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Double Pomeron Exchange in the Reactions $pp \to pp\pi^+\pi^-$, $K^+p \to K^+p\pi^+\pi^-$, $\pi^+p \to \pi^+p\pi^+\pi^-$ and $\pi^-p \to \pi^-p\pi^+\pi^-$ at 147 GeV/c

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ABSTRACT

We have measured the reactions $pp \to pp\pi^+\pi^-$, $K^+p \to K^+p\pi^+\pi^-$, $\pi^+p \to \pi^+p\pi^+\pi^-$ and $\pi^-p \to \pi^-p\pi^+\pi^-$ in the Fermilab 30-inch Hybrid Spectrometer System at 147 GeV/c and analyzed them in a Double Pomeron Exchange (DPE) picture. We find agreement between predictions of a DPE calculation and the experimental results.

It has been argued[1] that reactions of the type $A+p \rightarrow A+p+\pi^+ +\pi^-$, where A is the beam particle, can be accounted for by two types of mechanisms: a) one involving the exchange of a single Pomeron (Fig. 1a), in which either the beam A diffracts into an $(A\ \pi^+\pi^-)$ system or the target p diffracts into a $(p\ \pi^+\pi^-)$ system, and b) one in which the beam projectile and the target particle both emit a Pomeron, and the remaining $\pi^+\pi^-$ are centrally produced via the two-Pomeron interaction (Fig. 1b). This latter mechanism is called double Pomeron exchange (DPE). Many experiments[2] have shown evidence for the single Pomeron mechanism, but much less information has been obtained[3-8] on the DPE contribution to this type of reaction. In addition to the difficulties arising from lack of statistical resolution, there is also no precise definition of a DPE sample.

One definition of the DPE region is given[9] by a cut on the variable

$$Z_i \equiv \ln(s/M_{xi}) \simeq \ln\left(\frac{1}{1-|x_i|}\right)$$

where s is the square of the total center of mass energy, M^2_{xi} is the invariant mass squared recoiling against particle i, and X_i is the Feynman variable, $X = \frac{2P_L}{\sqrt{s}}$, for particle i. The DPE region is defined as that which satisfies both $Z_A \cdot Z_p \geq \ln 10 = 2.3$. This definition is in fact equivalent to the Feynman-x requirements: $|x_A|, |x_p| > 0.9$ for both of the outgoing particles A and p. In addition, for either of these definitions the rapidity of each of the central pions in the overall center of mass, Y^*_π, must be near zero to insure a large rapidity gap

between the central and the leading particles.

In this publication we present a DPE analysis of the four reactions

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

$$K^+p \rightarrow K^+p\pi^+\pi^- \quad (2)$$

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

$$\pi^-p \rightarrow \pi^-p\pi^+\pi^- \quad (4)$$

at 147 GeV/c beam momentum. Using the DPE definitions described above, we have determined the DPE cross section for these reactions and find them to be in agreement with theoretical predictions[1,10].

The data used in the present study come from two exposures in the Fermilab 30-inch hybrid spectrometer; one with a tagged negative beam, mainly π^-, and one with a tagged positive beam composed of π^+, K^+, and p. Beam particles were identified by threshold and differential Čerenkov counters. Some results of the 105,000-picture π^-p exposure[11] and the 400,000-picture positive beam exposure[12] have been published previously. We have obtained our sample of reactions (1)-(4) by performing 4-constraint (4C) fits with the kinematic fitting program SQUAW modified for ultra-relativistic particles. Further details of the data reduction can be found in refs. 11 and 12. The results reported here are based on 272 events of reaction (1), 34 of reaction (2), 441 of reaction (3) and 344 events of reaction (4). The measured cross sections are presented in column 2 of Table I.

Figures 2a-2d show the triangle plot of Z_A versus Z_p for the reactions (1)-(4), respectively. The two variables Z_A and Z_p span a triangular region of phase space which is limited by

$$(Z_A + Z_B) < \ln (s/s_0)$$

where $s_0 = 0.14$ GeV^2. The lines correspond to the values $Z_A = Z_p = 2.3$. As can be seen, most events lie in the region where either Z_A or Z_p is large, but not both. These are the single diffractive events, described by Fig. 1a. The events in the region where Z_A and Z_p are both bigger than 2.3 have been defined as possible DPE events[9]. Table I gives the number of events and the corresponding cross sections. Reaction (2) has no events in this region, and we can therefore only give an upper limit to the cross section for DPE production in this reaction.

The properties expected in DPE events can be summarized as follows[6,7]: a) both leading particles should have nearly the full longitudinal momentum, $|x| \approx 1$; b) the sum of the rapidities of the remaining two pions should be small; c) the invariant mass of combinations containing one of the leading particles is expected to be large; d) the invariant mass of the remaining dipion system should not show a $\rho(765)$ signal and should be concentrated at masses below 1 GeV/c^2. This last is the consequence of the fact that if only DPE is present, the allowed quantum numbers of the $\pi^+\pi^-$ system are restricted to $I = 0$ and $J^P = 0^+, 2^+, 4^+ \ldots$

We studied these features in all events of reactions (1), (3) and (4) which satisfied the conditions $Z_A > 2.3$ and $Z_p > 2.3$. As mentioned above, these cuts insure that $|x| > 0.9$ for particle

A and the proton p. Figures 3a-3d show the sum of the center of mass rapidities of the π^+ (the slower one in reaction (3)) and the π^- (the slower one in reaction (4)) for all events in reactions (1)-(4). One clearly observes two peaks, centered around ± 4.5, which correspond to the single diffractive dissociation described by the diagram in fig. 1a. In addition, one observes an accumulation of events near zero rapidity, which may come from double Pomeron exchange. The shaded events are indeed those satisfying the DPE criteria of ref. 9. As mentioned above, no such events are found for reaction (2), where our number of events is very low.

Figure 4 shows the invariant mass distributions of all dipion systems. A clear ρ (765) signal is observed in reactions (3) and (4). There is a suggestion of ρ in the other two reactions as well. The strong source of ρ in reactions (3) and (4) is the decay into $\rho^0\pi$ of the $(\pi^\pm\pi^+\pi^-)$ system produced via single Pomeron exchange. We have indeed observed A_1 and A_2 production in reaction (3)[11] and in reaction (4)[13]. Neither of the diffractively-produced $(p\pi^+\pi^-)$ or $(K^+\pi^+\pi^-)$ systems has a strong decay mode into $p\rho^0$ or $K^+\rho^0$, and therefore very little ρ^0 signal is observed in reactions (1) and (2). The shaded area is the invariant mass distribution of $\pi^+\pi^-$ coming from the DPE events. These distributions show no ρ signal and are concentrated below 1 GeV/c^2 as expected.

We have also checked the invariant masses of combinations involving one of the leading particles, such as $(p\pi^+)$ or $(p\pi^+\pi^-)$.

Although a strong Δ^{++} signal is seen in all four reactions, coming mainly from the decay of the diffractively produced $(p\pi^+\pi^-)$ system, the DPE sample has no events in either the Δ^{++} region or in the low mass $(p\pi^+\pi^-)$ region. No other mass combinations show any low mass concentration. We thus believe that our candidates for DPE events are consistent with the mechanism described by the diagram in Fig. 1b. Column 3 of Table I presents the Double Pomeron cross sections for reactions (1)-(4) at 147 GeV/c.

The DPE cross sections for different reactions at a given energy are related to each other as follows[1]:

$$\sigma_{DPE}\ (pp) \simeq 2\sigma_{DPE}\ (\pi p) \simeq 4\sigma_{DPE}\ (Kp) \qquad (5)$$

Since we have measured all these interactions at the same energy with the same apparatus, and have analyzed them using the same procedure, systematic differences are minimized and we can perform a good test of relation (5). Figure 5a shows our measured cross sections at 147 GeV/c for the four reactions (1)-(4), together with the theoretical predictions[1]. As can be seen in fig. 5, there is good agreement between experimental and theoretical values of σ_{DPE}, and the predictions of relation (5) are indeed borne out by the data. In the same figure we have also included for comparison data at 205 GeV/c as analyzed in ref. 9, using the same definition of DPE as in our experiment. These data points agree well with our measurements.

Figure 5b shows the energy dependence of the DPE cross sections for reaction (1) using our result and those of ISR experiments[5-8]. Since the latter were obtained using cuts ($|Y_\pi^*| < 1$ and $|Y_\pi^*| < 1.5$) on the rapidity of the pions, we have made the same cuts on our result. The values which we obtain are given in the last column of Table I. The dotted lines in fig. 5b are the corresponding theoretical predictions of ref. 10. Although all the data are not in good agreement with the predictions, their general trend follows the theoretical expectations.

In conclusion, we have measured the four reactions (1)-(4) and analyzed them in a DPE picture. We have obtained a cross section for the DPE contribution in three reactions and an upper limit for the fourth, and find it to be in agreement with predictions of a DPE calculation.

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References

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TABLE I

Channel and Double Pomeron Cross Section for Reactions (1)-(4)

Channel	σ(mb)	N_{DPE}	σ_{DPE} (μb)	$\lvert Y_\pi \rvert < 1.0$	$\lvert Y_\pi \rvert < 1.5$
$pp \to pp\pi^+\pi^-$	.72 ± .04	18.5	49 ± 11	30 ± 9μb	46 ± 11μb
$K^+p \to K^+p\pi^+\pi^-$	.38 ± .07	0	< 11		
$\pi^+p \to \pi^+p\pi^+\pi^-$	.68 ± .03	14	22 ± 6		
$\pi^-p \to \pi^-p\pi^+\pi^-$	.67 ± .04	15	29 ± 8		

Figure Captions

Figure 1: Diagrams representing a) single diffraction and b) double Pomeron exchange.

Figure 2: The triangle plot of Z_A versus Z_p for events of the reactions a) $pp \to pp\pi^+\pi^-$, b) $K^+p \to K^+p\pi^+\pi^-$, c) $\pi^+p \to \pi^+p\pi^+\pi^-$ and d) $\pi^-p \to \pi^-p\pi^+\pi^-$.

Figure 3: Sum of the center of mass rapidities of the π^+ and π^- produced in the reactions a) $pp \to pp\pi^+\pi^-$, b) $K^+p \to K^+p\pi^+\pi^-$, c) $\pi^+p \to \pi^+p\pi^+\pi^-$ (the slower π^+ for this reaction) and d) $\pi^-p \to \pi^-p\pi^+\pi^-$ (the slower π^- for this reaction). The shaded events are those satisfying the DPE criteria (see text).

Figure 4: The $\pi^+\pi^-$ invariant mass distribution for events of the reactions a) $pp \to pp\pi^+\pi^-$, b) $K^+p \to K^+p\pi^+\pi^-$, c) $\pi^+p \to \pi^+p\pi^+\pi^-$ and d) $\pi^-p \to \pi^-p\pi^+\pi^-$. The shaded events are those satisfying the DPE criteria (see text).

Figure 5: a) Double Pomeron cross section as a function of the lab momentum. The dotted lines are prediction of a DPE calculation of ref. 1. The data at 205 GeV/c are taken from an analysis of ref. 8.
● - pp, x - π^+p, o - π^-p, and + - k^+p.
b) s-dependence of the double-Pomeron cross section using data from this experiment (■) and from ISR experiments (●-ref. 7 and ▲-ref. 8) for rapidity cut $|Y^*_\pi| < 1.0$. Also from this experiment (□)

Figure Captions (cont'd)

and from ISR experiments (o-ref.5 and Δ-ref.6) for rapidity cut $|Y_{\pi}^{*}| < 1.5$. The dotted lines are predictions of ref. 10.

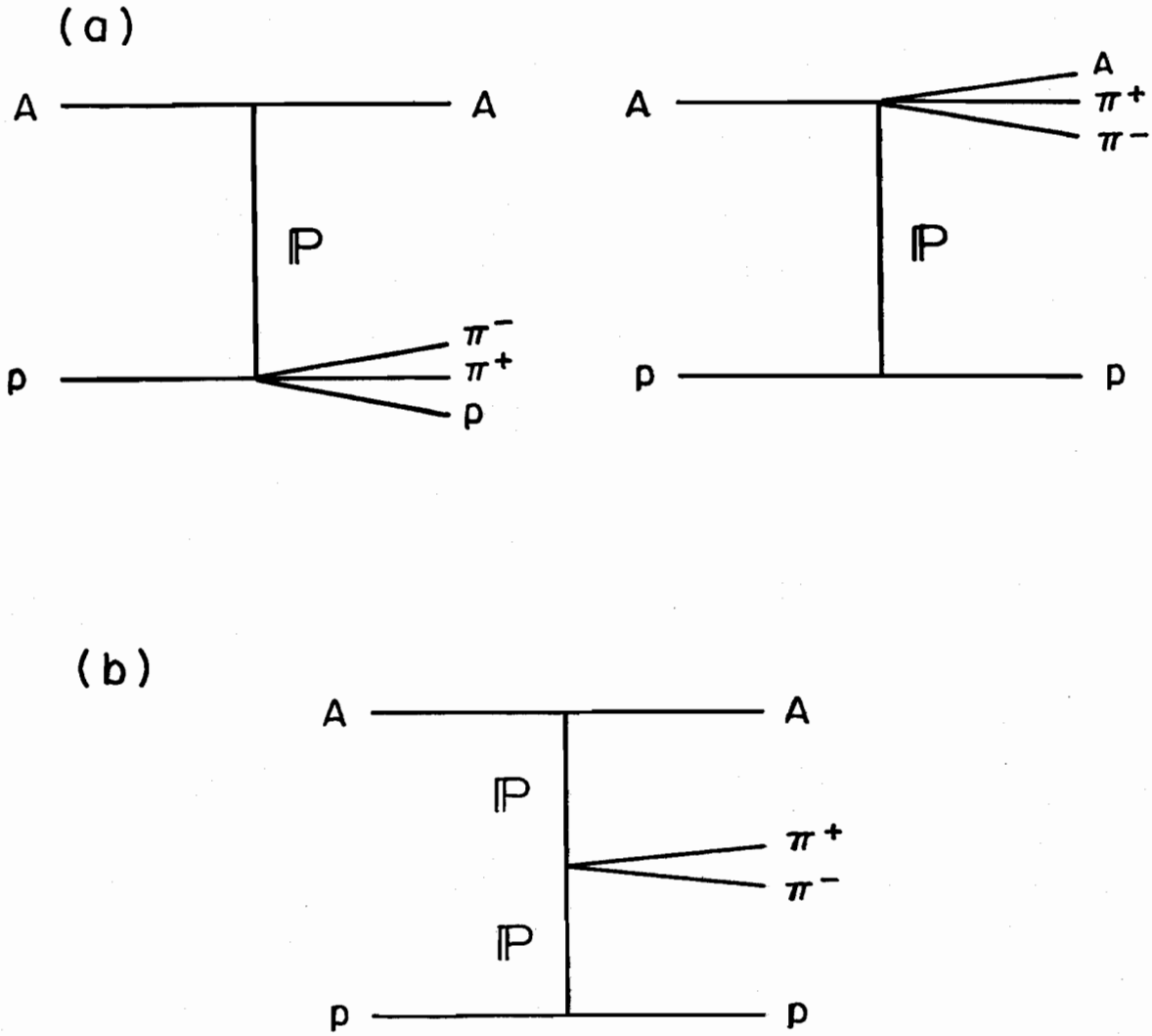


Figure 1

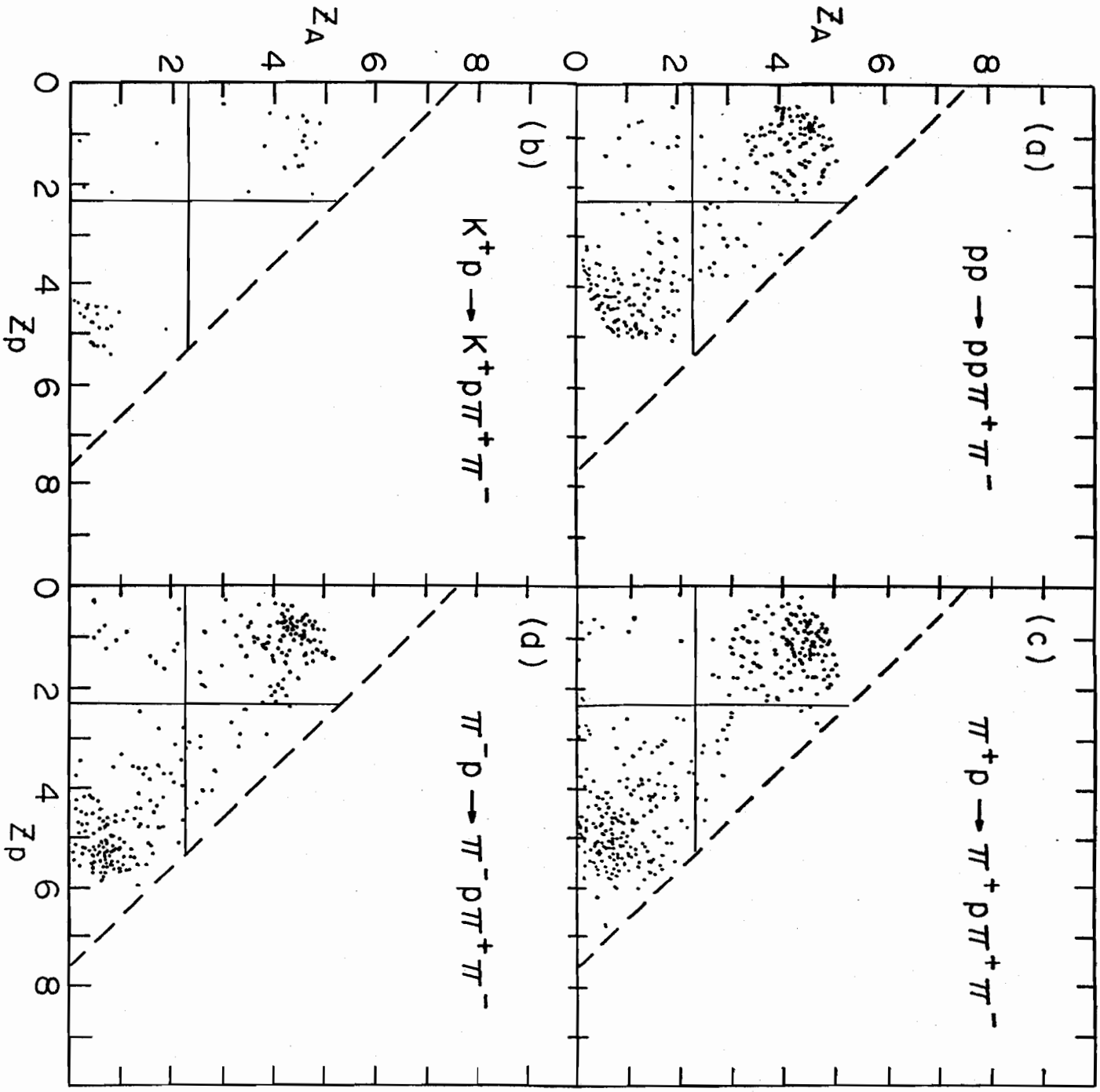
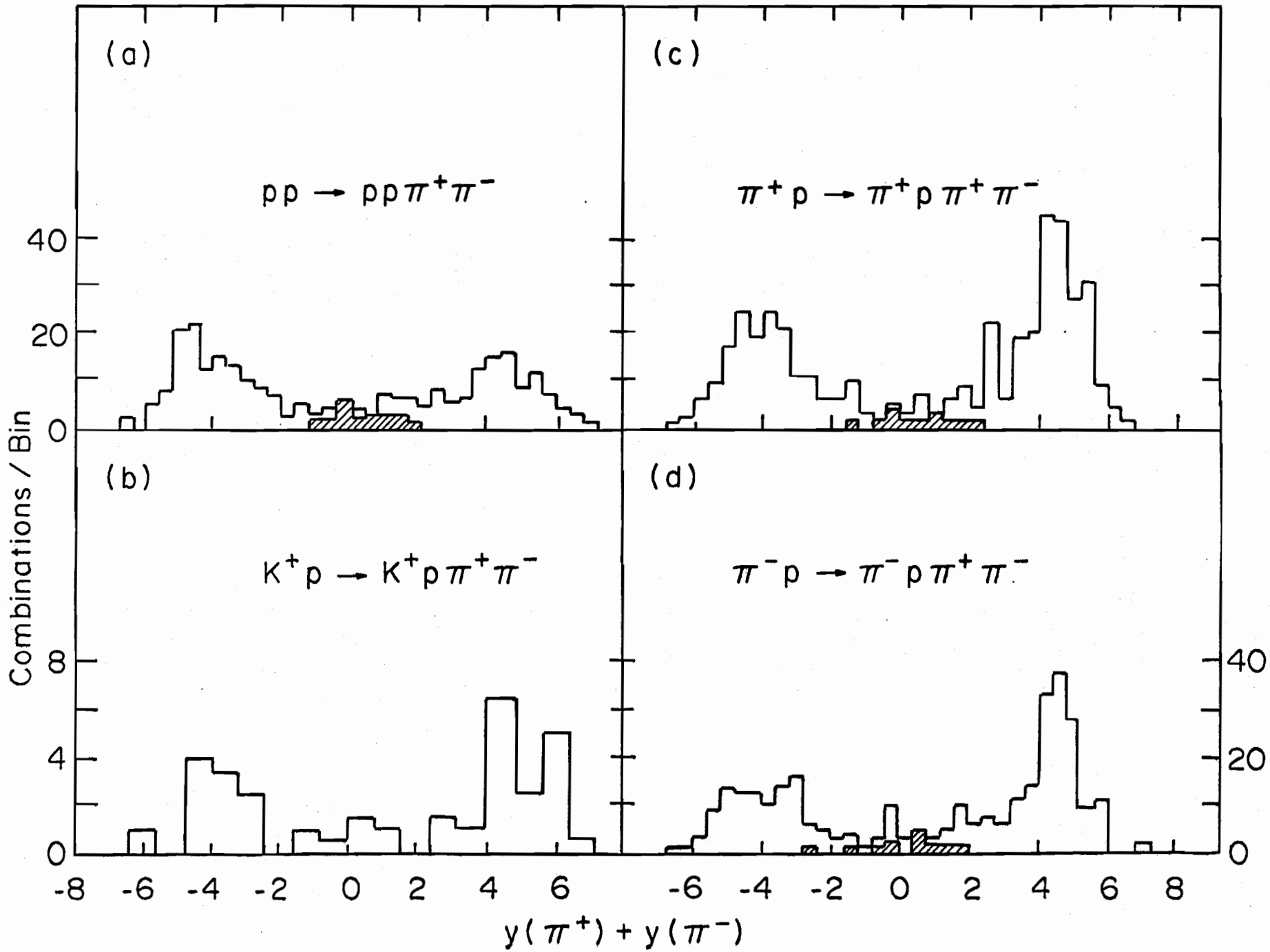


Figure 2



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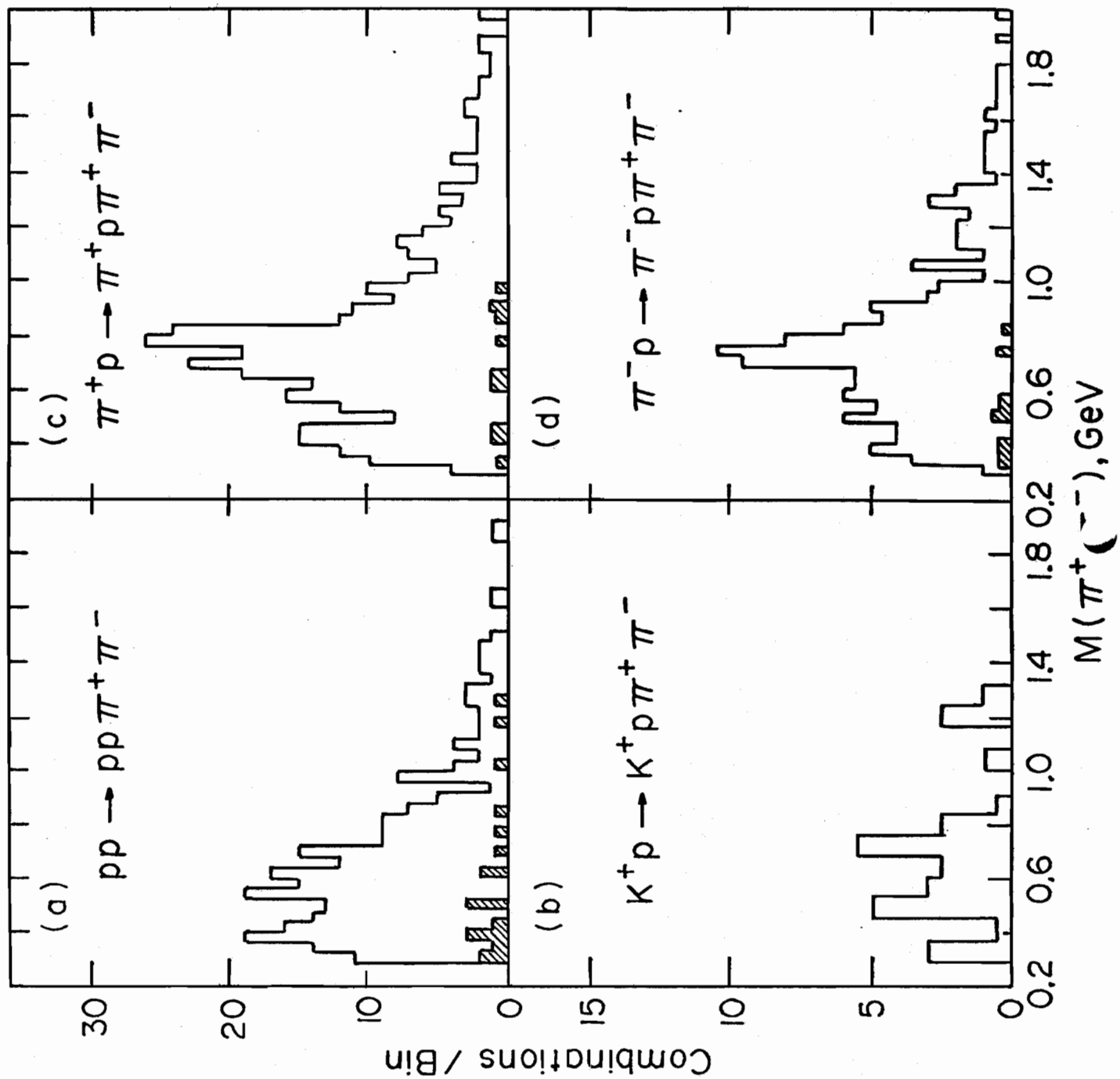

Figure 4

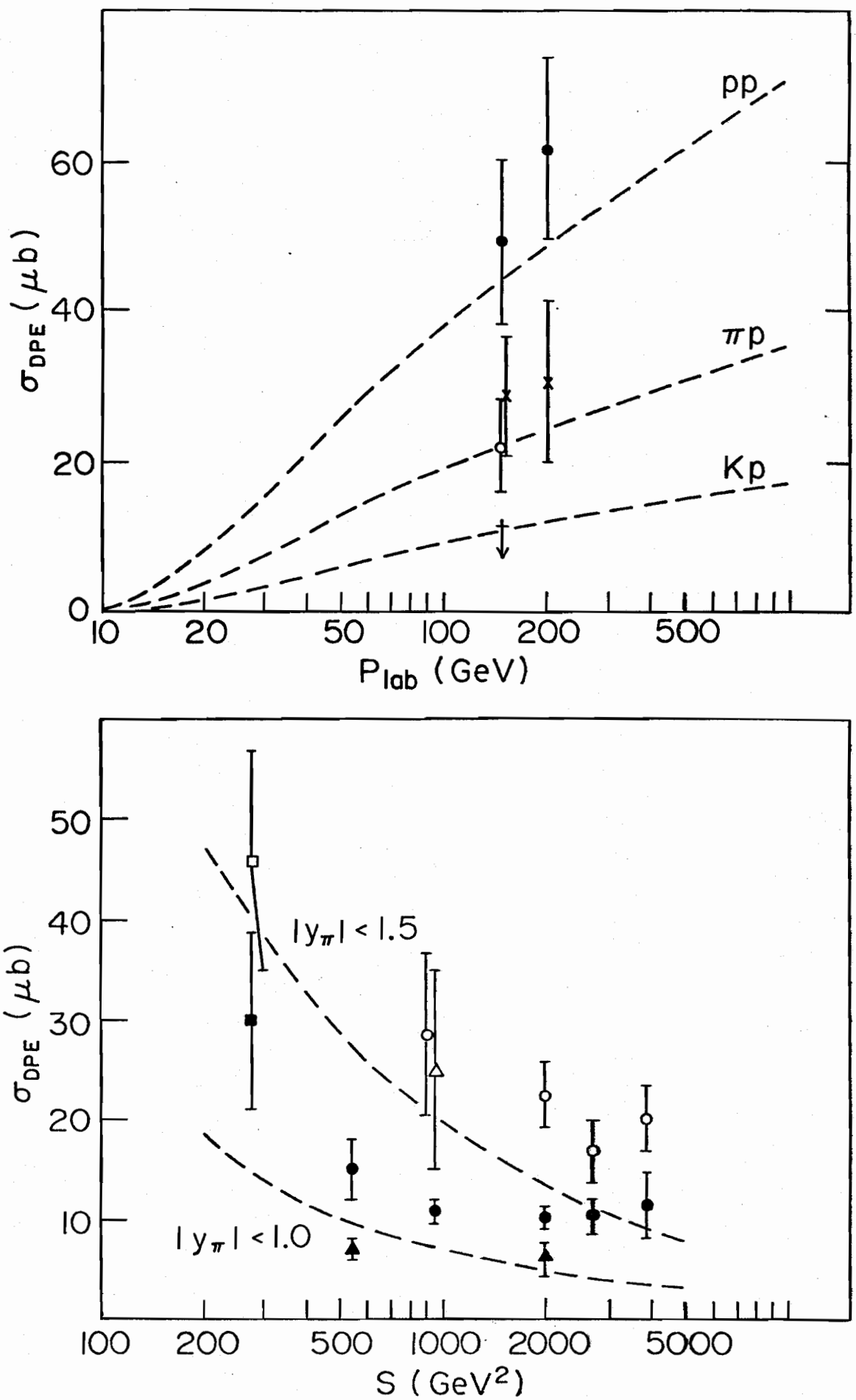
pp
πp
Kp
60
40
20
0
10
20
50
100
200
500
σ_{DPE} (μb)
P_{lab} (GeV)
50
40
30
20
10
$|y_\pi| < 1.5$
$|y_\pi| < 1.0$
100
200
500
1000
2000
5000
σ_{DPE} (μb)
S (GeV^2)

Figure 5