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

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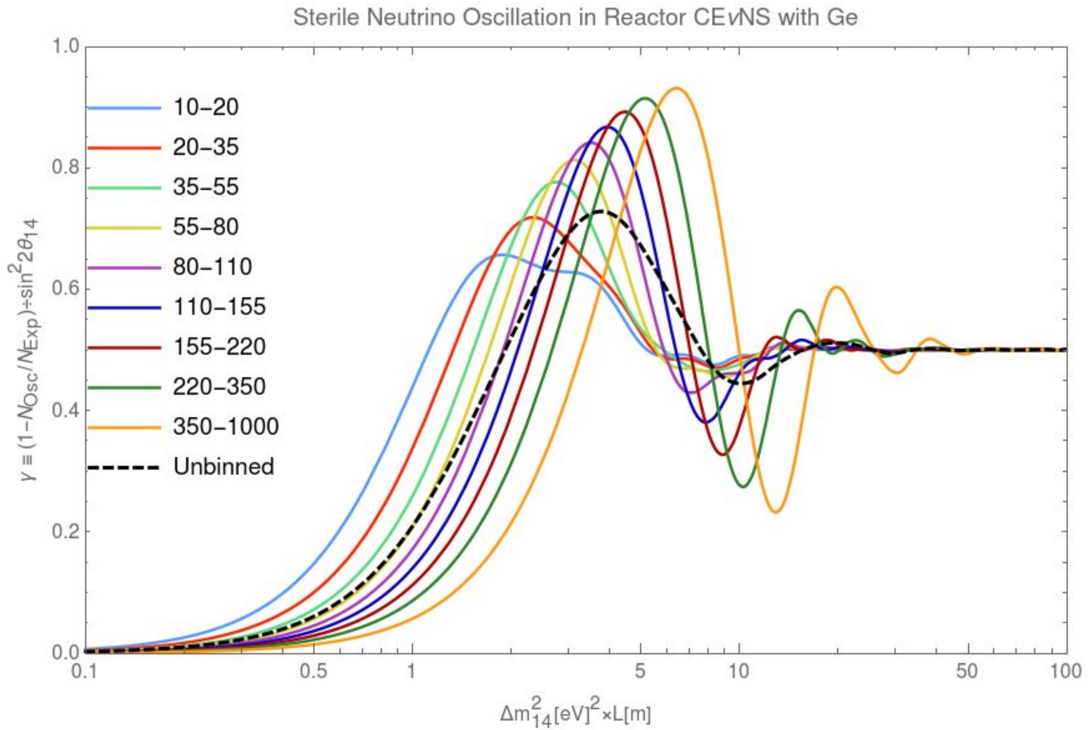
Introduction

- 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:

- Δm^2
- $\mathrm{Sin}^2(2\theta)$

$$P_{(\alpha\to\beta)} = \sin^2\left[2\theta\right] \times \sin^2\left[\frac{\Delta m^2 L}{4E_\nu}\right]$$

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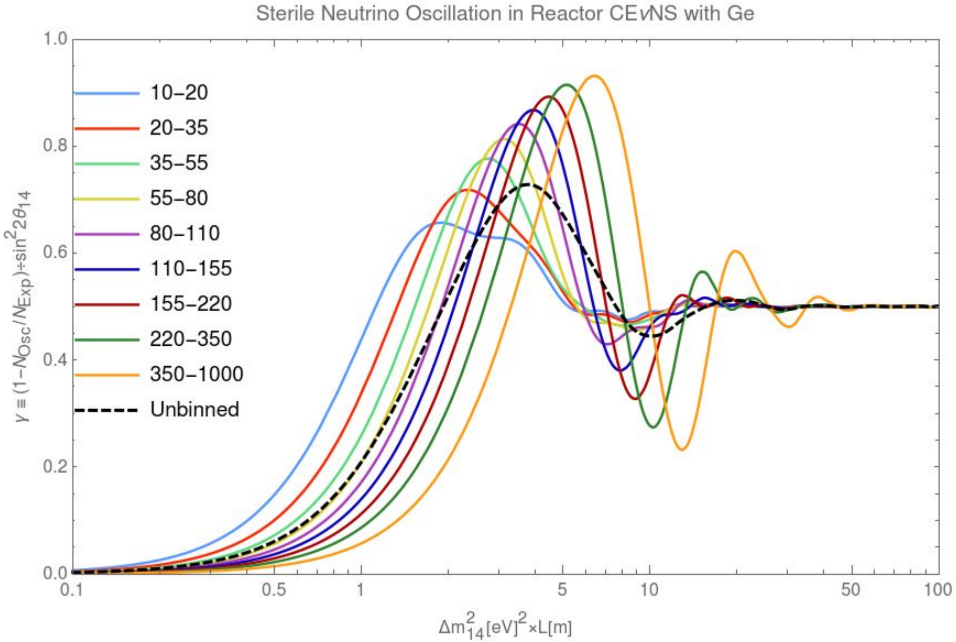
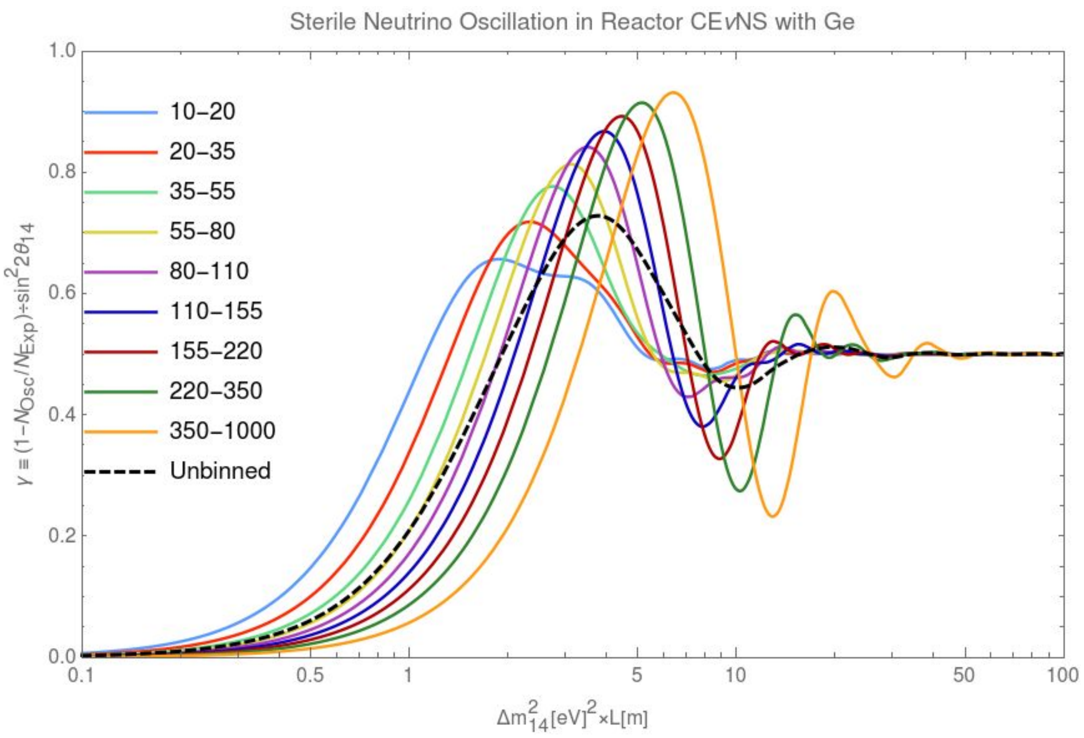
Questions of Interest

- 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

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- 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

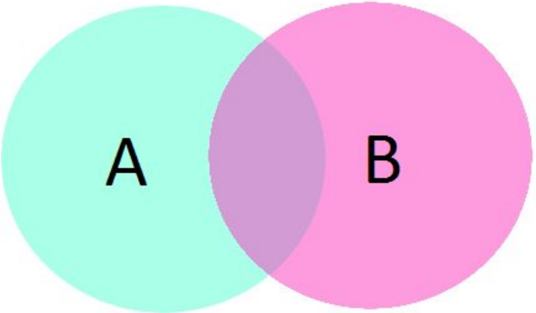
The Evidence

The probability of getting this evidence if this hypothesis were true

The Prior

The probability of H being true before gathering evidence

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

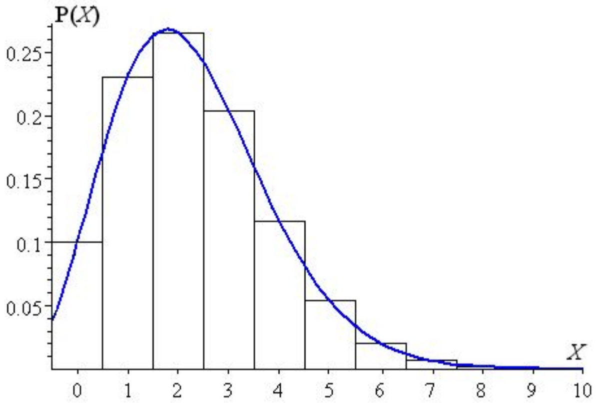


$$P(A|B)P(B) = P(B|A)P(A)$$

Likelihood Functions - Gaussian and Poisson Distributions

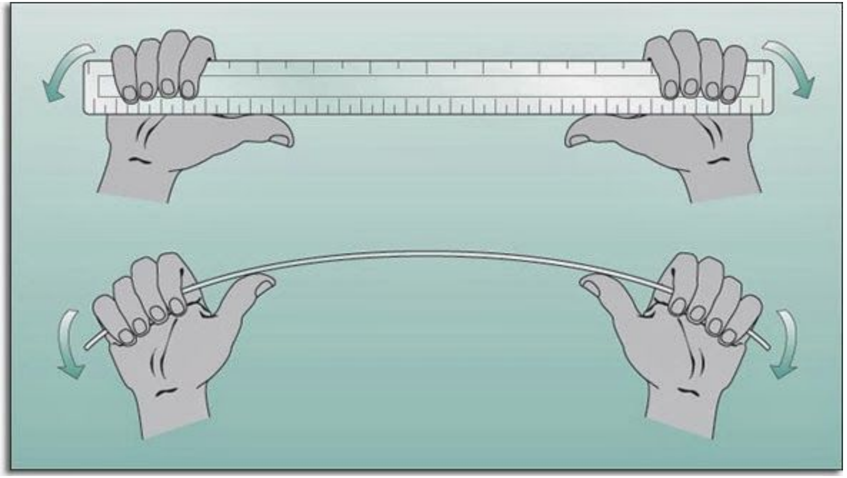
$$L_D = P(D|\theta) = \prod_m P(x_m|\theta)\, S(x_m)$$

$$P(X) = \frac{\lambda^x e^{-\lambda}}{X!}$$



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?

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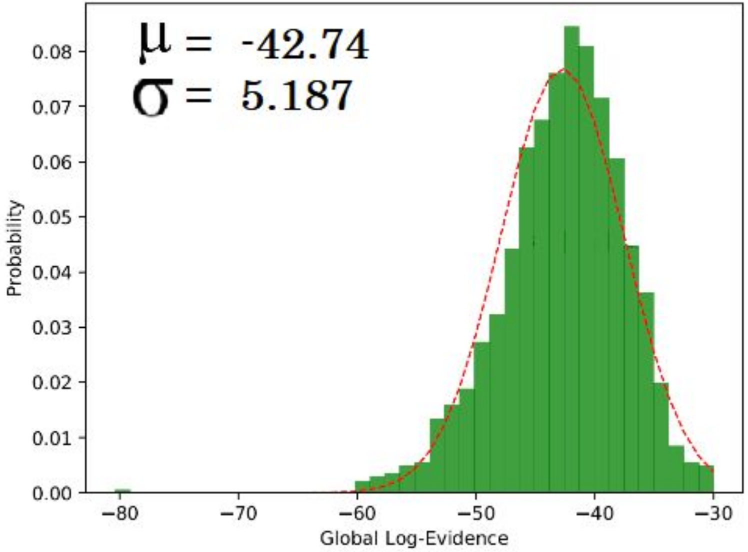
- Allows input of a prior and a likelihood function.
- Returns Parameters of Best Fit and their error.
- Returns posterior and relation between parameters

```
D Parameter:
Mean: 12.0110622229
Standard Deviation: 0.200583092612
Most frequent histogram value: 11.9576348919
Correct Value: 12.0

E Parameter:
Mean: 0.120608118532
Standard Deviation: 0.115976420488
Most frequent histogram value: 0.0951341765873
Correct Value: 0.125663706144

Global Log Evidence:
Mean: -42.7401375839
Standard Deviation: 5.1871037815
Most frequent histogram value: -42.5917808219

Importance Global Log Evidence:
Mean: -42.7401375839
Standard Deviation: 5.1871037815
Most frequent histogram value: -42.5917808219
```

$$\begin{bmatrix}\text{Model}\\ \text{Likelihood Function}\\ \text{Parameters}\\ \underline{\text{Prior}}\end{bmatrix} \rightarrow \boxed{\text{Multinest}} \rightarrow \begin{bmatrix}\text{Parameters of Best Fit}\\ \text{Width of Parameters}\\ \underline{\text{Evidence}}\end{bmatrix}$$

Why MultiNest?

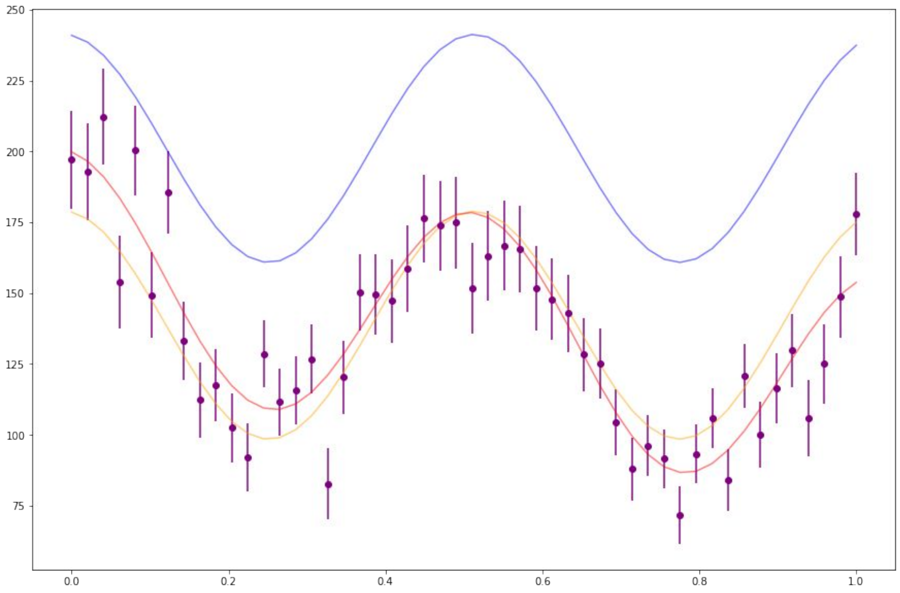
- Returns Log Evidence and its Error for the given model.
- Evidence can (and will) be used as a tool to compare models.



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

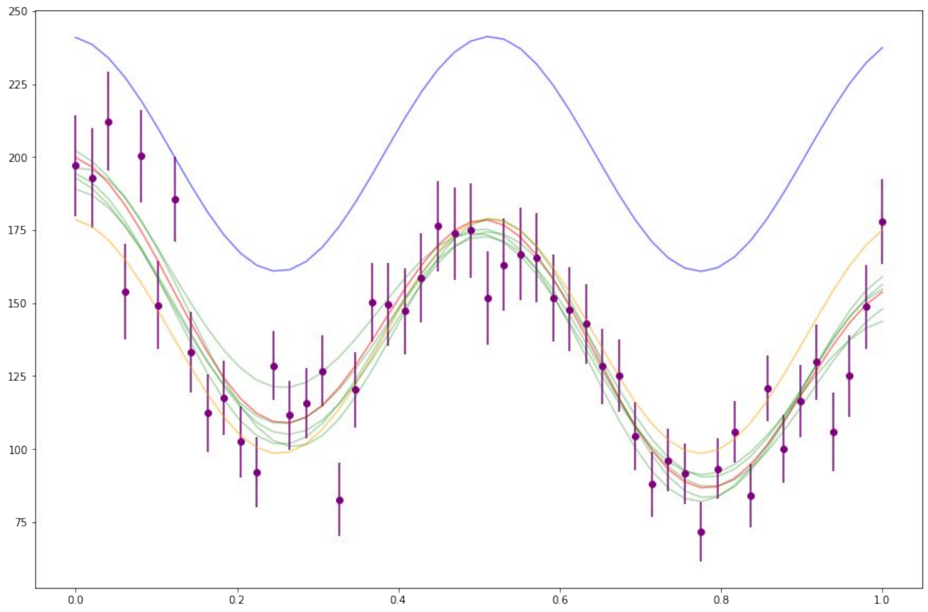


The Toy Model

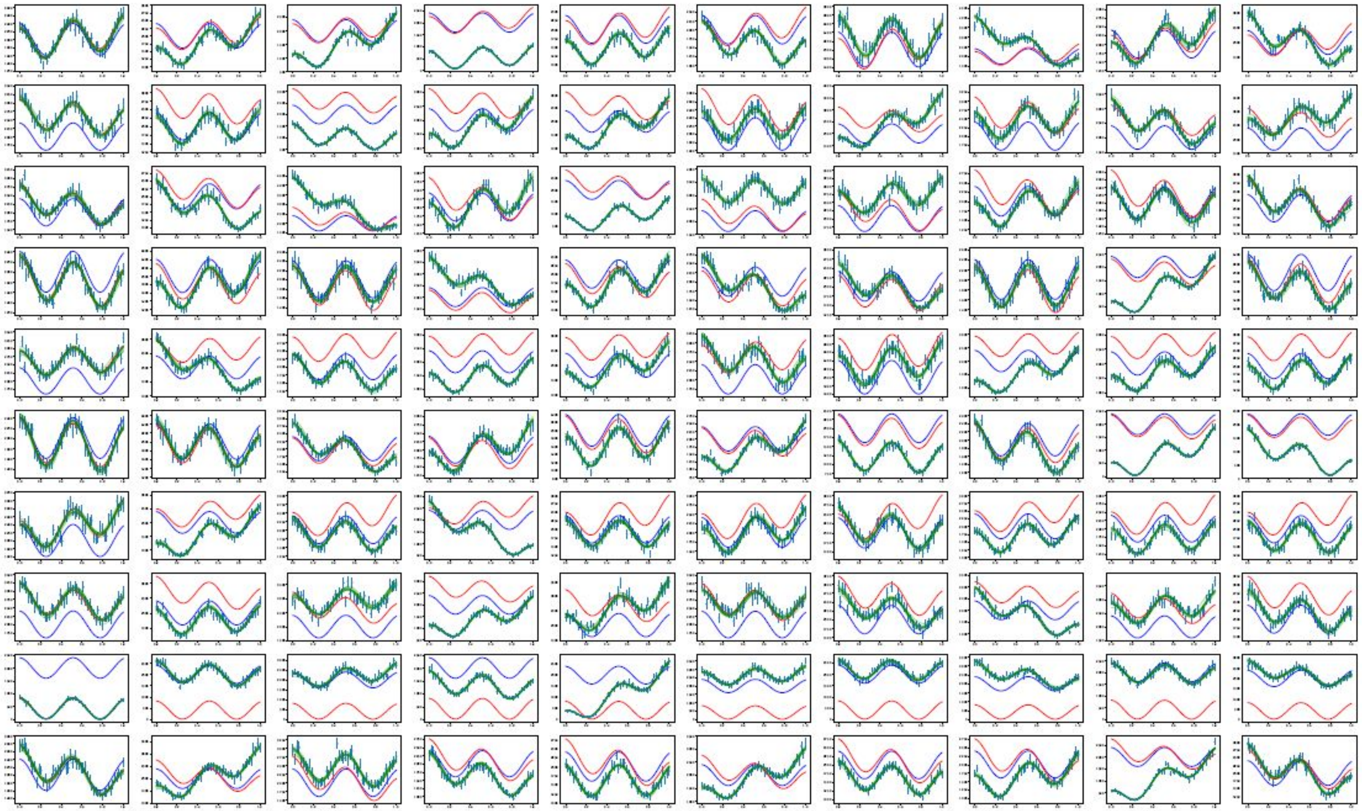
- Run MultiNest.
- Record Output
- Generate new data set
- Repeat

A+Bx+C*Cos(Dx+E)

A = 154.07 ± 4.09
B = -36.45 ± 6.87
C = 39.20 ± 2.68
D = 11.98 ± 0.21
E = 0.09 ± 0.11
Log - Evidence = -48.29 ± 0.28



The Toy Model



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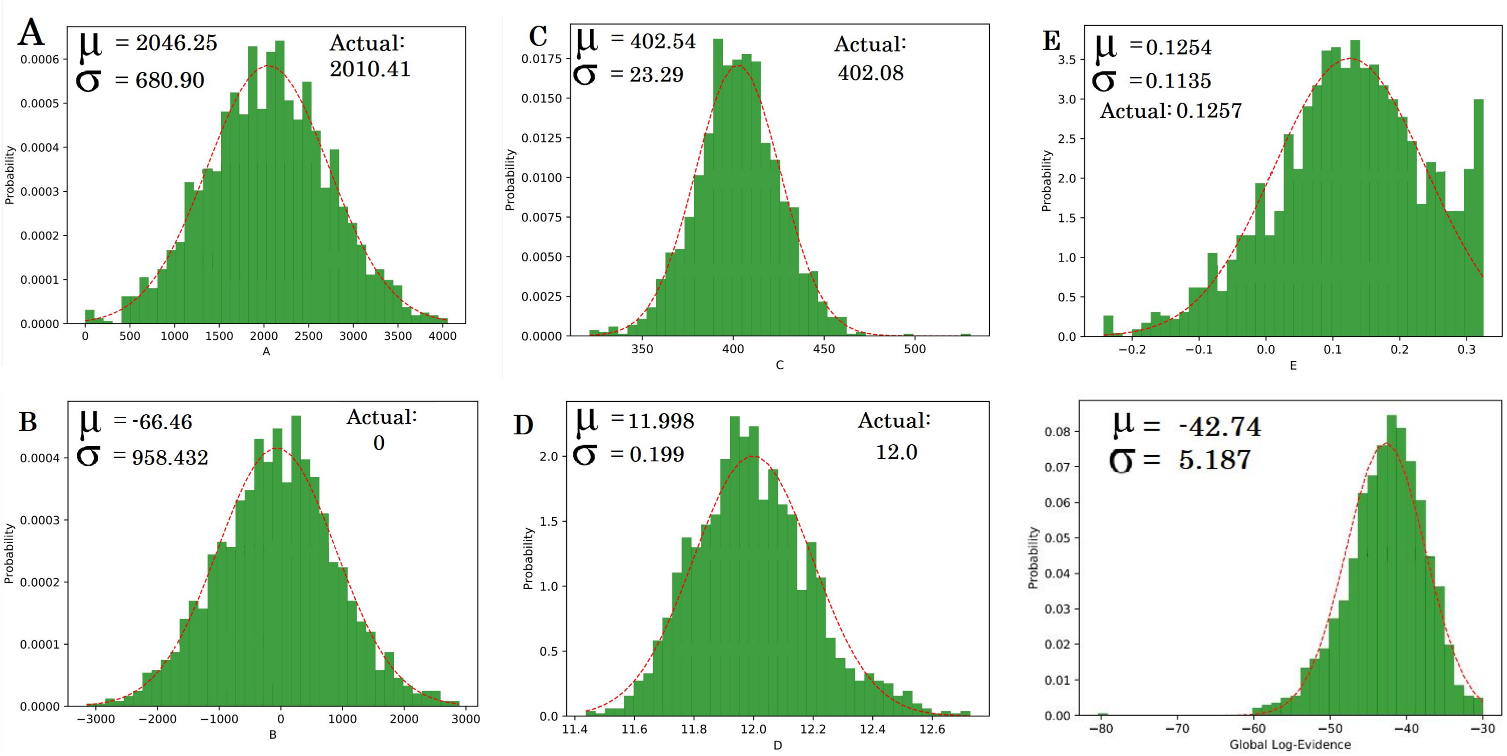
The Toy Model

A+Bx+C*Cos(Dx+E)



The MIνER Experiment - Texas A&M University

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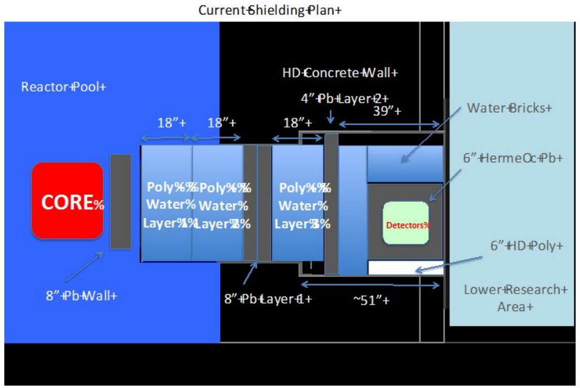
- Reactor Facility offers superior prospects for Short Baseline Neutrino studies
  - Megawatt Class Nuclear Reactor
  - Has a Flux on the order of 10^{12} Neutrinos / cm^2 / s at 1 m
  - Moveable Core
  - Experimental baseline as short as 3 m with full shielding
  - Ultra low threshold detectors allow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