Computing for Neutrino Physics

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Experimental neutrino physics in NP

- Subset of Fundamental Symmetries
- Lots of neutrino physics in HEP, too

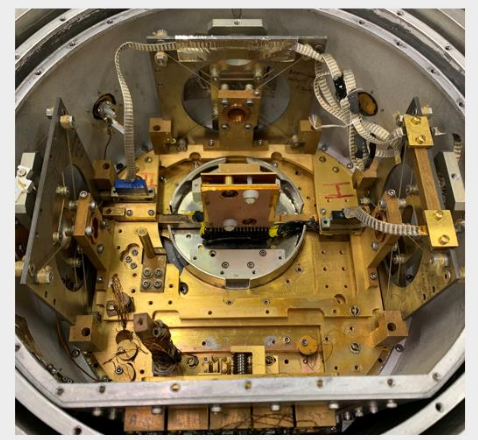
- Neutrinoless double beta decay
- Neutrino absolute mass
- Sterile neutrino searches
- Neutrino-nucleus inelastic scattering

- Some non-neutrino FS has similar needs, some is quite different

Two main concepts for neutrino computing

- Focused on hardware
- Lots of overlaps with HEP dark matter

Neutrino experiment computing



BeEST

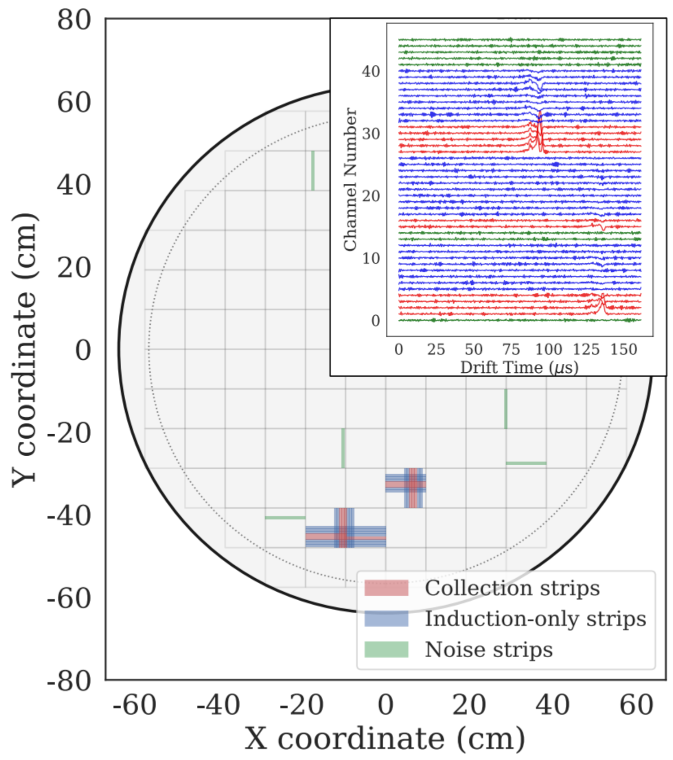
- Highly bespoke detectors
  - Limited opportunities to use commonly available hardware
  - Customized sensors with niche userbase
  - Often a radically new detection scheme

- Much less reliance on nuclear physics modelling
  - Easily possible to run an experiment and analyze data with little reference to theory
  - Theory is important to justify experiments and interpret final results

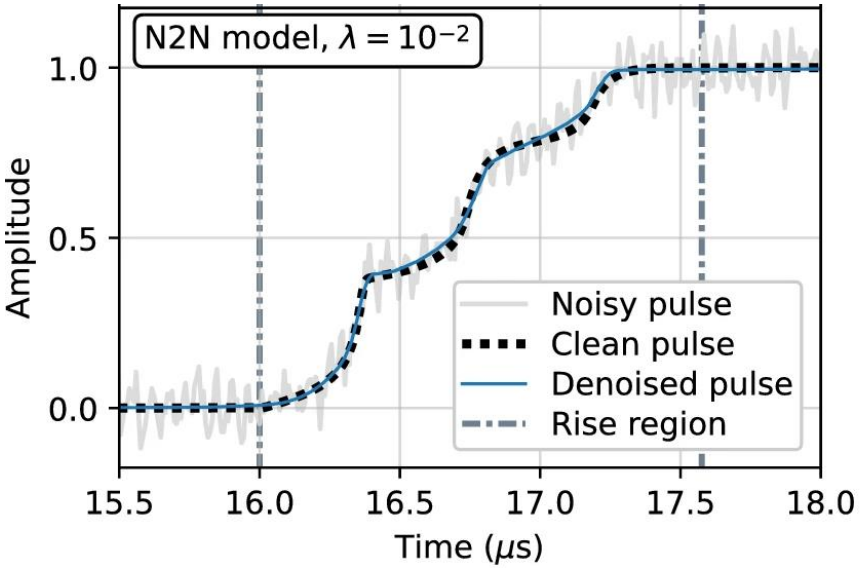
Neutrino experiment computing

- Processing raw data demands sophistication
  - Little on-hardware data reduction
  - Raw (or close) data analysis is often the meat of the problem

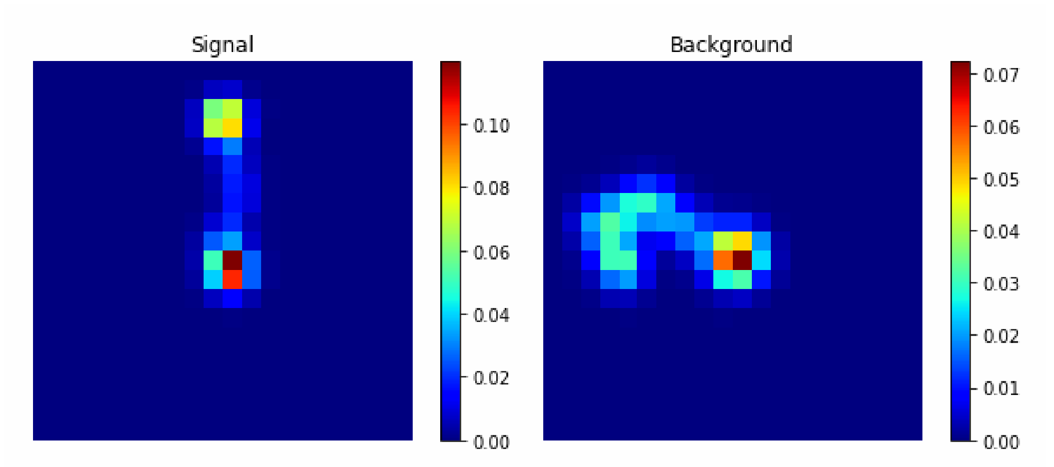
- Rare event simulations
  - Large volume of simulations makes systematics hard to model
  - Computing that aids design needs to consider many hardware details
  - Originality of hardware makes precision simulation challenging high likelihood of simulation/experiment discrepancies



Examples of hardware-focused computing

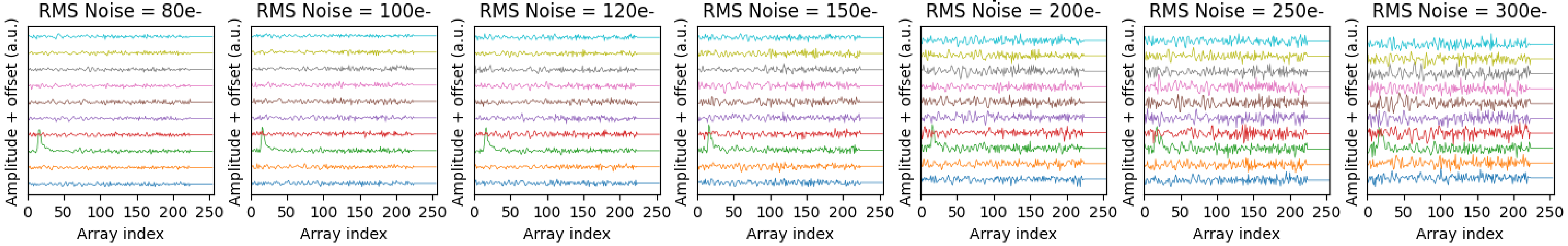


[Anderson et al., 2022](#)
Germanium detector denoising



[J. Renner](#)
NEXT Experiment

[S. Schwartz](#)
nEXO Experiment



Computing needs for bespoke detectors

- Small, modular utilities
  - Not every piece of software is fated to be reusable
  - Large toolkits that cover a variety of needs of a single experiment are rarely reusable
  - Small utilities that solve narrow problems are great
  - Good papers explaining a method are extremely valuable

Computing needs for hardware focus

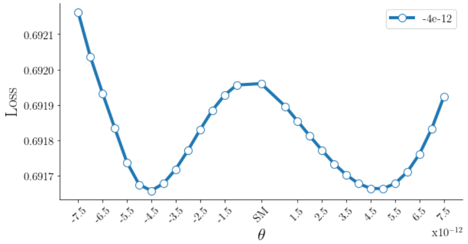
- “Medium” data needs to be portable
  - E.g. nEXO ~100 TB/year, LEGEND-1000 1 PB/year
  - Junior scientists need access to unreduced data to do exciting work
  - Portable: efficiency is important, even given massive computing resources
    - “Only works on the cluster” craters collaboration productivity
    - How fast can you do something interesting to 5 GB of data?
  - Combining efficiency with the algorithms people actually want to write
  - Driving shift towards fast python, Julia, etc.
  - Echoed in work on HEP side, e.g. IRIS-HEP

Computing during neutrino experiment design

- Neutrino experiments are tightly constrained by challenging engineering
- Design moves in leaps, not along a continuum
- A leap in design requires extreme flexibility from simulations and analysis
- ML-powered design searches not interesting without a continuum
- ML-powered flexibility extremely valuable: how quickly can we evaluate a qualitatively new design?

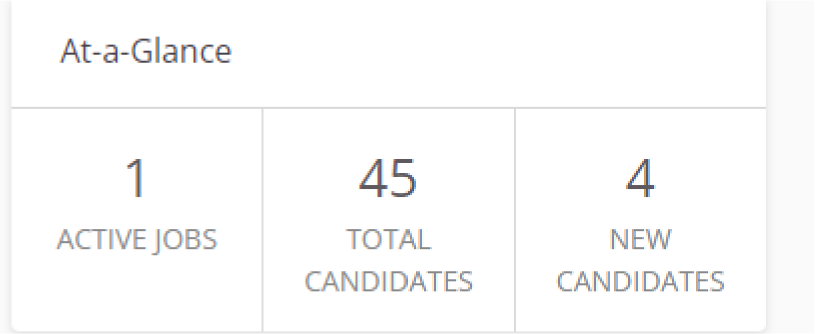
Machine learning

- Necessarily more personal, since no long-standing consensus
- What is important to NP neutrinos AND underdeveloped
- Hardware & raw signals analysis
  - Denoising, dimensionality reduction
  - Unsupervised, as much as possible
  - Differentiable simulations
- Simulations-based inference
  - Learning likelihood functions from simulations
  - Robust handling of systematics without excessive simulations
  - Useful for reconstruction too
  - Not generative ML proxies for simulations: too hard to validate for rare events



The training program is robust

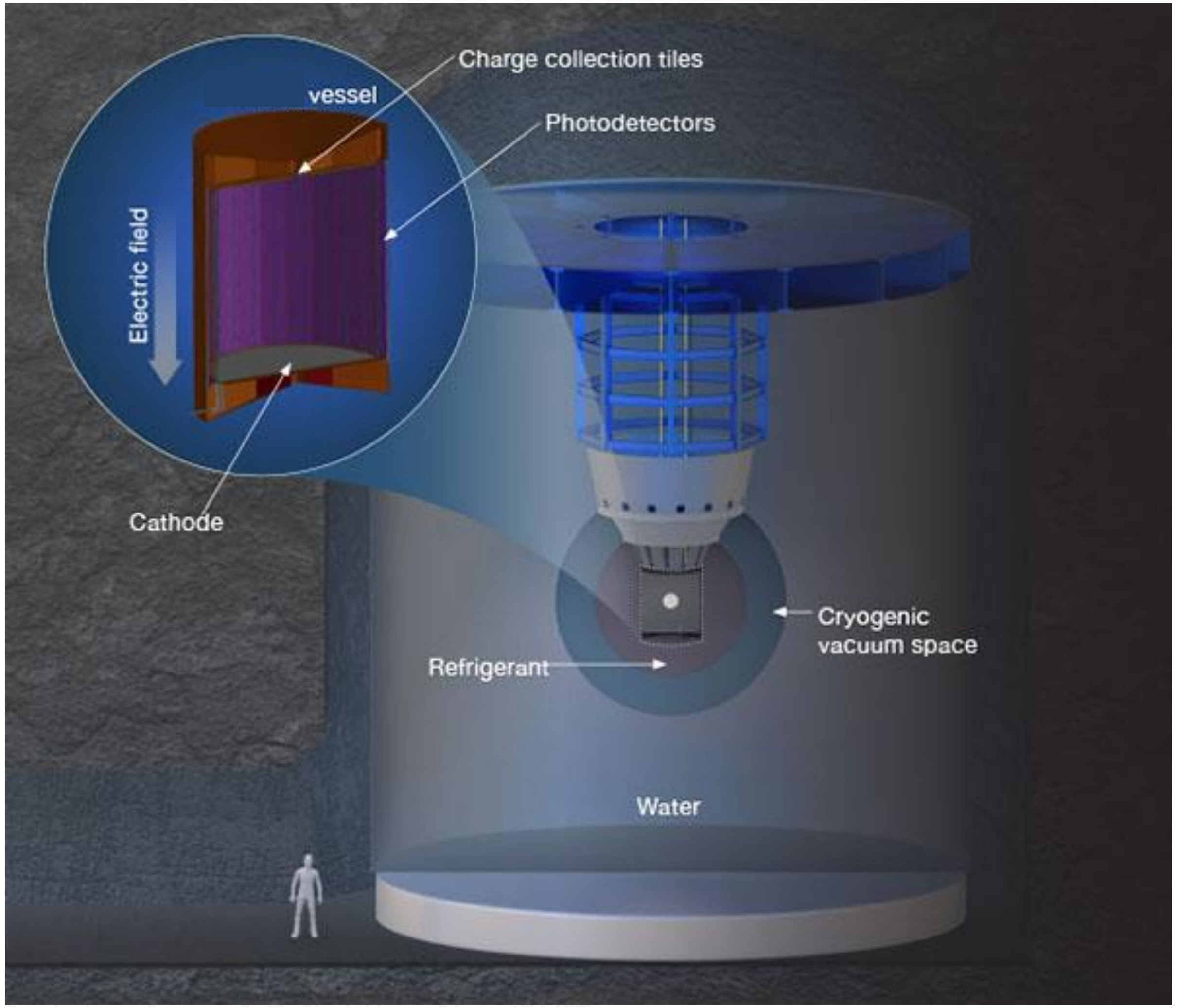
- Excellent postdoctoral candidates with strong software skills are being trained
- Standout candidates have engaged with *recent* ML research
- Onramp to basic ML proficiency seems in good shape
- More room for improvement in training advanced skills?

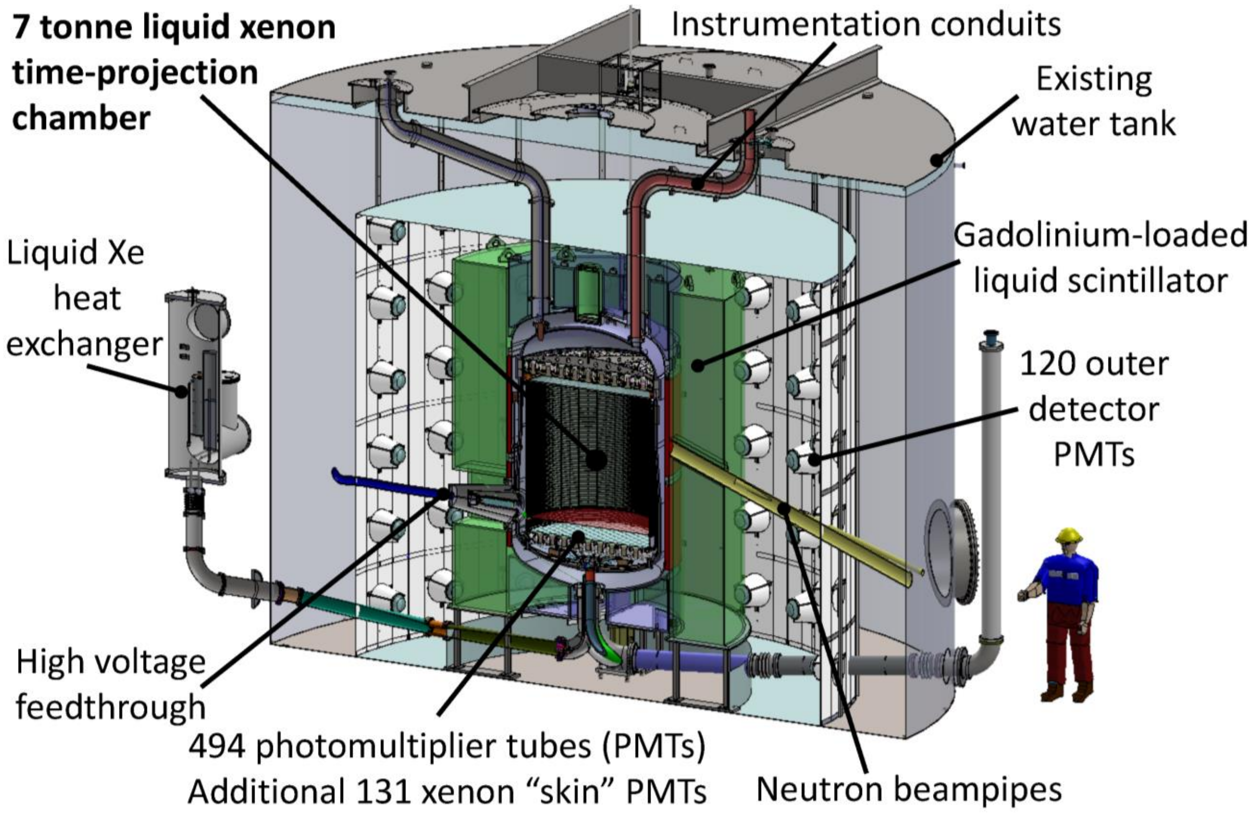


[My posting]() dashboard

Neutrino experiments in NP look like HEP experiments

Which one is NP?





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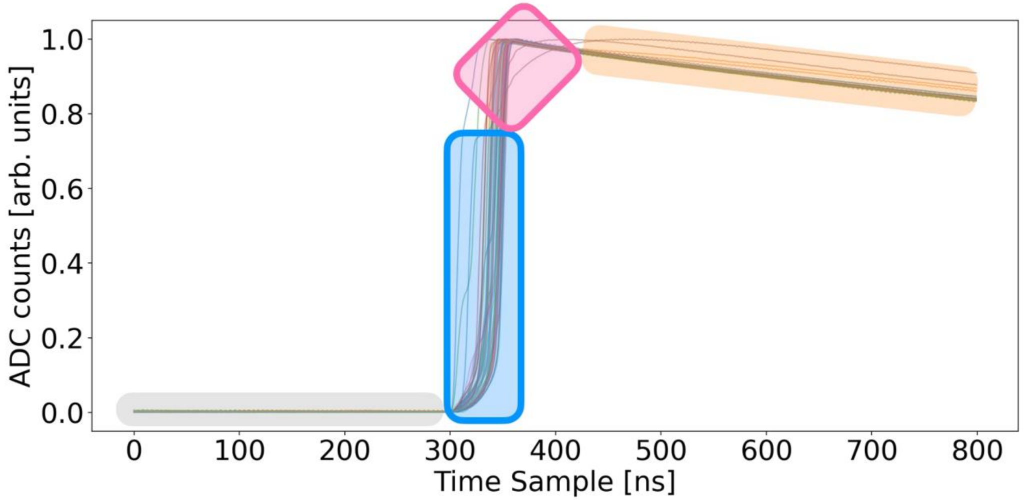

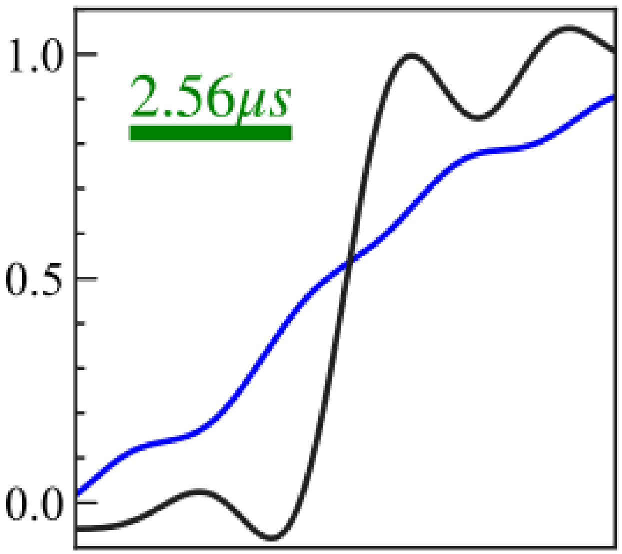

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NP neutrino physics and dark matter

- Compare:
  - nEXO to liquid noble WIMP detectors
  - LEGEND to solid-state WIMP detectors
  - Project 8 / BeEST / SALER to ADMX
- Hardware, software, and physics are similar
- Collaborations often literally overlap

NP neutrinos vs HEP neutrinos

- Often less overlap in computing than you'd think
- Accelerator & atmospheric neutrinos at quite different energy scales leads to different computing challenges (e.g. track reconstruction into reduced quantities)
- Reactor neutrinos closer
- Inelastic neutrino-nucleus scattering in COHERENT

Communities coming together

- DANCE, feeding into Snowmass
- Neutrino Physics and Machine Learning

Top Pragmatic recommendations

- Opportunities to advance small, modular data analysis utilities
- A home for computing research that crosses the NP/HEP divide
- ML priority should be cutting-edge; on-ramp has never been easier