

Atmospheric Neutrino Production

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Current Status

- We have no sensitivities for atmospheric neutrino oscillations that are based on fully simulated and reconstructed samples
 - Example: DUNE's official mass hierarchy sensitivities with atmospheric neutrinos are based on a ~decade-old phenomenological study
- Several people in the group are interested in working on producing new sensitivities:
 - Mass hierarchy
 - CP violation with sub-GeV atmospheric neutrinos
 - NSI, steriles, etc
- We have been discussing the need to produce an atmospheric neutrino MC sample for oscillation studies

Available files

- We have a set of atmospheric neutrino files produced for background studies for nucleon decay, $n\bar{n}$, etc
 - For details, see https://indico.fnal.gov/event/57274/contributions/255126/attachments/161878/213773/DUNE_n-nbar_Atmo_Systematics.pdf
 - Uses Honda flux
 - Oscillations already applied
 - Sets of files for different nuclear models (Bodek-Ritchie relativistic nonlocal Fermi gas vs local nonrelativistic Fermi gas vs effective spectral function) and intranuclear cascade models (hA vs hN)
 - Do not have up-to-date reconstruction
- List can be found here: https://wiki.dunescience.org/wiki/High-E_and_Non-accelerator_Physics#Currently_Available_MC_Samples_.28as_of_August_2022.29

Needs

- Updated vertexing for non-beam events (see https://indico.fnal.gov/event/53749/contributions/237491/attachments/153385/198979/atmos_vertex.pdf)
- Way to apply oscillations (which means including tau neutrinos even though they are not in original flux)
 - What was done for previous samples was to apply oscillations at the flux level and “hack” the Genie code to allow taus in the flux
- Produce CAFs (currently have ‘anatrees’)
- Proper normalization (want to specify an exposure in kiloton-years rather than a number of events)
- Make sure coordinate system is correct (previous problem with Genie generator)
- Ability to apply different nuclear model configurations, etc. for assessment of systematic uncertainties
- Stay up-to-date with DUNE defaults for reconstruction, detector simulation (moving to wirecell soon), Genie (talk later in this meeting)

Summary of recent discussions

- Short-term goal (in the next ~month)
 - Use Genie events that have already been produced
 - Can use existing reco files to re-reconstruct to get latest vertexing
 - Work out a scheme to reweight to apply different oscillation parameters
 - This gets us some files that people can use to get started on analysis
- Long-term goal (implement in the next year)
 - Agree on strategy for how we want to simulate atmospheric neutrinos in DUNE
 - Get atmospheric neutrinos implemented in large-scale productions so that we keep up with official reco, det sim, etc
 - Implement analysis in same framework that long-baseline group uses

Beam simulation for oscillation analysis

- Three samples are produced (x2 for FHC/RHC)
 - Nominal flux (NuMus and Nues)
 - Nominal NuMus->Nues, Nominal Nues->NuTaus
 - Nominal NuMus->NuTaus, Nominal Nues->NuMus
 - (Antineutrinos included treated same way)
- Flux files only contain nominal neutrinos; flavor swapping is done later in the process (before Genie applies cross section)
- Genie stage, detector simulation, reconstruction, selection cuts are applied to each sample
- Each initial-final flavor pair is weighted according to oscillation probability (NuMu->NuMu, NuMu->Nue, NuMu->NuTau, Nue->Nue, Nue->NuMu, Nue->NuTau) and summed in analysis
- We could implement a similar process – the direct flavor swapping means oscillated neutrinos will have correct energy and angular distribution

Open Questions

- Long-term plan for how to do simulation in DUNE production chain (instead of our makeshift procedure used for previous samples)
 - Some proposals on the agenda in this meeting
 - Use Genie atmospheric generator or some custom procedure?
- Simulation of rock muons
 - There is surrounding rock in the simulation, BUT default geometry is limited to 1x2x6 at the center of the detector, with surrounding argon to mimic the full width of the detector not simulated – could be added for us
- What else?