High Precision Measurements of Muon Decay at TWIST

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Abstract. As a test of the Standard Model in a purely leptonic decay interaction, the TWIST experiment is designed to precisely measure Michel parameters. TWIST has just published its first measurements of Michel parameters ρ and δ from the 2002 data, with a precision 2 to 3 times better than the previous results. The physics analyses of the 2004 data, taken under better conditions, are in progress. Some reductions in the systematic uncertainties have been achieved.

Keywords: muon decay, electroweak interactions, Michel parameters, Standard Model
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INTRODUCTION

Muon decay, $\mu \to e\nu\bar{\nu}$, is a purely leptonic process, which can be calculated unambiguously with high accuracy in the framework of a theoretical model. It therefore provides a good experimental tool for studying the structure of the weak interaction. Ignoring the neutrino mass and radiative corrections, the differential decay rate for positive muon decay is given in terms of four parameters ρ, η, δ and ξ, commonly referred to as the Michel parameters, by [1]

$$\frac{d^2\Gamma}{x^2 dx d\cos\theta} \sim 3(1-x)+\frac{2}{3}\rho(4x-3)+3\eta x_0(1-x)/x+P_\mu\xi\cos\theta\left[1-x+\frac{2}{3}\delta(4x-3)\right], \tag{1}$$

where θ is the angle between the muon polarization and the decay positron direction, x $(=\frac{E_e}{W_{e\mu}})$ is the reduced energy, $x_0 = \frac{m_e}{W_{e\mu}}$, and P_μ is the muon polarization.

The Standard Model predicts the Michel parameters to take the values $\rho = \frac{3}{4}$, $\eta = 0$, $\delta = \frac{3}{4}$ and $\xi = 1$. Previous experimental results [2] are consistent with these values. TWIST will determine ρ, δ, η and $P_\mu\xi$ with significantly improved precision, providing an excellent chance to observe new physics if the measured Michel parameters differ from the Standard Model predictions.

THE TWIST EXPERIMENT

The TWIST spectrometer, shown in Fig. 1, consists of an array of 44 planar drift chambers and 12 proportional chambers located within a 2 T uniform magnetic field.

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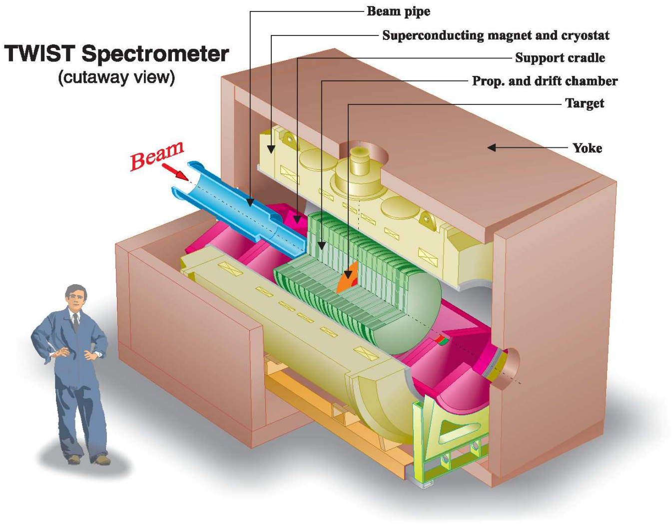

FIGURE 1. The TWIST spectrometer.

The chambers are constructed to very high precision with attention paid to minimizing the amount of material in the tracking region. The sense wires are positioned within a standard deviation of 3 μm, and the longitudinal and transverse dimensions are aligned with an extreme accuracy of 5×10^{-5} [3]. A minimum bias trigger is provided by a thin plastic scintillator read out.

TWIST uses a highly polarized muon beam which is obtained by selecting muons originating from pions decaying on the surface of the production target at a time between the proton beam pulses. The muons are stopped in a thin target at the center of the highly symmetric detector system. The decay positrons then follow helical trajectories through the detectors allowing us to precisely measure their energies and angles.

In 2004, TWIST published its first physics results from the 2002 data samples. The uncertainties in ρ and δ were reduced by factors of 2.5 and 2.9, respectively [4]. These are also the first measurement in 35 years to improve the value of ρ, and the first in 15 years to improve δ.

$$\rho = 0.75080 \pm 0.00032(stat) \pm 0.00097(syst) \pm 0.00023(\eta) \tag{2}$$

$$\delta = 0.74964 \pm 0.00066(stat) \pm 0.00112(syst) \tag{3}$$

where the last quoted uncertainty for ρ is due to the uncertainty in the assumed value for $\eta = -0.007 \pm 0.013$ [2], which was held fixed in the analysis. Unlike any previous muon decay parameter measurements, the TWIST analysis is done with the true decay parameters hidden (so called “blind analysis”), and the systematic uncertainties are determined prior to revealing the hidden values.

The results for ρ and δ set a new upper limit on the mixing angle in the left-right symmetric models, $|\zeta| < 0.030$ (90% c.l.), and slightly increase the lower limit on the right-handed boson mass M_R.

The final goal of TWIST experiment is to determine the Michel parameters to a few parts in 10^4, an improvement of at least an order of magnitude in each case.

CURRENT STATUS

The experience gained in the first measurements of the muon decay parameters allows us to know which systematic uncertainty can be expected to dominate and how it can be reduced. Therefore, some improvements to the detector and beam line systems were made when we collected the data in 2004:

- A high-purity aluminum target was used (compared with a Mylar target used in 2002). This helps us to reduce the depolarization of the muon beam and to reduce the uncertainty in the target thickness.
- A beam monitoring chamber was installed. This enables us to characterize the muon beam more precisely.
- A refined online monitor system was implemented. The gas absorber in the beam line was regulated to make the muons stop at the expected z positions, and the cathode foil position of the drift chamber was monitored better.

A direct measurement of $P_\mu \xi$ from the 2004 data has been completed and will be published soon. The uncertainty on the previous measurement is reduced by about a factor of 2. The analysis of ρ and δ from the 2004 data is still underway. The improvements so far identified are:

- The data runs within each data sample become more consistent with each other.
- The helix tracking code takes into account the energy loss of the positron tracks. Also, a more precise space-time relationship file is provided.
- The Monte Carlo simulation of the detector is refined. A realistic beam input is measured by the beam monitoring chamber. The drift chamber cell geometry is well determined. The GEANT3 simulation of the physics of positron interactions in materials is better validated.

The measurements for ρ and δ will be finished in Spring of 2006. We expect to reduce the uncertainties on the previous measurements by a factor of 2.

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