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ABSTRACT

Deuteron photodisintegration total cross section has been measured in the gamma-ray energy range between 15 and 75 MeV, by using the LADON photon beam. The proton has been detected. The results are in substantial agreement with the standard theory and do not provide evidence for contributions of quark degrees of freedom.

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High energy experiments[1,2] on deuteron interactions with elementary particles and nuclei indicate the existence in the deuteron of strong two nucleon correlations at shorth distances, whose origin can be traced to the overlap of the two nucleonic three-quark bags. It is generally believed that up to distances of the order of the natural length scale of QCD, about 1 fm, the N-N forces should be interpreted in terms of quark interchanges and multiple gluon exchanges, rather than by the conventional meson-nucleon models. A focal point, then, is to understand how this short range quark regime ties with the large distance standard constraints of nuclear physics. In addition, since QCD should be able in principle to describe nuclear system at a fundamental level, a very relevant experimental question is at which momentum transfers the phenomenology becomes sensitive to nucleon substructures.

Based on this, some years ago E. Hadjimichael and D.P. Saylor[3] pointed out that an interesting quantity to explore would be the deuteron photodisintegration total cross section at low energy. In fact, from a careful analysis of a selected number of experiments, in their opinion the most reliable, they reached the conclusion that the data could not be interpreted in terms of meson and nucleon degrees of freedom only, but the quark structure of the nucleon had to be explicity considered. They proposed to take into account the short distance two-nucleon interaction by exchanging quarks and gluons, while meson exchange would as usual describe the long and intermediate range. Their approach to a complete description of the deuteron wave function was too crude, but refinements of this idea can be found in various paper[4,5], although applied to the deuteron photo-and/or-electrodisintegration at intermediate energy only.

However, an analysis by H. Arenhövel[6] of the existing experimental data of $d(\gamma,p)n$ total cross section, where no particular selection of the data is made, shows that the standard theory including meson exchange currents (MEC) and isobar configurations (IC), works quite satisfactorily. Furthermore, even our critical review[7] of the same process measurements, which considers also the complete set of the differential cross sections, does not agree with the far reaching conclusions of Ref. (3), allowing for the rather large statistical and systematic uncertainties of the data. As a result it was suggested that new high quality experiments were needed in order to explore how far one can go using an effective theory with conventional hadronic degrees of freedom, before one is forced to introduce a quark model description.

In this framework, we performed a new measurement of the deuteron photodisintegration total cross section at low energy with good statistical and systematic accuracy. This has been made possible by using the monochromatic LADON photon beam[8] of the Frascati National Laboratories (LNF), which is obtained by Compton backscattering of laser light against the high energy electrons circulating in the Adone storage ring, and by using a proton detector with a very large angular acceptance ($\sim 4\pi$). The most important features of the LADON beam are the energy resolution which ranges from approximately 400 keV at 15 MeV to 4 MeV at 80 MeV, an extremely low bremsstrahlung background ($\lesssim 5\%$ on the whole spectrum of the electron beam), an intensity of $\sim 10^5 \gamma/s$ and an almost complete linear polarization.

The experimental apparatus basically consisted of an integrated system composed of a gas container, surrounded by a 6.75 cm thick NE213 liquid scintillator for particle detection. A schematic diagram is shown in Fig. 1. High pressure (~ 30 atm) deuterium or hydrogen samples

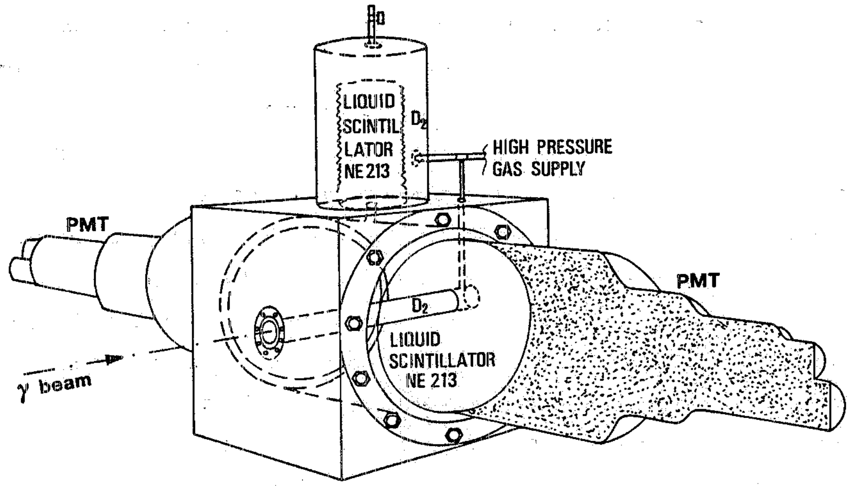

FIG. 1 - Schematic diagram of the target and detector system.

filled a very thin (0.16 mm) cylindrical alluminium tube, 15 cm in lenght and 1.5 cm in diameter, with sticked end caps of LEXAN. A mechanical device mantained both gas and scintillator at the same pressure, so that the lateral surface of the tube was not subjected to any mechanical stress, but acted exclusively as a separation wall between gas and detector. The whole system was held in an anticorodal container, internally painted by the reflecting NE560 varnish, with two holes for beam passage and two windows for two plexiglass light guides, separated by a mylar foil from the liquid and each one connected to an EMI 9823KB photomultiplier. The container geometry reduced the lenght of the target viewed from the scintillator at 10 cm. Pressure and temperature were continuously measured and recorded during the running time; deuterium and hydrogen densities were determined off line, by using the experimental data for a real gas given in Ref. (9), interpolated to our experimental conditions.

On the beam line, at 0°, a plastic scintillator with a hole in the center was placed to reject the forward components of atomic electromagnetic background that, seen even from the proton detector, escape through the anticorodal container.

The trigger for event processing was given by a coincidence, including a signal connected to the passage of an electron bunch through the laser cavity and both pulses of the proton detector. The plastic counter signal was placed in anticoincidence. The charge full pulses of the two photomultipliers, their sum and their corresponding tail contributions were acquired to provide a proton energy measurement and an off line p/γ discrimination by the head/tail method. In addition, a pulse shape analyzer was used jointly with a time to digital converter for a further off line p/γ discrimination procedure. All relevant information had been collected using CAMAC standard modules interfaced to a DEC PDP 11/34 minicomputer. In order to minimize the dead time introduced from data transfer to the computer, we adopted a very fast CAMAC auxiliary crate controller to derandomize, buffer and format data.

Beam monitoring was performed by a 10"x10" NaI(Tl) crystal, of which threshold stability was verified by acquisition of the photon spectrum; the efficiency has been calculated by using a Monte Carlo program for electromagnetic showers. In addition, the energy profile of the γ beam was continuously monitored by a magnetic pair spectrometer, while the bremsstrahlung contribution was systematically measured during the running time switching off the laser light. The electron flux in the storage ring, exponentially decreasing with time, were checked and recorded.

Data have been taken in several runs for effective photon mean energies E_γ=14.7, 19.3, 38.2, 47.5, 57.5 and 74.0 MeV, alternating deuterium and hydrogen gas as target. Moreover, measurements have also been performed using only the bremsstrahlung component of the beam. The photon polarization was changed several times to look at possible asymmetries in the proton detector. This effect resulted completely negligible within the statistical uncertainty.

Data were reduced to cross section in different steps. By using both pulse shape analyzer and head/tail information, we obtained an high quality p/γ discrimination, so that the largest part of atomic electromagnetic background was removed. In addition, the bremsstrahlung data were normalized to the same electron total flux and subtracted. After, the net hydrogen yield was subtracted from the net deuterium yield, to eliminate the contaminating counts from the LEXAN windows and residual electromagnetic background. Finally, in order to extract the total cross section, corrections were made for the proton counter angular acceptance, atomic absorption and threshold level, estimated by a Monte Carlo program, dead time and beam monitor efficiency.

The results of our measurements, with the statistical errors, are displayed in Fig. 2 and listed in Table I as a function of the photon energy. Additional systematic errors, including an overall

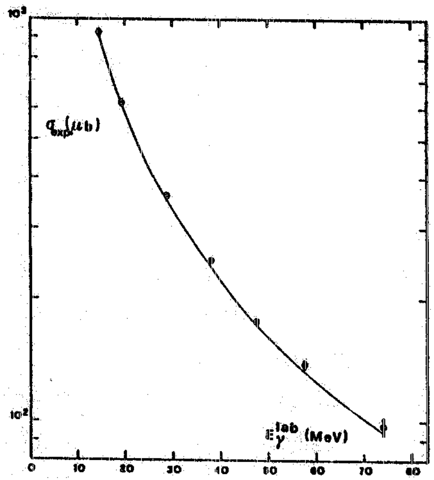

FIG. 2 - Plot of the total cross section σ_{exp} for the $^2H(\gamma,n)p$ reaction vs the laboratory gamma-ray energy (MeV). •) our experiment. The solid line represents a theoretical calculation of Ref. (10).

TABLE I - Our experimental results for the $^2H(\gamma,n)p$ process total cross section σ_{exp}, theoretical data σ_{th} of Ref. (10), ratio σ_{exp}/σ_{th} and systematic errors $\Delta\sigma_{exp}^{sys}$ as a function of the laboratory gamma-ray energy (MeV).

E_γ (MeV)	σ_{exp} (μb)	σ_{th} (μb)	σ_{exp}/σ_{th}	$\Delta\sigma_{exp}^{sys}$ (μb)
14.7 ± 0.1	925 ± 20	900.3	1.027 ± 0.022	44
19.3 ± 0.1	617 ± 9	627.3	0.984 ± 0.014	31
28.9 ± 0.1	361 ± 6	356.5	1.013 ± 0.017	12
38.2 ± 0.1	249 ± 3	239.1	1.041 ± 0.013	9
47.5 ± 0.2	177 ± 3	174.7	1.013 ± 0.017	6
57.5 ± 0.4	139 ± 3	133.1	1.044 ± 0.023	5
74.0 ± 0.5	97.6± 5.3	94.0	1.038 ± 0.056	3

uncertainty on the deuteron density, background subtraction, proton detector acceptance and efficiency determination and, finally, incident beam monitoring, have been evaluated and listed in the same Table. The continuous line in Fig. 2, with which we compare our data, is a theoretical prediction(10) obtained by using the Siegert operator and including additional explicit exchange effects, MEC and IC, and relativistic corrections to one-body ϱ_1 and two-body ϱ_2 charge densities. The Paris potential was employed in the calculus.

To detain a clear visualization of this comparison, there are shown in Fig. 3 and in Table I the ratio values between a set of experimental data at $E_\gamma \geq 9$ MeV (including, in addition to ours,

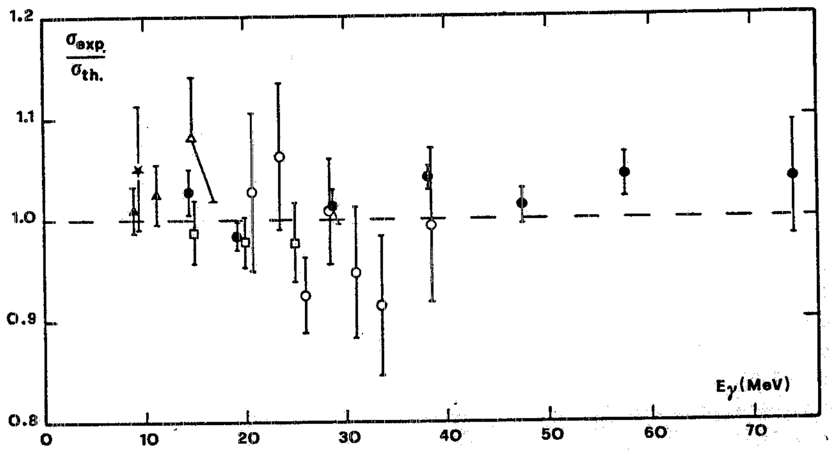

FIG. 3 - Plot of the ratio σ_{exp}/σ_{th}, between a set of experimental total cross sections σ_{exp} and the theoretical data σ_{th} of Ref. (10), vs the laboratory gamma-ray energy (MeV). ●) our experiment; □) Mainz(11); ▲) Negev(12); O) Louvain(13); Δ) Dresden(14); *) Zagreb(15). The Louvain, Dresden and Zagreb points are derived from total cross section measurements of radiative neutronproton capture by means of the detailed balance theorem.

the Mainz(11), Negev(12), Louvain(13), Dresden(14) and Zagreb(15) results) and the corresponding theoretical cross sections(10). The Mainz and Negev experiments are free from errors due to the usual bremsstrahlung techniques for incident photons, while the Louvain, Dresden and Zagreb data are derived from total cross section measurements of radiative neutron-proton capture by means of the detailed balance theorem. The general trend of this ratio does not present, in our opinion, any particular structure, as the parabolic behaviour in the energy region between 10 and 80 MeV shown in Ref. (3). In addition, the disagreement of the individual points from 1 is restricted within few per cent, in particular for our and Mainz data, and disappears if also systematic errors are included; in any case, it is very far from the 15% at 50 MeV reported in the same Ref. (3). This absence of a striking qualitative or quantitative difference between the standard theory and the experiments below 75 MeV does not support the claim of the real need for further subnucleonic degrees of freedom at low energy. However, it is to point out that definite disagreement exists at higher energies(16). This result can be explained in terms of rapidly increasing isobaric contributions and relativistic corrections.

In conclusion, our measurement of the deuteron photodisintegration total cross section at energies between 15 and 75 MeV confirms, within the obtained accuracy, the substantial validity of the current theory in the explored interval. The deviations are of the same order of the discrepancies expected for different potentials. This conclusion had been already reached as a result of an our previous measurement[17] of the asymmetry parameter $\Sigma(\vartheta)$ for this reaction, performed at the same energy range. Quark degrees of freedom effects in the electromagnetic interactions, and in particular in the deuteron photodisintegration, seem to be either confined in the high momentum transfer regions or too small to be put clearly in evidence at low energy.

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