Energy Reconstruction and oscillation analysis plan for Theia

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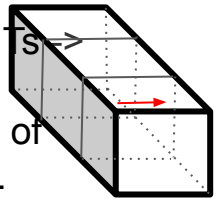
Simulation with ratpac



Geometry

- Considering a 25-kt Theia, 40% coverage results in >46,000 20-inch PMTs too heavy for simulation.
- Instead, having 14 big sensitive regions and look at the detailed location of each hit, with quantum efficiency from Hamamatsu R14688 without TTS.

Physics model

- Various GENIE versions (2_12 for today) are ready for the neutrino interaction.
- Various G4 models are ready for the particle propagation, default QGSP_BERT.

WbLS Optical model

- Scintillation code in RAT is based on GLG4Sim with model parameter inputs.
- Light yield from measurement: here.
- Rayleigh scattering from BNL measurement.
- *Absorption length from combination of BNL LABPPO measurement and Pope+Smith for water.*
- Refractive index, scintillation rise time and spectrum are from measurements.

Output information

- Ratpac output root with true PE location and time.
- PMT Transit time spread, charge can be added, but not at the moment.

Fast energy reconstruction - Methodology

Muon can be measured with Cherenkov ring.

- **Energy excluding muon ~ Total scintillation light - muon energy equivalent scintillation light**

In addition, pions may be measured with Cherenkov ring if above Ch. threshold.

- **Energy excluding muon and pions ~ Total scintillation - muon energy scintillation - pion energy scintillation**

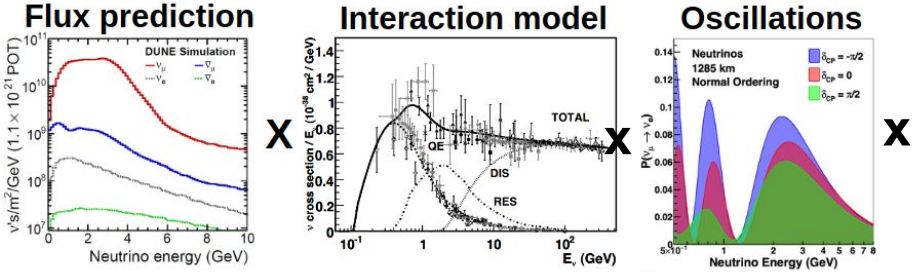
All remaining energy may be measured calorimetrically.

Neutrino and antineutrino interaction with DUNE spectra with 5% WbLS target
-> focus on FHC for today

Toward the DUNE LBL analysis

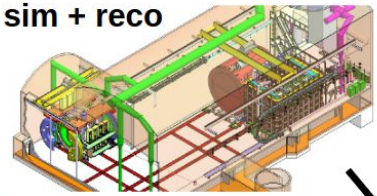
Callum Aug. 2022

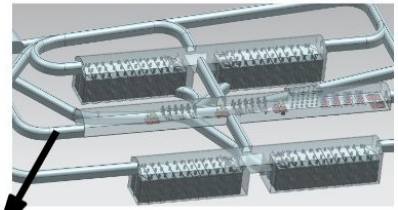
Detected event Rate for each Energy bin =



Detector non-perfection (energy resolution, efficiency etc.)

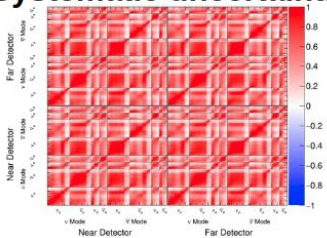
SAND and PRISM
Not immediate
ND constrains the flux and nu-Ar interaction syst.





FD takes the constrained flux and interaction syst. with its own detector syst. (energy + efficiency)

Correlated syst. as floating parameters



Fitting framework

$$\chi^2(\vec{\vartheta},\vec{x}) = 2\sum_i^{N_{\text{bins}}}\left[M_i(\vec{\vartheta},\vec{x}) - D_i + D_i \ln\left(\frac{D_i}{M_i(\vec{\vartheta},\vec{x})}\right)\right] + \sum_j^{N_{\text{systs}}}\left[\frac{\Delta x_j}{\sigma_j}\right]^2$$

Toward the DUNE LBL analysis

- **DUNE LBL analysis is moving from Cafana (NOvA framework) to Mach3 (T2K framework). We need to stick to the latest one.**
- **The first step could be implementing our energy resolution with all existing systematics in DUNE LBL framework-> not realistic, but a ramp-up work.**
  - **the study would show "assuming the same level of constraints on the flux and interaction obtained for the H2O target with some near detectors, the WbLS far detector can lead to a sensitivity of X."**
- **Modifying the systematics in the framework will be a longer-term work. It requires:**
  - **Knowledge of the near detector**
  - **If combing with Ar in any way: Implementing the correlation between Ar and H/C/O**
  - **If independent near-far WbLS target: T2K-style implementation**

Toward the DUNE LBL analysis

- Started conversation with Callum Wilkinson and Patrick Dunne - conveners of LBL group and MaCh3 group
- Started conversation with Ed and Asher - major force in MaCh3
- Started conversation with Liban - major force in MaCh3_DUNE
- Started conversation with Dominic - FD simulation convener
- Able to go through the chain of GENIE-> Ratpac-> Fast energy handling -> CAF format conversion (CAF is required by DUNE OA)
- Compiled and run MaCh3 successfully to obtain event rate and systematic variations

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Integrals of nominal hists:

FHC_numu unosc:      25941.57467
FHC_numu   osc:      7977.36857

FHC_nue unosc:       390.85150
FHC_nue   osc:       1698.28486

RHC_numu unosc:      12492.61743
RHC_numu   osc:      4217.78039

RHC_nue unosc:       208.31873
RHC_nue   osc:       447.09422
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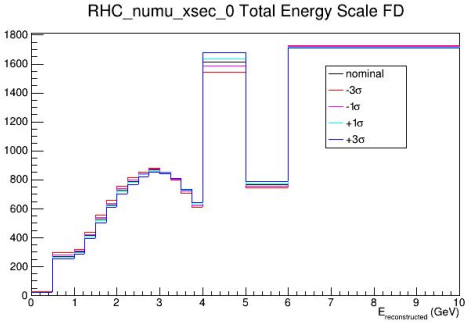

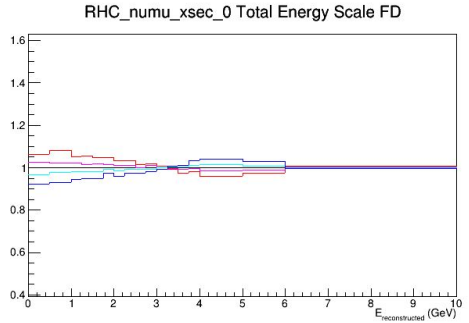

Neutrino sample requirement

Currently MaCh3 is taking flavor x to flavor y sample with the selection of flavor z. Here x and z loop over numu and nue; y loops over numu, nue, nutau. Same thing for antineutrinos and do it for both FHC and RHC -> 48 samples in total (2x2x3x2x2). However, we can simplify this:

- Let's worry about the selection at a later stage
- Wrong-sign generated with the right-sign
- Two swapped samples can be generated at once

The resulting sample number is 6 at least:

- FHC unoscillated
- FHC numu->nue, nue->nutau, same for antinu
- FHC numu->nutau, nue->numu, same for antinu
- RHC unoscillated
- RHC numubar->nuebar, nuebar->nutaubar, same for nu
- RHC numubar->nutaubar, nuebar->numubar, same for nu

Summary

Steven and I have completed a first pass of the sample generation, all the way from ratpac to caf.

- However, many more events are needed.

We are able to run MaCh3. We are trying to get our samples out and plug them into MaCh3.

- However, MaCh3 is still in a developing stage, the framework is not fully finalized for official result yet. We are following MaCh3 group closely.