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Near Detector Neutrino Flux with Horn/Current Configurations

14th June 2018 / University of Warwick / DUNE BIWG Meeting

Motivation

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Cross-section Calibration

- Accurate reconstruction of true neutrino energy is difficult due to uncertainties from missing p_t techniques and measurements of neutrals.
- Without a well-defined incoming neutrino beam energy, extrapolation to Far Detector without good calibration / well-known ν cross-sections is limited.
- Near Detector cross-section and flux measurements would benefit from some restriction of the wide-band neutrino beam to a more well-defined neutrino energy.

Concept

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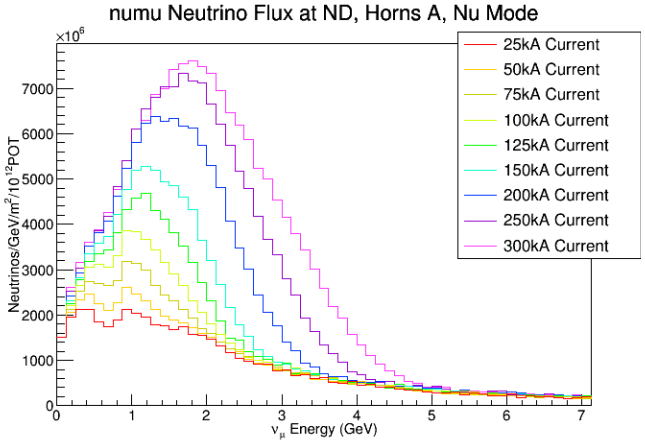
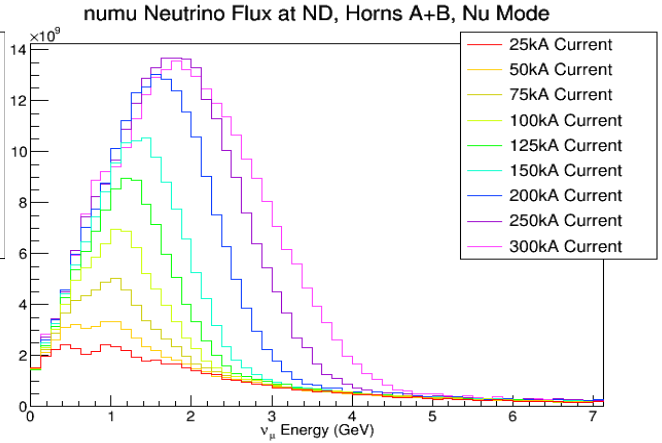
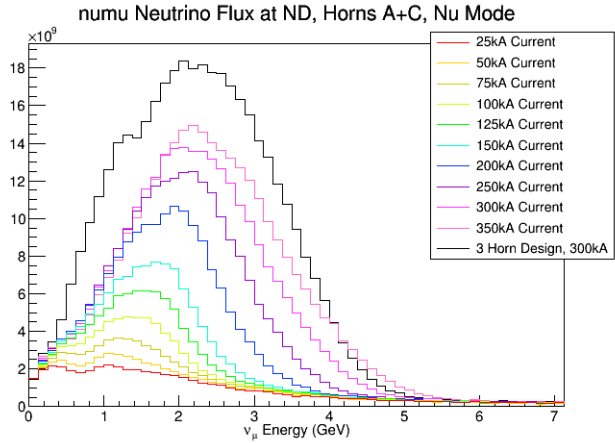
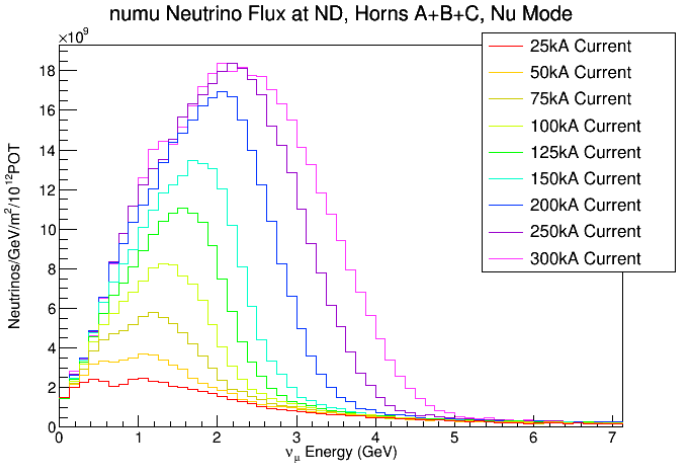
- Horn currents and configurations can be varied, with the caveat that all powered horns need operate on the same current value.
- We consider 5 options in configuration: A only, A+B, A+C, B+C, and A+B+C
- Tune-ability of neutrino flux over a range of current and configuration settings is shown in the following slides

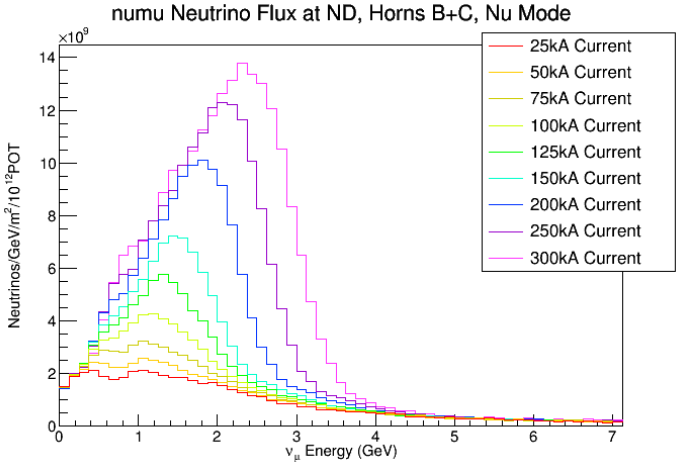
NuMu Fluxes On-Axis



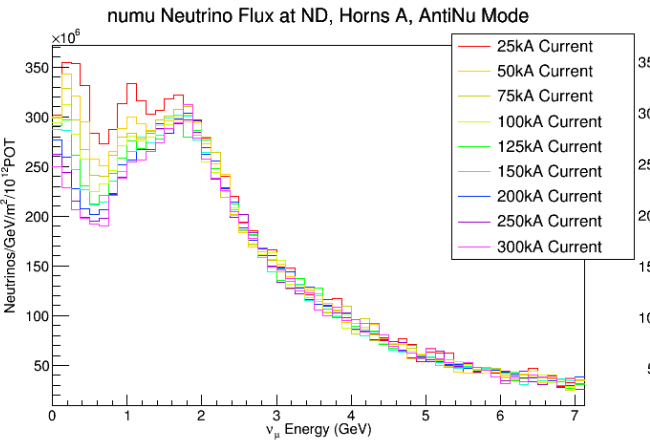


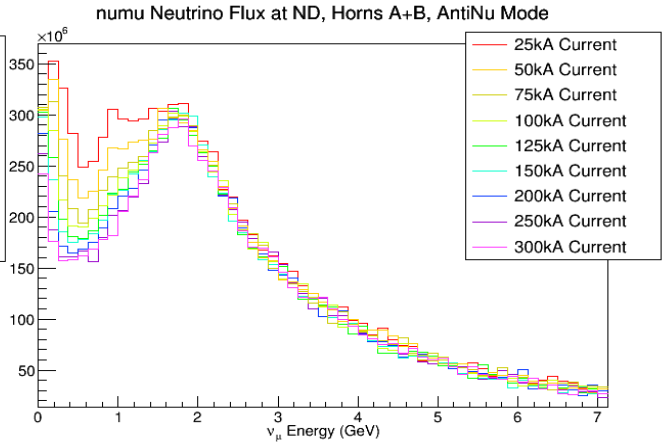


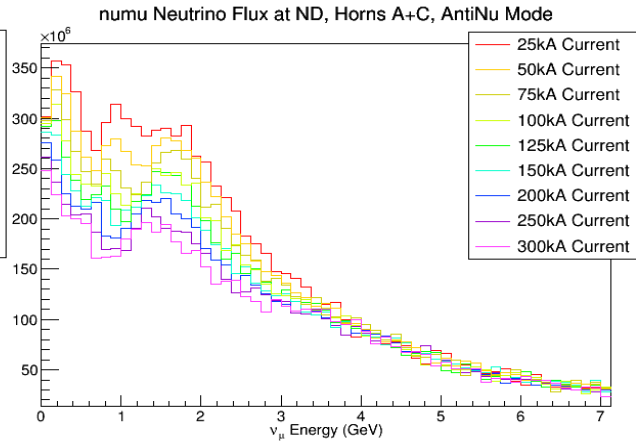


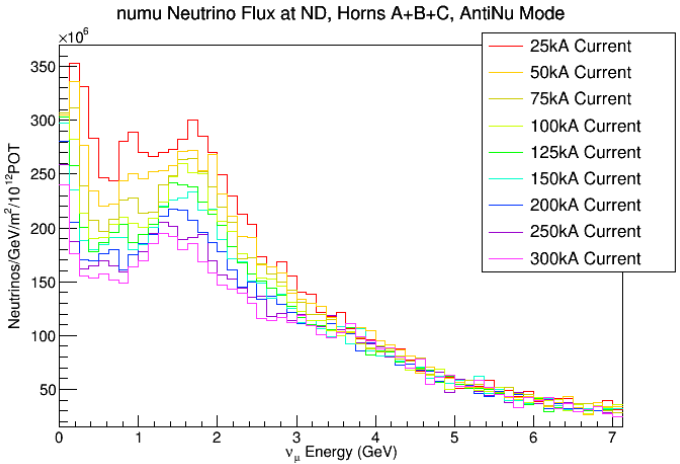


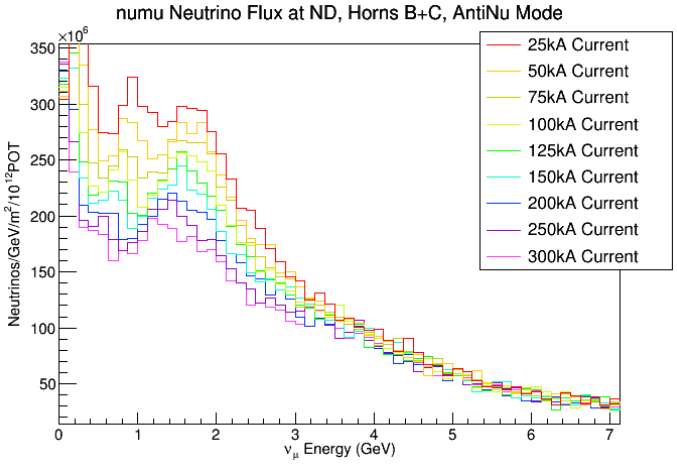
NuMu Fluxes On-Axis











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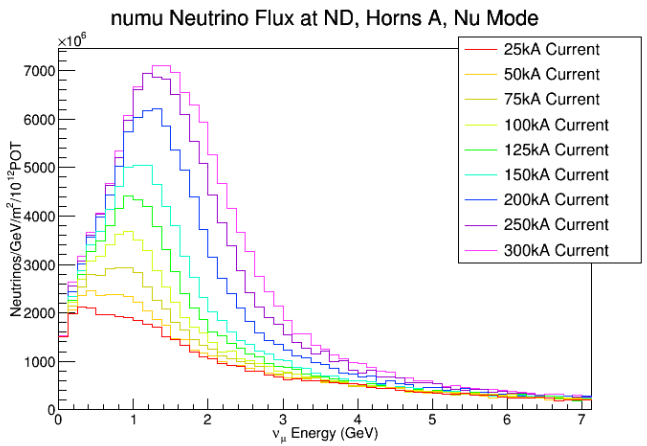
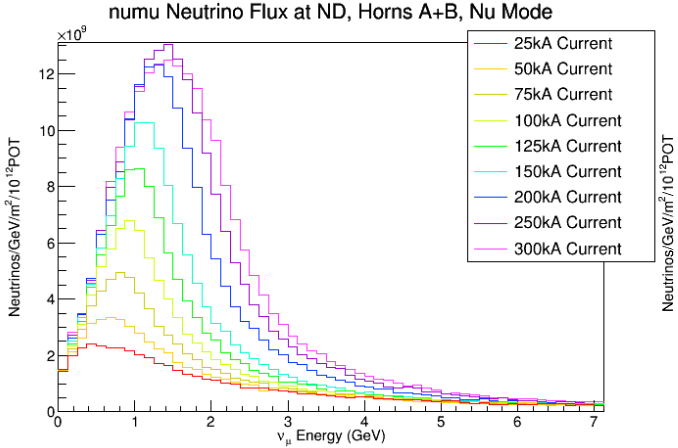
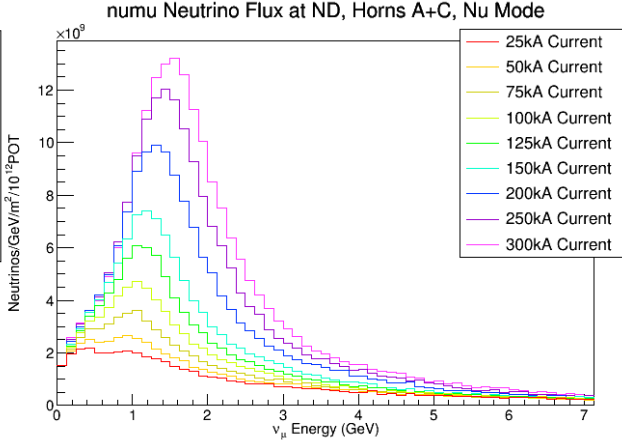
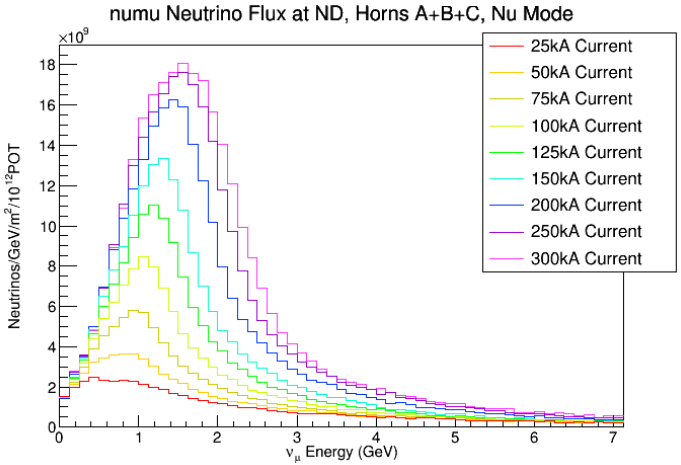
Off-Axis Fluxes

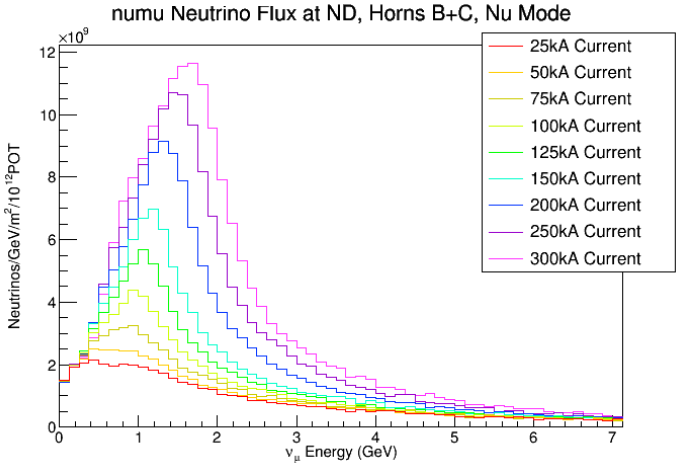
NuMu Fluxes 6m



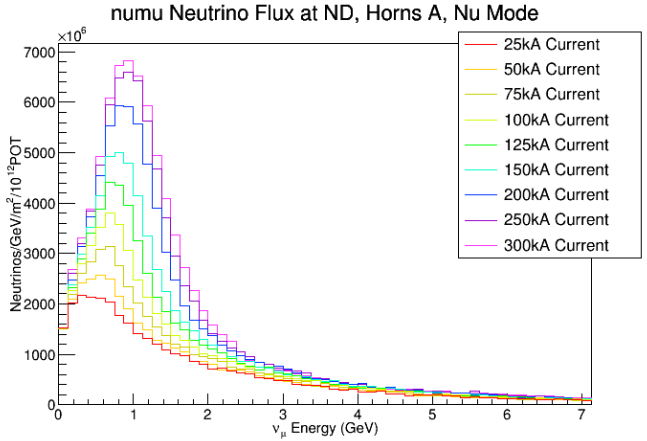


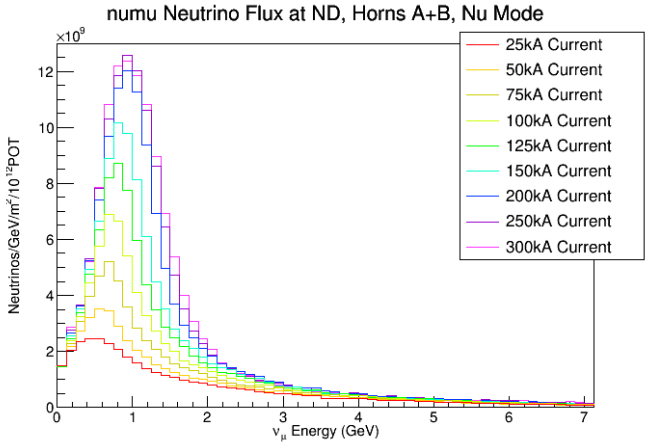


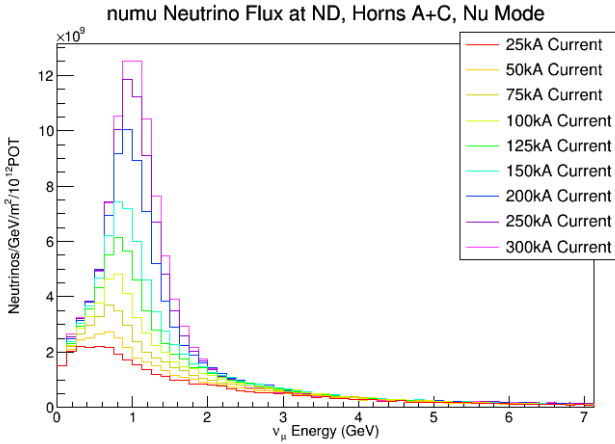


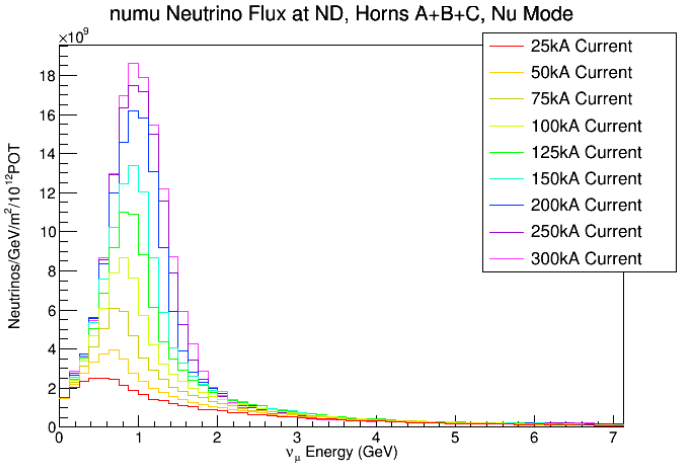


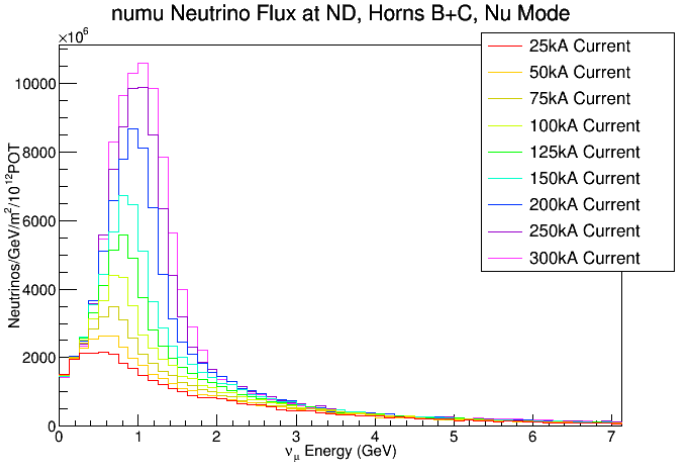
NuMu Fluxes 12m



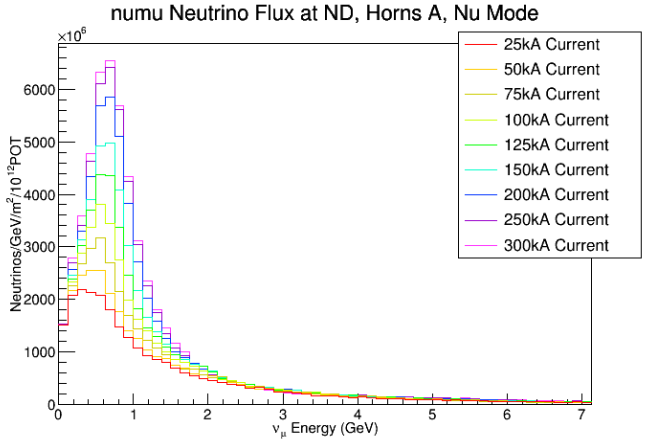


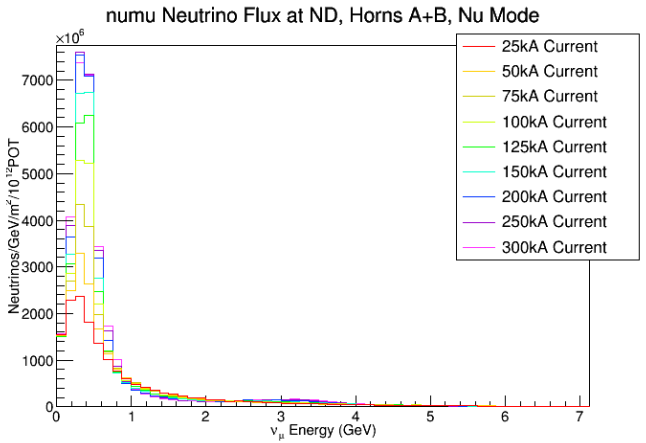


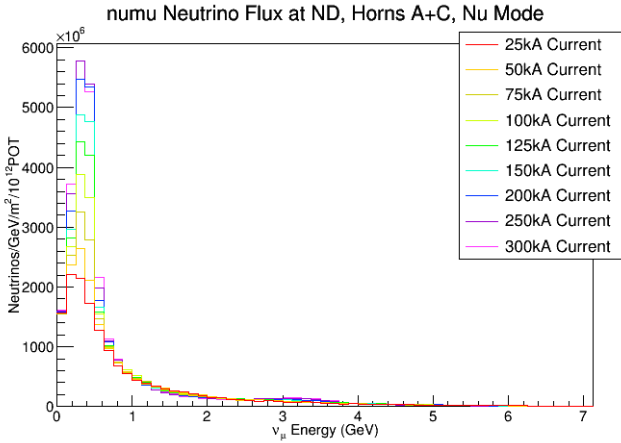


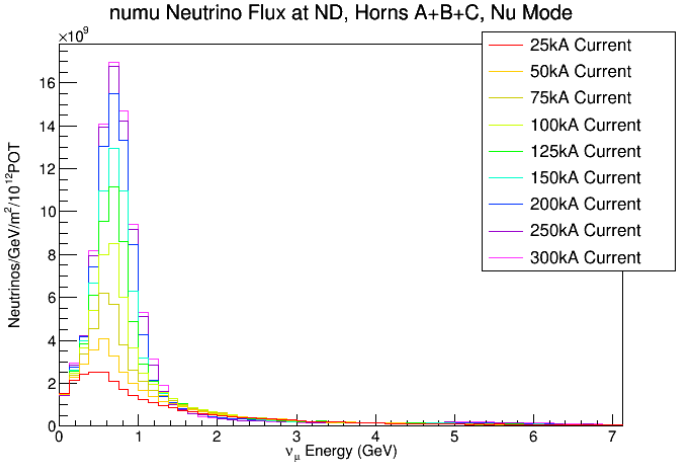


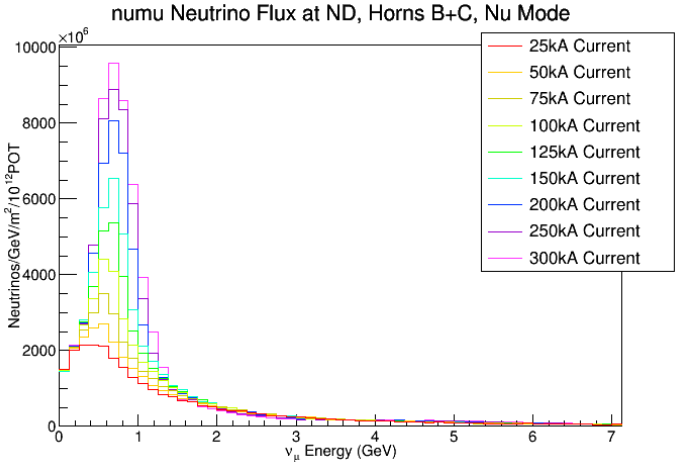
NuMu Fluxes 18m



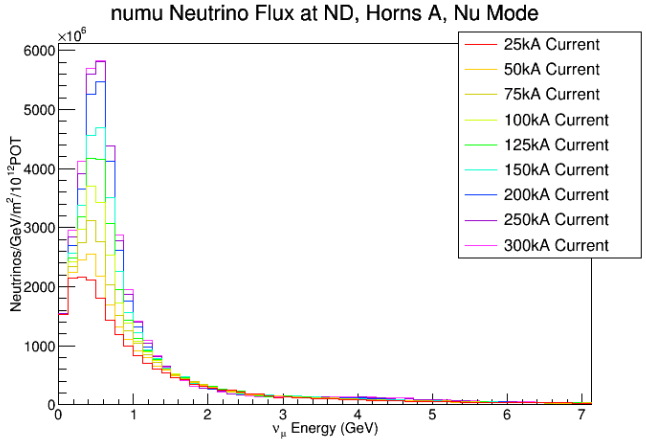


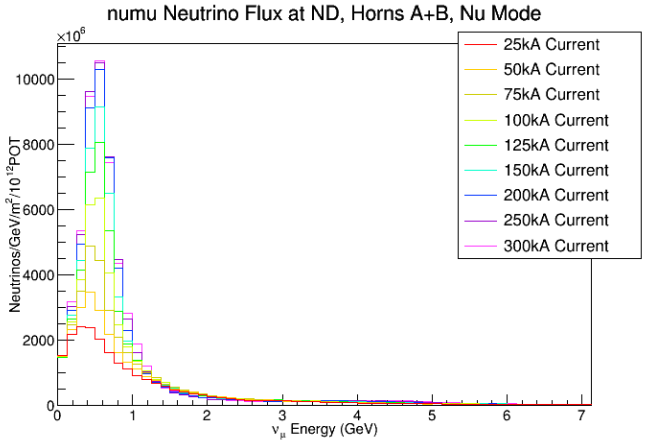


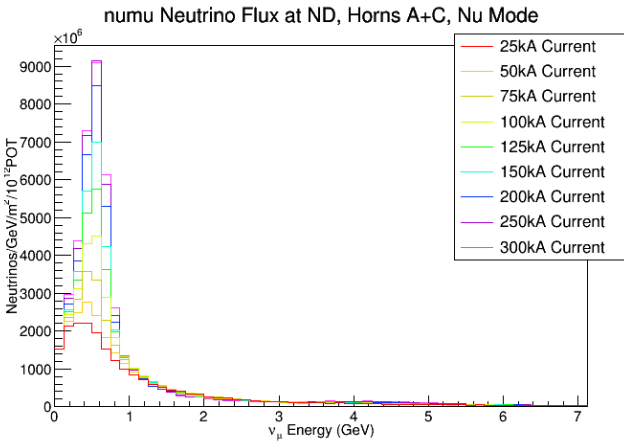


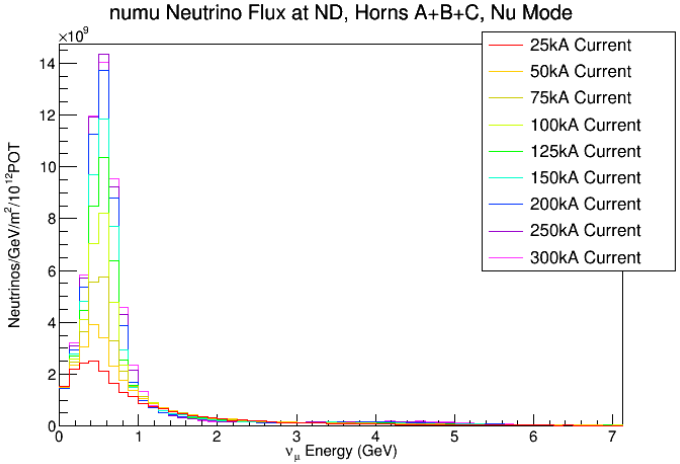


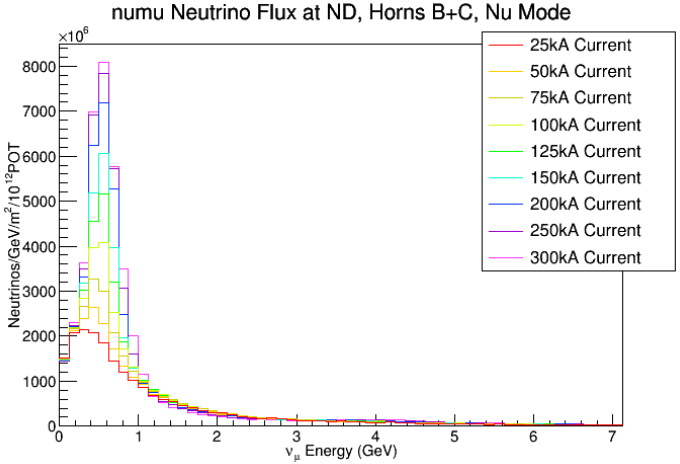
NuMu Fluxes 24m



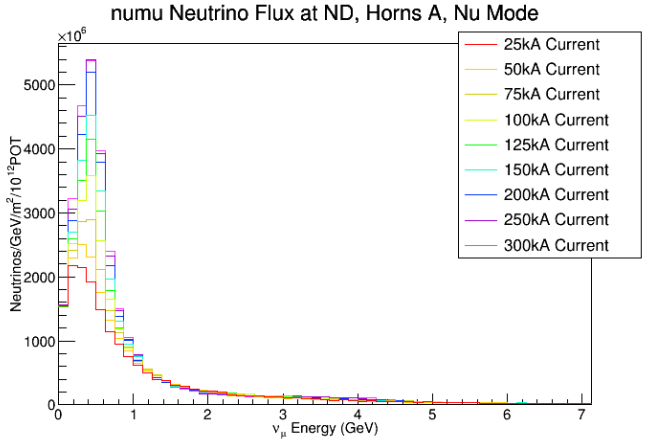


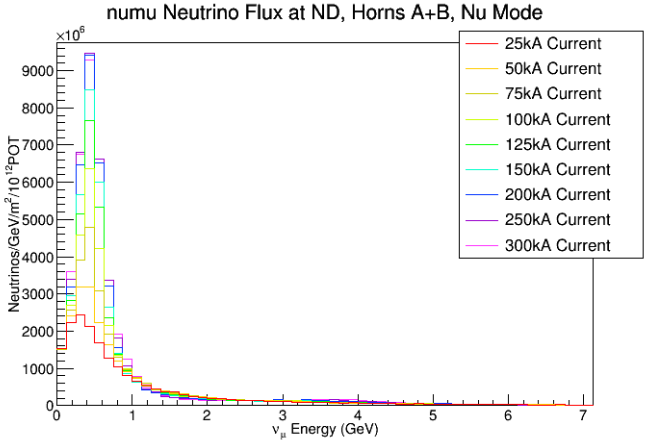


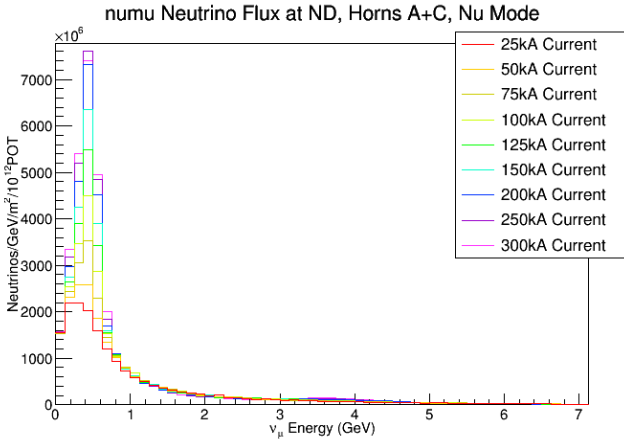


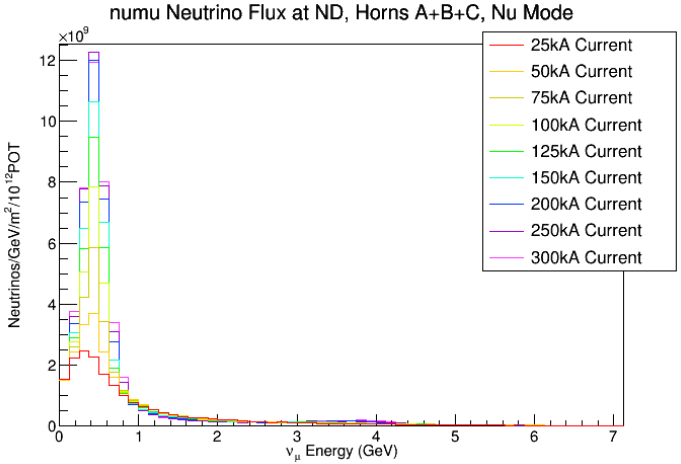


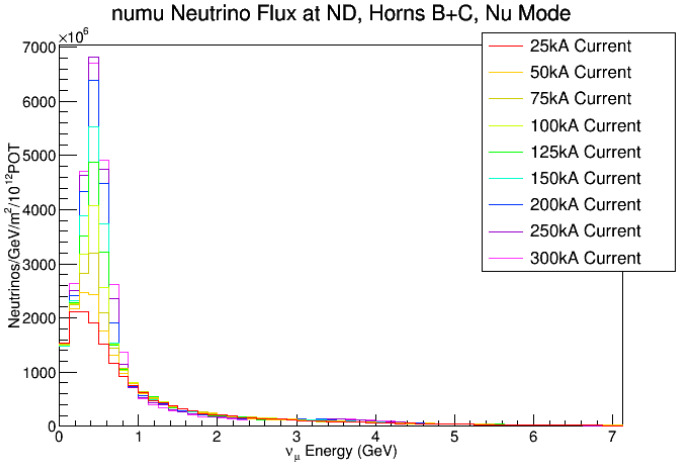
NuMu Fluxes 30m



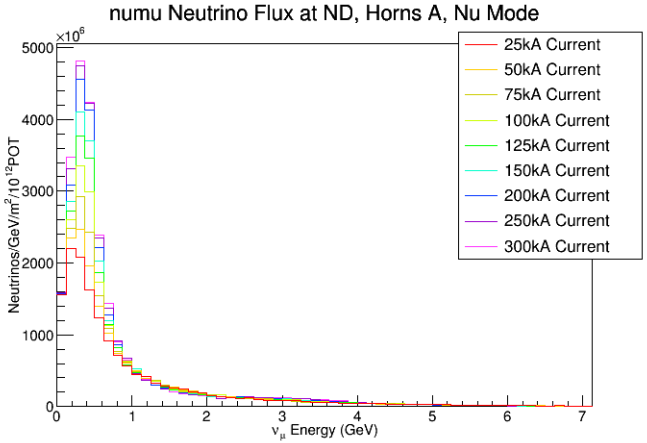


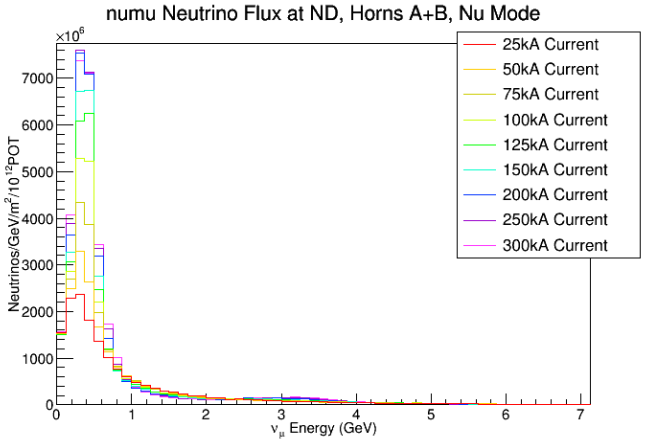


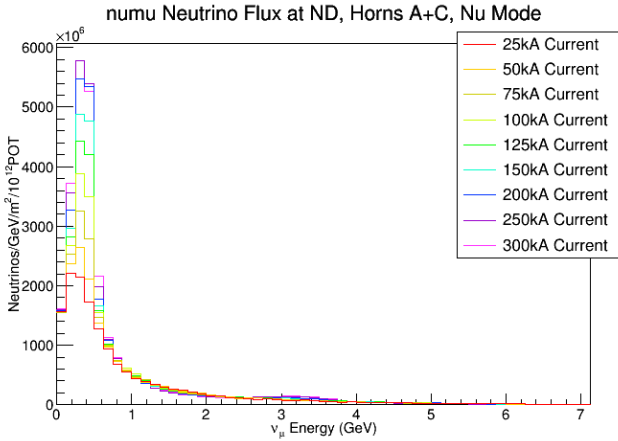


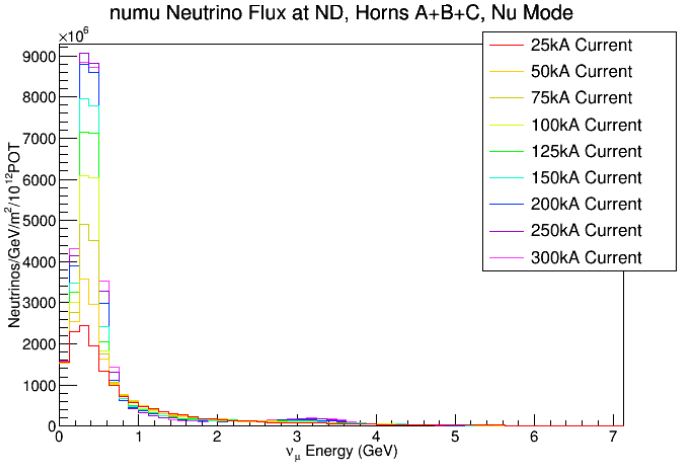


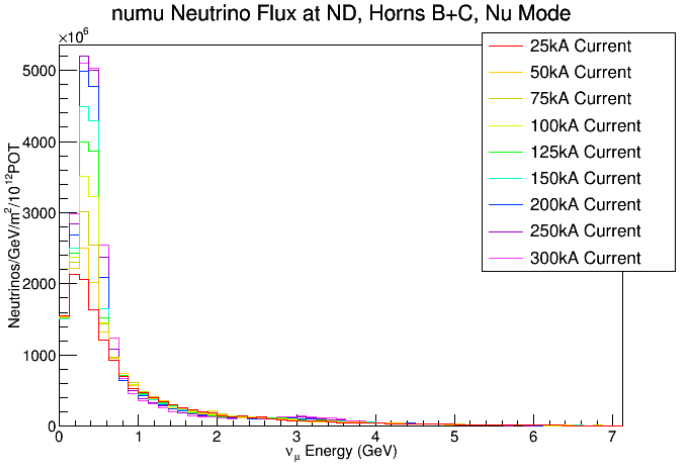
NuMu Fluxes 36m











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Linear Combination Fit

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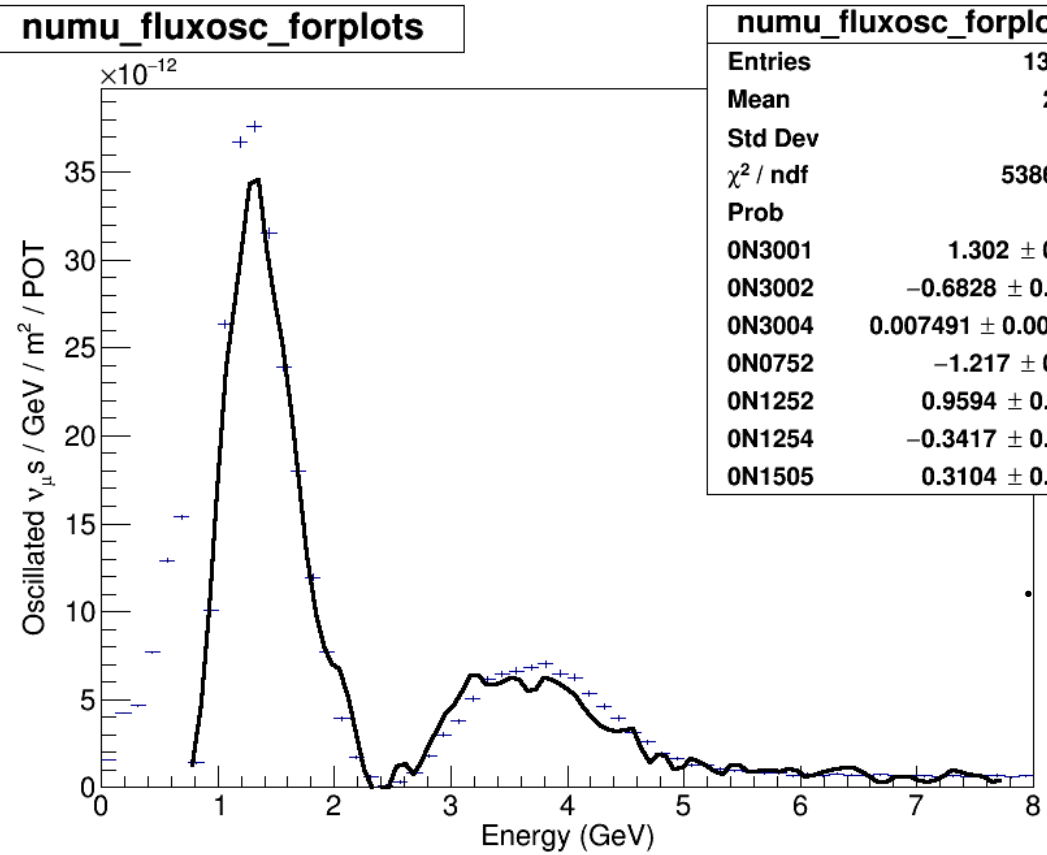
- A linear combination of these ND neutrino fluxes can be superposed to fit a number of functions.
- Some refinement of fitting to FD oscillated flux is shown, along with first fits to gaussians

Linear Combination Fit



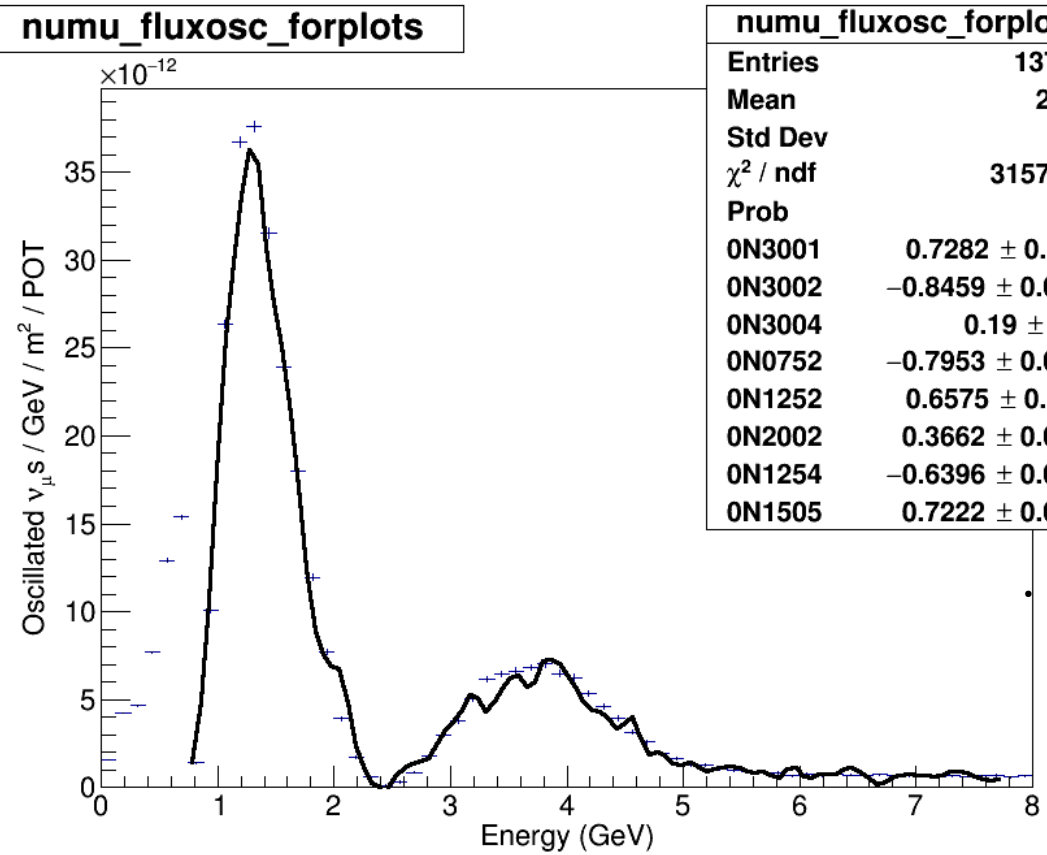
numu_fluxosc_forplots	
Entries	137152
Mean	2.092
Std Dev	1.54
χ^2 / ndf	5386 / 49
Prob	0
0N3001	1.302 ± 0.012
0N3002	−0.6828 ± 0.0045
0N3004	0.007491 ± 0.002556
0N0752	−1.217 ± 0.010
0N1252	0.9594 ± 0.0103
0N1254	−0.3417 ± 0.0057
0N1505	0.3104 ± 0.0109

7 param fit

Range – 0.75 – 7.75GeV

XMYYYZ
0-6 - Distance Off-Axis (x 6 metres)
N / A - NuMode / AntiNuMode
YYY = current
Z = Horn Config
1 - A
2 - A+B
3 - A+C
4 - A+B+C
5 - B+C

Linear Combination Fit



numu_fluxosc_forplots	
Entries	137152
Mean	2.092
Std Dev	1.54
χ^2 / ndf	3157 / 48
Prob	0
0N3001	0.7282 ± 0.0171
0N3002	−0.8459 ± 0.0057
0N3004	0.19 ± 0.00
0N0752	−0.7953 ± 0.0136
0N1252	0.6575 ± 0.0121
0N2002	0.3662 ± 0.0078
0N1254	−0.6396 ± 0.0085
0N1505	0.7222 ± 0.0139

8 param fit

<u>Range</u> – 0.75 – 7.75GeV

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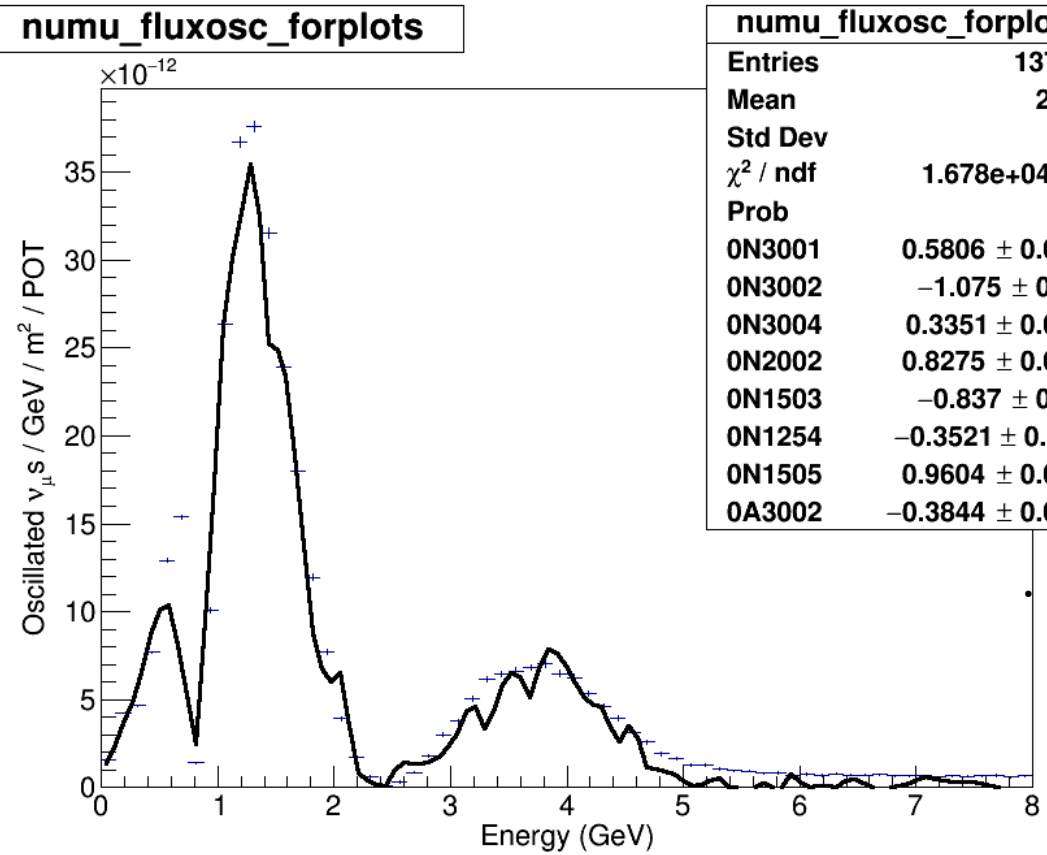
Linear Combination Fit



numu_fluxosc_forplots	
Entries	137152
Mean	2.092
Std Dev	1.54
χ^2 / ndf	1.678e+04 / 54
Prob	0
0N3001	0.5806 ± 0.0089
0N3002	−1.075 ± 0.004
0N3004	0.3351 ± 0.0022
0N2002	0.8275 ± 0.0054
0N1503	−0.837 ± 0.015
0N1254	−0.3521 ± 0.0111
0N1505	0.9604 ± 0.0109
0A3002	−0.3844 ± 0.0064

8 param fit

Range – 0.0 – 7.75GeV

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DUNE PRISM vs Horn Configs

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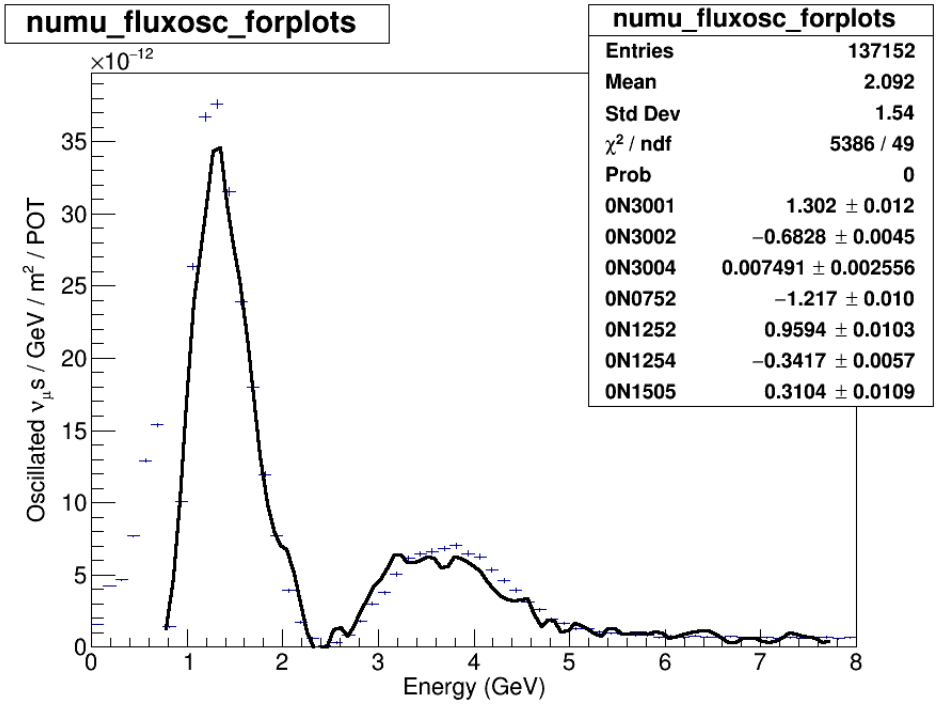
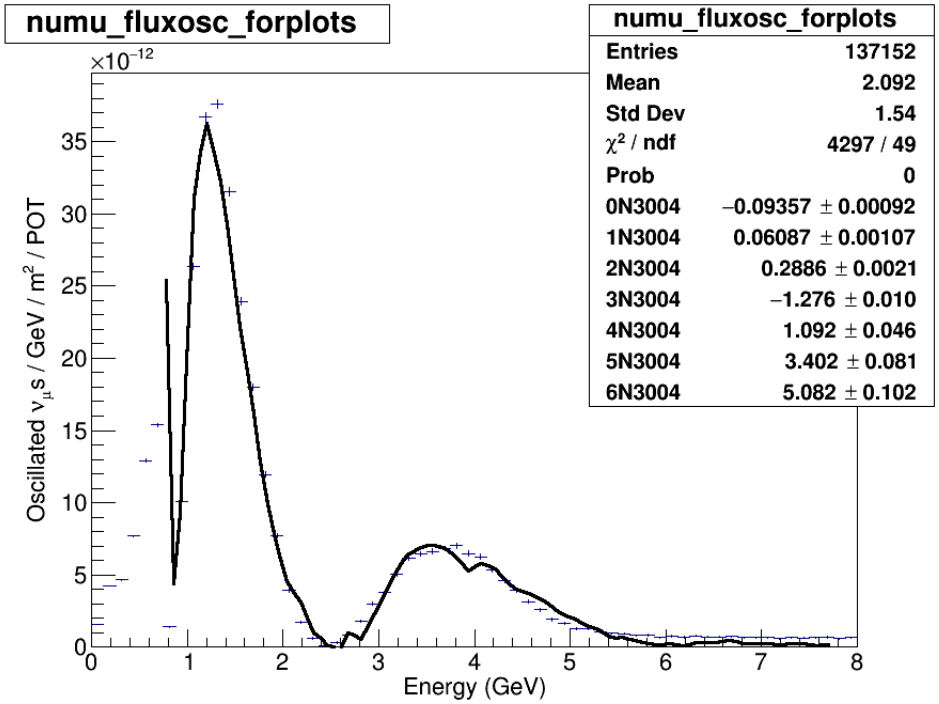
Horn Configs – 7 params



DUNE PRISM



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YYY = current
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5 - B+C

DUNE PRISM vs Horn Configs

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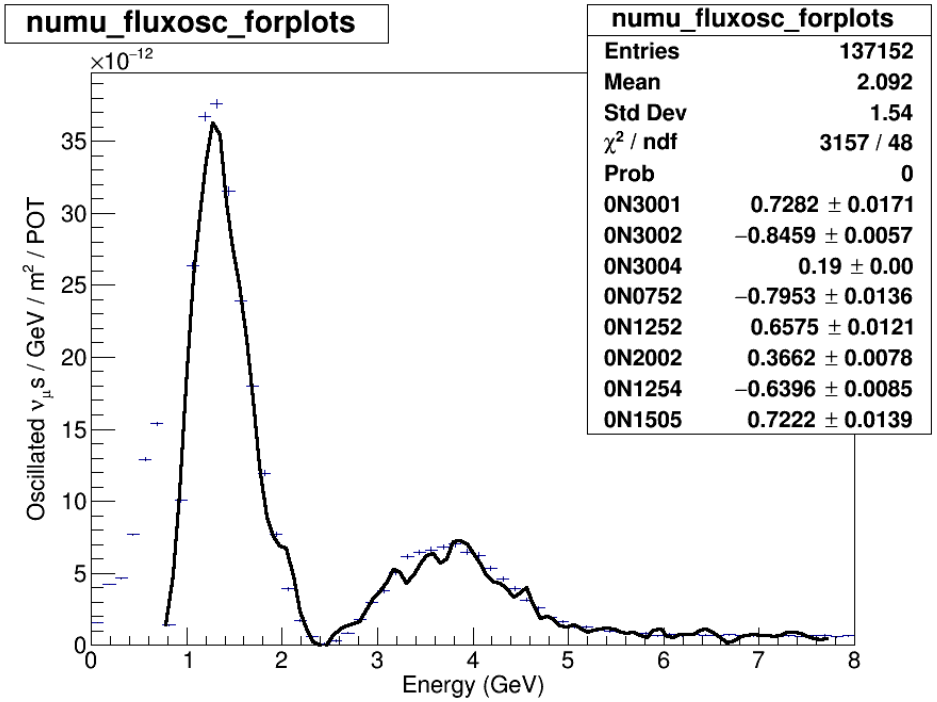
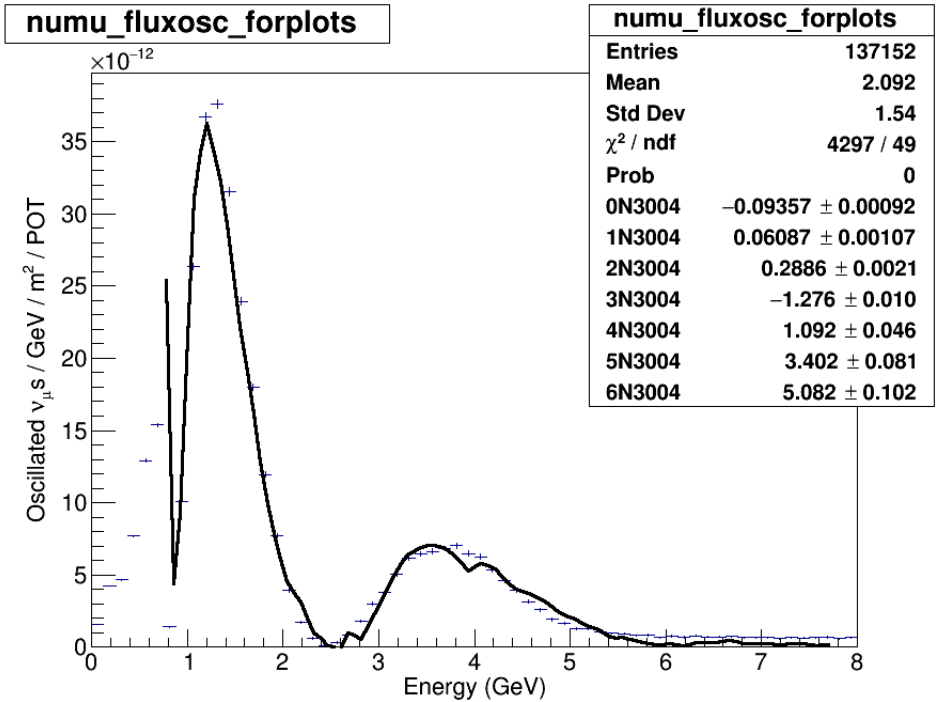
Horn Configs – 8 params



DUNE PRISM



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DUNE PRISM vs Horn Configs

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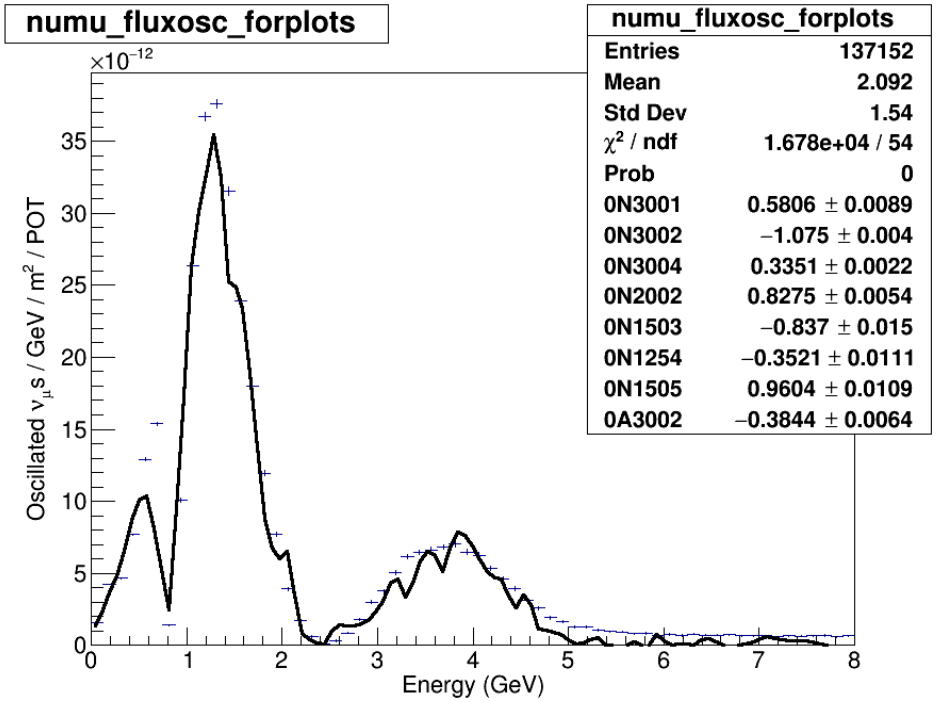
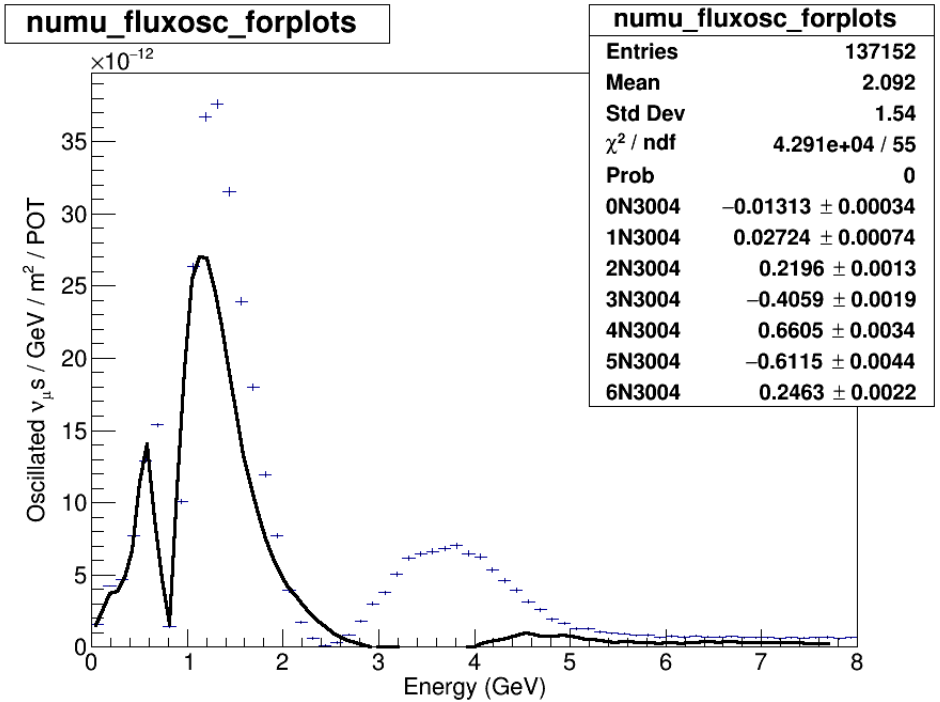
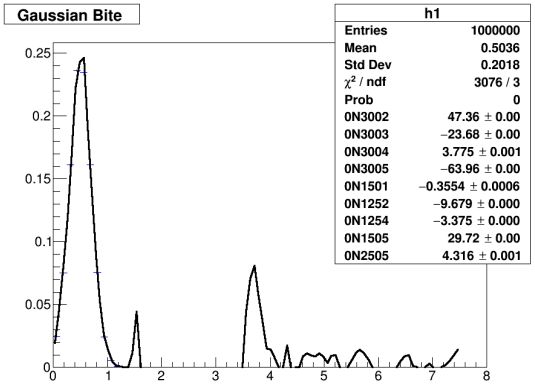
Horn Configs – 8 params

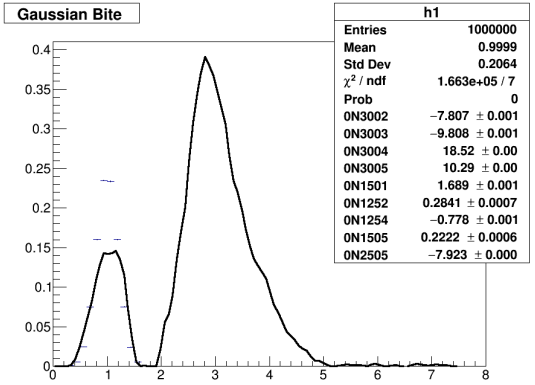


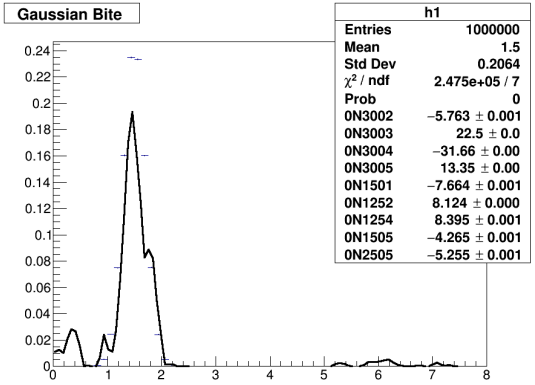
DUNE PRISM

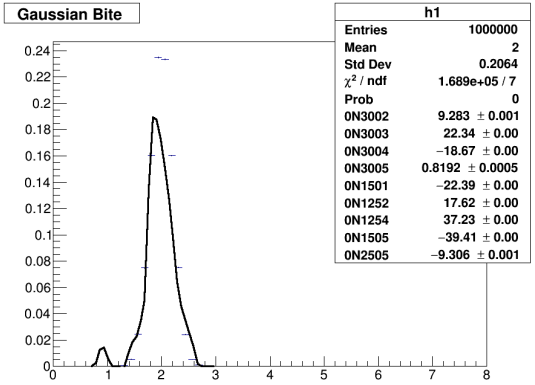


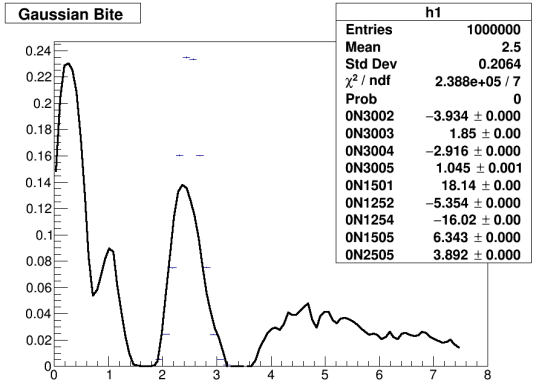
9 Param Thin Gaussian Fits

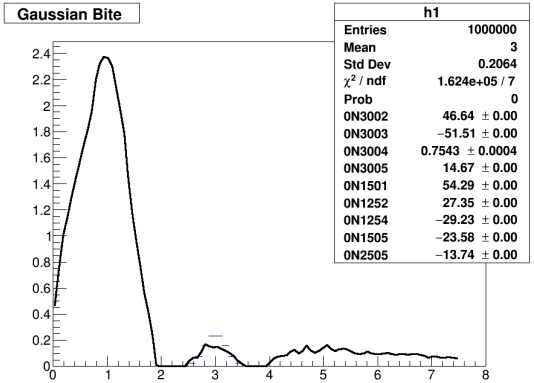












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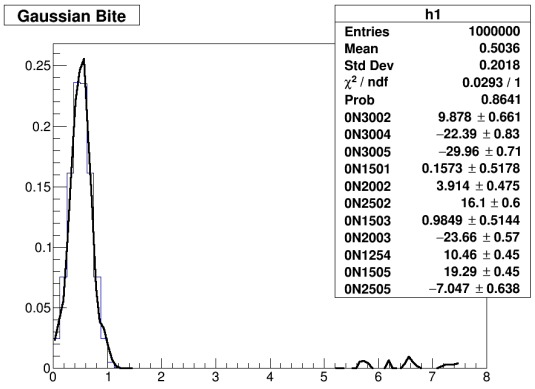
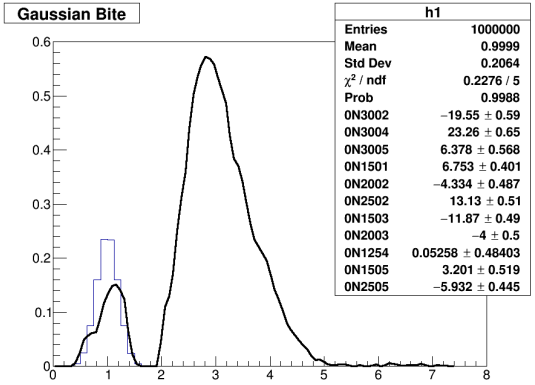
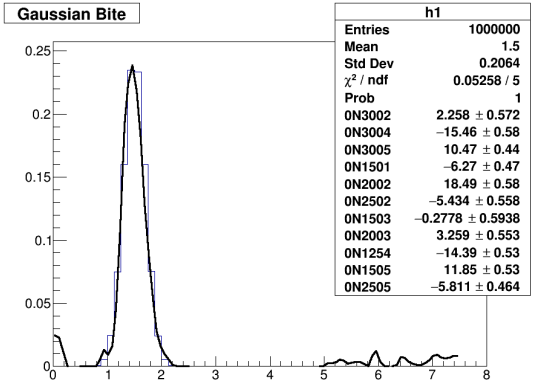
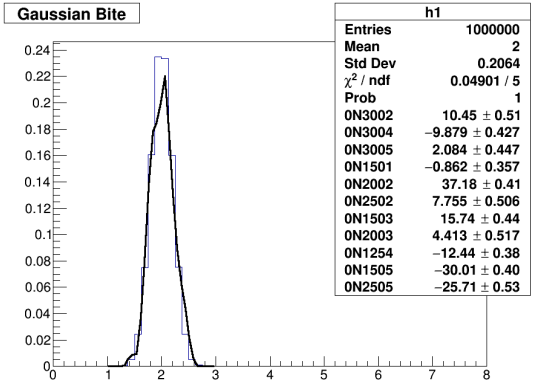
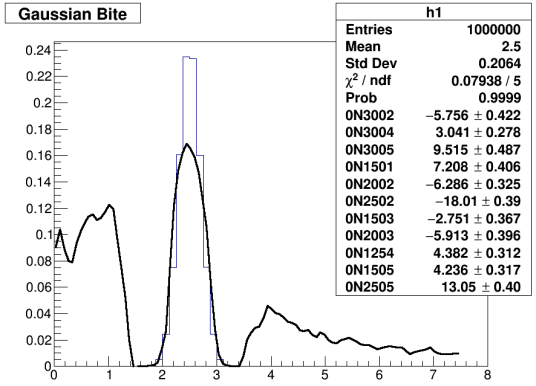
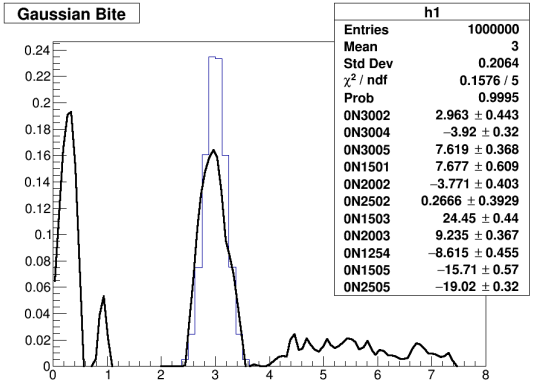




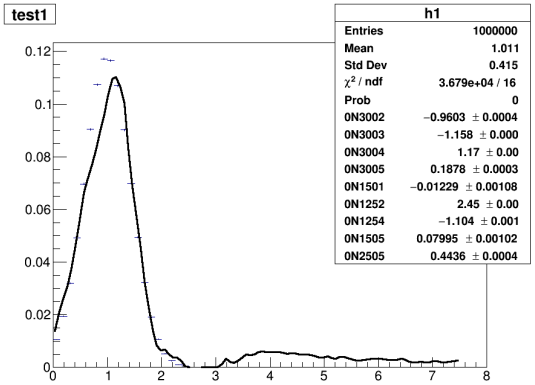


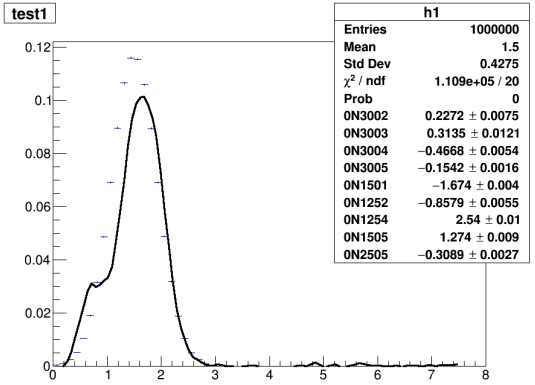


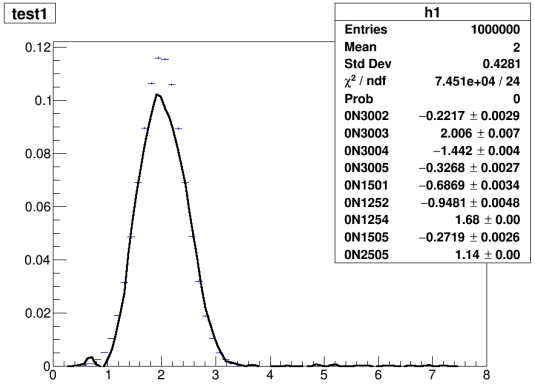


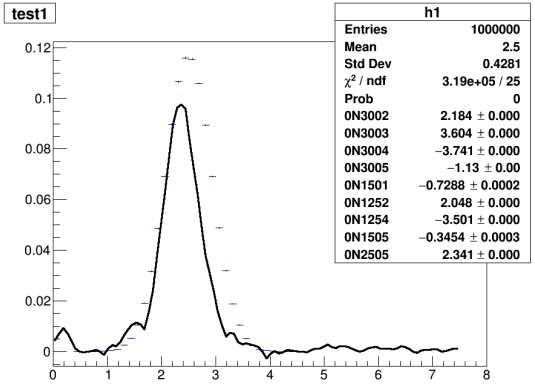


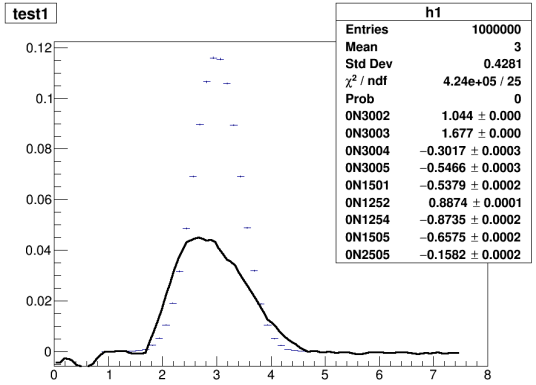
9 Param Wider Gaussian Fits

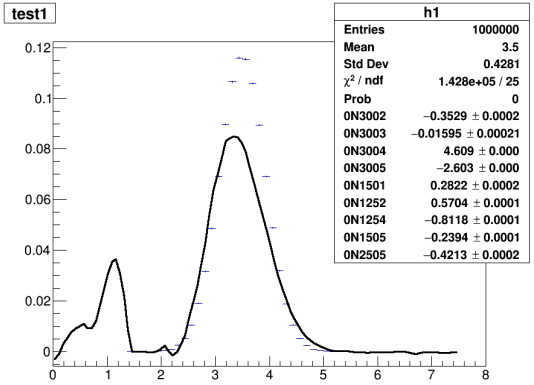












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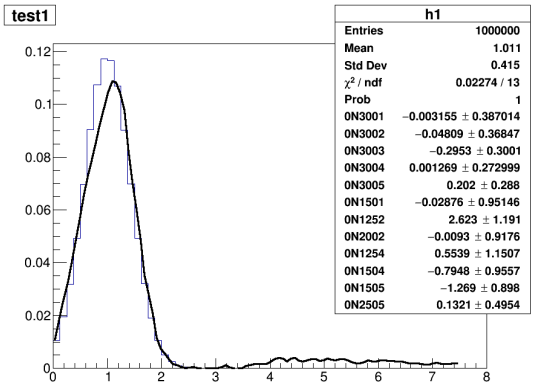

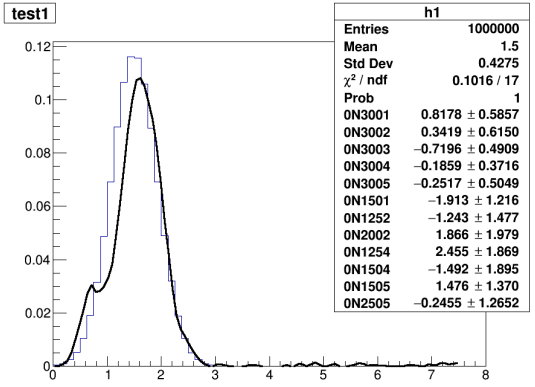

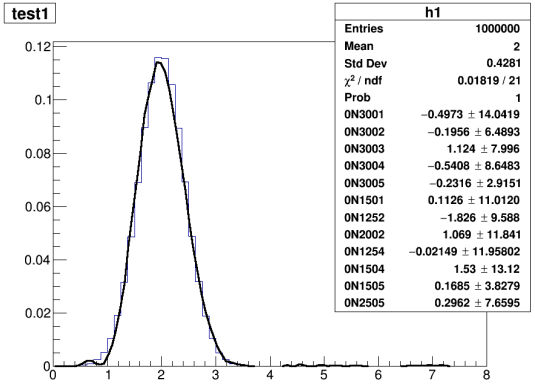

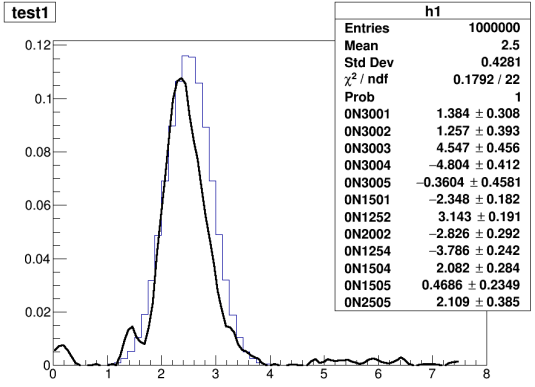

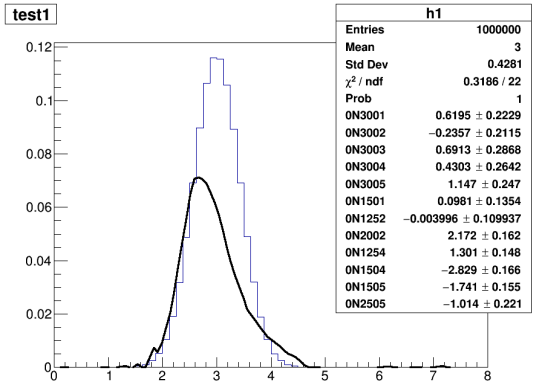

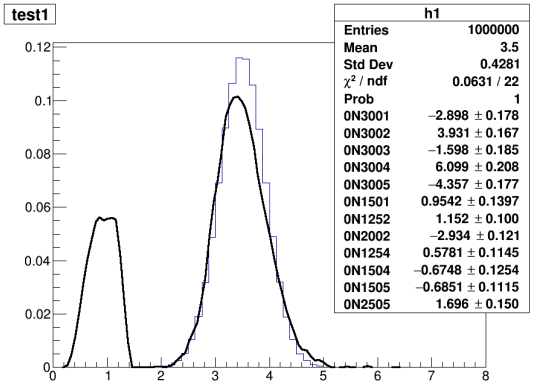

Concluding Remarks

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- Current program used for fitting may be somewhat rudimentary compared to full DUNE PRISM analysis. Can aim to echo DUNE PRISM's fitting to improve quality of fit if this becomes a priority

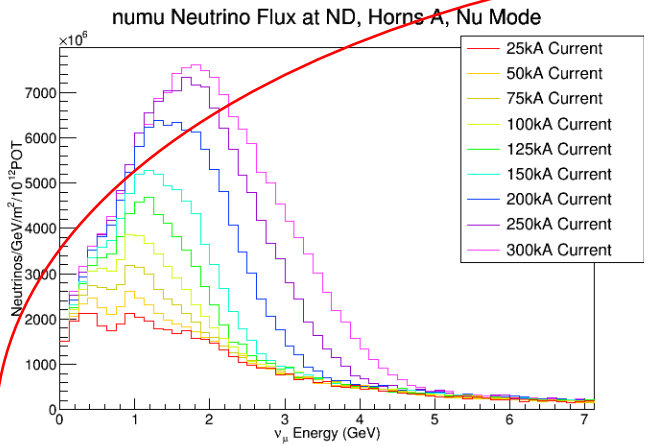
- DUNE PRISM appears to provide a better fit quality (*how much* of this is due to fit program uncertain..), but this avenue may be complementary to DUNE PRISM and provide better coverage of some spectral regions – eg:
  - possible improvement to gaussian fits around 2 GeV,
  - off-axis + horn current could enable better fitting of lower end of spectrum (currently excluded from DUNE PRISM fit below 2nd Osc. Maximum ~0.7GeV),

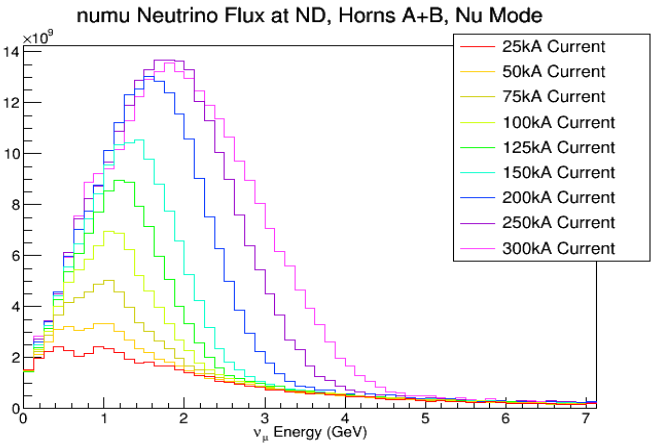
- More direct coordination with DUNE PRISM / ND plans may provide better focus for further investigation. Currently have a LOT of potential parameters for fitting..

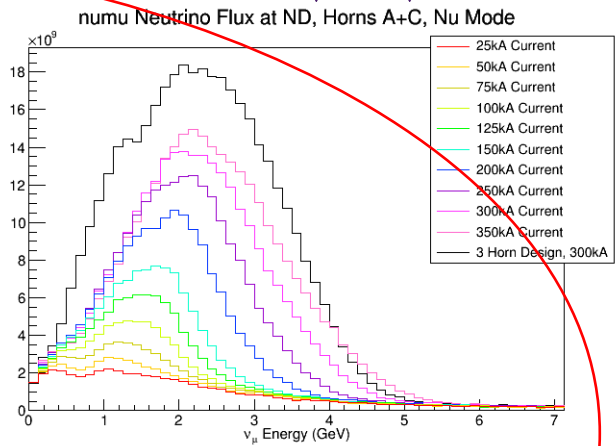
- Modelling response function *could* help find a good/optimal fit analytically

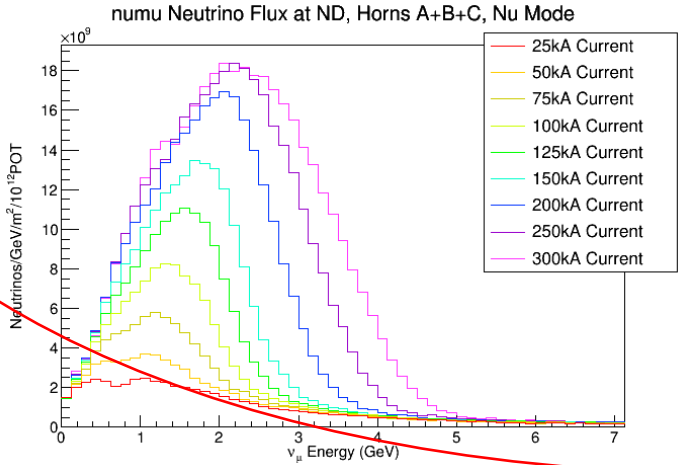
Poster Images

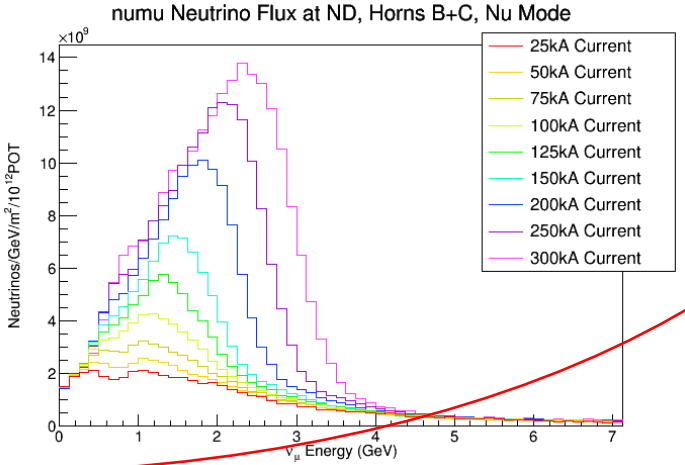
NuMu Fluxes On-Axis









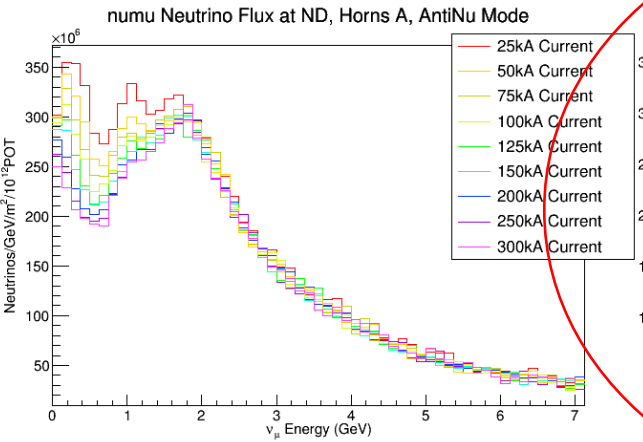


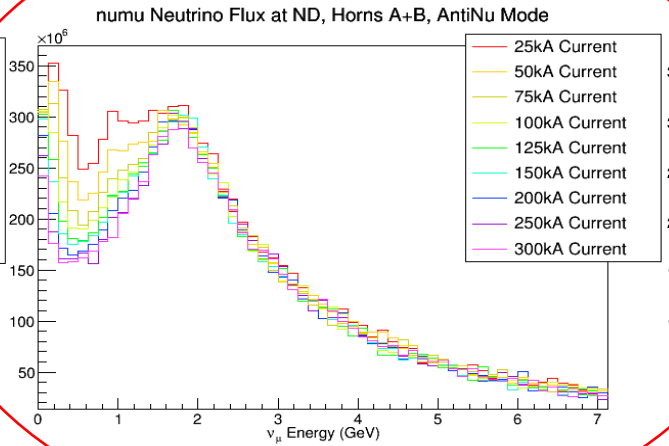
Some/all of NuMu Flux Plots

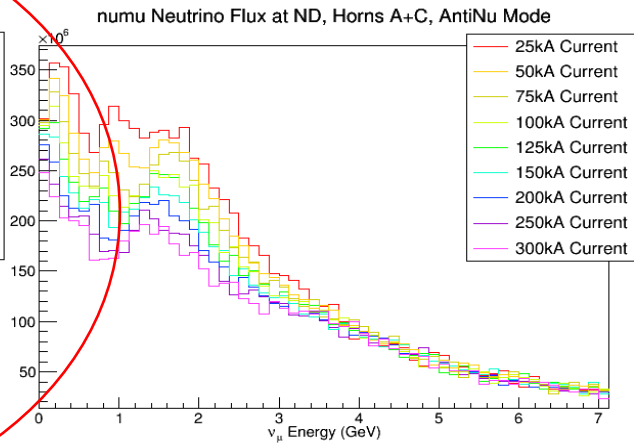
with/without y-axes?

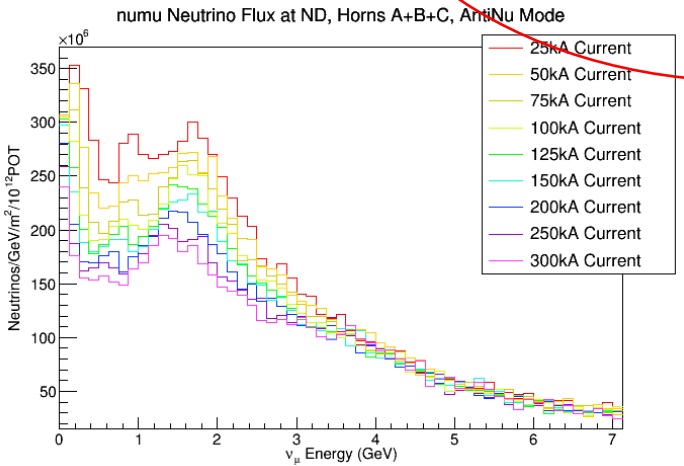
Poster Images

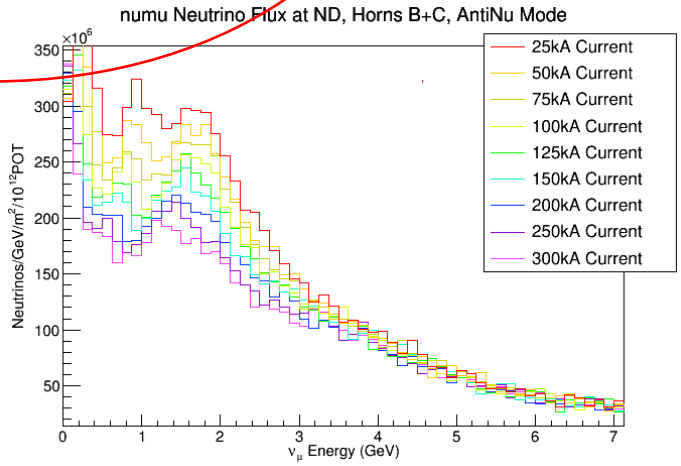
NuMu Fluxes On-Axis









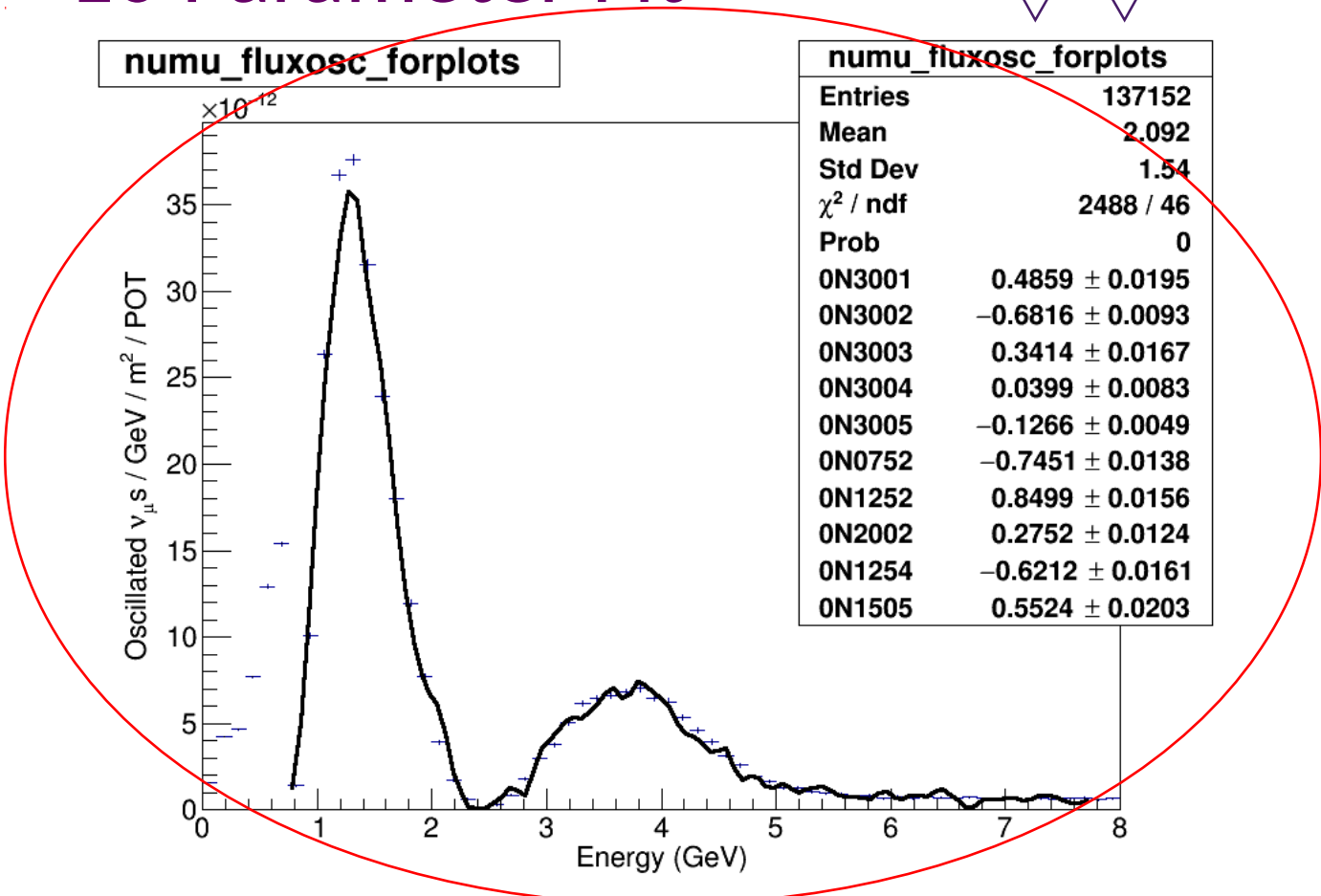


Some/all of NuMu Flux Plots

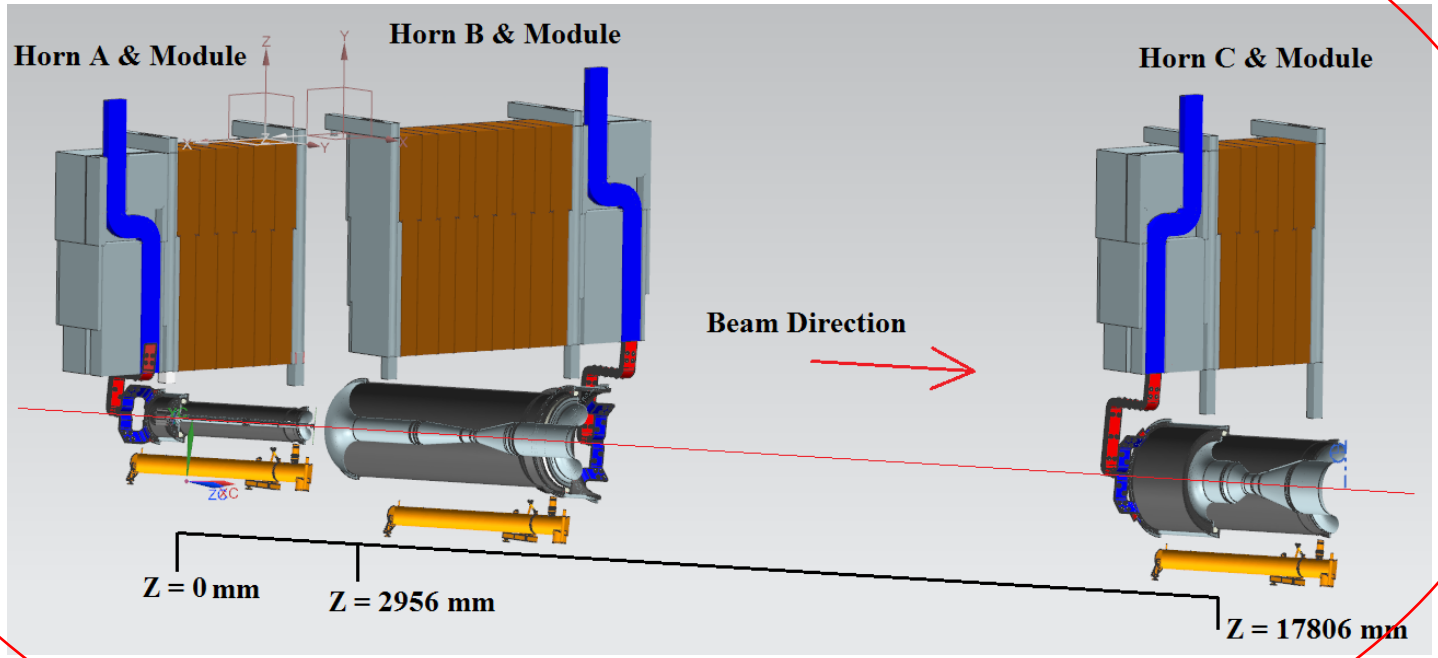
with/without y-axes?

XMYYYZ
0-6 - Distance Off-Axis (x 6 metres)
N / A - NuMode / AntiNuMode
YYY = current
Z = Horn Config
1 - A
2 - A+B
3 - A+C
4 - A+B+C
5 - B+C

10 Parameter Fit



Poster Images



Illustrative horn drawings for poster

From: LBNF Optimized Horn Systems Summary - DUNE-doc-4949-v3

WARWICK

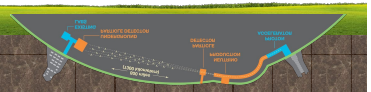
Bonus Slides

Near Detector Neutrino Flux Superposition at the DUNE Experiment

Tom Lord, on behalf of the DUNE Collaboration
Supervisor: Dr. S. Boyd
Department of Physics, University of Warwick, Gibbet Hill Road, Coventry, CV4 7AL

DEEP UNDERGROUND NEUTRINO EXPERIMENT

WARWICK



CP Violation at DUNE

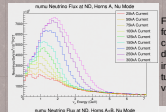
The DUNE experiment is the future long-baseline neutrino experiment in the US, and aims to pioneer the advance into high-precision long-baseline neutrino physics measurements with the primary goal of precisely measuring leptonic CP violation. Such measurements require exceptionally low uncertainties, with a necessary signal normalization uncertainty at the level of 5%@ 2% in order to reach 5σ sensitivity for 75% of δ_{CP} values with exposures less than ~900kt*MW*year in the case of the Optimized Design. [1]

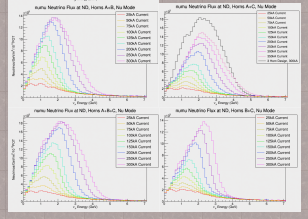
Therefore, in order to achieve DUNE's physics goals, systematic uncertainties due to neutrino interaction modelling must be controlled, with 2% taken as a goal for the effect of interaction model uncertainties on the DUNE ν_e signal normalization. This predicted level of interaction uncertainty depends upon the cancellation of near-far uncertainties from isolation of neutrino-argon interactions in the Near Detector (ND).

CP Violation sensitivity?

Include plot(s) of CP violation sensitivity?

ν_μ Flux with Horn Configurations





Figures show ND muon neutrino flux for several magnetic horn configurations. Under the current design proposal, horns must be run in series when connected, restricting tunability of horn current to one value for all powered horns.

Further Study

Quote some of your summary from presentation for this section..

DUNE PRISM appears to provide a better quality fit, but this avenue may be complementary to DUNE PRISM and provide better coverage of some spectral regions.

References

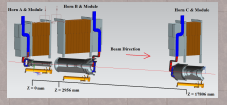
[1] – LBNF & DUNE Conceptual Design Report - Volume 2: The Physics Program for DUNE at LBNF (Dec. 2015)
or
[1] - Long-Baseline Neutrino Facility (LBNF) and Deep Underground Neutrino Experiment (DUNE) Conceptual Design Report - Volume 2: The Physics Program for DUNE at LBNF (Dec. 2015)

Interaction Uncertainties

To make precision neutrino oscillation measurements, the energy of each interacting neutrino must be precisely determined. This is difficult due to our understanding of the outgoing leptonic and hadronic final states of neutrino-nucleus interactions, particularly the fraction of "missing" energy due to unseen neutrons and low energy hadrons.

Whilst a projected improved model of neutrino interactions from the program of more immediate experiments like ProtoDUNE will reduce the impact of imperfect reconstruction of energy on the DUNE analysis, an experimental solution to the neutrino energy measurement problem can be provided by producing a set of measurements of neutrino-nucleus interactions at the ND, with a range of different incident neutrino energy spectra. This would allow for the association of incident neutrino energy to the distribution of experimental observables without heavy reliance on modelling of neutrino-nucleus interactions.

This idea is the basis of the current DUNE PRISM program, which relies on movement of the ND to a number of off-axis positions to form this set of measurements. A similar measurement set could be produced by running with a variety of powered magnetic horn configurations, using different combinations of the three horns, labelled A, B and C, over some set of currents.



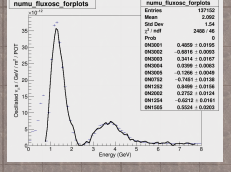
Linear Flux Combinations

Analogous to the DUNE PRISM analysis, one avenue to reduce these uncertainties is through the linear combination of various near detector fluxes to construct the expected oscillated energy spectrum at the far detector for a chosen set of oscillation parameters, allowing a direct comparison of near and far detector flux such that like-uncertainties between detectors, for instance those from missing energy, will cancel. This can result in a significant de-coupling of the flux and neutrino interaction uncertainties.

In this way, resulting linearly combined measurements can be used to effectively calibrate the relationship between observed and true neutrino energies. A first analysis of the utility of this technique with this set of spectra is shown.

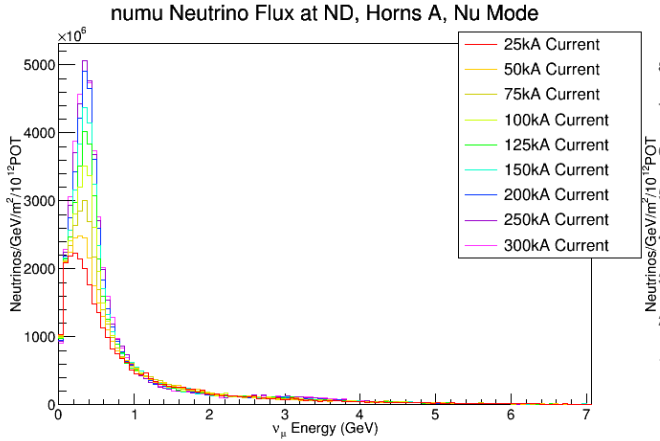
Far Detector Oscillated ν_μ Flux Fitting

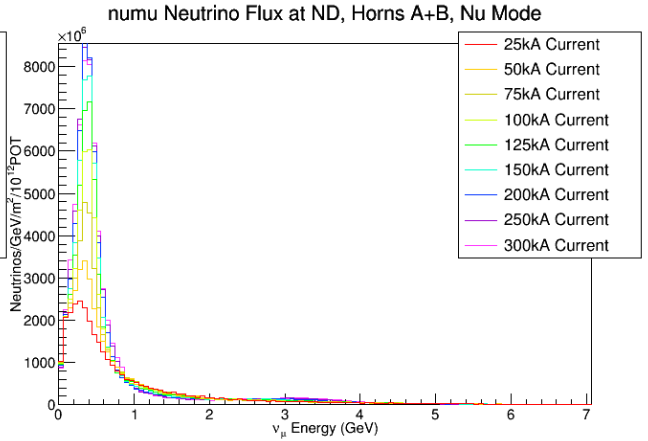
These fits have been performed using ... a first fit analysis showing reasonable agreement over a number of fitted spectra, with the goal of improving upon these results with a fewer number of horn configurations required so as to minimise time running non-optimal beamline configurations for the far detector.

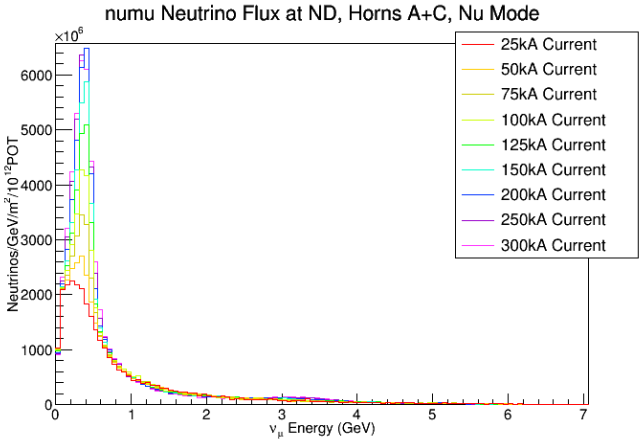


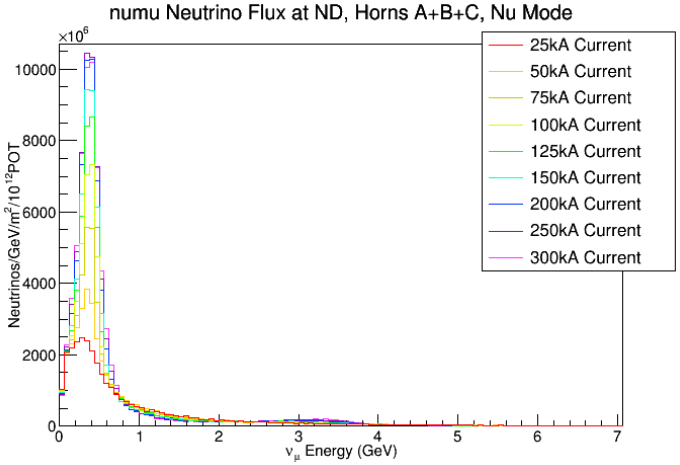
DEEP UNDERGROUND NEUTRINO EXPERIMENT

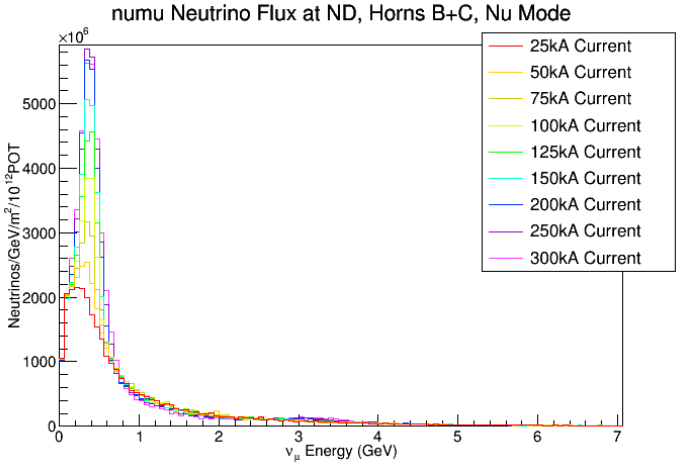
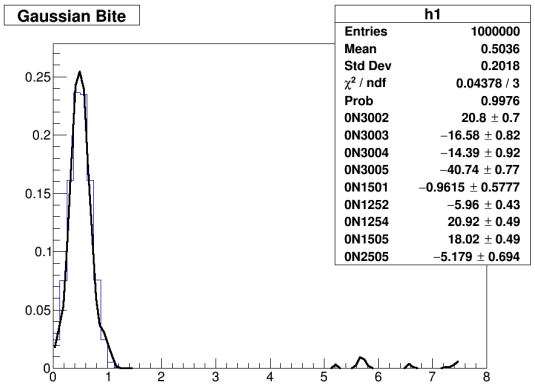
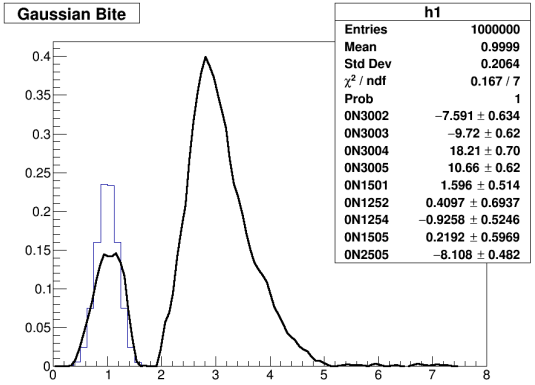
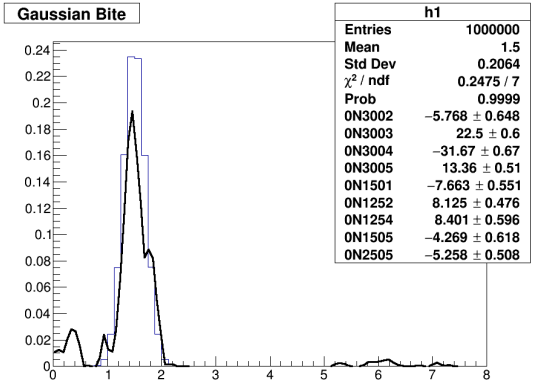
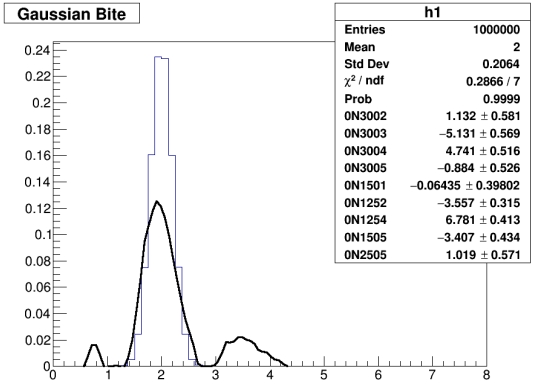
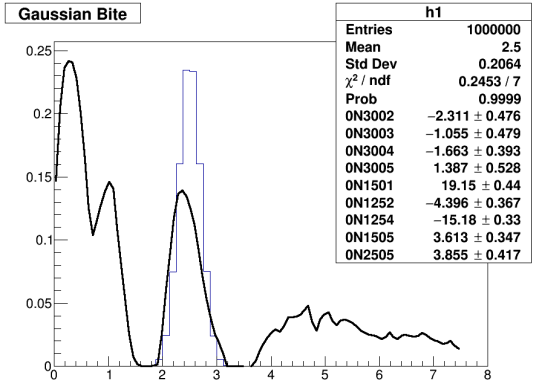
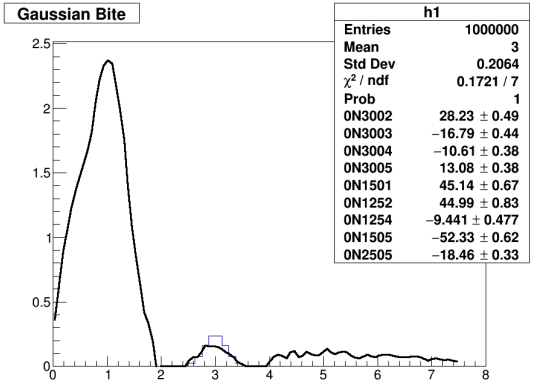
NuMu Fluxes 36m - Finer Binning











9 Param Thin Gaussian Fits –