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Implementing Nuisance Parameters in SBNfit

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SIST Final Presentations

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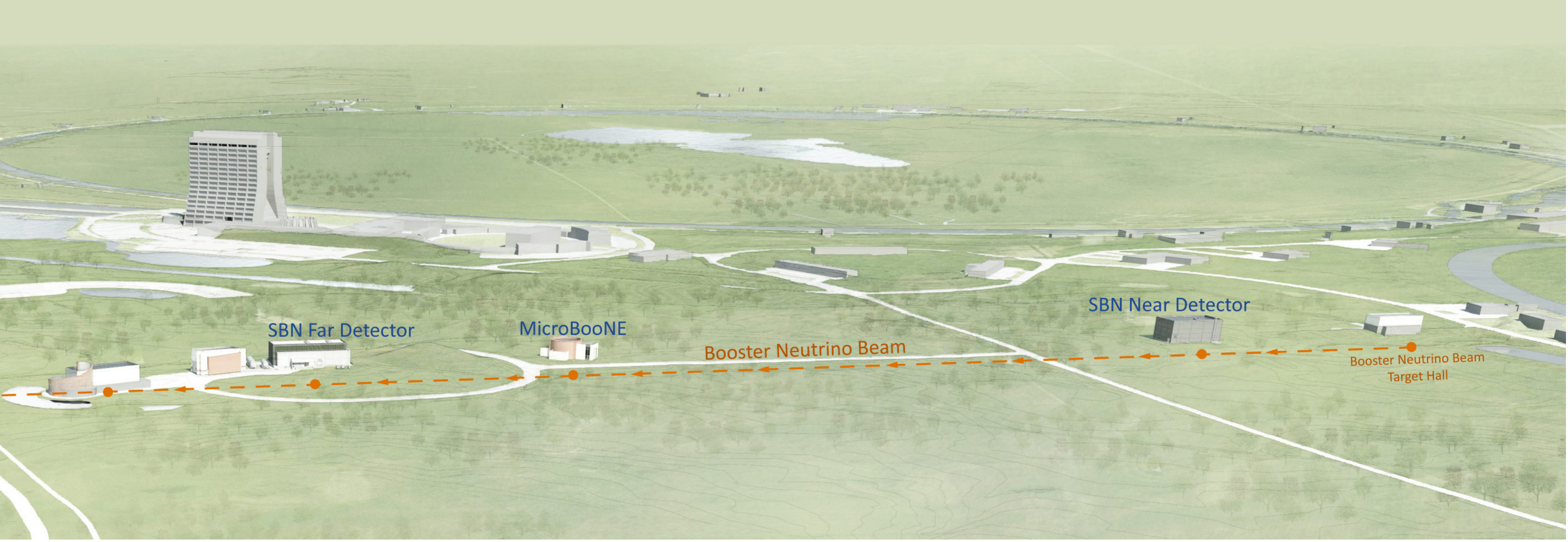
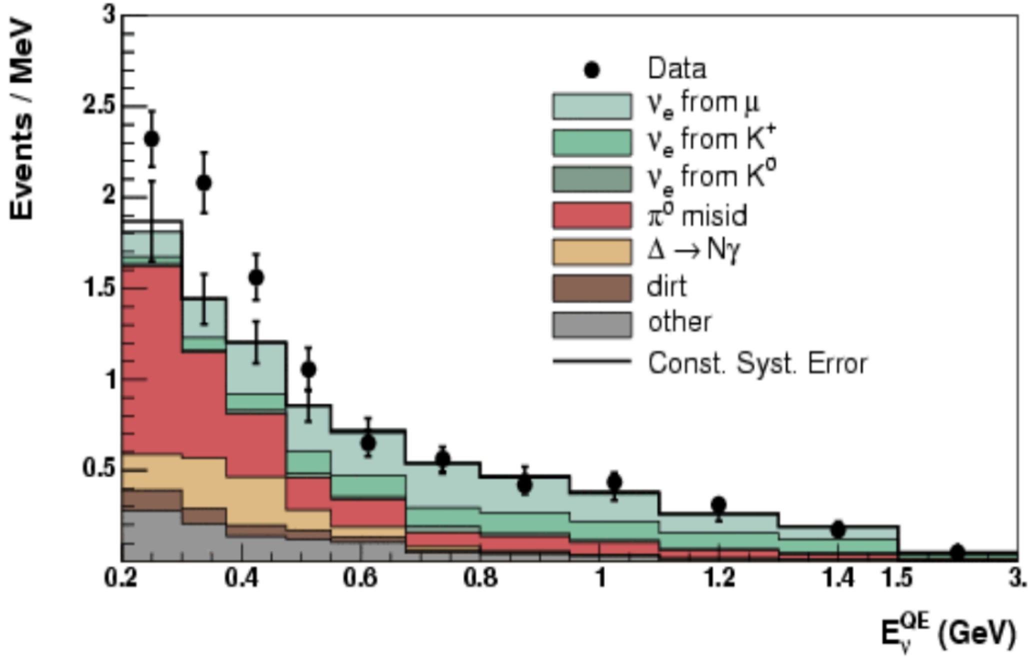
SBN Facilities



- Oscillation experiment at Fermilab located on the Booster Neutrino Beam (BNB)
- Consists of 3 liquid argon time projection chambers (LArTPC)s: the Short-Baseline Near Detector (SBND), MicroBooNE, and ICARUS
- Placing the three detectors at varying distances from the BNB target allows us to observe neutrino flavor oscillations

Goals & the LEE

- MiniBoone & Liquid Scintillator Neutrino Detector (LSND) experiments observed an excess of electron-like events at low energy, known as the low energy excess (LEE)

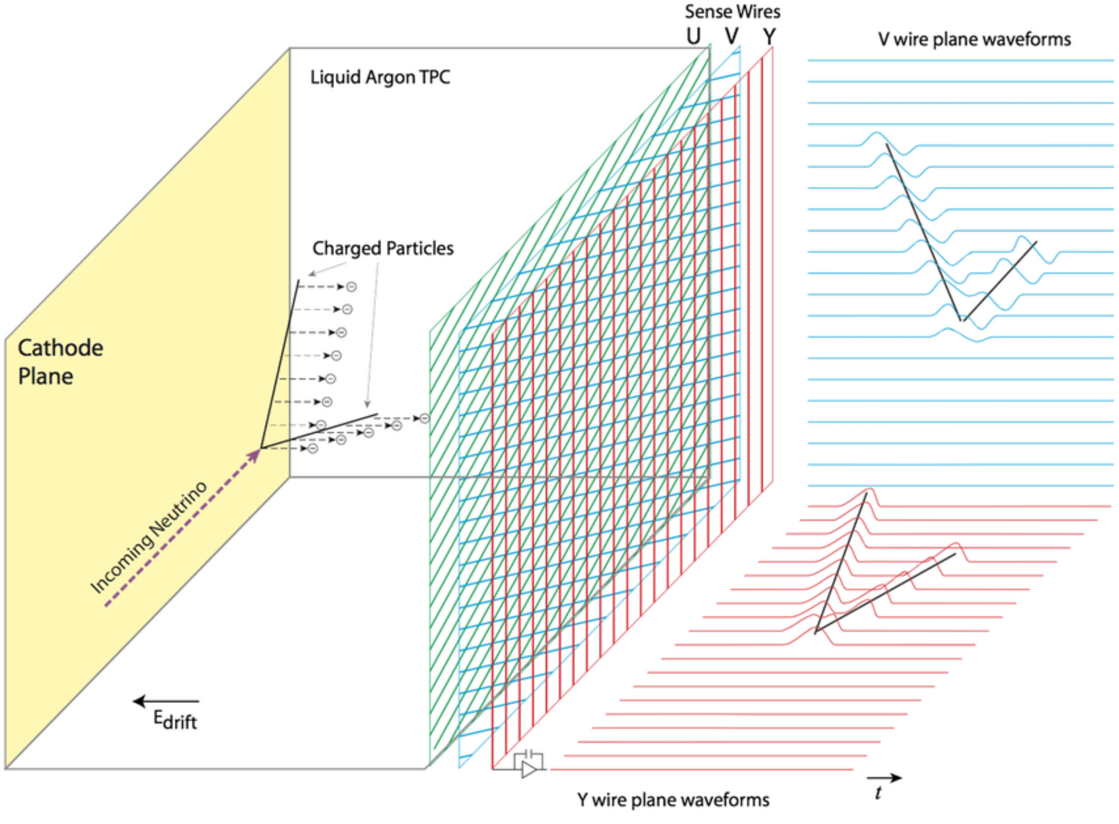


- Origin of excess is still unknown but possibly due to the presence of a sterile neutrino that amplifies the ($v_\mu \rightarrow v_e$) oscillation or unknown background
- Goal of MicroBooNE is to investigate this excess of events by utilizing the ability of liquid argon time projection chambers (LArTPC) to perform electron/photon separation

MicroBooNE

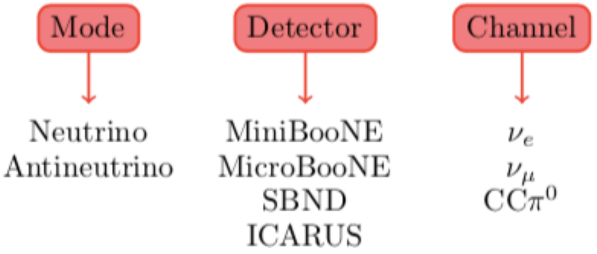
Micro Booster Neutrino Experiment

- 40-ft LArTPC with an active volume of 87 tons
- TPC consists of a cathode plane, a field-shaping cage around the drift perimeter, and three wire planes
- Charged particles travel through the detector and ionize the liquid argon. The electrons are drifted by a strong electric field towards the three wire planes, where they are detected.



SBNfit

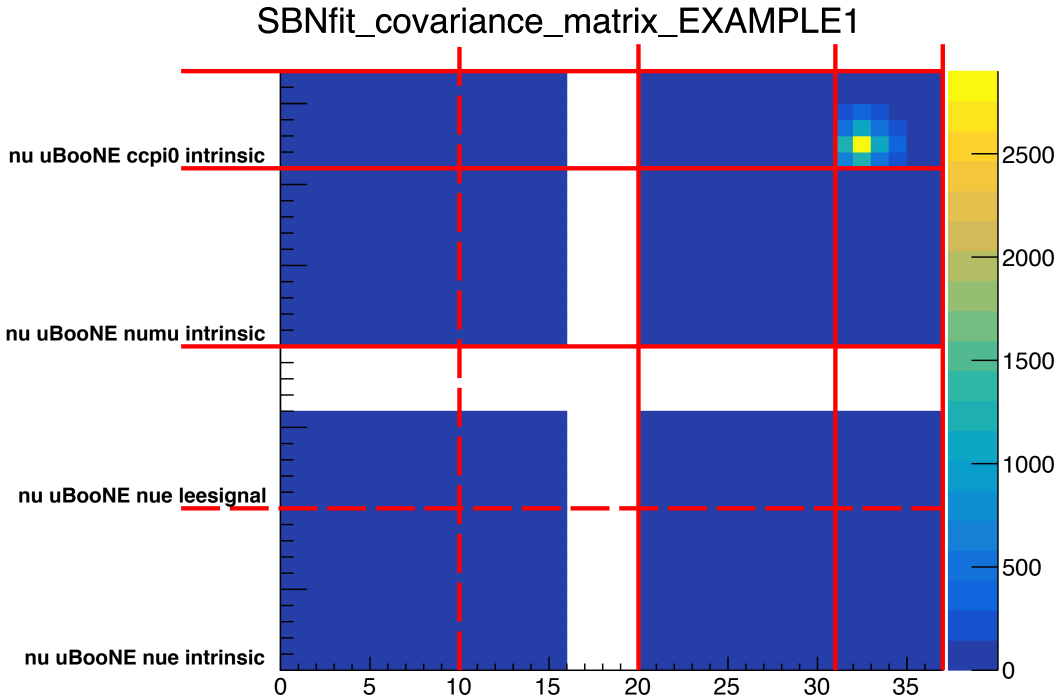
- SBNfit is a data fitting framework that allows the fitting of multiple modes, detectors, and channels simultaneously[1]
- Utilizes the covariance matrix approach used by MinibooNE[2] to calculate a χ^2



- Project aims to implement ability to marginalize and extract additional parameters correlated to the spectra that describe the systematic uncertainties (nuisance parameters) within SBNfit
  - Allows us to better understand the fit by identifying nuisance parameters with large pull & to represent several systematic errors as nuisance parameters in combination with the covariance matrix

[1]M. Ross-Lonergan & the Nevis MicroBooNE group, https://github.com/NevisUB/whipping_star
[2]D. Cianci, M. Ross-Lonergan, G. Karagiorgi, A. Furmanski, arXiv:1702.01758

Covariance Matrix Calculation in SBNfit



$$E_{ij}^{sys} = \frac{1}{N}\sum_{k}^{N}(N_i^{CV} - N_i^k)(N_j^{CV} - N_j^k)$$

Equation: Calculating a covariance matrix, where N is the total number of variations, N_i^k is the value in the i-th bin of the k-th variation and N_i^{CV} is that of the central value. 54 sources of uncertainty (variations) were used to build a 37 x 37 covariance matrix.

χ^2 Calculation

χ^2 for covariance matrix approach:

$$\chi^2 = \sum_{l,k=1}^{M} (N_k - N_k^{null}) E_{kl}^{-1} (N_l - N_l^{null})$$

where M is the total number of bins and E^{-1} is the inverse of the covariance matrix associated with the null hypothesis

Statistical error only:

$$\chi^2 = \sum_{i=1}^{M} (\frac{N_i^{null} - N_i}{\sqrt{N_i}})^2$$

where N_i^{null} are the theoretical predictions associated with the null hypothesis, N_i are the bins of observed data, and $\sqrt{N_i}$ is the Gaussian statistical error. When N_i^{null} are controlled by systematic uncertainties,

$$\chi^2(\xi) = \sum_{i=1}^{M} (\frac{N_i^{null}(1 + \sum_k \xi_k) - N_i}{\sqrt{N_i}})^2 + \sum_k (\frac{\xi_k}{\sigma_{\xi_k}})^2$$

where ξ are nuisance parameters describing systematic uncertainties and σ are the flat (normalization) systematics associated with the nuisance parameters.

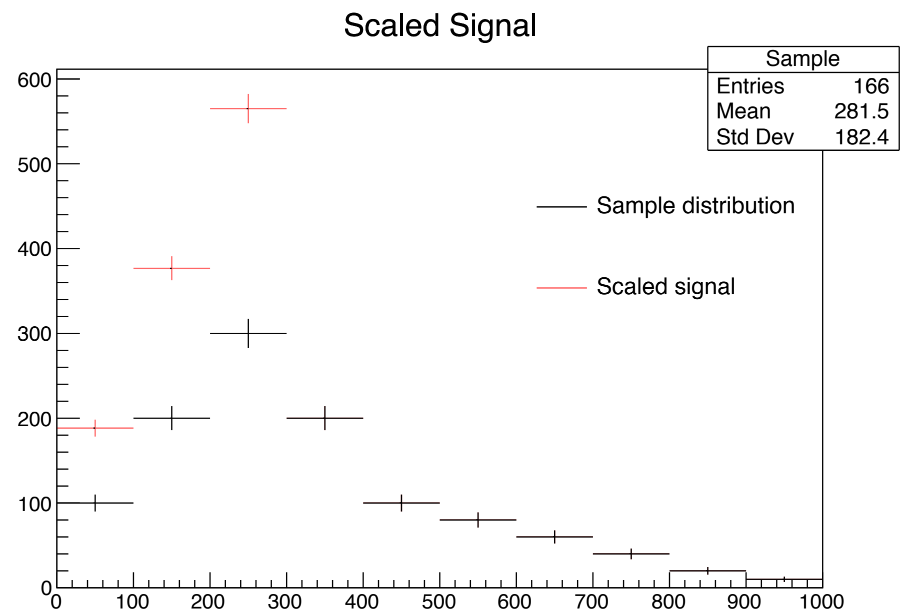
χ^2 Implementation

- Currently, only the weight of each nuisance parameter is accessible in SBNfit and not actual values of the parameters
- Using flat normalization values for testing
- We have begun implementation
  - Created stand-alone toy example code outside the SBNfit framework and validated that the method works
  - Implemented the method in SBNfit and validated that it also works
- Plans to continue improving and validating the method

Toy Example

- Sample a Gaussian distribution to fill a histogram of 10 bins
  - First 3 bins are set as the signal spectra and scaled from .1 to 100 in steps of $10^{.025}$
  - Remaining 7 bins are assigned as background spectra
  - We assign δ_{sys}=(10%, 15%, 5%) respectively to sample, signal, and background
  - Build the covariance matrix using the systematic errors as follows:

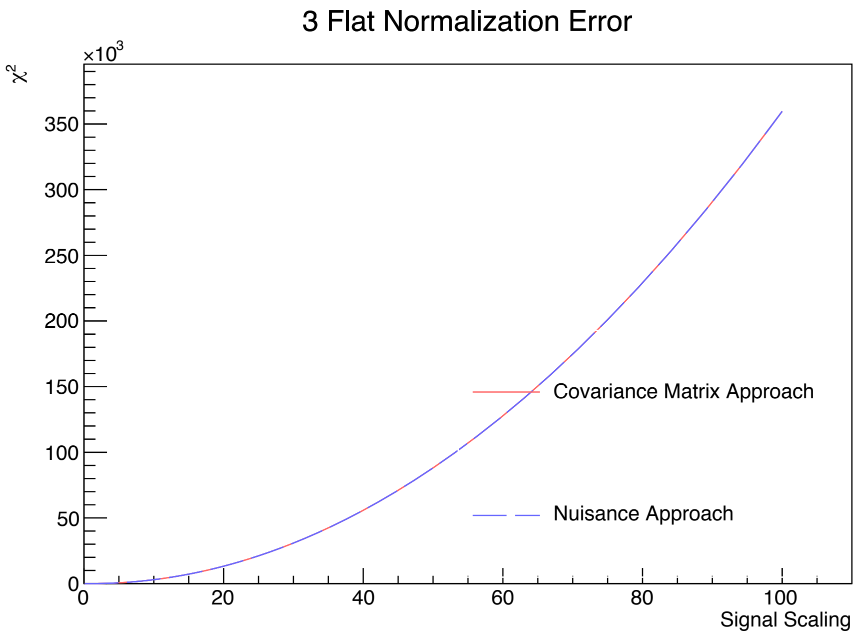
$$E_{ij} = \delta_{ij}\sigma_{stat} + \sigma_{sys} N_i N_j$$

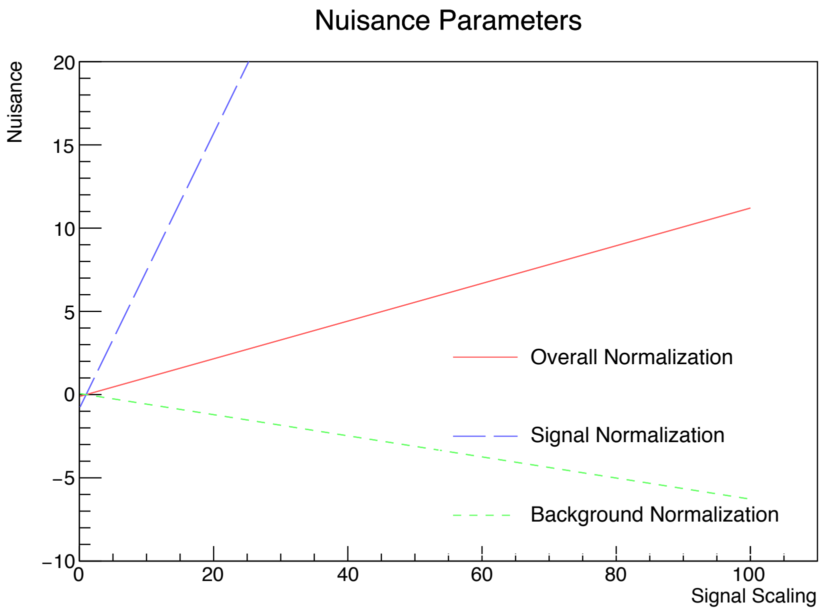


Toy Example

$$N_i^{null}(E_\nu) = \xi_1(\xi_2 S_i + \xi_3 B_i)$$
$$\approx (1 + \delta_1 + \delta_2) S_i + (1 + \delta_1 + \delta_3) B_i$$

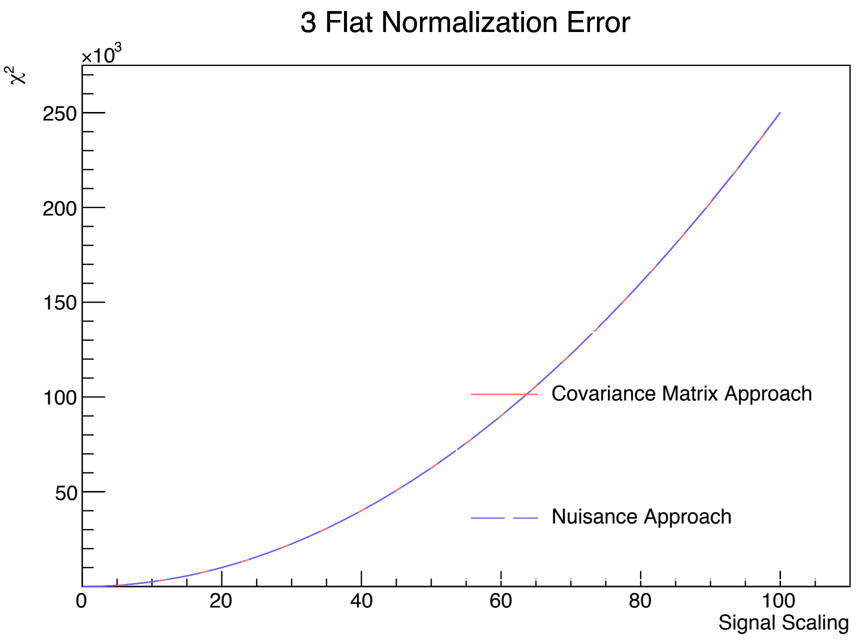
where δ_1 is the overall normalization (set to 10%), δ_2 is the signal normalization (15%), and δ_3 is the background normalization (5%)

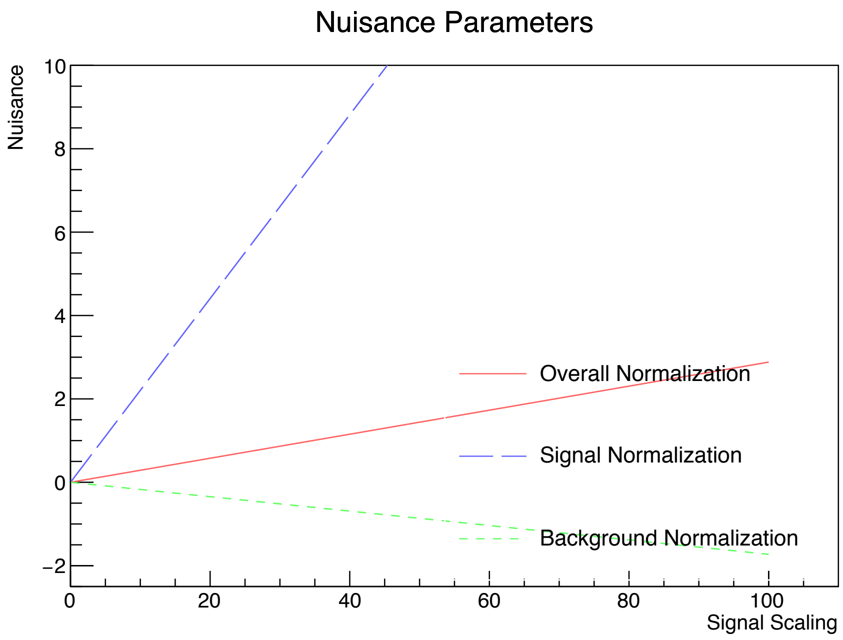




Fermilab

SBNfit Plots





Future Steps

- To continue improving the implementation, we will need to validate the nuisance method using the actual parameter values and identify several systematic errors that we can describe as nuisance parameters
  - In order to get actual parameter values, we will vary the systematic parameters randomly using their assumed probability distribution, then save these varied parameters to be used in the nuisance parameters approach

Summary

- Have started the preliminary study to test the implementation of nuisance parameters in the SBNfit
- Need values of the parameter for real analysis
- Created a simple toy model for testing
- When run in SBNfit, results of the nuisance method agree with the covariance matrix using a flat normalization error

Acknowledgments

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