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STUDY OF THE FOUR FERMION WEAK INTERACTION AND EXOTIC BETA DECAYS USING ν SCATTERING ON HIGH-Z MATERIALS

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Our knowledge of the fundamentals of the weak interactions without the associated complication of strong interactions is grossly limited. Only one purely leptonic process has been studied so far, namely μ decay. With the advent of high-intensity, high-energy neutrino beams and large, high-Z detectors this situation will change.

There are three fundamental leptonic classes of scattering processes which are of interest to study within the context of the Fermi V-A phenomenological theory of weak interactions, namely:

$$\nu_\mu + \mu^+ \rightarrow \nu_e + e^+ \tag{1a}$$

$$\bar{\nu}_\mu + \mu^- \rightarrow \bar{\nu}_e + e^- \tag{1b}$$

$$\nu_\mu + \mu^- \rightarrow \nu_\mu + \mu^- \tag{2a}$$

$$\nu_e + e^- \rightarrow \nu_e + e^- \tag{2b}$$

$$\nu_\mu + e^- \rightarrow \nu_\mu + e^- \tag{3a}$$

$$\nu_e + \mu^- \rightarrow \nu_e + \mu^- . \tag{3b}$$

Process (1) is simply related to $\mu^\pm$ decay and is, therefore, well understood, at least, for low momentum transfer. These processes come about, in the context of the current $\times$ current interaction from the coupling of $(\nu_e e)(\nu_\mu \mu)$ currents. Process (2) has no analogous decay process and has therefore never been experimentally observed (although it has perhaps been indirectly observed in cosmological processes); this process comes about through self-interaction of lepton currents [i.e. $(\nu_\mu \mu)(\nu_\mu \mu)$ and $(\nu_e e)(\nu_e e)$]. Process (3) can only occur if neutral lepton currents exist (or alternatively if a W^o exists and couples to leptons). It should be emphasized that there is no reliable way to exclude neutral lepton currents on the basis of present studies of semi-leptonic processes (like $K^+ \to \pi^+ e^+ e^-$ or $K^o \to \mu\bar{\mu}$) since these processes involve the coupling of a hadron neutral current with a lepton neutral current and either or both may be absent, or the coupling between the two may vanish for presently unknown reasons.

The direct observation of processes (1), (2), and (3) suffer from the absence of suitable targets in some cases, from the extremely small cross sections and from the overwhelming background for the detection of the reaction.

For example, the cross section for (2b) has the form

$$\sigma \sim 4G^2k^2$$

where k is the c.m. momentum, and G is the W.I. coupling constant. For 10 BeV/c ν_e's the cross-section is $\sim 2 \times 10^{-40}$ cm^2. The background for these processes appears to be almost insurmountable due to Compton scattering of stray photons (say the γ's from π^o's made in the shield by ν's).

Fortunately, alternate techniques for studying processes (1), (2), and (3) are available using dissociation of neutrinos into three leptons. In recent years analogous hadronic processes have become of great interest. The analogous reactions to processes (1), (2), and (3) are

$$\nu_\mu + Z \rightarrow \mu^- e^+ \nu_e Z \tag{1'}$$

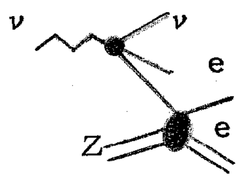
$$\nu_\mu + Z \rightarrow \mu^+ \mu^- \nu_\mu Z$$

$$\nu_e + Z \rightarrow e^+ e^- \nu_e Z \tag{2'}$$

$$\nu_\mu + Z \rightarrow e^+ e^- \nu_\mu Z$$

$$\nu_e + Z \rightarrow \mu^+ \mu^- \nu_e Z \tag{3'}$$

the diagrams for these processes have the form



The cross section for process (1') and (2') have the form $\sigma \sim Z^2 E_\nu$ for neutrino energy suitably above threshold, the cross section being of order magnitude $\sim 10^{-41}\,\mathrm{cm}^2$ per nucleus.

Experimentally, the detection of these modes is not free of background. The expected event rate for these processes in a neon bubble chamber with an eighteen feet fiducial region is

$\sim 10^{-4}$ events/10^{13} protons. Thus, from the standpoint of rate alone the study of reactions (1') and (2') will be feasible for the first time at NAL. Because of the fundamental nature of the weak interaction information obtained from these reactions, it seems to us that these reactions should be studied at the earliest possible time after the machine turns on. To facilitate this possibility it seems useful if two large bubble chambers are available at the time, to place these bubble chambers in series in the ν beam.

The experimental background for processes (1'), (2'), and (3') will come primarily from other classes of ν reactions. The background for (1') will come primarily from the ν_μ production process

$$\nu_\mu + A \rightarrow \pi^+ + A \ , \tag{4}$$

with the π^+ decaying in flight. Assuming a cross section of $\sim 10^{-40}$ for reaction (4) and a ~ 1% probability for the π decay reduces this background considerably. Of course, in order to confirm that the (+) track is in fact a μ^+ will undoubtedly require a spark-chamber detection device outside of the bubble chamber.

The primary background for reactions (2') (assuming that the μ^+ is reliably established outside of the bubble chamber) comes from W^+ production, namely

$$\nu_\mu + Z \rightarrow W^+ + \mu^- + Z \qquad W^+ \rightarrow e^+ + \nu_e \tag{5}$$

Turning the argument around, the process (2') is the main background for the detection of the W^+ provided the mass of the W^+ is greater than ~3 BeV. In fact, for 5 BeV W^+'s the cross section with the $e^+\nu_e$ decay probability folded in for W^+ production will probably be an order of magnitude smaller than the cross section for reaction Z'. In this case in order to detect the W^+, it will probably be necessary to observe the non-leptonic decays of the W^+ (i.e. observation of $W^+ \to \pi^+\pi^o$ and $W^+ \to \pi^+\pi^+\pi^-$ would be a strong hint for W^+ production).

The background for reaction (3') will come primarily from Dalitz pairs and pair production. Suitable invariant mass cuts should remove this background. The process

$$\nu_e + Z \to e^+e^-\nu_e Z, \tag{6}$$

will provide a background but the small ν_e flux (~1%) will make this background negligible for a good test of the existence (or non-existence) of neutral lepton currents using reactions (3').

While the neon bubble chamber is well suited to the detailed comparisons of cross sections for reactions (1') and (2') and, therefore, provides a strong check on the low-energy V-A phenomological model, the detailed study of angular correlations in process (1') can probably be adequately achieved using a large spark-chamber array. Although we are not aware of any theoretical calculations it seems that a detailed study of the high invariant mass dimuon spectrum of reaction (1') might be sensitive to departures from a local 4 fermion interaction.

There are other classes of coherent processes that may be of great interest which are unique to high A materials. These processes can be visualized as dissociation of the ν_μ into μ + (hadrons). The hadrons then undergo a diffraction scatter on the nucleus. In order to reasonably prove that the process is coherent, the momentum transfer distribution list of these reactions is given below along with the analogous leptonic decay process.

$$\begin{aligned} \nu_\mu + \text{Ne} &\to \mu^- \rho^+ n_e \to \rho \to \mu\nu \\ \nu_\mu + \text{Ne} &\to \mu^- K^+ n_e \to K^+ \to \mu\nu \\ \nu_\mu + \text{Ne} &\to \mu^- A_1^+ n_e \to A_1 \to \mu\nu. \end{aligned} \tag{7}$$

The threshold for the coherent production of these final states is 5, 8, and 12 BeV/c p_ν for the lowest possible (μ+ hadron) invariant mass. Experience with hadronic diffraction dissociation indicates that the assumption of low invariant mass for the coherent processes is reasonable. In addition to these processes, there is an interesting process

$$\nu_\mu + \text{Ne} \to \nu_\mu + \rho^o + \text{Ne} \to \rho^o \to \nu\bar{\nu} \tag{8}$$

this process requires a neutral weak interaction current which couples to the ρ and $\nu\bar{\nu}$ systems. At present, there is no evidence one way or the other concerning such currents. (Note that processes like $K_L \to \nu\bar{\nu}$

violate helicity selection rules and are, therefore, forbidden independent of neutral lepton currents).

There are many other classes of such coherent processes which will be of great interest, namely,

$$
\begin{aligned}
\nu_\mu + \mathrm{Ne} &\to \mu^-\pi^+\mathrm{Ne} &&\to \pi \to \mu\nu \\
&\to \mu^-K^+\mathrm{Ne} &&\to K \to \mu\nu \\
&\to \mu^-\pi^+\eta\,\mathrm{Ne} &&\to \eta \to \pi\mu\nu \\
&\to \mu^-\pi^+\eta'\,\mathrm{Ne} &&\to \eta' \to \pi\mu\nu \\
&\to \mu^-\pi^+K^o\mathrm{Ne} &&\to K \to \pi\mu\nu \\
&\to \mu^-\pi^+\pi^o\,\mathrm{Ne} &&\to \pi \to \pi\mu\nu \text{ (virtually).}
\end{aligned}
\tag{9}
$$

For these processes the study of π_{e3} and K_{e3} decays will provide a strong consistency check on the theoretical models applies to the latter two processes. It seems likely that a broad new class of semi-leptonic decays which are not accessible otherwise will become available using these coherent reactions.

Most of the processes discussed in this report have final states with either two fast charged leptons or fast charged π's and fast-charged leptons. In the latter case the fast hadrons are a direct consequence of the hadrons coming from the ν vertex. In order to reliably study these final states, it seems apparent that a μ detection device external to the bubble chamber will be necessary. We suggest that early in the ν facility planning stage than the necessity for these heavy plate spark chambers be taken into account.

It seems to us that there are many exciting experiments to be done with Ne exposed to a high energy ν_μ beam. For this reason we suggest that the capability for neon running be made early in the NAL neutrino experiments so that the fundamental questions about neutral leptonic currents and self-coupling of the weak currents can be tested.