Galactic Supernova Neutrino Detection with the NOvA Detectors

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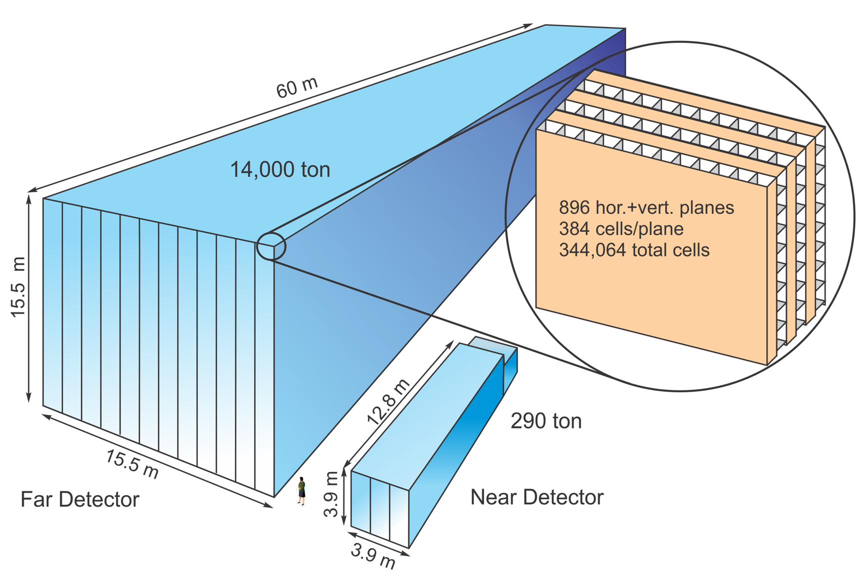
THE NOvA DETECTORS



NOvA consists of two detectors; both are functionally equivalent.

The far detector (FD) is 14 kt and sits on the Earth's surface. The near detector (ND) is 290 tons and is 105 m underground.

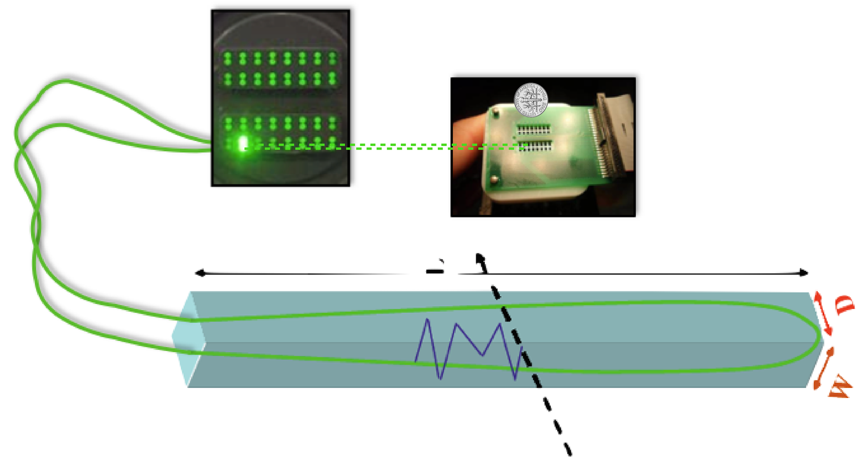
Extruded PVC cells are filled with liquid scintillator. A wavelength-shifting fiber is looped through the length of the cell and the ends are fed into an avalanche photo-diode (APD).

Multiple cells are joined together to form a plane, and multiple planes are joined together to form the full detector. Planes alternate orientation, providing two orthogonal views (XZ & YZ) of detector activity.

Cells dimensions are 3.6 cm x 5.6 cm. Good for tracking electron tracks and showers.

Timing resolution is a few 10's of ns.

Background rate from noise and cosmic activity at FD ~150 kHz.



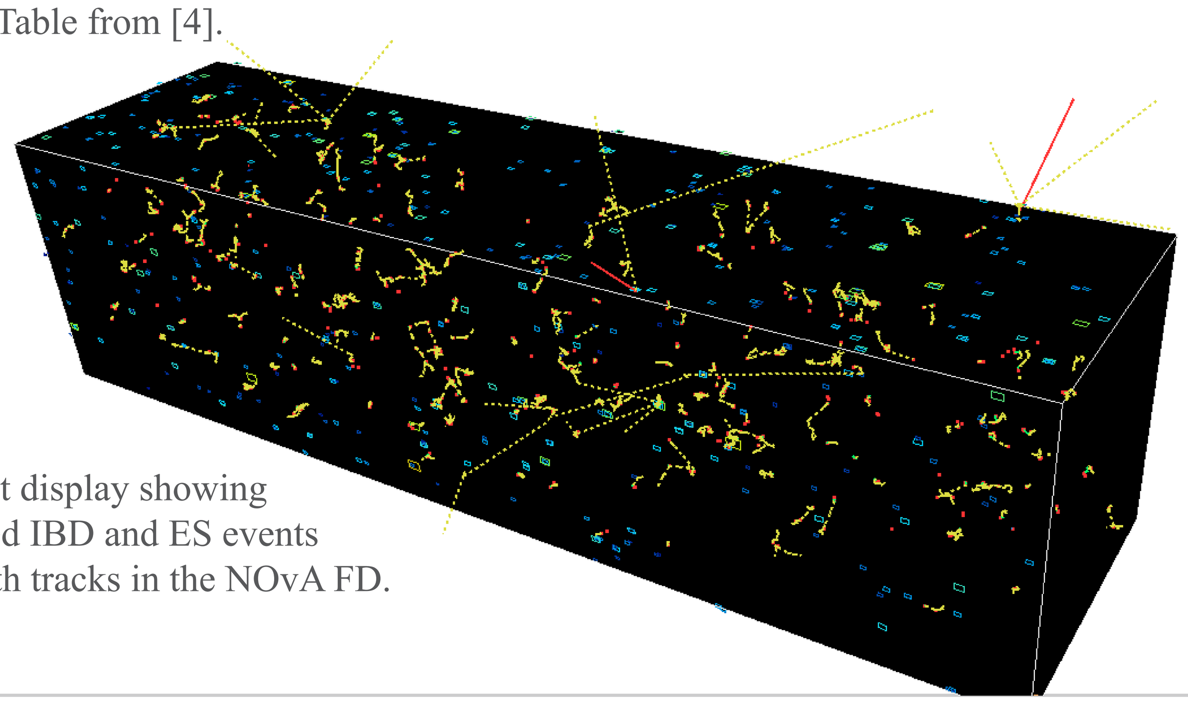
Schematic of a single NOvA PVC cell. Scintillation light is emitted and absorbed by a wavelength-shifting fiber. The light is directed to an avalanche photo-diode whose accumulated charge is digitized and shaped by front-end board electronics (not shown).

CORE-COLLAPSE SUPERNOVAE

For a 10 kpc supernova, we expect a few x 10^3 interactions to occur in our detectors, though some fraction of those will be below detection threshold. The dominant interaction channel is inverse beta decay (IBD).

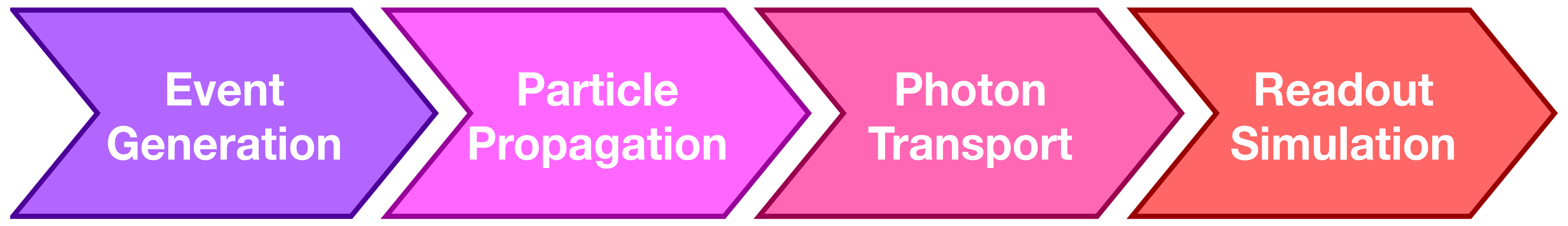
Interaction channel	Far Detector 9.6 $M_\odot$	Far Detector 27 $M_\odot$	Near Detector 9.6 $M_\odot$	Near Detector 27 $M_\odot$
Inverse beta decay	1593	3439	24	51
Elastic scattering on e^-	143	259	3	5
Neutral current on ^{12}C	67	166	1	3
Total	1803	3864	28	59

Estimated average number of neutrino interactions in the NOvA detectors for dominant interaction and detection channels for Garching [2] supernova neutrino flux simulations from 9.6 $M_\odot$ and 27 $M_\odot$ progenitor stars at a distance of 10 kpc. Table from [4].



3D event display showing simulated IBD and ES events with truth tracks in the NOvA FD.

SUPERNOVA SIMULATION



Event Generation — *GENIE*
We use GENIE [1] as an event generator for the production of secondary particles. Inputs include the SN neutrino flux, interaction cross sections, detector geometry, and maximum path-lengths.

Particle propagation — *Geant4*
The GENIE output is piped into Geant4 [3] to propagate the secondary particles throughout the detector geometry.

Photon Transport — *Custom*
Charged particles deposit energy in the scintillator which is released as photons and ultimately absorbed by the fiber and transported to the APD. The production of photons and their subsequent transport and attenuation is simulated at this stage.

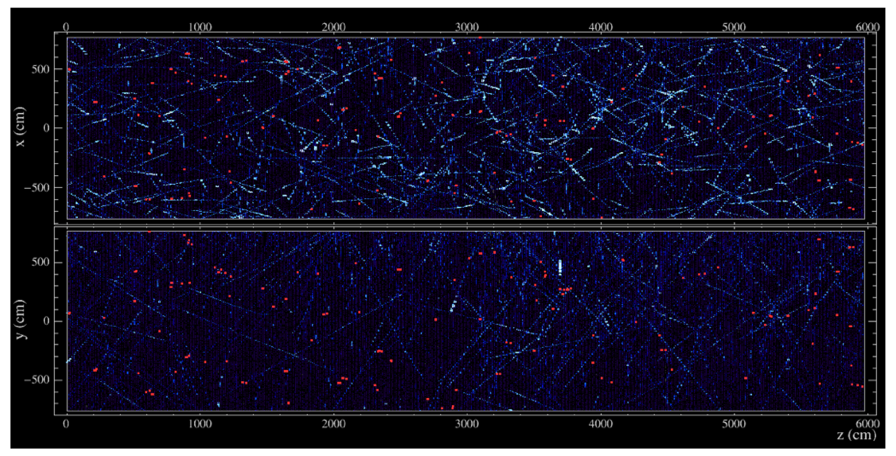
Readout Simulation — *Custom*
Simulation of detector APD and electronics response to the light.

BACKGROUNDS

Once per day we trigger detector readout on a heartbeat from SNEWS. This is identical to the type of readout we would do in the event of a true SNEWS alert.

This provides us with a library of minimum-bias, background-only data, which we overlay with the MC files, thus eliminating the need for simulating background.

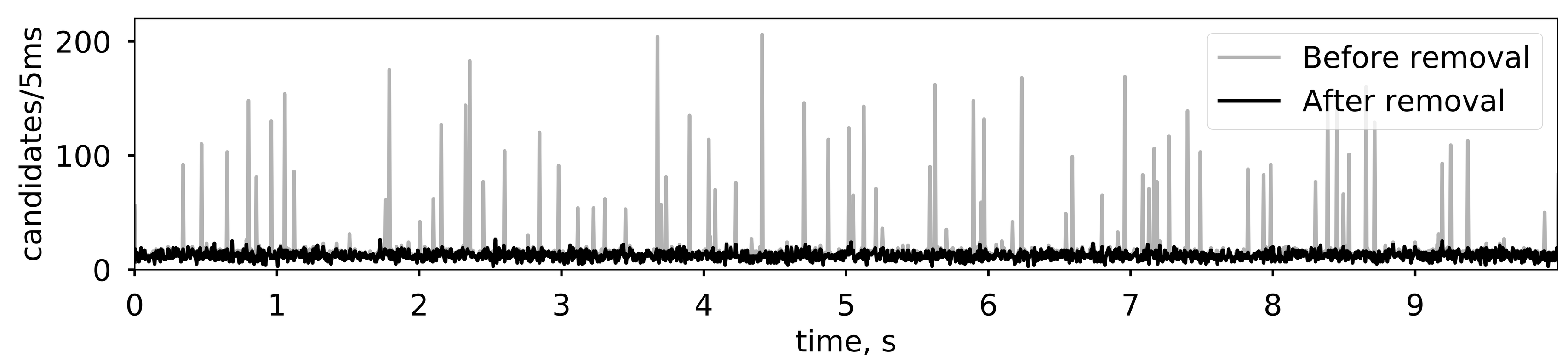
Before attempting to look for a SN signal in the data, we remove all known and identifiable background sources.



Event display showing MC hits (red) overlaid with real detector minimum-bias data (blue) at the far detector.

Known Background Sources

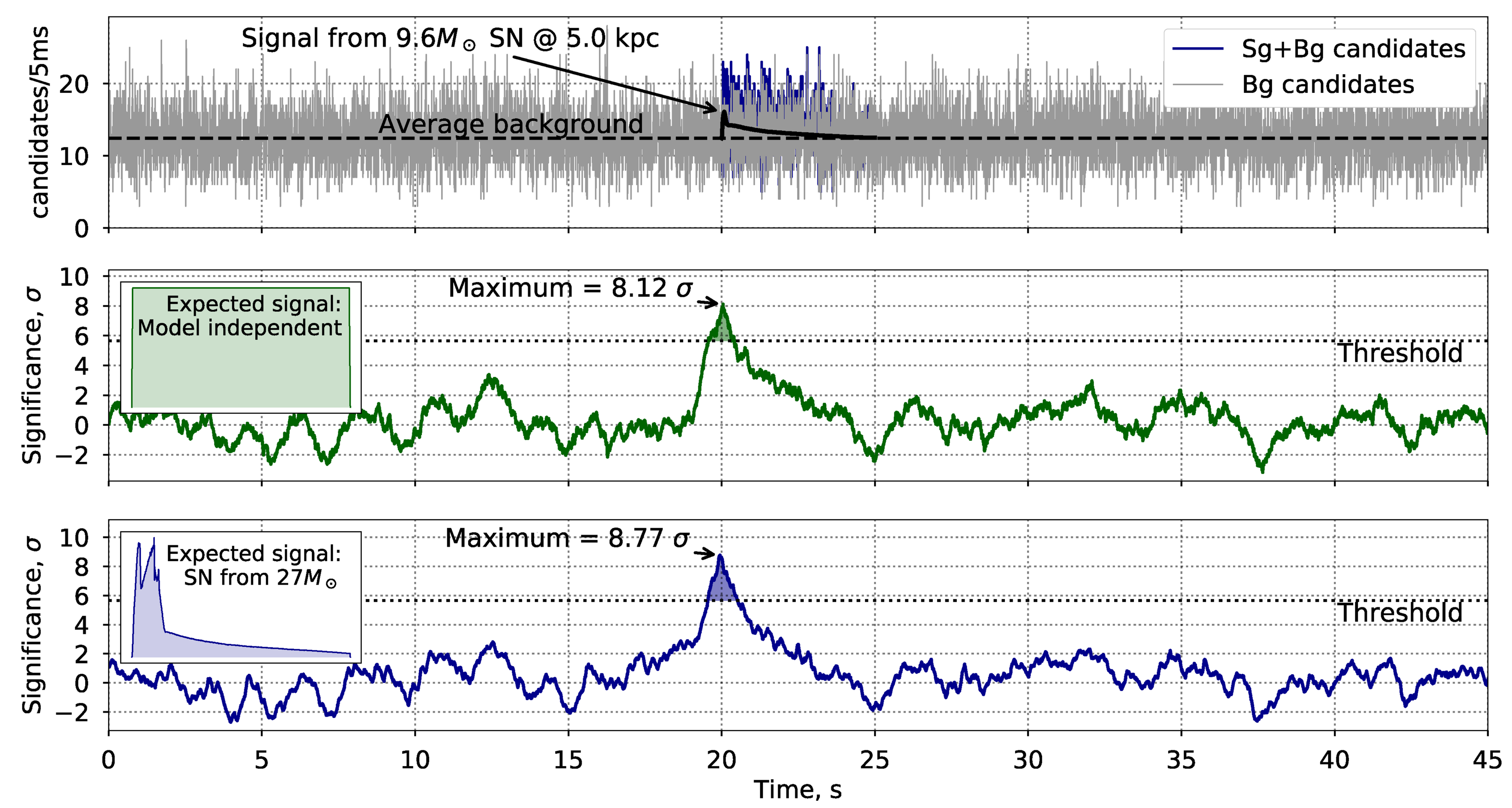
Bad Channels
Excessively noisy or quiet channels
Electronic ringing effects ("FEB Flashers")
High/low ADC hits
Cosmogenic activity



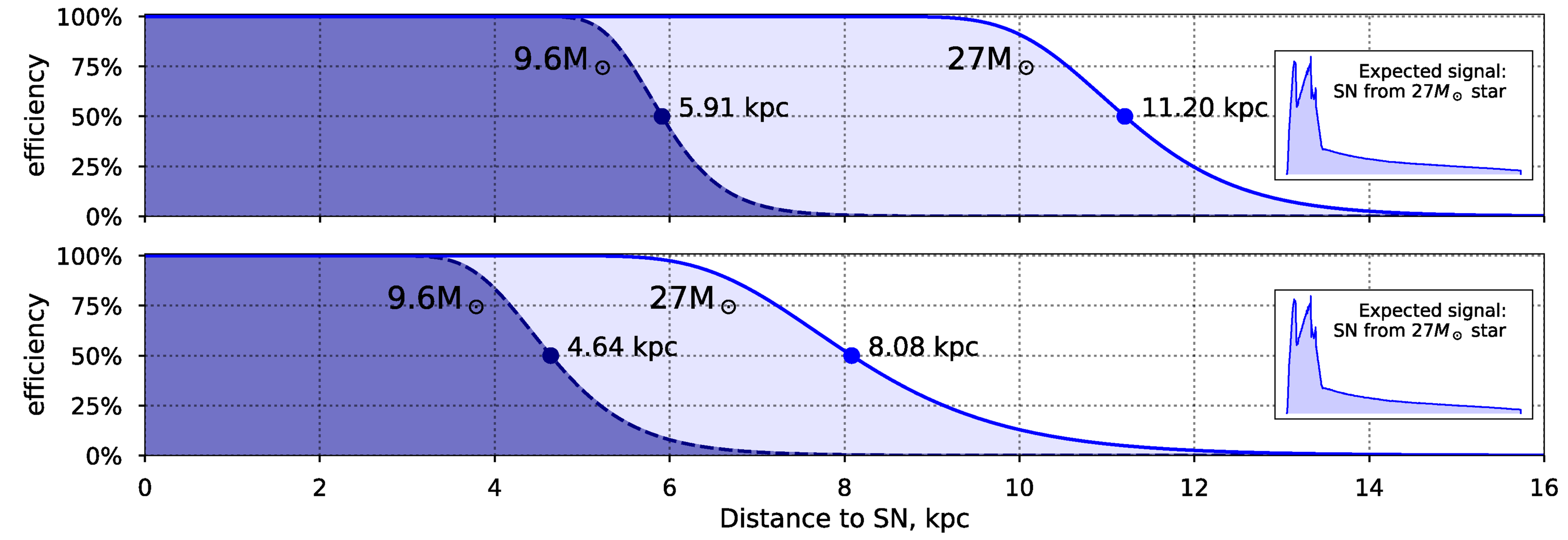
A time series of potential SN neutrino candidates seen at the Far Detector, before and after removal. The background can easily be removed by cutting out the peaks, causing 0.15% deadtime. Figure from [4].

TRIGGERING ON SUPERNOVAE

Live data from both detectors is monitored by a data-driven supernova trigger process, which removes known backgrounds and clusters remaining hits by proximity in time and space. A log likelihood ratio hypothesis test is performed on the data in a sliding 5 s window, which produces a significance of matching an expected signal shape. A trigger is issued when the significance exceeds a specified threshold, and 45 s of continuous data are read out to disk. A complete description of our SN trigger is available at [4].



Example of the trigger system detecting a simulated 5 kpc supernova signal. The top time series of neutrino candidates per 5 ms bin in the Far Detector shows the location and size of an injected signal. The next two time series are significances of the data matching expected signal shapes (flat and expected 27 $M_\odot$ progenitor) starting at that point in the time series, expressed as Gaussian sigmas. Models are from [2]; figure is from [4].



NOvA's sensitivity to a galactic supernovae vs. distance by supernova model and expected signal shape for the Far (top) and Near (bottom) Detectors. The fraction of supernova occurrences for which the signal probability would be above threshold is plotted as a function of distance for the model of a 27 $M_\odot$ progenitor. Figure from [4].

ONGOING & FUTURE WORK

Hits from an IBD positron tend to occur within 150-250 ns of each other, and are spatially compact, usually only spanning several cells or planes. Based on this topology we cluster low-ADC hits which occur close in space and coincident in time.

Recent attempts to separate signal and background clusters have achieved a signal-to-noise ~1:1.7 at the Far Detector and ~3:1 at the Near Detector for a 2 kpc supernova, and work is ongoing to optimize this process. Such improvements to reconstruction and signal discrimination will be used to enhance the sensitivity of the trigger and any offline analysis of a real supernova event.

REFERENCES

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http://novaexperiment.fnal.gov

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