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(Nota interna n. 235)

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R. Del Fabbro, M. De Pretis, R. Jones(*), G. Marini(+), A. Odian(x), G. Stoppini(+) and L. Tau(+): TWO-BODY EFFECTIVE MASS SPECTRA IN THE PRODUCTS OF THE REACTION $\gamma + p \rightarrow p + \pi^+ + \pi^-$.
(Submitted to Phys. Rev. Letters)

We report here the preliminary results of an experiment on the reaction

(1) $$\gamma + p \rightarrow p + \pi^+ + \pi^- ,$$

in which we have measured the (π^+,π^-) invariant mass spectrum, in the interval from 280 to 600 MeV, at a fixed proton laboratory angle of 35°. Our data may be interpreted as indicating a resonance of the (π^+,π^-) system at a total center-of-mass energy of 379±4 MeV with a full width at half maximum of 139±13 MeV.

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The experimental apparatus is shown in fig.1. The photon beam of the Frascati electronsynchrotron operated at 1000 MeV, was collimated into a 1 cm diameter spot to strike a liquid hydrogen target 1 cm in length. Protons emitted at $35\pm3°$ in the momentum interval from 346 to 455 MeV/c are detected by a thin plate spark chamber followed by a "range" spark chamber made up of 25 aluminum plates 1 mm in thickness[1].

In addition to this we determine the direction of the two pions by letting each traverse a system of two spark chambers. The positions of these were chosen so as to select, with reasonably flat geometrical efficiency, total centre of mass energies of the $\pi-\pi$ system within the interval from roughly 280 to 600 MeV. As a consequence of this, the accepted production angles of the $\pi-\pi$ system in the c.m. of the reaction ranged from 45° to 90°. Fig.1 also shows 8 scintillators (viewed by 56 AVP phototubes) which establish a fast time coincidence of the three particles and also reject some of the spurious events by means of a final anticoincidence on the proton side. A further experimental check to filter out the background was the measurement of the proton pulse height in counter 3P. Another was the measurement of the proton time of flight, obtained by displaying pulses from counters 1P and 3P on a fast oscilloscope. A marked separation in time and pulse height was found between protons and other particles.

Multiple scattering of the three final particles and γ-ray conversion were kept to a minimum i) by making the outher jacket wall of the hydrogen target with aluminum 0.5 mm thick; ii) by using 2 mm thick scintillator for counters 1,2,3,4 and 1P and iii) by constructing the first spark chamber in each branch with five 0.07 mm aluminum foil plates. The spark chambers, filled with commercial He, were operated with a clearing field of 75 volts/cm and triggered by pressurized nitrogen spark gaps. The total delay time was about 200 nsec. Under these conditions the measured efficiency per gap was more than 85% for tracks with angles up to 30° with respect to the electric field direction.

The coordinates of the three particles in the six spark chambers constitute the input data for an analysis made on an IBM 1620 computer. The first operation of the program is a least square fit to find the reaction point within our target. The results of this analysis are shown in fig. 2a. Most of the points cluster very well within the known target dimensions and a criterion for getting rid of background was introduced on this basis.

The spatial directions of the particles, together with the proton momentum, overdetermine by one the kinematical parameters of the reaction. We chose this additional parameter to be the π_1 and π_2 masses, assumed equal, i.e. the known value of the pion mass μ is not used in the data analysis, but is left as a free parameter to be calculated by the computer. Fig. 2b shows the spectrum of values obtained for μ. Another criterion for selecting events was decided on this basis, taking into account the calculated resolution function. The low amount of background outside the peak assures us that the contamination due to three pion photoproduction is less than 2%. We find that most of the events with wrong masses have also erratic source points. Of a total of 1315 events in which there was at least one trace in each spark chamber, 1037 passed our selection criteria.

The (π^+,π^-) effective mass spectrum is shown in figure 3a; in fig. 4 we show the (π,p) effective mass spectrum, which is actually the sum of the (π^+,p) and (π^-,p) spectra, as we are unable to distinguish the charge of the pions. As a starting point for a discussion of our data, we compared these spectra with the invariant phase space factor normalized to the same number of events. To obtain this factor we made a Montecarlo calculation which takes into account the bremsstrahlung, spectrum. Folded into the calculation was the resolution curve of our detection system, which we had obtained by another Montecarlo(2). The data are not is agreement with the curves.

As seen in fig. 4, we are investigating a kinematical region of our process where the contribution of the 3/2, 3/2 pion-nucleon isobar is not negligible. This contribution is taken into account by the Cutkowsky and Zachariasen model(3) (abbreviated CZ). This model predicts(4) correctly the total cross sections for the reaction (1) as measured by Chasan et al.(5). The next step of our analysis was therefore the comparison of our data with this model(6). While it is in reasonable agreement in the case of the (π,p) sepctrum, it fails in the case of the (π^+,π^-) spectrum. Fig. 5a shows the Dalitz-Fabri plot of all the events. The distribution of the points is another confirmation of the fact that the anomaly cannot be ascribed to the effect of the 3/2, 3/2 nucleon isobar.

The invariant matrix element squared, as a function of the (π^+,π^-) mass, is shown in fig. 3b. There is a broad but clear peak around $m_{\pi\pi}$ =380 MeV. To our knowledge there is no obvious interpretation of this fact, even from a qualitative standpoint. There seem to be two possible explanations: the first, which we cannot exclude with the present set of data, is connected with the fact, shown in figure 5b, that there exists in our experiment a narrow correlation between the $m_{\pi\pi}$ value and the energy, k, of the photon initiating the reaction[7]. The explanation would then be that photons with energies around 610 MeV excite the nucleon to an isobar which then decays emitting two pions. The isobar mass would be 1420 MeV; some indication for this has probably been found by Cocconi et al.[8] and by Bareyre et al.[9]. The second possible interpretation is that of assuming a strong $\pi - \pi$ final state interaction. Following this line, we conclude that the $\pi - \pi$ invariant scattering amplitude shows a maximum, probably connected with a resonance of which however this experiment does not allow a spin and isospin assignment. On the other hand, as the dipion energy is fairly low, it is not unreasonable to assume that the resonant state has J=0. Assuming this to be the case, we tried to fit the data introducing, as an enhancement factor, an invariant pion-pion scattering amplitude squared given by the following S-wave resonance formula:

$$|T|^2 = \frac{\beta^2}{(W^2-W_0^2)^2+\beta^2 q^2/W^2}$$

This corresponds to the effective-range equation

$$(q/W)\cot\delta = (1/\beta)\ (W_0^2-W^2) \quad ,$$

where $W=m_{\pi\pi}$, $q=(W^2/4-\mu^2)^{1/2}$, and β and W_0 are two adjustable parameters. The fitting procedure takes into account the finite resolution of our detection system and determines also the unknown faction α due to the contribution of other processes, as described by the CZ model. We find that in 23% of the cases the reaction goes through these processes and in 77% of the cases through the resonant state. We find χ^2_{min} = 20 where 23 is expected. The fit, shown in fig. 3, gives

$$\begin{aligned} &W_0=379\pm4 \text{ MeV} \\ (2) \qquad &\Gamma=\frac{b}{2W_0}\left[1-\left(\frac{2\mu}{W_0}\right)^2\right]^{1/2}=139\pm13 \text{ MeV}, \\ &\alpha=0.23\pm0.04, \end{aligned}$$

where Γ is the full width at half maximum.

In the above procedure we have assumed that when the J=0 state is produced the amplitude for process (1) differs from a constant only because of the final state interaction between the two pions. A more rigorous procedure necessitates the proper symmetrization of the two pion final state wave function[10]. This symmetrization effect can be approximately taken into account by introducing in the phase space the factor $1+\exp[-4q^2(R/2.15)^2]$, where R is the radius of the interaction volume. We have repeated the above calculations for $R/(\hbar/\mu c)=0.5$, 0.75 and 1.0 but the values (2) do not change appreciably.

Fig. 6 shows the experimental distribution of cos θ^*, where θ^* is the angle in the dipion rest system between one pion and the dipion flight direction. The data are in agreement with the 23%-77% mixture of CZ model and S-wave resonance, in accordance with our hypothesis of J=0.

As stated above, the recoil proton is emitted at a laboratory angle of 35° in the momentum interval from 346 to 455 MeV/c. An average over this interval gives a photoproduction cross-section for the resonant state which, in the c.m. of reaction (1), has the values $\sim 2\times10^{-30}$ cm^2/ster.

Analysing the products of (π^-,p) collisions at 4.7 GeV/c, Samios et al.[11] found some evidence for (π^+,π^-) resonances with I=0 or 1 and with masses 395 and 520 MeV. Further anomalies near $m_{\pi\pi}$ =400 MeV have been found in the I=0 or 2 states by Richardson et al.[12] in $(\pi^\pm,d)$ collisions at 1.23 GeV/c. On the contrary no resonances in this mass region were observed by Alff et al.[13] in the products of (π^+,p) collisions for incident pion momenta of 2.34, 2.62 and 2.90 GeV/c.

Kirz, Schwarz and Tripp[14] have measured spectra of (π^+,π^-) masses by using secondary pions of the process $\pi^-+p\to\pi^++\pi^-+n$. They were able to prove that a peak exists in the case of the I=0 pion-pion state. Unfortunately, the position of the peak changes with the kinetic energy of the incident pions in the interval 360-780 MeV. In this energy interval the effect of the lowest pion-nucleon isobar is predominant, but an analysis due to Olsson and Yodh(15) shows that the observed anomaly is not completely ascribable to the isobar effect. It may be worth noticing that, while Kirz et al. observe for each (π^+,π^-) mass the total cross-section of the production process, the detected dipions in our experiment are emitted between 45° and 90° in the c.m. of the reaction.

A pion-pion resonance with I=J=0 and mass around 400 MeV (σ resonance) has been assumed by Brown and Singer(16) to explain the energy spectra and decay branching ratios of the η and K mesons. Following this line, Crawford et al.(17) are able to fit the π^o energy spectrum from the $\eta \to \pi^+ + \pi^- + \pi^0$ decay with m_σ=381 MeV and Γ_σ=48 MeV. More recently Nishijima(18) was able to evaluate the K_1-K_2 mass difference by introducing the same resonance.

In conclusion, the interpretation of our data in terms of a $\pi - \pi$ resonance with I=J=0 is the simplest and is consistent with theoretical calculations and other experimental evidence, but more experimental work has to be done to clarify the picture completely.

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(1) - The momentum error due to the finite thickness of the plates is less than 5 MeV/c. The nuclear absorption alters the range-momentum correlation only in 4% of the events.

(2) - The Montecarlo for the resolution includes the effects of scattering of the particles in the target, counters and spark chambers, and also the error in the position of the sparks. The results of the Montecarlo for the phase space factor have been checked by comparing them with the results of a direct integration.

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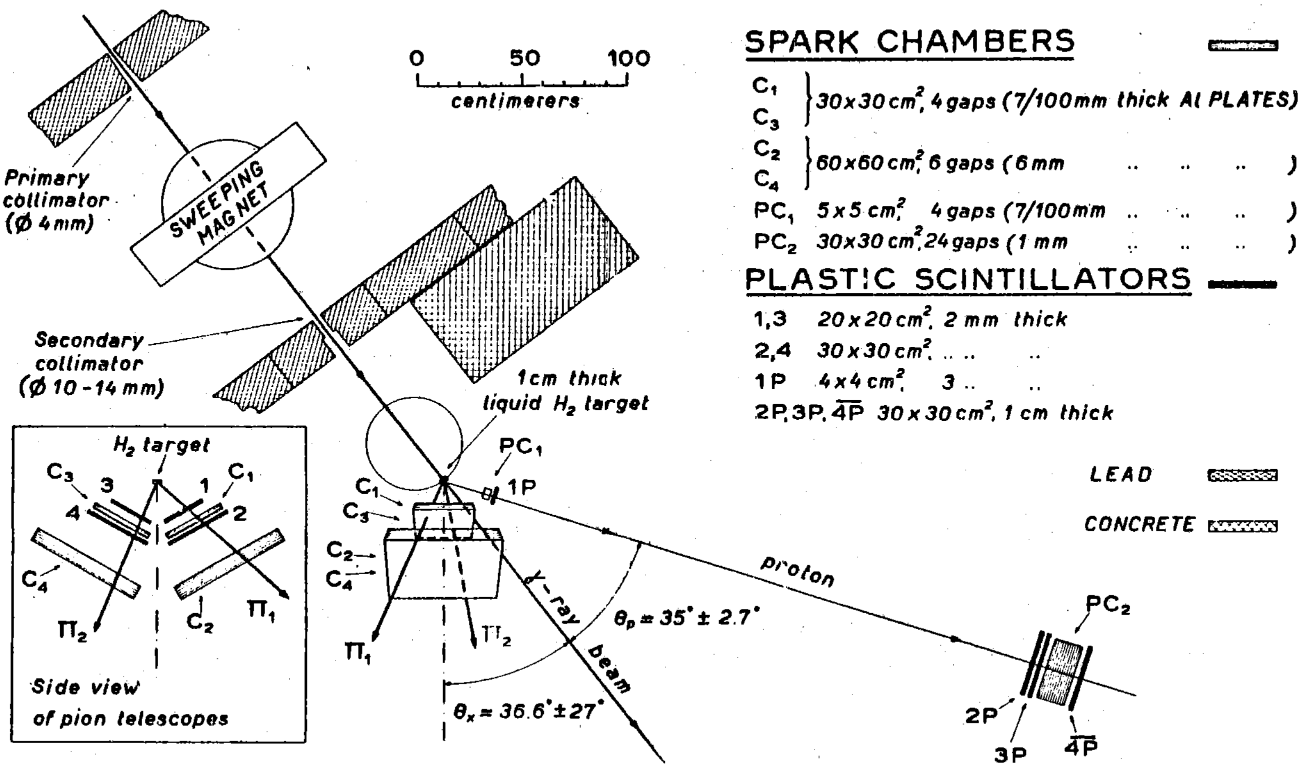

FIG. 1 - A drawing of the experimental apparatus.

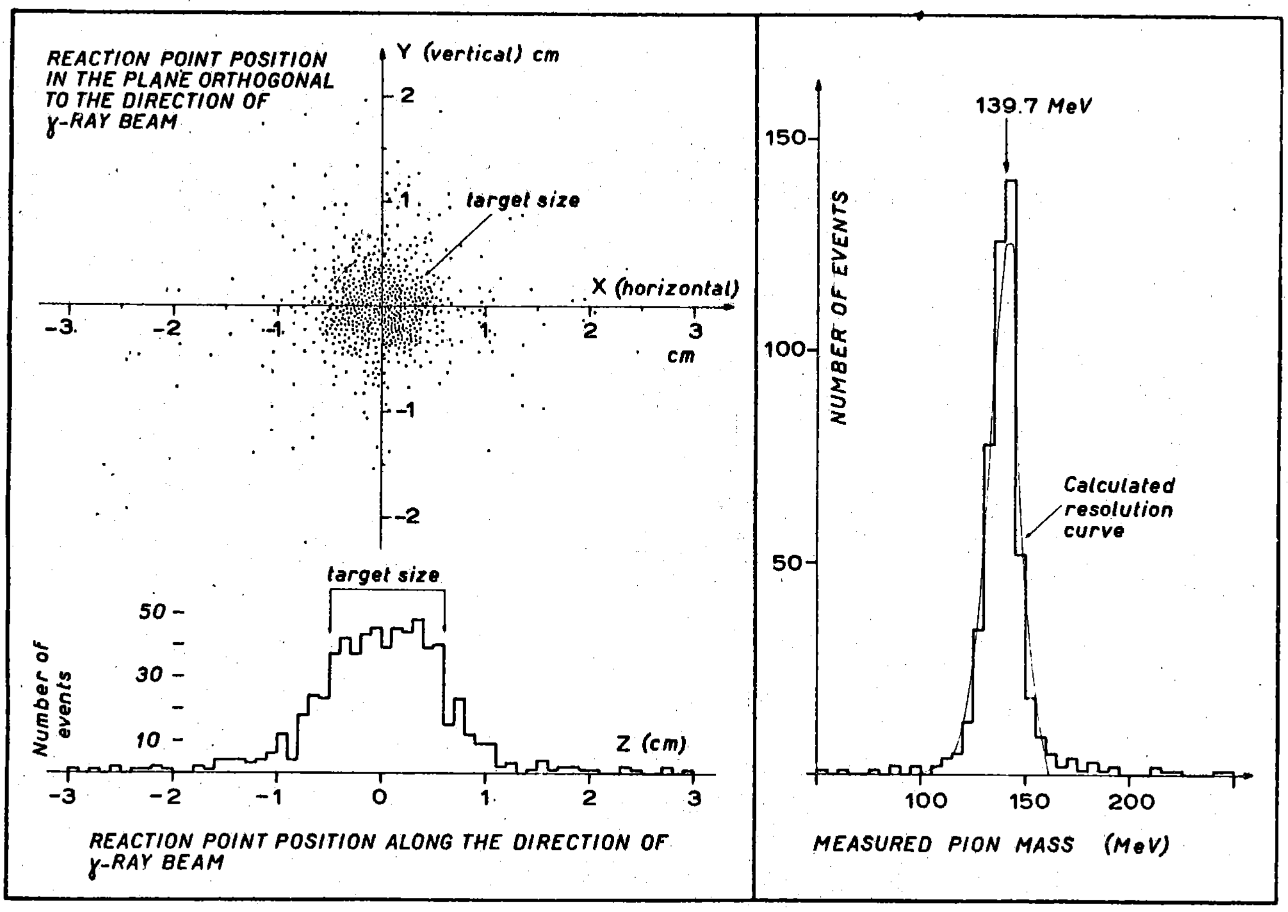

FIG. 2 - (a) shows the distribution of the reaction points;
(b) shows the spectrum of the measured pion masses.

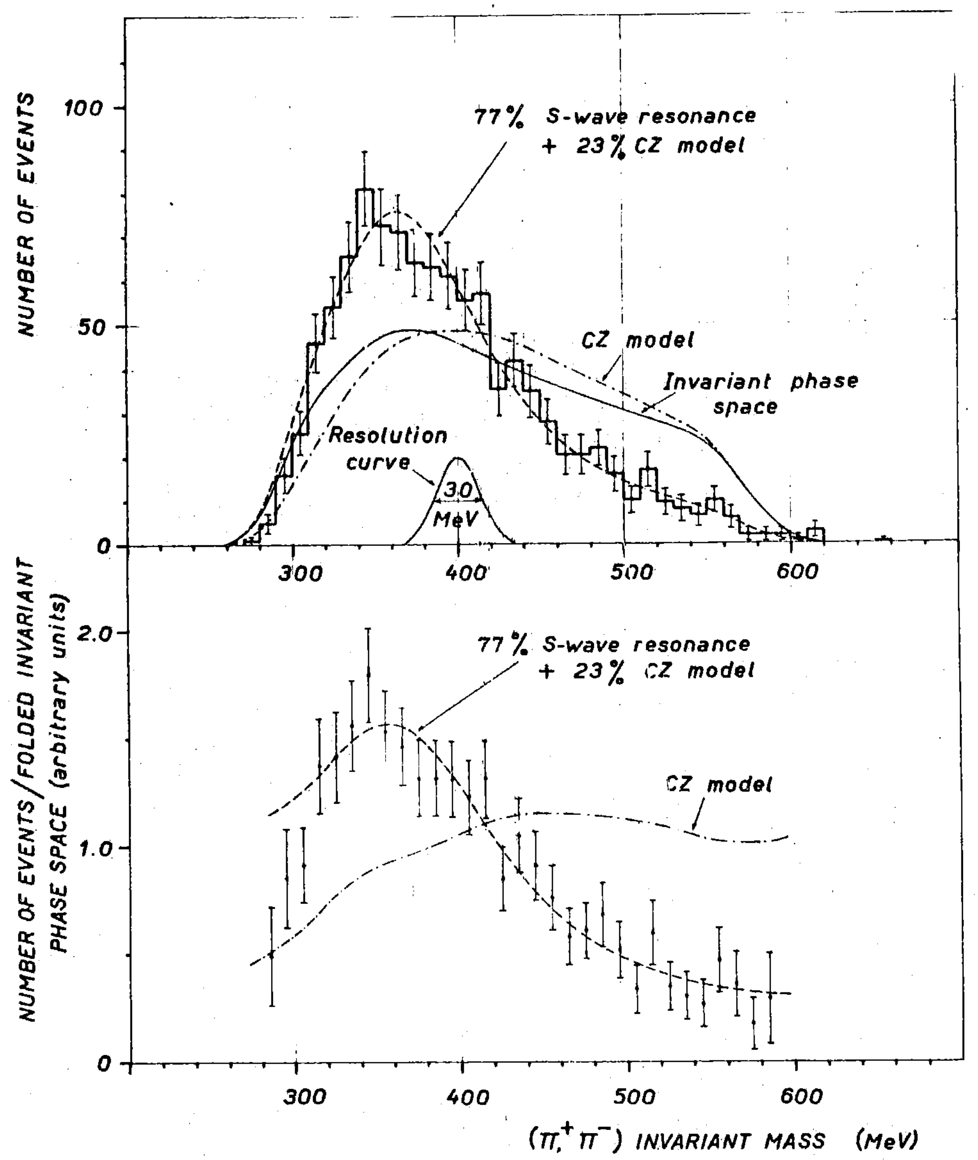

FIG. 3 - (π^+, π^-) effective mass spectrum: (a) shows the experimental data and (b) the invariant matrix element squared. The gaussian curve is the calculated resolution function; its width is a constant over the full mass interval.

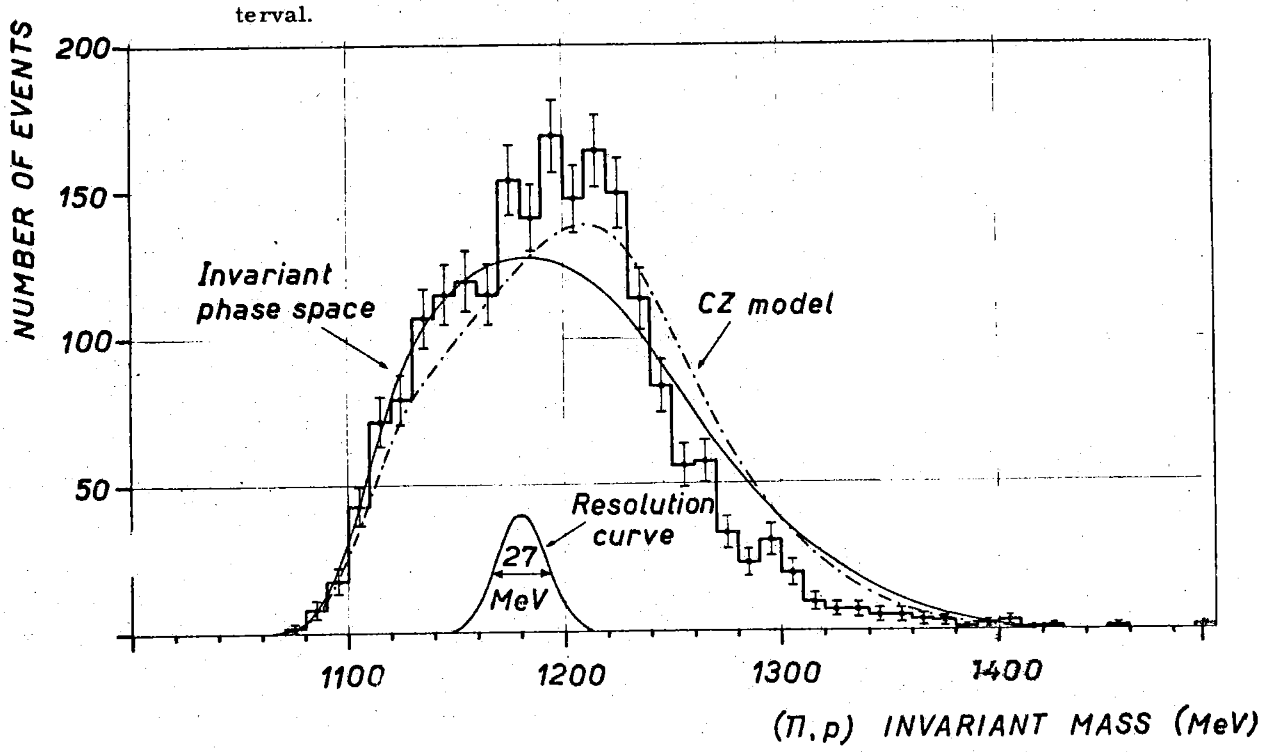

FIG. 4 - Sum of the (π^+, p) and (π^-, p) effective mass spectra. The gaussian curve is the calculated resolution function; its width is a constant over the full mass interval.

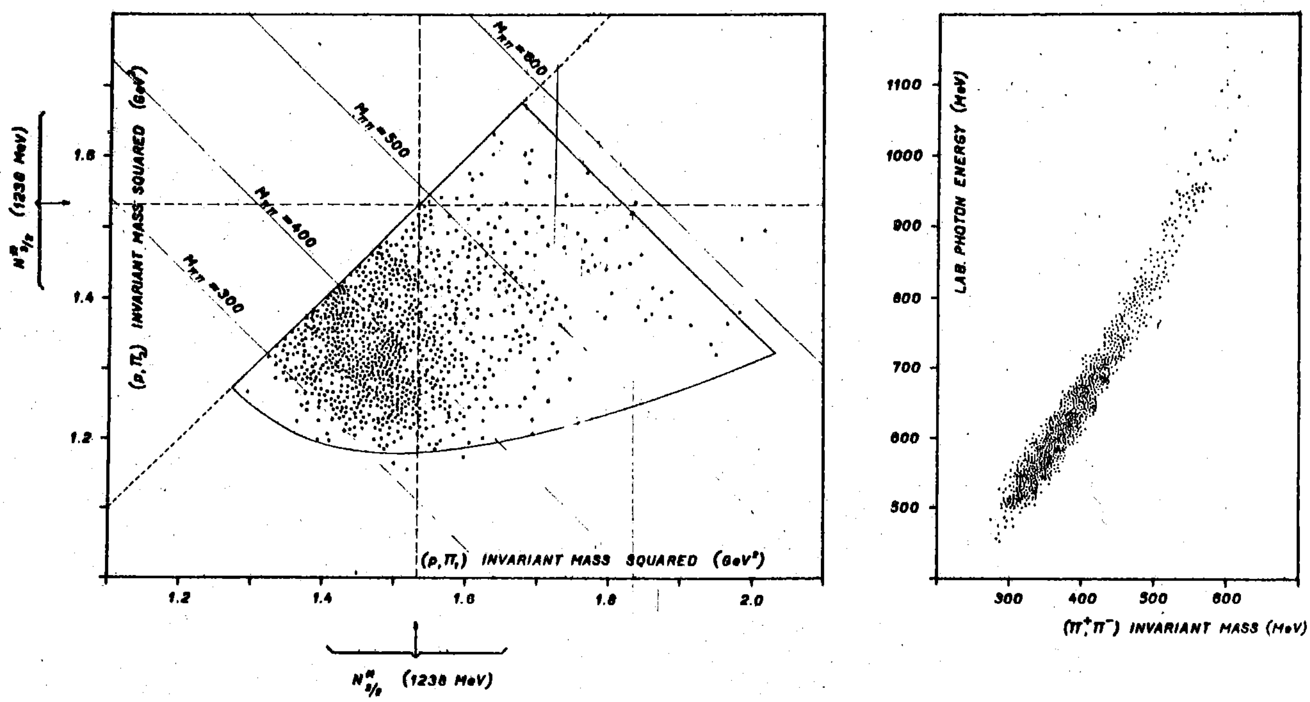

FIG. 5 - (a) shows the Dalitz-Fabri plot; (b) shows the correlation between the laboratory photon energy and the dipion effective mass.

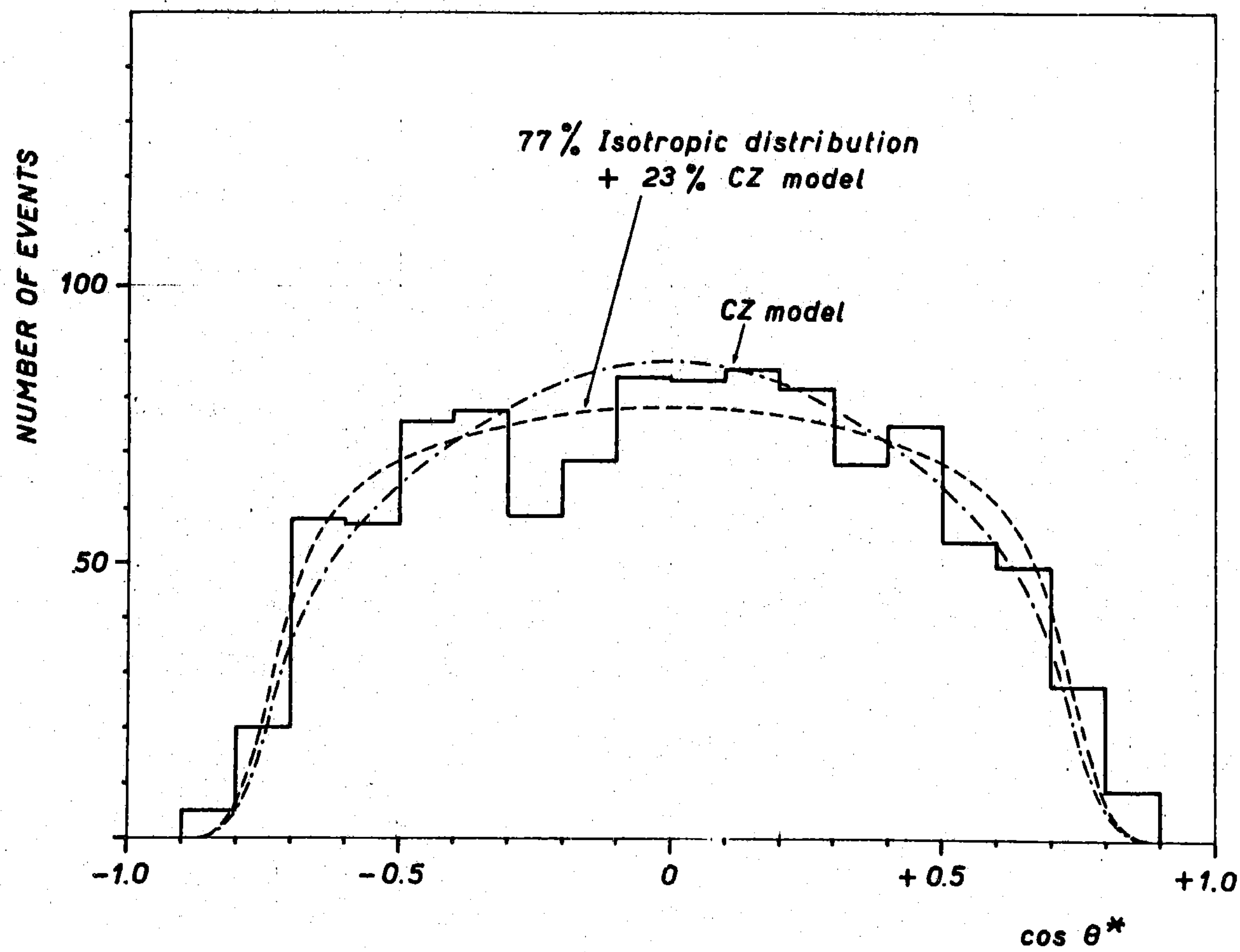

FIG. 6 - The experimental distribution of the angles in the dipion rest system between one pion and the dipion line of flight.