NAL PROPOSAL No. 296

Scientific Spokesman:

C. Baltay
Department of Physics
Nevis Laboratories
P.O. Box 137
Irvington, New York 10533

FTS/Off-net: 8 914-423-0201
591-8100

Study of Electron-Neutrino (ν_e and $\bar{\nu}_e$) Interactions in a Liquid Neon Bubble Chamber

C. Baltay, D. Cohen, and M. Kalelkar
Columbia University

C. Coffin, B. Roe and A. Seidl
University of Michigan

March 1974

March 1974

Experimental Proposal Submitted to the
National Accelerator Laboratory

Study of Electron-Neutrino (ν_e and $\bar{\nu}_e$) Interactions in a Liquid Neon Bubble Chamber

C. Baltay, D. Cohen, and M. Kalelkar
Columbia University

and

C.T. Coffin, B.P. Roe and A. Seidl
University of Michigan

Summary of Proposal:

10^6 photographs of the 15 foot bubble chamber exposed to a proposed ν_e and $\bar{\nu}_e$ beam; $\sim$ 1/2 at presently available accelerator energies, $\sim$ 1/2 at the increased energies made possible by the energy doubler.

Spokesmen: C. Baltay and B. Roe will alternate as spokesmen at six-month intervals starting at the date of approval of the proposal.

Physics Motivation:

a) Search for the purely leptonic diagonal processes $\nu_e + e^- \rightarrow \nu_e + e^-$ and $\bar{\nu}_e + e^- \rightarrow \bar{\nu}_e + e^-$

b) Test of universality of the charged weak current by comparison of the interactions of ν_e and $\bar{\nu}_e$ with ν_μ and $\bar{\nu}_\mu$ in an experiment where the ratio of their incident fluxes is well known.

c) Test of electron-muon universality of the weak neutral currents by comparing the ratios of neutral to charged currents in this experiment with those obtained in muon-neutrino beams.

d) Search for electron-type heavy leptons, which can be produced in electron-neutrino beams but not in muon neutrino beams,

e) Measurement of the antineutrino to neutrino crossection ratios in an experiment where the incident neutrino and antineutrino fluxes are known to be identical, both in shape and in magnitude.

I. INTRODUCTION

Conventional neutrino beams produced at high energy accelerators consist predominantly of muon neutrinos, produced in the dominant $\pi^{\pm}\to\mu^{\pm}\nu_{\mu}$ and $K^{\pm}\to\mu\,\nu_{\mu}$ decays. The electron neutrino content of these beams is typically $\nu_e/\nu_{\mu}\sim 1/200$. For this reason the interactions of electron neutrinos have not been subjected to quantitative study.

We propose here an electron neutrino beam* where the neutrinos are produced in the neutral K decays $K^0\to\pi+e+\nu_e$. The charged $\pi^{\pm}$ and $K^{\pm}$ mesons are swept out by a dipole magnetic field so that the neutrinos from their decays are suppressed. The target, decay tube, muon shield, and neutrino detector could be the same as in the existing wide band neutrino beam. In such a beam the ν_e/ν_{μ} ratio would be about 1.4/1. Furthermore, the energy spectra of the four kinds of neutrinos, $\nu_e,\nu_{\mu},\bar{\nu}_e,\bar{\nu}_{\mu}$, would be essentially the same, and their relative fluxes would be very precisely known, since they all originate from the same K^0_L parents.

The 15-foot bubble chamber filled with liquid neon is an ideal detector for this experiment. Due to the short radiation and collision lengths in the liquid and the large magnetic field, the charged leptons produced by the four different kind of neutrinos, e^-, e^+, μ^- and μ^+, can be identified and distinguished from each other reliably. In addition, such a detector has large target mass and allows the measurement of the hadronic as well as the leptonic energy, and thus an estimate of the incident neutrino energy.

---

* This type of electron neutrino beam and essentially this experiment was first suggested by two of the authors (C. Baltay and B. Roe) in a paper at the 1973 NAL Summer Study at Aspen (copy enclosed).

II. Physics Motivation

A. Search for the diagonal four Fermion processes

$$\nu_e + e^- \rightarrow \nu_e + e^- \qquad (1)$$

$$\overline{\nu}_e + e^- \rightarrow \overline{\nu}_e + e^- \qquad (2)$$

These fundamental processes have never been observed. It would be extremely interesting to detect these processes and to measure their crossections, or even to set upper limits on their crossections.

In the conventional V-A theory the crossection for processes (1) and (2) are uniquely predicted to be $1.6 \times 10^{-41} E_\nu$ cm^2 and $0.53 \times 10^{-41} E_\nu$ cm^2, respectively. However, many of the currently fashionable theories of the weak interactions predict different crossections. One particular example is the Weinberg model[1] in which the crossections[2] could vary from 0.4 to $4.3 \times 10^{-41} E_\nu$ cm^2. These crossections are shown as a function of the mixing angle Θ in this model in Fig. 1. We use the Weinberg model here only as an example to show the kind of variations that can be expected for the crossections for these reactions. It is quite possible that this model will have ceased to be of any interest by the time this experiment is performed. However we believe that the measurement of these very basic processes is of fundamental and lasting importance, independently of any existing theory, since any future theory of the weak interactions must unambiguously predict the behavior of these processes.

There are other attempts to measure these crossections (Reines et al)[3] at very low energies (few MeV). We feel that even if these attempts succeed it is important to measure them at the 10^4 to 10^5 times higher energies available at NAL.

Due to the smallness of these crossections the experimental problems connected with distinguishing these processes from background are very severe. It is very important to reduce the very large ν_μ background present in conventional wide band neutrino beams. This would be even more critical if neutral currents were to exist, allowing the processes

$$\nu_\mu + e^- \rightarrow \nu_\mu + e^- \qquad (3)$$

$$\bar{\nu}_\mu + e^- \rightarrow \bar{\nu}_\mu + e^- \qquad (4)$$

In a wide band neutrino beam these reactions would swamp reactions 1 and 2 by two orders of magnitude. In the proposed electron neutrino beam, however, the electron neutrino induced processes 1 and 2 would dominate by a factor of 2 or 3 or more due to the larger ν_e flux and also the larger crossections (see Fig. 1). The rates for the ν_μ processes will be measured in the runs with ν_μ beams, and a subtraction can be made to measure the crossections for the ν_e processes in this experiment.

The other major background in this search will be the process

$$\nu_e + n \rightarrow e^- + p \qquad (5)$$

when the proton is of sufficiently low energy to be invisible. From experience at CERN, we expect the proton to be invisible 1/30 of the time. The crossection for this process is expected to be $.75 \times 10^{-38} \mathrm{cm}^2$

independently of the neutrino energy,[4] while the crossections for the processes 1 and 2 are expected to rise linearly with E_ν. Thus, at the high energies available at NAL, this background should be quite manageable (see Section V and Figs. 7 and 12 for a more detailed and quantitative discussion).

B. Test of universality of the charged weak currents by comparing the interactions

$$\nu_e+Z\rightarrow e^-+\Gamma \tag{6}$$

$$\nu_\mu+Z\rightarrow \mu^-+\Gamma \tag{7}$$

where Z is some target nucleus and Γ consists of hadrons. The comparison can be done both for specific final states Γ, and for the inclusive inelastic process where Γ represents the summation over all hadronic states. The neutrino detector used for this purpose must be able to detect electrons as well as muons with high efficiency and be able to uniquely distinguish e^+, e^-, μ^+ and μ^- from each other. A test of universality would include both a comparison of the cross sections for the two processes, and comparisons of detailed distributions and structure functions. It is therefore very important to observe the two reactions under identical experimental conditions, with similar energy spectra for the incident neutrinos, and with a well known relative ν_e/ν_μ flux.

C. It is known that, at least at $q^2 \sim o$, electron-muon universality holds well for the <u>charged</u> weak currents. However, nothing is known about electron muon universality for the <u>neutral</u> weak currents. Furthermore, there is now some reason to believe that while it may be natural for the charged currents to display this feature there is no corresponding constraint on the neutral currents.[5] As an example, in the specific calculation of Georgi and Pais[6] one of the two may be suppressed by a factor of about 10^4. Thus, if it is confirmed that neutral currents exist at the rate of about 20% of the charged currents for muon neutrinos there may be virtually no neutral current interactions for electron neutrinos. On the other hand if the muon neutrino induced neutral currents turn out to be absent, a sizable neutral current signal could still exist with electron neutrinos.

These possibilities can easily be detected in our proposed experiment. If there are muon but no electron neutral currents the ratio of neutral to charged currents (including both ν_μ and ν_e charged events) will be $\sim$ 40% of what is observed for the horn beams (muon neutrinos only). Since the two groups represented in this experiment will be analyzing NAL horn beam muon neutrino and anti neutrino experiments in neon, there would seem little problem minimizing systematics and determining this ratio to better than the factor of about 2 1/2 required. Even more dramatic would be the case of no muon neutral currents. Then the present proposal may be the only hope of finding neutral weak currents.

D. The possibility that leptons heavier than the ν, e, or μ exist has been discussed for a long time. These leptons could belong to new lepton families, or, as hypothesized by the currently fashionable gauge theories, there could be electron and muon type heavy leptons, E and M, which belong to the existing electron and muon lepton families, with the corresponding conserved lepton numbers. The electron type heavy leptons would then be made in electron neutrino beams, while the muon type heavy leptons would be produced in muon neutrino beams in the reactions

$$\nu_e + N \rightarrow E^{\pm} + \text{hadrons} \quad (8)$$

$$\nu_\mu + N \rightarrow M^{\pm} + \text{hadrons} \quad (9)$$

The crossections for these processes have been calculated[7] and are shown in Fig. 2. They are very strong functions of the heavy lepton mass.

It is quite possible (or even likely, since the e and the μ have different masses) that the two types of heavy leptons, E and M, have different masses, in which case they will be produced at different rates. This may lead to very different total crossections for electron and muon neutrinos in this experiment. Another possibility is that the muon type heavy lepton is too heavy to be seen in the muon neutrino experiments, but the electron type heavy lepton is in a mass range where it is produced by the electron neutrinos in this experiment. Fig. 8 shows the numbers of events expected in this experiment as a function of M_E.

The detection of these heavy leptons depends on their decay modes which in turn are somewhat model dependent. Their decays into charged leptons should have characteristic q^2 and ν dependences, different from those in inelastic neutrinos interactions with the usual leptons.[7,8] Thus the numbers of e^+ and e^- produced, and their angular and energy distributions, both in this and in other muon-neutrino experiments, will yield information relevant to the possible existence and nature of heavy leptons.

E. Comparison of the ν and $\bar{\nu}$ cross sections

$$\nu_e+Z\rightarrow e^-+\Gamma$$

$$\bar{\nu}_e+Z\rightarrow e^++\Gamma$$

and also the analogous processes with ν_μ and $\bar{\nu}_\mu$. These cross sections, especially for the muon neutrinos, might be done earlier in the wide band neutrino beams. The advantage of using the beam proposed here is that both the ν and $\bar{\nu}$ events are observed in the same experiment with identical ν and $\bar{\nu}$ fluxes and energy spectra. Thus many of the systematic biases are eliminated and more reliable cross section ratios can be obtained.

III. Detection Capabilities of the Neon Chamber

Liquid neon has the following properties:

atomic number	$Z = 10$
atomic weight	$A = 20$
Isotopic spin	$I = 0$
density	$\rho = 1.2$ gr/cm^3 (or tons/m^3)
radiation length	$x \simeq 25$ cm
interaction length	$L = 60$ cm
Effective interaction length	$\simeq$ 75 cm

(The effective interaction length is our estimate of the length if only those interactions are counted which are detectable in the chamber.)

The 15 foot chamber filled with liquid neon has many advantages as a neutrino detector:

(a) High event rates. The event rates in neon are 20 or 10 times those in hydrogen or deuterium, respectively. The total mass of liquid in the chamber is around 40 tons, of which 20 tons are in the usable fiducial volume. This compares favorably even with presently existing large spark chamber detectors.

(b) Identification of e, μ, and hadrons. Because of the short radiation length in neon, electrons can be identified as such due to their characteristic appearance in the chamber.

Muons can be distinguished from hadrons by the fact that muons will leave the chamber without interacting, while hadrons, due to their short interaction lengths, are likely to interact in the chamber. For events in which muon-hadron distinction is important, a fiducial volume can be chosen such that the outgoing tracks traverse on the average four effective interaction lengths of liquid, and thus 98% of these should have a detectable interaction. Thus 2% or less of the hadrons could be confused with muons.

The ability to identify electrons and muons is important in distinguishing ν_e interactions and ν_μ interactions from each other. The magnetic field of the chamber allows a distinction between e^- and e^+, or μ^- and μ^+, which is very important for separating ν from $\bar{\nu}$ events. This is an important advantage over detectors without magnetic fields over the entire target volume. The magnetic field will also enable us to distinguish electrons from showers caused by Dalitz pairs produced in π^0 decays by visibly separating the e^+ and the e^- before either of them showers (which is typically 25 cm in neon). This feature combined with the small probability of Dalitz pair production ($\sim 1/80$ per π^0) will make Dalitz pairs not a problem even for events in which many π^0's are produced.

(c) Detection of neutral particles.

K° and Λ° decays can be detected from their charged decay products, as usual in bubble chambers. Photons will convert into e^+e^- pairs, and thus they can be detected and their energy measured with average efficiencies better than 98% since there are many radiation lengths from the center of the chamber to the edge. π°'s can thus be detected and reconstructed with detection efficiencies $\sim$ 96%. Neutrons will interact in the chamber most of the time. Even though only some fraction of the energy of the neutron is given to charged particles, this information can be used in a statistical way to estimate the average amount of energy going into neutrons.

(d) Momentum measurement from curvature in the 30 kgauss magnetic field of the chamber.

(e) Measurement of the total incident neutrino energy.

In the wideband run the incident neutrino energy is not known and has to be obtained by the measurement of the total energy of the final state. We expect that on the average $\sim\frac{1}{2}$ of the energy will go to the electron or muon, about $\sim\frac{1}{3}$ to charged hadrons and $\sim\frac{1}{6}$ to neutrals. Thus if the energy of the charged particles is measured to 5%, and the neutrals to 25%, as discussed above, we should be able to get the total energy to $\sim$10%.

(f) The usual feature of bubble chambers, 4π solid angle geometry, will be also useful in neutrino physics. The large transverse dimensions of the visible liquid in the 15 foot chamber allows good muon and electron identification at all angles. The fine grain, i.e. the ability to see tracks down to a few millimeters in length, will be important to detect short muons or other stopping hadrons. In particular, as discussed in Section II A above, this will make it possible to eliminate the bulk of the background due to $\nu_e + n \rightarrow e^- + p$ in the $\nu_e + e^- \rightarrow \nu_e + e^-$ search by detecting the proton even when it has very low energy. Otherwise this background would make the search impossible.

IV. Design of the Electron-Neutrino Beam

We list in Table I the π and K decays that are the sources of neutrinos at high energy accelerators. The product of the branching ratio of each decay times the relative content of the parent meson in the beam, serves as a rough guide to the contribution of each source to an unfocused neutrino beam. Focusing of the charged mesons toward the detector increases the neutrino flux originating from the decay of charged mesons by up to a factor of ten or so. It is apparent from Table I that sweeping out the charged $\pi^{\pm}$ and $K^{\pm}$ mesons would eliminate the bulk of the muon neutrinos, but would lose only a small fraction of the electron neutrinos (from $K^{\pm}$ decays).

The short lived K^0's will decay predominantly into pions and thus will not contribute appreciably to the electron neutrino flux. These pions from $K_S{}^0$ decay must also be swept out by the magnetic field so that they do not produce background muon neutrinos in the detectors. We are thus left with the $K_L{}^0$ decays

$$\begin{aligned} K_L{}^0 &\to \pi^-+e^++\nu_e \\ &\to \pi^++e^-+\bar{\nu}_e \\ &\to \pi^-+\mu^++\nu_\mu \\ &\to \pi^++\mu^-+\bar{\nu}_\mu \end{aligned}$$

These decays will produce roughly equal intensities of the four kinds of neutrinos, with similar energy spectra.

The general layout of the electron neutrino beam could be the same as that of the existing wide band neutrino beam at NAL, i.e. 400 m long decay path and $\sim$ 1000 m earth shield. In case the accelerator energy is increased to $\sim$ 1000 BeV, the geometry of the wide band beam proposed for that energy with a 900 meter decay path and a 500 m shield would be used.* The only change necessary from the wide band beam is to replace the focusing horn on the target train with a dipole sweeping magnet with an inserted collimator.

A ± 2 1/2 mradian tapered collimator will transmit essentially all of the useful K^0's whose decays are the source of the desired neutrinos. All charged particles produced at the target, which is situated at the upstream end of the magnet and the collimator, can be deflected into the walls of the collimator by a 40 k gauss dipole field $\sim$ 5 meters long. The aperture of the magnet has to be only 1 inch x 1 inch. The transverse momentum given the charged mesons is

$$\Delta P \approx .03\ \mathrm{BeV/c} \times B \times \ell$$

where B is in k gauss, ℓ in meters. In 0.4 meters of 40 k gauss field, the particles acquire 1/2 BeV/c of transverse momentum. For a 200 BeV particle, this corresponds to an angular deflection of $\sim$ 2 1/2 mrad. The detectors subtend typically $\sim$ 1 1/2 mrad at the target. Thus the typical decay path in which a charged meson has to decay to put a neutrino into the detector is of the order of 0.4 meters, instead of the 400 m of decay path in the wide band beam. Furthermore, the detector subtends a smaller solid angle near the target, than it does at the rest of the 400 m decay path. Thus the reduction in ν_μ flux from charged meson decay should be between 10^{-3} and 10^{-4} relative to an unfocused spectrum, or 10^{-4} to 10^{-5} relative to the usual horn focused wide band ν_μ spectrum. Thus it should be possible to reduce the muon neutrino contamination from charged meson decay in the electron neutrino beam to a few percent.

---

*See report of the Neutrino group in the 1973 Aspen Summer Study Report.

Another source of muon neutrinos, as mentioned above, is the decay of $\pi^{\pm}$ produced in K_S^0 decays. To estimate the magnitude of this background, we consider 200 BeV/c K^0 decays. The mean decay path of K_L^0 is

$$\lambda_{K_L^0} = \left(\frac{P}{m}\right)\tau c = 6200\ \mathrm{m}$$

so that 400/6200 = 1/15 of the K_L^0 decay in the 400 m decay path. Essentially all of the K_S^0 will decay producing a 100 BeV/c π^+ each on the average. The mean decay path of such a π^+ is ∿ 5500 m, so that 400/5500 or ∿ 1/14 will decay in the 400 m decay path. We thus have ν_μ from K_S^0 decay/ν_e from K^0_L decay ∿ 2. Such a background is too high and must be reduced by a factor of ∿ 100 or so by sweeping the K_S^0 decay products out of the beam. This can be easily done by a relatively weak, ∿ 10 k gauss, field. The length of the field is determined by the K_S^0 mean free path. Calculating again for 200 BeV/c K's, $\lambda_{K_S^0} \approx 11$ meters. We thus need at least 40 meters of field. Fig. 3 is a schematic drawing of such a beam.

We have carried out a detailed design of such a beam using two independent Monte Carlo calculations. We find that a ± 2 1/2 mrad tapered collimator will accept the bulk of the K_L^0 which produce the desired neutrinos. Five meters of 40 k gauss field plus 40 meters of 10 k gauss field is sufficient to reduce the muon neutrino fluxes to below 10% with 500 BeV primary protons as shown in Fig. 4. We feel that such a level of background is tolerable since its magnitude can be estimated fairly well and a correction to the final results can be made, with a final uncertainty of the order of a few percent. We have not explicitly calculated the backgrounds due to a number of other sources such as $\Lambda \rightarrow p\pi^-$, $K_L \rightarrow 3\pi$, $K_L \rightarrow \pi \ell \nu$, followed by $\pi \rightarrow \nu\mu$; decays of $\mu \rightarrow e\nu\nu$; and scattering of particles on the faces of the collimator. We estimate that these backgrounds should be smaller than those we have calculated.

We have done a preliminary design of the sweeping magnets required. The magnet could be a conventional warm iron magnet. Even the 40 k gauss section presents no problems since we require a very small aperture, 1" x 1". We have broken the 10 k gauss magnet into eight sections, 5 m long each. The parameters of the magnets are summarized in Table II. The total for the nine magnets is 73 tons of iron and 10 tons of copper. Estimating \$300/ton for iron and \$6000/ton for copper yields an estimate of \$95,000 for the sweeping magnets. We estimate the total power requirement of the magnet to be 2 1/2 megawatts.

The 45 meter long sweeping magnet with the inserted collimator should fit quite conveniently on the target train in the existing target tube.

This preliminary design is presented to show feasibility at a reasonable cost. We will continue work toward a (hopefully better) final detailed design and welcome any suggestions for improvement. We have also investigated the possibility of a new neutrino beam to the 15 foot chamber with different decay path length and shield length from the existing beam. We have calculated the ν_e flux, integrated over neutrino energy and the detector area, as a function of decay path length for 250 meter, 500 meter, and 1000 meter long muon shields. These are shown in Fig. 5. The best combination is in the vicinity of a 400 meter decay path with a 250 meter shield, yielding $\sim 5.6 \times 10^8$ $\nu_e/10^{13}$ protons. A shorter shield would be even better, but since our calculations indicate that there are substantial numbers of muons up to $\sim$ 400 BeV with 500 BeV protons on the target, a shield much shorter than 250 meters seems unrealistic to us. Even a 250 meter shield would have to contain some magnetized iron to be feasible. The flux of the existing beam with 400 meter decay path and 1000 meter shield is $\sim$ 1.5 x 10^8 $\nu_e/10^{13}$ protons, or about a factor of 4 worse than a beam with a 250 meter shield. Thus a beam with a short shield, which would quadruple the event rates shown in Table III, seems very attractive to us, if it can be reconciled with the financial realities and the logistics of the neutrino area.

V. NEUTRINO FLUXES AND EVENT RATES

We have used Monte Carlo techniques to calculate the ν fluxes from K_L^0 decays as well as the background ν_μ fluxes in the beam described above for a range of primary proton energies. Two independent programs were used, one using a fit to the CERN ISR particle production data, the other using the empirical particle production formula by Wang. The results of the two calculations for the ν_e fluxes agreed to better than 20%. The calculated ν_e, $\overline{\nu}_e$, ν_μ and $\overline{\nu}_\mu$ spectra for 500 BeV incident protons are shown in Fig. 4. Also shown are the two major ν_μ backgrounds, due to π^+ and K^+ decays and $K_S^\circ \rightarrow 2\pi$, $\pi \rightarrow \mu\nu$ decays.

We have calculated the expected numbers of events for the following conditions:

500 and 1000 BeV primary protons
10^{13} protons/pulse
500,000 pictures at each primary proton energy
20 m^3 fid. vol. in neon (24 tons)

We have assumed a total crossection of $0.8 \times 10^{-38}\ E_\nu$ cm^2/nucleon for ν_e and ν_μ, and 1/3 of that for $\overline{\nu}_e$ and $\overline{\nu}_\mu$. For the process $\nu_e + n \rightarrow e^- + p$, the main background to the search for $\nu_e + e^- \rightarrow \nu_e + e^-$, we have used the crossection 0.75×10^{-38} cm^2/neutron,[4] with the proton not visible 1/30 of the time. For the purely leptonic processes we have used the crossections shown in Fig. 1. For 500 BeV protons we used the 400 m decay path and 1000 m shield of the existing beam. For 1000 BeV protons we used a 900 m decay path and a 500 m shield.

The results of these calculations are shown in Table III. The total number of ν_e and ν_μ interactions as a function of E_ν are shown in Fig. 6.

We note that the energy dependence of these events is not as steep as in the usual wideband beams. The number of ν_e interactions/BeV with 500 BeV primary protons is within a factor of ten for the entire E_ν range from 0 to 200 BeV, and within a factor of two from 20 to 130 BeV.

The neutrino flux and the crossections are both strongly dependent on the energy of the incident protons. Figures 9 to 12 show this dependence. It is clear that the number of interactions increases very sharply with energy. The "new beam" indicated in figures 10 and 11 is the hardened neutrino beam proposed in the 1973 NAL Aspen summer study with a 900 m decay path and a 500 m shield.

For the very important diagonal interactions part of this experiment it is clear that the energy doubler could make quite significant improvements in the rate. The signal to background ratio also improves with increasing energy (see Fig. 12) since the $\nu_e + e^- \rightarrow \nu_e + e^-$ crossection rises with energy but the crossection of the main backgrounds are energy independent.

Our calculations indicate that if the sweeping magnet remains as designed for 500 BeV protons, the background rate for charged muon events increases somewhat as the proton energy increases but is still tolerable even at the highest doubler energies. We note that this slightly increased background of muon neutrino events would have no effect on our search for diagonal interactions of electron neutrinos.

VI. The Specific Proposed Runs

In view of the sharp increase of intensity with machine energy we propose two runs:

1. 500,000 pictures at the highest available present day energy (400-500 BeV) with 10^{13} interacting protons on target.
2. 500,000 pictures at the highest practical energy when the energy doubler is operative, with 10^{13} interacting protons on target.

The first run should enable us to test muon electron universality with the numbers of charged current events given in table III. If the neutral current for muon neutrinos is about 20% of the charged current we would expect about 2000 neutral current events induced by electron neutrinos and 1200 induced by muon neutrinos. By comparison with our already approved muon neutrino exposures we should be able to check the universality for the neutral currents quite well.

We should be able to look at $\bar{\nu}/\nu$ cross sections within the same experiment with beams of identical flux as described earlier. Finally because of the mild energy dependence of the event rate we should be able to examine energy dependences with less bias than previous experiments.

We will search for and perhaps find some initial evidence for the high energy diagonal processes $\nu_e + e^- \rightarrow \nu_e + e^-$ and $\bar{\nu}_e + e^- \rightarrow \bar{\nu}_e + e^-$, and study the background problems for them. Even an upper limit on these processes of several times the V-A rate would be of great importance.

The second run will of course depend upon successful completion of the first and upon the interest of the results obtained by the first run. In this second run we would be able to improve all of the results indicated above and most importantly get a good measurement of the diagonal process.

The energy at which the second part can be run depends on the repetition rate possible with the doubler. For example, if injection takes place at 300 GeV and if the $\frac{dE}{dt}$ is 100 GeV/5 seconds as presently envisaged than 700 GeV would correspond to about every 4th machine pulse and have about a 20 second repetition rate. At this rate 500,000 pictures would require about four months. If the doubler should prove capable of multiple pulse injection then the number of pictures requested could be proportionately reduced.

VII. CONCLUSIONS

The numbers of events expected (see Table III) allow a detailed test of universality by comparing ν_e and $\bar{\nu}_e$ induced semileptonic interactions with those induced by ν_μ and $\bar{\nu}_\mu$ in the same as well as other experiments. We will test universality separately for the charged and the neutral weak currents. The search for electron-type heavy leptons is possible in an electron neutrino beam. Also, the detection of the diagonal four fermion process $\nu_e + e^- \rightarrow \nu_e + e^-$ might be feasible, both from the point of view of the number of events produced and the relative smallness of the major background. Another measurement that will be possible is the ratio of the $\bar{\nu}_e$ and ν_e cross sections, as well as the ratio of the $\bar{\nu}_\mu$ to ν_μ cross section, in a beam where the ν and $\bar{\nu}$ fluxes are equal and therefore their ratio is precisely known.

The last point is worth reemphasizing. In the beam discussed here, we have the four kinds of neutrinos with precisely known relative fluxes:

$$\frac{\bar{\nu}_e}{\nu_e} = \frac{\bar{\nu}_\mu}{\nu_\mu} = 1.0$$

$$\frac{\nu_e}{\nu_\mu} \quad \frac{\bar{\nu}_e}{\bar{\nu}_\mu} = 1.44$$

The energy spectra of the neutrinos and antineutrinos must be the same, and the spectra of electron and muon neutrinos are very similar since all of the neutrinos originate from the decays of the same K_L^0 parents. This knowledge of the flux ratios is crucial in both the universality test and the antineutrino - neutrino cross section ratio measurements.

TABLE I

Sources of Neutrinos

Decay	Relative Content of Parent Meson in Beam	Decay Branching Ratio	Relative Contribution to ν Beam
$\pi^+ \rightarrow \mu^+\nu_\mu$	1.0	1.0	1.0
$\pi^- \rightarrow \mu^-\bar{\nu}_\mu$	0.4	1.0	0.4
$K^+ \rightarrow \mu^+\nu_\mu$	0.15	0.64	0.10
$\mu^+\pi^0\nu_\mu$		0.03	0.0005
$e^+\pi^0\nu_e$		0.05	0.008
$K^- \rightarrow \mu^-\bar{\nu}_\mu$	0.05	0.64	0.03
$\mu^-\pi^0\bar{\nu}_\mu$		0.03	0.002
$e^-\pi^0\bar{\nu}_e$		0.05	0.003
$K^0 \rightarrow \pi^-\mu^+\nu_\mu$	0.15	0.27	0.05
$\pi^-e^+\nu_e$		0.39	0.06
$\bar{K}^0 \rightarrow \pi^+\mu^-\bar{\nu}_\mu$	0.05	0.27	0.015
$\pi^+e^-\bar{\nu}_e$		0.39	0.02

TABLE II

Sweeping Magnet Paramaters

Field	Length	Aperture	Number Needed	Iron Dimens. cm	Iron Mass tons	Copper Dimens. cm	Copper Mass tons	Power
40 kg	5m	1" x 1"	1	25 x 45	3.6	10 x 12	1.0	1/4 mega watts
10 kg	5m	4" x 4"	3	30 x 50	5.0	8 x 10	0.72	1/6 mega watts
10 kg	5m	7" x 7"	3	40 x 60	10.0	10 x 14	1.26	0.3 mega watts
10 kg	5m	9" x 9"	2	45 x 65	12.0	10 x 18	1.62	0.4 mega watts

Total materials: 73 tons of Iron, 10 tons of copper

Total power: 1/4 + 3 x 1/6 + 3 x .3 + 2 X .4 = 2.5 mega watts

TABLE III

Expected Numbers of Events

Calculate for:

500 and 1000 BeV primary protons

10^{13} protons/pulse

500,000 pictures at each proton energy

20 m^3 of neon fid. vol. (24 tons)

400 meter decay, 1000 meter shield length at 500 BeV

900 meter decay, 500 meter shield length at 1000 BeV

Reaction	500 BeV	1000 BeV
$\nu_e + N \rightarrow e^- +$ hadrons	8000	60,000
$\bar{\nu}_e + N \rightarrow e^+ +$ hadrons	2500	20,000
$\nu_\mu + N \rightarrow \mu^- +$ hadrons	4500	35,000
$\bar{\nu}_\mu + N \rightarrow \mu^+ +$ hadrons	1500	12,000
$\nu_e + n \rightarrow e^- + p$, p not visible	2	10
$\nu_e + e^- \rightarrow \nu_e + e^-$ $\bar{\nu}_e + e^- \rightarrow \bar{\nu}_e + e^-$ } using V-A prediction	11	90
$\nu_e + e^- \rightarrow \nu_e + e^-$ $\bar{\nu}_e + e^- \rightarrow \bar{\nu}_e + e^-$ } using Weinberg model	3 to 36	25 - 300

References

1. See for example S. Weinberg, Physics Rev. D5, 1412 (1972).
2. See for example t'Hooft, Physics Lett. 37B, 195 (1971).
3. F. Reines et al, Experimental Proposal to LAMPF.
4. W.A. Mann et al, Physics Rev. Lett. 31, 844 (1973).
5. A. Pais, private communication.
6. H. Georgi and A. Pais, Rockefeller University Preprint.
7. A. Soni, to be published in Physics Rev. (April 1974). See also J.D. Bjorken and C.H. Llewellyn-Smith , Physics Rev. D7, 887 (1973).
8. C.H. Albright, Physics Rev. Lett. 28, 1150 (1972).

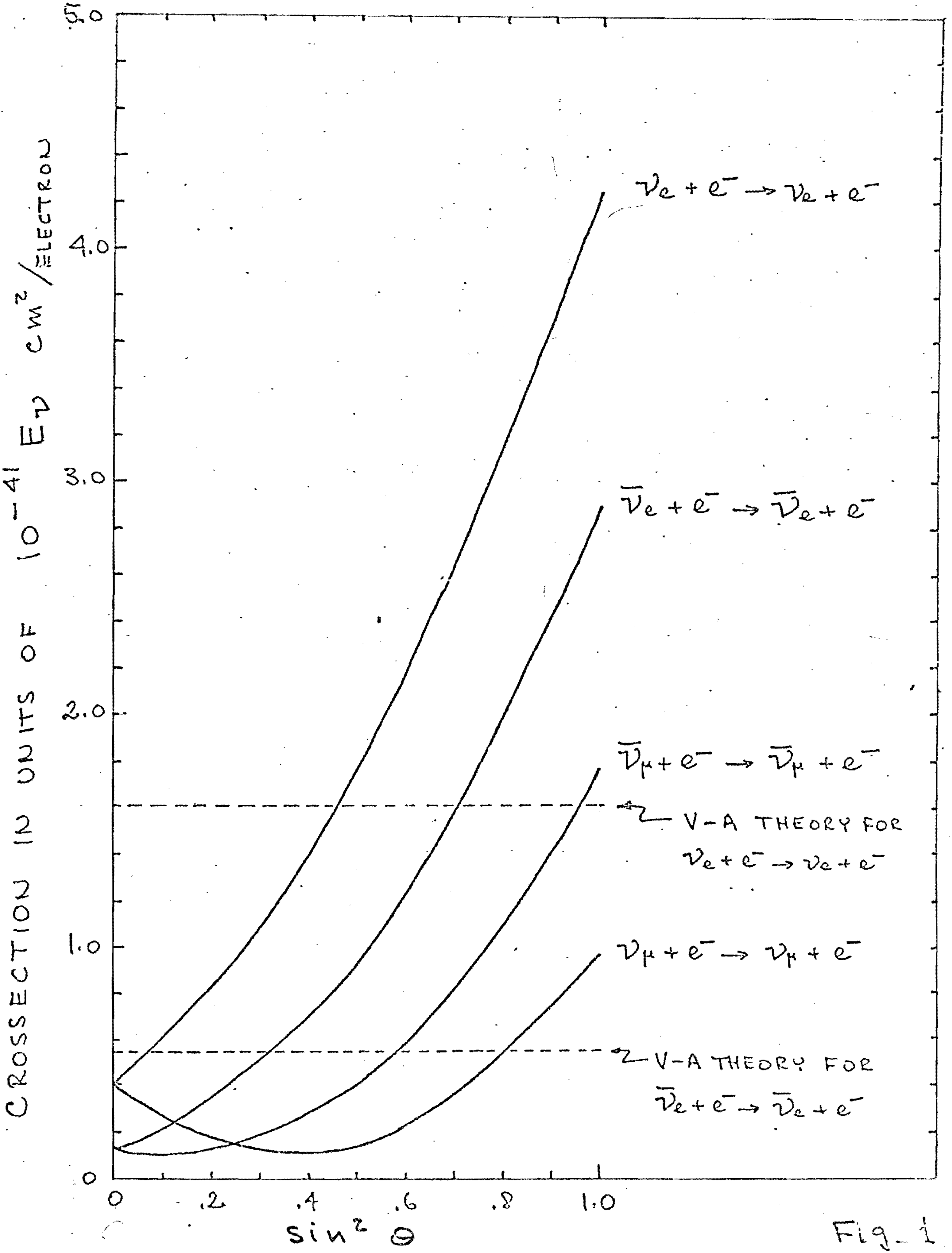

CROSSECTION IN UNITS OF 10^{-41} E_ν cm^2/ELECTRON
5.0
4.0
3.0
2.0
1.0
0
0
.2
.4
.6
.8
1.0
$\sin^2\theta$
$\nu_e + e^- \rightarrow \nu_e + e^-$
$\bar{\nu}_e + e^- \rightarrow \bar{\nu}_e + e^-$
$\bar{\nu}_\mu + e^- \rightarrow \bar{\nu}_\mu + e^-$
V-A THEORY FOR $\nu_e + e^- \rightarrow \nu_e + e^-$
$\nu_\mu + e^- \rightarrow \nu_\mu + e^-$
V-A THEORY FOR $\bar{\nu}_e + e^- \rightarrow \bar{\nu}_e + e^-$

Fig. 1

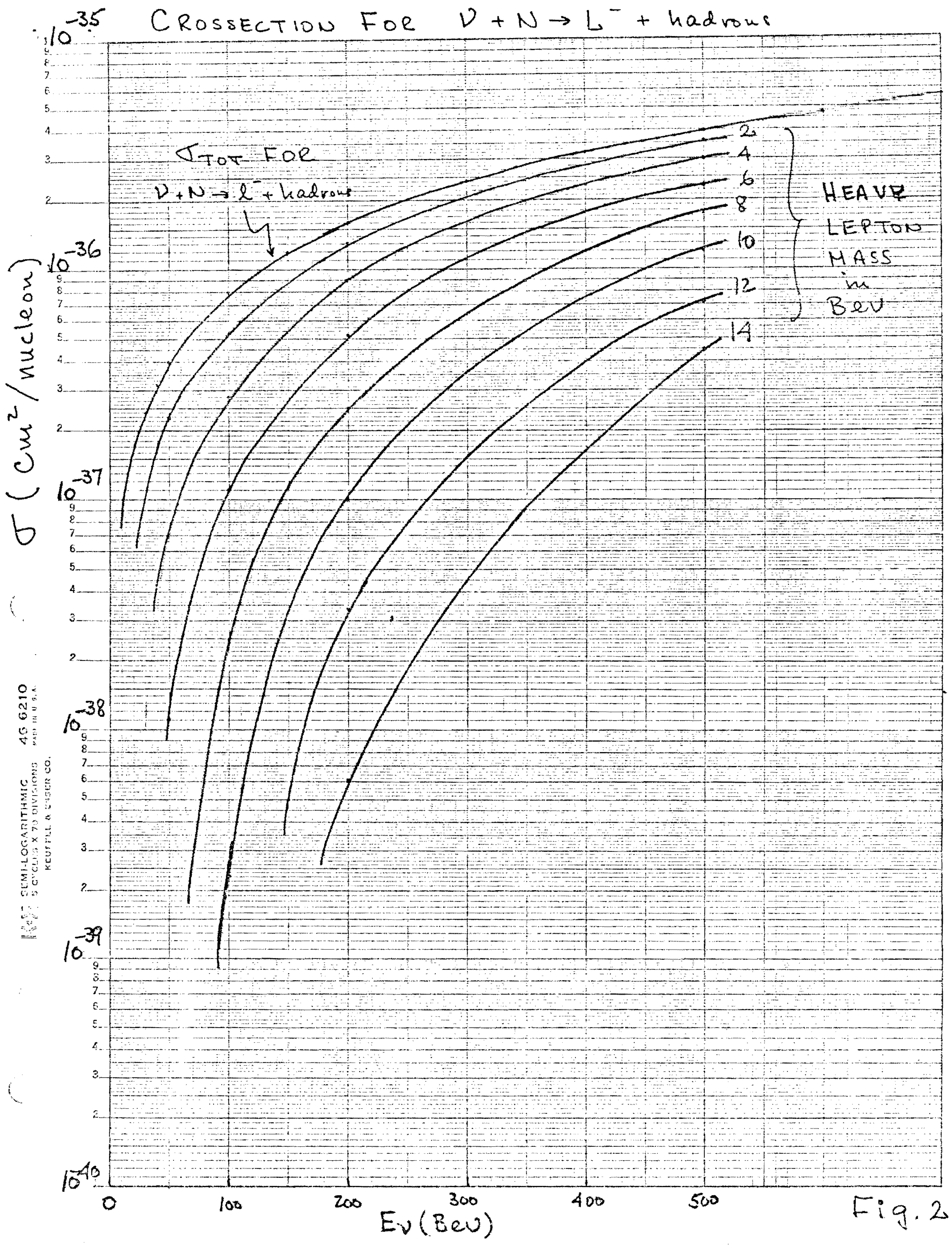
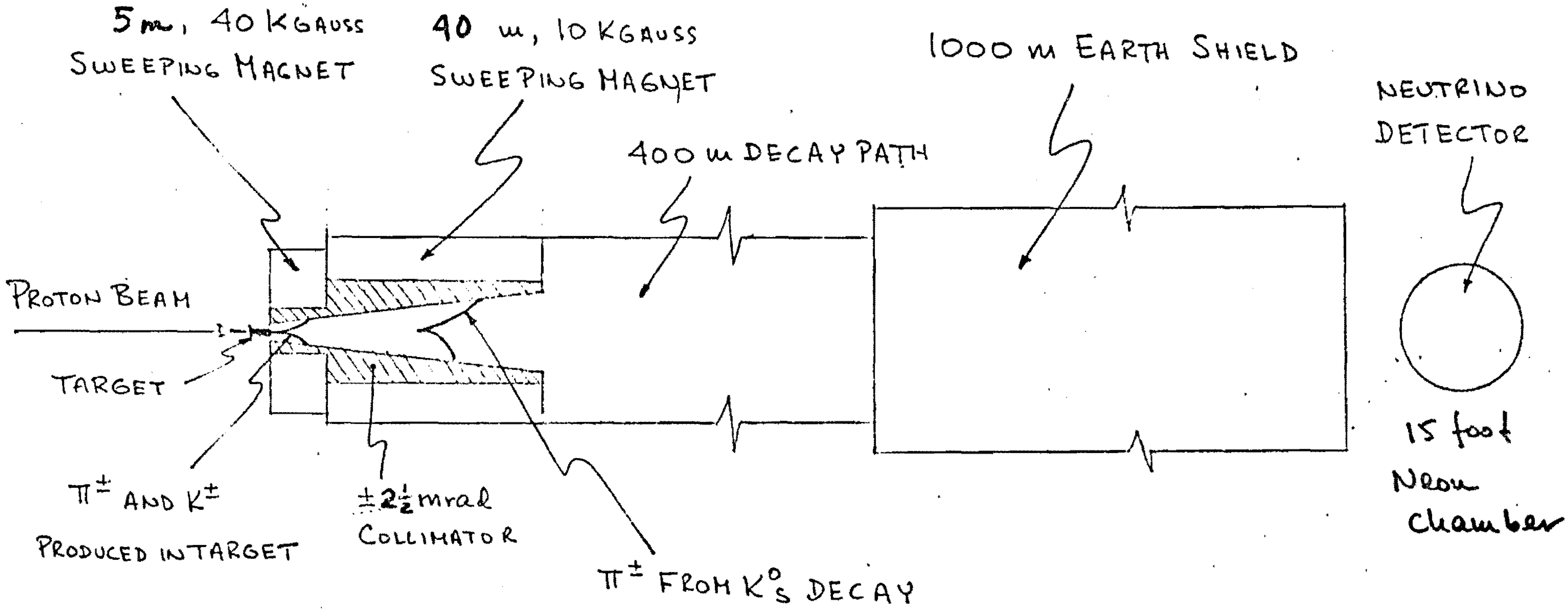

CROSSECTION FOR ν + N → L⁻ + hadrons
σ_TOT FOR ν + N → ℓ⁻ + hadrons
σ (cm²/nucleon)
Eν (BeV)
10^-35
10^-36
10^-37
10^-38
10^-39
10^-40
0
100
200
300
400
500
2
4
6
8
10
12
14
HEAVY LEPTON MASS in BeV
K&E SEMI-LOGARITHMIC 5 CYCLES X 70 DIVISIONS KEUFFEL & ESSER CO.
46 6210 MADE IN U.S.A.

Fig. 2

ν_e BEAM



NOT TO SCALE

FIG. 3

500 Bev Protons, ±2½ mrad coll, 1000m Decay, 1000m

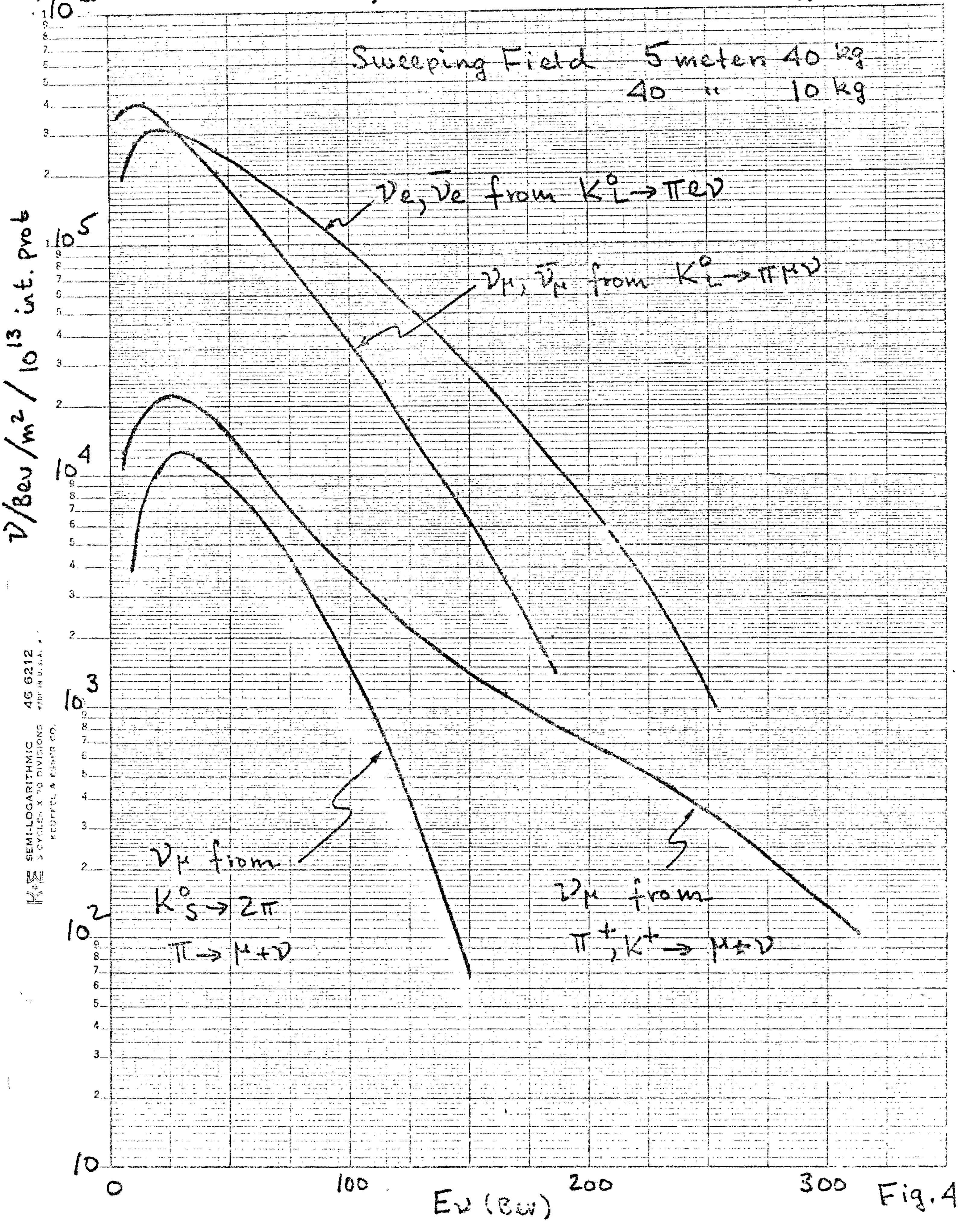


Fig. 4

ν_e flux hitting 5.7 m² Fid. Vol. for 10^{13} int. prot.

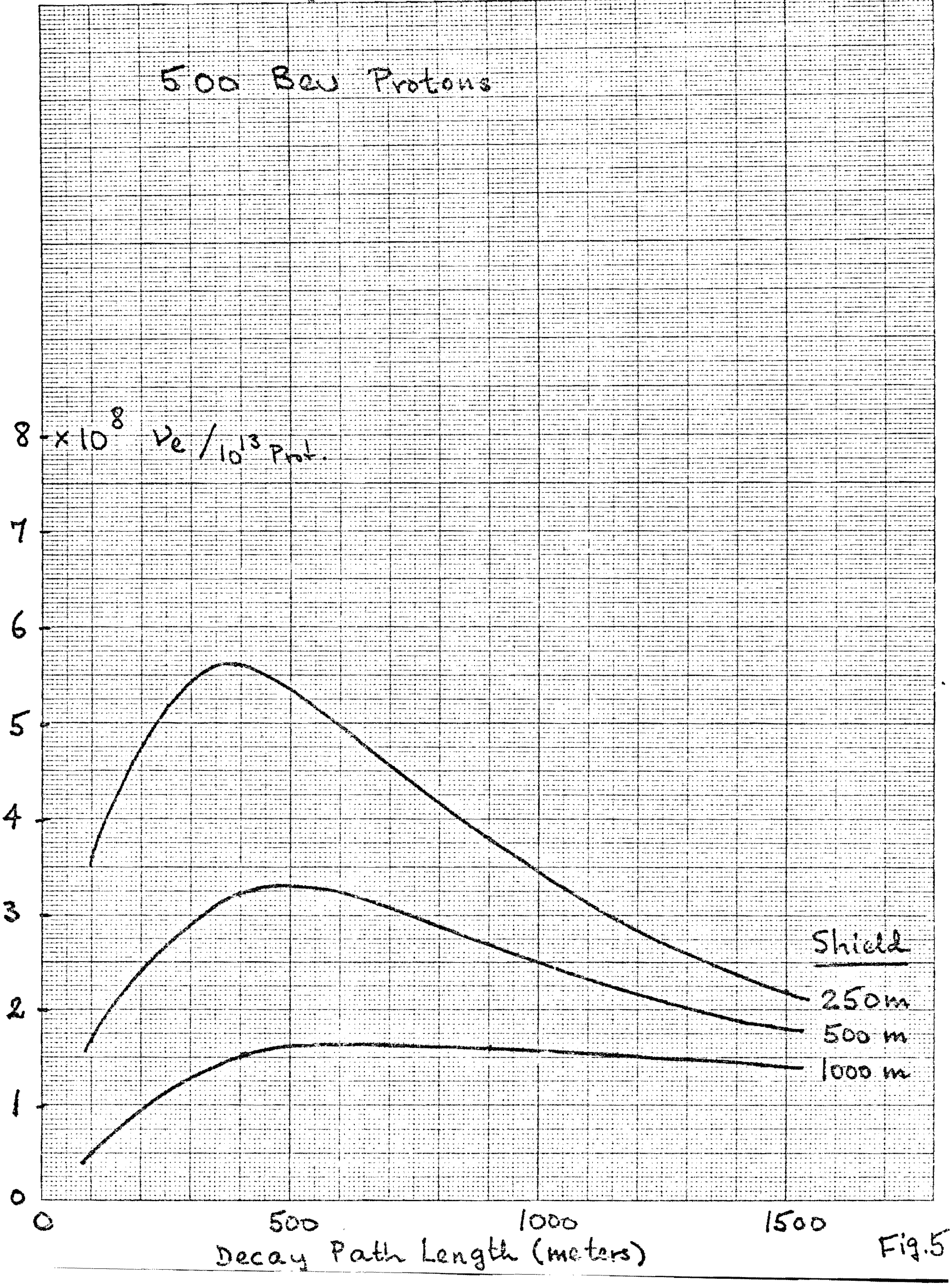


Fig.5

TOTAL NUMBER OF INTERACTIONS

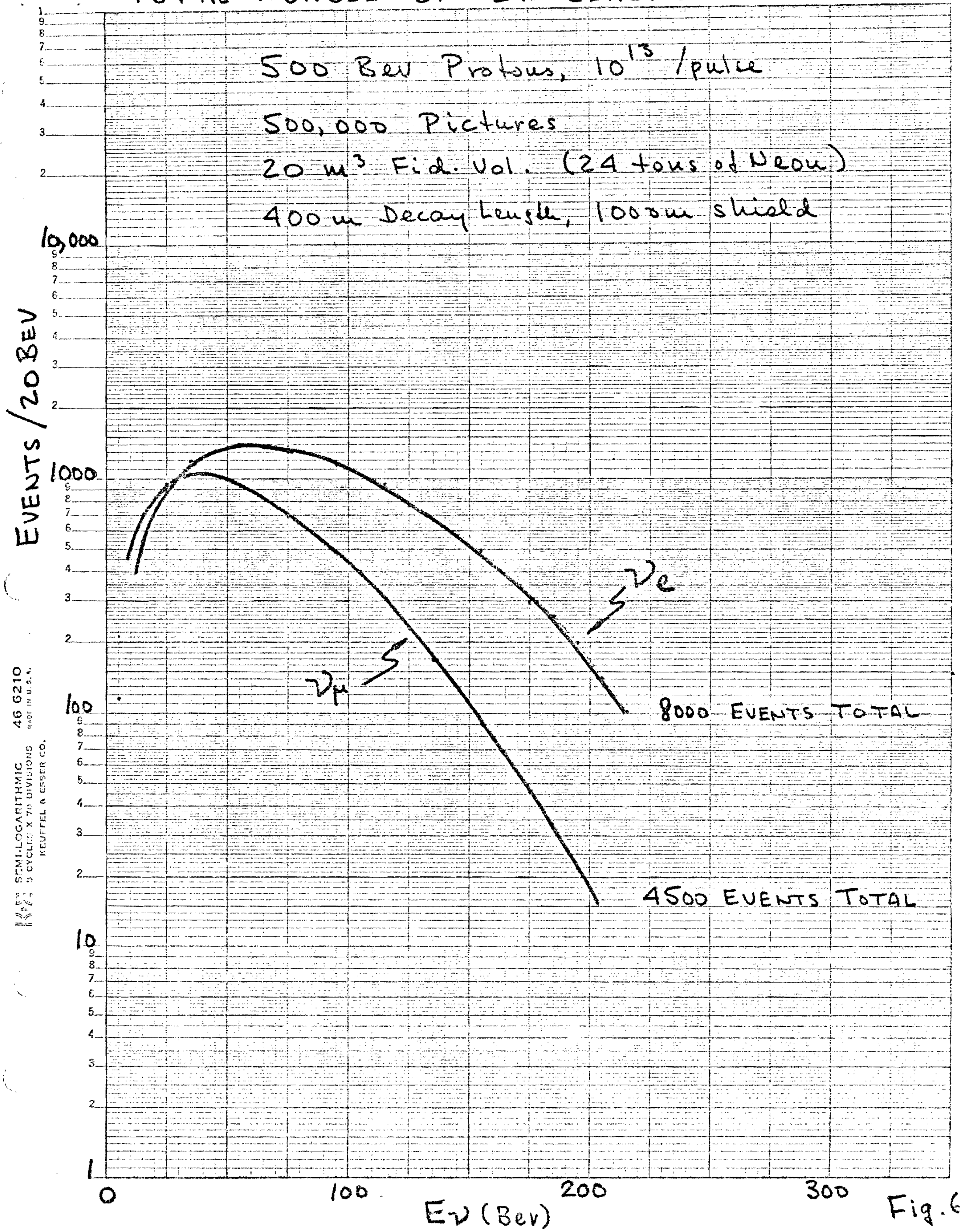
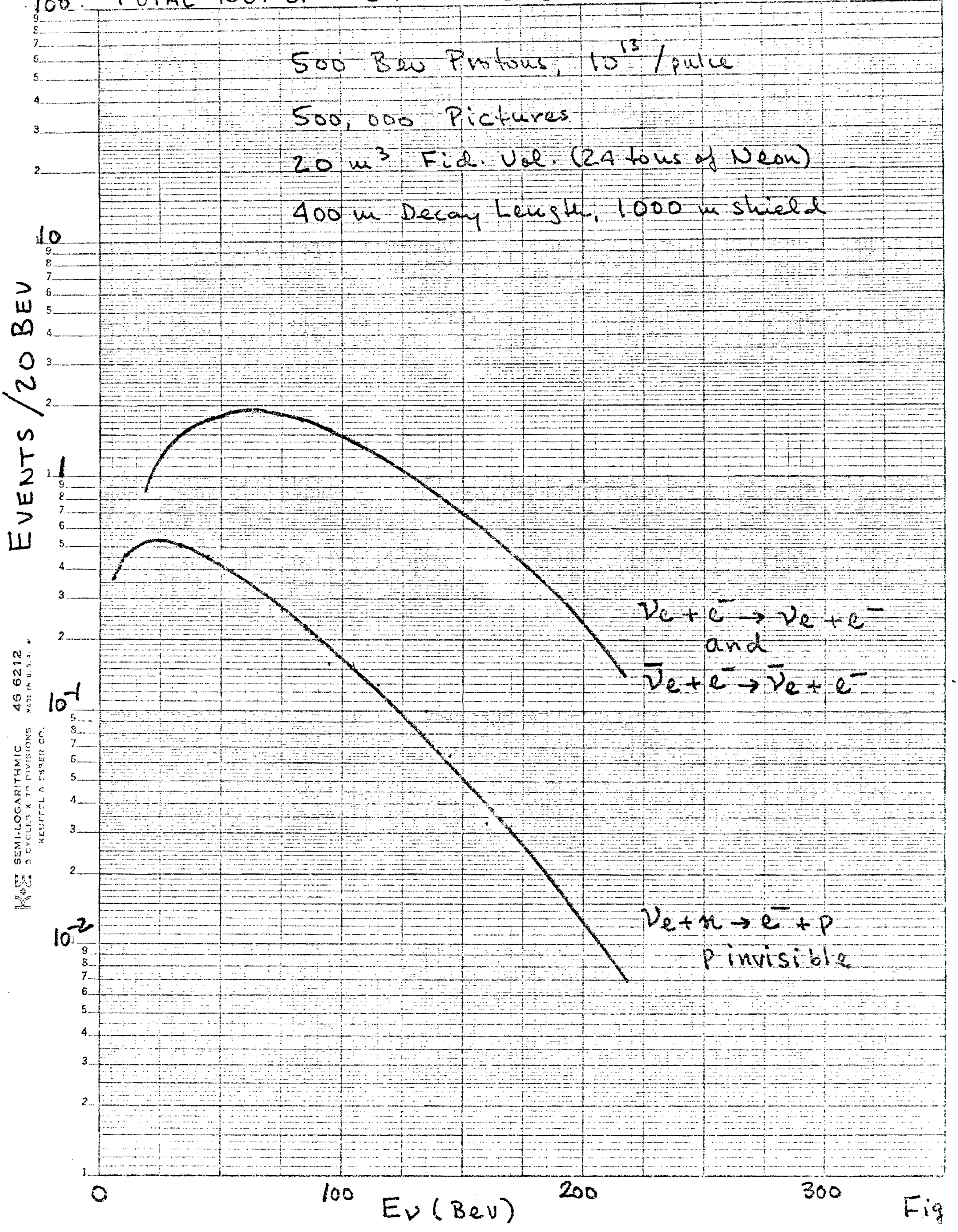


Fig. 6

TOTAL NO. OF $\nu_e + e^- \to \nu_e + e^-$ AND $\nu_e + e \to \nu_e + e$ EVENTS



500 Bev Protons, 10^{13}/pulse

500,000 Pictures

20 m³ Fid. Vol. (24 tons of Neon)

400 m Decay Length, 1000 m shield

$\nu_e + e^- \to \nu_e + e^-$
and
$\bar{\nu}_e + e^- \to \bar{\nu}_e + e^-$

$\nu_e + n \to e^- + p$
p invisible

Fig

TOTAL NUMBER OF HEAVY LEPTONS PRODUCED VS. MASS

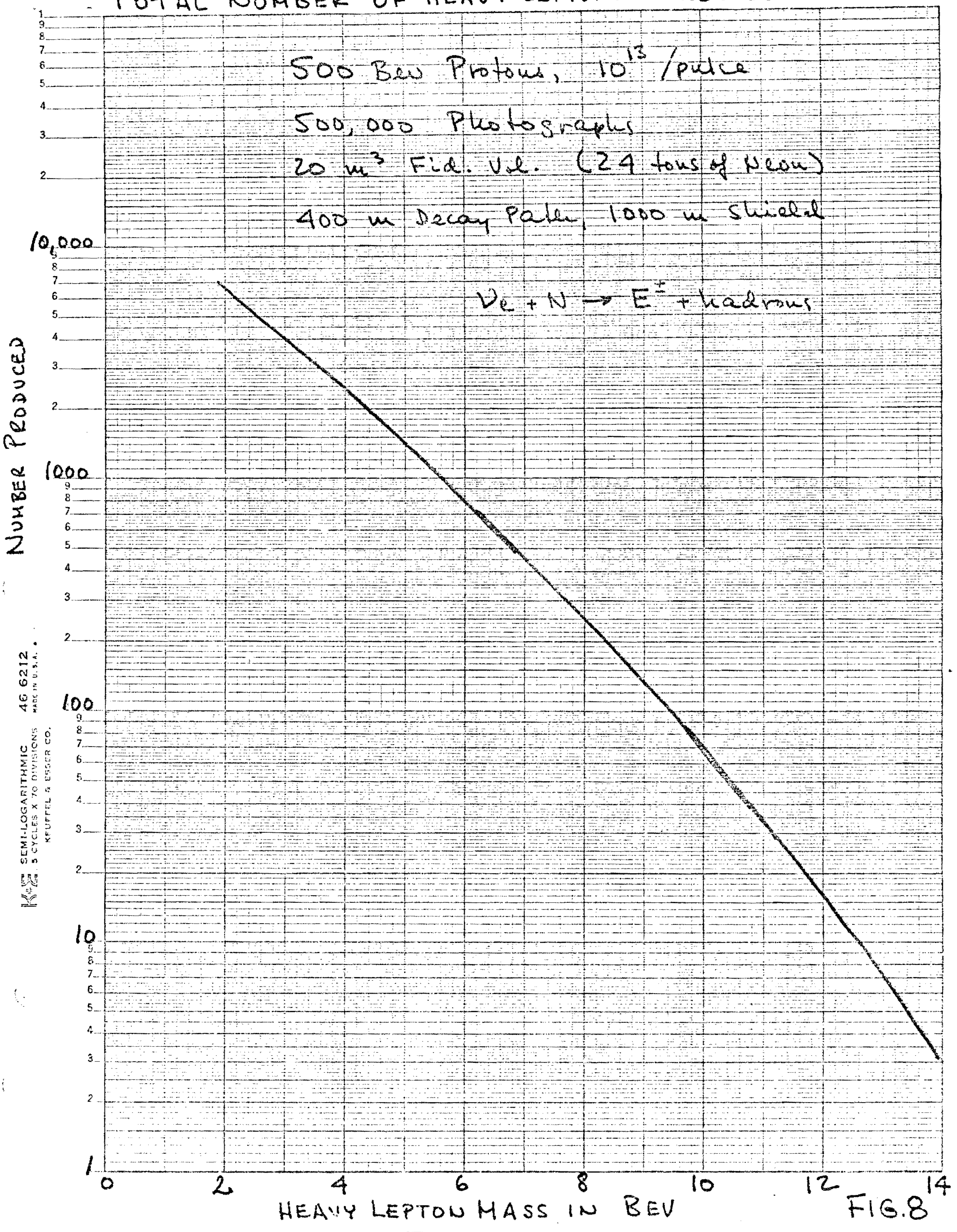


FIG.8

-TOTAL NO. OF ν_e INTERACTIONS FOR VARIOUS PROTON ENERGIES

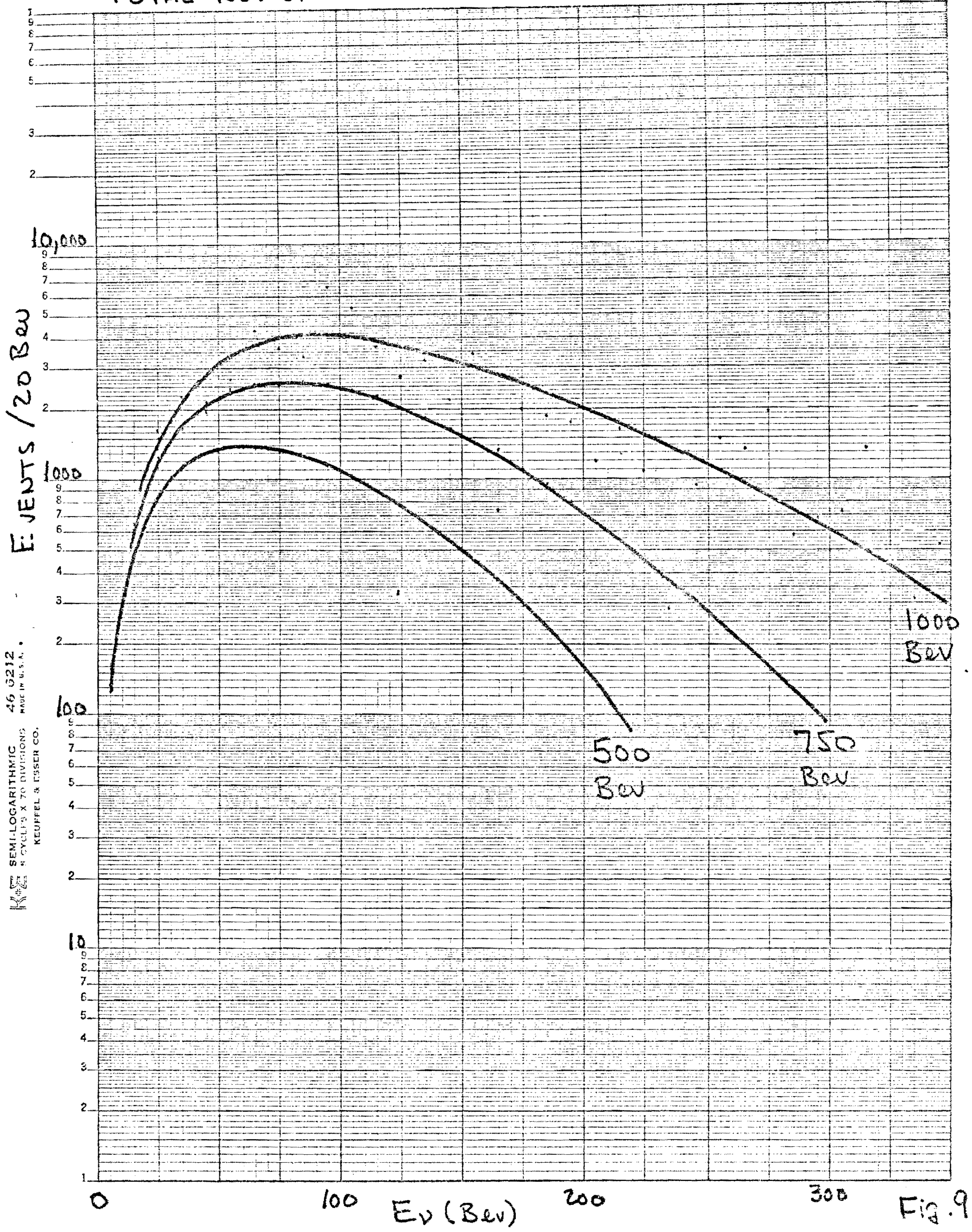
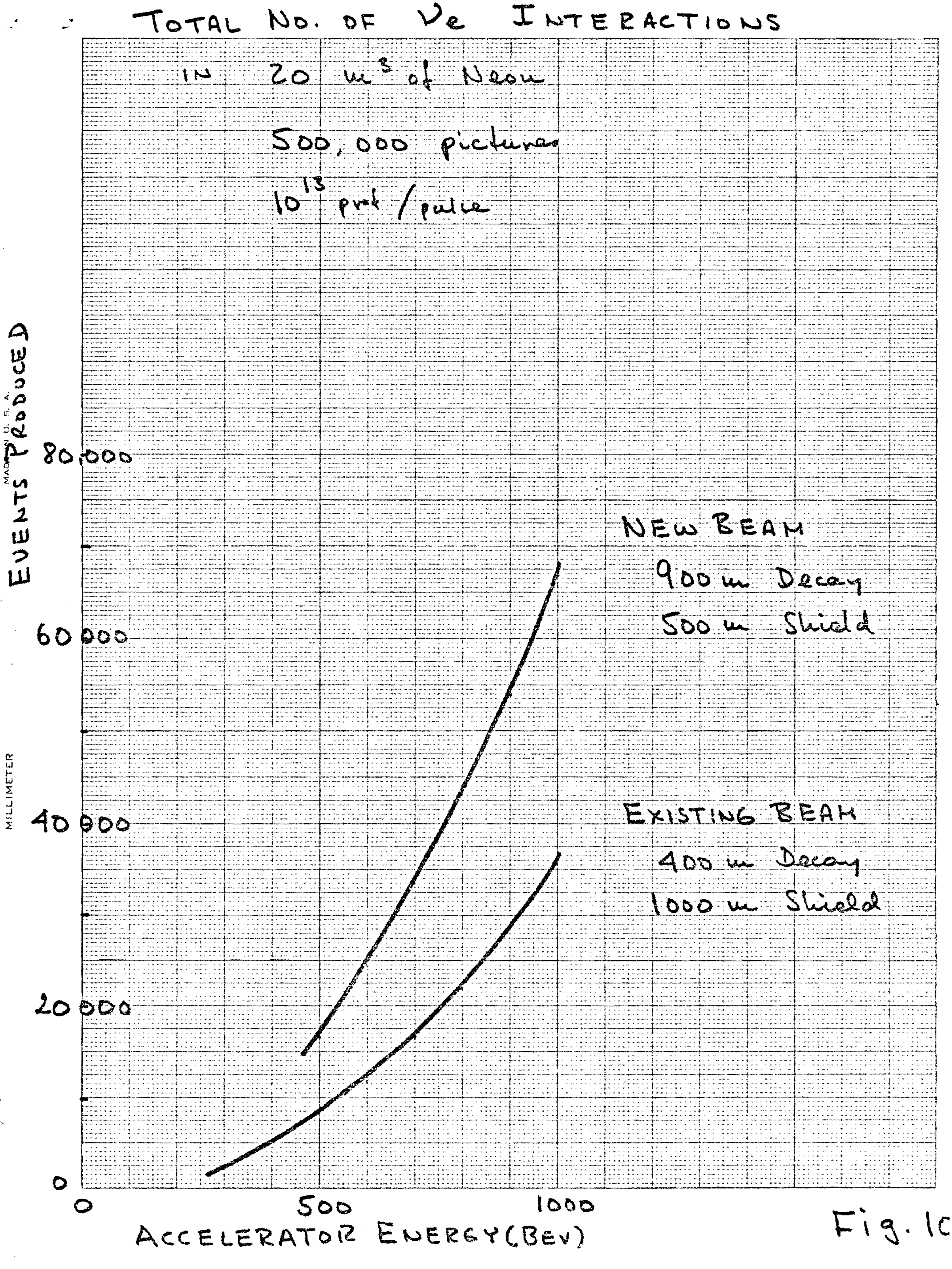


Fig. 9



TOTAL NO. OF ν_e INTERACTIONS

IN 20 m^3 of Neon

500,000 pictures

10^{13} prot / pulse

Fig. 1c

NUMBER OF EVENTS PRODUCED

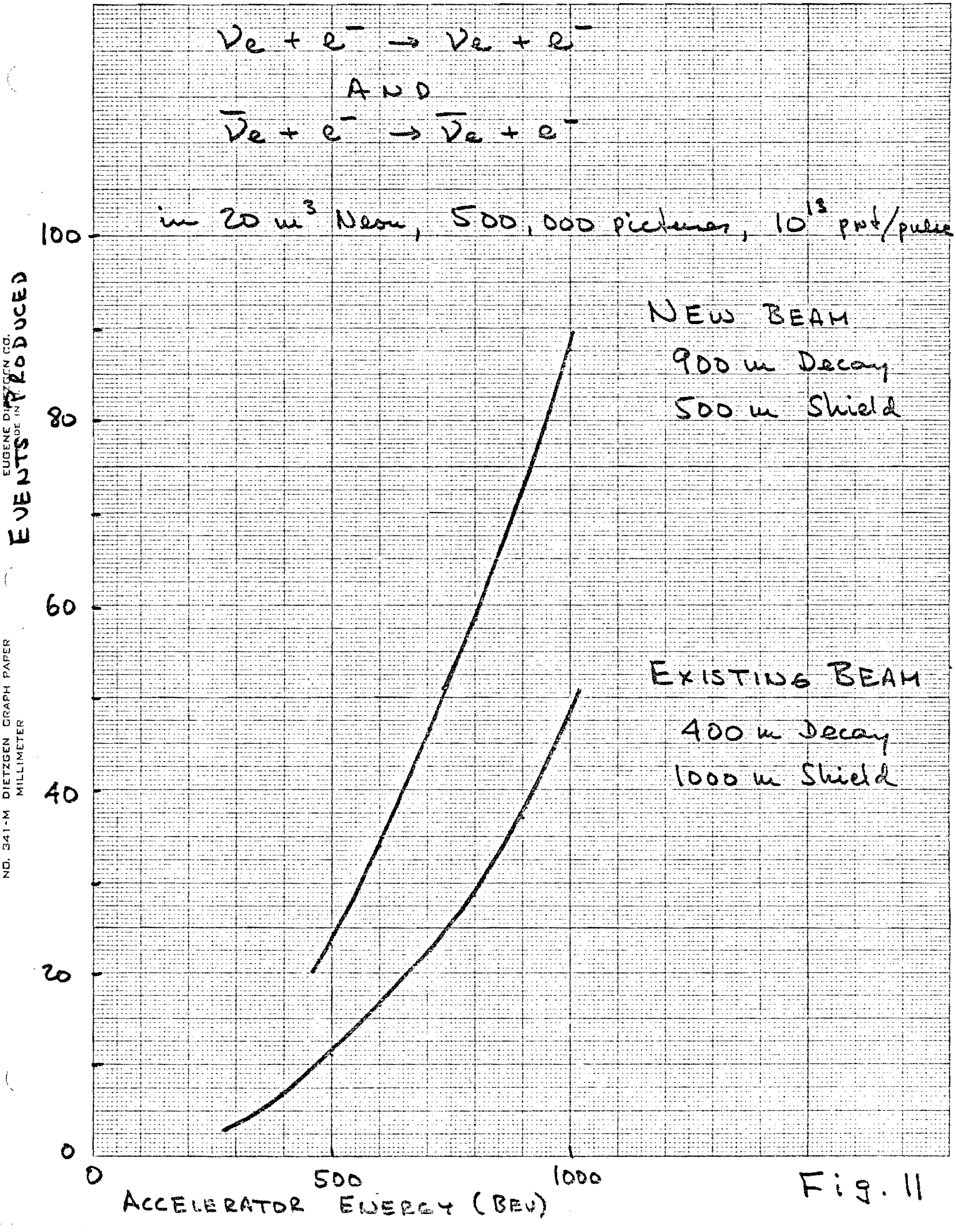
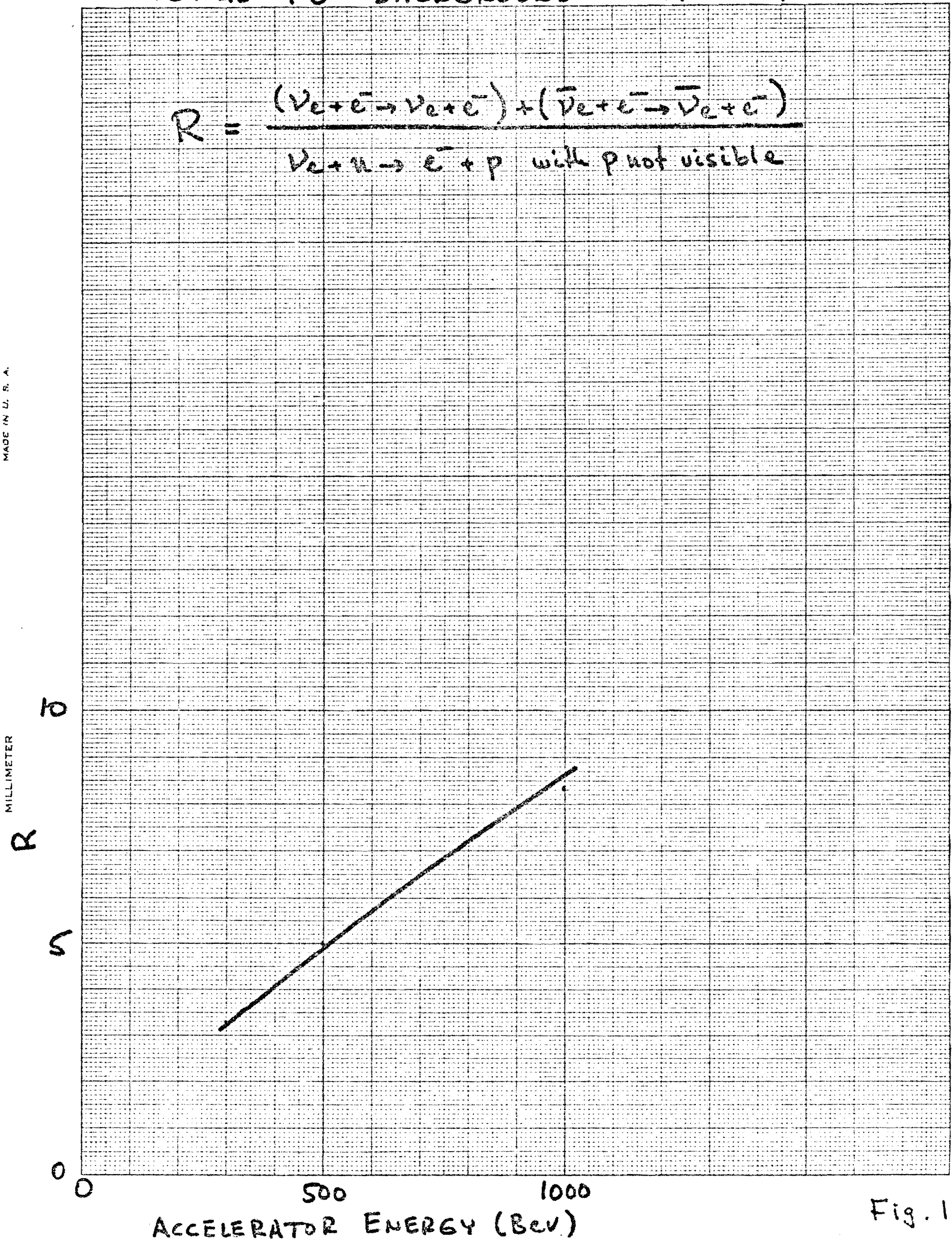


Fig. 11

SIGNAL TO BACKGROUND RATIO R



$$R = \frac{(\nu_e + e^- \rightarrow \nu_e + e^-) + (\bar{\nu}_e + e^- \rightarrow \bar{\nu}_e + e^-)}{\nu_e + n \rightarrow e^- + p \text{ with } p \text{ not visible}}$$

Fig. 12

Electron Neutrino Beams

Charles Baltay
Columbia University

and

Byron Roe
University of Michigan

I. INTRODUCTION

In the past, neutrino beams produced at high energy accelerators consisted predominantly of muon neutrinos, produced in the dominant $\pi^{\pm}\rightarrow\mu^{\pm}\nu_{\mu}$ and $K^{\pm}\rightarrow\mu^{\pm}\nu_{\mu}$ decays. The electron neutrino content of the beams were of the order of $\nu_e/\nu_{\mu}\approx 1/200$. For this reason the interactions of electron neutrinos have not been subjected to quantitative study.

We propose here an electron neutrino beam where the neutrinos are produced in the neutral K decays $K^{o}\rightarrow\pi+e+\nu_e$. The charged $\pi^{\pm}$ and $K^{\pm}$ mesons are swept out by a dipole magnetic field so that the neutrinos from their decays are suppressed. The target, decay tube, muon shield, and neutrino detector could be the same as in the existing wide band neutrino beam. In such a beam the ν_e/ν_{μ} ratio would be about 1.4/1. Furthermore, the energy spectra of the four kinds of neutrinos, $\nu_e,\nu_{\mu},\bar{\nu}_e,\bar{\nu}_{\mu}$, would be essentially the same, and their relative fluxes would be very precisely known, since they all originate from the same K^{o}_{L} parents.

II. PHYSICS MOTIVATION

A. Test of universality by comparing the interactions

$$\nu_e+Z\to e^-+\Gamma \quad (1)$$

$$\nu_\mu+Z\to \mu^-+\Gamma \quad (2)$$

where Z is some target nucleus and Γ consists of hadrons. The comparison can be done both for specific final states Γ, and for the inclusive inelastic process where Γ represents the summation over all hadronic states. The neutrino detector used for this purpose must be able to detect electrons as well as muons with high efficiency and be able to uniquely distinguish e^+, e^-, μ^+ and μ^- from each other. A test of universality would include both a comparison of the cross sections for the two processes, and comparisons of detailed distributions and structure functions. It is therefore very important to observe the two reactions under identical experimental conditions, with similar energy spectra for the incident neutrinos, and with a well known relative ν_e/ν_μ flux.

B. Search for the diagonal four Fermion process

$$\nu_e+e^-\to\nu_e+e^- \quad . \quad (3)$$

This fundamental process has never been observed. It would be extremely interesting to detect this process and measure its cross section, or even to set an upper limit on its cross section. The cross section predicted for this process by the universal V-A theory is very small, $\sigma=1.5\times10^{-41}E_\nu$ cm^2/electron. Due to the smallness of this number, the experimental problems connected with distinguishing this process from background is very severe, and it is important to reduce the very large ν_μ background present in conventional wide band neutrino beams. This would be even more critical if neutral currents were to exist, allowing the process $\nu_\mu + e^- \rightarrow \nu_\mu + e^-$.

C. Comparison of the ν and $\bar{\nu}$ cross sections

$$\nu_e + Z \rightarrow e^- + \Gamma$$

$$\bar{\nu}_e + Z \rightarrow e^+ + \Gamma$$

and also the analogous processes with ν_μ and $\bar{\nu}_\mu$. These cross sections, especially for the muon neutrinos, might be done earlier in the wide band neutrino beams. The advantage of using the beam proposed here is that both the ν and $\bar{\nu}$ events are observed in the same experiment with identical ν and $\bar{\nu}$ fluxes and energy spectra. Thus many of the systematic biases are eliminated and more reliable cross section ratios can be obtained.

D. The neutrinos in this experiment are the products of strangeness changing (K) decays. If these neutrinos are for any reason different from the neutrinos produced in strangeness conserving (π) decays, then these differences could manifest themselves by different kinds of interactions that are seen in beams where the bulk of the neutrinos originate from π decays.

III. BEAM DESIGN

We list in Table I the π and K decays that are the sources of neutrinos at high energy accelerators. The product of the branching ratio of each decay times the relative content of the parent meson in the beam, serves as a rough guide to the contribution of each source to an unfocused neutrino beam. Focusing of the charged mesons toward the detector increases the neutrino flux originating from the decay of charged mesons by up to a factor of ten or so. It is apparent from Table I that sweeping out the charged $\pi^{\pm}$ and $K^{\pm}$ mesons would eliminate the bulk of the muon neutrinos, but would lose only a smallish fraction of the electron neutrinos (from $K^{\pm}$ decays).

The short lived K^{o}'s will decay predominantly into pions and thus will not contribute appreciably to the electron neutrino flux. These pions from K_s^{o} decay must also be swept out by the magnetic field so that they do not produce background muon neutrinos in the detectors. We are thus left with the K_L^{o} decays

$$K_L^{o} \rightarrow \pi^-+e^++\nu_e \qquad (4)$$

$$\rightarrow \pi^++e^-+\bar{\nu}_e \qquad (5)$$

$$\rightarrow \pi^-+\mu^++\nu_\mu \qquad (6)$$

$$\rightarrow \pi^++\mu^-+\bar{\nu}_\mu \qquad (7)$$

These decays will produce roughly equal intensities of the four kinds of neutrinos, with similar energy spectra.

The general layout of the electron neutrino beam could be the same as that of the existing wide band neutrino beam at NAL, i.e. 400 m long decay path and ~ 1000 m earth shield. In case the accelerator energy is increased to ~ 1000 BeV, the geometry of the wide band beam proposed for that energy, with a 800 to 900 m decay path, would be used. The only change necessary from the wide band beam is to replace the focusing horn on the target train with a dipole sweeping magnet with an inserted collimator.

A ±5 milliradian tapered collimator will transmit essentially all of the useful K^o's whose decays are the source of the desired neutrinos. All charged particles produced at the target, which is situated at the upstream end of the magnet and the collimator, can be deflected into the walls of the collimator (up to the full 500 BeV) by a 40 k gauss dipole field 10 meters long. The aperture of the magnet has to be 10 cm x 10 cm. The transverse momentum given the charged mesons is

$$\Delta p = .03 \text{ BeV/c} \times B \times \ell$$

where B is in k gauss, ℓ in meters. In 0.4 meters of 40 k gauss field, the particles acquire 1/2 BeV/c of transverse momentum. For a 200 BeV particle, this corresponds to an angular deflection of ~ 2 1/2 mrad. The detectors subtend typically ~ 1 1/2 mrad at the target. Thus the typical decay path in which a charged meson has to decay to put a neutrino into the detector is of the order of 0.4 meters, instead of the 400 m of decay path in the wide band beam. Furthermore, the detector subtends a smaller solid angle at the target, near to which the 0.4 m decay path is, then it does at the rest of the 400 m decay path. Thus the reduction in ν_μ flux from charged meson decay should be between 10^{-3} and 10^{-4} relative to an unfocused spectrum, or 10^{-4} to 10^{-5} relative to the usual horn focused wide band ν_μ spectrum. Thus it should be possible to reduce the muon neutrino contamination from charged meson decay in the electron neutrino beam to a few percent.

Another source of muon neutrinos, as mentioned above, is the decay of $\pi^\pm$ produced in K_s^o decays. To esstimate the magnitude of this background, we consider 200 BeV/c K^o decays. The mean free path of $K^o{}_L$ is

$$\lambda_{K_L^o} = (\frac{p}{m})\tau c = 7200 \text{ m}$$

so that 400/7200 = 1/18 of the K_L^o decay in the 400 m decay path. Essentially all of the K_s^o will decay producing a 100 BeV/c π^+ each on the average. The mean free path of such a π^+ is ~ 5500 m, so that 400/5500 or ~ 1/14 will decay in the 400 m decay path. We thus have ν_μ from K_s^o decay/ν_e from $K^o{}_L$ decay ~(1/14)/(1/2 x .39 x 1/18). Such a background is too high and must be reduced by a factor of ~ 100 or so by sweeping the K_s^o decay products out of the beam. This can be easily done by a relatively weak, ~ 10 k gauss, field. The length of the field is determined by the K_s^o mean free path. Calculating again for 200 BeV/c K's, $\lambda_{K_s^o} \approx 12$ meters. We thus need ~60 meters of field, i.e. 50 meters of ~ 10 k gauss field in addition to the 10 meters of 40 k gauss field. The aperture of such a magnet, which would no doubt be built in segments, would have to vary from 10 cm x 10 cm to 50 cm x 50 cm. Fig. 1 shows a sketch of such a beam.

IV. ESTIMATE OF THE ν_e FLUX

The ν_e flux should be calculated by Monte Carlo techniques in a manner similar to that used for the wide band ν_μ fluxes. Not having the facility to do such a calculation, we made a rough estimate using the wide band ν_μ fluxes calculated by Nezrick for 500 GeV incident protons. We start with the unfocused spectrum for ν_μ from the decay $K^+ \to \mu^+ + \nu_\mu$ and estimate the ratio

$$R = \frac{\nu_e \text{ flux from } K_L^o \to \pi^- e^+ \nu_e}{\nu_\mu \text{ flux from } K^+ \to \mu^+ \nu_\mu} \quad .$$

The following considerations enter:

(a) We assume equal number of K^+ and K^o produced in the target, with the same angular and momentum distributions.

(b) The energy of the neutrino in the laboratory is

$$E_\nu = \gamma(E_\nu^* + \beta P_\nu^* \cos\theta)$$

$$= \gamma E \ (1+\beta\cos\theta)$$

where E_ν^*, P_ν^* are the energy and momentum of the neutrino in the K meson rest frame. In $K^+ \to \mu^+\nu_\mu$ decay, $E_\nu^* = 236$ MeV. In the $K_L^o \to \pi^- e^+ \nu_e$ decay, the average $E_\nu^* \approx 2/3 \times 229$ MeV. Thus

$$E_{\nu_e}/E_{\nu_\mu} = \frac{\gamma(2/3 x 229)(1+\beta\cos\theta)}{\gamma(236)(1+\beta\cos\theta)} \approx 2/3 \quad .$$

We thus reduce the energy of the ν_μ from $K^+ \to \mu^+\nu_\mu$ by 2/3 to estimate the ν_e lab energy.

(c) The ratio of lifetimes is

$$\frac{\tau_{K^+}}{\tau_{K^o}} = \frac{1.23 \times 10^{-8}}{5.18 \times 10^{-8}} \sim 1/4 \quad .$$

(d) The branching ratios are

$$\frac{K^+ \to \mu^+ + \nu_\mu / \text{all } K^+ \text{ decays}}{K_L{}^o \to \pi e \nu / \text{all } K_L{}^o \text{ decays}} = \frac{0.64}{0.39} \quad .$$

(e) We assume that the $\bar{K}^o$ production is ~ 1/3 of the K^o production. Thus $K^o + \bar{K}^o$ is 4/3 the K^+ production. One-half of $(K^o+\bar{K}^o)$ decay as $K_L{}^o$, and of these, one-half give ν_e and one-half give $\bar{\nu}_e$. The product of these factors is 1/2 x 1/2 x 4/3 = 1/3 .

Combining the above, we get

$$R = \frac{1.23}{5.18} \times \frac{0.39}{0.64} \times 1/3 \approx 0.05 \quad .$$

We thus take the ν_μ spectrum from $K^+ \to \mu^+ \nu_\mu$ decays in an unfocused beam (see curve on Fig. 2), reduce it by the factor R, reduce the energy by $E_{\nu_e}/E_{\nu_\mu} = 2/3$ and renormalize, and obtain the ν_e spectrum shown in Fig. 2. This spectrum peaks around $E_{\nu_e} \sim 100$ GeV and has a flux of $10^5\ \nu_e/\text{GeV}/\text{m}^2/10^{13}$ interacting protons at the peak. The $\bar{\nu}_e$ spectrum should be identical both in shape and normalization. The ν_μ flux from $K_L{}^o \to \pi^- \mu^+ \nu_\mu$ decays should have a similar spectrum, with a slightly lower intensity because of the different branching ratios

$$\frac{\nu_\mu}{\nu_e} = \frac{BR(K_L{}^o \to \pi\mu\nu)}{BR(K_L{}^o \to \pi e \nu)} = \frac{0.27}{0.39} = 0.7 \quad .$$

The $\bar{\nu}_\mu$ flux should be the same as the ν_μ flux.

We realize the roughness of this flux estimate and the need for a more careful calculation using Monte Carlo techniques. For example, for ease of calculation, we have here taken the energy of the neutrino in the center of mass of the $K^o \rightarrow \pi e \nu$ decay to be 2/3 the maximum value. The fact that these neutrinos have a broad energy distribution may seriously affect the low end of the resulting ν_e spectrum at the detector.

V. EVENT RATES

For the purpose of estimating event rates, we assume the cross sections for processes 1 and 2 to be $0.8 \times E_\nu \times 10^{-38}$ cm^2/nucleon, and the cross section for the corresponding antineutrino induced processes to be $\sigma_{\bar{\nu}} = 1/3\ \sigma_\nu$. For the purely leptonic processes $\nu_e + e^- \rightarrow \nu_e + e^-$ and $\nu_\mu + e^- \rightarrow \nu_e + e^-$, we use the V-A prediction of $1.5 \times E_\nu \times 10^{-41}$ cm^2/electron. We calculate the number of events produced in an experiment using a total of 10^{19} protons interacting in the neutrino target, and using a 20 ton neutrino detector with $Z/A \approx 1/2$.

One example of a possible detector of that mass is the 15 ft bubble chamber filled with liquid neon, using 20 m^3 (out of the total of 33 m^3) as a fiducial volume.

The numbers of events expected under these assumptions are summarized in Table II. We have also made a very rough estimate of these numbers for 1000 GeV incident protons.

The energy distribution of reaction 1 is shown in Fig. 3.

The major background to the process $\nu_e + e^- \rightarrow \nu_e + e^-$ is the semi-hadronic process

$$\nu_e + n \rightarrow e^- + p \tag{8}$$

when the proton is too slow to be detected. The cross section for this reaction is expected to be 0.75×10^{-38} cm^2, independent of E_ν. From experience in the CERN neutrino experiments, the proton is not detected 1/30 of the time in a bubble chamber. (This fraction is probably independent of the incident ν energy since it is mainly determined by the nucleon form factor.) Thus, at a mean neutrino energy of 100 GeV,

$$\frac{\nu_e + n \rightarrow e^- + p,\ \text{undetected proton}}{\nu_e + e^- \rightarrow \nu_e + e^-\ \text{expected}} \sim \frac{1}{30} \times \frac{0.75 \times 10^{-38}}{1.5 \times 10^{-41} \times 100} \sim 1/6$$

which is quite nice, thanks to the factor of 100 due to the high neutrino energy and the fact that the cross section for the purely leptonic process rises linearly with E_ν.

VI. CONCLUSIONS

The numbers of events expected (see Table II) allow a detailed test of unitarity by comparing ν_e and $\bar{\nu}_e$ induced semileptonic interactions with those induced by ν_μ and $\bar{\nu}_\mu$ in the same experiment. Also, the detection of the diagonal four fermion process $\nu_e + e^- \rightarrow \nu_e + e^-$ might be feasible, both from the point of view of the number of events produced and the relative smallness of the major background. Another measurement that will be possible is the ratio of the $\bar{\nu}_e$ and ν_e cross sections, as well as the ratio of the $\bar{\nu}_\mu$ to

ν_μ cross section, in a beam where the ν and $\bar{\nu}$ fluxes are equal and therefore their ratio is precisely known.

The last point is worth reemphasizing. In the beam discussed here, we have the four kinds of neutrinos with precisely known relative fluxes:

$$\frac{\bar{\nu}_e}{\nu_e} = \frac{\bar{\nu}_\mu}{\nu_\mu} = 1.0$$

$$\frac{\nu_e}{\nu_\mu} = \frac{\bar{\nu}_e}{\nu_\mu} = 1.44 \quad .$$

The energy spectra of the neutrinos and antineutrinos must be the same, and the spectra of electron and muon neutrinos are very similar since all of the neutrinos originate from the decays of the same K_L^o parents. This knowledge of the flux ratios is crucial in both the unitarity test and the antineutrino - neutrino cross section ratio measurements.

TABLE I

Sources of Neutrinos

Decay	Relative Content of Parent Meson in Beam	Decay Branching Ratio	Relative Contribution to ν Beam
$\pi^+ \rightarrow \mu^+ \nu_\mu$	1.0	1.0	1.0
$\pi^- \rightarrow \mu^- \bar{\nu}_\mu$	0.4	1.0	0.4
$K^+ \rightarrow \mu^+ \nu_\mu$	0.15	0.64	0.10
$\mu^+ \pi^0 \nu_\mu$		0.03	0.005
$e^+ \pi^0 \nu_e$		0.05	0.008
$K^- \rightarrow \mu^- \bar{\nu}_\mu$	0.05	0.64	0.03
$\mu^- \pi^0 \bar{\nu}_\mu$		0.03	0.002
$e^- \pi^0 \bar{\nu}_e$		0.05	0.003
$K^0 \rightarrow \pi^- \mu^+ \nu_\mu$	0.15	0.27	0.05
$\pi^- e^+ \nu_e$		0.39	0.06
$\bar{K}^0 \rightarrow \pi^+ \mu^- \bar{\nu}_\mu$	0.05	0.27	0.015
$\pi^- e^+ \bar{\nu}_e$		0.39	0.02

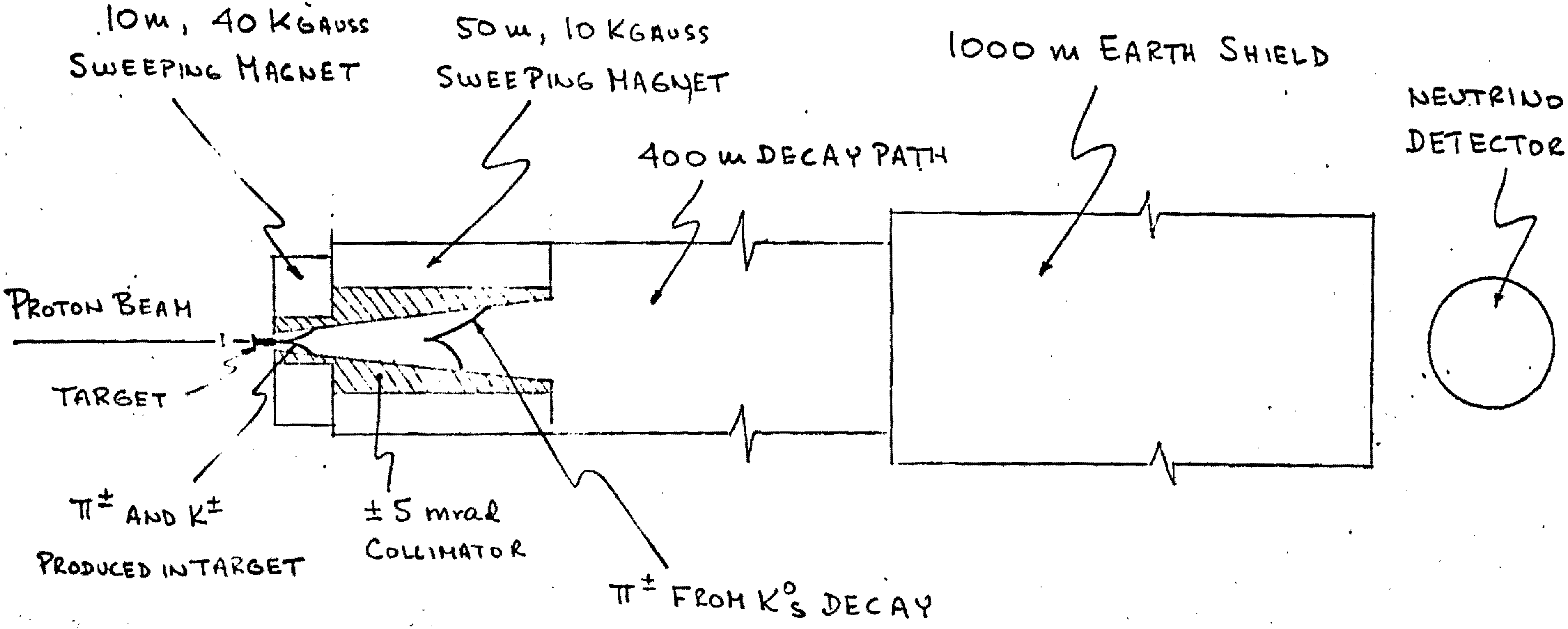
TABLE II

Numbers of Events Produced by the ν_e Beam

Calculate for: 10^{19} protons
20 ton detector
$\sigma_\nu = 0.8 \times 10^{-38}\ E_\nu\ \text{cm}^2/\text{nucleon}$
$\sigma_{\bar{\nu}} = 1/3\ \sigma_\nu$

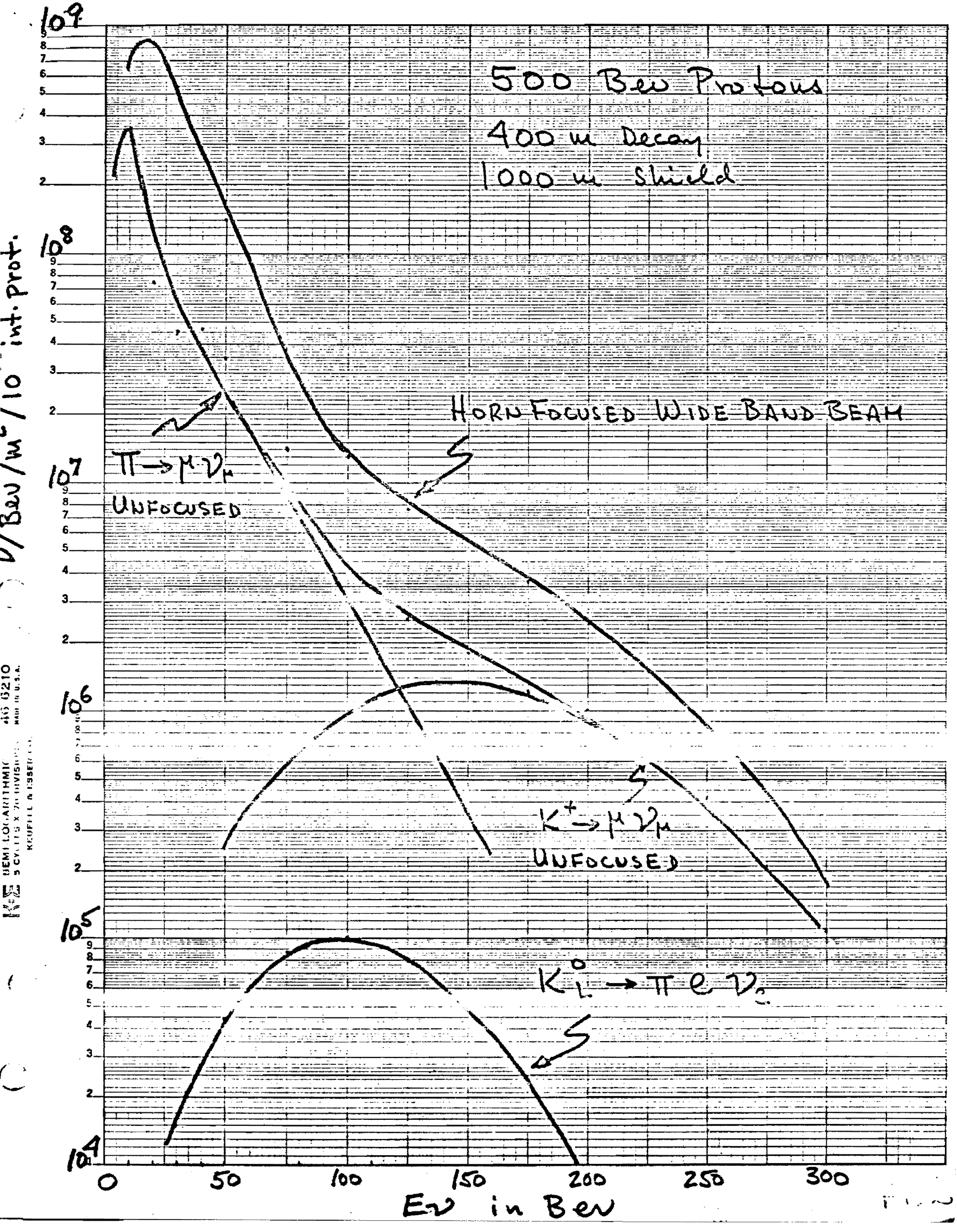
Reaction	500 GeV	1000 GeV
$\nu_e + N \rightarrow e^- +$ hadrons	16,000	50,000
$\nu_\mu + N \rightarrow \mu^- +$ hadrons	11,000	33,000
$\bar{\nu}_e + N \rightarrow e^+ +$ hadrons	5,000	15,000
$\bar{\nu}_\mu + N \rightarrow \mu^+ +$ hadrons	3,700	11,000
$\nu_e + e^- \rightarrow \nu_e + e^-$	16	50
$\nu_\mu + e^- \rightarrow \nu_e + \mu^-$	16	50

ν_e BEAM



NOT TO SCALE

FIG. 1.


500 Bev Protons
400 m Decay
1000 m Shield
HORN FOCUSED WIDE BAND BEAM
π → μ ν_μ
UNFOCUSED
K⁺ → μ ν_μ
UNFOCUSED
K°_L → π e ν_e
ν/Bev/m²/10 int. prot.
Eν in Bev
10⁹
10⁸
10⁷
10⁶
10⁵
10⁴
0
50
100
150
200
250
300

NUMBER OF $\nu_e + N \to e^- +$ hadrons in

20 ton detector

10^{19} interacting protons

500 Bev protons

400 m Decay, 1000 m shield

$\sigma = 0.8 \times 10^{-38}\ E_\nu$

16,000 events total