The Future of Ultra-high Energy (GZK) Neutrino Searches

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Harvard CfA

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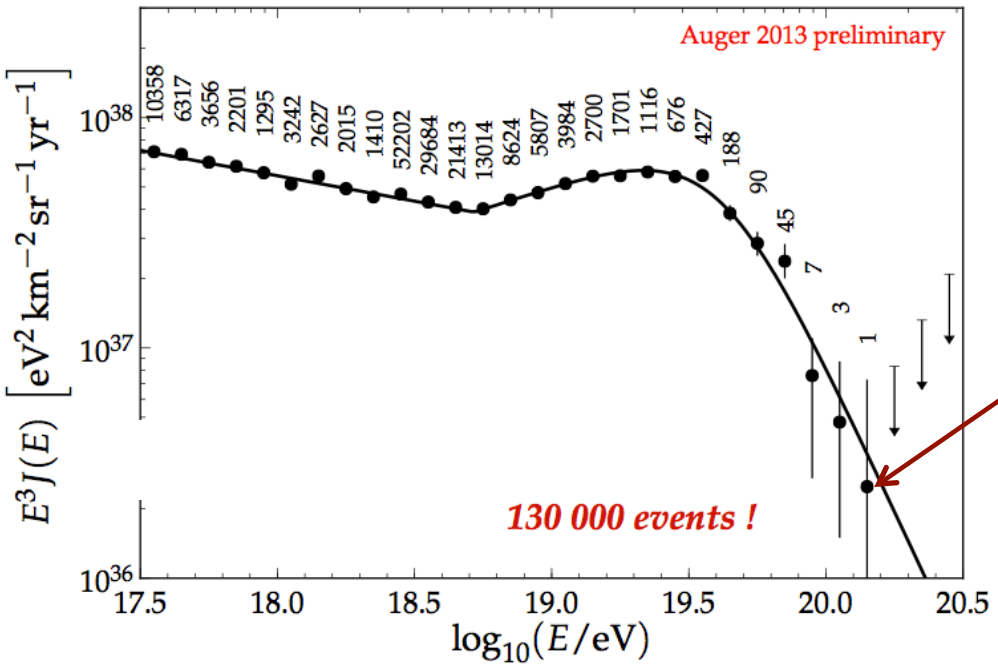
Neutrinos: The Ideal UHE Messenger

UHE Cosmic Ray Flux



- Photons lost above 100 TeV (pair production on CMB & IR)
- Protons and Nuclei suffer curvature induced by B fields
- But: we know there are sources up to 10^{20} eV!!

UHE Neutrino Detectors:

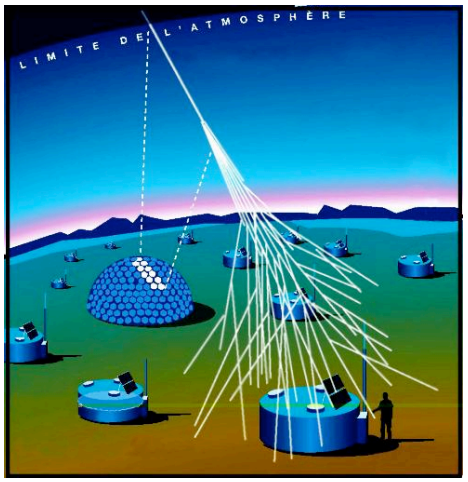
- Highest energy observation of extragalactic sources
- Very distant sources
- Deep into opaque sources

Neutrino Production: The GZK Process

GZK process: Cosmic ray protons (E> $10^{19.5}$ eV) interact with CMB photons

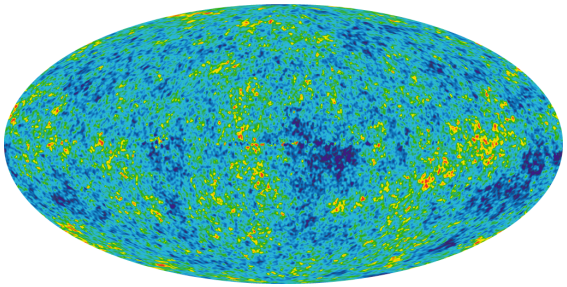
$$p + \gamma_{cmb} \rightarrow \Delta^+ \rightarrow n + \pi^+$$
$$\rightarrow \mu^+ + \boxed{\nu_\mu}$$
$$\rightarrow e^+ + \boxed{\bar{\nu}_\mu + \nu_e}$$

cosmic rays

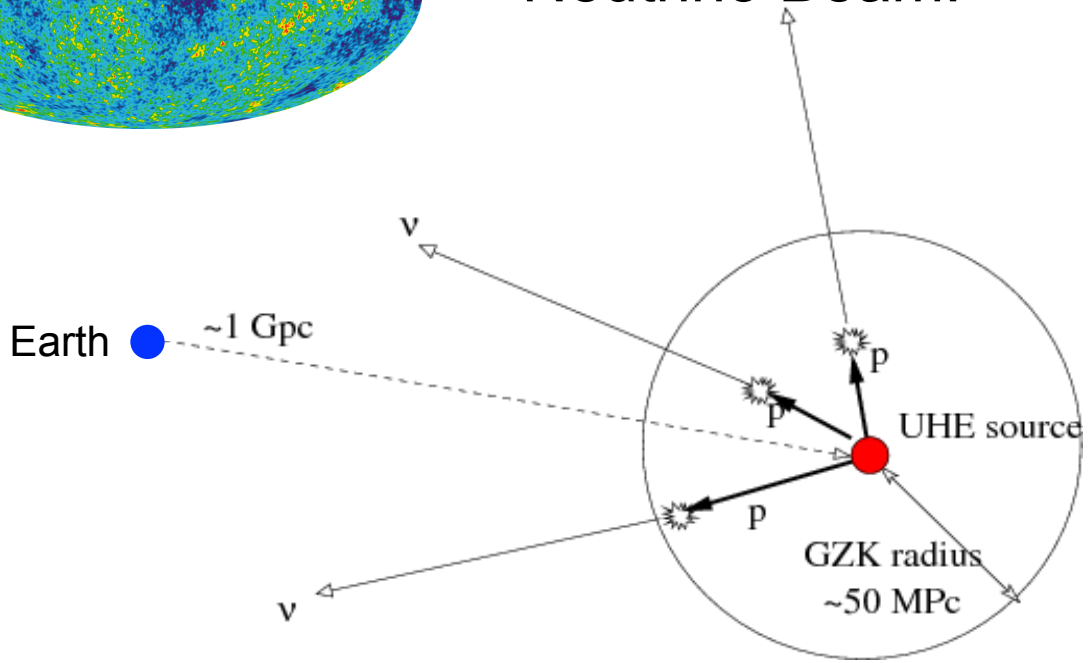


+

CMB



= Neutrino Beam!



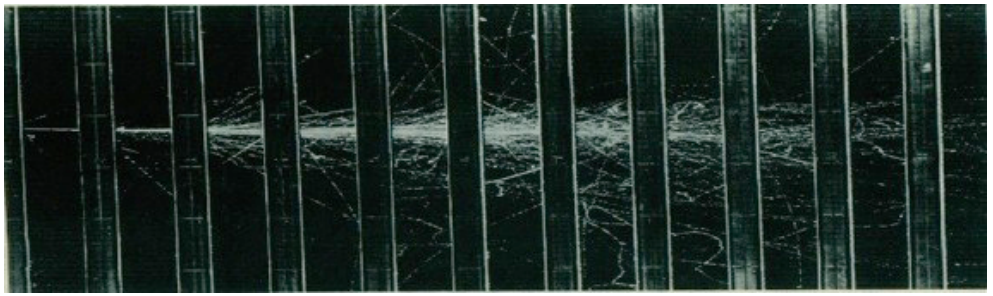
Discover the origin of high energy cosmic rays through neutrinos?

Possible Mechanisms for Detection

Bright, broadband radio emission: the Askaryan Effect

- EM shower in dielectric (ice) → moving negative charge excess
- Coherent radio Cherenkov radiation ($P \sim E^2$) if $\lambda >$ Moliere radius

$e^+, e^-, \gamma \longrightarrow$

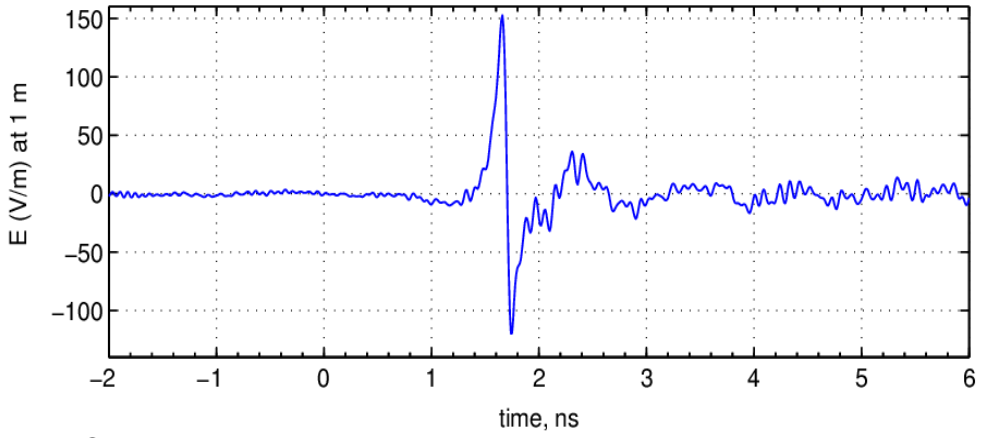


Typical Dimensions:
L ~ 10 m
$R_{moliere}$ ~ 10 cm

Other detection techniques:

- Optical Cherenkov emission
- Acoustic signal

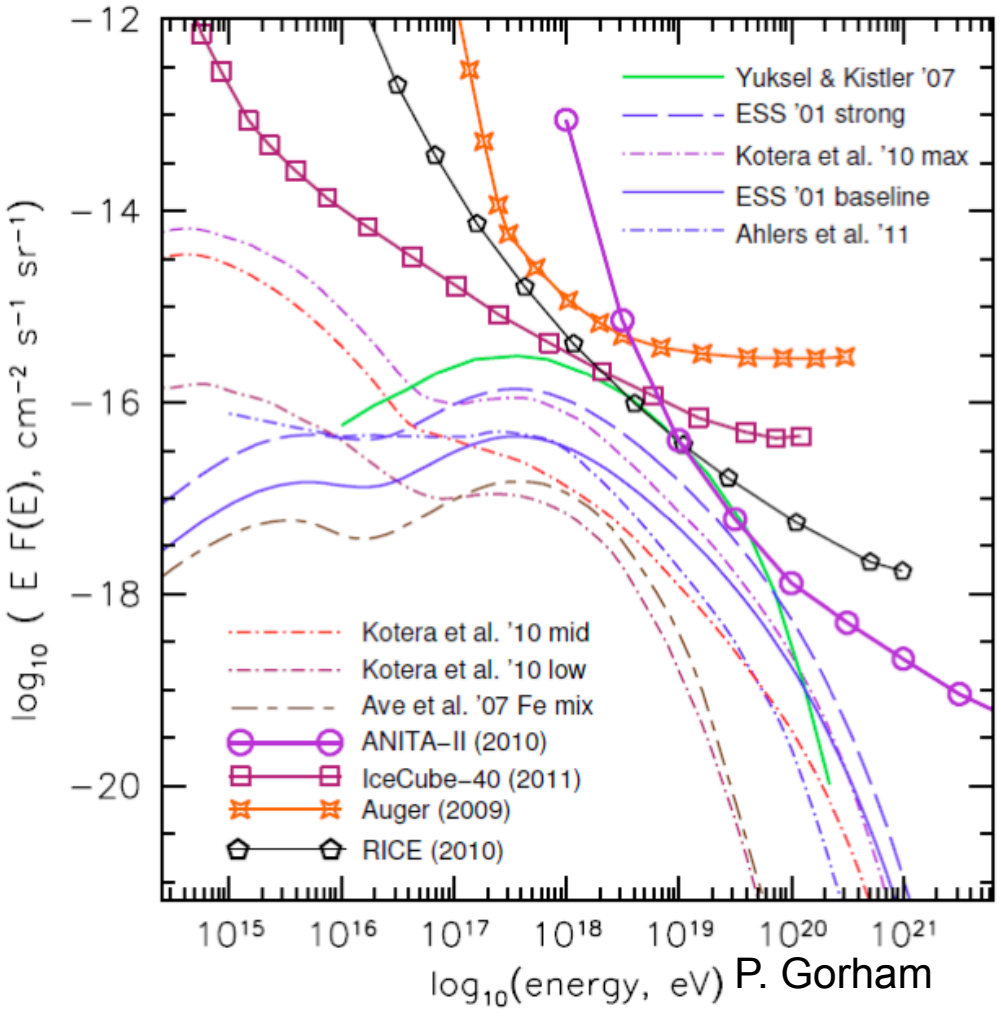
Askaryan Effect Observed at SLAC



ANITA Coll., PRL (2007)

Models & Current Constraints

- Best current limits:
  - ANITA at highest energies ($>10^{19}$ eV)
  - IceCube at lower energies ($<10^{18}$ eV)
- Starting to constrain some models (source evolution and cosmic ray composition)
- How do we get a factor of ~100 to dig into the interesting region and make a real UHE neutrino observatory?
- Why bother? Not a fishing expedition! There is a floor on the expectation (unlike some other search experiments)

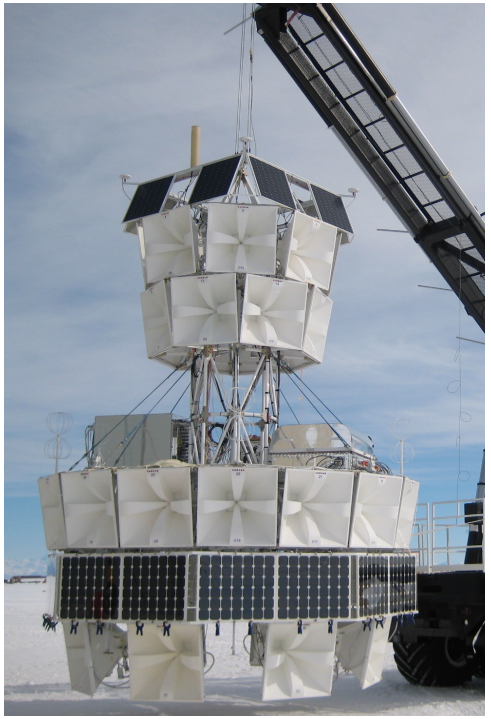


P. Gorham

ANITA-I & ANITA-II: Best Limit > 10^{19} eV

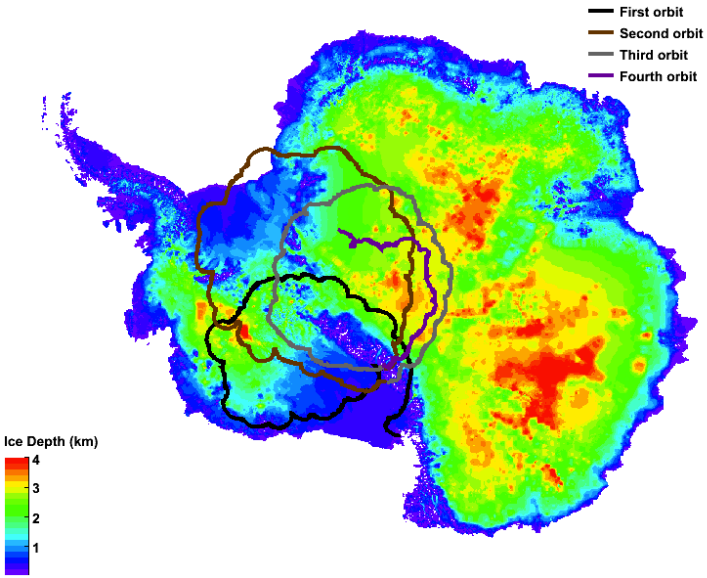
NASA Long Duration Balloon, launched from Antarctica

- ANITA-I: 35 day flight 2006-07
- ANITA-I: 30 day flight 2008-09



Instrument Overview:

- 40 horn antennas, 200-1200 MHz
- Direction calculated from timing delay between antennas
- In-flight calibration from ground
- Threshold limited by thermal noise



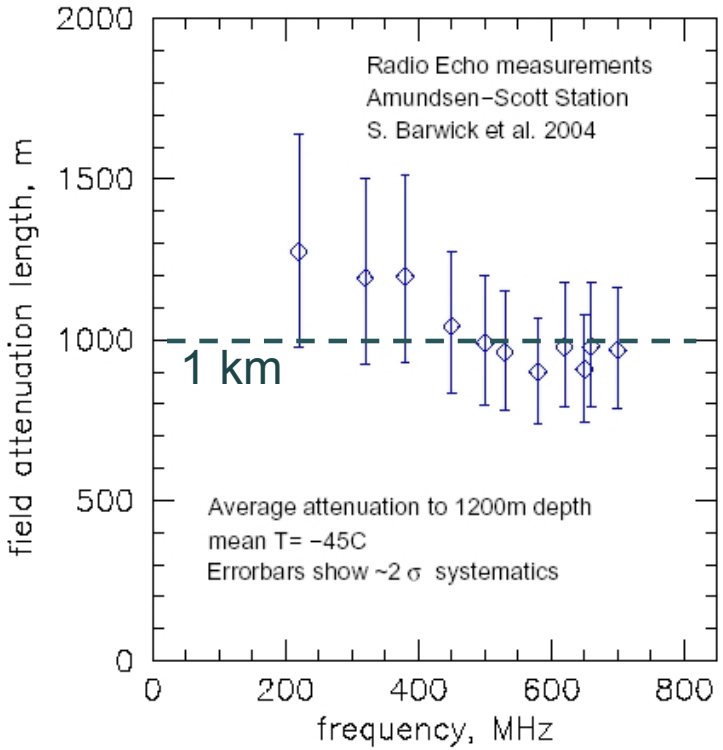
UHE Neutrino Search Results:

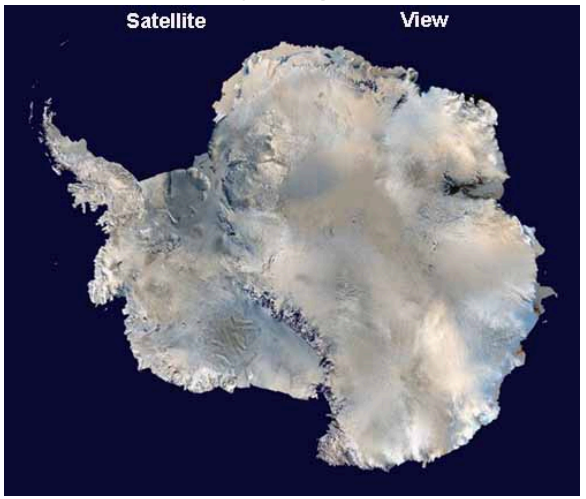
	ANITA-I	ANITA-II
Neutrino Candidate Events	1	1
Expected Background	1.1	0.97 +/- 0.42

UHE Neutrino Radio Detector Requirements

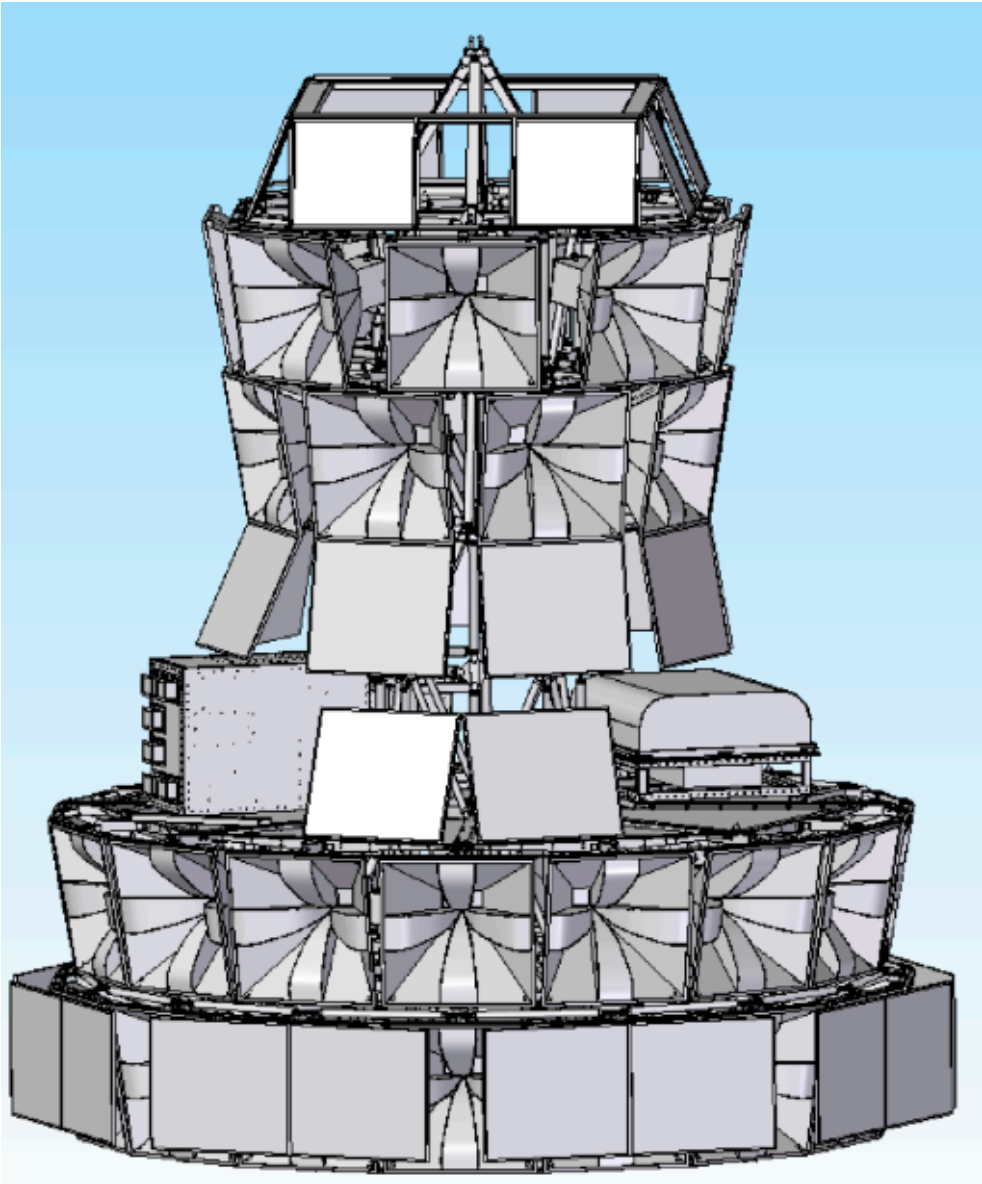
- ~1-10 GZK neutrinos/km^2/year
- L_{int} ~ 300 km
  → ~ 0.01 neutrinos/km^3/year
- Need a huge (>> 100 km^3), radio-transparent detector
- 3 media: salt, sand, and ice
- Long radio attenuation lengths in south pole ice
  - 1 km for RF (vs. ~100 m for optical signals used by IceCube)

→ Antarctic ice is good for radio detection of UHE neutrinos!





ANITA-III: 2014-2015



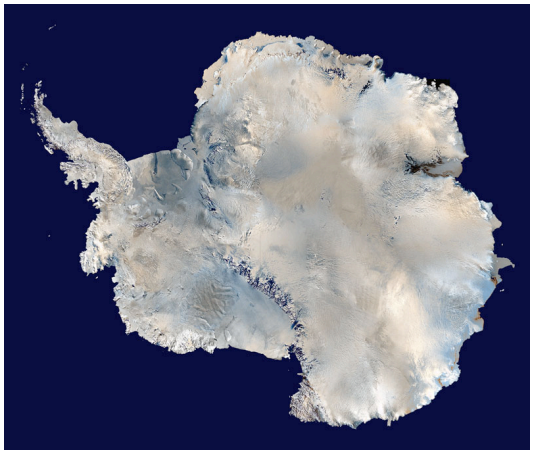
- Flight scheduled for 2014
- More antennas
- Digitize longer traces
- New: interferometric trigger
- Lower noise front-end RF system

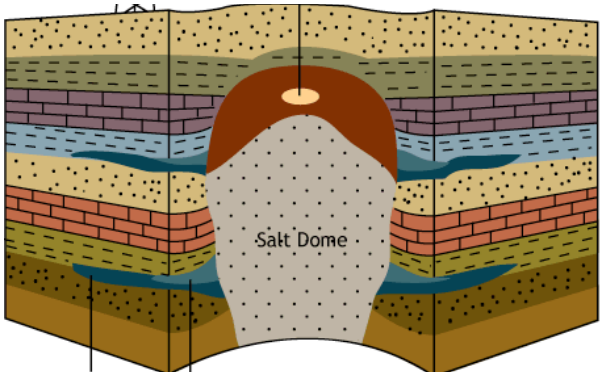
→ Factor of 5 improvement in neutrino sensitivity compared to ANITA-II

Beyond ANITA: Going to the Ground

Why go to the ground?

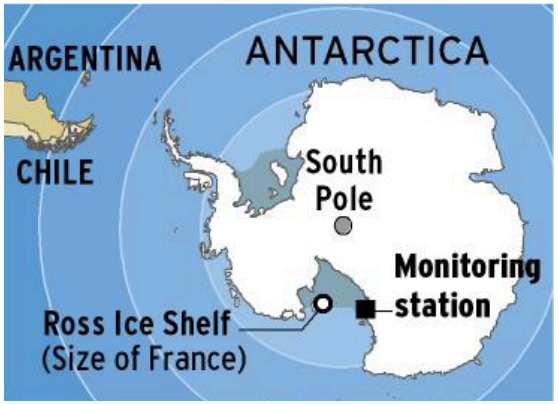
- Much more livetime
- Understandable man-made background
- Lower energy threshold
- Use more antennas than on a balloon
- But: smaller instrumented volume

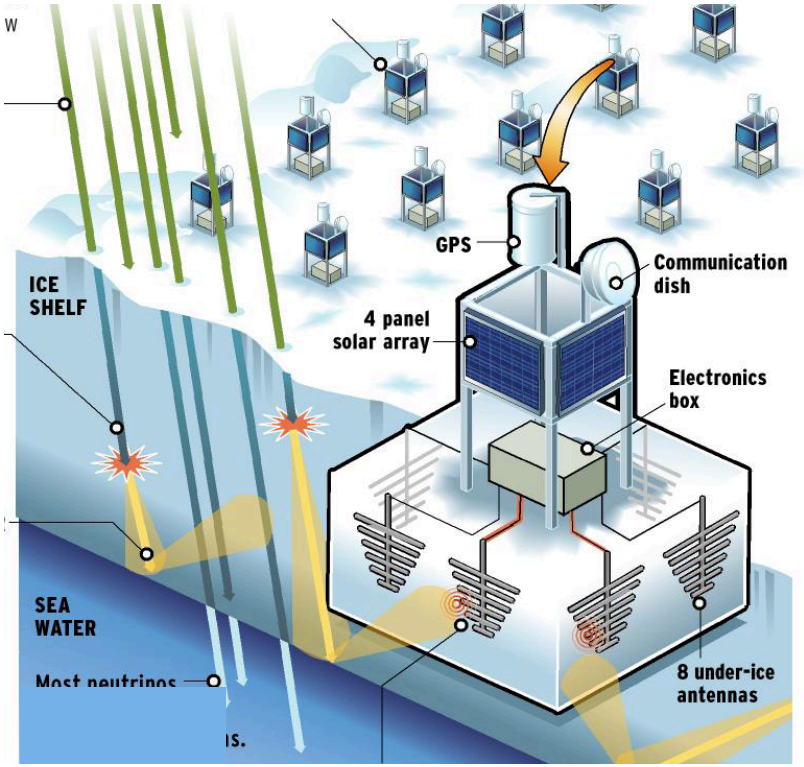




ARIANNA

- Idea: Ground-based array of antennas on the surface of the Ross Ice Shelf
- Currently: 4 stations operating well, 3 more coming in December
- Plan: future proposal for many more stations
- Attempting to use wind power: very promising but the kinks have not all been worked out

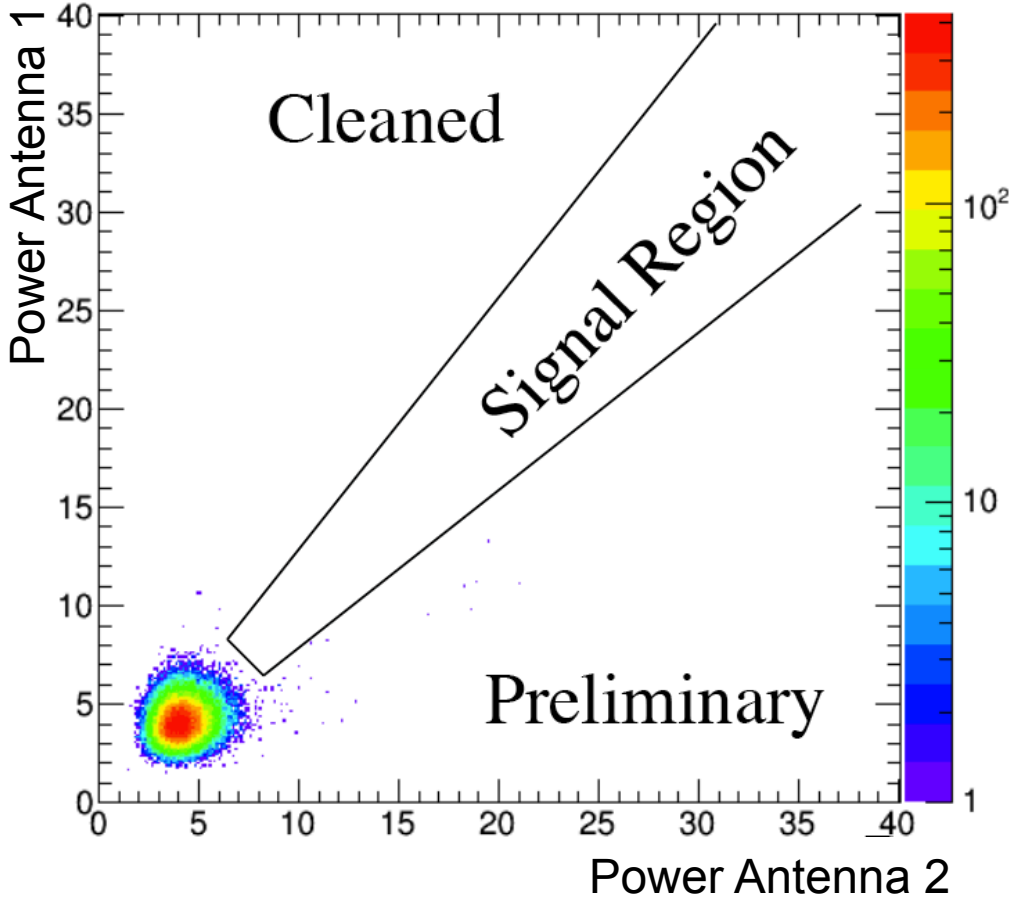




ARIANNA Coll. See arXiv:1207.3846

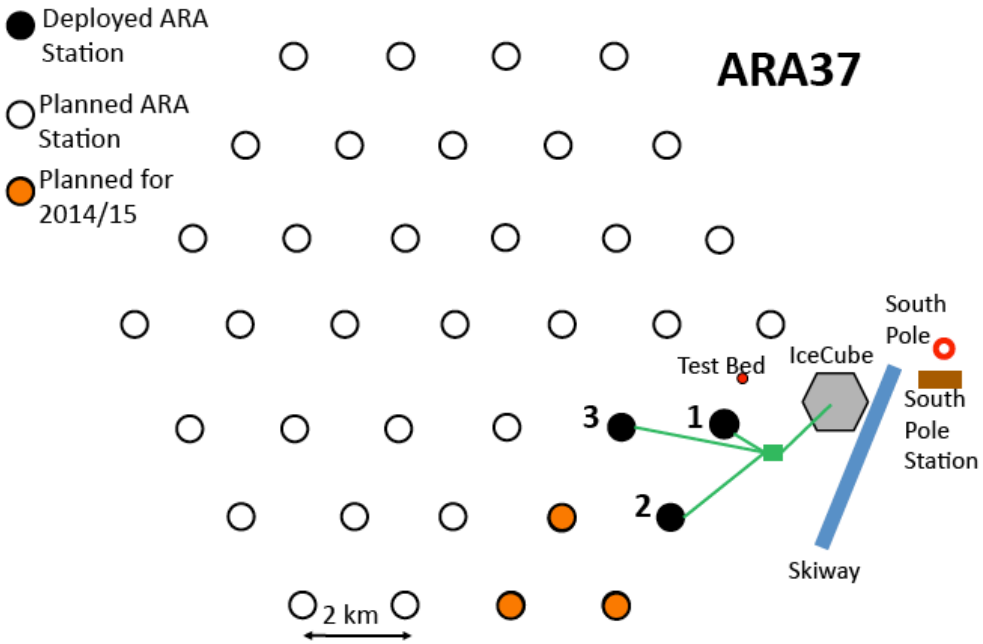
ARIANNA Data from 3 Months of Station 3

- Dec 15 2012 - Mar 15 2013
- 552473 events collected at 5 sigma thresholds on each channel
- Cuts to data before this plot was made:
  - Too much power below highpass
  - CW power (peaks in frequency domain)
  - Time-domain waveform shape
- Complete separation (for this sample) of background events from the signal region
- No directional reconstruction used yet



From ARIANNA ICRC Talk – S. Barwick

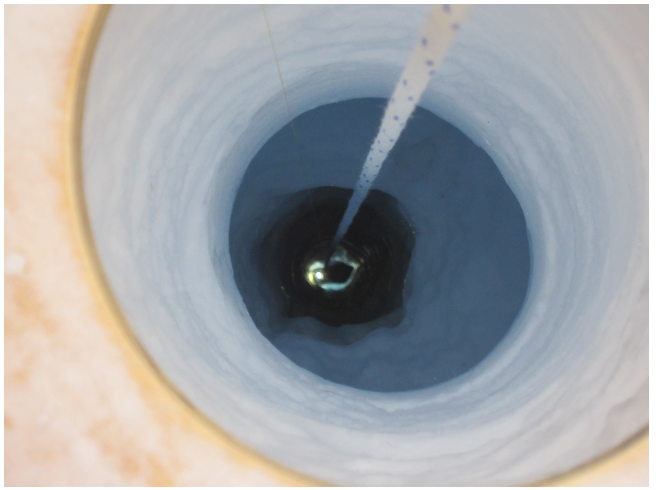
ARA: Askaryan Radio Array



- Idea: 37-station array of antennas buried 200m below the surface at the South Pole
- Currently: 3 stations + testbed deployed and working
- Plan: 3 more stations this year, propose pending for next stage of deployment

V Pol Antennas

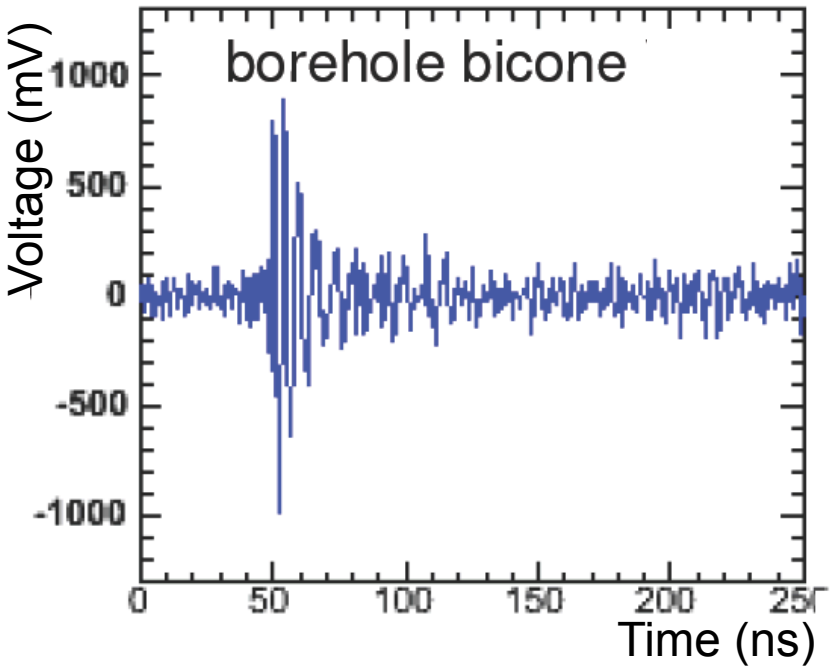
H Pol Antennas

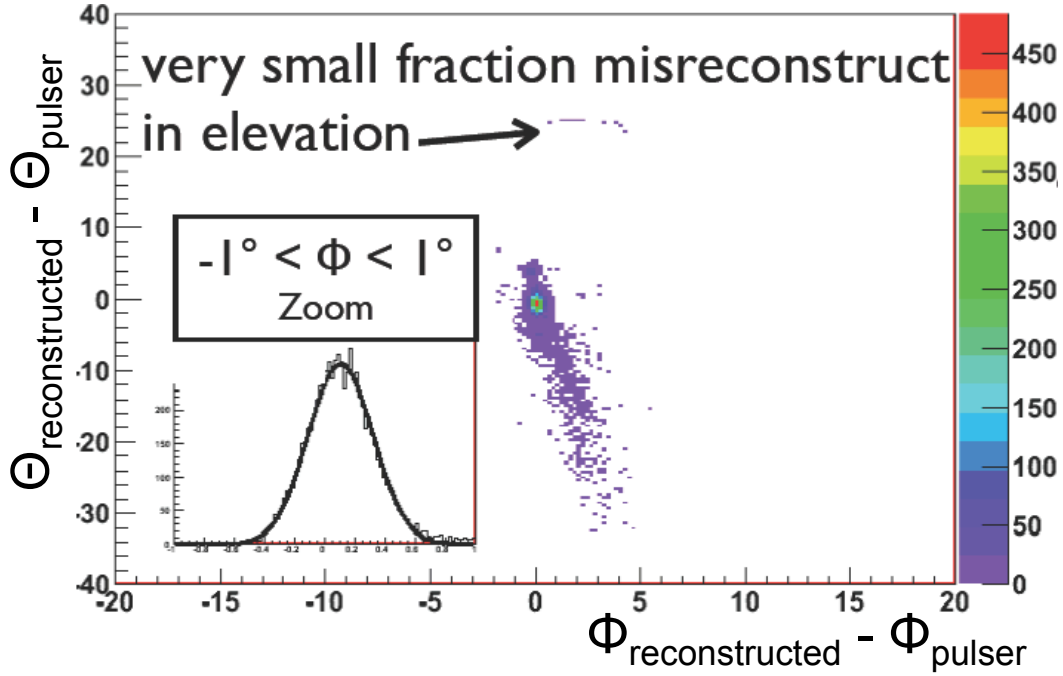


ARA Collaboration. Astropart. Phys. (2012)

ARA Calibration Pulser Event Reconstruction

- Underice pulsers @ 1 Hz
- Really useful: trigger efficiency, event timing
- Cross-correlate waveforms from different antennas to find system delays



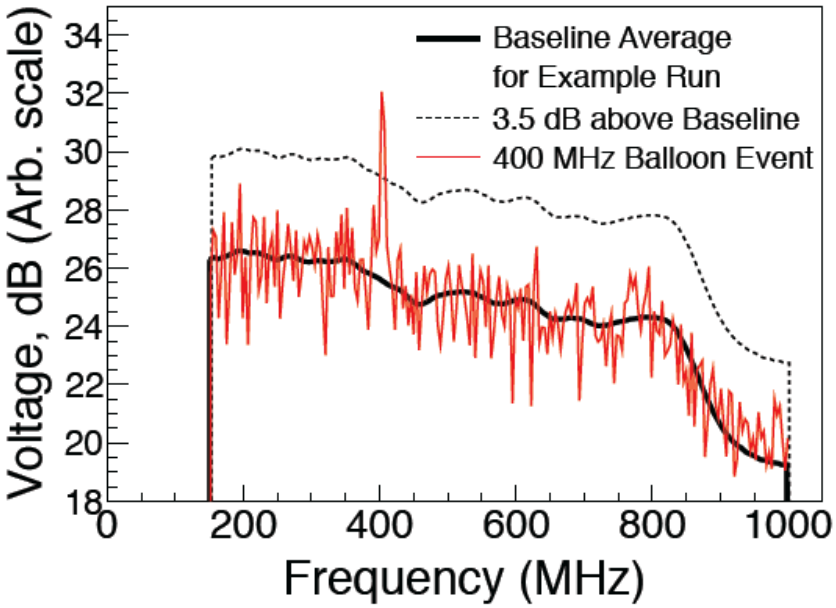


- Alive and triggering
- Nice event reconstruction!
- Exercises analysis code

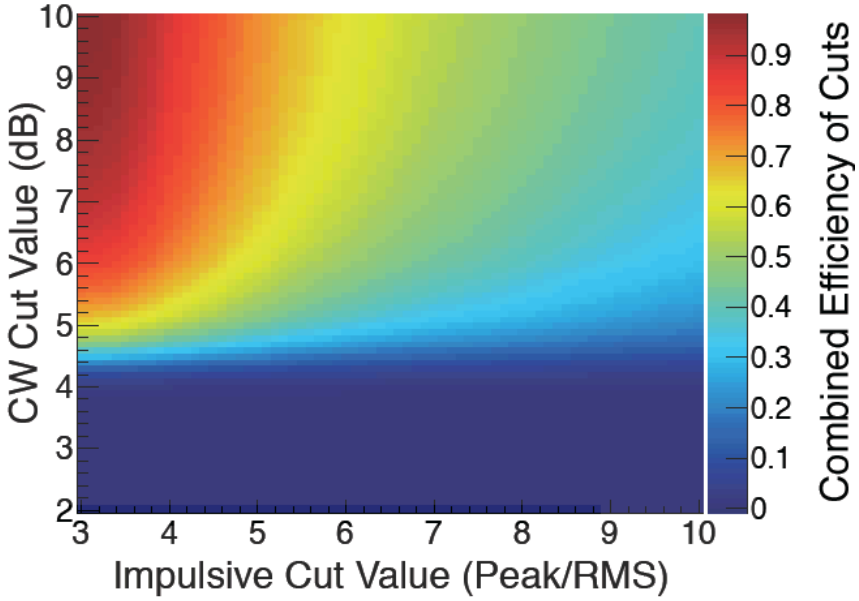
ARA Collaboration. Astropart. Phys. (2012)

ARA Testbed Data Analysis

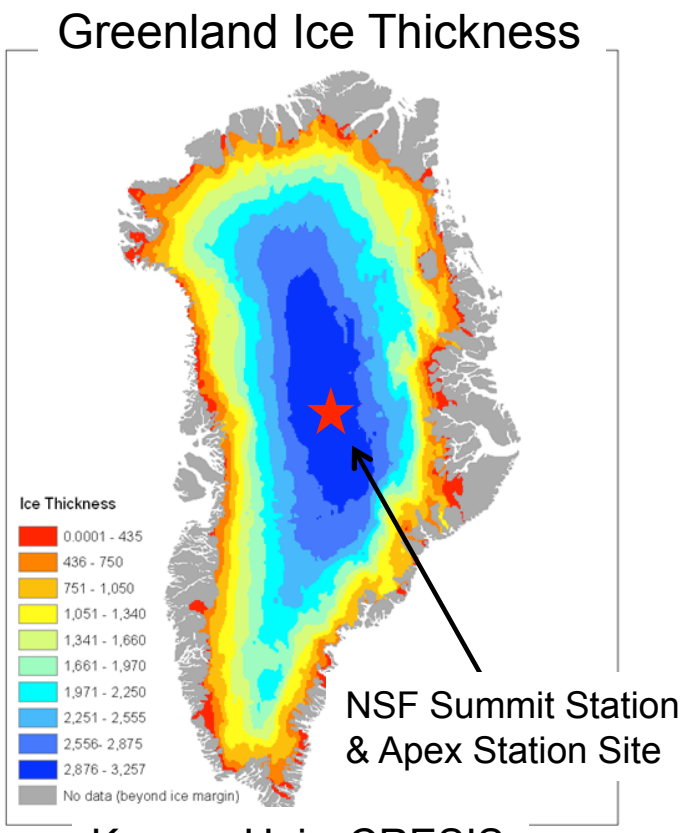
- 20 Feb 2012 – 30 Jun 2012, look at 10% sample
- Two independent blind analyses
- Cut-based analysis:
  - Impulsiveness cut (V_{peak}/V_{rms})
  - Directionality cuts
  - CW cut



Analysis Efficiency: $10^{17.5}$ eV neutrinos



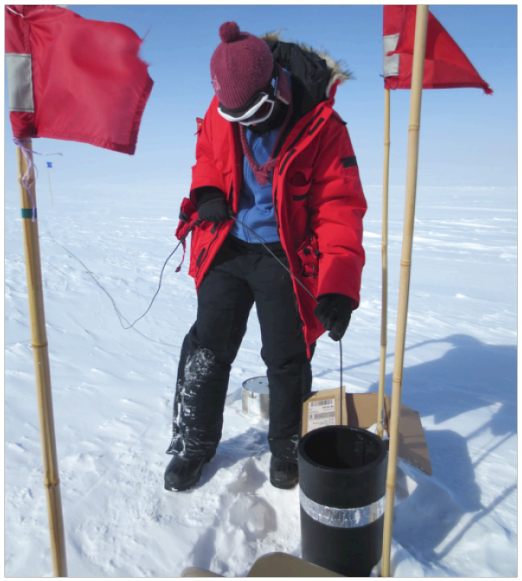
Summit Station Greenland



- 3 km thick ice at Summit Station
- Measurements by glaciologists (Paden et al.) suggest as good radio properties as the best Antarctic ice
- Radio quiet site (small station)?
- Logistical advantages: longer season, easier deployment

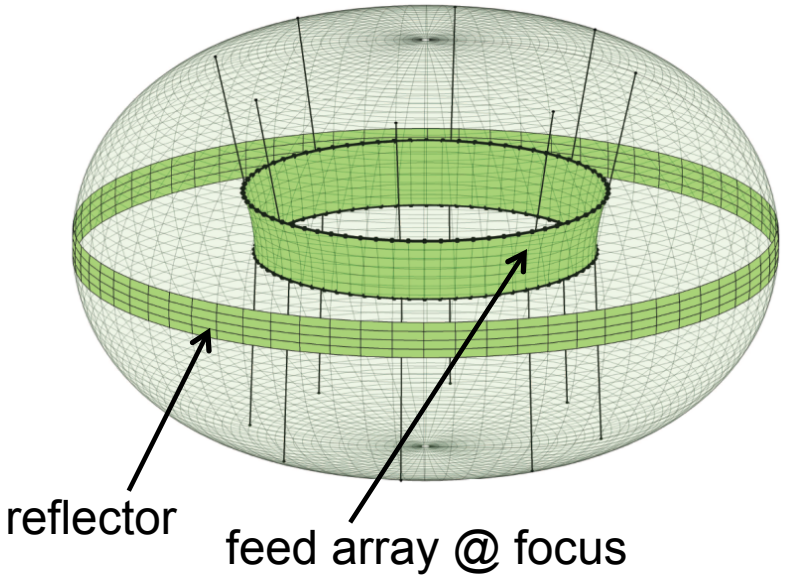
→ Site characterization visit June 2013 – directly measure radio properties (ground bounce and borehole). Results forthcoming and promising.

→ Next: Prototype station ready by summer 2014?



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 summer 2014
- Full Balloon: similar sensitivity to full, 3-year ARA, and ARIANNA

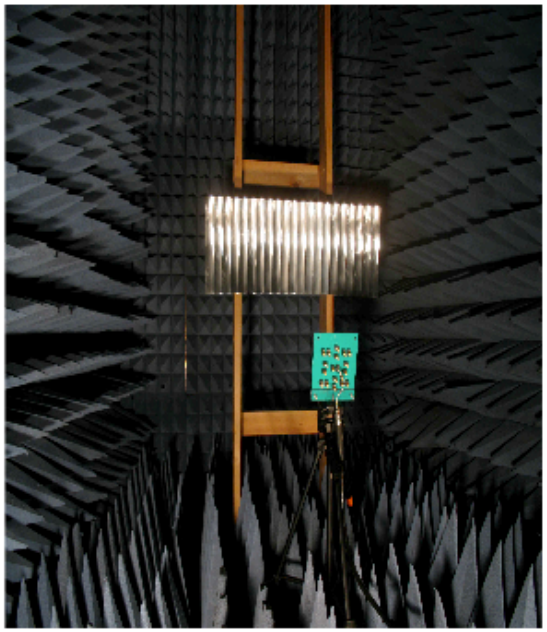


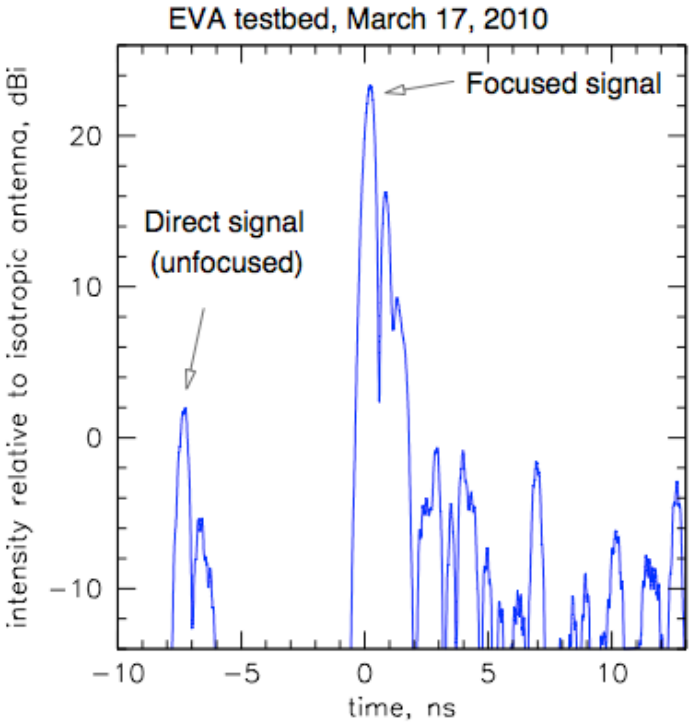
Gorham et al. (2011)

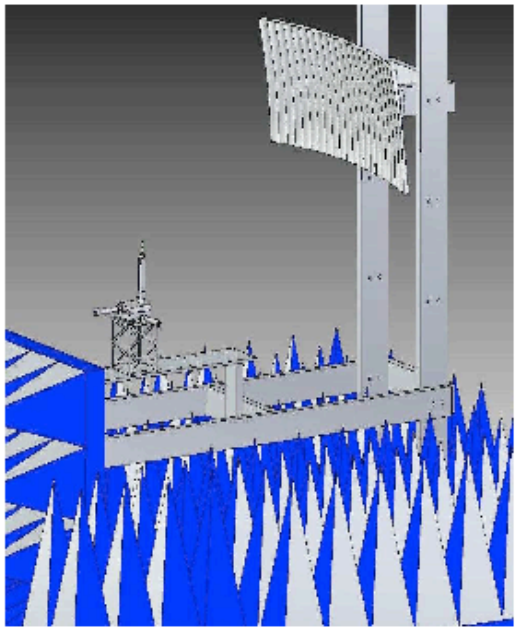
→ Feed design: dual-polarization, broadband, sinuous antennas on inner membrane

EVA Scale Model Test Results

- Microwave scale model testbed
- 1/35 and 1/26 scale models
- Measured directivity ~22dB



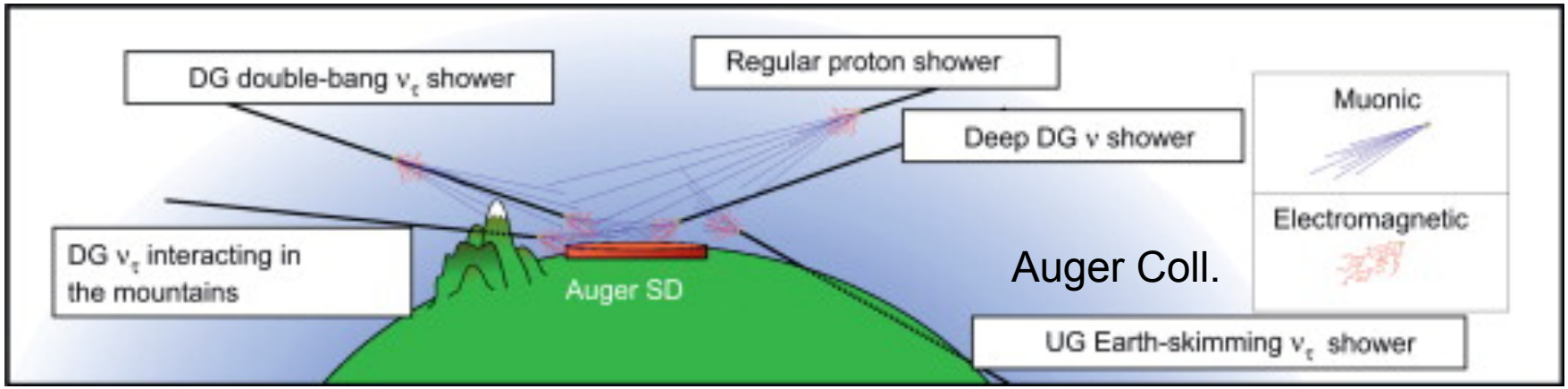




Gorham et al. (2011)

Other Ways of Seeing UHE Neutrinos

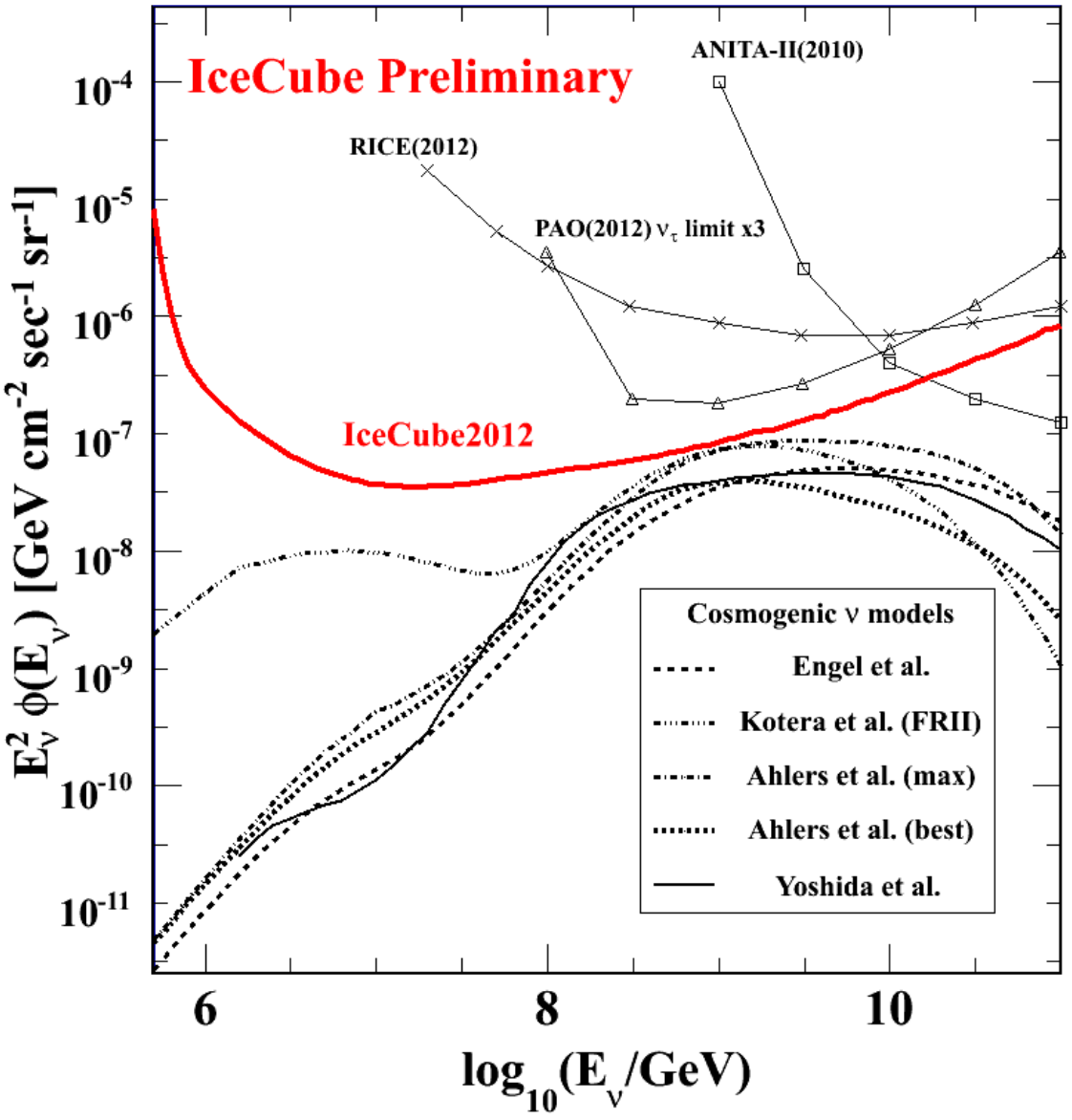
- Auger: Earth-skimming neutrinos and deep downgoing showers



- SKA: sensitivity to neutrinos interacting in the lunar regolith

IceCube Sensitivity to UHE Neutrinos

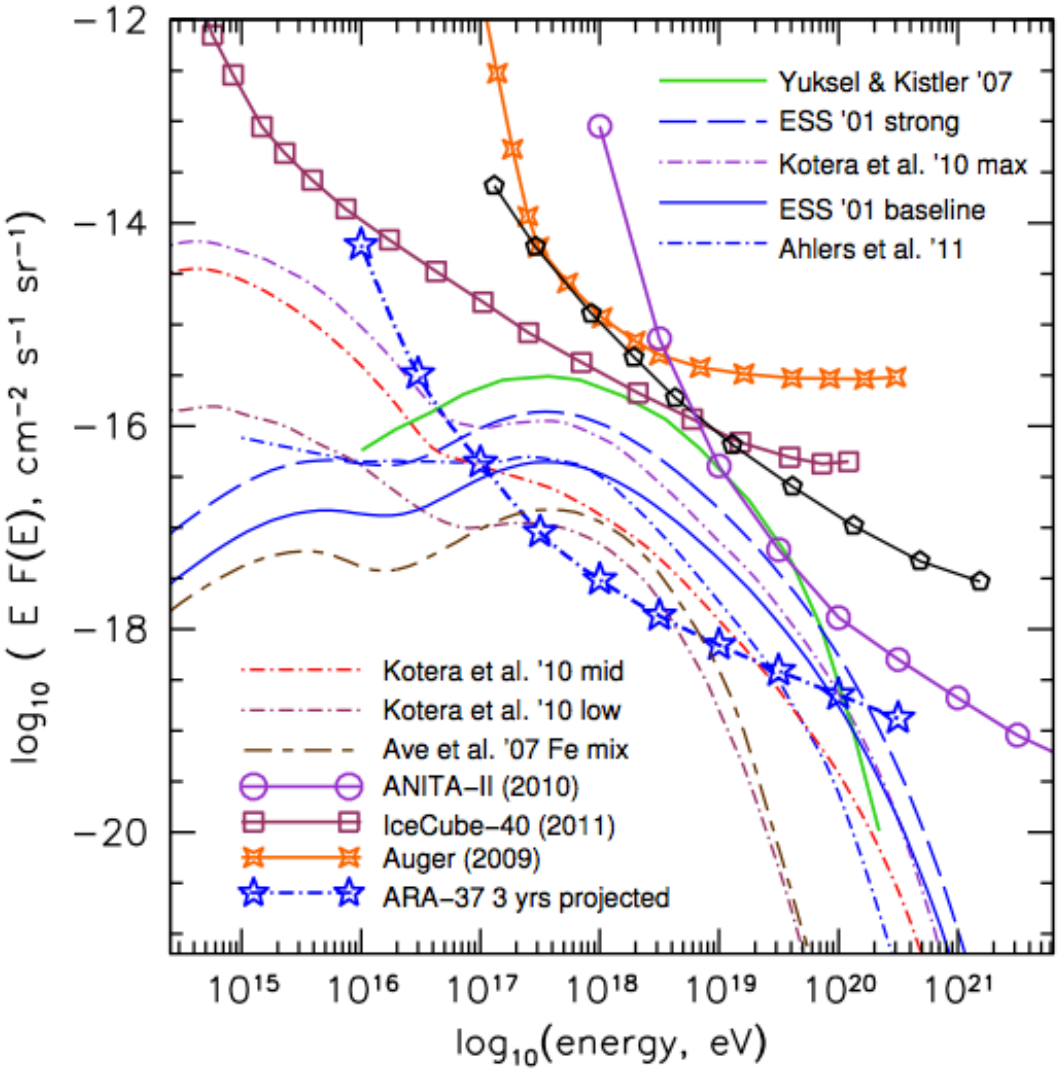
- Best current limit $<10^{19}$ eV
- IceCube prospects: a factor of a couple more?



Projected UHE Neutrino Sensitivity

What the sensitivity of a next-generation UHE neutrino detector looks like:

→ With tens of events per year, we'll have a real high-energy neutrino observatory for particle physics and astrophysics



ARA Coll. arXiv:1105.2854

Summary

- It is an exciting time in the search for UHE neutrinos!
- Probing lots of fundamental particle physics and astrophysics
- Radio technique has been proven, current results constrain models
- ANITA-III 2014, IceCube ongoing
- Large forward-looking efforts in initial stages: ARIANNA, ARA, EVA
- In 5-10 years, we hope to have a real UHE neutrino observatory and to observe for many years