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October, 10, 1988

Dear Professor Rubinstain !

We present you an official suggestion of the experiment on the uranium nucleus photo- and electrofission for the energy range 100-500 GeV. To carry out the first stage of the total hadronic photoabsorption cross section measurement on the uranium nucleus 100 hours of the FNAL accelerator time is necessary. Your polite estimates of the accelerator time sent to us in the letter of December 9, 1987 are fair for one section of low-pressure chambers. Now we have 50 operating chambers of this kind and all of them can be under the beam at the same time because of insignificant quantity of the matter in the chamber. Therefore, the economy of the accelerator time will take place.

A list of equipment and means necessary to carry out the experiment is given in the list. We can bring all this equipment from Yerevan. To minimize the transport expenses we ask you to inform us what enumerated means can FNAL present without any difficulties.

As to people reserves. We plan to send 5-6 specialists from the Yerevan Physics Institute. The participance of 2 or 3 FNAL specialists is desirable. We would be very glad if you personally take part in the suggested experiment.

Yours sincerely
Professor Amatuni A.Ts.

Amatuni

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THE MEASUREMENT OF THE TOTAL CROSS SRCTION OF THE REAL AND VIRTUAL PHOTON ABSORPTION ON THE URANIUM NUCLEUS AT ENERGIES OF HUNDREDS OF GeV

We propose to measure the cross section of the uranium nucleus fission by real and virtual photons within 200-400 GeV on an electron beam by the method of simulteneous detection of fragments and recoil electrons. These cross sections are equal to those of hadron photoabsorption, since each inelastic interaction of real and virtual photons with the uranium nucleus leads to its fission. The proposed techique is devoid of the systematic errors connected with the electromagnetic background and geometry for real photons, and with the radiativ corrections for virtual photons.

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MEASUREMENT OF THE TOTAL CROSS SECTION OF REAL AND VIRTUAL PHOTON ABSORPTION ON URANIUM NUCLEI AT ENERGIES OF HUNDREDS GeV

Introduction

We propose to measure the cross section of uranium nucleus fission induced by real and virtual photons at energies of hundreds GeV and small momentum transfers ($Q^2 \rightarrow Q^2_{min}$) on the electron beam of FNAL. The cross section are equal to hadron photoabsorption cross sections because the fissility of uranium is unity, i.e.each inelastic interaction of a photon with uranium nucleus lead to the fission of the latter. Up to now the total cross sections of photon-nucleon and photon-nucleus interactions are measured up to photon energies $E \leq 200$ GeV, the accuracy of measurements on heavy nuclei (errors about 10 %) not allowing to draw unambiguous conclusions in favour of this or that model.Precision measurements of the total cross section of hadron photoabsorption on heavy nuclei by means of usual techniques is hindered by the presence of an electromagnetic background and large systematic errors due to geometric factors, because:

1) the measurement of uranium photofission cross section is an alternative method for the measurement of total photoabsorption cross section, is devoid of the mentioned drawbacks and the measurement errors in this case is mainly due to the statistics;

2) it becomes possible to measure the cross section of the inelastic scattering of electrons on uranium at $Q^2 \rightarrow Q^2$min, allowing to test the predictions of the VDM model, which suggest that at such Q^2 the real and virtual photon absorption cross sections are equal.

At present, in Yerevan Physics Institute, an experimental technique based on the uranium fission fragments detection by low-pressure proportional chambers is developed to measure the cross section of photoabsorption on the uranium nucleus. This technique has been worked out during the experiment on measurement of the total cross section of hadronic photoabsorption of real and virtual photons in the energy range 0,2 - 4,0 GeV on the Yerevan Physics Institute accelerator. It is planned to measure the total hadronic photoabsorption cross section at FNAL, in the energy range up to 400 GeV.

Physical Basis

The development of strong interactions theory is connected in many respects with the possibility of using the quantum chromodynamics at comparatively large distances. From this point of view, it is interesting to investigate high-energy photons in the interactions of which with nucleons and nuclei their dual properties of a point-like formation (a quark-antiquark pair at short distances where QCD can be applied) and of a hadron-like system (a pair of constituent quarks at distances of the order of hadronic sizes)can manifest. It is obvious, that,contrary to hadronic interactions, in the space-time picture of photon interactions with nucleons and nuclei, the quark-antiquark photon structure evolution from a point-like state to a hadronic one must be reflected, which can take place during a characteristic time /1/of $t = 2E_\gamma/M^2$ (E_γ is the photon energy, M is the effective mass of the quark-antiquark pair). The presence of a strongly expressed point-like component in the photon structure leads to an interesting opportunity to study the effect of the quarks colour screening at small distances /2/ The allowance for this effect was made in Ref./3/, where a stronger dependence on the nucleus atomic number for the total photoabsorption cross section than in VMD-type models (in which the effect of colour screening is not taken into account), as well as absence of energy dependence of the total photon-nucleon and photon-nucleus cross sections in the energy range E $>$ 50 GeV (in the prediction about approximate constancy of interaction cross sections of the vector mesons with nucleons) were predicted. The absence of the energy dependence of the total photon-nucleon cross sections follows also from more detailed calculations in the framework of QCD, where the colour screening effects appear already in the one-gluon exchange approximation. A notable energy dependence of the total photon-nucleon (hence, photonuclear) cross sections is predicted in a number of reports, which do not take the colour screening effects into account. For example, in the framework of the additive quark model, a logarithmic dependence on energy, $\sigma(\gamma, N) \sim \ln E_\gamma$ is predicted in Ref./4/.

In Ref./7/, they predict that at high energies

$$\sigma(\gamma, N) = a + b \ln E_\gamma + c \ln^2 E_\gamma$$

A slight decrease of effective nucleon numbers $A_{eff} = \sigma(\gamma, A)/\sigma(\gamma, N)$ with energy is predicted in the approaches based on the models like VDM. By this time, the total cross sections of photon-nucleon and photon-nucleus interactions have been measured /6/ up to the energies $E_\gamma \lesssim 200$ GeV, the accuracy of measurements on nuclear targets (~ 10% error) not allowing to make unambiguous conclusions in favour of one or another model. In view of this fact, it is undoubtedly interesting to measure the energy dependence of the total photoabsorption cross section on heavy nuclei (for which the screening effects are more essential) with errors ~ 3% and, if possible, in larger energy range.

In case of virtual photons the coherent length (or the characteristic fluctuation time) is expressed as:

$$t = 1/\Delta E = 2E_\gamma (m^2 + Q^2)$$

where E_γ is the photon energy, m is the vector meson mass; $Q^2 = -q^2 = 4EE' \sin^2\frac{\theta}{2}$ is the momentum transferred.

In the framework of the VMD it is predicted that screening must appear also in the interaction of virtual photons with the nuclei and besides, at sufficiently small values of $Q^2 (Q^2 \lesssim 0,1 (\frac{GeV}{c})^2)$ the degree of virtual photons screening is equal to that of real photons. At low E_γ , the screening decreases with increasing Q^2 (the coherent length is decreasing). At large $Q^2 (Q^2 \simeq 1 (\frac{GeV}{c})^2)$ and $E_\gamma (E_\gamma > 10\ GeV)$ the roie of heavy vector mesons becomes more essential and the screening does not disappear. Observation of screening at large values of Q^2 and E_γ is a direct evidence for the contribution of vector mesons heavier than ρ^0 -meson into photon-hadron interactions. The experiments available in this region can be grouped as follows:

The first group - experiments with one-arm arrangements where scattered electrons are only detected (the so-called inclusive electroproduction). In these experiments the investigations in the region of low transferred momenta are hindered by the presence of large radiative corrections, the final result depending on their correct account. The available experimental data, though contradictory, indicate to screening at low Q^2, which in spite of the theoretical predictions , rapidly disappears with increasing Q^2/8-12/. Unlike inclusive electroproduction, in the experiments on inclusive μ - production /13-15/, where the radiative corrections are not so essential as in the case with electrons, at small momentum transfers screening is observed, the value of which in some cases /14/ exceeds that of the screening arising at the interaction of real photons with nuclei and it does not rapidly vanish with increasing in accordance with theoretical predictions /15/.

Another group of experiments is the coincidence of the scattered electron with the signal from produced hadrons. In this case the allowance for radiative corrections is strongly simplified and measurements at $Q^2 \to 0$ become possible. Such a measurement was carried out at CORNELL /16/ at $Q^2 = 0.1 \left(\frac{GeV}{c}\right)^2$. The investigations gave the screening, the absolute value of which was less than the theoretically expected. Thus, the present experimental situation is not quite clear. The available experimental data are contradictory even at $Q \to 0$. The theory fails to explain the absence of screening at $Q \to 0$ and $E_\gamma > 2$ GeV. Further experimental investigations of this problem which is so important for photon-hadron interactions, are of great interest. The measurements on heavy nuclei are of a special interest as the effect of screening is the highest here.

MEASUREMENT OF THE CROSS SECTION OF URANIUM FISSION BY REAL AND VIRTUAL PHOTONS IN THE ENERGY RANGE 200 - 400 GeV.

The presence of electromagnetic background and systematic errors due to geometric factors hider the measurement of the total cross section of hadronic photoabsorption on heavy nuclei by means of conventional methods. At Yerevan Physics Institute an experimental technique, based on the detection of uranium fission fragments with the help of low-pressure proportional chambers (PC) /5/has been recently developed for measuring the photoabsorption cross section on uranium nucleus. The uranium fissility ability is equal to unity, i.e. each inelastic interaction of a photon with the uranium nucleus leads to its fission. The uranium target of 1 mg/cm^2 thickness is placed in the PC and a stack of such PC with an overall target thickness of 50 mg/cm^2 is assumed to be used. The performance of PC was specially chosen so that the detection efficiency of uranium fission fragments be 100%. The experimental set-up is schematically shown in Fig.1. The PC are placed under the tagged photon beam, in front of the shower detector. To suppress the random coincidences of PC signals with tagged photons, not interacted in the target, the signal from shower detector was brought in anticoincidence with those from the tagging system.

The detection of fission fragments in coincidence with the tagging - system counters allows one to determine the number of photons of given energy, which interacted with the uranium nucleus. Thus, this technique is not sensitive to the electromagnetic background, because the nucleus does not get sufficient momentum for fission during electron-positron pair production. As the angular distribution of fission fragments weakly depends on the incident photon energy, the systematic errors in these measurements will be independent of the energy. Unlike traditional measurements, the [illegible] errors will be determined mainly by statistics.

MEASUREMENT OF THE CROSS SECTION OF INELASTIC SCATTERING OF ELECTRONS ON URANIUM AT $Q^2 \rightarrow Q^2$min AND $E_\gamma = 200 - 400$ GeV.

The experimental set-up for the measurement of electrofission cross sections at $Q^2 \longrightarrow Q^2$min in coincidence with scattered electrons is shown in Fig.2. The electron beam traverses a low-pressure PC. As the experimental investigations shown /5/, such a detector works stable under electron beams of intensities up to 10^8 el/s, which allows to measure the uranium electrofission cross section at the energy range 1-4 GeV both in the mode of coincidence with the scattered electron and without it /5/. The inelastic interaction of electrons with uranium nuclei placed on the PC electrodes leads to the fission of uranium. The fission fragments are registered in the PC and form hadronic trigger.

The electrons scattered at small angles are detected by the tagging system. The coincidence of the tagging system signals with those of fission fragments allows to get rid of the main radiative processes (bremsstrahlung, radiative tail of the elastic scattering). The shower detector in the mode of anticoincidence with the PC also allows to get rid of the bremsstrahlung resulting from the inelastic scattering of electrons. Thus, the contribution of radiative processes in such an approach is minimized. It is expedient to carry out such measurements on high-energy proton beams of low intensity. And to use the available tagging systems as magnetic spectrometers for inelastically scattered electrons at $\theta \sim 0^\circ$ angles.

A FISSION FRAGMENTS DETECTOR BASED ON A LOW-PRESSURE PC.

The general scheme of the detector is shown in Fig.3. The detector is a multiwire low-pressure PC /5/. The high-voltage electrodes are made of 1 mm - spaced gilt tungsten wires of 40 μm in diameter. The signal plane is formed from 2 mm - spaced wires of 20 μm in diameter. The uranium target is glued on the high-voltage electrode. The chamber is filled with hydrocarbon vapours under a pressure of tens mm of Hg.c. and produces fast signals with a front of 2 ns and a total duration of 10 ns. Fast linear amplifiers with gain factor of $\sim$ 100 are used. The low-pressure chamber was tested in laboratory as well as under electron and photon beams and its operation with different fillings and at different pressures of hydrocarbon vapours was investigated.The efficiency of fission fragments and α -particle detection as a function of the applied voltage was checked up to 1 kV. For the values of voltage up to 400 V the chamber was sensitive only to heavy fragments, and then registration of α-particles with 100 % efficiency began at 800 V (Fig.4).

Investigations of the chamber characteristics show that the plateau in the region of the highest efficiency of registration of the fission fragments continued under photon and electron beams of intensities up to $5 \cdot 10^7$ e^-/s.

The fission fragments detector was used in the experiments on the measurement of the cross section of uranium total photoabsorption by real and virtual photons in the energy range 0,2 - 4,0 GeV and $Q^2 \sim 0{,}01$ (GeV/s)^2.

THE CROSS SECTION AND BEAM -TIME ESTIMATES

To estimate the beam time one can assume, that the uranium total photofission cross section at energies more than 10 GeV $\sigma(\gamma, U) = 30$ mb. When the angular range of electron scattering is (Qmin , Qmax), and the energy range is (E_1 - E_2), the uranium electrofission cross section can be estimated from the expression

$$\sigma(e,U) = \int_{\theta_{min}}^{\theta_{max}} \int_{E_1}^{E_2} \frac{d^2\sigma}{d\Omega\, dE} = \sigma(\gamma, U)\, \frac{\alpha}{\pi} \ln \frac{\theta_{max}}{\theta_{min}} \left[0{,}5\, \frac{E_1^2 - E_2^2}{E^2} + \frac{E_1 - E_2}{E} + 2 \ln \frac{E - E_1}{E - E_2} \right]$$

where

$$\theta_{min} = (m_e / E E')(E - E')$$

θ max is defined by the geometry of the experiment.

For 400 Gev electrons the cross section (within (θmin, 1mrd) and (200-400) GeV) is equal to

$$\sigma(e,U) = 10^{-2}\sigma(\gamma,U)$$

With the electron beam intensity of $N_e = 5 \cdot 10^5$ e^-/s, the radiator thickness of $5 \cdot 10^{-2}$ rad.units and the uranium target thickness of 50 mg/cm^2, about 50 hours of machine time is necessary to gather statistics of 3 % accuracy in the experiment on the measurement of total cross section of hadroproduction by real photons in each of the ten channels for energies ranged from 200 to 400 GeV. For measurements with virtual photons with their energy in each of these ten channels being within the 3 % accuracy, the traversal of $2.5 \cdot 10^{11}$ electrons through the stack of uranium targets of a total thickness of 50 mg/cm^2 is needed and the corresponding machine time is estimated to be about 125 hours. Thus, about 200 hours of the Fermilab machine time is needed to realize the program of the proposed experiment.

1. Bauer T.H., Spital R.D., Yennie D.R., Pipkin F.M. The hadronic properties of the photon in high-energy interactions. Rev.of Mod.Phys., 1978, vol.50, p.261.
2. Bjorken T.D., Hadron final states in deep inelastic processes. SLAC-Pub, 1976, vol.1756.
3. Gevorkyan S.R., Gulkanyan H.R. Influence of color screening effect on interaction of high energy photons with nucleus and nuclei. Preprint EFI-872(23)86, Yerevan 1986.
4. Halzen F., Keung W.Y., Scott D.M. Production of heavy quarks. A nonperturbative approach. Phys.Rev. 1983, vol.D27, N.7, p.1631.
5. Arakelyan E.A., Bayatyan G.L., Grigoryan N.K. et al. Low-pressure chamber for registration of fission fragments of heavy nuclei. Preprint EFI 1000(50)-87, Yerevan, 1986.
6. Caldwell D.O., Cumalat Y.P., Eisner A.M. et al Measurement of the photon total cross section on photon from 18 to 185 GeV. Phys.Rev.Lett. 1978, vol.40, p.1222.
7. Bayatyan G.L., Margaryan A.T. On growth of hadronic photoabsorption total cross section. Journal of Nuclear Physics, vol.43, p.954, 1986.
8. Ditzler W.R., Breidenbach M., Freidman Y.I. et al. A - dependence of high-energy inelastic electron-nucleus scattering. Phys.Lett. 1975, vol. B57, p.201.
9. Stein S., Atwood W.B., Bloom E.D. et al. Electron scattering at 4° with energies of 4,5-20 GeV. Phys.Rev. 1975, vol.D12, p.1884.
10. Baily S., Botterill D.R., Montgomery H.E. et al. Measurement of shadowing in low Q^2 electroproduction on nuclei. Nucl.Phys.1979, vol.B151, p.367.
11. Huber G., et al. Zeitschriff F. Physik, 1979, vol C2, p. 279.
12. Franz S., Guzielski G., Huber G. Total cross section for inclusive electron scattering in the low Q^2 region. Preprint DESY 81-023, 1981. Z.Phys. C10(1981)105.
13. May M., Alsanides E., Lederman L.M. et al. Scattering of 7 GeV muons in nuclei. Phys.Rev.Lett.,1975, vol.35, p.407.

14. Miller M., Moskowitz R., Britton J.Le et al. Shadowing in muon-nucleus scattering. Phys.Rev.Lett., 1981, vol.D24, N.1, p.1.

15. Goodman M.S., Hall M., Loomis W.A. et al. Observation of shadowing in the virtual photon.. Phys.Rev.Lett. 1981, vol.47 N.5. p.293.

16. Eikmeyer T., Michalowski S., Misterg N. Experimental study of nuclear shadowing in low Q^2 electroproduction. Phys.Rev.Lett.1976, vol.36, p.289.

17. Michalowski S., Andrews D., Eickmeyer J. et al. Experimental study of shadowing in photoproduction. Phys.Rev.Lett. 1977, vol.39, p.737.

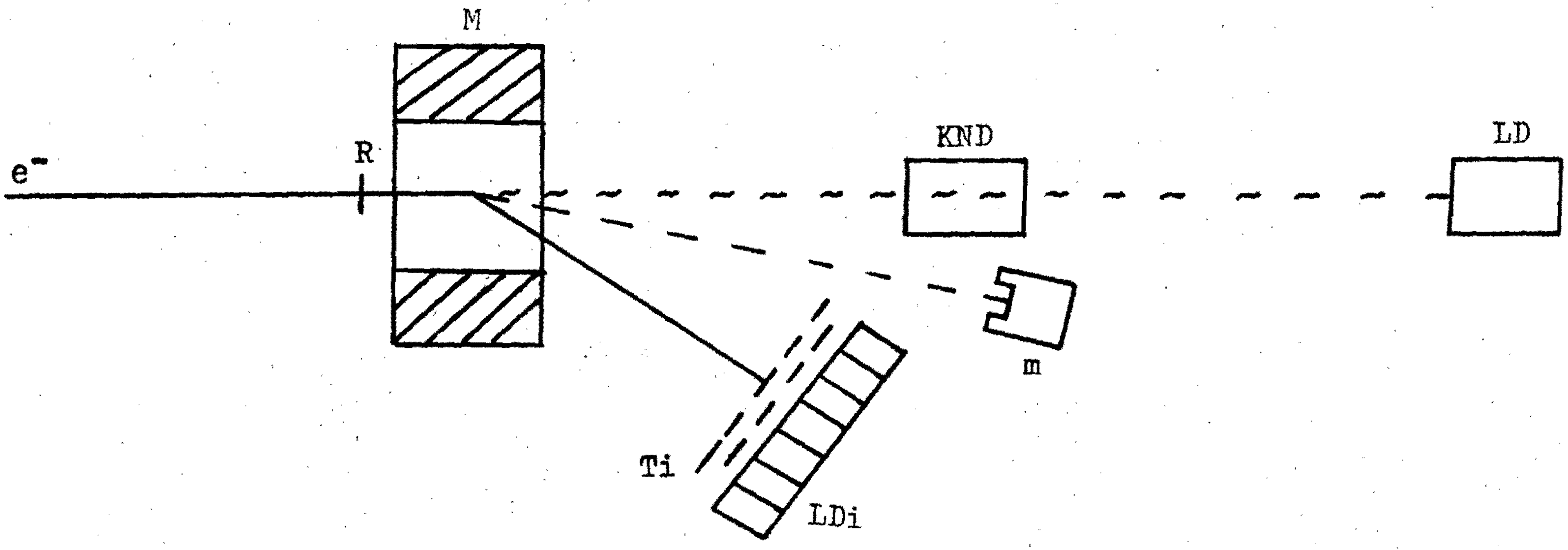

Fig 1 Schematic diagram of the Photofission experiment

R - Radiator
M - Tagging Magnets
Ti - Hodoscope
LDi - Tagging shower counters
m - Beam Dump
KND - Low-Pressure MWPC

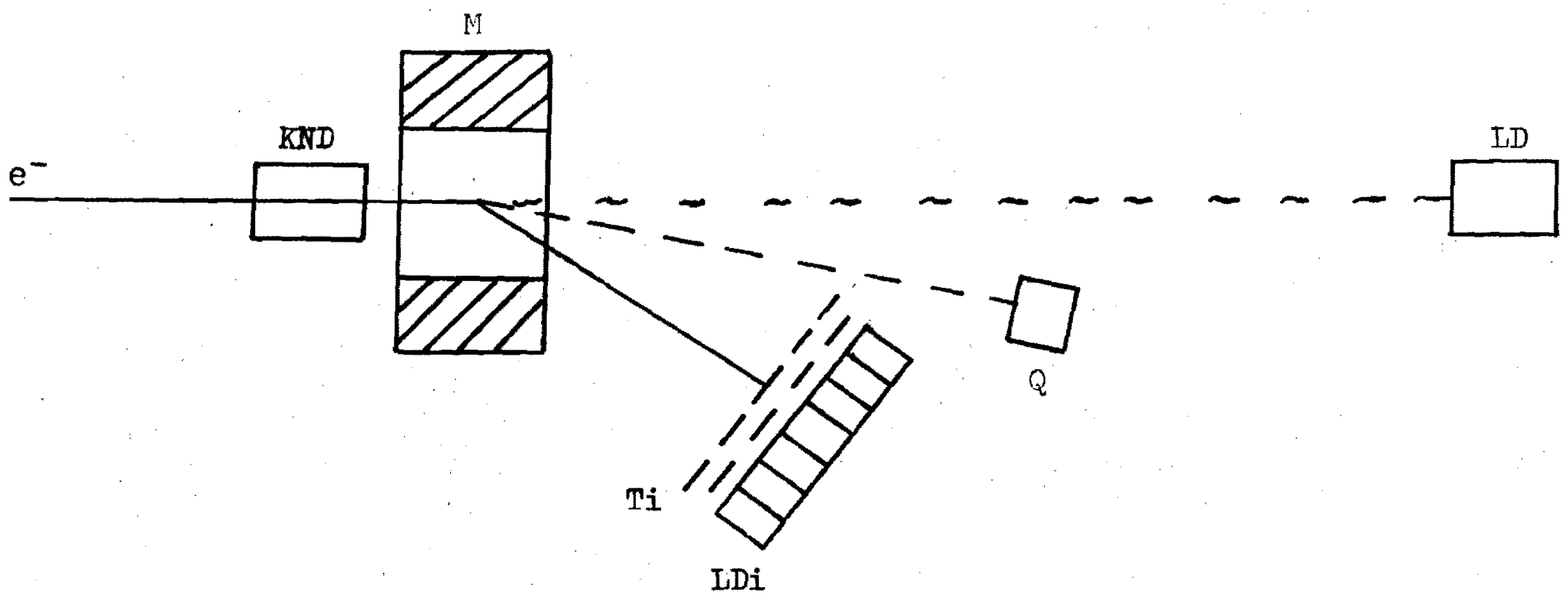

Fig.2 Schematic diagram of the Electrofission experiment

KND - Low-Pressure MWPC
M - **Tagging Magnets**
Ti - Hodoscope
LDi - Tagging Shower Counter
Q - Beam Monitor
LD - Shower Counter

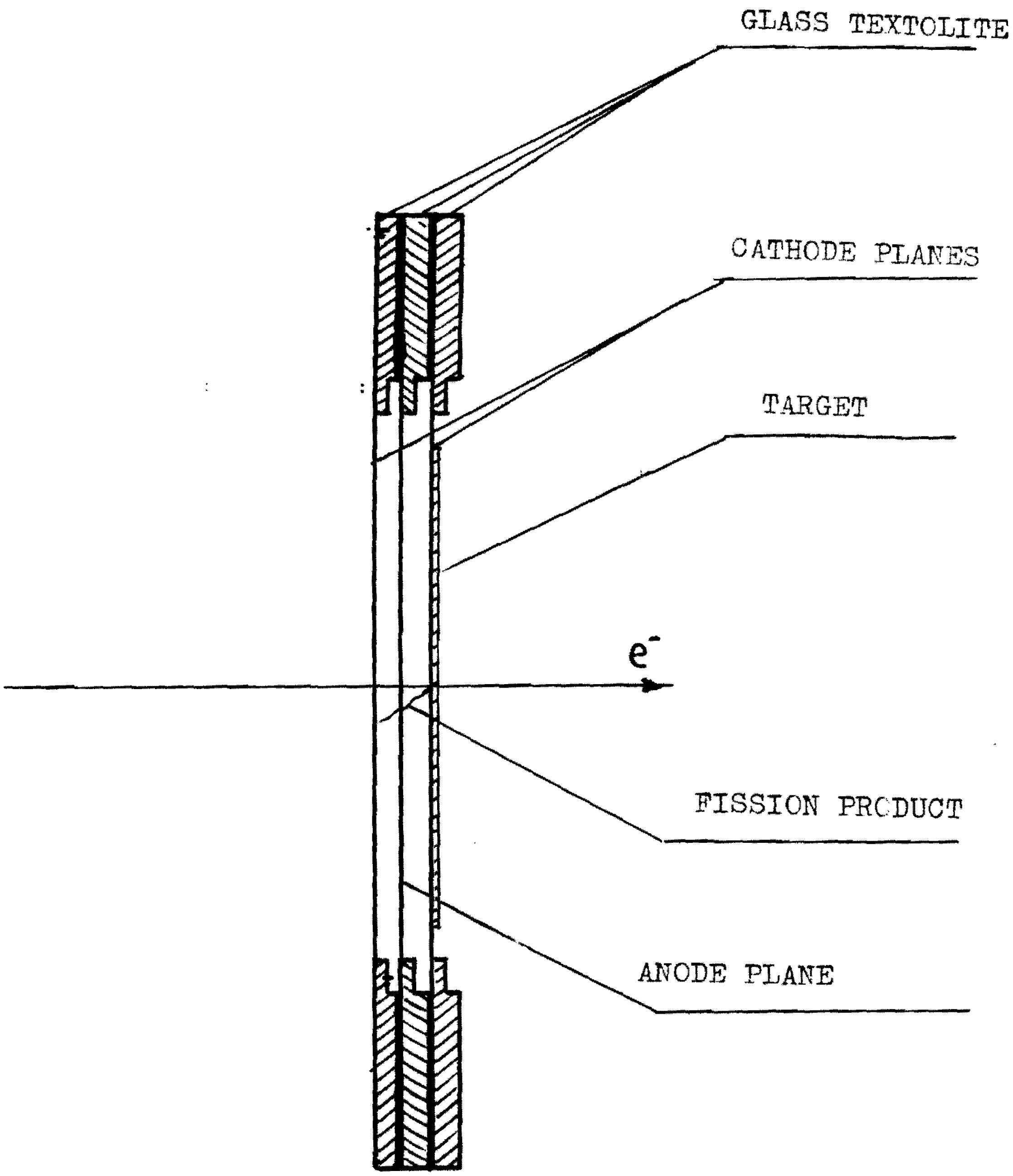

Fig.3 A schematical diagram of the low-pressure chamber.

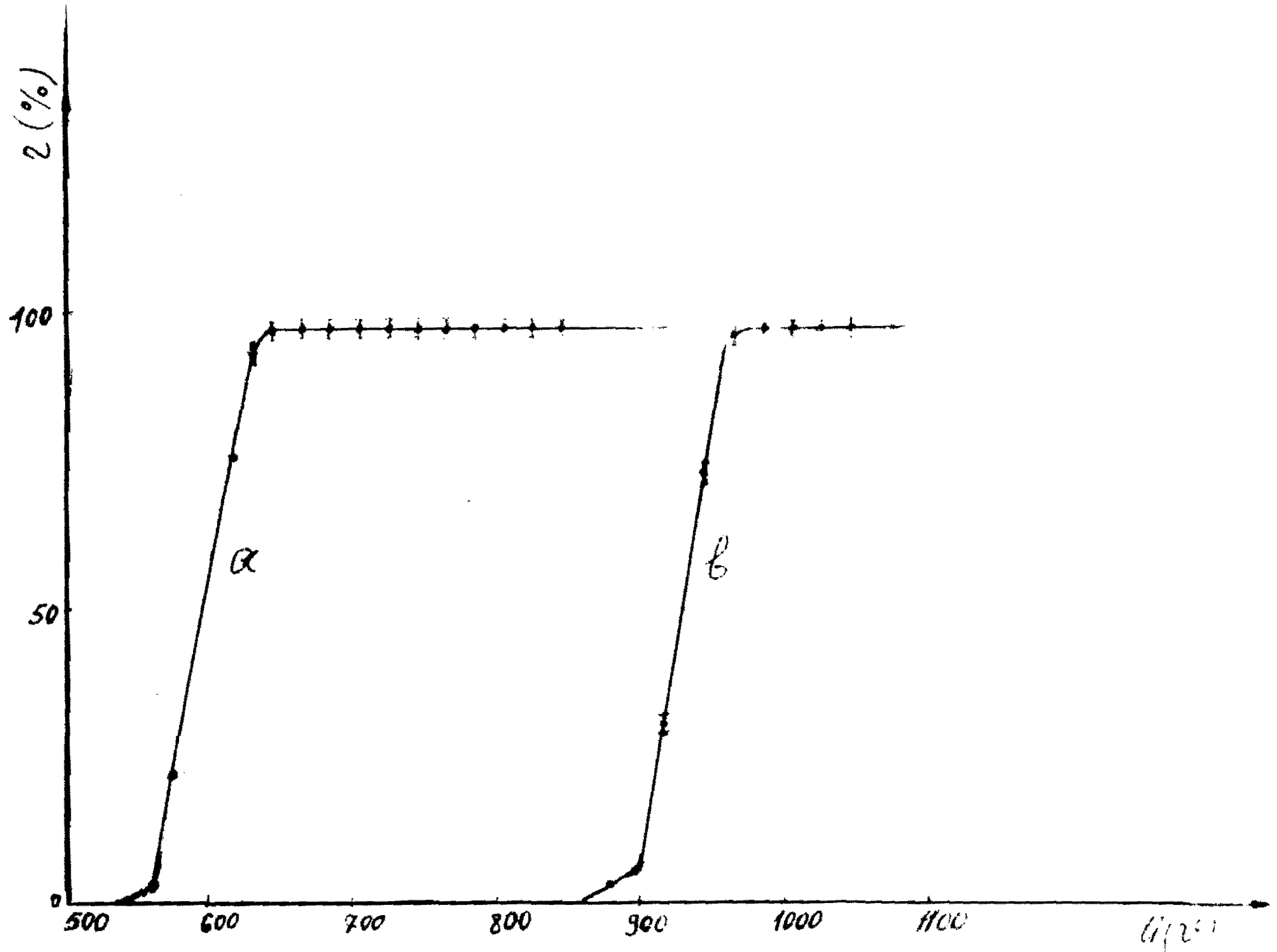

Fig.4 The efficiency of the low-pressure chamber as a function of the applied voltage.

a) - the registration region of the fission fragments;

b) - the registration region of α-particles.

Addendum to P801

The purpose of P801 is to accurately measure (<3% errors) the degree of shadowing in photon-nuclear interactions in the energy range 100-350 Gev. The degree of shadowing is determined by the parameter Aeff, which is defined by :-

$$\frac{A_{eff}}{A} = \frac{Gt(A)}{Z\,Gt(p) + (A-Z)\,Gt(n)} < 1$$

where A = atomic nambεr, Z = nuclear charge, Gt(p),Gt(n) and Gt(A) = total photon absorption cross sections correspondingly on proton, neutron and nucleus. When this ratio is 1, then shadowing is absent. When this ratio is significantly < 1 , then shadowing is present.

By measuring Gt(A) for uranium and comparing with nucleon data of Caldwell's group [Caldwell D.C. et al. Phys. Rev. Lett., 1978, 40, p. 1222] one can determine the degree of shadowing in photon-nuclear interactions.

At present data exists for carbon up to 130 Gev and lead at 60 Gev. This data has large errors (~10%) due to the difficulty of suppressing the large background from e+e- pairs. (In the case of lead, approximatly 6*e4 e+e- per hadronic interaction.) Usually this background is suppressed using veto shower-counters with very high efficiency for e+e- detection. This technique suffers in that some fraction of hadronic interactions will also be vetoed. This problem is worse in the high energy regime, where many secondary particles are produced in the small forward solid angle covered by the veto counter. Thus creating a systematic error which is difficult to correct for and creates an artificial shadowing signal. Moreover, the fact that these shower counters are not 100% efficient means that the signal will be contaminated by residual e+e- background events; an effect which depends strongly on A.

All experiments, where evidence for shadowing has been observed have used this method.

P801 proposes to use a new technique which is completely insensitive to the e+e- bacground and hence enables a precision measurement of the degree of shadowing at very high energies.

Another notable property of this technique is its complete insensivity to the muon background in the experimental hall, which leads to additional bacground counts in the hadron detectors of traditional methods.

The technique of P801 may be usful for experiment E665 also.

It should be noted that the aproximate independence of Gt(p) and Gt(n) on energy above 50 Gev does not mean that the Gt(A) must also be constant. This is becouse shadowing in photon-nuclear interactions, in contrast to hadron-nuclear interactions depends significantly on energy (see the data of Caldwell's group for copper in fig.4, Phys. Rev. Lett. 1979, 42, p. 553). Thus the energy dependence of Gt(A) over the range 100 to 350 Gev may be quite large.

We may add, that the approximate constancy of Gt(p) and Gt(n) enables us to extrapolate to energies above 185 Gev where nucleon data is absent.

In conclusion, we expect that if we can measure Gt(A) for uranium with errors < +-3% over the energy range of FNAL's wide band photon beam 100-350 Gev we will be able to make unambigous conclusions in favour of one or another of the theoretical models, which predict different levels of shadowing and different energy dependences for Gt(A).

2. Feasibility of parasitic running

It is possible to realise the goals of P801 by running parasitically on E687.

In order to obtain the necessary good energy resolution without using the E687 beam tagging stations or reducing the beam intensity, P801 may be able to trigger on only the low energy part of the incident electron spectrum by using a small (2mm thickness, 10mm wide) scintilator counter in the momentum dispersed part of the beam (PB5). This will necessitate putting a gap in the beam pipe in the PB5 enclosure, but should in principle give us 5% momentum resolution for the incident electron. It will also mean, that we will trigger on only 5% of the beam and will want to run with a 400 Gev electron tune. These conditions will combine to extend the required parasitic beam time from 1 day to 40 days.

3. Costs to Fermilab

Yerevan Physics Institute is able to supply all the equipment necessary to carry out the experiment. However, in order to minimise our transportation expences, we would like to use whatever part of the equipment that can be supplied by Fermilab without difficulty. This would amount to ~ $30K. If this is a problem YERPI will transportate all the equipment.

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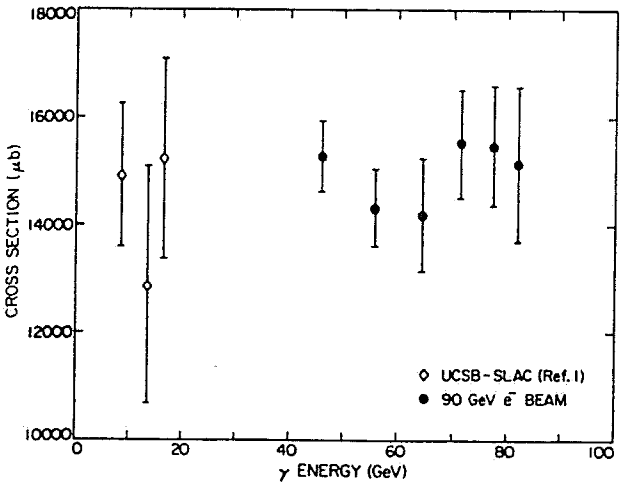

FIG. 3. Photoproduction cross section from lead.

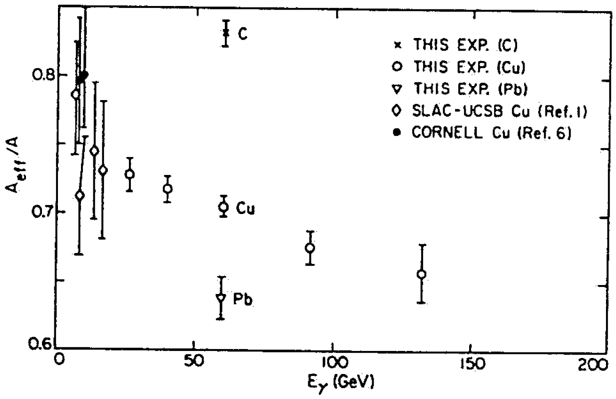

FIG. 4. Energy dependence of A_{eff}/A for carbon, copper, and lead (see text for explanation).