COMITATO NAZIONALE PER L'ENERGIA NUCLEARE
Laboratori Nazionali di Frascati

LNF - 66/37
25 Luglio 1966

C. Bacci, C. Mencuccini, G. Penso, A. Reale, G. Salvini, V. Silvestrini, M. Spinetti, B. Stella: PHOTOPRODUCTION OF NEUTRAL PIONS AT 500 ÷ 800 MeV. SEARCH FOR A "RESONANT" P_{11} AND η CUSP EFFECT. -

(Nota interna: n. 330)

Servizio Documentazione
dei Laboratori Nazionali di Frascati del CNEN
Casella Postale 70 - Frascati (Roma)

Laboratori Nazionali di Frascati del CNEN
Servizio Documentazione

LNF-66/37

Nota Interna: n° 330
25 Luglio 1966

C. Bacci[x], C. Mencuccini, G. Penso[x], A. Reale, G. Salvini[x], V. Silvestrini, M. Spinetti and B. Stella: PHOTOPRODUCTION OF NEUTRAL PIONS AT 500 ÷ 800 MeV. SEARCH FOR A "RESONANT" P_{11} AND η CUSP EFFECT. -

INTRODUCTION. -

This paper reports the results obtained with the Frascati 1.1 GeV electronsynchrotron for the reaction

$$\gamma + p \longrightarrow \pi^0 + p$$

for an incident photon energy (l. s.) $E_\gamma = 450 \div 850$ MeV at $\vartheta^{o *}_{\pi^o} = 90^o$, 120^o and 135^o pion c.m. angles. The main characteristics of this experiment with respect to the similar ones(1 ÷ 5)(o) are better statistics and higher energy resolution ($\pm$ 6 MeV). Both these conditions are needed in order to achieve the purposes of the present measurement:

first: to collect data with a p-γ coincidence method on the differential cross section at 120^o, 135^o in an energy region where the experimental situation is at the moment too scanty;

(x) - Istituto di Fisica dell'Università, Roma and INFN, Sezione di Roma.
(o) - We quote here only the experiments where both the proton and a γ from the π^o decay were detected.

second: to look for the presence of any bump or enhancement in the photoproduction cross section due to the new isobaric state P_{11} whose existence has been inferred from the results of many experiments[7, 8, 9];

third: to get evidence for a fine structure in the region of the second resonance (where, for instance, a cusp η effect could be present in the π^0 photoproduction amplitude due to the opening of the new (η p) channel at E_γ = 710 MeV).

2. EXPERIMENTAL APPARATUS AND RESULTS.

The experimental layout is shown in fig. 1. The telescope is an array of spark-chambers and scintillation counters to measure the emission angles and the range of the protons. A suitable pulse height analysis and the use of a plexiglass Cerenkov in anticoincidence eliminate the electrons and pions background.

The measurements at the same angle are taken at different energies of the synchrotron. The experimental points are lumped together after having checked their consistency. The results are given in fig. 2, 3, 4 for $\vartheta^{*}_{\pi^0}$ = 135°, 120°, 90° respectively.

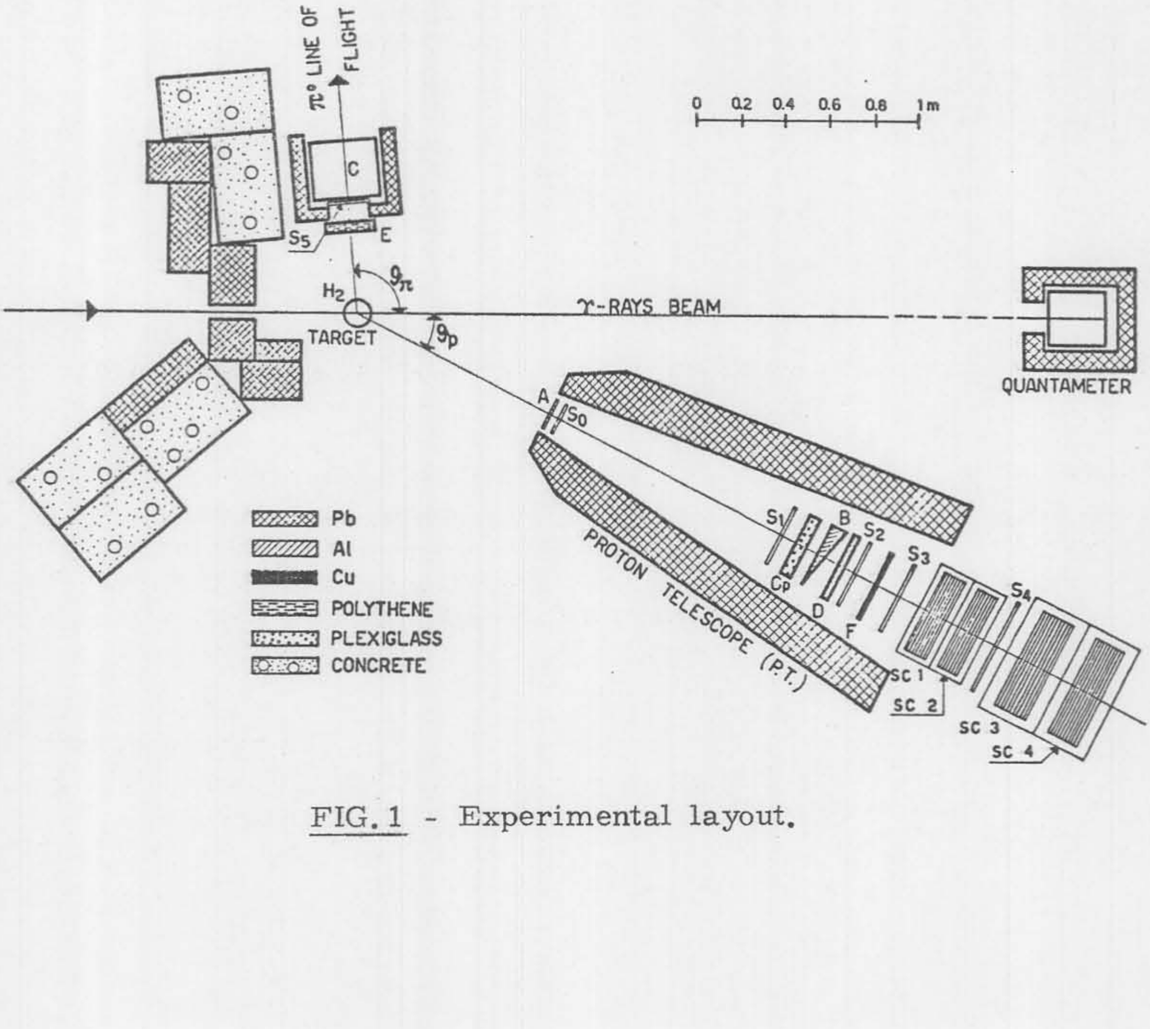

FIG. 1 - Experimental layout.

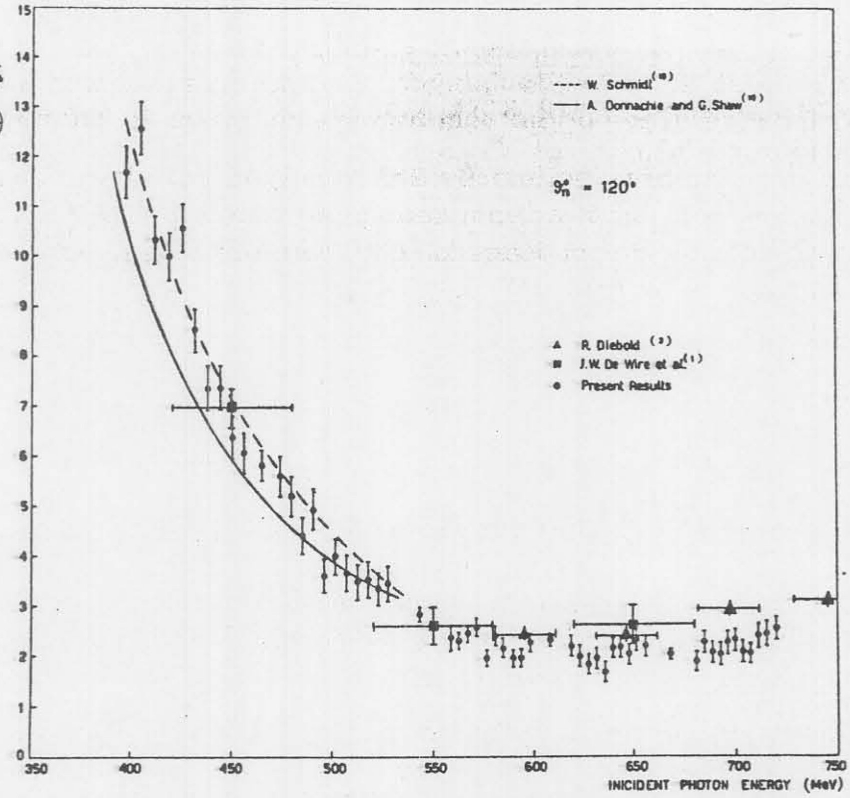

FIG. 2 - Differential cross section at a pion c.m. angle $\vartheta^{*}_{\pi^0}$ = 135°.

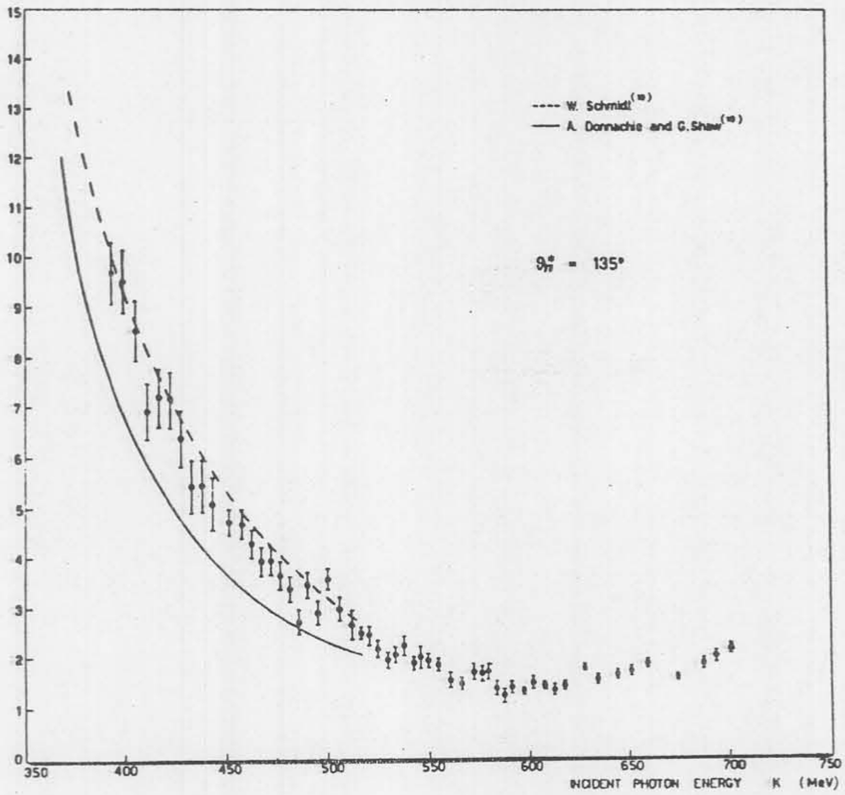

FIG. 3 - Differential cross section at a pion c.m. angle $\vartheta^{*}_{\pi^0}$ = 120°.

Full and dotted lines are theoretical predictions, as we shall discuss later.

It is rather interesting to compare the 90^{o} data with the 1962 Frascati results(2) obtained by a different apparatus but with the same technique. One can see from fig. 4 and 5 the quite good agreement between the two measurements, which allows us to be confident that no great systematic errors are present in our experimental results. This is further confirmed by the quite good agreement between all our results and the overall situation for the 90^{o} distribution in the considered energy region (see fig. 6). Data from different authors are shown there. The few data existing at 120^{o} and 135^{o} are reported in the same figures 2 and 3.

3. DISCUSSION.

For sake of convenience we first discuss the results for $E_{\gamma} = 450 \div 650$ MeV (E^{x} = c. m. total energy $\simeq 1310 \div 1450$ MeV), and afterwards the results in the region of the second resonance ($E \simeq 750$ MeV, $E^{*} \simeq 1520$ MeV).

For the first point we observe - see figs. 2, 3, 4 - that no significant bump appears in our cross sections between 500 and 650 MeV, where the P_{11} resonance could be, according to the other experimental indications(7, 8, 9).

Actually, we did not expect the isobar very easy to be observed; moreover its position is not well localized and the width could be rather large. However it is worth to notice that the experimental values (see fig. 2, 3, 4) seem to match quite well with the predictions of W. Schmidt(10) and A. Donnachie et al. (10). These authors made use of the fixed t dispersion relations and neglected the contribution of the immaginary part of the M_{1-} multipole, as well as the immaginary parts of the higher multipoles(x).

The comparison between the theoretical curves and the experimental ones is made without any relative normalization. So we can see that the agreement is good. Perhaps an upper limit for the amplitude of this "resonating" multipole could be calculated.

(x) - This approximation in calculating the dispersive integrals was done, as there is no way of the predicting the behaviour of $\mathrm{Im}(M_1)$ by the knowledge of the $\delta_{P_{11}}$ phase shift and the Watson theorem, because elastic unitarity does not apply to P_{11} wave, already at very low energy.

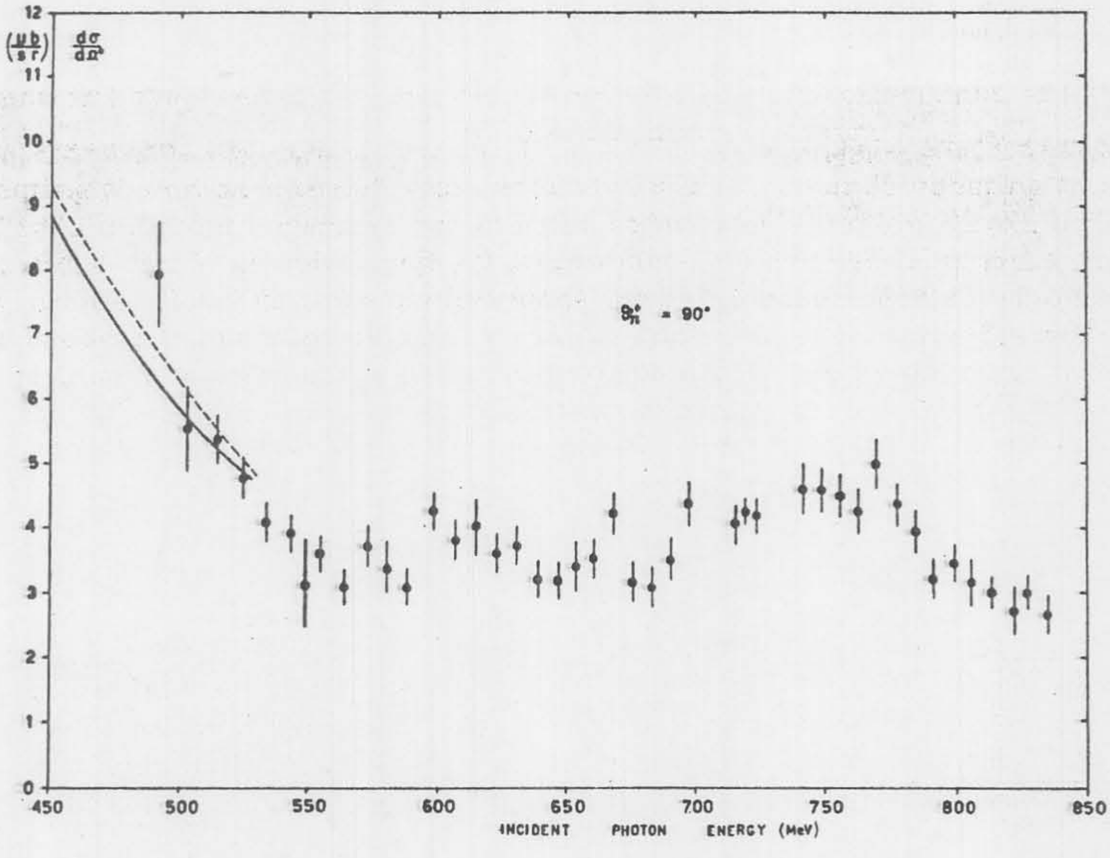

FIG. 4 - Differential cross section at a pion c.m. angle $\vartheta^{\text{*}}_{\pi^o} = 90^o$.

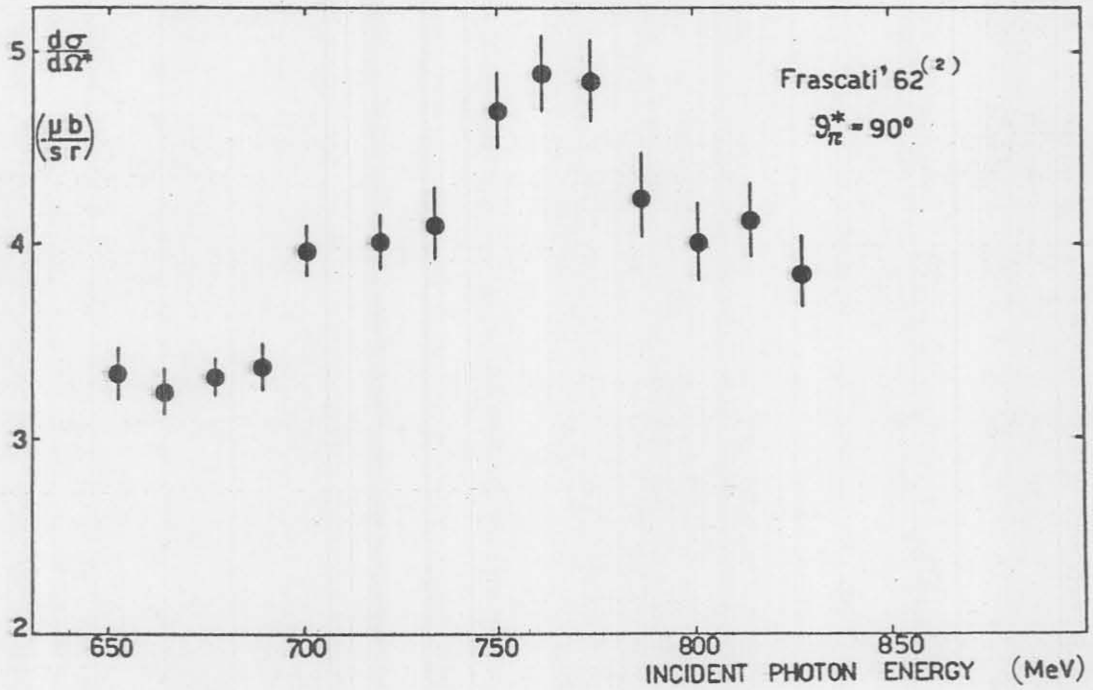

FIG. 5 - Frascati 1962 results for differential cross section at a pion c.m. angle $\vartheta^{\text{*}}_{\pi^o} = 90^o$ - Ref. (2).

Beyond $\sim$550 MeV the experimental results do not have theoretical predictions to be compared with. As it is well known, in this energy region only phenomenological attempts are possible to determine the multipoles which appear in the formulas for the cross section. We hope our results will make easier these analysis.

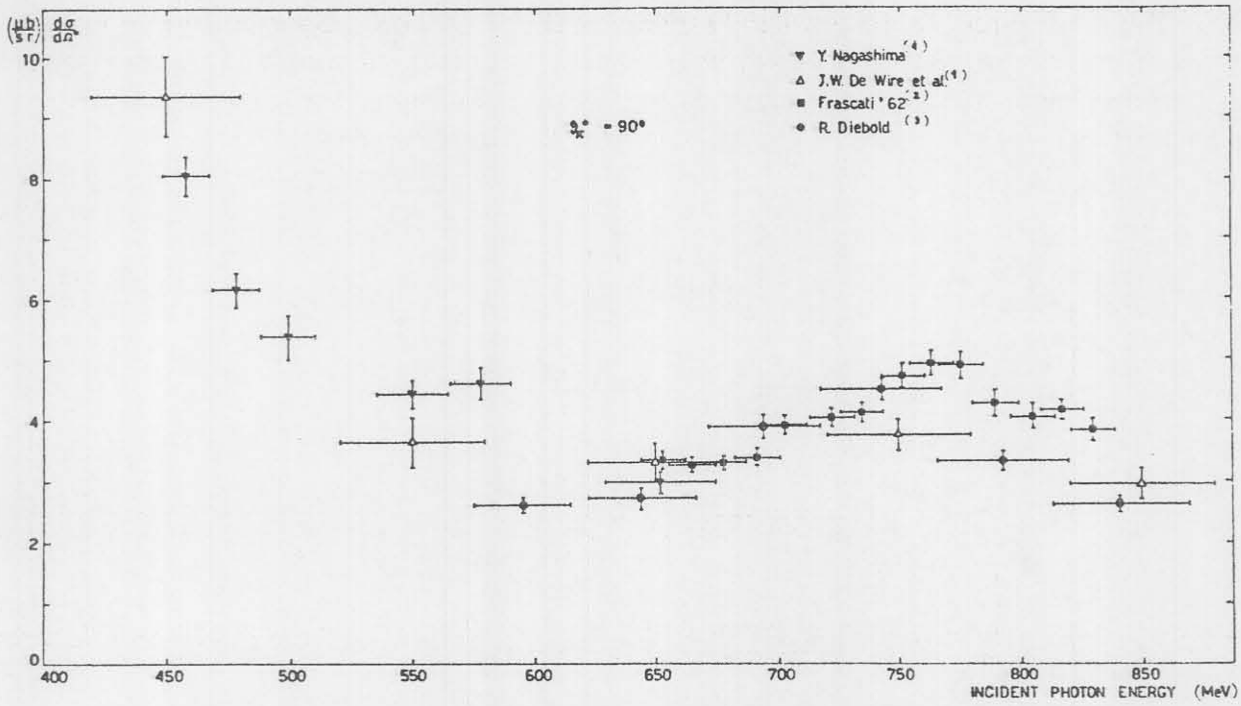

FIG. 6 - Previous results for differential cross section at a pion c.m. angle $\vartheta^{*}_{\pi^0}$ $= 90^{\circ}$ - Ref. (1, 2, 3, 4).

Let us switch now to the discussion of the results in the region of the II resonance ($E^{*} = 1518$ MeV). In fig. 7 we give the 90° results of the photoproduction experiments which have been done with the best energy resolution.

In this figure we can see that the region of the II resonance seems to show a structure: something like a rise wich starts at E $\simeq$ 680 MeV, followed by a flat region around $\sim$ 720 MeV and a rise again. No one of these measurement by itself gives a definite evidence of this sort of shoulder, but all the results together are consistent with this indication.

In the following, we try to interprete the shoulder on the left side of the second resonance as due to the sharp opening of the η production channel according to a mechanism first predicted by Rekalo in π^0 photoproduction(11). In fact our comparative analysis(12) of π and η photoproduction has shown that, no far from the η threshold, the behaviour with the energy of the production of π's and η's in the T = 1/2 state (as well as the relative abundancy of π's with respect to η's for both initial states π+N and γ+N) are practically the same. Moreover, the η cross section rises very fast from the threshold. This allows us to

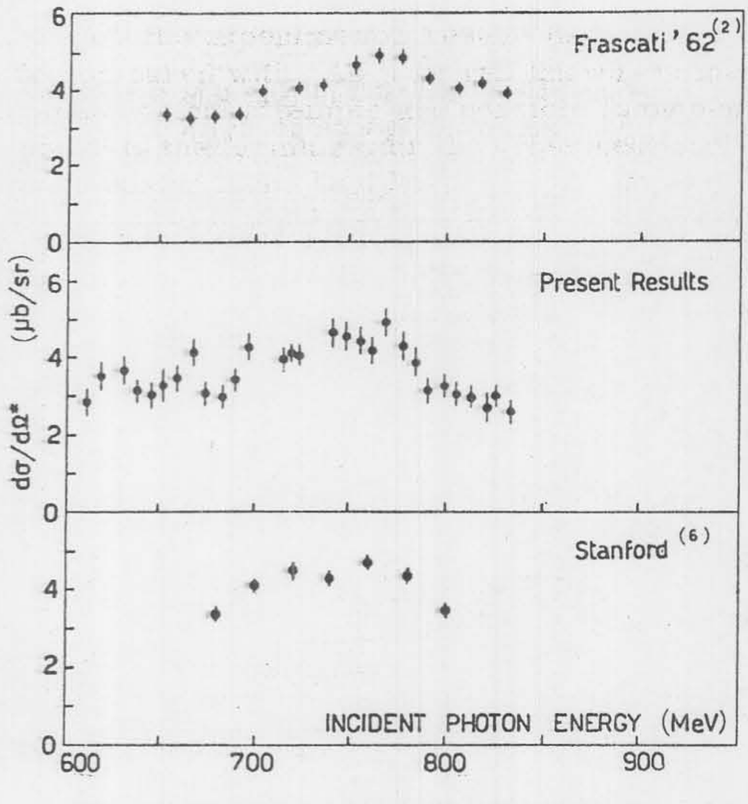

FIG. 7 - Differential cross section at a pion c.m. angle $\vartheta^{*}_{\pi^0} = 90^o$ according to the experiments with the best resolution in energy. See references.

look in photoproduction for a cusp effect which is rather small in absolute value (because of a factor ~ 5 between the relative T = 1/2 π to η production cross sections) and strongly energy dependent. We estimated this cusp effect, trying to overcome the present lack of knowledge of the multipoles in the region of the second resonance, assuming a simplified model.

Our calculations stand on few basic assumptions:

a) - According to the results of ref. (13) we assume that the ηN system resonate at $E^* \simeq 1510$ in an S_{11} state; the multipole then implied in π^o photoproduction is mainly the electric dypole E_{o+};

b) - We neglect the production of two pions, as the behaviour of the inelasticity parameter in the S_{11} partial wave seems to suggest[14]. In this way, we apply the unitarity and time reversal invariance of the S matrix to the following reactions;

$$\pi N \rightarrow \pi N, \quad \pi N \rightarrow \eta N, \quad \gamma N \rightarrow \pi N, \quad \gamma N \rightarrow \eta N, \quad \eta N \rightarrow \eta N.$$

One can easily show[15] that in the region of the II resonance the T = = 1/2 electric dypole E_{o+} can be given in terms of measured quantities, i.e. the S_{11} wave elasticity parameter and phase shift, the η photoproduction total cross section and some other kinematical factors;

c) - We assume that in our energy region the most important multipoles are:

$$M_{1+} (\rightarrow P_{33} \text{ state}), \quad E_{o+} (\rightarrow S_{11} \text{ state}), \quad E_{2-} (\rightarrow D_{13} \text{ state}).$$

The last one has been assumed to be of the Breit-Wigner type ($E_\gamma \simeq$ at 760 MeV, $\Gamma = 100$ MeV[14]). The normalization of the theoretical cross section in terms of these multipoles has been chosen to agree with the experimental value at the maximum.

The resulting anomaly in the shape of the II resonance is shown in fig. 8. As one can see the form of the anomaly seems to be similar to that one can argue from the experimental distribution. Notwithstanding the calculated order of magnitude is lower that one can estimate from the experimental distributions given in fig. 7.

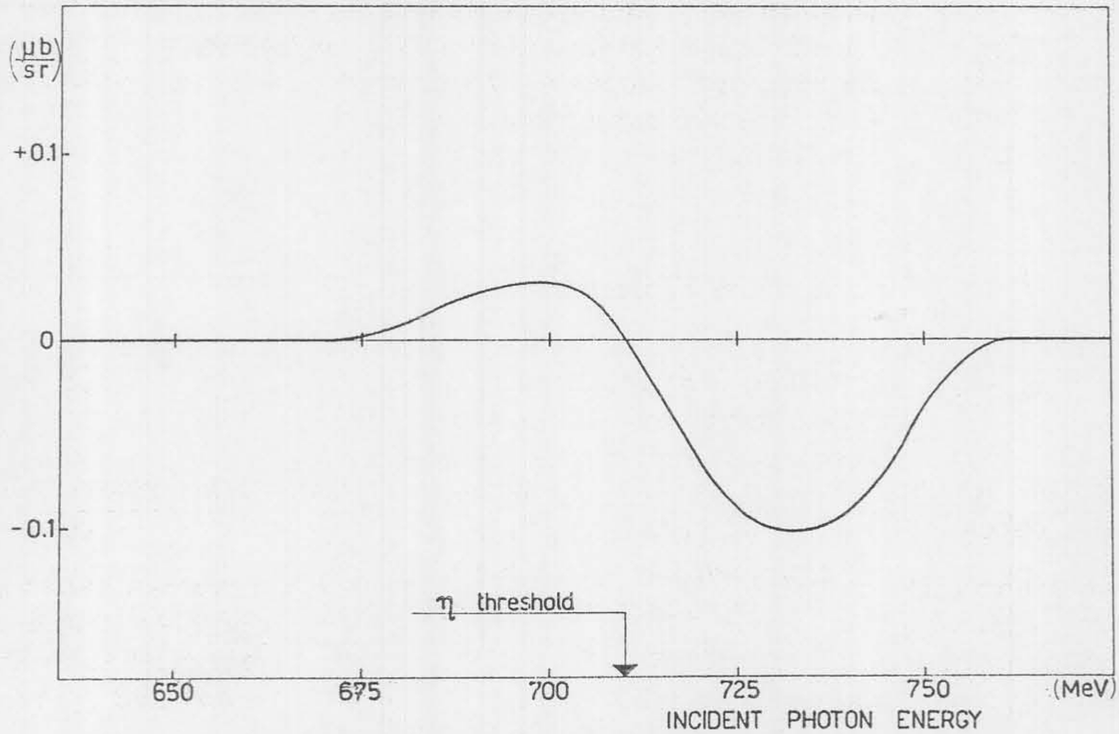

FIG. 8 - Calculated η cusp effect on the π^0 differential cross section at $\vartheta^K_{\pi^0} = 90^o$.

This discrepancy can hardly be explained by the oversimplified model we assumed. An alternative explanation can be guessed in the following lines.

As we stated before, our predictions assume that the (ηN) resonance is in an S_{11} state.

Just very recently, however, the development of the analysis of π-N scattering and the results of the pion-and photo-production reactions have cast serious doubts on the quantum numbers of the ηN resonance: actually the resonance could be a P_{11} state as well as an S_{11} state, or even to be a mixture of more states.

The results which could more suggest this point of view come from Cence's phase shift analysis, (who gives a P_{11} as well a S_{11} amplitude in π-N scattering with an anelasticity parameter changing quite abruptly from ~ 1 just at the opening of the ηN channel, $E^* = 1488$) and from a careful study of the energy behaviour of the cross section for the $\pi^- p \rightarrow \rightarrow \eta n$ reaction, near the η threshold. The energy behaviour, taking in account the experimental uncertainties, is at present compatible with the hypothesis of an S state (η N) real resonance or with a P wave bound state below the threshold.

The calculation of the cusp effect in the P_{11} case is a bit more complicated than in an S_{11} case, and we did not try to do it.

CONCLUSIONS.

We summarize the discussion of our results in the following points:

1) - The photoproduction of the π^0 seems to be well described by the theoretical calculations based on the dispersion relations[10] up to E_γ = 550 MeV of the incident photon (E^* = 1380 MeV total energy in the c.m.).

2) - We do not see significant evidence for a new isobaric state, like the P_{11} quoted in many experiments[7, 8, 9] and phase shift analyses[14] below E^* = 1480 MeV.

3) - There is rather clear evidence of a structure around the II resonance at E^* = 1480 ÷ 1510 MeV. We tend to interprete it as a cusp effect of the η. A calculation in the assumption that the ηN system is an S-wave gives a cusp effect smaller than the experimental indication.

4) - The hypothesis that the η is produced close to threshold in a P_{11} wave is not inconsistent with our results.

5) - Our improvement in energy resolution shows that the photoproduction below 1 GeV with higher energy resolution and better statistics is still an open field of research.

REFERENCES.

(1) - J. M. De Wire, H. E. Jackson and R. Littauer, Phys. Rev. 110, 1208 (1958).

(2) - M. Deutsch, C. Mencuccini, R. Querzoli, G. Salvini, V. Silvestrini and R. Stiening, Proceedings of the Frascati Congress (1962), pag. 28.

(3) - R. Diebold, Phys. Rev. 130, 2089 (1963).

(4) - Y. Nagashima (Thesis).

(5) - G. Cortellessa, A. Reale and P. Salvadori, Estratto dai Rendiconti dell'Istituto Superiore di Sanità 23, 1177 (1960).

(6) - H. De Staebler, E. F. Erickson, A. C. Hearn and C. Schaerf: Phys. Rev. 140, B336 (1965).

(7) - P. Bareyre, C. Bricman, G. Valladas, G. Villet, J. Bizard and J. Sequinot, Phys. Letters 8, 137 (1964).
(8) - G. Cocconi, E. Lillethun, J. P. Scanlon, C. A. Stahlbrandt, C. C. Ting, J. Walters and A. M. Wetherell, Phys. Letters, 8, 134 (1964);
- G. Bellettini, G. Cocconi, A. N. Diddens, E. Lillethun, J. P. Scanlon and A. M. Wetherell, Proceedings of Hamburg Intern. Conference (1965), pag. 97;
- G. Bellettini, G. Cocconi, A. N. Diddens, E. Lillethun, J. P. Scanlon, A. M. Shapiro and A. M. Wetherell, Phys. Letters 18, 167 (1965).
(9) - S. L. Adelman, Phys. Rev. Letters 13, 555 (1964).
(10) - W. Schmidt, Zeit. Physik 182, 76 (1964);
- A. Donnachie and G. Shaw: Photopion Production, Dispersion Relation and γ - ρ - π coupling.
(11) - M. P. Rekalo, Soviet Phys. JETP 19, 152 (1964).
(12) - C. Bacci, C. Mencuccini, G. Penso, G. Salvini and V. Silvestrini: Phys. Rev. 16, 157 (1966).
(13) - A. W. Hendry and R. G. Moorhouse: Phys. Letters 18, 171 (1965).
(14) - L. D. Roper: Phys. Rev. Letters 12, 340 (1964);
- P. Auvil, C. Lovelace, A. Donnachie and A. T. Lea, Phys. Letters 12, 76 (1964);
(15) - S. L. Adelman, Phys. Rev. Letters 14, 1043 (1965);
- P. Bareyre, C. Brickman, A. V. Stirling and G. Villet, Phys. Letters 18, 342 (1965);
- L. D. Roper, R. M. Wright and B. T. Feld, Phys. Rev. 138, B190 (1965).
(15) - C. Mencuccini, A. Reale and G. Salvini, To be published.