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# Measurement of the transverse polarization of positrons from the decay of polarized muons: A status report

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A new experiment [1] to measure both transverse components of the positron polarization from the decay of polarized muons starts data taking at PSI in Switzerland. The experiment aims at an accuracy of $\Delta P_{T_1} = \Delta P_{T_2} = 3 \times 10^{-3}$ and by that at an improvement of the existing limit by nearly one order of magnitude. These results will be sensitive tests for the contribution of exotic couplings to muon decay. In particular, the measurement of $P_{T_1}$ allows the extraction of the so-called low energy Michel parameter $\eta$, the accuracy of which presently limits a more precise model independent determination of the Fermi coupling constant $G_F$. The measurement of $P_{T_2}$ is at present the only possibility to test time reversal invariance in a purely leptonic reaction. The physics motivation is discussed together with a description of the experimental setup and results from test measurements.

## 1. INTRODUCTION

Measurements of muon decay are low energy tests of the standard model. In fact, only a few years ago it has been shown that $V - A$, as one of the basic assumptions of the standard model, *follows* from the results of a selected set of muon decay experiments (including inverse muon decay) [2]. The experimental limits obtained up to now, however, still allow for substantial contributions from non-standard couplings which differ in their spin structure from the $V - A$ interaction. The limits on these couplings can be efficiently improved by performing experiments with polarized muons and positrons. The measurement of the transverse positron polarization $P_{T_1}$ as a function of the positron

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energy, in particular, offers the possibility to obtain the low energy parameter $\eta$ without the suppression factor $m_e/m_\mu$, which makes the determination of $\eta$ from the electron energy spectrum extremely difficult. The simultaneous measurement of the polarization component $P_{T_2}$ allows to test time reversal invariance.

## 2. TRANSVERSE POLARIZATION IN THE STANDARD MODEL AND BEYOND

Fig. 1 shows the kinematic variables for muon decay. While the $e^+$ from $\mu^+$ decay is mainly longitudinally polarized (polarization $P_L$), there also is a transverse polarization component $P_{T_1}$ lying in the plane of muon polarization $\boldsymbol{P}_\mu$ and positron momentum $\boldsymbol{k}_e$. Within the standard model $P_{T_1}$ is negligibly small at large positron energies, but

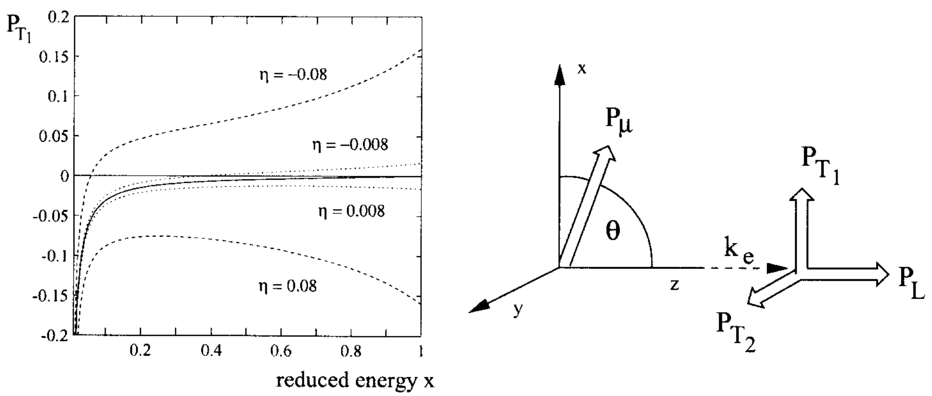


Figure 1. Transverse positron polarization $P_{T_1}$ as a function of the reduced positron energy. The standard model predicts $\eta = 0$ (solid curve), the experimental limit from the direct measurement [3] is $\eta = (11 \pm 85) \times 10^{-3}$, the fit to all available data [3] is $\eta = (-7 \pm 13) \times 10^{-3}$.

substantial at lower energies and reaches the value $-1/3$ in the limiting case of a positron at rest (see Fig. 1, $\eta = 0$). Due to the low rate at small positron energies the energy averaged transverse polarization predicted by the standard model is $< P_{T_1} >= 0.003$ and therefore at present cannot be detected.

One can, however, obtain large transverse polarizations by including an additional interaction which renders the positrons with opposite chirality so that for a given final state the two interactions will interfere. In the general case there will be a phase between the two interactions which leads to a transverse component $P_{T_2}$ *perpendicular* to the plane of muon polarization and positron momentum, and which violates time reversal invariance. With the experimental knowledge that $V-A$ is dominant [2] and neglecting exotic contributions in second order, one derives from the two polarization components

$$P_{T_1}(E_e) \to \quad \eta \approx \frac{1}{2}\, Re\{g^S_{RR}\} \qquad \text{and} \qquad P_{T_2}(E_e) \to \quad \frac{\beta'}{A} \approx \frac{1}{4}\, Im\{g^S_{RR}\},$$

where $g^S_{RR}$ represents a scalar, charge-changing interaction with right-handed charged leptons [4].

A more precise value of $\eta$ is urgently needed for a model-independent determination of the Fermi coupling constant $G_F$: The influence of the uncertainty in the experimental value of $\eta$ on the value of $G_F$ is at present 20 times larger than the one of the more precisely known muon life time [4].

## 3. EXPERIMENT

The experimental setup is shown in Fig. 2 . A beam of highly polarized muons enters the Be stop target with bunches every 20 ns. The polarization of the stopped muons precesses in a homogeneous magnetic field with the same frequency as the accelerator RF. Thus every new muon bunch is added coherently with the same direction of the polarization vector. Decay $e^+$ emitted parallel to the B-field are tracked by drift chambers and can annihilate with polarized $e^-$ in a magnetized foil. The two annihilation quanta are detected by a wall of 127 BGO crystals. A valid annihilation event requires a coincidence of two plastic scintillator counters before the magnetized foil with two separated clusters of BGO detectors and an anticoincidence with a plastic counter array in front of the BGO wall. A possible transverse polarization would be detected as a harmonic time dependence of the annihilation rate for a given detector pair.

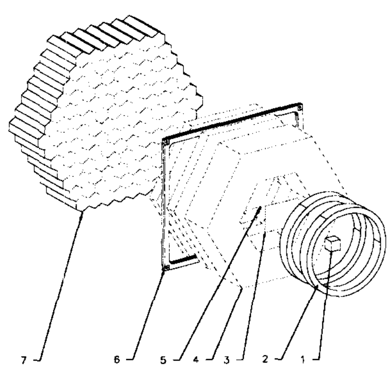


Figure 2. Experimental setup: 1 - Be target, 2 - spin precession magnet, 3 and 5 - plastic trigger counters, 4 - drift chamber (10 planes), 6- iron yoke of the magnetized Vacoflux foil, 7 - BGO calorimeter. Two additional drift chambers (2 planes each) sandwich the magnetized foil. An array of plastic veto counters (ANTI) in front of and cosmic trigger scintillators on top and below the BGO wall are not shown.

In summer 1998 for the first time a test measurement with nearly complete experimental setup and a preliminary version of the Cluster Recognition Unit was performed. The main goal was to establish the optimum trigger conditions and to test the interplay of the different subsystems under run conditions. True annihilation events were identified with 10 % trigger efficiency; with appropriate geometry and energy cuts, however, the background could be efficiently reduced. The resulting annihilation energy spectrum, together with the difference of the spectra taken with $\mu^+$ (true events and background) and $\mu^-$ (only background), and the $e^+$ energy (Michel) spectrum are shown in Fig. 3. On this basis the features of the final hardware trigger setup have been determined. An improved cluster recognition unit will also measure the distance of the clusters in the BGO wall and apply distance cuts. The implementation of the new features is under way for the next run in 1999.

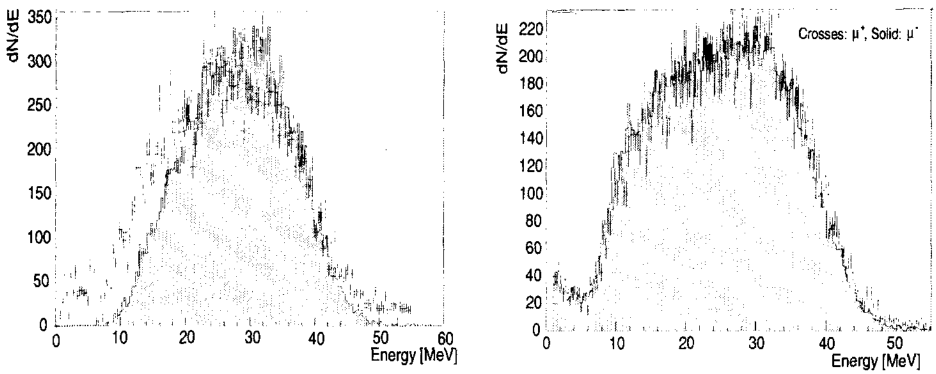


Figure 3. Annihilation and Michel energy spectra taken with the BGO calorimeter. The solid spectrum (left picture) is obtained from $\mu^+$ annihilation events after the full analysis. The crosses are obtained from the subtraction $\mu^-$ from $\mu^+$ annihilation trigger events. The difference between the two spectra is mostly due to true annihilation events in which for one of the annihilation photons only part of the energy is deposited in the BGO wall. On the right hand side Michel spectra are shown. The $e^+$ spectrum (crosses) is slightly shifted to higher energies compared to the $e^-$ spectrum (solid) due to the annihilation of the stopped positrons in the BGO crystals.

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