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INCLUSIVE POMERON-POMERON INTERACTIONS AT THE CERN ISR

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

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ABSTRACT

Data are presented for the first time on inclusive Pomeron-Pomeron interactions which produce a central system X (composed mainly of multi-meson states) in proton-proton collisions at $\sqrt{s} = 62$ GeV at the CERN ISR. The system X has a Feynman- x distribution which is sharply peaked at $x_f = 0$, is inconsistent with any significant contributions from Reggeon exchange processes, and has an invariant mass dependence in good agreement with the predicted form M_X^{-2} . Kaon production is about 15% of pion production, nearly independent of M_X , while proton-antiproton production averages about 5% of pion production and increases with M_X . The structure of the central system X develops into a jet-like shape, as M_X increases, as would be expected from a model of Pomeron fragmentation. The shape of the $x_f(\pi)$ distribution in the center of mass of the X system (although not proving existence) is consistent with a *soft* partonic substructure of the Pomeron.

1. Introduction

The characteristic features of hadronic diffractive processes can be understood as due to the exchange of the Pomeron. It has been suggested that the Pomeron, which has the quantum numbers of the vacuum, might be generated by multiple gluon exchange [1]. Even though total cross-sections at high energy are dominated by the exchange of the Pomeron, its nature is still not well understood. Pomeron-hadron interactions, which occur in diffractive elastic scattering and inelastic diffractive dissociation, have been studied extensively. However, very few investigations of Pomeron-Pomeron scattering have been performed; in particular, no studies of the inclusive process *Pomeron-Pomeron into anything* have been attempted. In this paper, we present for the first time an examination of both *exclusive* and *inclusive* Pomeron-Pomeron collisions. These results provide further knowledge of the characteristics of the Pomeron.

Pomeron-Pomeron interactions are investigated by selecting proton-proton collisions which have two diffractively scattered outgoing protons at large Feynman- x , x_f , and a system of centrally produced particles. The exchanged Pomerons produce the central system, X , as the final state of their interaction, (see Figure 1). This is very similar to the way two-photon reactions have been studied in electron-positron interactions. Since the Pomeron-Pomeron reaction shares many characteristics with the two-photon reaction, it may provide an important laboratory for comparing QCD effects with QED effects.

We investigate properties of Pomeron-Pomeron (**PP**) interactions up to an energy of approximately 5 GeV in the **PP** system. Comparison of our cross-section measurements is made with theoretical estimates based on a triple-Regge formalism which includes the

triple-Pomeron vertex [2]. To examine the role of strangeness and baryon production in Pomeron-Pomeron scattering, we present measurements of K/π and p/π ratios, which can be compared to those from hadron-hadron interactions. Finally, to study the internal structure of the central system X , we examine the question of whether Pomeron-Pomeron interactions are isotropic in their c.m.s. or become more longitudinal (jetlike) along the Pomeron axis with increasing **PP** energy. For example, the latter behavior might be expected should the Pomeron have gluon substructure.

In the following, data are presented on the exclusive reactions:

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

$$pp \rightarrow pp(2\pi^+2\pi^-) \quad (2)$$

$$pp \rightarrow pp(3\pi^+3\pi^-) \quad (3)$$

$$pp \rightarrow pp(K^+K^-) \quad (4)$$

$$pp \rightarrow pp(K^+K^-\pi^+\pi^-) \quad (5)$$

$$pp \rightarrow pp(p\bar{p}) \quad (6)$$

$$pp \rightarrow pp(p\bar{p}\pi^+\pi^-), \quad (7)$$

which can be appropriately combined (see section 4) to approximate the inclusive reaction:

$$pp \rightarrow ppX. \quad (8)$$

The data presented have been obtained at $\sqrt{s} = 62$ GeV in the kinematical region where Pomeron-Pomeron interactions play an important role (see below).

2. Data Acquisition and Selection

The Intersecting Storage Rings (ISR) at the CERN Laboratory provided good conditions for the study of reactions 1 through 8 because of their high luminosity and open geometry, i.e., the experiments were performed essentially in the center-of-mass system (c.m.s.) of the colliding protons. In references [3-4] it was shown that **PP** 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 limited to $|x_f| > 0.9$ for the protons and with pions of c.m.s. rapidity $|y| < 1$.

In the present experiment, data were taken at $\sqrt{s} = 62$ GeV with the Split-Field-Magnet (SFM) detector [5], which had good solid-angle coverage for charged particles. The SFM had a 1 Tesla magnetic field and was composed of multiwire proportional chambers (MWPC) arranged into a central detector plus 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 detector. The data analyzed in this paper were taken with a trigger which required the detection of a fast charged particle in each forward telescope, plus at least one charged particle detected in the central region. To enhance the **PP** contribution, the trigger incorporated a veto on charged particles produced at intermediate polar angles, and this produced a rapidity gap of at least two units between each fast proton and the particles produced in the central region. The integrated luminosity was 50 nb^{-1} .

In a previous work [6] we published evidence that with the kinematic constraints imposed by the trigger the exclusive reaction (1) was dominated by Double-Pomeron-Exchange. We also presented an analysis of the mesonic invariant mass distribution for that reaction. In the current work we analyze the seven exclusive reactions (1) - (7).

Events satisfying the trigger conditions were processed with the standard SFM reconstruction codes. Events with exactly one positive forward track in each of the two telescopes with $|x_f| > 0.7$ and two, four, or six central ($|x_f| < 0.3$) tracks of zero net charge were selected.

In order to reject events with missing neutral particles and to assign events to the correct kinematic hypothesis, the selected events were subjected to four-constraint kinematic fits to the hypotheses of reactions (1) - (7). Only those hypotheses which fit the data with χ^2 probability > 0.1 were accepted. In addition, positive identification (by TOF or by dE/dx) of at least one of the charged kaons or of at least the central region proton or antiproton was required for the hypotheses with charged kaons, protons, or antiprotons. In the case of reactions (5) and (7), where only one central particle was identified and two ambiguous fits resulted, we used an equal weighting of 0.5 for the two hypotheses.

In Table 1 we show the numbers of events remaining after all appropriate cuts were made, and the corresponding cross sections for the seven exclusive reactions. The cross sections have been corrected for all acceptance effects, and these are discussed in the next section.

For the selected events the leading protons have $|x_f| > 0.9$ and $|t| \geq 0.08 \text{ GeV}^2$ (t is the four-momentum-transfer squared), with $\langle |t| \rangle \simeq 0.3 \text{ GeV}^2$. The c.m.s. rapidity of all central particles is limited to the region $|y| \leq 1.5$. The rapidity distribution of all final state particles for reaction (1) was presented in reference [6], and it showed the clear separation of the leading protons from the central region. The rapidity distributions of the final state particles for reactions (2) - (7) are similar.

3. Acceptance Corrections

Acceptances have been calculated using a two-stage Monte-Carlo technique. In the first stage, single particles were generated for all momenta and angles that could envelop the trigger chambers. The particle trajectories were tracked through the magnetic field, the detector chambers, and the TOF counters [7]. Energy losses, scattering, and particle decays were included as were the effect of cuts on ‘measured’ TOF masses for kaons and protons. With the information obtained from this tracking, ‘trigger-tables’ were constructed which define the regions (in polar angle θ , azimuth ϕ , and momentum p) where particle trajectories satisfied a trigger requirement.

In the second stage, complete events were generated for reactions (1) - (7) using a double-peripheral model [8]. Peripheral production of the outgoing protons was accomplished by using a matrix-element squared of the form $e^{-6|t_1|} \cdot e^{-6|t_2|}$. The t distributions produced with this model agree with the data for all the reactions considered. An isotropic decay was used for those reactions which feature only two particles in the central system [reactions (1), (4), and (6)]. For these reactions we formed acceptance tables, at 100 MeV steps of M_X , which were calculated in two dimensions corresponding to the decay angles θ and ϕ , defined with respect to the Pomeron direction in the central system X . For the other reactions which feature either four or six particles in the central region we used a p_T -damped decay, where p_T is defined with respect to the Pomeron direction in the system X ; the matrix-element squared

$$\prod_{i=1}^n e^{-A m_L}, \quad m_L = \sqrt{(p_T)_i^2 + m_i^2}$$

was used. The distributions predicted by this matrix element, with $A \simeq 2$ and independent of M_X , are in good agreement with the data. In order to obtain an estimate of the systematic error resulting from model dependences, we compared the acceptances resulting from this model with that from a model which assumed an isotropic decay of the central system. The differences in acceptance obtained by the two methods were small (generally less than 10%), and we therefore believe that the p_T -damped model is sufficient for the present work.

The trigger acceptance for a Monte-Carlo event was obtained by examining each track in the event against the ‘trigger-tables’ to determine if the trigger requirement was satisfied. To obtain the full acceptance, the trigger acceptance was combined with the SFM track reconstruction efficiency calculated for the complete event.

Figure 2 shows the absolute acceptance corrections for each of reactions (1) - (7) as functions of M_X . We remark that the large corrections which result from the forward proton acceptance (e.g., from limited t and azimuthal ϕ) are essentially the same for

reactions (1) - (7). As seen in the figure, the values of the relative acceptances are at most a factor of ≈ 10 between the different reactions.

4. Multi-Pion Mass and Feynman- x Distributions

The measured multi-pion invariant mass distribution is shown in Figure 3 for all events of reactions (1), (2), and (3). The 2π mass distribution from reaction (1) features a large low mass enhancement and a peak at the $f^0(1270)$ resonance. This was studied in detail in reference [6]. The 4π and 6π mass distributions from reactions (2) and (3) respectively are much broader and show no significant narrow structures. The 4π mass distribution does show a broad enhancement around 1.8 GeV, and a shoulder near 1.2 GeV. All three distributions are shown in absolute cross section units with all corrections, including those for the geometrical acceptance of the trigger and for track finding and reconstruction in the different regions of the detector. The behavior of the ‘inclusive’ sum of these distributions will be studied below.

An important condition to be verified (for a test of the existence of **PP** reactions) is that the system X be truly centrally produced; i.e., the distribution in $x_f(X)$ should be *sharply peaked* at $x_f = 0$. The distributions in $|x_f|$ for the central pionic systems of reactions (1) - (3) are shown in Figure 4. Feynman- x , e.g. for the $\pi^+\pi^-$ system, is defined:

$$x_f(\pi^+\pi^-) = \{p_L(\pi^+) + p_L(\pi^-)\} / p_{beam}. \quad (9)$$

The mass intervals used for Figure 4 were $0.6 \rightarrow 1.0$, $1.5 \rightarrow 2.5$, and $2.5 \rightarrow 4.0$ GeV for the 2π , 4π , and 6π distributions respectively. It was necessary to impose these limits because events with either low or very high Q -values (momenta in the rest system of the central system) did not have a sufficiently wide acceptance in x_f . The average values of the invariant mass for the three intervals shown are 0.8, 1.8, and 3.2 GeV respectively.

Model predictions for the $|x_f|$ distributions for a central mesonic system with invariant mass $M_X = 0.8, 1.8$, and 3.2 GeV are shown in Figure 5. Predictions of both a Pomeron-Pomeron (**PP**) and a Pomeron-Reggeon (**PR**) exchange model are shown. A standard formulation of a Reggeized double-peripheral model was used which incorporates the matrix element:

$$|M|^2 \propto e^{A_1 t_1} e^{A_2 t_2} S^{2\alpha_P(p_1, X)} S^{2\alpha_{P[or R]}(p_2, X)}. \quad (10)$$

The variable S is the square of the invariant mass of an outgoing proton, p_1 or p_2 , and the central system X . The Pomeron trajectory is assumed to have zero slope and unit intercept. For the Pomeron-Reggeon exchange model the Reggeon (i.e., rho) trajectory

is taken to have a slope of unity and an intercept of 0.5 units. Exponential dependences on the four-momentum transfers, t_1 and t_2 , of the external proton-proton vertices are introduced in order to reproduce the behavior seen in the data. The exponential slopes, A_1 and A_2 , ranged from 5 to 8 GeV^{-2} .

In the region, $x_f < 0.15$, where the experimental data are available, the **PR** exchange model predicts an essentially flat distribution in disagreement with the data. The amount of background from Reggeon exchange reactions appears not to be significant. In each case the observed x_f -distributions are consistent with the predictions of the Pomeron-Pomeron exchange model.

To compare the experimental results with theoretical predictions for the s -dependence of Pomeron-Pomeron interactions, we present the square of the invariant mass of the central pionic system for reactions (1) - (3), and their ‘inclusive’ sum, in Figures 6 and 7a, respectively. The smooth curve, in Figure 7a, has a $1/M_X^2$ dependence and is predicted from double-Pomeron-exchange models which incorporate the triple-Regge formalism [2]. Reactions (4) - (7), which involve kaons or protons and antiprotons in the central system are not included in this analysis because the $K^+K^-4\pi$ and $p\bar{p}4\pi$ channels, corresponding (in multiplicity) to the 6π channel were not available. To show what would be more representative of ‘inclusive’ behavior and to compare the data to a simple power law in M_X , we have included only the multi-pion channels. We note that the data fall below the curve at the highest masses, which may result from the fact that higher-multiplicity channels (not studied in this work) would normally contribute there.

In Figure 7b we show the same data as in Figure 7a, but here we have attempted to correct for states with π^0 's. We assumed a simple model of $I = 0$ dominance for groups of outgoing particles with zero net charge, and then applied the appropriate Clebsch-Gordan coefficients to account for the missing states. Justification for this model comes from the assumption of a fragmentation picture for the incident state $I = 0$ Pomerons. We obtain correction factors for the 2π , 4π , and 6π systems of $3/2$, $9/4$, and $27/8$ respectively. The data shown in Figure 7 are in general agreement with an M_X^{-2} dependence on the mass of the central system. Since different model assumptions would yield somewhat different correction factors, one should not take the exact shape of the corrected data in Figure 7b too seriously. However, one might reasonably claim that the overall cross-section is increased by a factor of ≈ 2 by the correction for neutrals. With this assumption and our measured ‘inclusive’ cross-section (for the sum of reactions (1) - (7)) of $175 \mu\text{b}$, we obtain an estimate of approximately $400 \mu\text{b}$ for the ‘total inclusive’ cross-section with correction for neutrals. Considering the systematic error on our measurement (factor of 1.5), this is not in disagreement with the theoretical estimate of $250 \mu\text{b}$ from reference [2].

5. Kaon and Proton-Antiproton Production

It is interesting to compare the relative flavor production rates in Pomeron-Pomeron reactions to those in hadron-hadron reactions. Information may be gained on the characteristics of the Pomeron such as its SU(3)-structure. In addition, such information could be useful in determining the gluonic substructure of the Pomeron [9]. We present measurements of the kaon and proton-antiproton content of the central system X , for reactions (4) - (7). In Figure 8 we show the invariant mass distributions for the central K^+K^- (reaction (4)) and $K^+K^-\pi^+\pi^-$ (reaction (5)) systems. The mass distributions show no particular fine structure but feature a broad low-mass enhancement characteristic of many processes, including diffractive reactions and two-gamma interactions. Figure 9 shows the invariant mass distributions for the central $p\bar{p}$ (reaction (6)) and $p\bar{p}\pi^+\pi^-$ (reaction (7)) systems. Although statistics are poor the proton-antiproton data show qualitatively the same features as the K^+K^- data, i.e., a large low-mass enhancement and no other fine structure.

For a comparison of relative rates we present two different K/π and p/π ratios: an *event ratio* and a *particle ratio*. * The event ratio is defined as the ratio of the cross-section for producing an event containing a charged kaon to that of an event with only pions in the central system. Figure 10a shows the *event ratio* K/π as a function of M_X . The distribution shows only a weak dependence on M_X and indicates that on average the probability of producing an event with a charged kaon is about 30% of that of producing an event with only pions. The particle ratio is defined as the ratio of the single-particle cross-section for producing a charged kaon to that for producing a charged pion. Figure 10b shows the *particle ratio* K/π as a function of M_X . This ratio averages about 15%, and is similar to that measured in hadron-hadron and also photon-photon interactions. It should be noticed that the ratio rises very sharply at threshold. Our results differ from those of reference [4] which measures a much larger K/π ratio near threshold. The K^+K^- mass distribution (Figure 8) is rising rapidly, and the $\pi^+\pi^-$ mass distribution (Figure 3) is dropping rapidly near 1 GeV. This behavior may be related to the possible excitation of

* As in the case for the multi-pion states, we attempted to correct for states with neutrals. The ratios obtained with the corrected cross-sections were in close agreement with those obtained without the neutrals correction. However, since the correction is uncertain (i.e., model dependent) we present here only the results from the directly measured states. We also point out that the contribution from the reaction $pp \rightarrow pp(K^0 K^\pm \pi^\mp)$ is quite small; a cross-section upper limit was determined from the present data which is an order of magnitude smaller than the cross-section for reaction (5).

the $f_0(975)$ state. A detailed analysis of this effect will be presented in a future work. For an earlier observation of this effect see reference [4], the data of which has been analysed in terms of amplitudes and poles [10]. Also, a recent experiment at lower energy but with much higher statistics has seen similar behavior and has successfully fit it with the $f_0(975)$ interfering with background [11].

Figure 11a shows the *event ratio* p/π as a function of M_X . ** The data show that the probability of producing an event with a proton-antiproton relative to that for producing an event with only pions increases with M_X to a level of about 20% at the highest available values of M_X , i.e., 4 GeV, and averages about 10% over the entire range. Figure 11b shows the *particle ratio* p/π as a function of M_X . The ratio averages about 5%, and increases to about 10% at 4 GeV.

6. Structure (Event Shape) of the Central System X

To study the characteristics of Pomeron-Pomeron interactions, as would be represented by their event shapes, we have calculated the average transverse and longitudinal momenta ($\langle p_T \rangle$ and $\langle p_L \rangle$) in the Pomeron-Pomeron rest frame with respect to the Pomeron axis of the centrally produced pions for reactions (1) - (3). For comparison purposes the average longitudinal momenta have been multiplied by $\sqrt{2}$ to compensate for the phase-space differences resulting from the two-dimensional character of the transverse momenta. The data are shown in Figures 12a and 12b for reactions (1) - (3), and in Figure 13 for their ‘inclusive’ sum. In all three reactions, and their ‘inclusive’ sum, the growth of $\langle p_L \rangle$ continues with increasing M_X , whereas $\langle p_T \rangle$ appears to approach a limiting value, $\langle p_T \rangle \simeq 0.4$ GeV/c. An exception may be the growth of $\langle p_T \rangle$ for reaction (1); the 2π cross-section, however, is small at large masses and therefore it does not affect the inclusive distribution. These data show that the central pionic system is *not* spherically symmetric, especially at the larger values of M_X . The developing event shape would seem to indicate the emergence of Pomeron jets.

We now compare our results to that from a *more standard* hadron-hadron reaction. We use results from reference [12] on the reaction $\pi^- \pi^0 \rightarrow \pi^- \pi^0 \pi^+ \pi^-$ (the initial state π^0 is a virtual pion). Since this reaction does not involve an initial state baryon (with its associated inelasticity) it makes an ideal comparison. The measured average p_T from the above reaction is 300 MeV/c, and it is the same for the different charge state pions.

** We note that the reactions $pp \rightarrow pp(p\bar{n}\pi^-, n\bar{p}\pi^+)$ are not measured in this experiment and their cross-sections are unknown. As a result our p/π ratio is probably suppressed in the region around 2.5 to 3.0 GeV.

However, the average p_L is larger for the outgoing π^0 than that for the π^- , which is larger than that for the π^+ . This is easily explained as a leading particle effect. (The π^- 's, since there are two of them, have both leading and non-leading contributions.) The results for the $\pi\pi$ reaction are given in reference [12] for an integrated 4π mass spectrum having an average $M(4\pi) \approx 2.3$ GeV. We make our comparisons at that $M(4\pi)$ value. In Figure 12a we have included the $\langle p_T \rangle$ point from the $\pi\pi$ data (open triangle), and in Figure 12b, the $\langle p_L(\pi^0) \rangle$ and $\langle p_L(\pi^+) \rangle$ points (closed and open triangles) for leading and non-leading pions, respectively. A comparison of the $\pi\pi \rightarrow 4\pi$ reaction with our **PP** $\rightarrow 4\pi$ data indicates that the **PP** system is not as strongly jetlike as that from $\pi\pi$ reactions. Our $\langle p_T \rangle$ is larger than that from the $\pi\pi$ reaction, and our $\langle p_L \rangle$ is about equal to that from the non-leading π , and smaller than that from the leading π . These differences could be explained from the fact that there are hard constituents (valence quarks) in the initial $\pi\pi$ state (but not the **PP** system) which would produce the stronger jetlike behavior.

It may be possible to obtain further information on this and related questions of gluon distributions in the Pomeron from the 'inclusive' distribution of $|x_f(\pi)| = 2|p_L(\pi)|/M_X$, shown in Figure 14. The distribution is shown for two M_X intervals, $1.5 \rightarrow 3.0$ and $3.0 \rightarrow 4.5$ (the cross-section below 1.5 GeV is dominated by the 2π channel). The smooth curves have the form $(1 - x_f)^{2.5}$ and show the general trend of the data. The lack of an enhancement at large $|x_f|$ indicates the absence of any strong leading particle effect. This is in contrast to the $\pi\pi \rightarrow 4\pi$ data of reference [12] where a clear enhancement is seen at large $|x_f|$. If we interpret our data in terms of a parton picture, this suggests the *absence* of 'hard' partonic constituents (valence quarks or hard gluons) in the Pomeron.

If we follow the hypothesis of Low and Nussinov [1] and the analysis of Streng [2], that the Pomeron is a gluonic system, the Pomeron-Pomeron interaction could then be expected to proceed in a number of ways via gluon (g) exchange, with various diagrams involving, e.g. $3g$ couplings. Although counting rules are not well tested for fragmentation functions, if we turn the question around, look at the data in Figure 14 and ask how many gluons were involved in Pomeron break up to produce the $(1 - x_f)^{2.5}$ fall off, we find about three gluons in the Pomeron. The $3g$ coupling would inherently diffuse hard gluons within the Pomeron and leading particle-type behavior would not be expected [13].

5. Conclusions

Data have been presented on the production of charged particles in the central region from Pomeron-Pomeron reactions in proton-proton collisions at 62 GeV at the CERN ISR. The inclusive process *Pomeron-Pomeron into anything* was studied up to an energy of ≈ 5 GeV in the **PP** system. The central system X is produced with a cross-section and mass

dependence in agreement with theoretical estimates based on a triple-Regge formalism. The inclusive K/π and p/π production ratios are similar (not enhanced) compared to what is seen in hadron-hadron interactions. The event structure is inconsistent with a spherical (fireball) shape, but shows clear evidence for a longitudinal jetlike behavior in the Pomeron direction. The jetlike behavior is not, however, as strong as is observed in $\pi\pi$ reactions. If we adopt the language of the parton picture, the data are compatible (in a qualitative sense) with the Pomeron having a substructure composed of *soft* partonic constituents.

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References

- [1] F.E. Low: Phys. Rev. **D12**, 163 (1975); S. Nussinov: Phys. Rev. **D14**, 246 (1976); J. Pumplin and E. Lehman: Z. Phys. C - Particles and Fields **9**, 25 (1981)
- [2] A.B. Kaidalov and K.A. Ter-Martirosyan: Nucl. Phys. **B75**, 471 (1974); K.H. Streng: Phys. Lett. **166B**, 443 (1986)
- [3] R. Waldi, K.R. Schubert, and K. Winter: Z. Phys. C - Particles and Fields **18**, 301 (1983); D. Drijard et al.: Nucl. Phys. **B143**, 61 (1978); H. DeKerret et al.: Phys. Lett. **68B**, 385 (1977); L. Baksay et al.: Phys. Lett. **61B**, 89 (1976)
- [4] T. Åkesson et al.: Nucl. Phys. **B264**, 154 (1986); T. Åkesson et al.: Phys. Lett. **133B**, 268 (1983)
- [5] R. Bouclier et al.: Nucl. Instr. Meth. **115**, 135 (1974); R. Bouclier et al.: Nucl. Instr. Meth. **125**, 19 (1975); W. Bell et al.: Nucl. Instr. Meth. **156**, 111 (1978)
- [6] A. Breakstone et al.: Z. Phys. C - Particles and Fields **31**, 185 (1986)
- [7] R. Messerli: SFMGNER, CERN (unpublished)
- [8] F. James: FOWL, CERN, Program Library (1967); E. Byckling, M. Kaartinen, K. Kajantie, and H. Villanen: Res. Inst. Theor. Phys. Report No. 3-69, 1969 (unpublished)
- [9] H. Fritzsch and K.H. Streng: Phys. Lett. **164B**, 391 (1985)

- [10] K.L. Au, D. Morgan and M.R. Pennington: Phys. Rev. **D35**, 1633 (1987)
- [11] T.A. Armstrong et al. (WA76 Collaboration): preprint CERN/EP 88-124 (1988)
- [12] W.J. Robertson, W.D. Walker and J.L. Davis: Phys. Rev. **D7**, 2554 (1973)
- [13] K.E. Lassila and A. Ng: Proc. of the VII European Symposium on Antiproton Interactions, Ed. M.R. Pennington (Adam Hilger Ltd., Bristol, England 1985) p.511

Table 1. Cross-Sections for exclusive reactions. The quoted errors do not include a global systematic error (estimated as a *factor of 1.5*) which results from an overall uncertainty in the acceptance and the luminosity calibration.

Reaction	Number of Events	Cross Section [μb]
(1) $pp \rightarrow pp(\pi^+\pi^-)$	16400	79.0 ± 13.0
(2) $pp \rightarrow pp(2\pi^+2\pi^-)$	5800	46.0 ± 10.0
(3) $pp \rightarrow pp(3\pi^+3\pi^-)$	1900	32.0 ± 9.0
(4) $p\bar{p} \rightarrow p\bar{p}(K^+K^-)$	560	6.5 ± 1.7
(5) $pp \rightarrow p\bar{p}(K^+K^-\pi^+\pi^-)$	150	10.0 ± 3.3
(6) $pp \rightarrow p\bar{p}(p\bar{p})$	120	0.8 ± 0.17
(7) $pp \rightarrow p\bar{p}(p\bar{p}\pi^+\pi^-)$	65	1.3 ± 0.36

Figure Captions

Fig. 1 Double-Pomeron-Exchange diagram. A central mesonic system X , of mass M_X , is produced from the collision of two Pomerons.

Fig. 2 Absolute acceptances for reactions (1) - (7) as functions of M_X .

Fig. 3 Invariant mass distributions for the central $\pi^+\pi^-$, $2\pi^+2\pi^-$, and $3\pi^+3\pi^-$ systems from reactions (1), (2), and (3) respectively (in μb per 100 MeV bin). This figure, and all subsequent figures, show data which have been acceptance corrected.

Fig. 4 Feynman- x distributions of the central systems for reactions (1) - (3).

Fig. 5 Model predictions for Feynman- x distributions of a central mesonic system of invariant mass $M_X = 0.8, 1.8$, and 3.2 GeV. The solid (dashed) curves show the predictions of a Pomeron-Pomeron (Pomeron-Reggeon) exchange model. The vertical dashed line at $x_f = 0.15$ indicates the limit of measurement for the data, as shown in Figure 3.

Fig. 6 Invariant mass-squared distributions for the central $\pi^+\pi^-$, $2\pi^+2\pi^-$, and $3\pi^+3\pi^-$ systems from reactions (1), (2), and (3) respectively (in μb per 300 MeV² bin).

Fig. 7 (a) 'Inclusive' invariant mass-squared distribution for the sum of the central $\pi^+\pi^-$, $2\pi^+2\pi^-$, and $3\pi^+3\pi^-$ systems from reactions (1), (2), and (3) respectively (in μb per 300 MeV² bin). The smooth curve shows the form $1/M_X^2$. (b) The same as in part (a) except that the data have been corrected for final states containing π^0 's (see text). The smooth curve shows the form $1/M_X^2$.

Fig. 8 Invariant mass distribution for the central K^+K^- system (filled circles), and the $K^+K^-\pi^+\pi^-$ system (open circles), from reactions (4) and (5) respectively (in μb per 100 MeV bin).

Fig. 9 Invariant mass distribution for the central $p\bar{p}$ system (filled circles), and the $p\bar{p}\pi^+\pi^-$ system (open circles), from reactions (6) and (7) respectively (in μb per 100 MeV bin).

Fig. 10 (a) Event ratio K/π as a function of M_X . Defined as the ratio of the cross-section for producing an event with a charged kaon to that of an event with only pions. (b) Particle ratio K/π as a function of M_X . Defined as the ratio of the single-particle cross-section for producing a charged kaon to that for producing a charged pion.

Fig. 11 (a) Event ratio p/π as a function of M_X . Defined as the ratio of the cross section for producing an event with a proton-antiproton to that of an event with only pions. (b) Particle ratio p/π as a function of M_X . Defined as the ratio of the single-particle cross-section for producing a proton-antiproton to that for producing a charged pion.

Fig. 12 Distributions in (a) $\langle p_T \rangle$ and (b) $\sqrt{2} \langle p_L \rangle$ as functions of M_X . For individual pions in the central $\pi^+\pi^-$, $2\pi^+2\pi^-$, and $3\pi^+3\pi^-$ systems. The values represented by triangles are for the reaction $\pi\pi \rightarrow 4\pi$ from reference [12] (see text).

Fig. 13 ‘Inclusive’ distributions in $\langle p_T \rangle$ and $\sqrt{2} \langle p_L \rangle$ as functions of M_X . For individual pions from the sum of the central $\pi^+\pi^-$, $2\pi^+2\pi^-$, and $3\pi^+3\pi^-$ systems.

Fig. 14 ‘Inclusive’ Feynman- x distributions of individual pions from the sum of the central $\pi^+\pi^-$, $2\pi^+2\pi^-$, and $3\pi^+3\pi^-$ systems. The distribution is shown for two M_X intervals, $1.5 \rightarrow 3.0$ and $3.0 \rightarrow 4.5$. The smooth curves have the form $(1 - x_f)^{2.5}$.

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- 10 -