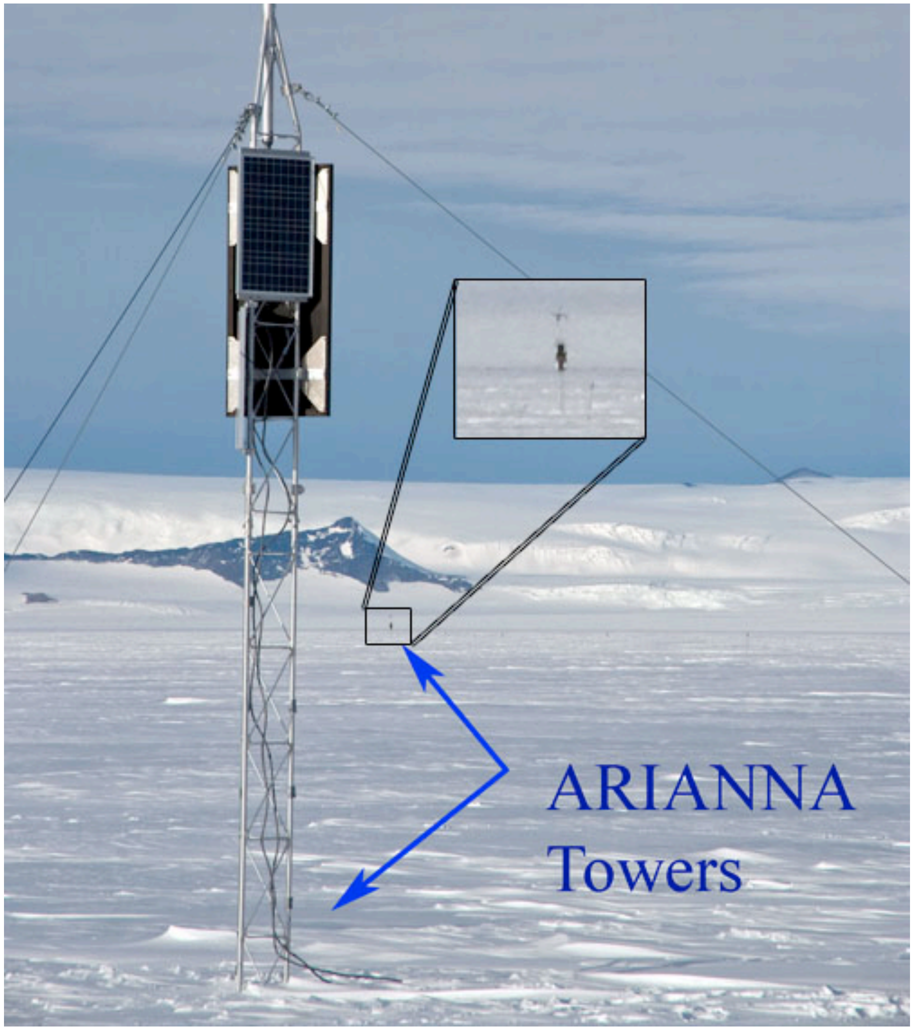
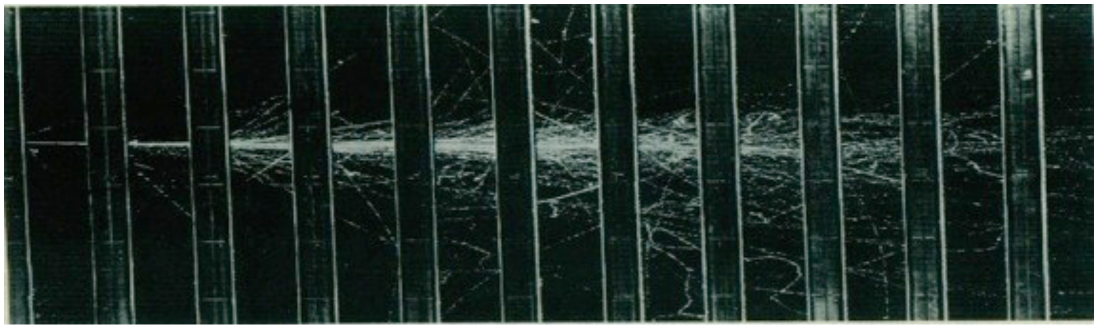
Progress in the Development of Radio Cherenkov Neutrino Detectors

Steve Barwick
UC Irvine, USA
ICRC, Aug 2015

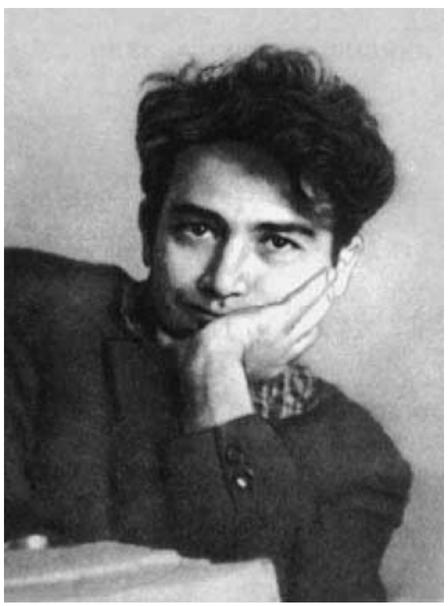


Radio Detectors: The Askaryan Effect

- EM, hadronic cascade in in dense, dielectric media (ice)
- Coherent radio Cherenkov radiation ($P \sim E^2$) if λ > Moliere radius

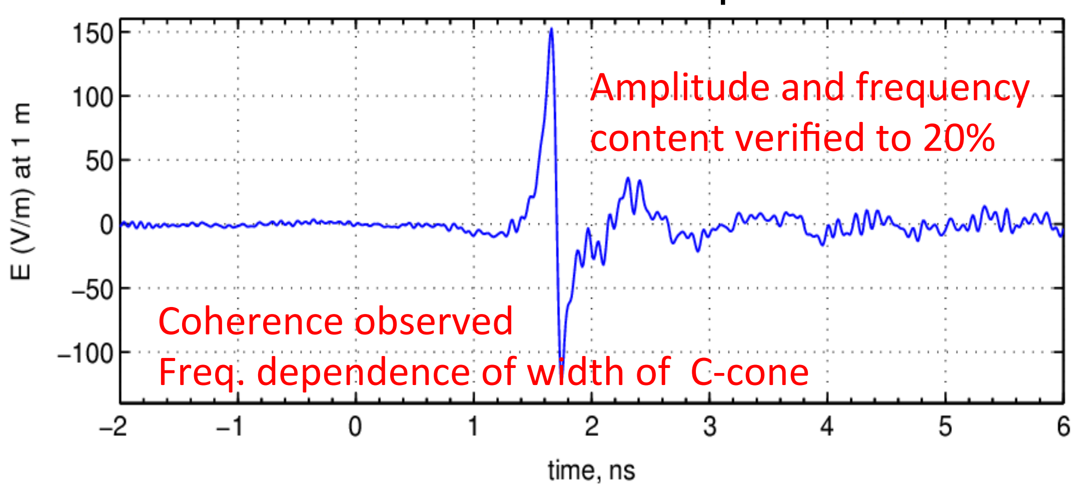


Typical Dimensions:
L ~ 10 m
$R_{moliere}$ ~ 10 cm



G. Askaryan

SLAC Tests confirmed expectation in ice



ANITA Coll., PRL (2007)


ANITA
Antarctica

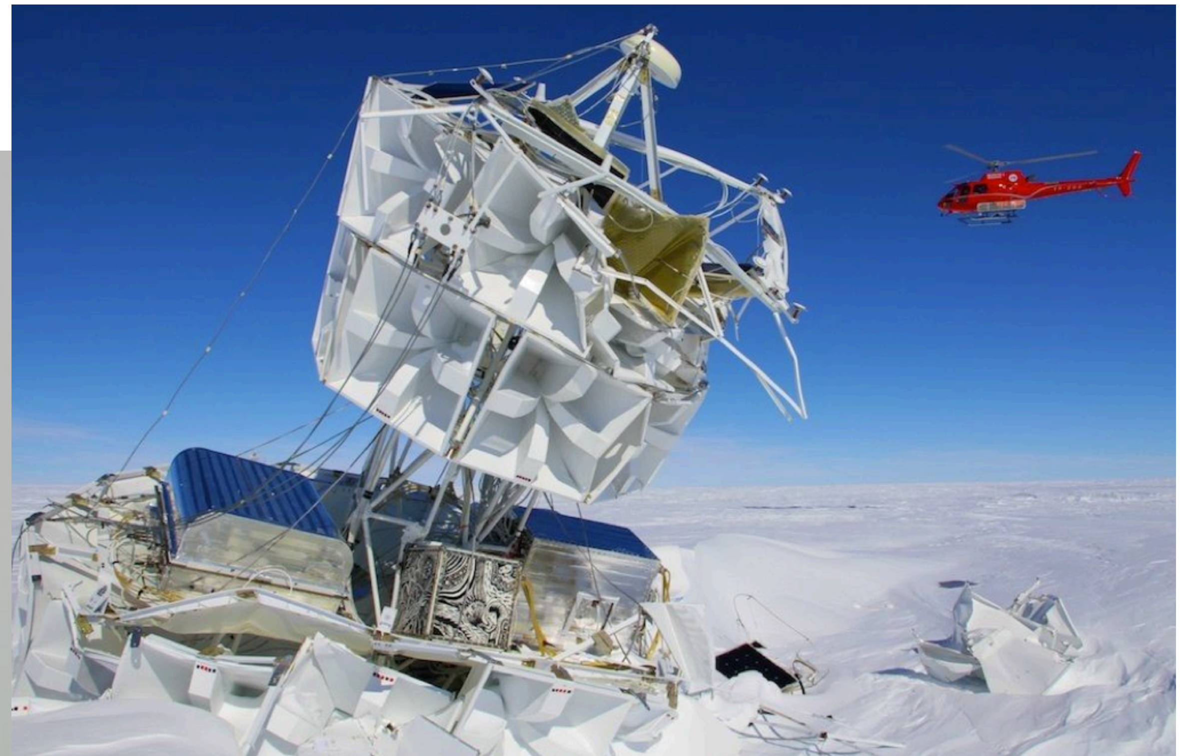

GNO
Greenland


ARIANNA
Antarctica
kitchen
science


ARA
Antarctica

Challenges in Polar Climates

Stormy Weather



Not always soft Landing

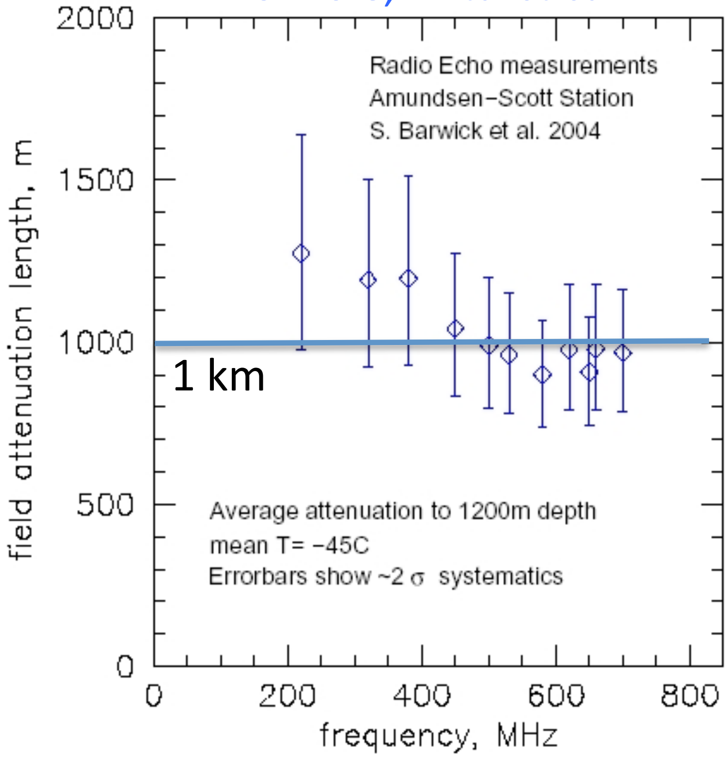
Why go to Polar Regions?

- Radio Quiet, but
  - Noisy near bases and/or experiments
  - Noise from satellites in case of ANITA-III
- Thick cold, RF transparent, (free) material
- Ice provides a dense target for neutrinos
- Surprisingly good infrastructure

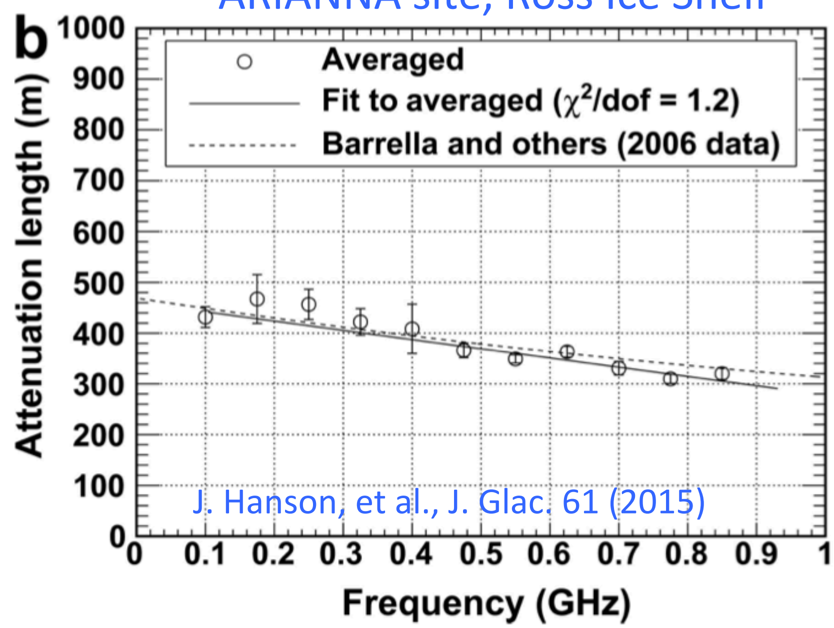
TeraTon Detectors at low cost
(~ $10M US in hardware)

Field Attenuation Length in ice

S. Pole, Antarctica



ARIANNA site, Ross Ice Shelf



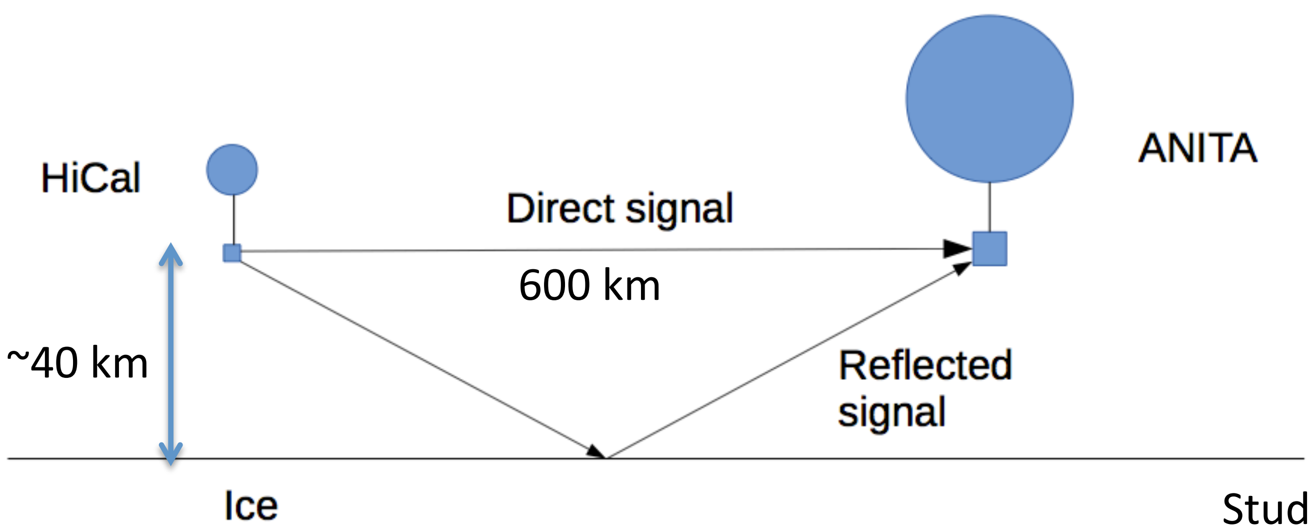
J. Hanson, et al., J. Glac. 61 (2015)

Similar numbers for Greenland at 75MHz
S. Wissel, et al. (ICRC -2015)

Shorter, due to warmer ice
Reflectivity ~ perfect mirror

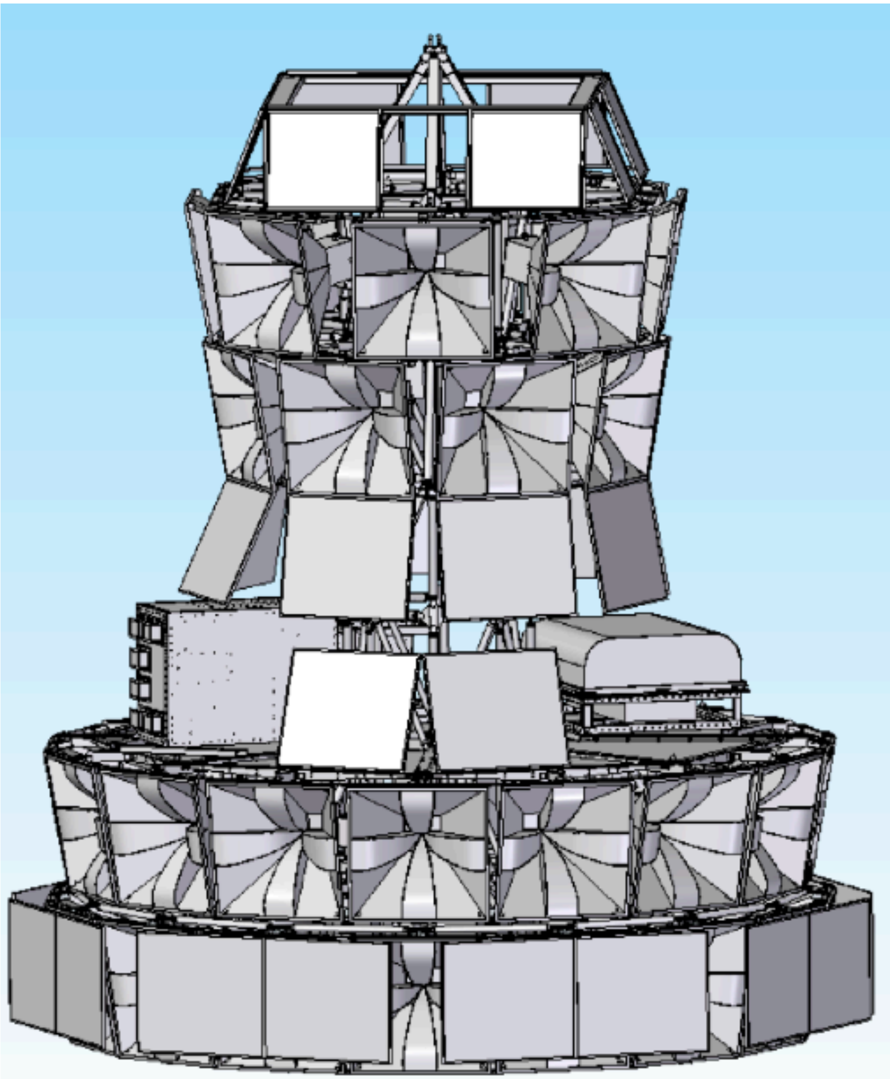
ANITA-3 launched Dec 2014

- Stayed aloft for 22 days, and more sensitive to CRs and neutrinos than previous missions.
- Unexpected satellite noise reduced efficiency
- Dual balloon tests



Study effects of surface roughness at shallow angles

ANITA-III: 2014-2015

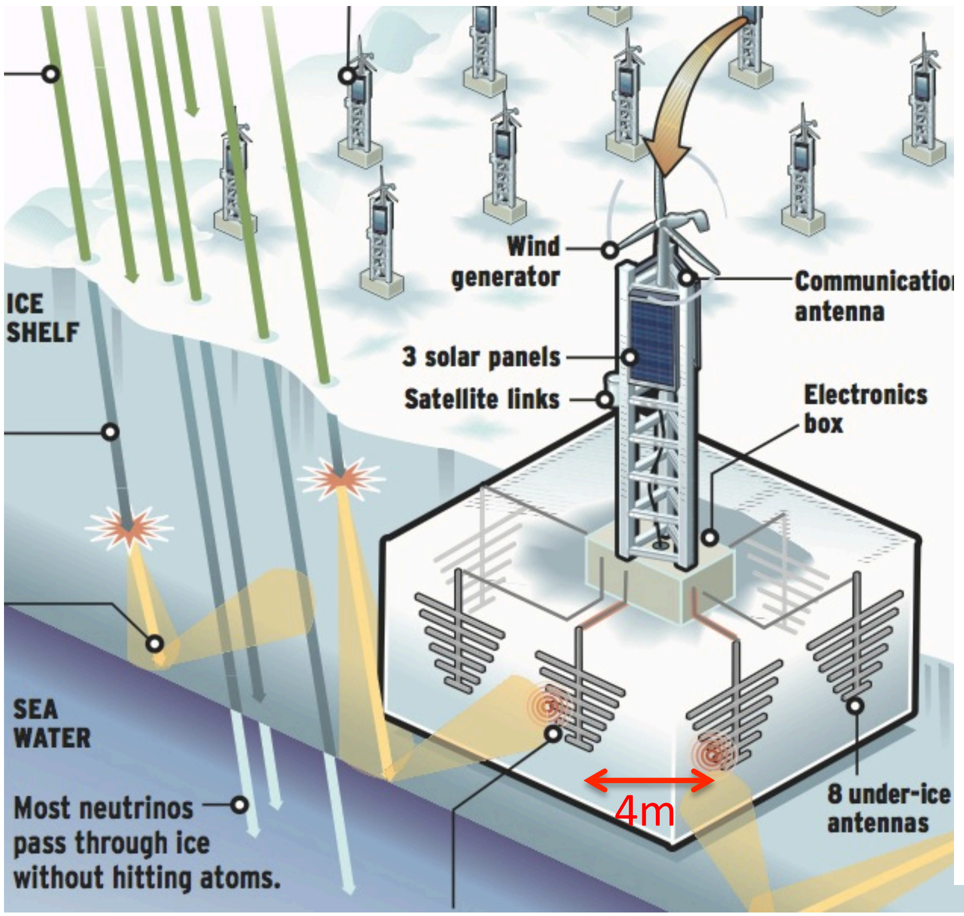


- More antennas (now 40 -> 48)
- Better antennas in 200-300MHz
- Digitize longer traces
- Better trigger and event priority
- Lower noise front-end RF system

→ Potentially factor of 2-3 improvement in neutrino sensitivity compared to ANITA-II (S. Wissel, ICRC-2015)

Detector Concepts

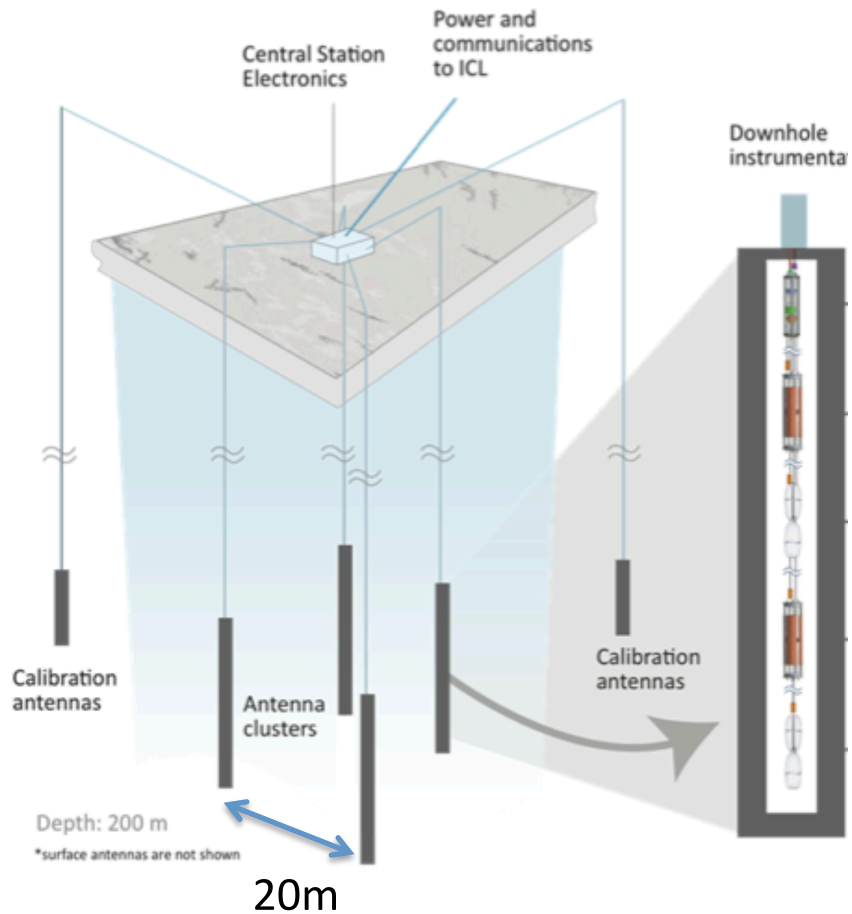
1 station in array of 36 x36, 1km spacing



ARIANNA

S. Barwick, et al., IEEE Trans. Nucl Sci. (2015)

1 station of 37

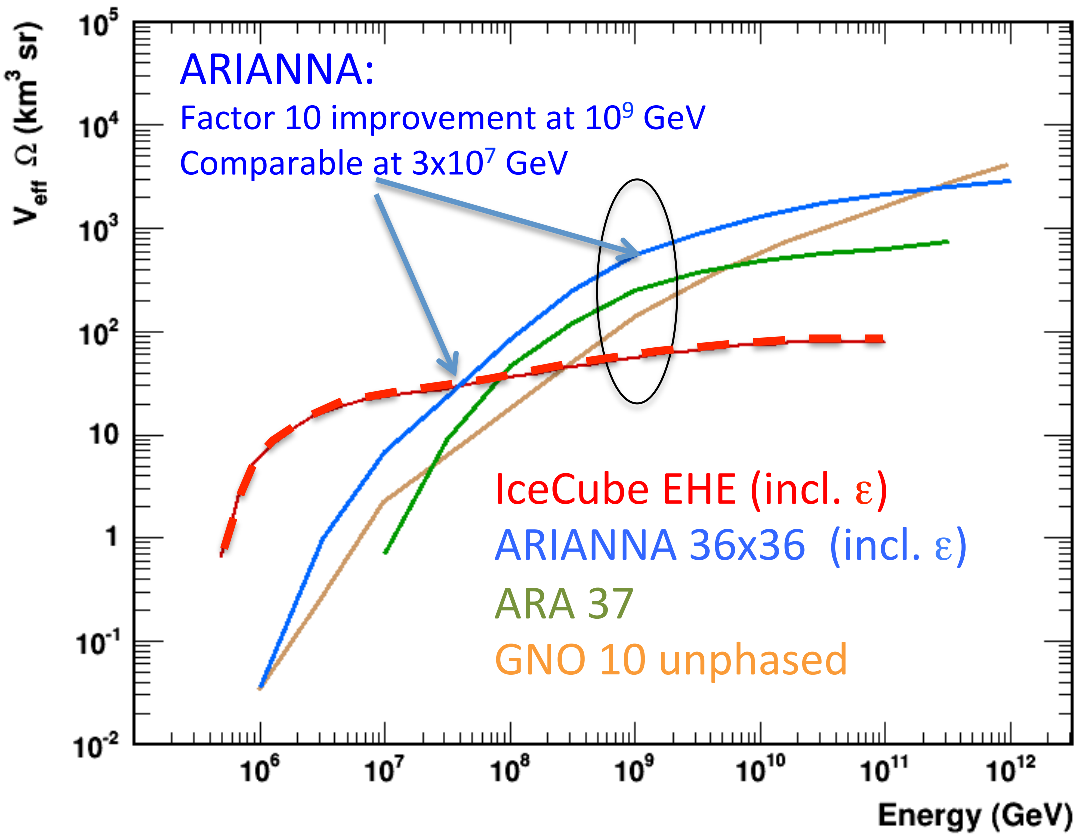


ARA

P. Allison, et al, Astropart. Phys. 35 (2012)

Effective Volumes ($V_{eff} * \Omega$)

(combines volume and viewing)

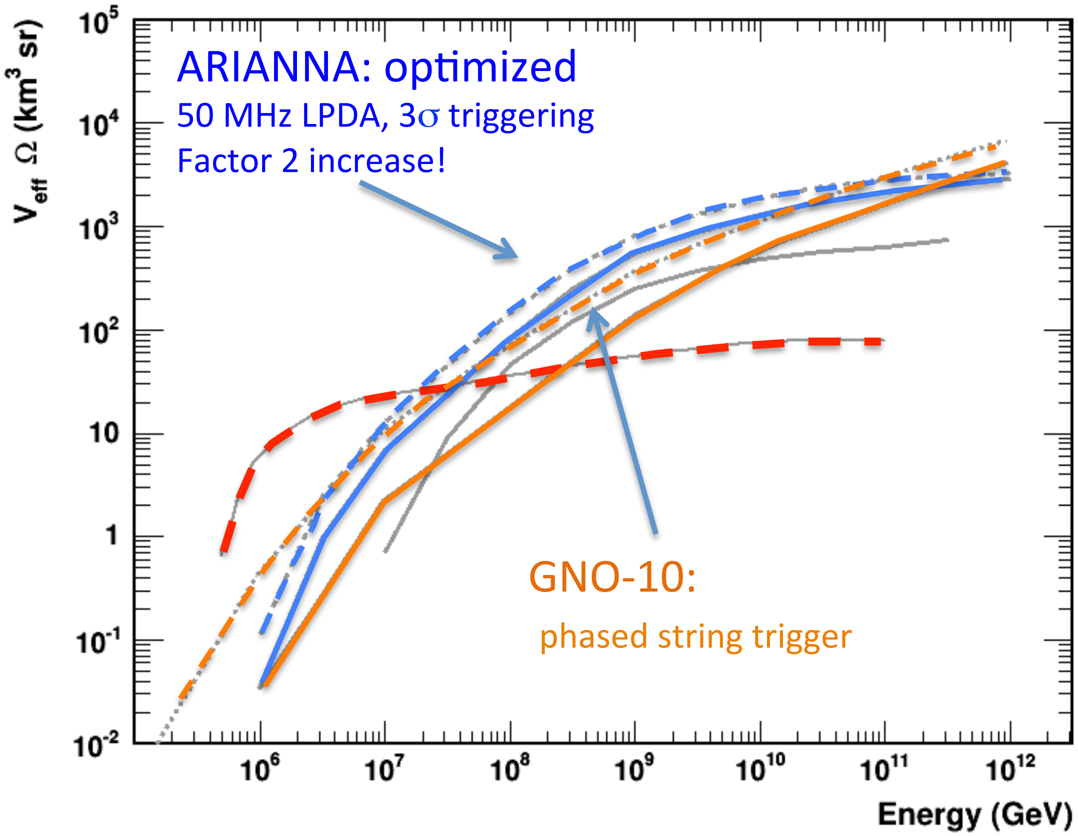


Radio techniques provide independent measurement and complement IceCube:

Radio better angular resol.
IC better energy resolution,
(rough generalization)

New Ideas for improvement

Encouraged by IceCube events, especially above 10^6 GeV, the collaborations are working on methods to improve low energy response of the detectors.



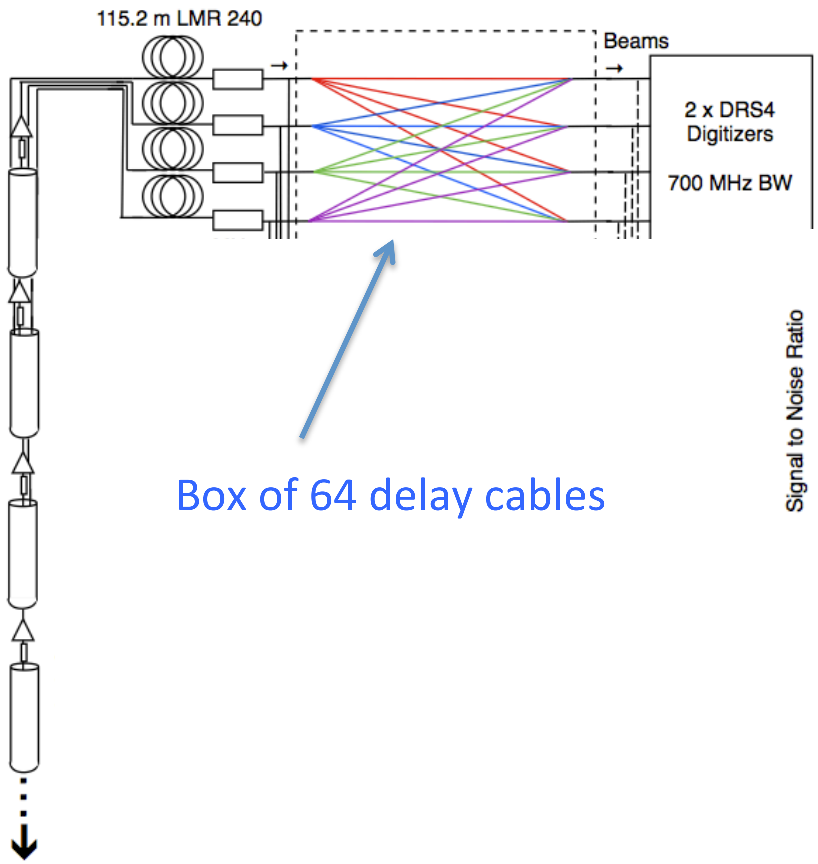
GNO: Phased antenna on a string to beam-form trigger. Shown: Phasing 16 antenna on 10 strings. Suggested possibility of phasing for 400 antenna strings.

K. Bechtol et al. (ICRC-1297)

GNO Testing of Phased Arrays

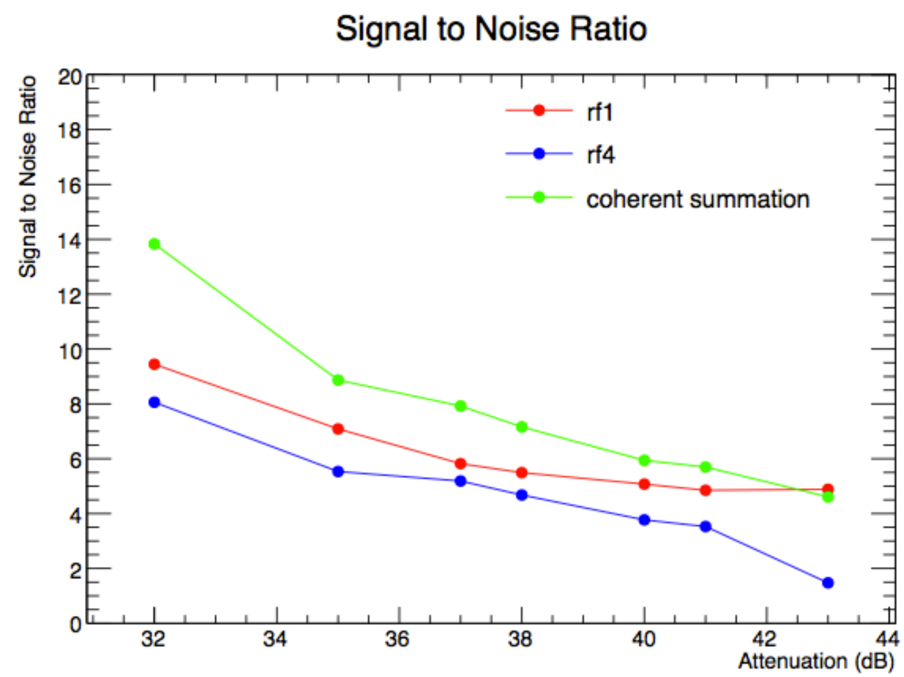
S. Wissel, ICRC-828

8 dipoles



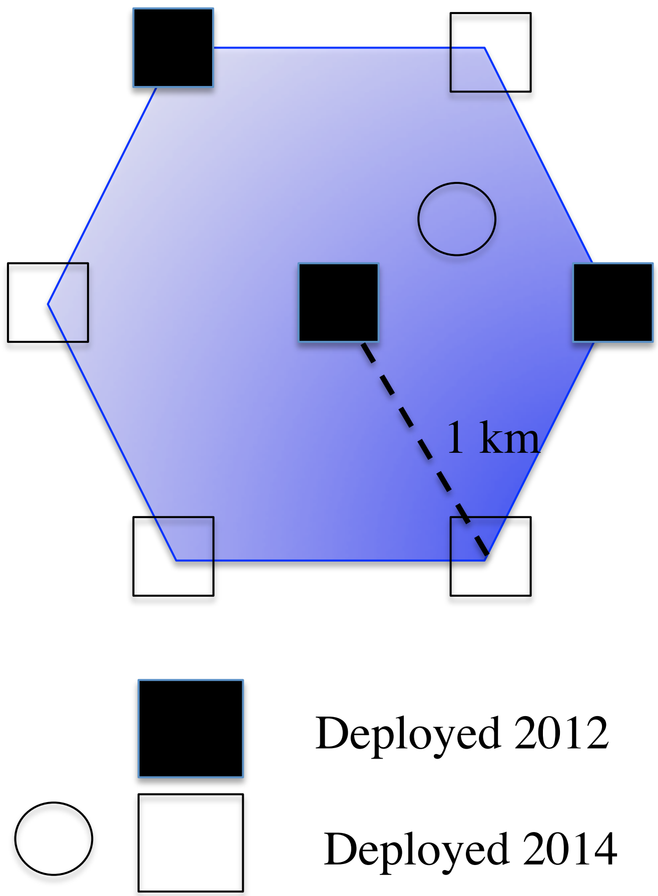
Box of 64 delay cables

2 antennas with phasing show factor ~1.4 improvement in signal/noise

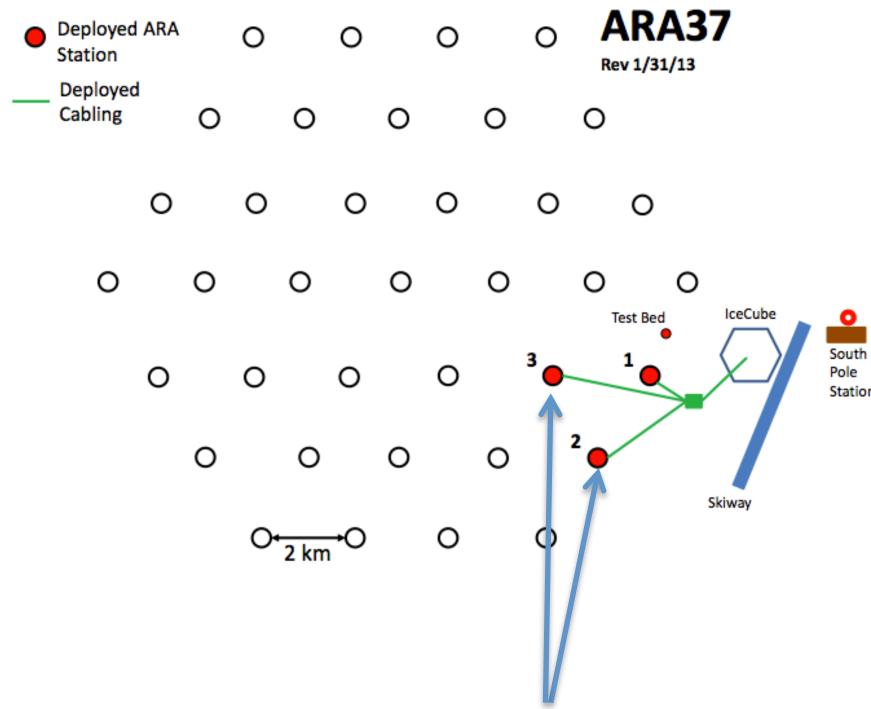


Pilot Arrays

Completed in Dec 2014



ARIANNA HRA

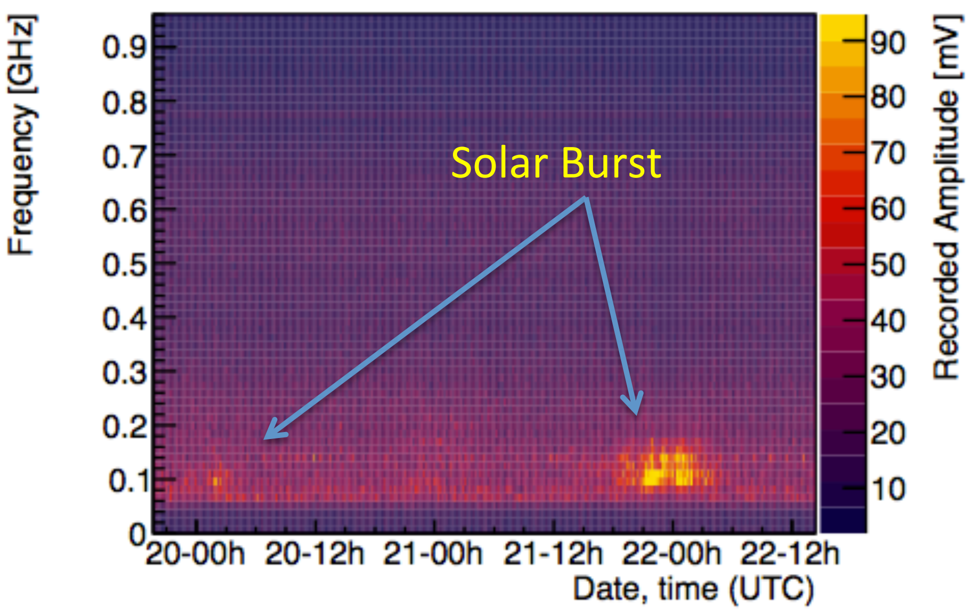


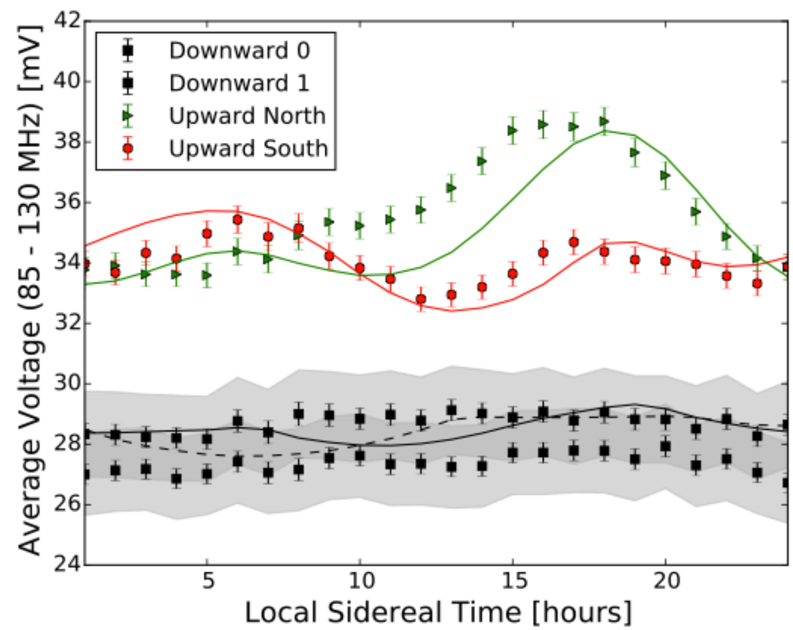
Data from stn 2,3 at this meeting

ARA

HRA observes galaxy and sun

A. Nelles (ICRC-822)





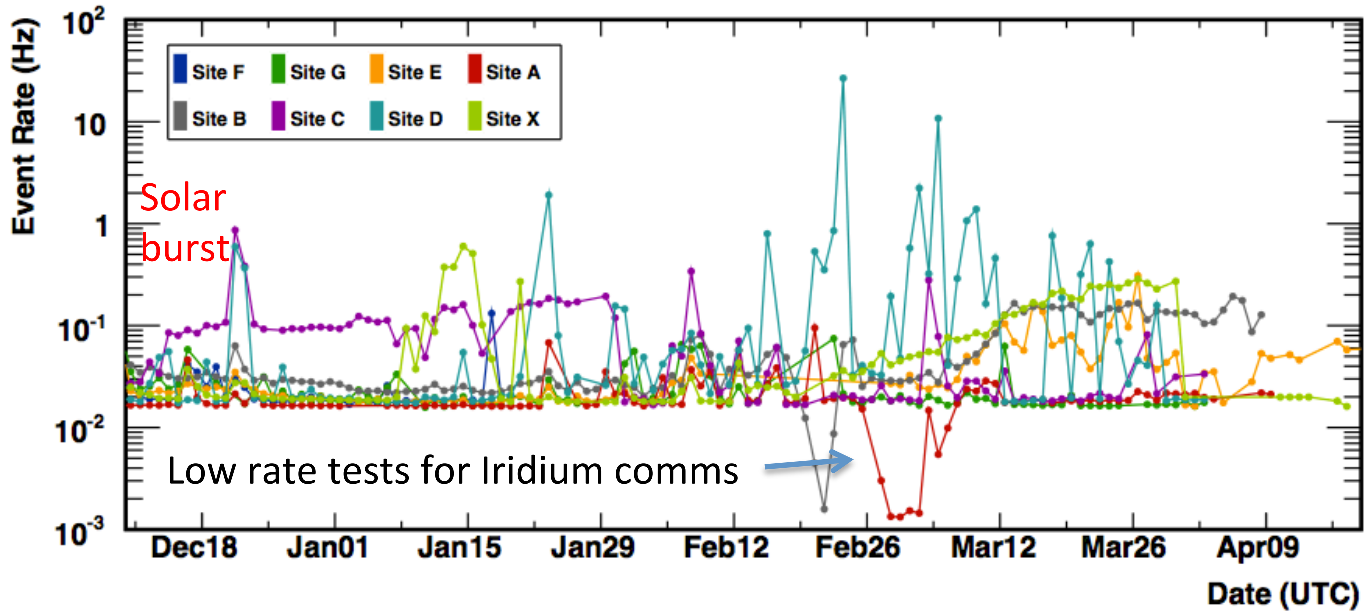
Large Solar Radio Burst
on Dec 22, 2014

Most power at 85-120MHz

Galactic emission

Modeled amplitude is correct, but periodicity needs additional study

HRA Trigger Rates

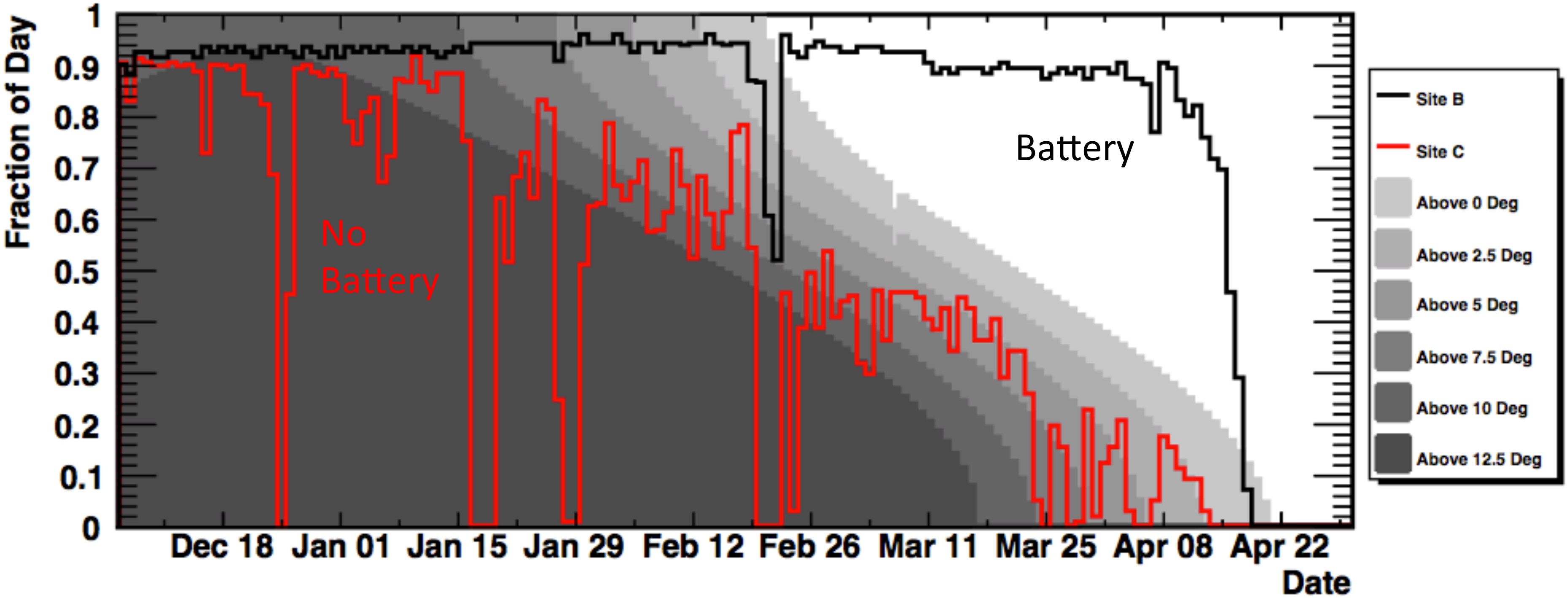


All stations ran well from commissioning in Dec 2014 to April, 2015 (Austral Sunset)

S. Barwick, ICRC-820

Station livetime

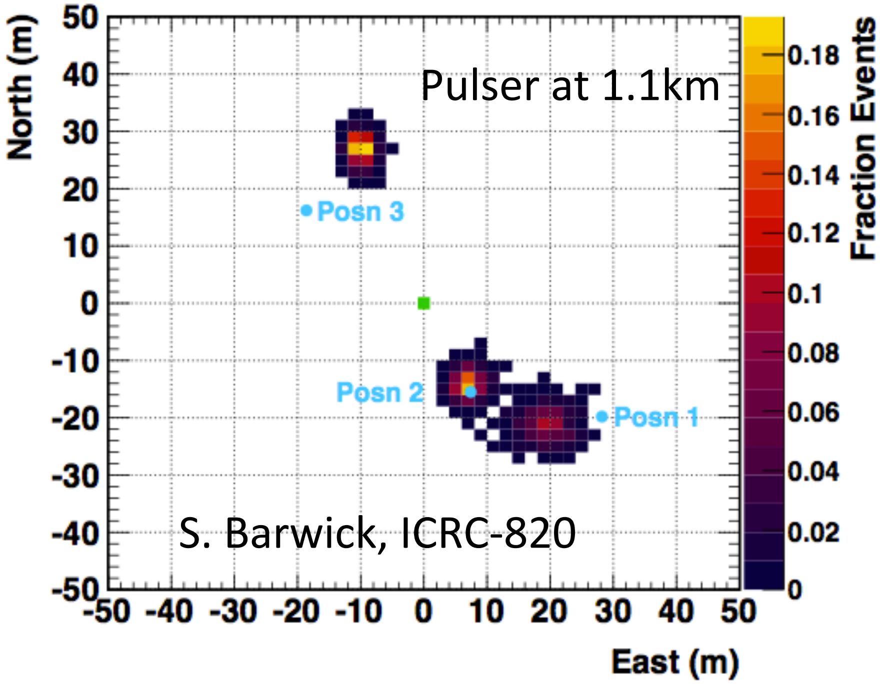
A. Nelles ICRC-822



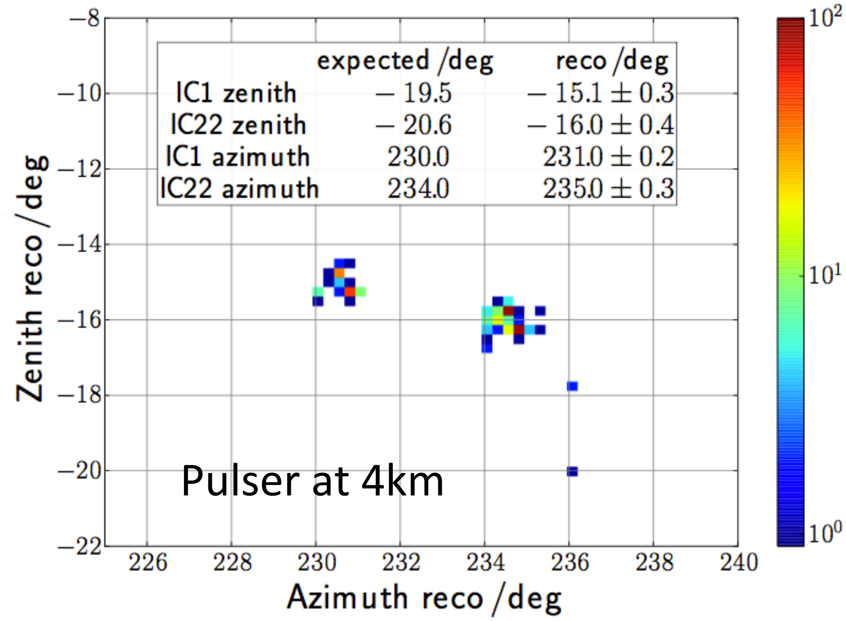
Site B station, with battery, achieves ~92% livetime, 8% loss from data transmission
Site C station, gaps due to un-transferred data. Requires sun >2-5° above horizon

Angular Reconstruction from Timing

ARIANNA Bounce studies

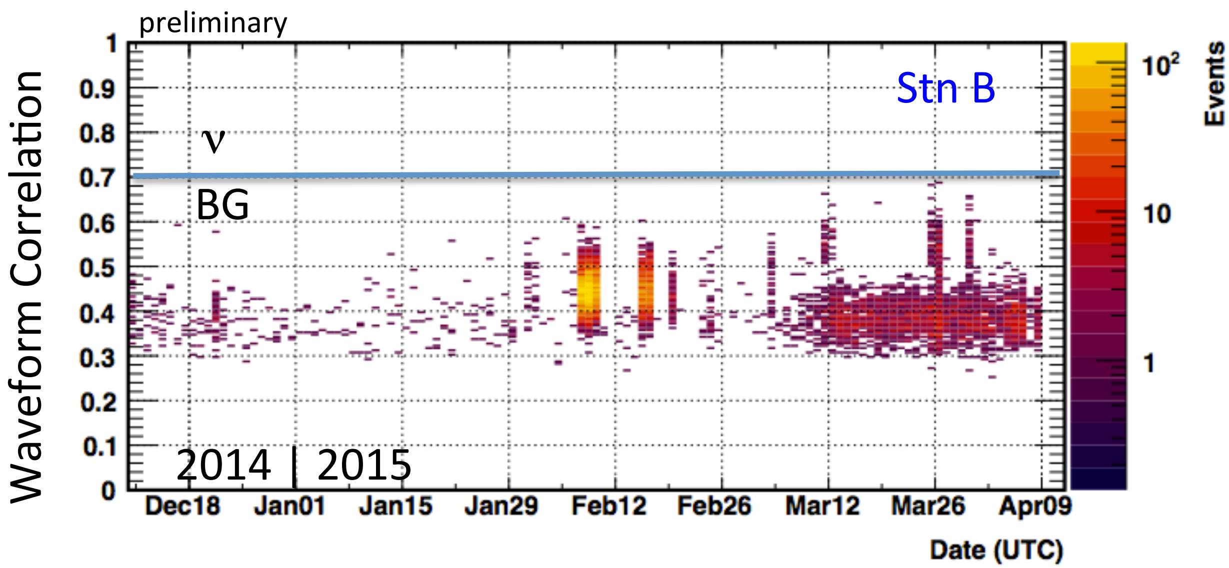


ARA Pulser studies



Both detectors show ~1 deg resolution for direction of radio pulse

Searching for Neutrinos with HRA



S. Barwick, ICRC-820

Cuts:
Good fit to plane wave
No spike in FFT spectrum
Waveforms appear ν-like

- No ν events from any of the HRA stations from 4 months of operation
- ARA reports results from 10 months O’Murchadha (ICRC-1293)

Flux Limits

Veff*Ω is only one important factor in determining the final sensitivity

$$E^2\Phi \sim \frac{E\lambda_\nu}{\varepsilon(V_{eff}\Omega)t_{live}}$$

Where

ε is analysis efficiency relative to trigger level (<1)

t_{live} is livetime (up-time - operational losses)

Solid progress – meeting goals

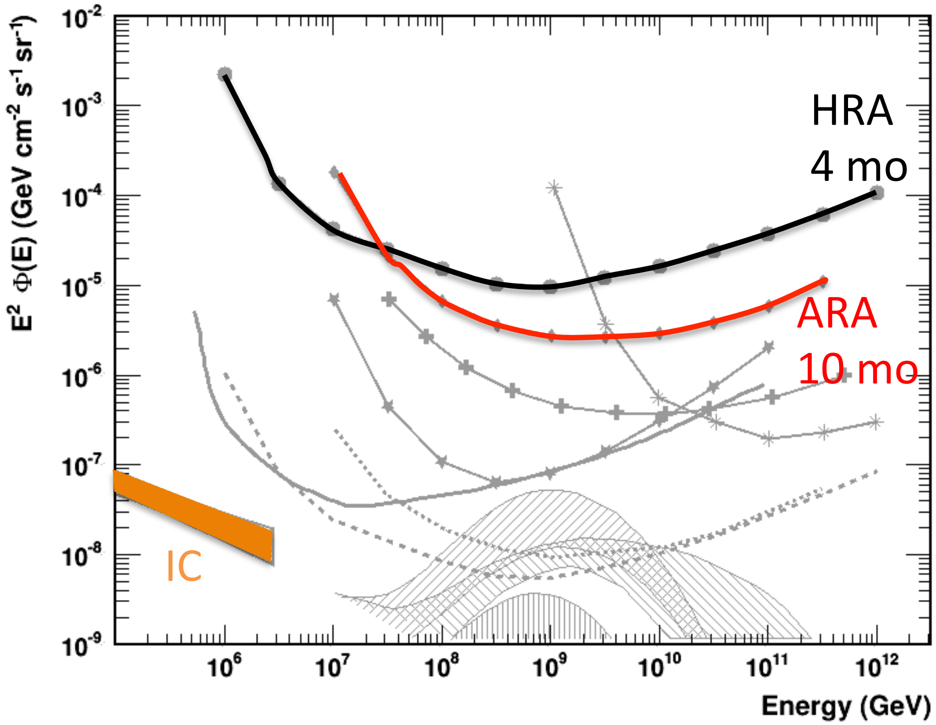
	Analysis Efficiency, ε	t_{live} (fraction of year)	
		Max	Current up-time (operational losses)
ARIANNA HRA	0.85 (10^9 GeV)	0.62*	0.57(0.9) = 0.51
ARA (2 of 3 stations)	0.6 (10^9 GeV)	1.0**	0.75
ANITA	0.61	0.1	varies with flight
GNO	-	0.83*	-

* Solar only
** power from SP Station

Refs
S.W. Barwick et al., Astropart. J, 70(2015)12 & ICRC-820
Aartsen, M.G, et al., O'Murchadha, ICRC-1293
P. Gorham, et al., Phys. Rev. D82 (2010) 022004
S. Wissel et al., ICRC-828

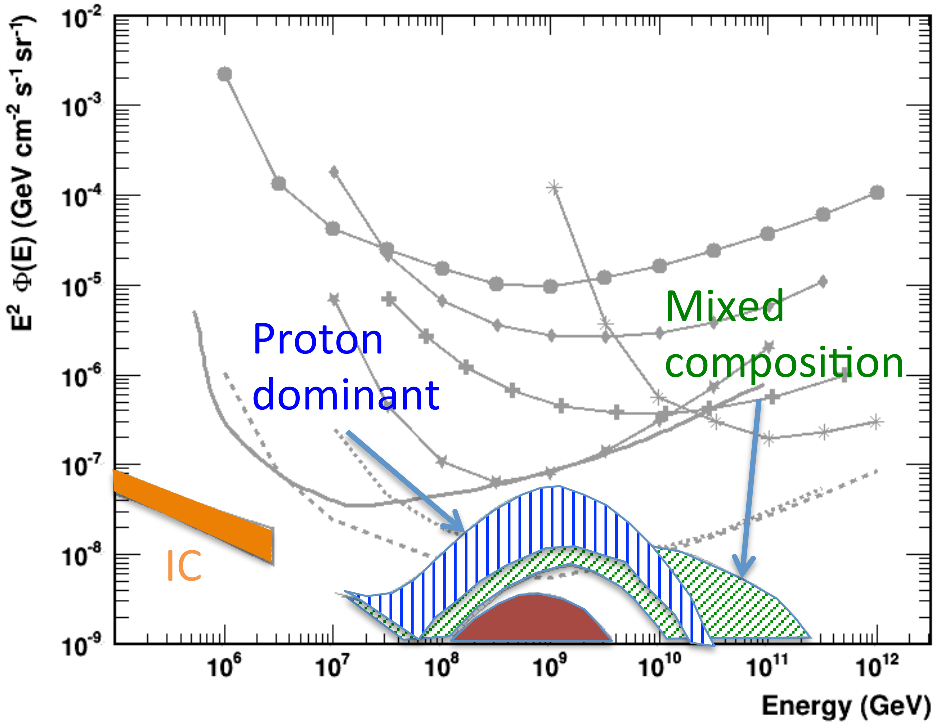
Neutrino Flux Limits from Pilot Programs

HRA = 7 stations in operation for 4 months, since commissioning
ARA = 2 stations in operation for 10 months



Cosmogenic (GZK) Neutrinos

- Created from collision of CR and CMB photons if $E_{CR}/A > \sim 5x10^{10}$ GeV

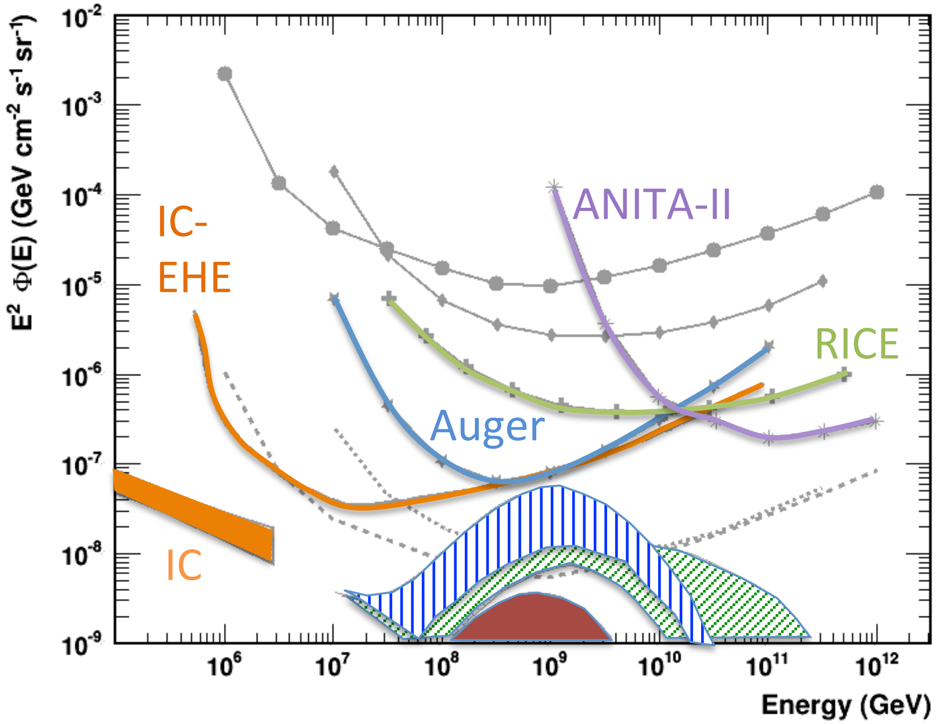


Calculations depend on:

1. Composition [p, mix, Fe]
2. Evolution of sources
3. Highest energy, E_{max}
4. Injection Spectrum
5. End of Gal. CR

Cosmogenic (GZK) Neutrinos

- Experimental Limits

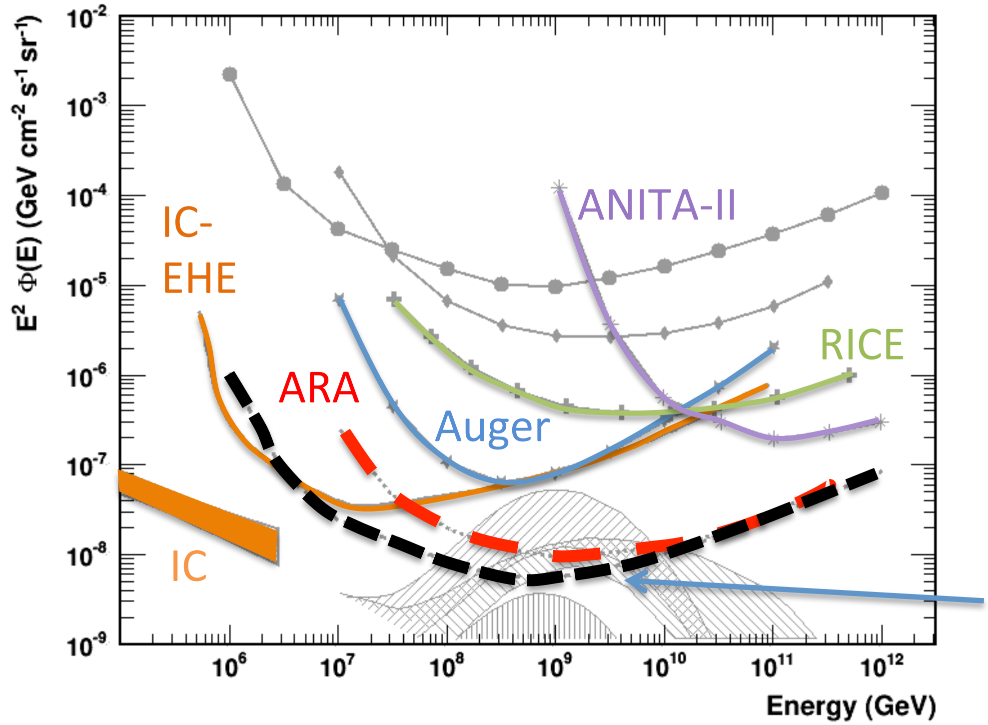


Calculations depend on:

1. Composition [p, mix, Fe]
2. Evolution of sources
3. Highest energy, E_{max}
4. Injection Spectrum
5. End of Gal. CR

Cosmogenic (GZK) Neutrinos

- ARIANNA and ARA37 3 year sensitivities



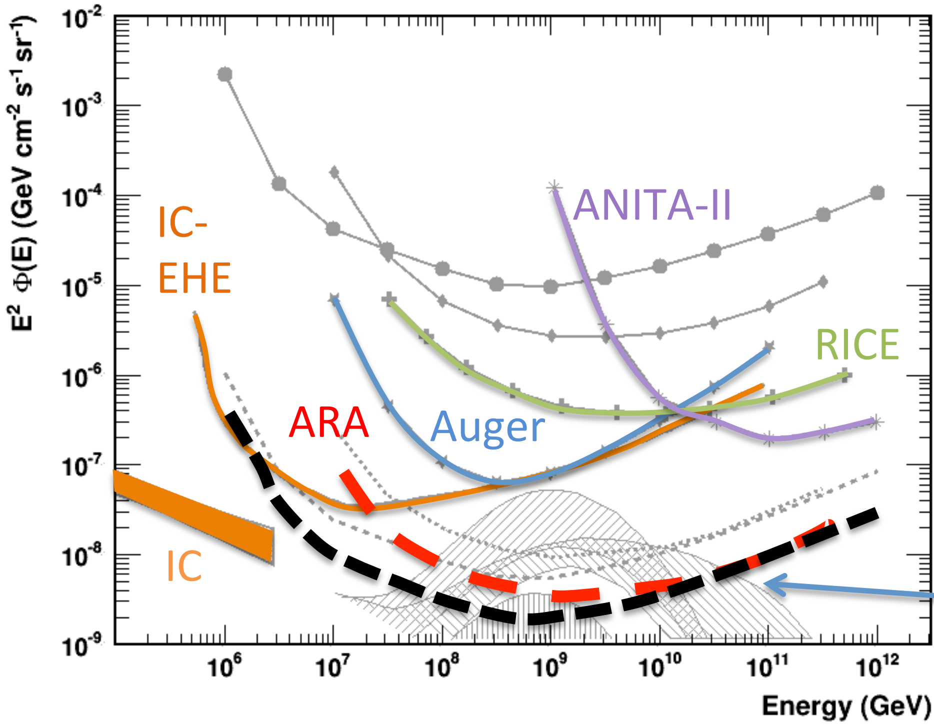
Calculations depend on:

1. Composition [p, mix, Fe]
2. Evolution of sources
3. Highest energy, E_{max}
4. Injection Spectrum
5. End of Gal. CR

ARIANNA baseline
Incl. t_{live}, ε from HRA

Cosmogenic (GZK) Neutrinos

- ARIANNA and ARA37 10 year sensitivities



ARIANNA baseline
Incl. t_{live}, ε from HRA

Calculations depend on:

1. Composition [p, mix, Fe]
2. Evolution of sources
3. Highest energy, E_{max}
4. Injection Spectrum
5. End of Gal. CR

Commentary

- IceCube neutrinos, especially those above 10^{15} eV provide strong incentive to probe to even higher energies with larger detectors.
- Pilot programs of next generation of EHE neutrino radio-based detectors are completed (e.g., ARIANNA-HRA), and teams are gaining experience with sustained operation. Plans for the next phase in construction are coalescing.
- Optimized for EeV (though with capability to 10^{16} eV, and perhaps 10^{15} eV with phased arrays).

EHE ν detectors: Comments

EHE neutrino detectors:

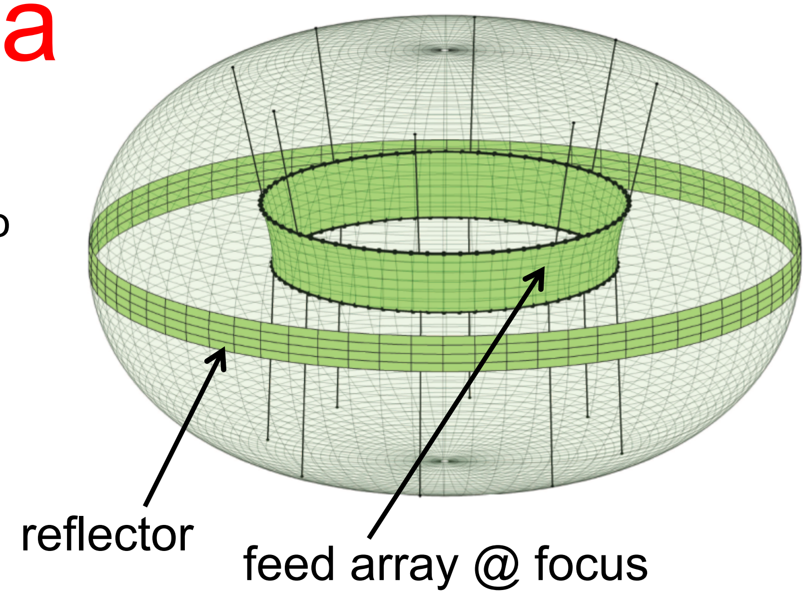
- Contribute to ongoing quest to understand EHE CRs
  - Neutrino measurements provide independent confirmation of GZK mechanism
  - Combined with CR and photon measurements, can help to constrain source class, evolution, E_{max}, and composition of CR
- Search for new physics
  - Beam of EeV neutrinos can uncover new physics at ~5-10 x E_{cm} of LHC through cross-section and spectral modifications
- Search for new sources:
  - EeV neutrinos must point back to sources and direction can be measured with good precision (and current procedures can be improved).

Huge upside at modest cost, deployment time, and risk

Shown: (Left to right) Joulien Tatar, Chris Persichilli, James Walker, Corey Reed

EVA: ExaVolt Antenna

- Idea: Turn an entire NASA super pressure balloon into the antenna
- Currently: 3 year NASA grant for developing 1/5 scale engineering test, full RF + float test
- Full Balloon: similar sensitivity to full, 3-year of ground-based arrays



Gorham et al. (2011)

→ Feed design: dual-polarization, broadband, sinuous antennas on inner membrane

Slide borrowed from A. Vieregg