Hard color-singlet exchange in dijet events in proton-proton collisions at $\sqrt{s} = 13$ TeV

Cristian Baldenegro Barrera [1] for the CMS and TOTEM Collaborations

1 The University of Kansas
c.baldenegro@cern.ch

July 27, 2021

Proceedings for the XXVIII International Workshop on Deep-Inelastic Scattering and Related Subjects, Stony Brook University, New York, USA, 12-16 April 2021
doi:10.21468/SciPostPhysProc.?

Abstract

We present a measurement of events with two jets separated by a pseudorapidity gap (jet-gap-jet). The signature is expected from hard color-singlet exchange. The jets are reconstructed with the CMS detector. The highest p_{T} jets have $p_{\mathrm{T}}^{\mathrm{jet1,2}} > 40$ GeV, with $1.4 < |\eta^{\mathrm{jet1,2}}| < 4.7$ and $\eta^{\mathrm{jet1}}\eta^{\mathrm{jet2}} < 0$. We measure the fraction of color-singlet exchange dijet events, f_{CSE}, and compare it to previous measurements and to predictions. We also study jet-gap-jet events where the colliding protons remain intact and are detected with the Roman pots of TOTEM. A larger fraction f_{CSE} is found in the latter subsample.

In this report, we present a study of two jets separated by a pseudorapidity interval void of radiation in proton-proton collisions at $\sqrt{s} = 13$ TeV [1]. The jets are reconstructed with the CMS detector [2]. The "jet-gap-jet" signature is expected from hard color-singlet exchange between partons, as shown in Fig. 1. In collisions with t-channel color-singlet exchange between partons, the net color-flow is neutralized. In perturbative quantum chromodynamics (pQCD), this can be achieved with t-channel two-gluon exchange, where one of the gluons screens the color charge of the other. In contrast, t-channel single-gluon exchange leads to a net exchange of color charges. In the latter case, the color field is such that, at the fragmentation process, numerous hadrons are produced in the η–ϕ region

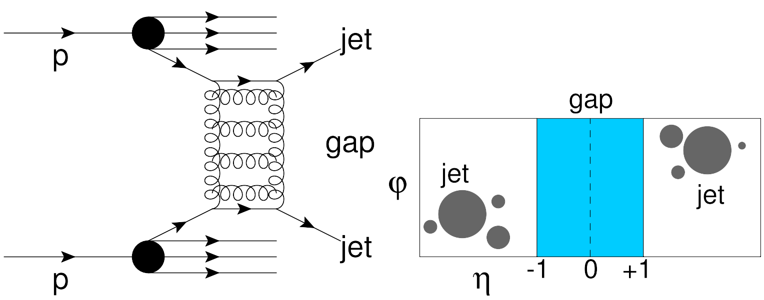

Figure 1: (Left) Schematic diagram of a jet-gap-jet event by hard color-singlet exchange in pp collisions. (Right) Jet-gap-jet event signature in the η-ϕ plane. The filled circles represent final-state particles. The shaded rectangular area between the jets denotes the interval $|\eta| < 1$ devoid of charged particles. The figure is extracted from Ref. [1].

between the final-state jets. The production of jets is mostly dominated by collisions with net color-exchange at the short-distance scattering.

The experimental signature of jet-gap-jet events is a rapidity interval void of particle production between the jets (rapidity gap). In the high-energy limit of QCD, color-singlet exchange corresponds to perturbative pomeron exchange (a two-gloun exchange with multiple virtual corrections, as shown in Fig. 1). Thus, the process can be used to probe Balitsky–Fadin–Kuraev–Lipatov (BFKL) evolution [3–5], which resums diagrams that contribute to the scattering amplitude with terms proportional to $\alpha_s^n \log^n(\hat{s}/|\hat{t}|) \lesssim \mathcal{O}(1)$ to all orders in α_s, where $\hat{s}$ and $\hat{t}$ are the partonic center-of-mass energy and four-momentum transfer squared, respectively. The Dokshitzer-Gribov-Lipatov-Altarelli-Parisi (DGLAP) dynamics are strongly suppressed in jet-gap-jet events [6–8], as expected from the Sudakov form factor for a gap between the jets. Such a Sudakov form factor is absent for color-singlet exchange dijet events.

The analysis is based on low pileup 2015 data $\sqrt{s} = 13$ TeV [1]. For this investigation, anti-k_t jets with $R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2} = 0.4$ are used. The two highest p_T jets should have $p_{\mathrm{T}} > 40$ GeV and $1.4 < |\eta^{\mathrm{jet1,2}}| < 4.7$ with $\eta^{\mathrm{jet1}}\eta^{\mathrm{jet2}} < 0$. The aforementioned η selection requirements favor t-channel color-singlet exchange to take place, and allows for a better separation of color-exchange background events from the color-singlet exchange signal events. In this study, the central pseudorapidity gap corresponds to absence of charged particle tracks between jets with $p_T^{\mathrm{ch}} > 200$ MeV and $|\eta| < 1$.

Standard dijet events, produced mostly by color-exchange, dominate at high N_{tracks} multiplicities. The high N_{tracks} region can be used to estimate the fluctuations at lower N_{tracks} , where signal events with jets produced by color-singlet exchange are expected to be present. Two data-based approaches are used to estimate the contribution of color-exchange dijet events at low multiplicities. The first one consists of forming a second set of multiplicity distributions obtained from a sample of events where the two leading jets are on the same hemisphere of the detector ($\eta^{\mathrm{jet1}}\eta^{\mathrm{jet2}} > 0$, whereas the second consists on the use of a fit based on the negative binomial distribution (NBD) function. The methods are consistent with each other, and avoid the use of model-dependent Monte Carlo generators to extract the f_{CSE} fractions, as described in detail in Ref. [1].

The measured f_{CSE} values are in the range of 0.6–1.0%. As seen in Fig.2, the ratio f_{CSE} increases with $\Delta\eta_{\mathrm{jj}}$, has a weak dependence on $p_{\mathrm{T}}^{\mathrm{jet2}}$, and increases as $\Delta\phi_{\mathrm{jj}}$ approaches π. The numerical results are tabulated in Ref. [1]. The results in Fig.2 are compared with calculations based on the BFKL framework with resummation of large logarithms of energy at next-to-leading logarithmic accuracy using leading order impact factors, and various treatments of gap survival probability effects. The implementation by Royon, Marquet, and Kepka [9,10] describes some features of the data, but is not able to simultaneously describe all aspects of the measurements. The implementation by Ekstedt, Enberg, Ingelman, and Motyka (EEIM) [11,12] describes the data in $\Delta\eta_{\mathrm{jj}}$ and $p_{\mathrm{T}}^{\mathrm{jet2}}$ within the uncertainties only when considering survival probability effects based on multiple-parton interactions (MPI) and their soft color interaction (SCI) model. The BFKL-based calculation with next-to-leading order impact factors has yet to be done, and it is possible that the comparison of the purely perturbative calculation with the data changes with this updated prediction. No significant difference in f_{CSE} is observed between the 13 TeV results and those presented by the CMS Collaboration at 7 TeV, as shown in Fig. 3. This is in contrast to the trend found at lower energies of 0.63 and 1.8 TeV by D0 and CDF, where a significant decrease of f_{CSE} with increasing $\sqrt{s}$ was observed, as illustrated in Fig. 3.

In addition to the aforementioned study, the first measurement of jet-gap-jet with an intact proton detected in the Roman pot detectors of the TOTEM experiment is presented in this analysis [1]. This corresponds to an effective "proton-gap-jet-gap-jet" topology, as

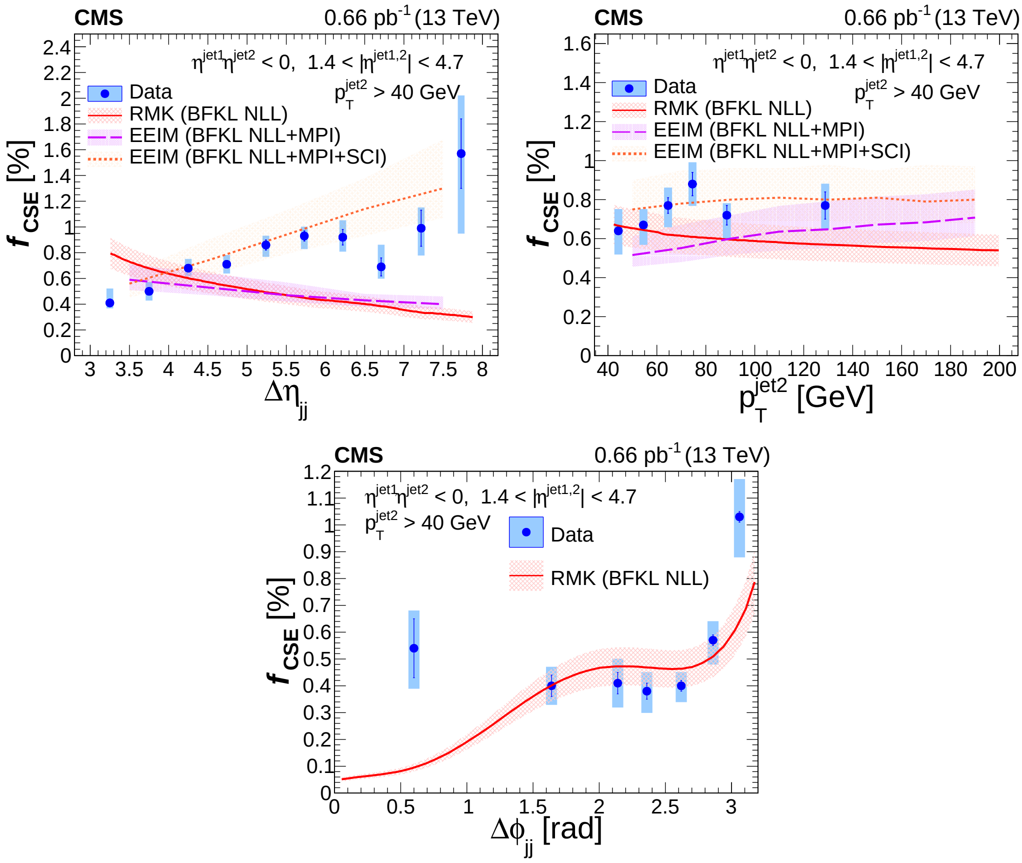

Figure 2: Fraction of color-singlet exchange dijet events, f_{CSE}, measured as a function of $\Delta\eta_{\mathrm{jj}}$, $p_{\mathrm{T}}^{\mathrm{jet2}}$, and $\Delta\phi_{\mathrm{jj}}$ in pp collisions at $\sqrt{s}$ = 13 TeV. The vertical bars represent statistical uncertainties, while boxes represent the combination of statistical and systematic uncertainties in quadrature. The results are plotted at the mean values of $\Delta\eta_{\mathrm{jj}}$, $p_{\mathrm{T}}^{\mathrm{jet2}}$, and $\Delta\phi_{\mathrm{jj}}$ in the bin. For a given plot of f_{CSE} versus a kinematic variable of interest ($p_{\mathrm{T}}^{\mathrm{jet2}}$, $\Delta\eta_{\mathrm{jj}}$, or $\Delta\phi_{\mathrm{jj}}$), the other kinematic variables are integrated over their allowed range. The red solid curve corresponds to predictions based on the RMK model [9, 10] with gap survival probability of $|\mathcal{S}|^2 = 10\%$. The EEIM model [11, 12] predictions with MPI-only contributions and $|\mathcal{S}|^2 = 1.2\%$ or MPI+SCI are represented by the purple dashed and orange dotted curves, respectively. The bands around the curves represent the associated theoretical uncertainties. The EEIM model has only small contributions far from back-to-back jets since no hard NLO $2 \to 3$ processes are included, and thus predictions are not shown for the lower panel of f_{CSE} versus $\Delta\phi_{\mathrm{jj}}$. The figure is extracted from Ref. [1].

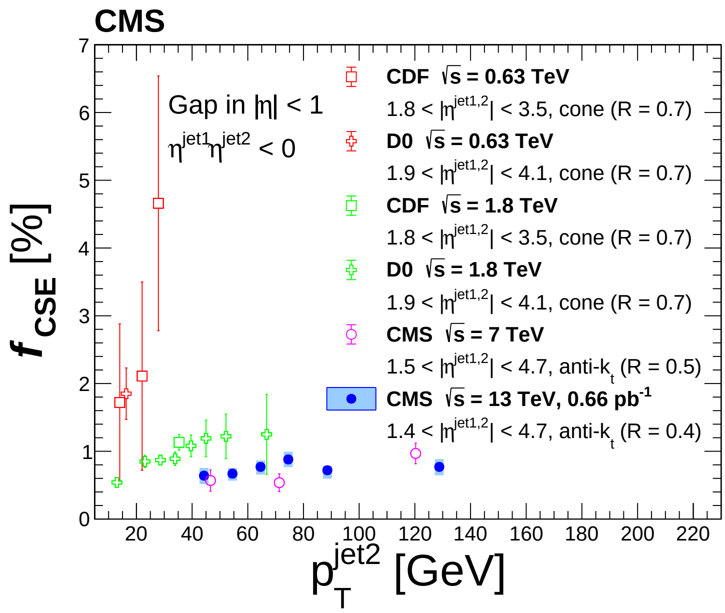

Figure 3: Fraction of color-singlet exchange dijet events, f_{CSE}, measured as a function of $p_{\mathrm{T}}^{\mathrm{jet2}}$ by D0 and CDF at $\sqrt{s} = 0.63$ (red open symbols) and 1.8 TeV (green open symbols), by CMS at 7 TeV (magenta open symbols), and the present results at 13 TeV (filled circles). The vertical bars of the open symbols represent the total experimental uncertainties. The vertical bars of the 13 TeV measurement represent the statistical uncertainties, and boxes represent the combination of statistical and systematic uncertainties in quadrature. The jet p_{T} and η requirements of the previous measurements are specified in the legend of the plot. The figure is extracted from Ref. [1].

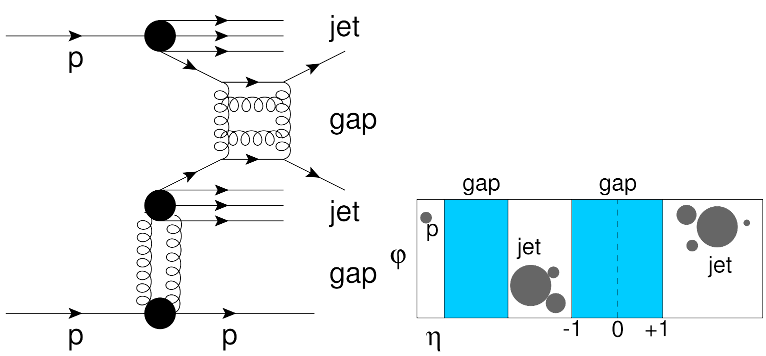

Figure 4: (Left) Schematic diagram of a jet-gap-jet event by hard color-singlet exchange with an intact proton in pp collisions. (Right) Signature in the η-ϕ plane. The filled circles represent final-state particles. The shaded rectangular areas denote the central gap region $|\eta| < 1$ devoid of charged particles and the forward gap that is inferred from the intact proton. The figure is extracted from Ref. [1].

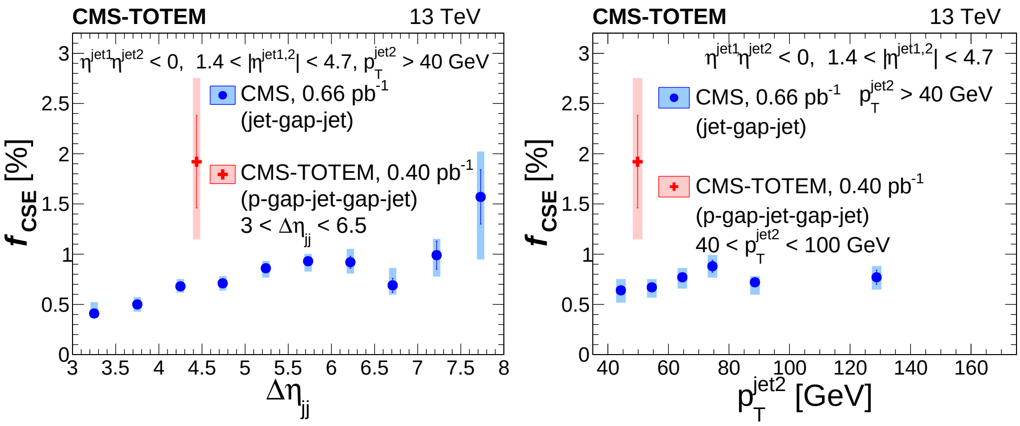

Figure 5: Fraction of hard color-singlet exchange dijet events f_{CSE}, measured as a function of $\Delta\eta_{\text{jj}}$ (Left) and $p_{\text{T}}^{\text{jet2}}$ (Right) extracted in inclusive dijet event production (labeled CMS, represented by the blue circle markers) and in dijet events with an intact proton at 13 TeV (labeled CMS-TOTEM, represented by the red cross marker). The vertical bars represent the statistical uncertainties, and boxes represent the combination of statistical and systematic uncertainties in quadrature. The figure is extracted from Ref. [1].

illustrated in Fig. 4. The intact protons have a fractional momentum loss (ξ) of up to 20%, with values of the square of the four-momentum transfer at the proton vertex (t) in the range between -4 and -0.025 GeV^2. The jets satisfy the same selection requirements as those in the "standard" jet-gap-jet analysis described in previous paragraphs. The f_{CSE} value extracted in this sample is 2.91 ± 0.70 (stat) $^{+1.02}_{-0.94}$ (syst) times larger than that found in inclusive dijet production. This suggests that there is a larger abundance of jets with central gaps in events with detected intact protons. This is observed in Fig. 5. This can be interpreted in terms of a lower spectator parton activity in events with intact protons, which decreases the likelihood of the central gap signature being spoiled.

To summarize, we have presented a study of jet-gap-jet events at $\sqrt{s} = 13$ TeV. The events consist of two jets separated by a large interval in η that is void of charged particles. The fraction of dijet events produced by color-singlet exchange, f_{CSE}, was extracted as a function of various kinematic variables of the dijet system. The results were compared to previous measurements at lower $\sqrt{s}$ and to pQCD calculations based on the BFKL framework. In addition, we presented the first study of jet-gap-jet events with an intact proton. This is the first study of this diffractive event topology. The corresponding f_{CSE} fraction in this subsample is larger than the f_{CSE} fraction in the analysis of inclusive dijet events.

Acknowledgements

CB acknowledges the U.S. Department of Energy's grant DE-SC0019389 for the financial support provided for the investigation of jets separated by a pseudorapidity gap.

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