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Increased Sensitivity to Possible Muonium to Antimuonium Conversion

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Abstract. A new experimental search for muonium-antimuonium conversion was conducted at the Paul Scherrer Institute, Villigen, Switzerland. The preliminary analysis yielded one event fulfilling all required criteria at an expected background of 1.7(2) events due to accidental coincidences. An upper limit for the conversion probability in 0.1 T magnetic field is extracted as $8 \cdot 10^{-11}$ (90% CL).

The hydrogen like muonium atom ($M = \mu^+e^-$) consists of two leptons from different generations. The close confinement of the bound state offers excellent opportunities to explore precisely fundamental electron-muon interaction. The dominant part of the binding in this system is electromagnetic and can be calculated to very high accuracy in the framework of quantum electromagnetics (QED). Indeed, precision experiments on electromagnetic transitions in muonium have been employed both to verify bound state QED calculations and for determining most accurate values of fundamental constants [1].

Since the effects of all known fundamental forces in muonium are calculable very well, it renders the possibility to search sensitively for yet unknown interactions between both particles. A conversion of muonium into its antiatom ($\overline{M} = \mu^-e^+$) would violate additive lepton family number conservation and is not provided in standard theory. However, muonium-antimuonium conversion appears to be natural in many speculative theories, which try to extend the standard model in order to explain some of its yet not well understood features like parity violation in weak interaction and particle mass spectra. The interaction could be mediated by a doubly charged Higgs boson [2], heavy Majorana neutrinos [3], a neutral scalar [4], e.g. a supersymmetric τ-sneutrino [5] or a dileptonic gauge boson [6].

An experiment had been set up to search for spontaneous muonium-antimuonium conversion at the Paul Scherrer Institute (PSI) in Villigen, Switzerland [7]. It uses the powerful signature developed in an experiment at the Los Alamos Meson Physics Facility (LAMPF) USA, which requires the coincident identification of both constituents of the antiatom in its decay [8].

Muonium atoms were produced by stopping a beam of surface muons in a SiO_2 powder target, where a fraction of them forms muonium by electron capture, some of which diffuse through the target surface with thermal energies into vacuum. Energetic electrons from the decay of the μ^- in the antiatom can be observed in a magnetic spectrometer at 0.1 T magnetic field consisting of five concentric multiwire proportional chambers and a 64 fold segmented hodoscope. The positron in the atomic shell of the antiatom is left behind after the decay with 13.5 eV average kinetic energy. It can be electrostatically accelerated to 8 keV and guided in a magnetic transport system onto a position sensitive microchannel plate detector (MCP). Annihilation radiation can be observed in a 12 fold segmented pure CsI calorimeter surrounding the MCP.

The muonium production was monitored regularly by reversing all electric and magnetic fields of the instrument every five hours for a duration of 20 minutes. Targets had to be replaced twice a week because of observed deterioration of muonium production on a one week time scale. In the course of the experiment $5.7 \cdot 10^{10}$ muonium atoms were observed in the interaction volume for antimuonium decays. There was one event which passed all required criteria, i.e. fell into a 99% confidence interval of each relevant distribution. The expected background due to accidental coincidences is 1.7(2) events.

The preliminary combination of all data recorded in the experiment between 1993 and 1996 [7,9,10] results in an upper limit for the conversion probability in 0.1 T magnetic field of $\mathrm{P}_{\mathrm{M\overline{M}}} \leq 8 \cdot 10^{-11}$ (90 % CL). For an assumed effective (V-A)x(V-A) type four fermion interaction this corresponds to an upper limit for the coupling constant of $\mathrm{G}_{\mathrm{M\overline{M}}} \leq 3 \cdot 10^{-3} \mathrm{G}_{\mathrm{F}}$(90 % CL), where G_{F} is the weak interaction Fermi coupling constant [9].

This new result allows to rule out definitively a certain Z_8 model with more than three particle generations [4] and to set a new lower limit of 2.6 TeV/c^2 * g_{3l} (g_{3l} depends on model, of order unity) on the mass of a dileptonic gauge boson in GUT models - well beyond the value extracted from high energy Bhabha scattering [6]. It can be further shown in the framework of minimal left right symmetric and supersymmetric models [11] that lepton number violating muon decay ($\mu^+ \rightarrow e^+ + \nu_\mu + \overline{\nu}_e$) is not an option for explaining the excess neutrino counts in the LSND neutrino experiment at Los Alamos [12].

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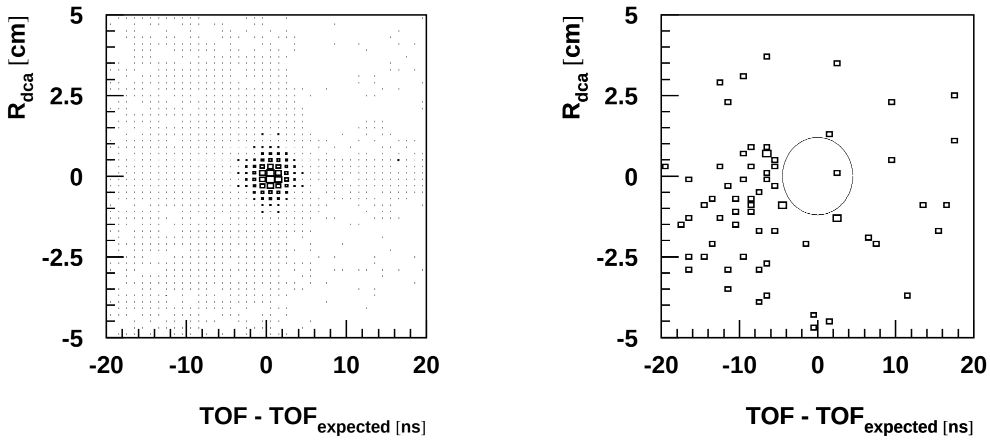

FIGURE 1. The distribution of the distance of closest approach (R_{dca}) between a track from an energetic particle in the magnetic spectrometer and the back projection of the position on the MCP detector versus the time of flight (TOF) of the atomic shell particle for a muonium measurement (left) and for all data recorded in 1996 while searching for antimuonium (right). One single event falls within 3 standard deviations region of the expected TOF and R_{dca} which is indicated by the ellipse. The events concentrated at early times and low R_{dca}correspond to a background signal from the allowed decay $\mu \rightarrow 3e + 2\nu$.

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