



University  
of Victoria

# Theoretical Implications of the TWIST Experiment Results

Poster presented by Anthony Hillairet on behalf of the TWIST collaboration.

University of Victoria, Victoria, BC, Canada.

TRIUMF, Vancouver, BC, Canada



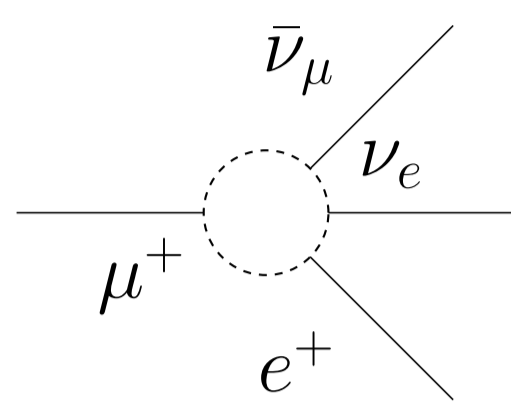
## Decay Parametrisation

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

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

$$\gamma = S(\text{calar}), V(\text{vector}), T(\text{ensor})$$

$$\epsilon, \mu = R(\text{ight}), L(\text{eft})$$



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

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

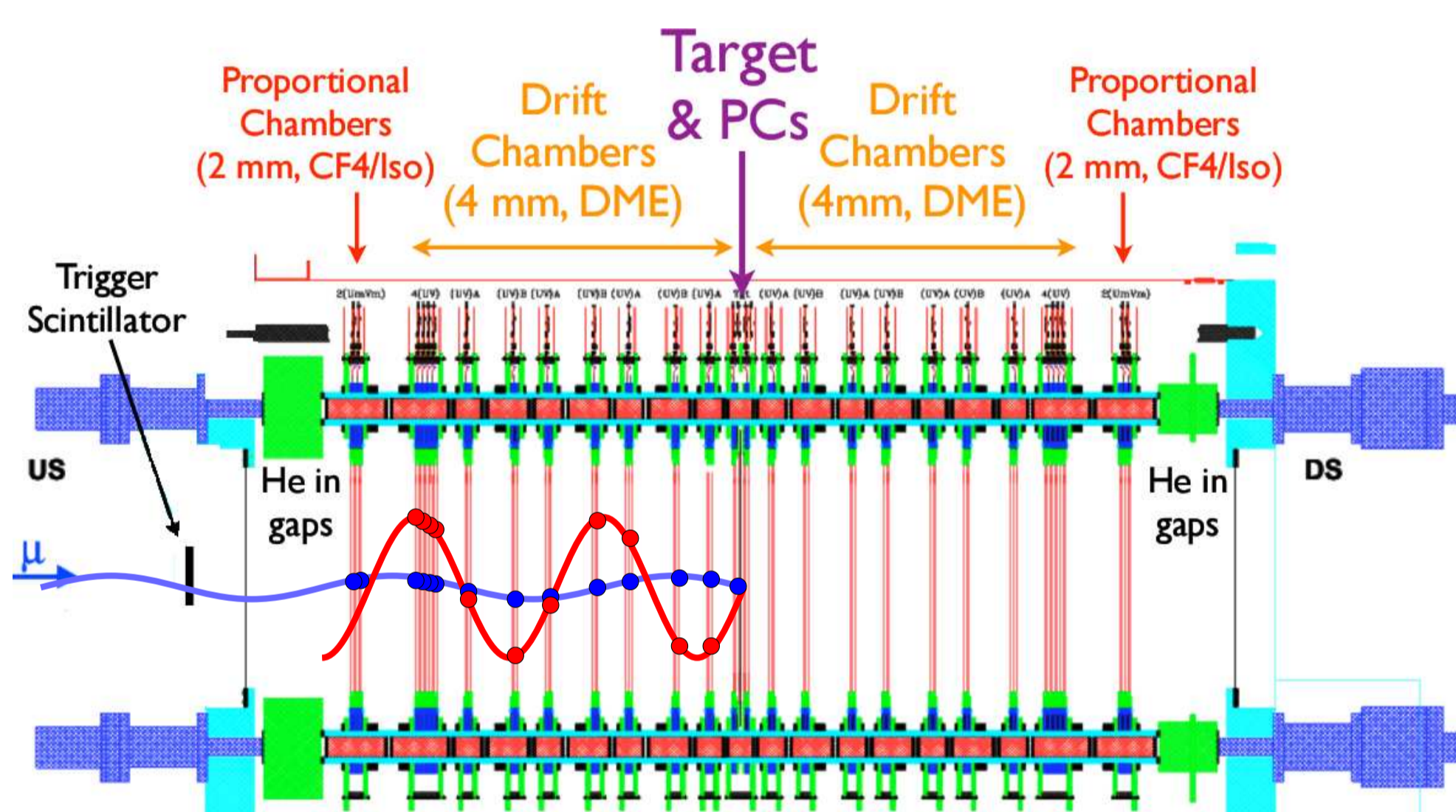
$$F_{IS}(x) = x(1-x) + \frac{2}{9}\rho(4x^2 - 3x - x_0^2) + \eta x_0(1-x)$$

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

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

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

## TRIUMF Weak Interaction Symmetry Test (TWIST)

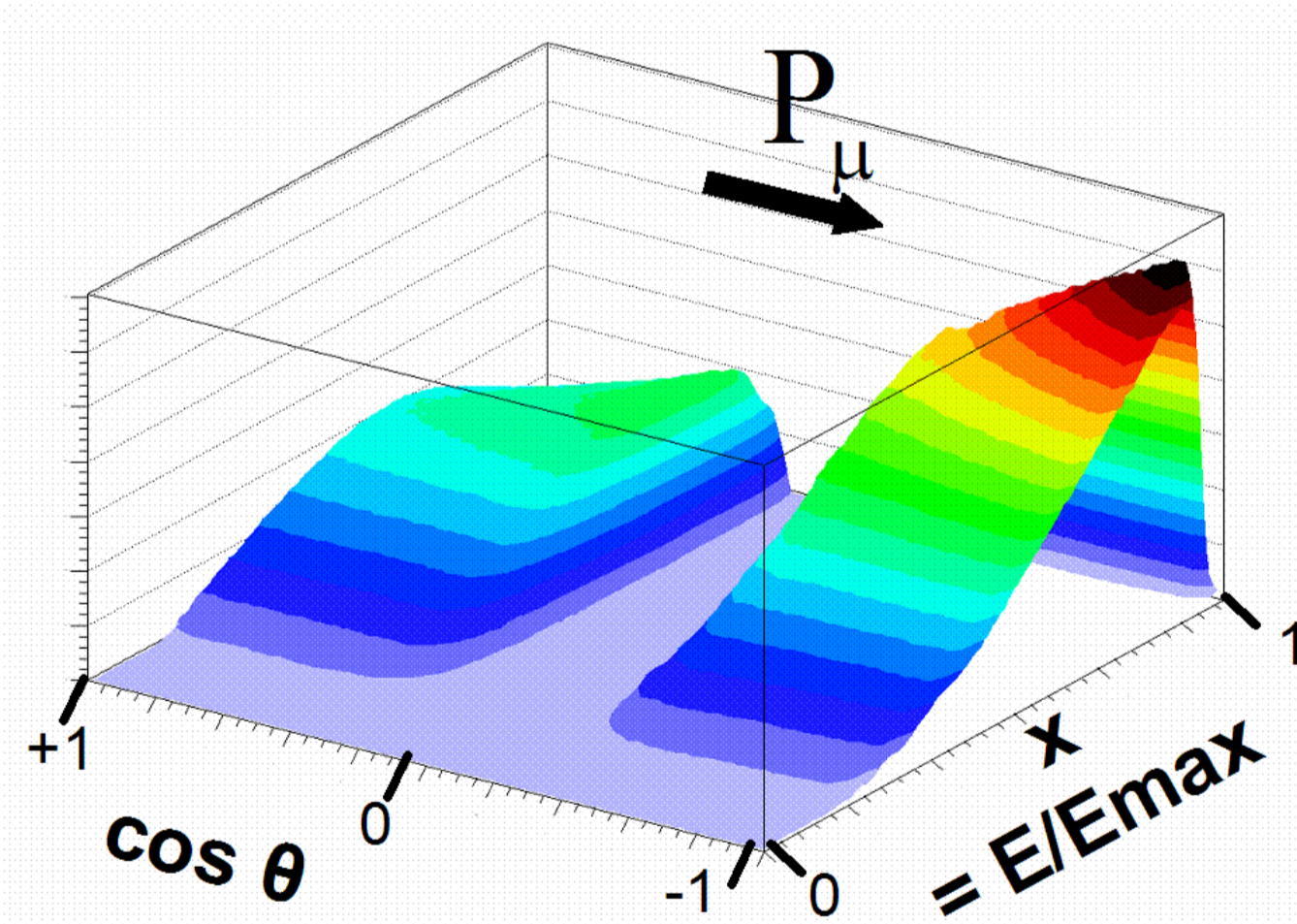


A low mass, high precision spectrometer inside 2T magnetic field measures **positrons ( $e^+$ )** and **muons ( $\mu^+$ )**.

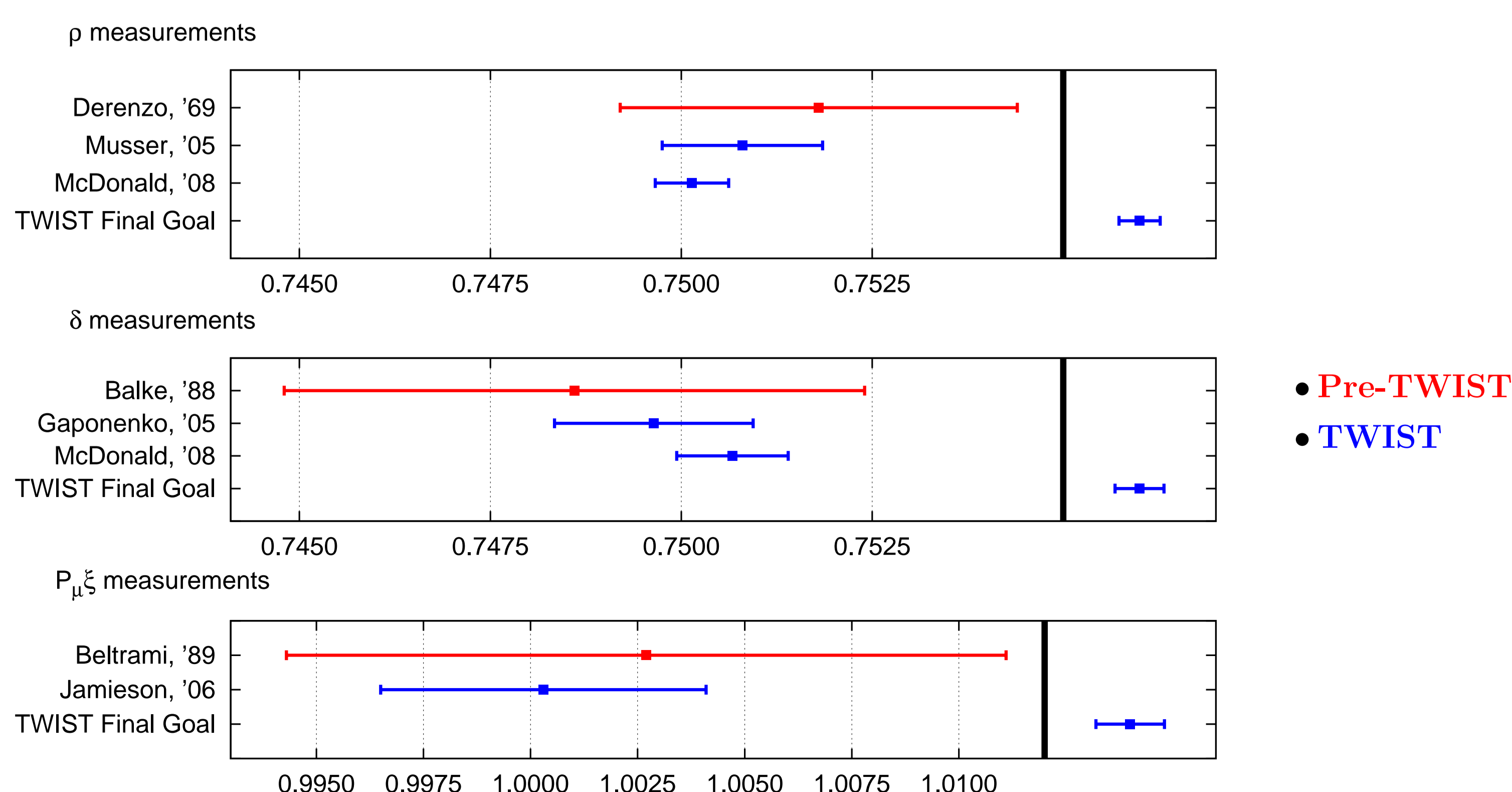
High precision reconstruction of the angle and energy of the positron.

Experimental spectrum with acceptance and efficiency effects.

The Michel parameters  $\rho$ ,  $\delta$  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:

$$Q_{RR} = \frac{1}{4}|g_{RR}^S|^2 + |g_{RR}^V|^2$$

$$Q_{LR} = \frac{1}{4}|g_{LR}^S|^2 + |g_{LR}^V|^2 + 3|g_{LR}^T|^2$$

$$Q_{RL} = \frac{1}{4}|g_{RL}^S|^2 + |g_{RL}^V|^2 + 3|g_{RL}^T|^2$$

$$Q_{LL} = \frac{1}{4}|g_{LL}^S|^2 + |g_{LL}^V|^2$$

$$B_{LR} = \frac{1}{16}|g_{LR}^S + g_{LR}^T|^2 + |g_{LR}^V|^2$$

$$B_{RL} = \frac{1}{16}|g_{RL}^S + g_{RL}^T|^2 + |g_{RL}^V|^2$$

$$I_{\alpha} = \frac{1}{4}[g_{LR}^V(g_{RL}^S + 6g_{RL}^T)^* + (g_{RL}^V)^*(g_{LR}^S + 6g_{LR}^T)]$$

$$I_{\beta} = \frac{1}{2}[g_{LL}^V(g_{RR}^S)^* + (g_{RR}^V)^*g_{LL}^S]$$

These bilinear combinations satisfy the following constraints:

$$0 \leq Q_{\epsilon\mu} \leq 1, \quad \text{where } \epsilon, \mu = R, L$$

$$0 \leq B_{\epsilon\mu} \leq Q_{\epsilon\mu}, \quad \text{where } \epsilon\mu = RL, LR$$

$$|I_{\alpha}|^2 \leq B_{LR}B_{RL}, \quad |I_{\beta}|^2 \leq Q_{LL}Q_{RR}$$

$$Q_{RR} + Q_{LR} + Q_{RL} + Q_{LL} = 1$$

A global fit was performed using the parametrisation above.

The experimental inputs of the fit were:

- the four Michel parameters  $\rho$ ,  $\eta$ ,  $P_{\mu}\xi$  and  $\delta$
- the measurement of  $P_{\mu}\xi\delta/\rho$
- the parameters  $\xi'$  and  $\xi''$  from the longitudinal polarisation of the outgoing electrons
- the parameters  $\eta'$ ,  $\alpha$ ,  $\beta$ ,  $\alpha'$  and  $\beta'$  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:

$$g_{RR}^S < 0.062$$

$$g_{RR}^V < 0.031$$

$$g_{LR}^S < 0.074$$

$$g_{LR}^V < 0.025$$

$$g_{LR}^T < 0.021$$

$$g_{RL}^S < 0.412$$

$$g_{RL}^V < 0.104$$

$$g_{RL}^T < 0.103$$

$$g_{LL}^S < 0.550$$

$$g_{LL}^V > 0.960$$

(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

$$Q_R^{\mu} = \frac{1}{4}|g_{LR}^S|^2 + \frac{1}{4}|g_{RR}^S|^2 + |g_{LR}^V|^2 + |g_{RR}^V|^2 + 3|g_{LR}^T|^2$$

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

- **Pre-TWIST:**  $Q_R^{\mu} < 0.0051$
- **Gagliardi:**  $Q_R^{\mu} < 0.0031$
- **Current:**  $Q_R^{\mu} < 0.0024$

## 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:

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

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

$$t = \frac{g_R^2 m_1^2}{g_L^2 m_2^2}, \quad t_{\theta} = t \frac{|V_{ud}^R|}{|V_{ud}^L|}, \quad \zeta_g^2 = \frac{g_R^2 \zeta^2}{g_L^2}$$

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

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

- [1] A. Gaponenko et al. (TWIST collaboration). *Phys. Rev. D*, 71:071101, 2005.
- [2] B. Jamieson et al. (TWIST collaboration). *Phys. Rev. D*, 74:072007, 2006.
- [3] J.R. Musser et al. (TWIST collaboration). *Phys. Rev. Lett.*, 94:101 805, 2005.
- [4] R.P. McDonald et al. (TWIST collaboration). *Phys. Rev. D*, 78:032010, 2008.
- [5] C. Gagliardi, R. Tribble, and N. Williams. *Phys. Rev. D*, 72:073002, 2005.