A Search for Rare Decays in the $TWIST$ Muon Decay Spectrum

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Outline

- *TWIST*
- Motivation for the Exotic Decay Search
- Methodology
- Results and Conclusions
The **TWIST** experiment

**Triumf Weak Interaction Symmetry Test**

A collaboration of 40 members in Canada, Russia, and the United States.

- Tests the weak nuclear interaction through the process:
  \[
  \mu^+ \rightarrow e^+ \nu_e \bar{\nu}_\mu
  \]
  
  by measuring the momentum and angle of \( e^+ \)

- **TWIST** has produced a detailed measurement of the muon decay spectrum.

- Goal of **TWIST** is to measure the Michel parameters describing the decay spectrum to an unprecedented accuracy
Motivation

- Large statistical sample of muon decay events allows for a more comprehensive search for rare (or forbidden) muon decays than any previous search.
- No strong argument currently exists for the forbidding lepton flavor violating processes.
Search for Two Body Decays

Target decay is

$$\mu^+ \rightarrow e^+ X^0$$

where $X^0$ is an unknown boson mediating lepton flavor violation

- Assume the decay is isotropic.
- Assume the decay products are long lived.
  If $\tau >> 2.8 \times 10^{-21} \text{s}$ the instrument response dominates the peak width.

We want a confidence interval for the branching ratio of all accessible particle masses.
Previous 90% upper limit on this process is $3 \times 10^{-4}$ (Bryman 1986)
Methodology for Our Search

- Divide momentum range into 70 subranges on the order of the momentum resolution.

- Fit the Michel spectrum plus a peak constrained to be within the each subrange.

- Define a confidence interval for the branching ratio corresponding to the peak.
Fitting Function

\[ f(p, \cos \theta) = N_\mu (F(p, \cos \theta; \rho, \eta, \xi, \delta) + \Gamma_{X^0} H(p; \bar{p}, \sigma(\bar{p}, \cos \theta)) \kappa(p, \cos \theta)) \]

\( F(p, \cos \theta; \rho, \eta, \xi, \delta) \) is the normal muon decay spectrum (Michel spectrum).

\( H(p; \bar{p}, \sigma(\bar{p}, \cos \theta)) \) represents the instrument response function

\( \kappa(p, \cos \theta) \) represents the acceptance of the detector

Note that the parameters varied during the fit are

- The Michel Parameters; \( \rho, \eta, \xi, \delta \) and the normalization \( N_\mu \).
- The mean peak momentum; \( \bar{p} \)
- The branching ratio for the unknown particle; \( \Gamma_{X^0} \)

This fitting method has been validated using Monte Carlo simulations.
Defining the Resolution

Momentum resolution of the detector measured using Monte Carlo

- Directly compare thrown track momentum to the reconstructed momentum
- Resolution dependent on the momentum and the angle of the positron
Confidence Intervals

Definition: The interval that has a given probability of containing the real value of an experimentally determined parameter

- Classical Neyman (frequentist) intervals do not necessarily cover the required intervals correctly; can lead to non-physical answers in the case of small signals

- Feldman Cousins method: Requires no \textit{a priori} assumption on whether we are defining a interval or an upper limit. By construction requires the interval to be physically bounded. Calculation of the confidence interval separated from the fitting procedure.
Results

- Plot shows the branching ratios of 70 independent fits within fiducial range.
- Results indicate a 99% upper limit for the branching ratio on the order of $10^{-5}$.
- Plot represents a fifth of the total data available.
Conclusions

- We can set a 99% upper limit for the branching ratio of a isotropic two body muon decay at a part in $10^5$ for the available mass regime.
- No new statistically significant particles have been found so far.
- We can further restrict the branching ratio by using the full amount of data available from TWIST. This should increase our sensitivity by a factor of $\sqrt{5}$.
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