A Two Body Decay Search in the TWIST Spectrum

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Winter Nuclear and Particle Physics Conference
February 13, 2010
Rare Decay Search in TWIST Data

- Good reconstruction for wide range of momenta and angles.
- Polarized muon decay event sample exceeds previous decay experiments.

- Main decay mode: $\approx 100\%$

$\mu^+ \rightarrow e^+ \nu_e \nu_\mu e^+ e^- : (3.4 \pm 0.4) \times 10^{-5}$

- Other rare decay modes should be visible in TWIST spectrum.
Two Body Muon Decays

- A result of symmetry breaking: ie Lepton Number or Family
- Effective Lagrangian $^1$: $\Delta L = F_{e\mu}^{-1} \mu \gamma^\rho e \partial^\rho f_{e\mu}$

### Nambu-Goldstone Bosons

- Massless $X^0$
- Due to global symmetry breaking

### Pseudo Nambu-Goldstone Bosons

- Massive $X^0$
- Due to local breaking of the symmetry

- Surplus of $e^+$ appear at momentum

$$p = \sqrt{\left(\frac{M_\mu^2 - m_X^2 + m_e^2}{2M_\mu}\right)^2 - m_e^2}$$

$^1$ F. Wilczek, PRL 49 1549, 1982
## Measurements of Rare $\mu$ decay

<table>
<thead>
<tr>
<th>Decay process</th>
<th>Upper Limit</th>
<th>Conf. level</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\mu^+ \rightarrow e^+ \gamma$</td>
<td>$1.2 \times 10^{-11}$</td>
<td>90 %</td>
</tr>
<tr>
<td></td>
<td>$3 \times 10^{-11}$</td>
<td></td>
</tr>
<tr>
<td>$\mu^+ \rightarrow e^+ e^-$</td>
<td>$1.0 \times 10^{-12}$</td>
<td>90 %</td>
</tr>
<tr>
<td>$\mu^+ \rightarrow e^+$</td>
<td>$3.4 \times 10^{-4}$</td>
<td>90 %</td>
</tr>
<tr>
<td>$X^0, m_{X^0} &gt; 0$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$X^0, m_{X^0} = 0$</td>
<td>$2.6 \times 10^{-6}$</td>
<td>90 %</td>
</tr>
</tbody>
</table>

\(^2\) Pre-print: arXiv:0908.2594
A Special Case: Anisotropic Decays

- Lepton number violation will produce Majorons.
- Decay mode can be enhanced in MSSM models with $R$-parity breaking. ³

Will occur with a distribution

$$\frac{\partial \Gamma}{\partial \cos \theta} \propto [1 \pm P_\mu \cos \theta]$$

- Has not been measured directly.
- Can be observed directly in TWIST data

³M. Hirsch and A. Vicente, PRD 79, 055023 (2009)
Method of $\mu^+ \rightarrow e^+ X^0$ Search

TWIST momentum response function is used to model two body decays.

- Assumes momentum response dominates

- True if decay time

\[ \tau > \frac{\hbar}{\sigma} \approx 10^{-22} \text{s} \]

assuming $\sigma \sim 100$ keV/c

- Peak fit to Decay Par. Fit residuals

- Determine a branching ratio, $B$
Results from Search in Initial Physics Data

Search for Massive $X^0$ was conducted in 2005

- Competed using $5.3 \times 10^7$ muon decay events
- 95% limit on isotropic, massive $X^0$ production: $B < 4.5 \times 10^{-5}$
- Observed peaks expected: $\sim 4$ for $\sim 60$ uncorrelated trials
Anisotropic Decays from Initial Physics Data

Positive anisotropy:
- decay probability $B < 3 \times 10^{-5}$

Negative anisotropy:
- decay probability $B < 5 \times 10^{-5}$
## Improvement in Statistics

<table>
<thead>
<tr>
<th></th>
<th>Initial Data</th>
<th>Final Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Events Collected</td>
<td>$1.3 \times 10^9$</td>
<td>$9.0 \times 10^9$</td>
</tr>
<tr>
<td>Events Left Cuts</td>
<td>12 %</td>
<td>13 %</td>
</tr>
<tr>
<td>Events Left by Fiducial Cuts</td>
<td>34 %</td>
<td>41 %</td>
</tr>
<tr>
<td>Total Events</td>
<td>$5.3 \times 10^7$</td>
<td>$5.5 \times 10^8$</td>
</tr>
</tbody>
</table>

- Branching ratio sensitivity decreases as $\sqrt{N}$, $N$ is the number of background events
- Factor of 3 improvement expected
Systematic Effects at Endpoint

Initial data results not reliable.
- Momentum resolution was not well matched
- $\Delta \sigma \approx 5$ keV, where $\sigma_0 \approx 70$ keV.

Better control of systematics in Final Data
- Resolution consistent between data and MC
  - Difference $< 1$ keV/c
- Momentum calibration less critical
  - Corrections $< 10$ keV/c, out of 90 keV/c
Conclusions

- Proposed search for rare decay signals will be completed on TWIST final data

Limits on two body signal set using TWIST initial physics data

<table>
<thead>
<tr>
<th>Isotropic</th>
<th>$\mathcal{B} &lt; 4 \times 10^{-5}$ (95% Confidence)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Positive anisotropy</td>
<td>$\mathcal{B} &lt; 2 \times 10^{-5}$ (95% Confidence)</td>
</tr>
<tr>
<td>Negative anisotropy</td>
<td>$\mathcal{B} &lt; 6 \times 10^{-5}$ (95% Confidence)</td>
</tr>
</tbody>
</table>

- Factor 3 decrease in limits expected in TWIST final analysis
- Most significant sensitivity to anisotropic signal of massless $X^0$
The **TWIST** Collaboration

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- Funding Support from NSERC and US DOE
- Additional support from TRIUMF, Russian Science Ministry, and NRC
- Computing resources provided by WestGrid