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ABSTRACT

Differential cross sections for the $^{2}H(\gamma,p)n$ reaction were measured at five laboratory angles, from 32° to 130°, for photon energies between 100 and 250 MeV. The LEALE quasi-monochromatic photon beam, obtained at Frascati by positron annihilation on liquid hydrogen target, was used; the photon beam spectrum was measured on-line by a pair spectrometer. Preliminary values of angular distributions and total cross sections at three laboratory photon energies are presented.

The photodisintegration of the deuteron is important for the knowledge of the neutron-proton interaction and the interaction of electromagnetic radiation with nucleons. In spite of the considerable amount of effort both theoretical and experimental spent up to now on studies of this reaction, knowledge of the cross section for deuteron photodisintegration is still unsatisfactory. This is true, in particular, in the energy region between the pion emission threshold and the $\Delta(1236)$ resonance, where the reaction is increasingly influenced by mesonic effects. In fact here the range of variation of the results reported by different Laboratories (Ref. 1-12) is well outside any reasonable estimate of the experimental errors. On the other hand, in this energy region, different theoretical approaches (Ref. 13-19) are able to describe the general features of the cross section, but they still differ from each other. Moreover the modifications introduced by the use of different realistic potentials, the addition of explicit exchange effects, the introduction of isobar configurations result of the same magnitude of the spread between each set of experimental data. Of course, due to the large discrepancy existing between the different experiments, a close comparison between theory and experiment has not been warranted up to now.

The aim of this talk is to present the preliminary results of a new measurement of the deuteron photodisintegration undertaken in view of the need for more reliable data. We have taken advantage of the availability at Frascati of a quasi-monochromatic photon beam, which, though not necessary for the measurement of a two body reaction, obviously offers important advantages.

The experiment was carried out using the LEALE photon beam facility described in details in Ref. (20). The positron beam of the Frascati Linac strikes a 0.0118 radiation lenghts thick liquid hydrogen target and produces a quasi-monochromatic photon beam. After passing through the annihilation target, the positrons are sweeped off from the photon beam and deflected into a Faraday cup, which measures the absolute value of the positron current.

The layout of the experimental apparatus is shown in Fig. 1. A rectangular flat pole c-type magnet is used as an on-line pair spectrometer (Ref. 21). Photons

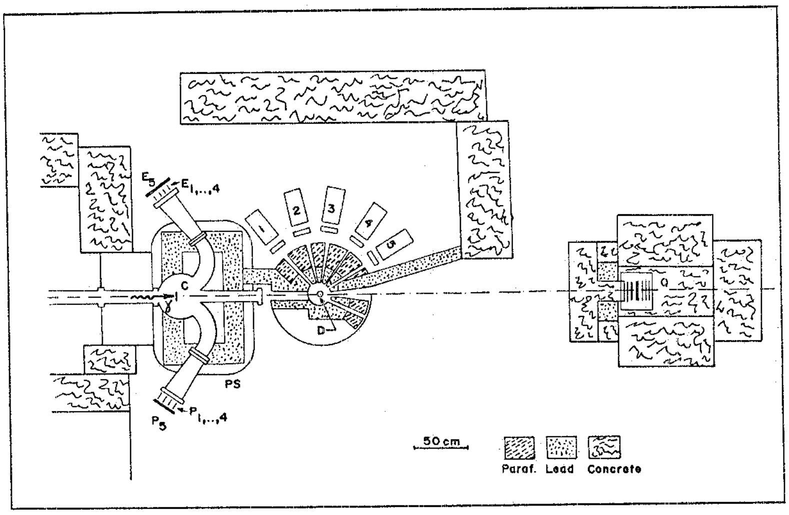

FIG. 1 - The experimental set up for $^2H(\gamma,p)n$ reaction study: PS pair spectrometer, with the associated electron (E_i) and positron (P_i) detection systems; D liquid deuterium target, 1÷5 E-dE/dx telescopes, Q quantameter.

enter the magnetic field region through a hole opened in the yoke of the magnet and are converted into an (e^-e^+) pair in a thin ($\lesssim 5\ 10^{-4}$ radiation lenghts thick) aluminium target. Electrons and positrons are detected by two identical arrays of four counters (E_i, P_i), set along the focal plane of the spectrometer, followed by a fifth back counter (E_5, P_5). In order to reduce background production from air, the photon beam is transported under vacuum from the hydrogen target up to the pair spectrometer exit window.

Having passed through the deuterium target the photon beam is finally absorbed in a Komar et al. type quantameter (Ref. 22), which provides a constant sensitivity in our energy range.

As a target a vertical mylar cylinder (4.0 cm diameter, wall thickness 0.08 mm), filled up with liquid deuterium, was used. The target was equipped with a two stages local refrigerator (Cryodine helium refrigerator mod. 360) installed directly on the deuterium cell. A series of termoresistors, placed in the cell and inside the refrigerator, monitored the level of liquid deuterium and ensured the automatic operation of the system. By monitoring continuously the deuterium vapor pressure we were able to keep the liquid deuterium density constant within 2% (Ref. 23).

The photon beam spot on the target had a circular shape of 3.8 cm diameter and was frequently measured with a beam profile monitor (Ref. 24) which could be inserted on the channel just after the pair spectrometer. The target vacuum chamber entrance and exit windows, of $4.4\ 10^{-3}$ mm mylar sheet, were situated at sufficient distance from the deuterium cell to prevent a directly line of sight between the windows and any detector.

Charged particle from the target were detected in five dE/dx and E telescopes connected on-line to a PDP 15/76 computer. In order to determine absolute cross sections the effective target volume along the beam for each detector was defined by two accurately machined slits: the front one, rectangular in shape, was 2 cm wide and 5 cm high, while the rear one was circular of 3.5 cm radius.

In order to minimize corrections for scattering and absorption, each employed telescope was a dual scintillator counter system (Ref. 25). The front counter gave a measure of dE/dx. It consisted of a 3 mm thick NE102A scintillator connected to two Philips 56 AVP photomultipliers by means of light-pipes formed by six sectors in order to assure a good homogeneity and optical efficiency. The back counter, a 5 cm radius x 12 cm high NaI crystal coupled to a 58 AVP Philips photomultiplier, gave a simultaneous measurement of the total energy E. The anode pulses from the 58 AVP were shaped with a 50 ns shorted delay line, permitting measurements to be made at high counting rates without pile-up affecting the coincidence resolution of the telescope.

The stored data were presented as a dE/dx against E plot and the particle discrimination was found to be sufficient to distinguish unambiguously protons from other particles.

Proton spectra were simultaneously recorded at lab angles of 32.5°, 55°, 80°, 105° and 130° with respect to the photon beam and for seven annihilation photons lab energies (100, 120, 140, 180, 205, 227 and 250 MeV). The measurements were made in several runs distributed over two years and the data from each run were separately analyzed so that results from the individual runs could be compared. This provided a check for systematic errors arising from factors in the experimental conditions which could have varied from run to run. The results of different runs up to now analyzed were indeed constistent within the 5%.

The stability of the electronics was regularly checked both with a precision pulse generator, whose wave form was a close approximation to that produced by a photomultiplier viewing the NaI crystal, and with the 4.43 MeV gamma radiation from an Am-Be source.

Fig. 2a) shows a typical photon energy spectrum measured on-line at the given positron energy, E, and photon collection angle, θ_γ. The full line curve represents the result of a Monte Carlo simulation (Ref. (26) which also reproduces the photon total energy measured by the quantameter. The excellent agreement between the computed and the measured spectra was obtained by slightly adjusting the values of two input quantities (positron emittance and photon collection angle) by amounts within the experimental errors. Fig. 2b) shows the simultaneous proton energy spectra measured by the five dE/dx-E telescopes. The line curves are only a guide for the eye. The photoproton peak, due to the annihilation contribution, is clearly evident at all angles, showing the

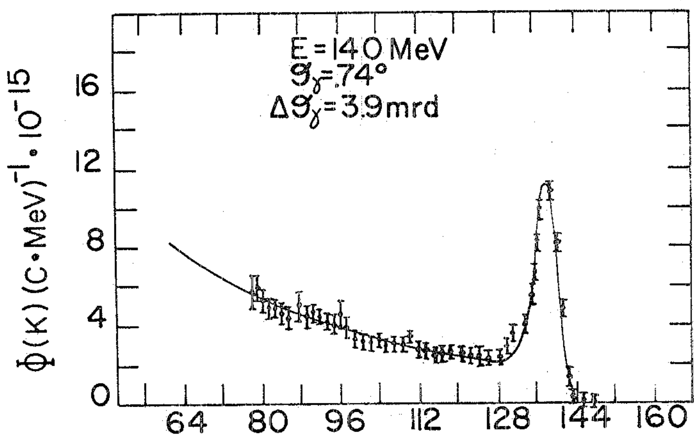

FIG. 2a) - Photon energy spectrum measured with the pair spectrometer at the given positron energy E, photon collection angle θ_γ and half angular geometric photon acceptance $\Delta\theta_\gamma$. The full line curve is a result of a Monte Carlo calculation.

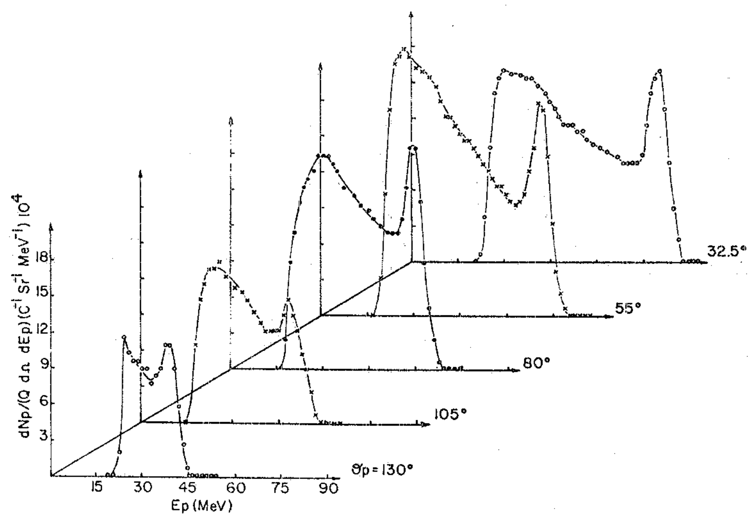

FIG. 2b) - Proton energy spectra measured with the E-dE/dx telescopes at the settled values of the laboratory proton angle θ_p. The solid line curves are only a guide for the eye.

remarkable improvement in data quality given by the use of a quasi-monochromatic photon beam.

A Monte Carlo computing program has been used to account for the effects of finite photon beam and target dimensions on the proton detectors. The program had as input quantities the measured photon energy spectrum and the complete geometry of the system. It enabled to calculate all the experimental corrections (effective solid angle value, multiple scattering, energy loss and nuclear absorption corrections) required to reproduce satisfactorily the measured proton spectrum in the peak region. Moreover, by using also the bremsstrahlung contribution this program made it possible to extend the determination of the cross section at photon energies lower than the peak energy, and to check the consistency of the cross section values obtained by using positron beam of different energies.

The preliminary results of the differential cross sections in the centre-of-mass system are plotted in Fig. 3 as a function of angle, for the given laboratory photon energies. In the figure are also shown experimental results from other experiments and recent theoretical calculations.

The values found in this experiment show the same qualitative features known from earlier studies: the angular distribution increases slowly with increasing angle in the forward region, reaches a maximum somewhere between 60° and 90°, and gradually decreases at backward angles. Of older data the set showing a moderately agreement with our values are those from Illinois (Whalin et al. (Ref. 1)). The same consideration applies to the Caltech data (Keek et al. (Ref. 3)), with the exception of data points at E_γ =100 MeV. The data of Buon et al. (Ref. 6) and Kose et al. (Ref. 4) are about 20% lower, while those of Dougan et al. (Ref. 9) are a bit higher.

The dotted curve represents a preliminary result from Arenhövel and Leideman (Refs. 16 and 17), who extended their low energy calculation up to the pion photoproduction threshold region, adding explicit MEC contribution beyond the Siegert operator, but neglecting inelasticities due to the opening of real pion production channel.

The dot-dashed line is the result of a recent calculation performed by Laget (Ref. 15) using a digram expansion technique with inclusion of final state interaction in S wave only. In this calculation Laget has used the values Λ_π=1.2 GeV, for the πNN form factor, and G_ρ^2/G_π^2=1.6, for the ρ coupling constant.

The full line curve refers to results from Cambi, Mosconi and Ricci (Ref. 18) who have studied the effect of higher-order contributions to the one-body (Darwin-Foldy and spin orbit terms plus relativistic correction to the wave functions) and to the two-body (one-pion-exchange in pseudoscalar coupling) charge densities.

The calculations have been performed using the Paris potential in Ref. 17) and 18), and the Reid one in Ref. 15).

All three curves reproduce the general trend of our data: the agreement is closer for Laget and for Mosconi et al. values, while the Arenhövel and Leideman results are roughly 20÷25% too high.

The measured differential cross sections (plus the values obtained at ϑ_p=0° by Hughes et al. (Ref. 10)) were fitted by a second order polynomial of the form

$$\frac{d\sigma}{d\Omega} = a_o + a_1 \cos\vartheta + a_2 \cos^2\vartheta$$

with photon energy dependent coefficients a_i. The integration of this function

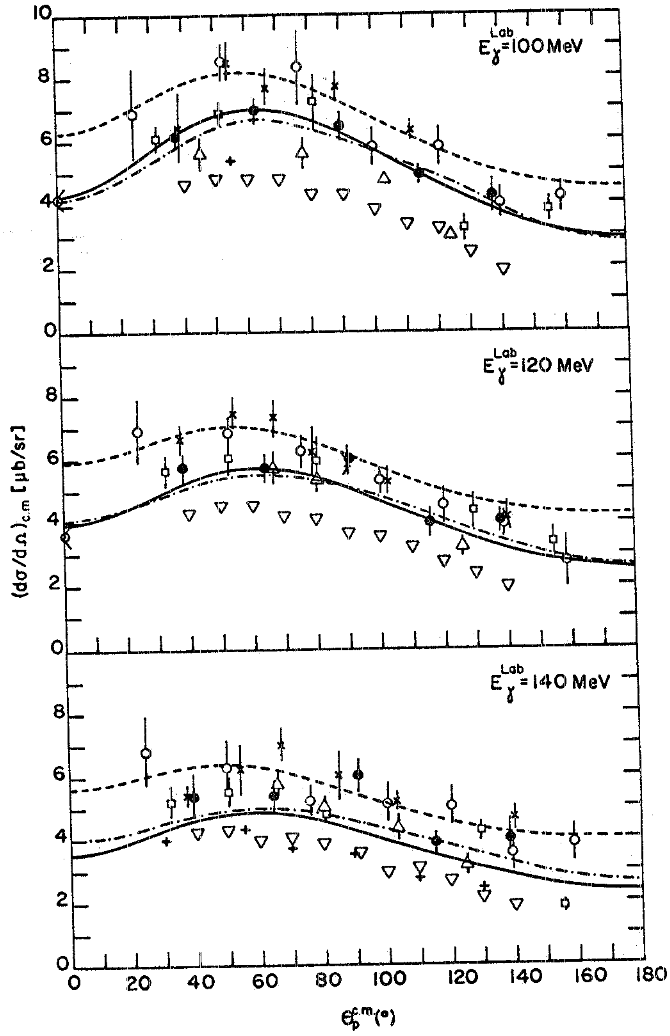

FIG. 3 - Centre of mass differential cross section as a function of centre of mass angles for the given laboratory photon energies. Our data ● are compared to the results of earlier measurements: ⊙ Hughes et al. (Ref. 10); o Alexandrov et al. (Ref. 2); △ Keck et al. (Ref. 3); □ Whalin et al. (Ref. 1); x Dougan et al. (Ref. 9); + Buon et al. (Ref. 6); ▽ Kose et al. (Ref. 4) and to theoretical calculations by Mosconi et al. (Ref. 18) (solid line), by Arenhövel and Leideman (Ref. 17) (dashed line) and by Laget (Ref. 15) (dot-dashed line).

yields the total cross sections as a function of E : $_T=4\ (a_0+a_2/3)$. In Table I the values of $_T$ so obtained are compared with those of previous measurements and of theoretical predictions. Again a better agreement is found with Whalin et al. data and with Mosconi et al. and Laget results.

TABLE I - Total centre-of-mass cross section values for the given laboratory photon energy E_γ .

E_γ (MeV)	Whalin et al. (Ref. 1)	Aleksandrov et al. (Ref. 2)	Keck et al. (Ref. 3)	Kose et al. (Ref. 4)	Buon et al. (Ref. 6)	Dougan et al. (Ref. 9)	This Work	Laget (Ref. 15)	Arenhövel et al. (Ref.17)	Mosconi et al. (Ref. 18)
100	71.2	77.3±5		47.5±1.4		91.9	67.5±2.2	68.0	84.25	69.53
105	67		57.0±4							
114	64		57							
120		61.4±5		43.8±0.8			61.1±2.2	57.5	73.38	57.37
125						72.1				
140	54		54.5±2	41.2±0.9	41.6±1	65.1	56.2±2.3	53.5	66.71	49.34
150	54	68.2±5								

In conclusion we stress that the use of a quasi-monochromatic photon beam, the simultaneous measurement of energy spectrum, total energy and profile of the photon beam are important improvements for a correct determination of the absolute value of the deuteron photodisintegration cross section.

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References

1) E.A. Whalin, B.D. Schriever and A.O. Hanson, Phys. Rev., 101, 377 (1956).
2) A. Aleksandrov, N.B. Delone, L.I. Slovokhotov, G.A. Sokol and L.N. Shtarkov, Soviet Phys. JEPT, 6, 472 (1958).
3) J.C. Keck and A.V. Tollestrup, Phys. Rev. 101, 360 (1958).
4) R. Kose, W. Paul, K. Stockhorst and K.H. Kissler, Z. Physik 202, 364 (1967).
5) A.M. Smith, S.J. Hall, B. Mann and D.T. Stewart, J. Phys. A (Proc Phys. Soc.) Ser. 2, Vol. 1 (1968) p. 553.
6) J. Buon, V. Gracco, J. Lefrancois, P. Lehmann, B. Merkel and Ph. Roy, Phys. Letters 26B, 595 (1968).

7) R.L. Anderson, R. Prepost and B.H. Wiik, Phys. Rev. Letters 22, 651 (1969).

8) D.I. Sober, D.G. Cassel, A.J. Sadoff, K.W. Chen and P.A. Crean, Phys. Rev. Letters, 22, 430 (1969).

9) P. Dougan, T. Kivikas, K. Lugner, V. Ramsay and W. Stiefler, Z. Physik A276, 55 (1976); P. Dougan, V. Ramsay and W. Stiefler, Z. Physik A280, 341 (1977).

10) R.J. Hughes, A. Zieger, H. Waffler and B. Ziegler, Nuclear Phys. A267, 329 (1976).

11) K. Baba, I. Endo, H. Fukuma, K. Inoue, T. Kawamoto, T. Ohsugi, Y. Sumi, T. Takeshita, S. Uehara, Y. Yano and T. Maki, Phys. Rev. Letters 48, 729 (1982).

12) J. Arends, H.J. Gassen, A. Hegerath, B. Mecking, G. Nöldeke, P. Prenzel, T. Reichelt, A. Voswinkel and W.W. Sapp, Bonn Intern. Report BONN-HE-83-1 (1983).

13) K. Ogawa, T. Kamae and K. Nakamura, Nuclear Phys. A340, 451 (1980).

14) M. Anastasio and M. Chemtob, Nuclear Phys. A364, 219 (1981).

15) J.M. Laget, Nuclear Phys. A312, 265 ('1978), and private communication.

16) H. Arenhövel, Nuclear Phys. A374, 521c (1982), and Nuovo Cimento 76C, 256 (1983).

17) H. Arenhövel and W. Leideman, contribution to this Workshop and private communication.

18) A. Cambi, B. Mosconi and M. Ricci, Phys. Rev. C26, 2358 (1982); Jour. of Phys. G, in press; contribution to this Workshop and private communication.

19) W-Y.P. Hwang, J.T. Londergan and G.E. Walker, Ann. of Phys. 149, 335 (1983).

20) G.P. Capitani, E. De Sanctis, C. Guaraldo, P. Di Giacomo, V. Lucherini, E. Polli, A.R. Reolon, R. Scrimaglio, M. Anghinolfi, P. Corvisiero, G. Ricco, M. Sanzone and A. Zucchiatti, Frascati Report LNF-82/80 (1982) and Nuclear Instr. & Meth., in press.

21) G.P. Capitani, E. De Sanctis, C. Guaraldo, P. Di Giacomo, V. Lucherini, E. Polli, A.R. Reolon and R. Scrimaglio, Nuclear Intr. & Meth. 178, 61 (1980).

22) A.P. Komar, S.P. Kruglov and I.V. Lopatin, Nuclear Instr. Meth. 82, 125 (1970).

23) M. Albicocco and A. Viticchié, LEALE Internal Memorandum, unpublished.

24) M. Albicocco, G.P. Capitani, E. De Sanctis, P. Di Giacomo, C. Guaraldo, V. Lucherini, E. Polli and A.R. Reolon, Nuclear Instr. & Meth. 203, 63 (1982).

25) A. Zucchiatti, M. Sanzone and E. Durante, Nuclear Instr. & Meth. 129, 467 (1975).

26) G.P. Capitani, E. De Sanctis, P. Di Giacomo, C. Guaraldo, V. Lucherini, E. Polli, A.R. Reolon and V. Bellini, Nuclear Instr. & Meth. 203, 353 (1982).