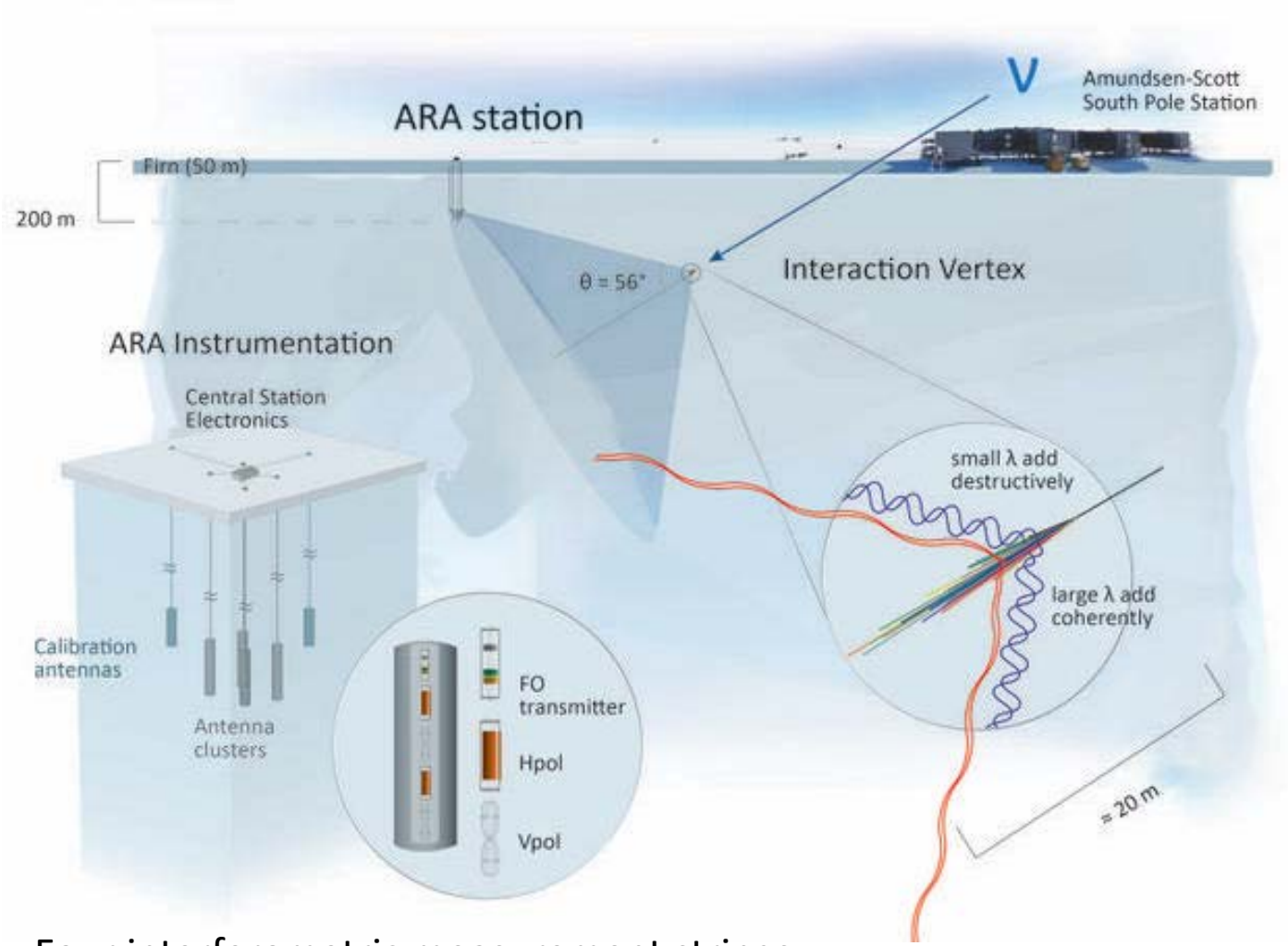
Update on Neutrino Observatory in Ice with Radio Technique

Allan Hallgren / Uppsala

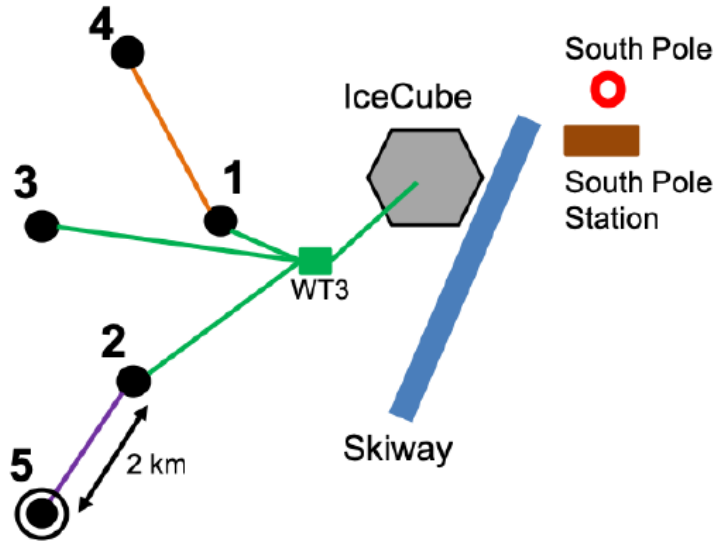
Partikeldagarna 2019

Linköping

Recent results from the Askaryan Radio Array (ARA)



Four interferometric measurement strings, each 2 V-pol + 2 H-pol antennas.



Contribution to ICRC 2019
ArXiv:1907.11125
Installed in stages from 2012, with variations
Deepest station at 200 m depth
Station 5 has an added phased array trigger

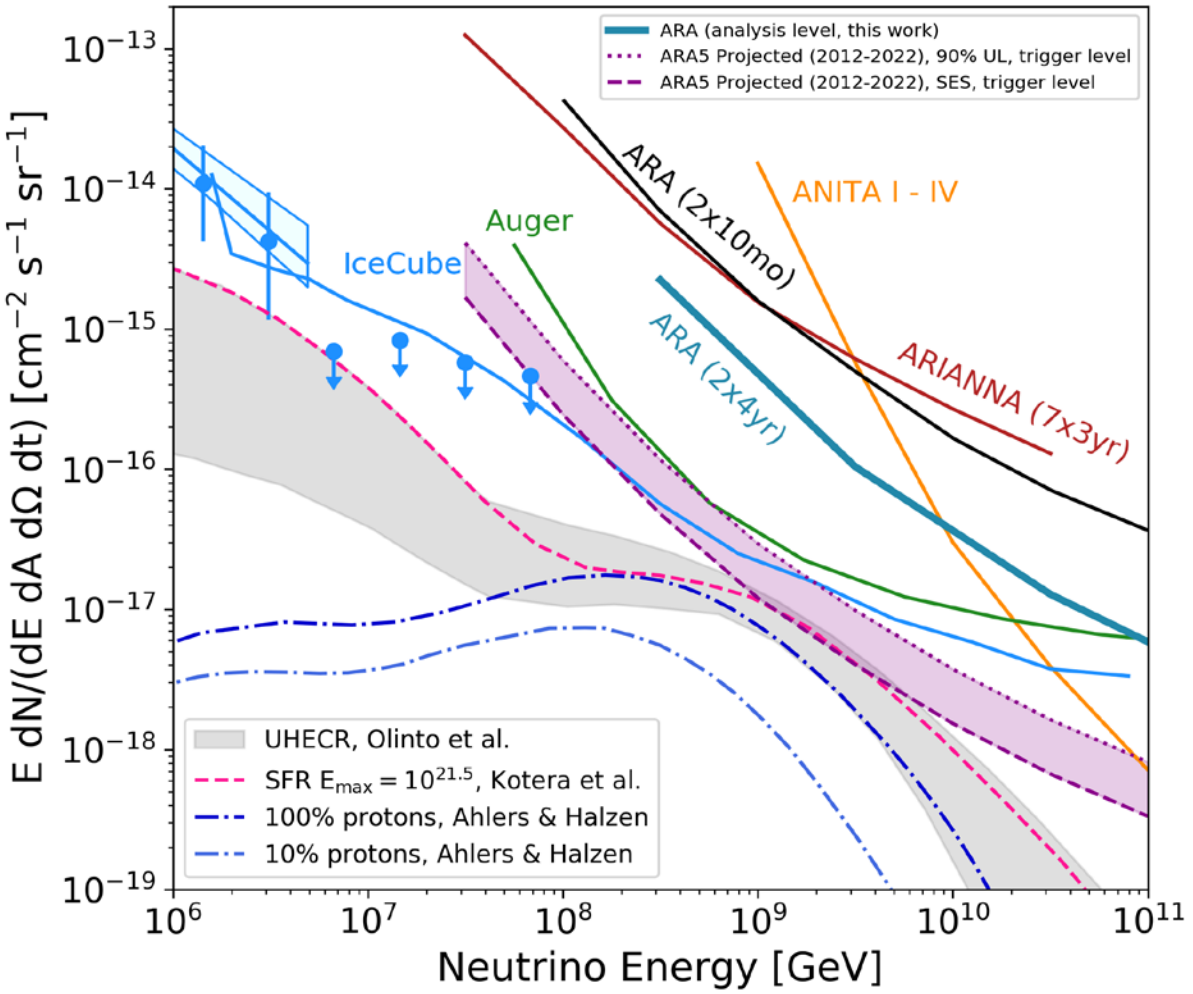
Recent results from ARA collaboration

- Previously published limit from 10 months operation with 2 stations (A2, A3) [Phys. Rev. D93 082003; arXiv:1507.08991]
- Now reporting close to final results from stations A2 and A3
- Data from period 2013-2016
- Improved Analysis efficiency wrt earlier analysis.
- Efficiency depends on neutrino energy and on Signal to Noise Ratio (trigger demanded 3 of 8 antennas above 5-6 * thermal noise).
- Two search versions for each polarization (vertical, horizontal) investigated. Expectations based on 10% burn sample reported. Analysis not unblinded,.
- Background from a model based on the 10% burn sample: 0.010 events expected in V-pol and 0.016 events in H-pol (in one analysis of A2)

Recent results from ARA collaboration

Fig 5 in ICRC proceedings, arXiv:1907.11125
The new ARA result (aqua) is an extrapolation from 10 % burn sample in one station (A2) to 2*90% blind sample in A2 and A3
(A3=A2 assumed)
(See paper for full figure caption)

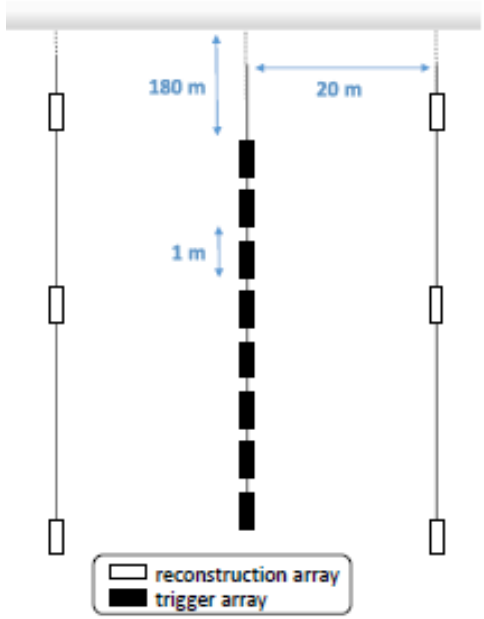
Purple band is an optimistic expected result for full 5 station ARA with data until 2022.
Assuming full analysis efficiency after trigger, no background.
Effect of Phased array threshold reduction included for A5 (energy dependent V_{eff} increase of 20-60%)

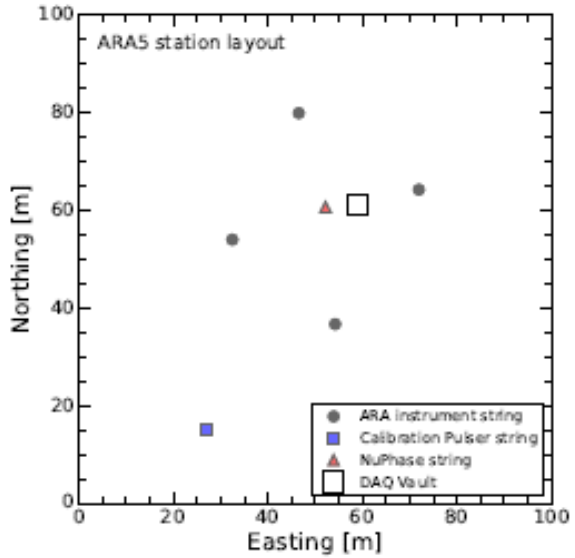


Phased Array Trigger development in ARA: NuPhase

[NIM A930 (2019) 112 (arXiv:1809.04573)]

- 8 dipole antennas on one central string in ARA-5, 180-190 m deep (10 deployed, 7 working)
- Hole diameter 16 cm
- Installed season 2017/2018
- Present NuPhase only V-pol
- Two H-pol antennas added in hole,
  not used in trigger
- Signal over fiber to surface
- 150-800 MHz, -450 MHz
- 25 W in downhole amplifiers
- 80 W for surface box electronics
- Signals added with phased delays in FPGA + electronics+electronics+electronics……
- Total 16 ADC, 7-bit, 1.5 GHz
- Temperature-55C
- Nominal operation at 11 Hz (0.75 Hz in each of 15 ‘beams’)

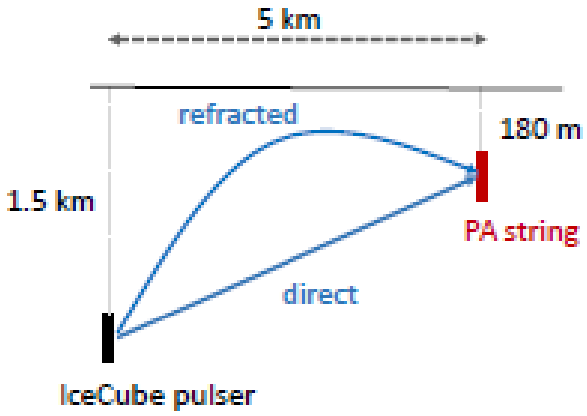


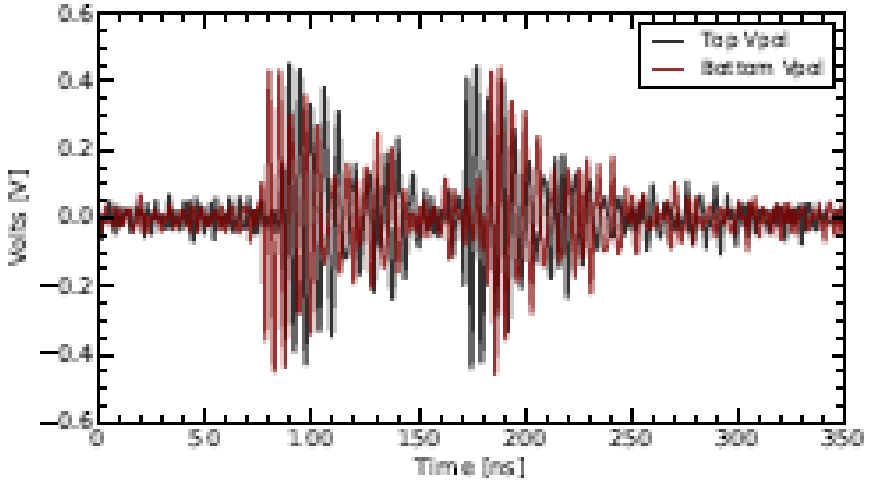


Phased Array Trigger development in ARA: NuPhase

[NIM A930 (2019) 112 (arXiv 1809.04573)]

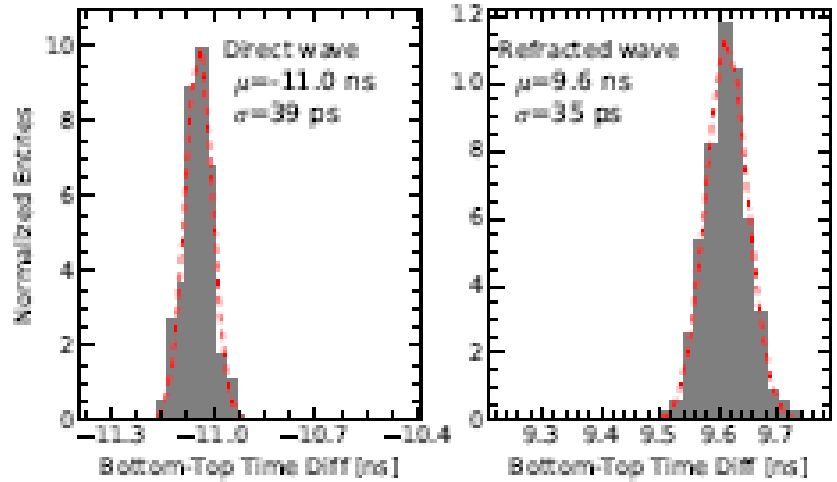
- Tested with a close calibration pulser string in the ARA 5 station, 175 m deep, 55 m distance. → channel amplitude response matching within 5%
- Dipole at 1450 depth, 5 km distance on an IceCube string gives direct and refracted signals
- Both signal directions clearly visible, two channel timing resolution < 40 ps.
- Allows timing offset calibrations in the 100-400 ps range. Not implemented in beamforming firmware
- For single events sampling time resolution dominates





Direct ray

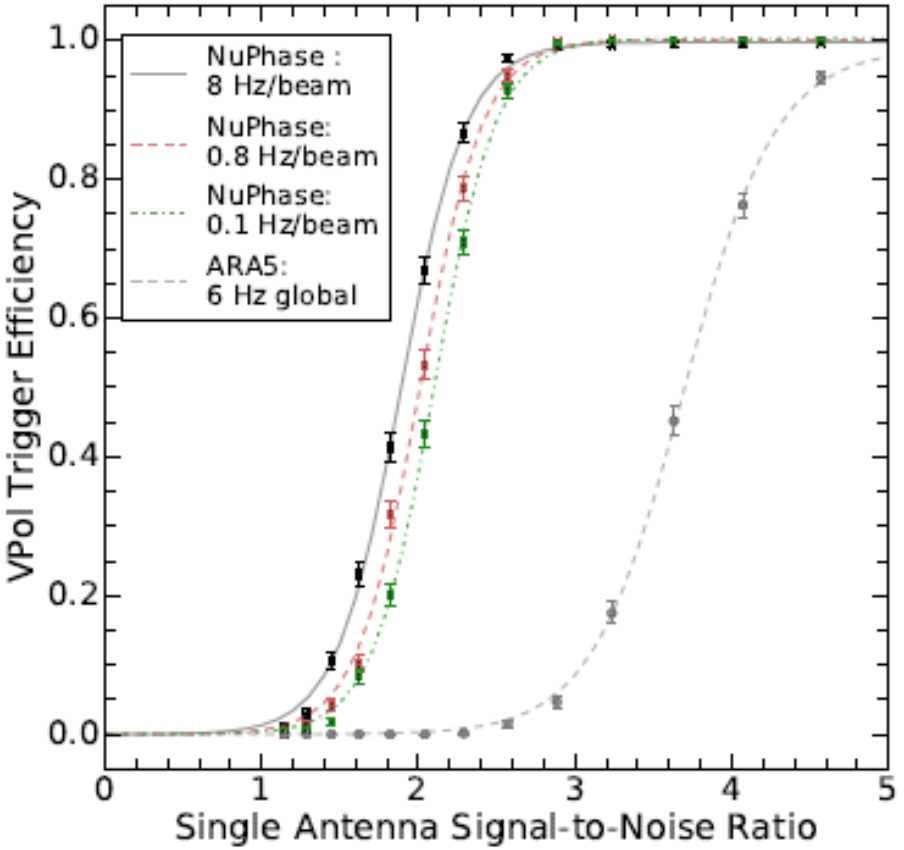
Refracted ray



Phased Array Trigger development in ARA: NuPhase

[NIM A930 (2019) 112 (arXiv 1809.04573)]

- Adapted summing scheme to situation with 3 broken antennas (deployment damage?)
- Aims to cover 100 deg elevation span
- 15 ‘beams’ with FWHM about 7 deg
- Trigger efficiency measured with calibration pulser
- Compensation for near field
- Some On/off beam effects (less if faster sampling)
- 16 antenna Phased array → 1 sigma threshold



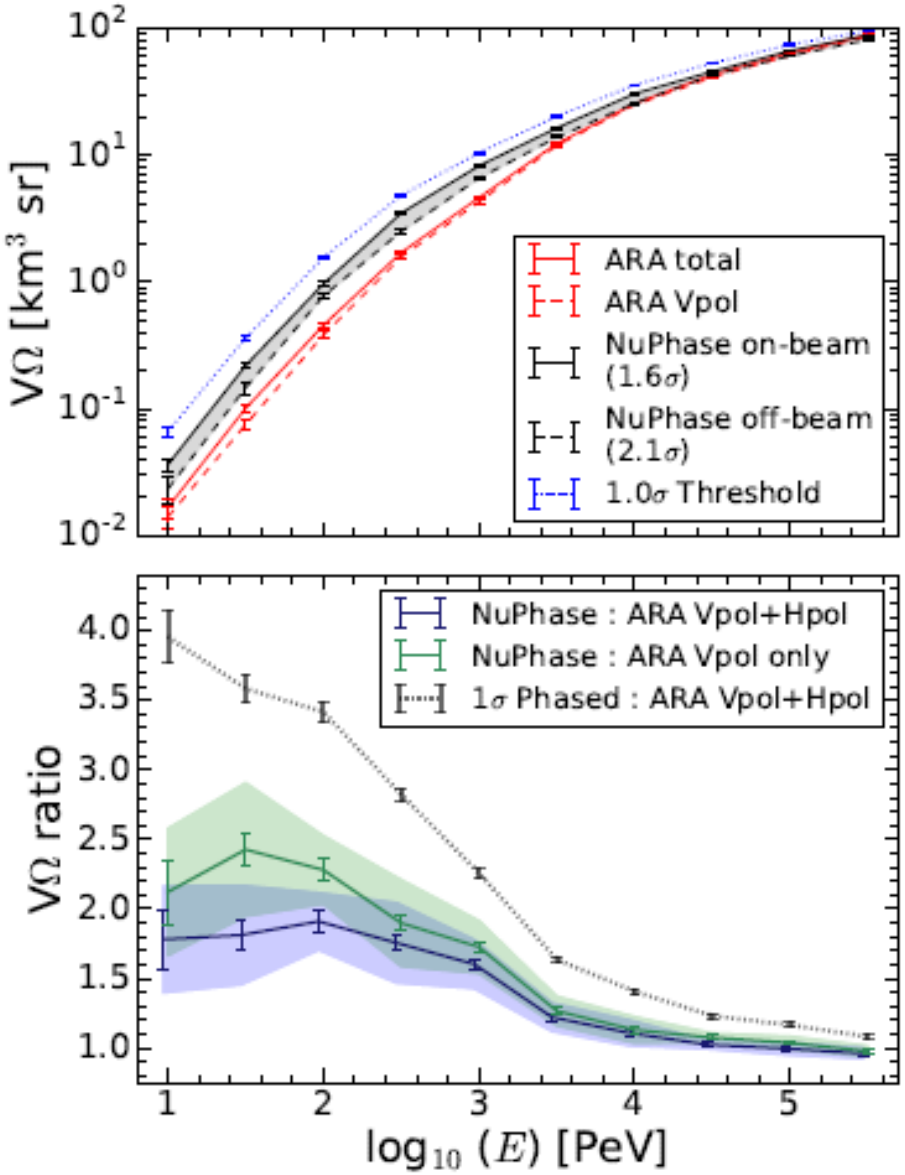
Conclusion:

A Phased Array trigger allows reduced threshold without increased noise rate

Phased Array Trigger development in ARA: NuPhase

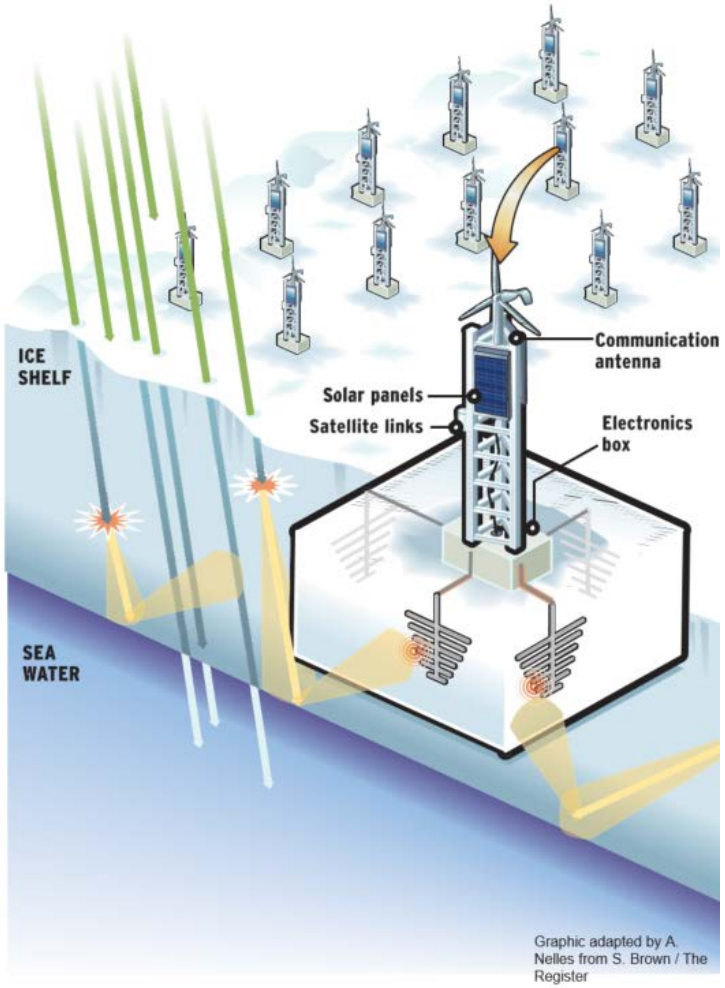
[NIM A930 (2019) 112 (arXiv 1809.04573)]

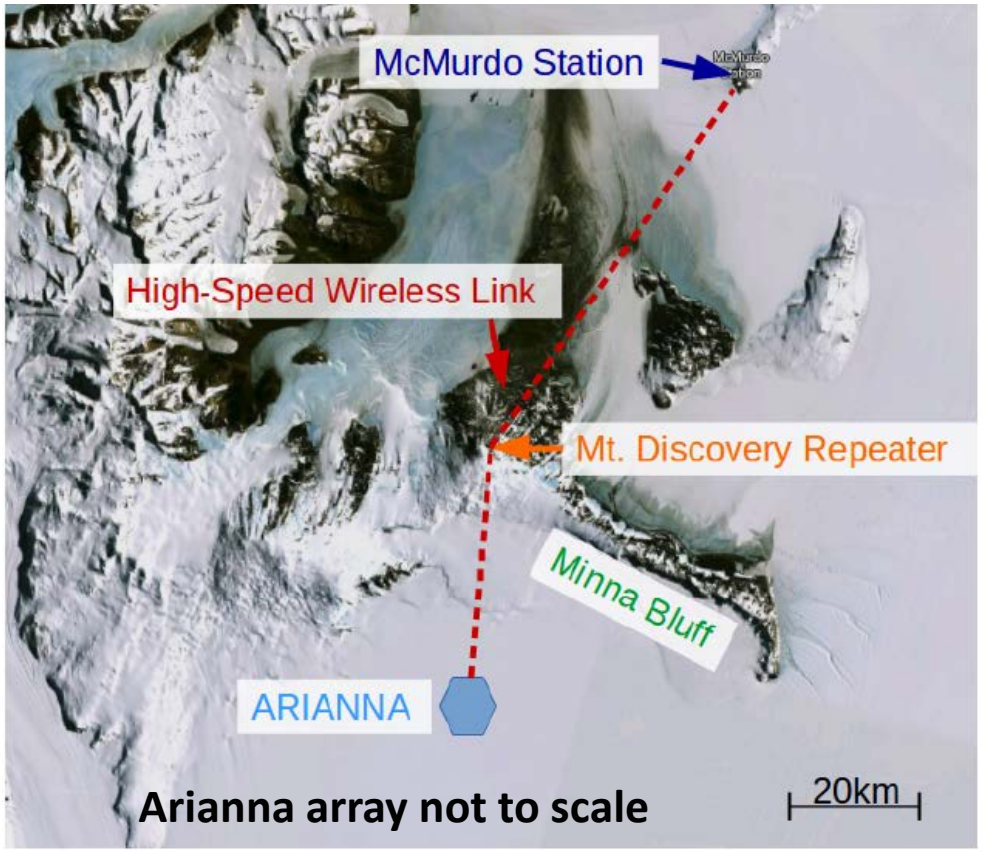
- Neutrino effective volume gain calculated through simulation, at trigger level (reconstruction not required in the simulation)
- Most V_{eff} gain at “low” energies, 10-1000 PeV
- Color bands show on-off beam variation
- An extended phased array with 16 dipoles shown as the 1 sigma curve.

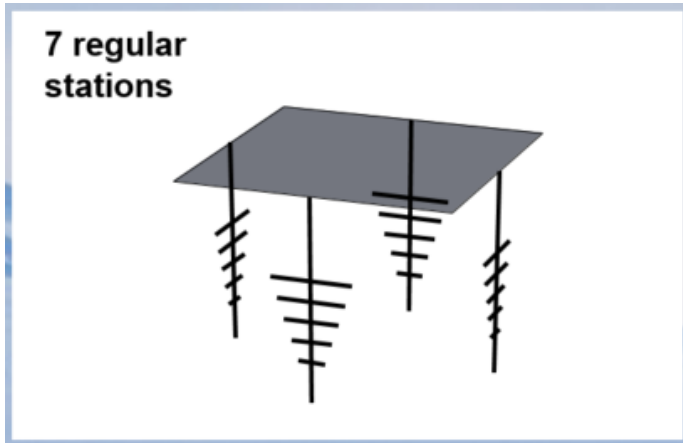


Results from the ARIANNA test bed system

- Publication submitted Sept. 2019 to JCAP, also on arXiv:1909.00840.







Initial station configuration with 4 LPDA antennas

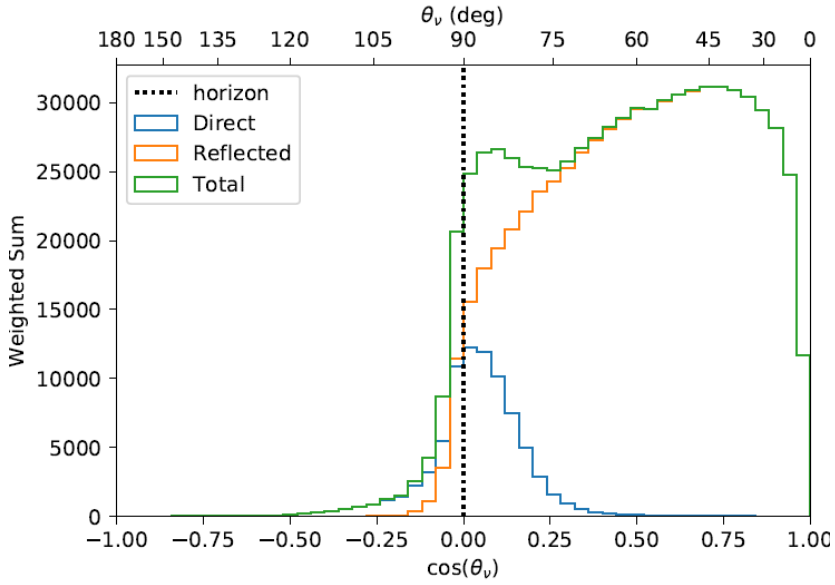
Various other configurations also tested

+ Two ARIANNA demonstrator stations at South Pole

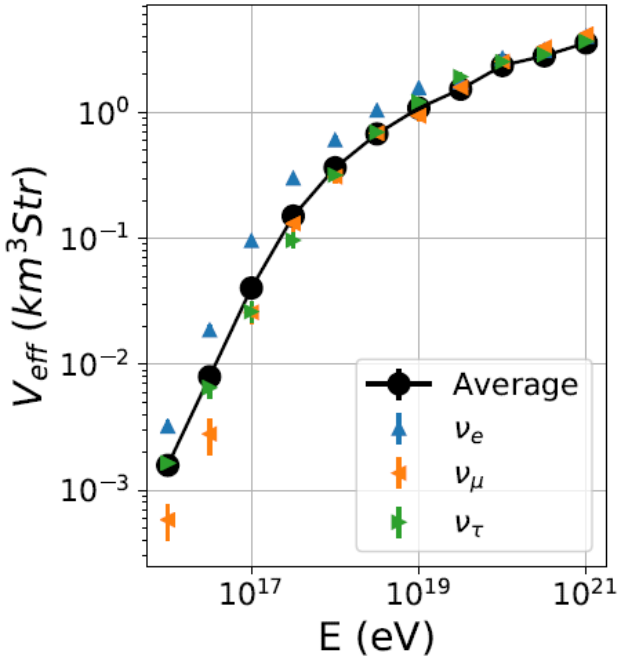
ARIANNA Results

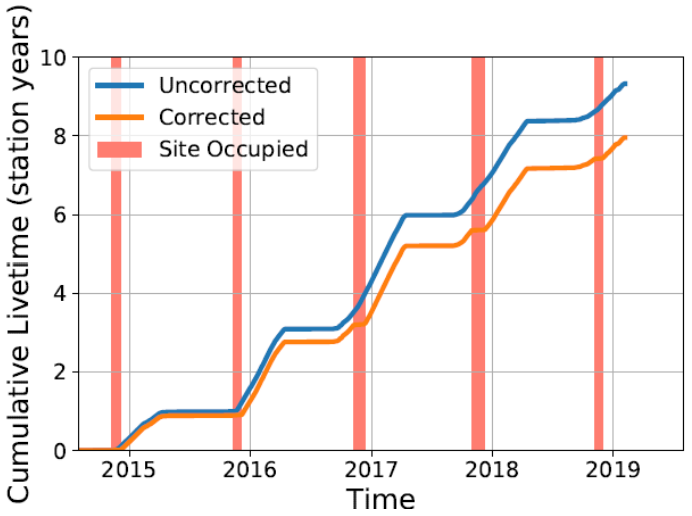
Publication submitted Sept. 2019 to JCAP, also arXiv:1909.00840

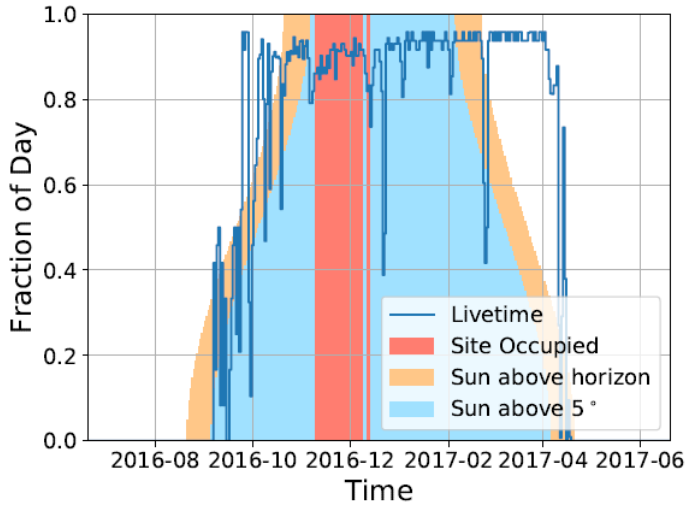
- Analyzed data from 4.5 years calendar time (Dec 2014 – Feb 2019)
- Earlier data published 2015, different electronics
- Live time depends on solar power, deployment work periods, data transmission windows -> 8 station years
- 90% live when efficiency made priority
- Angular coverage includes downgoing neutrinos, due to mirror effect



Single ARIANNA station





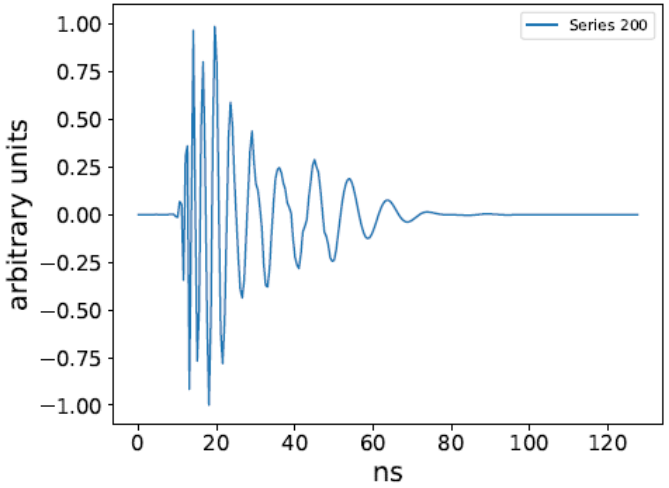


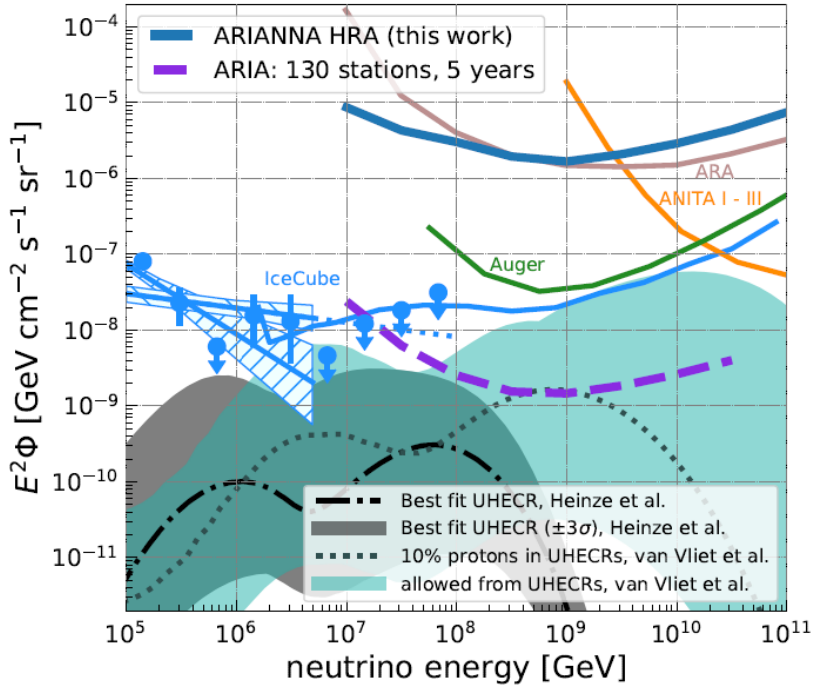
ARIANNA Results

Publication submitted Sept. 2019 to JCAP, also arXiv:1909.00840

- Template used for response to the sharp Askaryan pulse
- Response depends on dispersive response of both antenna and electronics
- Calculate max correlation with seen signals, take best pair average
- Plot versus signal amplitude and determine signal region
- Background from extrapolated data (fit without outliers), and desired bg level (0.5 event)
- No events found in signal region -> limit

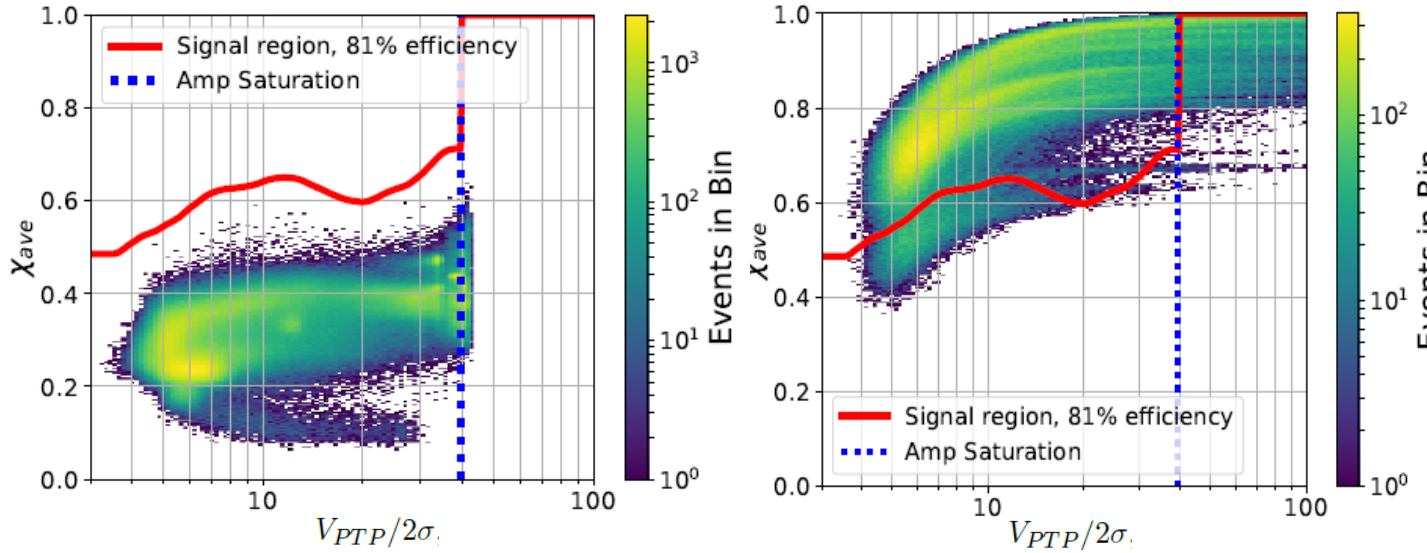
Series 200 amp





BACKGROUND/DATA

SIGNAL/SIMULATION

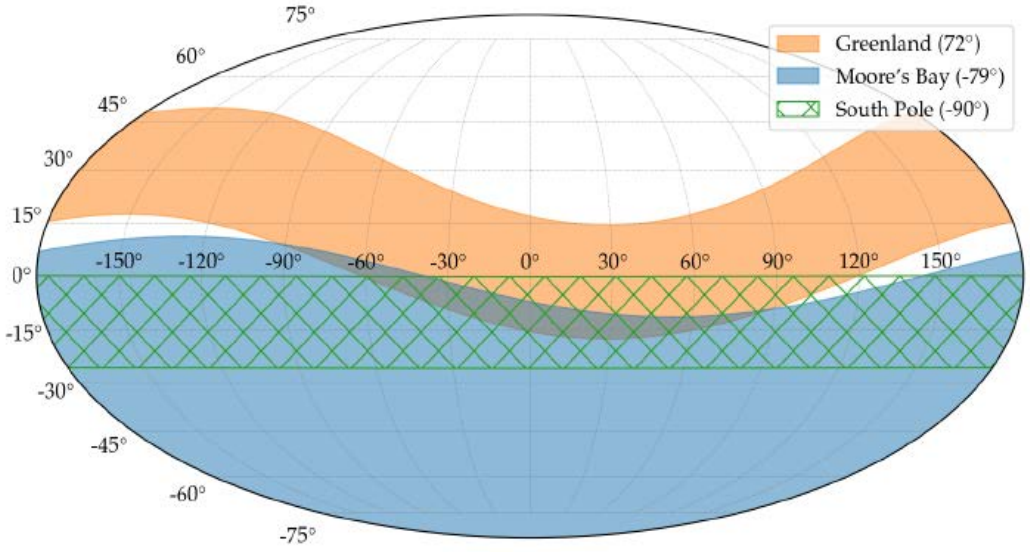


Series 100 amp

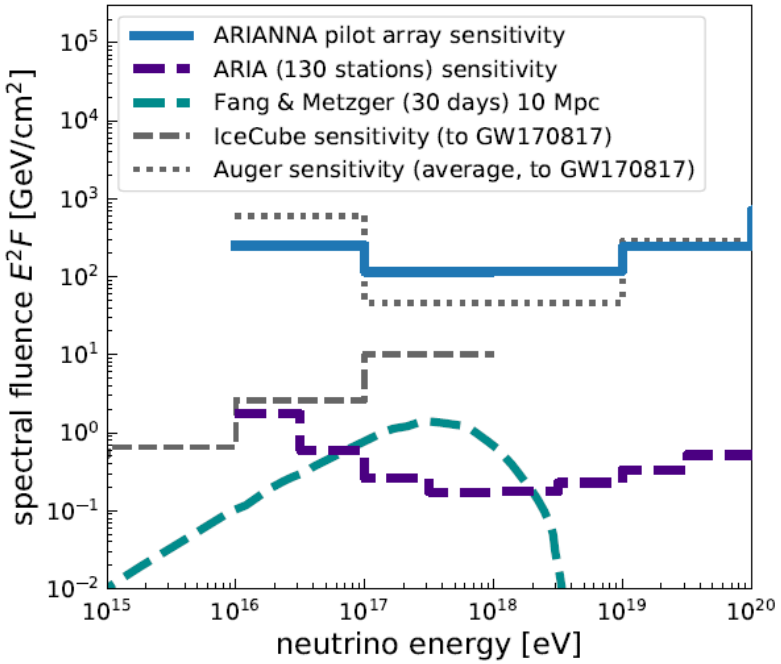
ARIANNA Results

Publication submitted Sept. 2019 to JCAP, also arXiv:1909.00840

Paper also describes some other aspects of ARIANNA at Moore's Bay. Added value to the direct results. Look up if interested!



Ex 1. Sky coverage from Moores Bay compared to Greenland and South Pole



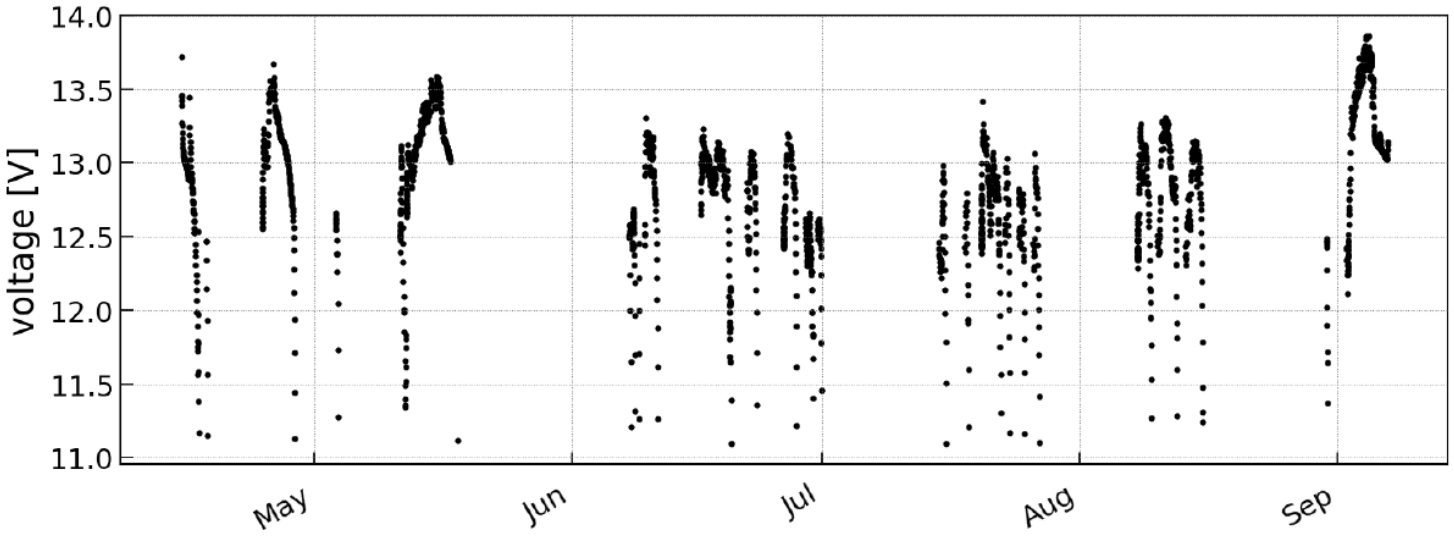
Ex 2. Sensitivity to transients, if they are in visible part of sky

Wind Power

ICRC 2019 contribution: PoS(ICRC2019)968

- Several previous attempts to use wind power with commercial units have failed, including special polar models.
- Robust model developed at Uppsala, Savant, primarily for use with a ARIANNA and tested at Moores Bay.
- Savant 1 and Savant 2 retrieved fully working after one field season.
- Savant 1 was not connected to station, only power performance logged over winter. Installed Dec. 2016. Power vs wind speed follows simulation.
- Savant 2 powered one station during the winter 2018. Electrical components after turbine reduced performance and RF noise was observed when turbine was charging the battery.

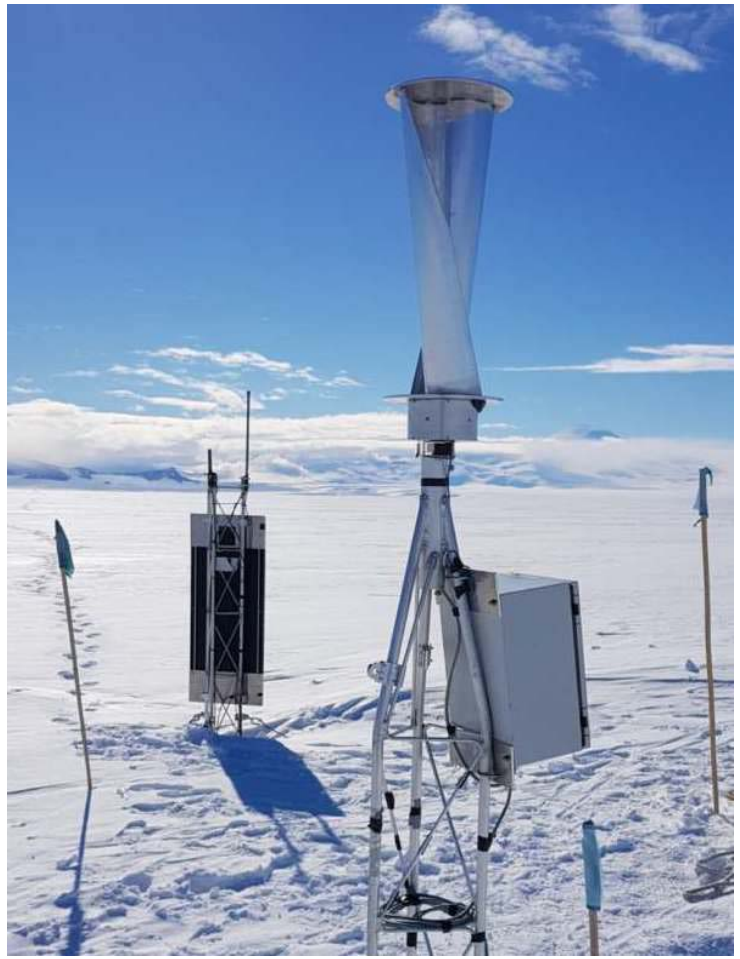
Savant 2,
Moores Bay, winter 2018
Battery fully charged at 13.5 V
24 % uptime.



Wind Power

ICRC 2019 contribution: PoS(ICRC2019)968

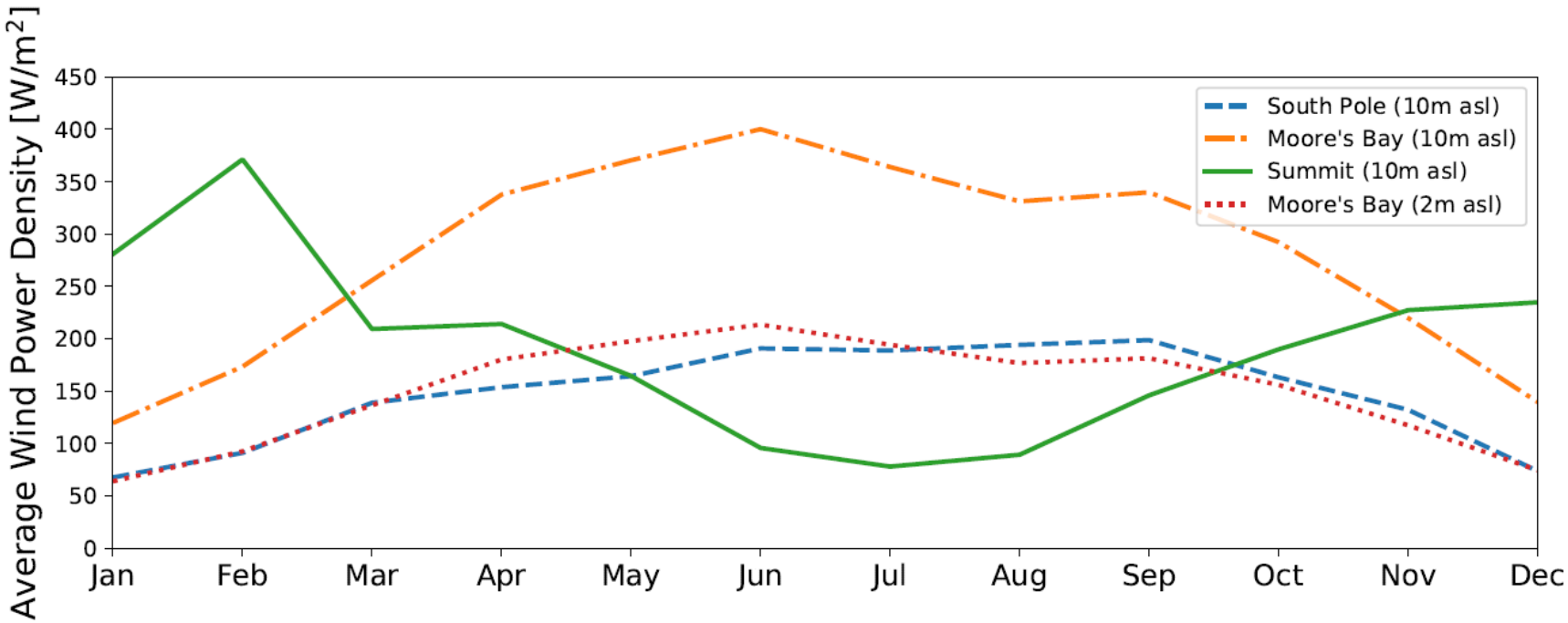
- Savant 3 installed Dec 2018. Larger area swept.
- Achieved 39 % uptime on wind only during Summer months, when wind is normally low.
- 85% uptime predicted for winter time, if battery capacity increased to 1800 Wh
- Contact lost end of March. Next access December 2019.
- In attempts to reduce RF interference various components exchanged in the field. Probable cause exchanged Zener with higher resistance than original version. → overvoltage → damage to the BMU
- RF noise can most likely be eliminated by changing configuration parameter in the BMU. The parameter controls if BMU has mode with fast switching that gives RF around 100 MHz.
- Testing will be difficult as ARIANNA will be decommissioned
- We plan to do some tests in Abisko, Polar's research station



Wind Power

ICRC 2019 contribution: PoS(ICRC2019)968

- Wind power OK for Moores Bay. Tested systems at about 2 m height.
- South Pole and Greenland sites are more challenging.
- Larger turbine (heavy for field installation) or a number of smaller turbines
- Higher above ground (10 m instead of few m)
- Station total power needs to be as low as possible, or turbine+ batteries become large harder to install.
- Temperature much lower, especially at SP, down to -80 C
- Batteries in firn, down to -55 C (OK in ARIANNA test station @ SP)

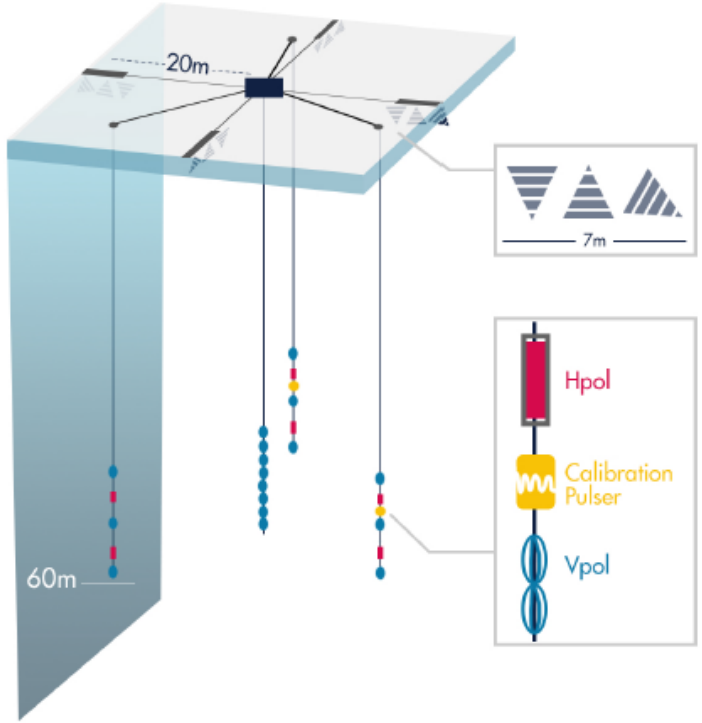


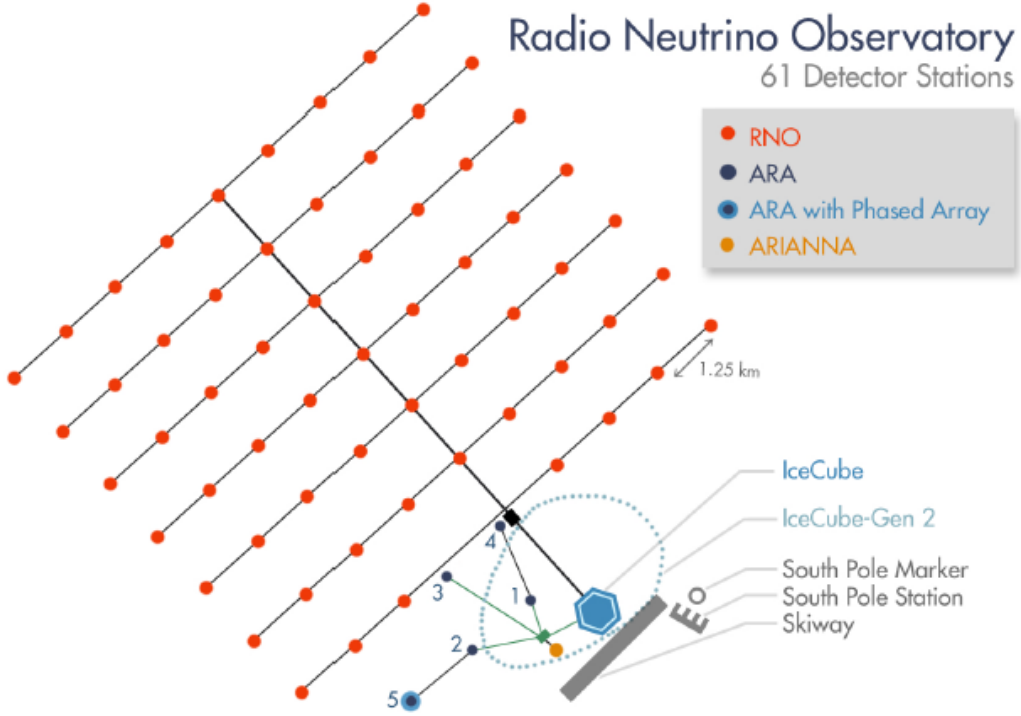
RNO and ARIA

- NSF advised a larger array at SP would be possible
- → ARA and ARIANNA joined in common effort to write one proposal, but finally disagreed on realistic costs and layout
- → two proposals to NSF December 2018, RNO and ARIA

Radio Neutrino Obseravtory (RNO)

- RNO proposed 61 stations, 1.25 km spacing, deploy before 2024
- Each station had a deep part at 60 m (possibly later 100 m) and a shallow part just below surface
- Cabled network for power and communication (over fiber)
- Neutrino energy threshold 30 PeV
- Phased array trigger, 8 channel

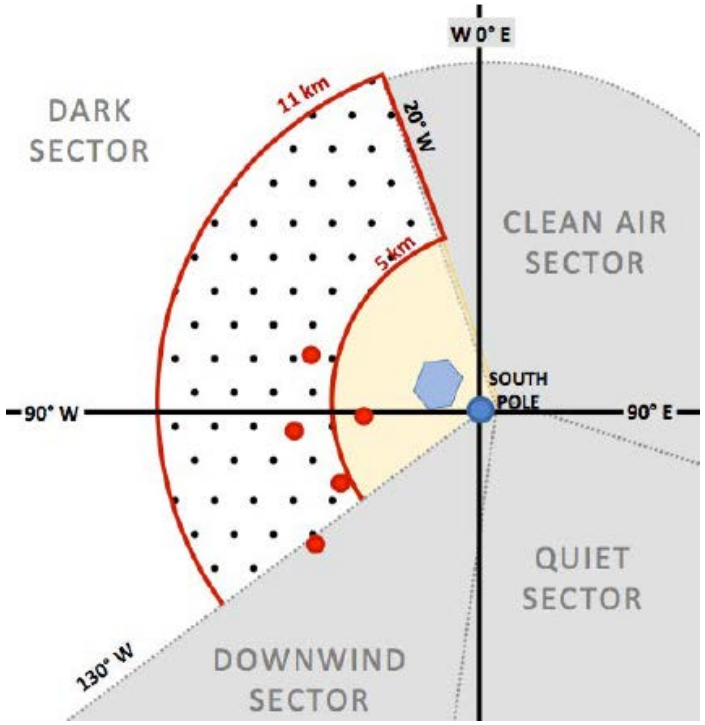


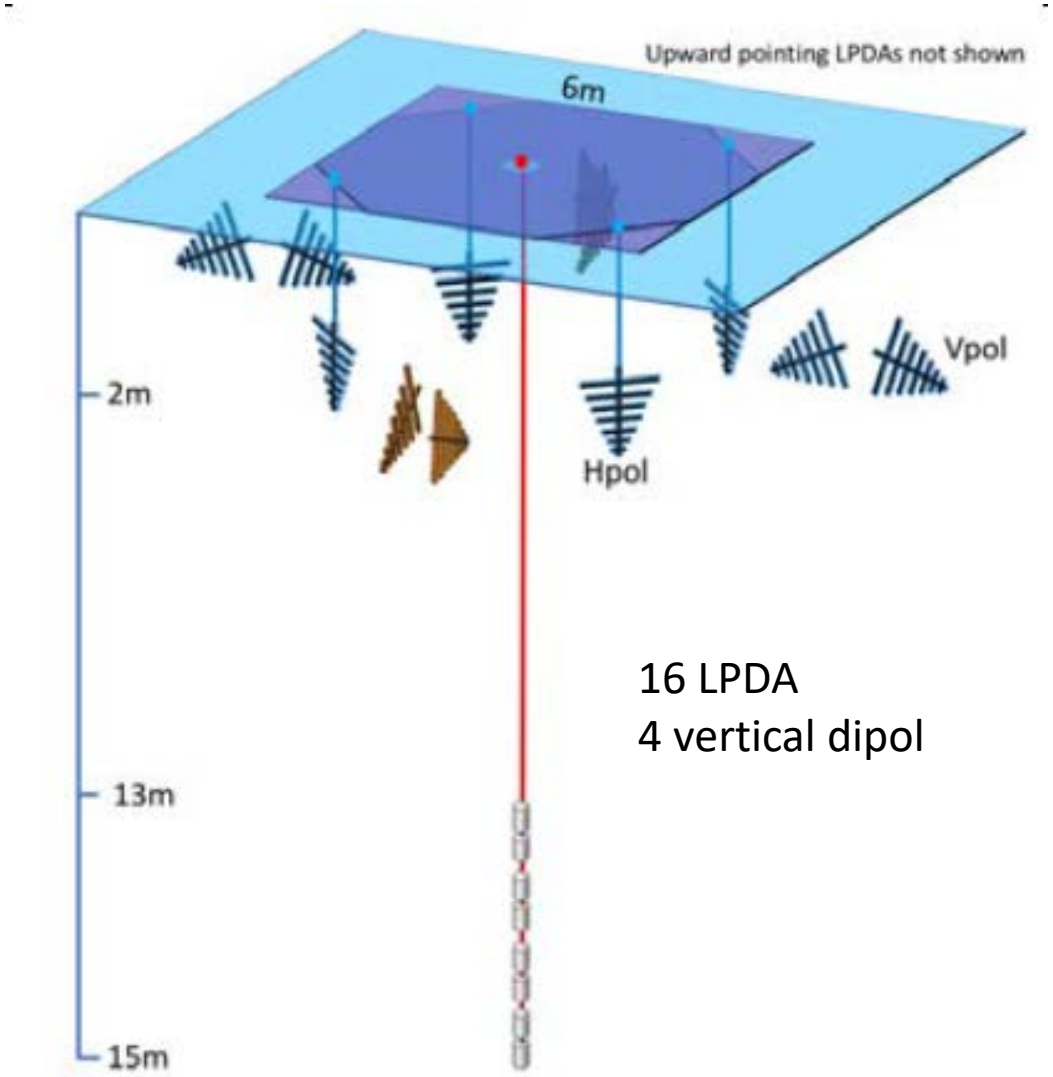


Antarctic Radio Ice Array (ARIA)

- 130 stations, 1 km spacing
- Autonomous, 10 W power, Solar power and batteries, Possibly wind power (from UU)
- 30 PeV neutrino energy threshold
- Cost $9.3M (US-NSF 7.3M, International 2.0M anticipated)

Black dots: ARIA stations
Red dots: ARA (installed)
Blue Hexagon: IceCube





16 LPDA
4 vertical dipol

RNO and ARIA

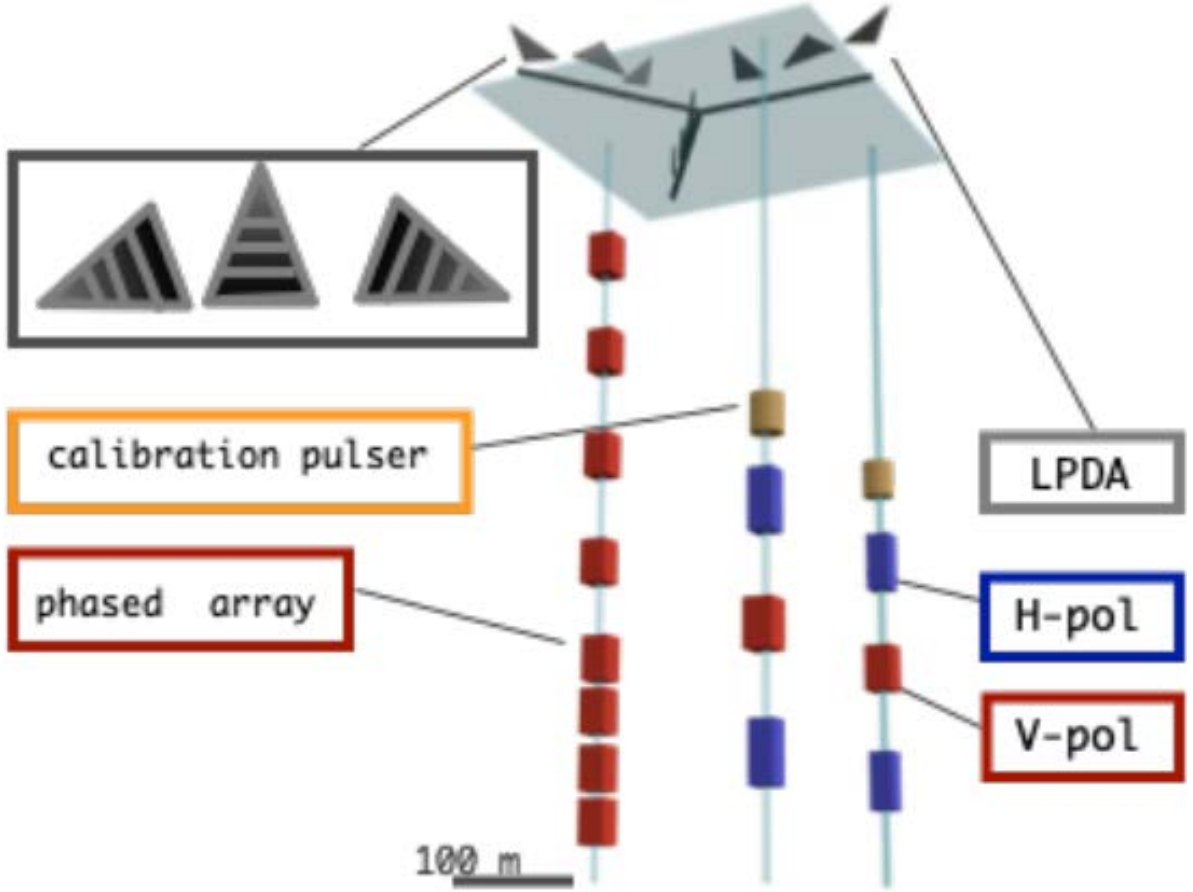
- NSF advised a larger array at SP would be possible
- → ARA and ARIANNA joined in common effort to write one proposal, but finally disagreed on realistic costs and layout
- → two proposals to NSF December 2018, RNO and ARIA

- Both proposals were turned down
- Logistics overload (IceCube upgrade etc) at SP
- Now NSF advices against near term radio detector at SP…..

“Greenland”

- Funding available!
  - Total about 6 MUSD available (Belgium 4 MUSD (time limited), Germany(Desy) Chicago, Penn)

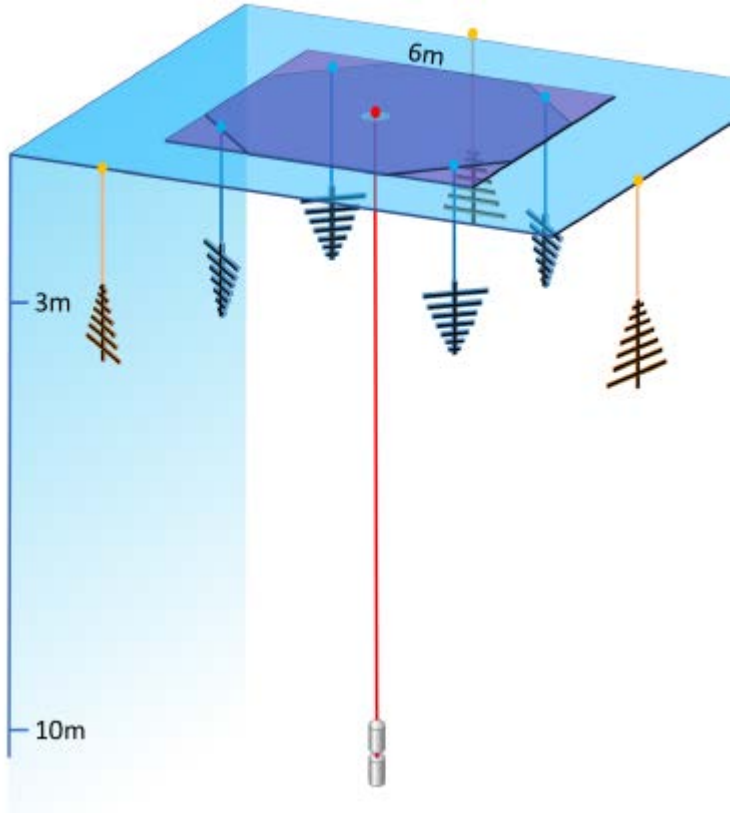
- Proposes a ‘Lean RNO’, 45 autonomous stations, fewer antennas/channels, Deep part in holes drilled 100 m deep and shallow part w reduced number of antennas (9 vs 12 or 16). Phased array trigger, 4 channels. Power reduced to 25 W/station
- Summit station (NSF driven)
- Start summer 2020, deployment of 5 stations



ARIANNA-100 (?)

- Proposal to NSF in preparation, due December 2019
- Estimated cost about 6 M$
- 100 Stations at Moores Bay, autonomous, solar and wind (if UU….)
- Design for Multi-messenger: Neutrino direction angular resolution < 3 degree for all neutrino candidates. Energy resolution: factor 2 (DnR technique)
- 110 km from McMurdo facilitates deployment, logistics
- Performance estimates based on ARIANNA experience
- Triangular array, 1 km spacing
- 4 LPDA downward, 3 LPDA upward, 1 V-dipole
- Trigger threshold equivalent 2 sigma

- Proposal being worked out, all now preliminary



What Next?

- The IceCube collaboration recognizes the importance of the radio based technology
- IC Collaboration consider Radio as an important element in a future IC Gen II
- Proposes to invite Radio Community members to become associate members of IC. The format of collaboration is not yet worked out.

- The proposed arrays, “Greenland” and ARIANNA-100 considered to be path-finders for a IceCube Gen II suggested 500 km^2 radio array