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G. Barbiellini, C. Bernardini, F. Felicetti and G. P. Murtas: PHOTO-DISINTEGRATION OF THE DEUTERON BY POLARIZED GAMMA RAYS.

(To be submitted to the Physical Review for publication)

1 - INTRODUCTION.

Deuteron photodisintegration has been extensively investigated in the past years: a complete reference index can be found in the report by M. E. Toms⁽¹⁾.

Experiments above the pion threshold have been done measuring the differential cross section and the distribution of the plane of disintegration by the use of linearly polarized γ -rays. The present experiment is concerned with this last kind of measurements in the energy region 200 - 400 MeV (lab. system) of the incident γ ray beam, that is around the first nucleon resonance. The present status of the knowledge about high energy deuteron photodisintegration is shortly summarized in the following.

a) - Theory.

The photodisintegration problem looks at first quite similar to the usual photoelectric effect in atoms. There a knowledge of the static (Coulomb) potential between bound charges allows a very accurate computation of the cross section. Corrections arising from the interaction of the incoming γ ray with extra-charges brought in by vacuum polarization do not change in a relevant way the results concerning the photoelectric effect.

In the case of photodisintegration, however, the presence of charged strong field particles in the two nucleon interaction leaves serious

doubts on a description of the process based on the use of a nucleon-nucleon potential. In fact the charge in the deuteron is not strongly localized on the proton but can travel from one nucleon to the other for a substantial fraction of the time in the form of charged meson exchange currents. It is expected on qualitative grounds that because of the pion mass, the charge can be considered as localized on the average on the nucleons when the frequency k of the incoming γ ray is such that $k \ll m_\pi (\hbar=c=1)$. That is when k is below the π meson threshold. The nucleon itself can undergo transitions to isobaric states like the first 33 resonance.

Low energy theoretical results ($k < 10$ MeV) are in good agreement with the static potential picture. A very refined calculation of this kind has been recently performed by Partovi⁽²⁾ using the well known multipole series technique. The number of involved multipoles is quite high in order to give results accurate to $k \lesssim 100$ MeV (in the frame of the static potential picture).

Even a careful analysis like Partovi's one (or the recent work by LeBellac, Renard, Tran Thanh Van including relativistic corrections⁽³⁾) is not able to reproduce the high energy data. A peak appears (see fig. 1) in the total cross section at $k = 250$ MeV and this seems unambiguously related to the first nucleon resonance, N^* .

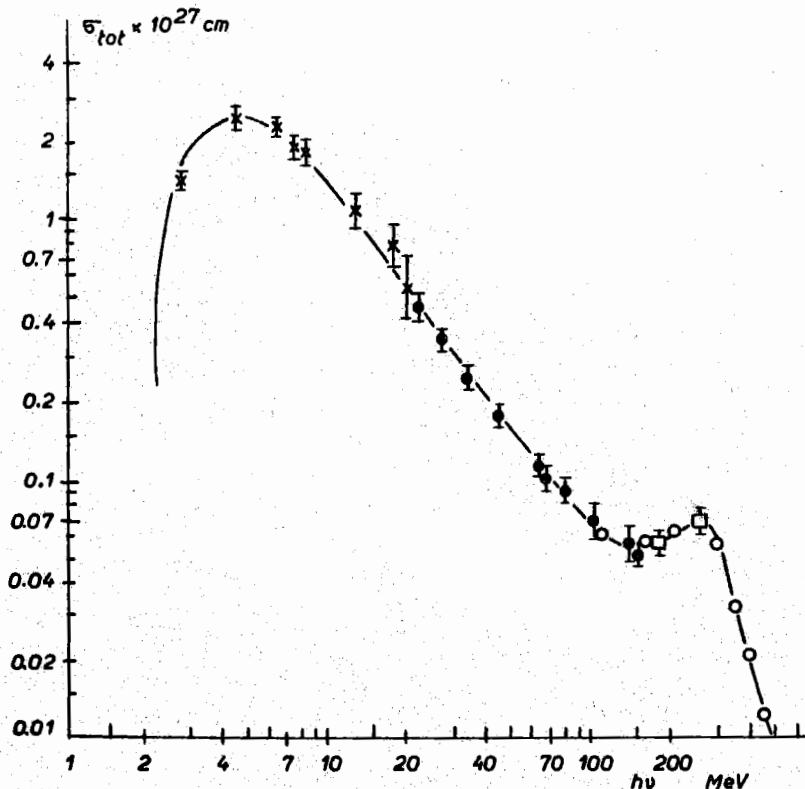


FIG. 1 - Total cross section for deuteron photodisintegration as a function of laboratory photon energy.

After some attempts to interpret the peak on a field theoretical basis (Austern⁽⁴⁾, Zachariassen⁽⁵⁾) a phenomenological model by Wilson⁽⁶⁾ succeeded to give a good fit to the total cross section. The phenomenological input to this model is given by the π photoproduction data together with the assumption that every π is reabsorbed by one of the nucleons if they met in a given range.

Giving credit to this model, a dominance of N^* and S wave production is recognized as compared to the classical photoelectric mechanism (e. m. part).

The interpretation of the angular distribution data appears a bit more complicated: the role of interference terms between e. m. and mesonic contributions is not clear. The same applies to the recent asymmetry data from polarized γ rays (Liu⁽⁷⁾, this experiment).

Concerning the asymmetry parameter $\Sigma(k, \theta)$ defined by

$$(1) \quad \Sigma(k, \theta) = \frac{1}{P} \frac{d\sigma_{\parallel}(P, k, \theta) - d\sigma_{\perp}(P, k, \theta)}{d\sigma_{\parallel}(P, k, \theta) + d\sigma_{\perp}(P, k, \theta)}$$

where :

- P = polarization of the (linearly polarized) γ rays;
- θ = c. m. proton angle;
- $d\sigma_{\parallel(\perp)}$ = differential photodisintegration cross section for production plane parallel (orthogonal) to the polarization vector.

one can definitely say that the results of calculations including only e. m. contributions markedly disagree with the experimental results at energies ≥ 80 MeV.

b) - Experiments.

Results on the photodisintegration cross section have been published by many authors: note in particular in the Toms recollection⁽¹⁾ the work by Keck and Tollestrup extending to $k = 450$ MeV^(x).

Besides the already mentioned peak at $k = 250$ MeV, the cross section shows a peculiar $2 + 3 \sin^2 \theta$ behaviour as a function of the c. m. proton angle at the resonance. This can be attributed to magnetic dipole absorption as expected if the N^* contributes.

We are mainly concerned with measurements of the asymmetry parameter $\Sigma(k, \theta)$ in the energy range in which meson currents play the relevant role; previous measurements of Σ have been published by Liu⁽⁷⁾ for the θ values 45° , 90° , 135° and $k \lesssim 230$ MeV, that is just below the resonant peak.

- (x) - Recent data by a group at Bonn⁽⁸⁾ disagree with all previous results. As far as we know this discrepancy is not yet understood. Accurate data in the high energy region ($500 \leq k \leq 1000$ MeV) have been recently given by R. Ching, C. Schaerf⁽⁹⁾.

2 - THE EXPERIMENTAL APPARATUS.

A polarized γ ray beam is one of the facilities of the Frascati electron synchrotron (Barbiellini et al. ⁽¹⁰⁾). This beam is obtained by the crystal technique whereas the beam used by Liu is obtained by the angular sampling technique (Mozley et al. ⁽¹¹⁾). In both cases the head of the γ ray spectrum is at higher energies than those of the polarized γ rays so that a selection of the photodisintegration among π photo-production processes (p. p. π .) is desirable when p. p. π . comes into play. At Frascati the γ beam pulse length is ~ 2 msec allowing for neutron-proton coincidences so that the energy range can be extended to about 400 MeV; at this energy the linear polarization of the γ rays is still fairly good. The counting rate however falls dramatically, down, as the cross section does (see fig. 1).

The contamination to be expected in the p - n coincidences due to p. p. π . has been estimated by using the total p. p. π . cross section (White et al. ⁽¹²⁾) and a phase space distribution of the reaction products. This contamination is completely negligible.

The asymmetry data in this experiment have been taken in two different runs in which both the γ ray beam and the experimental apparatus were slightly changed. In run n. 1 the polarized beam was obtained by the technique described in ref. (10). In this run the polarization vector was either parallel or orthogonal to the production plane according to the symbols used in formula (1).

In run n. 2 the crystal orientation was changed to a new working point giving better beam polarization, as suggested by G. Bologna⁽¹³⁾. In this run however the polarization vector was rotated by 13° with respect to the previous axes so that the effective polarization was smaller than expected by a factor $\cos 26^\circ = 0.90$.

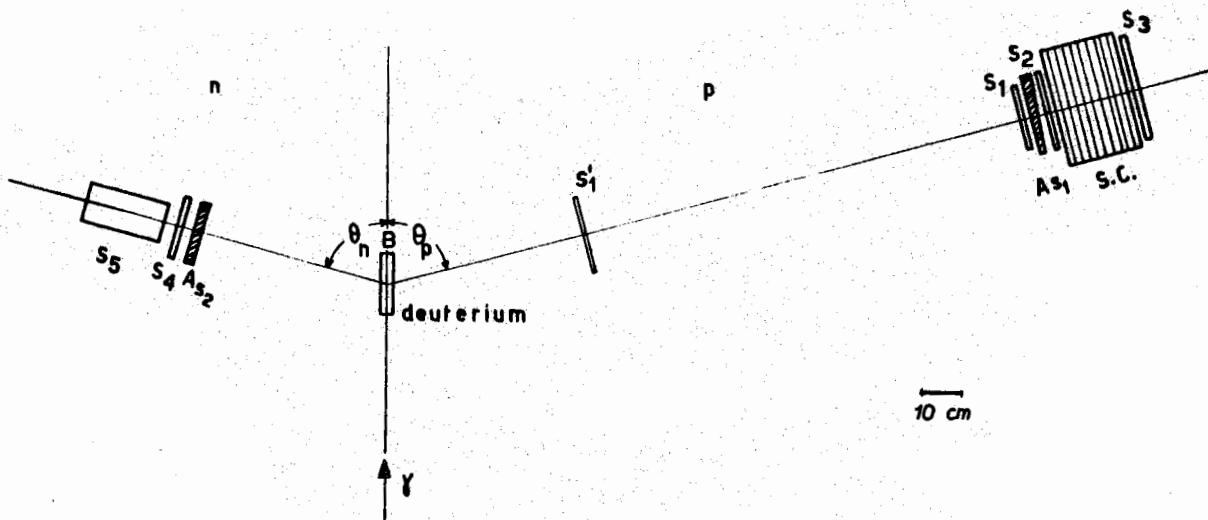


FIG. 2 - Experimental apparatus.

Fig. 2 shows the experimental apparatus used in the run n. 2; it consists of a proton range telescope $S'_1 S_1 S_2$ (S. C.) \bar{S}_3 (S are scintillation counters, S. C. is a 31 plate spark chamber) and a neutron counter $\bar{S}_4 S_5$ on the other side of the target.

In fig. 3 the block scheme of electronics is given. The spark chamber was triggered by $(S'_1 + S_1 + S_2 + \bar{S}_3 + S_5) - (S'_1 + S_1 + S_2 + \bar{S}_3 + S_5 + \bar{S}_4)$.

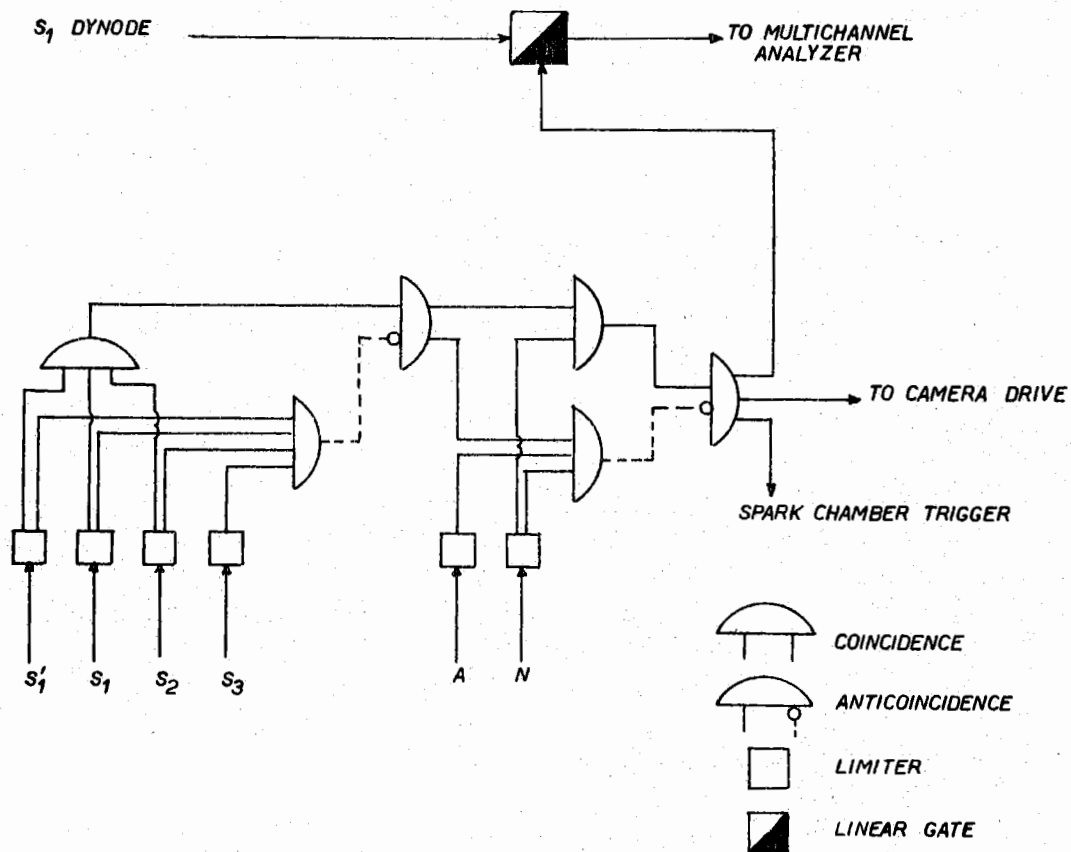


FIG. 3 - Electronics block scheme.

Detailed characteristics of the apparatus are as follows :

- S'_1 is a $20 \times 10 \times 0.3 \text{ cm}^3$ plastic scintillator;
- S_1 is a $16 \times 16 \times 1 \text{ cm}^3$ plastic scintillator, 160 cm far from the target;
- AS_1 is a wedge shaped aluminium absorber;
- S_2 is a $20 \times 20 \times 0.3 \text{ cm}^3$ plastic scintillator;
- S. C. is a $29 \times 29 \text{ cm}^2$ front area spark chamber (31 plates, 1 mm Al each);
- \bar{S}_3 is a $29 \times 29 \times 1 \text{ cm}^3$ plastic scintillator (in anticoincidence);
- AS_2 is a 3 cm thick lead absorber to eliminate soft charaded particles;

6.

\bar{S}_4 is a $25 \times 25 \times 1 \text{ cm}^3$ plastic scintillator, 50 cm far from the target (in anticoincidence);

S_5 is a liquid scintillator (NE 213) cylindrical neutron counter, 25 cm deep, 20 cm base diameter.

In run n. 1 counter S_1 was not present and counter S_2 was 1.25 cm thick. The addition of S_1 in run n. 2 gave a better confidence in the performances of the proton telescope by allowing time of flight discrimination of the background pions at the lower energies. Discrimination was also checked by pulse height analysis from S_1 . Both these modifications from run n. 1 to run n. 2 were not strictly necessary: some overlapping points have been taken in the two runs and they agree well within the statistical errors.

The solid angles and the neutron counter efficiency have not been accurately determined since ratios of cross sections are not affected by them (the proton telescope is about 10 msterad wide and the neutron counter efficiency is 10 - 15%: this helps in estimating the counting rate).

The target was a liquid deuterium cylinder 15 cm long, 3 cm base diameter.

Due to the near proportionality of the σ ray energy to the proton kinetic energy, the crystal bremsstrahlung peak can be reproduced in the spark chamber S. C. as a peak in a curve counts versus range. This allows a good energy calibration by comparison of the proton spectrum shape to the one obtained by a pair spectrometer, as shown in fig. 4.

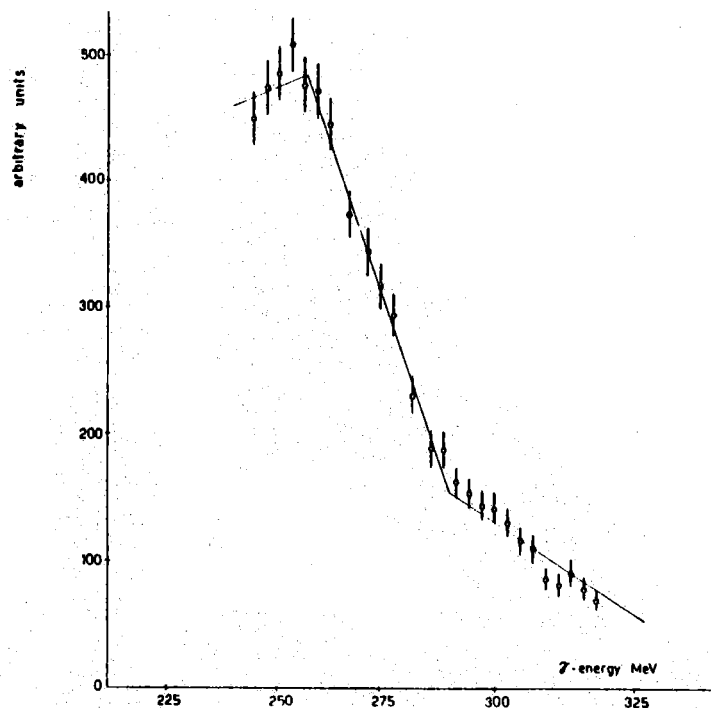


FIG. 4 - Typical coherent bremsstrahlung peak as seen by the proton range spectrum in the spark chamber.

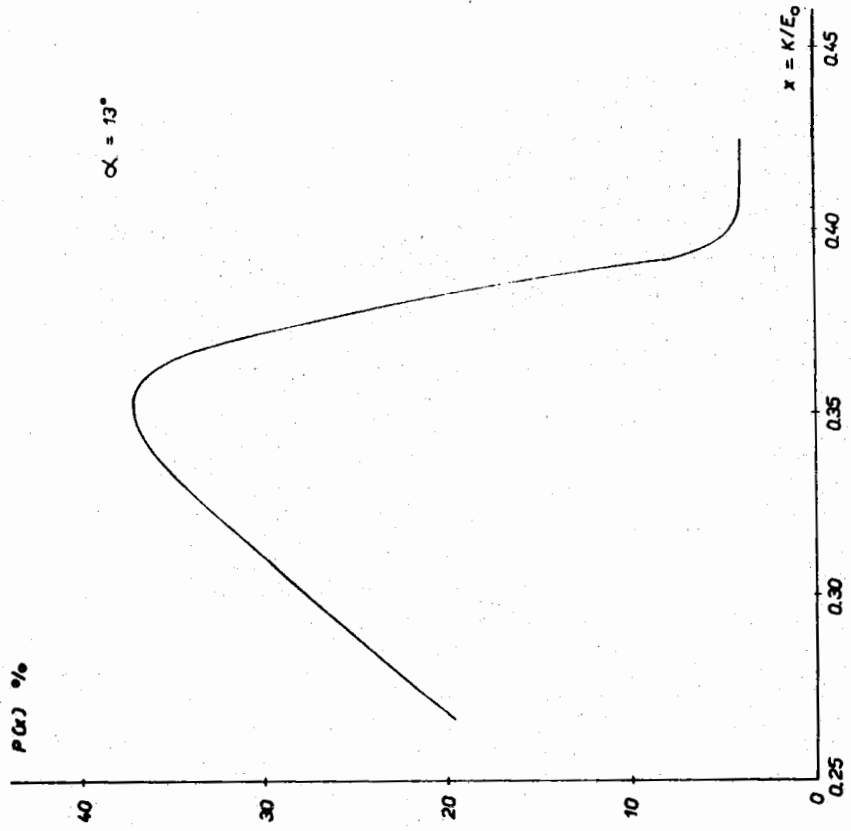
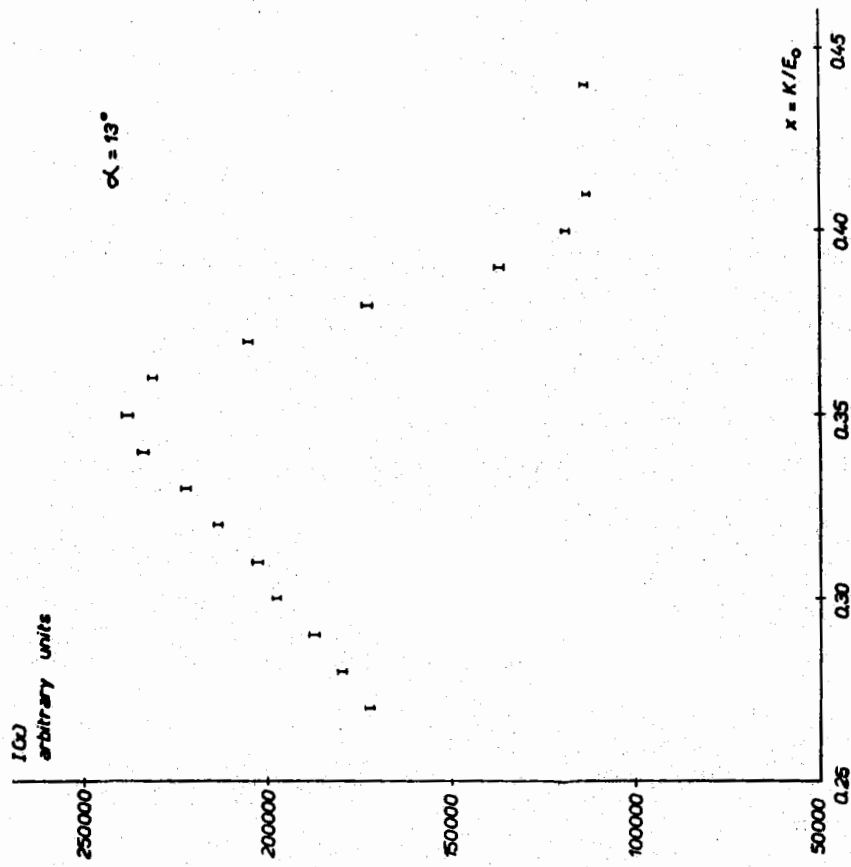


FIG. 5a) - Typical bremsstrahlung spectrum used in run 2 as seen by the pair spectrometer.

FIG. 5b) - Beam polarization as a function of the fractional photon energy corresponding to the spectrum shown in fig. 5a).

3 - THE POLARIZED γ -RAY BEAM.

The spectrum and the polarization of the γ rays from the diamond radiator in the synchrotron have been chosen by calculating the orientation of the crystal in order that the photons in the coherent peak corresponded to the accepted angle and energy intervals of the proton. The coherent peak was subsequently checked by determining the spectrum with a pair spectrometer. The same spectrum was also checked in one case by reproducing the peak in the spark chamber as shown in fig. 4.

The polarization was computed following the procedure described in ref. (10) with the improvements of a more correct atomic model and several experimental corrections (such as multiple scattering and so on), as calculated by G. Bologna.

Fig. 5a shows a typical spectrum as used in run 2. The polarization corresponding to this spectrum is shown in fig. 5b. The behaviour of the peak polarization as a function of the peak energy of the coherent bremsstrahlung is also shown in fig. 6. These curves are labeled $\alpha = 13^\circ$ to indicate the orientation of the polarization vector in run 2 as mentioned in par. 2.

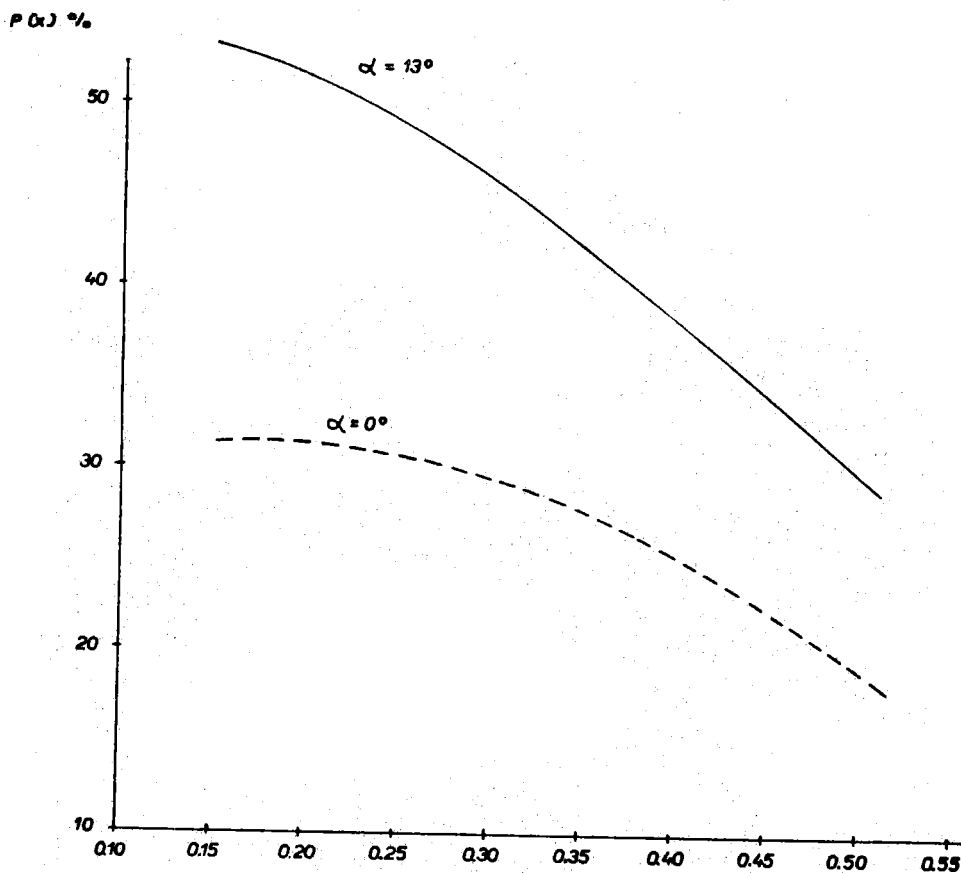


FIG. 6 - The peak polarization as a function of the fractional peak photon energy.

The peak polarization referring to the crystal parameters in run 1 is also shown in fig. 6 where it is labeled $\alpha = 0^\circ$.

4 - RESULTS.

By using the experimental apparatus described above, points have been measured giving the asymmetry function $\Sigma(\theta, k)$ at $\theta = 90^\circ$ (c. m. proton angle) and various laboratory photon energies k . The data are summarized in the Table I. Error estimates on P have not been included.

TABLE I - Table of the results.

k	P	Σ	$\delta \Sigma$	Δk
235	0.29	0.276	± 0.038	24
253	0.25	0.330	± 0.090	19
260	0.37	0.228	± 0.028	21
277	0.30	0.260	± 0.070	22
310	0.30	0.350	± 0.040	11
330	0.34	0.275	± 0.045	19
380	0.22	0.370	± 0.090	22
404	0.27	0.340	± 0.110	24

$k, \Delta k$ in MeV

The statistical error on Σ has been computed by

$$(2) \quad \frac{\delta \Sigma}{\Sigma} = \frac{\sqrt{1 - (P\Sigma)^2}}{P\Sigma\sqrt{n}}$$

where n is the total number of counts.

The values of the asymmetry parameter Σ in the table have been obtained by averaging over an interval Δk of the energy of the primary γ ray; the value of Δk is given in the table.

The results are also shown in fig. 7 together with some of the points measured by Liu⁽⁷⁾ in the high energy region.

There is no theoretical prediction for the asymmetry parameter above the first resonance. If the process were dominated by π^+ photopro

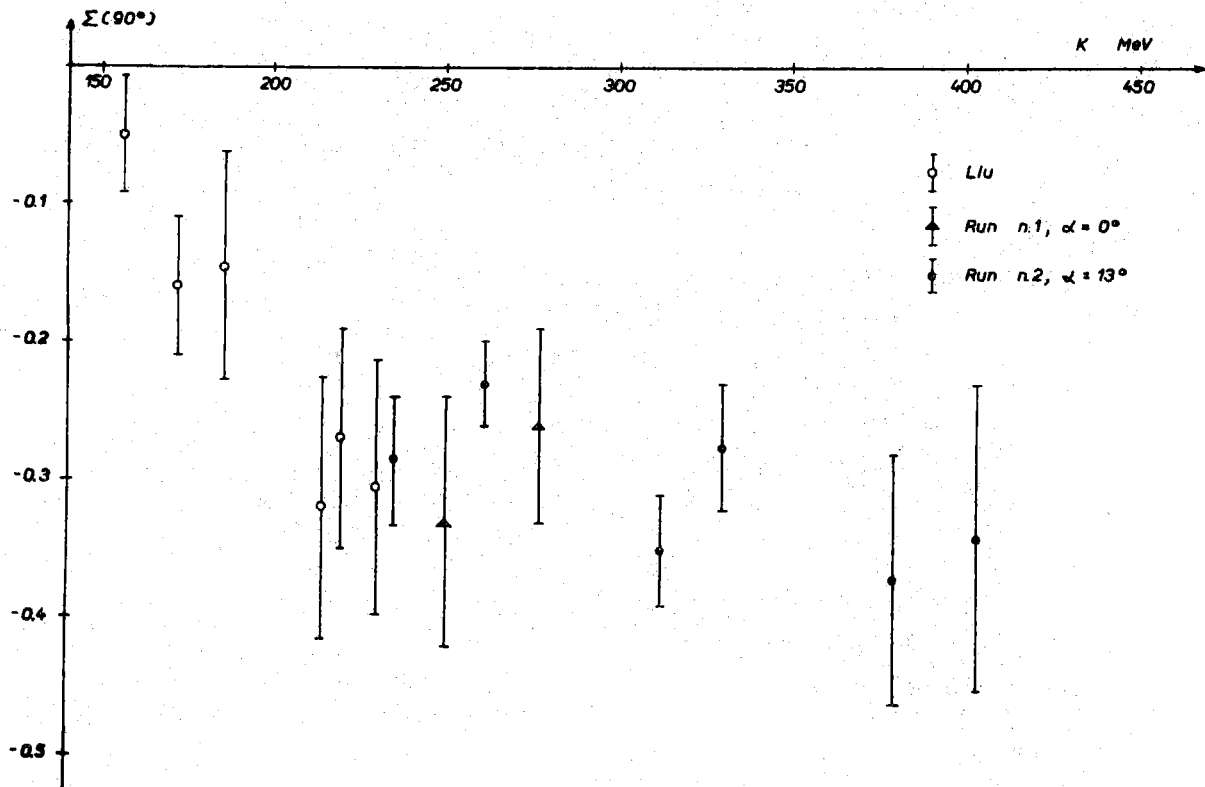


FIG. 7 - Experimental results for the asymmetry function Σ at 90° in the c. m. system. Symbols are as follows: hollow circle - Liu⁽⁷⁾; solid triangle - present experiment run n. 1; solid circle - present experiment run n. 2.

duction and reabsorption as suggested by Wilson, the asymmetry in the photodisintegration should bear some resemblance to the corresponding asymmetries in the photoproduction of π^0 and π^+ (actually a suitable mixture of the two). The presently known results for the photoproduction of π 's are given in reference (14, 15, 16). We just notice that both in the photodisintegration and the photoproduction processes the asymmetry behaves in a similar way being monotonic and having the same sign all over the investigated energy interval.

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