A NOVEL TRIGGER BASED ON NEURAL NETWORKS FOR RADIO NEUTRINO DETECTORS

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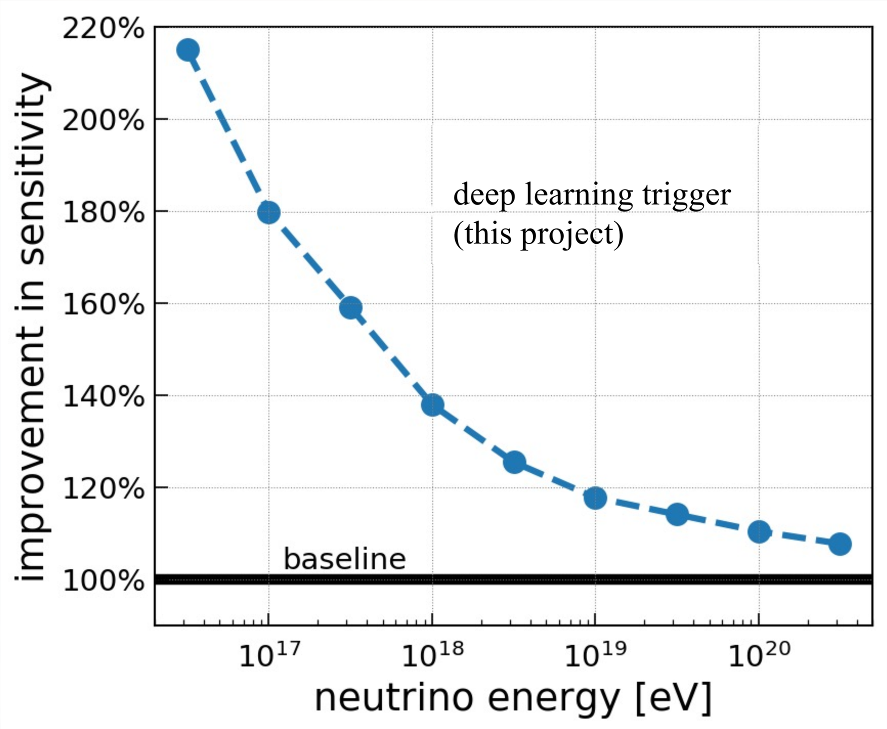
1. Introduction

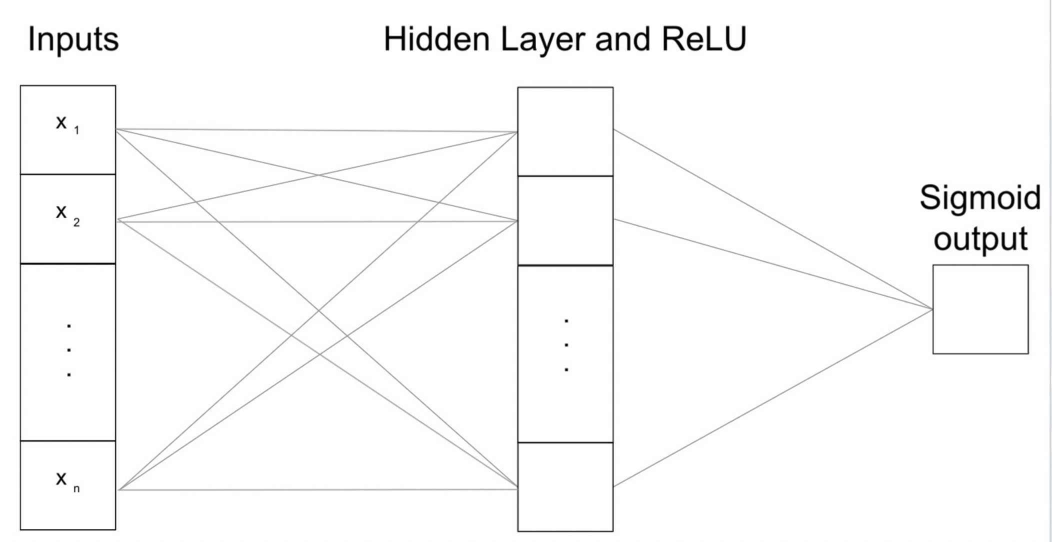
- To increase the effective volume of the ARIANNA detector, one option is to lower the trigger thresholds
- Trigger rates are dominated by thermal noise fluctuations
- Next generation of ARIANNA will likely rely on constrained data transmission via Iridium satellite
- Deep Learning (DL) can be used to reject thermal noise events at these lower thresholds while keeping the same data transmission rate
- Lowering the trigger threshold improves the sensitivity by up to a factor of two at low energies
- Also, deep learning is implemented on existing micro-controller hardware of ARIANNA pilot station and verified in lab tests



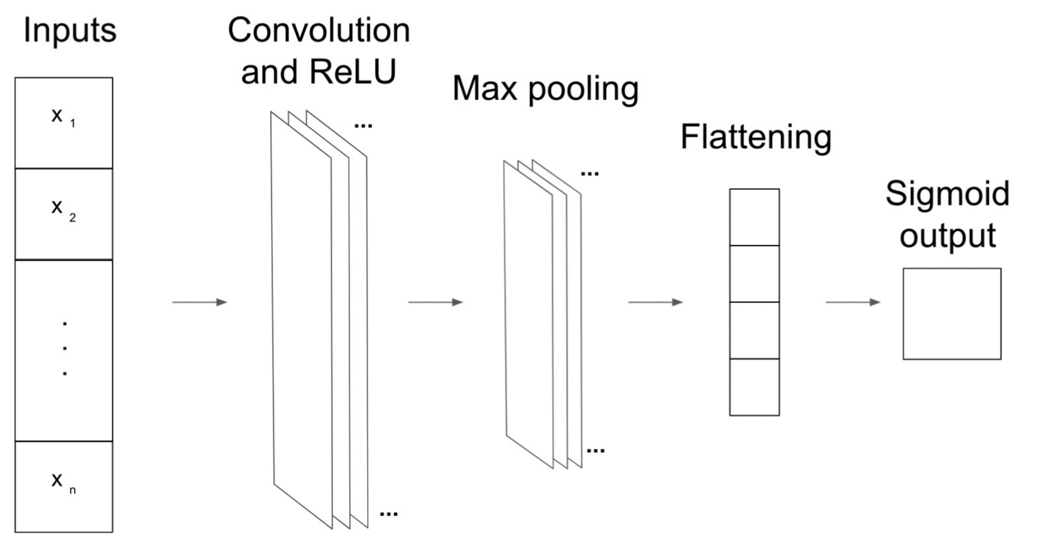
2. Rejection of Thermal Events

Two input data sizes for this analysis: the 2 channels with max amplitude (512 samples), and only 100 samples around the position of maximum signal

- Fully Connected Neural Network (FCNN)
  - One layer with variable node size and ReLU activation
  - Sigmoid activation in output layer

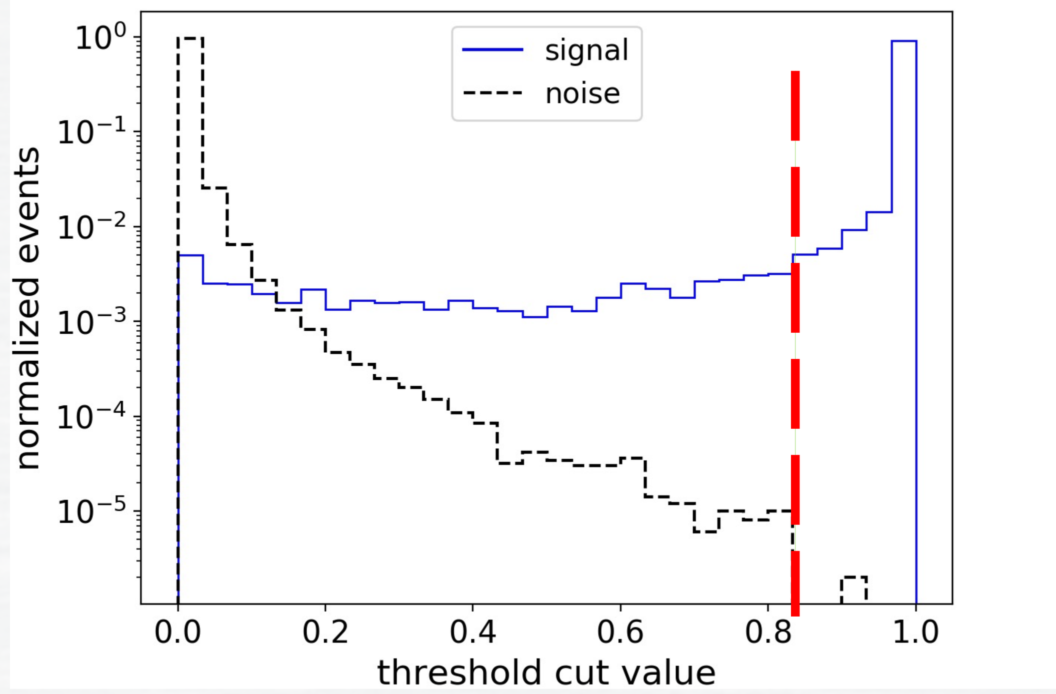


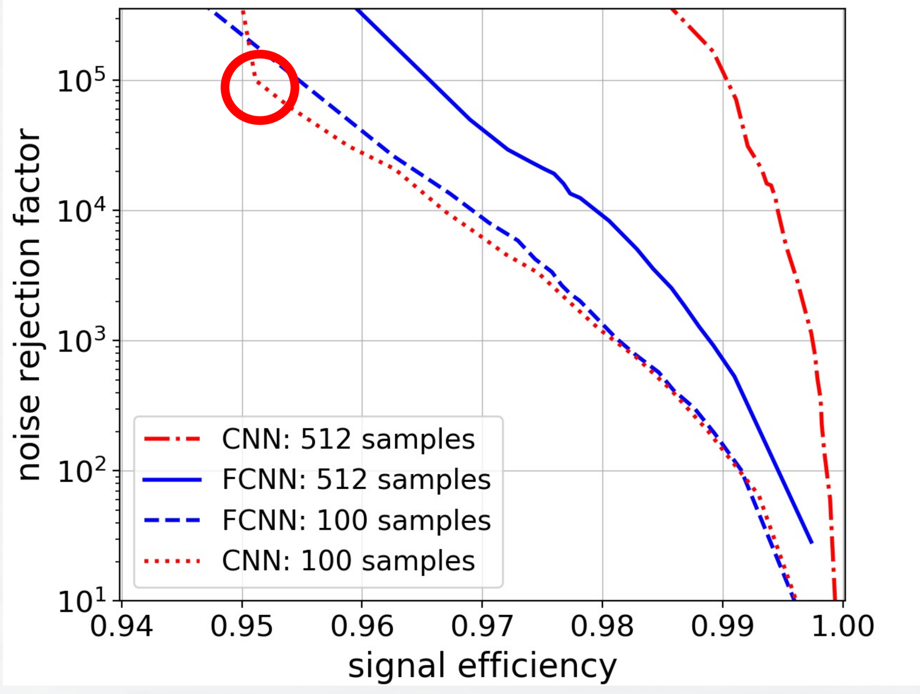
- Convolutional Neural Network (CNN)
  - One convolutional layer of size 5 10x1 kernels and ReLU activation
  - Max pooling of 10x1
  - Flattening
  - Sigmoid activation in output layer



Once trained, the classification distribution for 'CNN: 100 samples' is plotted on the left (other models omitted) where close to 0 is noise-like and 1 is signal-like.

From the left plot, the signal efficiency and thermal noise rejection is controlled by the threshold cut value. The data point circled in the right plot corresponds to the cut value indicated by the vertical dashed line for the 'CNN: 100 samples' data



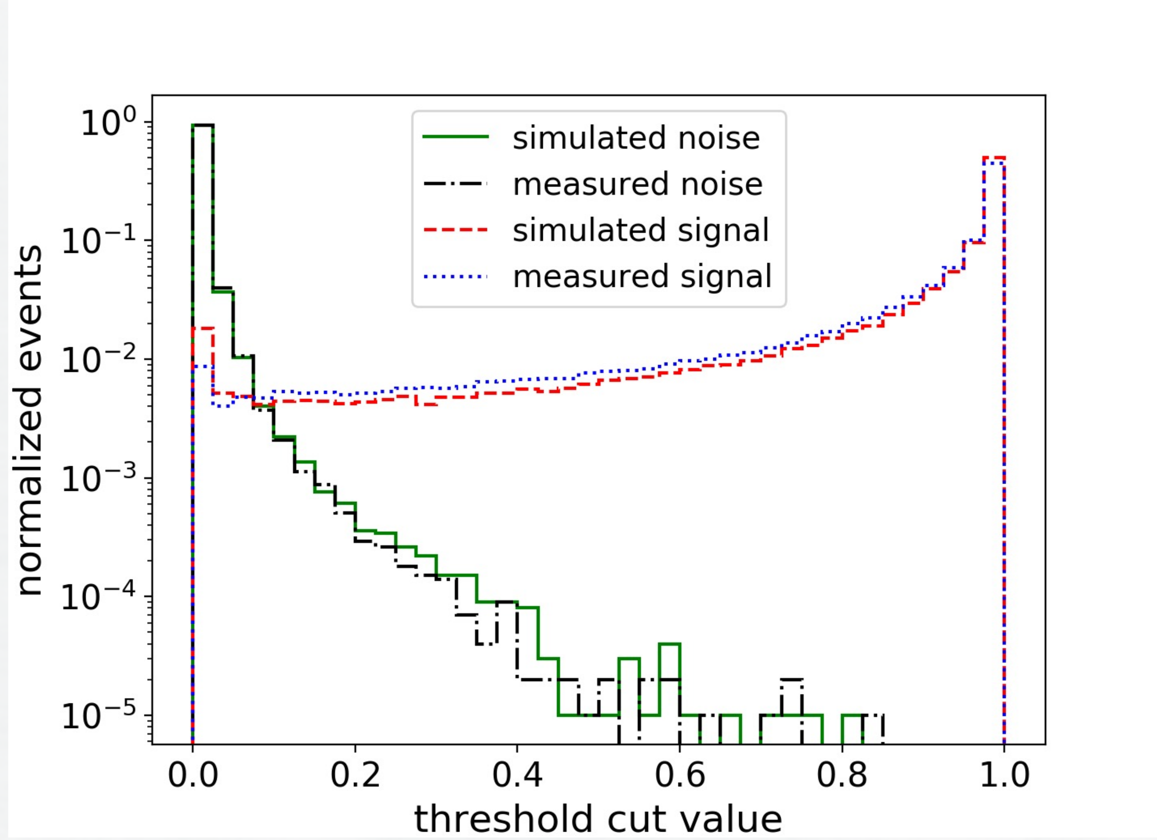


3. Microcontroller Processing Time

- Processing times below for current MBED microcontroller in ARIANNA hardware and a possible upgrade, a Raspberry Pi
  - T_{ref} is the time to reformat and calibrate raw data for DL evaluation
  - T_{dl} is the time to evaluate an event with DL
- Floating Point Operations (FLOPS) provide a reasonable estimate for relative speeds of DL models
- In section 2, the 100 sample CNN achieves 10^5 noise rejection and 95% signal efficiency while having a combined processing time of 5 ms

Variable	model	FLOPS	MBED	Raspberry Pi
T_{dl}	FCNN 512 samples	61,568	45 ms	2.5 ms
	FCNN 256 samples	16,448	13 ms	1.0 ms
	CNN 256 samples	12,815	9.4 ms	0.95 ms
	FCNN 100 samples	6,464	4.7 ms	0.46 ms
	CNN 100 samples	5,045	3.7 ms	0.39 ms
T_{ref}	all networks		1.3 ms	0.095 ms

4. Experimental Verification



- A neutrino template and noise events are simulated
- Then compared to the threshold cut values of a measured neutrino template and noise events
- Excellent agreement between simulated and experimental distributions for both signal and noise

5. Conclusion

- A CNN was implemented on an MBED microcontroller in ARIANNA pilot station
- Achieved thermal noise rejection of 10^5 and signal efficiency above 95% in simulation, and verified in lab tests
- With DL implementation on ARIANNA microcontroller, trigger rates can be increased to 10 Hz
- Identified low power computer upgrade that increases trigger rate to 100 Hz