Machine Learning and High-Energy Radio Neutrino Astronomy Trigger Thresholds

Brian Clark

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Department of Physics
The Ohio State University

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Punchline First

ML is great at the analysis level…

But why can't its answer help you at the trigger/ filter level?

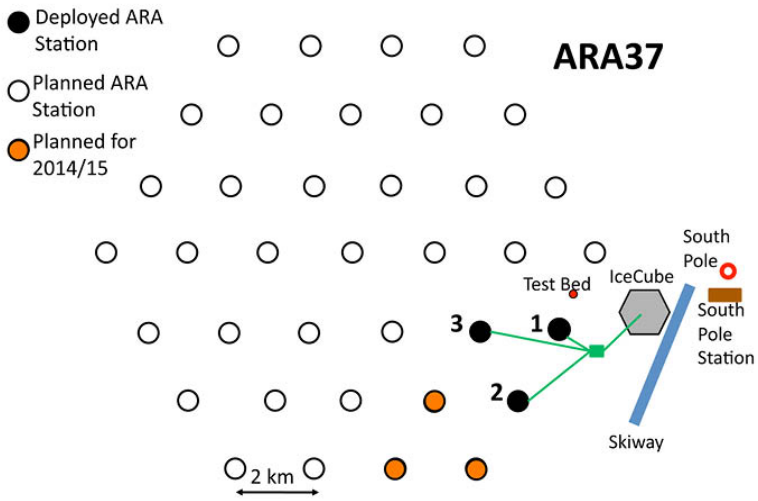
High-Energy Radio Neutrino Experiments

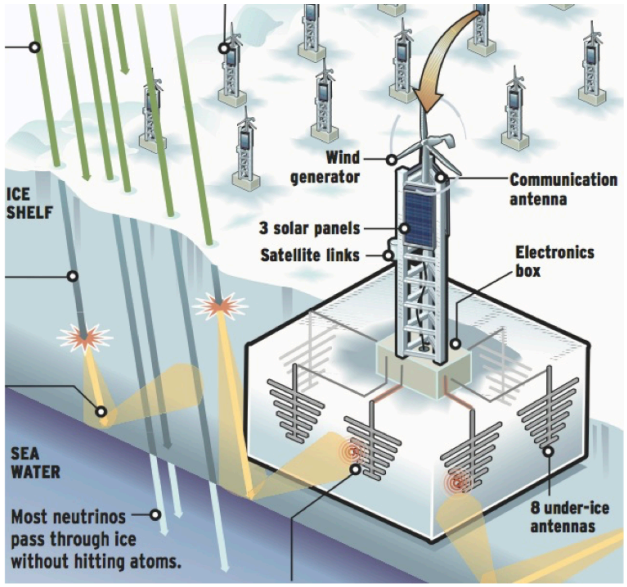
Antarctic Impulsive Transient Antenna (ANITA)

Askaryan Radio Array (ARA)

Where I'll focus today

Antarctic Ross Ice-Shelf Antenna Neutrino Array (ARIANNA)





Triggering and Experimental Sensitivity

Trigger Motivation

- Constant readout and storage of a sensor is not practical
- Need ways to reject background without losing efficiency on rare astrophysical events

Backgrounds

- Radio thermal emission of ice
- Anthropogenic sources: satellites, radios, …
- Electromagnetic interferences: lighters, static discharge, …

Evaluating a Trigger

- **Energy "Threshold":** Energy below which an experiment expects to detect no (or few) events
- **Effective Volume:** "aperture" for event collection
  - Computed by Monte Carlo: interact N_{int} neutrinos, in volume V_{int}, detect N_{det}

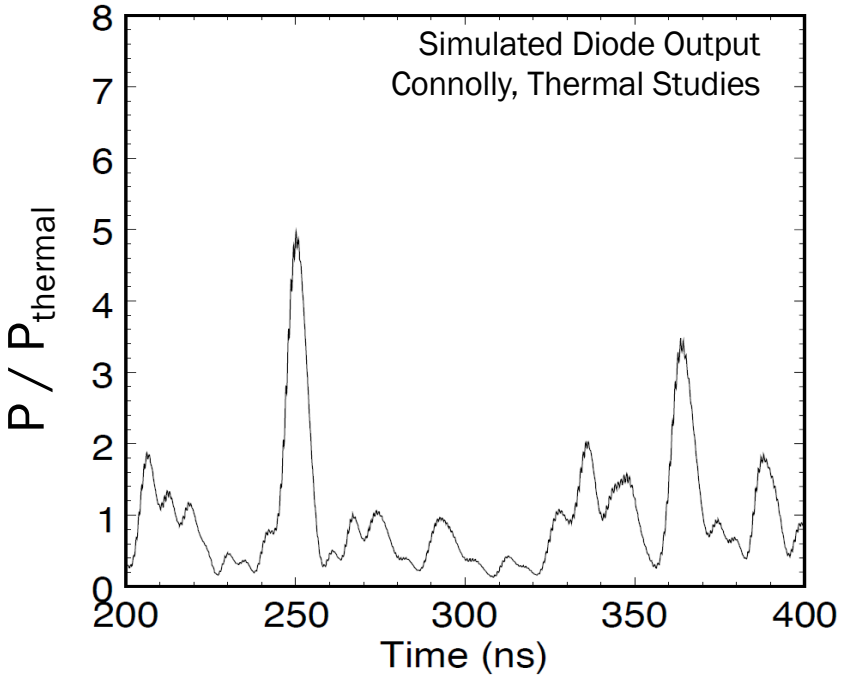
$$V_{eff}(E) = \frac{N_{det}(E_\nu, \vec{r})}{N_{int}} \times V_{int}$$

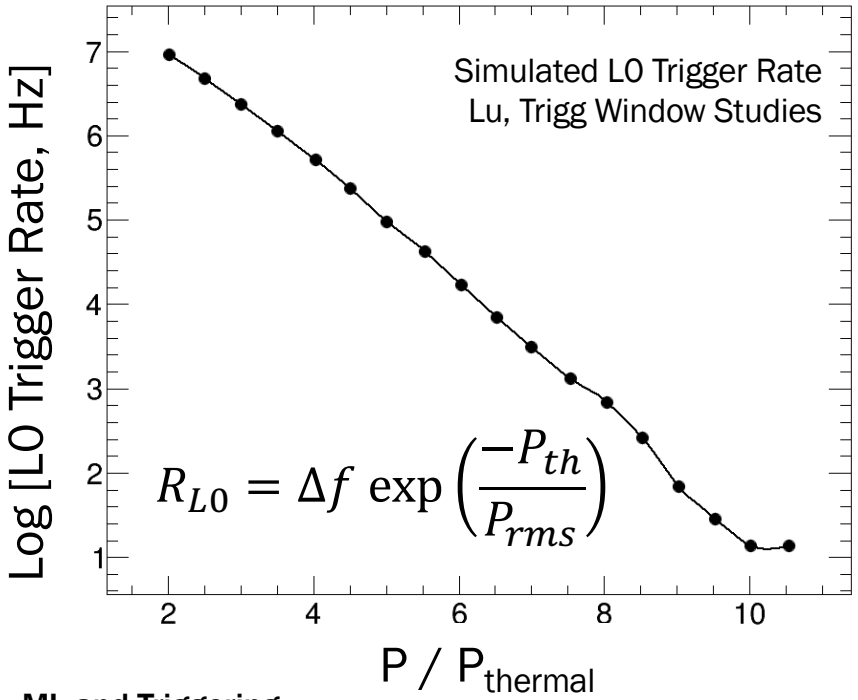
ARA Trigger

Hardware Constraints: Storage space: 5.4 TB/yr ⟶ 5 Hz max *storable* trigger rate

Trigger Process: 2 Tiers

- L0: Power at a single antenna exceeds threshold : Rate = 10 kHz
- L1: 3/8 same pol L0 triggers in 170 ns window : Rate = 5-25 Hz

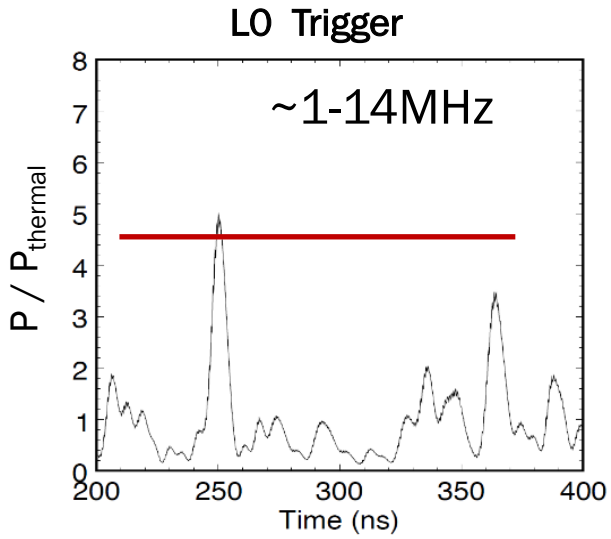


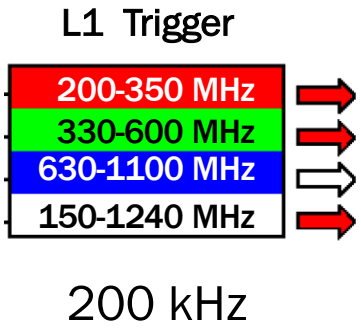


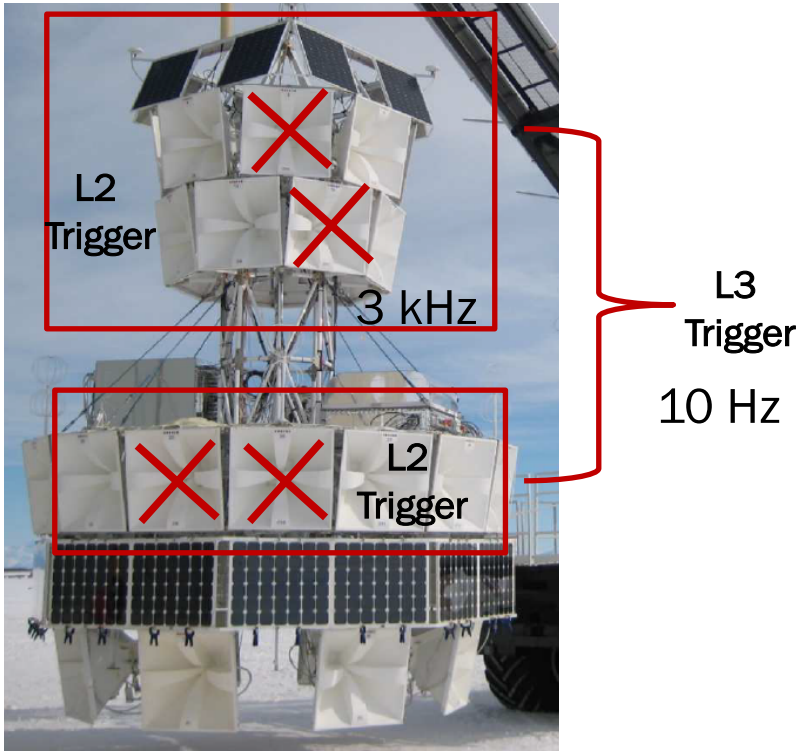
ANITA-2 Trigger

Hardware Constraints: 30 Hz max "write-to-disk" rate

Trigger Process: 4 Tiers (L0 → L3)







Evolution of the ANITA Trigger

ANITA-1

- Same power threshold and coincidence requirement as ANITA-2
- BUT, conversion to right and left circular polarization **(LCP and RCP) *before* trigger**! (combinatorics boost)

ANITA-2

- See previous slide…
- Summary: power thresholds + combinatorics, **V-pol trigger only**

ANITA-1 discovers CRs

ANITA-3

- No banded trigger, **V and H-pol trigger**
- Rough "interferometry pass"
  - Triggers between stacked antennas must have causal timing
  - Require adjacent antennas

ANITA + ARA: Sensitivity and the Trigger

- **Lower thresholds = weaker signals pass the trigger**

- For fixed SNR, can have…
  - Events of lower energy
  - Events from further distances away
  - More accepted viewing angles
  - Larger effective volumes: $V_{eff} \propto R^3$

$$V_{signal} \propto \frac{E_0}{R} \exp\left(-\frac{\theta - \theta_C}{2.2^\circ}\right)^2$$

ML Prospects

- Trigger level: build ML equation into firmware trigger logic
- Filter level: prioritize data for transmission to the north
- Practical example: Regression: solve for a threshold of zero

- Discussion: Any ideas from the participants?

Summary

1. Trigger thresholds govern the accessible physics, particularly the energy

2. Can ML make our *triggers/filters* smarter?

3. Discussion please!

Thank You!