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Exclusive central $\pi^+\pi^-$ production in CDF

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Using the Collider Detector at Fermilab, CDF, we have measured exclusive $\pi^+\pi^-$ production at $\sqrt{s} = 900$ GeV and 1960 GeV. The $\pi^+\pi^-$-pair is central, $|y| < 1.0$, and there are no other particles detected in $|\eta| < 5.9$. We discuss the mass spectrum, showing $f_0(980)$ and $f_2(1270)$ resonances, s-dependence, p_T-dependence, and angular distributions.

1 Introduction, CDF detector and data sets

In Regge phenomenology, high mass single diffraction implies a non-zero triple-pomeron coupling , which in turn implies, through the optical theorem, double pomeron exchange, DPE ,: $p + p \to p(*) \oplus X \oplus p(*)$. Here p means a proton or antiproton, the final state protons may be quasi-elastic or they may dissociate ($p(*)$), and $\oplus$ represents a large rapidity gap $\Delta y \gtrsim 3$ with no hadrons. See Ref.[1] for a review. By "exclusive" we mean that the central state X is simple and fully measured. At low masses, in the resonance region $M(X) \lesssim 3$ GeV, DPE is non-perturbative and QCD (or QCD-inspired) calculations are challenging; there are new efforts by the Durham [2] and Cracow [3] groups. The quantum numbers of X are restricted to be mostly $I^G J^{PC} = 0^+\text{even}^{++}$, so s-channel resonances $f_0(600)$, $f_0(980)$, $f_2(1270)$, $\chi_{c0}(3415)$ and $\chi_{c2}(3556)$ are allowed. Resonances with a high gluon content will be favored, especially in comparison with $\gamma\gamma \to X$. For the χ_c and χ_b states perturbative calculations of $g + g \to \chi_{c,b}$ are applicable, related to the very interesting channels $X = \gamma\gamma$ [4] and $X =$ Higgs. So we have several motivations: improving our understanding of the pomeron, meson (especially glueball) spectroscopy, and testing the QCD physics of exclusive production (especially $\gamma\gamma$ and Higgs).

The CDF detector at the Fermilab Tevatron is well-known. For this study we used data not only at the usual $\sqrt{s} = 1960$ GeV, but also at 900 GeV in a special run. We only used bunch crossings with a single interaction, i.e. no pile-up, and we required all the CDF detectors, covering $-5.9 < \eta < +5.9$ to be empty, except for two oppositely-charged tracks and their corresponding calorimeter hits. The trigger for these events was ≥ 2 calorimeter showers with $E_T \gtrsim 0.5$ GeV, with a veto on beam shower counter hits ($|\eta| = 5.4 - 5.9$), Cherenkov luminosity counters ($|\eta| = 3.7$ - 4.7) and forward calorimeters ($|\eta| = 1.32$ - 3.64). We had 22M (90M) triggers at $\sqrt{s} = 900$ (1960) GeV. Off-line we required the central calorimeters ($|\eta| < 1.3$) to be also empty, apart from the trigger clusters.

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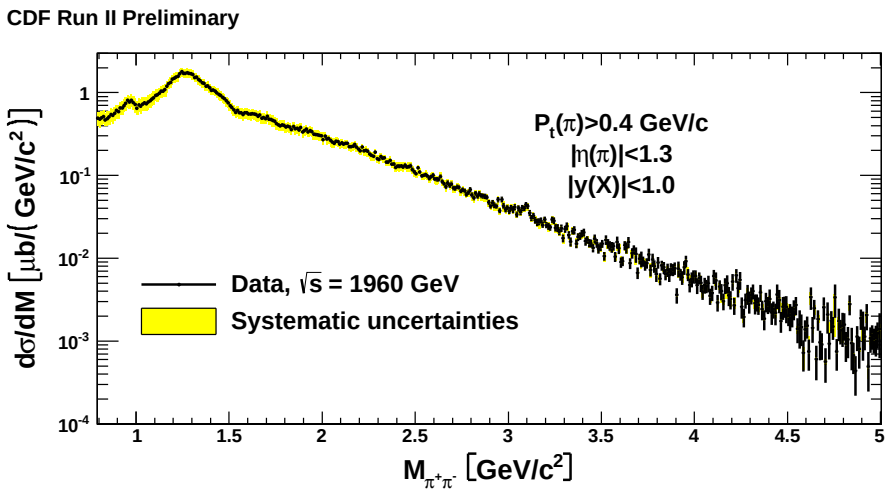

Figure 1: Differential cross section $d\sigma/dM$ for two particles, assumed to be $\pi^+\pi^-$, in the stated kinematic region, between two rapidity gaps Δy >4.6, at $\sqrt{s}$ = 1960 GeV.

2 Exclusivity cuts, luminosity normalization, and event selection

Importantly, we simultaneously recorded a large sample of 0-bias (bunch crossing) triggers. Dividing these into "interaction" and "non-interaction" samples, as in Ref. [4], allowed us to determine the noise levels in all the detectors, and to measure the total visible cross section $\sigma(vis)$, which is the inelastic cross section $\sigma(inel)$ times the fraction f_{vis} of inelastic events with particles in $|\eta| < 5.9$, estimated to be 0.90±0.05 (0.85±0.05). At 1960 GeV $\sigma(vis)$ agreed with global fits; at 900 GeV we used $\sigma(vis)$ to normalize our cross sections, as the luminosity counters were not calibrated. The total delivered luminosity at the two energies was 0.056 (7.12) pb^{-1}. The effective "no-pile-up" luminosity was 0.0435 (1.18) pb^{-1}, determined by counting empty 0-bias events as a function of the bunch luminosity. Off-line we required exactly two well-measured opposite-charge tracks with $|\eta| < 1.3$ and $p_T > 0.4$ GeV/c. The pair $X = \pi^+\pi^-$ (π-masses assumed) was required to have $|y(\pi\pi)| < 1.0$, and $M(\pi\pi) > 0.8$ GeV to have acceptance down to $p_T = 0$. We calculated the acceptance and efficiencies for the above fiducial region, and with the effective luminosity calculated the differential cross section $d\sigma/dM(\pi\pi).dp_T(\pi\pi)$, assuming an isotropic (S-wave) $X \to \pi^+\pi^-$ distribution.

3 Results

Fig. 1 shows the differential cross section integrated over $p_T(\pi\pi)$ as a function of $M(\pi\pi)$, and Fig. 2a shows the low mass region on a linear scale, and at both energies. A small $f_0(980)$ signal is seen, and a dominant $f_2(1270)$ (also dominant in $\gamma\gamma \to \pi^+\pi^-$). A possible shoulder on the high mass side ($f_0(1370)$?) is followed by a distinct change of slope at 1500 MeV, which was also seen at lower energies [6]. While the cross section shapes are similar at the two energies, they differ in detail as seen in the ratio plot Fig. 2b. In addition to any s-dependence of the

$p \oplus \pi^+\pi^- \oplus p$ cross section (expected from Regge to be $\sim \ln s^{\sim -1.25}$) there is more rapidity available for proton dissociation at 1960 GeV, the beam rapidities being 6.87 and 7.64 while the detector extends to $\eta = 5.9$ in both cases. We observe that the ratio is lower in the region of the $f_2(1270)$ than it is below 1 GeV, expected to be dominated by S-wave. We also find that the mean $p_T(\pi^+\pi^-)$ has a minimum in the $f_2(1270)$ region, and rises abruptly at 1.5 GeV.

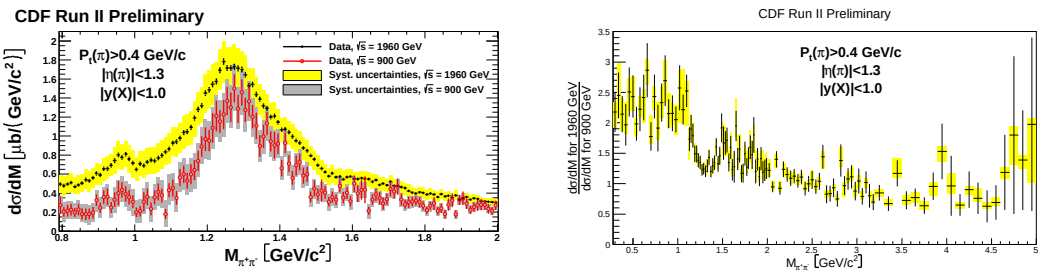

Figure 2: (a) Differential cross section $d\sigma/dM$ for two particles, assumed to be $\pi^+\pi^-$, in the stated kinematic region, between two rapidity gaps $\Delta y > 4.6$, at $\sqrt{s} = 900$ GeV (red) and 1960 GeV (black). (b) Ratio of cross sections $d\sigma/dM$ at $\sqrt{s} = 1960$ GeV and 900 GeV as a function of mass. In both cases rapidity gaps extend to $\eta_{max} = 5.9$, and p-dissociation is included.

We previously observed [5] exclusive χ_c^0 production in the mode $J/\psi(\rightarrow \mu^+\mu^-) + \gamma$, but could not distinguish the three χ_c states. The $\pi^+\pi^-$ and K^+K^- channels have larger branching fractions and enough resolution to separate the χ_c states. We do not see significant signals in this data, and give upper limits (90% C.L.) on $d\sigma/dy|_{y=0}(\chi_{c0}) = 21.4 \pm 4.2$(syst.)nb (in $\pi^+\pi^-$) and 18.9 ± 3.8(syst.)nb (in K^+K^-). This implies that $< 25\%$ of the $J/\psi + \gamma$ events were $\chi_{c0}(3415)$. Even though the $\chi_{c2}(3556)$ may have a much smaller production cross section its branching fraction is $17\times$ larger.

We studied the cos θ^* distributions of the π^+ in the X-frame relative to the incoming p-direction. The data are consistent with isotropy up to 1.5 GeV, above which they become progressively more forward-backward peaked. Isotropy is expected if any polarization at production is washed out after integration over the unseen protons or $p*$-dissociations.

The "Durham" and "Cracow" groups [2, 3] have predicted the differential cross section with the same cuts as Fig. 1, but with no dissociation. Theoretical uncertainties in the region $\sim 3 < M < 4$ GeV are about $^{\times 3}_{\div 3}$, but the data are within these uncertainties.

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