Slow magnetic monopoles search in NOvA

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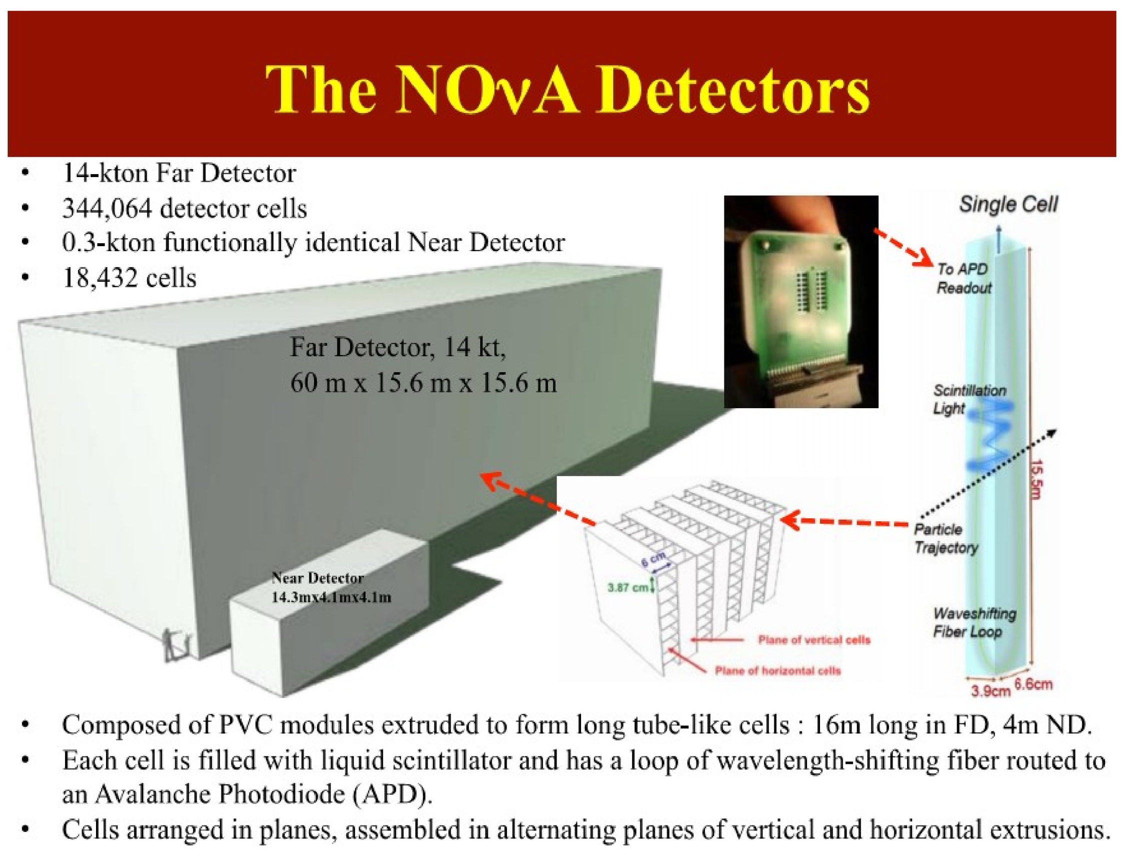
Abstract

The NOvA far detector (FD) is well suited for finding exotic particles due to its specific technical features. With a surface area of 4,000 m^2 and a location near the earth's surface, the 14 kt FD provides unique sensitivity to potential low-mass magnetic monopoles at subluminal velocities (v < c/100). As a whole, slow monopole analysis can lead to a discovery, or it can limit the existence of such monopoles in a wide range of parameters, previously unreachable in other experiments (MACRO, SLIM, IceCube). The main challenge of this analysis is to distinguish monopole-like patterns from the speed-of-light cosmic ray (around 148,000 Hz) and other background sources. Several special software tools have been developed. Slow monopole trigger has been created and implemented for primary events selection and offline reconstruction algorithm has been developed and tested for effective selected signals analysis. Preselection algorithm has been developed, tested and implemented like the middle step between primary monopole-like patterns selection and final analysis.

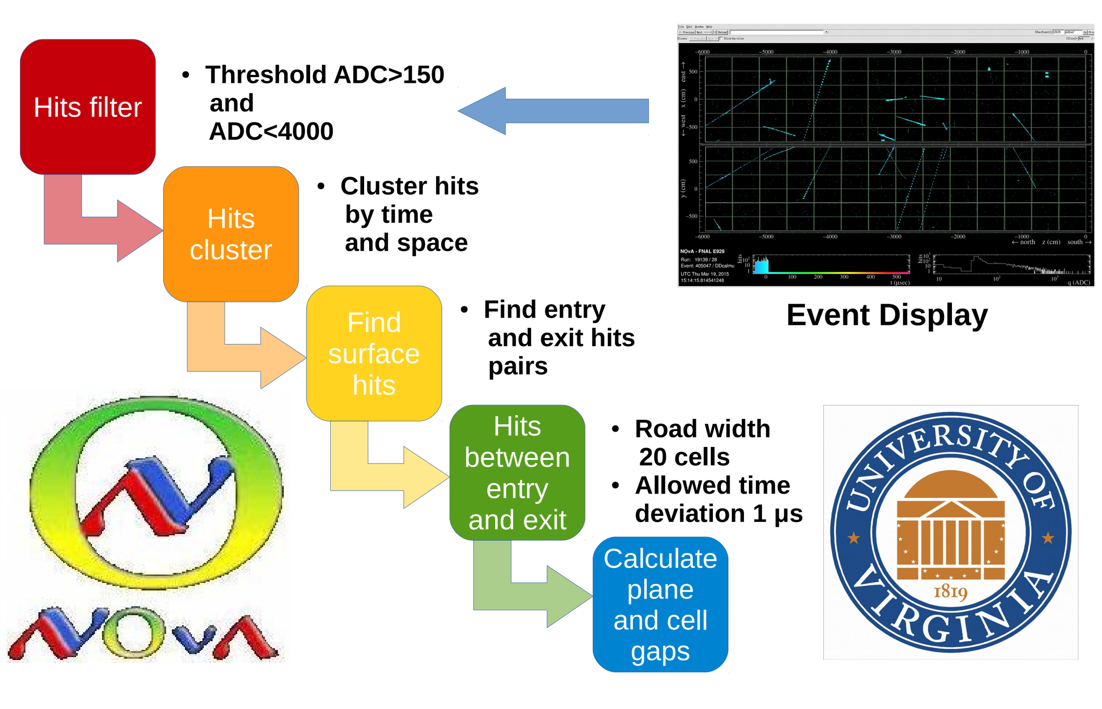
The NOvA Experiment

NOvA is a long-baseline neutrino experiment that was built to study various parameters of neutrinos.
The NOvA experiment uses two detectors: a 330 metric-ton near detector at Fermilab and a much larger 14 metric-kiloton far detector in Minnesota just south of the U.S.-Canada border. The detectors are made up of 344,000 cells of extruded, highly reflective plastic PVC filled with liquid scintillator. Light from the scintillator is captured by the fibers and is transmitted to an Avalanche Photodiode (APD). Fibers from 32 cells are grouped on one APD board. Each cell in the far detector measures 3.9 cm wide, 6.0 cm deep and 15.5 meters long. The far detector itself measures 15.6×15.6×60 meters.
Such a large and sensitive detector has never been constructed so close to the Earth's surface. It is a good opportunity to detect lighter monopoles which do not penetrate far into the earth, even with the problem of cosmic background due to the large size of our detector and sufficient accessible angular region.

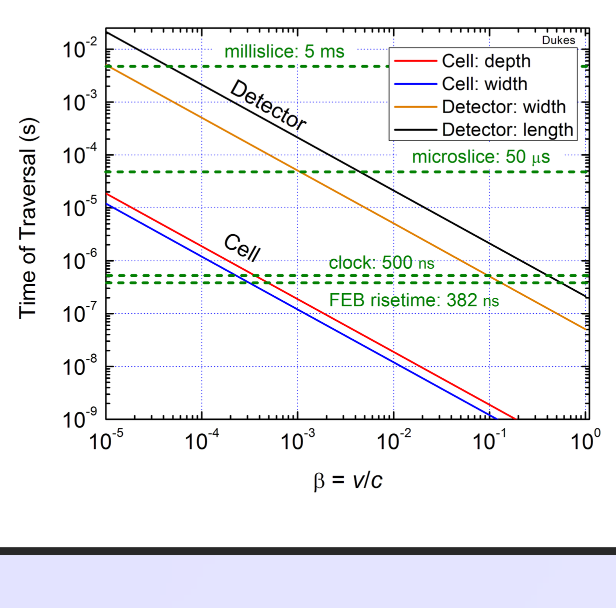


Slow monopole Trigger

Slow monopole trigger is a part of NOvA Data-Driven Trigger (DDT) system. In a nutshell, trigger looks at the live data and tries to identify straight lines of hits that would be consistent with a slow track. Events stored by slow monopole trigger are used like the starting point for our analysis chain.



I would like to thank **Enhao Song (University of Virginia)** for providing me with the information about this trigger.



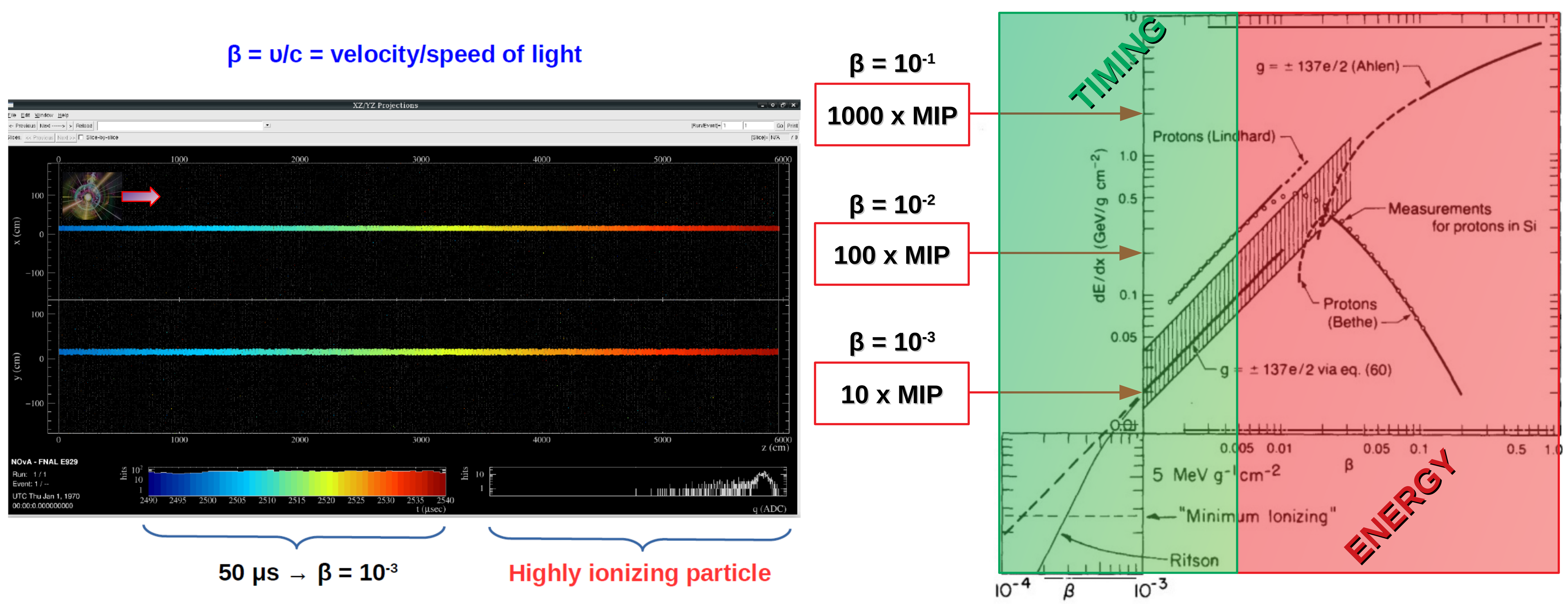
Why are we interested in monopoles?

Quantum mechanical formulation of the magnetic monopoles was made by Paul Dirac in 1931. Searches for these particles are very important for several reasons:

* Their existence would explain the quantization of electric charge.
* It is possible to restore symmetry between electricity and magnetism by means their introduction into the theory of electromagnetism.
* Magnetic monopoles naturally appears in Grand Unification Theories (GUT).

Searching strategies in NOvA

The Dirac's electric charge quantization relation says $e \times g = n \times \frac{\hbar c}{2}$, where e is a basic electric charge and n is an integer. It means that magnetic monopoles could have a magnetic charge (g) 68.5 times greater than the charge of the electron. As the result they are expected to be very highly ionizing. For example, for $\beta = 10^{-3}$ one can expect ionization 10 times larger then for the cosmic muon (see the right figure). We call this muon MIP (Minimum ionizing particle) due to it's mean energy loss rate through matter.
"Slow" monopoles with $\beta < 10^{-2}$ and less can be identified due to their linear tracks with long transit times through the detector. In the left figure one can see a software visualization of the Far detector and the monopole in it's center. The monopole's energy in this case is almost at the ADC saturation limit (12 bits – 4096 counts). In terms of energy it is more then 650 MeV.
Monopoles with $\beta = 10^{-3}$ take 5 μs to cross the whole detector in comparison with cosmic muons, which take only 50 ns.



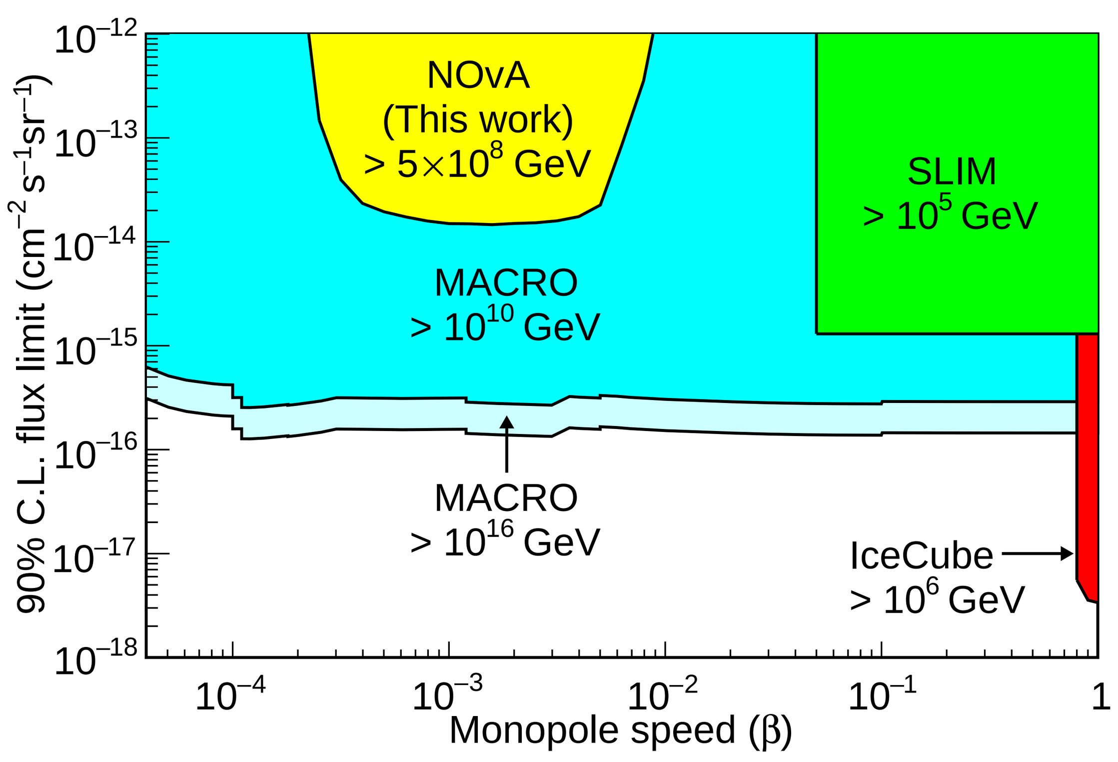
Offline reconstruction

The Far Detector electronics collect data in two projected views separately, the xz- and yz- views. The y-direction is the vertical dimension while the z-direction points along the neutrino beam. Analysis algorithm starts by extracting two-dimensional information from each view separately and then combines this 2D information into 3D objects known as monopole tracks. Reconstruction algorithm structure:

- Monopole cluster
  - Cosmic Ray Removal
  - Low Energy Hit Removal
  - Isolated Hit Removal
- Monopole Slice
- Monopole Track
  - High Energy Slice Removal
  - Hough Tracking
  - 2D Track
  - 3D Track
- Analysis module

In a nutshell, analysis algorithm removing all of the speed-of-light rays to form a single monopole cluster. This cluster is then divided into several monopole slices. Finally, we look for track-like objects in the monopole slices and form monopole tracks.

NOvA Sensitivity - First results



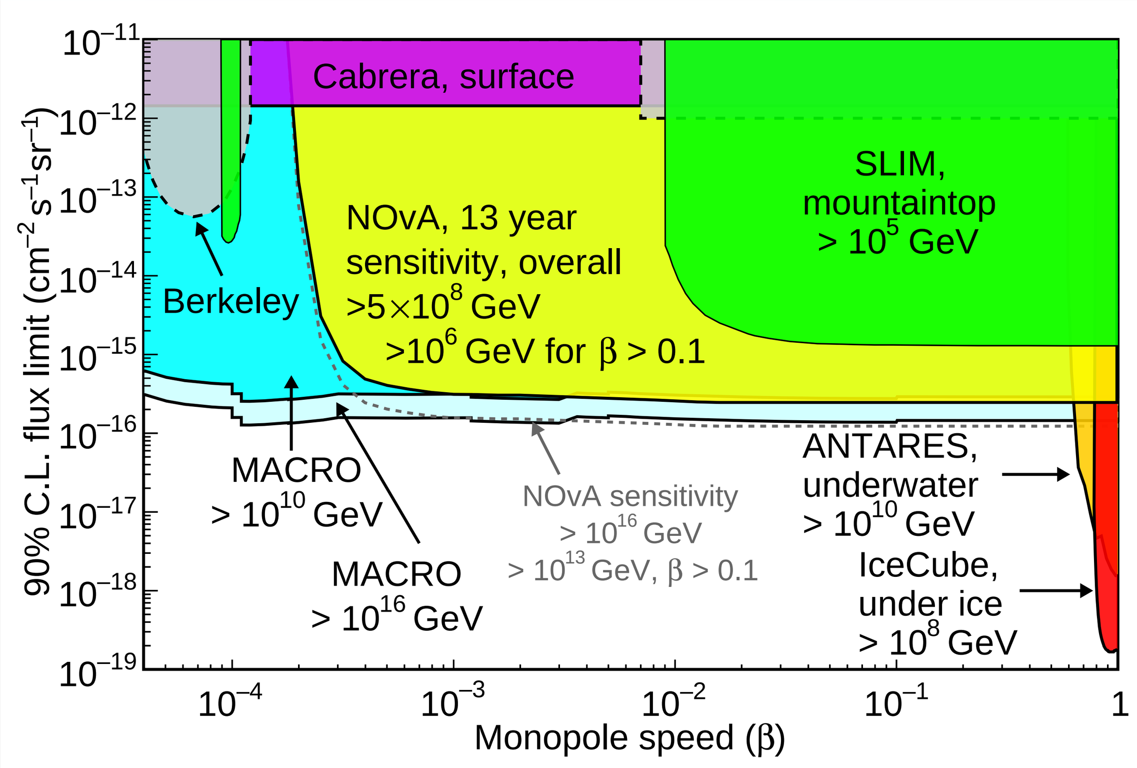
We have constrained the flux of this population of monopoles in a large region of speed-mass space which has previously been unconstrained, setting an upper limit on the flux of $2 \times 10^{-14} cm^{-2}s^{-1}sr^{-1}$ at 90% C.L. for $6 \times 10^{-4} < \beta < 5 \times 10^{-3}$.

Pre-Selection

We used **reconstruction algorithm** like the basis and added several modifications. The main goal is to decrease the resulting dataset size and events count by removing obvious background. Another important parameter is the status of events – the primary raw/root files are stored on magnetic tapes and we have to request them for analysis. This process is slow and you can spend more time waiting but not analyzing. The pre-selection procedure moves the resulting files to an easily accessible disk and we can analyze them at any time.

- **Events that timed out removal**
- Monopole cluster
  - ...
- Monopole Slice
- Monopole Track
  - ...
- **Pre-selection analysis module**
- **Pre-selection filter module**

NOvA Sensitivity - Future plans



Data of 13 years run would give an estimated flux limit of $4 \times 10^{-16}\ cm^{-2}s^{-1}sr^{-1}$ for monopoles with $3 \times 10^{-4} < \beta < 0.8$.

Conclusions

The NOvA Far detector is pretty sensitive to lighter monopoles, and has the unique potential to "touch" a new region of phase space due to it's location on the surface and large surface area. Pre-selection algorithm is a powerful tool that helped to lower the size of final dataset (**filtered**) for more than **20** times.

Acknowledgments

This work was supported by the Russian Science Foundation under grant #**18-12-00271**