Study of multiple partonic interactions in DØ

Georgy Golovanov for the DØ Collaboration

Joint Institute for Nuclear Research, 6 Joliot-Curie, Dubna, Russia, 141980

DOI: http://dx.doi.org/10.3204/DESY-PROC-2012-03/14

The samples of inclusive $\gamma + 3$ jet and $\gamma + 2$ jet events collected by the DØ experiment with an integrated luminosity of 1 fb^{-1} in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV were used to study processes with multiple parton interactions (MPI). Using the sample of $\gamma + 3$ jet events we measured: (a) the fraction of events with double (f_{DP}) and triple (f_{TP}) parton interactions, (b) effective cross section, σ_{eff}, a scale parameter related to the parton density inside the nucleon and (c) cross section as a function of the angle between the transverse momentum (p_{T}) of the γ+leading jet system and p_{T} sum of the two other jets. The sample of $\gamma +$ 2 jet events allowed us to measure the fraction of events with double parton interactions and cross sections as a function of the angle between the p_{T} of the γ+leading jet system and p_{T} of the other jet. We also estimated the contribution of events with double parton interactions as a background to the associated Higgs boson (H) and W production (with $H \to b\bar{b}$ decay) at the Tevatron.

1 Introduction

High energy inelastic scattering of nucleons occurs mainly through a single parton-parton interaction but the contribution from multiple parton interactions (MPI) can be significant. Studying the MPI at high p_{T} regime gives the important information about hadron structure and is needed for precise estimates of backgrounds to many rare processes.

2 Double parton interactions in $\gamma + 3$ jet events

The cross section of a process with double parton (DP) interaction is proportional to cross sections of two partonic scatterings A and B.

$$\sigma_{DP} \equiv \frac{\sigma^A \sigma^B}{\sigma_{\text{eff}}}. \tag{1}$$

The scaling parameter σ_{eff} has the units of cross section and characterizes a size of the effective interaction region. We use a sample of $\gamma + 3$ jet events collected by the DØ experiment with an integrated luminosity of about 1 fb^{-1}. The DØ detector is a general purpose detector described in [1]. The events should pass triggers based on the identification of high p_{T} cluster in the electromagnetic calorimeter with loose shower shape requirements for photons. Jets are reconstructed using the DØ Run II iterative midpoint cone algorithm [2] with a cone size 0.7. Each event must contain at least one photon in the rapidity region $|y| < 1.0$ or $1.5 < |y| < 2.5$ and at least three jets with $|y| < 3.0$. Events are selected with photon transverse momentum

$60 < p_T^{\gamma} < 80$ GeV, leading (in p_T) jet $p_T > 25$ GeV, while the next-to-leading (second) and third jets must have $p_T > 15$ GeV. The DP fractions and $\sigma_{\rm eff}$ are determined in three $p_T^{\rm jet2}$ bins: 15–20, 20–25, and 25–30 GeV.

In order to extract $\sigma_{\rm eff}$ we compare rates of double interaction (DI) events (events with interactions at two separate $p\bar{p}$ collisions) and DP events. Assuming that scatterings in the two DP hard processes are uncorrelated, DP and DI events should be kinematically identical. The DP $\gamma + 3$ jet event sample is selected from data with a single $p\bar{p}$ collision vertex, while DI $\gamma + 3$ jet event sample contains events with two separate $p\bar{p}$ vertices. Effective cross section is extracted from the ratio of observed DP and DI $\gamma + 3$ jet event rates.

An event in DP $\gamma + 3$ jet sample can be produced by the two independent parton-parton scatterings or by a single parton-parton (SP) scattering with gluon radiation in initial or final state as well.

To identify the events with two independent parton-parton scatterings that produce $\gamma +$ 3 jet final state, we use an angular distribution sensitive to the kinematics of the DP events. We define a variable:

$$\Delta S \equiv \Delta\phi \left(\vec{p}_T^{\,\gamma,\ \rm jet1},\ \vec{p}_T^{\,\rm jet2,\ jet3} \right), \tag{2}$$

where $\Delta\phi$ is an azimuthal angle between the p_T vectors of the total transverse momenta of the two two-body systems, $\vec{p}_T^{\,\gamma,\ \rm jet1}$ and $\vec{p}_T^{\,\rm jet2,\ jet3}$, in $\gamma + 3$ jet events. This angle is schematically shown in Fig. 1. The distribution of ΔS variable reflects angular properties of a mixture of

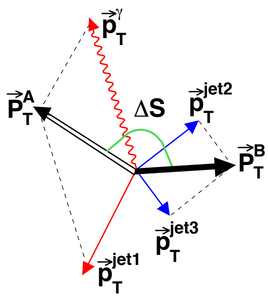

Figure 1: A possible orientation of photon and jets transverse momenta vectors in $\gamma +$ 3 jet events. Vectors $\vec{P}_T^{A}$ and $\vec{P}_T^{B}$ are the p_T imbalance vectors of γ+jet and jet-jet pairs. The figure illustrates a general case for the production of γ+3 jets +X events.

$\gamma + 3$ jet events containing both single and double parton scatterings. To extract fraction of DP events ($f_{\rm DP}$) we consider a data-driven method which uses two adjacent p_T intervals of the second jet. Since we know properties of data and DP model, the only unknown parameter is the fraction of DP events in one $p_T^{\rm jet2}$ bin. It is obtained from a minimization.

The found $f_{\rm DP}$ values with total uncertainties are 0.466 ± 0.041 for $15 < p_T^{\rm jet2} < 20$ GeV, 0.334 ± 0.023 for $20 < p_T^{\rm jet2} < 25$ GeV, and 0.235 ± 0.027 for $25 < p_T^{\rm jet2} < 30$ GeV. They are shown on the left plot of Fig. 2 (three sets of the points correspond to three possible definitions for the ΔS variable [3]). The values of $\sigma_{\rm eff}$ are shown in Fig. 2 (right). The main systematic uncertainties are caused by determinations of the DI and DP fractions giving a total systematic uncertainty of $(20.5-32.2)\%$. The obtained $\sigma_{\rm eff}$ values in different $p_T^{\rm jet2}$ bins agree with each other within their uncertainties. They are highly uncorrelated and are used to calculate the average value:

$$\sigma_{\rm eff}^{\rm ave} = 16.4 \pm 0.3({\rm stat}) \pm 2.3({\rm syst}) \ \ {\rm mb}. \tag{3}$$

This average value is in the range of those found in previous measurements [4, 5, 6, 7] performed at different energy scales of parton interactions.

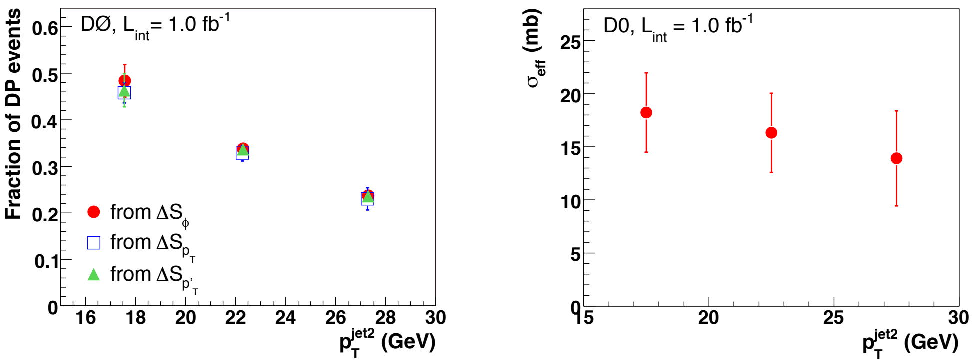

Figure 2: Left: Fractions of $\gamma + 3$ jet events with double parton interactions in the three $p_T^{\rm jet2}$ intervals. Right: Effective cross section $\sigma_{\rm eff}$ (mb) measured in the three $p_T^{\rm jet2}$ intervals.

3 Azimuthal decorrelations and multiple parton interactions in $\gamma + 2$ jet and $\gamma + 3$ jet events in $p\bar{p}$ collisions

As an extension of our study of $\gamma + 3$ jet events described in previous section we measure normalized differential cross sections of the azimuthal angle between the p_T vectors obtained by pairing the photon and leading jet and the p_T vector of the other one (two) jet(s) in $\gamma+2(3)$-jet+X events [8]. These cross sections are very sensitive to the contribution from jets originating from additional parton hard interactions (beyond the dominant one) and can be used to tune existing MPI models and to estimate the fractions of such events.

Samples of $\gamma+2(3)$ jet events with the same cuts as [3] are considered. The next modifications are applied: each event must contain at least one γ in the pseudorapidity region $|y| < 1.0$ or $1.5 < |y| < 2.5$ and at least two (or three) jets with $|y| < 3.5$. Events are selected with γ transverse momentum $50 < p_T^\gamma < 90$ GeV, leading jet $p_T > 30$ GeV, and the second jet $p_T > 15$ GeV. If there is a third jet with $p_T > 15$ GeV that passes the selection criteria, the event is also considered for the $\gamma + 3$ jet analysis.

To identify events with two independent parton-parton scatterings which produce γ+3 jet final state we use the variable defined in (2). Analogously, to be sensitive to DP events in $\gamma + 2$ jet final state, we define an azimuthal angle between p_T vectors obtained by pairing photon and leading jet p_T vectors ($\vec{p}_T^{\,A}$) and the second jet p_T vector:

$$\Delta\phi \equiv \Delta\phi\left(\vec{p}_T^{\,A},\ \vec{p}_T^{\,jet2}\right), \tag{4}$$

where $\vec{p}_T^{\,A} = \vec{p}_T^{\,\gamma} + \vec{p}_T^{\,jet1}$. Figure 3 illustrates a possible disposition of photon and jets transverse momenta vectors in $\gamma + 2$ jet events.

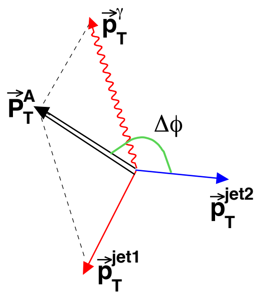

Figure 3: Diagram showing the p_T vectors of the γ+leading jet system (p_T^A), and p_T^{jet2} in $\gamma + 2$ jet events.

We consider a few MPI models and two models without MPI simulated by PYTHIA [9] and SHERPA [10] MC generators. Figure 4 shows the measured cross section for the two angular variables ΔS (left plot) and $\Delta\phi$ (right plot). The data have a good sensitivity to the various MPI models, which predictions vary significantly and differ from each other by up to a factor 2 at small ΔS and $\Delta\phi$, i.e. in the region where the relative DP contribution is expected to be highest.

From these plots we may conclude that: (a) a large difference between single parton-parton interaction (SP) models and data confirms a presence of DP events in the data sample; (b) the data favor the predictions of the MPI models with Perugia-0, S0 and Sherpa MPI tunes with p_T-ordered parton showers; (c) the predictions from tune A and DW MPI models are disfavored. It is important that our preferable choice of MPI models is stable for all our measurements.

In $\gamma + 2$ jet events in which the second jet is produced in the additional independent parton interaction, the $\Delta\phi$ distribution should be flat. Using this fact and also SP prediction for $\Delta\phi$, we can get the DP fractions from a fit to data. The distributions in data, SP, and DP models, as well as a sum of the SP and DP distributions, weighted with their respective fractions for $15 < p_T^{jet2} < 20$ GeV, are shown in the left plot of Fig. 6. The DP fractions in the $\gamma + 2$ jet samples decrease in the bins of p_T^{jet2} as $(11.6 \pm 1.0)\%$ for $15 - 20$ GeV, $(5.0 \pm 1.2)\%$ for $20 - 25$ GeV, and $(2.2 \pm 0.8)\%$ for $25 - 30$ GeV. To determine the fractions as a function of $\Delta\phi$, we perform a fit in the different $\Delta\phi$ regions by excluding the bins at high $\Delta\phi$. We find that they grow significantly towards the smaller angles and are higher for smaller p_T^{jet2} (right plot of Fig. 6).

We also estimate the fraction of $\gamma + 3$ jet events from triple parton interactions (TP) in data as a function of p_T^{jet2}. In $\gamma + 3$ jet TP events, the three jets come from three different parton

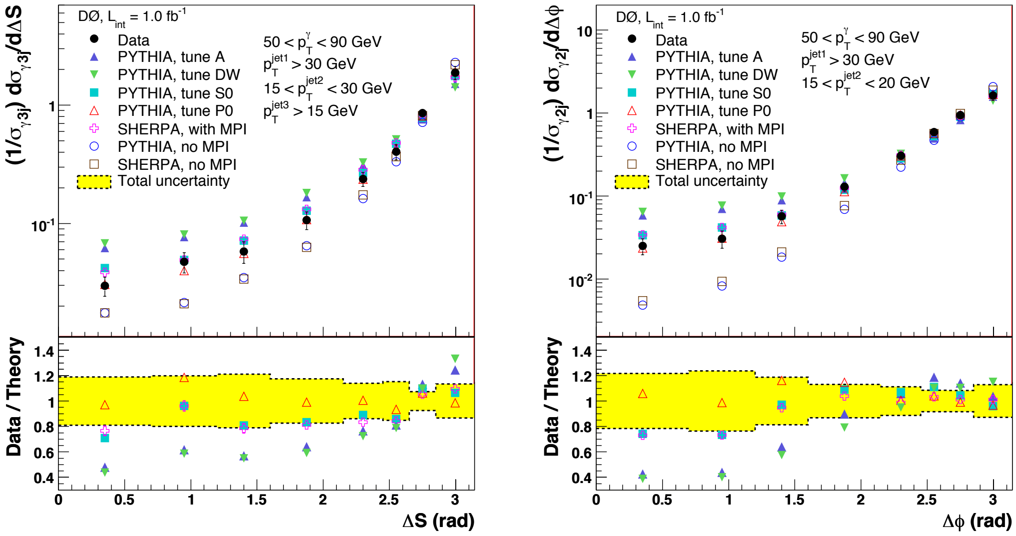

Figure 4: Left: Normalized differential cross section in the γ+3-jet events, $(1/\sigma_{\gamma 3j})\ d\sigma_{\gamma 3j}/d\Delta S$, in data compared to MC models and the ratio of data over theory, only for models including MPI, in the range $15 < p_T^{\rm jet2} < 30$ GeV. Right: Normalized differential cross section in $\gamma+2$-jet events, $(1/\sigma_{\gamma 2j})\ d\sigma_{\gamma 2j}/d\Delta\phi$, in data compared to MC models and the ratio of data over theory, only for models including MPI, in the range $15 < p_T^{\rm jet2} < 20$ GeV.

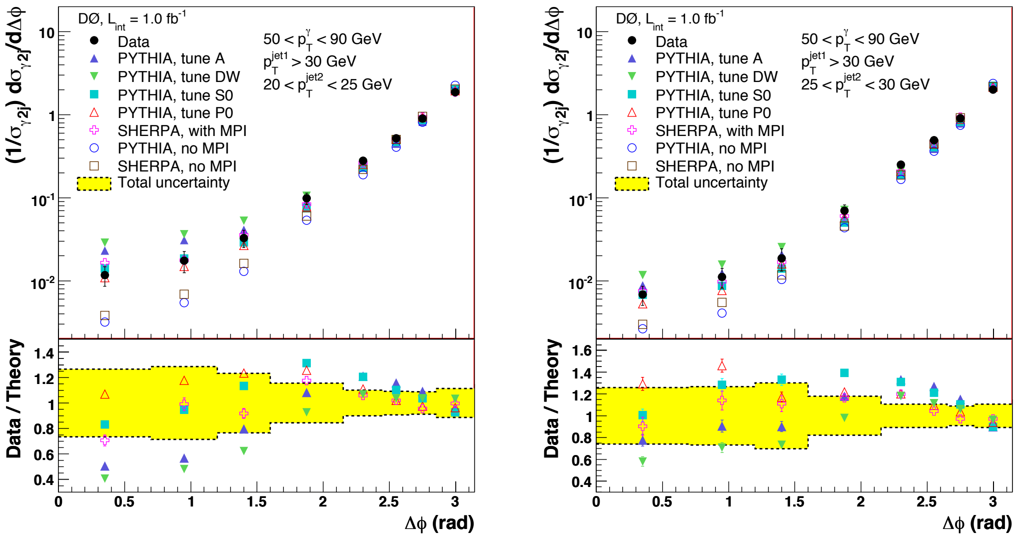

Figure 5: Normalized differential cross sections in $\gamma+2$-jet events, $(1/\sigma_{\gamma 2j})\ d\sigma_{\gamma 2j}/d\Delta\phi$, in data compared to MC models and the ratio of data over theory, only for models including MPI, in the range $20 < p_T^{\rm jet2} < 25$ GeV (left) and $25 < p_T^{\rm jet2} < 30$ GeV (right).

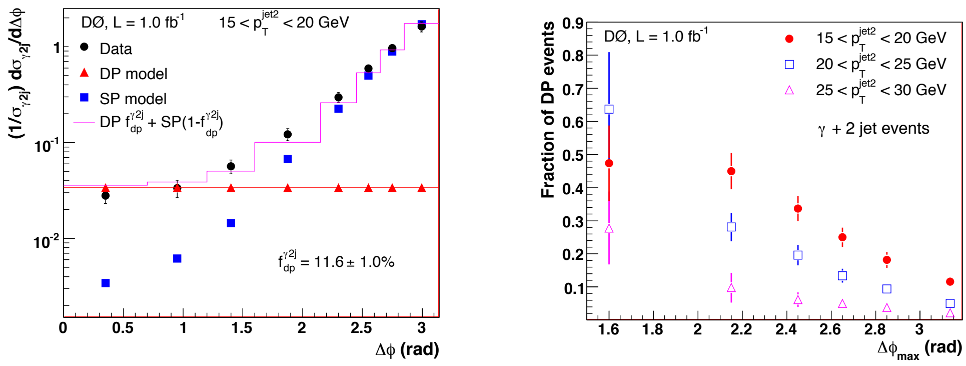

Figure 6: Left: the $\Delta\phi$ distribution in data, SP, and DP models, and the sum of the SP and DP contributions weighted with their fractions for $15 < p_T^{\rm jet2} < 20$ GeV. Right: the fractions of DP events with total uncertainties in $\gamma + 2$ jet final state as a function of the upper limit on $\Delta\phi$ for the three $p_T^{\rm jet2}$ intervals.

interactions, one γ + jet and two dijet final states. In each of the two dijet events, one of the jets is either not reconstructed or below the 15 GeV p_T selection threshold. The fractions of TP events in the $\gamma + 3$ jet data have been estimated and are shown in Fig. 7. As we see, they vary in the $p_T^{\rm jet2}$ bins as $(5.5 \pm 1.1)\%$ for $15 - 20$ GeV, $(2.1 \pm 0.6)\%$ for $20 - 25$ GeV, and $(0.9 \pm 0.3)\%$ for $25 - 30$ GeV.

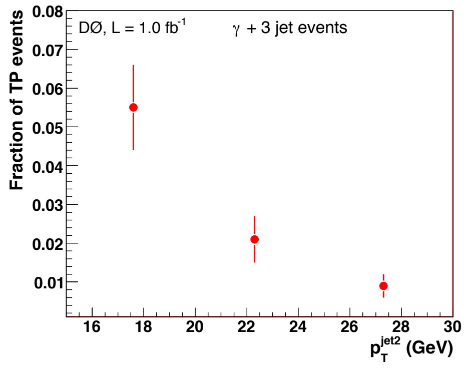

Figure 7: Fractions of $\gamma + 3$ jet events with triple parton interactions in the three $p_T^{\rm jet2}$ intervals.

4 Conclusions

In recent DØ measurements we have studied properties of events with multiple parton interactions using $\gamma + 3$ jet and $\gamma + 2$ jet final states. We measured fractions of DP events which vary from 46.6% to 23.5% in $\gamma + 3$ jet and from 11.6% to 2.2% in $\gamma + 2$ jet events at $15 < p_T^{\text{jet2}} < 20$ GeV and $25 < p_T^{\text{jet2}} < 30$ GeV respectively. For the first time the triple event fraction has been determined in $\gamma + 3$ jet events. It drops from 5.5% to 0.9% in the same p_T^{jet2} intervals. The process independent parameter σ_{eff}, which defines the rate of DP events has been measured and found to be $\sigma_{\text{eff}}^{\text{ave}} = 16.4 \pm 0.3(\text{stat}) \pm 2.3(\text{syst})$ mb. Measured ΔS and $\Delta\phi$ cross sections can be useful to tune theoretical MPI models. As an application, we studied events with W+dijet final state, produced in DP interactions. We found that these events can compose quite sizable background to the associated HW production with $H \to b\bar{b}$ decay [11]. Its relative fraction is found to be 4–8% in the dijet mass region $115 < M_{jj} < 150$ GeV. A set of angular and p_T variables that are sensitive to the difference between the HW and DP kinematics was suggested. A neural network built using these variables allows to significantly suppress the DP background to a desirable level.

References

[1] DØ Collaboration, Nucl. Instrum. Methods Phys. Res. A **565** (2006) 463.

[2] G.C. Blazey *et al.*, arXiv:hep-ex/0005012.

[3] DØ Collaboration, Phys. Rev. D **81** (2010) 052012.

[4] AFS Collaboration, Z. Phys. C **34** (1987) 163.

[5] UA2 Collaboration, Phys. Lett. B **268** (1991) 145.

[6] CDF Collaboration, Phys. Rev. D **47** (1993) 4857.

[7] CDF Collaboration, Phys. Rev. D **56** (1997) 3811.

[8] DØ Collaboration, Phys. Rev. D **83** (2011) 052008.

[9] T. Sjöstrand *et al.*, J. High Energy Physics **0005** (2006) 026.

[10] T. Gleisberg *et al.*, J. High Energy Physics **0902** (2009) 007.

[11] D. Bandurin, G. Golovanov and N. Skachkov, J. High Energy Physics **1104** (2011) 054.