NOvA in 10 minutes

Andrey Sheshukov
JINR, Dubna
Main goal: study of neutrino oscillations in a muon (anti)neutrino beam with $<E>=2$ GeV

Two detectors with similar structure: extruded PVC cells filled with liquid scintillator. The scintillation light is transported by the wavelength shifting fibers, then read by APD.

Large and segmented NOvA detectors provide both calorimetry and tracking information.
NOvA Near detector: 5ms time slice

- $M = 300$ ton
- $N_{\text{channels}} = 21504$
- Location: Fermilab 100m underground

15 meters
256 planes

3.9 m
96 cells/ plane
NOvA Far Detector: 5ms time slice

- $M = 14 \text{ kton}$
- $N_{\text{channels}} = 344064$
- Location: Ash river on surface

60 meters
896 planes

15.6 m
384 cells/ plane
Neutrino oscillations analysis

Comparing the measured events in Far Detector with the prediction based on the Near Detector allows to probe oscillation parameters.

Using both muon neutrino and antineutrino modes of the beam, NOvA is sensitive to: neutrino mass ordering, $\theta_{23}$, $\delta_{\text{CP}}$

Near + Far detectors: reduce the systematic errors from beam uncertainty, neutrino interaction cross-sections, detector effects.
NOvA analyses results

- $\Delta m^2_{23} = (2.41\pm0.07)\times10^{-3}\text{ eV}^2$
- $\sin^2\theta_{23} = 0.57^{+0.04}_{-0.03}$
- IH, $\delta = \pi/2$: excluded at $>3\sigma$
- NH, $\delta = 3\pi/2$: disfavored at $\sim2\sigma$

A dedicated test beam experiment is performed to reduce energy scale systematics
NOvA Data Driven Triggering

For beam analyses, the data is taken in coincidence with the beam spill.

Additional analyses require more complicated preselection of the data from the detector data stream.

Data Driven Trigger system: fast realtime reconstruction to decide which data should be saved.

Data is processed in parallel:
170 nodes * 13 processes, each processing a 5ms “milliblocks”

This allows to broaden the physics goals of NOvA:
- Studies of atmospheric muons
- Magnetic monopole search
- Detection of galactic supernova neutrinos
- Neutron-antineutron oscillations
- and others
Neutrino signal from the core-collapse supernova

Type II SN radiates ~99% of the collapse energy in neutrinos:

\[ \sim 10^{58} \text{ neutrinos: } E_\nu \sim 10^{-60} \text{ MeV within } T \sim 10\text{s} \]

Neutrino signal: probe of

- Neutrino properties
- Supernova properties

Galactic SN are very rare: \( \sim 1-3 \) per century!
(and have never been observed in the neutrinos in our galaxy)

Far Detector: 5ms of cosmic data + SN simulation
Signal selection

Our signal is small showers (light in 1-4 cells)

Remove all signals from known sources!

Among remaining signals find groups:

- Close in space: in the consecutive planes/cells
- In both \textbf{X} and \textbf{Y} cells (3d position)
- Close in time: \( DT < 62.5 \text{ ns} \)
Results of the neutrino candidates selection

In order to trigger on the galactic supernova neutrino signal, we need to observe the signal excess above the background fluctuations. This has to be performed in realtime.

If the observed signal significance exceeds threshold, the trigger saves the SN data for offline analysis.
Signal processing and triggering: example

Signal from $9.6M_\odot$ SN @ 5.0 kpc

Average background

Expected signal
Model independent

Maximum = 7.57 $\sigma$

Threshold...

Expected signal
SN from $9.6M_\odot$ star

Maximum = 8.34 $\sigma$

Threshold...

Expected signal
SN from $27M_\odot$ star

Maximum = 8.17 $\sigma$

Threshold...
Supernova significance vs. distance
NOvA supernova trigger sensitivity

[Diagram showing the distribution of supernovae from different types of stars in the Milky Way, with sensitivity levels indicated.]
BACKUP
Events classification

An approach from computer vision: convolutional neural network (CVN)

- Detector views of the contained event, associated with beam spill time: analyzed as image
- Learned features, corresponding to the considered event topologies
- Efficiency and purity: about 90%
Supernova trigger commissioning

Expectation:
stable trigger rate
1/week

Reality: supernova trigger is sensitive to instabilities of background:
- Run start instabilities
- Detector environment condition
- Noise channel masking failure

After fixing these problems:
- Filtering data with incomplete detector
- Strict data quality cuts
- Monitoring of NoiseMap service
Summary

● Real-time detection of SN signals is crucial for studying supernova.

● The dedicated SN triggering system extends the NOvA physical program.
  ○ Signal selection and reconstruction in real time.
  ○ Operating since Nov 2017, tuned to false triggering rate ~1/week.
  ○ Expected signal shape is used for hypotheses testing.

● SNEWS alert network was operating since 1998,
  ○ now SNEWS v2.0 is being designed.

● Proposed significance combination method (Stouffer’s weighted linear combination):
  ○ good for the case of high background experiments (like NOvA of Ice-Cube)
  ○ applicable for pre-supernova signals in low-BG experiments.

● Server prototype was developed and soon will be tested on NOvA detectors.
Supernova: a multi-messenger view
Supernova significance vs. distance: FarDet

![Graph showing significance vs. distance for different stellar masses and detection rates.](image)
Supernova significance vs. distance: NearDet

- **9.6M☉**:
  - 4.09 kpc
  - 4.75 kpc
  - 4.64 kpc

- **27M☉**:
  - 7.50 kpc
  - 7.92 kpc
  - 8.08 kpc

- **Expected signal**: Model independent 1σ
- **Expected signal**: SN from 9.6M☉ star
- **Expected signal**: SN from 27M☉ star
SuperNova Early Warning System

A global network to make sure we don’t miss a galactic event.

Neutrinos arrive several minutes to hours prior to optical signal

SNEWS works since 1998
A planned upgrade of SNEWS: in progress

A joint effort to build a new system, combining significance and parameters estimation measurements in real-time.

Status: design and prototyping.
Many exciting tasks ahead!
SN neutrinos interactions in the NOvA Detectors

Main detection channels:

- **Inverse Beta Decay**
  - signature: positron shower (10-60 MeV)

- **Neutral Current**
  - signature: deexcitation gamma (15.1 MeV)

Other channels give negligible contribution: energy too low or small interaction rate.
Our signal is small showers (light in 1-4 cells)

Remove all signals from known sources!

Using Hough transform

Muon tracks and surroundings, to reject michel electrons
Signal selection

Our signal is small showers (light in 1-4 cells)

Remove all signals from known sources!

Using noisy channels map, updated every hour

Noisy channels

SIMULATED HITS
BACKGROUND HITS
Signal selection

Our signal is small showers (light in 1-4 cells)

Remove all signals from known sources!

High energy atmospheric showers!

By energy deposit peaked in time
Signal selection

Our signal is small showers (light in 1-4 cells)

Remove all signals from known sources!

Among remaining signals find groups:

- Close in space: in the consecutive planes/cells
- In both $X$ and $Y$ cells (3d position)
- Close in time: $DT < 62.5$ ns

Select the signal region in the light amplitude: ADC counts
Signal processing and triggering: example

Trigger system needs to distinguish between $H_0=\text{Bg}$ vs $H_1=\text{Bg+SN}$ hypotheses.

Easiest thing: just look for the N events in a sliding time window. Easy. But:

- Short window (1s): we lose a lot of signal
- Long window (10s): we gain a lot of background

But we can use also the knowledge of the signal shape.

We use log likelihood ratio, to enhance the hypotheses discrimination:

$$\ell(\vec{n}) \equiv \log \frac{P(\vec{n}|H_1)}{P(\vec{n}|H_0)} = \sum_i n_i \cdot A_i, \text{ where } A_i = \log \left(1 + \frac{S_i}{B}\right)$$