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TOTAL PHOTONUCLEAR CROSS SECTION IN THE NUCLEON RESONANCE REGION

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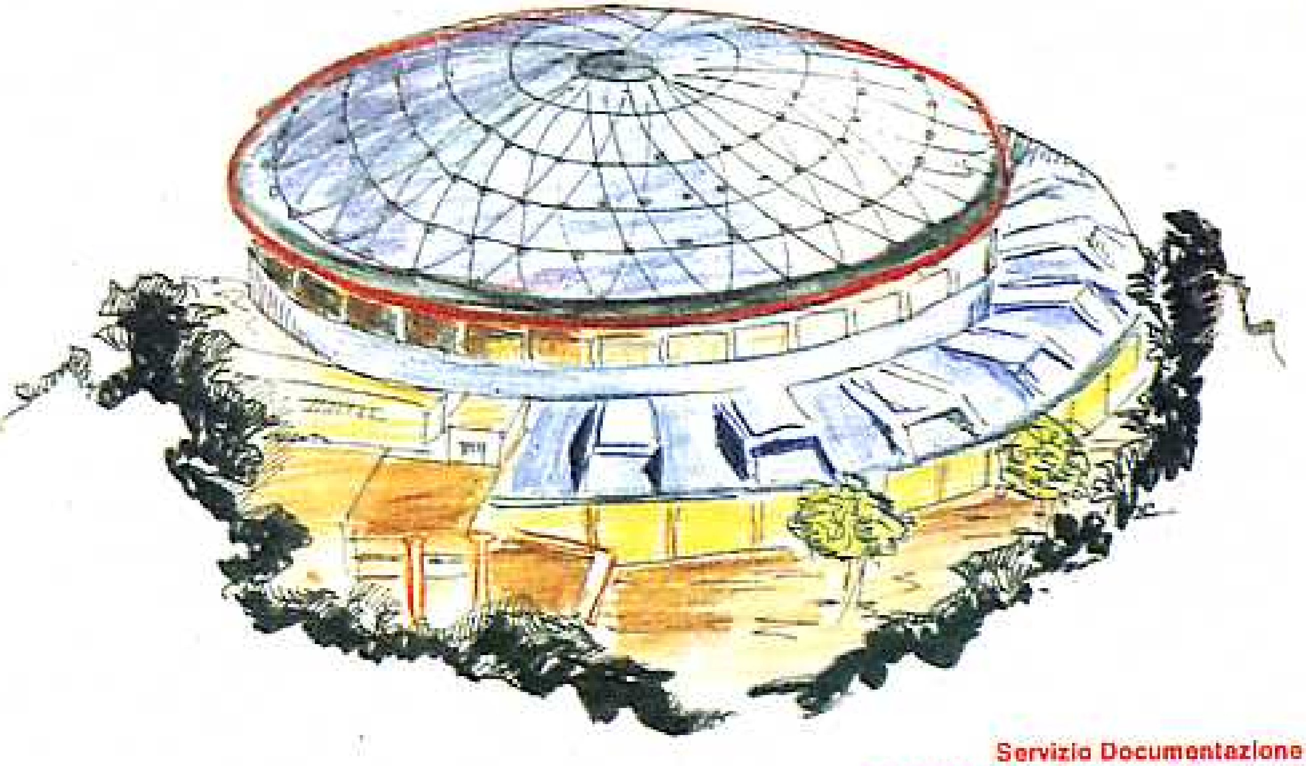

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TOTAL PHOTONUCLEAR CROSS SECTION IN THE NUCLEON RESONANCE REGION*

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ABSTRACT

We present the results of measurements of the total photonuclear absorption on light, medium–heavy and heavy nuclei carried on at Frascati with 200–1200 MeV monochromatic photons, to obtain information on the excitation of baryon resonances in nuclei and on the possible onset of the shadowing effect. The results show no evidence of baryon resonances at about 700 and about 1000 MeV seen in the photon absorption on the proton and the deuteron.

1. - INTRODUCTION

The absorption of photons by nuclei has been investigated in many laboratories over a wide range of mass numbers and photon energies in order to get precise and systematic information on fundamental questions, like the possible change of the intrinsic properties of free nucleons in nuclei, or the hadronic nature of the photon.

In the Δ region existing data[1,2] on the total photo–absorption cross sections on different nuclei suggest that the shape of the cross section normalized to A deviates strongly from the free–proton value, mainly due to the Fermi motion, while the strength is essentially the same. Moreover there is no significant dependence on the mass number A of the nucleus from ^{9}Be to ^{238}U, indicating a volume–like absorption.

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* Presented by E. De Sanctis

Above 2 GeV, on the contrary, the shadowing effect is well established:[3] the cross section per nucleon decreases with increasing mass number and is proportional to A^a, with $a \approx 0.9$ intermediate between a volume absorption, $a=1$, typical of an electromagnetic probe, and a surface absorption, $a=2/3$, typical of a hadronic probe.

In the region between about 500 MeV and about 2 GeV, the data on proton[4] and deuteron[5] show that the photon is able to excite nucleon resonances of mass higher than the Δ and with different quantum numbers. For the other nuclei the data are rather scarce and do not have sufficient accuracy There are only the Yerevan data for Be, C, H_2O, and Cu[6,7] collected with the photohadronic method between 250 and 2700 MeV, and for ^{235}U and ^{238}U obtained through electrofission and photofission measurements.[8,9] These data suffer for a poor energy resolution, which could have led to smoothing of the higher resonance peaks.

This short review indicates that the photon energy region between 500 MeV and about 2 GeV is still poorly known and calls for an experimental clarification, in order to ascertain first of all if the nucleon resonances can be excited in the nuclear medium or if, for some unexpected reason, they are strongly damped or scattered over a wide energy interval. There are other reasons of interest for the nucleon resonances in nuclei, among them one can quote the following items: *a*) the study of the γNN^* vertex in nuclei in order to evidence possible modification induced by the nuclear medium on the photon–nucleon coupling; *b*) the study of the interaction between nucleons and resonances in nuclei, to evidence the excitation of possible collective structure (like dibaryon states); *c*) the research of quark effects, like the generation of exotic structures (multiquark bags, coloured clusters, etc.). Moreover, the low and high energy photonuclear absorption regions are connected by sum rules and this connection has been used to establish constraints for the integrated total photonuclear cross section in the nucleon resonance region. In particular, Weise[9] showed that one could reconcile the data for the enanchement factor value and the shadowing effect with a dispersion relation approach and proposed that some non negligible shadowing effect in nuclei should manifests below 2 GeV.

In this paper we present the research studies on total photonuclear absorption carried out at Frascati between 200 and 1200 MeV over a wide range of mass numbers, to obtain information on the interaction of baryon resonances with nucleons and on the possible onset of the shadowing effect.

2. – EXPERIMENTAL

2.a – The photon beam

The measurements were carried out at Frascati with the *Jet Target* tagged photon beam.[12] This beam was produced by the bremsstrahlung from an internal target traversed by the electrons circulating in the ADONE storage ring. The radiator was a clustered molecular Argon beam[11] of $\leq 10^{-10}$ radiation length thickness in order not to degrade the circulating beam quality, and lifetime.[12] The recoil electrons were momentum analyzed by the next ADONE dipole and detected by a tagging hodoscope (two arrays of scintillation counters in coincidence), which provided a constant 1% photon energy resolution at the maximum electron energy ($E_0=1500$ MeV) over the whole tagging range $0.4 \cdot E_0 \leq k \leq 0.8 \cdot E_0$. Under normal operating conditions (circulating electron current ≈ 60 mA and jet thickness ≈ 5 ng/cm^2), the maximum photons intensity was $\approx 5 \cdot 10^7$ s^{-1}.

A schematic view of the experimental apparatus is shown in Fig. 1. The three magnets M1, M2, and M3 swept the charged particles off the photon beam, which was defined in size by the two collimators C1 and C2. The signals of the ADONE electron orbit monitors M8 and M9 were used in feedback to maintain stable to better than 0.1 mm the electron orbit in the Jet Target straight section. Two multiwire proportional chambers (P1 and P2) allowed to measure the position, dimension and angular divergence of the photon beam. Two thin plastic scintillators (I), positioned on the photon beam, were used as a relative intesity monitor, detecting in coincidence the Compton and pair electrons produced by the photons on a thin gold converter: the stability of this simple detector was checked over several days and found to be about ±0.1%. Finally, a cylindrical BGO crystal (32 cm long and 9.8 cm in diameter) or a dense lead–glass counter was used as a photon spectrometer, respectively for low and high rate measurements.

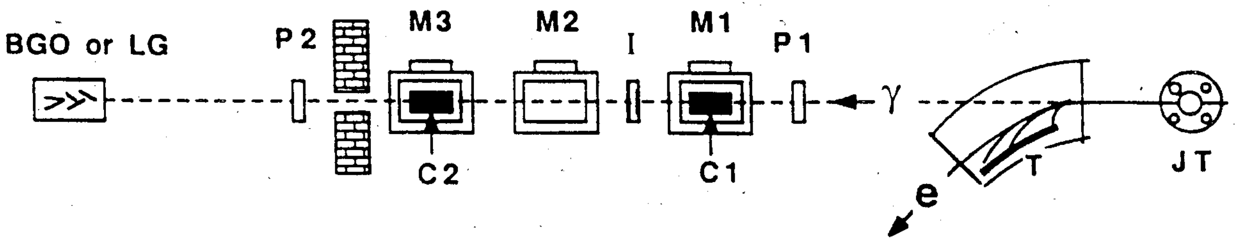

FIG. 1 – Layout of the *jet target* photon beam (not to scale): JT, jet target; TS, tagging system; P1 and P2, movable photon beam profile chambers; M1, M2, and M3, sweeping magnets; C1 and C2, collimators; M8 and M9, electron orbit monitors; I, photon beam relative monitor; BGO or LG, photon spectrometer.

2.b – The methods of measurement

The measurement of the total nuclear photoabsorption cross section is made difficult by the large contribution of the pure electromagnetic interaction. Then, to reduce the indetermination due to the systematic errors we used three different experimental methods, specifically: (*i*) the transmission technique for light nuclei, (*ii*) the photofission technique for heavy fissile nuclei, and (*iii*) the photohadronic technique for light, medium and heavy nuclei.

(*i*) First we studied the Be and C nuclei with the transmission technique, which consists in measuring the total attenuation cross section and subtracting the atomic absorption cross section, which is calculable for light nuclei with great accuracy[13].

Photons crossed the absorption target (a 85.77±0.01 cm long 99.9% pure Be or a 59.95±0.06 cm long nuclear reactor graphite containing $<0.15\cdot10^{-3}$ impurities) put inside a 12 KG magnetic field (M2 dipole in Fig. 1) and were detected, about 13 m downstream, by the above described BGO spectrometer. This layout afforded a very good rejection of the forward components of the electromagnetic showers created in the absorber, as shown by a simulation of the experiment using the GEANT code[14]. To normalize the target–in and target–out photon spectra, we used the photon monitor I. Running conditions, such as jet thickness and electron current, were adjusted to maintain constant (≈2 kHz) BGO rates with target in and target out, and to keep stable within 0.8% the response of the BGO spectrometer. Moreover, the spectra from the coincidence of the BGO and four tagging channels (suitably selected) allowed the control of the energy calibration of the spectrometer. Measurements were carried out at several electron beam energies and were divided into several runs (for each injection in the ring). For each injection the same statistics with target–in and target–out were accumulated. The data obtained for the various injections showed good consistency and could be averaged.

Details on this measurement are given elsewhere,[15] here we limit ourselves to mention that this method allowed us to provide a reliable energy behaviour of the cross section (systematic error ≈5%), while for the absolute normalization of the data we resorted to the overlap with the existing data in the Δ region, where the quantitative agreement of different data sets ensured a good "calibration".

(*ii*) Second, we measured the total photofission cross section for the ^{238}U target, because for this nucleus the probability of fission after the absorption of a high energy photon (k>50 MeV) has been generally assumed to be close to one.[16]

The main advantages of this method are the weak sensitivity to the electromagnetic background and the absence of systematic errors associated with the geometry of the detectors recording the fission fragments, since the angular distribution of the fragments has only a weak dependence on the energy of the primary photons.

One gaseous ionization detector (positioned behind P2 in Fig.1) of the parallel plate avalanche (PPAD) type was used to detect the fission fragments. The detector[16,17] consisted of two components: the main multiplates photofission detector, and the calibration detector. The main detector consisted of 54 aluminium plates (each 50μm thick and 6.5 cm diameter), coated on one side with a uniform deposition of UO_2 (≈2 mg/cm^2 each). The gas used was isobutane maintained at a pressure of 7.60±0.01 mbar and the working high voltage was (430.0±0.1) V. The calibration detector consisted of a single thin target of well known thickness (244±5 μg/cm^2) placed between two single PPADs, which could detect with efficiency equal to 1 the two fission fragments.

Coincidence of the signals from the PPAD and the *i*–th channel of the tagging system corresponded to the fission of a nucleus by a photon of energy $k_i = (E_0 - E_i)$. The total number of photons of the *i*–th energy bin hitting the target was determined by the coincidence of signals from the lead glass and the counters of the *i*–th channel of the tagging system. The random coincidences due to the beam time structure and (mainly) to the spontaneous α decay of the U nuclei were measured on–line and then subtracted. Data were collected at different electron energies and the good overlap between different data sets showed a good control of the systematic errors due to the photon beam flux monitoring, the tagging efficiency and the detector efficiency. The systematic error was ≈9% in the Δ region, and ≈6% in the higher energy region. Details on this measurement are given in Ref. [18].

(*iii*) Finally, we used the photohadronic technique for several nuclei (Li, C, CD_2, Al, Sn, Cu, and Pb), which consists in measuring the photoproduction rate of hadronic events while rejecting the preponderant electromagnetic events by an angular separation. The basis of this method is that the products of the pure electromagnetic interactions are contained in an extremely small angular cone, while the products of hadronic interactions are more broadly distributed in angle.

We used a NaI crystal anulus (which consisted of three cylinder sectors, each 32 cm long and 15 cm thick, positioned behind P2 in Fig. 1) surrounding the target (0.1 radiation lenght thick) to detect the charged particles and neutral pions product of the photon interaction in the target. The lead glass counter, positioned ≈80 cm downstream, was used to veto the electromagnetic events.

Hadronic absorption of a photon of given energy was indicated by a coincidence between signals from one tagging channel and the NaI, in anticoincidence with the lead–glass signals. The total number of photons of the *i*–th energy bin hitting the target was determined by the coincidence of signals from the lead–glass and the counters of the channel of the *i*–th tagging system. The beam intensity was adjusted to keep random coincidence and veto rates at a level below 10% of the rate of real events. The random coincidences were measured on–line and then subtracted.

A Monte Carlo simulation of the process in our geometry, using the code GEANT and the Barashenkov et al. cascade–evaporative model,[19] showed that the probability of finding a contamination of an electromagnetic event in the hadron detector was less than 1%, and that the loss of events due to charged particle or π^0 below the detection threshold was at most a few percent.

This program is still running and only the preliminary results for C will be presented here. As said above, we will measure the total photoabsorption cross section on Li, C, CD_2, Al, Sn, Cu, and Pb. Data from C and Pb will allow to check with the transmission and photofission measurements, while the subtraction of CD_2 and C measurements will allow to obtain the total absorption cross section for deuteron.

3. - RESULTS

In Fig. 2 the results obtained from Be, C, and U, normalized to the respective number of nucleons, are compared with the data available for deuteron[5] and the so–called universal curve (that is $\sigma_{\gamma A} \sim A$) obtained from the data existing in the literature in the Δ region for different nuclei, normalized to their respective number of nucleons[1,2] (area between the two solid line curves in the figure). Only the statistical errors are quoted.

Moreover, in the bottom figure we give also the extrapolation to the low energies of the Regge form fit ($a+bk^{-1/2}$) on the total cross section for U measured at Cornell with the photohadronic method.[20] We used this energy law because it has been shown that the Regge pole formulation provides an acceptable parametrization of the photon absorption on free nucleon.[4] The agreement between our points and the fit supports the assumption that also in the GeV region the U fissility is very close to 1 and that the photofissioin method can be safely used to measure the total cross section for fissile nuclei.

As it is seen there is a substantial agreement in the energy behaviour of the data for the three given nuclei, which were obtained with three different experimental apparata and procedures. Moreover, our data: reproduce the Δ resonance shape obtained at other laboratories in the energy region below 500 MeV do not show evidence of the baryon resonances seen in the photon absorption on free deuterons (and protons) at energies of ≈0.7 and ≈1 GeV and which correspond mainly to the $D_{13}(1520)$ and $F_{15}(1680)$ resonances, and are compatible with existing data at higher energies. Finally, for all the studied nuclei the strength of the normalized cross section is reduced by a factor >1.1 in the range between 600 and 1200 MeV with respect to that for the deuteron, while it is conserved in the range 300–600 MeV.

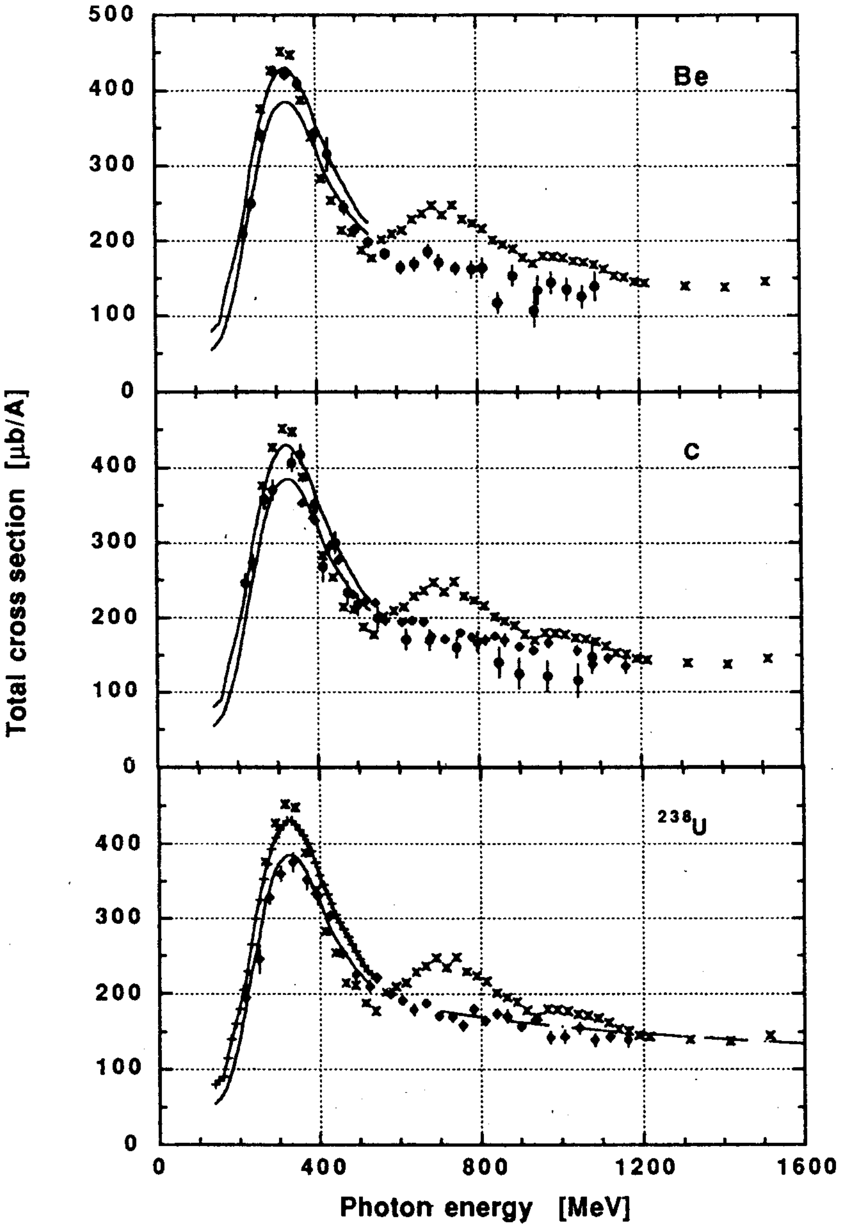

FIG. 2 – The experimental results obtained at Frascati for the total photonuclear cross section, normalized to the number on nucleons, for Be; C (transmission method results: full diamonds, photohadronc method results: full circles); and U. The crosses are the experimental data for deuteron[5]; the full lines are. the so–called "universal curve", the dashed line is the extrapolation of a Regge fit to the data of ref. [18].

The Fermi motion and the propagation and interaction of resonances inside the nucleus produce a broadening of the resonances, as in the Δ region, which increases with the resonance masses, and could destroy the resonant behaviour. However, these effects are not able to to account for the reduction of the strength[21]. Therefore, one has to resort to other causes, like the onset of the shadowing effect, which at these low energies should be related to some low mass non resonant hadronic state given by two pions rather than to vector mesons, or a possible damping of the excitation of resonances in the nuclear medium, which might be more effective on deformed resonances like the $D_{13}(1520)$ and $F_{15}(1680)$ resonances, which correspond to the excitation of orbital angular momentum, than on spherical ones like the Δ [$P_{33}(1232)$], which is spherical and excited by a quark spin flip.

This different behaviour in nuclei of the higher nucleon resonances is not yet understood. With the planned further measurements on light (CD_2,and Li) and medium heavy nuclei (Al, Sn, Cu, and Pb) we hope to confirm irrefutably the existence of the damping of the higher baryon resonances and to study its mass dependence.

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