the measured resolution, and comparing the smeared result with the measured cross section. This procedure is repeated until the observed cross section and smeared trial spectrum are in good agreement. The correction reduces the observed cross section by 20±5% (10±5%) at 60 GeV (400 GeV).

V. RESULTS

The inclusive jet cross sections are computed in contiguous E_T ranges from the individual trigger sets. The relative normalizations of the four 1994–1995 sets are established by requiring agreement in the regions where two trigger sets overlap and are efficient. The adjustments are 2.8±1.3%, 5.7±1.5%, and 6.3±1.6% for the three highest E_T trigger sets. The final observed cross section for jets of $|\eta| \leq 0.5$, shown in Fig. 1, includes data from the lowest E_T trigger in the range 50–90 GeV, from the next trigger in the range 90–130 GeV, then 130–170 GeV, and above 170 GeV from the highest E_T trigger. The errors are statistical only and they are uncorrelated from point to point. There is an overall luminosity error of 8%. The same procedure was performed on the 1992–1993 data set, with a 5.4% luminosity normalization error. The E_T values plotted are the mean value of the E_T bin center and the average jet E_T in the bin. The inset shows the total systematic error as a function of E_T .

Figure 1 also shows a theoretical prediction for the cross section from the NLO event generator JETRAD (1). Note the good agreement over seven orders of magnitude. The data and theoretical calculation are binned identically in E_T. The NLO calculation requires specification of the renormalization and factorization scale, ($\mu = E_T/2$ where E_T is the maximum jet E_T in the generated event), parton distribution function (pdf = CTEQ2ML (11)), and the parton clustering algorithm. Partons within 1.2 $\mathcal{R}$ of one another were clustered if they were also within $\mathcal{R}$=0.7 of their E_T weighted $\eta - \phi$ centroid.

Figure 2 shows the ratio, $(D-T)/T$, for the data (D) and NLO theoretical (T) predictions based on the CTEQ2M, CTEQ2ML, and CTEQ3M pdf's (11). The CTEQ2M and CTEQ2ML pdf's are derived from fixed lower energy inelastic scattering data and from HERA ep data. The shapes of the predictions, based on the NLO parton distribution

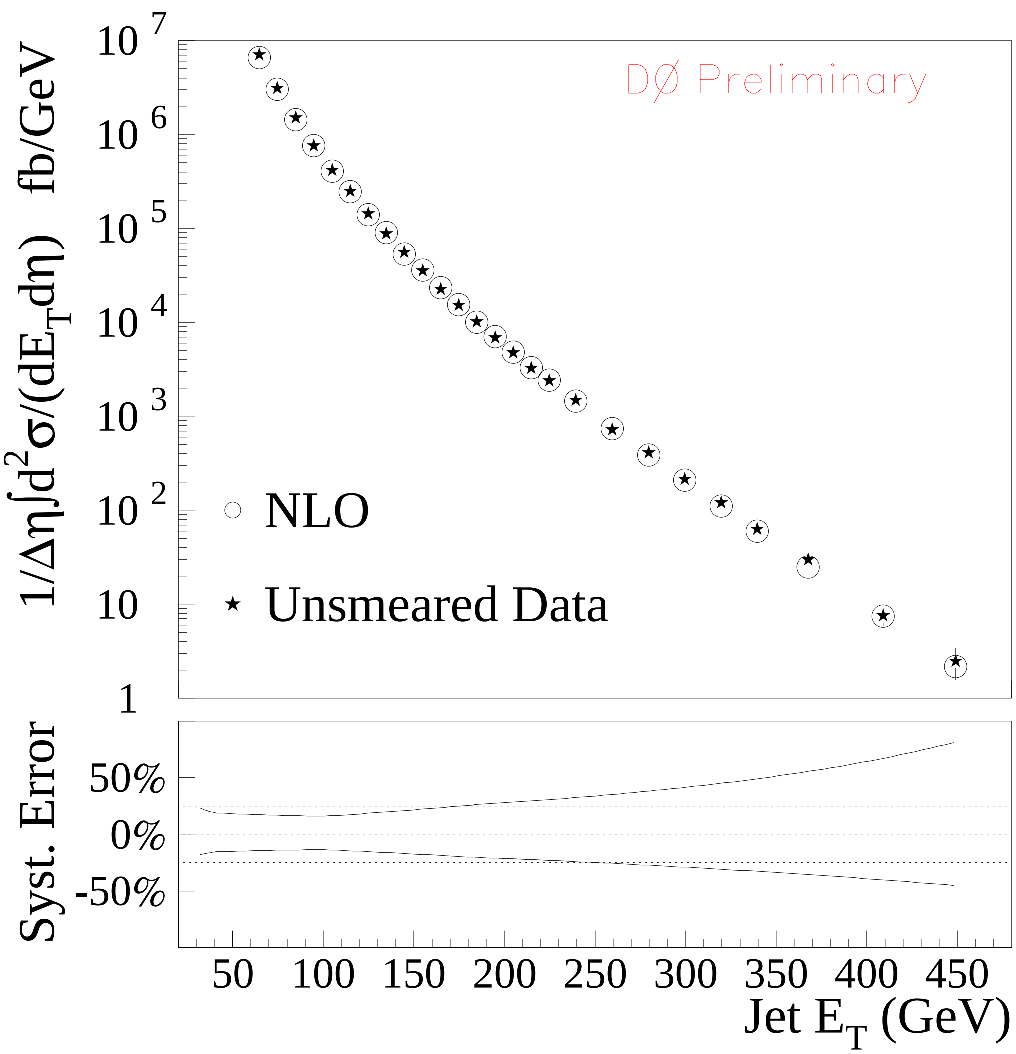

FIG. 1. A comparison of the central, $|\eta| \leq 0.5$, inclusive cross section to a NLO calculation. The points include statistical errors. The inset curves represent plus and minus 1σ systematic error. The horizontal lines are grid lines.

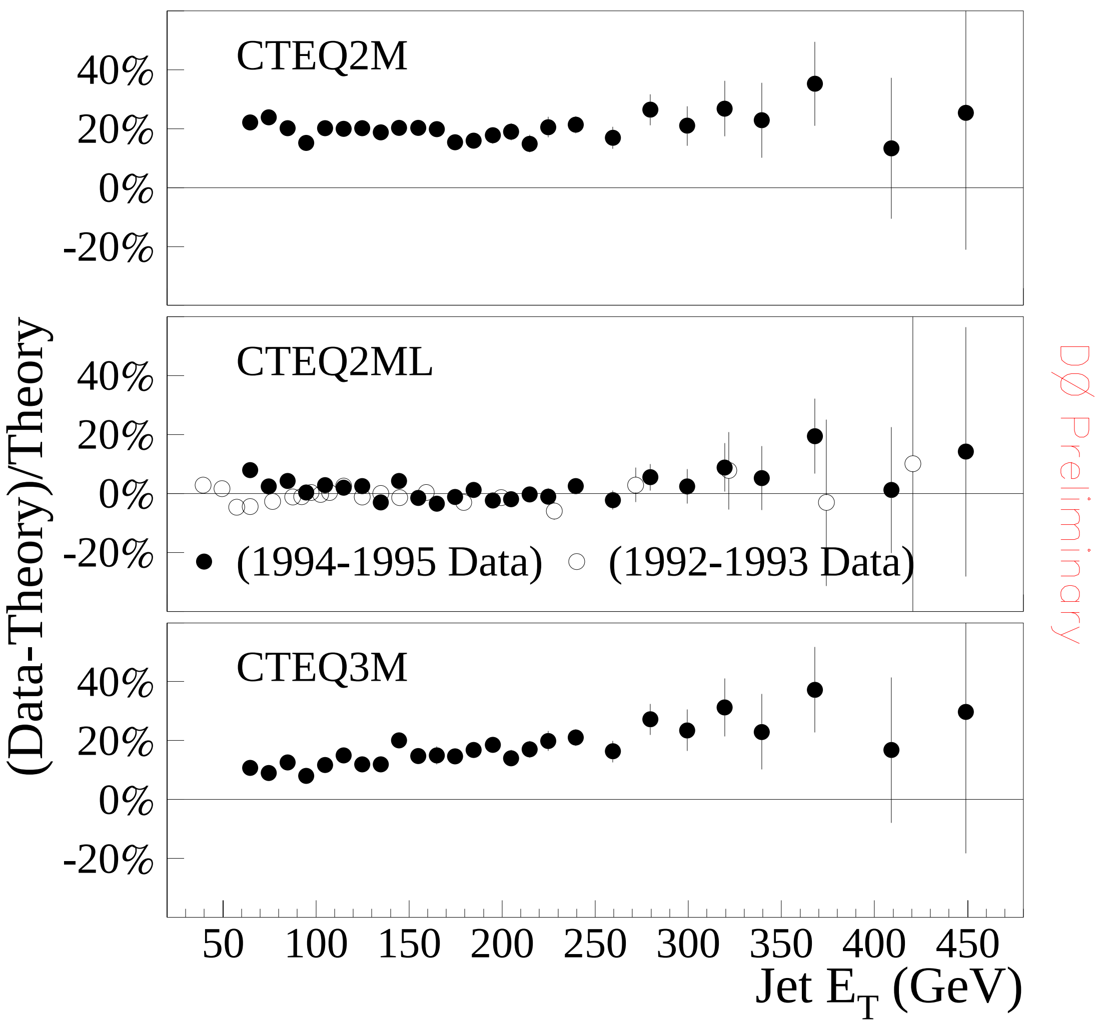

FIG. 2. Difference between the data and three QCD predictions normalized to the theoretical prediction ($(D - T)/T$). The solid (open) symbols are for the 1994–1995 (1992–1993) data.

functions CTEQ2M and CTEQ2ML, are in excellent agreement with the data, as is the CTEQ2ML normalization. The CTEQ2ML pdf was derived by imposing the LEP value of α_s during the pdf derivation. The 1992–1993, data, shown in the central plot, are in excellent agreement with the 1994–1995 data and the CTEQ2ML prediction. The CTEQ3M pdf includes the deep inelastic and recent HERA data as well as recent W boson asymmetry and Drell-Yan measurement.

In conclusion, we have done a preliminary measurement of the inclusive jet cross section for $|\eta| \leq 0.5$ and 35 GeV $\leq E_T \leq 470$ GeV. The QCD NLO model, using different pdf's, is in excellent agreement with the E_T – dependent shape of the observed central inclusive cross section and within experimental and theoretical error agrees well in absolute normalization.

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