# SEARCH FOR ELASTIC MUON-NEUTRINO ELECTRON SCATTERING

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One possible event of the process $\nu_\mu^- + e^- \to \nu_\mu^- + e^-$ has been observed. The various background processes are discussed and the event interpreted in terms of the Weinberg theory. The 90% confidence limits on the Weinberg parameter are $0.1 < \sin^2\theta_W < 0.6$.

Recently many theoretical models have been postulated in an attempt to resolve the divergency of the classical current-current theory by unifying the weak and electromagnetic interactions. All these theories require neutral currents, heavy leptons or both. One of these theories, that of Salam and Ward [1] and Weinberg [2], gives specific predicitons about the amplitudes of the neutral currents which are susceptible to experimental tests.

In particular, using this model, t'Hooft [3] has calculated the differential cross sections for the purely leptonic processes

$$\nu_\mu + e^- \to \nu_\mu + e^- \tag{1}$$

$$\bar{\nu}_\mu + e^- \to \bar{\nu}_\mu + e^- \tag{2}$$

which are forbidden to first order in the conventional Feynman Gell-Mann theory. The predicted cross-sections are of the order of $10^{-41}$ cm$^2$/electron at 1 GeV, depending on the Weinberg angle $\theta_W$, which is the only free parameter of the theory.

A search for these processes has been carried out in the large heavy liquid bubble chamber Gargamelle, useful volume 6.2 m$^3$, filled with freon CF$_3$Br, exposed to both the neutrino and antineutrino beams at the CERN PS. The large length of the chamber, 4.8 metres, compared to the radiation length of freon, 11 cm, ensured that electrons were unambiguously identified.

These interactions are characterized by a single electron ($e^-$) originating in the liquid, unaccompanied by nuclear fragments, hadrons or $\gamma$ rays correlated to the vertex. The kinematics of the reactions are such that the electron is emitted at small angle, $\theta_e$, with respect to the neutrino beam; the electron is expected to carry typically one third of the energy of the incident neutrino which is peaked between 1 and 2 GeV. As the neutrino interactions in the surrounding magnet and shielding produce a low energy background of photons and electrons, a lower limit on the electron energy was set at 300 MeV. This energy cut ensures that all electrons from reactions (1) and (2) will have $\theta_e < 5°$.

A total of 375 000 $\nu$ and 360 000 $\bar{\nu}$ pictures were scanned twice and one single electron event satisfying the selection criteria was found in the $\bar{\nu}$ film. This event is shown in fig. 1. The curvature of the initial part of the track shows the negative charge, and the spiralisation and bremsstrahlung prove unambiguously that the track is due to an electron. The electron energy is 385 ± 100 MeV, and the angle to the beam axis is $1.4°^{+1.6°}_{-1.4°}$. The electron vertex is 60 cm from the beginning of the visible volume of the chamber and 16 cm from the chamber axis.

The scanning efficiency for single electrons with an energy > 300 MeV was determined to be 86% using the isolated electronpositron pairs found in the chamber.

The main source of background is from the process

$$\nu_e + n \to e^- (\theta_e < 5°) + p \tag{3}$$

where the proton is either of too low an energy to be



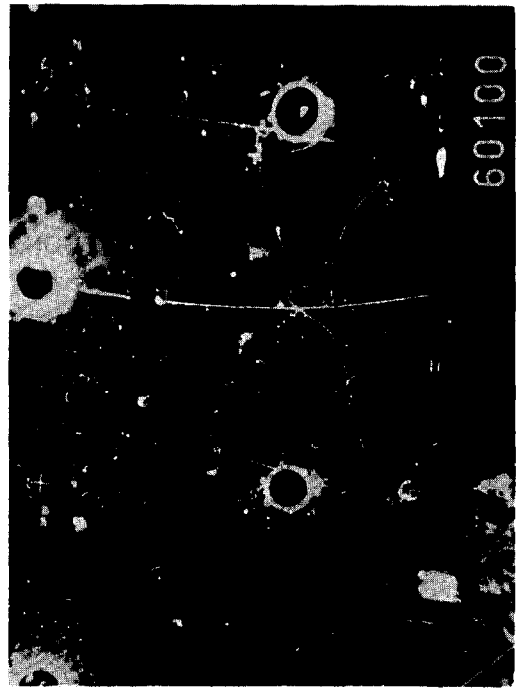Fig. 1. Possible event of the type $\bar{\nu}_\mu + e^- \to \bar{\nu}_\mu + e^-$.

observed or is captured in the nucleus and no visible evaporation products are formed. This is due to the small (< 1%) $\nu_e$ flux present in the predominantly $\nu_\mu$ or $\bar{\nu}_\mu$ beam.

This background has been determined empirically using the observed events of the type

$$\nu_\mu + n \to \mu^- (\theta < 5°) + p \tag{4}$$

where the proton is not observed, and the $\nu_e$ flux calculated from the observed electron-neutrino events.

This is a good estimate as the two processes are kinematically similar at these energies and the $\nu_\mu$ and $\nu_e$ spectra have nearly the same shape. In a partial sample of the film we have observed 450 events, occurring in a fiducial volume of 3 m$^3$, of the type:

$$\mu^- + m \text{ protons } (m \geqslant 0)$$

where the visible energy is > 1 GeV, and the momentum in the beam direction is > 0.6 GeV/$c$. These cuts eliminate the background due to incoming charged particles.

In these events, only 3 have no protons and a $\mu^-$ angle < 5°. The scanning efficiency for single $\mu^-$ has

been assumed to be the same as that for the single $\mu^+$ found in the anti-neutrino film. This was determined to be 50% using the sample of 200 single $\mu^+$.

Hence we obtain that

$$\frac{\mu^-(\theta_\mu < 5°) + 0_p}{\mu^- + mp} = 1.3 \pm 7\%$$

This ratio is an over-estimate as the inclusion of events of energies < 1 GeV would be expected on kinematical grounds to lower it.

In the neutrino film 15 $\nu_e$ events of the type $e^- + m$ protons ($m > 0$) have been observed in the fiducial volume (3 m$^3$). This number is in agreement with the one expected from the estimated $\nu_e/\nu_\mu$ flux ratio (0.7%). Hence one deduces a background from this source 0.3 ± 0.2 events.

Another estimate using the calculated $\nu_e$ and $\nu_\mu$ fluxes and expected cross-sections, gives 0.4 ± 0.2.

In the $\bar{\nu}$ film zero $e^- + m$ proton events have been observed and a background estimate is obtained as above using the calculated $\nu_e$ and $\nu_\mu$ fluxes. The $\nu_e$ flux in the anti-neutrino film is an order of magnitude less than in the neutrino film. Hence the background from the above source in the $\bar{\nu}$ film is 0.03 ± 0.02 events.

The other sources of background could be due to Compton electrons or asymmetric electron pairs. Only 2 isolated electronpositron pairs having an energy greater than 300 MeV and making an angle of less than 5° with the beam direction were observed in the visible volume of the chamber in the $\nu$ film, and none in the $\bar{\nu}$ film.

Given these events and using the ratio of Compton to pair production cross-sections as well as the differential cross-section for pair production for the energy repartition among the electron and positron, this source of background is estimated to be 0.04 ± 0.02 events in $\nu$ and negligible in $\bar{\nu}$.

As the $\nu_e$ flux is less than 1% of the $\nu_\mu$ flux the background from the V-A reactions

$$\binom{\nu_e}{\bar{\nu}_e} + e^- \rightarrow \binom{\nu_e}{\bar{\nu}_e} + e^- ,$$
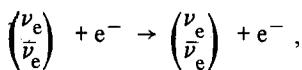
of which the cross-sections are of the same order as processes (1) and (2), are negligible. Similarly the lack of high energy neutrons (> 16 GeV) eliminates the background contribution from the electro-magnetic interaction $n + e^- \rightarrow n + e^-$.

To calculate the detection efficiency, i.e. the fraction of reaction (1) and (2) that would survive the selection criteria, the electron laboratory energy and angular distributions have to be known. These spectra are not uniquely predictable but depend on the model assumed to introduce the neutral currents into the weak interactions. However, the detection efficiency in the present experiment is not very sensitive to these uncertainties since the electron minimum energy accepted is small compared to the incident neutrino energy.

In the case of isotropy in the centre of mass the detection efficiency is 87%.

Table 1
Number of single $e^-$ events of $E_e$ > 300 MeV, $\theta_e$ < 5°

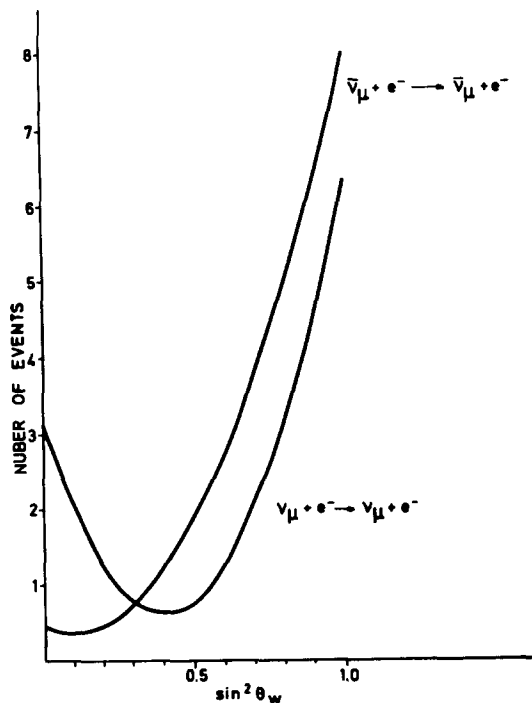| Flux neutrinos/m$^2$ | | Weinberg predictions | | Background | Observed |
|---|---|---|---|---|---|
| | | Minimum | Maximum | | |
| $\nu$ | $1.8 \times 10^{15}$ | 0.6 | 6.0 | 0.3 ± 0.2 | 0 |
| $\bar{\nu}$ | $1.2 \times 10^{15}$ | 0.4 | 8.0 | 0.03 ± 0.02 | 1 |



Fig. 2. Expected event rate as a function of the Weinberg parameter.

In this case the 90% confidence upper limits for the cross-sections for the processes (1) and (2) are:

$$0.26 \, E_\nu \times 10^{-41} \, \text{cm}^2/\text{electron}$$

and

$$0.88 \, E_\nu \times 10^{-41} \, \text{cm}^2/\text{electron}$$

respectively.

Table 1 shows the upper and lower event rates expected from the Weinberg model, taking into account the detection efficiencies, and using the measured $\nu_\mu$ and $\bar{\nu}_\mu$ fluxes. The estimated backgrounds are also shown. These are to be compared with the one event found in the $\bar{\nu}$ film.

Fig. 2 shows the number of expected $\nu$ and $\bar{\nu}$ events as a function of the Weinberg parameter $\sin^2\theta_W$.

In order to combine the neutrino and anti-neutrino results a maximum likelihood method has been used, taking into account the fluxes and backgrounds. The 90% confidence limit gives:

$$0.1 < \sin^2\theta_W < 0.6.$$

It may be remarked that, in the context of the Weinberg theory, the proportion of electrons with $E_e > 1$ GeV is much lower in neutral current events than in the $\nu_e$ background, and hence our quoted background is over-estimated. We conclude that the probability that the single event observed in the $\bar{\nu}$ film is due to non-neutral current background is less than 3%.

It is a pleasure to expresss our thanks to the members of the CERN TC-L group who have carried the technical responsibility for the experiment. We also thank the CERN PS operational staff, and the scanning the programming personnel in the various laboratories.

### References

[1] A. Salam and J.G. Ward, Phys. Lett. 13 (1964) 168.
[2] S. Weinberg, Phys. Rev. Lett 19 (1967) 1264.
[3] G. t'Hooft, Phys. Lett. 37B (1971) 195.