vPRISM Software Status

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Goals of the vPRISM Software

- Generate vPRISM neutrino fluxes and perform the linear combinations to reproduce oscillated (or other) fluxes
- Generate MC events in vPRISM with the same flux and cross section models as T2K
- Model the reconstruction efficiencies and resolution in a WC detector
- Build predicted distributions from the SK MC for specified oscillation hypothesis
- Apply flux and cross section model systematic variations in a correlated manner between vPRISM and SK

vPRISM MC

- The simulated vPRISM event distributions are generated with the following steps
  - Flux files are generated for 320 kA and -320 kA horn currents
  - Use neutgeom (NEUT) and the flux files to generate interactions in a column of water corresponding to the vPRISM detector size
- SK efficiency tables and resolution histograms are used to select and smear generated neutrino vectors to get vPRISM observed events

vPRISM Software & Installation

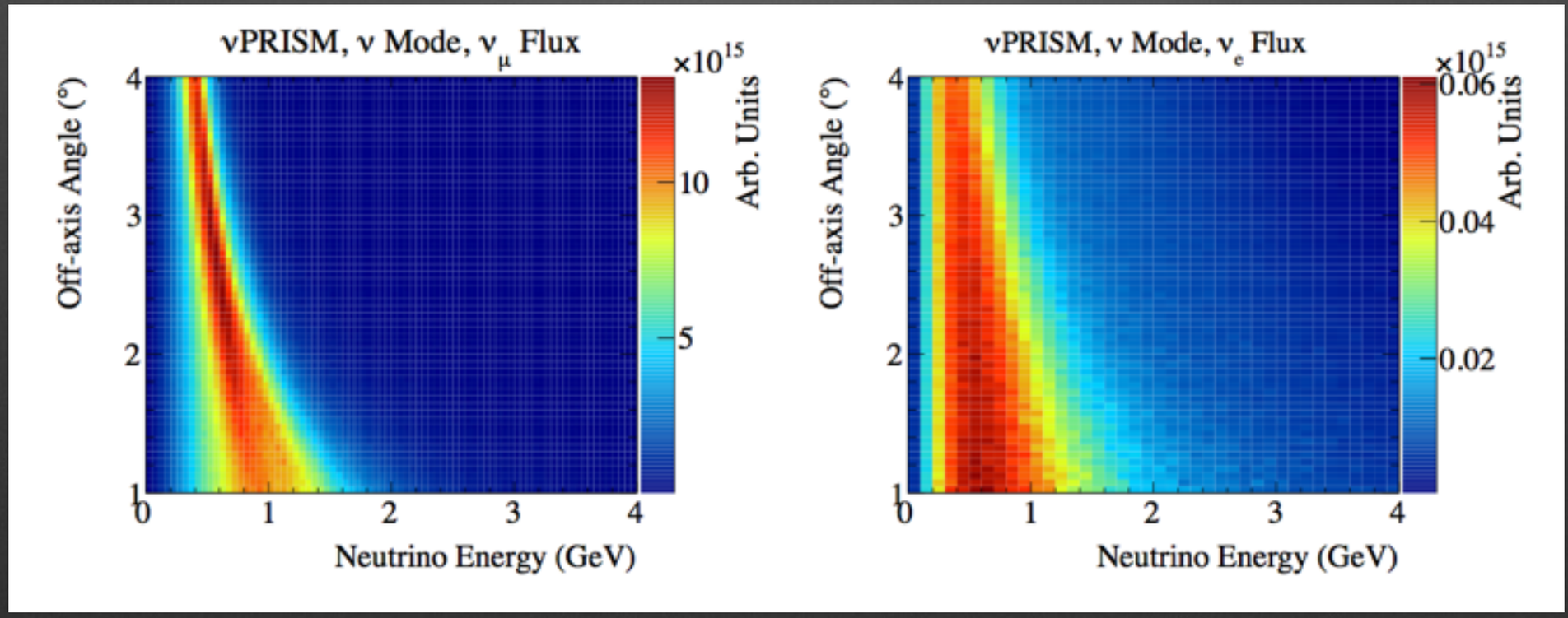
- The analysis software in the repository can be used to:
  - Generate the linear combination fits with nuPRISM fluxes
  - Run over the nuPRISM neutrino vectors and apply efficiencies and smearing
  - Apply flux and cross section systematic variations by reweighting the generated events
- It is in the T2K repository at: T2KRepository/GlobalAnalysisTools/nuPRISM
- Installation instructions are at: http://www.t2k.org/ndup/nuprism/software/nuprismsoftware

Flux Generation

- Generated 200 million triggers in both neutrino mode (320 kA horn current) and antineutrino mode (-320 kA horn current)
- The nuPRISM plane is broken into 5 segments at 1 km from the target
- The x position of the plane is 0 (so we can study the on-axis flux if necessary)
- Also generate flux 40 m upstream of nuPRISM on larger flux planes - use for sand muon simulation
- Flux files are moved to a local IPMU computer since disk space on KEKCC was becoming limited.
  - Could copy them over to NEUT cluster as well

Flux Histograms

- The energy vs. off-axis angle histograms are used for the flux linear combination fits
- Located in the macros/nuprism_spectra.root file
- Have the flux tuning applied so they are consistent with the tuned nuPRISM MC



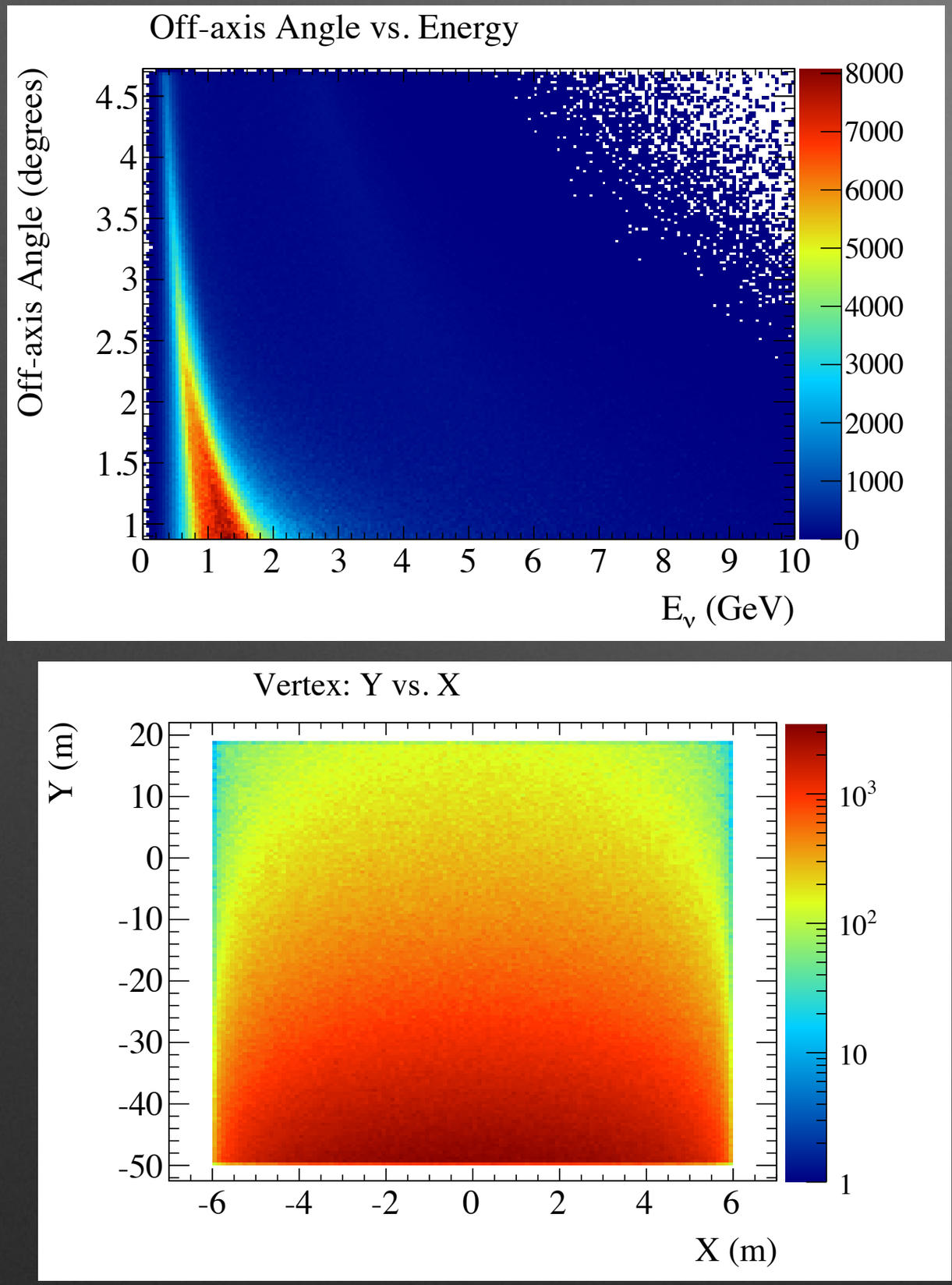
Flux Linear Combination Fits

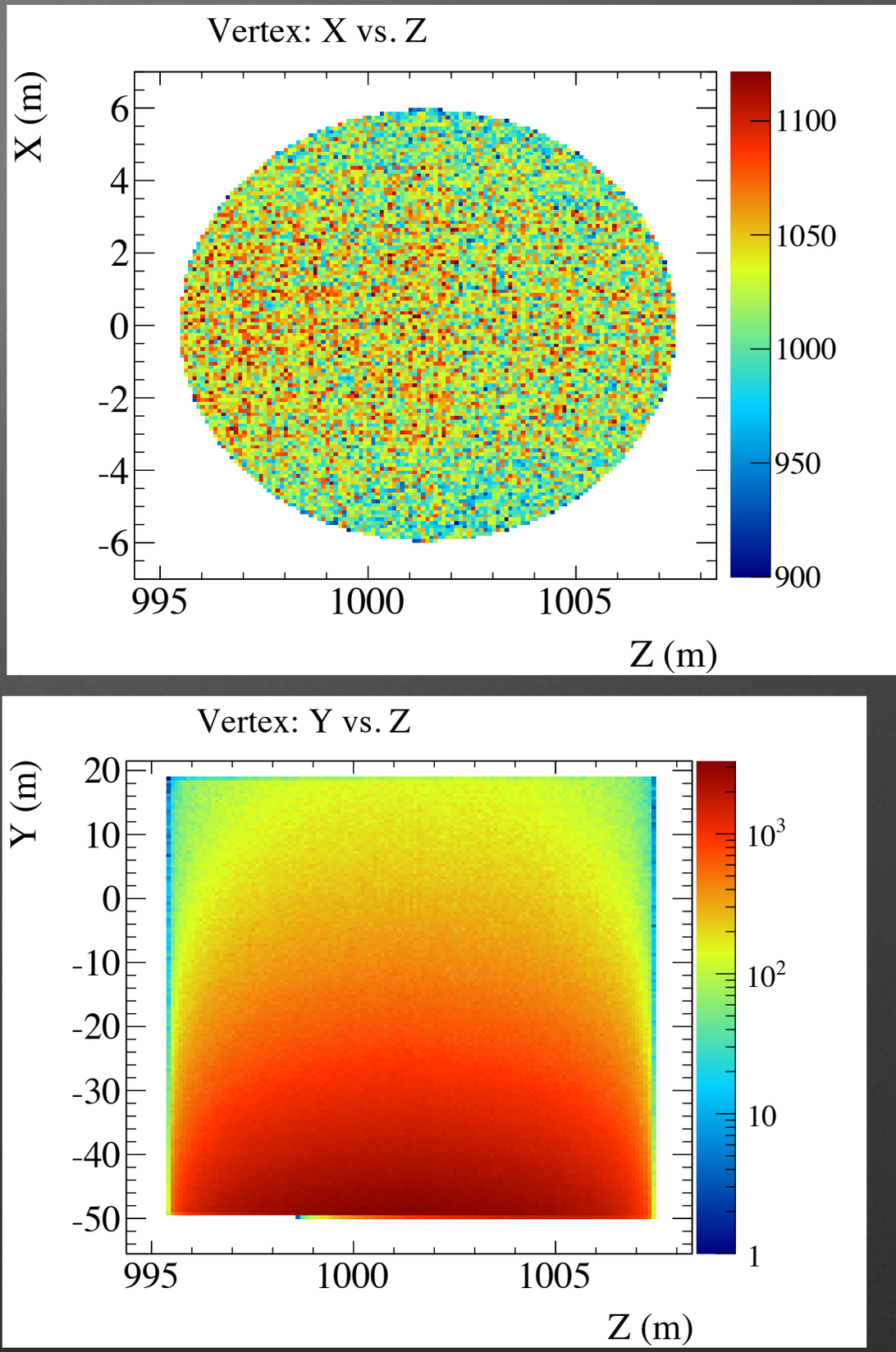
- The macros directory also constains the macros for doing the flux linear combination fits.
- There are now a few options:
  - fit_spectrum_numu_disappearance.cc - for the SK disappearance spectrum
  - fit_spectrum_BeamNue.cc - for fitting the nuPRISM nu_mu to the intrinsic nu_e spectrum
  - fit_spectrum_SKNue.cc - for fitting the nuPRISM nu_mu to the appearance+intrisic nu_e at SK
  - fit_spectrum_WrongSign.cc - for fitting the nuPRISM wrong sign nu_mu from antineutrino mode with right sign nu_mu from neutrino mode
- Some of these use Prob3++ for oscillations, so need to load the library - see macros/README.txt

Neutrino Vector Generation

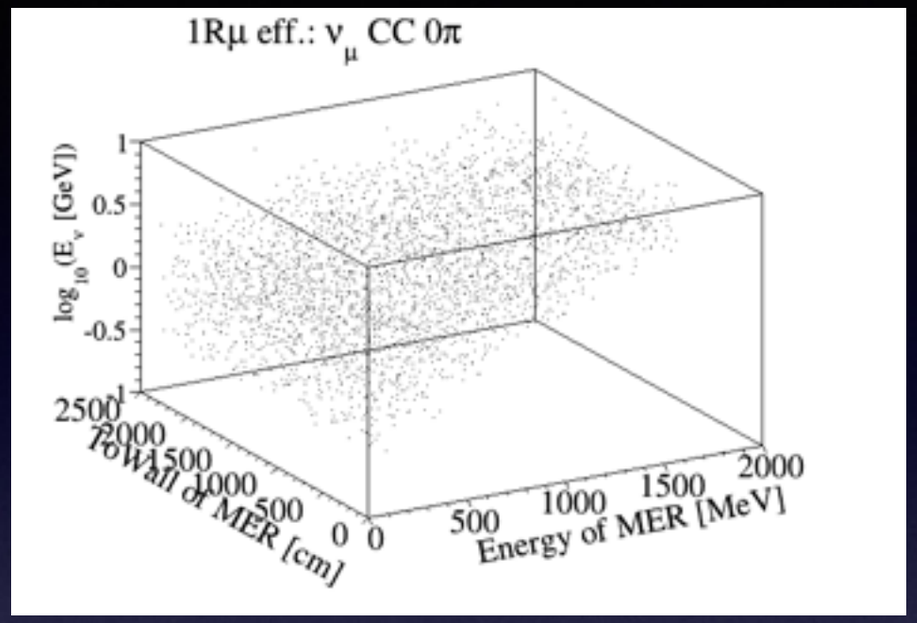
- The default neutrino vectors are generated with NEUT 5.1.4.2
  - 3.6e21 POT for neutrino mode
  - 6.3e20 POT for antineutrino mode
- NEUT 5.3.2 are also generated so the MEC interactions can be used
  - 5.4e20 POT for neutrino mode
- May want to generate more 5.3.2 and antineutrino mode statistics
- Files are on the GRID:
  - /grid/t2k.org/nd280/contrib/nuprism/neut_5142
  - /grid/t2k.org/nd280/contrib/nuprism/neut_532
- File name looks like: genev_<HCURR>a_1km_<ND>_7xx_<RAND>.root

Neutrino Vector Plots





fiTQun Efficiencies



Efficiencies are given as 3D histograms
Bins of:
True visible energy of most energetic ring (MER)
True distance to the wall along direction of MER
True neutrino energy

Efficiencies tables are provided for 1ring-mu and 1ring-e selections
Efficiency tables are provided for 10 topologies:

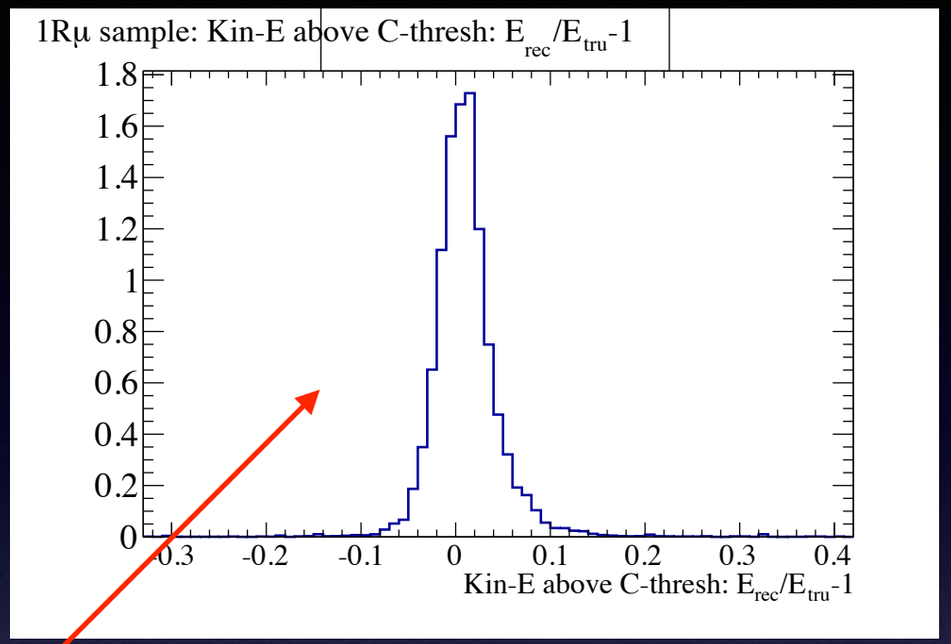
CC0π(ν_e)	CC0π(ν_μ)	NC0π
CC1$\pi^\pm$(ν_e)	CC1$\pi^\pm$(ν_μ)	NC1$\pi^\pm$
CC1π^0(ν_e)	CC1π^0(ν_μ)	NC1π^0
CCN$\pi^\pm$(ν_e)	CCN$\pi^\pm$(ν_μ)	NCN$\pi^\pm$
CCOther(ν_e)	CCOther(ν_μ)	NCOther

fiTQun Resolutions

Resolution histograms are given for bins in:
  True visible energy of MER
  True distance to the wall along direction of MER

They are provided for visible energy of MER, vertex position and direction of MER

Separate histograms are provided for the muon and electron hypotheses



Example visible energy resolution histogram for one bin in visible energy and distance to wall

To apply the resolution, random throws are pulled from these histograms for each event

Analysis Software

- There are two main classes for processing the neutrino vectors to make event histograms:
  - NuPrismVector - iterates through the neutrino vectors, applies flux and cross section weights, calculates true quantities
  - fiTQunEfficiency - applies efficiency and smearing tables and calculates measured quantities
- Example code for using these can be found in:
  - src/nuprism_nue_selection.cc
  - src/nuprism_numu_selection.cc

SK MC

- We need to apply simultaneous variations to the nuPRISM and SK MC in the long baseline oscillation analyses
- SK MC files are stored on the NEUT cluster and SRM. Need to be copied to the GRID.
- The SKNtple class iterates through the SK MC events and applies the flux and cross section weights, selection and calculates observables
- Example code for iterating through the SK files are at: src/skntple_example.cc

Flux Systematic Variations

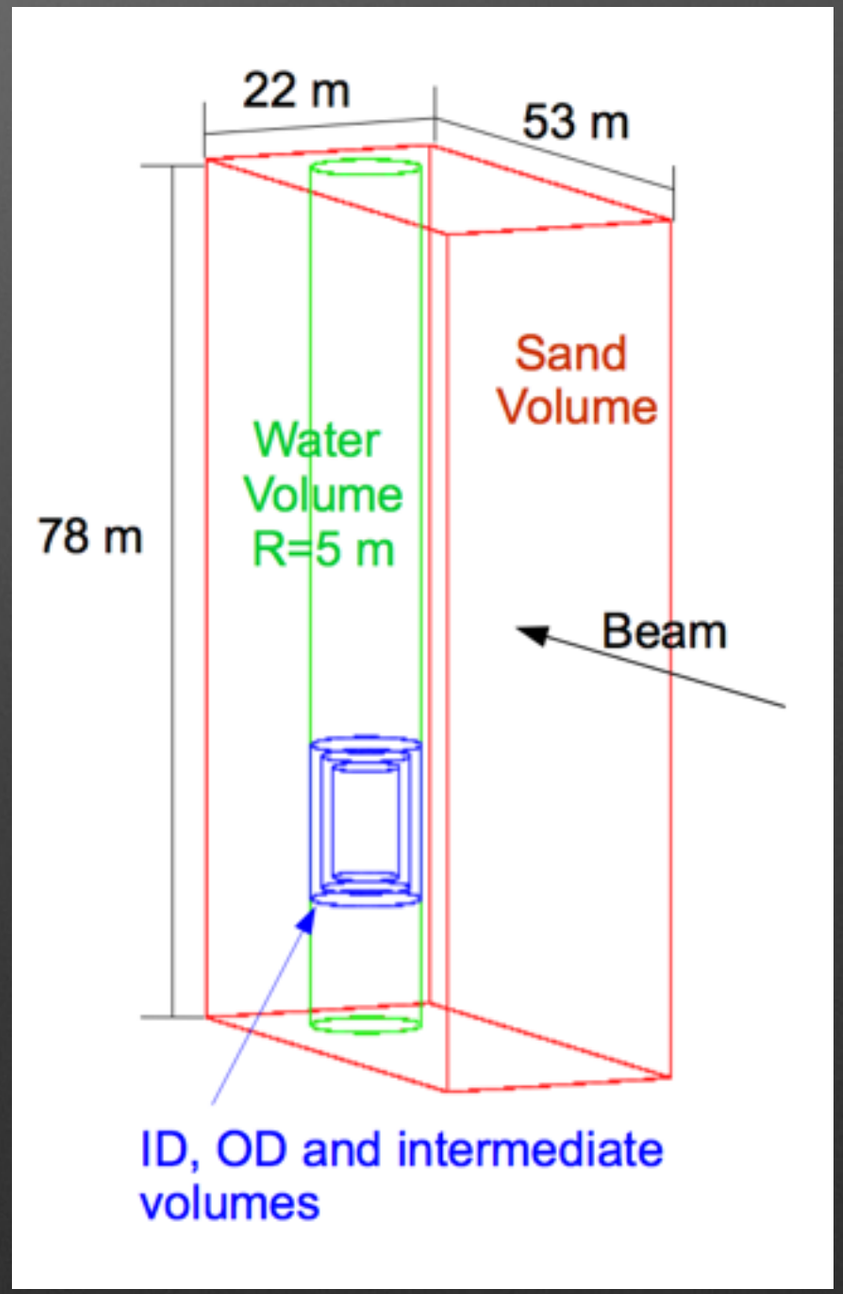
- We generate systematic variations for each error source and save weights for each of the nuPRISM vectors
- For the error sources, we either make 100 random throws or +/-1 sigma or +1 sigma
- nuPRISM flux weight files are generated for all of the generated neutrino vectors, stored in same location as vector files
  - File name is like: fluxweights_11b_<HCURR>a_1km_nd4_8xx_<RAND>.root
  - Files have to be loaded in the same order as neutrino vector files
- Reweighting of SK with the systematic variations is also implemented (done by weight histograms)
  - Weights are uploaded in sk_flux_weights/sk_weights_numode.root
  - Antineutrino mode weights will be uploaded soon
- Examples of flux variations in src/nuprism_fluxerrors.cc

Cross Section Systematic Variations

- 200 variations of the cross section parameters were generated weights for each of the SK and nuPRISM MC events are saved
- nuPRISM weight files are in the same location as the flux weight and neutrino vector files
  - Name like: xsec_var_<HCURR>a_1km_<ND>_5xx_25938.root
  - Have to be loaded in same order as flux and vector files
- New files with 500 systematic variations have been generated and will be released.

Sand Muon Simulation

- Neutrino flux 40 m upstream of the nuPRISM water volume is simulated
- Neutrino vectors are produced in an SiO2 and H2O volume
- The propagation of particles to the nuPRISM detector is simulated with a GEANT4 simulation
- Code currently is not checked into repository
  - Will do it soon



Improvements to Existing Software

- We should add functions to the NuPrismVector and SKNtple classes to do random throws of the flux systematics
- Generate larger antineutrino vector statistics and antineutrino vectors for NEUT 5.3.2
- Generate nu_e interaction in nuPRISM with the nu_mu flux for sterile analyses?
- Document the current state of the software

Limitations of Current nuPRISM MC/Software

- The nuPRISM vector files are broken up by planes - convenient to change position and extent of nuPRISM detector
  - Only file name contains information of the plane position
  - Want to add the plane position information to a TTree stored in the file
- Use of SK efficiencies and smearing has limitations
  - Only treating 1 ring samples, no NC selection or multi-ring
  - Difficult to adjust 1 ring selections
  - Can’t check how changes to the PMT size and granularity affect the selection
  - Need a full MC simulation and reconstruction chain

New Vector File Tree

- A new tree has been added to the vector files called Settings
- Contains
  - NPOT - equivalent POT for the file
  - RandSeed - the random seed used in the generation
  - NuIdfd - the ID of the nuPRISM plane generated
  - NuIdfdPos[3] - the position of the nuPRISM plane in the NEUT coordinate system
  - NuIdfdSize[2] - the size of the plane in the dimensions perpendicular to NEUT z (beam direction)
  - NuHcurr[3] - the horn current settings
  - NuTargCent[3] - the coordinates of the target center
  - NuBeamAng - the vertical deflection of the beam
  - JnuBeamVersion - the version of the flux
  - NEUTVersion - the version of NEUT
  - GenLabel - the version of nuPRISM vector generation

nuPRISM Simulation & Reconstruction

- We want to input the new vector files into a WCSim simulation of nuPRISM (see Carl's talk next)
- After the WCSim simulation, we can run event reconstruction with fiTQun
  - HK work by B. Jamieson to interface WCSim and fiTQun
    - Will need to do some work to get multi-vertex reconstruction working in fiTQun
- Expect that treatment of flux and cross section systematic variations will be the same

Sand Simulation Update

- The sand simulation is being updated with a few improvements
  - Now simulating the full nuPRISM all at once - since sand segments have large extent than nuPRISM detector segments, it was more complicated to combine individually simulated segments
  - The output of the simulation will be particles entering the detector stored in the nRooTracker format so they can be input into WCSim
  - Timing information relative to the interaction vertex will be stored

Conclusion

- First version of nuPRISM analysis tools are in place
  - Can do single ring analyses
  - In principle antineutrino mode analyses can be done, but statistics need to be increased
  - To go further with nuPRISM analyses we need a detector simulation and construction
- Work on simulating nuPRISM is now starting
  - Update to the neutrino vector file format
  - See next talk by Carl on the implementation in WCSim
  - Updating sand simulation to feed into WCSim simulation
  - Next-next step is getting reconstruction working with fiTQun