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

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A STUDY OF FOUR-JET EVENTS AND SEARCH FOR DOUBLE PARTON INTERACTIONS AT $\sqrt{s} = 1.8$ TeV

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ABSTRACT

Kinematic properties of four-jet events in $p\bar{p}$ collisions at $\sqrt{s} = 1.8$ TeV are compared with the predictions of leading order quantum chromodynamics. We place an upper limit on the double parton scattering cross of $\sigma_{\rm DP} < 120$ nb (95% C.L.) for partons with transverse momenta greater than 18 GeV/c. Defining the effective cross section $\sigma_{\rm eff}$ through the equation $\sigma_{\rm DP} = \sigma^2_{\rm dijet}/(2\sigma_{\rm eff})$, where $\sigma_{\rm dijet}$ is the cross section for two-jet events, the limit $\sigma_{\rm eff} > 3.9$ mb (95% C.L.) is also placed. Implications for physics at the SSC ($\sqrt{s} = 40$ TeV) are discussed.

1. Introduction

In the context of the standard model, the dominant production mechanism for events containing four high transverse momentum (p_T) jets at the Tevatron collider is double gluon bremsstrahlung (DB). In principle, four-jet events may also be produced by double parton (DP) scattering, where two hard scatters occur within one hadron interaction[1]. Such events are expected to contain valuable information on parton correlations. The predicted rise[2] in the ratio $\sigma_{\rm DP}/\sigma_{\rm DB}$ with $\sqrt{s}$ merits a search for double parton scattering at CDF.

2. Comparison of Data and QCD Double Bremsstrahlung (DB)

We test the leading order DB matrix element at $\sqrt{s} = 1.8$ TeV using a data sample of integrated luminosity 325 nb^{-1} collected during the 1988/89 collider run. Jet clustering is performed using a fixed cone algorithm, with a cone of size $R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2} = 0.7$, where $\eta = \ln\cot(\theta/2)$. All jets are corrected for detector mismeasurement[3]. Events are selected by requiring four (and only four) jets with $p_T > 25$ GeV/c, $\sum_{i=1}^{4} p_{Ti} > 140$ GeV/c, jet pseudorapidity $|\eta| < 3.5$ and jet centroid separation $|\Delta R| > 1.0$. These cuts leave a final sample of 2213 events. Jets are ordered by p_T, so that $p_{T1} > p_{T2} > p_{T3} > p_{T4}$. DB events are simulated using an approximate matrix element[4] using the structure function Morfin-Tung set 1 (DIS) with $Q = \langle p_T \rangle$. Fragmentation and detector effects are modeled using a parton-level simulation[5].

We observe excellent agreement between data and the predictions of QCD for the distributions of p_{Ti} and $\sum_{i=1}^{4} p_{Ti}$. These distributions, however, are also

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well reproduced by a four-body phase space simulation. In order to make a more discriminative test of QCD we use inter-jet angles. We define Ω_{ij} as the angle between jets i and j in the CM system. Fig. 1 shows $\cos\Omega_{ij}$ for the four-jet data, in comparison with QCD and phase space results. The agreement between QCD and data is impressive.

3. Search For Double Parton (DP) Interactions

We perform a statistical search for DP interactions using two variables. The first variable, S, exploits the tendency of jets produced by double parton scattering to balance pairwise in p_T:

$$S(1+2,3+4) \equiv \sqrt{\left[\left(\frac{|\vec{pT_1}+\vec{pT_2}|}{\sqrt{pT_1+pT_2}}\right)^2+\left(\frac{|\vec{pT_3}+\vec{pT_4}|}{\sqrt{pT_3+pT_4}}\right)^2\right]/2}, \qquad (1)$$

where S is minimized over the three possible independent jet pairings [12, 34], [13, 24] and [14, 23]. The second variable, Δ_S, uses angles. We define ϕ_{ij} to be the azimuthal angle of the vector $\vec{p}_{Ti}+\vec{p}_{Tj}$ formed with jets i and j. Assuming that the minimization of S results in the pairing $[ij, kl]$, then $\Delta_S = \phi_{ij} - \phi_{kl}$.

A Monte Carlo DP sample is formed by merging simulated dijet events at the parton level. A fit to the data using an admixture of DP and DB shapes results in a 16% DP signal for Δ_S, but only a 2% signal for S, as shown in Fig. 2a). The difference in results is due to fifth jets in the data from additional gluon radiation. Using a five-jet Monte Carlo simulation we observe that such jets cause an enhancement in the signal region for S, and a depletion for Δ_S. As expected, performing a cut on the p_T of 5th jets in the data (p_{T5}) leads to a convergence of the results obtained with S and Δ_S (see Fig. 2b). We measure $N_{\rm DP}/N_{\rm DB} = 0.051 \pm 0.013$ (stat.) for $p_{T5} < 13$ GeV/c. A preliminary determination of systematic uncertainties yields $\sigma_{\rm DP} = 68 \pm 28$ mb, from which we derive the limit $\sigma_{\rm DP} < 120$ nb (95% C.L., parton $p_T > 18$ GeV/c).

A comparison of our result with previous results can be made using the effective cross section $\sigma_{\rm eff}$, defined through the relation $\sigma_{\rm DP} = \sigma^2_{\rm dijet}/(2\sigma_{\rm eff})$ where $\sigma_{\rm dijet}$ is the two-jet cross section. Using a theoretical determination of the dijet cross section for parton $p_T > 18$ GeV/c we find $\sigma_{\rm eff} = 11.3$ mb. The corresponding limit is $\sigma_{\rm eff} > 3.9$ mb (95% C.L.), consistent with the UA2 result[6] ($\sigma_{\rm eff} > 8.3$ mb).

We have simulated DB and DP processes under SSC conditions ($\sqrt{s} = 40$ TeV) at the parton level. With the value $\sigma_{\rm eff} = 11.3$ mb, we find $\sigma_{\rm DP}/\sigma_{\rm DB} > 1$ when $p_{T4} < 40$ GeV/c. Note, however, that this result is subject to large uncertainty.

4. Conclusions

We observe good agreement between the results of leading order QCD and data for the p_T spectra and inter-jet angles of four-jet events. Using variables sensitive to a double parton signal, we find a small ($\sim 5\%$) double parton content is necessary in order to best describe our data. We place a limit on the double parton cross section, $\sigma_{DP} < 120$ nb (95% C.L., parton $p_T > 18$ GeV/c) and on the effective cross section, $\sigma_{eff} > 3.9$ mb (95% C.L.). A Monte Carlo study indicates a large double parton rate at the SSC for sufficiently low jet p_T.

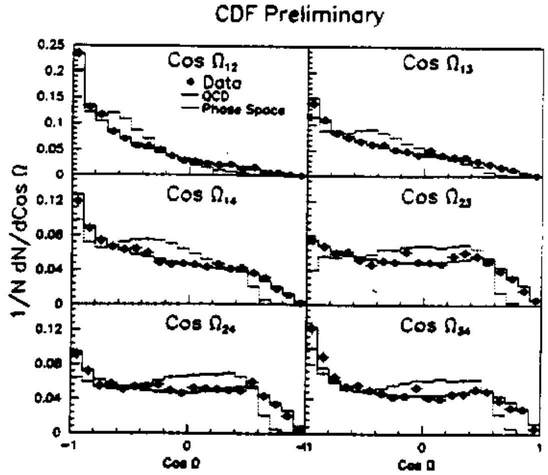

Figure 1: Variables $\cos\Omega_{ij}$ for Data, QCD and four-body phase space.

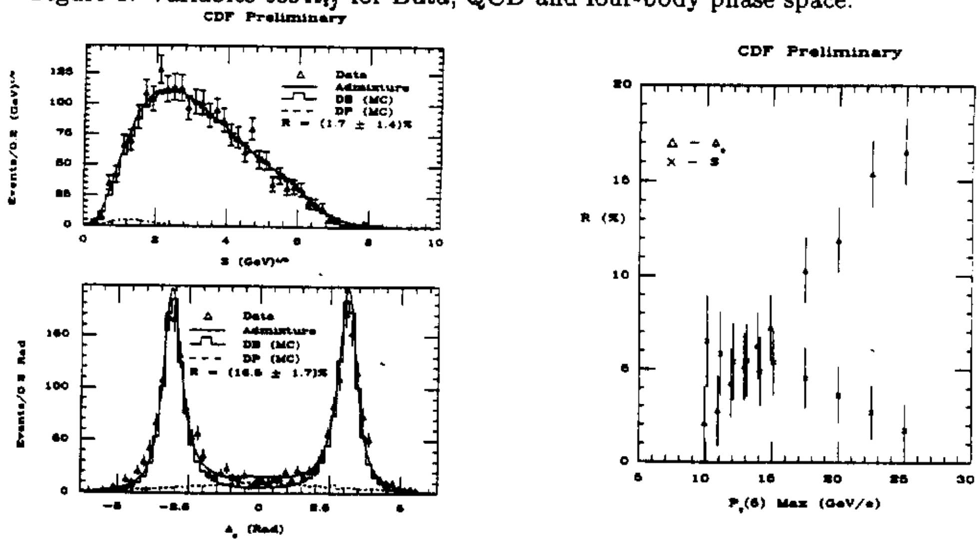

Figure 2: a) (LEFT) Four-jet data fitted to an admixture of DB and DP shapes using S and Δ_S, b) (RIGHT) DP fraction $\mathcal{R}$ for S and Δ_S versus maximum allowed p_{T5}.

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