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Muon Decay Parameters (TWIST experiment at TRIUMF)

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The TRIUMF Weak Interaction Symmetry Test (TWIST) experiment has measured the spectrum of positrons from muon decay and determined the decay parameters: $\rho = 0.75014 \pm 0.00017(stat.) \pm 0.00044(syst.) \pm 0.00011(\eta)$, $\delta = 0.75067 \pm 0.00030(stat.) \pm 0.00067(syst.)$, $P_{\mu}^{\pi}\xi = 1.0003 \pm 0.0006(stat.) \pm 0.0038(syst.)$. The results are in good agreement with the Standard Model. Future prospects for this measurement are discussed.

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1. Introduction

Muon decay is a rather mature subject. In 1948 Jack Steinberger carried some Geiger tubes and plastic absorbers up a mountain. His measured spectrum of the range of charged particles following a stopped muon showed evidence that the final state consisted of three light particles. However, quoting the paper, “the uncertainties (in the decay spectrum) are unknown but large” [1]. Since then we have seen a shrinkage in the uncertainties together with corresponding increases in the size of the experimental collaborations. The experimental status of muon parameter measurements, apart from the work reported here, are measurements of ρ[2], δ[3] $P_\mu^\pi\xi$[4], $P_\mu^\pi\xi\frac{\delta}{\rho}$[5], and a recent determination of η from the polarisation of the decay positron[6], all in agreement with the Standard Model (SM).

The TWIST experiment, a collaboration of ≈ 50 scientists and engineers that has been active for more than a decade, continues the process of reducing these uncertainties. We are aiming at an order-of-magnitude improvement over the pre-TWIST status. This is made possible by advances in detector and computational technologies, which allows a measurement of most of the phase space with high statistics, enabling TWIST to simultaneously extract the ρ, δ , and $P_\mu^\pi\xi$ parameters.

2. Very Brief Review of Muon Decay Theory

Muon decay can be understood in terms of a lepton number conserving general Lorentz invariant four-particle weak local interaction without derivative couplings[7]; this has ten complex coupling constants. This is greatly simplified in the Standard Model (SM), which assumes V-A, predicting $\rho = \delta = \frac{3}{4}$, $P_\mu^\pi = \xi = 1$ and $\eta = 0$. The decay spectrum is relatively insensitive to η and only the product $P_\mu^\pi\xi$ is determined.

3. Description of the TWIST Experiment

The experiment used the M13 channel at the TRIUMF laboratory in Vancouver, Canada. Positive muons were selected from pions decaying near the surface of the graphite production target to minimise their loss of helicity from scattering in the target. The helicity is preserved through their transport into the TWIST solenoid and their emittance is determined by a time expansion chamber[8], which was inserted at the entrance to the solenoid. The polarisation is then determined from tracking the muons through the solenoidal field. Further depolarisation after the muons stop inside the target is monitored from the time dependence of the decay asymmetry.

The TWIST detector [9] consists of an array of planar wire chambers placed symmetrically about a thin target in which the muons are stopped. The chambers are constructed and aligned to a relative dimensional precision of 5×10^{-5}, and are immersed in a 2T uniform magnetic field mapped to a precision of $\sim 10^{-5}$T. The decay positrons are then tracked and their initial momentum and angle relative to the magnetic field are determined. The muon decay parameters are determined by comparison with a corresponding spectrum produced from a simulation including radiative corrections to order α^2 together with a detailed description of the spectrometer and ionisation processes.

The decay parameters used in the simulation are chosen so that they are within a certain region around the SM values. In order to blind the analysis, their exact values are revealed only after the analysis is finalised and the consistency of the data and the sensitivity of the analysis to the various uncertainties in the simulation are ascertained. These uncertainties are derived from data/simulation comparisons that are independent of the muon decay parameters.

4. Results

Data with an aluminium target were analysed to determine $\rho = 0.75014 \pm 0.00017(stat.) \pm 0.00044(syst.) \pm 0.00011(\eta)$, $\delta = 0.75067 \pm 0.00030(stat.) \pm 0.00067(syst.)$[10]. The leading systematic uncertainties come from understanding of the chamber response, validation of the simulation of the positron interaction physics, and chamber calibrations. These results are a factor-of-two more precise than previous measurements published by TWIST [12, 13]. They are consistent with Standard Model predictions, placing more stringent limits on new physics in the weak interaction. The same data was used to measure $P_\mu^\pi \xi = 1.0003 \pm 0.0006(stat.) \pm 0.0038(syst.)$[11]. The uncertainty in this measurement is dominated by the degree to which the depolarisation in the solenoid's fringe field could be determined.

5. Outlook

TWIST has completed its physics data taking, and a final analysis for all muon decay parameters is underway. The final data sets contain more statistics, and benefit from improvements in the data taking conditions, such as chamber stability and beam monitoring. Addressing the sources of leading systematic uncertainties, analysis algorithms and calibrations have been refined significantly. These improvements are expected to lead to additional factor-of-two reductions in the uncertainties on muon decay parameters, providing another incremental improvement to searches for new physics.

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