EXPERIMENTAL EVIDENCE FOR DOUBLE-POMERON

EXCHANGE AT ISR ENERGIES

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ABSTRACT

Studying the reaction $pp \rightarrow pp\pi^+\pi^-$ at $\sqrt{s} = 23$ GeV and 45 GeV at the CERN ISR we have found an experimental definition of a new class of diffractive events which we attribute to double-Pomeron exchange. The correlation of the quasi-elastically scattered protons, the energy dependence of the cross-section, and the angular momentum of the $(\pi^+\pi^-)$ state are analysed and found to be in agreement with theoretical expectations for double-Pomeron exchange.

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The SFM detector has been described elsewhere [4]; it contains two forward telescopes equipped with 28 multiwire proportional chambers of two wire planes each, and a central detector [5] equipped with six multiplane proportional chambers. The magnetic field is 0.5 T and 1.0 T for $\sqrt{s} = 23$ GeV and 45 GeV, respectively, resulting in a momentum resolution of $\Delta p/p = \pm 6\%$ for scattered protons. The central detector provides an average $(\pi^+\pi^-)$ mass resolution of ± 40 MeV at $m_{\pi\pi} = 0.8$ GeV.

Events were selected in two steps: a fast trigger requires at least one charged particle in each forward telescope, using signals from the proportional chambers; a slow trigger imposes multiplicity conditions and performs a rough track-finding using memory levels of groups of 32 wires [6]. At least one charged particle was required in the central detector to suppress single-diffractive scattering.

Owing to the presence of beam tubes in the forward telescopes, leading protons with momentum transfer of $-t < 0.03$ GeV² remain undetected at $\sqrt{s} = 45$ GeV. Protons with $-t > 0.5$ GeV² remain undetected at $\sqrt{s} = 23$ GeV, because of the aperture of the small-angle telescope of the SFM. We have therefore selected events in the following t -range at both energies:

$$0.06 < -t < 0.5 \text{ GeV}^2 . \quad (3)$$

We have recorded 355,000 triggers at $\sqrt{s} = 23$ GeV and 360,000 triggers at $\sqrt{s} = 45$ GeV, and have processed them with an off-line analysis chain consisting of three programs. A pattern recognition program finds track candidates [7]; the trajectories of the charged particles are reconstructed using a geometrical fit program [8], and their direction, charge and momentum are calculated. Finally, events with the topology of reaction (1) are submitted to a kinematic fit with four constraints. We retain 3,535 events at $\sqrt{s} = 23$ GeV and 5,190 events at $\sqrt{s} = 45$ GeV, after application of conditions (2) and (3). Figure 1a shows the χ^2 distribution of the kinematical fit of these events. A clear signal is present, although superimposed on a large background, containing 800 events at $\sqrt{s} = 23$ GeV and 600 events at $\sqrt{s} = 45$ GeV. Inspecting the distribution of energy imbalance,

Three types of diffractive processes have at present been established and studied: elastic diffraction scattering, single-diffractive excitation, and double-diffractive excitation. They can be consistently described in terms of Pomeron exchange and vertex functions [1]. It is tempting to speculate on the iteration of this picture to double-Pomeron exchange [2] and even higher-order terms, in analogy with the photon-exchange Feynman diagrams of quantum electrodynamics.

We report here on results [3] of an experimental study of the reaction

$$pp \rightarrow pp\pi^+\pi^- \quad (1)$$

at the CERN Intersecting Storage Rings (ISR) using the Split-Field Magnet facility (SFM). We are limiting our discussion to data taken at two centre-of-mass energies, $\sqrt{s} = 23$ GeV and 45 GeV.

Reaction (1) is dominated by single-diffractive excitation characterized by a leading, quasi-elastically scattered proton and a flare of particles from the excited hadronic state, here $(p\pi^+\pi^-)$. Double-Pomeron exchange contributions to reaction (1), if they exist, would be characterized by two leading, quasi-elastically scattered protons and a centrally produced $(\pi^+\pi^-)$ pair:

We have therefore studied reaction (1) in a kinematical domain where double-Pomeron exchange, if present, would dominate over the single-Pomeron exchange, by selecting events with two leading protons,

$$|x_p| > 0.9, \quad (2a)$$

where x is the reduced longitudinal momentum, and with two centrally produced pions,

$$|y_\pi| < 1.0, \quad (2b)$$

where y is the centre-of-mass rapidity. Selection of this rapidity interval ensures a large gap between the pion and a proton, and thereby reduces single-Pomeron exchange contributions.

In particular, we have searched for a feature of the data itself which would distinguish these two diffractive components of reaction (1) and thereby demonstrate the existence of double-Pomeron exchange.

We note that these slope parameters describe also the distribution of $t_1 + t_2$, and from this conclude the absence of correlation in ϕ_J and t as expected for factorizing double-Pomeron exchange.

We observe a strong energy dependence of events peaking at $\phi_J = 0^\circ$, whereas events with $\phi_J > 90^\circ$ have nearly energy-independent cross-section. Evaluating the partial cross-section for all events with $\phi_J > 90^\circ$ satisfying conditions (2) and (3), using a factorizing model of double-Pomeron exchange for acceptance correction^{*)}, we find:

$$\begin{aligned}\sigma'(23 \text{ GeV}) &= (1.9 \pm 0.3) \mu\text{b} , \\ \sigma'(45 \text{ GeV}) &= (1.3 \pm 0.2) \mu\text{b} .\end{aligned}\tag{4a}$$

We note that the data sample used to obtain these partial cross-sections may still be contaminated by background from single-diffractive excitation. Lacking a reliable way of subtraction, we neglect this contamination. Extrapolating into the kinematical region beyond condition (3) and over all ϕ_J , with the help of the model we find a cross-section of the double-Pomeron contribution to reaction (1) with $|y_\pi| < 1.0$ at the two energies studied so far:

$$\begin{aligned}\sigma(23 \text{ GeV}) &= (7.1 \pm 1.0) \mu\text{b} , \\ \sigma(45 \text{ GeV}) &= (6.0 \pm 1.5) \mu\text{b} .\end{aligned}\tag{4b}$$

The errors include an estimate of the model dependence. We note their equality as strong evidence for the double-Pomeron exchange nature of this process.

Further evidence for the existence of double-Pomeron exchange may be obtained by studying the $(\pi^+\pi^-)$ system. Assuming the pion pair to be produced by the interaction of two Pomerons, one expects s- and d-wave states with isospin zero, hence low mass $(\pi^+\pi^-)$ states, absence of the ρ meson, and possibly the occurrence of 0^+2^+ (I^G_{JP}) resonances, e.g. the f meson. The observed mass distribution as shown in Fig. 3a for events with $\phi_J > 90^\circ$ is peaked around 800 MeV, and there is no evidence for ρ production.

*) This model has been adjusted to reproduce the observed t dependence and the observed $m_{\pi\pi}$ distribution.

$\Delta E = E_{\text{initial}} - E_{\text{final}}$, we observe a large background with $\Delta E > 0$, due to undetected additional particles. We therefore restrict the analysis to events with $\Delta E < 0$ and a χ^2 probability larger than 1%, thus retaining one-half of all real events and a background of 5% at $\sqrt{s} = 23$ GeV and of 20% at $\sqrt{s} = 45$ GeV, as shown in Fig. 1b. Applying the same selection criteria to simulated events, one can be convinced that the biases of the kinematics, introduced by the rejection of events with $\Delta E > 0$, are negligibly small.

To search for the occurrence of double-Pomeron exchange, we have studied possible correlations of the scattered protons. We have observed two distinctly different correlation phenomena in the azimuthal angular distribution in the Gottfried-Jackson system [9]. Figure 2a shows the observed distributions without correction for geometrical acceptance. At $\sqrt{s} = 23$ GeV, we observe a prominent peak in the production plane at $\phi_J = 0^\circ$ and a broad distribution for $\phi_J > 90^\circ$. Similar peaking of the ϕ_J distribution in the production plane has been reported recently [10] for single-diffractive excitation in the ISR energy range. The observed broad distribution for $\phi_J > 90^\circ$ is in agreement, after correction for geometrical acceptance, with no correlation between the azimuthal angles of the two protons as expected for double-Pomeron exchange. We therefore tentatively attribute these two components to single-diffractive excitation and to double-Pomeron exchange, respectively. Dividing the data into two samples, one with $\phi_J < 90^\circ$ attributed to single-diffractive excitation, the other with $\phi_J > 90^\circ$ attributed to double-Pomeron exchange, we can compare their properties and try to justify this identification.

In both cases we find no correlation between the momentum transfers t_1 and t_2 of the scattered protons. The observed distribution of the sum of the momentum transfer t_1 and t_2 of the two protons is shown in Fig. 2b. Also shown are the results of a fit to the single momentum transfer distribution parametrized as

$$\frac{d\sigma}{dt_{1,2}} = C \exp(bt_{1,2})$$

with values of

$$b = \begin{array}{ll} (7.5 \pm 1.0) \text{ GeV}^{-2} & \text{at } \sqrt{s} = 23 \text{ GeV} \\ (7.0 \pm 0.7) \text{ GeV}^{-2} & \text{at } \sqrt{s} = 45 \text{ GeV} . \end{array}$$

REFERENCES

- [1] U. Amaldi, M. Jacob and G. Matthiae, Annu. Rev. Nuclear Sci. 26 (1976) 385.
- [2] D.M. Chew and G.F. Chew, Phys. Letters 53B (1974) 191.
- [3] H. de Kerret et al., Search for double-Pomeron at ISR energies, presented at 18th Internat. Conf. on High-Energy Physics, Tbilisi, USSR.
- [4] R. Bouclier, G. Charpak, E. Chesi, L. Dumps, H.G. Fischer, H.J. Hilke, P.G. Innocenti, G. Maurin, A. Minten, L. Naumann, F. Piuze, J.C. Santiard and O. Ullaland, Nuclear Instrum. Methods 115 (1974) 235.
- [5] R. Bouclier et al., Nuclear Instrum Methods 125 (1975) 19.
- [6] A. Brandt, H. Dibon, G. Flügge, F. Niebergall, K.R. Schubert, P.E. Schumacher and W. Wilmsen, Nuclear Instrum. Methods 126 (1975) 519.
- [7] H. Grote, M. Metcalf, C. Onions and F. Ranjard, CERN SFM Users' Guide, OM Div. Note AP/18-CERN (1975).
- [8] M. Metcalf, M. Regler and C. Broll, CERN 73-2 (1973).
- [9] K. Gottfried and J.D. Jackson, Nuovo Cimento 33 (1964) 309.
- [10] H. de Kerret et al., Phys. Letters 63B (1976) 483.
- [11] M. Derrick et al., Phys. Rev. D 9 (1974) 1215.
- [12] L. Backsaj et al., Phys. Letters 61B (1976) 89.
- [13] M. della Negra et al., Phys. Letters 65B (1976) 394.

The absence of a peak in the region of the f meson is not due to poor $(\pi^+\pi^-)$ mass resolution, but possibly to the geometrical acceptance of the detector, dis-favouring detection of highly asymmetric pion pairs. The angular momentum of the $(\pi^+\pi^-)$ state may be determined by studying the angular distribution of one of the pions in the dipion rest system. The distribution for events with $\phi_J > 90^\circ$ shown in Fig. 3b is isotropic and hence evidence that the dipion is dominantly in a state of zero angular momentum, in agreement with the assumption that it is produced by the interaction of two Pomerons.

In conclusion, we have found an experimental definition of a new class of diffractive events which we attribute to double-Pomeron exchange. Its properties are in agreement with theoretical expectation derived from phenomenological models.

Previous experiments could not establish the presence of double-Pomeron exchange, either because of a lack of statistics and a too low energy [11] or because of incomplete kinematical reconstruction of the events [12], or owing to the lack of data at more than one energy [13].

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Figure captions

- Fig. 1 : χ^2 distribution after the kinematical fit with four constraints at $\sqrt{s} = 23$ GeV and $\sqrt{s} = 45$ GeV:
- a) all events with $|x_p| > 0.9$, $|y_\pi| < 1.0$ and $0.06 < -t < 0.5$ GeV²;
 - b) events selected as for (a) but with energy imbalance $\Delta E = E_{\text{initial}} - E_{\text{final}} < 0$ to reduce background due to undetected additional particles.
- Fig. 2a : Observed azimuthal angular distributions in the Gottfried-Jackson system. The crosses connected by dashed lines give the expected distribution for double-Pomeron exchange after folding with the geometrical acceptance, with no correlation between the azimuthal angles of the two leading protons assumed.
- Fig. 2b : Distribution of the sum of momentum transfers squared of the two protons. The lines represent a fit to the single proton momentum transfer distribution and hence demonstrate the absence of correlation between t_1 and t_2 .
- Fig. 3a : Invariant mass distribution of the $(\pi^+\pi^-)$ system for events with $\phi_J > 90^\circ$ after correction for geometrical acceptance. We observe no evidence for ρ - or f -meson production.
- Fig. 3b : Angular distribution of the π^+ in the dipion rest system for events with $\phi_J > 90^\circ$ after correction for geometrical acceptance. The observed isotropy is evidence that the dipion is dominantly in a state of zero angular momentum.

 

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FIG. 1

FIG. 3a

FIG. 3b

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