Laboratori Nazionali di Frascati

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The Asymmetry in the Coherent Photoproduction of π^0 on Deuterons by Polarized Gamma-Rays.

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Summary. — The asymmetry ratio in the coherent photoproduction of π^0-mesons on deuterons has been measured in the region of the first resonance, by using the Frascati linearly polarized γ-ray beam. The mean value obtained, $\Sigma = 0.63 \pm 0.03$, is of the same order and sign as the asymmetry in the photoproduction on protons. The dependence of the asymmetry on energy and angle is also given within the limits of the acceptance of the experimental apparatus.

1. – Introduction.

A linearly polarized γ-ray beam provides a useful tool to obtain detailed information about the γ-induced processes: with this technique it is possible, in fact, to measure separately the $d\sigma_\perp/d\Omega$ and the $d\sigma_\parallel/d\Omega$, *i.e.* the differential cross-section with polarization vector normal and parallel to the production plane.

Usually, the results are expressed in terms of the asymmetry ratio

$$\Sigma = \frac{d\sigma_\perp - d\sigma_\parallel}{d\sigma_\perp + d\sigma_\parallel}.$$

A systematic investigation of the photoproduction reactions, in the first resonance region, by means of polarized γ-rays, has been in progress at Frascati

since 1964; experiments of the same kind have been performed at Stanford and, more recently, at Tokyo.

Among all the data now available [1-9] we collect in Table I the results around 300 MeV.

The work described in this paper represents the first contribution to the study of the elastic photoproduction on deuterons

$$\gamma + d \to d + \pi^0$$

by polarized γ-rays.

TABLE I.

Process	E_γ	θ^*	Σ	References
$\gamma p \to \gamma p$	305	90°	0.52 ± 0.03	[9]
	380	90°	0.58 ± 0.05	
$\gamma p \to p\pi^0$	290	90°	0.59 ± 0.04	[1]
	305	90°	0.52 ± 0.03	
	320	90°	0.67 ± 0.03	
	325	90°	0.60 ± 0.03	
	325	90°	0.61 ± 0.05	
$\gamma p \to n\pi^+$	300	90°	0.47 ± 0.05	[2]
	380	90°	0.75 ± 0.07	
$\gamma d \to \pi^- pp$	330	90°	0.42 ± 0.03	[4]
	330	135°	0.18 ± 0.05	
$\gamma d \to \pi^+ nn$	330	90°	0.43 ± 0.03	[4]
	330	135°	0.25 ± 0.05	
$\gamma d \to pn$	310	90°	0.35 ± 0.04	[7]
	380	90°	0.37 ± 0.09	
$\gamma H_3 \to dp$	250	90°	0.36 ± 0.08	[8]

([1]) G. BARBIELLINI, G. BOLOGNA, G. CAPON, G. DE ZORZI, F. L. FABBRI, G. P. MURTAS, G. DIAMBRINI, G. SETTE and G. DE WIRE: *Phys. Rev.*, **184**, 1402 (1969); G. BOLOGNA, *et al.*: to be published.

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Several theoretical and experimental studies have already been performed on this topic, nevertheless the situation is confused and many problems still remain. From the theoretical point of view, most of the difficulties arise from the application of the impulse approximation, which is the usual approach when processes involving deuterium are concerned ([10;14]). In the case of elastic photoproduction, the final-state interactions are expected to play an important role ([15]). Furthermore, the structure of the deuteron must to be taken into account; this lowers the cross-section rapidly with increasing momentum transfer.

The experimental situation is even more confused. The data now available ([16-26]) are difficult to compare since they refer to different kinematical conditions. A systematic investigation is now in progress at Bonn. The preliminary results ([27]) show a strong discrepancy of more than a factor of two with respect to previous data in the region of the first resonance. The comparison was made using the form factor as calculated by HADJIOANNOU ([28]).

The aim of this experiment is to offer a contribution to the study of this process by measuring the asymmetry ratio at the energy of the resonance. This kind of measurement has the advantage of being unaffected by any multiplicative factor present in both $d\sigma_{\perp}$ and $d\sigma_{\parallel}$, such as a form factor. Also the final-state interactions have negligible effect on the asymmetry ratio. For this

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reason the results can be useful for a better understanding of the reaction mechanism. Particularly, they can be used in a phenomenological analysis in terms of multipoles, as already done in the case of photoproduction on nucleons.

2. – Experimental procedure.

We have measured the asymmetry ratio in the following experimental conditions: energy of the incident photons between 300 and 400 MeV, angle of π^0 in c.m. from 100° to 127° (which corresponds to the interval from 24° to 36° for the emission of deuterons in the laboratory). The momentum transfer is, in this situation, $(2 \div 3)\,\mathrm{fm}^{-1}$.

The experiment was carried out by using the linearly polarized γ-ray beam which has already been described ([1]): in our case the peak energy was chosen at 375 MeV. The polarization obtained was rather high: the maximum was over 44%; and the mean value, integrated over our energy acceptance, was about 37%.

In order to avoid introducing a systematic error in the asymmetry evaluation, much care has been devoted to the measurement of the energy spectrum of the beam and to its reproducibility after each change of the orientation of the axis of the crystal.

The detection apparatus consists of two telescopes of scintillation counters: one of them detects heavy particles by measuring the energy loss, the range

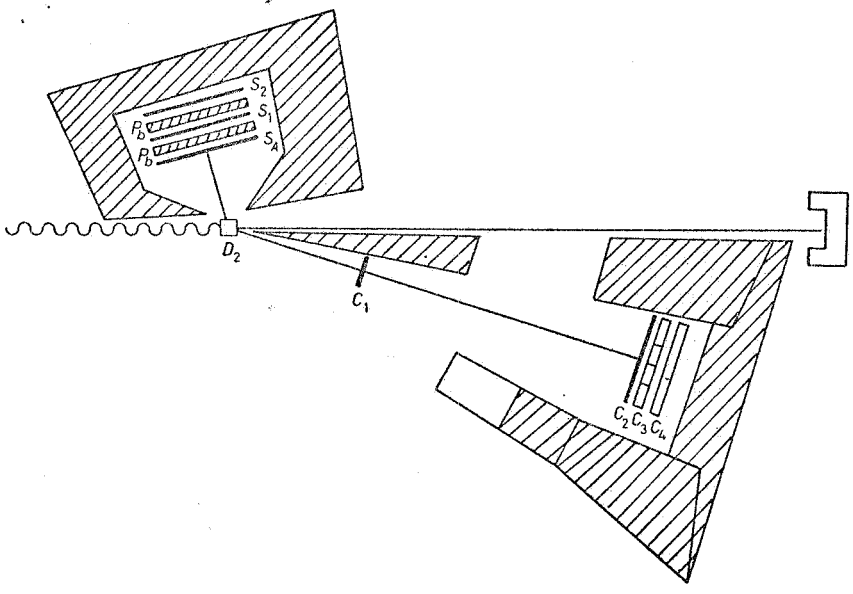

Fig. 1. – Sketch of the experimental set-up: C_1, C_2, C_3, C_4, S_A, S_1, S_2 are scintillation counters; shaded areas represent lead absorbers and shielding.

and the time of flight; the other one is a shower sandwich for the detection, in coincidence, of one of the photons from π^0 decay.

The scheme of the apparatus is shown in Fig. 1. A more complete description of the set-up and the block scheme of the electronics, as well as the details of the measuring method, is reported elsewhere [29].

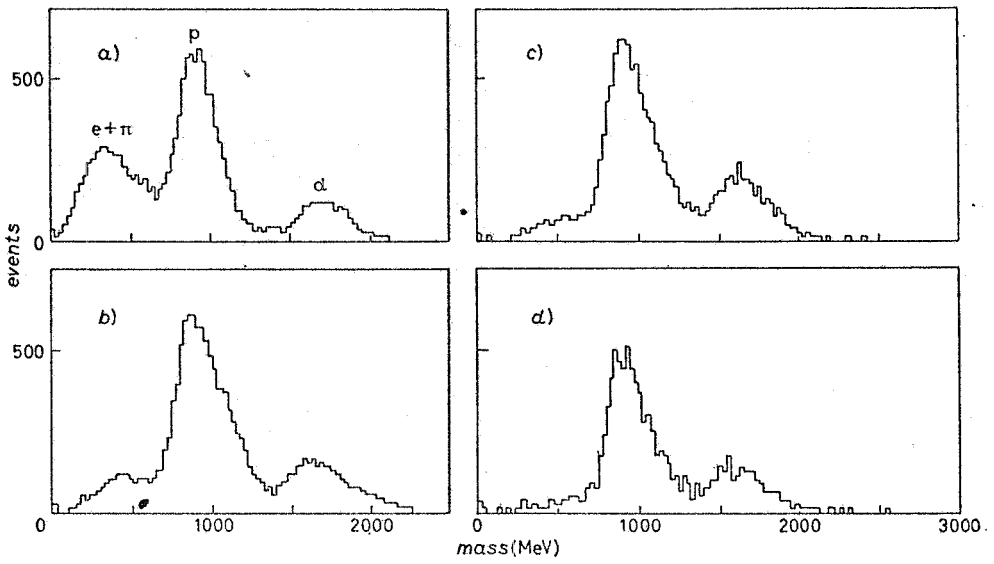

Fig. 2. – Typical mass spectra obtained in the four counters of C_3.

The angle of emission of the deuteron is measured by C_3, which is a hodoscope of four counters, each subtending an angle $\Delta\theta = 3°$ in the laboratory. A better angular definition would be useless because of the uncertainties in the kinematical reconstruction of events due to energy losses in the target, multiple scattering, etc.

The trigger is defined by the coincidence

$$(C_1 C_2 C_3 \bar{C}_4)(\bar{S}_4 S_1 S_2) ;$$

the energy of the detected deuterons varies from 45 to about 85 MeV. As the measurement is not absolute, no care is necessary in the evaluation of overall efficiency.

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[29] G. Bologna, I. Peruzzi, M. Piccolo and G. Troise: Frascati report LNF-72/2 (1972).

A small on-line computer (a DEC PDP8) records the following data for each triggering event:

pulse height in $C_1C_2C_3$,

time of flight between C_1 and C_2,

identification mark of C_{3i}.

This collection of data allows the reconstruction of the mass of the particle stopping in C_3 and its direction, as well as the energy of the incoming photon. Furthermore, the value of the beam intensity and its energy spectrum, the counting rate and several standard checks are periodically recorded.

A calibration of the deuteron telescope has been previously performed using monochromatic protons from the reaction $\gamma p \to p\pi^0$, selected by means of a magnetic analyser, in a wide range of momenta.

Figure 2 shows the typical mass spectrum obtained in the four angular regions: the pion and relativistic particle background is much greater in C_{ia} which is the nearest to the beam, and decreases with the distance from the beam.

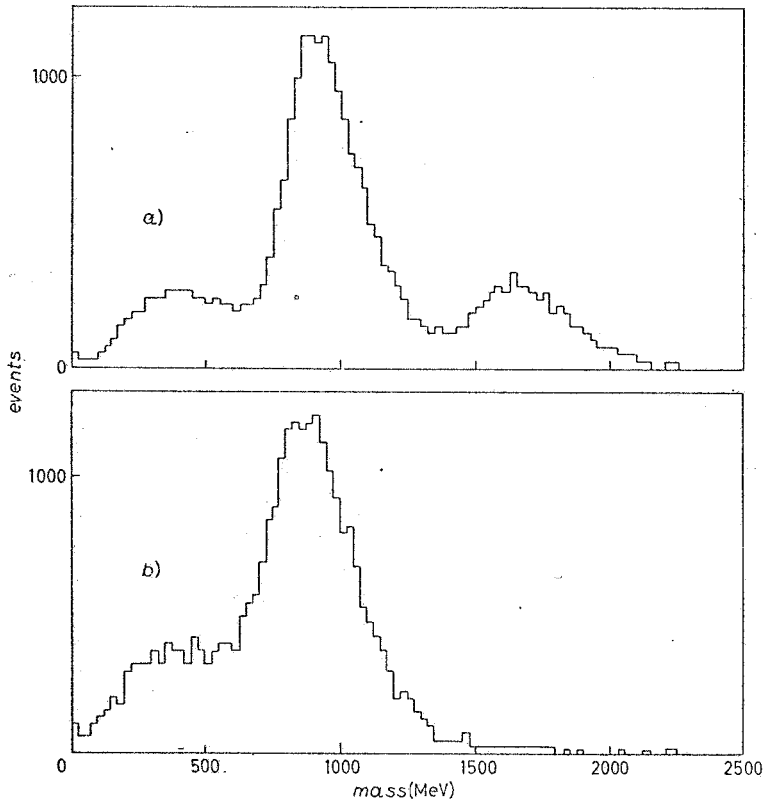

Fig. 3. – Total mass spectra: *a*) events from deuterium target, *b*) events from hydrogen target.

As one can see, in spite of a prevailing presence of protons with respect to deuterons and a nonnegligible number of lighter particles, the deuteron peak in the total mass spectrum is sufficiently well separated. A further indication of the feasibility of the mass separation is given by Fig. 3, which shows the total mass spectrum compared with the one obtained, in the same experimental conditions, but using a hydrogen target.

3. – The results.

About 23000 deuterons has been identified among 120000 triggering events: the runs were alternatively performed in the two polarization conditions, in order to prevent time-dependent effects (such as machine or apparatus instabilities) affecting the asymmetry measurement.

The subtraction of the background has been very carefully performed: control runs were carried out with both a hydrogen and an empty target, and a check was made using the amorphous bremsstrahlung beam.

The contribution of the empty target is shown in Fig. 4 by the shaded area. Figure 5 reports the contribution of protons and random coincidences.

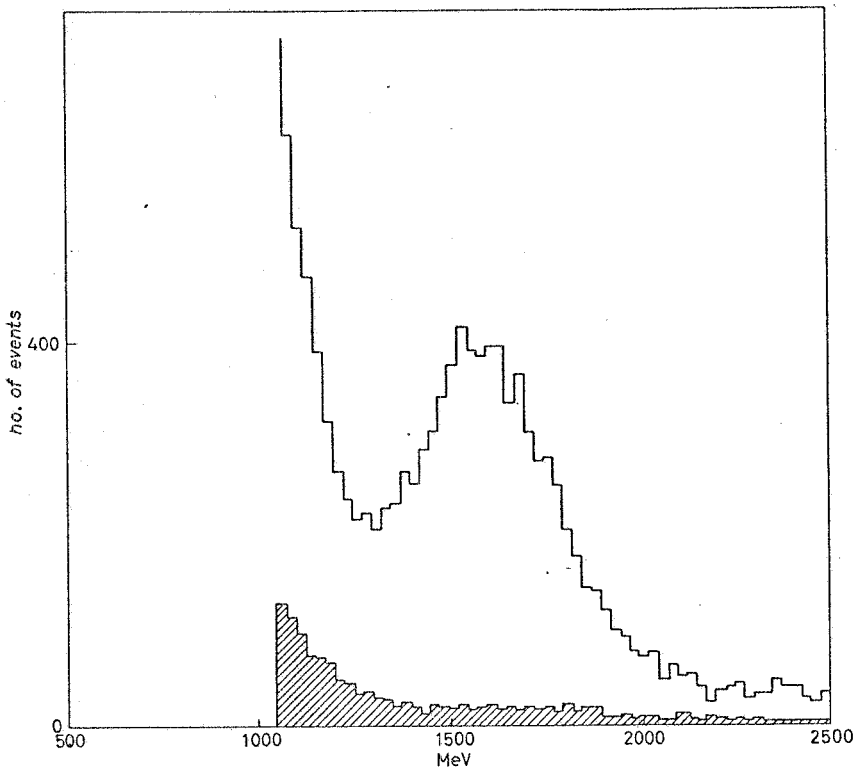

Fig. 4. – The shaded area represents the empty target contribution to the deuteron mass peak.

We estimate that the deuteron background from other processes (such as Compton effect or double photoproduction) has a negligible effect on the asymmetry.

After background subtraction, we have selected 9827 and 13582 deuterons, in the two polarization conditions respectively. After normalization to the same number of incident photons, 9827 deuterons produced in the plane perpendicular to the polarization vector correspond to 6098 in the parallel plane. Thus, if only statistical errors are considered, the counting asymmetry ratio

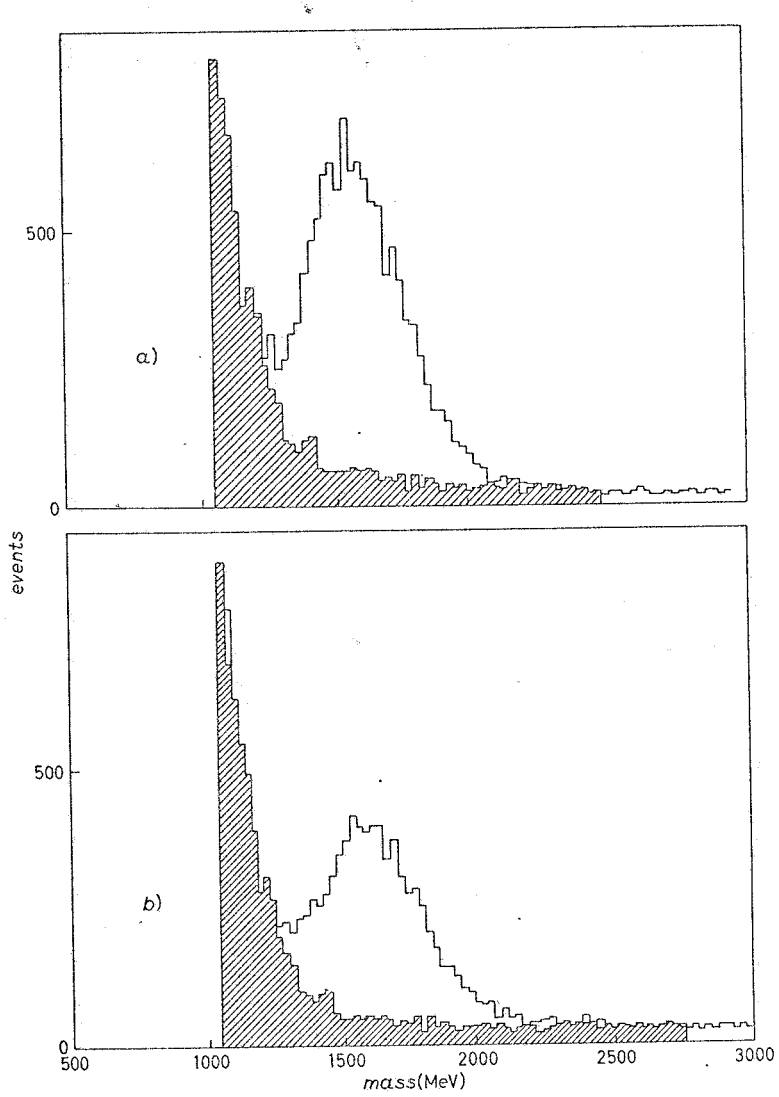

Fig. 5. – The shaded area represents the background to the deuteron peak as obtained from H_2 target measurements: *a*) vertical polarization, *b*) horizontal polarization.

is

$$\frac{N_\perp - N_\parallel}{N_\perp + N_\parallel} = \frac{(9827 \pm 201) - (6098 \pm 69)}{(9827 \pm 201) + (6098 \pm 69)} = 0.234 \pm 00.013 .$$

The value $\langle P \rangle$ of the polarization, folded with the energy resolution of our apparatus is 0.368 ± 0.003 (the error is only statistical); this gives the asymmetry ratio

$$\Sigma = \frac{1}{\langle P \rangle} \frac{N_\perp - N_\parallel}{N_\perp + N_\parallel} = 0.63 \pm 0.03 ,$$

averaged over our range of energy and angle.

The angular acceptance can be reduced by a factor of 4 if each strip of C_3 is considered; we can thus deduce the angular dependence of the asymmetry in the range between 104° and 124° in the c.m.; the results are summarized in Table II. Even if the errors are larger due to the poor statistics, there is a clear indication of a rather strong dependence.

TABLE II.

θ_π^*	Σ
$(104 \pm 3.5)°$	0.49 ± 0.06
$(111 \pm 3.5)°$	0.58 ± 0.05
$(118 \pm 3.5)°$	0.67 ± 0.05
$(125 \pm 3.5)°$	0.73 ± 0.10

TABLE III.

E_γ (MeV)	Σ	$\langle P \rangle$
280÷320	0.60 ± 0.05	0.311 ± 0.003
320÷360	0.66 ± 0.05	0.377 ± 0.004
360÷400	0.69 ± 0.05	0.385 ± 0.004

We can also try to have an idea of the energy dependence of the asymmetry in the range (300≃400) MeV; in this case care must be taken in the evaluation of the mean polarization; we have divided our acceptance in three regions; the results obtained are listed in Table III.

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It is a pleasure for us to thank Drs. F. VANOLI and F. RONGA who, have collaborated in different stages of the experiment. We have a special debt of gratitude for Prof. C. BERNARDINI for encouraging us to do this work and for continuous interest and stimulating discussions.

RIASSUNTO

Si riportano i risultati di un esperimento per la misura del fattore di asimmetria nella fotoproduzione coerente di π^0 su deutoni nella zona della prima risonanza. Questa misura, per cui non esistono dati precedenti, è stata effettuata usando il fascio γ polarizzato in funzione a Frascati. Il valore medio ottenuto $\Sigma = 0.63 \pm 0.03$ mostra che l'asimmetria è dello stesso segno e dello stesso ordine di grandezza di quella per fotoproduzione su protone. Viene anche riportato l'andamento di Σ in funzione di E_γ e θ_π^* entro i limiti dell'accettanza sperimentale.

Асимметрия в когерентном фоторождении π^0 при взаимодействии поляризованных гамма-пучей с дейтерием.

Резюме (*). — Было измерено отношение асимметрии в когерентном фоторождении π^0-мезонов на дейтерии в области первого резонанса, при использовании пучка линейно поляризованных гамма-лучей в Фраскати. Полученное среднее значение $\Sigma = 0.63 \pm 0.03$ имеет тот же порядок и знак, что и для асимметрии в фоторождении на протонах. Также приводится зависимость асимметрии от энергии и угла в диапазоне измерений экспериментальной аппаратуры.

(*) *Переведено редакцией.*