Precision Measurement of the Muon Decay Parameter $P_\mu\xi$

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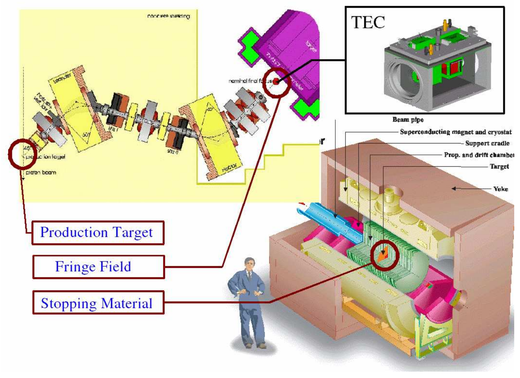
1. Objective

- Improve the measurement of the muon decay parameter $P_\mu\xi$
- Determine the level of left-handedness of Electro-Weak decays
- Put limits on or validate Left-Right Symmetric (LRS) Models

2. The $\mathcal{TWIST}$ Experiment

- TRIUMF Weak Interaction Symmetry Test ($\mathcal{TWIST}$) measures the momentum and angle of e^+ from muon decay: $\mu^+ \to e^+\nu_e\bar{\nu_\mu}$
- $\mathcal{TWIST}$ made precision measurements of the muon decay parameters ρ [2] and δ [3]
- Indirect Measurement ($\mathcal{TWIST}$ and Jodidio [4] $P_\mu\xi\rho/\delta$): $0.9960 < P_\mu\xi \leq \xi < 1.0040$ at 90% conf. level
- Goal of $\mathcal{TWIST}$ is to reduce the uncertainty in the muon decay parameters to parts in 10^4.

Muon Beam, Detectors, and Locations of Muon Depolarization:



3. Physics Motivation

3.1 General Matrix Element

General matrix element:

$$M = 4\frac{G_F}{\sqrt{2}}\sum_{\substack{\gamma=S,V,T\\ \epsilon,\mu=R,L}} g^{\gamma}_{\epsilon\mu} < \bar{e}_\epsilon|\Gamma^\gamma|\nu_e >< \bar{\nu}_\mu|\Gamma_\gamma|\mu_\mu > \quad (1)$$

- $g^{\gamma}_{\epsilon\mu}$ are the decay coupling constants
- $\gamma = S, V, T$ are the scalar, vector, and tensor interactions
- $\epsilon, \mu = L, R$ are the chirality of the electron or muon
- SM: all zero coupling constants, except $g^V_{LL} = 1$

3.2 Muon Decay Parameters

- Muon decay parameters, ρ, η, $P_\mu\xi$, and δ, are bilinear combinations of $g^{\gamma}_{\epsilon\mu}$
- Muon decay rate in terms of muon decay parameters, reduced energy, x, and angle θ:

$$\frac{d^2\Gamma}{dx d\cos\theta} \propto F_{IS}(x,\rho,\eta) + P_\mu\xi\cos\theta F'_{AS}(x,\delta) \quad (2)$$

where $x = E_e/W_{e\mu}$, $W_{e\mu} = \frac{m_\mu^2+m_e^2}{2m_\mu}$, $x_0 = \frac{m_e}{W_{e\mu}}$, and

$$F_{IS}(x) = x(1-x) + \tfrac{2}{9}\rho(4x^2 - 3x - x_0^2) + \eta x_0(1-x)$$
$$F'_{AS}(x) = \tfrac{1}{3}\sqrt{x^2-x_0^2}[1 - x + \tfrac{2}{3}\delta(4x - 3 + (\sqrt{1-x_0^2} - 1))] \quad (3)$$

3.3 Handedness of Muon Decay

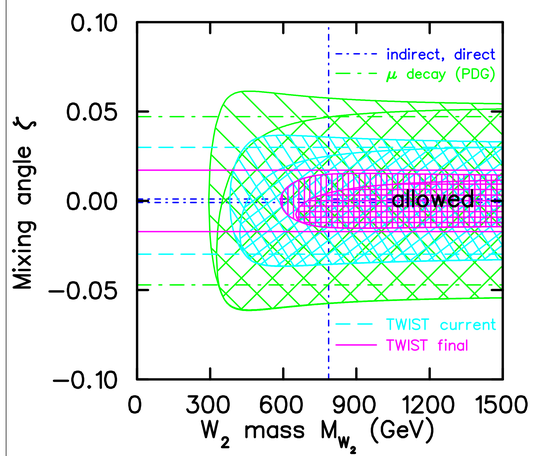
- ξ and δ limit right-handed interactions:

$$Q^\mu_R = \frac{1}{2}(1 + \frac{1}{3}\xi - \frac{16}{9}\xi\delta) \quad (4)$$

3.4 LRS Models

$P_\mu\xi$ sets limit on W_L/W_R mass ($\epsilon = (\frac{g_R M_1}{g_L M_2})^2$) and LR mixing parameter ($\zeta_g = \frac{g_R}{g_L}\zeta$) [5]:

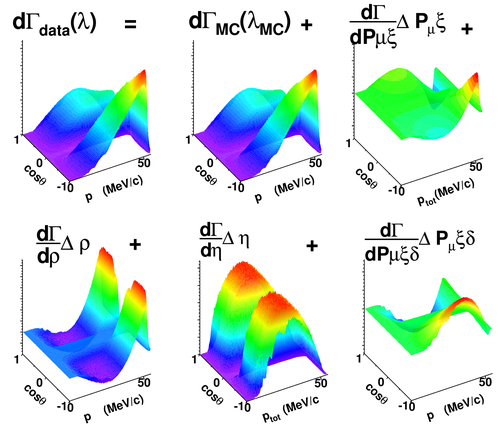
$$P_\mu\xi \approx 1 - 2\epsilon^2 - 4\zeta_g^2 - 2\epsilon^2(\frac{\cos\theta_1^R}{\cos\theta_1^L})^2 - 4\epsilon\zeta_g\frac{\cos\theta_1^R}{\cos\theta_1^L}\cos(\alpha+\omega) \quad (5)$$



4. Analysis

4.1 Blind Analysis Procedure

Fit data to Monte-Carlo with hidden muon decay parameters using $\lambda_{MC} = (\rho, \eta, P_\mu\xi|_{P_\mu\xi\delta}, P_\mu\xi\delta)$

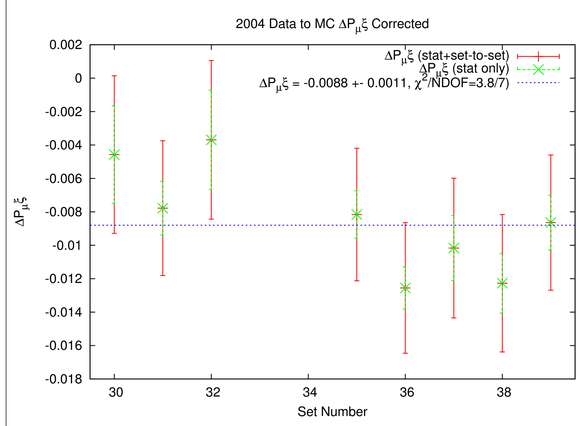


4.2 Systematic Uncertainty Estimates

Systematic Effect	Uncertainty ($\times 10^3$)	Total
Muon Beam and Polarization		3.69
fringe field (ave)	3.40	
stopping target (ave)	1.40	
production target	0.21	
Chamber Response		0.98
t_0 variations (ave)	0.89	
foil bulges (ave)	0.22	
cell asymmetry	0.22	
up-down efficiency	0.19	
density (ave)	0.17	
Positron Interactions		0.32
hard interactions (ave)	0.29	
radiative corrections	0.10	
multiple scattering	0.08	
outside material	0.02	
Spectrometer Alignment		0.31
rotations	0.22	
z position	0.22	
B field to axis	0.03	
Momentum Calibration		0.19
end point fits	0.16	
B field uniformity	0.09	
Total Systematic Uncertainty		3.8

4.3 $P_\mu\xi$ Offset from Black Box

- Consistency check with unknown offset (still blind)



5. Summary and Outlook

- Difference in $P_\mu\xi$ from black box value:

$$\Delta P_\mu\xi = (-8.8 \pm 1.1(stat) \pm 3.8(syst)) \times 10^{-3} \quad (6)$$

- Result will reduce error in PDG value by a factor of about 2. Current PDG value = $1.0027 \pm 0.0079 \pm 0.0030$[6]. Our statistical error ≈ 0.001.
- Largest systematic error is due to fringe field depolarization
- Remaining tasks include:
  - solenoid field consistency check
  - open the black box to obtain the final value for $P_\mu\xi$

References

[1] twist.triumf.ca
[2] J.R. Musser et al., PRL 94, 101805 (2005).
[3] A. Gaponenko et al., PRD 71, 071101(R) (2005).
[4] A. Jodidio et al., PRD 34, 1967 (1986), PRD 37, 237 (1988).
[5] P. Herczeg, PRD 34, 3449 (1986).
[6] I. Beltrami et al., PLB 194, 326, (1987).

This research is funded by NSERC, DOE, Russian Ministry of Finance
Analysis completed with Westgrid computing resources.