Reweighing tool for Analyses

Corey Adams

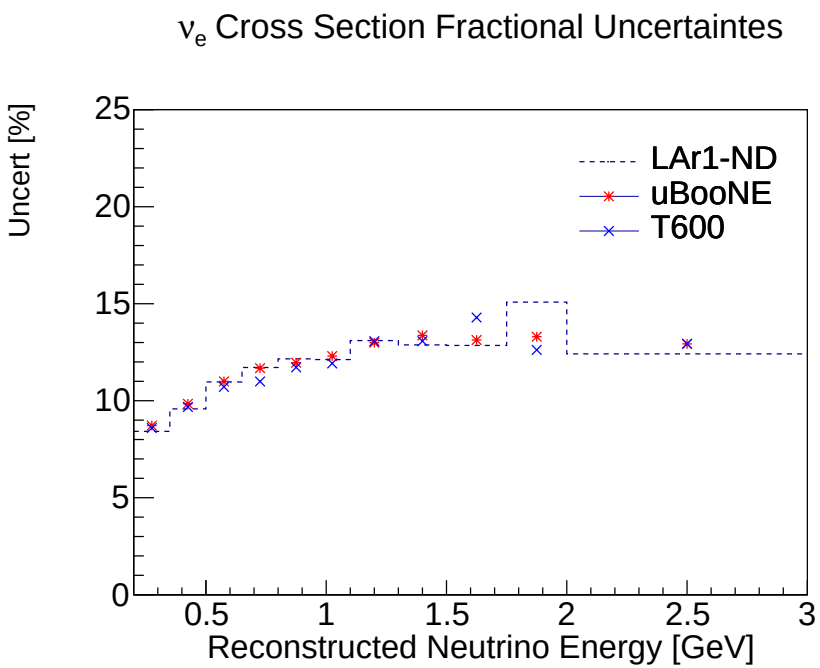
Yale University

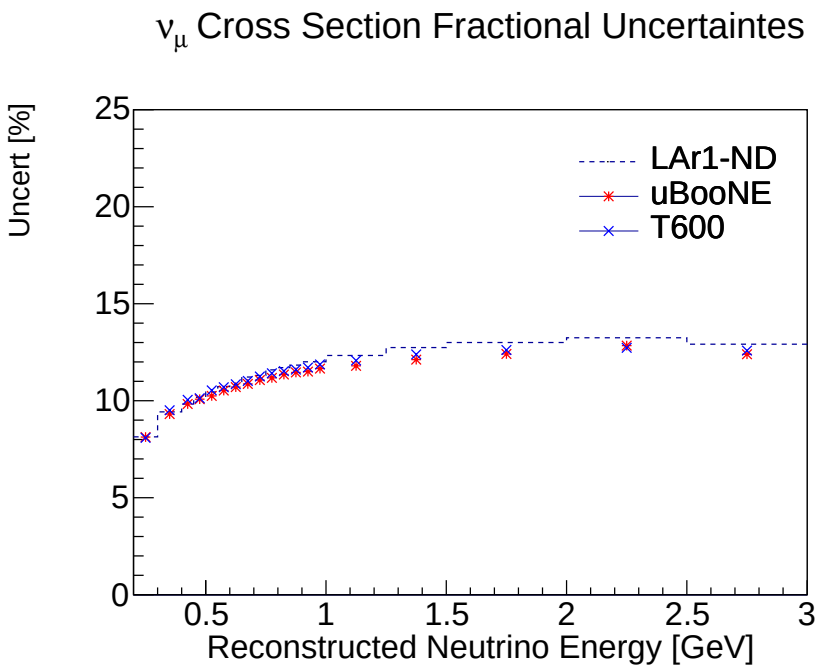
April 10, 2015

Outline

- What was done for the SBN Proposal?
- What is the current status?
- What are the future developments?

Cross Secion Uncertainties in the SBN Proposal

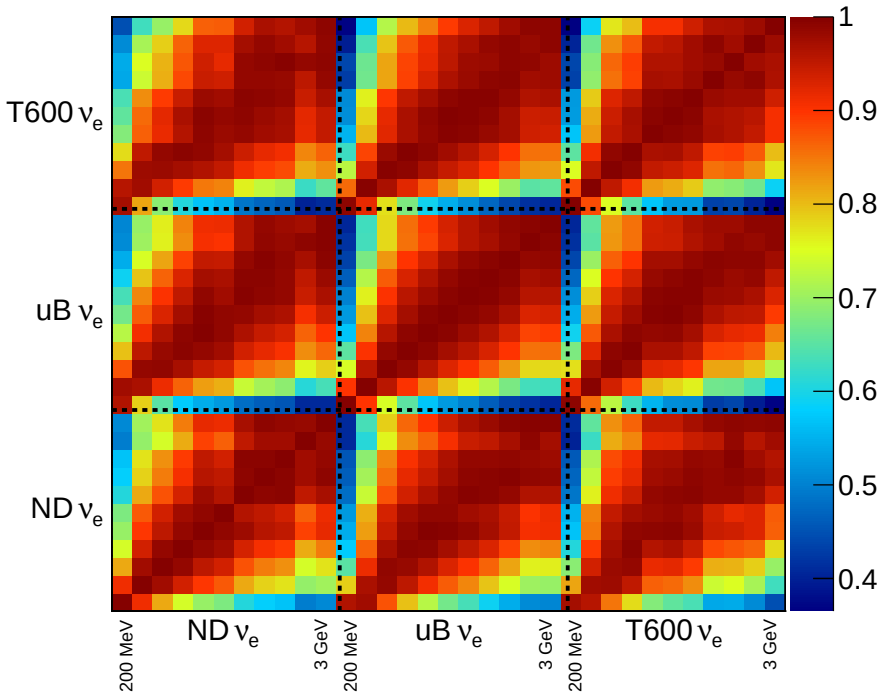




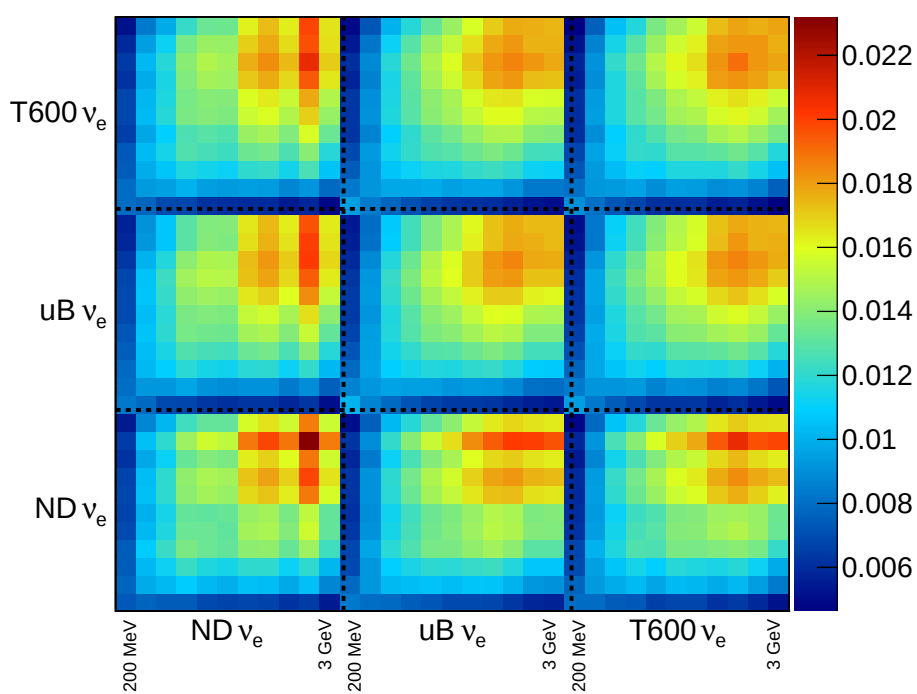
These plots show the total fractional uncertainty in event rates due to cross section uncertainties as reported in the SBN proposal.

Correlations in Cross Section Uncertainties

Correlation Matrix



Fractional Error Matrix

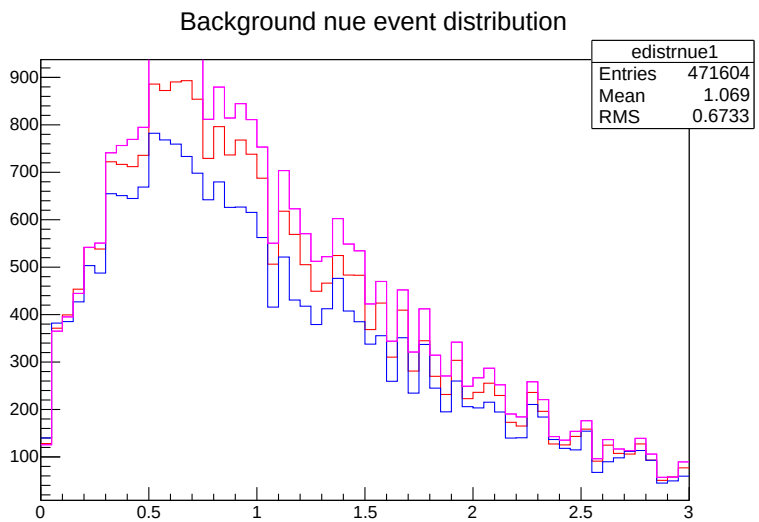


The uncertainties in the event rates are highly correlated, leading to large cancellations of the systematic uncertainty from cross sections.

Calculating Correlations

For each neutrino interaction, GENIE can be used to recalculate the cross section for that interaction with slight changes in the underlying physical paramaters. The ratio of cross sections has information about the relative probability of that interaction as parameters change.

$$\omega_i = \frac{\sigma_i}{\sigma_{Nom.}}$$



Weigh each neutrino with the weight calculated for it's cross section in the same set of alternate parameters to obtain a varied distribution.

Varying physical parameters

Parameter	Description	1σ Uncertainty (%)
M_A^{CCQE}	Axial mass for CC quasi-elastic	-15%+25%
M_A^{CCRES}	Axial mass for CC resonance neutrino production	$\pm$20%
M_A^{NCRES}	Axial mass for NC resonance neutrino production	$\pm$20%
$R_{bkg}^{\nu p,CC1\pi}$	Non-resonance background in νp, CC 1π reactions.	$\pm$50%
$R_{bkg}^{\nu p,CC2\pi}$	Non-resonance background in νp, CC 2π reactions.	$\pm$50%
$R_{bkg}^{\nu n,CC1\pi}$	Non-resonance background in νn, CC 1π reactions.	$\pm$50%
$R_{bkg}^{\nu n,CC2\pi}$	Non-resonance background in νn, CC 2π reactions.	$\pm$50%
$R_{bkg}^{\nu p,NC1\pi}$	Non-resonance background in νp, NC 1π reactions.	$\pm$50%
$R_{bkg}^{\nu p,NC2\pi}$	Non-resonance background in νp, NC 2π reactions.	$\pm$50%
$R_{bkg}^{\nu n,NC1\pi}$	Non-resonance background in νn, NC 1π reactions.	$\pm$50%
$R_{bkg}^{\nu n,NC2\pi}$	Non-resonance background in νn, NC 2π reactions.	$\pm$50%
NC	Neutral current normalization	$\pm$25%
DIS-NuclMod	DIS, nuclear model	Model switch

From the SBN Proposal: A table of the physical parameters that were considered and the 1 σ uncertainties in their nominal values.

Creating a "Universe" of Parameters

- For each physical parameter (previous slide) choose at random a deviation in the parameter.

  $\rightarrow$ Draw the weight from a Gaussian distribution with mean of 0 and width of 1. The weight represents the σ deviation from nominal values.
- Repeat this process once per Universe, leading to a set of physical parameters that alter cross sections by some amount consistent with 1 σ uncertainties in parameters.
- For each neutrino, recompute it's cross section in each universe and store the ratio to nominal cross section. This is the weight ω_i.
- To find the event rates in an alternate universe, bin each neutrino with the weight ω_i.

  $\rightarrow$ See Slide 5 for example with 3 Universes used in the SBN uncertainty calculation.

Useful tool for exploring systematic Uncertainties

Covariance Matrix:

$$E_{ij} = \frac{1}{\mathcal{N}} \sum_{m=1}^{\mathcal{N}} [N^i_{\mathrm{CV}} - N^i_m] \times [N^j_{\mathrm{CV}} - N^j_m]$$

Correlation Matrix:

$$\rho_{ij} = \frac{E_{ij}}{\sqrt{E_{ii}}\sqrt{E_{jj}}} \qquad [-1 \leq \rho \leq 1],$$

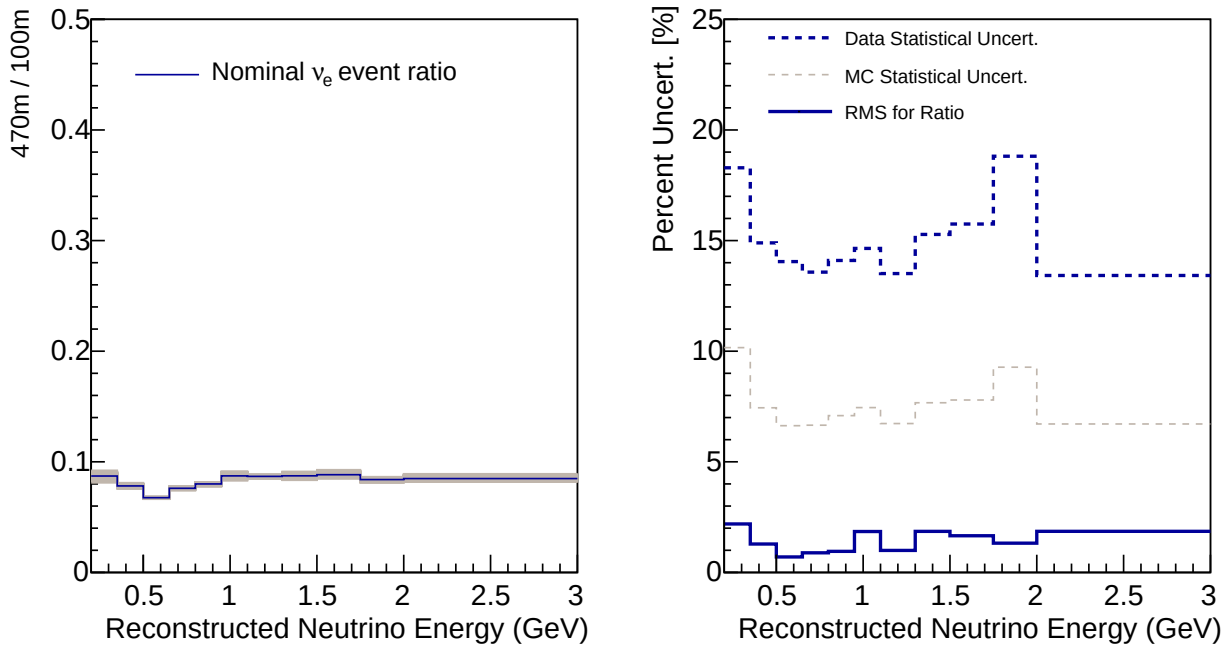
Bin-by-Bin Uncertainties:

$$\sigma_i = \sqrt{\frac{1}{\mathcal{N}} \sum_{m=1}^{\mathcal{N}} [N_i^{\mathrm{CV}} - N_i^m]^2}$$

Uncertainty in Event Rate Ratios (between detectors):

$$R_i = \frac{E_i^{uB}}{E_i^{ND}}, \quad \sigma_{R_i} = \sqrt{\frac{1}{\mathcal{N}} \sum_{m=1}^{\mathcal{N}} [R_i^{\mathrm{CV}} - R_i^m]^2}$$

Using Different "Universes" to Extract Physics



Each gray line on the left frame is the ratio of event rates (uB/ND) in each universe. They fall so closely together that they appear as a band and not individual lines.

Larsoft Implementation

- All of the hard physics work is done by GENIE - see Chapter 8 of the manual GENIE.
- Intefacing with GENIE is done in Nutools, allowing to create instances of different physical parameters NuTools.
  - I believe there may be one or two bugs in the way Nutools is working with GENIE that we should address.

Link to my feature branch starting this project

Link to the relevant code in Nutools.

A General Framework for Weights in Larsoft

Cross Section systematic uncertainties are not the only interesting question we can address with a reweighing framework - beyond the generation of the weights, these frameworks should function in a very similar (identical?) way.

Any framework should be:

- Reasonably easy to use to generate systematic uncertainties via weights, and have a default set of uncertainties that is applicable to most cases.
- Able to run on already generated neutrino events *after they have been generated.*
- Decoupled between the producer of the weights, storage of the weights, and analysis of the weights.
  - It should be pretty easy to add more algorithms to compute weights without worrying about how to store, extract, and use weights.

Start implementation with Cross Sections

- I have started a module that makes a simple interface to all of this, allowing a user to specify which knobs to turn and how many weights to product. It's currently a feature branch in larana.
- The current implementation needs work, both in implementation and in output - I think it makes sense to have an analysis data product available to save weights. (**how can we store the weights efficiently?** M **weights** $\times$ N **events adds up)**
  - This is a discussion to include larsoft personnel in - how can we ensure the framework suits our analysis needs?

Cross Section Systematics "To Do"

- **Most Important:** The list of uncertainties used in the SBN analysis is hardly complete and the variation of underlying physical parameters needs to be reviewed by experts before MicroBooNE can use it with confidence on data.
- Secondary Importance: The framework and algorithms for computing these uncertainties could use some work and development. I am working on this but also acknowledge that this should be stewarded by the analysis groups and not a lone graduate student.

Questions?