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JET PHYSICS AT CDF RUN II

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The latest results on jet physics at CDF are presented and discussed. Particular attention is paid to studies of the inclusive jet cross section using 177 pb^{-1} of Run II data. Also discussed is a study of gluon and quark jet fragmentation.

1 Introduction

Jet production is by far the dominant process at hadron colliders, which makes its understanding very important. First, it allows for precision testing of next-to-leading order perturbative QCD (NLO pQCD) predictions and helps in constraining parameters of the parton distribution functions (PDF). Possible deviations could indicate the presence of new physics. Second, for many new phenomena searches, jet production with its enormous cross-section is a very large background, and thus accurate predictions on jet production will improve our reach for new physics.

While measurements of inclusive jet cross-section tests QCD at very high momenta transfer, jet fragmentation studies probe the soft region. Analysis of the intra-jet properties presents a unique testing ground for resummed pQCD calculations and tests applicability of perturbative methods down to very low scales.

2 Inclusive Jet Cross Section

In Run I, the CDF measurement of the inclusive jet cross section showed an excess of events at very high transverse momentum of the jet [1]. It has been shown later that the excess can be accounted for by increasing the gluon fraction in proton PDF at high x. Run II presents new opportunities for exploring the high E_T domain of the jet production. For reference, the 10% higher center-of-mass energy of the upgraded Tevatron translates into a five times higher inclusive jet cross-section at $E_T \simeq 600$ GeV.

It is important to realize that new physics will exhibit itself primarily in the detector's central region making it difficult to disentangle new phenomena from PDF uncertainties. At the same time, agreement between theory and data in the higher η range most of the time is limited by the accuracy of QCD calculations and PDF uncertainties. Therefore, forward measurements are very important as they provide additional constraints on PDFs. The improved CDF detector provides a reliable measurement of jet E_T spectra in expanded ranges of pseudorapidity. Figure 1a shows inclusive distribution of raw transverse jet energy in bins of pseudorapidity

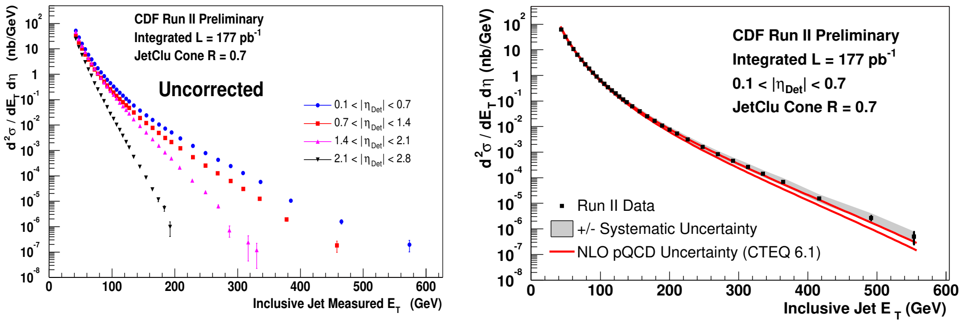

Figure 1. a) The measured inclusive jet E_T distribution for different regions of pseudorapidity; b) Prreliminary measurement of the inclusive jet cross section compared to the NLO QCD expectation determined using the CTEQ 6.1 parameterization of the parton density functions. The variation in the cross section due to the systematic uncertainty is shown as the band. The two lines show the range and uncertainty in the cross section prediction due to the PDFs.

up to $\eta = 2.8$.

Figure 1b shows a preliminary measurement of the inclusive jet cross-section using 177 pb^{-1} of Run II data collected in 2002-2003. Jets are reconstructed using cone algorithm (JetClu, $R = 0.7$, see [2] for details) in the pseudorapidity range $0.1 < |\eta| < 0.7$. Jet energy is corrected for detector inefficiencies and physics effects [3] and the full spectrum is unsmeared to compensate for resolution effects. The data is compared to the NLO pQCD predictions [4] using CTEQ6.1 PDF parametrization [5] and is in generally good agreement with theory. The two lines show the range and uncertainty in the prediction due to limitations in knowledge of the PDFs. The grey band shows the range of the systematic uncertainty of this measurement. It is driven by the accuracy in the knowledge of the jet energy scale. Although it is currently known to about 5%, the exponentially falling shape of the E_T spectrum makes this effect significant. Extensive studies are underway at CDF to further improving this energy scale uncertainty.

3 Charged Particle Multiplicity in Quark and Gluon Jets

In QCD, quarks and gluons have different coupling strengths to emit extra gluons and, therefore, it is expected that jets originating from quarks and gluons should show a difference in the average multiplicities of hadrons.

Quantitative estimations are difficult to make because of the softness of the fragmentation process. Most theoretical predictions are derived in the framework of the Next-to-Leading Log Approximation (NLLA) [6] complemented with the hypothesis of Local Parton-Hadron Duality (LPHD) [7]. In this approach, jet fragmentation is viewed as a predominantly perturbative QCD process. The NLLA calculations give the average number of partons, N_{part}, in a small cone with opening angle θ around jet direction. N_{part} is a function of the scaling variable $Y = \ln(Q/Q_0)$,

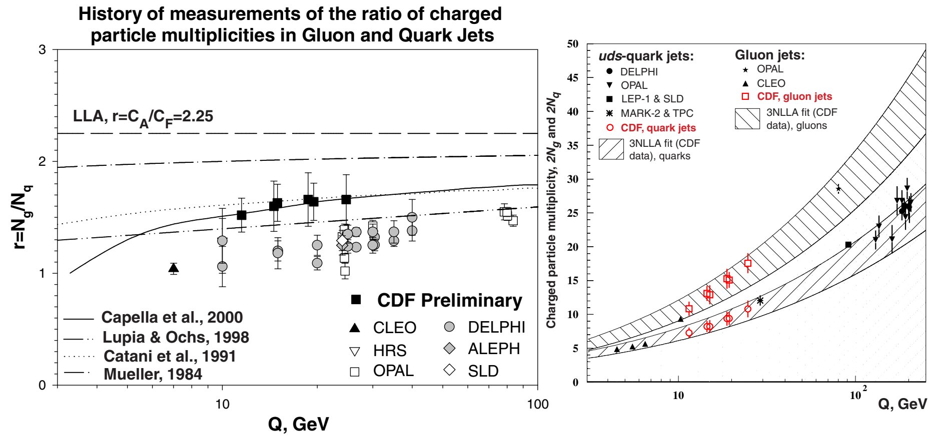

Figure 2. a) Ratio of charged particle multiplicities in gluon and quark jets compared to theoretical predictions and earlier experimental results. b) Charged particle multiplicities in gluon and quark jets obtained for two jet energies of 41 and 53 GeV, and three different opening angles of 0.28, 0.36 and 0.47 rad. Results are compared to other experimental data. The hatched bands show the results of 3NLLA fit to CDF Run I data.

where Q is the jet hardness, defined as $Q = E_{jet}\theta$, and θ is the size of the cone in which partons are counted. Q_0 is the lowest allowed transverse momentum of partons with respect to the jet direction. The LPHD hypothesis assumes that hadronization occurs locally at the end of the parton shower development so that the properties of hadrons are closely related to those of partons. For instance, the hadron and parton multiplicities are assumed to be related via a constant factor $N_{had} = K_{LPHD} \times N_{part}$, which is independent of the jet energy and of whether the jet originates from a quark or a gluon. In this approach, the ratio of hadron multiplicities in gluon and quark jets is the same as the ratio of partons.

Experimental verification of differences between quark and gluon jets has proven to be quite difficult. Early attempts to measure the ratio $r = N_g/N_q$ had large errors and were consistent with unity. Over the 10 year period of LEP era, the reported values of ratio varied from r 1.1 to r 1.5 with typically rather small errors, see Figure 2a). These inconsistencies stem from the necessity to manipulate three-jet events, the only source of gluon jets at LEP. The results turned out to be sensitive to jet definition and event topology. These ambiguities motivate an independent measurement of $r = N_g/N_q$ in a different environment such as in $p\bar{p}$ collisions.

Measurement at the Tevatron has an advantage of having gluon jets and quark jets produced and identified on equal footing. In this recent Run I analysis, two datasets consisting of γ+jet and dijet events are analyzed. These datasets have very different fractions of quark and gluon jets in them: γ+jet events are dominated by quark jets, while jets in dijet events are mostly gluon jets. Events from both datasets are selected in a similar way and divided into two dijet (or γ+jet) mass bins with average jet energies $E_T = 41$ and 53 GeV, measured in the center-of-mass system of two jets (pr photon and jet). Charged particle multiplicity is measured in restricted cones of sizes $\theta = 0.28$, 0.36 and 0.47 rad around jet axis. Using fractions of quark and gluon jets extracted from Monte Carlo, one can obtain the ratio of true multiplicities in gluon and quark jets, r, which is found to be in a good agreement with theoretical prediction and latest LEP results, see Figure 2b).

We further extract charged particle multiplicities for quark and gluon jets separately as shown in Figure 2b. Using these results and the earlier CDF measurement of $Q_{eff} \simeq 230$ MeV [8], we plot the predicted charged particle multiplicities for quark and gluon jet as a function of jet hardness, Q. Fit of the recent 3NLLA prediction [9] to CDF data with the normalization as a free parameter is shown in Figure 2b (band shows the uncertainty). We further compare it to other existing experimental results and find a good agreement between the predictions based on CDF data and a majority of the data from other experiments, except for CLEO.

Conclusion

CDF results presented in this contribution show the enormous success of perturbative QCD. New data being collected in Run II significantly expands the reach for high E_T jets, e.g. even current preliminary results extend 150 GeV beyond Run I. There is a generally good agreement with NLO QCD predictions. With improved systematics, the new data will allow further constraining proton PDF at high x region.

While the inclusive jet E_T measurement emphasizes good agreement with pQCD at very high transverse momenta, studies of jet fragmentation test resummed perturbative QCD at the very soft limit, and again show good agreement with NLLA predictions.

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