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THE FRASCATI PROGRAM FOR MEASURING THE TOTAL PHOTONUCLEAR CROSS SECTION IN THE NUCLEON RESONANCE REGION*

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ABSTRACT: We present the research studies on the total photonuclear absorption carried on at Frascati between 200 and 1200 MeV, to obtain information on the interaction of baryon resonances with nucleons and on the possible onset of the shadowing effect. The preliminary results on Be and C obtained using the transmission technique and the Jet Target tagged photon beam are presented in this paper.

1. INTRODUCTION

The absorption of photons by nuclei has been investigated 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 particular, existing data[1,2] on the total photo-absorption cross sections per nucleon, $\sigma_{\gamma A}/A$, on different nuclei suggest that, in the Δ-region, $\sigma_{\gamma A}/A$ deviates strongly from the free-proton value but is not significantly dependent on the mass

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number A of the nucleus. The observation is that the resonance shape and strength is nearly universal from ^{9}Be to ^{238}U, indicating a volume absorption. Above 2 GeV, on the contrary, the shadowing effect starts to become visible: the cross section per nucleon decreases with increasing mass number and can be written as $\sigma_{\gamma A} = A_{eff}\sigma_{\gamma N}$, with $A_{eff}=A^{\alpha}$. The present experimental data at high energies suggest a value $\alpha \approx 0.9$, intermediate between a volume absorption, $\alpha=1$, typical of an electromagnetic probe, and a surface absorption, $\alpha=2/3$, typical of a hadronic probe. However, the amount of shadowing found in various studies is contradictory and does not agree quantitatively with the theoretical predictions.[3]

In the region between about 500 MeV and about 2 GeV data are rather scarce: there are data for the proton and deuterium and with low precision for Be, C, H_2O and Cu. These latter data were collected at Erevan[4] with large acceptance over the actual photon energy and fluctuate well above the experimental errors. When one takes their mean value, normalized to A, two facts seem to emerge: i) the smearing of the nucleonic resonances at ≈700 MeV and ≈1 GeV clearly seen in the photoabsorption on proton and deuteron; ii) the onset, already at ≈1100 MeV, of the "shadowing" effect . It is worth to note, moreover, that subsequent Erevan data on electrofission of ^{238}U[5] and photofission of ^{235}U and ^{238}U[6] have not clarified the scenario.

Moreover, the low and high energy regions are connected by dispersion relation sum rules and this connection has been used to establish constraints for the integrated total photonuclear cross section in the nucleon resonance region by measuring the behaviour of photon interaction at asymptotic energies. In particular, Weise[7] showed that one could reconcile the data for the enhancement factor value and the shadowing effect with a dispersion relation approach and proposed that some shadowing effects in nuclei should manifest below 2 GeV.

From what above, it is clear that to test these predictions and search for a deviation from the presumed independence of $\sigma_{\gamma A}/A$ of the mass number A, it is needed an accurate knowledge of cross sections between 500 and 2000 MeV, where existing data are rather sparse and do not have a sufficient accuracy.

In this paper we present the research studies on the total photonuclear absorption carried on at Frascati between 200 and 1200 MeV, to obtain information on the interaction of baryon resonances with nucleons and on the possible onset of the shadowing effect. This experimental program is still at its beginning and only preliminary results on Be and C will be presented in this paper.

2. EXPERIMENTAL

a) The photon beam

The measurements are carried on at Frascati with the *Jet Target* tagged photon beam. This beam is produced by the bremsstrahlung on an internal target of the electrons circulating in the ADONE storage ring. The radiator (Jet Target), which is a molecular Argon beam crossing at supersonic speed the ring vacuum pipe,[8] is thin enough ($\approx 10^{-10}$ X_0, where X_0 is the radiation lenght) not to degrade the circulating beam quality, and to assure several minutes of beam lifetime.[9] The recoil electrons are momentum analyzed by the next ADONE dipole and detected by two arrays of scintillation counters in coincidence (there are 39 counters in each array).[10] The scintillators define 76 energy channels and have different sizes in order to give a constant 1% photon energy resolution at the maximum electron energy (E_0=1500 MeV) over the whole tagging range $\Delta k = (0.4 \div 0.8) \cdot E_0$. Then, the range (200-1200) MeV can be covered with three energy settings of the machine (respectively 500, 1000, and 1500 MeV). Under normal operating conditions (circulating electron current ≈60 mA and jet thickness ≈ 5 ng/cm^2), the maximum intensity of photons is of ≈$5 \cdot 10^7$ photons/s.

In Fig. 1 is shown the experimental set-up of the facility: three magnets MP1, MP2 and MP3) sweep out charged particles from the photon beam which is defined in size by two collimators. Four multiwire proportional chambers (CM1 ÷ CM4) allow to determine the dimension and angular divergence of the photon beam. Two thin plastic scintillators NE 102 A (each 3 mm thick, and 25 x 25 mm^2), disposed one behind the other, are used as a relative photon beam monitor detecting in coincidence the Compton electrons and pairs produced by the photons in a thin (0.792 mm) gold converter positioned in front of the first scintillator. The stability of this simple device was found to be ≈ ±0.1%.

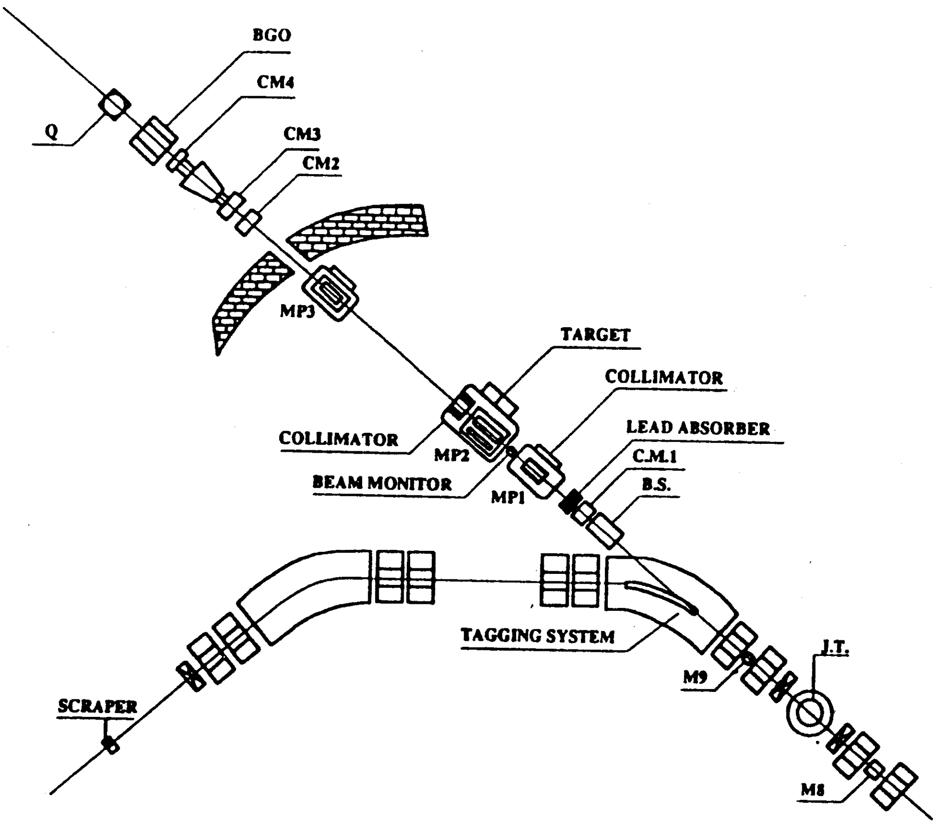

FIG.1 – A schematic view of the Jet Target tagged photon beam used for the total photonuclear cross section measurements: JT, Jet Target; M8 and M9, electron orbit monitors; CM1+CM4, movable photon beam profile chambers; MP1, MP2, MP3: sweeping magnets; BGO, photon spectrometer.

A cylindrical BGO crystal, 32 cm long and 9.8 cm in diameter, is used as photon spectrometer. Its diameter is sufficient to transversely contain about the 97% of the shower energy for a photon beam of 1 GeV energy and ≈2 cm diameter.[11]

b) Methods of measurement

Three different methods are used to determine the total nuclear absorption cross section, $\sigma_{\gamma A}$, on nuclei of different atomic mass, specifically: (*i*) the transmission technique for light nuclei; (*ii*) the photo-fission technique for fissile nuclei; and (*iii*) the photo-hadronic technique for medium-heavy nuclei.

(i) For Be and C targets we used the transmission technique, which consists in measuring the total attenuation cross section, σ_{tot}, and subtracting the calculated atomic absorption cross section, σ_{at}. In spite of continuos effort to improve the computation of σ_{at}[12], this method cannot be used for the evaluation of absolute value of $\sigma_{\gamma A}$ and can hardly be applied for nuclei with $Z>20$. In fact, the large uncertainties in the calculated atomic absorption cross section values, mostly due to the Coulomb correction term and to the structure effects on the cross section for pair production, are of the same order of magnitude or even larger than the desired $\sigma_{\gamma A}$ values, thus making any extension of this method to heavy nuclei highly problematical.

Photons crossed the absorption target (a 60.00±0.06 cm [85.00±0.01 cm] long nuclear reactor graphite containing $<0.15 \cdot 10^{-3}$ impurities [99.9% pure Be] put inside the MP2 magnet and were detected, about 13 m downstream, by the above described BGO spectrometer. This lay-out afforded good rejection of the forward components of the electromagnetic showers created in the absorber. A Monte Carlo simulation of the experiment, made using the code GEANT 3, showed that in the worst case, occuring at the maximum ADONE energy $E_0 = 1.5$ GeV, the region above $\approx 0.5 \cdot E_0$ in the photon spectrum resulted negligible affected ($\approx 1 \div 3 \cdot 10^{-3}$). This region was larger for lower E_0 values.

To normalize the target-in and target-out photon spectra, we used the photon monitor permanently inserted on the photon beam, before the target position. Running conditions, such as jet thickness and electron current, were adjusted to mantain constant (≈2 kHz) the 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 BGO spectrometer.

Measurements were carried out at several electron beam energies and were divided in several runs (corresponding to different injection in the ring). For each injection the same statistics with target-in and target-out was accumulated. The data obtained with the various injections and incident beam energies showed good consistency over the regions of overlap.

(*ii*) For U and Th we will use the photo-fission technique, which consists in measuring the total photo-fission cross section. In fact, for the fissile nuclei the probability for the emission of fission fragments after the absorption of a high photon energy (E_γ>50 MeV) has been generally assumed very close to one.[13]

Recent calculations by A.S. Iljinov and M.V. Mebel[14] have questioned this statement and given a value of the fissility of ≈0.8 and ≈0.6 for uranium and thorium, respectively. Then, we decided to measure the photofission cross section on ^{238}U and ^{232}Th to determine $\sigma_{\gamma A}/A$ and check the fissility values given by the cascade-evaporative model mentioned.

This method has two main advantages in comparison with direct measurement of the photoabsorption cross section. These are the weak sensitivity to the electromagnetic background and the absence of systematic errors associated with geometry of the detectors recording the fission fragments, since the angular distribution of the fragment has only a weak dependence on the energy of the primary photons.

Two gaseous ionization detectors (positioned behind CM3 in Fig. 1) of the parallel plate avalanche detector (PPAD) type will be used to detect the fission fragments. These PPADs have been kindly provided by the Saclay Laboratory. Each detector[13,15] consists of three components: the calibration detector, the photofission detector and the background detector. The U and Th targets were coated on one side of aluminium plates with a uniform deposition of ≈2 mg/cm^2 UO_2 or ThO_2 providing a total target thickness of ~120 mg/cm^2). The gas used is isobutane mantained at a pressure of 7.600±0.001 mbar. The calibration detector consists of a single thin target of well known thickness placed between two single PPAD, whereas the background detector has an identical structure but without the fissille material.

Coincidence of the signals from the PPAD and the *i*-th channel of the tagging system in the absence of a signal from the shower detector (the BGO crystal) corresponds to the case of fission of a nucleus by a photon of energy E_0-E_i. The total number of photons of the *i*-th energy bin hitting the target is determined by the coincidence of signals from the BGO and the counters of the *i*-th channel of the tagging system.

(*iii*) For medium-heavy nuclei (C, Al, Sn, Cu, and Pb) we will use the photo-hadronic technique, which consists in measuring the photoproduction rate of hadronic events rejecting the wastly preponderant electromagnetic events by an angular separation. The photon beam will interact in a $0.1 \cdot X_0$ thick target positioned between the profile chamber CM2 and CM3 in Fig.1. A NaI crystal (which consists of three cylinder sectors each 32 cm long and 15 cm thick) surrounding the target will detect the charged particles and neutral pions product of the photon interaction in the target, while the electromagnetic events close to the photon direction will be vetoed by the BGO crystal, positioned ≈80cm downstream. Hadronic absorption of a photon of given energy will then be indicated by a coincidence between signals from one tagging channel and the NaI , without a coincidence pulse in the shower detector. The total number of photons of the *i*-th energy bin hitting the target is determined by the coincidence of signals from the BGO and the counters of the *i*-th channel of the tagging system.

A Monte Carlo simulation of the process in our geometry, using the code GEANT 3 and the Barashenkov et al.[16] cascade-evaporative model, showed that the probability of finding a contamination of an electromagnetic event in the hadron detector is less than 1%, and that the loss of events due to charged particles or π^0 below the detection threshold is at most a few percent.

The beam intensity will be adjusted to keep random coincidence and veto rates at a level below 0.1% of the rate of real events. Data runs will be carried out with electron beam energies between 500 and 1500 MeV. Data from C and Pb targets will allow to check with the transmission and photofission measurements.

3. RESULTS

As mentioned in par. 1, this experimental program is still at its beginning and, up to now, only the measurements on Be and C with the attenuation technique have been carried out. Here, we present the values of the total photo-absorption cross sections per nucleon obtained from a preliminary analysis.

As said, the absolute value of the nuclear cross section obtained with this method dramatically depends on the accurate knowledge of the absolute value of the atomic cross section and of the stability of the photon monitoring system. However, the imprecise determination of these quantities essentially produces a simple upward-downward shift of all experimental points, while keeping unchanged their relative energy behavior. At the present stage of the analisys we are only able to give the energy behavior of the cross section. The absolute normalization of our data was provided by the overlap to existing data in the Δ region, where the quantitative agreement of different data sets ensured a good "calibration".

In Fig. 2, the results obtained for 30 and 50 MeV bins of photon energy are shown together with all previous data available in the literature in the given energy interval.

From these preliminary data it results that: (i) the cross section values per nucleon, $\sigma_{\gamma A}/A$, relevant to Be and C agree among each other within the experimental errors; (ii) in the energy region below 500 MeV, our data reproduce well the Δ resonance shape obtained by other laboratories; (iii) there is no evidence of the baryon resonances seen in the photon absorption from free protons (and deuterons) at energies of $\approx$700 and $\approx$1100 MeV.

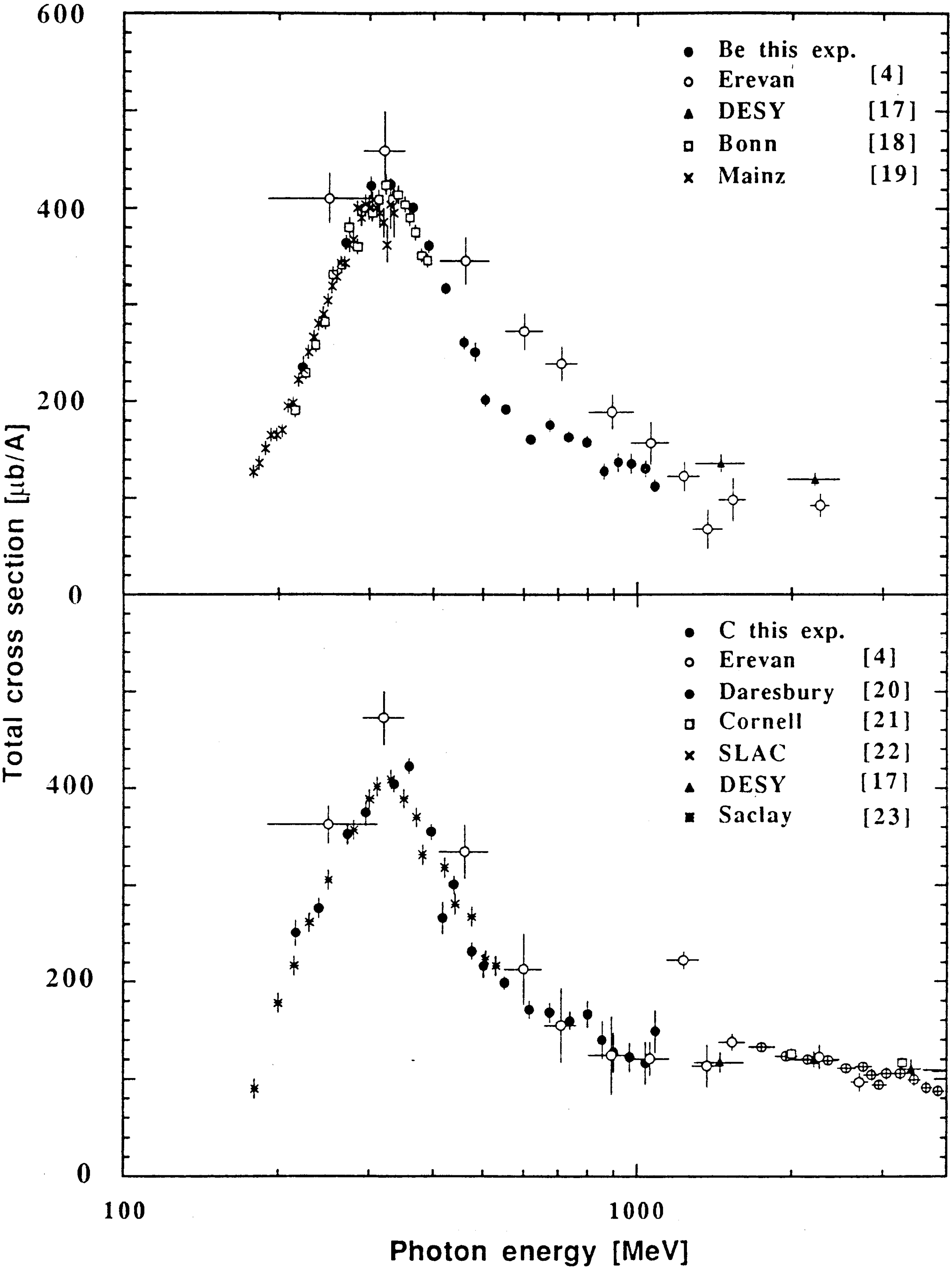

FIG. 2 – The $\sigma_{\gamma A}$ values for berillium and carbon (full circles) of this experiment together with all data available in the given energy range.

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