The Radio Neutrino Observatory

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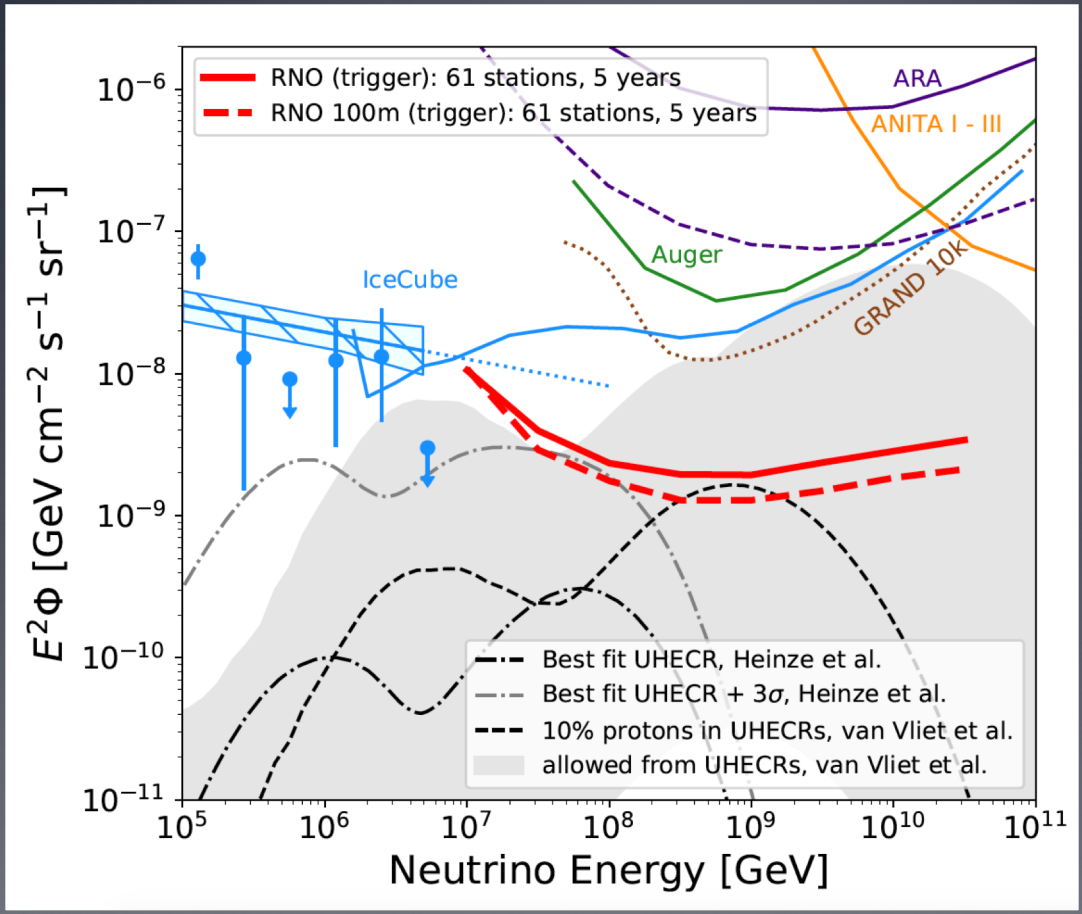
For the RNO Collaboration

The Radio Neutrino Observatory (RNO)

- A proposed radio observatory at the South Pole, which is the result of a year of discussion, simulations, telecons, some arguments, more phone calls, more simulations, a DAQ meeting at UCI, and a workshop at Ohio State
- Takes the best of the current generation of radio detectors (ARA, ARIANNA, and ANITA) and combines expertise from those groups + IceCube to form an international, 18-institution collaboration.

RNO Sensitivity



Two-fold goal:

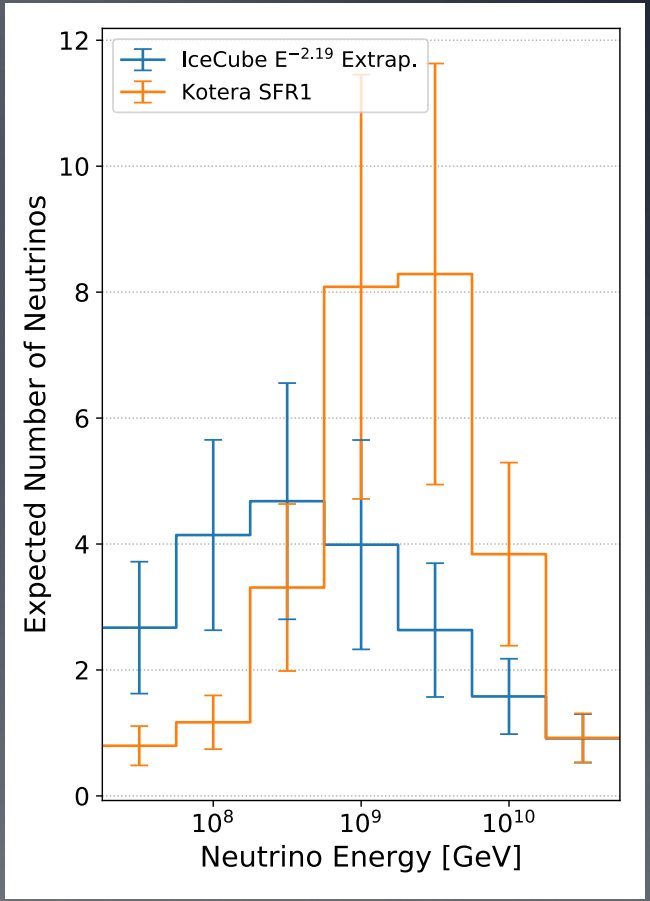
1) Measure the astrophysical flux beyond 10^{16} eV
2) Measure the cosmogenic neutrino flux to 10^{20} eV

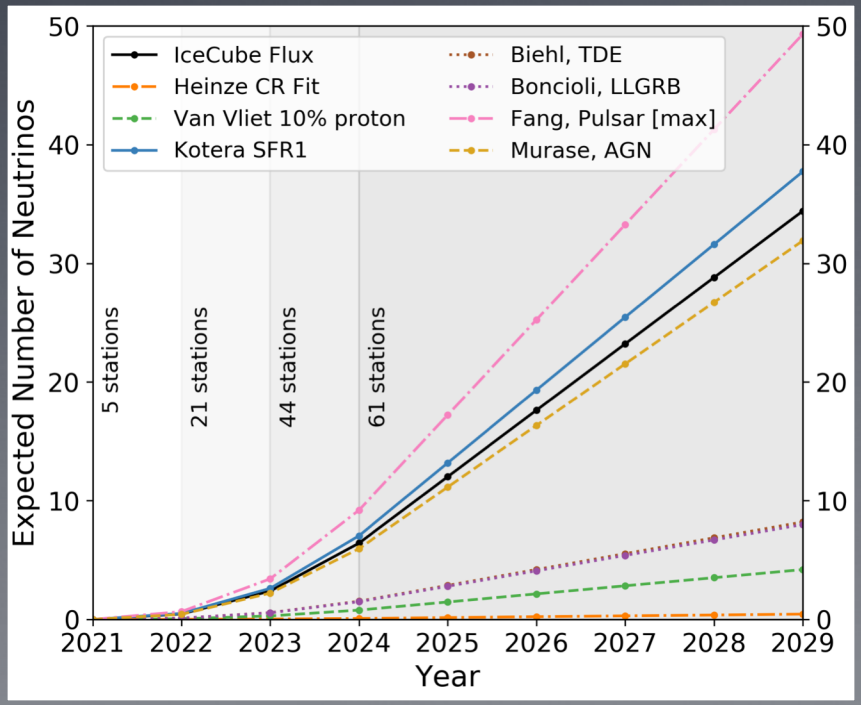
RNO Expected Numbers of Neutrinos

Expected Number of Neutrinos in 5 Years with RNO

Model	AraSim	PyRex	NuRadioMC	Mean	σ
IceCube Flux [5]	9.8	24.9	27.1	20.6	7.7
Biehl, TDE [12]	1.8	4.9	3.9	3.5	1.3
Boncioli, LLGRB [15]	1.4	3.8	2.8	2.7	1.0
Fang, NS-NS Merger [13]	11.1	29.3	30.5	23.6	8.9
Fang, Pulsar (max) [14]	16.0	39.2	46.6	33.9	13.0
Heinze, CR fit [9]	0.1	0.3	0.3	0.3	0.1
Kotera, SFR1 [11]	12.3	29.8	37.1	26.4	10.4
Murase, AGN [18]	10.1	25.1	28.7	21.3	8.1
Van Vliet, 10% proton [10]	1.4	3.3	4.2	3.0	1.2

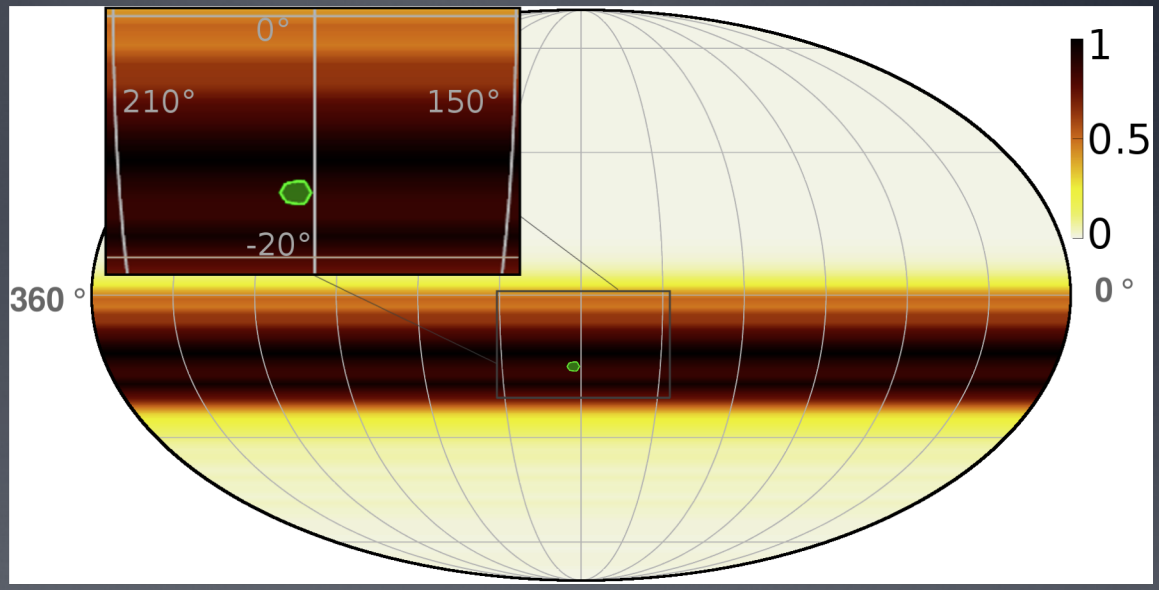
Cutoff Energy on IceCube Flux	10^{17} eV	$10^{17.5}$ eV	10^{18} eV	$10^{18.5}$ eV	10^{19} eV
Expected Number of Neutrinos	5.1	9.7	14.3	18.2	21.4





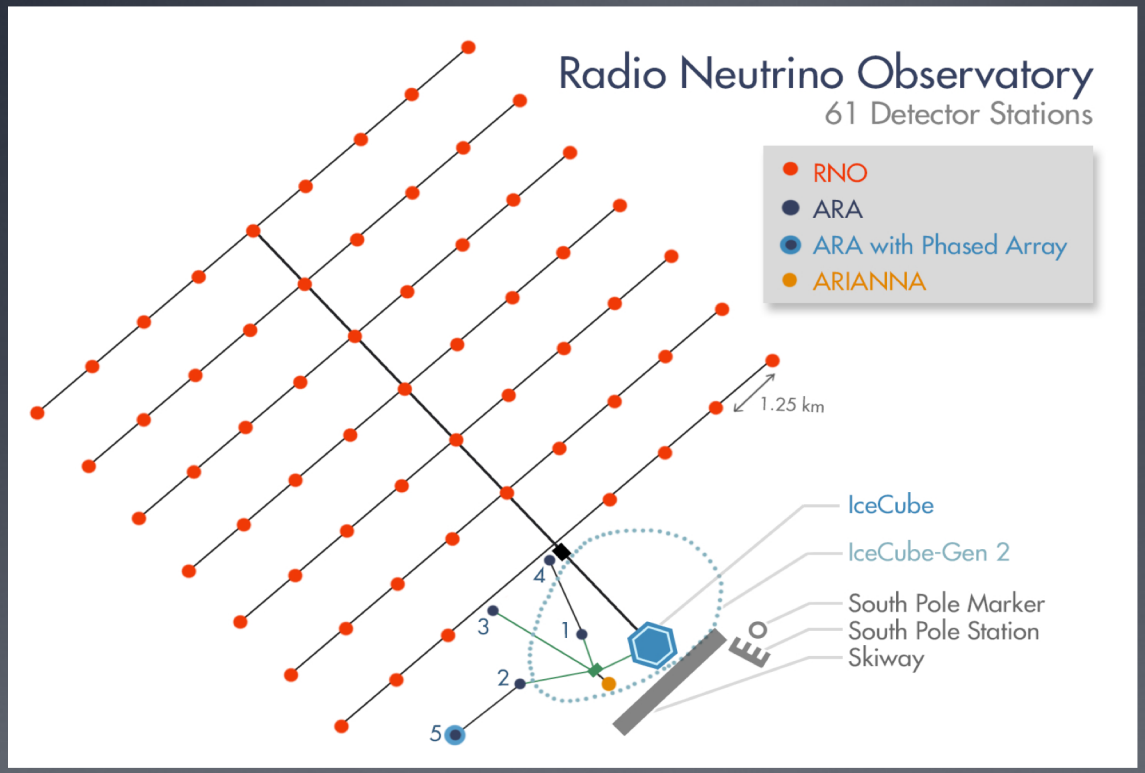
Multi-messenger and Point Source Studies with RNO

- A multi-messenger alert system
  - Receiving alerts and changing the trigger accordingly is straightforward
  - Sending alerts is harder, but possible?



- Expected 90% containment, assuming:
  - 1 degree radio-frequency reconstruction
  - 10 degree polarization angle resolution
  - 2 degree off-cone angle resolution
- Acceptance band is for 10^{17} eV

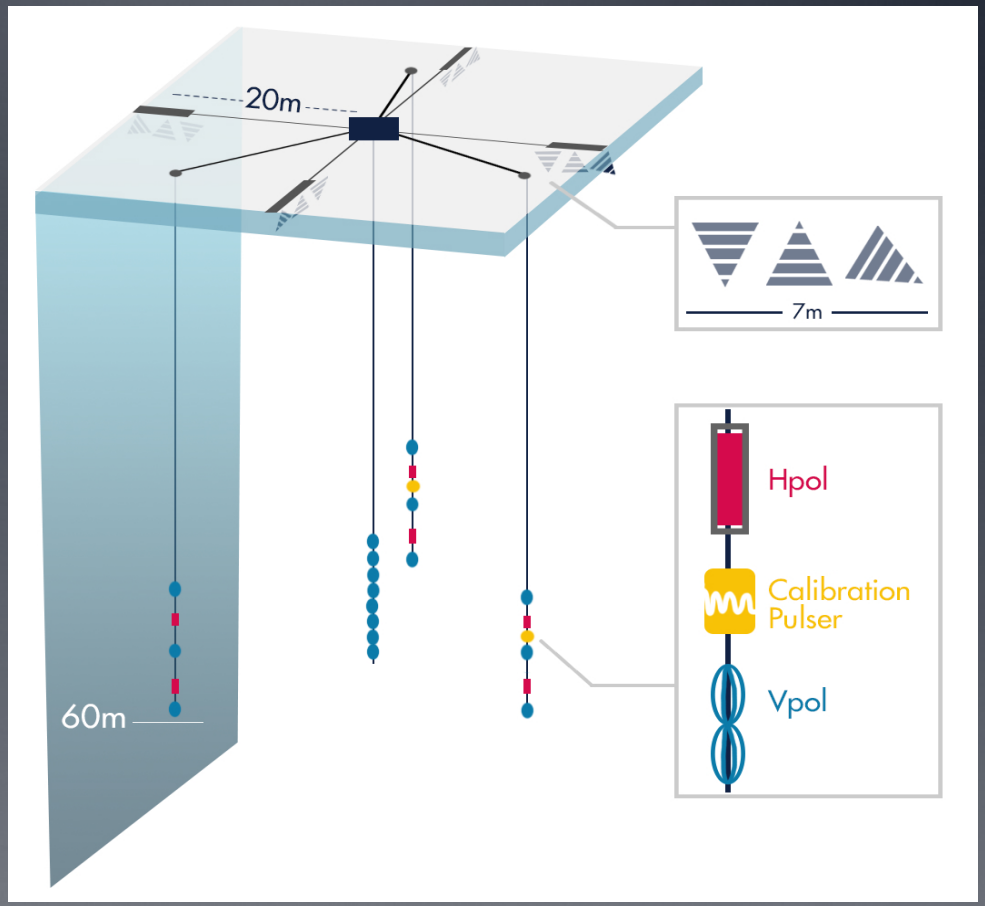
The Radio Neutrino Observatory (RNO) Layout



- Uses phased array trigger + DAQ
- Cabled power and communications to each station, for year-round livetime
- Construction proposal submitted to NSF

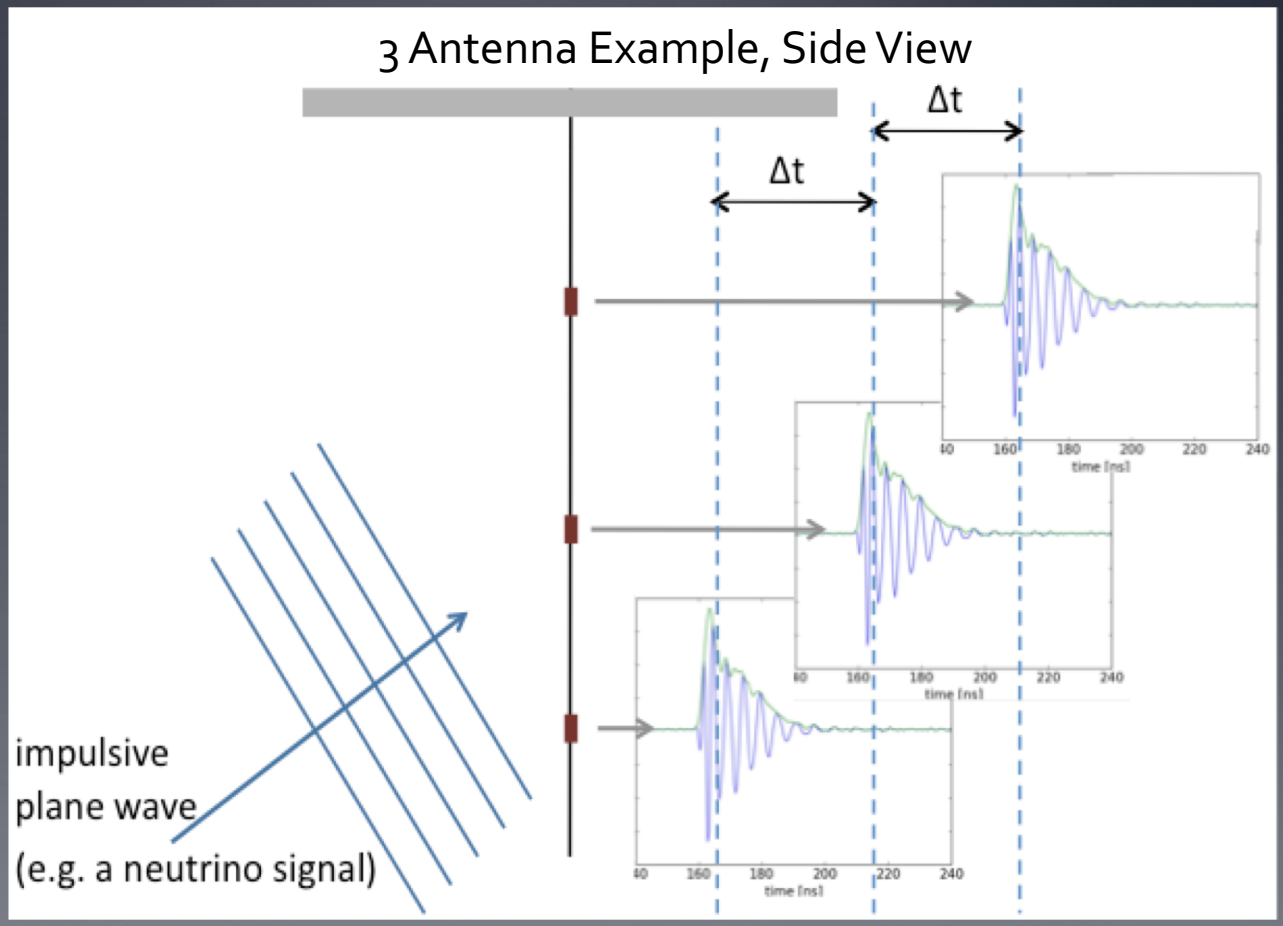
The RNO Station Design

- Combines surface and deep components, with separate triggers:
  - Deep Component: 6-inch holes. Central trigger string, and outrigger dual-polarization reconstruction antennas
  - Surface Component: high-gain LPDAs (larger bandwidth)
- The combination yields: high sensitivity per station, low background, good pointing resolution (for multi-messenger studies), and cosmic ray detection and veto

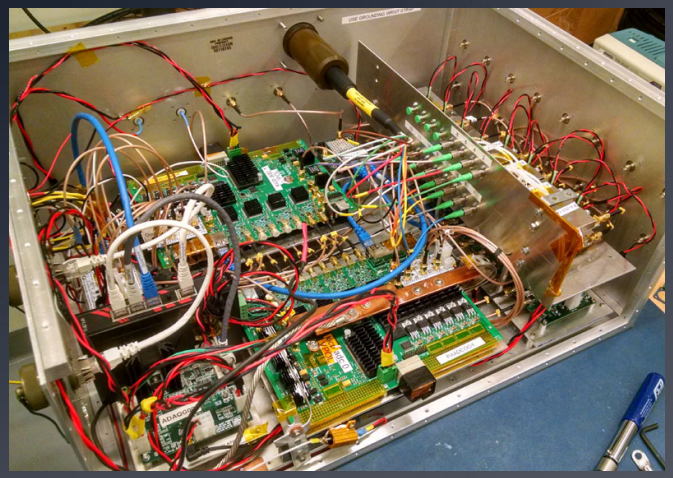


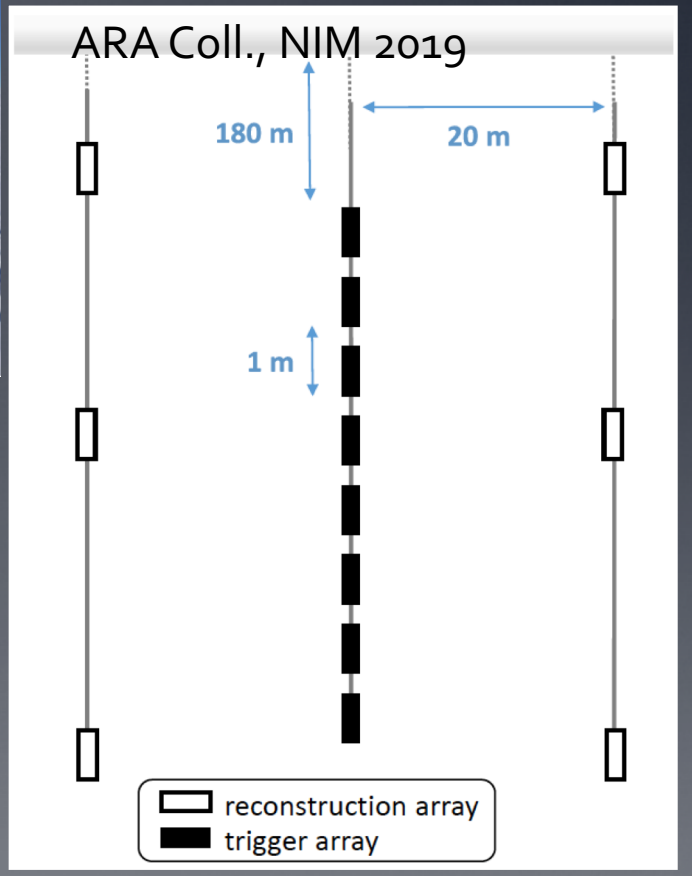
Pushing the Threshold Down: A Phased Array

- You know Δt based on the antenna geometry and the speed of light in ice
- Line up signals according to the Δt you know, then sum
- For real neutrino events (plane waves), you a get a higher signal-to-noise sqrt(N) in voltage
- Do this beamforming all the time for all possible incoming angles



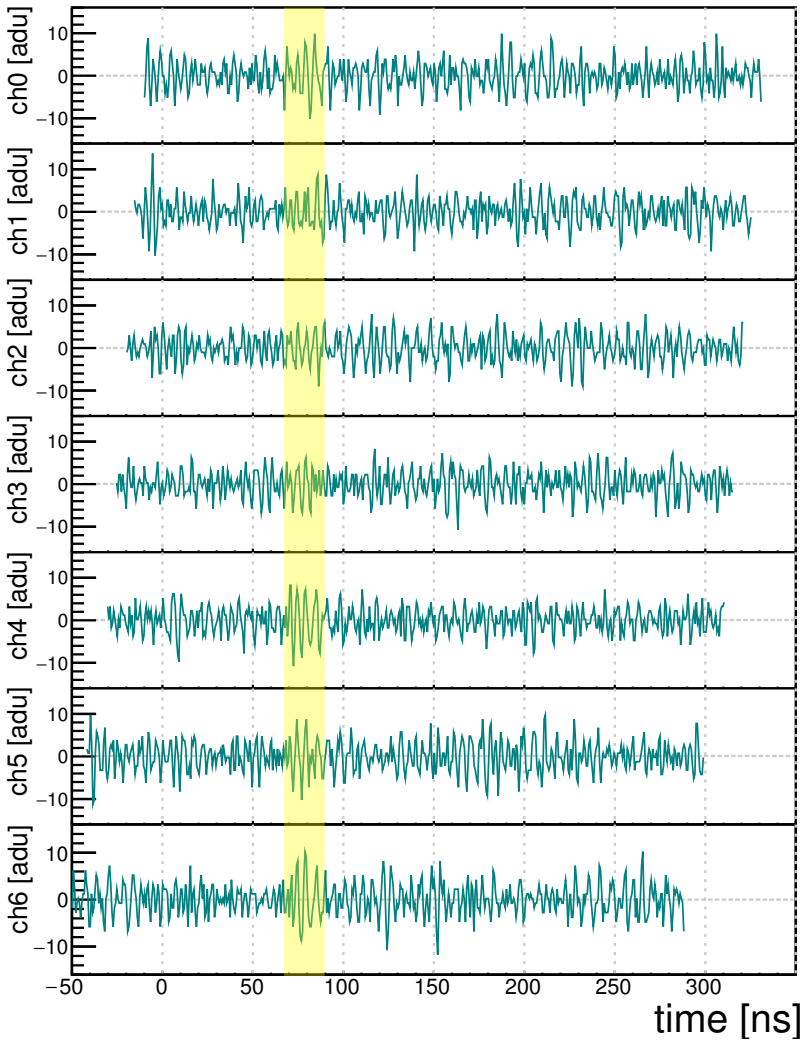
A Phased Array Trigger for ARA

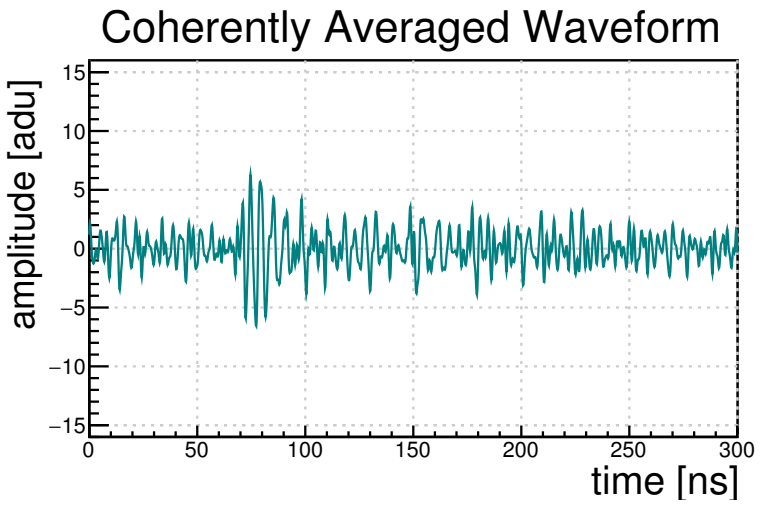


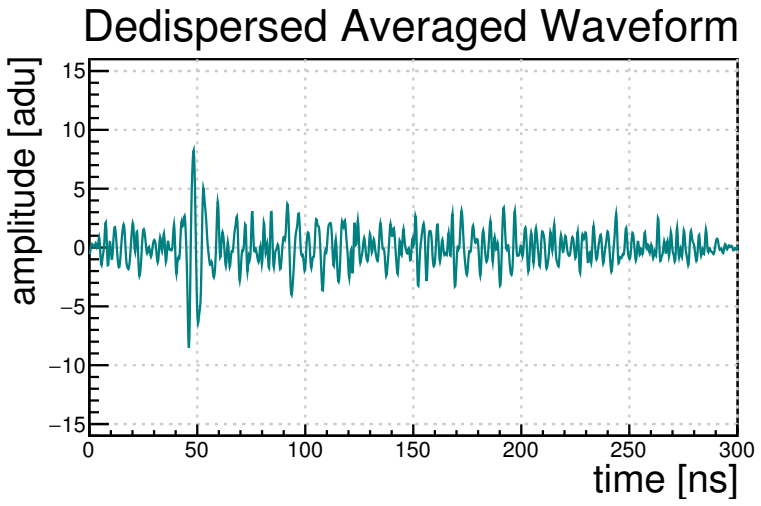


- Installed December 2017 at South Pole
- Custom 1.5 GSa/sec, 8-channel board
- Beamforming and power calculation done on FPGA
- Extends to more channels by daisy-chaining

Example Calibration Event with ARA Phased Array

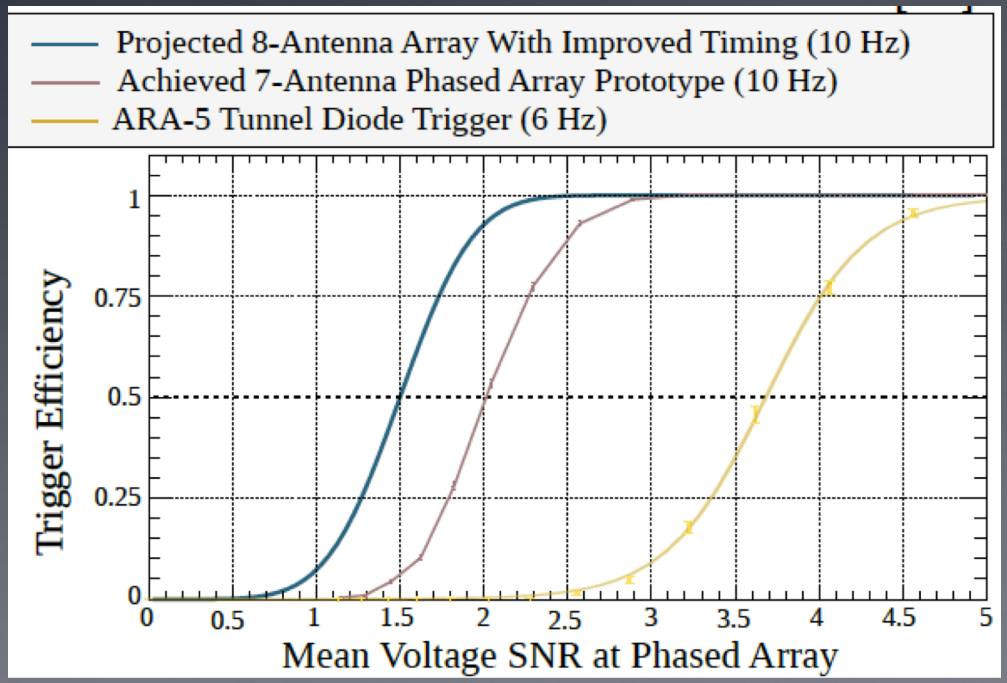


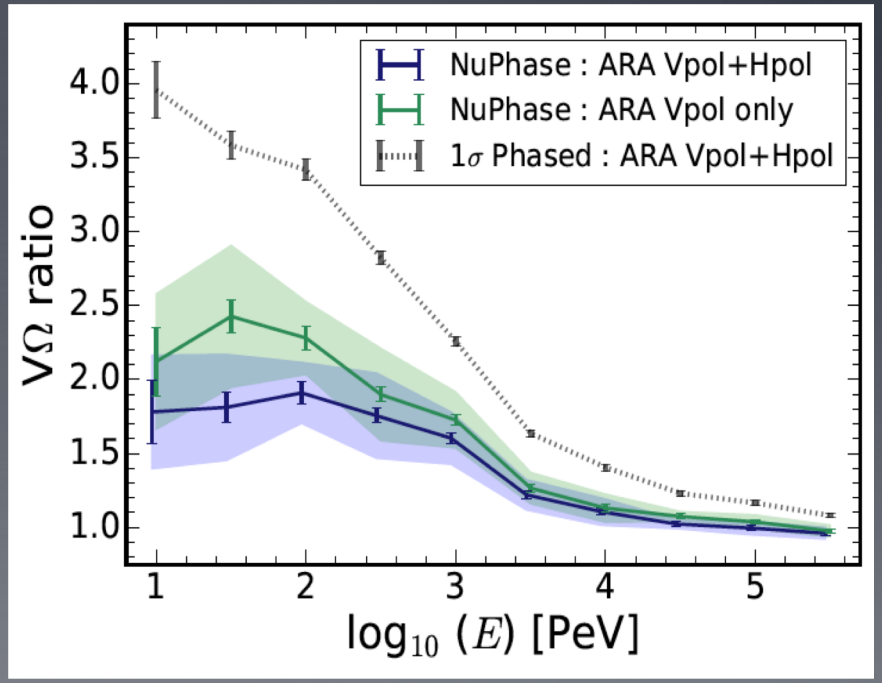




Phased Array Performance

- Measured Trigger efficiency vs. SNR: 50% at 2.0σ, compared to ANITA3 (50% efficiency at 4.0σ) and previous ARA (50% at 3.7σ)
- Factor of 2 achieved, Factor of 3-4 with easy improvements

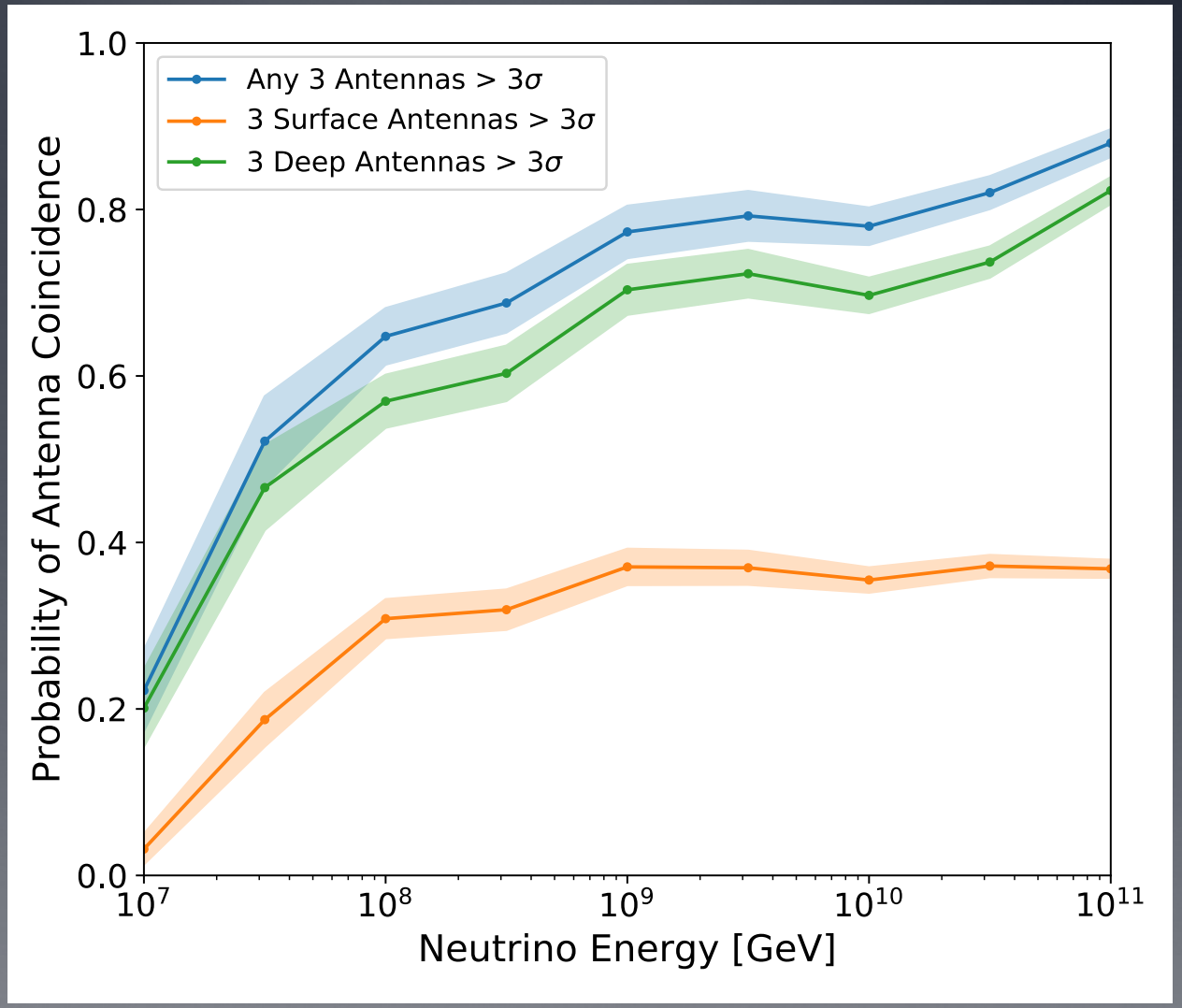




ARA Coll., NIM 2019

Analysis Efficiencies

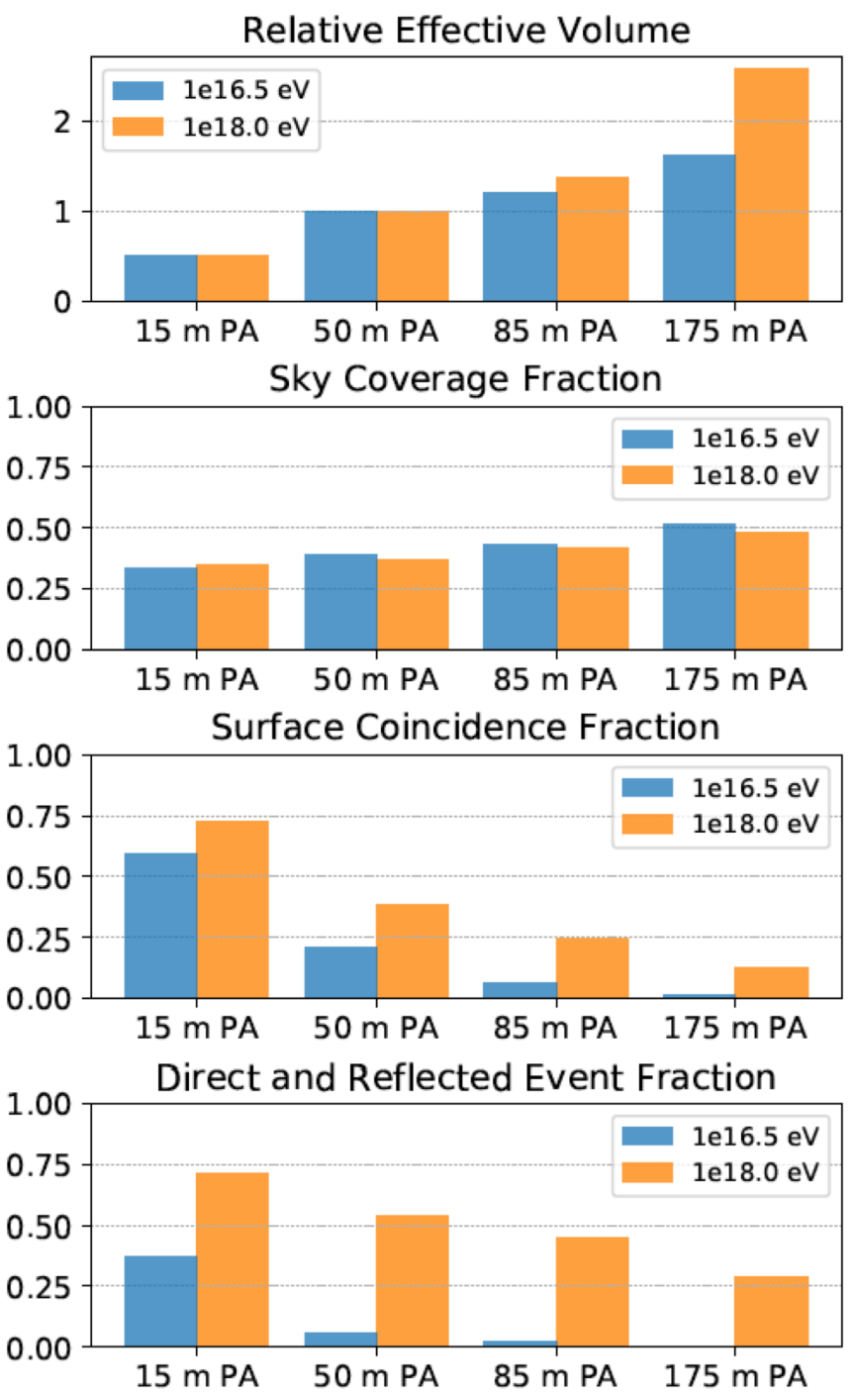
- A low-threshold trigger is only useful if you can reconstruct the events (separate neutrinos from background, which is dominated by thermal noise for ARA)
- Applying a conservative analysis criterion based on analyses already performed on ARIANNA, ARA, and ANITA, we can already reconstruct a high fraction of events
- Working on analysis of ARA5 data, including the phased array, to further improve these techniques



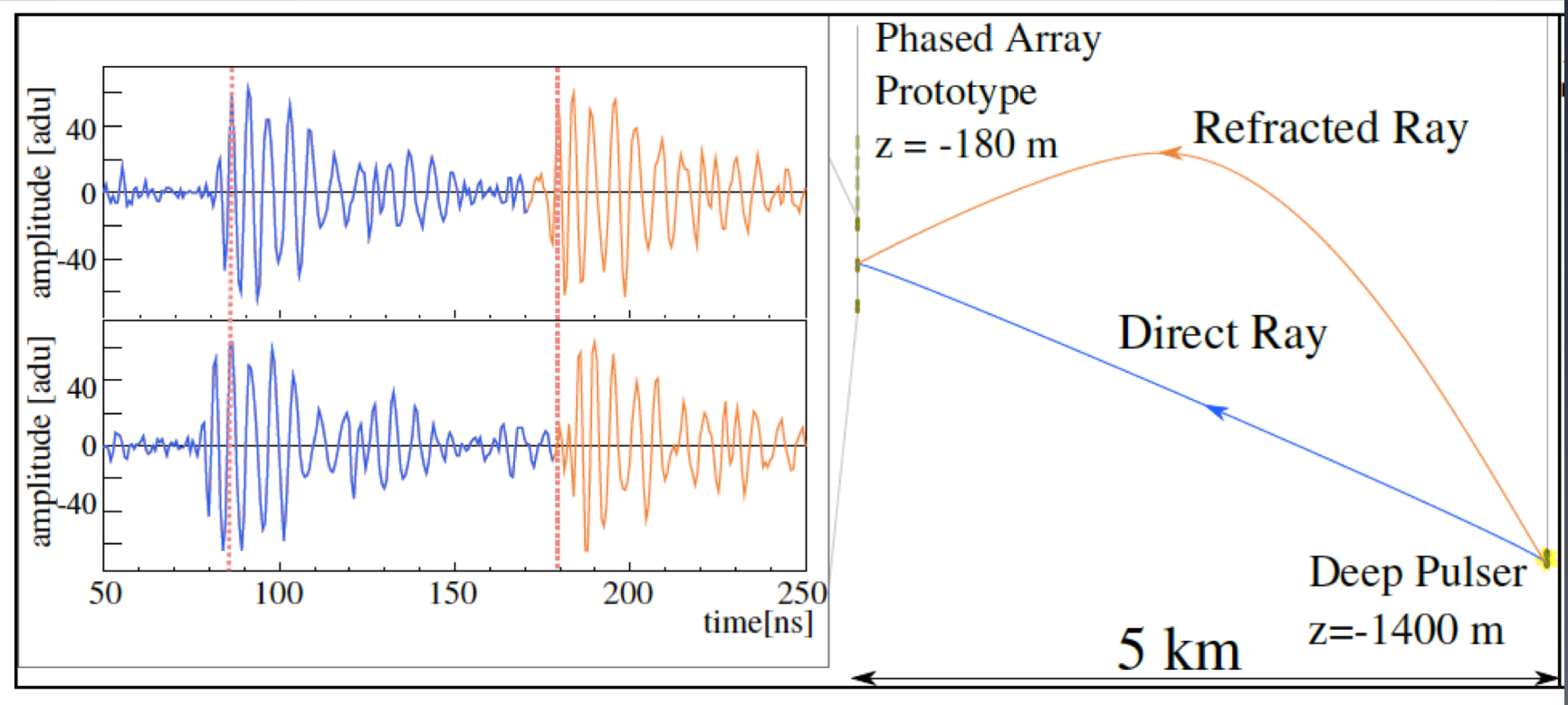
Design Optimization: Surface+Deep Components

- The desire for large effective volume per station and large sky coverage drives the deep component deeper
- The surface and deep components see a fraction of events in coincidence, providing a low-background channel. This fraction goes down as the deep component goes deeper
- Another low-background channel is events seen via two paths for radio propagation through the firn (direct+refracted/reflected rays). This fraction goes down as the deep component goes deeper

→ The desire for large effective volume and sky coverage is countered by the desire for a high fraction of neutrino events to be in one of these two "golden channels." 6om depth is a good balance.

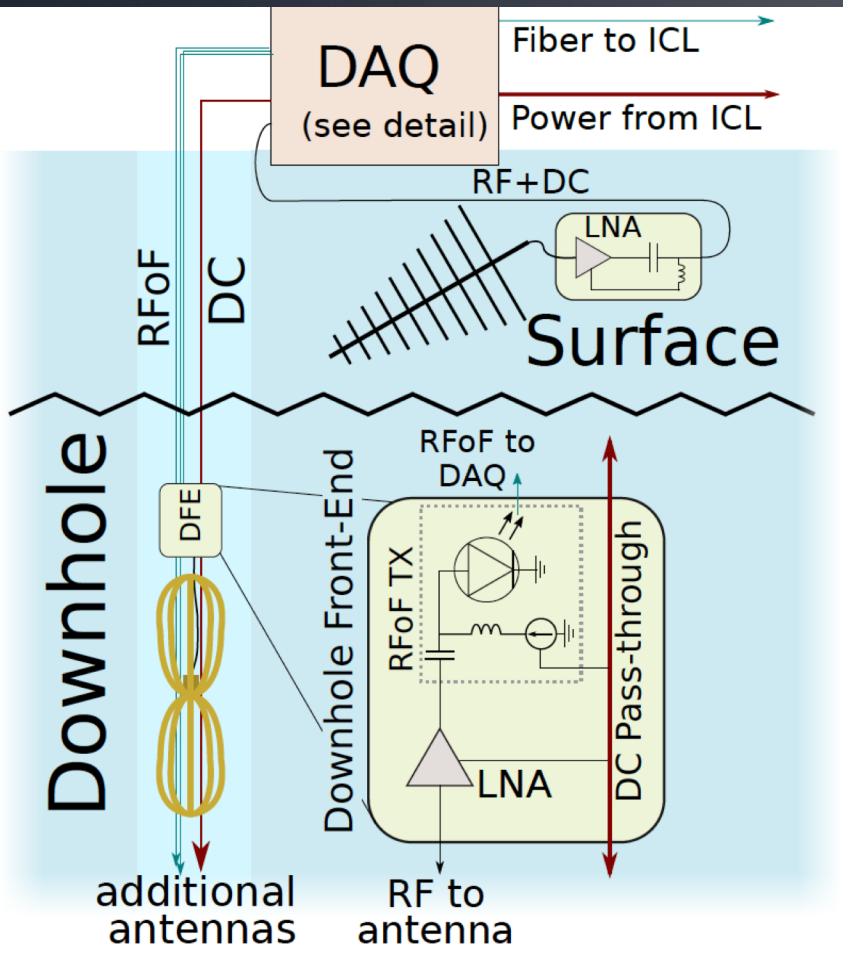


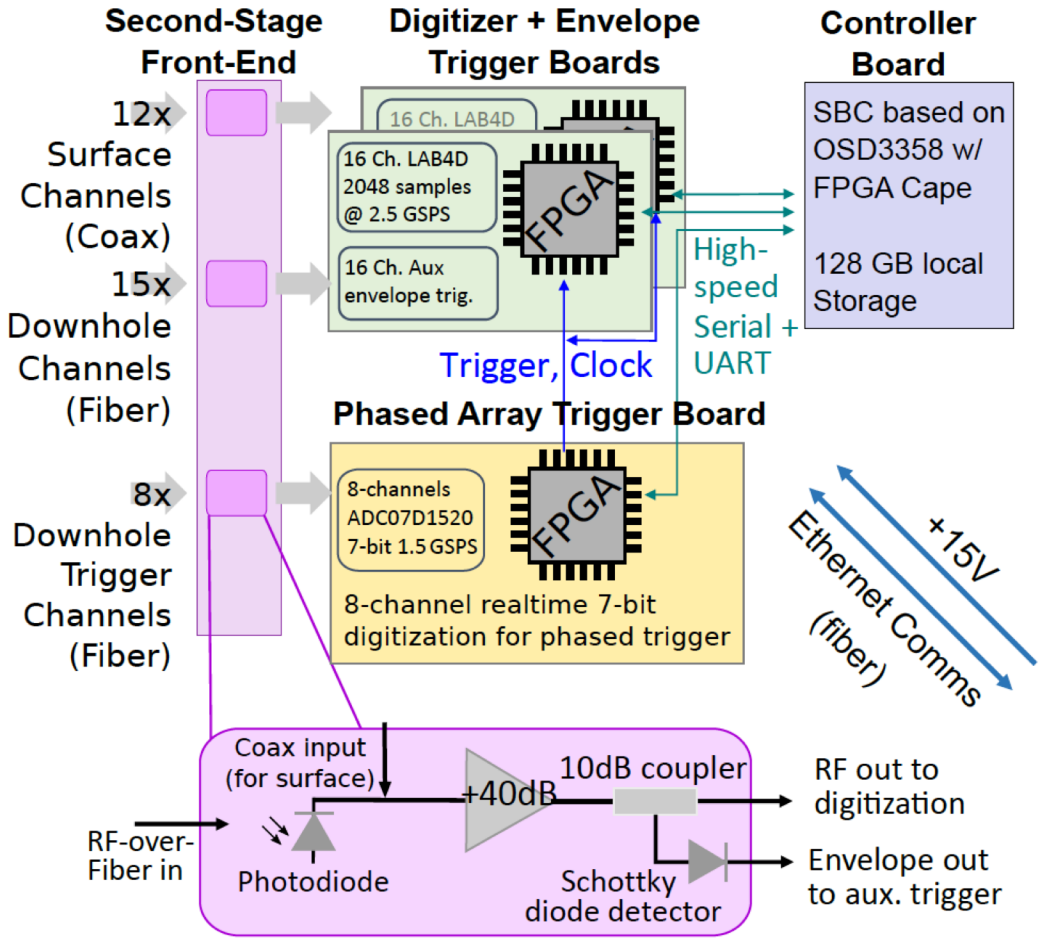
Direct + Reflected/Refracted Event Example



- Deep pulser calibration source viewed with the phased array on ARA5

RNO System Diagram

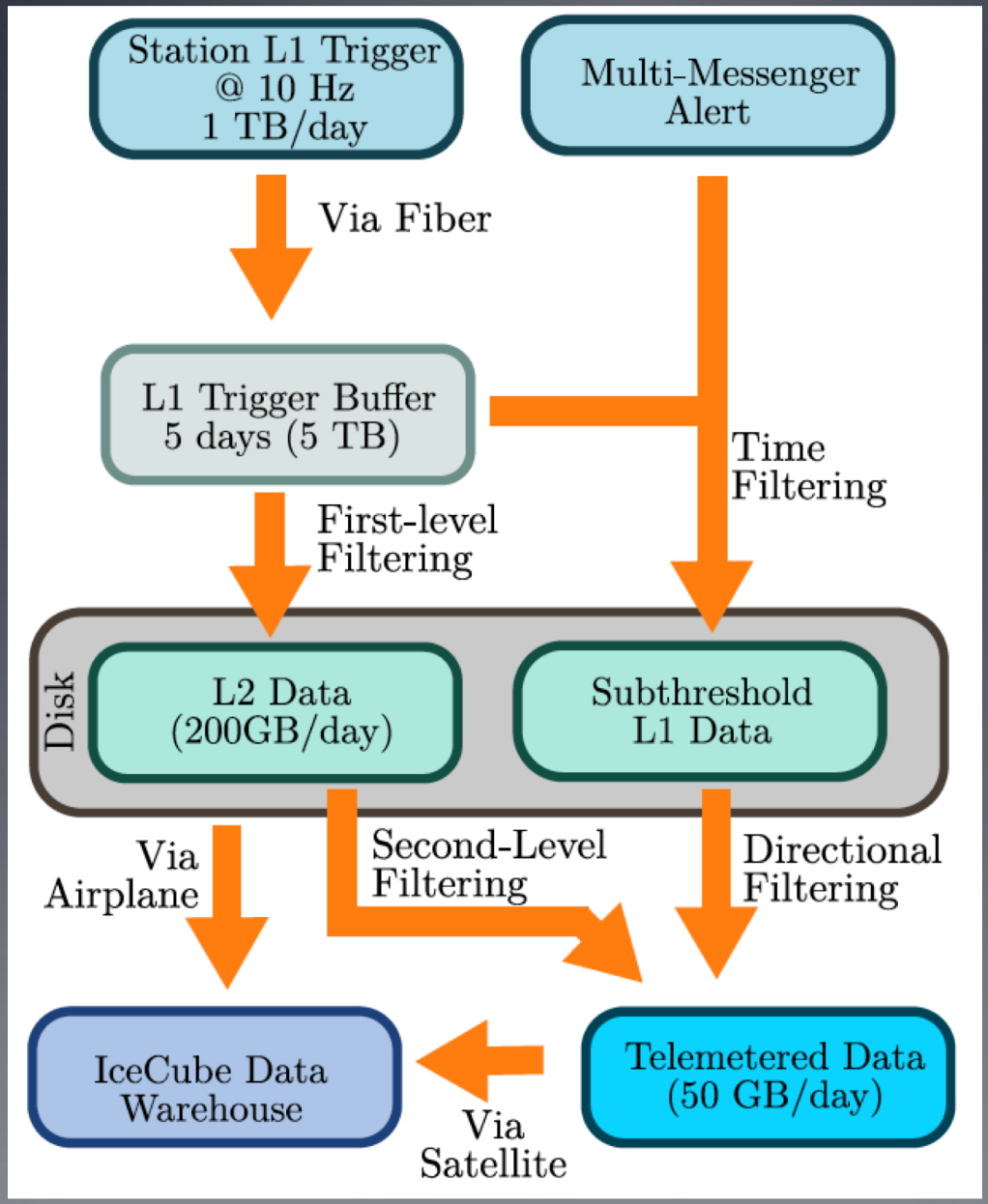




New: ASIG Drill

- Auger drill from IDPO-IDDO capable of drilling to 100m at South Pole, 6-inch diameter dry holes, in 1 day, with 3 operators (2 provided by IDPO-IDDO).
- With two working shifts, can drill and install up to ~25 stations/season.
- This is significantly more lightweight than the ARA drill, which was capable of getting to 200m, but required more people and time.

RNO Online Dataflow



Proposed RNO Schedule

- Begin deployment of stations in 2020-2021, 4 full deployment seasons