Maximizing the potential of DUNE

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University of Oxford

April 9, 2020

Big questions in neutrino oscillations

- Do neutrinos violate CP?
- What does this imply for the baryon asymmetry of the universe?
- Answers from $P(\nu_\mu \to \nu_e)$ vs $P(\bar{\nu}_\mu \to \bar{\nu}_e)$ at $E_\nu \sim$ GeV

$$P(\nu_\mu \to \nu_e) \qquad\qquad P(\bar{\nu}_\mu \to \bar{\nu}_e)$$

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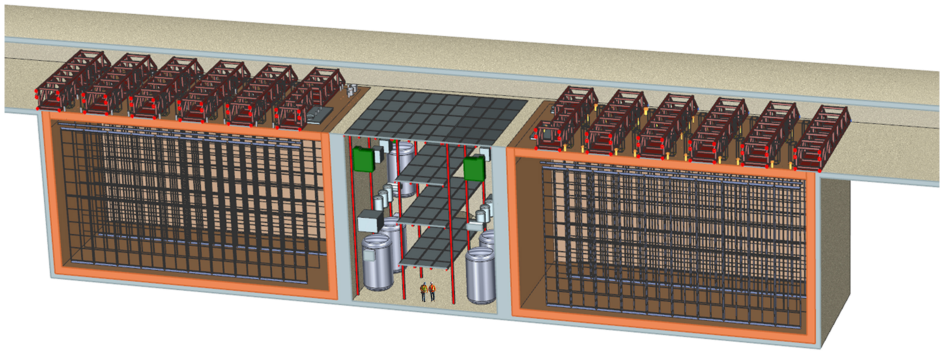
$$P(\nu_\mu \to \nu_e)$$



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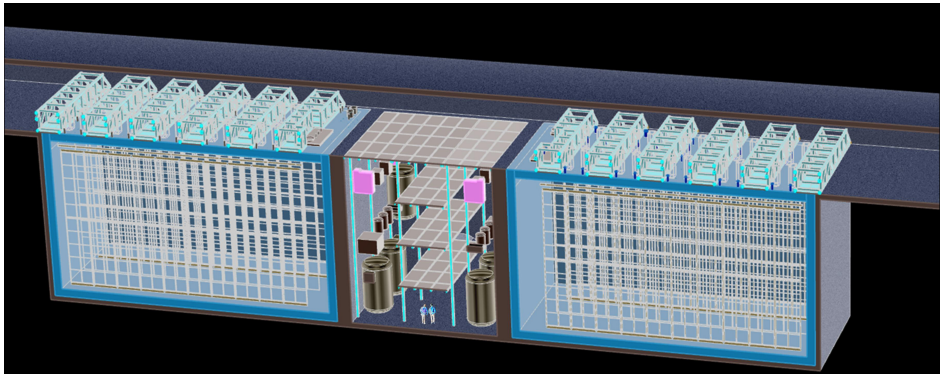
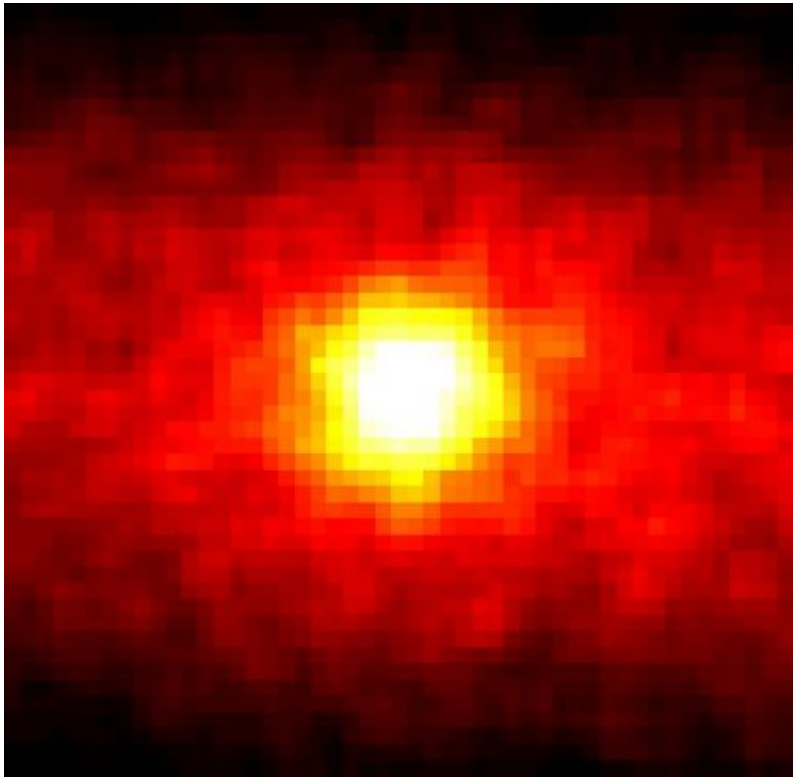


Neutrinos are messengers of otherwise-inaccessible astrophysical environments

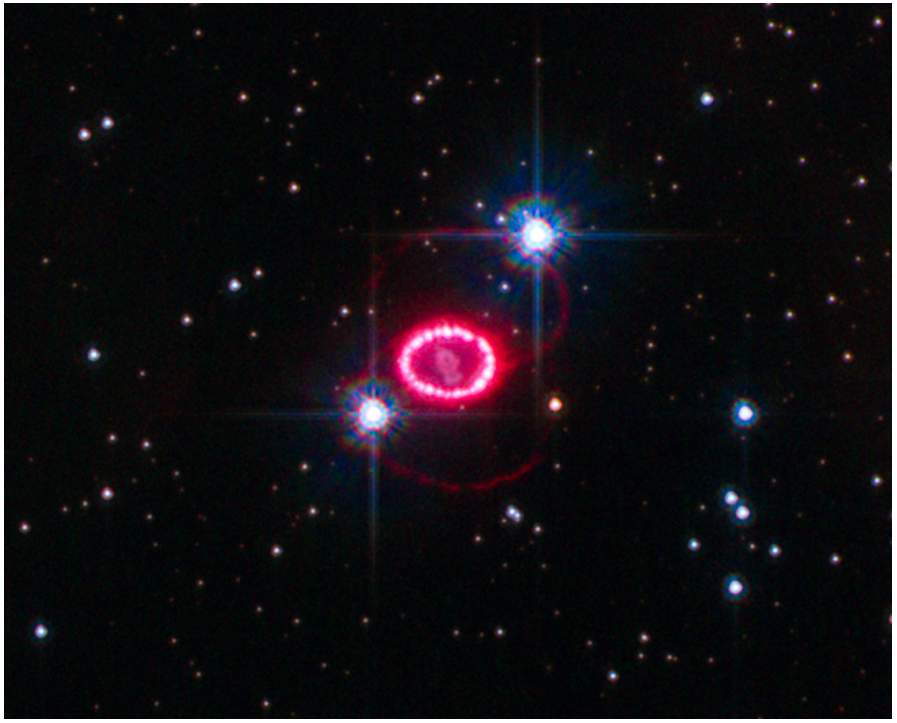
Solar neutrinos



SuperKamiokande/R. Svoboda

- Neutrinos direct from the sun's core

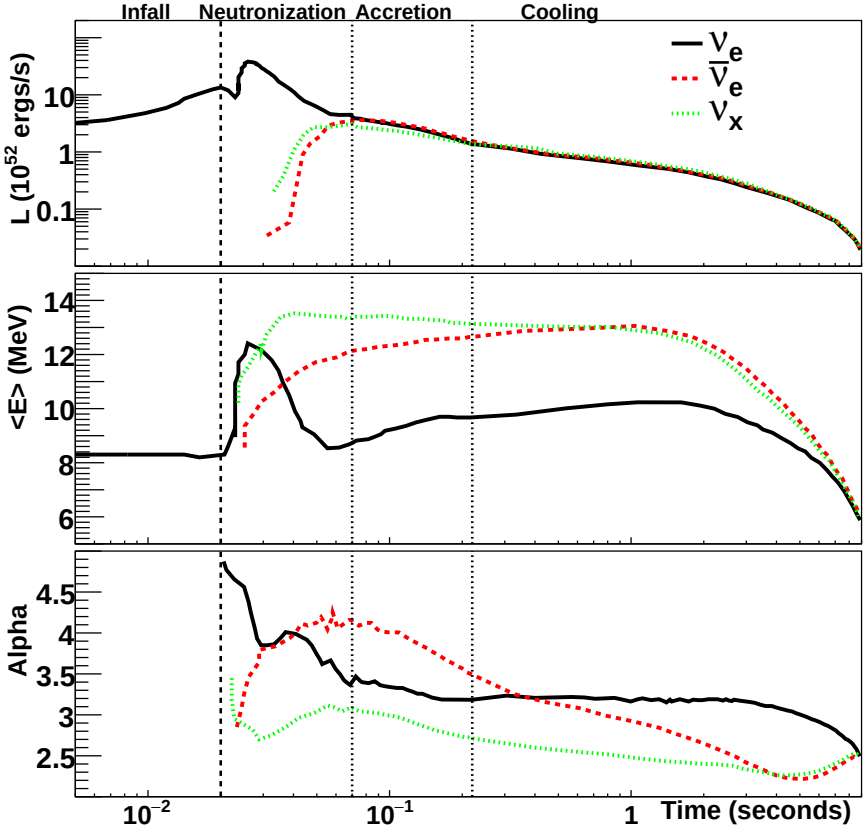
Supernova neutrinos



Hubble/NASA

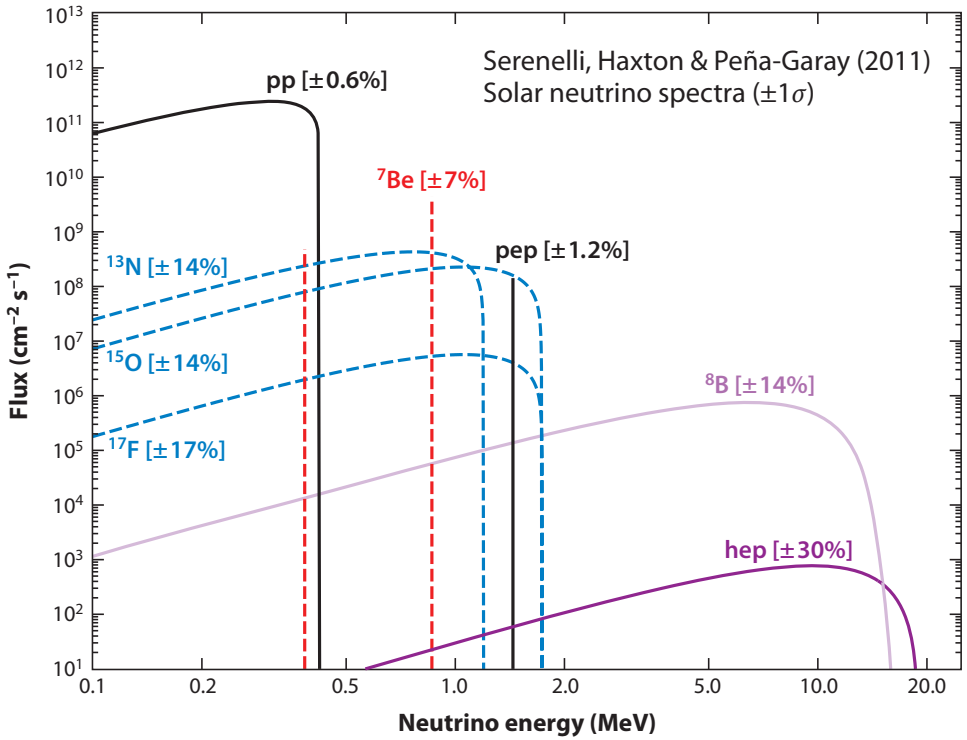
- 99% of energy in neutrino burst
- A once-in-a-generation science opportunity

Physics and astrophysics from supernova neutrinos

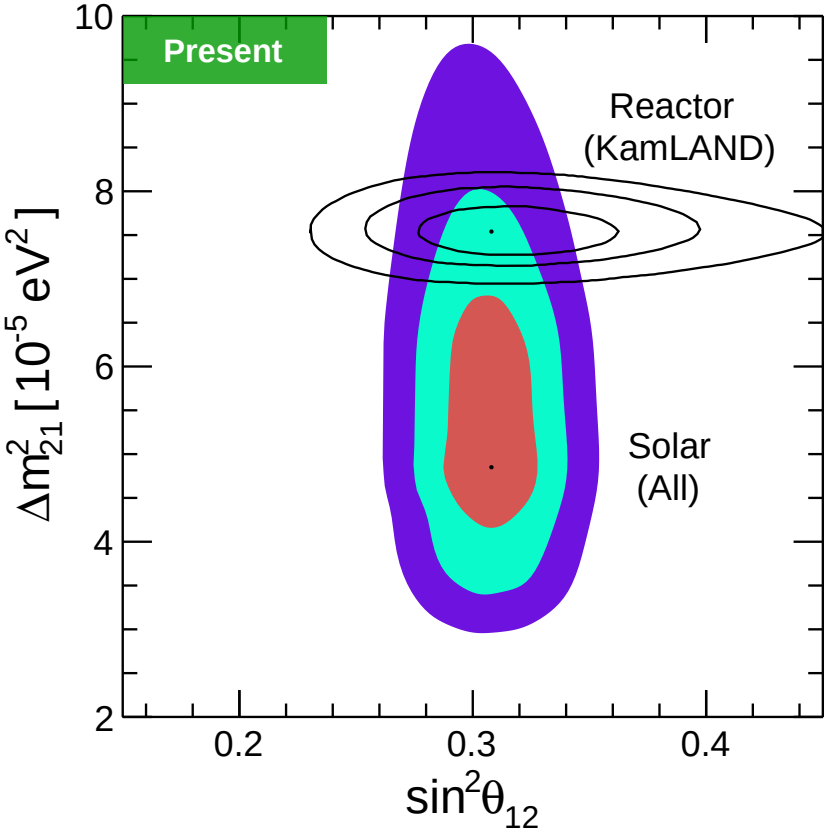


- 99% of SN energy in few-second burst of neutrinos, direct from the moment of explosion
- Timing and spectrum sensitive to details of SN explosion mechanism, and oscillation parameters
- Early warning for optical astronomy

Physics and astrophysics from solar neutrinos



Haxton et al, Annu. Rev. Astron. Astrophys. 2013. 51:21–61



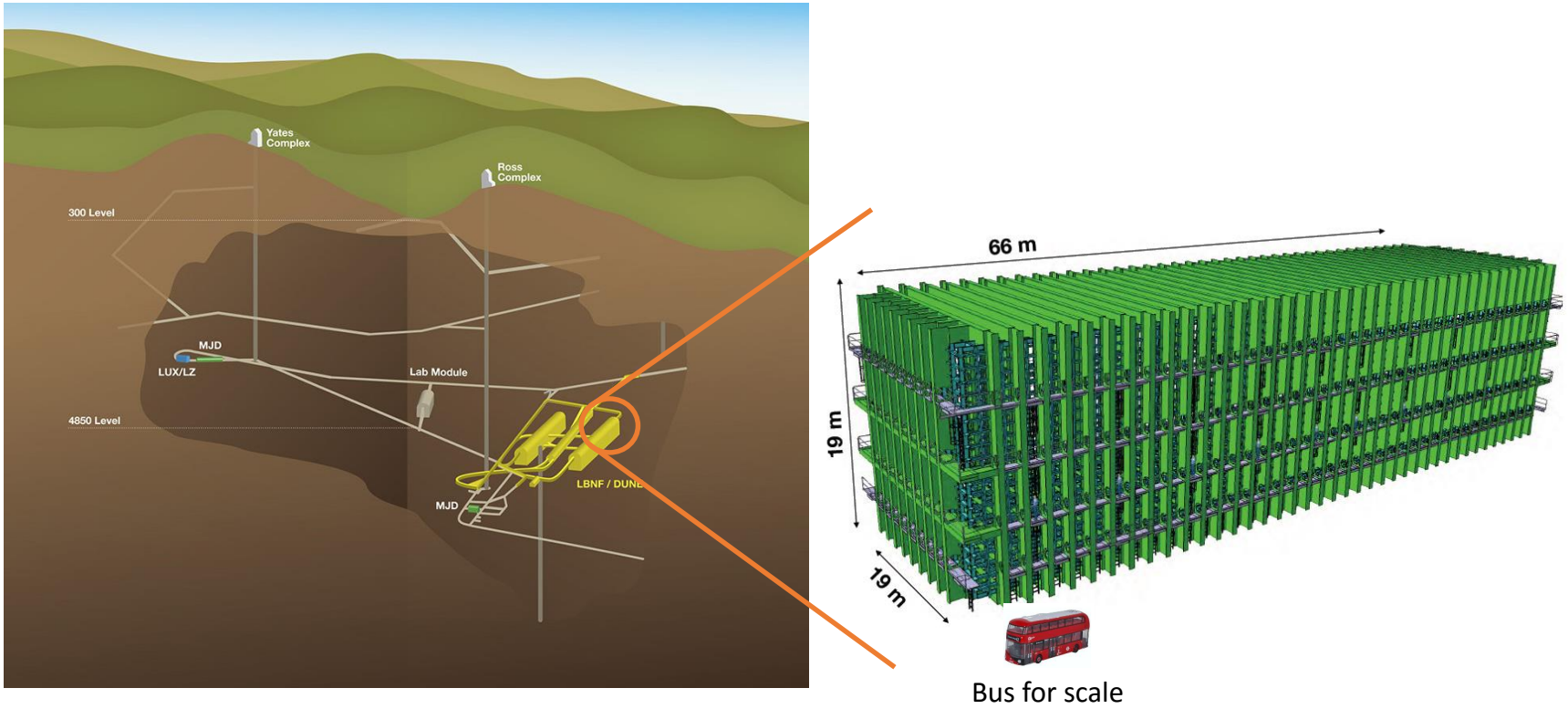
Capozzi et al, Phys. Rev. Lett. 123, 131803 (2019)

- Sensitive to Δm^2_{21}, $\sin^2\theta_{21}$
- ^8B flux proportional to T_c^{25}!

DUNE science goals

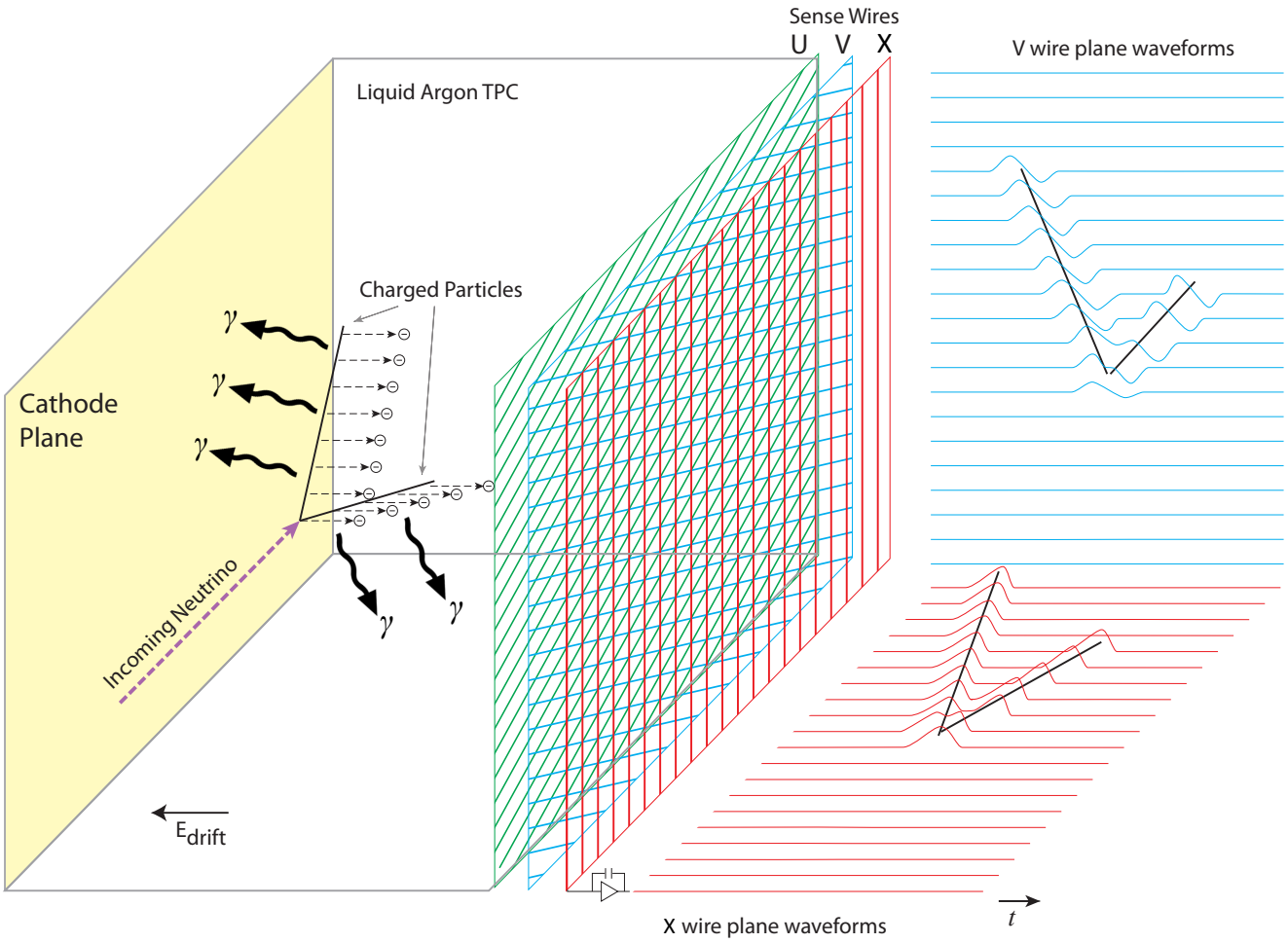
- Primary goal: neutrino CP violation from beam neutrinos
- Supernova neutrinos
- Solar neutrinos?
- Atmospheric neutrinos
- Proton decay

The DUNE far detector

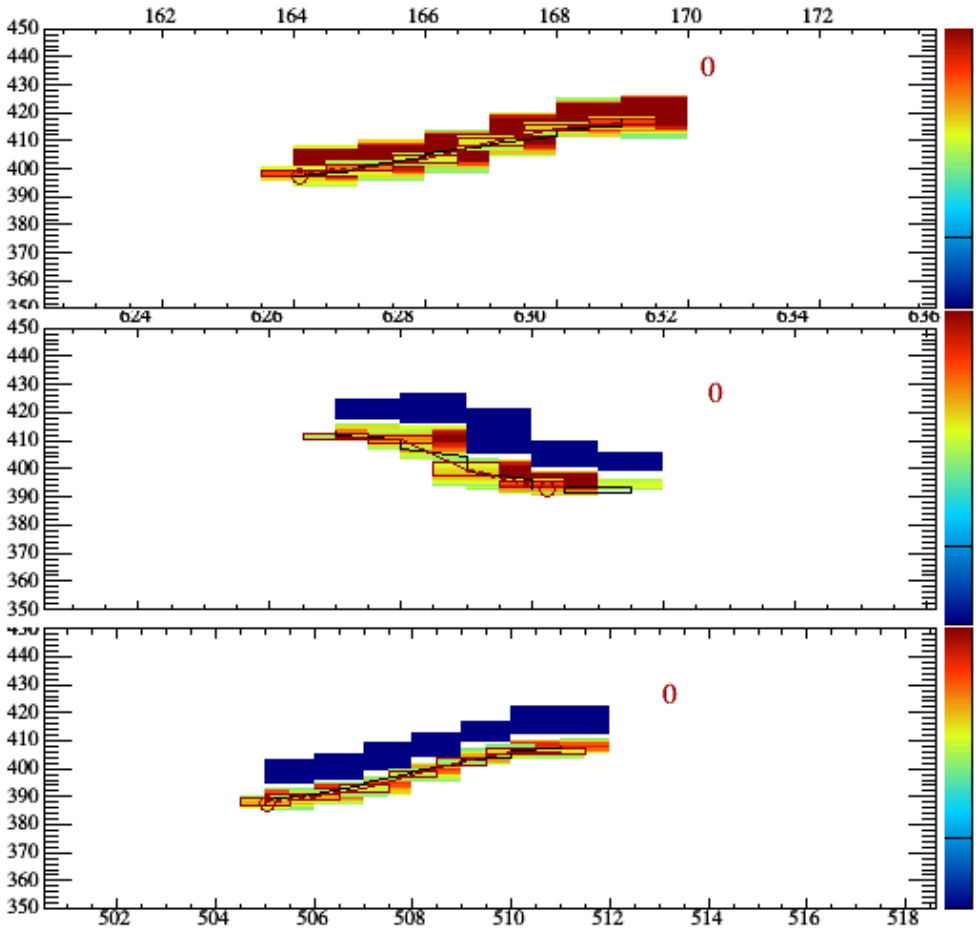


- 40 kt of liquid argon
- Large size and high resolution: a new type of neutrino facility

Liquid argon TPC



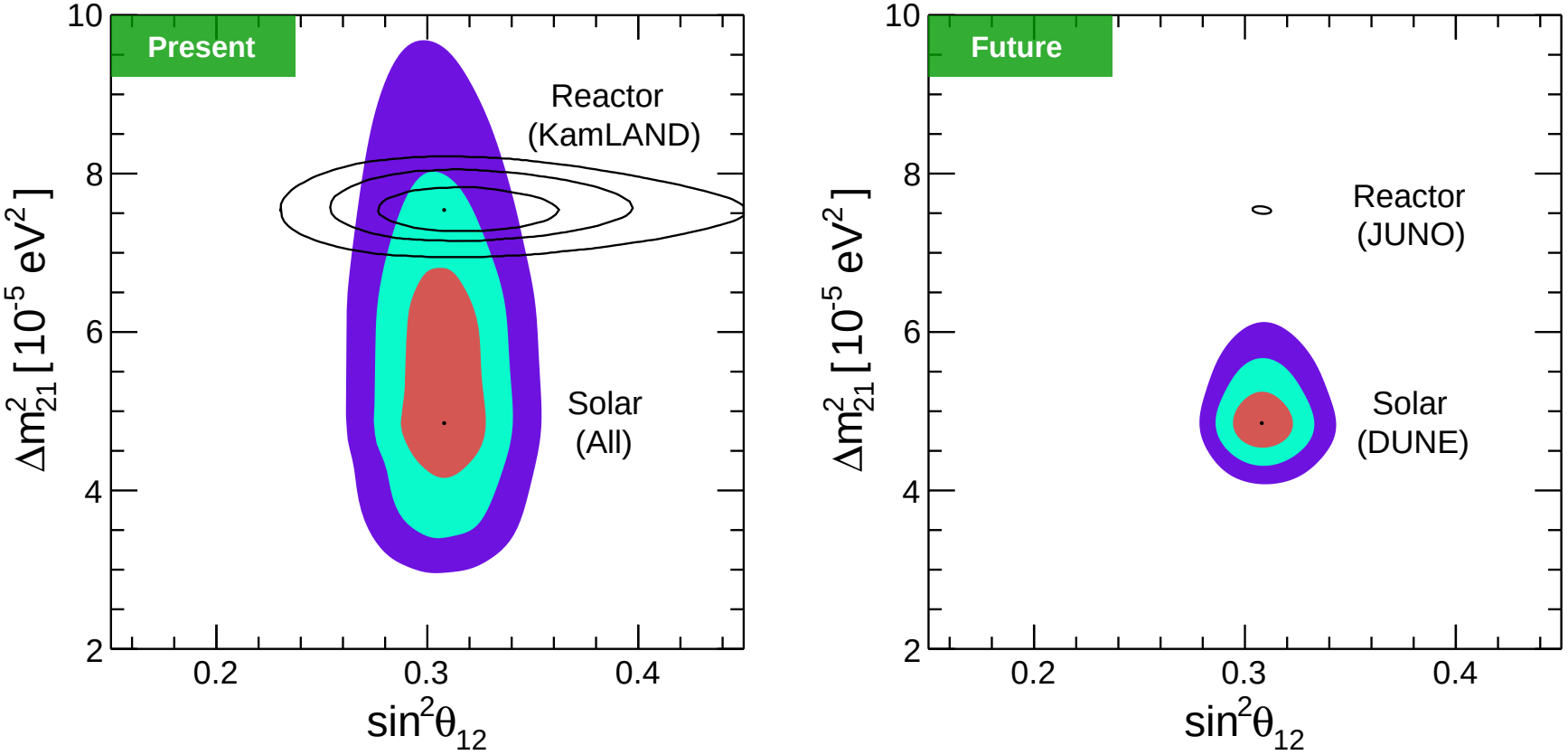
Supernova neutrinos in DUNE



A 10 MeV electron in DUNE simulation

- 100s to 1000s of interactions from a galactive supernova
- Complementary to HyperK/JUNO: ν_e rather than $\bar{\nu}_e$

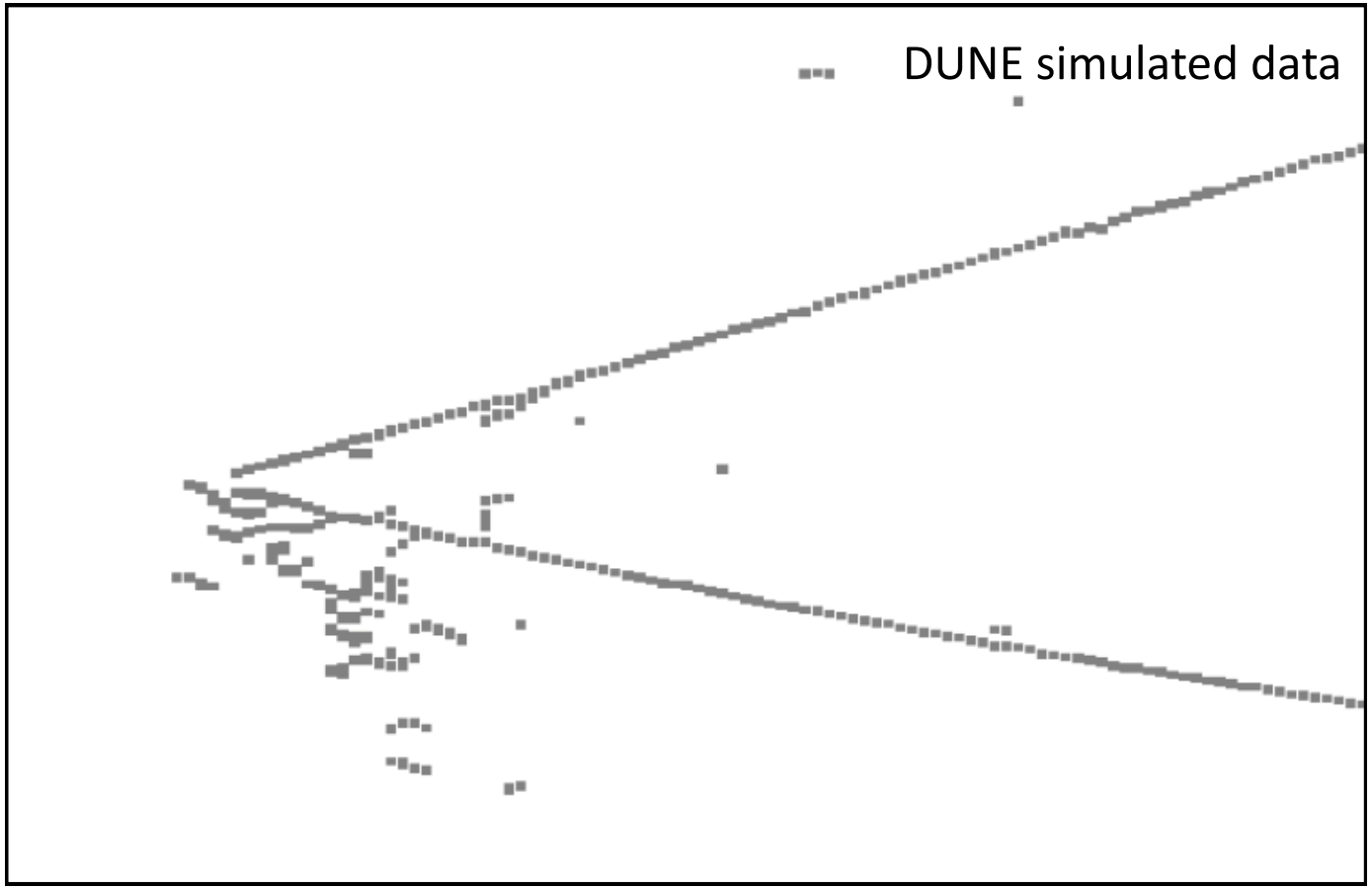
Possible physics with solar neutrinos in DUNE



Capozzi et al, Phys. Rev. Lett. 123, 131803 (2019)

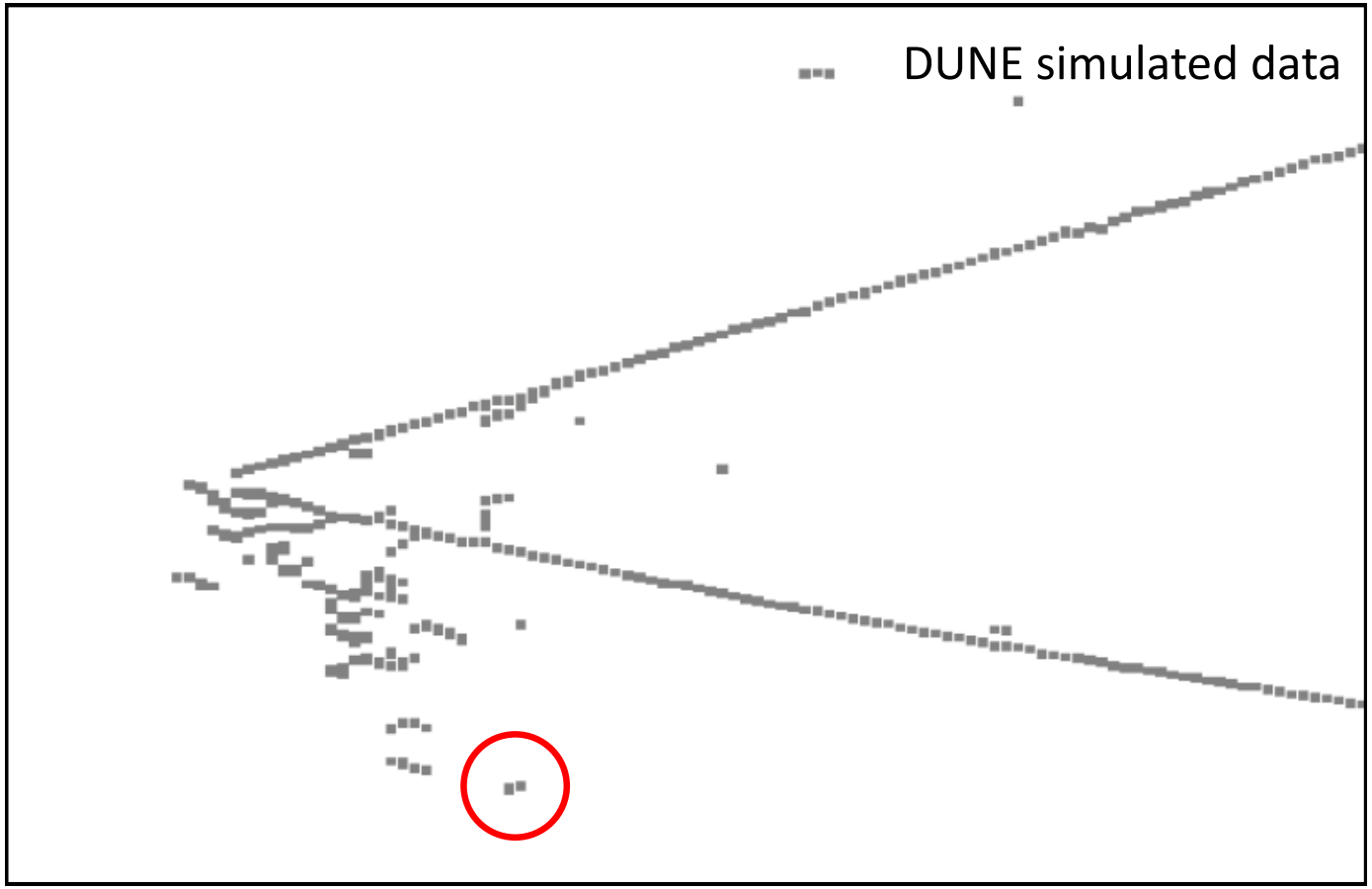
- Solar/reactor discrepancy resolve/increase to $\sim 5\sigma$
- Precise measurement of ^8B flux $\Rightarrow$ T_c
- First detection of *hep* flux

Increased physics reach at low energies



- Solar and SN neutrinos much lower energy than beam neutrinos
- Backgrounds from radioactive decays

Increased physics reach at low energies



- Solar and SN neutrinos much lower energy than beam neutrinos
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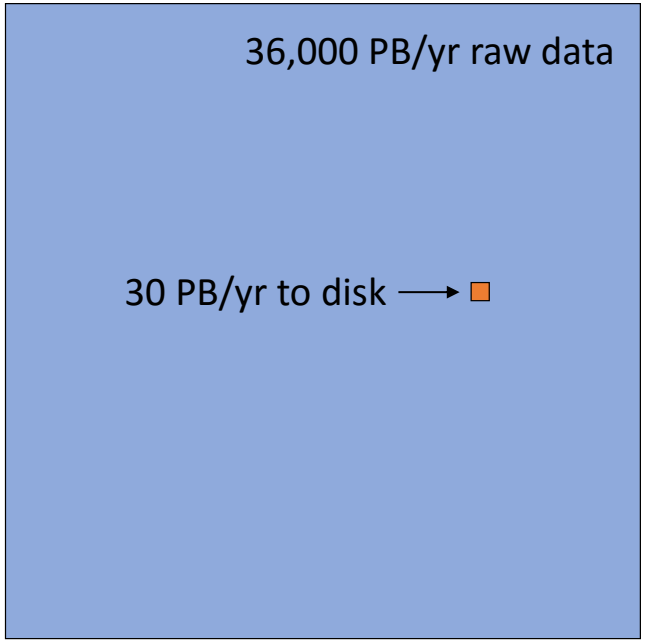
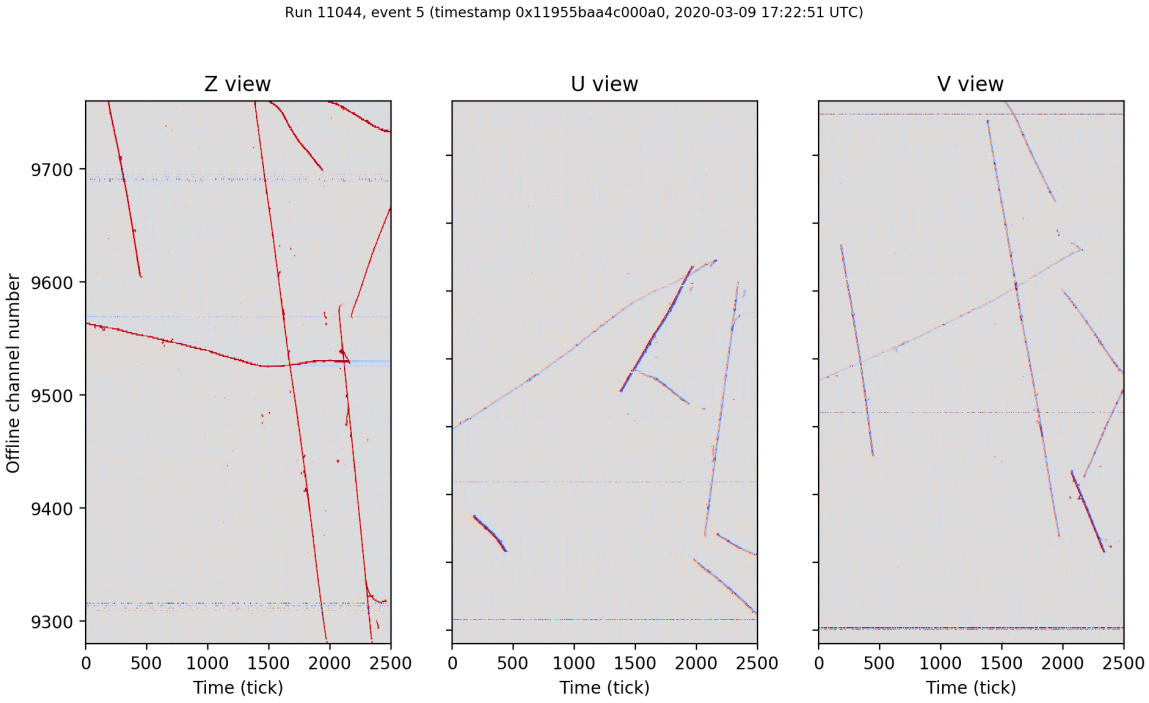
DUNE FD DAQ challenges

- Challenges:
  - High data rate: 1 TB/s per 10 kt module
  - Electrical power restrictions
  - Space restrictions
  - $>$ 99% uptime requirements
  - Remote location



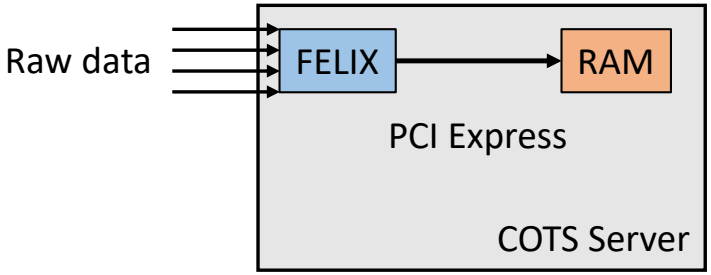
- Non-challenges:
  - Trigger decision latency
  - Complicated reconstruction needs

Tests at ProtoDUNE



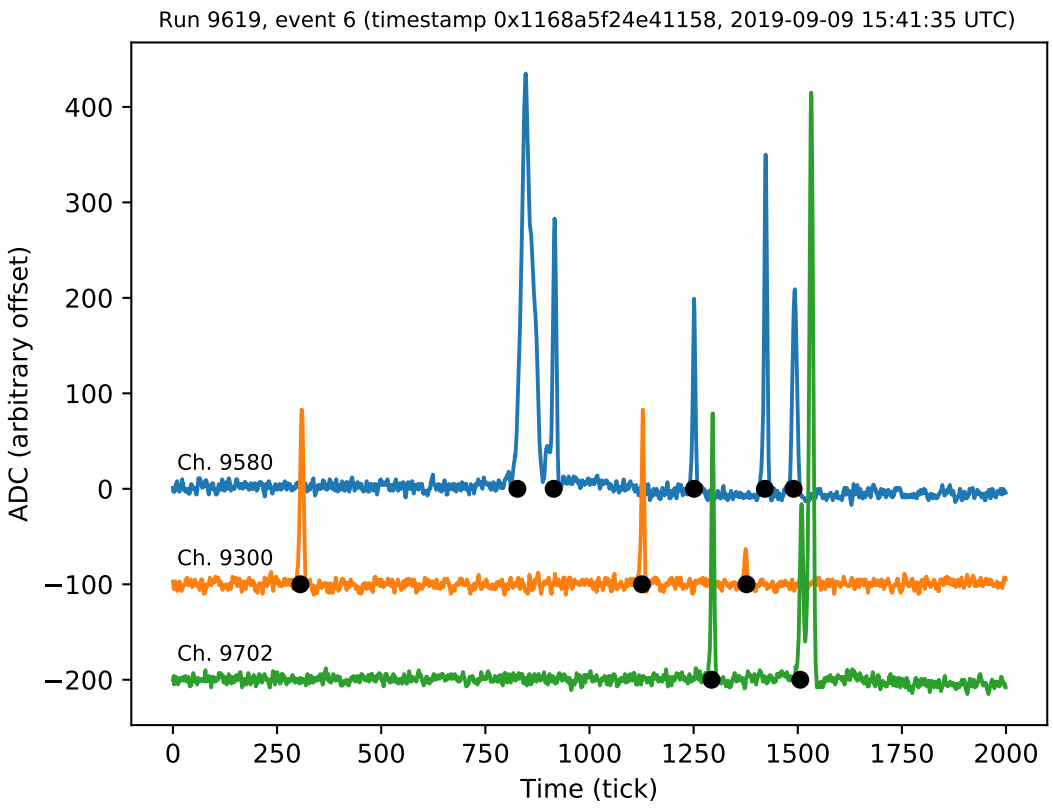
- ProtoDUNE at CERN
- Great detector performance
- Difference to FD: 10^4 Hz cosmic ray rate

Meeting data rate challenge with FELIX and CPU-based hit finding



- COTS hardware for flexibility, "free" upgrades
- CPU algorithms for ease of development
- But:
  - Per server: 9 GiB/s, 2 Gsamples/s to process
  - Requires highly optimized code to keep up

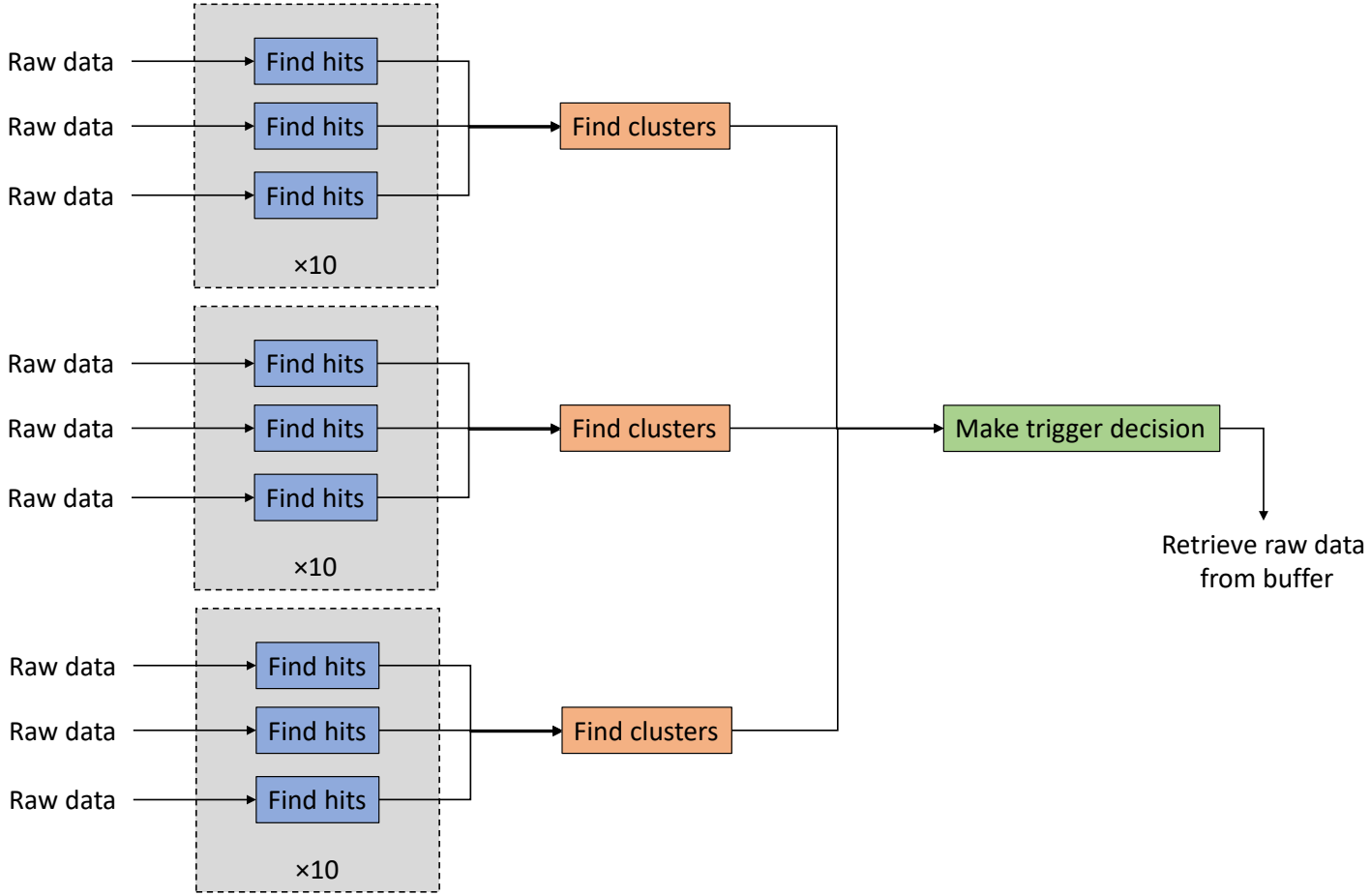
First stage of data selection: hit finding



- Simple hit finding running in CPUs on FELIX BR hosts

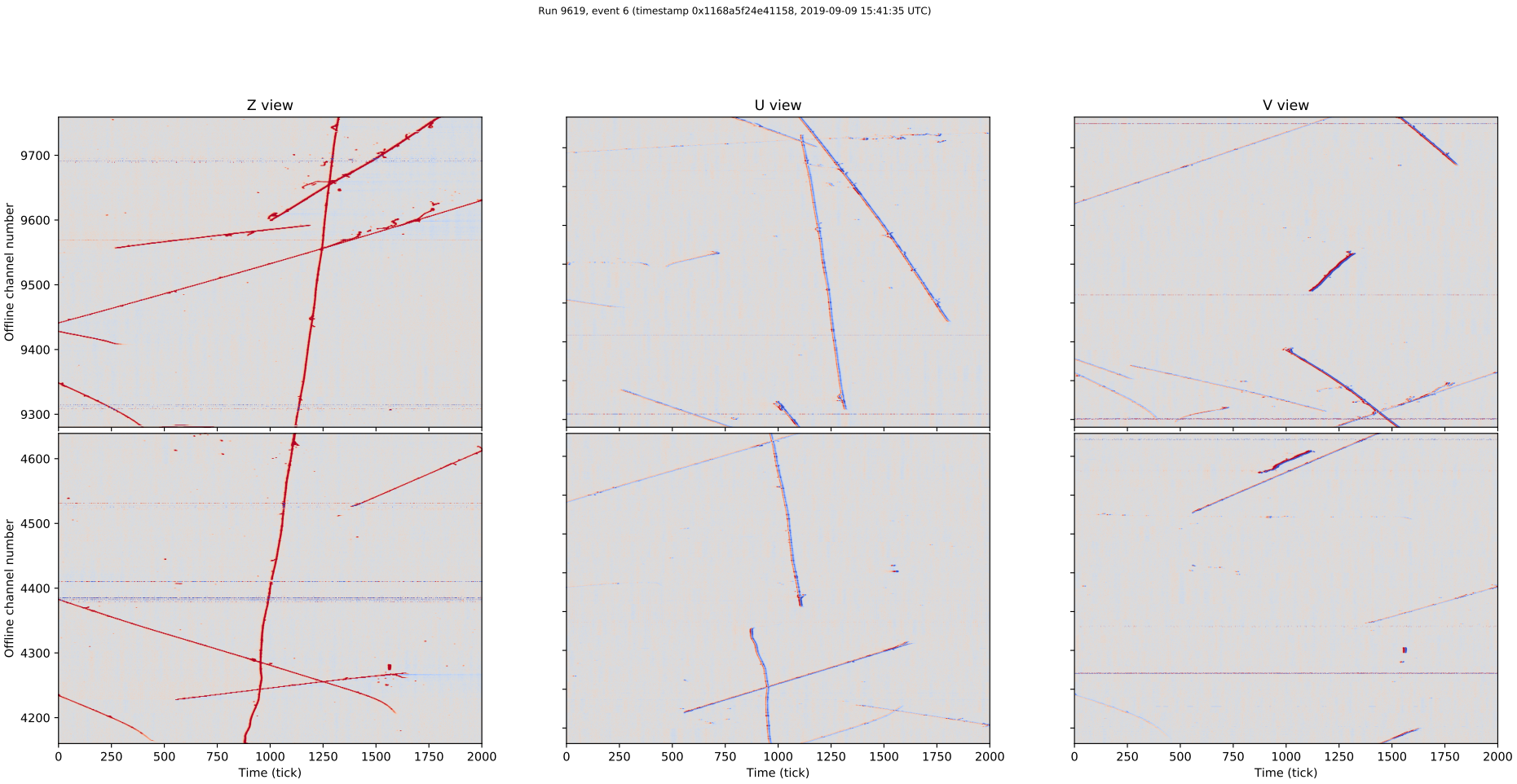
1. Find pedestal and pedestal variance
2. Apply finite impulse response noise filter
3. Sum charge above threshold

A full self-trigger chain at ProtoDUNE



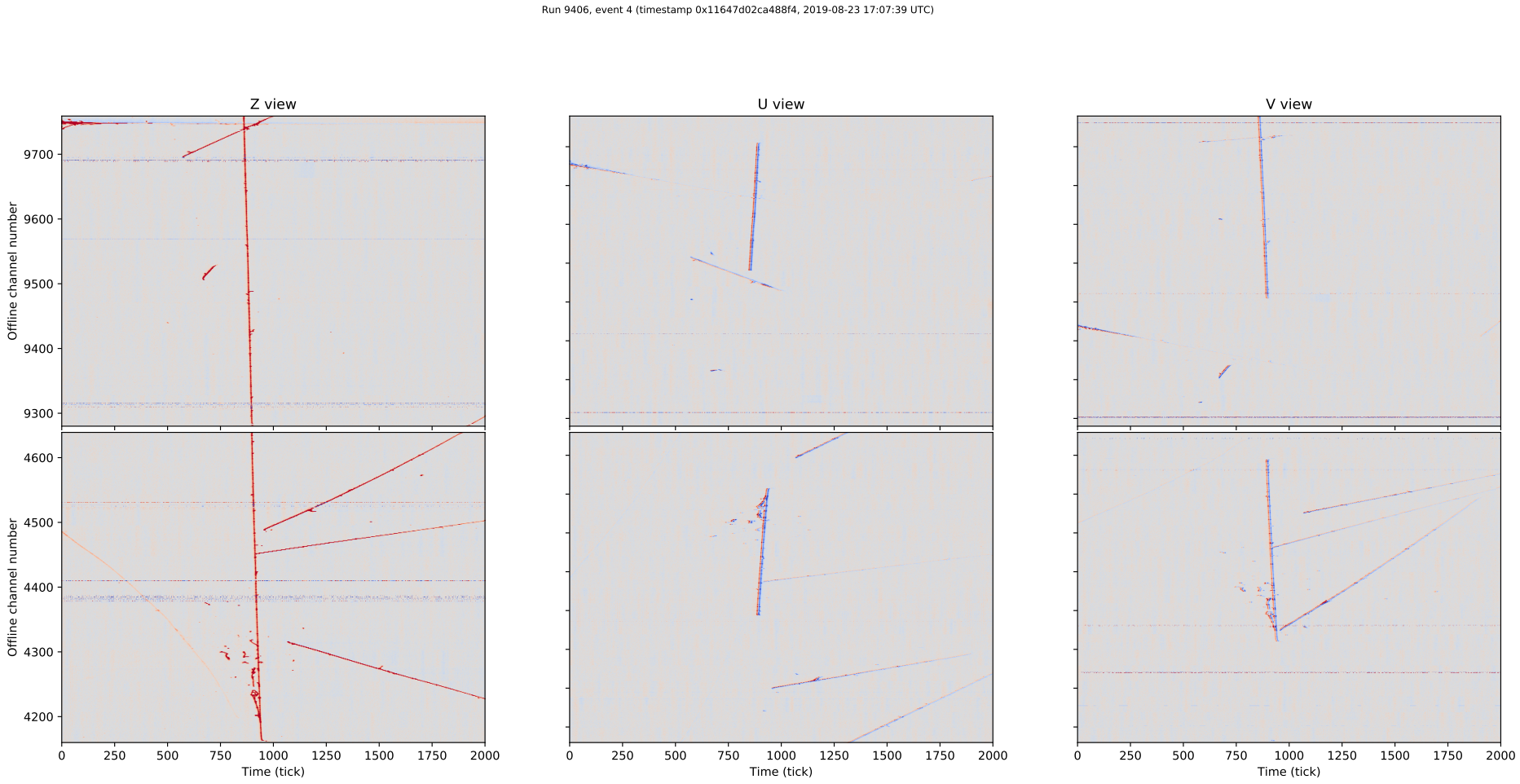
- Rest of self-trigger chain: hierarchical trigger with message-passing using zeromq
- Convenience trigger condition: "isochronous" track hitting all collection wires

It works!



- Read out 1000 ticks before and after the trigger time

Another event

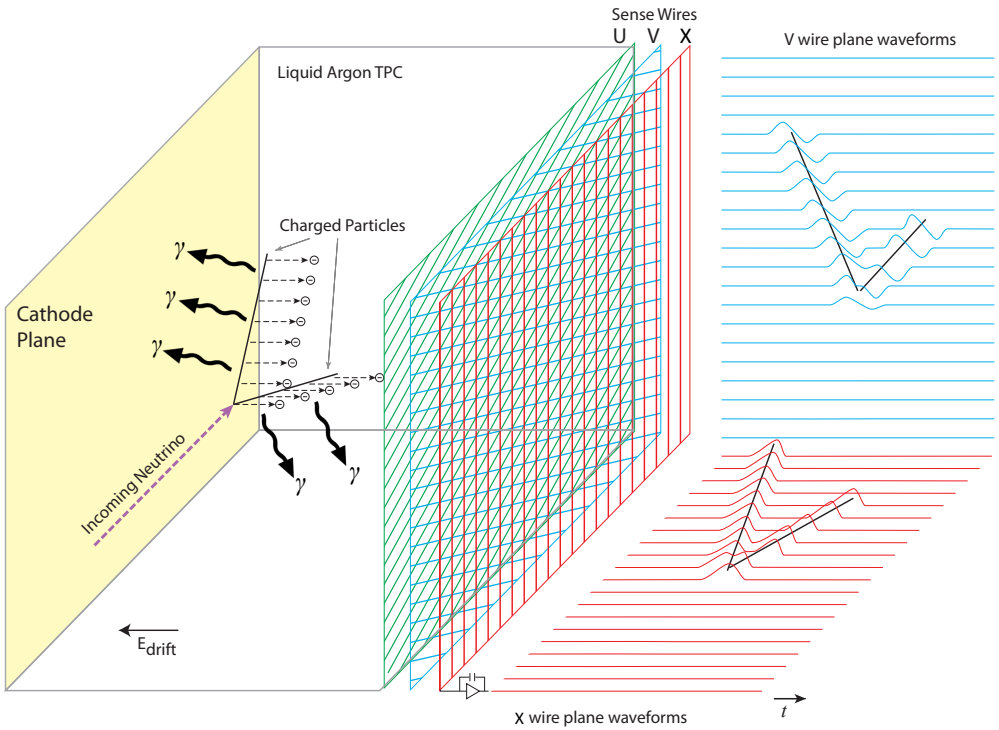


- Read out 1000 ticks before and after the trigger time
- Event from lower-purity period

From here to maximizing DUNE physics potential

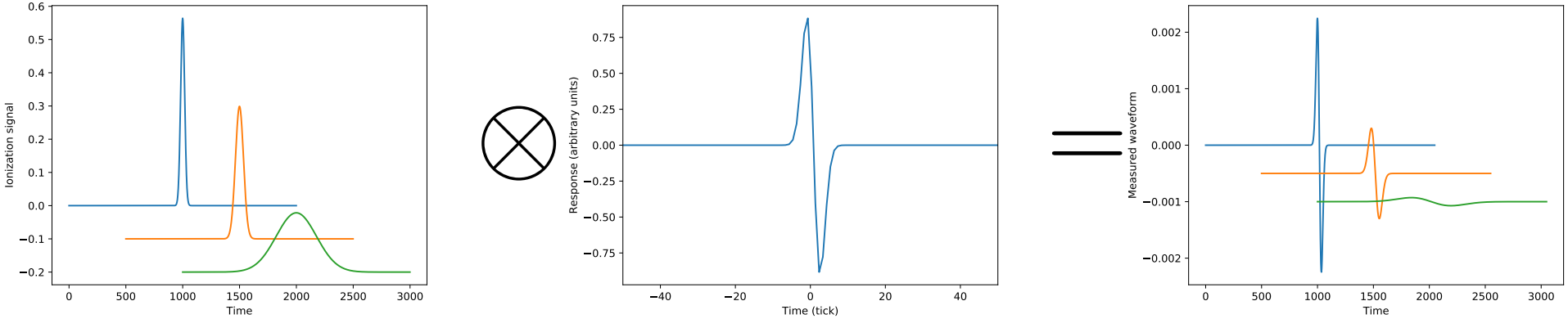
- Push triggering to lowest energies for supernova and solar neutrino physics
- Challenge at lower energies is backgrounds: radioactive decays close in energy to SN and solar neutrinos
- Three ways to meet the low-energy challenge:
  - Use induction-wire hits
  - Include photon system for improved energy resolution
  - Alternative readout schemes to allow lower trigger thresholds

Induction wire hits



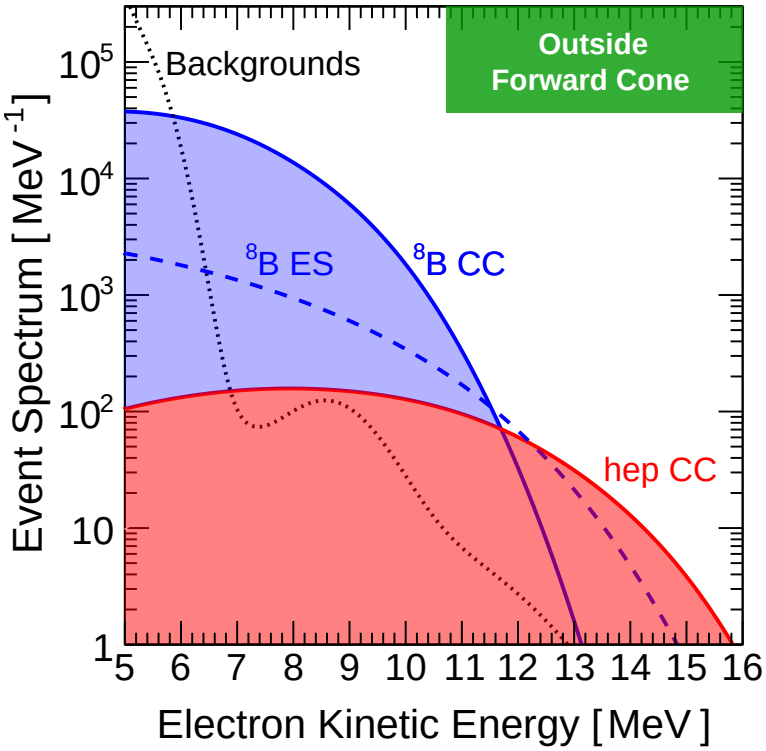
- Fiducialization
- Matching to photon system signal
- Supernova pointing

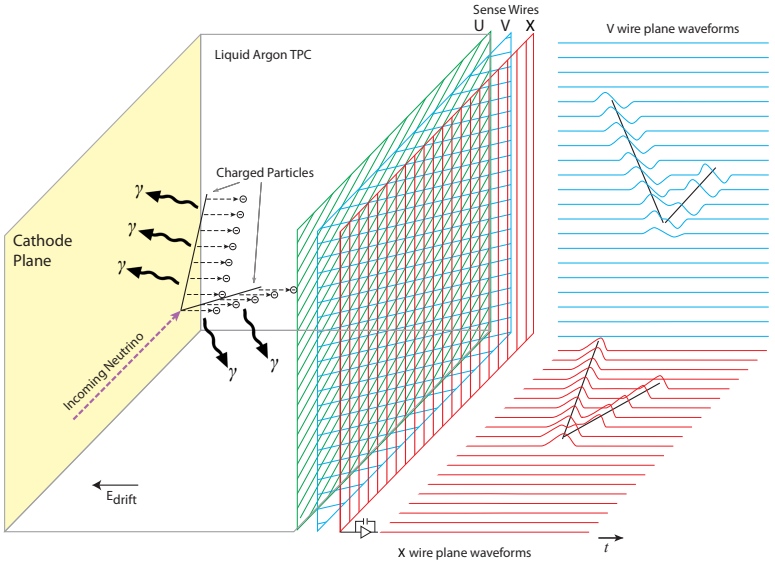
Finding hits on induction wires can be harder



- Extended signals tend to cancel when convolved with detector response
- Offline reconstruction uses expensive 2D FFT deconvolution: in DAQ, need something simpler

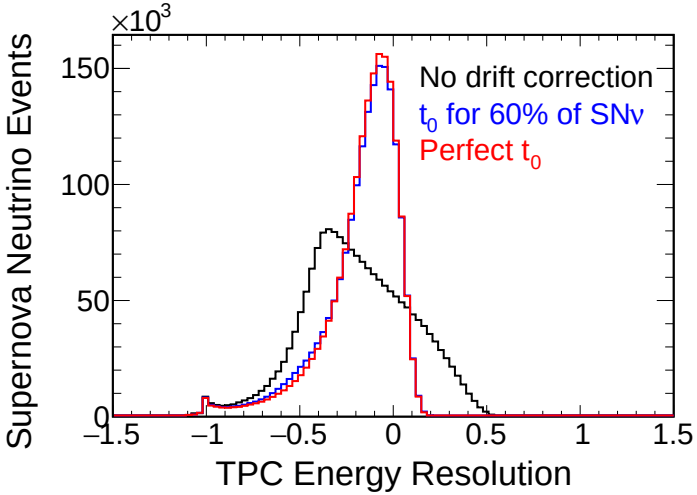
Energy resolution

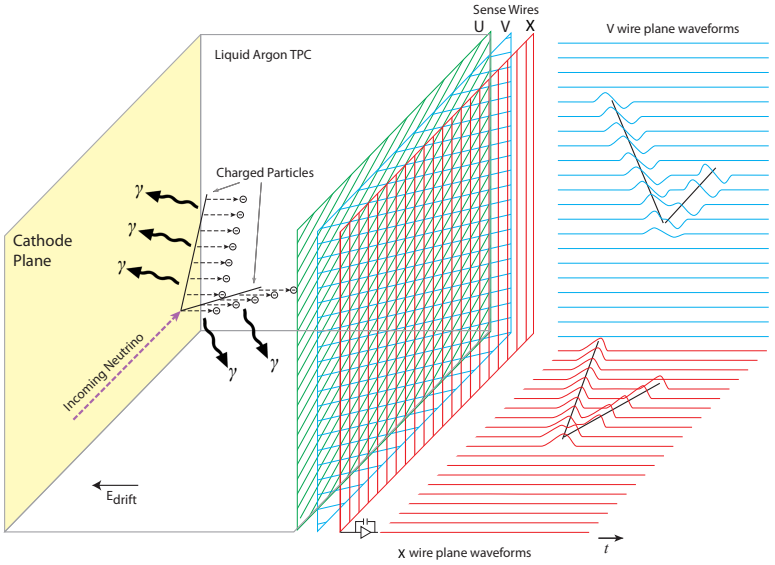




- Better energy resolution means better signal:background discrimination

Including PDS information

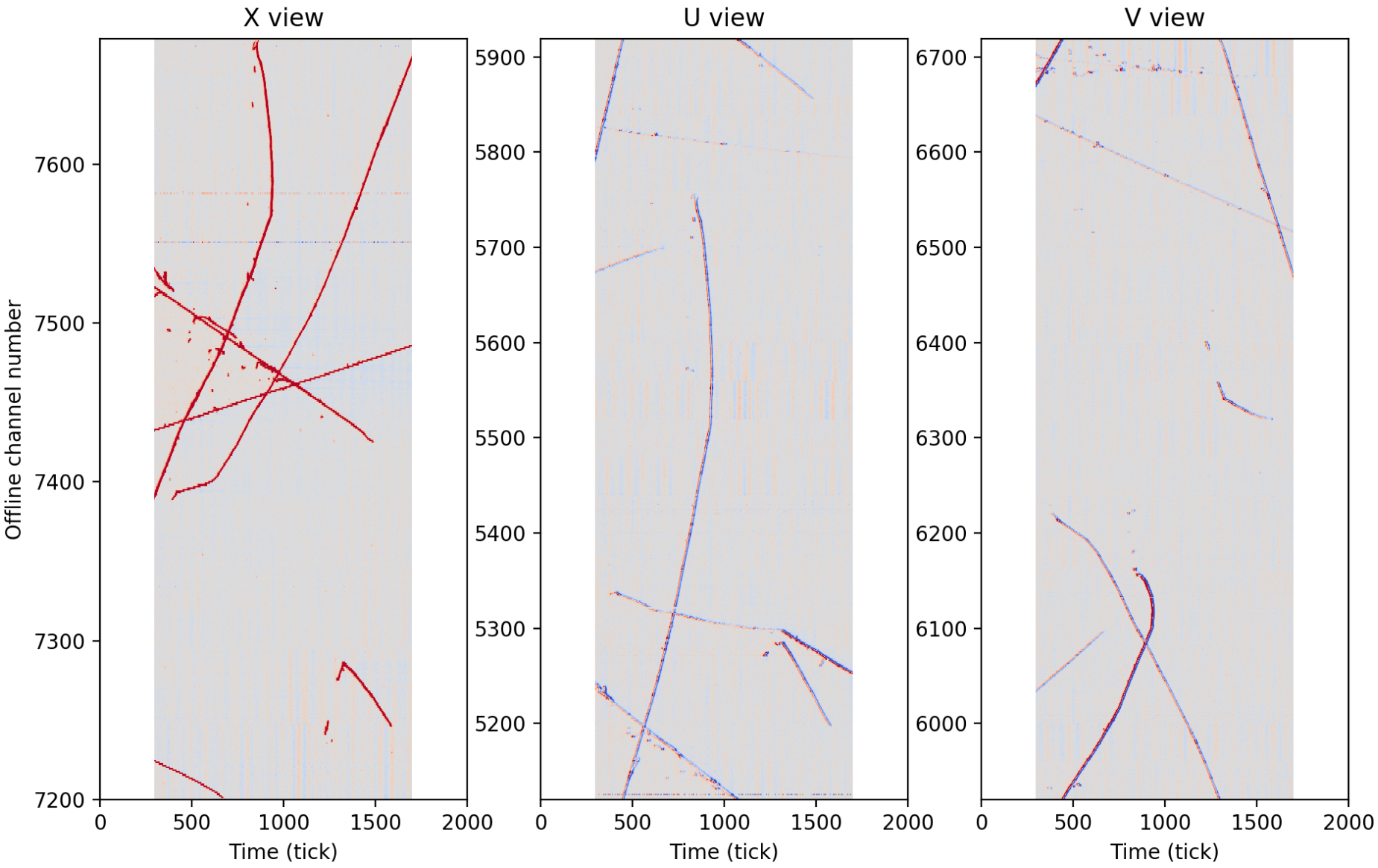




Alternative readout scheme

- Less data per readout $\Rightarrow$ higher readout rates $\Rightarrow$ lower energy thresholds
- Just read out data around hits (similar to MICROBOONE-NOTE-1030-PUB)

Mocked-up example (ProtoDUNE data)



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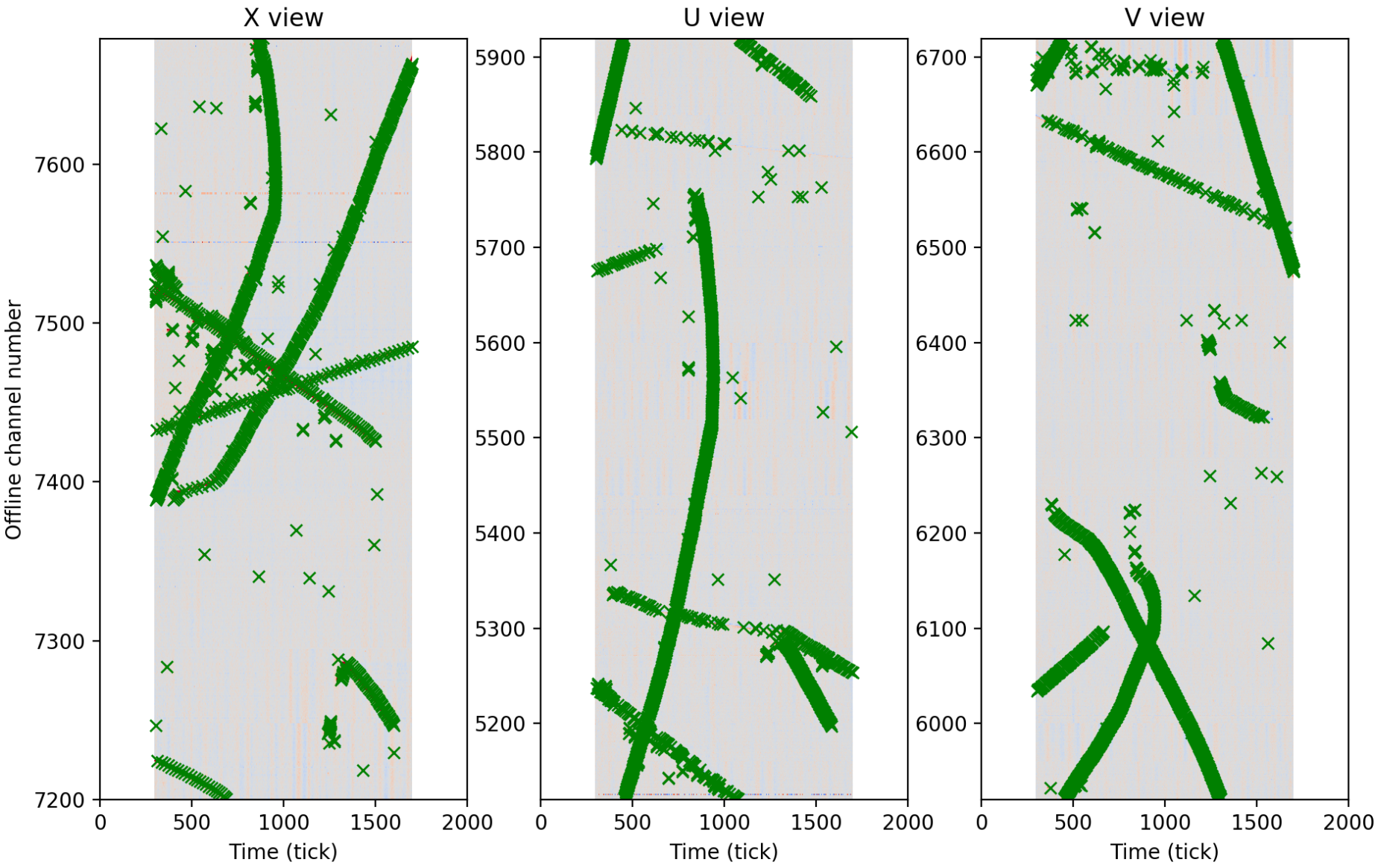

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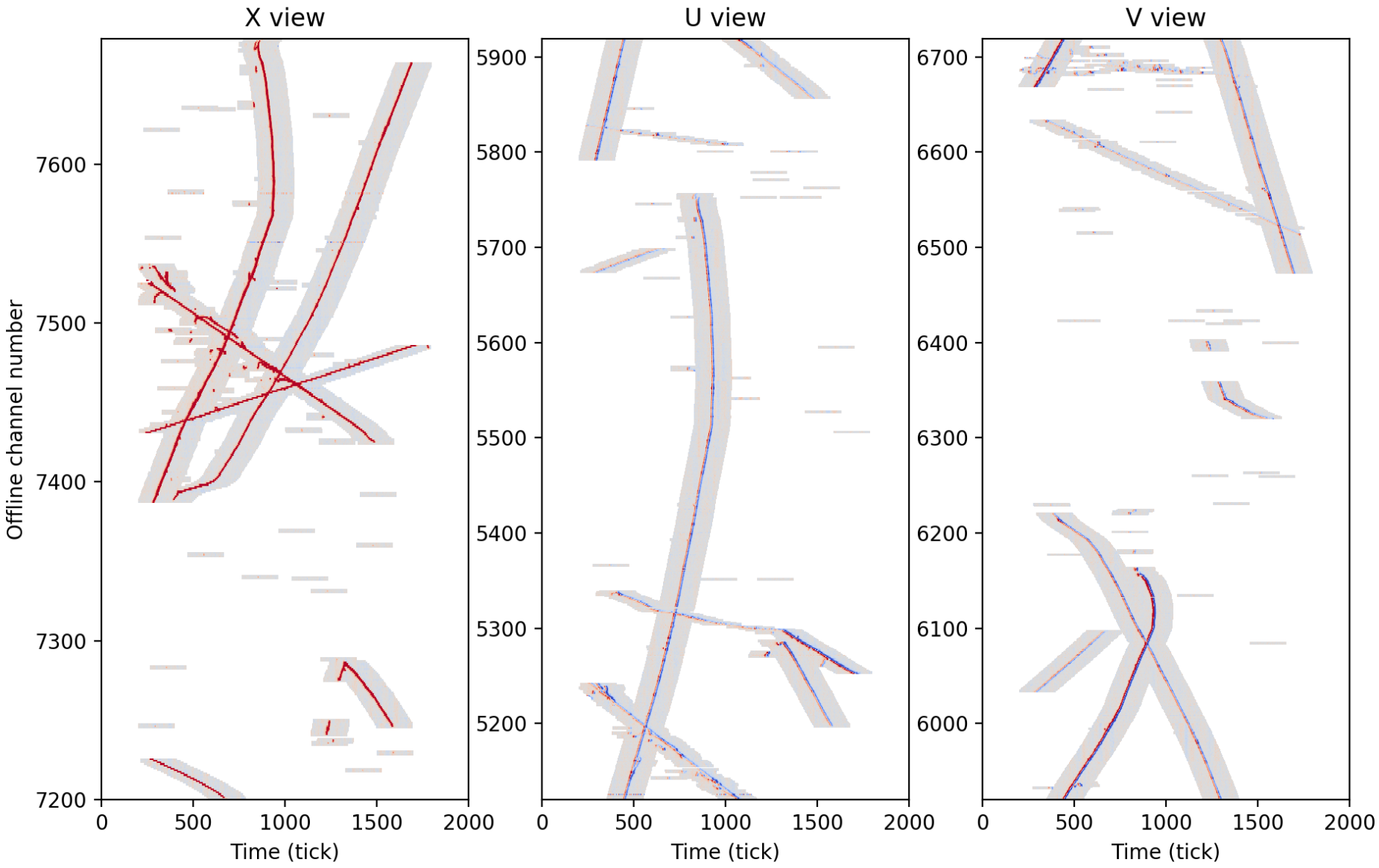
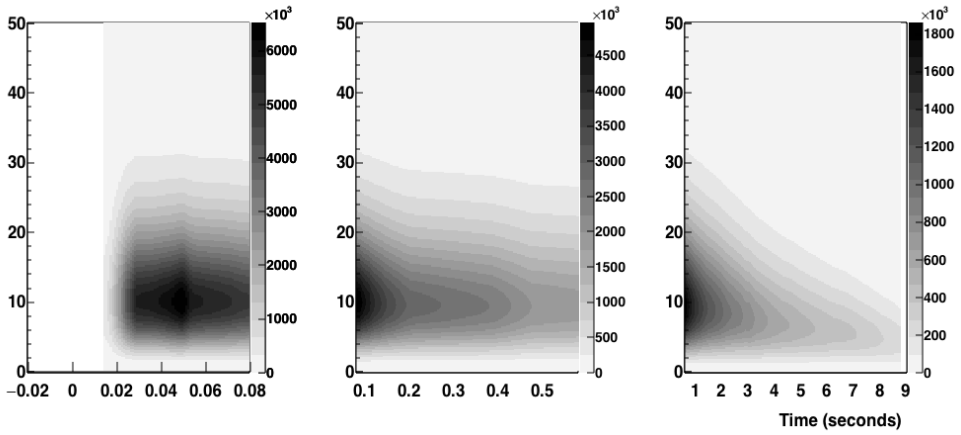


Recap

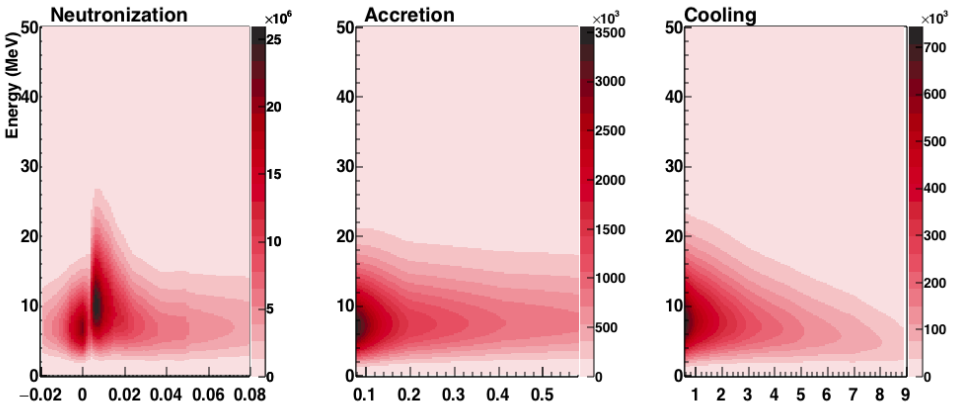
- DUNE has the potential to be a world-class astrophysical neutrino observatory
- Performance of the DAQ is key to achieving this potential

Backup slides

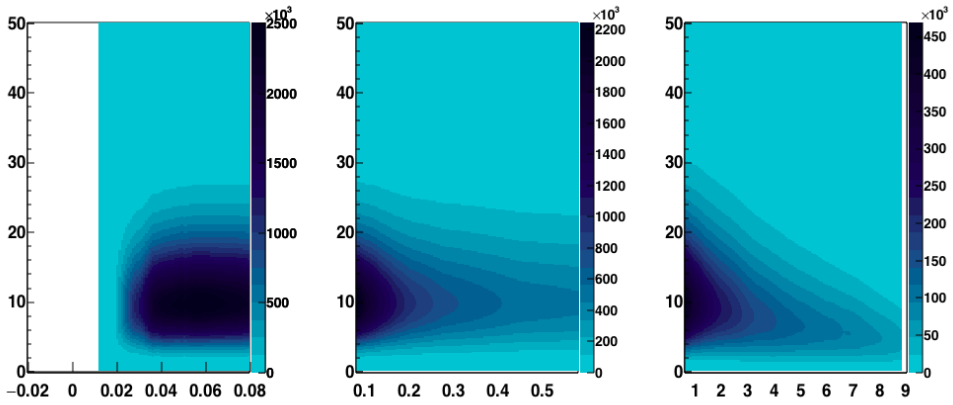
garching_nux_flux_3timescales.png



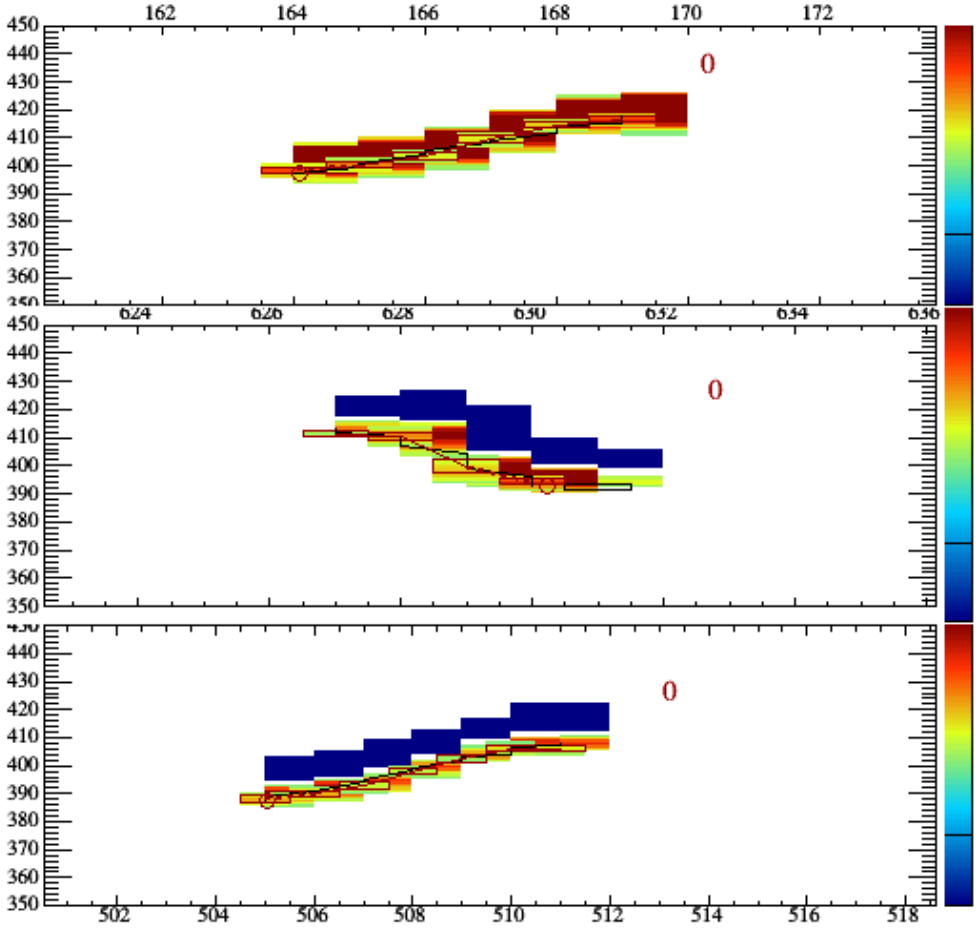
garching_nue_flux_3timescales.png



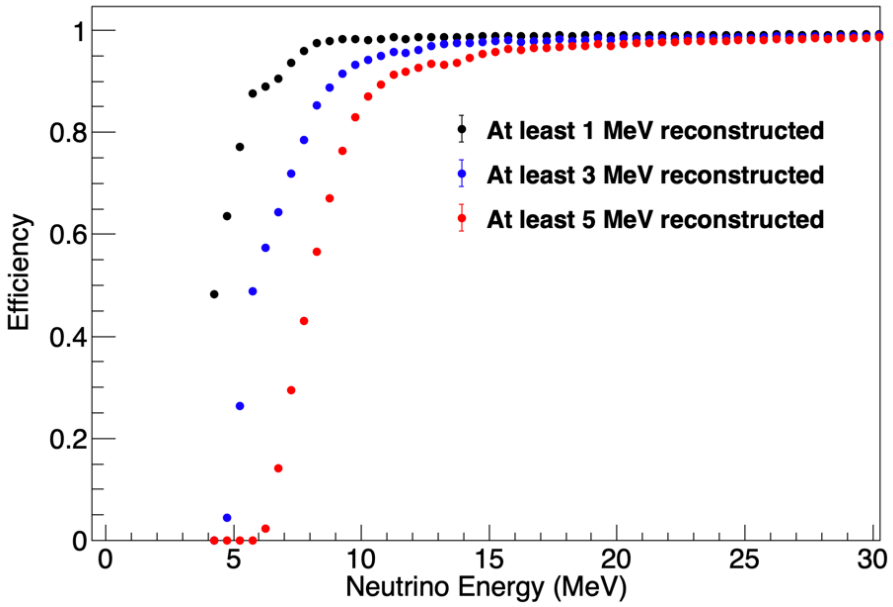
garching_nuebar_flux_3timescales.png



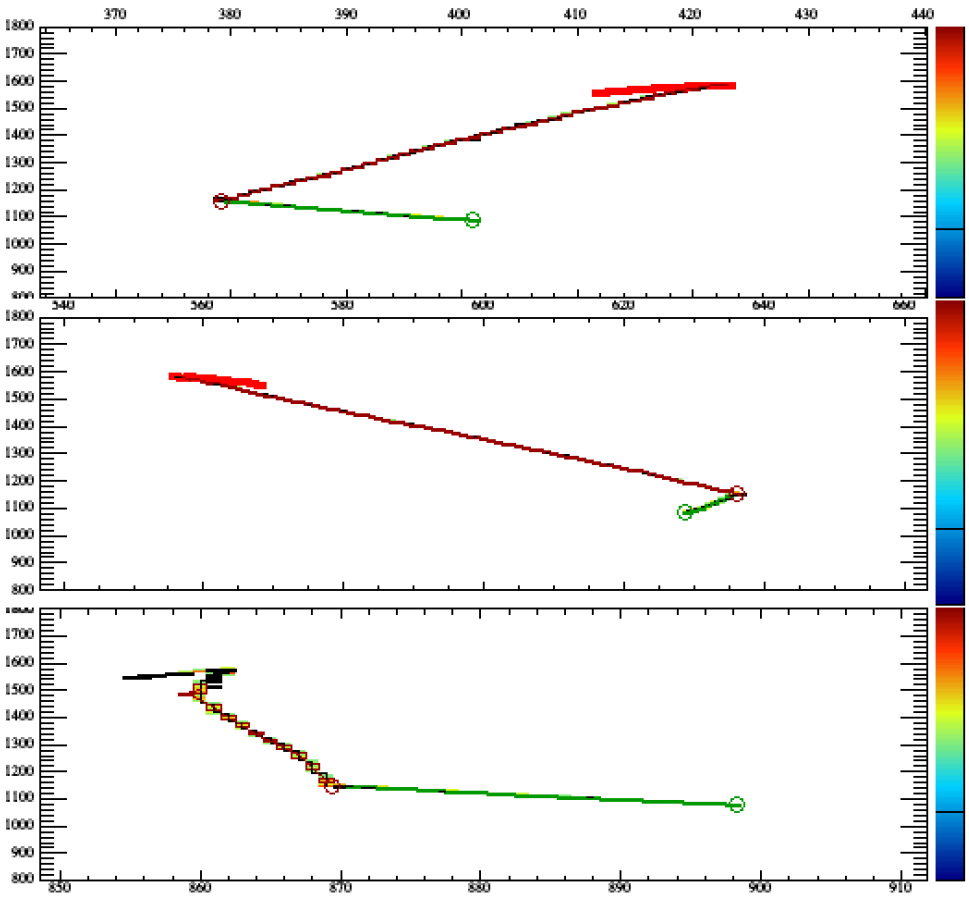
ES_10-25MeV_Event9001_TDR.png



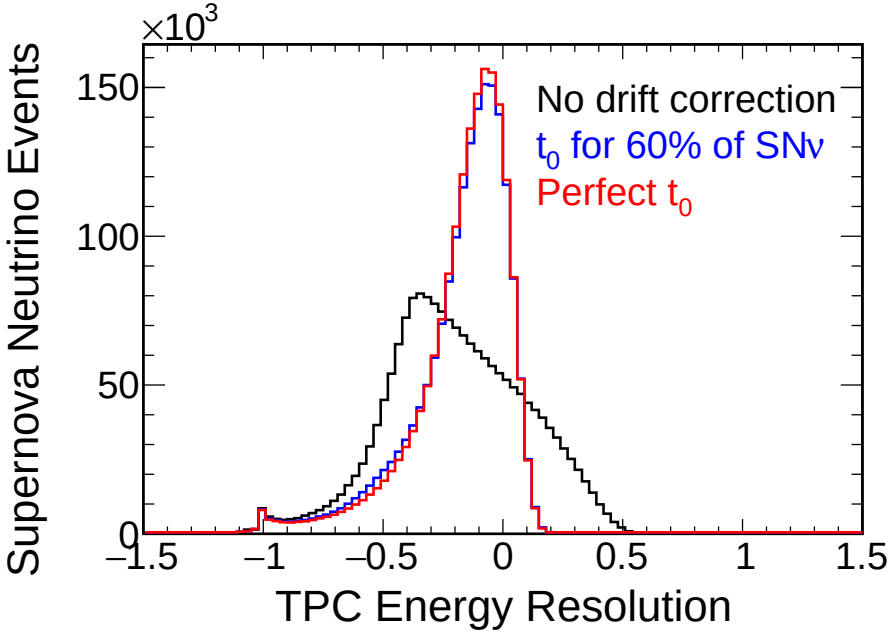
EfficVsNeutrinoEnergy.png



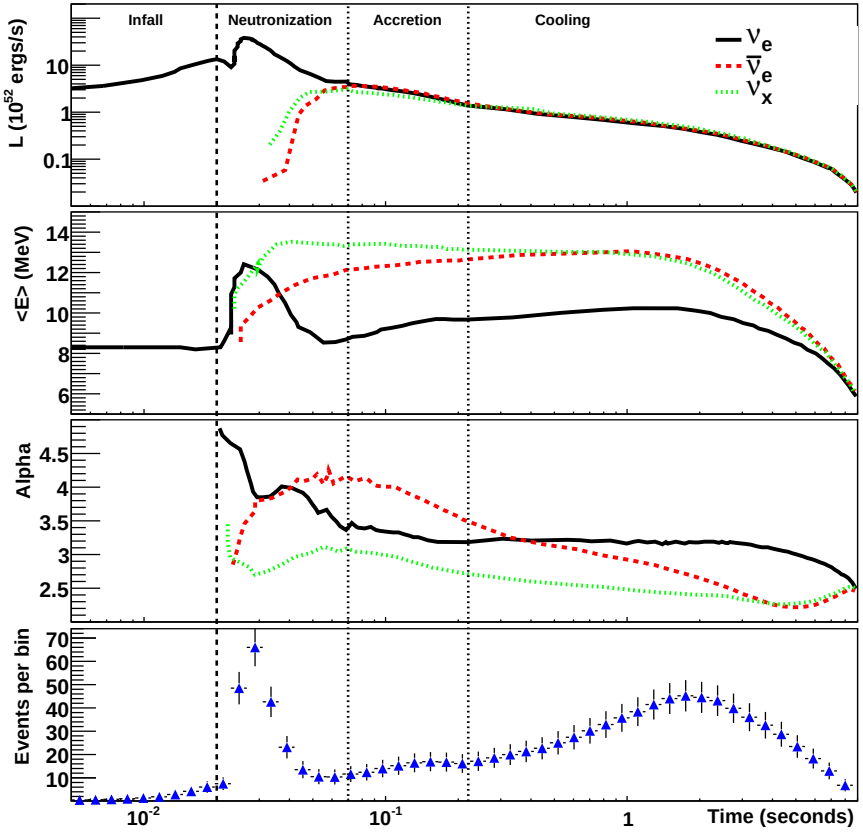
p-to-k-nu-signal.png



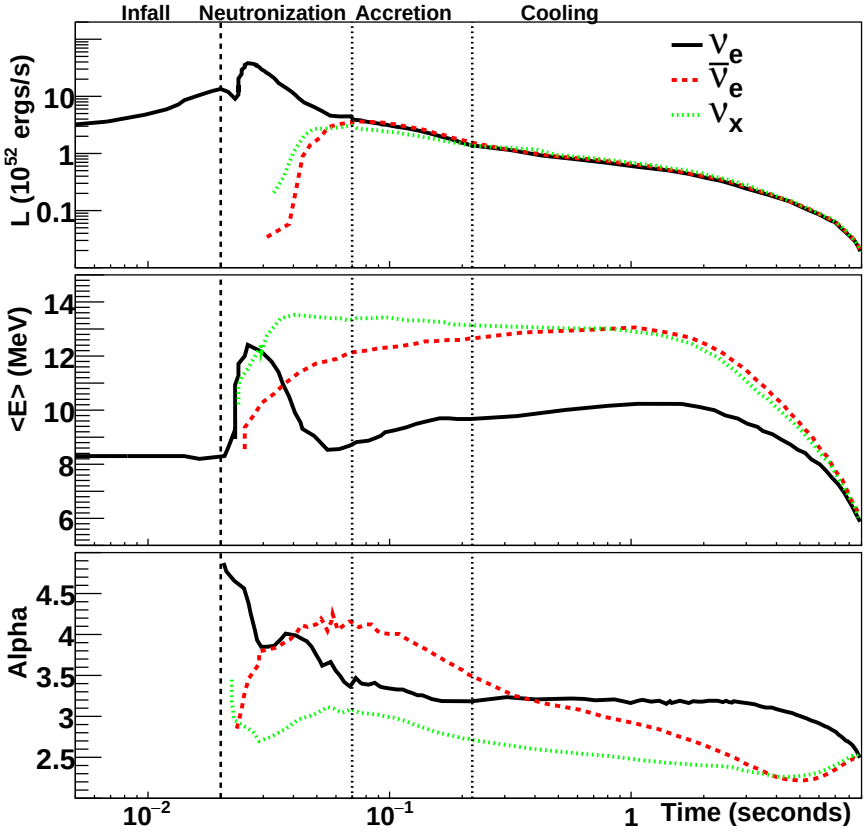
pds-snb-drift-corr.pdf



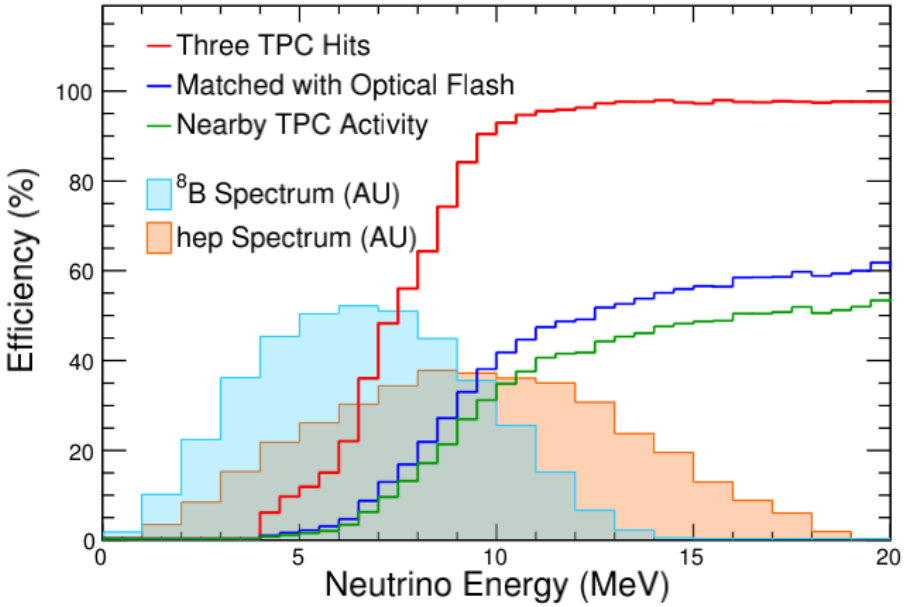
garching.pdf



garching_paramonly.pdf



solar-nu-efficiency.png



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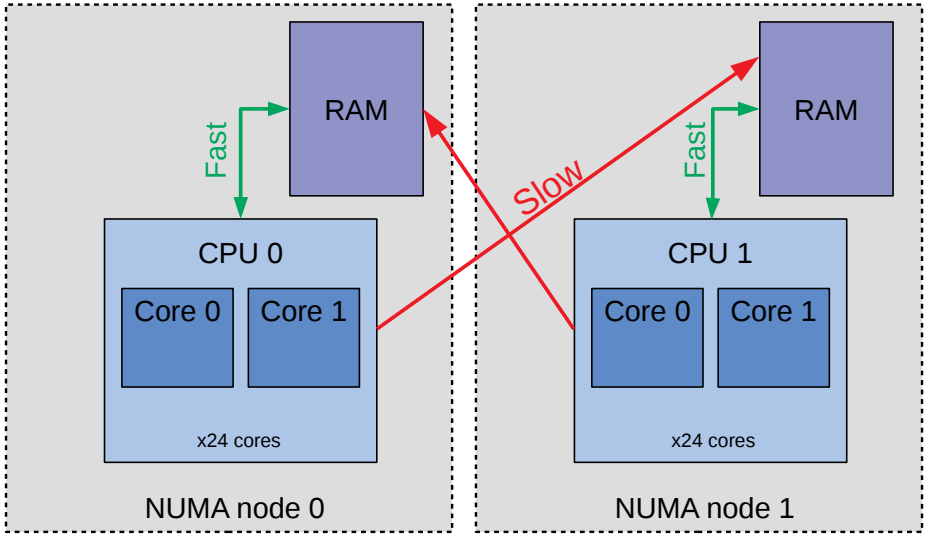
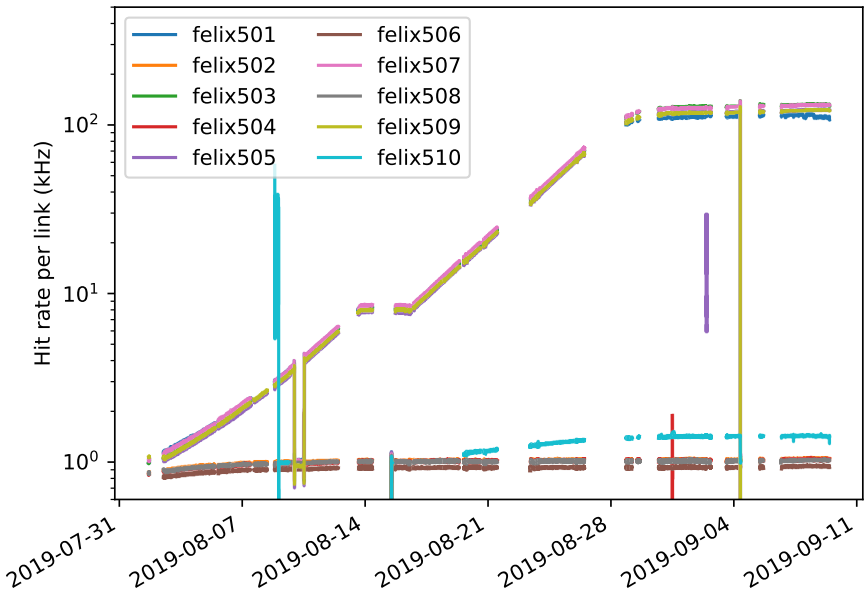
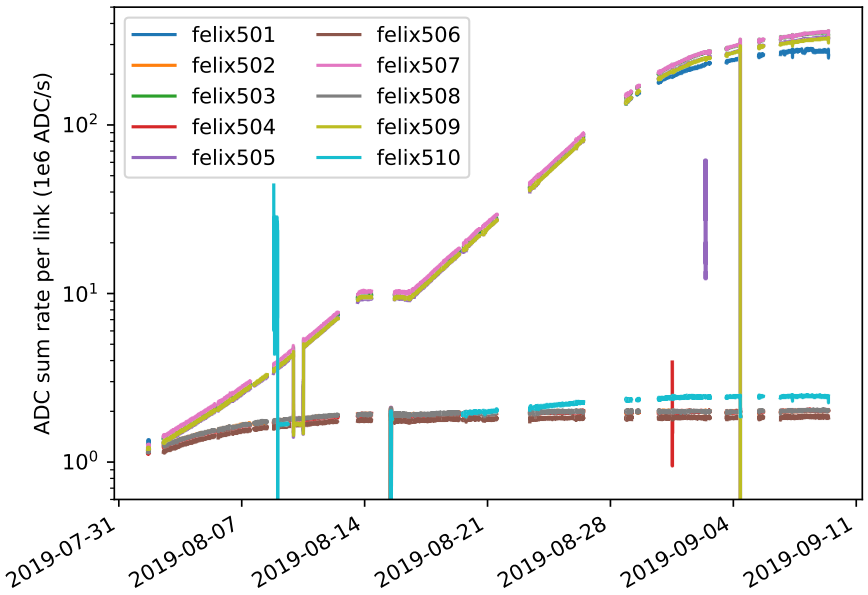
protodune-assembly-cern3-crop.jpg


RAM
Fast
CPU 0
Core 0
Core 1
x24 cores
NUMA node 0
Slow
RAM
Fast
CPU 1
Core 0
Core 1
x24 cores
NUMA node 1

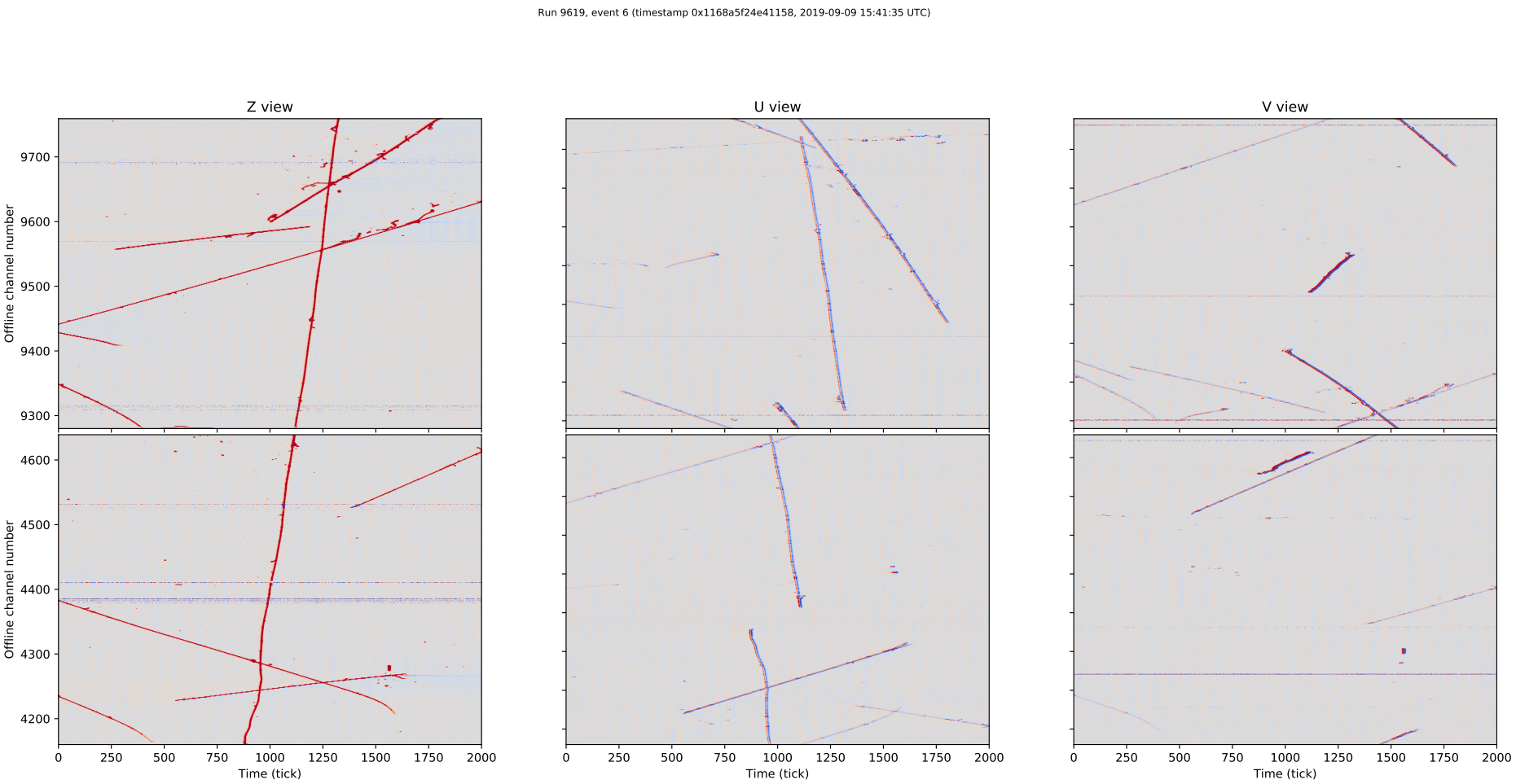
Rates for APA 5 through 9 September: smoothed, log y





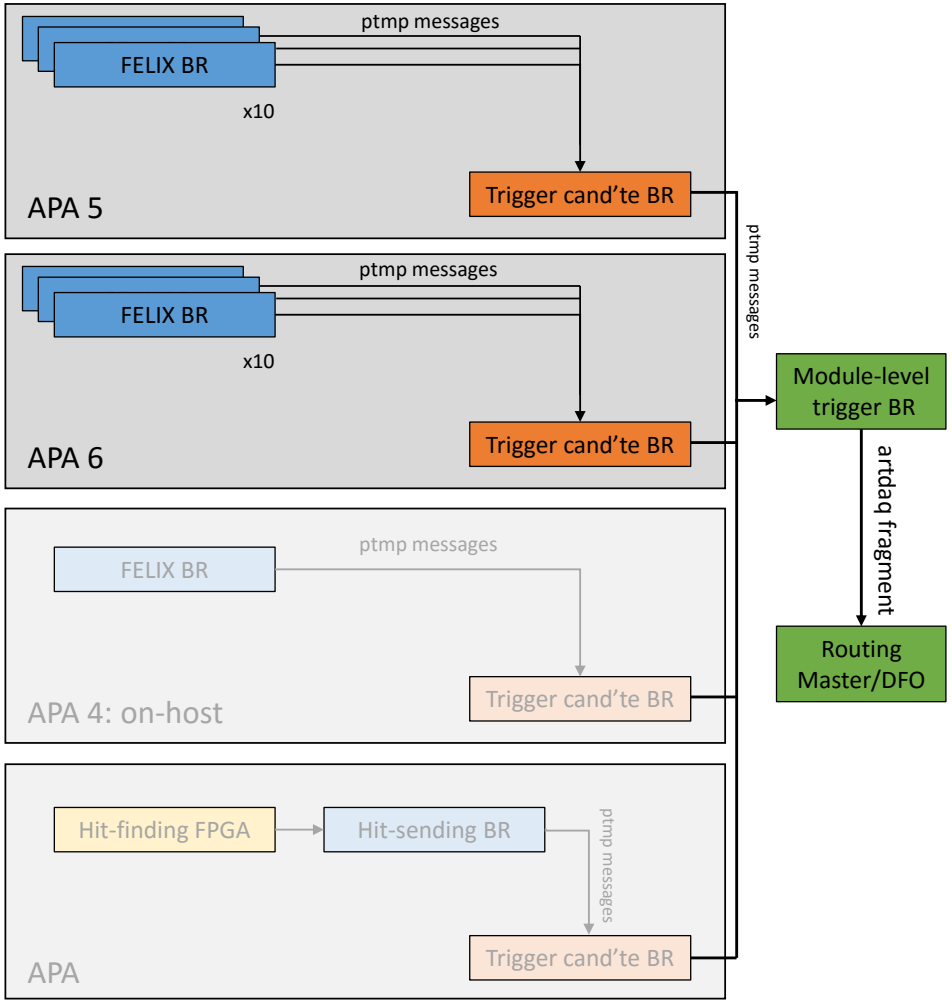
- The logarithmic plot makes the exponential behaviour before plateau more clear
- Exponential fit to that region gave $\tau \approx 110\,\mathrm{hr}$, the turnover time of the argon in the cryostat (see backups)

A self-triggered muon parallel to the APA face

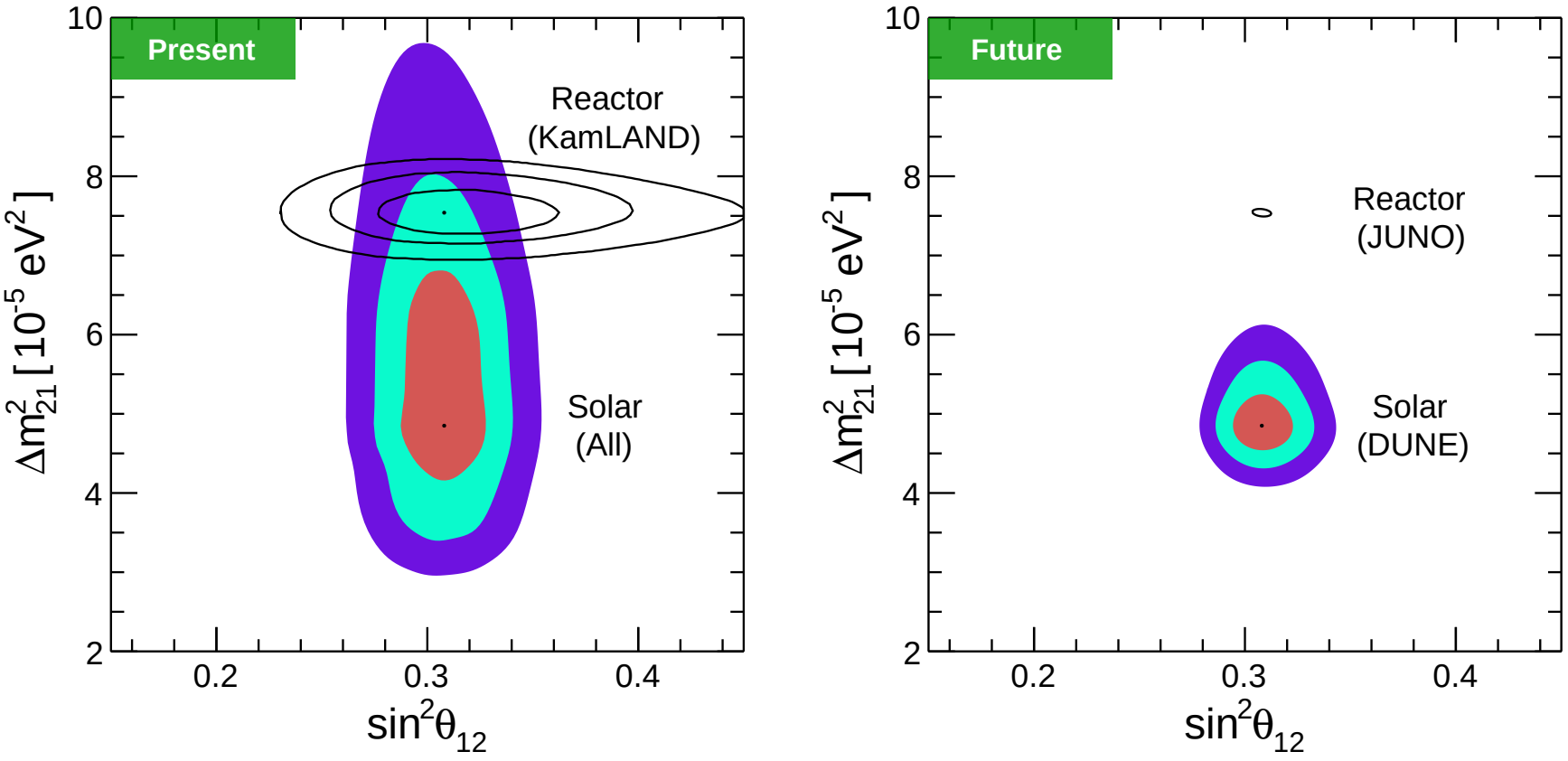


- Read out 1000 ticks before and after the trigger time

System overview



- Implement code inside `artdaq` board readers:
  - Advantages: integration with run control, log file handling, saving of raw data and metadata
- Trigger primitives and candidates are sent using (from Brett Viren: https://github.com/brettviren/ptmp)
  - Data structures
  - Message passing
  - Algorithms
- Not shown: SSPs don't participate in generating triggers, but will provide data in response to a trigger request



- Capozzi et al, Phys. Rev. Lett. 123, 131803 (2019)