Triple Differential Dijet Cross Sections at the Tevatron

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We present the triple differential dijet cross section measured at the DØ and CDF detectors at the Fermilab Tevatron collider at a center of mass energy of 1.8 TeV. The DØ experiment presents this cross section as a function of the transverse energy (E_T) of the two leading jets, where the jets have been ordered in descending E_T, for different configurations of the pseudorapidity (η) of the two jets. The cross sections are measured for eight different configurations: four different η regions of 0.5 size extending to $\eta = 2.0$ and two different topologies for each η region. We consider the opposite-side (OS) topology where the two jets are in different η hemispheres and the same-side (SS) topology where the two jets are in the same η hemisphere. These topologies exploit the fact that OS events have similar initial parton x values and SS events tend to have a combination of a high x and a low x value. The preliminary results are compared to recent parton distribution functions (pdf's) available from the CTEQ and MRST collaborations. The CDF experiment uses a probe jet to sweep the entire detector to $\eta = 3.0$ and present this cross section as a function of the E_T of a trigger jet always in the central part of the detector. The preliminary cross sections from CDF are presented in four different η bins of the probe jet.

I. INTRODUCTION

In an ideal $p\bar{p}$ hard scatter, two partons interact, are liberated and produce at least two jets. From a measurement of the position and energy of the final state jets, much can be learned about the initial state momentum distributions of the partons. The jet cross section measured from two jet final state events, per unit pseudorapidity, per unit transverse energy is known as the Triple Differential. According to the QCD factorization theorem, the triple differential can be factorized in the following way:

$$\frac{d^3\sigma}{d\eta_1 d\eta_2 dE_T} = \sum_{i,j,k,l} x_1 f_i(x_1, Q^2) x_2 f_j(x_2, Q^2) \hat{\sigma}(i, j \to k, l) \tag{1}$$

where, $f_{i,j}$ are the parton distribution functions (pdf's) and $\hat{\sigma}$ is the parton-parton hard scattering cross section. Next-to-Leading order (NLO) QCD predictions can calculate $\hat{\sigma}$ with high precision ($\sim$ 20%) [1–3]. Hence, knowing this parameter, the experimental measurement of the triple differential gives us a direct measurement of pdf's. Measurement of the cross section at a center of mass energy of 1.8 TeV allows us to confirm pdf's measured and extrapolated from lower Q^2 values. By extending the measurement up to higher values of η, we can extend quark density measurements to unexplored x values. Also, a significant contribution to jet production in $p\bar{p}$ collisions come from gluons in the proton and anti-proton. The single effective parton density $f_{i,j}$ can be written as:

$$f(x, Q^2) = g(x, Q^2) + \frac{4}{9}(q(x, Q^2) + \bar{q}(x, Q^2)) \tag{2}$$

Hence, this measurement gives us an opportunity to extract and constrain gluon density.

The experimentally measured jet quantities can be mapped directly into parton x space through:

$$x_{1,2} = \frac{1}{\sqrt{s}} \sum_{jets} E_{T_{jet}} e^{\pm \eta_{jet}} \tag{3}$$

By properly choosing the event topologies we can maximize the x coverage that can be obtained from these measurements. Accordingly, events can be divided into two categories, same sided (SS) with both jets in the same η hemisphere ($\eta_1 \sim \eta_2$) and opposite sided (OS) with the two jets in opposite η hemisphere ($\eta_1 \sim -\eta_2$). Table 1 summarizes the range of x values we can probe with such topologies in different η bins, assuming two jets of equal E_T [4]. The present measurement allows us go down to a x value of 0.01 at $|\eta| \sim 2.0$.

TABLE I. x range covered by Triple Differential.

η bin	Topology	x_{min}	x_{max}
0.0-0.5	SS	0.05	0.57
0.0-0.5	OS	0.06	0.45
0.5-1.0	SS	0.03	0.70
0.5-1.0	OS	0.08	0.43
1.0-1.5	SS	0.02	0.29
1.0-1.5	OS	0.13	0.54
1.5-2.0	SS	0.01	0.80
1.5-2.0	OS	0.19	0.52

It can be seen from the table that at high η (1.5-2.0), SS events probe large values of x up to 0.80, whereas, in lower η regions, both SS and OS events can be used to confirm pdf's measured in previously explored x regions.

Experimentally, the triple differential cross section is measured according to the following formula:

$$\frac{d^3\sigma}{d\eta_1 d\eta_2 dE_T} = \frac{\Delta N}{LC\Delta\eta_1\Delta\eta_2\Delta E_T\epsilon_{cut}} \qquad (4)$$

where N is the number of events that pass all event and jet selection cuts, in a given $\Delta\eta$ and $\Delta \mathrm{E_T}$ bin normalized by the total luminosity L and the efficiency of the cuts ϵ_{cut}. C stands for the unsmearing correction.

II. TRIPLE DIFFERENTIAL AT DØ

The DØ detector [5] has a liquid argon-uranium calorimeter with full pseudorapidity ($|\eta| \leq 4.1$) coverage for detection of final state jets. The calorimeter has azimuthal symmetry. The single particle electromagnetic and hadronic fractional energy resolutions are $15\%/\sqrt{\mathrm{E}}$ and $50\%/\sqrt{\mathrm{E}}$, respectively, with E in GeV.

The detector was read out if a hardware jet trigger based on $\mathrm{E_T}$ in calorimeter towers and a subsequent software jet trigger were satisfied. The software thresholds were 30, 50, 85 and 115 GeV. The data taken during the 1994-95 collider run corresponding to an integrated luminosity of $92\mathrm{pb}^{-1}$ are used for this study.

Jets were reconstructed offline using a fixed cone algorithm with a radius of $\mathrm{R} = \sqrt{\Delta\eta^2 + \Delta\phi^2} = 0.7$. Data are used only when the triggers are 100% efficient. Background from noisy electronic cells and accelerator losses were removed from the sample using offline jet quality cuts. Background from cosmic rays is eliminated by requiring the ratio of the missing $\mathrm{E_T}$ in an event to the $\mathrm{E_T}$ of the leading jet to be less than 70%. The efficiencies of these offline cuts are dependent on $\mathrm{E_T}$ and η and are above 95%. Also, to ensure selection of events properly measured and reconstructed by the detector, a cut of $|\mathrm{z}| \leq 50$ cm was required on the event vertex.

One of the most important aspects of jet physics is the determination of corrections to the measured jet energy. A multistep process is used to calibrate the jet energy [6]. First of all the electromagnetic scale of the calorimeter is measured using $\mathrm{Z}^0 \rightarrow$ ee events and scaling the energies of the electrons so that the corrected Z^0 mass coincides with the value measured at LEP [7]. Next, the response as a function of jet energy in the central calorimeter is measured from photon-jet events using conservation of momentum in the transverse plane. After the response in the central calorimeter has been measured, the relative η dependence of the response is measured with both photon-jet and dijet events. One jet (photon) is required to be in the central calorimeter and the other jet (probe) is allowed to be anywhere in the detector and the response is measured as a function of the η of this probe jet. The jet energy is also corrected for effects of noise, underlying event, multiple $\mathrm{p\bar{p}}$ interactions and energy losses due to out-of-cone showering. For example, at 100 GeV $\mathrm{E_T}$ for central jets ($\sim$0.0), the average energy scale correction factor is 15$\pm$3.0%. In the forward region ($\sim$2.0) at 60 GeV, this factor is 18$\pm$4.5%.

After these corrections, the steeply falling jet spectra are still smeared by the finite resolution of the detector. The fractional jet E_T resolution is measured from dijet events and corrected for additional soft radiation and smearing due to particles outside the reconstruction cone. By fitting the convolution of a trial function $(AE_T^{-B})(1-2E_T/\sqrt{s})^C$ and the measured jet E_T resolution, resolution unsmearing of the measured cross section is performed. For example, the unsmearing correction factor for 100 GeV E_T jets in $|\eta| \leq 0.5$ is $\sim$10%. In the forward region, $1.5 \leq |\eta| \leq 2.0$, this correction is $\sim$15% for 65 GeV E_T jets.

Also, in case of multiple interactions, the reconstruction algorithm sometimes picks up the wrong vertex when they are too close together giving rise to an effective vertex resolution. This effects the jet E_T and η measurements. However, these two effects anticorrelate resulting in a 1% correction to the cross section.

Figures 1 and 2 show the ratio (Data-Theory)/Theory as a function of jet E_T. Figure 1 shows this comparison for $|\eta| \leq 0.5$ and $0.5 \leq |\eta| \leq 1.0$ with both SS and OS topologies. Figure 2 shows the same for $1.0 \leq |\eta| \leq 1.5$ and $1.5 \leq |\eta| \leq 2.0$. The theory is a NLO QCD prediction [3] generated using the CTEQ3M pdf [8] and a renormalization/factorization scale (μ) of half of the energy of highest energy jet in the event. In the triple differential measurement at DØ events are counted twice, once for each jet. The error bars are statistical, while the outer band is statistical and systematic errors added in quadrature. The preliminary DØ triple differential cross section are in good agreement with the CTEQ3M family with a scale of μ = E/2. The DØ triple differential cross sections are also compared to predictions using different pdf's. For example, the CTEQ4M pdf which includes the preliminary inclusive jet data from the DØ and CDF experiments, from the 1994-95 run, in their global fits, compare well with the DØ preliminary data. Comparisons are also performed with the CTEQ4HJ pdf which was specially designed to accommodate the high E_T excess in the CDF inclusive jet data. DØ preliminary data are also compared to pdf's from the MRST group [9] and show qualitative agreement, although there are differences in normalization.

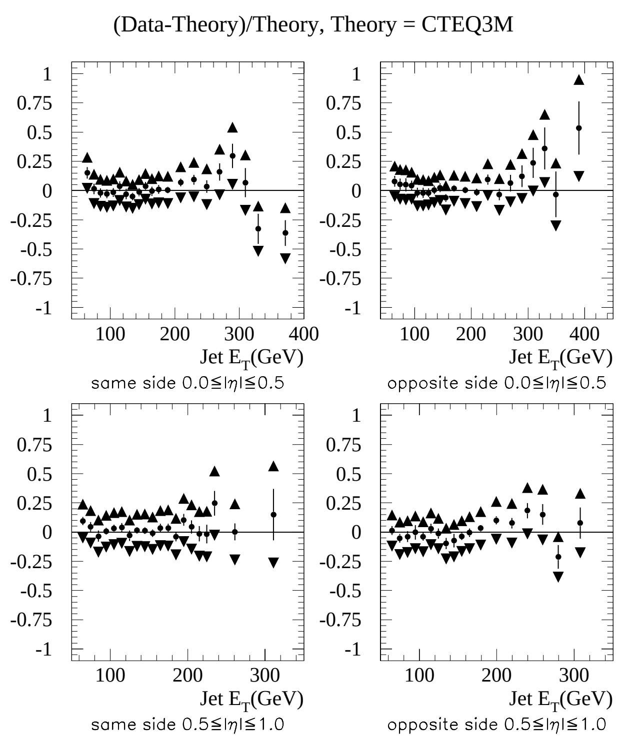

FIG. 1. Fractional difference between DØ Preliminary data and NLO QCD with CTEQ3M pdf.

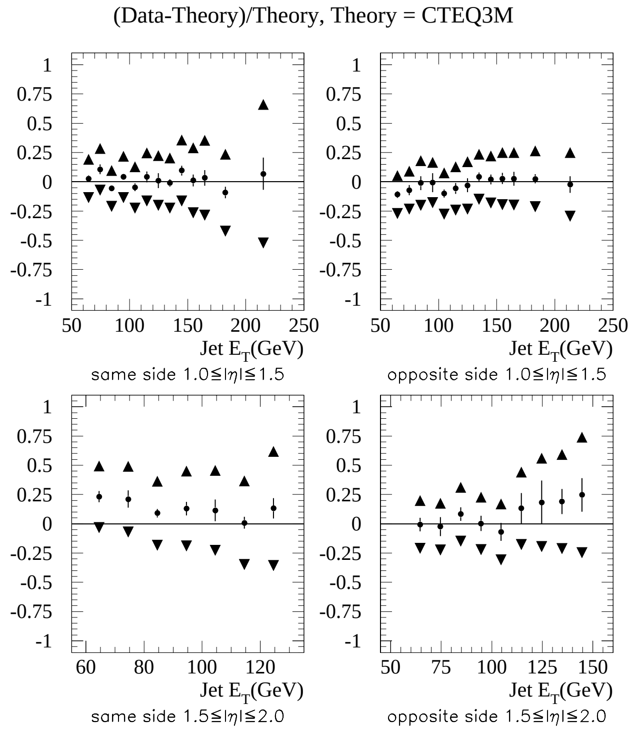

FIG. 2. Fractional difference between DØ Preliminary data and NLO QCD with CTEQ3M pdf.

III. TRIPLE DIFFERENTIAL AT CDF

The CDF experiment measures the triple differential cross section in a slightly different manner, although the same set of jet variables are used. The CDF analysis starts with a set of inclusive jet triggers and requires at least two reconstructed jets in an event. The event configuration requires a trigger jet with E_T >40 GeV and another jet used to sweep the entire detector, known as the probe jet with E_T >10 GeV. The trigger jet is always required to be in the central pseudorapidity region $0.1< |\eta_1| <0.7$. With the trigger jet fixed in the central region, the probe jet is used to sweep the entire detector up to η=3.0. The trigger jet E_T distributions are then plotted when the probe jet sits in different η_2 intervals. Altogether four different probe jet pseudorapidity intervals are used: $0.1< |\eta_2| <0.7$, $0.7< |\eta_2| <1.4$, $1.4< |\eta_2| <2.1$ and $2.1< |\eta_2| <3.0$. Also, if there are two jets which pass the trigger jet cuts in the central region, both combinations contribute to the cross section.

Figure 3 shows the triple differential dijet cross section measured at CDF, for the four different probe jet pseudorapidity intervals. The measurement is based on a 88pb^{-1} data sample taken during the 1994-95 collider run. Error bars on the data points are statistical. Also shown are the NLO QCD predictions from JETRAD [3] with different pdf's.

The fractional difference of CDF data from NLO QCD predictions show the data to be sensitive to differences in pdf's and also that traditional pdf's underestimate high E_T jet production in the data.

The CDF experiment also maps the measured jet variables directly into the intial state x fractions of the partons according to Equation 3. The four momentum transferred (Q^2) in the interaction can also be calculated in the following way:

$$Q^2 \sim -\hat{t} = 2E_T^2 cosh^2\eta^*(1 - tanh\eta^*) \quad (5)$$

where $\eta^* = 0.5(\eta_1 - \eta_2)$. Figure 4 show the data span in Q^2 and x. The data are seen to sit in the high Q^2 and high x region. This dependence can be used to constrain pdf's and α_s simultaneously.

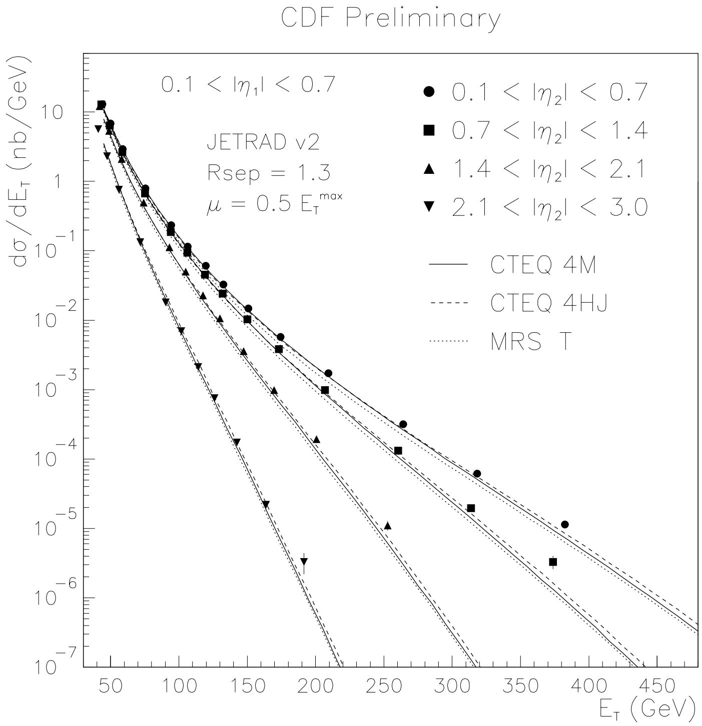

FIG. 3. CDF Preliminary Triple Differential dijet cross section.

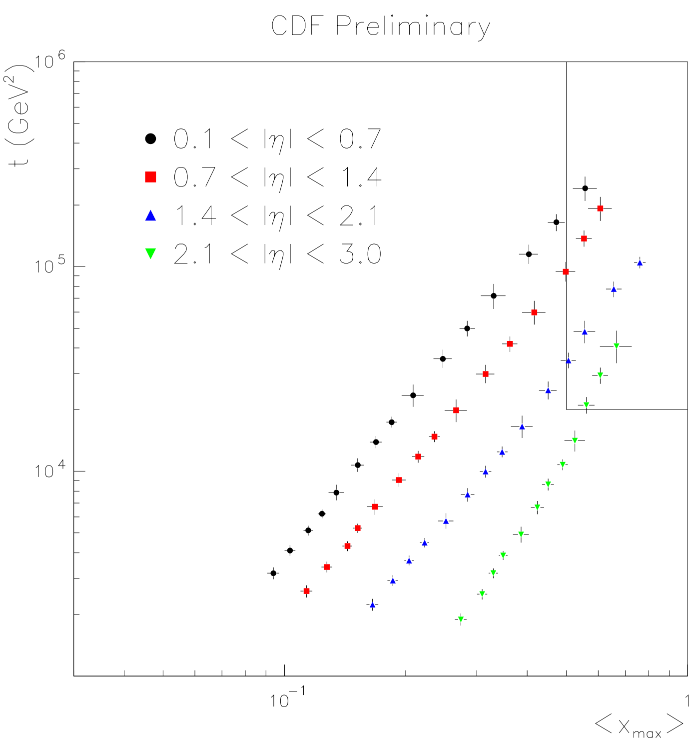

FIG. 4. x and Q^2 coverage of CDF Preliminary triple differential cross section.

IV. CONCLUSIONS

The triple differential dijet cross sections are measured in $p\bar{p}$ collisions at a center-of-mass energy of 1.8 TeV at the Fermilab Tevatron collider both at the DØ and the CDF experiments.

The DØ experiment measured the triple differential cross section to η=2.0 and by employing SS and OS topologies has been able to probe very high values of parton x (0.80 with SS events). Preliminary measurements by the DØ experiment are consistent in shape with modern pdf's from the CTEQ and MRST groups. Covariant error analysis of the data are underway to quantify the comparison with various pdf's.

The CDF experiment measured the triple differential cross section to η=3.0. However, SS and OS topologies were not employed. The CDF data are sensitive to the choice of pdf's and moreover, traditional pdf's are unable to model the high E_T excess in the data. CTEQ4M is 5-10% (50%) lower than CDF data at low (high) E_T. MRST is 30% lower than the data. CTEQ4HJ qualitatively reproduces the shape of the CDF data.

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