The TWIST experiment (TRIUMF Weak Interaction Symmetry Test)

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Abstract

The TRIUMF Weak Interaction Symmetry Test (TWIST) experiment aims at a precision measurement of the energy spectrum and of the angular distribution of the decay positrons from highly polarized muons. The experiment has been designed to reach a precision of a few parts in 10^{-4} for the so-called Michel parameters which are used to parametrize these distributions. After an engineering run in the fall of 2001, the current data taking phase should provide intermediate results for the ρ and δ parameters at the 10^{-3} level by the end of 2003 which will be used to place largely model independent constraints on new physics beyond the Standard Model. A review of the status of the experiment is presented.

Key words: muon decay, electroweak interactions, Standard Model
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1 Introduction

The purely leptonic decay $\mu \to e\nu\nu$ is one of the best experimental tools for studying the structure of the weak interaction and provides a window of opportunity to explore physics beyond the V-A structure of the Standard Model. By determining with high precision the observables accessible in experiments, largely model independent constraints can be placed on new physics possibilities.

With more and more sophisticated detection techniques, several groups are pushing the limit of precision with which muon decay is known. Groups at RAL and PSI are attempting to determine the lifetime of μ^+ to extract a more

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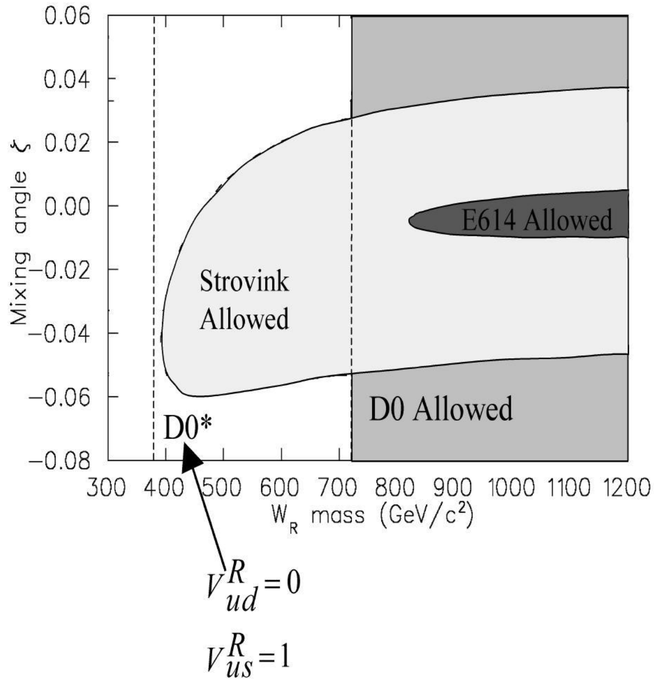

Fig. 1. Limits on right handed W mass and mixing from the TWIST experiment (E614) at TRIUMF.

precise value of the Fermi coupling constant G_F while two groups at TRIUMF and PSI are focusing on the determination of the Michel parameters which parametrize the energy spectrum, angular distribution and the polarization of the positron emitted in the decay of a positive muon.

In a most general, derivative free, Lorentz invariant Lagrangian formulation, these Michel parameters can be expressed as linear combinations of the squares of the coupling constants which include both right handed and left handed fermions interacting through a scalar, vector or tensor interaction. The current knowledge of the Michel parameters in muon decay and in the inverse neutrino electron charged current reaction cannot place severe enough constraints on the non V-A part of the interaction to preclude a scalar interaction at the level of 50% . For a detailed review of the current constraints, see the summary by W. Fetscher in the Review of Particle Physics [2].

2 The TWIST experiment

While the PSI program is focusing on the determination of positron polarization observables [3], the new TWIST experiment at TRIUMF is aimed at providing a 10^{-4} precision determination of the four parameters describing the angular and momentum distributions of fully polarized muon decay. This could be used to limit for example the mass and mixing of a possible right handed sector in left-right symmetric models in a complementary way to the direct searches for a right handed W at the CDF and D0 hadron collider experiments (Fig. 1). A 10^{-4} determination of the $P_\mu \xi$ parameter would constrain a right handed W to have a mass above 700 GeV, with very small mixing to its left handed partner.

As another example of the possible use for a high precision determination of the ρ parameter, Babu et al. have presented a model of anomalous muon decay which could explain the LSND anomaly by allowing a branch that decays to two antineutrinos [4]. The model is constructed to avoid lepton flavor violating decays at the current level of sensitivity. A possible signature of such a muon decay branch would be a reduction of the ρ Michel parameter from its V-A value of 0.75 to 0.7418, which should even be within the range of precision of the initial phase in the TWIST experiment.

A determination of tight constraints on the scalar part of the weak interaction would be very welcomed by many groups attempting to introduce supersymmetry and or M-brane theoretical ideas.

The TWIST experiment currently taking data at TRIUMF relies on a specially prepared muon beam with high polarization, obtained by selecting muons originating from pions decaying on the surface of the production target in between proton beam bursts. The high polarization is maintained during the transport of the muon to a thin (75 μm) stopping target located at the center of a 2 T solenoid, containing a set of 52 low mass wire chambers to track the decaying positrons. Initially a mylar stopping target has been used but an ultrapure aluminum or gold target will be required to reach the ultimate goal of the experiment. The detector has been designed to offer a uniform acceptance over a large part of the phase space available for the positron. In particular, the detector is made as symmetric as possible in the forward and backward decay region to enhance sensitivity to the asymmetry parameters ξ and δ. It also helps to reduce the systematic uncertainty on ρ and η. At the present muon stopping rate of 2,500 s^{-1}, it is relatively easy to acquire the event samples (10^9 events) required for reaching the 10^{-4} statistical precision, but the experiment will have to control the systematic errors at the same level and will need many samples of data taken in different running conditions.

Many data sets have been accumulated during the current beam period, with surface muons ($P_\mu = -1$) and also with muons from pion decay in flight($P_\mu \sim +0.3$). Both types will be used to determine ρ, and since ρ characterizes the polarization independent part of the energy distribution, this represents a consistency check.

A full simulation of the experiment has been developed in GEANT3, including muon beam production and transport to the target, the detector wire chamber response, and hit digitization. For the simulation of the stopping muon, GEANT4 has been used to improve the tracking in thin films and gases.

The radiative correction calculations to muon decay have been improved [5] to include second order terms in the leading log approximation. Evaluation of next to leading terms will be necessary to reach the 10^{-4} precision and these are currently under investigation at the University of Alberta[6].

3 Conclusion

A high precision measurement of the Michel parameters describing muon decay is underway at TRIUMF with an aim of providing stringent tests of the V-A structure of the weak interactions between leptons. Preliminary results at the 10^{-3} level of precision should become available in 2003.

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