Title
EVIDENCE FOR A n-p INTERACTION PRODUCED IN THE n+p REACTION AT 3.65 BeV/c

Authors
Goldhaber, Gerson
Brown, John L.
Goldhaber, Sulamith
et al.

Publication Date
1964-01-23

University of California

Ernest O. Lawrence Radiation Laboratory

EVIDENCE FOR A $\pi^{-}\rho$ INTERACTION PRODUCED IN THE $\pi^{+}p$ REACTION AT 3.65 BeV/c

Berkeley, California

DISCLAIMER

Submitted for publication in Phys. Rev. Letters

UCRL-11183

UNIVERSITY OF CALIFORNIA
Lawrence Radiation Laboratory
Berkeley, California

AEC Contract No. W-7405-eng-48

EVIDENCE FOR A π-ρ INTERACTION PRODUCED IN THE π^+p REACTION AT 3.65 BeV/c

Gerson Goldhaber, John L. Brown, Sulamith Goldhaber,
John A. Kadyk, Benjamin C. Shen, and George H. Trilling

January 23, 1964

Evidence for a π-ρ Interaction Produced in the π^+p Reaction at 3.65 BeV/c*

Gerson Goldhaber, John L. Brown, Sulamith Goldhaber, John A. Kadyk, Benjamin C. Shen, and George H. Trilling

Lawrence Radiation Laboratory and Department of Physics
University of California, Berkeley, California

January 23, 1964

In this note we wish to discuss our results on the study of the π^+p reaction at 3.65 BeV/c leading to four charged particles in the final state. In particular we wish to point out an anomaly we have observed in the mass distribution of the $\pi\rho$ system. This work was carried out in the 20-inch BNL hydrogen bubble chamber[1] exposed in the Yale-Brookhaven beam[2] at the AGS. The analysis[3] of the four-prong events permitted us to identify the three reactions[4]

$\pi^+p \to \pi^+\pi^-\pi^+p$,	1784 events,	$\sigma = 3.85 \pm 0.30$ mb,	(1)
$\pi^+p \to \pi^+\pi^-\pi^0\pi^+p$,	1998 events,	$\sigma = 4.3 \pm 0.35$ mb,	(2)
$\pi^+p \to \pi^+\pi^+\pi^+\pi^-n$,	359 events,	$\sigma = 0.76 \pm 0.07$ mb.	(3)

In what follows we discuss Reaction (1) only. The analysis of the reaction products indicates that only a small fraction of the cross section yields four "nonresonant" particles. Table I gives the summary of the cross section for all the channels identified in Reaction (1).

The production of ρ^0 mesons can proceed via two channels, i.e., together with an N^{*++} (1238) giving double resonance formation or with a proton and pion outside the N^{*++} resonance band, i.e.,

$$\pi^+ + p \rightarrow \rho^0 + N^{*++} \quad (1a)$$

$$\pi^+ + p \rightarrow \rho^0 + \pi^+ + p. \quad (1b)$$

The production mechanism of the ρ^0 meson appears to be distinctly different in the two channels. In channel (1a) ρ^0 mesons are produced with small four-momentum transfer Δ_1^2 to the N^{*++}, which we interpret to mean that the reaction proceeds principally via a peripheral collision. The Δ_1^2 distribution has a full width at half maximum of about 15 m_π^2. In channel (1b), on the other hand, the formation of ρ^0 mesons proceeds via much larger momentum transfers to the nucleon and pion system (full width at half maximum about 50 m_π^2). It is in this latter channel that we observe a strong enhancement in the distribution of $M(\rho^0\pi^+)$ in the mass region 1.0 to 1.4 BeV over that predicted by phase-space considerations. For purposes of discussion we refer to this enhancement as the formation of a state A^+ according to

$$\pi^+ + p \rightarrow A^+ + p, \quad (4)$$

which breaks up according to

$$A^+ \rightarrow \pi^+ + \rho^0. \quad (5)$$

One of the dominant processes in Reaction (1) is the formation of the N^{*++} resonance.[5] We found it expedient to classify our events into types according to whether or not a π^+p mass value falls inside the N^{*++} band, defined by $1.12 \leq M(p\pi^+) \leq 1.32$ BeV. We call that group of events for which one π^+p mass falls inside the N^{*++} band "type 1" (1024 events). Those events for which <u>both</u> π^+ mesons form a π^+p mass which lies inside the N^{*++} band we call "type 2" (118 events). Finally, "type 3" (642 events) refers to events for which both π^+p mass combinations lie outside the N^{*++} band.[6] This breakdown into types is illustrated in Fig. 1. In Fig. 1a we present a scatter plot of the π_a^+p mass against the $\pi_b^+\pi^-$ mass. As was pointed out in an earlier communication[7,8] the kinematical limits for the resulting scatter plot are given by an isosceles triangle. Since each event has two π^+ mesons it is represented by two points in this triangle plot. For clarity we have left out from Fig. 1a those points of type 1 events which correspond to the reflection of the N^{*++} band. These points are shown separately in Fig. 1e, with their projections (Figs. 1f and 1g). The most prominent feature of the $M(\pi^+\pi^-)$ distribution is ρ^0 production[9, 10], defined here by $0.65 \leq M(\pi^+\pi^-) \leq 0.85$ BeV (Figs. 1c and 1d), which proceeds with comparable cross sections through channels (1a) and (1b). When we examine the projection of points due to type 1 events in which we form the $\pi_1^+\pi^-$ mass by combining the π^+ of the N^{*++} isobar with the π^- meson, we find no appreciable ρ^0 production above background.

In an attempt to investigate a possible π-ρ interaction we considered channels (1a) and (1b) as a three-"particle" final state, viz. $\rho^0\pi^+p$. Interactions among particles in a three-particle final state are best investigated by plotting the variables in a Dalitz plot. In Figs. 2a and 2b we have plotted $M^2(p\pi^+)$ versus $M^2(\rho^0\pi^+)$. Because of the width of the ρ^0 meson we have two boundaries for the Dalitz plot. We note the strong N^{*++} band as well as a distinct enhancement in the region $M^2(\rho^0\pi^+)$, between 1.0 and 2.0 (BeV)^2. In Fig. 2a <u>all</u> $\pi^+\pi^-$ mass doublets falling inside the ρ^0 band are shown. This means that two points are shown for each event in which both mass doublets fall inside the ρ^0 band. The two points correspond to different $M^2(p\pi^+)$ but equal $M^2(\rho^0\pi^+)$ values ("double-ρ events"). In Fig. 2b and in all subsequent discussion we have left out the $\pi_1^+\pi^-$ type-1 combinations to avoid excessive background in our ρ^0 sample. Also for the 110 type-3 double-ρ^0 events we show only one point, chosen arbitrarily, in Fig. 2b and in their projections in Figs. 2c and 2d. The projection on the $M^2(p\pi^+)$ axis is given in Fig. 2c.

The N^{*++} band is clearly seen as well as a long tail towards higher π^+p mass values. The latter events belong exclusively to type 3. In Fig. 2d, we show the projection of the type-3 events on the $M^2(\rho^0\pi^+)$ axis (i.e., excluding the N^{*++} band). It is in this projection as well as in the Dalitz plot itself that we note the A^+ enhancement effect over phase-space predictions. The 110 double-ρ^0 events (out of 428 type-3 events) are indicated by the dotted histogram in Fig. 2d. It is noteworthy that the double-ρ events contribute considerably to the A^+ enhancement. This raises the question whether the A^+ enhancement might be related to Bose symmetrization or possibly be a dynamical effect favoring "double ρ" formation. However, on closer examination of the problem, double-ρ formation does not appear to be unduly enhanced. This can be appreciated by making a two-dimensional array in which the mass of the $\pi_1^+\pi^-$ pair is plotted against that of the $\pi_2^+\pi^-$ pair. Such an array for type-3 events clearly shows the two ρ^0 bands. The crossing of these ρ^0-meson bands corresponds to a particular symmetry in the $\pi^+\pi^-\pi^+$ system, i.e., double-ρ^0 events. We find that the number of double-ρ^0 events agrees with a simple superposition of the two ρ^0 bands.

We have mentioned above that in the $\rho^0\pi^+p$ final state, channel (1b), the ρ^0 mesons are not preferentially produced with small momentum transfer Δ_1^2 to the $p\pi^+$ system. We note, on the other hand, that the A^+ state is produced with small momentum transfer to the proton. This can be seen in the Chew-Low plot for these events (type 3 only). The projection of the four-momentum transfer, Δ^2, is given on the coordinate for the $M^2(\rho^0\pi^+)$ region 1(BeV)^2 to 2 (BeV)^2 and separately for the remaining mass regions. The peaking of the small values of Δ^2 for the region of the A^+ enhancement is self-evident. The distribution falls to half its intensity at about 25 m_π^2. On the abscissa we show mass projections for $\Delta^2 \leq 50\ m_\pi^2$ and those for higher four-momentum transfers. The enhancement in the A^+ region for low momentum transfer is clearly seen.

A possible interpretation of our observation is that we are dealing with a resonance in the $\pi^+\rho^0$ system.[11] In this case the relevant parameters known at present are $E_{A^+} = 1.2$ BeV, $\Gamma_{A^+} = 0.35$ BeV, the G parity is odd, and the isotopic spin T = 1 or 2. Alternatively there may be some structure to the A^+ enhancement and our observations could arise from two unresolved peaks. Furthermore the enhancement effects considered by Nauenberg and Pais,[12] which would not correspond to a unique isotopic spin and angular momentum state, could play a rôle in accounting for the lower half of the observed A^+ enhancement, i.e., in the region near 1 BeV.

We wish to thank the many members of the staff of the Brookhaven National Laboratory for their great helpfulness in making this experiment possible. In particular, we would like to express our appreciation to Dr. Hildred Blewett, Dr. Hugh Brown, Dr. Ralph Shutt, and the AGS operating crew. We also wish to thank Dr. Nicola Cabbibo, Dr. Geoffrey Chew, and Dr. Charles Zemach, for a number of helpful discussions, as well as Miss Ling-Lie Chau, Mr. Allan Hirata, Dr. Thomas O'Halloran, and Mr. Victor Seeger, who have participated in various aspects of this work. Finally, this work would not have been possible without the active help and interest of the Lawrence Radiation Laboratory scanning, measuring, and computing personnel.

Table I. Partial cross sections for channels leading to ρ^0, f^0, and N^{*++} (1238) formation in the reaction $\pi^+p \rightarrow \pi^+\pi^-\pi^+p$ at 3.65 BeV/c.[a]

Channel	Final state	Branching ratio (%)	Cross section (mb)
1a	$\rho^0 N^{*++}$	30.5	1.17 ± 0.12
1b	$\rho^0 \pi^+ p$	23.0	0.86 ± 0.09
1c	$\pi^+\pi^- N^{*++}$	30.1	1.16 ± 0.12
1d	$f^0 N^{*++}$	3.4	0.13 ± 0.04
1e	$\pi^+\pi^-\pi^+ p$ ("nonresonant")	13.0	0.53 ± 0.1
	Total	100.0	3.85 ± 0.30[b]

a. This table refers only to the most prominent features. Finer features such as the A^+ effect, N^{*0} (1238) formation, etc., are not explicitly incorporated.

b. The cross sections were calculated by calibration of the total number of π^+p interactions against the cross-section measurements by Longo and Moyer, Phys. Rev. 125, 701 (1962).

FOOTNOTES

*Work done under the auspices of the U. S. Atomic Energy Commission.

1. R. I. Louttit, in Proceedings of the International Conference on Instrumentation for High-Energy Physics, Berkeley, California, September 1960 (Interscience Publishers Inc., New York, 1961), p. 117.
2. C. Baltay, J. Sandweiss, J. Sanford, H. Brown, M. Webster, and S. Yamamoto, in Proceedings of the High-Energy Instrumentation Conference, CERN, 1962 (CERN, Geneva, 1962), p. 37.
3. In this work we utilized a modification of the geometrical reconstruction (PANG) and kinematical fitting (KICK) programs of the Alvarez Group: J. P. Berge, F. T. Solmitz, and H. D. Taft, Rev. Sci. Instr. **32**, 538 (1961); A. H. Rosenfeld and J. M. Snyder, Rev. Sci. Instr. **33**, 181 (1962).
4. Identification was made by χ^2 criteria for the various hypotheses and by visual inspection of the ionization for each event. This left 6.5 % of the events as ambiguous. These events are not included here.
5. This observation was also made by C. Alff, D. Berley, D. Colley, N. Gelfand, U. Nauenberg, D. Miller, J. Schultz, J. Steinberger, T. H. Tan, H. Brugger, P. Kramer, and R. Plano, Phys. Rev. Letters **9**, 322 (1962), and by M. Abolins, R. L. Lander, W. A. W. Mehlhop, N. Xuong, and P. M. Yager, Phys. Rev. Letters **11**, 381 (1963), who have investigated the same reaction at lower incident π^+ momenta.
6. For type 1 the two π^+ mesons are labeled π_1^+ and π_2^+; the π_1^+ is associated with the N^{*++}. For types 2 and 3 the subscripts are assigned randomly. In general when we wish to distinguish between the two π^+ mesons without reference to possible resonance formation we use subscripts "a" and "b."

7. G. Goldhaber, W. Chinowsky, S. Goldhaber, W. Lee, and T. O'Halloran, Phys. Letters 6, 62 (1963).

8. G. Goldhaber, in Proceedings of the Athens Topical Conference on Recently Discovered Particles (Ohio University, Athens, Ohio) p. 80.

9. In the reaction observed here resonance parameters for the ρ^0 meson differ somewhat from the ones quoted in the literature. We find the central value of the experimental ρ peak to lie at $E_{\rho^0} = 770 \pm 10$ MeV with a full width at half maximum of approximately 130 MeV. For a compilation of ρ^0 resonance parameters together with references, see M. Roos, Rev. Mod. Phys. 35, 314 (1963).

10. We have observed f^0 production (60 ± 20 events). This process is clearly present and occurs almost exclusively with N^{*++} formation. The f^0 was originally observed in a three-particle final state: W. Selove, V. Hagopian, H. Brody, A. Baker, and E. Leboy, Phys. Rev. Letters 9, 272 (1962).

11. In experiments at pion energies ranging from 8 to 16 BeV in a heavy-liquid bubble chamber, peaks in the 3π mass distribution have been reported in a region similar to that observed here. G. Bellini, E. Fiorini, A. J. Herz, P. Negri, and S. Ratti, Nuovo Cimento 29, 896 (1963); F. R. Huson and W. B. Fretter, Bull. Am. Phys. Soc. 8, 325 (1963).

12. M. Nauenberg and A. Pais, Phys. Rev. Letters 8, 82 (1962).

Figure Legends

Fig. 1. Scatter plots of the effective mass distributions for the two-particle composites in the reaction $\pi^+ p \rightarrow \pi^+ \pi^- p \pi^+$. The triangle shown in the insert to the figure as well as on the following figures indicates in the shaded region that part of the four-particle phase-space triangle which is displayed in the particular figures. The mass projections also are shown. In the present reaction each event contributes two points to the scatter plot. Those points corresponding to the reflection of the N^{*++} band of Fig. 1a are shown separately in Fig. 1e. The projections have been similarly separated. The triangles delineate the kinematical limits. Figure 1h shows the projection of all points (each event taken twice on the $M(\pi^+\pi^-)$ axis). It should be noted that the scale for mass projection is not the same in all figures.

Fig. 2. (a) A Dalitz plot for the three "particles" $\rho^0 \pi^+ p$. The two curves correspond to the two mass limits used to define the ρ^0 meson. In Fig. 2b a Dalitz plot of the same variables as in 2a is shown--excluding, however, the points due to the reflection of the N^{*++} and showing one point only per event for double-ρ^0 events. Figures 2c and 2d show the projection of 2b on the M^2 axes as indicated.

Fig. 3. A Chew-Low plot for the events of type 3. The four-momentum transfer to the proton Δ^2 is plotted against the M^2 of the $\rho^0\pi^+$ system. Figures 3b and c show the projections on the Δ^2 axis for the events respectively inside and outside the A^+ band. The projections on the $M^2(\rho^0\pi^+)$ axis are shown in Figs. 3d and e for Δ^2 values less than and greater than 50 m_{π^2} respectively.

UCRL-11183

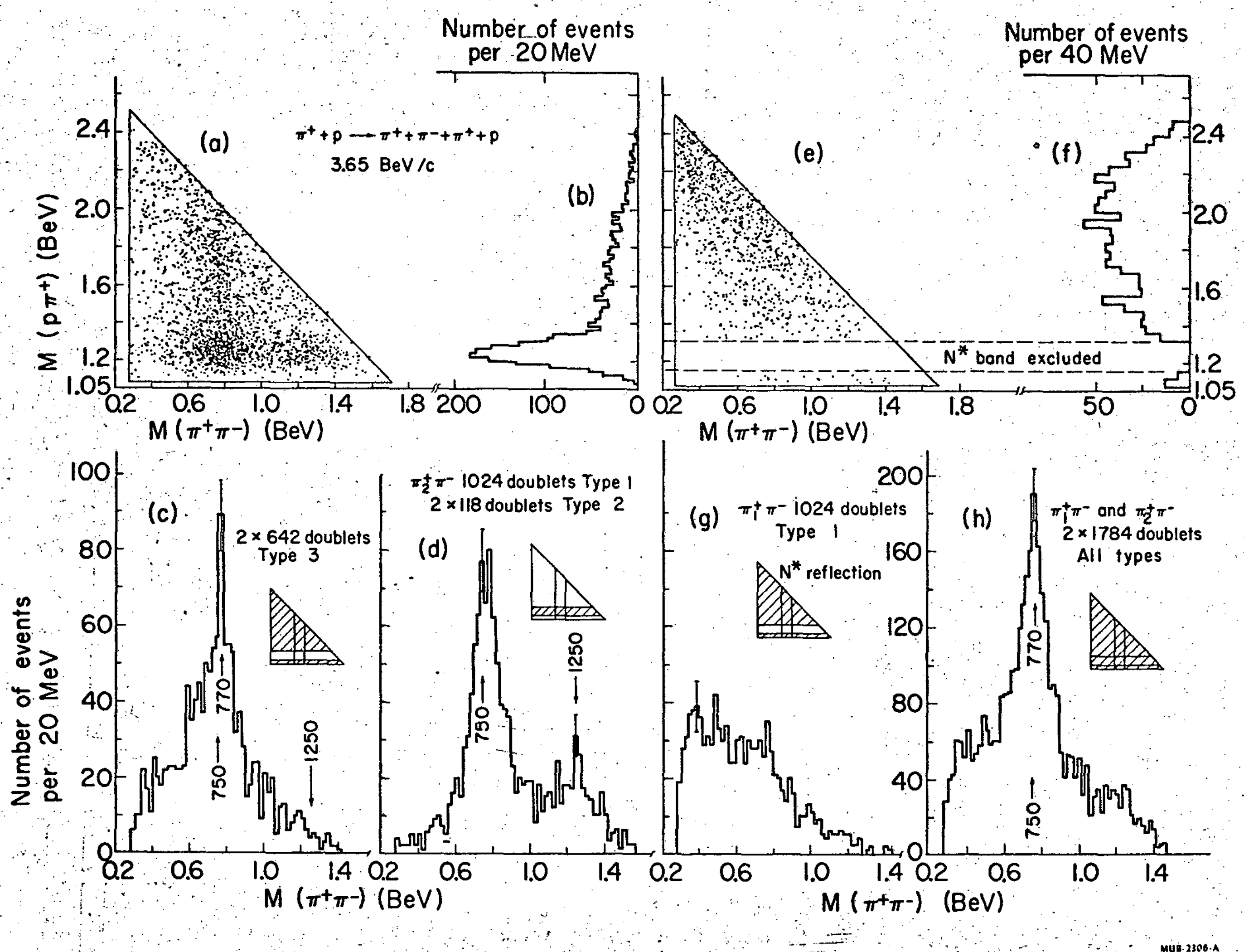
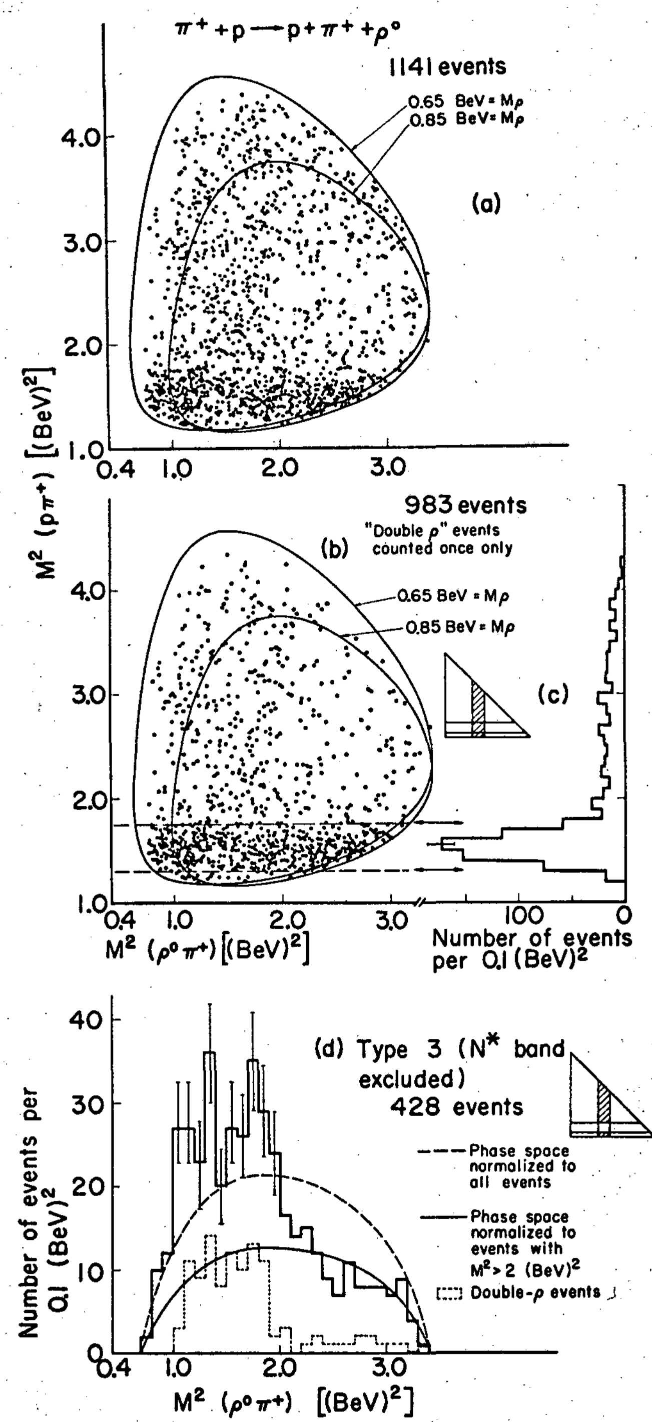


Fig. 1



π⁺+p → p+π⁺+ρ°
1141 events
0.65 BeV = Mρ
0.85 BeV = Mρ
(a)
983 events
"Double ρ" events counted once only
(b)
(c)
M² (pπ⁺) [(BeV)²]
M² (ρ°π⁺) [(BeV)²]
Number of events per 0.1 (BeV)²
(d) Type 3 (N* band excluded)
428 events
Phase space normalized to all events
Phase space normalized to events with M² > 2 (BeV)²
Double-ρ events
Number of events per 0.1 (BeV)²
MUB-2396-A

Fig. 2

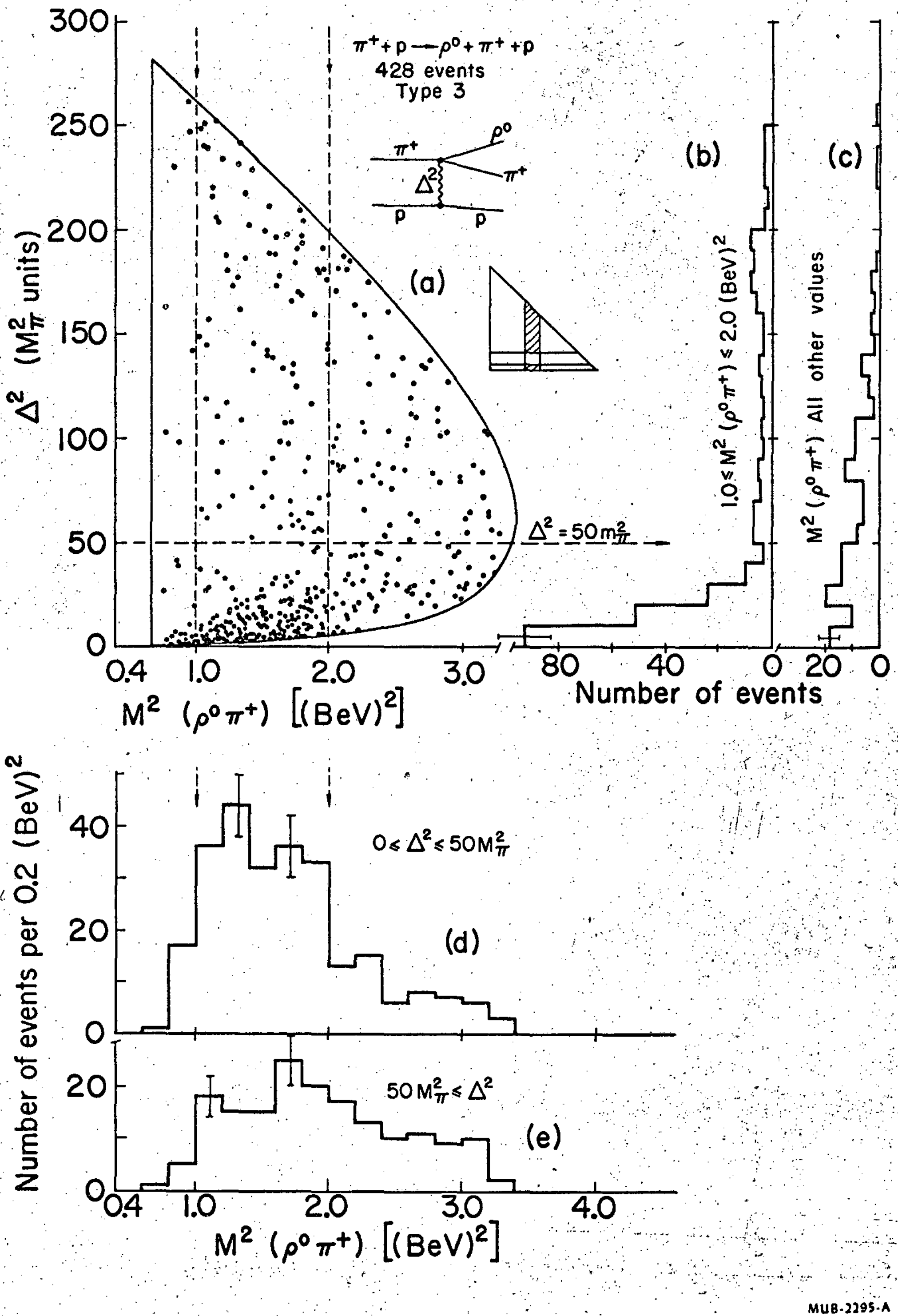

π⁺ + p → ρ⁰ + π⁺ + p
428 events
Type 3
(a)
(b)
(c)
Δ² (M²π units)
Δ² = 50 m²π
M² (ρ⁰π⁺) [(BeV)²]
Number of events
1.0 ≤ M² (ρ⁰π⁺) ≤ 2.0 (BeV)²
M² (ρ⁰π⁺) All other values
0 ≤ Δ² ≤ 50 M²π
(d)
50 M²π ≤ Δ²
(e)
Number of events per 0.2 (BeV)²
M² (ρ⁰π⁺) [(BeV)²]
MUB-2295-A

Fig. 3

[illegible]