PROCEEDINGS OF SCIENCE

Preliminary Results on Multiple Parton Interactions from HERA and TEVATRON

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Recently the new results on measuring of multi-parton interactions (MPI) came from H1 and D0 Collaborations. Photoproduction data of HERA-I ($\sqrt{s} = 318$ GeV) recorded by the H1 experiment in 1999-2000 with a luminosity L =48 pb^{-1} are analysed by requiring dijets with transverse momenta of at least 5 GeV. The two jets define in azimuth a towards region (leading jet) and an away region (2nd jet) and transverse regions between them. The charged particle multiplicity is measured in these regions as a function of the variables x_γ and PT (leading jet). PYTHIA predictions including contributions of MPI are able to describe the measurement, whereas without them they lie below the measurements, especially at low x_γ, the region of enhanced contributions from the resolved photon. The D0 experiment used a sample of $\gamma + 3$ jets events (collected in RunII with an integrated luminosity of about L =1 fb^{-1}) to determine the fraction of events with double parton (DP) scattering in a single $p\bar{p}$ collision at $\sqrt{s} = 1.96$ TeV. The DP fraction ($f_{\rm DP}$) and effective cross section ($\sigma_{\rm eff}$), a process-independent scale parameter related to the parton density inside the nucleon, are measured in three intervals of the second (ordered in p_T) jet transverse momentum p_T^{jet2} within the range $15 \leq p_T^{jet2} \leq 30$ GeV. In this range, $f_{\rm DP}$ varies between $0.23 \leq f_{\rm DP} \leq 0.47$, while $\sigma_{\rm eff}$ has the average value $\sigma_{\rm eff}^{\rm ave} = 16.4 \pm 0.3({\rm stat}) \pm 2.3({\rm syst})$ mb.

European Physical Society Europhysics Conference on High Energy Physics
July 16-22, 2009
Krakow, Poland

*Speaker.

PoS(EPS-HEP 2009)301

1. Introduction

The multi-parton interactions are not well studied yet. The results obtained in the last two years (see [1] and [2]) are presented here. These processes are of interest from the point of view of QCD as well as a possible background for searches of New Physics signals at Tevatron and LHC.

2. Study of Multiple Parton Interaction in photoproduction at HERA

The first measurement of MPI in ep-scattering was done by H1 in 1996 [3]. In the recent paper [1] the photoproduction events are selected by requiring a signal in the electron tagger which has acceptance in the inelasticity range 0.3< y <0.65, which results in $Q^2 < 0.01$ GeV^2 . Jets are selected with the inclusive k_t -jet algorithm using the information from tracks and clusters. At least two jets are required with $P_T^{jet} > 5$ GeV within a pseudorapidity range -1.5 < η_{lab} <1.5. The jet with the highest P_T^{jet} defines the leading jet, Jet1. From the jets the value x_γ is calculated:

$$x_\gamma = \frac{\Sigma_{h\in Jet_1}(E-P_z)+\Sigma_{h\in Jet_2}(E-P_z)}{\Sigma_h(E-P_z)} \tag{2.1}$$

Tracks are selected having a P_T^{track} > 150 MeV within $|\eta|$ <1.5. The difference in azimuthal angle $\Delta\phi = \phi_{Jet1} - \phi_i$ with i running over all charged particles (h) satisfying the above cuts, is calculated, with the leading jet set to $\phi = 180^o$. Four different regions in azimuth with respect to the leading jet are defned (see Fig.1, **a)**): 1) the toward region (including the leading jet) with $120^o < \Delta\phi < 240^o$; 2) the away region with $300^o < \Delta\phi < 60^o$; the transverse region which consists of two parts: 3) $60^o < \Delta\phi < 120^o$ and 4) $240^o < \Delta\phi < 300^o$.

In the transverse region the scalar sum of the transverse momenta $E_t^{sum} = \Sigma_i^{tracks} P_T^i$ is calculated and the region with the higher E_t^{sum} is defned as the **high activity** region. The direction of ϕ is defined such, that the *high activity* is always $240^o < \Delta\phi < 300^o$.

In quasi-real photoproduction ($Q^2 \approx 0$) the photon has a point-like as well as a hadronic (resolved) component. According to the model used in PYTHIA [4] (see also [5]) multi-parton interactions are expected for resolved photons ($x_\gamma < 1$) but not for the point-like photons which have $x_\gamma \approx 1$. The results presented in the following are always shown for two regions in x_γ: a resolved photon enriched region with x_γ < 0.7 and a point-like photon enriched region with x_γ > 0.7. The average track multiplicity as a function of $\Delta\phi$ is shown in Figs. 1 **b**), **c**) for these two regions in x_γ.

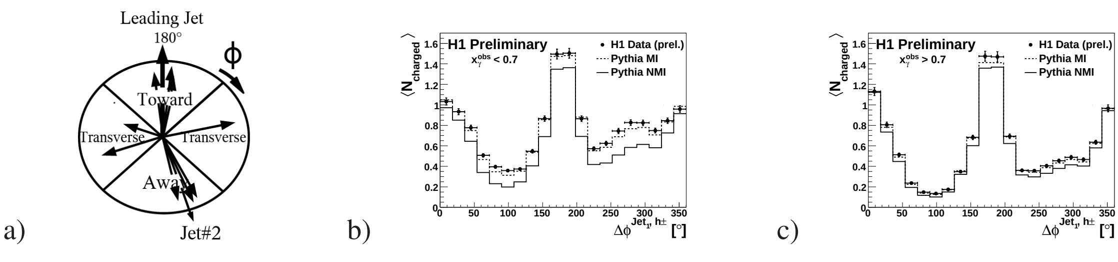

Figure 1: **a)** *Toward, away and transverse regions defined. In the toward region the leading jet is always at* $\phi = 180^o$ *and is the reference to define the other regions.* **b)** *and* **c)** *Charged particle multiplicity for* x_γ < *0.7 (***b***) and for* x_γ > *0.7 (***c***). Data is compared to PYTHIA with MPI (MI) and without MPI (NMI).*

One can see clearly the leading jet which is by definition at $\Delta\phi \approx 180^o$, the second jet at $\Delta\phi \approx 0^o$ and $\Delta\phi \approx 360^o$ as well as contributions of a third jet which is in the region of $\Delta\phi > 240^o$ (

high activity). The data are compared to predictions of PYTHIA. In the large x_γ region $x_\gamma > 0.7$ (see Fig.1**c**)) the effect of MPI is very small. In a resolved photon enriched region $x_\gamma < 0.7$ (see Fig.1**b**)) the inclusion of multi-parton interactions clearly improves the description in the transverse regions as well as in the toward and away regions.

Figure 2 shows the average charge particle multiplicity $< N_{charged} >$ dependence on P_T^{Jet1} separatly for all four angle regions presented in the plot **a)** of Fig1. Thus, plots **a)** and **b)** of Fig.2 demonstraite this dependence in the toward regions: $x_\gamma < 0.7$ and $x_\gamma > 0.7$, respectively, while plots **c)** and **d)** illustrate the P_T^{Jet1} dependence in the away region for $x_\gamma < 0.7$ and $x_\gamma > 0.7$, respectively. In the region of $x_\gamma > 0.7$ the measurements are reasonably well described with a simulation containing only one hard interaction whereas in the region $x_\gamma < 0.7$ this is clearly not enough, especially at the lower values of P_T^{Jet1}. Including multi-parton interactions brings the prediction in good agreement with the measurement. The same conclusion about the presence of MPI contribution in the resolved photon region $x_\gamma < 0.7$ can be done by comparing the plots **e)** and **g)** of Fig.2 given, respectively, for the *high activity* and *low activity* intervals of the transverse region (see plot **a)** of Fig1), with their analogs (plots **f)** and **h)** of Fig.2) done for the point-like photon enriched aria $x_\gamma > 0.7$.

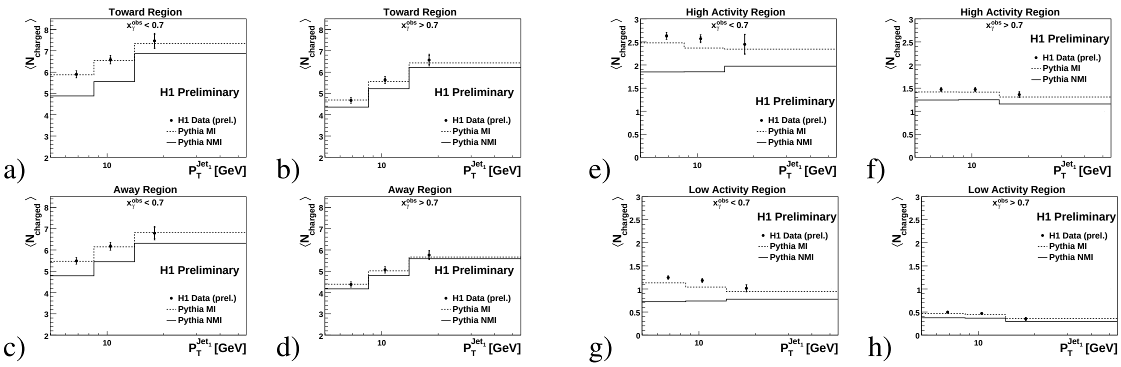

Figure 2: Charged particle multiplicity versus P_T^{Jet1} in four angle regions for x_γ< 0.7 and x_γ> 0.7

The analysis was completed by investigation whether the measurements can also be described by including more higher order QCD radiation. It was shown, that the charged particle multiplicity in the transverse region cannot be accounted for by increasing the amount of initial and final state radiation. It was also observed that MPI simulation describes the measurement better when the colour structure of the final state is chosen such that long string lengths are preferred.

3. Double parton interactions in γ+3 jet events in $p\bar{p}$ collisions at $\sqrt{s}$ =1.96 TeV

It is commonly assumed that high energy inelastic scattering of nucleons occurs through a single parton-parton interaction and the contribution from double (A and B) parton collisions (see its schematic view in Fig.3 **a)**) is a negligible one. The DP cross section can be defined as:

$$\sigma_{DP} \equiv \frac{\sigma^A \sigma^B}{\sigma_{\text{eff}}} \tag{3.1}$$

Here σ_{A} and σ_{B} are the cross sections of two independent partonic scatterings A and B. The normalization factor σ_{eff} (it has the units of cross section) is a process-independent parameter that can be related to the parton spatial density (see [6], [7], [8], [9], [4], [5]).

Table 1: Summary of the results, experimental parameters, and event selections for the double parton analyses performed by the AFS, UA2 and CDF Collaborations.

Experiment	$\sqrt{s}$ (GeV)	Final state	p_T^{min} (GeV)	η range	$\sigma_{\rm DP}$, $f_{\rm DP}$
AFS (pp)	63	4 jets	$p_{\rm T}^{\rm jet} > 4$	$\lvert\eta^{\rm jet}\rvert < 1$	$\sigma_{\rm DP}/\sigma_{\rm dijet} = (6 \pm 1.5 \pm 2.0)\%$
UA2 ($p\bar{p}$)	630	4 jets	$p_{\rm T}^{\rm jet} > 15$	$\lvert\eta^{\rm jet}\rvert < 2$	$\sigma_{\rm DP} = 0.49 \pm 0.20$ nb
CDF ($p\bar{p}$)	1800	4 jets	$p_{\rm T}^{\rm jet} > 25$	$\lvert\eta^{\rm jet}\rvert < 3.5$	$\sigma_{\rm DP} = (63^{+32}_{-28})$ nb, $f_{\rm DP} = (5.4^{+1.6}_{-2.0})\%$
CDF ($p\bar{p}$)	1800	$\gamma/\pi^o + 3$ jets	$p_{\rm T}^{\rm jet} > 5$, $p_{\rm T}^{\gamma} > 16$	$\lvert\eta^{\rm jet}\rvert < 3.5$, $\lvert\eta^{\gamma}\rvert < 0.9$	$f_{\rm DP} = (52.6 \pm 2.5 \pm 0.9)\%$

To date there were only four dedicated measurements of double parton scattering: the AFS experiment in pp collisions at $\sqrt{s} = 63$ GeV [6], UA2 in $p\bar{p}$ collisions at $\sqrt{s} = 630$ GeV [7] and twice by CDF in $p\bar{p}$ collisions at $\sqrt{s} = 1.8$ TeV [8], [9] (see Table 1). The four-jet final state has been used in the first three measurements while the last, the most precise one, CDF measurement [9] have used $\gamma/\pi^0 + 3$ jets events (accumulated with L =16 pb^{-1}) having the p_T of the second jet (ordered in p_T) within the interval $5 < p_T^{\rm jet2} < 7$ GeV and $p_T^{\gamma} > 16$ GeV.

Three DP signal diagrams (DP Type I, DP Type II, DP Type III), which give the most conribution to the cross section, are shown in plot **b)** of Fig.3 together with the diagram of single parton-parton (SP) collision with hard gluon bremsstrahlung $qg \to q\gamma gg$, $q\bar{q} \to g\gamma gg$ that give the same $\gamma +$ 3jets signature. In plot **b)** the light and bold lines correspond to two separate parton interactions. The dotted line represents unreconstructed jet. The SP events together with double interaction (DI) events (i.e. events produced in two distinct hard interactions occurring in two separate $p\bar{p}$ collisions in the same beam crossing) provide an essential background.

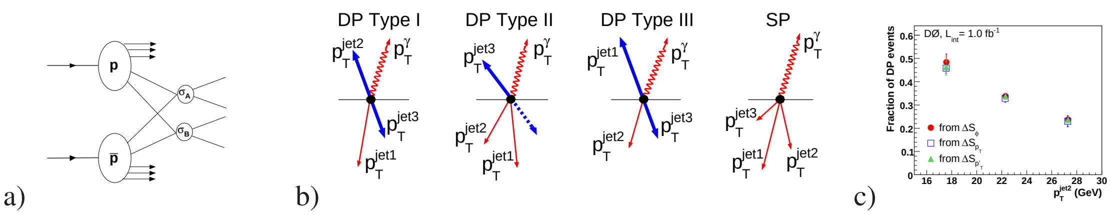

Figure 3: **a)** Schematical diagram of a double parton scattering event. **b)** Diagrams of DP Types I, II, III and SP events. For DP events, the light and bold lines correspond to two separate parton interactions. The dotted line represents unreconstructed jet. **c)** Fractions of DP events in the three "p_T^{jet2}" intervals.

A new technique for extracting $\sigma_{\rm eff}$ was proposed in [9]. It uses only quantities determined from data analysis and minimizes the impact of theoretical assumptions used in previous three measurements with a 4-jet final state [6, 7, 8]. This method was used here. The value of $\sigma_{\rm eff}$ was extracted by comparing the number of the observed DP $\gamma +$ 3 jets events occurring in one $p\bar{p}$ collision to the number of DI $\gamma +$ 3 jets. The knowledge of cross section of inelastic non-diffractive (hard) $p\bar{p}$ interactions σ_{hard} was needed also. It was found by extrapolation of the values σ_{hard}, measured by CDF in RunI, up to $\sqrt{s} = 1.96$ TeV.

D0 experiment use $\gamma + 3$ jets events, collected at $\sqrt{s} = 1.96$ TeV with the integrated luminosity L =1.02 ± 0.06 fb^{-1} in three intervals of the second jet transverse momentum: $15 < p_T^{jet2} < 20$

GeV, $20 < p_T^{jet2} < 25$ GeV and $25 < p_T^{jet2} < 30$ GeV. The events used in this analysis should first pass triggers based on the identification of high p_T clusters in the EM calorimeter with loose shower shape requirements for photons. These triggers are 100% efficient for $p_T^{\gamma} > 35$ GeV. Jets are reconstructed using the iterative midpoint cone algorithm with a cone size of $R_{\eta,\phi} = 0.7$. Jets must satisfy quality criteria which suppress background from leptons, photons, and detector noise effects. The jet transverse momenta are corrected to the particle level. Each event must contain at least one γ 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 γ 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 high p_T^{γ} scale (i.e. the scale of the first parton interaction) allows a better separation of the first and second parton interactions in momentum space.

The fraction of DP events is determined by using a set of ΔS_{ϕ} , ΔS_{p_T} , and $\Delta S_{p'_T}$ variables sensitive to the kinematic configurations of the two independent scatterings of parton pairs, specifically to the difference between the p_T imbalance of the two object pairs in DP and SP $\gamma+$ 3jets events. The $\Delta S_{p_T}, \Delta S_{p'_T}$ variables are used in [7, 9], while the ΔS_{ϕ} is first introduced in this measurement.

The extracted values of DP fraction are shown in Fig.3, **c**). It is seen that the DP fraction, measured in three (of equal width) intervals of the second (ordered in p_T) jet transverse momentum p_T^{jet2}, gives an essential contribution to total cross section (from about 50% down to 25%) to the total cross section within the $15 < p_T^{jet2} < 30$ GeV range. It is worth mentioning that in addition to the essential advancement into the region of much higher p_T^{jet2}, the present D0 measurement used (in contrast to the RunI CDF measurement [9]) the jets with the calibrated energy scale and the high energy photons from the interval $60 < p_T^{\gamma} < 80$ GeV, where the photon purity is well known from previous D0 RunII measurements. The found sizable DP contribution can provide an important background for searches of deviations from Standard Model at Tevatron and it indicates the importance of performing the analogous measurements of double parton interactions at LHC for searches of Higgs boson and New Physics signals.

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