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Search for Muon-Electron Conversion at TRIUMF

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Abstract

A TRIUMF experiment, using a time projection chamber (TPC), is searching for the reactions $\mu^- Z \rightarrow e^\pm Z'$. Tests of the TPC are described. In a short test run a new limit, $\Gamma(\mu^- Mn \rightarrow e^- Mn)/\Gamma(\mu^- Mn \rightarrow \text{capture}) < 2 \times 10^{-9}$ has been obtained.

Introduction

An experiment at TRIUMF is under way to search for the reactions $\mu^- Z \rightarrow e^\pm Z'$ in which a negative muon captured by a nucleus converts to an electron or positron. Previous searches have yielded the following limits:

$$R_-(Z) = \frac{\Gamma(\mu^- Z \rightarrow e^- Z)}{\Gamma(\mu^- Z \rightarrow \text{capture})} < 7 \times 10^{-11} \text{ in S (Ref. 1)}$$
$$< 1.6 \times 10^{-8} \text{ in Cu (Ref. 2)}, \quad (1)$$

$$R_+(Z) = \frac{\Gamma(\mu^- Z \rightarrow e^+ (Z-2))}{\Gamma(\mu^- Z \rightarrow \text{capture})} < 1.5 \times 10^{-9} \text{ in S (Ref. 1)}$$
$$< 2.6 \times 10^{-8} \text{ in Cu (Ref. 2)}$$
$$< 2 \times 10^{-10} \text{ in I (Ref. 1)}. \quad (2)$$

Processes (1) and (2) are examples of lepton flavor changing (LFC) reactions, which are expressly forbidden by the Weinberg-Salam (WS) theory of the electroweak interaction. Extensions of the WS theory which postulate the existence of additional leptons, exotic gauge bosons, or scalar Higgs bosons with LFC couplings predict non-zero rates for reactions (1) and (2). Shanker[3] has shown that the branching ratio for the coherent process can be written in a model-independent manner:

$$R_-(Z) = \frac{\omega(Z)}{\Gamma(\mu^- Z \rightarrow \text{capture})} \left[g^{(0)} + g^{(1)} (Z-N)/3A \right]^2, \quad (3)$$

where $\omega(Z)$ is a nuclear structure factor, and $g^{(0)}$, $g^{(1)}$ are phenomenological isoscalar and isovector coupling constants, respectively. Using the measured limits for R_- the following limits for the coupling constants, $g^{(0)} < 0.7 \times 10^{-6}$ and $g^{(1)} < 0.3 \times 10^{-3}$, are obtained.

The goal of the TRIUMF experiment is to reach a sensitivity of 10^{-11}–10^{-12} in branching ratios (1) and (2). The experiment involves searching for an electron or positron with momentum ~100 MeV/c associated with a muon capture. In order to reach high sensitivity an intense muon beam and large solid angle detector are required. The detector should have good momentum resolution and a selective trigger for background suppression.

Experimental Method

The TRIUMF detector is a time projection chamber (TPC). The design parameters and principle of operation of the TPC are given in Ref. 4. Basically the TPC is a large volume drift chamber situated in a magnetic field which is parallel to the drift direction. The magnetic field bends particles so that momentum measurements can be made, reduces the transverse diffusion of drifting electrons, and prevents low-momentum particles (the major source of false triggers) from reaching trigger counters surrounding the TPC.

The TPC is capable of three-dimensional position readout of a particle's trajectory. In addition the TPC provides sufficient dE/dx information to distinguish electrons from heavier particles.

TPC Tests

The TPC has been installed in its magnet and run under several conditions. In initial tests the TPC was triggered on cosmic rays. An axial position resolution of 1.5 mm (FWHM) was achieved. The reduction of transverse diffusion of the drifting electrons was observed (Fig. 1). Also observed was an effect due to the non-zero value of $\vec{E} \times \vec{B}$ near the TPC anode wires. This effect is shown schematically in Fig. 2. The data shown in Fig. 3 indicate the xy resolution for electrons will be better than that for positrons. A minimum xy resolution of ~0.2 mm was achieved. Monte Carlo calculations based on the results of these cosmic-ray studies indicate the momentum resolution at 100 MeV/c will be ~4.6 MeV/c and ~6.9 MeV/c (FWHM) for electrons and positrons, respectively.

In other measurements positive pions were stopped in a balsa wood target and the decay positrons observed. The momentum spectrum of the positrons is shown in Fig. 4. The ratio of $\pi e \nu$ events to μ decay events is large, and the μ decay events appear to form a peak because the TPC acceptance is rapidly

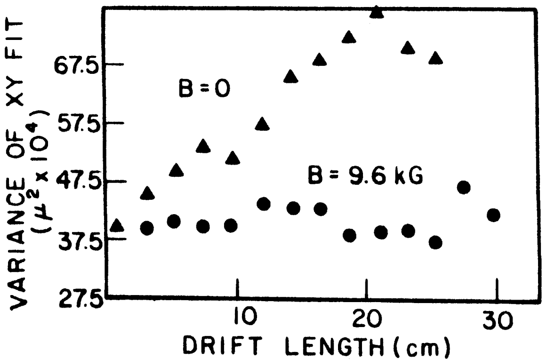

Fig. 1. Variance of the xy fit versus drift length for magnetic fields of 0 and 9.6 kG. The improved resolution at 9.6 kG is due to a reduction of the diffusion coefficient for electrons drifting in a magnetic field, $D(B) = D(0)/(1+w^2\tau^2)$, where w is the cyclotron frequency, and τ is the electron mean collision time.

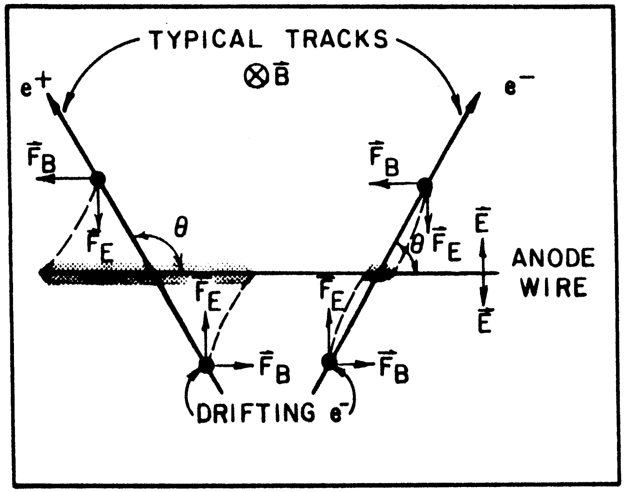

Fig. 2. $\vec{E}\times\vec{B} \neq 0$ effect near an anode wire. The non parallel fields cause the drifting electrons to travel along the dashed trajectories, making the charge distribution widths for electron-like tracks ($\theta < 90°$) smaller than for positron-like tracks ($\theta > 90°$).

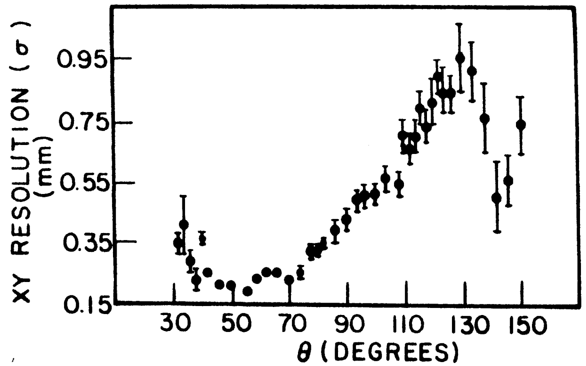

Fig. 3. xy resolution as a function of angle of the track with respect to the anode wire (see Fig. 2 for the definition of θ). The minimum in resolution at $\theta \sim 60°$ is in good agreement with the calculated value.

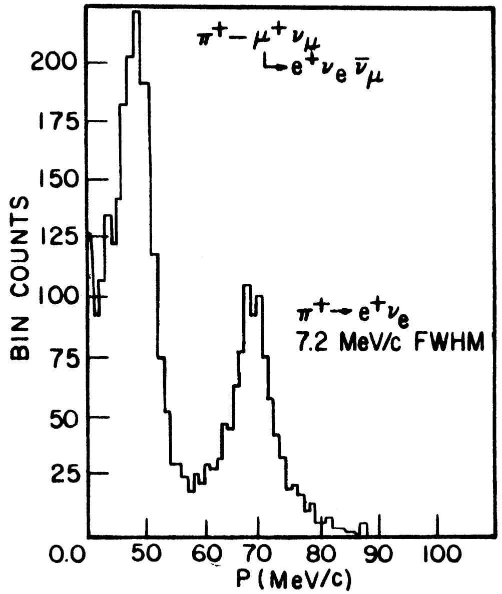

Fig. 4. Momentum distribution of positrons from stopped pions. Non pile-up events which originate within the target and have dE/dx values consistent with positrons are included.

decreasing with decreasing momentum. A momentum resolution of 7.2 MeV/c (FWHM) has been obtained.

During a short test run some data on reactions (1) and (2) were accumulated. The following limit, based on 2.2×10^{10} μ stops in a Mn target,[5] has been obtained:

$$\frac{\Gamma(\mu^- Mn \rightarrow e^- Mn)}{\Gamma(\mu^- Mn \rightarrow \text{capture})} < 2 \times 10^{-9} \text{ (90\% confidence level)} .$$

From this branching ratio measurement a new limit for the isovector coupling constant is obtained: $g^{(1)} < 0.8 \times 10^{-4}$.

No limit on reaction (2) is now available because the final state is not well defined. A detailed study of the acceptance of the TPC as a function of positron momentum (in the range 70-100 MeV/c) remains to be carried out. Final data taking for this experiment should begin in the winter of 1981.

References
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[5] Mn was chosen as a target because it has a large capture probability (0.9). Also the end-point energy of electrons from asymmetric conversion following radiative muon capture:

$$\mu^- Z \rightarrow \nu_\mu (Z-1)\gamma \quad \gamma \rightarrow e^+ e^-$$

is 3.6 MeV lower than the energy of electrons from reaction (1) and so this background can in principle be separated from the process searched for.