

ISTITUTO NAZIONALE DI FISICA NUCLEARE
Laboratori Nazionali di Frascati

LNF-85/24(P)
3 Giugno 1985

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MeV

Talk given, by E. De Sanctis, at Intern. Symp. on "Mesons and Light
Nuclei", Bechyně Castle, May 27th - June 1st 1985.

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DEUTERON PHOTODISINTEGRATION BETWEEN 100 MeV AND 255 MeV⁽¹⁾

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ABSTRACT

Differential cross sections for the $d(\gamma,p)n$ reaction were measured at five laboratory angles, from 32° to 130° , for seven photon energies (100, 120, 140, 180, 200, 220 and 255 MeV). A quasi-monochromatic photon beam was used and the photon spectrum was measured on-line by a pair spectrometer. The absolute normalization uncertainty is within $\pm 5\%$. Data agree, within the total errors, with results of recent monochromatic photons experiments.

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- (1) Presented by E. De Sanctis at the International Symposium on "Mesons and Light Nuclei", Bechyně Castle, Czechoslovakia, May 27th - June 1st, 1985.
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The photodisintegration of deuteron has been fairly extensively studied both by experimentalists and theoretists, because this process can provide a basic information on the properties of nuclear forces, the effects of intrinsic degrees of freedom of a nucleon on nuclear properties, the N-N resonances interaction, and exotic multiquark excited states (dibaryon resonances). Nevertheless, in spite of the considerable effort spent up to now on these studies, knowledge of the deuteron photodisintegration cross section is still unsatisfactory. This is in particular true in the energy region between the pion emission threshold and the $\Delta(1236)$ resonance, where the spread of experimental values^{/1-3/} covers a factor of two in absolute normalization, well outside the published error limits. On the other hand, in this energy region, where mesons exchange currents and isobar phenomena give relevant contributions, several theoretical approaches (Ref. 4-10) are able to describe the general features of the cross section, but they still differ from each other. Of course, due to the large discrepancy existing between experiments, a detailed comparison between theory and experiment has not been warranted up to now.

Recently, the development of advanced computational capabilities and of new techniques for producing monochromatic photon beams has pushed the $d(\gamma, p)n$ reaction into the forefront of renewed theoretical and experimental interest.

Here are reported the results of a new experiment on the deuteron photodisintegration at intermediate energies, performed in view of the need for more reliable data. The measurement was carried out using the LEALE photon beam^{/11/} produced at Frascati by in-flight positron annihilation. The layout of the experimental apparatus is shown in Fig. 1. Positrons left the beam pipe through an aluminium window (0.05 mm thick) and annihilated on a liquid hydrogen target H₂ (0.0118 radiation lengths thick). The intensity of the positron beam was continuously monitored by a non-intercepting ferrite toroid, M, and measured by a Faraday cup (also used as beam catcher), placed in the focal plane of a damping magnet, S. The photon beam was defined by five cylindrical lead collimators inserted in the yoke of the damping magnet. The next dipole magnet B₇ swept off the charged particles surrounding the beam. A rectangular flat pole C-type magnet was used as an on-line pair spectrometer^{/12/}. Photons entered the magnetic field region through a hole opened in the yoke of the magnet and were converted into an $(e^- e^+)$ pair in a thin ($\approx 5 \cdot 10^{-4}$ radiation lengths thick) aluminium

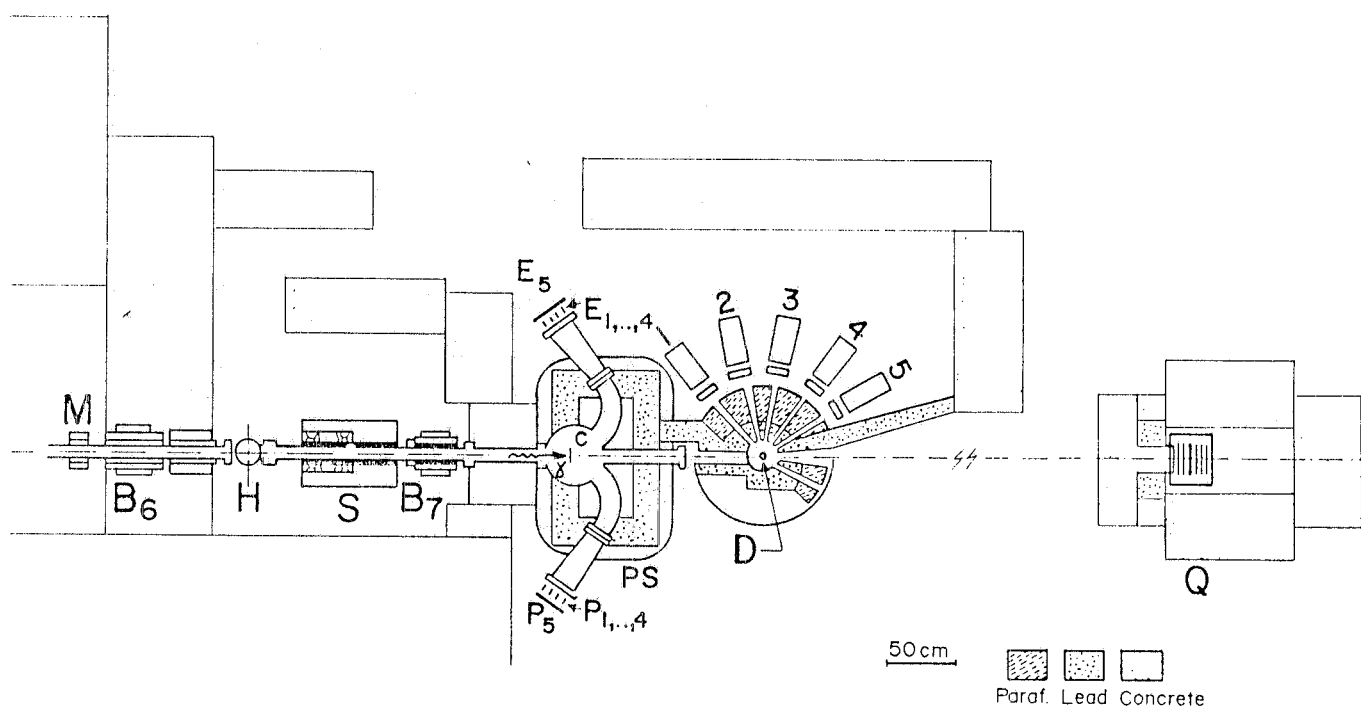


FIG. 1 - The experimental set-up for the $d(\gamma,p)n$ reaction study: M ferrite toroid monitor; B_6 steering magnet; H liquid hydrogen target; S damping magnet; B_7 sweeping magnet; PS pair spectrometer, with the associated electron (E_i) and positron (P_i) detection systems; D liquid deuterium target: 1+5 E- ΔE telescopes; Q quantameter.

target. Electrons and positrons were 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). The total energy of the beam was measured by a total absorbing quantameter. The target was a vertical mylar cylinder (4.0 cm diameter, 10 cm high, wall thickness 0.08 mm), filled with liquid deuterium.

Protons were detected by five telescopes connected on-line to a PDP 15/76 computer. Each telescope consisted of a dual scintillator counter system. The front counter, a 3 mm thick NE 102A scintillator, gave a measure of ΔE . The back counter, a 5 cm radius and 12 cm deep NaI crystal, gave a measurement of the total energy E. The stored data were presented on-line as a ΔE against E plot and the mass discrimination was found to be sufficiently good 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 at annihilation photon energies of 100, 120, 140, 180, 200, 220

and 255 MeV. The measurements were made in several runs distributed over two years and the data from each run were separately analyzed and compared. This provided a check for systematic errors arising from factors in the experimental conditions which might have varied from run to run. The results of different runs were consistent within $\pm 5\%$.

Fig. 2a) shows a typical photon energy spectrum measured on-line at the

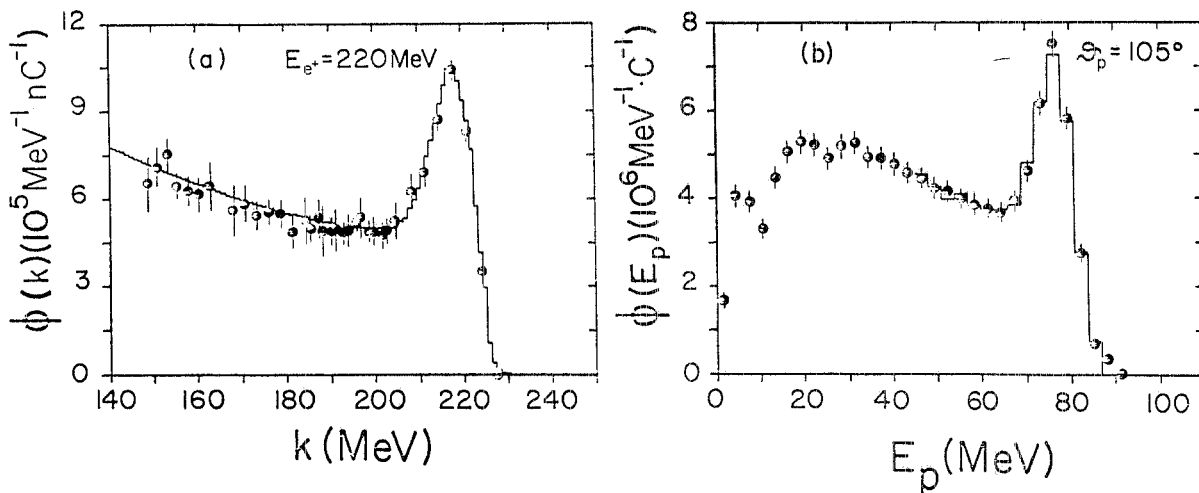


FIG. 2 - a) Photon energy spectrum measured with the pair spectrometer (positron energy 200 MeV, photon collection angle 0.9° and half angular geometric photon acceptance 3.9 mr). The full line curve is a result of a Monte Carlo calculation. b) Proton energy spectrum measured with the telescope set at $\theta_p = 105^\circ$ in the laboratory. The solid line curve is a result of a Monte Carlo calculation.

given positron energy, E_{e^+} , and photon collection angle, θ_γ . The full line curve represents the result of a Monte Carlo simulation (PHOCHA^{13/}) 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 105° telescope. The photoproton peak, due to the annihilation contribution, is clearly evident, showing the remarkable improvement in data quality given by the use of a quasi-monochromatic photon beam. Similar spectra were measured for all the positron

energies and proton angles. The positions and shapes of proton peaks were strictly related to the relevant annihilation photon peaks. Being the proton energy also measured, the reaction was kinematically overdetermined, and the linear dependence of the proton peak energy versus the photon annihilation peak energy provided a check of the proton energy calibration.

A Monte Carlo computing program (TARGET) 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. In Fig. 2b) the full line curve is the result of this Monte Carlo simulation: as shown, the agreement between the computed and the measured spectra is excellent.

At first, only the peaks in the photon and proton spectra were used to determine the cross sections. Subsequently, by means of the TARGET program, it has been possible to determine the cross section also in the bremsstrahlung tail region. This allowed a cross check on the consistency of cross sections obtained at different positron beam energies: good agreement was found between values obtained from the annihilation peaks and those from the bremsstrahlung tails.

The results of the differential cross sections in the centre-of-mass system are plotted, as solid dots, in Fig. 3 for the given laboratory photon energies. The points have been averaged over an energy bin $\Delta E_\gamma = 10$ MeV. The errors quoted are statistical only, and do not include a $\pm 5\%$ systematic uncertainty on the absolute value. Fig. 3 also shows the results of other recent measurements, specifically the radiative neutron-capture experiment of Meyer et al.^{/18/}, and three photodisintegration experiments: the tagged-photon study by Arends et al.^{/3/}, the 0° experiment by Hughes et al.^{/15/} and the 180° experiment by Altoff et al.^{/16/}. The data of Meyer et al.^{/14/} are found to be in agreement with our results within their experimental errors, which include systematic contributions except for the uncertainty on the nucleon-nucleon cross section. The tagged photon data^{/3/} include only statistical errors; when we take into account their ($\pm 4\%$) and our ($\pm 5\%$) systematic uncertainties, the two measurements are compatible. Moreover, it may be worthwhile to note that our data in the 100-140 MeV range are well compatible with the fit obtained by De Pascale et al.^{/17/} from a critical review of

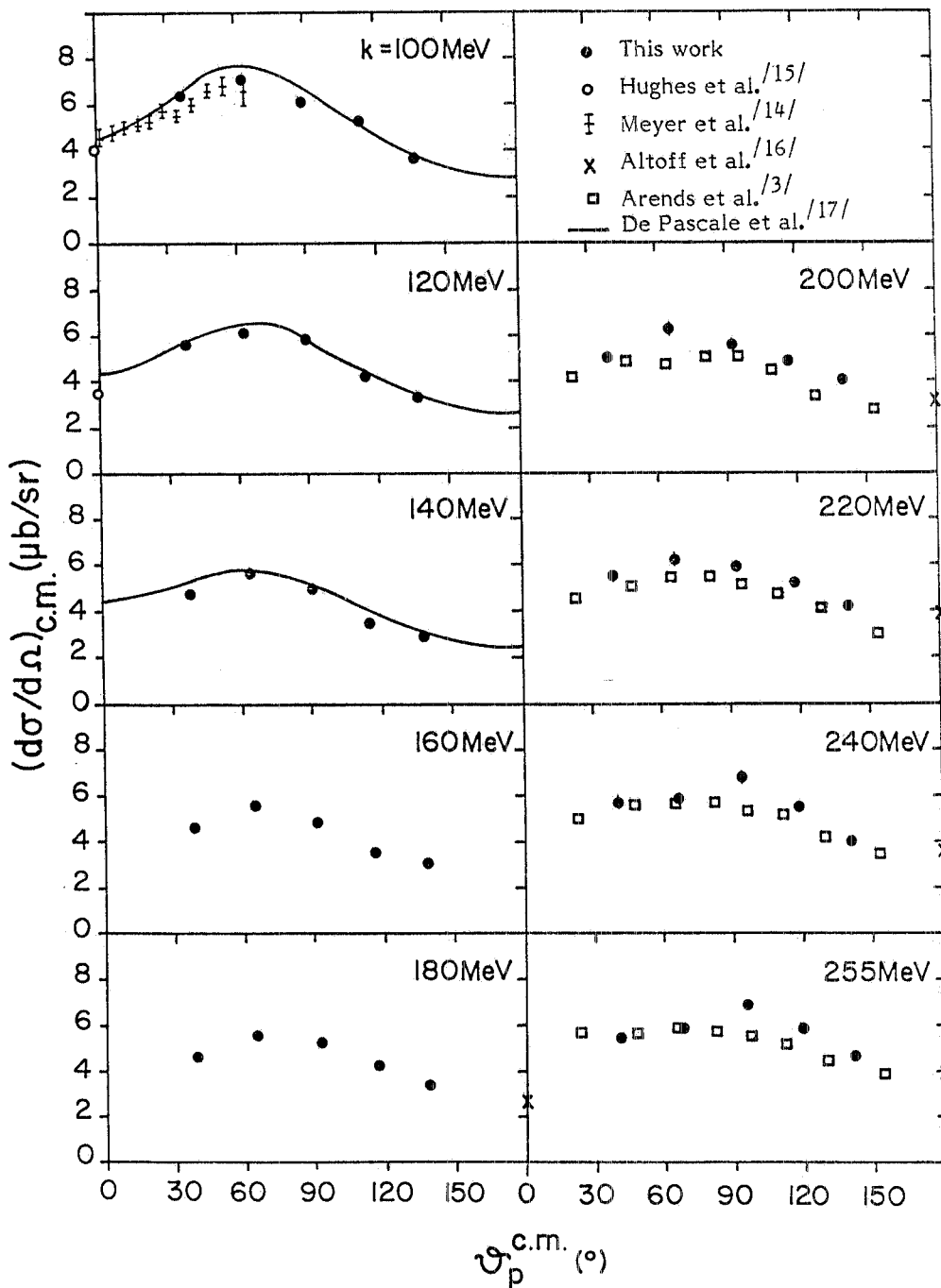


FIG. 3 - Comparison among recent angular distribution measurements for $d(\gamma,p)n$ process. Our point and those of Ref. /3/ do not include systematic errors ($\pm 5\%$ and $\pm 4\%$, respectively).

all the $d(\gamma,p)n$ data in the 6-140 MeV range, published before 1982 (full line curve in the Figure).

Therefore it is definitively encouraging that the new data obtained by using different techniques are found to be in agreement among each other within the quoted total errors. Consequently a stronger constraint is offered to the theory.

Finally in Fig. 4 our data at $E_\gamma=100, 140, 180$ and 220 MeV are compared with the most recent calculations: the dashed line results from a calculation performed

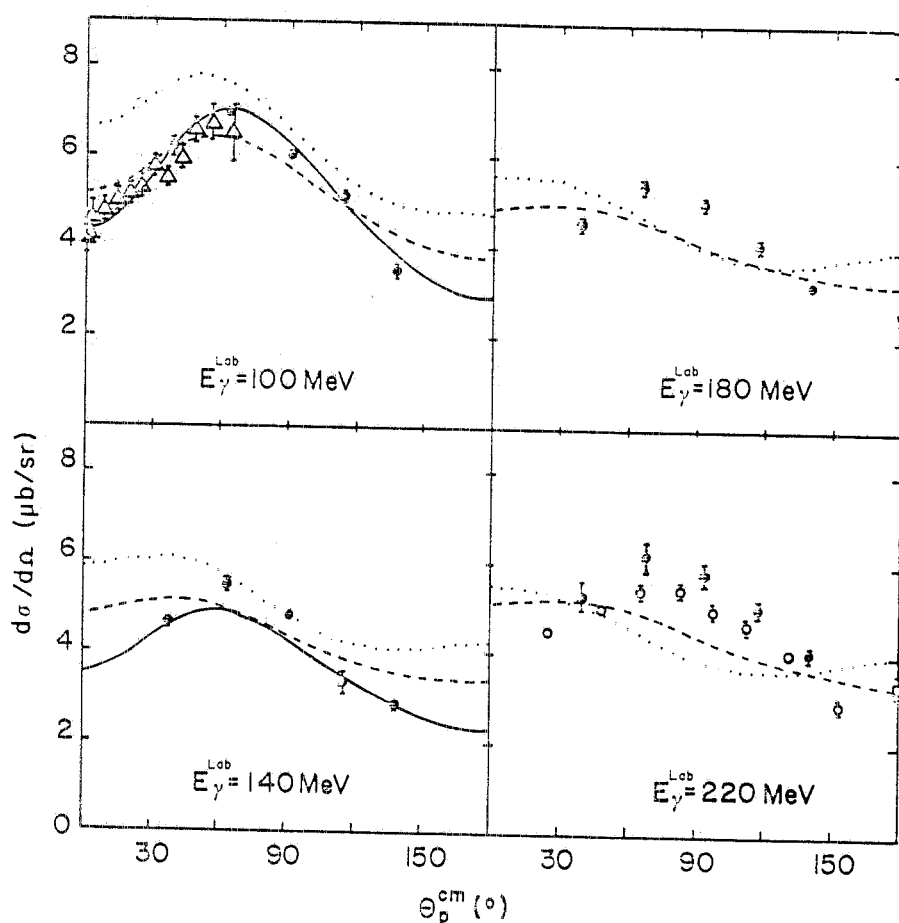


FIG. 4 - $d(\gamma,p)n$ differential cross section for the given photon energies. Our data (solid dots) are compared to most recent experimental results and theoretical predictions: open triangles, Ref. /14/; closed triangles, Ref. /15/; open circles, Ref. /3/; open squares, Ref. /16/; solid line, Ref. /9/; dashed line, Ref. /6/; dotted line, Ref. /8/. Our points and those of Ref. /3/ do not include systematic errors ($\pm 5\%$ and ± 4 , respectively).

by Laget using an expansion of the photodisintegration amplitude in terms of dominant diagrams. Final state interactions are taken into account by including the neutron-proton rescattering in S and P waves. The dotted curve is a result from Leidemann and Arenhövel^{/8/} who have extended their low energy calculation beyond the pion photoproduction threshold with explicit Δ degrees of freedom in a coupled channel treatment including all final state interactions. The full line curve is from Cambi, Mosconi and Ricci^{/9/} 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 both in pseudoscalar and in pseudovector coupling) charge densities. The full line curve shape seems to agree better with experimental points, particularly at $E_\gamma = 100$ MeV, while the other two curves are systematically higher at forward and backward angles, the discrepancy increasing with the photon energies.

In conclusion, a quasi monochromatic photon beam has been used to measure differential cross sections for the deuteron photodisintegration process below the Δ region. The simultaneous determination of both photon energy and photon flux by a pair spectrometer and a quantameter made an accurate measurement of the reaction possible. Moreover, it has been shown that there is an agreement among measurements of the $d(\gamma,p)n$ differential cross section performed by using quasi-monochromatic photons and tagged photons.

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