ISTITUTO NAZIONALE DI FISICA NUCLEARE
Laboratori Nazionali di Frascati

LNF-79/57

L. M. Barone, et al.

STUDY OF THE PRODUCTION OF THREE CHARGED PIONS IN $\bar{p}n$ ANNIHILATION AT 3 GeV/c

Estratto da:

Nucl. Physics B155, 1 (1979)

Servizio Documentazione
dei Laboratori Nazionali di Frascati
Cas. Postale 13 - Frascati (Roma)

Nuclear Physics B155 (1979) 1–12

STUDY OF THE PRODUCTION OF THREE CHARGED PIONS IN $\bar{p}n$ ANNIHILATION AT 3 GeV/c

L.M. BARONE *, A. BETTINI **, R. BIZZARRI *, E. CASTELLI ***, M. CRESTI **, C. DIONISI *, P.F. LOVERRE *, M. MAZZUCATO **, C. QMERO ***, L. PERUZZO **, P. POROPAT ***, P. ROSSI **, V. ROSSI *, G. SARTORI **, S.M. SARTORI **, M. SESSA ***, G. SUSINNO ‡, E. VALENTE *, L. VENTURA **, L. VOTANO ‡ and G. ZUMERLE **

Received 24 April 1978
(Revised 12 March 1979)

We have measured 1320 events from the reaction $\bar{p}n \to \pi^+\pi^-\pi^-$ at 2.98 GeV/c incident momentum (2.76 GeV total c.m. energy). The regular structure of zeros present in the three-pion Dalitz plot at lower energies is not found at this energy, except for a depopulation of events at $m^2(\pi^+\pi_1^-) = m^2(\pi^+\pi_2^-) \simeq 1.1$ GeV^2. The Dalitz plot population presents other structures which appear to be correlated with the angular variables describing the reaction.

1. Introduction

The reaction

$$\bar{p}n \to \pi^+\pi^-\pi^- \tag{1}$$

has been studied, at rest, by the Rome-Syracuse collaboration [1] and, at $\bar{p}$ momenta from 1.0 to 1.6 GeV/c, (c.m. energy from 2.08 to 2.29 GeV) by the Berkeley-Padova-Pisa-Torino collaboration [2].

The Dalitz plot of reaction (1) shows some interesting features. At rest, in addition to the resonance bands at about the ρ^0 and f^0 masses (that are not well-described by simple Breit-Wigner line shapes; see ref. [1]) two other structures are present. The most striking is the complete depopulation in a roughly circular region

‡ Laboratori Nazionali di Frascati, Frascati, Italy
* Istituto di Fisica dell'Università and INFN, Roma, Italy
** Istituto di Fisica dell'Università and INFN, Padova, Italy.
*** Istituto di Fisica dell'Università and INFN, Trieste, Italy.

centered at $m^2(\pi^+\pi_1^-) = m^2(\pi^+\pi_2^-) \simeq 1.1$ GeV^2, of radius about 0.2 GeV^2. The other is an accumulation of events in a region around $m^2(\pi^+\pi_1^-) = m^2(\pi^+\pi_2^-) \simeq 1.65$ GeV^2.

At the higher energies the Dalitz plot shows a similar behaviour, i.e., a "hole" and a "maximum" in the same positions as at rest. Furthermore, similar structures appear in the phase-space region made available by the increased c.m. energy of the reaction. These new structures are a second "hole" along the diagonal of the Dalitz plot at $m^2(\pi^+\pi^-) \simeq 2.17$ GeV^2 and two more holes placed symmetrically with respect to the diagonal of the Dalitz plot at $m^2(\pi^+\pi_1^-) \simeq 1.1$ GeV^2, $m^2(\pi^+\pi_2^-) \simeq 3.2$ GeV^2 and its symmetrical partner. The three new holes fall near the Dalitz plot contour and, together with the hole and maximum present also at rest, form a pattern suggesting some regularity, falling at the vertices of a square lattice.

We have studied reaction (1) at 3 GeV/c of incident $\bar{p}$ momentum, to see if this pattern persists.

The experimental method is described in sect. 2. The Dalitz plot is discussed in sect. 3, where our data are compared with those at lower energies. In sect. 4 we will discuss the effects on the Dalitz plot population of some angular cuts.

Preliminary results from this experiment have already been presented at Stockholm (1976) [3a] and Budapest (1977) [3b].

2. Experimental method

The data come from an analysis of ~400 000 pictures taken in the CERN 2m deuterium filled bubble chamber exposed to a separated beam of antiprotons of 2.98 GeV/c momentum from the CERN PS. The magnetic field in the chamber was 1.7 T.

All the 3-prong events from this film (~190 000) have been measured, $\frac{2}{3}$ of them on a PEPR at Padova, operated in zone guidance, the remaining $\frac{1}{3}$ on a HPD at CNAF *, operated in road guidance.

The events have been reconstructed using the CERN program THRESH (mass dependent). About one third of the events could not be successfully reconstructed after the first measurement and were remeasured. The fraction of failures for the remeasurements was again one third. A careful analysis of the failures after the first measurement and visual inspection of part of the failures after the second measurement, showed that the failures were independent of the particular nature of the events. No third measurement was therefore performed on the remaining 13% of the events.

A kinematical fit was performed on the events using the CERN program GRIND. In the final state there is always an unseen spectator proton (p_s) which was treated as a measured track with $p_x = p_y = 0 \pm 30$ MeV/c, $p_z = 0 \pm 40$ MeV/c, following

* Centro Nazionale di Analisi Fotogrammi, Bologna, Italy.

the standard procedure for deuterium experiments. 1513 events gave a fit to the hypothesis:

$$\bar{p}d \to p_s\pi^+\pi^-\pi^- , \tag{2}$$

with confidence level $P(\chi^2) > 0.005$.

The reconstructed momentum of the proton shows a spectrum in agreement with the deuteron wave function folded with errors as expected. Accepting only events with $P(\chi^2) > 0.02$ and beam momentum between 2.910 and 3.050 GeV/c reduces the sample to 1415 events. Some of these gave a fit to more than one hypothesis. When the ambiguity was between a 4C, $\pi^+\pi^-\pi^-$ final state and a state with an additional π^0, the former was always accepted. The only 4C-4C ambiguity present was between $\pi^+\pi^-\pi^-$ and $K^+K^-\pi^-$; the fit with a lower χ^2 was accepted. The final sample consisted of 1320 $\pi^+\pi^-\pi^-$ events.

The cross section for the three-prong $\bar{p}n$ interactions (topology 3) obtained from our data is 12.5 ± 0.4 mb, in good agreement with previous measurements by Eastman et al., at 2.9 GeV/c [4]. The branching ratio of reaction (2) is 0.90%. To evaluate the cross section of reaction (1) we must also take into account the events with a spectator proton momentum large enough to leave a visible track in the bubble chamber. The size of the chamber is such that practically all such protons stop in the liquid deuterium (we observe, with high efficiency stopping, spectators of momentum up to 400 MeV/c).

We have, therefore, scanned the film also for three-prong events plus a visible stopping proton track (topology 3s). From this scanning we obtain for the ratio $\frac{1}{3}(3 + 3s) = 1.52 \pm 0.04$. Applying the correction for the screening effect of the deuteron, which is estimated, from total cross-section measurements to be 1.08 at our energy [5], we get the cross section of reaction (1) in deuterium $\sigma = 0.18 \pm 0.01$ mb.

3. The Dalitz plot

Fig. 1 shows the (symmetrized) Dalitz plot and its projections on the $m^2(\pi^+\pi^-)$ and $m^2(\pi^-\pi^-)$ axes. The resolution in m^2 is about 2% on the whole range. On the Dalitz plot (and on the $m^2(\pi^+\pi^-)$ distribution) two accumulations of events are visible at the ρ^0 and f^0 masses; no signal is present at the g mass. However, a quantitative description of the Dalitz plot by simple incoherent superposition of known resonances is not possible, as it was not possible at lower energies. The limited statistical weight of the sample does not allow more complex parametrizations.

As stated in sect. 1, at lower energies a regular pattern of depopulated regions ("holes") was observed. The comparison of the Dalitz plot at rest [1] with that at 1.0–1.6 GeV/c [2] had suggested that its main features could be determined mainly by the values of $m^2(\pi^+\pi_1^-)$ and $m^2(\pi^+\pi_2^-)$, regardless of incident energy. To study whether this is supported by the present experiment, we counted, on the present

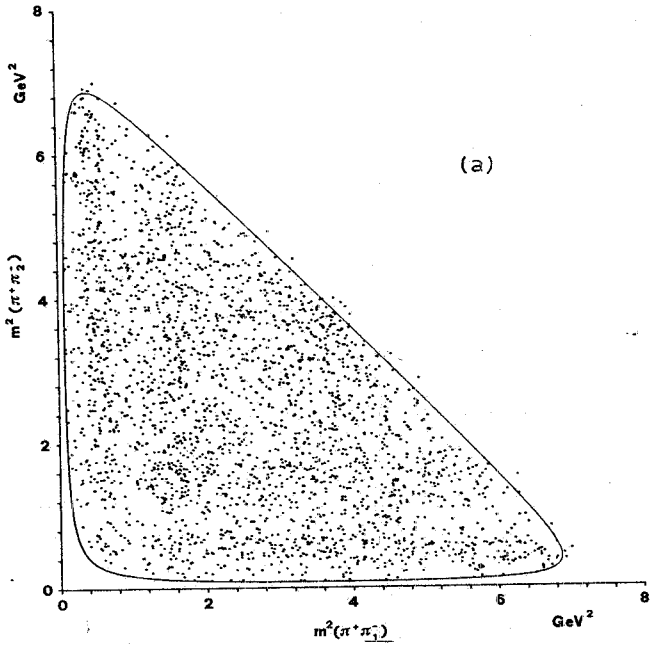

Fig. 1a. Dalitz plot for the 1320 events $\bar{p}n \to \pi^+\pi^-\pi^-$ at 3 GeV/c (2 X 1320 entries).

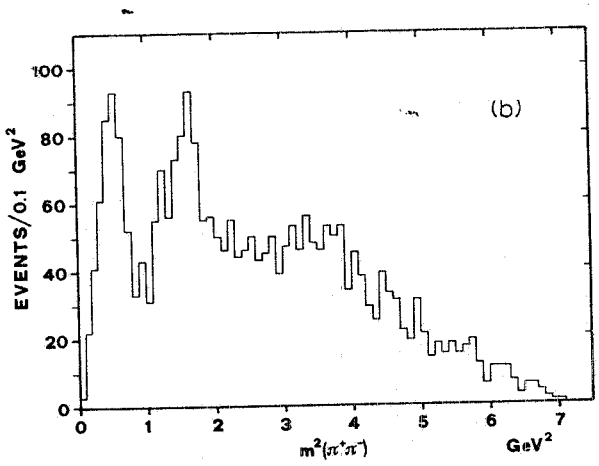

Fig. 1b. Invariant mass squared $\pi^+\pi^-$ (2 X 1320 entries).

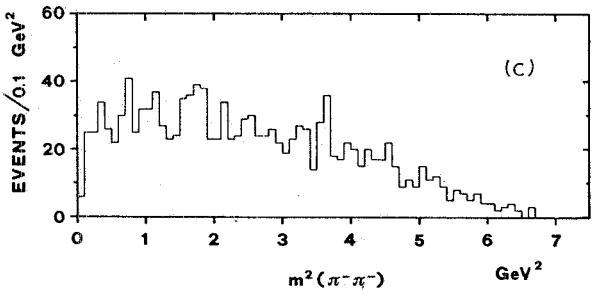

Fig. 1c. Invariant mass squared $\pi^-\pi^-$ (1320 entries).

Dalitz plot, the numbers of events contained in circular regions of 0.26 GeV^2 radius centered at the position of the holes observed at lower energies; we then compared these numbers with those expected in the following two hypotheses:

(a) the density of points in the "hole" position is that expected for a uniform Dalitz plot;

(b) the density expected is the average density in the "valley" between the ρ^0 and f^0 bands ($0.88 < m^2(\pi^+\pi_1^-) < 1.28$ GeV^2).

The same was done, for comparison, for the Dalitz plots of refs. [1,2] at lower energies.

The "hole" observed at rest [1] is centered at $m^2(\pi^+\pi_1^-) = m^2(\pi^+\pi_2^-) \simeq 1.1$ GeV^2; it contains (inside a radius of 0.26 GeV^2 as previously stated) 18 events, while 213 or 127 are expected in hypothesis (a) or (b) respectively. In the same region in the sample of ref. [2] (1.0–1.6 GeV/c) 20 events are present, while 50 or 33 are expected in the two above hypotheses. In the present sample at 3 GeV/c, we find 2 events against the 10.5 or 7.5 expected; the corresponding probabilities for this "hole" being a fluctuation are 0.2% and 2.0% respectively.

We can then conclude that the "hole" centred at 1.1 GeV^2 is likely to be a persistent feature of this Dalitz plot in the whole energy range explored so far.

The same is not true for the other features, for instance for the second "hole" along the diagonal, as seen at 1.0–1.6 GeV/c (ref. [2]). It is centred at $m^2(\pi^+\pi_1^-) = m^2(\pi^+\pi_2^-) = 2.17$ GeV^2 and contains 12 events, while 46 or 31 are expected in the two hypotheses. In our sample at 3 GeV/c we observe 12 events, while 10.5 or 7.5 are expected. Analogously, around $m^2(\pi^+\pi_1^-) = 3.2$ GeV^2, $m^2(\pi^+\pi_2^-) = 1.0$ GeV^2 at 1.0–1.6 GeV/c, 41 events are found while 92 or 62, respectively, are expected; at 3.0 GeV/c we observe 18 events, while 21 or 15 are expected.

We can then conclude that the only depopulated region ("hole") that persists at different c.m. energies is that at $m^2(\pi^+\pi_1^-) = m^2(\pi^+\pi_2^-) \simeq 1.1$ GeV^2.

Two new features are noticeable on the present Dalitz plot: a depopulation of events near $m^2(\pi^+\pi_1^-) = m^2(\pi^+\pi_2^-) \simeq 2.6$ GeV^2, that, as we will see in sect. 4, is

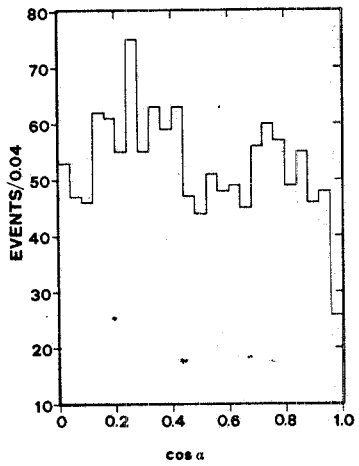

Fig. 2. Distribution of cos α between 0 and 1. α is the angle between the normal to the plane containing the three pions and the direction of the incident $\bar{p}$.

correlated with the orientation of the production plane, and an accumulation of events where the diagonal meets the kinematical boundary of the Dalitz plot. This accumulation corresponds to an enhancement visible at 3.65 GeV^2 in the $m^2(\pi^+\pi^-)$ distribution.

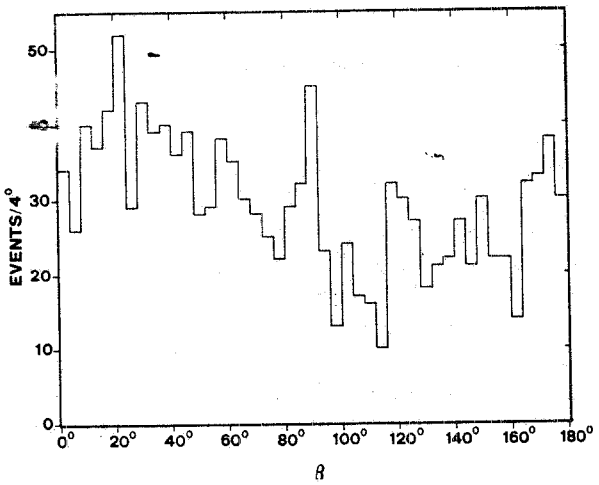

Fig. 3. Distribution of β between 0° and 180°. β is the angle between the projection of the $\bar{p}$ momentum on the plane containing the three pions and the π^+ momentum.

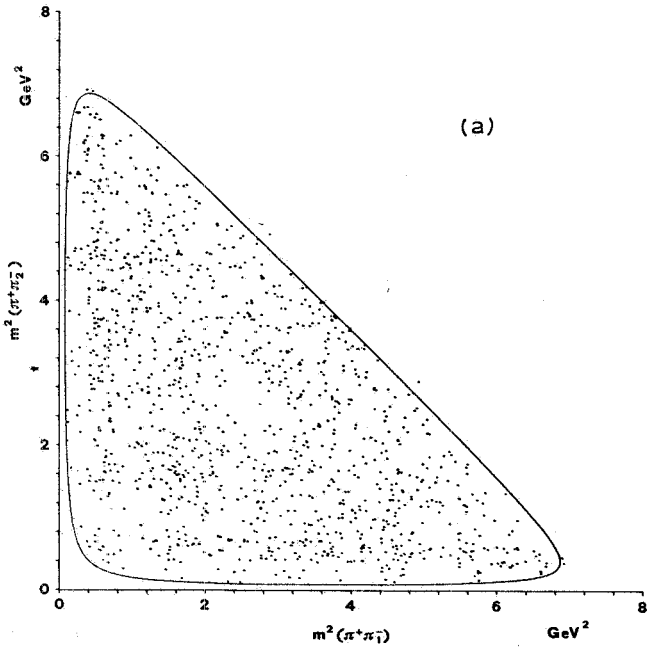

Fig. 4a. Dalitz plot for the events with cos α > 0.5 (2 × 610 entries).

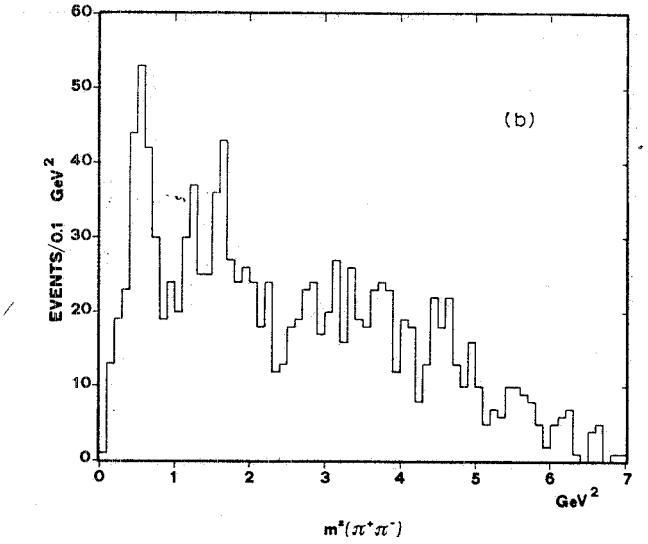

Fig. 4b. Invariant mass squared $\pi^+\pi^-$ for cos α > 0.5 (2 × 610 entries).

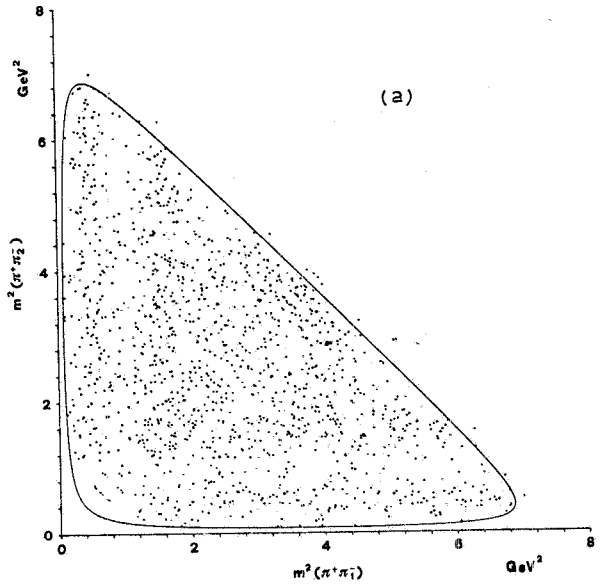

Fig. 5a. Dalitz plot for the events with $\cos\alpha < 0.5$ (2 X 710 entries).

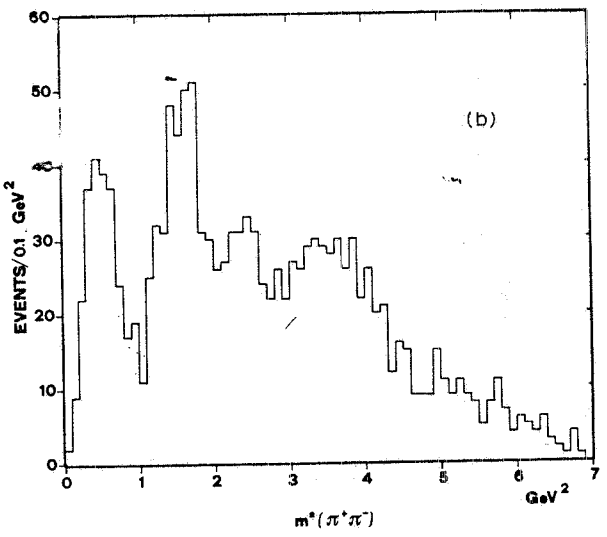

Fig. 5b. Invariant mass squared $\pi^+\pi^-$ for $\cos\alpha < 0.5$ (2 X 710 entries).

4. Angular distributions

Reaction (1) is completely defined in its centre of mass by five independent parameters. Two can be chosen as $m^2(\pi^+\pi_1^-)$ and $m^2(\pi^+\pi_2^-)$, the remaining three are angles. Due to the fact that both beam and target are not polarized, only two of these angles are significant. We then choose for the two remaining parameters the angle α between the direction of the incident $\bar{p}$ and the normal to the plane containing the three pion momenta and the angle β between the π^+ momentum and the projection of the $\bar{p}$ momentum on the three-pion plane.

Before discussing the angular distributions we note that in our reaction the final state in an eigenstate of the G-parity operator, while in the initial state $G|\bar{p}n\rangle = |n\bar{p}\rangle$ [6]. Therefore, all the angular distributions of the pions must be (and are in our data) symmetric under inversion of the $\bar{p}$ momentum. We, therefore, discuss in the

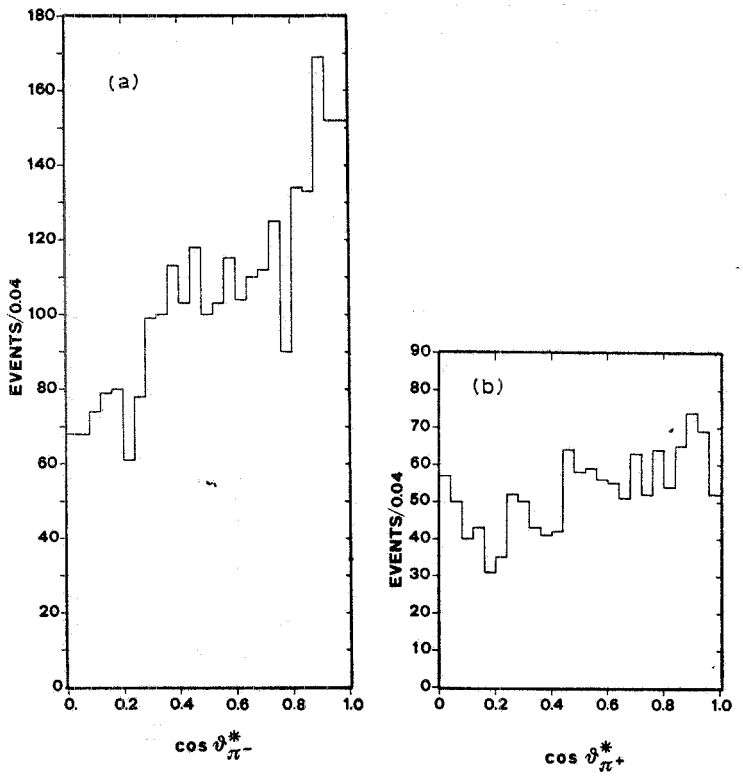

Fig. 6. (a) Distribution of cos $\theta^*_{\pi^-}$ between 0 and 1 (2 × 1320 entries). (b) Distribution of cos $\theta^*_{\pi^+}$ between 0 and 1 (1320 entries).

following only symmetrized distributions. The distributions of cos α between 0 and 1 and of β between 0° and 180° are shown in figs. 2 and 3, respectively. We have then studied the Dalitz plot and the squared mass spectra with different cuts in cos α and β. No clear correlation is evident for the Dalitz plot and its projections with the value of β. As for cos α, selecting events with cos $\alpha > 0.5$ and cos $\alpha < 0.5$ gives the Dalitz plots shown in figs. 4a and 5a, respectively.

The selection of large values of cos α enhances (in the limits of the reduced statistics) the depletion of events at the centre of the Dalitz plot. In the area of radius 0.4 GeV^2 centered at $m^2(\pi^+\pi_1^-) = m^2(\pi^+\pi_2^-) = 2.6$ GeV^2, only 2 events are found with cos $\alpha > 0.5$ against 17 with cos $\alpha < 0.5$. The same cut also has a marked effect in the mass projections: the peak at the f^0 mass almost completely disappears for cos $\alpha > 0.5$ (figs. 4b, 5b).

Another angular variable of physical interest is the c.m. angle, θ^*, of emission of the pions with respect to the $\bar{p}$ line of flight. The observed symmetrized distributions for cos $\theta^*_{\pi^-}$ and cos $\theta^*_{\pi^+}$ are shown in figs. 6a, b. The tendency for the pions to follow the $\bar{p}$ line of flight is more pronounced for the π^- than for the π^+.

A curve $1 - b + 3b \cos^2\theta^*_{\pi^\pm}$ fits the data with $b_- = 0.27 \pm 0.02$ and $b_+ = 0.18 \pm 0.03$ (C.L. 5% and 35%, respectively). There is a correlation between the angle of

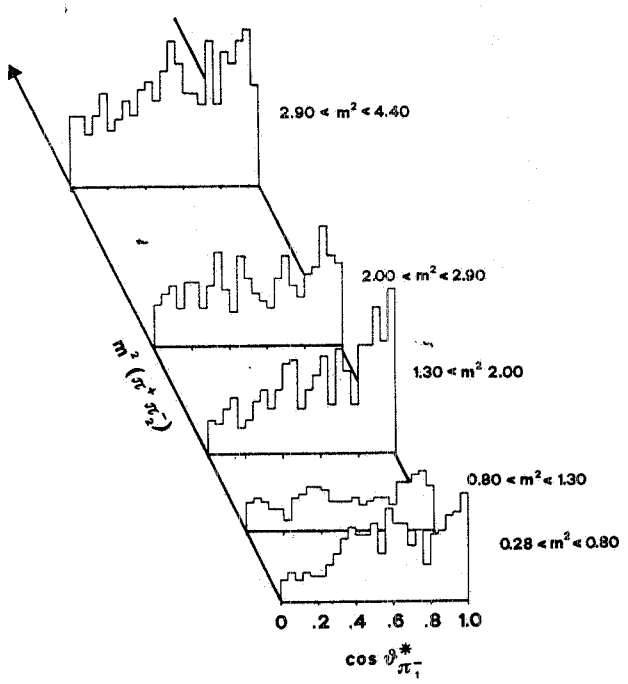

Fig. 7. Distribution of cos $\theta^*_{\pi_1^-}$ as a function of $m^2(\pi^+\pi_2^-)$.

emission $\theta^*_{\pi\bar{1}}$ of a negative pion, and the recoiling mass $m^2(\pi^+\pi_2^-)$. This is displayed in fig. 7 which gives the distribution of cos $\theta^*_{\pi\bar{1}}$ for different slices of $m^2(\pi^+\pi_2^-)$. The events in the ρ and f bands show a peaking along the collision line that is not present for events in the "valley" between these bands. For higher masses, the tendency to peak near cos $\theta^*_{\pi^-} = 1$ is still present but not so strong. This effect is clearly demonstrated also in figs. 8a, b where $m^2(\pi^+\pi_2^-)$ is plotted for cos $\theta^*_{\pi\bar{1}} > 0.5$ and cos $\theta^*_{\pi\bar{1}} < 0.5$. The peaks at the ρ and f masses are enhanced in fig. 8a, and practically absent in fig. 8b. A cut at higher values of cos $\theta^*_{\pi\bar{1}}$ also reduces the ρ peak as compared to that of the f.

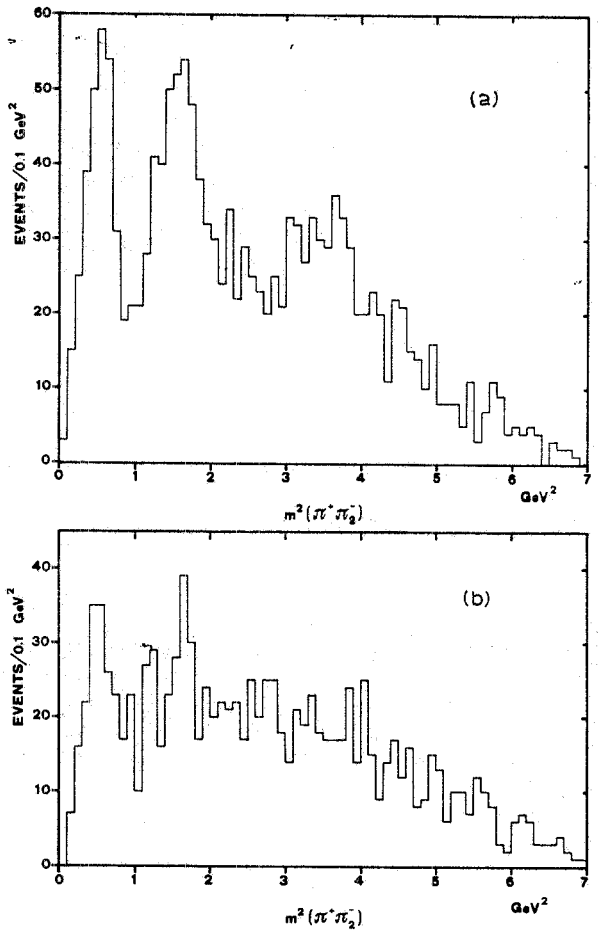

Fig. 8. (a) Invariant mass squared $\pi^+\pi_2^-$ for cos $\theta^*_{\pi\bar{1}} > 0.5$ (1542 entries), (b) for cos $\theta^*_{\pi\bar{1}} < 0.5$ (1098 entries).

5. Conclusions

We have analyzed the reaction $\bar{p}n \to \pi^+\pi^-\pi^-$ at 2.76 GeV total c.m. energy. At lower energies (1.88 and 2.2 GeV) a regular structure was observed in the Dalitz plot and interpreted as a general property of the meson → 3 mesons decay amplitude which was assumed to dominate the reaction [7,8]. This regular structure is not observed at our energy and this might be due to the onset of different amplitudes. The "hole" observed at rest at $m^2(\pi^+\pi_1^-) = m^2(\pi^+\pi_2^-) \simeq 1.1$ GeV is still present at our energy. A new depletion appears at $m^2(\pi^+\pi_1^-) = m^2(\pi^+\pi_2^-) \simeq 2.6$ GeV^2. This last effect is correlated with the orientation, with respect to the incident $\bar{p}$, of the 3-pion production plane.

Correlations are present between the angular distributions and the population of the Dalitz plot. In particular, a selection for high values of $\cos\theta^*_{\pi\bar{1}}$ enhances the peaks in the recoiling $m^2(\pi^+\pi_2^-)$ mass at the ρ and at the f positions.

We are pleased to acknowledge the efficient work of our scanning staff and of the measuring staff of the Padova PEPR and of the HPD at CNAF, Bologna. Dr. C. Pinori and Mr. G. Pasquali (Padova), Dr. N. De Seriis (Roma), Mr. F. Beccari and Mr. M. Mengotti (Trieste) contributed most of the necessary programming work. We are grateful to Dr. M.L. Luvisetto (CNAF) for her collaboration in the processing of the events measured on HPD.

References

[1] P. Anninos, L. Gray, P. Hagerty, T. Kalogeropoulos, S. Zenone, R. Bizzarri, G. Ciapetti, M. Gaspero, I. Laakso, S. Lichtman and G. Moneti, Phys. Rev. Lett. 20 (1968) 402.
[2] A. Bettini, M. Cresti, M. Mazzucato, L. Peruzzo, S. Sartori, G. Zumerle, M. Alston-Garnjost, R. Huesman, R. Ross, F.T. Solmitz, L. Bertanza, R. Carrara, R. Casali, P. Lariccia, R. Pazzi, G. Borreani, B. Quassiati, G. Rinaudo, M. Vigone and A. Werbrouck, Nuovo Cim. 1A (1971) 333.
[3] (a) S. Susinno, L. Votano, A. Bettini, M. Cresti, M. Mazzucato, L. Peruzzo, R. Rossi, G. Sartori, L. Ventura, G. Zumerle, L. Barone, R. Bizzarri, G. Ciapetti, C. Dionisi, P.F. Loverre, V. Rossi, E. Valente, E. Castelli, C. Omero, P. Poropat and M. Sessa, Antinucleon-nucleon interactions, ed. G. Ekspong and S. Nilsson (Wenner-Gren, 1976) vol. 29, p. 197.
(b) G. Susinno et al., presented at European Conf. on Particle physics, Budapest, July 1977.
[4] P.S. Eastman, Z. Ming Ma, B.Y. Oh, D.L. Parker, G.A. Smith and R.J. Sprafka, Nucl. Phys. B51 (1973) 29.
[5] R.J. Abrams, R.L. Cool, G. Giacomelli, T.F. Kycia, B.A. Leontic, K.K. Li and D.N. Michael, Phys. Rev. D1 (1970) 1917.
[6] E. Gold et al., University of Melbourne, preprint 76-34.
[7] C. Lovelace, Phys. Lett. 28B (1968) 264.
[8] R. Odorico, Phys. Lett. 33B (1970) 489.