A3D3 Postbac Fellowship Update

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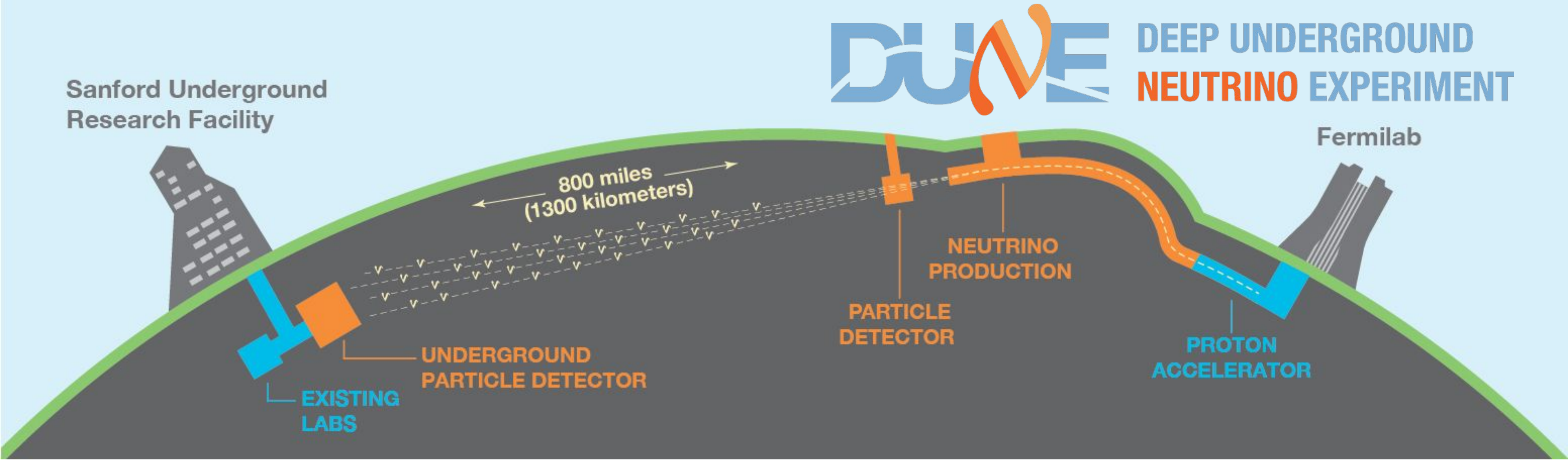
Accelerated AI Algorithms for Data-Driven Discovery

DEEP UNDERGROUND NEUTRINO EXPERIMENT

Overview

- How am I doing?
- What I’ve been doing (extracurricular activities)
  - Soccer, gym, swim
- Current work
  - Autoencoder for denoising signals at DUNE’s LArTPC Detectors

Background:



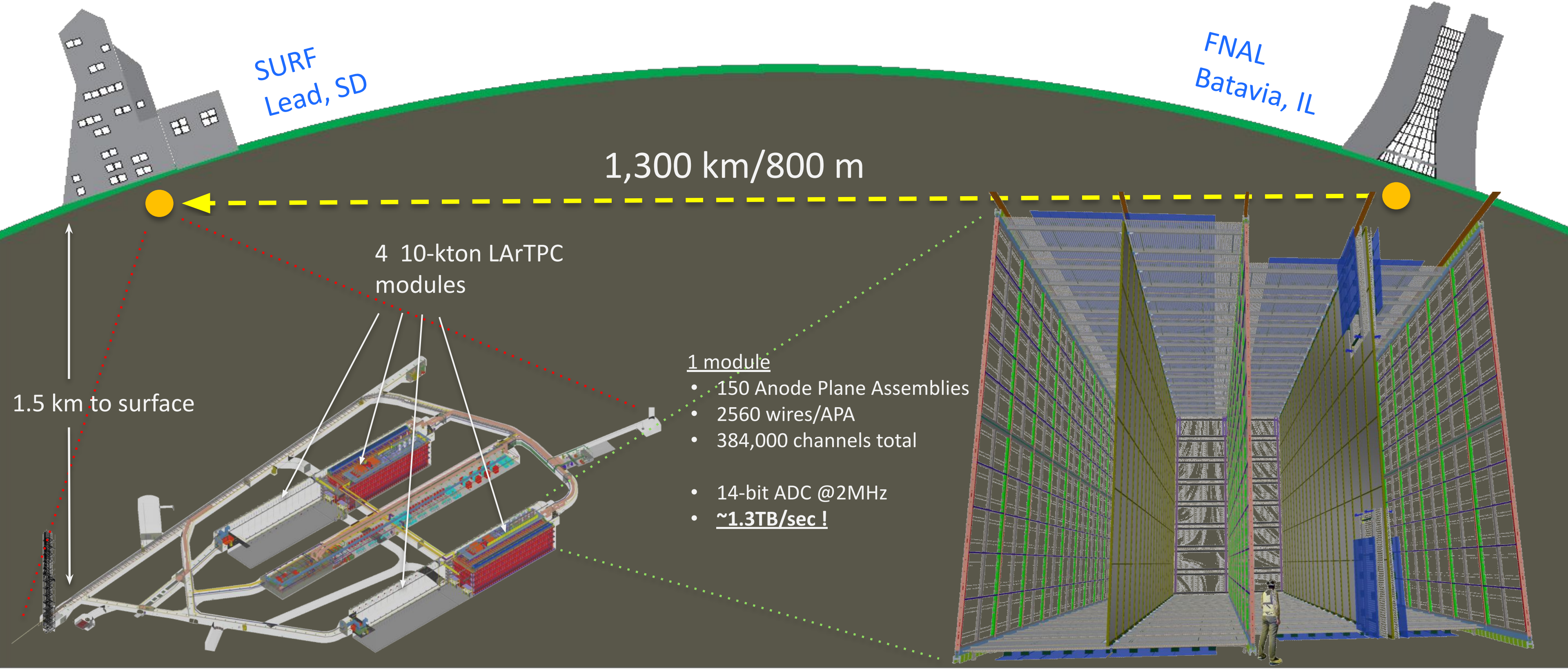
DUNE: long baseline physics program

- Determining neutrino mass hierarchy
- Observing CP violation
- Precise measurement of neutrino oscillation parameters

Beyond the long-baseline program

- **detection of neutrinos from core-collapse supernovae**, searches for nucleon decay, studies of solar neutrinos, and atmospheric neutrino oscillation studies to supplement the long-baseline measurements
- energy range in the 1MeV (solar) to 10 MeV(core-collapse)

Background: Liquid Argon Time Projection Chambers (LArTPC)



1 module
- 150 Anode Plane Assemblies
- 2560 wires/APA
- 384,000 channels total

- 14-bit ADC @2MHz
- **~1.3TB/sec !**

from Ben Hawk's fastml talk

Background: Liquid Argon Time Projection Chambers (LArTPC)

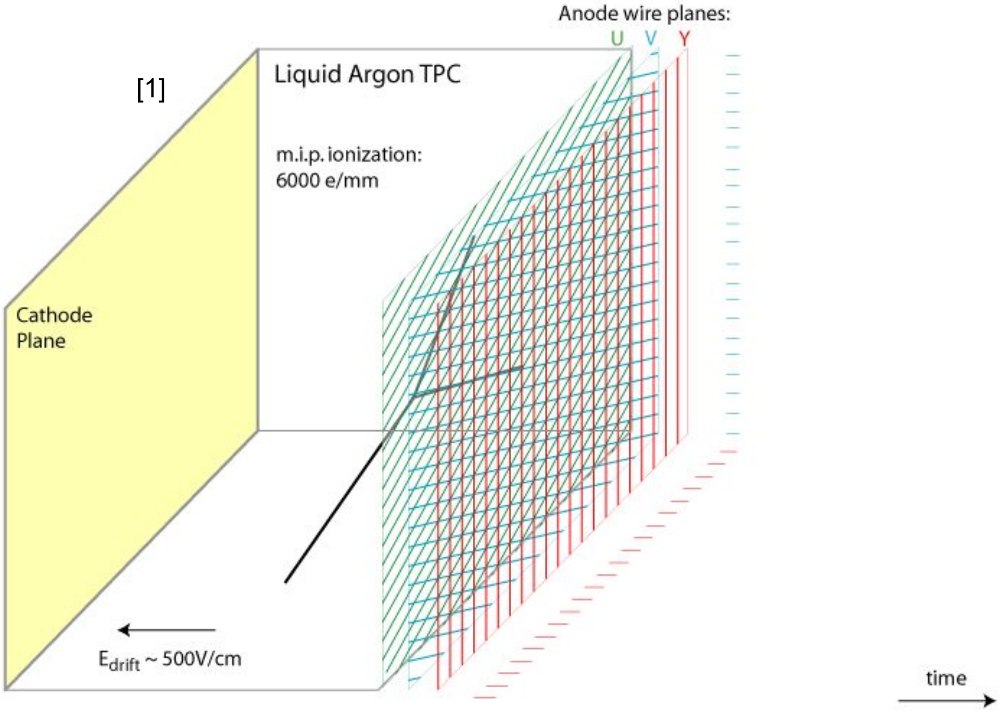
Always on Detectors

- Signals induced by ionization charges
- Wire planes at the end of drift path

Electronic readout

- Multiple wire planes with different angular orientations (2 spatial coordinates)
- Combined with a third from drift time, we can do detailed reconstruction

Technology of choice for massive next generation neutrino experiments like DUNE

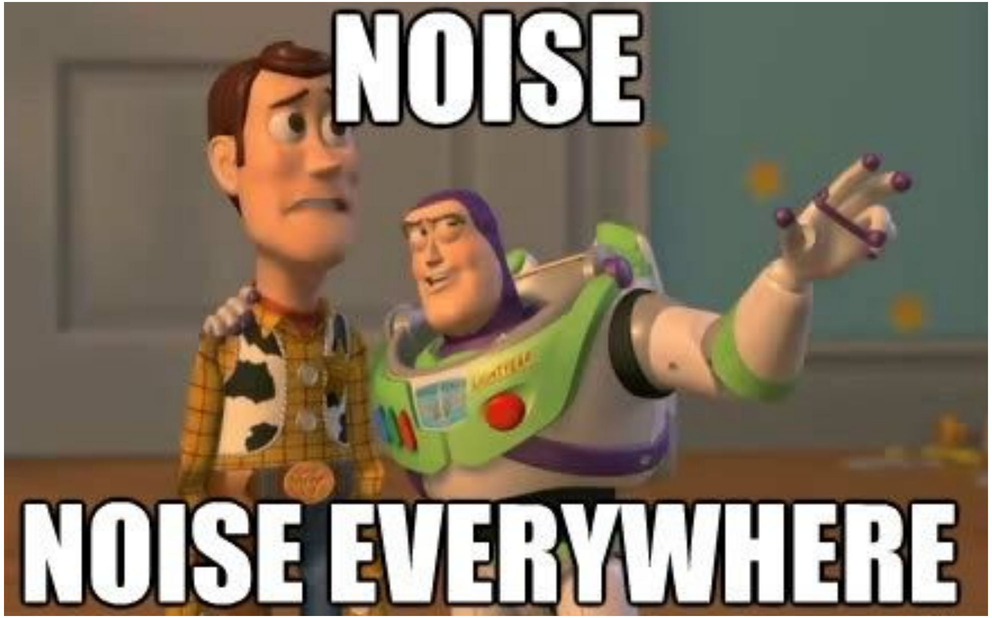


https://arxiv.org/pdf/2106.09911.pdf

Beyond the long-baseline program
- Detection of neutrinos from core-collapse supernovae
- have energy as low as 10 MeV

Induced signals
- They are close to the noise threshold
- Conventional approach applies a minimum ADC threshold cuts which discriminates signal waveforms from noise

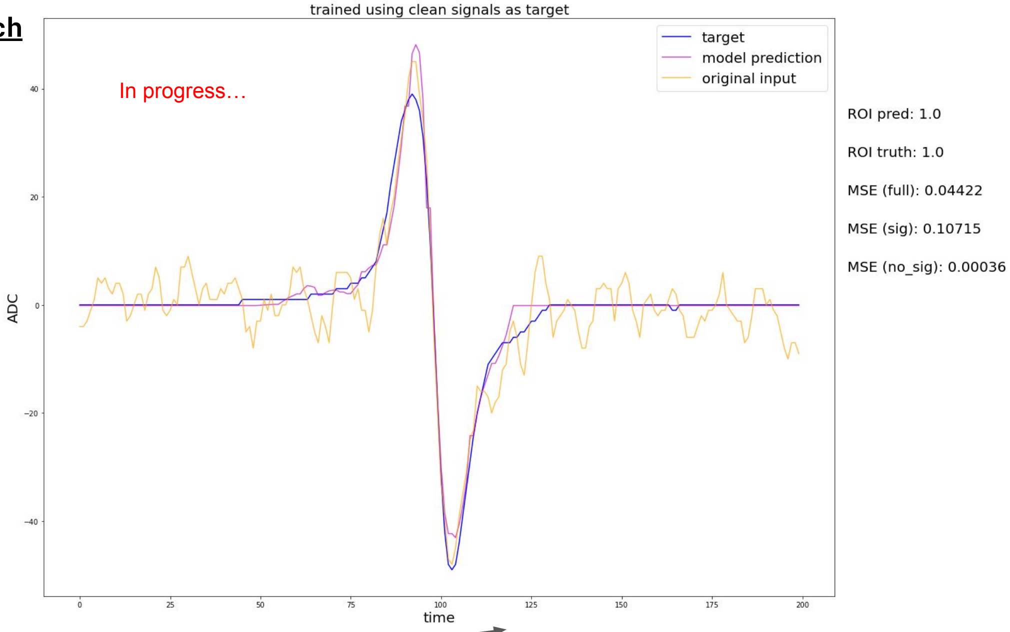
→ Results in poor low-energy efficiency

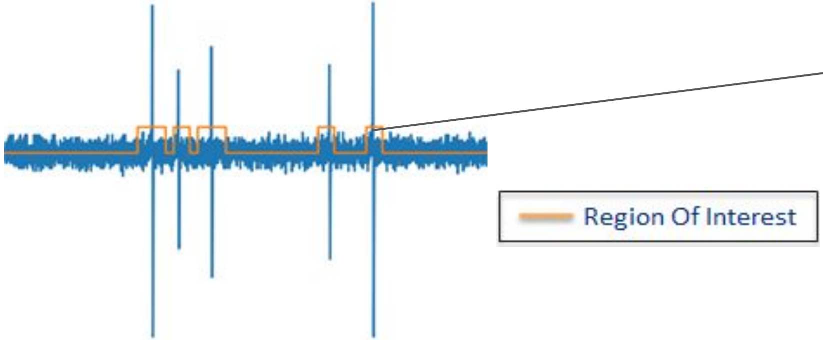


Task: Optimize low-energy efficiently using DL approach

Develop DL technique to apply to the raw waveforms from individual LArTPC wires

- Detect presence of a signal and identify a region of interest (ROI)
- First attempt to apply DL methods directly to raw waveforms associated with single LArTPC wires
- Potential to be applied in the low-level filtering and triggering in online data acquisition (DAQ) systems
  - **UPDATE:** [already applied to FPGA chips]



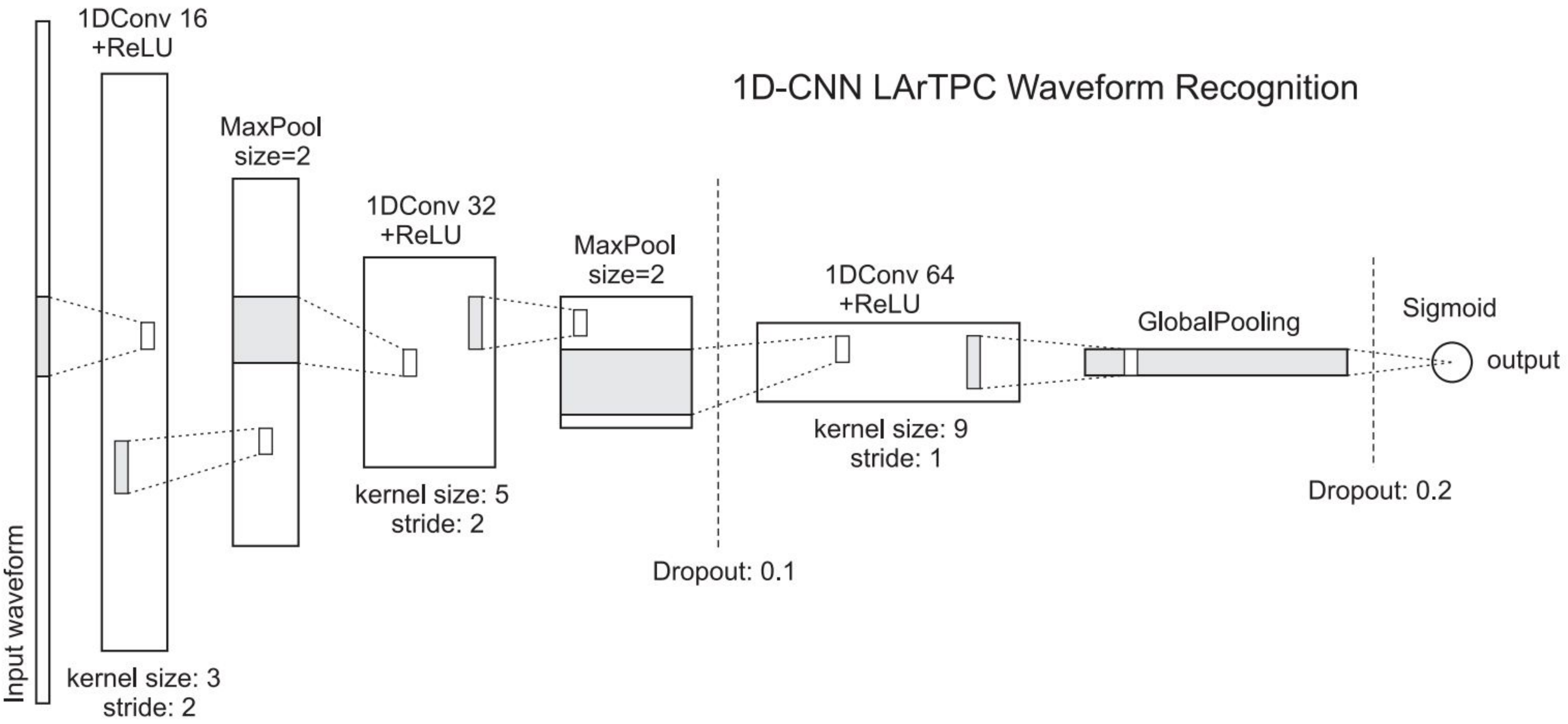


ROI pred: 1.0

ROI truth: 1.0

ROI pred >= 0.94 consider signal

Task: Optimize low-energy efficiently using DL approach

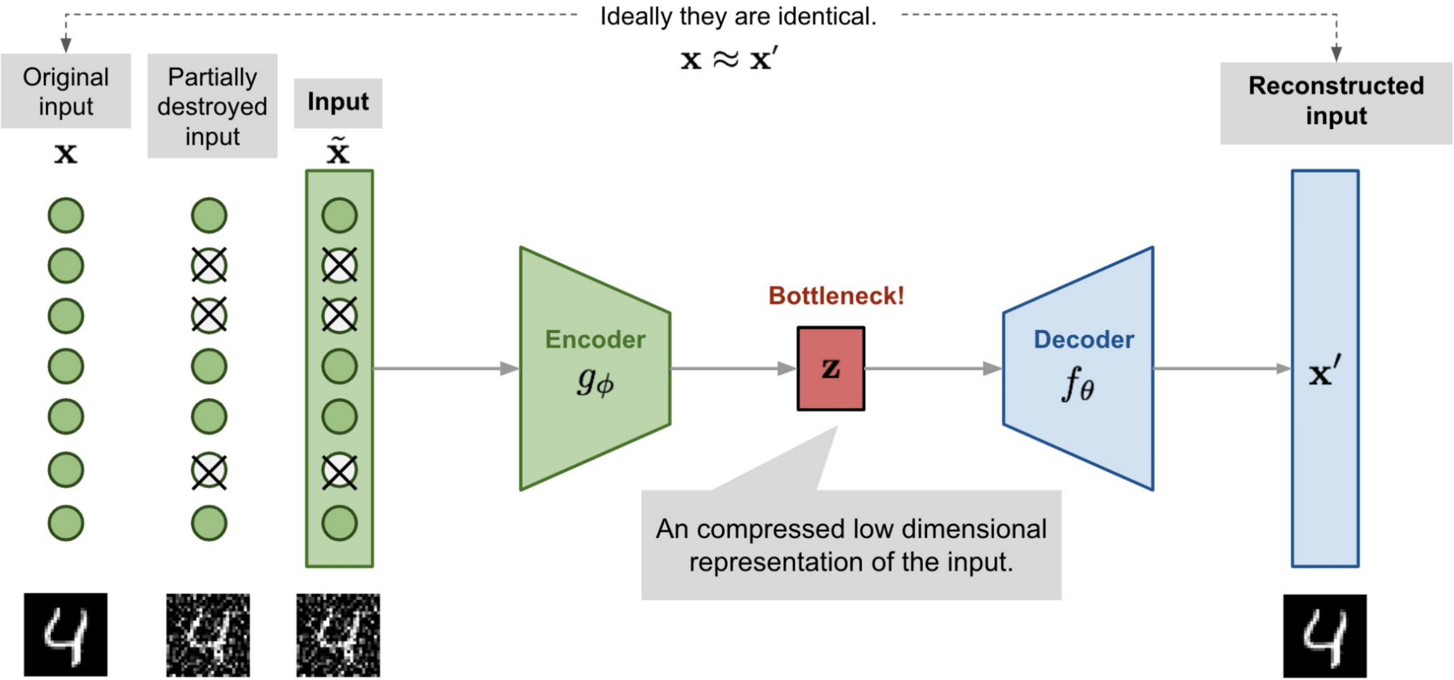


ALGORITHM - ROI FINDER 1DCNN MODEL

[More on in-storage computing + FPGA implementation of 1-DCNN here]

from Ben Hawk's fastml talk

Current: Autoencoder based on 1DCNN



ROI from 1D CNN → input

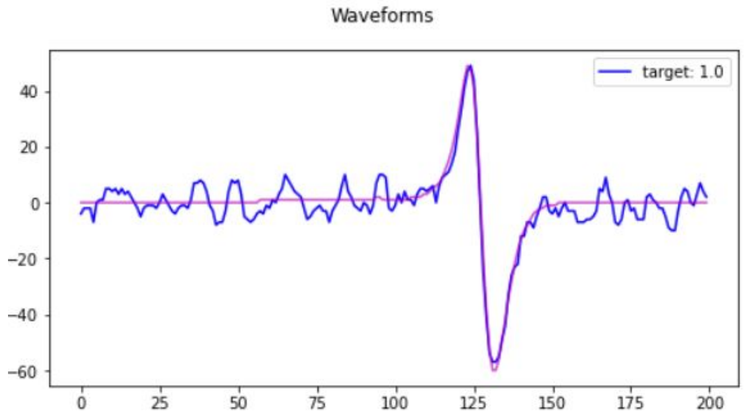
Ideal: noise/background not reconstructed, only signal

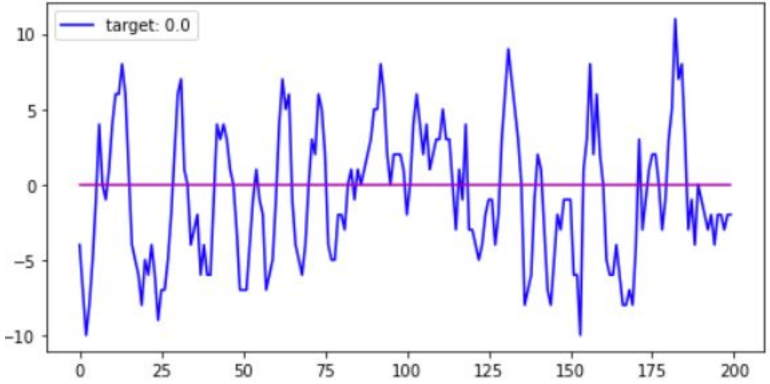
Current: Data + Preprocessing

Updated + more realistic simulation from Mike Wang:

Plane U:
- 218382 waveforms (total)
- 126383 waveforms (after min ADC < 3 applied)
- train test split size: 0.5

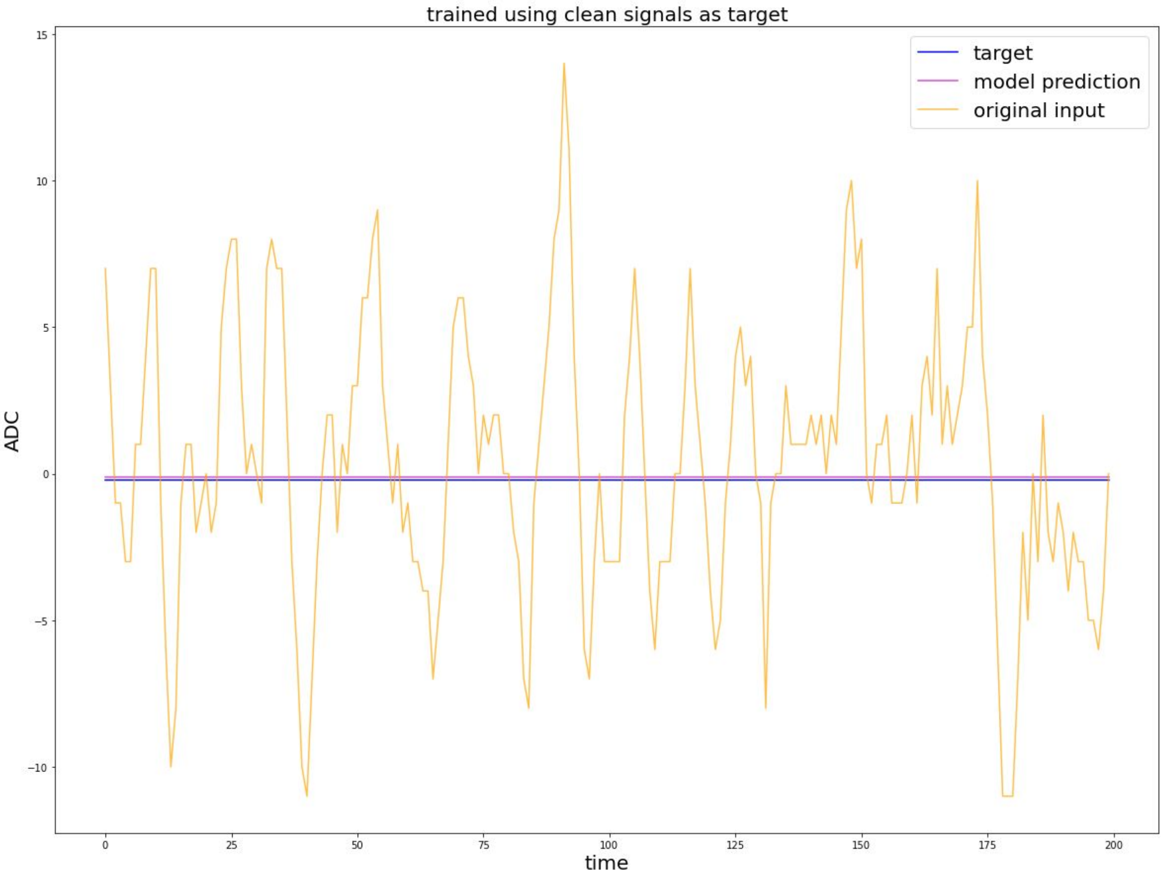
- Electronic noise
  - 100000 per wireplane





blue: input waveform
magenta: truth/target for AE
0, 1: truth/target for 1dcnn

Current: Prelim - Results



ROI pred: 0.17653

ROI truth: 0.0

MSE (full): 9e-05

MSE (sig): 0

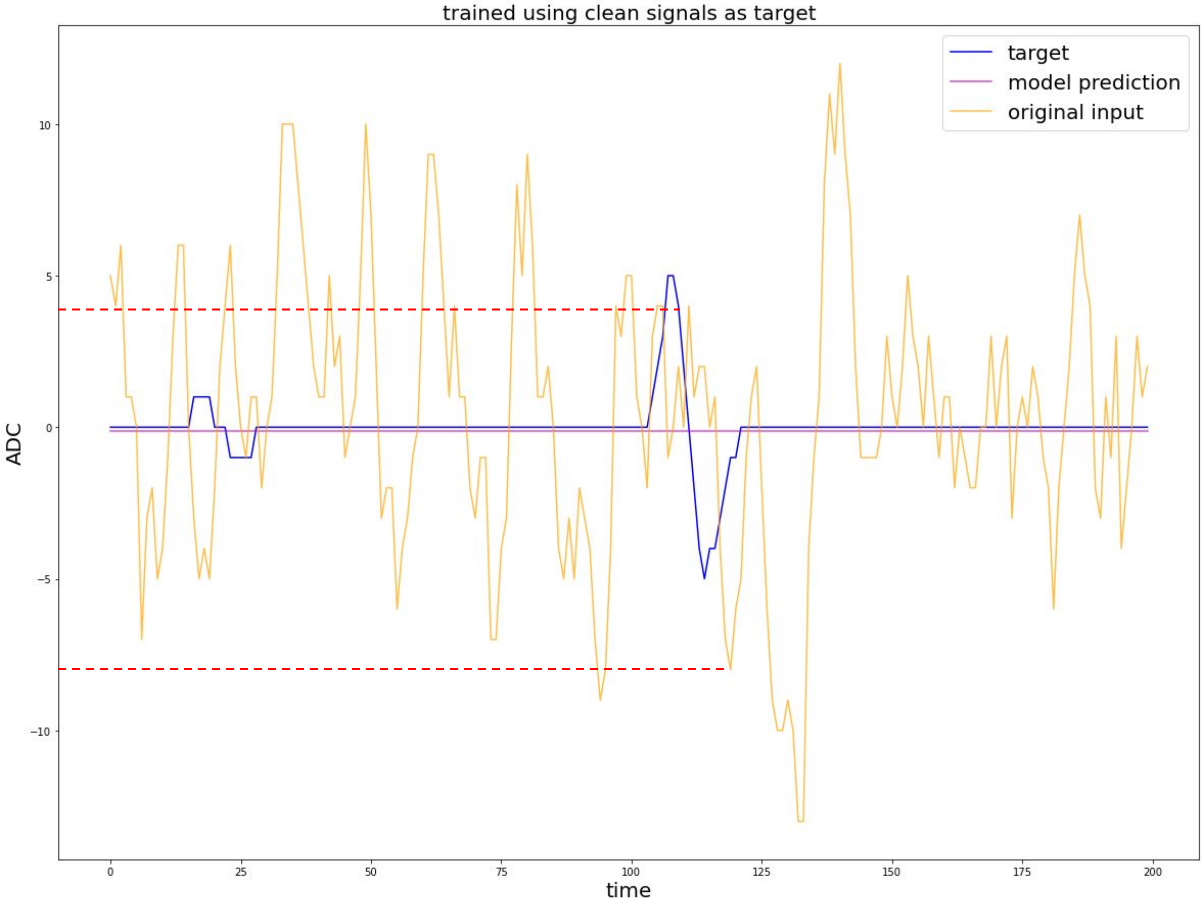
MSE (no_sig): 0

Note:

- CNN output of >=0.94 to be considered a signal

Current: Prelim - Results

Example where both AE & ROI Finder would throw away signal



ROI pred: 0.11503

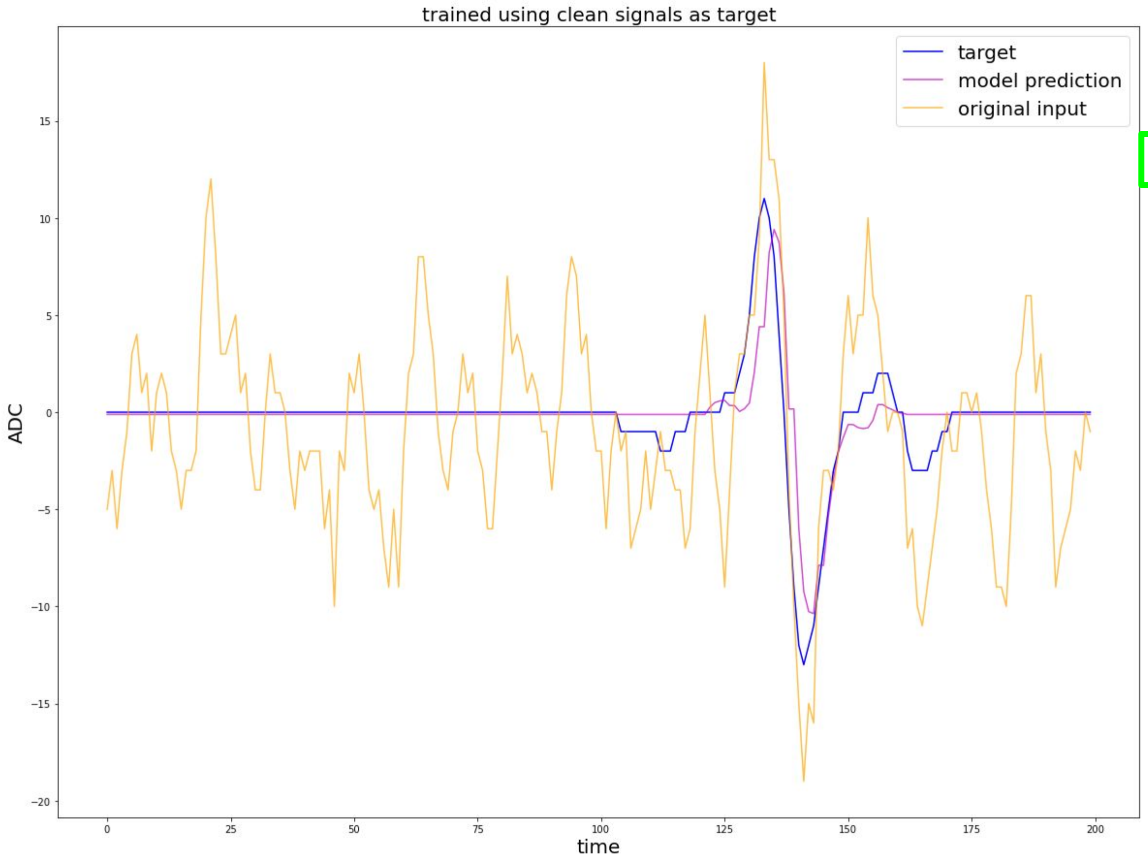
ROI truth: 1.0

MSE (full): 0.00822

MSE (sig): 0.09187

MSE (no_sig): 0.00036

Current: Prelim - Results



ROI pred: 0.99242

ROI truth: 1.0

MSE (full): 0.02044

MSE (sig): 0.09429

MSE (no_sig): 0.00077

Note:

- CNN output of >=0.94 to be considered a signal

Apply Custom Loss Function

$$MSE_{weighted} = w_1 MSE_{signal} + w_2 MSE_{no\_signal} \qquad (1)$$

$$loss = \frac{1}{batch} \sum_{i=0}^{batch} MSE_{weighted(i)} \qquad (2)$$

```
compiled_model.compile(optimizer='adam', loss=custom_mse2, run_eagerly=True)
```

Trained last weekend - outputs very noisy

[ON GOING]

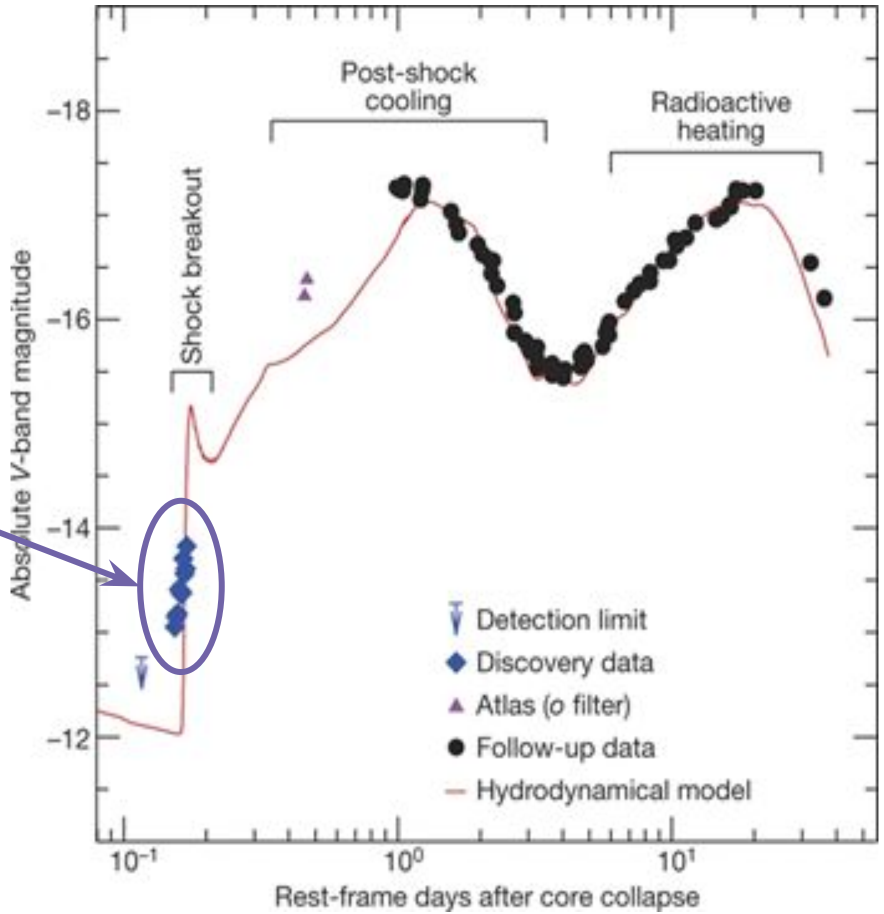
BACKUP

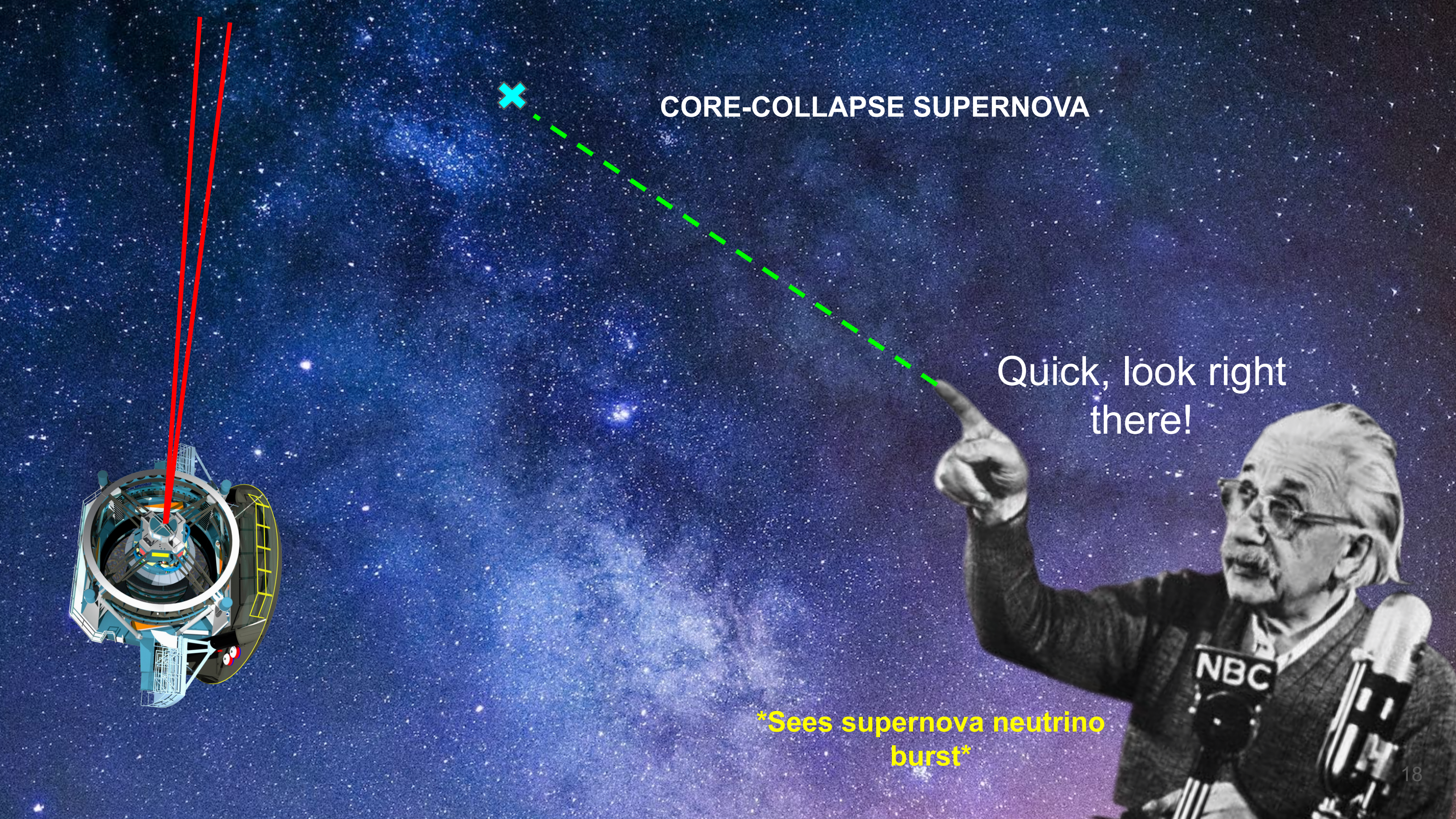
Background: Motivation

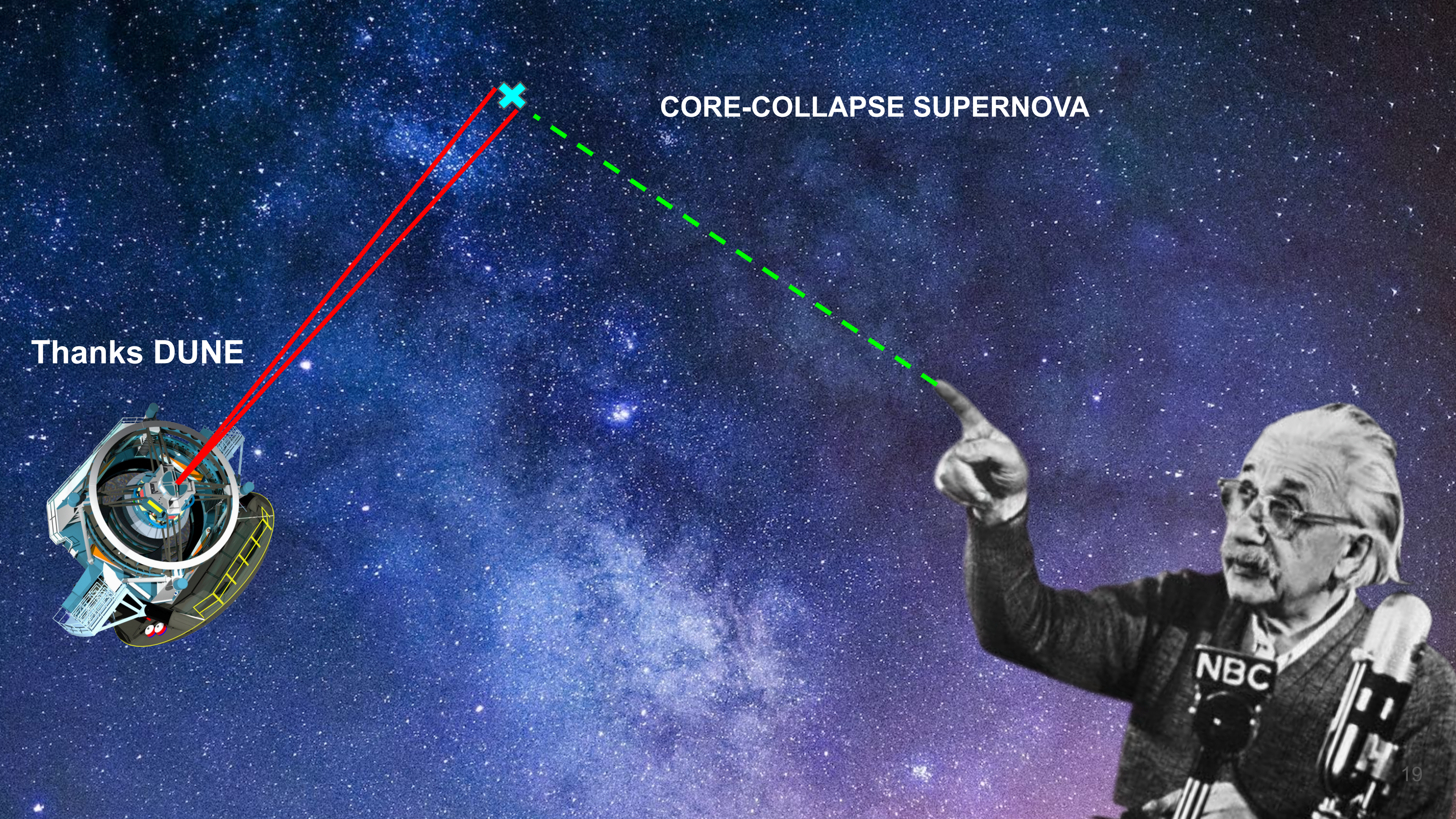
LEGACY SURVEY OF SPACE AND TIME @ RUBIN OBSERVATORY

- Scan entire visible sky every few nights for 10 years
- Unparalleled tool for study of transients – supernovas, kilonovas
- **Discovery Data**
  - Happens in the first few hours of a Supernova!
  - Only managed to observe due to amateur astronomer happening to be looking at the right spot!

Time is *critical* for some events, so we can perform Multi Messenger Astronomy (MMA) to coordinate different instruments, like the LSST, to better observe and understand these events in real time




CORE-COLLAPSE SUPERNOVA
Quick, look right there!
NBC
Sees supernova neutrino burst


CORE-COLLAPSE SUPERNOVA
Thanks DUNE
NBC