DETECTION OF THE ATMOSPHERIC NEUTRINOS IN THE NOVA EXPERIMENT

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1. NOvA experiment. Problem descriptions

The NOvA experiment uses two detectors the NOvA near detector (ND) at Fermilab and the NOvA far detector (FD) at a distance 810 km in northern Minnesota weighing 14 kilotons and 300 tons respectively, to measure νe appearance in a narrow-band beam of νμ peaked at 2 GeV in energy. The detectors are made up of 344 cells of extruded, highly reflective plastic PVC filled with liquid scintillator.

When a neutrino strikes an atom in the liquid scintillator, it releases a burst of charged particles. As these particles come to rest in the detector, their energy is collected using wavelength-shifting fibers connected to photo-detectors. Using the pattern of light seen by the photo-detectors, scientists can determine what kind of neutrino caused the interaction and what its energy was.

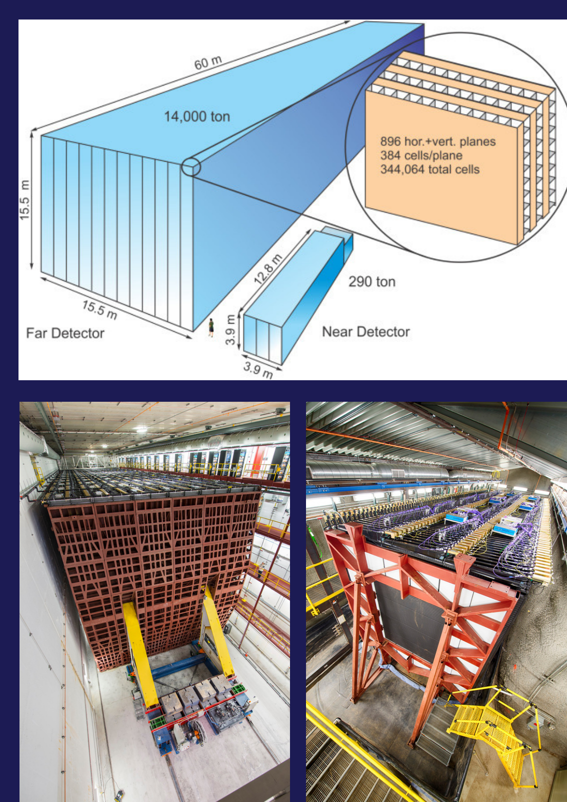

Fig.1 Far and near NOvA detectors

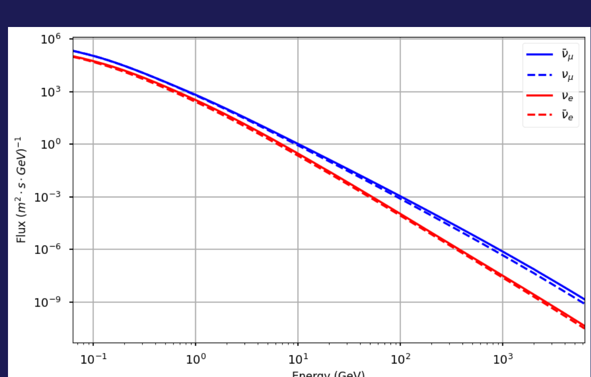

Fig.2 heoretically predicted neutrino flux

NOvA is aimed at studying neutrino oscillations, namely:

- determination of the neutrino mass hierarchy;
- definition of the octant θ_{23}, the refinement θ_{13};
- restrictions on the δ_{cp}.

The neutrino oscillations can be studied not only in beam events, but also in atmospheric ones. Atmospheric neutrinos are one of the main experimentally available sources of neutrinos observed in a wide energy range - from 100 MeV to 1 PeV scale. They are born after the interaction of primary cosmic radiation with the atoms of the atmosphere. The theoretically predicted neutrino flux is shown in the Fig.2. In addition, atmospheric neutrinos are the background for solving many additional physical problems, in particular, the search for Dark Matter particles or registration of the shadow from the Moon. In this regard, the task was set to measure the spectrum of the atmospheric neutrinos in the NOvA experiment.

2. Simulated signal/background database

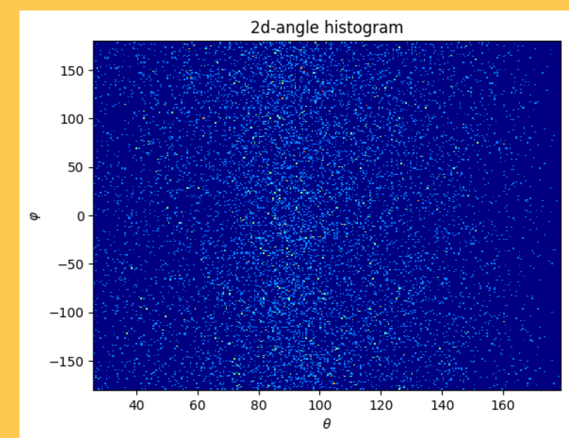

Fig.3 The angular distribution of the simulated events

NOvASoft software packages are used to generate the signal dataset of the atmospheric neutrinos νμ(ν̄μ) and νe(ν̄e). NOvASoft is based on the art software developed at Fermilab. NOvA uses the GENIE software package to directly simulate neutrino interactions. GENIE uses both theoretical models and experimental data on neutrino interaction cross sections.

10 thousand signal events were simulated from all directions(Fig.3).

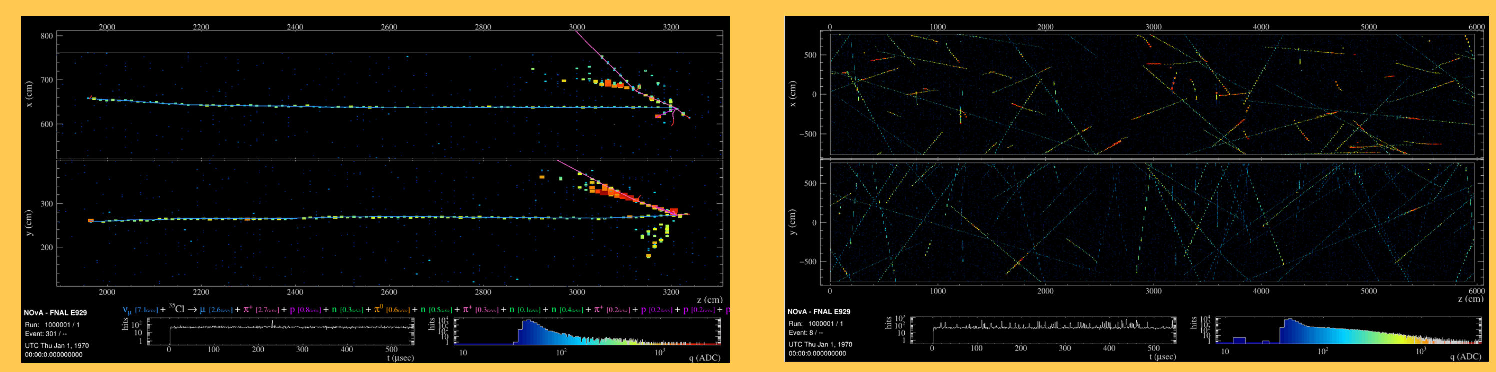

Fig. 4 The examples of the signal event from the atmospheric neutrino (to the left) and background one from the comic rays (to the right)

The interaction of particles with the substance of the detector is modeled using the GEANT4 software. The G4Event class, which uses the Geant4 tools, has programmed the geometry and substance of the detector through which neutrinos pass, as well as particle physics, which contains decays of secondary particles that generate neutrinos.

To simulate the background dataset, an example of which is shown in Fig. 4, the software package CORSIKA (COsmic Ray Simulations for KAscade) is a program for detailed simulation of extensive air showers initiated by high energy cosmic ray particles.

3. DDTriggers: description/selection conditions

After the generating the signal and background dataset, you need to have a procedure in place to select them. By default, such events are selected that coincide in time with the beam. For solving other tasks, there is a system of software triggers based on Data Driven Triggers (DDT) data. Their device is as follows. All data is written to a circular buffer and analyzed by fast algorithms that allow you to save the necessary data for later offline-analysis.

For analysis based on stored data, two triggers are considered: **Upmucontained** and **Neutronosc**, designed to search for the signature of their tasks, but allowing to separate νμ CC events (charged current) and νe NC (neutral current), respectively.

4. Reconstruction of the neutrino events

The main event identification algorithm used in the NOvA detectors is the CVN (convolutional neural network). The input is images of events in the detector in the form of fired cells, the energy release is indicated by the color intensity, and the result for each event is a number that determines the similarity of the event with one of 5 classes: νe, νμ, ντ , an event through neutral currents and cosmic muons. Fig. 4 shows the histogram of simulated and reconstructed events. The reconstruction efficiency is 45%.

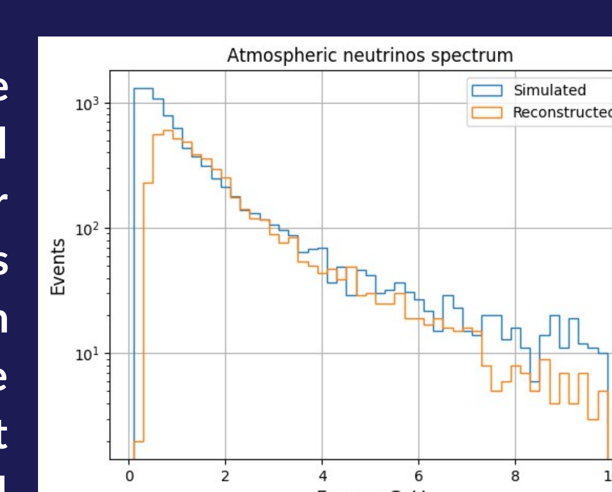

Fig. 5 Energy spectrum: the blue color shows simulated neutrinos, the orange – reconstructed ones

The reconstruction efficiency for neutral (NC) and charged (CC) currents were build (Fig. 6). On the left side for CC events the efficiency is stable, apparently everything is determined by the fact that the μ is being reconstructed. On the right side for NC ones the more Eν, the greater the efficiency.

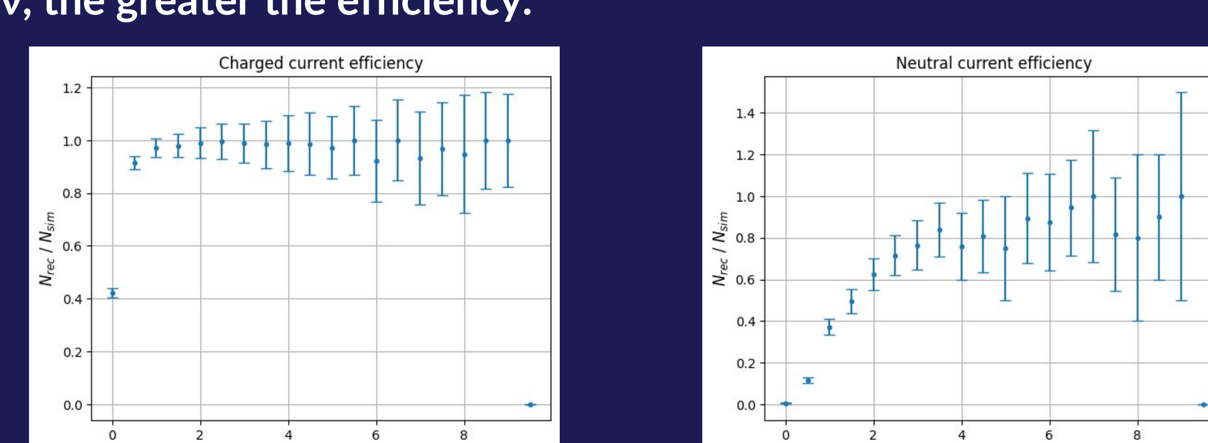

Fig. 6 The reconstruction efficiency vs Eν for νμ CC and NC

5. Summary

The registration of the atmospheric neutrinos in the NOvA experiment will allow:

- study the parameters of neutrino oscillations and carry out joint analysis with the accelerator neutrinos;

- use the flow of the atmospheric neutrinos as a background for various applied tasks: studying the magnetic moment of neutrinos, searching for Dark Matter and others;

- evaluate the signal received as a result of the interaction of the cosmic rays with the atmosphere of the Sun and the surface of the Moon.

It is planned to use the results of existing triggers to analyze the already collected data, whose effectiveness is to be evaluated. For future data, since the data set in the experiment will be carried out until 2026, it is expected to write own trigger.