Preliminary estimation of the atmospheric neutrinos detection efficiency in NOvA

A.D. Ivanova [a,b,c,1], *A.S. Sheshukov* [c], *O.B. Samoylov* [c]

[a] Moscow Institute of Physics and Technology, Moscow, Russia

[b] Institute of Applied Physics, Irkutsk State University, Irkutsk, Russia

[c] Joint Institute for Nuclear Research, Dubna, Russia

В эксперименте NOvA, направленном на изучение нейтринных осцилляций в пучке мюонных нейтрино и антинейтрино, используются два сегментированных жидкостных сцинтилляционных детектора массой 300 тонн и 14 килотонн соответственно. Большой размер и высокая сегментация детекторов NOvA, а также гибкая система программного триггера и сбора данных позволяют решать дополнительные физические задачи, в частности, обнаруживать и изучать поток атмосферных нейтрино. В работе представлено моделирование событий от взаимодействий атмосферных нейтрино в дальнем детекторе эксперимента NOvA, а также предварительная оценка эффективности отбора сигнальных событий.

The NOvA experiment, aimed at studying the neutrino oscillations in the muon neutrino and antineutrinos beam, uses two segmented liquid scintillator detectors, with masses of 300 tons and 14 kilotons, respectively. The large size and high segmentation of the NOvA detectors, as well as a flexible system of software triggers and data acquisition, make it possible to solve additional physical problems, in particular, to detect and study the atmospheric neutrino flux. This paper presents simulating events from interactions of the atmospheric neutrinos in the far detector of the NOvA experiment, as well as a preliminary evaluation of the efficiency of signal event selection.

PACS: 13.15.+g; 95.55.Vj

Introduction

NOvA (NuMI Off-Axis ν_e Appearance) [1] is an experiment aimed at studying neutrino oscillations, measuring ν_e ($\overline{\nu}_e$) appearance in a narrow-band beam of ν_μ ($\overline{\nu}_\mu$) peaked at 1.8 GeV. NOvA consists of two detectors: the near detector (ND) located at Fermilab and the far detector (FD) in northern Minnesota, at a distance 809 km from the ND. These detectors are composed of 20,192 (ND) and 344,064 (FD) cells of extruded highly reflective plastic, filled with liquid scintillator.

The goals of the main NOvA analysis [1] are determination of the neutrino mass ordering, restrictions on the CP violation in lepton sector, refinement of θ_{23} and θ_{13} measurements. Moreover, NOvA detectors allow performing additional physics searches such as sterile neutrinos, Dark Matter and so on.

It's possible to explore neutrino oscillations not only in beam events, but also in the interactions of atmospheric neutrinos in NOvA detectors. The atmospheric neutrinos are one of the main experimentally available sources

[1] E-mail: ivanova.aleksandra@phystech.edu

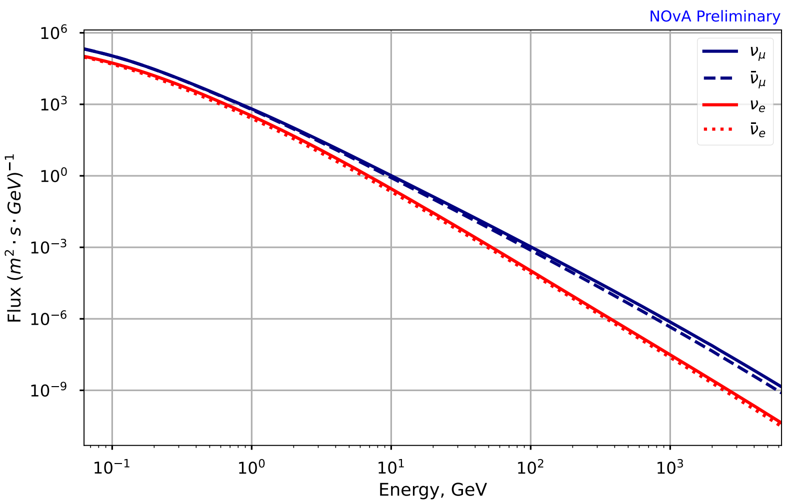

Fig. 1: Energy spectrum of atmospheric neutrinos [2]

of neutrinos in this energy range from 100 MeV to 1 PeV scale. They are produced after the interaction of primary cosmic rays with the Earth atmosphere, and consist mostly of electron and muon flavors, while the contribution of ν_τ is negligible and will not be considered in this study. The theoretically predicted atmospheric neutrino flux is shown in Fig. 1. In addition, atmospheric neutrinos present a background for additional physical studies. In this regard, the task was set to measure the spectrum of the atmospheric neutrinos in the NOvA experiment.

Simulation of the signal and background samples

The signal dataset of the atmospheric neutrinos $\nu_\mu(\bar{\nu_\mu})$ and $\nu_e(\bar{\nu_e})$ is generated using NOvASoft software packages. The NOvASoft is based on the "art" software [3] developed at the Fermi laboratory. Using GENIE software package [4] we simulated 10 thousand atmospheric neutrino interactions in the NOvA far detector, following the expected atmospheric neutrino flux shown on Fig. 1. This dataset corresponds to exposure of 2.3 years. The Fig. 2 shows an example of the signal event from an atmospheric neutrino. The GENIE package allows to generate the primary vertex of neutrinos interaction with detector nucleons. The interaction between particles and a substance of the detector is modeled by GEANT4 software [5]. The background in the NOvA FD for our study consists of muons and other cosmic rays induced activity (delayed neutrons, electromagnetic processes). An average rate of 150 thousand muons per second are observed in the far detector. The software package CORSIKA [6] is used to simulate the background sample. This program is designed to accurately simulate extensive air showers that are initiated by high-energy cosmic ray particles. These signal and background samples will be used in future tuning of the signal selection procedure.

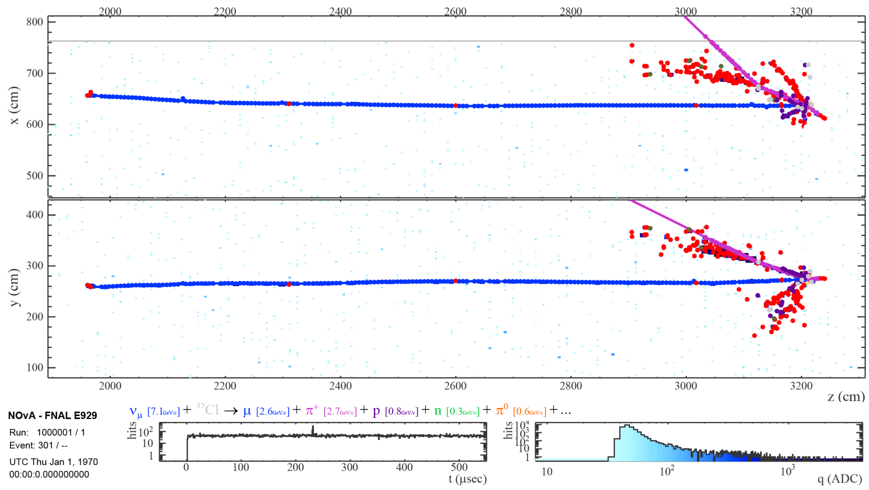

Fig. 2: Simulation example of modeling the atmospheric ν_μ CC interaction with $E_\nu = 7.1\,\text{GeV}$ deep inelastic with the production of μ and hadronic shower in FD. Circular markers show the energy release by the simulated particles, and the lines show the simulated trajectory

DDTriggers: description and selection efficiency

Because of high background activity in the NOvA detectors, a procedure is required to perform selection of signal events from the detector data. For the beam neutrino interactions such selection is done by requiring time coincidence with the beam spill. For searching for other signatures in the data outside of the beam, NOvA uses a flexible system of Data Driven software Triggers (DDT) [7]. The data stream from the detector is written to a circular buffer, to be reconstructed and analyzed by fast algorithms that select specific signatures and save the necessary data for later offline analysis.

At the moment NOvA doesn't have a dedicated trigger algorithm for selecting atmospheric neutrino interactions. The development of such trigger is planned for the near future, while in this work we consider efficiency of the existing trigger algorithms, which have been taking data for several years. It is planned to analyze the current experimental data before creating a new trigger. The signal dataset, consisting of 10,000 atmospheric neutrino events, was processed by all DDT algorithms to estimate the selection efficiency.

Fig. 3 shows the energy distribution of the selected events (left) and the selection efficiency for charged and neutral current neutrino interactions. The total selection efficiency was 11.7%. Note that this is a preliminary estimation of the trigger efficiency based on the limited simulated sample. The most suitable triggers for solving our problem turned out to be "NNBAR" with efficiency 11.6%. This trigger was designed to look for exotic signature from neutron-antineutron oscillations, however it's optimized for selecting neutral-current interactions, hadronic and electromagnetic showers contained in the detector. Other triggers have much lower efficiency for our task:"UPMU" (searches for upward going muons from neutrino interactions in the rock surrounding the detector) — 0.06%, "CONTAINED" (searches for upward going muon tracks from neutrino interactions within the detector, and it requires tracks begin and end within the detector limits) — 0.04%. These estimations of the efficiencies are preliminary and the study is in progress.

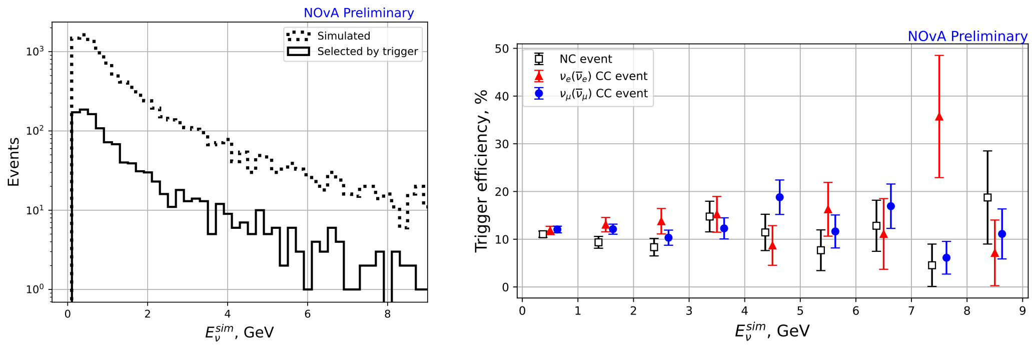

Fig. 3: Left: energy spectrum of simulated events (dotted line) and events selected by trigger (solid line). Right: trigger efficiency vs E_ν for charged and neutral current events for the "NNBAR" trigger with bin width = 1 GeV

Reconstruction of the neutrino events

Standard steps for neutrino interaction reconstruction include [8] applying calibrations, searching for geometry information; clustering in space and time to isolate separate physics interactions, reconstruction of tracks using breakpoint fitter; finding the vertex position and estimating E_ν.

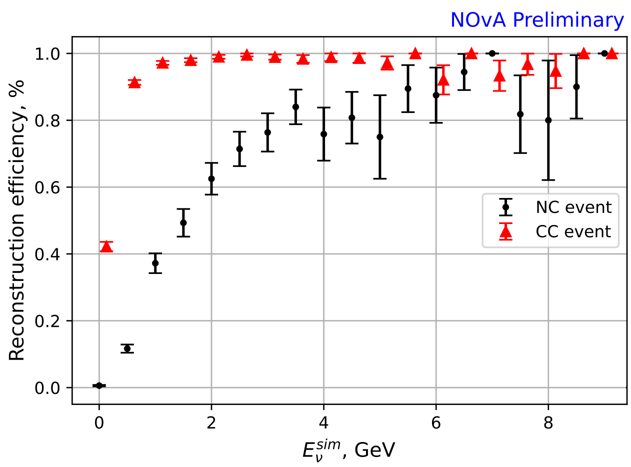

Fig. 4: Reconstruction efficiency vs E_ν for CC and NC events

This reconstruction procedure was applied to the generated signal sample, resulting in 45% reconstruction efficiency, integral over the all neutrino energies and flavors. The reconstruction efficiency for neutral (NC) and charged (CC) currents was built (Fig. 4). Efficiency for the CC events is mostly determined by the muon track reconstruction, therefore it becomes stable for the $E_\nu > 1\,\text{GeV}$, while for NC the event reconstruction depends on the hadronic shower energy, and has a stronger dependency on E_ν.

Conclusions

We present the current status of the atmospheric neutrino search in the NOvA far detector. A signal and background datasets were simulated. The signal sample was processed by the existing trigger algorithms, and the preliminary estimation of triggering efficiency is 11.7%. The presented event reconstruction technique was applied to the signal dataset, and efficiency was estimated for the charged and neutral currents interactions. As expected, the efficiency behaves almost stably for CC events, while the dependence on energy is observed for NC ones. The overall reconstruction efficiency is 45%.

In the near future it is planned to increase statistics of the signal and background samples, evaluate the efficiency of background rejection by the trigger and reconstruction procedures , create the procedure for the signal and background selections, and implement the dedicated trigger for the selection of atmospheric neutrino interactions in the future data.

REFERENCES

1. *Acero M.A. et al.* [NOvA Collaboration] Improved measurement of neutrino oscillation parameters by the NOvA experiment // Phys. Rev. D. — 2022. — V. 106, no. 3. — P. 032004. — arXiv:2108.08219.

2. *Honda M., Sajjad Athar M., Kajita T., Kasahara K., Midorikawa S.* Atmospheric neutrino flux calculation using the NRLMSISE-00 atmospheric model // Phys. Rev. D. — 2015. — V. 92, no. 2. — P. 023004.

3. *Green C., Kowalkowski J., Paterno M., Fischler M., Garren L., Lu Q.* The Art Framework // J. Phys. Conf. Ser. — 2012. — V. 396. — P. 022020.

4. *Andreopoulos C., others.* The GENIE Neutrino Monte Carlo Generator // Nucl. Instrum. Meth. A. — 2010. — V. 614. — P. 87–104.

5. *Agostinelli S. et al.* [GEANT4 Collaboration] GEANT4–a simulation toolkit // Nucl. Instrum. Meth. A. — 2003. — V. 506. — P. 250–303.

6. *Heck D., Knapp J., Capdevielle J.N., Schatz G., Thouw T.* CORSIKA: A Monte Carlo code to simulate extensive air showers. — 1998. — 2.

7. *Norman A., others.* Performance of the NOνA Data Acquisition and Trigger Systems for the full 14 kT Far Detector // J. Phys. Conf. Ser. — 2015. — V. 664. — P. 082041.

8. *Baird M., Bian J., Messier M., Niner E., Rocco D., Sachdev K.* Event Reconstruction Techniques in NOvA // J. Phys. Conf. Ser. — 2015. — V. 664, no. 7. — P. 072035.