A brief history of radio at pole

Prof. Amy Connolly

April 28, 2019

The plan for this talk

- Motivation for radio, in-ice detectors
- Early days
- Askaryan Radio Array
- SpiceCore
- Future

Motivation for radio in the ice

The case for going beyond optical

~ 10 cosmogenic neutrinos / km^2 / year

10^{18} eV: νN interaction length O(1000) km

→ 0.01 neutrinos / km^3 / year

At most, we see 1/2 the sky

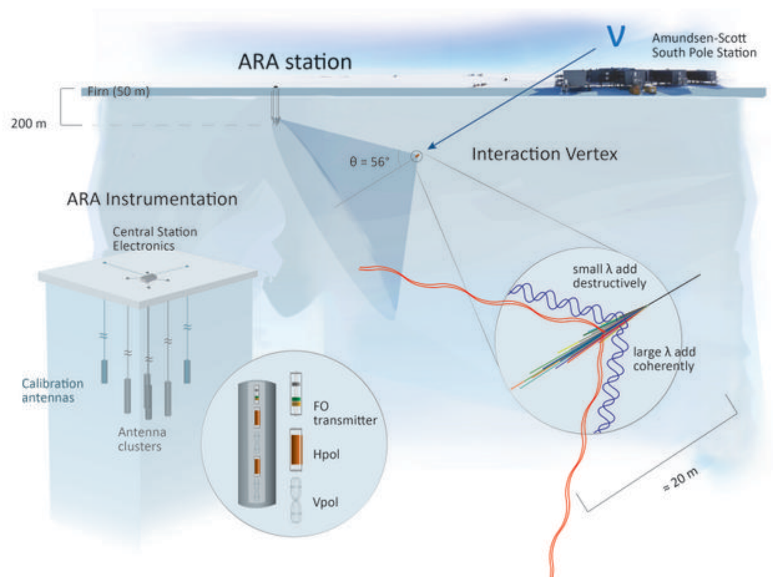
→ 0.005 neutrinos / km^3 / year

Neutrinos from sources at a similar level

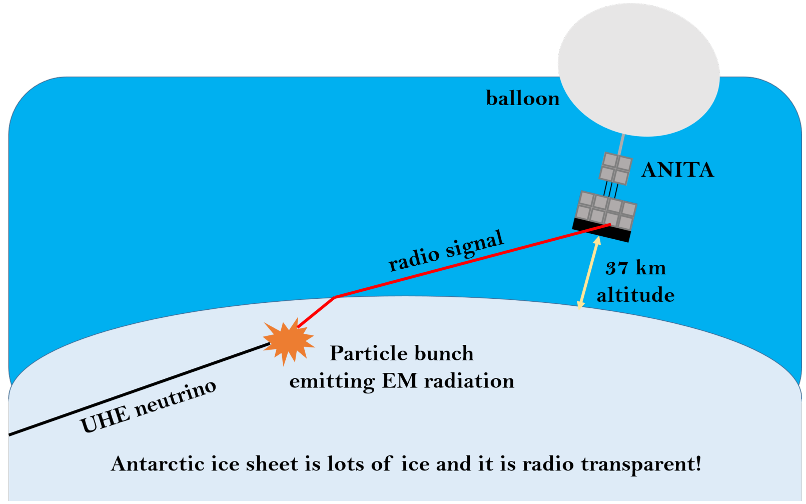
We need >100's of km^3 detection volumes

Two classic approaches

Instrument the ice



View from a distance



Graphic: Oindree Banerjee

- Pure ice is low-loss for radio: field attenuation lengths ~1 km

Early days

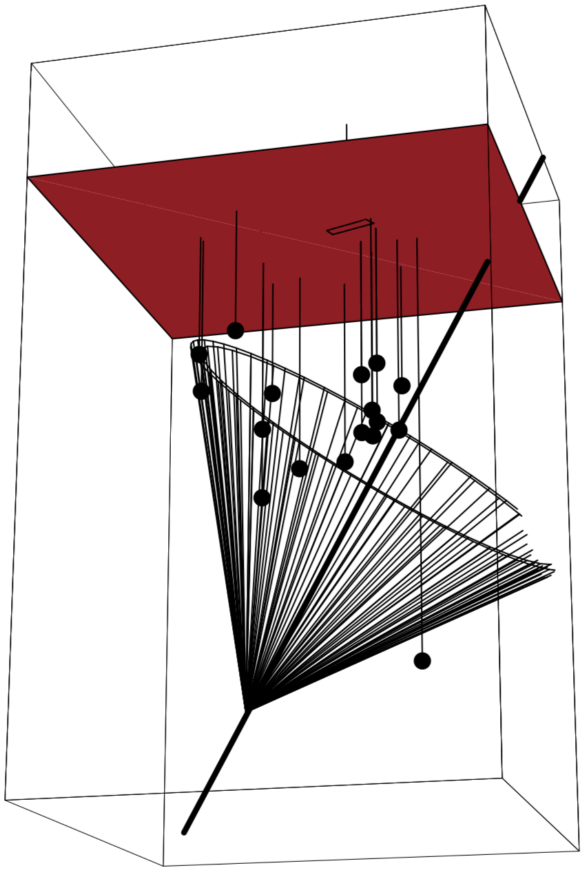
RICE

- RICE (Radio Ice Cherenkov Experiment) 1995-2012

  - Ilya Kravchenko, Dave Besson, *et al.*

  -Antennas deployed along strings of AMANDA ~100-200 m depth

- World's best limits in energies between ~50 PeV-1 EeV for ~a decade



Astropart.Phys.19:15-36,2003

Other early efforts

RICENARCAURASATRAARARASTA

or

How many acronyms can one slide hold?

South Pole Under Ice RF instrumentation:
- RICE (*Ilya Kravchenko*)

Part of IceCube DAQ:

This talk

- "AURA" sub-working group (Full WF digitization)
  Askaryan Underice Radio Array
- "SATRA" sub-working group (Transient detection)
  Sensor Array for Transient Radio Astrophysics

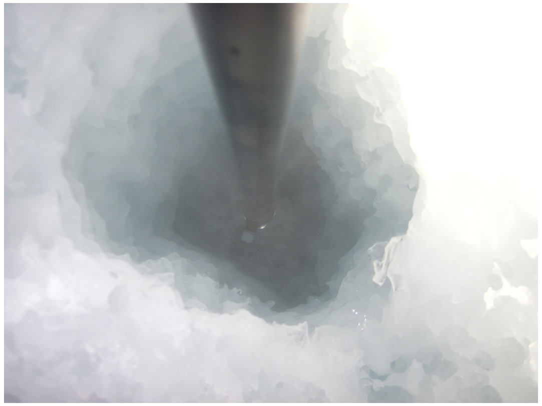
2008 "NARC"
Neutrino Array
Radio Calibration

Future independent collaboration:
- ARA – Askaryan Radio Array *(Kara Hoffman)*

South Pole Surface RF Instrumentation:

- Surface radio - RASTA – Radio Air Shower Transient Array
  (Sebastian Boser)

ARA
South Pole



Credit: Mike Duvernois, ARA/NSF

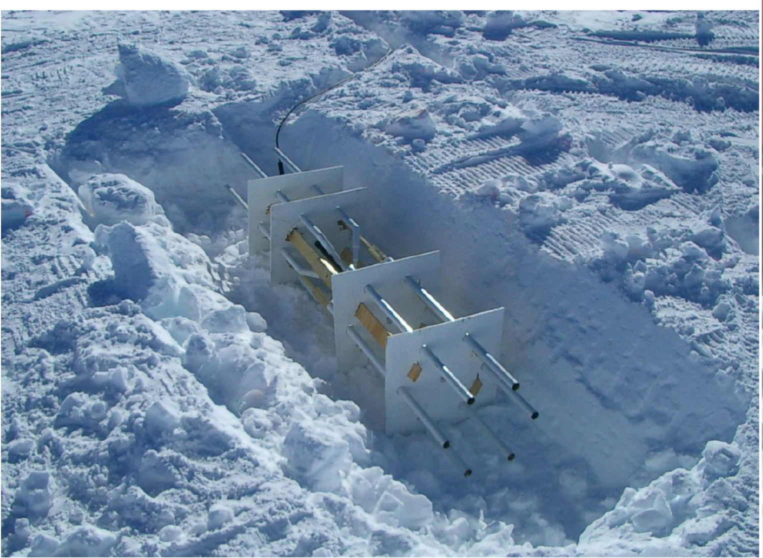
ARIANNA
Minna Bluff

- Observes ~3 CRs/day
- Successfully run autonomously during summer months for ~10 years

Askaryan Radio Array

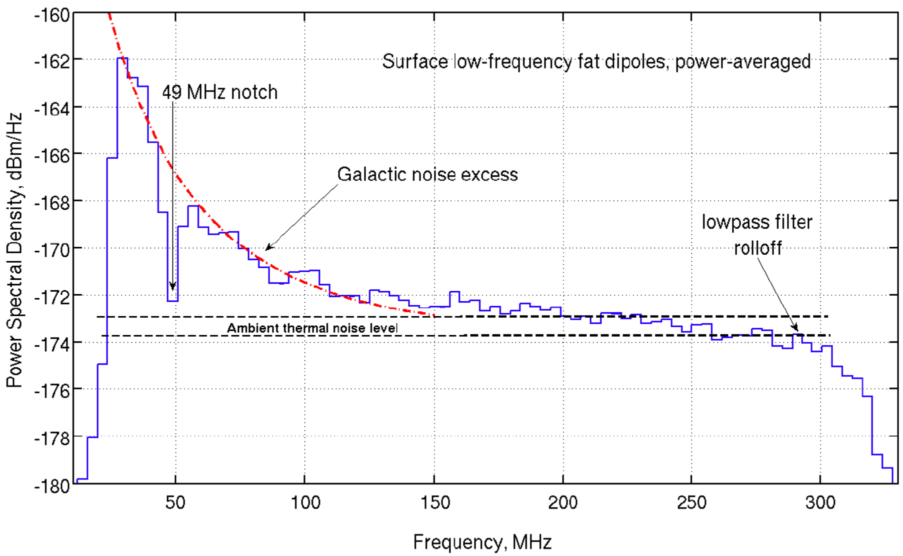
Askaryan Radio Array (ARA) Testbed

- Prototype station deployed 2010-11 season
  - 16 HPol, VPol antennas down to 30 m



ARA Testbed Results

- Established feasibility of larger array
- Attenuation length measurement
- Diffuse flux limits
- Quasi-diffuse GRB limit
- Solar flares



Astropart.Phys. 35 (2012) 457-477

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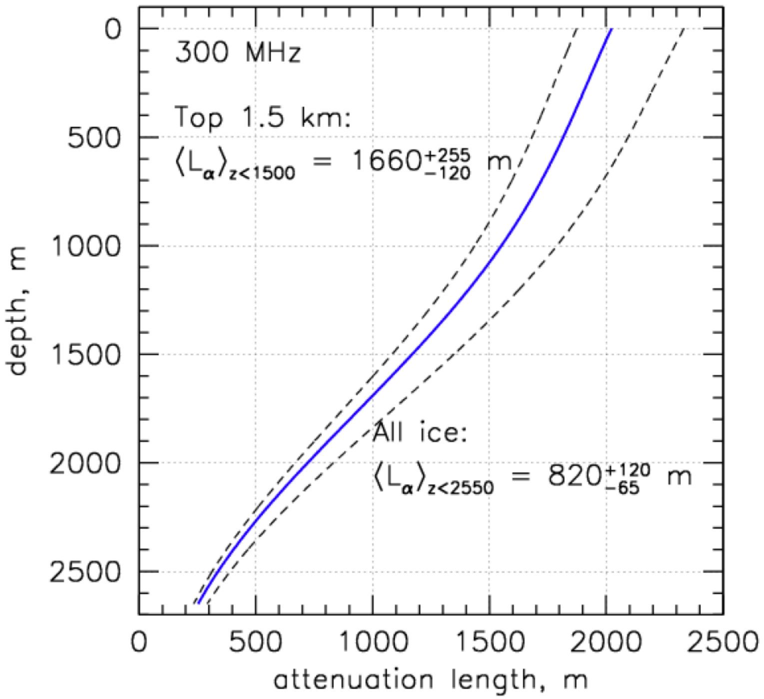

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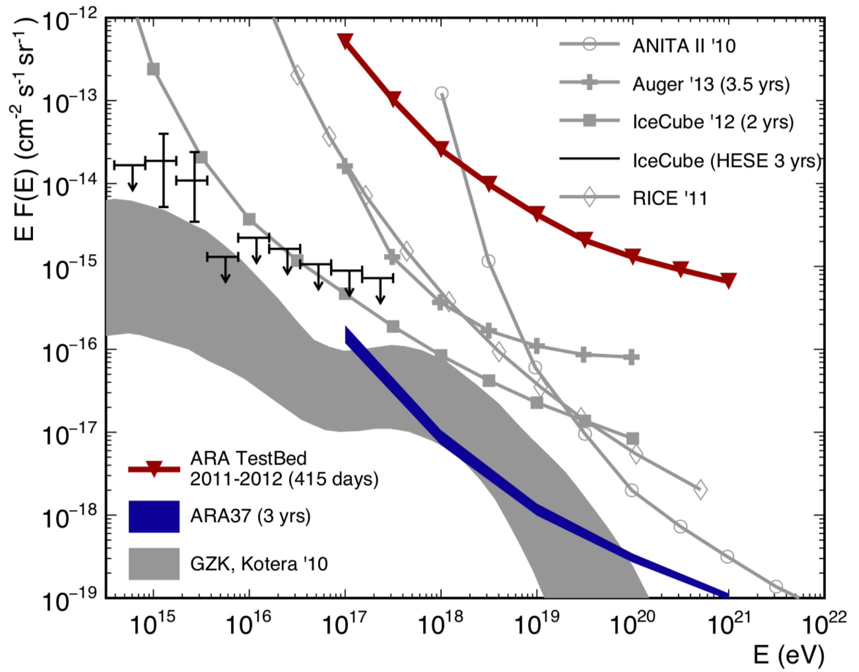

Astropart.Phys. 70 (2015) 62-80

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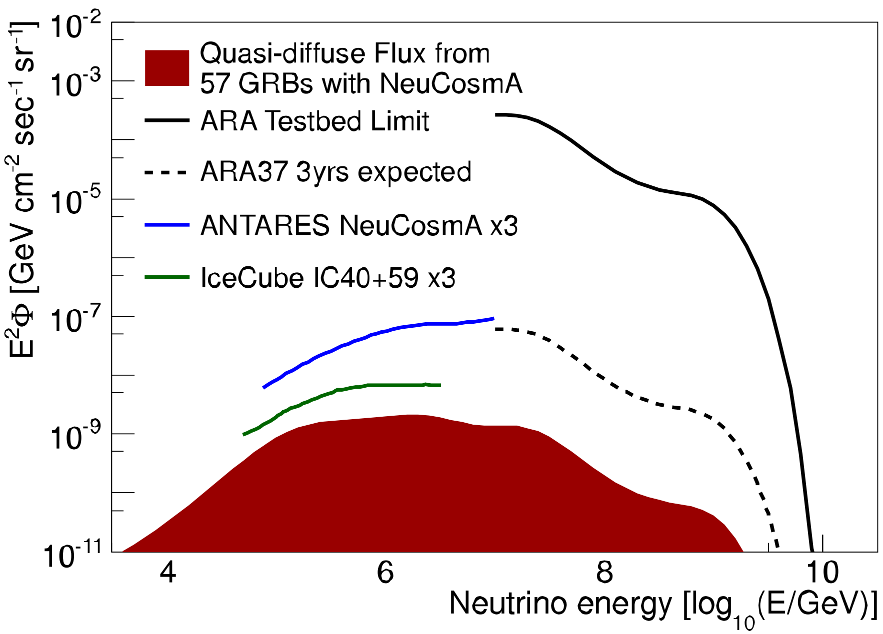

Astropart.Phys. 88 (2017) 7-16

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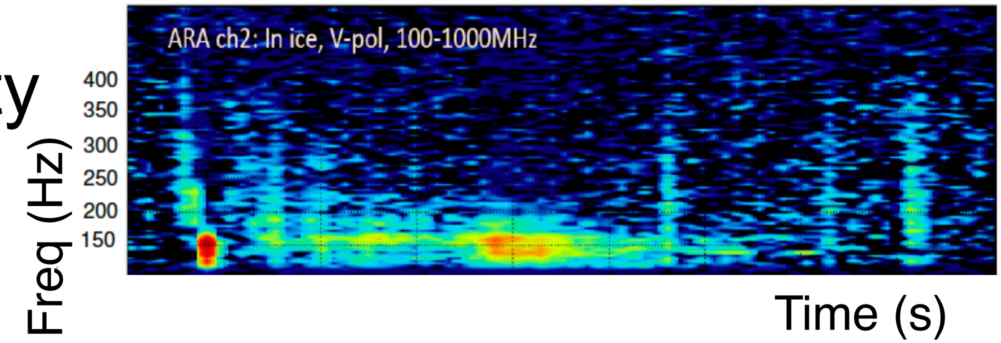
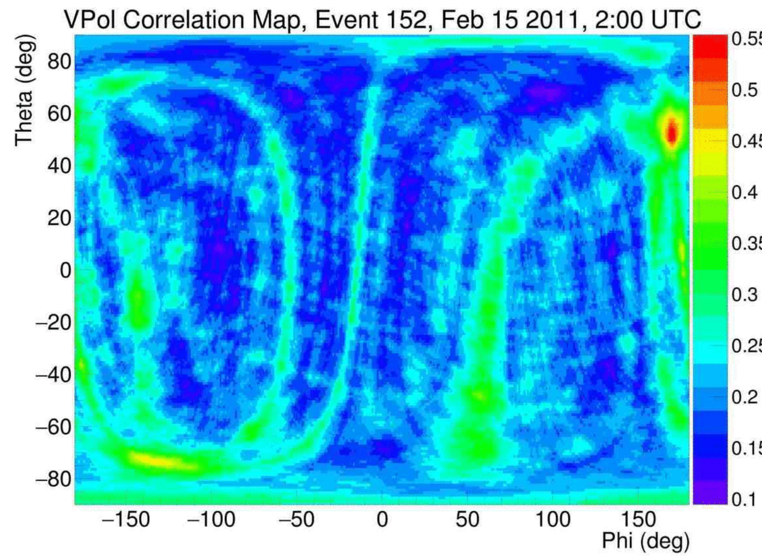


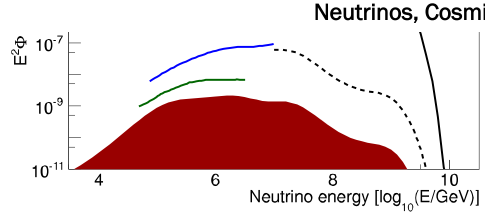


arXiv:1807.03335

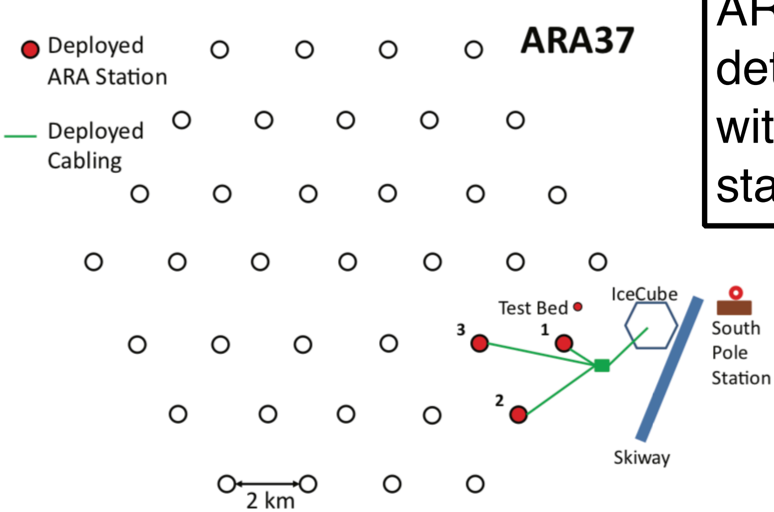
The ARA Collaboration

Figure credit: C. Pfendner

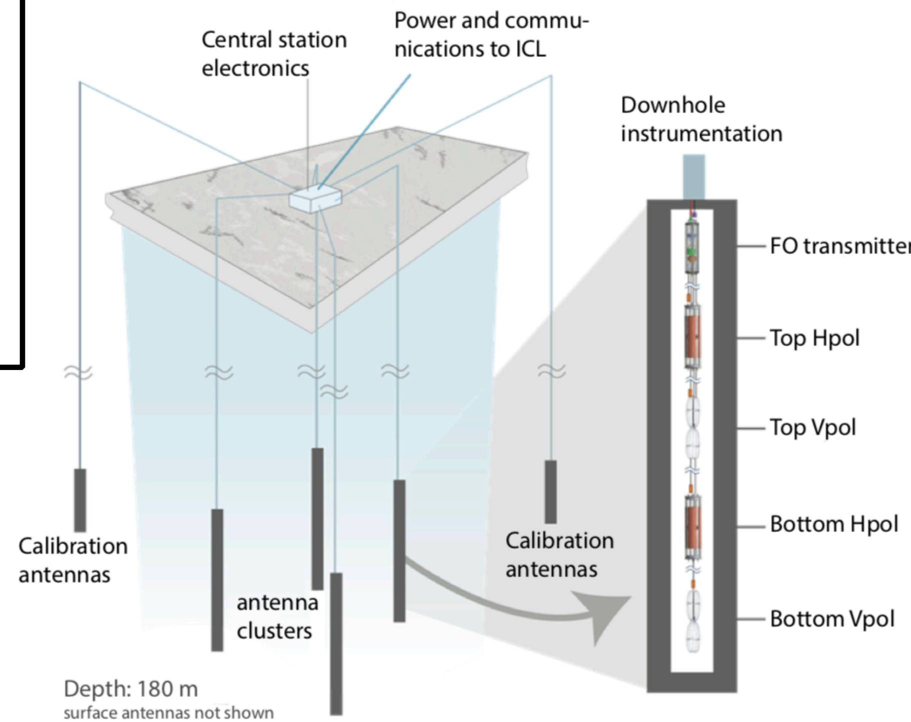
USA		International Collaborators
Cal Poly	University of Kansas	Chiba University
The Ohio State University	University of Maryland	National Taiwan University
Otterbein University	University of Nebraska	University College London
University of Chicago	University of Wisconsin-Madison	Vrije Universiteit Brussel
University of Delaware	Whittier College	Weizmann Institute of Science



Deep: A1-3



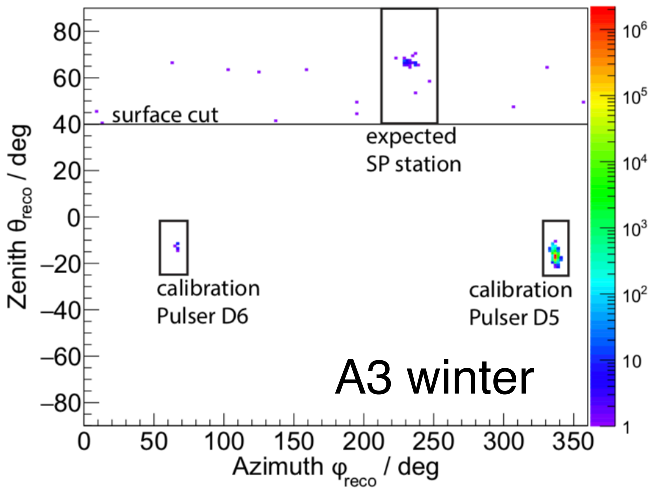
A3 is 3rd station; ARA3 is detector with 3 stations



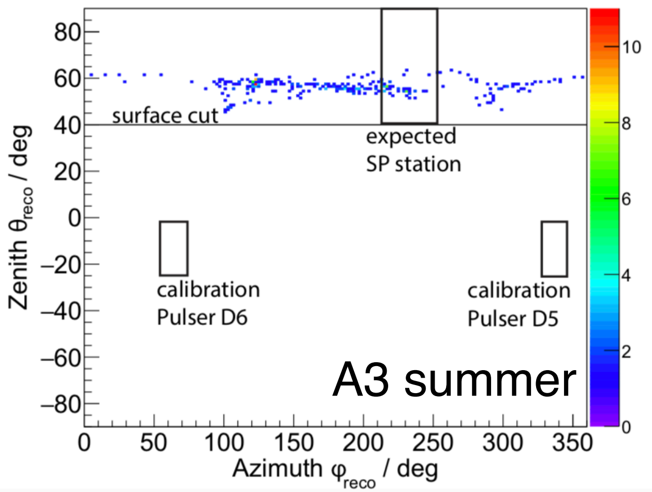
Credit: Mike Duvernois, ARA/NSF

A1-3 Results

- Even quieter environment at deep
- Improved limits
- Ice properties



(a)



Phys.Rev. D93 (2016) no.8, 082003

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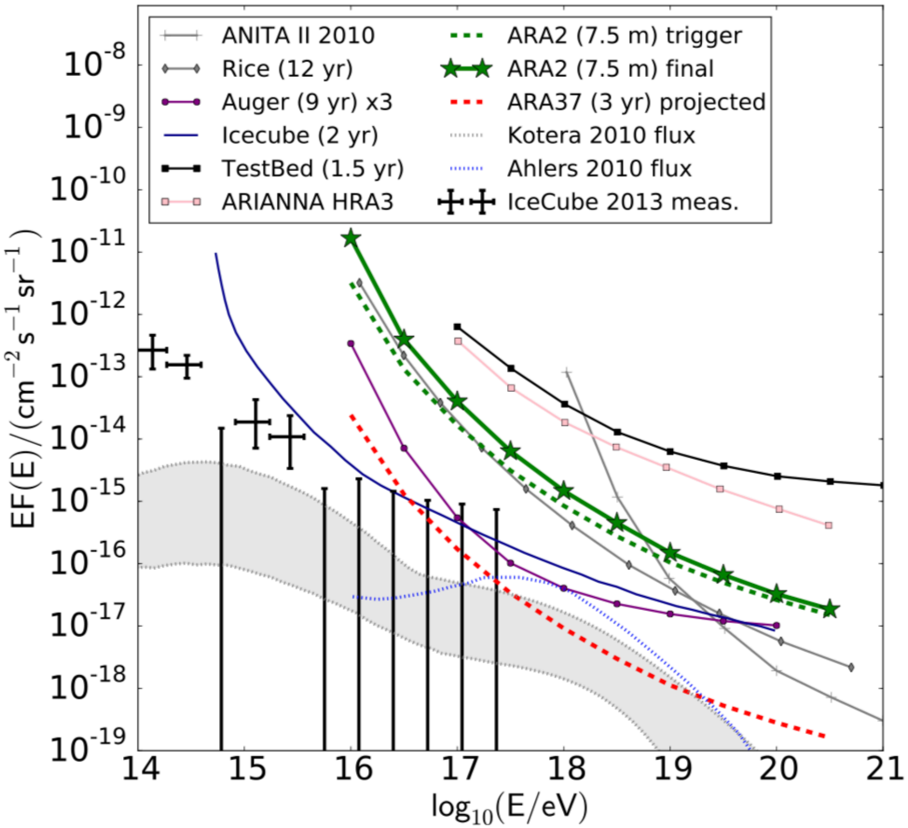

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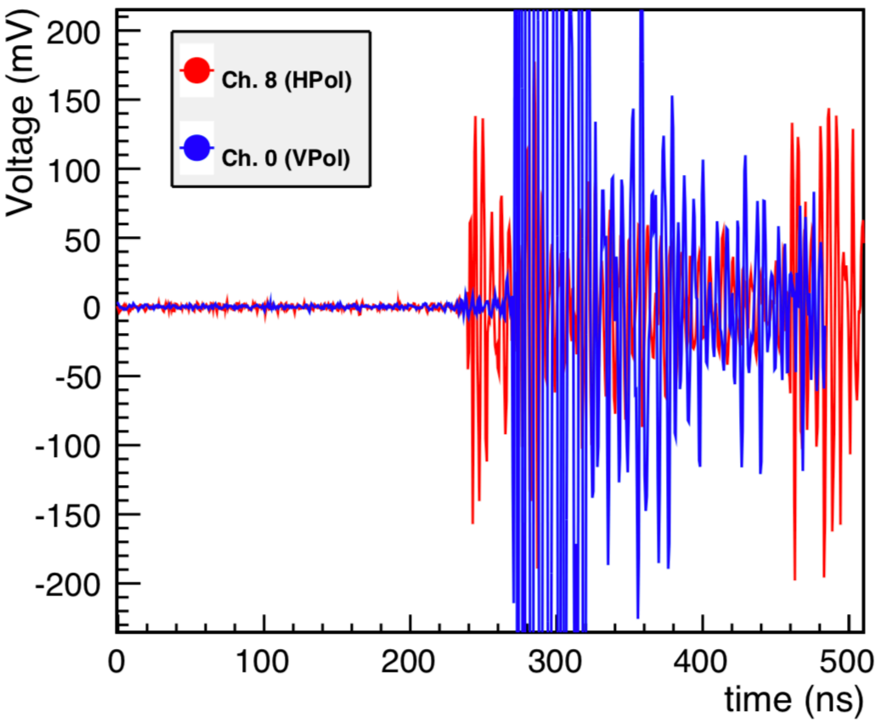
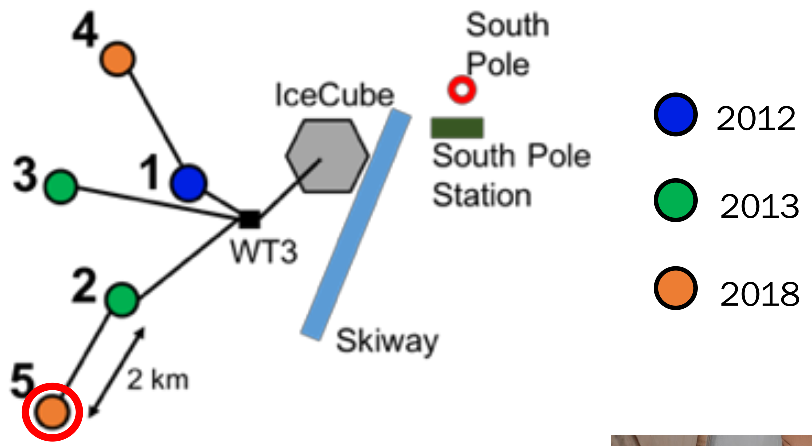
ICS1 signals measured in co-located HPol (red) vs. VPol (blue)



Astropart.Phys. 108 (2019) 63-73

Small ~0.1% birefringence effect could aid in distance measurement → energy

Deep: A4-5



- Stations A4 and A5 most distant yet
- A5 with new phased array trigger

A4-5: ARAFE (Front End)

- Variable attenuators adjusted with microcontroller
- Correct for ~5 dB variation in attenuation during runtime
  - Better use of dynamic range
  - Can simplify analysis

Ohio State: paper in progress

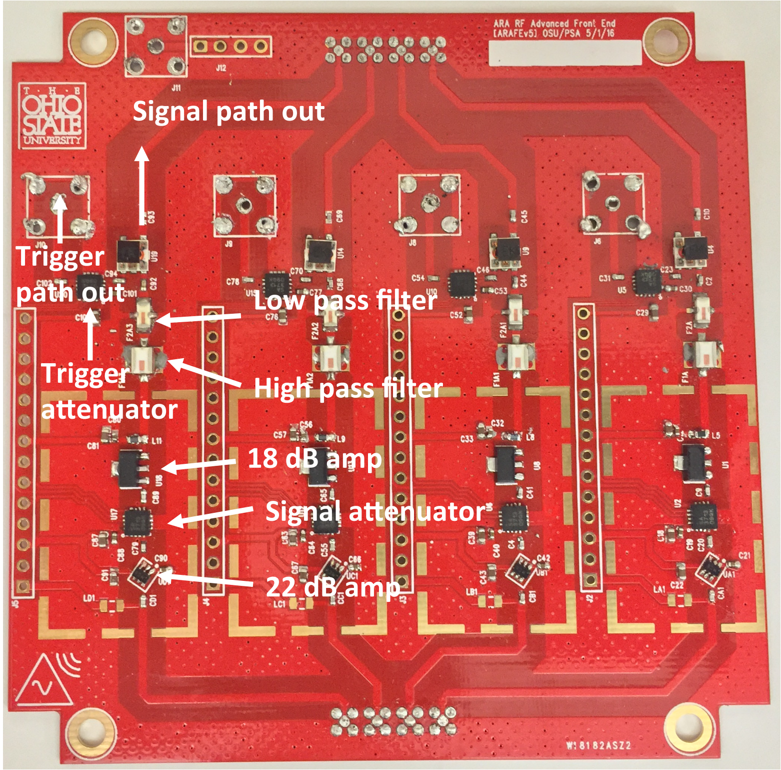
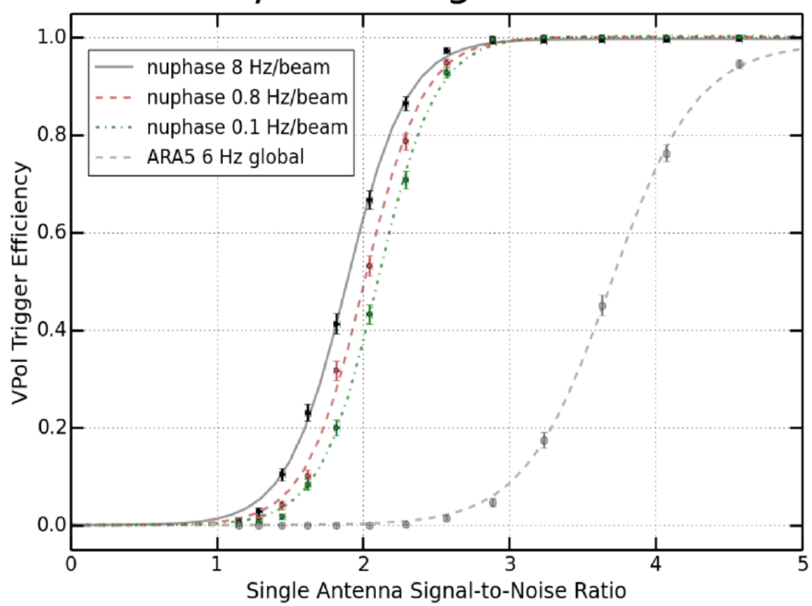


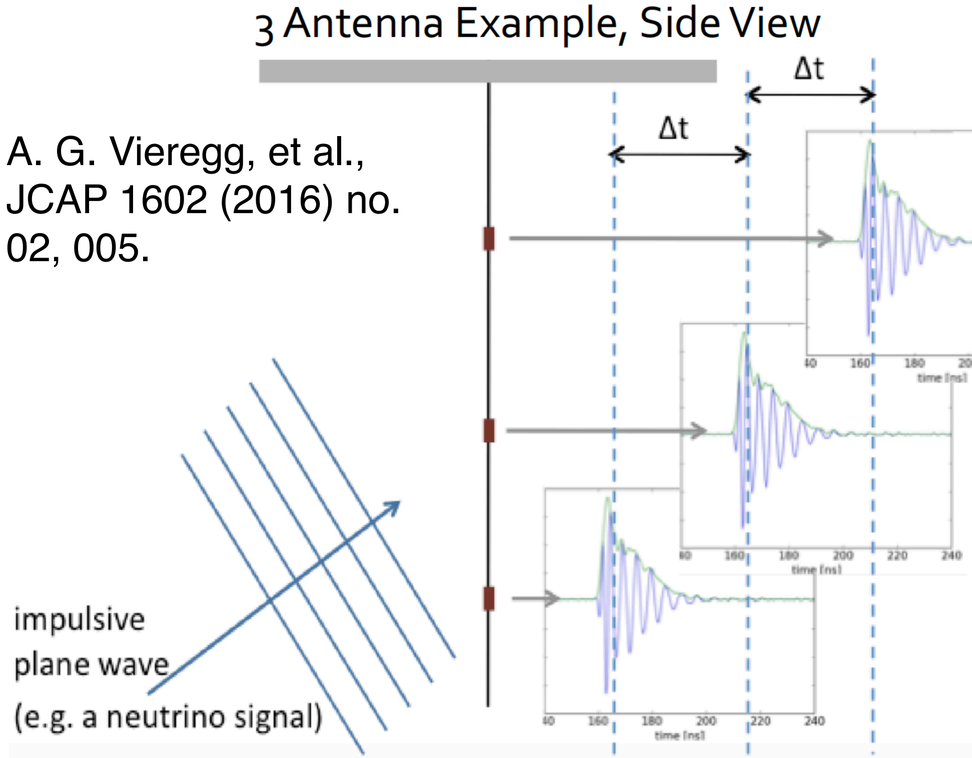
Figure credit: Univ. of Chicago

A5: Phased array

ARA Coll., NIM 2019

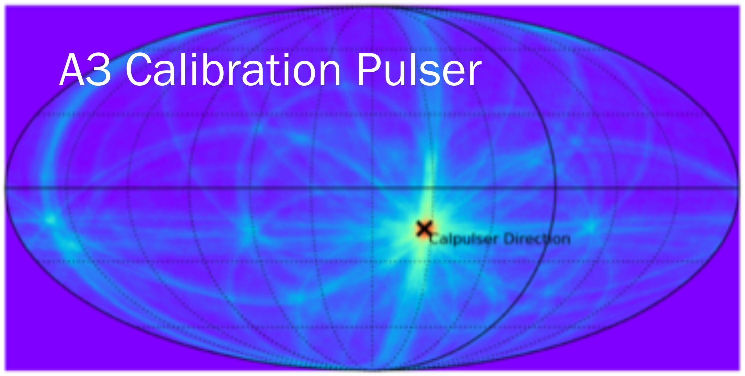


A. G. Vieregg, et al., JCAP 1602 (2016) no. 02, 005.

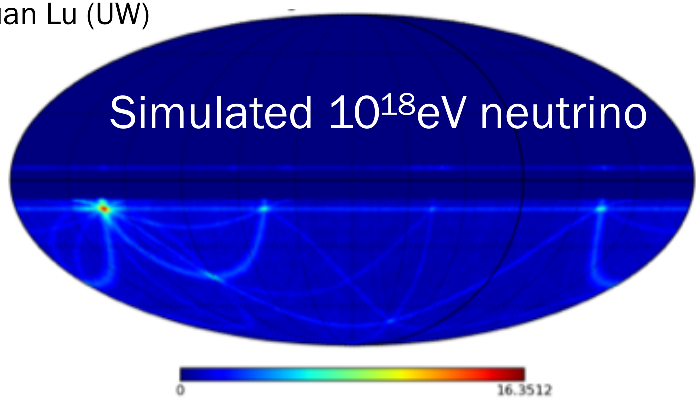


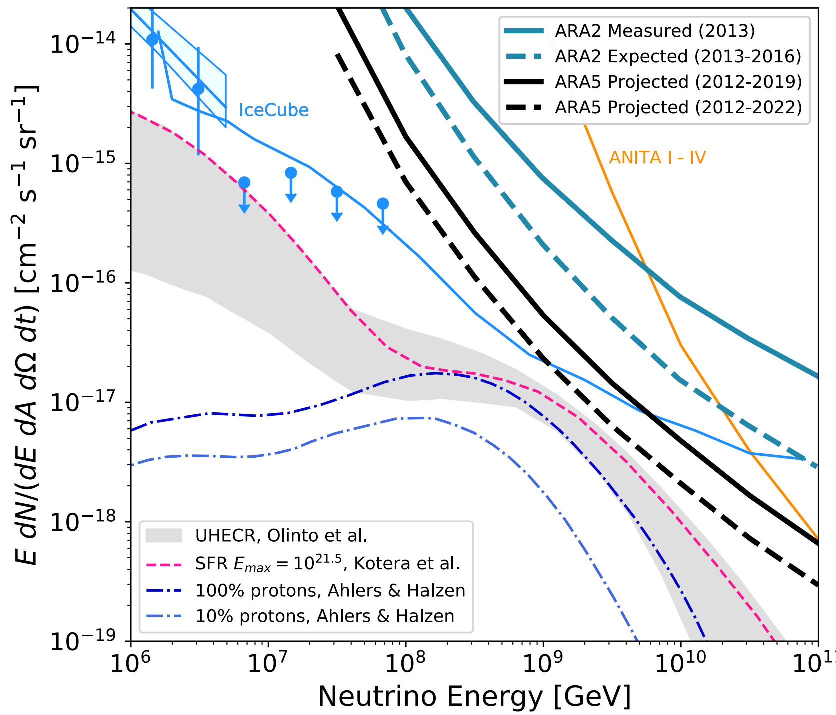
- Calculate *summed correlation* in electronics before trigger decision
- Newly deployed in 2017-2018 in ARA station #5
  - signal-to-noise reduction as expected!

ARA5: Diffuse Searches



Plots by Ming-Yuan Lu (UW)



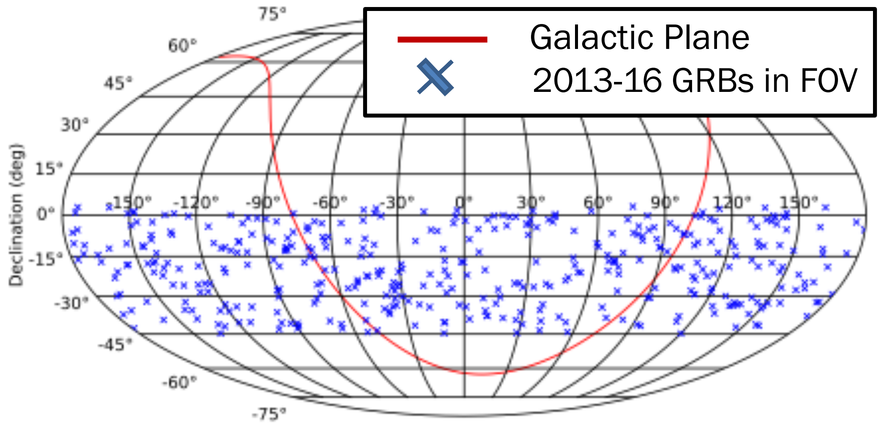


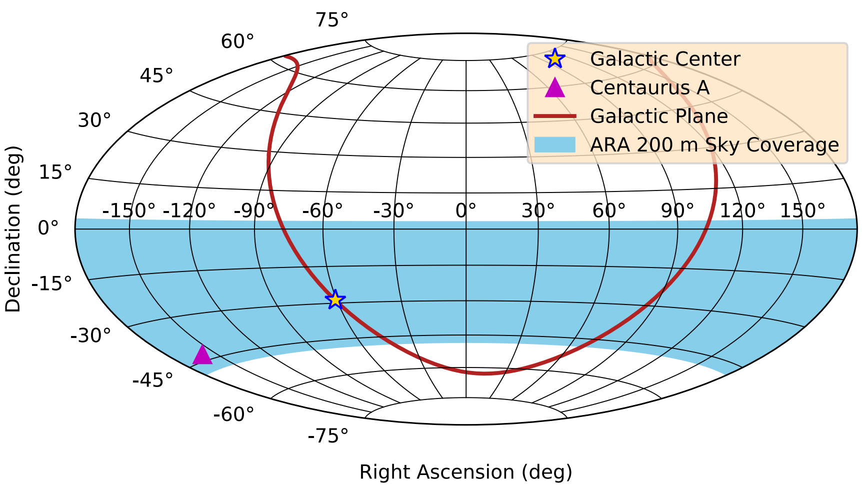
- Accumulated 5-station data expected to give *world's best limits above 10^{19} eV*

ARA5: Source searches

- Wide field of view
- Sources continuously in view
  - 100s of GRBs
  - Exciting sensitivity to CenA: UHE neutrino emission may be expected

    Cuoco '08, Kachelriess '09

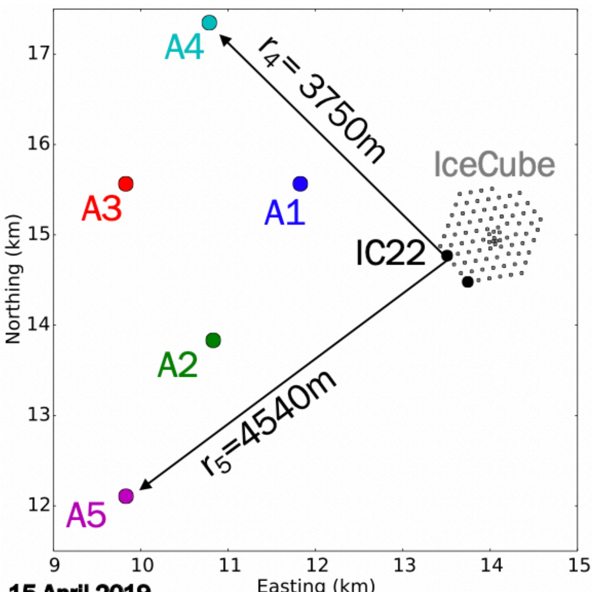




SpiceCore

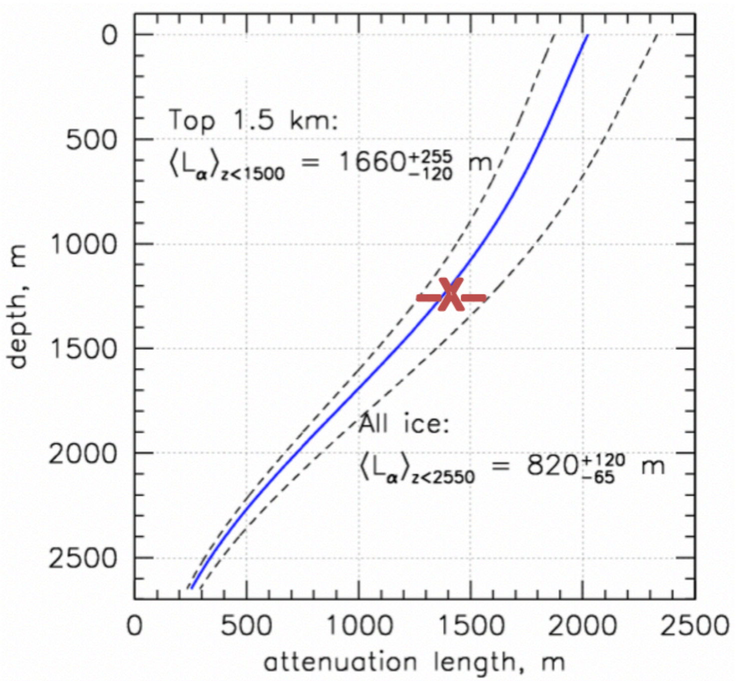
Antarctic Ice Properties: Attenuation Length

- Pulsers deployed on IceCube strings 1 and 22 illuminate the entire array
- Pulse amplitude at A4 vs A5 is the longest horizontal-baseline measurement of L_α



$$\frac{SNR_{A5}}{SNR_{A4}} = \frac{r_4}{r_5} e^{\frac{r_4 - r_5}{L_\alpha}}$$

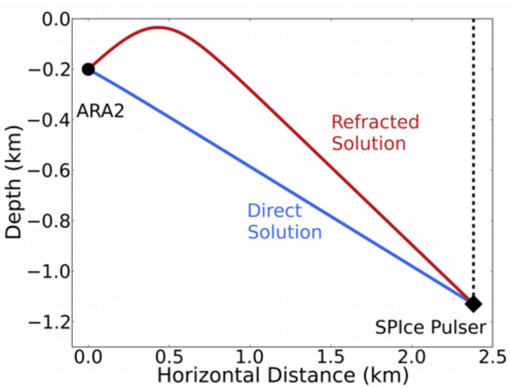
Adapted from [P. Allison et. al. j.astropartphys.2011.11.010]

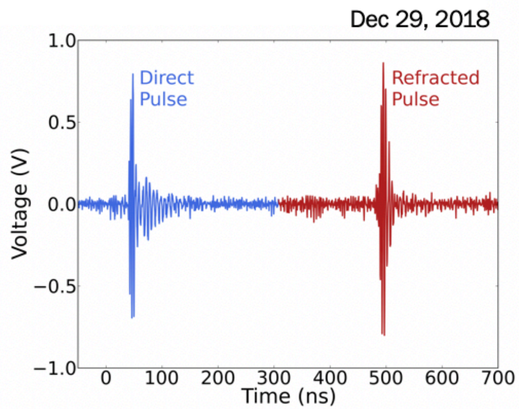


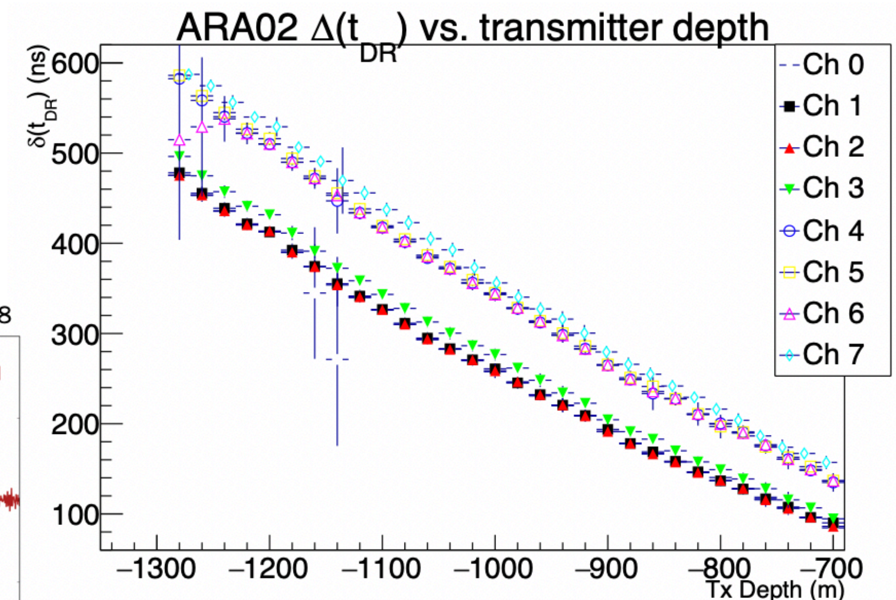
New measurement:
$L_{\alpha,1500m} = 1.43 \pm 0.25$ km

Antarctic Ice Properties: Constraining $n(z)$

- In Austral season ‘18 and ‘19, we deployed pulsers down the South Pole IceCore (SPIce) hole
- The depth dependent index of refraction produces two solutions: direct and reflected/refracted
- Time-difference between pulses is sensitive to n(z)

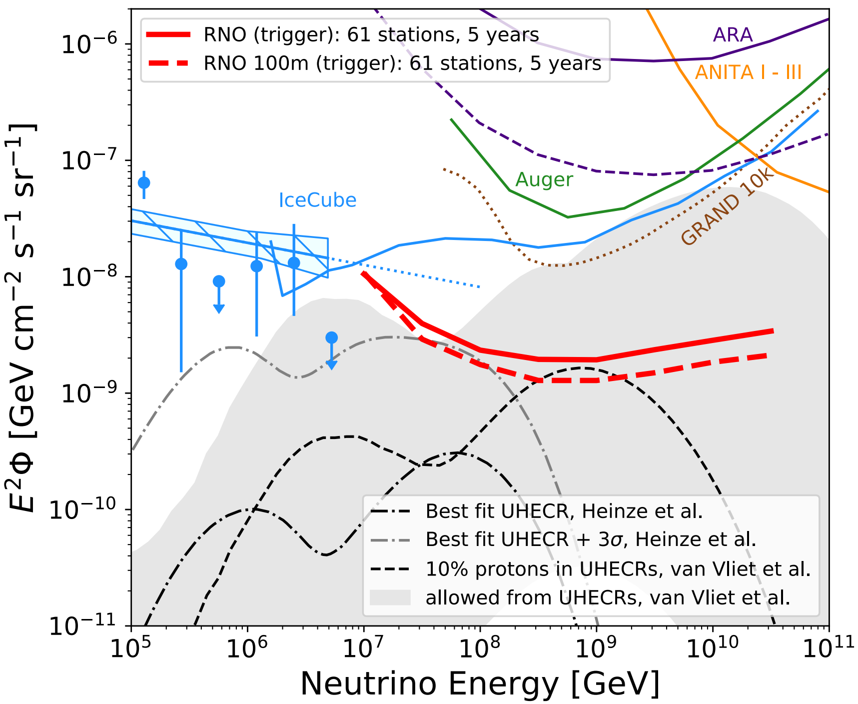






Future

Radio Neutrino Observatory



- Broad program astrophysics, particle physics
- Aims:
  - Astrophys. flux > 10^{16} eV
  - UHE flux to 10^{20} eV
- Building on existing arrays
  - Decade of Antarctic deployments
  - Data sets ~20 station-years

Summary

- Radio in-ice has history going back to mid-90s
- Expertise built in detectors, deployments, analysis, simulations
- ARA5 will have world's best sensitivity above 10^{18} eV until next generation detector is built
- Looking forward to RNO for the next leap

Thank you!