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We have studied the interactions

$$\pi^- + p \rightarrow \pi^- + \pi^+ + n \qquad \text{(a)}$$

and

$$\pi^- + p \rightarrow \pi^- + \pi^0 + p \qquad \text{(b)}$$

in the Lawrence Radiation Laboratory 72-in. Hydrogen Bubble Chamber exposed to a 3.3 ± 0.1 BeV/c π^- beam from the Bevatron. The beam momentum and uncertainty were determined by the measured momentum distribution of incoming tracks of length greater than 60 cm and proper entrance angles.

Data reduction was performed with the FOG CLOUDY FAIR system. With the above beam momentum and uncertainty, two-prong events were fitted to reaction types (a) and (b). Events with proper beam acceptance angles, converging iterations, and χ^2 values ≤ 5.5 for either reaction were examined. Separation into reaction (a) or (b) was done by determining the ionization and range of the positively-charged tracks, up to 1.0 BeV/c momenta. The missing neutral masses were computed for both types by using measured parameter values. For the separated events, the distribution of missing mass squares of (a) gave a peak at the neutron mass and another near the $(n + \pi^0)$ mass. For (b), we obtained a peak at the π^0 mass, and enhancement at the η mass. The missing mass squares were computed by $M_0^2 = (E^i_{\pi^-} + M_p - E^s_{\pi^-} - E_{\pi^+,p})^2 - (P^i_{\pi^-} - P^s_{\pi^-} - P_{\pi^+,p})^2$.

Cuts were then imposed to define the desired neutral masses for the entire sample. Further, a "good measurement" criterion was applied to the entire data. Including 1700 elastic interactions, a total of 5000 two-prong events were measured. Thus, 532 events were identified as reaction (a) and 365 events as reaction (b); these include 30 half-weighted ambiguous events which had high momentum transfers to the nucleon.

Experimental Results. We have computed the "dipion" effective mass, ω, the invariant momentum transfer to the nucleon, $t = \Delta^2/\mu^2$, and the angle between the incoming and outgoing π^- in the barycentric system of the final pions, $\Theta_{\pi\pi}$. The beam momentum uncertainty contributed approximately 15 MeV to the error in ω and other errors brought this to about 35 MeV; accordingly we chose to histogram ω in 50 MeV intervals. Figures 1(a) and 1(b) show the histogram of the "dipion" mass for the $(\pi^-\pi^+)$ and $(\pi^-\pi^0)$ states, respectively. The (π^-, π^0) spectrum is strongly peaked at $\omega_r = 775$ MeV, which accounts for the ρ^- meson. The dashed curve in Fig. 1(b) represents the sum of 50% invariant phase space and 50% invariant phase space with a normalized Breit-Wigner resonance term of the form $N/[(\omega-\omega_r)^2 + (\Gamma/2)^2]$. The resonance term used has a value of full width at half maximum $\Gamma = 125$ MeV. This curve is normalized to the ρ^- peak. The (π^-, π^+) spectrum is also strongly peaked at a central value of $\omega_r = 775$ MeV, which accounts for the ρ^0 meson; however, here the resonance width appears to be broader than the width of the ρ^- meson. With the mixture of invariant phase space and phase space with resonance, determined by the ρ^- spectrum, the dashed curve in Fig. 1(a) is computed by using a value of $\Gamma = 175$ MeV. This curve fits best around the ρ^0 region and is normalized to the ρ^0 peak.

A second peak in the (π^-, π^+) spectrum is observed with a central value $\omega_r = 1250$ MeV and a width of $\Gamma \approx 200$ MeV. Similar peaks have been seen in two recent experiments.[1,2,3] The shoulder seen around 1050 MeV which appeared to be resolved at an earlier stage of this experiment has lost its resolution in this final analysis.

To study the resonant behavior of these peaks we have constructed distributions in $\cos \Theta_{\pi\pi}$ for several segments of the ω spectrum. Due to the ω^2/μ^2 vs Δ^2/μ^2 phase-space limitations, the angular distributions are presented with lower limits of t chosen as $t_{min} \approx 0$ for $275 < \omega < 1000$ MeV, and $t_{min} = 4.0\ \mu^2$ for $1000 < \omega < 1450$ MeV. Distributions were made in t for various segments of ω in both reactions. All of these distributions showed a characteristic dependence $t/(t+1)^2$. Most of the events were confined to values below $t = 25\ \mu^2$, the rest being dispersed in a tail extending to $t_{max} = 275\ \mu^2$. Accordingly, the angular distributions are presented with the upper limit of $t = 20\ \mu^2$. Figure 2(a) is the angular distribution at the ρ^- resonance showing a characteristic $\cos^2 \Theta$ dependence over a constant background, $700 \leq \omega(\pi^-, \pi^0) < 850$ MeV. Figure 2(b) is the angular distribution above the ρ^- resonance, $850 \leq \omega(\pi^-, \pi^0) < 1000$ MeV. The forward peak indicates that the p-wave phase shift δ_1, has crossed over 90°. Figure 2(c) shows that the angular distribution at the ρ^0 resonance is strongly peaked in the forward direction, $700 \leq \omega(\pi^-, \pi^+) < 850$ MeV. This behavior continues after the ρ^0 resonance as seen in Fig. 2(d), $850 \leq \omega(\pi^-, \pi^+) < 1000$ MeV. This indicates that an s-wave or a d-wave phase shift from the isotopic spin $T = 0$ component of the (π^-, π^+) state is sufficiently strong to interfere with the p-wave phase shift of the $T = 1$ component δ_1, such that it prevents the effective phase shift from reaching 90° at the ρ^0 resonance. The $T = 2$ component is ruled out for such a behavior since it would have appeared in both reactions.

Figures 2(e), (f), and (g) show the angular distribution before the peak, $1000 \leq \omega(\pi^-, \pi^+) < 1150$ MeV, at the 1250 MeV peak $1150 \leq \omega(\pi^-, \pi^+) < 1300$ MeV, and after the peak $1300 \leq \omega(\pi^-, \pi^+) < 1450$ MeV, respectively; Fig. 2(f) is a non-isotropic symmetric distribution. The 1250 MeV peak is seen in the (π^-, π^+) state and not in the (π^-, π^0), so that this resonance has isotopic spin T = 0; whereby, it is confined to even angular momenta. Although Fig. 2(f) does not show the characteristic d-wave hump at $\Theta_{\pi\pi} = 90°$, the J = 0 value is ruled out by nonisotropy. Dalitz plots were constructed for reactions (a) and (b). Figure 3 represents the projections of those plots in terms of the final pion reaction center of mass kinetic energies, T_π. The curves shown are the invariant phase-space integrals normalized to the total area of each histogram. The position of possible pion-nucleon resonances are indicated accordingly. Figure 3 (a_1) and (a_2) are the T_{π^+} and T_{π^-} projections, which are equivalent to the (π^-, n) and (π^+, n) effective mass spectra, respectively. No appreciable deviation from phase space is seen in either state. Figure 3(b_1) and (b_2) are the T_{π^+} and T_{π^-} projections, giving the (π^-, p) and (π^0, p) effective mass spectra, respectively. Deviations from phase space are evident in both states. The T_{π^0} distribution has a 4-standard-deviation peak corresponding to 2400 MeV(π^-, p) effective mass. The T_{π^-} distribution has a 3.5-standard-deviation peak at the $N^*_{3/2}(1238)$ position. If the peak in the T_{π^-} distribution is assumed to be due to the $N^*_{3/2}(1238)$ resonance, then the 2400 MeV peak in the T_{π^0} distribution must be considered as spurious. An examination of the Dalitz plot of reaction (b) shows that 40% of the events at the 2400 MeV region of T_{π^0} come from the $N^*_{3/2}(1238)$ of T_{π^-}, and 25% from the ρ^- resonance.

In reaction (a) the final state π-π resonances dominate over (π, n) interactions, whereas in reaction (b), with the presence of a single π-π resonance, the remaining phase space is available to the pions for any (π, p) interactions.

Conclusion. The striking difference in the angular distribution between the ρ^0 and ρ^- needs further explanation. This difference seems to be independent of energy.[5] If the apparent enlarged width of the ρ^0 is due to an adjacent ω^0 production which decays electromagnetically[6] into 2π's, then the same process cannot explain the forward peaking of the ρ^0 angular distribution for the following reason. In reaction (a), virtual ω^0 production would be through a ρ^+ exchange, whereas a ρ^0 production proceeds through a π^+ exchange; it has been indicated[7] that the π-π angular distribution combined from both processes would still be symmetric and of the form $a + b \cos^2\Theta_{\pi\pi}$.

Recent experiments of high energy p-p elastic scattering indicate that the first Pomeranchuk trajectory may have a slope[4] of $\alpha'_{P_1}(0) \approx 1/80\,\mu^2$. If the Regge singularities are confined to simple poles and if a constant slope of Regge trajectories is assumed[8] over a wide energy range, then the 1250 MeV $T = 0$ π-π resonance can be interpreted as the physical manifestation of P_1. Recently, a second Pomeranchuk trajectory P_2, with the intercept value[12] $\alpha_{P_2}(0) \approx 0.5$, has been postulated.[9-12] Under the above assumptions this should manifest itself as a $T = 0$ π-π resonance at 1800 MeV, which is above the phase-space limitations of this experiment.

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References and Footnotes

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1. J. Hennessy, J.J. Veillet, M. di Corato and P. Negri, Proc. Intern. Conf. High Energy Physics, CERN, 1962, reported by F. Muller.
2. W. Selove, N. Hagopian, H. Brody, A. Baker and E. Leboy, Phys. Rev. Letters 9, 272 (1962).
3. J.J. Veillet, J. Hennessy, H. Bingham, M. Bloch, D. Drijard, A. Lagarrigue, P. Mittner, A. Rousset, G. Bellini, M. di Corato, E. Fiorini, and P. Negri, Phys. Rev. Letters 10, 29 (1963).
4. K.J. Foley, S.J. Lindenbaum, W.A. Love, S. Ozaki, J.J. Russell and L.C.L. Yuan, Brookhaven National Laboratory, preprint (1963).
5. For a discussion on the ρ width at a lower energy see Saclay-Orsay-Bari-Bologna Collaboration: π^--p Interactions at 1.59 GeV/c, submitted to Nuovo Cimento.
6. J. Bernstein and G. Feinberg, Proc. Intern. Conf. High Energy Physics, CERN, 1962.
7. S.M. Berman, Stanford Linear Accelerator Center, (private communication).
8. G.F. Chew and S.C. Frautschi, Phys. Rev. Letters 8, 41 (1962).
9. K. Igi, Phys. Rev. Letters 9, 76 (1962).
10. S.D. Drell, Proc. Intern. Conf. High Energy Physics, CERN, 1962.
11. F. Hadjioannou, R.J.N. Phillips, and W. Rarita, Phys. Rev. Letters 9, 183 (1962).
12. K. Igi, Two Vacuum Poles and Pion-Nucleon Scattering, University of California, Berkeley (submitted to Phys. Rev.).

Figure Captions

Fig. 1(a) Spectrum of $\omega(\pi^-, \pi^+)$ from 532 events of reaction $\pi^- + p \rightarrow \pi^- + \pi^+ + n$. Dashed curve: 50% invariant phase space and 50% invariant phase space with Breit-Wigner resonant term using $\Gamma_r = 175$ MeV, $\omega_r = 775$ MeV.

(b) Spectrum of $\omega(\pi^-, \pi^0)$ from 365 events of reaction $\pi^- + p \rightarrow \pi^- + \pi^0 + p$. Dashed curve: same as in (a) with $\Gamma_r = 125$ MeV, $\omega_r = 775$ MeV.

Fig. 2. Distributions in $\cos \Theta_{\pi\pi}$, the angle between the incoming and outgoing π^- in the barycentric system of the final pions, for

(a) $700 \leq \omega(\pi^-, \pi^0) < 850$ MeV, and $t_{min} < t \leq 20\,\mu^2$,

(b) $850 \leq \omega(\pi^-, \pi^0) < 1000$ MeV, and $t_{min} < t \leq 20\,\mu^2$,

(c) $700 \leq \omega(\pi^-, \pi^+) < 850$ MeV, and $t_{min} < t \leq 20\,\mu^2$,

(d) $850 \leq \omega(\pi^-, \pi^+) < 1000$ MeV, and $t_{min} < t \leq 20\,\mu^2$,

(e) $1000 \leq \omega(\pi^-, \pi^+) < 1150$ MeV, and $4.0\,\mu^2 < t < 20\,\mu^2$,

(f) $1150 \leq \omega(\pi^-, \pi^+) < 1300$ MeV, and $4.0\,\mu^2 < t \leq 20\,\mu^2$,

and

(g) $1300 \leq \omega(\pi^-, \pi^+) < 1450$ MeV, and $4.0\,\mu^2 < 5 \leq 20\,\mu^2$.

Fig. 3. Projections of Dalitz plots in terms of final pion c.m. kinetic energies. (a_1) and (a_2) are projections from $\pi^- + p \rightarrow \pi^- + \pi^+ + n$; (b_1) and (b_2) are from $\pi^- + p \rightarrow \pi^- + \pi^0 + p$. Solid curves are phase-space integrals. Position of possible N^* resonances are indicated by arrows.

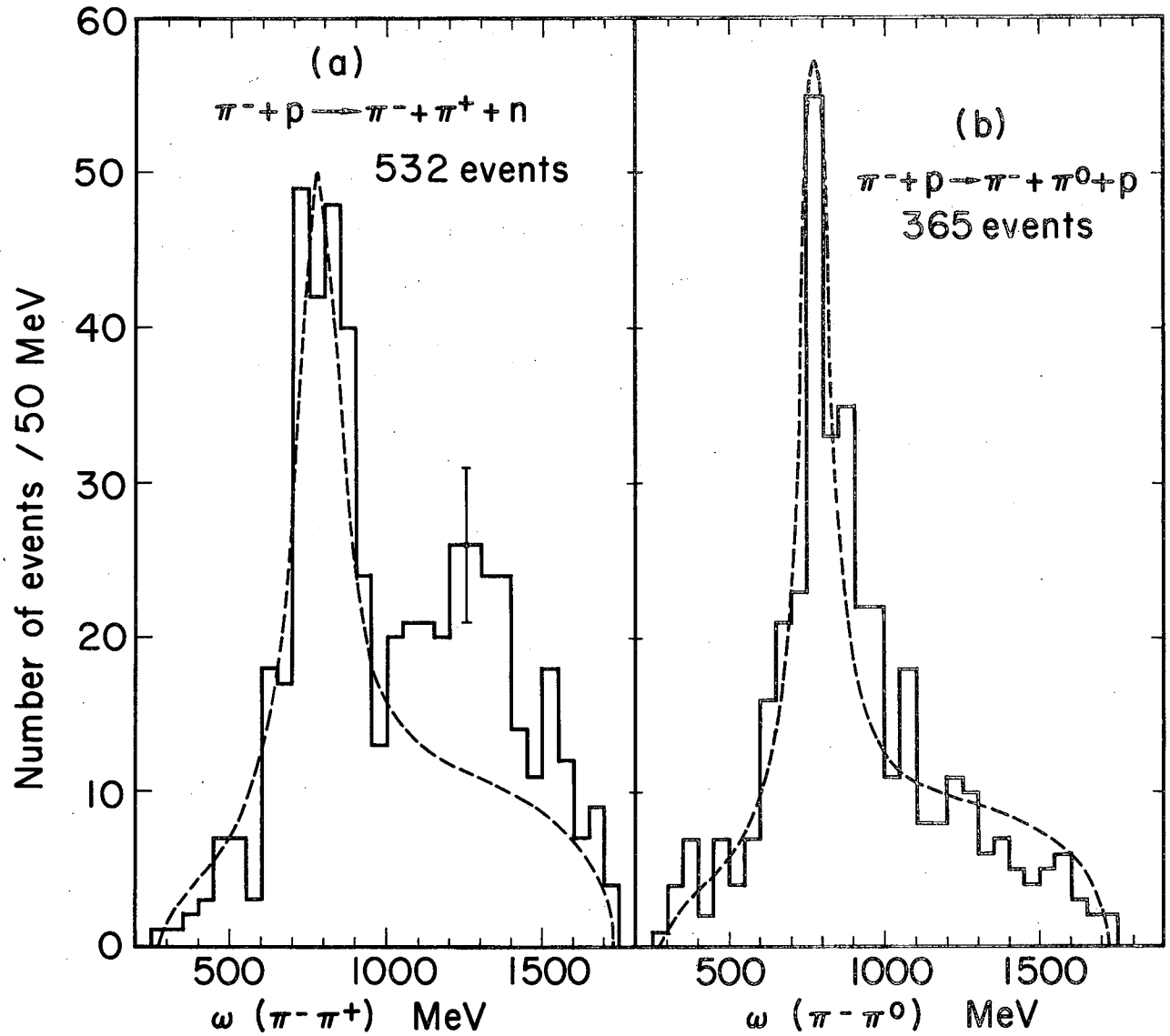

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Fig. 1.

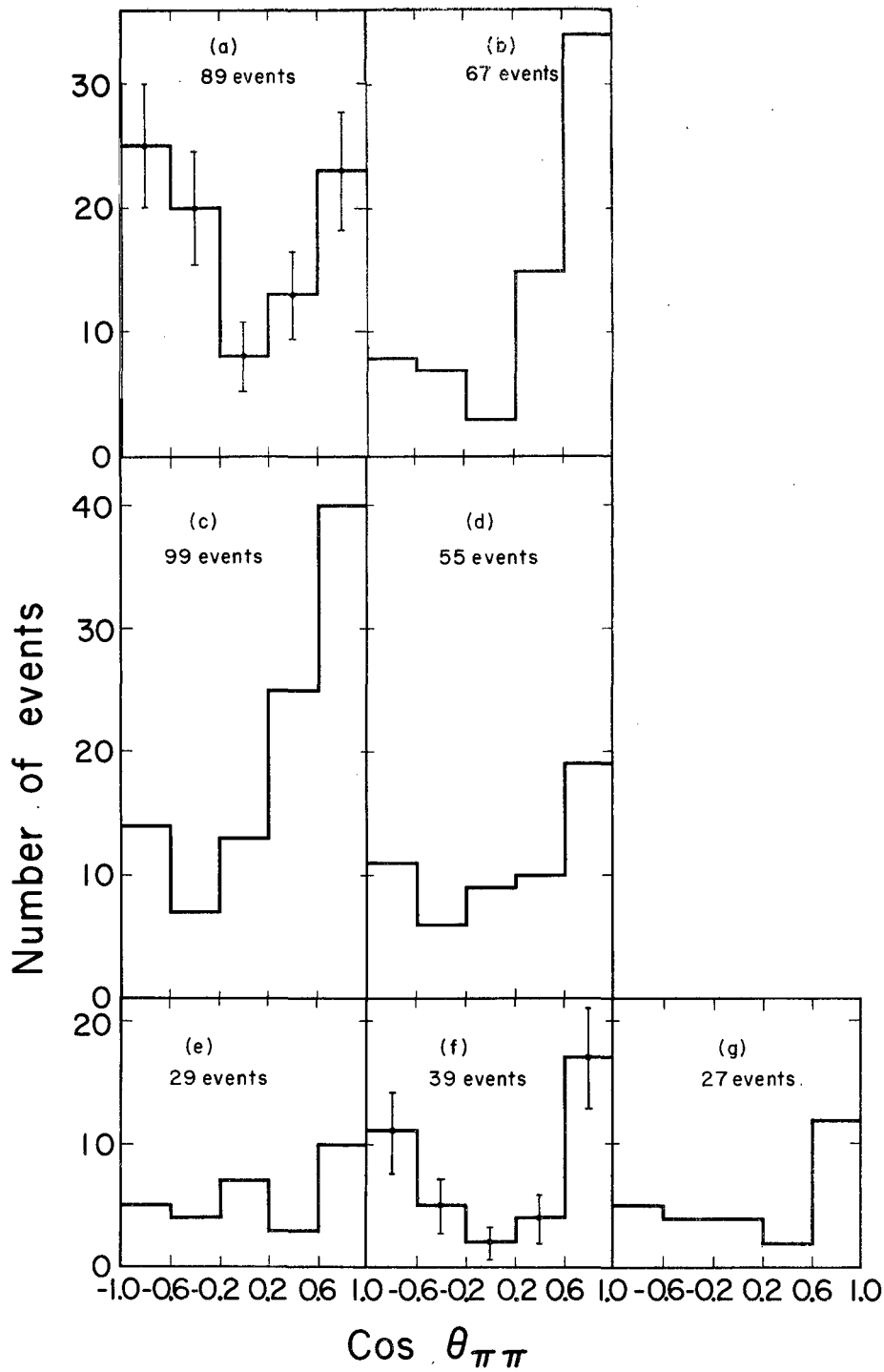
(a)
89 events
(b)
67 events
(c)
99 events
(d)
55 events
(e)
29 events
(f)
39 events
(g)
27 events
Number of events
Cos $\theta_{\pi\pi}$
MUB-1684

Fig. 2.

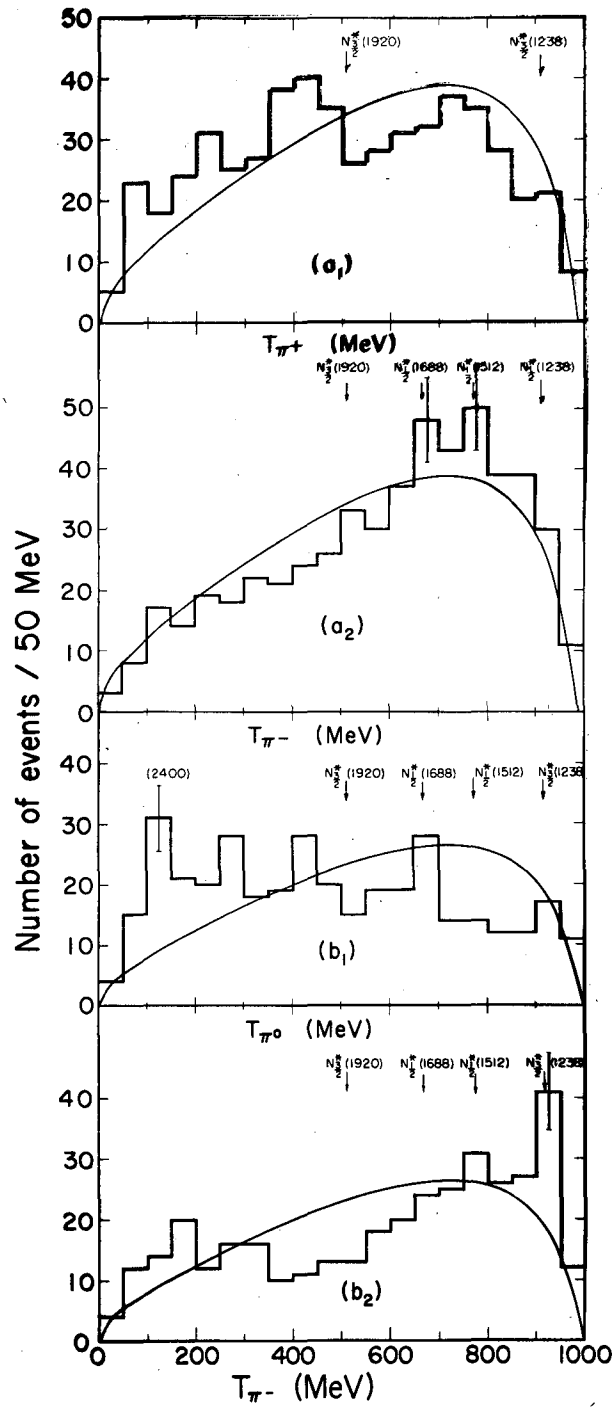
Number of events / 50 MeV
(a1)
(a2)
(b1)
(b2)
Tπ+ (MeV)
Tπ- (MeV)
Tπo (MeV)
(2400)
(1920)
(1688)
(1512)
(1238)
0
10
20
30
40
50
200
400
600
800
1000
MUB-1685

Fig. 3.

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