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QCD Tests and New Physics Search with Jets at CDF

Anna Maria Zanetti
for the CDF Collaboration

Fermi National Accelerator Laboratory
P.O. Box 500, Batavia, Illinois 60510

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QCD TESTS AND NEW PHYSICS SEARCH WITH JETS AT CDF

The CDF collaboration
Anna Maria Zanetti
Istituto Nazionale di Fisica Nucleare
Area di Ricerca - I34012 Trieste, Italy

Abstract

The dijet invariant mass spectrum at a center of mass energy $\sqrt{s} = 1.8$ TeV measured at the Tevatron Collider by CDF in the 1988-1989 run is presented. Comparison with leading order and next-to-leading order QCD theoretical calculation is performed. A search for a possible quark compositeness and for axigluons, while not showing evidence for new physics, allows one to put limits on the compositeness mass scale Λ_c and on the axigluon mass M_a.
Preliminary results for the inclusive jet and the total transverse energy cross section from the high statistics data collected in the present run are shown.

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1 Introduction

Jets arise from the hard scattering of the elementary constituents of hadrons, providing a powerful tool to quantitatively test our level of understanding of perturbative QCD and to search for a breakdown of the Standard Model.

At CDF, jets are measured in a large range of transverse energy (E_T), namely from $20\,GeV$ to over $400\ GeV$, making possible the study of jet cross sections over several orders of magnitude. Furthermore, our ability to look for signatures of possible new physics has profited from such large values of the measurable jet energies.

On the theoretical side, in the last years major improvements have been pursued in the QCD calculations of jet cross sections. The next-to-leading order (NLO) predictions recently computed exhibit a dependence on the jet definition and a lower sensitivity on the choice of renormalization scale compared to the leading order (LO) calculations resulting in a much reduced uncertainty on the cross section [1, 6].

2 Jet identification

A reliable comparison between perturbative QCD calculations and the experimental measurements requires a jet definition easy to implement and as similar as possible on both sides. In the results here presented, jets are identified via the fixed-cone clustering algorithm suggested by the *Snowmass Accord* (for details see ref.[2]). The cone is defined in the (η, ϕ) space by fixing the radius R = $\sqrt{\Delta\eta^2 + \Delta\phi^2}$, where $\eta = -ln[tan(\theta/2)]$ is the pseudorapidity, ϕ is the azimuthal angle and θ is the polar angle.

To ensure a full containment of the jet energy in the CDF detector [3], the primary event vertex is required to be within 60 cm from the center of the detector along the beam direction. No correction for the energy lost outside of the clustering cone and for the energy associated with the underlying event has been applied.

3 Dijet Mass Distribution

The differential production cross section of the process $p\bar{p} \to jet+jet+X$ has been measured as a function of the invariant mass of the two leading jets (M_{jj}) for an integrated luminosity of 4.2 pb^{-1} . Two cone sizes, R = 1 and R = 0.7, have been used; the jet pseudorapidity is required to be in the interval $|\eta| < 0.7$.

The main contributions to the systematic error on the cross section come from the uncertainties in the integrated luminosity, in the fragmentation tuning and in the calorimeter response [4]. These errors and their point to point correlations have been taken in account.

Comparison to leading and next-to-leading order QCD, a search for quark compositeness and for axigluons are reported in the next sections. A model independent study of the production of new particles decaying to two jets has been carried out as well (see ref.[7]).

3.1 Comparison to QCD

The leading order QCD predictions for recent structure function parametrizations (HMRS, MT, DFLM [5]) and for five values of renormalization scale in the range $p_T/2 < \mu < 2p_T$ have been folded with the detector resolution and compared with the observed M_{jj} spectra. Almost all the LO theoretical prediction are rejected at 95% C.L. for a cone size R = 0.7, while the agreement is good for R = 1.

The QCD predictions at order α^3 [6], that recently have become available for HMRSB and for MTS1, show an improvement, compared to LO, in the description both of the absolute value and of the shape of the measured cross section. This change in the shape predictions

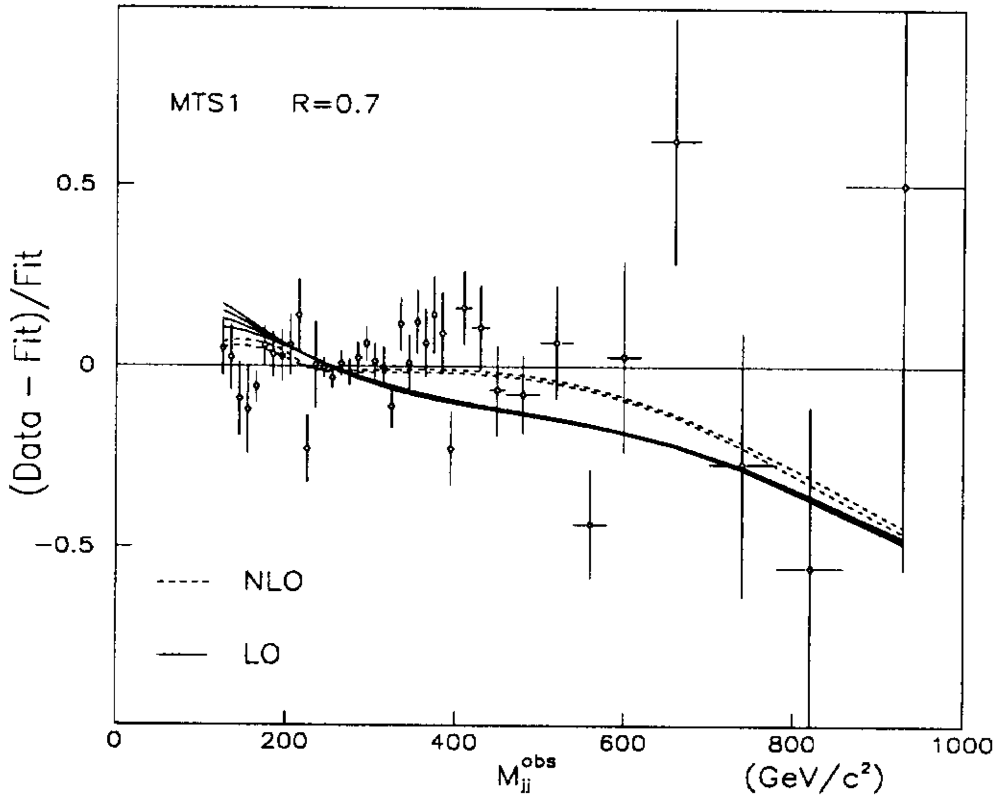

Figure 1: Residuals of data and of QCD theory to the parametric function $f(M_{jj})$ used as reference (horizontal line). The errors on the data points are statistical only.

can be seen from fig.1 where the residuals of the data and of the theory (LO and NLO) to the best fit of a parametric function $f(M_{jj})$ are shown for the MTS1 structure function and for different renormalization scales. The fitted function has the form $f(M_{jj}) = aM_{jj}^{-b}e^{-cM_{jj}}$

and has been folded with the detector resolution; the QCD predictions are fit to the data allowing for a free normalization factor. Data agree with NLO QCD (for MTS1) at 95% C.L. both for R = 0.7 and R = 1. For the HMRSB structure function a smaller change in the shape prediction is observed when using the NLO calculations.

3.2 Compositeness

The existence of a quark substructure should manifest itself at energies well below the characteristic energy scale (Λ_c) of the new strong interaction between the constituents. This low energy effect can be parametrized by the addition of a four-fermion contact interaction to the QCD lagrangian [8]:

$$\mathcal{L}_{int} = \frac{4\pi}{\Lambda_c^2}\,\overline{\psi}\gamma_\mu\psi\overline{\psi}\gamma^\mu\psi$$

that, if present, would lead to an increase of the cross section in the high mass region of the M_{jj} spectrum.

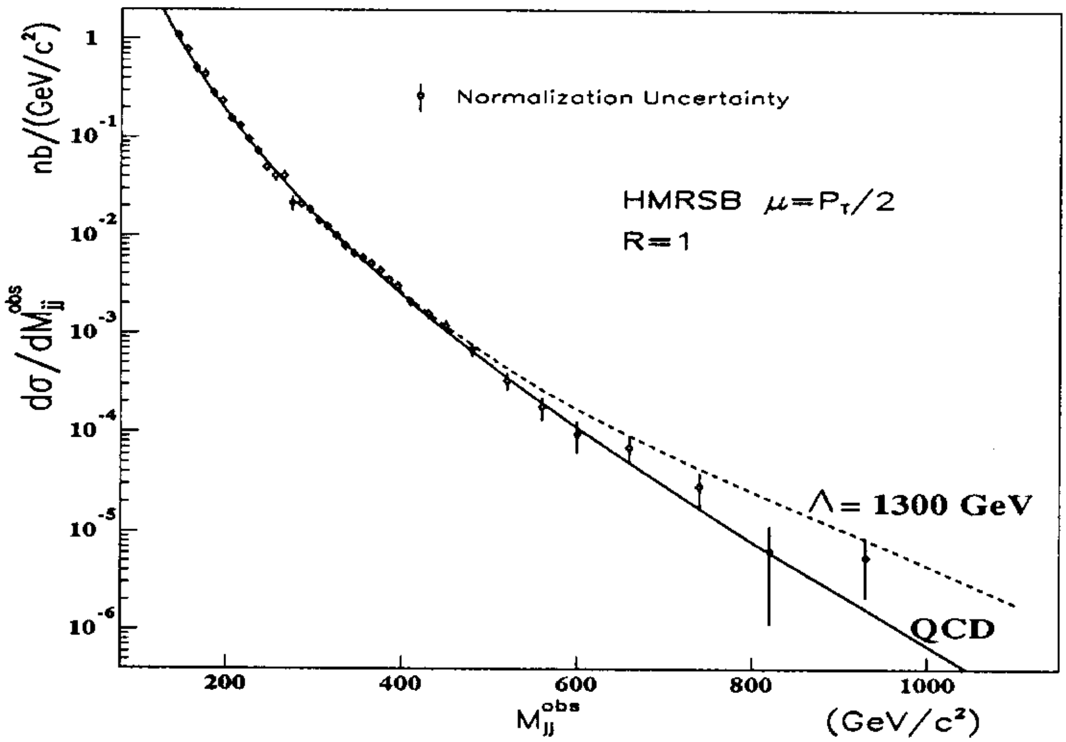

Figure 2: Dijet mass distribution. The error bars represent the statistical errors and the M_{jj}-dependent part of the systematic errors combined in quadrature.The QCD and the compositeness predictions for $\Lambda_c = 1300\ GeV$ are shown.

In this analysis, a clustering cone radius R = 1 is used; the QCD background is described by the leading order calculations and it is normalized to the data in the region $160 < M_{jj} < 300\ GeV$, where no substantial deviation from QCD due to compositeness is expected. The measured excess number of events with respect to the QCD background having $M_{jj} >$

580 GeV is compared with the prediction for composite quarks. The limits on Λ_c at 95% C.L. for different structure functions and renormalization scales are obtained: it can be concluded that $\Lambda_c > 1300$ GeV (fig.2). A more stringent limit on Λ_c of 1400 GeV has been set from the inclusive jet cross section analysis [9].

3.3 Axigluons

The idea that the hadronic sector may not be completely described by color SU(3) has brought, for instance, to the introduction of the 'chiral color' and many models have been proposed [10]. A common prediction of all these models is the existence of an octet of massive coloured vector bosons, the so called *axigluons*. These are characterized to be strongly coupled to quarks, to decay in $q\bar{q}$ and to have a width proportional to the mass of the axigluon. As such they would appear as a pronounced jet-jet resonance in the dijet mass spectrum.

At CDF this search has been pursued comparing our data with a theoretical prediction obtained summing coherently to QCD the axigluon amplitudes [11], convoluted with the structure functions. The excluded axigluon masses are shown in table 1 for two values of N, the number of open decay channels of the axigluon.

	$N = 10$	$N = 20$
MT B2	$240 \leq M_a \leq 730$	$260 \leq M_a \leq 280 - 420 \leq M_a \leq 580$
HMRS-B	$220 \leq M_a \leq 640$	$240 \leq M_a \leq 330 - 450 \leq M_a \leq 550$

Table 1: Axigluon masses (GeV/c^2) excluded by CDF data.

4 New results from 1992-1993 run

The increased luminosity of the Tevatron collider with $L = 0.5 \times 10^{31} cm^{-2} sec^{-1}$ as a typical value, is providing us with a high statistics data sample that allows more precise tests of QCD and of other theoretical models to be performed. So far, an integrated luminosity of 20 pb^{-1} has already been collected by CDF and it is foreseen to match the goal of 100 pb^{-1} within the next year.

Preliminary results for the inclusive jet and the total transverse energy cross sections are presented.

4.1 Inclusive jet cross section

The differential production cross section as a function of the E_T of the leading jet in the process $p\bar{p} \rightarrow jet + X$ has been measured for a cone radius $R = 0.7$. Jets are restricted to the

central pseudorapidity interval $0.1 \leq |\eta| \leq 0.7$. For $E_T > 160\ GeV$ the processed data sample corresponds to an integrated luminosity of 9 pb^{-1} while for lower E_T it varies from 4 to 5 pb^{-1} (depending on trigger requirements). The observed inclusive jet spectrum has been corrected for energy loss and resolution effects and compared on absolute scale to the NLO QCD calculation [1] for the HMRSB structure function and the renormalization scale $\mu = p_T$ (fig.3). A compositeness prediction for a mass scale $\Lambda_c = 1000\ GeV$ is plotted as well. The error bars on the data points represent the statistical uncertainties on the cross section.
On a qualitative ground, the agreement between the QCD theoretical curve and the data over nine orders of magnitude in cross section is impressive.

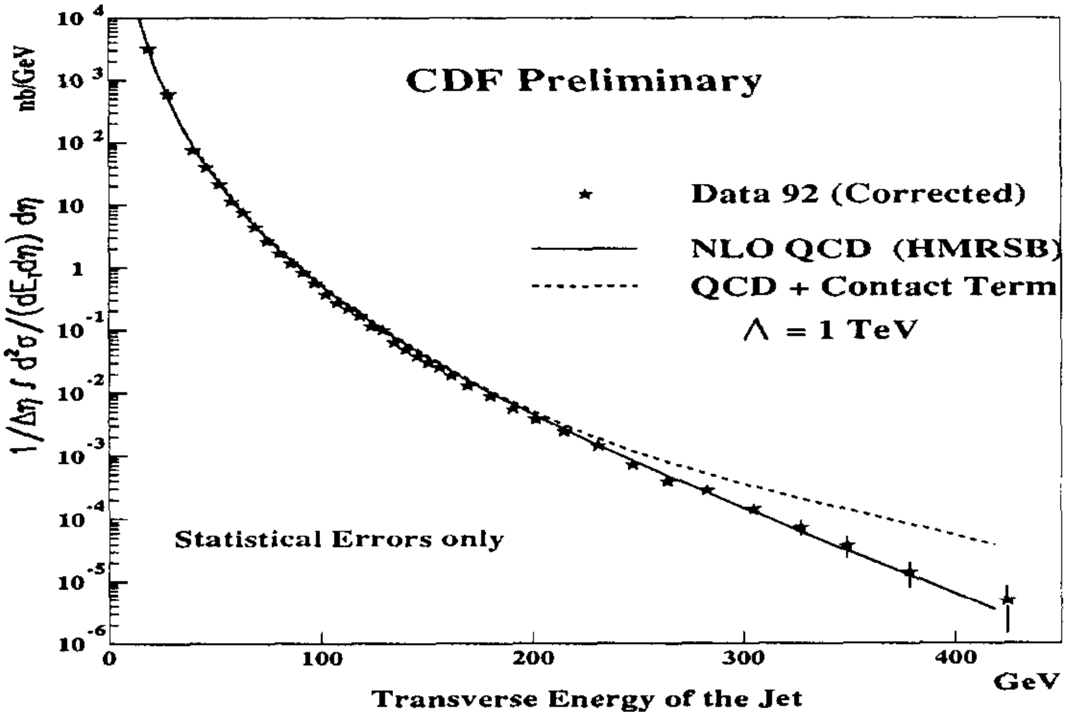

Figure 3: Inclusive jet cross section.

4.2 Total transverse energy cross section

It is interesting to check if the rate of the "hottest events" produced by CDF are consistent with the LO QCD expectations.
In the whole CDF detector, the sum of the transverse energy ($\sum E_T$) over the calorimeter energy clusters that exceed $10\ GeV$ is performed. Events satisfying the requirement $\sum E_T > 320\ GeV$ are retained. Additional cuts have been applied to remove the background that is mainly due to high energy cosmic-rays and beam halo particles interacting in a calorimeter. The HERWIG Monte Carlo [12] is used to generate events with the p_T of the two outgoing partons greater than $100\ GeV/c$. The QCD predictions are obtained processing the Monte Carlo generated events (10 pb^{-1} for the MT and the 5.3 pb^{-1} for the CTEQ structure

function) through a full simulation of the CDF detector.

The uncorrected $\sum E_T$ cross section for an integrated luminosity of 12.26 pb^{-1} is then compared in fig.4 with the QCD predictions.

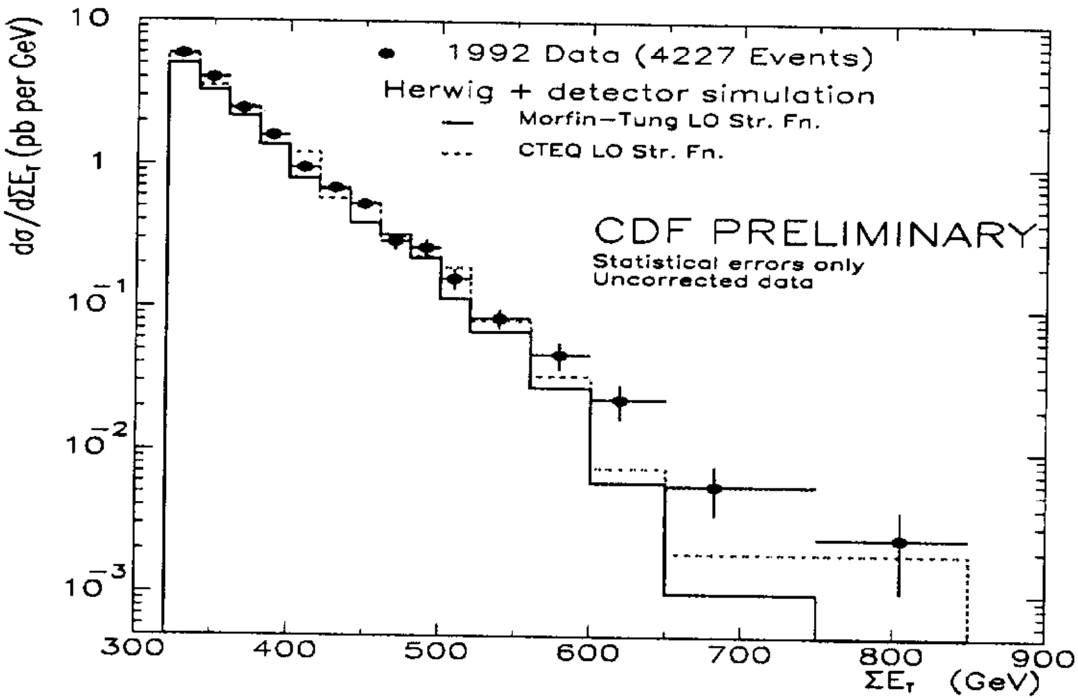

Figure 4: Total transverse energy cross section.

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