Fermi National Accelerator Laboratory

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A Study of Four Jet Events and Search for Double Parton Scattering at $\sqrt{s}$ = 1.8 TeV

CDF Collaboration
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ABSTRACT

Kinematic properties of four jet events taken during the 1988/89 run of the Tevatron at Fermilab are compared with the predictions of a leading order QCD calculation. Preliminary work on a search for double parton scattering is presented.

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1. Introduction

A large sample of four jet events was accumulated with the Collider Detector at Fermilab[1] (CDF) during the 1988/89 run using a special multi-jet trigger. With this sample it is possible to make a high statistics test of QCD at the highest center of mass energy currently available. In addition to the more standard QCD mechanism of double gluon bremsstrahlung, the parton model allows for four jet production via scattering of two pairs of partons within one $\bar{p}p$ collision[2]. There is potentially useful information on parton correlations contained in events of this kind[3]. Also, a search for double parton scattering at the Tevatron may provide the best indication of the expected rate of such events at SSC/LHC energies.

2. Kinematic Comparison

Jets are clustered with a fixed cone clustering algorithm[4] using a cone size of $R = 0.7$, where $R = (\Delta\phi^2 + \Delta\eta^2)^{1/2}$, pseudo-rapidity, η, is defined as $\eta = \ln\cot(\theta/2)$, θ is the polar angle with respect to the beam and ϕ is the azimuthal angle around the beam. The response of the calorimetry to jets is not constant as a function of η. Also the calorimeters exhibit significant non-linearities in response, particularly to low energy particles. Using a dijet P_T balancing technique, we have been able to reduce the η-dependant deviations in energy scale to the level of a few percent. We have also used a detailed detector simulation and a tuned Feynman-Field fragmentation model to reproduce the effects of non-linearities on jet measurement. Using these results in functional form we correct calorimeter clustered P_T back to the $|\sum \vec{P_T}|$ of the particles that initiated the cluster.

To select the four jet sample, the following cuts were imposed:

- $|Z_{\mathrm{vertex}}| < 60$ cm, where Z_{vertex} is the primary interaction vertex.
- $|\eta| < 3.5$ where η is measured assuming $Z_{\mathrm{vertex}} = 0$.
- Four jets with $P_{T_i} > 25$ GeV/c and $\sum_{i=1}^{4} P_{T_i} > 140$ GeV/c after corrections.

From our data sample having an integrated luminosity of 330 nb$^{-1} \pm 7\%$ we are left with around 2200 events.

The QCD calculations were performed using the program PAPAGENO[5]. For speed, an approximation to the exact four jet matrix element[6] is used. Partons from PAPAGENO are converted directly to jets by a fast jet detector simulation. Figure 1 shows the quantity $\cos\theta_{ij}$, where θ_{ij} is the angle between jets i and j, for both data and QCD simulation. Four out of the possible six combinations are shown. The jets have been ordered in P_T, jet 1 being the largest, jet 2 the next largest etc. The structure function set EHLQ1 has been used, with $Q^2 = \langle P_T \rangle^2$. The agreement between data and QCD predictions is excellent.

3. Search For Double Parton Scattering

Double parton events are expected to be composed of dijet pairs, approximately balanced back-to-back in P_T. By contrast, gluons emitted in the bremsstrahlung process tend to be close to the emitting parton in η-ϕ space. Using these two features, we have constructed several variables having good signal-finding resolution. These are:

- S : defined by

$$S(1+2,3+4) \equiv \sqrt{\left[\left(\frac{|\vec{P_{T_1}} + \vec{P_{T_2}}|}{\sqrt{P_{T_1} + P_{T_2}}}\right)^2 + \left(\frac{|\vec{P_{T_3}} + \vec{P_{T_4}}|}{\sqrt{P_{T_3} + P_{T_4}}}\right)^2\right]/2} \qquad (1)$$

  The S variable is computed for each different pairing of the four jets, and the minimum value is taken.

- ϕ_S : Once the jets have been paired up to minimize S, the ϕ angle between the largest jets in each pair is evaluated. ϕ_S is constrained to be in the range $0 \to \pi$.

- Δ_S. The resultant $\Sigma\vec{P_T}$ vector is computed for each pair of dijets, and the difference in ϕ between these is taken.

Variable shapes for double parton scattering have been obtained by merging two dijet events at the parton level and then using the fast jet simulation. Figure 2a) shows data overlaid on predictions for signal and conventional QCD background. Fitting to an admixture of both shapes allows us to extract the ratio of double parton events to double bremsstrahlung events, $\mathcal{R}$. The larger values of $\mathcal{R}$ obtained with the angular variables ϕ_S and Δ_S seems to be a result of 5th jet effects. Figure 2b) demonstrates that the three variables converge at roughly $\mathcal{R} = 5\%$ when we require $P_{T_5} < 15$ GeV/c.

In conclusion, QCD predictions fit the four jet data very well. The double parton content of the data is small (consistent with zero). In our analysis, we have found it necessary to consider the effects of 5th jets when extracting $\mathcal{R}$. An upper limit on the double parton scattering cross section will be published in the near future.

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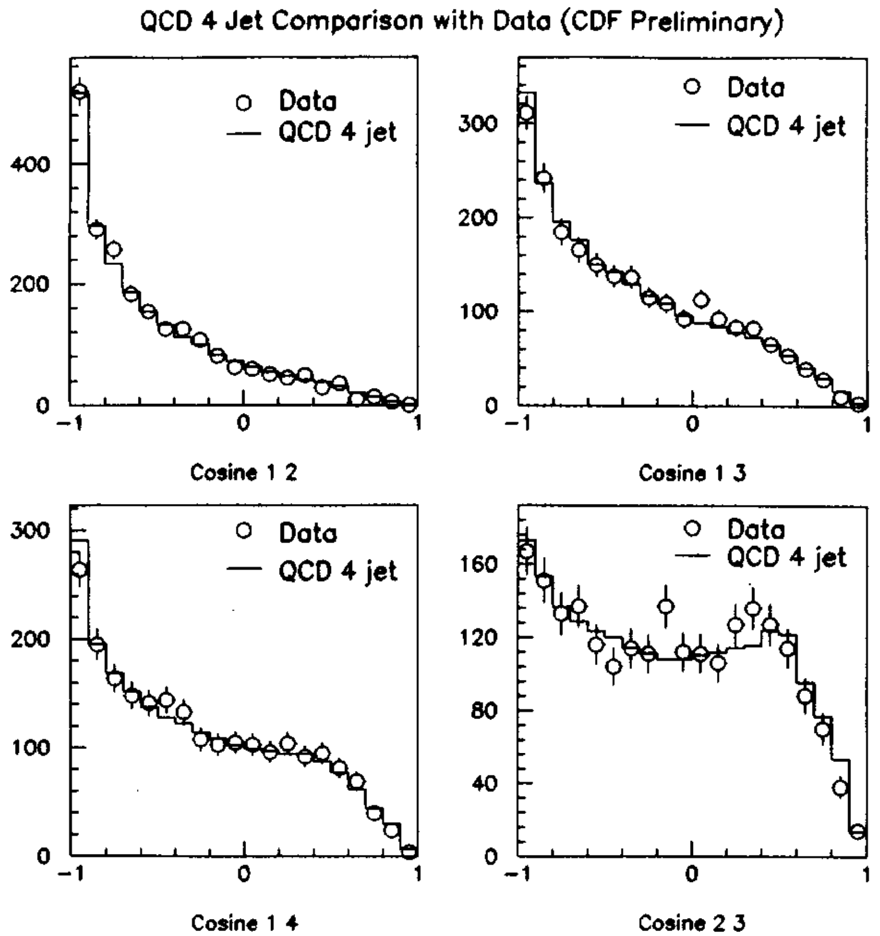

Figure 1: Four jet separation angles compared with QCD predictions.

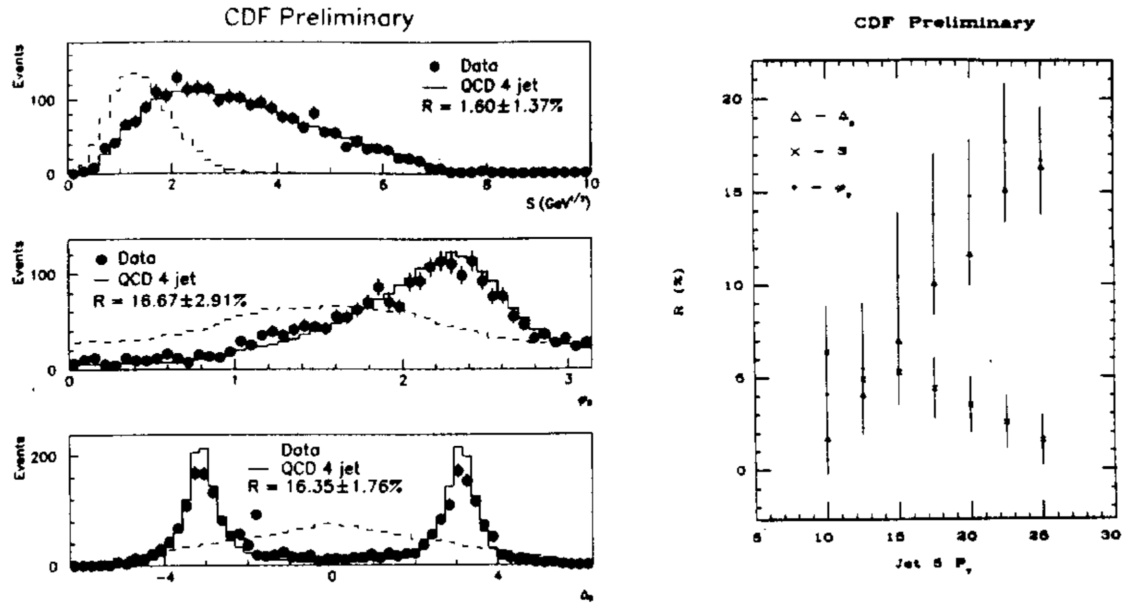

Figure 2: LEFT: Data overlaid on expected signal (solid) and background (dashed) shapes for each topological variable. RIGHT: Fitted double parton fraction vs. maximum allowed 5th jet P_T.