

Central exclusive $\pi^+\pi^-$ production in $p\bar{p}$ collisions at $\sqrt{s} = 0.9$ and 1.96 TeV at CDF

M. Żurek

Forschungszentrum Jülich, 52425 Jülich, Germany; University of Cologne, 50937 Cologne, Germany

Abstract. Exclusive $\pi^+\pi^-$ production in proton-antiproton collisions at $\sqrt{s} = 0.9$ and 1.96 TeV in the Collider Detector at Fermilab has been measured. Events with exactly two particles with opposite charge, in $|\eta(\pi)| < 1.3$, with no other particles detected in $|\eta(\pi)| < 5.9$, were selected. We require the central $\pi^+\pi^-$ state to have rapidity $|y(\pi\pi)| < 1$. The data are expected to be dominated by double pomeron exchange. Therefore, the quantum numbers of the central state are constrained. The data show resonance structures attributed to the f_0 and f_2 mesons. The results are valuable for light hadron spectroscopy, and for understanding the nature of the pomeron in a region between non-perturbative and perturbative QCD.

Keywords: Double Pomeron Exchange, Central Exclusive Production

PACS: 13.85.Ni, 13.30.Eg

INTRODUCTION

The pomeron can be defined as the carrier of 4-momentum between protons when they scatter elastically at high energies. It is a strongly interacting color-singlet state. At leading order it is a pair of gluons. In Quantum Chromodynamics (QCD) it cannot be a pure state. Quark pairs and other gluons must evolve in when the scale Q^2 , becomes large. Perturbative QCD cannot be used to calculate cross sections when Q^2 is small ($< 2 \text{ GeV}^2$), which is usually the case with pomeron exchange, because the coupling $\alpha_s(Q^2)$ becomes of order 1. In this case, non-perturbative methods, such as Regge theory, are more applicable [1].

The transition between perturbative QCD and Regge behavior is a challenge. The data presented in this paper extend to above the charmonium threshold, where exclusive $g + g \rightarrow \chi_c$ production involves perturbative calculations [2, 3]. With the requirements of two large rapidity gaps and central hadrons, the observed processes are expected to be dominated by double pomeron exchange.

EVENTS SELECTION

Exclusive $\pi^+\pi^-$ pair production was measured using the CDF II detector. CDF II is a general purpose detector for proton-antiproton collisions, located at the Tevatron at the Fermi National Accelerator Laboratory. Detailed description one can find in [4].

We require the events to be exclusive 2-particle final states. Therefore, events with exactly two Central Outer Tracker tracks with $\sum Q = 0$ were selected. We require all the calorimeters (except around the impact point of the charged particle), the forward Beam Shower Counters, and the Cherenkov Luminosity Counters (CLC) to have signals consistent with noise. Thus, we are blind to pseudorapidity $|\eta(\pi)| > 5.9$, and accept events where one or both protons fragmented into a low-mass state, or were quasi-elastically scattered.

We use unbiased bunch-crossing trigger data ("0-bias") to understand the noise levels in all the detectors. We divide these events into two subsamples (1) no tracks, no CLC hits and no muon stubs and (2) all other events, dominated by one or more interactions. The noise levels are determined by comparing the noise and signal-dominated distributions for each detector. The distributions of the summed signals and of the highest E_T tower in each event, for each of the subdetectors, are examined. Cuts both on $\sum E(EM + HAD)$ and on the highest $E_T(EM)$ tower are applied. For the central detectors, the tracks are extrapolated to the calorimeters. We ignore any energy in a cone $\sqrt{(\Delta\eta)^2 + (\Delta\phi)^2} < 0.3$ around the impact points. We require all the other calorimeter elements to have the readout consistent with the noise. The selection of 2-track exclusive events is made with a sequence of cuts. The central exclusivity requirement vetoes most inelastic collisions, as well as pile-up (more than one inelastic collision in the same bunch-crossing). The tracks are required not to be tagged as muons, to be of high quality, to both pass within

0.5 mm of the beam line in the transverse plane, and to be within 1 cm of each other in z at that point. To remove a small number of cosmic ray tracks, the opening angle cut $\theta_{3D} \approx \pi$ is applied. Finally, the opposite charge for measured particles is required. The final sample consists of 127,340 (6,240) events in our track fiducial region, $p_T > 0.4$ GeV/ c and $|\eta| < 1.3$, and with $|y(\pi\pi)| < 1.0$ at $\sqrt{s} = 1.96$ (0.9) TeV.

EXCLUSIVE EFFICIENCY

Since any cross sections that we measure use data with no other inelastic collision to spoil the exclusivity (no pile-up), we need to know the probability of having no pile-up. This is the exclusive efficiency ϵ_{excl} . We measure the probability P of a bunch crossing with no tracks and all subdetectors passing the exclusivity cuts as a function of the instantaneous bunch-crossing luminosity, L_{bunch} . We measure the fraction of events with all detectors at the noise level. The distribution is an exponential, $P = e^{-\sigma_{\text{vis}} \times L_{\text{bunch}}}$, σ_{vis} is the part of the inelastic cross section, σ_{inel} , for events with particles in $-5.9 < \eta < 5.9$. We find $\sigma_{\text{vis}} = 55.9 \pm 0.4$ mb at 1.96 TeV, which agrees with an expectation from global fits [5] of $\sigma_{\text{inel}} = 61.0 \pm 1.8$ mb, corrected for the estimated fraction visible in $-5.9 < \eta < 5.9$ [6] $\sigma_{\text{vis}}/\sigma_{\text{inel}} = (0.85 \pm 0.05)$, which gives $\sigma_{\text{vis}}(\text{expected}) = 51.8 \pm 3.4$ mb.

For $\sqrt{s} = 0.9$ TeV data sample, the CLC counters were not calibrated for absolute luminosity. We calibrate the luminosity using σ_{vis} , from the global fit, $\sigma_{\text{inel}} = 52.7 \pm 1.6$ mb, multiplied by an estimate [6] of $\sigma_{\text{vis}}/\sigma_{\text{inel}} = (0.90 \pm 0.05)$. This method agrees with the standart CLC method for $\sqrt{s} = 1.96$ TeV data. At $\sqrt{s} = 1.96$ TeV, the effective luminosity equals about 1.16 pb^{-1} , and for $\sqrt{s} = 0.9$ TeV $\sim 0.59 \text{ pb}^{-1}$.

ACCEPTANCE

To calculate differential cross sections $d\sigma/dM(\pi\pi)$ corrected for selection effects, the acceptance and reconstruction efficiency are needed. The trigger efficiency is determined using minimum-bias data. We select isolated tracks and calculate the probability that the hit towers fire the trigger. We generate single pions and simulate the CDF detector using GEANT3. The event acceptance and cut efficiency is determined by passing the generated events through the detector simulation and applying our selection criteria. As a result, the 4-dimensional acceptance \times efficiency is obtained: $A[p_T(\pi^+), p_T(\pi^-), \eta(\pi^+), \eta(\pi^-)]$. It is fitted with an empirical smooth function. The acceptance is dependent not only on single track properties, but also on correlations between the two tracks. To estimate this contribution, a parent state X is generated in $[M(\pi\pi), p_T(\pi\pi)]$ bins, uniformly in rapidity over $-1.0 < y(\pi\pi) < +1.0$, using a mass range $M(\pi\pi)$ from 0 to 5000 MeV/ c^2 , and $p_T(\pi\pi)$ from 0 to 2.5 GeV/ c . Isotropic parent state decays were assumed.

CROSS SECTION DISTRIBUTIONS

The differential cross section as a function of $M(\pi\pi)$ above 1000 MeV/ c^2 integrated over all $p_T(\pi\pi)$ is presented in Figs. 1 and 2. A peak centered at 1270 MeV/ c^2 with a full-width at half-maximum ~ 200 MeV/ c^2 , consistent with the $f_2(1270)$, is visible. The $f_0(1370)$ may be the cause of the shoulder on the high-mass side of the $f_2(1270)$. A change of slope at 1500 MeV/ c^2 can be seen. At lower \sqrt{s} it is a dip, caused possibly by interference between resonances [7, 8]. At higher masses up to 2000 MeV/ c^2 , there are structures in the mass distribution, suggesting the production of other resonances; some structure is visible up to 2400 MeV/ c^2 . The data fall monotonically with $M(\pi\pi)$ from 2000 to 5000 MeV/ c^2 , as shown in Fig. 2. The small peak at 3100 MeV/ c^2 is consistent with photoproduced $J/\psi \rightarrow e^+e^-$ [9].

Fig. 3 presents ratio of invariant mass distributions for two different \sqrt{s} . The ratio $d\sigma/dM(900) : d\sigma/dM(1960)$ rises from about 1.2 at 1000 MeV/ c^2 to about 2.0 at 4000 MeV/ c^2 with no significant structures.

The requirement $p_T > 0.4$ GeV/ c results in the acceptance vanishing at low $p_T(\pi\pi)$ for $M(\pi\pi) < 1000$ MeV/ c^2 . Therefore, Figs. 1, 2 are shown only for higher masses. Additionally, we show the acceptance-corrected cross section for $p_T(\pi\pi) > 1000$ MeV/ c^2 in Fig. 4. The cross section is flat, with no ρ -meson signal, up to a sharp drop at $M(\pi\pi) = 1000$ MeV/ c^2 , where the $f_0(980)$ and the K^+K^- threshold occur.

In summary, we measured exclusive $\pi^+\pi^-$ production with $|y(\pi\pi)| < 1.0$ and rapidity gaps to $|\eta| = 5.9$ in $p\bar{p}$ collisions at two centre-of-mass energies, namely $\sqrt{s} = 0.9$ and 1.96 TeV. The cross section shows a sharp decrease at 1000 MeV/ c^2 , a strong $f_2(1270)$ resonance, and other features at higher mass of uncertain origin. The cross sections at 0.9 TeV are similar in shape but are higher by a factor 1.2 - 2.0.

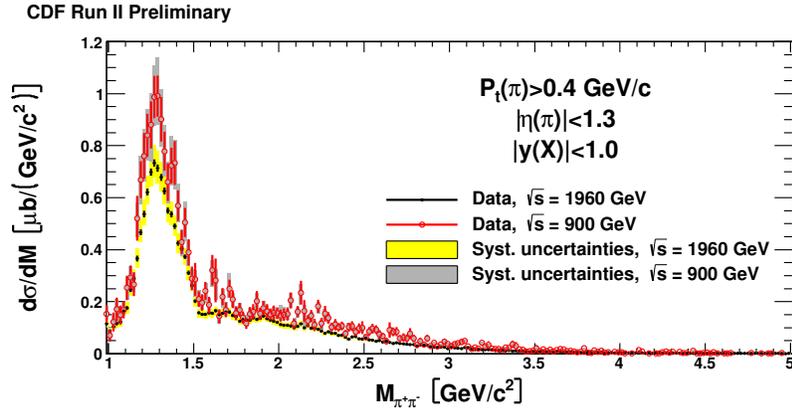


FIGURE 1. Differential cross section $d\sigma/dM(\pi\pi)$ for two charged particles, assumed to be $\pi^+\pi^-$, with $p_T > 0.4 \text{ GeV}/c$, $|\eta| < 1.3$ and $|y(\pi\pi)| < 1.0$ between two rapidity gaps $1.3 < |\eta| < 5.6$. Red open circles are for $\sqrt{s} = 0.9 \text{ TeV}$ and black points for $\sqrt{s} = 1.96 \text{ TeV}$.

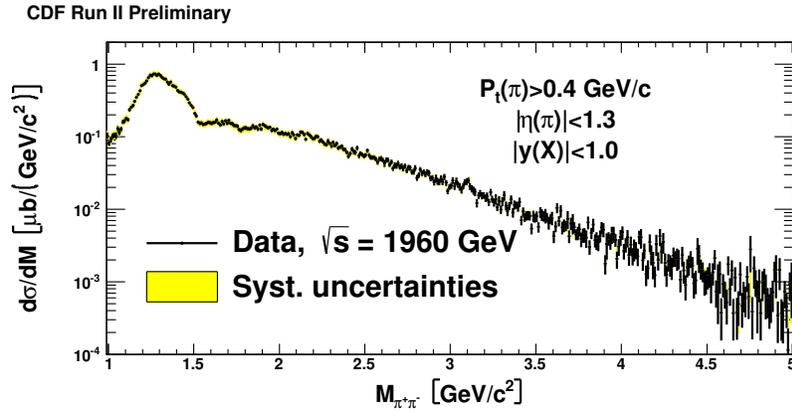


FIGURE 2. Differential cross section $d\sigma/dM(\pi\pi)$ at $\sqrt{s} = 1.96 \text{ TeV}$ on a semi-log scale for two charged particles, assumed to be $\pi^+\pi^-$, with $p_T > 0.4 \text{ GeV}/c$, $|\eta| < 1.3$ and $|y(\pi\pi)| < 1.0$ between two rapidity gaps $1.3 < |\eta| < 5.6$.

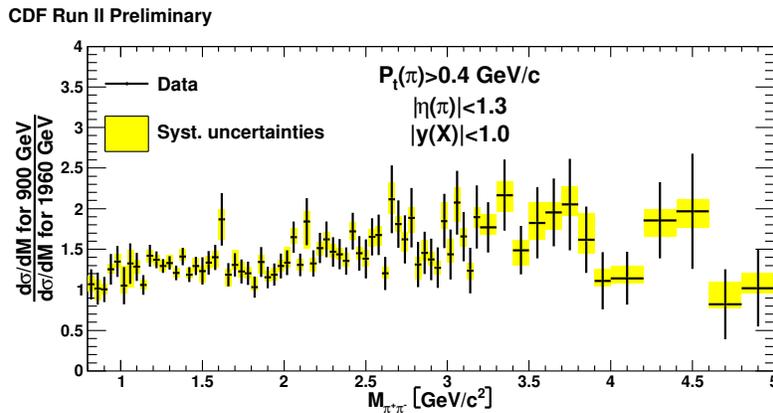


FIGURE 3. Ratio of cross sections $d\sigma/dM(\pi\pi)$ measured at 900 GeV and 1960 GeV.

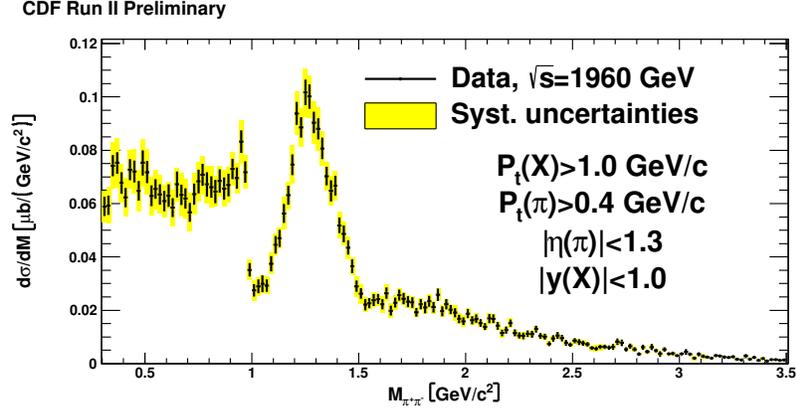


FIGURE 4. As Fig. 1 at $\sqrt{s} = 1.96 \text{ TeV}$, but with $p_T(\pi\pi) > 1.0 \text{ GeV}/c$ for which the acceptance extends to low $M(\pi^+\pi^-)$.

ACKNOWLEDGMENTS

The participation of Maria Żurek to Diffraction 2014 was partially supported by HadronPhysics3 within the Seventh Framework Programme (FP7) of EU. I thank my colleagues in the CDF Collaboration, especially Mike Albrow (Fermilab).

REFERENCES

1. J.R. Forshaw, and D.A. Ross, *Quantum Chromodynamics and the Pomeron*, Cambridge University Press, Cambridge, 1997.
2. L.A. Harland-Lang, V.A. Khoze, M.G. Ryskin, and W.J. Stirling, *Eur. Phys. J. C* **65**, 433 (2010).
3. P. Lebiedowicz, R. Pasechnik, and A. Szczurek, *Phys. Lett. B* **701**, 434 (2011).
4. D. Acosta *et al.* (CDF Collaboration), *Phys. Rev. D* **71**, 032001 (2005).
5. G. Antchev *et al.* (TOTEM Collaboration), *Europhys. Lett.* **101**, 21002 and 21004 (2013); *Phys. Lett.* **111**, 012001 (2013).
6. R. Ciesielski and K. Goulianos, arXiv:1205.1446.
7. T. Åkesson *et al.* (AFS Collaboration), *Nucl. Phys. B* **264**, 154 (1986).
8. A. Breakstone *et al.*, *Zeit. Phys. C* **1**, 185 (1986).
9. T. Aaltonen *et al.* (CDF Collaboration), *Phys. Rev. Lett.* **102**, 242001 (2009).