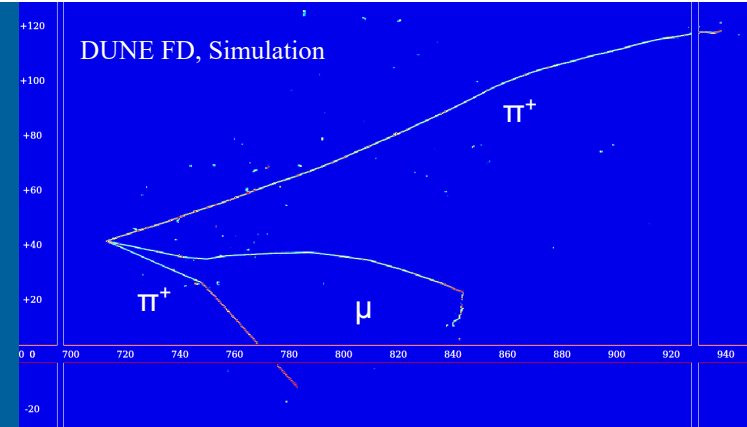


NEUTRINO ENERGY SCALE MEASUREMENTS FOR FINAL STATE INTERACTIONS USING ADVANCED COMPUTING IN DUNE



ALEENA RAFIQUE

On behalf of the DUNE collaboration

Argonne National Laboratory

NuPhys 2023

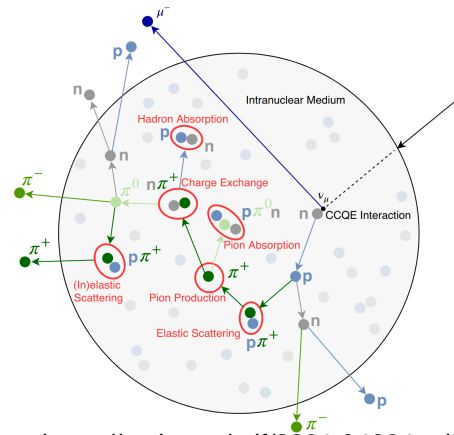
INTRODUCTION

- ANL Computing resources
 - ANL Leadership Computing Facility
 - Laboratory Computing Resource Center

Resource	Description
Bebop	Intel Xenon CPUs with 1024 public nodes
Swing	NVIDIA AI100 GPUs with 6 public nodes



- Final State Interactions
 - After an initial neutrino interaction with Ar nuclei, The initial state hadrons undergo secondary interactions, called final state interaction (FSI), with the other nucleons within the same nucleus.
 - FSI can change the topology of the interactions



<https://arxiv.org/pdf/2201.04664.pdf>

ANALYSIS AND RESULTS

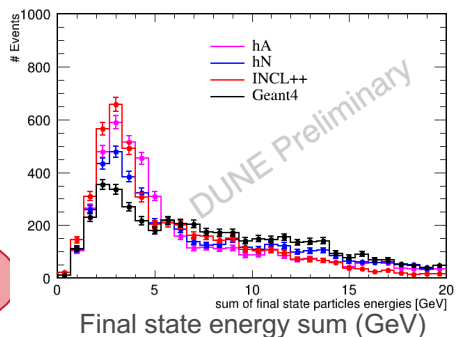
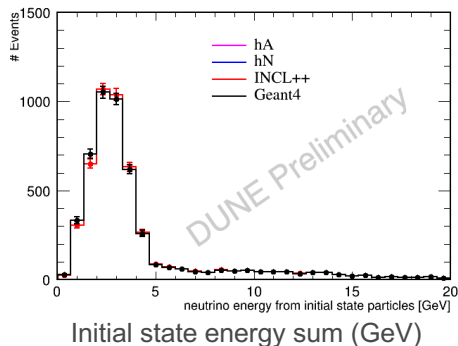
Standalone
event
generator

Alternate
FSI models

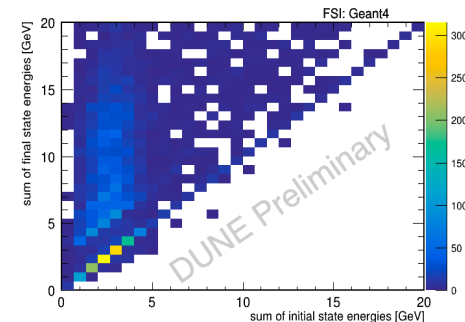
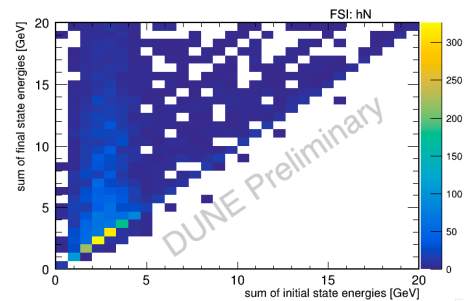
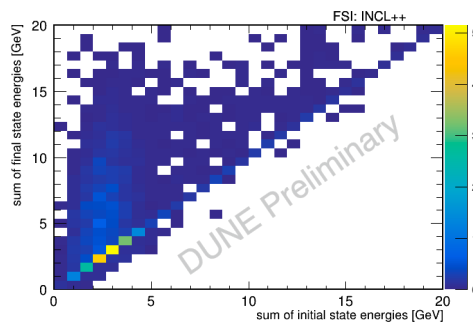
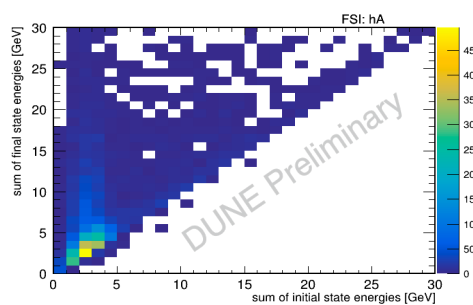
Impact on true
neutrino energy

Impact on reco
neutrino energy
in ND and FD

Estimate the impact
on the DUNE
physics sensitivity



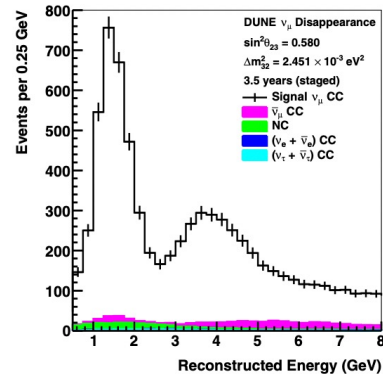
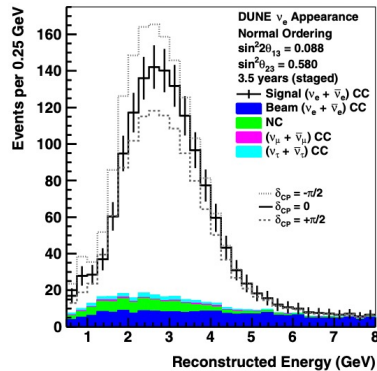
For the same initial state interactions, the FSI energy sum differs for up to 45%



Initial versus final state energies for different FSI models. Better agreement in energies for the models hN and INCL++.

SUMMARY AND NEXT STEPS

- First demonstration of utilizing ANL computing for DUNE physics studies
- Observed how FSI can impact the neutrino energy spectrum
- Plan to look for the reconstructed neutrino energy
- Will calculate the impact on the CP violation sensitivity studies



Neutrino energy scale measurements for final state interactions using advanced computing in DUNE

Aleena Raftue, ANL
 On behalf of the DUNE Collaboration
 NuPhys 2023

DUNE
 DEEP UNDERGROUND NEUTRINO EXPERIMENT

Argonne
 NATIONAL LABORATORY

1. DUNE and DUNE-FD

DUNE:
 • 1000 km baseline
 • 40 line active mass Liquid Argon Time Projection Chamber (LArTPC) Far Detector (FD) at SPOD South Dakota, 1.2 km underground [1]
 • Multiple technologies for the Near Detector (ND) [2] at Fermilab
 • TPC ensure sensitive oscillation probability to determine mass ordering and CP violation phase via $\cos(\delta_{CP})$ appearance and $\sin(\delta_{CP})$ disappearance, search for BSM physics and improve sensitivity

DUNE-FD:
 • Consists of two LArTPC modules each having a fiducial mass of 10 kt at SURF
 • First module is a hexacore drift LArTPC, second module will be a vertical-drift TPC, 3rd and 4th module technology R&D in ongoing.

2. Neutrino event displays

A few neutrino event displays from DUNE FD simulation. LArTPC experiments present neutrino event images with superimposed tracks.

3. ANL computing resources

Argonne Leadership Computing Facility
 Laboratory Computing Resource Center

Resource	Configuration	Resource	Description
Theta	117 topology supercomputer based on Intel processors	Beepup	Intel Xeon CPUs with 12.5-peta nodes
ThetaGPU	NVIDIA DGX A100-based	Swing	NVIDIA A100 GPUs with 6 public nodes
ANL AI-Tier1	Machine learning based high-performance computing applications		
Pelican	44 petaflop peak performance CPU/GPU platform to test and optimize codes for Aesara		
Aesara	ANL's first machine learning-optimized projected peak performance of 2 exaflops		

4. Final State Interactions

When a neutrino interacts with the argon nucleus, the final state particles are generated. The final state includes secondary interactions, called final state interactions (FSI), with other nucleons within the same nucleus. FSI provide an important way to study the identity of the primary vertex and can readily change the topology of the interaction and can also impact the final state energy.

FSI are dominant in lower-momentum argon. They can change the topology of an interaction completely.

5. Sample generation and workflow

5 events were generated using GENIE (version 1.4.8.21) [3] final state interaction event generator using ANL computing resources.
 The same initial state interactions were propagated in the following FSI models:
 • NC: the default model used in most current neutrino simulations. It only considers non-hadronic rescattering.
 • ANL: considers multiple rescatterings until the hadron escapes the nucleus.
 • DNCL: the newer hadronic model system changes through time steps.
 • General Hadronic Cascade (GHC) [4], more sophisticated model.
 • How we present the impact on the reconstructed neutrino energy.
 • How we plan to use the impact on the reconstructed neutrino energy to estimate the impact on the DUNE physics sensitivity studies.

Workflow: GENIE → ANL FSI model → Signal and event energy → Signal and event energy → Signal and event energy → Signal and event energy

6. Initial and final state energy sum

The sum of all initial and final state energies is calculated by:
 $E_{\text{sum}} = E_{\nu} + E_{\text{FSI}}$

where E_{ν} is the initial (final) state neutrino energy; E_{FSI} is the total final state energy; E_{ν} is the primary neutrino energy and E_{FSI} is the final state energy.

We use the initial state energies we calculated as input.

There is a discrepancy from the default case to large as $\sim 1\%$.
 These discrepancies lead to model understanding and will impact the energy scale and reconstruction.

7. Observations and results

Initial versus final state energies are plotted for different FSI models.
 There seems to be a better agreement in initial and final state energies for the models NC and DNCL.

For track-only energy sum, the discrepancy between initial versus final energy reduces to 3%. This may hint that the energy modeling is mostly different between different FSI.

8. Summary and next steps

This is the first demonstration of utilizing ANL computing for DUNE physics studies.
 We observed how FSI can impact the neutrino energy spectrum.
 In future, we plan to look into the dependence of the energy difference between different neutrino interaction types (QE, RES, etc.).
 We plan to reconstruct the neutrino energy using FD reconstruction tools.
 Calculate the effect of these uncertainties on the CP violation sensitivity studies.

UChicago Argonne | Office of Energy Sciences | NuPhys | 2023-11-16 10:00:00Z | November 5, 01:11:00Z | Poster No. Math. Phys. Ex. 4.00 (DUNE) FS-01 | Contact: aleena@anl.gov | U.S. DEPARTMENT OF ENERGY NATIONAL LABORATORY



U.S. DEPARTMENT OF
ENERGY

Argonne National Laboratory is a
U.S. Department of Energy laboratory
managed by UChicago Argonne, LLC.

Argonne 
NATIONAL LABORATORY



U.S. DEPARTMENT OF
ENERGY

Argonne National Laboratory is a
U.S. Department of Energy laboratory
managed by UChicago Argonne, LLC.

Argonne 
NATIONAL LABORATORY