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QCD Tests at CDF

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1 Introduction

Jet measurements at CDF provide the possibility of exploring new physics beyond the Standard Model and supply a rich testing ground for the properties of QCD. Cross section measurements at the highest available jet E_T are potentially sensitive to the production of new particles or to the presence of quark substructure; deviations from the QCD predictions may signal the onset of new physics. Within the framework of conventional QCD, jet measurements can be used to extract fundamental QCD parameters such as α_s. Large datasets with good statistics over a large kinematic range can be combined with the improved theoretical calculations to yield precision tests (at the 10–20 % level) for both next-to-leading order (NLO) QCD matrix-element calculations and Parton Shower (PS) models of QCD. Owing to the sensitivity of jet production on the gluon distribution, these data provide direct constraints on the gluon distribution in the range $10^{-3} \lesssim x \lesssim .5$.

Many QCD analyses are being pursued at CDF. Inclusive, two-jet and multijet differential cross section and angular-distribution measurements test the detailed predictions of perturbative QCD. Photon cross section and angular-distribution measurements provide further tests and additional constraints on the gluon distribution. Studies of heavy flavor production inside jets and in association with photons yield information on gluon splitting and the heavy-flavor content of the proton. Studies of jet production in association with W's and Z's provide complementary tests of QCD and parton distributions. Finally, the diffractive and soft regions are probed by the study of events with rapidity gaps. In this talk, we will concentrate on inclusive single-jet and dijet production, with particular emphasis on the observed excess of events at high E_T.

2 Jet Measurements

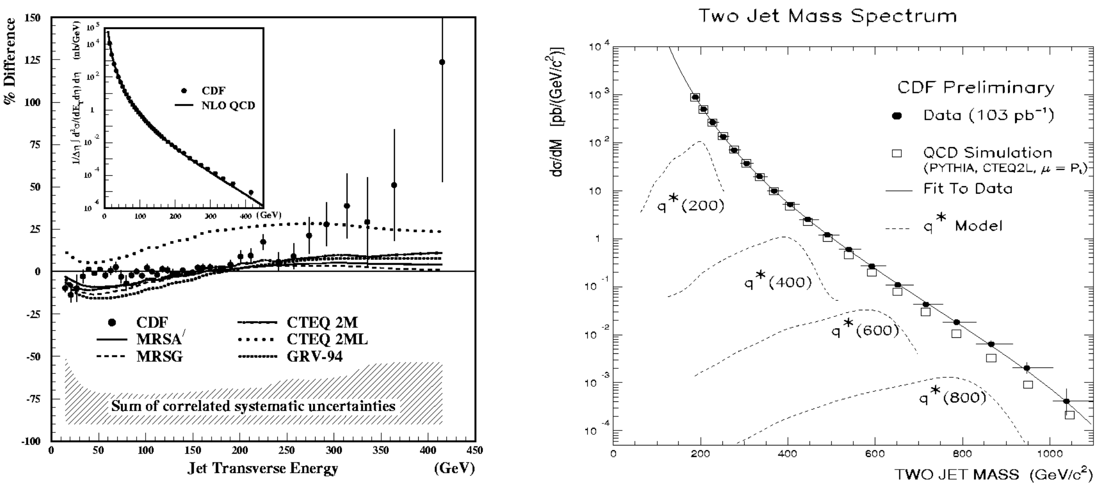
2.1 The Inclusive Jet Cross Section

The single-jet inclusive cross section is a probe of new physics at the highest available energies. The measurement provides a stringent test of NLO ($O(\alpha_s^3)$) QCD calculations over a huge dynamic range and can be incorporated into a global parton distribution analysis to provide a direct constraint on the gluon distribution for the x range $10^{-2} \lesssim x \lesssim 0.5$.

The measurement$^{1)}$ is based on $19.5 pb^{-1}$ of data, recorded by the CDF detector$^{2)}$ during the 1992-93 (Run 1A) Tevatron $p\bar{p}$ collider run at $\sqrt{s} = 1800$ GeV. The data were collected using triggers with E_T thresholds of 20, 50, 70 and 100 GeV. These triggers were prescaled by factors of 500, 20, 6 and 1 respectively. Minimum bias data were used for the measurement in the jet E_T range 15-25 GeV. Jets were reconstructed using a cone algorithm with a cone-radius R given by $R \equiv \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2} = 0.7$. Here, $\eta = \log(\tan(\theta/2))$, where θ is the polar angle with respect to the beam line and ϕ is the azimuthal angle around the beam. Jets were further required to lie in the pseudorapidity interval $0.1 \leq |\eta_{jet}| \leq 0.7$. The measured E_T spectrum is corrected for detector and smearing effects arising from nonlinearities, energy losses and finite energy resolution via an unsmearing procedure.$^{3)}$. A trial true spectrum is smeared by detector effects and compared with the measured spectrum. The procedure is iterated until the best match is obtained.

In Fig. 1a), the corrected cross section is compared with the NLO QCD prediction$^{4)}$ calculated using MRSD0' parton distributions with a renormalization and factorization scale choice of $\mu = E_T/2$. Other parton distribution choices are also shown. Below $E_T = 200$ GeV, there is excellent agreement with the prediction over the six orders of magnitude of dynamic range spanned by these data. Above 200 GeV, there is an excess of events above the NLO QCD prediction.

The systematic errors on the cross section have been evaluated by varying each of the sources of systematic uncertainty by ± 1 standard deviation and repeating the unsmearing procedure. The shaded band in Fig. 1a) shows the sum in quadrature of these errors. No single source of systematic error can account for the excess at high E_T. An attempt to explain the excess as a systematic effect requires the introduction of a large (several sigma) variation in



(a) (b)

Figure 1: A comparison of a) the inclusive jet cross section with the NLO QCD prediction evaluated with MRSD0' parton distributions and b) the dijet mass spectrum with the predictions of PYTHIA and the CDF detector simulation.

least two sources of systematic error in such a way as to obtain a cancellation of effects below 200 GeV and a rising enhancement above 200 GeV.

2.2 The Dijet Mass Analysis

This analysis is of interest because it provides an important cross check of the inclusive jet measurement. Of course, it must be remembered that the two measurements are highly correlated since they have many events in common, particularly at high jet E_T, where the dijet mass spectrum is dominated by events whose pseudorapidities lie in the central regions of the detector.

The results shown here are based on $103pb^{-1}$ of data collected from Run 1A and 1B. The triggers and the jet reconstruction algorithms are identical to those described for the inclusive jet analysis. The dijet mass is defined as the invariant mass associated with 4-vectors of the two highest E_T jets in the event. The jets are required to satisfy $|\eta_1|, |\eta_2| \leq 2.0$, and the events are required to have $\cos\theta^* \leq 2/3$, where θ^* is the center-of-mass scattering angle. This analysis differs from that of the inclusive jets in that the jet energies have been corrected for the calorimeter response but no unsmearing corrections are applied to the spectrum.

In Fig 1b), the measured dijet mass spectrum and the predictions of a LO QCD PS Monte Carlo (PYTHIA) together with a full CDF detector simulation are compared with the best fit to the CDF data. (The QCD prediction is normalized to the data in the mass range 150-300 GeV/c^2.) Once again, there is a clear excess of events above a dijet mass of 400 GeV/c^2. The excess is consistent with that observed for the inclusive jet spectrum. This analysis uses five times more data than the inclusive jet analysis and establishes that the observed excess is not a statistical fluctuation. Furthermore, since no unsmearing corrections are applied to these data, it is clear that the excess cannot be simply a pathology of the unsmearing corrections.

The dijet angular distribution is of particular interest because it is a powerful probe of the jet-production mechanisms and may be sensitive to anomalous jet production arising from new physics. For example, effective models of quark compositeness containing[5)] four-Fermi contact interactions predict a rise in the jet cross section at high E_T that resembles the behavior of the CDF data. However, since these models also predict an enhancement in the isotropic contribution to jet production, the dijet angular distribution can be used to discriminate between conventional QCD and this type of new physics. At present, this analysis is underway; however, until the theoretical uncertainties and the experimental systematics are better understood, it is not possible to make a definitive claim about the presence or absence of new physics.

3 Possible Explanations for the High-E_T Excess

3.1 Sources of Uncertainty on the Cross Section

In this section, we consider the possibility that the explanation for the high E_T excess can be found within the framework of conventional QCD. There are a number of well-known theoretical uncertainties in the perturbative calculations: The dependence on the choices for the renormalization and factorization scale is small, and results in about a 10 % change, with very little dependence in E_T.[4,6)] Changes in the value of α_s that arise from variations of Λ_{QCD}[7,8)] also affect the overall normalization of the cross section rather than its shape. Another possible uncertainty is the effect of resumming large logarithms of x_T. This resummation has a substantial effect on the predictions for Drell-Yan production,[9)] but has not yet been carried out for jet production. One hint that this will not be a large correction for CDF jets comes from an examination of the K-factor (ratio of NLO to LO QCD) as a function of the jet E_T: Typically, divergent behavior of this quantity can signal the need for resummation. In our case, it is well behaved and flat over the entire CDF E_T range. Finally, there are uncertainties arising from the choice of parton distribution function (PDF). As can be seen in Fig. 1a), a variation in the choice from the commonly available sets of PDF gives about 15% variation in normalization, with small shape differences. However, these changes do not reflect the true uncertainty due to PDF choice, since the parametrizations available through the usual PDF sets are limited. We now look in detail at the possibility that the excess can be explained by a new parton distribution.

3.2 A New Gluon Distribution

For a jet E_T in the range 200–400 GeV, the fraction of the jet cross section attributable to quark-quark scattering rises from about 50% to 85%, whereas that attributable to quark-gluon scattering falls from about 40% to 10%. Since the quark distributions are strongly constrained by precise data from deeply inelastic scattering (DIS), one must look to the gluon distribution