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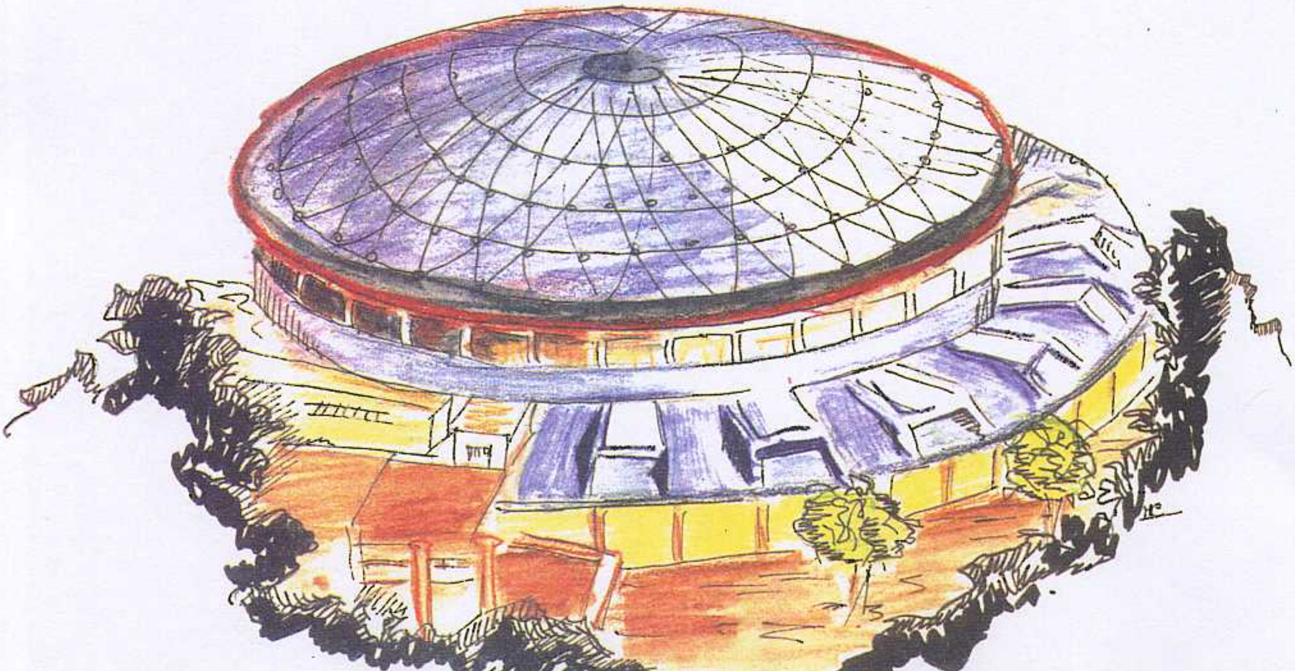

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MEASUREMENT OF THE TOTAL CROSS SECTION FOR ^{238}U PHOTOFISSION IN THE NUCLEON RESONANCE REGION

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We present the results of the photofission cross section for ^{238}U measured between 200 and 1200 MeV. In the Δ region our results agree with existing data on total photoabsorption cross section, while at higher energy they show no evidence of the higher nucleon resonances, clearly seen in the photon absorption on proton, and a damping of the absolute value.

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The total nuclear absorption cross section of photons has been measured, over a wide range of mass number and photon energy, yielding information on the possible change of the intrinsic properties of free nucleons in nuclei, or on the hadronic nature of the photon. In the Δ resonance region, [1,2] the data of the total cross section per nucleon measured on different nuclei from ^{6}Li to ^{238}U, show that the resonance shape and strength is nearly universal, indicating an incoherent volume photoabsorption mechanism. The response of bound nucleons differs from the free nucleon case, mainly because of the Fermi motion and of the propagation and interaction of the Δ in the nucleus, but the total strength of the interaction in this region seems to be almost the same.

Above 2 GeV, on the contrary, the total cross section shows some coherent behaviour and can be written as $\sigma_{\gamma A}= A^{\alpha}\,\sigma_{\gamma N}$, where A is the mass number and $\sigma_{\gamma N}$ is the cross section on free nucleons. 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 an hadronic probe. This is the well known shadowing effect, that is generally explained in the framework of the Vector Meson Dominance Model. However, the available experimental data show a shadowing-like behaviour at energy as low as 2 GeV but the amount of shadowing found in various studies is contradictory and does not agree quantitatively with the theoretical predictions.[3]

In the region between 500 MeV and about 2 GeV data are rather scarce and do not have a sufficient accuracy: there are precise data only for the proton[4] and deuterium[5] and with very low precision for Be, C, H_2O and Cu. These latter data were collected at Erevan[6] with large acceptance over the actual photon energy and fluctuate well above the experimental errors. The subsequent Erevan data on photofission of ^{235}U and ^{238}U[7] have not clarified the scenario. In this energy region there is interest in observing whether and how the higher nucleon resonances like the D_{13}(1520) and F_{15}(1680) survive in the nuclear medium and in determining the onset of the shadowing effect. Moreover, the low and high energy 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 by measuring the behaviour of photon interaction at asymptotic energies. In particular, Weise[8] 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 non negligible shadowing effects in nuclei should manifest below 2 GeV.

From the discussion above, it is clear that an accurate knowledge of cross sections between 500 and 2000 MeV is required to test these predictions and search for a deviation from the presumed independence of $\sigma_{\gamma A}/A$ of the mass number A.

In this paper we present the data on the total cross section for ^{238}U photofission 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 measurement was carried on with the *Jet Target* tagged photon beam.[9] 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,[10] is thin enough ($\approx 10^{-10}$ X_0, where X_0 is the radiation length) not to degrade the circulating beam quality, and to assure several minutes of beam lifetime.[11] The recoil electrons are momentum analysed by the next ADONE dipole and detected by two arrays of scintillation counters in coincidence (there are 39 counters in each array). The scintillators define 76 energy channels and have different sizes in order to give a constant 1% of FWHM photon energy resolution at the maximum electron energy (E_0=1500 MeV) over the whole tagging range Δk= (0.4-0.8)·E_0. Then, the range (200-1200) MeV can be covered with different energy settings of the machine. In this measurement the channels were grouped four by four, since a high energy resolution was not needed.

In Fig. 1 is shown the experimental set-up of the facility: three magnets (M1, M2 and M3) swept the charged particles produced in the two collimators (C1 and C2) defining the beam size out of the photon beam. Two multiwire proportional chambers (P1 and P2) allowed measurements of the dimensions and angular divergence of the photon beam. Two thin plastic scintillators were used as a relative photon beam monitor (I) detecting in coincidence the Compton and pair electrons, produced by the photons in a thin gold converter; the stability of this simple device was found to be better then 1%. A dense lead-glass detector (LG) was used as photon spectrometer for on-line measurement of the tagging efficiency.

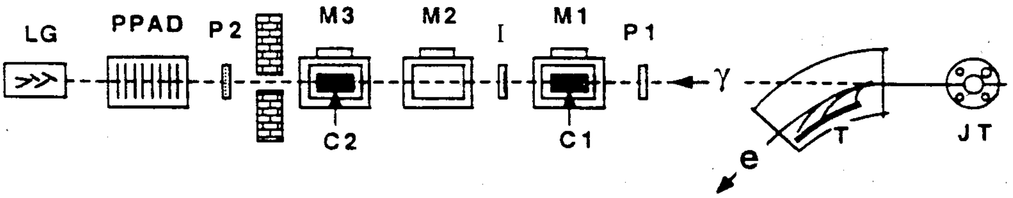

FIG. 1 – Layout of the Jet Target tagged photon beam (not to scale): JT, Jet Target; T, tagging system; P1, P2, movable photon beam profile chambers; M1, M2, M3, sweeping magnets; C1, C2, collimators; I, relative intensity beam monitor; PPAD, Parralel Plates Avalanche Uranium target detector; LG, Lead-glass photon spectrometer.

The ^{238}U total absorption cross section has been determined via the measurement of total photo-fission cross section. In fact, for such a nucleus 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.[12] This assumption was confirmed up to the energy region of the Δ resonance by the Bonn data for ^{238}U and ^{235}U which agree within the errors among each other and with the data of the total absorption cross section on different nuclei.[13]

One gaseous ionisation detector (positioned behind P2 in Fig. 1) of the parallel plate avalanche detector (PPAD) type has been used to detect the fission fragments. The detector[12,14] consists of two components: the main multiplates photofission detector and the calibration detector. The main detector consists of 54 Aluminum foils (50μm of thickness and 6.5 cm of diameter), coated on one side with a uniform deposition of UO_2 (approximately 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 Volt. The contribution of the Al foils to the fission rate was measured and found negligible. The calibration detector consists of a single thin target of well known thickness (244±5 μg/cm^2) placed between two single PPADs which can detect with efficiency equal to 1 the two fission fragments. The solid angle covered by the calibration detector was calculated by the knowledge of the photon beam transverse distribution on the detector measured by the wire profile chambers. The ratio of counts between the main and the calibration detectors with a full intensity bremsstrahlung beam gave the product of the effective thickness of the target by the main detector efficiency.

The signals of the PPADs were amplified and discriminated to form a common OR signal. Coincidence of the signal from the PPAD and the *i*-th channel of the tagging system corresponded 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 was determined by the coincidence of signals from the lead-glass and the counters of the *i*-th channel of the tagging system. Random coincidences due to the beam time structure (one pulse wide about 1 ns every about 20 ns) and to the spontaneous α decay of the U target were measured online and then subtracted.

Data were collected at five different electron beam energies (from 400 MeV to 1500 MeV) and the good overlaps between the different data sets evidence a good control of systematic errors due to the photon beam flux monitoring, the tagging efficiency and the detector efficiency. The systematic error was estimated to be $\approx$ 6% in the D_{13} and F_{15} region and $\approx$ 9% in the Δ region: the larger magnitude of the systematic and the statistical errors at low energies is due to the larger cut of the collimator on the photon beam.

In Fig. 2, the results obtained on U are compared with the more recent monochromatic data available in the literature; only the statistical errors are quoted. As it is shown at low energy

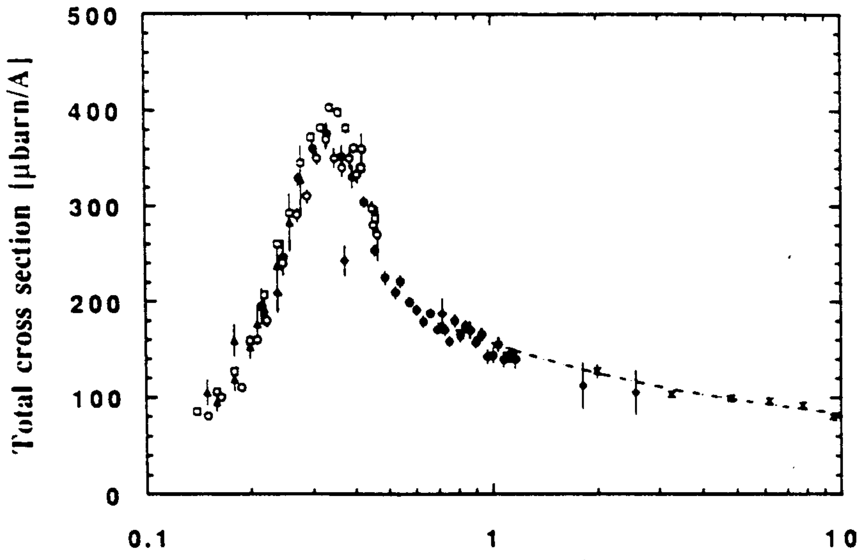

FIG. 2 – Our $\sigma_{\gamma A}/A$ values for ^{238}U (full circles) are compared with previous results on ^{238}U(close triangles [15], open triangles [16], stars [17], open diamonds [7], open squares [13]) and ^{235}U (open circles[13]); the dotted line is a fit in the Regge form (a+b$E^{-1/2}$) to high energy data from. [17]

our data are in an excellent agreement with the previous measurement made at Frascati with the positron in flight annihilation beam where the cross section was deduced from the experimental yields by unfolding methods.[15] In the Δ region, there is also a good agreement with the Bonn[13] and Novosibirsk[16] data. At higher energies, apart from the few data points with large error bars from Erevan,[7] there are no data up to 2 GeV; so we compare our results with the extrapolation to the lower energies of a Regge form fit ($a+bE^{-1/2}$), on total cross section of U measured at Cornell with the photohadronic method.[17] We use this energy law because it has been shown that the Regge-pole formulation provides an acceptable parametrization of the photon absorption on free nucleons.[4] The agreement between our points and the fit supports the assumption that also in the GeV region the U fissilty is very close to 1 and that the photofission method is a useful technique to measure the total cross section of fissile nuclei.

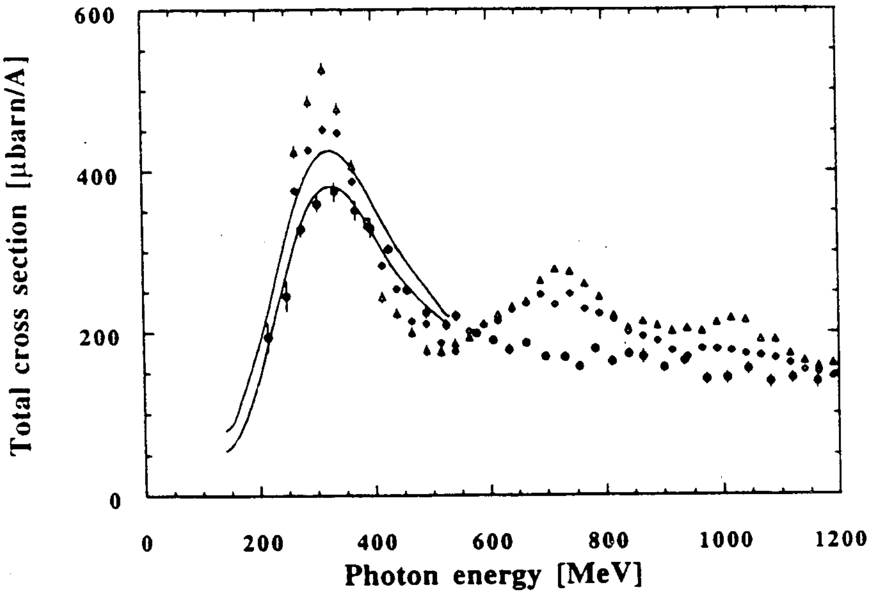

FIG. 3 - The $\sigma_{\gamma A}/A$ values for ^{238}U of this experiment (full circles) togheter with the available data on H (open diamonds),[4] D (open triangles),[5] and with the universal behaviour in the Δ region (area between the two curves) calculated from data on Be,[18,19] C[20] and Pb.[20,21]

In Fig. 3, our results are compared with the hydrogen[4] and deuterium[5] data in the whole energy range, and with the universal nuclear behaviour deduced from data on light (Be),[18,19] (C)[20] and a heavy (Pb)[20,21] nuclei, in the Δ region. From this comparison it results that:

(i) in the energy region below 500 MeV, our values of the cross section per nucleon, $\sigma_{\gamma A}/A$, reproduce within the systematic errors the Δ resonance shape and strength obtained by other laboratories on different nuclei, confirming that the fission probability for U in this energy region is very close to one;

(ii) compared to the free nucleon, the Δ resonance is broadened by the Fermi motion and by the interaction in the final state. An energy shift of the maximum of the resonance, from about 310 MeV to about 340 MeV, is observed; an even larger energy shift came out from preliminary results from a recent experiment performed at Mainz.[22]

(iii) there is no evidence of the excitation of higher baryon resonances clearly seen in the photon absorption on free protons and deuterons at energies of ≈700 and ≈1000 MeV, which correspond mainly to the $D_{13}(1520)$ and $F_{15}(1680)$ resonances. In the range between 600 and 1200 MeV the strength is reduced by a factor 1.2 with respect to the deuteron, while is conserved in the range 300-600 MeV. This different behaviour in nuclei of the higher nucleon resonances is confirmed by new data on Be and C obtained at Frascati with the transmission technique.[23]

It is worth to note that the Fermi motion and the propagation and interaction of the resonances inside the nucleus produce a broadening of the resonances which increases with the resonance masses, but these effects should not be able to completely sweep away the resonances.[24] Therefore, to account for this reduction of the strength one has to resort to other causes, like the onset of the shadowing effect, although at these low energies it can be hardly related to vector mesons, or a possible damping of excitation of resonances in the nuclear medium. This damping might be more effective on deformed resonances like $D_{13}(1520)$ and $F_{15}(1680)$, which correspond to the excitation of orbital angular momentum, than on spherical ones like the Δ [$P_{33}(1232)$], which is excited by a quark spin flip.

REFERENCES

1) J. Ahrens et al., Phys. Lett. **146B**, 303, (1984); J. Ahrens, Nucl Phys. **A 466**, 229c, (1985) and reference therein.
2) R. Bergère, Proc.2nd Workshop on Perspectives in Nuclear Physics at Int. Energies, Trieste, March 25-29, 1985, p.153, Eds. S. Boffi, C. Ciofi degli Atti and M.M. Giannini, World Scientific,Singapore 1985.
3) T.H. Bauer et al., Rev. Mod. Phys. **50**, 261 (1978) and references therein.
4) T.A. Armstrong et al., Phys. Rev. **D5**, 1640, (1972).
5) T.A. Armstrong et al., Nucl. Phys. **B41**, 445, (1972).
6) E.A. Arakelyan et al., Sov. J. Nucl. Phys. **38**, 589, (1983).
7) E.A. Arakelyan et al., Sov. J. Nucl. Phys. **52**, 878, (1990).
8) W.Weise, Phys. Rev. Lett., **31**, 773, (1973), and Phys. Rep. **2**, 53 (1974).
9) N. Bianchi et al., Nucl. Instr. and Meth. **A311**, 173 (1992)
10) M. Taiuti et al., Nucl. Instr. and Meth. **A297**, 354 (1990).
11) V. Muccifora et al., Nucl. Instr. and Meth. **A295**, 65 (1990).
12) A. Lepretre et al., Nucl. Phys., **A 472**,533, (1987).
13) J. Ahrens et al., Phys. Lett. **146B**, 303 (1984).
14) P. Garganne, Saclay Internal Report, CEA-N-2492 (1986).
15) V.Bellini et al., Nuovo Cim. **85A**, 75 (1985).
16) A.S. Iljinov et al., Nucl. Phys. **A539**, 263, (1992).
17) S. Michalowski et al., Phys. Rev.Lett. **39**, 737, (1977).
18) J. Arends et al., Phys. Lett. **98B**, 423, (1981).
19) J. Ahrens et al., Proc. Int. Conf. on High Energy Physics and Nuclear Structure, Vancouver 1979, eds. D.F.Measday and A.W.Thomas, North-Holland 1980, p.67.
20) P. Carlos, Proc. of Int. Sch. of Intermediate Energy Nuclear Physics, Verona 1985, eds. R. Bergere, S. Costa and C. Schaerf, World Scientific, p. 1.
21) P. Carlos et al., Nucl. Phys. **A431**, 573, (1984)
22) T. Frommhold et al., Book of abstract of Int. Nucl. Phys. Conf.,Wiesbaden 1992, eds.U. Grundinger GSI, 2.3.11.
23) M. Anghinolfi et al., **LNF-91/089** (IR) and Proc. of Int. Nucl. Phys. Conf.,Wiesbaden 1992, eds.U. Grundinger GSI, in print.
24) L.Kondratyuk, private communication.