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Measurement of Double Parton Scattering at CDF

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Abstract. A strong signal for Double Parton scattering (DP) is observed in p̄p $\rightarrow \gamma$ + 3 jets data from the CDF experiment. The process-independent DP parameter, σ_{eff}, is obtained using a new technique. The result, σ_{eff}=$(14.5 \pm 1.7^{+1.7}_{-2.3})$ mb, represents a significant improvement over previous measurements. For the first time, the Feynman x dependence of the σ_{eff} parameter is investigated, and no dependence is seen.

Studies of proton structure at p̄p colliders have traditionally focused on the kinematics of individual parton constituents, e.g. on the character and evolution of the structure functions. New and complementary information on the structure of the proton can be obtained by identifying and analyzing events in which two parton-parton hard scatterings take place within one p̄p collision. This process, Double Parton scattering [1], can provide information on both the spatial distribution of partons within the proton, and on possible parton-parton correlations: topics difficult to address within the framework of perturbative QCD. Furthermore, an understanding of DP is important for estimating backgrounds to such processes as di-boson (W^+W^-, etc.) and boson + jets production, and for making accurate predictions of hard-scattering rates at future high energy hadron colliders like the LHC.

The cross section for DP is comprised of scatterings A and B is written

$$\sigma_{\text{DP}} \equiv \frac{\sigma_A \sigma_B}{\sigma_{\text{eff}}}, \tag{1}$$

where σ_{eff} is the process-independent parameter of interest [2–5]. This expression assumes that the number of parton-parton interactions per collision is distributed according to Poisson statistics [6], and that the two scatterings are distinguishable [7]. Previous measurements of σ_{eff} have come from the AFS [3], UA2 [4], and CDF [5] experiments. The most significant measurement, $\sigma_{\rm eff}$=$12.1^{+10.7}_{-5.4}$ mb, was obtained from the CDF analysis of four jet events. Based on a model which assumes that the proton is a uniformly dense ball of partons and the measured inelastic $\bar{\rm p}$p cross section at $\sqrt{s}$=1.8 TeV, the expected value is $\sigma_{\rm eff}$=11 mb [5].

CDF has recently reported a measurement of $\sigma_{\rm eff}$ using a photon + 3 jets final state [8,9]. DP in this event sample consists of photon + 1 (or 2) jet production overlaid with 2 (or 1) observed jets from dijet production. Single parton-parton scattering (SP) backgrounds consist of QCD photon + 3 jet production.

A new technique for extracting $\sigma_{\rm eff}$ was developed for this analysis. In previous analyses $\sigma_{\rm eff}$ was derived using the measured DP cross section, and QCD calculations for the two cross sections in Eq. 1. This technique suffers from sizeable uncertainties in the predicted cross sections [10,11]. In the present analysis, $\sigma_{\rm eff}$ is extracted independently of theoretical calculations, through a comparison of observed DP events to events with hard-scatterings at two separate $\bar{\rm p}$p collisions within the same beam crossing (Double Interactions, or DI). The number of observed $\bar{\rm p}$p collisions per crossing is used to segregate data into DP candidates (one collision) and DI candidates (two collisions). The ratio of the observed number of events is proportional to $\sigma_{\rm eff}$. In the new technique, the predicted cross sections drop out of the ratio. The trade-off is that two quantities, the number of DP and DI events, have to be measured instead of just the number of DP events in the previous method. In the current CDF data, the new method has a much smaller uncertainty.

In the 1992-3 Collider Run, 16 pb^{-1} of data was accumulated with an inclusive photon trigger [12] which demanded a predominantly electromagnetic transverse energy deposition in the CDF Central Calorimeter above 16 GeV. No jets were required in the trigger. Offline, jet reconstruction was performed on these events using a cone of radius 0.7 in (η, ϕ) to define jet E_T. Events with three and only three jets with $E_T > 5$ GeV (uncorrected for detector effects) were accepted. A further requirement of $E_T < 7$ GeV was made on the two lowest E_T jets, which enhances DP over SP. Events with a single collision vertex found in the vertex detector ("1VTX") were taken as DP candidates, while two-vertex events ("2VTX") formed the DI candidate sample. A total of 16853 and 5983 events respectively pass the two selections.

A set of six variables were identified which exploit the independence and pairwise momentum balance of the two scatterings in DP events. The most sensitive variable, ΔS [5], is the azimuthal angle between the transverse momentum (p_T) vectors of the two best-balancing pairs (photon + 1 jet, and dijet). In SP events, momentum conservation biases ΔS towards 180^o, while in DP events the ΔS distribution is flatter. The ΔS distribution for 1VTX data is shown in Fig. 1.

Event mixing of two CDF events was used as a model ("MIXDP") for photon + 3 jet DP events. MIXDP and data events were used to obtain the

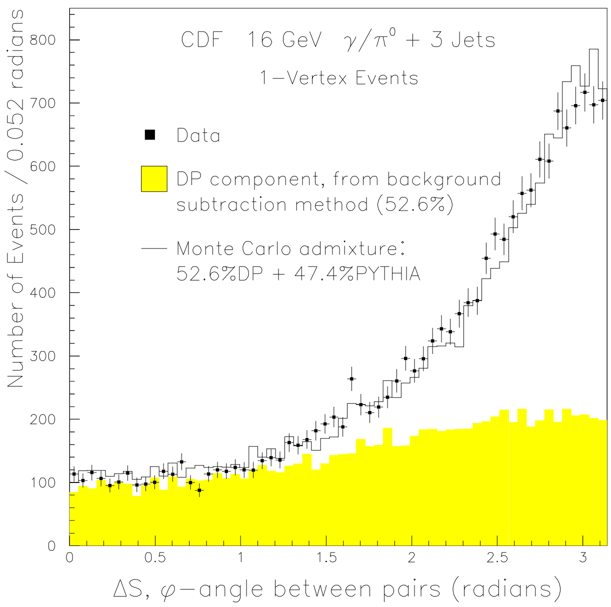

FIGURE 1. ΔS distribution for 1VTX data (points). The DP component to the data, determined by the two-dataset method to be 52.6% of the sample, is shown as the shaded region (the shape is taken from MIXDP). Also shown is the admixture 52.6% MIXDP + 47.4% PYTHIA, normalized to the data (line).

number of 1VTX DP events, via a background subtraction technique [9]. SP background was statistically removed from 1VTX data through the use of a second photon + 3 jets dataset, chosen to be less pure in DP, and consisting of events which pass a modified 1VTX selection criteria requiring $7 \leq E_T \leq 9$ GeV for the two lowest E_T jets. This "two dataset" method does not invoke any prediction or model for the SP component of the data. We find that the fraction of DP events in the 1VTX sample is (52.6±2.5±0.9)%. As a check of this large DP fraction, the admixture 52.6% MIXDP + 47.4% PYTHIA is compared to the 1VTX sample in Fig. 1. The data are well described by this admixture.

The number of DI events in the 2VTX sample was determined by identifying events with jets originating from both $\bar{p}p$ collisions. CTC tracks were used to specify jet origins. We find that 16.8±1.9±1.8% of these events are DI. These numbers for DP and DI production imply $\sigma_{\text{eff}}=(14.5\pm1.7^{+1.7}_{-2.3})$ mb.

The possible Feynman x ($\equiv p_{\text{parton}}/p_{\text{beam}}$) dependence of σ_{eff}, such as would arise from variations of parton spatial density with $\hat{s}$, was studied by searching for deviations from the MIXDP model, which by construction has the x dependence of the two scatterings only. We begin by selecting a sample enriched in DP events. Events in Fig. 1 that pass the cut $\Delta S < 1.2$ (2575 events) cut

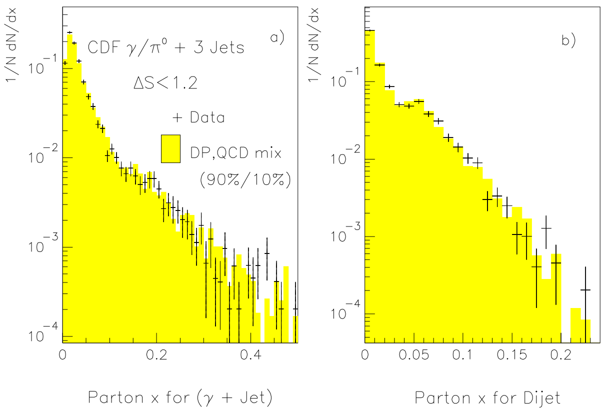

FIGURE 2. Results of the Feynman x analysis on DP-enriched 1VTX data. Distributions, two entries per event, of (a) $\gamma+$ 1 jet x values ($x^{\gamma \mathrm{J}}_{\mathrm{p},\bar{\mathrm{p}}} = [p^{\gamma}_T/p_{\mathrm{beam}}][\mathrm{e}^{\pm\eta_\gamma} + \mathrm{e}^{\pm\eta_{\mathrm{J}}}]$), and (b) dijet x values ($x^{\mathrm{JJ}}_{\mathrm{p},\bar{\mathrm{p}}} = [(E_T(i) + E_T(j))/(2p_{\mathrm{beam}})][\mathrm{e}^{\pm\eta_{\mathrm{J}i}} + \mathrm{e}^{\pm\eta_{\mathrm{J}j}}]$, where i, j signify the two jets of the dijet). The prediction, 90% MIXDP+10% PYTHIA, is shown as the shaded area. The distributions are presented without acceptance corrections.

are 90% DP according to the MIXDP+PYTHIA histogram. Each event was subdivided into the two best-balancing pairs. Four x values were evaluated, since two partons contribute to each of the two pairs. Distributions of x are plotted in Fig. 2, along with the admixture 90% MIXDP + 10% PYTHIA. No systematic deviation of the DP rate vs. x is observed. We conclude from this that no x-dependence to σ_{eff}, is apparent over the range accessible to this analysis ($0.01 \le x \le 0.40$ for the photon + jet scatter, $0.002 \le x \le 0.20$ for the dijet scatter).

In summary, a strong signal for DP has been observed in CDF photon + 3 jet data. The process-independent parameter σ_{eff} is measured to be $(14.5 \pm 1.7^{+1.7}_{-2.3})$ mb, and was determined to first order without reliance on theoretical QCD calculations. High statistics and a large DP fraction have permitted, for the first time, a search for Feynman x dependence of σ_{eff}. We see no evidence for an x-dependence of σ_{eff} within the kinematic range of this analysis.

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