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Central Exclusive $\pi^+\pi^-$ Production in $p\bar{p}$ Collisions at $\sqrt{s} = 0.9$ and 1.96 TeV at the Tevatron

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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. We selected events with exactly two particles with oposite charge, in $|\eta| < 1.3$, with no other particles detected in $|\eta| < 5.9$. We require the central $\pi^+\pi^-$ to have rapidity $|y| < 1$. Since these events are dominated by double pomeron exchange, the quantum numbers of the central state are constrained. The data show resonance structures attributed to the f_0 and f_2 mesons.

1 Introduction

The pomeron, $\mathbb{P}$, is a strongly interacting color singlet state; at leading order it is a pair of gluons: $\mathbb{P} = gg$. It can be defined as the carrier of 4-momentum between protons when they scatter elastically at high (i.e. collider) energies. In QCD it cannot be a pure state, quark pairs and other gluons must evolve in when Q^2, becomes large. When Q^2 is small ($\lesssim 2$ GeV^2) which is usually the case with pomeron exchange, perturbative QCD cannot be used to calculate cross sections, as the coupling $\alpha_s(Q^2)$ becomes of order 1. Non-perturbative methods, such as Regge theory, are more applicable [1].

Bridging the transition between perturbative QCD and Regge behavior is a challenge. The data presented in this paper, from $p\bar{p}$ collisions at $\sqrt{s} = 0.9$ and 1.96 TeV, extend to above the charmonium threshold where exclusive $g + g \to \chi_c$ production involves perturbative procedures [2, 3]. With two large rapidity gaps and central hadrons, the process is expected to be dominated by double pomeron exchange.

2 Experimental setup

We measure exclusive meson pair production using the CDF II detector. CDF II is a general purpose detector for proton-antiproton collisions at the Fermilab Tevatron. For the detailed describtion see [4]. We select events with exactly two Central Outer Tracker tracks, with $\sum Q = 0$. We want to select events with no other hadrons produced. All the calorimetry (except around the impact points of the charged particles), the forward Beam Shower Counters, and the Cherenkov Luminosity Counters

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(CLC) are required to have signals consistent with noise. We are therefore blind to pseudorapidity $|\eta| > 5.9$, and accept events where the proton was quasi-elastically scattered, or where it fragmented into a low mass state.

3 Candidates selection

We require the events to be exclusive 2-particle final states. To understand the noise levels in all the detectors, we use unbiased bunch-crossing triggers (“0-bias"). We divide these events into two classes (A) no tracks, no CLC hits and no muon stubs and (B) all other events, dominated by one or more interactions. Comparing the noise and signal-dominated distributions for each subdetector we determine the noise levels. For the central detectors, the tracks are extrapolated to the calorimeters, and ignoring any energy in a cone $\sqrt{(\Delta\eta)^2 + (\Delta\phi)^2} < 0.3$ around the impact points. All the other calorimeter elements have to have the readout consistent with the noise.

The selection of 2-track events is made with a sequence of cuts. A big reduction comes from the central exclusivity requirement, which vetoes most inelastic collisions. The tracks are required to be of high quality, to not be tagged as muons, 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. The opening angle cut $\theta_{3D} \approx \pi$, removes a small number of cosmic ray tracks. Finally we require the tracks to have opposite charge. The final sample is 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.

4 Exclusive efficiency

We need to know the probability of having no pile-up, as any cross sections that we measure use data with no other inelastic collision to spoil the exclusivity (no pile-up). This is the exclusive efficiency ε_{excl}. The probability P(0) 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}, was measured. The distribution is an exponential, $P(0) = e^{-\sigma(vis)\times L(bunch)}$, where $\sigma(vis)$ is the part of the inelastic cross section, σ_{inel}, for events with particles in $-5.9 < \eta < 5.9$. We find $\sigma(vis) = 55.9 \pm 0.4$ mb at 1.96 TeV. This result agrees with an expectation from global fits [5] of $\sigma(inel) = 61.0\pm1.8$ mb, corrected for the estimated fraction visible in $-5.9 < \eta < 5.9$ [6] $\sigma(vis)/\sigma(inel) = (0.85 \pm 0.05)$, which gives $\sigma(vis)$(expected)= 51.8±3.4 mb. The CLC counters were not calibrated for absolute luminosity measurement at $\sqrt{s} = 0.9$ TeV. We calibrate the luminosity using $\sigma(vis)$, from the global fit, $\sigma(inel) = 52.7 \pm 1.6$ mb, multiplied by an estimate [6] of $\sigma(vis)/\sigma(inel) = (0.90 \pm 0.05)$. At $\sqrt{s} = 1.96$ TeV this method agrees with the usual CLC method. For $\sqrt{s} = 1.96$ TeV data the effective luminosity equals about 1.16 pb $^{-1}$, for $\sqrt{s} = 0.9$ TeV amounts to 0.59 pb $^{-1}$.

5 Acceptance calculation

The acceptance and reconstruction efficiency are calculated to present differential cross sections $d\sigma/dM(\pi\pi)$ corrected for selection effects. We obtain the trigger efficiency from minimum-bias data. Isolated tracks were selected and the probability that the hit towers fire the trigger is calculated. We generate single pions and simulate the CDF detector using GEANT4. We determine the event acceptance by passing the generated events through the detector simulation and applying the selection criteria. This gives the 4-dimensional acceptance × efficiency: $A[p_T(\pi^+), p_T(\pi^-), \eta(\pi^+), \eta(\pi^-)]$, which is fitted with an empirical smooth function. The acceptance is dependent not only on single track properties, but on correlations between two tracks. To estimate this contribution, a parent state X is generated,

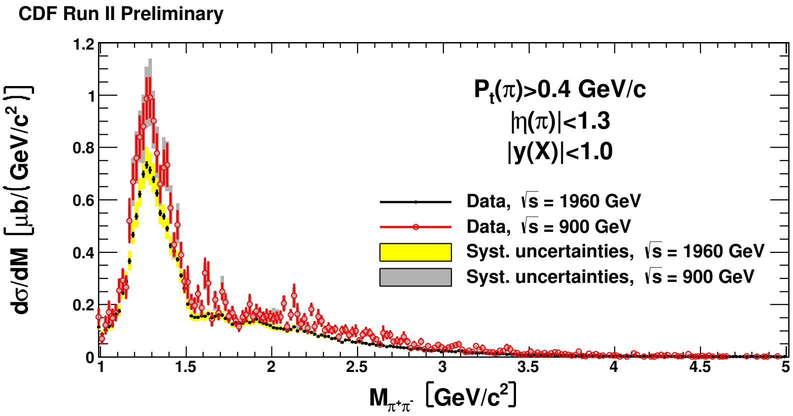

Figure 1. Differential cross section $d\sigma/dM(\pi\pi)$ for two charged particles, assumed to be $\pi^+\pi^-$, with $p_T > 0.4$ GeV/c, $|\eta| < 1.3$ and $|y(\pi\pi)| < 1.0$ between two rapidity gaps $1.3 < |\eta| < 5.6$. Red open circles are for $\sqrt{s} = 0.9$ TeV and black points for $\sqrt{s}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

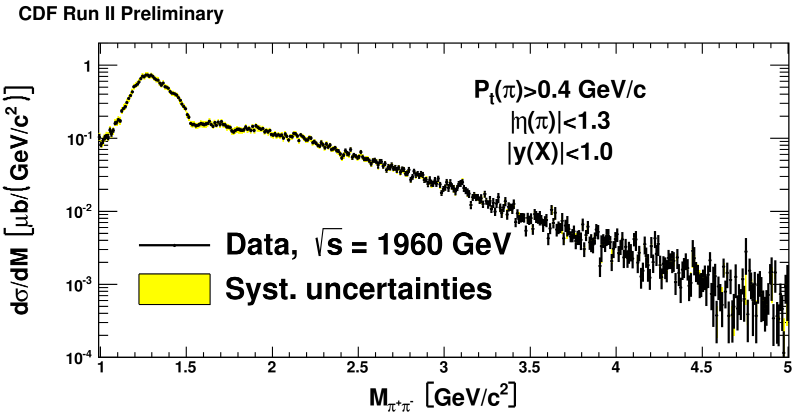

Figure 2. Differential cross section $d\sigma/dM(\pi\pi)$ at $\sqrt{s} = 1.96$ TeV on a semi-log scale for two charged particles, assumed to be $\pi^+\pi^-$, with $p_T > 0.4$ GeV/c, $|\eta| < 1.3$ and $|y(\pi\pi)| < 1.0$ between two rapidity gaps $1.3 < |\eta| < 5.6$.

uniformly in rapidity over -1.0 < $y(\pi\pi) < +1.0$, in $[M(\pi\pi), p_T(\pi\pi)]$ bins, 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, and with isotropic $X \to \pi^+\pi^-$ decays.

6 Cross section distributions

Figs. 1 and 2 present the differential cross section as a function of $M(\pi\pi)$ above 1000 MeV/c^2 integrated over all $p_T(\pi\pi)$. 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 $\sqrt{s}$ [7, 8] it is a dip, caused possibly by interference between resonances. At higher masses up to ~ 2000 MeV/c^2,

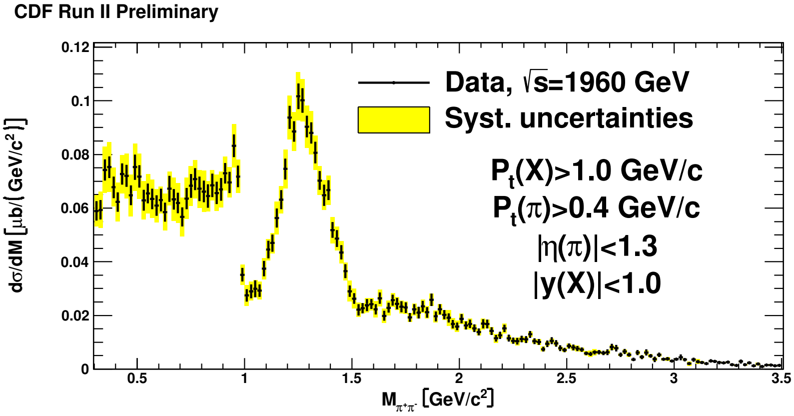

Figure 3. As Fig. 1 at $\sqrt{s} = 1.96$ TeV, but with $p_T(\pi\pi) > 1.0$ GeV/c for which the acceptance extends to low $M(\pi^+\pi^-)$.

there are structures in the mass distribution, suggesting the production of other resonances. 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. Figure 2 shows that from 2000 to 5000 MeV/c^2, the data fall monotonically with $M(\pi\pi)$. There is some structure visible up to 2400 MeV/c^2. The small peak at 3100 MeV/c^2 is consistent with photoproduced $J/\psi \to e^+e^-$ [9].

The requirement $p_T > 0.4$ GeV/c results in the acceptance vanishing at low $p_T(\pi\pi)$ for $M(\pi\pi) \lesssim 1000$ MeV/c^2. Therefore, we show the acceptance-corrected cross section for $p_T(\pi\pi) > 1000$ MeV/c^2 in Fig. 3. 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.

Summing up, we have measured exclusive $\pi^+\pi^-$ production with $|y(\pi\pi)| < 1.0$ and rapidity gaps to $|\eta| = 5.9$ in $p\bar{p}$ collisions at $\sqrt{s} = 0.9$ 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.

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