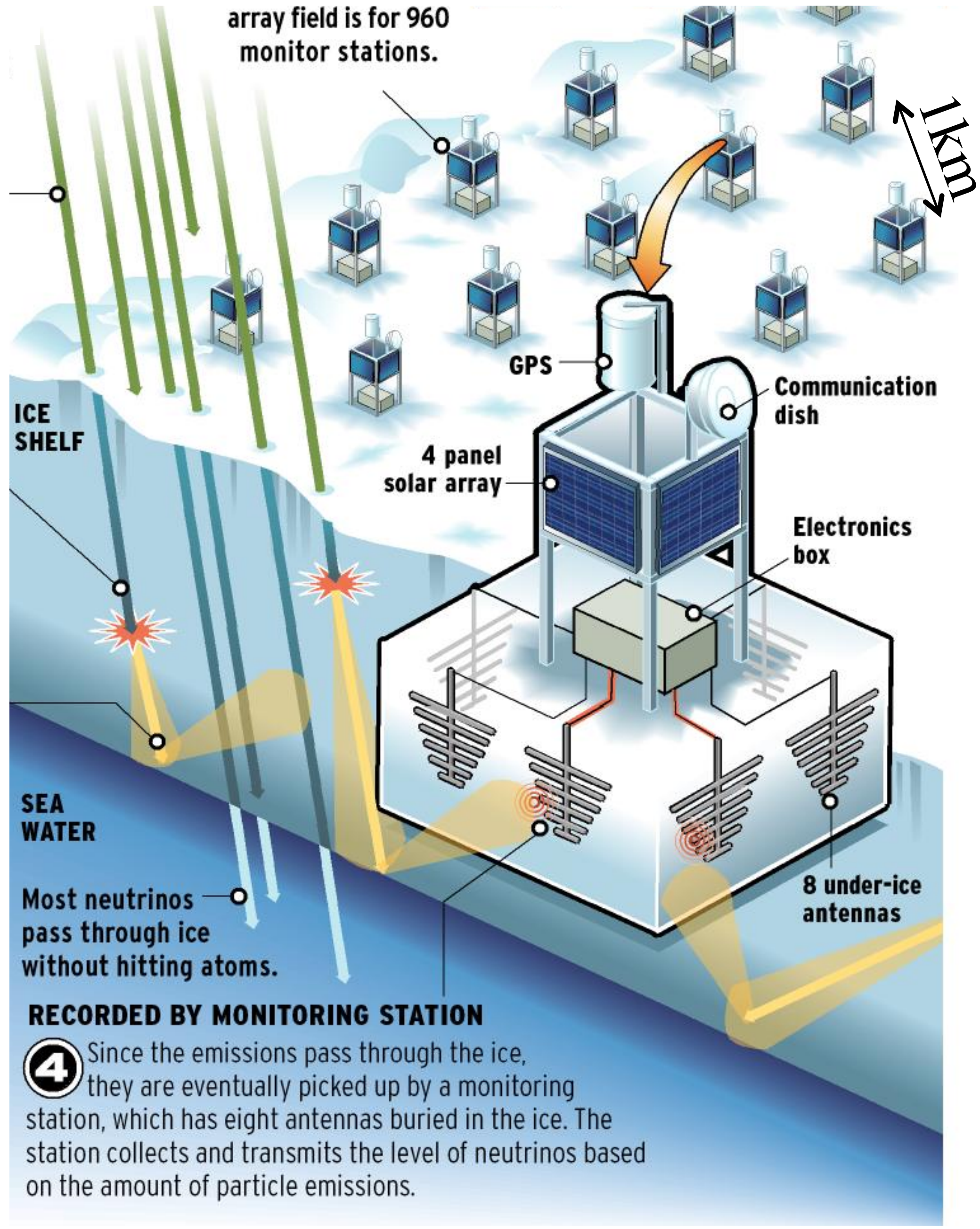
# EHE Physics and ARIANNA

http://arianna.ps.uci.edu

Steve Barwick, UCI

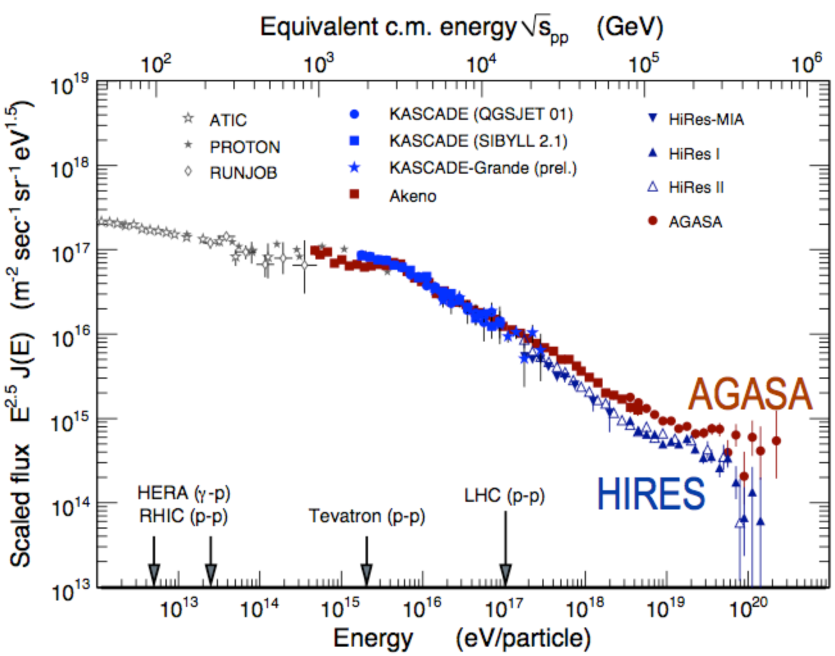
for the ARIANNA collaboration

*US*
*Sweden*
*New Zealand*

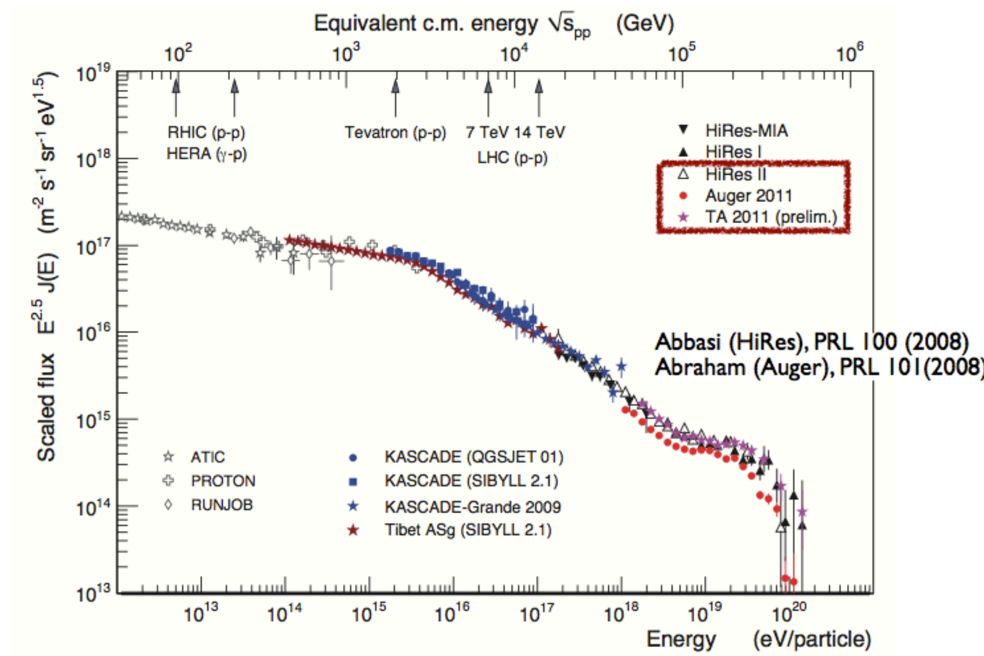



From OC Register 2012

# Cosmic Ray Spectrum

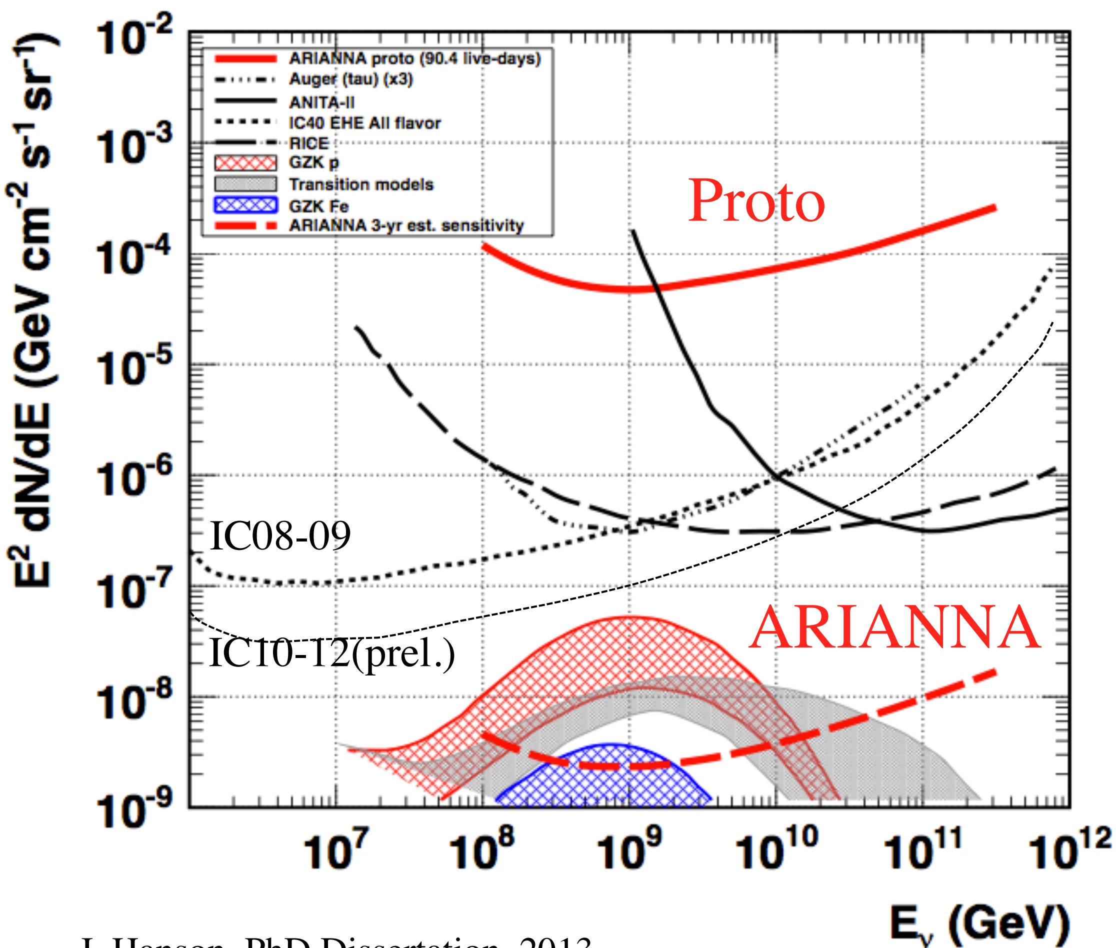



before 2008




after 2008

# Cosmogenic neutrino flux



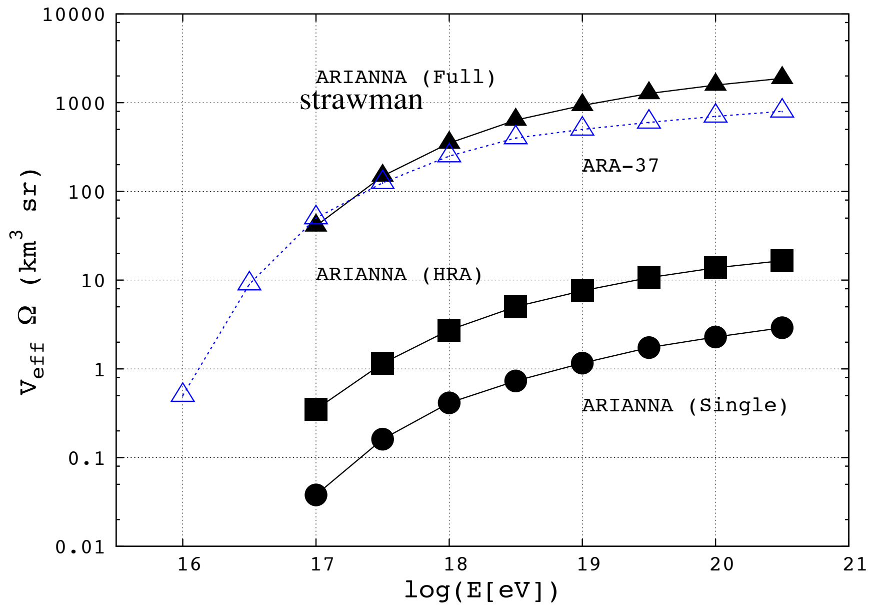

J. Hanson, PhD Dissertation, 2013
Fig. adapted from Kampert&Unger

Calculations depend on:

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

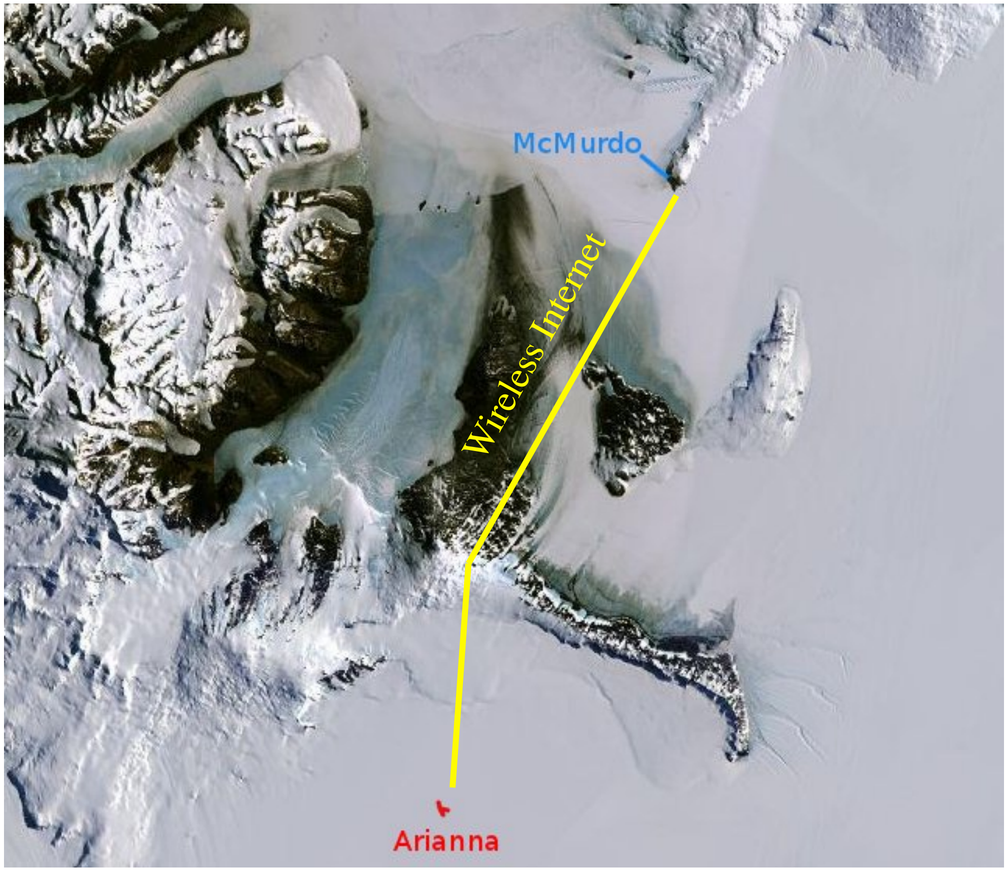
# Aperture and Rates (3 year)

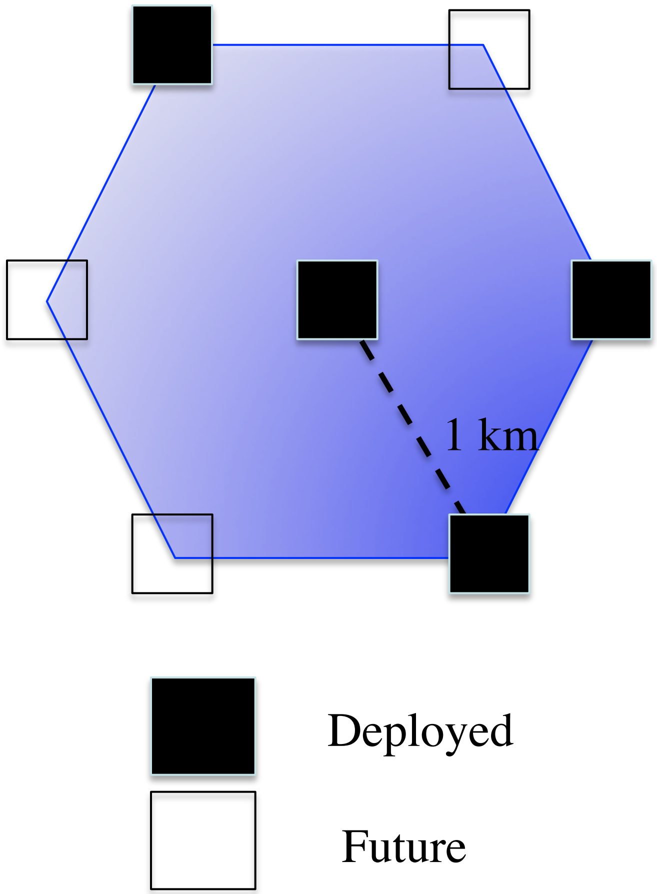
| Model and Reference | Model Class | Predicted $N_\nu$ |
|---|---|---|
| ESS Fig. 4 ($\nu_e + \nu_\mu$) [71] | No source evo. | 30.8 |
| Kotera (2010) Fig. 1 [33] | SFR1, Pure Proton | 37.1 |
| ESS Fig. 9 [71] | Strong evo. | 104.9 |
| Kalashev Fig. 2 [69] | High $E_{max}$, $z \leq 2$ | 96.1 |
| Barger Fig. 2 [42] | Strong evo. | 114.9 |
| Yuksel, Kistler (2007) [53] | SFR evo. | 45.4 |
| Yuksel, Kistler (2007) [53] | QSO evo. | 55.5 |
| Yuksel, Kistler (2007) [53] | GRB evo. | 156.1 |
| Ave et al. (2005) [24] | Pure Fe comp. | 11.3 |
| Todor Stanev [80] | Fe, CMB+IRB | 2.40 |
| Kotera Fig. 7 upper [33] | Mixed comp. | 21.7 |
| Kotera Fig. 7 lower [33] | Pure Fe | 7.50 |
| Fermi-LAT [22] | $E_{cross} = 10^{17.5}$ eV | 15.5 |
| Fermi-LAT [22] | $E_{cross} = 10^{18.0}$ eV | 21.1 |
| Fermi-LAT [22] | $E_{cross} = 10^{18.5}$ eV | 32.9 |
| Fermi-LAT [22] | $E_{cross} = 10^{19.0}$ eV | 42.8 |
| WB (1999) [17] | No source evo. | 22.4 |
| WB (1999) [17] | QSO evo. | 67.1 |
| Olinto review (2011) [23] | Fe, $E_{max} = 100$ EeV | 0.14 |
| Olinto review (2011) | Mixed, $E_{max} = 10$ EeV | 0.068 |
| Olinto review (2011) | Proton, $E_{max} = 3$ ZeV | 101.3 |
| Olinto review (2011) | Various protonic, SFR | 37.1 |




J. Hanson, UCI
PhD Dissertation, 2013

# Hexagonal Radio Array (HRA): 2012-2013

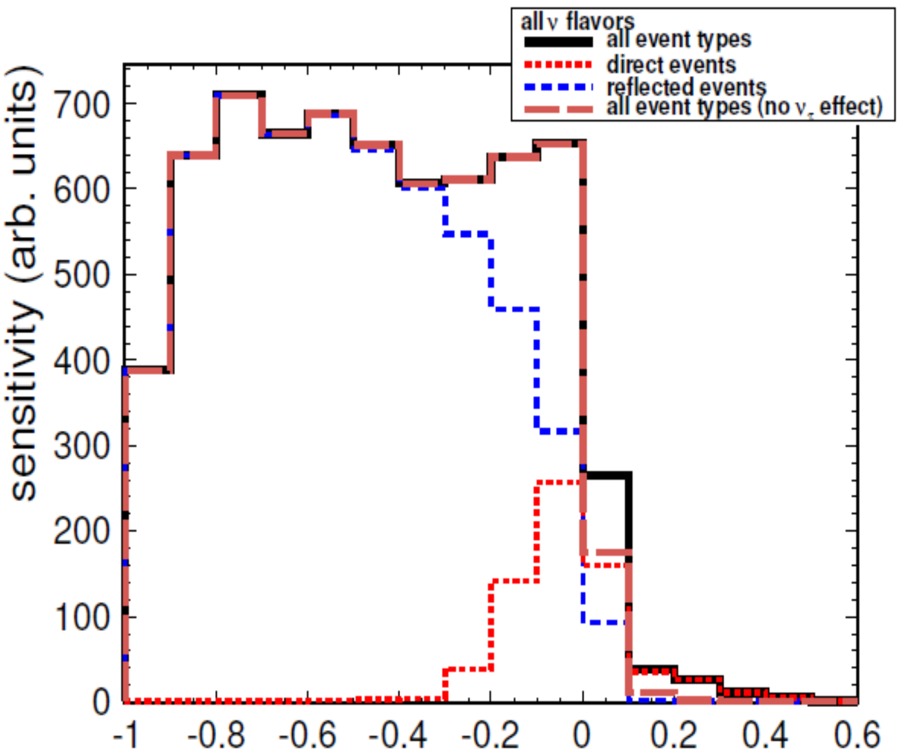


# ARIANNA Advantages

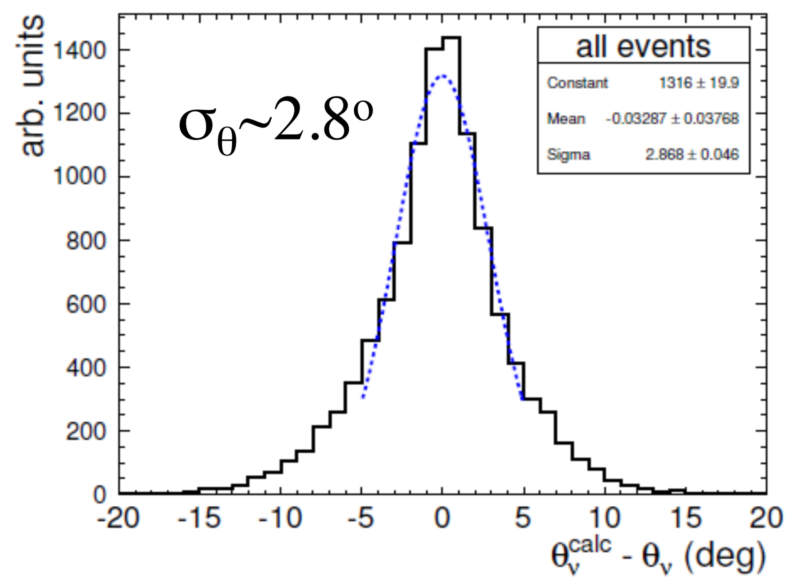
- Straightforward logistics
  - not far (~120 km) from main US science station
  - surface deployment (no drilling)
- Excellent site properties
  - Protected from man-made noise
  - Good attenuation length and reflectivity from bottom
- Lightweight, robust technologies (so low $$)
- Internet access 24/7
- Array is reconfigurable to follow science
- Green Technologies: solar and wind only

# Capabilities



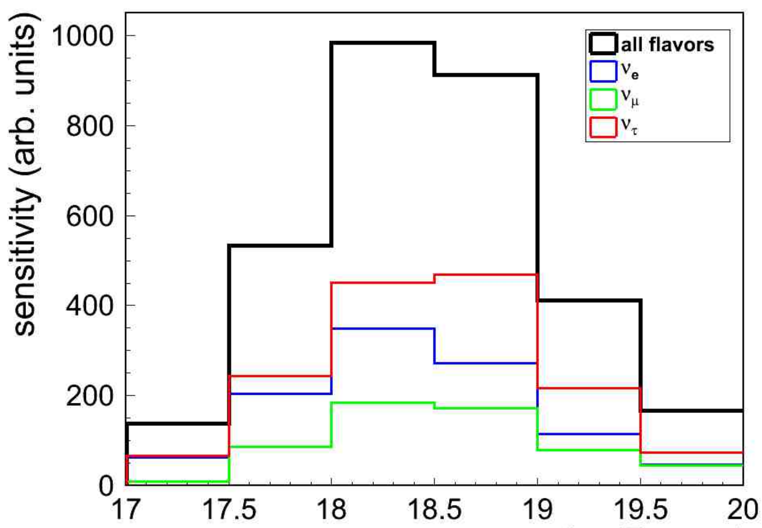

Down horizon $\cos(\theta)$

Angular resolution

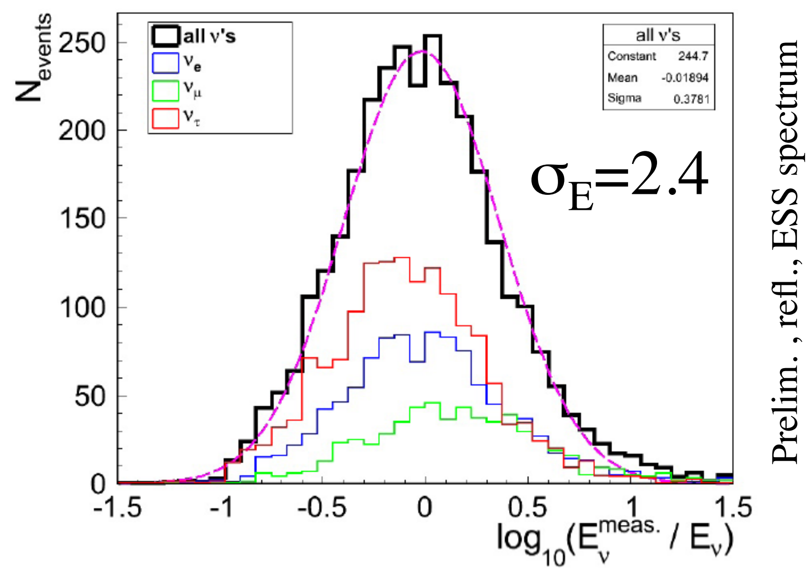



K. Dookayka, UCI PhD dissertation, 2011

# ARIANNA Characteristics




$\log(E_\nu)$ eV




Energy Resolution

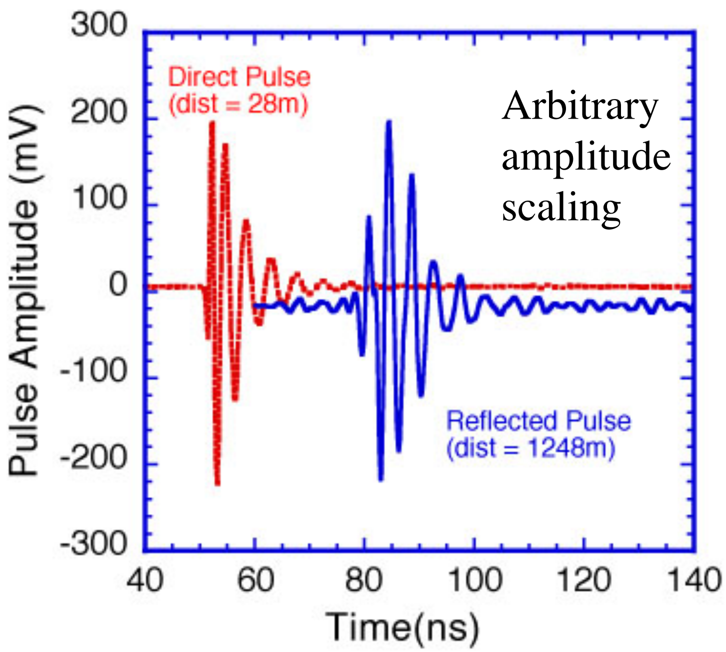
*Peak response at "sweet spot" of GZK spectrum*

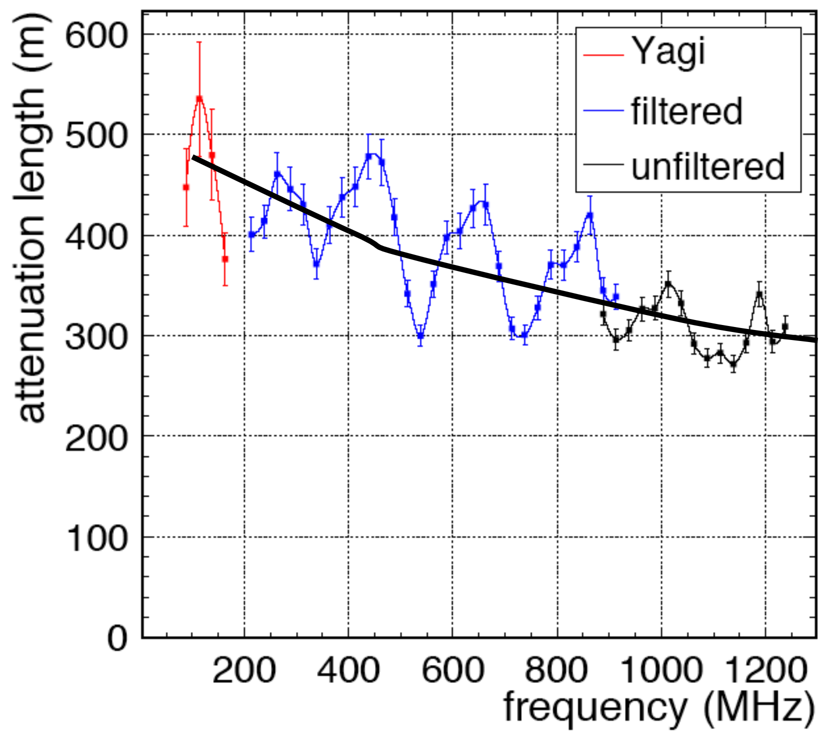
*Details of waveform give energy info*

K. Dookayka, UCI PhD dissertation, 2011

# ARIANNA Site Studies

T. Barrella, et al., J. Glaciology, 2010



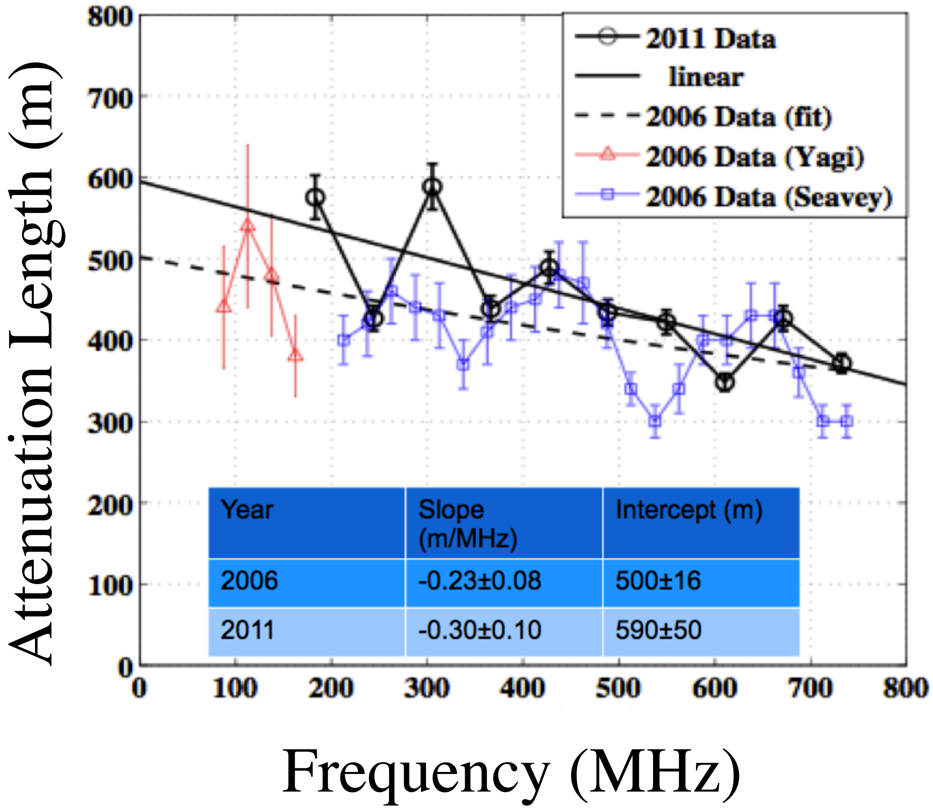




Amazing fidelity of reflected pulse from sea-water bottom -behaves as nearly flawless mirror

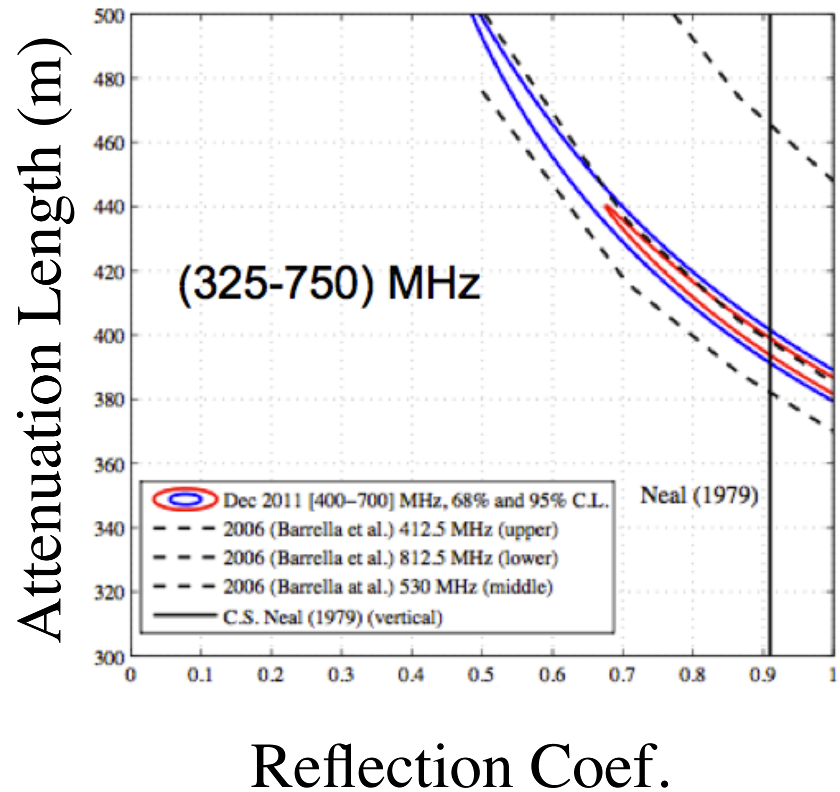
1-way attenuation length, averaged over depth and temperature

And Radio Quiet!

# Ice Properties

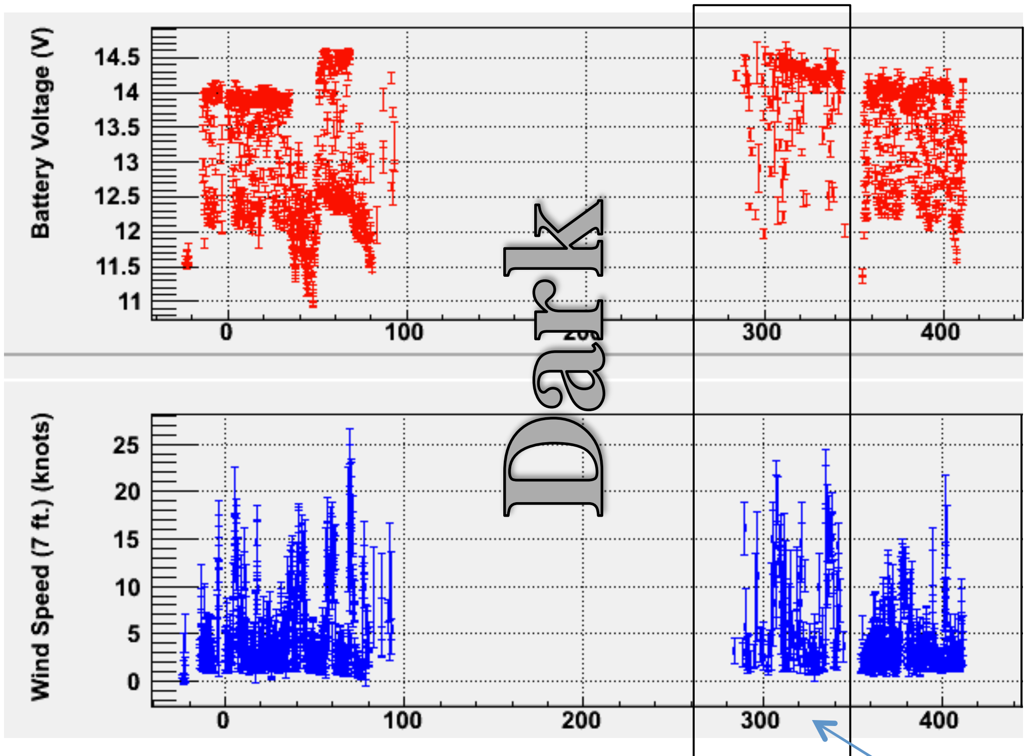



| Year | Slope (m/MHz) | Intercept (m) |
|---|---|---|
| 2006 | -0.23±0.08 | 500±16 |
| 2011 | -0.30±0.10 | 590±50 |

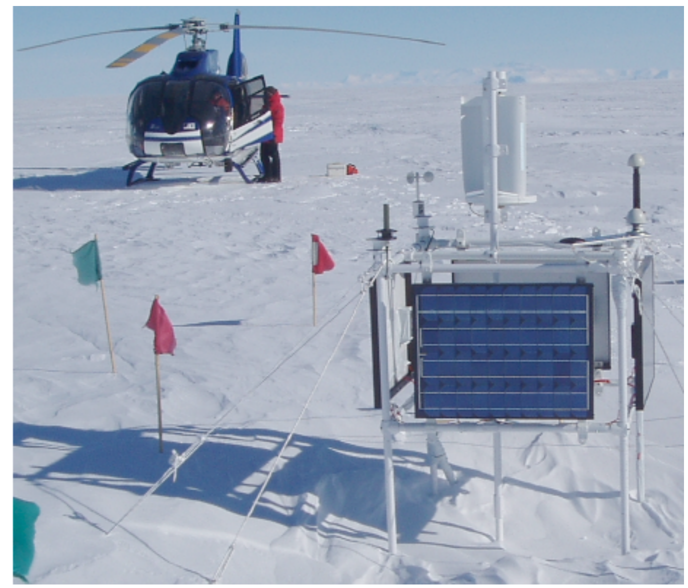



Reflection consistent with flat reflector ($R^{1/2}$=0.92)

# Protostation LiveTime



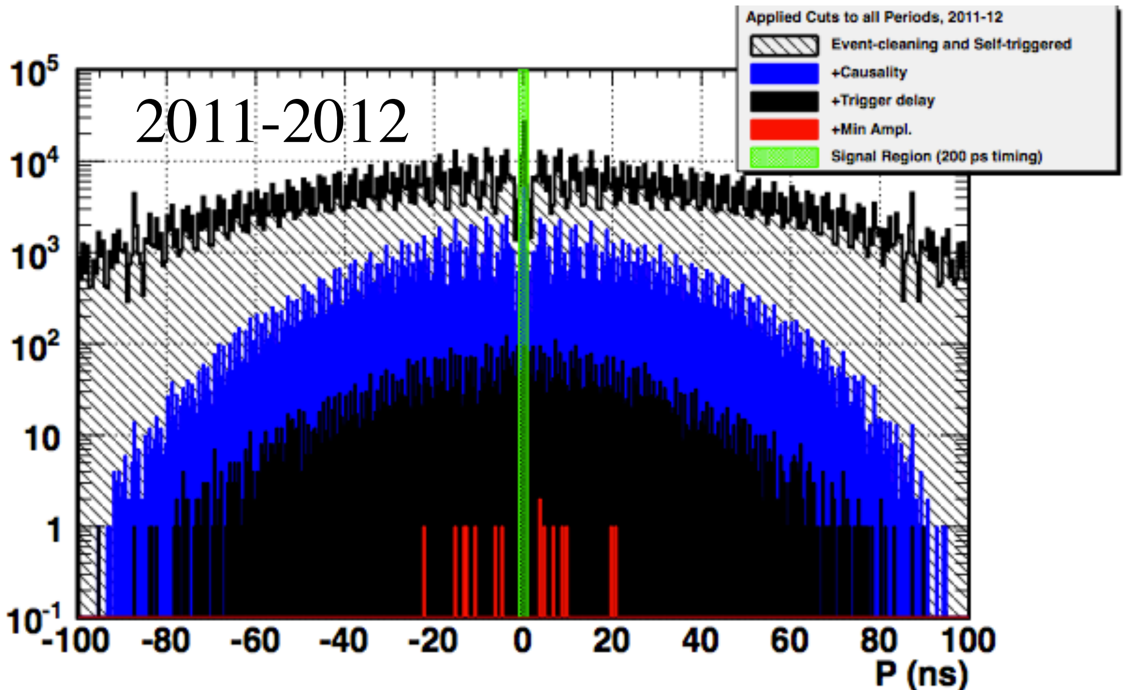

Day since Jan 1, 2010



Automatically restarted in Austral Spring

# Protostation Event Analysis

(J. Hanson, UCI Dissertation, 2013)

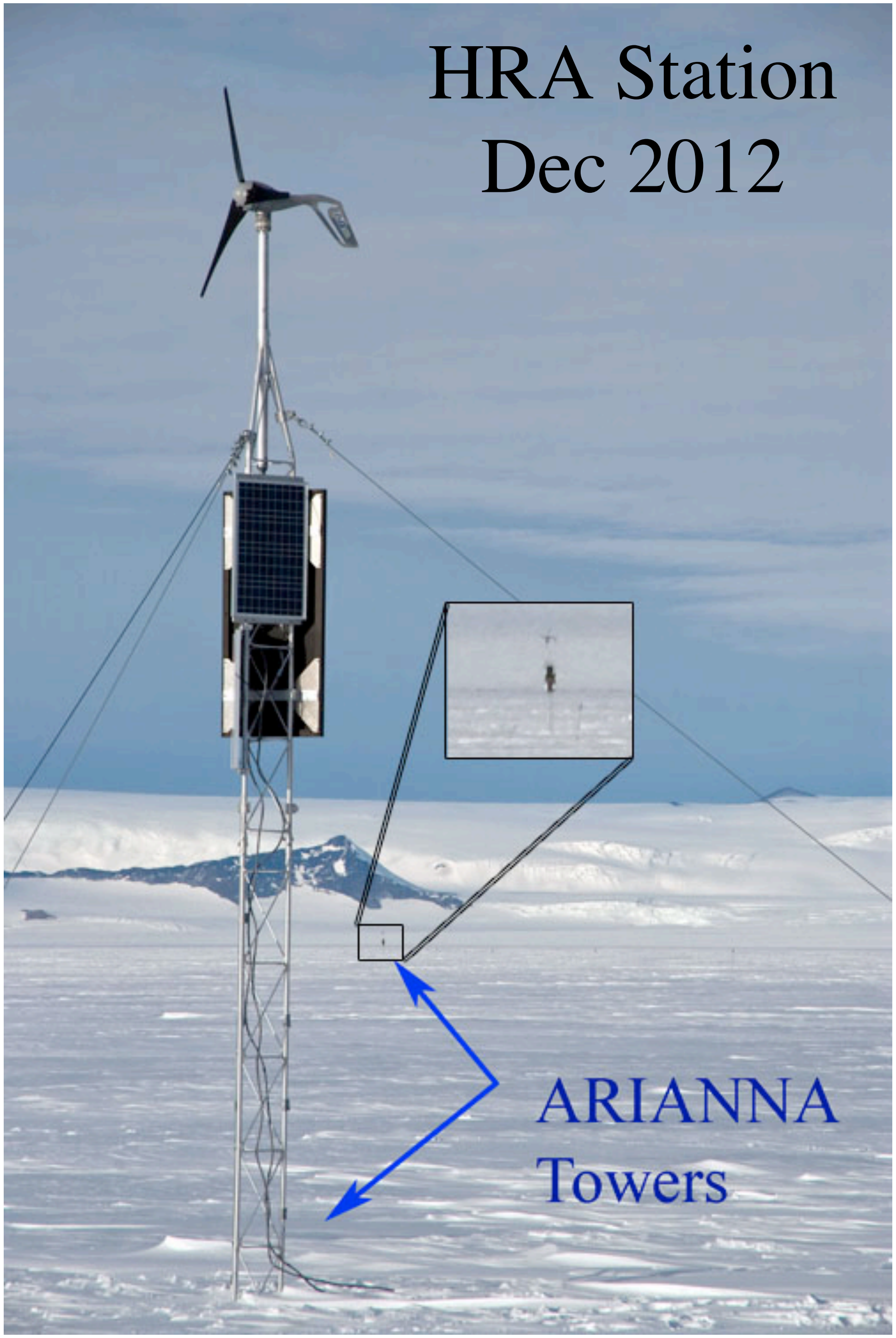



No events in signal region

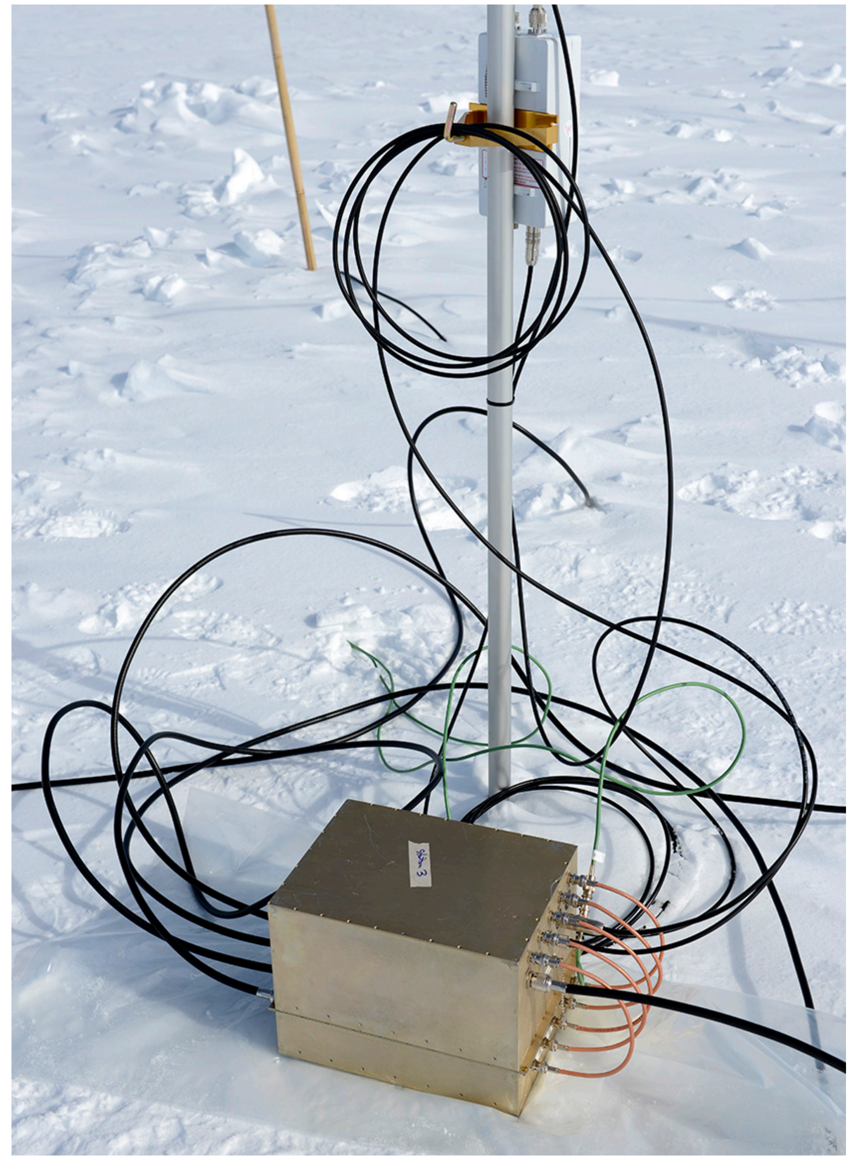
Data collected over 3 years (2009-2012)

No impulsive backgrounds which mimic neutrino signals

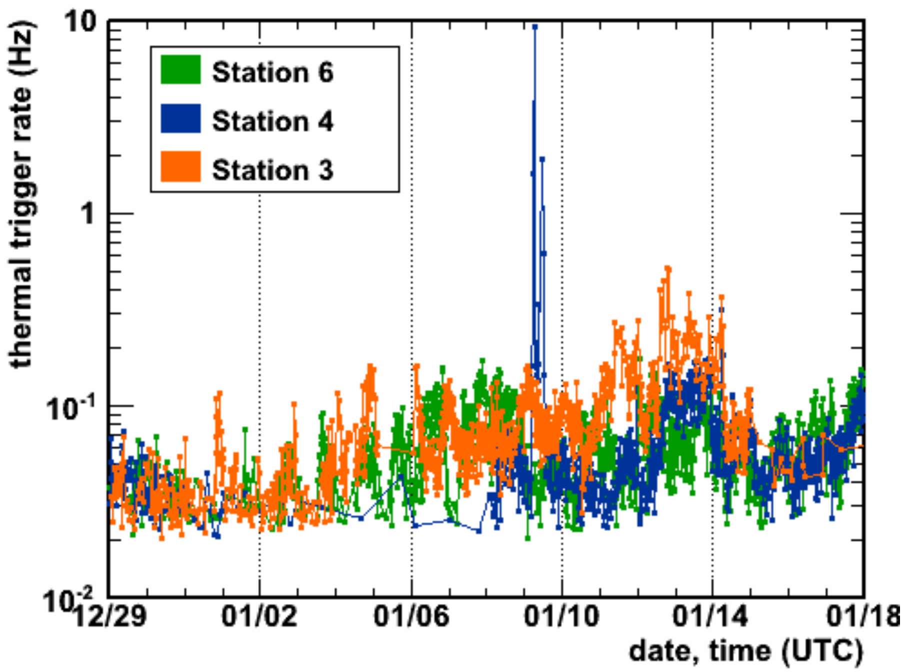
| Cut | Value | Events Remain. | Cut efficiency |
|---|---|---|---|
| Event Cleaning, 1 | $\Delta t$ analysis | 1717295 | 96.5% |
| Event Cleaning, 2 | Self-triggered | 1645466 | 96.0% |
| Causality | $\lvert\tau_{ij}\rvert < nx_{ij}/c$ | 174043 | $\geq$ 99% |
| $T_{pp}$ | $\geq$ 60 ns all chan. | 8077 | $\geq$ 99% |
| $A$ | $\geq$ 5 (excl. West) | 15 | 64.2% |
| Plane wave | $\lvert P\rvert \leq 1.0$ ns | 0 | $\geq$ 99% |
| – | – | – | 59.5% |

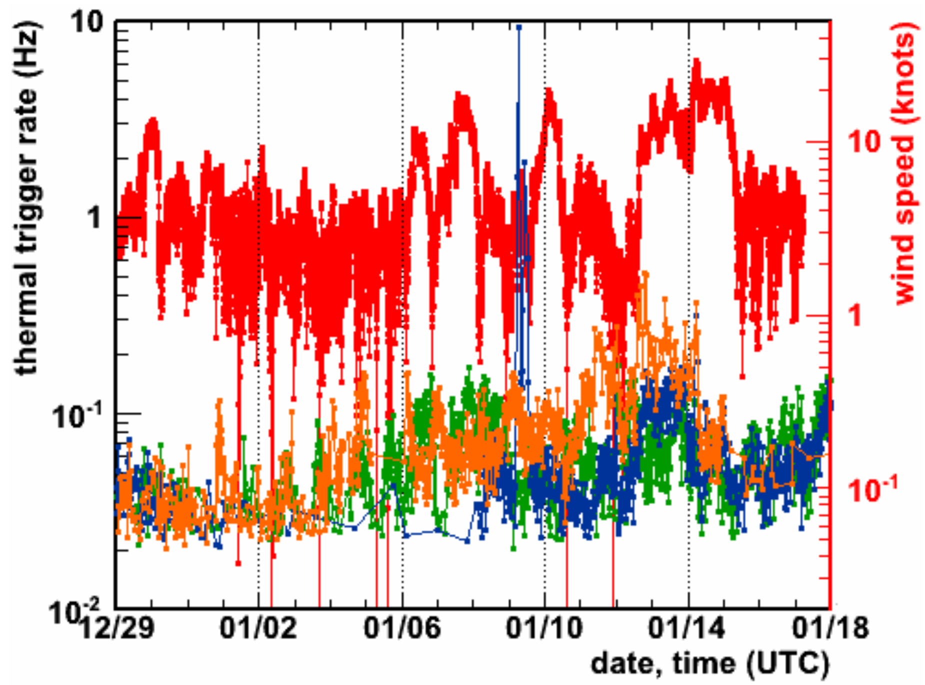



Electronics and base of
comms tower (AFAR+Irid)



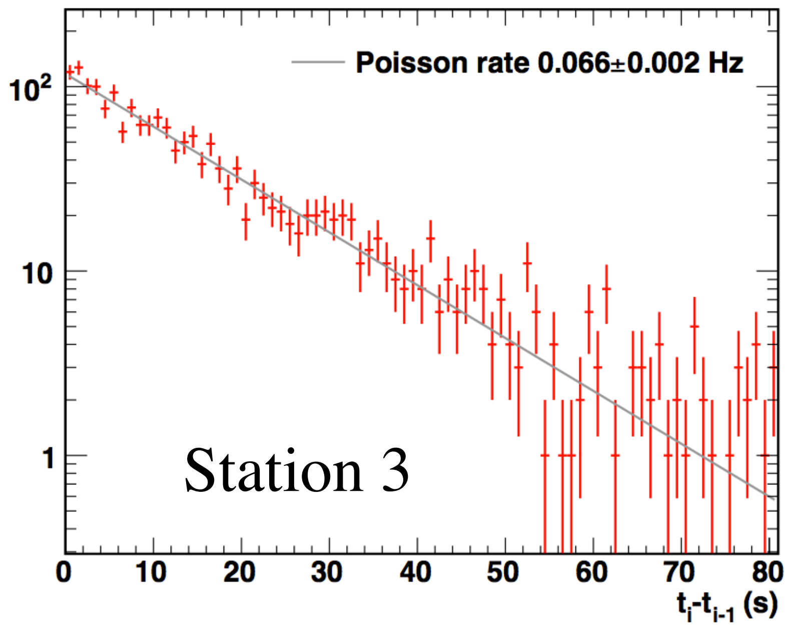
# Trigger Rates vs Wind Speed

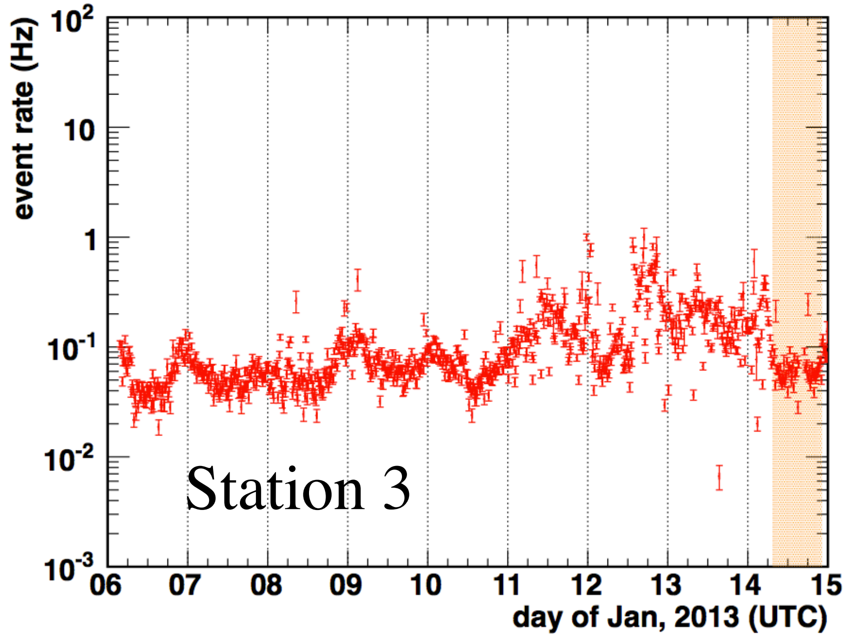


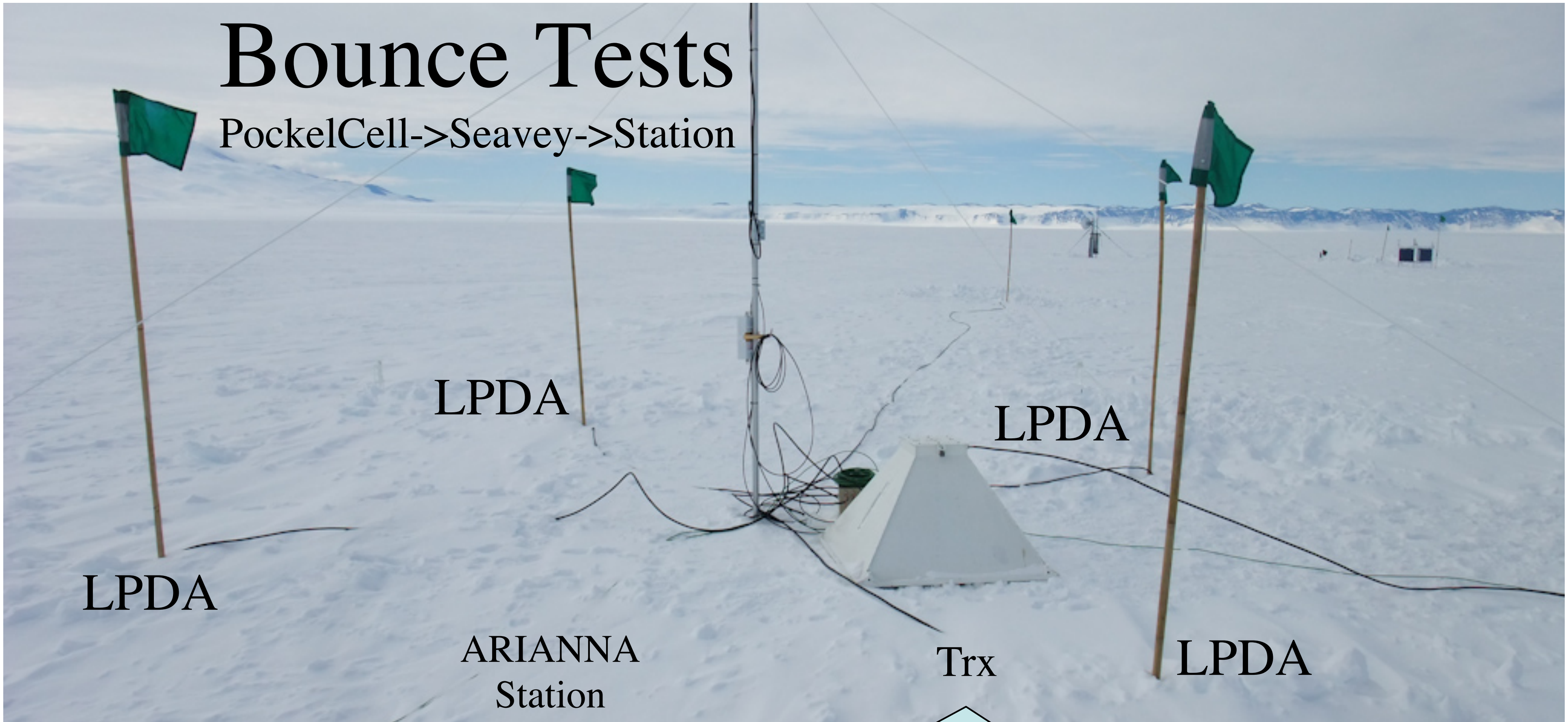

No obvious dependence of trigger rates on wind speed

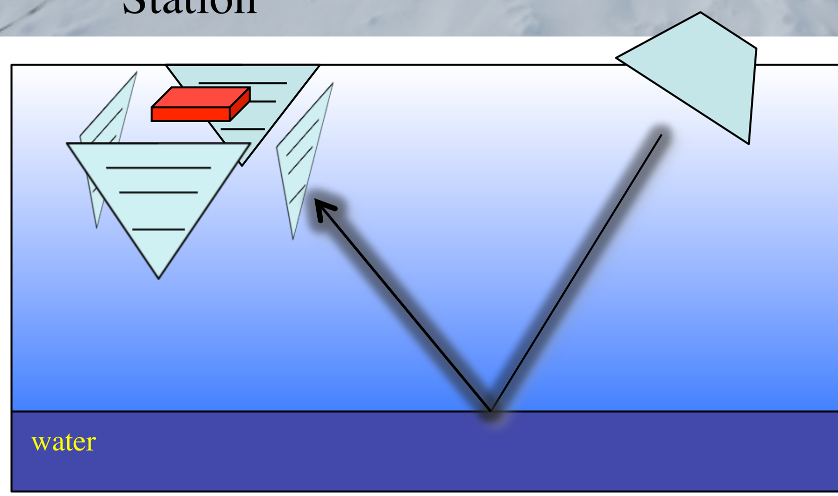
# Rates are random and stable



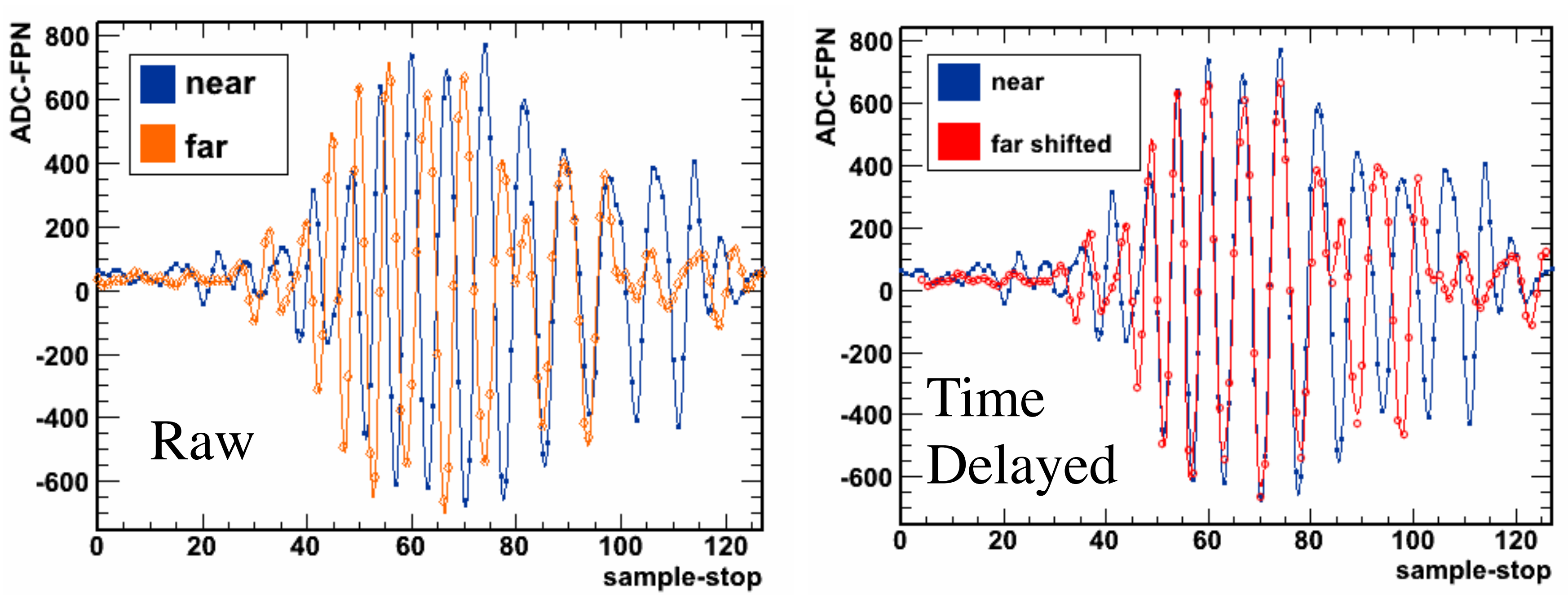

All rate periods show exponential time distributions between consecutive events.


Bounce Tests
PockelCell->Seavey->Station
LPDA
LPDA
LPDA
LPDA
ARIANNA
Station
Trx


water

# Bounce Tests

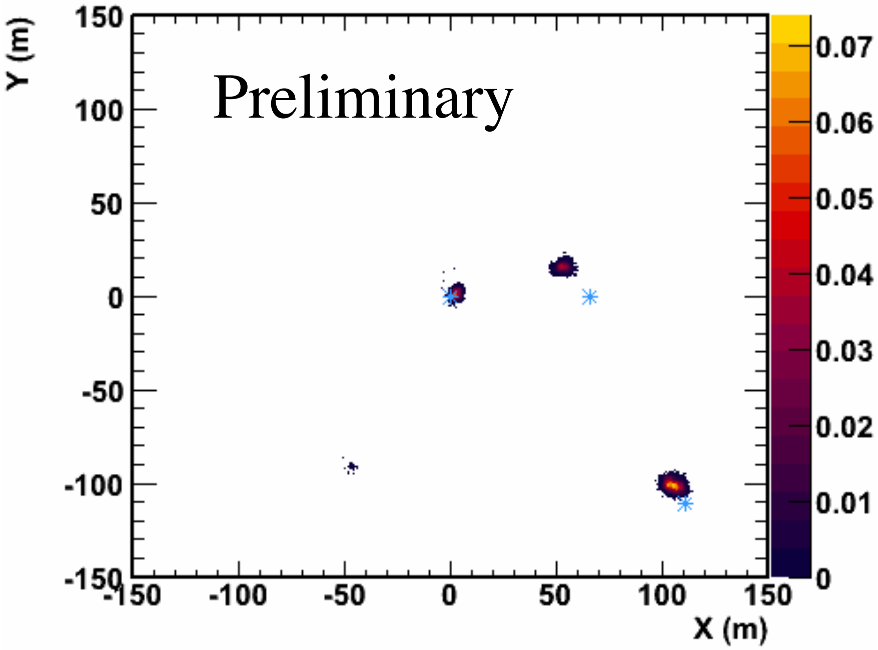
Pulser->Seavey TRX->Station

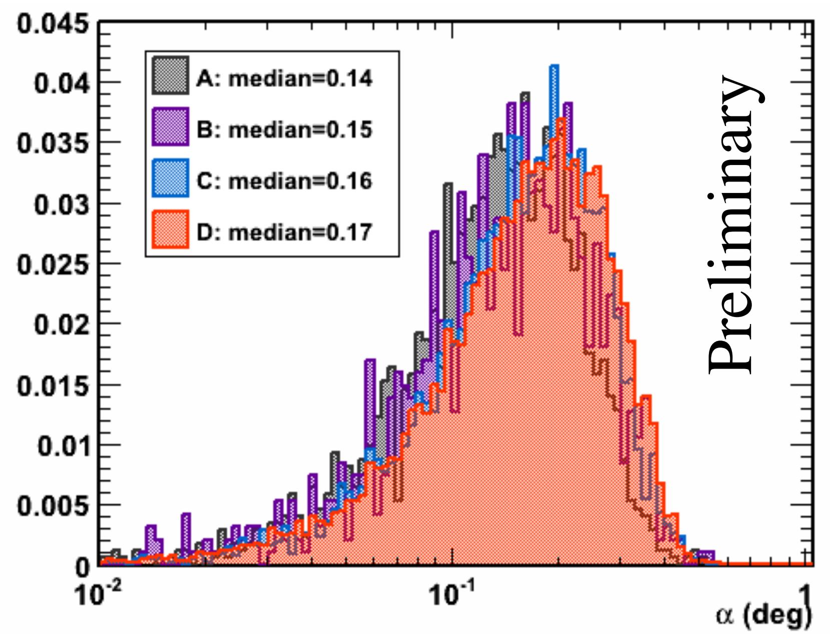



Notes:  Time delays are determined from all 4 antennas, compatible with plane wave

# Bounce Tests

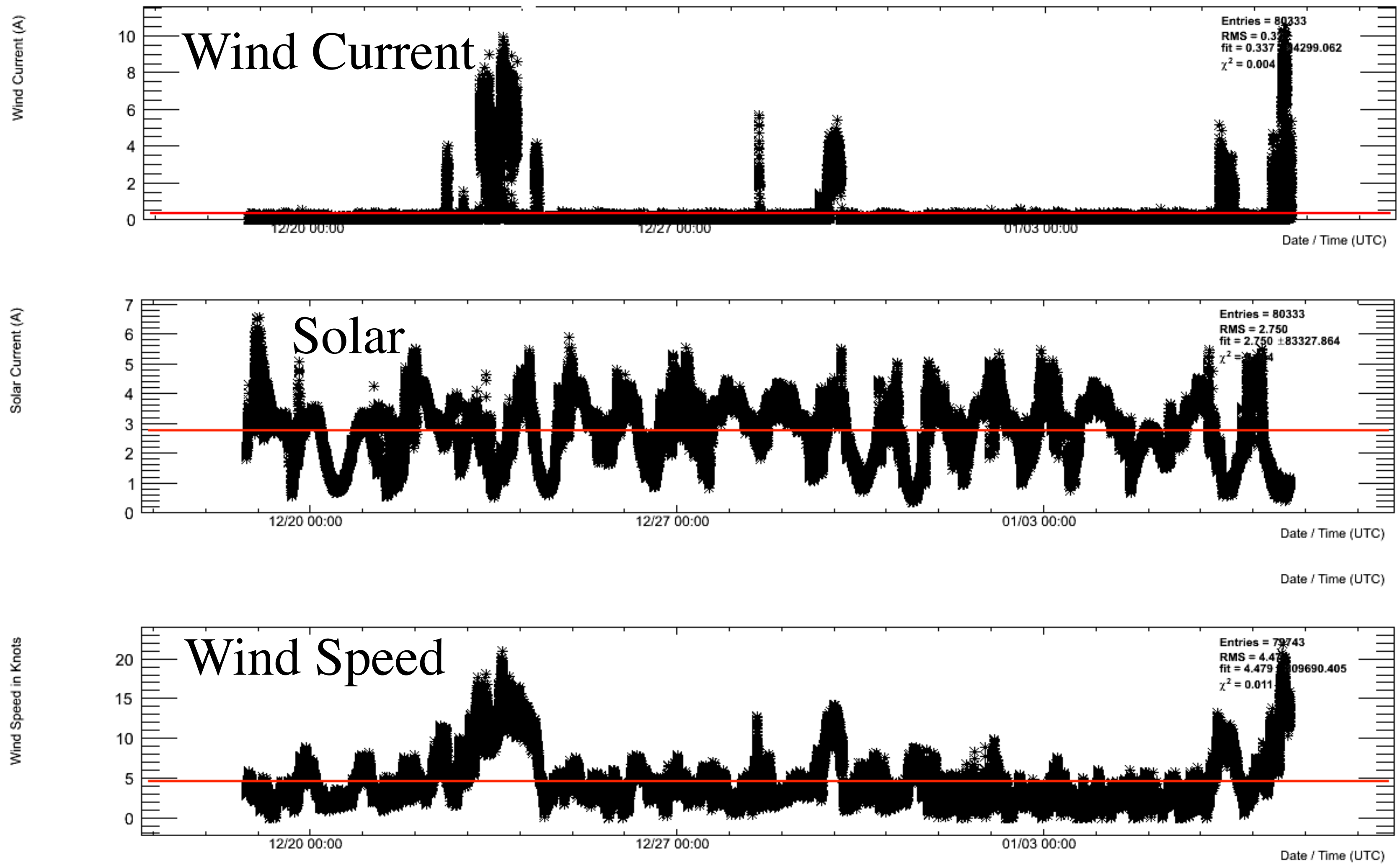
Pulser->Seavey TRX->Station



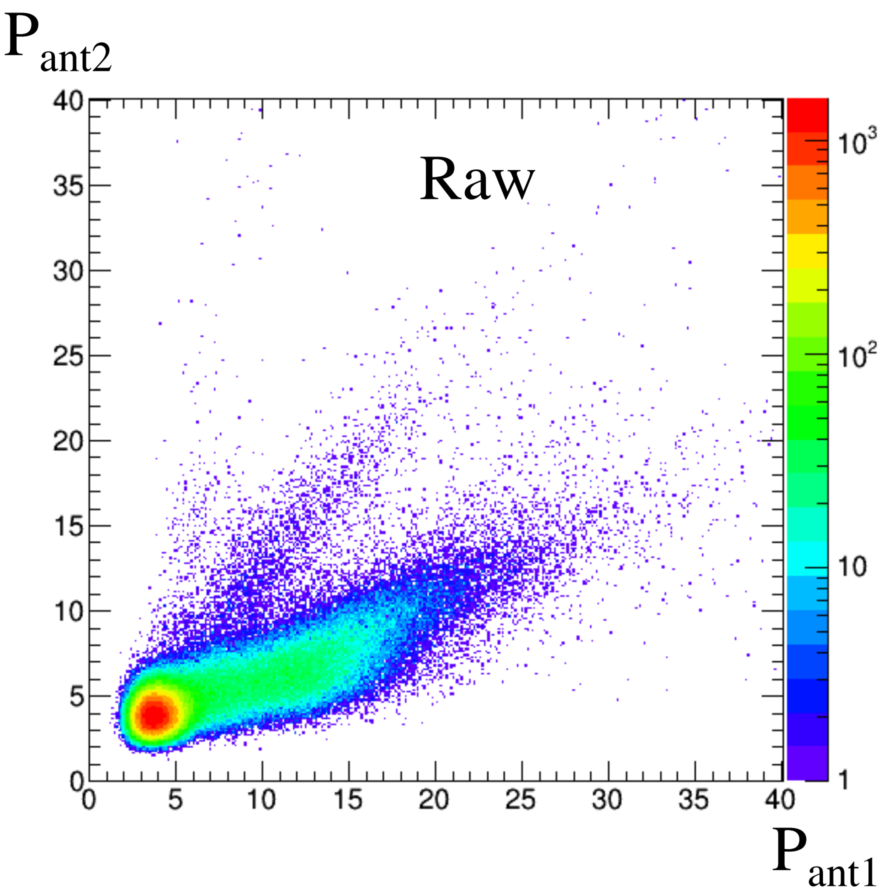

~0.16 deg angular resolution for EM wave

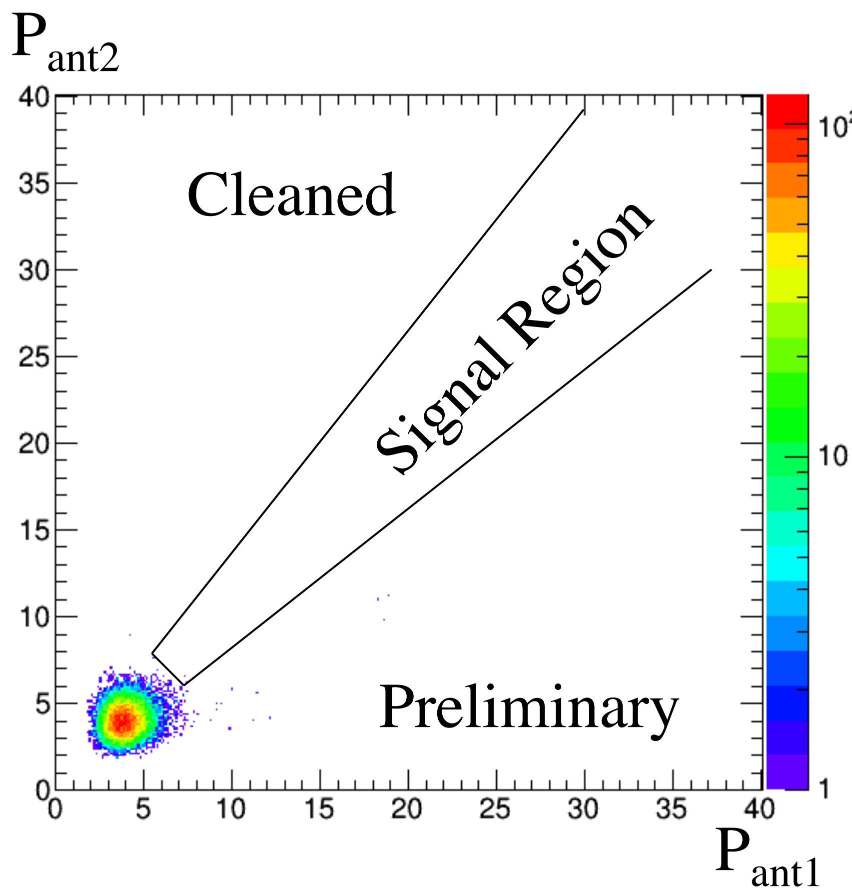
# System Health and Power
## (from solar and wind)



# Data Analysis: HRA Station

(Jan 1-Jan 30, 2013)




Almost complete rejection of BG without timing or event reconstruction

# Summary: So far, so good

- New DAQ electronics function as expected and latest design operates on 10 Watts/station
- Station communicates via high speed wireless and Iridium satellites
- Station automatically restarted during austral spring
- No evidence of impulsive background that resembles neutrinos -> straightforward analysis
- Significant power from wind gen in 2013
- Angular resolution of 0.16 deg of EM plane wave

# ARIANNA Projected Costs

Very hard to give precise number until HRA completed in December, 2013 and full proposal developed by collaboration, but here goes

| | | |
|---|---|---|
| Hardware: $10k/station | ~ 9.6M | target |
| Personnel: | ~10 M | |
| Logistics (3 year install): | ~5 M | guess |
| Total: | ~24.6M | |

# EHE $\nu$ detectors: Comments

EHE neutrino detectors:

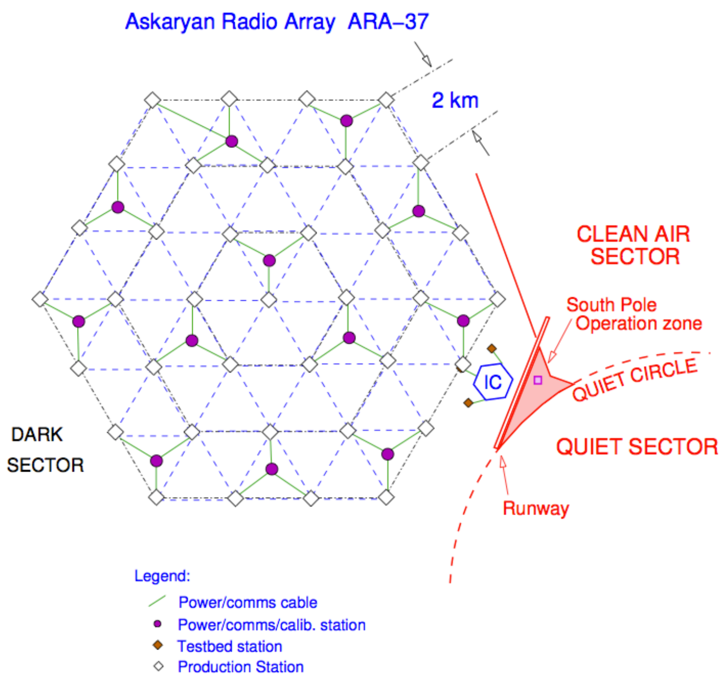
- Contribute to ongoing quest to understand CRs
  - Neutrino measurements provide independent confirmation of GZK mechanism
  - Combined with CR and photon measurements, can help to constrain source class, evolution, Emax, and composition of CR
- Search for new physics
  - Beam of EeV neutrinos can uncover 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 can be improved.

Huge upside at modest cost, development time, deployment and risk

# Backup Slides

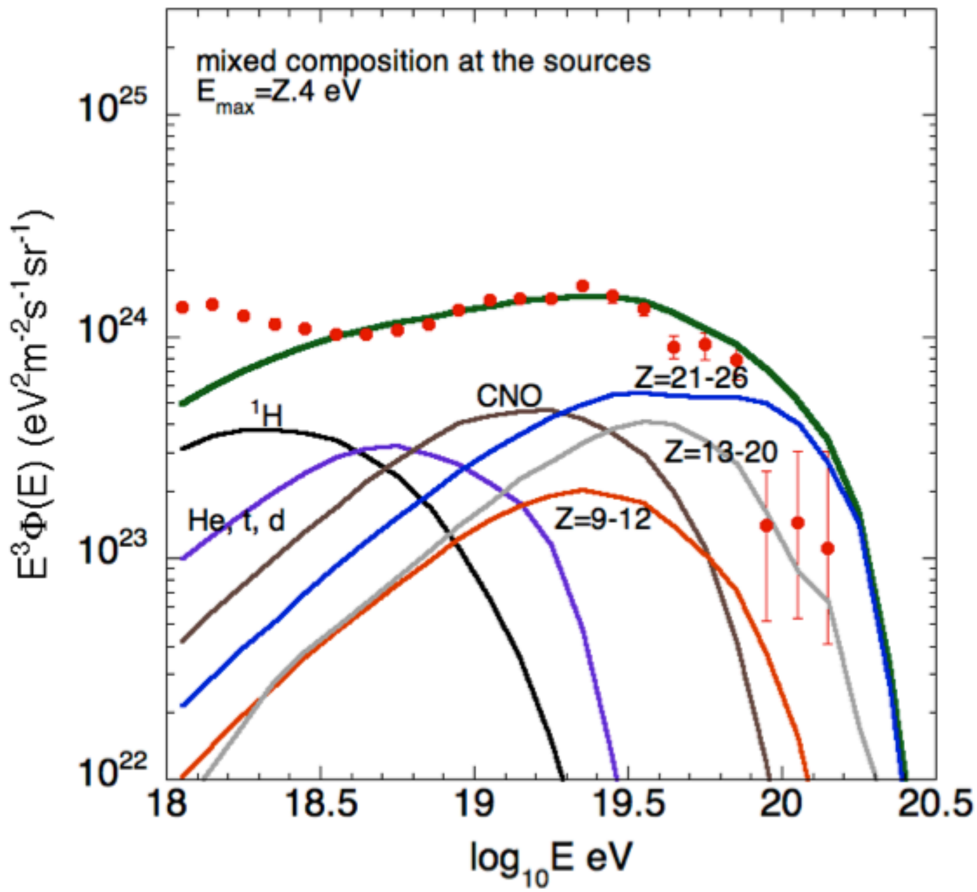
# Askaryan Radio Array: ARA

P. Allison et al., Astropart. Phys 35(2012)457




- Located at South Pole
- Detects radio pulses
- Similar sensitivity to ARIANNA
- Installed two stations this season at depth of 200m; drilling smooth
- Excellent angular resolution

# Low $E_{max}$ Sources



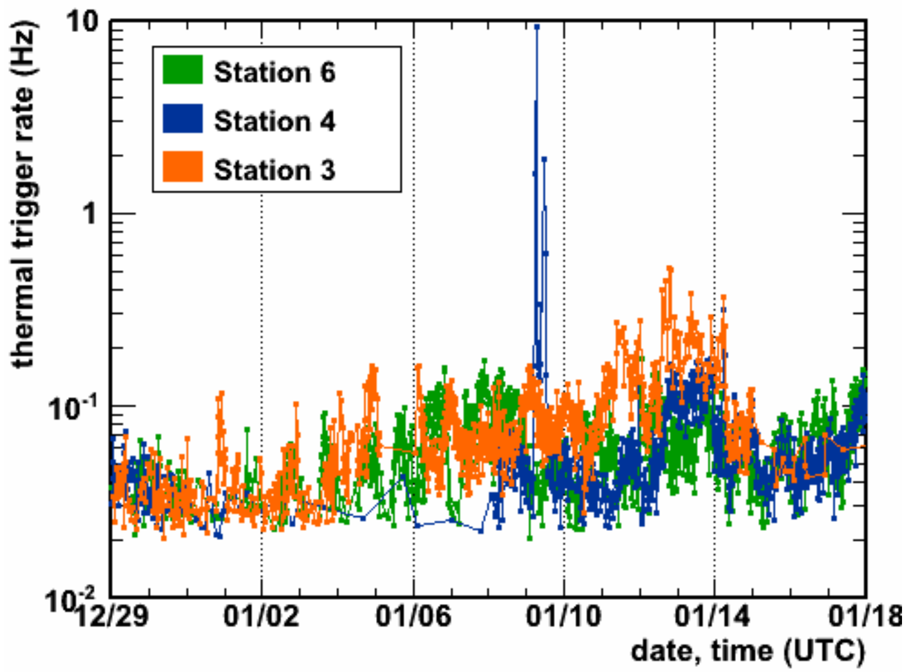

D. Allard, APP 39-40(2012)33

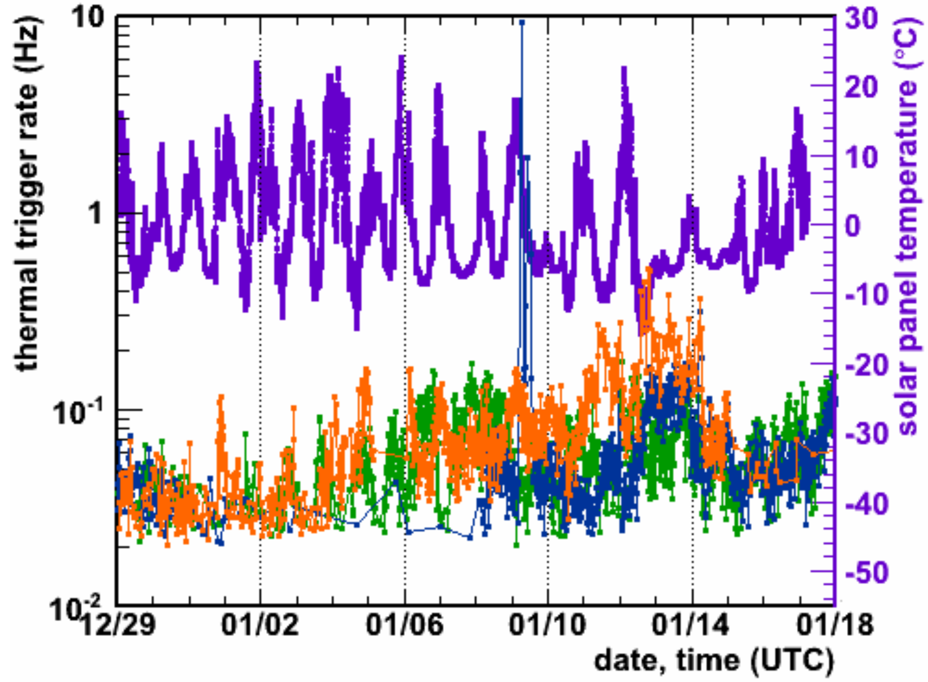
$dN/dE \sim E^{-1.6}$ (very hard)

No magic number at $Zx10^{18.4}$ eV
Every source in Universe cuts off at this energy to prevent photodisintigration?

CR should not point (compatible with Auger anisotropy?)

# Trigger Rates vs Temp

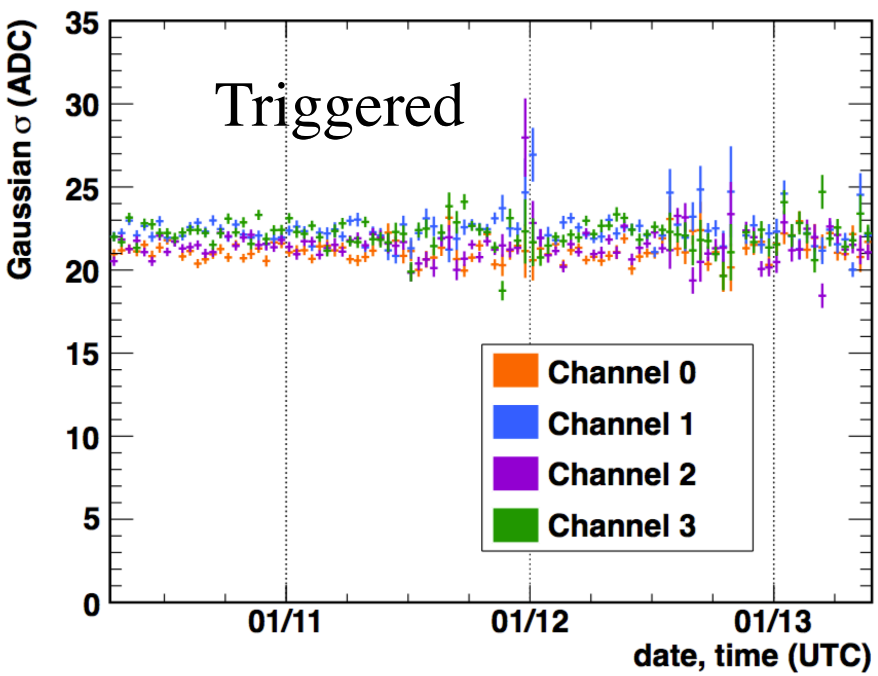


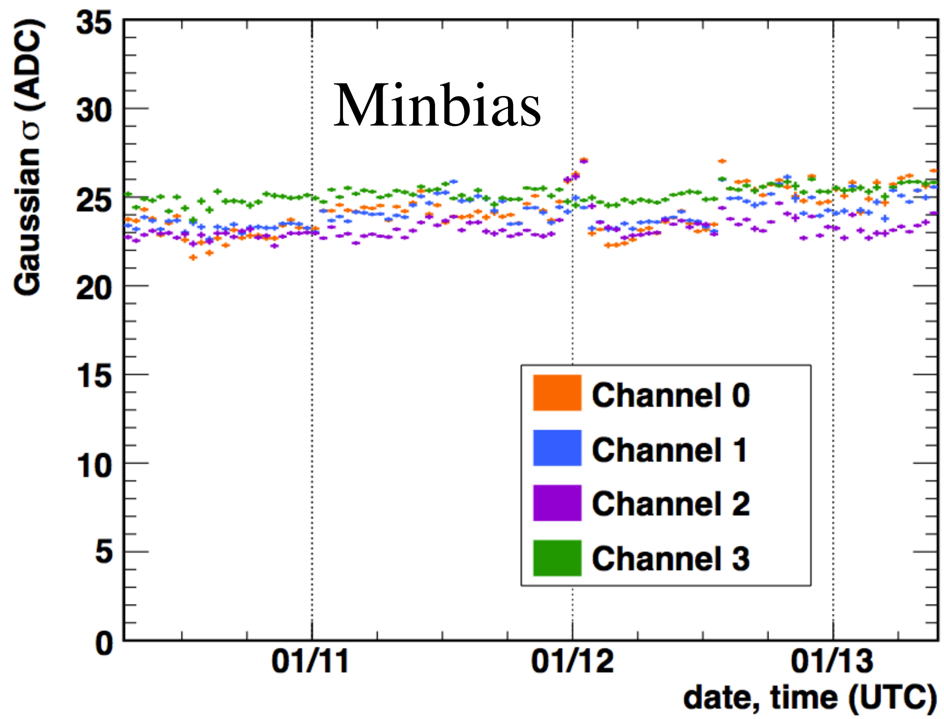




No obvious dependence of trigger rates on Solar Panel Temp

# Noise distributions are stable

Station 3



# Noise characteristics

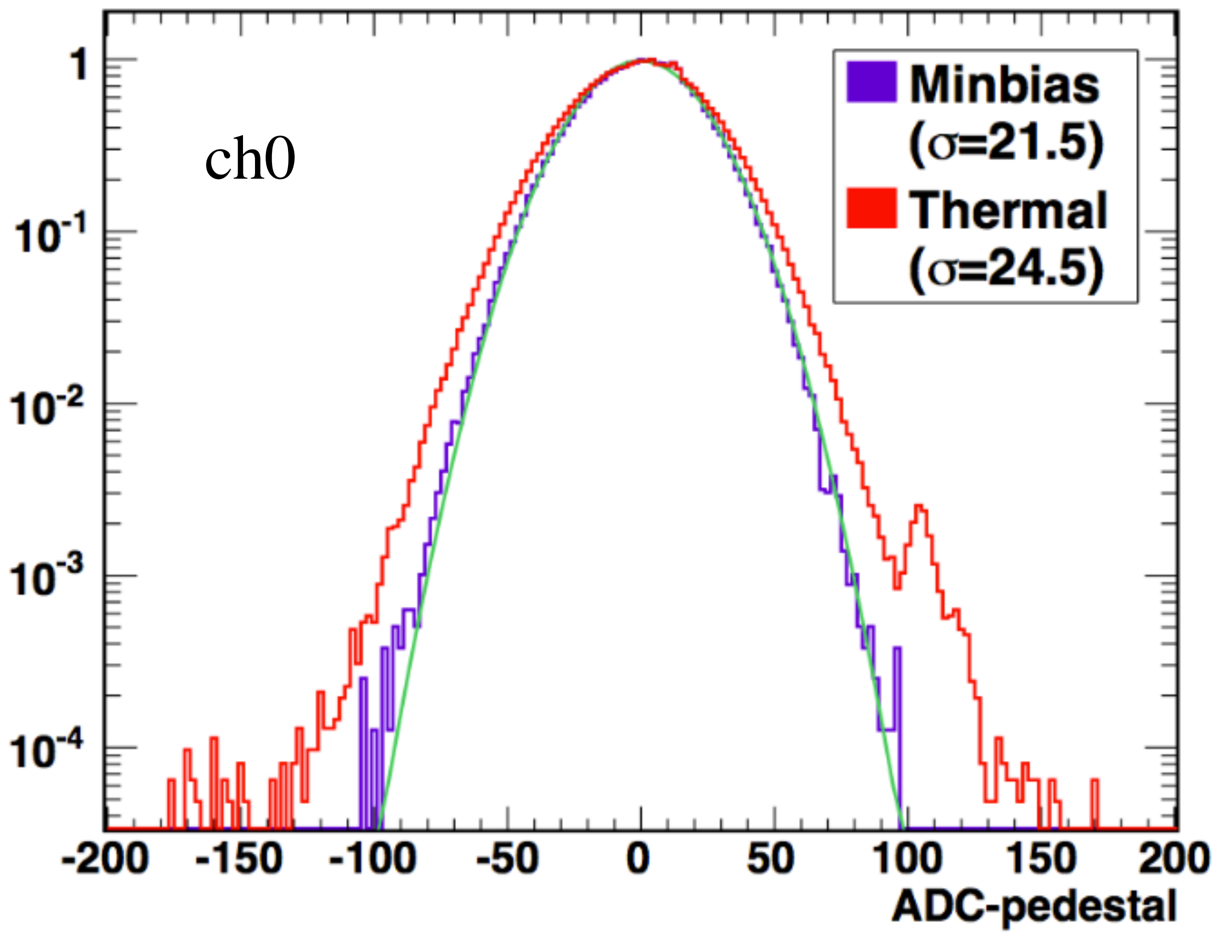
Channel 0 of station 3: all other channels similar

Minbias data is collected by randomly triggering in time.

Thermal data is biased by majority logic trigger

Gaussian structure shows measured noise is consistent with pure thermal

Extra width from trigger is expected. High side peak is artifact of digitizer



1. Installed 3 ARIANNA stations with new technologies and reconfigured one previously deployed station to monitor the environment for a total of 4 operational stations. Features of the new stations:

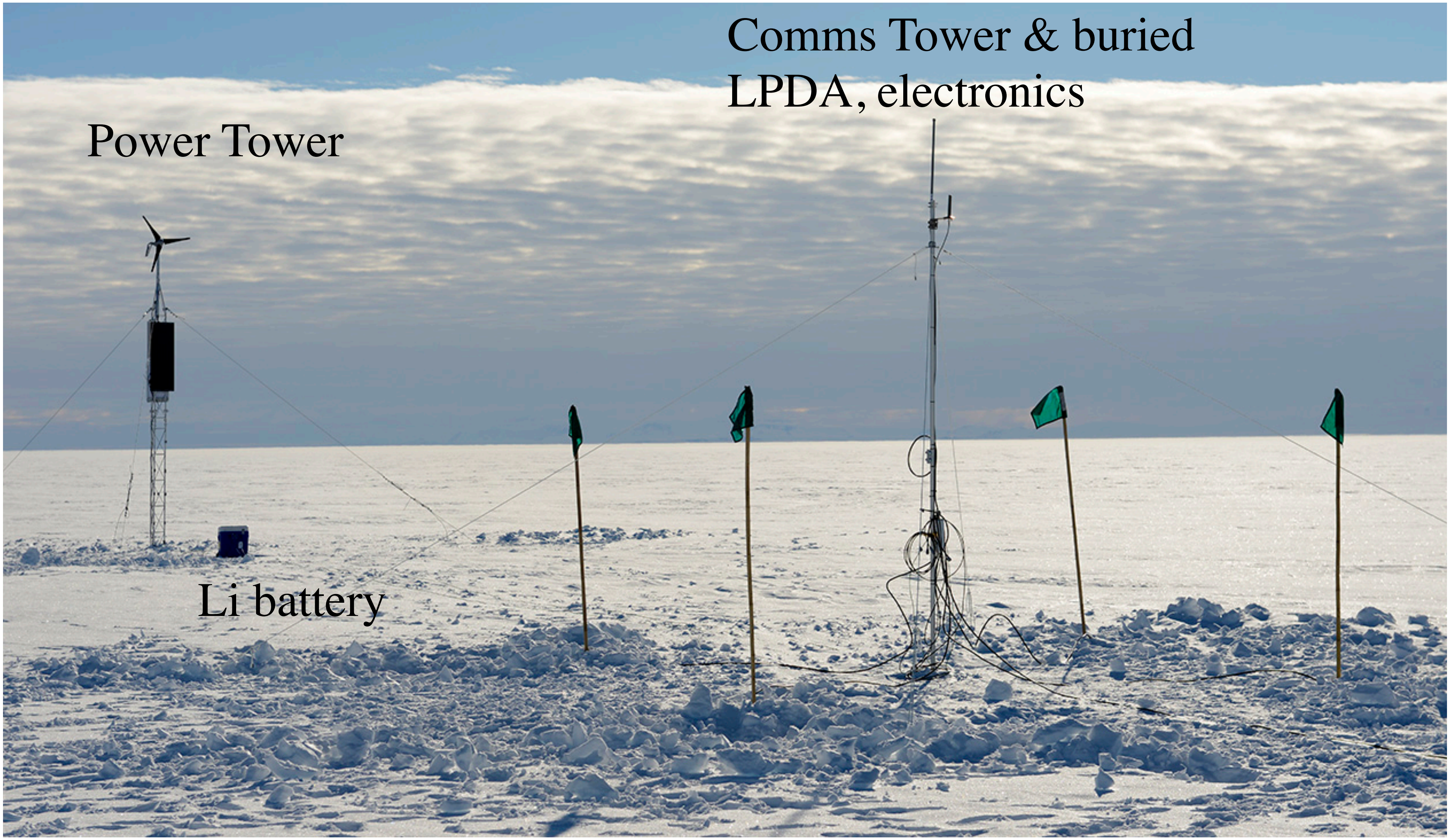
- -low power consumption of 10W on average
- -more robust design of amplifier reduces oscillation. Gain and frequency response matched to data acquisition requirements.
- -reduced cost by eliminating cpu, commerical power convertors, and pulse generator. The last two features were implemented in special purpose board
- -Housekeeping and data calibration implemented in electronic design
- -Lithium battery storage (tested to –30C)
- -improved power tower mechanism – simpler to install, taller, less vibration
- -New wind generator designed for 100mph winds, more efficient in low winds, rated to 200W for 25mph winds
- -increased solar power to 160W to test if station can be powered by sunlight for more than 0.5 year
- -smaller footprint
- -8GB local storage

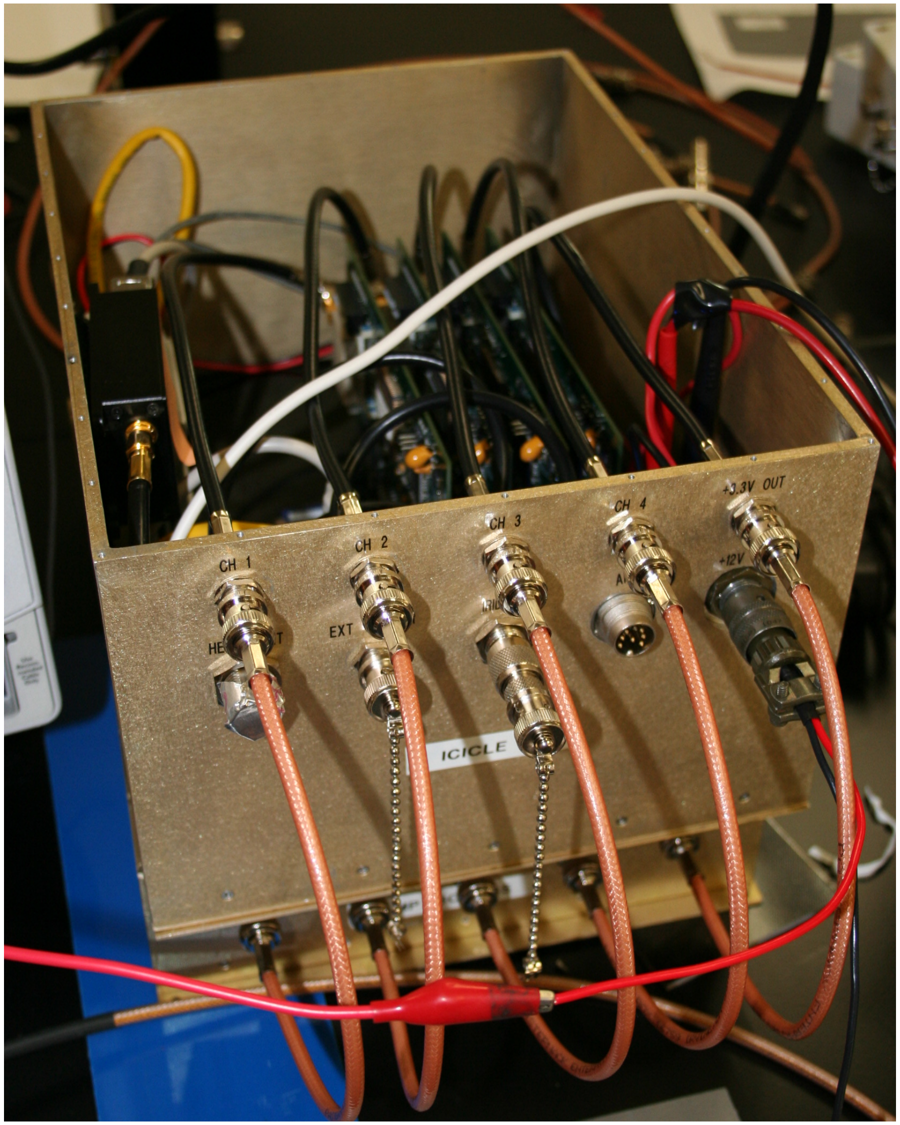
2. Refurbished technology from last season to monitor power from wind, solar to power consumption. Replaced failed Iridium modem.
3. Retrieved wind data for full year at site. Useful input for wind generators
4. Used reflected RF pulses to calibrate timing constants and evaluate angular resolution
5. Learned to reduce time to install power tower, communication tower and station
6. Wireless communication done solely through line of sight communication with transceiver on Mt. Discovery. We no longer require ASC supplied communication equipment at the ARIANNA site.
7, Heavy tower components and camp tents, floors, etc left at site for next season to reduce helo time for science cargo and camp put in.

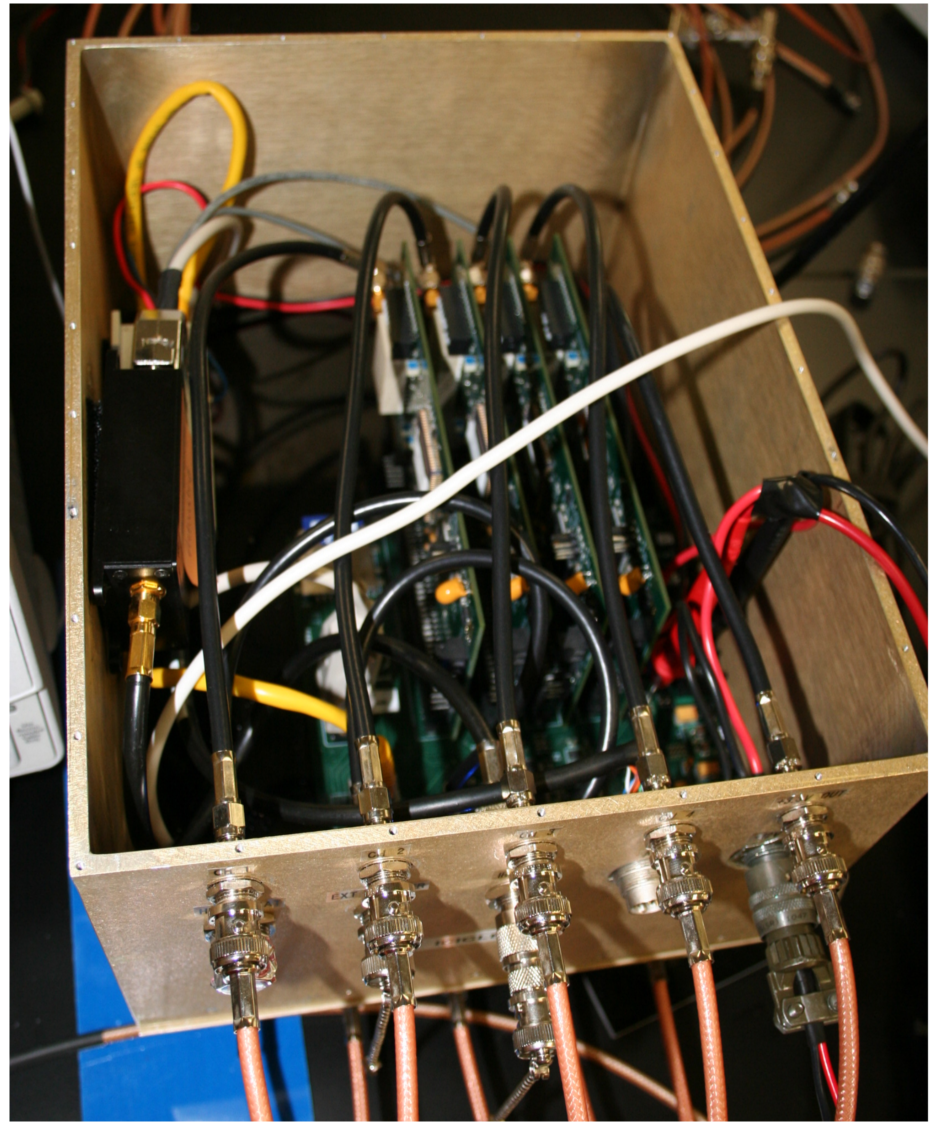
# Preliminary Goals for Dec 2013

1. Focus on cost reduction, deployment speed and overwinter operation
2. Replace 3 current stations with improved MotherBoard power system
    1. Use components rated to 23V
    2. Encapsulate to mitigate radiation leaks through AFAR port
3. Install 4 new stations (including site of monitoring station)
    1. We have 3 complete stations at UCI (or stored in the field) and plan to fabricate 1-2 more
    2. Improve Amp design to reduce costs and match physics
4. Investigate less costly wireless comm for local communication to more central AFAR link. Comm should be coaxial throughout
5. Improve calibration
    1. Bounce tests for all stations
    2. Thorough study of pattern trigger to reduce threshold

# Station Overview

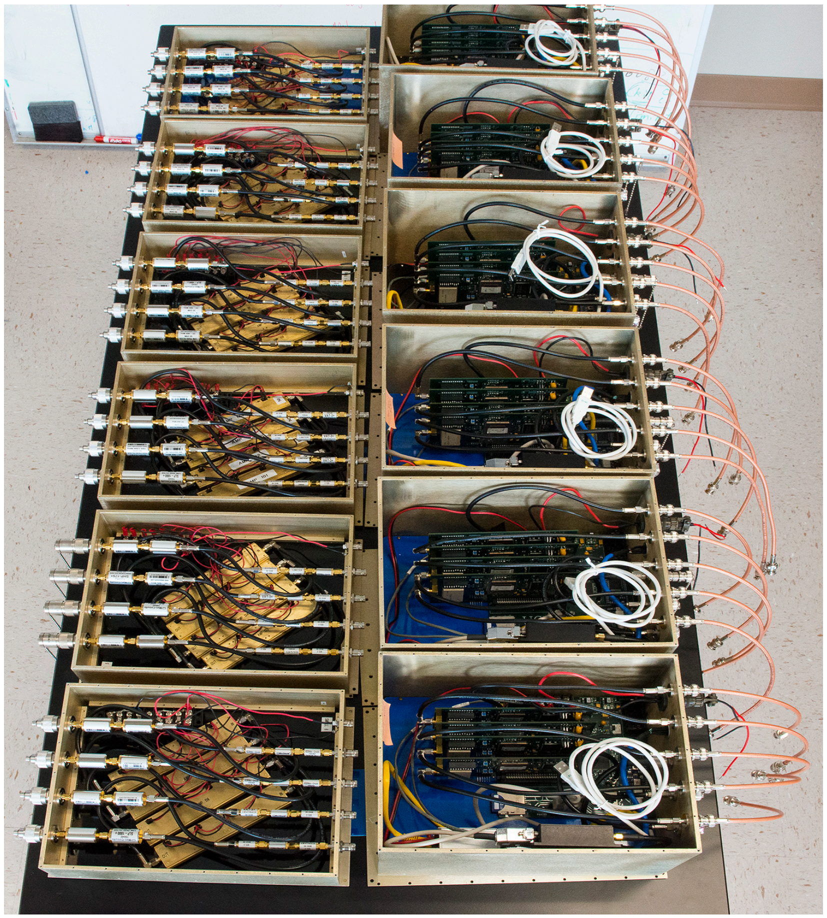




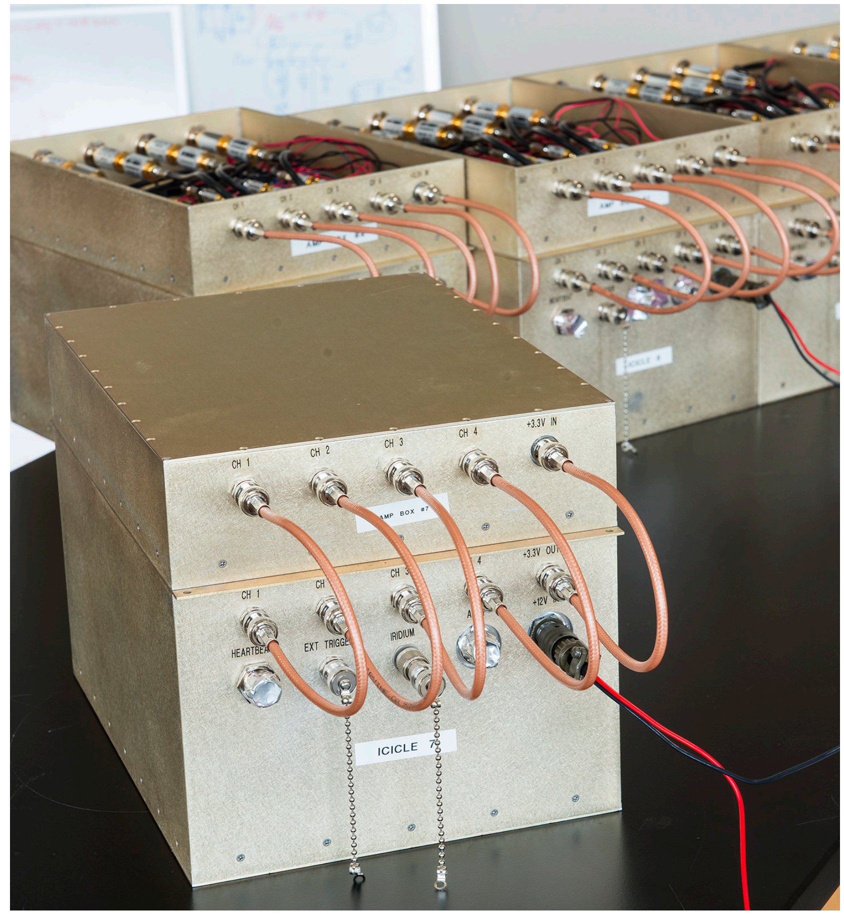


2012: More streamlined design
(smaller, lighter, less costly, more robust)

# “Mass” production



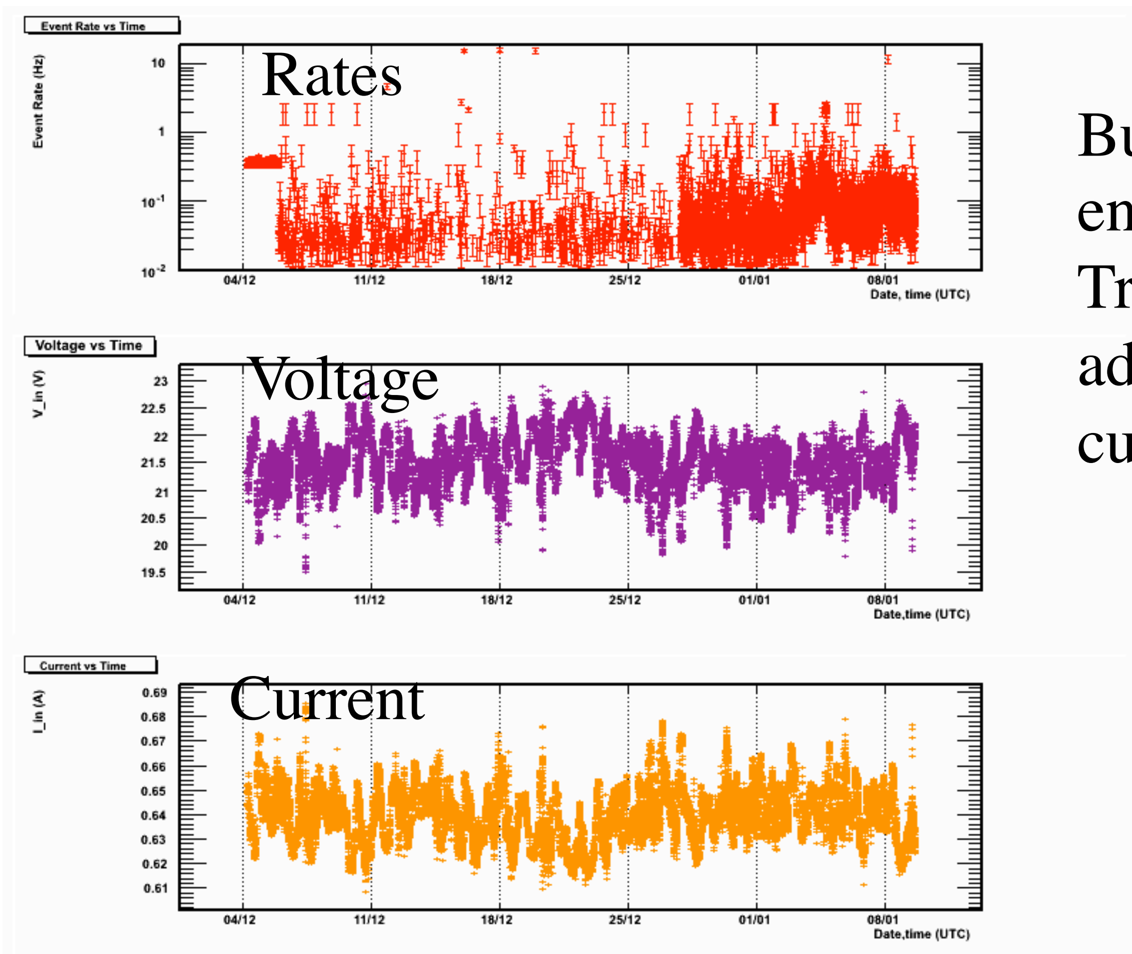
2012:
6 DAQ ready for integration




2012:
6 DAQ ready for calibration

# Trigger rates

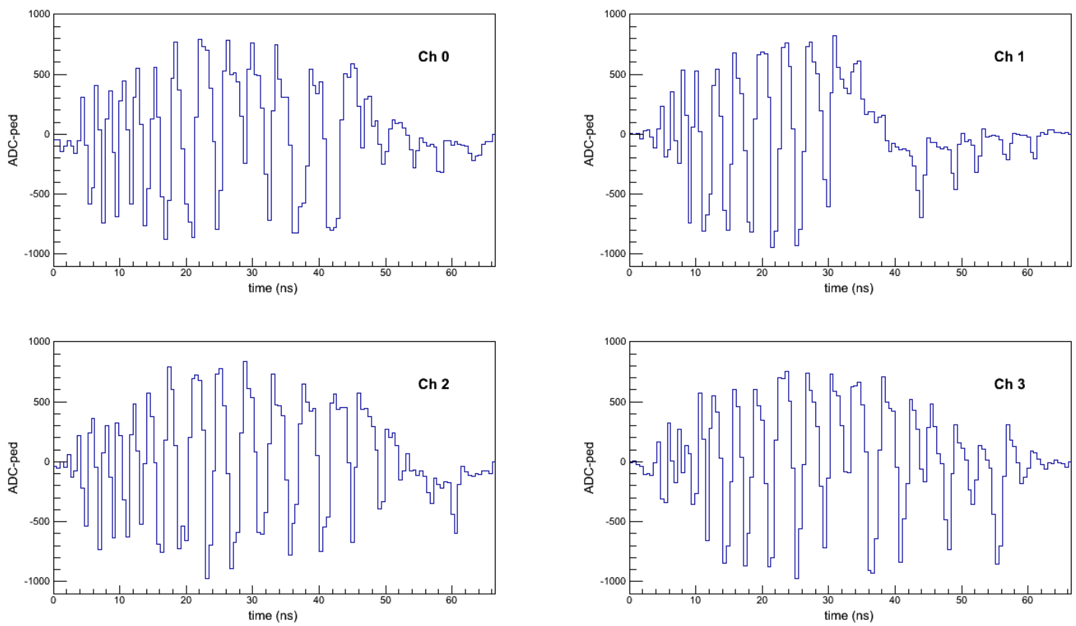
http://arianna.ps.uci.edu/~arianna/status/cstatus3.html
http://arianna.ps.uci.edu/~arianna/status/cstatus4.html
http://arianna.ps.uci.edu/~arianna/status/cstatus6.html




But rates are stable enough and low enough. Trigger thresholds adjusted several times, but currently are ~$5.5V_{rms}$

# Bounce Tests (0 deg)

PockelCell->Seavey->Station




Notes: RF Signals are strong, arrive within 2ns of each other so ice related and electronic/cable related delays are small. Ch1 feature at 30ns due to saturation of ATWD. Took data at station and 180m from station to measure angular resolution.


ARIANNA

ARIANNA

# Trigger Rates: What have we learned

1. In January 2013, there are short episodes of extra power at ~150MHz on 6 different occasions, which turn on and turn off quickly (perhaps related to helo activity). These events impact live time at very small levels and do not mimic neutrino signatures.
2. In Feb 2013, there are no episodes of extra power (compatible with reduced helo activity).
3. In Feb, there are diurnal rate changes correlated with ambient temp. There are rate changes associated with cold fronts and longer term trends of decreasing temp.
4. Amp noise is not getting worse during the cold periods, so rate changes are due to temp dependence of trigger thresholds. Slight adjustments required.