Theoretical Implications of the TWIST Experiment Results

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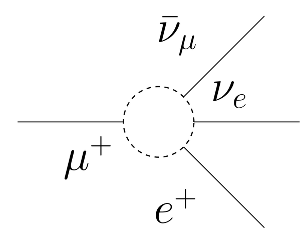
Decay Parametrisation

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

$$M = 4\frac{G_F}{\sqrt{2}} \sum_{\gamma,R,L} g^\gamma_{\epsilon\mu} < \bar{e}_\epsilon|\Gamma^\gamma|\nu_e >< \bar{\nu}_\mu|\Gamma_\gamma|\mu_\mu >$$



γ=S(calar),V(vector),T(ensor)

ϵ,μ=R(ight),L(eft)

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 $g^\gamma_{\epsilon\mu}$, commonly referred to as the **Michel parameters** (in red):

$$\frac{d^2\Gamma}{dx\,d\cos\theta} = \frac{m_\mu}{4\pi^3}W^4_{e\mu}G^2_F\sqrt{x^2-x_0^2}\,(F_{IS}(x,\rho,\eta) + P_\mu\cos\theta F_{AS}(x,\xi,\delta)) + \text{RC}.$$

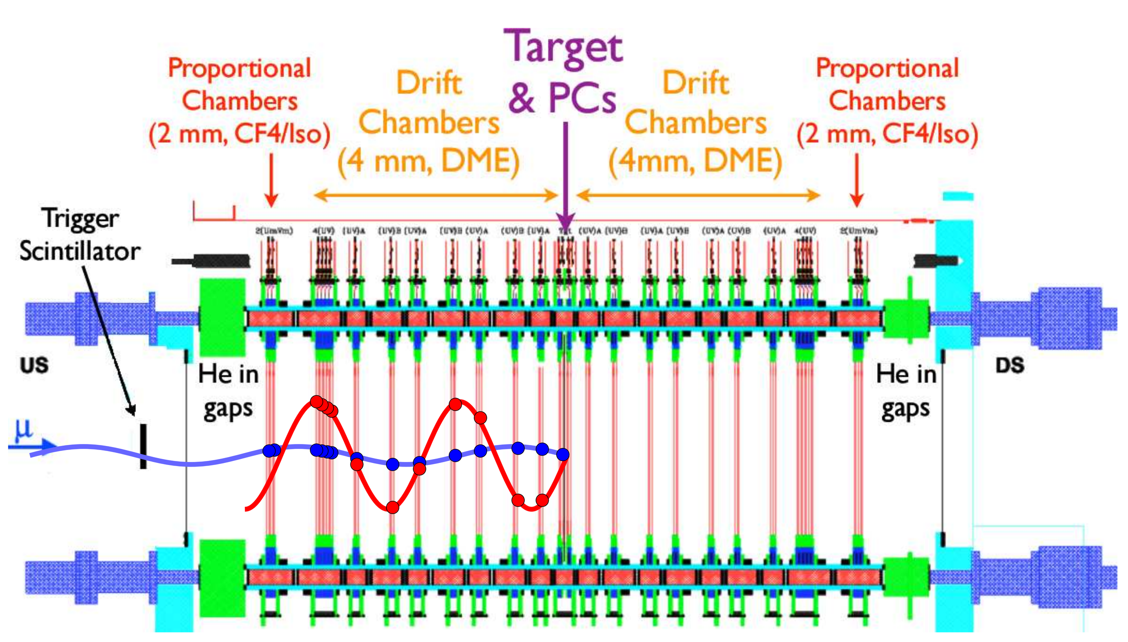
$$F_{IS}(x) = x(1-x) + \frac{2}{9}\rho(4x^2-3x-x_0^2) + \eta x_0(1-x)$$

$$F_{AS}(x) = \frac{1}{3}\xi\sqrt{x^2-x_0^2}\left[1-x+\frac{2}{3}\delta(4x-3+(\sqrt{1-x_0^2}-1))\right]$$

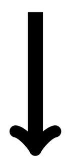
In the Standard Model the decay is purely V-A therefore all the $g^\gamma_{\epsilon\mu}$ are zero except $g^V_{LL}=1$

Consequently: $\rho = \frac{3}{4}$, $\eta = 0$, $P_\mu\xi = 1$, $\delta = \frac{3}{4}$

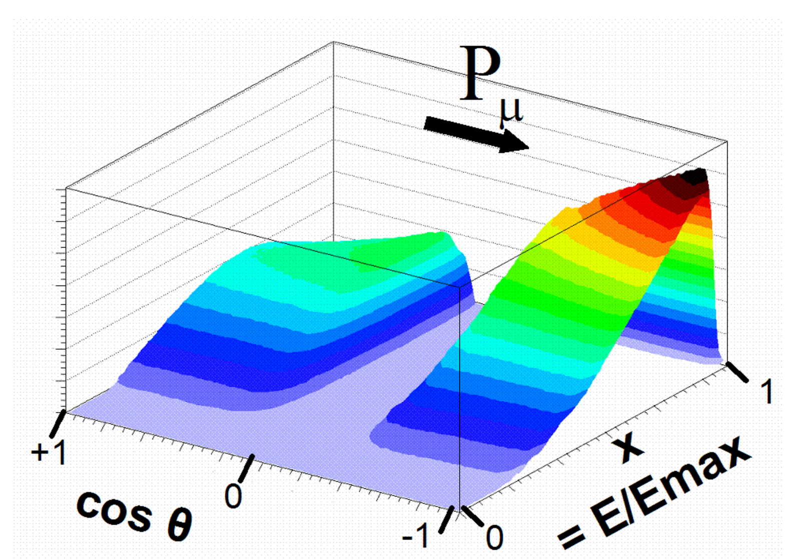
TRIUMF Weak Interaction Symmetry Test (TWIST)



A low mass, high precision spectrometer inside 2T magnetic field measures **positrons** (e^+) and **muons** (μ^+).



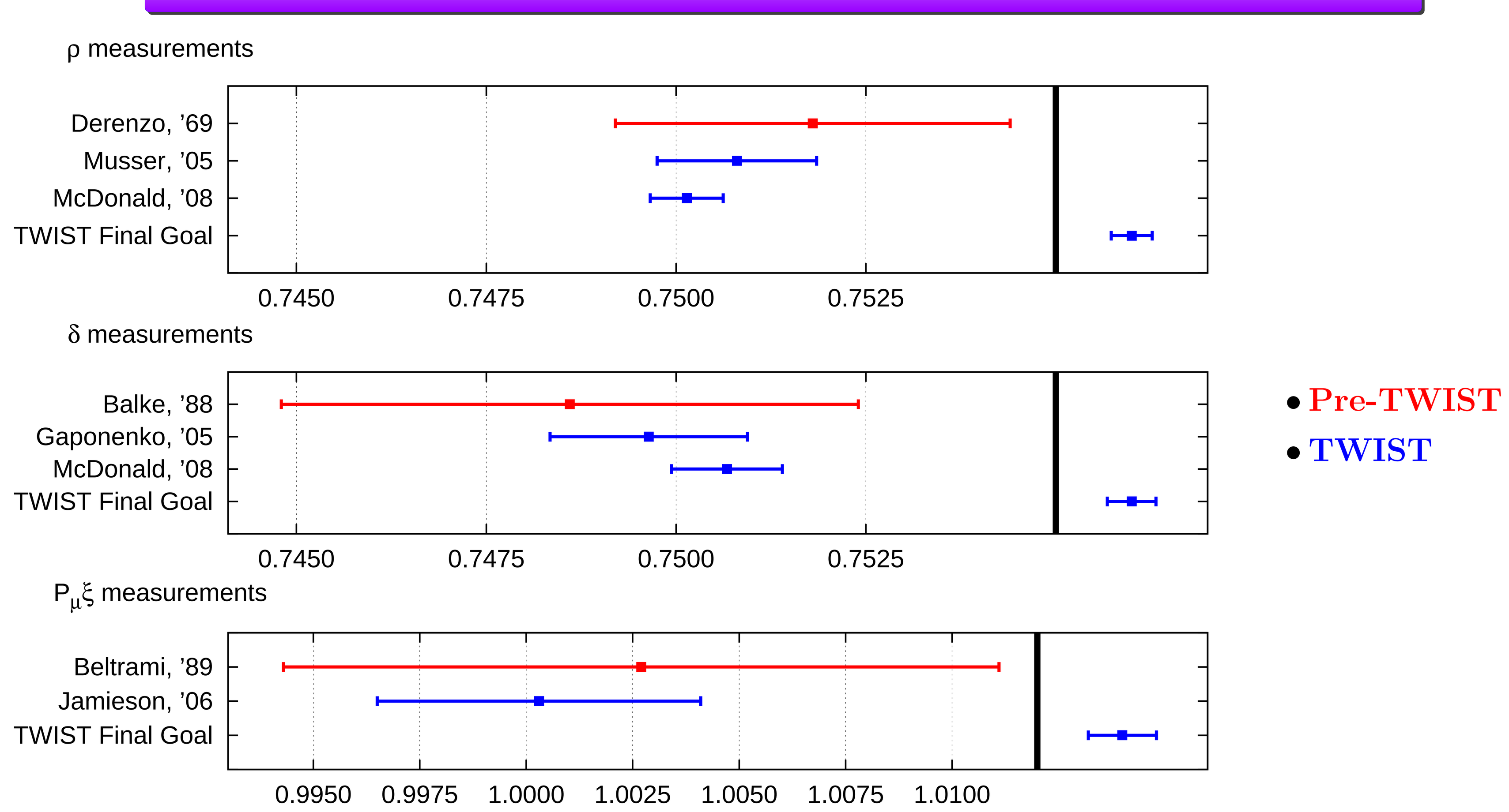
High precision reconstruction of the angle and energy of the positron.



⟸ Experimental spectrum with acceptance and efficiency effects.

The Michel parameters ρ, δ and $P_\mu\xi$ are extracted from the spectrum.

TWIST Latest Results



Global Analysis

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

$$Q_{RR} = \frac{1}{4}|g^S_{RR}|^2 + |g^V_{RR}|^2 \qquad B_{LR} = \frac{1}{16}|g^S_{LR} + g^T_{LR}|^2 + |g^V_{LR}|^2$$

$$Q_{LR} = \frac{1}{4}|g^S_{LR}|^2 + |g^V_{LR}|^2 + 3|g^T_{LR}|^2 \qquad B_{RL} = \frac{1}{16}|g^S_{RL} + g^T_{RL}|^2 + |g^V_{RL}|^2$$

$$Q_{RL} = \frac{1}{4}|g^S_{RL}|^2 + |g^V_{RL}|^2 + 3|g^T_{RL}|^2 \qquad I_\alpha = \frac{1}{4}[g^V_{LR}(g^S_{RL} + 6g^T_{RL})^* + (g^V_{RL})^*(g^S_{LR} + 6g^T_{LR})]$$

$$Q_{LL} = \frac{1}{4}|g^S_{LL}|^2 + |g^V_{LL}|^2 \qquad I_\beta = \frac{1}{2}[g^V_{LL}(g^S_{RR})^* + (g^V_{RR})^* g^S_{LL}]$$

These bilinear combinations satisfy the following constraints:

$$0 \le Q_{\epsilon\mu} \le 1, \quad \text{where } \epsilon,\mu = R,L \qquad |I_\alpha|^2 \le B_{LR}B_{RL}, \qquad |I_\beta|^2 \le Q_{LL}Q_{RR}$$

$$0 \le B_{\epsilon\mu} \le Q_{\epsilon\mu}, \quad \text{where } \epsilon\mu = RL, LR \qquad Q_{RR}+Q_{LR}+Q_{RL}+Q_{LL} = 1$$

A global fit was performed using the parametrisation above.
The experimental inputs of the fit were:

- the four Michel parameters ρ, η, $P_\mu\xi$ and δ
- the measurement of $P_\mu\xi\delta/\rho$
- the parameters ξ' and ξ'' from the longitudinal polarisation of the outgoing electrons
- the parameters η'', α, β, α' and β' from the transverse polarisation of the outgoing electrons
- the parameter $\bar{\eta}$ from the radiative muon decay

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

g^S_{RR}	$<$	0.062	g^S_{RL}	$<$	0.412
g^V_{RR}	$<$	0.031	g^V_{RL}	$<$	0.104
g^S_{LR}	$<$	0.074	g^T_{RL}	$<$	0.103
g^V_{LR}	$<$	0.025	g^S_{LL}	$<$	0.550
g^T_{LR}	$<$	0.021	g^V_{LL}	$>$	0.960

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

Right-Handed Muon Decay

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

$$Q^\mu_R = \frac{1}{4}|g^S_{LR}|^2 + \frac{1}{4}|g^S_{RR}|^2 + |g^V_{LR}|^2 + |g^V_{RR}|^2 + 3|g^T_{LR}|^2$$

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

- **Pre-TWIST:** $Q^\mu_R < 0.0051$
- **Gagliardi:** $Q^\mu_R < 0.0031$
- **Current:** $Q^\mu_R < 0.0024$

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:

$$W_L = W_1\cos\zeta + W_2\sin\zeta, \qquad W_R = e^{i\omega}(-W_1\sin\zeta + W_2\cos\zeta)$$

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

$$t = \frac{g^2_R m^2_1}{g^2_L m^2_2}, \qquad t_\theta = t\frac{|V^R_{ud}|}{|V^L_{ud}|}, \qquad \zeta^2_g = \frac{g^2_R}{g^2_L}\zeta^2$$

$$\rho = \frac{3}{4}(1-2\zeta^2_g), \qquad \xi = 1-2(t^2+\zeta^2_g), \qquad P_\mu = 1-2t^2_\theta-2\zeta^2_g-4t_\theta\zeta^2_g\cos(\alpha+\omega)$$

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

- **Pre-TWIST:** $|\zeta_g| < 0.066$
- **Current:** $|\zeta_g| < 0.022$

- **Pre-TWIST:** $\left(\frac{g_L}{g_R}\right) m_2 > 294\text{GeV/c}^2$
- **Current:** $\left(\frac{g_L}{g_R}\right) m_2 > 364\text{GeV/c}^2$

References

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[5] C. Gagliardi, R. Tribble, and N. Williams. *Phys. Rev. D*, 72:073002, 2005.