Virtual conference July 20-21

New Perspectives 2020

A conference for early career researchers

NOvA in 10 minutes

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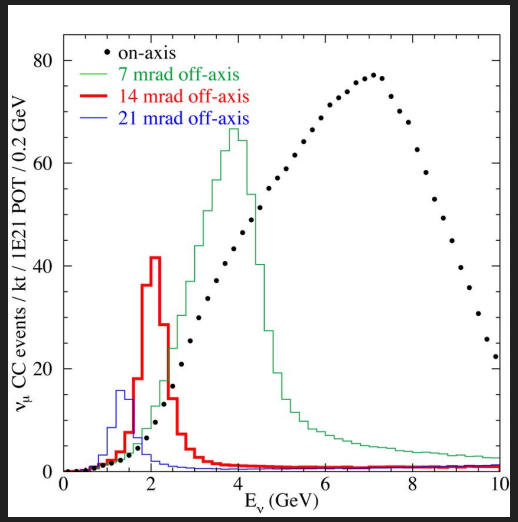
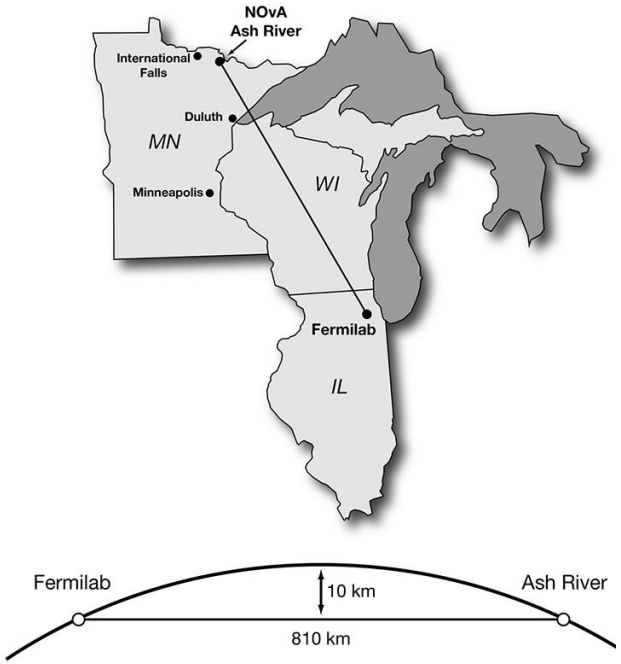
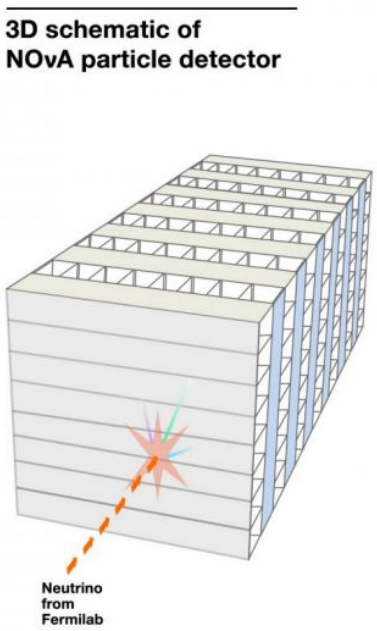
The NOvA experiment

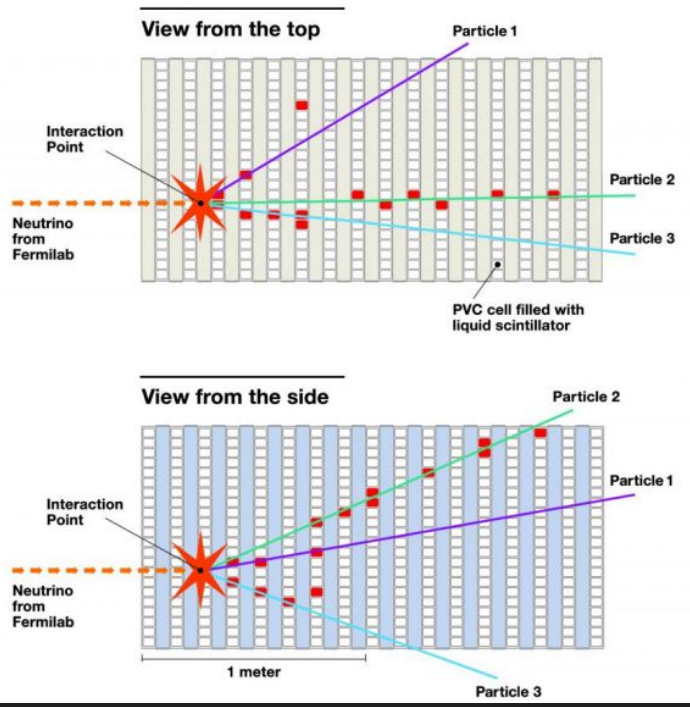
Main goal: study of neutrino oscillations in a muon (anti)neutrino beam
with **<E>=2 GeV**

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









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

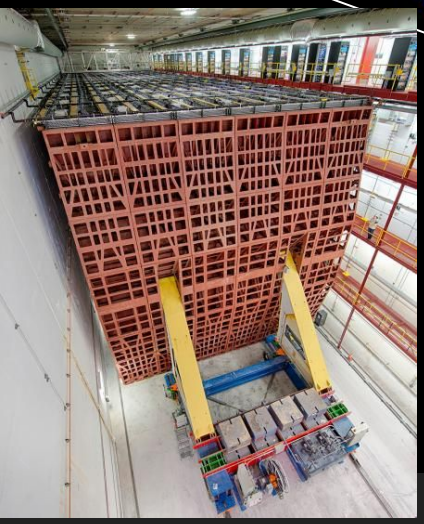
15 meters
256 planes

3.9 m

3.9 m
96 cells/ plane

NOvA Far Detector: 5ms time slice

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

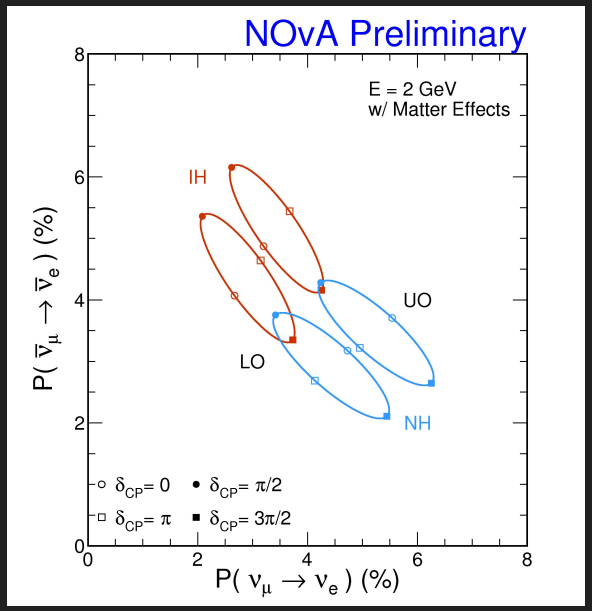


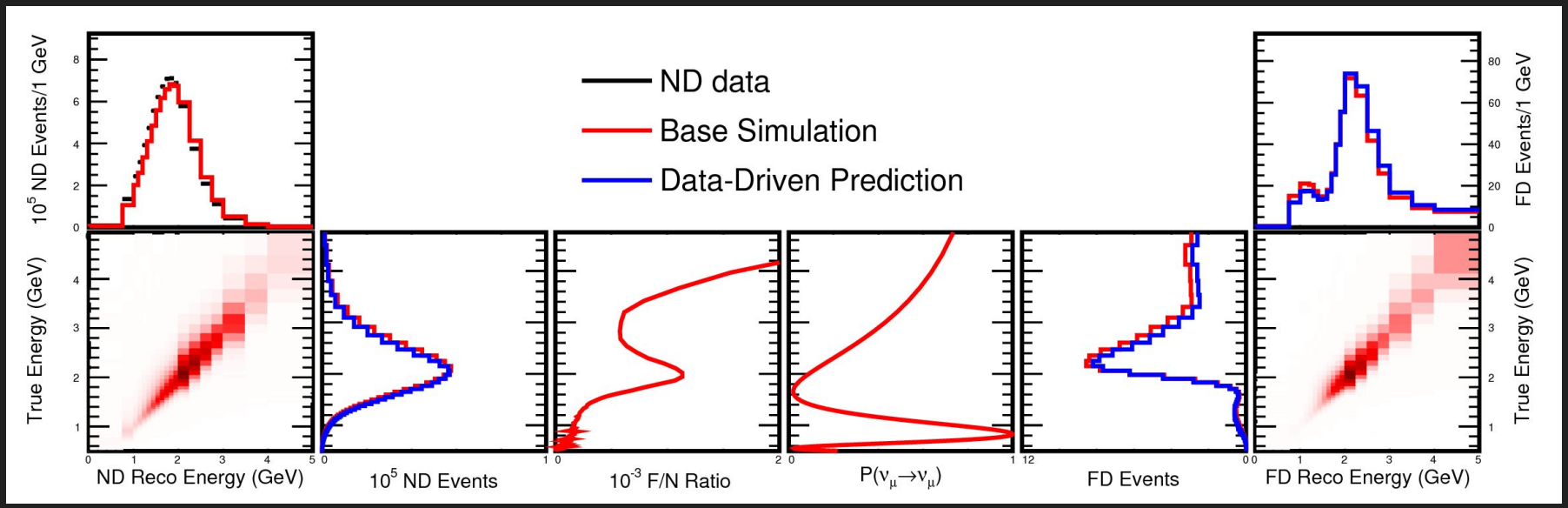
Neutrino oscillations analysis

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

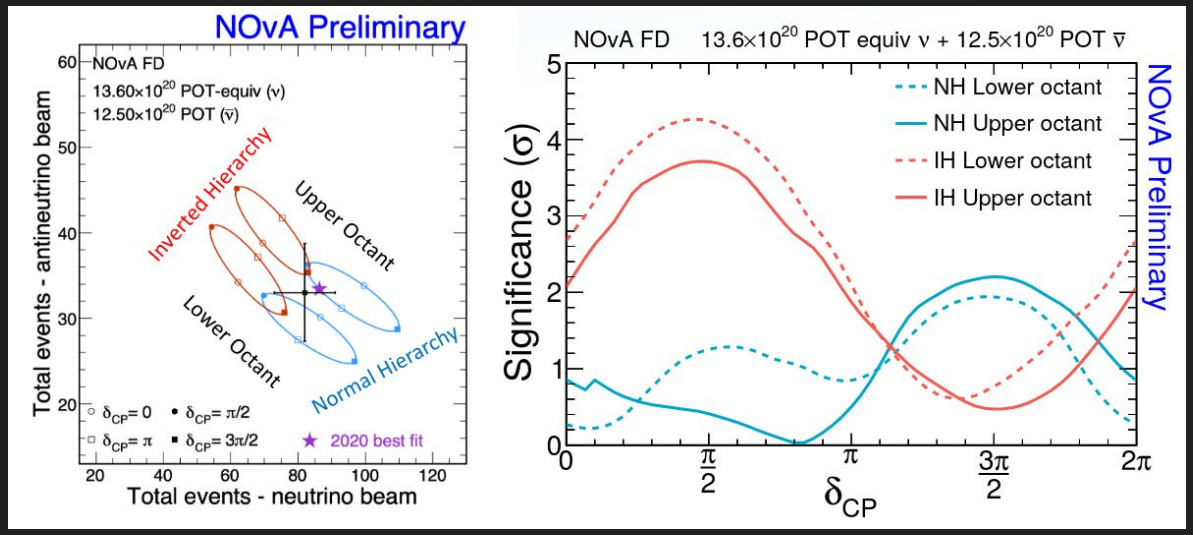
Using both muon neutrino and antineutrino modes of the beam, NOvA is sensitive to: neutrino mass ordering, theta23, δ_{CP}

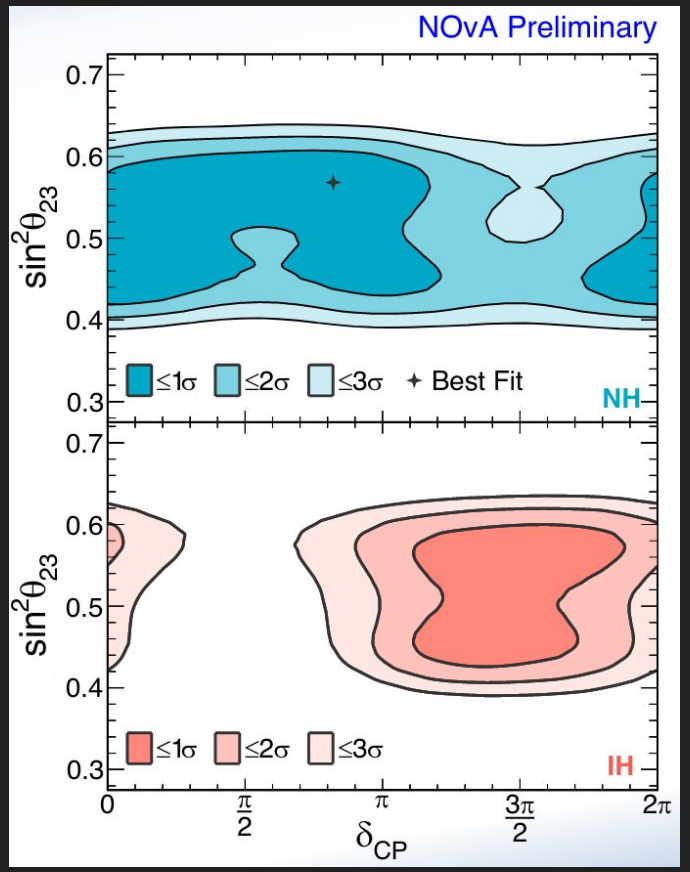
Near + Far detectors: reduce the systematic errors from beam uncertainty, neutrino interaction cross-sections, detector effects.





NOvA analyses results





- $\Delta m^2_{32} = (2.41 \pm 0.07) \times 10^{-3}\ eV^2$
- $\sin^2\theta_{23} = 0.57^{+0.04}_{-0.03}$
- IH, δ= π/2: excluded at > 3σ
- NH, δ= 3π/2: disfavored at ~2σ

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.

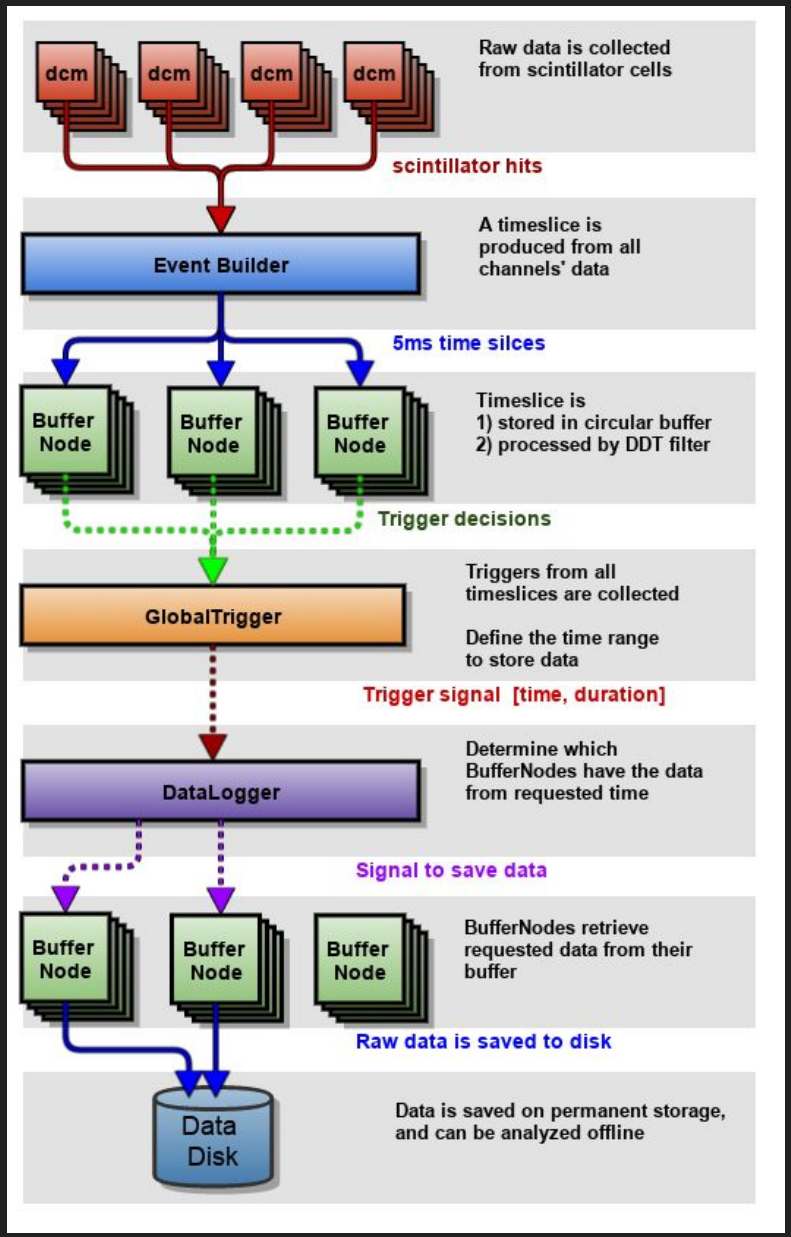
Additional analyses require more complicated preselection of the data from the detector data stream.

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

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

~10^{58} neutrinos: **E_ν~10-60 MeV** within **T ~10s**

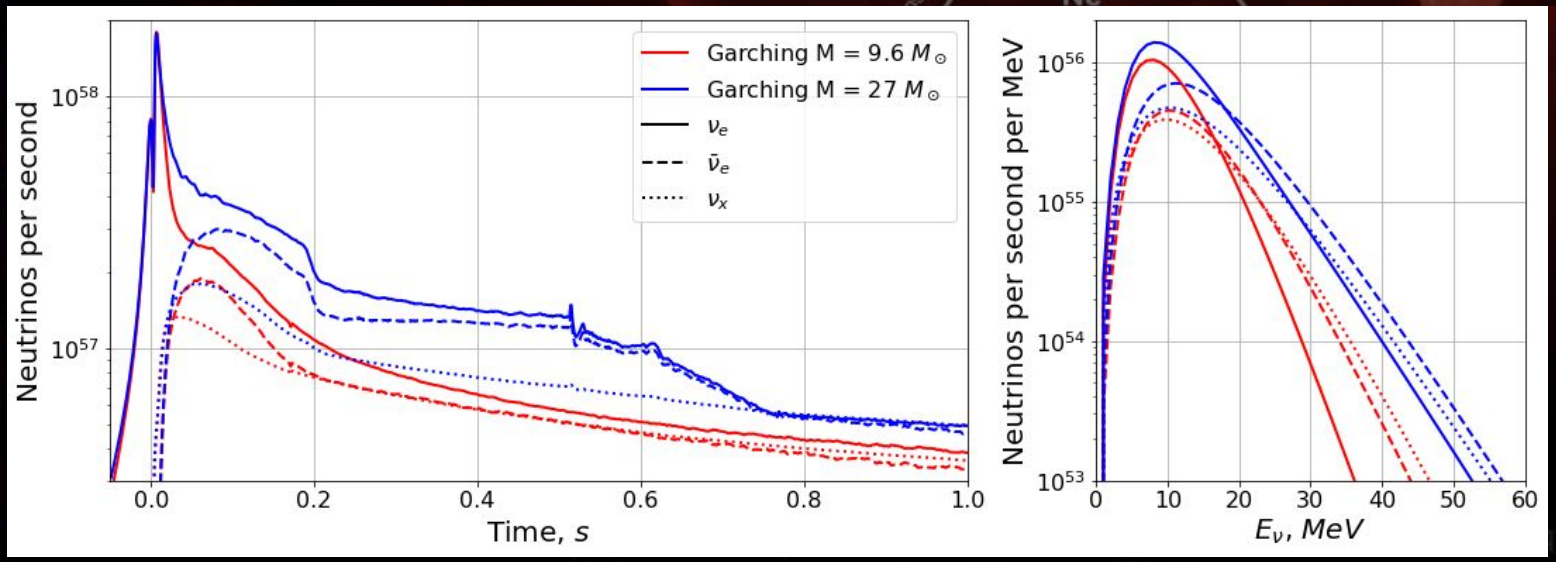
Neutrino signal: probe of

- Neutrino properties
- Supernova properties

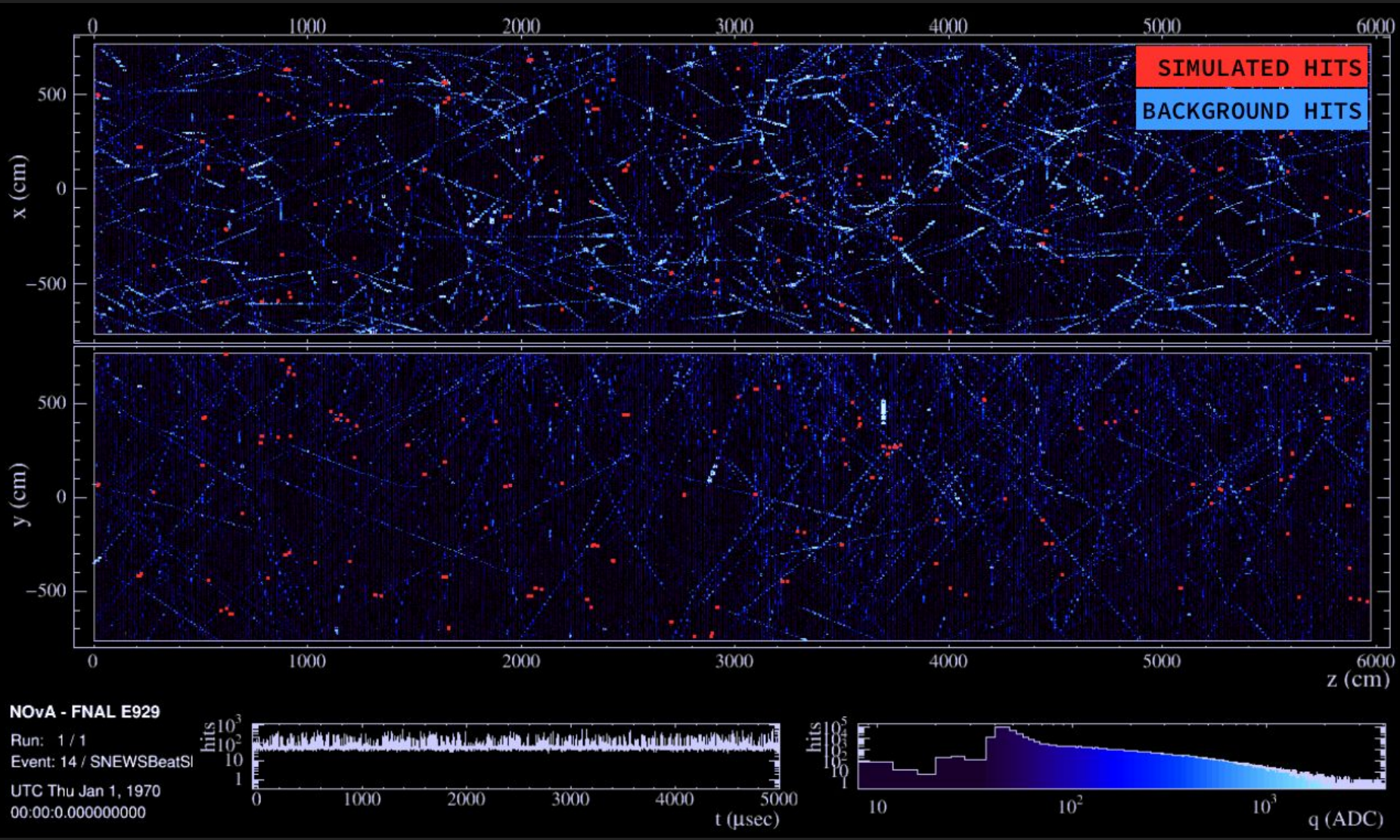
arXiv:1508.00785 [astro-ph.HE]

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



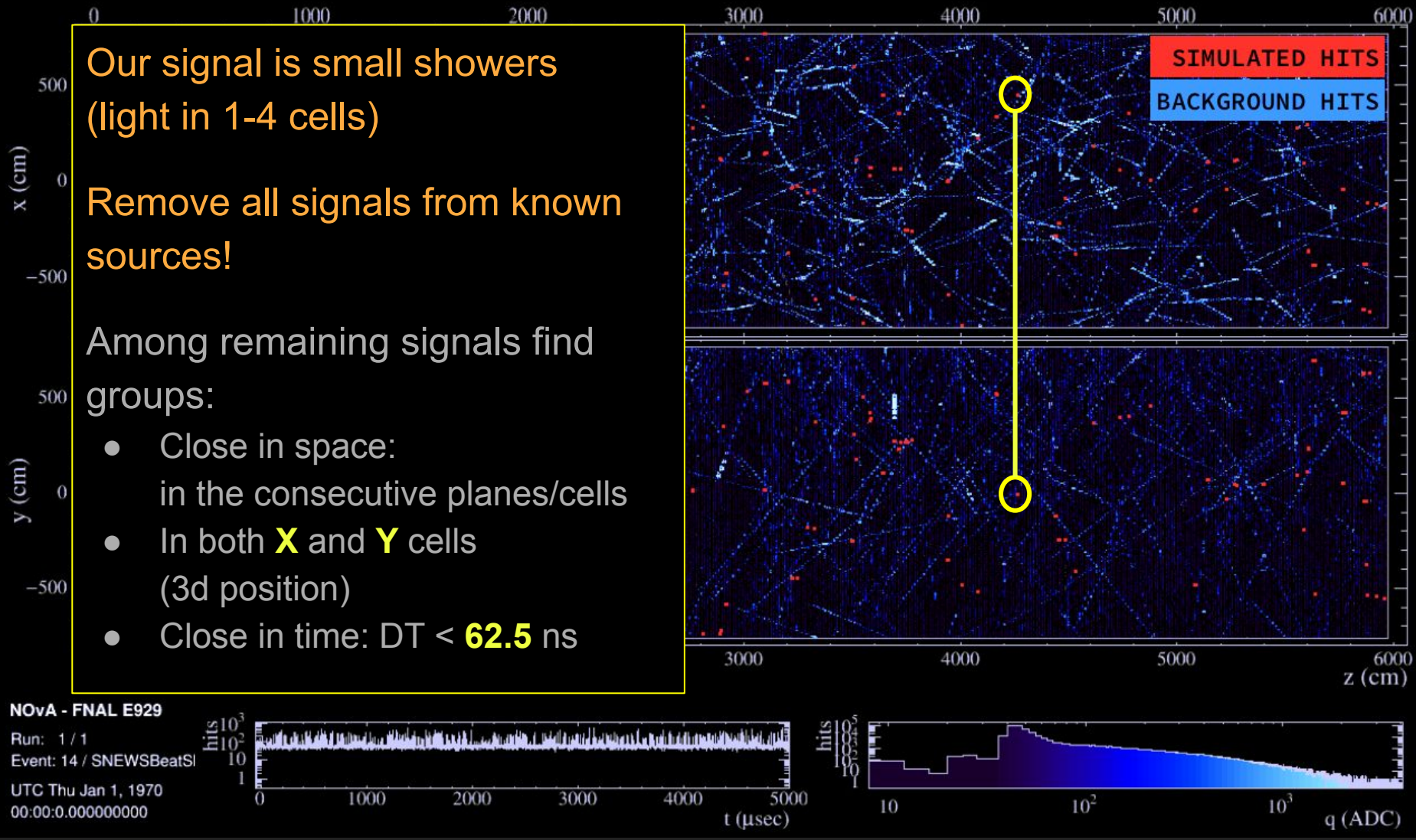
Signal selection

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

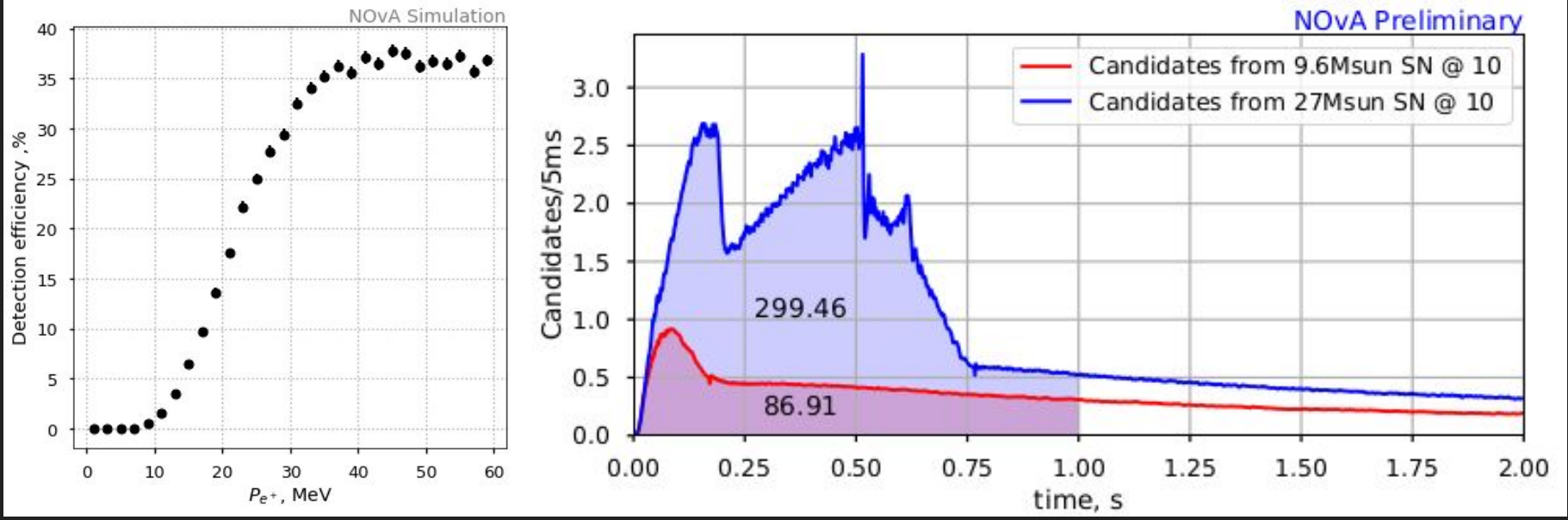
Remove all signals from known sources!

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



Results of the neutrino candidates selection



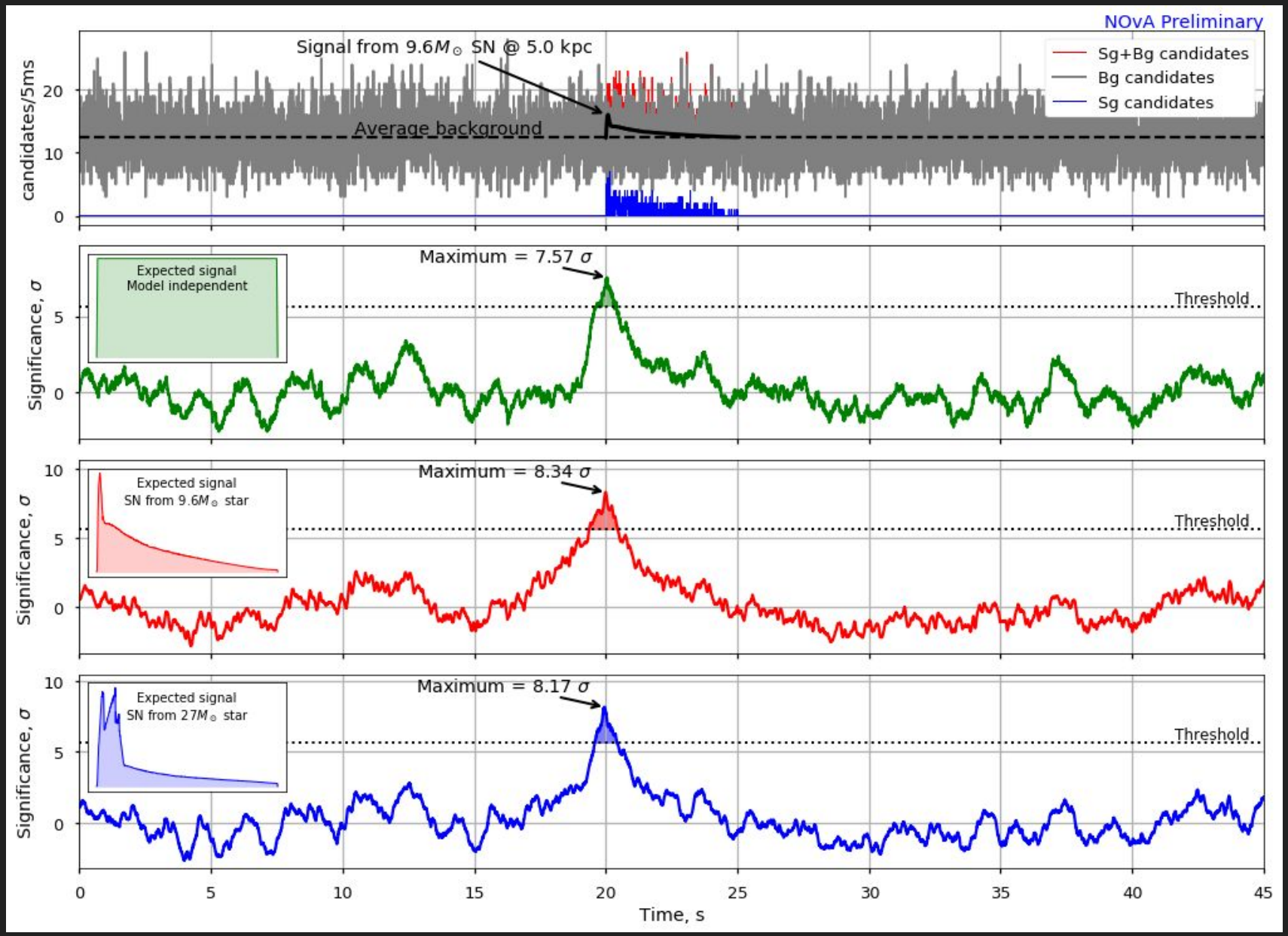
In order to trigger on the galactic supernova neutrino signal, we need to observe the signal excess above the background fluctuations.

This has to be performed in realtime

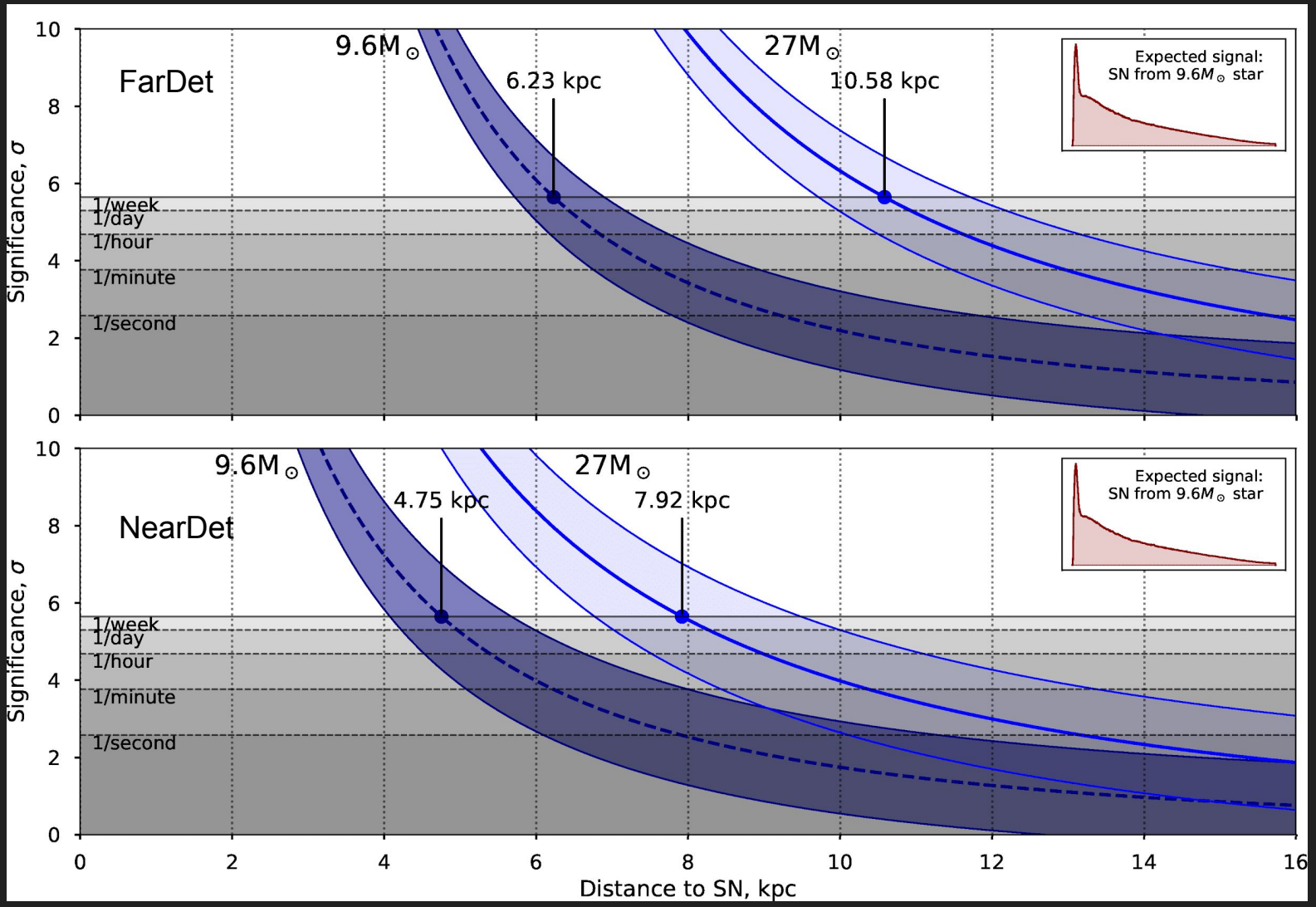
Detector	Signal	Background
Near	1.28/s	0.52/s
Far	87/s	2500/s

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

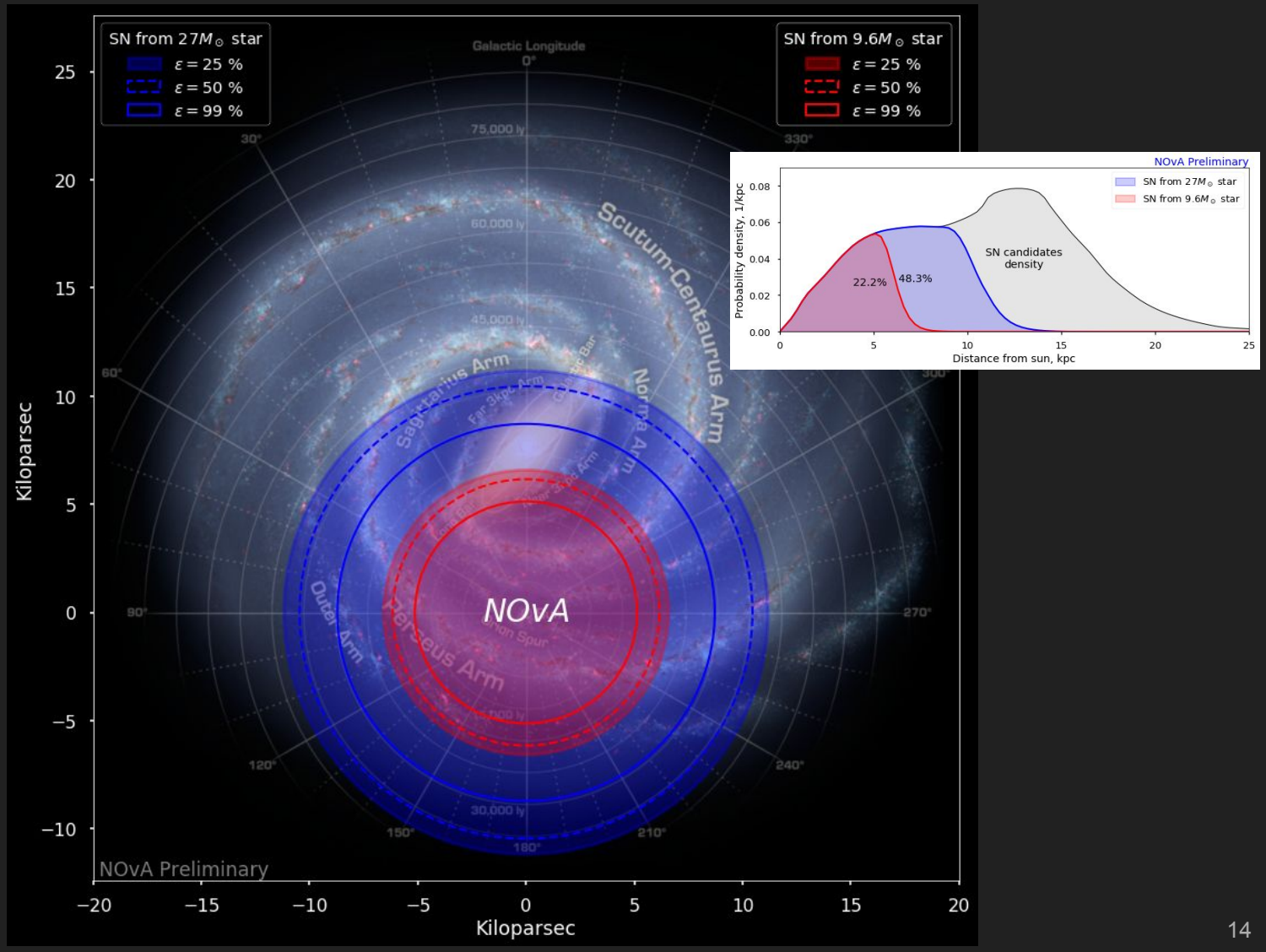
Signal processing and triggering: example



Supernova significance vs. distance



NOvA supernova trigger sensitivity



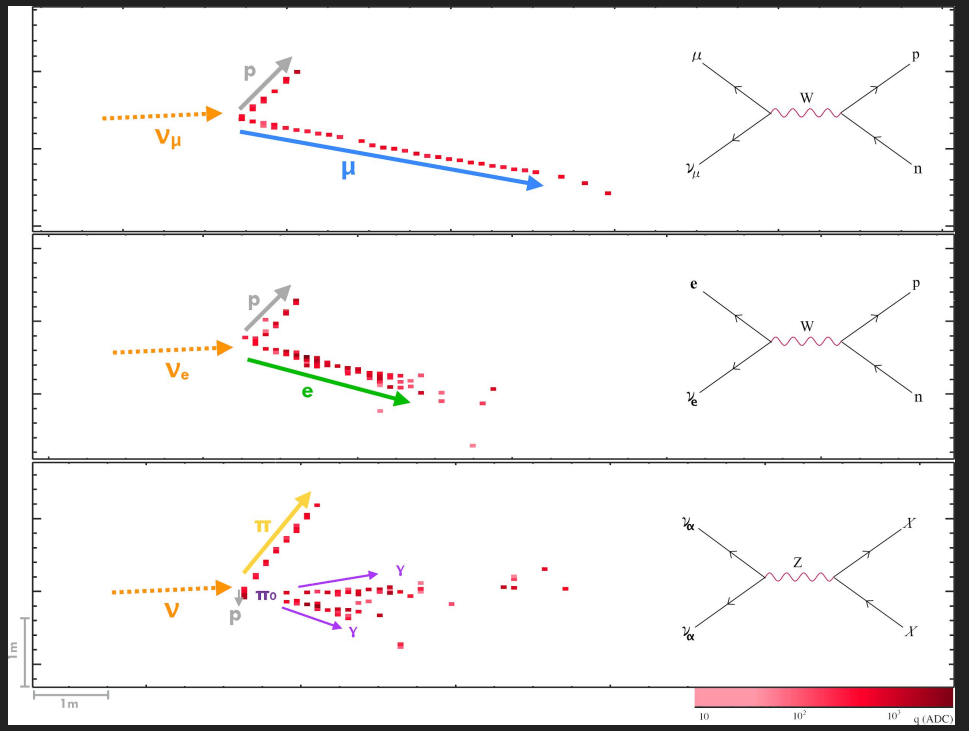
MAY 2020

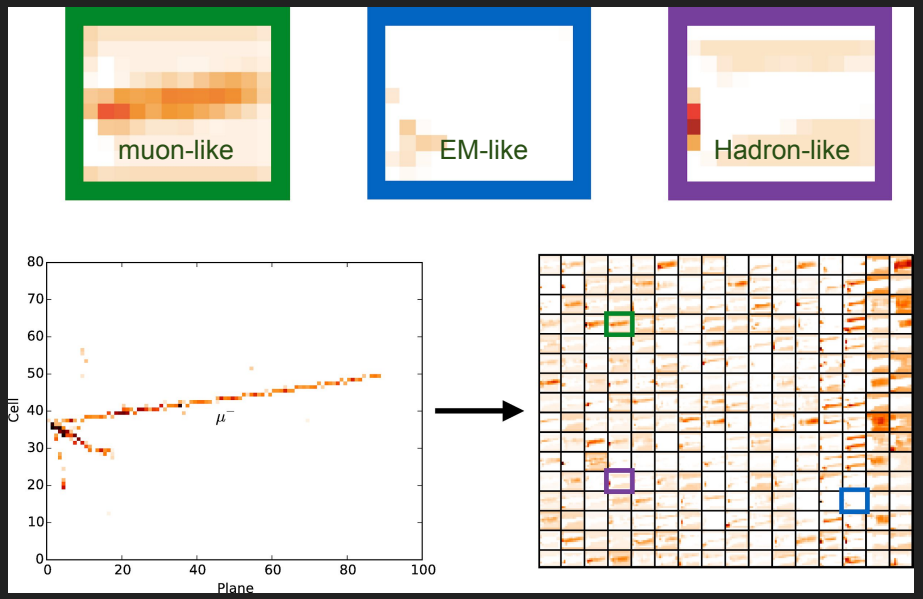
BACKUP

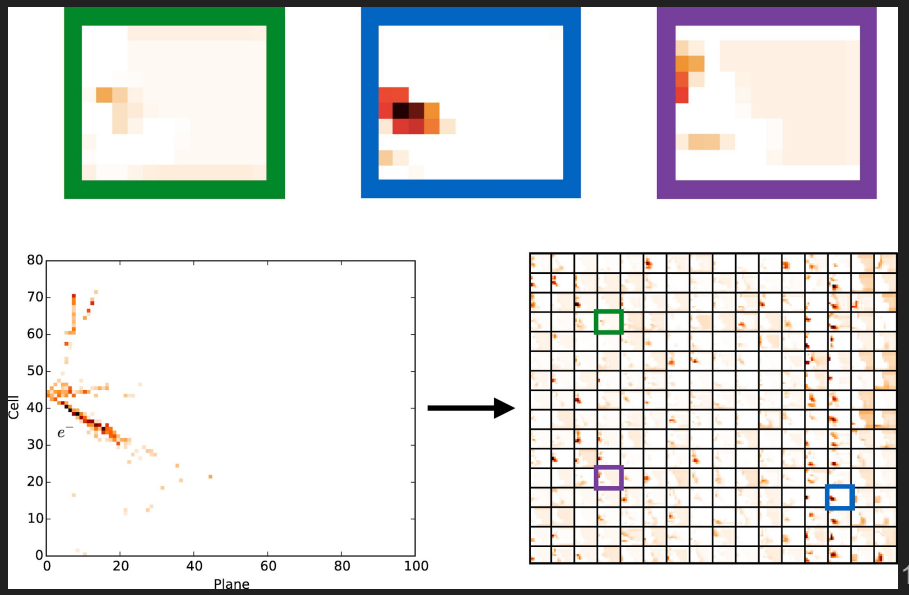
Events classification

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

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

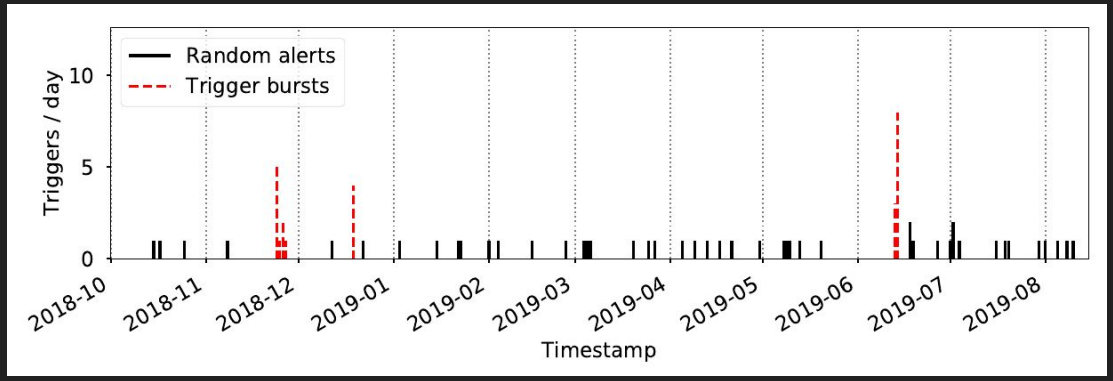






Supernova trigger comissioning

Expectation:
stable trigger rate
1/week

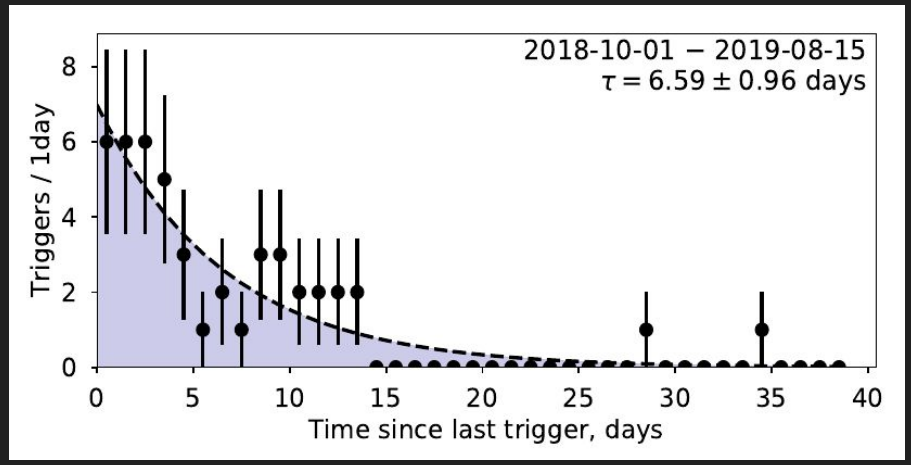


Reality: supernova trigger is sensitive to instabilities of background:

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

After fixing these problems:

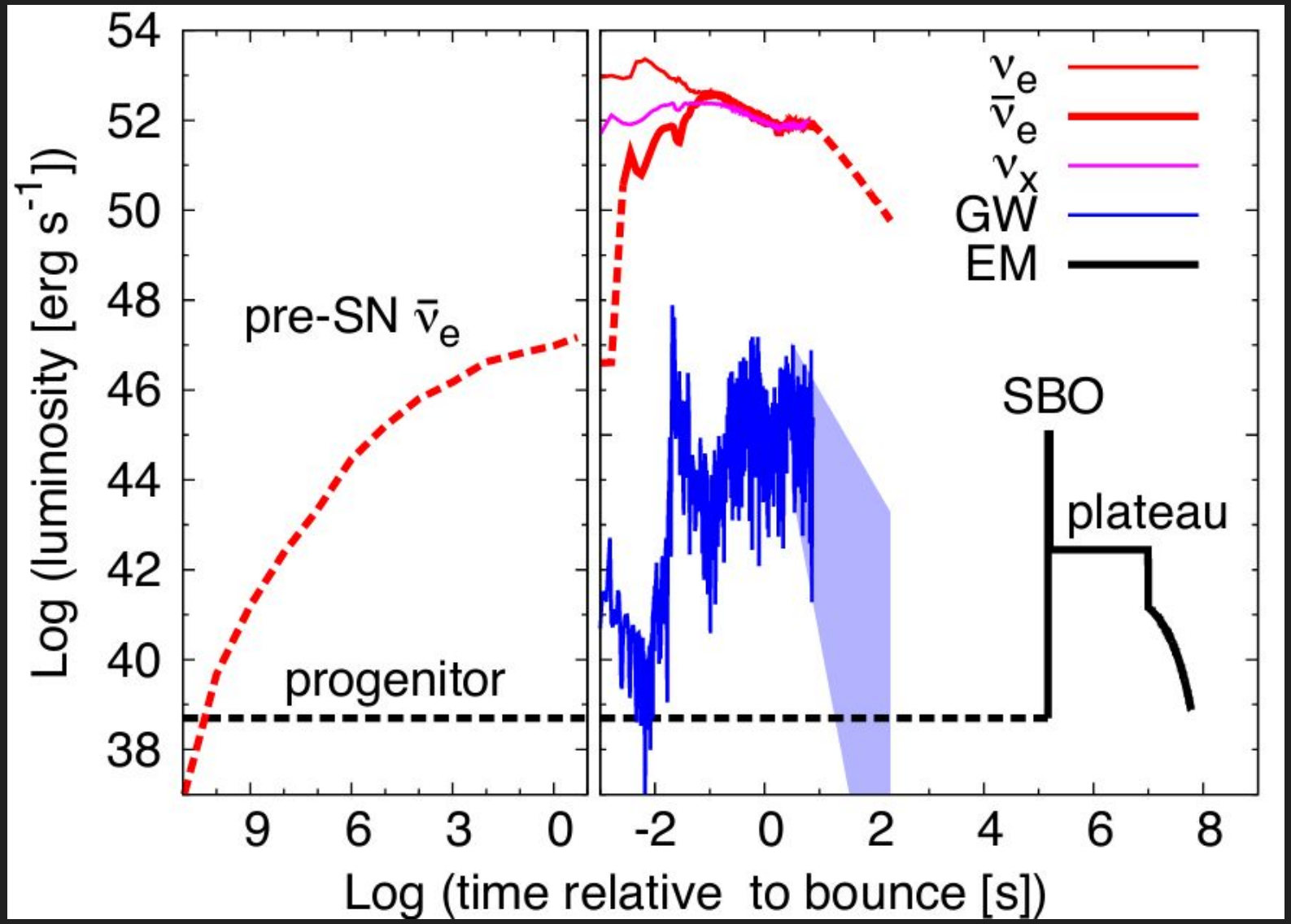
- Filtering data with incomplete detector
- Strict data quality cuts
- Monitoring of NoiseMap service



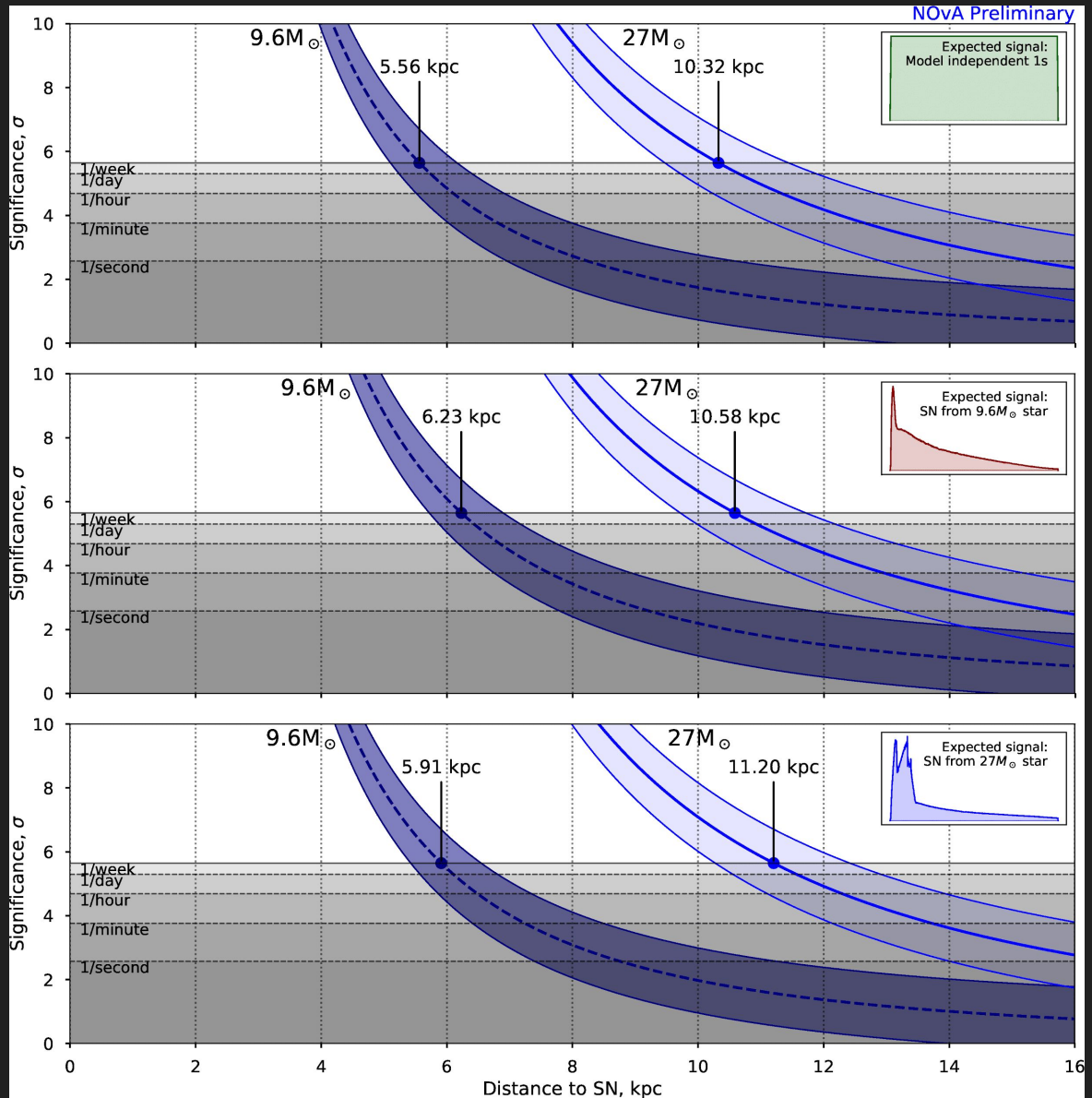
Summary

- 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 ~1/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.

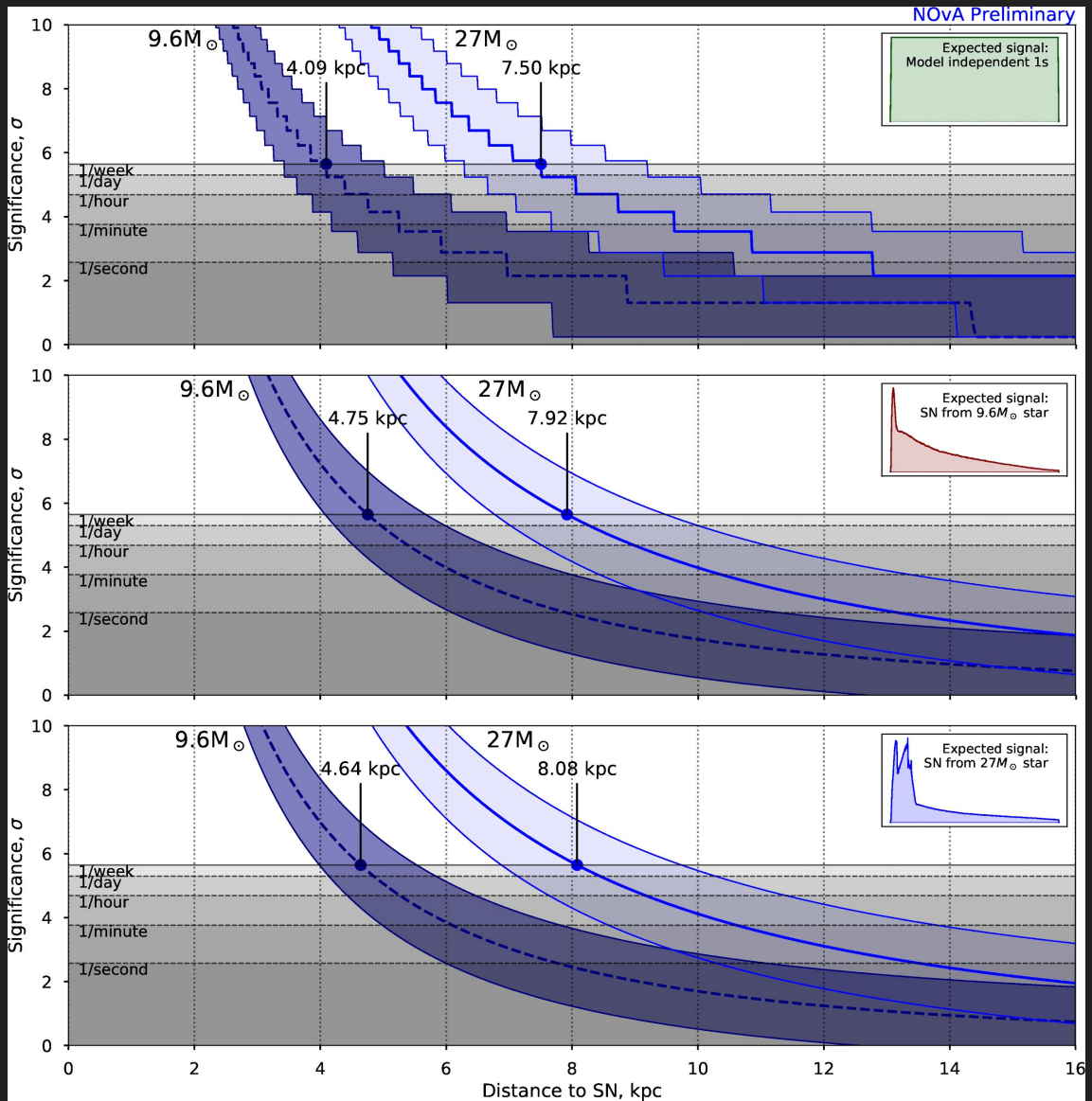
Supernova: a multi-messenger view



Supernova significance vs. distance: FarDet



Supernova significance vs. distance: NearDet



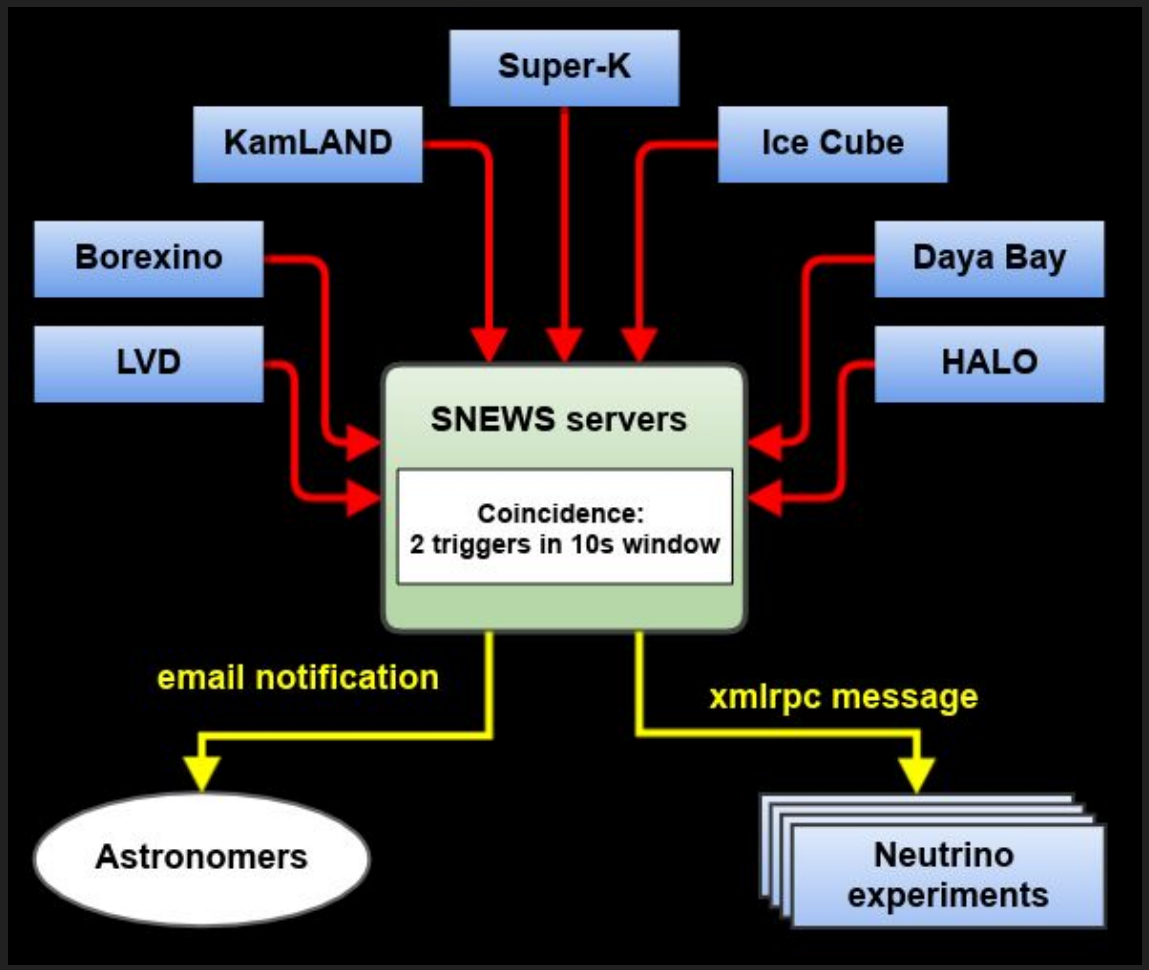
SuperNova Early Warning System

snews.bnl.gov

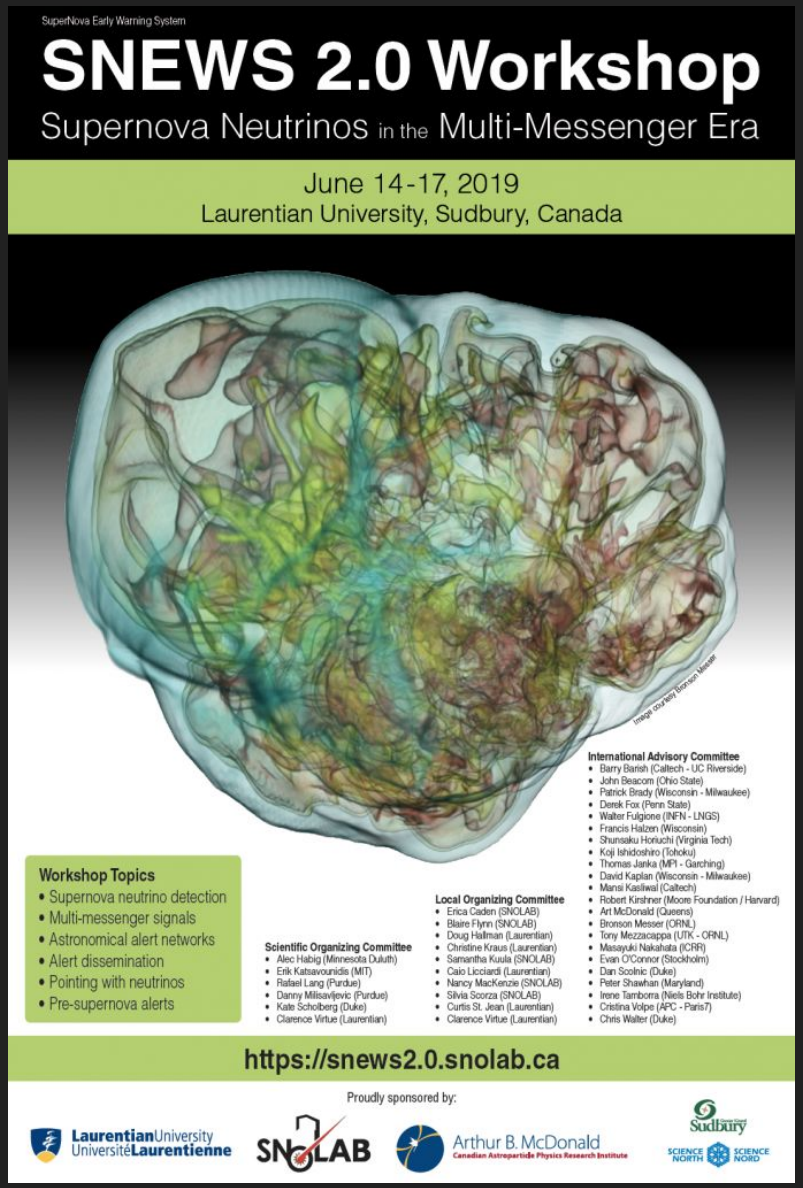
A global network to make sure we don't miss a galactic event.

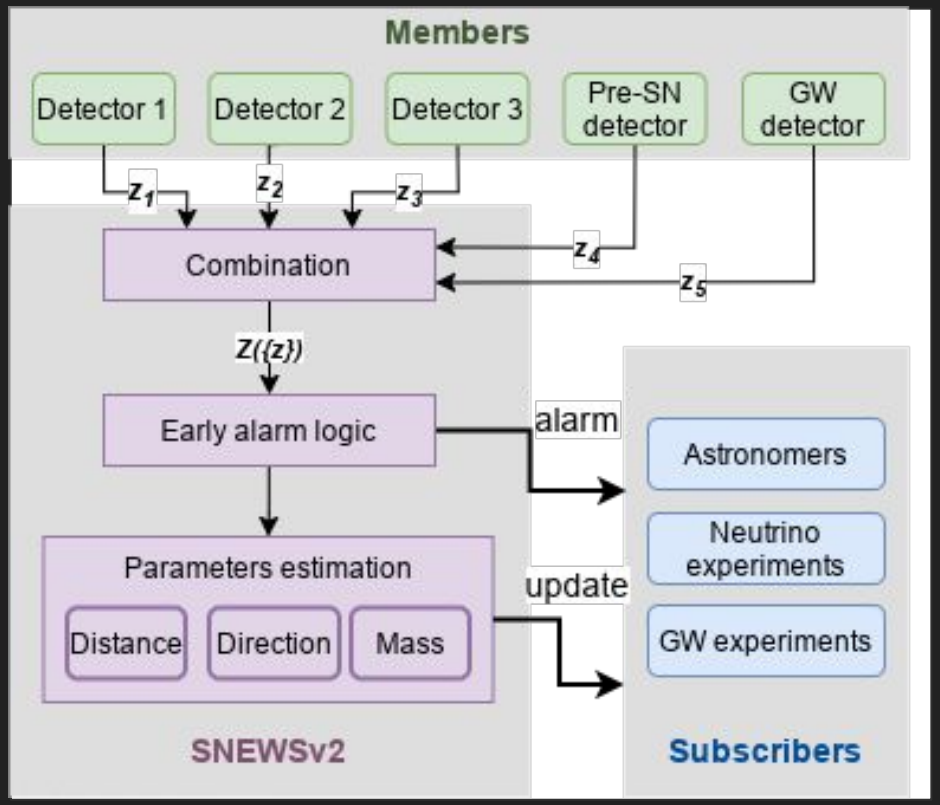
Neutrinos arrive several minutes to hours prior to optical signal

SNEWS works since 1998



A planned upgrade of SNEWS: in progress



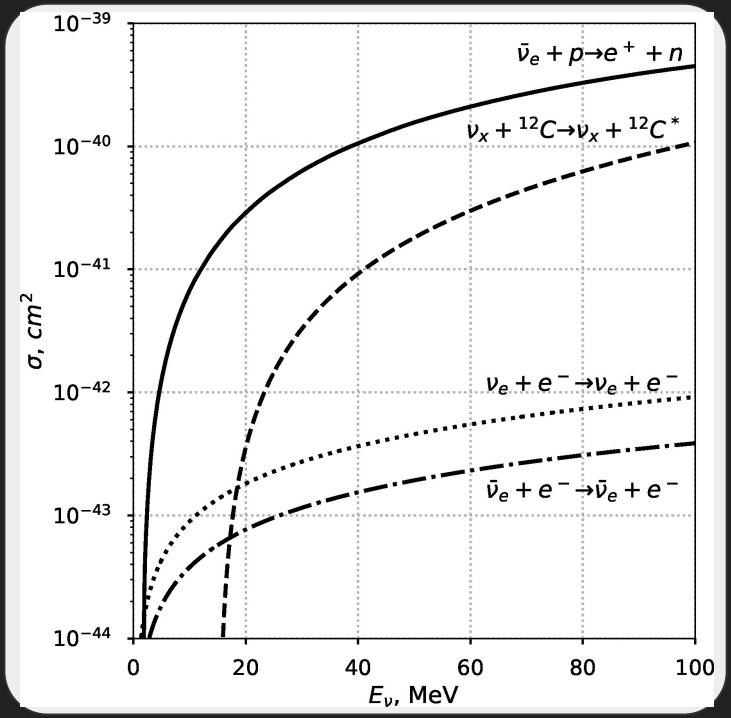


A joint effort to build a new system, combining significance and parameters estimation measurements in real-time.

Status: design and prototyping.

Many exciting tasks ahead!

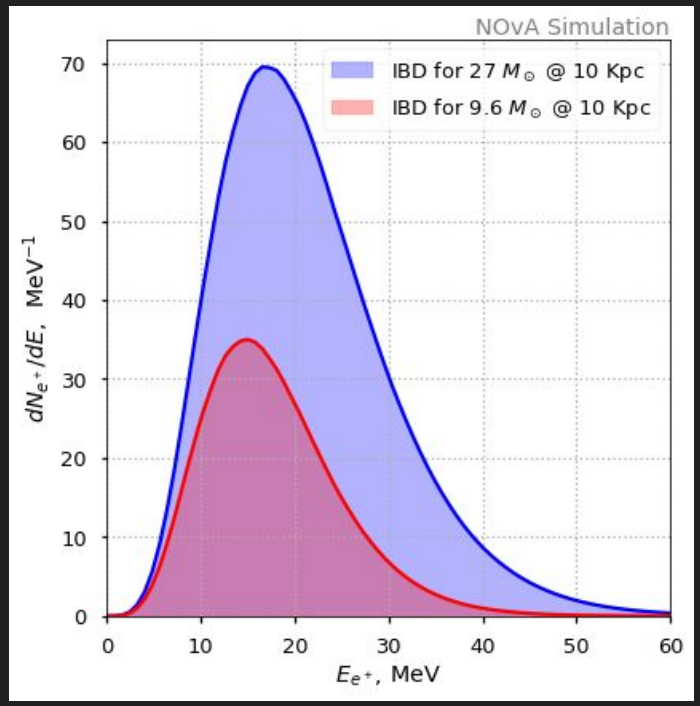
SN neutrinos interactions in the NOvA Detectors



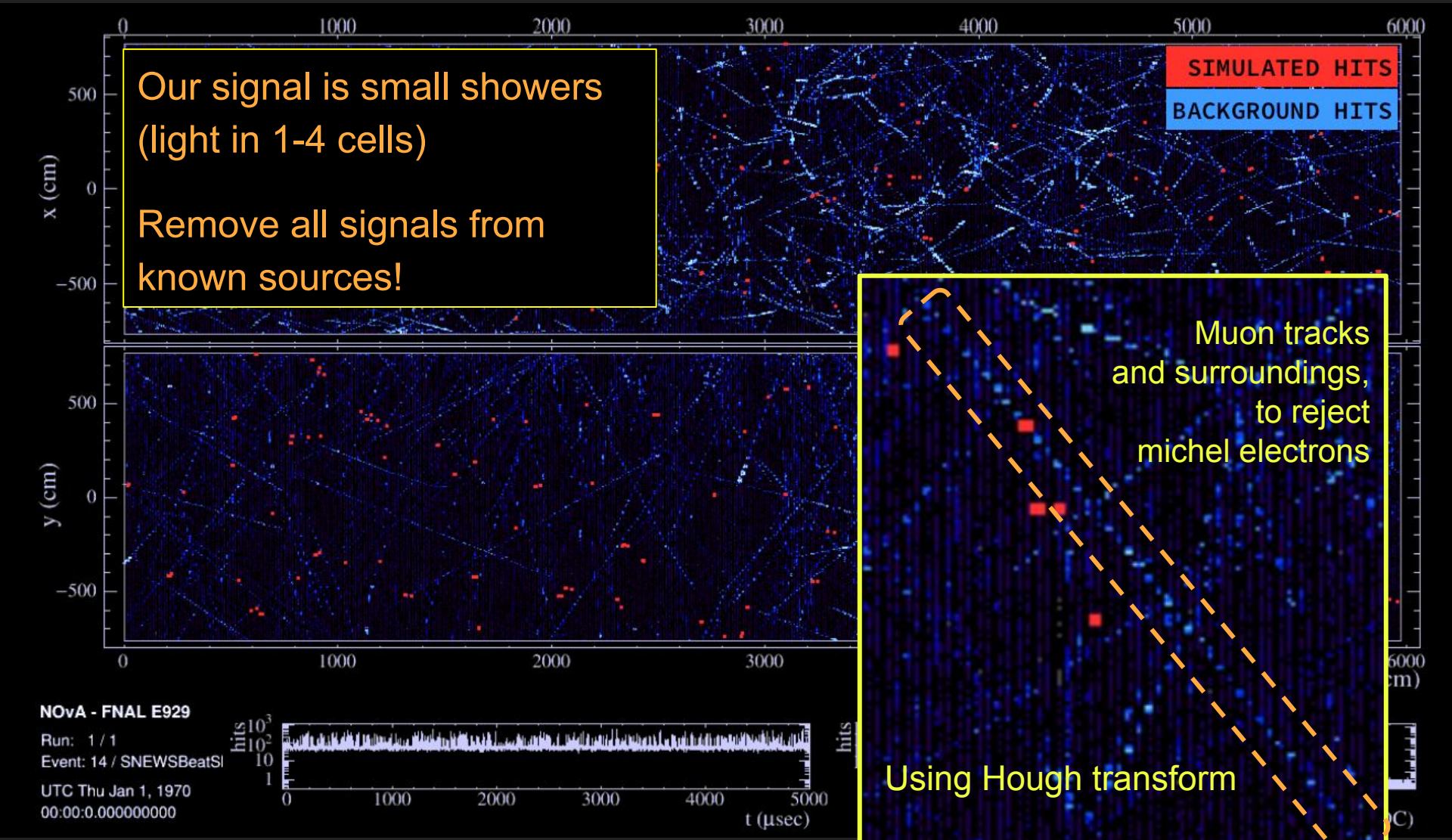
Other channels give negligible contribution: energy too low or small interaction rate.

Main detection channels:

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



Signal selection



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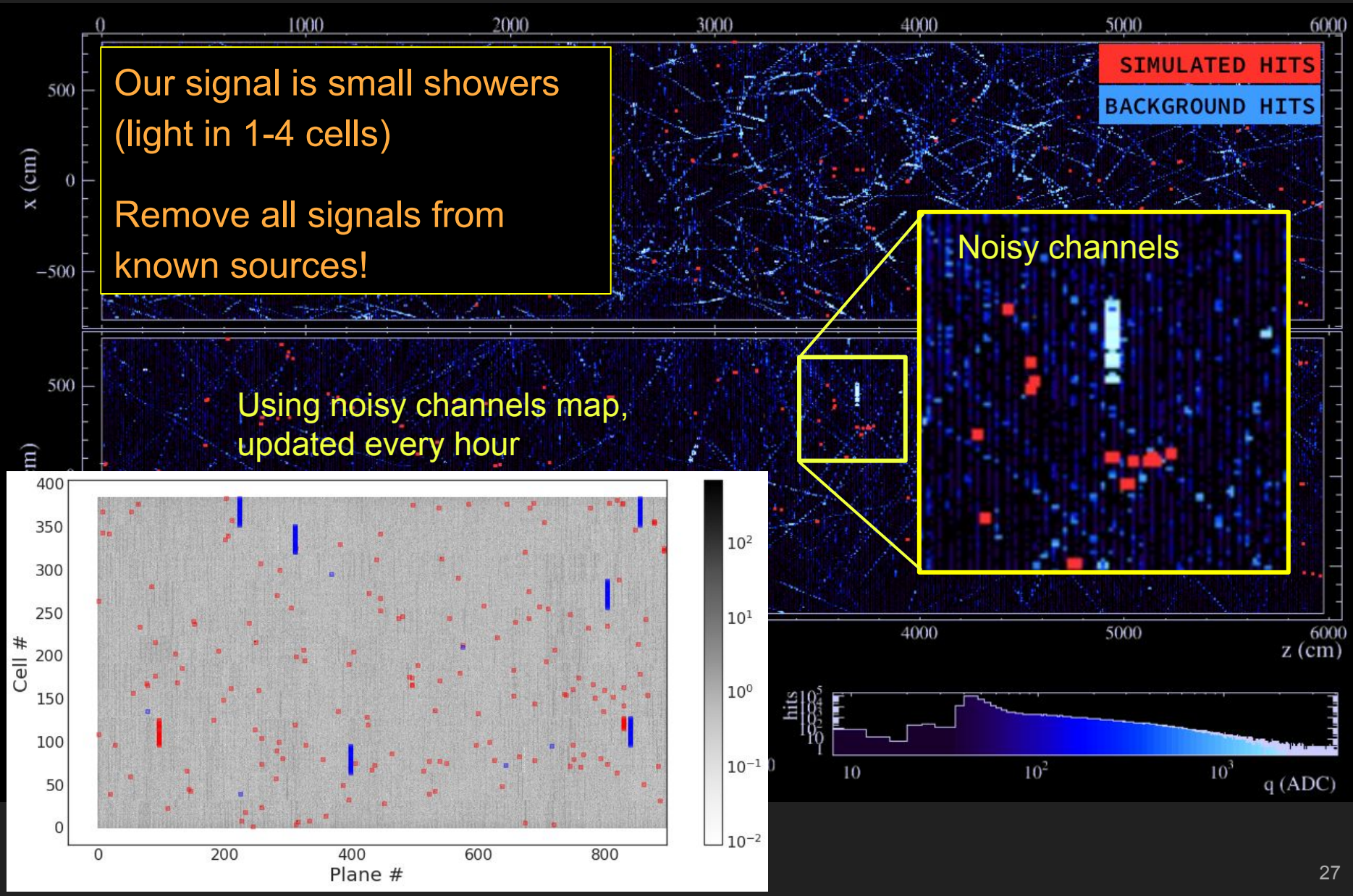

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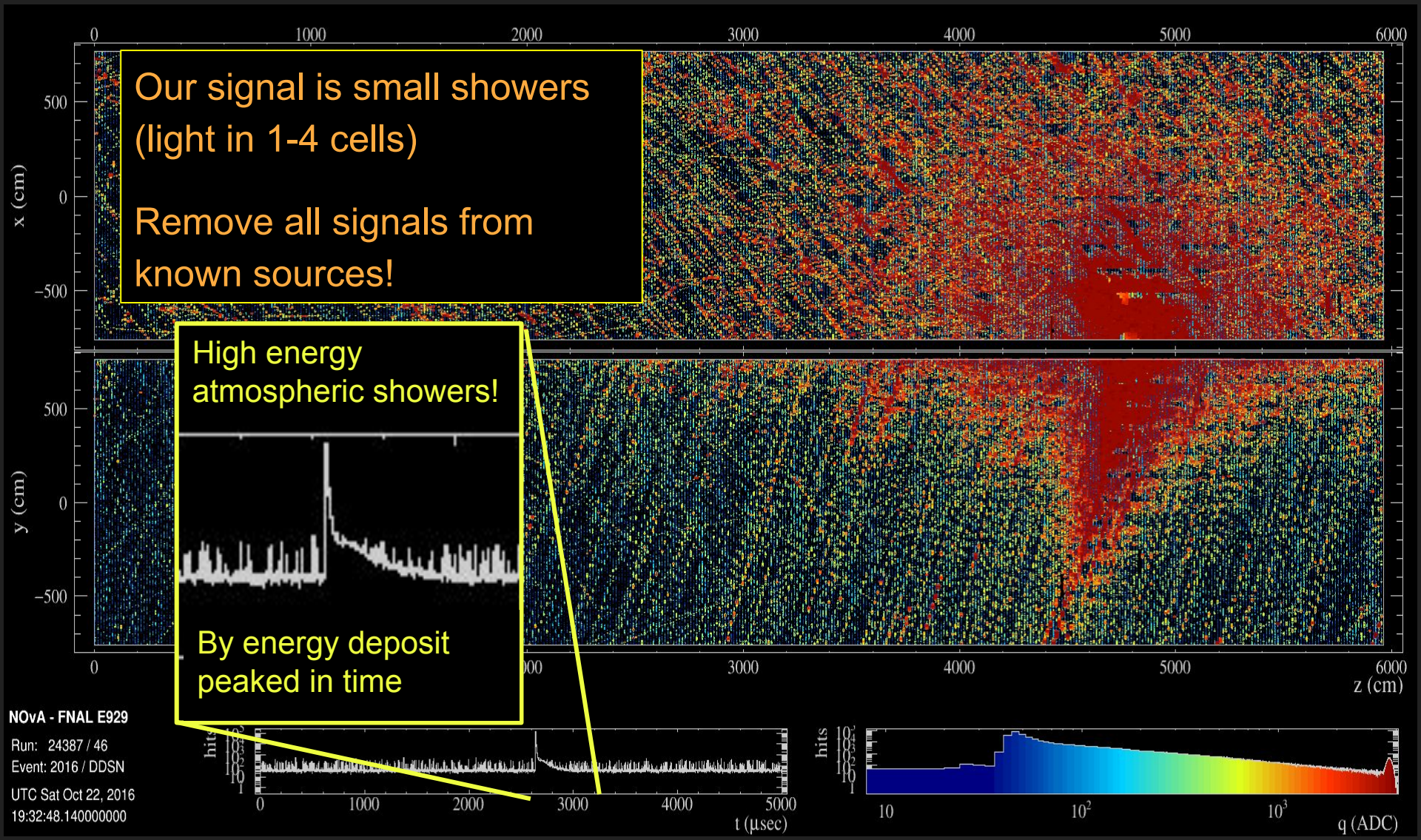

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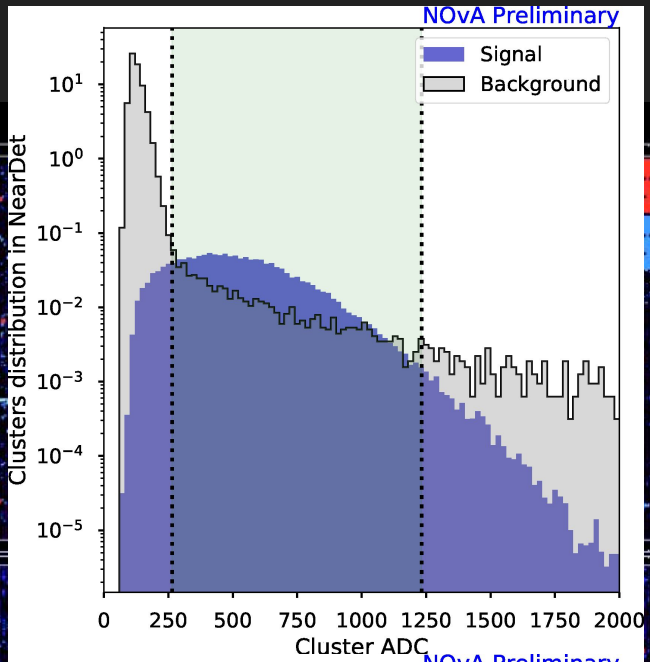
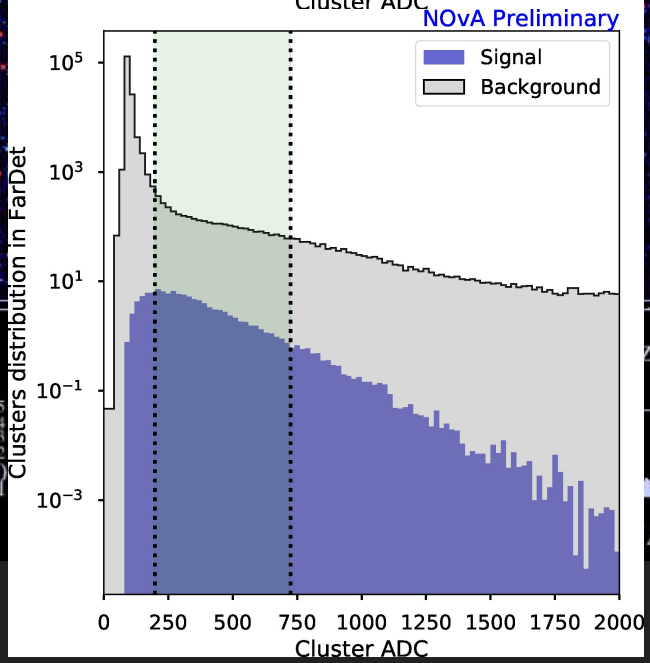
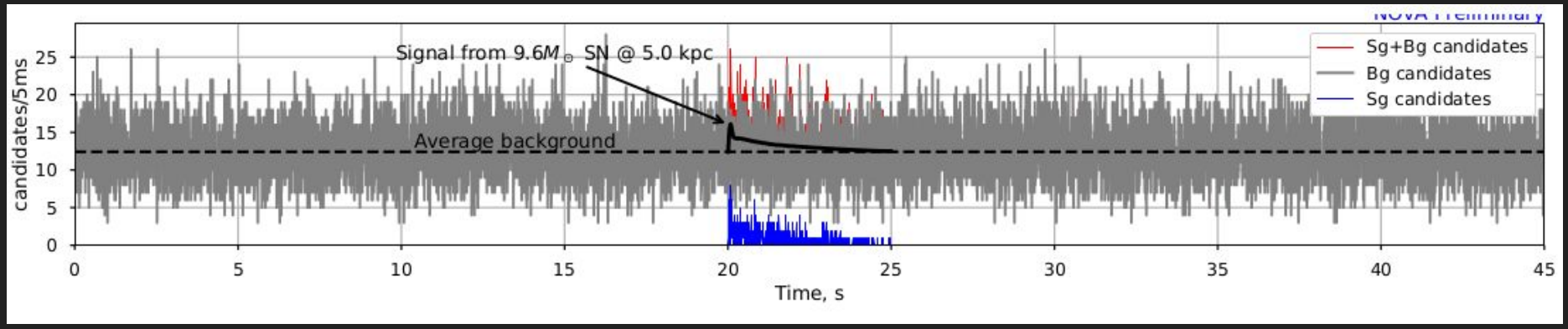
- Close in time: DT < **62.5** ns

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:

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