NAL PROPOSAL No. 257

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PROPOSAL FOR THE INVESTIGATION OF VIRTUAL PHOTOABSORPTION BY NUCLEAR MATTER

Chicago-Harvard-Illinois-Oxford Muon Collaboration (Exp.98)

October 1973

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FROM

CHICAGO-HARVARD-ILLINOIS-OXFORD MUON COLLABORATION (EXP.98)

Introduction and Summary

We ask to study muon scattering from carbon, copper and lead, in the region $0.05 < q^2 < 1\ (\mathrm{GeV}/c)^2$ and $\nu \gtrsim 100$ GeV to investigate the coherence properties of virtual photons. Previous data indicate that we can expect a considerable change in coherence properties in this q^2 range. These data can be taken when the muon beam is operating at low intensity (10^4 muons/pulse).

Motivation

The fact that nuclei seem to be opaque to γ rays of high energy came as a surprise at first; it is now understood, as discussed below. The present surprise is that virtual (spacelike) photons do not show these same coherence properties under conditions where the simple theory suggests that they should.

When the DeBroglie wavelength $\lambda\!\!\!^{-} \simeq \frac{0.2\ \mathrm{Fm}}{p\,(\mathrm{GeV}/c)}$ becomes very small relative to nuclear dimensions, it becomes possible to simplify some high energy scattering processes by treating them with the methods of classical optics. The processes amenable to this analysis are the so-called diffractive processes in which the only quantum numbers exchanged between projectile and target are those of momentum and angular momentum (the Pomeron). The "optical theorem", which relates the imaginary part of the forward scattering amplitude to the total cross section, enables the optical treatment of the forward amplitude to be related to the total cross section, a quantity which includes processes not satisfying the optical conditions themselves.

When these methods are applied to the propagation of photons (real and virtual) in nuclear matter, the states of interest are those with photon quantum numbers. In the low mass regime, this means ρ°, ω°, ϕ°. An interesting and

seemingly paradoxical situation results. Photons couple only weakly ($\sim \alpha$) to hadrons, yet they are attenuated strongly in nuclear matter at high energy. We see this by noting that the total photoabsorption cross section on protons is about 125 μb while its geometric value might be more like 40 mb. These numbers predict an absorption length of some 320 fermis in nuclear matter. The observed result for real photons ($q^2 = 0$) in lead and gold[1/] is shown in Fig. 1. From these results, the nucleus appears almost totally black (absorptive)! This result is totally in conflict with the naive inference from knowledge of the total cross section. By way of contrast, the spacelike photons exhibit no shadowing at all as can be seen on the same graph.[2/] The most dramatic recent evidence of a strict $A^{1.0}$ dependence comes from the BNL inelastic muon scattering experiment.[3/] These results are shown in Fig. 2, where it is seen that a dependence $A^{0.98}$ is ruled out by the data. In this energy-q^2 regime, the nucleus is totally transparent to virtual photons in the way one might naively have predicted for all photons.

Two views have been advanced to account for the apparent paradox. The notion of "vector dominance", wherein the photon turns into a $\rho^\circ(\omega^\circ, \phi^\circ)$ with some amplitude γ_ρ before reaching the nuclear surface and then propagates as a vector meson with SI through the nuclear matter. This view corresponds to the picture of Bell.[4/] Stodolsky[5/] has taken a view in which the photon first interacts directly with a nucleon to produce a real ρ° meson after which the real ρ° propagates through the nucleus. Later work by Brodsky and Pumplin, Gottfried and Yennie and D. Schildknecht[6/] has reconciled, generalized and expanded these views to a rather complete description of the behavior of real and spacelike virtual photons in nuclear matter. The theory is now called generalized vector dominance (GVD). The conclusions reached by these authors indicate that measurements in heavy nuclei of the total photo cross section in the range $\nu \sim 100$ GeV, $q^2 \lesssim 2(\mathrm{GeV}/c)^2$ will contribute significantly to our knowledge of the higher mass states with photon quantum numbers. In particular, at these values of ν, q^2, the shadowing from the low mass vector mesons, ρ°, ω°, ϕ° is

expected to be substantially smaller than contributions from the higher mass states with the same quantum numbers. The exact amount of shadowing is a fairly sensitive test of the presence of these higher mass states and thereby the assumptions of GVD. The predictions of Schildknecht based upon GVD are shown in Figs. 3 and 4.

Once the shadowing behavior has been made clear by systematic study of the A, ν, q^2 behavior, the $\rho^\circ N$ cross section can be extracted and compared to the values obtained in strong interactions. The ν dependence enables us to separate out the effects of the higher mass states as noted above.

An even more useful means of establishing the behavior of the real ρ° production and propagation is to measure the ρ° electroproduction directly as a function of A. To our knowledge, the NAL Muon Scattering Facility is uniquely equipped to carry out this investigation at the energies of prime interest. We feel that targets of appropriate thickness for this second set of measurements, combined with present muon beam intensities are compatible with obtaining both the total nuclear cross section and the ρ° photoproduction cross section for several significant nuclei. The details are given in the section on rates, and here we wish only to present the possibility and point out the advantage of having both sets of data (obtained simultaneously, of course).

Experimental Procedure

The Muon Scattering Facility has now been completed through the cooperative efforts of NAL and the CHIO Collaboration. Practical circumstances seem to preclude our using the facility continuously for measurements on liquid hydrogen in the immediate future (Fall 1973). Furthermore, experience seems to indicate that parasite running of the muon beam may be possible with reduced beam intensity during periods of narrow band neutrino operation. We, therefore, feel that these periods should be used to conduct and investigation of the photo-absorption processes discussed above.

As noted in the original Harvard and Chicago proposals to NAL, it has always been clear that the nuclear scattering data would be very interesting. They were de-

emphasized relative to the hydrogen data only as a matter of taste in the earlier proposals. It now appears that practical considerations would indicate that the most efficient use of beam might be to interleave periods of running with heavy elements and parasite beam with primary runs using the hydrogen target.

Greater efficiency in using the beam results from the fact that targets forty times as thick as the present hydrogen target (7 gm/cm^2) could be used and both final state pions from ρ° production detected without rescattering 20% of the time (in lead). This rate increase over hydrogen brings the event rate up to about optimum for the present data collection system. Moreover, the most interesting events from the GVD point of view are in moderate to low q^2 regions ($\sim$ 0.1-2.0 $(GeV/c)^2$), and again the useful rate is enhanced. If we were to concentrate on measuring only the <u>total</u> cross section, the target thickness is limited by the allowable loss in resolution due to target multiple scattering of the muons. For a point with $q^2 \cong 1(GeV/c)^2$ measured with 5% precision, this implies a thickness up to 500 (gm/cm^2) in lead and even more in lighter elements. Targets of comparable thickness were used in the BNL muon experiment with complete success. One useful principle exploited in that experiment was to use distributed targets with the same overall length as the LH_2 target. This insures that the variable densities of different target materials cancel to first order in all efficiency and acceptance functions. The multiple scattering remains to be corrected, but is readily calculable and influences only the resolution of q^2 and ν.

Finally, we note that it will be more important to explore a larger ν- q^2 region for a few nuclear species than to do many nuclei with poorer statistics. In this respect, we would propose to use distributed targets of lead, copper and carbon. These elements would lated be combined with our liquid hydrogen and deuterium data to span the maximum A range. This program was proved sensible at Brookhaven National Laboratory.

μe Scattering Background

We note that μ-e scattering is kinematically possible at momentum transfer up to $q^2 = 2m_e E_e \approx 0.1(\mathrm{GeV}/c)^2$. At any kinematically accessible momentum transfer, $d^2\sigma/dq^2 d\nu$ is similar for all point particles; thus we expect μe scatttering to be comparable to μ nucleon or μ nucleus scattering below $q^2 = 0.1(\mathrm{GeV}/c)^2$, and this is borne out by detailed calculations.

The μe background is subtracted from the nuclear scattering by the showering property of electrons. For thin targets, the original electron will escape from the target without further interaction. These events are cleanly separable by simple event topology. In thicker targets, a jet of electrons, positrons and photons will proceed forward through the magnet and shower in the photon converter. The shower will be stopped by the lead wall. The signature for μe events is a shower with a low energy muon. The neutron chambers will see only the muon.

Nuclear events with comparable energy loss (moderate to high ν) will deposit nuclear "splatter" in the neutron chambers. This difference can serve to separate the two classes of events. For the small (inevitable!) class of ambiguous cases, we will assign events to the μe or μ nuclear on the basis of relative probabilities as established by the unambiguous cases in the same kinematical regime. The problem is messy but solvable.

Rates and Data Plan

The rates for obtaining data can be obtained by scaling the numbers in our recent (September 1973) letter to you. For the events with $q^2 < 1(\mathrm{GeV}/c)^2$ we use the approximate formula:

$$\frac{d^2\sigma}{d\nu dq^2} \cong \frac{4\pi\alpha^2}{q^4} \frac{\nu W_2}{\nu} \left[\left(1 - \frac{\nu}{E}\right) (\text{factors } \theta(1)) \right]$$

The scaling rule is given by:

$$R(A) = R(H) \times \left(\frac{tgt_A}{tgt_H}\right) \times \left(\frac{beam_A}{beam_H}\right) \times \left(\frac{hrs_A}{hrs_H}\right)$$

$$= R(H) \times (30.0) \times (0.02) \times (0.10)$$

$$= \frac{R(H)}{14}$$

This means that we assume a beam of 10^4/pulse and 40 hrs on each of the thick targets (say Pb, Cu, C). Such conditions would provide the results shown in Table I.

low rate

q^2 $(GeV/c)^2$	0	15	30	45	60	75	90	105	120	135	150
2.0											
1.0		60	70	80	80	80	80	80	70	30	
0.5			20	70	90	100	110	110	90	40	
0.2				50	150	230	250	220	190	80	
0.1					110	260	270	220	180		
0.05					120	290	300	230	170		
0.02					170	380	370	200			

ν GeV

Table I

Number of events for 40 beam hrs. at 150 GeV. @ 10^4 μ/pulse

2×10^8 muons on a heavy target

($\sim$ 200 gm/cm^2)

As can be seen from Figs. 3 and 4, a 10% type measurement should be adequate to resolve the GVD predictions from ρ° dominance or the simple A dependence observed at lower values of ω for the same q^2 range. By running more than one heavy element, some of the predictions sensitive to the interaction distance of vector mesons in nuclear matter can be tested, and if the sensitivity is great enough in the theory, a value derived for these interaction lengths (hence the ρN total inelastic cross section).

For the subset of events in which a real rho is produced and detected, the variation of this production with A compared to the overall A dependence of the total cross section establishes an important constraint and a significant test of consistency for the particular case of the rho, and by extension, for the entire GVD picture. We already know that rhos will constitute less than 15% of the total cross section, and we can only use the rear part of the segmented target, so the number of events in each bin of Table I might be about 1/30 for this specific process. Still, we can expect a 20% measurement of real rho production in 4 bins and this should be adequate for comparison with the total cross section behavior. Data will be available in this case from each of three nuclear species.

A study of the character of the showers as a function of A will have some bearing on the theory of multi particle production as has been discussed recently by Fishbane and Trefil.[7/]

Manpower and Funding

The group proposing this experiment is identical with that of Exp. 98, so the manpower, equipment and funding are subsumed within the operation of that experiment. The ability to run nuclear targets for new physics greatly improves the efficiency of the Muon Scattering Facility during periods of low beam intensity. Since the beam and spectrometer are now ready and fully adequate to carry out the physics discussed, we seek approval to commence measurements at once!

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7. Fishbane and Trefil, PRL 31, p. 734 (1973).

Figure Captions

Fig. 1 Measured inelastic cross sections for real and virtual photons in Au,Pb. Theoretical curves are from the paper of Schildknecht (ref. 6).

Fig. 2 The total nuon-nucleus scattering cross section for a fixed range of ν, q^2 plotted versus atomic number. Preliminary data from the BNL experiment.

Fig. 3 Theoretical predictions for the shadowing effect in nuclear matter at high ν, moderate q^2 (from Schildknecht ref. 6).

Fig. 4 Theoretical predictions for muon inelastic scattering from lead relative to the muon-nuclear total cross section (see ref. 6).

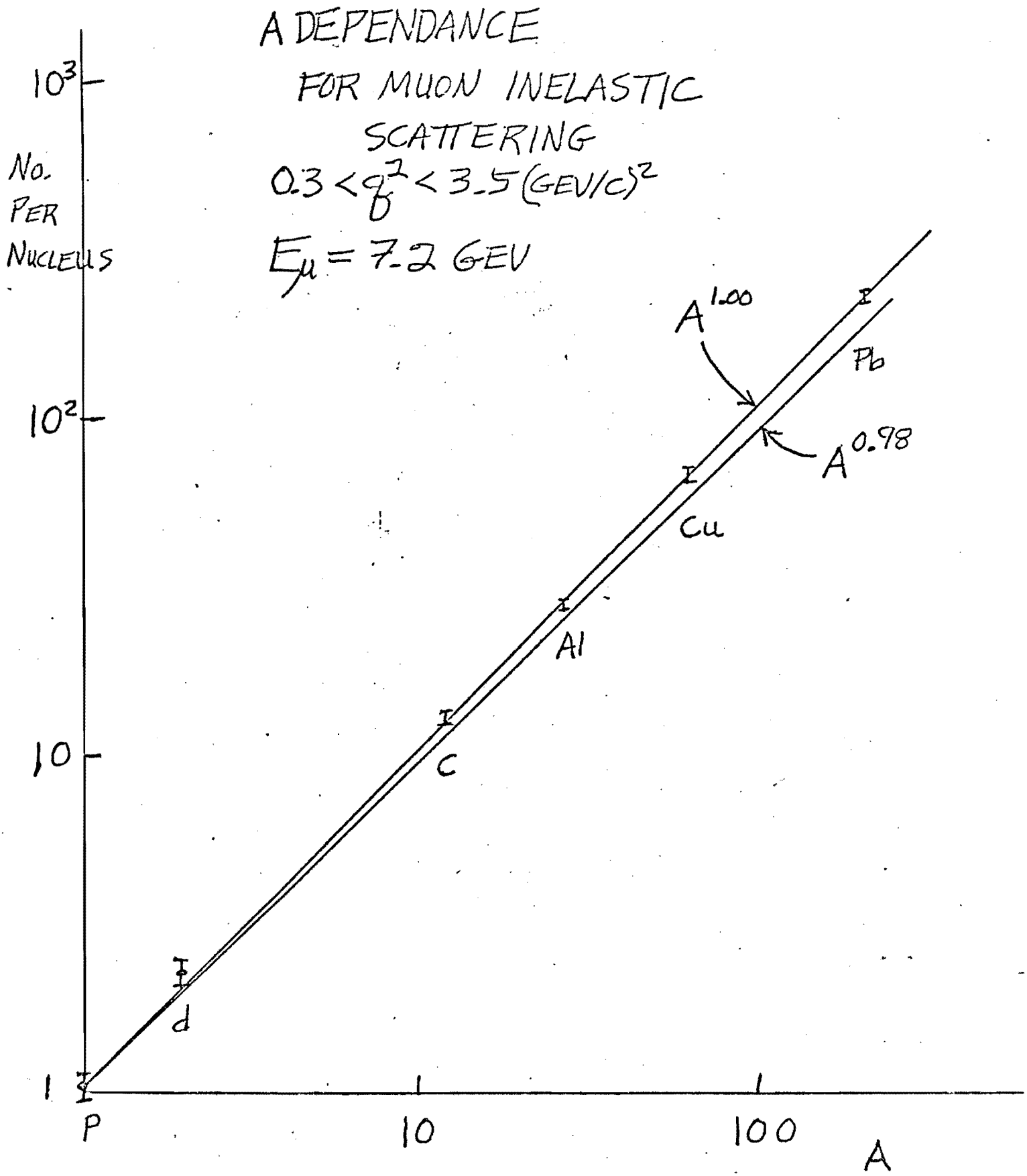
A DEPENDANCE
FOR MUON INELASTIC
SCATTERING
$0.3 < q_0^2 < 3.5\ (GEV/c)^2$
$E_\mu = 7.2$ GEV
No. PER NUCLEUS
10^3
10^2
10
1
$A^{1.00}$
$A^{0.98}$
Pb
Cu
Al
C
d
P
10
100
A

Fig. 2

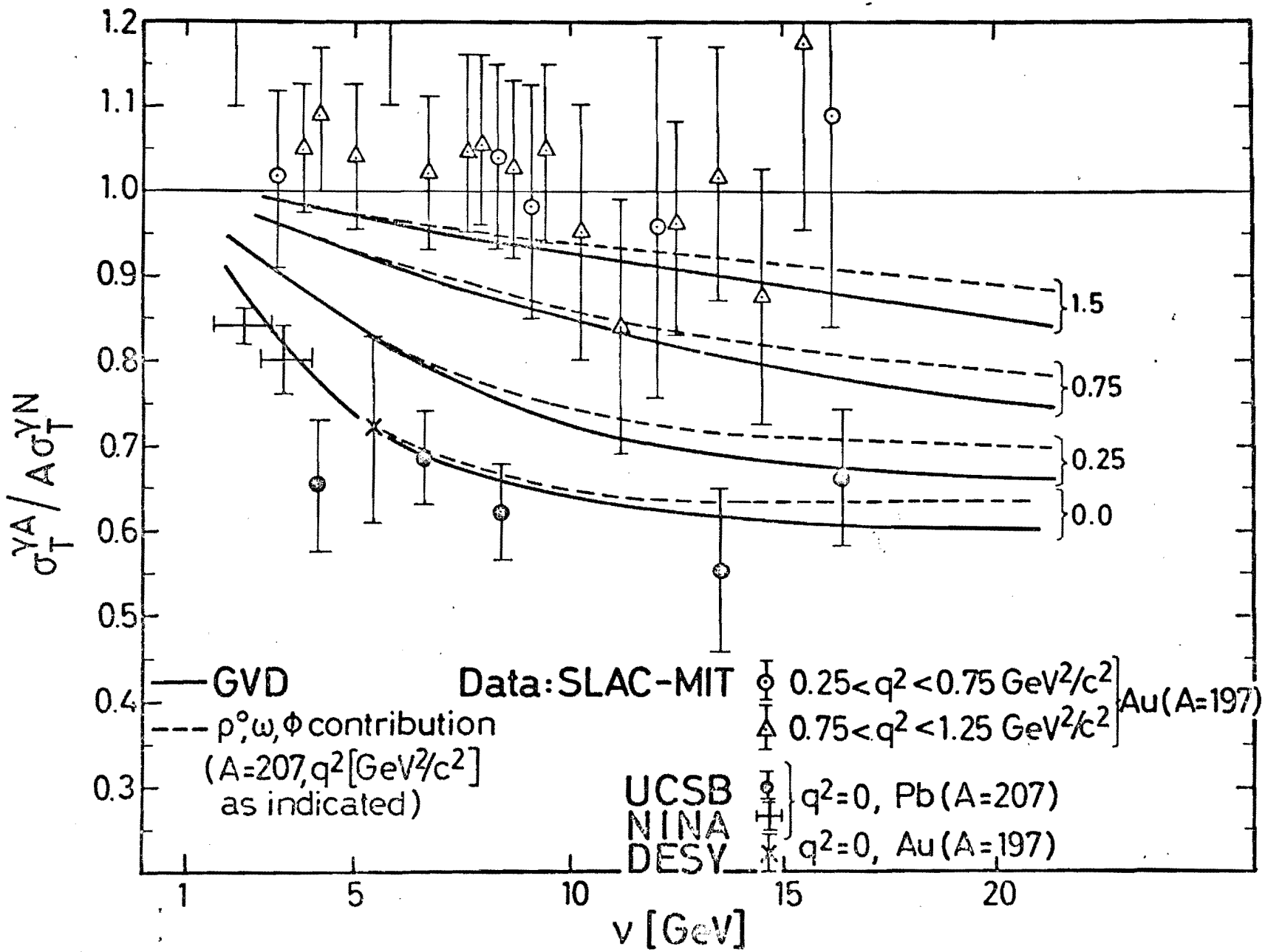
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
$\sigma_T^{\gamma A} / A\sigma_T^{\gamma N}$
1.5
0.75
0.25
0.0
GVD
ρ^0, ω, ϕ contribution
(A=207, q^2[GeV^2/c^2]
as indicated)
Data: SLAC-MIT
0.25<q^2<0.75 GeV^2/c^2
0.75<q^2<1.25 GeV^2/c^2
Au(A=197)
UCSB
NINA
q^2=0, Pb(A=207)
DESY
q^2=0, Au(A=197)
1
5
10
15
20
ν [GeV]

Fig. 1

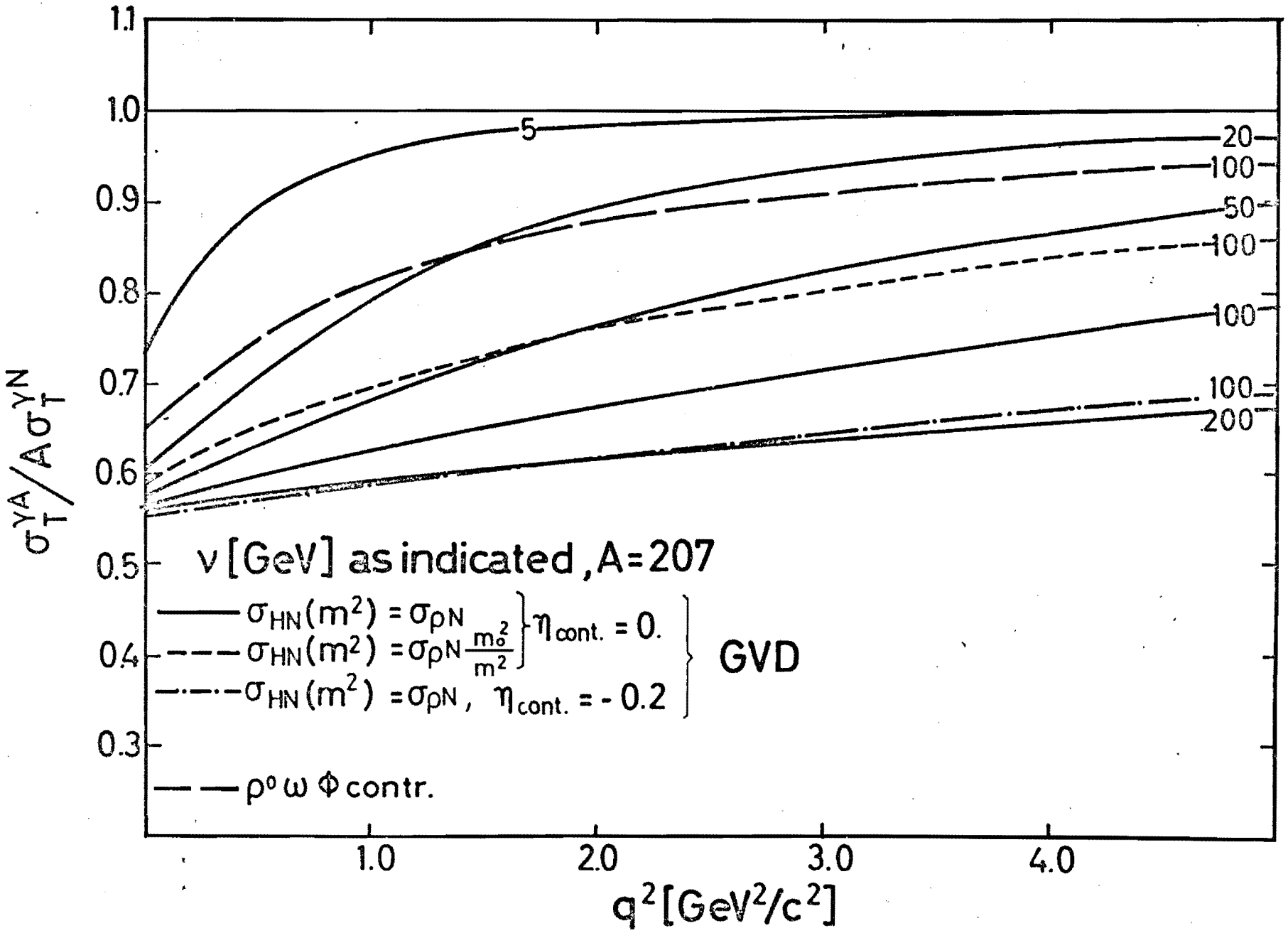
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
$\sigma_T^{\gamma A}/A\sigma_T^{\gamma N}$
5
20
100
50
100
100
100
200
ν [GeV] as indicated, A=207
$\sigma_{HN}(m^2) = \sigma_{\rho N}$
$\sigma_{HN}(m^2) = \sigma_{\rho N}\frac{m_0^2}{m^2}$
$\eta_{cont.} = 0.$
$\sigma_{HN}(m^2) = \sigma_{\rho N}$, $\eta_{cont.} = -0.2$
GVD
$\rho^0\,\omega\,\Phi$ contr.
1.0
2.0
3.0
4.0
q^2 [GeV^2/c^2]

Fig. 3

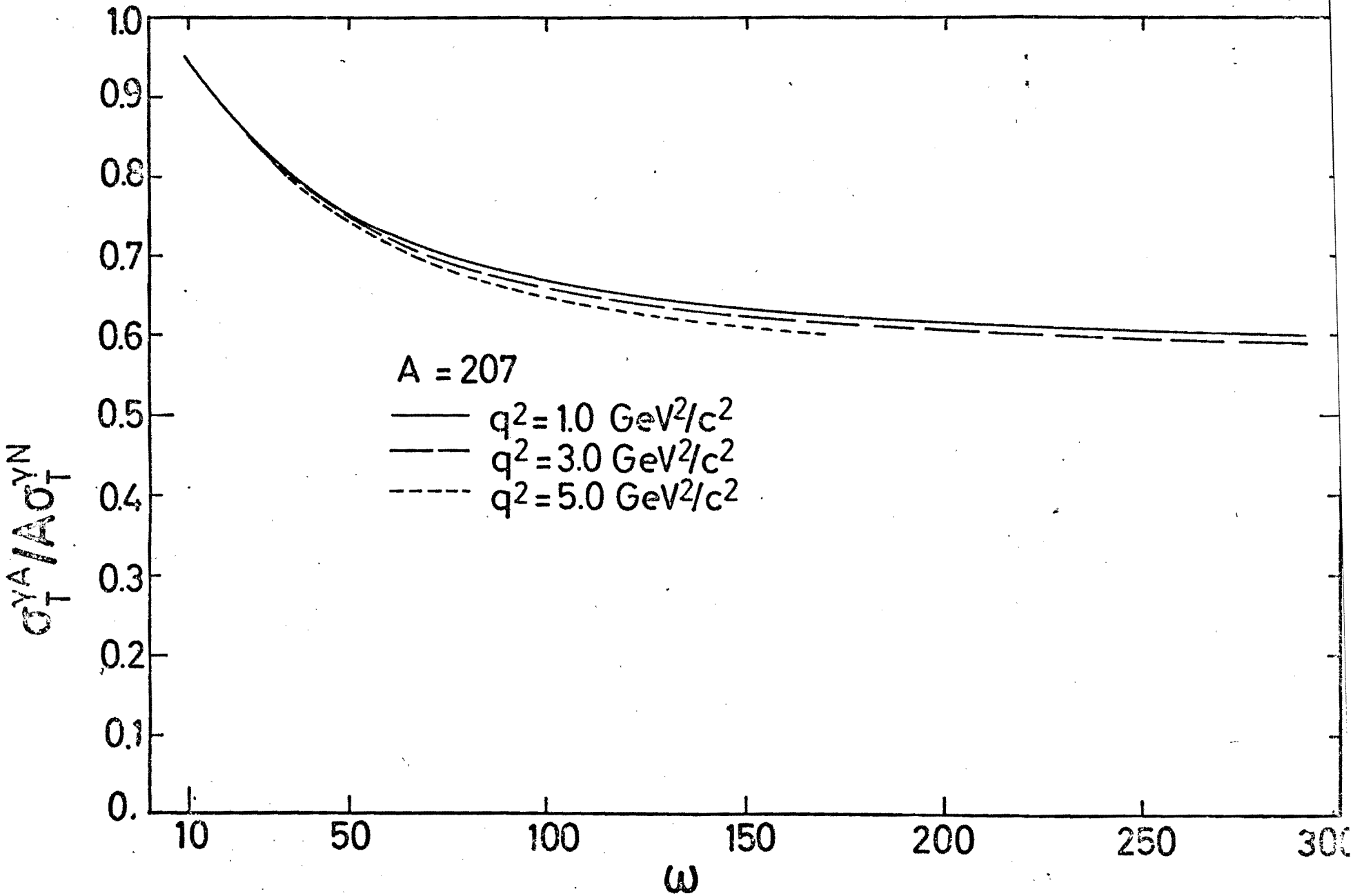
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.
10
50
100
150
200
250
300
ω
$\sigma_T^{\gamma A}/A\sigma_T^{\gamma N}$
A = 207
$q^2 = 1.0\ GeV^2/c^2$
$q^2 = 3.0\ GeV^2/c^2$
$q^2 = 5.0\ GeV^2/c^2$

Fig. 4

REVISED PROPOSAL

FOR THE

INVESTIGATION OF VIRTUAL PHOTOABSORPTION BY NUCLEAR MATTER

FROM

CHICAGO-HARVARD-ILLINOIS-OXFORD MUON COLLABORATION (E-257)

Abstract

The behavior of muon nucleus scattering presents an apparent paradox which can possibly be resolved by various forms of Generalized Vector Dominance. The experimental investigation of the paradox requires that data be taken at very large values of the scaling parameter

$$\omega = \frac{2\ M\nu}{q^2} \quad .$$

The Muon Scattering Facility is ideally and uniquely equipped for these studies and we propose to carry out the investigation.

REVISED
PROPOSAL FOR THE

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Introduction and Motivation

When the DeBroglie wavelength $\lambda\!\!\!^{-} \sim \frac{0.2 \text{ Fm}}{p(\text{GeV}/c)}$ becomes very small relative to nuclear dimensions, it becomes possible to simplify some high energy scattering processes by treating them with the methods of classical optics. The processes amenable to this analysis are the so-called diffractive processes in which the only quantum numbers exchanged between projectile and target are those of momentum and angular momentum (the Pomeron). The "optical theorem", which relates the imaginary part of the forward scattering amplitude to the total cross section, enables the optical treatment of the forward amplitude to be related to the total cross section, a quantity which includes processes not satisfying the optical conditions themselves.

When these methods are applied to the propagation of photons (real and virtual) in nuclear matter, the states of interest are those with photon quantum numbers. In the low mass regime, this means ρ°, ω°, ϕ°. An interesting and seemingly paradoxical situation results. Photons couple only weakly ($\sim \alpha$) to hadrons, yet they are attenuated strongly in nuclear matter at high energy. We see this by noting that the total photoabsorption cross section on protons is about 125 μb while its geometric value might be more like 40 mb. These numbers predict an absorption length of some 320 fermis in nuclear matter. The observed result for real photons ($q^2 = 0$) in lead and gold[1/] is shown in Fig. 1. From these results, the nucleus appears almost totally black (absorptive)! This result is totally in conflict with the naive inference from knowledge of the total cross section. By way of contrast, the spacelike photons exhibit no shadowing at all as can be seen on the same graph.[2/] The most dramatic recent

evidence of a strict $A^{1.0}$ dependence comes from the BNL inelastic muon scattering experiment.[3] These results are shown in Fig. 2, where it is seen that a dependence $A^{0.98}$ is ruled out by the data. In this energy-q^2 regime, the nucleus is totally transparent to virtual photons in the way one might naively have predicted.

Two views have been advanced to account for this apparent paradox. The notion of "vector dominance", wherein the photon turns into a $\rho^\circ(\omega^\circ, \phi^\circ)$ with some amplitude γ_0 before reaching the nuclear surface and then propagates as a vector meson with SI through the nuclear matter. This view corresponds to the picture of Bell [4]. Stodolsky[5] has taken a view in which the photon first interacts directly with a nucleon to produce a real ρ° propagates through the nucleus. Later work by Brodsky and Pumplin, Gottfried and Yennie , D. Schildknecht and J. J. Sakurai[6] has reconciled, generalized and expanded these views to a rather complete description of the behavior of real and spacelike virtual photons in nuclear matter. The theory is now called generalized vector dominance (GVD). The conclusions reached by these authors indicate that measurements in heavy nuclei of the total photo cross section in the range $\nu \sim 100$ GeV, $q^2 \sim 2$ $(\mathrm{GeV/c})^2$ will contribute significantly to our knowledge of the higher mass states with photon quantum numbers. In particular, at these values of ν, q^2, the shadowing from the low mass vector mesons, ρ°, ω°, ϕ° is expected to be substantially smaller than contributions from the higher mass states with the same quantum numbers. The exact amount of shadowing is a fairly sensitive test of the presence of these higher mass states and thereby the assumptions of GVD. The predictions of Schildknecht based upon GVD are shown in Figs. 3 and 4. The interest in higher mass and mesons has much increased since the CEA colliding beam experiments. The cross section $e^+e^- \rightarrow$ hadrons is higher than can be explained by a parton model, and it seems that many high mass states may be responsible.

The full shadowing effect (high ω) expected does not seem to depend much on which thoery (Brodsky-Pumplin;Gottfried Yennie; Schildknecht) is used.

$\frac{\sigma(\gamma A)}{A\,\sigma(\gamma\,\text{nucleon})}$	Nucleus	A
1	½(H)+ ½(N)	1
0.93	D	2
0.77	Be	9
0.69	Al	27
0.61	Cu	64
0.51	Pb	207

This could be appreciably watered down for some reason, but the A dependence is a function of nuclear radius and is likely to have the same form no matter which vector mesons are involved and what the photon-vector meson couplings are.

In the simple theory, shadowing should disappear as $\omega = \left(\frac{2\,M\nu}{q^2}\right)$ becomes smaller. All theories seem to agree that the relevant parameter is ω, or perhaps $\omega' = \frac{2\,M\nu}{(q^2+m^2_{vector})}$

The simple rho dominance models find that the shadowing is halved for $\omega' \approx 6$ $(\frac{\sigma\gamma A}{A\sigma\gamma})$ changes for lead from 0.51 to 0.75). However, in the generalized vector dominance model this happens at lower values of q^2 ($\omega' \approx 40$). As shown in the section on rates ω' will be well within the shadowing region over most of our range. If shadowing does appear, and does not disappear at the lower ω' ($\omega' = 40$) we will propose additional runs to study the disappearance.

Once the shadowing behavior has been made clear by systematic study of the A, ν, q^2 behavior, the $\rho^\circ N$ cross section can be extracted by theoretical analysis and compared to the values obtained in strong interactions. The ν dependence enables us to separate out the effects of the higher mass states as noted above. Of course it will be especially interesting if strong ρ° production is present and shadowing is not. Such an unexpected result could be detected as described below.

We can establish the behavior of the real ρ° production and propagation by measuring the ρ° electroproduction directly as a function of A. To our knowledge, the NAL Muon Scattering Facility is uniquely equipped to carry out this investigation at the energies of prime interest. With the recent increase in machine intensity, targets of appropriate thickness for this second set of measurements are now practical for obtaining both the total nuclear cross section and the ρ° muoproduction cross section for several significant nuclei. The details are given in the section on rates, and here we wish only to present the possibility and point out the advantage of having both sets of data (obtained simultaneously, of course).

Experimental Plan

The proposal has been revised in order to include the results of some data already obtained and to use this experience to help formulate improved running plans for the future. Data taking so far has been impeded by the necessity of establishing compatability with the narrow band neutrino beam; considerable additional time was used up in a series of pion absorber and beam tuning studies. We now feel, however, that we have adequate information and data to outline a realistic schedule. The small amount of actual beam received in March, 1974, while not adequate for production run purposes, nevertheless has provided us with valuable triggering knowledge and helped us recognize problems not foreseen. These areas now seem well understood.

The principal conclusions which emerged from our March run on Cu and Pb are: a) Compatible running between muon and neutrino experiments is feasible but careful mutual planning and coordination of running conditions is necessary, b) Thick targets and very low muon intensities for data acquisition are not practical for this experiment. These two points are elaborated below.

The desirability of compatible running of muon and neutrino experiments was emphasized in the 1968 NAL Summer Study; the means of implementing it has been discussed from that time on. Only in the past three months has the compatibility been demonstrated experimentally. Of the three modes of neutrino focussing, two

are appropriate for simultaneous muon work. These are the high-band neutrino beam (pions focussed by a quadrupole triplet lens) and the narrow band beam. The horn mode of focussing cannot be useful due to its short duty factor.

When the quadrupole lens is in place, both muon and high energy neutrino production is optimal and both types of experiments can run (either by sharing all the protons in a slow spill or by dividing them into a slow spill for muons followed by a fast spike to the neutrino area). Which experiment is prime and which is parasite depends essentially on the division of protons in the slow/fast mode. Both are clearly prime in the slow/slow mode. This is our preferred configuration for both the present experiment and the liquid target experiment (E-98). The yield of muons per incident proton in this mode at 150 GeV/c (with 300 GeV p's incident) is 1.2×10^{-7} for positives and 0.5×10^{-7} for negatives.

When the narrow band neutrino focussing system is in place, there is again a choice of slow/slow and slow/fast beam sharing. The slow/slow mode has a muon yield of 0.5×10^{-7} for positives and 0.2×10^{-7} for negatives under optimum conditions and can be useful for muon experiments. As we see below, it should be quite good for the present proposal. The slow/fast mode is usually relevant only for tuneup and test since the protons must be shared. The caution about careful planning noted above refers to the fact that rapid declines from the optimal muon yields are observed when the momentum collimator slits on the train are narrowed to improve ν_π, ν_K separation or central energies for neutrino and muon running are set at different values. It is very important therefore to coordinate plans between neutrino and muon users before attempting shared running.

In summary, we feel that experience has validated our early view of the possibility of running both lepton scattering programs compatibly; it has also shown that careful planning and mutual goodwill are necessary to bring the concept to fruition.

The March run enabled us to advance our knowledge of triggering conditions and event yields over the state outlined in the original proposal. We found that low q^2 brehmsstrahlung in Cu and Pb caused a problem with the trigger rate. This problem motivated us to undertake an energetic review of our deadtime constraints and by diligent labor we managed to cut the event deadtime by a factor of two. This will help to alleviate trigger inroads into the beam livetime. The other problem which surfaced in the March run was the excessive electromagnetic showering in the target from nuclear events. This effect has caused us to retreat from the thick targets proposed earlier to a target of much smaller thickness. This decision was heavily influenced by our desire to reconstruct final state hadrons in the low q^2, high ν region, thereby establishing the flux of real ρ° mesons produced in heavy nuclei. Formerly, we had expected to use a thin target for this purpose, separated by a gap from a thicker target upstream, but our reconstruction resolution for the event vertex along the beam is not adequate to do this cleanly. The result of a decision to use thinner targets necessitates an increase in necessary muon flux in inverse proportion. Our minimum practical intensity requirement will therefore rise from 10,000 per burst to perhaps 200K. This intensity should be able to be satisfied by recent intensity improvements in the accelerator. We now have much more sophisticated acceptance programs to calculate event yields and the estimates in the following section on rates should be more reliable on this account.

Taking the above details into consideration, we believe the muon nucleus experiment has now been shown to be practical as well as exciting. We feel that it should be upgraded in the view of the lab from a peripheral parasite status to full standing as a scheduled experiment. We further expect that it might best be run during periods of dichromatic neutrino operation since the trigger rate is unavoidably higher than for the majority of our deuterium and hydrogen running in E-98. We cannot tolerate the maximum beam intensity and still be sensitive to the very low q^2 values that are so important to this particular physics situation. The section on rates and yields will outline this more specifically.

Rates and Yields

We propose to run this experiment with three nuclear targets, beryllium, copper and lead. These data will be combined with the deuterium results from E-98 to cover the entire range of nuclear radii with an appropriate number of sample nuclei. We have enough data from our previous test runs to estimate both the trigger rates and event yields. Since there are a number of relevant considerations involving beam intensities, target thicknesses, acceptances, and q^2-ν weighting, we will quote the rate and yield information in more than one format. The final number of beam hours needed will be stated in terms of our estimate of the most probable beam conditions, plus our constraints on target thickness and trigger conditions. If these beam conditions do not obtain at the point of actual running, it will be possible to scale the running time in a realistic manner from the data below.

Basic to the calculation of rates is the need to obtain data over a very large range of q^2 with emphasis on reaching values of q^2 as low as possible. The trigger condition (beam veto size and position) controls this rate. We display in Fig. 5 a calculation of the target associated nuclear rates for our two "standard" beam veto configuarations. The lower graph is appropriate for high intensity running on liquid targets (where a strong emphasis on high q^2 is desirable). The smaller veto gives a high acceptance for very low q^2 and is appropriate for the present experiment. The total number of events are those which we would obtain under the requested program. This trigger has a high deadtime fraction and therefore does not optimize accumulation of high q^2 events. We base our event yields on the use of this veto.

The trigger rate for a given target and veto has several important contributions. For the thin targets proposed here, the target empty rate is appreciable and must be included in the rate estimates. The trigger rates shown in Table I assume the small veto described above and targets of one half radiation length (14% in the case of Be) in order to suppress electromagnetic showering and nuclear reinteraction in the target. It is seen that muon bremsstrahlung and target empty rate dominate the trigger in all cases. This is the price we pay to reach the lowest q^2 values.

Table I. Trigger Rates* for Nuclear Targets (per beam muon)

	7.5 gm/cm^2 Cu	9.4 gm/cm^2 Be	3.2 gm/cm^2 Pb
μN	3.0×10^{-6}	3.8×10^{-6}	1.3×10^{-6}
μe	2.8	3.4	1.0
μγ	23.4	5.7	19.7
MT tgt	18.0	18.0	18.0
Total	47.2×10^{-6}	30.9×10^{-6}	40.0×10^{-6}

* Assumes the smaller standard beam veto shown as a solid line in Fig. 5.

From the trigger rates shown in Table I we can calculate event yields. In order to get a realistic picture, we must calculate with appropriate beam intensities and apparatus deadtime. We know that a yield of 0.5×10^{-7} μ/p can be achieved for positive muons by the narrow band trainload. If we have perhaps 6×10^{12} protons targeted, this means a beam of 3×10^{5} muons per pulse at our nominal energy of 150 GeV/c. We take this as a likely running condition. Our apparatus operates at high trigger rates with a 50 ms/event deadtime. Combining these factors, we calculate event yield rates as shown in Table II.

Table II. Event Rate Yields for Nuclear Targets (per hour)

Target	Livetime fraction	no nuclear rescattering	"good" event rate
7.5 gm/cm^2 Cu	0.58	0.96	250
9.4 gm/cm^2 Be	0.68	0.92	356
3.2 gm/cm^2 Pb	0.57	0.99	110

The basic nuclear rates are eroded by corrections for livetime fraction and nuclear rescattering in the target (calculated for real rhos).

In order to see the shadowing effect clearly, we would like to have about 10,000 events on each target (3% statistics in each of 10 ω bins). This requires the following amounts of "perfect" beam times:

Cu	40 hours
Be	30 hours
Pb	90 hours
Total	160 hours

With thin targets we must add to this about 25% additional empty target running. Since the beam phase space has been observed to vary with time (probably due to many small effects acting collectively), we also must take periodic beam runs. This requires an additional 5% of beam time. Finally, our experience over the period of recent good running is that all other problems and conditions which prevent running (CCM crashes, run terminations, beam tuning, etc.) lose us another 50% of potential beam time. Adding all these effects together, we come out with a total "realistic" beam requirement of 285 hours. This amount of running should provide a clear and unequivocal answer to the nuclear shadowing question and a 15% type measurement of the behavior of real rho production in an equivalent binning. We therefore request 285 hours of beam at 3×10^5 per pulse, or 4.3×10^{10} muons at 150 GeV/c. The distribution of the sum total of these events in q^2 is shown as the solid line in Figure 5.

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Figure Captions

Fig. 1 Measured inelastic cross sections for real and virtual photons in Au,Pb. Theoretical curves are from the paper of Schildknecht (ref. 6).

Fig. 2 The total nuon-nucleus scattering cross section for a fixed range of ν, q^2 plotted versus atomic number. Preliminary data from the BNL experiment.

Fig. 3 Theoretical predictions for the shadowing effect in nuclear matter at high ν, moderate q^2 (from Schildknecht ref. 6).

Fig. 4 Theoretical predictions for muon inelastic scattering from lead relative to the muon-nuclear total cross section (see ref. 6).

Fig. 5 Total event yield for μN scattering on nuclear targets.

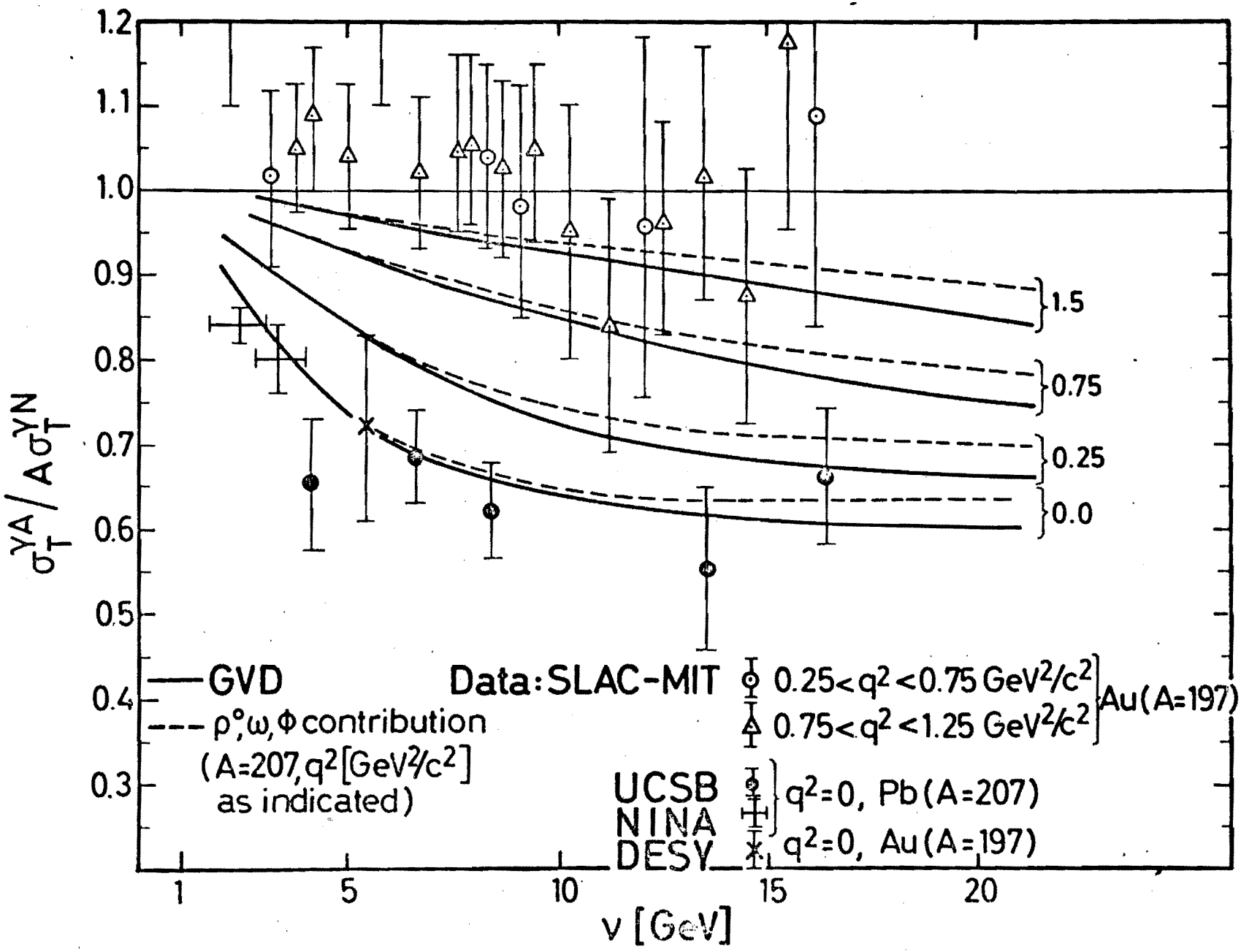
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
$\sigma_T^{\gamma A} / A\sigma_T^{\gamma N}$
1
5
10
15
20
ν [GeV]
1.5
0.75
0.25
0.0
GVD
ρ°,ω,Φ contribution
(A=207, q² [GeV²/c²]
as indicated)
Data: SLAC-MIT
0.25<q²<0.75 GeV²/c²
0.75<q²<1.25 GeV²/c²
Au (A=197)
UCSB
NINA
q²=0, Pb (A=207)
DESY
q²=0, Au (A=197)

Fig. 1

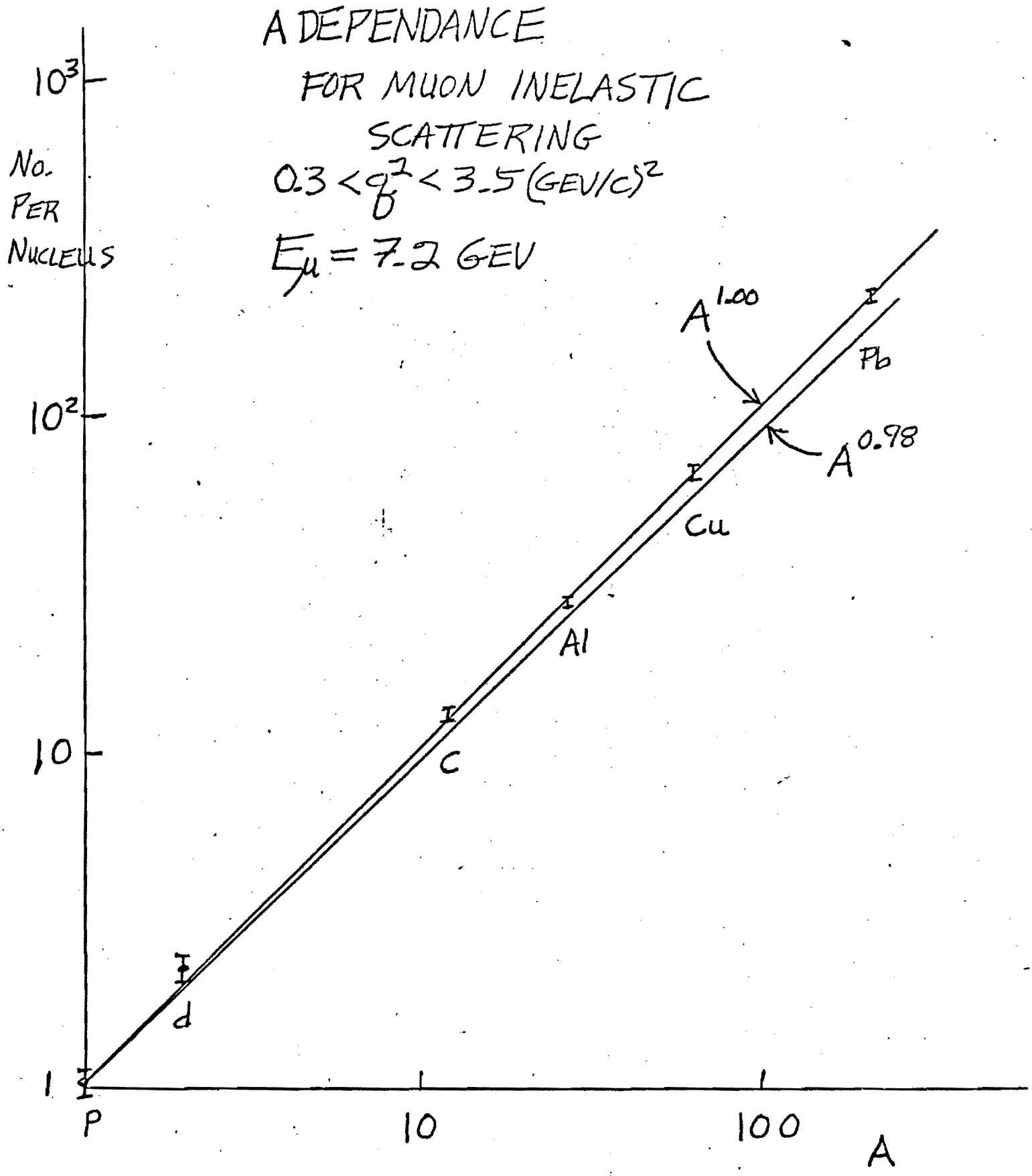
A DEPENDANCE
FOR MUON INELASTIC
SCATTERING
$0.3 < q_0^2 < 3.5\ (GEV/c)^2$
$E_\mu = 7.2$ GEV
No. PER NUCLEUS
10^3
10^2
10
1
P
10
100
A
$A^{1.00}$
$A^{0.98}$
Pb
Cu
Al
C
d

Fig. 2

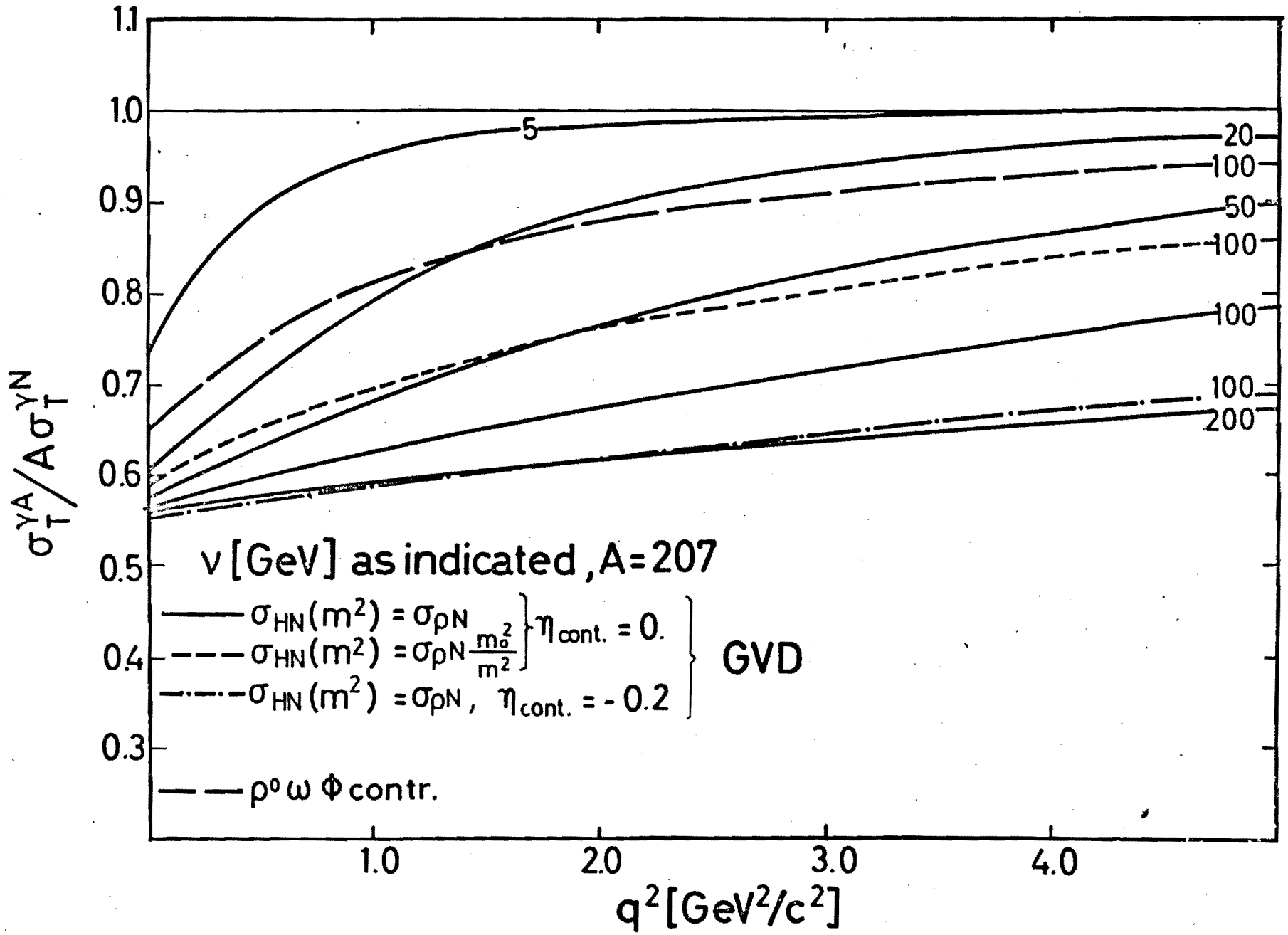
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
$\sigma_T^{\gamma A}/A\sigma_T^{\gamma N}$
5
20
100
50
100
100
100
200
ν [GeV] as indicated, A=207
$\sigma_{HN}(m^2) = \sigma_{\rho N}$
$\sigma_{HN}(m^2) = \sigma_{\rho N}\frac{m_0^2}{m^2}$
$\eta_{cont.} = 0.$
$\sigma_{HN}(m^2) = \sigma_{\rho N}$, $\eta_{cont.} = -0.2$
GVD
$\rho^0\ \omega\ \Phi$ contr.
1.0
2.0
3.0
4.0
q^2 [GeV^2/c^2]

Fig. 3

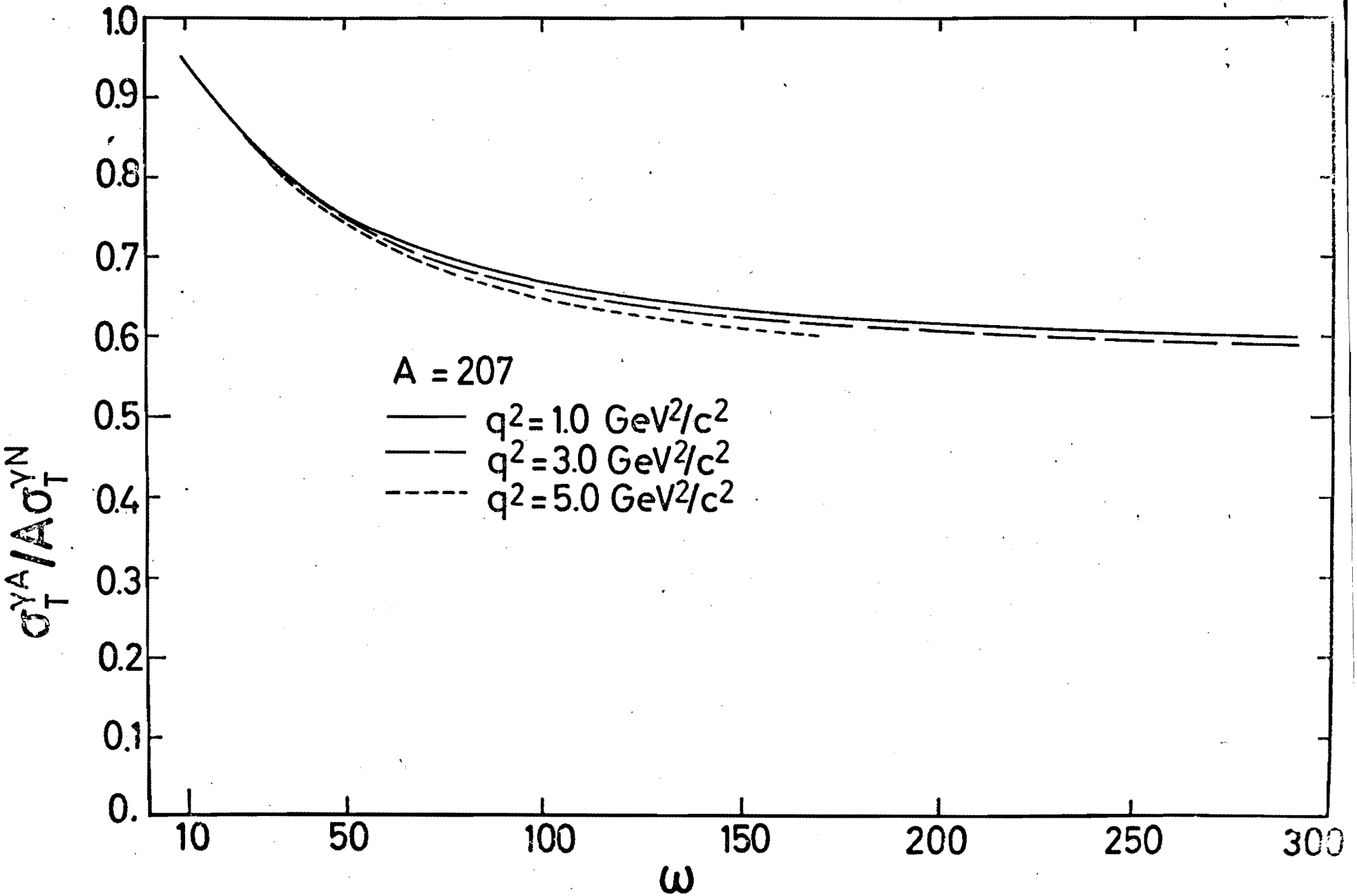
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.
10
50
100
150
200
250
300
ω
$\sigma_T^{\gamma A}/A\sigma_T^{\gamma N}$
A = 207
$q^2 = 1.0\ GeV^2/c^2$
$q^2 = 3.0\ GeV^2/c^2$
$q^2 = 5.0\ GeV^2/c^2$

Fig. 4

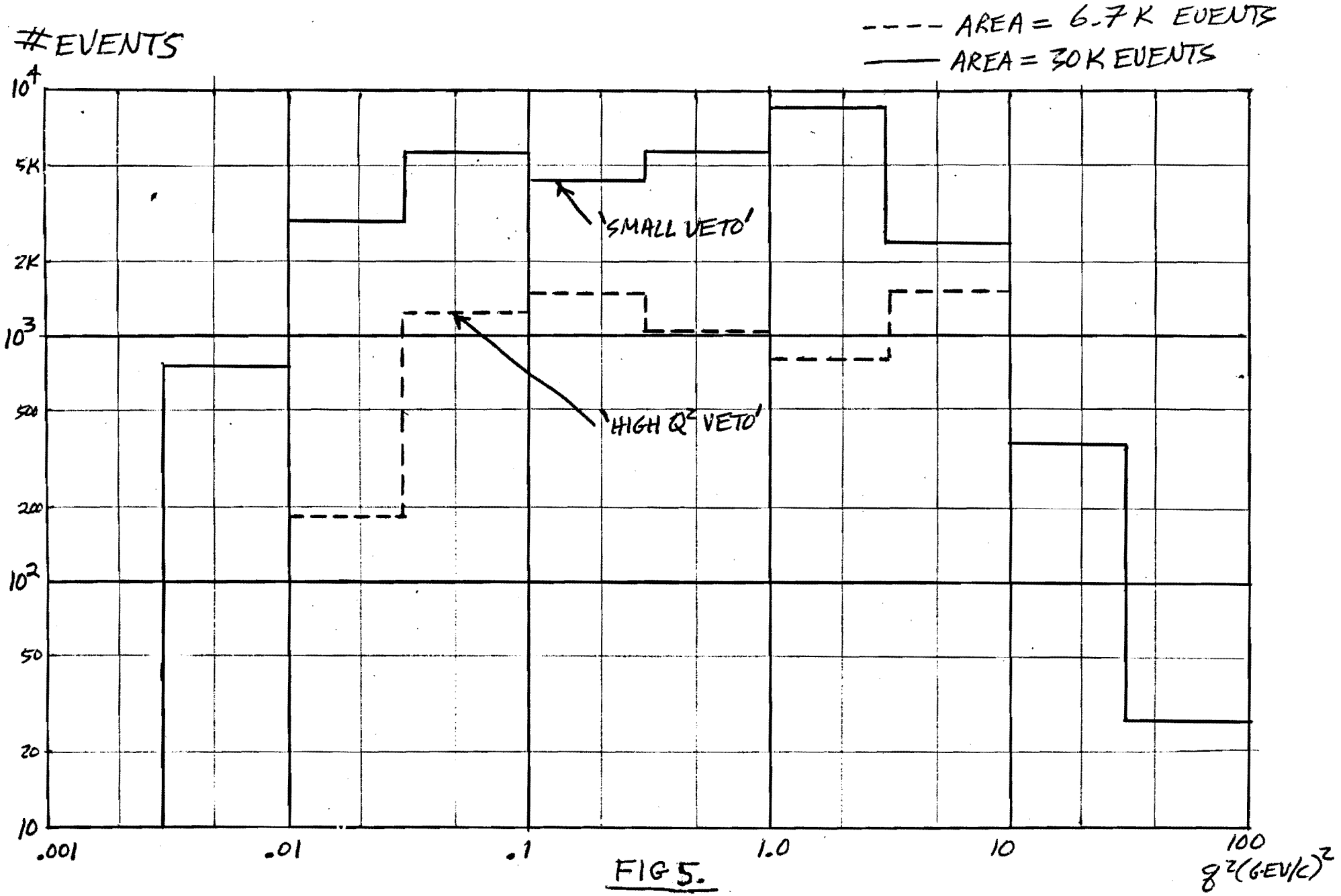

FIG 5.

TOTAL EVENT YIELD FOR μN SCATTERING ON NUCLEAR TGTS

$N_\mu = 4.3 \times 10^{10}$; Cu(7.5 gm/cm²), Be(9.4 gm/cm²), Pb(3.2 gm/cm²)

SOLID LINE GIVES 'SMALL' VETO YIELD

DOTTED LINE GIVES 'HIGH Q²' VETO YIELD