Status of the TWIST Measurement of the Muon Decay Asymmetry

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for the TWIST Collaboration

OVERVIEW

• Physics of $\mu$ decay asymmetry
• Brief review of past measurements
• Systematic error estimates
• Data Sets and Consistency
• Conclusions
Muon Decay $\mu^+ \rightarrow e^+ \bar{\nu}_\mu \nu_e$

General derivative free interaction matrix element:

$$M = 4\frac{G_F}{\sqrt{2}} \sum_{\gamma=S,V,T} g_{\epsilon\mu}^{\gamma} < \bar{e}_\epsilon | \Gamma_{\gamma} \nu_e > < \bar{\nu}_\mu | \Gamma_{\gamma} \mu_\mu >$$  \hspace{1cm} (1)

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

- $P_\mu$ is the polarization of the muon, $\xi$ is asymmetry in angle of decay positrons from normal $\mu$ decay

- Standard Model (V-A) predicts $\xi = 1$ and $P_\mu = -1$

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

\[
x = \frac{E_e}{W_{e\mu}}
\]

\[
W_{e\mu} = \frac{m_\mu^2 + m_e^2}{2m_\mu}
\]

\[
x_0 = \frac{m_e}{W_{e\mu}}
\]
Measurements and Motivation for $P_{\mu \xi}$

- Direct Measurements:
  - $P_{\mu \xi} = 1.0027 \pm 0.0079 \pm 0.0030$ (Beltrami et. al., PLB194 1987)
  - $P_{\mu \xi} \delta/\rho > 0.99682$, 90% conf. level (Jodidio et.al., PR D34, PR D37 1986)

- Indirect Measurement ($TWIST \ \rho/\delta$ PRL 94, 101805 + PRD 71, 071101(R) (2005)):
  $0.9960 < P_{\mu \xi} \leq \xi < 1.0040$ at 90% conf. level

- $\xi$ and $\delta$ limit probability of right-handed muon decaying into any handed positron:
  \[
  Q_{R}^{\mu} = \frac{1}{2}(1 + \frac{1}{3}\xi - \frac{16}{9}\xi\delta)
  \]  \(3\)

- In Left-right symmetric models, $P_{\mu \xi}$ sets limit on $W_L/W_R$ mass ($\epsilon$) and LR mixing parameter ($\zeta$):
  \[
  P_{\mu \xi} = 1 - 2\epsilon^2 - 2\zeta^2 - 2\epsilon^2\left(\frac{V_{ud}^R}{V_{ud}^L}\right)^2 - \epsilon\zeta\frac{V_{ud}^R}{V_{ud}^L}
  \]  \(4\)
Left-Right Symmetric Model Limits

\begin{figure}
\centering
\includegraphics[width=\textwidth]{figure}
\caption{Graph showing the mixing angle $\xi$ vs. $W_2$ mass $M_{W_2}$ (GeV). The figure includes the limits from PDG and TWIST current and future data.}
\end{figure}
Locations of Muon Depolarization

- Production Target
- Fringe Field
- Stopping Material
Short Systematic Error Estimate List $\times 10^{-3}$

- Muon beam and polarization $\approx \pm 2.00$
  - Fringe field depolarization $\approx \pm 1$ to $\pm 2$
  - Depolarization in prod. target $-1.17$

- Chamber response $\pm 0.69$
  - Dead zone $\pm 0.54$

- Spectrometer alignment $\pm 0.40$
  - B field to detector axis $\pm 0.39$

- Momentum calibration $\pm 0.27$

- Positron interactions $\pm 0.11$
  - Hard interactions $\pm 0.10$

Total systematic error $\approx \pm 2.3$
Fringe field depolarization

- Muons depolarized in solenoid magnet fringe field
- Estimate by knowing:
  - muon beam size + divergence (from TEC)
  - magnetic field map
- Transport Spins in Monte-Carlo
Time Expansion Chamber - Muon Beam

Mean dx angle for each Y vs X pixel

RMS dx angle for each Y vs X pixel

66% of beam inside contour

Mean dy angle for each Y vs X pixel

RMS dy angle for each Y vs X pixel

90% of beam inside contour
<table>
<thead>
<tr>
<th>Set #</th>
<th># Runs (2 GB)</th>
<th>Description</th>
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<tbody>
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<td>12</td>
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<td>28.9 MeV/c</td>
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<tr>
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<td>115</td>
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<td>14</td>
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<td>2003 Nominal</td>
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<td>2004 Stop at 3/4</td>
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<td>37</td>
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<td>38</td>
<td>303</td>
<td>Aperture In</td>
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<td>39</td>
<td>211</td>
<td>2004 Stop at 3/4</td>
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<tr>
<td>Total</td>
<td>2819 (5.6 TB)</td>
<td>2272 Nominal Runs</td>
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Material Dependent Depolarization

Sum of all 2003+2004 data asymmetry vs decay time fit to half-gaussian (still blind):

\[ P_\mu(t) = P_\mu(0)e^{-t^2/2\sigma^2} \]  \hspace{1cm} (5)

\[ \chi^2 / \text{ndf} \quad 152.428 / 171 \]
\[ \text{Prob} \quad 0.842964 \]
\[ P_\mu(0) \quad -1.00174 \pm 0.00049 \]
\[ \sigma \text{ (ns)} \quad 54412.4 \pm 5157.3 \]

Residual Data-Fit
Data Set Consistency

- Consistency check with unknown offset (still blind)

\begin{align*}
P_{\mu}(0) \text{ for Gaussian Extrapolation vs Data Set} \\
\begin{array}{|c|}
\hline
\chi^2 / \text{ndf} & 26.2877 / 9 \\
\text{Prob} & 0.00183281 \\
p0 & -1.00117 \pm 0.00056 \\
\hline
\end{array}
\end{align*}

\[ \sqrt{\chi^2 / \text{dof}} = 1.71 \]
\[ \rightarrow \text{Syst error} = 0.00078 \]
Conclusions

- Direct measurement of $P_{\mu \xi}$ by end of this summer
- Result will reduce error in PDG value by a factor of about $3 \times$
- Largest systematic error will be due to fringe field depolarization
- Remaining tasks include:
  - generation and analysis of MC to match 2004 data
  - finalize systematic error estimates

Results made possible by NSERC funding, and by the use of Westgrid Computing Resources.
**TWIST People**

**TWIST Participants**

<table>
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<tr>
<th><strong>TRIUMF</strong></th>
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<th><strong>British Columbia</strong></th>
<th><strong>Kurchatov Institute</strong></th>
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<tr>
<td>Ryan Bayes*†</td>
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<td>Mike Hasinoff</td>
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<td>Art Olin†</td>
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<td>Robert Openshaw</td>
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**Previous collaborators:**

Peter Green, Arkadi Khruchinsky, Michael Kroupa, Farhana Sobratee, Sun-Chong Wang, Dennis Wright.

**Professional and technical support:**

Daniel Allen, Pierre Amaudruz, Willy Andersson, Curtis Ballard, Michael Barnes, Brian Evans, Marielle Goyette, Peter Gumplinger, Doug Maas, Jan Soukup, Len Wampler, and many undergraduate student research assistants.

*graduate student  †also UVic  ‡also UNBC  
§deceased  ‡‡also Saskatchewan
80 sense wires (20 µm Φ) + 2x3 guard wires at 4 mm distance. 22 pairs of drift chambers (each one U and V plane) with DME gas, 6 pairs of proportional chambers with CF₄ / Isobutane. ~5000 wires with VTX preamplifiers
Spectrum Fit Procedure

Extracting Michel parameters

Need to take into account detector response. The technique:

\[ n_i(\rho_{\text{Data}}) = n_i(\rho_{\text{MC}}) + \frac{\partial n_i}{\partial \rho} (\rho_{\text{Data}} - \rho_{\text{MC}}) \]

Data \hspace{1cm} MC \hspace{1cm} Fit parameter

(\rho \text{ stands for any spectrum parameter}).

- Many effects of reconstruction cancel.
- Monte-Carlo must reproduce effects of the detector.
  - But spectrum distortions by the thin detector are small.
Spectrum Distributions

Muon decay spectrum

\( \rho \) derivative

\( \delta \xi \) derivative

\( \xi \delta \) derivative

LNF Seminar 2004-11-08
Data Set Summary for \textit{TWIST} $P_\mu\xi$

Material Dependent Depolarization

Data Set Consistency

Conclusions

\textit{TWIST} People

Detector Concept

Detector Planes

Detector End View

Spectrum Fit Procedure