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27 January 1986PRODUCTION OF THE f^0 MESON IN THE DOUBLE POMERON EXCHANGE REACTION

$$pp \rightarrow pp\pi^+\pi^- \text{ AT } \sqrt{s} = 62 \text{ GeV}$$

Ames-Bologna-CERN-Dortmund-Heidelberg-Warsaw Collaboration

A. Breakstone^{1(*)}, H.B. Crawley¹, M. Cuffiani², G.M. Dallavalle³,
K. Doroba⁶, D. Drijard³, F. Fabbri², A. Firestone¹, H.G. Fischer³,
H. Frehse^{3(**)}, W. Geist^{3(***)}, L. Gesswein⁵, G. Giacomelli², R. Gokieli⁶,
M.S. Gorbics¹, P. Hanke⁵, M. Heiden^{3(***)}, W. Herr⁵, E.E. Kluge⁵,
L.D. Isenhower¹, J.W. Lamsa¹, T. Lohse³, R. Mankel⁴, W.T. Meyer¹,
T. Nakada⁵⁽⁺⁾, M. Panter³, A. Putzer⁵, K. Rauschnabel⁴, B. Rensch⁵,
F. Rimondi², M. Schmelling⁴, G.P. Siroli²⁽⁺⁺⁾, R. Sosnowski⁶,
M. Szczekowski⁶, O. Ullaland³ and D. Wegener⁴

- 1 Ames Laboratory and Physics Department, Iowa State University, Ames, USA
- 2 Dipartimento di Fisica dell Università and INFN, Bologna, Italy
- 3 CERN, European Organization for Nuclear Research, Geneva, Switzerland
- 4 Institut für Physik der Universität Dortmund, Germany
- 5 Institut für Hochenergiephysik der Universität Heidelberg, Germany
- 6 University and Institute of Nuclear Studies, Warsaw, Poland

ABSTRACT

Data are presented for the exclusive reaction $pp \rightarrow pp\pi^+\pi^-$ at $\sqrt{s} = 62 \text{ GeV}$ with two leading protons at large Feynman- x and a centrally produced $\pi^+\pi^-$ system. In this kinematical configuration one expects a substantial contribution from Double Pomeron Exchange, which is a potential source of glueballs. The experiment was performed at the CERN ISR using the Split Field Magnet spectrometer. In the mass range between 1000 and 1700 MeV/c^2 the invariant mass distribution for the central $\pi^+\pi^-$ system exhibits a very significant signal for the $f^0(1270)$ and no other obvious resonant states.

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- (*) Present address: Department of Physics, University of Hawaii, USA.
(**) Present address: CDC, Zurich, Switzerland.
(***) Present address: LBL, Berkeley, California, USA.
(+) Present address: SIN, Villigen, Switzerland.
(++) Present address: Univ. of Maryland, College Park, Maryland, USA.

1. INTRODUCTION

The purpose of this experiment is to look for the existence of possible gluonium states in pp interactions at ISR energies, in reactions with two leading protons and a system of centrally produced particles. When both final-state protons are very fast (Feynman x_f near 1), these reactions are believed to be mediated by two Pomerons, from which central particles originate (Double Pomeron Exchange (DPE), fig. 1(a)). Pomeron exchange may be interpreted as a complicated phenomenon involving exchange of at least two gluons with possible insertion of gluon and quark loops (fig. 1(b)) [1]. Hence it has been suggested that bound states of gluons (glueballs [2]) could be produced in a DPE reaction [3]. In the following, data are presented on the exclusive reaction

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

at $\sqrt{s} = 62$ GeV in the kinematical region where DPE plays an important role (see below).

2. DATA ACQUISITION AND SELECTION

The Intersecting Storage Rings (ISR) at CERN provided good conditions for a study of reaction (1) because of their high luminosity and open geometry, i.e. experiments were performed almost in the centre-of-mass system (c.m.s.) of the colliding protons. In refs [4-6] it was shown that DPE reactions at ISR energies can be isolated from the background. A cross section of approximately 10 to 30 μb was estimated for the exclusive channel $pp \rightarrow pp \pi^+ \pi^-$, with Feynman x_f limited to $|x_f| > 0.9$ for the protons and with pions of c.m.s. rapidity $|y| < 1$.

In the current experiment, data were taken at $\sqrt{s} = 62$ GeV with the Split Field Magnet (SFM) spectrometer, which had good solid-angle coverage for charged particles. The SFM [7] had a 1 Tesla magnetic field and was composed of multiwire proportional chambers (MWPC) arranged into a central detector and two forward telescopes along the outgoing beams. A system of time-of-flight (TOF) counters and MWPC's with analog readout (dE/dx

chambers) for particle identification surrounded the central region. The trigger required a fast particle in each forward arm, plus (a) at least one central particle (trigger A) or (b) at least two central particles, one opposite in azimuth to the other (trigger B). To enhance the DPE contribution, the trigger also incorporated a veto at intermediate polar angles to create a rapidity gap of at least two units between each fast proton and the central particles.

Events satisfying the trigger condition were processed with the standard SFM reconstruction program. Events with two positive forward tracks with $|x_f| > 0.7$ and two central ($|x_f| < 0.3$) tracks of opposite charge were selected, yielding 58300 events of trigger type A and 16500 events of trigger type B.

In order to reject events with missing neutrals or with kaons or protons, instead of pions, in the central region, each event was subjected to a 4-constraint kinematic fit to the hypothesis $pp \rightarrow pp\pi^+\pi^-$ and only those events with a χ^2 probability > 0.1 were accepted. After this selection our final $pp \rightarrow pp\pi^+\pi^-$ sample consisted of 12500 events of type A and 4200 events of type B. In these events the leading protons have $|x_f| > 0.9$ and $|t| \geq 0.08 \text{ GeV}^2$ ($t = 4$ -momentum transfer), with $\langle |t| \rangle \sim 0.3 \text{ GeV}^2$. The pion c.m.s. rapidity is limited to the region $|y| \leq 1.5$. The rapidity distribution of all final state particles for these events is shown in fig 1(c). The clear separation of the leading protons from the central region is obtained.

3. DATA ANALYSIS: $\pi^+\pi^-$ EFFECTIVE MASS SPECTRUM

The mass calibration of the detector was tested by verifying the relative alignment of sectors of the detector through studies of cosmic-ray tracks without magnetic field. The largest systematic mass shift which could be caused by alignment errors is of the order 1 to 10 MeV/c^2 in the mass range from 800 to 1800 MeV/c^2 . A further test consisted in a search for two particles with well-known masses: the K_s^0 ($K_s^0 \rightarrow \pi^+\pi^-$) and the K^{*890} ($K^{*890} \rightarrow \pi^+\pi^-$ and $K^{*890} \rightarrow \pi^0\pi^0$ decay modes). A sample of 17000 inclusive events with at least one identified (by TOF or by dE/dx) charged kaon among the central tracks was analysed. This was done to provide a sample

of events with enhanced $K^*(890)$ and K_S^0 signals. The mass peaks from reconstructed K_S^0 and $K^*(890)$ were both found to be centred at the known standard masses, proving the correctness of the mass scale to a precision of better than $10 \text{ MeV}/c^2$.

The measured $\pi^+\pi^-$ invariant mass distribution is shown in fig. 2 for events selected with trigger A and in fig. 3 for events selected with trigger B. Clearly discernible are the following features:

- (a) In sample B, the region of $(\pi^+\pi^-)$ masses below $\sim 1 \text{ GeV}/c^2$ is depleted with respect to sample A, because trigger B required one π^+ and one π^- detected on azimuthally opposite sides of the interaction region, thus accepting only open $\pi^+\pi^-$ pairs and hence favouring contributions from higher-mass states. In particular the minimum relative angle between π^+ and π^- was 120° and their average p_t was $0.5 \text{ GeV}/c$.

In both samples A and B the $(\pi^+\pi^-)$ mass spectrum increases smoothly up to $900 \text{ MeV}/c^2$. No clear enhancement due to production of the $\rho^0(770)$ ($J^{PC} = 1^{--}$, $I = 1$) is seen. Note that a dominance of the Double Pomeron Exchange mechanism would force the central $\pi^+\pi^-$ system to prefer states with $J^{PC} = N^{++}$, where N is even, thus suppressing the ρ^0 .

- (b) Furthermore, one observes a rapid drop around $950 \text{ MeV}/c^2$, which is very clear in sample A and still detectable in sample B, despite the suppression due to low acceptance. Other experiments [8,9] have reported the existence of a similar sharp structure around $950 \text{ MeV}/c^2$ in the $(\pi^+\pi^-)$ mass spectrum for reaction (1). This could be attributed to the $S^*(980)$ resonance and/or the opening of the K^+K^- channel. A coupled analysis of the $(\pi^+\pi^-)$ mass spectrum and the K^+K^- mass spectrum near threshold is needed to clearly interpret the structure seen in the data [10].
- (c) At higher masses a very significant peak at approximately $1230 \text{ MeV}/c^2$ is seen; no other obvious resonant structures are observed in the mass range between 1000 and $1700 \text{ MeV}/c^2$.

In the following we study the mass region above $1 \text{ GeV}/c^2$. In particular we analyze the compatibility of the structure at $\sim 1230 \text{ MeV}/c^2$ with the $f^0(1270)$ resonance.

The $f^0(1270)$ ($J^{PC} = 2^{++}$) is the only known resonance with the proper quantum numbers which could generate a structure consistent in width with the structure observed between 1100 and $1400 \text{ MeV}/c^2$. To test that the enhancement results from a d-wave ($J = 2$) resonant state, the $(\pi^+\pi^-)$ mass spectrum was studied for different intervals in the pion polar-angle. The polar decay angle θ was defined by the π^+ direction with respect to the incident Pomerons (collinear) in the rest frame of the $(\pi^+\pi^-)$ system. Although the SFM had the capability to cover the full $\cos\theta$ range, the effective acceptance was limited to $-0.8 < \cos\theta < 0.8$ due to the trigger on central pions. The pion angular distribution reflects the spin of the parent state. Assuming zero component of the angular momentum along the Pomeron-Pomeron axis, the pion angular distribution can be described as

$$\begin{aligned} dN/d\cos\theta \text{ (s-wave)} &\propto 1 \\ dN/d\cos\theta \text{ (p-wave)} &\propto 3\cos^2\theta \\ dN/d\cos\theta \text{ (d-wave)} &\propto (5/4)(3\cos^2\theta - 1)^2 \end{aligned} \quad (2)$$

according to the spin (0, 1 or 2) of the parent state. At $\cos\theta$ near zero only s- and d-wave contribute; at $\cos\theta$ near $\pm 1/\sqrt{3}$ only s- and p-wave contribute. In fig. 4 the $(\pi^+\pi^-)$ mass spectrum (sample A) for $|\cos\theta| < 0.3$ (solid line) is compared with the $(\pi^+\pi^-)$ mass spectrum for $0.4 < |\cos\theta| < 0.7$ (dashed line). While the lower and higher mass regions show similar shapes, the enhancement at $1230 \text{ MeV}/c^2$ becomes more evident for $|\cos\theta| < 0.3$. This is in support of a strong d-wave component in the mass region of the enhancement.

The $(\pi^+\pi^-)$ invariant mass distribution $dN/dM(\pi^+\pi^-)$ in the mass range between 970 and $1750 \text{ MeV}/c^2$ was then parametrized as

$$dN/dM(\pi^+\pi^-) = BG \cdot (1 + \alpha \cdot BW(f^0)) \quad (3)$$

where α is a parameter to be determined, BG is the background distribution and $BW(f^0)$ is a relativistic d-wave Breit-Wigner distribution for f^0 mesons, with central mass and width to be determined.

In sample B (which has a highly biased mass acceptance), the shape of the background cannot be safely estimated in the mass range 970 to 1100 MeV/c² without making assumptions on the structure at 900 MeV/c². Consequently we restrict the analysis to sample A.

A reasonable shape for the background BG can be chosen for sample A, where the f^0 signal sits on a decreasing distribution: the background was assumed to have the simple form

$$BG = A \cdot M(\pi^+\pi^-)^{-\beta} \quad (4)$$

The fit of the data to (3) and (4) gives $\chi^2/\text{DOF} = 22.9/21$ and β is determined to be 3.9 ± 0.3 . Resulting values for fitted f^0 mass and width are 1270 ± 10 MeV/c² and 220 ± 30 MeV/c², which becomes 196 ± 34 MeV/c² when the calculated mass resolution of ± 50 MeV/c² is taken into account. These parameters are in good agreement with the Particle Data Group [11] values for f^0 . A relative contribution of $47 \pm 8\%$ from events belonging to the f^0 resonance in the mass range 1000 to 1500 was calculated from the fit. Fig. 5 shows the measured $(\pi^+\pi^-)$ mass distribution after the background BG is subtracted; the solid line is the predicted mass distribution from the fit for f^0 production.

After subtracting the background, 1665 ± 291 events are attributed to the f^0 resonance. The error is determined mainly by the uncertainty in the background. Acceptances were calculated by a Monte-Carlo technique. Events were generated [12,13] with two peripheral protons with $d\sigma/dt \sim e^{-b \cdot |t|}$, $b = 6 \text{ GeV}^{-2}$, and an f^0 decaying into $\pi^+\pi^-$. The acceptance was determined to be $(0.5 \pm 0.2)\%$, which includes also the loss of events because one of the two central tracks was missed at the reconstruction stage. The acceptance error comes mainly from the uncertainty in b ; $b = 6 \text{ GeV}^{-2}$ was chosen by requiring agreement with the data. Corrections were applied for losses due to nuclear absorption of protons in the beam pipe (about 10%) and to the cut in the 4C-fit χ^2 probability (10%). With an integrated luminosity of 50 nb^{-1} a cross section $\sigma(pp \rightarrow pp f^0, f^0 \rightarrow \pi^+\pi^-)$ of $8 \pm 1 \pm 3 \text{ } \mu\text{b}$ was determined. The first quoted error represents the statistical error combined with the error in determining the background; the second quoted error represents the additional systematic uncertainty in the acceptance. Note that although

the f^0 signal was well established and very significant, the cross section is presently not determined very well due to the difficulty of a precise calculation for a very low acceptance. This cross section is above the value quoted in ref. [6], but not inconsistent with it.

4. DISCUSSION AND CONCLUSIONS

The reaction $pp \rightarrow pp\pi^+\pi^-$ at $\sqrt{s} = 62$ GeV in the Double Pomeron Exchange kinematical region has been analyzed. The scattered protons have $|x_f| > 0.9$ and $|t| \geq 0.08$ GeV² and the pion c.m.s. rapidity is limited to the region $|y| \leq 1.5$. These data can be compared to those recently presented in ref. [9] where a $(\pi^+\pi^-)$ mass spectrum with a different shape from that displayed in fig. 2 was shown. The reason for this difference may come from the fact that the t range of the protons in that experiment is limited to $|t| \leq 0.05$ GeV², while the present experiment is confined to $|t| \geq 0.08$ GeV², and the angular acceptance for central tracks in this experiment extends to higher rapidities.

In the present analysis the $(\pi^+\pi^-)$ mass spectrum below 1000 MeV/c² shows a rapid drop around 950 MeV/c² and no clear indications for resonant structures, in particular for ρ^0 production. Similar features are present in ref. [9], where the drop at 950 MeV/c² is more drastic. Evidence for a sharp structure in this mass region for the same reaction at a lower c.m.s. energy ($\sqrt{s} = 13$ GeV) was also reported in ref. [8]. The opening of the K^+K^- channel together with the $S^*(980)$ resonance could be responsible for the observed structure; a coupled analysis of the $\pi^+\pi^-$ channel and the K^+K^- channel at threshold may clarify the subject.

In the $(\pi^+\pi^-)$ invariant mass distribution between 1000 and 1700 MeV/c² a very significant $f^0(1270)$ signal of 1665 ± 291 events is seen. The calculated f^0 mass and width are 1270 ± 10 MeV/c² and 196 ± 34 MeV/c², which are in good agreement with the world average values. There is no evidence for additional resonant states in this mass range. This is unlike ref. [9], where it is argued that the f^0 alone does not explain the behaviour of the data and the $\epsilon(1300)$ and possibly a 2^{++} resonance with mass about 1480 MeV/c² must be added. In agreement with ref. [9], our data do not show any indication for a G(1590) state [14], which has been suggested as a glueball candidate.

The observed $f^0(1270)$ signal appears to be shifted towards a lower mass at approximately $1230 \text{ MeV}/c^2$. This can be understood with a steeply falling background underneath the f^0 peak. A similar shift for the f^0 mass was observed in experiments on pion pair production in photon-photon collisions, i.e. the processes $e^+e^- \rightarrow e^+e^-\pi^+\pi^-$ [15] and $e^+e^- \rightarrow e^+e^-\pi^0\pi^0$ [16], where the observed peak was generally found near $1240 \text{ MeV}/c^2$, with a width of $\sim 250 \text{ MeV}/c^2$.

In conclusion, we have measured the invariant-mass distribution of $\pi^+\pi^-$ pairs produced in the Double Pomeron Exchange reaction $pp \rightarrow pp \pi^+\pi^-$ at $\sqrt{s} = 62 \text{ GeV}$. A rapid drop in the $(\pi^+\pi^-)$ mass spectrum is observed around $950 \text{ MeV}/c^2$. Between 1000 and $1700 \text{ MeV}/c^2$ the $(\pi^+\pi^-)$ invariant-mass distribution is dominated by the $f^0(1270)$.

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REFERENCES

- [1] F. Low, Phys. Rev. D12 (1975) 163;
S. Nussinov, Phys. Rev. Lett. 34 (1975) 1286;
J. Pumplin and E. Lehman, Zeit. f. Phys. C9 (1981) 25.
- [2] R.L. Jaffe and K. Johnson, Phys. Lett. 60B (1976) 201.
- [3] D. Robson, Nucl. Phys. B130 (1977) 328.
- [4] D. Drijard et al., Nucl. Phys. B143 (1978) 61.
- [5] L. Baksay et al., Phys. Lett. 61B (1976) 89.
- [6] R. Waldi, K.R. Schubert and K. Winter, Zeit. f. Phys. C18 (1983) 301.
- [7] R. Bouclier et al., Nucl. Instr. and Meth. 115 (1974) 135;
R. Bouclier et al., Nucl. Instr. and Meth. 125 (1975) 19;
W. Bell et al., Nucl. Instr. and Meth. 156 (1978) 111.
- [8] Athens-Bari-Birmingham-CERN Collaboration, Proc. of the Int. Conf. on
Hadron Spectroscopy Univ. of Maryland (April 1985) 155.
- [9] T. Akesson et al., Phys. Lett. 133B (1983) 268.
T. Akesson et al., CERN EP/85-115 (22 July 1985).
- [10] S.M. Flatté et al., Phys. Lett. 38B (1972) 232.
- [11] Review of Particle Properties, Particle Data Group, Rev. Mod. Phys.
56, No. 2, Part. 2, April 1984.
- [12] F. James, FOWL, CERN, Program Library (1967);
E. Byckling, M. Kaartinen, K. Kajantie and H. Villanen, Research
Institute for Theoretical Physics, Report No. 3-69, 1969
(unpublished).
- [13] R. Messerli, SFMGENER, CERN (unpublished).
- [14] F. Binon et al., Nuovo Cimento 78A (1983) 313.
S.S. Gershtein, A.A. Likhoded and Yu.D. Prokoshkin, Zeit. f. Phys.
C24 (1984) 305.
- [15] Ch. Berger et al., Phys. Lett. 94B (1980) 254.
R. Brandelik et al., Zeit. f. Phys. C10 (1981) 117.
A. Roussarie et al., Phys. Lett. 105B (1981) 304.
H.J. Behrend, et al., Zeit. f. Phys. C23 (1984) 223.
A. Courau et al., Phys. Lett. 147B (1984) 227.
- [16] C. Edwards et al., Phys. Lett. 110B (1982) 82.

FIGURE CAPTIONS

- Fig. 1 (a) Double Pomeron Exchange in $pp \rightarrow pp\pi^+\pi^-$.
 (b) Example of gluon ladders and quark loops which may sum to produce a Pomeron trajectory.
 (c) Rapidity distribution of particles from 4-C fits to the reaction $pp \rightarrow pp\pi^+\pi^-$ at $\sqrt{s} = 62$ GeV. (Uncorrected)
- Fig. 2 Invariant mass distribution for the central $\pi^+\pi^-$ system (uncorrected) in events selected with trigger A (see text). Errors shown are statistical.
- Fig. 3 Invariant mass distribution for the central $\pi^+\pi^-$ system (uncorrected) in events selected with trigger B (see text). Errors shown are statistical.
- Fig. 4 Uncorrected $(\pi^+\pi^-)$ invariant mass distribution for sample A for two different regions of the π^+ polar-angle in the Pomeron-Pomeron c.m.s.:
 (a) $|\cos\theta_{\pi^+ \text{Pom}}| < 0.3$ (solid line).
 (b) $0.4 < |\cos\theta_{\pi^+ \text{Pom}}| < 0.7$ (dashed line).
- Fig. 5 Uncorrected invariant mass distribution for the central $\pi^+\pi^-$ system obtained from fig. 2 after subtraction of the non-resonant background. Errors shown are statistical. The solid line is the predicted mass distribution as determined from the fit described in the text.

(a)

(b)

(c)

Fig. 1

Fig. 2

Fig. 3

Fig. 4

Fig. 5