File Copy

FERMILAB-PUB-75-184-E

(Submitted to Nuclear Physics B)

$\rho^0\rho^0\pi^-$ Production In the Reaction $\bar{p}n \to 3\pi^-2\pi^+$ Near 2190 MeV C.M. Energy*

P. D. Zemany**,†, Z. Ming Ma, J. M. Mountz‡ and G. A. Smith
Department of Physics, Michigan State University
East Lansing, Michigan 48824

ABSTRACT

The s-channel behavior of intermediate states in the reaction $\bar{p}n \to 3\pi^-2\pi^+$ are examined for a possible resonant structure at a center of mass energy of 2190 MeV, the existence of which has been suggested in previous experiments.

---

*Work supported in part by the National Science Foundation.

**Work presented in partial fulfillment of the requirements for the Ph.D. degree at Michigan State University.

†Present address: Department of Physics, University of Toronto, Toronto, Canada, M5S 1A7.

‡Present address: Department of Biophysics, Michigan State University, East Lansing, Michigan 48824.

1. Introduction

In a high statistics counter experiment of Abrams et al.,[1] an enhancement at a center of mass energy (ECM) of 2190 ± 10 MeV was observed in the total $\bar{p}d$ and $\bar{p}p$ cross sections. The authors concluded that this structure is an I=1 state with a width, Γ, of 85 MeV and a resonant height, $\pi\lambda\!\!\!^{-2}(J + \frac{1}{2})$, of 5.5 mb. Since this enhancement may be due to a resonance, a threshold effect or both, there have been several attempts to uncover its source.[2-9] In studying the reaction $\bar{p}p \to 2\pi^+2\pi^-\pi^\circ$, Kalbfleisch et al.,[2] observed a s-channel structure in the reaction $\bar{p}p \to \rho^\circ\rho^\circ\pi^\circ$. They suggested that this structure, having a mass of 2190 MeV and a width between 20 and 80 MeV, may be partially responsible for the 2190 MeV enhancement in the total cross sections. However, Donald et al.[3] and Handler et al.[4] failed to confirm these results in similar experiments.

Since the $\bar{p}n$ system is a pure I=1 state and the $\bar{p}p$ system is an equal admixture of I=1 and I=0 states, an I=1 s-channel resonance should be twice as strong in the $\bar{p}n$ system. In particular, the reaction $\bar{p}n \to \rho^\circ\rho^\circ\pi^-$ should have an enhancement twice as large as the 0.5 ± 0.1 mb enhancement reported by Kalbfleisch et al.[2] in $\bar{p}p \to \rho^\circ\rho^\circ\pi^\circ$, if the amplitude for producing the $\rho\rho$ subsystem in an I=0 state is dominant. In fact, this has been suggested to be the case by Kalbfleisch.[5] Therefore, it is of interest to see if this enhancement is present in the reaction $\bar{p}n \to 3\pi^-2\pi^+$. In particular the $\rho^\circ\rho^\circ\pi^-$ state has been examined in detail.

2. The Reaction $\bar{p}n \to 3\pi^-2\pi^+$

The reaction $\bar{p}n \to 3\pi^-2\pi^+$ has been examined at thirteen different beam momentum values: 1.09, 1.19, 1.31, 1.43, 1.60, 1.75, 1.85, 2.00, 2.15, 2.30,

2.45, 2.60, and 2.90 GeV/c. The data were collected in three different bubble chamber experiments. The four lowest momentum values were taken at Brookhaven National Laboratory in the 31-inch deuterium filled chamber. The cross sections for the reaction $\bar{p}n \rightarrow 3\pi^-2\pi^+$ at these momenta are given in Table 1. No selection on the spectator momentum has been made in obtaining these values. However, a multiplicative factor of 1.1 has been introduced to account for the screening effect of the proton. Further details of these data are described elsewhere.[10] These cross sections are in good agreement with cross sections obtained in a similar manner at the highest nine momenta published previously by Eastman et al.[11]

To be included in this analysis, an event must have a fit to the reaction $\bar{p}d \rightarrow p_s 3\pi^-2\pi^+$. To obtain a pure sample of such events, the calculated missing mass squared of the fit was required to be within two standard deviations of zero and the ionization density of the tracks predicted by the fit was required to be consistent with the results of an ionization scan. In addition, the spectator proton momentum was required to be less than 190 MeV/c. The purpose of this latter cut was to remove events in which both nucleons participate in the scattering processes. The momentum distribution of protons from the reaction $\bar{p}d \rightarrow p_s 3\pi^-2\pi^+$ shows evidence for this double scattering processes, as illustrated in Figure 1. The solid curves represent predictions of the Reid soft core deuteron wave function.[12] As may be seen, there is a definite excess above 200 MeV/c. This excess is attributable to the double scattering effect.[13] All the data satisfying the above criteria were used to examine s-channel structure of the intermediate states of $\bar{p}n \rightarrow 3\pi^-2\pi^+$ for possible resonances.

3. Intermediate States in $\bar{p}n \to 3\pi^- 2\pi^+$

There are several possible intermediate states in the reaction $\bar{p}n \to 3\pi^- 2\pi^+$ involving the production of multipion resonances (ρ, f, A_2, etc.). To determine which of these resonances are produced, the invariant mass distributions for all neutral or singly charged 2π, 3π, or 4π systems were examined. These distributions, shown in Figure 2, contain events from the four lowest incident beam momenta. Inspection of the distributions show that the ρ° is the only resonance that is obviously present. Similarly, the higher momentum data also involve only ρ° production.[14] Therefore, for the purpose of this work, it will be assumed that the $\bar{p}n$ annihilation into five charged pions can only proceed by the following reactions:

$$\bar{p}n \to 3\pi^- 2\pi^+, \tag{1a}$$

$$\bar{p}n \to \rho^\circ 2\pi^- \pi^+, \tag{1b}$$

and

$$\bar{p}n \to \rho^\circ \rho^\circ \pi^-. \tag{1c}$$

These reactions will be referred to as nonresonant, single rho, and double rho production respectively.

To determine the amounts of each type of production, distinguishing characteristics must be found. There are six possible $\pi^+\pi^-$ pairs in the $3\pi^- 2\pi^+$ final state which could possibly be a ρ°. For single rho or double rho production, only one or two of these pairs can be ρ°'s. The remaining pairs comprise the background distribution. The shape of the background distribution depends on the amounts of each type of production. The feature of the background due to each type of production were simulated using the Monte Carlo event generating program SAGE.[15] In each case, a simple statistical production mechanism was assumed with the mass and width of the ρ° set equal to 745 and 120 MeV respectively. The results show that the $\pi^+\pi^-$ invariant mass distributions involving nonresonant, single rho and double rho production are

similar in shape. The nonresonant and double rho cases are illustrated in Figure 3, where only the non-ρ(background) $\pi^+\pi^-$ pairs have been plotted. It is apparent that the shapes of the distributions are quite similar. The distinguishing characteristic differentiating single rho and double rho production is, in fact, the number of ρ^o's observed above the background. Furthermore, because of the similarities in the background distributions, it is possible for a combination of nonresonant production and double rho production to look like single rho production. Therefore, an anticorrelation between the amount of $\rho^o\rho^o\pi^-$ and $\rho^o 2\pi^-\pi^+$ is anticipated.

4. Analysis

The $\pi^+\pi^-$ invariant mass distribution is assumed to be the sum of the Monte Carlo generated distributions for nonresonant, single rho and double rho channels. Fitting was done using the following expression:

$$M(\pi^+\pi^-) = (1-A-B)\, M_n + AM_\rho + BM_{\rho\rho} . \qquad (2)$$

Here, M_n, M_ρ, and $M_{\rho\rho}$ are the Monte Carlo invariant mass distributions for the nonresonant, single rho, and double rho events respectively. Each of these distributions is normalized to the data. The quantities A and B are fit parameters corresponding to the fractional amounts of single rho and double rho production respectively.

The ECM quantity for each beam momentum setting is not well defined. This is due to finite spread in beam momentum (±0.5%), energy loss of the antiproton as it passes through the chamber, and the Fermi momentum of the nucleons in the deuteron. A spread of ±17 MeV in ECM is due to the Fermi momentum of the target. The momentum spread of the beam and energy loss in the chamber each contribute an additional ±2 MeV. Also, experimental measurement errors contribute a ±10 MeV spread in ECM. Combining these errors in quadrature

gives an ECM H.W.H.M. resolution of ±20 MeV. Hence, for the subsequent analysis the data have been grouped into 40 MeV ECM bins. The numbers of events corresponding to each momentum setting and ECM bin are shown in Table 2.

In Figure 4 we show the results of fits to equation (2) for the data in selected ECM bands from the four lowest momenta. The contours, which correspond to one standard deviation departures from the fits, show that there is a strong anticorrelation between A and B, as discussed previously. It is possible for a combination of double rho and nonresonant production to appear to be single rho production. Therefore, the only meaningful information that can be obtained from the invariant mass distribution is the magnitude of the ρ° signal above background. To determine this magnitude, the following expression was used to fit the data:

$$M(\pi^+\pi^-) = (1-f)\, M_n + fM_R. \qquad (3)$$

Here, M_n is the nonresonant phase space distribution and M_R is given by M_n times a Breit-Wigner function having the mass (745 MeV) and width (120 MeV) of the ρ°. The sums of M_n and M_R are each normalized to the data. Therefore, f gives the fraction of $\pi^+\pi^-$ pairs associated with the decay of a ρ°. The resulting values of f are presented in Table 3 and Figure 5.

5. Conclusions

It is apparent from Figure 5 that the fractional amount of ρ° has no obvious s-channel structure. This fraction appears to be nearly constant throughout the entire range of this experiment. We also note that, since the average number of ρ°'s per event (six times f) is systematically greater than unity, the $\rho^\circ\rho^\circ\pi^-$ state must be present. If the 0.5 ± 0.1 mb structure of Kalbfleisch *et al.*[2] were present, the $\bar{p}n$ system would show a similar effect

with twice the strength (1.0 ± 0.2 mb), assuming the dominance of the I=0 $\rho\rho$ amplitude. However, any such enhancement in the $\rho^\circ\rho^\circ\pi^-$ channel would necessarily require a dip in the cross section for the $\rho^\circ 2\pi^-\pi^+$ channel at the same ECM value.

Assuming that the behavior of the $\rho^\circ\pi^+2\pi^-$ channel is smooth in this energy range, a 1.0 mb enhancement in $\rho^\circ\rho^\circ\pi^-$ at 1.31 GeV/c would correspond to an enhancement of ~0.09 in f. This follows from the fact that if the reaction $\bar{p}n \rightarrow 3\pi^-2\pi^+$ proceeds purely via the $\rho^\circ\rho^\circ\pi^-$ intermediate state, two out of the six total $\pi^+\pi^-$ combinations would be in the ρ° signal. Therefore, Δf, the expected enhancement in f, is given by

$$\Delta f \simeq \frac{1}{3} \frac{\Delta\sigma(\rho^\circ\rho^\circ\pi^-)}{\sigma(3\pi^-2\pi^+)} = 0.09, \qquad (4)$$

where $\Delta\sigma(\rho^\circ\rho^\circ\pi^-) = 1.0$ mb and $\sigma(3\pi^-2\pi^+) = 3.68$ (Table 1). We have tested this hypothesis by fitting the data of Figure 5 to a Breit-Wigner shape suitably corrected for experimental resolution. For assumed widths of 20 (80) MeV for the $\rho^\circ\rho^\circ\pi^-$ object, we calculate probabilities of 0.03 (0.14) for this hypothesis. Therefore, the conjectured $\rho^\circ\rho^\circ\pi^-$ enhancement in these data appears unlikely.

6. Acknowledgments

The authors are grateful to the Argonne and Brookhaven National Laboratories for support given during the bubble chamber exposures. The diligent and talented effort of our scanning and measuring staff is gratefully acknowledged.

REFERENCES

1. R. J. Abrams et al., Phys. Rev. Lett. 18 (1967) 1209; R. J. Abrams et al., Phys. Rev. D1 (1970) 1917.
2. G. Kalbfleisch et al., Phys. Lett. 29B (1969) 259; G. Kalbfleisch et al., "Status of $\bar{p}p \to \pi(2190) \to \rho^\circ\rho^\circ\pi$", Brookhaven National Laboratory preprint NG-283, submitted to the Experimental Meson Spectroscopy Conference, Northeastern University, April, 1974.
3. R. A. Donald et al., Phys. Lett. 40B (1972) 586; R. A. Donald et al., Nuc. Phys. B61 (1973) 333.
4. T. Handler et al., "$\bar{p}p$ Annihilation into Four and Five Pion Final States in the T(2190) Region", Rutgers University, Stevens Institute of Technology, State University of New York (Albany) preprint, submitted to the Experimental Meson Spectroscopy Conference, Northeastern University, April, 1974.
5. G. R. Kalbfleisch, "The T Region", Experimental Meson Spectroscopy, ed. C. Baltay and A. H. Rosenfeld (Columbia University Press, 1970), 409.
6. J. Alspector et al., Phys. Rev. Lett. 30 (1973) 511; K. J. Cohen, "Direct Channel T and U Meson Formation in $\bar{p}p$ Interactions", Experimental Meson Spectroscopy - 1972, ed. A. H. Rosenfeld and K. W. Lai (American Institute of Physics, 1972) 242.
7. D. B. Cline, "Comments on Meson States with $M > 2M_N$", Experimental Meson Spectroscopy - 1972, ed. A. H. Rosenfeld and K. W. Lai (American Institute of Physics, 1972) 205.
8. G. A. Smith, "A Search for $\rho^\circ\rho^\circ\pi^-$ Enhancement in Antiproton-Neutron Annihilation in the T-Meson Region", Symposium on Antiproton-Nucleon Interactions (Liblice-Prague, 1974), CERN 74-18, 105.

9. J. Chapman, B. Green, A. Honma and B. P. Roe, "$\rho^\circ\rho^\circ\pi^\circ$ in the T Region", Symposium on Antiproton-Nucleon Interactions (Liblice-Prague, 1974), CERN 74-18, 108.

10. P. Zemany, Ph.D. Thesis, "A Study of $\bar{p}d$ Interactions from 1.09 to 1.43 GeV/c", Michigan State University (1975).

11. P. S. Eastman et al., Nuc. Phys. B51 (1973) 29.

12. R. Reid, Annals of Physics 50 (1968) 411.

13. P. Zemany, "A Study of Double Scattering Effects In Antiproton-Deuteron Annihilations", to appear in the Proceedings of the IV International Nucleon-Antinucleon Symposium, Syracuse, New York, 1975.

14. Z. Ming Ma et al., Nuc. Phys. B51 (1973) 77.

15. J. Friedman, SAGE, A Las Vegas Event Generator, Univ. of California, Berkeley, Note Number P-189, 1969.

Table 1. $\bar{p}n \rightarrow 3\pi^- 2\pi^+$ cross sections. No spectator cuts have been applied. Each cross section has been multiplied by 1.1 to correct for screening effects.

Momentum (GeV/c)	σ(mb)
1.09	4.08 ± .26
1.19	4.01 ± .22
1.31	3.68 ± .17
1.43	3.40 ± .17

Table 2. Number of events of the type $\bar{p}n \rightarrow 3\pi^- 2\pi^+$ used in fits.

P(GeV/c)	Events	ECM (GeV)	Events
1.09	680	2.09 - 2.13	633
1.19	997	2.13 - 2.17	1171
1.31	1852	2.17 - 2.21	1494
1.43	1123	2.21 - 2.25	920
1.60	679	2.27 - 2.31	381
1.75	381	2.32 - 2.36	352
1.85	383	2.36 - 2.40	336
2.00	380	2.41 - 2.45	241
2.15	277	2.46 - 2.50	135
2.30	252	2.52 - 2.56	222
2.45	248	2.57 - 2.61	180
2.60	266	2.62 - 2.66	191
2.90	217	2.72 - 2.76	90

Table 3. Fitted values of f, the fraction of ρ^{o}'s in $\bar{p}n \rightarrow 3\pi^{-}2\pi^{+}$.

ECM (GeV)	f
2.09 - 2.13	.202 ± .027
2.13 - 2.17	.197 ± .021
2.17 - 2.21	.181 ± .024
2.21 - 2.25	.221 ± .033
2.27 - 2.31	.209 ± .052
2.32 - 2.36	.235 ± .046
2.36 - 2.40	.209 ± .044
2.41 - 2.45	.190 ± .043
2.46 - 2.50	.195 ± .068
2.52 - 2.56	.185 ± .056
2.57 - 2.61	.188 ± .059
2.62 - 2.66	.187 ± .054
2.72 - 2.76	.193 ± .060

FIGURE CAPTIONS

Figure 1 - Momentum distributions of spectator protons from the reaction $\bar{p}d \rightarrow p_s 3\pi^- 2\pi^+$ for: (a) events with beam momenta of 1.09-1.43 GeV/c and (b) 1.60-2.00 GeV/c. Also shown, as the curves, is the calculated internal Fermi momentum distribution of the nucleons normalized to the data below 190 MeV/c.

Figure 2 - Invariant mass distributions of neutral or singly charged systems for (a) $\pi^+\pi^-$, (b) $\pi^-\pi^+\pi^+$, (c) $\pi^-\pi^-\pi^+$, and (d) $\pi^+\pi^+\pi^-\pi^-$.

Figure 3 - Monte Carlo generated $\pi^+\pi^-$ mass distributions for nonresonant (dashed) and double rho (solid) background at (a) 1.09 GeV/c and (b) 2.90 GeV/c.

Figure 4 - Fractional amounts of $\rho^\circ 2\pi^-\pi^+$ (A) and $\rho^\circ\rho^\circ\pi^-$ (B) production at ECM values of (a) 2.09-2.13 GeV, (b) 2.13-2.17 GeV, (c) 2.17-2.21 GeV and (d) 2.21-2.25 GeV. The contours correspond to one standard deviation departures from the fitted values.

Figure 5 - Dependence of f, the fraction of $\pi^+\pi^-$ pairs in the ρ° signal, on ECM. Also shown is the average number of ρ°'s (6xf) for the same data.

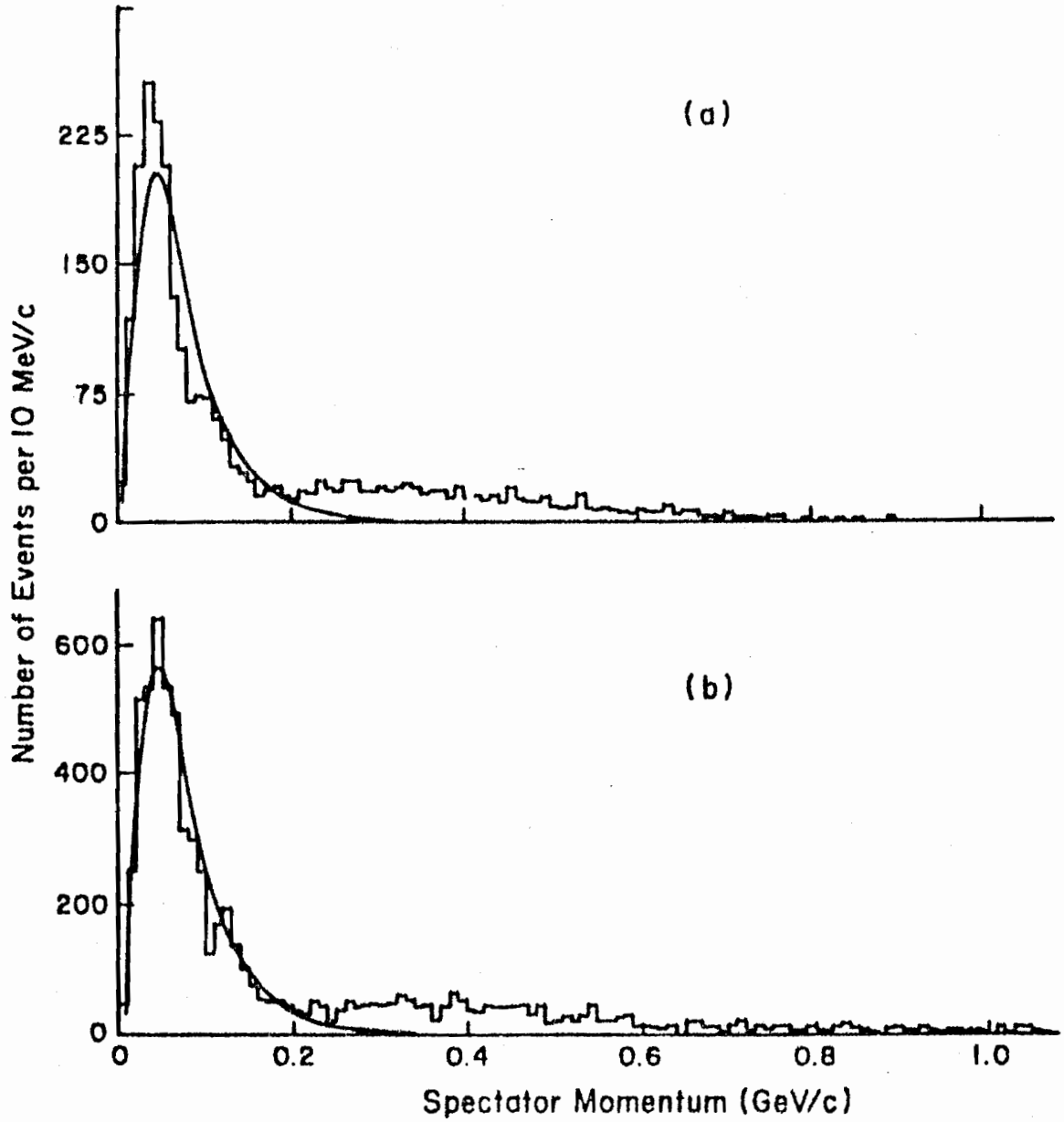
(a)
(b)
225
150
75
0
600
400
200
0
0
0.2
0.4
0.6
0.8
1.0
Number of Events per 10 MeV/c
Spectator Momentum (GeV/c)

Figure 1

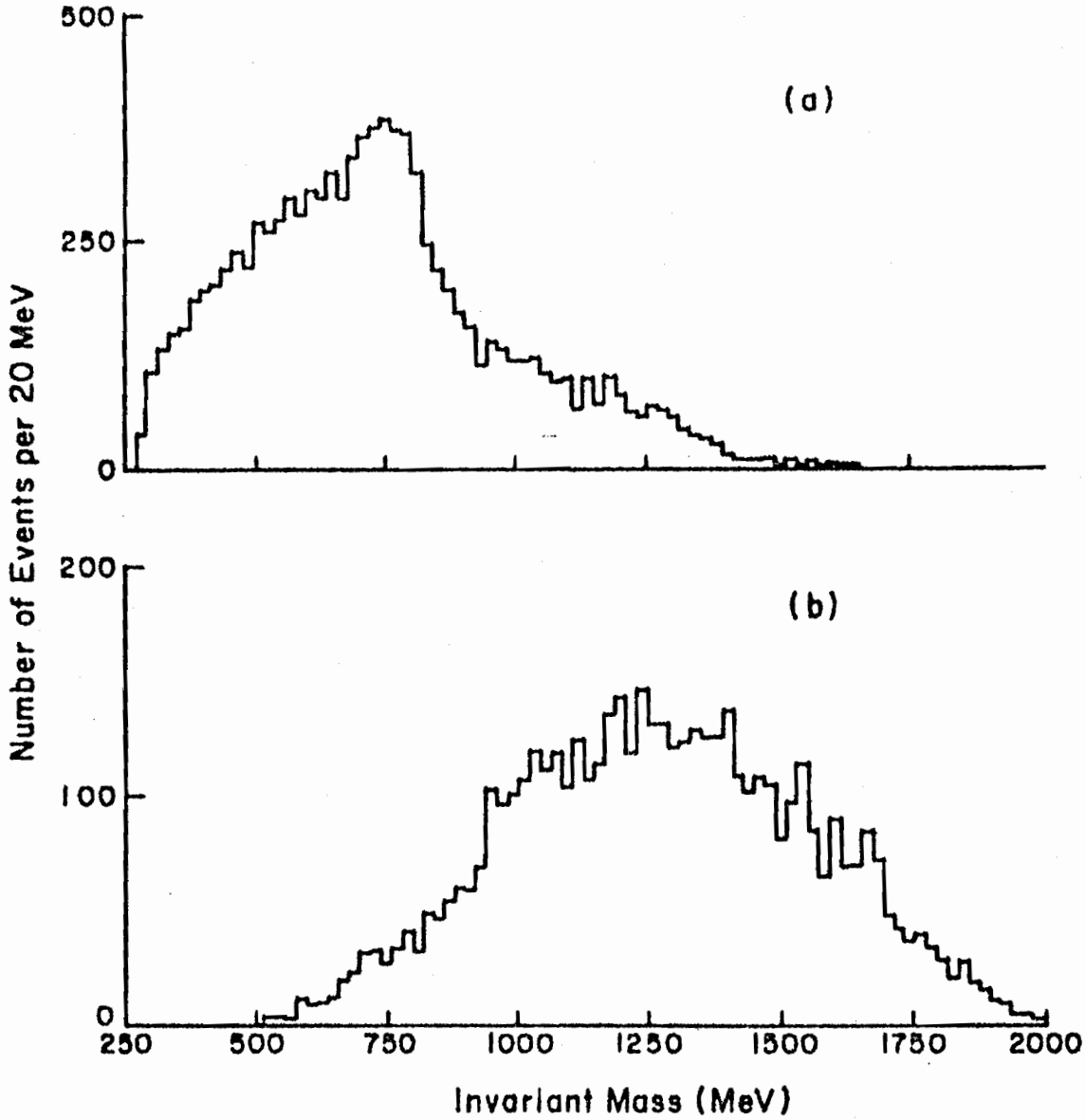
500
250
0
(a)
200
100
0
(b)
Number of Events per 20 MeV
250
500
750
1000
1250
1500
1750
2000
Invariant Mass (MeV)

Figure 2(a,b)

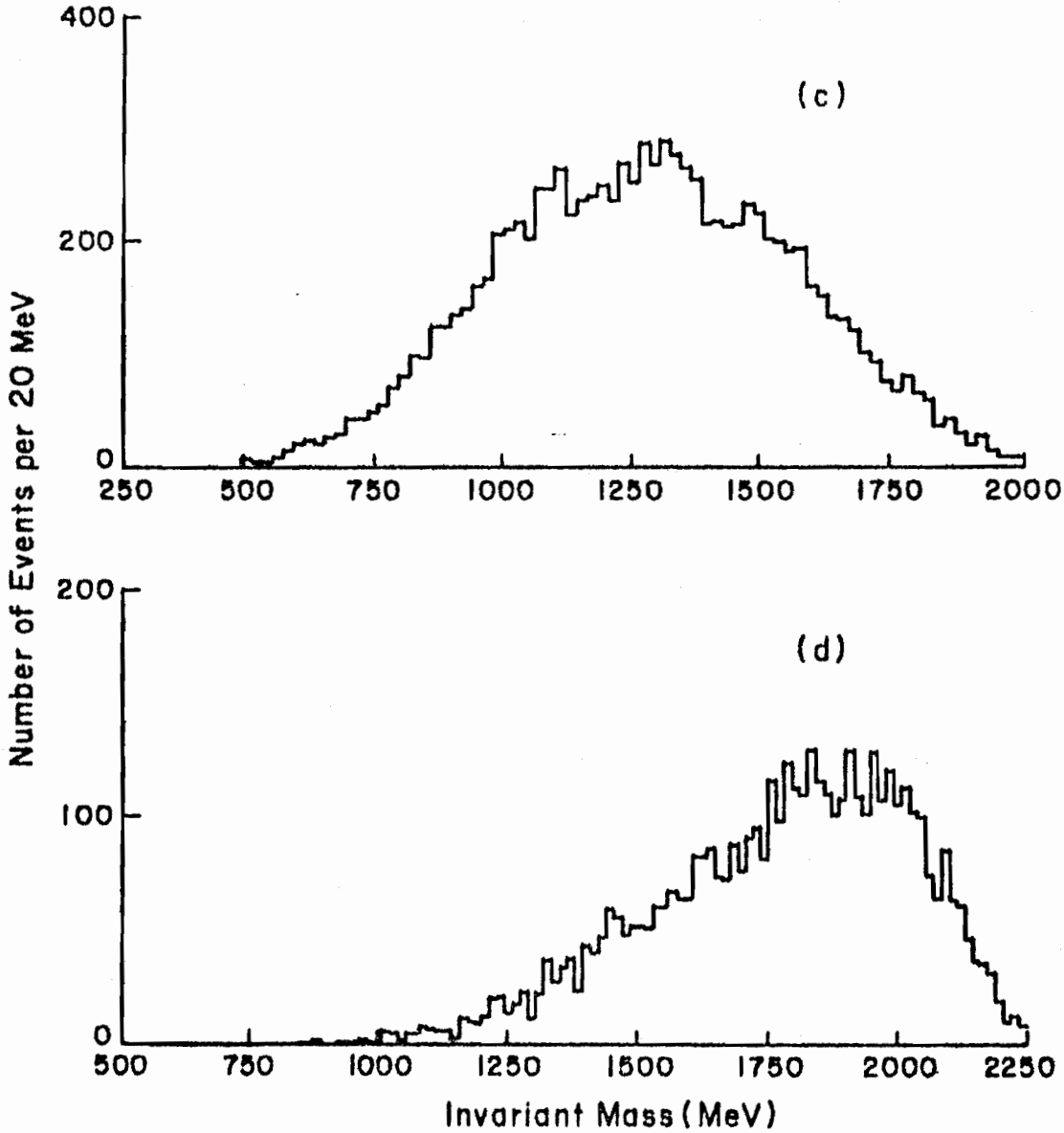
400
200
0
(c)
250
500
750
1000
1250
1500
1750
2000
200
100
0
(d)
500
750
1000
1250
1500
1750
2000
2250
Number of Events per 20 MeV
Invariant Mass (MeV)

Figure 2(c,d)

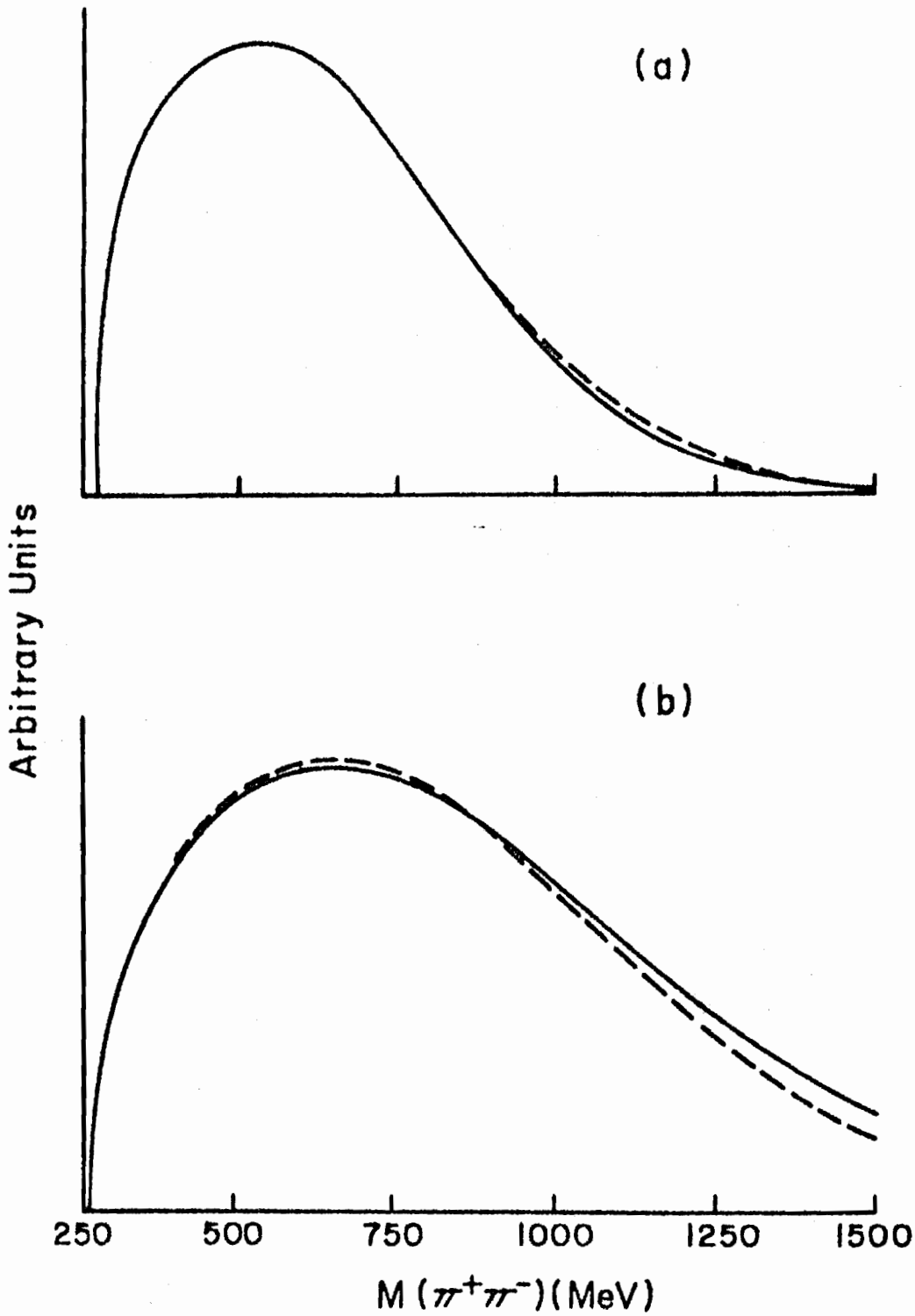

Figure 3

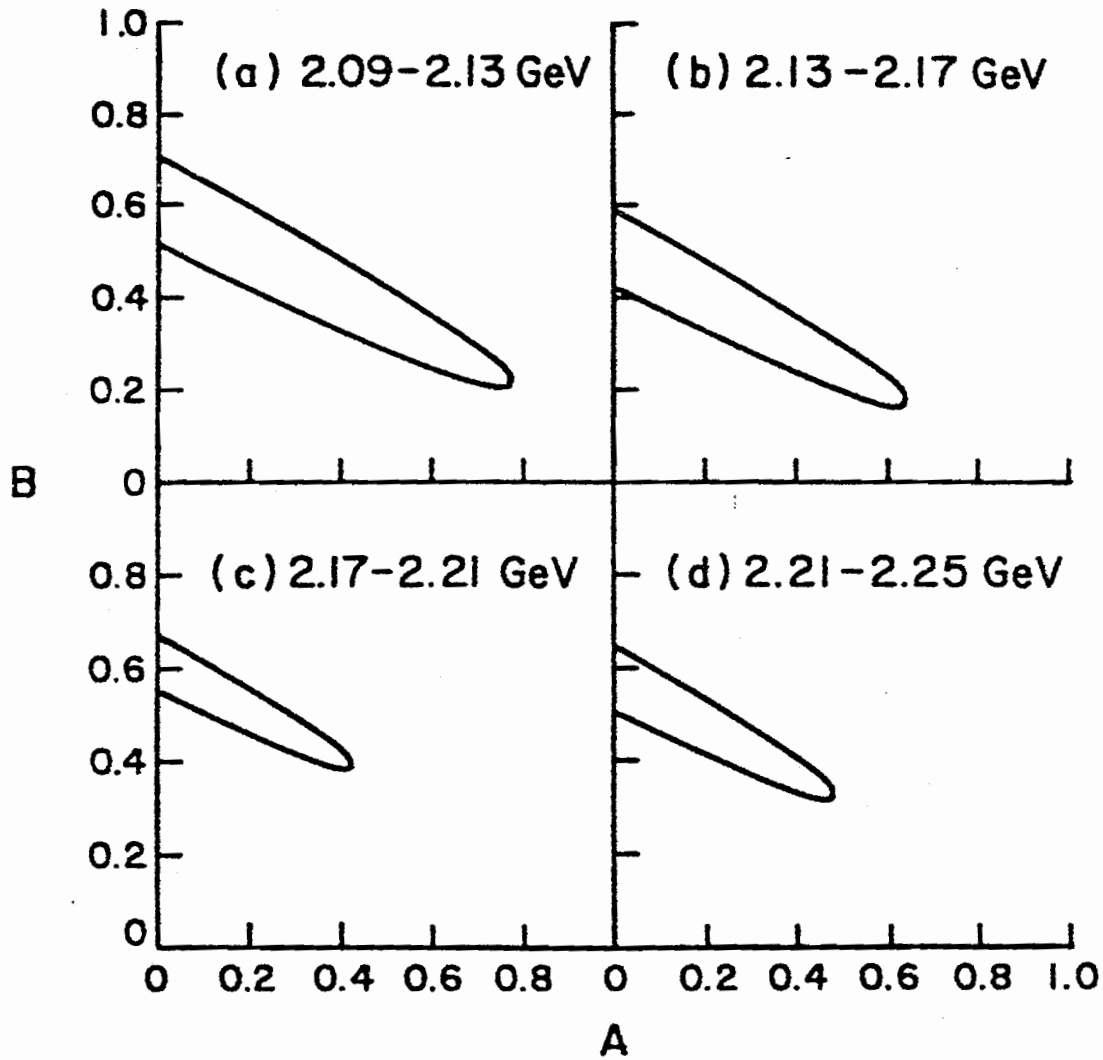
(a) 2.09-2.13 GeV
(b) 2.13-2.17 GeV
(c) 2.17-2.21 GeV
(d) 2.21-2.25 GeV
B
A
0
0.2
0.4
0.6
0.8
1.0

Figure 4

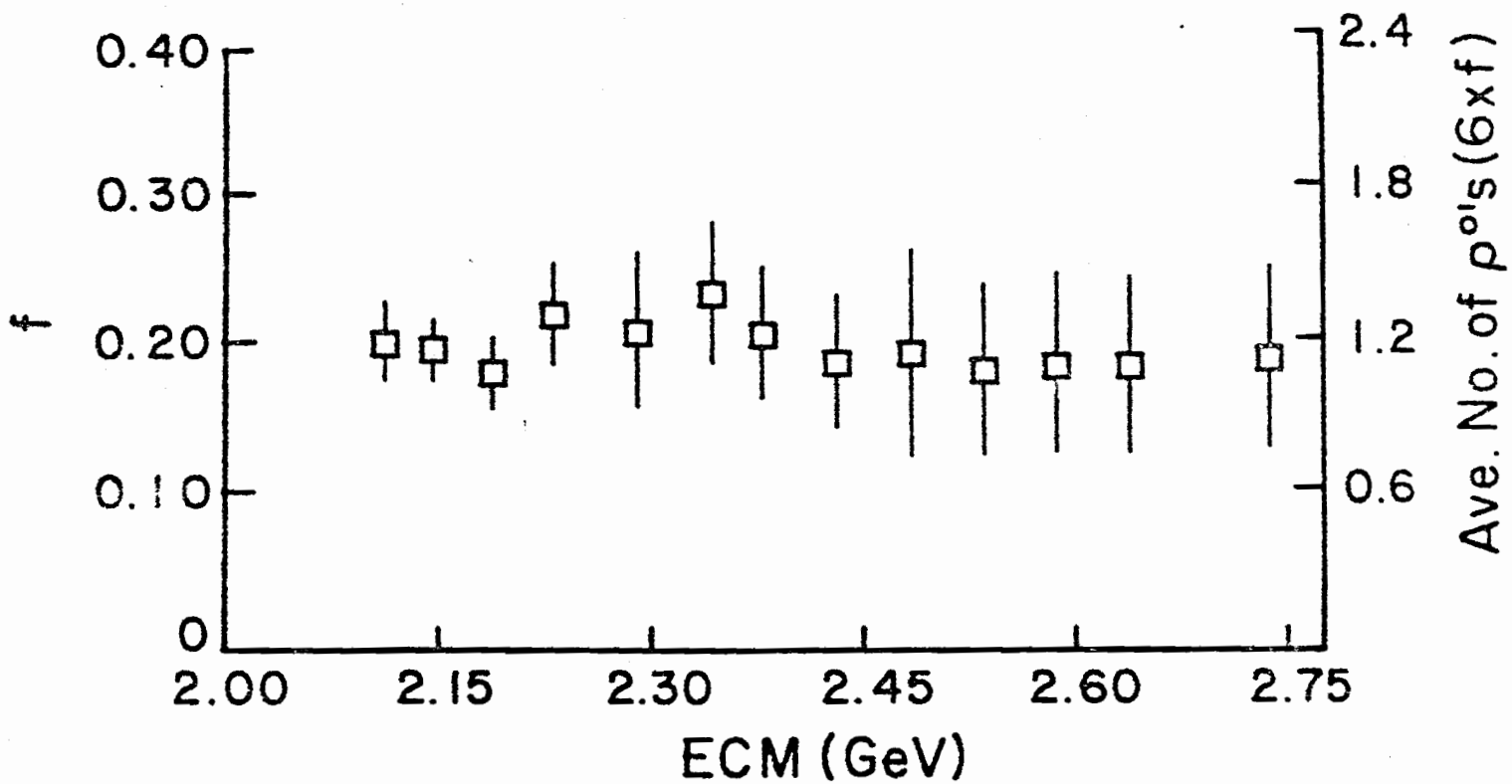
0.40
0.30
0.20
0.10
0
f
2.4
1.8
1.2
0.6
Ave. No. of ρ^{o}'s (6xf)
2.00
2.15
2.30
2.45
2.60
2.75
ECM (GeV)

Figure 5