Fast Software Trigger Algorithms To Search for Magnetic Monopoles With the NOνA Detector

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On Behalf of the NOνA Collaboration

1. The NOνA Detector

The 14 kt far detector, located at Ash River, MN, is a highly segmented X/Y rangestack/calorimeter using liquid scintilator filled detection cells. When completed it will be the largest self supporting plastic structure in the world.

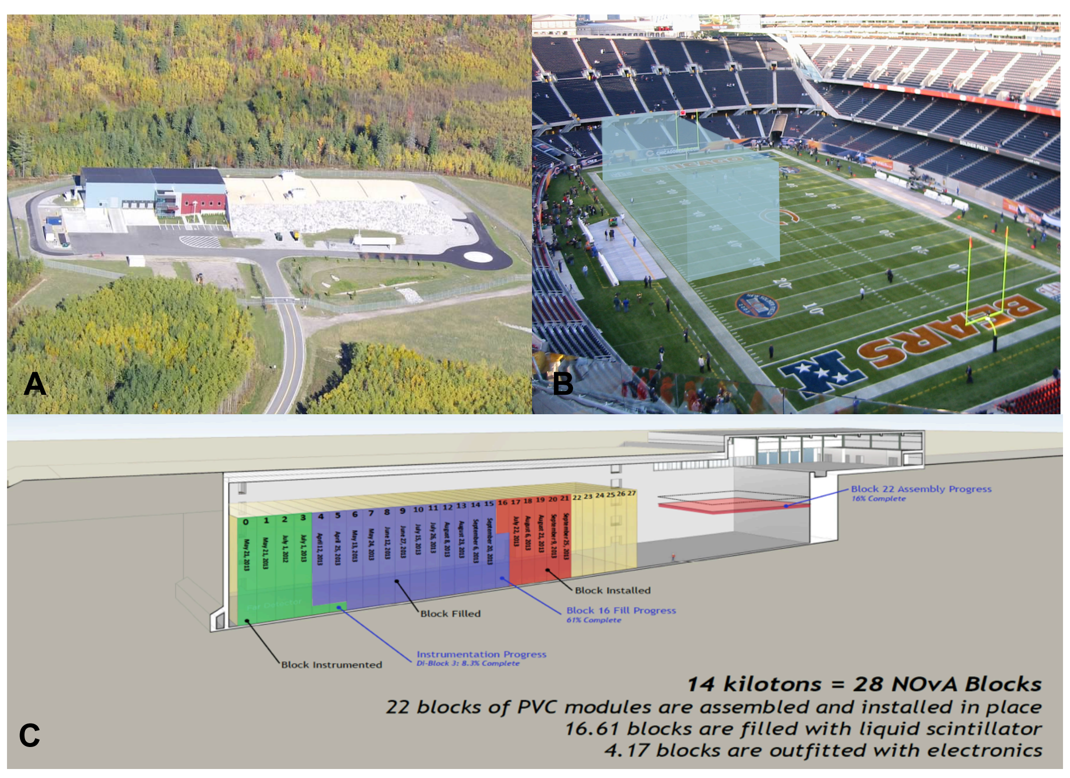


Figure 1: (A) The top view of the detector site at Ash River. (B) A scale of the entire effective region of the detector compared to a football stadium. (C) Current status of detector construction.

Each of the 340,000 detection cells is a 15.6 m long extrusion filled with a mineral oil based scintillator and a wave-shifting fiber readout.

The trajectory of a charged particle is determined as it passes through adjacent horizontal and vertical planes, as shown in the layout picture below.

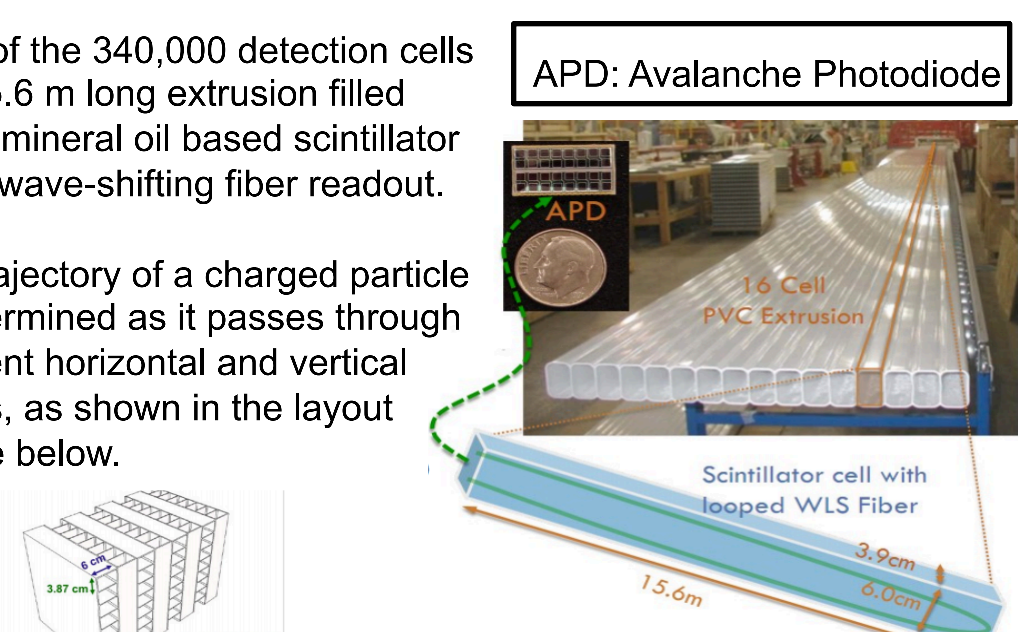


Figure 2: NOνA readout cell

2. Magnetic Monopole Simulation & Searching Strategy

Theoretic predictions for the mass and velocity distributions of relic magnetic monopoles are highly model dependent. The NOνA detector, due to its surface location, physical size, timing characteristics, energy response threshold and continuous readout design, is sensitive to the detection of GUTS scale monopoles from $\beta=10^{-1}$ down to $\beta=10^{-5}$. Several tracking algorithms are needed to spam the entire β range.

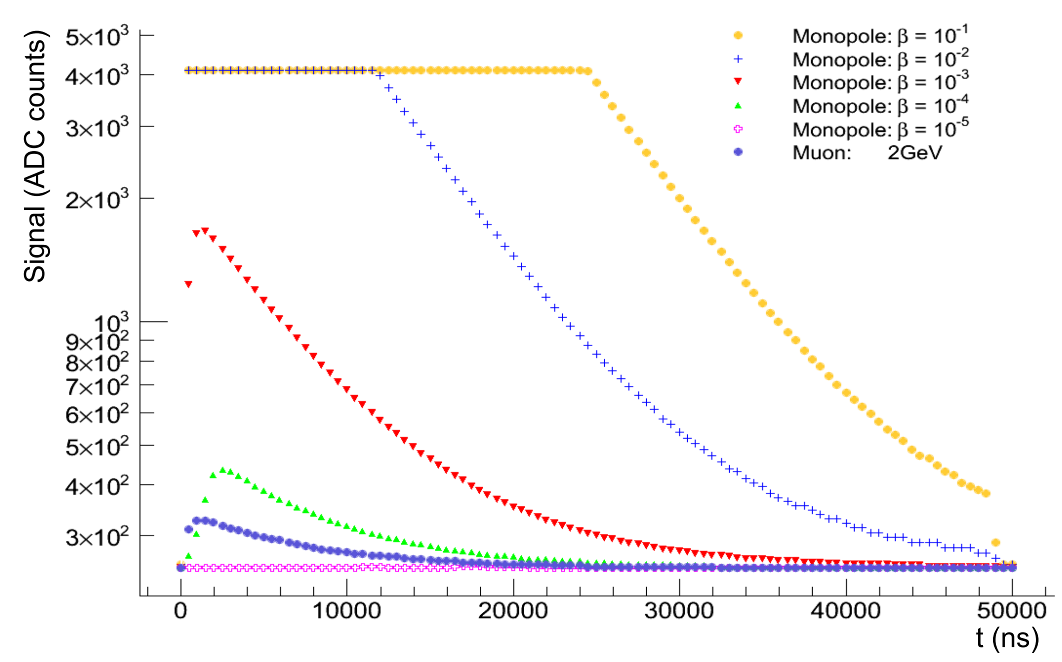


Figure 3: Electronics response of the front end electronics for monopoles crossing a detector cell. Fast (high β) monopoles are characterized by large energy depositions, close to or exceeding the dynamic range of the ADCs.

Monopole Signatures

Fast Monopoles ($\beta > 10^{-2}$) are identified by their high energy deposition as they cross the detector. This leads to well defined linear tracks with large numbers of channels at or near saturation of dynamic range of the front end ADCs. This energy deposition is >10 X the typical minimum ionizing cosmic ray.

Slow Monopoles ($\beta < 10^{-2}$) are identified by their well defined linear tracks with long transit times across the detector. A $\beta = 10^{-2}$ monopole takes 5 μs to cross from the bottom to the top of the detector. A cosmic ray muon takes only 50 ns to cross the detector.

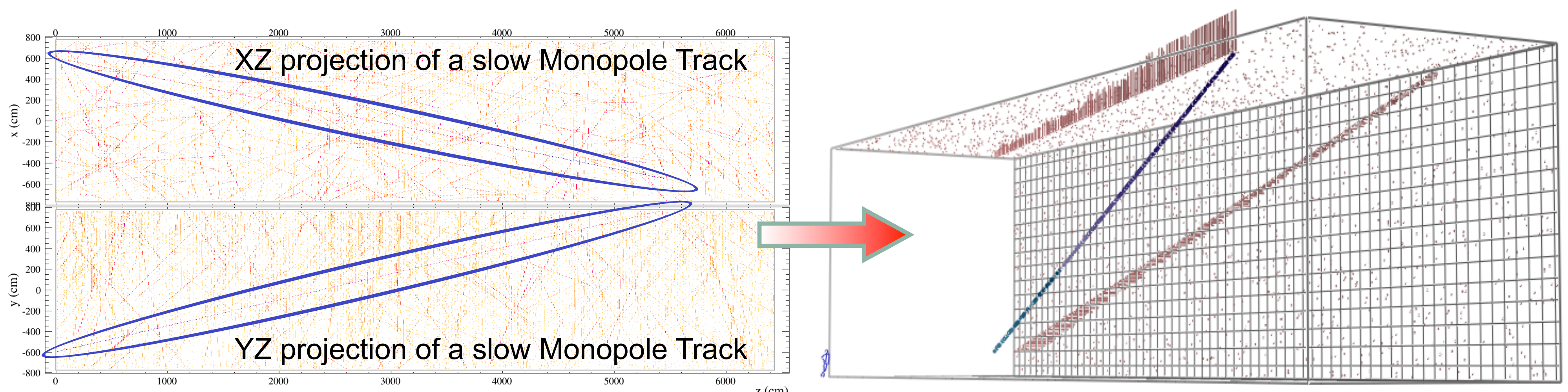
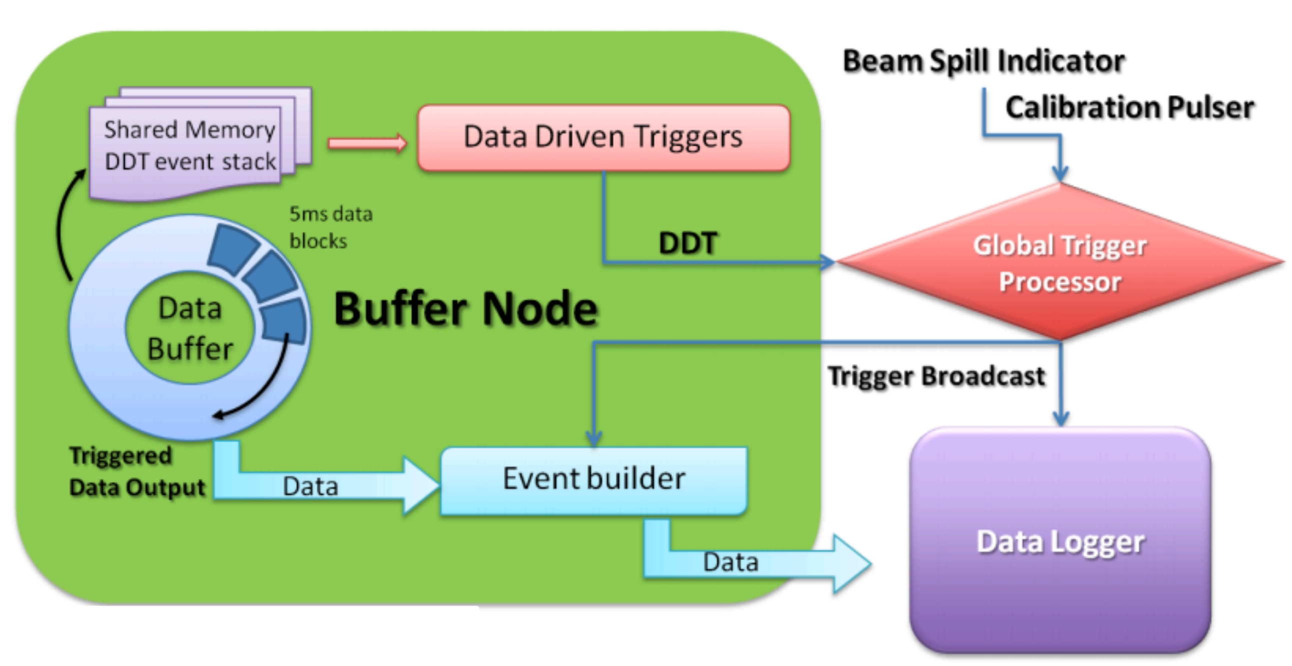


Figure 4: Simulation of a magnetic monopole with mass = 10^{16} GeV/c^2 and $\beta = 10^{-3}$ against a 5-ms readout window dominated by cosmic rays and detector noise. The monopole track is easily separable from cosmic ray background due to timing and pulse height information. The 3D trajectory is reconstructed from the 2D projections of the XZ and YZ views.

3. Data Driven Trigger (DDT) Topology

The NOνA readout design streams the continuous digitization of the detector in large 5-ms time windows to a large farm of commodity computers. This farm buffers several seconds of raw data. While the data is still in the active memory buffers a series of analysis processes operate on the data in parallel to the DAQ event builders and examine the data for physics signatures of interest. The analysis processes are then able to issue "data driven triggers " to the full DAQ system which initiate data extraction and logging from the buffers.



4. Algorithm of the Slow Monopole Trigger: 3D Hough Transform

Global pattern recognition is used to extract slow monopole tracks from the prompt cosmic ray background in each 5-ms readout window. This is done by performing a pairwise transformation of the hit data to a traditional 2D (linear) Hough space and then simultaneously introducing a 3rd parameter to the Hough transform that represents the temporal propagation of the track through the space. This results in a mapping of all tracks into well defined peaks in the 2D space, and clouds in the 3D space. The fast (β=1) cosmic ray backgrounds give hit clusters along the 1/v = 0 plane in the 3D space. These hits are filtered out to allow for the identification of the slow monopole track candidates from the remaining peaks in the Hough space.

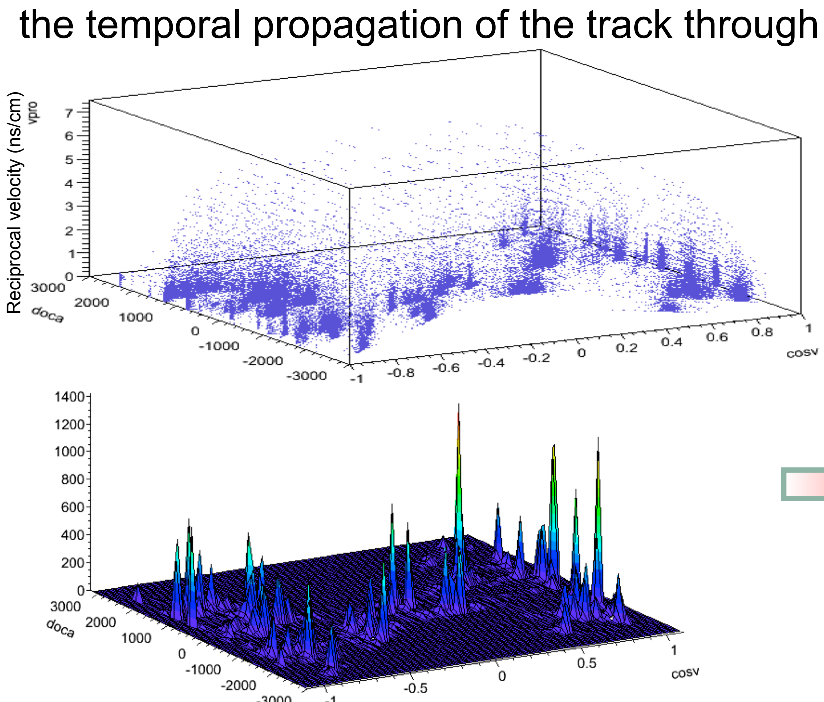


Figure 6: 2D (bottom) and 3D (top) Hough spaces corresponding to the global tracking information in the detector. Cosmic rays are characterized by hit clouds near the 1/v=0 axis in the 3D space.

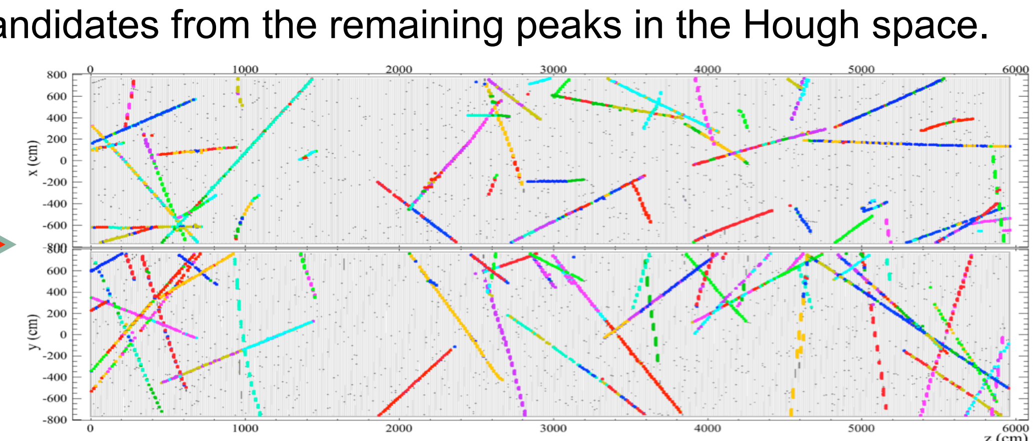


Figure 6: Pattern recognition track candidates after pre-filtering removal of β=1 cosmic rays hits from the 3D Hough space. Remaining candidate tracks are fed to reconstruction algorithms.

5. Algorithm of the Fast Monopole Trigger

Fast monopoles (unlike slow monopoles) can have extremely high energy depositions when crossing a single detector cell. The signals (E > 10X MIP) produce large ADC values (energy) on the front end boards. This is easily distinguished from cosmic ray background and from single channel noise. Under these conditions the trigger can use a faster (than Hough Transform) pattern recognition chain.

Slicing — 1. Hits are sorted and grouped according to the time stamp and detector location. Track seeds–"slices" are formed from these groupings.

Crossing Criteria — 2. High β monopoles are not likely to range out inside the detector (unlike much of the cosmic ray background), so a "through going" criteria is placed on the track seeds.

Trigger Decision — 3. Two trigger thresholds are placed on the track seeds, a minimum number of high ADC hits and minimum ADC per hit in the slice to decide whether this slice contains a monopole candidate.

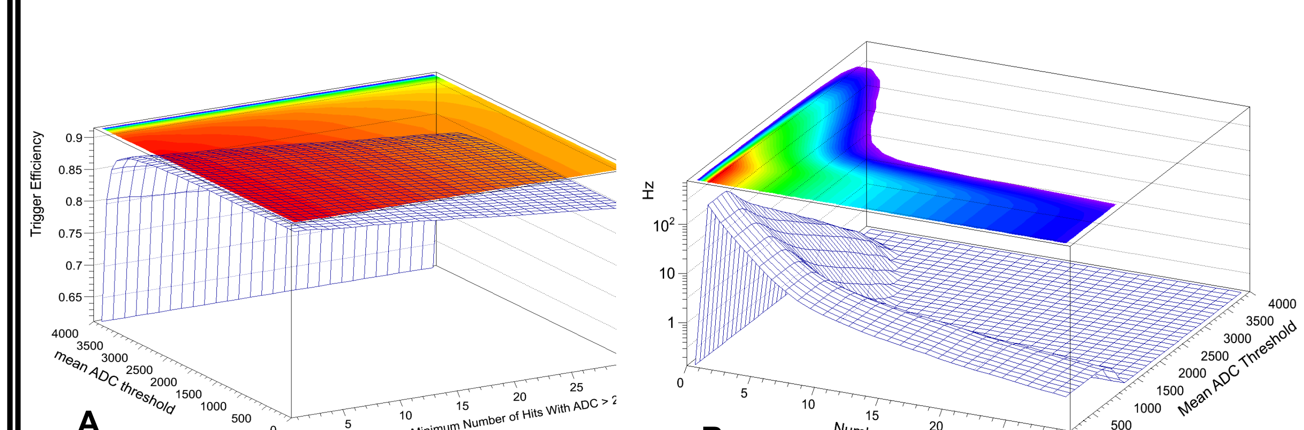


Figure 7: The fast monopole trigger, as one of the first implemented data driven triggers, has been tested with a large number of simulated isotropic fast (β>0.01) monopoles overlaid with cosmic rays and noise hits. The trigger efficiency as a function of both trigger thresholds (A) and the projected trigger rate as the function of the ADC thresholds (B) under normal cosmic ray backgrounds.