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

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A B S T R A C T

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) in order to see if it was present the regular structure of zeroes in the Dalitz plot, suggested by measurements at lower energies. It is not so, except for the zero at $m^2(\pi^+\pi_1^-) = m^2(\pi^+\pi_2^-) \simeq 1.1$ GeV^2 which is observed also in present data. The Dalitz plot is anyhow rich of structures which appear to be correlated with the angular variables describing the reaction.

1. - INTRODUCTION

The reaction

$$\bar{p}n \to \pi^+\pi^-\pi^- \qquad (1)$$

has been found, at rest, by the Rome-Syracuse collaboration[1], to yield a peculiarly populated Dalitz Plot (D.P.). The main features of this D.P. are, in addition to two bands at about the ρ^0 and f^0 masses, a complete absence of events in an approximately circular region centred around $m^2(\pi^+\pi_1^-) = m^2(\pi^+\pi_2^-) \simeq 1.1$ GeV^2 and a maximum at $m^2(\pi^+\pi_1^-) = m^2(\pi^+\pi_2^-) \simeq 1.65$ GeV^2.

The same reaction has also been studied by the Berkeley-Padova-Pisa-Torino collaboration[2] at $\bar{p}$ momenta from 1.0 to 1.6 GeV/c where the total c.m.s. energy is increased to 2.08 ÷ 2.29 GeV. The D.P. shows similar hole and maximum in the same positions observed at rest. Furthermore a second hole appears along the diagonal of the plot at $m^2(\pi^+\pi_1^-) = m^2(\pi^+\pi_2^-) \simeq 2.17$ GeV^2, and two more are observed on either side of the diagonal, at $m^2(\pi^+\pi_1^-) \simeq 1.1$, $m^2(\pi^+\pi_2^-) \simeq 3.2$ GeV^2 and its symmetrical. The latter three holes fall near the contour of the D.P..

These holes and the maxima that separate them seem to fall at the vertices of a square lattice and are strongly suggestive of a regular behaviour.

To see whether such a regularity repeats itself at still higher energies, the present experiment has been carried out at 3 GeV/c.

The experimental method is described in Sect. 2. The D.P. of reaction (1) is discussed in Sect. 3, where the present data is compared with the previous measurements at lower energies. The more significant angular distributions and the effects on the D.P. of cuts on these angles are analysed in Sect. 4. In the last Section the present results are summarized.

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

2. - EXPERIMENTAL METHOD

The data comes from the analysis of ~ 400 K pictures from the 2m DBC exposed to a separated beam of antiprotons of 2.98 GeV/c momentum from the CERN PS. The magnetic field of the chamber was 1.7 T.

All the 3-prong events from this film (~190K) have been measured. About 2/3 of the events have been measured on the Padova PEPR operated in zone guidance. The remaining 1/3 has been measured on the HPD of CNAF(+) operated in road guidance.

The events have been reconstructed using the CERN program THRESH (mass-dependent). About 13% of the events failed to be successfully measured or reconstructed after the second measurement. This sample did not show any significant bias and therefore was not remeasured.

On each event a kinematical fit has been performed using the CERN program GRIND. In the final state there is always an unseen spectator proton (p_s) which has been treated as a measured track with all three cartesian components of momentum equal to zero with suitable errors.

1513 events gave a fit to the hypothesis:

$$\bar{p}d \rightarrow p_s \pi^+ \pi^- \pi^-$$

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

The reconstructed momentum of the proton has a spectrum in agreement with the expected behaviour. Considering only events with $P(\chi^2) > 0.02$ and beam fitted momentum between 2.910 and 3.050 GeV/c a sample of 1415 events has been obtained.

Some of these events gave a fit to more than one hypothesis. The 4c - 1c ambiguity between the $\pi^+\pi^-\pi^-$ and $\pi^+\pi^-\pi^-\pi^0$ hypothesis has been always solved in favour of the 4c hypothesis. The ambiguity with the 4c hypothesis $K^+K^-\pi^-$ has been solved in favour of the hypothesis with the largest value of $P(\chi^2)$. The final sample consists of 1320 events.

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The three charged prong cross-section obtained from our data is 12.5 ± 0.4 mb, in good agreement with previous measurements of P.S. Eastman et al. at 2.9 GeV/c [4]. The frequency of reaction (1) is 0.90% of this cross-section.

3. - DALITZ PLOT

The resulting symmetrized D.P. and its projections on the $m^2(\pi^+\pi^-)$ and $m^2(\pi^-\pi^-)$ axis are shown in Fig. 1 (a,b,c). The resolution on the invariant squared mass is of the order of 2% over the whole range.

A hole is apparent at $m_1^2 = m_2^2 \simeq 1.1$ GeV^2 (where $m_1^2 = m^2(\pi^+\pi_1^-)$, $m_2^2 = m^2(\pi^+\pi_2^-)$), very similar in position and dimension to those observed at lower momenta [1,2]. A depletion of events is also noticeable around $m_1^2 = m_2^2 \simeq 2.6$ GeV^2, but this structure is quite different from the hole observed at $m_1^2 = m_2^2 \simeq 2.2$ GeV^2 in Ref. 2, being wider, less pronounced and centred at higher m_1^2 and m_2^2 values. There is also a strong depletion of events in the bands $m_{2,1}^2 \simeq 0.8$ GeV^2, $m_{1,2}^2 > 5$ GeV^2. Accumulations of events are noticeable in the two bands about the ρ° and f° masses and also in the region $m_1^2 = m_2^2 \simeq 3.65$ GeV^2, near the kinematical limit of the D.P..

The distribution of $m^2(\pi^+\pi^-)$ reflects these structures: two peaks are evident, the first at $m \simeq 0.73$ GeV with a poorly defined Breit-Wigner width of about 0.20 GeV, somewhat lower and wider than the ρ°, the second at $m \simeq 1.26$ GeV with $\Gamma \simeq 0.18$ GeV at the f° position. A third broad bump appears at $m \simeq 1.9$ GeV, corresponding to no established mesonic state. This bump reflects the accumulation of events on the diagonal of the D.P. at the same mass. No enhancement at the g meson mass is observed.

A comparison of the results of Ref. 1 and 2 suggested that the main features of the D.P. could be determined by the values of m_1 and m_2, regardless of the incident energy. Present data do not support this assumption since the features observed in Ref. 2, and in particular the holes at $m_{1,2}^2 \simeq 1$ GeV^2, $m_{2,1}^2 \simeq 3.2$ GeV^2, do not appear in the present D.P. with any statistical significance. The only structures of the D.P. which appear to persist regardless of the total energy are therefore the hole at $m_1^2 = m_2^2 \simeq 1.1$ GeV^2 and the accumulation at $m_1^2 = m_2^2 \simeq 1.65$ GeV^2.

4. - ANGULAR DISTRIBUTIONS

Reaction (1) is completely defined by 5 independent variables which reduce to 4 making allowance for the overall azimuthal symmetry since beam and target are unpolarized. Two of these variables are $m^2(\pi^+\pi_1^-)$ and $m^2(\pi^+\pi_2^-)$ which describe the D.P.; to these we can add two more independent angular variables which are suitably defined in the c.m.s.. Before discussing the angular distributions we remark that in our reaction the final state is an eigenstate of the G-parity operator, while in the initial state $G\,|\bar{p}n> = |\,n\bar{p}>$. Therefore all the angular distributions of the pions must be symmetric under inversion of the $\bar{p}$ momentum[5]. We have checked that this is true for our data and we shall further discuss only symmetrized distributions.

A possible choice for the angular variables is the angle α between the normal to the plane containing the three pions and the direction of the incident $\bar{p}$, and the angle β between the projection of the $\bar{p}$ momentum on the plane containing the three pions and the π^+ momentum. The distributions of $\cos\alpha$ between 0 and 1 and β between 0° and 180° are shown in Fig. 2 and 3 respectively. We have investigated if these angular variables are correlated with the D.P. structures, examining the D.P. and the squared mass spectra with different cuts in $\cos\alpha$ and β. The latter has no clear correlation with the D.P. and its projections. As for $\cos\alpha$, selecting events with $\cos\alpha > 0.5$ and $\cos\alpha < 0.5$ gives the D.P. shown in Fig. 4a and 5a respectively.

The selection of large values of $\cos\alpha$ strongly enhances the depletion of events at the centre of the D.P.. In an area of diameter 0.8 GeV^2 centred at $m_1^2 = m_2^2 = 2.6$ GeV^2 only 2 events are found with $\cos\alpha > 0.5$ against 17 with $\cos\alpha < 0.5$. The same cut has a marked effect also in the mass projections: the peak at the f° mass almost completely disappears for $\cos\alpha > 0.5$ (Fig. 4b).

A different angular variable of physical interest is the 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, 6b. There is a preference for the pions to follow the $\bar{p}$ line of flight more pronounced for π^- than for π^+.

A curve $1 - b_{\pm} + 3\, b_{\pm} \cos^2\theta^{*}_{\pi^{\pm}}$ represents well the data with $b_- = 0.27 \pm 0.02$ and $b_+ = 0.18 \pm 0.03$. There is a correlation between the angle of emission $\theta^{*}_{\pi^-_1}$ of a negative pion, and the recoiling mass $m^2(\pi^+\pi^-_2)$. This is displayed in Fig. 7 which gives the distribution of $\cos\theta^{*}_{\pi^-_1}$ for different slices of m^2_2. The events in the "ρ" and more so in the f band show a peaking along the collision line in the centre of mass while the same cannot be said for the events in the "valley" in between these two bands. For higher masses, the trend to peak near $\cos\theta^{*}_{\pi^-_1} = 1$ is still present but not so strong. This effect is clearly demonstrated also in Figs. 8a and 8b where m^2_2 is plotted for $\cos\theta^{*}_{\pi^-_1} > 0.5$ and $\cos\theta^{*}_{\pi^-_1} < 0.5$. The peaks at the ρ and f masses are strongly enhanced in Fig. 8a, while practically disappear in Fig. 8b. A cut at higher values of $\cos\theta^{*}_{\pi^-_1}$ would reduce also the ρ peak as compared to f.

5. - CONCLUSION

We have analysed 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 of zeroes was observed in the D.P. and interpreted as a general property of the meson → 3 mesons decay amplitude which was assumed to dominate the reaction[6,7]. This regular structure is not observed at our energy and this might be due to the onset of different amplitudes. It is however remarkable the persistence of the zero at $m^2_1 = m^2_2 \simeq 1.1$ GeV^2 and the appearance of a new depletion at $m^2_1 = m^2_2 \simeq 2.6$ GeV^2. This last effect is correlated with the orientation with respect of the incident $\bar{p}$ of the 3-pions production plane.

Correlations are present between the angular distributions and the population of the D.P.. In particular a selection for high values of $\cos\theta^{*}_{\pi^-_1}$ strongly enhances the peaks in the recoiling $m(\pi^+\pi^-_2)$ mass at the ρ and mostly at the f positions.

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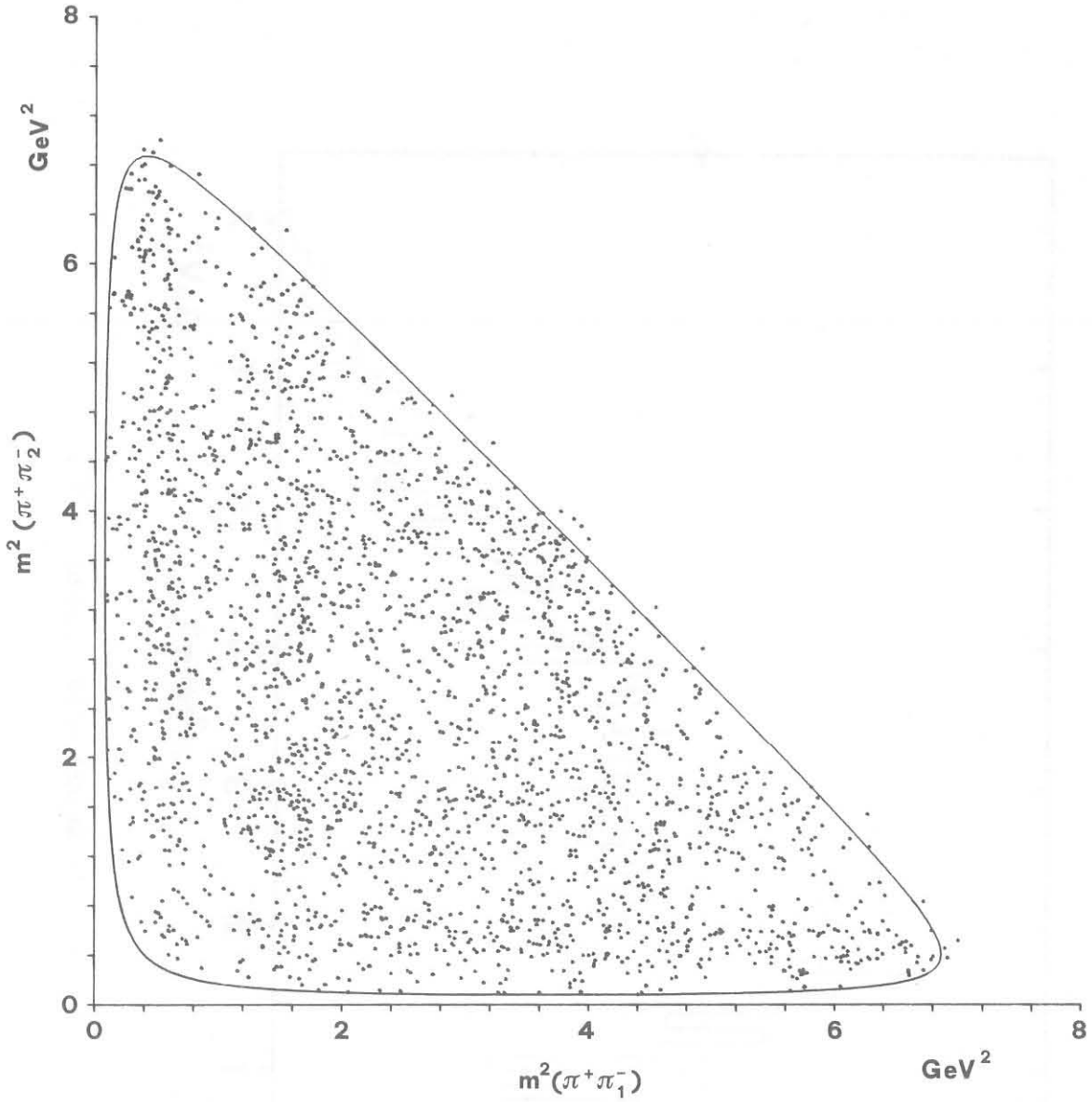

Fig. 1a - Dalitz plot for the 1320 events $\bar{p}n \to \pi^+\pi^-\pi^-$ at 3 GeV/c (2640 combinations).

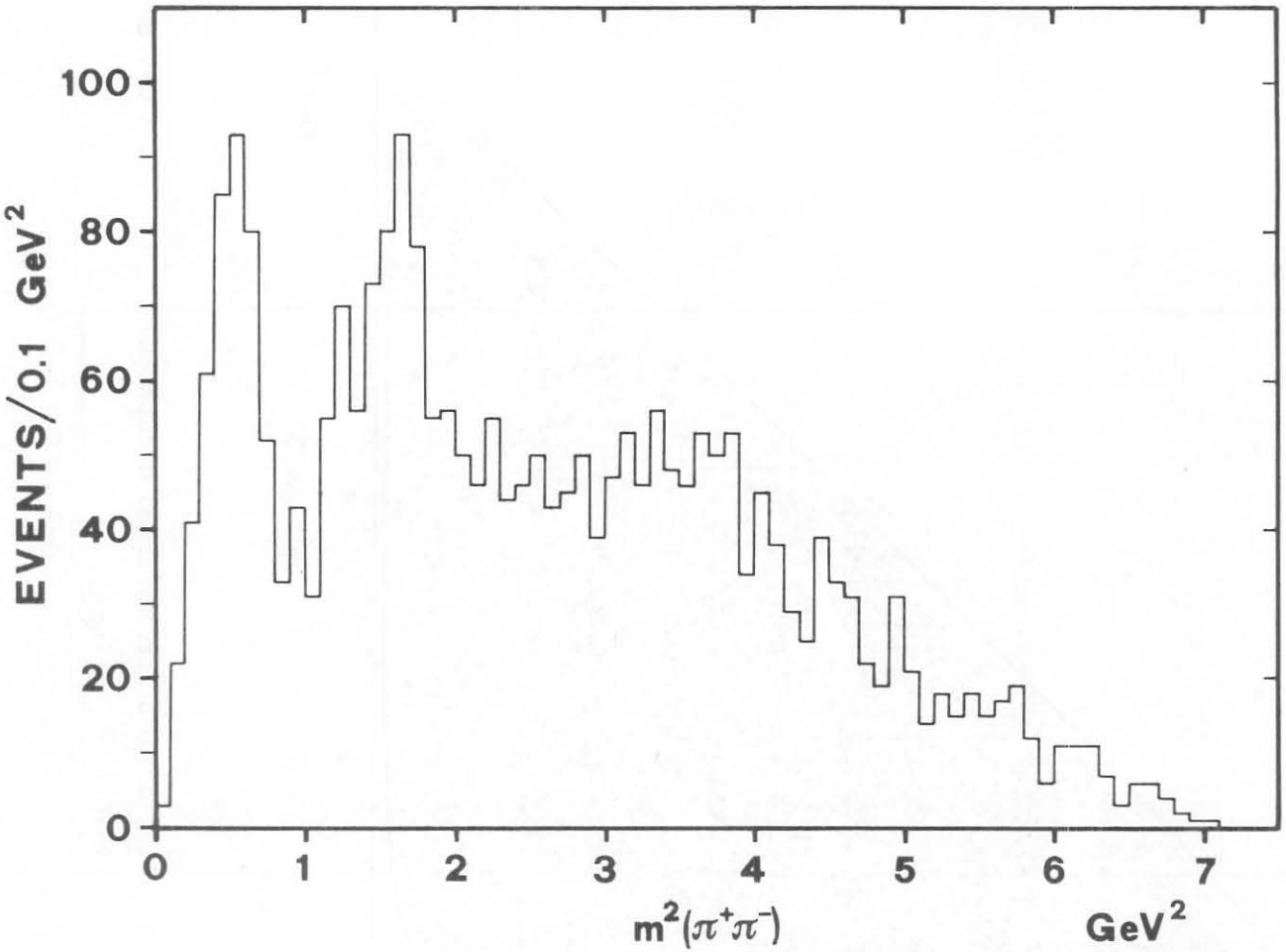

Fig. 1b - Invariant mass squared $\pi^+\pi^-$.

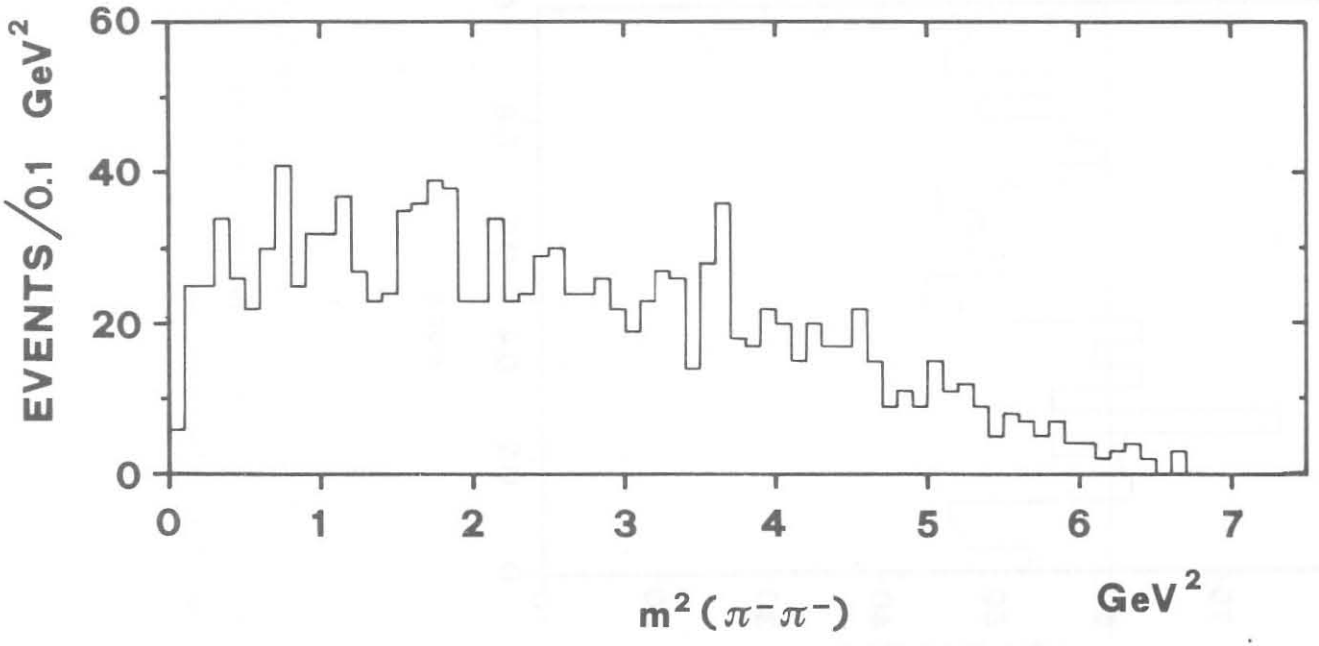

Fig. 1c - Invariant mass squared $\pi^-\pi^-$.

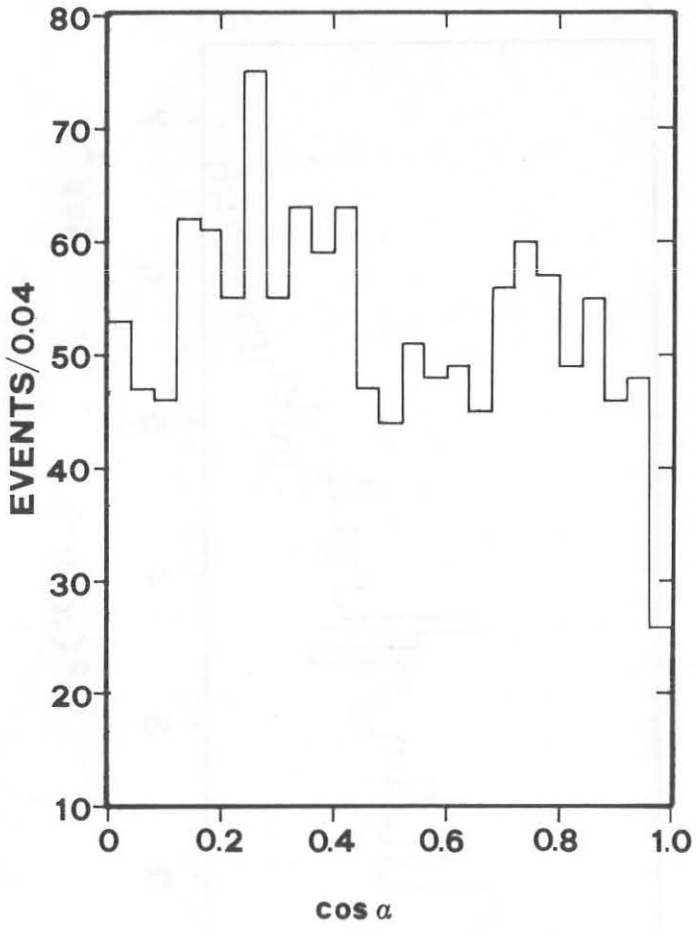

Fig. 2 - Distribution of cosα between 0 and 1. α is the angle between the normal to the plane containing the three pions and the direction of the incident $\bar{p}$.

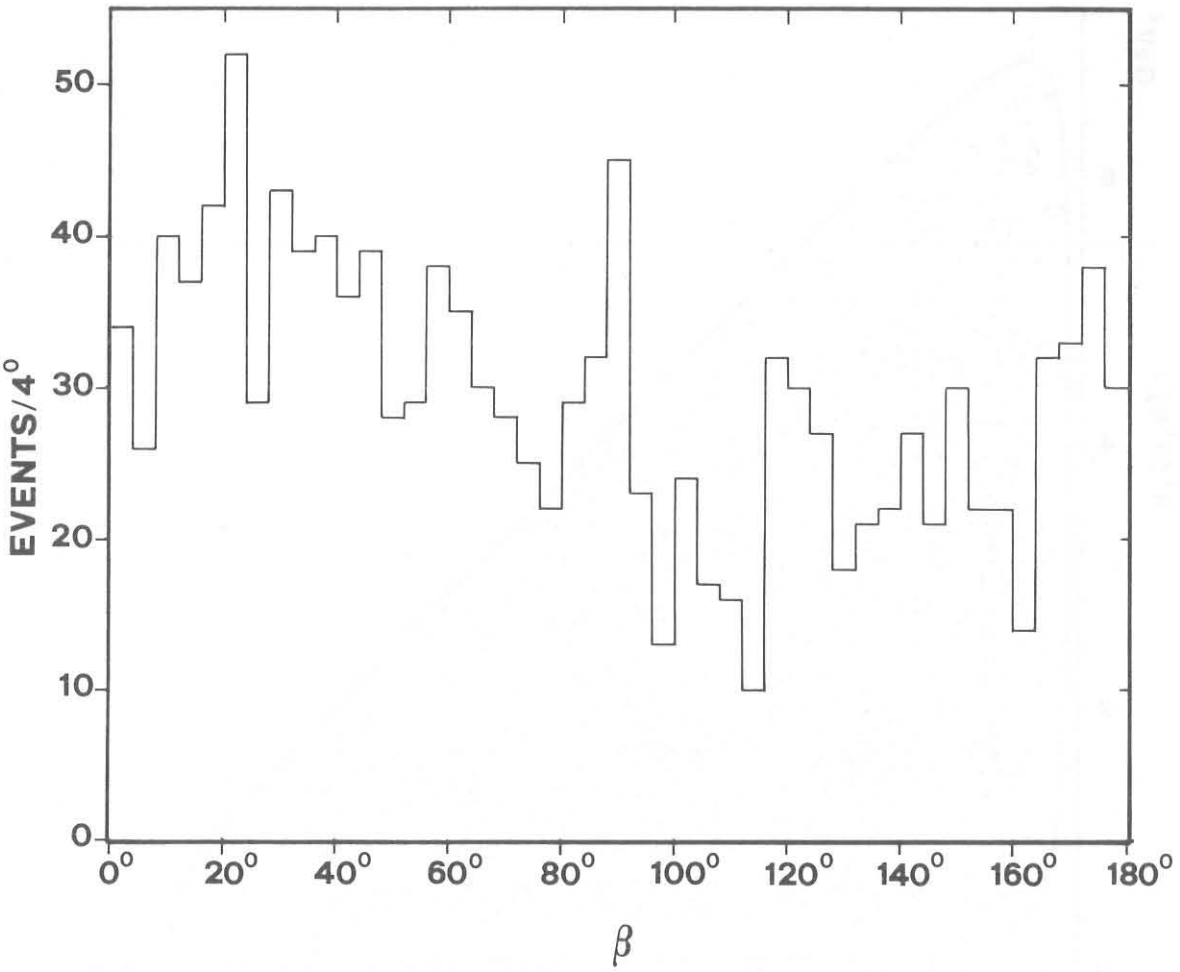

Fig. 3 - Distribution of β between 0° and 180°. β is the angle between the projection of the $\bar{p}$ momentum on the plane containing the three pions and the π^+ momentum.

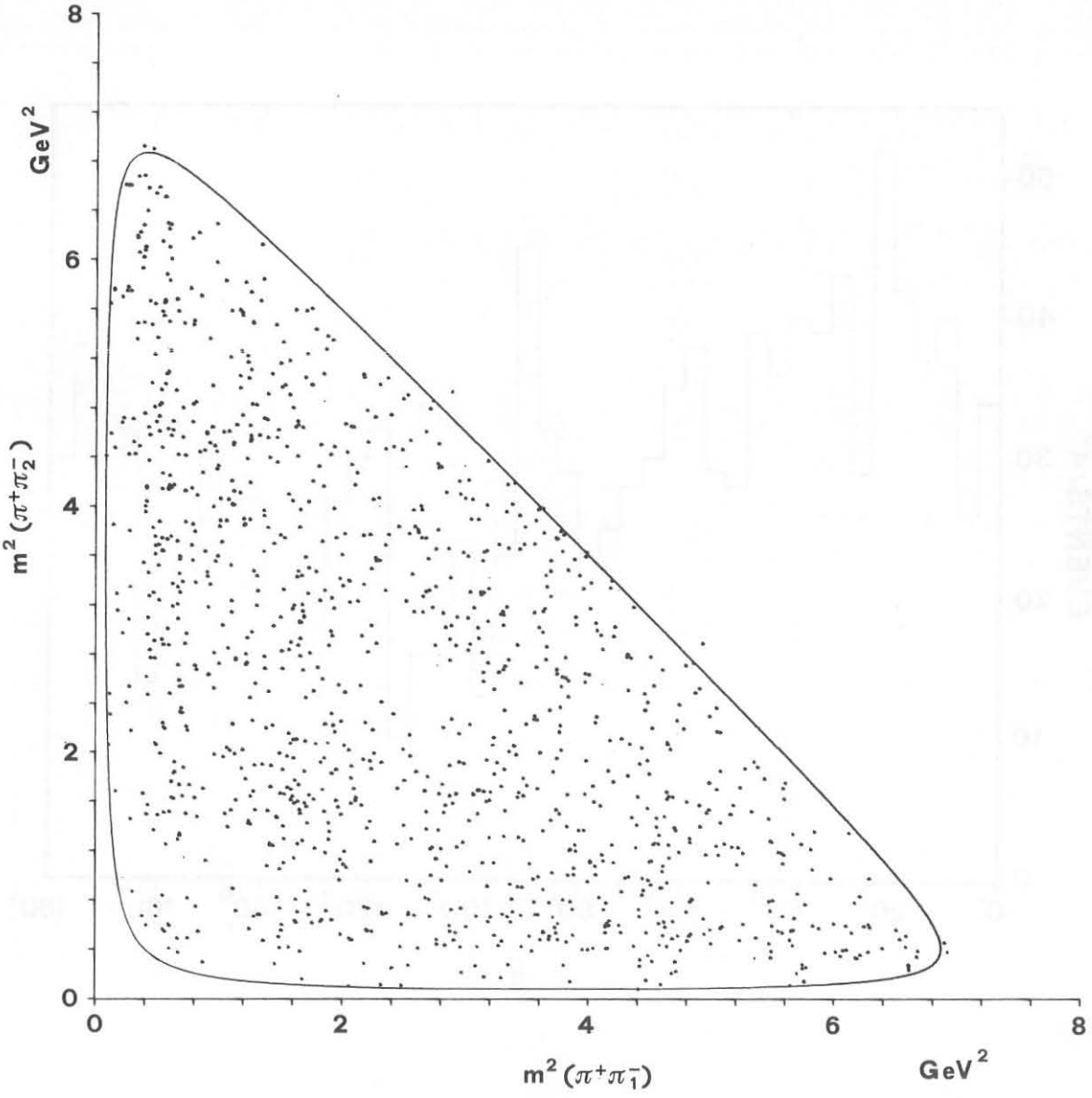

Fig. 4a - Dalitz plot for the events with $\cos\alpha > 0.5$ (1220 combinations).

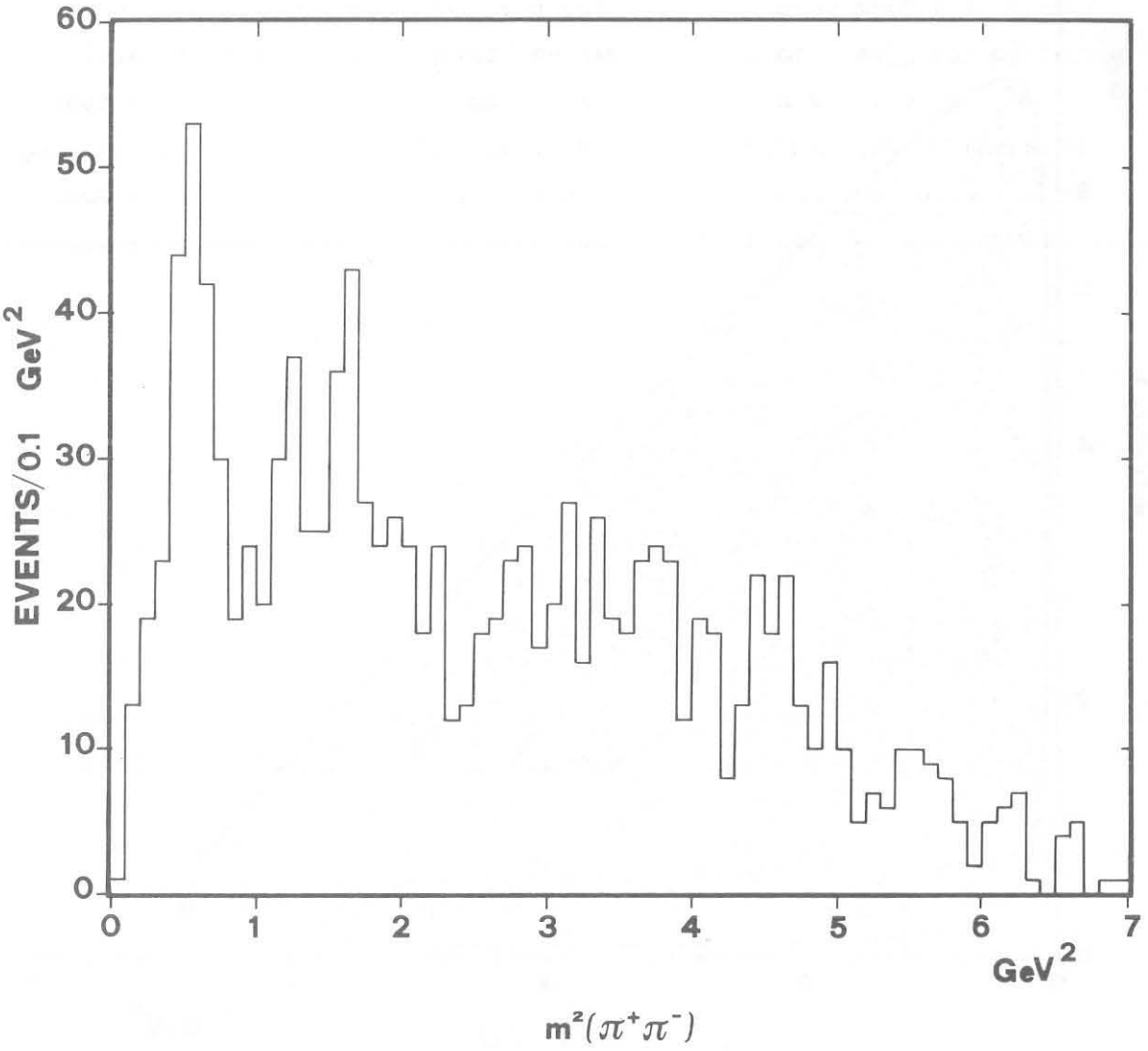

Fig. 4b - Invariant mass squared $\pi^+\pi^-$ for $\cos\alpha > 0.5$.

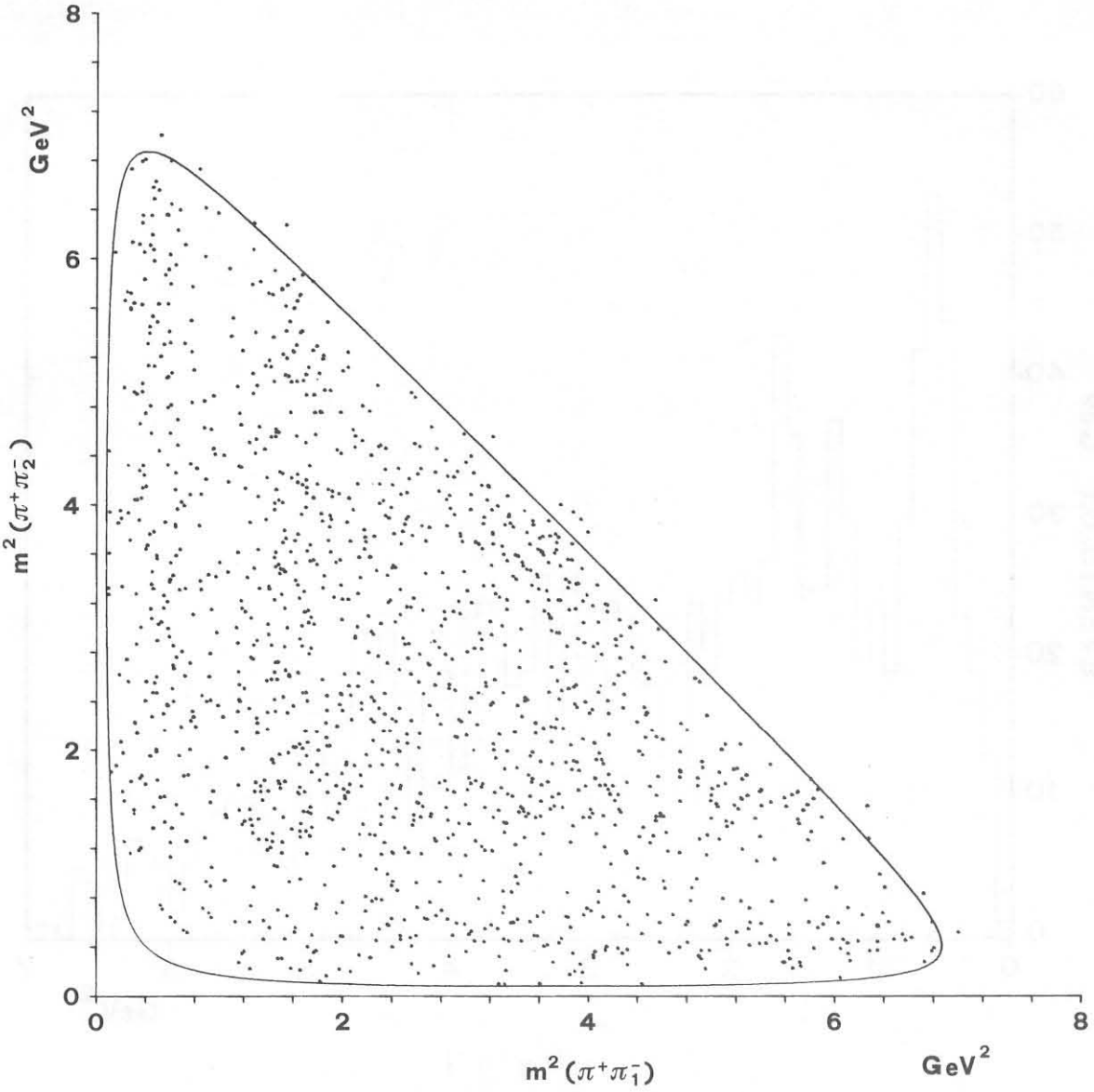

Fig. 5a - Dalitz plot for the events with $\cos\alpha < 0.5$ (1420 combinations).

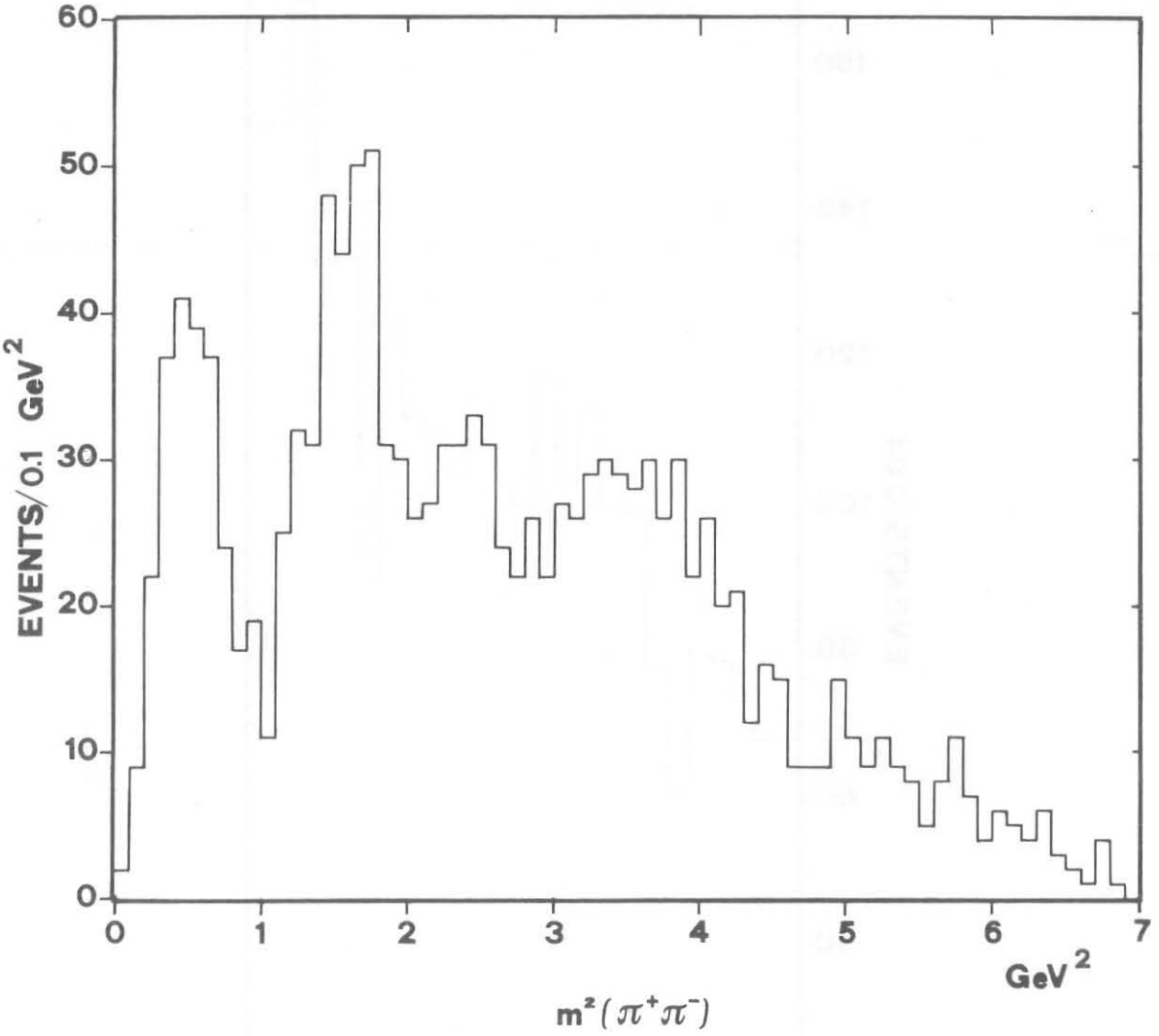

Fig. 5b - Invariant mass squared $\pi^+\pi^-$ for $\cos\alpha < 0.5$.

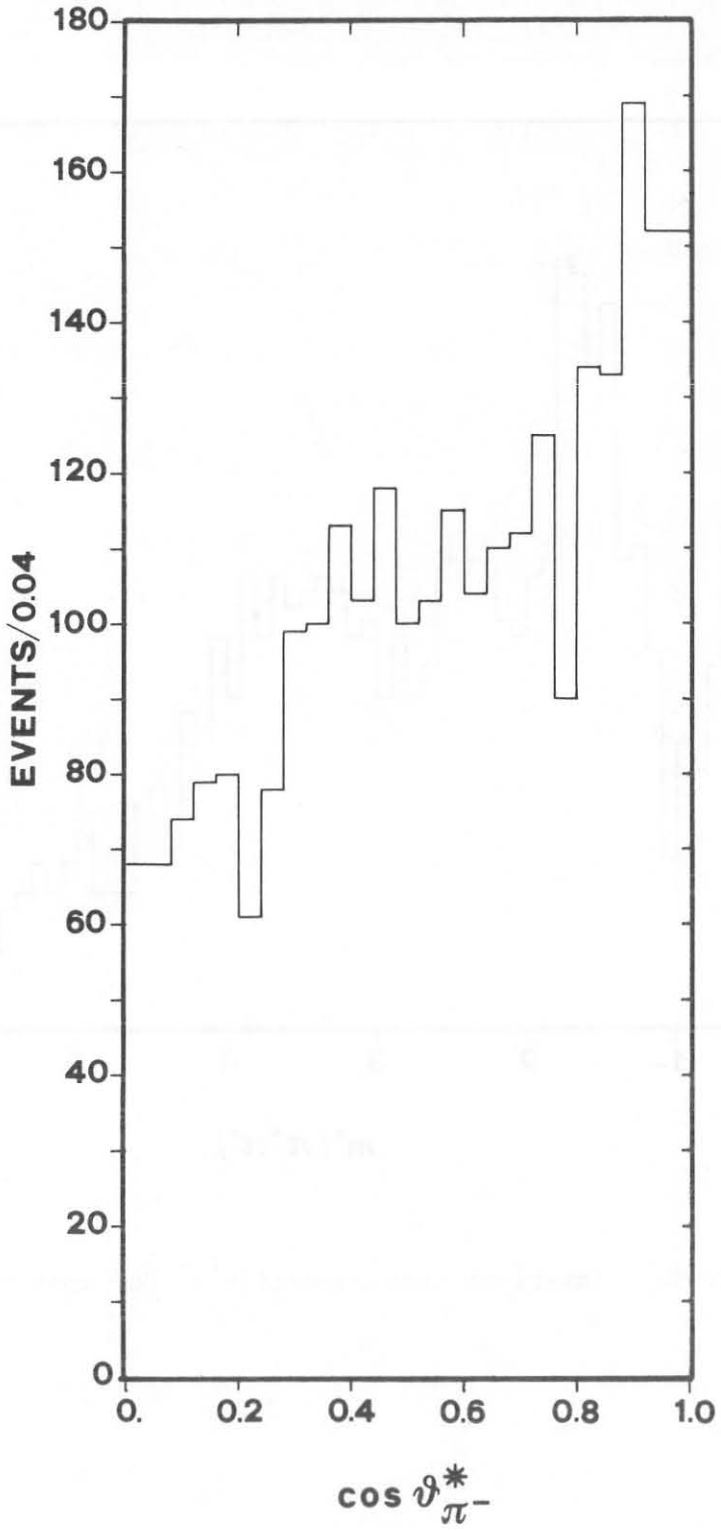

Fig. 6a - Distribution of $\cos\theta^*_{\pi^-}$ between 0 and 1 (2640 entries).

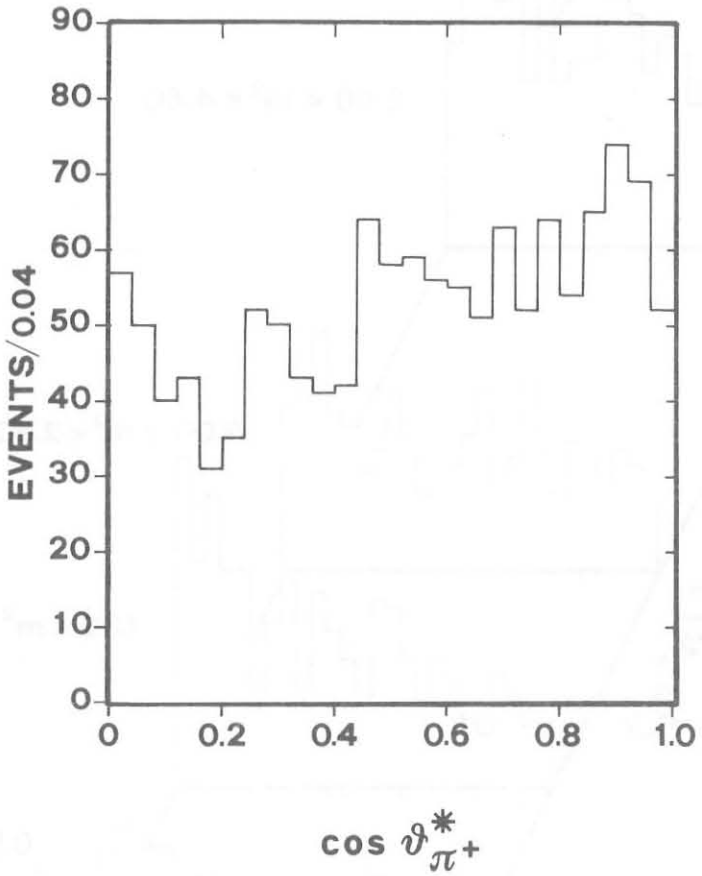

Fig. 6b - Distribution of $\cos\theta^*_{\pi^+}$ between 0 and 1 (1320 entries).

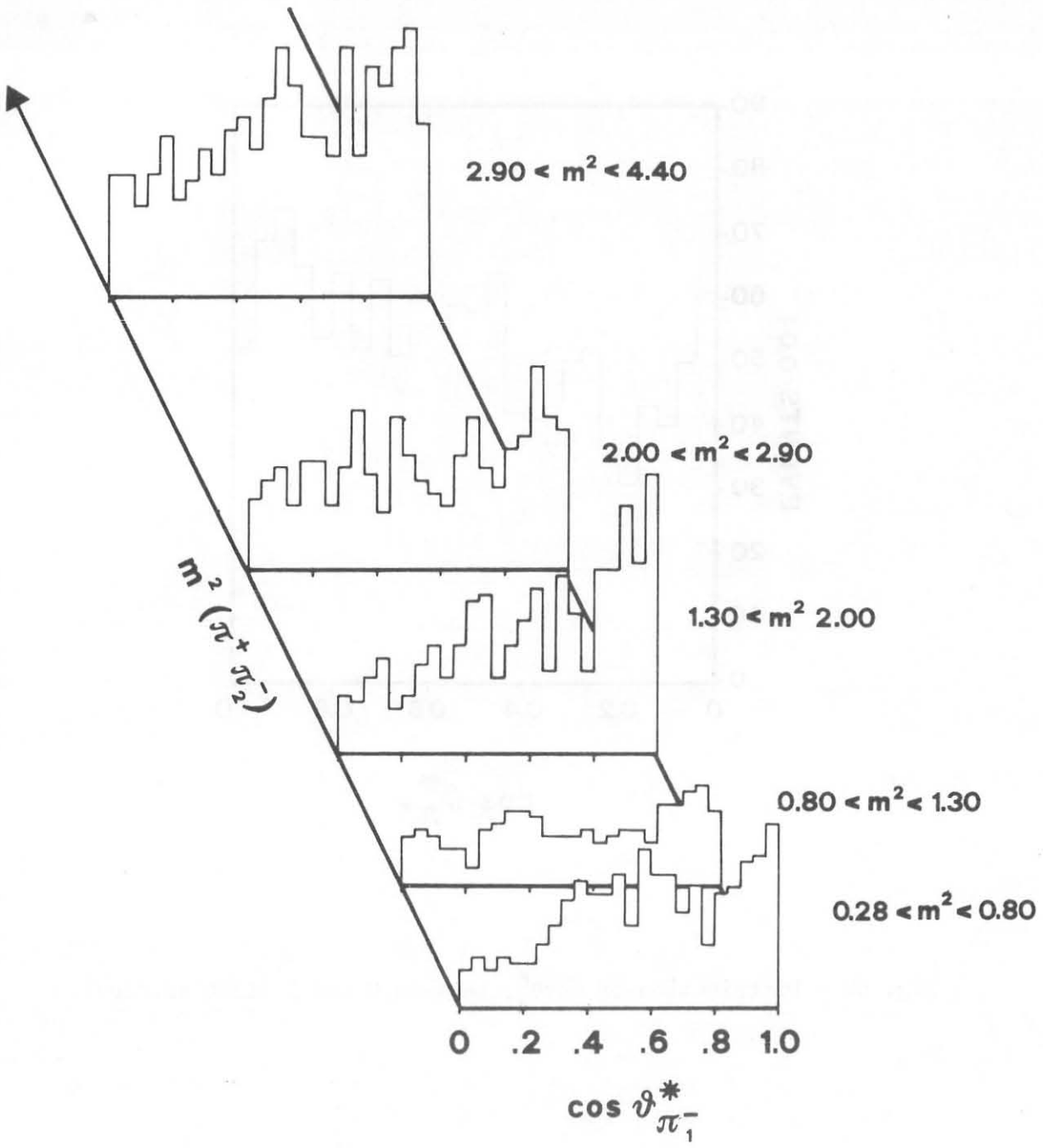

Fig. 7 - Distribution of $\cos\theta^{*}_{\pi^-_1}$ as a function of $m^2(\pi^+\pi^-_2)$.

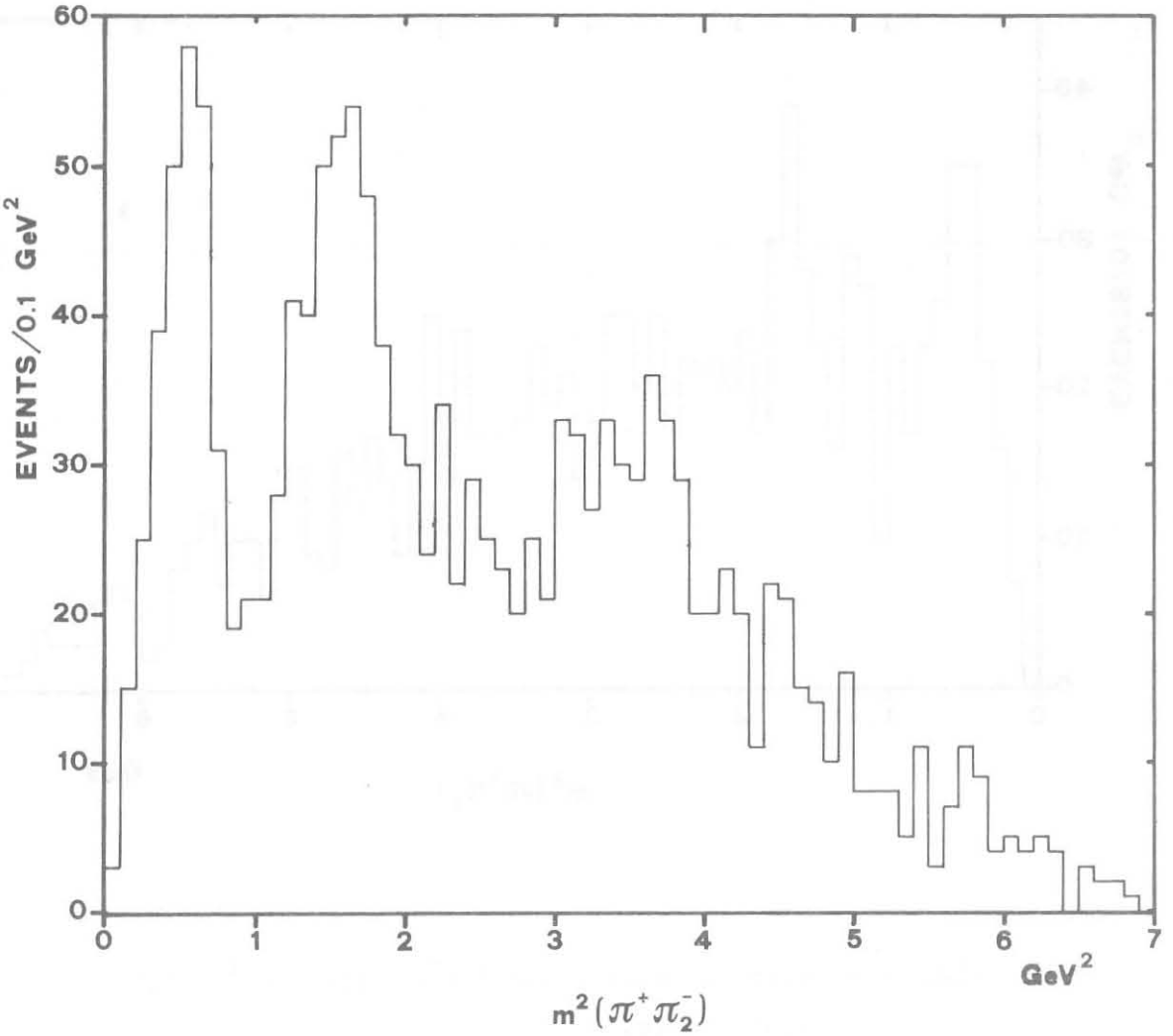

Fig. 8a - Invariant mass squared $\pi^+\pi_2^-$ for $\cos\theta^*_{\pi_1^-} > 0.5$ (1542 entries).

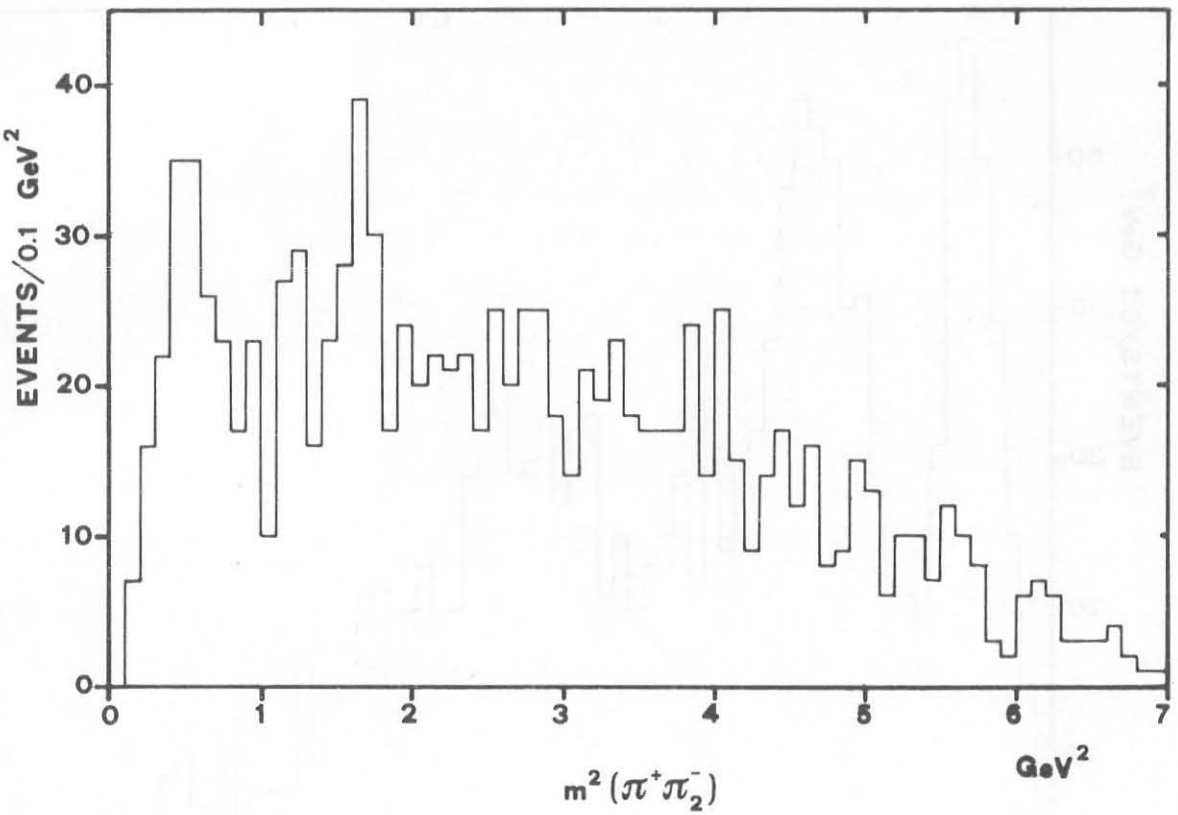

Fig. 8b - Invariant mass squared $\pi^+\pi_2^-$ for $\cos\theta^*_{\pi_1^-} < 0.5$ (1098 entries).