MULTIJET PRODUCTION AT DØ

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We describe studies of jet production in $p\overline{p}$ collisions at $\sqrt{s} = 1.8\,\mathrm{TeV}$. We have investigated topological distributions in inclusive three and four-jet events and find them to be well-described by tree-level QCD matrix elements and also by the HERWIG Monte Carlo. We have measured the ratio of inclusive three-jet to two-jet cross sections as a function of summed jet transverse energy. This is found to be in good qualitative agreement with QCD; the data show some preference for a softer renormalization scale for emission of the third jet.

1 Outline

We describe studies of topological variables in inclusive three and four-jet events, and a preliminary study of the inclusive three-jet to two-jet production ratio. These analyses exploit the large dataset and excellent calorimetry of the DØ detector at the Fermilab Tevatron Collider to test and explore QCD in $p\overline{p}$ collisions at $\sqrt{s} = 1.8\,\mathrm{TeV}$.

2 Topological Distributions in 3 and 4-jet Events

This analysis [1] tests QCD at higher orders ($\geq \alpha_s^3$) in a way which is complementary to measuring cross sections. The large pseudorapidity coverage of the DØ detector enables previously untested regions of phase space to be explored. The data will be compared with the expectations of:

- pure phase space, which was generated using the PAPAGENO [2] generator with a constant matrix element;
- tree level QCD, as implemented in the NJETS [3] program;
- the HERWIG 5.8 [4], ISAJET 7.13 [5] and PYTHIA 5.6 [6] showering Monte Carlo generators.

As is customary, the jets are labelled (1,2) for the incoming partons and (3,4,5) or (3,4,5,6) for the final state, in decreasing order of jet energy in the center of mass of the 3 or 4-jet system respectively. We have investigated the following quantities (not all of which are independent):

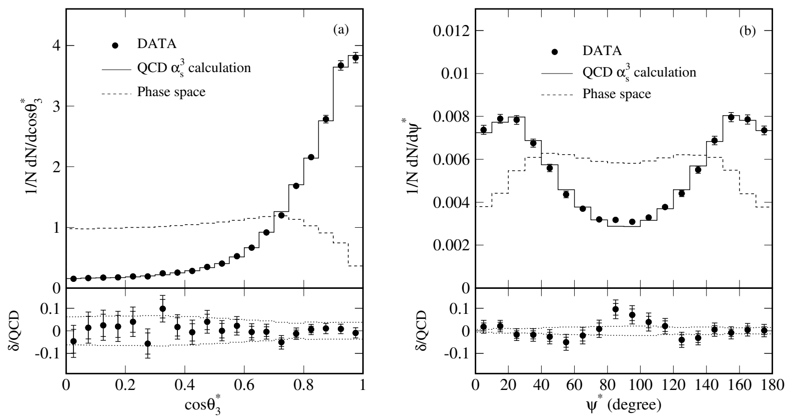

Figure 1: The distributions for three-jet events of (a) the cosine of the leading jet polar angle and (b) the angle ψ^* (defined in the text) in their center of mass system. The dotted lines show the estimated 6% systematic uncertainty.

- the scaled jet energies, $x_i = 2E_i/\sqrt{s}$;
- the jet pair scaled invariant masses, $\mu_{ij} = m_{ij}/\sqrt{s}$, and opening angles ω_{ij};
- the center of mass scattering angles $\cos\theta_i^*$;
- for three-jet final states,

$$\cos\psi^* = \frac{(\mathbf{p_1} \times \mathbf{p_3}) \cdot (\mathbf{p_4} \times \mathbf{p_5})}{|\mathbf{p_1} \times \mathbf{p_3}||\mathbf{p_4} \times \mathbf{p_5}|};$$

- for four-jet final states, the Bengtsson-Zerwas and Nachtmann-Reiter angles [1].

Events were selected using 1.2 pb^{-1} of data from the 1992–93 collider run. Jets were found using a cone algorithm with a cone radius $R = 0.7$ within $|\eta^{jet}| < 3.0$. Jets were required to be separated by $\Delta R > 1.4$ in η, ϕ space. The invariant mass of the 3 (4) leading jets was required to be greater than 200 GeV to avoid threshold and resolution effects. Because of the large angular acceptance of the detector, no cuts were needed on any of the angular variables. These selections yield 46,000 events with 3 or more jets and 8100 events with 4 or more jets.

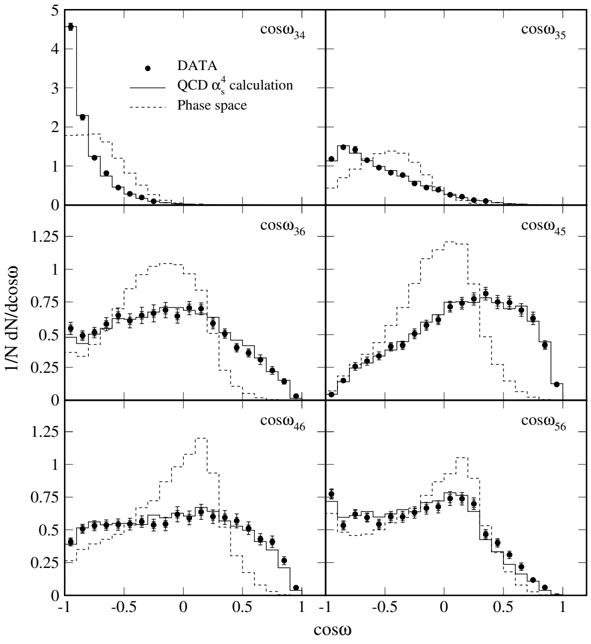

Figure 2: Distributions of the space angle between jet pairs for four-jet events in the center of mass system. Only statistical errors are shown. The estimated systematic uncertainty on the measurement is 6%.

The use of normalized distributions minimizes the impact of most systematic effects. We estimate that uncertainties of $\sim$ 4% are introduced by hadronization (estimated using HERWIG); $\sim$ 3% from renormalization scale uncertainty, $\sim$ 3% from parton distributions, $\sim$ 5% from detector energy resolution, angular resolution, and trigger efficiency; and $\sim$ 3% from detector energy scale uncertainty.

Some representative distributions are shown in Figs. 1, 2 and 3. (For more details, the reader is referred to Ref. 1). It will be seen that the topological distributions for both inclusive 3 and 4-jet events are well-reproduced by tree-level QCD. We may thus infer than tree-level is a good aproximation to the full matrix element. The HERWIG Monte Carlo also provides a good descripition of the data; PYTHIA, and especially ISAJET, less so.

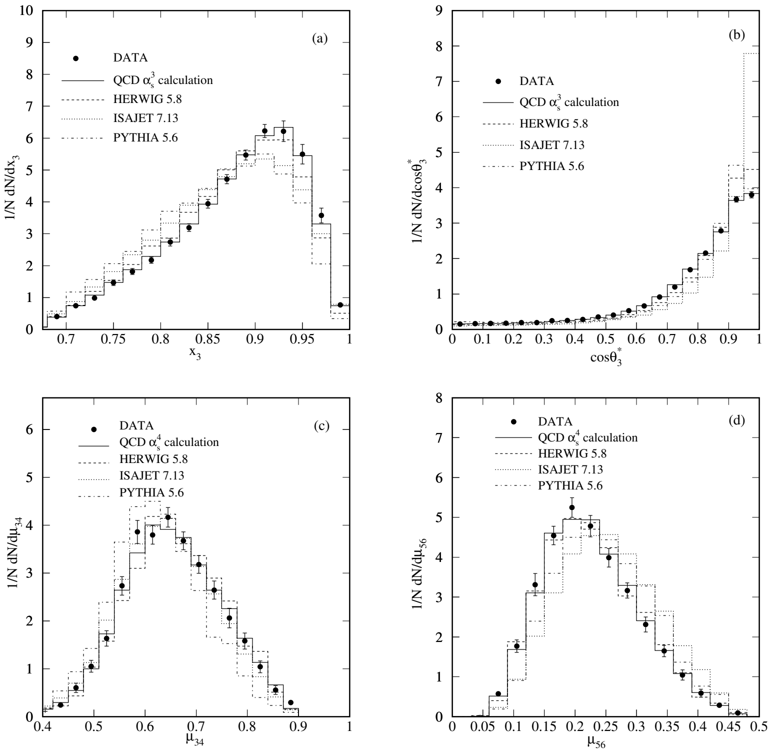

Figure 3: Comparison between the data, exact tree-level QCD calculations, and HERWIG, ISAJET and PYTHIA Monte Carlo prections. Shown are (a) the scaled energy of the leading jet and (b) the cosine of the leading jet for three-jet events, and the scaled invariant mass distributions of (c) the leading two jets and (d) the two non-leading jets in four-jet events. Statitsical errors only are shown; the systematic uncertainty on the measured distributions is less than 6%.

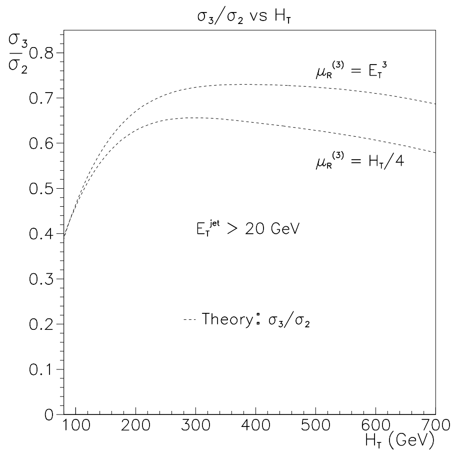

Figure 4: Predicted value of σ_3/σ_2 as a function of H_T, for two choices of $\mu_R^{(3)}$.

3 Multijet Cross Section Ratios

Here we shall explore two-scale QCD processes such as $p\overline{p} \rightarrow 3$ jets, where $E_{T,1} \approx E_{T,2} >> E_{T,3}$ ($E_{T,i}$ is the transverse energy of the i'th jet). These processes test next-to-leading order (NLO) QCD predictions, and will also enable the applicability of various renormalization scale prescriptions to be judged. We shall study the ratio:

$$\frac{\sigma_3}{\sigma_2} = \frac{\sigma(p\overline{p} \rightarrow n\,\text{jets} + X;\ n \geq 3)}{\sigma(p\overline{p} \rightarrow m\,\text{jets} + X;\ m \geq 2)}$$

as a function of $H_T = \sum E_{T,i}$ and of E_T^{min}, the minimum transverse energy for a jet to be counted.

This preliminary analysis uses 10 pb^{-1} of data from the 1992–93 run. Single jet inclusive triggers were selected, and jets were found using a cone algorithm with $R = 0.7$ and $|\eta^{jet}| \leq 3.5$. Cuts were applied to remove cosmic rays, calorimeter noise, electromagnetic objects and multiple interaction events (which can give fake low-E_T jets). Minimum jet transverse energies E_T^{min} of 20 and 30 GeV were used.

The data were compared with the theoretical prediction of Summers and Zeppenfeld [7]. These authors used the JETRAD next-to-leading order QCD Monte Carlo[8] (with MRSD′_ parton distributions) and a renormalization scale

$\mu_R^{(1)} = \mu_R^{(2)} = H_T/4$ for the leading two jets. For the third jet, the program was modified to use either $\mu_R^{(3)} = H_T/4$ or $\mu_R^{(3)} = E_{T,3}$. In the former case, all three jets experience the same renormalization scale; in the latter, $\mu_R^{(1)} = \mu_R^{(2)} >> \mu_R^{(3)}$. (The factorization scale was fixed to $H_T/4$ throughout.) The predicted ratio σ_3/σ_2 in these two cases, with $E_T^{min} = 20\,\text{GeV}$, is shown in Fig.4. We note firstly that for moderately large values of H_T, the ratio σ_3/σ_2 is large, between 0.6 and 0.7. Thus the majority of events having two jets with $E_T \geq 100\,\text{GeV}$ also have a third jet with $E_T \geq 20\,\text{GeV}$. Secondly we note that there is a difference in the shape and value of σ_3/σ_2 predicted using the two renormalization scale recipes.

In Fig.5, the preliminary data are compared with the predicted σ_3/σ_2 for $E_T^{min} = 20$ and 30 GeV. Statistical errors only are shown; the expected systematic uncertainties on the ratio are $\sim 2\%$ from jet selection cuts, $\sim 5-6\%$ from multiple interaction removal, and $\sim 7\%(3\%)$ in the region $H_T < 180(> 180)\,\text{GeV}$ from jet energy scale. Additional uncertainties, not yet evaluated, will arise from trigger efficiencies, acceptance, reconstruction efficiency and jet energy resolution. From the figure, it can be seen that the data agree qualitatively quite well in both shape and value of σ_3/σ_2. The change between E_T^{min} values of 20 and 30 GeV is also quite well reproduced. Especially for $E_T^{min} = 30$ GeV, the data prefer the renormalization scale prescription with $\mu_R^{(3)} = E_{T,3}$ rather than that with $\mu_R^{(3)} = \mu_R^{(1)} = \mu_R^{(2)}$. For $E_T^{min} = 20$ GeV the behavior is not so clear but the systematic errors are expected to be larger in this case especially at low H_T.

The behavior of the ratio σ_3/σ_2 as a function of H_T and E_T^{min} is therefore in reasonable agreement with the QCD prediction. The data seem to prefer the choice of $\mu_R^{(3)} = E_{T,3}$ rather than that with all scales equal; in other words, the third jet appears to be emitted with a softer scale than that of the $2 \rightarrow 2$ hard scattering process. Intuitively, this is perhaps what might be expected; this soft third jet may be thought of as a start in the fragmentation process, in which we know the scale evolves downward, eventually reaching that of hadronization $\mathcal{O}(1\,\text{GeV})$.

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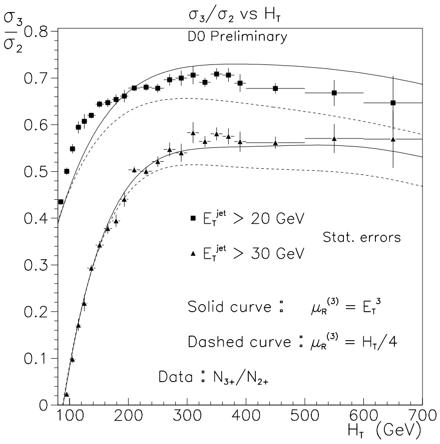

Figure 5: Measured and predicted values of σ_3/σ_2 as a function of H_T, for $E_T^{min} = 20$ and 30 GeV. Statistical errors only are shown.

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