MUON NEUTRINO - ELECTRON ELASTIC SCATTERING

G. Carnesecchi
EP Division, CERN, Geneva
WA14 Collaboration: Bari, CERN, Ecole Polytechnique, Milano, Orsay

Abstract: A search for the reaction $\nu_\mu + e^- \rightarrow \nu_\mu + e^-$ was performed in the bubble chamber Gargamelle, exposed to the wide-band neutrino beam of the CERN-SPS. Ten isolated e^- were found above 2 GeV energy with a background of 0.2 ± 0.2 events. Results on the cross-section are given in terms of vector and axial-vector coupling constants and a comparison is made with the standard SU(2) $\otimes$ U (1) model.

Résumé: La recherche de la réaction $\nu_\mu + e^- \rightarrow \nu_\mu + e^-$ a été effectuée dans la chambre à bulles Gargamelle exposée au faisceau neutrino à bande large du CERN-SPS. Dix e^- isolés ont été trouvés avec une énergie supérieure à 2 GeV et un bruit de fond de 0.2 ± 0.2 événements. Les résultats sur la section efficace sont donnés en fonction des constantes de couplage vecteur et vecteur-axial et une comparaison est faite avec le model standard SU(2) $\otimes$ U (1).

The purely leptonic reactions

$$\nu_\mu + e^- \rightarrow \nu_\mu + e^- \qquad (1)$$

and

$$\bar{\nu}_\mu + e^- \rightarrow \bar{\nu}_\mu + e^- \qquad (2)$$

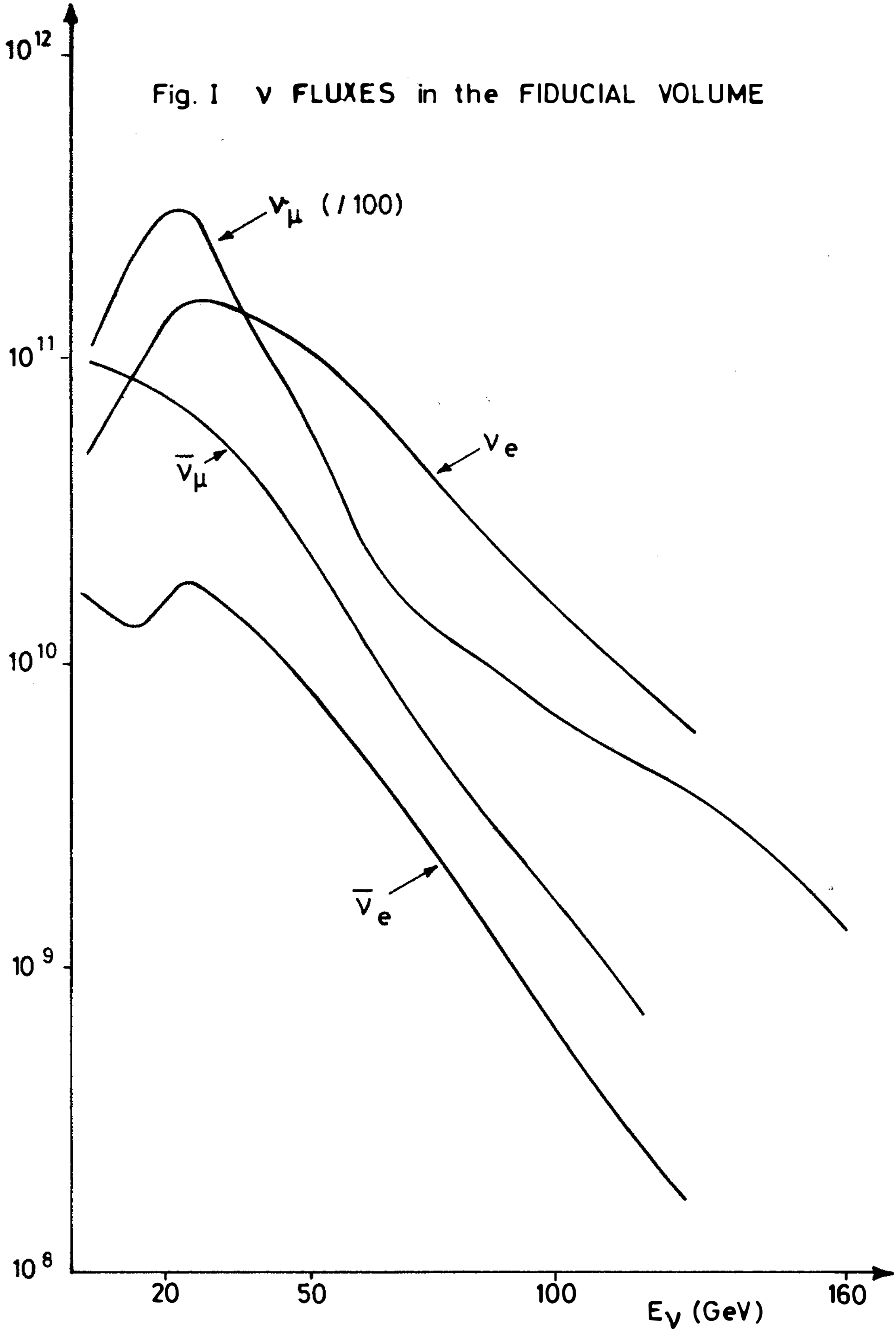
are of great importance for the study of weak interaction processes induced by neutral currents since only the leptonic current is involved.

However, only limited results [1,2,3] have been obtained so far, due to the exceedingly low cross-section and to difficult background problems. Reaction (1) has been searched for in the heavy liquid bubble chamber Gargamelle exposed to the wide-band neutrino beam of the CERN-SPS which peaks at 25 GeV and extends up to 200 GeV (fig. 1). The chamber was filled with a mixture of propane (90.5% in moles) and Freon CF_3Br (9.5%), yielding a radiation length X_o = 61.5 cm. This value ensures an excellent efficiency for the signature of electrons, either by spiralization or by electromagnetic shower development, although large enough to allow a clear separation between γ-rays and electrons.

The experimental set-up was completed by two MWPC placed respectively upstream and downstream against the chamber body (fig. 2), for detecting particles entering or leaving the chamber and by two planes of MWPC interpersed with an iron shielding for the identification of muons above 2.5 GeV.

A sample of 128,000 pictures, taken during the end of 1977, was scanned for spiralizing tracks or electromagnetic showers, with no visible source in the chamber. The events were retained only if they occured in a fiducial volume of 5.09 m^3 inside a visible volume of 7.2 m^3 and if they satisfied the conditions $E > 2$ GeV and $\theta_{(beam-e)} < 3^o$. No good event is cut by the last condition which takes into account the kinematical constraint for reaction (1) $\theta^2_{(beam-e)} < \frac{2m_e}{E_e}$ and the angular resolution for electrons. The probability for an electron to be signed by electromagnetic processes is then > 98% at 90% CL. A sub-sample of 36% of the films was scanned twice giving a scanning efficiency of 85% per scan, within the cuts, or (90 ± 6)% on average in the total sample.

The events were classified as "isolated e^-" candidates if just a single track was at the interaction vertex. No bremsstrahlung e^+e^- pair above 30 MeV energy was allowed on the first 7 centimetres of the track and no e^+ above 2.5 MeV on the first centimetre of the track. Events which did not



10^12
10^11
10^10
10^9
10^8
Fig. I ν FLUXES in the FIDUCIAL VOLUME
ν_μ (/100)
ν_e
ν̄_μ
ν̄_e
20
50
100
160
E_ν (GeV)

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353

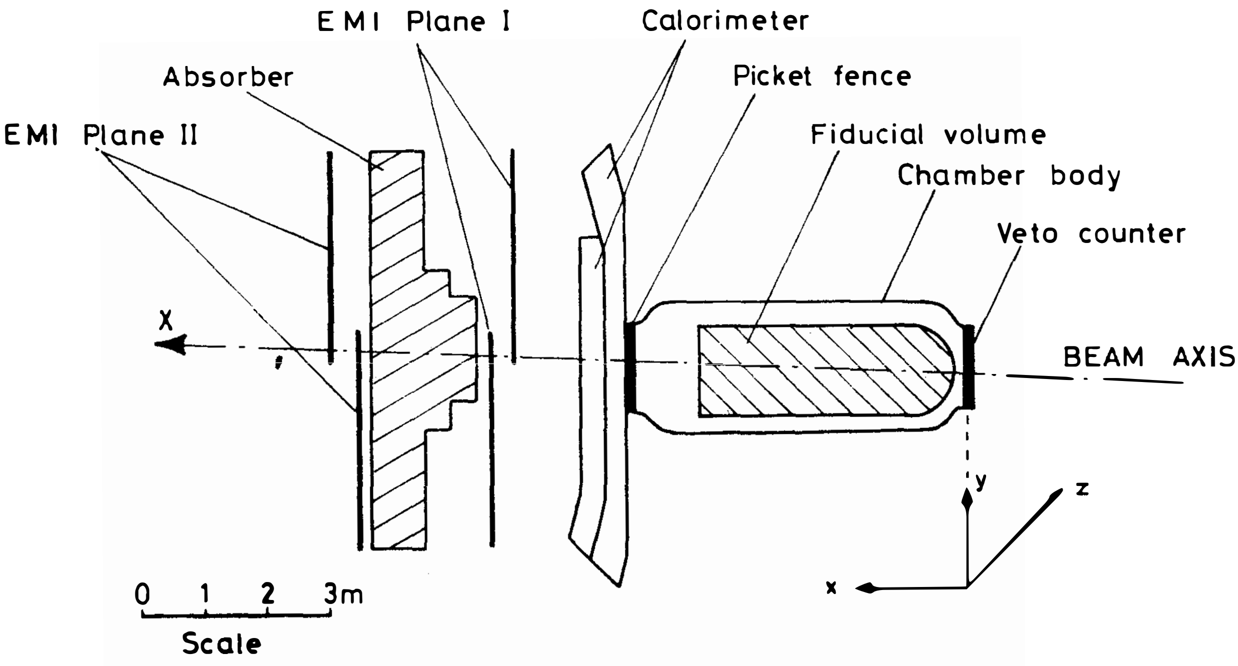


Fig. 2 Experimental set up

satisfy these two criteria were classified as "isolated γ-rays". The probability to misclassify as a γ-ray a genuine electron by the selection criteria was estimated by a Monte-Carlo method and found to be equal to $(8 + 3.7 \text{ Log } E_e \text{ (GeV) })\%$.

Ten e^- and 13 γ-rays fulfilling these conditions were found (fig. 3).

The separation between events with 1 or 2 electrons at the vertex was checked by counting the bubble density near the vertex relatively to that of the electrons at minimum ionization in the same shower. A ratio between 0.8 and 1.2 was found for each of the 10 e^- candidates, while the same ratio was found to be greater than 1.5 for identified γ-rays. We can conclude that our 10 e^- candidates are true single electrons.

Three background processes could give rise to isolated single electrons:

i) high energy γ-rays, by asymmetric e^+e^- pair creation, Compton effect or annihilation of the e^+ close to the vertex of the e^+e^- created pair;

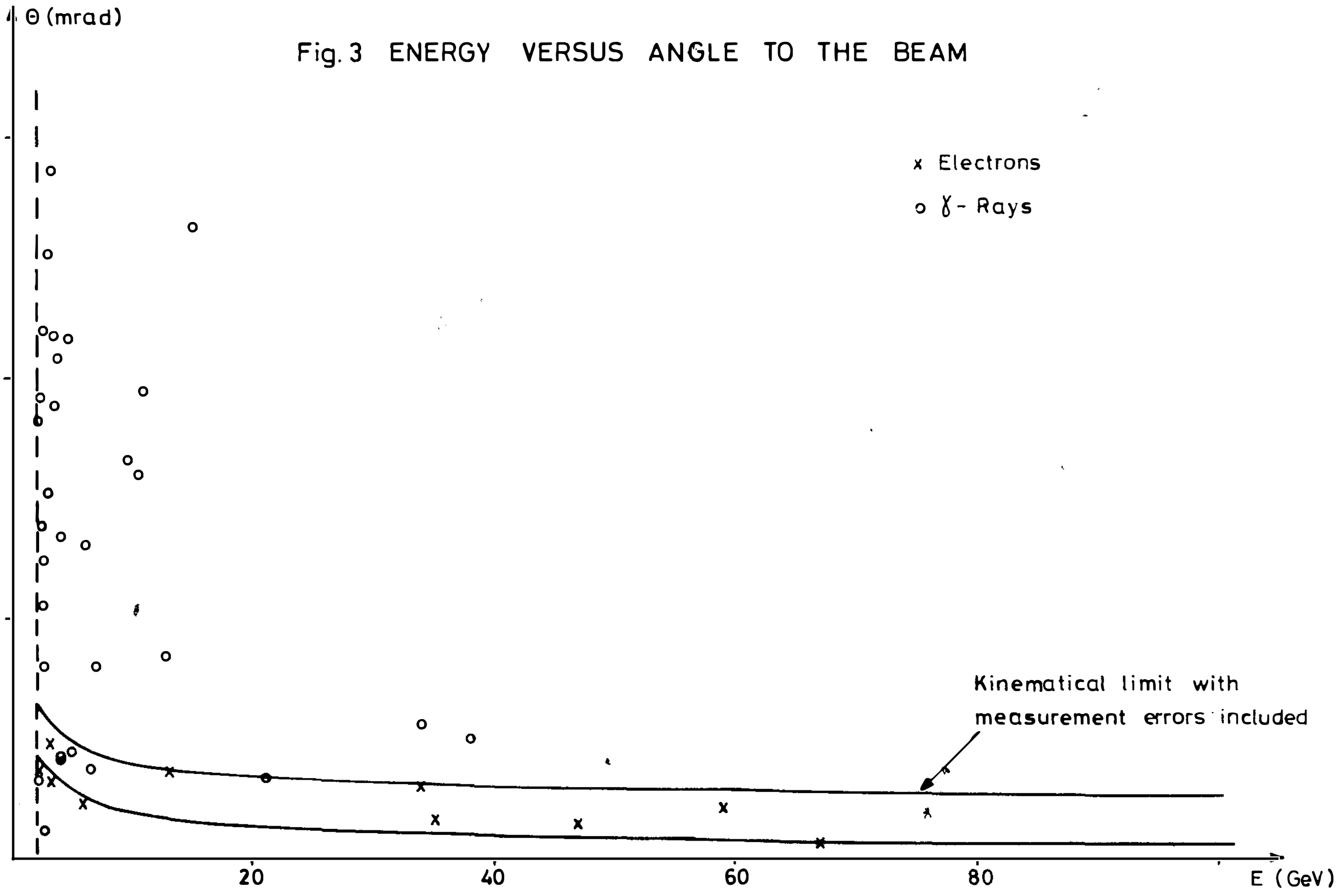
ii) isolated μ^-'s or π^-'s which by emission of δ-rays can develop an electromagnetic shower and simulate an electron;

iii) charged current interaction of ν_e (or $\bar{\nu}_e$) with nuclei in which hadrons escape detection.

The photon background was estimated experimentally using a sample of 183 e^+e^- pairs or $e^\pm$ in the 2 to 20 GeV energy range, associated with interactions of neutrinos in the chamber. Indeed, no signle e^- or e^+ was found is this sample, thus giving a limit on this background process of 1.2% at 90% CL, in excellent agreement with theoretical calculations. From the sample of isolated γ-rays, this background is thus found smaller than 0.13 events.

To estimate the background ii), it was checked that none of the 10 e^- candidates were associated with hits in the EMI. Since the EMI efficiency was already determined to be almost 100% for muons produced in the beam direction, it is concluded that the background from muons is negligible. All the negative leaving particles without any shower were found to hit the EMI, meaning that no leaving isolated π^-'s along the beam direction were observed. Since the probability for a π to give an electromagnetic shower was estimated to be $< 2\%$, also the background from π^- is negligible.

Fig. 3 ENERGY VERSUS ANGLE TO THE BEAM



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The charged current reaction $\nu_e + n \to e^- + p$ could fake a $\nu_\mu + e^- \to \nu_\mu + e^-$ reaction if no protons are seen. The probability that all protons escape detection has been computed from the similar reaction $\nu_\mu + n \to \mu^- + p$. The ratio

$$R_\mu = \frac{\mu^- \ (\theta_\mu < 3^o) + \text{unseen proton}}{\mu^- + p}$$

has been estimated in two ways. First, the q^2 distribution of $\mu^- p$ events was compared to the prediction of a Monte Carlo using $M_A^2 = 0.9 \ GeV^2/c^4$ for the axial mass M_A in the form factor and taking into account the nuclear re-interactions. From the loss of events at low q^2, attributed to event classified as isolated μ^-, we compute $R_\mu = (6 \pm 3)\%$. Secondly, R_μ was computed from the observed μ^- events. At energies above 11 GeV, some of the isolated μ^-'s are producted through the reaction $\nu_\mu + e^- \to \mu^- + \nu_e$. This contribution has been estimated 6 ± 3 events, using the theoretical cross-section, and it has been subtracted from the observed 15 μ^- events. We estimate with this method that $R_\mu = (5 \pm 3)\%$ in agreement with the previous determination. From the 3 $e^- p$ events observed in our films this background therefore amounts to 0.2 ± 0.2 events. Other background sources such as $n + e^- \to n + e^-$ have been found completely negligible.

Another source of isolated e^- is the reaction $\nu_e + e^- \to \nu_e + e^-$, which is allowed by charged and neutral current processes. Nevertheless, these events cannot be experimentally separated from the $\nu_\mu e^-$ events and furthermore the $\nu_e e$ contribution depends not only on the experimental cuts, but also on the vector and axial-vector constants which are related to those of $\nu_\mu e$ reactions. So it was chosen not to subtract a possible $\nu_e e$ contribution to our signal, but to compare the signal to the sum of predicted ν_μ and ν_e cross sections weighted by the corresponding fluxes.

To summarize, the signal of isolated e^- consists of 10 events; with a total background of 0.2 ± 0.2 events.

In order to obtain the cross-section, the neutrino flux has been computed by a Monte-Carlo method. The production spectra of the π and K parents of the ν's were taken from the thermodynamical model [4], taking also into account experimental points obtained by hadronic experiments at Fermilab [5].

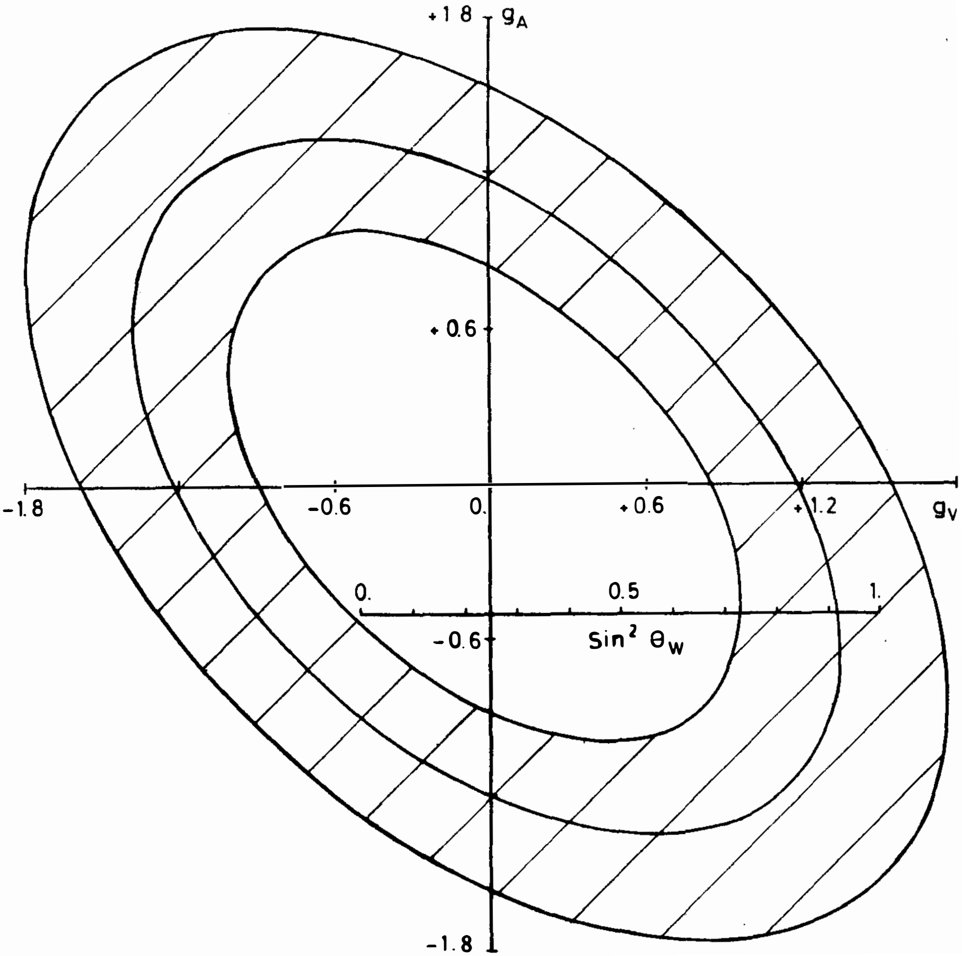

Fig.4 DOMAIN ALLOWED IN THE $g_V - g_A$ PLANE FROM THE REACTION $\nu_\mu + e^- \rightarrow \nu_\mu + e^-$

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From this flux, and using for the total cross-section the value

$$\sigma_{tot}\ (\nu_\mu + N \to \mu^- + x) = 0.7\ 10^{-38}\ E_\nu\ \text{cm}^2/\text{nucleon}$$

as measured in other high energy experiments [6]. The total number of expected inclusive charged current ν_μ^- events is 23 600 in the fiducial volume. This number was checked counting in a sample of pictures the number of interactions in the fiducial volume with a μ^- signed in the EMI. After normalization to the total number of pictures we find 24 500 ± 3 000 in excellent agreement with the previous estimate. The calculated flux is also in very good agreement with the observed $\mu^- p$ events. The error on the flux is estimated to be 10%. The calculated ν_e flux is about 2% of the ν_μ flux, confirmed by the observed rate of ν_e events.

Assuming that the weak current is made only of V and A terms, the cross-section is written as:

$$\frac{d\sigma}{dE_e} = \frac{G^2 m_e}{2\pi} \left\{ (g_V + g_A)^2 + (g_V - g_A)^2 \left(1 - \frac{E_e}{E_\nu}\right)^2 \right\}$$

where $g_{V,A}^{\nu_e} = 1 + g_{V,A}^{\nu_\mu}$, the constant 1 for the $\nu_e e$ reaction being due to the charged current contribution. Thus, the number of expected events is

$$N\ (g_V,\ g_A)\ \alpha \iint_{Ee\,>\,2} \left\{ \phi_{\nu_\mu} \frac{d\sigma^{\nu_\mu}}{dE_e} + \phi_{\nu_e} \frac{d\sigma^{\nu_e}}{dE_e} \right\} \beta(E_e)\ dE_e\ dE_\nu$$

where $\beta(E_e)$ is the electron detection function product of the different efficiencies defined above:

$$\beta(E_e) = 0.90\ \text{(scanning)} \times (0.92 - 0.037\ \text{Log}\ E_e)\ \text{(misclas)} \times 0.99\ \text{(ident.)}$$

Fig. 4 shows the limits at 90% CL of the domain in the g_V, g_A plane allowed by the signal of 10 events, using the Poisson distribution.

Depending on the g_V/g_A ratio, the value of the slope

$$S = \frac{\sigma_{tot}\ (\nu_\mu + e^- \to \nu_\mu + e^-)}{E_\nu}$$

is always found in the range

$$(0.73\ {}^{+0.33}_{-0.26})\ 10^{-41}\ \text{cm}^2/\text{GeV} \leqslant S \leqslant (0.82\ {}^{+0.37}_{-0.28})\ 10^{-41}\ \text{cm}^2/\text{GeV}.$$

It must be remarked that the signal is higher than what was foreseen from the results on the same reaction at PS energies [2,3].

In the framework of the standard SU(2) ⊗ U (1) model, at 90% CL $\sin^2\theta_w$ is found to be greater than 0.74.

With the currently accepted value $\sin^2\theta_w \simeq 0.25$, 1.7 ± 0.2 events are expected whereas 10 are observed.

REFERENCES

1) J. Blietschau et al., Nuclear Physics B114 (1976) 189.

2) H. Faissner et al., to be published.

3) J. Blietschau et al., Phys. Lett. 73B (1978) 232.

4) H. Grote et al., Atlas of Particle Production Data, CERN 1970; J. Ranft et al., CERN Lab II-RA/74-2 (1974).

5) W.F. Baker et al., Phys. Lett. 51B (1974) 303; R. Stefansky, La Physique du Neutrino à Haute Energie, Paris (1975); B. Aubert et al., Fermilab. Conference 1975/31-Exp (1975).

6) K. Schultze and F. Sciulli, Talks at the Symposium on Lepton and Photon Interactions, Hamburg (1977).