Laboratori Nazionali di Frascati

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The formation of $P_{11}(1470)$ Resonance in the γ-n Interaction.

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The question whether the $P_{11}(1470)$ resonance can be photoproduced on nucleons has become of relevant interest in the last years because of its connection with the assignment of this resonance to an SU_3 multiplet and the related consequences on the quark model.

The P_{11} resonance has been established in many reactions induced by protons, pions and kaons both on proton and neutron (1).

If the P_{11} belongs to an SU_3 antidecuplet, it can be photoproduced on neutrons only, because of the U-spin conservation (2).

Experimentally it seems that the P_{11} is not photoproduced on protons (3) and then an accurate investigation of the same reactions on neutrons can contribute to clarify the question.

A further powerful way of testing the P_{11} assignment comes from the consideration that if the P_{11} belongs to $\overline{10}$ its decay in $\Delta+\pi$ is forbidden since $8\otimes 10$ does not contain $\overline{10}$.

(1) PARTICLE DATA GROUP: *Rev. Mod. Phys.*, **43**, No. 2, Part 1 (1971).
(2) H. J. LIPKIN: *Phys. Lett.*, **12**, 154 (1964).
(3) R. G. MOORHOUSE and W. A. RANKIN: *Nucl. Phys.*, **23** B, 181 (1970).

Some previous experimental results (4), compared with theoretical calculation seemed to rule out the P_{11} photoexcitation on neutrons.

In order to investigate the formation of the $P_{11}(1470)$ in pion photoproduction on neutrons we report in this letter

a) the results of an analysis on total and differential cross-sections of the reaction

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

b) the results of a fit to the pion-nucleon effective-mass distributions in the reactions

$$\gamma n \to n\pi^+\pi^- , \tag{2}$$

$$\gamma p \to p\pi^+\pi^- , \tag{3}$$

observed in the same experiment.

The actual statistics is double than in our previous papers (5,6). The complete experimental results of these reactions will be published in a forthcoming paper.

In Fig. 1 the total cross-section of the reaction (1) is shown. The superimposed curve is the total cross-section for the corresponding reaction on protons, *i.e.* $\gamma + p \to n + \pi^+$.

To take into account the nucleon motion and to make the comparison with the cross-section on free protons possible, we always refer to the squared c.m. energy E^{*2} of the $(p\pi^-)$ final state (5).

For convenience, the energy E'_γ is also quoted which is the photon energy necessary to get the same E^{*2} on a free nucleon.

Deuteron corrections other that the above one have not been introduced, since they certainly do not affect so much the cross-sections shapes considered in this paper and they involve many theoretical questions which are not yet completely clear. Their effect is more important in the first resonance region, where recently very interesting implications seemed to arise from the available experimental data on reaction (1) and the inverse reaction, *i.e.* a possible isotensor-current contribution and a possible time-reversal violation.

In the energy range considered here ($\geqslant 400$ MeV), the deuteron effects are expected to be nonrelevant, as results from the measurements of NEUGEBAUER *et al.* (7).

The quite different behaviour in the region of the so-called second resonance is evident in Fig. 1.

We tried to interpret the peak at $E'_\gamma = 580$ MeV as due to the $D_{13}(1520)$ resonance shifted back because of the interference between the resonant and nonresonant amplitude, assumed as given by Born terms with electric coupling only.

Assuming a resonant amplitude of the Breit-Wigner type for the D_{13} multipoles (E_{2^-}, M_{2^-}), because of the interference, the cross-section bump can be shifted back at

(4) AACHEN-BERLIN-BONN-HAMBURG-HEIDELBERG-MÜNCHEN COLLABORATION: *Nucl. Phys.*, **8** B, 535 (1968); M. BENEVENTANO, F. DE NOTARISTEFANI, P. MONACELLI, L. PAOLUZI, F. SEBASTIANI and M. SEVERI: *Lett. Nuovo Cimento*, **1**, 113 (1969); F. A. BERENDS and A. DONNACHIE: *Phys. Lett.*, **30** B, 555 (1969).

(5) E. LODI-RIZZINI, G. C. MANTOVANI, A. PIAZZOLI, L. FIORE, G. GIALANELLA, V. ROSSI, A. PIAZZA, G. SUSINNO, F. CARBONARA, M. NAPOLITANO and R. RINZIVILLO: *Lett. Nuovo Cimento*, **3**, 697 (1970).

(6) A. PIAZZA, G. SUSINNO, L. FIORE, G. GIALANELLA, E. LODI-RIZZINI, G. C. MANTOVANI, A. PIAZZOLI, F. CARBONARA, G. PALOMBA-NICODEMI and R. RINZIVILLO: *Lett. Nuovo Cimento*, **3**, 403 (1970).

(7) G. NEUGEBAUER, W. WALES and R. L. WALKER: *Phys. Rev.*, **119**, 1726 (1960).

most to $E'_\gamma \simeq 700$ MeV. Repeating the calculation with a resonant M_1 multipole the amplitude needed to shift the bump back to 580 MeV agrees with the one found in the phenomenological fit.

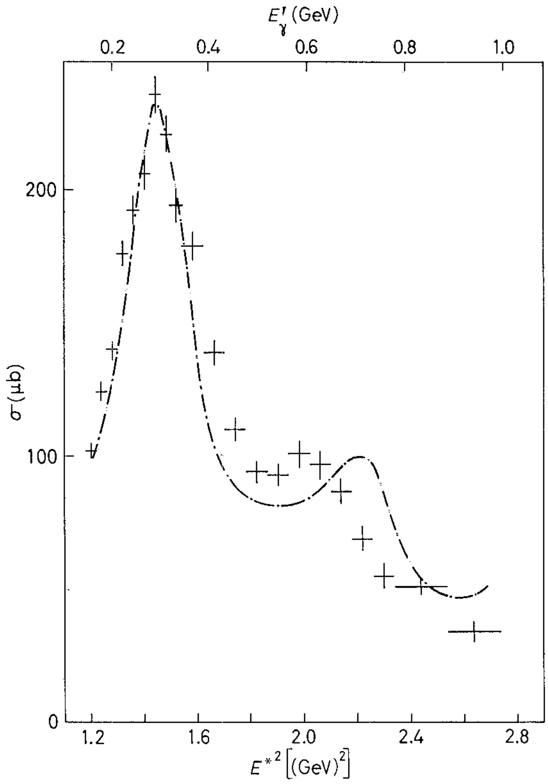

Fig. 1. – Total cross-section for the reaction $\gamma+n \to p+\pi^-$ as a function of E^{*2} (c.m. energy squared for the π^-p system); + present work, —·—·— $\gamma+p \to n+\pi^+$ (ref. (8)).

In our opinion it is very hard to explain the found shift without the P_{11} resonance and we think that this is the more impressive result of our investigation.

Further evidence for the P_{11} excitation is obtained in a phenomenological fit of the differential cross-sections extending from 400 to 1000 MeV and including some data on polarization (9) and asymmetry (10) in the reaction (1).

For the method used and the formalism adopted we refer to the paper by WALKER (11).

In his work WALKER adds to the gauge-invariant Born terms with electric coupling only and to the resonant ones some background contributions varying very slowly with energy.

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(8) J. T. BEALE, S. D. ECKLUND and R. L. WALKER: Report CTSL-42, Calt 68-108 (1968).
(9) M. BENEVENTANO, S. D'ANGELO, F. DE NOTARISTEFANI, P. MONACELLI, L. PAOLUZI, F. SEBASTIANI, M. SEVERI and B. STELLA: *Lett. Nuovo Cimento*, **3**, 840 (1970).
(10) K. KONDÔ, T. NISHIKAWA, T. SUZUKI, K. TAKIKAWA, H. YOSHIDA, Y. KIMURA and M. KOBAYASHI: *Journ. Phys. Soc. Japan*, **29**, 13 (1970).
(11) R. L. WALKER: *Phys. Rev.*, **182**, 1729 (1969).

We assumed these contributions to be purely real and constant in the whole energy interval.

In Table I our results for the resonant amplitudes and the added contributions are presented, together with the results of the fit by WALKER for π^+ photoproduction.

TABLE I.

Resonant helicity element	Added contributions	Resonance	Energy W_0 (GeV)	Width Γ_0 (GeV)	Walker results for $A^+(W_0)$ ($\mu b^{\frac{1}{2}}$)	Our results for $A^-(W_0)$ ($\mu b^{\frac{1}{2}}$)
A_{1^+}		P_{33}	1.236	0.120	1.00	1.00 (fixed to Walker value)
	ΔA_{1^+}					$-0.30+0.11$ $-0.35-0.05$
B_{1^+}		P_{33}	1.236	0.120	-2.43	-2.43 (fixed to Walker value)
	ΔB_{1^+}					$1.09+0.07$ $1.21-0.07$
A_{2^-}		D_{13}	1.519	0.102	-0.20	$-0.29+0.09$ $-0.25-0.09$
	ΔA_{2^-}					$-0.36+0.07$ $-0.36-0.08$
B_{2^-}		D_{13}	1.519	0.102	-1.32	$-0.08+0.09$ $-0.15-0.14$
	ΔB_{2^-}					$0.84+0.02$ $0.96-0.07$
A_{0^+}		S_{11}	1.561	0.180	-0.65	$-0.37+0.15$ $-0.36-0.16$
	ΔA_{0^+}					$0.48+0.11$ $0.71-0.09$
A_{1^-}		P_{11}	1.471	0.200	-0.25	$-0.99+0.08$ $-1.06-0.09$
	ΔA_{1^-}					$0.54+0.10$ $0.55-0.12$

The χ^2/degree of freedom of the fit was 1.4.

Figure 2 shows our differential and total cross-sections together with the fitted curves.

The polarization and asymmetry values obtained in our fit are presented in Fig. 3.

The main result of this analysis is the strong depression of the D_{13} and the large contribution of the P_{11} with respect to π^+ photoproduction.

This fact argues for the assignment of the P_{11} to an SU_3 antidecuplet. If this is the case the decay of the P_{11} in $\Delta+\pi$ is forbidden. As a consequence the $\Delta(1236)$ production in the final state of the reaction (2) must be quite different from that in reaction (3), in which the channel $\Delta^{++}\pi^-$ is predominant in the energy region of the P_{11}.

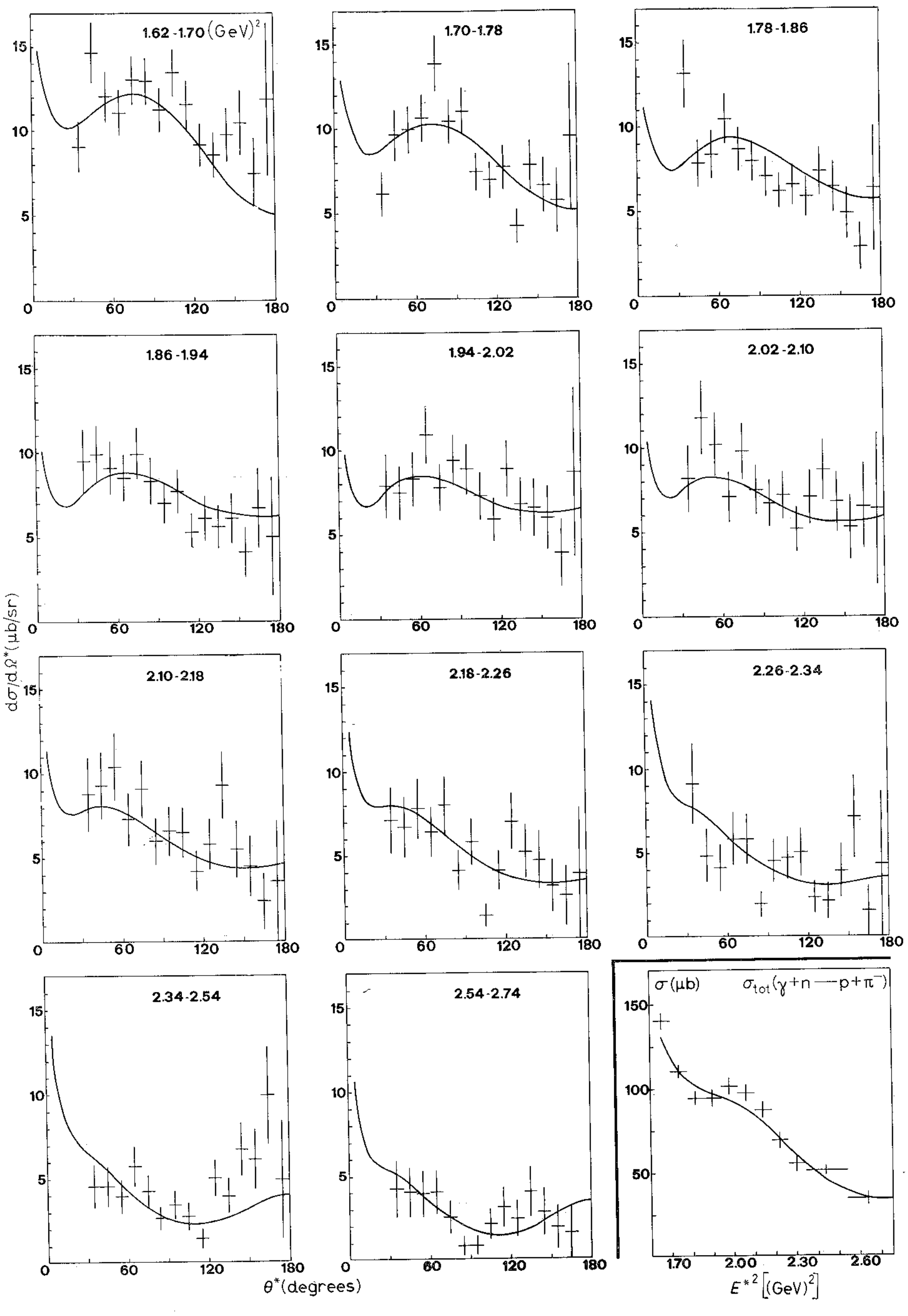

Fig. 2. – Differential cross-sections for eleven intervals of E^{*2} as a function of θ^*, the angle between the π^- and the incident photon in the π^-p c.m.s. Total cross-section for the same energy intervals is also reported. The superimposed curves are the result of the fit.

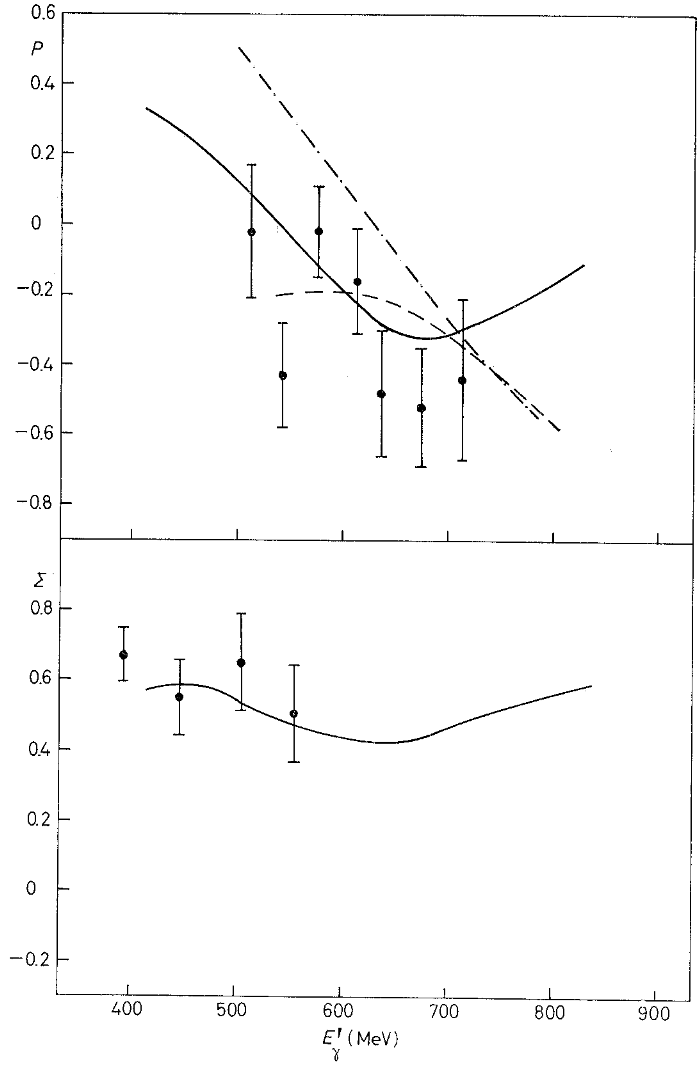

Fig. 3. – Polarization P and asymmetry Σ (at 90°) as obtained in our fit (———) together with the experimental results of ref. (9,10) as a function of E'_γ (for the meaning of E'_γ see text). The fit by PROIA and SEBASTIANI (12) (— — —) and that by WALKER (11) (—·—·—) are also reported.

We carried out a preliminary analysis of the production of $\Delta(1236)$ in the final state of the reactions (2) and (3) by fitting the two-body effective-mass distribution under the following simplifying assumptions:

i) in the reactions (2) and (3) the production of $\Delta(n\pi^-)$ and $\Delta(p\pi^+)$ is predominant with respect to that of $\Delta(n\pi^+)$ and $\Delta(p\pi^-)$, as suggested also by previous results in hydrogen (13);

ii) we neglect any interference effects between the different Δ charge states.

(12) A. PROIA and F. SEBASRIANI: *Lett. Nuovo Cimento*, **3**, 483 (1970).
(13) AACHEN-BERLIN-BONN-HAMBURG-HEIDELBERG-MÜNCHEN COLLABORATION: *Phys. Rev.*, **175**, 1669 (1968).

TABLE II.

E^{*2} [(GeV)^2]	$\gamma n \to n\pi^-\pi^+$		$\gamma p \to p\pi^+\pi^-$	
	%Δ^-	χ^2/ν	%Δ^{++}	χ^2/ν
1.54÷1.84	38 ± 7	1.2	38 ± 9	0.5
1.84÷1.94	76 ± 7	0.9	73 ± 7	2.8
1.94÷2.02	56 ± 10	0.7	86 ± 7	0.5
2.02÷2.10	68 ± 10	1.1	89 ± 8	1.1
2.10÷2.20	34 ± 11	1.5	77 ± 10	1.3
2.20÷2.30	65 ± 11	0.9	59 ± 14	0.9
2.30÷2.46	55 ± 12	0.8	72 ± 10	0.7
2.46÷2.60	43 ± 40	1.7	46 ± 13	1.1

An energy-dependent Breit-Wigner formula was used. The fitted parameter is the Δ percentage with respect to the phase-space contribution.

The results of the fit are reported inTable II. As can be seen the percentage of Δ^- is significantly smaller than the Δ^{++} percentage in the P_{11} energy region ($1.9 \leqslant E^{*2} \leqslant 22$ (GeV)^2).

We want to stress that the comparison between the reactions (2) and (3) is particularly meaningful, since the data for both reactions are obtained in the same experiment.

We conclude that

a) the experimental results on the reaction (1) and the related analysis show that the $P_{11}(1470)$ is strongly photoexcited on neutrons;

b) the result of the analysis of the effective-mass distributions of the reactions (2) and (3), although not a proof, is, however, indicative that the P_{11} does not decay in $\Delta + \pi$.

From *a*) and *b*), together with the experimental fact that in the photoproduction reactions on protons the P_{11} was not observed, we conclude that this resonance could be classified into an SU_3 antidecuplet.

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It is a pleasure to thank Dr. A. PROIA for the help and the continuous interest during this work.

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(*Lett. Nuovo Cimento*, **2**, 1183 (1971))

On page 1186, Table I should read:

TABLE I.

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TABLE I (*continued*).

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