IN ICE NEUTRINO RADIO DETECTION PROJECTS

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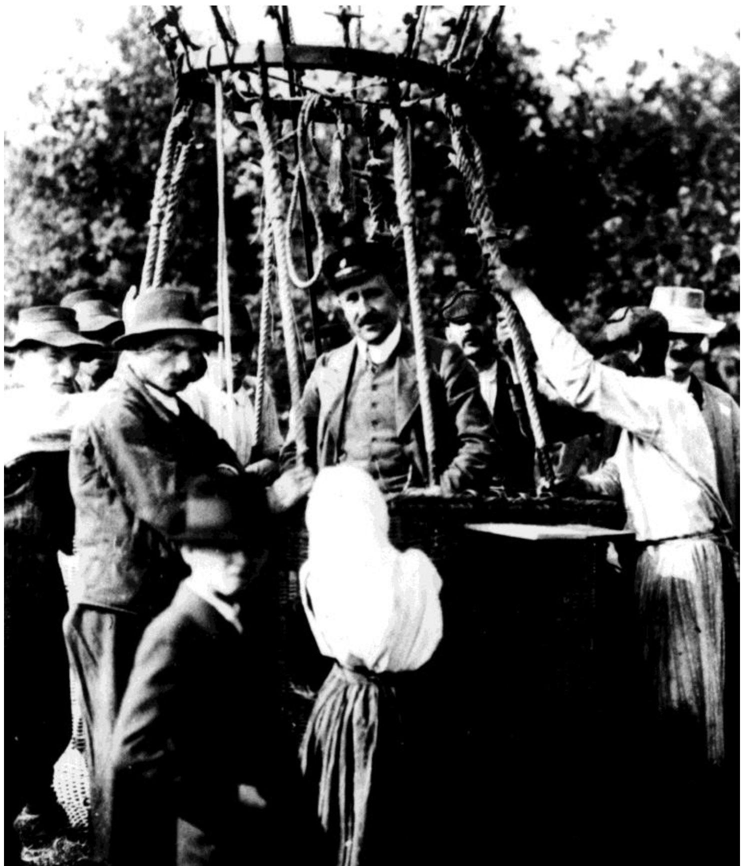
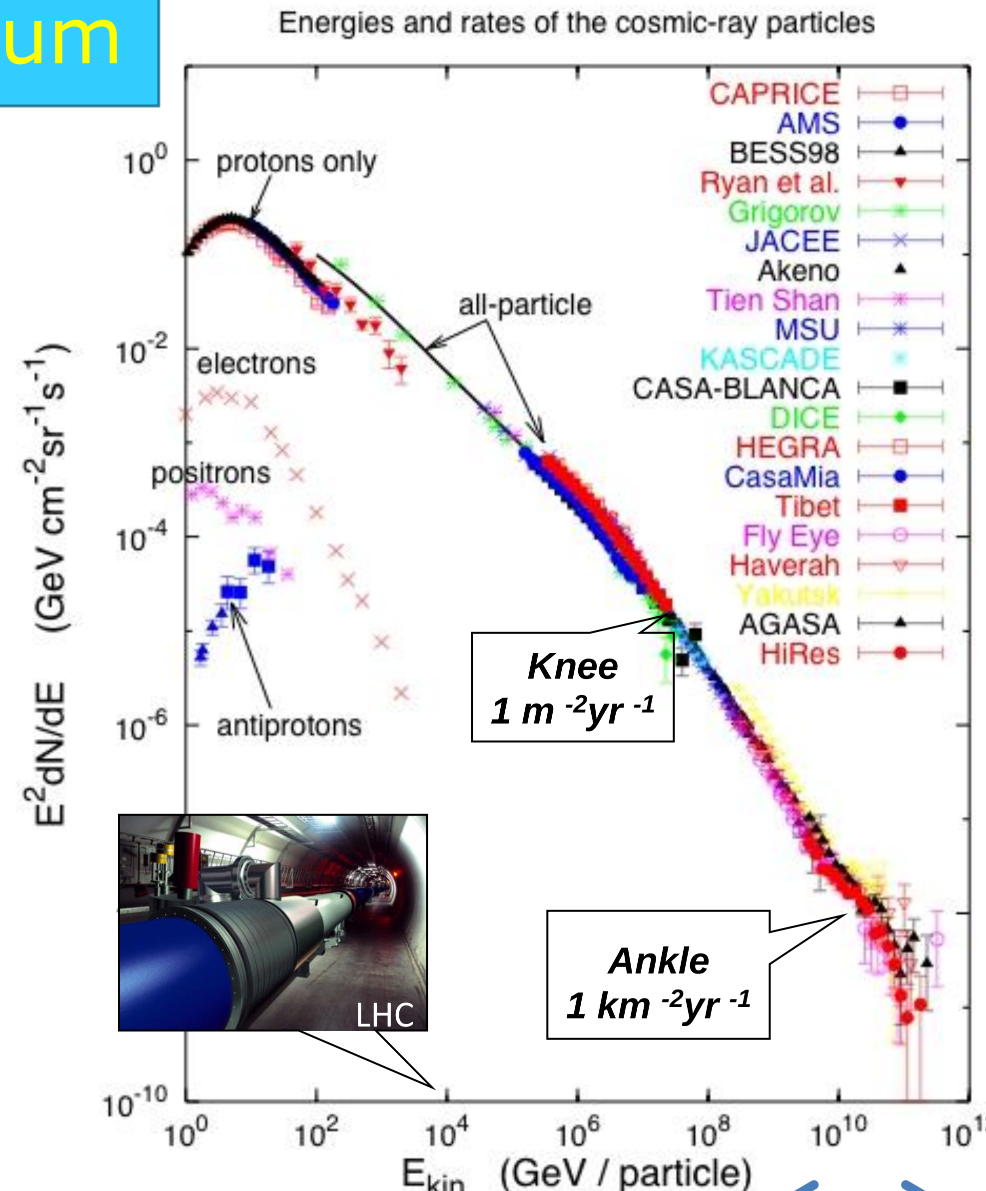
XVI International Workshop on Neutrino Telescopes

Cosmic Ray spectrum

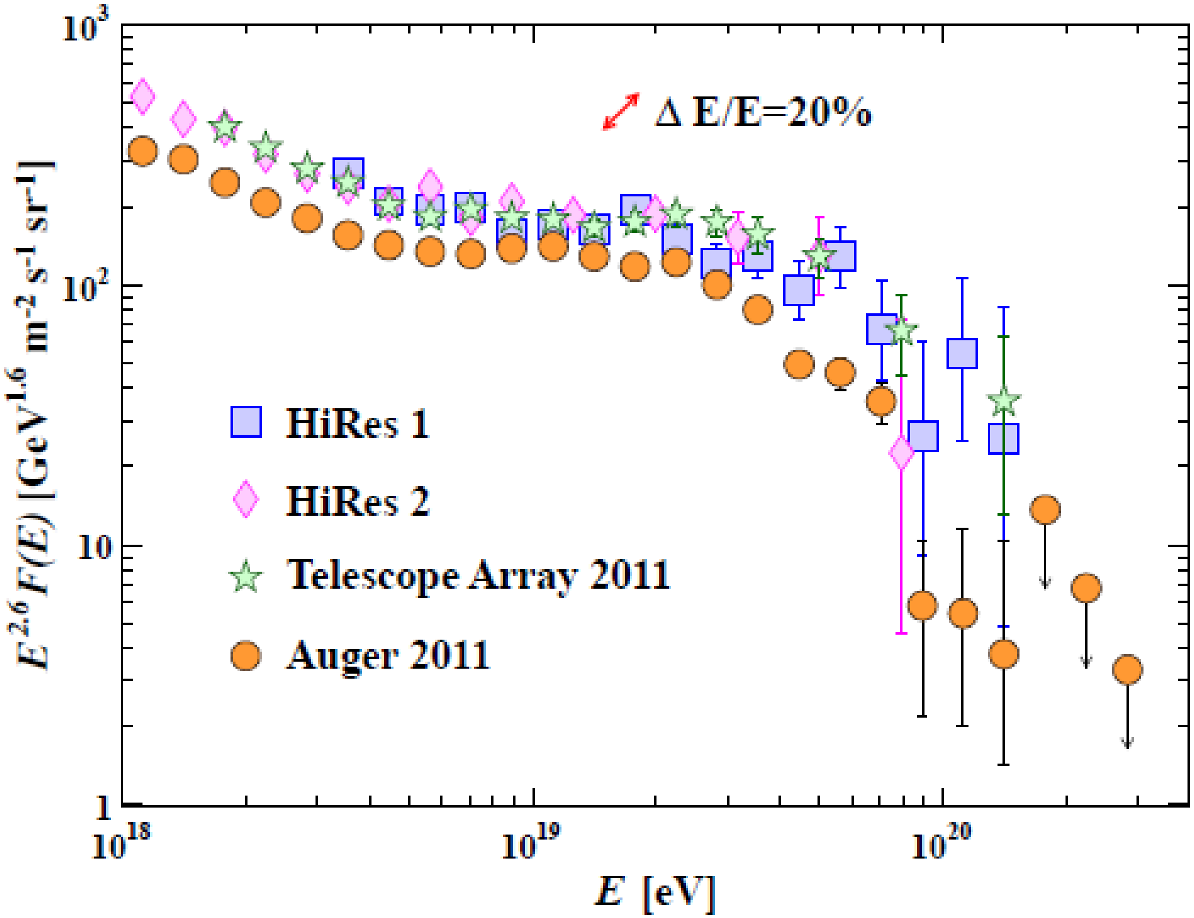
Acceleration to 10 ^{21}eV?
~ 100 Joule ~ 0.01 M_{GUT}


Victor Hess, Nobel Prize 1936



Next slide

The high energy end of the CR spectrum



End of spectrum
The GZK-limit at $5*10^{19}$eV
(*Greisen–Zatsepin–Kuzmin, theoretical limit*)

↓

GZK-neutrinos
(”cosmological”)

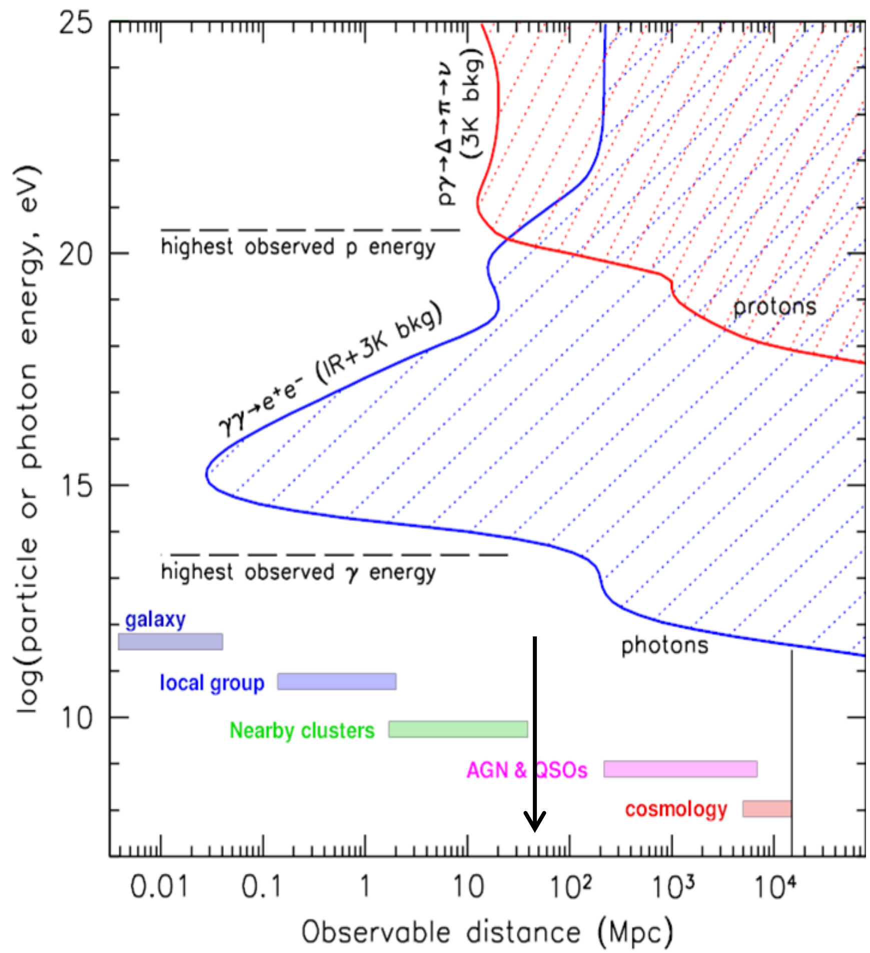
*pdg.lbl.gov/2013/.../rpp2012-rev-**cosmic**-**rays**.pdf*

The proton horizon

- Protons interact with CMBR

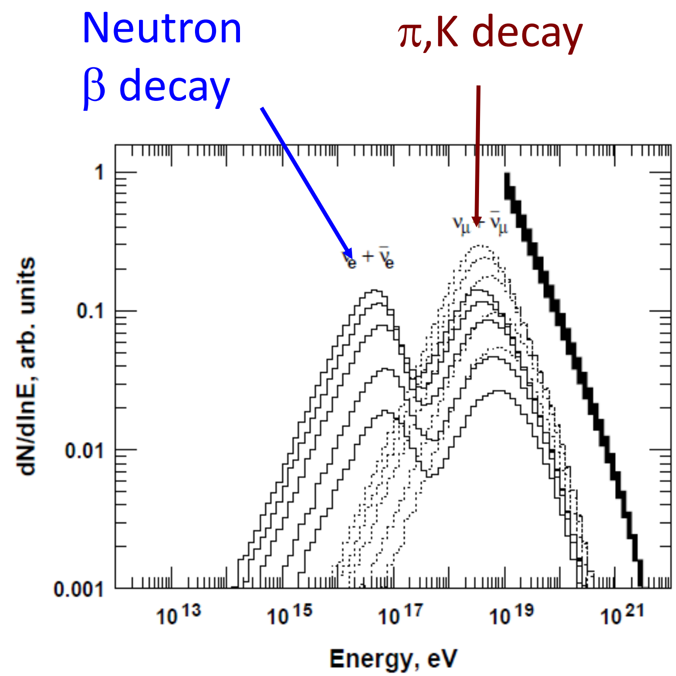
With 10^{20} eV energy, protons do not reach us from beyond our local supercluster, (about 50 Mpc) because of their small mean free path in the CMBR

Photon range also limited due to background radiation



GZK Neutrinos

- Flux depends on cosmic-ray spectrum & composition
- ν energy spectrum probes cosmic evolution out to redshift ~ 3-5
  - As redshift increases, the cosmic microwave photons are more energetic
    - Protons interact at lower energies.
- ν spectrum peaks just below 10^{19} eV (ν_e,ν_μ) with a 2nd peak at 10^{16} eV (ν_e)
  - All experiments focus on higher energy peak
- ν from π,K decay have ν_e:ν_μ:ν_τ = 1:2:0
  - Oscillations alter this to a nearly 1:1:1 ratio



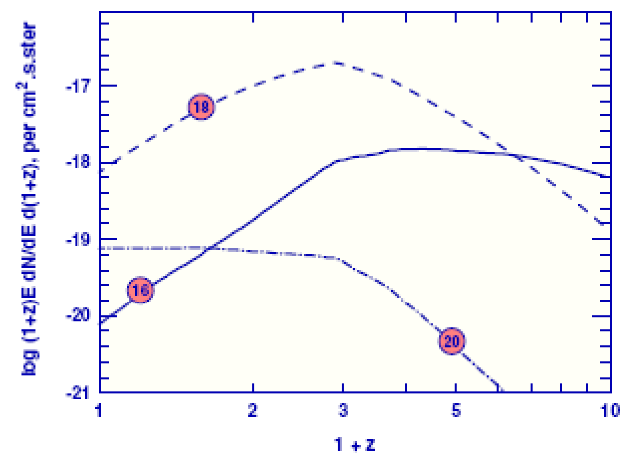
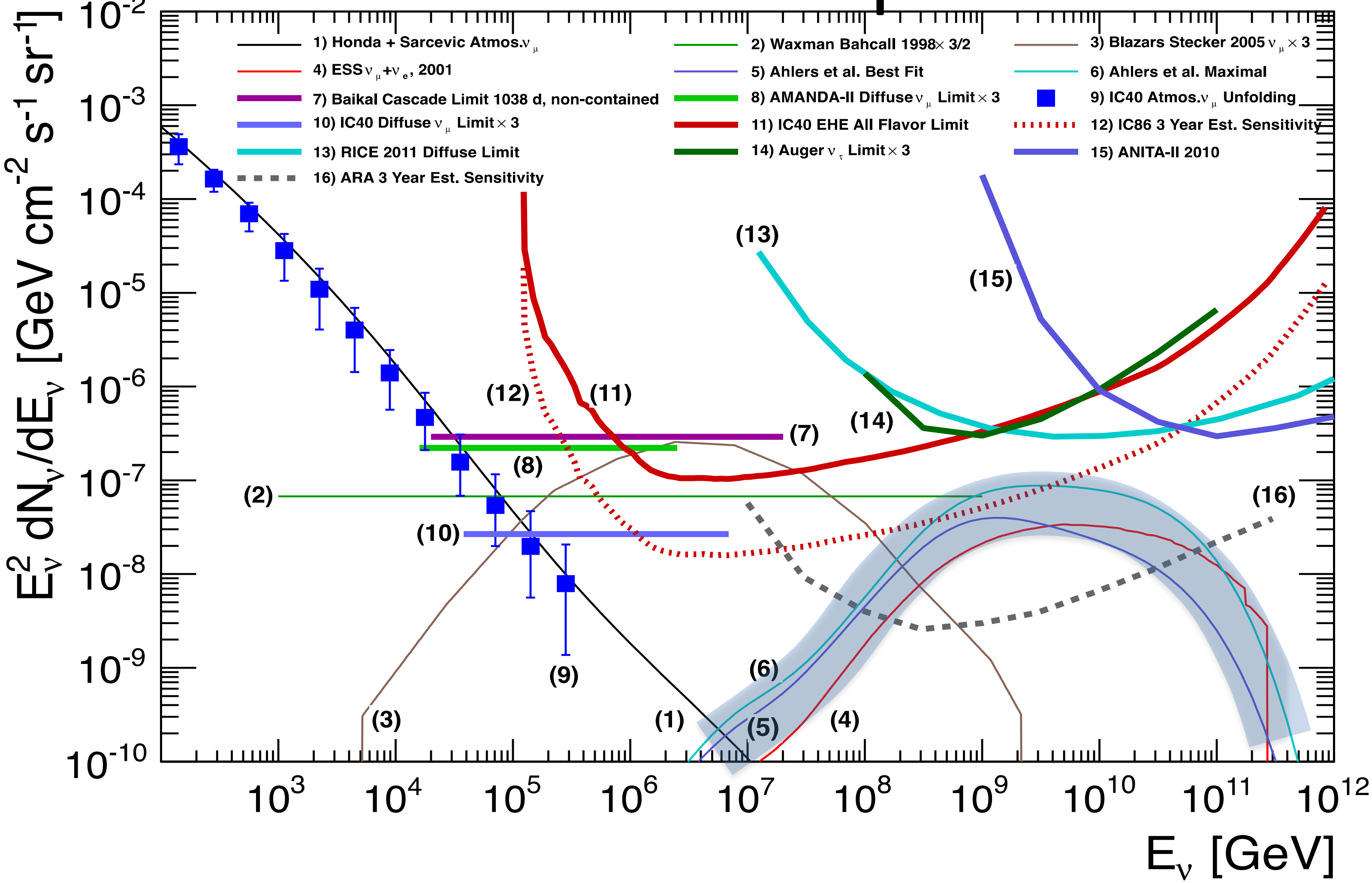


Figure 4. Contribution of different redshifts to the cosmogenic neutrino flux at 10^{16}, 10^{18}, and 10^{20} eV.

Engel, Stanev, Seckel, PRD 64, 093010 (2001)
Via S.Klein, Neutrino 2010

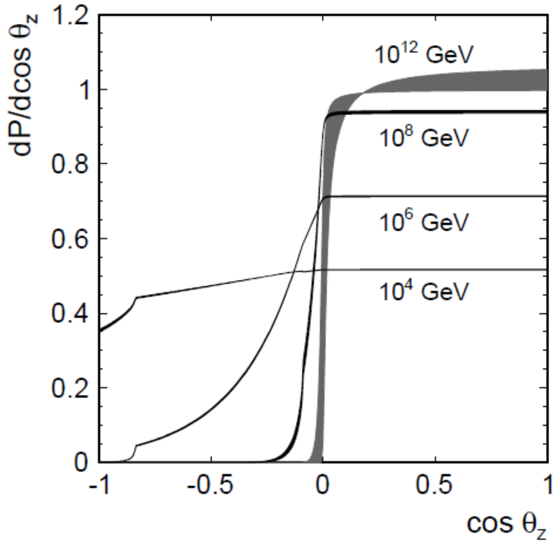
GZK-ν Models and predictions



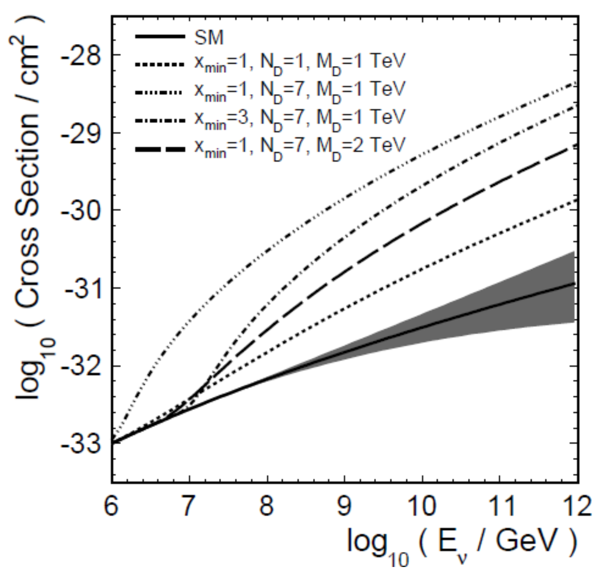
CR Composition, Cosmic evolution, γ constraints..... Different predictions

Predicted event rates/mass low → Need large mass detector → 100 km^3

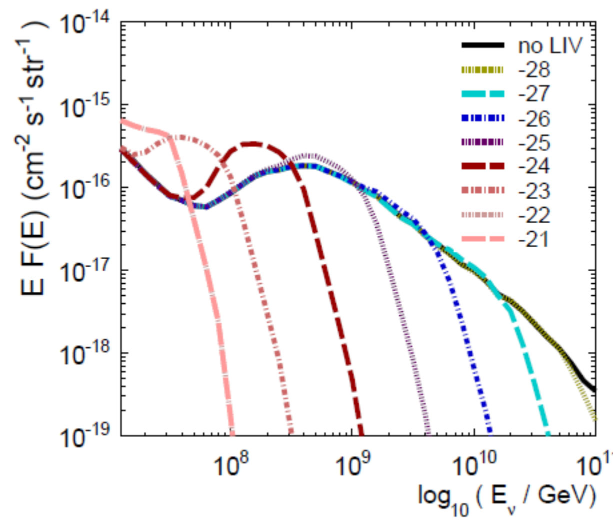
Measure Neutrino Cross-Section at Extreme Energy



With a sufficient number GZK neutrinos,
the cross-section can be determined from events just under the horizon.
Could indicate new physics.
Figs from S. Klein et al. arXiv 1304:4891



More exotics:
If neutrinos would be superluminal
→ cut-off in energy spectra
Fig from P. Gorham et al.
arXiv 1207:6425



Detection mechanism proposed by G. Askaryan (1962):
Measure the coherent RF signal generated by neutrino interaction in dielectric media (such as ice)

charge asymmetry in particle shower development results in a 20% excess of electrons over positrons in a particle shower

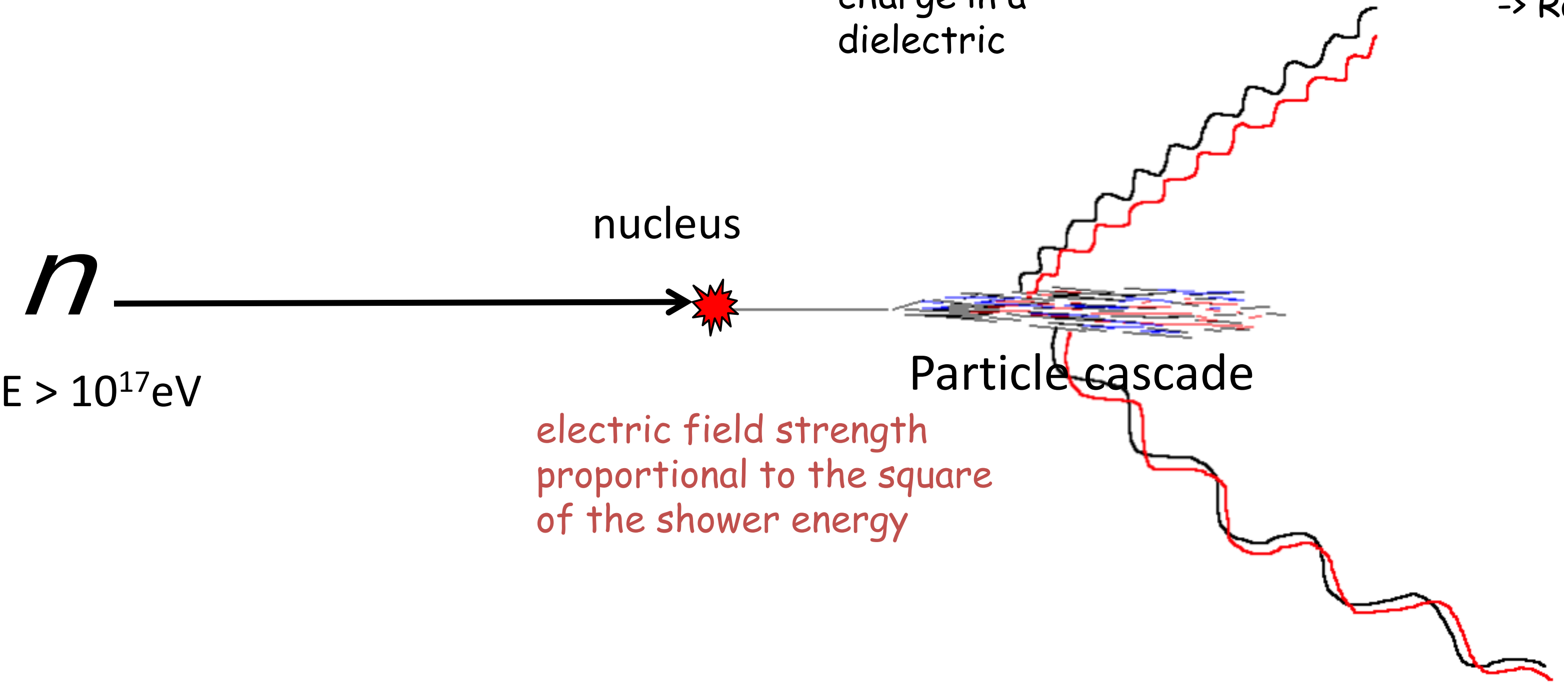
→ moves as a compact bunch, a few cm wide and ~1cm thick → Moving net charge in a dielectric

→ Emission at 'cherenkov'-angle

But wider than optical

$\lambda \gg R_M$ Add coherently!

-> Radio-waves



E > 10^{17}eV

electric field strength proportional to the square of the shower energy

Radio detector?

G.A. Askaryan JETP 14 (1962) 441
G.A. Askaryan, At. Energ., vol 3/8 (1957) 152

in ice : λ_{abs}(radio)~ 1000m cf λ_{abs}(optical)~100m

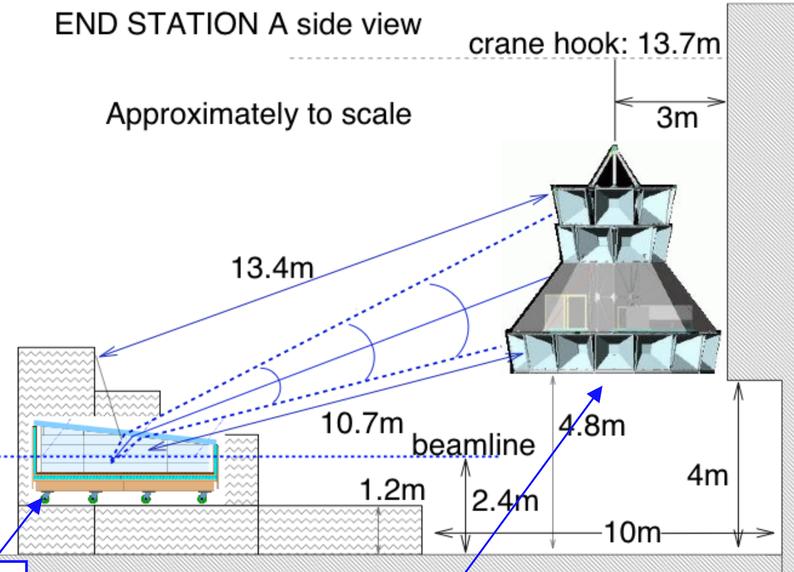
- detect mainly the vertex showers from ν's interacting via CC or NC
- such showers in matter develop a ≈20 % e^- over e^+ excess since target material contains atomic e^-'s
- resulting EM emission coherent for wavelengths longer than lateral shower size (O(few cm))
- emitted power $\propto N^2 \propto E^2$
- effect confirmed by measurements in silica sand, and in ice.

Experiments:

- In ice detection **RICE**
- Planned/prototype/test: **ARIANNA, ARA and GNO**
- Above ice detector: ANITA and EVA (proposed)
- Other media: Salt, Lunar regolith...

Observations of Askaryan Effect

- Used beamline at SLAC
- ~10^9 electrons at 28.5 GeV
- Total shower energy ~3×10^{19} eV



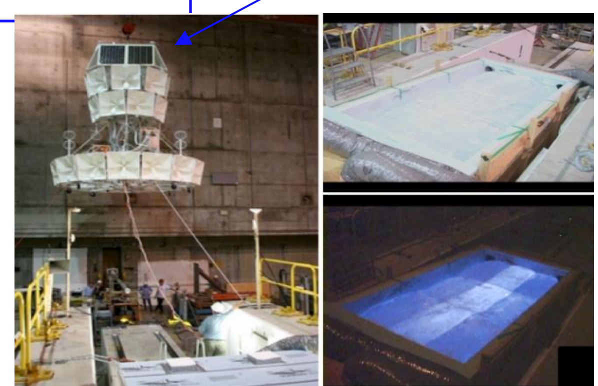
e⁻

NATIONAL ACCELERATOR LABORATORY

Ten tons of high quality carving ice

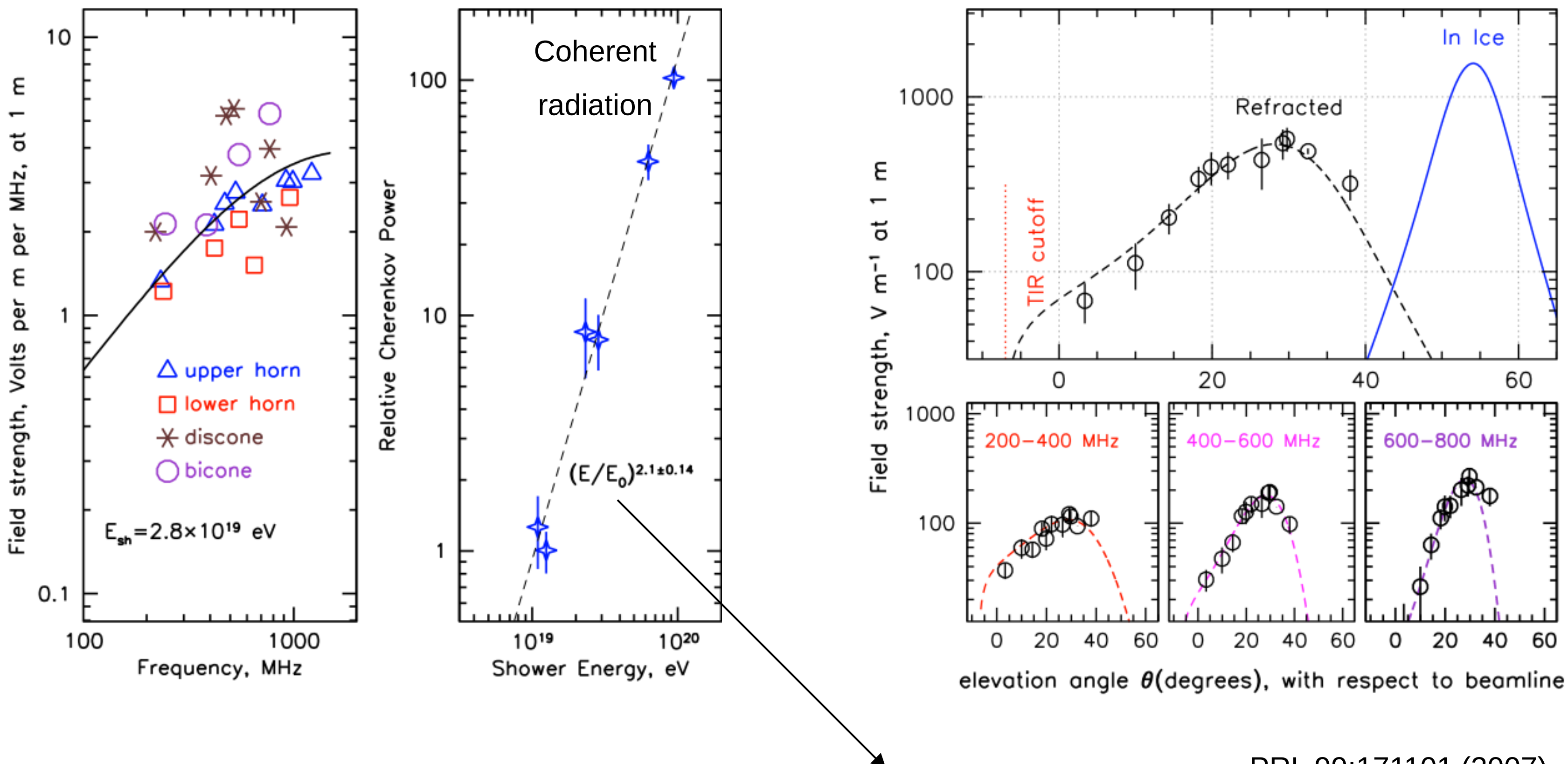
Hand chipped!

ANITA Radio telescope



PRL 99:171101 (2007)

Coherent Emission Measured

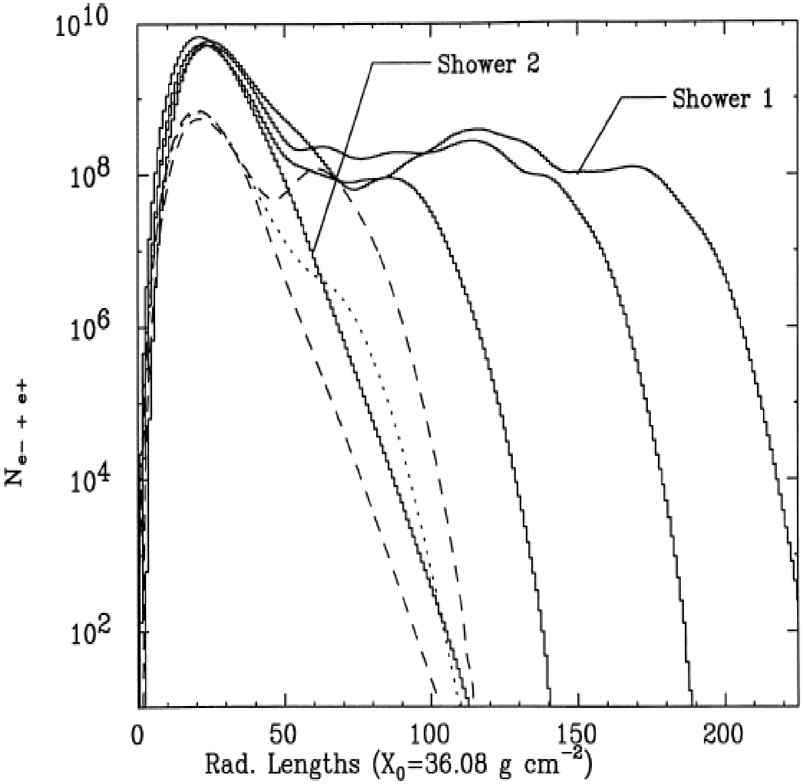


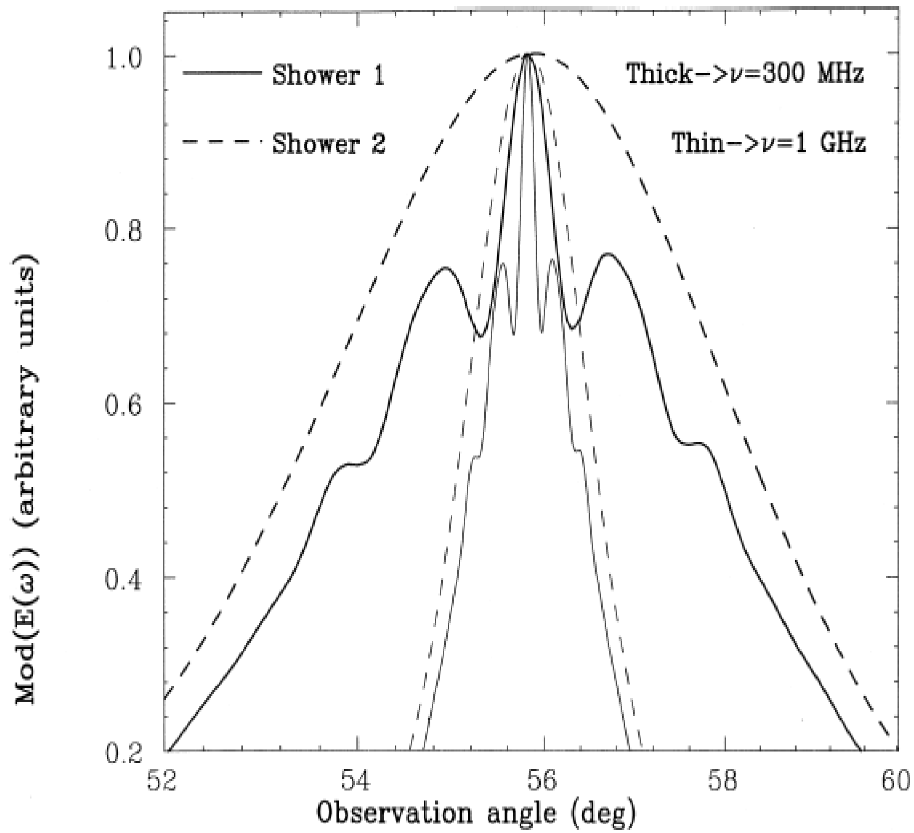
PRL 99:171101 (2007)

Power $\propto$ E^2

Good agreement with predictions for ice, salt, and sand

Shower development differences → Radio emission differences

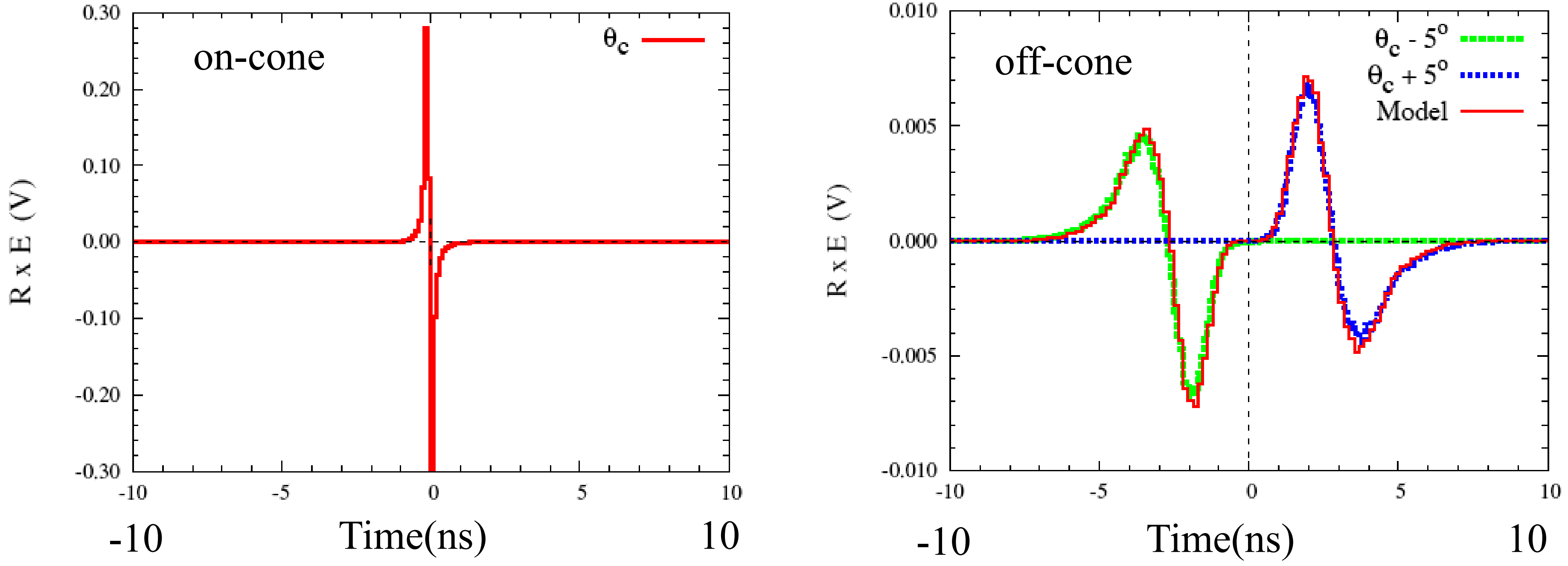




- *Left: Shower development of individual showers of energies 10^{19} eV (solid lines) and 10^{18} eV (dashed).*
- *Right: Radio pulse angular distribution around the Cherenkov angle illustrating the individual variations from shower to shower at the same energy, and the narrowing of the angular distribution with higher frequency.*

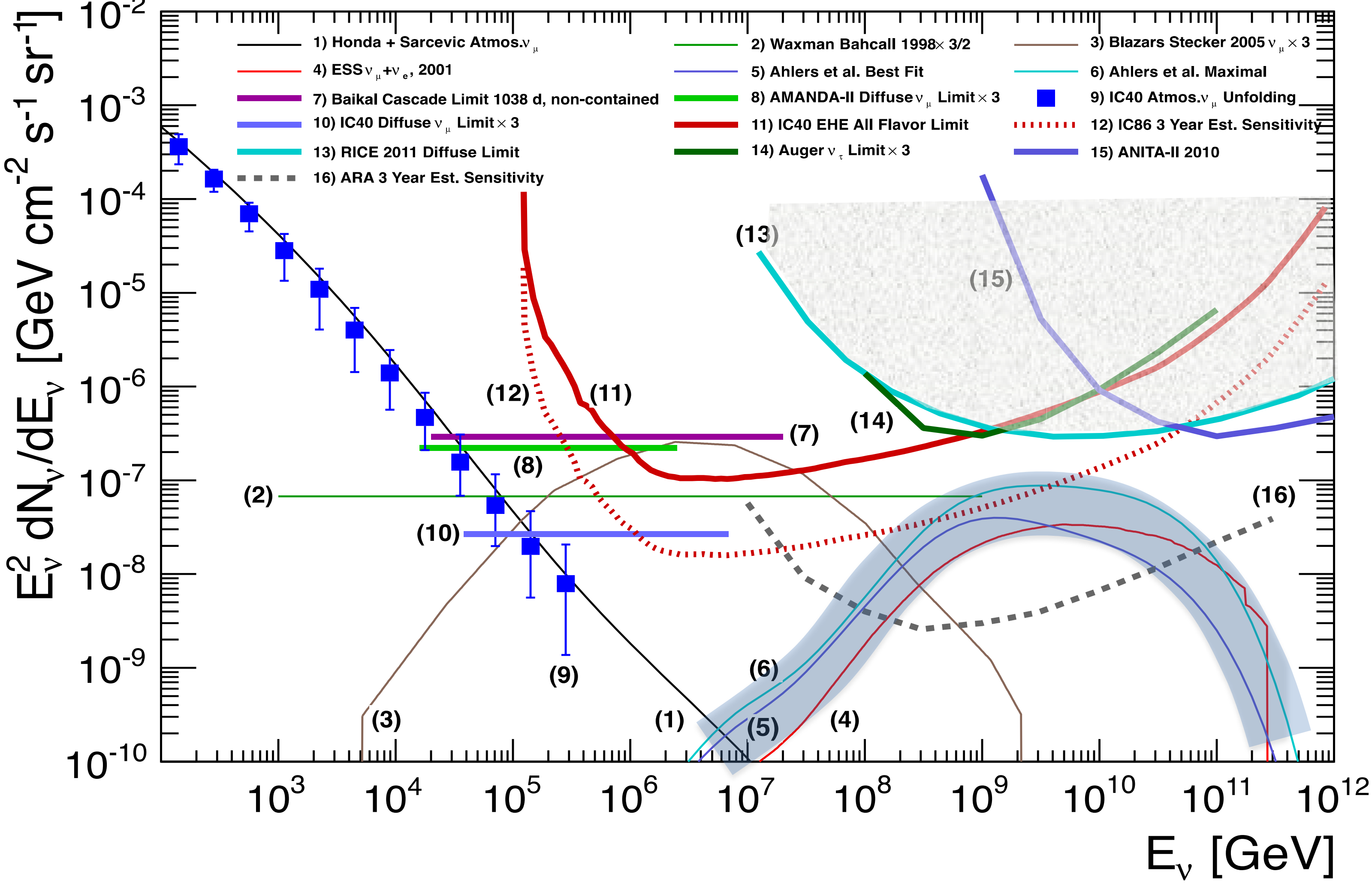
J. Alvarez-Muñiz and E. Zas, Phys. Lett. **B434**, 396 (1998)

Time-domain is rich in information



J. Alvarez-Muniz, A. Romero-Wolf, and E. Zas, arXiv:1002.3873v1

RICE Limit



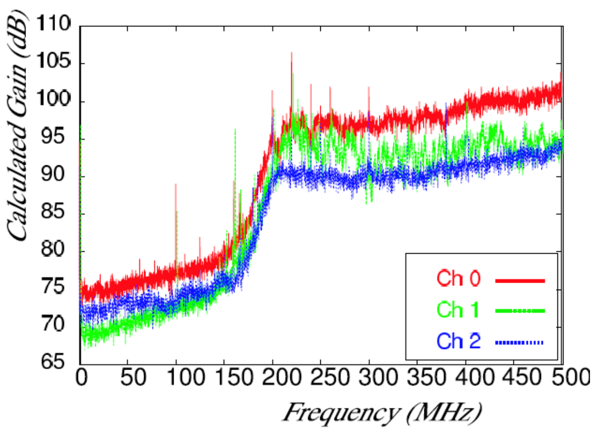
Radio **I**ce **C**herenkov **E**xperiment: Performance & Simulation APP 19 (2003) 15-36

Limits reported in: Phys Rev D 73 (2006) 082002, NIM A 692 (2012) 233-235

RICE Detector

- 20 recievers installed in top of holes for AMANDA
- Depth Z ~100-200 m, 350 m, Δ X/ΔY 200m /200 m
- $\frac{1}{2}\lambda$-dipole + electronics
  →200 – 500 MHz band
- Filter $\nu < 200\text{MHz}$

Reduces PM-tube noise from AMANDA



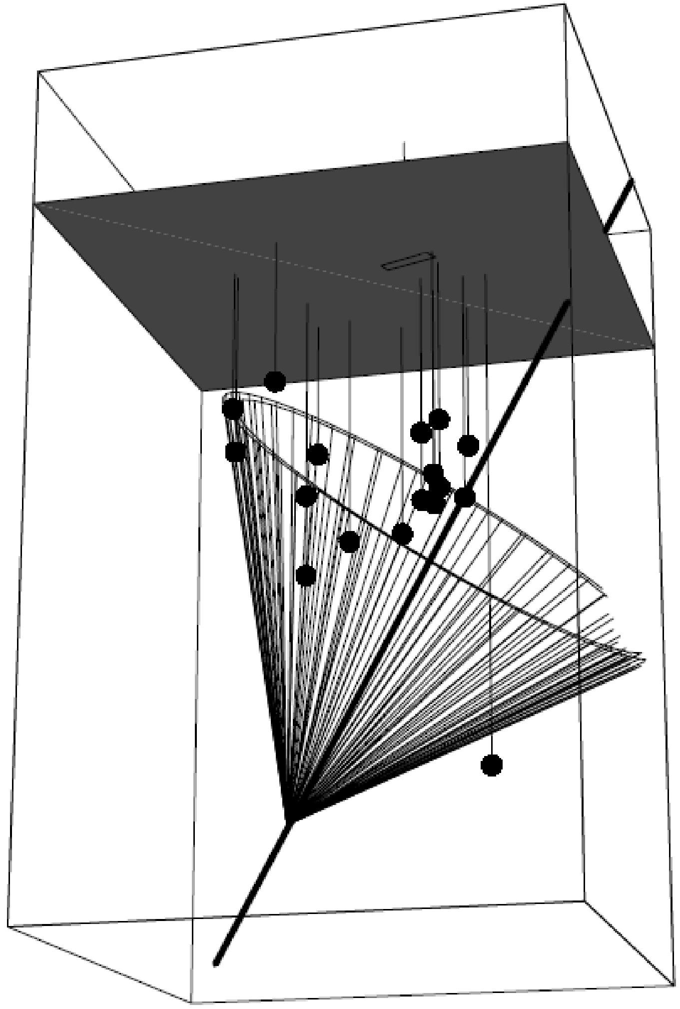
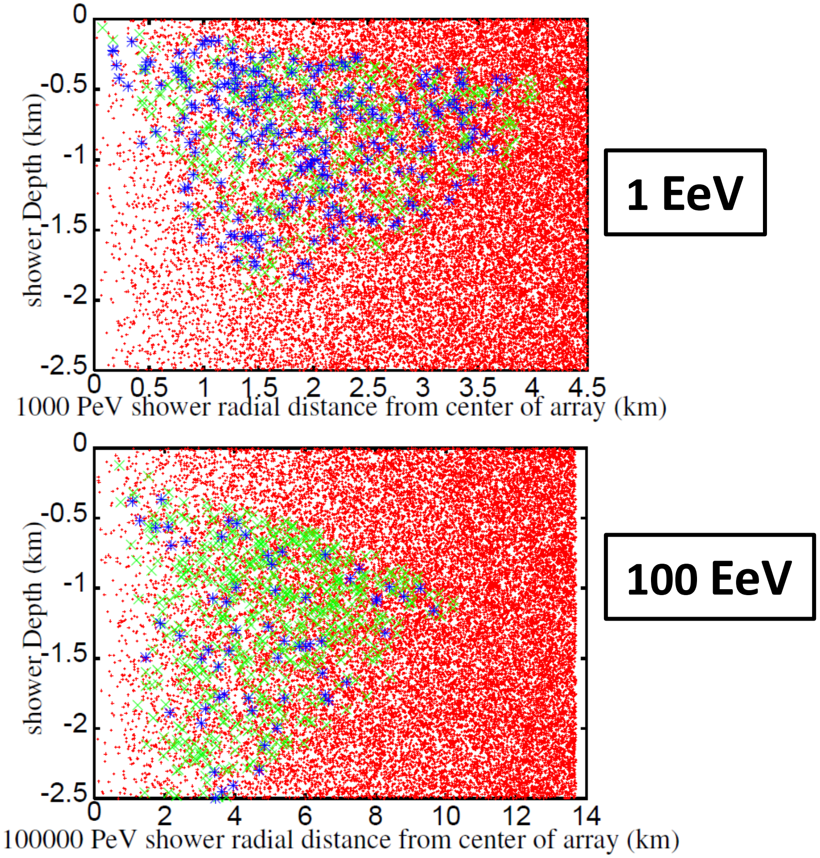


Fig. 1. Simulated RICE event. The actual detector geometry is shown, to scale.

RICE Analysis

Data set 1999 – 2005 – 2010
~ 1700 days live-time

Simulation include
- pure EM shower
- hadron induced shower
- LPM effect
- Charge-by-charge superposition of Cherenkov radio emission
- Systematics from refraction, attenuation, antenna response air-ice, gain variation etc....



Simulated ν-interactions (red)
detected EM showers (blue)
detected hadron showers (green)

RICE Analysis

Background reduction

- **Continous Wave from radio tranmitters on surface**
  - Recognized frequencies and operating times
  - High trigger rate
  - Seen in forced trigger readouts
  - .....
- **True thermal noise**
  - Vertex locations (Gaussian around detector center)
  - Small Time-over-Threshold
  - No double pulse signature
  - .....
- **"Loud" transients from AMANDA/IceCube PMs**
  - (1-2 km distant -> highpass filter > 250 MHz inserted)
- **"Loud" transients from anthropogenic signals from surface**
  - Vertex requirement deeper than 200 m
  - Vertex resolution tested with transmitter in hole at different depths

Expected backgrounds

- **Atmospheric Muons -> bremsstrahlung or photonuclear interactions → EM shower**
  - 100 PeV muons worst combination of energy and rate
  - Calculated, **expected < 0.01** events (1999 – 2005)
- **Atmospheric neutrinos (prompt). Low rate & interaction probability → no events**
- **Air Shower dense core, could give Askaryan pulse in firn.**
  - **Surface events, none found in 1 year CR triggered sample**

No events remain after cuts → Limit

Askaryan Radio Array (ARA)

Ref: Allison et al., Astropart.Phys. 35 (2012) 457-477, arXiv:1105.2854 (Design and performance paper)

In December 2010 installed TestBed detector at 20-30 m depths

Testbed station was used for a first ARA limit. arXiv:1404.5285 Submitted to Astroparticle Physics

First proper ARA station (ARA1) installed 2011 at about 70- 100 m in depth (drill limitations).

Stations ARA2 and ARA3 installed 2012-2013 at full design depth of 200m.

2013-2015 Calibrations + repair ARA1

Deliver science data -> work on neutrino limit from the ARA data, hope for submission in a couple of months.

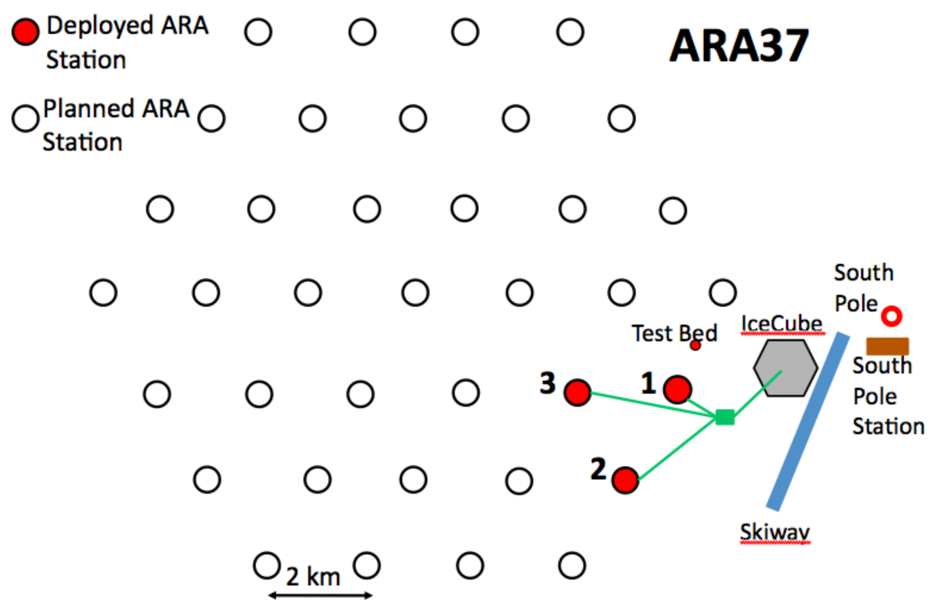
Planned array: ~ 150 km^2 near South Pole

Total ARA stations planned: 37

Phase 1 operation: 3 stations

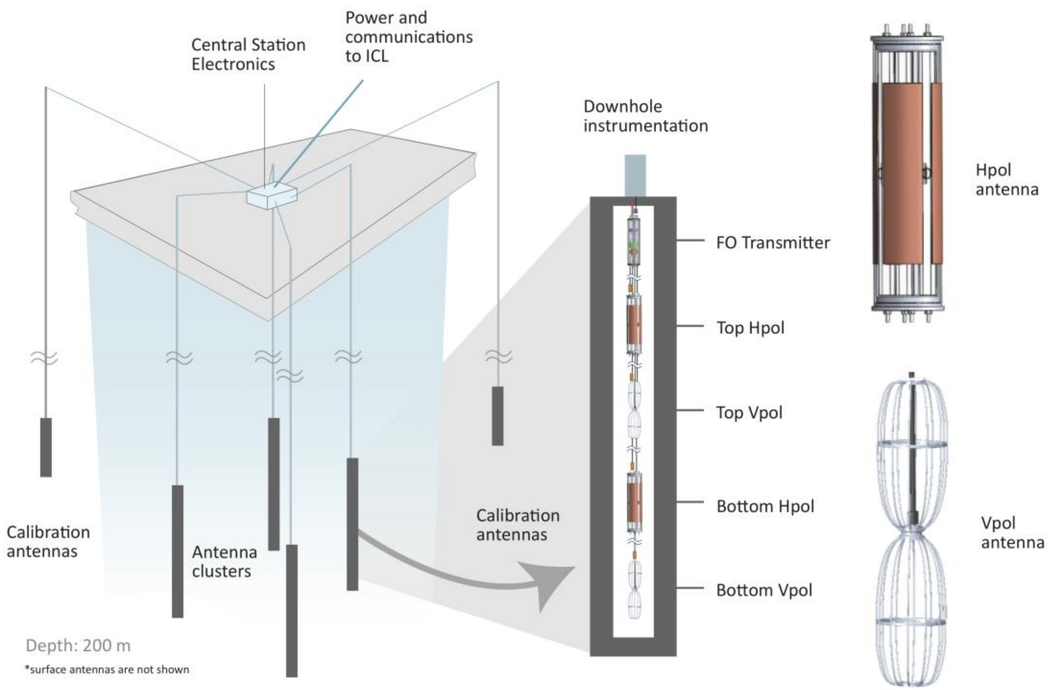
Ice thickness: 2.8 km

Attenuation length: ~ 1 km

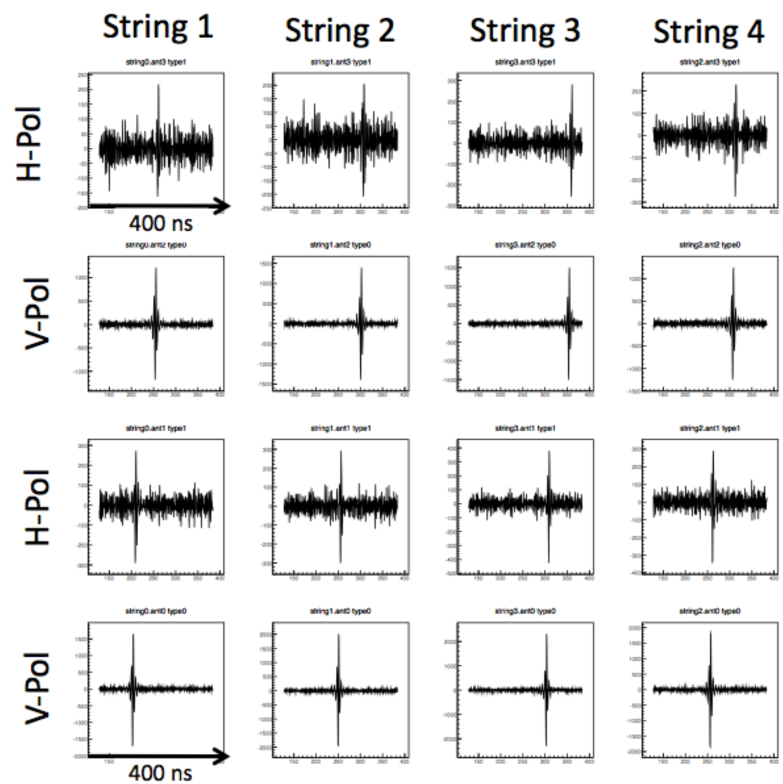


ARA station

A station consists of 4 strings with 4 antennas each located at ~200m depth.
Each station is an independent detector.

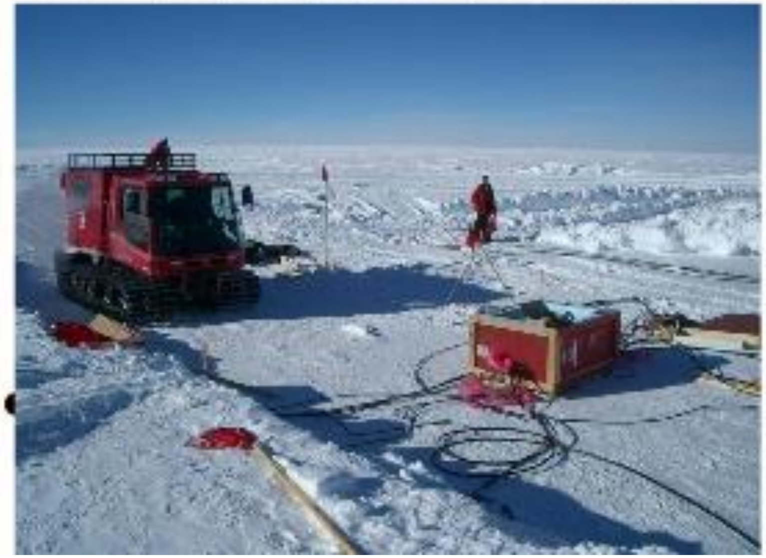


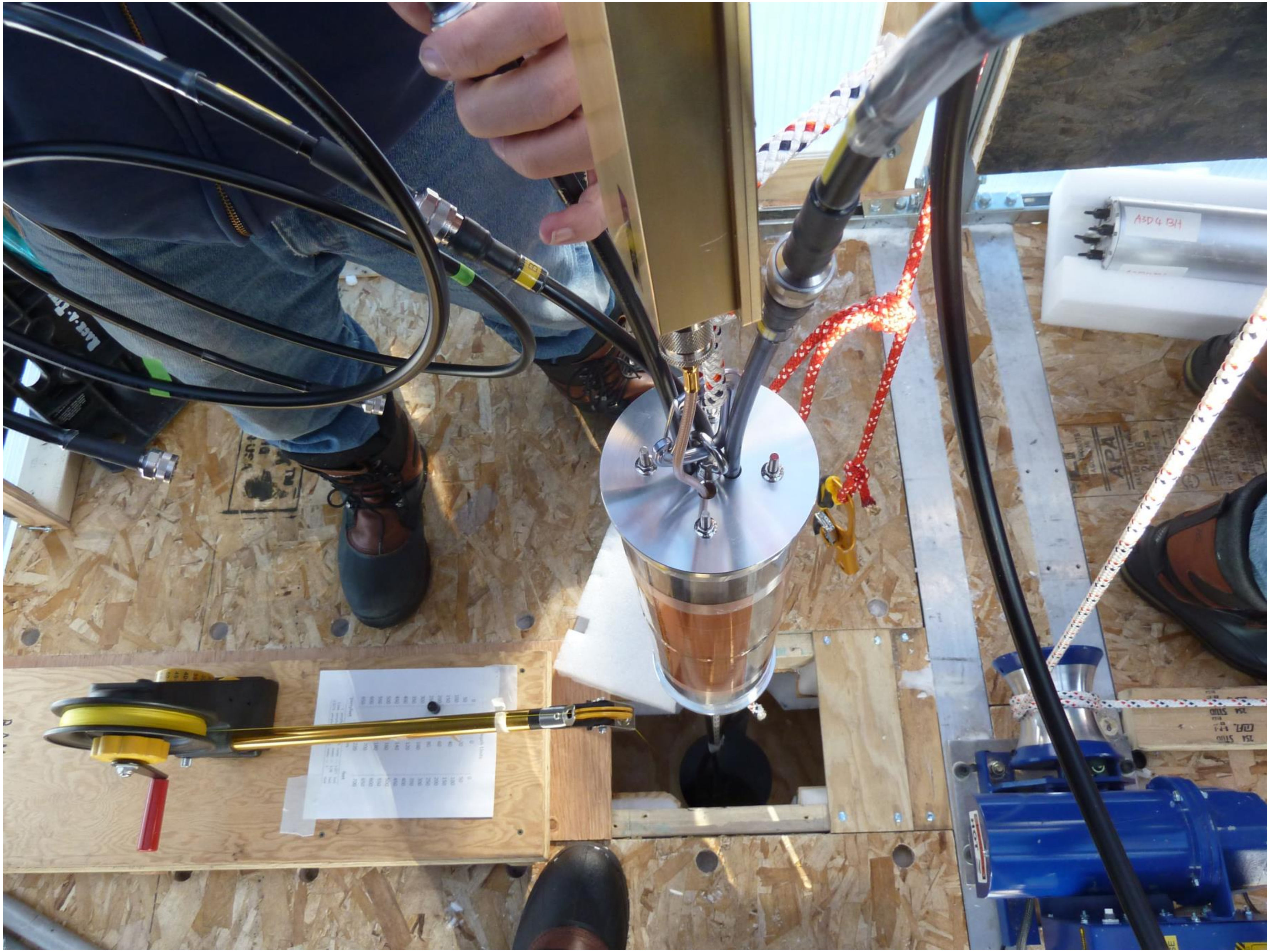
Simulated waveforms of a neutrino event of energy: E=10^{18} eV recorded in ARA station Distance: 1.2km ("~on cone")



High signal/noise in all 16 antennas

ARA field activities on the ice



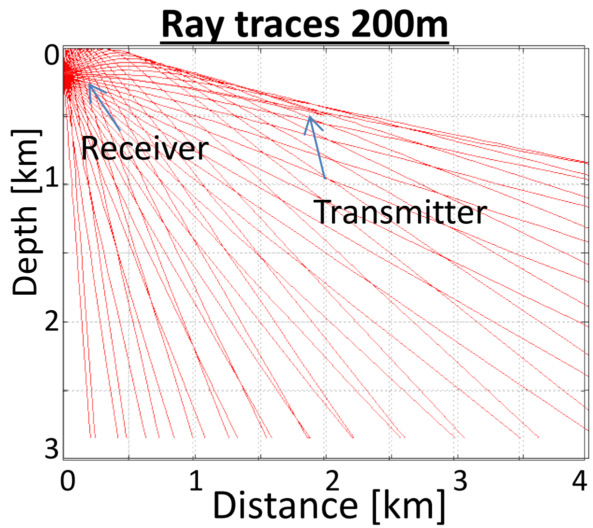

APA

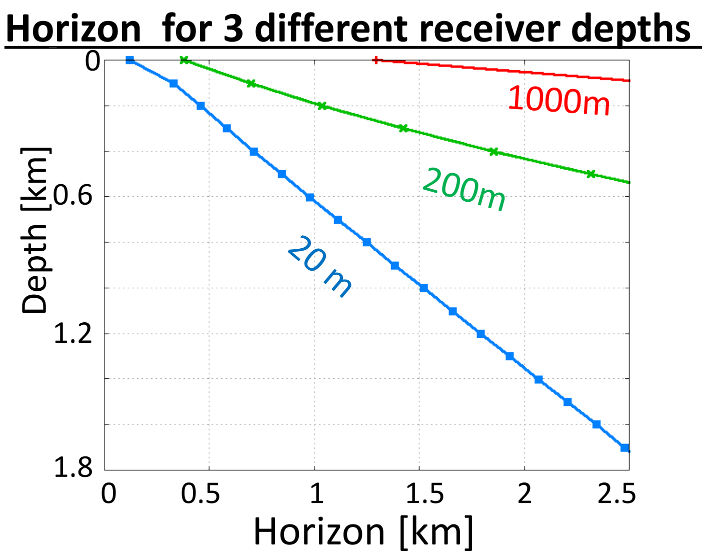
Why strings?

(rather than surface antennas)

- Acceptance: x2
  - Embedded detectors have larger acceptance due to shadowing caused by gradual change of index of refraction in the upper 200m of ice.
  - Gain at 200m depth compared to surface: > x2 event rate

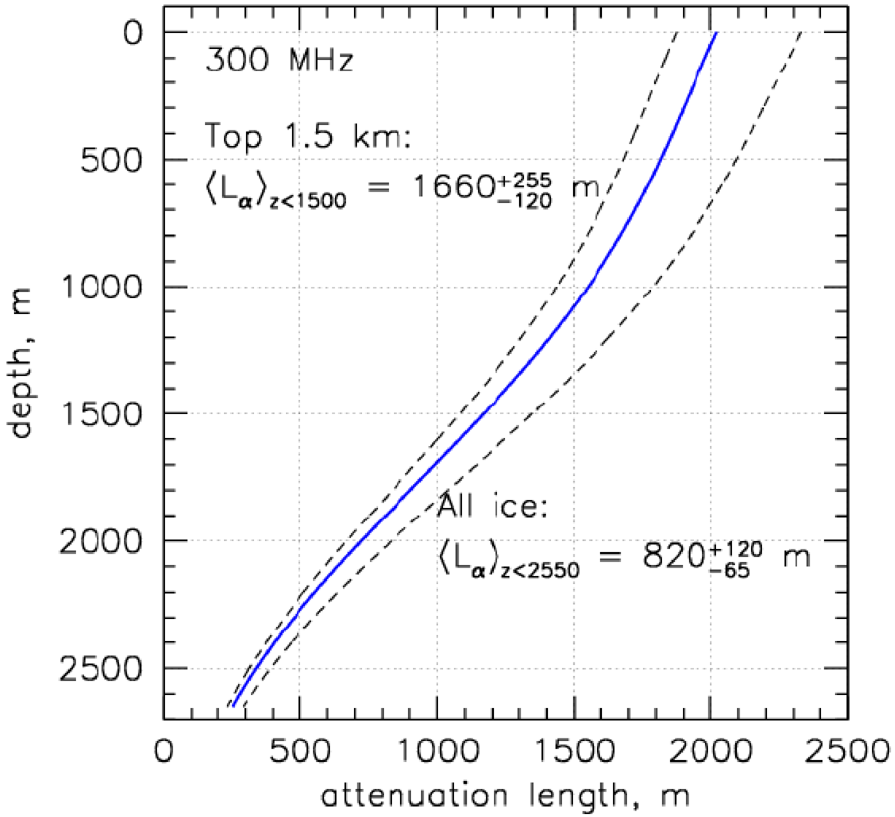
- Background rejection:
  - Transient backgrounds, man made and natural come from surface!
  - Neutrino events generate vertex in the ice and the signal can be uniquely separated by basic event reconstruction.

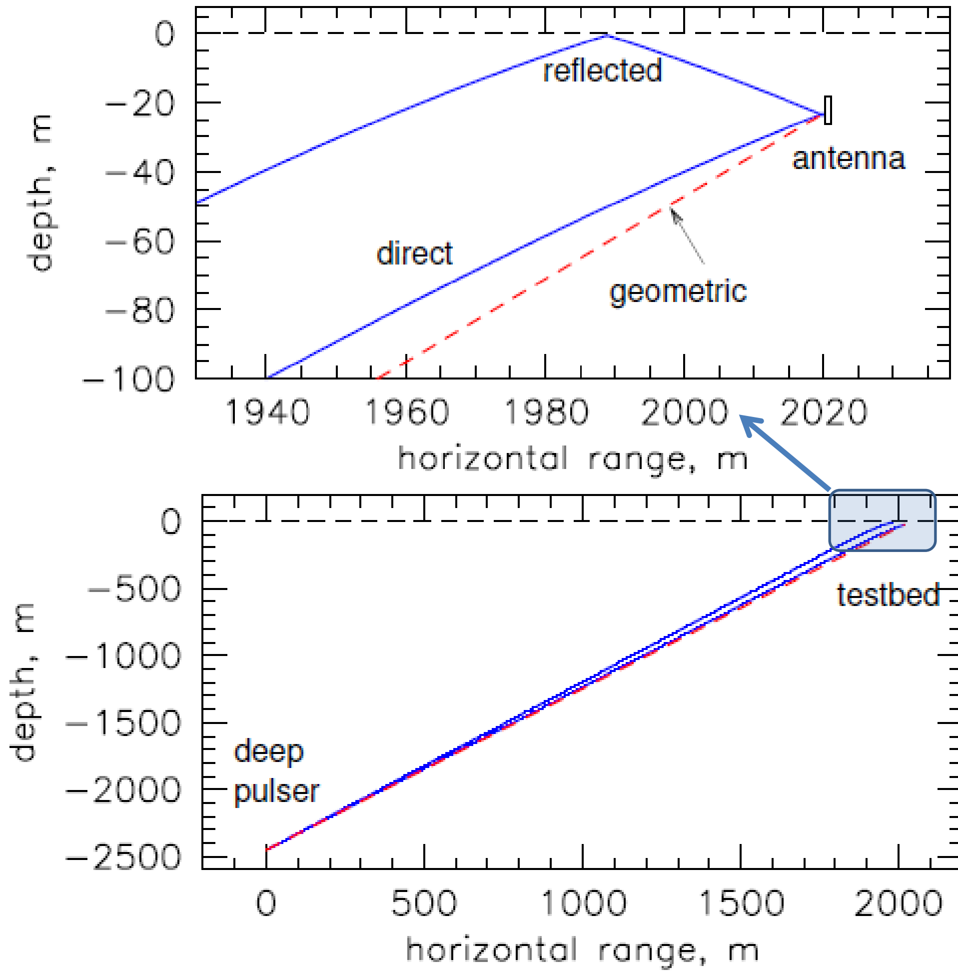




ARA Ice Properties

APP 35 (2012) 454-477 arXiv:1105.2854



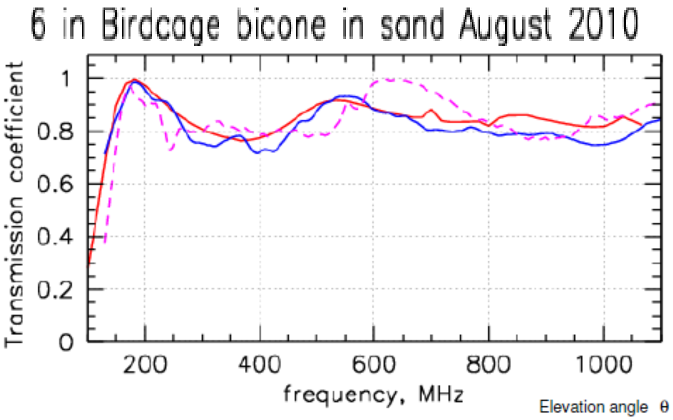


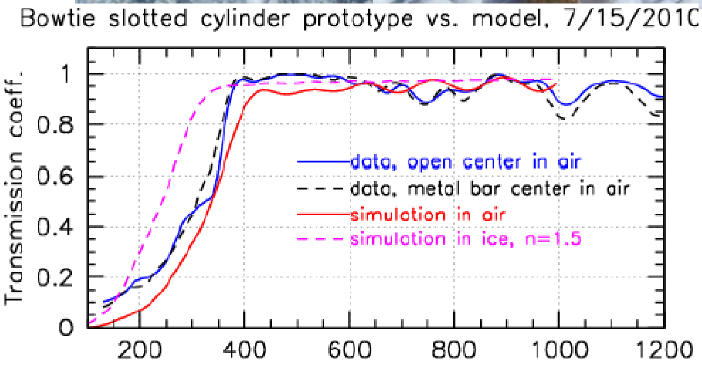
Effect of refraction on timing
Note Fig is for Testbed depth

ARA Design

APP 35 (2012) 454-477 arXiv:1105.2854

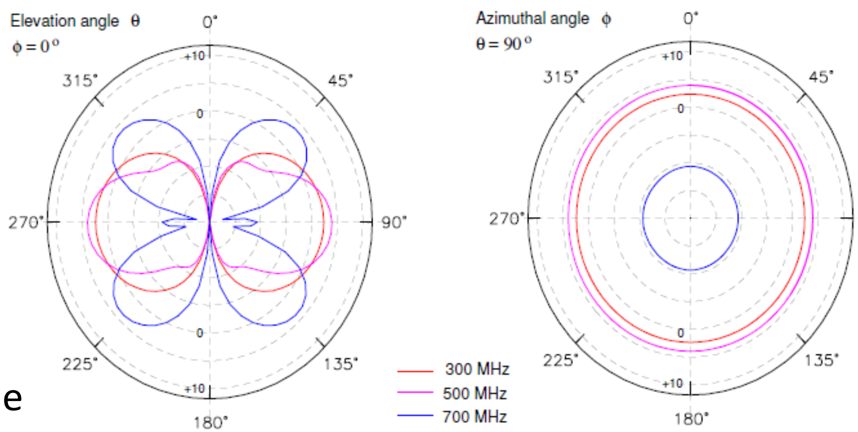
Antenna to fit in
Hole diam 15 cm





Bandwidth 150-850 MHz

Bandwidth 200-850 MHz

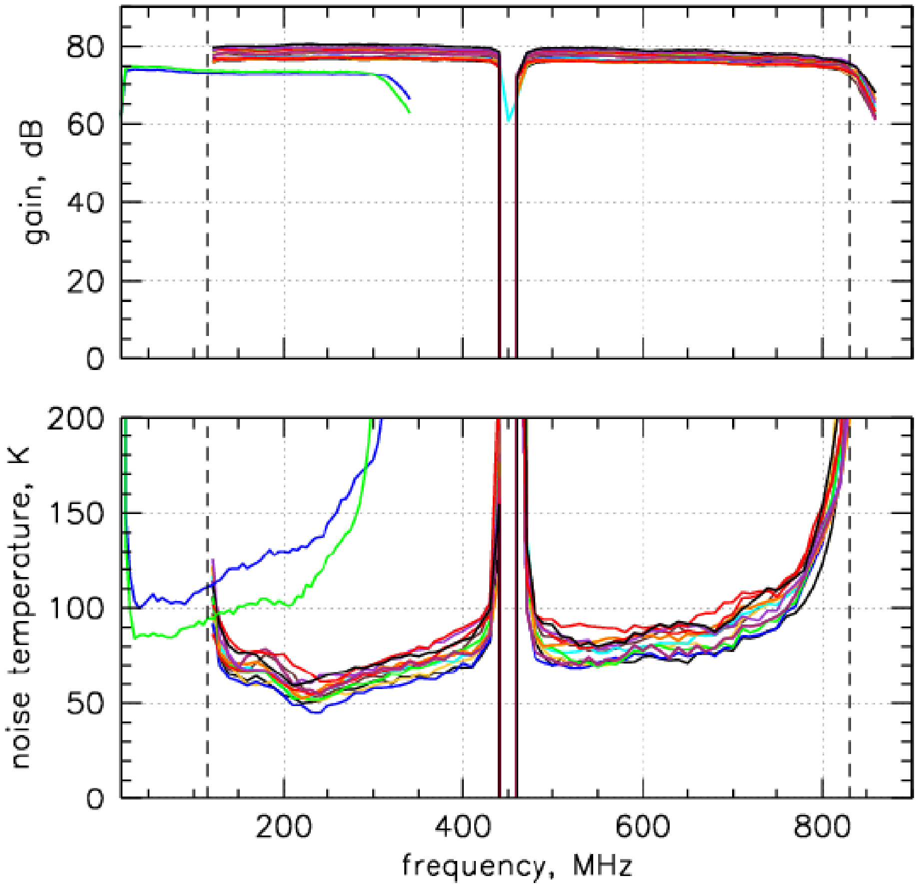


Elevation angle

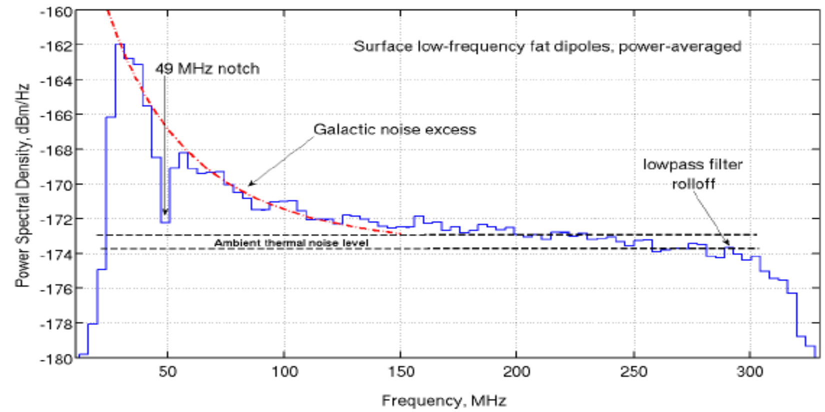
Azimuthal angle

ARA Design

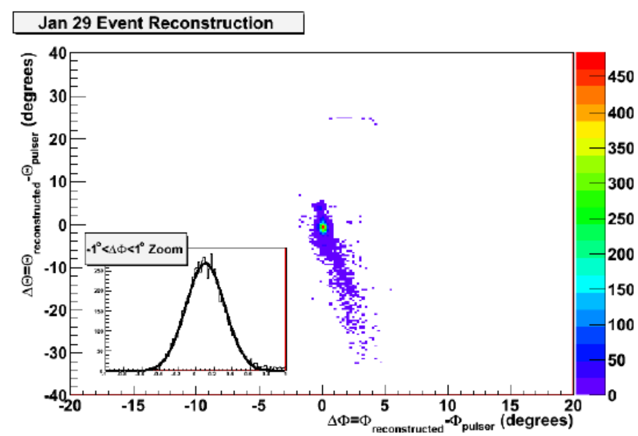
APP 35 (2012) 454-477 arXiv:1105.2854



Pre-amp and receiver
Notch filter at 450 MHz used against
local communication radio frequency



Low frequency surface antennas + amps
Galactic center noise visible

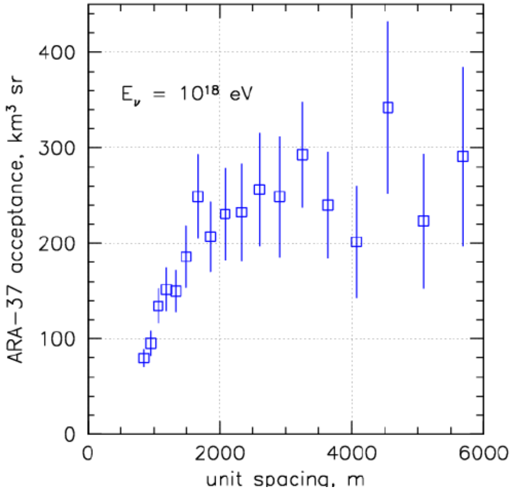


Directional resolution to calibration pulser
Better than 1°

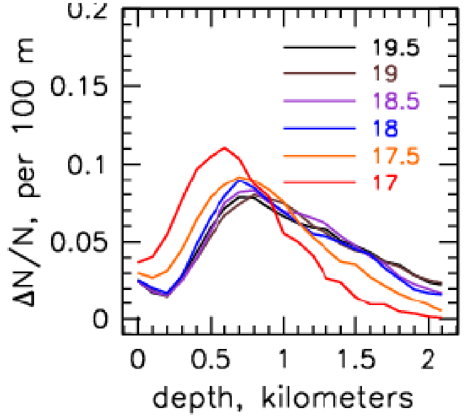
ARA Design

APP 35 (2012) 454-477 arXiv:1105.2854

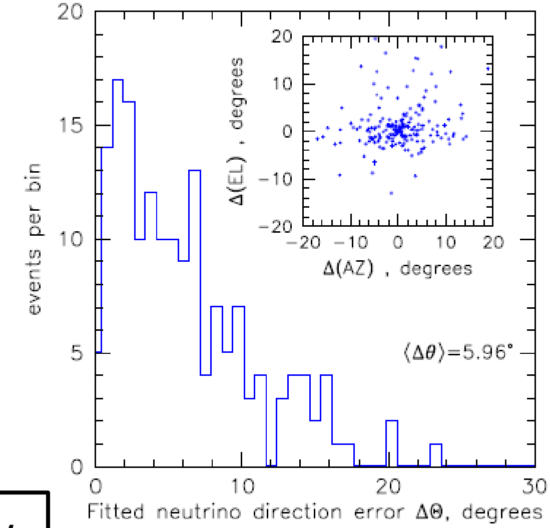
Acceptance / Station spacing

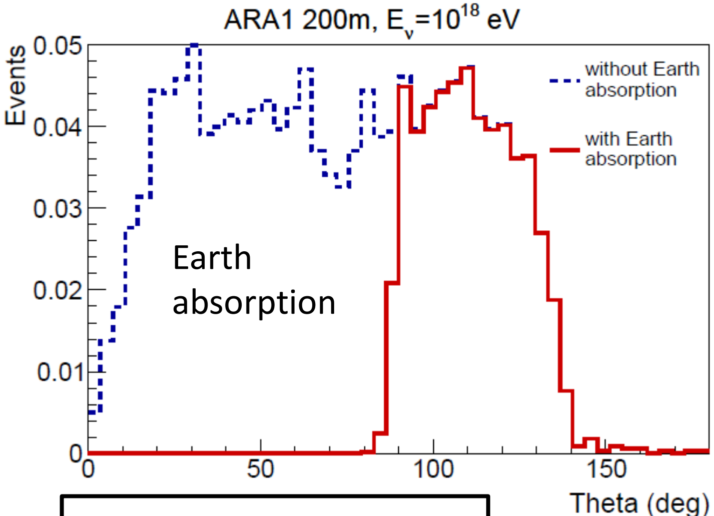


Depth distribution seen events



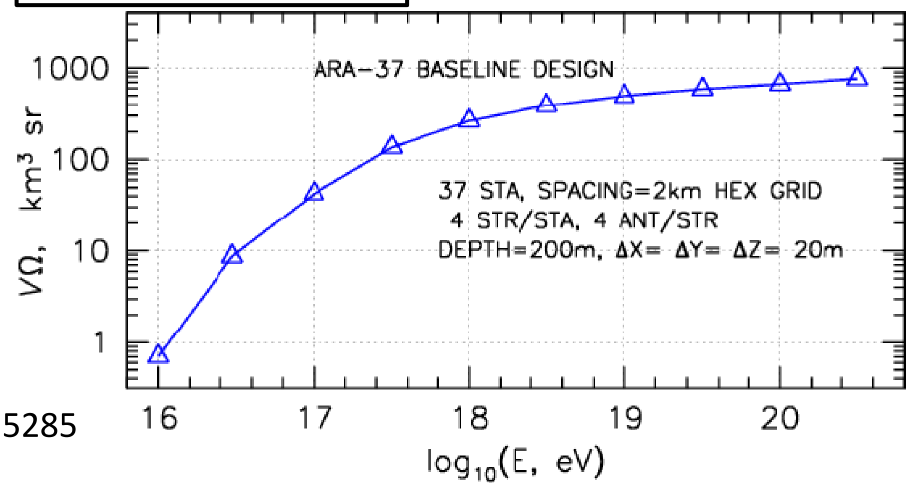
Neutrino direction resolution (~6 deg)





Angular acceptance

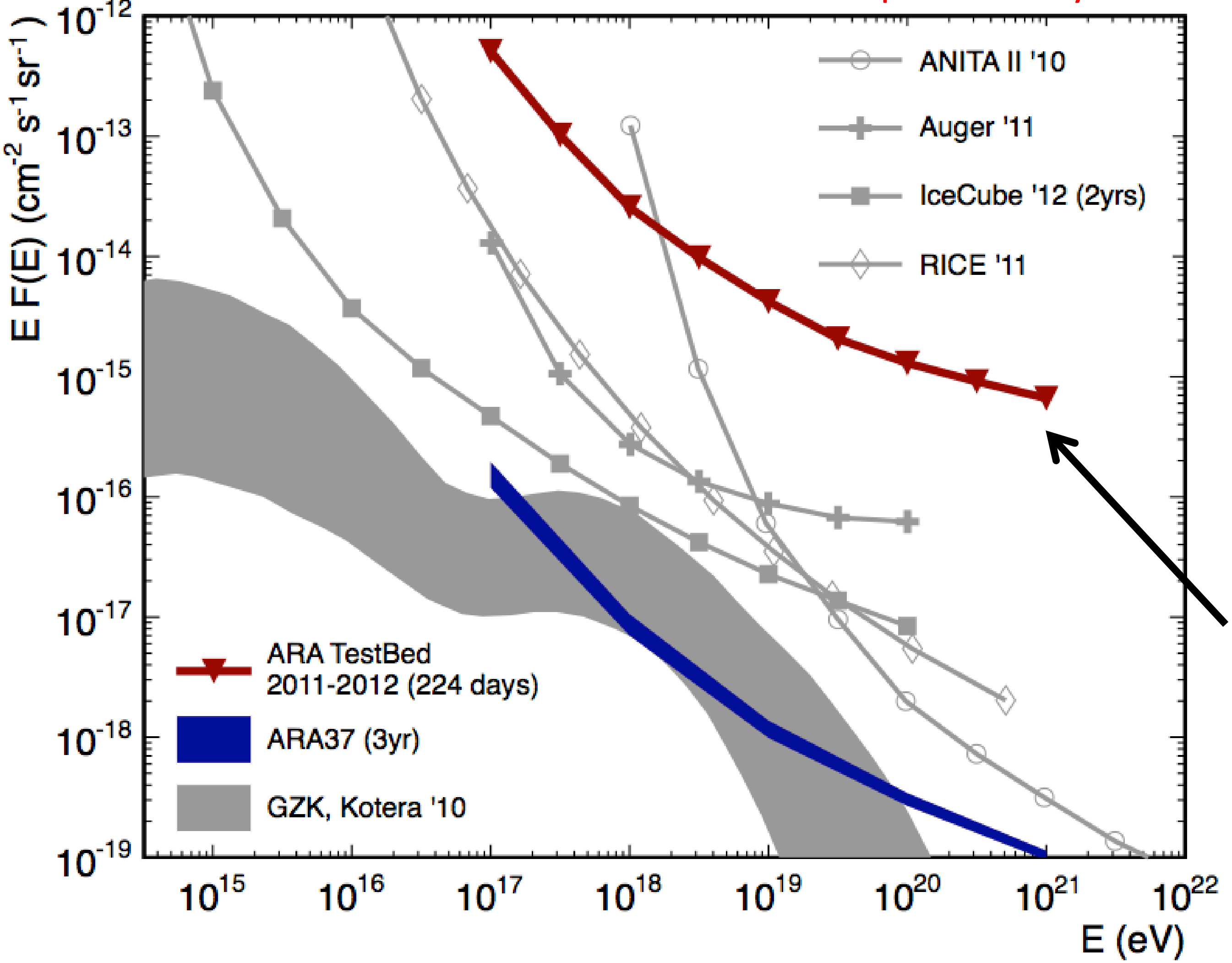
Aperture/ Energy



arXiv 1404.5285

TestBed limit to exercise full analysis process with new simulations

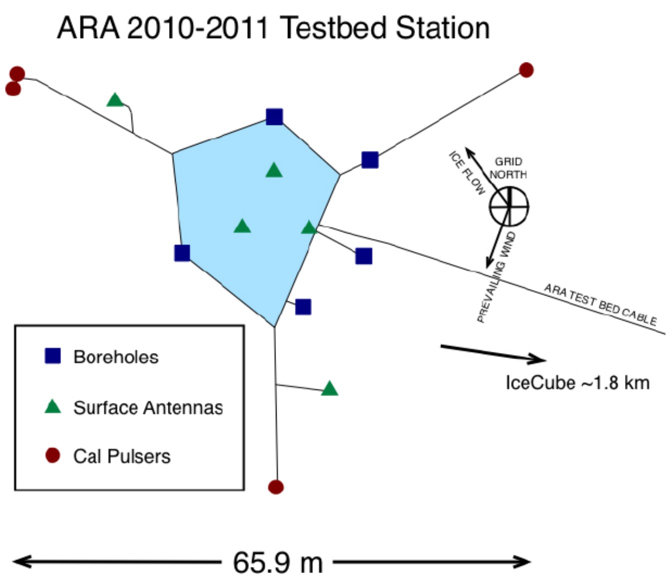
arXiv:1404.5285 Submitted to Astroparticle Physics



ARA Testbed
224 days

TestBed limit to exercise full analysis

arXiv:1404.5285 Submitted to Astroparticle Physics



First cuts:
Anomalous electronic behaviour
Exclude **'South Pole summer** work period' (keeps Feb. 16 – Oct 22)
Period with **electronics instability**
80 ms each second (calibration pulses)
Corrupted waveforms (1%)
To much **power below 150 MHz** (below amp cut-off)

Differences to full ARA:
Testbed antennas at 20-30 m depth
Calibration sources at 20-30 m depth + surface
Some differences in antenna design, their arrangement and in electronics chain.

Three different analysis schemes on Testbed:

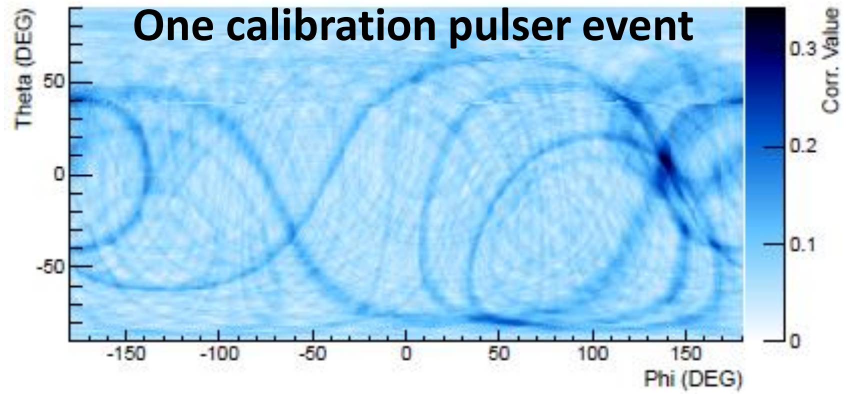
- **Interferometric mapping** (main method)
- Coherent summing of Waveforms
- Template based

Clock time January 2011 – December 2012
Main objective is to find efficient methods to eliminate background events. (330 M → 0)

Adaptive blind analysis on each of two data periods.

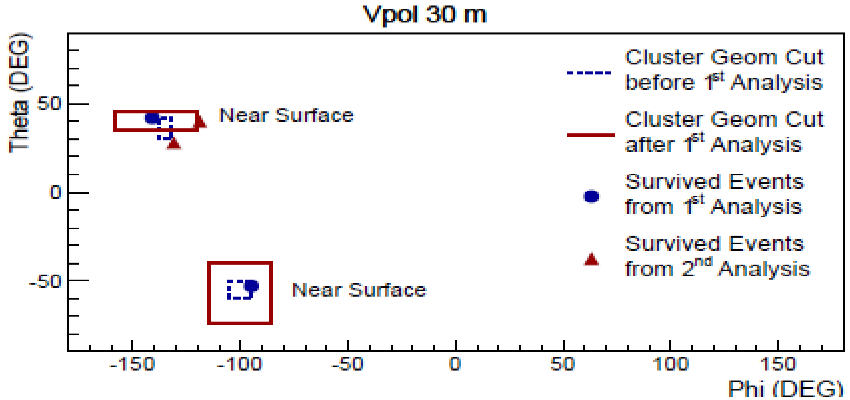
TestBed limit, Interferometric maps

arXiv:1404.5285 Submitted to Astroparticle Physics



Match waveforms using time delays
Ray-tracing to calculate expected time delays from grid of source positions at test distances of 30 m and 3000 m

Directional maps, after cuts on reconstruction quality, consistency with equipment resolution, direction to S P Station or 'unknown repeating sources' (Is "200 MHz" an SPS "ghost" ?)



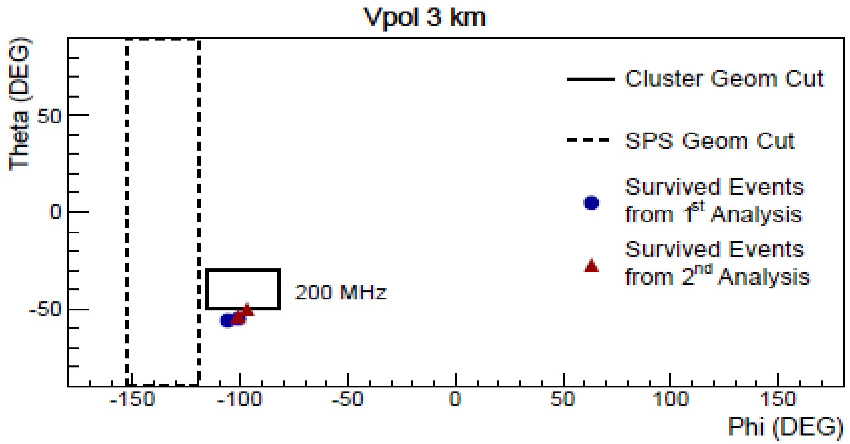
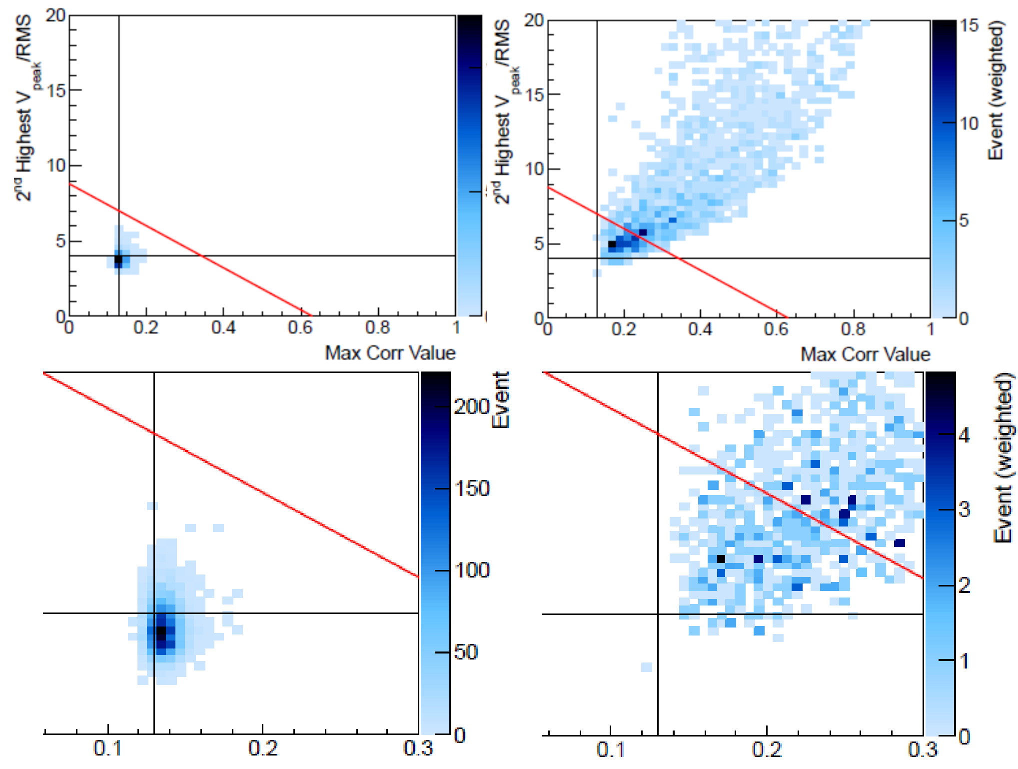


Figure 9: The reconstruction directions of the events that passed both Stage 1 and Stage 2 of the analysis in the 30 m (upper) and 3 km (lower) maps. Events that passed the unaltered cuts in Stage 1 are shown in blue and those that passed the Stage 2 cuts are shown in red. The initial Geometric Cut regions (dashed blue line) were adjusted after Stage 1 (solid red lines) based on a Gaussian fit to the background event distribution with a limited set of cuts applied.

TestBed limit, additional cuts

arXiv:1404.5285   Submitted to Astroparticle Physics

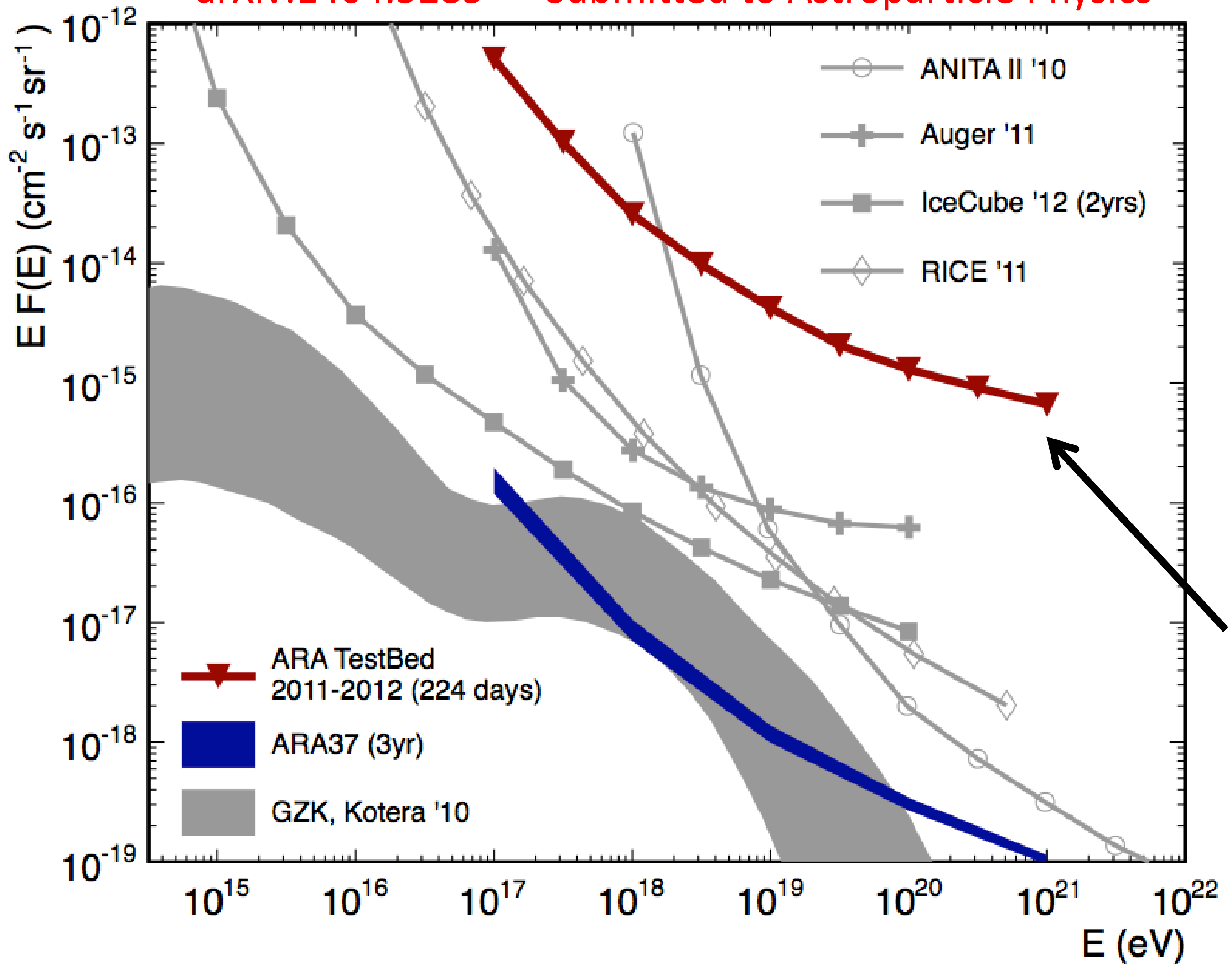
- **Saturation Cut** (Dynamic range minus 5 mV)
- **Gardient Cut** (remove events with to strong gradient for distant origin)
- Delay Difference Cut (strongest pair direction should be consistent with direction from all)
- **In-Ice Cut** (rejects events above horizontal as seen from Testbed)
- **Continous Wave Cut** (remove events with narrowband anthropogenic noise)
- **Peak/Correlation Cut** (2^{nd}high V_{peak}/RMS vs max correlation value)



Data, 10% sample   Simulation, $E_\nu=10^{18}$eV

TestBed limit to exercise full analysis process with new simulations

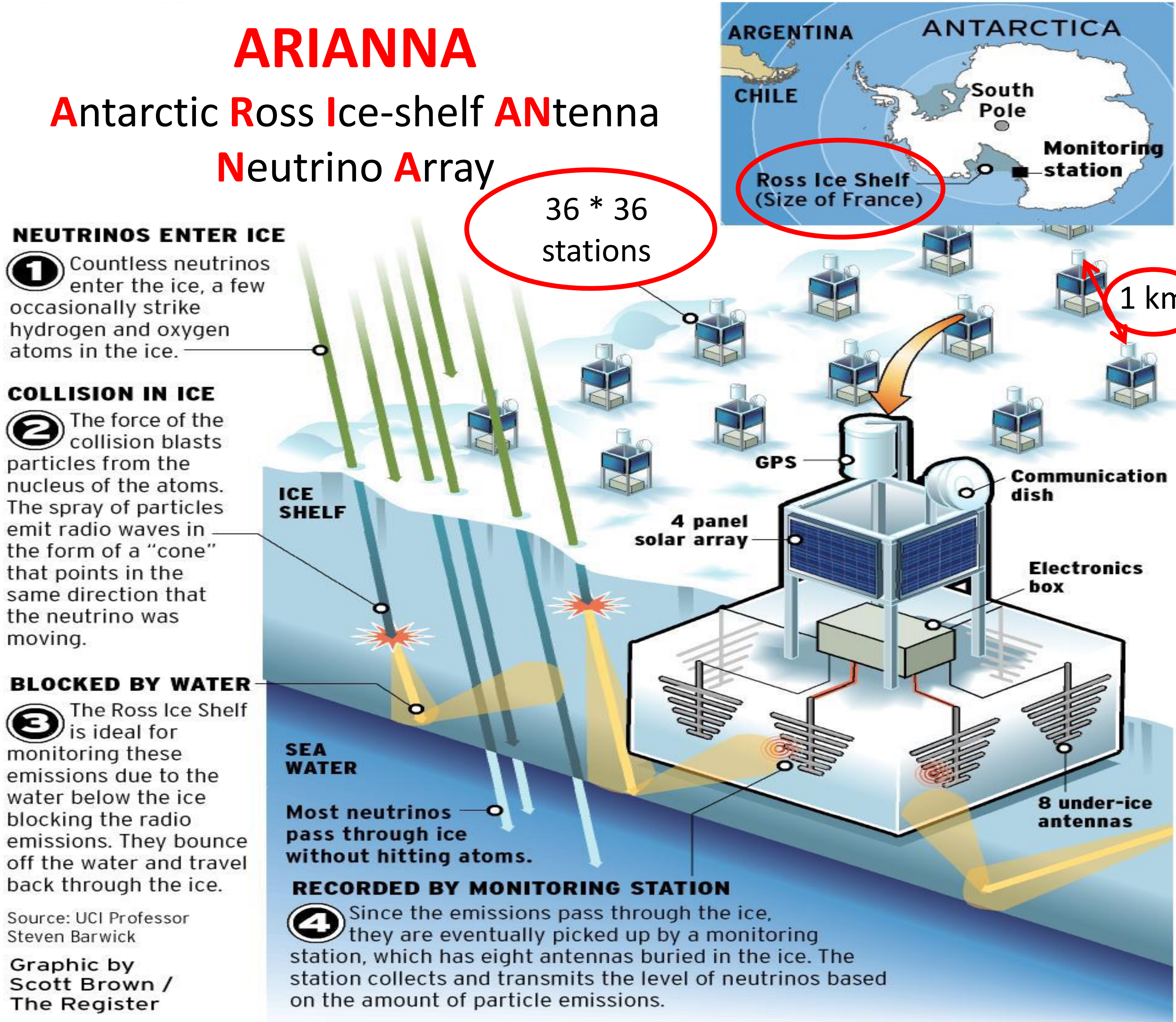
arXiv:1404.5285 Submitted to Astroparticle Physics



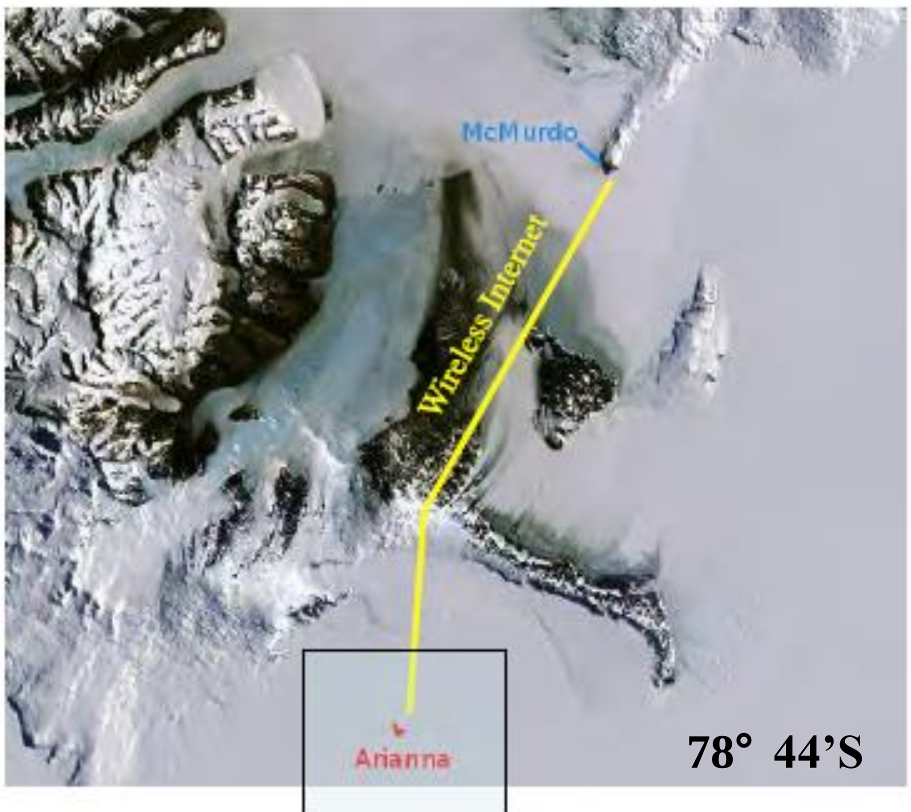
ARA Testbed
224 days

ARIANNA

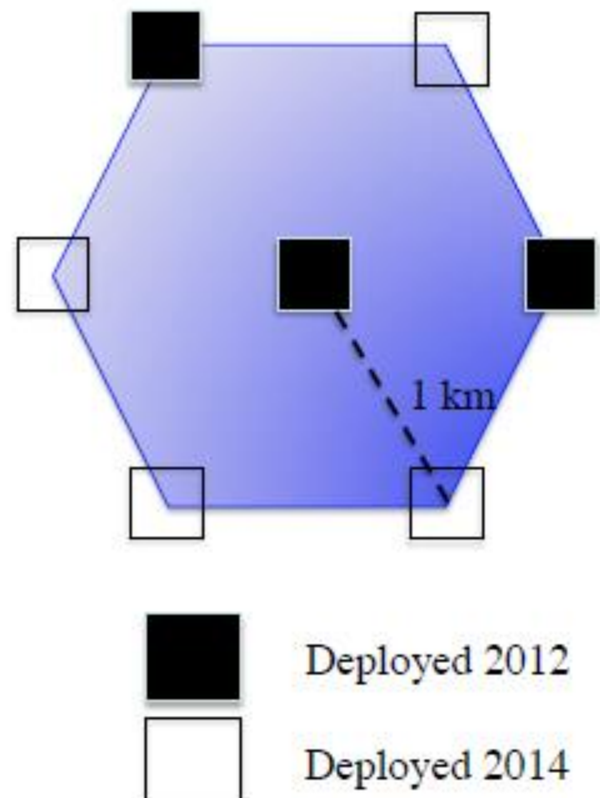
Antarctic Ross Ice-shelf ANtenna Neutrino Array



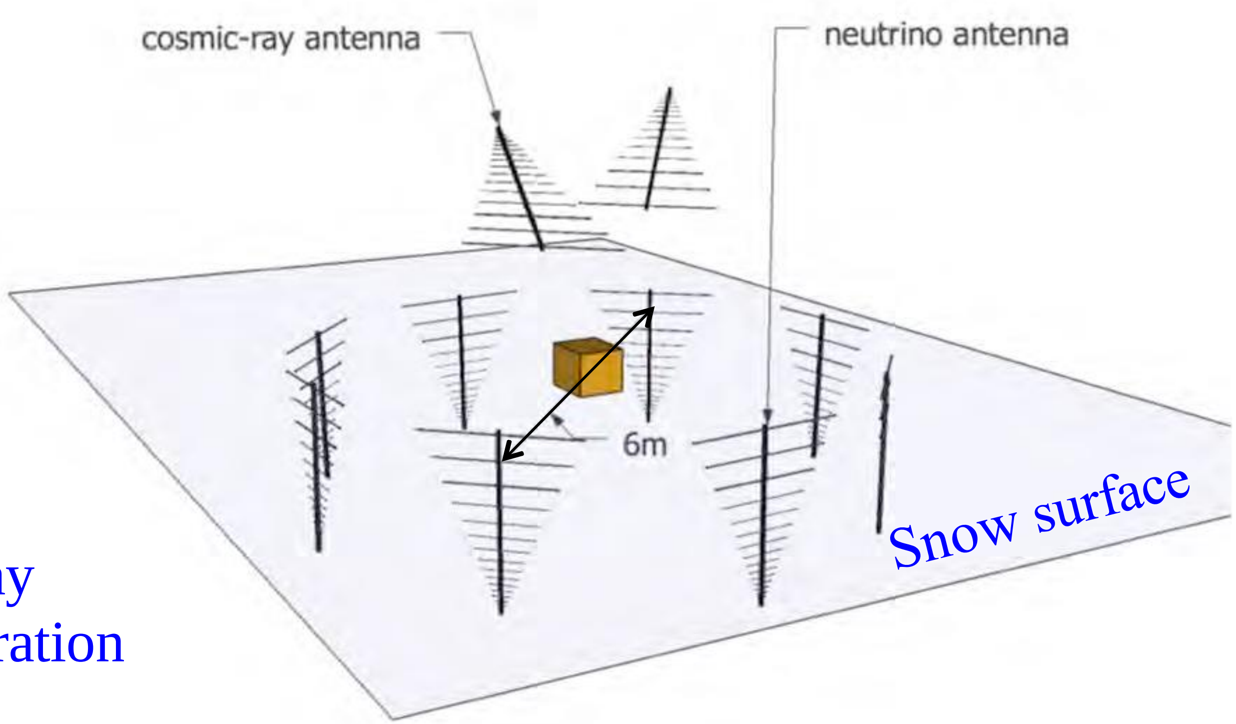
Hexagonal Radio Array (HRA): 2012-2014



Moore's Bay, 110 km from McMurdo Station



ARIANNA Station

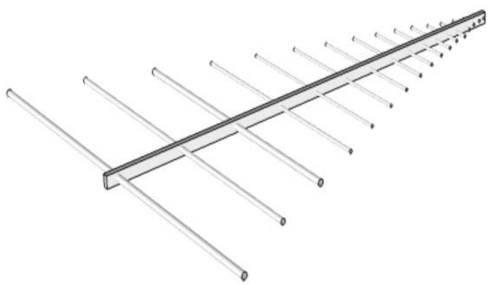


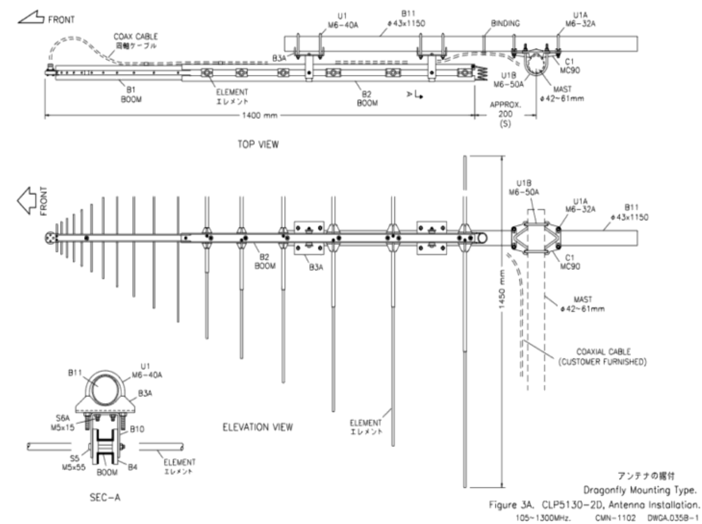
36x36 array
1 km separation

HRA Pilot station is reduced version:

4 down antenna and no CR up antenna

The signal antenna: Log-Periodic Dipole Array



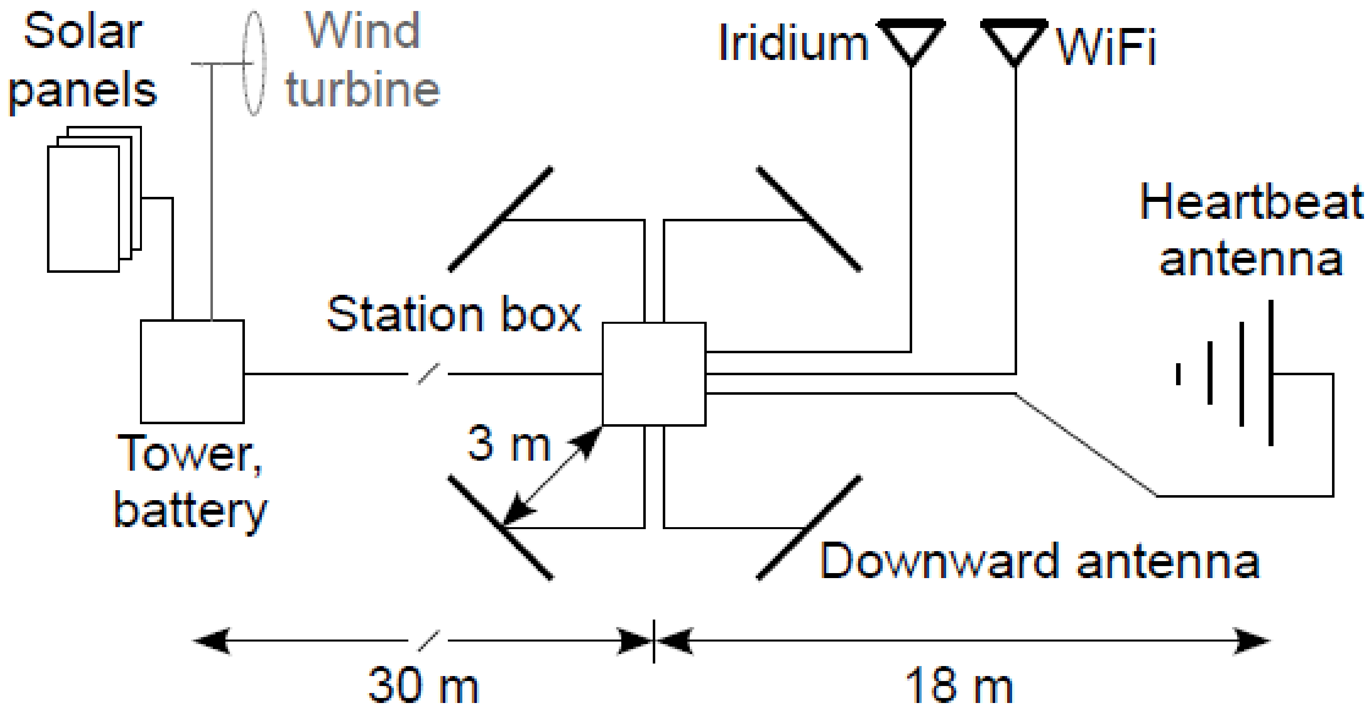


Example of a ***frequency-independent*** antenna (bandwidth of 100-1300 MHz)

Radiation pattern is maximal in direction of ***bore-sight*****.** The *bore-sight* configuration (shown above) optimizes reception.

Linearly polarized**.** The E-plane is the plane containing the dipole elements, the H-plane is perpendicular to E-plane, containing only the ***spine*** of the antenna

HRA Station



Heartbeat antenna, horisontal, pulsed for monitoring of station performance
WiFi communication for high speed internet,
Iridium for SMS type data transfer (planned sufficient for normal running)
Power system, Solar panels, Lithium battery and experimental Wind power
Running stations on only solar power (+ battery) gave 58% (65-70%) up-time

ARIANNA HRA Stations

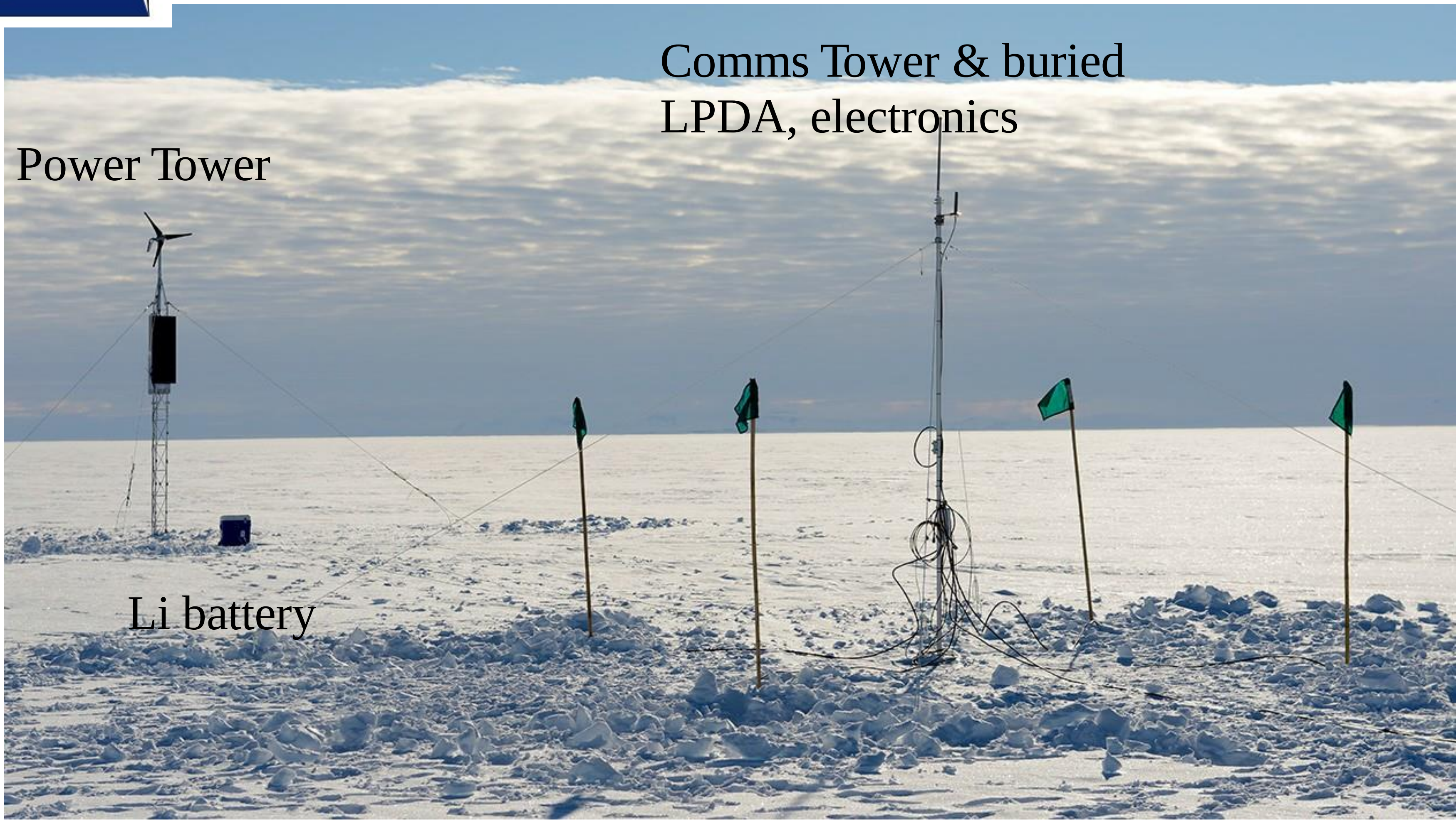
Dig and deploy!

Constructing Station

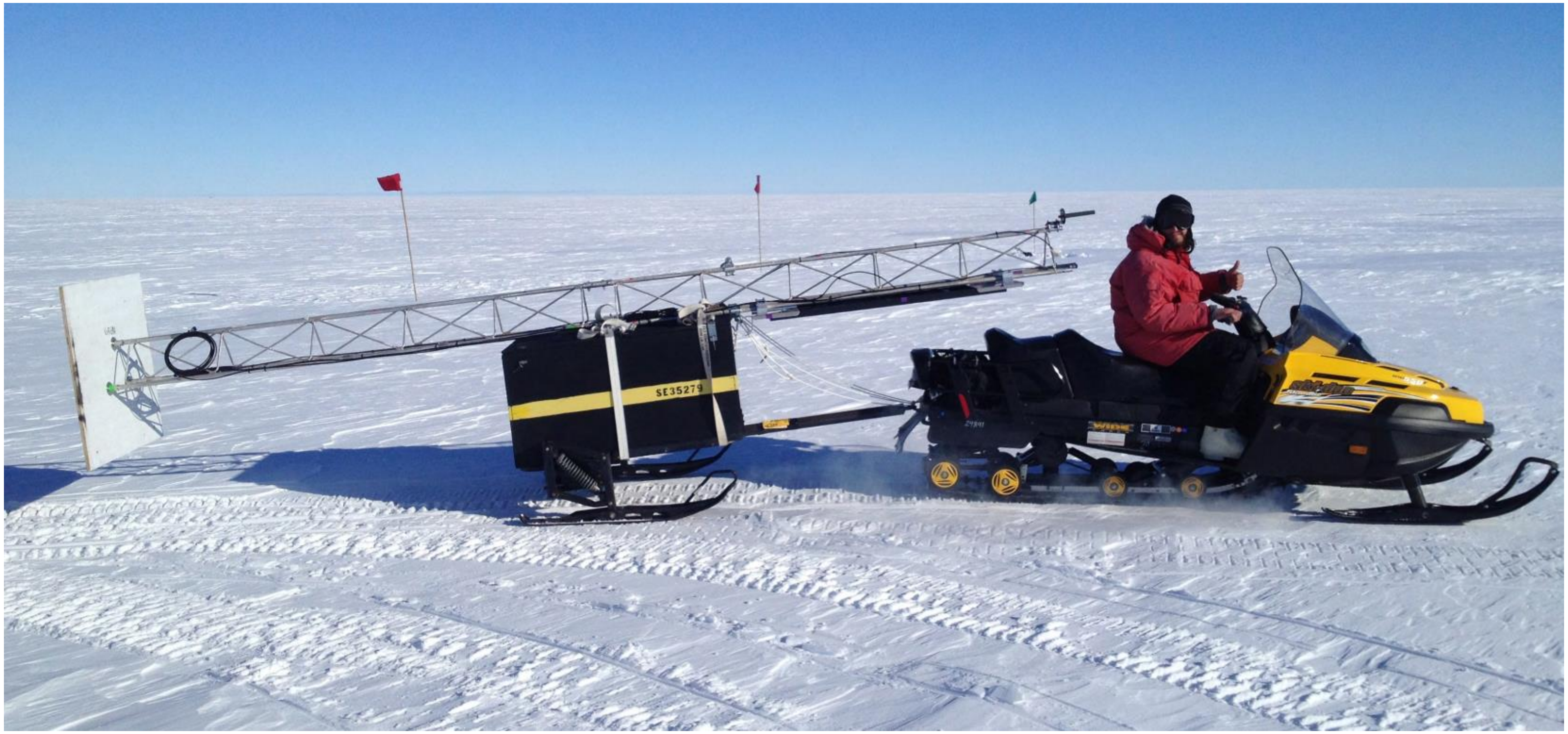
Digging hole for antenna

Installing Power Tower

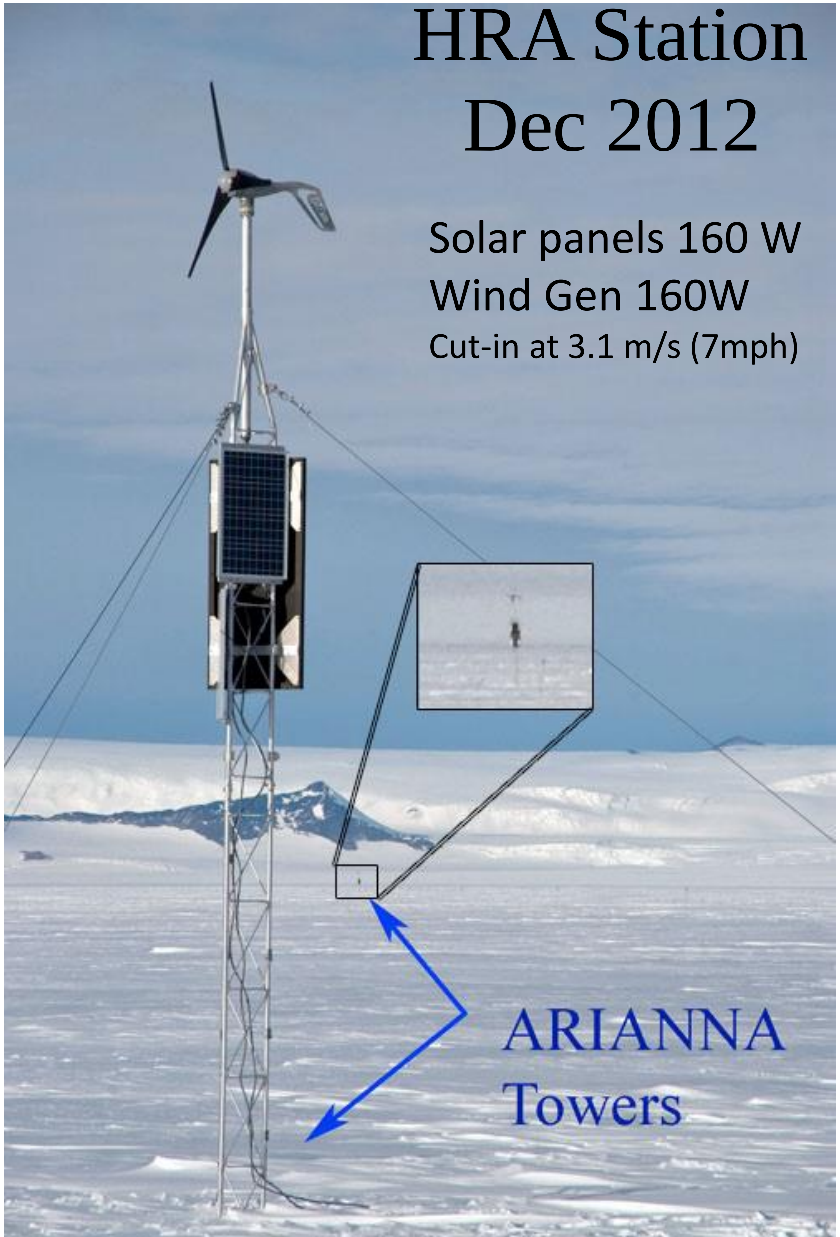
Station Overview



ARIANNA tower

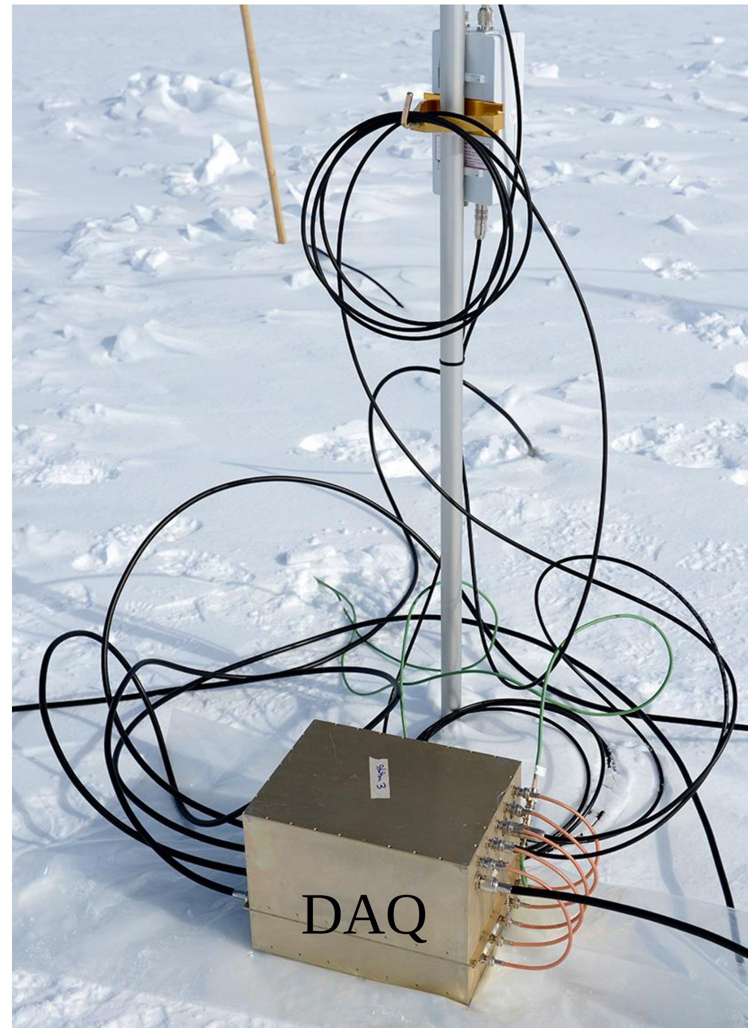


Hexagonal Rado Array deployment completion work, **December 2014**



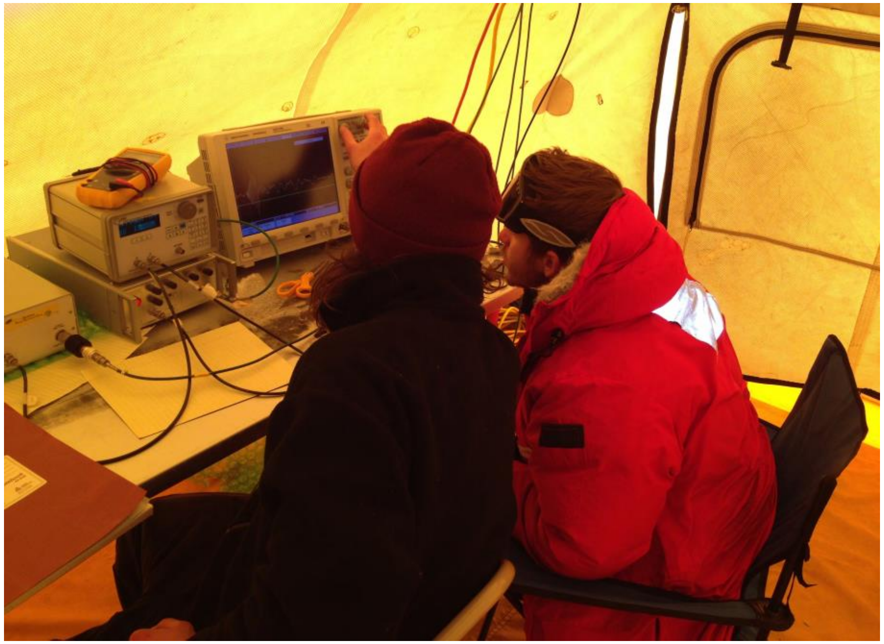
Electronics and base of comms tower (AFAR+Irid)

(AFAR=high speed internet)



Assemble and test!

Checking out operation



All stations in prototype system HRA 7 are taking data now (March 3, 2015)

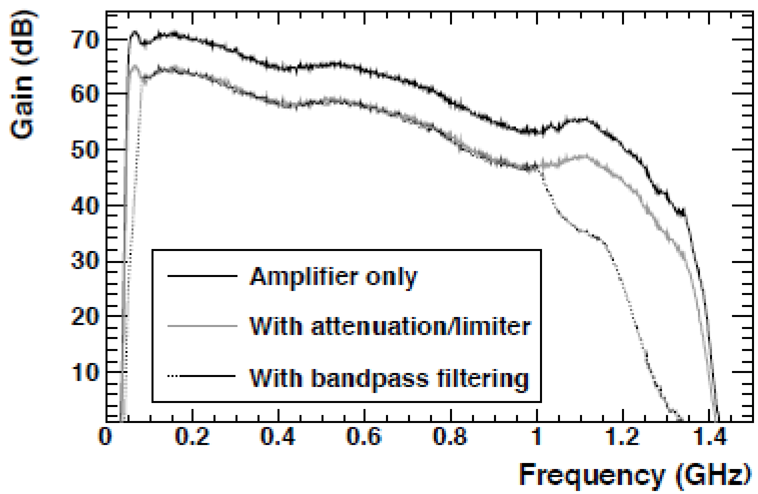
Setting up camp for 24 days

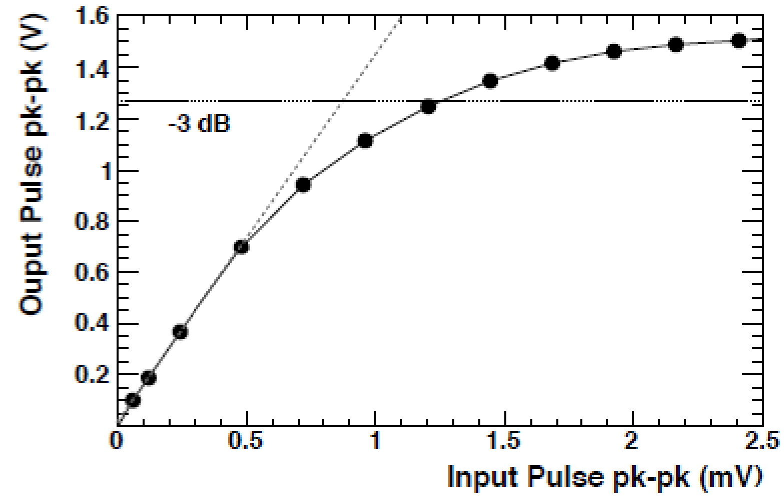
22 days by ourselves

Five ARIANNA workers on ice
Deployed 4 new HRA stations
+ 1 Upward CR station
+ Service, calibration, etc

Deployment time: 1 station 4 hrs, can be reduced

ARIANNA Electronics





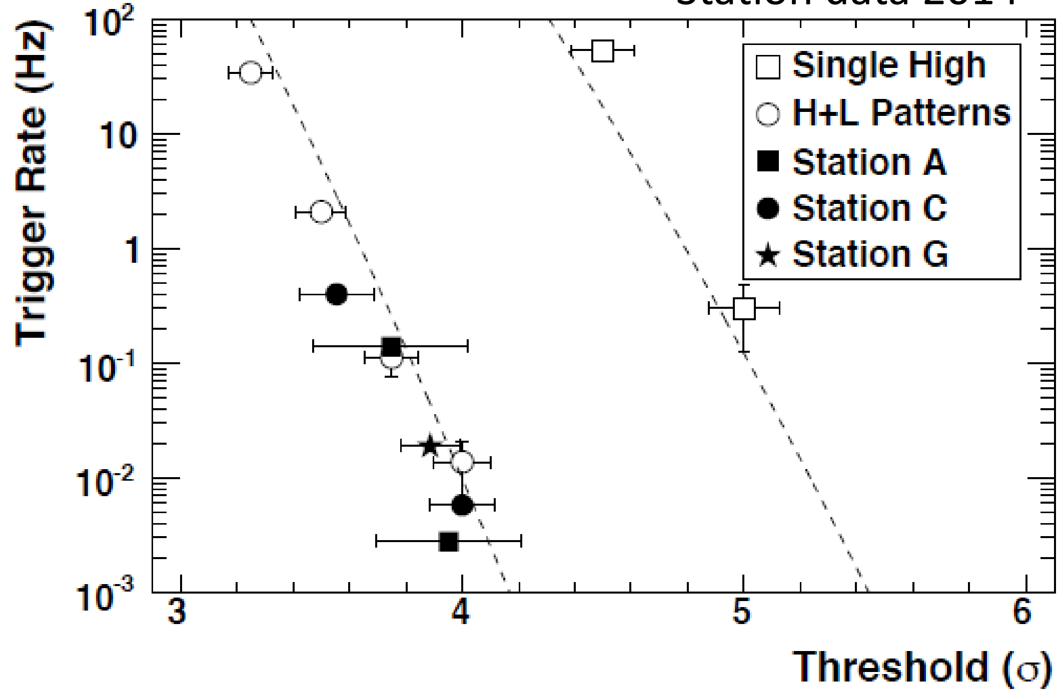
NOTE: Input in mV, output in V

arXiv 1410:7369

Amplifier handles high input signals with smooth attenuation and limiting.
Cut on events with large signals not needed.
Frequency response amplifier without gaps.
Bandwidth digital part 850 MHz (-3dB)
7 W total per station

ARIANNA Trigger

Station data 2014



Low trigger threshold: < $4*\sigma_{V\text{-therm}}$
High-Low criterium used -> strong rate reduction
Field verified early 2014
Rates in fig includes majority 2 of 4 channels
DAQ can handle > 100 Hz

ARIANNA HRA-7

Noise RMS

(forced triggers)

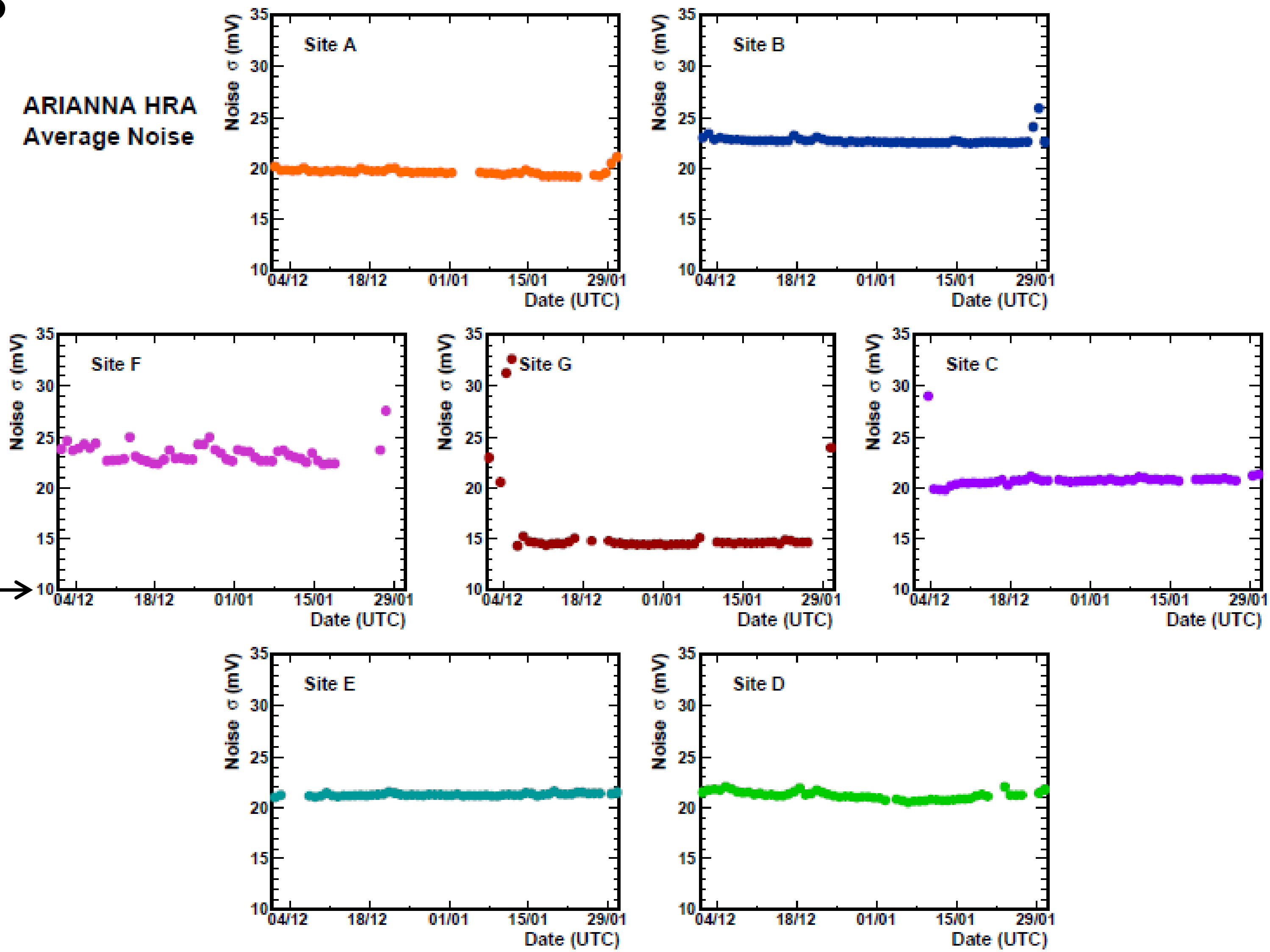
4/12 -- 2014

29/1 -- 2015

ARIANNA HRA
Average Noise

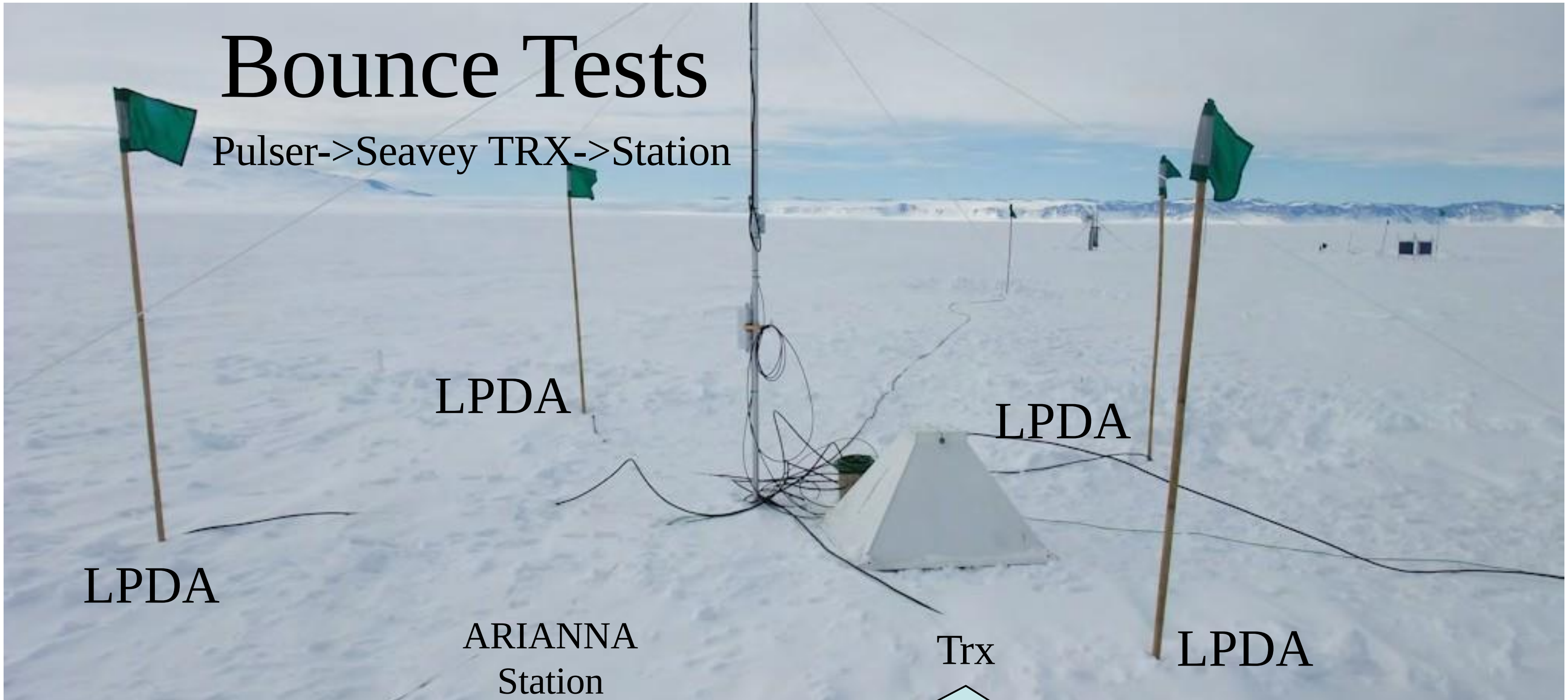
35 mV

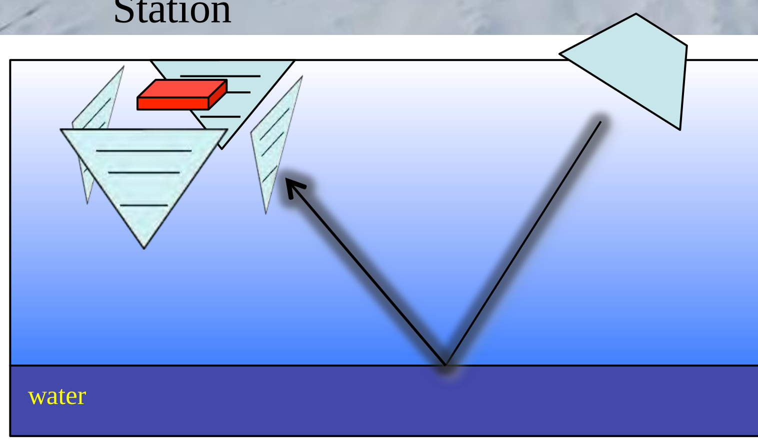
10 mV



Bounce Tests

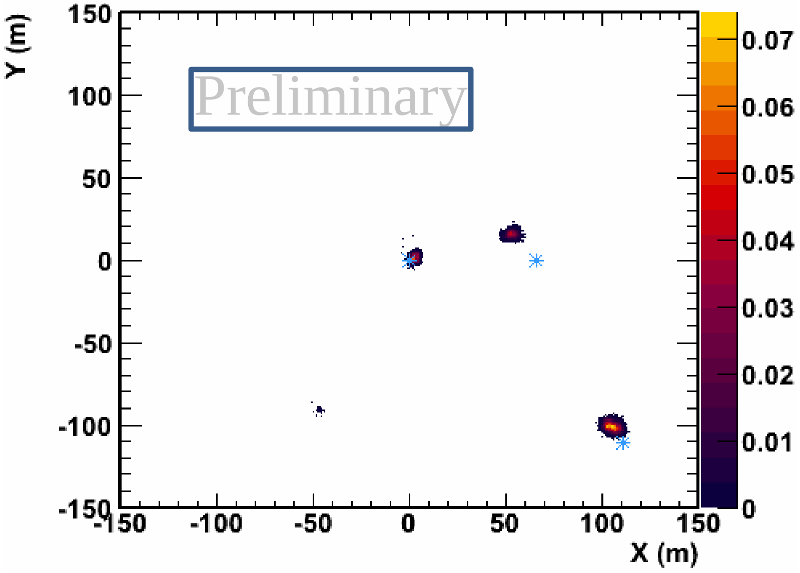
Pulser->Seavey TRX->Station

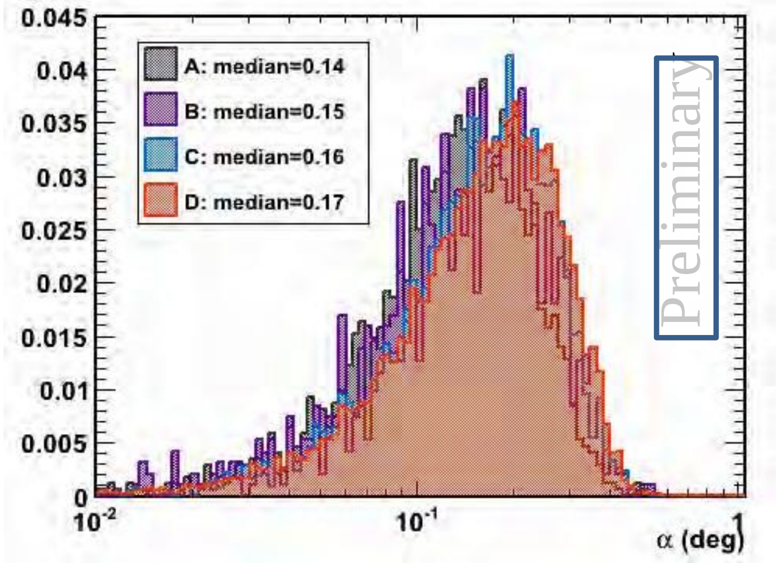




Bounce Tests

Pulser->Seavey TRX->Station

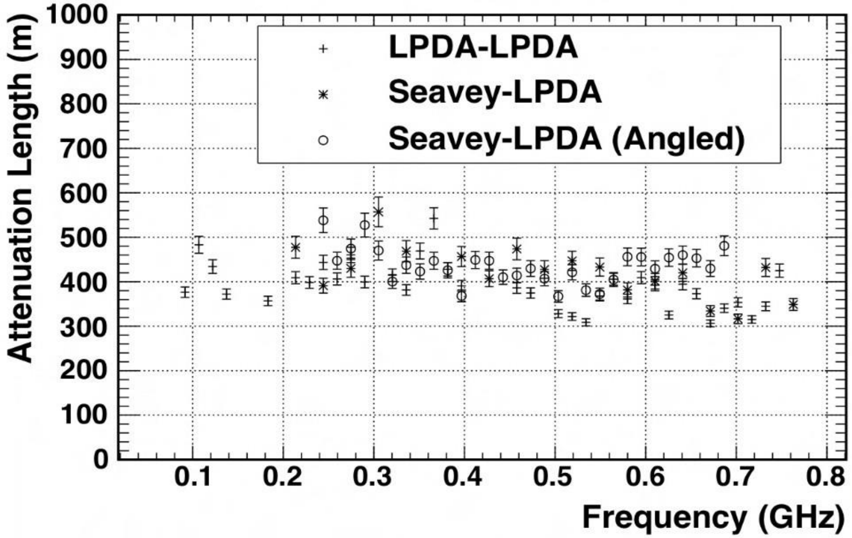


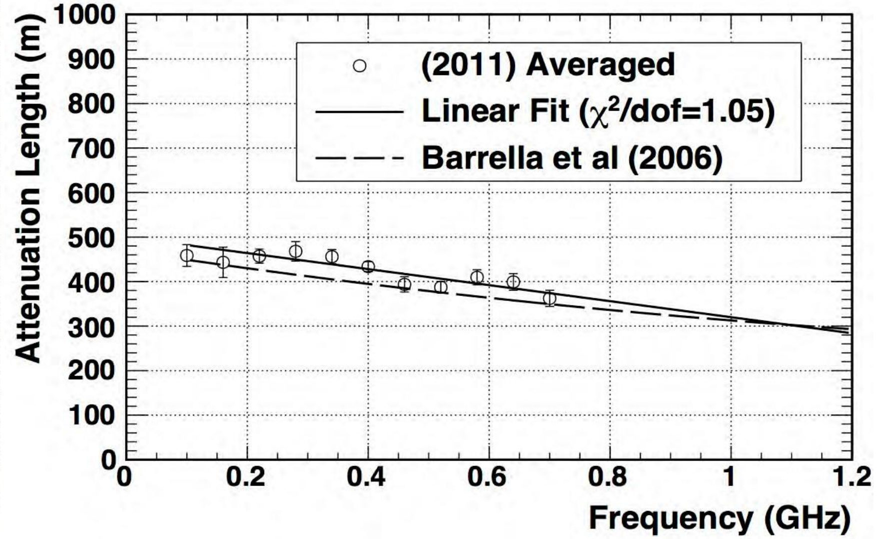


~0.16 deg angular resolution for EM wave

Design and performance: arXiv:1410.7369 (resolution, not figs)

Ave. Attenuation Length



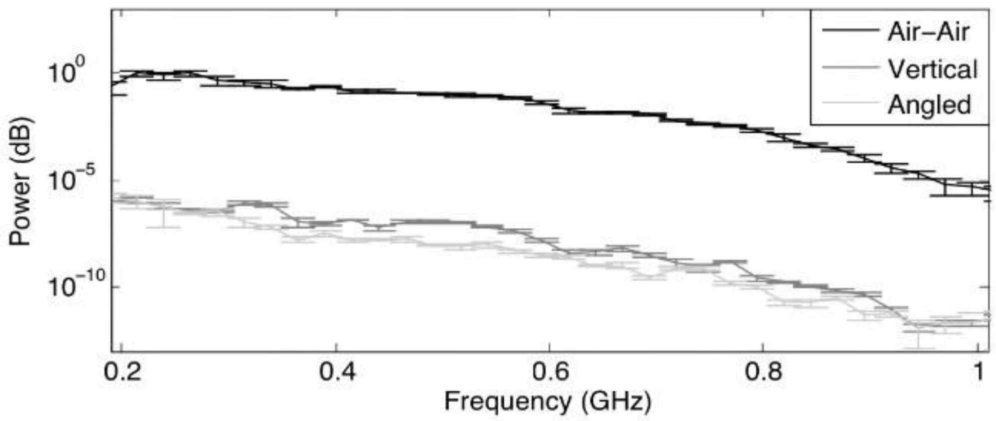


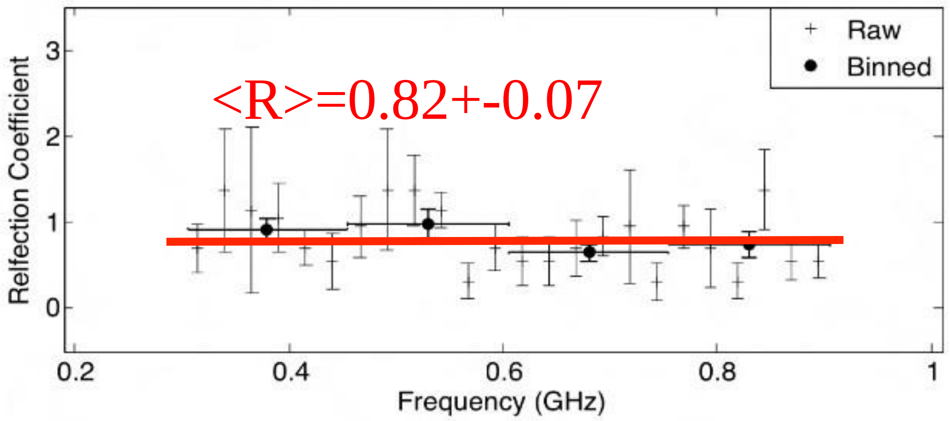
Attenuation length averaged over full depth of ice

No evidence of birefringence from combination of data

Ice measurments: arXiv:1410.7134 Submitted to Journal of Glaciology

Reflection from bottom



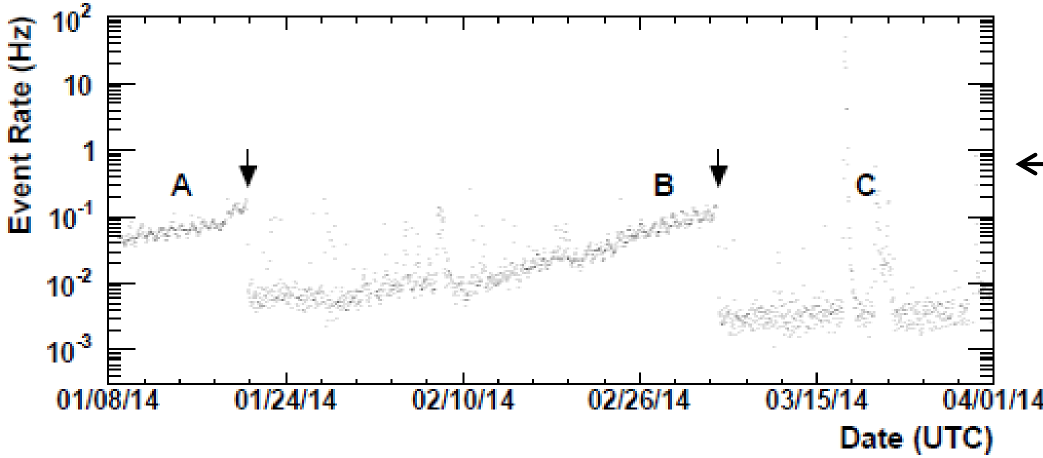


$R^{1/2}$ consistent with theoretical expectation of 0.92

Ice measurments: arXiv:1410.7134 Submitted to Journal of Glaciology

ARIANNA limit - HRA-3 data analysed

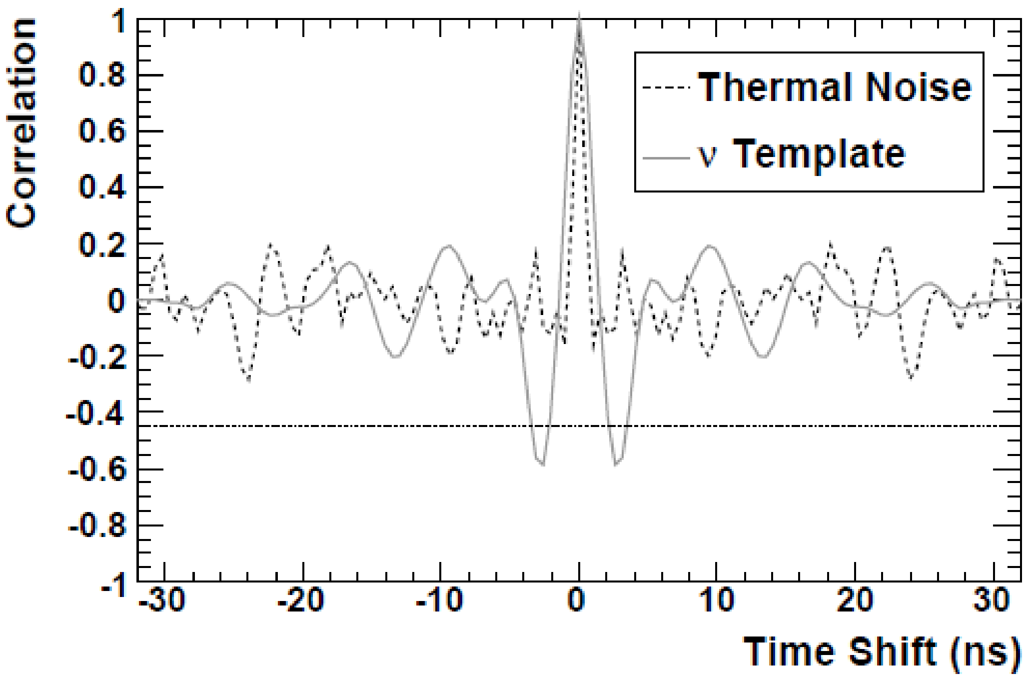
HRA-3 limits etc: arXiv:1410.7352 , Accepted Astroparticle Physics Journal



Sample: Jan. – April 2014
170- live station-days

Trigger rate and noise reduction
Site is free of antropogenic noise

Thermal noise dominates trigger
Temperature variation visible
as initial rate variation



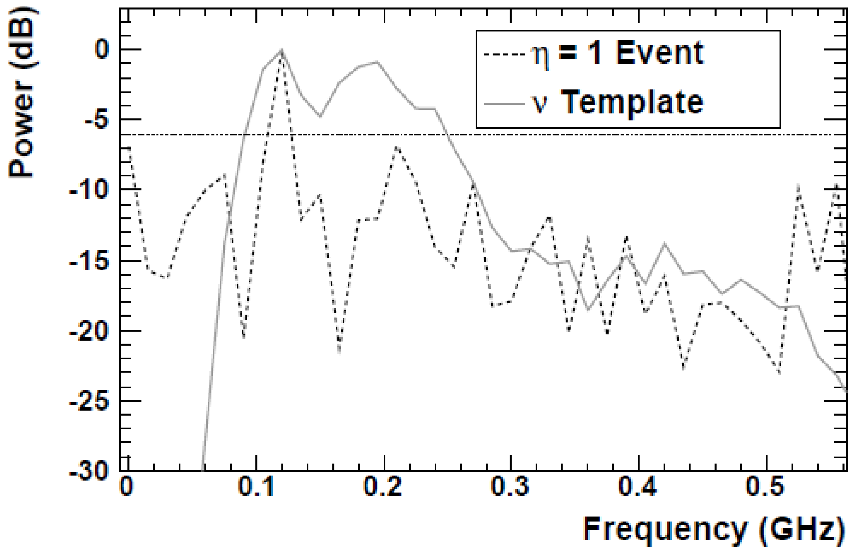
CUT 1

Autocorrelation of pulse
Thermal noise has correlation
only at time-shift =0

Simulated neutrino signals has
visible correlation, at shifted
time
require corrlation < - 0.45

ARIANNA limit - HRA-3 data analysed

Cut 2

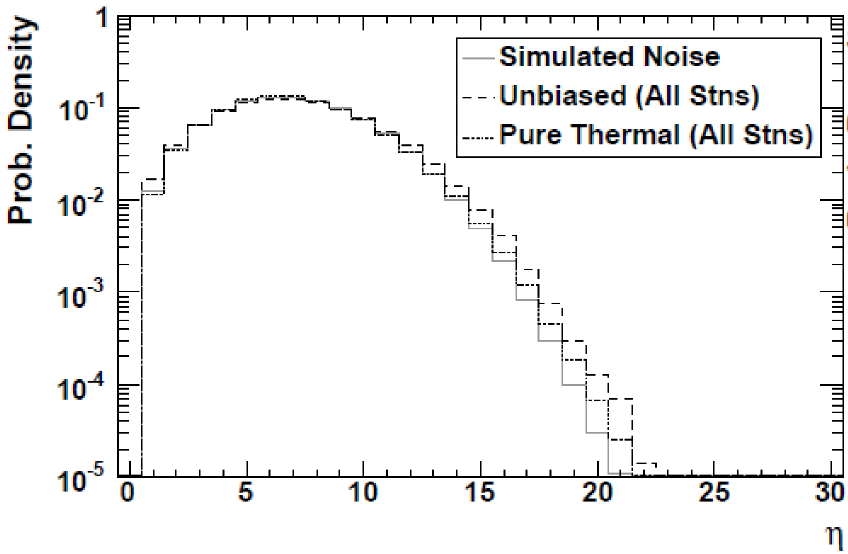


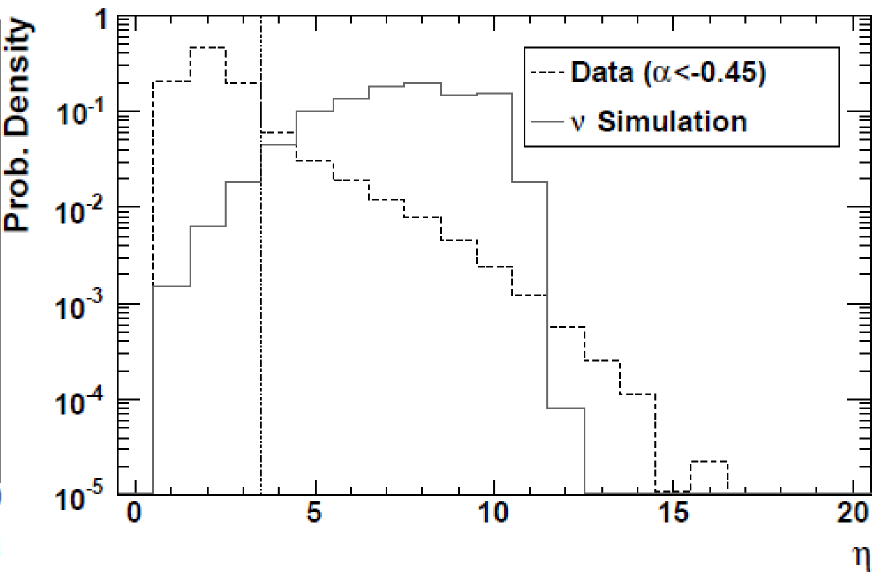
Investigate frequency content

Noise from station itself and other sources has power concentrated in frequency

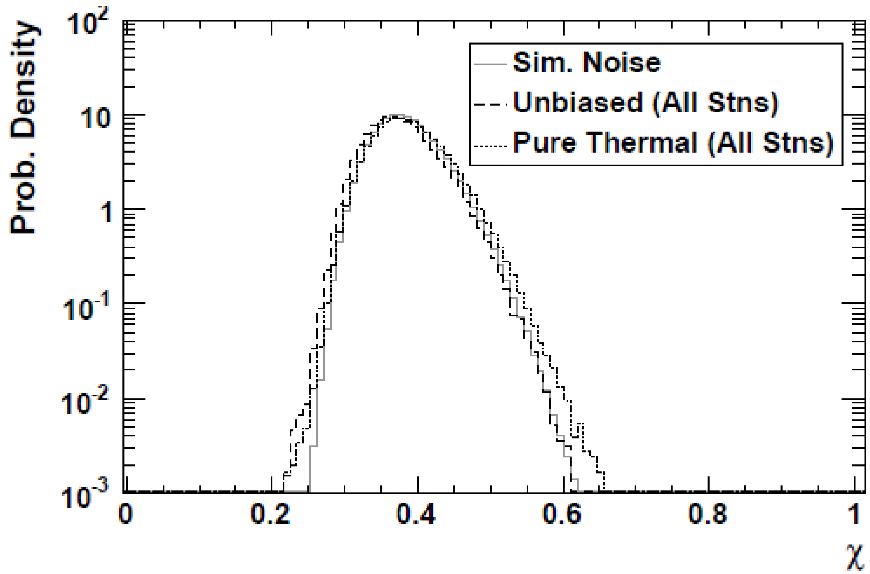
→ Count number of bins with high relative power (above line)

Neutrino events have several high power frequency bins, require > 3





ARIANNA limit - HRA-3 data analysed



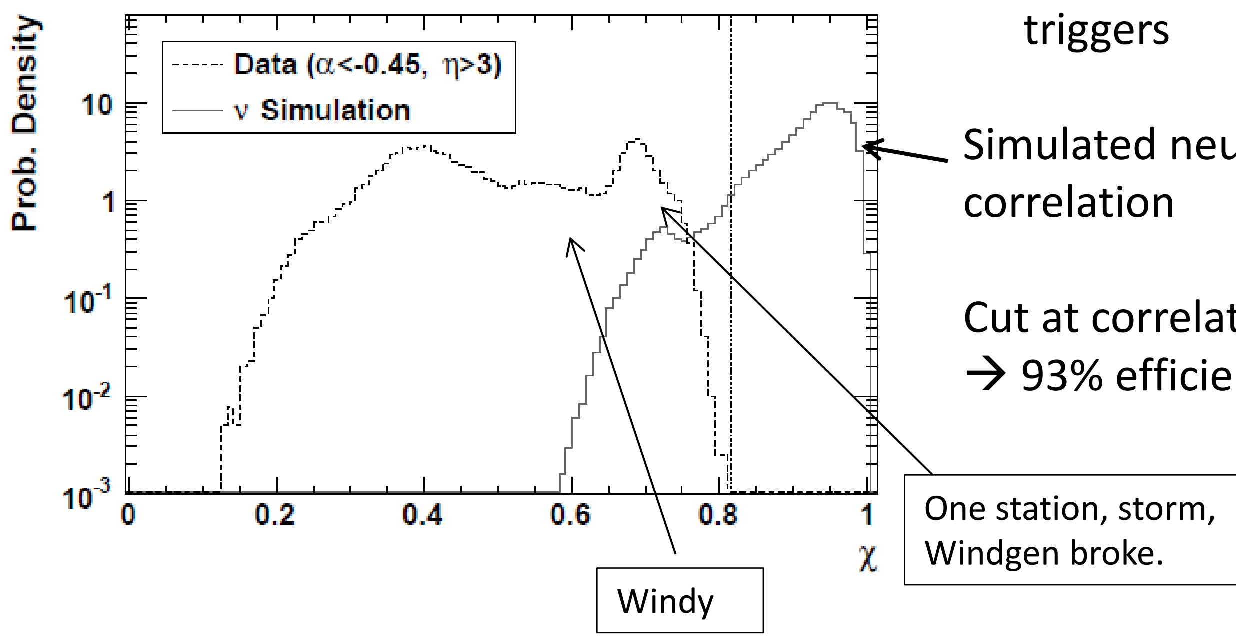
Cut 3

Create **template for neutrino event** signals by simulation.
Astroparticle Physics 62 (2015) 139-151

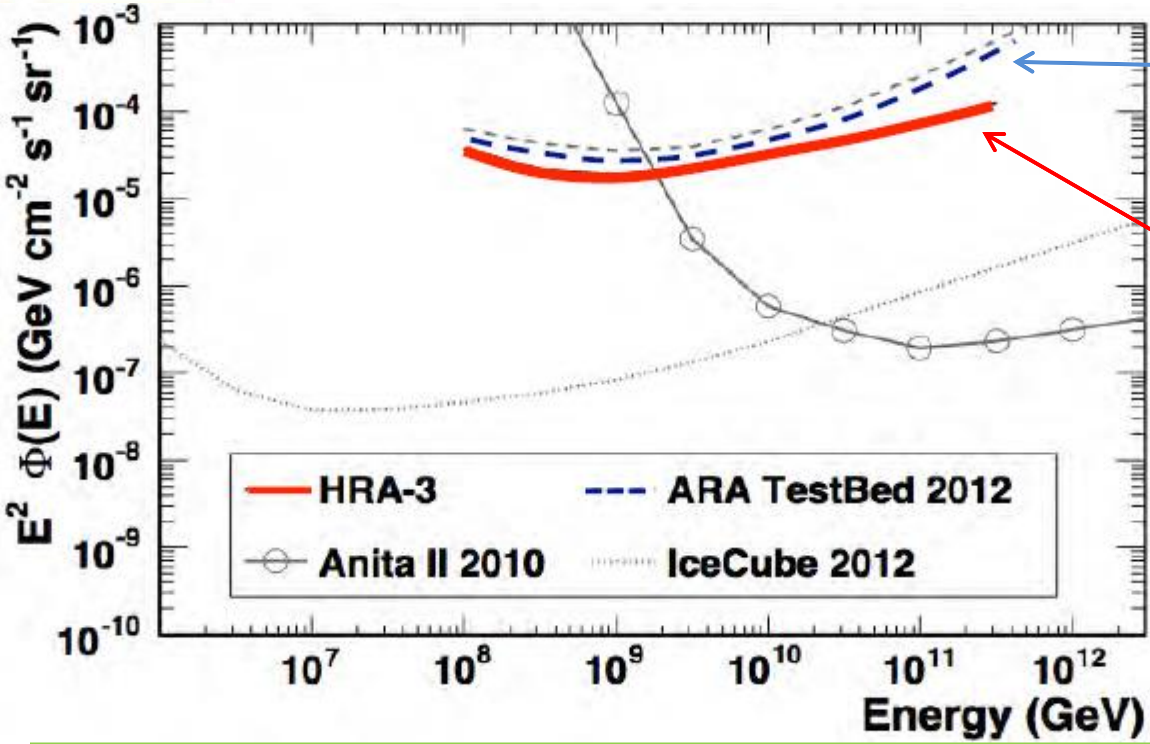
Calculate **correlation to observed signals**
Plot (best) correlation value for data
← Both clock triggers and all normal triggers

Simulated neutrino events show high correlation

Cut at correlation value 0.81 in HRA
→ 93% efficiency , no remaining event



ARIANNA HRA Limits (2014)



Ara Testbed

HRA-3: 3 months

HRA-3 limits etc: arXiv:1410.7352, Accepted Astroparticle Physics Journal

Ice measurments: arXiv:1410.7134, Submitted to Journal of Glaciology

Time domain response: arXiv:1406.0820, Astroparticle Physics 62 (2015) 139-151

Design and performance: arXiv:1410.7369, Submitted IEEE TNS

ARIANNA
Some additional info

Further tools will be used in analysis of complete ARIANNA stations with 8 downward antennas and 2 upward antennas.

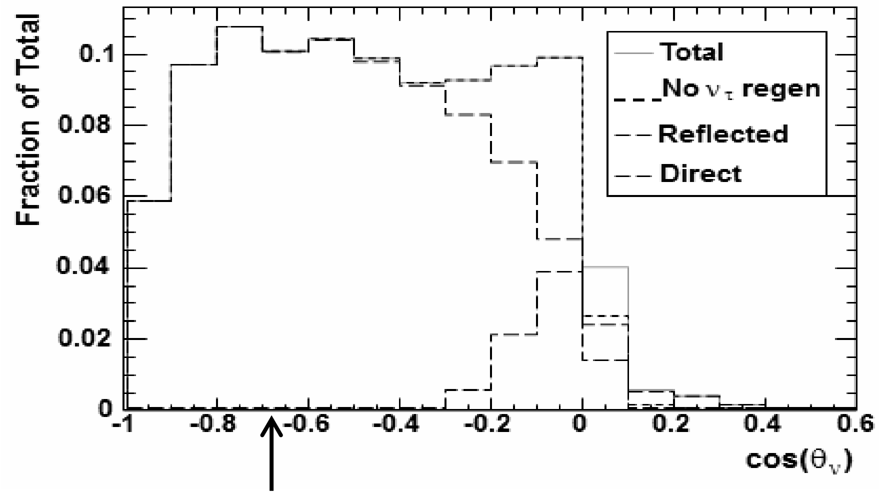
- Likelihood analysis for reconstruction of incoming **radio signal direction**
- Likeliehood analysis for incoming **neutrino direction and energy**
- **Cosmic ray** signal **suppression** using upward antennas.
- ....

32 Gb Compact flash memory/station. Sufficient to keep full year data, also at highest expected rates.

Autocorrelation cut can be implemented locally, this will reduce the rate of physics to 0.1 mHz, without loss of physics events. --> Data transfer on Iridium link OK.

Expected ARIANNA performance

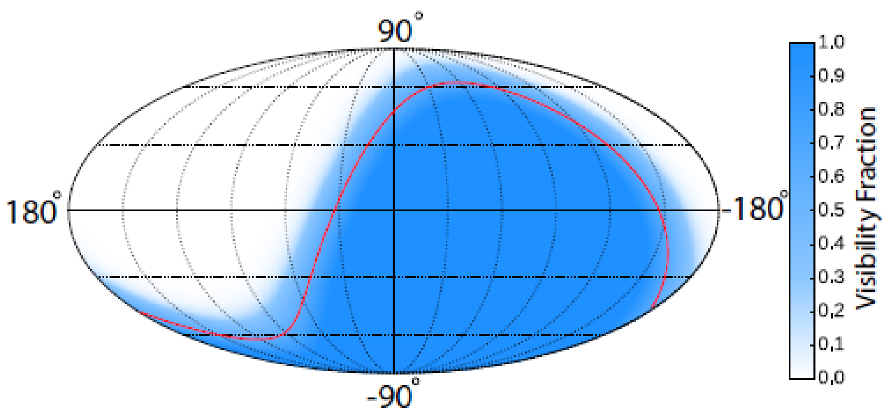
Based on measurments of ice, simulations + ”known physics”, conservative estimates ....



Angular acceptance

Most events from Radio signals reflected at ice-sea interface.

Earth absorption cuts below horizon



Angular coverage and Visibility fraction

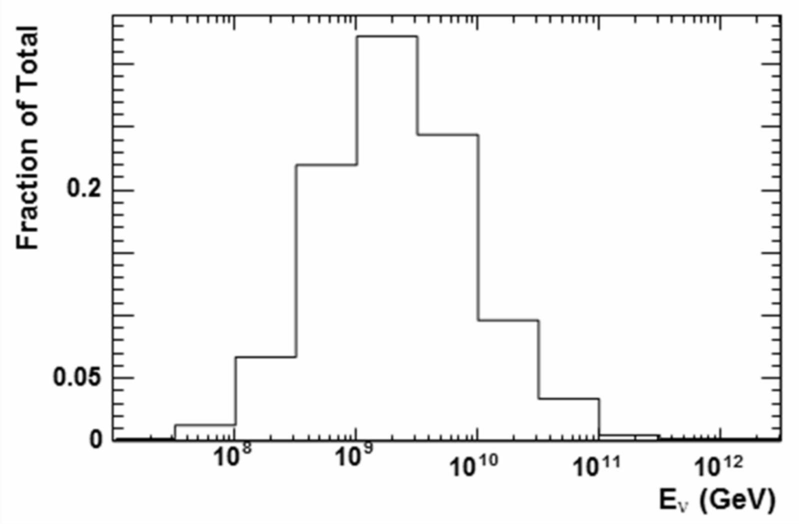
In Galactic coordinates

Red line for detector at South Pole

Ice measurments: arXiv:1410.7134 Submitted to Journal of Glaciology
HRA-3 results: arXiv 1410.7352 To be published in Astroparticle Physics

Spectral response & energy resolution

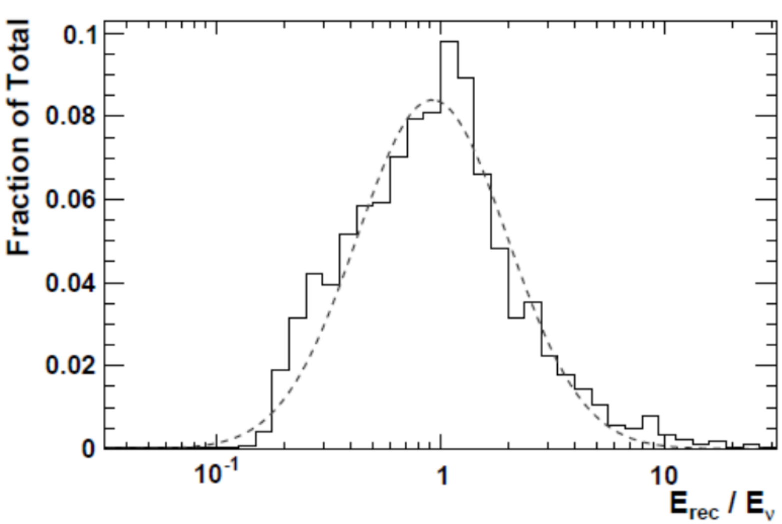
(simulation, in situ beam to weak.....)



For ’typical’ input spectrum

Threshold at 10^{17} eV

Flux limits upper end

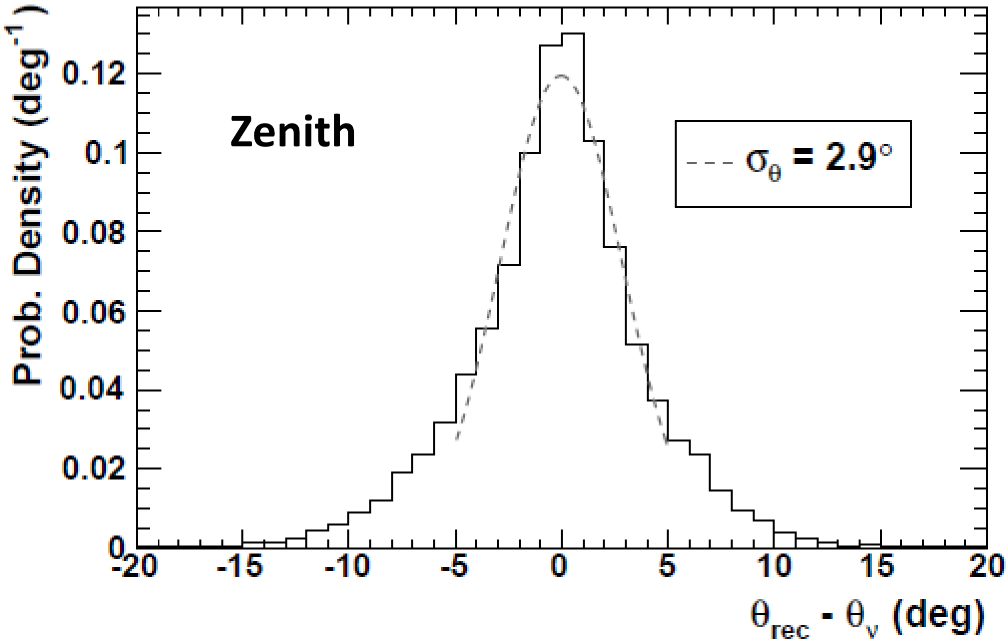


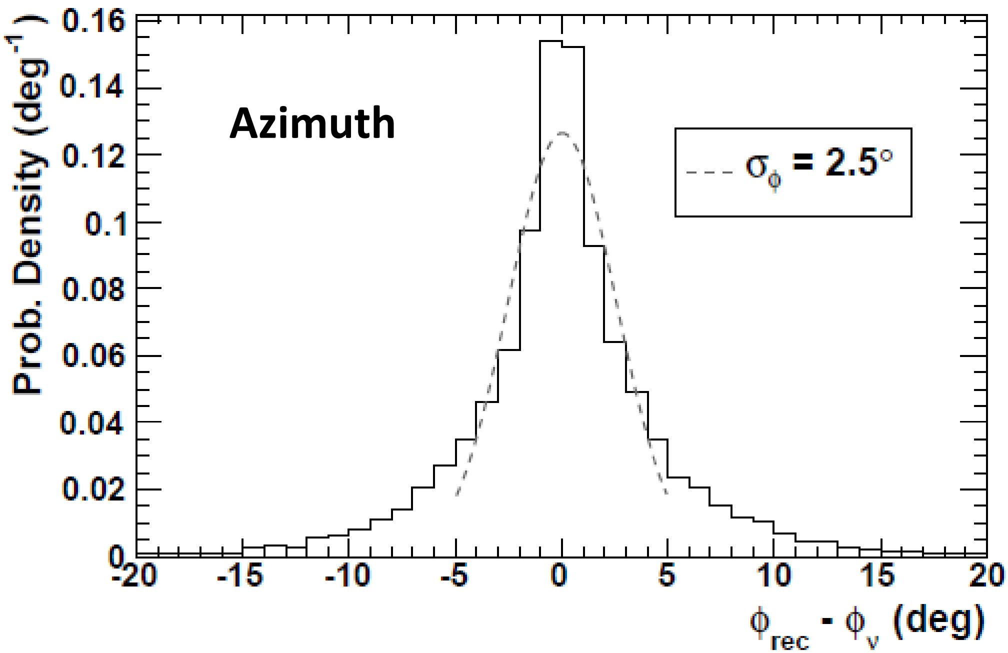
Energy resolution

Dominant factors contributing is uncertainty on angular distance to cherenkov angle and variations in transfer of neutrino energy to shower. Distance, reflexion, antenna response contributions smaller.

Energy resolution

in range 2.2 – 5 on ratio E-rec/E-neutrino





Angular resolution

Timing of signals on the different antennas, 100 ps, give direction of RF within 1 degree.

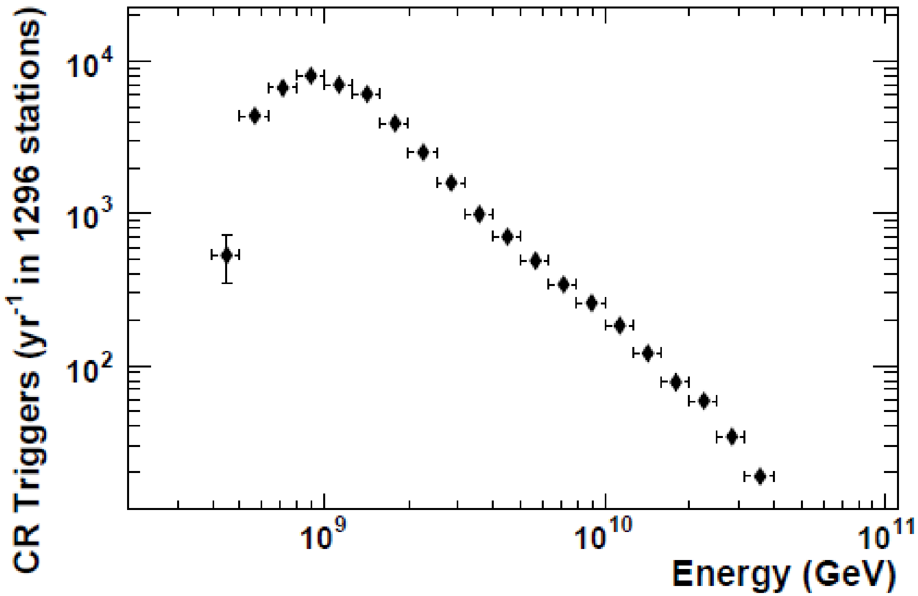
Cherenkov radiation is polarized,

→ different amplitudes in the antennas with different orientation

→ direction of incoming neutrino.

Resolution on Zenith and Azimuth of about **2.5 – 3 degree.**

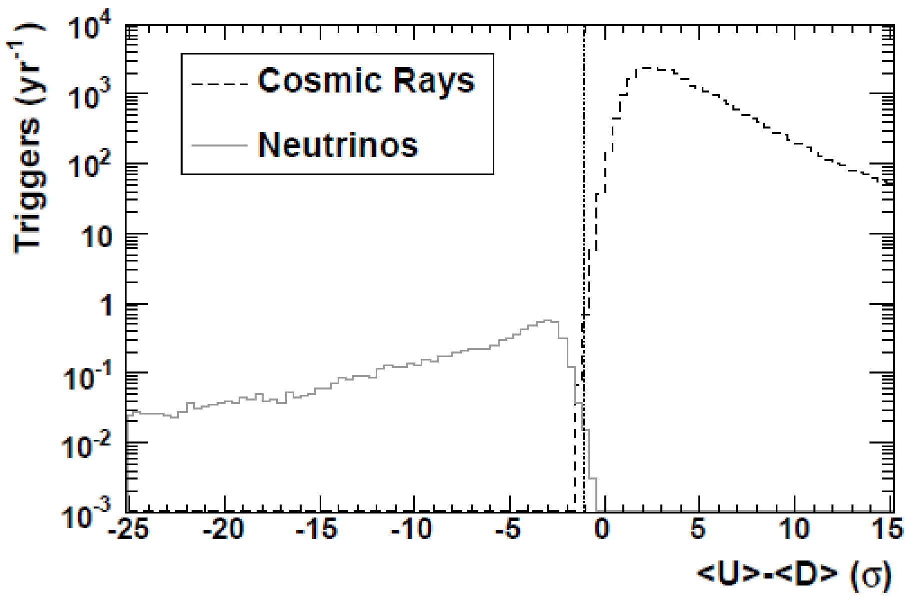
Cosmic ray detection & background



Cosmic ray events will trigger the array

Background and calibration/monitoring

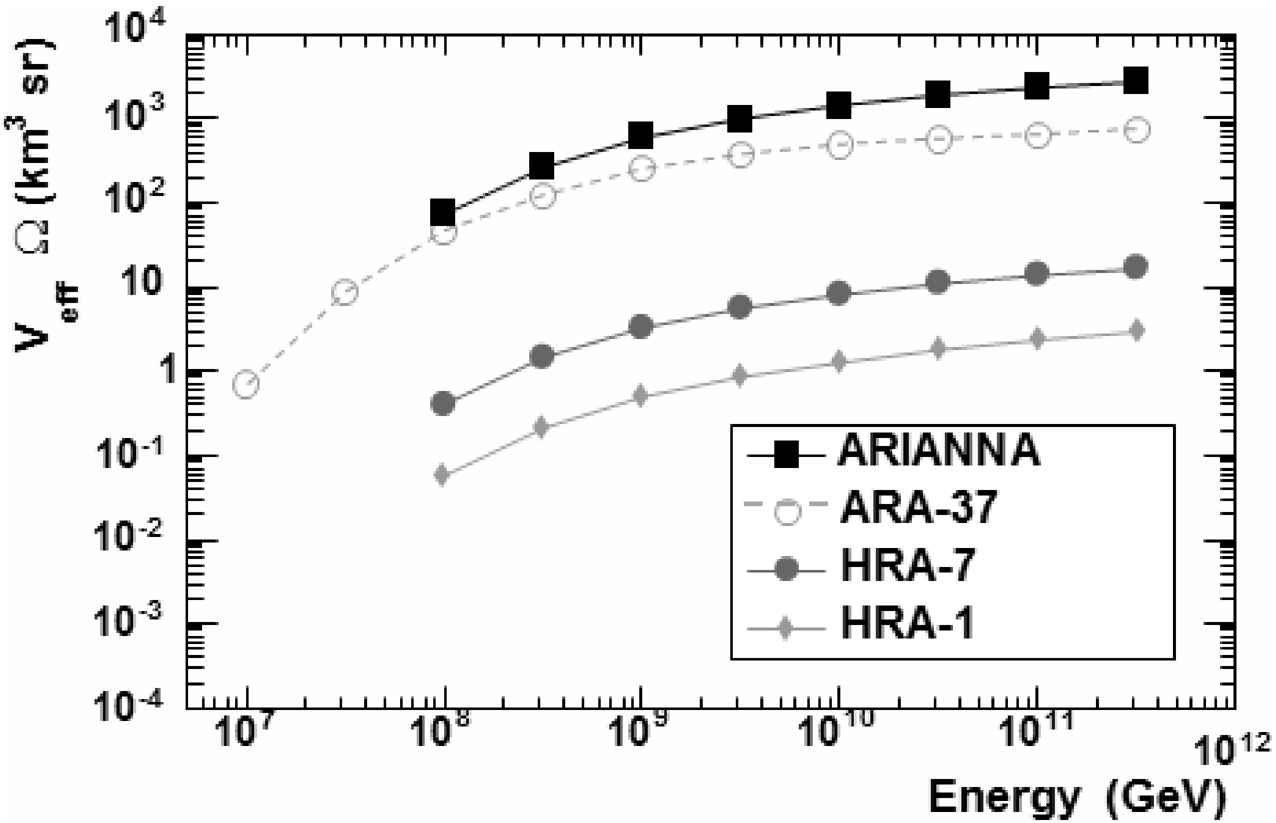
Simulated Full ARIANNA,
with backward gain in antennas overestimated (need to improve lab measurment)
→ Rate overestimated in plot



2 upward antennas, 8 downward
Strong separation in difference of average power Up-Down
←
CR mis-ID < 10^{-5}
Cut in plot → 0.2 events/year (conservative)

Neutrino signal scaled to 10/year

Effective volume



ARIANNA 1296 stations

HRA1 – prototype with one station

HRA –prototype system with 7 stations

ARA-37 Proposed Askaryan Radio Array for South Pole.

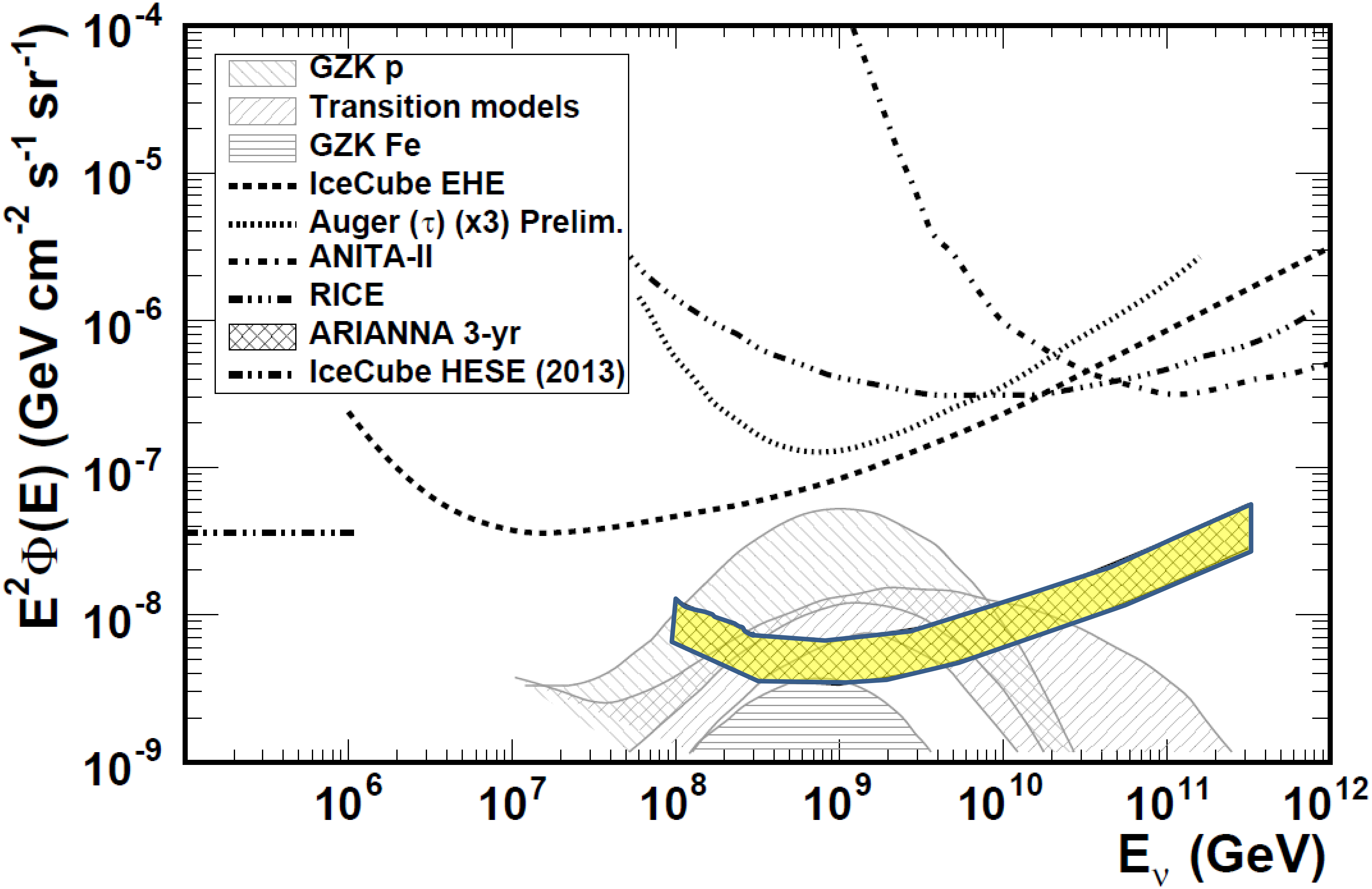
Averaged over neutrino flavors and neutrino/antineutrino
At trigger level (4 sigma thermal noise)

Extends to lower energy but simulation accuracy must be improved

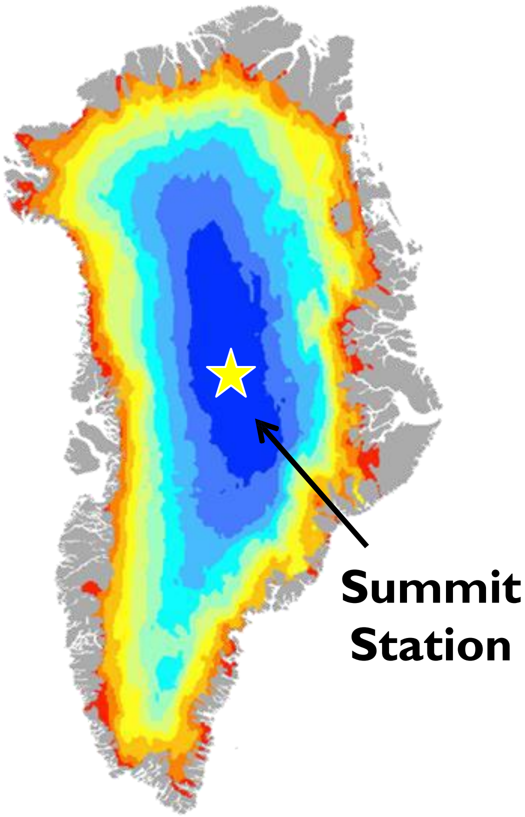
ARIANNA SENSITIVITY

If no event seen → limits

1296 stations running 58% of 3 calender years, 83% analysis efficiency, background level 3*0,1 events



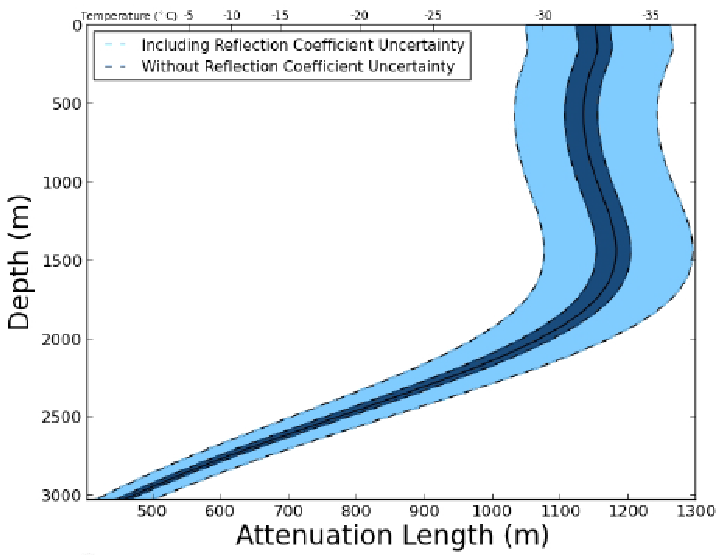
Greenland Neutrino Observatory

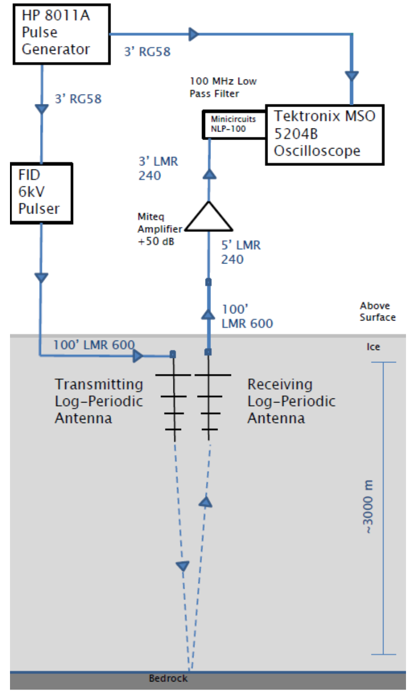


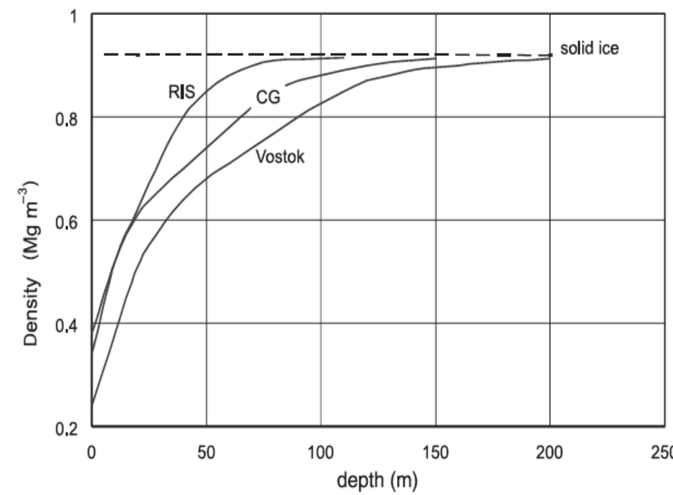
- Use 3 km thick ice on Greenland at the Summit station
- Water layer at bottom gives good reflections
- Solar power(latitude N 72^{o}37’)
- Ice attenuation measured 2013
  - arXiv:1409.5413

- Material from slides by
  - A. Connolly (neutrinos beyond Icecube 2014)
  - K. Bechtol (ICHEP 2014, ARENA 2014)
- arXiv 1409.5413 (submitted to Journal of Glaciology)
- A. Vieregg, E-mail

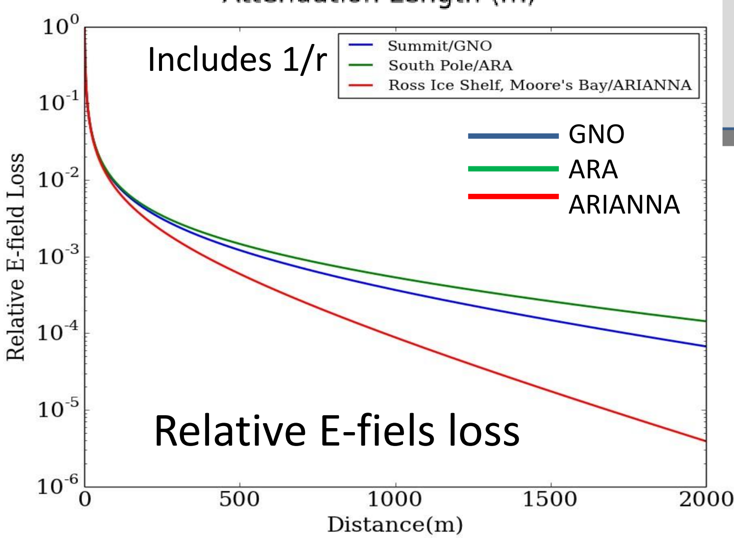
Greenland Neutrino Observatory







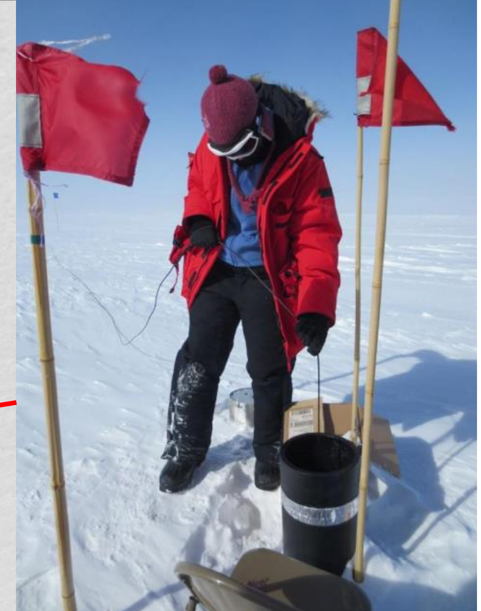
FIRN density - depth



Ice transmission OK

Firn thinner than SP, do not need to go as deep

Plans to install first RF equipment this summer (near surface, no hole drilling)



DISC Borehole

2 holes down to bedrock
→calibration !

GISP2 Borehole

Things I did not cover

- ANITA (ANtarctic Impulsive Transient Antenna)– Ballon born radio recievers floating over Antarctica, looking for GZK-neutrino signals refracted out from the ice sheet.
- EVA (ExaVolt Antenna) – Evolution of ANITA aiming for increased sensitivity by using part of interior of a super-pressure balloon as a radio-reflector.
- Radio telescopes looking for signals from neutrinos interacting in the rim of the moon.
- Radar detection. Feasability study of possibility to use radar technology to detect the plasma created in the wake of a neutrino induced shower.
- PRIDE – Passive Radio Ice Depth Experiment – Satellite born radio receiver in orbit to measure ice on moons of outer planets by use of EHE neutrinos
- ……………………….

Summary and Conclusion

- Compelling scientific reasons to measure the 'guaranteed' flux of cosmological GZK neutrinos in the EeV energy range
- Best limit on GZK neutrinos from (non-)detection of Askaryan signals are obtained with radio recievers installed in ice.
- Two prototype projects in Antarctica (ARA, ARIANNA) are well developed and there is a promising new project started at Greenland (GNO).
- Technology has been developed and demonstated to have the required performance.
- The radio detection of neutrinos in ice is a very cost effective technology for obtaining large samples of GZK neutrinos.

We should start building these detectors now!

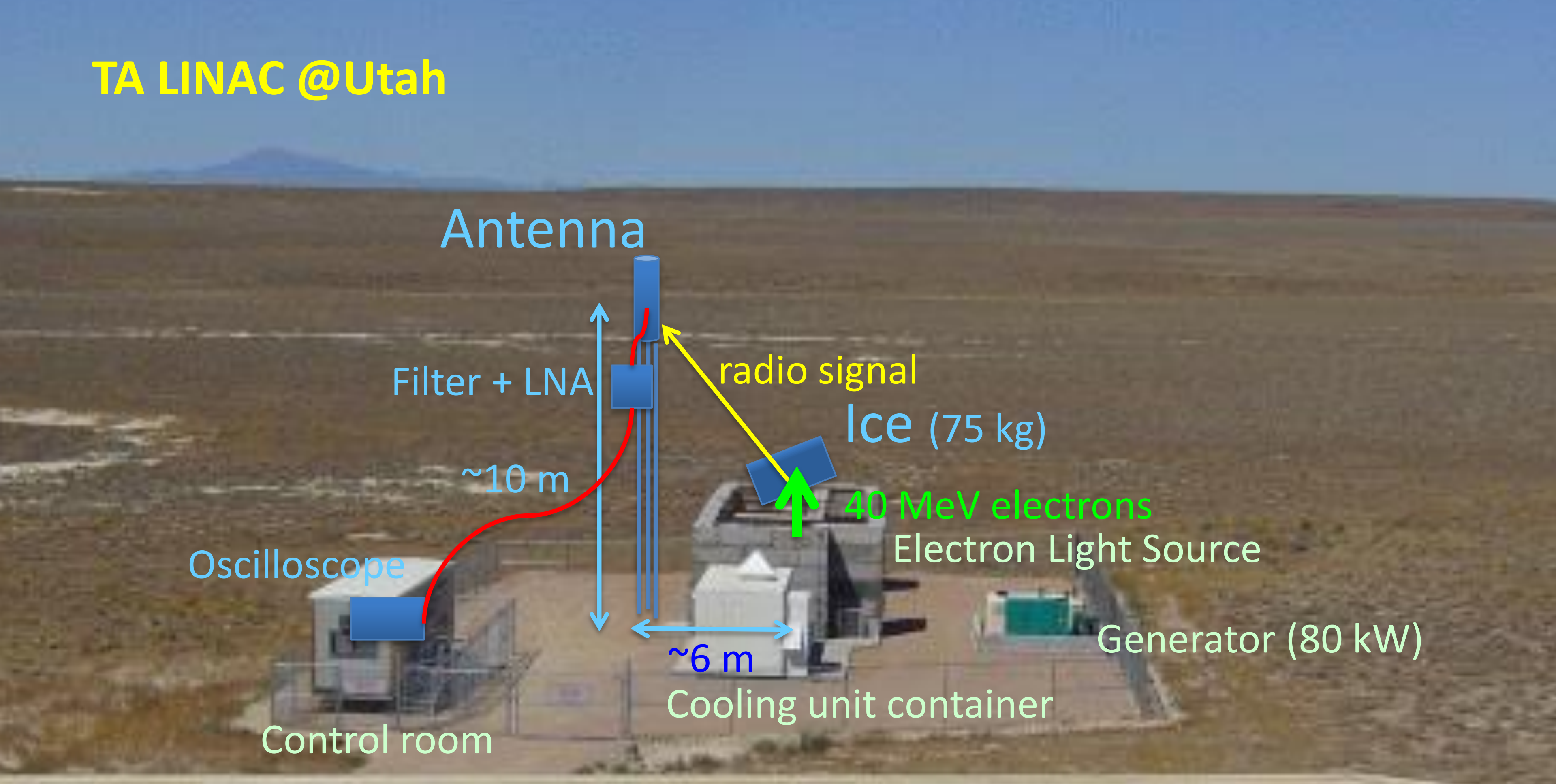
Backup slides

ARA Design

APP 35 (2012) 454-477 arXiv:1105.2854

Specified parameter	ARA 2012++ planned	ARA 2010-2011 prototype
Number of Vpol antennas	8	2 near-surface, 4 in ice
Vpol antenna type	bicone	bicone
Vpol antenna bandwidth (MHz)	150-850	150-850
Number of Hpol antennas	8	2 near-surface, 6 in ice
Hpol antenna type	quad-slotted cylinder	bowtie-slotted-cylinder
Hpol antenna bandwidth (MHz)	200-850	250-850
Number of Surface antennas	4	2
Surface antenna type	fat dipole	fat dipole
Surface antenna bandwidth (MHz)	30-300	30-300
Number of signal boreholes	4	6
Borehole depth (m)	200	30
Vertical antenna configuration	H,V above H,V	V or H above H or V
Vertical antenna pair spacing (m)	20	5
Approximate geometry	trapezoidal	trapezoidal
Approximate radius (m)	10	10
Number of calibration antenna boreholes	3	3
Calibration borehole distance from center (m)	40 (2), 750 (1)	30
Calibration borehole geometry	isosceles triangle	equilateral triangle
Calibration signal types	noise and impulse	impulse only
LNA noise figure (K)	< 80	< 80
LNA/amplifier dynamic range	30:1	30:1
RF amplifier total gain (dB)	> 75	> 75

■ End-to-end calibration of the ARA detectors using the Telescope Array LINAC



Purpose: Confirmation of Askaryan signals and the ARA detector calibration

Expected number of events above 10^{17} eV at trigger level

arXiv 1410.7352 accepted, Astroparticle Physics

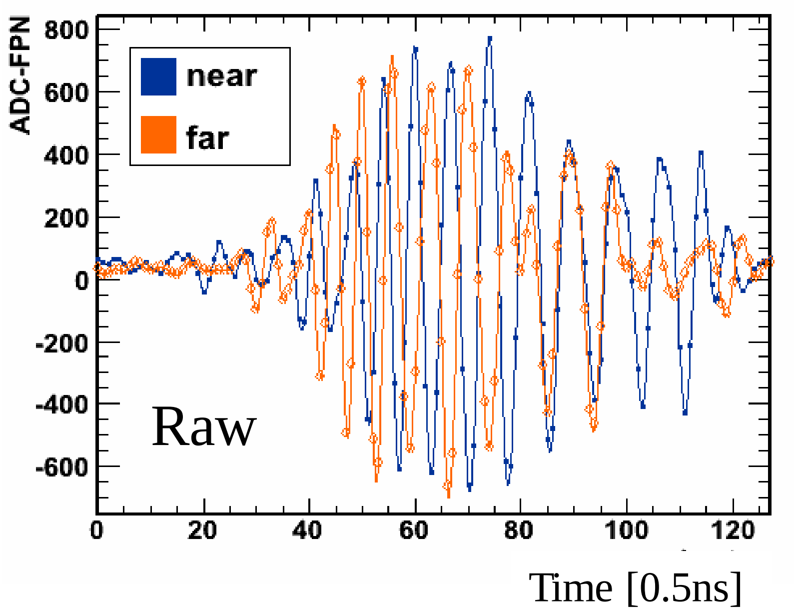
Neutrino Model	Model Type	N_ν Triggers ($E_\nu > 10^8$ GeV) ARIANNA	IceCube [13]
ESS (2001) [38]	$m = 4$, $\Omega_M = 1$	55	
WB (1999) [66]	E_ν^{-2} QSO source evolution	65	
Yuksel *et al.* (2007) [67]	E_ν^{-2} GRB source evolution	100	
Kotera *et al.* (2010) [68]	Protons, SFR1 evolution	7.3	0.46 (0.64)
Kotera *et al.* (2010) [68]	Protons, GRB2 evolution	9.0	0.48 (0.67)
Kotera *et al.* (2010) [68]	Protons, FRII evolution	48	2.9 (4.0)
Yoshida *et al.* (1993) [69]	$m = 4$, $z_{max} = 4$	34	2.0 (2.8)
Ahlers *et al.* (2010) [70]	$E_{min} = 10^{10}$ GeV (best fit)	26	1.5 (2.1)
Ahlers *et al.* (2010) [70]	$E_{min} = 10^{10}$ GeV (maximal)	58	3.1 (4.3)
Kotera *et al.* (2010) [68]	Mixed composition	7.4	
Kotera *et al.* (2010) [68]	Pure Iron	2.5	
Ave *et al.* (2005) [71]	Pure Iron, $m = 4$, $z_{max} = 1.9$	18	
Olinto *et al.* (2011) [42]	Pure Iron, $E_{max}/Z = 10^{11}$ GeV	0.097	
Aartsen *et al.* (2014) [24]	$E_\nu^{-2.3}$ IceCube best fit	2.8	
Fang *et al.* (2013) [72]	Young pulsar sources	43	

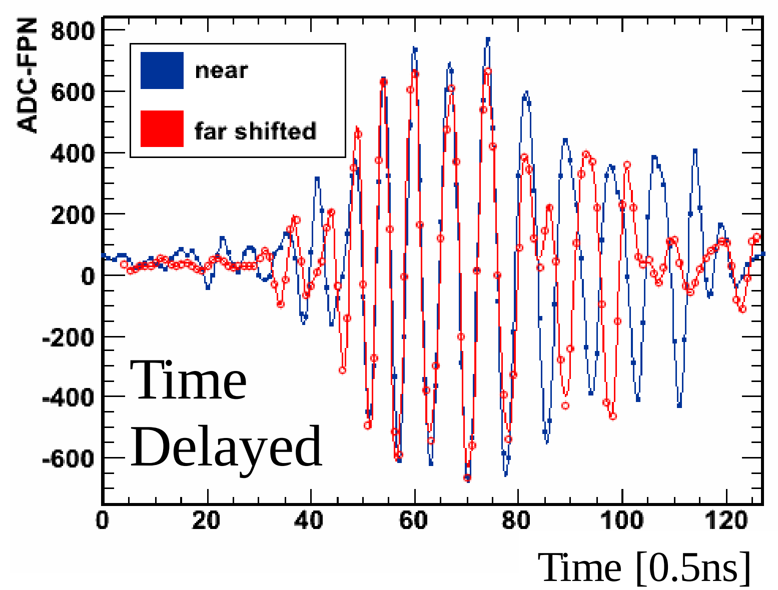
Some of above models may already be disfavored/ruled out, but are kept for reference

Bounce Tests

Pulser->Seavey TRX->Station

Excellent mirror





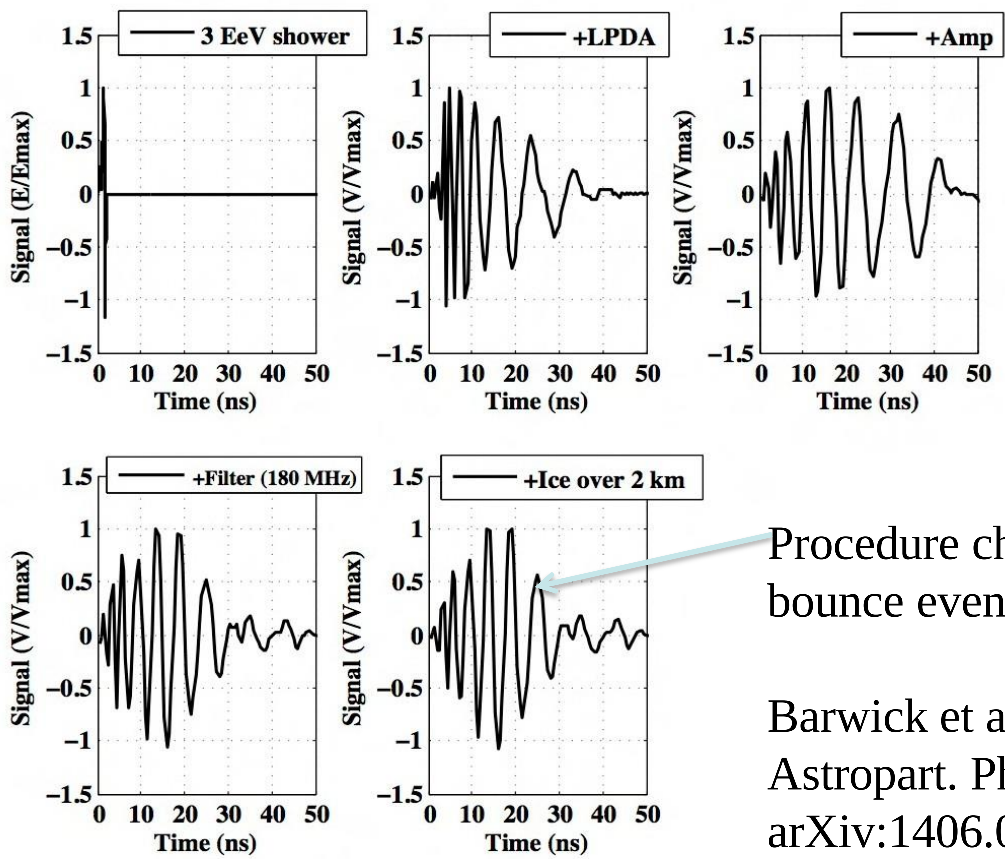
Notes: Time delays are determined from all 4 antennas, compatible with plane wave

Building a Neutrino Template

(J. Hanson, KU)

Signal scales with energy.

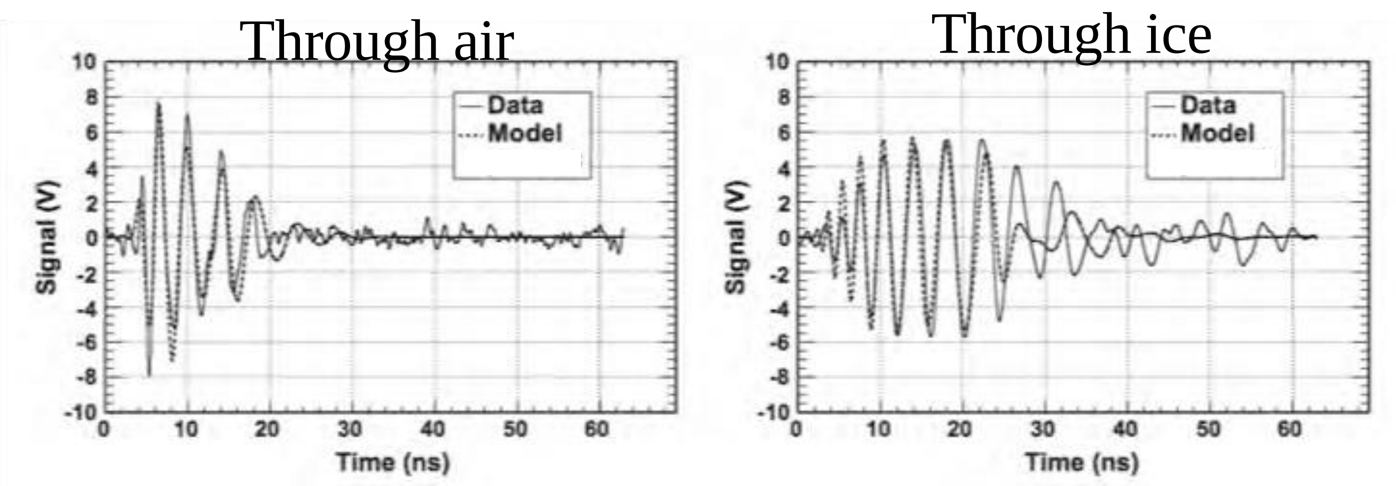
Small variation in shape due to emission angle



Procedure checked with bounce events, χ>0.8

Barwick et al,
Astropart. Phys 2014, published
arXiv:1406.0820

Checking Template Procedure



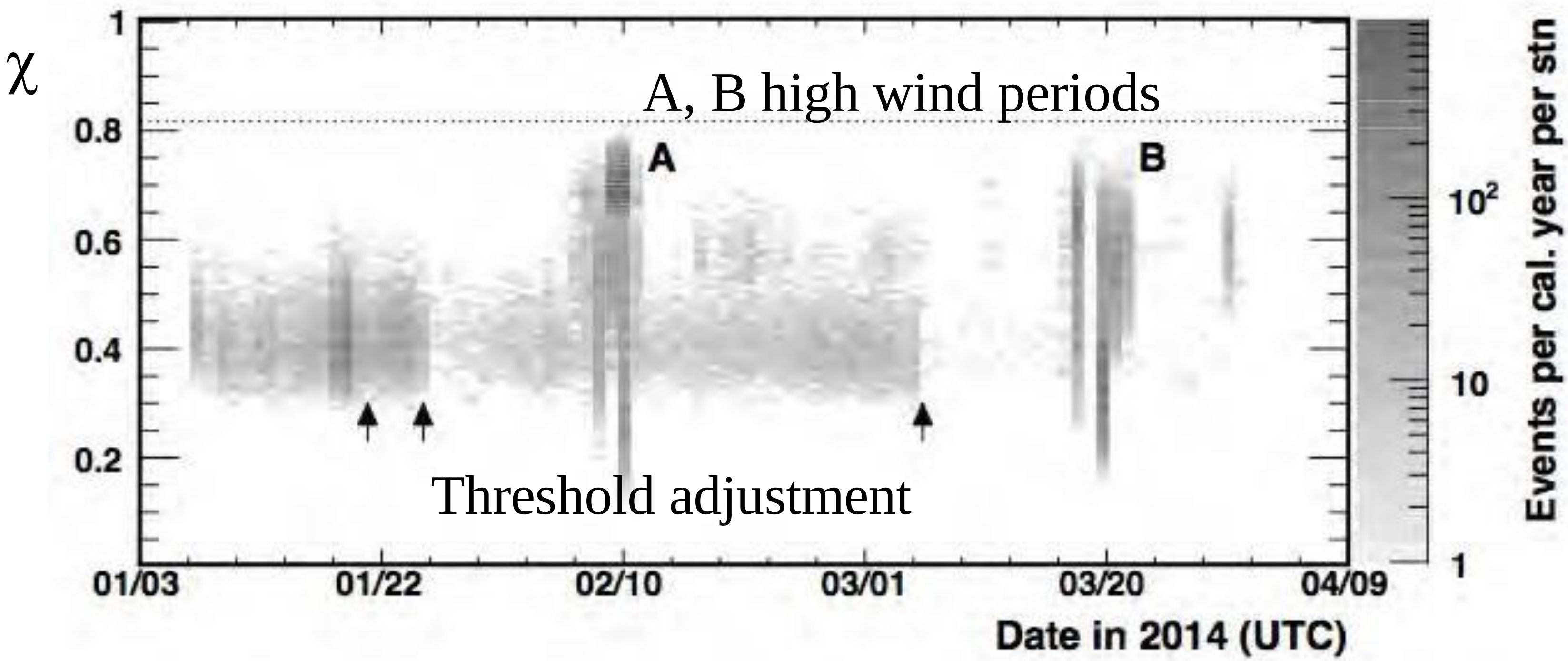
Average cross-correlation over all tests is $\chi = 0.84$

Can be improved with better amp response model

Barwick et al, Astropart. Phys 2014, accept arXiv:1406.0820

ross-Correlation analysis (χ)

2 of 4 majority, $4V_{rms}$

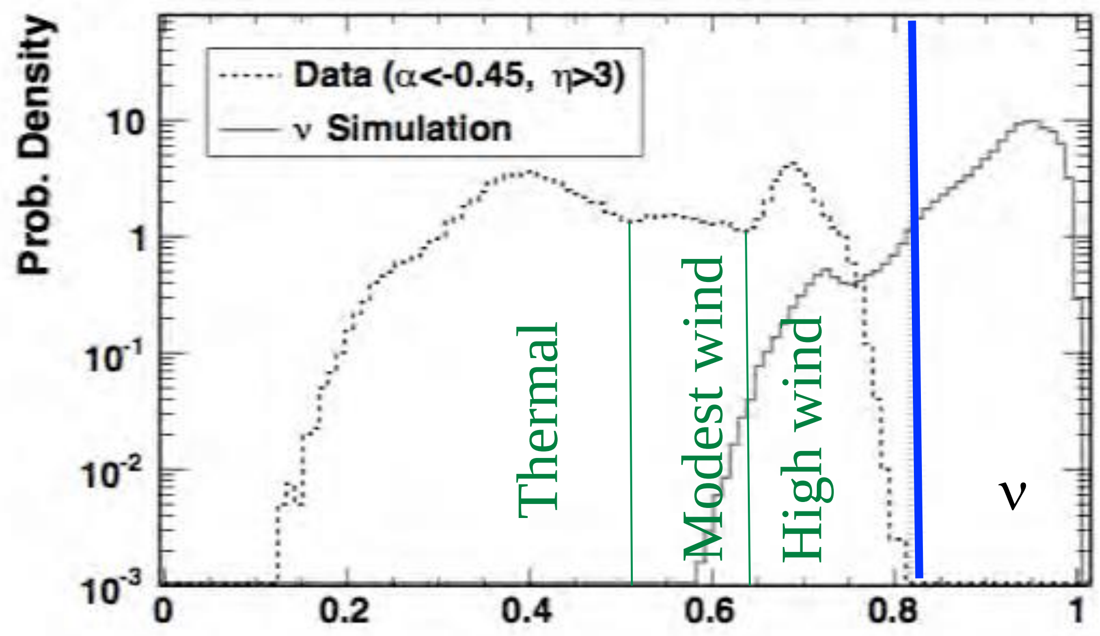


- High wind periods produce max $\chi < 0.8$.

S. Barwick et al, in prep 2014

Cross-Correlation analysis (χ)

2 of 4 majority, $4V_{rms}$



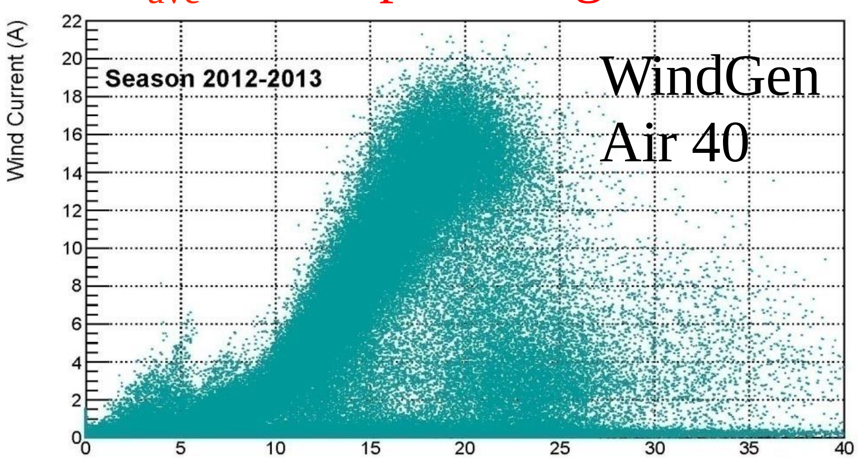
- 90% of signal retained with full rejection of background.

S. Barwick et al, in prep 2014

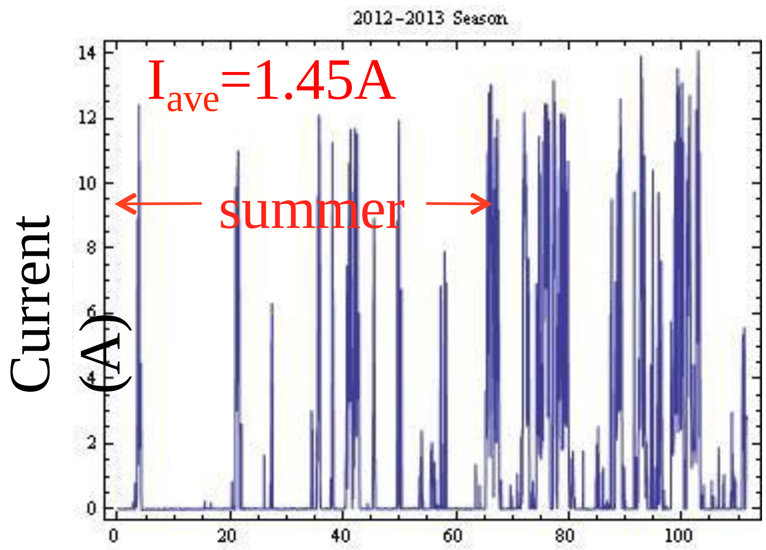
Wind Power is Sufficient!

(Southwest WindPower Air 40)

V_{ave}= 7.4 mph during summer



Wind Speed (mph)



Days after deployment

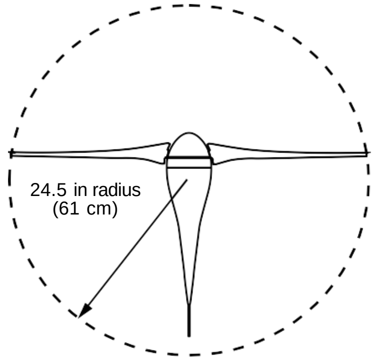
Require ~0.9A to operate station and station produced 1.45A

Wind expected to stronger in winter

However, low temps in winter lead to loss of efficiency

AIR 40 Technical Specifications

Model	AIR 40
Weight	13 lb / 6 kg
Rotor Diameter	46 in / 1.17 m
Start Up Wind Speed	7 mph / 3.1 m/s
Kilowatt hours/month	38 kWh/month @ 12 mph / 5.4 m/s avg. wind speed
Maximum Wind Speed	110 mph
Rated Power	160 watts @ 28 mph / 12.5 m/s wind speed
Certifications	CSA (certificate 1954979), CE
Operating Temperature Range	AIR 40 are certified under IEC requirements applying to the temperature range 14º F (-10º C) to 104º F (40º C)



12 volt, 24 volt and 48 volt AIR 40 wind turbines are eligible to bear the CSA mark with “C” and “US” indicators. The “C” and “US” indicators signify that the product has been evaluated to the applicable CSA and ANSI/ UL standards for use in Canada and the US.

Voltage Regulation Set Point (factory setting)

12 Volt Systems	14.1 Volts
24 Volt Systems	28.2 Volts
48 Volt Systems	56.4 Volts

Regulator Adjustment Range

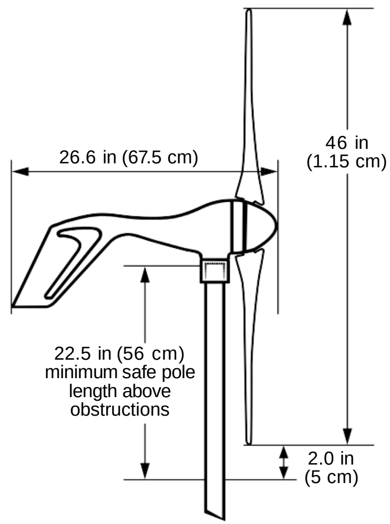
12 Volt Systems	13.6 to 17.0 Volts (approximately)
24 Volt Systems	27.2 to 34.0 Volts (approximately)
48 Volt Systems	54.4 to 68.0 Volts (approximately)

Recommended fuse Size

12 Volt Systems	20 amp (slow blow)
24 Volt Systems	10 amp (slow blow)
48 Volt Systems	5 amp (slow blow)

Tower Loads

Shaft Thrust* 52 lb @ 100 mph wind speed (230 N @ 45 m/s)

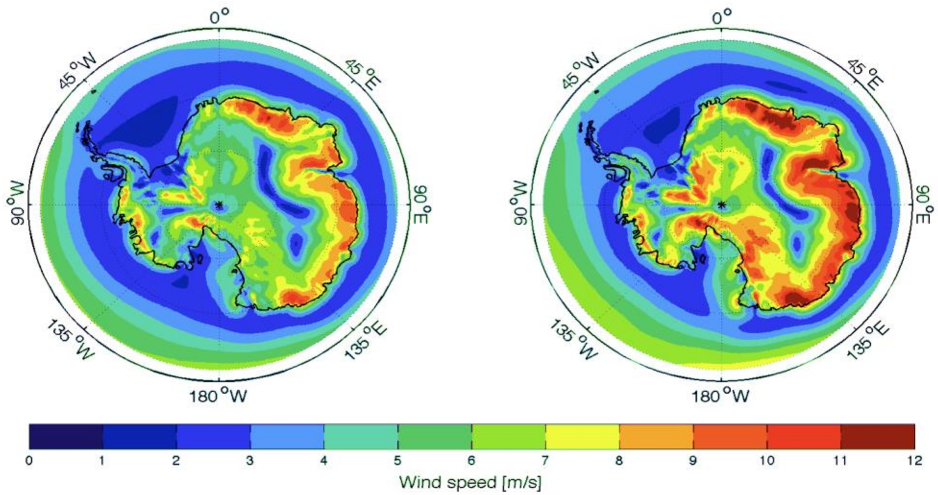


*Value does not include safety factor. SWWP recommends safety factor of 1.5.

Assessment of green power production in Antarctica

Christoffer Hallgren

Figure 2: Average wind speed in Antarctica during summer (left) and winter (right).



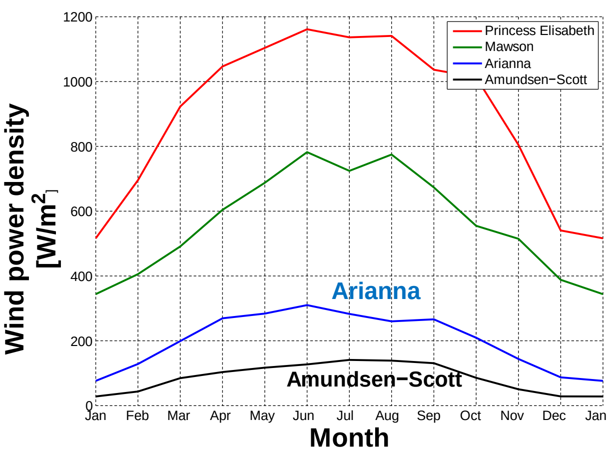


Figure 4: Monthly change of WPD for the research stations investigated.

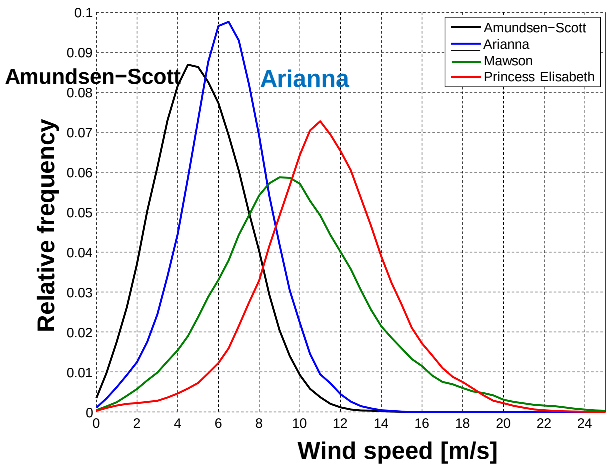


Figure 5: Distribution of wind speeds for the four research staions investigated.

3. The MERRA data set

To be able to study the Antarctic wind resource and compare the wind power potential at several scientific stations, reanalysis data from the Modern-Era Retrospective Analysis for Research and Applications (MERRA) (Rienecker et al. 2011) has been used for the calculations. The data set is provided by National Aeronautics and Space Administration (NASA) and covers the modern era, from 1979 and onwards, during which remote sensing has been dominant when collecting data about the atmosphere.

The reanalysis data is created by combining different types of measurements (such as (surface observations, radio soundings and satellite data) and using a numerical model to calculate a gridded data set in a consistent way.

Arianna	78.5 °S	165.3 °E
Amundsen-Scott	90.0 °S	0.0 °E
Mawson[1]	68.0 °S	62.7 °E
Princess Elisabeth	71.5 °S	23.3 °E

Assessment of green power production in Antarctica

Christoffer Hallgren

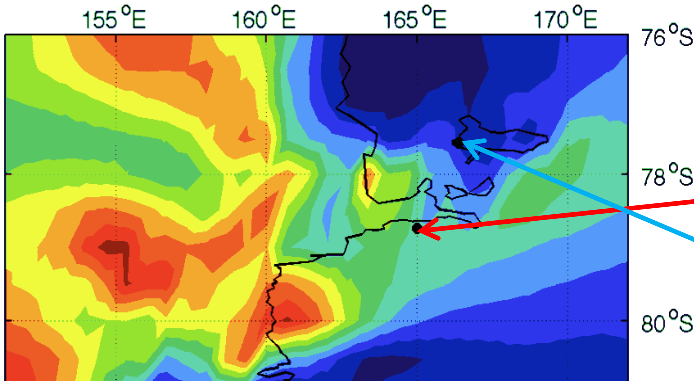


Figure 8: Median WPD in the Arianna area.

Arianna site

McMurdo Station

The resolution of the MERRA data is too low to accurately depict the wind conditions in the coastal zones. However, in combination with measurements from a weather station it should be possible to long time correct the results. It is also concluded that the extreme high wind speeds are underestimated in the MERRA data.

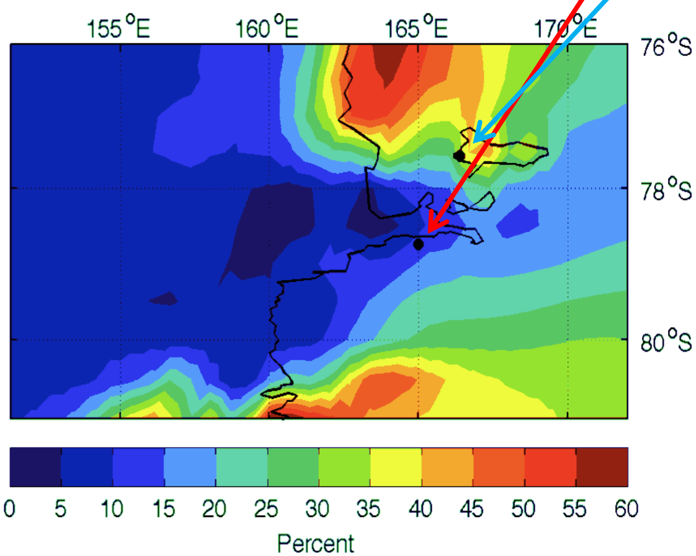


Figure 9: Percent of time that the wind speed is less than 4 m/s in the Arianna area.

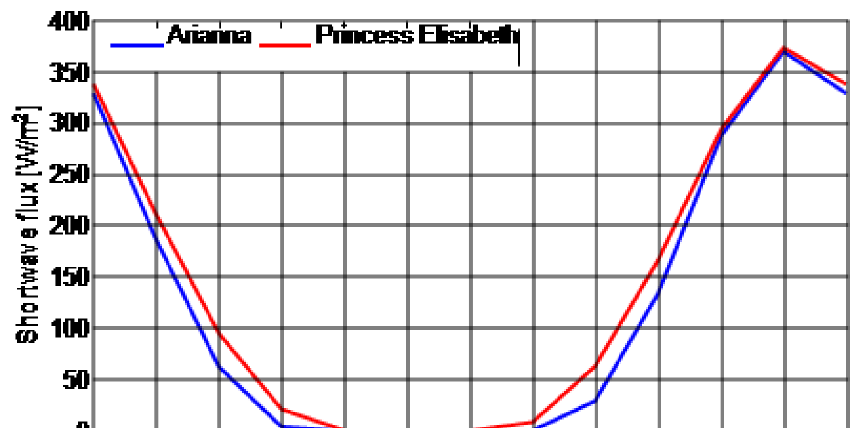


Figure 11: Average monthly incoming shortwave flux for Arianna and Princess Elisabeth.

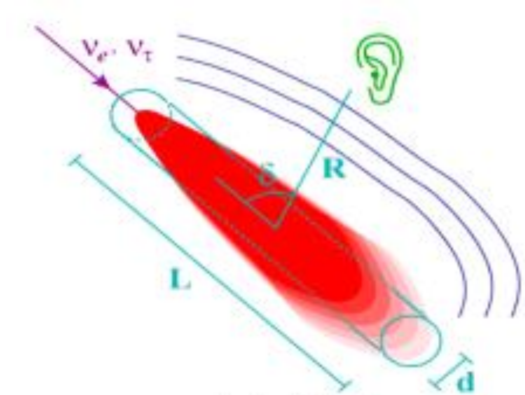
Acoustic detector?

in ice : λ_{abs}(radio)~ λ_{abs}(sound)~1000m cf λ_{abs}(optical)~100m

G.A. Askaryan JETP 14 (1962) 441
G.A. Askaryan, At. Energ., vol 3/8 (1957) 152

Radio methods

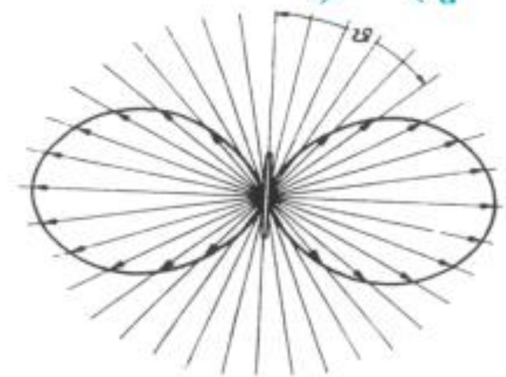
- detect mainly the hadronic showers from ν's interacting via CC or NC
- such showers in matter develop a (10-30)% e^- over e^+ excess since target material contains atomic e^-'s
- resulting EM emission coherent for wavelengths longer than lateral shower size (O(few cm))
- effect confirmed by measurements in silica sand, and in ice.



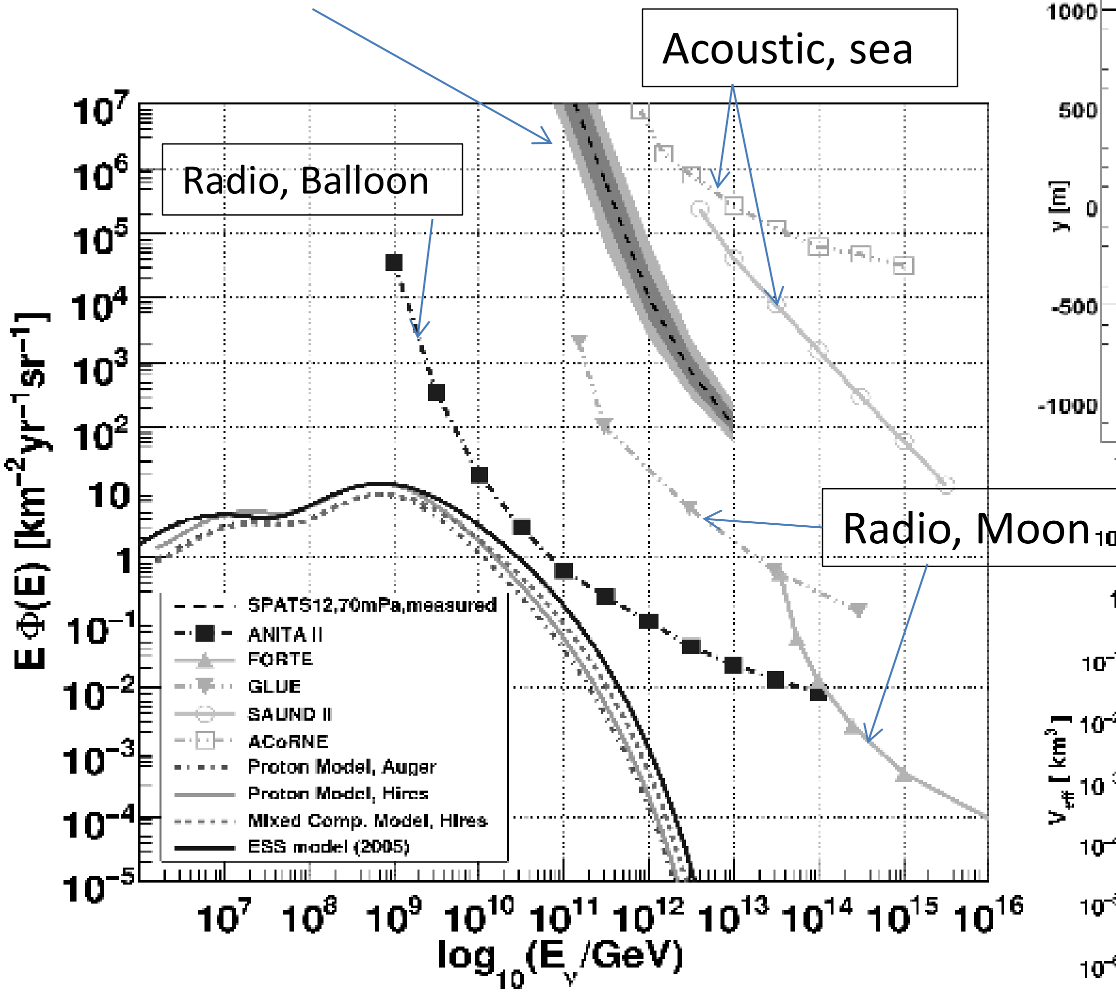
Acoustics methods (only on next slide)

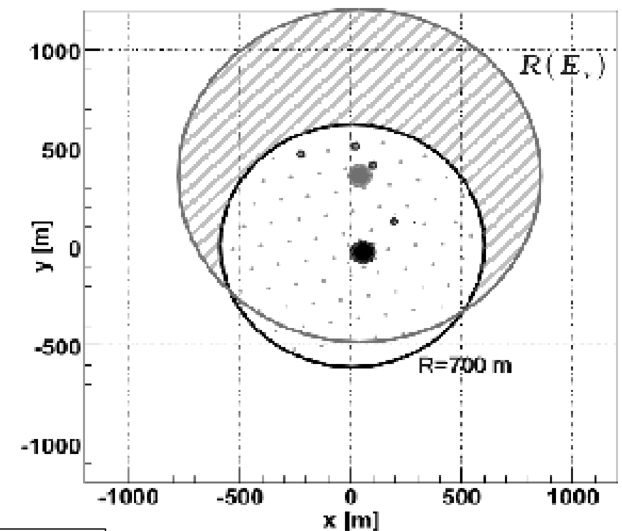
- a ν at 10^{21} eV produces a shower which deposits ~ 30J of heat in a highly localized region
- pressure pulse propagates outward
- pressure amplitude measures energy
- pressure distribution measures incoming direction

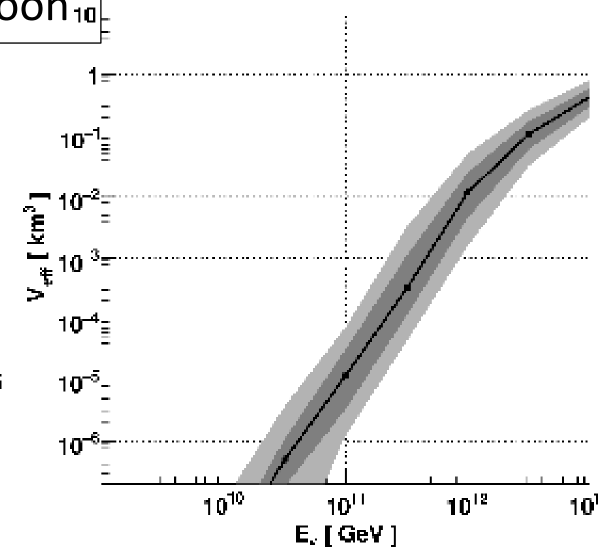
•Tested by group in IceCube, SPATS, actual $\lambda_{abs,ice}$<500 m



SPATS neutrino flux limit







APP 35 (2012) 312-324, arXiv 1103.1216