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SEARCH FOR MUON ELECTRON CONVERSION $\mu^-+Ti \rightarrow e^-+Ti$

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A progress report on a search for the lepton flavor violating reaction $\mu^-+Ti \rightarrow e^-+Ti$ is presented. No evidence for this process has yet been found leading to an upper limit $< 2 \times 10^{-11}$ (90% confidence level) relative to ordinary muon capture.

A search is being performed for the neutrinoless lepton flavor violating reaction

$$\mu^-+Ti \rightarrow e^-+Ti \quad . \qquad (1)$$

In the coherent process, the nucleus remains in the ground state resulting in emission of a single electron with energy $E_e = m_\mu - B \cong 104$ MeV where m_μ is the muon mass and B is the muon binding energy. Incoherent muon-electron conversion resulting in an excited nucleus is suppressed by Pauli blocking. Previous attempts to observe muon-electron conversion have yielded

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limits to the branching ratios (90% confidence level): $< 1.6 \times 10^{-8}$ for $\mu^-+Cu \rightarrow e^-+Cu$[1] and $< 7 \times 10^{-11}$ for $\mu^-+S \rightarrow e^-+S$[2].

The experiment is being performed using the TRIUMF cloud muon beamline M9. The 73 MeV/c beam passes through an RF particle separator[3] and is degraded and stopped in a 2 gm/cm^2 thick shredded titanium target (density 0.1 gm/cm^3) at the rate of 5×10^5 μ^-/s. Surrounding the target is the electron detection system consisting of a Time Projection Chamber (TPC) and two sets of trigger counters as shown in Fig. 1. The TRIUMF TPC is a large volume atmospheric pressure drift chamber operating with parallel electric and magnetic fields[4]. Some parameters of the TPC system are listed in Table 1. The central high voltage plane causes ionization electrons from charged particle tracks to drift to either end-cap where they are detected by an array of proportional

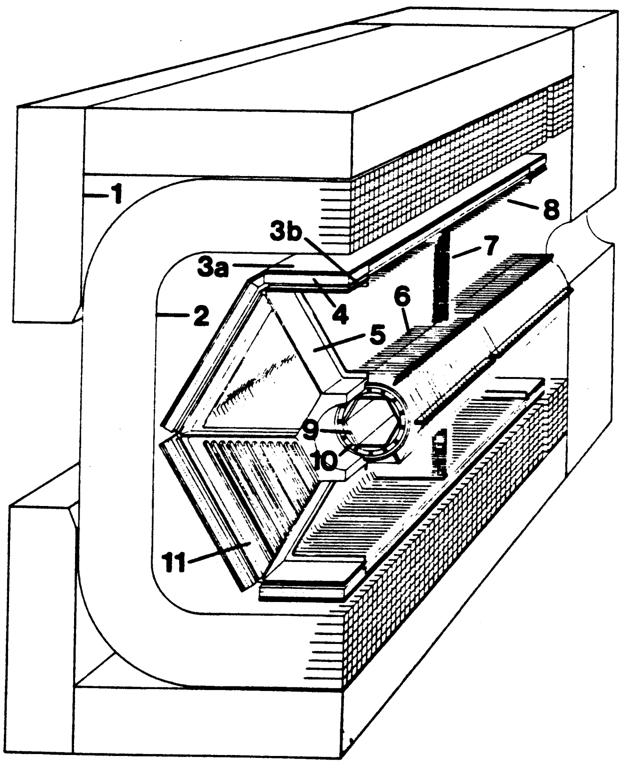

FIGURE 1
A perspective view of the TPC. The TPC has 12 sectors with 12 anode wires per sector separated radially by 2.54 cm. The innermost wire is at a radius of 19 cm. The maximum drift length to the central high voltage plane is 34 cm. The numbered elements are: (1) the magnet iron, (2) the coil, (3a) and (3b) trigger scintillators, (4) outer trigger proportional counters, (5) end cap support frame, (6) central electric field cage wires, (7) central high voltage plane, (8) outer electric field cage wires, (9) inner trigger scintillators, (10) inner trigger cylindrical proportional wire chamber, and (11) end cap proportional wire modules for track detection.

Table 1

TPC Parameters

Gas	Ar(80%), CH_4(20%) at 1 atm
Magnetic Field	9 kG
Drift Field	250 V/cm
Drift Velocity	7 cm/μs
Anode wire gain	5×10^4

wires. Independent x, y and z coordinate information is obtained for each of up to twelve track segments. The anode wire positions and the induced charge distributions on the segmented cathode pads give the y and x positions, respectively, and the drift times relative to the trigger determine the z coordinates. The inner trigger counter set consists of six scintillators and a cylindrical MWPC and the outer set is made up of six planar MWPCs each sandwiched between scintillators as shown in Fig. 1.

The trigger is enabled for a period 20 to 600 ns following a stop signal, the coincidence of four beam scintillators preceding the target in anticoincidence with veto counters which surround it. The first level trigger requires a coincidence of both inner counters and at least two outer counters. In order to eliminate space charge effects due to leakage of positive ions from the proportional wire region into the drift region of the TPC, a dual grid structure[5] blocks all ionization from reaching the endcap wires except when a first level trigger signal is present. For the second level trigger, at least six TPC wires are required to fire in the appropriate sectors of the TPC.

The acceptance and performance of the detection system is monitored by studying the decay $\pi^+ \to e^+\nu_e$. Pions are stopped in the target and the 70 MeV/c positrons are observed in the TPC with the magnetic field lowered to B = 6 kG so that their curvatures match those of electrons at 104 MeV/c when B = 9 kG. The acceptance of the detector system was approximately 20%. The momentum resolution for positrons at 70 MeV/c was found to be approximately 6 MeV/c (FWHM) in agreement with Monte Carlo calculations which use position resolution data derived from cosmic ray tests.

The position resolution of the TPC, discussed in detail in Ref. 4, is plotted in Fig. 2 as a function of the angle at which tracks cross the anode wires. The best resolution σ_x = 200 μm occurs at the minimum drift length and at a crossing angle of approximately θ = 30° at B = 9 kG. The resolution asymmetry evident in Fig. 2 arises from $\overline{E} \times \overline{B}$ effects in the neighborhood

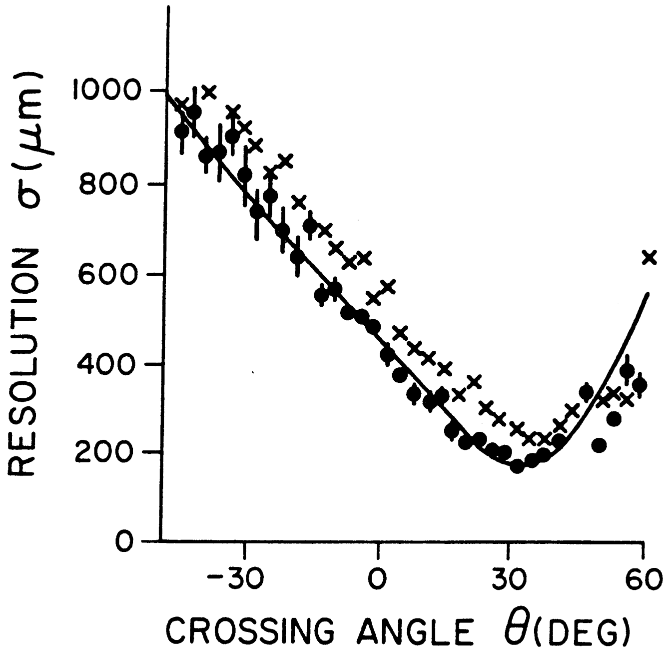

FIGURE 2
The rms spatial resolution (σ) of the TPC as a function of the angle θ at which tracks cross the anode wires. The solid points were taken before the installation of the pulsing grids described in the text and those marked x were obtained afterwards (see Ref. 4 and 5).

of the anode wires and from the non-uniform primary ionization distribution. For 104 MeV/c electrons which tend to cross the wires near $\theta = 30°$ the momentum resolution expected is approximately 4 MeV/c (FWHM). This is considerably better than for the positrons from $\pi^+ \to e^+\nu$ decay which tend to cross in the region of $\theta \cong -30°$ where the position resolution is poorer.

Potential sources of background for coherent muon-electron conversion in the present system are listed in Table 2 along with their estimated levels. Pion contamination in the beam could produce single 100 MeV/c electrons via

Table 2

Background Estimates

Process	Equivalent Branching Ratio Level
Beam pions	$\sim 10^{-13}$
Cosmic Rays	$\sim 10^{-12}$
μ^- decay in atomic orbit	$\sim 10^{-12}$
Radiative muon capture	$< 10^{-12}$

radiative capture and subsequent asymmetric conversion. Pions are suppressed by the RF separator and subsequent range telescope from an initial ratio $\pi/\mu \simeq 1$ to $\pi/\mu < 10^{-4}$ at the experimental target. Adequate rejection of the remaining pion-induced events is obtained by eliminating any event candidate which is in prompt coincidence with a beam particle. Cosmic ray-induced backgrounds have been studied during beam off periods and have been substantially suppressed by large drift chambers which surround the TPC magnet. The expected levels of background from radiative muon capture and from bound μ^- decay are derived from Monte Carlo calculations.

During an initial running period, $N_\mu = 3 \times 10^{12}$ muons were captured in the Ti target. After all cuts were applied the electron momentum spectrum shown in Fig. 3a was obtained. This spectrum is consistent with being due to bound μ^- decay. Figure 3b shows a calculated spectrum for the coherent reaction (1) with a branching ratio of 10^{-10}. Using the data of fig. 3a a preliminary upper limit (90% C.L.) for the branching ratio is:

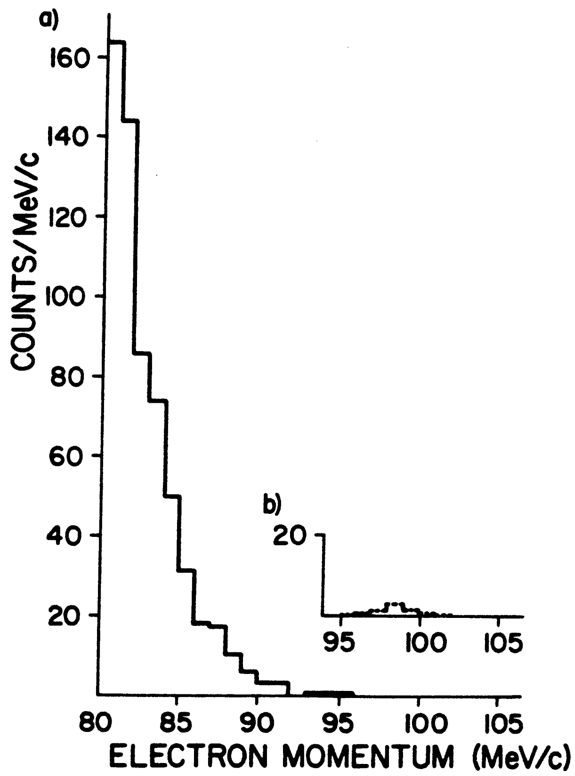

FIGURE 3
a) The observed electron spectrum. b) The dashed lines represent a Monte Carlo generated spectrum for $\mu^- + Ti \rightarrow e^- + Ti$ with a branching ratio of $R \simeq 10^{-10}$.

$$R = \frac{\Gamma(\mu^- + Ti \rightarrow e^- + Ti)}{\Gamma(\mu^- + Ti \rightarrow \nu_\mu + \ldots)}$$

$$< \frac{2.3}{N_\mu \bar{\varepsilon}}$$

$$< 2 \times 10^{-11}$$

where $\bar{\varepsilon} \cong 3.5\%$ is the effective acceptance for this data set. The experiment is continuing.

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