The ARIANNA Hexagonal Radio Array Performance and prospects

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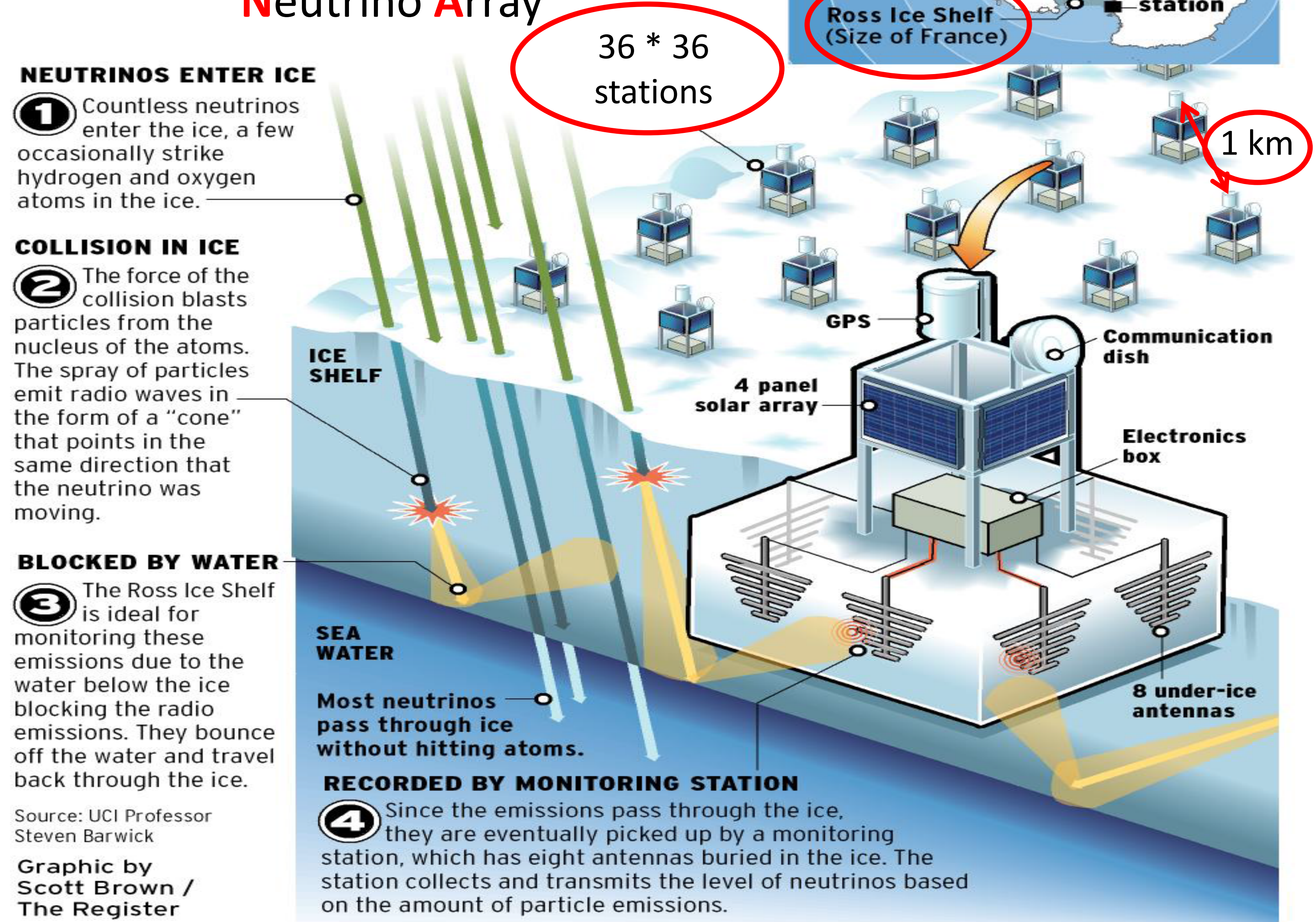
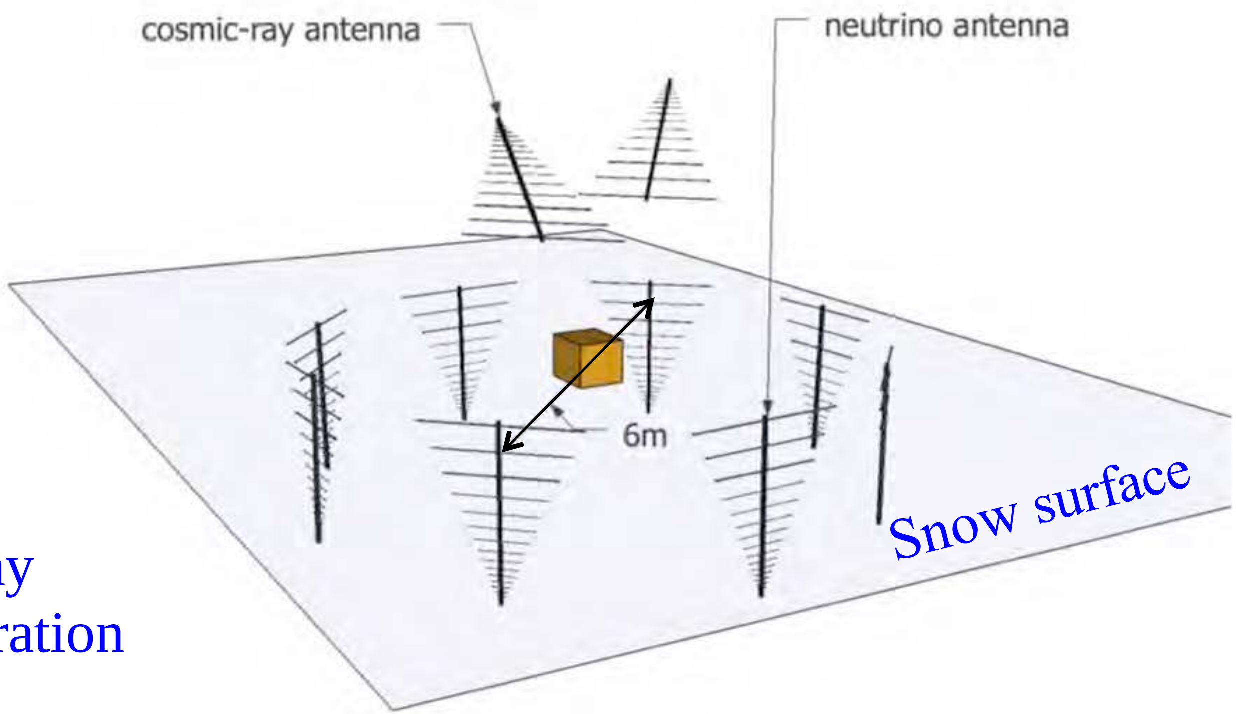
VLVνT-2015

ARIANNA

Antarctic **R**oss **I**ce-shelf **AN**tenna **N**eutrino **A**rray



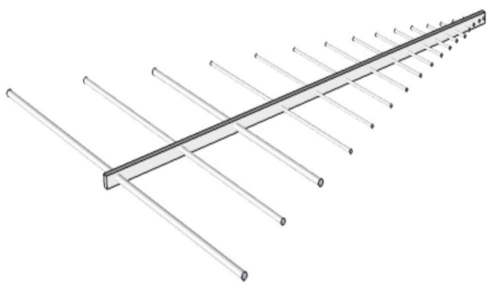
ARIANNA Station

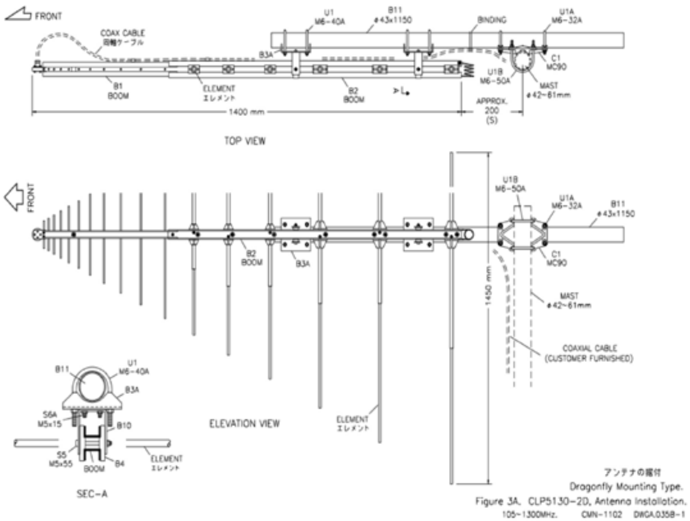


36x36 array
1 km separation

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

Off the shelf antenna from Creative design Corp (1pc 400€)

HRA

Model	CLP5130-1 (*CLP5130-1D)	CLP5130-2 (*CLP5130-2D)	CLP5130-3 (for Air, TV)	CLP5130-1X	CLP3100
Frequency (MHz)	50 ~ 1300	105 ~ 1300	90 ~ 220 (Receiver:80 ~ 250)	50 ~ 500	30 ~ 1000
No. of Element	21	17	10	15 × 2	27
Forward Gain (dBi)	10.0 ~ 12.0	11.0 ~ 13.0	12.0 ~ 13.0	10.0 ~ 12.0	10.0 ~ 12.0
F / B Ratio (dB)	15	15	15	15	15
Impedance (Ω)	50	50	50 ~ 75	50	50
Power Capability (PEP/kW)	0.5	0.5	0.5	0.5	0.5
BoomLength (m)	2.0(3.4)	1.4(1.9)	1.7	1.9	4.7
VSWR	Less than 2.0	Less than 2.0	Less than 2.0	Less than 2.5	Less than 2.0
Element Length (m)	3.0	1.3	1.6	3.0	5.3
Rotational Radius (m)	1.8(2.4)	1.0(1.6)	1.2	1.8	3.2
Mast Diameter (mm)	48 ~ 61	42 ~ 50	42 ~ 50	48 ~ 61	48 ~ 61
Wind Surface Area (m^2)	0.2(0.33)	0.08(0.13)	0.13	0.28	0.37
Weight (kg)	5.0(8.5)	3.0(4.0)	3.5	10.0	15.5
Recommended Rotator	RC5-x	RC5-x	RC5-x	RC5-x	RC5-x

http://www.cd-corp.com/english/index.html

Off the shelf antenna from Creative design Corp (1pc 400€)

FUTURE?

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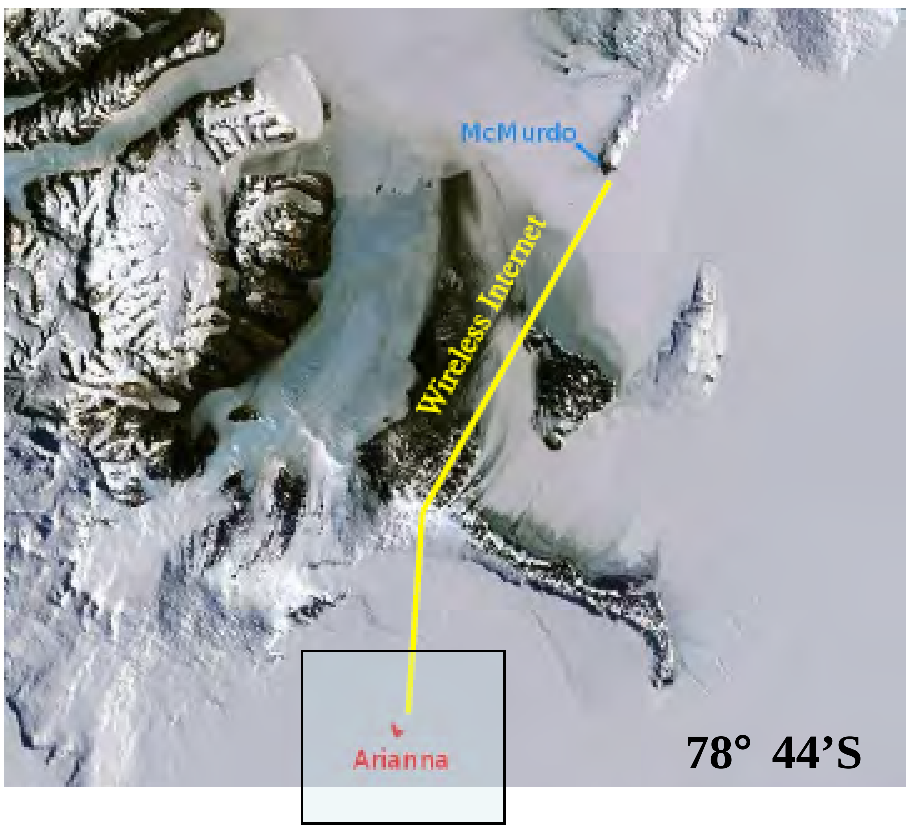
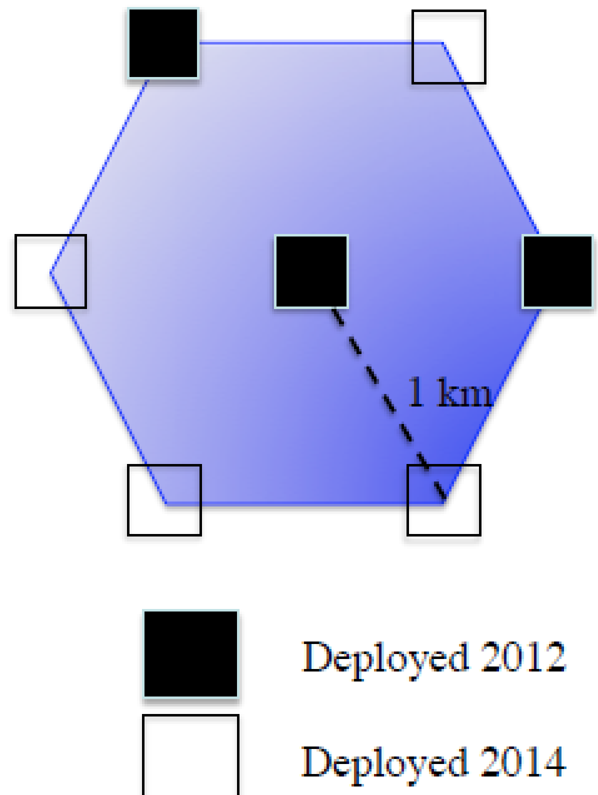
Including Lower frequencies lowers threshold. Noise will be investigated this season

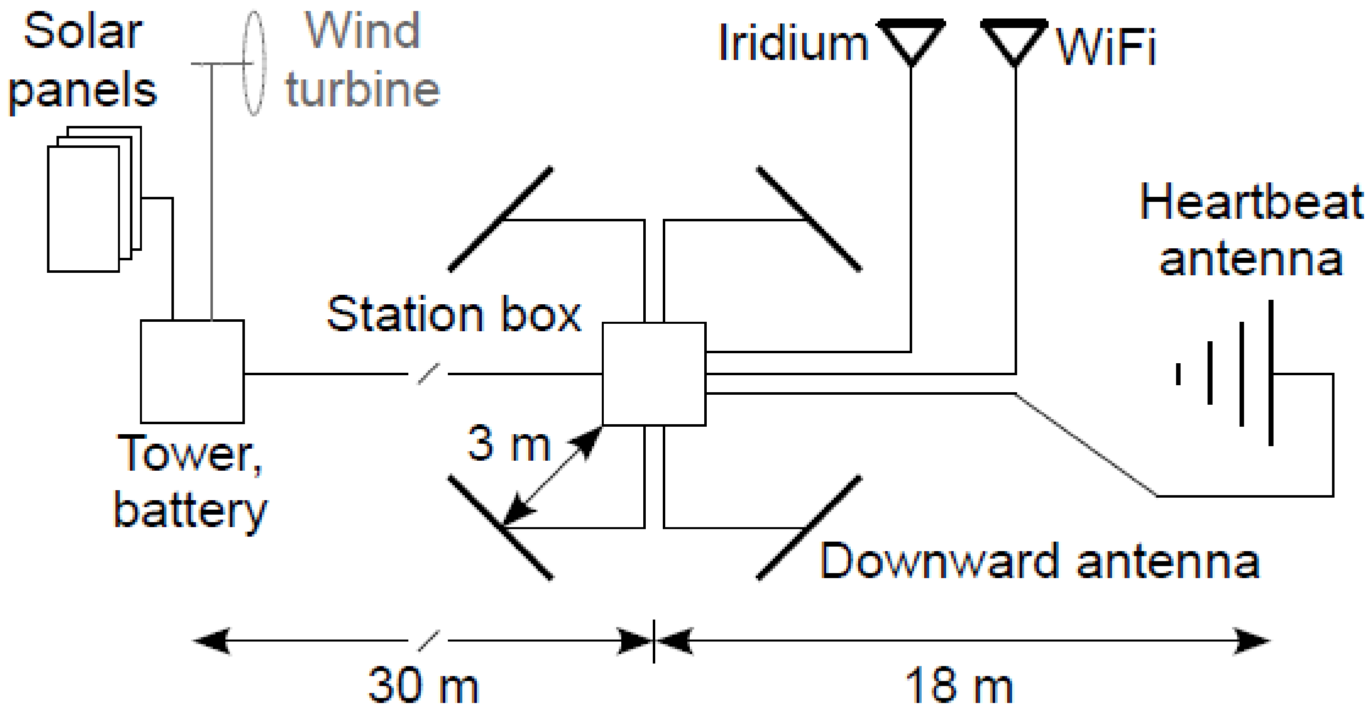
Hexagonal Radio Array (HRA): 2012-2014



Moore's Bay, 110 km from McMurdo Station



HRA Station

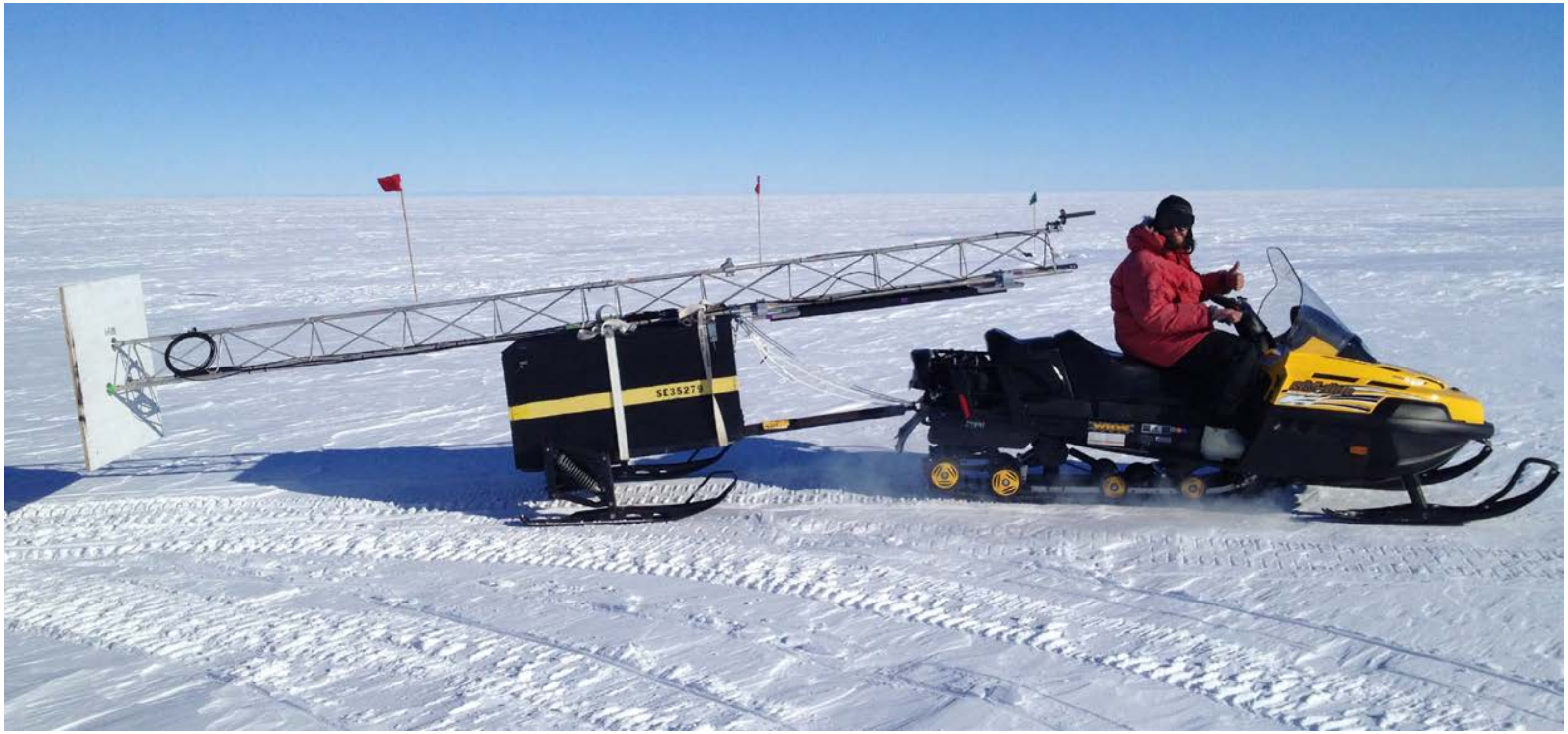


Heartbeat antenna, horisontal, pulsed for monitoring of station performance
WiFi communication for high speed internet,
Iridium for SMS type data transfer (340 B, planned sufficient for normal running)
Power system, Solar panels, Lithium battery and experimental Wind power
Running stations on only solar power (+ battery) gave 58% (65-70%) up-time

ARIANNA HRA Stations

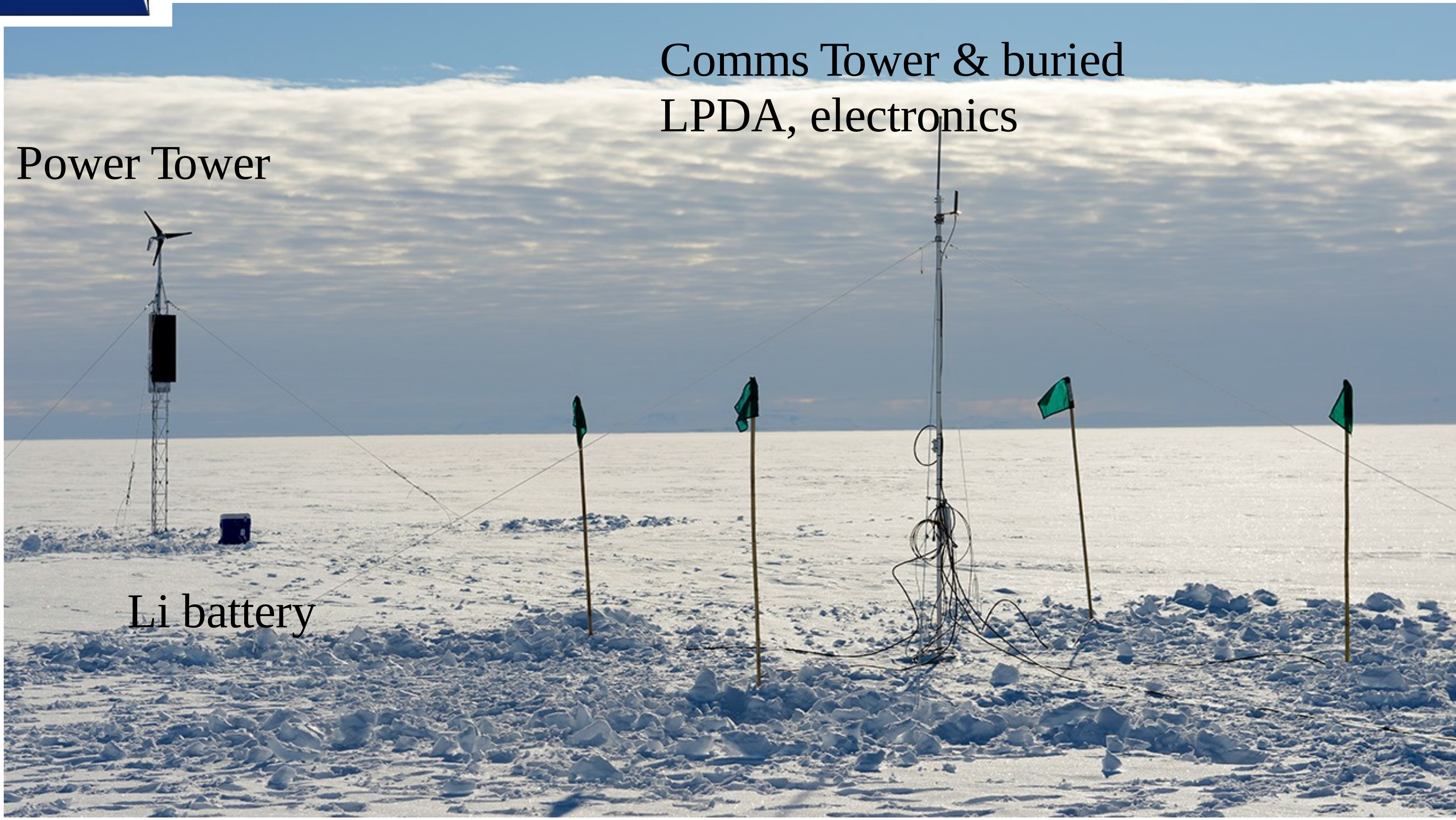
Dig and deploy!

ARIANNA tower



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

Station Overview



Nov. – Dec. 2014

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

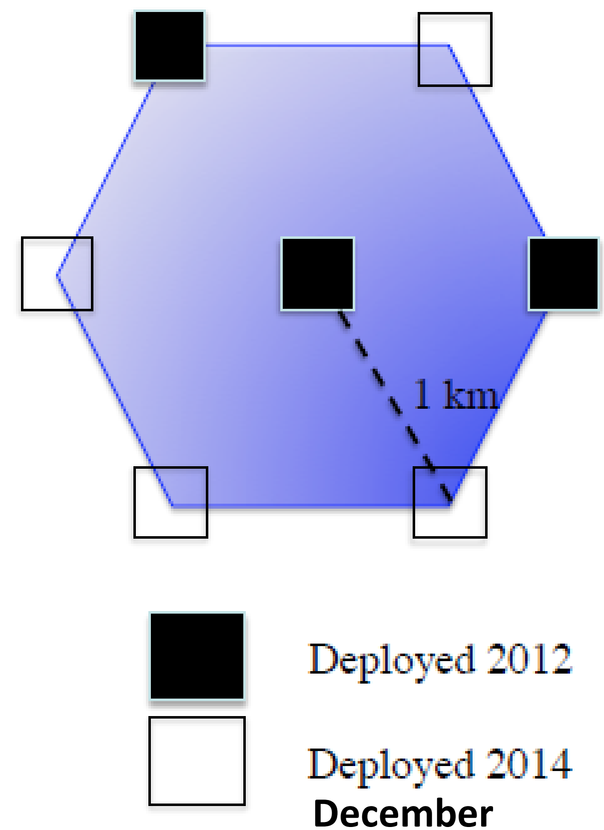
Deployment time: 1 station 4 hrs, can be reduced

Hexagonal Radio Array (HRA): 2012-2014

Results from HRA – 3 published
'Test-limit' to demonstrate first level performance, including expected ARIANNA performance;

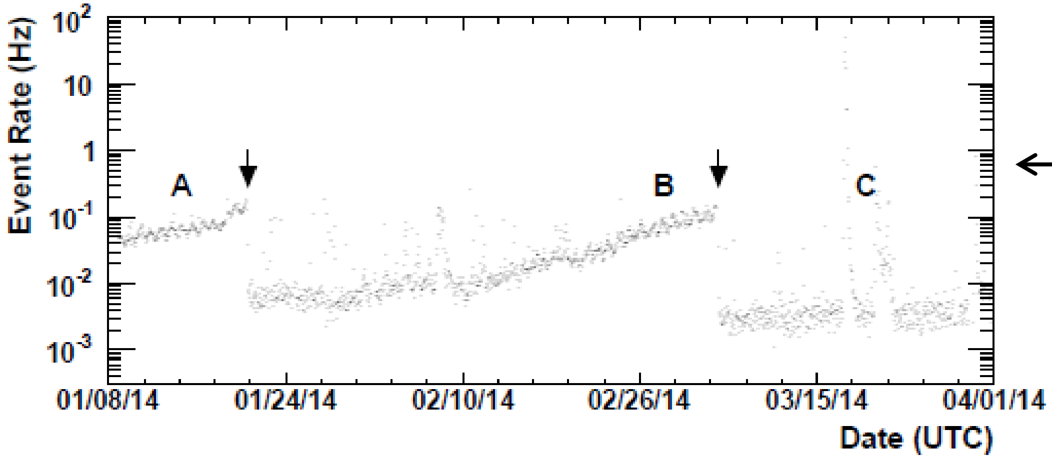
"A first search for comogenic neutrinos with the ARIANNA Hexagonal Radio Array"
in press
Astroparticle Physics 70 (Oct. 2015) 12-26

Papers also published on
Ice-properties at the Ross Ice shelf,
HRA Electronics and systems,
Neutrino signal simulation.



ARIANNA limit - HRA-3 data analysed

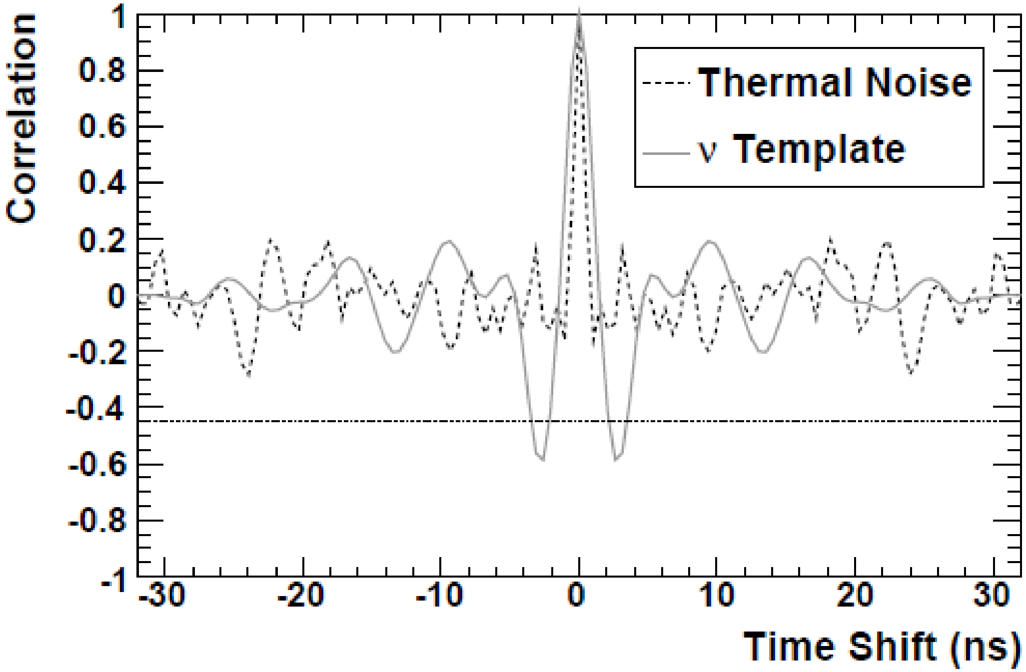
HRA-3 limits etc: arXiv:1410.7352 , Accepted Astroparticle Physics Journal



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



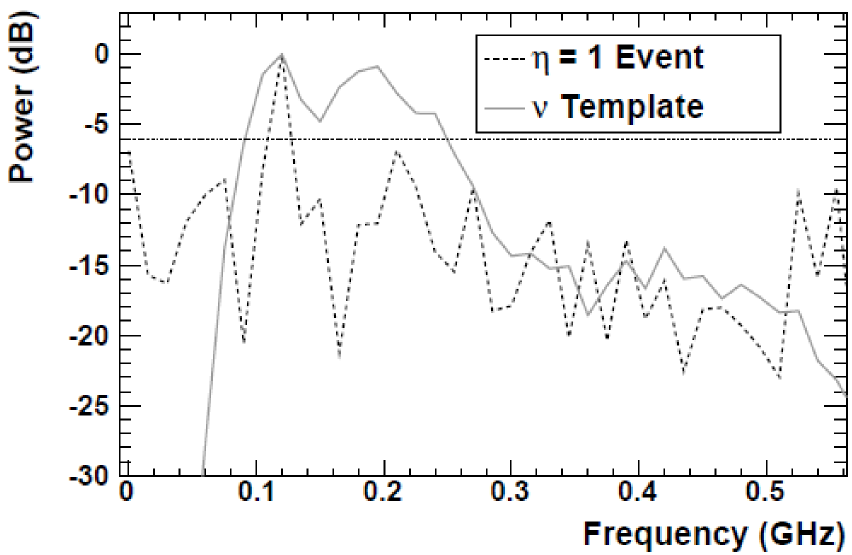
CUT 1

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

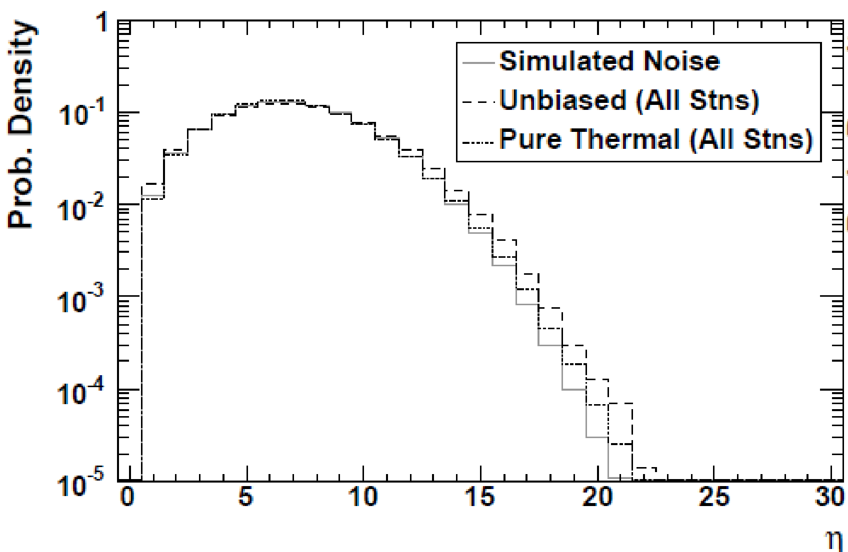


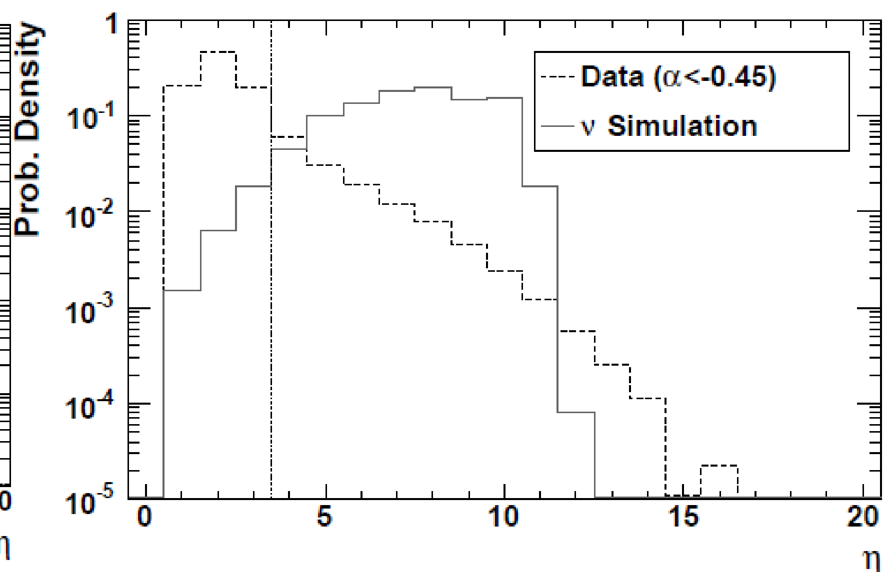
Investigate frequency content

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

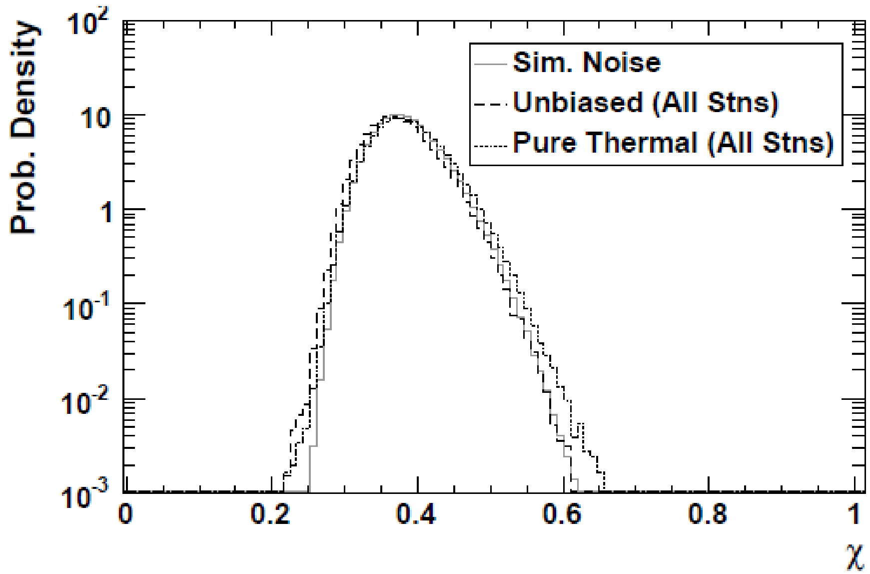
→ Count number of bins with high relative power (above line)

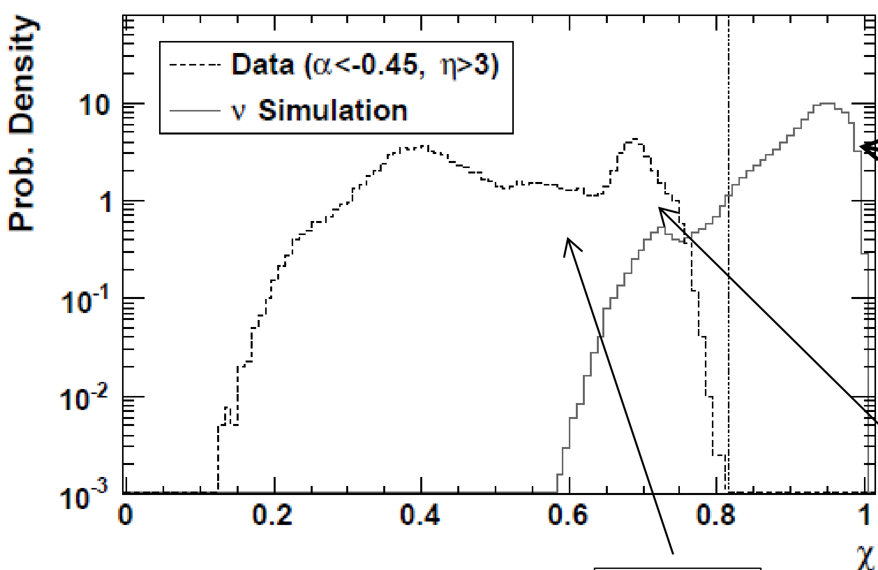
Neutrino events have several high power frequency bins, require > 3





ARIANNA limit - HRA-3 data analysed





Cut 3

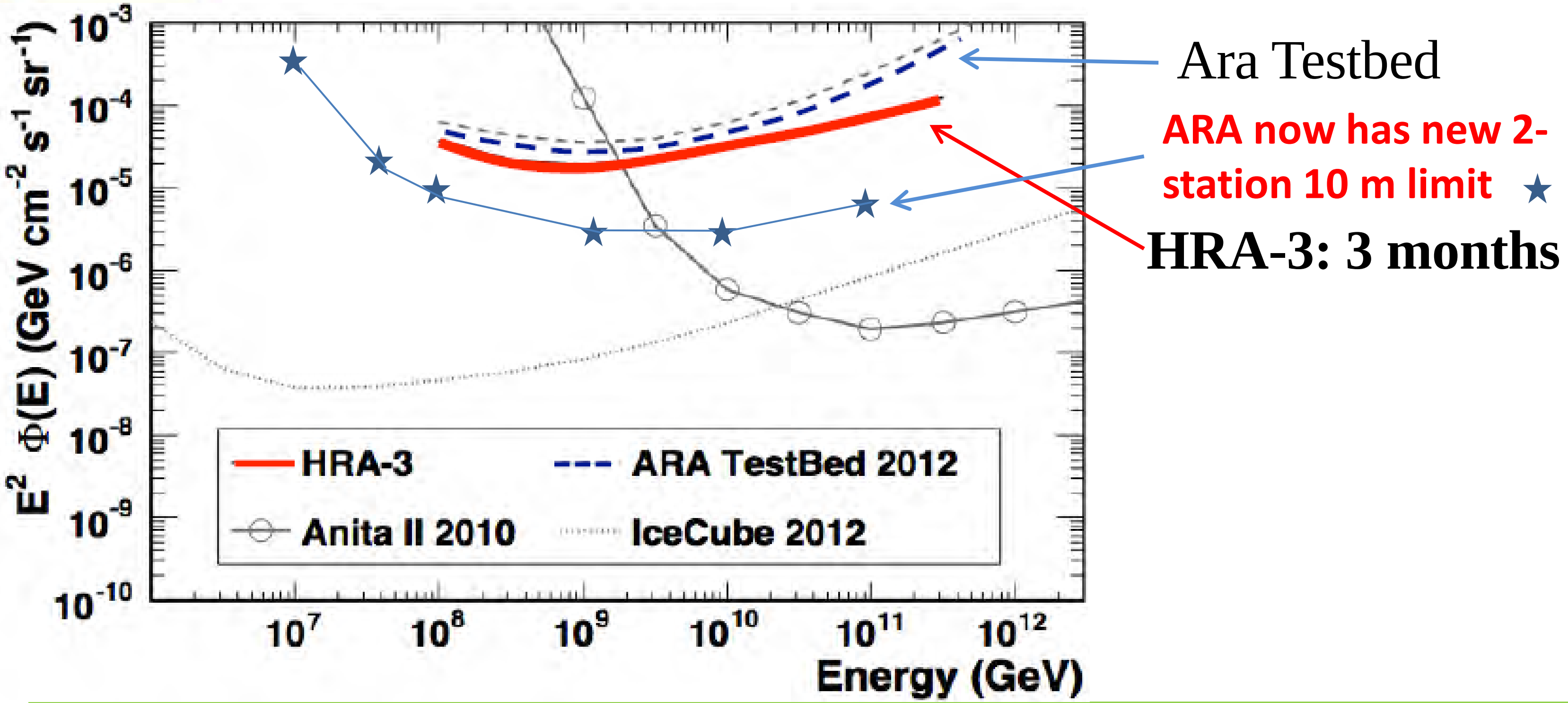
Create **template for neutrino event** signals by simulation.
Astroparticle Physics 62 (2015) 139-151

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)



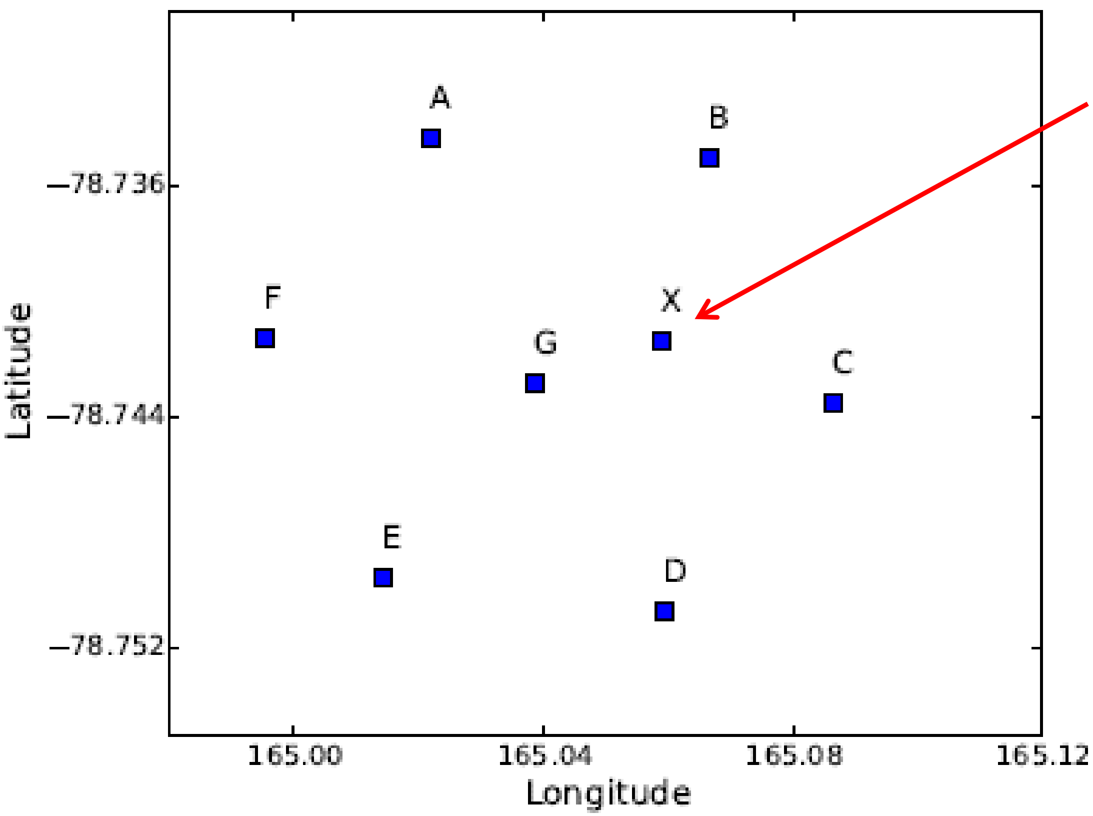
HRA-3 limits etc: arXiv:1410.7352, Accepted Astroparticle Physics Journal

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

Hexagonal Radio Array
Deployment completed December 2014

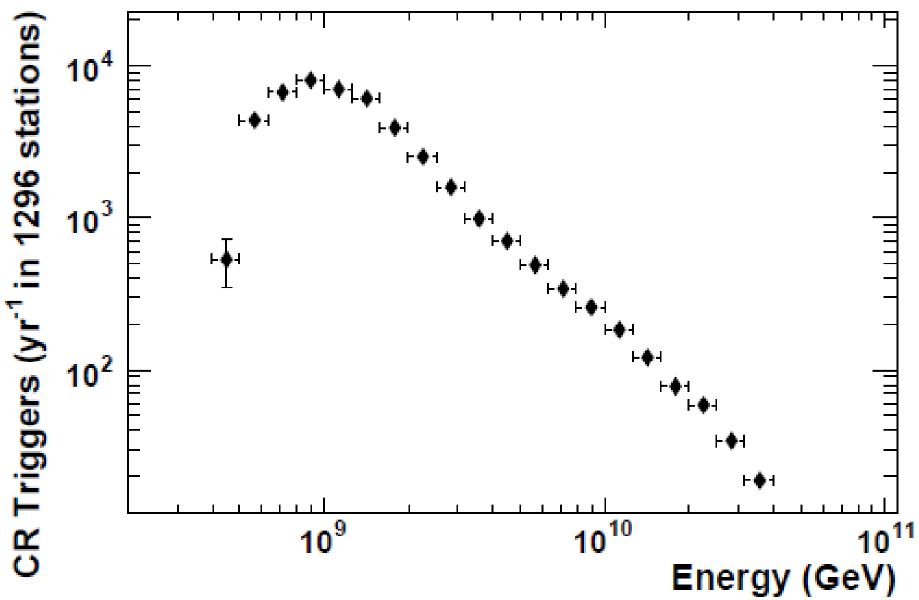


One extra HRA station has upward pointing antennas
Study cosmic ray as potential background and as performance moitor.

Two LPDA
30^o elevation
Pointing North and South
Work in progress

LPDA response in back lobe important for background will be re-measured

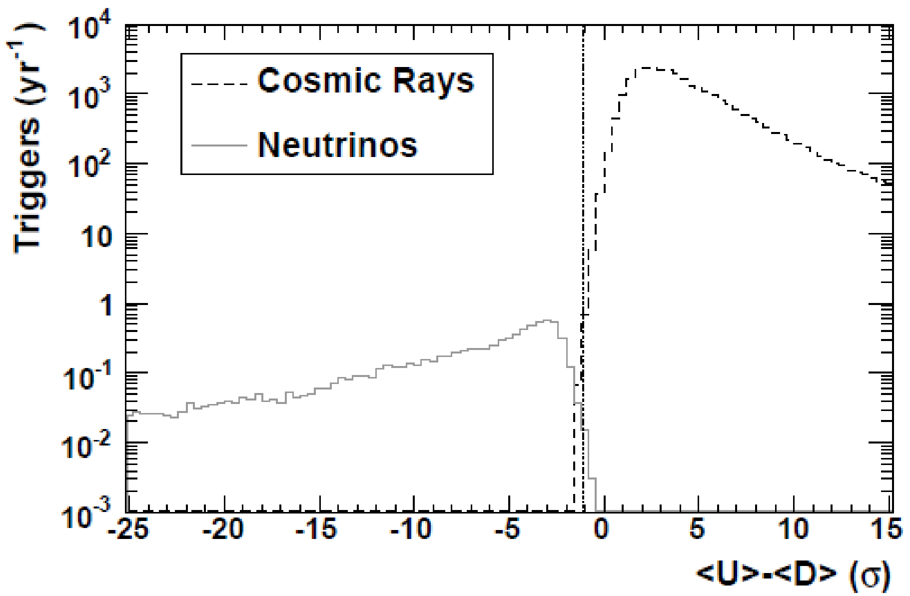
Cosmic ray detection & background



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

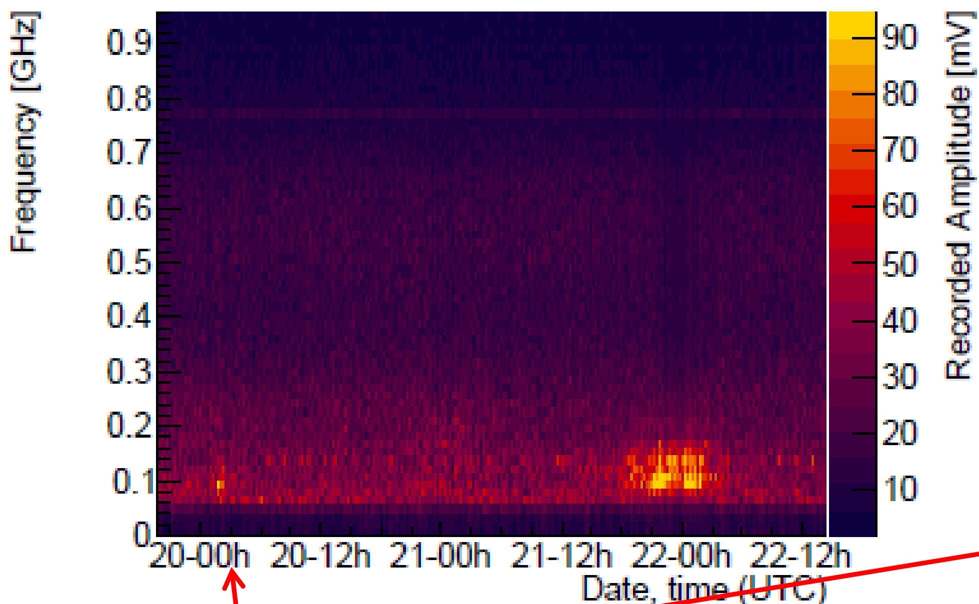


2 upward antennas, 8 downward
Strong separation in difference of average power Up-Down
←
CR mis-ID < 10^{-5}
Cut in plot → 0.2 events/year (conservative)

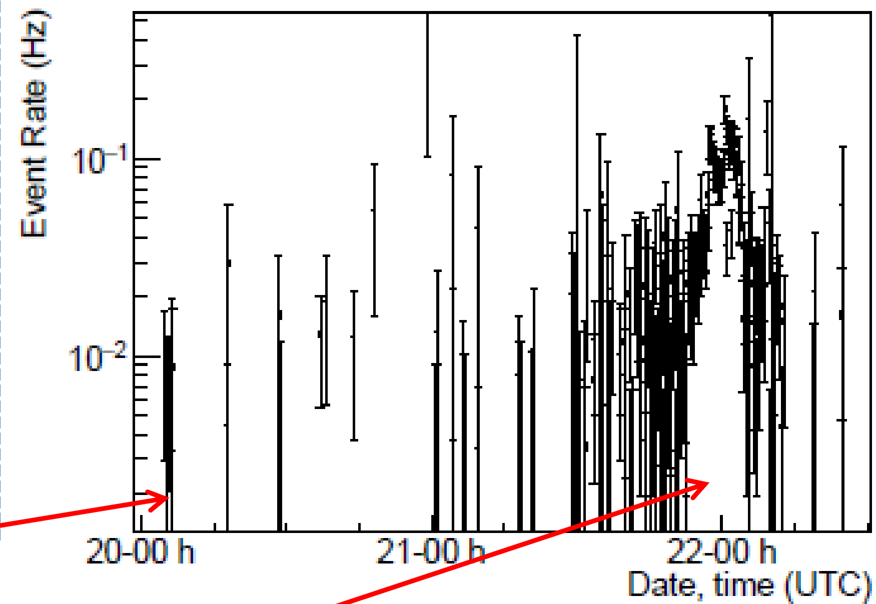
Neutrino signal scaled to 10/year

HRA observes Solar flare and Auroras

Upward antenna in Station X



Trigger rate downward antenna



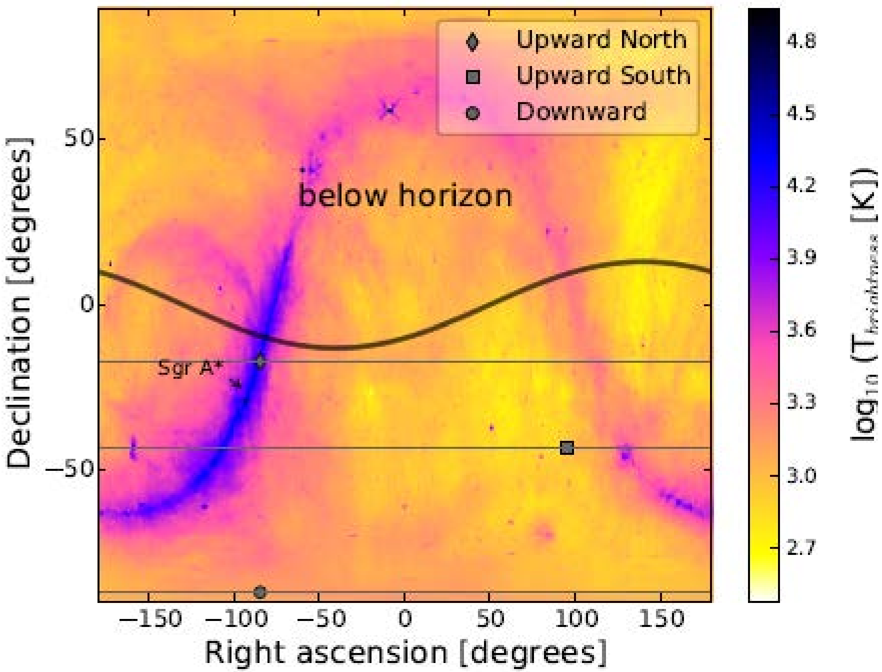
Large Solar flare on Dec 20

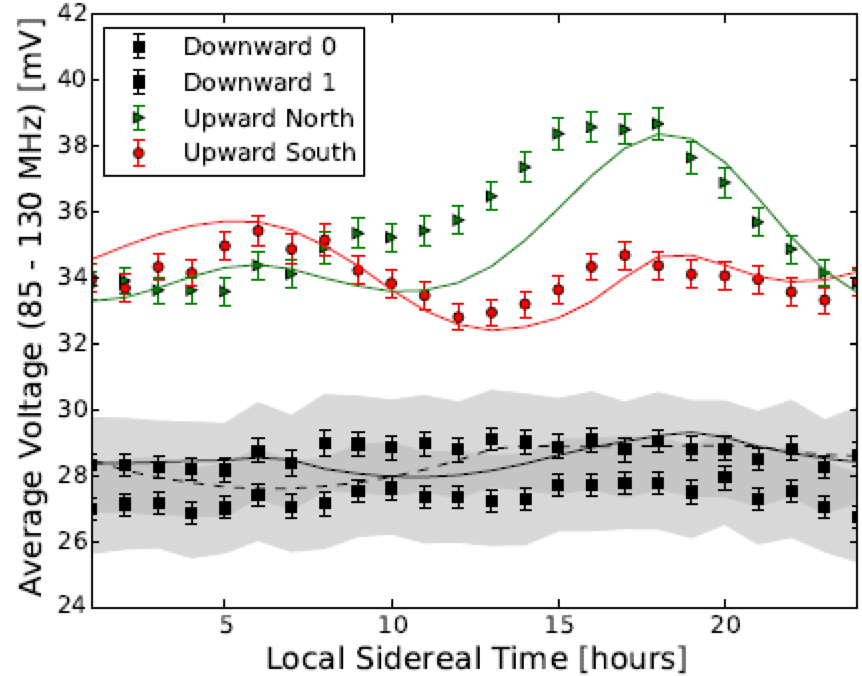
Auroras from CME of flare

Auroras and flare also influence downward antennas
LPDA response in back directions important

Most power 85 - 120 MHz

HRA observes the Galaxy

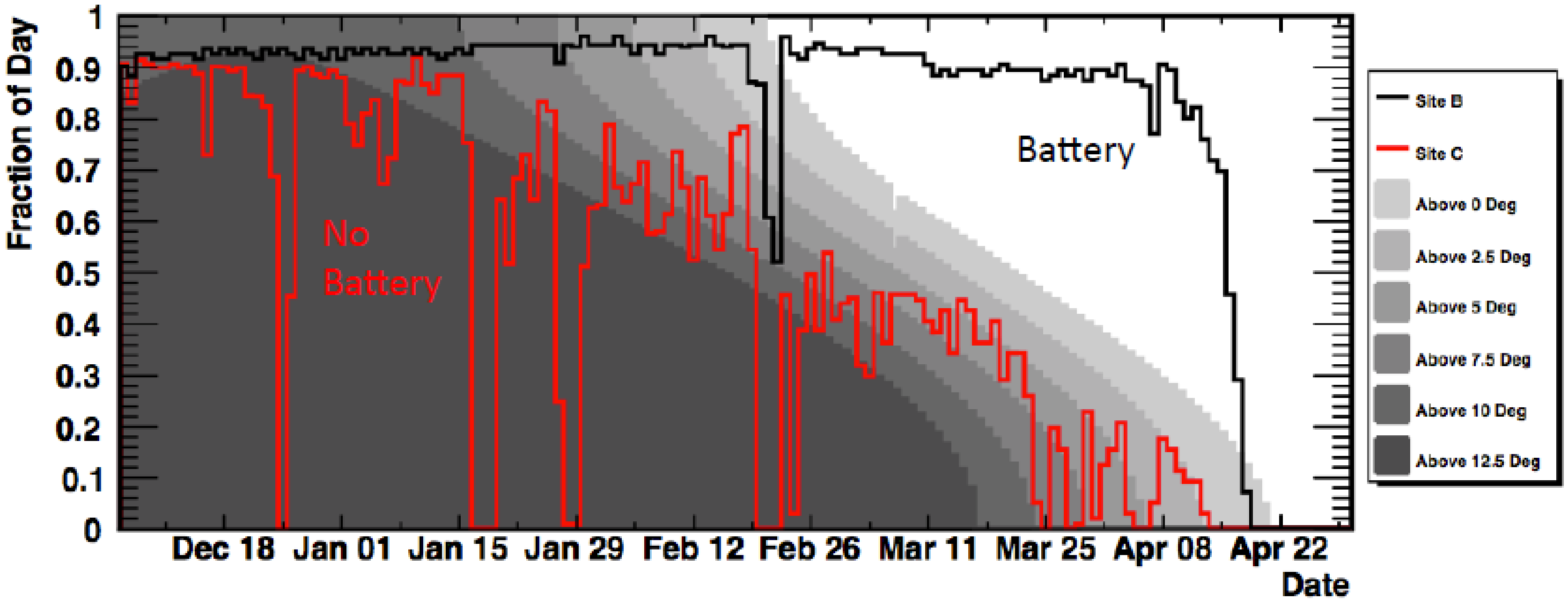




Radio noise from galaxy modelled for four different antennas
Amplitude OK
Time dependence needs further study

Station livetime

A. Nelles ICRC-822



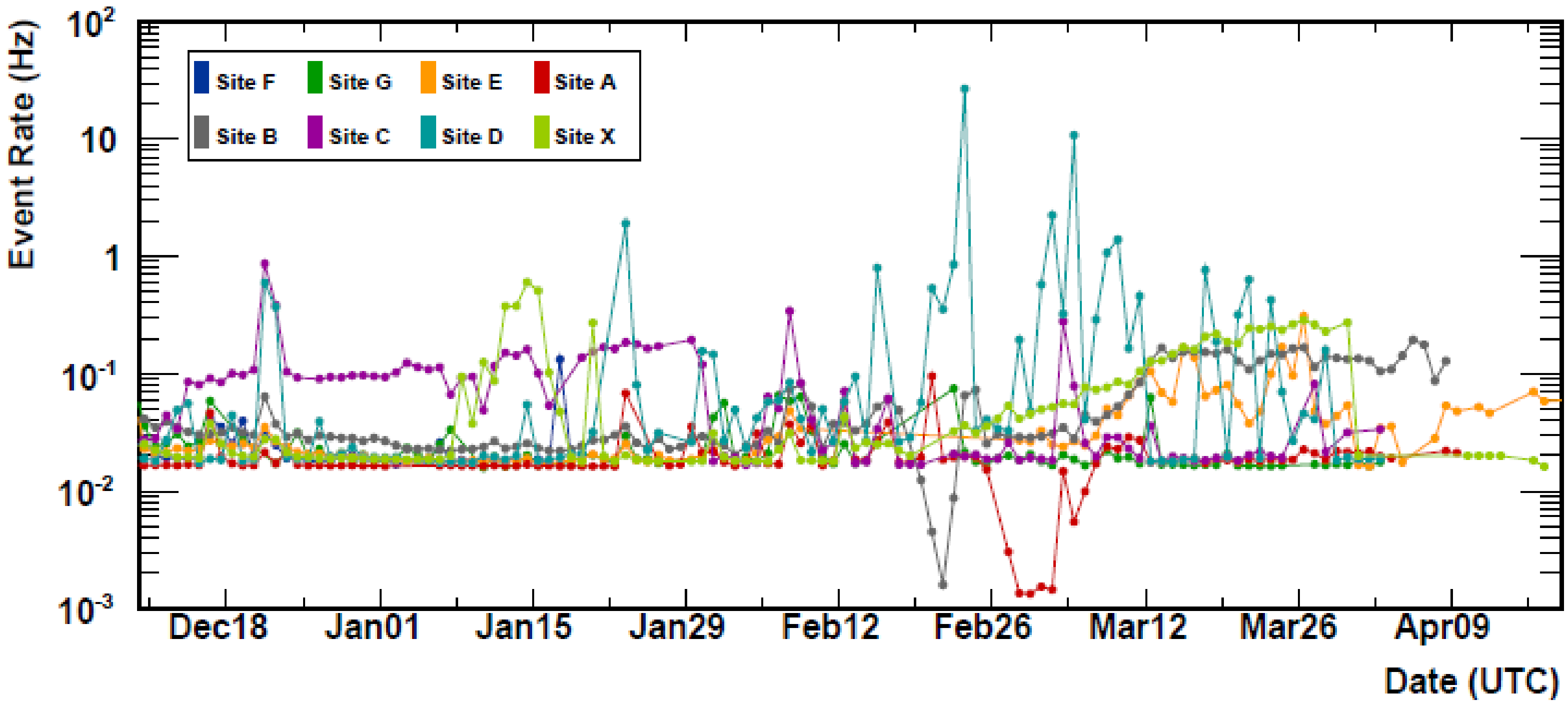
Site B station, with battery, achieves ~92% livetime, 8% loss from data transmission

Site C station, gaps due to un-transferred data. Requires sun >2-5° above horizon

Stations will get new type batteries with improved performance 2015

Wake-up of 7 stations between 3 Sept and 13 Sept.

Trigger rates



Normal trigger condition: < 0,1 Hz

Two LPDA with bipolar pulse

-> $+4\sigma_{th}$ and $-4\ \sigma_{th}$

Solar burst 20 Dec. seen

Site C initially not adjusted

All stations run well from commisioning

Dec 2014 to April 2015 (austral sunset)

Iridium data transfer test → low rate

Colder temps-> gain up.

Rate up until thresholds adjusted

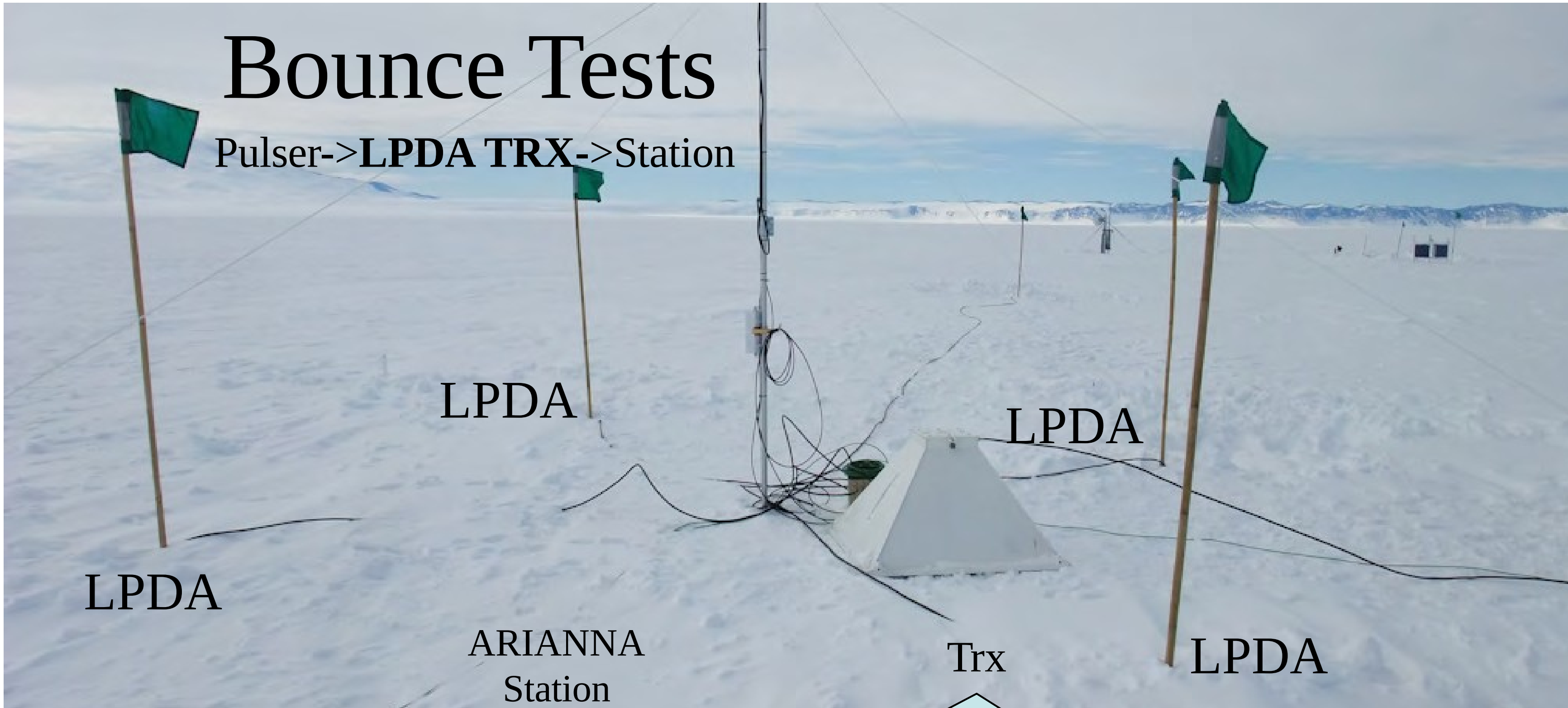
Strong wind periods visible.

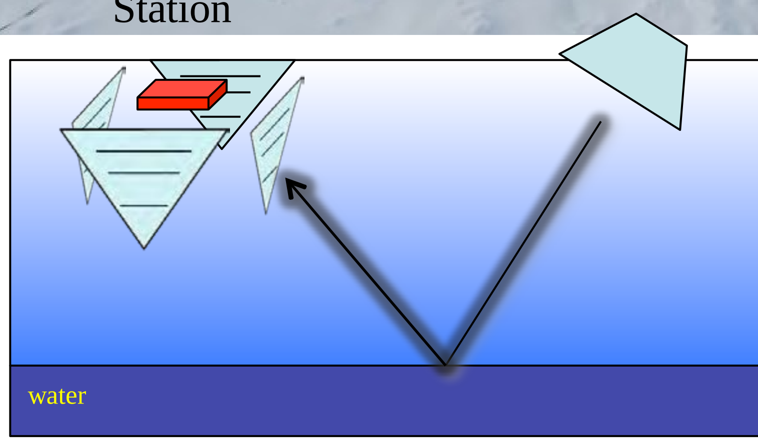
Battery charge controller switching seen

Will be shielded 15-16 season

Bounce Tests

Pulser->**LPDA TRX-**>Station

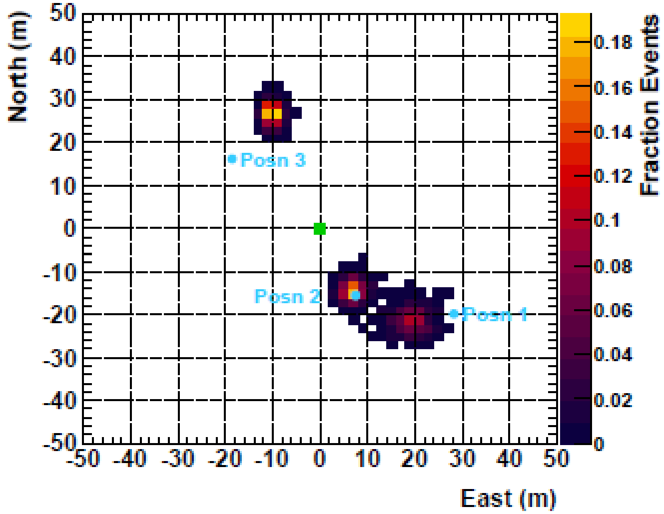


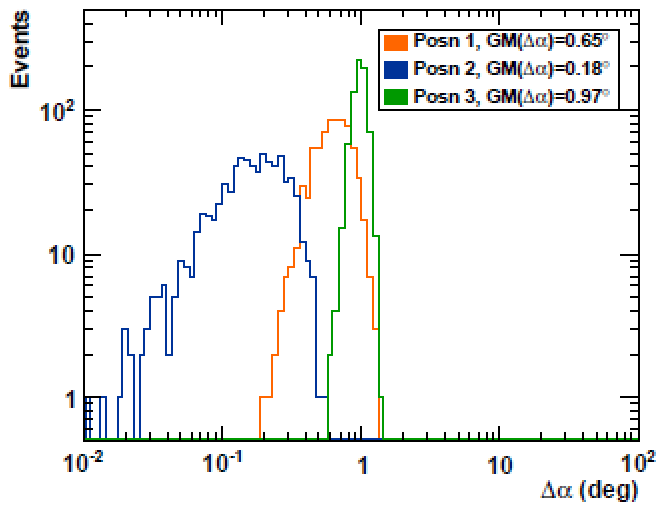


Now with LPDA TRX

(earlier Seavay)

Directional reconstruction for event position





3 ns unipolar pulse sent
Directed down reflected up
Direction reconstructed from correlations of signals in array

OBS:
Source seen as if about 1.1 km distant, mirror image

Good directional resolution
~ 1^{o}, and fit Likeliehood
Direction determines expected LPDA response function used in search for ν-events

This is **not** the neutrino direction

Search for ν events

One station, site B, December – April, first analysis.

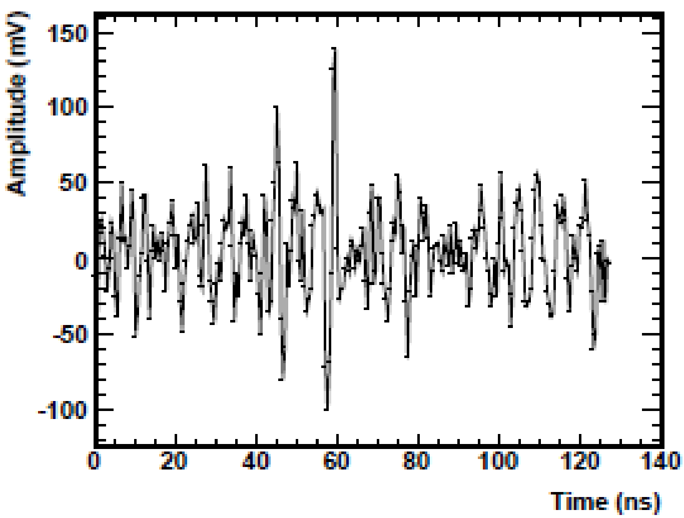
I. Single frequency cut:

Remove events that has most power concentrated in narrow frequency range.

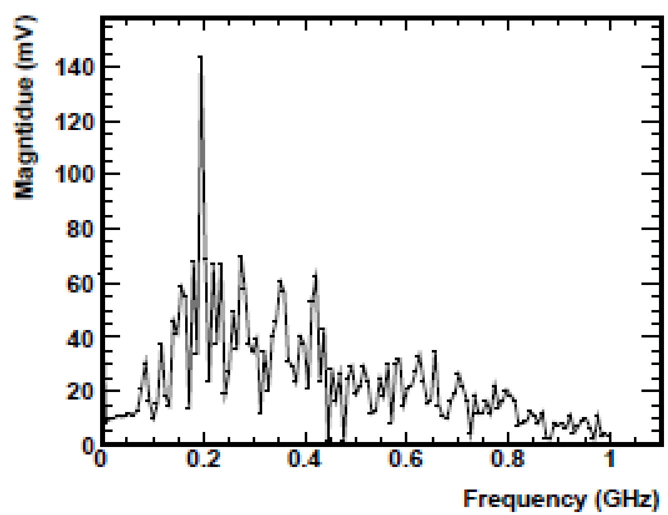
Binned distribution frequency domain, η_{LPDA} = number of bins > max power/4.

Check all LPDA: $\eta = \min(\eta_{LPDA})$

Require $\eta > 3$, keeps 99 % of simulated neutrino events, 75 % of triggered events



Time domain, not a neutrino event



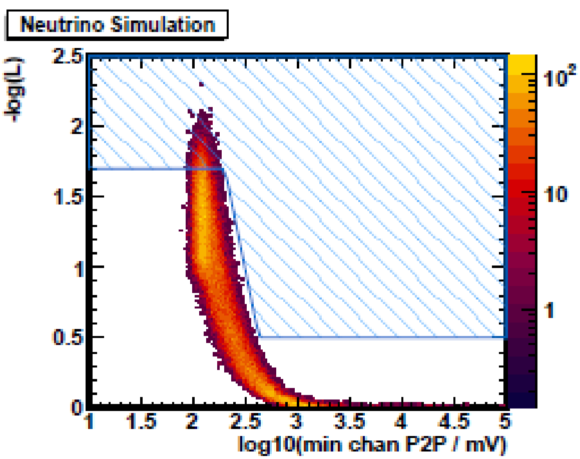
Frequency domain, same event

Search for ν events

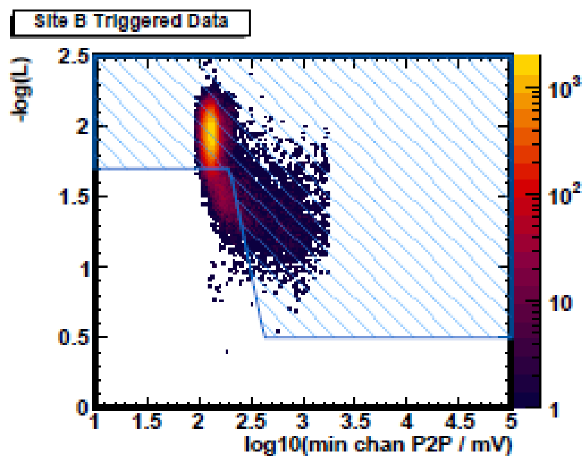
One station, site B, December – April, first analysis.

II. Directional fit likelihood:

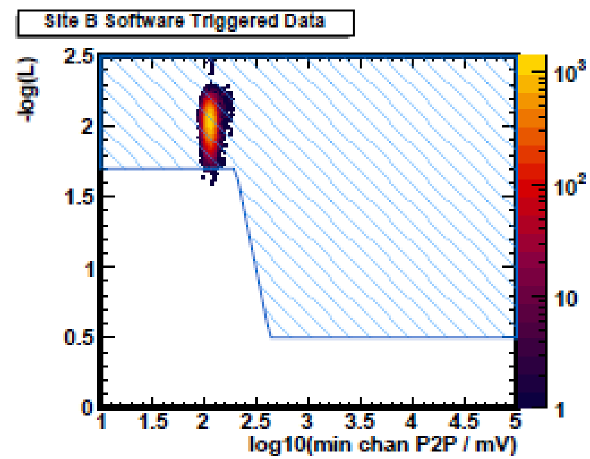
Distribution of directional fit likelihood vs event amplitude



Simulated signal
96 % pass cut



Triggered events, site B
(after single frequency cut)
Accepts **2.7 %**



Thermal noise events
Software triggered readout

Search for ν events

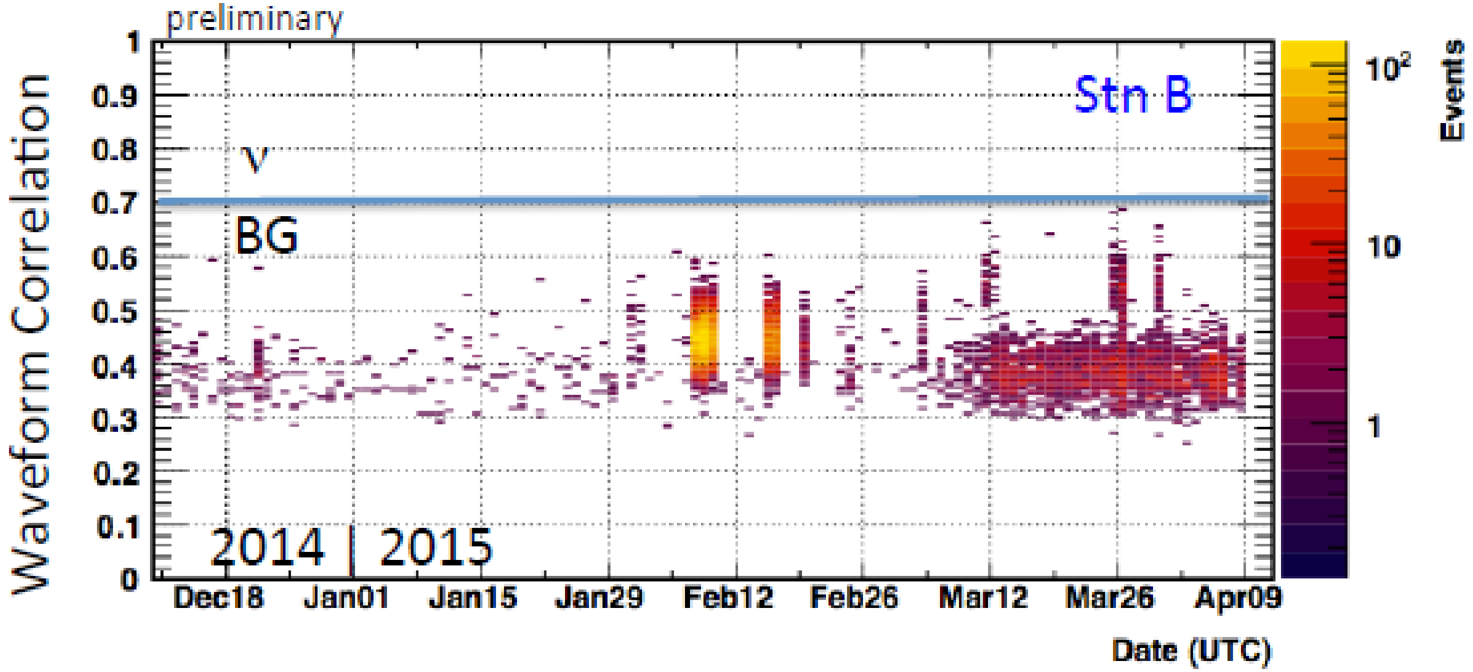
One station, site B, December – April, first analysis.

III. Template correlation:

Correlate waveform to simulated neutrino events with same incidence direction, $10^o * 10^o$- library for LPDA response

Scan over Time shift etc. Max correlation for the LPDA is ξ_{LPDA}

ξ= max (ξ_{LPDA}) **Cut $\xi < 0.7$** **No event pass.**



Search for ν events

One station, site B, December – April, first analysis.

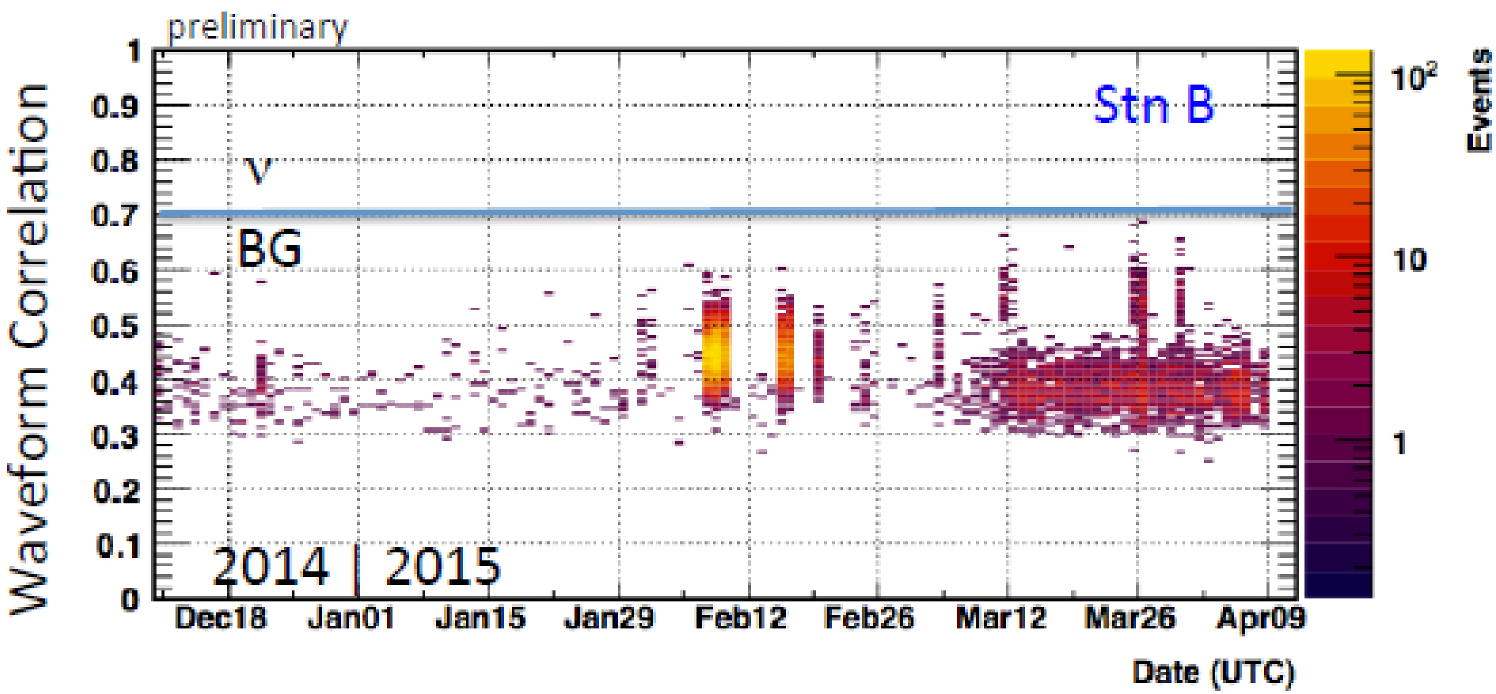
ξ distribution is populated where:

Charge controller switch battery on/off, will be fixed by RF tight enclosure

Strong wind periods contribute to populate the distribution

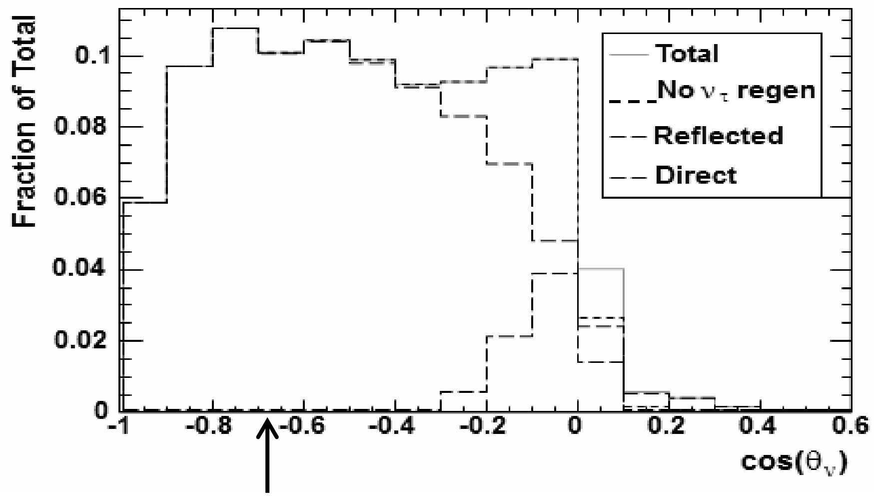
But all background events are below the cut value of 0.7

TOTAL ANALYSIS NEUTRINO EFFICIENCY IS 85.4 %



Expected ARIANNA performance

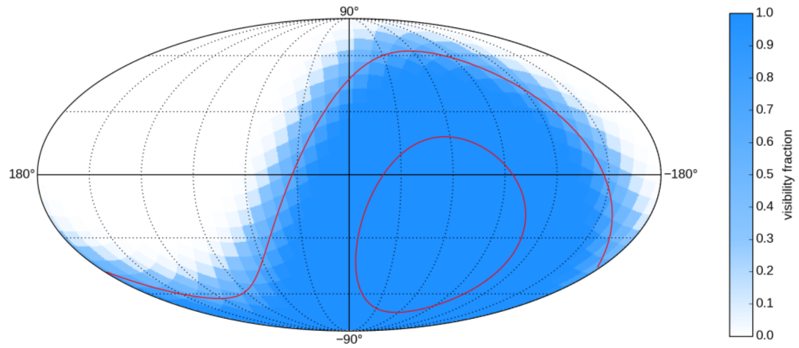
Based on measurments of ice, simulations + ”known physics”, conservative estimates ....



Angular acceptance

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

Earth absorption cuts below horizon



Angular coverage and Visibility fraction

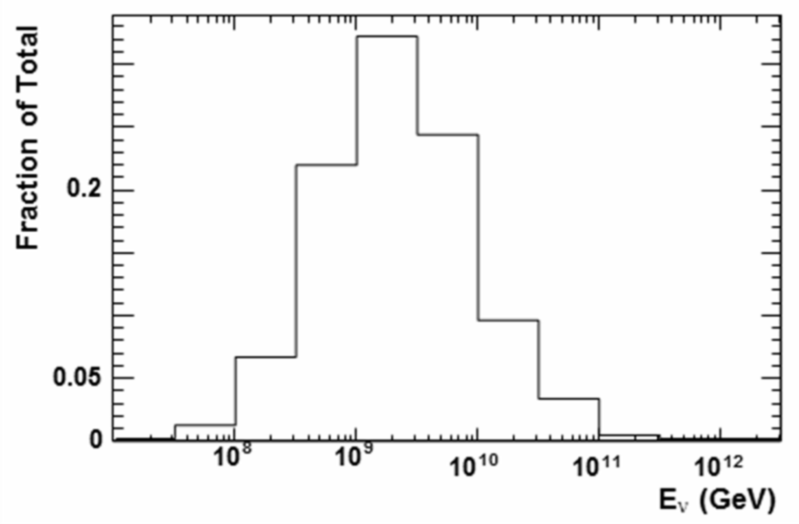
In Galactic coordinates

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

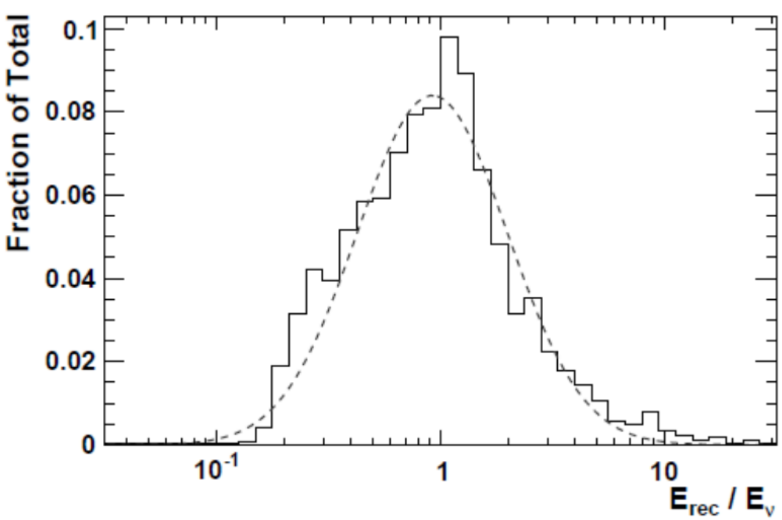
Spectral response & energy resolution

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



For ’typical’ input spectrum

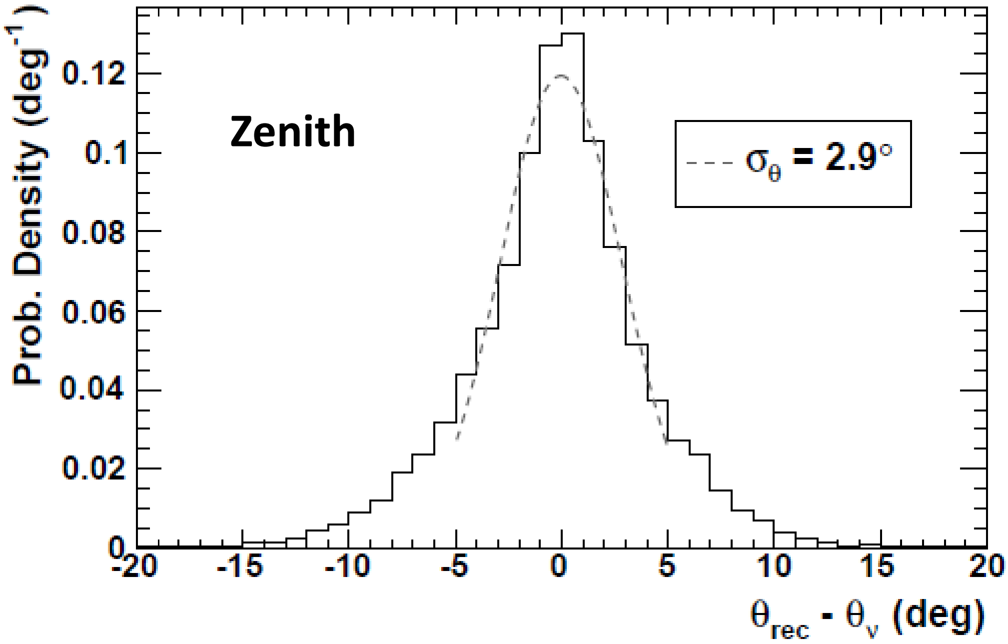
Threshold at 10^{17} eV
Flux limits upper end

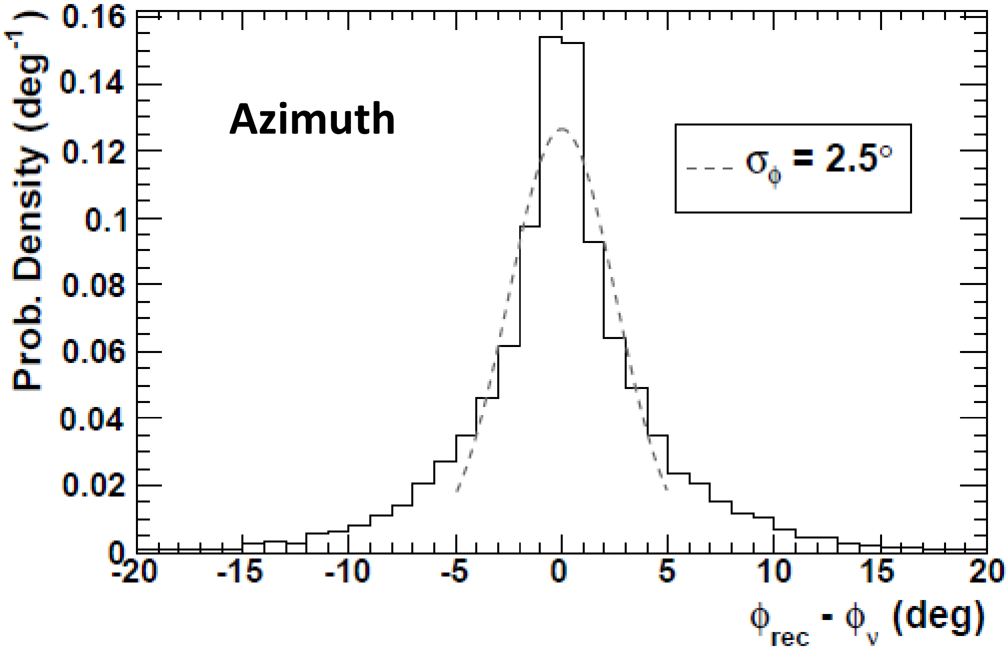


Energy resolution

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.

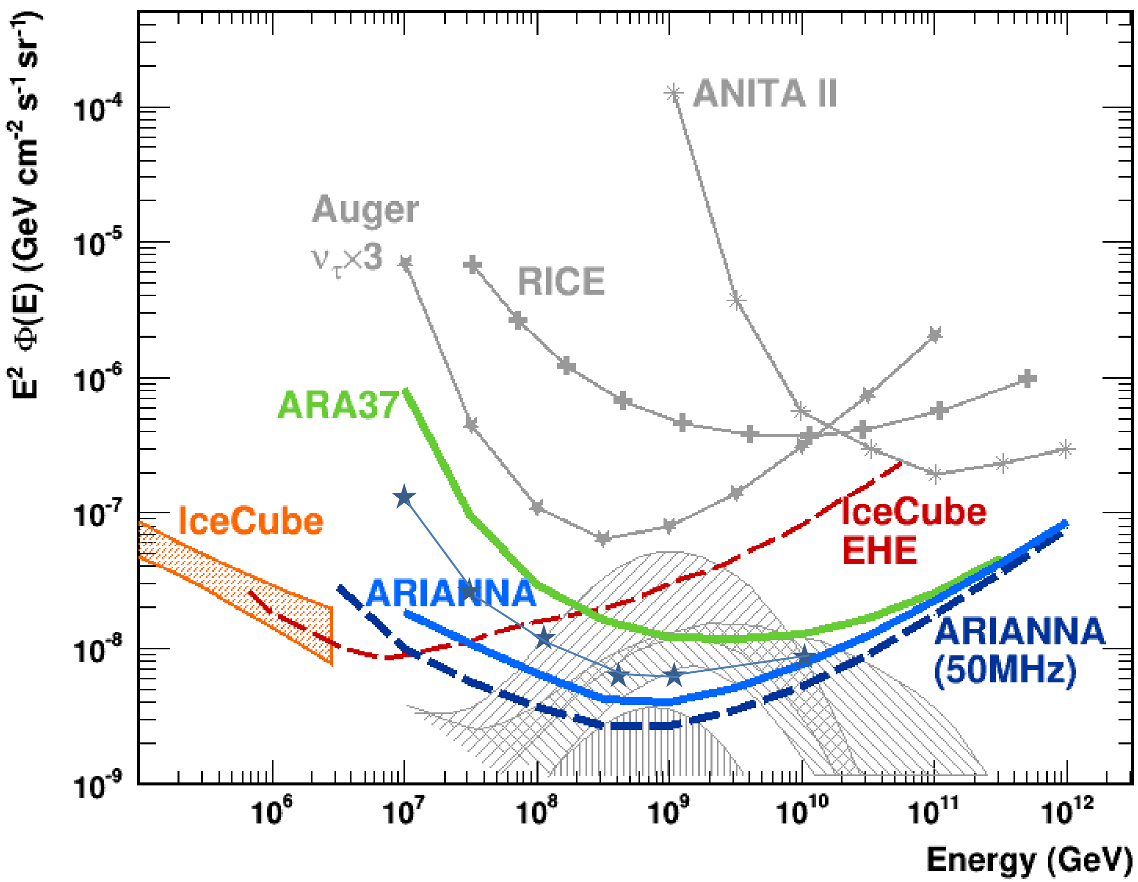
Cherenkov radiation is polarized,
→ different amplitudes in the antennas with different orientation
→ direction of incoming neutrino.

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

Predicting sensitivities

Difficult!.........
Partly as ARIANNA and e.g. ARA has used different methods, crosssections etc etc
ONE attempt to put ARA and ARIANNA sensitivities on the same footing......
But a colleague did this 'translation' (reservation for misstakes):

- Used same bin width for diff limit
- Changed to 2.3 events FC type limit (instead of 1 event)
- Changed crosssection for ARIANNA to same as ARA
- Used efficiency and live time fraction *as is* in latest papers (ARA 2 station 10 month)
- I've added with ★ the 3/5 scaled sensitivity from ARA paper (no other change)



2015-16 Field work

- Install new type battery. A123. Better performance in cold conditions.
- RF-shield exposed electronics to reduce interference
- Test 50 MHz antenna, Noise environement at 50 MHz?
- Update electronics on stations with old type
- More bounce studies
- ....

Conclusion

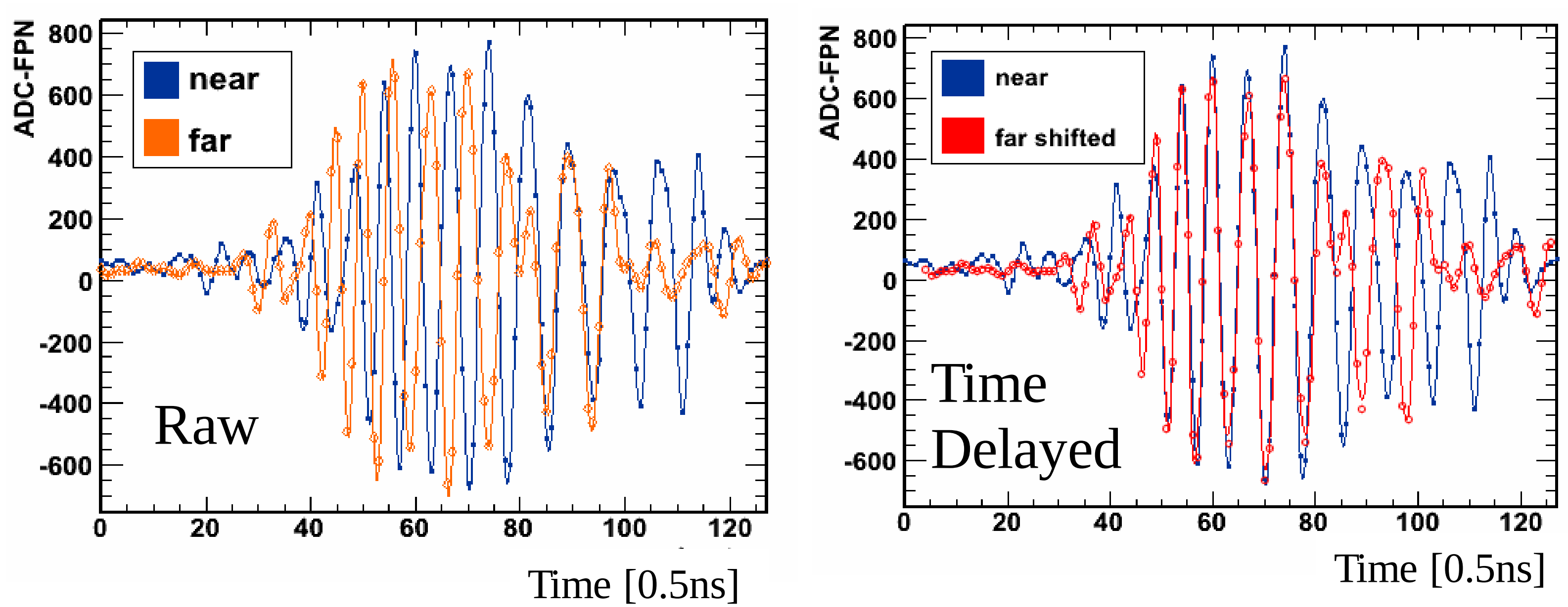
- Science case for EHE neutrino search is clear
- Radio Cherenkov with detectors in ice is the most promising technique
- Very cost effective
-
- ARIANNA is in good shape!

We should start building soon!

Bounce Tests

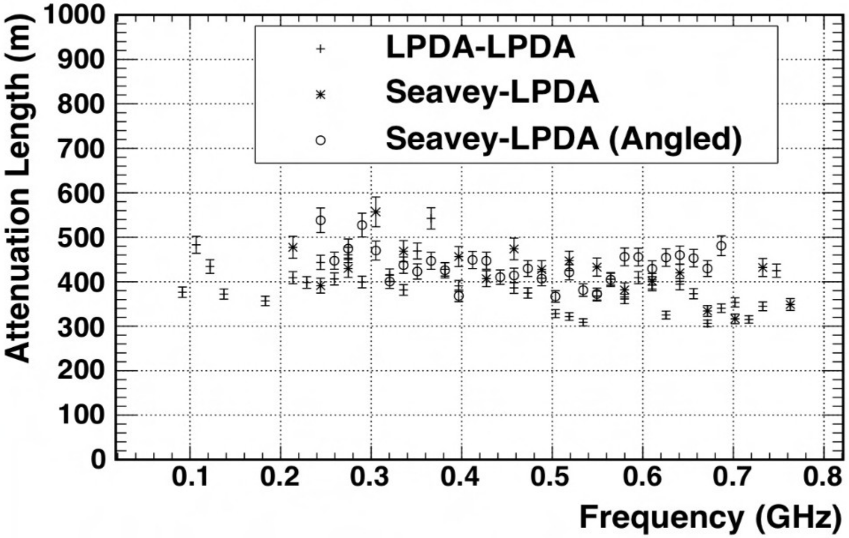
Pulser->Seavey TRX->Station

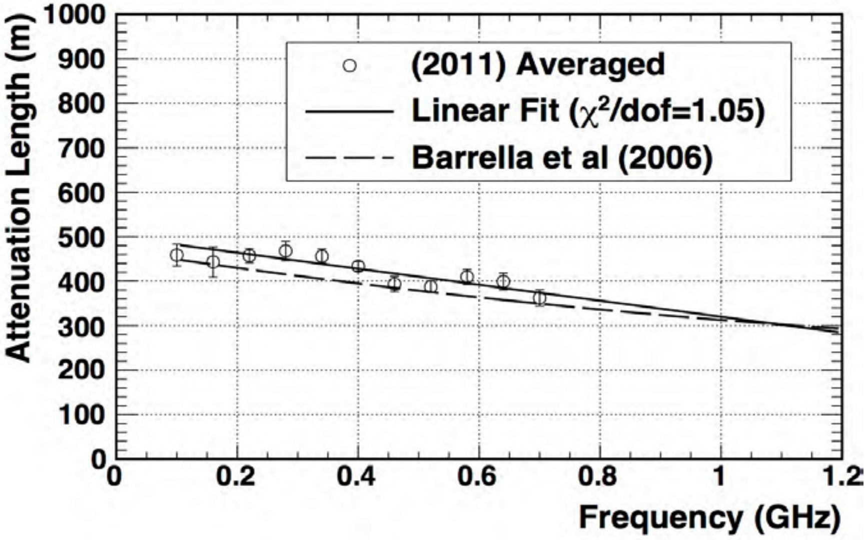
Excellent mirror



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

Ave. Attenuation Length

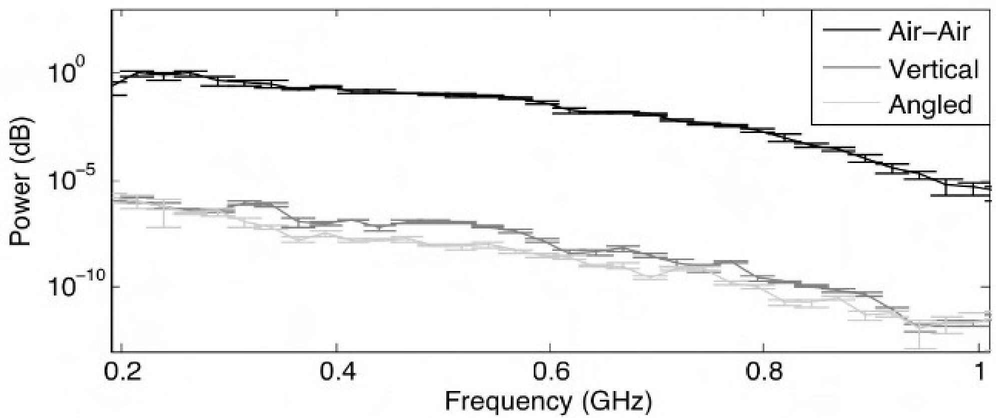


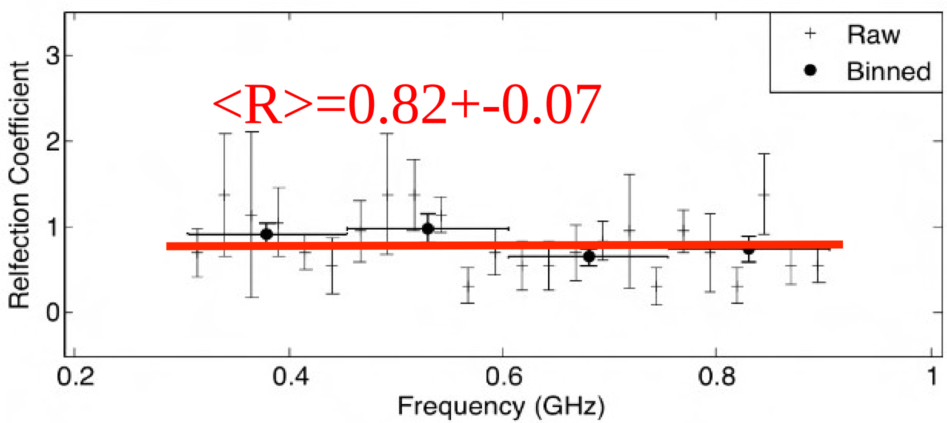


Attenuation length averaged over full depth of ice
No evidence of birefringence from combination of data

Ice measurments: arXiv:1410.7134 Submitted to Journal of Glaciology

Reflection from bottom



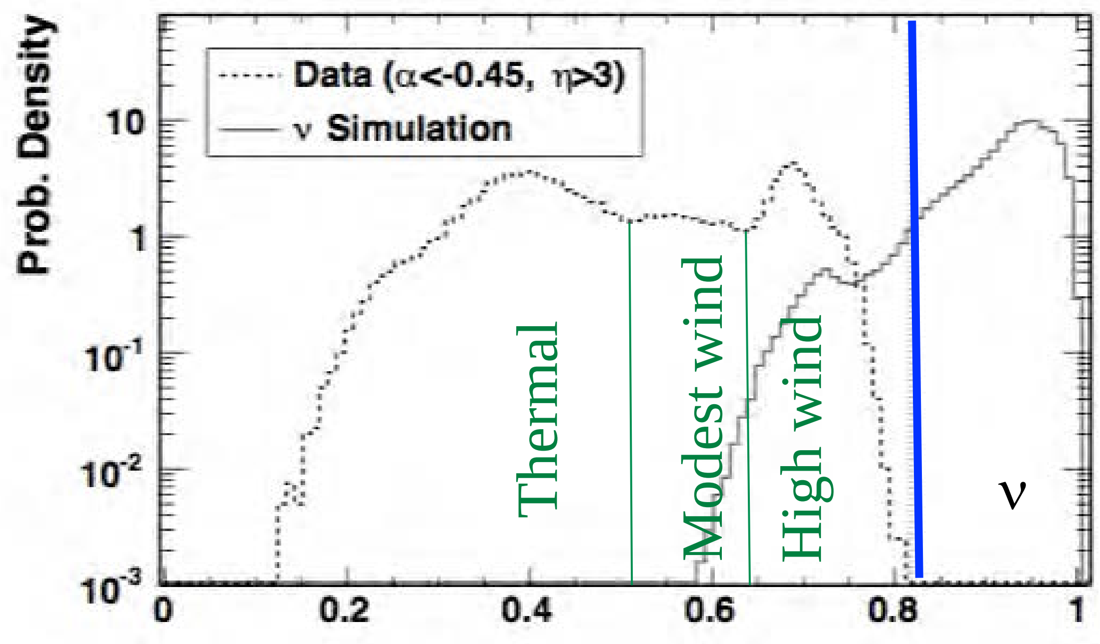


$R^{1/2}$ consistent with theoretical expectation of 0.92

Ice measurments: arXiv:1410.7134 Submitted to Journal of Glaciology

Cross-Correlation analysis (χ)

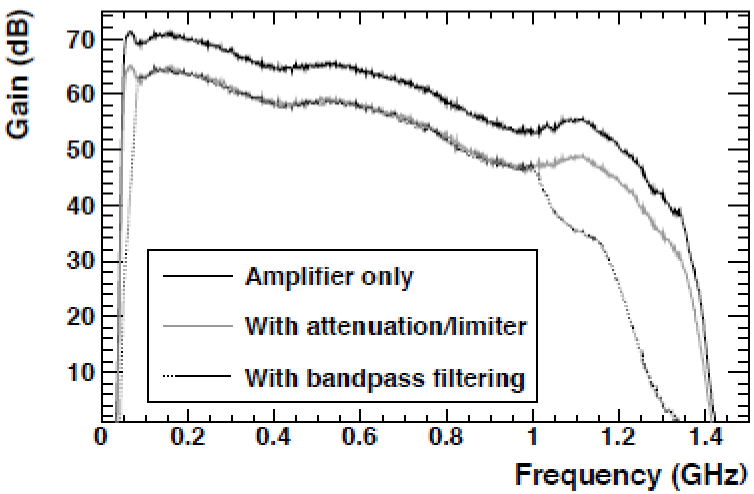
2 of 4 majority, $4V_{rms}$

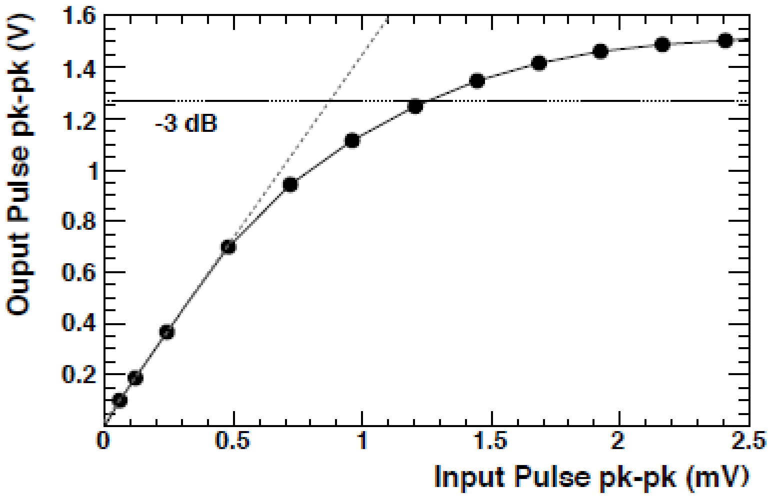


- 90% of signal retained with full rejection of background.

S. Barwick et al, in prep 2014

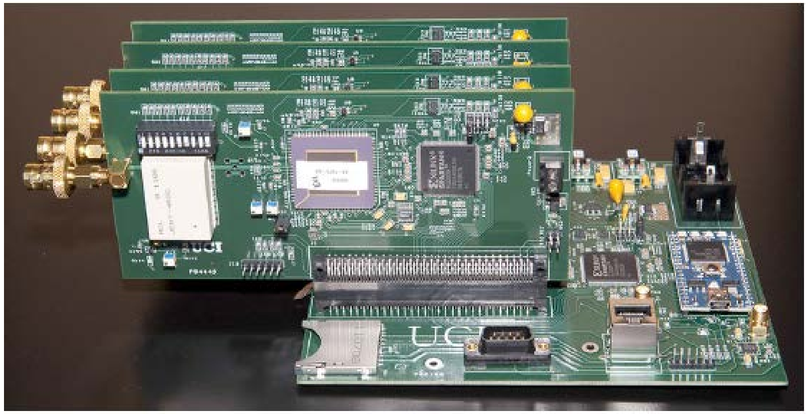
ARIANNA Electronics





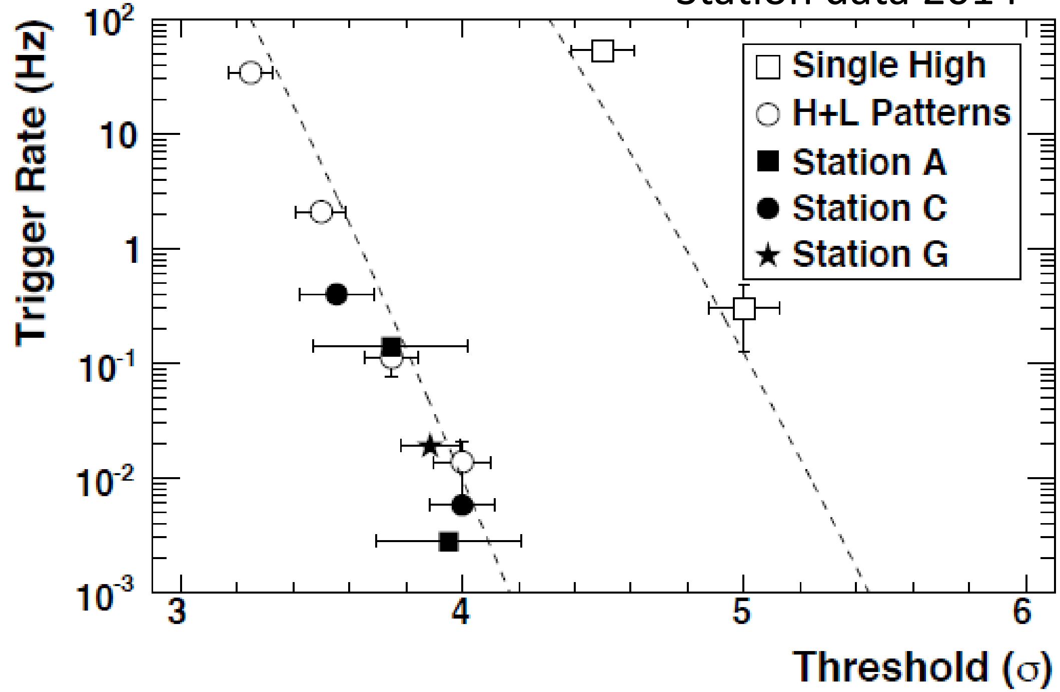
NOTE: Input in mV, output in V

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



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

New Electronics

- Three HRA stations + Station X has electronics as above.
- Four stations has improved electronics
  - the ‘SST data acquisition chip’
  - improved amplifiers with flatter frequency response
  - greater stability
  - integration of all band-pass filtering
  - a single data acquisition board (vs. a motherboard plus daughter-card)
  - considerably less expensive
  - use three times less power
  - offer deeper analog waveform capture (4 channels of 256 samples at 2 G-samples/s per chip)
  - include a simplified yet high-performance trigger system

S. A. Kleinfelder, E. Chiem, and T. Prakash, The SST Fully-Synchronous Multi-GHz AnalogWaveform Recorder with Nyquist-Rate Bandwidth and Flexible Trigger Capabilities, Proc. IEEE Nuclear Science Symposium, Seattle, WA (2014).

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