EXPLORING EXOTIC AND NON-STANDARD PHENOMENA IN THE NOVA EXPERIMENT

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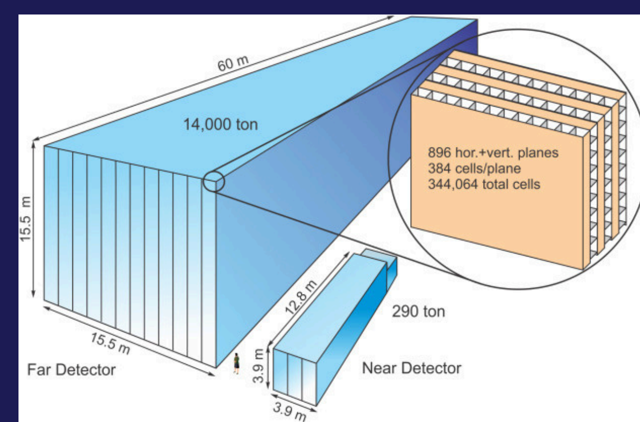
Particle Physics

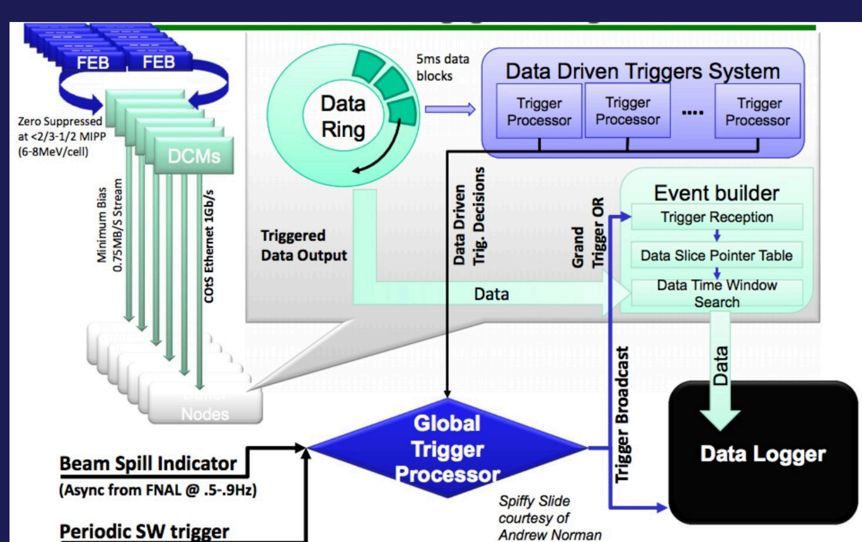
1. NOvA experiment

The NOvA experiment:

- two detectors:
  - near detector (ND, 300 tons) at a distance of 1 km from the neutrino source at Fermilab;
  - far detector (FD, 14 kilotons) at a distance of 810 km, in the state of Minnesota.
- to measure ν_e appearance in a narrow-band beam of ν_μ peaked at 2 GeV;
- PVC tubes filled with liquid scintillator based on mineral oil.



Far and near NOvA detectors



Data Acquisition System in NOvA

Data Driven Triggers (DDT)

- For solving tasks beyond basic analysis
- By default, events are selected that coincide in time with the beam

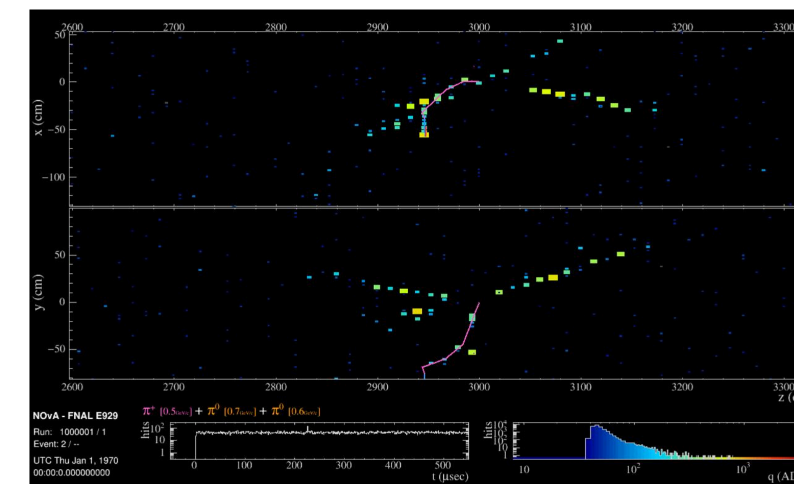
All data is written to a circular buffer and analyzed by fast algorithms that allow you to save the necessary data for later offline analysis.

2. Neutron-antineutron oscillation

- The NOvA experiment has potential for the search for neutron-antineutron oscillation, using "NNBAR" trigger
- The trigger system was developed to collect signal-like events in the FD
- After successful deployment, this system has been operating smoothly for nearly seven years, providing a large dataset
- This dataset is critical not only for the neutron oscillation search but also for various other analyses involving exotic physics phenomena

FUTURE WORK

- Background modeling including real data from atmospheric and cosmogenic neutrinos
- Improving of signal event reconstruction and identification methods
- Finalising of the analysis, including prediction and calculation of systematic uncertainties

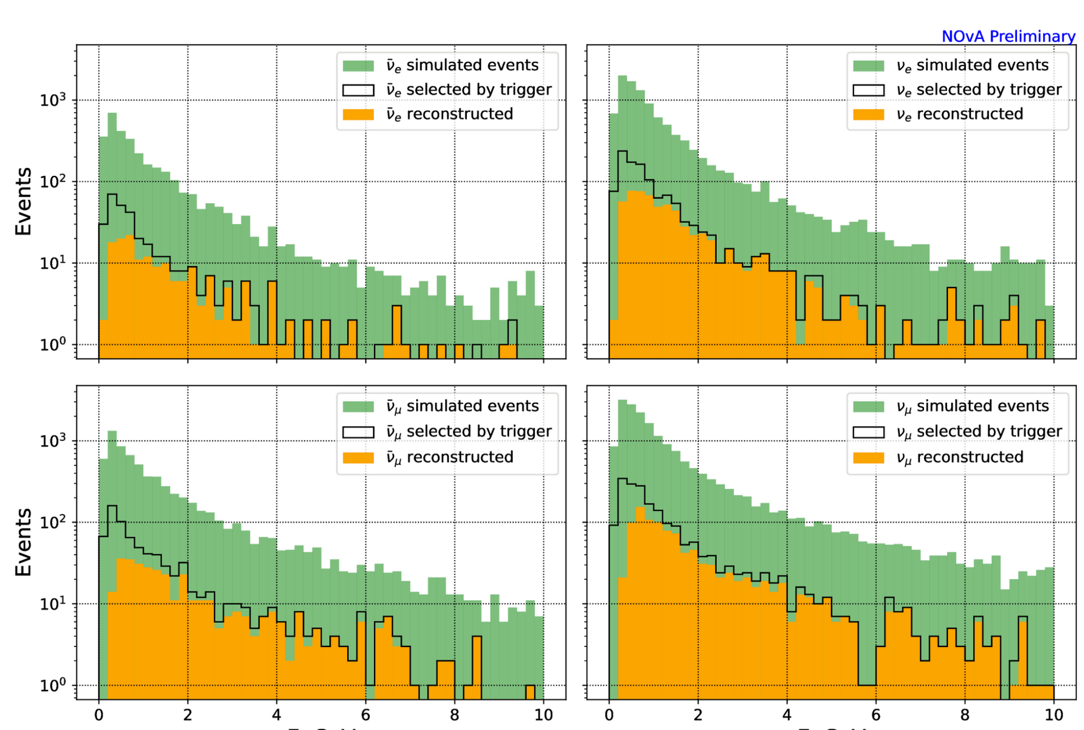


The event example in NOvA simulation

3. Atmospheric neutrinos

The procedure is proposed to search for atmospheric neutrino interactions in the NOvA dataset:

- 40k atmospheric neutrino interactions were simulated in FD (9.2 years)
- After selection by the "NNBAR" trigger ~ 11% of events
- After applying the standard reconstruction procedure to the "NNBAR" algorithm dataset ~ 6% (250 events per year)

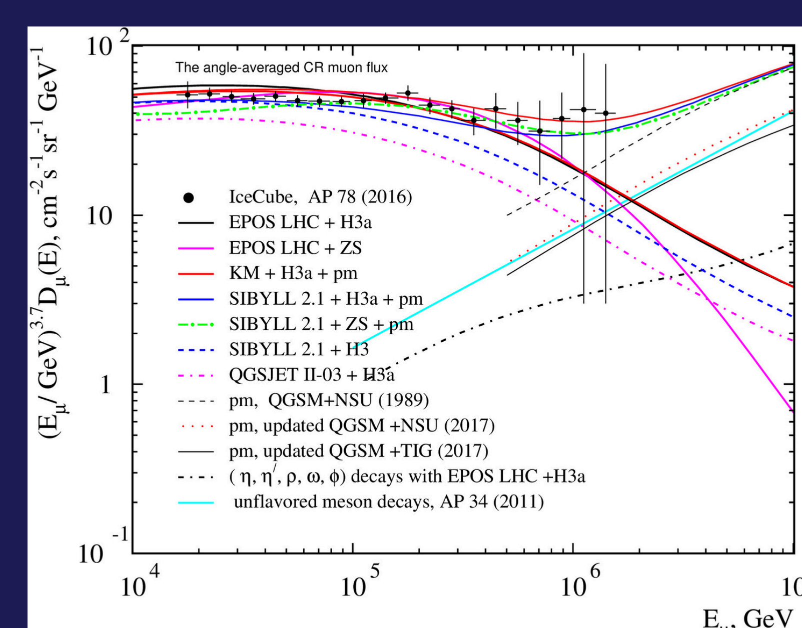


The distributions represent different types of observed atmospheric neutrino events

FUTURE WORK

- Analyze existing experimental data ("NNBAR") using the proposed procedure
- Create a background suppression procedure based on the reconstruction
- Make a dedicated trigger for the future dataset

4. Atmospheric high energy muons



The angle-averaged CR muon flux

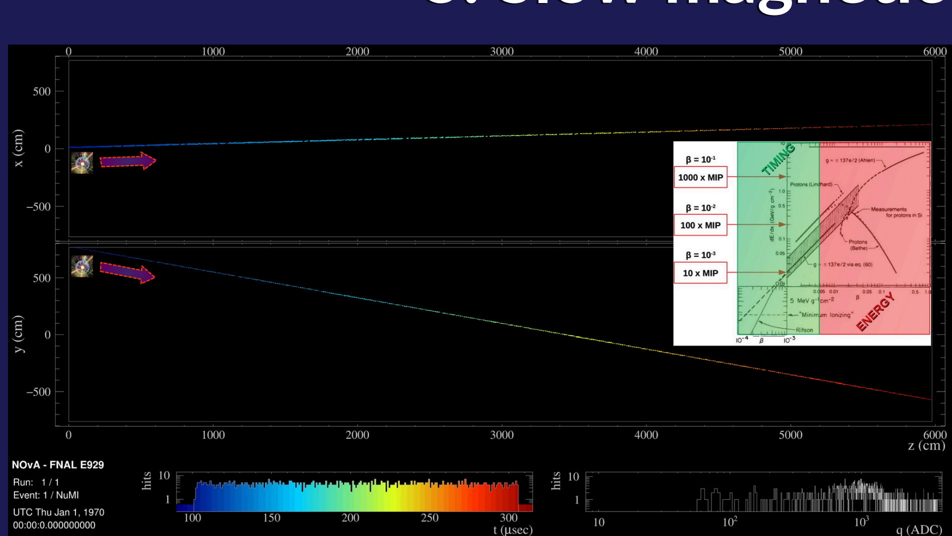
- atmospheric muon flux is a tool to study the cosmic ray (CR) spectrum and elemental composition.;
- provide information on the mechanisms of charm production in hadron-nuclear collisions;
- verify of neutrino event reconstruction data in neutrino telescopes.

- Based on Pairmeter method NOvA's algorithm selects processes such us direct production e^+e^-, ionization, bremsstrahlung, muon nuclear interaction and gives an estimate of the dE/dx limits for each of processes at different muons energy
- The analysis will provide a spectrum of atmospheric muons and compare it with current experimental data

FUTURE WORK

- Improve the algorithm for selecting muon processes
- Test selection on real data and reconstructed E

5. Slow magnetic monopole



- Slow monopoles with β {v/c} < 10^{-2} and less can be identified due to their linearity with long transit time through the detector
- Search algorithm consists of primal trigger (DDT) along with pre-selection and final reconstruction

- Analysis will give the monopole discovery or the flux limit
- Their existence would explain the quantization of electric charge
- It is possible to restore symmetry between electricity and magnetism
- Magnetic monopole naturally appears in Grand Unified Theories (GUT)

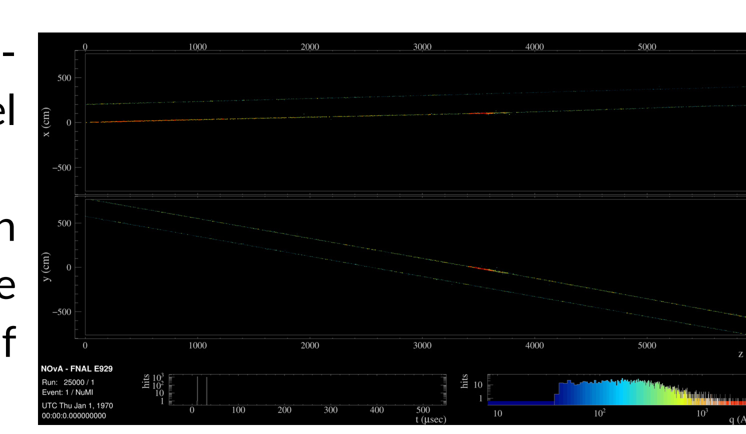
FUTURE WORK

- Final testing of signal event reconstruction algorithm
- Finalising of the analysis, including evaluation of total dataset lifetime (estimated flux limit) and calculation of systematic uncertainties.
- CNN implementation for the slowest monopoles (β ~ 10^{-4}) identification.

6. Weakly Ionising fractionally charged particles (FCP)

The discovery of FCP can provide non-perturbative information about Standard Model (SM) physics.

Light FCP's lose energy more slowly than minimally ionizing particles such as muons. The result is a difference in the time of flight of each.



FUTURE WORK

- Investigate the lightly ionizing particle (LIP) properties and make the isotropic simulation.
- Evaluate the energy deposition cut for muon and LIP separation.

- Assumption: the existence of composite objects with a large (10^{12} GeV) confinement scale.
- Search FCP using detector gratings, special methods: levitometer and Millikan oil drop method, see [1].

	Experiments	Fractional charge (e)	Upper limit ($cm^{-2}sr^{-1}s^{-1}$)
Underground	LSD	2/3	2.7 $\times10^{-13}$
	Kamiokande II	1/3	2.1 $\times10^{-15}$
	MACRO	1/4 - 2/3	6.1 $\times10^{-16}$
In-space	AMS01	2/3	3.0 $\times10^{-7}$
	BESS	2/3	4.5 $\times10^{-7}$
	DAMPE	2/3	6.2 $\times10^{-10}$

The table summarizes the results of various experiments to search for fractionally charged particles

[1] Cai, None, et al. (DAMPE Collaboration). Search for relativistic fractionally charged particles in space. Phys. Rev. D, 106(6), 063026 (2022).

CONCLUSION

The NOvA experiment demonstrates its potential not only for studying neutrino oscillations, but also as a powerful tool to search for a variety of exotic phenomena. The presented analyses on atmospheric neutrinos, magnetic monopoles, high-energy muons, low-ionization particles, and neutron-antineutron oscillations are actively underway and allow us to look beyond the known models. Further results of these searches can significantly expand our understanding of the fundamental laws of physics.

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