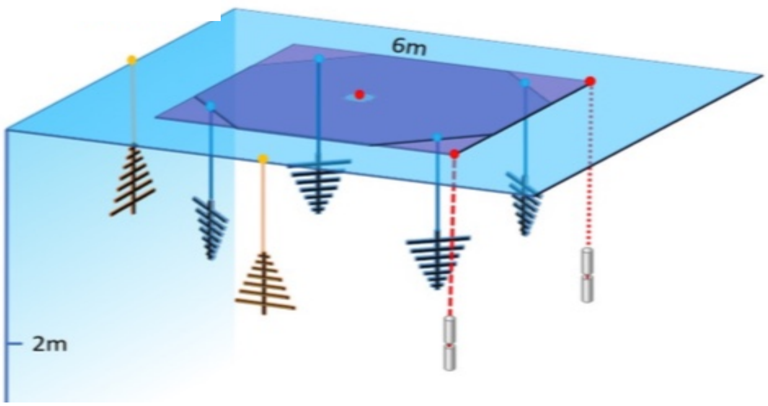
Developing New Tools for Near Surface Radio-based Neutrino Detectors



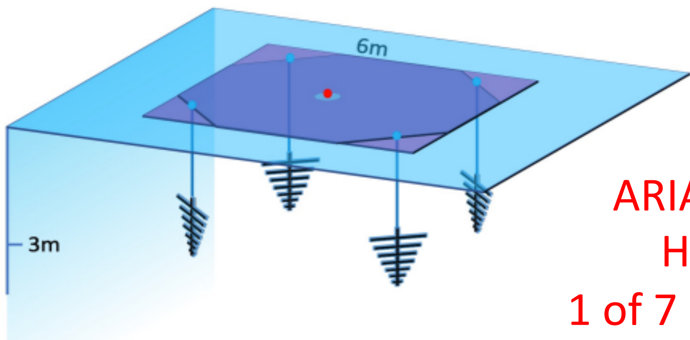
ARIANNA Station 61:
Located at South Pole,
5 km from Amundsen-Scott

Steven W. Barwick
For ARIANNA Collaboration
38th ICRC
Nagoya, Japan, 2023

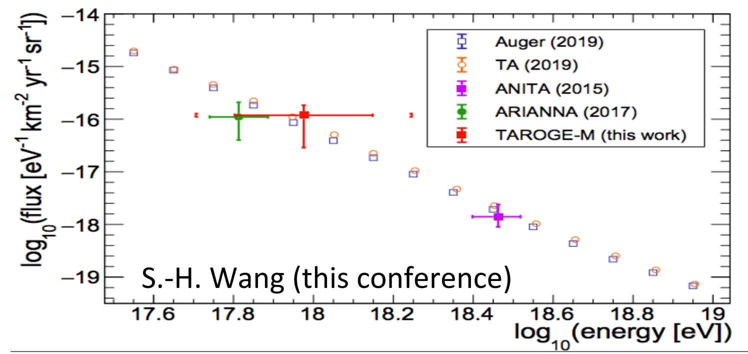
UCI University of California, Irvine

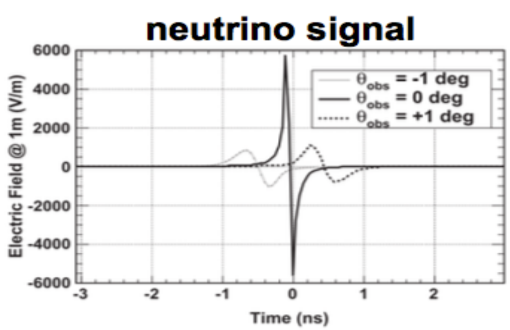
LPDA cut

- LPDA cut relies on template matching to find neutrino events
- Procedure confirmed by Cosmic Ray Flux measurement: Astropart. Phy. 90 (2017) 22

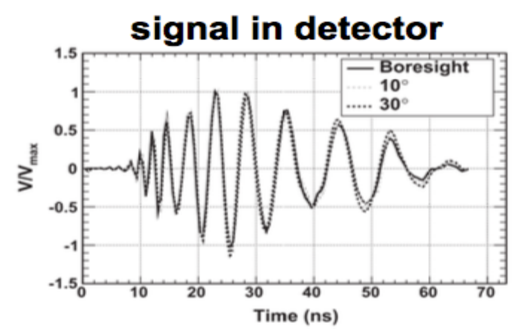


ARIANNA
HRA
1 of 7 stations



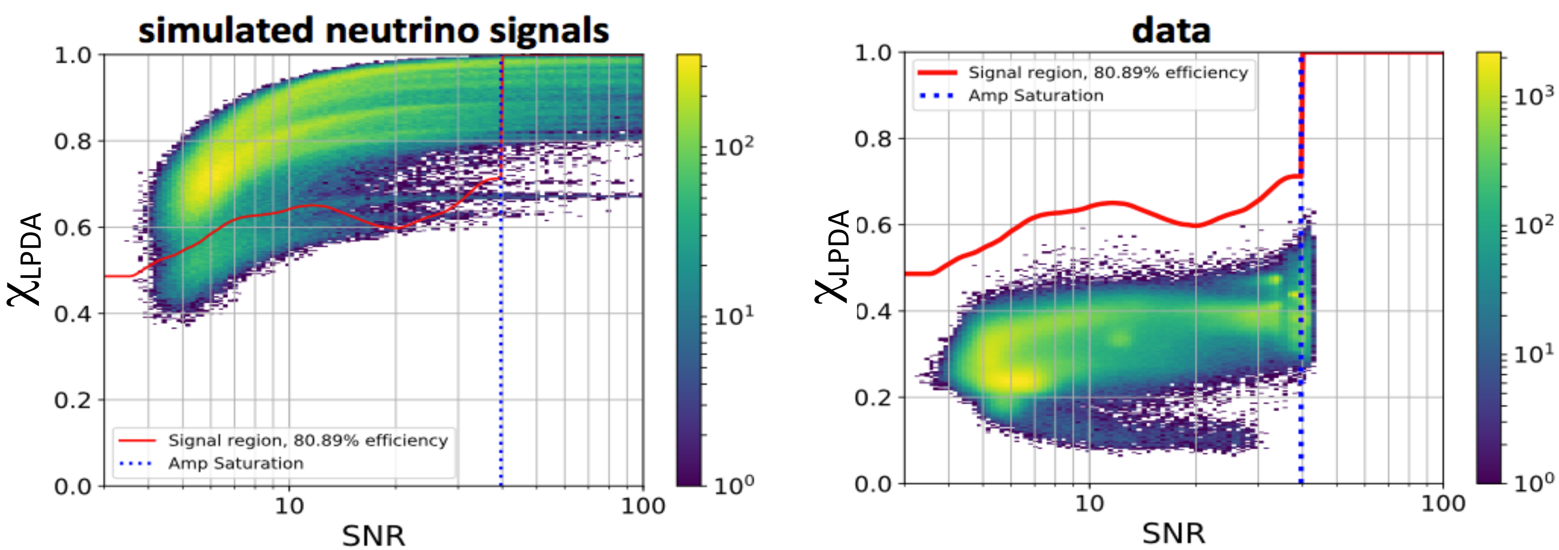


→ hardware response →



LPDA cut (previously developed)

A. Anker, JCAP 03 (2020) 053

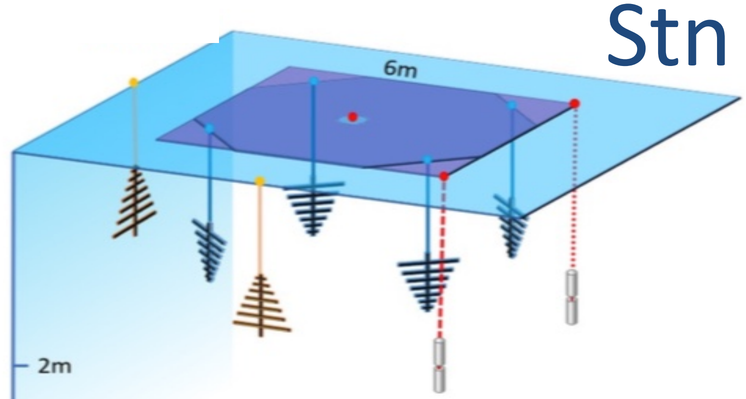


- All background events rejected with one cut (the LPDA cut)
- Signal efficiency ~ 80% for 8 station-years of livetime

New Analysis Cuts
(astro-ph/2307.07188)

Stn 61

- Updown cut
- Dipole cut
- “Deep Learning” cut



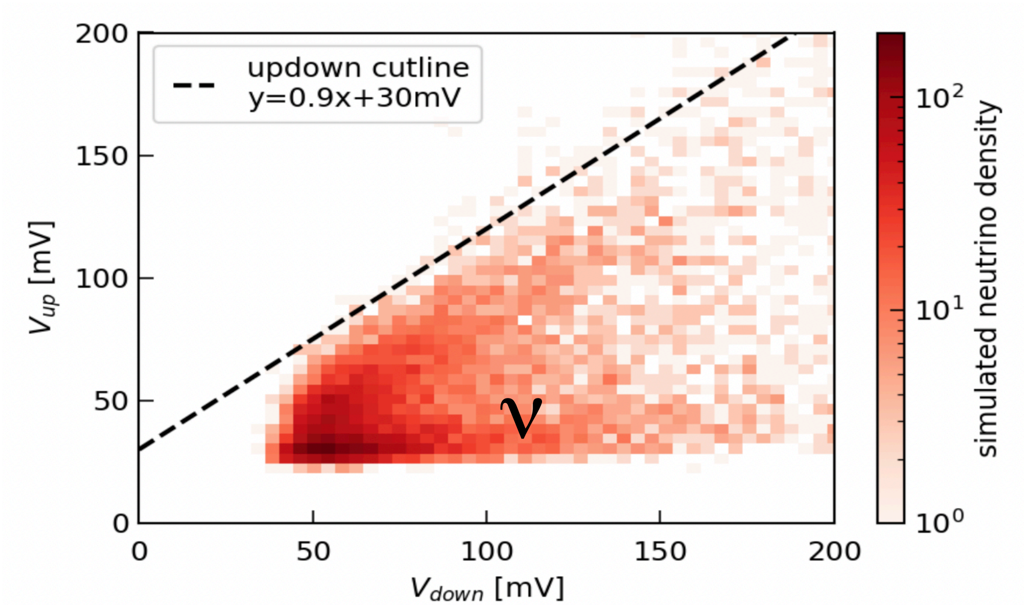
All the antenna elements of next gen detector

Development of new cuts relied on archival data from Stn 61

Dec 10, 2018-Mar 20, 2019
Sep 25, 2019-Mar 15, 2020
Oct 15, 2020-Jan 10, 2021

Total Livetime: 12 months

Updown Cut



Neutrino efficiency:

ε_{updown} = 99%

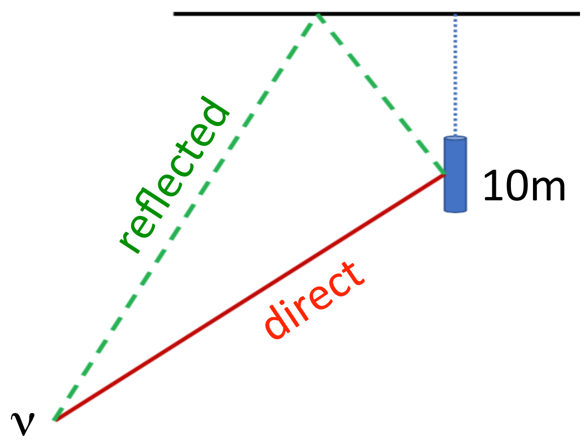
Data events:

42k out of 74.5k

Vup = max voltage in any of the upward facing LPDA
Vdown = max voltage in any of the downward facing LPDA

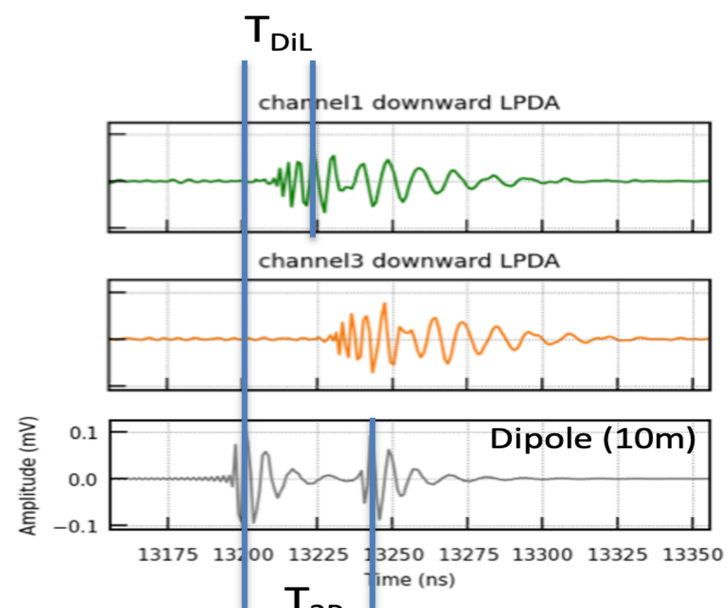
Dipole Cut

Note: not to scale!



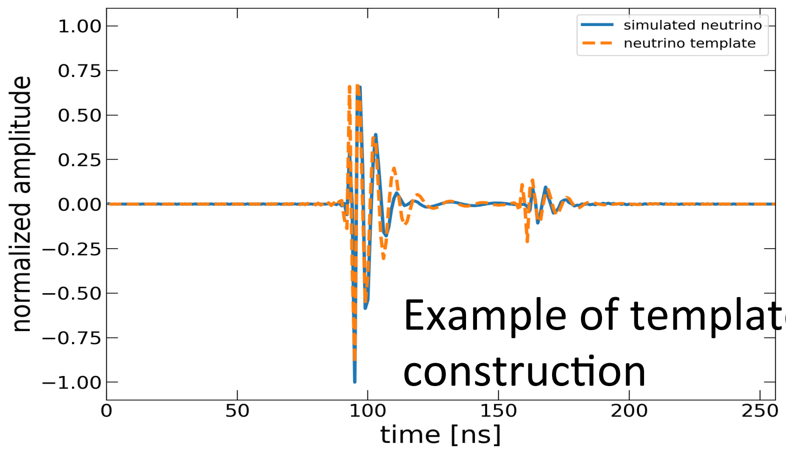
Based on D'n'R signature

ARIANNA collaboration, JCAP 11(2019)030

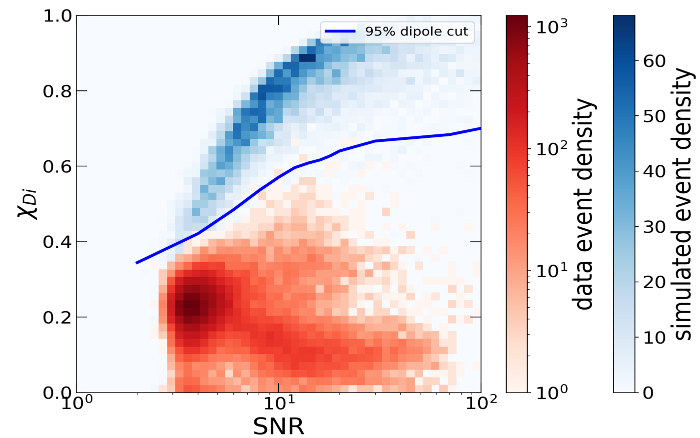


Dipole Cut

Similar to LPDA cut, use template matching procedure and cross-correlate, χ_{Di}

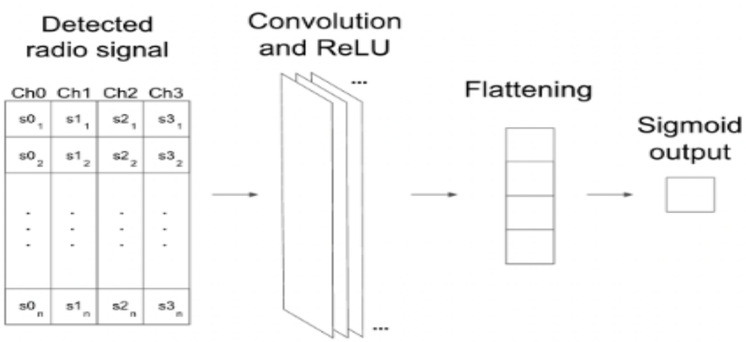


Example of template construction

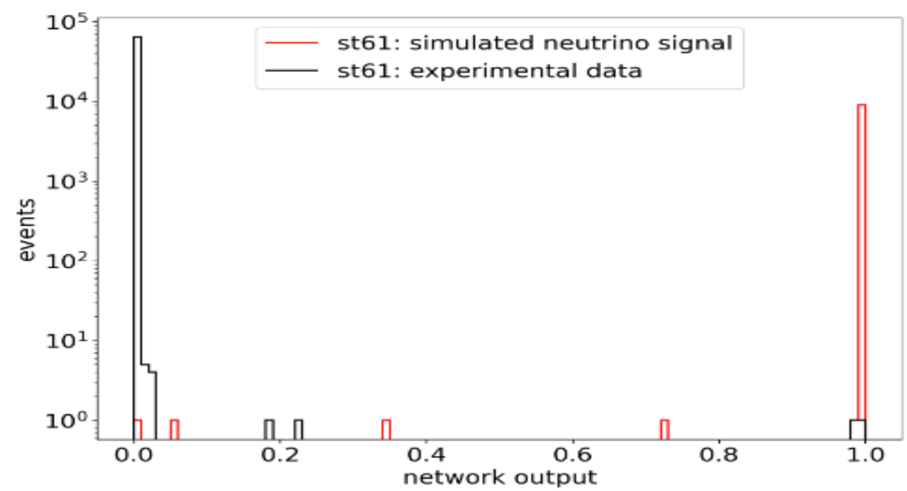


Neutrino efficiency = 95%

Deep Learning cut

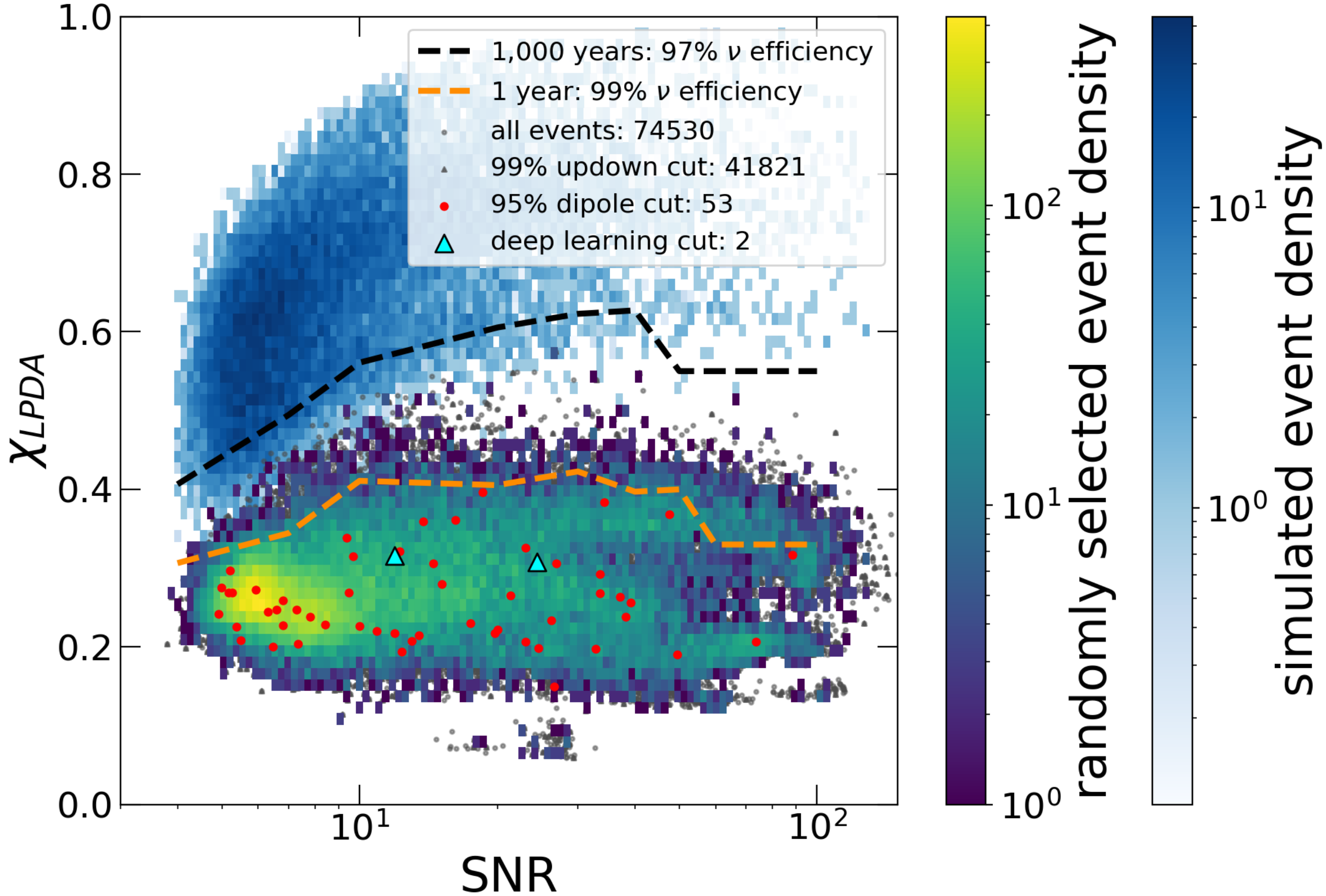


Convolutional Neural Network:
8 ch input of 256 voltage samples
10 kernals, ReLU activation



Use simulated signal
Use data from Station 61 as background
Procedure checked with cosmic ray events

Results:


1,000 years: 97% ν efficiency
1 year: 99% ν efficiency
all events: 74530
99% updown cut: 41821
95% dipole cut: 53
deep learning cut: 2
χ_{LPDA}
SNR
randomly selected event density
simulated event density
1.0
0.8
0.6
0.4
0.2
0.0
10^1
10^2
10^0

Projecting to 1000 station-years

(For Updown/Dipole/LPDA cut combination)

- Assuming data from Stn 61 is representative of non-thermal background at South Pole
- Assuming dipole and LPDA cuts are not strongly correlated (as expected)
- Randomly select 53,000 BG data
  - 53 events/(station year) * 1000 station-years
- BG free at 97% neutrino efficiency for LPDA cut

Projected Analysis efficiency, ε

- $\varepsilon = \varepsilon_{updown} * \varepsilon_{dipole} * \varepsilon_{LPDA} = 0.99*0.95*0.97 = 0.91$

For 1000 station-years of operation

Future work:

plan to optimize all cuts (LPDA, updown, dipole and DeepLearning)

Conclusions

- Special purpose ARIANNA station (61) has all the antenna types anticipated for future station
  - Data driven results
- Near-surface stations satisfies the baseline requirements for shallow radio-neutrino component of IceCube-Gen2 project
- CNN's provide a powerful new tool to identify neutrinos
  - Encouraging results with simple network suggest it may be possible to incorporate DeepLearning directly in the trigger!
  - (see C. Glaser, et al, this conf)

Radio technique promising to measure UHE neutrinos

- ARIANNA test bed detector
  - autonomous, independent, shallow detector stations
  - proof-of-concept of radio technique to measure UHE neutrinos
  - ARIANNA's shallow station design part of RNO-G and IceCube-Gen2
- Neutrino event reconstruction
  - end-to-end test of reconstruction using MC simulations
    - 3° statistical uncertainty for all triggered events
  - in-situ verification of
    - signal direction and ice properties (syst. uncertainty 0.3°)
    - polarization (syst. uncertainty 1°-2.7°)
  - verification using cosmic rays (1.3° polarization resolution)
- Several detector improvements for increased neutrino sensitivity
- Development of MC simulation and reconstruction tools
  - NuRadioMC/NuRadioReco
- Future:
  - IceCube-Gen2 (next decade)

ARIANNA collaboration, Astropart. Phys. 90, 50-68 (2017)
ARIANNA collaboration, Advances in Space Research 64 (2019) 2595-2609
ARIANNA collaboration, JCAP 03(2020)053

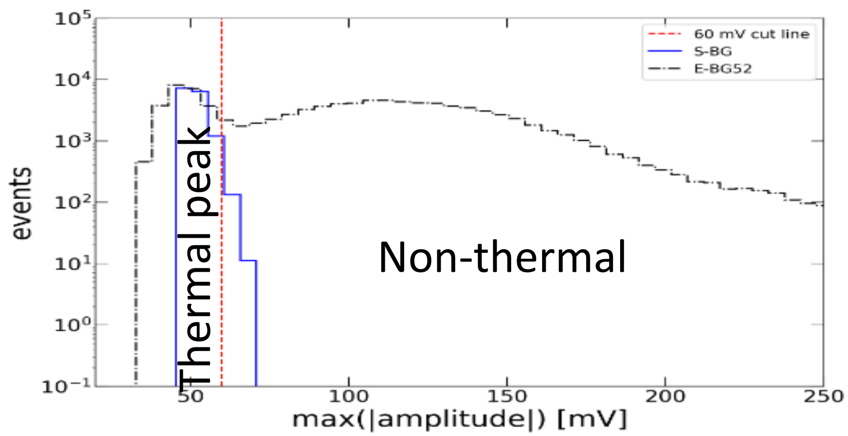
ARIANNA collaboration, JCAP 11(2019)030
ARIANNA collaboration, JINST 15 (2020) P09039
ARIANNA collaboration, JCAP 04(2022)022,
Glaser et al. arXiv:2205.15872

Glaser & Barwick, JINST 16 T05001 (2021)
ARIANNA collaboration, JINST 17 P03007 (2022)

github.com/nu-radio/NuRadioMC
C. Glaser et al., EPJ C 79, 464 (2019)
C. Glaser et al. EPJ C 80, 77 (2020)
D. García-Fernández, CG, A. Nelles, PRD 102 083011 (2020)
N. Heyer, CG, arXiv:2205.06169

BACKUP SLIDES

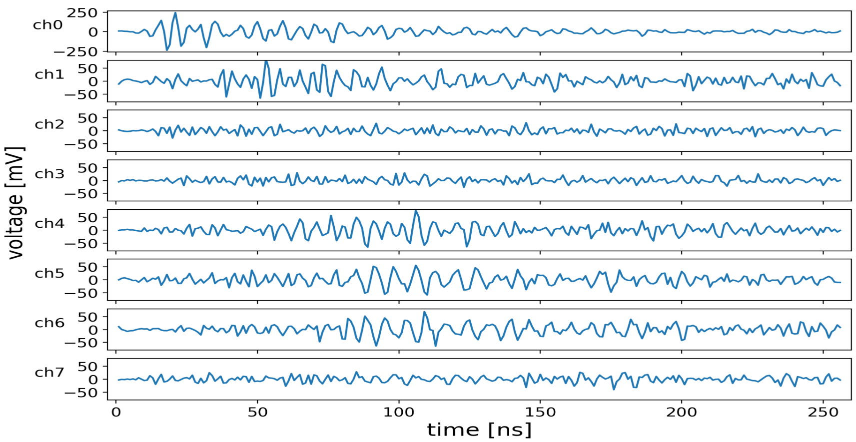
Amplitude distribution

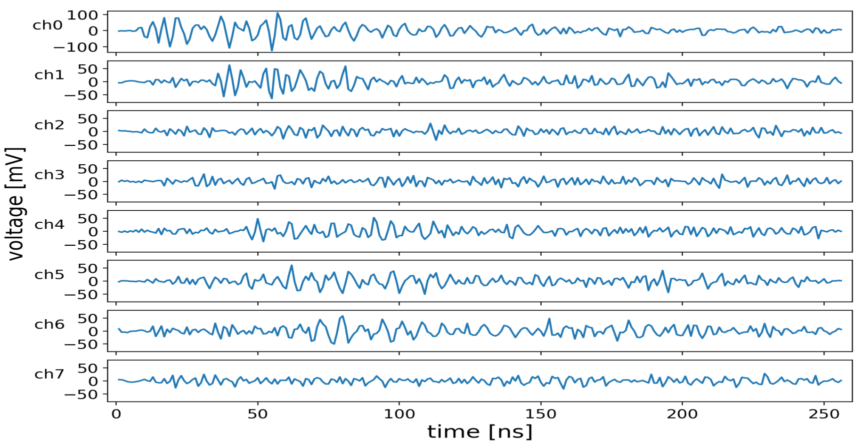


Non-thermal events peak at ~120mV

Reducing threshold in future will not introduce large increase in this event population

2 events that survive Deep Learning cut



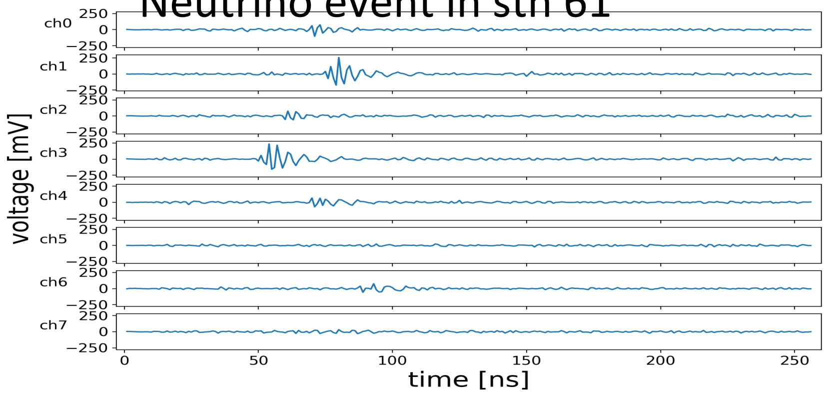


Several characteristics of these events not consistent with neutrino hypothesis

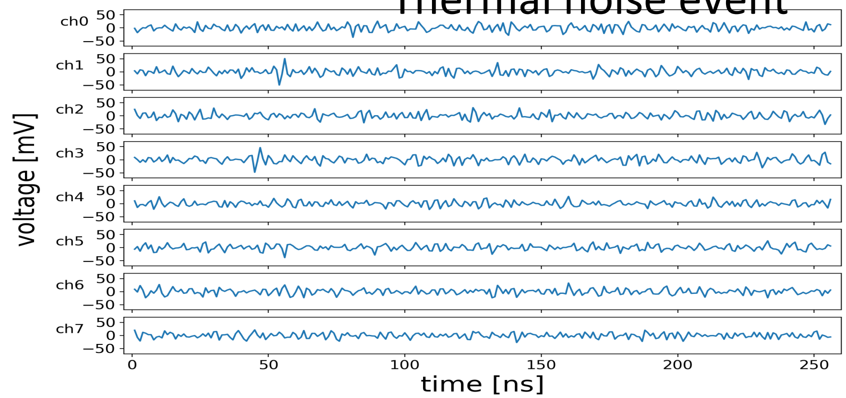
1. Down LPDA have waveforms that extend over 75 ns with ~ constant amplitude
2. Channels involved in trigger are orthogonal, with little signal in parallel channels

Typical Waveforms

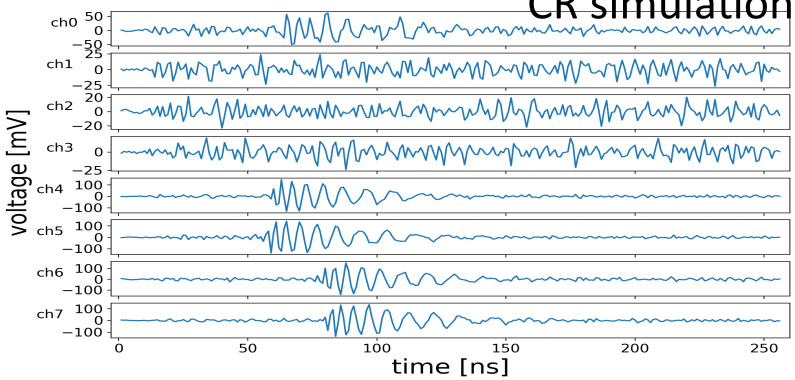
Neutrino event in stn 61



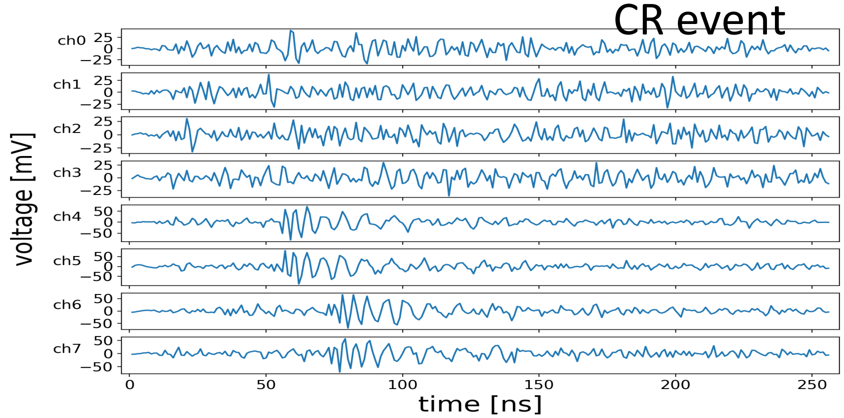
Thermal noise event



CR simulation



CR event



IceCube Gen2 Radio Detector