A Search for Rare Decays in the TWIST Muon Decay Spectrum

Ryan Bayes
University of Victoria, Representing the *TWIST* Collaboration
rbayes@uvic.ca

Objective

To measure the branching ratios for two body muon decays (a forbidden process under the standard model) within the *TWIST* (*T*riumf *W*eak *I*nteraction *S*ymmetry *T*est) muon decay spectrum and to define confidence intervals for all accessible candidate processes.

- The *TWIST* experiment has gathered a data set of unrivaled quality and size for the purpose of testing the standard model weak nuclear interaction to an unprecedented precision.
- *TWIST* spectrum produces an excellent background in which to search for decays that are so far unknown to the standard model, ie. lepton flavour violating two body decays.
- While the standard model forbids such processes there is no inherent theoretical justification for excluding them.
- The previous upper limit on the branching ratio of a decay of this type is 3×10^{-4} (Bryman 1986).

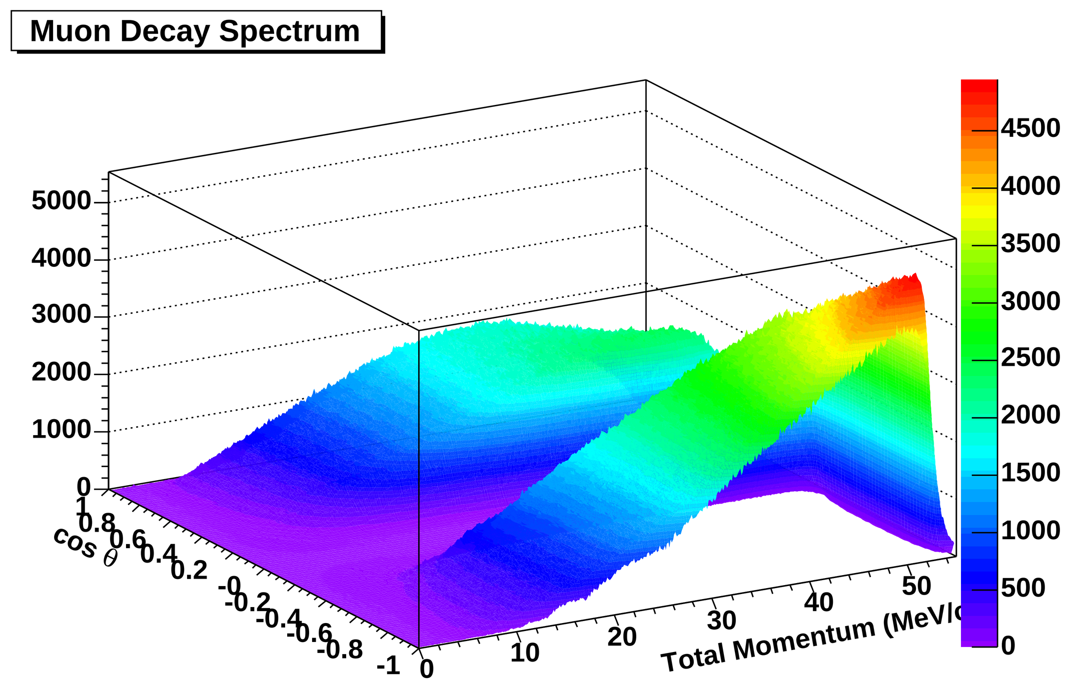
The *TWIST* Experiment

- Tests the weak nuclear interaction through the process

$$\mu^+ \to e^+ \nu_e \bar{\nu}_\mu$$

by measuring the momentum and angle of e^+.

- *TWIST* has produced a detailed measurement of the muon decay spectrum (see Ref. [1] and [2]).
- Goal of *TWIST* is to measure the parameters describing the muon decay spectrum (Michel Parameters) to parts in 10^4.



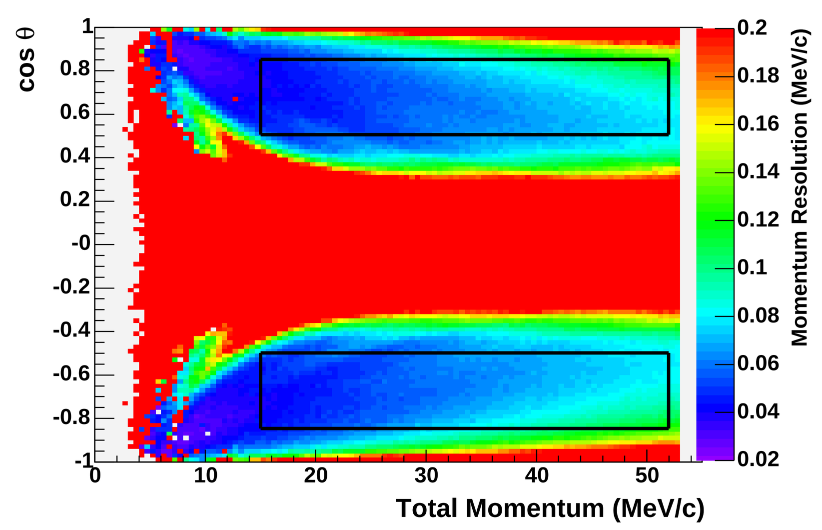
Two Body Decay Search

Target decay is

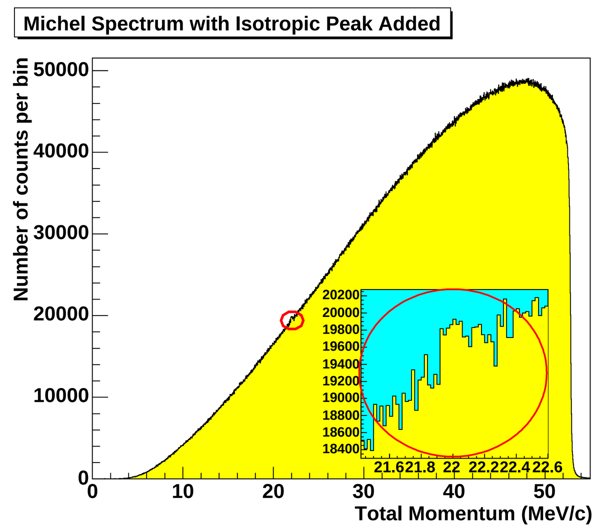
$$\mu^+ \to e^+ X^0$$

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

- Two primary assumptions are made:
  1. **The decay signature is isotropic**
  2. The unknown boson is long lived
     The width of the decay signal is dominated by the detector resolution



- The resolution of our detector as generated from our Monte Carlo simulations.
- The black box describes the edges of the fiducial region chosen for this study.
- This demonstrates that the data are well behaved. within the selected fiducial.



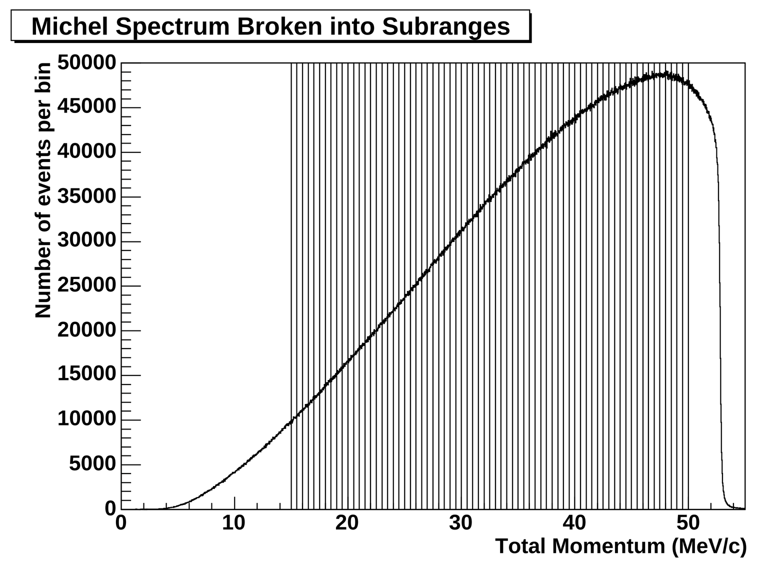
- Here we show a peak added to a typical background data set (integrated over $\cos\theta$).
- The red circle indicates the peak location.
- The B.R. here is 6.37×10^{-6} and is easily measured by this analysis.

Analysis Algorithm

To generate the required exclusion plot we need to sample the muon decay spectrum and separate any possible decays from the background (Michel) spectrum. This is a three step process:

- **Step 1**

The momentum range is divided into 70 subranges whose width is on the same order of size as the momentum resolution.



- **Step 2**

Fit a Michel spectrum plus a peak, where the peak is constrained to be within a given subrange (this is repeated for each subrange).

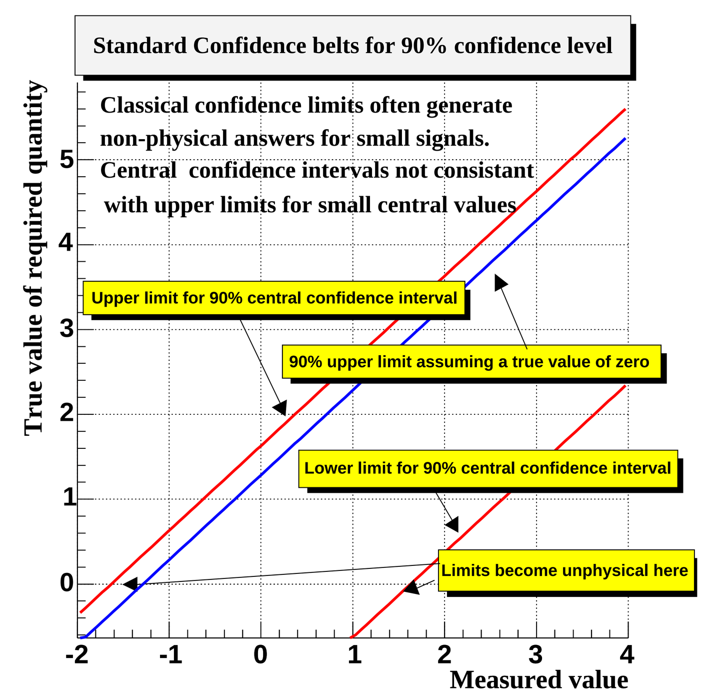
- Fitting Function is given by

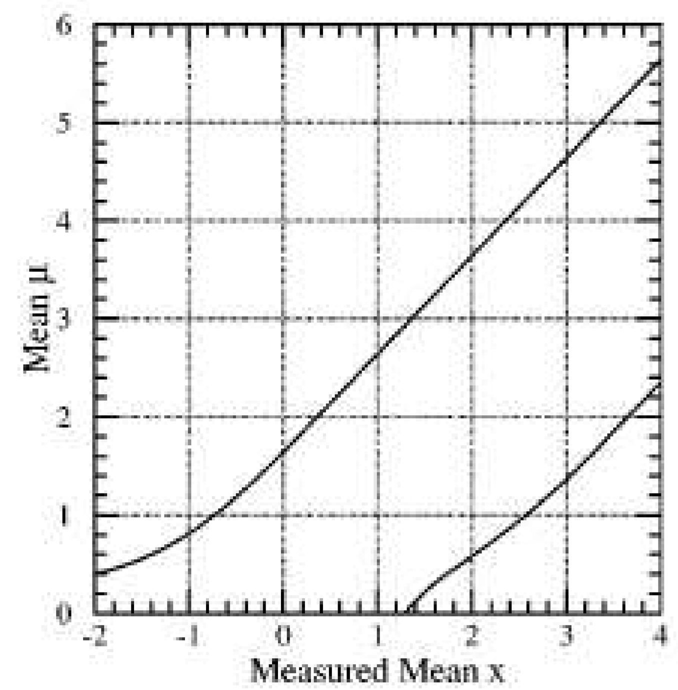
$$f(p,\cos\theta) = N_\mu(F(p,\cos\theta;\rho,\eta,\xi,\delta) + \Gamma_{X^0} H(p;\bar{p},\sigma(\bar{p},\cos\theta))\kappa(p,\cos\theta))$$

- This is used in a standard χ^2 fitting procedure (with some modifications) to generate a fit to the data.
- $F(p,\cos\theta;\rho,\eta,\xi,\delta)$ is the Michel spectrum.
- $H(p;\bar{p},\sigma(\bar{p},\cos\theta))$ represents the instrument response function where $\bar{p}$ is the mean peak momentum.
- $\kappa(p,\cos\theta)$ represents the acceptance of the detector.
- The following parameters are varied freely during the fitting procedure:
  - Michel parameters ρ, η, ξ, δ .
  - the Michel spectrum normalization N_μ.
  - the branching ratio for the unknown particle, Γ_{X^0}.
- $\bar{p}$ is constrained by the subrange.
- Note that $\sigma(\bar{p},\cos\theta)$ is taken from the momentum resolution data perviously described.

Step 3

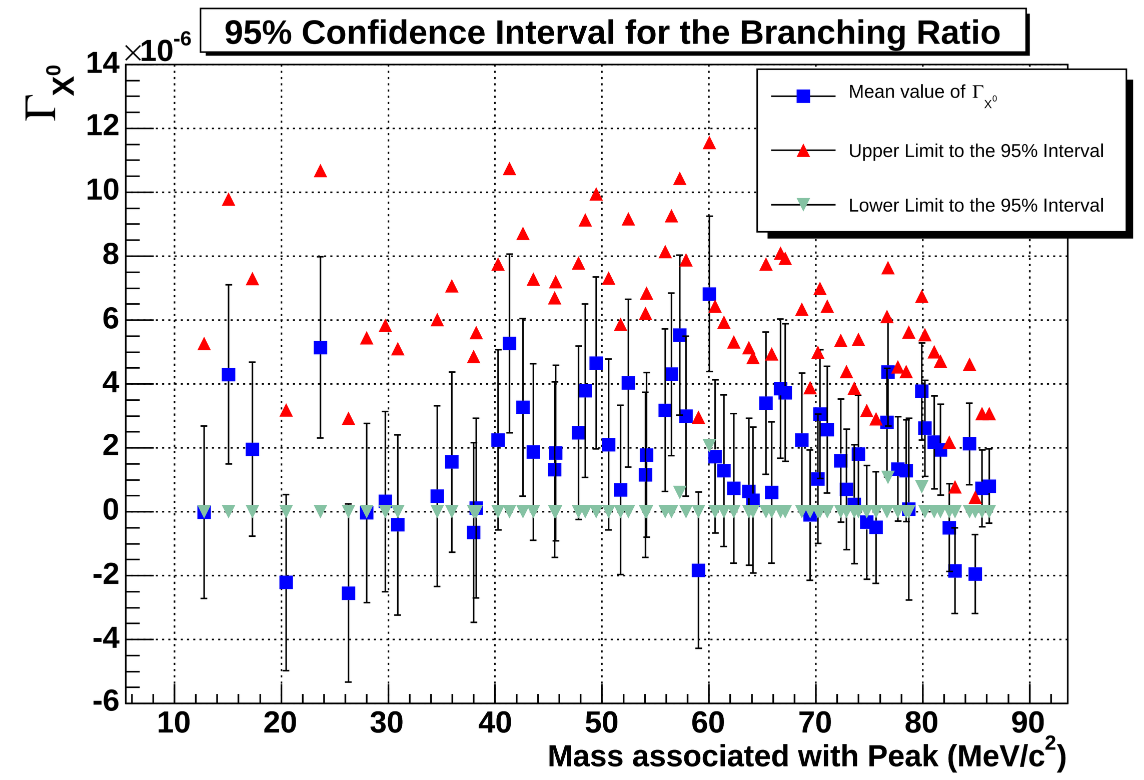
- Define a confidence interval for each of the branching ratios defined.





- An unbiased, realistic, measure of the interval is required.
- Classical method of defining a confidence limit has a number of inherent weaknesses (see the top plot on the right).
- For the purposes of this study the confidence intervals were generated using the method described by Feldman and Cousins [3].
- The chosen method requires no *a priori* decision whether the confidence interval is one sided or central.
- Uses a predefined criterion to force the summation of the probability distribution function necessary for the definition of the interval away from non-physical values of the measured parameters.
- *Bottom figure was taken from ref.[3].*

Results and Discussion



- This plot shows the results using the process described here for a subset of the total available data from *TWIST*.
- Upper limit of the interval indicates that we can set the 95% Upper limit to the branching ratio for this decay at $\Gamma_{X^0} \approx 10^{-5}$.
- This upper limit can be improved with the inclusion of the full statistics available.
- Lower limit *may* suggest the presence of unknown particles at a given mass value where the mean branching ratio is significantly greater than zero (would be the subject of further evaluation).
- A possible candidate decay occurs here (at 60 MeV$/c^2$), however similar analyses of other subsets indicate that this can be attributed to statistical fluctuations.

References

[1] J.R. Musser et al., PRL 94, 101805 (2005).
[2] A. Gaponenko et al., PRD 71, 071101(R) (2005).
[3] G.J. Feldman, R.D. Cousins, PRD 57, 3873(1998).

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