Precision Measurement of the Muon Decay Parameter $P_{\mu \xi}$
Blair Jamieson
University of British Columbia, Representing the TWIST [1] Collaboration
jamieson@phas.ubc.ca

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 TWIST Experiment
- TRIUMF Weak Interaction Symmetry Test (TWIST) measures the momentum and angle of $e^-\gamma$ from muon decay: $\mu^- \rightarrow e^-\gamma\nu\bar{\nu}$
- TWIST made precision measurements of the muon decay parameters $\rho$ [2] and $\eta$ [3]
- Indirect Measurement (TWIST and Jodidio) [4] $P_{\mu \xi}(\xi)$:
  - 0.990 < $P_{\mu \xi} < 1.010$ at 90% conf. level
- Goal of 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:
$$M = \frac{G_F}{\sqrt{2}} \sum_{f = e, \gamma} \bar{\psi}_f < i \gamma_\mu (\mu_{\xi} / \xi - \eta) > \psi_f (i \gamma_\mu p - m_f >$$

3.2 Muon Decay Parameters
- Muon decay parameters, $\rho$, $\eta$, $P_{\mu \xi}$, and $\xi$, are bilinear combinations of $g_{\mu \xi}$

$$\text{Muon decay rate in terms of muon decay parameters, reduced energy, } \xi, \text{ and angle } \delta.$$ 

$$\frac{d\Gamma}{d\delta} = P_{\mu \xi}(\rho\xi + P_{\mu \xi}(\eta)$$

where $x = E_e / \sqrt{2} M_{\mu \xi}$, $\bar{E}_e = \frac{m_{\mu \xi}}{\sqrt{2}}$, $\xi = \frac{m_{\mu \xi}}{m_{\mu \xi}}$ and

$$P_{\mu \xi}(\xi) = \frac{4}{3\xi^2} \left(1 - x + \frac{4}{3\xi^2} \right)$$

3.3 Handedness of Muon Decay
- $\xi$ and $\eta$ limit right-handed interactions:

$$Q_{\mu \xi}^2 = \frac{1}{3} + \frac{16}{9} \xi$$

3.4 LRS Models
$P_{\mu \xi}$ sets limit on $W_0 / W_3$ mass ($= \frac{1 - \eta_{\mu \xi}}{\xi}$) and LR mixing parameter ($\xi = \frac{\eta_{\mu \xi}}{\xi}$) [1]:

$$P_{\mu \xi} \approx 1 - 2\beta - 2\alpha \cos(\alpha + \omega)$$

4. Analysis
4.1 Blind Analysis Procedure
Fit data to Monte-Carlo with hidden muon decay parameters using $\chi^2_{\text{MC}} = (x, n, P_{\mu \xi}(\xi), P_{\mu \xi}(\eta))$

4.2 Systematic Uncertainty Estimates
- Difference in PDG value by a factor of about $\pm 2$
- Current PDG value $= 1.025 \pm 0.013(\text{stat}) \pm 0.037(\text{sys})$
- Our statistical error $\leq 0.001$.

5. Summary and Outlook
- 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

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