LNF–97/039

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Physics Letters B 407, 225–228, (1997)

4 September 1997

ELSEVIER

PHYSICS LETTERS B

Physics Letters B 407 (1997) 225–228

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Received 28 April 1997; revised manuscript received 9 June 1997
Editor: J.P. Schiffer

Abstract

The total photoabsorption cross section for carbon and lead has been measured in the energy range 0.5 ÷ 2.6 GeV at Bonn using the SAPHIR tagged photon beam. Nuclear data show a significant reduction of the absorption strength with respect to the free nucleon case suggesting a shadowing effect at low energies. © 1997 Elsevier Science B.V.

PACS: 25.20.Gf; 12.40.Vv
Keywords: Photoabsorption; Shadowing; Nuclear medium effect

The study of nuclear medium effects on the elementary couplings and the properties of hadrons is one of the main fields of interest in modern nuclear physics. The experimental finding of shadowing in the real photon absorption on nuclei has been largely explored during the '70s, in a wide photon energy range $k \sim 2 \div 200$ GeV [1–5]. The effect was generally explained in terms of the vector meson dominance (VMD) model which was able to reproduce the experimental behavior. [6]

Interest in this field has been recently renewed for different reasons:

i) low energy photoabsorption and photofission experiments at Frascati [7,8] and Mainz [9] showed a large nuclear medium effect in the second and third nucleon resonance region with a depletion of the absorption strength with respect to the free nucleon case; *ii)* deep inelastic experiments at CERN [10] and FNAL [11] have proved a large shadowing effect at low x (x being the Bjorken variable) and close to the real photon point; *iii)* theoretical speculations derived from QCD sum rules suggest hadronic mass modifications in the nuclear medium and in particular a large decrease of the ρ-meson mass μ_ρ up to $10 \div 15\%$ [12]. This reflects into an increase of the coherence length of the hadronic fluctuation $\lambda_\rho = 2k/\mu_\rho^2$ of the photon thus lowering the energy threshold for the shadowing effect; *iv)* recent standard VMD calculations predict a negligible shadowing effect [13] or an anti-shadowing behavior [14] in the photon energy region below 2 GeV.

All these arguments raised the interest to look for

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PII S0370-2693(97)00764-8

the onset of the shadowing effect in the energy region of $k \sim 1 \div 2$ GeV which suffered from a lack of data.

Therefore a total hadronic photoabsorption measurement on nuclei was performed in the photon energy range from 0.5 to 2.6 GeV, thus providing a full coverage of the almost unexplored energy region between 1.2 and 1.8 GeV while overlapping with the well known lower and higher energy regions. The measurement was carried out in Bonn, using the SAPHIR [15] tagged photon beam of the ELSA accelerator. The fourteen timing scintillators of the tagging system were used to define the photon beam energy. The tagging system covered a photon energy range from 30% to 95% of the incoming electron beam energy E_0. The photon beam was collimated in order to have a beam spot on the target of about 1.5 cm, 3 cm being the target diameter.

The photoabsorption cross section on nuclei was measured with the photohadronic technique using an apparatus similar to the one previously used in the experiment carried out at Frascati. [7] This technique consists in measuring the hadronic yield with a large angle hadron detector and rejecting the electromagnetic background with a forward angle shower detector.

Here we present the results obtained with a $0.08X_0$ thick carbon target and a $0.2X_0$ thick lead target (X_0 being the material radiation length). Targets were changed about every twenty minutes and moved into the beam vacuum pipe by a remote controlled system.

As a hadron detector (HD) we used a cylindrical NaI crystal annulus (60 cm long, 12 cm thick and 10 cm of internal diameter) made of four sectors surrounding the target. The HD angular coverage was $8^o < \theta < 169^o$ for the polar angle and almost 2π for the azimuthal one, which corresponds to more than 98% of total coverage in the laboratory system. The HD provided a high efficiency detection of charged hadrons and showers from decay photons of neutral mesons. Moreover, thanks to its thickness, the HD enabled to measure most of the final state total energy for hadronic events, which is remarkably higher than that for the electromagnetic events.

A forward shower detector (SD) was used to veto the electromagnetic events. It was placed on the beam axis, about 1 meter downstream of the target, and consisted of a dense SF6 lead-glass cylinder, 30 cm long and 12 cm in diameter. The large detector thickness ($19\ X_0$) provided an efficiency close to unity for detecting electromagnetic showers due to the photon beam and to the Compton and pair production events off the target. A lead collimator, 30 cm long and 9 cm diameter, was placed between the HD and the SD for defining a maximum polar angle of 2.4^o for electromagnetic events originating from the target. Moreover the Cerenkov signal in the SD provided a good rejection of the low energy hadrons which might reach the SD. The SD allowed a simultaneous measurement of the tagged photon flux for each tagging channel. The measured tagging efficiency was stable within $\sim 1\%$ and ranged between 0.73 and 0.92 depending on both the photon and electron beam energies.

Empty-target measurements were regularly performed after each nuclear target cycle run and then subtracted. The empty-target yield was found stable within $\sim 0.8\%$ during the whole measurement. This background could be mainly ascribed to the electron beam halo and to the photon beam interactions on the collimators and on the target frame. The random to true coincidence ratio was measured on-line and stayed at a value of $\sim 5\%$ by keeping the tagged photon beam at a constant rate of $\sim 5 \cdot 10^4$ photons/s.

Monte Carlo (MC) corrections for the loss of hadronic events and for the electromagnetic contamination were applied to raw data. For this purpose a new hadronic [16] and an electromagnetic event generator were used. Several experimental verifications of the MC predictions were performed in order to test the effect of the energy and angular cuts on the efficiency and acceptance of both HD and SD. As an example, in Fig. 1 a comparison is shown between the predicted event yields for different HD solid angle coverage and the experimental yields which were measured for different target position upstream and downstream. The hadronic losses were slowly and linearly increasing with the missing HD solid angle, while the electromagnetic contaminations showed up as a yield increase at very small angle only in the case of the lead target. All experimental verifications were in good agreement with the MC predictions. The corresponding correction to raw data was strongly decreasing with the energy, being in average ~ 8 % for carbon and ~ 3 % for lead.

We covered the photon energy range from 0.5 GeV to 2.6 GeV with three different electron beam energies E_0=2.8, 2.2, 1.6 GeV which ensured large energy

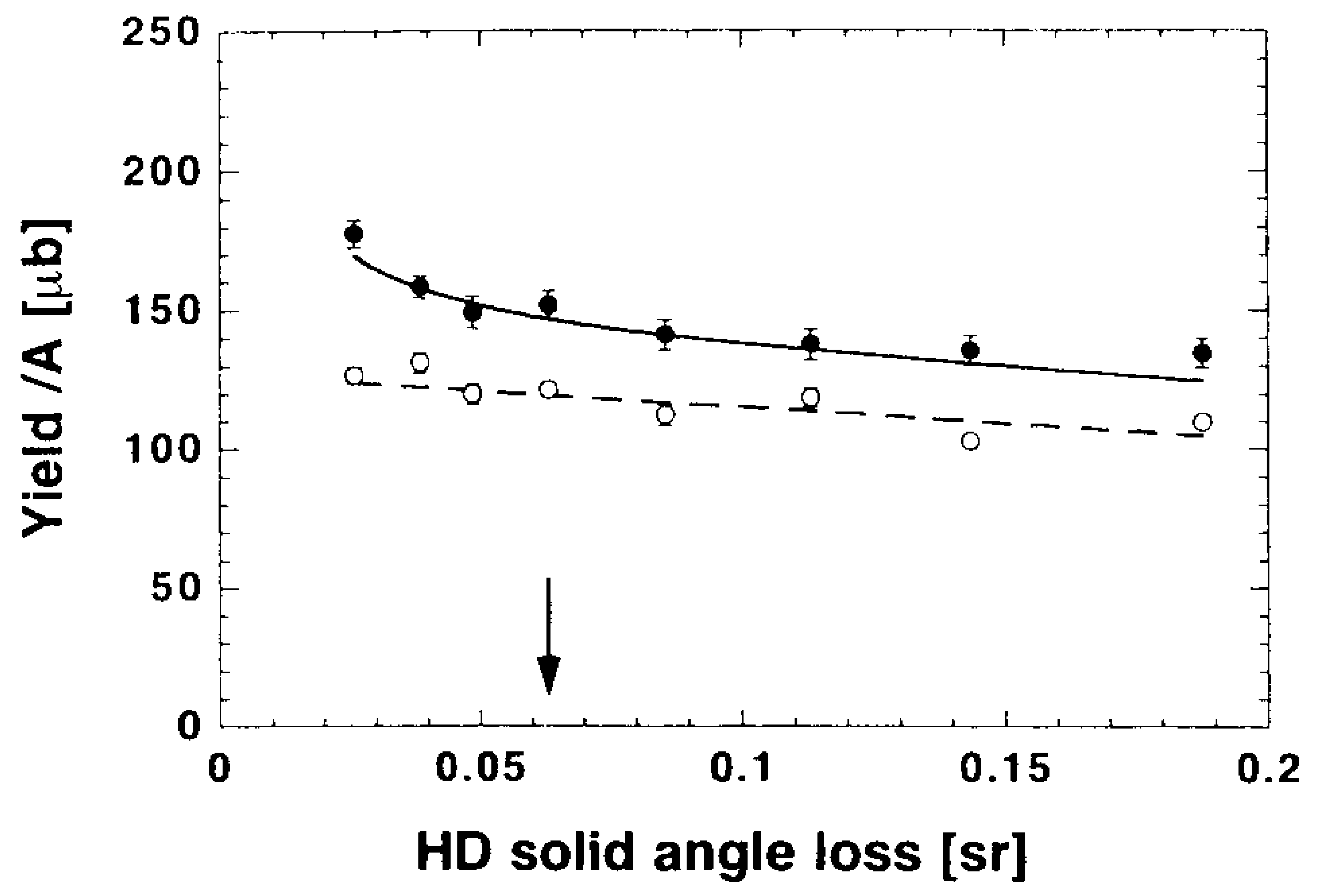

Fig. 1. The average yields measured with different solid-angle coverage of the HD. The carbon target data (open circles) are compared with the MC prediction (dashed line) for E_0 = 2.8 GeV; the lead target data (close circles) are compared with the MC prediction (solid line) for E_0 = 2.2 GeV. The arrow indicates the solid angle loss relevant to the measurement position.

overlapping regions and provided a good check of the systematic errors that could arise from different running conditions. Fig. 2a) shows the cross sections on carbon measured at the three electron beam energies. In Figs. 2b) and 2c) the carbon and lead data are shown averaged over bins of about 100 MeV together with previous data on the same nuclei. The solid line is the absorption cross section on the proton. The bars indicate the statistical errors while the bands at the bottom of the figures represent the systematic errors. The latter ones were mainly due to uncertainties in the target thickness (0.5% for carbon and 1.5% for lead), in the photon beam flux ($\sim$ 1%), in the background subtraction ($\sim 1 \div 3\%$) and in the MC correction ($\sim 2 \div 5\%$). Present data are well in agreement at low energy with data of Ref. [7] within the statistical errors and, at high energy, with data of Ref. [2] within the statistical plus systematic errors.

The new data confirm the absence of the second and third nucleon resonance structures in the bound nucleon cross section. They also show a significant reduction with respect to the free nucleon cross section above 1.2 GeV, where resonance effects are expected to be small. The reduction is emphasized by the ratio of the measured nuclear cross section to the free nucleon one. Fig. 3 shows the ratios of the measured cross sections for carbon and lead to the free nucleon one, derived in a previous paper [7] by fitting proton and deuteron data. As can be seen the reduction in the $1.2 \div 2$ GeV energy range, seems to be bigger for the lighter nucleus. This effect could be due to shadowing onset at lower energy for light nuclei and to a wider broadening of nucleon resonances in heavy nuclei. Also shown in Fig. 3, are the low-energy calculation of a $\Delta - hole$ model [19] and two recent VMD predictions above the resonance region [13,14]. Both VMD calculations assumed μ_ρ = 770 MeV. They are systematically higher than the data and thus do not predict the nuclear damping of the cross section clearly indicated by this experiment. Moreover in Ref. [14] the inclusion of nucleon correlations leads to an anti-shadowing behavior below 2 GeV. Therefore a different parameterization of the low-energy shadowing effect, in terms of spreads and shifts of vector-meson masses and of the low-energy behavior of the V-N cross sections could be considered in order to better reproduce the experimental data.

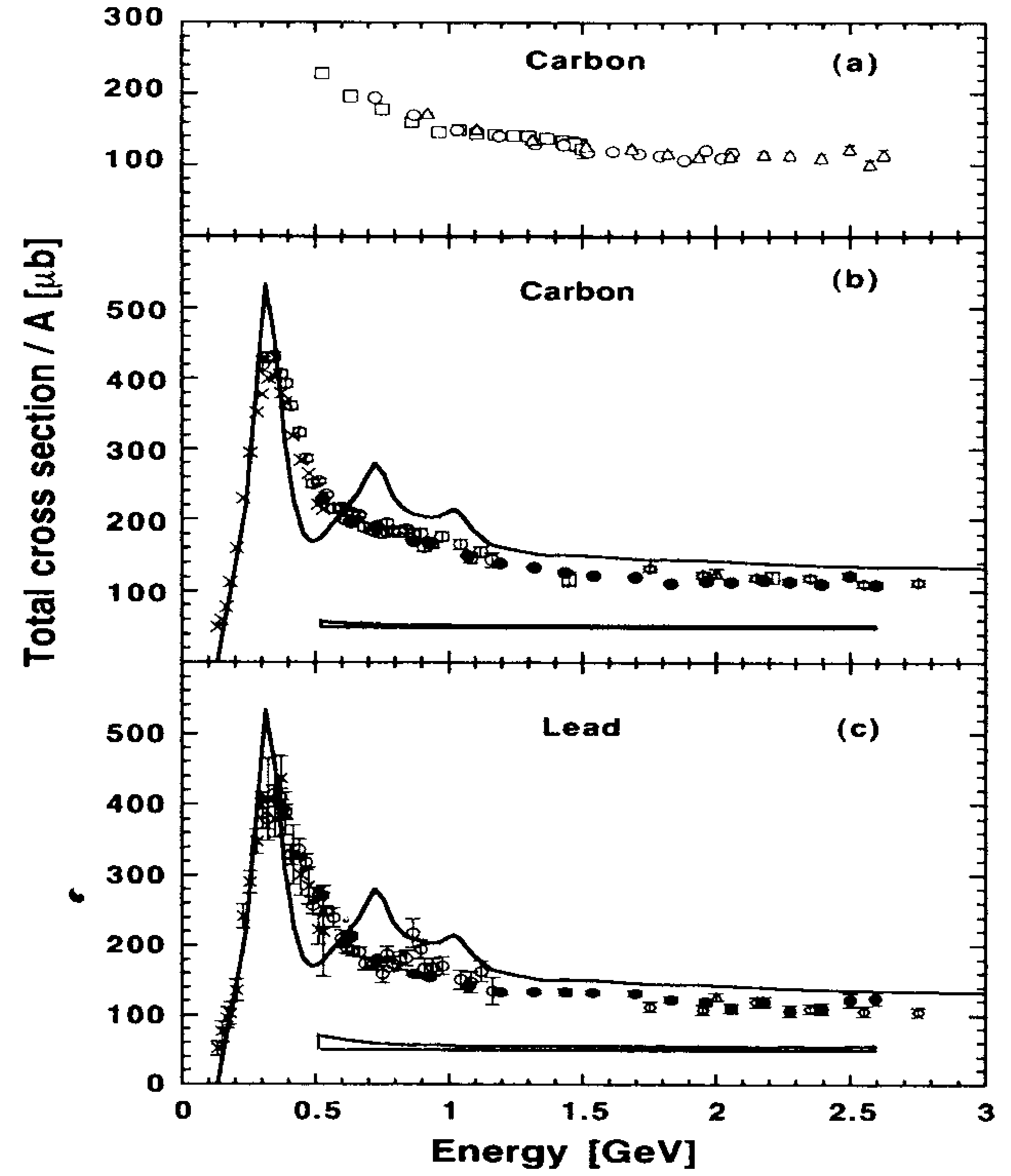

Fig. 2. (a)Total cross section measured on Carbon at three electron beam energies: 2.8 GeV (triangles), 2.2 GeV (circles) and 1.6 GeV (squares). (b)Total averaged cross section measured on carbon (solid circles) compared with previous experiments : squares [1], diamonds [2], triangles [4], open circles [7] and crosses [20]. Also shown is the proton absorption cross section(solid line). (c)Same as (b) but for lead.

In summary we have measured the total photoab-

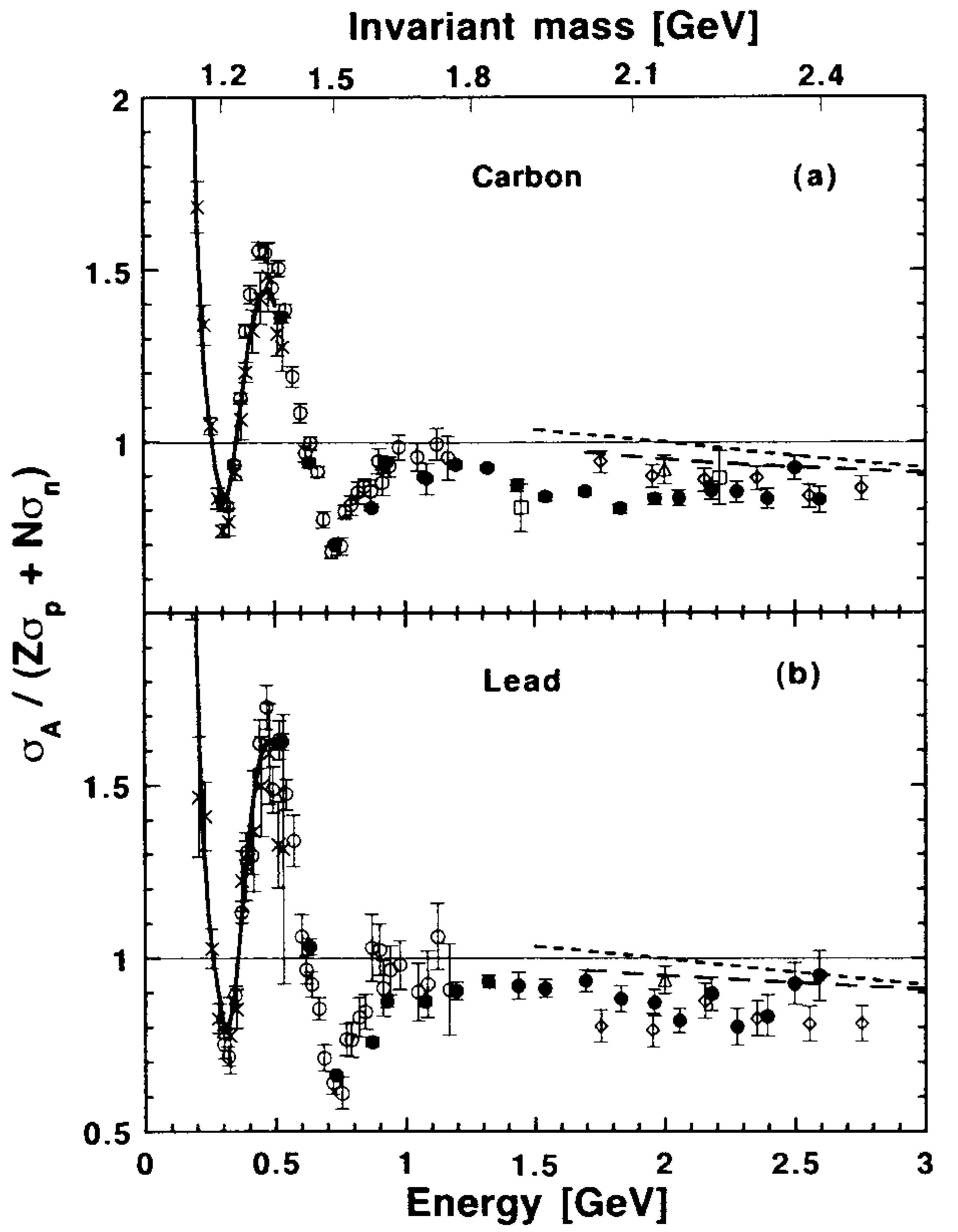

Fig. 3. Ratio of photonuclear and photonucleon absorption cross section. Same notation as Fig. 2. Solid line is a Δ-hole model [19] while dashed [13] and dotted [14] lines are VMD predictions.

sorption cross section for carbon and lead nuclei in the energy range $0.5 \div 2.6$ GeV, using the photohadronic technique with a 4π NaI detector to detect hadronic events and a lead-glass counter to tag the electromagnetic ones. From the comparison between the results for the nuclei and previous data for the free nucleon, we showed a considerable reduction of the cross section that could be ascribed to a low energy onset of the shadowing effect.

We are pleased to thank the Frascati technicians A. Orlandi, W. Pesci, W. Serafini and A. Viticchié for their continuous technical assistance and the ELSA machine staff and all members of the SAPHIR group for the efficiency in running the machine and the experiment.

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