Status of a Search for Rare Decays in the $\mathcal{TWIST}$ Muon Decay Spectrum

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Motivation

- Possibilities exist for lepton flavor violating decay
- Large statistical sample of muon decay events ($\mathcal{O}(10^7)$) allows for the possibility of a more comprehensive search.

Search for Two Body Decays

Target decay is

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

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

- Assume the decay is isotropic
- Assume decay products are long lived $\Rightarrow \tau >> 2.8 \times 10^{-21}$s.

We what a Confidence level for all accessible particle masses.

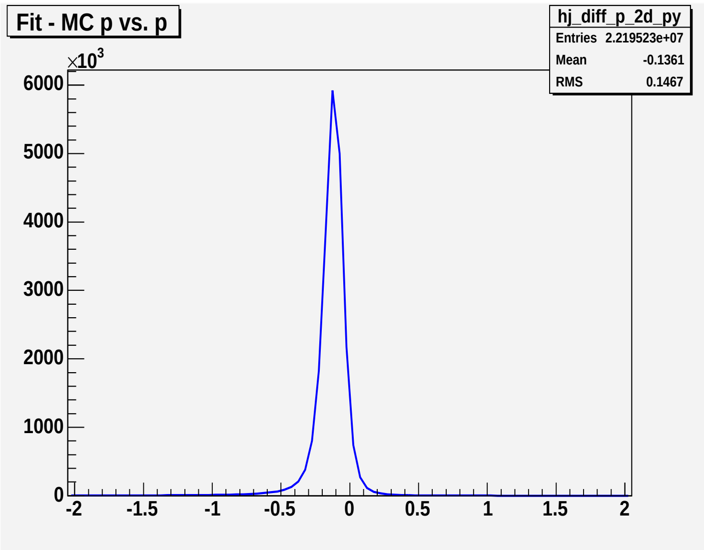
Methodology

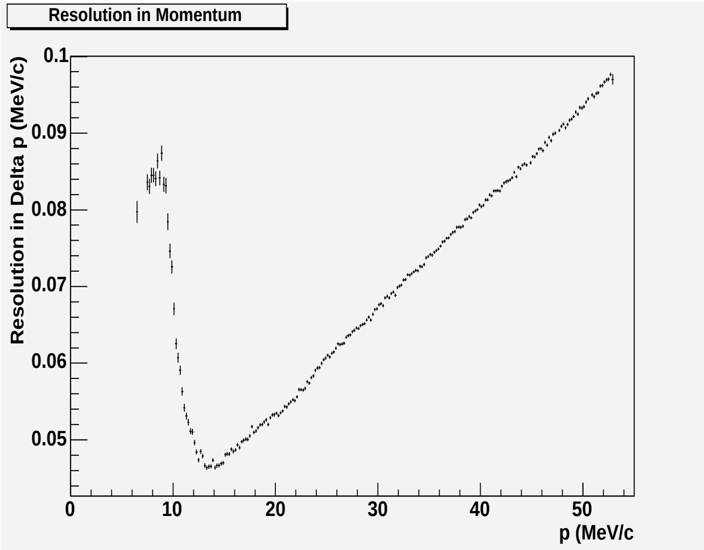
- Divide momentum range into subranges on the order of the momentum resolution.
- Fit the Michel spectrum with a peak contained within the range
- Define a confidence limit based on the Feldman Cousins method

Defining the Resolution

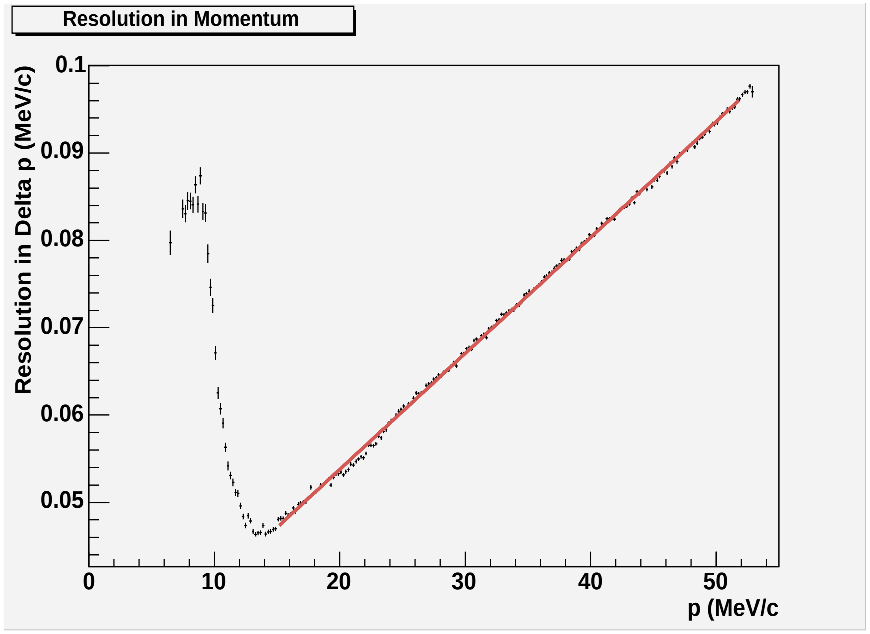
Momentum resolution of the detector measured using Monte Carlo

- Directly compare thrown track momentum to the reconstructed momentum
- The response of the detector is the primary factor in the resolution.
- Resolution dependent on the momentum and the angle of the track





- The momentum dependence is much stronger than the angular dependence
- momentum dependence is linear throughout the momentum range of interest



Fitting Function

$$f(p, \cos\theta; \varpi) = \left.\frac{\partial^2\Gamma}{\partial p \partial \cos\theta}\right|_{\varpi_0} + \sum_{\alpha_i \in \varpi} \Delta\alpha_i \frac{\partial}{\partial\alpha}\left[\frac{\partial^2\Gamma}{\partial p \partial \cos\theta}\right]_{\varpi_0 \neq \alpha_i} + H(p, \cos\theta)$$

$$\text{where} \quad \varpi \in \{\rho, \eta, P_\mu\xi, \delta\}$$

Note that $H(p, \cos\theta)$ represents the response peak

$$H(p, \cos\theta) = \frac{A(p, \cos\theta)N_1}{\sqrt{2\pi}\sigma_1}\left(\exp\left(\frac{-(p-\mu)^2}{2\sigma_1^2}\right) + \frac{N_2}{N_1}\frac{\sigma_1}{\sigma_2}\exp\left(\frac{-(p-\mu)^2}{2\sigma_2^2}\right)\right)$$

This function was chosen to get a better fit to the response from the data

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

- The probability that a particle at a given angle and momentum will be measured.
- Defined using the ratio of accepted and thrown Monte Carlo spectra.

Confidence Intervals - Feldman Cousins method

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. Vastly different results can appear depending on whether a limit or an interval is being assigned.

Feldman Cousins method: Confidence intervals based on an ordering principle

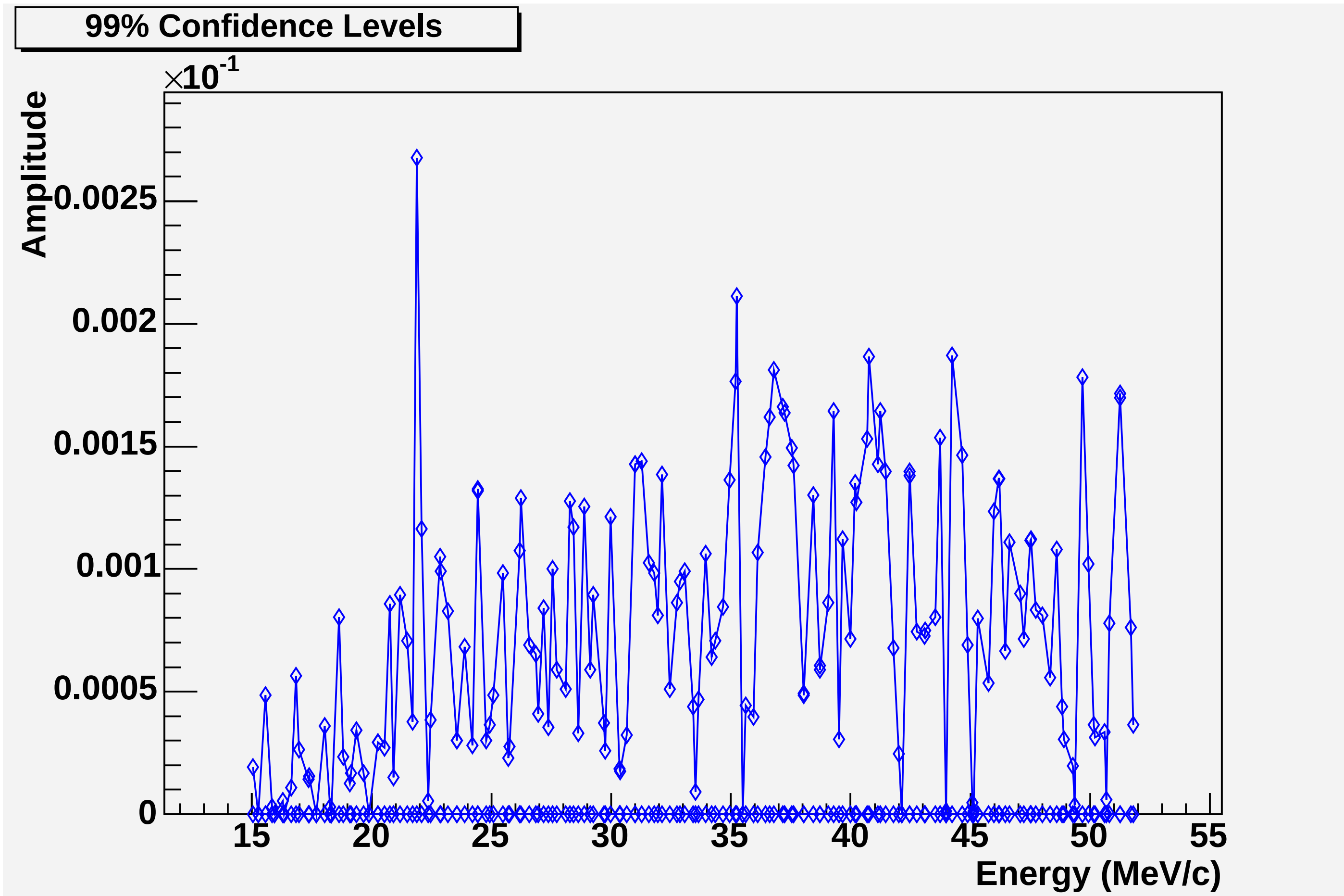
- Define a grid of discrete values over the parameter space
- For each point evaluate the probability of that value occurring given a best fit value for that parameter (μ_{Best})
- The ordering principle is generally based on the ratio of probabilities

In our case (constrained Gaussian probabilities) a difference of χ^2 may be used

$$R'(\mu_j) = \begin{cases} \sum_i \frac{(n_i - t_i(\mu_j))^2}{\sigma_i^2} - \frac{(n_i - t_{iBest}(\mu_{Best}))^2}{\sigma_i^2} & \text{for } n_i > 0 \\ \sum_i \frac{(n_i - t_i(\mu_j))^2}{\sigma_i^2} - \frac{(n_i)^2}{\sigma_i^2} & \text{for } n_i < 0 \end{cases}$$

- Sum the probabilities based on the corresponding value of the ordering principle (In the case of $R'(\mu_j)$, add corresponding values of probabilities from least to greatest) until total probability equals the required level of confidence
- extremes in the resulting ranges are designated as the confidence limits

Preliminary Results:



Here we have the confidence interval in terms of the positron momentum

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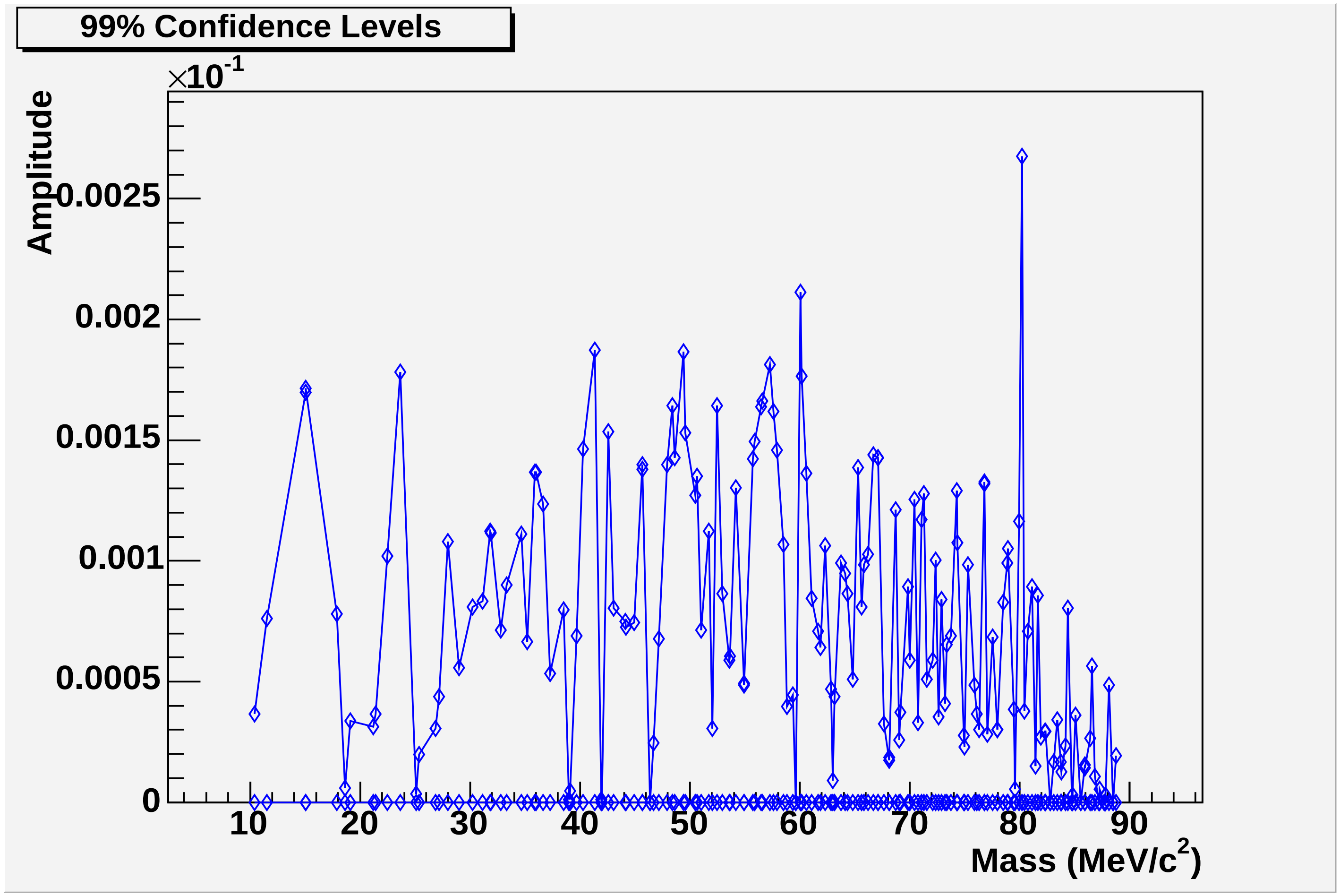

This shows the confidence interval in terms of the mass of X^0

Remaining Objectives:

- Generate a resolution function which recognizes the angular dependence of the detector response.
- Produce full Monte Carlo tests of the method.
- Use expanded data sets in the generation of the confidence levels.
- Expand the search to encompass three body decays.