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Spokesman: E.H.S. Burhop

University College London
Telephone 01-387 7050, ext. 372
Telex 28722

Proposal to search for short-lived particles produced in neutrino interactions in emulsion using an emulsion - spark chamber hybrid system

by

G. Coremans-Bertrand, J. Sacton, P. Vilain
University of Brussels, Belgium

A. Breslin, A. Montwill
University College Dublin, Ireland

L. Read, R. Stefanski,** L. Voyvodic
Fermi National Accelerator Laboratory, USA

E.H.S. Burhop, D.H. Davis, F.R. Stannard+, D.N. Tovee
University College London, UK

G. Baroni, C. Bernardini, G. Brosco, F. Ceradini, M. Conversi, M.L. Ferrer*, S. Di Liberto, S. Petrera, G. Romano, R. Santonico
University of Rome, and Sezione di Roma dell'INFN, Rome, Italy

G. Bassompierre, M. Jung, R. Klein≠, N. Kurtz, M. Paty, F.M. Schmitt≠, M. Schneegans
Centre de Recherches Nucleaires, University Louis Pasteur, Strasbourg, France

+ Open University, Milton Keynes, UK

* supported Academia Nazionale dei Lincei, Rome, Italy

≠ ISEA, CUHR, Mulhouse, France

** Coordinator with E-310; a sub-group of E-310 is also likely to participate in this experiment.

1. INTRODUCTION

Short lived particles of two kinds that could have lifetimes between 10^{-11} and 10^{-15} s have been postulated - heavy leptons and charmed hadrons. Many different models have been introduced which incorporate heavy leptons or charmed particles and only experiment can decide the extent to which they represent the real world. Limitations of spatial resolution make it impossible to detect directly the existence of such particles using bubble chambers except under special circumstances near the upper end of the above lifetime range. The spatial resolution available using emulsions however enables unstable particles of lifetimes down to 10^{-14} s to be detected readily, while under favourable conditions this limit could be extended down to 3×10^{-15} s or even lower.

1.1 Charmed Particles

The non-observance of the strangeness non-conserving neutral current decay, $K_L \rightarrow \mu^+\mu^-$, cannot be understood in terms of three-quark models of hadron structure[1]. A fourth quark carrying a new property called 'charm' has been proposed to overcome this difficulty, leading to a new type of hadron endowed with a new quantum number written C, the 'charm'[2, 3].

The recently observed narrow ψ resonances[4, 5, 6] at 3.1 GeV and 3.7 GeV have been attributed to mesons which, although themselves not possessing the property of charm, are composed predominantly of charmed quark and antiquark constituents, just as the ϕ meson is thought to be composed predominantly of strange quark and antiquark constituents. If this interpretation is correct, the ψ particles could decay by strong interaction processes into a pair of charmed mesons. The width of the ψ resonances is that characteristic of electromagnetic transition processes so that one can conclude that the decay to a pair of charmed mesons is inhibited on energetic grounds, implying a charmed meson mass above 1.85 GeV. On the other hand, if the observed structure around 4.1 GeV in the SLAC experiment can be attributed to a broad resonance it could suggest a charmed meson mass around 2 GeV.

The possible properties of charmed particles have been discussed by M.K. Gaillard et al[7]. The lowest lying charmed (C = 1) baryon states are expected to form an isospin singlet, C_0^+, and a triplet, C_1^{++}; C_1^+, C_1^0. These have strangeness 0. The lowest lying charmed meson states form the doublets (D^+, D^0) and (D^-, $\bar{D}^0$) with C = +1, -1, respectively and zero strangeness; and the two singlet states, F^+, F^- with C, S = (1, -1) and (-1, 1) respectively.

The threshold for charmed baryon production seems likely to be lower than that for charmed meson production. The production processes in neutrino interactions would be:

$$\nu + p \rightarrow C_1^{++} + \mu^- + \text{hadrons}$$

$$\nu + n \rightarrow C_1^{+} + \mu^- + \text{hadrons}$$

$$\text{or } C_0^{+} + \mu^- + \text{hadrons}$$

Provided the masses of the particles involved make it energetically possible the most probable process for charmed meson production would then arise from charmed baryon decay in the processes:

$$C_1^{++} \rightarrow \Sigma^+ + F^+$$

$$C_1^{+} \rightarrow N + D^+ \qquad \text{or } \Sigma^0 + F^+$$

$$C_1^0 \rightarrow N + D^0 \quad \text{or} \quad \Sigma^- + F^+$$

$$C_0^+ \rightarrow N + D^+ \quad \text{or} \quad \Lambda^0 + F^+$$

If the mass relations between members of charmed multiplets are similar to those familiar from SU_3, one might expect C_1^{++} to have the lowest mass of the C_1 triplets, so that it could happen that while C_1^+, C_1^0 could decay promptly to D, F, through a strong interaction process, the same process could be inhibited for C_1^{++}. The C_1^{++} would then decay through the weak processes:

$$C_1^{++} \rightarrow \mu^+ + p + \nu_\mu$$
$$\text{or} \quad e^+ + p + \nu_e$$

Assuming the coupling constant for charmed particle decays to be equal to the Fermi constant, G_F, the lifetime of the charmed baryon, C_1^{++}, would be expected to be:

$$\tau \approx 10^{-11} (M_N/Q)^5 \ \text{sec},$$

with $Q = M_C - M_N$, M_C, M_N being respectively the charmed baryon and nucleon masses.

The charmed mesons D^+, D^0, whether produced directly or following the decay of a charmed baryon, would be expected to decay to leptons or hadrons in the following predominant processes:

(i) leptonic:

$$D^+ \rightarrow \bar{K}^0 + e^+ + \nu_e \quad \text{or} \quad \bar{K}^0 + \mu^+ + \nu_\mu$$

$$D^0 \rightarrow K^- + e^+ + \nu_e \quad \text{or} \quad K^- + \mu^+ + \nu_\mu$$

(ii) hadronic:

$$D^+ \rightarrow K^- + \pi^+ + \pi^+$$

$$D^0 \rightarrow K^- + \pi^+ \qquad \text{or} \quad \bar{K}^0 + \pi^- + \pi^+$$

with a branching ratio of about 13 per cent for leptonic decays, 87 per cent for hadronic decays.

Strangeness-changing hadronic decays of charmed mesons are associated with the cosine of the Cabibbo angle and hence favoured relative to those not involving a change of strangeness.

Again assuming the Fermi constant, G_F, to be relevant to such decays, the lifetime of charmed mesons, D^+, D^0 of mass M_C, is expected to be $\tau \simeq 10^{-11}(M_N/M_C)^5$. If $M_C \simeq 2$ GeV/c^2 as speculated above, $\tau \simeq 3 \times 10^{-14}$ s, corresponding to a flight path of 10 μm for particles moving with velocity c. Flight paths of this magnitude before decay should be readily observed in nuclear emulsion. Such estimates of lifetime are very speculative but at least it can be said that charmed particle lifetimes in the range covered by this proposal are feasible.

The estimated cross-section for charmed baryon production depends on whether there is an appreciable strange parton constituent in the nucleon. Studies of deep inelastic scattering of electrons and neutrinos by nucleons give an upper limit of 10 per cent for this strange parton constituent. This would correspond to an upper limit of the ratios:

$$\frac{\sigma_c^\nu}{\sigma_{tot}^\nu} < 0.16 \qquad , \qquad \frac{\sigma_c^{\bar{\nu}}}{\sigma_{tot}^{\bar{\nu}}} < 0.35$$

where σ_c^ν is the cross-section for charmed baryon production and σ_{tot}^ν the total neutrino interaction cross-section. If the strange parton constituent of the nucleon is zero:

$$\frac{\sigma_c^{\nu}}{\sigma_{tot}^{\nu}} \approx \tan^2\theta_c \simeq 0.04, \qquad \frac{\sigma_c^{\bar{\nu}}}{\sigma_{tot}^{\bar{\nu}}} \approx 0.005.$$

In this case then, a sample of 500 ν interactions would contain 20 cases of charmed particles of which 3 would decay leptonically and 17 hadronically. These figures refer to estimates of upper limits that might be valid for very high energy neutrinos. A typical topology of such events is illustrated in Figure 1.

Fourteen cases of di-leptonic production were observed in the 1A experiment[8] but it is difficult to establish whether or not these are cases of charmed particle production. It could result from charmed baryon (C^{++}) production (Figure 1a), or from charmed meson production (D^{+}, Figure 1b; D^{0}, Figure 1d). A similar signature could however also imply production of the intermediate charged vector boson, $W^{\pm}$ (Figure 1f). Again the decay of a neutral heavy lepton, M^{0} (Figure 1h) would give a similar signature. The emulsion is the only technique that could establish definitely in di-leptonic events whether one of the leptons is the decay product of a particle with lifetime in the range 3×10^{-15} s $< \tau < 3 \times 10^{-11}$ s, thus greatly facilitating their interpretation.

1.2 Heavy Leptons

Renormalizable gauge theories[9] that unify weak and electromagnetic interactions require the postulation of neutral weak currents or of heavy leptons, or both. Evidence for the existence of neutral weak currents, both leptonic and hadronic, has been obtained recently but heavy leptons have not yet been found.

Corresponding to the two types of neutrino, ν_e, ν_μ, heavy electrons, E, and heavy muons, M, have been postulated[9] with decay modes:

$$M^+ \rightarrow \nu_\mu + \nu_\mu + \mu^+ \qquad M^0 \rightarrow \mu^+ + \mu^- + \bar{\nu}_\mu$$

$$\nu_\mu + \nu_e + e^+ \qquad \mu^+ + e^- + \bar{\nu}_e$$

$$\nu_\mu + \text{hadrons} \qquad \mu^- + \text{hadrons}$$

with parallel decay modes for the heavy electrons, E.

Once again, the decay rate would be expected to increase proportionately to M_L^5, M_L being the heavy lepton mass. Bjorken and Llewellyn-Smith[9] have estimated lifetimes for the mass range 2 - 5 GeV which are given in the table below:

M_L (GeV)	τ (sec)	cτ (μm)
2	3×10^{-13}	90
3	4×10^{-14}	12
4	1×10^{-14}	3
5	3×10^{-15}	1

A transition rate 3×10^{14} sec^{-1} corresponds to a heavy lepton mass of 5 GeV/c^2.

Heavy leptons should be produced in the fast neutrino reactions

$$\nu_\mu + N \rightarrow M^+ + \text{hadrons}; \qquad \nu_e + N \rightarrow E^+ + \text{hadrons}.$$

Typical topologies of such interactions are shown in Figure 1 g, h.

Such heavy leptons of the Bjorken-Glashow type could be identified by the emission of a 'wrong sign' ordinary lepton from the neutrino interaction.

The non-observance of such 'wrong sign' leptons in neutrino interactions led Barish et al[10] to place a lower limit of 8 GeV for the masses of Bjorken-Glashow heavy leptons. Other short-lived objects, distinct from heavy leptons associated with renormalizable gauge theories, have also been postulated and these might be produced in neutrino interactions. Thus, heavy leptons, h^0, h^+ with decay processes

$$h^0_\mu \rightarrow \pi^+ + \mu^- \quad \text{or} \quad \pi^0 + \nu_\mu \; ; \quad h^\pm \rightarrow \mu^\pm + \gamma \quad \text{or} \quad \mu^\pm + \pi^0$$

$$h^0_e \rightarrow \pi^+ + e^- \quad \text{or} \quad \pi^0 + \nu_e \; ; \quad h^\pm_e \rightarrow e^\pm + \gamma \quad \text{or} \quad e^\pm + \pi^0$$

have been proposed[11, 12]. The mass limit of Barish et al would not apply to such objects.

The emulsion is the only technique that could detect any such objects directly if their lifetimes lie in the range indicated in this paper.

2. OBSERVATION OF NEUTRINO INTERACTIONS IN NUCLEAR PHOTOGRAPHIC EMULSION

Nuclear photographic emulsion detectors have by far the highest spatial resolution of any particle detector. They can resolve events separated in space by a few μm. A particle travelling with the velocity c will traverse 1 μm in a time of 3×10^{-15} s, so that short-lived particles of mean life of the order 10^{-15} s should be capable of direct detection using this technique.

Neutrino interactions in nuclear emulsions have been located successfully[13] by observing secondary particles (usually muons) in a spark chamber accurately located relative to a photographic emulsion stack and following them back to their origin in a neutrino interaction in the emulsion.

With the more intense and more energetic beams of neutrinos now available at Fermilab it is proposed to repeat the experiment, aiming to obtain 500 interactions in a block of emulsion of volume 20 liters.

3. EXPECTED RATE OF NEUTRINO INTERACTIONS

Interaction rates expected for neutrinos from the wide-band beam and based on experience with experiment 1A have been given by Benvenuti et al in the proposal they have submitted for Experiment 310 (see 5/31/74). For 10^{17} protons of energy 400 GeV on beam target and employing the 2-horn arrangement, they estimate (Table IV) for the number of neutrino interactions in a target of mass 3.5 x 10^5 kgm:

(i)	$\nu_\mu + N \rightarrow \mu^- +$ hadrons	100,400 events
(ii)	$\nu_\mu + N \rightarrow \nu_\mu + N$	10,040 events.

Assuming 2 x 10^{18} protons in an exposure spread over a 6-week period of an emulsion stack of volume 20 litres (78 kgm) we obtain then the following estimates of the expected numbers of reactions:

(i)	Charged current reactions:	
(ii)	Neutral current reactions:	45

or a total of approximately 500 ν interactions in all. For the $\bar{\nu}$ beam this number would be reduced by a factor of about 3.5.

From the estimates of Section 1, assuming the existence of charmed quarks, the number of events in which charmed mesons are produced in such a sample would be expected to be between 18 and 72.

We can also evaluate, by assuming scaling and the lower bound computed by Llewellyn-Smith[14], the fraction of these events corresponding to production of heavy leptons of a given mass M_L. Detailed calculations and the approximations used are given in Appendix I. Figure 3 shows the results for the assumed neutrino spectrum shown in Figure 2.

4. GENERAL DESCRIPTION OF THE APPARATUS

The apparatus which it is proposed to use for the location of neutrino interactions in emulsion is shown schematically in Figure 4. The apparatus consists of the following parts:

A. To Locate the Neutrino Interactions:

(1) The 'emulsion stack', ES, in which the details of the interactions produced by the incoming neutrinos are observed and the decay of unstable particles with lifetimes greater than about 3×10^{-15} s can be detected.

(2) A system of two 'wide gap' spark chambers, WG, in which the charged secondaries of the neutrino interactions are seen as thin, bright tracks that in general allow one to localise the positions at which secondaries leave the stack, to give their direction and to determine a small fiducial region around the interaction point in ES.

(3) 'Veto' counters, V, and a narrow gap spark chamber, SC1, which are placed before ES in order to ensure that the observed events are actually produced by neutral particles. These veto counters also reject some cosmic ray muons.

B. To Enable the Analysis of Secondary Products of the Interactions

(4) The muon spectrometer of experiment 310. The use of these magnets will enable the sign and momenta of muons emerging from neutrino interactions in the emulsion to be determined.

(5) The hadron calorimeter of experiment 310. This will enable the energy in the hadronic component of the secondaries from the neutrino interactions to be estimated.

(6) Shower Detector, SD, to enable the electrons emitted in the decay of short-lived particles to be detected and to have their energies estimated.

In addition, the scintillation counters A and B are included as part of the system for triggering the spark chambers. In between these counters is located the shower detector (SD). The WG chambers would then be triggered by master coincidences of two types, viz:

(1) $ABMS\overline{V}$, to detect interactions produced in the emulsion stack by neutral primaries coming from the neutrino beam direction and with a fast muon among the secondary products.

(2) $A(SD)M\overline{V}$, to detect similar interactions having a fast electron among secondary products.

Here, M is a signal from the accelerator, S a signal from one of the counters of the experiment 310 arrangement. Depending on the particular counter chosen and the amount of matter between counters A and S the energy demanded of the fast muon can be varied. A typical value could be 1.5 GeV. (SD) is a signal from the shower detector.

The apparatus of the present experiment would be located immediately upstream of the apparatus of experiment 310. The maximum angle of emergence of a muon that could be analysed would be 12°. Figure 5 shows a schematic diagram of experiment 310 apparatus showing the location of the equipment for the present experiment.

In order to make use of the analysis system of experiment 310, it will be necessary to arrange for the triggering of the drift chambers by the same master pulse that triggers the wide gap chambers of the present experiment. It is anticipated that the counting rate will be about 1 per 400 machine pulses.

The spurious trigger rate due to cosmic rays is expected to be very small since we require that the events occur in coincidence with the signal M of the machine and the latter will operate with short spill-out time.

5. THE EMULSION STACK AND ITS MOUNTING

The volume of emulsion used is determined by a compromise between cost on the one hand and the need to examine a meaningful number of interactions. To obtain about 500 neutrino interactions for 2×10^{18} protons incident on target would require a volume of about 20 litres costing approximately $70,000.

It is proposed that the emulsion should be in the form of six stacks, each consisting of 333 pellicles 20 x 8.3 cm in surface dimensions and 0.6 mm thick. The pellicles in each stack would be clamped together to form a block of emulsion of volume 20 x 20 x 8.3 cm^3. The dimension is kept down to 8.3 cm in the direction of the beam. Narrowing the stack in this direction reduces the time required to find an event.

Figure 6 shows how the stacks will be mounted on a plate. Each stack will be located on the plate by means of dowel pins. Figure 7 shows the clamp used for holding each stack. The design permits the milling of the sides of the stack after assembly. Fiducial marks are provided on the base of each clamp and the distances between the milled sides of the emulsion and the fiducial marks will be measured prior to sealing the emulsion by wrapping in black tape.

Provision has to be made for removing the emulsion during beam adjustment if there should be any danger of spraying of the stack with stray hadrons. Since the total weight to be removed will weigh approximately 100 kg, this operation will require care.

Two perpendicular views of the spark chambers and emulsion stack will be photographed and recorded side by side on the film. Each view will show the sparks and the fiducial marks on the stack assembly. In principle then it is less important to ensure that the emulsion stack assembly should be returned to precisely the same place after removal. It is proposed to locate the plate to which the emulsion stacks are clamped, relative to another plate, also carrying fiducial marks. Any errors of relocation of the emulsion assembly would be evident from comparing the fiducial marks on the two plates (see Figure 6).

If the stack has to be milled in Europe it will need to be transported to the USA by ship to avoid contamination of the stack by the high cosmic ray background of a high altitude jet flight. If the stack could be assembled and milled at FNAL the emulsion could be flown from Europe and the plates shuffled before assembly, thus avoiding confusion from cosmic ray tracks that would follow through the whole stack from one emulsion pellicle to another.

After exposure the stack would be taken apart after numbering of the plates. They would then be shuffled before being flown to CERN where a grid would be photographed on to the individual pellicles to facilitate locating events and following from pellicle to pellicle. It is intended to process the stack using the facilities available at CERN. We return to the discussion of the cosmic ray background in Section 8.

6. SPARK CHAMBERS

With the event counting rate expected, simple multigap optical spark chambers should be quite satisfactory. For the event reconstruction however we need a chamber allowing the measurement of tracks over a sufficient length and with a good multitrack efficiency. Wide gap chambers have better spatial resolution than ordinary spark chambers. Furthermore, they can record up to 50 or more tracks per event. Radiofrequency interference can be avoided by double shielding of the wide gap chamber. A wide gap chamber with two gaps each of separation 15 cm is proposed (WG). For high energy events the multiplicity may be high and there may be some overlapping of secondaries beamed forward so that the distance between the emulsion and WG should be optimised in order to obtain at the same time a satisfactory precision (better than 0.3 mm) in the determination of the position at which the particles leave the emulsion and a good separation of the tracks at their point of entry into WG. The geometry shown in Figure 3 should enable this to be achieved.

7. SHOWER DETECTOR

Figure 8 shows the design of the shower detector. It is of modular type, made of 4 identical moduli. Each modulus - of dimensions

90 cm x 90 cm - consists of a 1 cm thick Pb plate, followed by a 2 cm thick plastic scintillator and by a double wide-gap spark chamber, with two 10 cm gaps. Each plastic scintillator is viewed by four photomultipliers. The chambers are sensitized by a trigger pulse which involves a signal from the photomultipliers in excess of a certain threshold. The same pulse is used to trigger the main wide gap spark chambers on high energy electron secondaries.

The detector has a total thickness of 1 m and contains about 70 gm/cm^2 of material (mostly lead) which should not interfere seriously with measurements of the muon momentum, and will give only a small correction to the estimate of the energy of the hadronic component using the calorimeter of experiment 310. At the same time it corresponds to about 9 radiation lengths and the efficiency of the detection for high energy electrons is very high.

The system selects high energy electrons on the basis of the large counter pulses associated with the development of the electromagnetic cascade, and yields an unambiguous recognition of the latter by direct observation in the track chambers, which detect many-particle events with good efficiency.

Bremsstrahlung losses suffered by $e^{\pm}$ electrons in the emulsion stack do not lead to any appreciable loss of events through deviations of the initial $e^{\pm}$ direction, since these deviations are of order $mc^2/E_e << 1$ mr, (mc^2 = electron rest energy; E_e = total energy of $e^{\pm}$).

High energy background photons can contribute of course to the trigger rate and even simulate 'good' events. In particular neutral pions produced in the ν_{μ} interactions can give rise, via γ ray conversion in the emulsion stack, to single tracks in the wide gap chambers (non-resolved e^+e^- pairs) followed by the development of the electromagnetic cascade in the shower detector. These background effects are now being estimated.

8. THE PROCEDURE FOR LOCATING NEUTRINO INTERACTIONS

The interactions may be located by line scanning along a track seen in the spark chamber as emerging from the stack. This technique was used in the earlier work. It ceases to be viable in the presence of a large muon background. The spark chamber enables the location of the exit point of a particle from the emulsion stack to within approximately 0.3 mm and its direction to within about 0.2^{o}. A muon background such that there are more than five possible candidate tracks in this area and in the right direction would be unacceptable on account of the time required to follow spurious tracks through the emulsion. It is estimated that the time required to find an event by this method could be 7.5 scanner days.

Alternatively, however, interactions may be located by area scanning of a cylinder of emulsion of cross-sectional area about 4 mm^2 and length equal to the thickness of the stack. For a stack of thickness 8 cm, this would involve area scanning of an area 80 x 2 mm^2 on each of four plates, i.e., an area of the order 6 cm^2, a task which a competent scanner should be able to accomplish in two days.

In many cases two or more tracks from a given neutrino interaction will be located by the wide gap spark chamber. In such cases it should be possible to locate the interaction within a cross-sectional area of 5 mm^2 and a depth of 20 mm. Finding the interaction would then involve scanning an area 20 x 2.25 mm^2 on each of four plates, i.e., an area of 1.8 cm^2 in all, yielding 1 event per 0.7 scanner days.

If an area scanning technique is used to locate neutrino interactions a very much larger muon background should be tolerable since the following of tracks through from one emulsion pellicle to another is not involved in finding the interaction. The tolerable muon background limit could then be set by the memory time of the spark chambers used for location of the secondary tracks from neutrino interactions. Typically this time is of the order of 10^{-6} s. Supposing in the whole experiment we need 2×10^{5} pulses and the spill-out time for each pulse is 50μs, the total spill-out time is 10 s. The tolerable muon background is then of the order of 10^{7} for the whole run over the area (1 m^{2}) of the spark chambers, or 10 muons per m^{2} per pulse. The maximum tolerable general background of tracks in the emulsion is considerably greater than this for area scanning.

Neutrons produced in neutrino interactions in the shield also provide a background which may be troublesome in an emulsion experiment in a neutrino beam. Slow neutrons accompanied by low energy gamma rays could produce an unacceptable density of particle tracks in the emulsion so that it may be necessary in an experimental arrangement to make provision for shielding the stack from the neutron background.

In the case of area scanning, stars due to neutrino interactions may be confused with cosmic ray stars. Assuming a delay of 2.5 months between manufacture and development of the emulsion we expect about 25 background stars in the fiducial volume defined by tracks observed in the WG chambers[15]. The number with minimum ionization tracks emerging at an angle less than 20° with the neutrino direction will be only 0.13 however. Most of the minimum ionization tracks coming from cosmic ray interactions may be distinguished from those coming from neutrino interactions if the pellicles are shuffled in the process of building up the stack and reshuffled again immediately after the exposure ends. Minimum tracks from cosmic ray stars produced before or after the exposure will not then follow through into the next pellicle while tracks from neutrino interactions should of course follow through. The confusion due to cosmic ray stars produced during the actual run should then amount only to approximately 0.02 in the fiducial volume of emulsion for an event defined by tracks in the WG chambers.

The cosmic ray background is discussed in more detail in Appendix II.

9. ANALYSIS OF THE NEUTRINO INTERACTIONS

The scanning of areas of the emulsion stack indicated by the spark chamber observations should lead to the location of neutrino interactions. The topology of types of interactions of interest is illustrated diagrammatically in Figure 1.

Under favourable conditions a separation of 1 μm between the neutrino interactions and the decay point of the heavy lepton or charmed particle should be detectable, corresponding to a lifetime of $(3 \times 10^{-15}/\gamma)$ s, where γ is the Lorentz factor of the unstable particle. The minimum detectable decay path will be larger however if many secondary particles are emitted in the interaction.

Kinematical calculations are described in detail in Appendix III. In these the angular and momentum distributions of the muons from $M^{\pm}$ decay are calculated and the detection efficiency of the apparatus estimated.

By linking the experiment with the calorimeter - spectrometer system of experiment 310 and also using the electron shower detector it should be possible to analyse any interactions that give rise to short-lived particles.

10. ESTIMATE OF BACKGROUNDS

In an experiment using nuclear emulsion there are rather stringent limits to the backgrounds that can be tolerated. The question of cosmic ray background has already been discussed. Muons accompanying the neutrino beam would be particularly troublesome since they give rise to tracks in emulsion nearly parallel to those sought among neutrino interaction secondaries. If the technique is used of picking up neutrino interactions by following muon tracks picked up from the spark chambers back to the interaction point where they are produced, background muon tracks are likely to be followed by mistake. The maximum tolerable muon background is about 5 tracks per mm^2. For area scanning a higher background is tolerable. A study of the backgrounds observed in the 15 foot bubble chamber and in the external muon identifier leads to the conclusion that for 300 GeV protons incident on the target the muon background within 20° of the beam direction would amount to 0.5 tracks per mm^2 per 2×10^{18} protons on the target. This is quite acceptable. It will be necessary however to check the muon background when 400 GeV protons are incident on the target.

The hadron background could also cause difficulty. It should not be difficult to avoid a large hadron background during normal running. The necessity to protect the emulsion stacks from heavy hadron background due to beam tuning etc. gives cause for concern. As already mentioned provision will be made to remove the stacks to a safe place provided adequate warning is given. Since the value of the emulsion will be about $70,000, it seems imperative to work out a fail-safe procedure to give adequate warning to a representative of the emulsion experiment group should it become suddenly necessary to change the running schedule of the accelerator so that the risk arises of spraying hadrons into the neutrino area.

Another development that could give difficulty arises from the possible use of double pulsed operation of the 15' chamber with alternate neutrino and hadron pulses. Although the hadron pulse is a very weak one, the emulsion exposure is such a long one that it may not be possible to operate the experiment under conditions of double pulsing unless very elaborate shielding is provided for the stack.

Test emulsion plates have been exposed in the neutrino beam in various positions relative to a thick concrete slab upstream from the position of the apparatus of experiment 310. The plates exposed upstream from the concrete (position 1) showed the presence of low energy electrons (energy 1 MeV). These were not present in the plates exposed in position 2, behind 4 metres of concrete. Interaction stars were also observed in these plates. Those exposed in position 1 exhibited a density of these stars about equal to that to be expected from cosmic radiation alone. Those exposed in position 2 showed a star density approximately twice as large. The additional interactions could have arisen from neutrons produced in the concrete by the neutrino beam. In general the characteristics of these stars were quite different from those to be expected in stars produced by fast neutrino interactions. In any case, extrapolating to the star density to be expected for an exposure corresponding to 2×10^{18} protons on target, it can be inferred that this source of background will not be significant. It is concluded therefore that the proposed location of the experiment behind a thick concrete slab and immediately upstream from the location of experiment 310 will be satisfactory

11. GENERAL CONSIDERATIONS OF COST, TIME-TABLE, ETC

If the proposal is accepted work will commence immediately on the preparation of the apparatus. The electronic and spark chamber arrangement will be set up and tested in CERN during April and May 1975. The equipment will then be shipped to FNAL and a prototype experiment carried out using 1 litre of emulsion and the other emulsion stacks simulated by matter of about the same density. It is expected this prototype experiment could be carried out during any suitable neutrino run after August 1975. It should then be possible to carry out the main experiment during the first part of 1976 when a suitable neutrino run is scheduled.

The design and construction of the wide gap chambers and associated optics is being carried out by the Strasbourg and Mulhouse groups. The rest of the electronics and particularly the shower detector will be the responsibility of the Rome group. These two groups will together organize the analysis of the spark chamber pictures. The design and construction of the clamps and other apparatus for the mounting of the emulsion stacks is the responsibility of the London (UCL) group. Arrangements have been made for processing of the emulsion after exposure using the processing plant at CERN. Discussions are at present taking place concerning the best procedure for the assembly and final milling of the emulsion stacks but this does not represent a real problem. All the laboratories concerned will participate in the scanning of the emulsion after exposure and in the analysis of the neutrino interactions. All the basic equipment, including electronics and optics,will be brought to FNAL from Europe together with the number of physicists and technicians necessary to operate the experiment. The personnel required to come for this purpose will be decided in consultation with the FNAL participants. We should of course need from FNAL help in the mounting of the apparatus in the agreed position in the neutrino beam and the use of technical services needed in the carrying out of the experiment. Also, although the experiment is conceived as parasitic to E310, the financial commitment in the form of 20 litres of nuclear emulsion is a substantial one. The nuclear emulsion will deteriorate if it is not used. Therefore once the experiment has been scheduled and commenced, it would be a considerable financial embarrassment if it had to be interrupted for any reason other than unavoidable ones, such as the breakdown of the accelerator, of the hardware for the neutrino beam or the malfunctioning of the part of the E310 equipment we hope to use. It appears desirable therefore to obtain agreement on the procedure, should,after the scheduling of the run, the E310 group not wish to proceed for any reason other than unavoidable ones such as those specified above.

The foreseen overall costs for the mounting of the experiment at FNAL which are to be borne by the visiting groups are set out below:

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Cost of emulsion and its processing	87,000
Cost of other hardware, including spark chambers, electronics, optics, mounting of emulsion, etc.	25,000
Travel and maintenance costs	20,000
TOTAL	$132,000

This cost will be shared equally between the visiting groups and approaches have been made to the appropriate grant-giving authorities in the various countries and it is possible to give the assurance that they will be covered provided the experiment is scheduled. Adequate resources are also available to enable the analysis of the results after the run to be carried out quickly and effectively (within 6 months after completion of the exposure in the ν beam).

APPENDIX I

CROSS-SECTION EVALUATION

Evaluation of thresholds is given in Table A1 for production on nucleons at rest assuming various values of the masses of heavy leptons, $M^{\pm}$ or charmed baryons, $C^{\pm}$. Fermi motion can lower these figures by about 25% when the target is a nucleus.

Table A1

$m(M^{\pm})$	E (threshold)
2 GeV	4.13 GeV
3	7.80
4	12.52
5	18.33

$m(C^{\pm})$	E (threshold)
2 GeV	1.86 GeV
3	4.67
4	8.51
5	13.42

(The difference in the two cases is in the availability of the nucleon mass for baryonic $C^{\pm}$ production but not for $M^{\pm}$ production).

The cross-sections are not easily predicted:

(a) Charmed Baryon Production

For charmed baryon production Gaillard et al[7] give for the differential cross-section of the 'elastic'processes, $\nu + N \rightarrow C + \mu$, in the threshold region,

$$\frac{d\sigma}{dy} = \frac{2}{\pi} G_F M^2 \sin^2\theta_c \frac{1}{y} \{ (\frac{g_A+g_V}{2})^2 (1 - y_{th}) + (\frac{g_A-g_V}{2}) (1 - y)(1 - y + y_{th}) \}$$

where $y = E_c/E_\nu$ is the fraction of the incident neutrino energy transmitted to the baryon, y_{th} the value of y corresponding to the charmed baryon production threshold, M the nucleon mass and θ_c the Cabibbo angle. Figure 9 shows $\frac{d\sigma}{dy}$ plotted against y for the case $M_c \simeq 3$ GeV, $\langle E_\nu \rangle = 25$ GeV, corresponding to $y_{th} = 18$. Curves are shown for pure V-A and V+A coupling. Also shown is $10^{-2} \frac{d\sigma_{tot}}{dy}$. The production of C_0^+ which is expected (on the basis of SU_4) to be almost pure V-A is most favoured but even here the cross-section is well below the 1 per cent level.

Charmed baryon production in deep inelastic processes can occur in the ranges

$$0 \lesssim x \lesssim 1 - \frac{E_{th}}{yE_\nu} \quad , \quad \frac{E_{th}}{E_\nu} \leqslant y \leqslant 1$$

of the usual scaling variables, x, y, where $E_{th} = M_c^2/2M_N$ is the threshold energy for production of a charmed baryon of mass M_c. Gaillard et al[7], estimate the corresponding production cross-sections using a parton model. If F_s, F_μ, F_d are respectively the proportions of strange, non-strange isospin up, and non-strange isospin down partons in the nucleon, then assuming $2F_s = 0.1\ (F_\mu + F_d)$, corresponding to the upper limit of strange parton proportion derived from deep inelastic electron and neutron scattering, Figures 10 and 11 show respectively the y and W^2 distributions for $\bar{\nu}$ interaction cross-sections (W is the invariant mass of the hadron distribution). The shaded portion in each case shows the contribution to the cross-section from charmed baryon production.

In the extreme asymptotic region these assumptions give the estimate $\sigma_c^{\bar{\nu}}/\sigma_{tot}^{\bar{\nu}} \simeq 0.35$. For ν interactions, $\sigma_c^{\nu}/\sigma_{tot}^{\nu} \simeq 0.16$ under similar assumptions. This follows because $d\sigma^{\bar{\nu}}_{tot}/dy$ falls off like $(1-y)^2$ for increasing y, where charmed baryon production becomes most important, while $d\sigma^{\nu}_{tot}/dy$ is independent of y. $d\sigma^{\bar{\nu}}_{c}/dy$, $d\sigma^{\nu}_{c}/dy$ are both expected to be independent of y. Since the overall ν flux is expected to be about 4 times the $\bar{\nu}$ flux, even under these conditions it would be advantageous to do the experiment using ν rather than $\bar{\nu}$.

These estimates are based on the upper limit of the estimates of the proportion of strange partons in the nucleon. This is probably a considerable over-estimate. If this proportion should be zero, charmed baryon production could still occur at a level of approximately $\tan^2\theta_c \simeq 0.04$ for $\sigma^{\nu}_{c}/\sigma^{\nu}_{tot}$ and $\simeq 0.005$ for $\sigma^{\bar{\nu}}_{c}/\sigma^{\bar{\nu}}_{tot}$.

(b) <u>Heavy Lepton Production</u>

For leptons, we have the unusually large mass of $M^{\pm}$ bringing into play a larger number of (unknown) structure functions as compared with the $\nu \to \mu$ inclusive reaction. For both leptons and charmed particle production, the assumption of universal coupling is generally made.

What we actually need for detection of special decay modes is the product of the cross-section times the branching ratio for that mode. This will make the rate of unusual events even more uncertain.

Following Llewellyn-Smith(14) we give here the lower bound for cross-sections for inclusive $M^{\pm}$ production by neutrinos assuming conventional scaling.

By introducing the usual variables x, y, already defined, we find that the inclusive cross-section is larger than or equal to:

$$\frac{d^2\sigma}{dxdy} = \frac{G^2(S - M^2)}{2\pi} F_2(x) \quad \{1 - \frac{M^2M_L^2}{(S-M^2)^2} - \frac{M_L^2}{(S-M^2)}\cdot\frac{1}{x} - \frac{M^2}{S-M^2}xy\} \quad .$$

Here, M is the nucleon mass, M_L the lepton mass, $S = 2ME_\nu + M^2$, G is the Fermi coupling constant and F_2 the scaling structure function.

The formula is simpler when $M_L > 2$ GeV and $E_\nu >> M$. To a very good approximation, after integration over y,

$$\frac{d\sigma}{dx} = \frac{G^2S}{2\pi} F_2(x) \quad (1 - \frac{M_L^2}{Sx})^2$$

To integrate over x, an explicit choice of F_2 must be made. We assume

$$F_2(x) = 2(1 - x)^3$$

compatible with $\nu + N \to \mu^- +$ anything,data. Putting $x_m = \frac{M_L^2}{S}$, we get

$$\sigma_{total} = \frac{G^2S}{4\pi} f(x_m) \quad , \qquad \text{where}$$

$$f(x) = 1 + \frac{44}{3}x - 4(2 + 3x)x\log\frac{1}{x} - 12\,x^2 - 4x^3 + \frac{1}{3}x^4.$$

Numerical values are given in Table A2:

<u>Table A2</u>

x	f(x)
0.0	1.0000
0.1	0.2280
0.2	0.0720
0.3	0.0248
0.4	0.0078
0.5	0.0021

(compare Figure 2)

In this range, a useful numerical interpolation is provided by:

$$f(x) = \frac{(1 - x)^6}{1 + 13x} .$$

Note than f(x) gives the ratio of production rates $(\nu \to M^+)/(\nu \to \mu^-)$, thus measuring the fraction of the usual muon-events corresponding to heavy-lepton production as a function of M_L^2/S.

APPENDIX II

BACKGROUND DUE TO COSMIC RAYS

Cosmic ray stars are produced in nuclear emulsion at a rate of $1.5/cm^3/day$ at sea level and $300/cm^3/day$ at a level of 10,000 m.

As is shown in Table A3, the stars generated at an altitude of about 10 Km simulate neutrino stars more closely than those produced at sea level.

Table A3

stars	sea level	10 Km
$n^o/cm^3/day$	~ 1.5	~ 300
neutral primary	95%	80%
$n_s = 0$	92%	82%
$n_s = 1$	5%	10%
$n_s = 2$	3%	8%
$n_H < 4$ (all n_s)	82%	62%

(n_s = number of minimum tracks; n_H = number of heavy tracks)

Due to the wide angular distribution of the particles producing the stars, the minimum tracks have a wide angular distribution so that only a small fraction of them would be accepted in the angular window allowed to those produced in neutrino events (8% within 20^o with respect to the beam). Assuming a stay of 12 hours at an altitude of 10 Km we should have 150 stars/cm^3, and 1 star/cm^3 with at least one minimum prong with $\theta < 20^o$. On the other hand, assuming a delay of 2.5 months between fabrication and development of the emulsions, we expect 110 stars/cm^3 generated at sea level, giving an even lower contribution (0.3 stars/cm^3) to misleading events, but with a higher fraction of stars with few heavy prongs that must be very carefully studied before being rejected.

The events with a minimum track in the allowed angular window require a lot of work (following the track, accurate angular measurement, etc) before rejection, and it may be that in some cases distinction between neutrino and other events will not be possible. However, one only expects 0.13 such ambiguous events in the fiducial volume of 0.1 cc per event, defined by tracks in the WG chambers. If the pellicles are shuffled before and after the exposure the number of ambiguous events in this volume is reduced to 0.02.

APPENDIX III

KINEMATICAL CALCULATIONS AND BRANCHING RATIO IN HEAVY LEPTON

The kinematical features of the process

$$\nu_\mu + p \rightarrow M^+ + \text{anything} \qquad (1)$$
$$\quad \hookrightarrow \mu^+ + \nu + \nu$$

have been studied by a Monte-Carlo calculation to evaluate the efficiency of the experimental apparatus in detecting events from process (1).

The kinematical magnitudes involved are defined in Figure 12.

The calculation proceeds as follows:

(a) The neutrino energy, E_ν, is generated in agreement with the spectrum in Figure 1.

(b) For a fixed value of the heavy lepton mass m, p_M and θ_M are obtained from the variables

$$x = -\frac{q^2}{2pq} \qquad\qquad y = \frac{2pq}{S - M^2}$$

where p is the proton four-momentum, q is the momentum transfer and M is the proton mass.

The cross-section $\frac{d^2\sigma}{dxdy}$ in these variables given by Llewellyn-Smith[14] is used.

(c) The heavy lepton disintegration is assumed to occur according to 3-body invariant phase space.

The distributions obtained for p_μ, θ_μ, $\theta_{\mu M}$ are represented in Figures 13, 14 and 15.

The detection efficiency of the experimental apparatus was calculated taking into account the following points:

(1) The angular acceptance of the apparatus in detecting the decay muons. Three cases were considered according as $\theta_\mu^{max} = 6^\circ$, 10° and 20°. The first two correspond to the magnetic angle and trigger angle of the apparatus described in paragraph 4.

(2) The scanning inefficiency for very small values of $\theta_{\mu M}$. We assumed that an event is lost in the scanning when it has $\theta_{\mu M} < \theta_{\mu M}^{min}$. We considered three cases: $\theta_{\mu M}^{min} = 0^\circ$, 1° and 2°.

(3) The threshold value $p_\mu^{thr} \simeq 1.5$ GeV/c, has been assumed for the muon momentum. If $p_\mu < p_\mu^{thr}$ the muon does not have the penetration required by the master coincidence.

The calculated efficiencies for heavy leptons are given in Table A4. Furthermore, we give in Table A5 the minimum expected number of heavy lepton observed events, assuming that during the experiment, 10^3 ordinary muon events are produced. This mumber has been calculated assuming the total fraction of $\nu \to M^+$ to $\nu \to \mu^-$ events as in Figure 2 and considering the branching ratio

$$\frac{\Gamma_M \to \mu\nu\nu}{\Gamma_M \to \text{all}} = 0.3.$$

Table A4

Detection Efficiency of the Apparatus (in %) as a function of m, θ_μ, $\theta_{\mu M}$

m = 2 GeV

$\theta_{\mu M}^{min}$ \ θ_μ^{max}	6°	10°	20°
0°	50	70	83
1°	42	62	75
2°	29	48	60

m = 3 GeV

$\theta_{\mu M}^{min}$ \ θ_μ^{max}	6°	10°	20°
0°	49	72	87
1°	42	64	79
2°	30	52	67

m = 4 GeV

$\theta_{\mu M}^{min}$ \ θ_μ^{max}	6°	10°	20°
0°	54	75	90
1°	48	71	86
2°	38	59	74

Table A5

Minimum Expected Numbers of Heavy Leptons Detected for 1000 ν Interactions

m = 2 GeV

$\theta_{\mu M}^{min}$ \ θ_μ^{max}	6°	10°	20°
0°	44	61	72
1°	37	54	65
2°	25	42	52

m = 3 GeV

$\theta_{\mu M}^{min}$ \ θ_μ^{max}	6°	10°	20°
0°	19	28	34
1°	16	25	31
2°	12	20	26

m = 4 GeV

$\theta_{\mu M}^{min}$ \ θ_μ^{max}	6°	10°	20°
0°	8	11	14
1°	7	11	13
2°	6	9	11

References

1. Glashow, S., Illiopoulos, J. and Maiani, L., Phys. Rev., D2, (1970), 1285.

2. Bjorken, J.D. and Glashow, S., Phys. Letters, 11, (1964), 255.

3. Snow, G.A., Nucl. Phys., B55, (1973), 445.

4. Aubert, J.J., Becker, U., Biggs, J.P., Burger, J., Chen, M., Everhart, G., Goldhagen, P., Leong, J., McCorriston, T., Rhoades, T.G., Rohde, M., Ting, S.C.C., Sau Lan Wu and Lee, Y.Y., Phys. Rev. Lett., 33, (1974), 1404.

5. Augustin, J.E., Boyarski, A.M., Breidenbach, M., Bulos, F., Dakin, J.T., Feldman, G.J., Fischer, G.E., Fryberger, D., Hanson, G., Jean-Marie, B., Larsen, R.R., Lüth, V., Lynch, H.L., Lyon, D., Morehouse, C.C., Paterson, J.M., Perl, M.L., Richter, B., Rapides, P., Schwithers, R.F., Tanenbaum, W.M., Vannucci, F., Abrams, G.S., Briggs, D., Chinowsky, W., Friedberg, C.E., Goldhaber, G., Hollebeck, R.J., Kadyk, J.A., Lulu, B., Pierre, F., Trilling, G.H., Whitaker, J.S., Wiss, J. and Zipse, J.E., Phys. Rev. Lett., 33, (1974), 1406, 1453.

6. Bacci, C., Baldini-Celio, R., Bernardini, M., Capon, G., Del Fabbro, R., Grilli, M., Larocci, E., Jones, L.H., Locci, M., Mencuccini, C., Murtas, G.P., Penso, G., Salvini, G., Spinetti, M., Spano, M., Stella, B., Valente, V., Bartoli, B., Bisello, D., Esposito, B., Felicetti, F., Monacelli, P., Nigro, M., Paoluzi, L., Peruzzi, I., Piano Mortari, G., Piccolo, M., Ronga, F. Sebastiani, F., Trasatti, L., Vanoli, F., Barbarino, G., Barbiellini, G., Bemporad, C., Biancastelli, R., Castellano, M., Cevenini, F., Calvetti, M., Costantini, F., Lariccia, P., Parascandolo, P., Patricelli, S., Sassi, E., Spencer, C., Tortora, L., Troya U. and Vitale, S. Phys. Rev. Lett., 33, (1974), 1408.

7. Gaillard, Mary K., Lee, B.W., and Rosner, J.L., Preprint Fermilab Pub., 74/86 - Thy Aug. 1974.

8. Aubert, B., Benvenuti, A., Cline, D., Ford, W.T., Imlay, R., Ling, T.Y., Mann, A.K., Messing, F., Piccione, R.L., Pilcher, J., Reeder, D.D., Rubbia, C., Stefanski, R., and Sulak, L., Presented to 17th International Conference on High Energy Physics, London, July 1974.

9. Bjorken, J.D. and Llewellyn-Smith, C.H., Phys. Rev. D7, (1973), 887.

10. Barish, B.C., Bartlett, J.F., Buchholz, D., Humphrey, T., Merritt, F.S., Nagashima, Y., Sciulli, F.J., Shields, D. and Suter, H., Krafczyk, G., and Maschke, A. Phys. Rev. Lett., 31, (1973), 410.

11. Albright, C.H., Lettere al Nuovo Cimento, 3, (1972), 71.

12. Ramm, C.A., Nature, 227, (1970), 1323.

13. Burhop, E.H.S., Busza, W., Davis, D.H., Duff, B.G., Garbutt, D.A., Heymann, F.F., Potter, K.M., Wickens, J.H., Bricman, C., Lemonne, J., Sacton, J., Schorochoff, G., Roberts, M.A., and Toner, W.R., Nuovo Cimento, 39, (1965), 1037.

14. Llewellyn-Smith, C.H., Nuclear Physics, 1356, (1973), 325.

15. Teucher, M., Z. für Naturforschung, 7a, (1952), 61.
8a, (1953), 127.

Figure Captions

Figure 1:

Typical topologies of different processes involving production of charmed particles and heavy leptons.

(a) Production of charmed baryon, C^{++}, in the process $\nu + p \rightarrow \mu^- + C^{++}$ $(+K^0)$. (The production of the K^0 is not essential but strangeness-changing processes of charmed particle production are more probable). The C^{++} is then supposed to decay leptonically in the process,

$$C^{++} \rightarrow \mu^+ + p + \nu_\mu.$$

Other detection processes would observe a signature only of two fast muons and a hadron shower.

(b) Production of charmed meson, D^+ in the process $\nu + N \rightarrow \mu^- + D^+ + N$, followed by leptonic decay $D^+ \rightarrow \mu^+ + \bar{K}^0 + \nu_\mu$. (The D^+ may either be produced directly or in the strong decay process of a charmed baryon).

Other detection processes would observe only two fast muons and a hadron shower.

(c) Production of charmed meson, D^+ as in (b) followed by the hadronic decay

$$D^+ \rightarrow K^- + \pi^+ + \pi^+$$

(d) Production of charmed meson, D^0, (either directly or in strong decay of a charmed baryon), in process $\nu + N \rightarrow \mu^- + D^0 + N$, followed by leptonic decay $D^0 \rightarrow \mu^+ + K^- + \nu_\mu$.

Other detection processes would observe a signature of two fast muons, a hadron shower and a K^-.

(e) Production of charmed meson, D^O, as in (d), followed by hadronic decay

$$D^O \rightarrow K^- + \pi^+.$$

(f) Production of W^+ in the process

$$\nu_\mu + N \rightarrow \mu^- + W^+ + N$$

followed by the decay $W^+ \rightarrow \mu^+ + \nu_\mu$. In this case, the W^+ decay would be too rapid to observe directly in emulsion.

(g) Production of heavy muon, M^+, in the process $\nu + N \rightarrow M^+$ + hadrons, followed by the decay $M^+ \rightarrow \mu^+(e^+) + \nu_\mu(\nu_e) + \nu_\mu$.

(h) Production of heavy muon, M^O, in the process $\nu + N \rightarrow M^O$ + hadrons, followed by the decay $M^O \rightarrow \mu^- + \mu^+(e^+) + \nu_\mu(\nu_e)$.

Note that other detection processes could not distinguish between (a), (b), (d), (f), (h).

Figure 2:

The dotted lines show the branching ratio $f(x_m) = \dfrac{\sigma(\nu \rightarrow M^+)}{\sigma(\nu \rightarrow \mu^-)}$ as a function of neutrino energy, E_ν, where $x_m = M_L^2/2ME_\nu$, M_L, M being respectively masses of the heavy lepton and the nucleon. $f(x_m)$ is shown for M_L = 2 GeV (curve 1) and M_L = 4 GeV (curve 2). The full curve 3 shows the assumed neutrino spectrum, $n(E_\nu)$, multiplied by E_ν. The kaon decay shoulder of the spectrum is not included.

The other two full curves show the rate of heavy lepton emission, $E_\nu n(E_\nu) f(x_m)$ versus E_ν for M_L = 2 GeV (curve 4) and M_L = 4 GeV (curve 5).

<u>Figure 3:</u>

The total ratio (integrated over the neutrino spectrum) of $\nu \rightarrow M^+$ to $\nu \rightarrow \mu^-$ events as a function of M_L. (The branching ratio for $M^+ \rightarrow \mu^+$ decay is not included in this calculation).

<u>Figure 4:</u>

Schematic arrangement of apparatus for locating neutrino interactions.

V_1, V_2, A, B	scintillation counters
W.G.	wide gap chambers
SC1	narrow gap spark chamber
E.S.	emulsion stack
S.D.	shower detector
M.S.	muon spectrometer (from expt. 310 apparatus)
S.	scintillation counter from expt. 310 apparatus providing master signal.

<u>Figure 5:</u>

Arrangement of apparatus of expt. 310 showing suggested location of apparatus of this experiment.

<u>Figure 6:</u>

Illustrating the mounting of the emulsion stacks together with fiducial marks relative to the spark chamber assembly.

Figure 7:

Illustrating clamp used for holding each stack of emulsion pellicles.

Figure 8:

Illustrating the shower detector (S.D.). It is of modular type, made of four identical moduli. Each modulus, of 90 x 90 cm^2 useful area, consists of a 1 cm thick Pb plate (A) followed by a 2 cm thick plastic scintillator (S) and a double wide-gap spark chamber (WG). The spark chambers are triggered by a pulse involving an integrated signal from the photomultipliers connected to the scintillation counters,in excess of a certain threshold.

Figure 9:

Differential cross-section for elastic neutrino production of charmed baryons with C = L, S = O, in the processes $\nu + p \to \mu^- + C^{++}$; $\nu + n \to \mu^- + C^+$. The cross-section is a coherent sum of V-A and V+A contributions (after Gaillard et al[7]). The calculations are calculated for a charmed baryon mass, $M_c \simeq$ 3 GeV and mean neutrino energy $\langle E_\nu \rangle \simeq 25$ GeV. Correspondingly, $y_{th} = 0.18$.

Figure 10:

Differential cross-section $d\sigma^{\bar{\nu}}/dy$ for charm production (shaded area) and ordinary deep inelastic scattering (dashed line) by antineutrinos for the case $E_{th}/E_\nu = 0.5$ (as would for example be the case for $M_c \simeq 5$ GeV, $E_\nu \simeq 25$ GeV). The solid line,which represents the total inelastic production, shows a threshold effect. A five per cent s-parton content of the nucleon has been assumed (after Gaillard et al[17]).

Figure 11:

Differential cross-section $d\sigma^{\bar{\nu}}/dW^2$ for charm production (shaded area), ordinary deep inelastic scattering from anti-partons (dashed line) for production by $\bar{\nu}$ under the same assumptions as for Figure 10. The charm threshold effect can be seen in the total contribution (solid line) (after Gaillard et al[7]).

Figure 12:

Definition of kinematic quantities.

Figure 13:

Momentum distribution of muons from heavy lepton decay, (a) for all events, (b) for events with $\theta_\mu < 6^\circ$. About 10,000 events are included in (a) and 5,000 in (b).

Figure 14:

Angular distribution (with respect to incident muon direction) for secondary muons from heavy lepton decay.

Figure 15:

Angular distribution of secondary muons with respect to the heavy lepton direction, (a) for all events, (b) for events with $\theta_\mu < 6^\circ$.

Fig 1

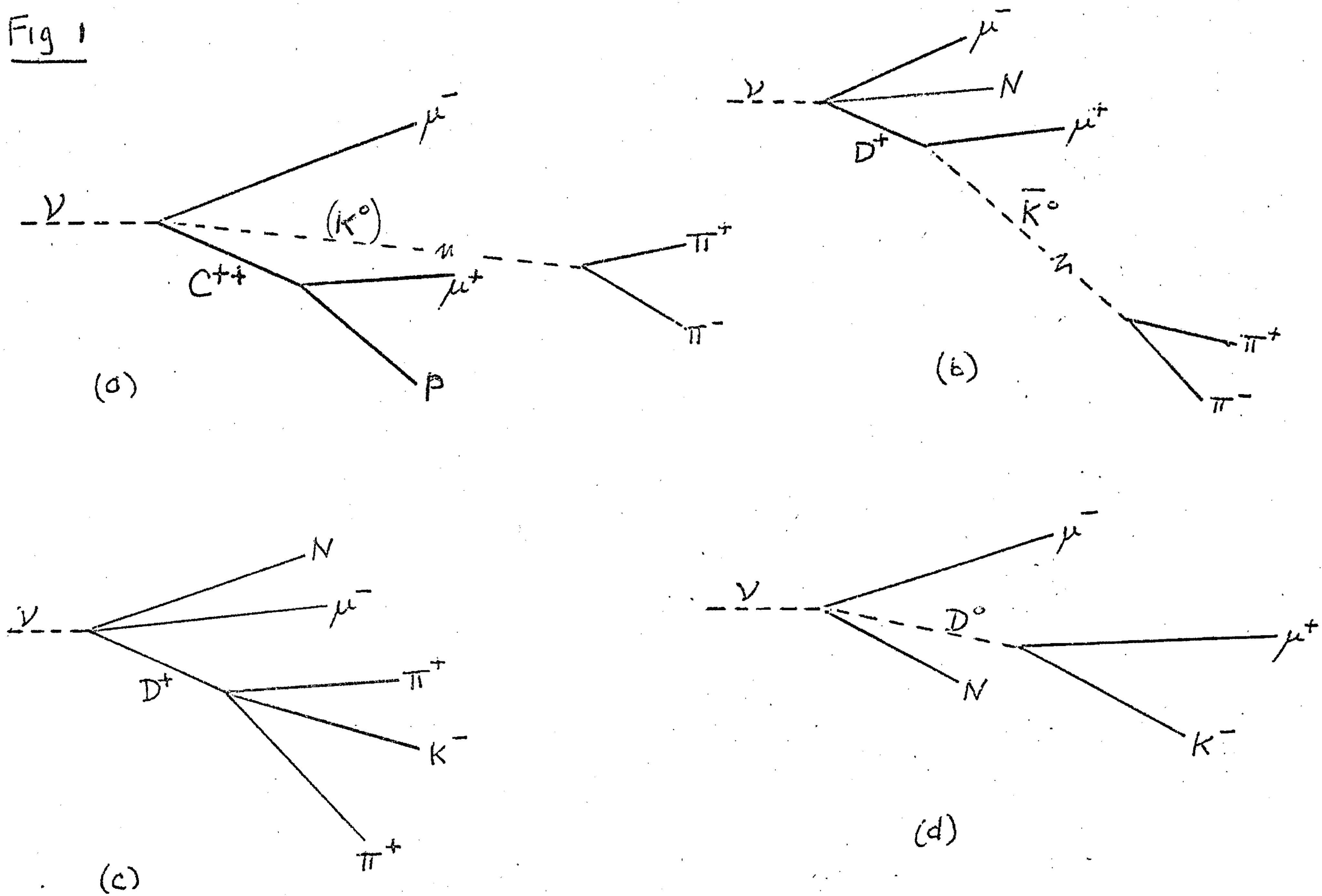


Fig 1 (contd)

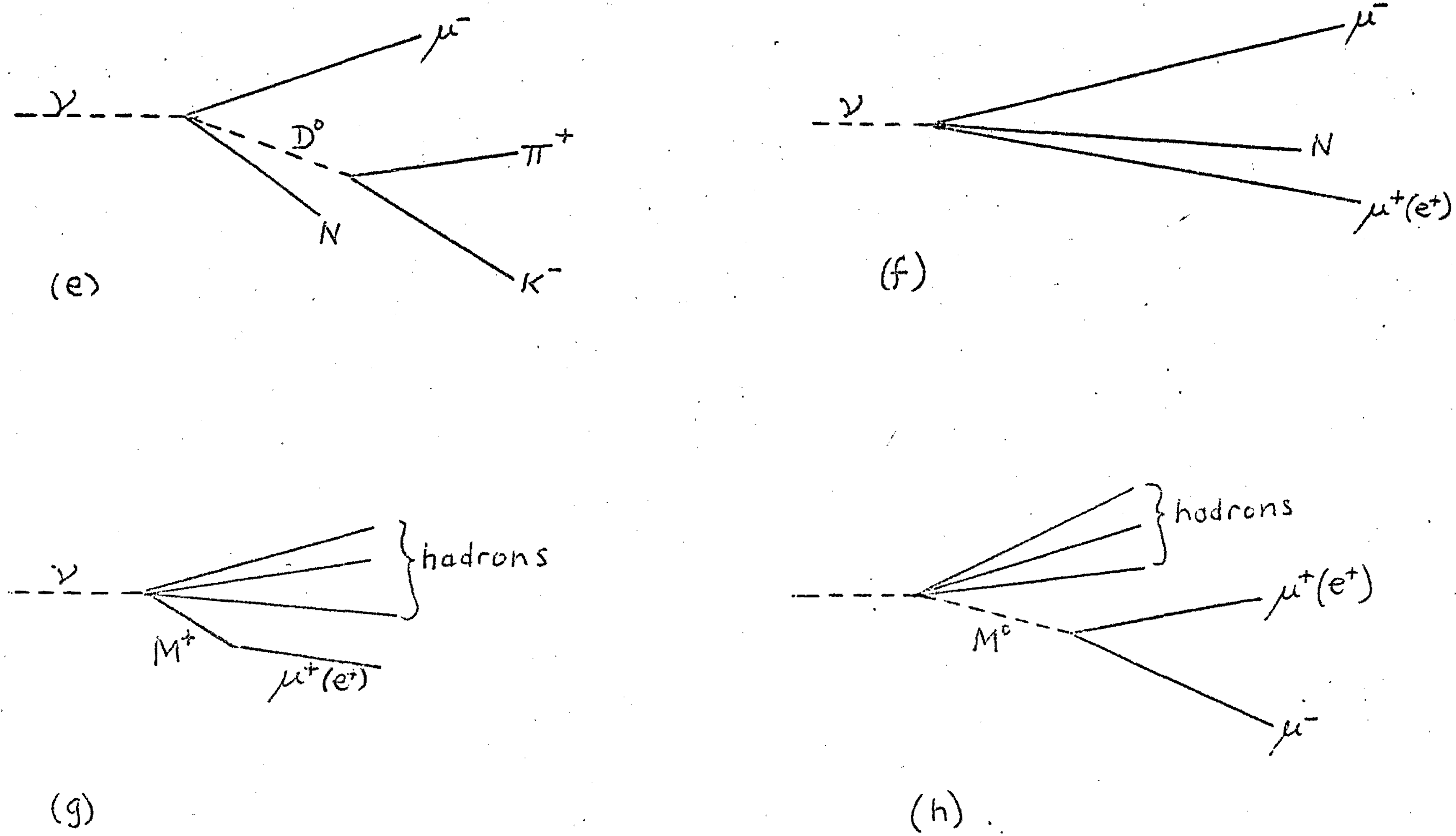
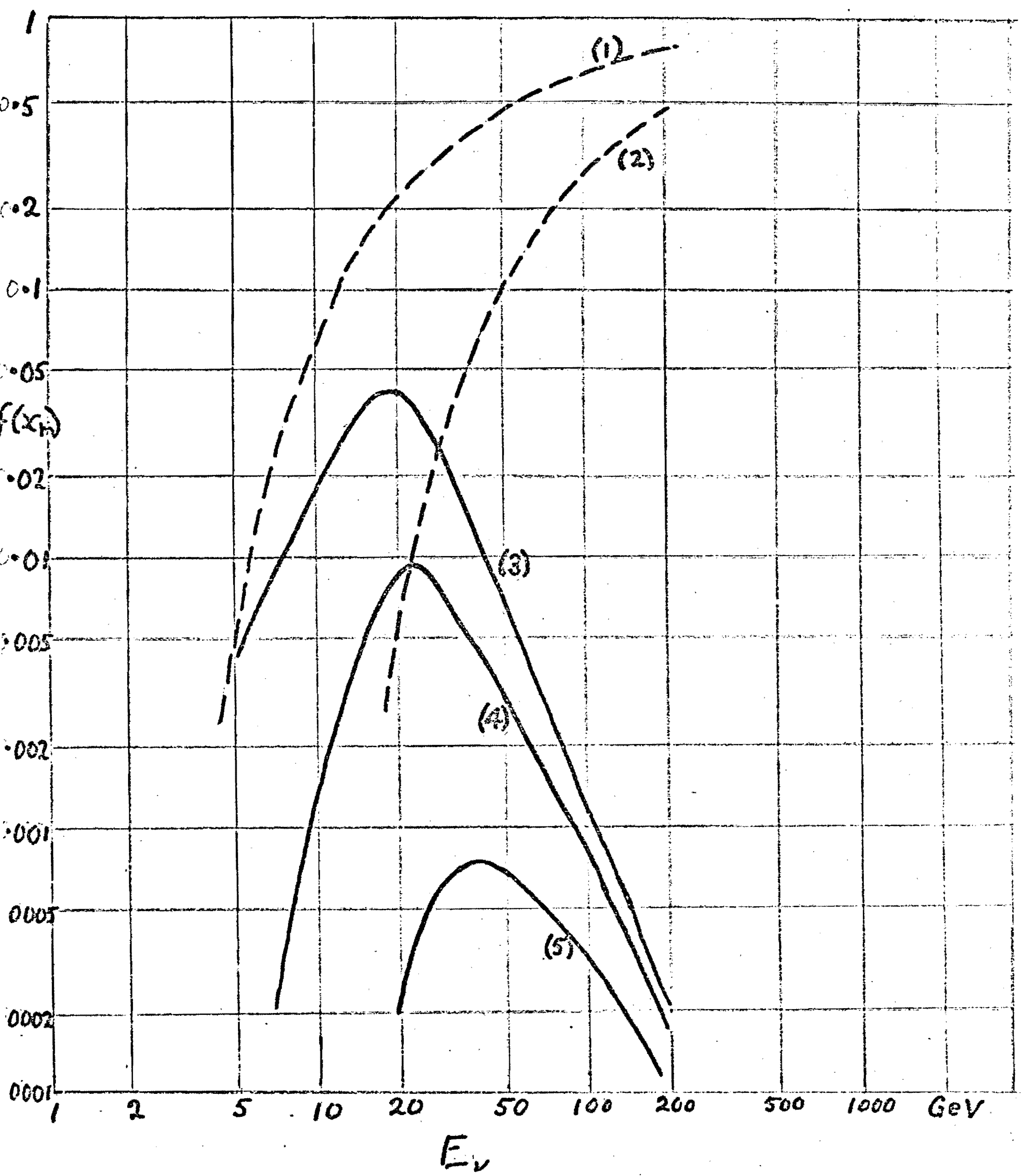


Fig. 2



1
0·5
0·2
0·1
0·05
f(x_n)
0·02
0·01
0·005
0·002
0·001
0·0005
0·0002
0·0001
1
2
5
10
20
50
100
200
500
1000
GeV
E_ν
(1)
(2)
(3)
(4)
(5)

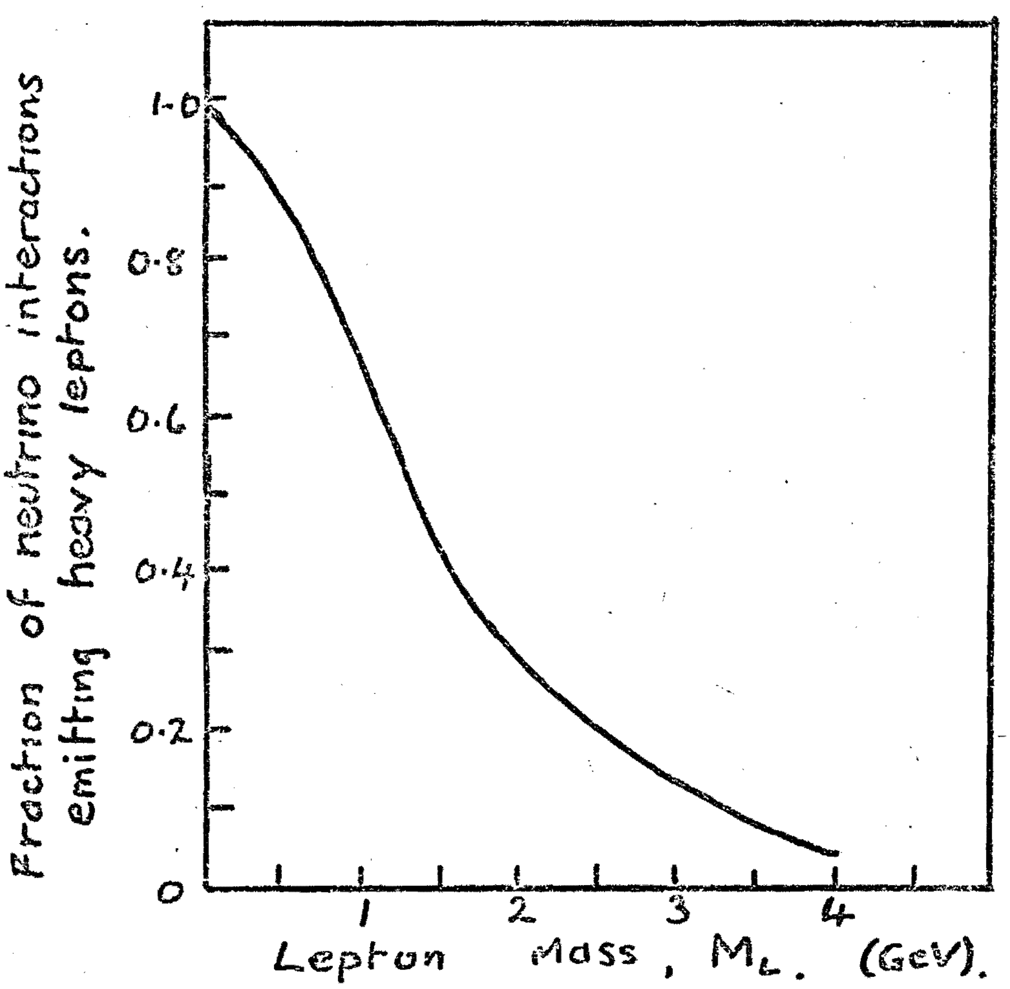

Fraction of neutrino interactions emitting heavy leptons.
1·0
0·8
0·6
0·4
0·2
0
1
2
3
4
Lepton Mass, M_L. (GeV).

Fig. 3

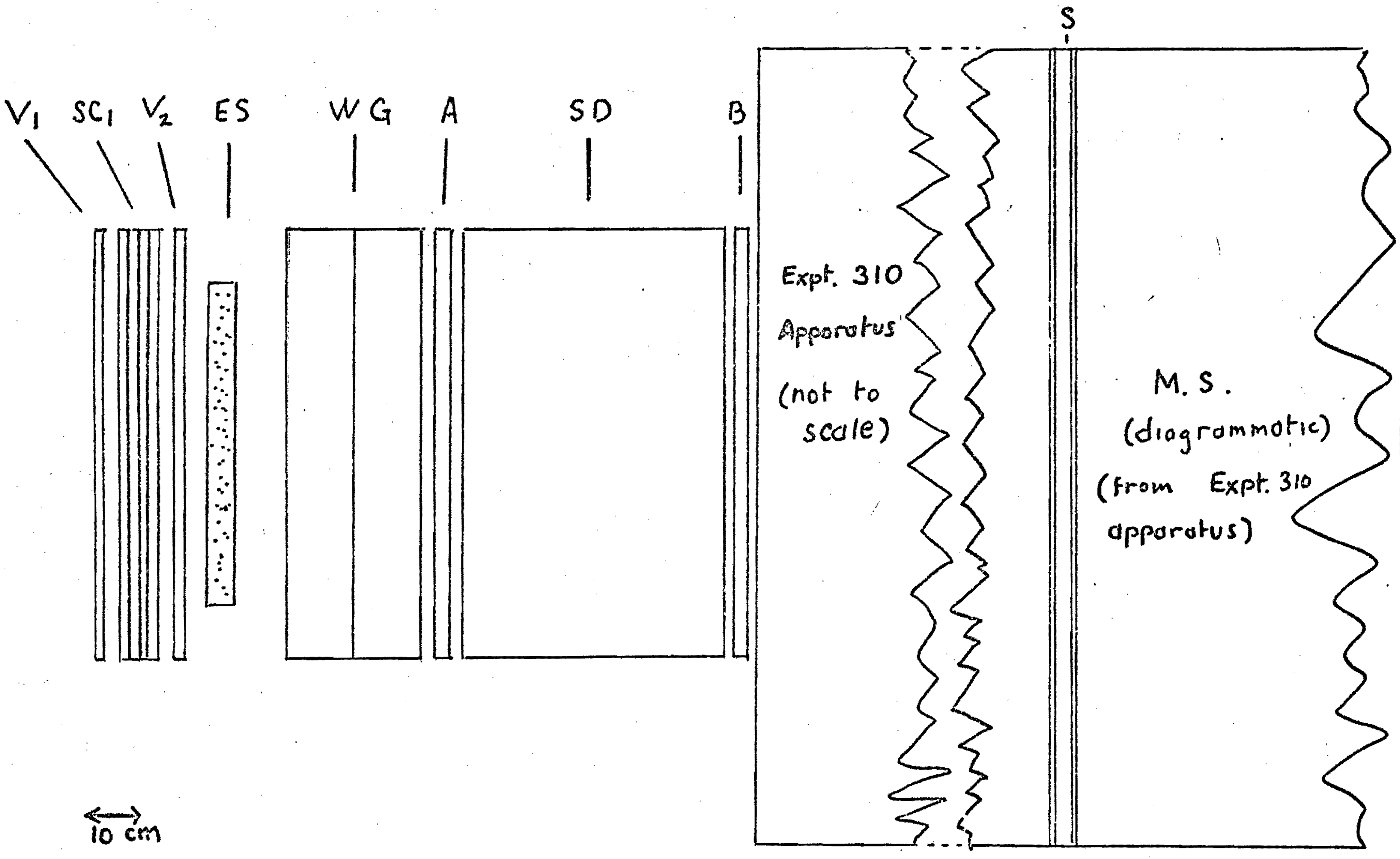
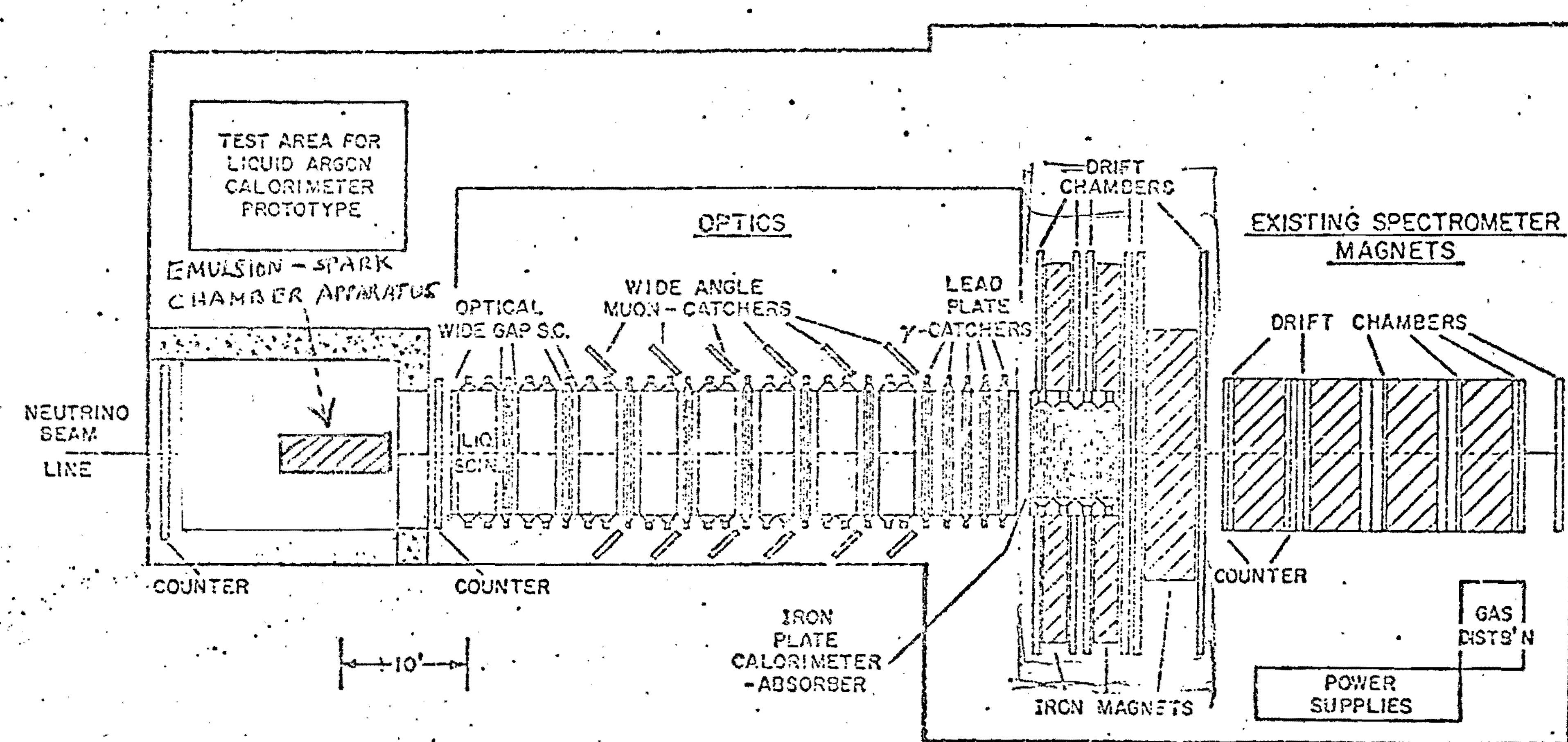

V1
SC1
V2
ES
WG
A
SD
B
S
Expt. 310
Apparatus
(not to
scale)
M. S.
(diagrammatic)
(from Expt. 310
apparatus)
10 cm

Fig. 4

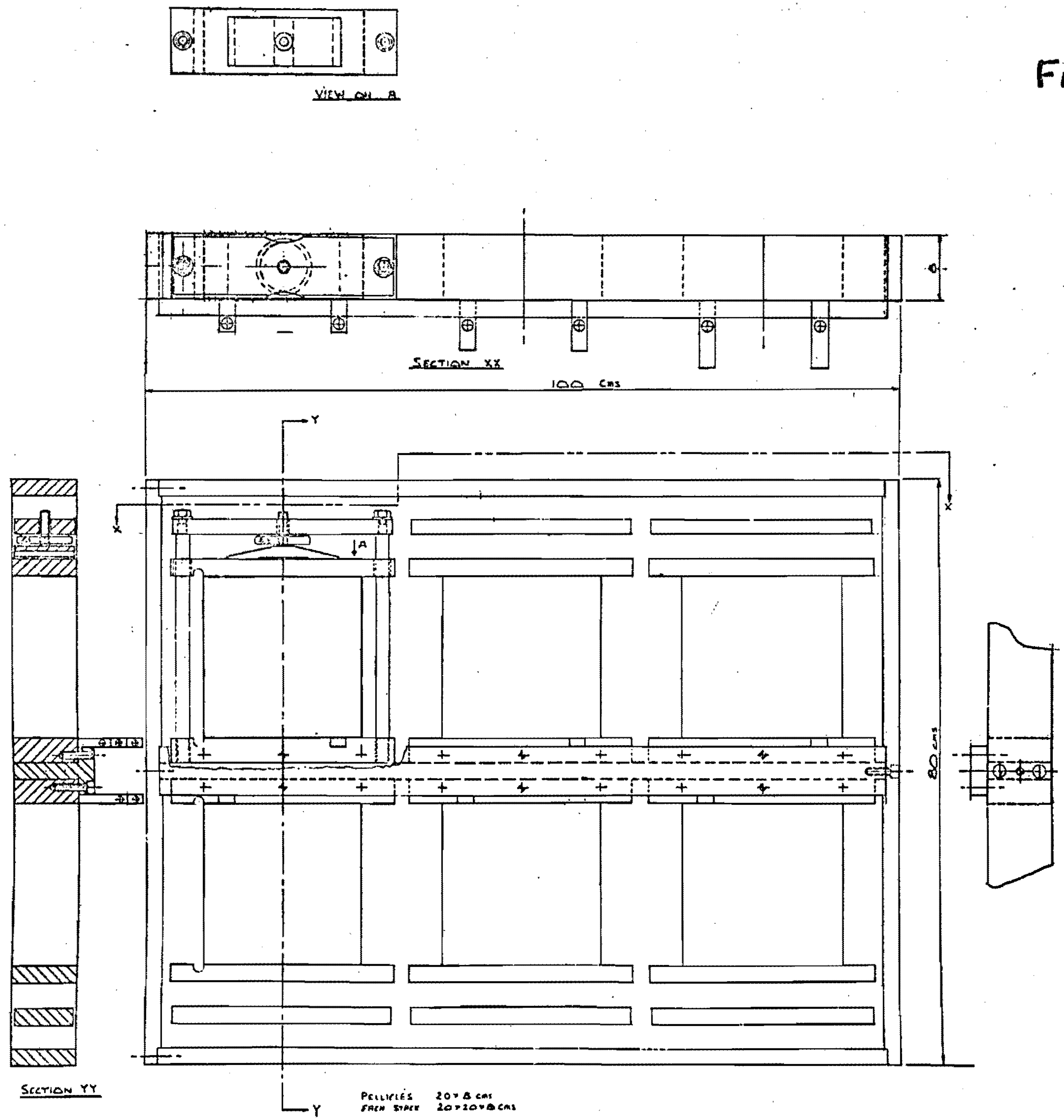


PLAN VIEW OF APPARATUS

EARLY, 1975

FIG. 5

Fig. 6



PROPOSED EMULSION STACK

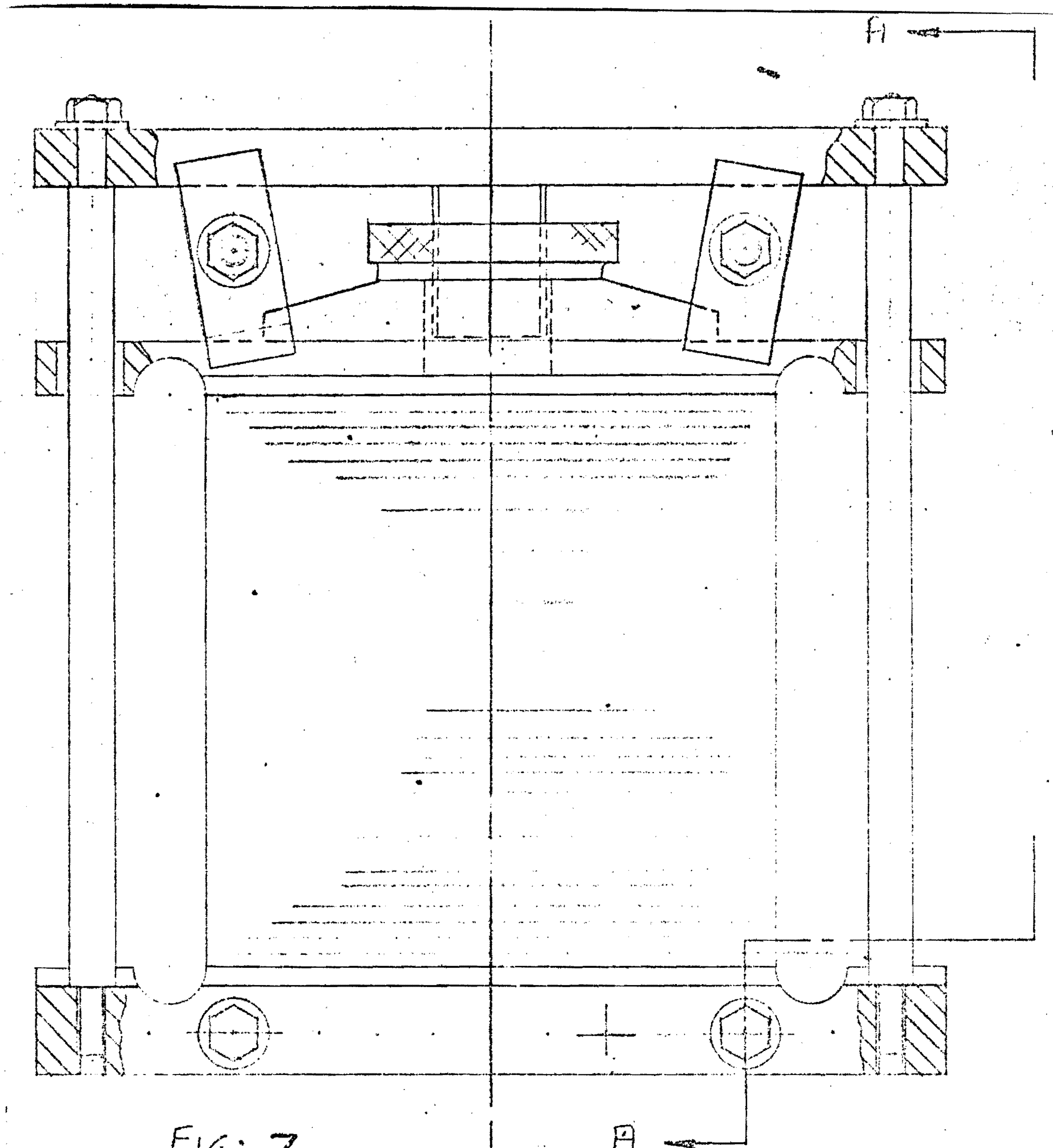
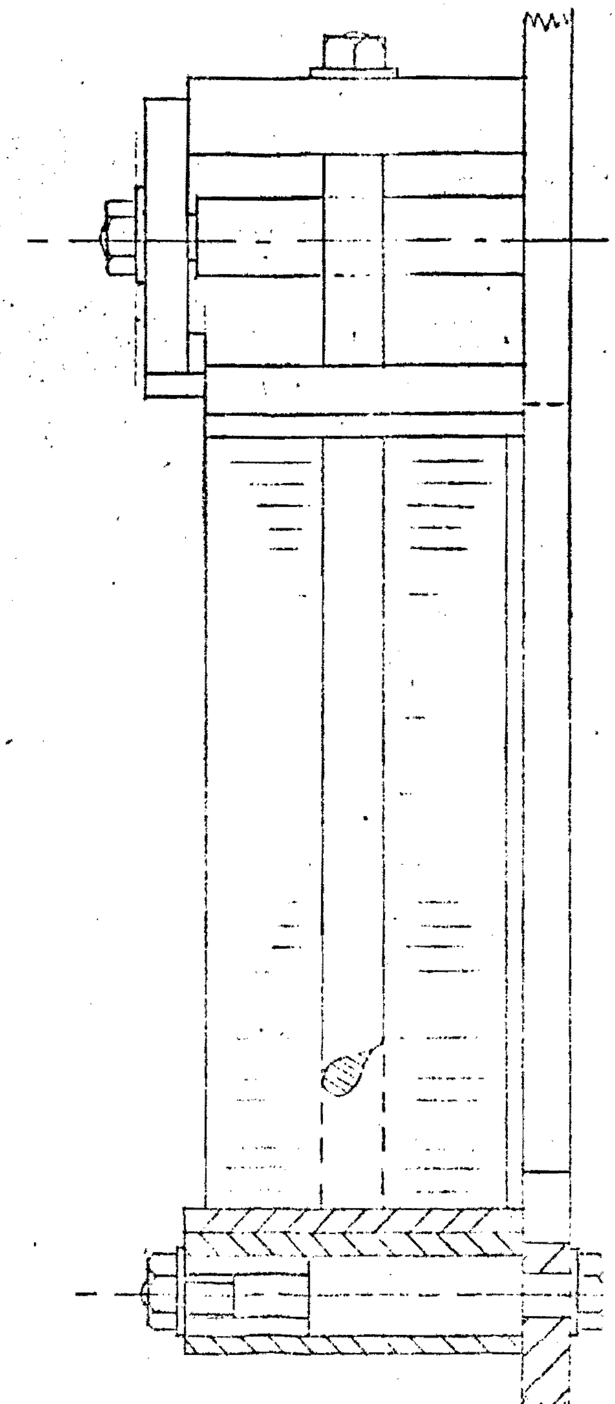


FIG: 7



SECTION AA

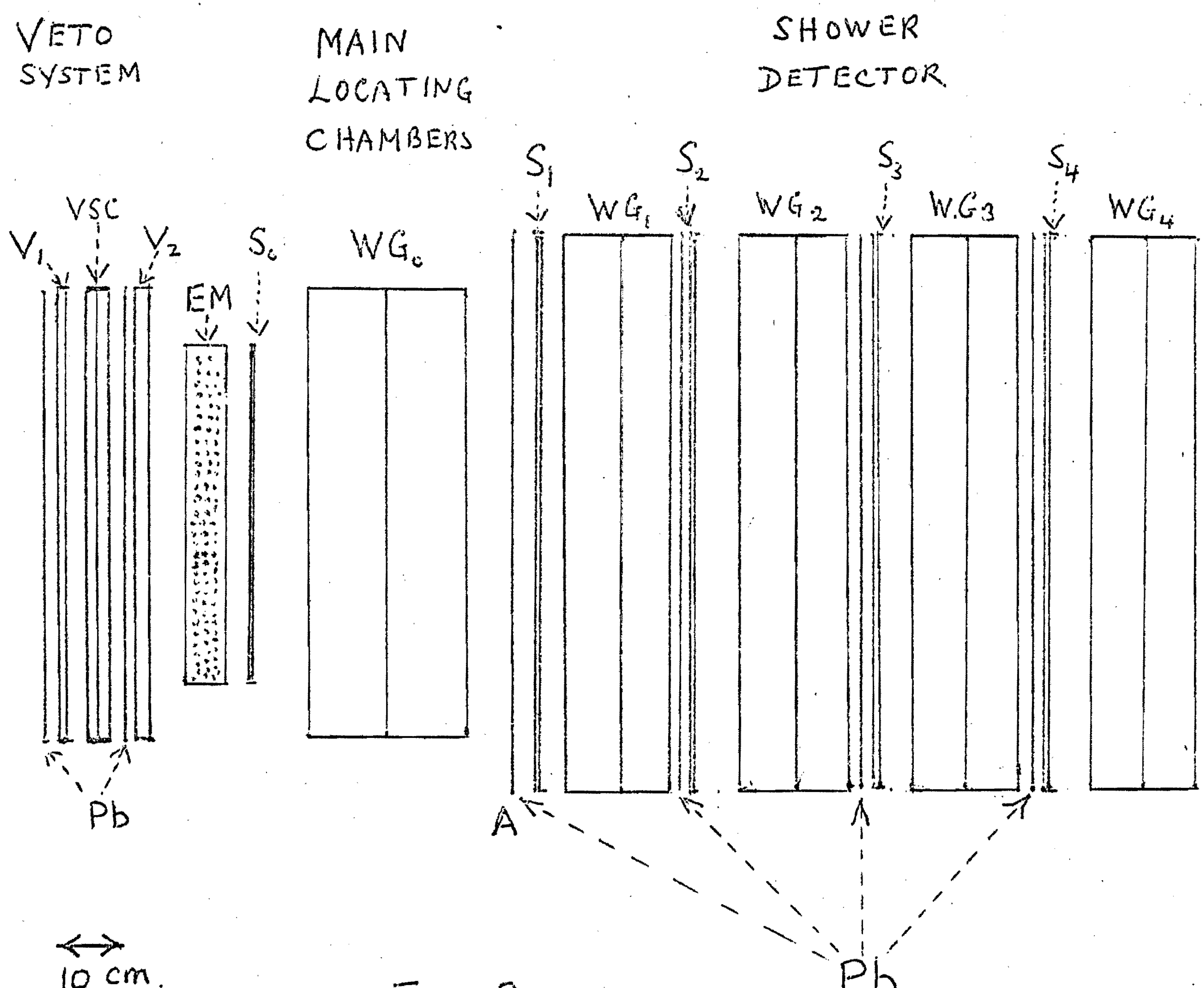
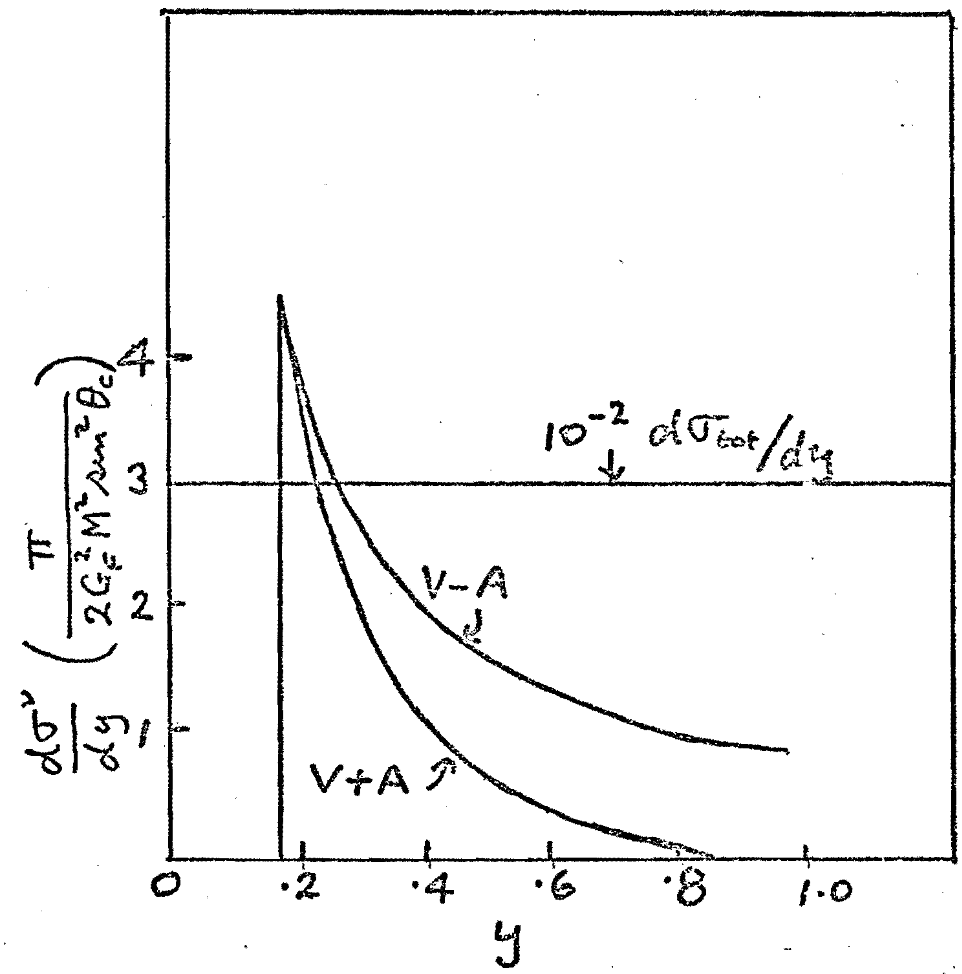

VETO SYSTEM
MAIN LOCATING CHAMBERS
SHOWER DETECTOR
VSC
V1
V2
EM
S0
WG0
S1
S2
S3
S4
WG1
WG2
WG3
WG4
Pb
A
Pb
10 cm.

Fig 8



$\frac{d\sigma^{\nu}}{dy}\left(\frac{\pi}{2G_F^2 M^2 \sin^2\theta_c}\right)$
4
3
2
1
0
·2
·4
·6
·8
1·0
y
$10^{-2}\, d\sigma_{tot}/dy$
V–A
V+A

Fig 9.

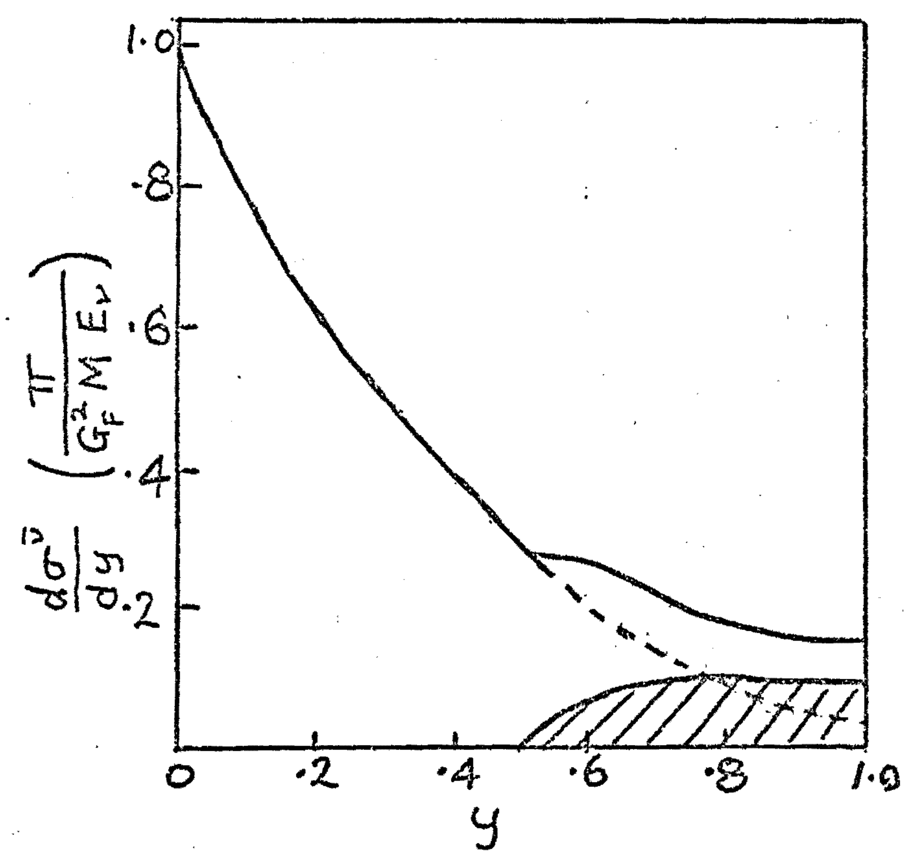


Fig. 10.

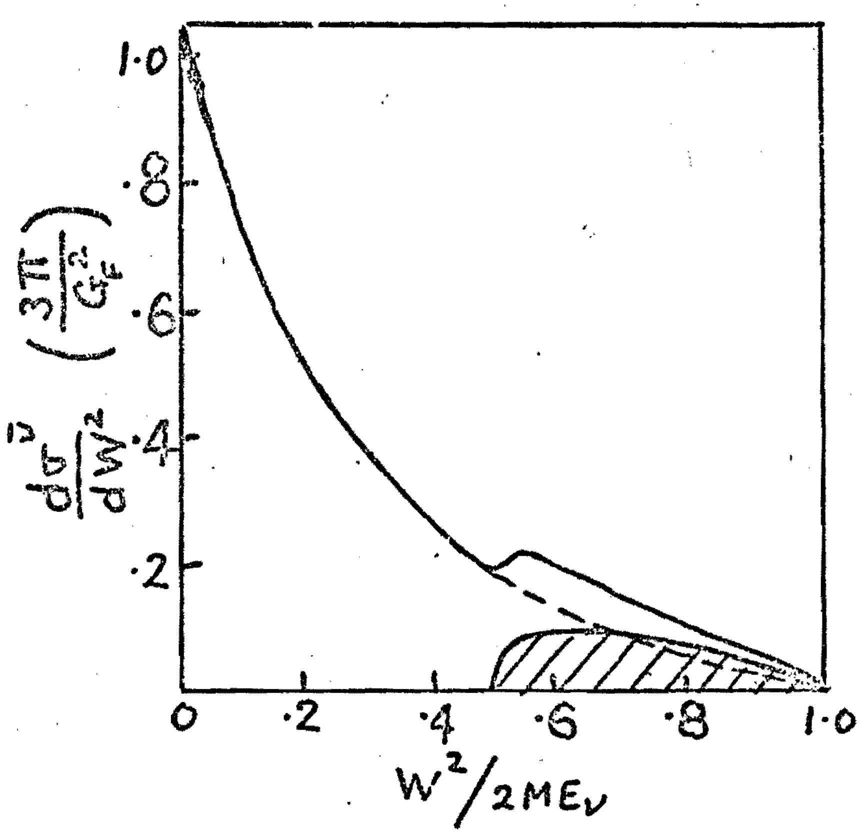
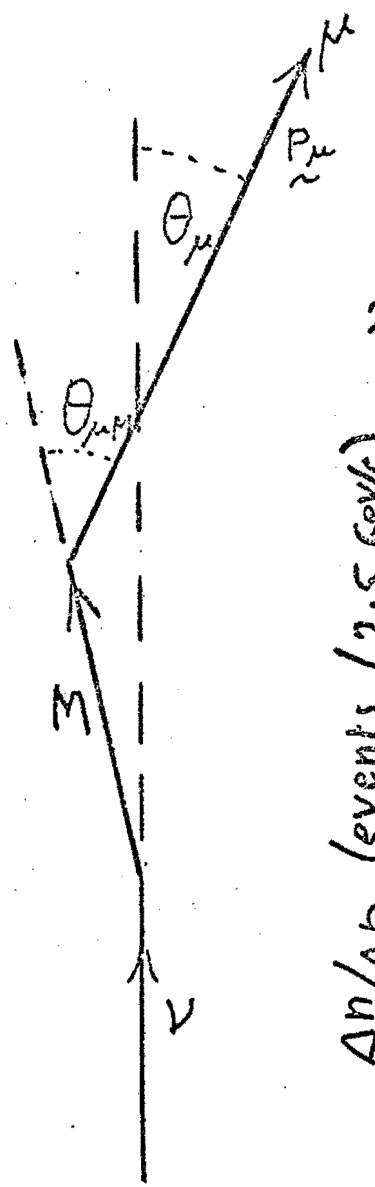
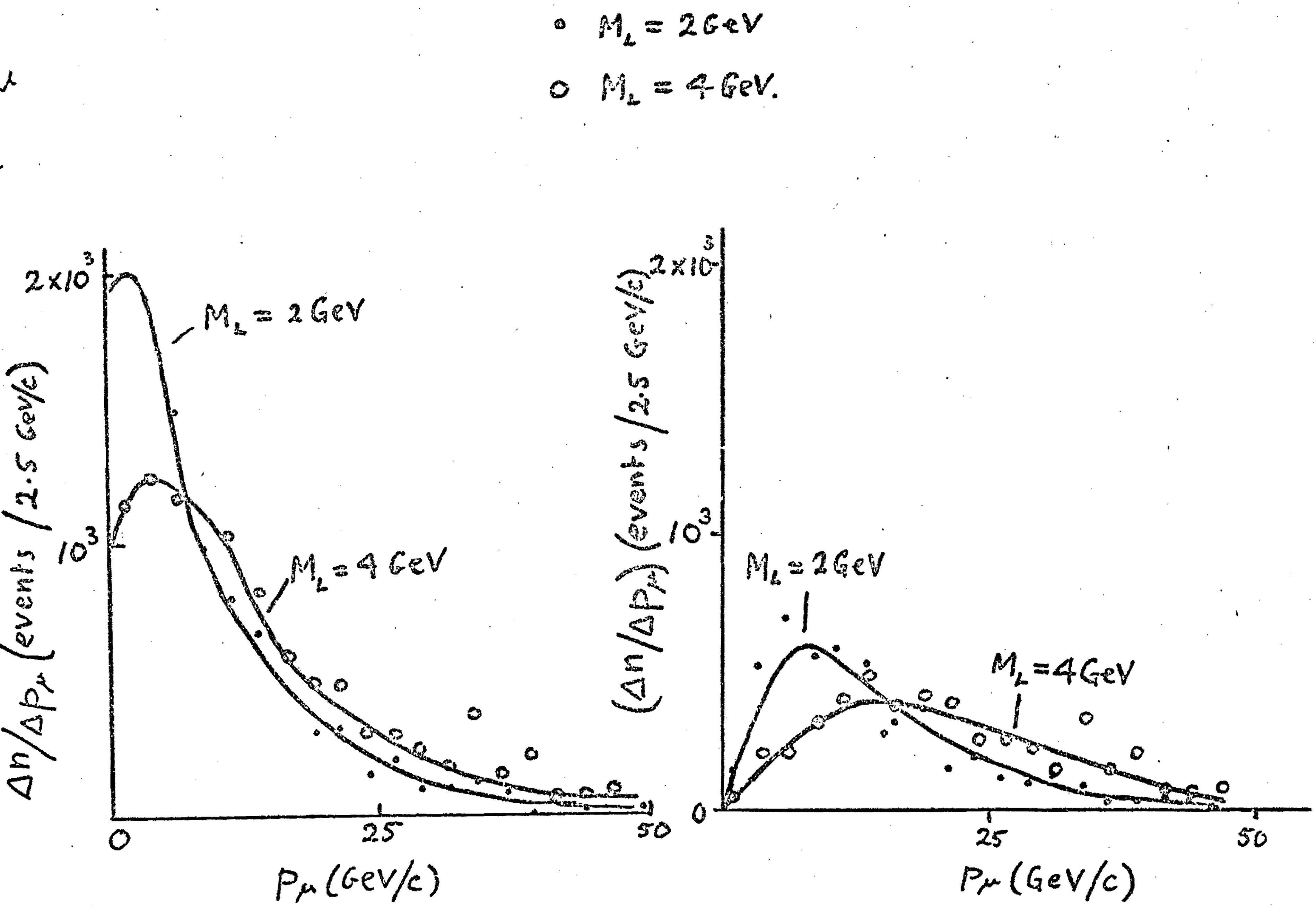


Fig. 11



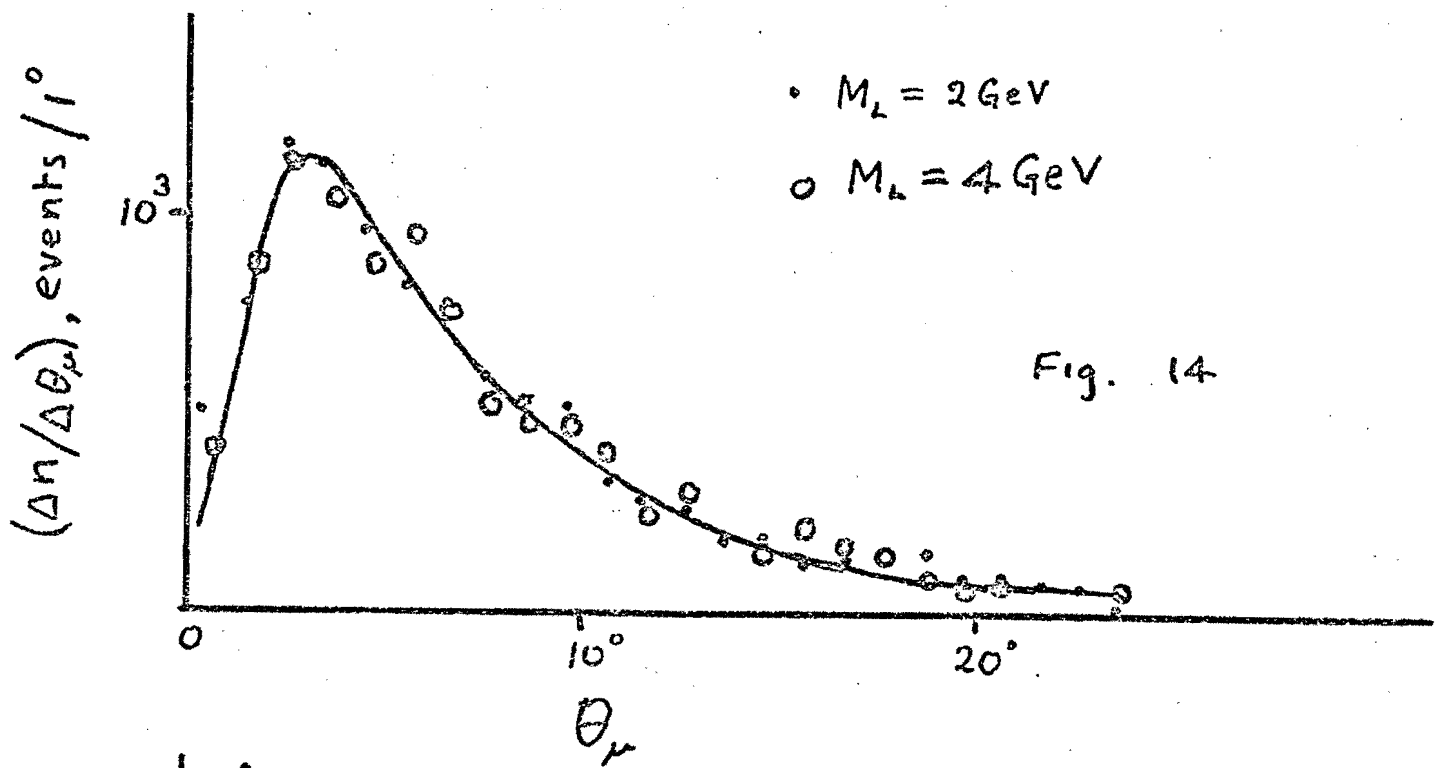
μ
P_μ
θ_μ
$\theta_{\mu M}$
M
ν

Fig. 12



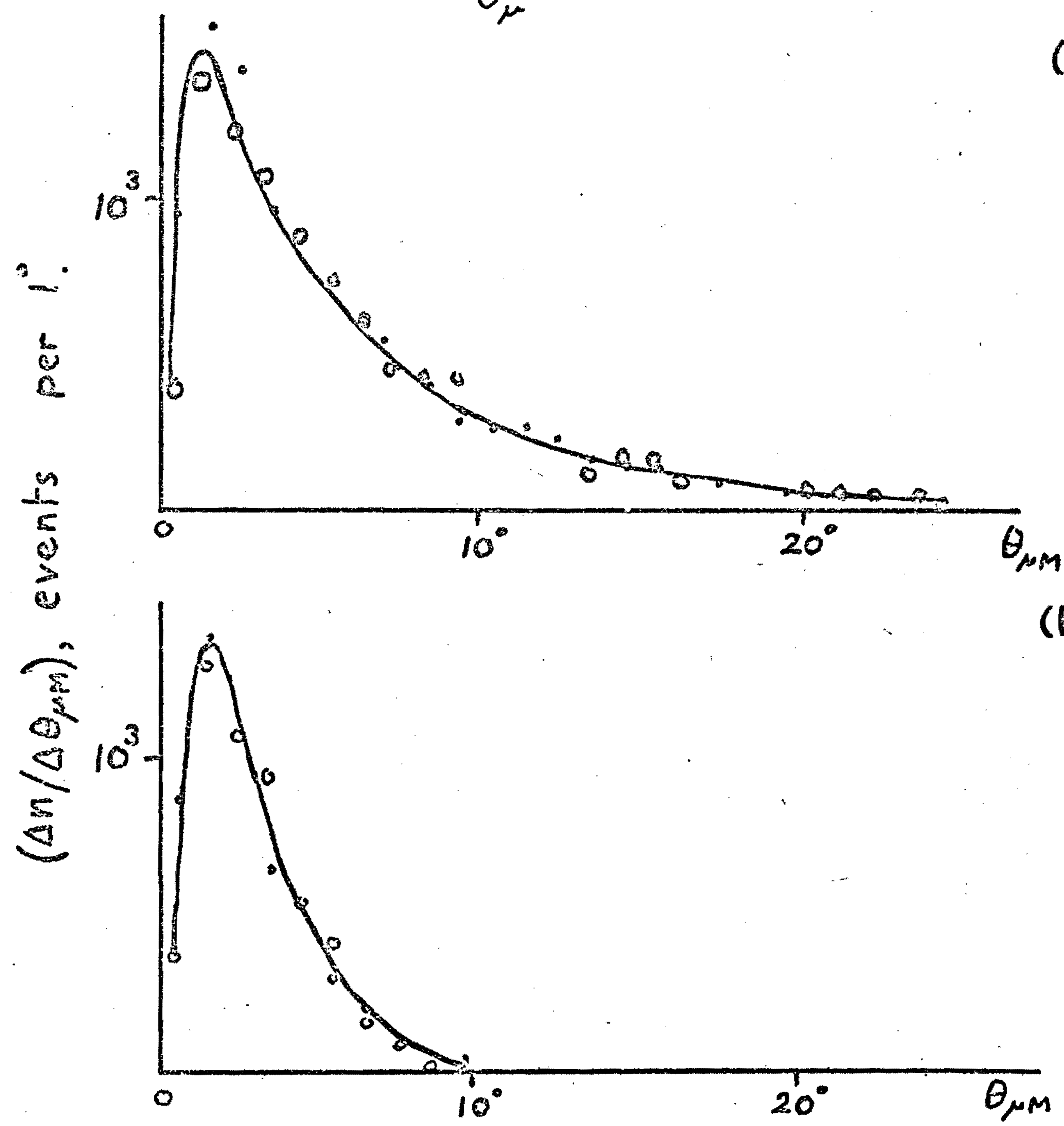
• M_L = 2GeV
o M_L = 4GeV.
2×10³
M_L = 2GeV
10³
M_L = 4GeV
Δn/Δp_μ (events /2.5 GeV/c)
0
25
50
P_μ (GeV/c)
(a)
(Δn/Δp_μ) (events/2.5 GeV/c)
2×10³
10³
M_L = 2GeV
M_L = 4GeV
0
25
50
P_μ (GeV/c)
(b)

Fig 13.



• $M_L = 2$ GeV
o $M_L = 4$ GeV
$(\Delta n/\Delta\theta_\mu)$, events/1°
10^3
0
10°
20°
θ_μ

Fig. 14



(a)
(b)
10^3
10^3
$(\Delta n/\Delta\theta_{\mu M})$, events per 1°
0
10°
20°
$\theta_{\mu M}$
0
10°
20°
$\theta_{\mu M}$

Fig 15

Updated Version of Proposal # 247
T. H. Groves
5/28/74

An experiment to search for short-lived particles $(10^{-15}s < \tau < 10^{-12}s)$ produced in the interaction of ν, $\bar{\nu}$ in emulsion.

Renormalized unified theories of weak and electromagnetic interactions require the postulation of neutral weak currents or of heavy leptons,or both. The discovery of neutral weak current processes makes it of special interest to investigate the possible existence of heavy leptons. Corresponding to the two types of neutrino, ν_e, ν_μ, heavy electrons, E, and heavy muons, M, have been postulated[1] in several models, produced in reactions

$$\nu_\mu + N \rightarrow M^+ + \text{hadrons}$$
$$\nu_e + N \rightarrow E^+ + \text{hadrons}$$

with the decay modes,

$$M^+ \rightarrow \nu_\mu \nu_\mu \mu^+ \qquad\qquad E^+ \rightarrow \nu_e \nu_e e^+$$
$$\nu_\mu \nu_e e^+ \qquad\qquad \nu_e \nu_\mu \mu^+$$
$$\nu_\mu \text{hadrons} \qquad\qquad \nu_e \text{hadrons}$$

(Note that for the heavy leptons the positive charge is supposed to go with positive lepton number).

Neutral heavy leptons with decay modes

$$M^0 \rightarrow \mu^+ \mu^- \bar{\nu}_\mu \qquad\qquad E^0 \rightarrow e^+ \mu^- \bar{\nu}_\mu$$
$$\mu^+ e^- \bar{\nu}_e \qquad\qquad e^+ e^- \bar{\nu}_e$$
$$\mu^+ \text{ hadrons} \qquad\qquad e^+ \text{ hadrons}$$

are also predicted, but possibly most readily produced by incident charged leptons. Their production by neutrinos involves neutral weak currents. Other objects decaying like

$$h^0 \rightarrow \pi^+ \mu^- \qquad \text{or} \qquad h^\pm \rightarrow \mu^\pm \gamma$$
$$\pi^0 \nu_\mu \qquad\qquad \mu^\pm \pi^0$$

have also been proposed[2].

Fig. 1 shows the relation between decay rate and mass of heavy leptons, given by Bjorken and Llewellyn-Smith. A transition rate of

$10^{15}sec^{-1}$ corresponds to a heavy lepton mass of $\approx 5\ GeV/c^2$.

The existence has also been postulated of hadrons whose isospin and hypercharge values are incompatible with the usual SU(3) scheme. They are called "charmed" particles and, if their existence could be verified, they would be characterised by a non-vanishing value for a new quantum number, called charm.[3] Charmed particles, if they exist, should also be produced in reactions like

$$\nu_\mu + n \rightarrow \mu^- + B_c + \text{hadrons}$$

with B_c, the "charmed" baryon decaying in processes

$$\begin{aligned} B_c \rightarrow\ & N\ \Pi \\ & N^*\ \Pi \\ & N^*\ \Pi\ \Pi \\ & N\ \nu_\mu\ \mu \\ & N\ \nu_e\ e \end{aligned}$$

The decay rate should be similar to that for M^+ decay, but there will be a factor $\left(\frac{g_{\Delta c(\neq 0)}}{g_F}\right)^2$, where $g_{\Delta c}$ is the coupling constant corresponding to weak decays of charmed particles. If this factor is appreciably less than unity charmed particles of masses well above 5 GeV/c^2 could have mean lives > 10^{-15}sec. The existence of charmed mesons has also been postulated and these could presumably have a similar lifetime.

Observation of neutrino interactions in nuclear photographic emulsion.

Nuclear photographic emulsion detectors have by far the highest spatial resolution of any particle detector. They can resolve events separated in space by 1 μm. A particle travelling with the velocity C will traverse 1 μm in a time of 3×10^{-15}s, so that short-lived particles of mean life of the order 10^{-15}s should be capable of direct detection using this technique.

Neutrino interactions in nuclear emulsion have been located successfully[4] by observing secondary particles (usually muons) in a spark chamber accurately located relative to a photographic emulsion stack and following them back to their origin in a neutrino interaction in the emulsion.

With the more intense and more energetic beam of neutrinos now available at NAL it is now proposed to repeat the experiment, aiming to obtain 1000 interactions in a block of emulsion of volume 10 l.

Using figures obtained with the CERN neutrino beam, for nuclear emulsion of density 4 gm cm^{-3} one would expect for the number of neutrino interactions occuring in the emulsion, 2×10^5 interactions per metre^3 per 10^{19} protons incident on the target. The higher energy neutrinos available using the NAL machine should have a larger interaction cross section, but taking the CERN figures as applicable, 10^{19} stopping protons should give 2000 ν interactions in the emulsion block. For the $\bar{\nu}$ beam this figure should be reduced by a factor of 6. At NAL the estimated number of primary protons per 6 week period is 3×10^{18}. An exposure of the stack for three six-weeks periods, spread over perhaps six months should give therefore about the required number of interactions.

The interactions may be located by line scanning along a track seen in the spark chamber as emerging from the stack. This technique was used in the earlier work. It ceases to be viable in the presence of a large muon background. The spark chamber enables the location of an event in position to within approximately 1 mm and in direction to within 1^o. A muon background such that there are more than five possible candidate tracks in this area and in the right direction would be unacceptable on account of the time required to follow spurious tracks through the emulsion. It is estimated that the time required to find an event by this method could be 7.5 scanner days.

Alternatively however interactions may be located by area scanning of a cylinder of emulsion of cross sectional area about 4 mm^2 and length equal to the thickness of the stack. Supposing a stack of thickness 5 cm this would involve area scanning of an area 50 x 2 mm^2 on each of four plates, i.e. an area of the order of 4 cm^2, a task which a competent scanner should be able to accomplish in a few hours. The time required to find an event by this method is estimated to be not more than 2.5 scanner days.

In many cases two or more tracks from a given neutrino interaction should be located by the wide gap spark chamber. In such cases it should be possible to locate the interaction within a cross sectional area of 5 mm^2 and a depth of 20 mm. Finding the interaction would then involve scanning an area 20 x 2.25 mm^2 on each of four plates, i.e. an area of 1.8 cm^2 in all.

If an area scanning technique is used to locate neutrino interactions a very much larger muon background should be tolerable since the following of tracks through from one emulsion pellicle to another is not involved. The tolerable background muon limit is then set by the memory time of the spark chambers used for location of the secondary tracks from neutrino interactions. Typically this time is of the order of 10^{-6} sec. Supposing in the whole experiment we need 10^6 pulses and the spill-out time for each pulse is 50 μsec the total spill-out time is 50 sec. The tolerable muon background is then of the order 5 x 10^7 for the whole run. In the experimental arrangement proposed below the area of stack exposed to the neutrino beam is 0.2 m^2 so that the tolerable muon background is 250 x 10^6 muons per m^2, or 250 muons per m^2 per pulse. This gives also about the maximum tolerable general background of tracks in the emulsion for an exposure of 10^6 pulses.

Neutrons produced in neutrino interactions in the shield also provide a background which may be troublesome in an emulsion experiment in a neutrino beam. Slow neutrons accompanied by low energy gamma rays could produce an unacceptable density of particle tracks in the emulsion so that it may be necessary in an experimental arrangement to make provision for shielding the stack from the neutron background.

The experimental arrangement.

Fig 2 shows the proposed experimental arrangement. Charged secondary products of neutrino interactions occuring in the emulsion stack, EM, are observed in the wide gap spark chamber, SC_2. A narrow gap chamber SC_1 together with two scintillation counters, C_1 C_2 are used to veto events in which a charged particle entered the emulsion stack. SC_1 is not essential but is useful to correct for the (small) inefficiency of C_1 and C_2. A scintillator C_3 is placed between EM and SC_2. Lead blocks downstream from SC_1 together with the scintillators C_4 and C_5 and the narrow gap chamber SC_3 enable muon secondaries to be detected.

The signal $\overline{C}_1\overline{C}_2C_3C_4C_5$ is used to trigger the spark chambers. SC_3 provides confirmation that the muon seen by C_5 is indeed correlated in direction with the muon measured in SC_2. The time of flight between C_3 and C_5 is $\sim$6 nsec so that time information from these two counters should permit rejection of particles from the cosmic ray background going through the apparatus from back to front. The lead plate behind SC_3 protects C_5 and SC_3 from the noise of low energy particles entering the system from the back.

It is proposed to insert counters at intervals along the lead degrader to permit range measurements of the secondary particles. The exact type of counter to be employed is under discussion.

The arrangement is designed to permit detection of secondary particles emitted at angles within 10° of the incident neutrino beam direction.

Emulsion stack. This is designed to be as thin as possible in the direction of the neutrino beam. If the method of along the track scanning is used this reduces the time-consuming work of following the track from pellicle to pellicle. If the method of area scanning is used it reduces slightly the area to be scanned since multiple scattering effects are kept small.

The actual volume of the emulsion is determined largely by cost considerations and the need to examine a meaningful number of interactions. To obtain about 1000 neutrino interactions in a time of about 6 months a volume of about 10 litres of emulsion is needed. The present cost of emulsion is £1400 per litre.

It is proposed that the dimension of the emulsion stack in the direction of the neutrino beam should be 5 cm and that the emulsion should be in the form of four stacks each consisting of 416 pellicles 20 x 5 cm in surface dimensions, 0.6 mm thick. These four stacks would be held in clamps and the face to be placed nearest the spark chamber SC2 milled. Fiduciary marks on each pellicle would enable it to be located accurately relative to the clamp holding it. Fiduciary marks on the clamp mountings and on the spark chamber SC2 would then make it possible to locate the tracks in the spark chamber relative to their expected position in the emulsion stacks to the required accuracy (~1 mm in position, 1° in direction).

Fig 3 shows the estimated positions of the four emulsion stacks (clamps not shown). Each will form a block of emulsion of dimensions 25 x 20 x 5 cm. Allowing for the size of the clamps the emulsion will be spread over a cross sectional area of approximately 60 x 60 cm. This determines in turn the area of the counters and spark chambers of the detection system.

If it proves necessary to shield the emulsion from a neutron and γ-ray background it may be necessary to surround the stacks with properly designed shields of paraffin wax, cadmium or boron and lead.

Spark chambers. With the event counting rate expected simple multigap optical spark chambers should be quite satisfactory. For the event reconstruction however we need a chamber allowing the measurement of tracks on a length of more than 10 cm and with a good multitrack efficiency. A wide gap chamber with separation ≈20 cm is proposed (SC_2). For high energy events the multiplicity may be high and there may be some overlapping of secondaries beamed forward so that the distance between the emulsion and SC_2 should be optimized in order to obtain at the same time a satisfactory precision (better than 1 mm) in the determination of the position at which the particles leave the emulsion and a good separation of the tracks at their point of entry into SC_2. The geometry shown in fig 2 should enable this to be achieved.

<u>Analysis of the neutrino interactions.</u>

The scanning of areas of the emulsion stack indicated by the spark chamber observations should lead to the location of neutrino interactions. The topology of types of interaction of interest to us is illustrated diagramatically in fig 4 for the cases

(a) $\nu_\mu + p \to M^+ + \text{hadrons}$

$\quad \hookrightarrow \nu_\mu + \mu^+ + \nu_\mu$

$\quad$ or $\nu_\mu + e^+ + \nu_e$ etc

(b) $\nu_\mu + p \to M^o + \text{hadrons}$

$\quad \hookrightarrow \nu_\mu + \mu^+ + \mu^-$

$\quad$ or $\mu^- + e^+ + \nu_e$

$\quad$ or $\nu_\mu + e^+ + e^-$ etc

(c) $\nu_\mu + p \to \mu^- + c^\pm + \text{hadrons}$

(d) $\nu_\mu + p \rightarrow \mu^- + C^o$ + hadrons

A separation of 1 μm between the neutrino interaction and the decay point of the heavy lepton or charmed particle should readily be detectable, corresponding to a lifetime of $3 \times 10^{-15}/\gamma$ sec, where γ is the Lorentz factor of the unstable particle.

Identification of the details of the interaction.

The information that can be expected about the secondary particles from measurements in the emulsion is limited, especially as their tracks would usually be expected to show minimum specific ionization. The short dimension of the stack in the forward direction means that information on specific ionization and multiple scattering will be meagre. The lead degrader in the electronic detection part of the apparatus should permit the separation of muons from hadrons. The introduction of counters of a suitable type at intervals along the lead degrader should permit muon energy estimates.

It would of course be useful also to know the sign of the muon. This would be difficult and costly to achieve owing to the large dimensions of the wide gap chambers over which a magnetic field would need to be established. If one were to attempt a sign determination it would be economical to introduce extra wide gap chambers. If the total length of path of the muons in wide gap chambers were 80 cm a particle of momentum 2 GeV/c would be deflected by 2 mm in a field of 500 oersted. To establish a field of this magnitude over the necessary volume two coils each of diameter 1 m separated by 1 m, each with 50, 000 ampere turns would be needed. On conservative estimates each coil would need to contain about 700 kg of copper. This would be a major addition to the cost of the experiment that would probably not be justified. If a suitable magnet were available it would be worth considering its use but it does not seem worth while to introduce a facility for sign determination otherwise at this stage. The main task at present is to investigate whether heavy leptons or charmed particles of lifetimes within the range 10^{-12}-10^{-15} sec can be detected. If positive results are obtained other experiments can be devised to investigate their nature further.

Preliminary studies to establish most suitable available location of the experiment and the backgrounds to be expected.

A cursory examination of the neutrino beam lay-out at NAL suggests that the most convenient position for the apparatus would be between the large bubble chamber and the large wide-band neutrino beam detectors. In this position the magnet of the large bubble chamber would help to sweep away the muon background. The lay-out and the backgrounds (muon, neutron, γ- ray) can only be determined in discussions and measurements on the spot. It is therefore proposed that test exposures of emulsion plates should be made at various possible locations to determine these backgrounds. Muon backgrounds should ideally be determined with the bubble chamber magnet on. If tests could also be made with it off this would also be useful. If there is serious intention to use along-the-track scanning for the detection of the neutrino interactions the muon tests would need an exposure of about 10 per cent of the proposed exposure for the whole experiment (i.e. about 10^5 pulses). If area scanning is to be used a much smaller (1 per cent) test exposure would suffice (i.e. about 10^4 pulses).

Arrangements should also be made to carry out exposures unshielded and also inside a neutron and γ-ray shield. An exposure of 10^4 pulses should suffice for this.

It has been pointed out above that the total duration of the experiment may amount to six months or more so that it is necessary to ensure that fading of the latent image of the tracks should not occur in this time. It is known that fading of the latent image is associated with humidity of the surroundings. It is intended to seal the stacks hermetically to prevent fading due to this cause. Fading may also be dependent on temperature so that it is necessary to know whether the stacks should be kept refrigerated. Test plates have been exposed to a 20 GeV proton beam at CERN and are being processed at intervals up to 6 months at Strasbourg. All the plates are hermetically sealed. Half are being kept refrigerated. The remainder are being kept at room temperature. From the results of this test run it will be decided whether continuous refrigeration of the stacks of the actual run will be necessary.

Provision will also need to be made for the storage of the stacks (presumably underground) between runs to reduce the cosmic ray background. This means also that the arrangements for mounting the stacks relative to the wide gap chamber must be very positive to ensure that it is always returned to the same position after removal.

Steps are also needed to ensure that due notice is given if part of the shielding of the neutrino beam is to be removed to enable test beams of muons or other charged particles to reach the wide band neutrino detectors behind the stack. A single pulse of this kind could completely ruin the whole experiment so that it is necessary to devise a fool-proof procedure to prevent this happening. It is proposed that the test runs at NAL should be carried out during summer 1974. If the results indicate the feasibility of the experiment a firm proposal for the main experiment will then be placed before the NAL selection committee and, if approved, it is expected the main run will be carried out during 1975.

(1) Bjorken, J.D., and Llewellyn-Smith, C.H., Phys. Rev. D 7(1973), 8887.

(2) Albright, C.H., Lettere al Nuovo Cimento 3 (1972), 71.
Ramm, C.A., Nature 227 (1970), 1323.

(3) Snow, G.A., Nucl. Phys. B55 (1973), 445-454.

(4) Burhop, E.H.S., Busza, W., Davis, D.H., Duff, B.G., Garbutt, D.A., Heyman, F.F., Potter, K.M., Wickens, J.H., Bricman, C., Lemoune, J. Sacton, J., Schorochoff, G., Roberts, M.A. and Taner, W.T., Nuovo Cimento, 39 (1965), 1037.

Figure Captions

Fig 1. Illustrating estimated production cross sections by neutrinos and decay rates of heavy leptons[1].

(a) The ratio of heavy lepton to muon production cross sections is written

$$\frac{\sigma(\nu_\mu N \rightarrow M^+ + \text{hadrons})}{\sigma(\nu_\mu N \rightarrow \mu^- + \text{hadrons})} = \left(\frac{g^M}{g^\mu}\right)^2 \Phi\left(\frac{S}{M_L^2}\right)$$

(g^M, g_μ coupling constants for the two processes,
S = (total energy)^2, M_L = heavy lepton mass)

The figure shows Φ plotted against S/M_L^2.

(b) Decay rate of heavy leptons, Γ, plotted against M_L.

Fig 2. Experimental lay out proposed
EM, emulsion stack; SC_1, SC_3, narrow gap spark chambers; SC_2 wide gap spark chambers (one may be sufficient); C_1, C_2, C_3, C_4, C_5, scintillation counters; C represent arrays of counters of a type still to be decided placed at different depths in the lead to enable muon range determination.

Fig 3. Arrangement proposed for the four stacks of emulsion, each of 2.5 litre.

Fig 4. Typical topologies of different processes involving production of heavy leptons and charmed particles.

FIGURE # 1

OMITTED

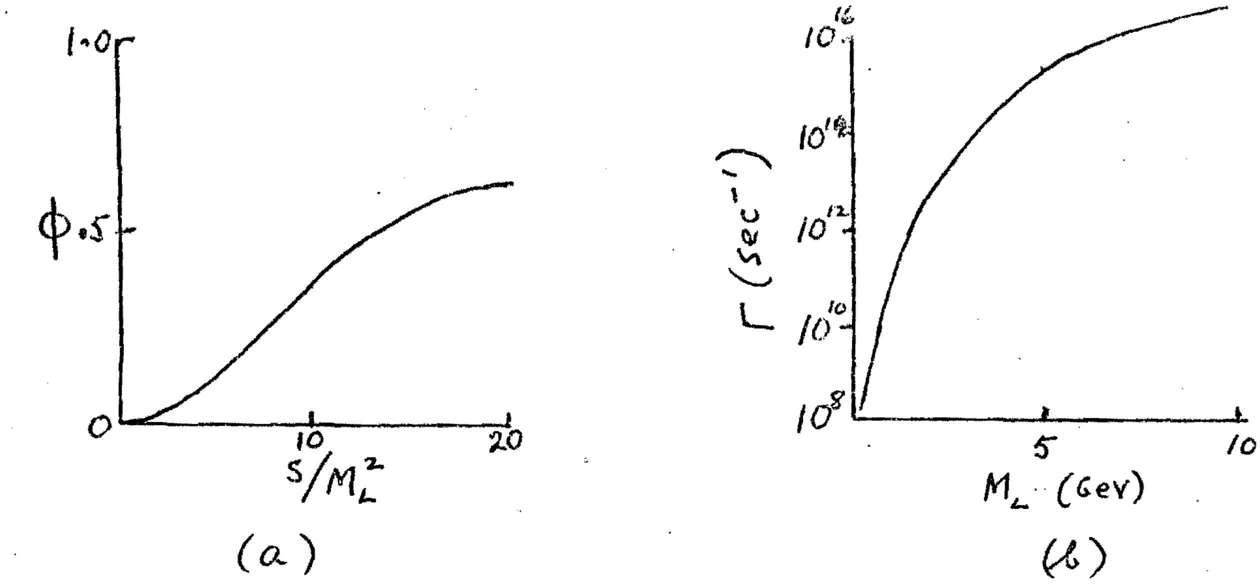

1.0
φ .5
0
10
20
s/M_L^2
(a)
10^16
10^14
10^12
10^10
10^8
Γ (sec^-1)
5
10
M_L (Gev)
(b)

Fig 1.

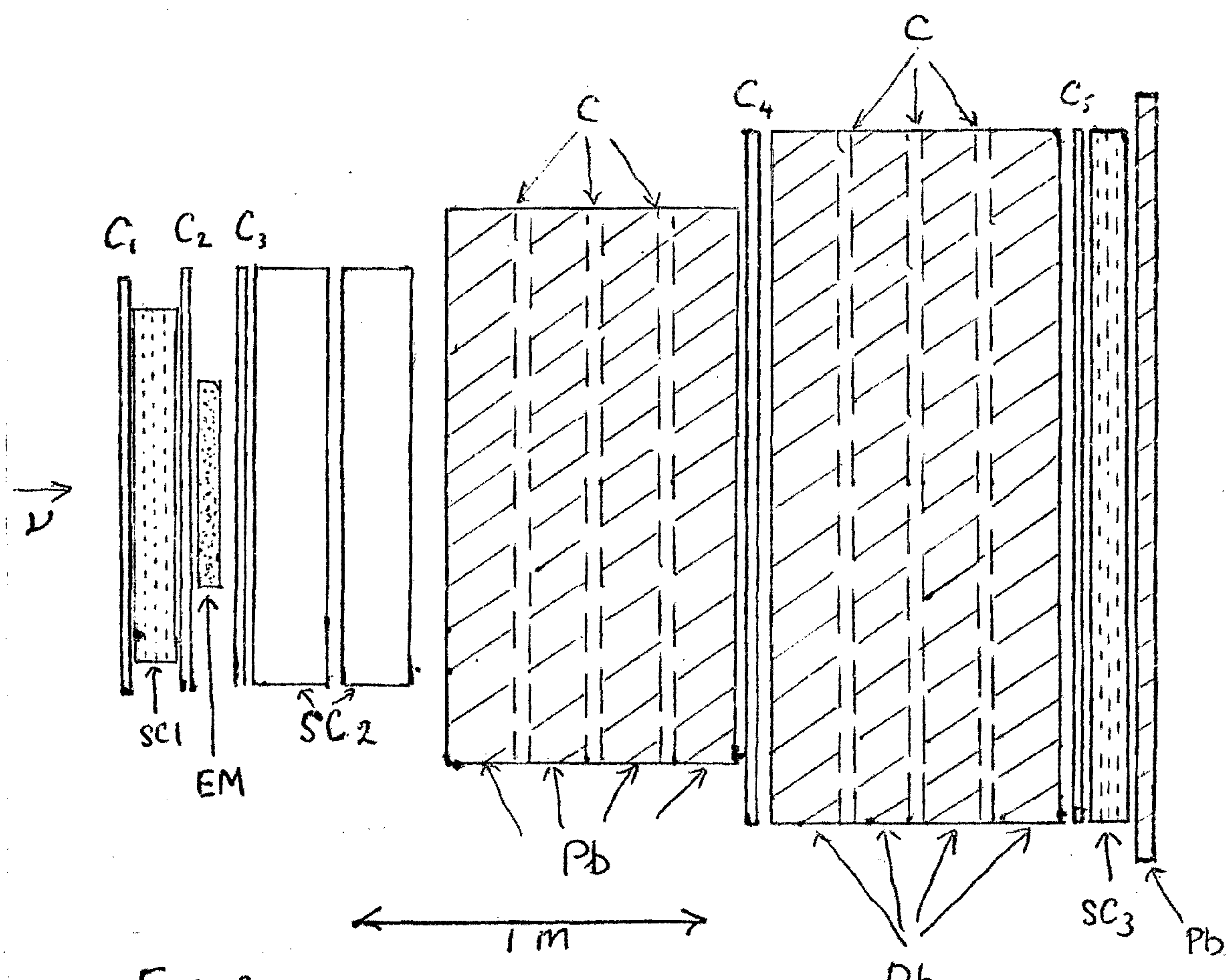

C1
C2
C3
SC1
EM
SC2
ν
C
C4
C
C5
Pb
Pb
SC3
Pb
1 m

Fig 2

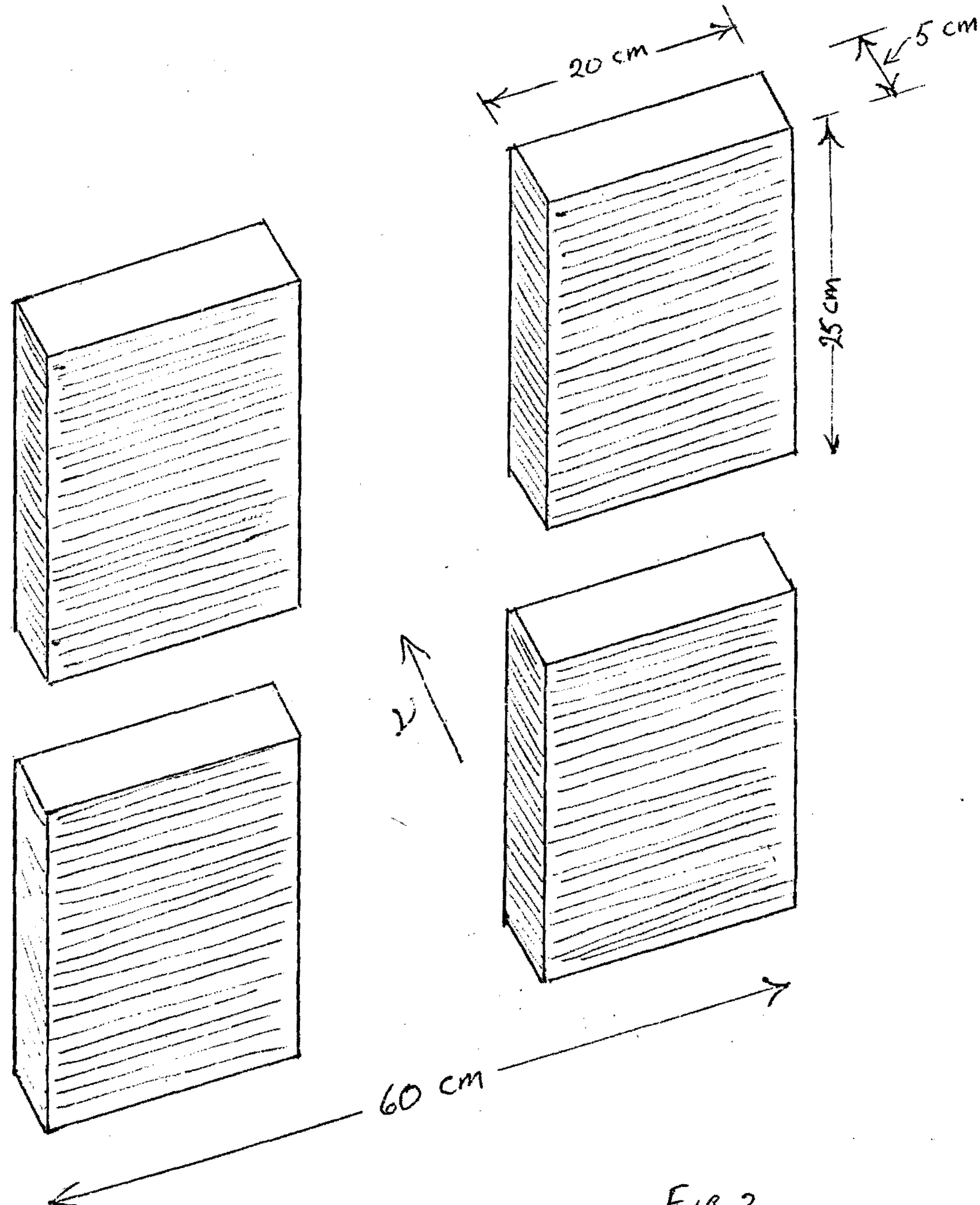
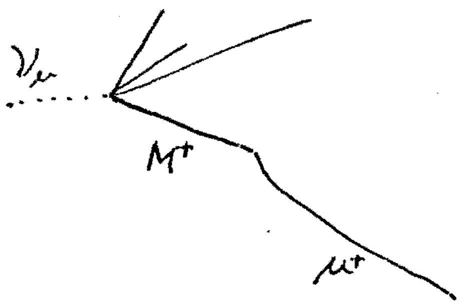
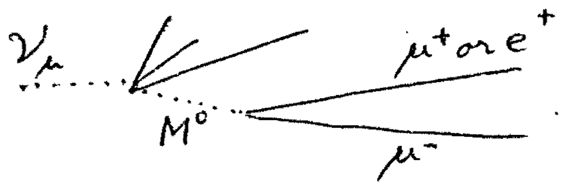


Fig 3.



(a) $\nu_\mu + p \to M^{+} + \text{hadrons}$

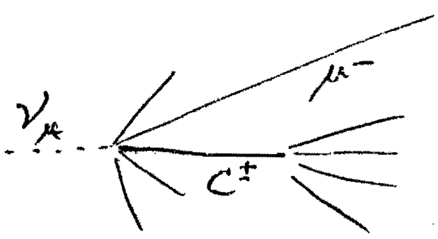
$\quad \hookrightarrow \nu_\mu + \mu^+ + \nu_\mu$



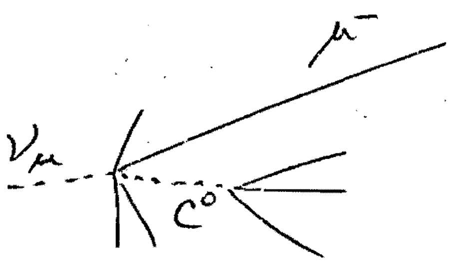
(b) $\nu_\mu + P \to M^0 + \text{hadrons}$

$\quad \hookrightarrow \nu_\mu + \mu^+ + \mu^-$

$\quad$ or $\nu_e + e^+ + \mu^-$



(c) $\nu_\mu + P \to \mu^- + C^\pm + \text{hadrons}$



(d) $\nu_\mu + p \to \mu^- + C^0 + \text{hadrons}$

Fig 4.

PROPOSAL TO SEARCH FOR SHORT-LIVED PARTICLES PRODUCED IN ν INTERACTIONS IN EMULSION, USING AN EMULSION-SPARK CHAMBER HYBRID SYSTEM (PROPOSAL 247)

Bruxelles, Dublin, FNAL, London, Rome, Strasbourg Collaboration

Summary. The discoveries of non-strangeness changing weak neutral currents and of ψ particles have focussed interest on the possible existence of charmed particles and heavy leptons that could well have lifetimes in the range 3 x 10^{-15} to 3 x 10^{-12} sec. One way of producing these could be in the interactions of fast neutrinos with nucleons. Bubble chamber and spark chamber detectors have insufficient spatial resolution to detect such short-lived particles directly but the nuclear emulsion should enable their detection if they are produced in this way. To scan a large emulsion stack for neutrino interactions without any other aid would be practically impossible. By using a hybrid arrangement in which secondaries from such interactions are located in associated spark chambers and then followed back through the emulsion to their origin, however, such neutrino interactions in emulsion have been located. It is proposed to use a similar technique in the present experiment, the neutrino interaction either being located by track following as previously, or by area scanning of the region of the emulsion where the origin of the interaction is predicted from a reconstruction of the secondary tracks observed in high-space-resolution wide gap spark chambers.

The present agreement envisages a search for neutrino interactions in an emulsion stack of volume 20 litres, the secondaries being located by wide gap chambers down-beam from the stack. These chambers would be triggered by a scintillation counter system coincidence signal indicating a neutrino interaction in the emulsion stack. The arrangement will be triggered for interactions in which either one of the secondary particles is a muon or electron of energy greater than some specified value. A spark-chamber-scintillation counter arrangement, constituting a shower detector, will be used to estimate fast secondary electron energies.

For an exposure of 2 x 10^{18} protons on target approximately 500 neutrino interactions would be expected in the emulsion stack. With the scanning and analysis strength available to the collaboration it is anticipated that the work of locating and analysing these would take approximately one year.

Annex 1

Annex 2

ORGANISATION EUROPÉENNE POUR LA RECHERCHE NUCLÉAIRE
CERN EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

1211 GENÈVE 23
SUISSE / SWITZERLAND

Téléphone: (022) 41 98 11
Telex: GENÈVE - 2 36 98
Télégramme: CERNLAB-GENÈVE

Votre référence
Your reference

Notre référence
Our reference NP/MC/sm

A rappeler dans la réponse
Please quote in your reply

Dr. L. Voyvodic
Fermi National Accelerator
Laboratory
P.O. Box 500
BATAVIA, Ill. 60510
USA

Genève, July 2, 1975

Dear Voyvodic,

As agreed after the phone conversations Burhop and I had a few days ago with Lincoln Read, I am sending you, enclosed herewith, the drawings of the experimental set-up to be installed at FNAL for our experiment E247. These drawings, as well as the figure captions - also enclosed - are an integral part of the official "Agreement" which Professor Burhop has sent to you in the meantime. They correspond to a solution which was first discussed at the last collaboration meeting, held at CERN on June 25 and 26.

After this meeting I learnt from Carlo Rubbia that experiment E310 will run with fast ejection (20 microsec) at a machine intensity which cannot exceed 1.2×10^{12} ppp, due to background problems in their wide-gap chambers. Furthermore we have now received the drawing of the lay-out of E310, sent by Lincoln Read, from which it would appear that 1 foot is the space available for us... All this reinforced the view, already expressed by several of us at the meeting, that a self-contained apparatus must be used for our experiment.

The solution proposed here is based on the presumption that a trailer of convenient dimensions can be found and installed in the free area after the 15 foot bubble chamber, and that iron or concrete blocks can be provided at FNAL in the quantitity necessary to filter muons of energies greater than ~1.5 GeV.

Such a solution appears satisfactory in many respects:

a) It gives E247 complete independence from E310, yet leaving the possibility of a future link (if judged convenient in spite of our present view) between the set-ups of the two experiments.

b) It allows us to start the test run, possibly in October, without disturbing E310 with a small emulsion stack (e.g. 1 litre).

c) It yields a larger number of events then foreseen in the original proposal, since the muon trigger has now an effective solid angle larger than before.

d) It allows one to keep all delicate instrumentation well protected in place (inside the trailer) during the period between the end of the test run and the start of the final runs at FNAL.

The drawback with respect to the original proposal is that the information on the secondary particles from the neutrino events is not as rich as we expected originally from the link to E310. Nevertheless, in the solution proposed here the direction of the outgoing muons can be measured in a simple way, with an accuracy of $\pm 2^{o}$, as explained below (see point 2). This possibility is not indicated in the enclosed drawings of the set-up, since we decided to keep them as close as possible to the sketch of the original proposal. You will judge yourself if it will be convenient to mention explicitely such a possibility in the "Agreement" once you have read point 2 below.

As a matter of fact the enclosed figure captions give only a brief description of the main parts of the experimental set-up. They can be changed and enlarged with further information, if you and Lincoln Read will judge it convenient on the basis of what I am now going to add for your own information.

1. General lay-out

It is assumed that the veto system, the emulsion stack (ES), the wide gap chamber (WG), the shower detector (SD), the electronics yielding the trigger pulses and the optical system can all be contained in a trailer, or in convenient huts, equipped with electric power, where at least two physicists can stay also for long period of times to run the experiment. The drawing of Fig. 1 assumes that a single trailer of useful dimensions 8mx3mx3m (height) is available. The lay-out indicated in the figure should be re-arranged of course to adapt it to the type of geometry really available.

The equipment contained in the trailer (self-consistent for the part of the experiment related to the "electron trigger") is the same already indicated in the rough dimensioned sketch attached to my letter of June 20 to you, Read and Stefanski, except that only one veto counter has been left.

2. The muon detector

In order to make the experiment fully self-consistent, we propose to instal outside the trailer a simple detector providing the muon direction and the "muon trigger". The latter is obtained by requiring that a charged particle penetrates a convenient thickness of dense material (e.g. a 1.2 m thick block of iron, as in Fig. 1) and traverses a scintillation counter, S_{μ}, placed with its photomultipliers under convenient protection. The method for measuring the muon energy by large and unexpensive "pulsed counters" (see my previous letter) cannot probably be applied at maximum beam intensity with short spill-out because there will be in general more than one muon traversing the counters.

The direction of the muons emerging from the trailer can be obtained with the help of honeycomb structured "plastic chambers" with electric read-out. This technique has been the subject of a systematic investigation in Rome, partially reported at the last Instrumentation Conference (see Proc. of 1973 International Conference on Instrumentation for High Energy Physics, Frascati, 1973, page 184). These chambers are rugged, very easy to construct and to operate, unexpensive, well suited to our case where no high space-time resolution or large trigger rate are required. Each honeycomb element of the chambers provides an output pulse of a few Volt on a 50 ohm resistor, if it has been traversed by an ionizing particle just before the chamber was sensitized by a high voltage pulse (as in the familiar case of a spark chamber). The output pulses from the honeycomb elements are used to light little lamps to be recorded on the same picture frame containing the views of the WG and SD optical chambers.

Fig. E("Extra" figure for your own information, not to be attached to the "Agreement") illustrates the method. The muon trajectory is localized within a square of side Δ. Due to scattering in the dense material it is pointless to make Δ smaller than 2.5 cm.

The chambers are filled with an ordinary Ne-He gas mixture which flows slowly through the honeycomb elements. They can be left outside the trailer, with presumably no temperature control or any special protection, other than localized protection of particular points against humidity, easy to achieve.

3. Optics

The events will be recorded on 70 mm high sensitivity Kodak 2485 film. Two views of the WG and ordinary spark chambers will be recorded on a single frame, together with relevant information such as event number, date and time, pulse heights of counters of the S.D., lamps yielding the direction of the muons outside the trailer, etc.

The solution adopted for the optical recording of the events is obviously not unique and can be changed easily if required by geometrical contraints not foreseen at present.

4. Test run

During the last meeting we have reached the conclusion that the test run - to be carried out if possible in October - be made as a test of the experimental technique and of all main components of the apparatus, rather than as a test of some physical interest. Accordingly a sample emulsion stack of approximately one litre should be sufficient for this run. Moreover, all parts of the equipment of Fig. 2 should be transported to and installed at FNAL for being tested under the same conditions of the final runs.

In this connection it seems very important that you check whether the machine energy (300 or 400 GeV?), the primary beam intensity ($\sim 10^{13}$ ppp?) and the spill-out time (20 µsec?) can be in the test run as they are foreseen to be in the final runs.

5. Status of the experimental set-up

The main parts of the experimental apparatus are now ready, with the exception of the second (downstream) WG chamber of Fig. 2 and the plastic chambers to be installed eventually in order to detect the muons outside the trailer. All these chambers will not be ready before a few months; but we feel that their absence in the October test run would not make the latter less meaningful.

As I wrote in my previous letter of June 20 to you we have already tested in May, at the CERN PS, the two main parts of the apparatus of Fig. 2, i.e. the first (upstream) WG chamber and the shower detector. I am enclosing for your information a report by M. Schneegans on the results concerning the WG chamber. Another report on the behaviour of the shower detector is being prepared. We plan to complete the tests of the WG chamber and S.D. with further runs at the CERN PS in the third week of July. After that we could ship all the equipment, so that it will reach Chicago in September, provided we get a positive answer from you on the present proposal.

6. Conclusive remarks

I feel that it is extremely important to take soon a decision on this proposal and to coordinate accordingly the efforts here and there in order to avoid energy losses and useless time-consuming work. In order to know if the self-consistent solution proposed here appears realistic to you and Lincoln Read I will call you up from CERN on 11th of July (Friday) at 10 a.m. Chicago time.

I hope you will be able to answer the question posed at point 4 above concerning the machine operating conditions, as well as the following other questions:

1) Could you provide the trailer (or the huts) and the iron (or concrete) blocks for the muon trigger, once the possibility of installing all our self-consistent equipment after the 15' bubble chamber has been clarified?

2) Could we run our experiment in parallel with the 15' bubble chamber at the maximum beam intensity, as foreseen in the original proposal?

As soon as the July test runs at the CERN PS are completed, one of us could spend a visit to FNAL to clarify further points difficult to settle by letter or by phone.However, on account of our present financial and time limitations, this would represent an effort to be made only if essential for the success of the experiment. Unfortunately Eric Burhop will not be able to come. I have serious difficulties, but could come early in August if you think this would be really important. Could you please inquire before July 11 if Bob Wilson and/or Ned Goldwasser will be there in that period?

I hope that this long letter will be of some help in clarifying the rather complex situation and am looking forward to hearing from you by phone next week.

Sincerely yours,

Marcello Conversi
CERN-NP

c.c.: Professor E.H.S. Burhop, University College, London
Dr. Lincoln Read, Fermilab, Chicago
Group Leaders of the Bruxelles, Dublin, London, Rome, Strasbourg Collaboration

Enclosures:

3 drawings to be attached to the "Agreement"
1 "Extra"figure, Fig. E
1 report on WG chamber tests at CERN

FIGURE CAPTIONS

Fig. 1 Plant of general lay-out for experiment E247.

Fig. 2 Side view (A) and plant (B) of apparatus to be installed inside the trailer (or convenient huts) for experiment E247.

Fig. E The direction of the muon emerging from the trailer can be determined by means of two double-layer plastic chambers, with honeycomb square elements of side $\Delta = 2.5$ cm, provided with electric read-out (see 1973 Frascati Instrumentation Conference, p.184). These chambers can operate with 100% efficiency, free of spurious discharges, over a wide range of HV pulses, gas mixtures and rate of gas flow, at trigger rates up to about 1 per sec.

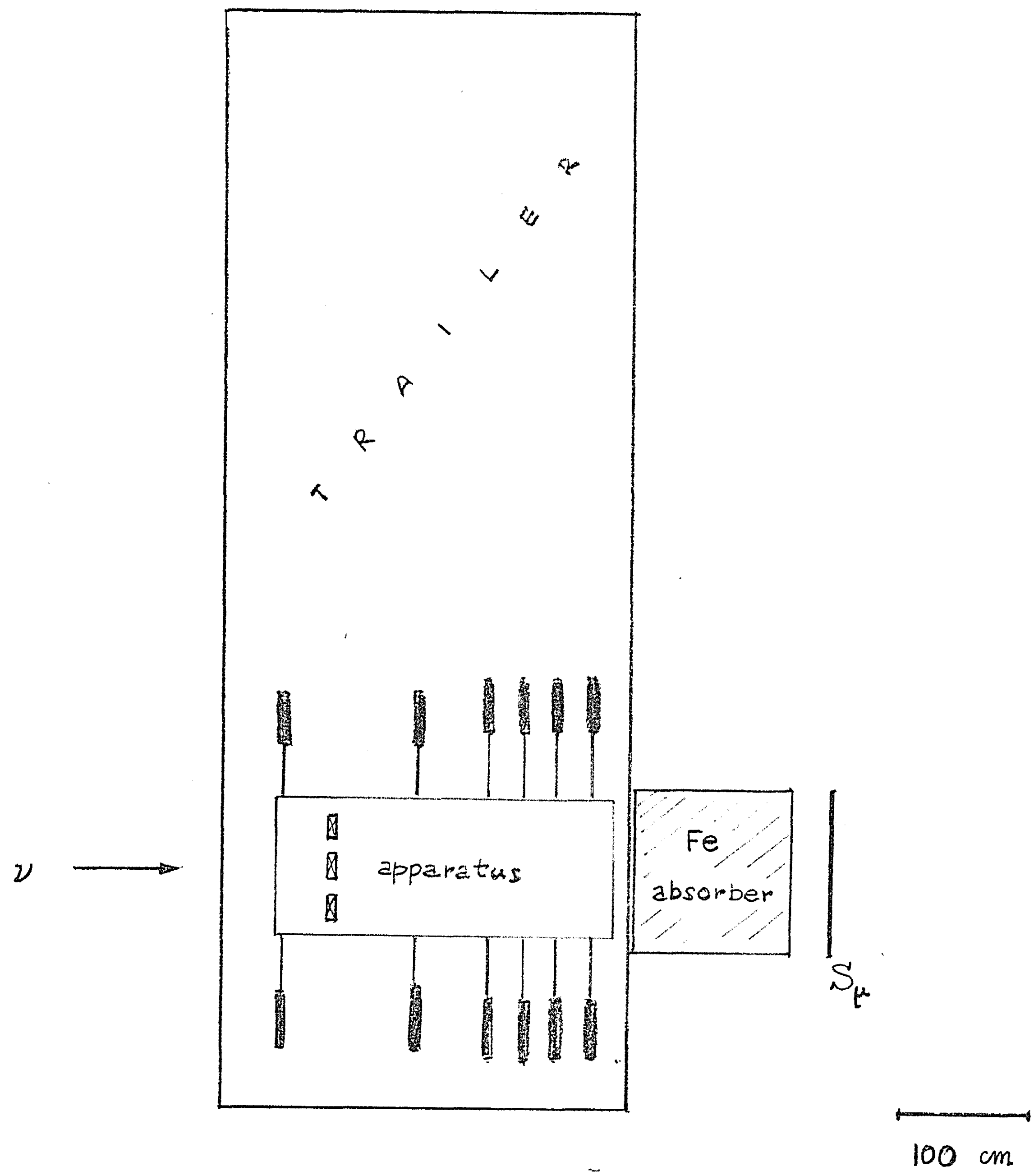


Fig. 1

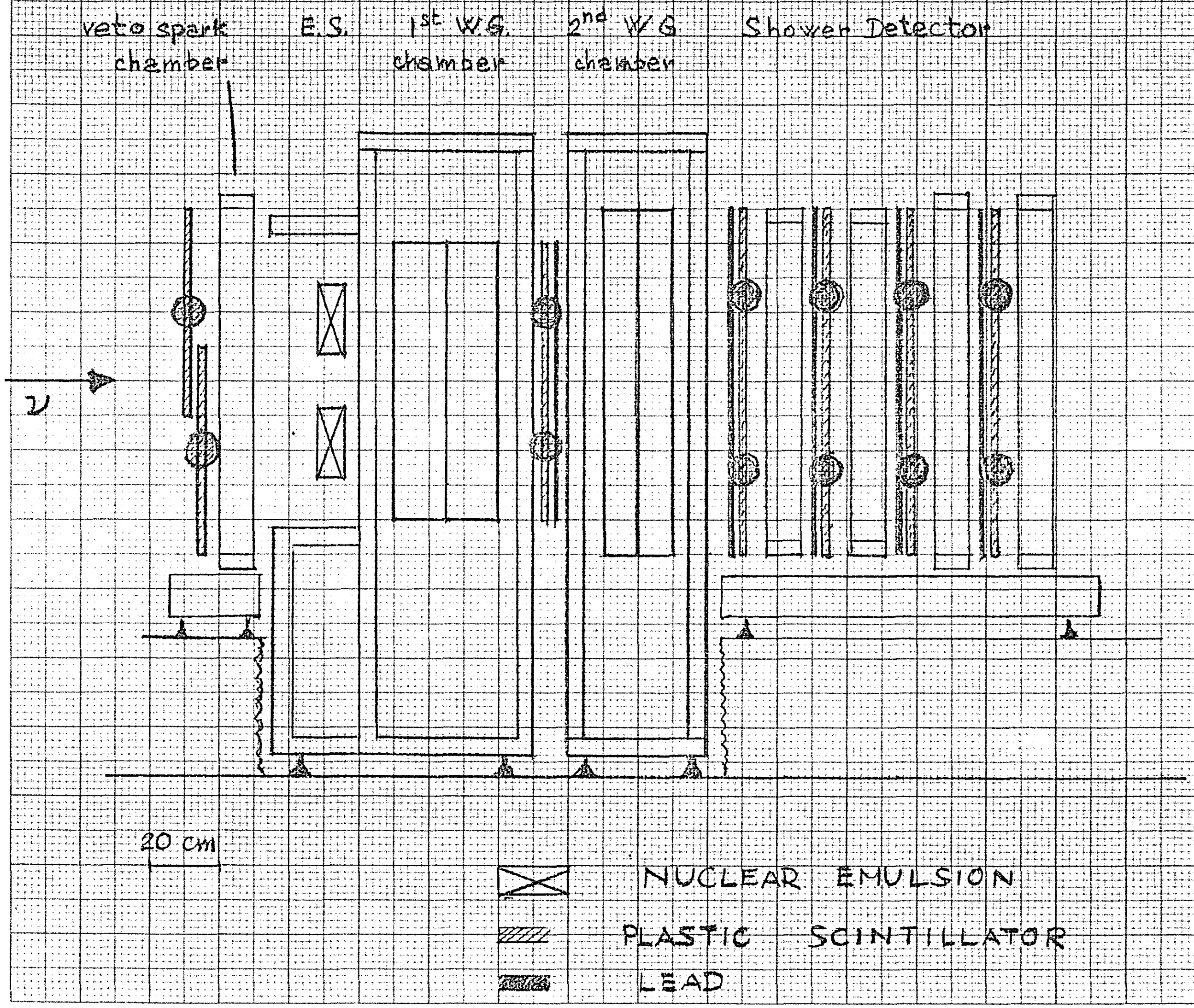
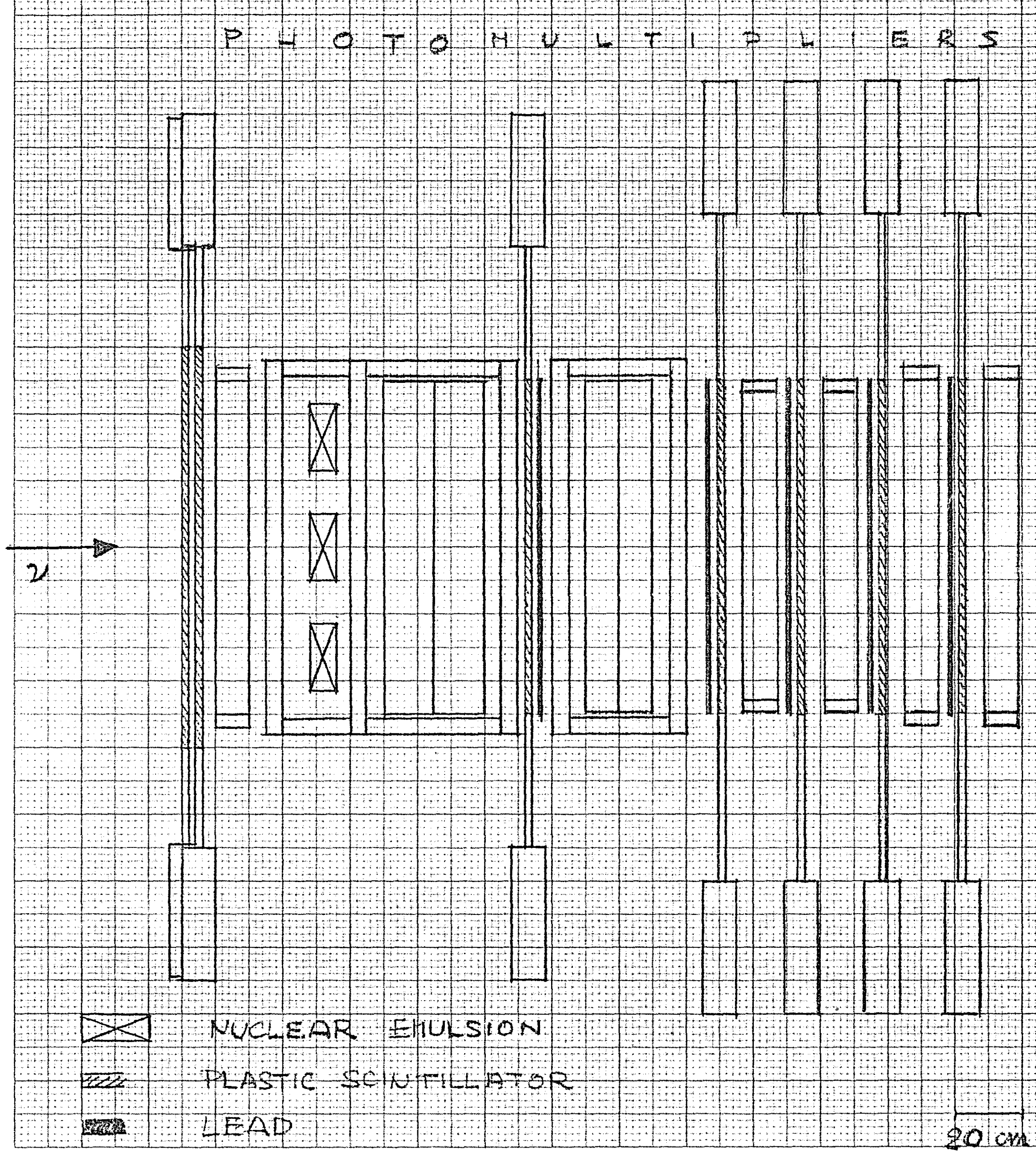
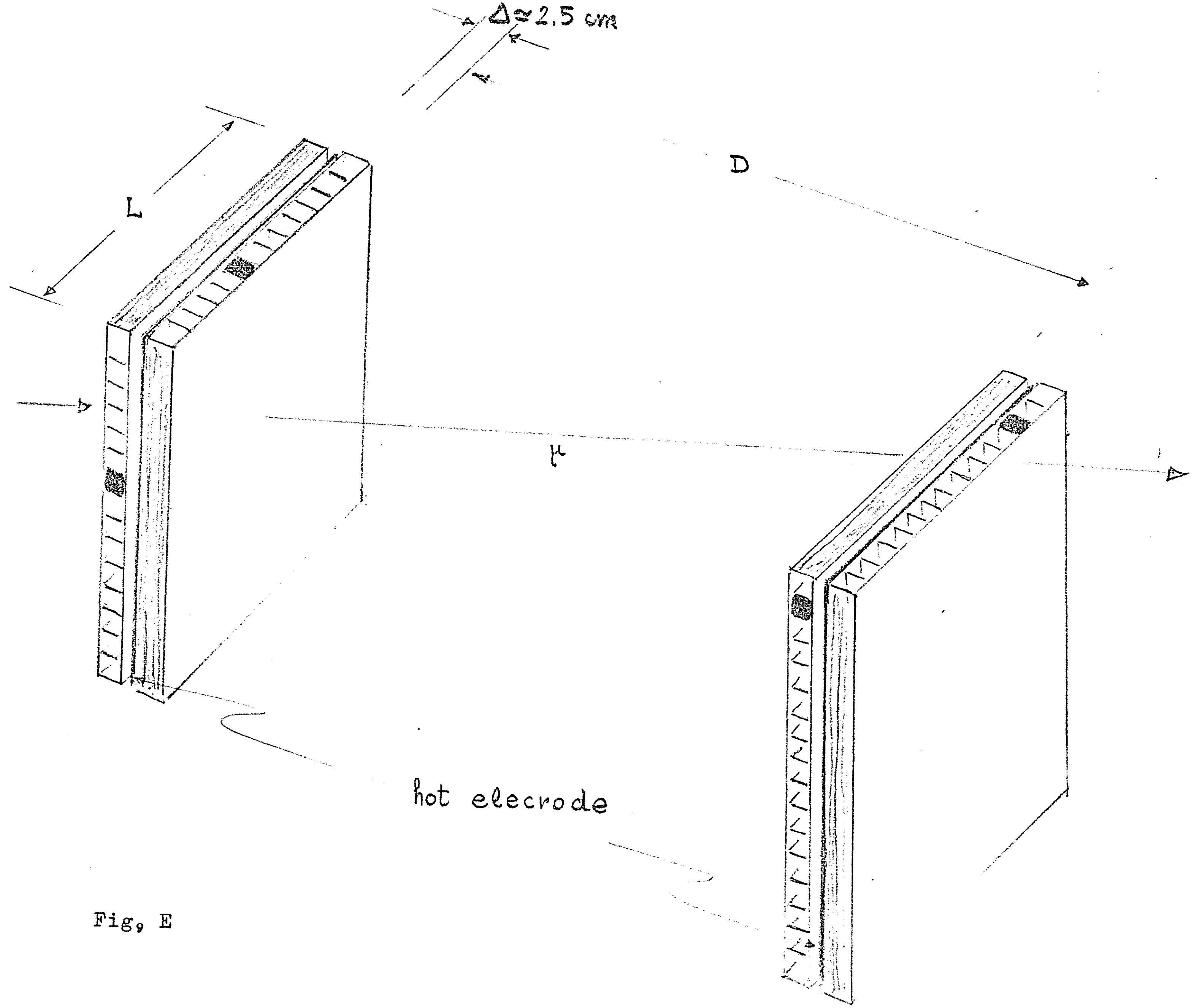

veto spark chamber
E.S.
1st W.G. chamber
2nd W.G chamber
Shower Detector
ν
20 cm
NUCLEAR EMULSION
PLASTIC SCINTILLATOR
LEAD

Fig. 2a



PHOTOMULTIPLIERS
ν
NUCLEAR EMULSION
PLASTIC SCINTILLATOR
LEAD
20 cm

Fig. 2b



Fig, E