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Jet Physics at the Tevatron

Iain A. Bertram
Lancaster University

ABSTRACT

Results are presented from analyses of jet data produced in $p\overline{p}$ collisions at $\sqrt{s} =$ 1960 GeV collected with the DØ and CDF detectors during 2002–03 at the Fermilab Tevatron Collider. Preliminary measurements of the inclusive jet cross section, the dijet mass spectrum, and jet structure are presented.

1 Introduction

Perturbative QCD (pQCD) predicts the production cross sections at large transverse momentum (p_T) for parton-parton scattering in proton–antiproton ($p\overline{p}$) collisions. The outgoing partons from the parton-parton scattering hadronize to form jets of particles. Calculations of high-p_T jet production involve the folding of parton scattering cross sections with experimentally determined parton distribution functions (PDFs). These predictions are calculated to next-to-leading-order (NLO) QCD calculations [1, 2, 3]. In this paper I present several measurements of jet cross sections at $\sqrt{s} = 1960$ GeV collected with the DØ and CDF detectors.

In the analyses presented in this paper Jets are reconstructed using an iterative cone algorithm, known as the improved legacy cone algorithm [4], with a fixed cone radius of $\mathcal{R} = 0.7$ in η–ϕ space, where φ is the azimuth. This cone algorithm clusters jets about seeds. If two seeds are within $2\mathcal{R}$ of each other, a third seed is created at the midpoint between them. Jets with overlapping cones are merged or split according to the following criteria: two jets are merged into one jet if more than 50% of the E_T of the jet with the smaller E_T is contained in the overlap region. If less than 50% of the E_T is contained in the overlap region, the jets are split into two distinct jets and the energy of each calorimeter cell in the overlap region is assigned to the nearest jet. The jet directions are then recalculated.

The analyses presented in this paper were carried out using data collected during 2002-2003. The DØ data sample corresponds to an integrated luminosity of 34 pb^{-1} and the CDF data sample 85pb^{-1}.

2 Run 2 at the Tevatron

The Tevatron has recently been upgraded to improve both the luminosity and the center-of-mass (CM) energy. During the shutdown between Run 1 (1992–1995) and the current Run 2 (2002–), the accelerator's Main Ring was replaced with the Main Injector which should provide higher beam currents and cycling rates. . The CM energy has been increased from $\sqrt{s} = 1800$ GeV in Run 1 to $\sqrt{s} = 1960$ GeV.

To cope with the increased luminosity the DØ and CDF experiments were both upgraded during the shutdown period. The DØ detector has upgraded its tracking system, with the addition of a 2T Solenoid magnet surrounding a silicon microstrip tracker, and a scintillating fiber tracker. The calorimeter's readout electronics have been replaced, and central and forward preshower detectors have been added between the solenoid and the calorimeter. The muon detector system has been extended by adding scintillating layers for triggering, extending the drift chamber coverage, and improving the beamline shielding. The entire trigger and DAQ system was also replaced to cope with the increased beam crossing rate.

The CDF detector underwent a similar upgrade. The tracking systems were replaces with a new silicon microstrip tracker, Time-of-flight detector, and drift chamber. The calorimeter coverage was improved by adding new plug and mini-plug calorimeters. The muon coverage was also improved. Finally, CDF also upgraded their entire trigger and DAQ system as well.

3 Inclusive Jet Cross Section

The high p_T behaviour of the inclusive jet cross section has been the subject of much discussion. The previous measurements of the cross section by DØ [5] and CDF [6] are compared with the JETRAD [3] NLO Monte Carlo prediction using the CTEQ4HJ PDF in Fig. 1. The CDF measurement showed a possible excess of high-p_T jet production, while the DØ measurement is in good agreement with the predictions. The two measurements are statistically consistent with each other [5]. The slight excess can be explained using PDFs that include the Run 1 high-p_T jet data (CTEQ6 [7] and MRST2001 [8]) or by the introduction of new phyiscs beyond the standard model.

The increase in CM energy from $\sqrt{s} = 1800$ to $\sqrt{s} = 1960$ GeV means that the cross section will increase by 40% (200%) for jets of 300 (400) GeV (Fig. 2). The Tevatron is expected to deliver 2 pb^{-1} during the first phase of Run 2 compared with a total data sample of approximately 110 pb^{-1} in Run 1. This will result in a dramatic increase of statistics that will result in measurements that are dominated by systematic uncertainties for almost the entire p_T range measured.

CDF has measured the inclusive jet cross section using a data sample of 85 pb^{-1} in the rapidity range $0.1 < |y| < 0.7$. The data was collected using four triggers with uncorrected jet transverse energy (E_T) thresholds of 20, 50, 70, and 100 GeV. The z-position of the event vertex was required to satisfy $| z |<$ 60cm, and the effects of noise and cosmic rays were removed using cuts on the missing-E_T and by event scanning. The resulting cross section was corrected for energy scale effects and unsmeared. The uncertainty on the jet E_T due to the jet energy scale correction is currently 5%. The resulting cross section is then compared with a JETRAD prediction with the CTEQ61 PDF [7] (Fig. 3). The data show good agreement with the theoretical predictions given the size of the experimental uncertainties.

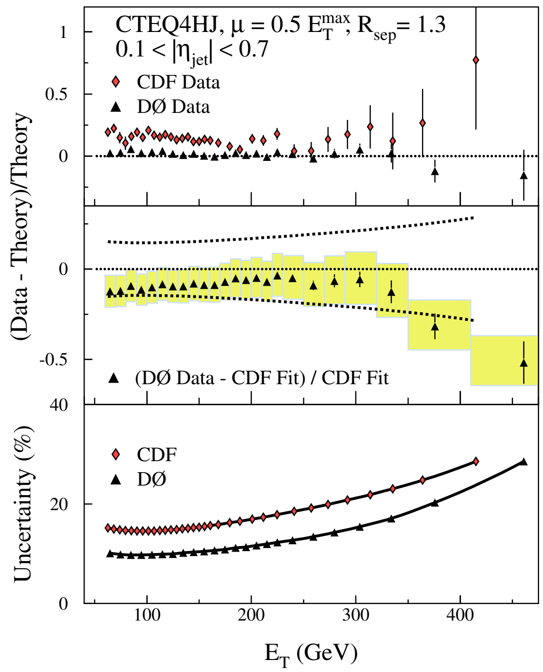


Figure 1: Inclusive Jet Cross Sections for $0.1 < |\eta| < 0.7$ from DØ and CDF compared to the theory prediction Jetrad with the CTEQ4HJ PDF.

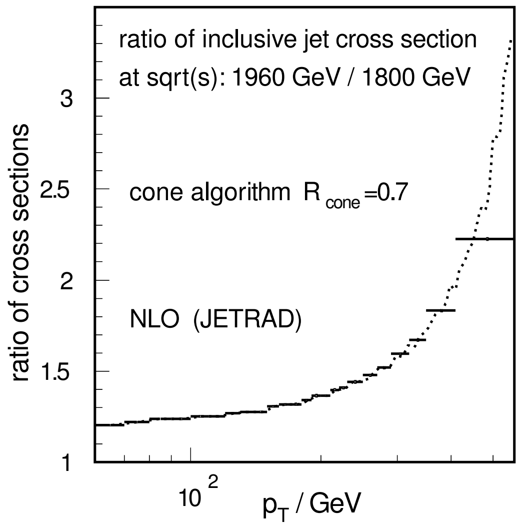


Figure 2: The ratio of predicted inclusive jet cross sections at $\sqrt{s} = 1960$ GeV and $\sqrt{s} = 1800$ GeV for $|\eta| < 0.5$ using Jetrad with the CTEQ4HJ PDF.

CDF has carried out a comparison between the inclusive jet cross section measured at $\sqrt{s} = 1800$ and $\sqrt{s} = 1960$ GeV (Fig. 4). The data are in good agreement with the theoretical predictions for jet-E_T greater than 250 GeV. At lower values of E_T the Run 2 data show an excess compared with the expected cross section. Increased statistics and improved understanding of systematic uncertainties over the next year should shed some light on this.

CDF has also measured the jet cross section out to an η of 2.8 for the first time (Fig. 5). These measurements will add to the current DØ Run 1 measurement [9] of the jet cross section at forward rapidities as an important component of future PDF fits.

DØ measured the inclusive jet cross section using a data sample of 34 pb^{-1} in the rapidity range $|y| < 0.5$. The data were collected with five triggers with uncorrected-E_T threshold of 5, 25, 45, 65, and 95 GeV. The z-vertex was required to satisfy the cut $|z| < 50$ cm. Jets caused by noise and cosmic rays were rejected using the cut: $\not{E}_T/p_T^{\rm jet1} < 0.7$, where $p_T^{\rm jet1}$ is the transverse momentum of the highest p_T jet in the event, and $\not{E}_T$ is the missing transverse energy in the event. Additional quality cuts are made on the jet shower shapes to eliminate any remaining noisy

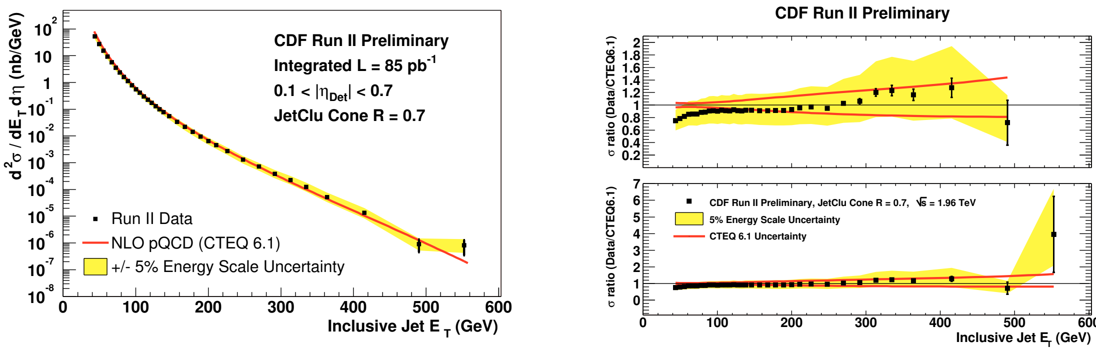


Figure 3: The inclusive jet cross section as measured by CDF for $0.1 < |y| < 0.7$ compared with the JETRAD prediction with the CTEQ61 PDF. The left hand plot is on a logarithmic scale and the right hand plot shows the data divided by the theoretical prediction.

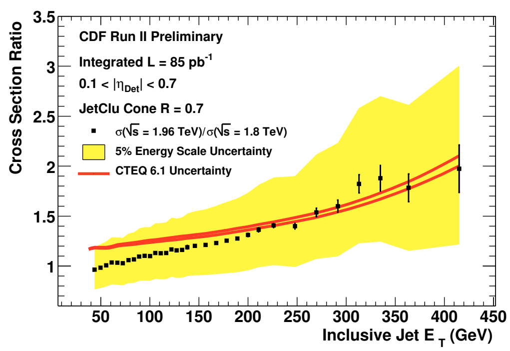


Figure 4: The ratio of inclusive jet cross sections at $\sqrt{s} = 1960$ divided by $\sqrt{s} = 1800$ GeV by CDF for $0.1 < |y| < 0.7$ compared with the JETRAD prediction.

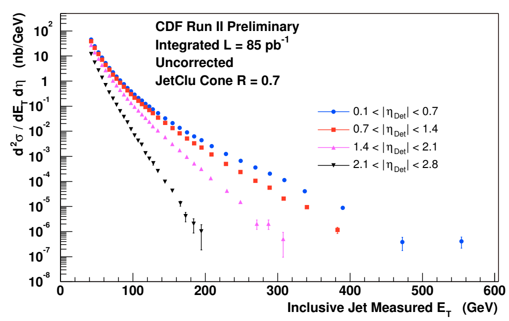
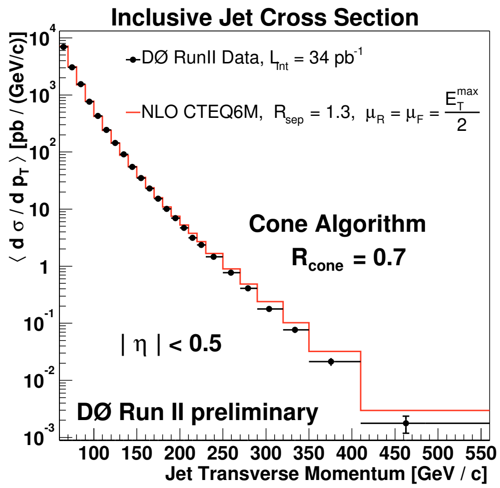


Figure 5: The CDF inclusive jet cross section for $0.1 < |y|0.7$, $0.7 < |y| < 1.4$, $1.4 < |y| < 2.4$, and $2.1 < |y| < 2.8$.

jets. The resulting cross section is then compared with a JETRAD prediction with the CTEQ6M PDF [7] (Fig. 6). The prediction and the measured cross section are in good agreement given the large size of the experimental uncertainties which are dominated by the uncertainty on the jet energy scale. The energy scale uncertainty is expected to halve by the end of summer 2003. At this time no comparison has been made between DØ and CDF results, and both experiments are in good agreement with JETRAD predictions that use the MRST2001 PDFs [8].



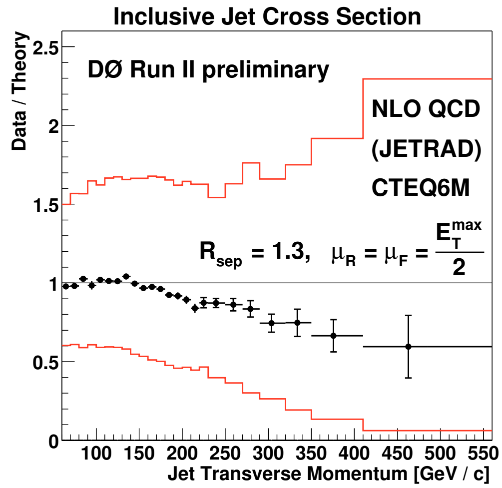


Figure 6: The inclusive jet cross section as measured by DØ for $|y| < 0.5$ compared with the JETRAD prediction with the CTEQ6M PDF. The left hand plot is on a logarithmic scale and the right hand plot shows The difference between the data and the prediction, divided by the prediction.

4 Dijet Measurements

DØ has made a measurement of the dijet mass cross section using the same data sample as used in the measurement of the inclusive jet cross section. The dijet mass is calculated using the two highest p_T jets in the event. The mass is defined as ${M_{JJ}}^2 = (E_1 + E_2)^2 - (\vec{p_1} + \vec{p_2})^2$. Both jets in the event are required to have $|y| < 0.5$. The data and theoretical predictions are in good agreement (Fig. 7).

In addition to measuring the mass in these events DØ also measured the separation in the azimuthal angle, ϕ, between the two highest p_T jets in the events that satisfy $|y| < 0.5$. Four measurements are made, using four triggers with thresholds 25, 45, 65, and 95 GeV corresponding to mass bins of 150, 180, 300, and 390 GeV/c^2 respectively. The resulting distributions (Fig. 8) show that jets become more back-to-back as the mass of the events increases.

CDF has used a data sample of 75 pb^{-1} to carry out a search for new resonances95% confidence level (CL) limits on the production cross section in the dijet mass spectrum, and set limits on their production within the context of different theoretical models. A comparison has been made between the dijet mass spectrum in Run 1 and Run 2 (Fig. 9) which is in reasonable agreement with a LO QCD prediction (PYTHIA). 95% confidence level (CL) limits on the production cross section of new particles are calculated and compared to theoretical predictions. The production of excited quarks [10] is a convenient model for comparing limits between

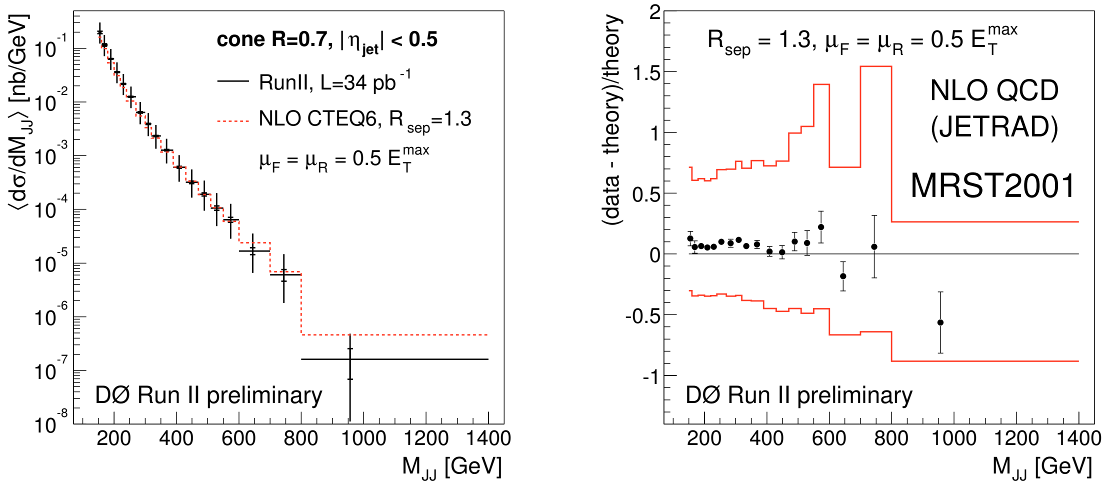


Figure 7: The dijet mass cross section as measured by DØ for $|y| < 0.5$ compared with JETRAD predictions. The left hand plot is on a logarithmic scale and uses the CTEQ6M PDF and the right hand plot shows The difference between the data and the prediction, divided by the prediction using the MRST2001 PDF.

experiments and CDF excludes excited quarks in the mass range $200 < M_{W'} < 760$ GeV/c^2. This compares well with the best Run 1 limit of 775 GeV/c^2 made by the DØ experiment [11]. See Fig. 10 for limits on additional models.

5 Jet Structure

The CDF experiment has made a series of studies of the structure of jets and the flow of energy with events with jets in them. These measurements allow us to test fragmentation and hadronisation models, such as those used in the PYTHIA and HERWIG Monte Carlo simulations. In addition they play an essential role in minimising the uncertainties in jet energy scale corrections, and hence are essential to measurements of the top mass, for example.

CDF has measured the jet transverse energy shape. Jets are identified using the cone algorithm with radius $\mathcal{R} = 1.0$. Each jet is then divided into 10 sub-cones around the jet axis with sizes varying from $\mathcal{R} = 0.1$ to $\mathcal{R} = 1.0$, in increments of $\Delta\mathcal{R} = 0.1$. The energy in each of these sub-cones is then divided by the total energy in the jet (represented by ρ, Fig. 11). Several measurements of ρ are made for different p_T and rapidity ranges and are compared to PYTHIA and HERWIG. In all cases the simulations are in good agreement with the data.

In addition CDF measures the energy outside of a jet, along a band of width $\Delta\phi = 0.7$ centered on the ϕ axis of the jets as a function of the separation

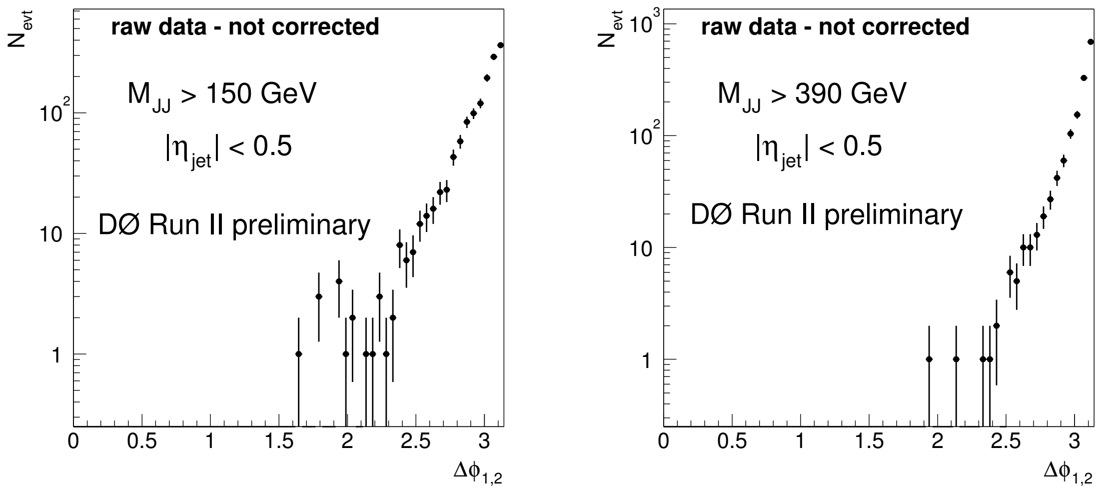


Figure 8: The separation in ϕ between the two highest-p_T jets in the event above a given mass threshold. The left hand plot is for $M_{JJ} > 150$ GeV/c^2 and the right hand plot is for $M_{JJ} > 390$ GeV/c^2.

between the two leading p_T jets in the event, $\Delta\eta$. This is an important test of the modeling of underlying event in $p\overline{p}$ collisions. The measured data are again compared with PYTHIA and HERWIG (Fig. 12). Again the data and predictions are in reasonable agreement.

6 Conclusions

Both the DØ and CDF experiments have made a promising start to Jet based analyses using Run 2 data at the Tevatron. I expect that over the next year we will see significant improvements in the systematic uncertainties, much larger data samples than those collected in Run 1. These improvements and the release of new results should lead to a much improved understanding of Jet production at hadron colliders that will be essential for a good understanding of LHC data in the future.

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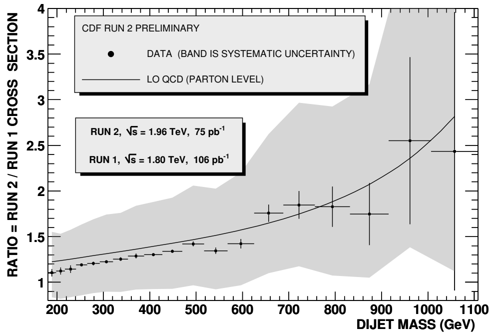

Figure 9: The CDF Run 2 dijet mass spectrum divided by the Run 1 spectrum.

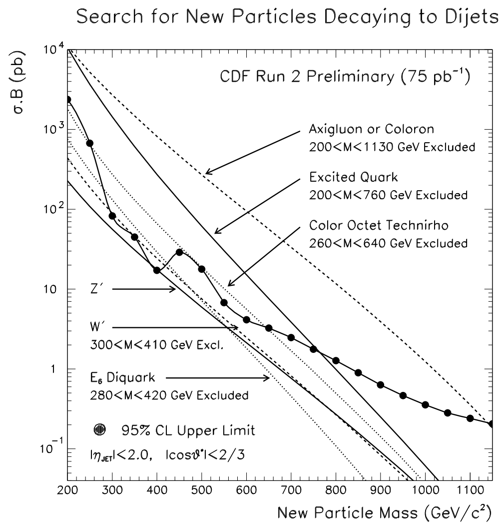

Figure 10: The 95% CL on the production cross section multiplied by $B(X \rightarrow$ dijet) and acceptance for various theoretical models.

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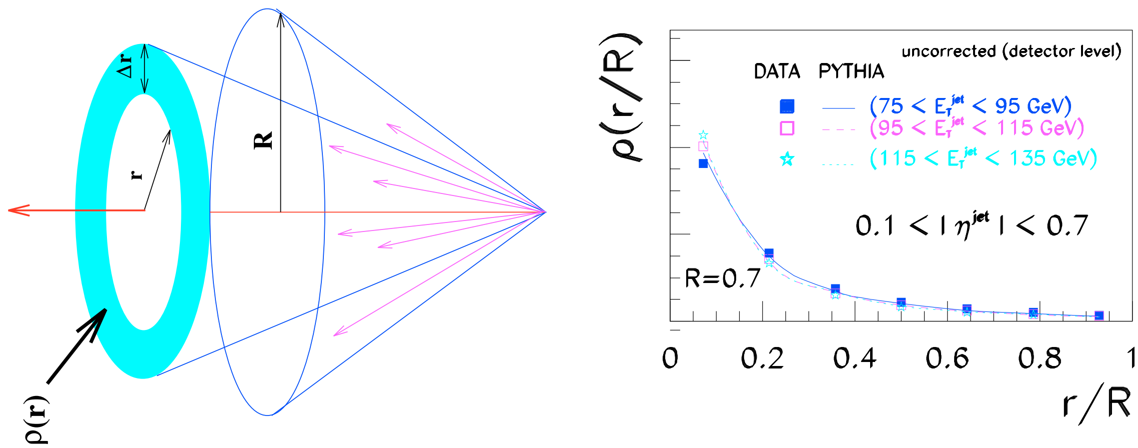

Figure 11: The CDF measurement of the jet transverse energy shape. The right hand plot illustrates the definition of the ρ variable, and the left hand plot shows the measurement for $0.1 < |y|0.7$ with different jet p_T cuts.

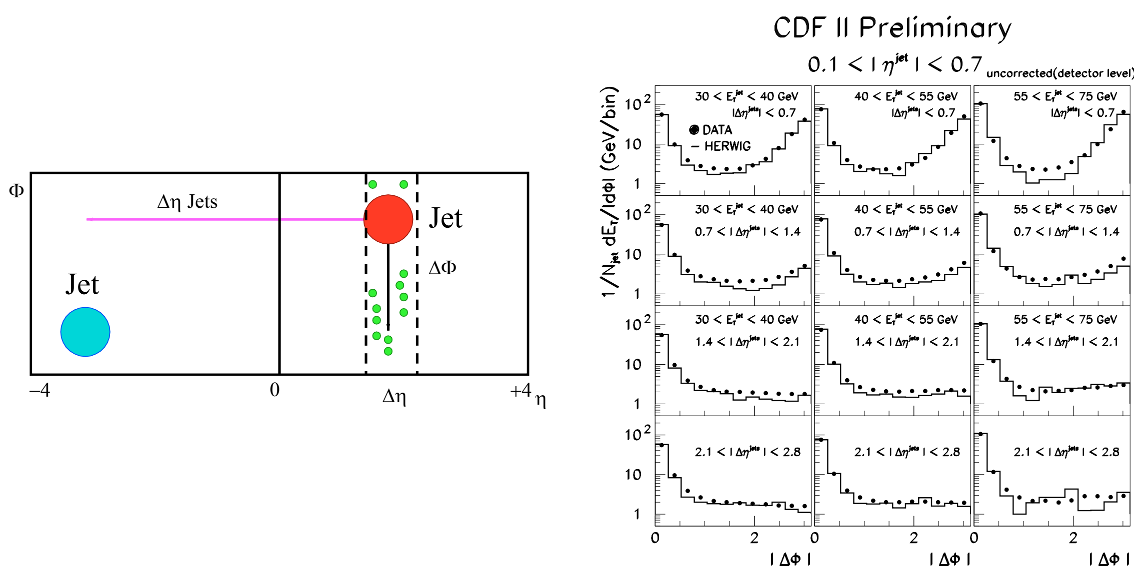

Figure 12: The CDF measures the energy outside of a jet, along a band of width $\Delta\phi = 0.7$ centered on the ϕ axis of the jets as a function of the separation between the two leading p_T jets in the event, $\Delta\eta$. The left hand plot illustrates the measurement and the right hand plot compares the data with Herwig.