PROCEEDINGS OF SCIENCE

Recent CMS and CMS-TOTEM results on diffraction

PoS(DIS2019)058

Ekaterina Kuznetsova*
On behalf of the CMS Collaboration
PNPI NRC «Kurchatov Institute», Russia
E-mail: ekaterina.kuznetsova@cern

The paper overviews common CMS and TOTEM studies on single-diffractive di-jet production, and CMS measurements of the jet-gap-jet event production. The obtained results are compared to the corresponding Monte-Carlo generator predictions, and contribution of the soft rescattering is evaluated in terms of gap survival probability.

XXVII International Workshop on Deep-Inelastic Scattering and Related Subjects - DIS2019
8-12 April, 2019
Torino, Italy

*Speaker.

1. Introduction

Mediated by pomeron, a hypothetical color-singlet object possessing the vacuum quantum numbers, diffractive processes are characterized by gaps in rapidities of final state particles. In contrast to non-diffractive scattering, when the rapidity gaps are suppressed exponentially with their size, in diffractive processes the rapidity gaps have almost equal probability for any range. The small proton fractional energy loss in diffractive scattering determines another experimental signature of such processes - at least one of incoming protons remains intact, or becomes excited into a low mass state.

Hard diffractive processes can be described within the perturbative Quantum Chromodynamics (pQCD), however are affected by soft rescattering between spectator partons or partons emerging from the hard inrteraction. This changes the topology of final states, significantly populating the rapidity gaps with products of the soft interactions, as was demonstrated at Tevatron [1].

Hard processes resulting in two jets separated by a large rapidity gap are also mediated by color-singlet exchange, however differ from the usual diffractive production by a larger squared four-momentum transfered between the protons. Such processes were described by Mueller and Tang [2] within the BFKL approach. In this case the rapidity gap is also suppressed due to the soft rescattering.

This paper overviews common CMS and TOTEM studies on diffractive di-jet production [3], and CMS measurements of the jet-gap-jet production [4]. The obtained results are compared to the corresponding Monte-Carlo generator predictions, and the contribution of soft rescattering is evaluated in terms of gap survival probability. In both studies detection of large rapidity gaps in the CMS detector was exploited, so the analyses were performed using the data obtained during special low luminosity runs to minimize contribution of simultaneous proton-proton collisions.

2. Single diffractive di-jet production

The analysis is performed on a common data set collected simultaneously with the CMS and TOTEM detectors, at the $\sqrt{s} = 8\,\text{TeV}$ proton-proton low luminosity collisions with special beam optics settings. Events with a primary vertex and two jets with $p_T > 40$ GeV and $|\eta| < 4.4$ recoded by the CMS detector were considered in the analysis if coincided with at least one proton track candidate found in the TOTEM Roman Pot detectors. The Roman Pots used in the data taking provide detection of intact protons and direct reconstruction of the squared four-momentum transfer t and fractional energy loss ξ in the following kinematic region: $0.03\ \text{GeV}^2 < |t| < 1.00\ \text{GeV}^2$, $0.0 < \xi < 0.1$. ξ evaluated from energies and longitudinal momenta of all particles detected by the CMS, $\xi^{\pm}_{CMS} = \Sigma_i(E^i \mp p^i_z))/\sqrt{s}$, has significant underestimation due to the limited detector acceptance. Nevertheless, comparison of ξ values measured by TOTEM and CMS for the same event helps to reject a significant fraction of the background and to correct the results for the irreducible background contribution. The background is formed by beam halo particles detected in the Roman Pots simultaneously with a non-diffractive di-jet event, or by an overlap of two simultaneous diffractive and non-diffractive events.

Corrected and unfolded differential cross-sections, $d\sigma/dt$ and $d\sigma/d\xi$ were obtained and compared to the corresponding predictions by POMWIG [5] and Pythia8 [6] MC generators. Both of them use the diffractive parton distribution function (dPDF) evaluated from NLO (POMWIG) and LO (Pythia8) dPDF fits to deep inelastic scattering data. To account for the soft rescattering contribution, POMWIG provides tunable rapidity gap survival probability, $< S^2 >$, while Pythia8 implements multiple parton interactions (MPI) for a proton-Pomeron system. The default inclusive diffraction model of Pythia8 was used with underlying event tunes 4C and CUETP8M1, also the Dynamic Gap (DG) hard diffraction model [7] based on the MPI was considered. The obtained results are shown in Fig. 1. Comparing the data to the POMWIG prediction for $< S^2 >= 1$, the gap survival probability was evaluated as 7.4%. The cross-section predictions obtained with POMWIG after the gap survival probability correction and with the Pythia8 DG tune were found to be in a good agreement with the data. To estimate the actual gap suppression, the dPDF normalisation factor was corrected to account for the proton dissociation, that brought the gap survival probability to $(9 \pm 2)\%$.

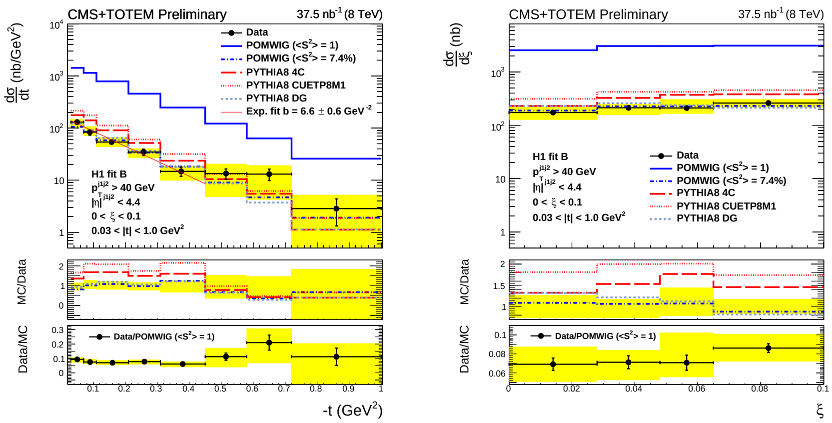

Figure 1: Differential cross section of the single diffractive di-jet production as a function of t (left) and ξ (right), together with the corresponding MC predictions. POMWIG predictions are shown for the gap survival probabilities of 1 and 7.4% [3].

As seen in Fig. 1, left, the single diffractive di-jet cross-section as a function of t has exponential behaviour and was fitted as $d\sigma/dt \propto e^{-b|t|}$ for small t values, 0.03 GeV$^2 < |t| < 0.45$ GeV^2, providing $b = 6.6 \pm 0.6^{+1.0}_{-0.8}$ GeV^{-2}.

Also the single-diffractive (SD) di-jet yield was obtained as a ratio of SD to inclusive di-jet cross-section, $R(x) = (\sigma^{pX}_{jj}(x)/\Delta\xi)/\sigma_{jj}(x)$, per unit of ξ, as a function of the momentum fraction of the partons initiating the hard scattering, estimated as $x^{\pm} = \Sigma_{jets}(E^{jet} \mp p_z^{jet}))/\sqrt{s}$. Fig. 2, left, shows the results compared to the corresponding MC predictions. As for the differential cross-section, the POMWYG corrected for the gap survival probability, and the Pythia8 DG model without any corrections are in a good agreement with the data. Fig. 2, right, compares the results to the CDF measurements done for $\sqrt{s} = 1.96$ TeV for jets with $Q^2 \approx 100$ GeV^2, $|\eta| < 2.5$ and $0.03 < \xi < 0.09$. The reduction of the diffractive di-jet production yield with respect to the CDF data is in agreement with the previous CDF observations, when a decrease of the ratio of diffractive to non-diffractive cross-sections for larger center-of-mass energies was seen comparing the results observed for $\sqrt{s} = 630$ and 1800 GeV.

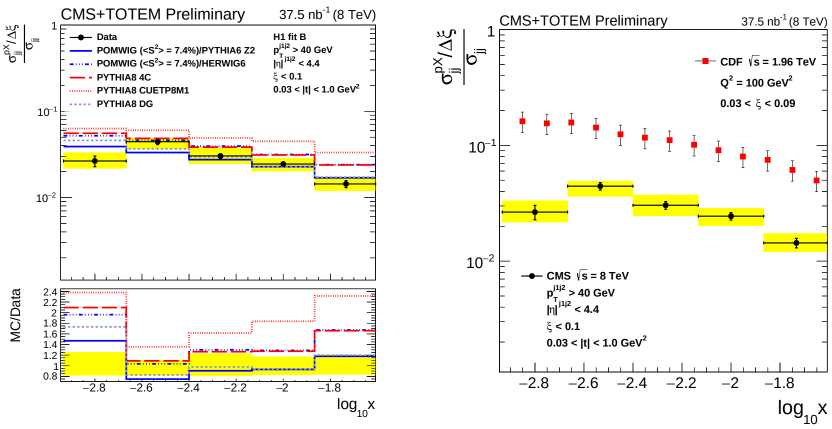

Figure 2: Single-diffractive (SD) di-jet yield estimated as a ratio of SD to inclusive di-jet cross-section, compared to **left:** the corresponding MC generator predictions. For the POMWIG case the non-diffractive di-jets were generated with Pythia6 Z2 tune and HERWIG6. **right:** CDF results obtained for $\sqrt{s} = 1.96$ TeV for jets with $Q^2 \approx 100\,\text{GeV}^2$, $|\eta| < 2.5$ and $0.03 < \xi < 0.09$ [3].

3. Colour Singlet Exchange in jet-gap-jet events

The analysis was performed on low luminosity proton-proton collision data with $\sqrt{s} = 7$ TeV. Events with two leading jets reconstructed at opposite sides of the CMS detector within $1.5 < |\eta^{jet}| < 4.7$ regions were considered in the analysis if both jets had p_T above 40 GeV. The event sample was divided in three sub-sets according to the second leading jet p_T: $p_T^{jet2} = 40-60$, $60-100$ and $100-200$ GeV. The central detector region, $|\eta| < 1$, was used to study the charged track multiplicity between the two jet, N_{track}, counting the number of reconstructed charged particles with $p_T > 200$ MeV. The N_{track} distributions were compared at the detector level to the corresponding Pythia6 [8] and HERWIG6 [9] predictions. Pythia6 is based on the leading order DGLAP evolution equations, and the Z2* tune describes well underlying event data at $\sqrt{s} = 7$ TeV. HERWIG6 was used to simulate events with hard color-singlet exchange (CSE) between two partons within the Mueller and Tang model based on leading-logarithm (LL) BFKL calculations. To compare to the data, Pythia6 N_{track} distributions were normalized to the total number of events with $N_{track} > 3$ in the corresponding data samples. The HERWIG6 distributions, containing only CSE events, were normalized to the number of data events having no tracks in the central region, $N_{track} = 0$. Fig. 3, left, shows the obtained distributions for the subset of events with $p_T^{jet2} = 100-200$ GeV. The DGLAP-based prediction of Pythia6 is unable to describe the excess in the low track multiplicity region observed in the data, while the combined sample of Pythia6 and HERWIG6 CSE events describes the data quite well. Similar results were obtained with other two data subsets for $p_T^{jet2} = 40-60$ and $60-100$ GeV.

To estimate contribution of the CSE events in the data samples, a negative binomial distribution (NBD) fit of the N_{track} distribution was performed. The NBD fit is known to describe charged-particle multiplicity distribution for a wide range of collision center-of-mass energies if performed around the mean of the distribution. The NBD, fitted to the data in the range $3 < N_{track} < 35$, was extrapolated into the low track multiplicity region to represent the contribution of non-CSE

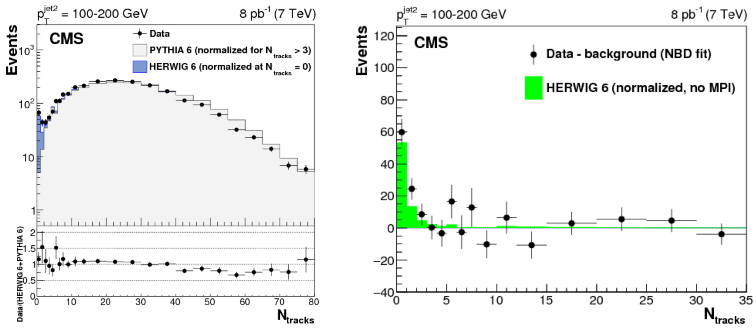

Figure 3: Left: Uncorrected distribution of the number of reconstructed tracks between the two leading jets in events with $p_T^{jet2} = 100-200$ GeV, compared to the normalized Pythia6 (inclusive di-jets) and HERWIG6 (CSE) predictions (top), and the ratio of the data to the combined MC sample (bottom). **Right:** the obtained N_{track} distribution for CSE events for the $p_T^{jet2} = 100-200$ GeV data sample, compared to the normalized HERWIG6 predictions without underlying event simulation [4].

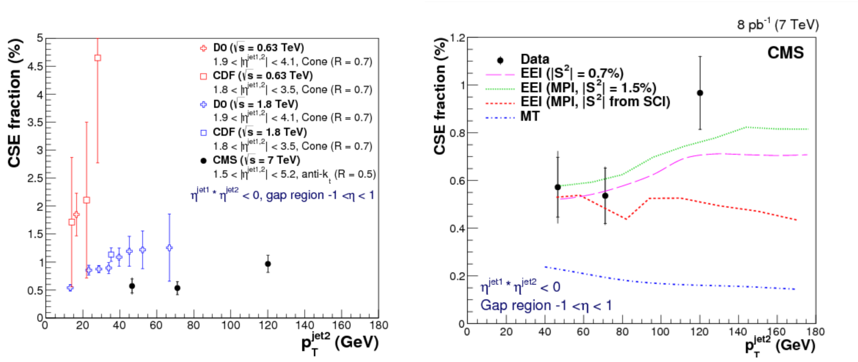

Figure 4: Fraction of di-jet events with a central gap, f_{CSE}, as a function of p_T^{jet2} at $\sqrt{s} = 7$ TeV, compared to : **left:** the D0 and CDF results at $\sqrt{s} = 0.63$ and 1.8 TeV. **right:** predictions of the Mueller and Tang (MT) and the Ekstedt, Enberg, and Ingelman (EEI) models with three different treatments of soft rescattering [4].

events, referred to as background in Fig. 3, right. To obtain N_{track} distribution for the CSE events, the background contribution was subtracted from the data. The obtained results are in a good agreement with the corresponding normalized HERWIG6 distributions for all considered sets of p_T^{jet2}. The fraction of the CSE events, f_{CSE}, was calculated as content of statistically significant bins of the derived multiplicity distributions (Fig. 3, right), normalized to the total number of events in the analysed data sub-set. For all tree considered data sub-sets the average p_T of the second leading jets was calculated, and Fig. 4, left, shows f_{CSE} as a function of p_T^{jet2} together with the D0 and CDF results obtained for $\sqrt{s} = 0.63$ and 1.8 TeV.

Fig. 4, right, compares the results with teoretical predictions of the Mueller and Tang (MT) [10] and the Ekstedt, Enberg, and Ingelman (EEI) BFKL-based models, normalized to the leading order di-jet production rates from Pythia6 Z2* tune. The MT prediction is obtained using HERWIG6 and does not include MPI. EEI includes dominant next-to-LL corrections of the BFKL equation, and the soft rescattering contribution is accounted for with a gap survival probability without and with MPI, or with a combination of MPI and soft color interaction (SCI). For first two cases, the $< S^2 >$ value is chosen to match the data in the best way. Fig. 5 shows fraction of di-jet events

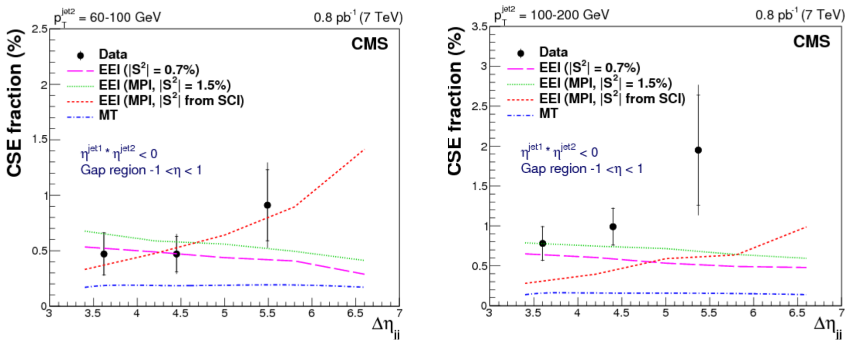

Figure 5: Fraction of di-jet events with a central gap, f_{CSE}, as a function of the jet separation, $\Delta\eta^{jj}$, for the $p_T^{jet2} = 60-100$ (left) and $100-200$ GeV (right) data sub-sets with the corresponding predictions from the MT and EEI models [4].

with a central gap, f_{CSE}, as a function of the jet separation, $\Delta\eta^{jj}$, for the $p_T^{jet2} = 60-100$ (left) and $100-200$ GeV (right), and the corresponding MT and EEI predictions. Though EEI with constant gap survival probability fits rather well the p_T^{jet2} dependence, it is not able to describe increasing probability of the CSE for large $\Delta\eta_{jj}$. The EEI with MPI and SCI describes quite well the $\Delta\eta_{jj}$ dependence of the CSE event fraction for lower p_T^{jet2}, but fails for $p_T^{jet2} \gtrsim 100$ GeV.

References

[1] CDF Collaboration, "Diffractive dijets with a leading antiproton in pp collisions at $\sqrt{s} = 1800$ GeV", Phys. Rev. Lett.84(2000) 5043

[2] A. H. Mueller and W. K. Tang, "High-energy parton-parton elastic scattering in QCD", Phys. Lett. B 284 (1992) 123

[3] CMS Collaboration, TOTEM Collaboration, "Measurement of dijet production with a leading proton in proton-proton collisions at $\sqrt{s} = 8$ TeV", CMS-PAS-FSQ-12-033, CERN-TOTEM-NOTE-2018-001, http://cds.cern.ch/record/2637333

[4] CMS Collaboration, "Study of dijet events with a large rapidity gap between the two leading jets in pp collisions at $\sqrt{s} = 7$ TeV", Eur.Phys.J. C78 (2018) no.3, 242, CMS-FSQ-12-001,C̃ERN-EP-2017-141

[5] B. E. Cox, J. R. Forshaw, "POMWIG: HERWIG for diffractive interactions", Comput. Phys. Commun. 144 (2002) 104

[6] T. Sjöstrand, S. Mrenna, and P. Skands, "A brief introduction to PYTHIA 8.1", Comput. Phys. Commun 178 (2008) 852

[7] C. O. Rasmussen and T. Sjöstrand, "Hard diffraction with dynamic gap survival", JHEP 02 (2016) 142

[8] T. Sjöstrand, S. Mrenna, P. Skands, "PYTHIA 6.4 physics and manual. JHEP 05, 026 (2006)

[9] G. Corcella et al., "HERWIG 6: an event generator for hadron emission reactions with interfering gluons (including supersymmetric processes). JHEP 01, 010 (2001)

[10] A.H. Mueller, W.-K. Tang, "High-energy parton-parton elastic scattering in QCD", Phys. Lett. B 284, 123 (1992)

[11] A. Ekstedt, R. Enberg, G. Ingelman, "Hard color singlet BFKL exchange and gaps between jets at the LHC", (2017)