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G. Barbàrino, G. Barbiellini, B. Barbini, M. Castellano, F. Cevenini, C. Guaraldo, S. Patricelli, M. Placidi, F. Picozza, E. Sassi, R. Scrimaglio, L. Tortora, U. Troya and S. Vitale: AN EXPERIMENT ON NEUTRINO-LEPTON SCATTERING
(Frascati - Napoli Collaboration). -

G. Barbarino^(x), G. Barbiellini, R. Barbini, M. Castellano^(x), F. Cevenini^(x), C. Guaraldo, S. Patricelli^(x), M. Placidi, F. Picozza, E. Sassi^(x), R. Scrimaglio, L. Tortora^(x), U. Troya^(x) and S. Vitale^(x):
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1. - INTRODUCTION -

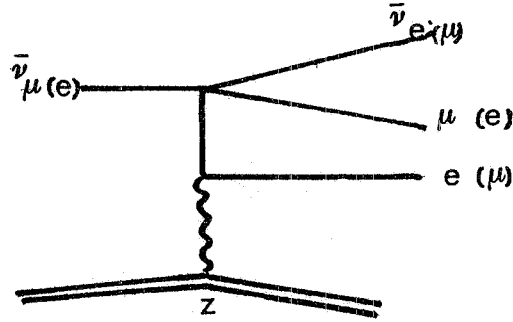
In the neutrino counter experiments proposed for the SPS the direction of the produced electrons cannot be measured with good angular resolution, because the subdivision of the sensitive and target materials is too coarse. We propose here a spectrometer for high energy electrons having a good angular resolution (~ 2 mrad) and which would allow measurements of the electron energy with a typical resolution $\Delta E/E = 0.15/\sqrt{E}$ GeV. This apparatus would be suitable for the study of neutrino-lepton interactions, which are characterized by a very forward peaked production of electrons, and in particular the study of the reactions

- (1) $\nu_{\mu} e \rightarrow \nu_{\mu} e$
(2) $\bar{\nu}_{\mu} e \rightarrow \bar{\nu}_{\mu} e$
(3) $\bar{\nu}_{\mu} Z \rightarrow \mu^{+} e^{-} \bar{\nu}_{e} Z$
(4) $\nu_{e} e \rightarrow \nu_{e} e$
(5) $\bar{\nu}_{e} Z \rightarrow e^{+} e^{-} \bar{\nu}_{e} Z.$

The reactions $\nu_{\mu} e \rightarrow \nu_{\mu} e$ and $\bar{\nu}_{\mu} e \rightarrow \bar{\nu}_{\mu} e$ are the cleanest test of the existence of neutral leptonic currents⁽¹⁾. For seventeen years the process $\nu_{e} e \rightarrow \nu_{e} e$ has been predicted to occur with a total cross-section of the order of $G^2 s \approx 2 G^2 m_e E_{\nu}^{\text{lab}} \approx 5 \cdot 10^{-43} E_{\nu}^{\text{lab}} \text{ cm}^2 \text{ GeV}^{-1}$, but until now it has not been experimentally observed. In order to use the proposed apparatus to study the reactions (4) and (5) an intense ν_{e} beam, of the type studied by ECFA⁽²⁾, would be necessary. We consider this as a second stage of the experiment, to be

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performed in the North Area, where a beam dump is at present foreseen. In the apparatus we propose low Z and high Z alternating materials, which would allow the investigation of elastic $\nu_\mu e$ ($\nu_e e$) scattering on quasi real electrons through the mechanism illustrated in the following graph.

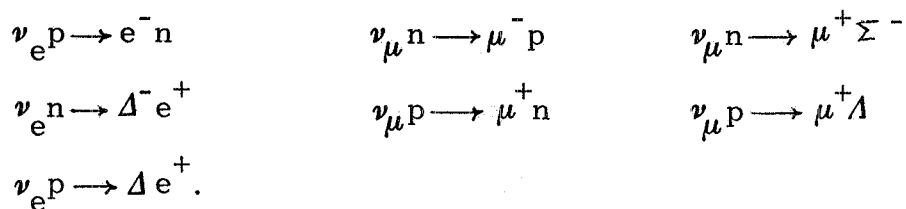


The main feature of neutrino-lepton scattering at these energies is the small angle of the final charged lepton $\theta_e = 2 m_e \times [(1/E_e) - (1/E_\nu)]$; for the reaction $\nu_\mu e \rightarrow \nu_\mu e$ initiated by a 100 GeV neutrino the angle θ_e of a 10 GeV electron is $\theta_e \approx 10$ mrad.

To make full use of this property, the apparatus has an angular resolution of the order of 2 mrad. This good angular resolution, together with the possibility of measuring deposited energies and the fine target subdivision, will also give a clear signature for the inverse μ decay



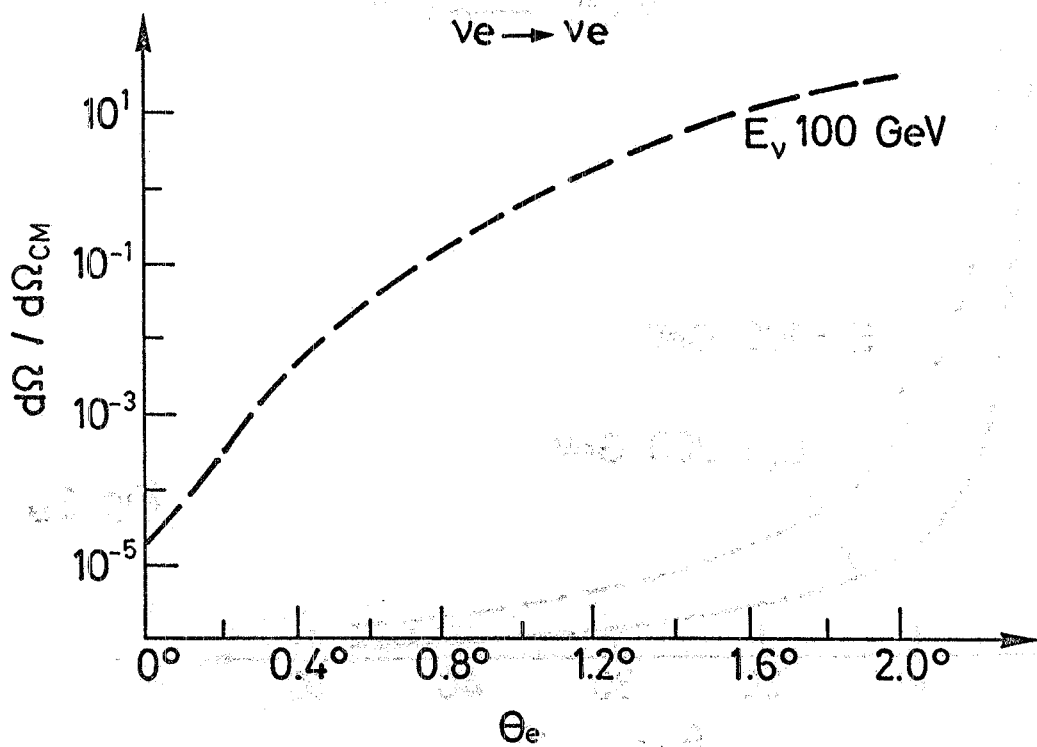
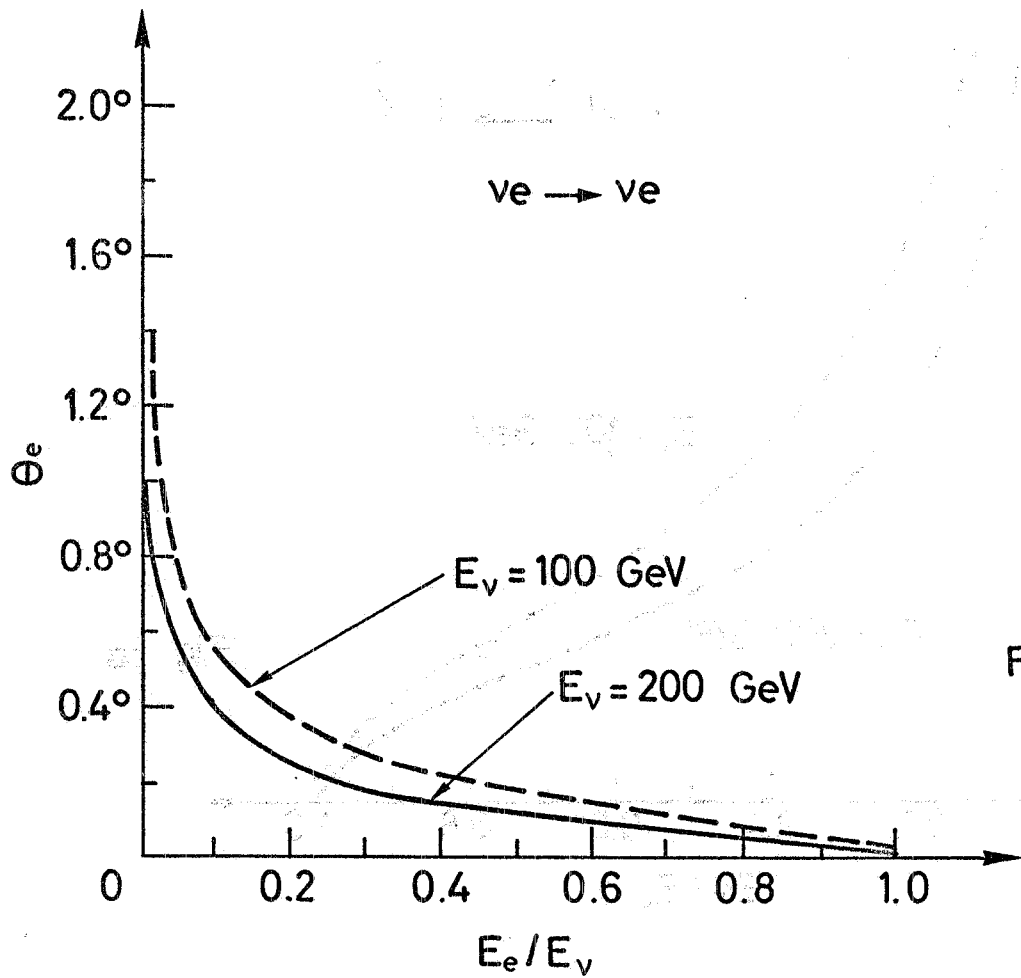
and for various two-body neutrino-hadron processes, such as



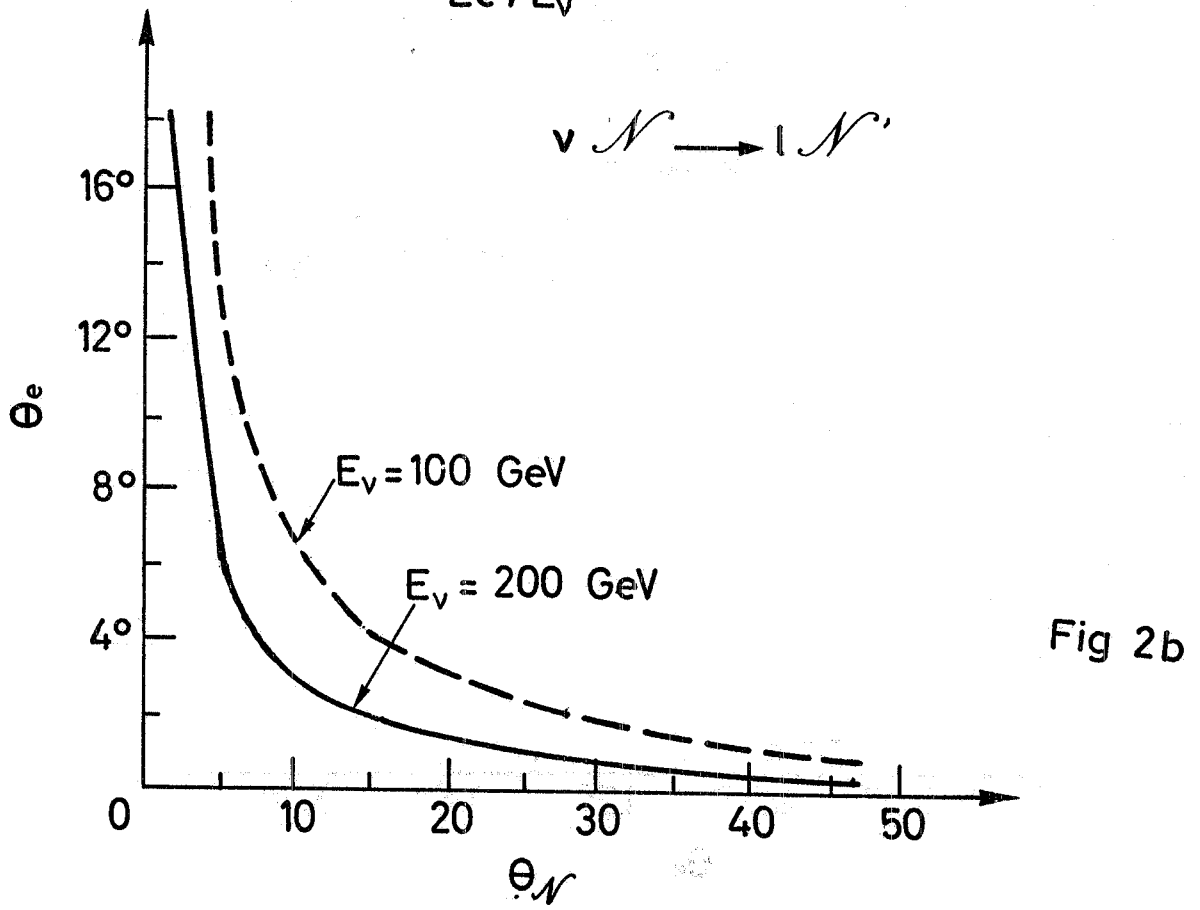
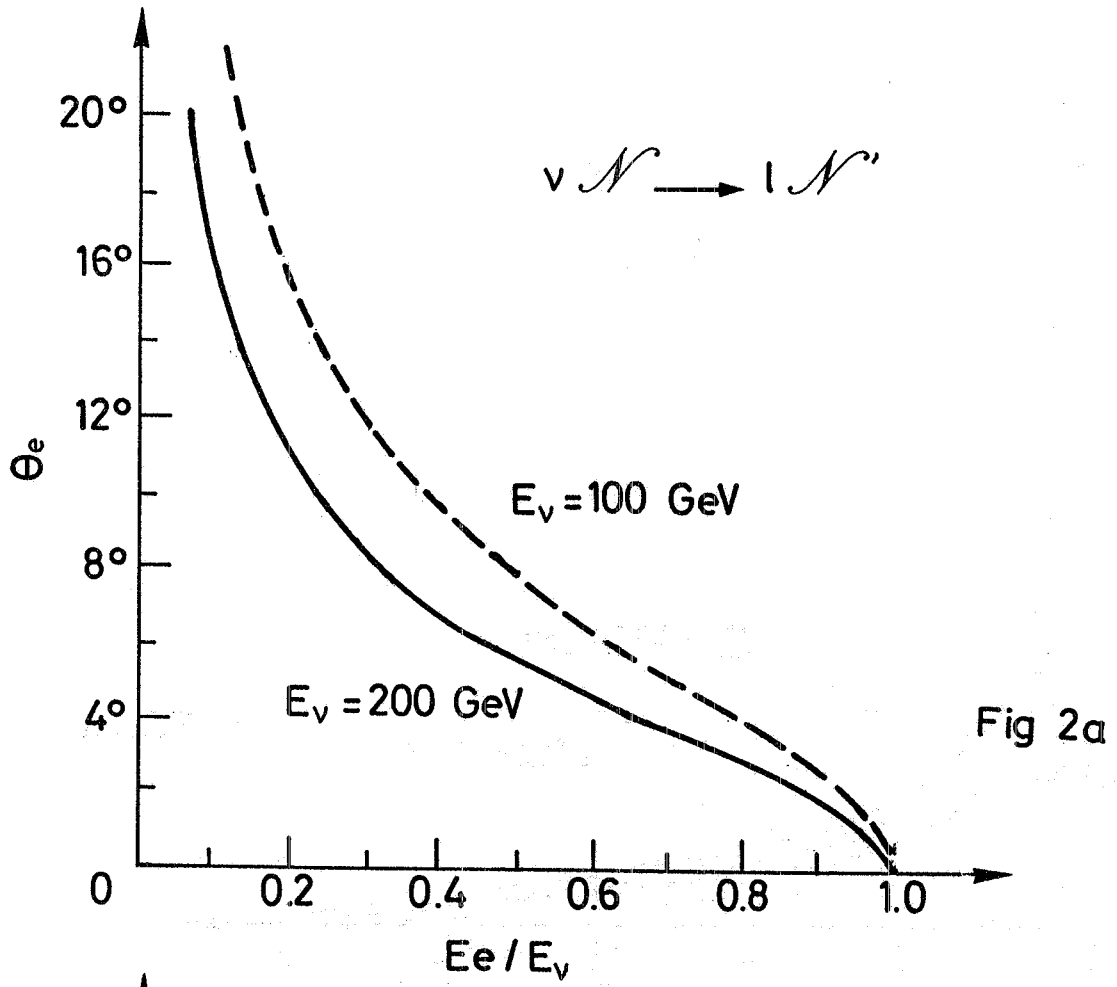
These hadronic processes will be studied as by products of the main experiment and will not be discussed any further in this first proposal.

2. - THE APPARATUS -

The kinematics of the elastic scattering of neutrinos on electrons and on nucleons appear in Figs. 1 and 2 respectively.



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The kinematics of the trilepton processes are illustrated in detail in the NAL proposal n. 1. Again the main feature of the process is the forward peaked angular distribution of one of the final leptons.

The most important properties required of the detector are: i) the resolution in the measurement of the electron direction has to be of the order of 2 mrad. ii) the energy of the electron has to be measured in order to have another kinematical constraint, also when monochromatic neutrinos are used. The resolution for a lead-scintillator sandwich is $\Delta E/E = 0.15/\sqrt{E_{\text{GeV}}}$. The good angular resolution requires a fine division of the target, and a track detector that gives a precise direction measurement after each target slab. The thickness of each target slab is fixed by requiring that the multiple scattering angle is of the order of the angular resolution: $\theta_{\text{sc}} < \delta\theta$. Since $\theta_{\text{sc}} \approx 21/E_{\text{MeV}} \sqrt{t}$ (t is target length in units of radiation length t_0), for an electron of 10 GeV the relation $\theta_{\text{sc}} < \delta\theta$ is fulfilled for $t < 1/2 t_0$ if $\delta\theta \sim 2$ mrad.

The module M of the apparatus that we believe will satisfy the previous conditions is shown in figure 3.

The scintillator counter S is made of a single liquid scintillator container optically divided in four sections; the upper one is used to veto cosmic rays that, travelling along the beam direction, could simulate in the trigger an elastic neutrino event.

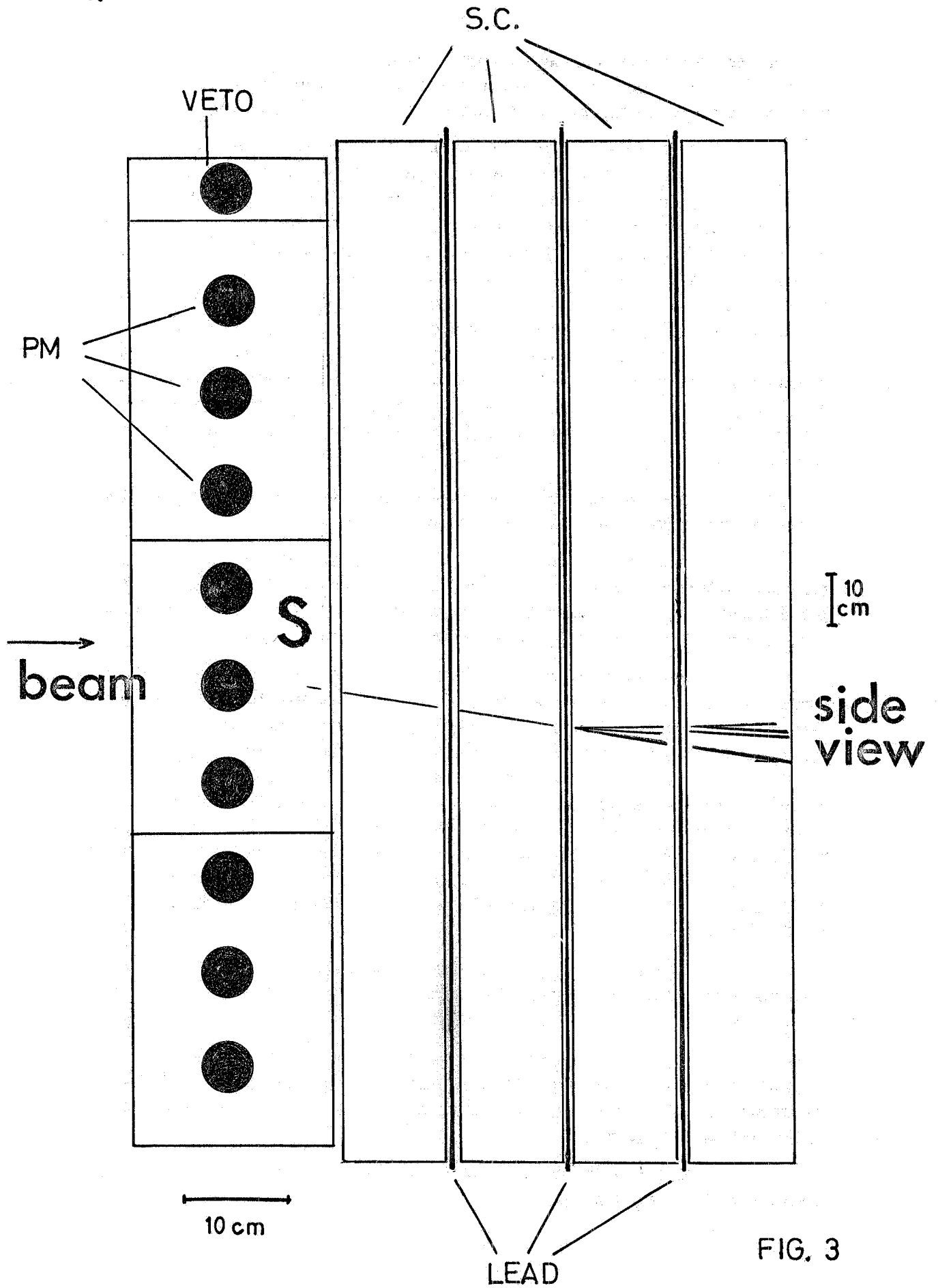
The separation of S in three other sections is made in order to reach a good time resolution and occasionally a rough angular information on the trigger. The light collection and the optical separation of S in four sections will be done with special panels (lucite, nylon, fish net, lucite sandwich) developed at Pisa⁽³⁾. These panels of easy construction guarantee a light collection of the liquid counter comparable to that of plastic scintillators. The thickness of the liquid scintillator S is of the order of 20 cm to obtain a division of the target before the spark chamber in pieces having a thickness $t = 1/2 t_0$. Each side of a single section of S is seen by three photomultipliers.

The other components of the module M are four wide gap spark chambers SC_i the first one after the counter S, the others, each one, after a slab of lead of thickness half a radiation length.

The side length of M, determined by the ν beam characteristics and the allocation of the apparatus on the floor, will be approximately two meters. If required the modules can be of two different side lengths.

The length of M along the beam direction is $L_M = 60$ cm. The specific weight of M is

6.



$$w_M = w_S + w_{\text{lead}} = (200 + 80) \text{ Kg/m}^2.$$

The module weight is $W_M = 1100 \text{ Kg}$.

The final number of modules N_M is 60 so that the total weight is

$$W_{\text{tot}} = N_M W_M = 67 \text{ ton.}$$

This is about seven times larger than the weight of the sensitive part of a large heavy liquid bubble chamber.

Due to the modular nature of the apparatus N_M can be increased during the experiment, starting from a smaller initial value.

The total length of the apparatus will be 36 metres.

3. - TRIGGER. -

The trigger for a neutrino scattering with an electron in the final state will be an eightfold majority coincidence of then successive modules. This will be obtained with a fast coincidence and a good synchronization of the signals coming from the photomultipliers. Taking into account that the drift time of the electromagnetic cascade generated by the electron from one module to the next is about 2 nsec, the previous condition is fulfilled by requiring a resolving time of the coincidence τ_R of the order of 20 nsec among the pulses coming from the photomultipliers previously synchronized. This trigger includes the possibility that the electromagnetic cascades develop with only neutral components in any two modules of the ten. Since ten modules correspond to a thickness of twenty radiation lengths, the electromagnetic cascade will deposit essentially all the energy in these modules. The trigger will contain also the energy information and a cut on the pulse height in order to reject unwanted events. The muons coming from the elastic scattering are forward emitted and will cross completely the part of the apparatus following the interaction point, so the trigger for elastic events with a muon in the final state will be a coincidence of all the modules following the interaction point. The proper timing will take into account the drift time from one module to the other cutting in this way cosmic rays travelling in the direction opposite to the beam direction.

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4. - EVENT RATE. -

The cross-section of the reaction $\nu_\mu e \rightarrow \nu_\mu e$ in the Weinberg theory⁽⁴⁾ has been calculated by Chen and Lee⁽⁵⁾:

$$\frac{1}{m_e} \frac{d\sigma}{dE_e} = \frac{G_W^2}{2\pi} \left[(C_V + C_A)^2 + (C_V - C_A)^2 \left(1 - \frac{E_e}{E_\nu}\right)^2 + (C_V^2 - C_A^2) \frac{m_e E_e}{E_\nu^2} \right]$$

In the Feynman-Gell-Mann theory $C_V = C_A = 1$ for the $\nu_e e \rightarrow \nu_e e$ process and $C_V = C_A = 0$ for the process $\nu_\mu e \rightarrow \nu_\mu e$, while in the previous expression according to Weinberg $C_V = -(1/2) + 2 \sin^2 \theta_W$ and $C_A = -1/2$. The rate of events has been calculated by N. E. Booth⁽⁶⁾. The lower limit of the reaction cross-section $\sigma = 1.3 \cdot 10^{-42} E_\nu \text{ cm}^2 \text{ GeV}^{-1}$ is $1.6 \cdot 10^{-4}$ times smaller than the ν_μ -nucleon total cross-section.

In the neutrino beam described in the proposal CERN/SPSC/P 73-1 our apparatus would collect $10^{-3} \nu_\mu e$ elastic scattering events per machine cycle. In a running time corresponding to 10^6 cycles one could thus obtain about 1000 events. The number of events due to reaction (6) is of the same order of magnitude.

5. - COSMIC RAY TRIGGERS AND OTHER BACKGROUNDS -

The flux of cosmic rays crossing eight consecutive modules in the beam direction has been computed to be about 10^2 s^{-1} . For a spill out of the neutrino beam of $25 \mu\text{s}$, the total number of cosmic ray triggers is 3800 in a running time of 10^6 cycles.

The neutrino events on nucleons which can simulate the events due to reaction (1) are the following one:



Reaction 7 is a background only if the muon escapes from the apparatus.

For this reaction the cross-section is estimated to be $10^{-39} \text{ cm}^2/\text{nucleon}$ independent of the neutrino energy. The cross-section of reaction 8, induced by the existence of neutral currents,

is somewhat smaller. The rejection factor in order to have 10% background at $E_\nu = 100$ GeV is of the order of 100 and is obtained in the apparatus by using the energy measurement of the electromagnetic shower, the possibility of distinguishing an electromagnetic from an hadronic cascade and the angular distribution of the photons from the π^0 decay.

In a ν_μ beam the reactions (1) and (4) cannot be separated and in the first stage of the experiment reaction (4) has to be considered a background for reaction (1), which depends only upon the ν_e contamination of the ν_μ beam. R. Turlay has estimated this contamination to be of the order of 2%.

The background for the inverse muon decay (reaction 6) is caused by the process $\nu_\mu n \rightarrow \mu^- p$. The apparatus has a high rejection power against this reaction because the liquid scintillation counters can detect recoil protons down to kinetic energies as low as 100 MeV.

The background for the trilepton processes (3) and (5) is extensively studied in the NAL neutrino proposal n. 1 from which it can be concluded that these events will be clearly distinguished from the background.

6. - CALIBRATION -

The calibration of the gain of the photomultipliers and of the stability of the linear electronic chains will be performed with a single light source which will be split into 240 channels using the very new low attenuation fiber glasses developed by Bell Telephone (2 db attenuation per Km). The light source will be a triggerable spark gap mounted as shown in the figure 4.

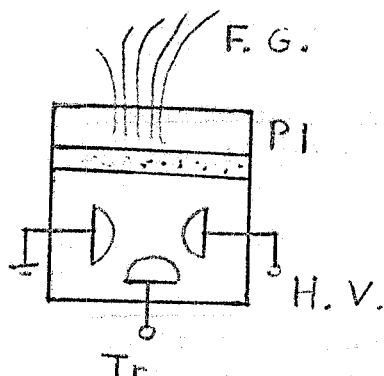


FIG. 4

The absolute stability of the light source will be checked by comparing, in a few counters, the pulse height spectrum from the light source with the spectrum due to cosmic rays having a defined path in the counters.

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7. - HIGH VOLTAGE POWER SYSTEM -

The high voltage on the wide gap spark chambers will be applied through a 4 stage Marx generator. Each module will have its own Marx generator made with commercial capacitors. Two power supplies of 25 KV and 100 mA already existing at Frascati will give the power to the whole system.

8. - OPTICAL SYSTEM -

The detailed study of the optical system has not yet been performed, but the following considerations will give an idea of the problems involved. To fix the main parameters of the system we have assumed:

- i) scanning accuracy on the film: 3 micron.
- ii) required space resolution: 150 micron.
- iii) film dimensions: 70 mm.
- iv) two stereo views at 90° .
- v) total surface to be photographed: 96 m^2 .

From conditions i) and ii) one derives a maximum value of the demagnification: 50. The two meter side length of the spark chambers will have an image on the film of about 40 mm and a single frame will contain the two stereo views of six modules.

The total number of cameras needed to photograph the full system is 10.

At present we are studying the alternatives of firing all the cameras or triggering only the useful ones. In the first solution the amount of film per event is about 1 m.

For the measurement of the film we plan to use the automatic scanning device PEPR.

A Vidicon system operating in parallel with the cameras is required to have online information on the working conditions.

9. - NEUTRINO BEAM -

Because it is preferable in the first stage of the experiment to have a few, but clean, events of reaction (1), we would require a narrow band ν_μ beam. The features of the WANF⁽⁷⁾ fit our requirements.

For the ν_e beam, as already mentioned, the proposed design of the ECFA neutrino working group is a good solution.

10. -COST ESTIMATE -

- Photomultipliers	6.0 10^5 SF.
- Liquid scintillator+mechanics	3.0
- Lead	1.0
- Spark-chambers	4.0
- Electronics	2.0
- Optics + Vidicon	3.0
- High voltage system	0.5
- Running cost (gas + travel expenses)	2.0
	<hr/>
Total	21.5 10^5 SF

11. - GROUP COMPOSITION -

At the present stage the people involved are:

Frascati National Laboratory: G. Barbiellini, R. Barbini, C. Guaraldo, M. Placidi, F. Picozza and R. Scrimaglio.

Napoli, INFN Section: G. Barbarino, M. Castellano, F. Cevenini, S. Patricelli, E. Sassi, L. Tortora, U. Troia and S. Vitale.

Other INFN Sections have shown interest in this program, but have asked some time to take their decision. At this early stage of the project no contact has been taken with groups from other Member States.

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