Supernova neutrinos at NOvA

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NuMI Off-axis ν_e Appearance (NOvA)

Two highly-active liquid scintillator detectors

- *Far Detector:* 14 kton located at Ash River, MN
- *Near Detector:* 300 ton located at Fermilab

NOvA is designed for...

- *2 GeV narrow-band neutrinos*
- *well-known arrival time of pulsed neutrino beam*
- *reading out data in <= 5ms chunks*

A burst of supernova neutrinos would be...

- *10s of MeV*
- *Unpredictable; could happen anytime*
- *Plays out over 10s of seconds*

There are technical challenges to overcome in order to make NOvA a supernova neutrino detector.

The NOvA Detectors

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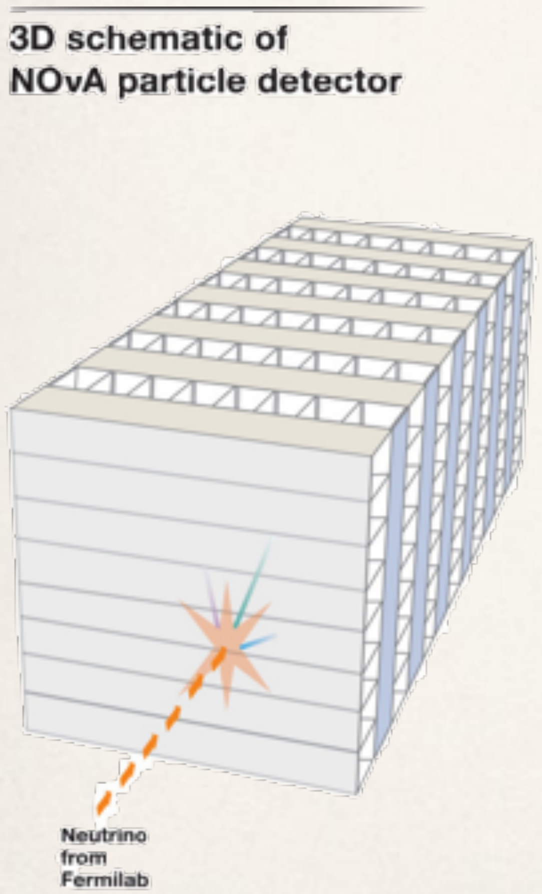
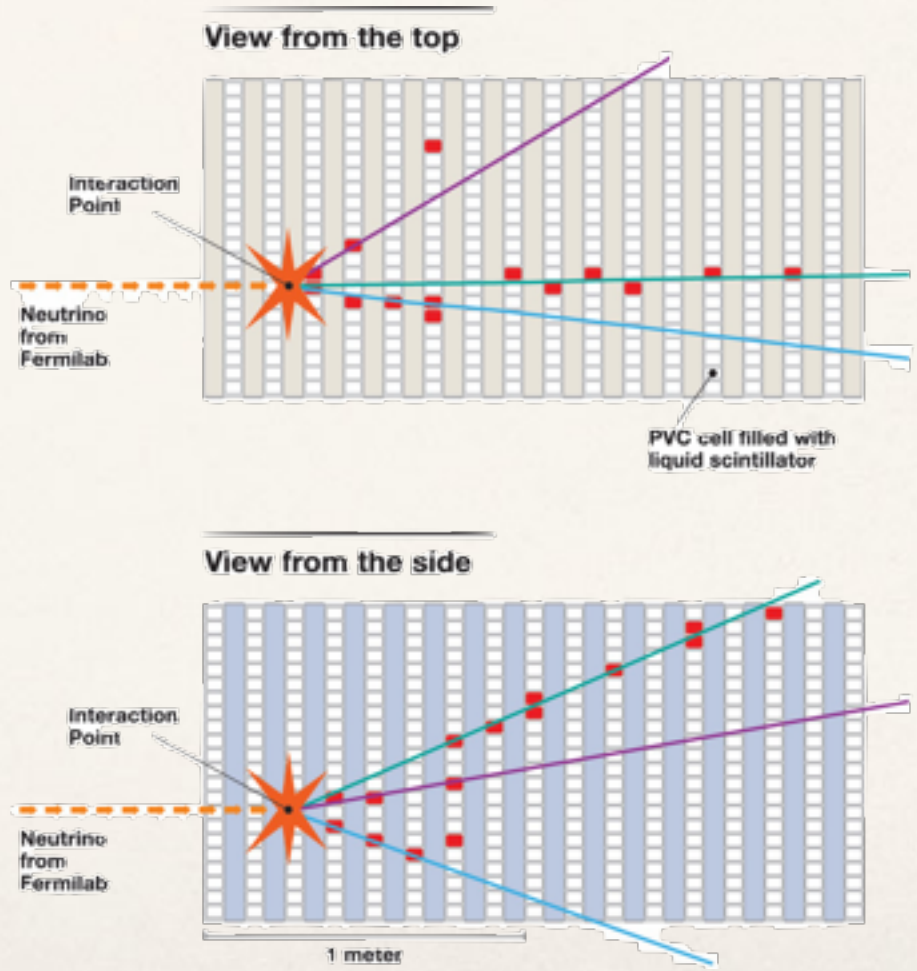
NOvA Detectors

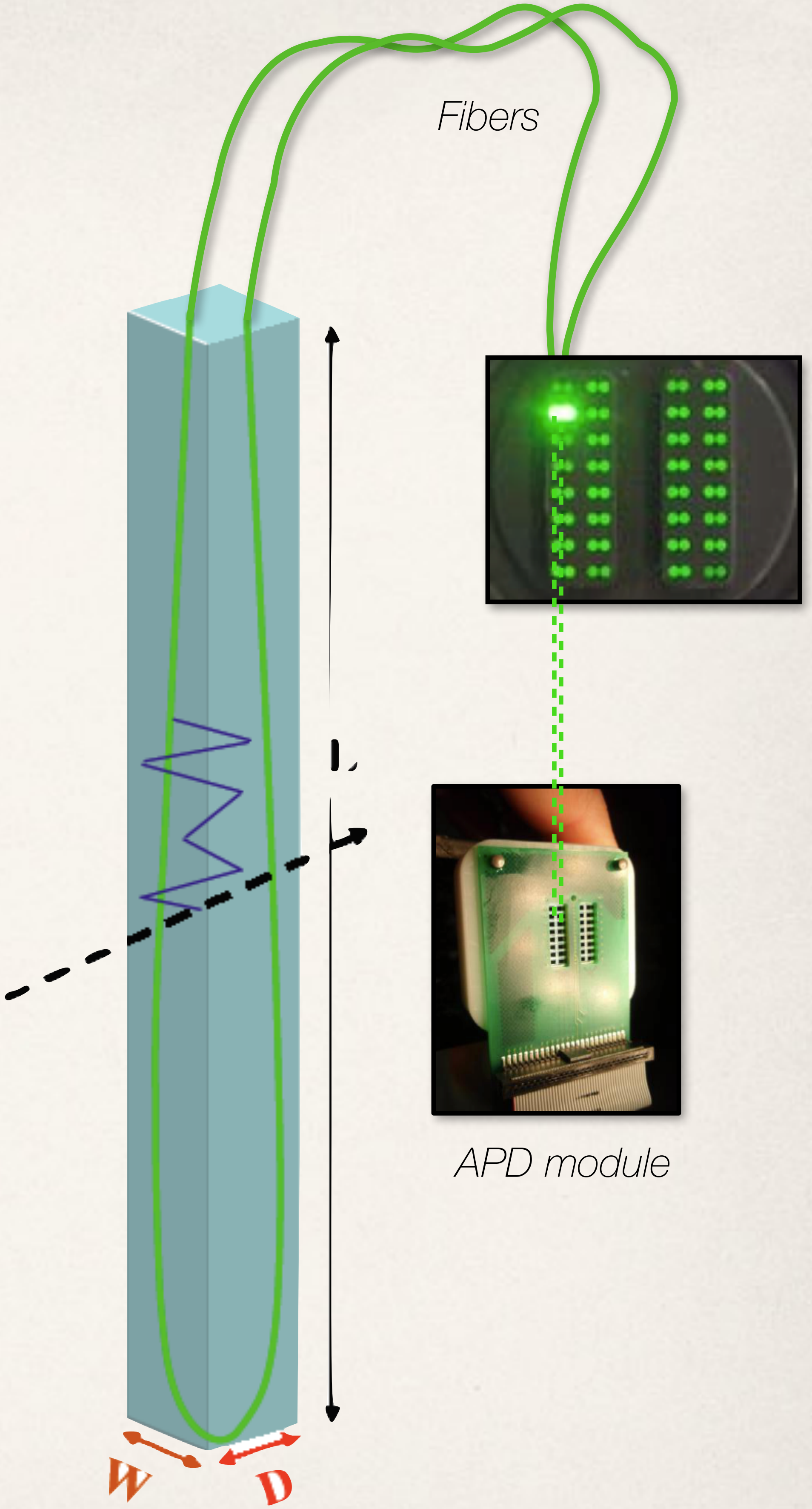
PVC cells (right) are joined to form planes.

Each consecutive plane is rotated 90 degrees to provide an x-view and y-view.

Detectors are designed for reconstructing electron showers from ν_e interactions.







Single cell, with fiber

NOvA Detectors Composition

Extruded PVC cells filled with liquid scintillator with a looped wavelength-shifting fiber (WLS)

36% PVC

63% **Scintillator mixture** (mineral oil + PPO scintillator + psuedocumene)

1% **Other stuff** (glue, WLS fibers, etc.)

NOvA PVC extrusions. Cells are gathered into planes, planes are rotated 90-degrees relative to adjacent planes.

	Fractional mass (%)
Carbon	66.7
Chlorine	16.1
Hydrogen	10.8
Titanium	3.2
Oxygen	2.9

NOvA Composition. This is taken to be the same for both detectors. Only top five elements shown here.

Supernova Cross sections in NOvA detectors

Inverse beta decay (IBD) is dominant process.

$$\bar{\nu}_e + p \rightarrow n + e^+$$

NC/CC interactions on ^{12}C less common, but not negligible.

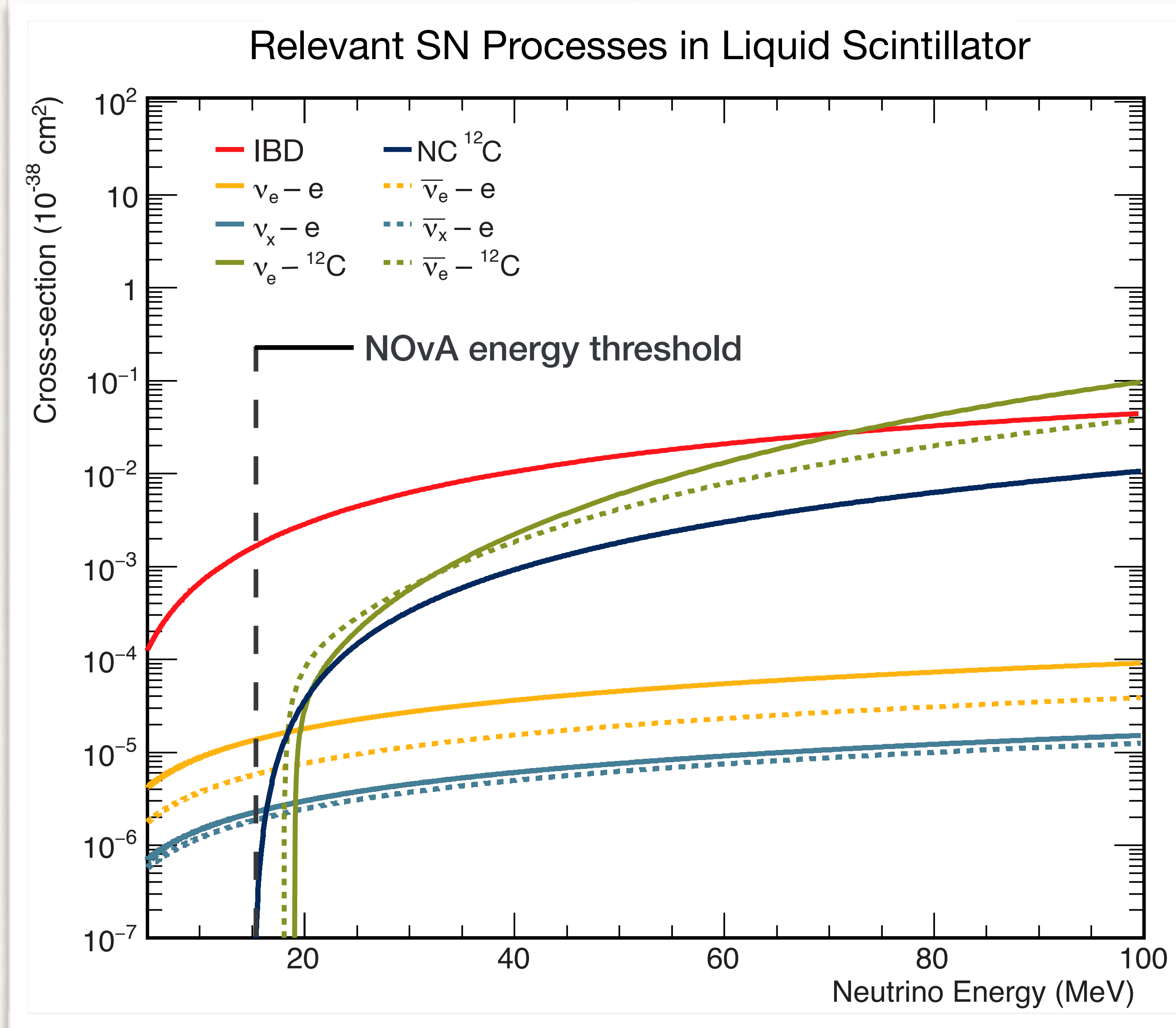
$$\nu_e + ^{12}C \rightarrow e^- + ^{12}N$$

$$\bar{\nu}_e + ^{12}C \rightarrow e^+ + ^{12}B$$

$$\nu_x + ^{12}C \rightarrow \nu_x + ^{12}C^*$$

ν-e scattering is sub-dominant.

$$\nu_x + e^- \rightarrow \nu_x + e^-$$



Cross sections for supernova interaction channels in liquid scintillator. As provided by SNOwGLoBES *(K. Scholberg)*.

Event Rates

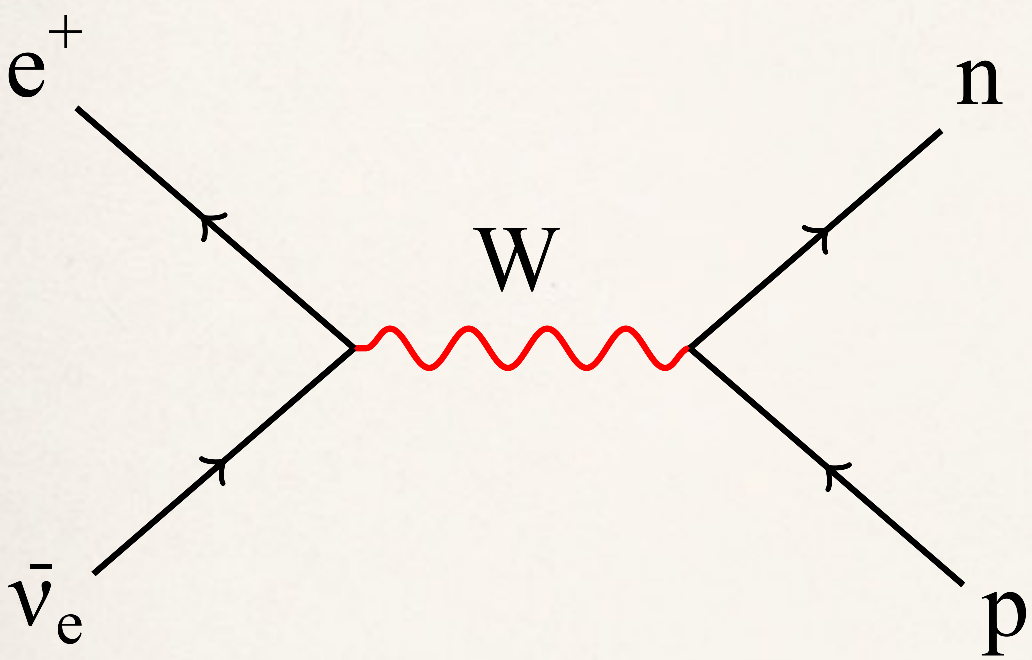
	Events	
Channel	Far	Near
$\bar{\nu}_e + p \longrightarrow e^+ + n$	2,163	46
$\nu_x + {}^{12}C \longrightarrow \nu_x + {}^{12}C^*$	393	9
$\nu_x + e^- \longrightarrow \nu_x + e^-$	199	4
$\nu_e + {}^{12}C \longrightarrow e^- + {}^{12}N$	137	3
$\bar{\nu}_e + {}^{12}C \longrightarrow e^+ + {}^{12}B$	139	3
Total	*3,031*	*65*

Expected event rates in the NOvA detectors, given these cross sections and the GVKM model flux. Integrated over 10s. Supernova 10 kPc away. Calculated using SNOwGLoBES *(K. Scholberg)*.

higher statistics; high noise

low noise; lower statistics

EVENT TOPOLOGY: INVERSE BETA DECAY



Low-energy positrons will not travel very far in the detector.

Tend to deposit energy into 1–3 cells.

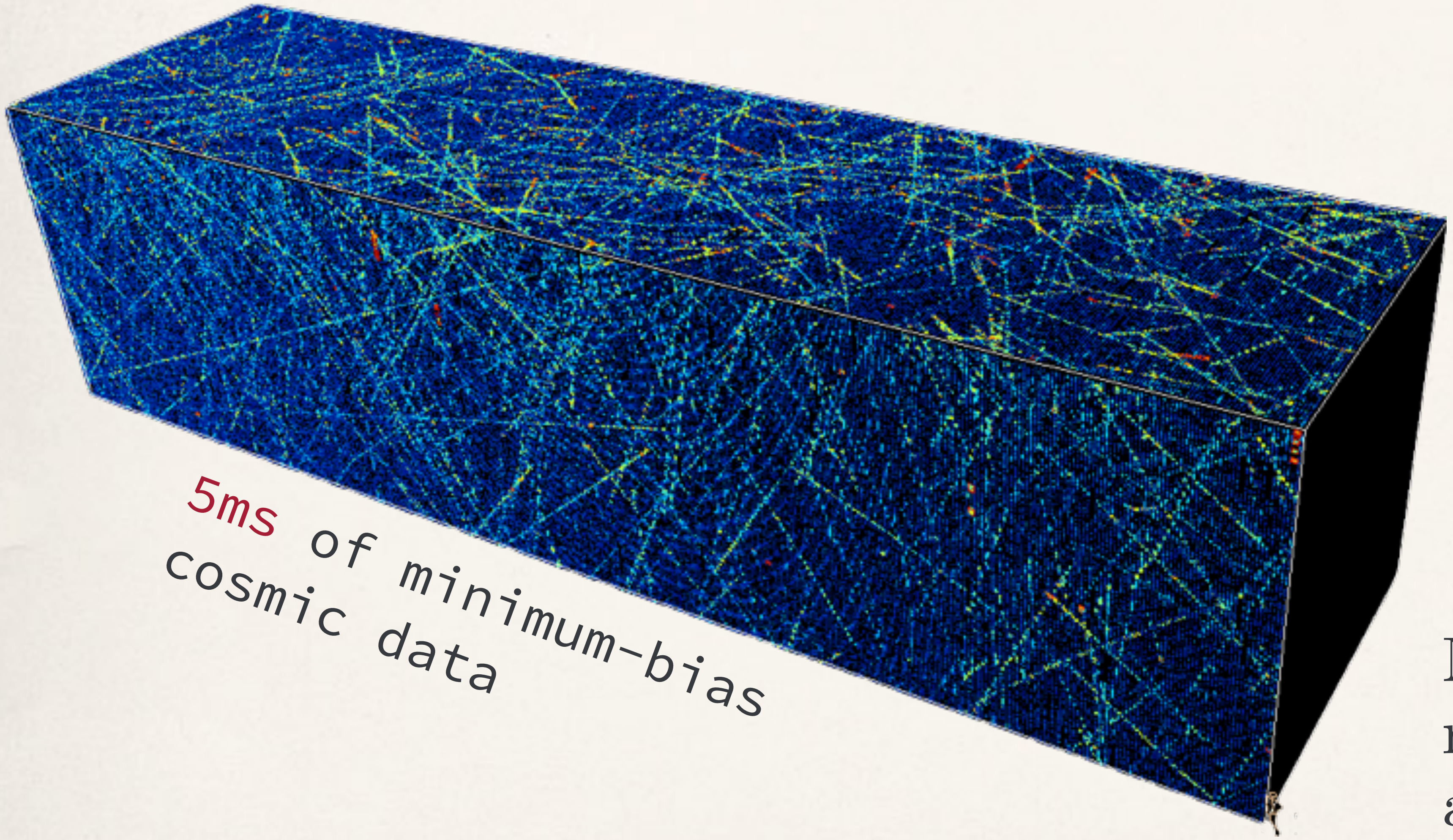
Neutrons will capture, produce gammas.

This delayed energy deposition could prove to be a useful tagging mechanism for this channel.

Low-energy Backgrounds

Far Detector sits on the surface. Minimal overburden.

140 kHz cosmic ray muons. → *Low-energy products due to cosmogenic sources.*



5ms of minimum-bias cosmic data

Electronic Noise

200 Hz single hit rate

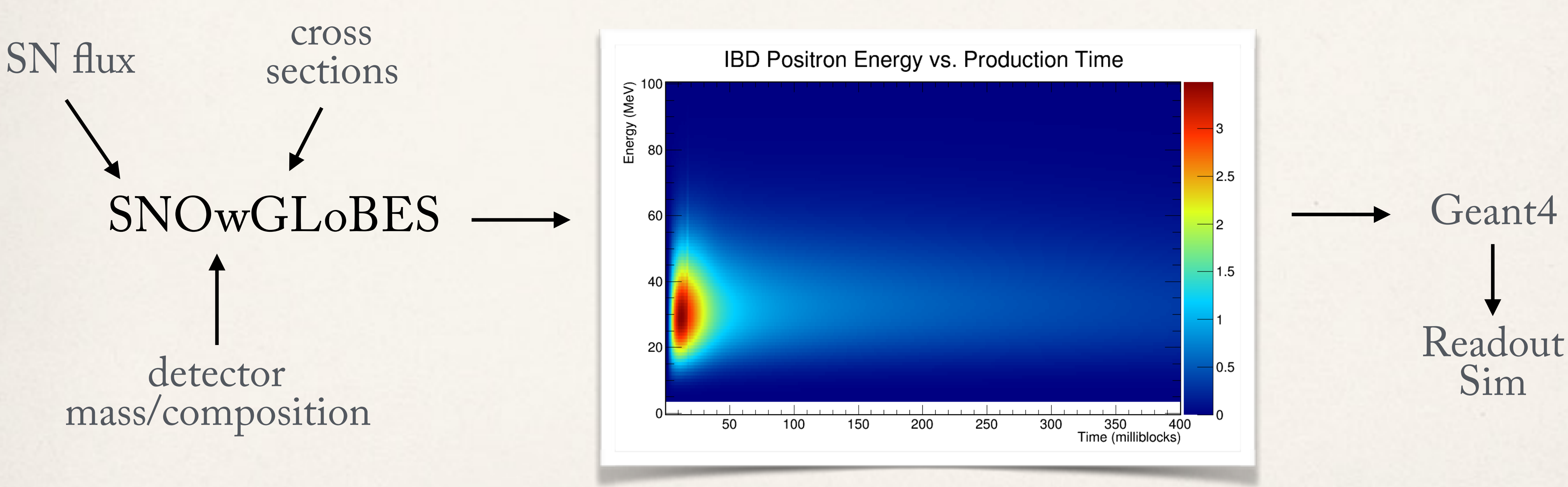
Need a robust method for reducing these backgrounds at the trigger level.

Simulating the Supernova Signal

Use SNOwGLoBES with NOvA configuration to produce final-state energy distributions for each 5ms time window.

Positrons (from IBD) are generated isotropically throughout the detector based on those distributions.

GEANT4 is used to propagate those particles through the detector.



Simulating the Supernova Signal

In development: Native GENIE simulation

Feed SN fluxes to GENIE; requires custom flux driver.

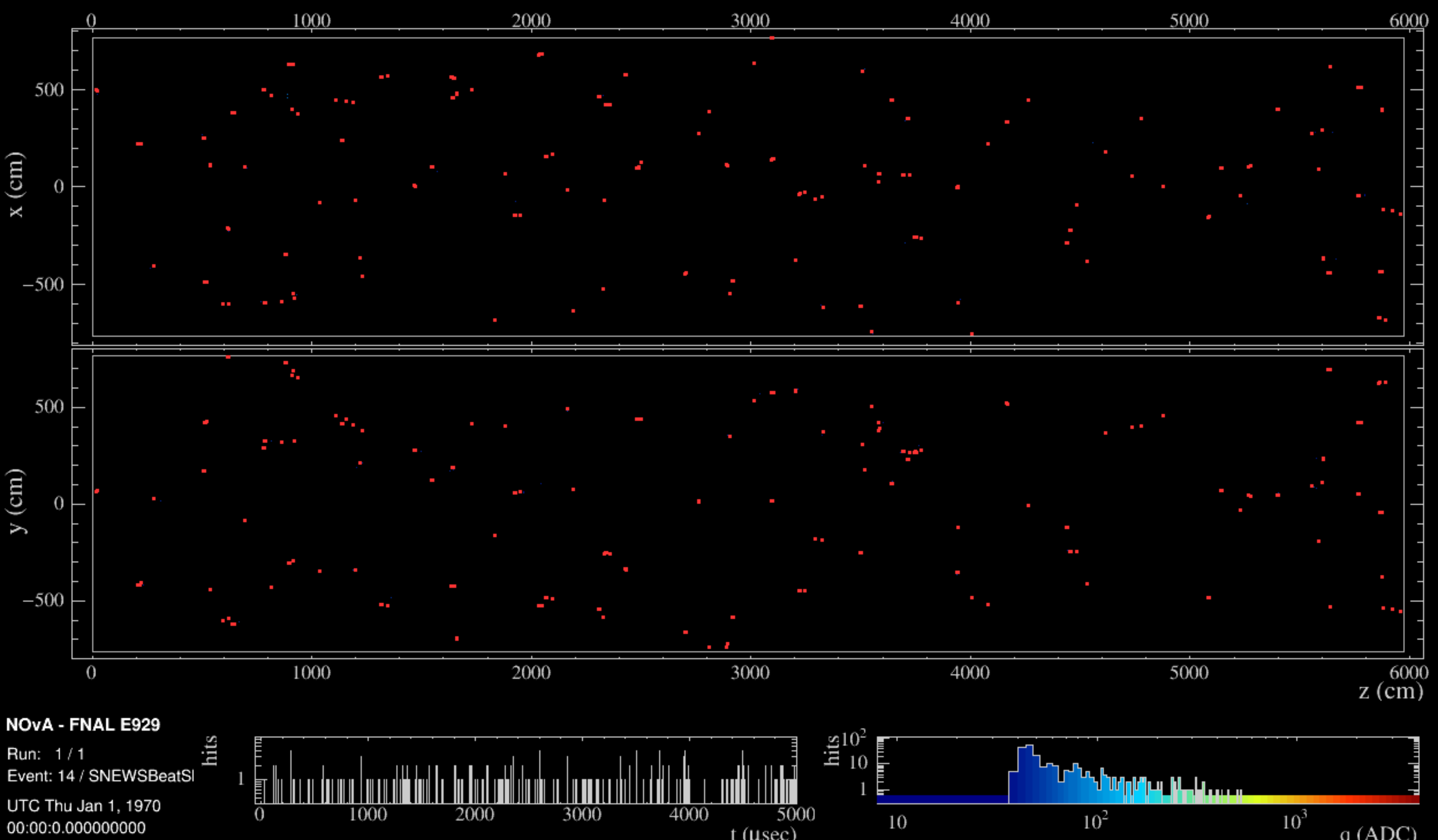
Implement better low-energy cross sections.

Covers all relevant interaction channels

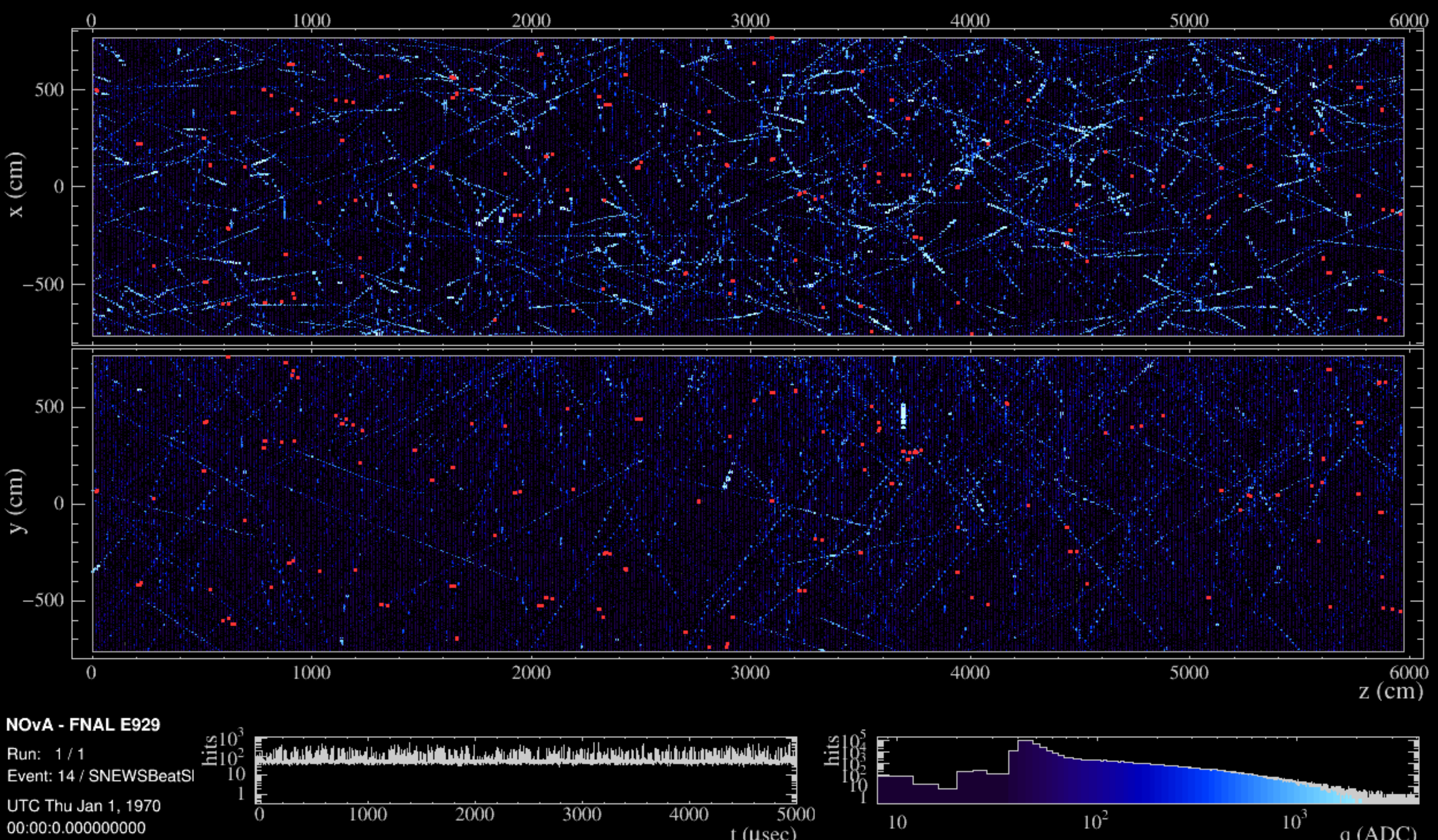
Includes secondary processes (neutron capture, nuclear de-excitations)

Ready for testing.

Simulated positron signal (t = 90–95 ms)

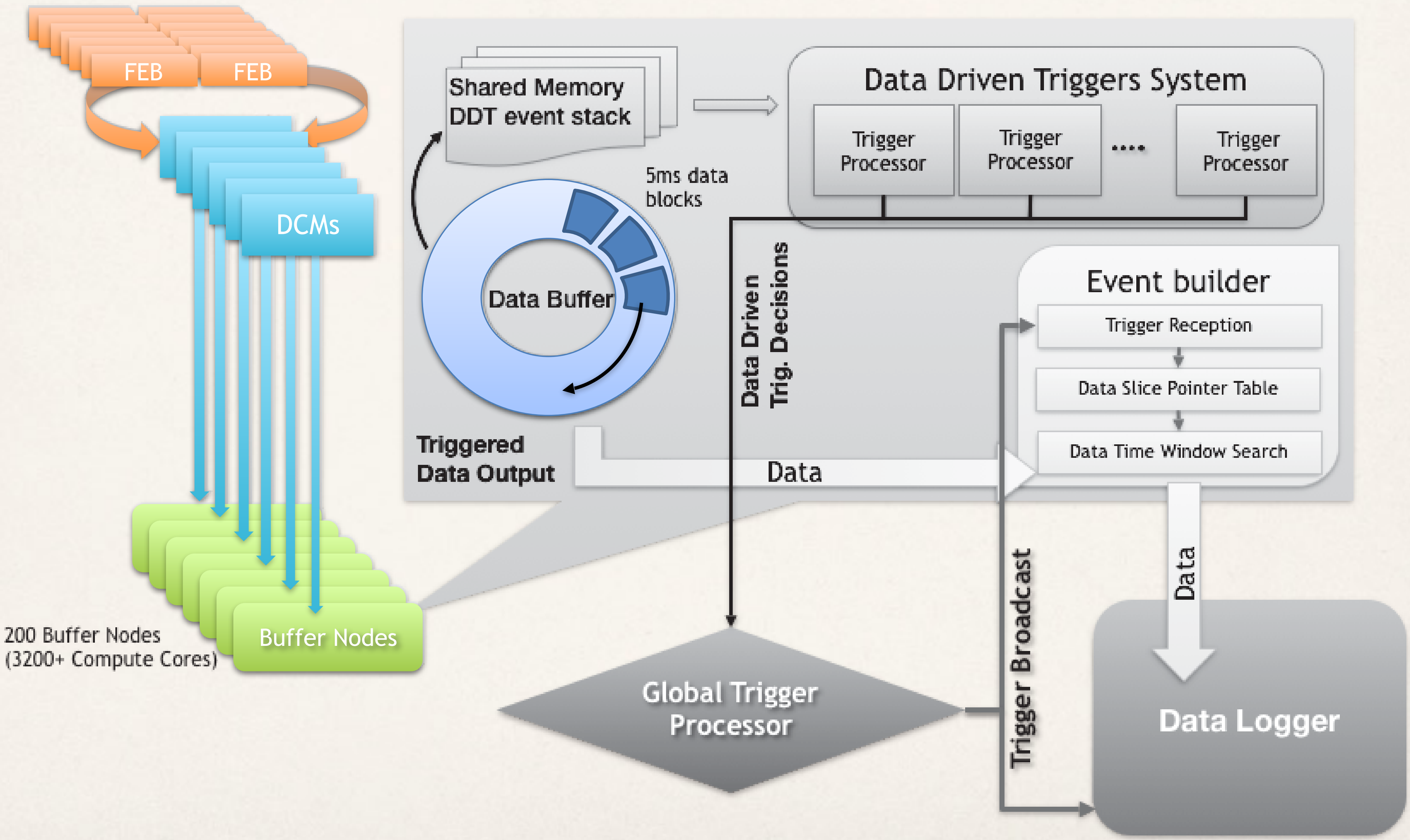


Simulation and background overlaid



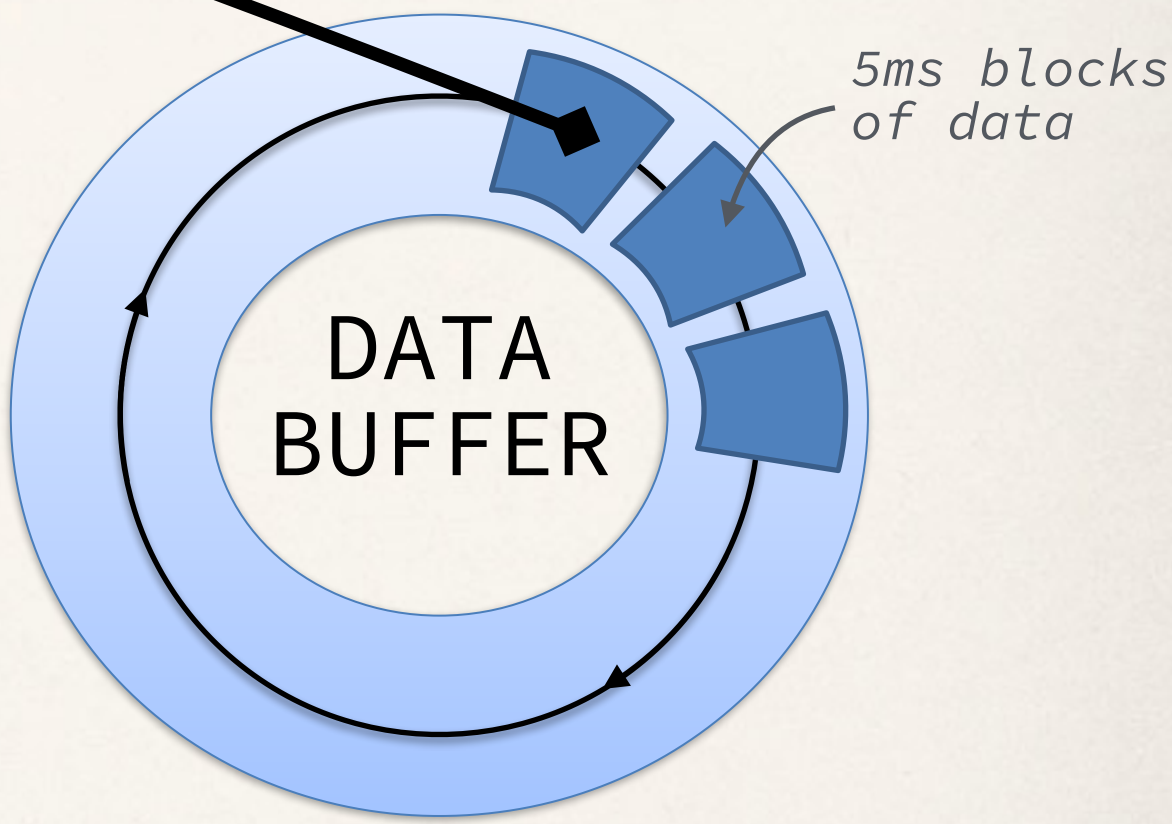
TRIGGERING/DAQ

Data is grouped into 5ms blocks, and placed into a circular buffer.



DAQ Data Buffering

DATA FROM DETECTOR → *TO SHARED MEMORY SEGMENT*



~1 GB/sec streaming from detector readout

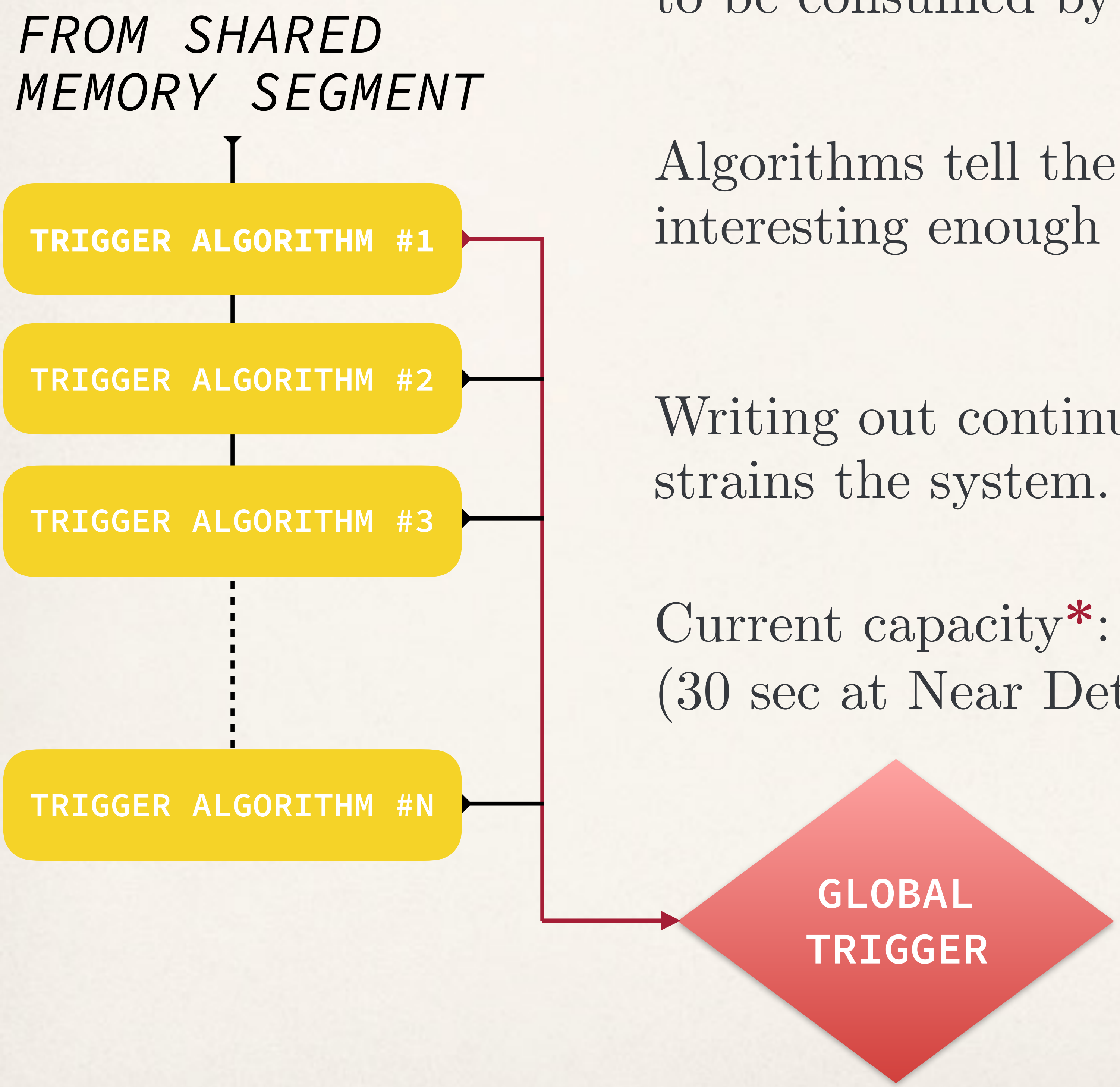
All data into circular ring buffer.
Oldest data is allowed to expire

We save everything into this buffer for a limited time.

Parallel trigger processing decides which data to store long-term.

Current buffer depth: ~15 minutes.
(look-back time)

Data-Driven Triggers



Data is also passed into a shared memory segment to be consumed by triggering algorithms.

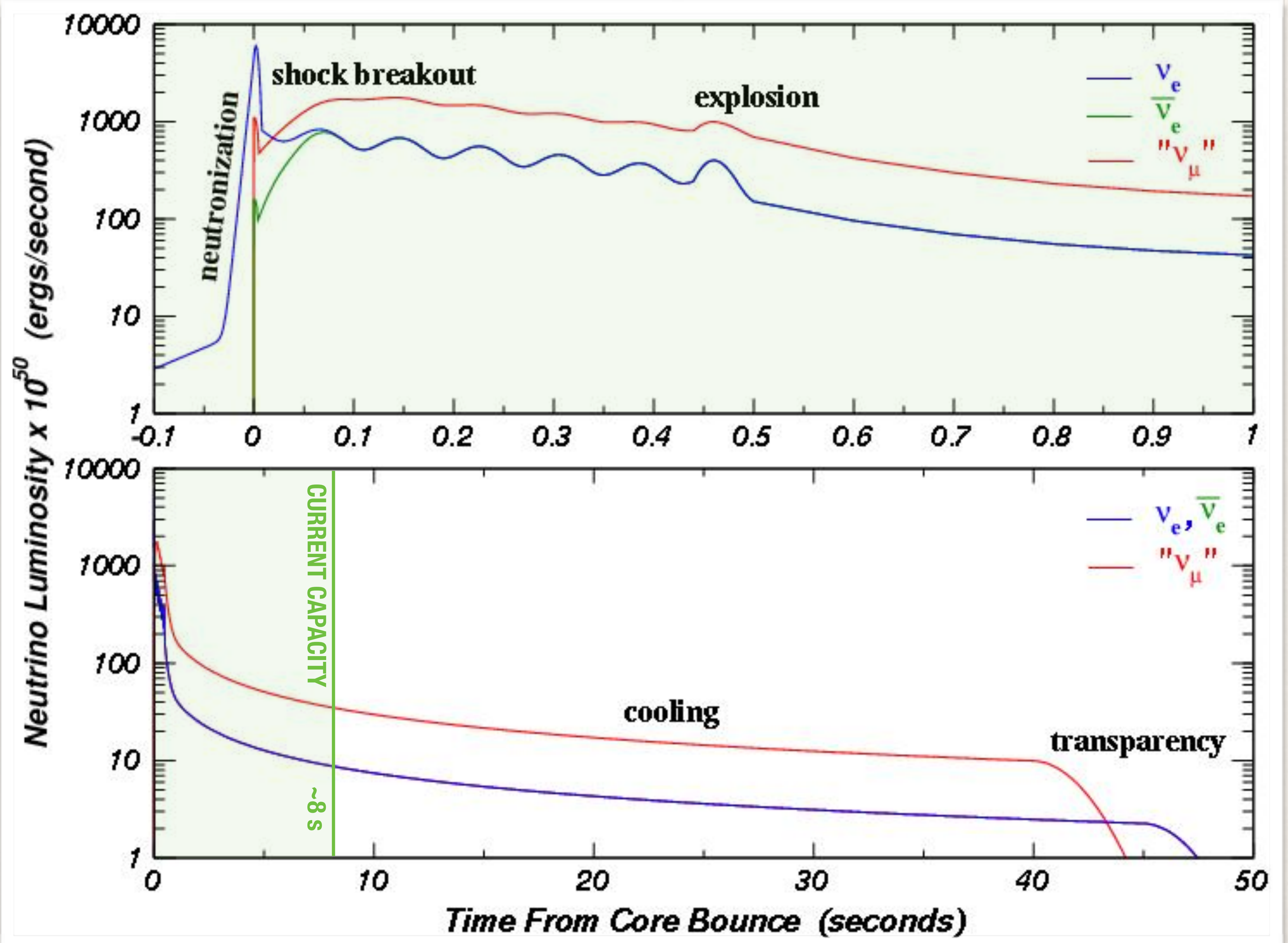
Algorithms tell the Global Trigger which data are interesting enough to keep.

Writing out continuously (supernova timescales) strains the system.

Current capacity*: ~8 sec. continuous data-logging (30 sec at Near Detector).

* This capacity will be increased in near future.

DAQ Readout Capabilities



Time profile of supernova neutrino luminosity. Credit: J. Heise.

Internal and External Triggering

SNEWS trigger *(deployed)*

1. Receive alert from SNEWS
2. Issue long, high-priority trigger on the data
3. Continuously write all data to disk for as long as we can.

Internal trigger *(in development)*

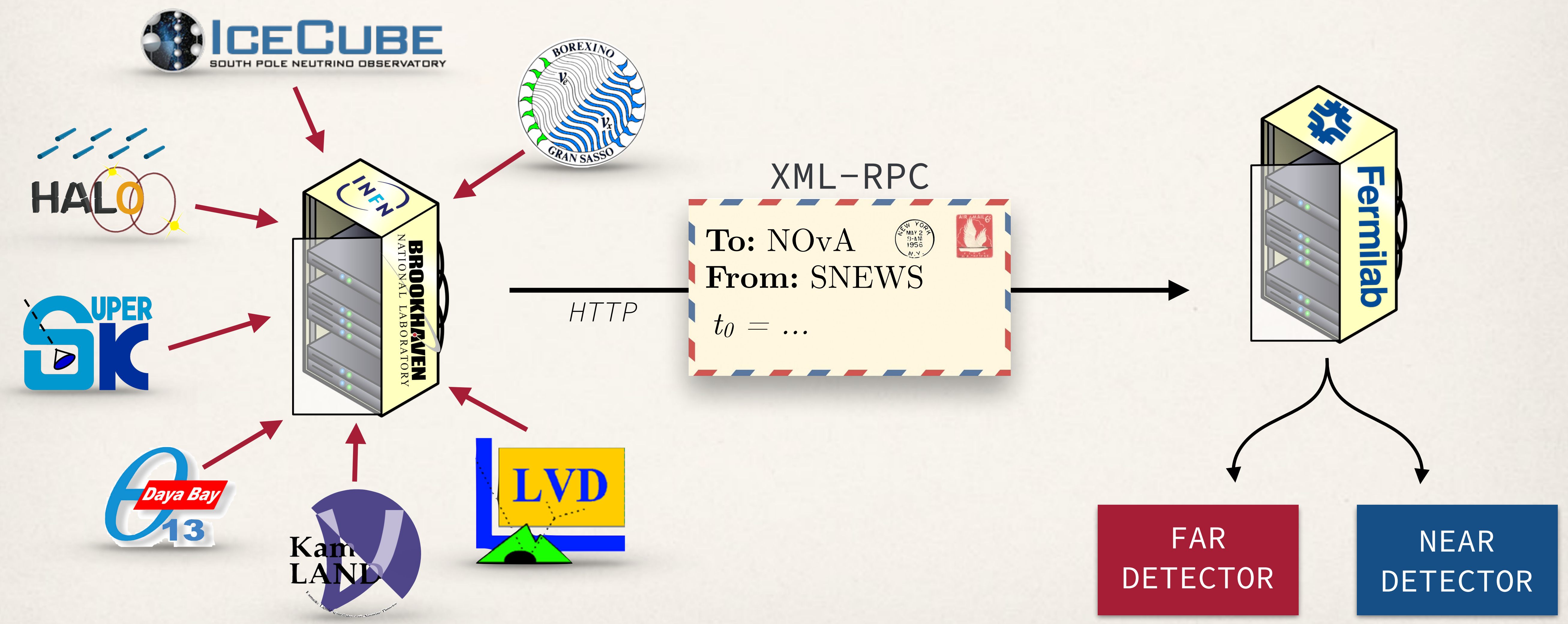
1. Recognize SN signal in one or both detectors
2. Send alarm to SNEWS
3. Issue long, high-priority trigger on the data
4. Continuously write all data to disk for as long as we can.

If a SN happens tomorrow, we'll know from SNEWS and save the data.

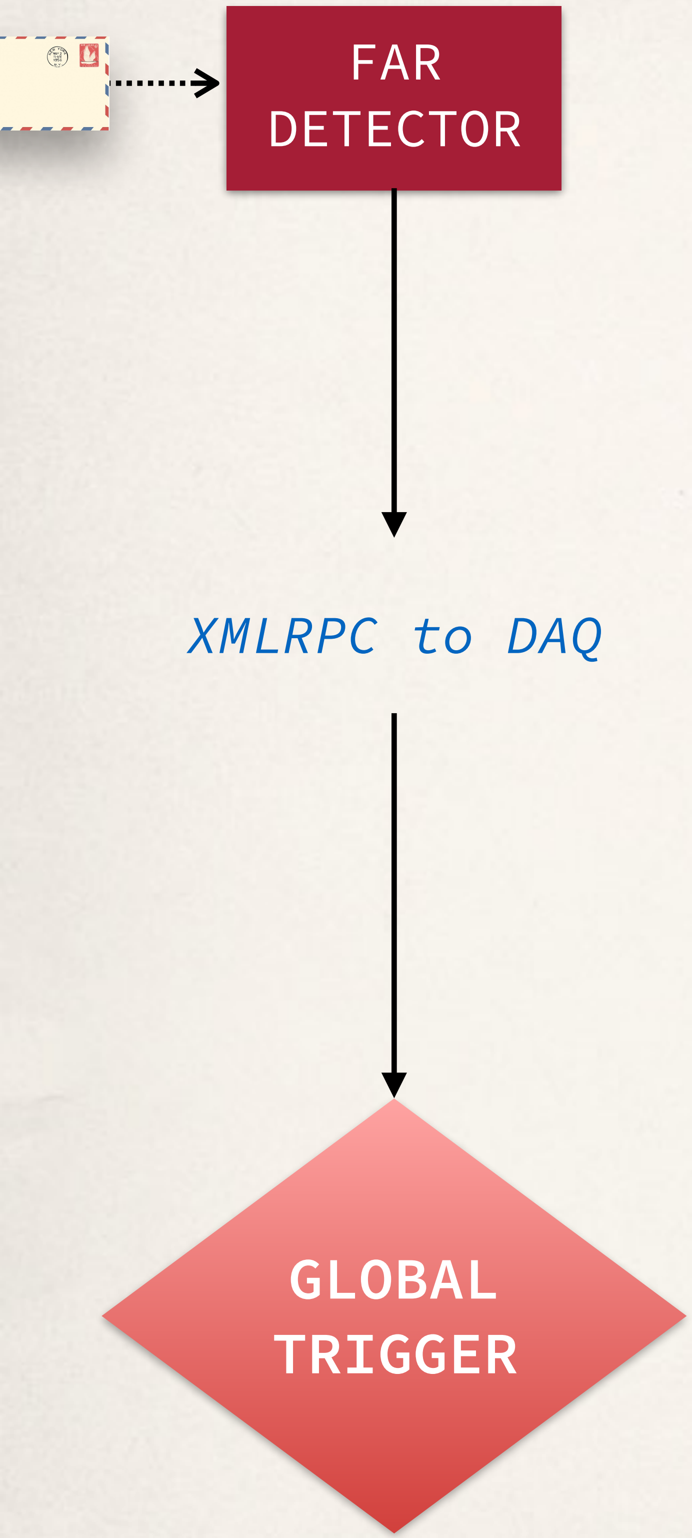
SNEWS EXTERNAL TRIGGER

Two experiments reporting within coincidence window triggers an alert:

1. SNEWS sends alert from server at BNL (INFN-Bologna backup) to subscribers.
2. Alert is received by NOvA at Fermilab and forwarded to both detectors.



SNEWS external trigger



Machines at both detectors receive the packet from SNEWS.

A daemon receives this packet and signals the Global Trigger. (Similar to how we handle beam triggers from the accelerator.)

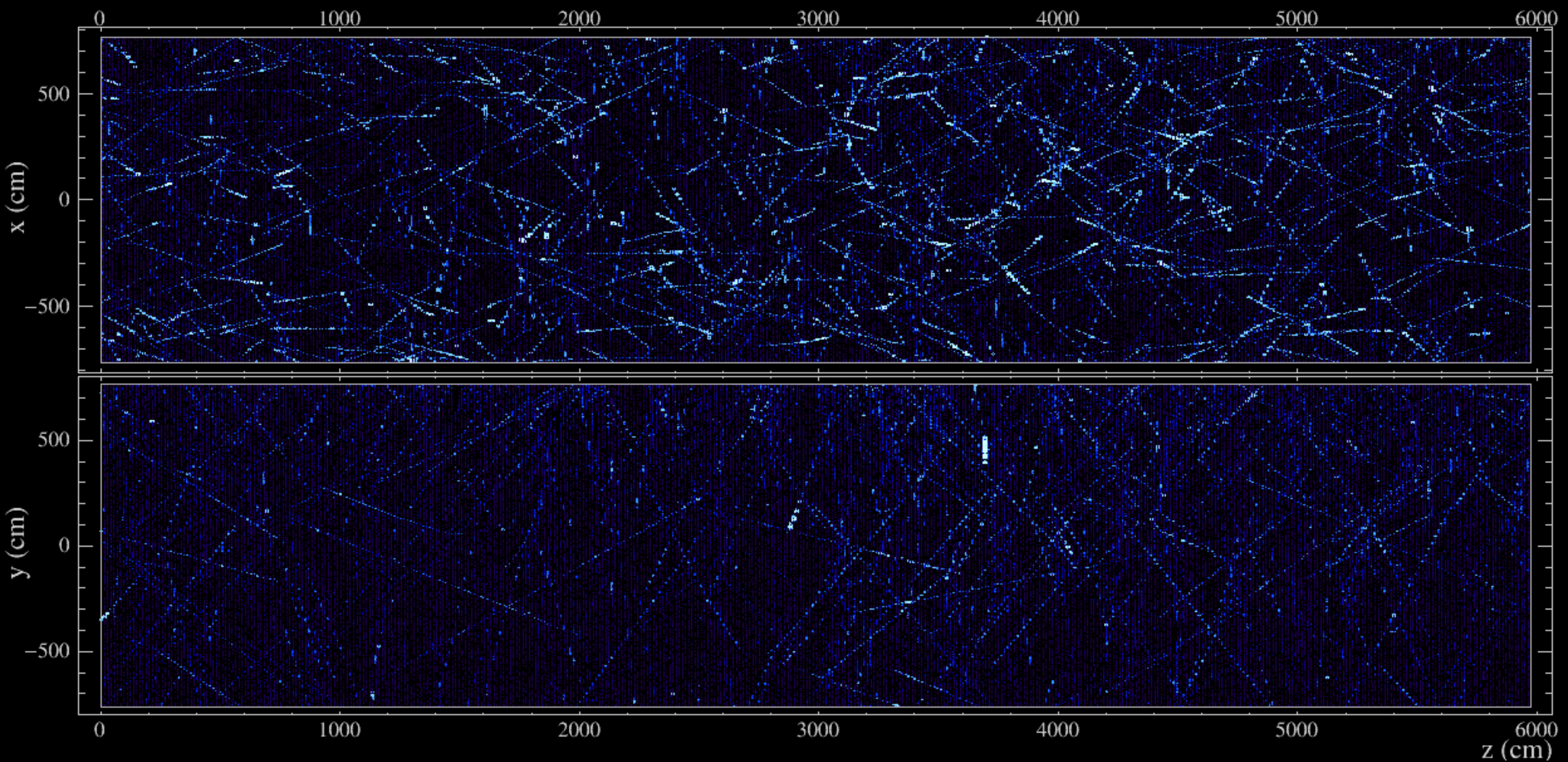
Global Trigger extracts the SN t_0 from the message, and issues a trigger for that time.

All data from t_0 onward in the data buffer is written to disk for as long as possible *(currently ~8 sec)*.

SNEWS Heartbeats

We test this trigger everyday.

Lets us know the system can handle reading out 8 seconds; someday the real SNEWS trigger will arrive.



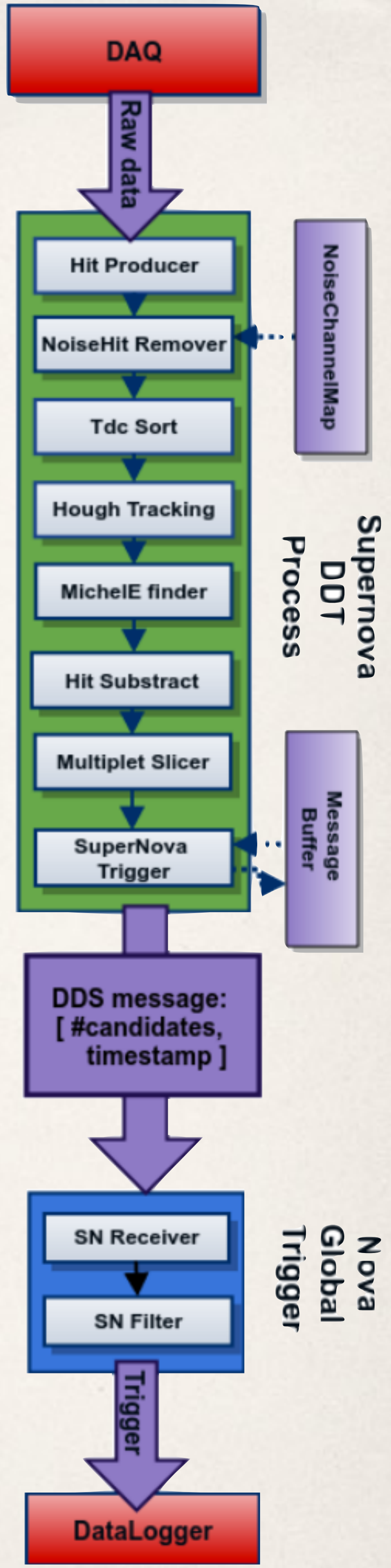
Online Reconstruction

We have a data-driven trigger process that can perform basic on-the-fly reconstruction to reject background.

1. Reject background hits
2. Count number of SN neutrino candidates
3. Global Trigger produces time series of N_{cand}.
4. A filtering kernel is applied to time series to enhance the signal.
5. Issue a trigger if filtered signal exceeds some threshold.

Infrastructure is mostly in place; we're currently in the process of testing and tuning these algorithms.

Under development; not ready for prime-time yet, but a good first pass.



Internal Trigger Development

Define an *interaction candidate* as a collection of hits in the detector that meet the following criteria.

Interaction Candidate

Hits localized in time and space

$$\Delta(\text{clock-ticks}) \leq 4$$
$$\Delta(\text{plane}) \leq 1$$

No association with recently-noisy channels

Low-energy (ADC) deposited

$$120 \leq \sum^{N_{\text{hits}}} (\text{adc})_i \leq 600$$

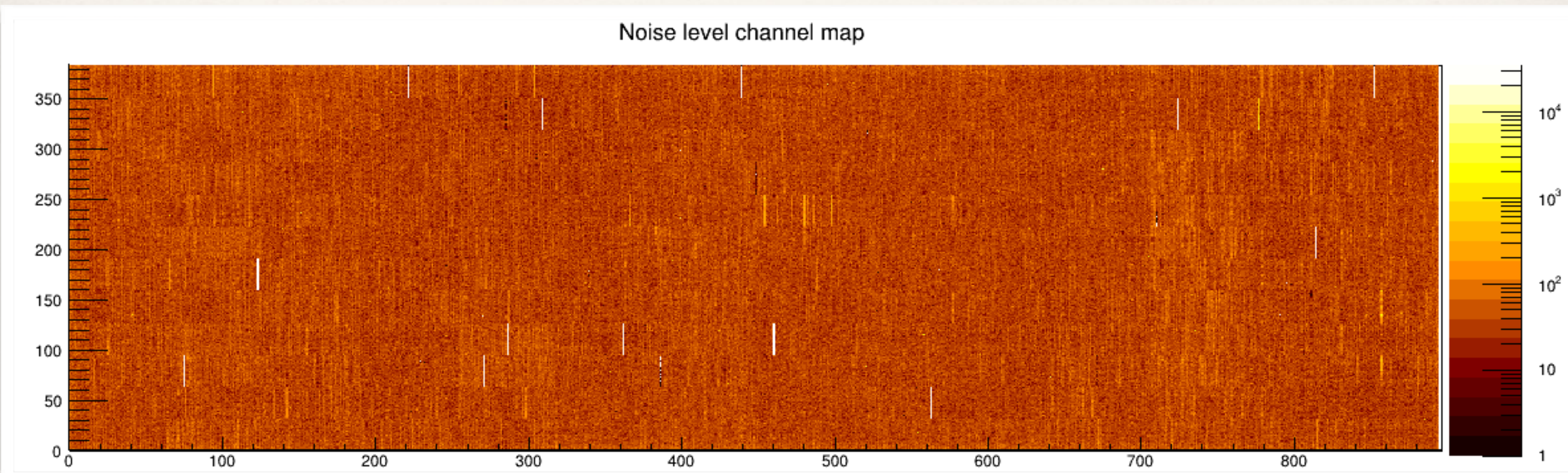
No association with μ^- track

This is a simple set of cuts that will be built upon and improved; gets a foot in the door.

Internal Trigger Development

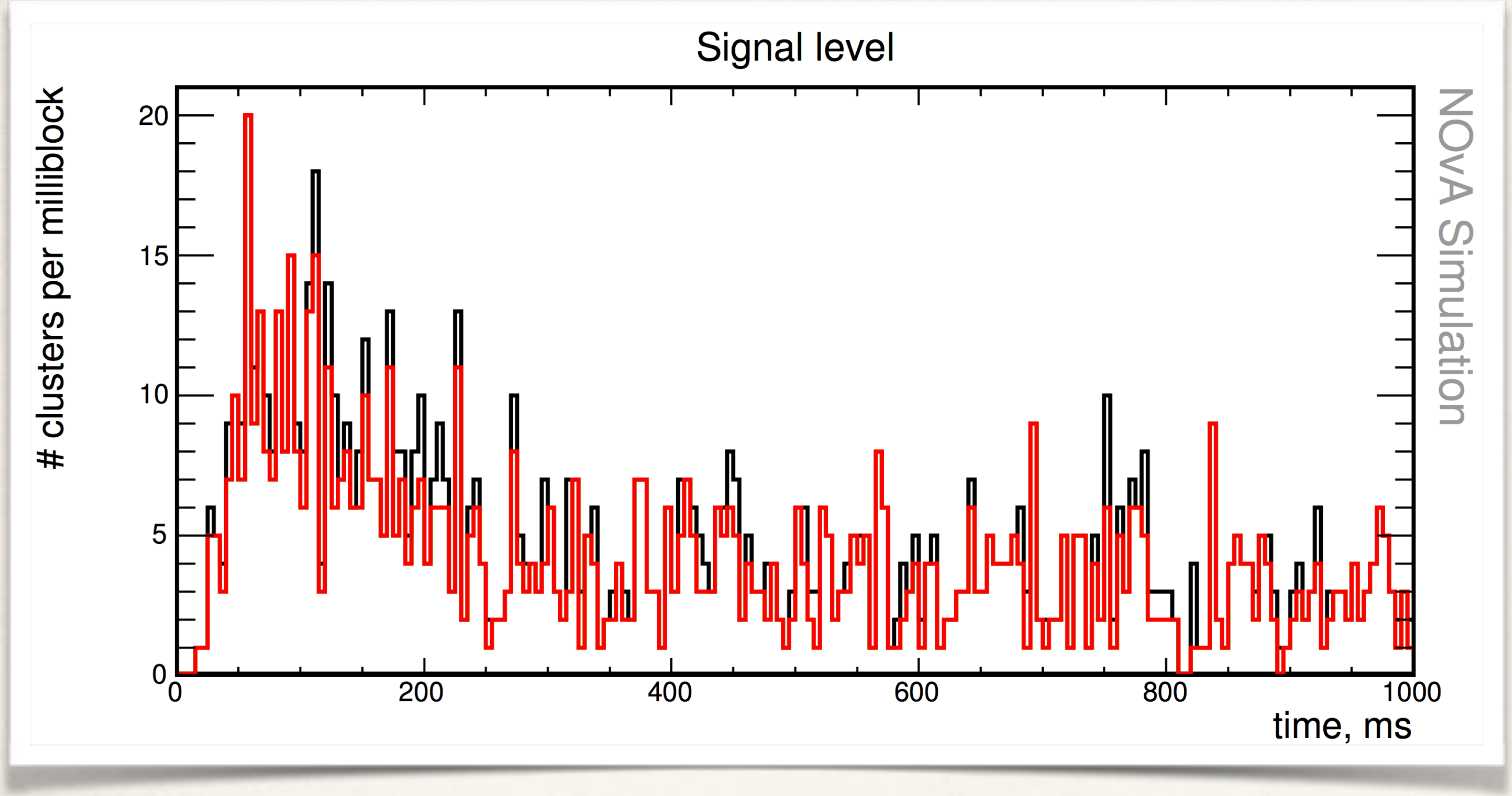
A map of channel noise activity for the past 250 μs is used to filter out noisy channels.

This plot shows the Far Detector in “channel space”. Lighter bins correspond to noisier channels.



Noise level channel map for Far Detector. Channel activity during past 250 ms.

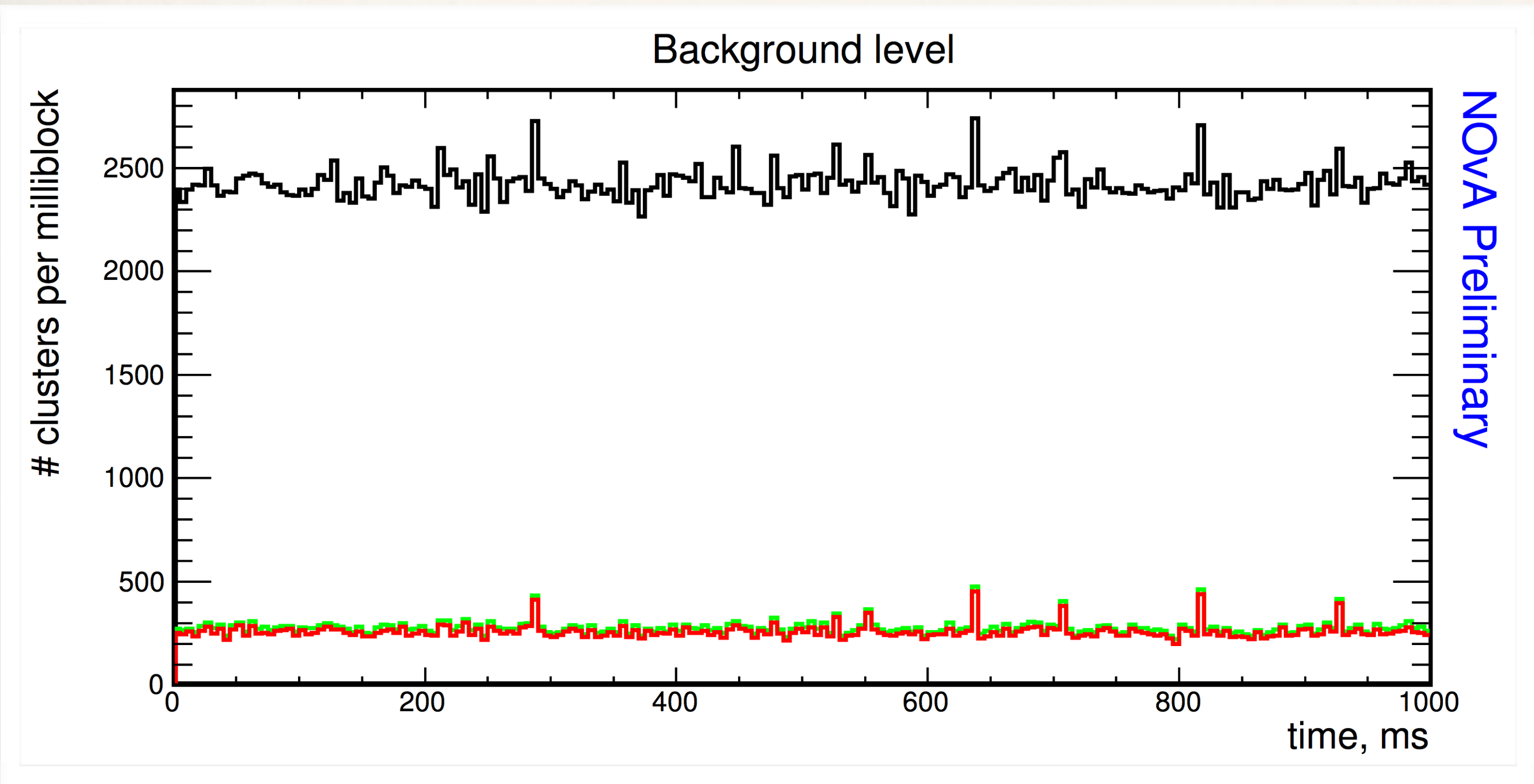
Internal Trigger Development



Signal

Applying localization, ADC, and noise filtering cuts, the **signal** (black) is reduced by 15% (red).

(for GVKM SN @ 10 kPc)



Background

Applying the same cuts reduces the **background** (black) by 90% (red).

This gets us to, at best, signal:noise = 1:25.

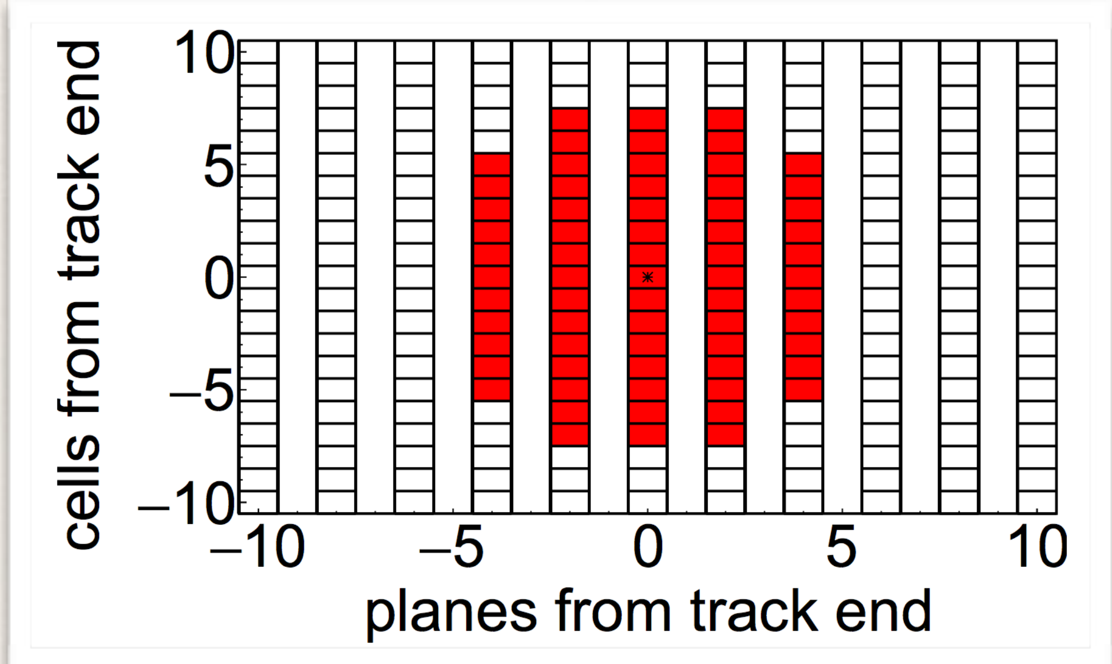
Need to do more, but this is a promising first pass.

Internal Trigger Development

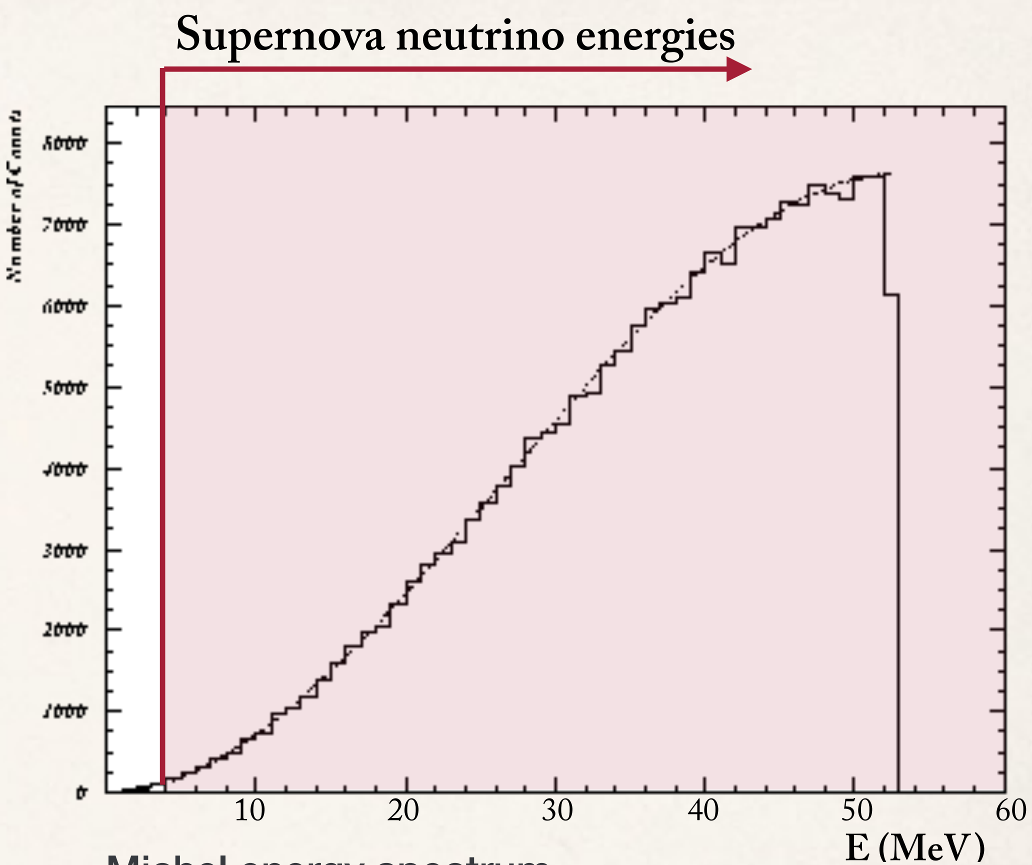
Michel e^- rejection

Draw a disk centered around the end of the muon track and veto any hits that are

1. Within 8 cells
2. Within 10 μs (4.6 μ^- lifetimes)



Vetoing around muon track ends.



Michel energy spectrum.

http://pibeta.phys.virginia.edu/docs/publications/ketevi_diss/node25.html

We can find Michels in our offline analysis; a proof-of-concept of our ability to see electrons at SN neutrino energies.

Under development.

Summary

NOvA expects ~3,000–4,000 SN neutrino interactions during the next galactic supernova (only those over ~15 MeV can be "seen").

External trigger is in place; we will save the data if SNEWS issues an alert. Can currently save any 8-second period within the past 15 minutes.

Internal trigger is being tested; expect to have something functional by the end of our beam shutdown (~October 2016).

Robust SN detector simulation is almost ready; Will use to test trigger algorithms for various models, distances, progenitors, etc.

Reconstruction methods are being devised to extract the SN signal for offline analysis.

Thank you

The NOvA Collaboration