

Virtual conference

July 20-21

New Perspectives 2020

A conference for early career researchers

NOvA in 10 minutes



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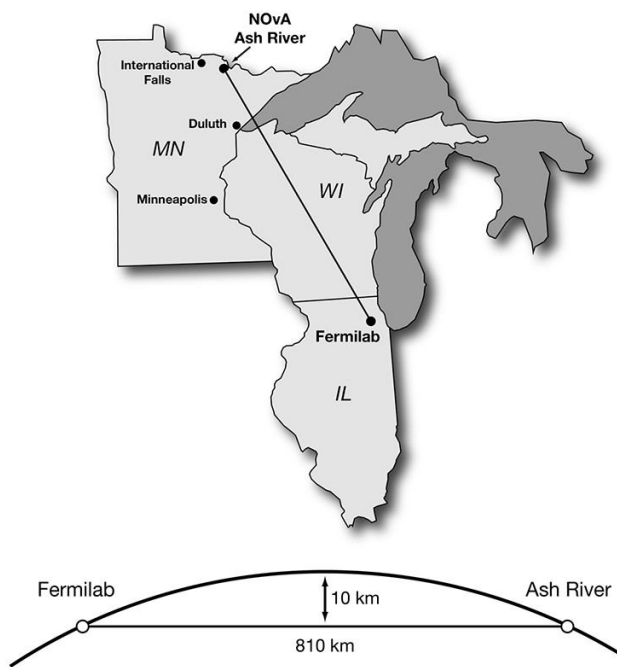
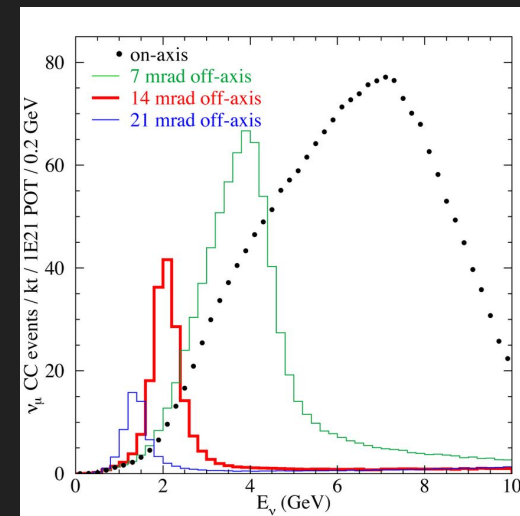


20 July 2020

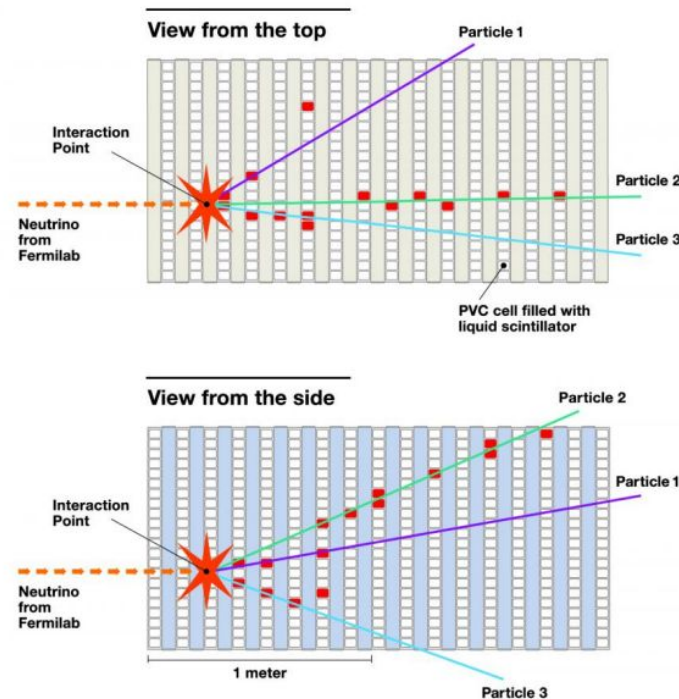
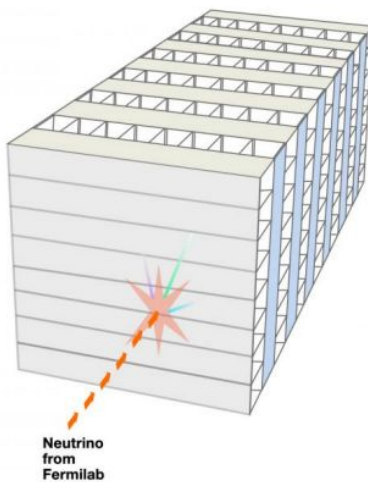
The NOvA experiment

Main goal: study of neutrino oscillations in a muon (anti)neutrino beam with $\langle E \rangle = 2 \text{ GeV}$

Two detectors with similar structure: extruded PVC cells filled with liquid scintillator. The scintillation light is transported by the wavelength shifting fibers, then read by APD



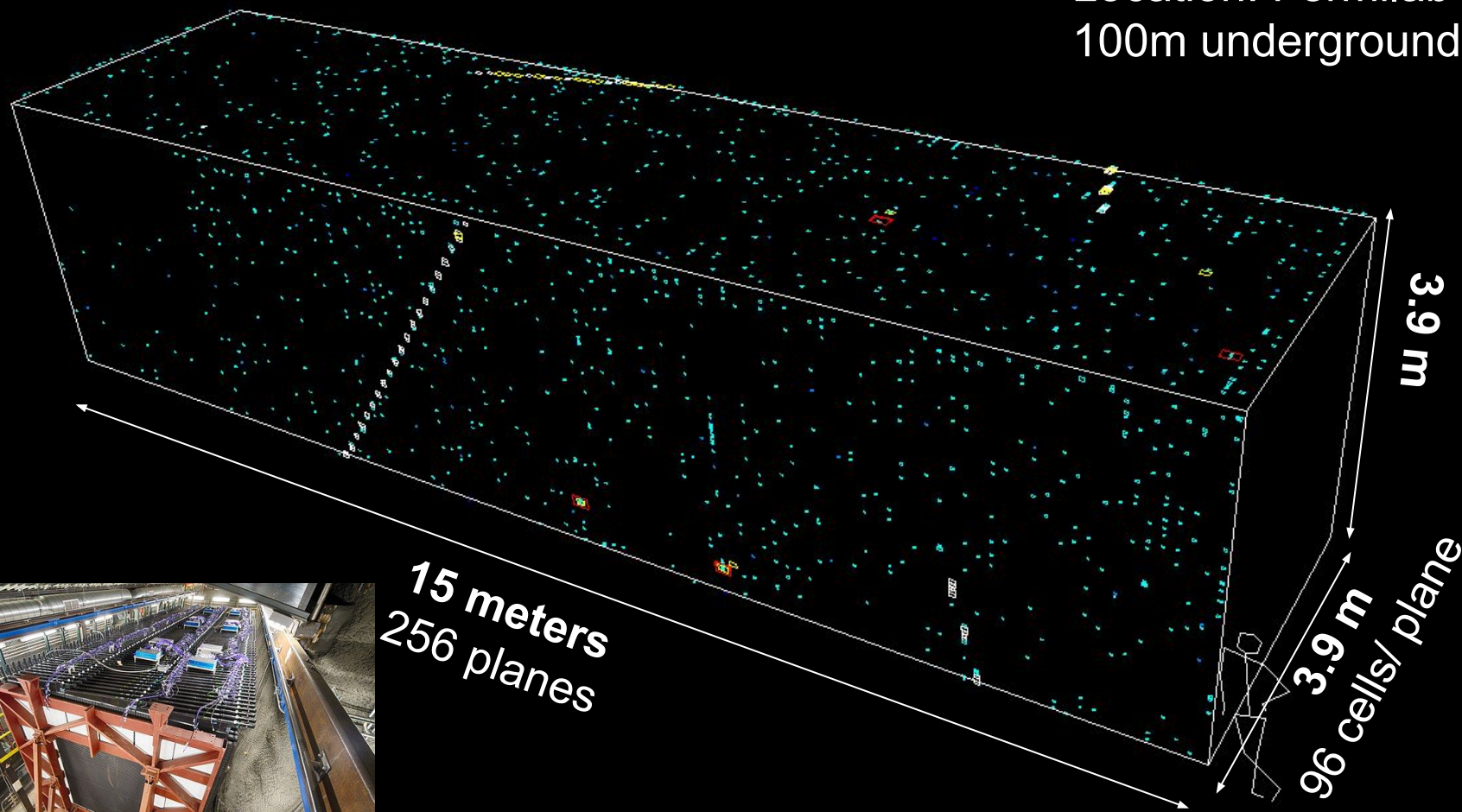
3D schematic of NOvA particle detector



Large and segmented NOvA detectors provide both calorimetry and tracking information.

NOvA Near detector: 5ms time slice

- M = **300 ton**
- Nchannels = **21504**
- Location: Fermilab
100m underground

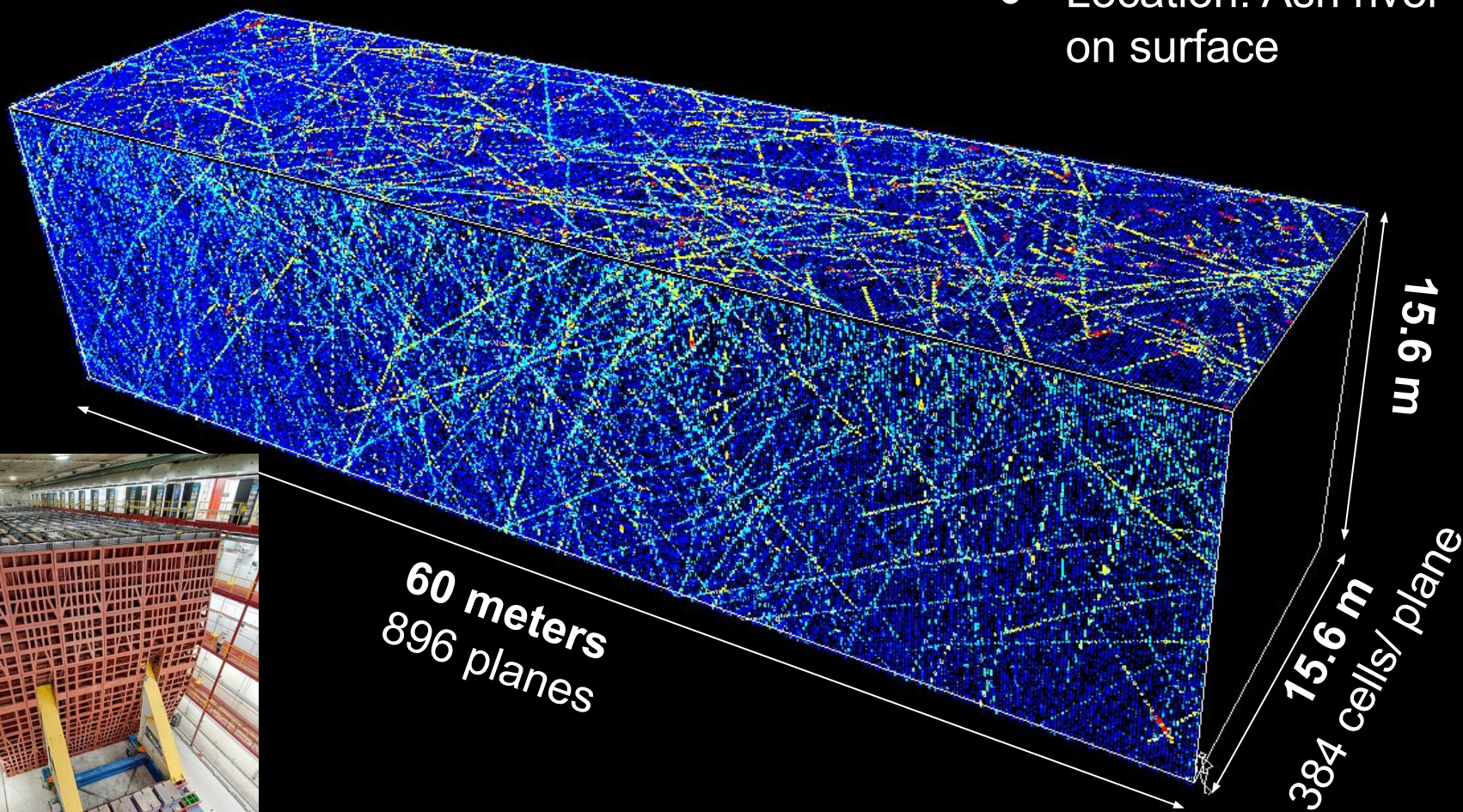


15 meters
256 planes



NOvA Far Detector: 5ms time slice

- M = **14 kton**
- Nchannels = **344064**
- Location: Ash river on surface

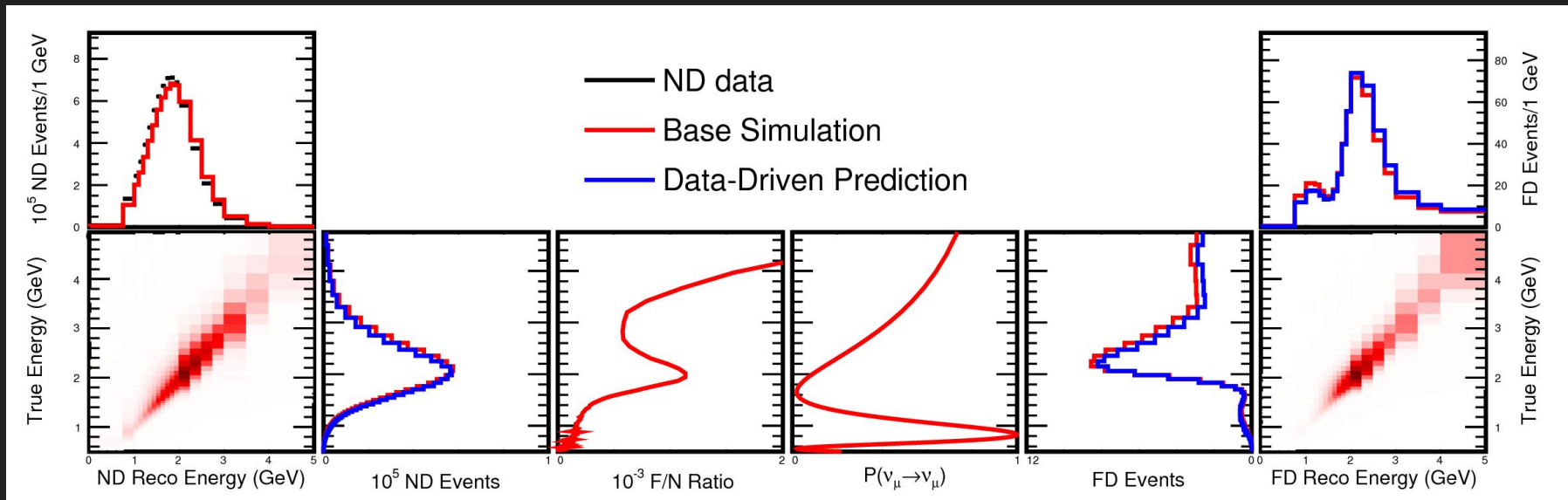
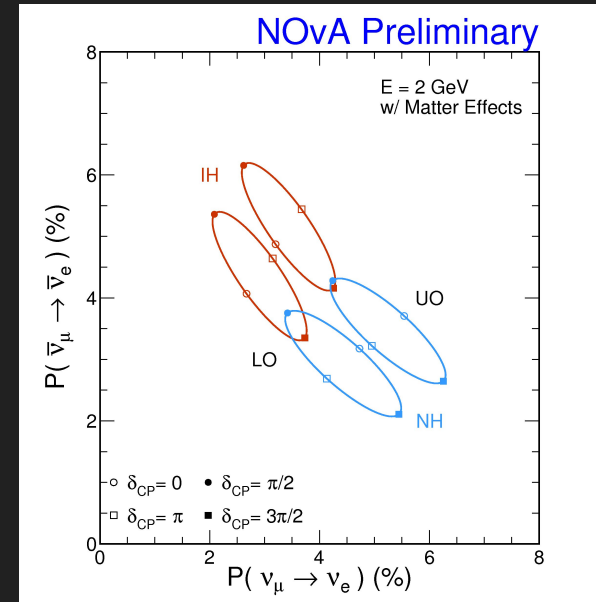


Neutrino oscillations analysis

Comparing the measured events in Far Detector with the prediction based on the Near Detector allows to probe oscillation parameters.

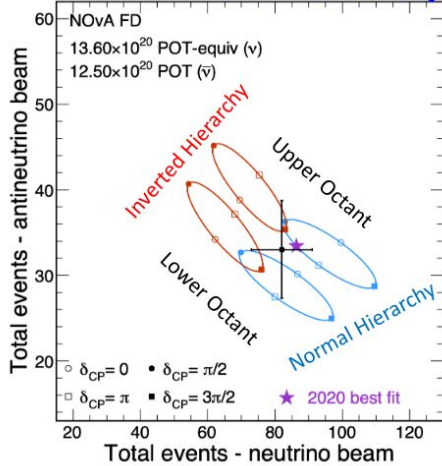
Using both muon neutrino and antineutrino modes of the beam, NOvA is sensitive to: **neutrino mass ordering**, θ_{23} , δ_{CP}

Near + Far detectors: reduce the systematic errors from beam uncertainty, neutrino interaction cross-sections, detector effects.

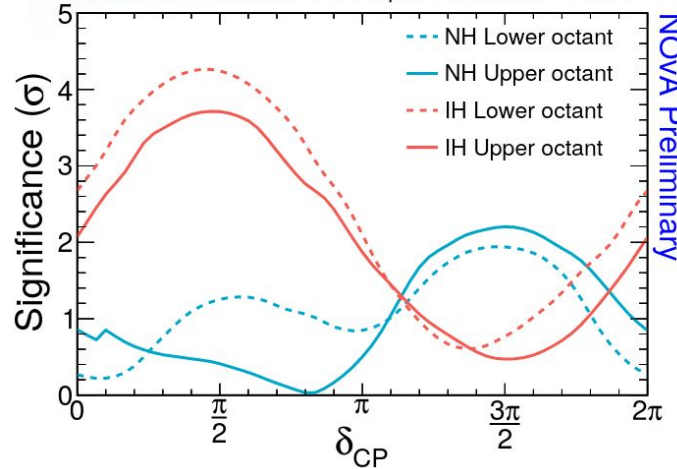


NOvA analyses results

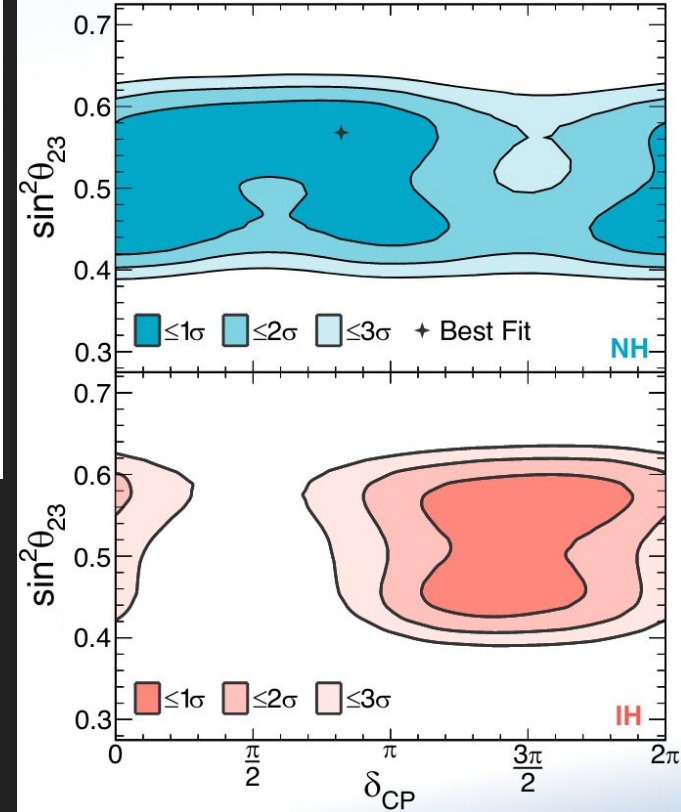
NOvA Preliminary



NOvA FD 13.6×10^{20} POT equiv ν + 12.5×10^{20} POT $\bar{\nu}$



NOvA Preliminary



- $\Delta m_{32}^2 = (2.41 \pm 0.07) \times 10^{-3} \text{ eV}^2$
- $\sin^2 \theta_{23} = 0.57^{+0.04}_{-0.03}$
- IH, $\delta = \pi/2$: excluded at $> 3\sigma$
- NH, $\delta = 3\pi/2$: disfavored at $\sim 2\sigma$

A dedicated test beam experiment is performed to reduce energy scale systematics

NOvA Data Driven Triggering

For beam analyses, the data is taken in coincidence with the beam spill.

Additional analyses require more complicated preselection of the data from the detector data stream.

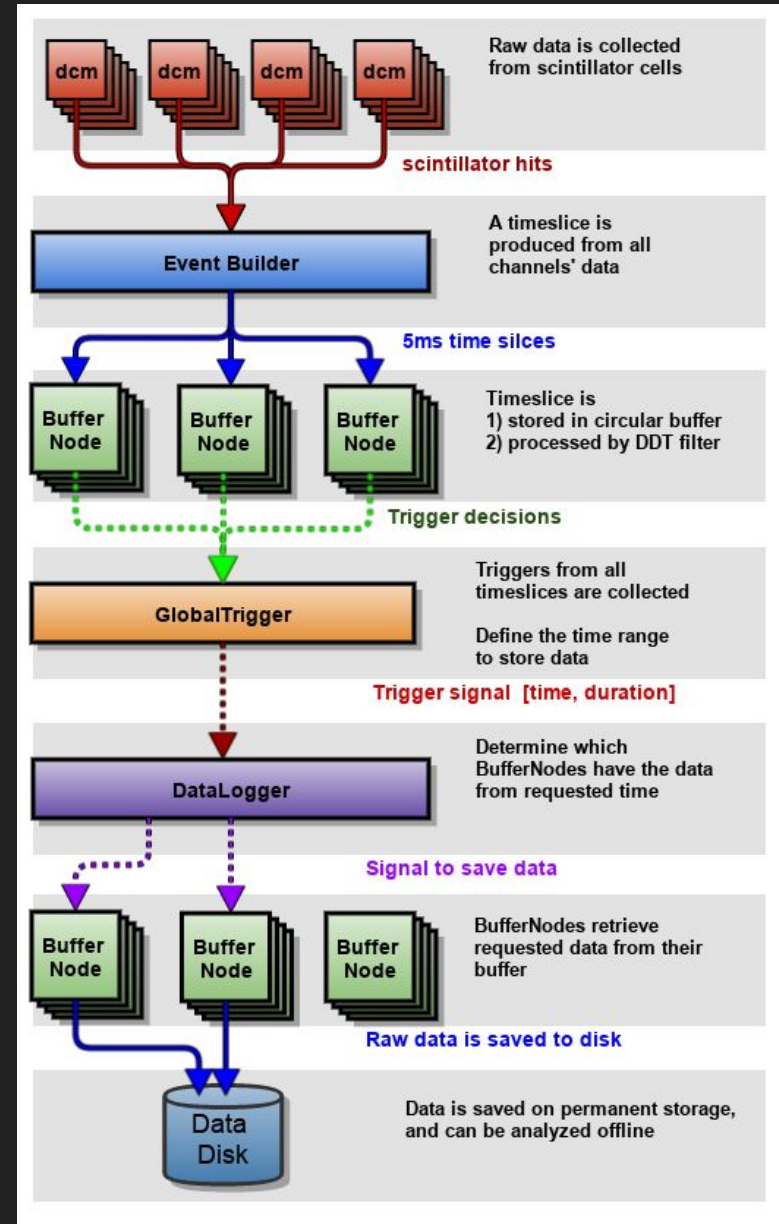
Data Driven Trigger system: fast realtime reconstruction to decide which data should be saved.

Data is processed in parallel:

170 nodes * 13 processes, each processing a 5ms “milliblocks”

This allows to broaden the physics goals of NOvA:

- Studies of atmospheric muons
- Magnetic monopole search
- Detection of galactic supernova neutrinos
- Neutron-antineutron oscillations
- and others



Neutrino signal from the core-collapse supernova



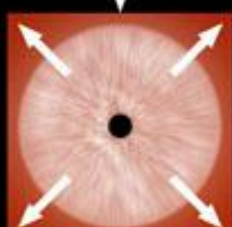
Core exceeds Chandrasekhar limit, $1.44 M_{\text{Sun}}$. Core Collapses.



Protons combine with electrons and form neutrons. Core shrinks.



Neutrons bounce back infalling matter, due to The Strong Nuclear Force.



Type II SN radiates **~99%** of the collapse energy in neutrinos:

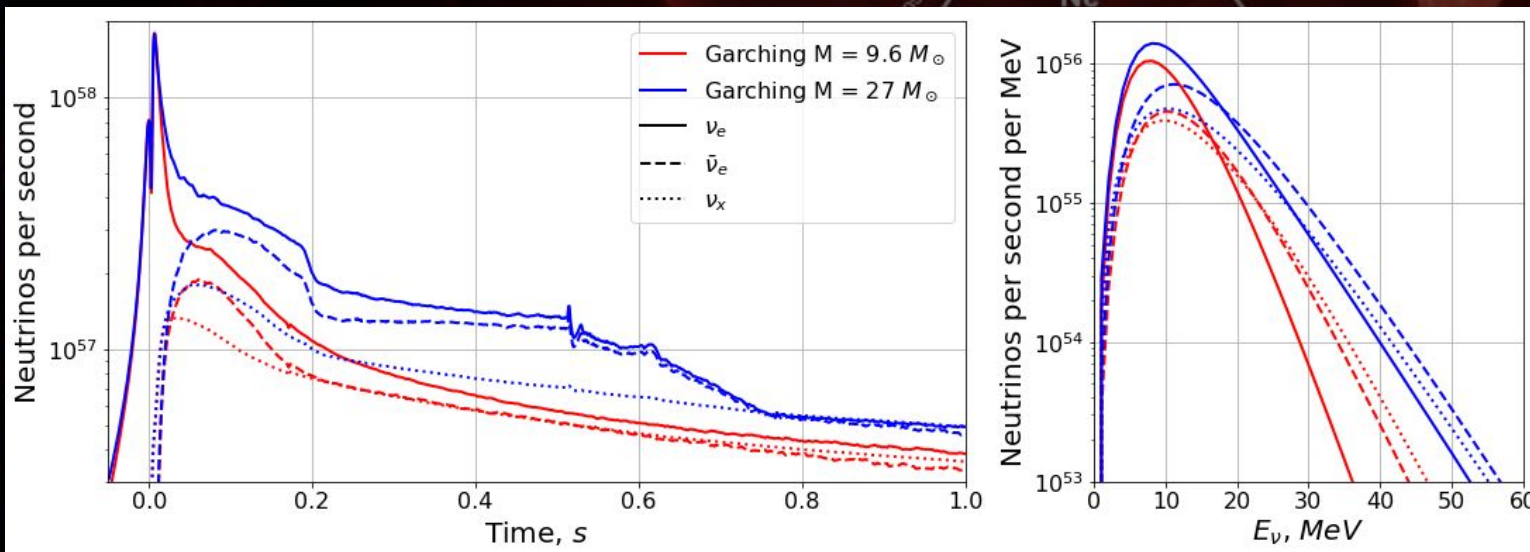
$\sim 10^{58}$ neutrinos: $E_{\nu} \sim 10\text{-}60 \text{ MeV}$ within $T \sim 10\text{s}$

Neutrino signal: probe of

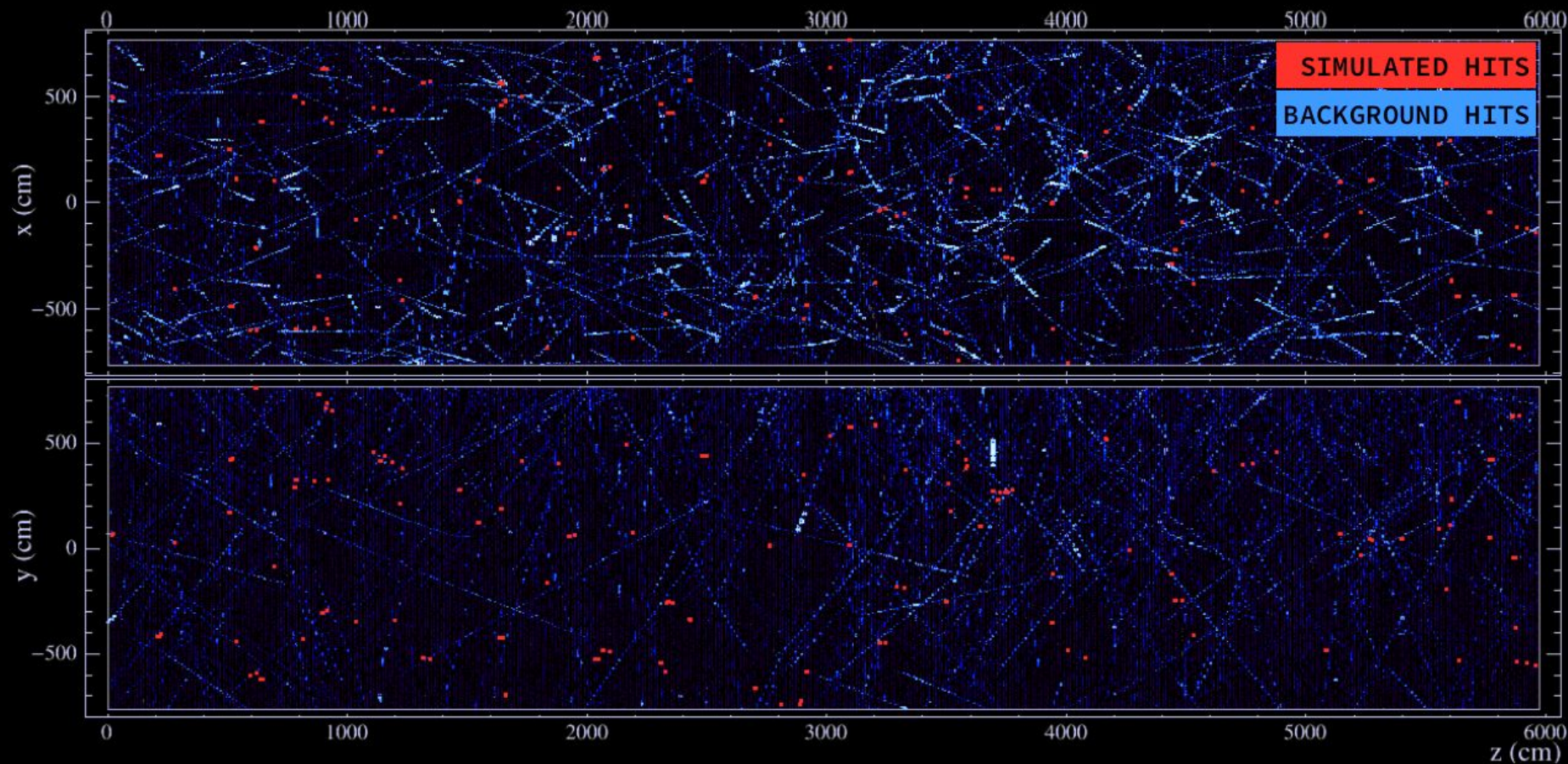
- Neutrino properties
- Supernova properties

arXiv:1508.00785 [astro-ph.HE]

Galactic SN are very rare: **~1-3** per century!
(and have never been observed in the neutrinos in our galaxy)



Far Detector: 5ms of cosmic data + SN simulation



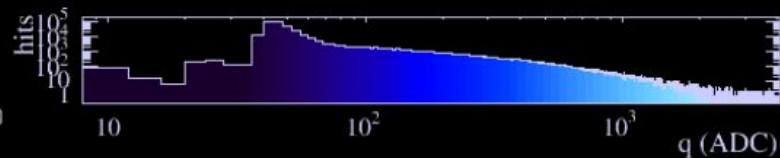
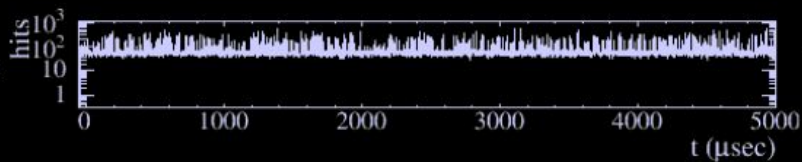
NOvA - FNAL E929

Run: 1 / 1

Event: 14 / SNEWSBeatSI

UTC Thu Jan 1, 1970

00:00:0.000000000



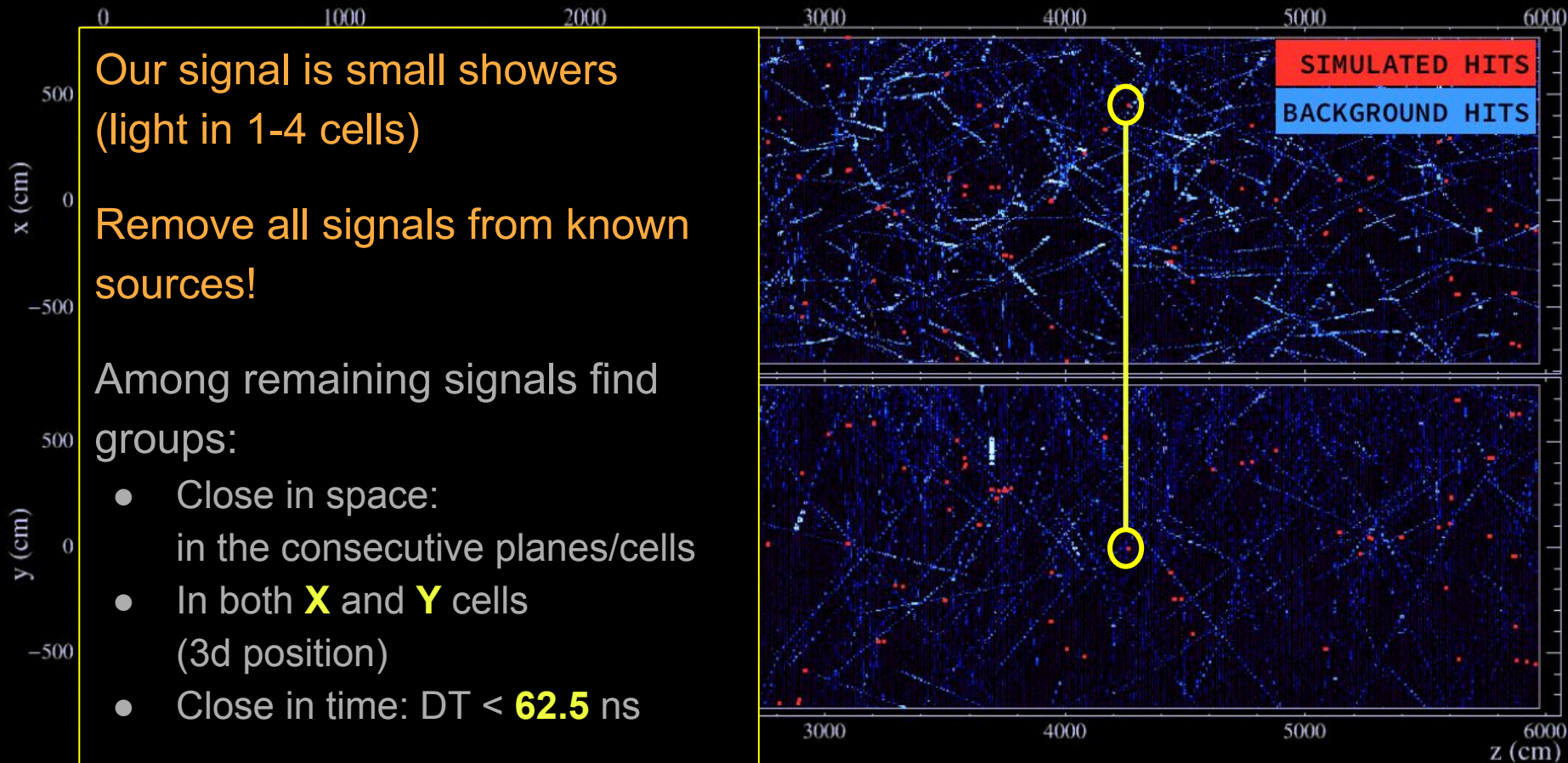
Signal selection

Our signal is small showers
(light in 1-4 cells)

Remove all signals from known
sources!

Among remaining signals find
groups:

- Close in space:
in the consecutive planes/cells
- In both **X** and **Y** cells
(3d position)
- Close in time: $DT < 62.5$ ns



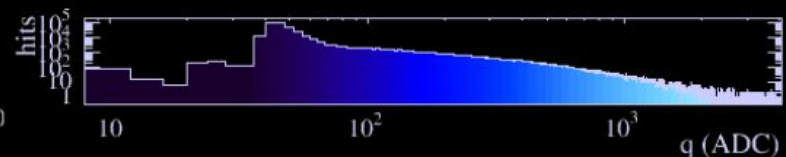
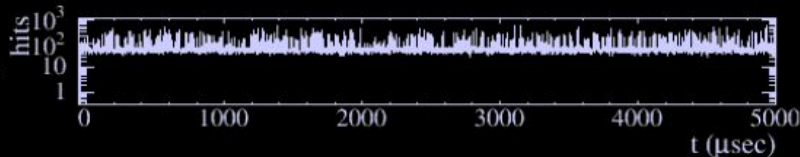
NOvA - FNAL E929

Run: 1 / 1

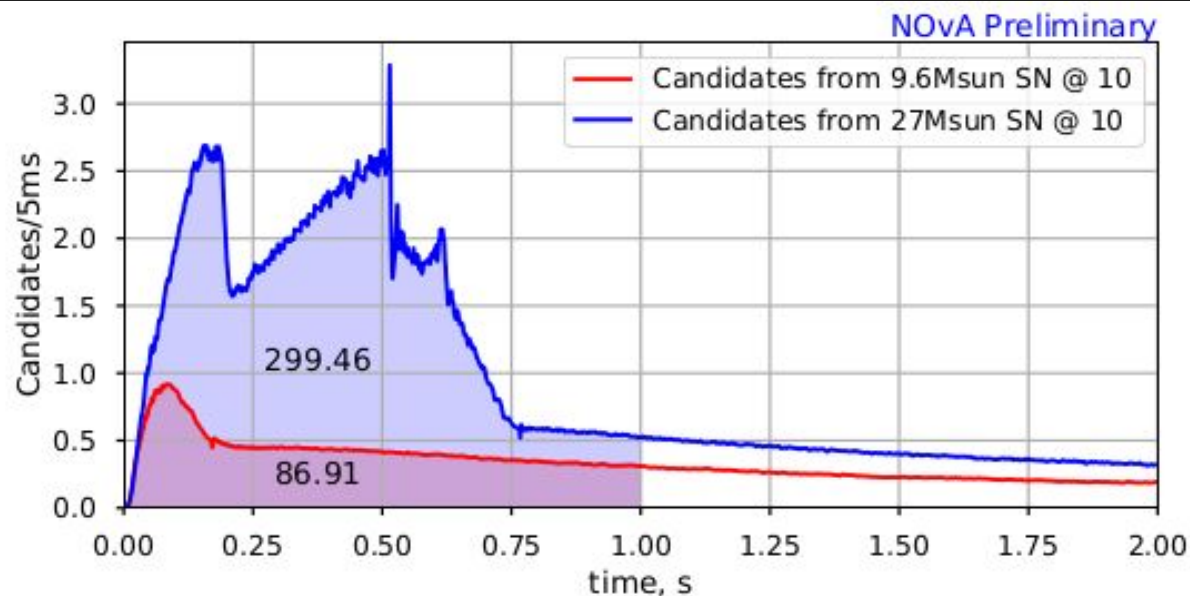
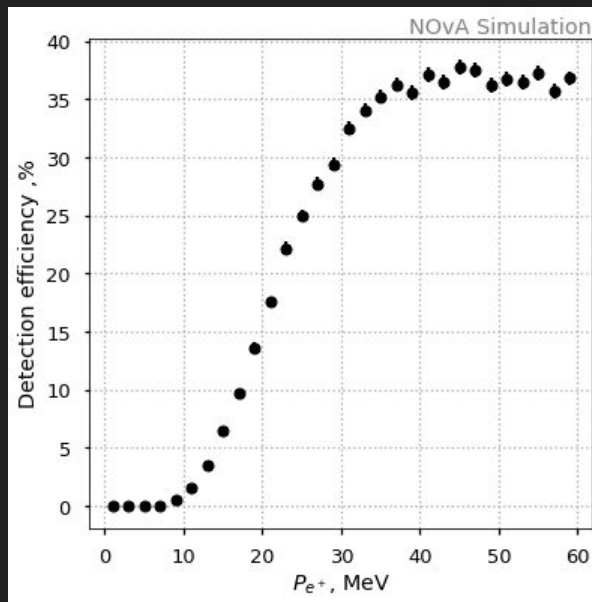
Event: 14 / SNEWSBeatSI

UTC Thu Jan 1, 1970

00:00:0.000000000



Results of the neutrino candidates selection



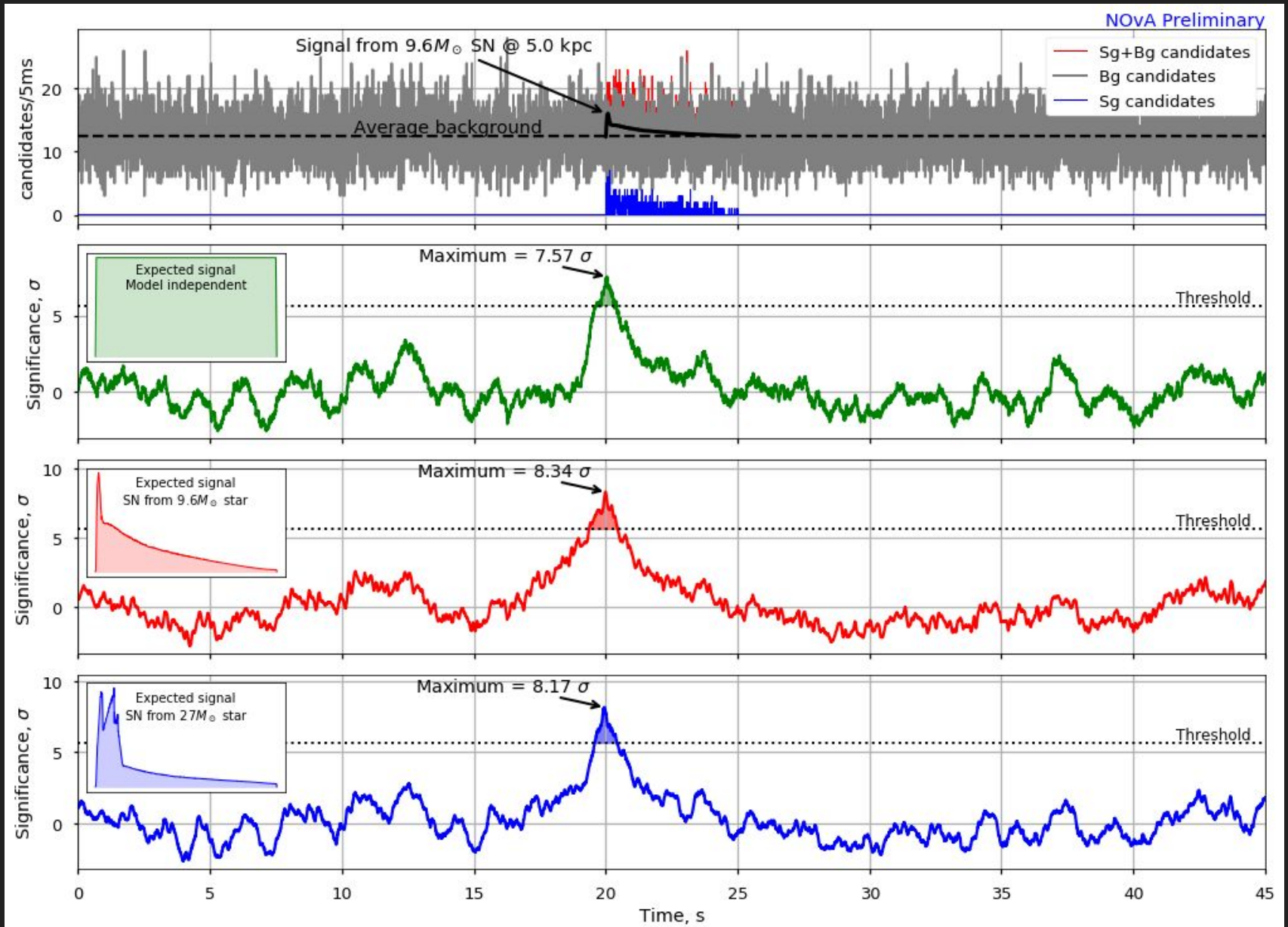
In order to trigger on the galactic supernova neutrino signal, we need to observe the signal excess above the background fluctuations.

This has to be performed in realtime

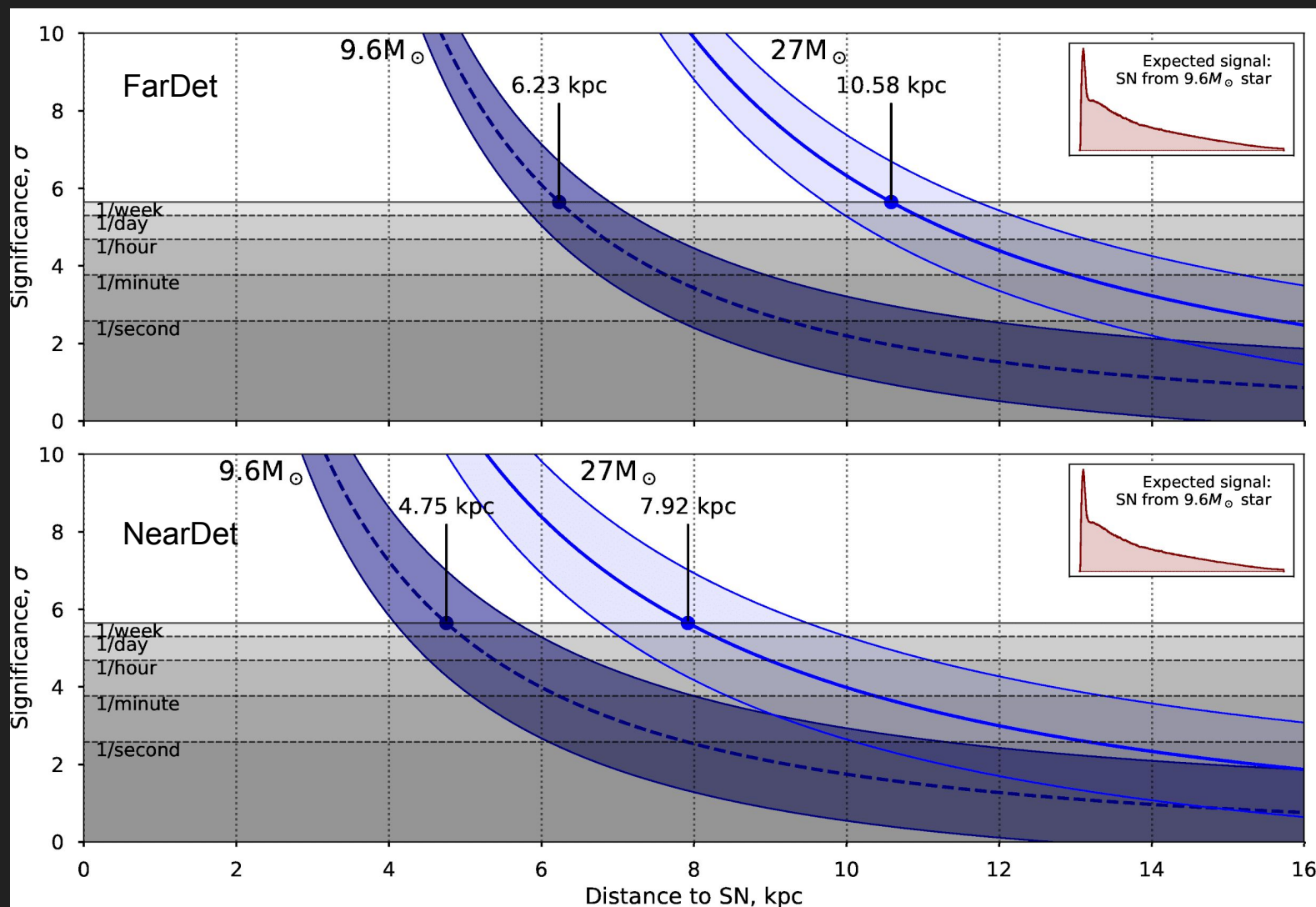
Detector	Signal	Background
Near	1.28/s	0.52/s
Far	87/s	2500/s

If the observed signal significance exceeds threshold, the trigger saves the SN data for offline analysis.

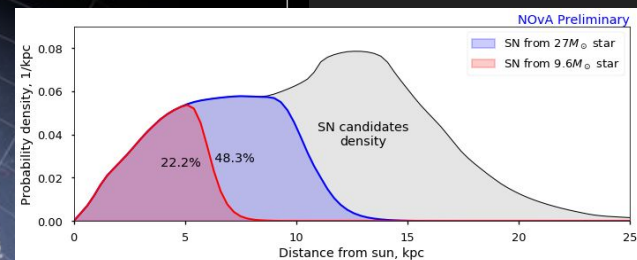
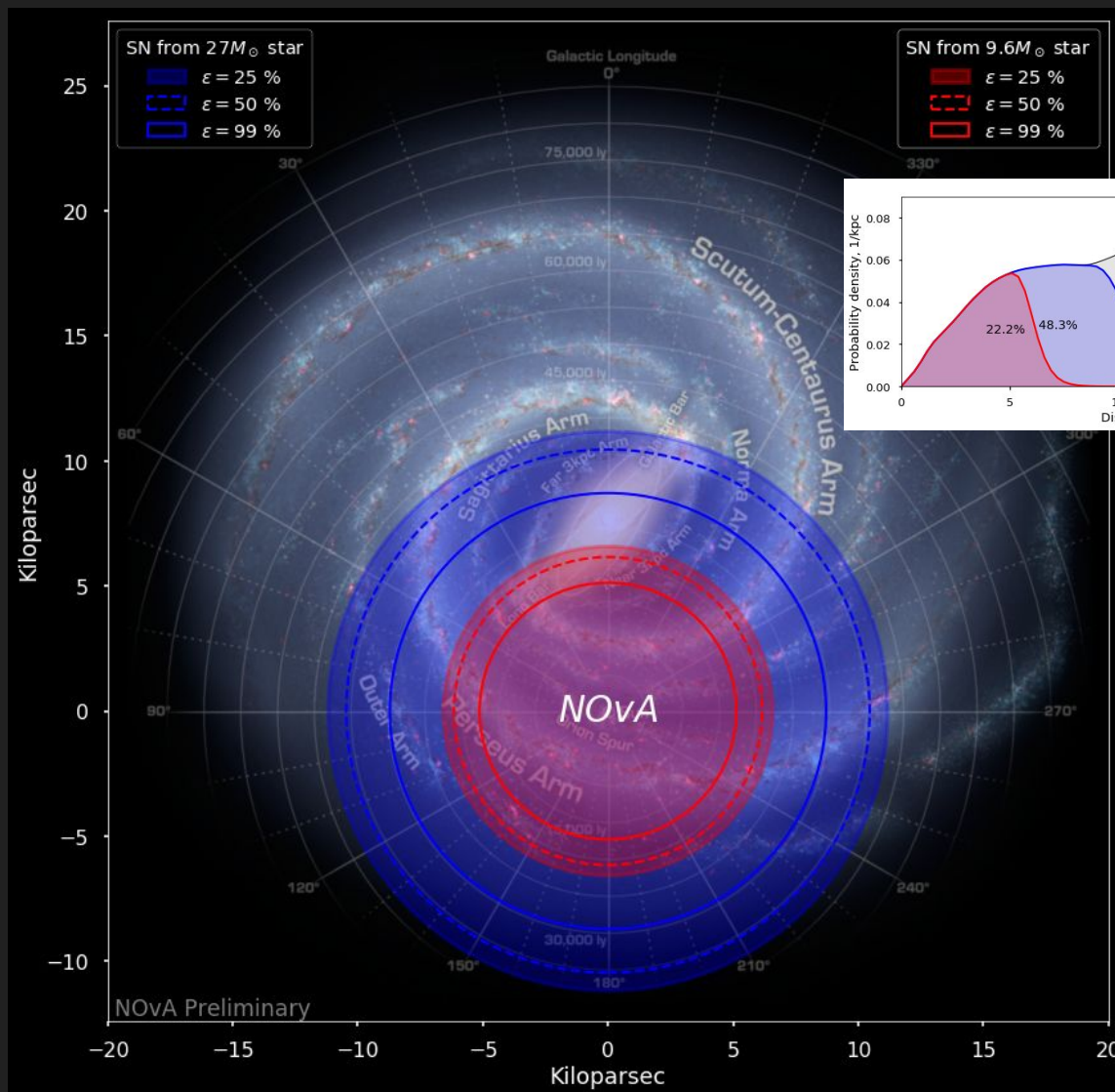
Signal processing and triggering: example



Supernova significance vs. distance



NOvA supernova trigger sensitivity





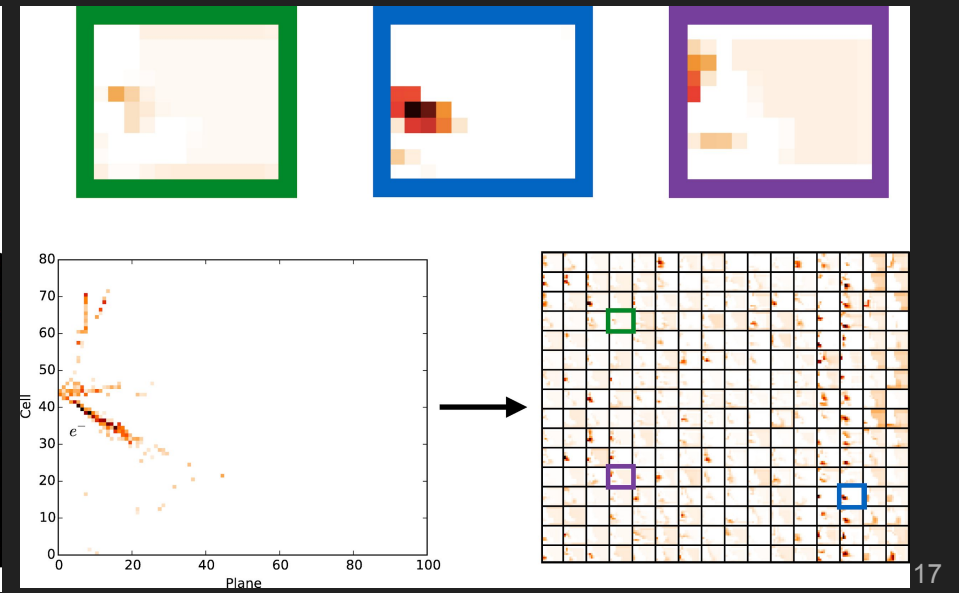
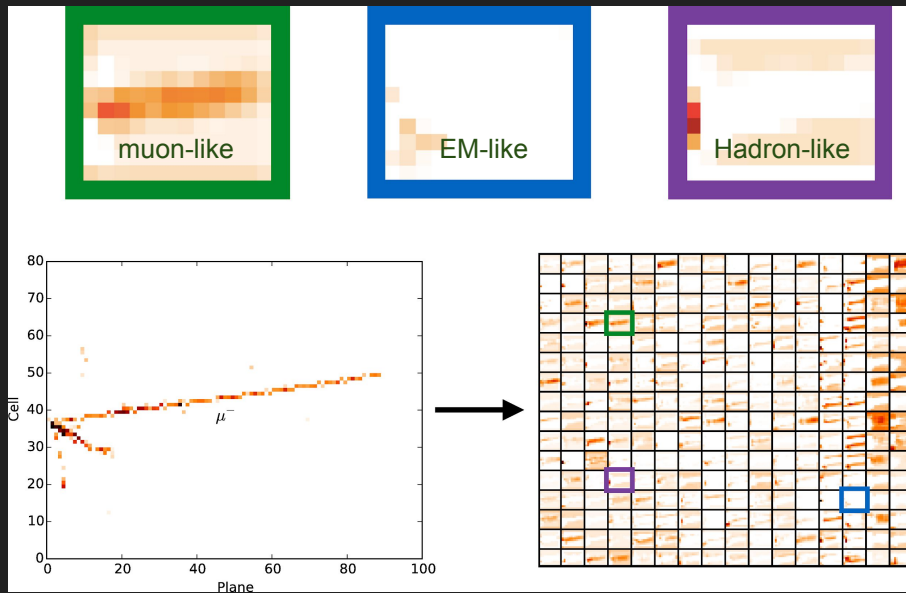
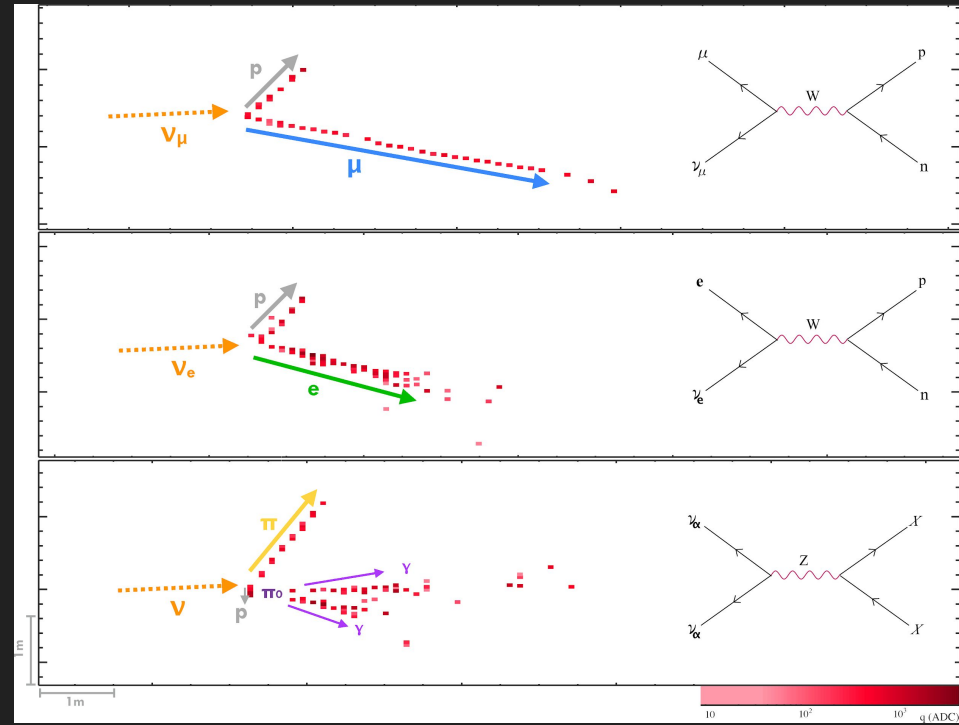
MAY 2020

BACKUP

Events classification

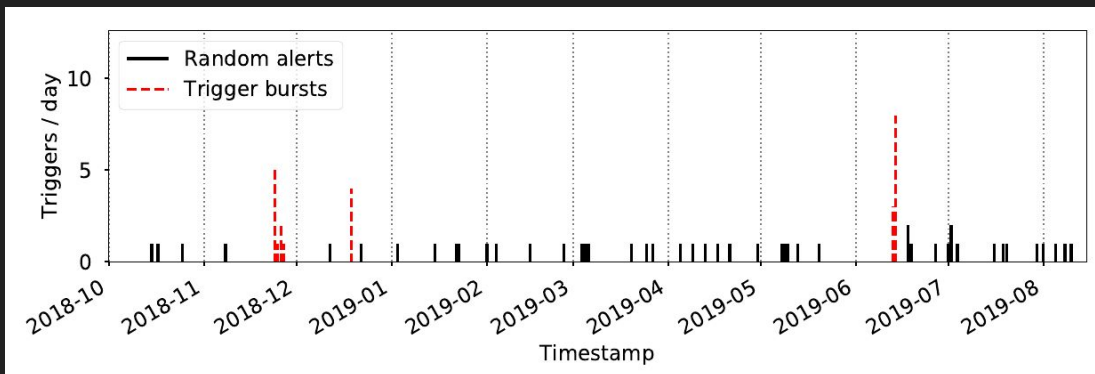
An approach from computer vision:
convolutional neural network (CVN)

- Detector views of the contained event, associated with beam spill time: analyzed as image
- Learned features, corresponding to the considered event topologies
- Efficiency and purity: about 90%



Supernova trigger commissioning

Expectation:
stable trigger rate
1/week

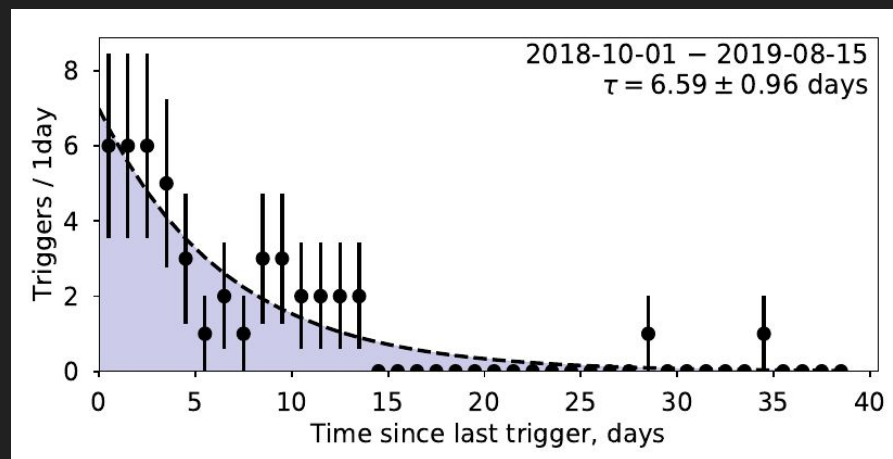


Reality: supernova trigger is
sensitive to instabilities of
background:

- Run start instabilities
- Detector environment condition
- Noise channel masking failure

After fixing these problems:

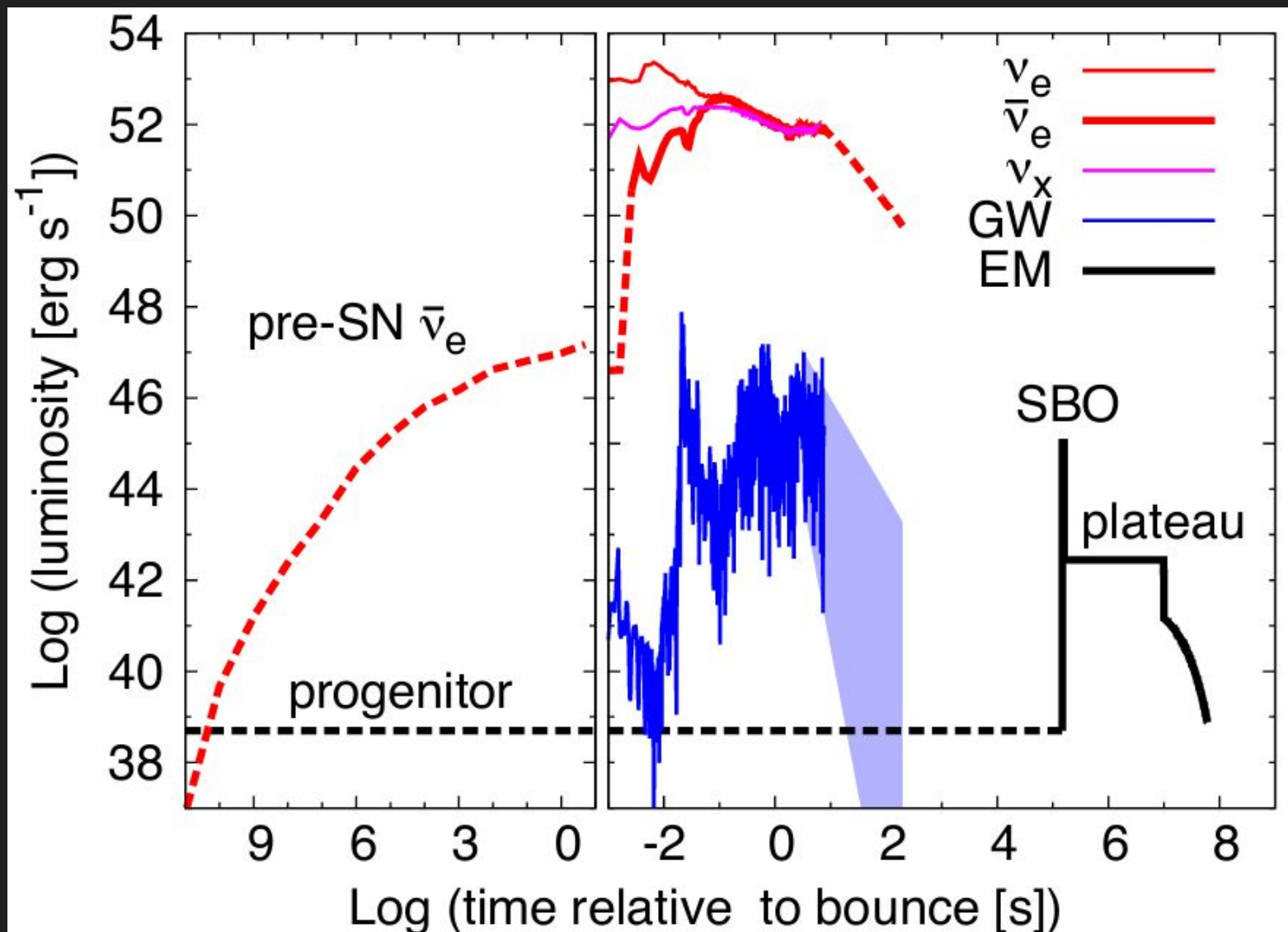
- Filtering data with incomplete detector
- Strict data quality cuts
- Monitoring of NoiseMap service



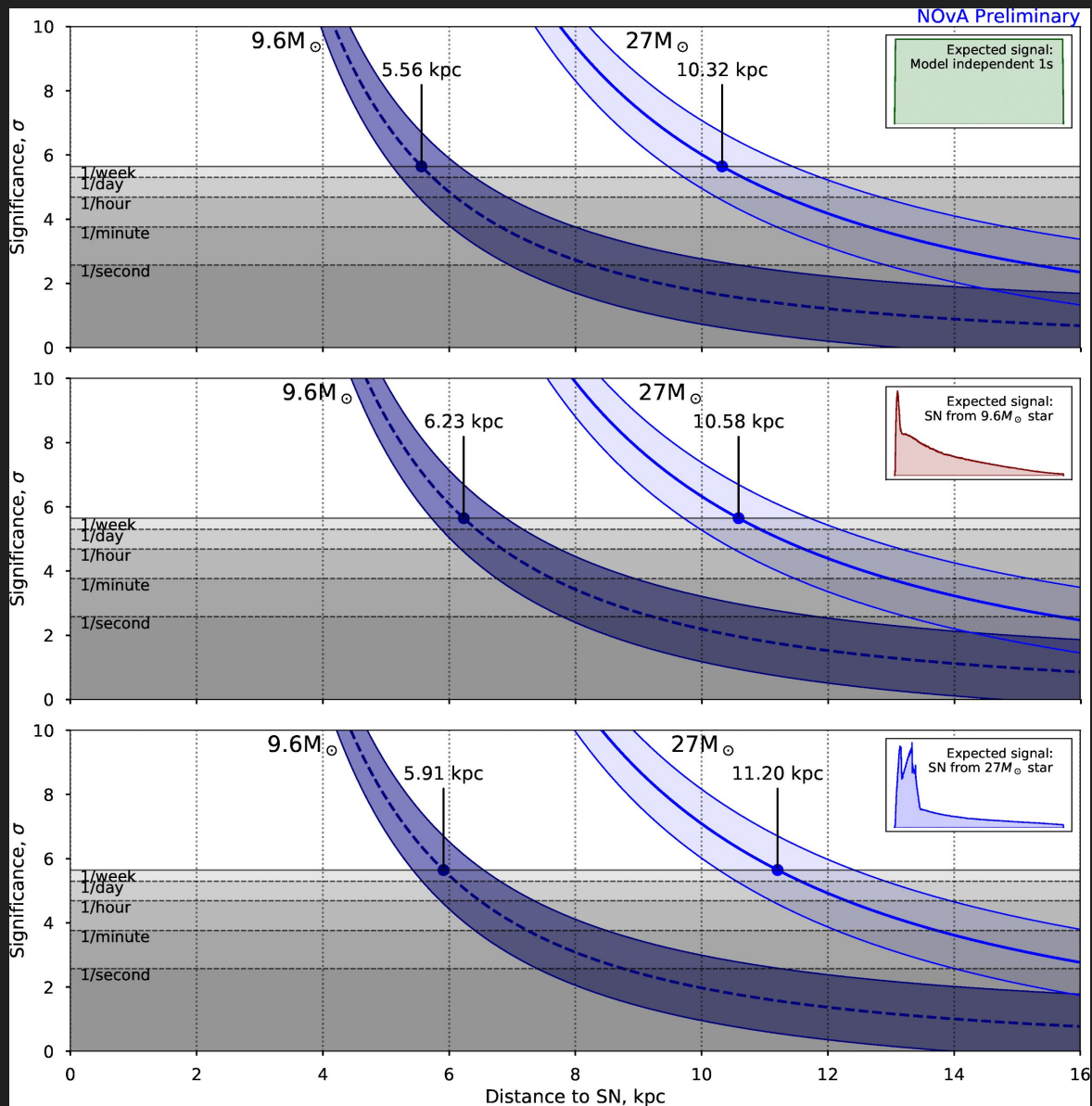
Summary

- Real-time detection of SN signals is crucial for studying supernova.
- The dedicated SN triggering system extends the NOvA physical program.
 - Signal selection and reconstruction in real time.
 - Operating since Nov 2017, tuned to false triggering rate $\sim 1/\text{week}$.
 - Expected signal shape is used for hypotheses testing.
- SNEWS alert network was operating since 1998,
 - now SNEWS v2.0 is being designed.
- Proposed significance combination method (Stouffer's weighted linear combination):
 - good for the case of high background experiments (like NOvA of Ice-Cube)
 - applicable for pre-supernova signals in low-BG experiments.
- Server prototype was developed and soon will be tested on NOvA detectors.

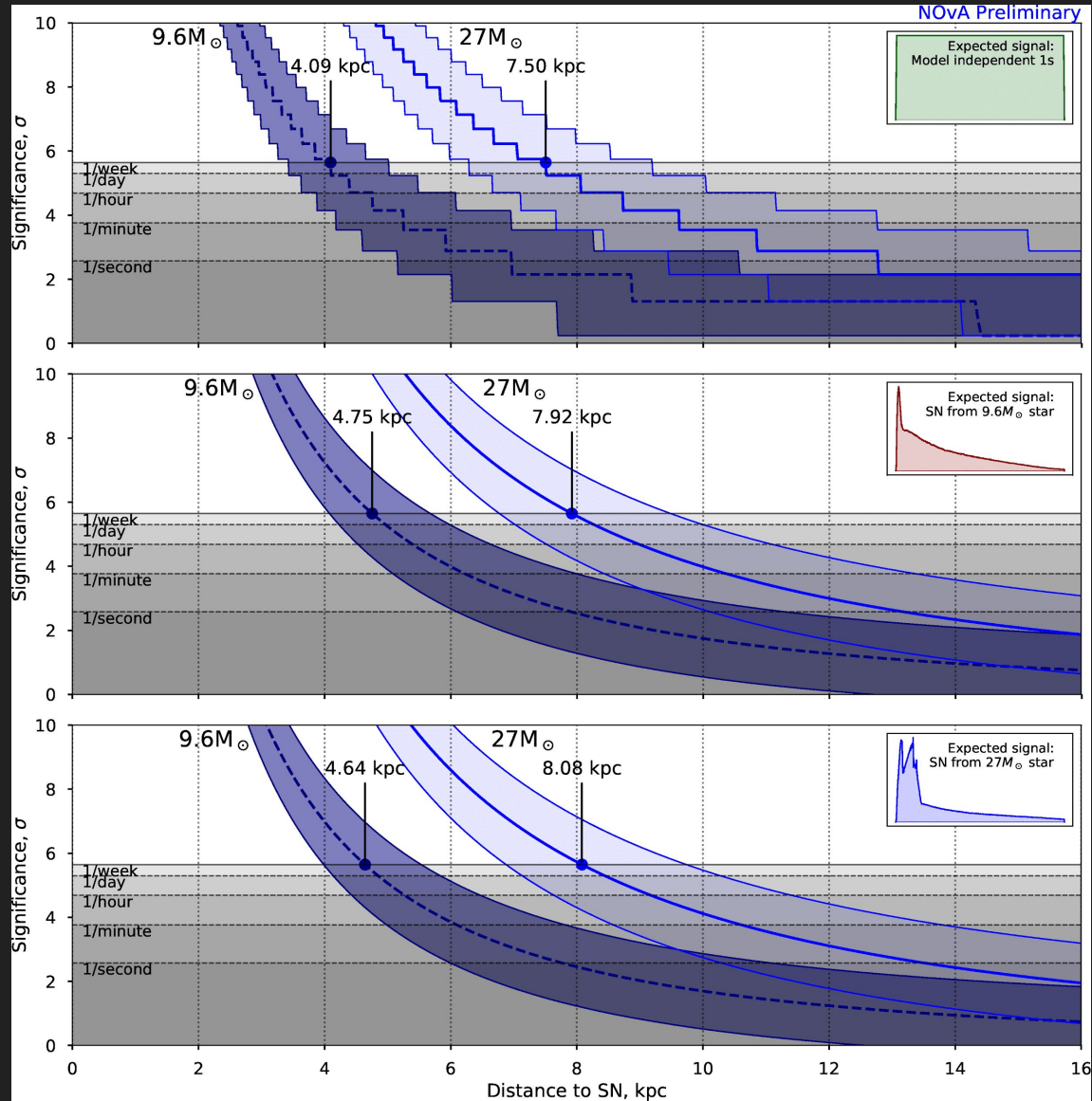
Supernova: a multi-messenger view



Supernova significance vs. distance: FarDet



Supernova significance vs. distance: NearDet



SuperNova Early Warning System

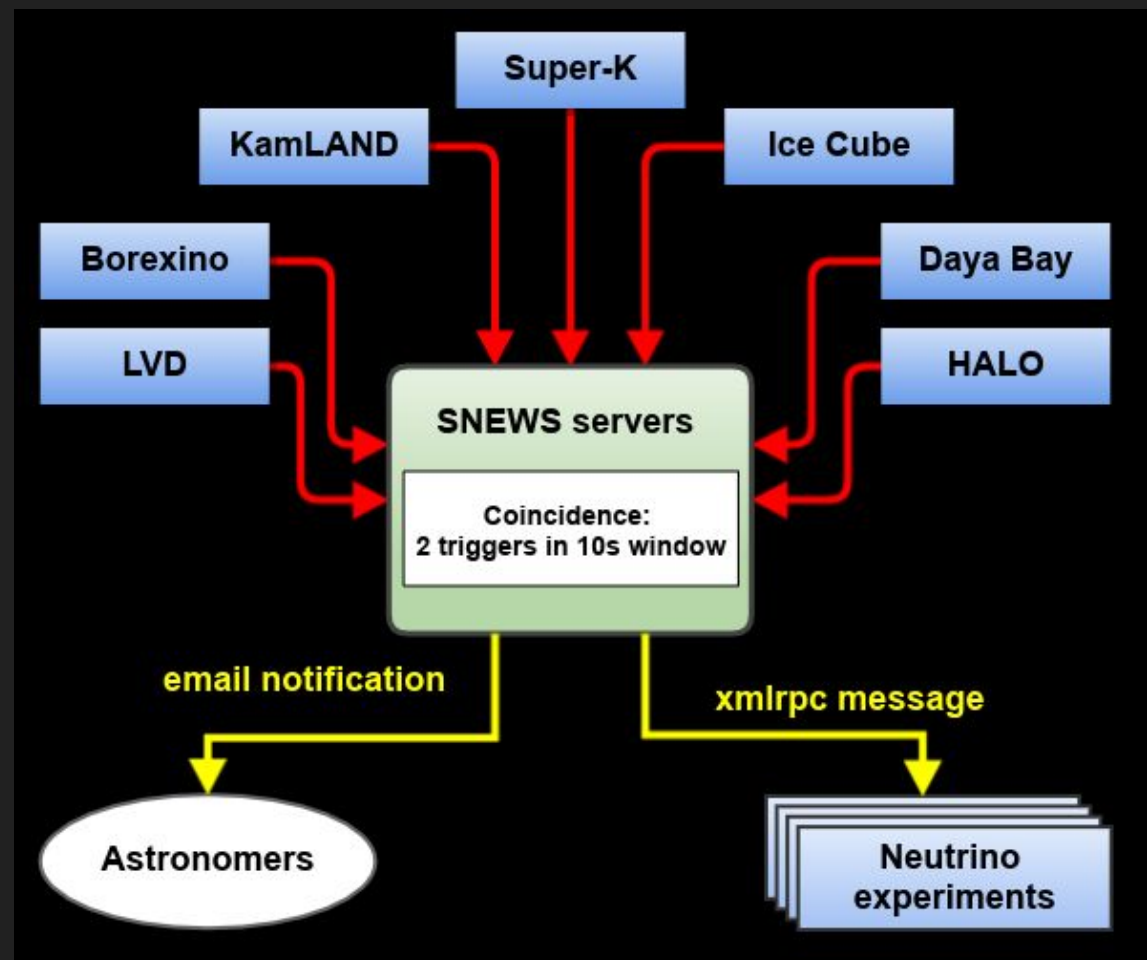


snews.bnl.gov

A global network to make sure we don't miss a galactic event.

Neutrinos arrive several minutes to hours prior to optical signal

SNEWS works since 1998



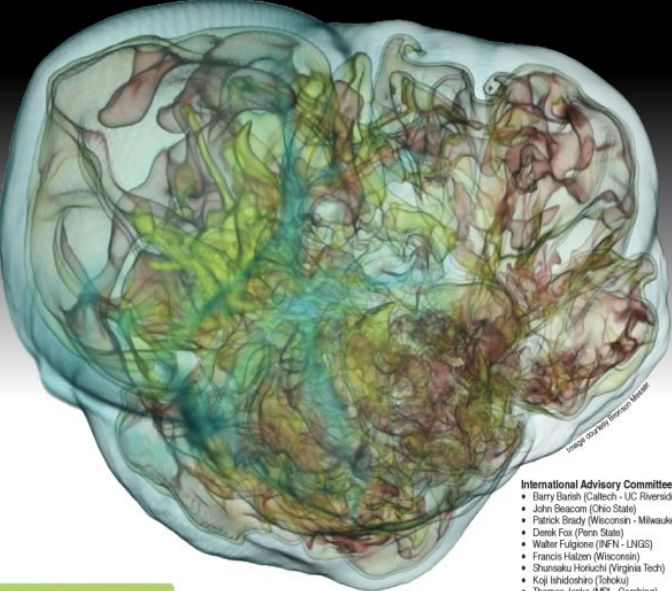
A planned upgrade of SNEWS: in progress

SuperNova Early Warning System

SNEWS 2.0 Workshop

Supernova Neutrinos in the Multi-Messenger Era

June 14-17, 2019
Laurentian University, Sudbury, Canada



Workshop Topics

- Supernova neutrino detection
- Multi-messenger signals
- Astronomical alert networks
- Alert dissemination
- Pointing with neutrinos
- Pre-supernova alerts

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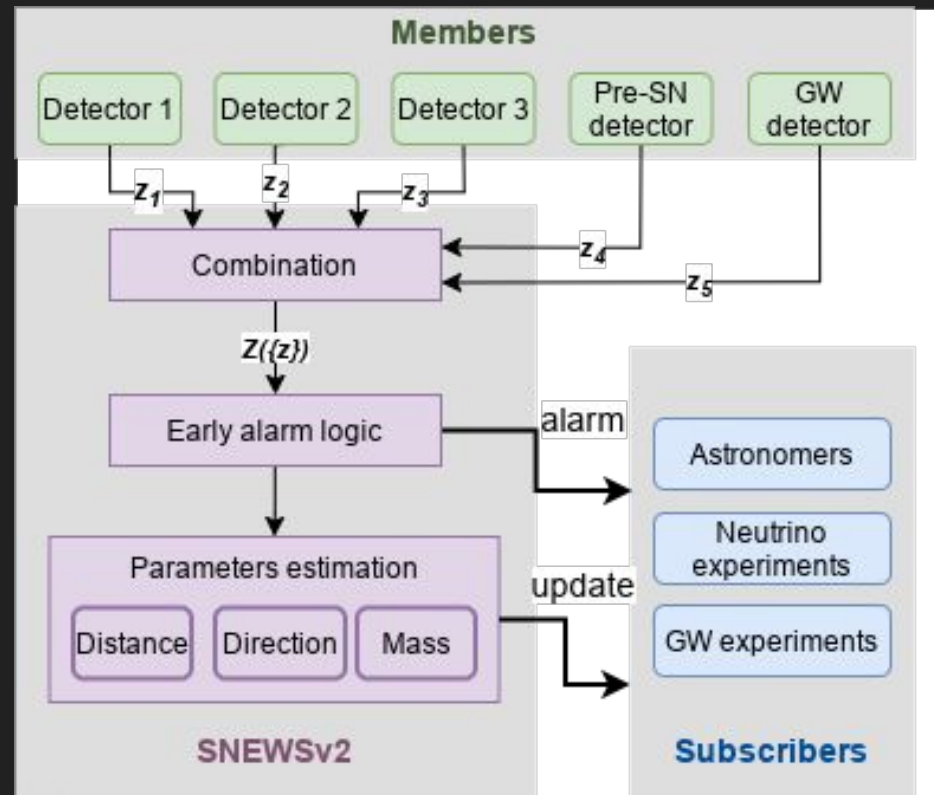
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<https://snews2.0.snolab.ca>

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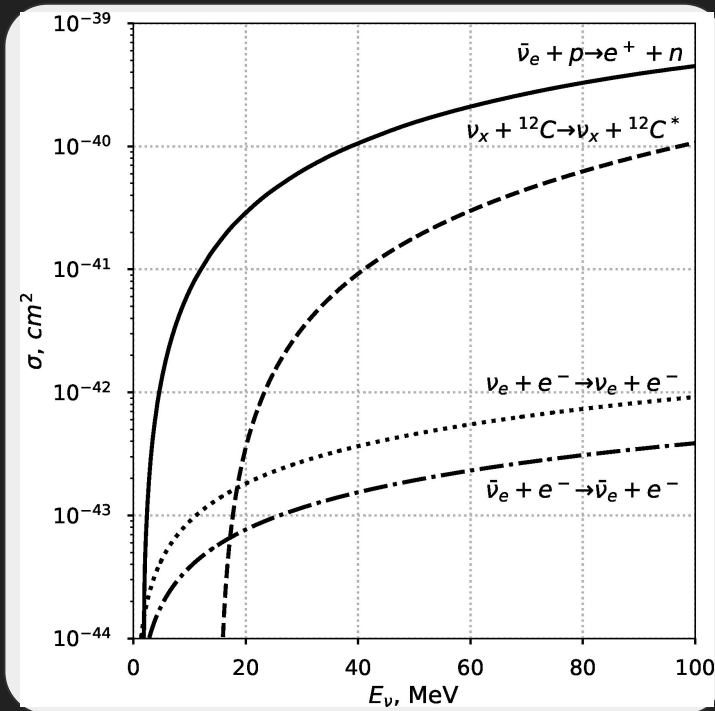



A joint effort to build a new system, combining significance and parameters estimation measurements in real-time.

Status: design and prototyping.

Many exciting tasks ahead!

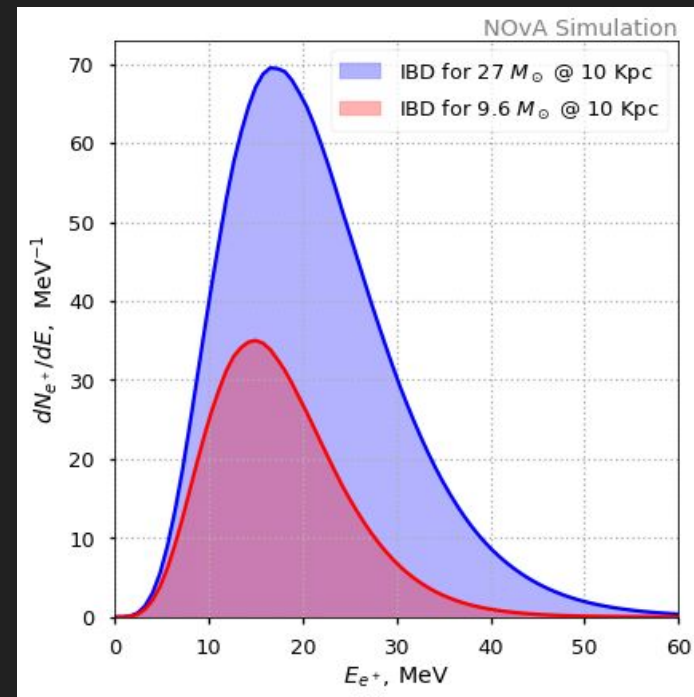
SN neutrinos interactions in the NOvA Detectors



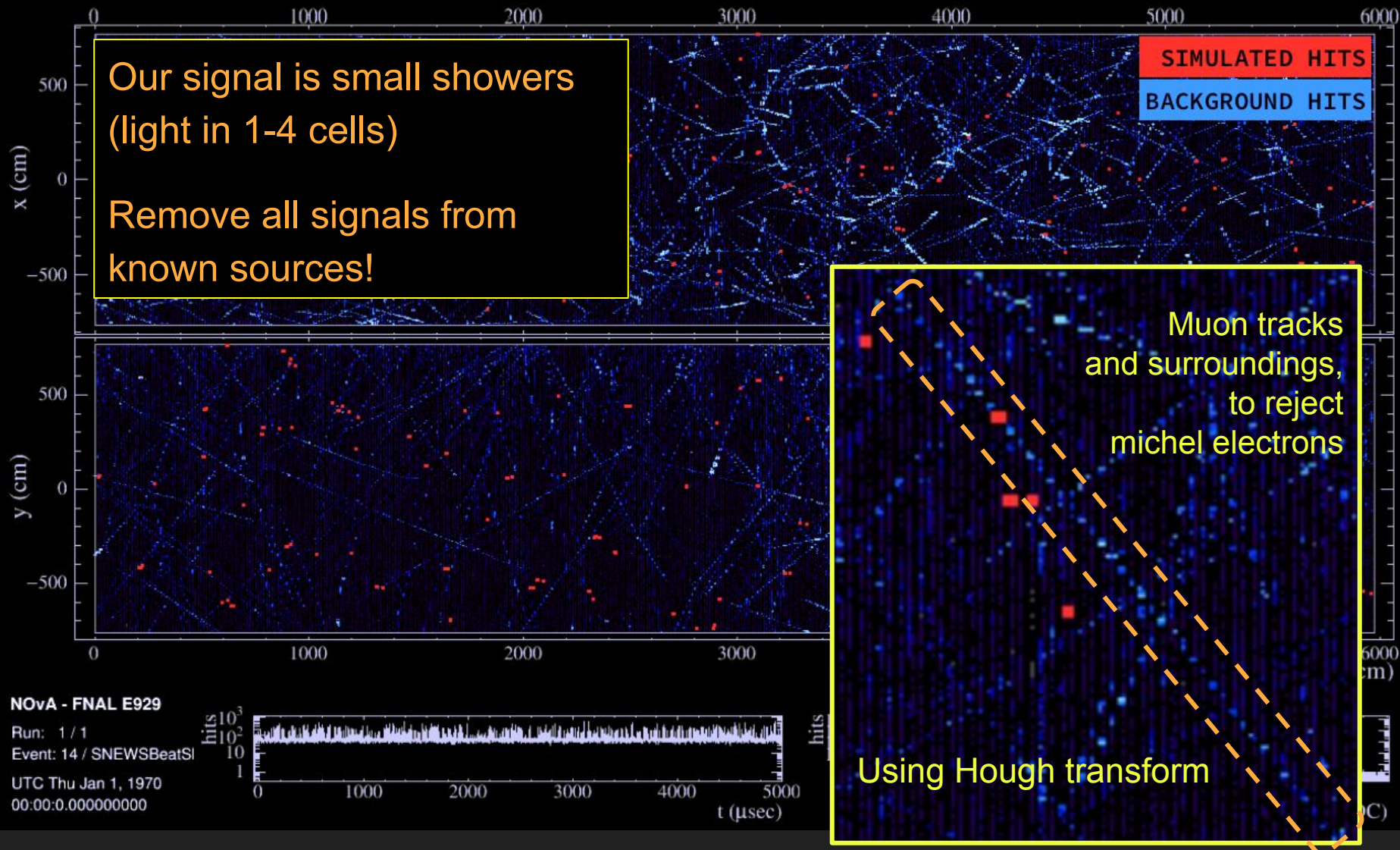
Other channels give negligible contribution: energy too low or small interaction rate.

Main detection channels:

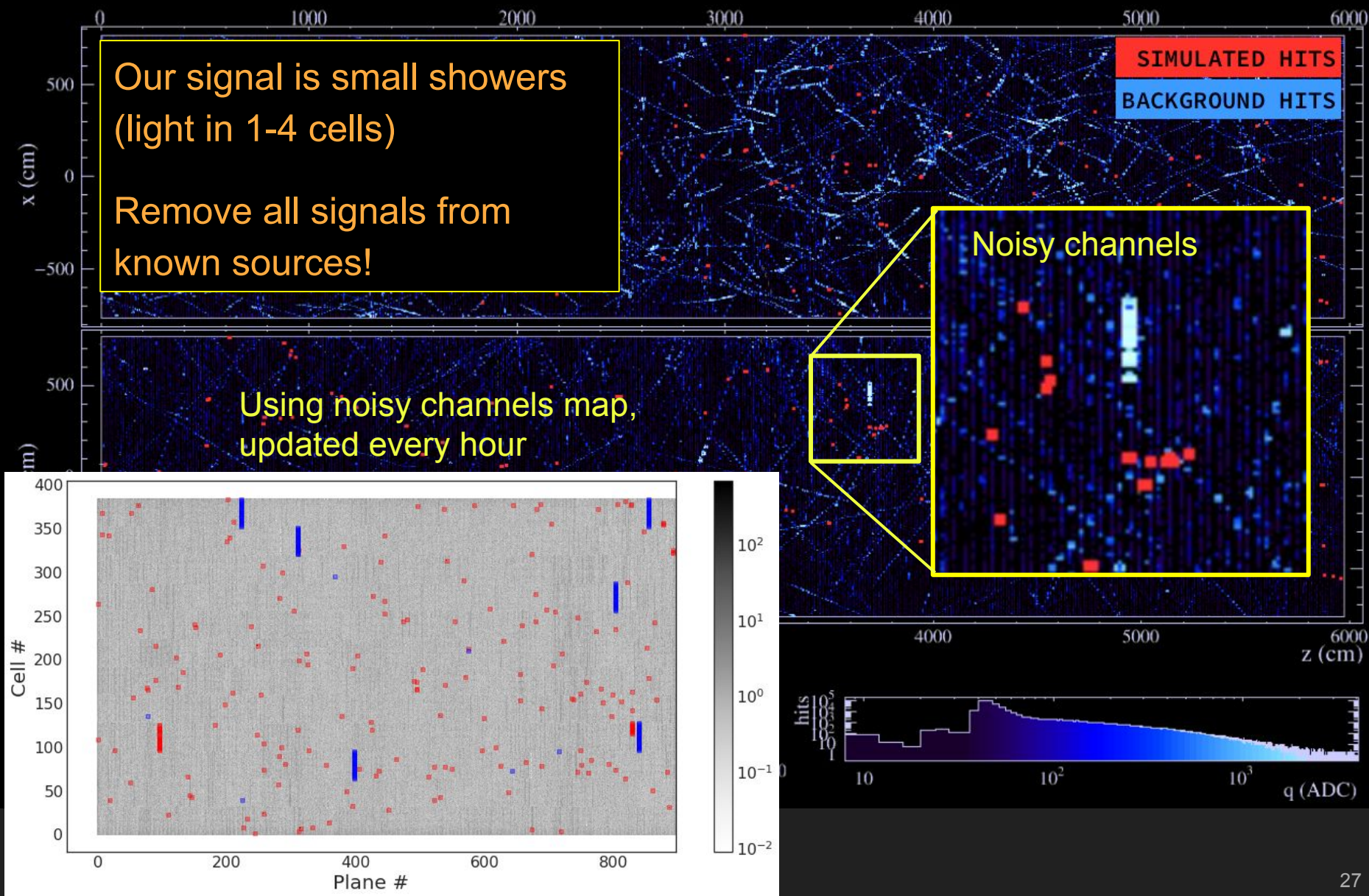
- **Inverse Beta Decay**
 - signature:
positron shower (10-60 MeV)
- **Neutral Current**
 - signature:
deexcitation gamma (15.1 MeV)



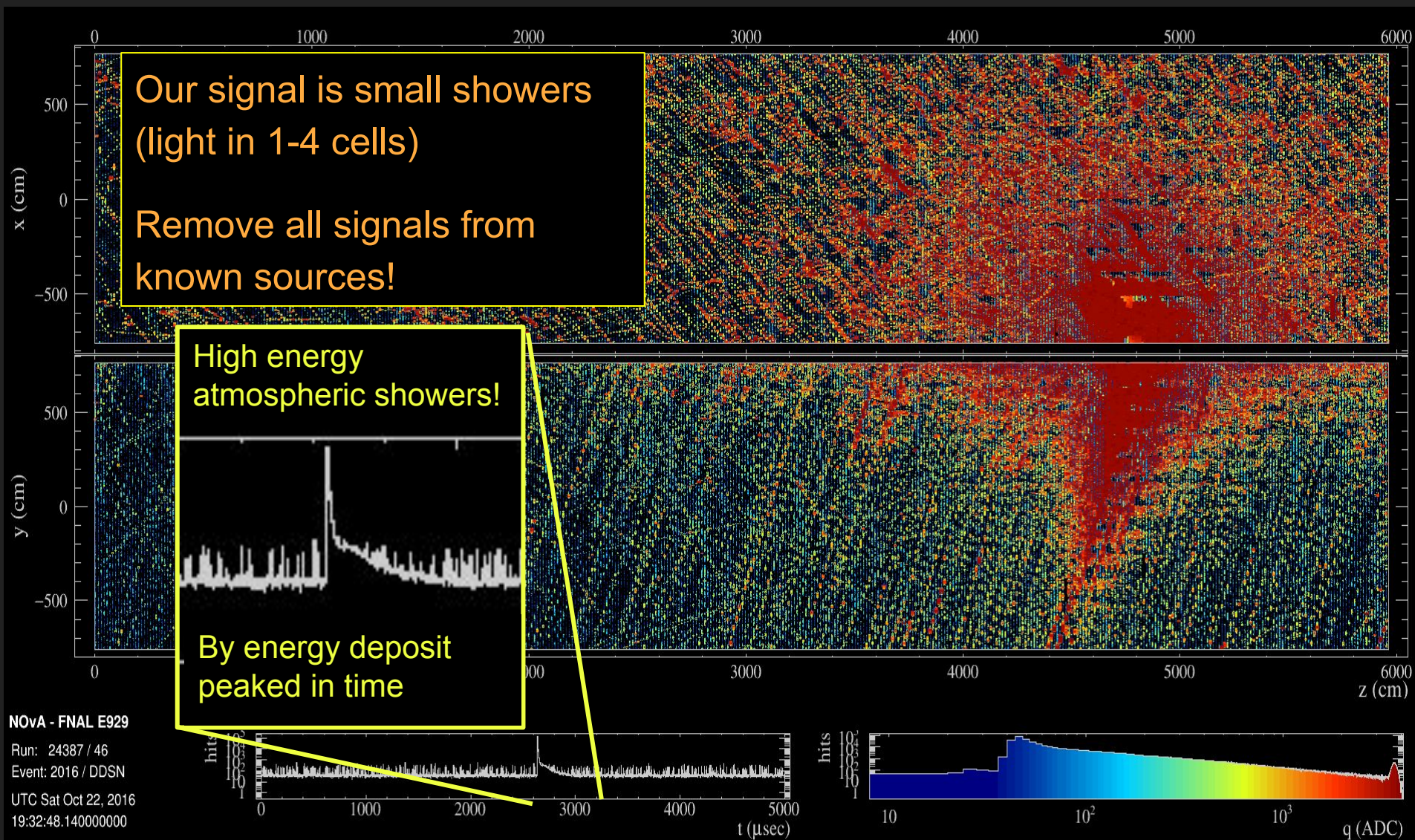
Signal selection



Signal selection



Signal selection



Signal selection

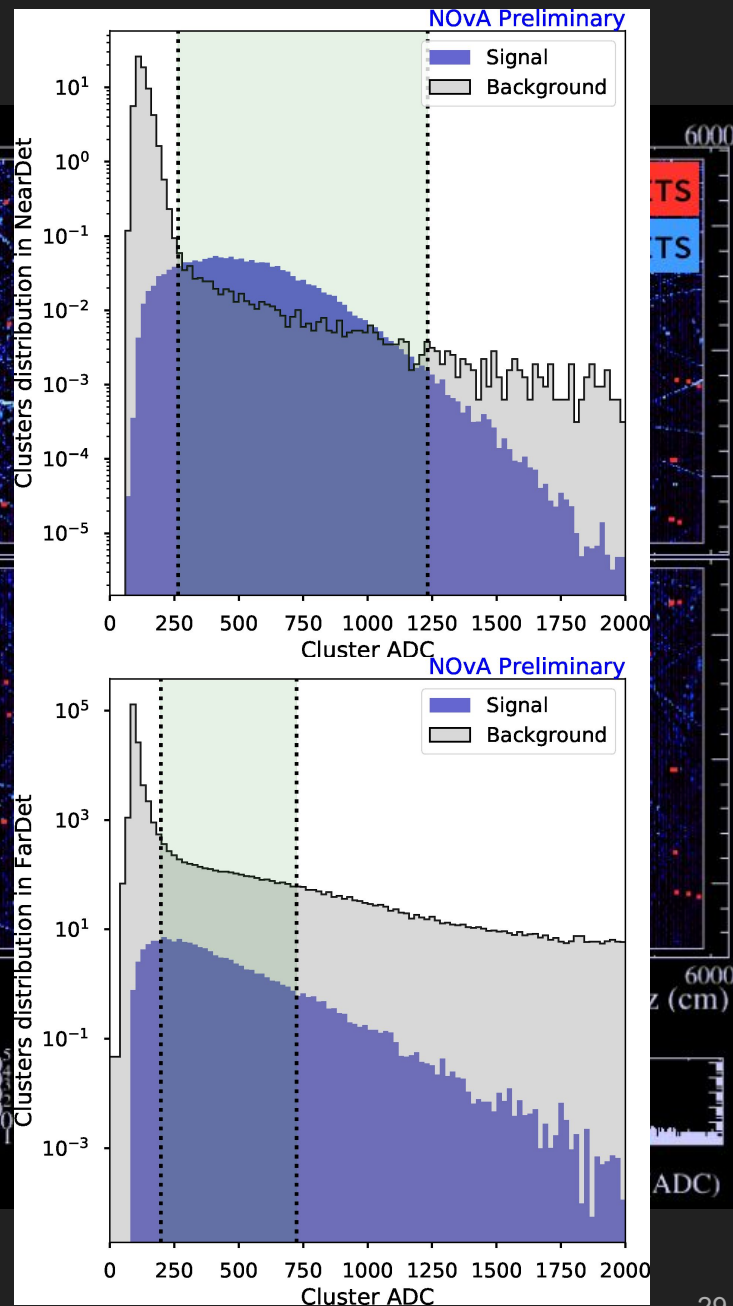
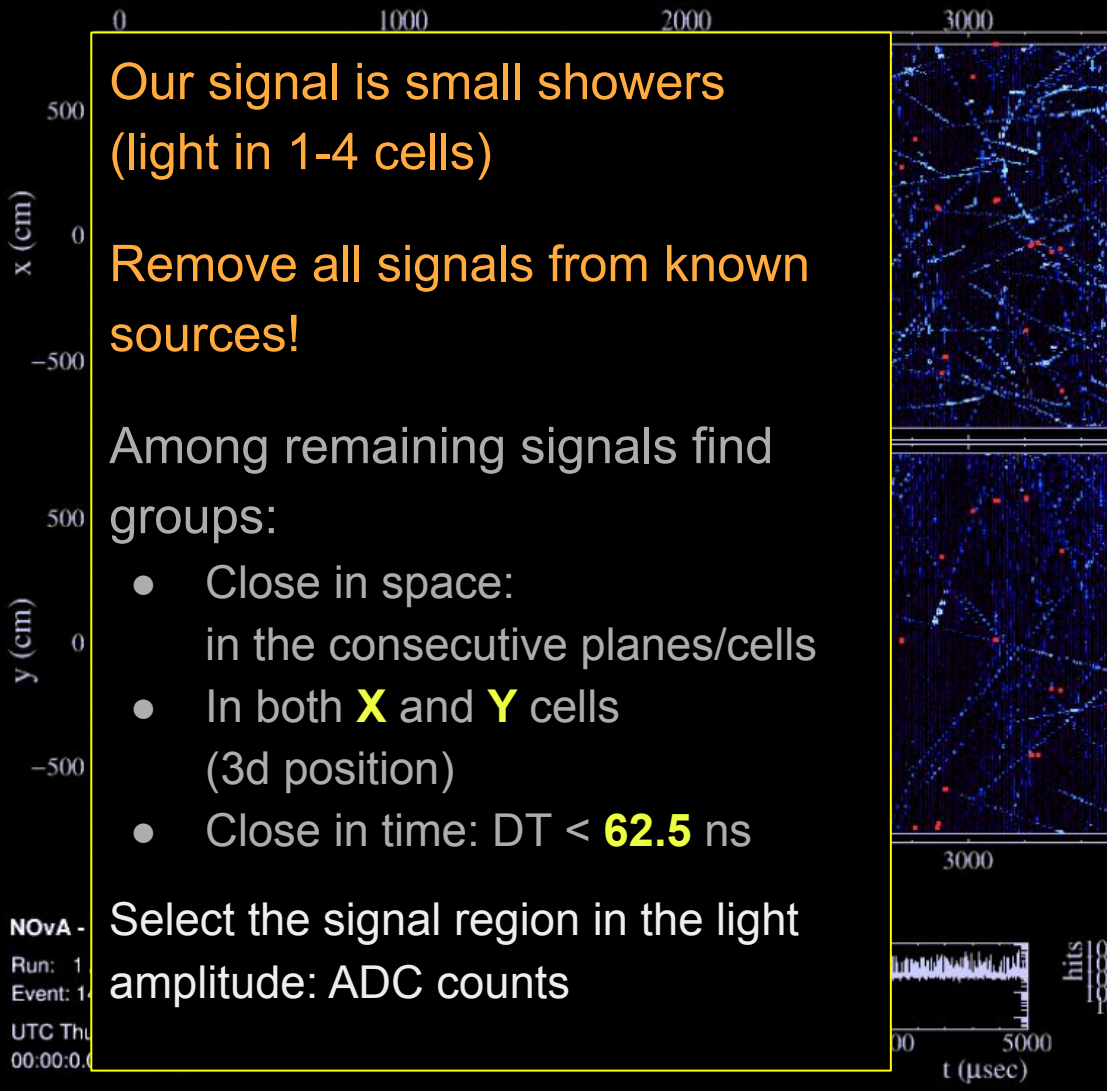
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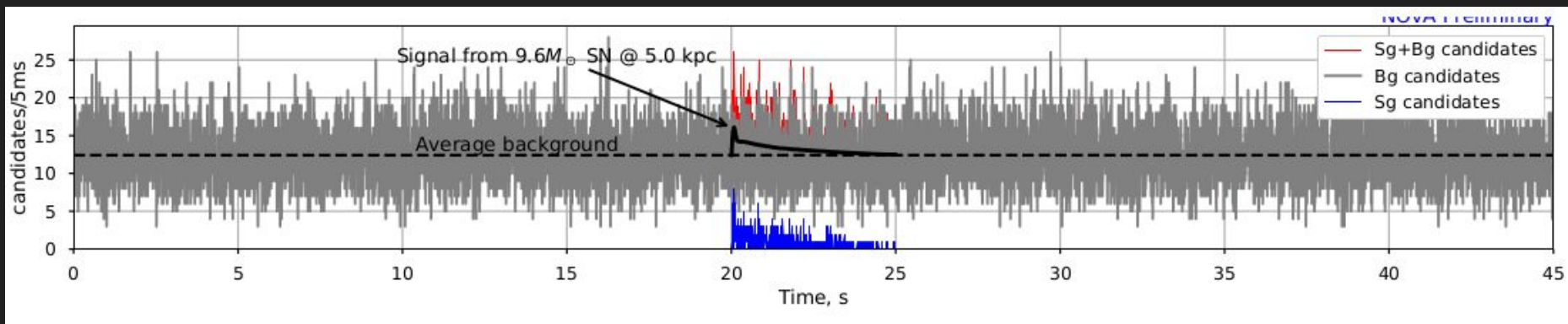
Among remaining signals find
groups:

- Close in space:
in the consecutive planes/cells
- In both **X** and **Y** cells
(3d position)
- Close in time: $DT < 62.5$ ns

Select the signal region in the light
amplitude: ADC counts



Signal processing and triggering: example



Trigger system needs to distinguish between $H_0 = Bg$ vs $H_1 = Bg + SN$ hypotheses.

Easiest thing: just look for the N events in a sliding time window. Easy. But:

- Short window (1s): we lose a lot of signal
- Long window (10s): we gain a lot of background

But we can use also the knowledge of the signal shape.

We use log likelihood ratio, to enhance the hypotheses discrimination:

$$\ell(\vec{n}) \equiv \log \frac{P(\vec{n}|H_1)}{P(\vec{n}|H_0)} = \sum_i n_i \cdot A_i, \quad \text{where } A_i = \log \left(1 + \frac{S_i}{B} \right)$$