CERN - EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Submitted to
Nucl. Physics B

CERN/EP/PHYS 78-10
(Rev. version of 77-23)
28 April 1978

DOUBLE POMERON EXCHANGE IN THE
REACTION $pp \rightarrow pp\pi^+\pi^-$ AT ISR ENERGIES

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ABSTRACT

Using the Split Field Magnet (SFM) of the CERN ISR, we have investigated the main features of the reaction $pp \rightarrow pp\pi^+\pi^-$ in the kinematical region where Double Pomeron Exchange (DPE) is supposed to play an important rôle. Using kinematically fitted events at the five standard ISR energies from $\sqrt{s} = 23.4$ GeV to $\sqrt{s} = 63.4$ GeV, we have studied different data subsamples as a means of distinguishing DPE from the tail of Single Diffraction (SD). Our results are compatible with a significant DPE contribution; in particular there is no correlation between the two protons and the s- and t-dependences follow the expected behaviour.

1. INTRODUCTION

The study of diffractive processes is one of the main sources of information on the properties of strong interaction amplitudes at very high centre of mass energies [1]. As is well known, there are two complementary descriptions of hadronic diffraction:

- (a) the optical or s-channel approach,
- (b) the Regge picture, where diffraction is described by the exchange of the Pomeron [2].

In a phenomenological Regge picture, diffractive excitation is described in terms of Pomeron-hadron interaction, where the clusters of secondary particles are separated by a large gap in rapidity.

In recent years, many analyses of experimental data at very high c.m. energies have sought evidence for Multi-Regge behaviour of the reaction amplitudes [3].

At ISR energies not only one but many clusters in rapidity can be produced, each one separated from its nearest neighbour by a large gap ($\Delta y > 2$). The question to be answered experimentally is whether those large gaps are simultaneously mediated by Pomeron exchange [4]. In order to check such ideas, the available energy must allow at least two large rapidity gaps in addition to a minimum decay width for the central cluster. This implies a lower limit on the energy, $\sqrt{s} > 20$ GeV.

In an optical model, the Pomeron is effectively considered only as a synonym for diffraction, and therefore cannot appear more than once in a single amplitude.

The proof or disproof of the existence of Double Pomeron Exchange (DPE) may help to distinguish between the different theoretical ideas and may provide a deeper knowledge of the nature of the Pomeron.

Many experiments [5] have been performed in recent years to search for evidence of DPE contribution to the cross section. However, due to lack of statistics or incomplete knowledge of the kinematical parameters of all particles involved, most of those experiments obtained only upper limits for the DPE cross section.

2. EXPERIMENTAL SET-UP AND DATA REDUCTION

This experiment was performed at the CERN ISR using the Split Field Magnet facility (SFM) to detect and measure the momenta of all charged particles in specific events. The detection system is composed of two forward telescopes along the outgoing beams, equipped with 28 Multiwire Proportional Chambers (MWPC) of two wire planes each and a central detector surrounding the intersection region with 8 multiplane proportional chambers [6].

The SFM detection system was used in a self-triggering mode [7] to preferentially select events of type $pp \rightarrow pp X$ with two leading protons and a central cluster of charged particles. Leading protons were indicated by a 6-fold coincidence of wire planes in both forward telescopes, and central charged particle production was signalled by coincidence of at least three pairs of wire planes in the central detector.

At the five standard ISR energies between $\sqrt{s} = 23.4$ and 62.3 GeV a sample of 2 650 000 events was recorded. The trajectories of all charged particles were reconstructed, thus determining their charges and momenta [8]. Selecting events with the reduced longitudinal momentum $x = 2p_L/\sqrt{s}$ of two positive particles bigger than 0.8 we retained 155 805 events. Of those, events with additional pairs of opposite charge were subjected to a four-constraint fit procedure to obtain events of the type $pp \rightarrow pp + n (\pi^+ \pi^-)$ ($n = 1, 4$). To ensure the purity of the sample a chi-square probability greater than 5% was required^(*).

In this paper we report results on the exclusive reaction $pp \rightarrow pp \pi^+ \pi^-$ [9]. Since we have no particle identification, this reaction cannot be separated from $pp \rightarrow pp K^+ K^-$ which is expected to have a much smaller cross section. The contribution from reactions with one or more π^0 in our sample is estimated to be less than 5% at the lowest energy, increasing up to 15% at the highest energy.

(*) A detailed statistics for all five energies is given in table 1.

3. EXPERIMENTAL RESULTS

Even at high c.m. energies, the exclusive reaction $pp \rightarrow pp \pi^+ \pi^-$ is dominated by Single Diffraction (SD). However, events produced by DPE should be enriched in the following restricted kinematical regions (see Appendix for details):

- (a) both protons have x values close to 1;
- (b) the rapidity difference (Δy) between each proton and the nearest pion is at least two units.

In order to study the different behaviour of DPE and SD two samples of events (*) have been defined:

- Sample A: $|x|$ of both protons bigger than 0.8;
- Sample B: $|x|$ of both protons bigger than 0.9 and rapidity of both pions $|y_\pi|$ smaller than 1 (i.e. Δy large).

Sample A contains all selected events and is expected to be still dominated by a high contribution from SD. Sample B is defined in a way to keep the contribution from DPE constant when increasing the energy, whereas the contribution from SD decreases. In fig. 1, we illustrate the kinematical behaviour of the exclusive reaction $pp \rightarrow pp \pi^+ \pi^-$ for both SD (fig. 1(a, b)) and DPE (fig. 1(c)). A detailed description of the kinematics is given in the Appendix.

Distributions for different energies are presented only when a clear energy dependence is observed. Otherwise, we show only distributions at $\sqrt{s} = 30.7$ GeV where the largest sample is available.

The acceptance losses for the forward protons were corrected for each event separately using a Monte-Carlo method. For the central pions, however, a global correction was applied, assuming a uniform distribution in the azimuthal angle ϕ . Moreover, the acceptance for central particles (i.e. $|y_\pi| < 1$, sample B) does not vary with the beam energy and hence does not influence the results for the s -dependence.

(*) The kinematical cuts defining the different event samples are summarised in table 2 .

3.1 x_1 versus x_2

In fig. 2, we display the density of events in terms of the x variables of both protons for sample A at $\sqrt{s} = 30.7$ GeV. This density is clearly larger in the region where both protons have a value of $|x|$ bigger than 0.9. In this kinematical region DPE is expected to dominate being the only mechanism with a double pole near $|x| = 1$ (Appendix).

3.2 Test for factorization

The DPE mechanism implies complete factorization of the two proton vertices, and the relevant kinematical variables should therefore be uncorrelated.

In fig. 3(a), the azimuthal angle ϕ of one proton is displayed as a function of the other one for sample B^(*). No obvious correlation is observed. This can be seen more clearly from the difference $\Delta\phi$ of the two ϕ angles (fig. 3(b)). This distribution is significantly non-uniform for sample A and is compatible with uniformity for sample B (shaded area).

Furthermore, there should be no correlation between the momentum transfers $t_{1,2}$ at the two proton vertices. As discussed later in sect. 3.4, each vertex should follow an independent exponential behaviour of the form e^{bt} where $b = -7.0 \text{ GeV}^{-2}$ at $\sqrt{s} = 30.7$ GeV. In fig. 4, e^{bt_1} is plotted as a function of e^{bt_2} for events belonging to sample B; this distribution is compatible with uniformity, yielding a χ^2 of 109.45 for 99 degrees of freedom (probability $\approx 45\%$).

3.3 $(p\pi^+)$ mass and $(p\pi^+\pi^-)$ mass

To illustrate the contribution from SD, which strongly increases as cuts are relaxed, we display in figs 5 and 6 the effectiveness of the cuts defining sample B, corresponding each time to the shaded distribution.

If we look at the distribution of the angle between a proton and the π^+ , we observe in sample A many events where this angle is rather small (fig. 5(a)). This is also reflected in the $(p\pi^+)$ mass distribution

(*) For fig. 3, a cut in p_T was applied: $p_T > 0.1 \text{ GeV}/c$.

(fig. 5(b)), where the prominent feature is the production of the $\Delta(1236)$ resonance. For the events of sample B both effects disappear, mainly due to the cut in the rapidity difference between the protons and the pions which removes a large part of the N^* production leading to the $\Delta(1236)$ resonance as one of the decay products.

The importance of SD production of N^* resonances in sample A can be seen in fig. 6, which shows the $(p\pi\pi)$ mass distribution for two different energies. For sample B (shaded area) this distribution shows a phase space behaviour.

3.4 t-dependence

The dependence of the cross section on the momentum transfer t of both protons can be written in the form

$$\frac{d\sigma}{dt_1 dt_2} \propto e^{bt_1} e^{bt_2} \quad (1)$$

If only DPE is present an estimate for the value b can be predicted from the t -dependence of the elastic cross section (Appendix), namely

$$\text{DPE slope} = \frac{1}{2} \text{ el. scattering slope} = -6 \text{ GeV}^{-2}.$$

In fig. 7, we show the t -dependence of the cross section at two different ISR energies (sample B). The errors given include all systematic uncertainties. Figs 7(a,b) show the dependence of the cross section on the single momentum transfer

$$\frac{d\sigma}{dt_{1,2}} \propto e^{bt_{1,2}}. \quad (2)$$

The results of a fit to the cross section are also shown as a function of the single momentum transfer squared parametrized as

$$\frac{d\sigma}{dt} = A_o e^{bt} . \quad (3)$$

The values for b - given in table 3 - have the expected magnitude.

Assuming factorization, the same slope value b should - for a given energy - also describe the two-dimensional distribution (1). This is demonstrated in figs 7(c, d) where we plot the projection onto the axis $t_1 + t_2$ in the form

$$\frac{1}{-b(t_1 + t_2)} \frac{d\sigma}{d(t_1 + t_2)} , \quad (4)$$

where $\frac{1}{t_1 + t_2}$ comes from the integration and the factor $\frac{1}{-b}$ ensures the same normalisation as for (3).

A fit to (4) in the form

$$\frac{1}{-b(t_1 + t_2)} \frac{d\sigma}{d(t_1 + t_2)} = A_o e^{b(t_1 + t_2)} , \quad (5)$$

gives, within the errors, the same results for A_o and b as in (3). To show this, we have drawn in figs 7(c,d) the results for the fit to (3). One observes that, at the same energy, the single and the double t distributions are well described by a common slope.

In fig. 8, the fitted values for the slope b are given as a function of $\log s$, where one can see little energy dependence. It is possible to fit the data from all energies with one single slope value

$$b = -(6.5 \pm 1.5) \text{ GeV}^{-2}$$

without seriously decreasing the chi-square probability of the fits at all energies.

3.5 $(\pi^+\pi^-)$ mass spectrum

In order to illustrate the dependence of the $(\pi^+\pi^-)$ mass distribution on different cuts, we introduce a new sample C where there is a chance to detect contributions from decay of resonances with higher spin values; in particular, we expect a non negligible production of the $f(1270)$ mesons with $J^P = 2^+$ (Appendix). We define sample C by requiring again that both protons have $|x| > 0.9$, but relax the cut on the central pions by requiring a rapidity difference from each pion to the nearest proton larger than two units. Figs 9(a,c) compare sample A and C (shaded area), while figs 9 (b, d) compare sample A and B (shaded area) at $\sqrt{s} = 30.7$ and 52.8 GeV.

The $(\pi^+\pi^-)$ mass spectrum is clearly dominated by an enhancement near threshold. Furthermore, there is no indication for the $\rho(765)$ meson and at the higher energy ($\sqrt{s} = 52.8$ GeV) one observes a signal in the mass region of the $f(1270)$ meson in sample A, which is still present in sample C but not visible in sample B.

For the events of sample B, we observe that the shapes of the mass distributions do not depend on the energy. This has the important consequence that the total cross section calculation for this sample at different energies involves integration over a unique mass spectrum of the $(\pi^+\pi^-)$ system.

3.6 Angular distributions of the $(\pi^+\pi^-)$ system

If only DPE is present, the allowed quantum numbers for the $\pi^+\pi^-$ system are restricted to $I = 0$ and $J^P = 0^+, 2^+, 4^+ \dots$. Some information on the spin of the $(\pi^+\pi^-)$ system may be obtained from the helicity angle, defined as the angle between the π^+ in the $(\pi^+\pi^-)$ system and the direction of the $(\pi^+\pi^-)$ system in the overall c.m. system. Fig. 10(a) shows the helicity angular distribution for sample A and B (shaded area). This distribution is compatible with uniformity for events in sample B thus suggesting $J = 0$ for the $(\pi^+\pi^-)$ system. Another spin analysis uses the production angle of the π^+ in the Pomeron-Pomeron (PP) rest system fig. 10(b). We observe a strong correlation between the directions of the PP and the π^+ for events of sample A, whereas this distribution is compatible with uniformity for sample B (shaded area).

From these two angular distributions, we deduce that the spin of the $(\pi^+\pi^-)$ system is compatible with 0.

3.7 Rapidity distributions $d\sigma/dy_{\pi\pi}$

We expect to see the clearest difference between DPE and SD in the rapidity dependence of the cross section (Appendix). To study this, we have defined 3 samples of events, sample B and C as already used before, where we expect that DPE is dominant and a sample D, which is dominated by SD. D is the sample complementary to C [$C + D = A$].

- D: $|x|$ of both protons larger than 0.8,
rapidity difference of at least one pion to the nearest proton smaller than two units.

In fig. 11, we illustrate the behaviour expected for the differential cross section $d\sigma/dy_{\pi\pi}$ where $y_{\pi\pi}$ is the rapidity of the central cluster (Appendix). The corresponding experimental results at two different energies are shown in fig. 12. Since the $(\pi^+\pi^-)$ mass spectrum shows practically no energy dependence (fig. 9), the cross section, as a function of the energy, is determined by an integration over $y_{\pi\pi}$, where the range of integration is related to the cuts.

The experimental distributions (fig. 12) are in reasonable agreement with the expected behaviour. In particular:

- (a) For sample B, the shape of the $y_{\pi\pi}$ distribution is independent of the ISR energy, thus leading to an approximately constant cross section.
- (b) For sample C, the absolute height of the $y_{\pi\pi}$ distribution is energy independent. Since the rapidity distance between the protons and each pion is held fixed ($\Delta y \geq 2$), the range of integration is proportional to the maximum rapidity ($y_{\max} \sim \log s$). Therefore, the cross section is approximately proportional to $\log s$.

- (c) For sample D we observe a depletion in the central region which becomes more pronounced as the energy increases. This is connected to the fact, that in SD both pions tend to be near one proton in rapidity. Therefore, we would expect that the distributions for sample B and C show a similar behaviour as sample D, if SD is dominating, independent of the cuts applied.
- (d) Since the $y_{\pi\pi}$ distributions of samples B and C show no depopulation of the central region, when increasing the energy, these distributions cannot be dominated by events from SD.

3.8 Energy dependence of the cross section

In order to further enhance the signal we introduce an even more restrictive cut, by requiring that the rapidity gaps between each pion and the protons are at least three units (sample E). The energy dependence of the cross section for this sample and for sample B is given in fig. 13 and in table 3. These results have been obtained by integrating over the full t -range, using the slope values of sect. 3.4 to extrapolate beyond the t -range measured by this experiment.

For sample B, we expect a constant or slowly decreasing cross section [10] as a function of s , if only DPE is present. As can be seen, the cross section decreases slowly with increasing energy, becoming nearly s -independent at the higher energies.

For the events from sample E we expect the cross section to increase like $\sim \log s$ for DPE and to remain constant for SD.

Fitting the energy dependence of the cross section for sample E in the form

$$\sigma = a + b \log s,$$

we can estimate the DPE contribution to the cross section for events with $|y_{\pi}| < 1$ as $\sigma = 9.5 \mu\text{b}$ independent of s . In fig. 14 we compare our results with those from previously published data [5,9]. One observed that all these results are in agreement with our data.

Assuming Pomeron exchange at all vertices and factorization, the cross section for the two-particle inclusive reaction $pp \rightarrow pp + X$ can be approximately related to the corresponding single particle cross section $pp \rightarrow p + X$ by the Mueller formula [10,11]

$$\frac{d\sigma}{dt_1 dt_2 d\Delta y_1 d\Delta y_2} = \frac{1}{\sigma_{\text{tot}}} \frac{d\sigma}{dt_1 d\Delta y_1} \frac{d\sigma}{dt_2 d\Delta y_2}.$$

This relation is valid only in the large mass limit, which is not reached even at ISR energies. Nevertheless one may use this formula - since the Pomeron Pomeron cross section does not vary appreciable with energy - to predict the magnitude of the DPE cross section in the reaction $pp \rightarrow pp\pi^+\pi^-$. One gets [10]

$$\sigma_{\text{DPE}}(q_m, s) \approx \frac{2}{3} \frac{C_{\text{pp}}^2}{\sigma_{\text{tot}}^{\text{pp}}} \frac{1}{b_{\text{pp}}^2} \frac{1}{\epsilon^2} \left\{ \left(\frac{1}{q_m} \right)^{2\epsilon} - \left(\frac{s_0}{s} \right)^{\epsilon} (1 + \epsilon \log \frac{s}{q_m^2 s_0}) \right\} \quad (6)$$

$$q_m = \text{minimum value of } \frac{1}{1 - |X_{1,2}|}.$$

$$s_0 = 0.14 \text{ GeV}^2 \quad \text{minimum value of } (M_{\pi\pi})^2$$

$$b_{\text{pp}} = 6 \text{ GeV}^{-2}$$

$$\epsilon = 0.5$$

$$C_{\text{pp}} = 23 \text{ mb GeV}^{-2}.$$

The values of the parameters are taken from [10]. For the total cross section an interpolation through the experimental results from [12] was used. In fig. 14, we show also the predictions from this relation for the three different cuts used in the experimental data.

Considering the many assumptions, which have been made to get formula (6), the theoretical predictions agree rather well with the experimental data.

CONCLUSION

In this experiment we have been able to study for the first time the presence of DPE over the full energy range available at the ISR with complete kinematical reconstruction. Due to the high statistics available rather restrictive cuts could be introduced. Since the ratio DPE/SD should strongly depend on the cuts used, the variation of the cuts allow us to estimate the relative contribution.

Studying the dependence of the cross section on the kinematical variables in a region, where one expects a high contribution from DPE, one observes that the experimental results for the exclusive reaction $pp \rightarrow pp\pi^+\pi^-$ are compatible with the predictions of a phenomenological model [1-4,10]. In particular we find no correlations between the protons. The s- and t-dependence of the cross section agrees with the expectation for DPE. The $\pi^+\pi^-$ system is concentrated near threshold in invariant mass. The decay angular distribution of the $\pi^+\pi^-$ system is compatible with what one expects from a spin 0 state. The energy dependence of the differential cross section $d\sigma/dy_{\pi\pi}$ allows us to estimate the DPE contribution as $\sigma = 9.5 \mu\text{b}$ in a restricted region of phase space, namely x of both protons bigger than 0.9 and the rapidity of both pions y_π smaller than 1.

Acknowledgements

This experiment was greatly helped in different phases by contributions from D.R.O. Morrison and H. Schneider. We are grateful to the SFM Detector Group and the ISR Division for their support. We are indebted for useful discussions to Drs M. Jacob and A. Kaidalow. The Heidelberg and Karlsruhe groups were supported by a grant from the Bundesministerium für Forschung und Technologie, Federal Republic, Germany. The Collège de France group was supported by the IN2P3.

APPENDIX

From Regge theory one knows that the DPE mechanism dominates when large rapidity gaps are present between the different clusters. The background in this kinematical region comes mainly from SD.

In fig. 1, we display the kinematics of the exclusive reaction $pp \rightarrow pp \pi^+ \pi^-$ for both SD (fig. 1(a-b)) and DPE (fig. 1(c)).

A.1 Predictions for the DPE amplitude

The properties of a process due to repetitive Pomeron exchange, e.g. DPE, can be derived from the well studied behaviour of reactions assigned to single Pomeron exchange:

- (a) The poles observed in DPE are the same as observed in elastic and inelastic diffraction processes.
- (b) The external proton-pomeron-proton coupling ($\gamma_{p\mathbb{P}p}$) is the same as in the elastic scattering.
- (c) The dependence of the amplitude on the $(p\pi\pi)$ sub-energies s_1 and s_2 is given in the form (s/s_i) .

However, one does not get information on the central Pomeron-Pomeron- $(\pi^+ \pi^-)$ coupling. The DPE amplitude is therefore parametrized as follows:

$$A = \gamma_{p\mathbb{P}p}(t_1) \left(\frac{s}{s_1}\right)^{\alpha_{\mathbb{P}}(t_1)} \gamma_{p\mathbb{P}p}(t_2) \left(\frac{s}{s_2}\right)^{\alpha_{\mathbb{P}}(t_2)} \cdot F.$$

The variables used in this formula are:

$$\begin{aligned} t_1 &= (p_1 - p_3)^2 & t_2 &= (p_2 - p_4)^2 \\ s_1 &= (p_4 + p_{\pi^+} + p_{\pi^-})^2 & s_2 &= (p_2 + p_{\pi^+} + p_{\pi^-})^2 \end{aligned}$$

$F = F(t_1, t_2, M_{\pi^+ \pi^-})$, the unknown Pomeron-Pomeron $(\pi^+ \pi^-)$ coupling.

Using the triple-Regge formalism and neglecting the slope of the $\mathbb{P}$ trajectory one gets the following predictions for DPE reactions:

- (a) If the Pomeron is a factorizable simple pole one should observe absence of correlation both in the azimuthal angle (ϕ) and in the four-momentum transfer (t) of the two protons.
- (b) Using an exponential form in t for the external coupling, as known to be valid for elastic scattering, we get the following form for the differential cross section for DPE

$$\frac{d\sigma}{d\Delta_1 d\Delta_2 dt_1 dt_2} \sim e^{b(t_1 + t_2)} \quad \text{independent of } \Delta_1 \text{ and } \Delta_2$$

Δ_i = rapidity difference between p_i and $(\pi^+ \pi^-)$.

- (c) The central cluster can only have the following quantum numbers

$$I = 0, C = +, J^P = 0^+, 2^+, 4^+, \dots$$

- (d) The total cross section σ_{DPE} is independent of s .
- (e) The cross section is independent of $y_{\pi\pi}$ as displayed in fig. 11, where $y_{\pi\pi}$ is the rapidity of the central cluster.

$$\frac{d\sigma}{dy_{\pi\pi}} \approx \text{constant}.$$

- (f) Approaching $|x| = 1$ for both protons the differential cross section shows a double pole behaviour (modified by phase space).

$$\frac{d\sigma}{dx_1 dx_2} \propto \frac{1}{(1 - x_1)(1 - x_2)}.$$

A.2 Predictions for the SD background

The amplitude for the SD background (fig. 1(a)) can be written in a similar way

$$A \sim \gamma_{p\mathbb{R}p}(t_1) \left(\frac{s}{s_1}\right)^{\alpha_{\mathbb{R}}(t_1)} \gamma_{p\mathbb{P}p}(t_2) \left(\frac{s}{s_2}\right)^{\alpha_{\mathbb{P}}(t_2)}$$

and a similar form for the diagram shown in fig. 1(b). In contrast to the DPE mechanism we get here the following behaviour assuming t_1 and t_2 small

(a) The cross section is strongly dependent on $y_{\pi\pi}$ (fig. 11)

$$\frac{d\sigma}{dy_{\pi\pi}} \sim \cosh(y_{\pi\pi}) .$$

(b) The dependence of the cross section on x_1 and x_2 is given in the form

$$\frac{d\sigma}{dx_1 dx_2} \sim \frac{b}{1-x_1} + \frac{b}{1-x_2} .$$

(c) The total cross section shows a strong dependence on the minimum rapidity gap required Δ in the form

$$\sigma \sim e^{-\Delta} .$$

We can estimate the SD background contribution by studying the dependence of the cross section on the energy and on the minimum rapidity gap requirement.

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TABLE CAPTIONS

Table 1 Number of events as a function of the energy under various cuts.

Table 2 Definitions of the different samples used.

Table 3 Energy dependence of the cross section for different cuts.
 Energy dependence of the slope parameter for sample C.

TABLE 1

Energy (GeV)	23.4	30.7	44.8	52.8	62.3
Triggers taken	150 000	1 300 000	350 000	650 000	200 000
2 fast proton $ x \geq 0.8$	13 211	85 584	20 360	28 052	8 598
$pp\pi^+\pi^-$ topology	3 867	21 896	5 133	5 514	1 445
Fitted $pp\pi^+\pi^-$ events	1 541	6 713	907	793	217
Events/ μb	433	2 362	326	280	84

TABLE 2

Sample	
A	$ x $ of both protons bigger than 0.8,
B	$ x $ of both protons bigger than 0.9, $ y $ of both pions smaller than 1
C	$ x $ of both protons bigger than 0.9, rapidity difference (Δy) of each pion to the nearest proton larger than 2
D	$ x $ of both protons bigger than 0.8, rapidity difference of at least one pion to the nearest proton smaller than 2
E	$ x $ of both proton bigger than 0.9, rapidity difference of each pion to the nearest proton larger than 3

TABLE 3

Energy (GeV)	23.4	30.7	44.8	52.8	62.3
$\sigma(\mu\text{b})$ sample C	14.4 ± 3.1	11.0 ± 1.2	9.4 ± 1.9	10.2 ± 2.1	11.5 ± 3.0
$\sigma(\mu\text{b})$ sample E	-	3.6 ± 1.7	6.8 ± 2.7	8.8 ± 2.8	11.7 ± 3.0
$b(\text{GeV}^{-2})$ sample C	-7.1 ± 0.7	-7.0 ± 0.5	-6.1 ± 0.9	-6.1 ± 0.8	-6.9 ± 1.1

FIGURE CAPTIONS

Fig. 1(a,b) Diffraction dissociation diagram;

(c) Double Pomeron Exchange diagram for $pp \rightarrow pp\pi^+\pi^-$.

Fig. 2 Scatter plot of the reduced longitudinal momenta x of the two protons (sample B).

Fig. 3(a) Scatter plot of the azimuthal angles of the two protons (sample B);

(b) difference in azimuthal angle of the two protons for sample A, and for sample B (shaded area).

Fig. 4 Scatter diagram of squares of the proton momentum transfer in a double exponential scale.

Fig. 5(a) Angle between one proton and the π^+ in the overall c.m.s. for sample A and for sample B (shaded area);

(b) invariant mass of the $(p\pi^+)$ system for sample A and for sample B (shaded area).

Fig. 6 Invariant mass $(p\pi^+\pi^-)$ for sample A and for sample B (shaded area).

Fig. 7(a,b) Distribution of proton momentum transfer squared for sample B;

(c,d) distribution of the sum of the momentum transfer squared of the two protons (sample B). The lines represent a fit to the single proton momentum transfer distribution.

Fig. 8 Energy dependence of the exponential slope of the single momentum transfer distribution.

FIGURE CAPTIONS (Cont'd)

- Fig. 9 Invariant mass ($\pi^+ \pi^-$) (sample A):
- (a,c) the shaded area corresponds to sample C,
 - (b,d) the shaded area corresponds to sample B.
- Fig. 10(a) Distribution of the helicity angle for sample A and for sample B (shaded area);
- (b) distribution of the π^+ production angle in the $\pi\pi$ rest system for sample A and for sample B (shaded area).
- Fig. 11 Schematic diagrams for the expected behaviour of $d\sigma/dy_{\pi\pi}$ for 2 different energies and different rapidity cuts both for DPE and SD processes.
- Fig. 12 Rapidity distributions of the central $\pi^+ \pi^-$ cluster.
- Fig. 13 s-dependence of the cross section for different cuts.
- Fig. 14 Cross section as a function of s from other experiments [5] compared with values obtained in this experiment. The result of a previous publication is also given -with a different cut- of this experiment [9]. The lines are predictions from [10] for different rapidity cuts.

Fig. 1a

Fig. 1b

Fig. 1c

$pp \rightarrow pp\pi^+\pi^- \quad \sqrt{s} = 30.7 \text{ GeV}$

X_1

Fig. 2

Fig. 3a

Fig. 3b

Fig. 4

$pp \rightarrow p p \pi^+ \pi^- \quad \sqrt{s} = 30.7 \text{ GeV}$

Fig. 5a

Fig. 5b

Fig. 6

$pp \rightarrow pp \pi^+ \pi^-$

$|y_\pi| \leq 1$

Fig. 7

Fig. 8

$$pp \rightarrow pp \pi^+ \pi^-$$

$$\sqrt{s} = 30.7 \text{ GeV}$$

Fig. 9a

Fig. 9b

$$pp \rightarrow pp \pi^+ \pi^-$$

$$\sqrt{s} = 52.8 \text{ GeV}$$

Fig. 9c

Fig. 9d

$pp \rightarrow pp \pi^+ \pi^- \quad \sqrt{s} = 30.7 \text{ GeV}$

Fig. 10a

Fig. 10b

DPE

$$\sigma = \sigma(s) \sim \text{const.}$$

$$\sigma = \sigma(s) \sim \text{logs}$$

SD

$$+ \frac{1}{\text{logs}} \text{ or } \frac{1}{\sqrt{s}}$$

constant

Fig. 11

$pp \rightarrow pp\pi^+\pi^- \quad \sqrt{s} = 30.7 \text{ GeV}$

$pp \rightarrow pp\pi^+\pi^- \quad \sqrt{s} = 52.8 \text{ GeV}$

Sample B

Sample C

Sample D

Fig. 12

Fig. 13

Fig. 14