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Double Pion Photoproduction on Protons below 1 GeV. An Investigation of the Isobar Excitation Mechanism.

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In this paper we report the analysis of the preliminary results of an investigation of the double photoproduction reaction

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

carried out by means of a hydrogen bubble chamber at the electrosynchrotron of the Laboratori Nazionali di Frascati.

In the past this reaction was investigated mainly with counter techniques and only recently a collection of data with considerable statistics was reached with hydrogen chambers at the CEA and DESY laboratories [1,2].

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(1) CAMBRIDGE BUBBLE CHAMBER GROUP: *Phys. Rev. Lett.*, **13**, 636, 640 (1964); *Proc. Intern. Symp. on Electron and Photon Interactions at High Energies*, vol. **2** (Hamburg, 1965), p. 21; *Phys. Rev.*, **146**, 994 (1966); **155**, 1468, 1477 (1967); **156**, 1426 (1967); **163**, 1510 (1967).

(2) AACHEN-BERLIN-BONN-HAMBURG-HEIDELBERG-MÜNCHEN COLLABORATION: *Proc. Intern. Symp. on Electron and Photon Interactions at High Energies*, vol. **2** (Hamburg, 1965), p. 36; *Nuovo Cimento*, **41** A, 270 (1966); **48** A, 262 (1967); **49** A, 504 (1967); *Phys. Lett.*, **23**, 707 (1966); *Nucl. Phys.*, **1**, B 668 (1967).

The 32 cm hydrogen bubble chamber used was constructed at CERN and was operating there until 1962. In 1965 it was carried to the Frascati Laboratories. Some technical modifications were necessary in order to expose it to the photon beam. These, as well as the exposing procedure, are described in detail in ref. (3).

About 400 000 pictures were taken at different photon beam intensities: 200 000 with about one photoproduction event every 100 pictures, the remaining with a beam intensity about 2 times higher. This became possible by setting up an external beam-monitoring system which furnished the incident-photon flux without necessity of counting the e^+e^- pairs.

The results reported here refer to the first group of pictures.

The measurements were carried out on conventional tables and processed with the standard THRESH-GRIND program chain.

Since in the 3-prong events under study the angles and momenta of the three charged particles, as well as the direction of the incoming photon and all the masses, were known, the kinematics of the investigated reaction was overdetermined and a 3C-fit was possible. This allowed us to distinguish the triple photoproduction events making also the kinematical reconstruction more accurate.

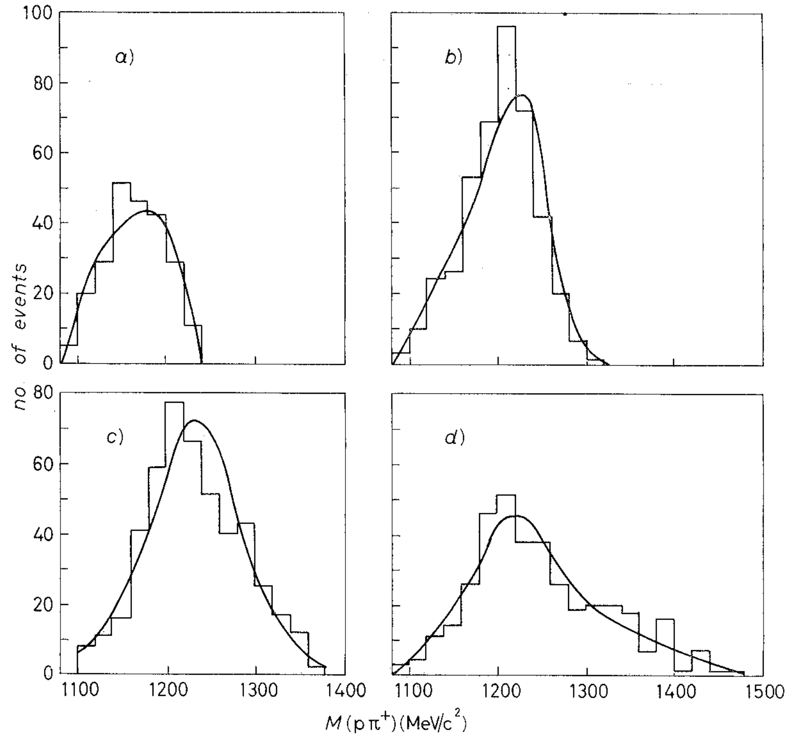

Fig. 1. – Distributions of the $(p\pi^+)$ equivalent mass for different photon energies. The curves represent the calculated distributions for the mixture of the phase-space and of a Breit-Wigner resonance for the Δ-isobar, that best fits the experimental data. *a)* $E_\gamma = (450 \div 550)$ MeV; *b)* $E_\gamma = (550 \div 650)$ MeV; *c)* $E_\gamma = (650 \div 800)$ MeV; *d)* $E_\gamma = (800 \div 1000)$ MeV.

(3) S. DE SCHRYVER, L. FIORE, S. FOCARDI, G. GIALANELLA, V. ROSSI, B. STELLA and G. SUSINNO: Laboratori Nazionali di Frascati, Internal Report LNF-68/21 (1968).

The main characteristics of reaction (1) is the very abundant production of $\Delta^{++}(1236)$-isobar. In Fig. 1 the mass distributions of the $(p\pi^+)$ system are shown for different energy intervals.

The continuous curves are best fits to the experimental data, obtained by superimposing a Breit-Wigner for the $\Delta^{++}(1236)$-isobar to the phase-space distribution.

In Table I the values of the mass, width and percentage relative to $\Delta^{++}(1236)$, as obtained in the fits, are reported.

TABLE I. – *Results of the fit of the* $(p\pi^+)$ *mass distribution obtained by superimposing a Breit-Wigner for the* Δ*-isobar to the phase-space distribution.* In Fit I the mixture percentages and the mass and width of the resonance were let free. In Fit II the resonance parameters ($M = 1236$ MeV, $\Gamma = 120$ MeV) were fixed and only the percentages had to be fitted.

E_γ (MeV)	Fit I				Fit II	
	% Δ	$M(\Delta)$ (MeV)	Γ (MeV)	$P(\chi^2)$	% Δ	$P(\chi^2)$
450 ÷ 550	100 ± 10	1208	102	0.10	100 ± 10	0.15
550 ÷ 650	90 ± 10	1216	86	0.50	85 ± 10	0.01
650 ÷ 800	100 ± 10	1231	132	0.01	90 ± 10	0.01
800 ÷ 1000	65 ± 6	1232	94	0.25	70 ± 10	0.35

The mass distributions for the $(p\pi^-)$ and $(\pi^+\pi^-)$ systems were calculated taking into account the $\Delta^{++}(1236)$ reflections added to the phase-space distributions. The calculated distributions, together with the experimental ones, are shown in Fig. 2 and 3. As one can see, they agree in the limits of the presently available statistics, so that no definitive conclusions can be drawn about the contribution of the $\Delta(1236)$-isobar in the zero-charge state as well as about the presence of the so-called σ-meson ($M = 400$ MeV, $J = I = 0$).

Many distributions of other conventional kinematical quantities are reported in ref. [3].

The present status of the phenomenological analysis of the experimental data concerning reaction (1) can be summarized as follows.

Because of the very abundant production of Δ-isobar in the final state of reaction (1), at least below 1.1 GeV, the CEA group tried to interpret the data in terms of an isobar excitation mechanism, assuming that the reaction goes following the scheme

$$\gamma + p \to \mathcal{N}^{**} \to \Delta + \pi \tag{2}$$

and involving only the known resonances P_{11}, D_{13}, F_{15}, F_{37}.

The best fit of the total production cross-section of the $\Delta(1236)$-isobar provides the relative strengths of the four isobars, which can be involved in reaction (2). Such a fit, however, is not very sensitive to the eventual presence of nonresonant contributions, which, on the contrary, could appreciably modify the angular distributions. The same group compared also the experimental angular distributions with those calculated through the resonant model. In general the predictions, both for the π^- pro-

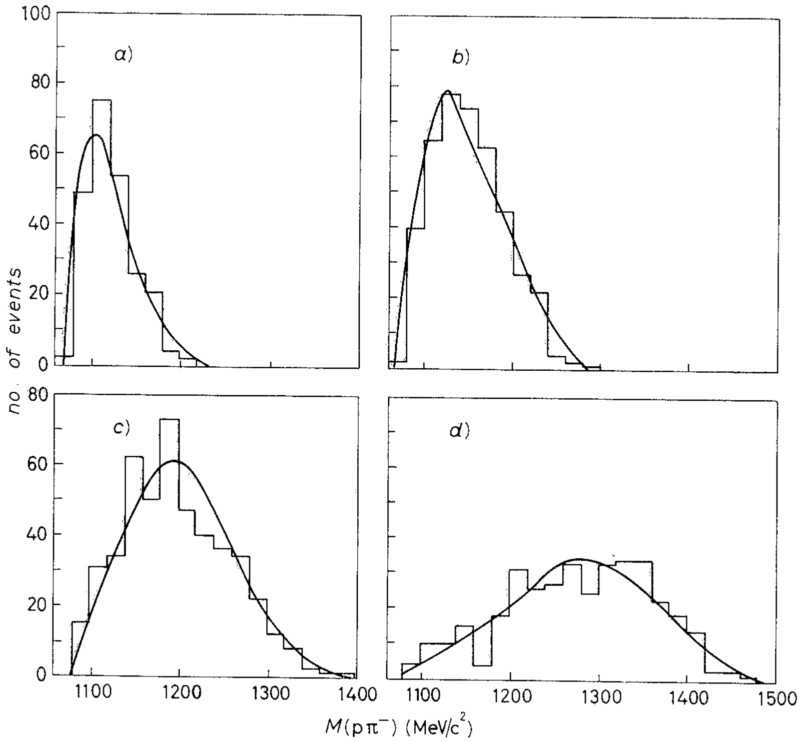

Fig. 2. – Distributions of the $(p\pi^-)$ equivalent mass for different photon energies. The curves represent the calculated distributions, taking into account the reflection of the Δ^{++}-isobar. *a*) $E_\gamma = (450 \div 550)$ MeV; *b*) $E_\gamma = (550 \div 650)$ MeV; *c*) $E_\gamma = (650 \div 800)$ MeV; *d*) $E_\gamma = (800 \div 1000)$ MeV.

duction angle in the total c.m.s. and for the π^+ decay angle in the $\Delta(1236)$-isobar rest system, are in agreement with the assumption of a dominant resonant production mechanism, at least below 1.1 GeV.

An alternative attempt was that carried out by the DESY group, which used the OPE model modified in order to achieve gauge invariance by introducing some additional diagrams. However, since the peripheral mechanism cannot account for experimental data at low energies, more recently the DESY group has tried an improved model, which, in one sense, includes both the above ones, by introducing an intermediate state in the Stichel-Scholz model (4).

In this paper we analyse our data through the resonant model, essentially as regards the decay angular distributions of the Δ-isobar at various photon energies, following the calculations reported in ref. (5). In this work the authors have determined the distribution of the proton angle in the Δ-isobar rest system, with respect to the direction of the Δ-isobar itself in the total c.m.s., without Adair's approximation, in the

(4) P. Stichel and M. Scholz: *Nuovo Cimento*, **34**, 1388 (1964); D. Lüke, M. Scheunert and P. Stichel: DESY Report 68/7 (1968).

(5) I. Giannini and A. Santroni: *Nuovo Cimento*, **45** A, 359 (1968). We thank the authors for communicating their results prior to publication. These authors are presently in a group working at Frascati on the same problem with electronic equipment.

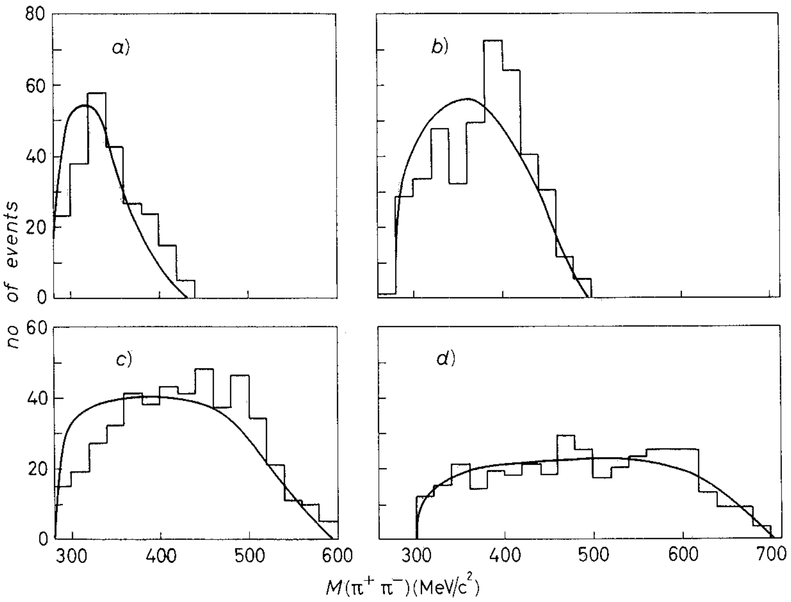

Fig. 3. – Distributions of the $(\pi^+\pi^-)$ equivalent mass for different photon energies. The curves represent the calculated distributions, taking into account the reflection of the Δ^{++}-isobar. *a*) $E_\gamma = (450 \div 550)$ MeV; *b*) $E_\gamma = (550 \div 650)$ MeV; *c*) $E_\gamma = (650 \div 800)$ MeV; *d*) $E_\gamma = (800 \div 1000)$ MeV.

hypothesis that reaction (1) goes entirely through the isobar excitation. They also assume that the intermediate state can be a pure P_{11} state ($M = 1420$ MeV), or a pure D_{13} state ($M = 1525$ MeV), or a mixture of these, taking also into account the interference effects. Furthermore, in agreement with previous experimental data, only the Δ^{++} state is taken into consideration, neglecting the small Δ^0 contribution.

In order to obtain the mentioned proton angular distribution, a Lorentz transformation must be done, which can change the Δ polarization and, by consequence, the final angular distribution. To overcome this difficulty a rotation has to be made so that the quantization axis coincides with the Δ-isobar direction in the total c.m.s. In this way the Adair approximation is no more needed.

The calculated distribution was integrated over the photon energy, as well as over all the π^- angles (in the total c.m.s.) and momenta, and over the other proton emission angle φ in the Δ-isobar rest system. In Fig. 4 the experimental angular distribution is shown for different photon energy intervals. The curves represent some calculated distributions.

As one can see, a predominant P_{11} state excitation in the channel $P_{11} \to \Delta^{++} + \pi^-$ can be excluded, while the discrimination becomes poor against a small presence of P_{11} with respect to the D_{13}.

A choice was attempted by fitting our experimental data to the various curves. The fits are obviously more significant in the first two energy intervals, because only the P_{11} and D_{13} intermediate states were taken into account. The results are reported in Table II.

The result of this fit is in contradiction with the fit of the total cross-section carried out by the CEA group, which gives the value 2.8 for the relative strength of the P_{11}

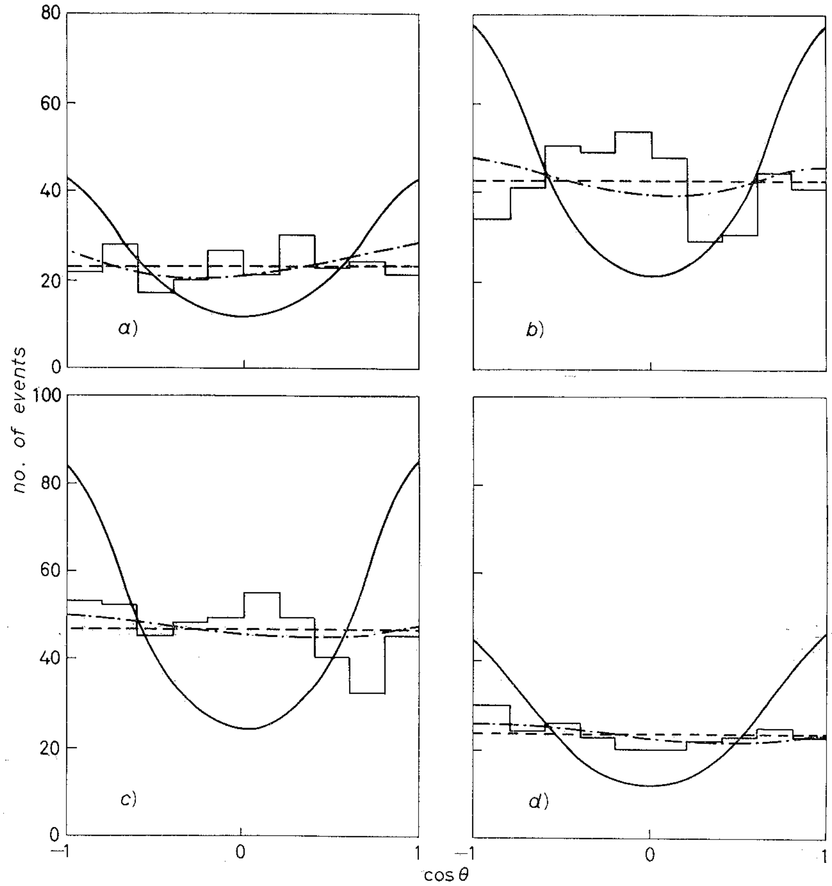

Fig. 4. – Angular distributions of the proton in the Δ^{++}-isobar rest system with respect to the direction of the Δ^{++}-isobar itself in the total c.m.s. The curves have been calculated through the resonant model with different mixtures of D_{13} and P_{11} states: —— P_{11}, – – – D_{13}, –·–·– $1P_{11}+1D_{13}$; *a*) (450÷550) MeV; *b*) (550÷650) MeV; *c*) (650÷800) MeV; *d*) (800÷1000) MeV.

state with respect to the D_{13} state. On the other hand, we also want to point out that our approach seems to be not conclusive as concerns the validity of the resonant model. In fact the proton angular distributions are expected to be flat also in the case of Δ^{++} production without excitation of any intermediate state.

Finally, we remark that perhaps a different approach would be useful following the phase-shift analysis of Lovelace [6], which shows that the P_{11}-isobar decays in a proton plus a $(\pi^+\pi^-)$ resonance (the σ-meson) rather than in Δ(1236) plus pion. Now, while our present statistics is too poor to try this interpretation of the data, we may note that the $(\pi^+\pi^-)$ mass distribution can be interpreted as giving some indication in this direction.

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(6) C. Lovelace: *Pion-nucleon phase shifts*, invited paper at the 1966 Berkeley Conference.

TABLE II. – *Results of the fit of the proton angular distributions obtained with different mixtures of* D_{13} *and* P_{11}. In the first column the relative strength of the D_{13}-state and P_{11}-state are reported.

D_{13}/P_{11}	E_γ (MeV) 450 ÷ 550		550 ÷ 650		650 ÷ 800		800 ÷ 1000	
	χ^2	$P(\chi^2)$	χ^2	$P(\chi^2)$	χ^2	$P(\chi^2)$	χ^2	$P(\chi^2)$
0:1	60.6	< 0.005	138.9	< 0.005	123.9	< 0.005	30.8	< 0.005
1:3	29.7	< 0.005	59.6	< 0.005	18.9	0.025	6.9	0.58
1:2	18.5	0.03	38.4	< 0.005	13.9	0.15	5.3	0.80
1:1	8.6	0.50	19.6	0.02	7.9	0.55	2.2	0.98
2:1	6.5	0.60	17.6	0.04	8.2	0.50	2.7	0.97
5:1	6.1	0.65	16.3	0.06	8.6	0.50	3.1	0.96
1:0	6.2	0.65	16.0	0.07	8.9	0.50	3.3	0.95

In conclusion, while the predictions of both models agree satisfactorily well as to the main features of the reaction (1), there are still some discrepancies as to the quantitative predictions which suggest the opportunity of further investigating this and other complementary processes and also of attempting some different approach in the interpretation of the experimental data.

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