PROCEEDINGS OF SCIENCE

Recent diffractive and exclusive results from CMS

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A measurement of the exclusive and semi-exclusive production of charged pion pairs in proton-proton collisions, $pp \to p(p^*) + \pi^+\pi^- + p(p^*)$, where the $\pi^+\pi^-$ pair is emitted at central rapidities, and the scattered protons stay intact (p) or diffractively dissociate (p^*) without detection is presented in these proceedings. The measurement is performed with the CMS detector at the LHC, using a data sample corresponding to an integrated luminosity of $450\mu b^{-1}$ collected at a center-of-mass energy of 7 TeV. The dipion cross section, measured for single-pion transverse momentum $p_T > 0.2$ GeV and rapidity $|y| < 2$, is $26.5 \pm 0.3(stat.) \pm 5.0(syst.) \pm 1.1\mu b$. The differential cross sections measured as a function of the invariant mass and p_T of the pion pair are compared to phenomenological predictions.

The European Physical Society Conference on High Energy Physics
5-12 July
Venice, Italy

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1. INTRODUCTION

The exclusive production in proton-proton collisions, $pp \to p + X + p$, is characterized by the produced system X, where X is emitted at central rapidities y and the incident protons stay intact or dissociate without detection. Exclusive production in proton-proton collisions at central rapidities is usually described in terms of double pomeron exchange (DPE) processes, when the mass of the central system is not very large, or perturbatively, as in central exclusive-production approaches where the partonic structure of the pomeron (color singlet exchange with vacuum quantum numbers) is explicitly taken into account. The CMS detector [1] provides a very wide range of opportunities to study these processes.

2. Exclusive and semi-exclusive $\pi^+\pi^-$ production in proton-proton collisions at $\sqrt{s} = 7$ TeV

At high center-of-mass energies, the process $pp \to p(p^*) + \pi^+\pi^- + p(p^*)$, where two pions are produced alone while the colliding protons either remain intact (exclusive production) or dissociate into low-mass systems denoted as p^* (semi-exclusive production, with all products having pseudorapidities $|\eta| > 4.9$), is dominated by double pomeron exchange (DPE) [2, 3]. Pion pairs from DPE come from the t-channel non-resonant continuum shown in Fig. 1 (left), as well as from decays of scalar and tensor meson resonances produced in the s-channel. Dipion decays from (semi-)exclusive vector meson photoproduction, such as from the ρ meson shown in Fig. 1 (right), contribute to a smaller degree, whereas the two-photon fusion process $\gamma\gamma \to \pi\pi$ is expected to have a much smaller cross section [4] and is disregarded hereafter.

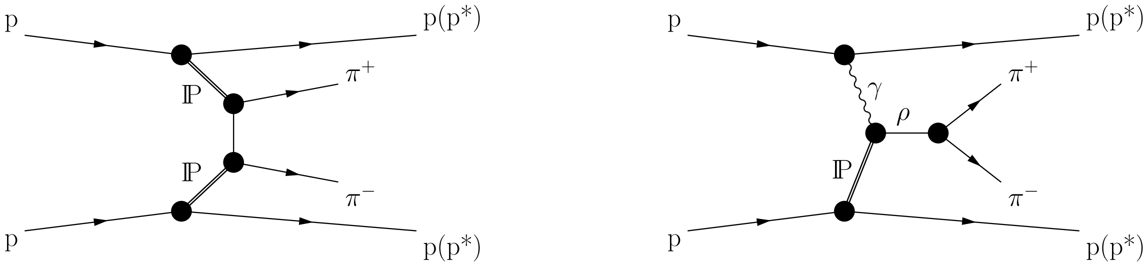

Figure 1: Representative diagrams for (semi)exclusive central $\pi^+\pi^-$ production in proton-proton collisions. Double pomeron exchange continuum [2, 3], and photon-pomeron interaction with production of a ρ meson that subsequently decays into a pair of pions.

The data samples used in this analysis correspond to an integrated luminosity of $450\mu b^{-1}$, collected in 2010 at $\sqrt{s} = 7$ TeV at a low instantaneous luminosity, with ≈1 inelastic pp interaction per bunch crossing. Events were selected with ≈100% efficiency using an unbiased trigger that required only the presence of proton bunches crossing at the CMS interaction point.

Offline, events are required to have two charged-particle tracks coming from a common point on the beam line, with no additional tracks and no activity in the calorimeters above the noise thresholds [5] to reject non-exclusive events, as well as events with more than a single pp interaction vertex (pileup). The following requirements are imposed to select two well-reconstructed tracks consistent with those originating from a pp collision.

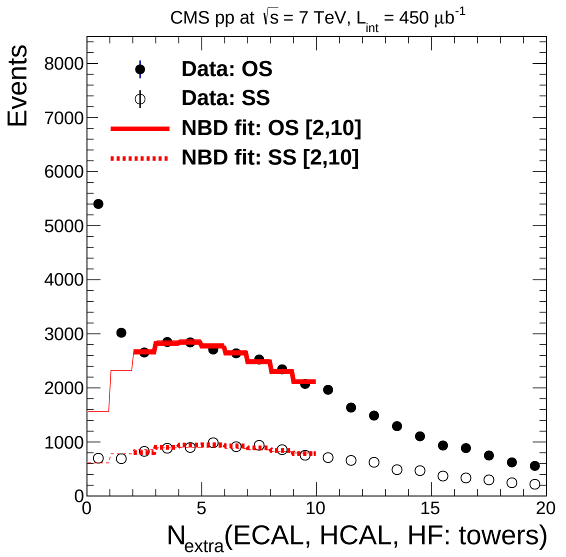

Figure 2: Distribution of the multiplicities of ECAL+HCAL+HF towers above noise thresholds, N_{extra}, in events with two opposite-sign (solid circles) and same-sign (open circles) tracks [6]. The negative binomial distributions used to reproduce the backgrounds in OS (solid curve) and SS (dashed curve) events are shown in their fitting range (thick lines), as well as their extrapolation below that range (thinner lines).

In addition to having only two reconstructed charged particles in the event (apart from the undetected p or p^*), the events are required to have no extra activity in the calorimeters up to $|\eta| = 4.9$. This condition is applied by counting the number of calorimeter towers, N_{extra}, that contain signals above the noise thresholds. The noise thresholds are 0.52, 2.18, 1.18, 1.95 and 4.00 GeV for the EB, EE, HB, HE and HF calorimeters, respectively. These thresholds are determined for each of the calorimeter regions using data taken with unpaired proton beam bunches [6].

A data-driven method is applied to correct for residual multihadron backgrounds and signal migration. Figure 2 shows the N_{extra} distribution of calorimeter towers above thresholds in the selected two-track events for opposite-sign (OS) and same-sign (SS) pairs. A clear rise in the number of OS events is observed in the signal region with $N_{extra} = 0$. The background contribution at values of $N_{extra} > 1$ is due to residual non-exclusive multihadron production. This residual multihadron background contains neutral particles and also charged particles outside of the acceptance of the tracker, in particular in the HF detector. The multihadron background seen in the data for OS and SS two-track events is very well described in the range $2 \leq N_{extra} \leq 10$ by a negative binomial distribution (NBD). The NBD is shown extrapolated down to $N_{extra} = 0$ in Fig. 2. Since the NBD background reproduces the full N_{extra} distribution measured in SS events, it is also considered to provide a faithful estimate of the multihadron background in OS events for signal events with $N_{extra} = 0$ and 1.

3. Total and differential cross sections

The cross section is obtained from the number of OS events passing the aforementioned selection criteria, requiring $N_{extra} \leq 1$ for the total cross section and $N_{extra} = 0$ for the differential cross section shapes. The results are corrected for pileup, noise, and background. The results are for charged particles, assuming the pion mass, and without subtracting the non-$\pi^+\pi^-$ backgrounds, estimated to be $\lesssim$10%, assuming the ratio of pions to kaons to be independent of their momentum.

The total cross section obtained after all corrections, for the single-pion kinematic region $p_T >$ 0.2 GeV and $|y| < 2$, is

$$\sigma_{\pi^+\pi^-} = 26.5 \pm 0.3(stat.) \pm 5.0(syst.) \pm 1.1 \mu b. \quad (3.1)$$

This is 50% larger than the cross section predicted by the PYTHIA8 [11] and DIME [12] models, which only simulate the exclusive component. Adding the contribution from the STARlight [13] calculation of exclusive ρ-meson photoproduction to the PYTHIA8 or DIME results, which only include DPE production, reduces the discrepancy to about 35%. It should be noted that the Monte Carlo predictions used here do not include the effect of low-mass proton dissociation, nor the production of specific resonances decaying into a pion pair, which would increase the visible cross section.

3.1 Differential cross sections

Figures 3 and 4 show the fully corrected differential exclusive and semi-exclusive $\pi^+\pi^-$ cross sections, in the stated fiducial region, after background subtraction as a function of the pion pair invariant mass $M(\pi\pi)$ and transverse momenta $p_T(\pi\pi)$. In each figure, the results are given on a linear (left) and logarithmic (right) scale. The error bars on the data points show the statistical uncertainty, while the systematic uncertainties are shown by the shaded band. Both figures also show the hadron-level predictions obtained from the Monte Carlo generators, where the requirement of two oppositely charged pions with $p_T > 0.2$ GeV and $|y| < 2$ has been applied. The DIME results are displayed on top of the STARlight results as a way to include contributions from both DPE and exclusive ρ-meson photoproduction. The PYTHIA8 MBR predictions are not combined with any other results. The PYTHIA8 4C predictions are found to be similar to the PYTHIA8 MBR results and are therefore not shown. Two DIME histograms are displayed, corresponding to exponential and Orear form-factors.

The invariant mass distribution, shown in Fig. 3, rises from threshold at $\approx$0.3 GeV and reaches a local maximum at around 0.8 GeV, consistent with a possible excess of ρ mesons produced in γp photoproduction. While the sum of DIME and STARlight in this mass region is below the experimental data, the sum of PYTHIA8 MBR and STARlight predictions would be in agreement with the measurement. A decrease is seen above 1 GeV, followed by a local peak at around 1.3 GeV. Excesses above the DIME and PYTHIA8 predictions are observed near 1 GeV and 1.3 GeV, the latter of which is consistent with the $f_2(1270)$, as seen in previous measurements [7, 8, 9, 10], and at around 1.65 GeV. The local maximum at 1 GeV, followed by a drop, is interpreted as the result of interference between the $f_0(980)$ and the two-pion continuum.

Figure 4 shows the differential cross sections as a function of the pion pair transverse momentum $d\sigma/dp_T(\pi\pi)$. For low values of pair transverse momentum, the predictions are compatible with the data. For $p_T > 0.5$ GeV, the data are higher than the predictions, as expected given that the Monte Carlo models do not contain proton-dissociation contributions, which lead to central particle production with a larger p_T tail.

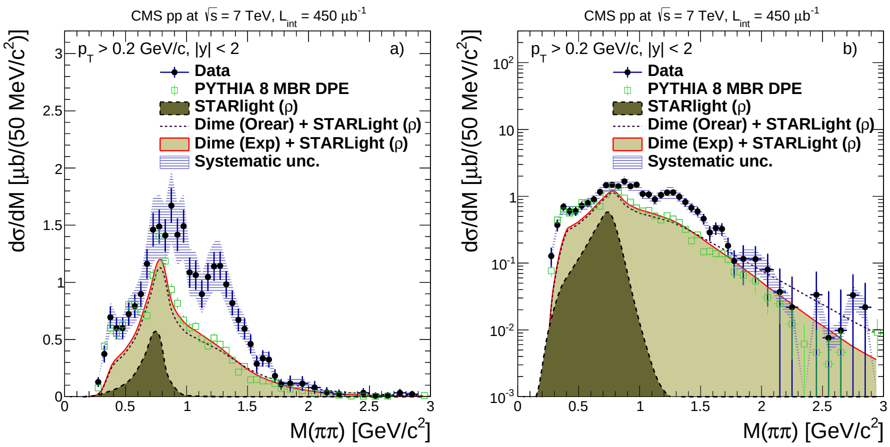

Figure 3: Differential cross sections [6] for $pp \to p(p^*) + \pi^+\pi^- + p(p^*)$ as a function of the pion pair invariant mass, compared to the predictions from DIME [12] (solid and dashed curves), added to ρ photoproduction from STARlight [13] (long dashed curve). The results are also compared to PYTHIA8 MBR [11] (open squares). The shaded band shows the overall systematic uncertainty, and the vertical error bars indicate the statistical uncertainty. The results are plotted on (a) linear and (b) logarithmic scales.

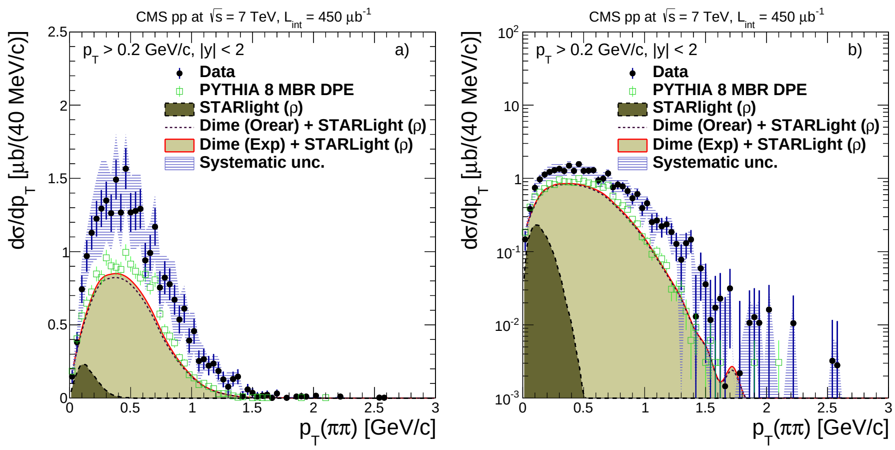

Figure 4: Differential cross sections [6] for $pp \to p(p^*) + \pi^+\pi^- + p(p^*)$ compared to the predictions of DPE production from DIME [12] (solid and dashed curves), added to ρ photoproduction from STARlight [13] (long dashed curve), and of PYTHIA8 MBR [11] (open squares). The data are also compared to the PYTHIA8 MBR (open squares). The shaded band shows the overall systematic uncertainty, and the error bar indicates the statistical uncertainties. The results are plotted on a linear (left) and a logarithmic (right) scale.

4. SUMMARY

Cross sections for pion pair production in the reaction $pp \to p(p^*) + \pi^+\pi^- + p(p^*)$, where the undetected protons stay intact (exclusive production) or dissociate into low-mass states (semi-exclusive production), have been measured in proton-proton collisions at $\sqrt{s} = 7$ TeV with the CMS detector using data corresponding to an integrated luminosity of $450 \mu b^{-1}$. By selecting events with exactly two oppositely-charged central particles, the multiplicity distribution of additional calorimeter towers, N_{extra}, shows an excess for 0 or 1 towers relative to a negative binomial distribution that reproduces the inclusive dipion production with $N_{extra} > 1$. This excess is attributed to exclusive and semi-exclusive production of $\pi^+\pi^-$. The results are compared to phenomenological predictions for (semi)exclusive dipion cross sections from double pomeron exchange (as modeled in PYTHIA8 and DIME) and from ρ-meson photoproduction (as modeled in STARlight).

The exclusive and semi-exclusive dipion cross section, for individual pions with $p_T > 0.2$ GeV and $|y| < 2$ and no additional particles produced within $|\eta| < 4.9$, is $26.5 \pm 0.3(stat.) \pm 5.0(syst.) \pm 1.1 \mu b$, which is 50% larger than that predicted by the PYTHIA8 (MBR and 4C tune) and DIME models. Such a result is expected as none of the models include the contributions from low-mass proton dissociation, nor the production of specific dipion resonances, which would increase the visible cross section. The $\pi^+\pi^-$ differential cross sections as a function of the pion pair invariant mass and p_T have also been compared to model predictions. The measured $p_T(\pi\pi)$ distribution shows a larger average p_T and a higher tail above $p_T > 0.5$ GeV than predicted by the models, suggesting the presence in the data of a significant contribution from semi-exclusive $\pi^+\pi^-$ production with proton dissociation. The invariant mass spectrum for dipions shows various resonant peaks (including a possible contribution from ρ mesons produced in γp photoproduction processes) and dips, similar to those observed in lower-energy pA and pp collisions.

This is the first measurement at the LHC of exclusive and semi-exclusive production of pion pairs from the nonresonant continuum, and from possible decays of various low-mass meson resonances. The understanding of the data requires the improvement of phenomenological double pomeron exchange models to consistently include continuum and resonant processes, and their interference, as well as similar contributions with proton dissociation.

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