# Detecting neutrinos from the next galactic supernova in the NOvA detector

Andrey Sheshukov
DLNP JINR



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# Neutrino signal from the core-collapse supernova


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

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

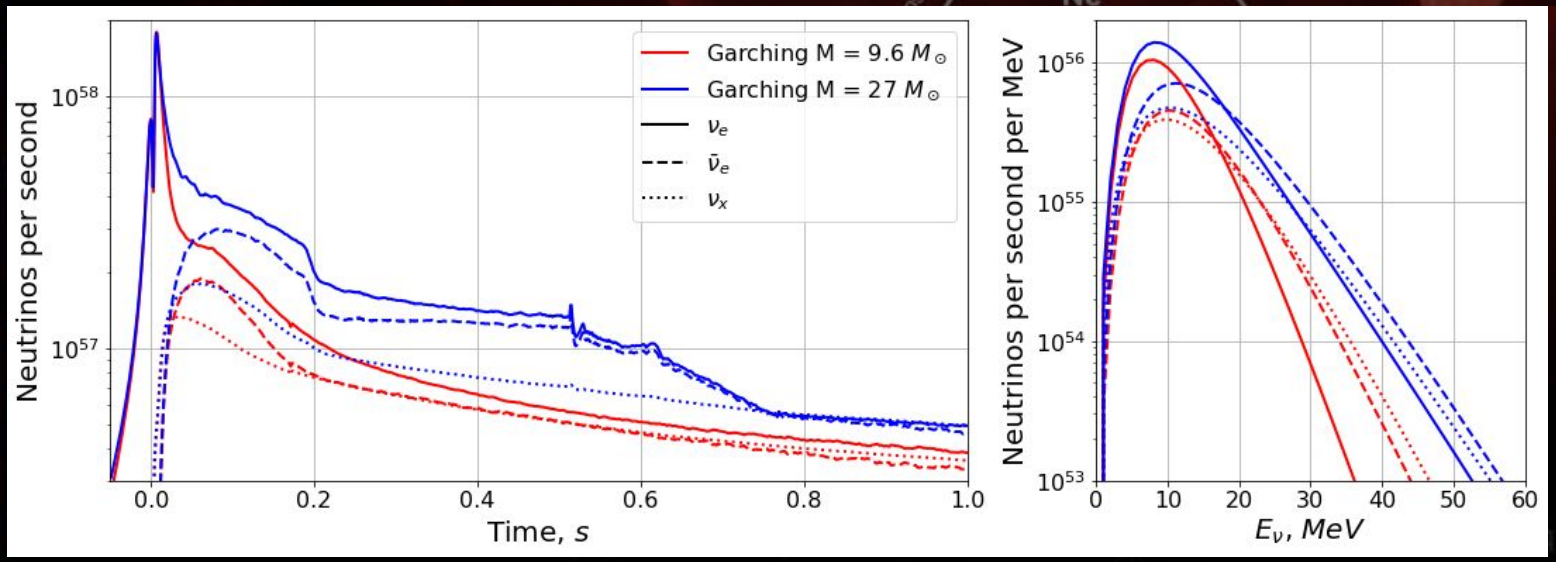
**Neutrino signal: probe of**

- 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)



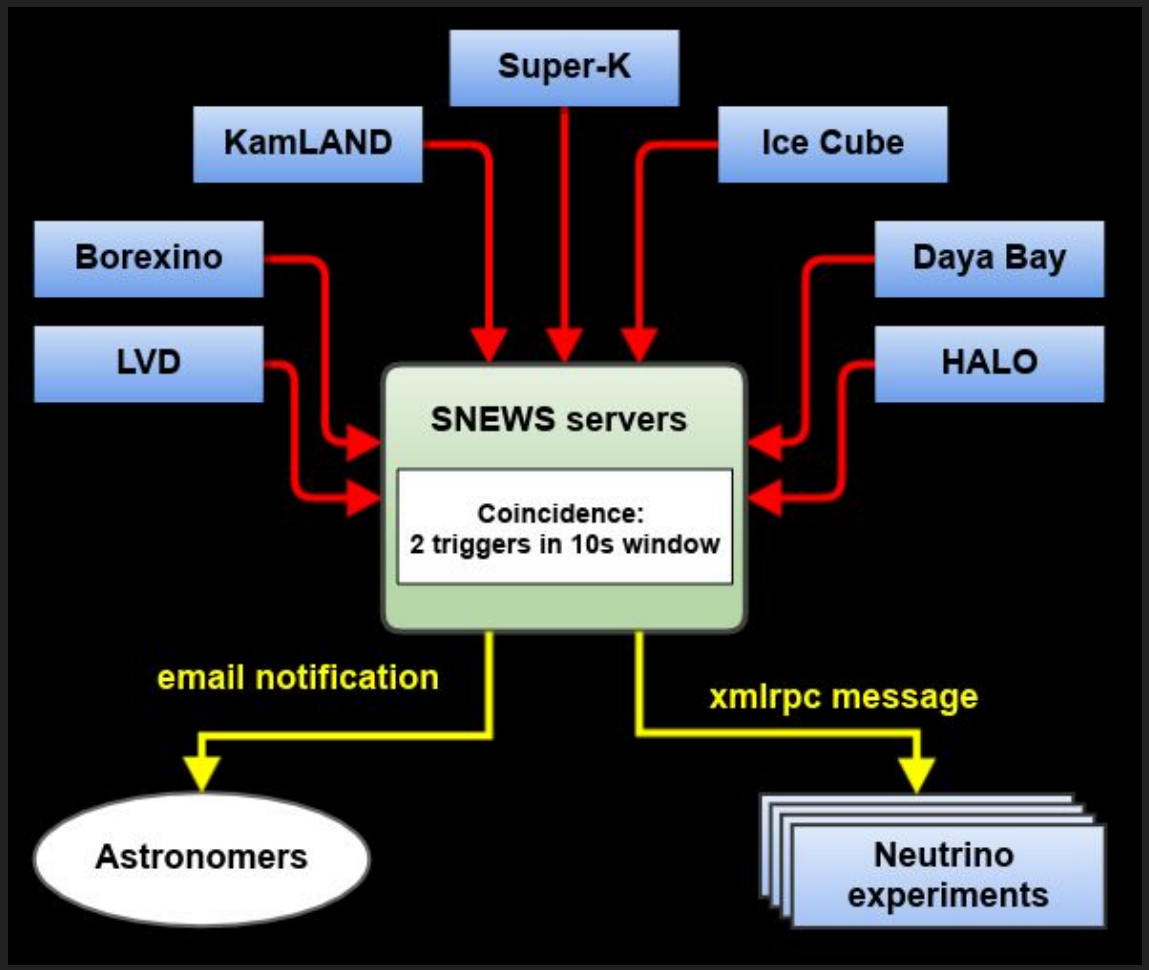
# SuperNova Early Warning System

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

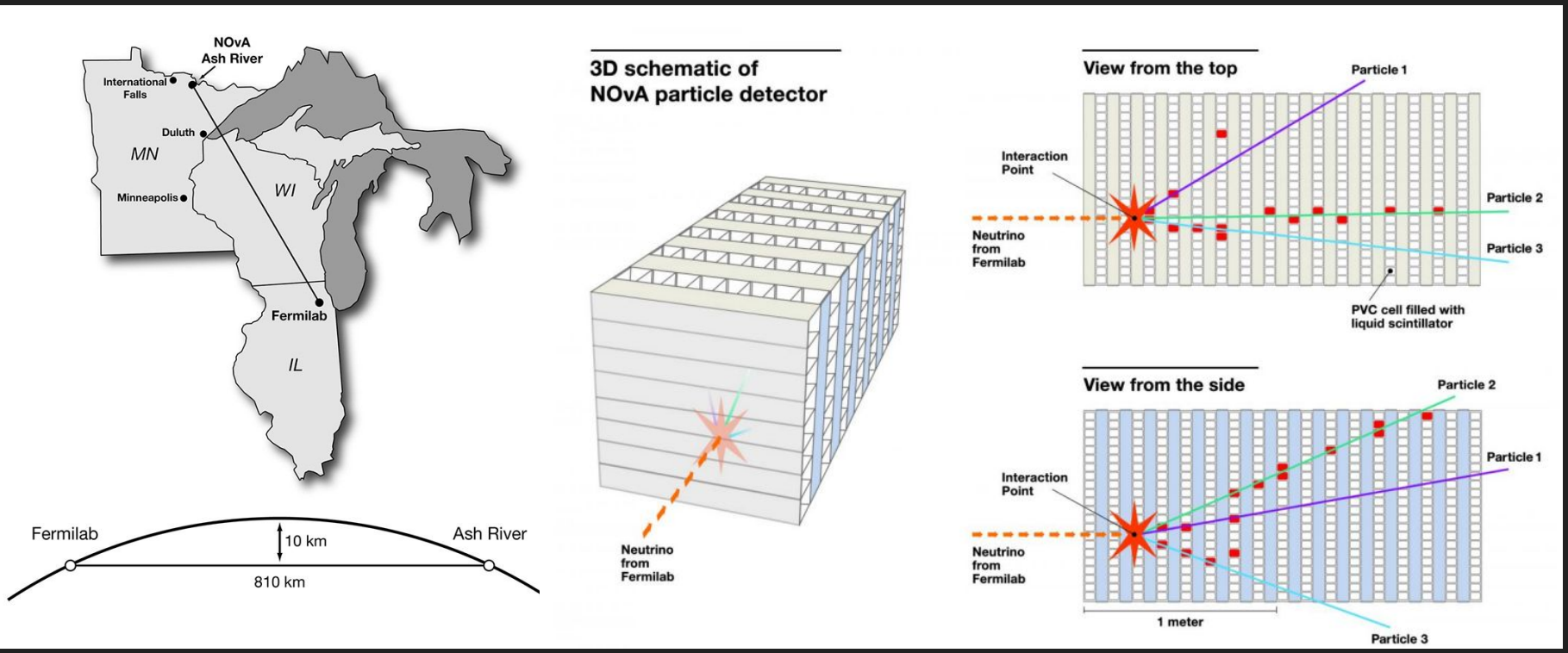
NOvA currently listens to a trigger from SNEWS, to save data in case of supernova.



# The NOvA experiment

**Main goal:** study of neutrino oscillations in a muon neutrino beam with **<E>=2 GeV**.
NOvA uses two detectors with similar structure.

Detectors are composed of extruded PVC cells filled with liquid scintillator.
The scintillation light is transported by the wavelength shifting fibers, then read by APD



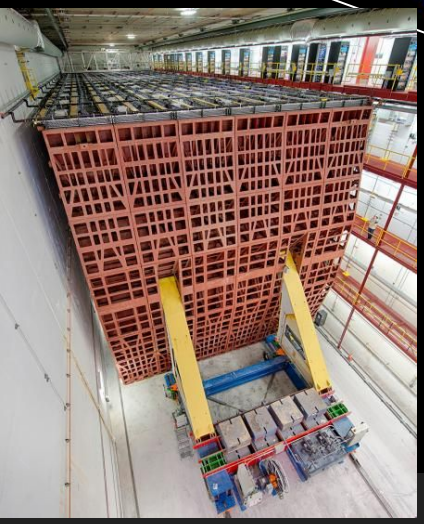

Large and segmented NOvA detectors can be used for additional physics goals.

# NOvA Near detector: 5ms time slice

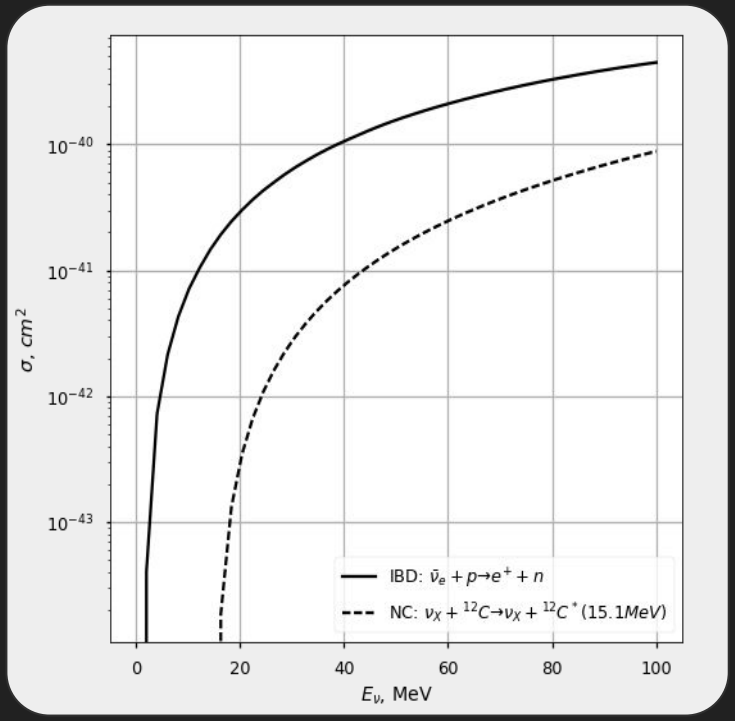
- M = **300 ton**
- Nchannels = **21504**
- Location: Fermilab 100m underground

# NOvA Far Detector: 5ms time slice

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



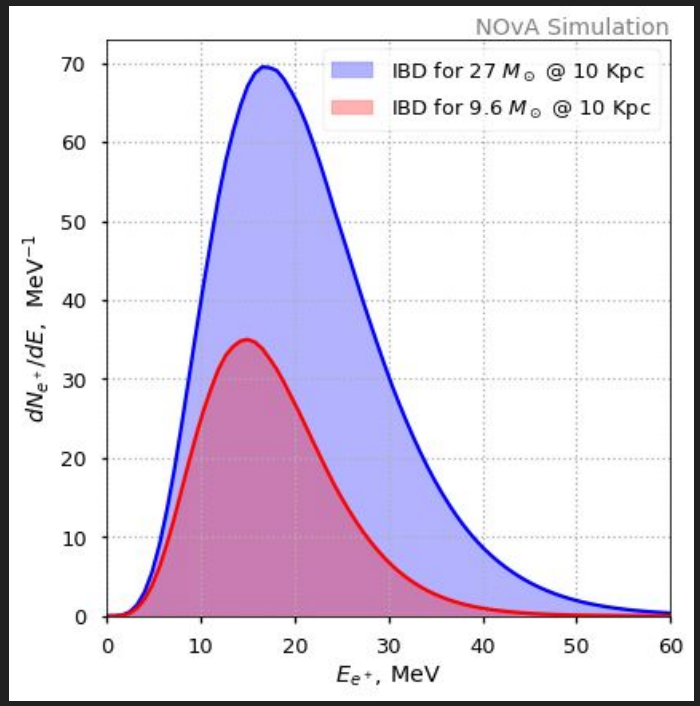
# SN neutrinos interactions in the NOvA Detectors



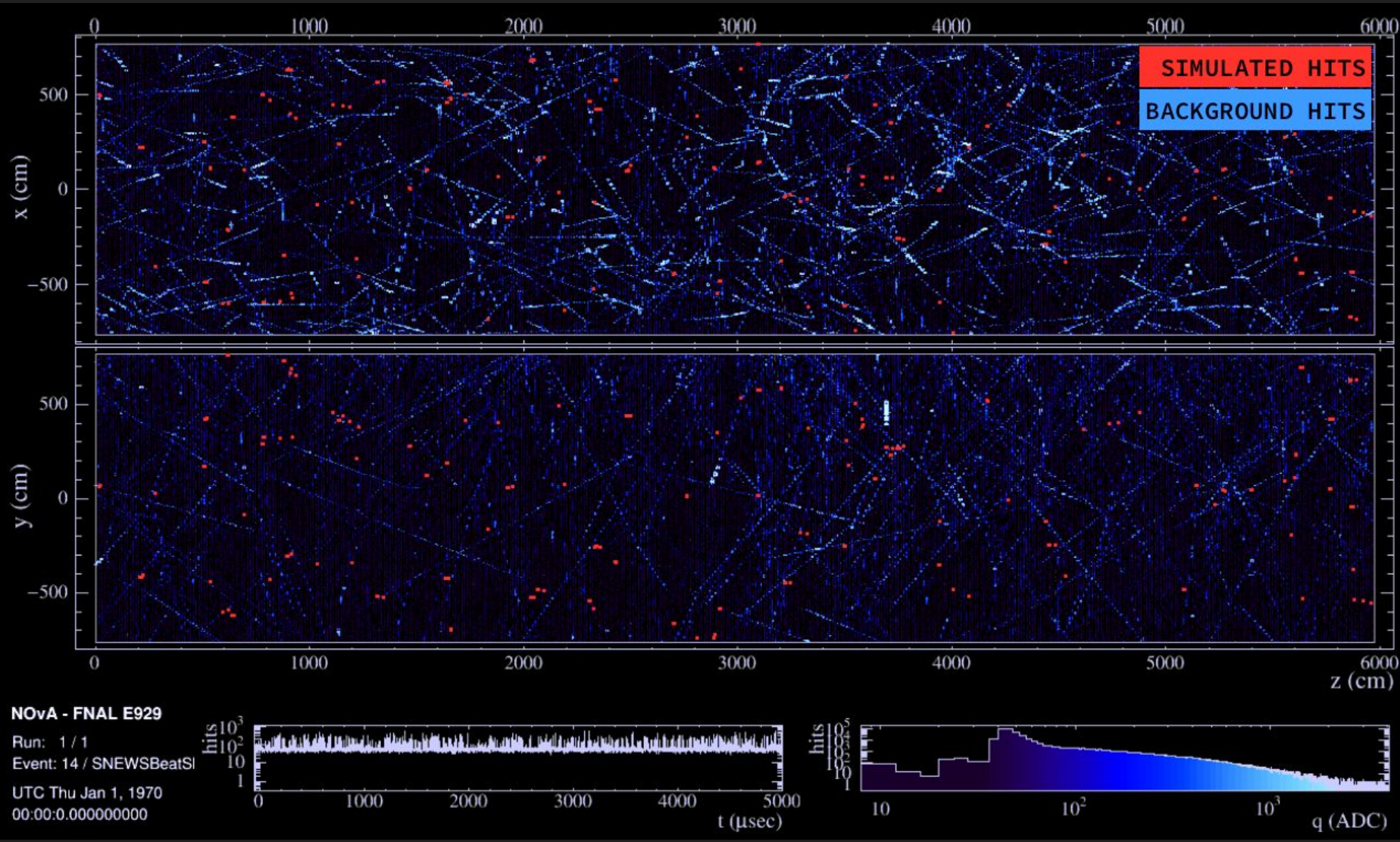

Other channels give negligible contribution: energy too low or small interaction rate.

Main detection channels:

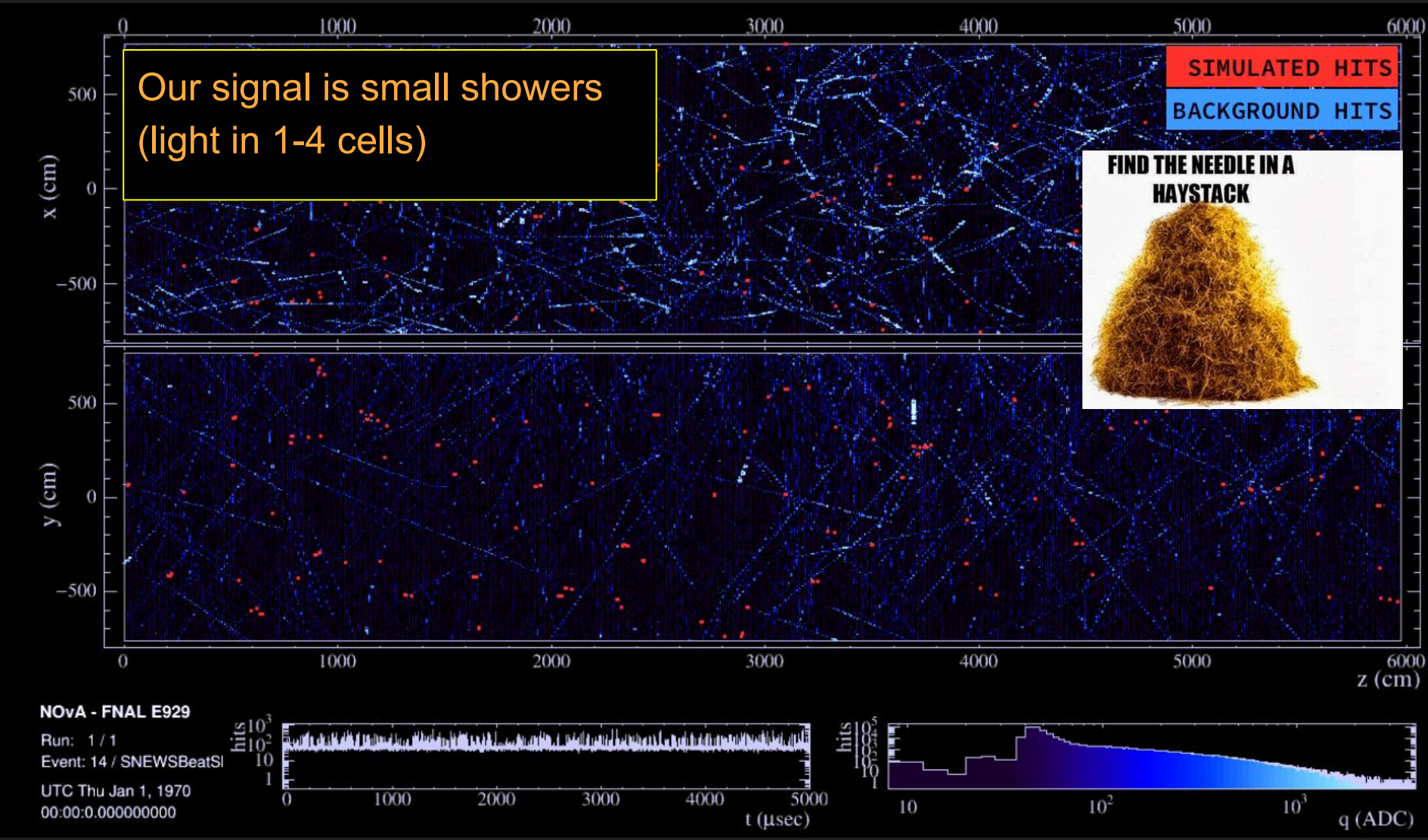
- **Inverse Beta Decay**
  - signature:
    positron shower (10-60 MeV)
- **Neutral Current**
  - signature:
    deexcitation gamma (15.1 MeV)



# Far Detector: 5ms of cosmic data + SN simulation



# Signal selection



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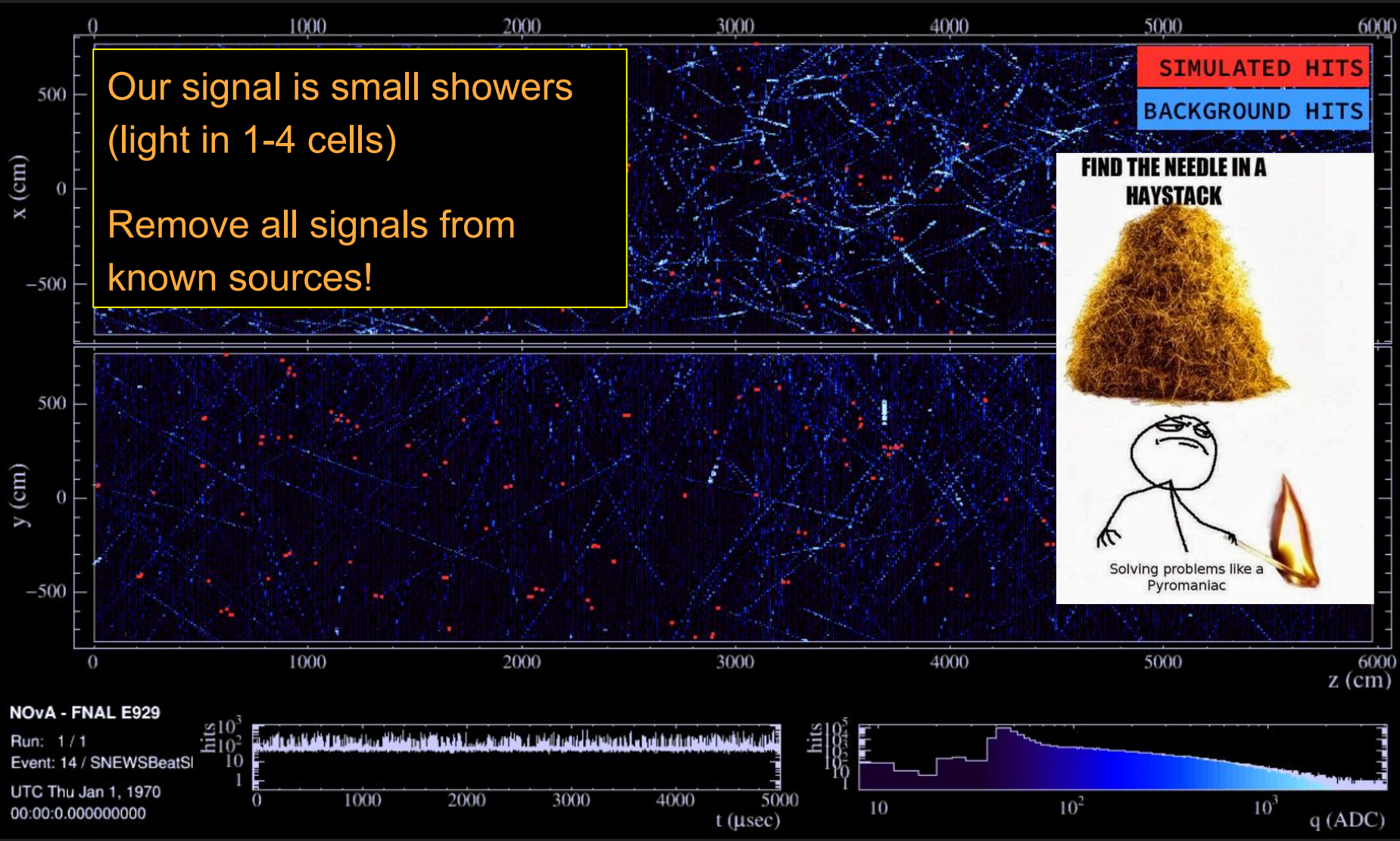

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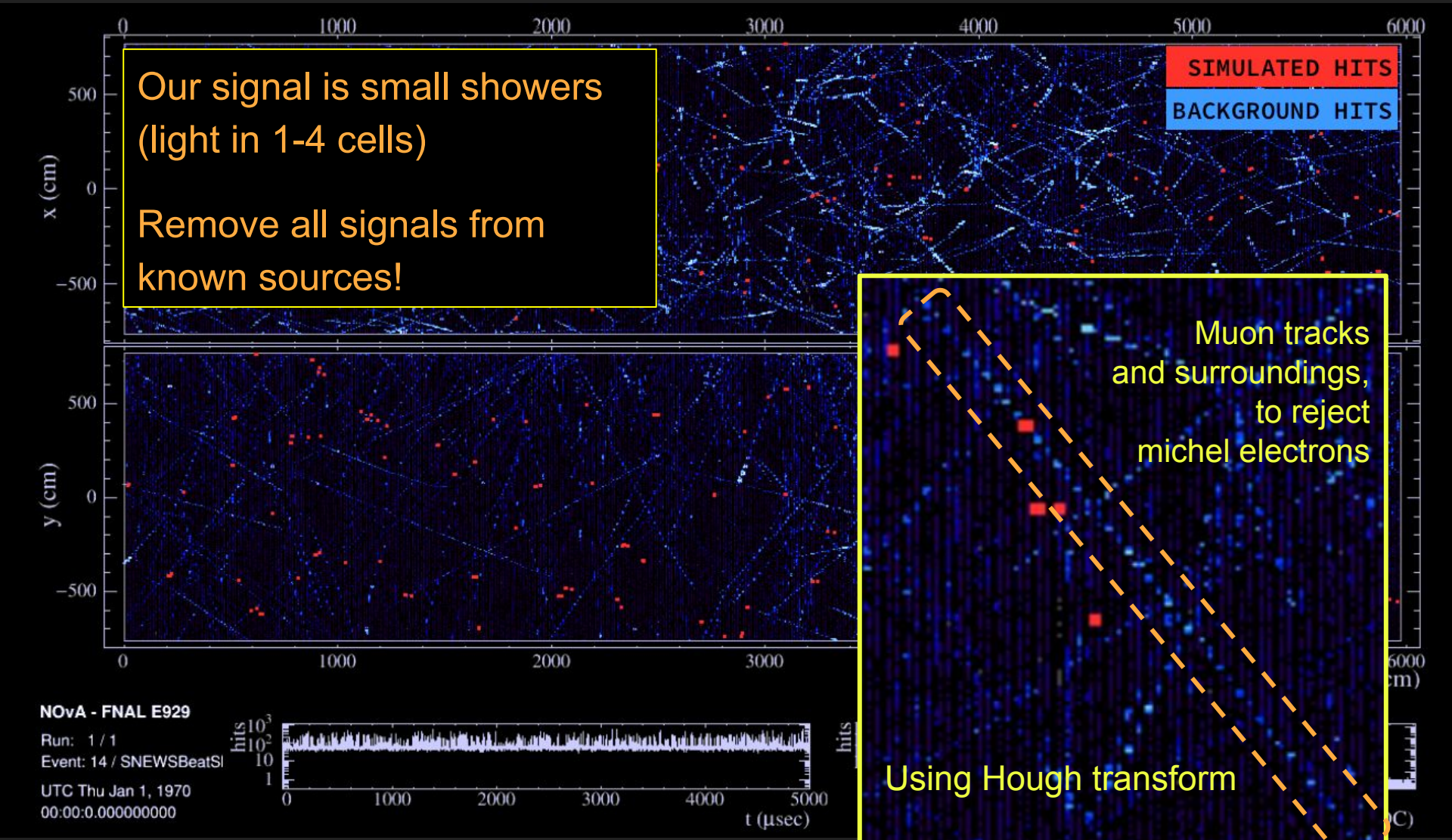

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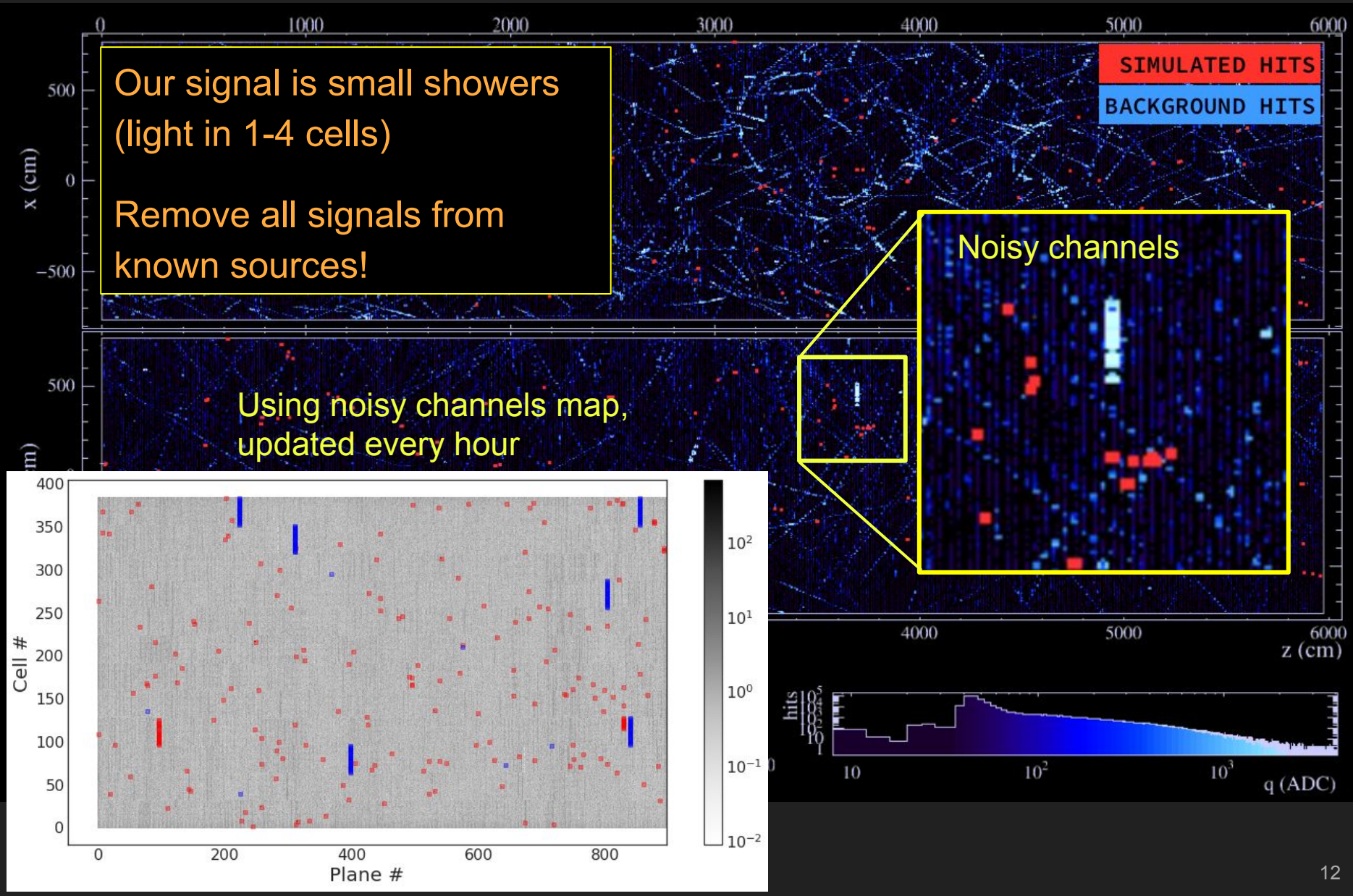

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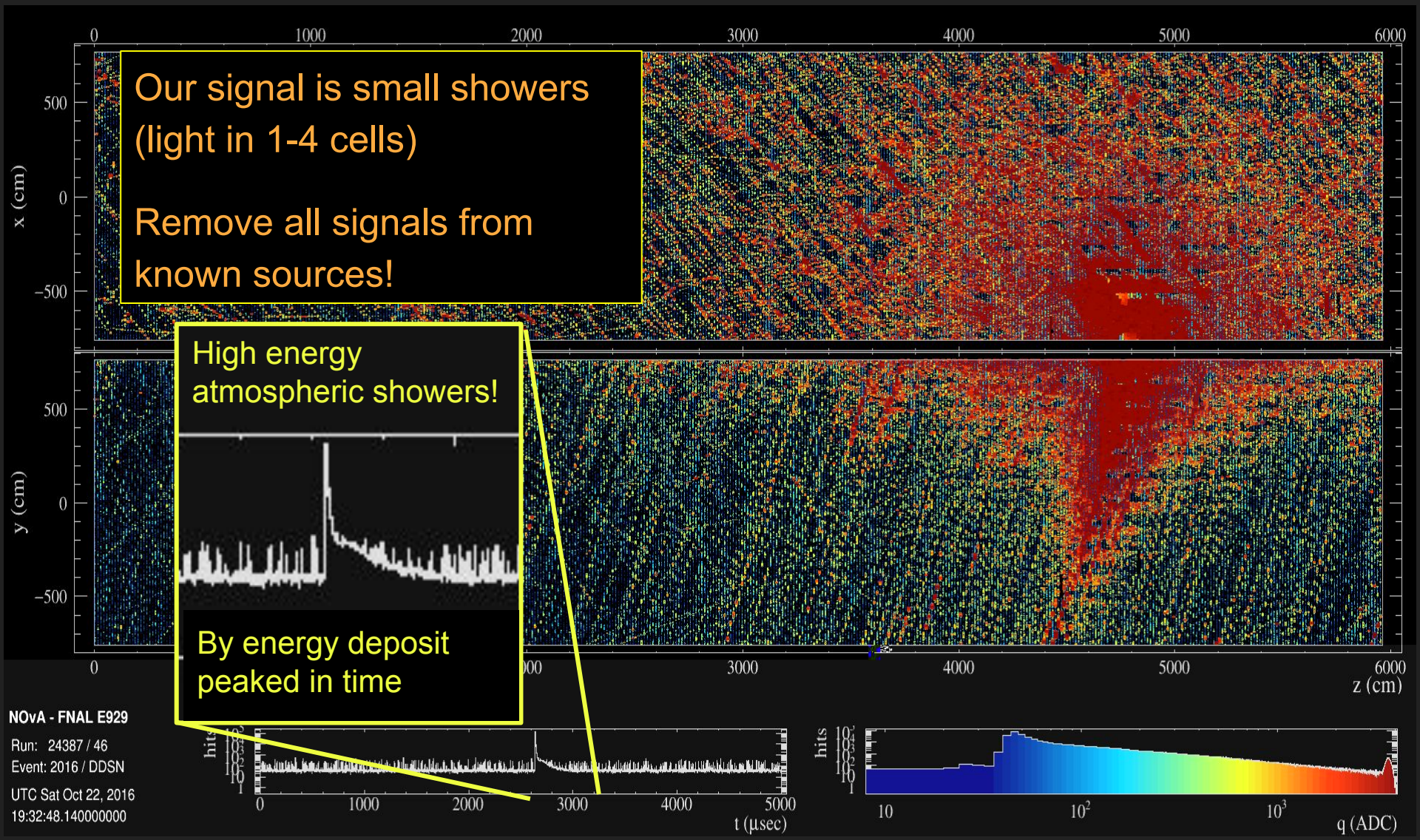


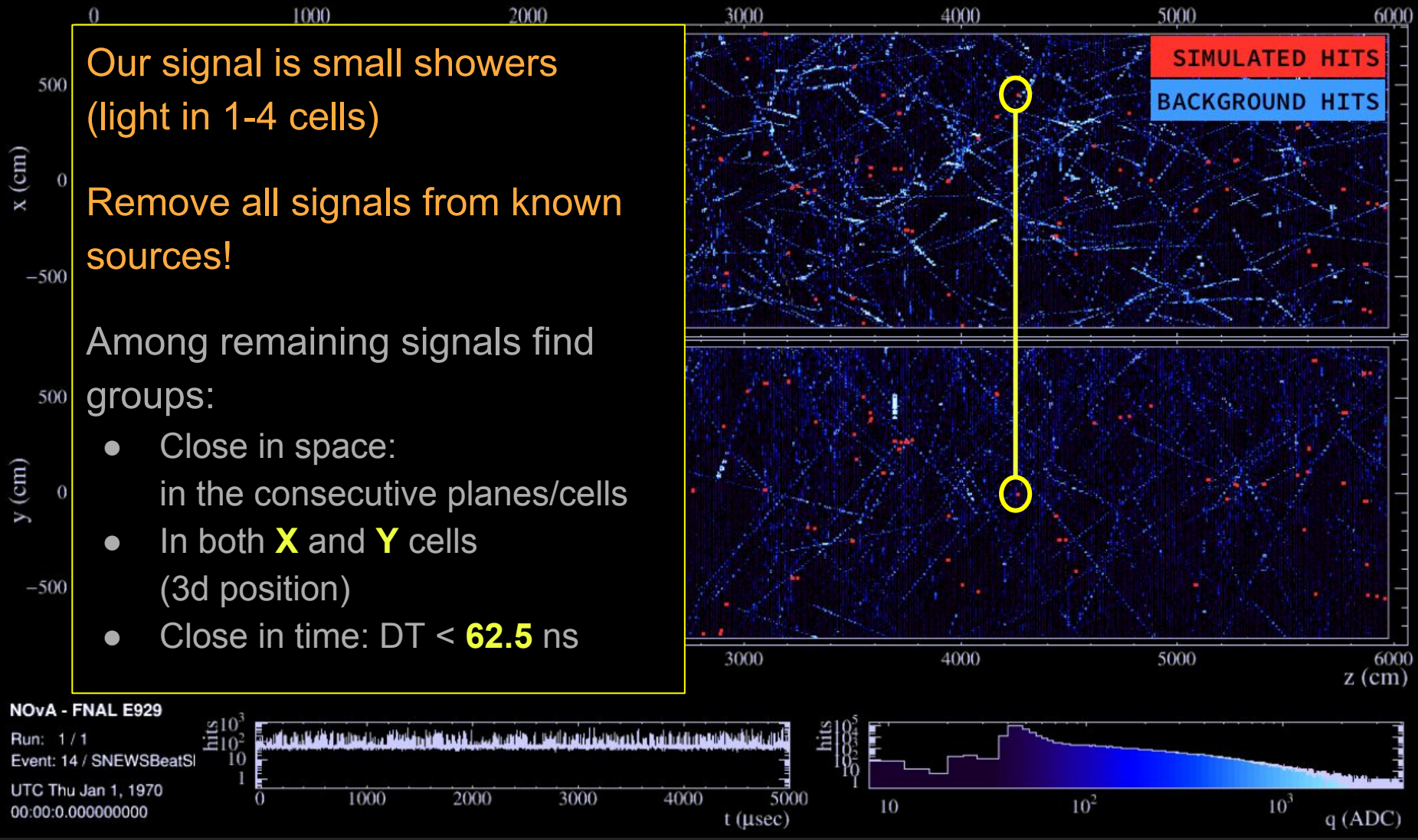
# Signal selection

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



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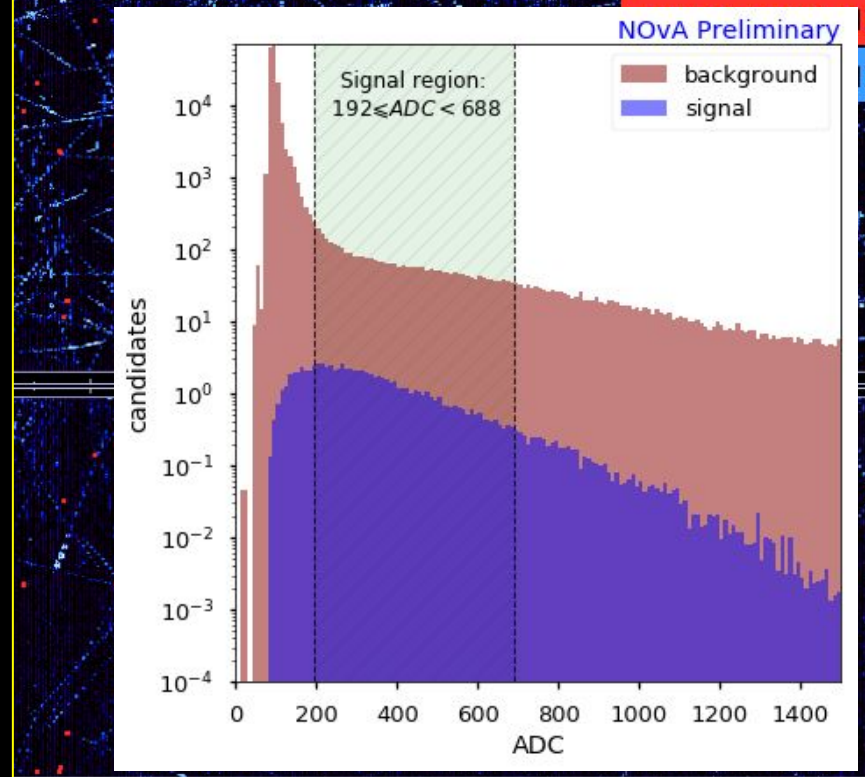
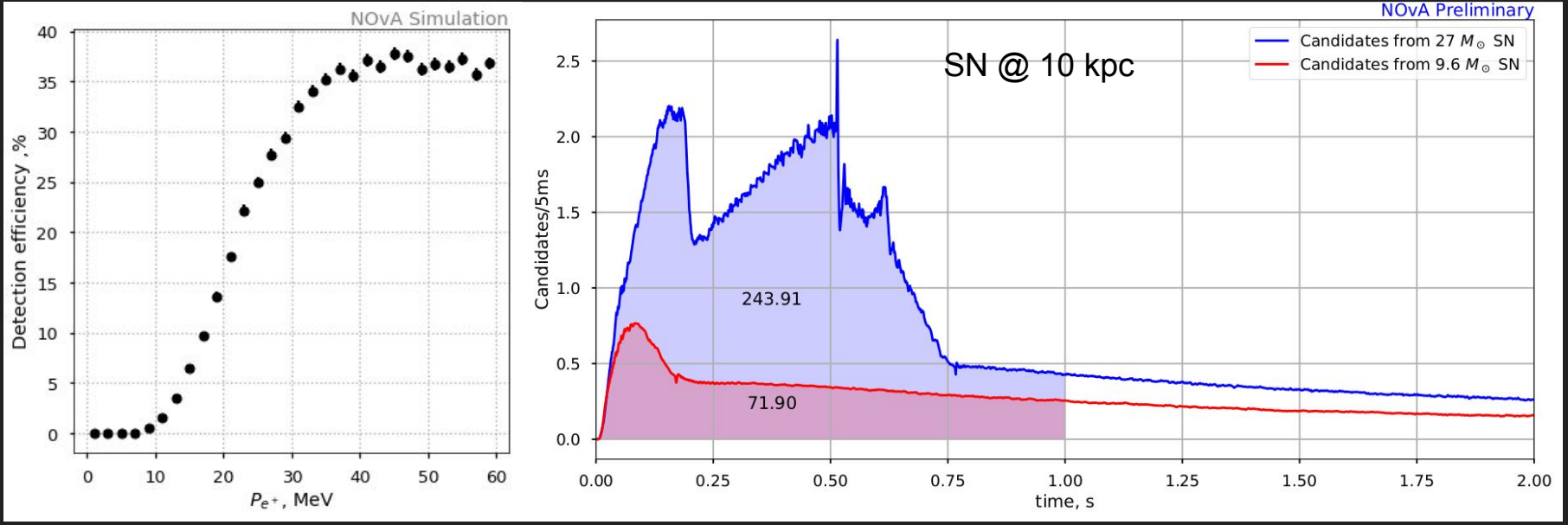
Select the signal region in the light amplitude: ADC counts



# 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

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

# SN triggering system for NOvA

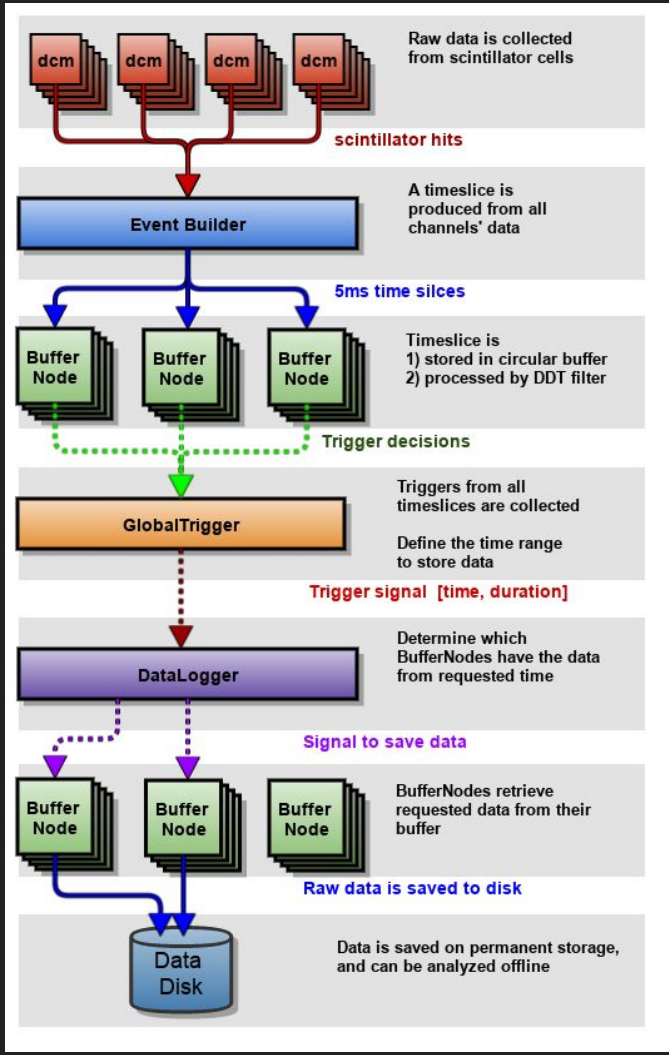
We want to react fast in case of a supernova.

A real-time reconstruction is needed, to decide if we see the signal.

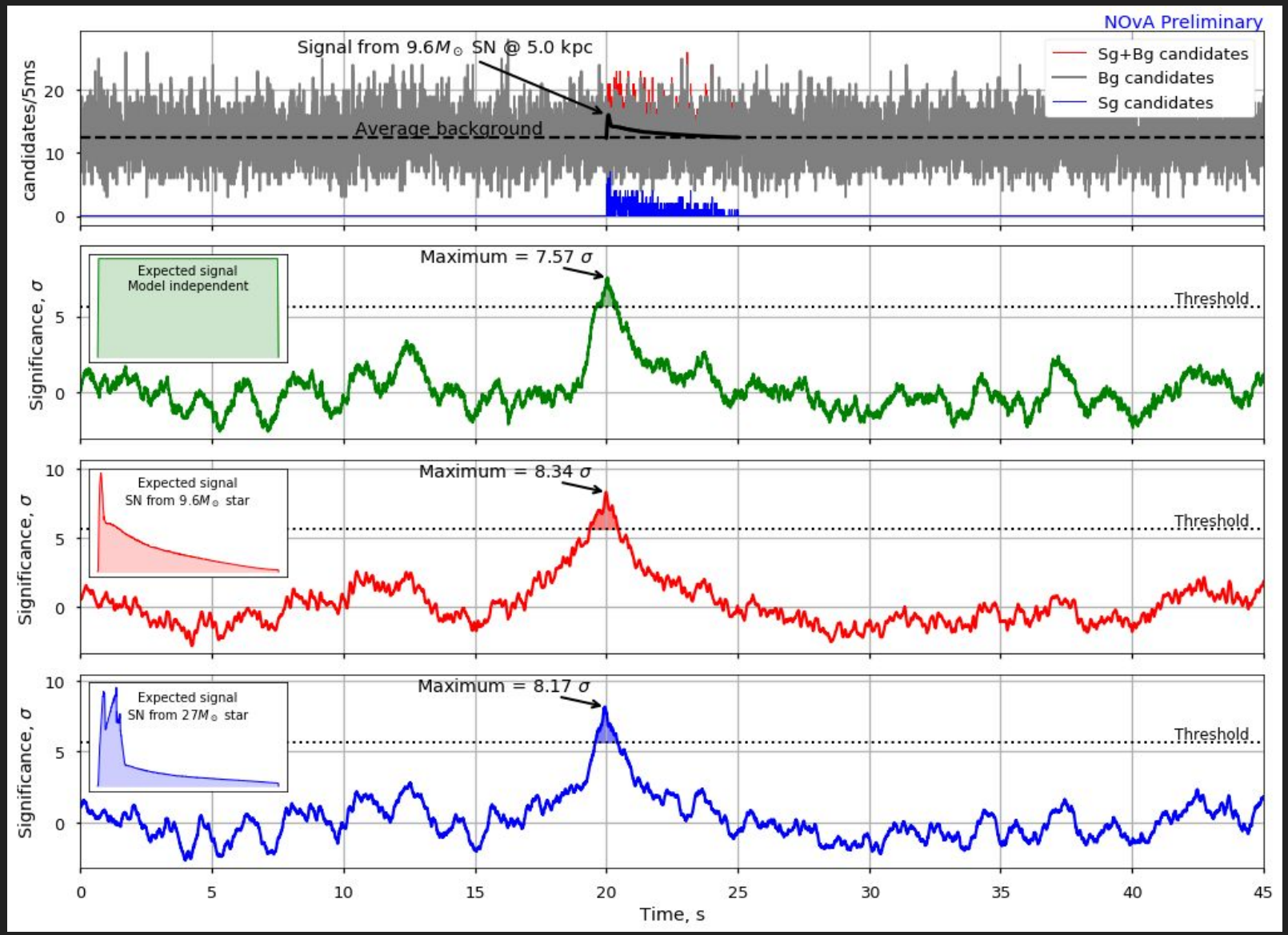
A dedicated triggering system was designed and developed to make SN detection possible.

Data is processed in parallel:
140 nodes * 13 processes,
each processing a 5ms “milliblocks”

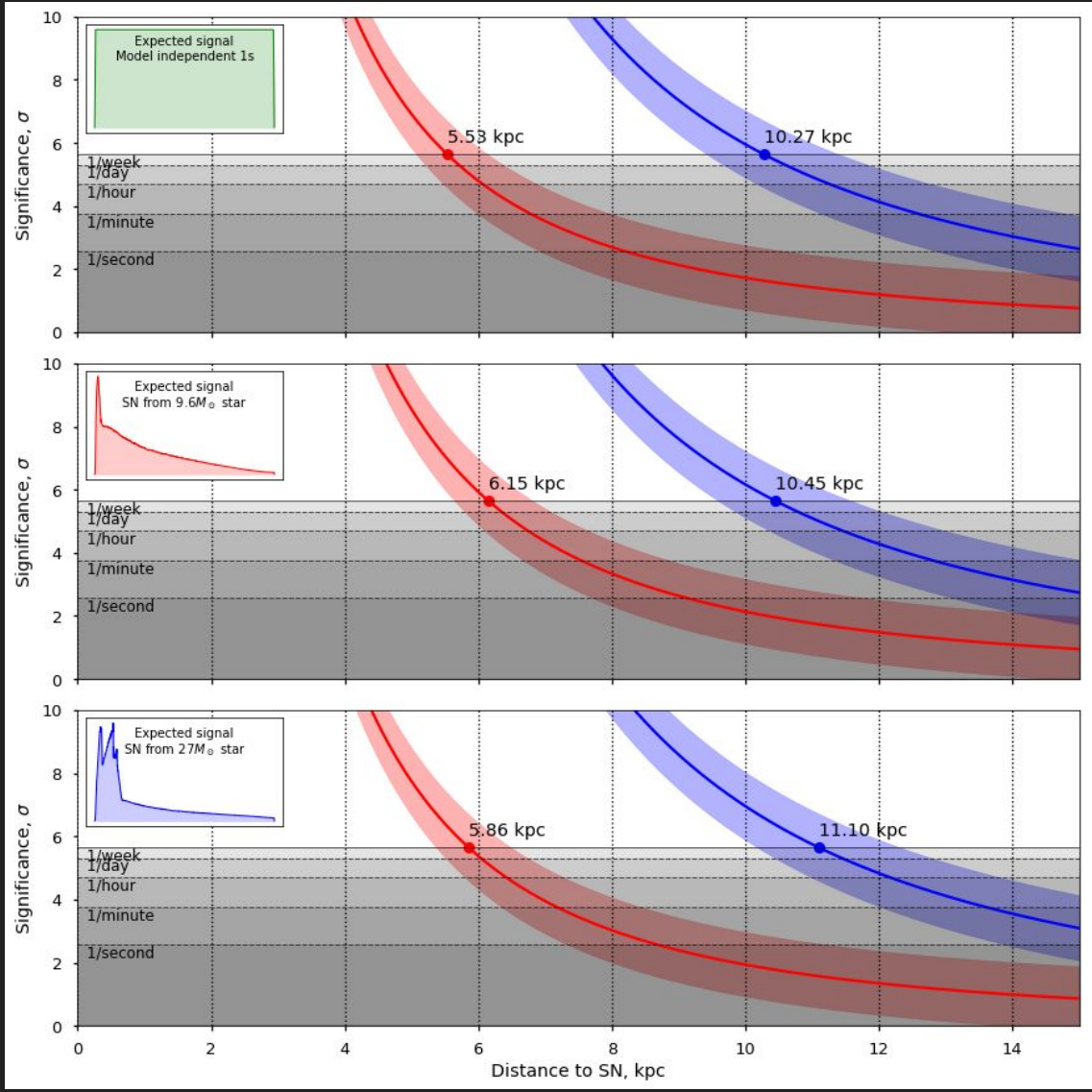
Rate of neutrino candidates vs time
is analyzed, to decide if we see a supernova.



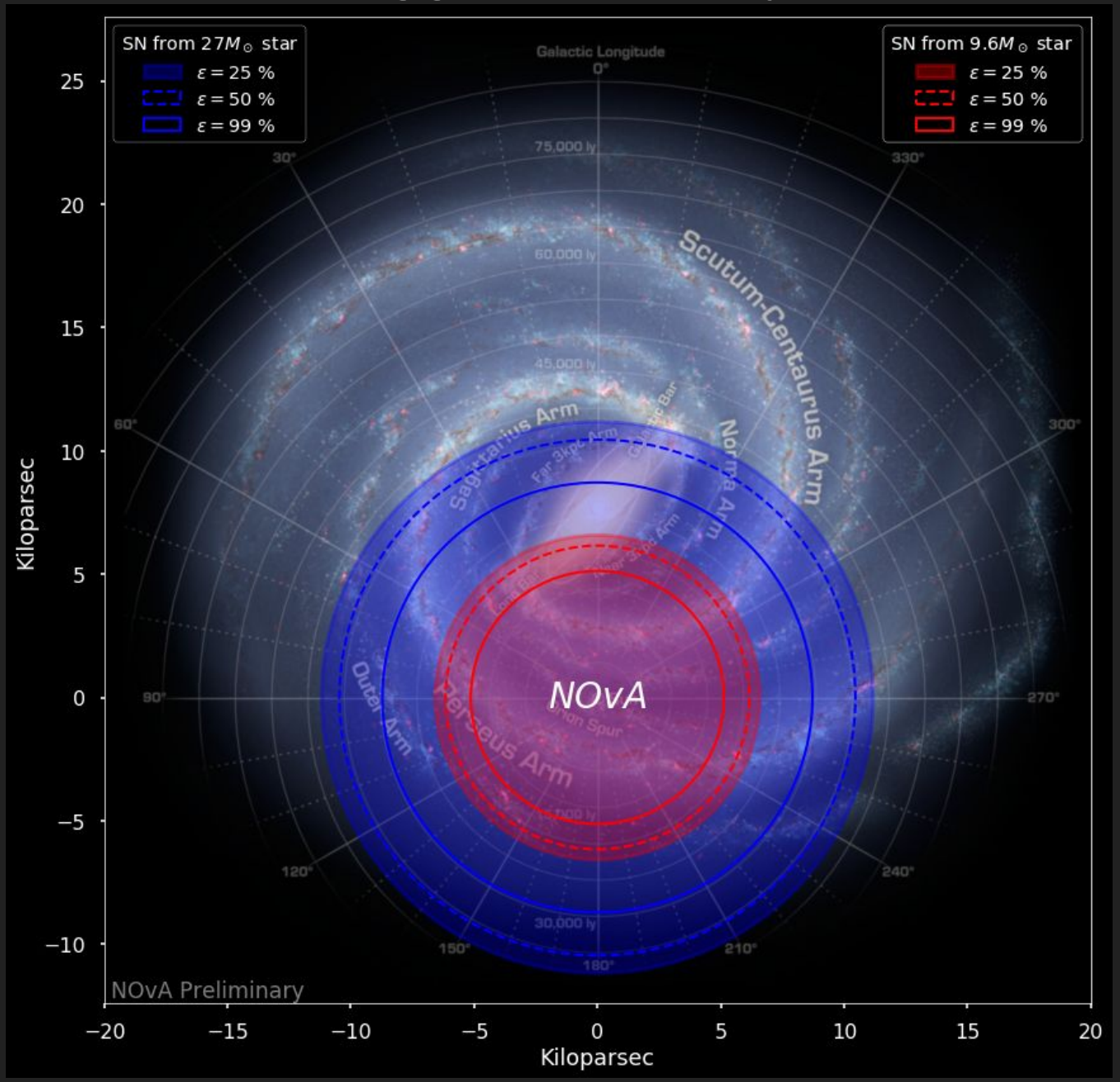
# Signal processing and triggering: example



# Supernova significance vs. distance: FarDet



# NOvA supernova trigger sensitivity



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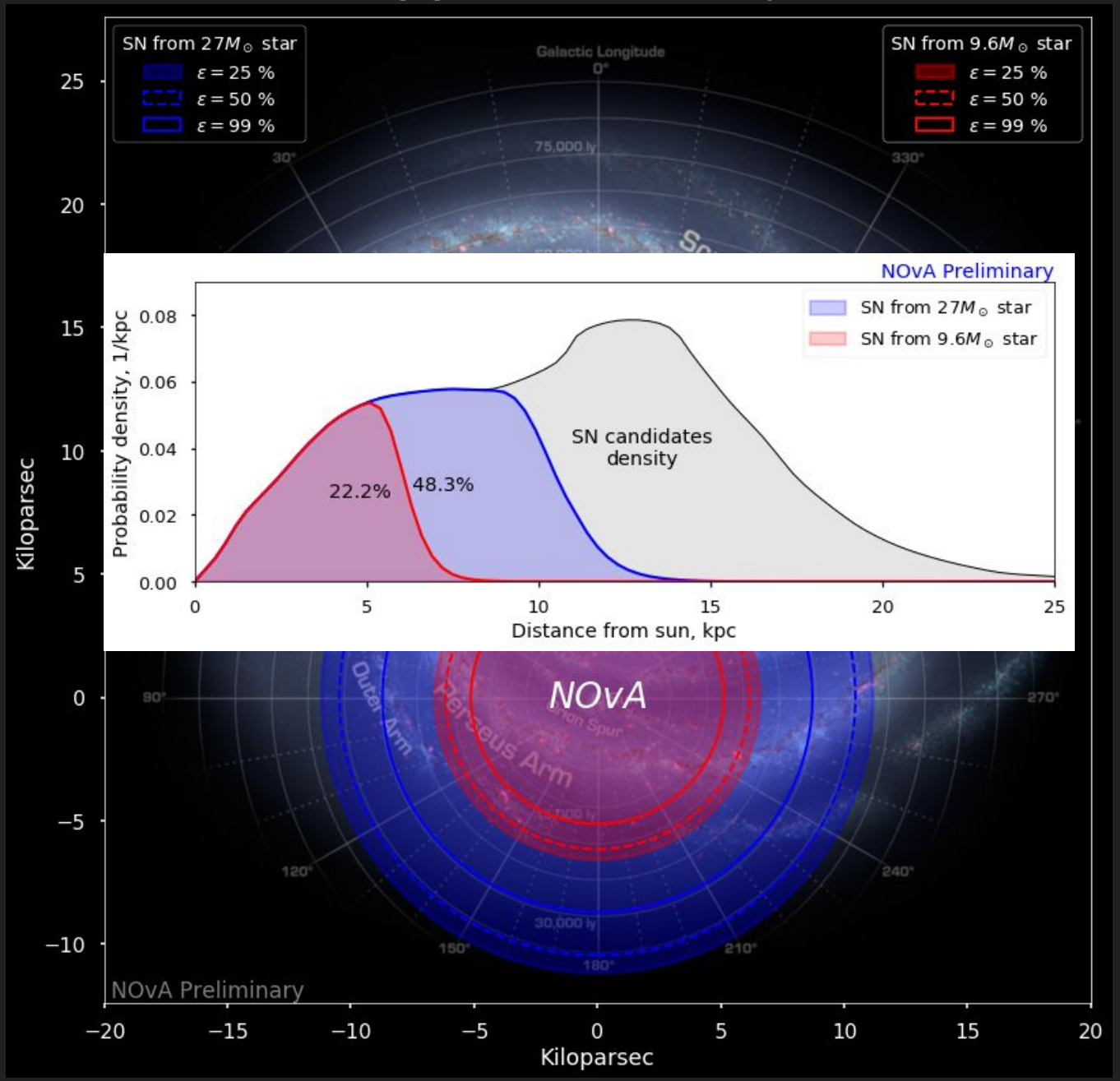


# Summary

NOvA is different from many experiments, sensitive to supernova neutrinos:

- Low overburden (high background)
- Two detectors (coincidence network)

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.
- Fast reaction time for SN (~10s).

## This work was presented on conferences:

- AYSS-2016, Dubna
- NEUTRINO-2016, London, UK
- ICRC-2017, Busan, South Korea
- AYSS-2018, Dubna
- NEUTRINO-2018, Heidelberg, Germany
- ICPPA-2018, Moscow

Two papers are currently in preparation:

- NOvA Data-Driven Triggers (technical description)
- Supernova neutrino detection in NOvA (detailed description and physics)

PhD thesis is in preparation.

The triggering system is being developed from scratch since 2015

- Development of the DAQ system
- Deployment and testing during summer beam shutdowns.
  - SN trigger should not affect beam data stability.
- DAQ release management
- Trigger monitoring and support

## Plans and perspectives

- Study the possibilities of SN models discrimination
  (M. Petropavlova master thesis)
- Combination of detectors' significances can improve sensitivity.
- We're getting ready to contribute to SNEWS.
- We're getting ready to contribute to GWNU
  - A search for coincidence with gravitational waves

# Backup

# Candidates selection: first second of SN signal

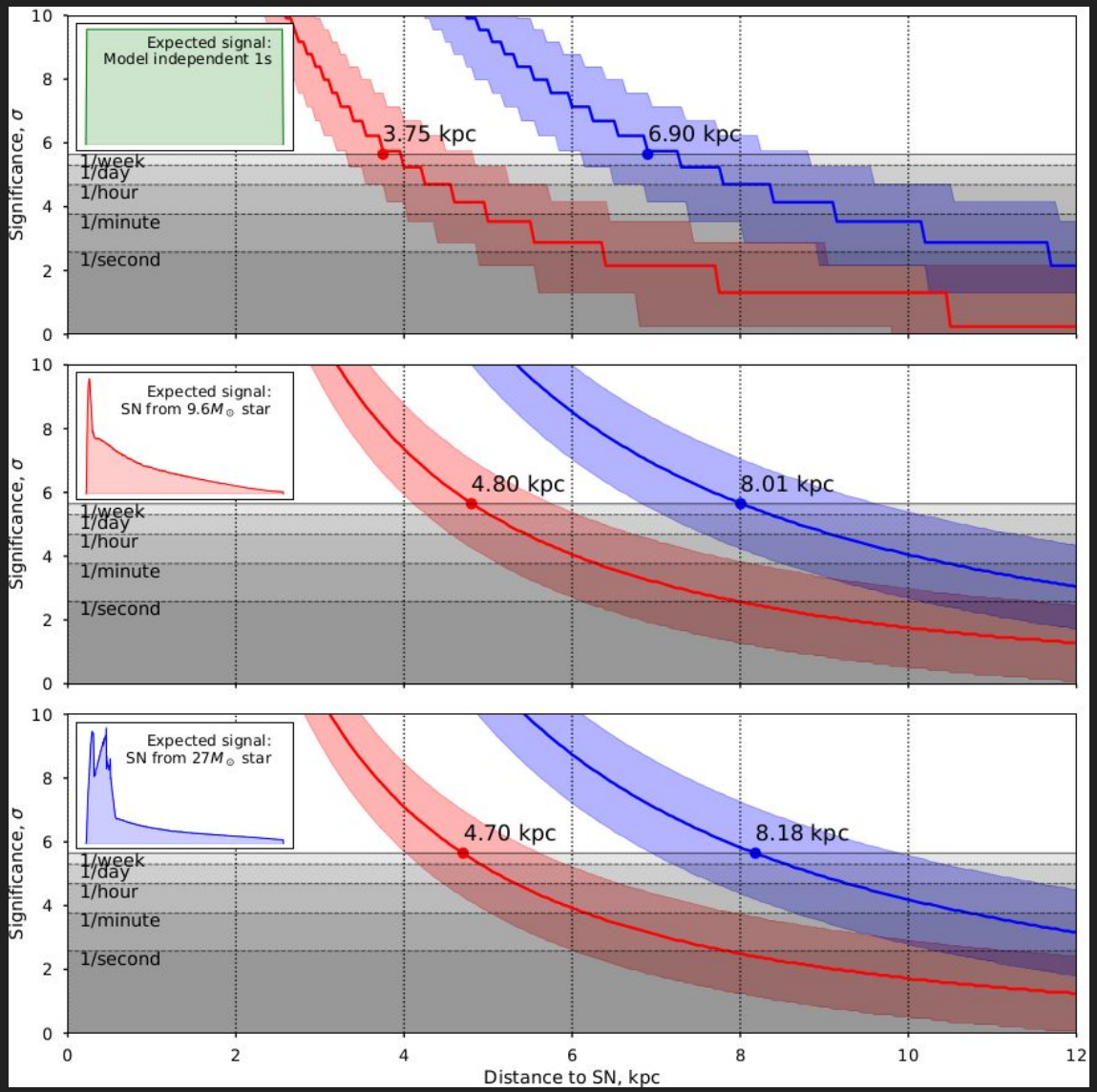
Far Detector

| | $N_{sg}$ | $\varepsilon_{sg}$ | $N_{bg}$ | $\varepsilon_{bg}$ | $N_{sg}/\sqrt{N_{bg}}$ |
|---|---|---|---|---|---|
| **Total** | 725.14 | nan% | nan | nan% | nan |
| **Reconstructed** | 316.24 | 43.61% | 322811.99 | nan% | 0.5566 |
| **XY hits** | 145.16 | 45.90% | 231866.53 | 71.83% | 0.3015 |
| **Nhits cut** | 144.29 | 99.40% | 224420.72 | 96.79% | 0.3046 |
| **Fiducial Volume cut** | 117.77 | 81.62% | 170436.38 | 75.95% | 0.2853 |
| **ADC cut** | 86.75 | 73.66% | 3429.27 | 2.01% | 1.481 |
| **Group removal** | 86.64 | 99.87% | 2483.21 | 72.41% | 1.739 |

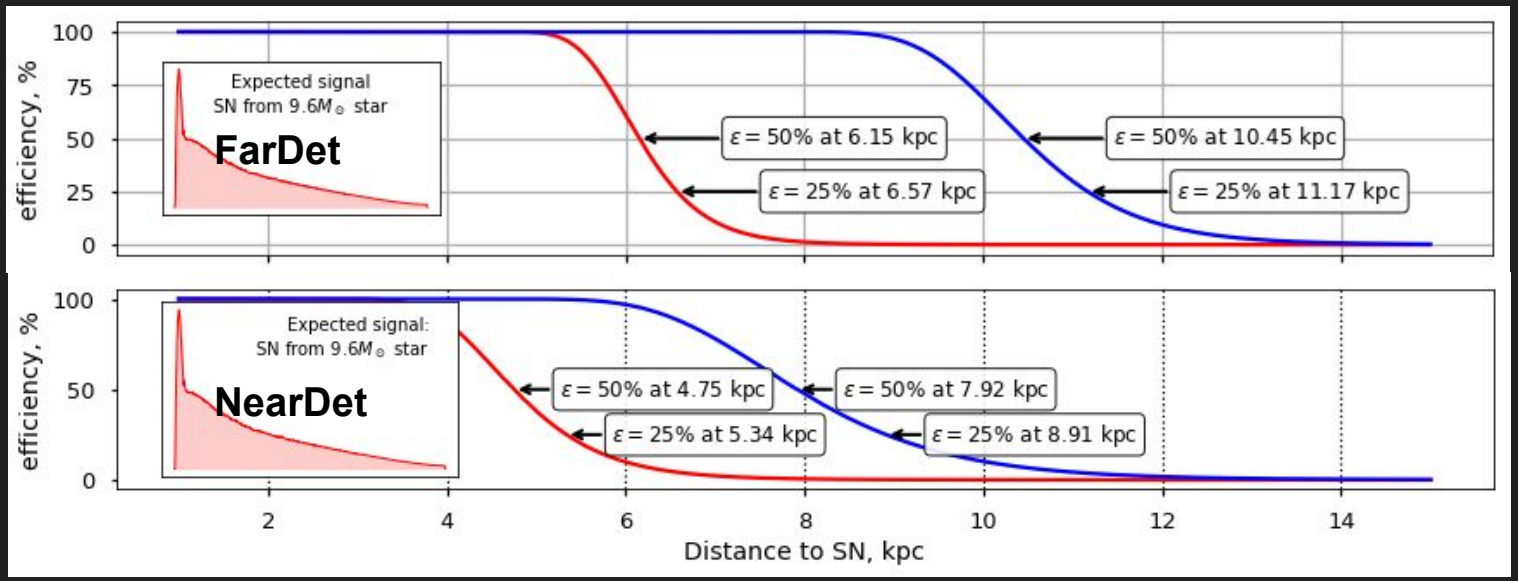
Near Detector

| | $N_{sg}$ | $\varepsilon_{sg}$ | $N_{bg}$ | $\varepsilon_{bg}$ | $N_{sg}/\sqrt{N_{bg}}$ |
|---|---|---|---|---|---|
| **Total** | 10.83 | nan% | nan | nan% | nan |
| **Reconstructed** | 3.16 | 29.16% | 403.95 | nan% | 0.1572 |
| **XY hits** | 2.19 | 69.35% | 215.64 | 53.38% | 0.1492 |
| **Nhits cut** | 2.18 | 99.54% | 208.86 | 96.85% | 0.1509 |
| **Fiducial Volume cut** | 1.48 | 68.05% | 67.63 | 32.38% | 0.1804 |
| **ADC cut** | 1.28 | 86.06% | 0.55 | 0.82% | 1.715 |
| **Group removal** | 1.28 | 100.00% | 0.52 | 93.42% | 1.774 |

# Supernova significance vs. distance: NearDet



# NOvA supernova trigger sensitivity




The efficiency for SN trigger system on Far and Near detectors using expected signal from small supernova with 1/week false triggering rate.

Combining the detectors will give improved sensitivity.