Theoretical Implications of the TWIST Experiment Results

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Decay Parametrisation

Muon decay can be described using the four-fermion interaction formalism as a derivative-free, Lorentz-invariant and lepton-number conserving matrix:

\[ M = \frac{\sqrt{2}}{2\pi} \sum_{\mu=e,\mu} g'_\mu \epsilon \langle \mu | \bar{\nu}_e | \nu_\mu \rangle, \]

where \( g'_\mu = (\mu/\nu_e)_{\mu=\ell} \) and \( \epsilon = S(\text{scalar}, V(\text{vector}), T(\text{tensor})) \).

In the case of an experiment measuring only the positron, one can write a differential decay rate parametrised by four bilinear combinations of the couplings \( g'_\mu \), commonly referred to as the Michel parameters (in red):

\[ \frac{d\Gamma}{dx} \propto \frac{m_W^4}{4\pi} G_F^2 [x^2 - \xi(x, \rho, \eta) + P_0 \cos \theta F_{\delta}(x, \xi, \delta)] + RC, \]

where \( x = 1 - \frac{m_0^2}{m^2}, \) \( \xi(x, \rho, \eta) = \frac{2}{3} x + \frac{4}{3} (1 - \xi(x, \rho, \eta) = \frac{2}{3} x + \frac{4}{3} (4 - x + \frac{1}{3} (1 - x^2)), \) and \( \delta = 3 \). 

In the Standard Model the decay is purely V-A, therefore all the \( g'_\mu \) are zero except \( g'_L = 1 \). 

Consequently: \( \rho = \frac{3}{4}, \) \( \eta = 0, \) \( P_0^L = 1, \) \( \delta = 3 \).

Global Analysis

The global analysis described in [5] uses an alternative parametrisation with a different set of bilinear combinations of the coupling constants:

\[ Q_L = \frac{1}{4} g'_{\mu L}^2 + \frac{1}{4} g'_{\mu R}^2 + g'_{\nu L}^2 + 3 |g'_{\nu R}|^2, \]

\[ Q_R = \frac{1}{4} g'_{\nu L}^2 + \frac{1}{4} g'_{\nu R}^2 + g'_{\mu L}^2 + 3 |g'_{\mu R}|^2. \]

These bilinear combinations satisfy the following constraints:

\[ 0 \leq Q_{LL} \leq 1, \]

where \( \mu = L, R \), \( 0 \leq Q_{RR} \leq Q_{LL} \) where \( \mu = L, R \). 

A global fit was performed using the parametrisation above. 

The experimental inputs of the fit were: 

- the four Michel parameters \( \rho, \eta, \tilde{P}_L^R, \xi, \delta \).
- the measurement of \( P_3^L \).
- the parameters \( \zeta \) and \( \zeta' \) from the longitudinal polarisation of the outgoing electrons. 
- the parameters \( s_{\rho, \alpha, \beta, \alpha', \beta'} \) and \( \beta' \) from the transverse polarisation of the outgoing electrons. 
- the parameter \( \eta \) from the radiative muon decay.

Using the latest results from TWIST, the global analysis gives the following 90% confidence limits:

\[ g'_{\mu L} < 0.02, \]

\[ g'_{\mu R} < 0.03, \]

\[ g'_{\nu L} < 0.074, \]

\[ g'_{\nu R} < 0.025, \]

\[ g'_{\nu L} < 0.021, \]

\[ g'_{\nu R} < 0.021. \]

(In red the coupling constants are most sensitive to the TWIST results.)

Right-Handed Muon Decay

This is a model-independent measure of the right-handed muon decay probability

\[ Q_{\mu L}^{RH} = \frac{1}{4} g'_{\mu L}^2 + \frac{1}{4} g'_{\mu R}^2 + g'_{\nu L}^2 + 3 |g'_{\nu R}|^2. \]

Results from the global analysis at a 90% confidence level:

- Pre-TWIST: \( Q_{\mu L}^{RH} < 0.0051 \)
- Gagliardi: \( Q_{\mu L}^{RH} < 0.0031 \)
- Current: \( Q_{\mu L}^{RH} < 0.0021 \)

Left Right Symmetry Test

In left-right symmetric models the \( (V+A) \) current is suppressed, but not exactly zero. The left- and right-handed gauge boson fields are given by:

\[ W_L = W_1 \cos \zeta + W_2 \sin \zeta, \]

\[ W_R = W_1 \cos \zeta - W_2 \sin \zeta. \]

The following notations assume possible differences in left and right coupling and CKM character:

\[ t = \frac{g'_{\mu L}^2}{|V_{\mu L}|^2} \rho, \]

\[ \xi = 1 - t(1 + c_\zeta), \]

\[ P_\rho = 1 - 2c_\zeta - 2c_\zeta^2 - 4s_\zeta^2 \cos(\alpha + \omega). \]

90% confidence level limits can be deduced from the TWIST results without making assumptions about the left-right symmetry model:

- Pre-TWIST: \( |\xi| < 0.066 \)
- Current: \( |\xi| < 0.022 \)
- Pre-TWIST: \( |\zeta| < 0.16 \)
- Current: \( |t| < 0.06 \)

References