Fermi National Accelerator Laboratory

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# Recent QCD Results from CDF *

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# RECENT QCD RESULTS FROM CDF

The CDF Collaboration: Argonne, Brandeis, Chicago, Fermilab, Frascati, Harvard, Illinois, KEK, LBL, Pennsylvania, Pisa, Purdue, Rockefeller, Rutgers, Texas A&M, Tsukuba,Tufts, Wisconsin

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In this paper we report recent QCD analysis with the new data taken from CDF detector. CDF recorded an integrated luminosity of 4.4 $nb^{-1}$ during the 1988-1989 run at center of mass system (CMS) energy of 1.8 TeV. The major topics of this report are inclusive jet, dijet, trijet and direct photon analysis. These measurements are compared to QCD predictions. For the inclusive jet and dijet analysis, tests of quark compositeness are emphasized.

## 1 Introduction

In the 1.8 TeV CMS energy, $p\bar{p}$ collisions at high transverse energies ($E_t$) are approximately the same as interactions of asymtotically free partons. At the moment CDF took data at the highest CMS accelerator energy providing a unique probe of the smallest distance scales. Large deviations from QCD predictions could be an indication of new phenomena. In particular possible quark compositeness is of interest.

So far there is no widely accepted theoretical prediction for quark compositeness. A common form used to parameterize the effect of quark compositeness is a contact interaction from constituent exchange [1]. An effective Lagrangian is,

$$L_{eff} \sim \frac{g^2}{4\pi\Lambda^{*2}}(\bar{q}_L\gamma^\mu q_L)^2$$

Where g is set to unity and $\Lambda^*$ is the effective compositeness scale (in GeV). In this form, the cross section rises with parton CMS energy squared so the deviation from QCD calculation should be pronounced at high $E_t$ region, if there is quark substructure at this energy scale.

In the light of recent development of theoretical calculation [2] , [3] at next-to-leading order (NLO), hadron collider experiments are obliged to refine their jet analysis further. For example the choice of jet clustering algorithm could be studied with NLO calculations. An advantage expected from NLO calculations over leading-order (LO) calculations is that the NLO calculations are less sensitive to renormalization scale $\mu$.

Direct photon analysis in CDF can probe the very low x region of the gluon distribution. In general, photon energies can be measured more precisely than jet energies. There are three diagrams for direct photon production in leading order. These are quark and gluon interaction diagram, quark annihilation diagram and photon radiation from quark. Quarks and gluons in the initial state interaction are predicted to dominate at the CDF CMS energy.

## 2 Jet Measurement

A description of the CDF detector can be found elsewhere [4]. There were three triggers based on cluster energy for jet events. Transverse cluster energies greater than 20, 40 and 60 GeV are triggered on. The first 2 triggers are prescaled by factors of 300 and 30 to reduce the trigger rate to an acceptable level. Also events with sum of $E_t$ greater than 120 GeV in calorimeter cells are triggered. The response of the calorimeters are measured using $\pi^\pm$ and $e^\pm$ test beams and isolated charged tracks in real data for low energy response. The response of the calorimeters over the range from 500 MeV to 225GeV in energy and position dependence were mapped out.

Since a jet is a combination of charged and neutral

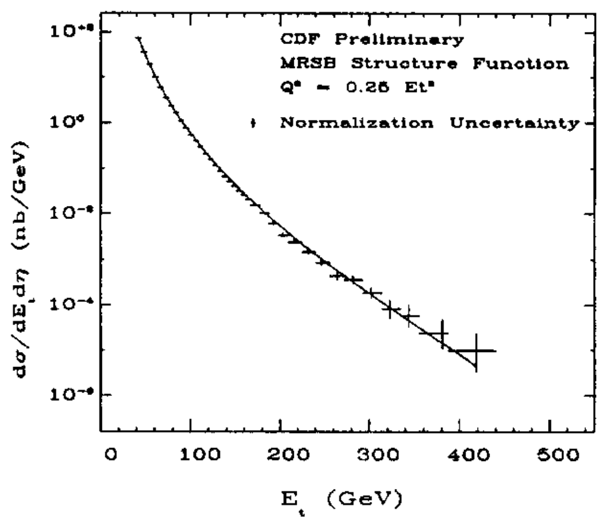


Figure 1: The inclusive jet cross section from CDF compared to the Next-to-leading order calculation. The theoretical curve is normalized to data points. Only statistical errors are shown for the data.

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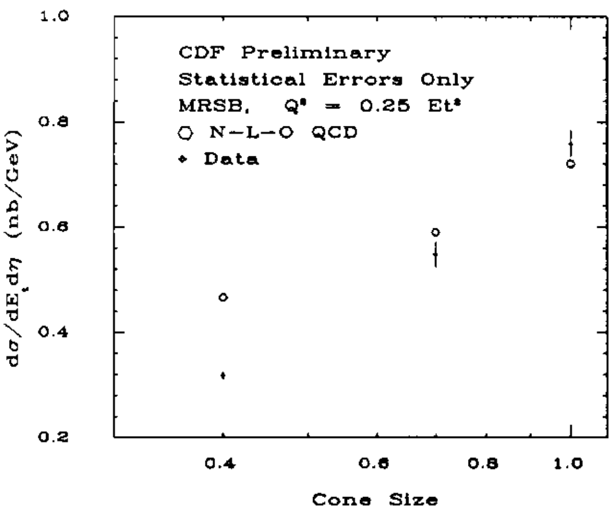


Figure 2: The inclusive jet cross section at $E_t$ =100 GeV with three cone sizes used in the jet clustering algorithm. Circles are from NLO calculation and compared with CDF data.

particles with a broad range of momenta, we correct jet energy according to a Monte Carlo simulation of detector response. This has a tuned fragmentation function along with a known single particle response of detector. Tuning of the fragmentation function[5] was performed by comparing Monte Carlo data with CDF data. In central region, jet $E_t$ resolution is about 10% of $E_t$ in the range of 30 GeV to 400 GeV excluding $3 \sim 4$ % of energy scale uncertainty.

In CDF we use a fixed cone algorithm to define jets. The cone is defined by $\sqrt{\Delta\eta^2 + \Delta\phi^2} \leq R$, where $\Delta\eta$ and $\Delta\phi$ are $\eta$ and $\phi$ intervals from calorimeter cell positions to jet centroid, and R is the cone size. In the following analysis we use a cone size of R=0.7 unless otherwise specified. There is some advantage in using a fixed cone algorithm over some other algorithms, as it is easier to directly compare with theoretical calculations [2]. Jet clustering in CDF is done in the following way. First a seed tower with measured transverse energy, $E_t$, greater than 1 GeV was found. The centroid is determined through iterative procedure. The cluster energy is a scalar sum of tower energies with $E_t \geq 0.2GeV$ in the cone. If two cones share more than 50% of their energy, they are merged together. Common cells of unmerged cones are assigned to the nearest cluster.

## 3 Inclusive Jet Analysis

Inclusive jet production here is the process of $p\bar{p} \rightarrow$ JET + X. The corrected jet $E_t$ spectrum is compared with the NLO calculation in figure 1. In this measurement jets are required to be in the central region $(0.1 \leq \eta \leq 0.7)$ with the event vertex within 60 cm of detector center along the beam axis. Cosmic ray bremsstrahlung were removed by rejecting jets with a) showers out of time with the beam crossing, with b) unrealistic shower deposition and c) events with large missing $E_t$ . QCD predictions agree quite well with data over 7 orders of magnitude in cross section.

In extracting the inclusive jet $E_t$ spectrum an unsmearing process was applied. The unsmearing procedures can reproduce the original $E_t$ spectrum from an uncorrected $E_t$ spectrum. We correct the $E_t$ spectrum using known distributions of calorimeter response.

The NLO calculation predicts the cone size dependence of the inclusive jet cross section. Cone sizes were set at 0.4, 0.7 and 1.0 for this study. In figure 2, a comparision between theory and data is made at a fixed $E_t$ of 100 GeV. The measured points show a steeper dependence on cone size than the theoretical predictions.

In figure 3, the theoretical curves of the LO calculation and the measurement are compared using structure functions from EHLQ I [6] with $Q^2$ scale of 0.5 $E_t^2$. The solid curve is the QCD prediction and dotted line includes the effect of quark compositeness term with $\Lambda^*$ equals 950 GeV. The theoretical curves are normalized by fitting with data from 80 to 160 GeV where the quark compositeness term is small. The measurement is consistent with a limit of $\Lambda^* \geq$950 GeV [7].

## 4 Dijet Analysis

This analysis is also sensitive to quark compositeness. Additional cuts are applied for dijet event selection. Two leading jets are required to be in the central region $(\eta \leq 0.7)$ and a loose cut is applied by requiring that the two

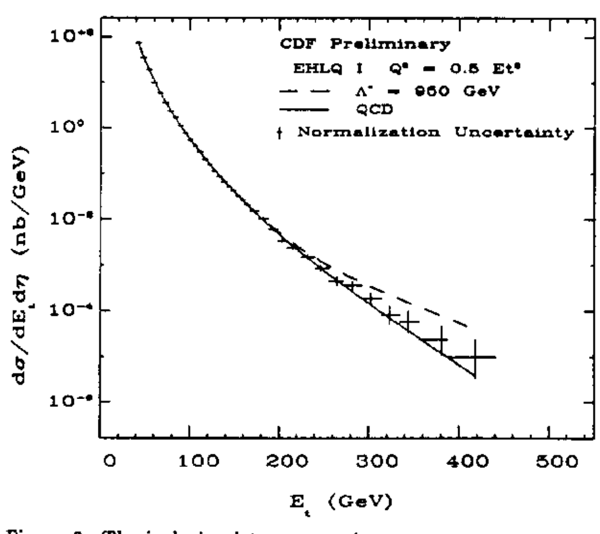


Figure 3: The inclusive jet cross section measurement compared with QCD(solid line) prediction and with a quark compositeness scale of 950 GeV(dotted line). Only statistical errors are shown.

triangular area. At the left corner of the distribution all three jets have same energies. The upper right corner is a region near infrared divergences where two leading jets take almost all of the energy and the least energetic jet has very little energy. The bottom right corner is a region near a collinear divergences where the two least energetic jets are parallel. Projection of the $x_3$ and $x_4$ distributions are also shown. Dotted lines are from a phase space calculation. The $x_3$ distribution is rising fast above 0.8 because of singularities in the theory. The data clearly favour the QCD predictions.

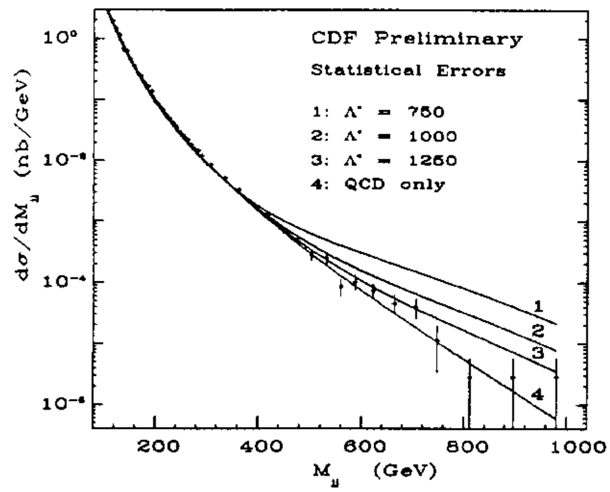


Figure 4: Dijet invariant mass spectrum compared with four theoretical curves using different compositness scale assumptions.

leading jets be back to back in azimuth ($\Delta\phi = 180^o \pm 15^o$).

The dijet mass spectrum is shown in figure 4. The four curves are correspond to theoretical calculation with $\Lambda^*$ values of 750 GeV, 1000 GeV, 1250 GeV and QCD only. In this plot we use structure function of Duke and Owens [8] with $Q^2$ scale of$E_t^2$. The measurement is consistent with the previous limit from preliminary CDF result of $\Lambda^*$=950 GeV [9].

## 5 Trijet Analysis

In $p\bar{p}$ collisions at CDF, three jet production is predominantly from a gluon emitted by gluon or quark. The study of the three jet system can allow us to look into details QCD processes of $gg \to ggg$, $qq \to qqg$ and $gq \to ggq$. For example the infrared or collinear divergent part can show up near kinematic limits.

Events satisfying the total sum trigger were used for this analysis. Cuts were made to produce a flat acceptance for the kinematic variables. We require that each of the three jets be less than 3.5 in $|\eta|$ and have a $E_t$ larger than 10 GeV. The mass of the three jet system is required to be greater than 260 GeV. Also other fiducial cuts on CMS angles are made. The three jets are ordered in energy in the center of mass system and labeled jets 3, 4 and 5. The kinematic variables $x_3$, $x_4$ and $x_5$ are the fractional energy in CMS and are defined as:

$$x_i = \frac{2 \cdot E_i}{M_{3jet}} ,$$

where $M_{3jet}$ is the invariant mass of the 3 jet system.

A Dalitz plot of two kinematic variable $x_3$ and $x_4$ is shown in figure 5. Phase space is uniform over the whole

## 6 Direct Photon Analysis

In CDF we have two methods in identifying direct photons from $\pi^o$ and $\eta$ decays. The first uses a shower profile measurement with sets of wire chambers at 5 radiation lengths in the electromagnetic calorimeter. With the known shower profile of $\gamma$ from test beam $e^{\pm}$ data and background from Monte-Carlo analysis, we can estimate efficiencies for $\gamma$ and background.

Secondly, a conversion method was used to identify direct $\gamma$ 's using drift tubes in front of the coil. The amount of conversion material is about 18% radiation length overall. $\gamma$ 's converted in the material are detected in central drift tubes. For a single $\gamma$ the conversion probability is $10 \pm 2\%$ and roughly twice for $\pi^o$ which decays to two $\gamma$ 's. This method is less dependant on $E_t$ , but is limited by low statistics. More detailed description of these methods are in reference [10].

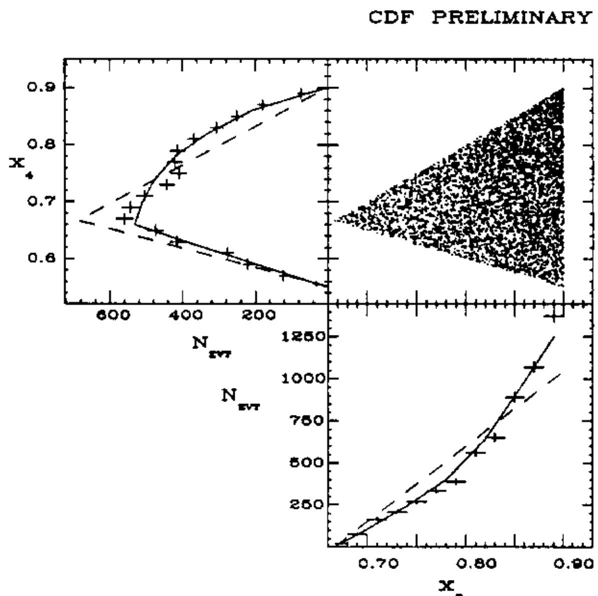


Figure 5: Dalitz plot and projections of variables $x_3$ and $x_4$. Pure phase space would have a uniform distribution on the scatter plot. Dashed lines on projected plots are shape from phase space and solid lines are from QCD calculation.

$\gamma$ 's are triggered when there is an isolated eletromagnetic cluster. Two triggers were implemented for direct photon events. One at a $E_t$ threshold of 10 GeV (prescaled) and the other is at 23 GeV without prescale. The isolation requirements are necessary to reduce background from jets with high electromagnetic content. In the analysis, fiducial cuts are made to insure a good shower shape. A requirement of no track pointing to the electromagnetic cluster is made as well as vertex Z value less than 50 cm. A partial data sample was analysed with 45 $nb^{-1}$ for $E_t$ threshold of 10 GeV and 1.6 $pb^{-1}$ for $E_t$ threshold of 23 GeV so far.

The cross section of direct $\gamma$ 's is shown in figure 6. The measurement points with circles are from the shower profile method and triangular points are from the conversion method. The systematic uncertainties for overall scales are also shown for the both methods. The large systematic uncertainly for conversion method is mainly coming from the uncertainty of detection efficiency of converted $\gamma$ 's.

The theoretical curves are from three different structure functions [11] with $Q^2$ scale is set equal to $E_t^2$ using next leading order calculation. The theoretical curve at high $E_t$ fit very well with data while there is some excess of signal at low $E_t$ . The excess at low $E_t$ is still under investigation.

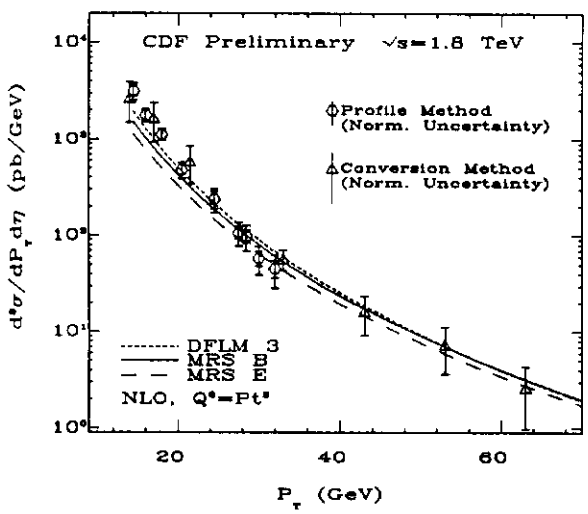


Figure 6: Inclusive direct photon cross section from two the independent methods explained in text. Circles are from the shower profile measurement and triangles are from the converted photon measurement.

## 7 Conclusions

The effect of the cone size of the jet clustering algorithm has been measured. The data show a steeper dependence on cone size than the NLO calculations. The inclusive jet cross section measurement matches very well with QCD calculation for 7 orders of magnitude. The dijet invariant mass distribution agrees well with QCD predictions also. From these two cross section measurement we can conclude that the quark compositeness scale is consistent with limit of $\Lambda^*$ 950 GeV. The direct $\gamma$ cross section agrees with QCD predictions reasonably well with some excess at low $E_t$ .

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