COMPARISON OF THREE-JET EVENTS AT CDF TO A NEXT-TO-LEADING ORDER QCD CALCULATION

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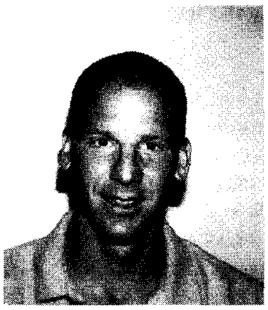

The properties of three-jet events in data of integrated luminosity 86±4 pb^{-1} from CDF Run 1b and with total transverse energy greater than 175 GeV have been analyzed and compared to predictions from a next-to-leading order perturbative QCD calculation. Special emphasis has been placed on analysis of the Dalitz variables.

1 Introduction

Proton-antiproton collisions at the Fermilab Tevatron Collider, which operates at a center-of-mass energy of 1.8 TeV, produce events that can be described within the framework of perturbative QCD. During collider Run 1b, CDF [1] recorded data corresponding to an integrated luminosity of 86±4 pb^{-1}. Data presented at this conference were reduced to events with total transverse energy ($\sum E_T$) > 175 GeV. The transverse energy of a jet or particle is defined as $E_T \equiv E \sin\theta$, where θ is the angle between the beam direction in the laboratory frame (which is the z-axis in the CDF detector) and the jet axis or outgoing particle direction.

In perturbative QCD, hard scattering of the constituent partons in the proton and antiproton results in events with large $\sum E_T$. The outgoing scattered partons hadronize and so are detected as hadronic jets. Three-jet events can be produced when a hard gluon is radiated from any of the initial, intermediate, or final state partons in an event with two primary outgoing partons.

We describe the analysis of the properties of three-jet events from CDF Run 1b. The results are compared to predictions from a next-to-leading order (NLO) calculation.[2] Special emphasis has been placed on the analysis of the Dalitz variables.

2 Three-jet Variables

The three leading jets in the laboratory frame are used as a basis of transformation into the three-jet rest frame. In the three-body rest frame, the incoming partons are labeled partons 1 and 2. The highest energy jets in this frame have energies labeled E_3, E_4, and E_5 and are ordered according to their energies such that $E_3 > E_4 > E_5$. The outgoing partons associated with these jets are correspondingly labeled partons 3, 4, and 5.

A three-jet system in the massless parton approximation can be uniquely defined by five independent variables. We choose: the mass of the three-jet system, m_{3J}; the cosine of the angle between the beam direction and parton 3 in the three-jet rest frame, $\cos\theta_3^*$; the angle between the plane containing the beam direction and parton 3 and the plane containing partons 3, 4, and 5, ψ^*; the Dalitz variable for the leading jet, X_3; and the Dalitz variable for the next-to-leading jet, X_4. The Dalitz variables, X_i, are defined as:

$$X_i \equiv \frac{2 \cdot E_i}{m_{3J}}, \quad (i = 3, 4, 5). \tag{1}$$

The Dalitz variables are used because the density at any point in the Dalitz plane is related to the square of the matrix element for the interaction.

3 Data Sample

The trigger hardware performs clustering in η-ϕ space, where η is the pseudorapidity, and ϕ is the azimuthal angle. All uncorrected calorimeter clusters with $E_T > 10$ GeV are summed for the high-$\sum E_T$ trigger. To pass the trigger, an event must have $\sum E_T > 175$ GeV. The iterative jet algorithm[3] with a cone size of $R = 0.7$ is used, where $R \equiv \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$, $\Delta\eta = \eta_2 - \eta_1$ and $\Delta\phi = \phi_2 - \phi_1$. The subscripts 1 and 2 correspond to the axis of the cone and the tracks off that axis, respectively. A set of trigger and offline requirements[4] ensures the rejection of events associated with cosmic rays, beam halo, and calorimeter malfunctions. Events are required to have a reconstructed primary vertex with $|z| < 60$ cm, and all of the calorimeter components and the tracking have to have been functional when the data were taken. Jet energies are corrected for errors in the absolute and relative energy scales and for additional energy associated with the underlying event. Since partons that are radiated out of the cone lead to the same losses in the theoretical calculation and in the data, out-of-cone corrections are not applied. E_T is calculated from the position of the primary event vertex, which is the vertex with the largest $\sum_i P_i$ (where P_i is the total momentum of each particle i leaving the vertex in the event). All jets in the data are required to have $E_T > 20$ GeV and $|\eta| < 2.0$. Events with less than three jets are rejected. To avoid collinear instability in the iterative jet clustering algorithm,[5] a cone overlap cut is imposed. Events are rejected if the distance ΔR in η-ϕ space between the axes of any two of the three leading jets is less than 1.0. To exclude regions where the geometrical acceptance is less than about 95%, we require:[6]

$$|\cos\theta_3^*| < \sqrt{1 - \left(\frac{\sum E_T}{m_{2J}}\right)^2}, \tag{2}$$

where $\sum E_T$ is the minimum total transverse energy (175 GeV) of the event, and m_{2J} is the mass of the two leading jets in the three-jet system. We require full trigger efficiency for this analysis. This occurs when $\sum_{\text{jets}} E_T > 320$ GeV, where the sum is over all jets with corrected $E_T > 20$ GeV.[7] Before they can be compared to the NLO prediction, the data must be corrected for the effects of "smearing," that is, the combination of detector resolution and energy mismeasurement. To unsmear the data, we compare the true event density distribution in the Dalitz plane to the smeared event density distribution. The true distribution is the hadron-level

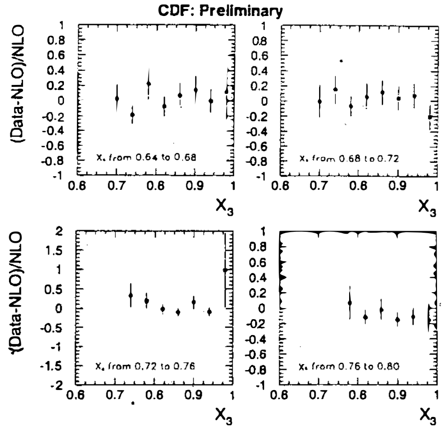

Figure 1: The fractional difference between the number of data events and the number of events predicted by the NLO calculation, using CTEQ3M with $\alpha_S = 0.116$ and $\mu = 100$ GeV, for a representative sample of bins in X_4.

HERWIG [8] calculation for the events. The CDF detector simulation, QFL, is not applied, and only hadronization effects for the final state partons are simulated by HERWIG. The smeared distribution is the event distribution in the Dalitz plane after the events pass QFL.

4 Monte Carlo Prediction

The data are compared to a NLO Monte Carlo event generator for hadronic three-jet production.[2] This program is the first one to calculate all parton sub-processes to NLO in perturbation theory. As output the Monte Carlo generator provides binned cross sections for the variables of interest. These cross sections are given in two parts (the one-loop $2 \longrightarrow 3$ parton virtual processes and the tree-level $2 \longrightarrow 4$ parton real emission processes) which must be added algebraically; the statistical errors on the calculation for each of the two cross section terms are added in quadrature.

5 Comparison of Data to Predictions from the Next-To-Leading Order Calculation

To compare the data to the NLO calculation, event information derived from the data and from the Monte Carlo prediction is separately binned in X_3-X_4 space. The binned cross sections provided by the calculation are multiplied by the total integrated luminosity associated with the data set to predict the number of events in each bin. The NLO prediction was computed using parton distribution function CTEQ3M with $\alpha_S = 0.116$ and scale factors $\mu = 100$ GeV, which corresponds to about $E_T/2$ for the average leading jet in the data sample.

Information about the agreement between the data and the NLO calculation can be obtained by calculating the fractional difference between them. The agreement is good, as is illustrated by the fractional difference in X_3, for a sample of bins in X_4, in Figure 1.

We also compute the difference between the data and the NLO calculation, scaled by error, for each bin. We find that the NLO calculation overestimates the data at high X_3 and underestimates it at low X_3. This is shown on the left side in Figure 2, where the difference is plotted as a function of bin number in the Dalitz plane. Bin numbers are assigned to non-zero bins in the Dalitz plane, starting at $X_3 = 0.66$ and $X_4 = 0.66$. The bin number increases systematically

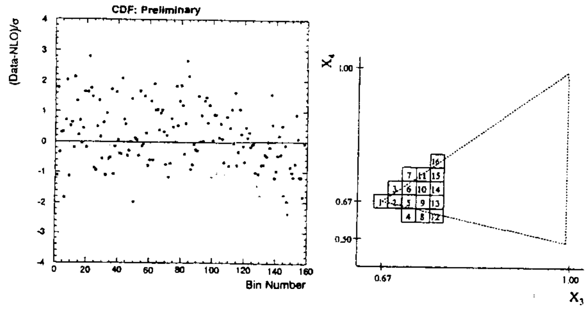

Figure 2: The difference between the number of data events and the number of events predicted by the NLO calculation, using CTEQ3M with $\alpha_S = 0.116$ and $\mu = 100$ GeV, scaled by the error, as a function of bin number. The schematic on the right shows the numbering scheme for non-zero bins in the Dalitz plane.

by one unit, first as a function of X_4, then as a function of X_3. The schematic on the right in Figure 2 illustrates the bin numbering system.

6 Conclusions

We compare three-jet events with total transverse energy > 175 GeV in CDF Run 1b to predictions from a next-to-leading order calculation, using CTEQ3M with $\alpha_S = 0.116$ and $\mu = 100$ GeV. Emphasis is placed on analysis of the Dalitz variables, X_3 and X_4. The agreement between the data and the prediction is good. Generation of a larger Monte Carlo sample is in progress. Application of this analysis to a measurement of the strong coupling constant, α_S, is being investigated.

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