Detection of Galactic Supernova Neutrinos at the NOvA Experiment

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Motivation

Supernova physics:
- Neutrino emission plays crucial role in the supernova explosion mechanism.
- Neutrinos produced in the early phases of the collapse carry information from the core.
- Existing models predict various neutrino luminosities & spectra.

Neutrino properties:
- Observable \( \nu \) flux is affected by many aspects of neutrino physics: neutrino mixing parameters, mass hierarchy, sterile neutrinos and others.
- Excessively dense neutrinos during the explosion make neutrino self-interactions important.

Challenging:
- Huge detectors are needed.
- Collaboration with other experiments → global network.
- Previously registered only once: SN1987a.
- Galactic supernovae are quite rare: \( \sim 1 \) event per century.

We need to be ready.

NOvA : NuMI Off-axis \( \nu_e \) Appearance

Primary goal: precise measurement of neutrino oscillation parameters, studying \( \nu_x \rightarrow \nu_y \) and \( \nu_y \rightarrow \nu_x \) oscillations in a CNO beam.

NOvA features two segmented liquid scintillator detectors of similar structure.

The NOvA detectors can be used to register the neutrino signal from the next galactic supernova, measuring the neutrino flux and providing the trigger signal to other neutrino experiments. The detailed description of the NOvA detectors can be found in [1].

Simulation of supernova neutrino interactions

A dedicated simulation package, \( \text{GeneNoV} \), was developed to simulate interactions of supernova neutrinos inside the NOvA detectors in a correct timing order, producing particles that can then be used in the full existing NOvA detector simulation chain.

The main signal signatures in the detector are a positron from BID process with energies up to tens of MeV and a 151 MeV photon from \( ^{12} \text{C} \) de-exitation. These particles produce small showers, which light up 1-4 scintillator cells, producing clusters of hits. In order to detect such candidates, we have to:

1. Reject the signals associated with muon tracks, Michel electrons, high energy showers and noisy electronic channels.
2. Find clusters of signals, close in time and space.
3. Request signals in both X and Y planes: reduce the background from electronic noise.
4. Apply fiducial volume cut: reject background from outside.
5. Select clusters in the amplitude range.

Selection of interaction candidates in NOvA Far detector

NOvA Preliminary

Using signal shape information, we can calculate the likelihood that the data follows expected shapes in time:

\[
\lambda_i = \log(1 + m_i S_i) - \log(1 + B_i) - \sum S_i
\]

Triggers are set when this LLR value exceeds a threshold.

Sensitivity to galactic supernovae

- SN1987a requires false trigger rate below 1/week.
- False trigger rate and LLR distribution for background define the triggering thresholds.
- Efficiency of supernova detection: probability for a SN signal to exceed the threshold.

Summary and current status

- The supernova triggering system is working on NOvA detectors since November 2017, with a false positive rate < 1/week. We plan to start sending trigger signals to SN1987a.
- Using the time profile of expected signal and the background distribution, the trigger can be sensitive to the supernova in the galactic center (7 kpc).
- The next upgrade of the system is planned for summer 2018. With improved reconstruction algorithms and monitoring systems, we expect to increase the stability and efficiency of the trigger.
- The \( \text{GENIE-based simulation package} \) for supernova neutrinos’ interaction is being developed. We plan to include more interaction channels and supernova models.
- An understanding of NOvA’s physics sensitivity and an offline analysis of the supernova neutrino signal is currently being developed.