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DIFFRACTIVE RESULTS FROM CMS*

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on behalf of the CMS and TOTEM collaborations

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Experimental results from the CMS and TOTEM collaborations on diffractive processes, namely nonresonant continuum central exclusive production of pion pairs, hard color-singlet exchange in dijet events, and single-diffractive dijet production in proton–proton collisions, are presented.

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1. Introduction

Diffractive processes result from interactions via Pomeron exchange that leads to a large rapidity gap, *i.e.*, a wide region devoid of particle activity in the final state. The concept of Pomeron originates from the Regge theory, where the Pomeron is interpreted as a family of particles with vacuum quantum numbers exchanged in the t-channel and is used to describe “soft” processes: the “soft” Pomeron accounts for the rising hadronic cross sections with increasing center-of-mass energy, $\sqrt{s}$. The concept of the “hard” or BFKL (Balitsky–Fadin–Kuraev–Lipatov) Pomeron exists in perturbative quantum chromodynamics (pQCD) and is described as a colorless compound of two interacting gluons. Pomeron physics is an ongoing research topic both experimentally and theoretically, and this proceedings paper summarizes experimental results on diffractive scattering processes measured by the CMS and TOTEM detectors [1, 2] at the LHC in proton–proton (pp) collisions.

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2. Nonresonant continuum CEP of pion pairs

The central exclusive production (CEP) of hadron particles in pp collisions at energies above 20 GeV and for proton momentum transfer above 0.2 GeV is dominated by the double-Pomeron exchange. There are two components of CEP (see Fig. 1): *(i)* a resonant component, where the Pomerons emitted by the protons fuse and produce a short-lived resonance that decays into a pair of oppositely-charged hadrons and *(ii)* a nonresonant continuum component, where Pomerons interact via the exchange of a virtual hadron producing a pair of oppositely-charged hadrons. Results on nonresonant continuum CEP of pion pairs in the resonance-free region of the mass of the centrally produced two-pion system, $m_{\pi^+\pi^-} < 0.7$ GeV or $m_{\pi^+\pi^-} > 1.8$ GeV, were published by the CMS and TOTEM collaborations in Ref. [3]. The data was collected in a special $\beta^* = 90$ m run of the LHC. Such a high-β^* setting reduces the beam divergence, allowing the forward detectors to measure the intact final-state protons at low angles and small transverse momenta. The amount of data collected corresponds to an integrated luminosity of 4.7 pb^{-1}. The detector-level signatures of a CEP of a pion pair are *(i)* two slightly scattered intact protons measured by the TOTEM detectors, *(ii)* two oppositely charged centrally produced hadrons measured by the central CMS detector, and *(iii)* the sum of the proton and hadron momenta close to zero.

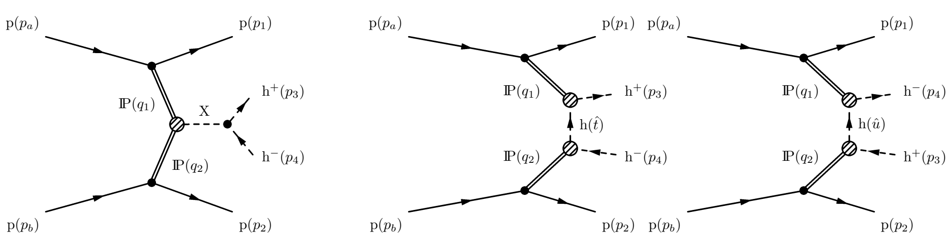

Fig. 1. Born-level Feynman diagrams for resonant (left) and nonresonant continuum (centre: t-channel; right: u-channel) CEP of a hadron pair in pp scattering via the double-Pomeron exchange. The Born-level picture becomes more complicated when the effects of suppression, absorption, and other corrections are properly included.

The studied variables (kinematic regions) were the transverse momenta of the scattered protons (0.2 GeV $< p_{1,\mathrm{T}}, p_{2,\mathrm{T}} <$ 0.8 GeV), the azimuthal angle between them (ϕ), the invariant mass of the pion pair (0.3 GeV $< m_{\pi^+\pi^-} <$ 0.7 GeV or 1.8 GeV $< m_{\pi^+\pi^-} <$ 2.2 GeV), and the squared four-momentum of the virtual hadron (-2.5 GeV$^2 < \max(t,u) < 0$). Triple differential cross sections, *i.e.*, in ranges of $p_{1,\mathrm{T}}$ and $p_{2,\mathrm{T}}$, distributions of ϕ, $m_{\pi^+\pi^-}$, and $\max(t,u)$, were measured. A parabolic minimum in the ϕ distribution was observed for the first time [3] as shown in Fig. 2. The minimum can be interpreted as an effect due to absorption corrections [4]. Models of CEP were tuned based on the measured distributions, and various physical parameters related to Pomeron physics were determined.

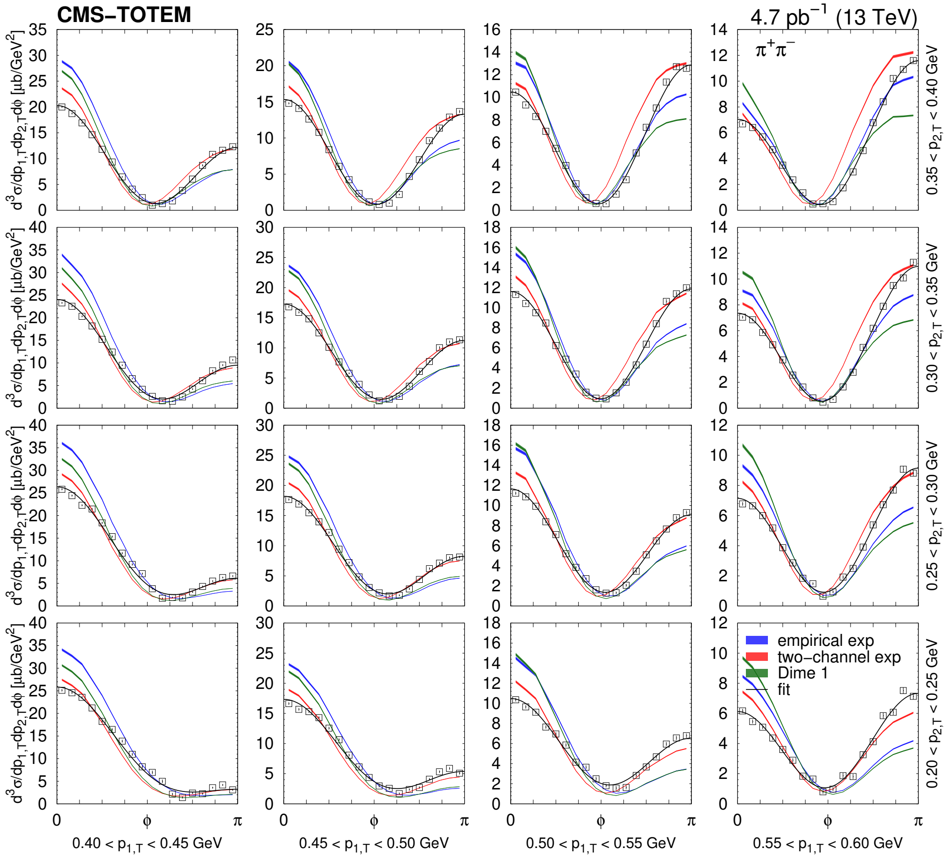

Fig. 2. Distributions of $\mathrm{d}^3\sigma/\mathrm{d}p_{1,\mathrm{T}}\,\mathrm{d}p_{2,\mathrm{T}}\,\mathrm{d}\phi$ as a function of ϕ in several $(p_{1,\mathrm{T}}, p_{2,\mathrm{T}})$ bins in the nonresonant mass range of 0.35 GeV $< m_{\pi^+\pi^-} <$ 0.65 GeV [3].

3. Dijet events with hard color-singlet exchange

Dijet events with the hard color-singlet exchange are characterized by a devoid-of-particle activity between the final-state jets due to the BFKL Pomeron exchange, and hence, such events are called jet–gap–jet events and serve as a tool to study BFKL dynamics. Jet–gap–jet events (Fig. 3 left) and jet–gap–jet events with an intact proton (Fig. 3 right) were measured by the CMS and TOTEM collaborations at $\sqrt{s} = 13$ TeV [5]. Data were recorded by CMS detector with an integrated luminosity of 0.66 pb^{-1} and $\beta^* = 90$ m setting; a subset of the data with an integrated luminosity of

0.40 pb^{-1} was collected jointly with the TOTEM experiment. The central the CMS detector measured the jets, while the TOTEM detectors measured the intact proton.

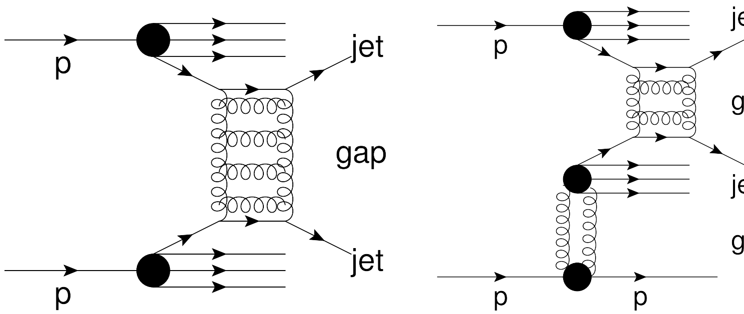

Fig. 3. Schematic diagrams of a jet–gap–jet event (left) and a jet–gap–jet event with an intact proton (right).

The fraction of dijet events produced via the hard-color singlet exchange, f_{CSE}, was studied in bins of the pseudorapidity difference of the two jets, $\Delta\eta_{jj} = |\eta_{\mathrm{jet1}} - \eta_{\mathrm{jet2}}|$, the subleading jet transverse momentum, $p_{\mathrm{T}}^{\mathrm{jet2}}$, and the azimuthal angle difference of the two jets, $\Delta\phi_{jj} = |\phi_{\mathrm{jet1}} - \phi_{\mathrm{jet2}}|$. The f_{CSE} as measured by CMS in bins of $\Delta\eta_{jj}$ compared with BFKL-based calculations by Royon, Marquet, and Kepka (RMK) [6, 7] and Ekstedt, Enberg, Ingelman, and Motyka (EEIM) [8, 9] in NLL accuracy is shown on the left-hand side of Fig. 4. These calculations are implemented in PYTHIA, and the EEIM results include the soft color interaction (SCI) and/or the multi-parton interaction (MPI) contributions. Later, in Ref. [10], good agreement was found

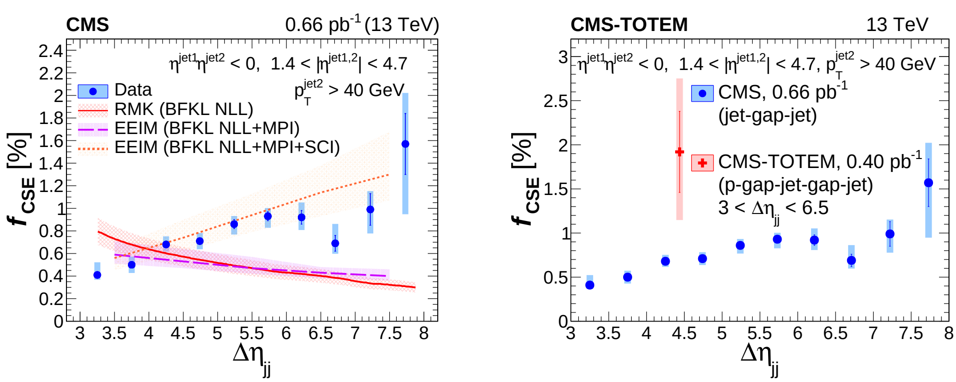

Fig. 4. The fraction of dijet events produced via the hard-color singlet exchange, f_{CSE}, in bins of the pseudorapidity difference of the two jets, $\Delta\eta_{jj} = |\eta_{\mathrm{jet1}} - \eta_{\mathrm{jet2}}|$, for jet–gap–jet events as measured by CMS (left) and for jet–gap–jet events with an intact proton as measured by CMS and TOTEM (right) [5].

between BFKL calculations and data, but the gap definition was different in theory and data (theory: no particles at all; experiment: no particles with $p_{\mathrm{T}} > 200$ MeV; explanation: too much ISR generated by PYTHIA). In Ref. [11], the full BFKL NLL prediction for the jet–gap–jet cross section was calculated. It was found that the full BFKL NLL result is below the BFKL LL estimate by 15–20% in the whole rapidity separation range.

The limited sample size allowed for the extraction of a single data point of f_{CSE} for the jet–gap–jet events with an intact proton by CMS and TOTEM using the entire sample of events. The comparison of this result to the exclusively CMS f_{CSE} measurement is shown on the right-hand side of Fig. 4. The larger f_{CSE} value in events with an intact proton may be interpreted by a reduced soft-parton activity. The soft-parton exchanges between the remnants of the broken-up proton and the partons produced in the collision can destroy the gap between the final-state jets. The result suggests that the gap is more likely to form or survive in the presence of another gap.

4. Single-diffractive dijet production

The measurement of single-diffractive (SD) dijet production was performed by the CMS and TOTEM detectors in pp collisions at $\sqrt{s} = 8$ TeV [12] (the schematic diagram of the SD dijet event is shown in Fig. 5). This was the first hard diffraction measurement with an intact proton detected at the LHC. The two high-p_{T} jets were measured in CMS, while the scattered proton was measured in the TOTEM detectors. The collected data corresponds to an integrated luminosity of 37.5 nb^{-1}. The SD dijet differential cross sections were measured as a function of intact proton's squared four-momentum transfer (t) and fractional momentum loss (ξ). The results were compared with predictions from models of diffractive and nondiffractive processes. It was found that Monte Carlo results agree well with the

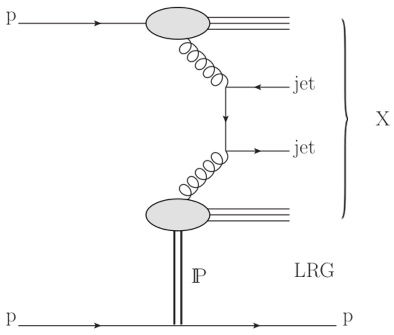

Fig. 5. Schematic diagram of single-diffractive dijet production with hard $gg \to$ dijet scattering process (note that the qq and gq initial states also contribute).

data when corrected for the effect of soft rescattering between the spectator hadrons. The ratio per unit ξ of the single-diffractive and inclusive dijet cross sections was measured in the kinematic region given by $\xi < 0.1$ and $0.03 < |t| < 1\ \mathrm{GeV}^2$ as a function of x, the momentum fraction of the parton initiating the hard scattering. It was found that the SD dijet production is further suppressed at the LHC as compared to the Tevatron CDF results.

5. Summary

CMS and TOTEM jointly measured various diffractive processes in pp collisions. A parabolic minimum in the distribution of the azimuthal angle difference of the final-state protons in central exclusive production was observed for the first time. Hard diffraction with a detected intact proton was measured for the first time at the LHC. The theory of "hard" Pomeron was further tested by jet–gap–jet measurements: good agreement between BFKL calculations and data was found.

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