Parameter Reconstruction and Estimation of Widths in Coherent Elastic Neutrino-Nucleus Scattering Experiments.

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Introduction

- Short Baseline Sterile Neutrino Searches
- The MIνER Experiment at Texas A&M University
- What are Bayesian and Frequentist Statistics?
- MultiNest - What is it? Why use this tool?
- Our Toy Model - What is it? What did we do with it? What did it tell us?
- Applications & Future Goals

Github link to the Jupyter Notebook

https://github.com/Andrerg01/Mathematica-Codes
Investigating Sterile Neutrino Hypothesis with Coherent Neutrino-Nucleus Scattering

**Coherent Scattering:**
Small momentum exchange means large wavelength; Individual nucleons are unresolved

**Sterile Neutrino Parameters:**
- $\Delta m^2$
- $\sin^2(2\theta)$

$$P(\alpha \rightarrow \beta) = \sin^2 \left[ 2\theta \right] \times \sin^2 \left[ \frac{\Delta m^2 L}{4E_\nu} \right]$$
Investigating Sterile Neutrino Hypothesis with Coherent Neutrino-Nucleus Scattering

Questions of Interest

- Given a data set, what are the parameters for which the model best reproduces the data?
- For which experimental layout can we optimize the coverage of the parameter space?
- How can we estimate widths for parameter distributions given correlated systematic uncertainties?
Project Goals

- Exclude Parameter Space
- Rule Out Null Hypothesis
- Explore ~1 eV Sterile Neutrinos
- Reconstruct Mass Gap and Mixing Angle
- Optimize distance and exposure balance
Frequentist Approach v. Bayesian Approach

- If I lose my keys where should I look?
  - Check Random Places?
  - Work from where I start and widen out from there?
  - Check the places where I usually am and where I use them?
    - My Desk?
    - The Car?
Bayesian Statistics

The Posterior
The probability of getting this evidence if this hypothesis were true

$P(H|E) = \frac{P(E|H)P(H)}{P(E)}$

The Evidence
The probability of H being true before gathering evidence

The Prior

$P(A|B)P(B) = P(B|A)P(A)$
Likelihood Functions - Gaussian and Poisson Distributions

\[ L_D = P(D|\theta) = \prod_{m} P(x_m|\theta) \cdot S(x_m) \]

\[ P(X) = \frac{\lambda^x e^{-\lambda}}{X!} \]
Penalyzing for putting too much strain on our model.

- Finding the parameters that most efficiently reflect the model.
- Allowing for lots of error allows for an easier fit but becomes meaningless.
- Allowing for no error makes it difficult if not impossible to fit and still meaningless.
What is MultiNest and why use it?

- Allows input of a prior and a likelihood function.
- Returns Parameters of Best Fit and their error.
- Returns posterior and relation between parameters

\[
\begin{bmatrix}
\text{Model} \\
\text{Likelihood Function} \\
\text{Parameters} \\
\text{Prior}
\end{bmatrix}
\rightarrow \text{MultiNest} \rightarrow
\begin{bmatrix}
\text{Parameters of Best Fit} \\
\text{Width of Parameters} \\
\text{Evidence}
\end{bmatrix}
\]
Why MultiNest?

- Returns Log Evidence and its Error for the given model.
- Evidence can (and will) be used as a tool to compare models.
The Toy Model

- Create “Perfect” data set.
- Add “Background Noise”
  - Shift vertically
  - Tilt curve
  - “Smudge” data points.
- “Simulate” N Data Points

Model: $A+Bx+C\cos(Dx+E)$
5 Parameters
Uniform Priors
Gaussian Likelihood Function
The Toy Model

- Run MultiNest.
- Record Output
- Generate new data set
- Repeat

\[ A + Bx + C \cos(Dx + E) \]

\[
\begin{align*}
A &= 154.07 \pm 4.09 \\
B &= -36.45 \pm 6.87 \\
C &= 39.20 \pm 2.68 \\
D &= 11.98 \pm 0.21 \\
E &= 0.09 \pm 0.11 \\
\text{Log - Evidence} &= -48.29 \pm 0.28
\end{align*}
\]
The Toy Model
The Toy Model

A + Bx + C*Cos(Dx+E)
The MLvER Experiment - Texas A&M University

- Reactor Facility offers superior prospects for Short Baseline Neutrino studies
  - Megawatt Class Nuclear Reactor
  - Has a Flux on the order of $10^{12}$ Neutrinos / cm$^2$ / s at 1 m
  - Moveable Core
  - Experimental baseline as short as 3 m with full shielding
  - Ultra low threshold detectors allow high sensitivity to CEvNS process.
Summary and Future Works

- MultiNest presents much potential to be used as a method for fitting parameters and comparing models.
- By interpolating numerically calculated functions where the parameter simply scale the axis, we can use multinest to fit parameters and examine the evidence for each model - likelihood function considered.
- By examining the output we can determine the exposure time / distance from the detector (among other external parameters) that will produce the most meaningful results.
Thank you!