Latest Jet Results From the Tevatron
or QCD: Approaching True Precision

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This article summarizes several analyses I discussed at Moriond and I attempt to maintain my speaking voice throughout. I extract several broad themes in the recent development of QCD, and emphasize how the latest results on jet physics reinforce these themes: that QCD is in a transitional stage from providing qualitative descriptions to providing true quantitative descriptions of the results. Certain figures presented in the talk are not reproduced here in the interest of space, but can be found directly in the transparencies available online, or in the references to the refereed journals.

1 Introduction

I have broken my talk into three parts. First come the experimental details that apply at least generally to all the analyses I will discuss. Second, I have a section describing jet quantities and event quantities observed at the two experiments. Finally, I will present a number of cross section results.

Before I begin, I want to outline what I see as a number of shifting paradigms in QCD; that is to say, there are shared traditions in our subfield that must now change. I believe there are four such trends, in both the experimental and theoretical sectors of QCD.

On the theoretical side, a great deal of recent work has focussed on putting error estimates into the parton distribution functions (PDFs). Currently an experimenter performs a data-to-theory comparison many times with different PDF sets. This is certainly not a valid measure of the uncertainty of the predictions. Additionally, there has been some recent progress toward next-to-next-to-leading order calculations (NNLO) of jet cross sections [1]. On the experimental side, CDF and DØ have endeavored to provide a meaningful estimate of systematic uncertainty, generally in the form of a covariance matrix. By quanitfying the correlations of any uncertainty with, for example, jet energy, it is possible to make χ^2 comparisons between data and predictions, and actually quantify the level of agreement or disagreement. Finally, in the future, studies will benefit from much more consistent jet definitions. There is some hope of better underlying event treatment in data and in Monte Carlo simulations. Also, there is an ongoing Jet Algorithms Workshop [2] with the two collaborations trying to eliminate small inconsistencies in their jet algorithms.

All these changes are not iterative so much as transformational. I mention all of this now, not because these four themes will play a central role in the remainder of my talk, but because they are the background over which I paint these experimental results.

2 Experimental Details

Most analyses use a simple cone definition of jets, with a radius $\sqrt{(\Delta\phi) + (\Delta\eta)} = 0.7$. There is a merging and splitting decision, where two jets are merged into a single jet if they share more than a certain fraction of their jet energies. Theoretical predictions require an additional parameter, called $R_{\rm sep}$, to allow parton-level cones to mimic the merging behavior observed at the calorimeter level.

A second algorithm has only recently taken root at Fermilab. This k_T definition of jets [3] has the benefit of simultaneous validity at the calorimeter level, particle level, and parton level. The k_T is the momentum of one object, projected onto the plane that is perpendicular to the other object. In essence, the algorithm combines energy clusters into a single entity if their relative k_T is smaller than some scaling parameter D, where $D = 1.0$ or 0.5 in the present work. One may also define subjets by rerunning the algorithm on each jet individually with a resolution parameter, $Y_{\rm cut}$, which prevents clusters with relatively large separation (but still within D) from being merged.

Jet selection criteria at both experiments are largely the same, without regard to algorithm. Without becoming entangled in specifics, suffice it to say that it is relatively easy to separate jets from electrons, photons, and noise. The cuts are at least 97% efficient, with a purity so high that we cannot measure any contamination (estimated at less than 0.5%).

The jet energy correction has three major parts. First, the offset correction removes from a jet any noise or energy contributions from the underlying event. Second, the calorimeter response correction restores the average energy losses due to cracks in the calorimeters and the losses due to the non-linear energy deposition of low momentum particles. Lastly, the showering correction removes a subtle effect at the cone boundary, where particles that lie inside the $R = 0.7$ cone prior to hitting the calorimeter, deposit some of their energy outside the cone solely because of interactions in the material of the calorimeter. Collectively, these three corrections are called the jet energy scale, and further discussion may be found in DØ[4] and CDF[5] references.

In the case of jet cross sections, or any rapidly-changing distribution, fluctuations in jet energy result in a large smearing effect. The correction is estimated using either the balancing of p_T in dijet events or through Monte Carlo simulation.

3 SubJets and Event Quantities

DØ uses the k_T algorithm to identify subjets in data collected at its two center-of-mass energies of 630 and 1800 GeV. Hypothesizing that the multiplicity of subjets for quark parents differs from that of gluon parents, the expected subjet multiplicity M can be expressed as

$$\langle M \rangle = f_g M_g + (1 - f_g) M_Q$$

where f_g is the fraction of gluons in the final state provided by PDFs and Monte Carlo simulation. Using jets of like energy in both data sets, and the assumption that M_g and M_Q depend only on

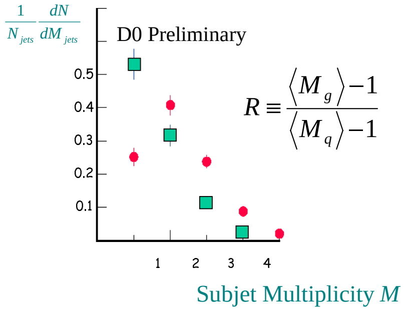

Figure 1: Extracted probabilities of observing M subjets for quark-like jets (squares) and gluon-like jets (circles) at 60 GeV.

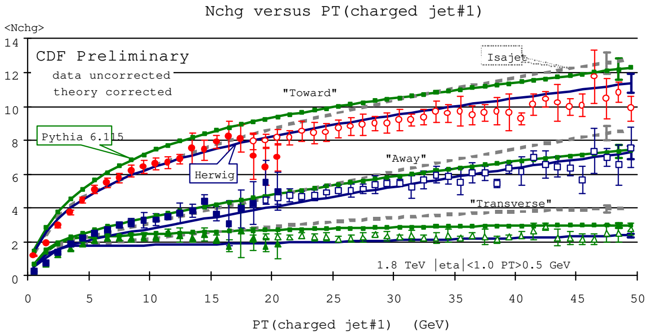

Figure 2: Ability of simulations to model observed charge track distributions.

jet energy (not center-of-mass energy), one extracts the multiplicities characteristic of the two partons. Taking the ratio, DØ finds

$$R = \frac{\langle M_g \rangle - 1}{\langle M_Q \rangle - 1} = 1.91 \pm 0.04(\text{stat}) \pm \begin{matrix} 0.23 \\ 0.19 \end{matrix} (\text{sys})$$

The prediction from Herwig is $R = 1.86 \pm 0.08(\text{stat})$. Figure 1 provides the spectrum of multiplicities. Although there has not yet been any attempt to create a "gluon likelihood" function based on these results, one could imagine significant background reduction in future analyses if jet parents could be tentatively identified on an individual basis.

At CDF, the central tracker provides a count of charged particles as a function of p_T and as a function of position relative to the leading jet. Within broad sectors, toward, away from, and transverse to the leading jet, the Monte Carlo generators predict the numbers of particles, with varying degrees of success. The simulations are each subdivided into three contributions, which are reweighted to yield the closest possible agreement with the data. Figure 2 displays the data (points) and the reweighted predictions (lines) in the three geometric sectors. The information in this figure is densely packed, exhibiting comparisons to all three Monte Carlo generators simultaneously. The results of this analysis can significantly improve the modeling of the underlying event and of low p_T physics.

At high transverse energies, NLO QCD is generally in good agreement with collider data. At low E_T however, QCD underpredicts the number of 3-jet and 4-jet events observed by DØ. The results, shown in Figure 3, debut here at Moriond. Simple DGLAP treatments suppress events with large numbers of jets, suggesting a higher order or BFKL-augmented prediction might provide better agreement. Ongoing studies of the angular distributions of these multijet events should provide an additional handle on the reason for the underprediction of NLO QCD.

4 Cross Sections

At Moriond, I promised and delivered a host of cross section results in this section. During the talk, I showcased several recently published and recently submitted analyses, but have space to only mention them here. From DØ, there were three new PRL's: the so-called R32 analysis, [6] the ratio of dimensionless cross sections, [7] and the inclusive jet cross section in DØ's full pseudorapidity range. [8] Just submitted to PRD were CDF's central $(0.1 < |\eta| < 0.7)$ inclusive jet cross section [5] and DØ's tour-de-force of four jet analyses and a full description of their covariance matrix techniques. [9] All of these analyses benefit from a rigorous treatment of experimental errors that makes possible meaningful χ^2 comparisons.

Finally, I present the inclusive k_T jet cross section. This analysis also makes its debut here at Moriond. The preliminary results differ from the cone-jet analogue by 20% or more, with some

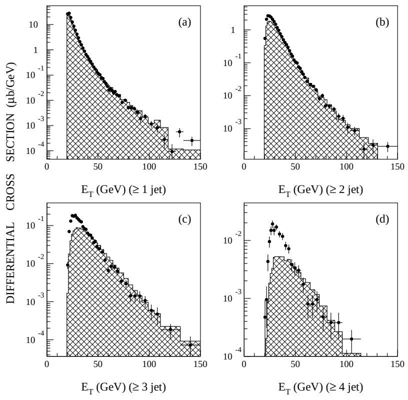

Figure 3: Data (points) and Pythia predictions (hatched) for the E_T spectra of njet events.

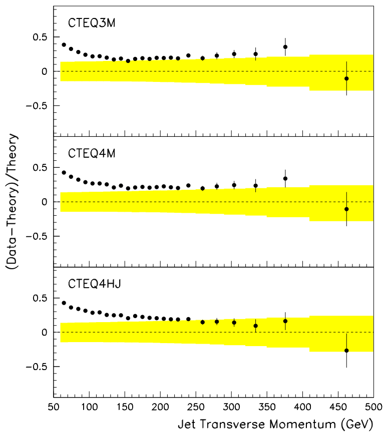

Figure 4: Preliminary (Data$-$Theory)/Theory, for k_T jet inclusive cross section and three NLO QCD predictions.

p_T dependence. DØ has an error matrix and expects to make χ^2 numbers available in the near future. There are no "significant" deviations between data and theory (Figure 4), but credibility demands further qualification: the entire distribution exhibits better than, say, 2σ agreement, with most deviations occuring at low p_T. DØ is exploring several possible reasons for the behavior at the low end of the spectrum, which include the treatment of underlying event and the effect of final-state hadronization on reconstructed energy.

5 Summary

The Tevatron stopped running in 1996, but there are still several interesting analyses in the queue. I have presented the latest results on jet substructure, underlying event structure, multijet topology, and numerous cross section measurements. I emphasize the underlying themes of these results, which are an increased consistency between the jet algorithms of different experiments, the extended use of error matrices to quantify results, and continuing work on improving the corrections applied to the jet data. I hope you agree that these changes, and similar advances in the theoretical sector, are not merely incremental improvements; instead, I believe that the study of QCD is turning into something quite different than it was, and within a very short time we will all be talking about the latest *precision* studies in QCD.

References

1. See talk and paper from Nigel Glover, same Moriond session.
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