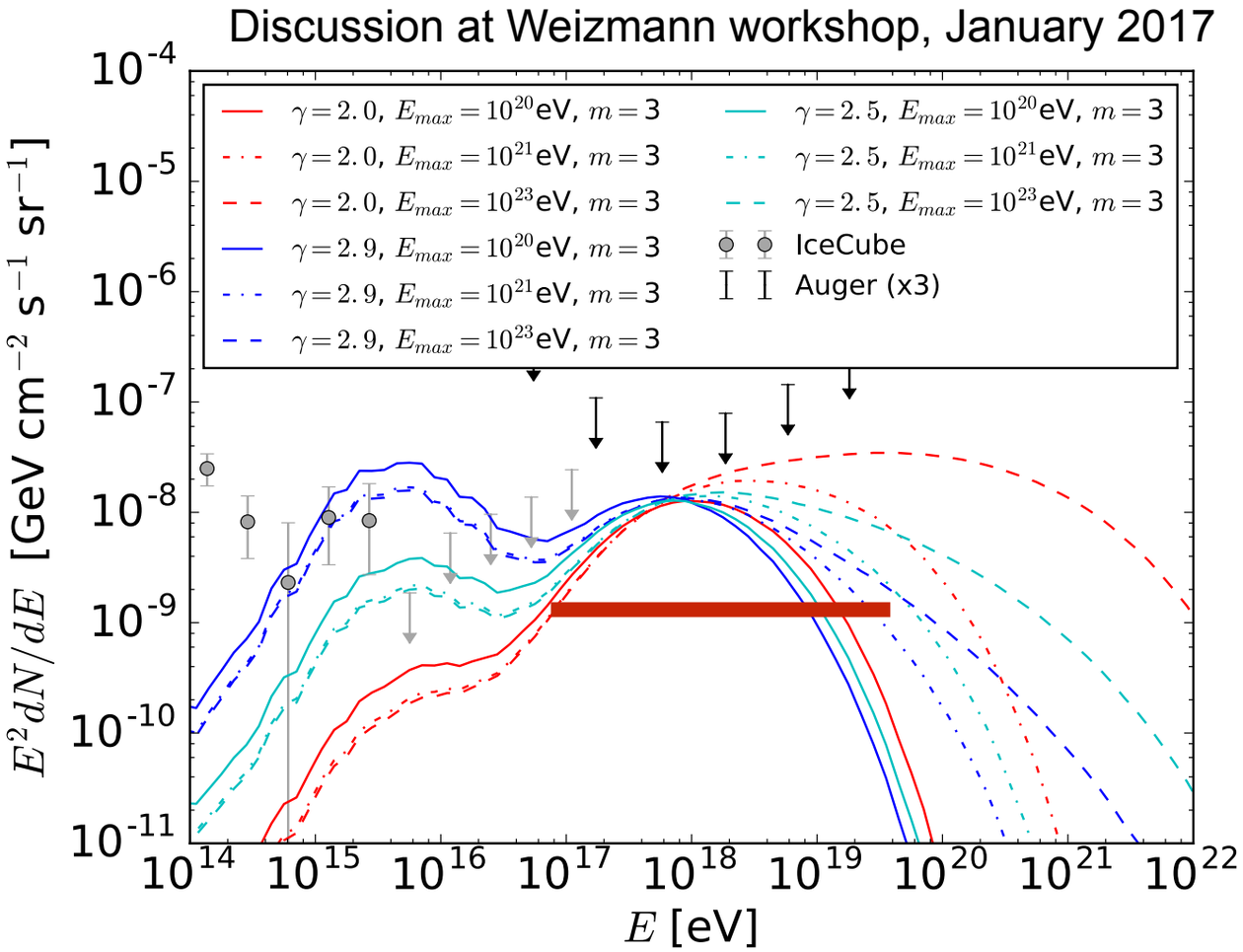
Highlights from ARIANNA

Anna Nelles
University of California Irvine

Detecting cosmogenic neutrinos

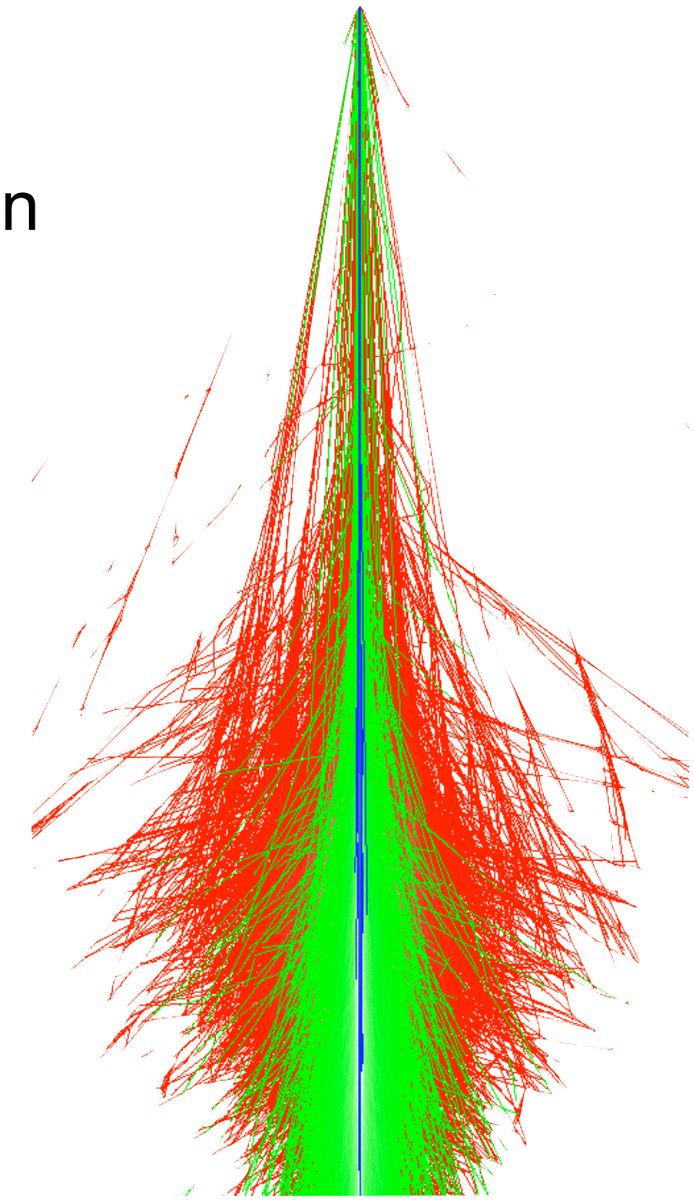


"Flux limit needed to exclude that all cosmic rays at the highest energies are protons"

- Various flux predictions depending on composition, source evolution, maximum acceleration energy, ….
- Need a detector with a significant bigger effective volume than IceCube to have a solid chance of detection
- Optical detectors are currently cost prohibitive at these scales
- Alternative:
  Radio detection of neutrinos

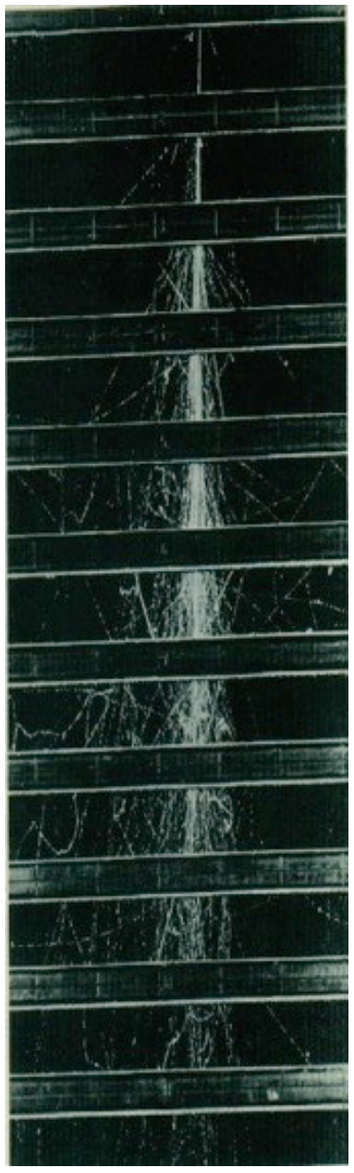
Radio emission of showers

- High energy particles interacting in dense medium (or atmosphere) likely to produce shower
- Electromagnetic part of shower creates radio emission
- Three ingredients:
  - (Geo-)**Magnetic field**
    Lorentz-force deflects particles that are created
  - **Charge imbalance,** “Askaryan effect”
    shower accumulates electrons from medium
  - **Relativistic compression**
    Cherenkov-like effects due to index of refraction



- This theory holds, as shown with air shower experiments such as LOPES, CODALEMA, AERA, LOFAR, Tunka-Rex

Emission of showers in dense media

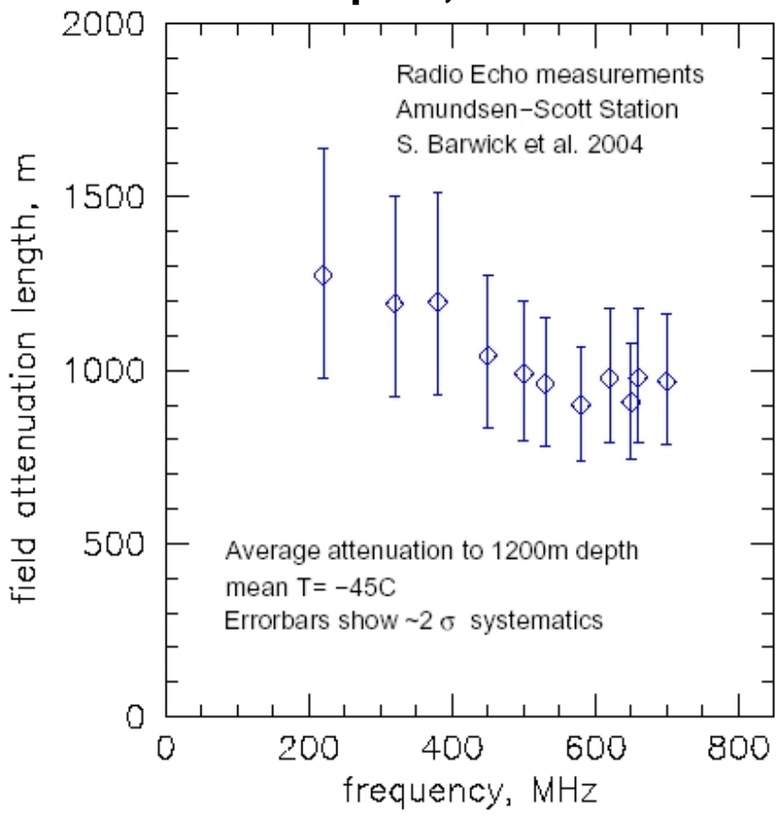


- Same emission mechanism as in air showers, however:
  - Charge excess emission becomes dominant process
  - Shower is shorter, so high frequencies become more relevant
- Emission confirmed in accelerator experiments at SLAC, for both with magnetic field (Belov et al., ICRC 2015) and without magnetic field (Phys. Rev. D 72(2005)023002)
- Simulations predict measurable neutrino signal > 10^{16} eV in radio above “normal” backgrounds
- First experimental detection of neutrino still to be done

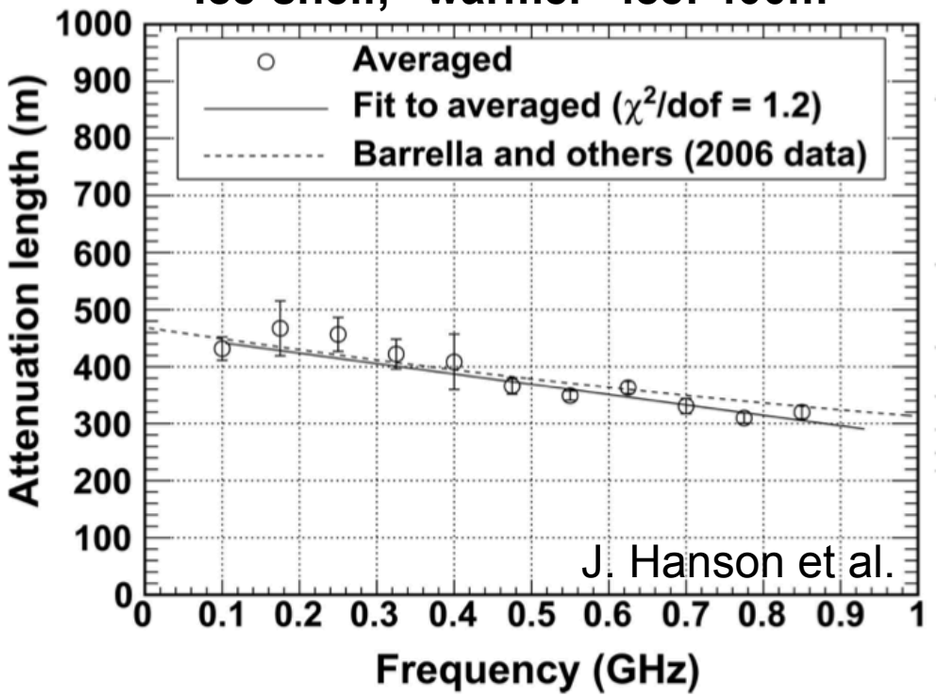
Going polar

- Large volumes of dense medium with reasonable attenuation length, at no cost

South pole, cold ice: 1km

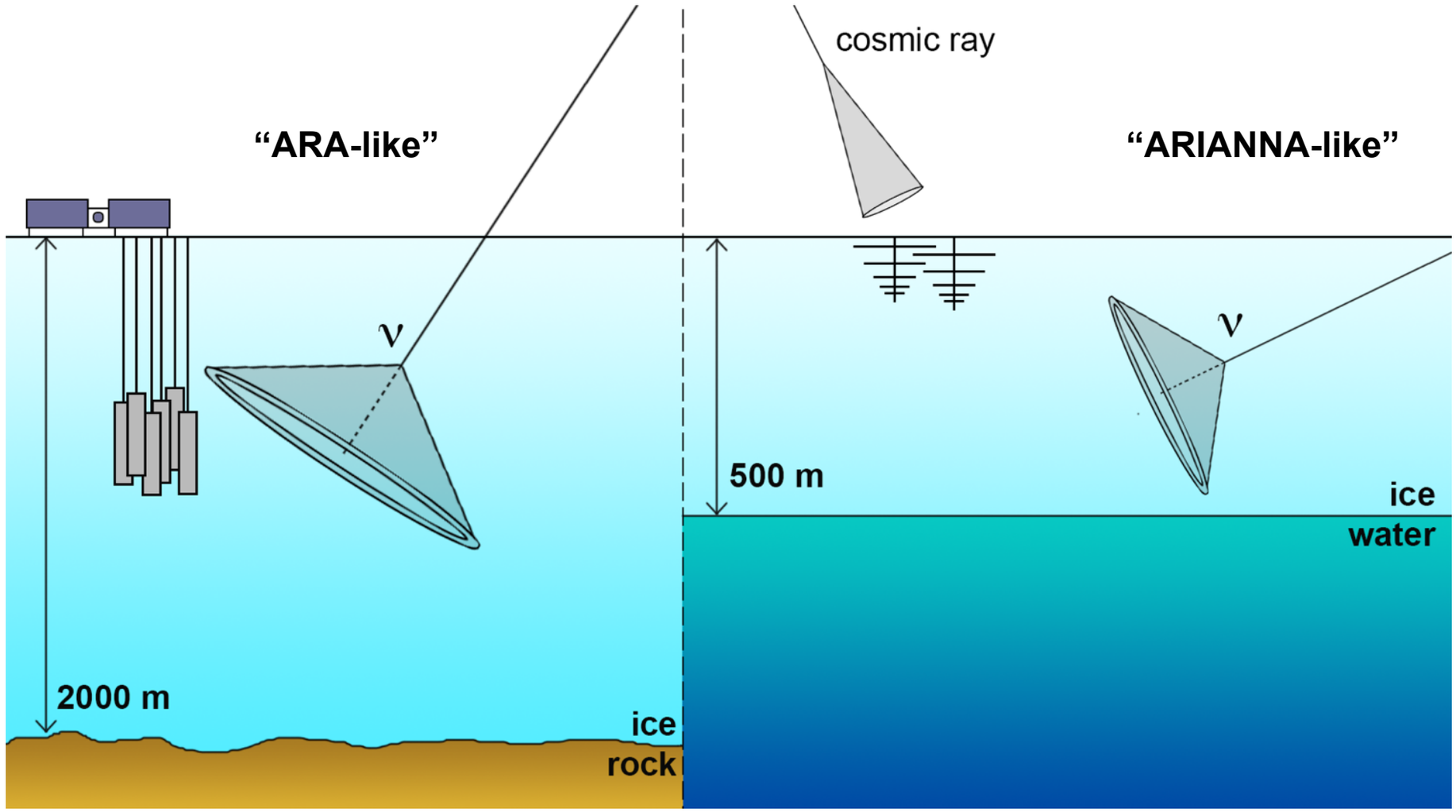


Ice-shelf, "warmer" ice: 400m



J. Hanson et al.

Same idea, different approaches



- Antennas deep vs. shallow
- Dipole antenna vs. log-periodic dipole antennas
- Run by a station vs. autonomous detectors
- South Pole vs. Ross Ice-Shelf
- Different electronics and trigger concept
- …

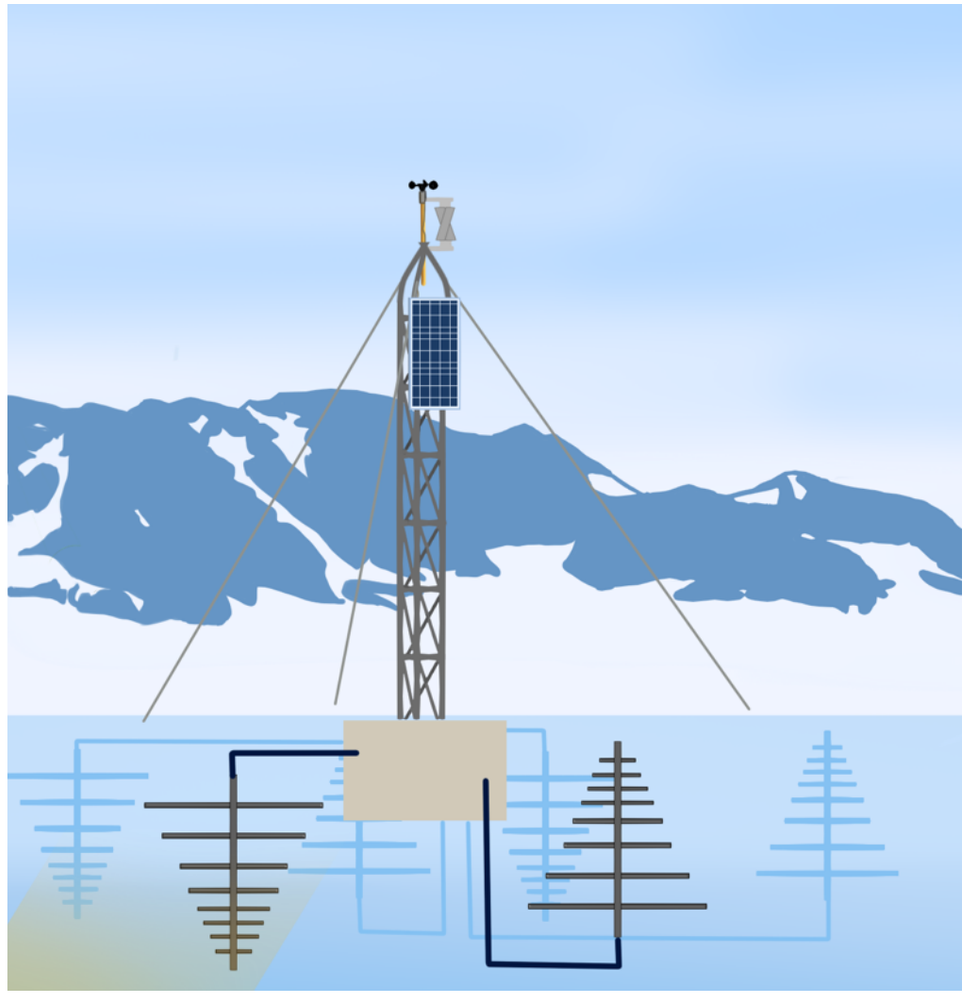
Concept of ARIANNA

- **Independent antenna stations** can be installed at low costs on the surface

- **High gain antennas** (50 - 1000 MHz) can be used to instrument a large volume

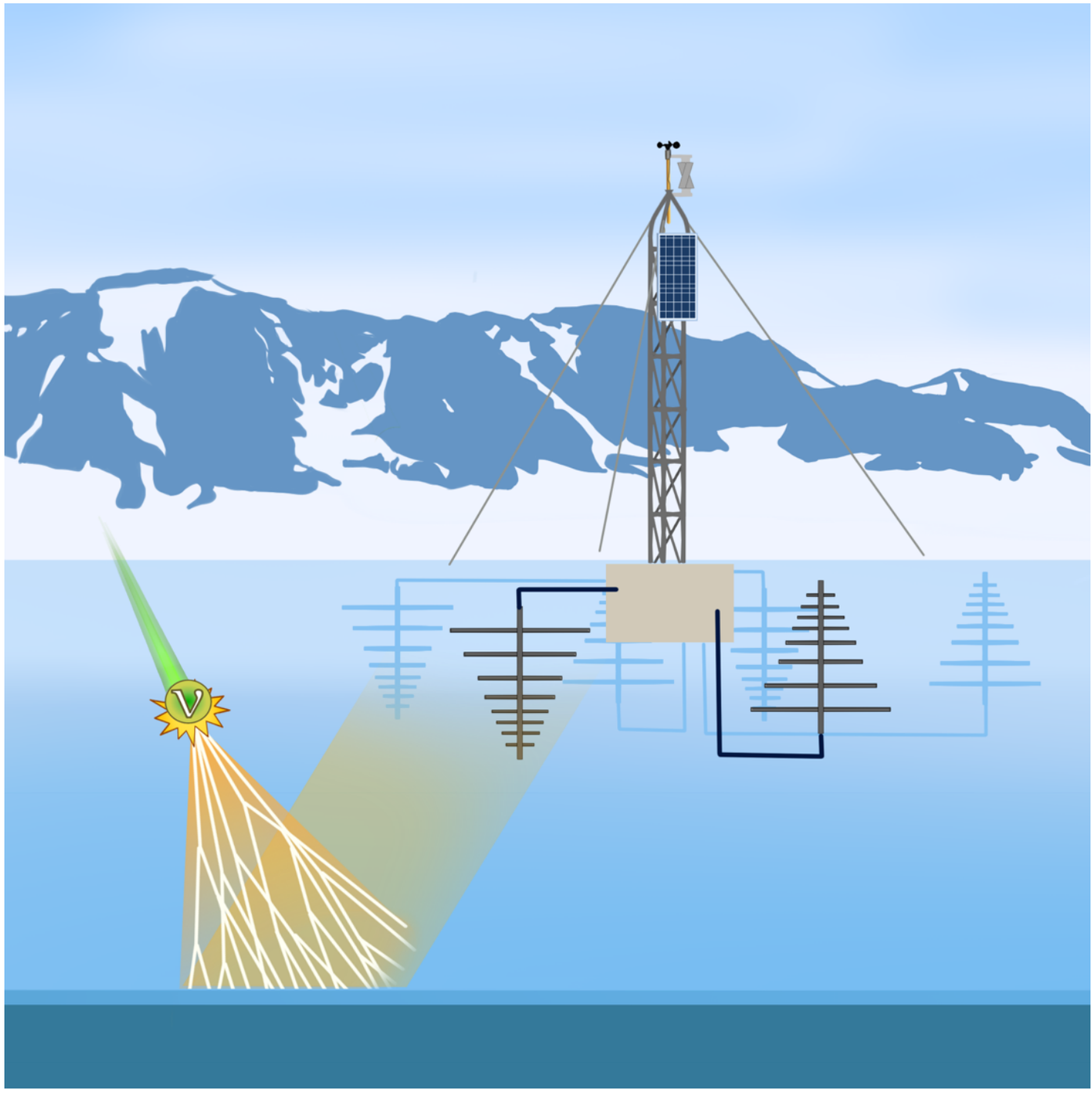
- Solar and wind power making the stations fully autonomous

- **Real-time data transfer** via satellite or long-range wifi



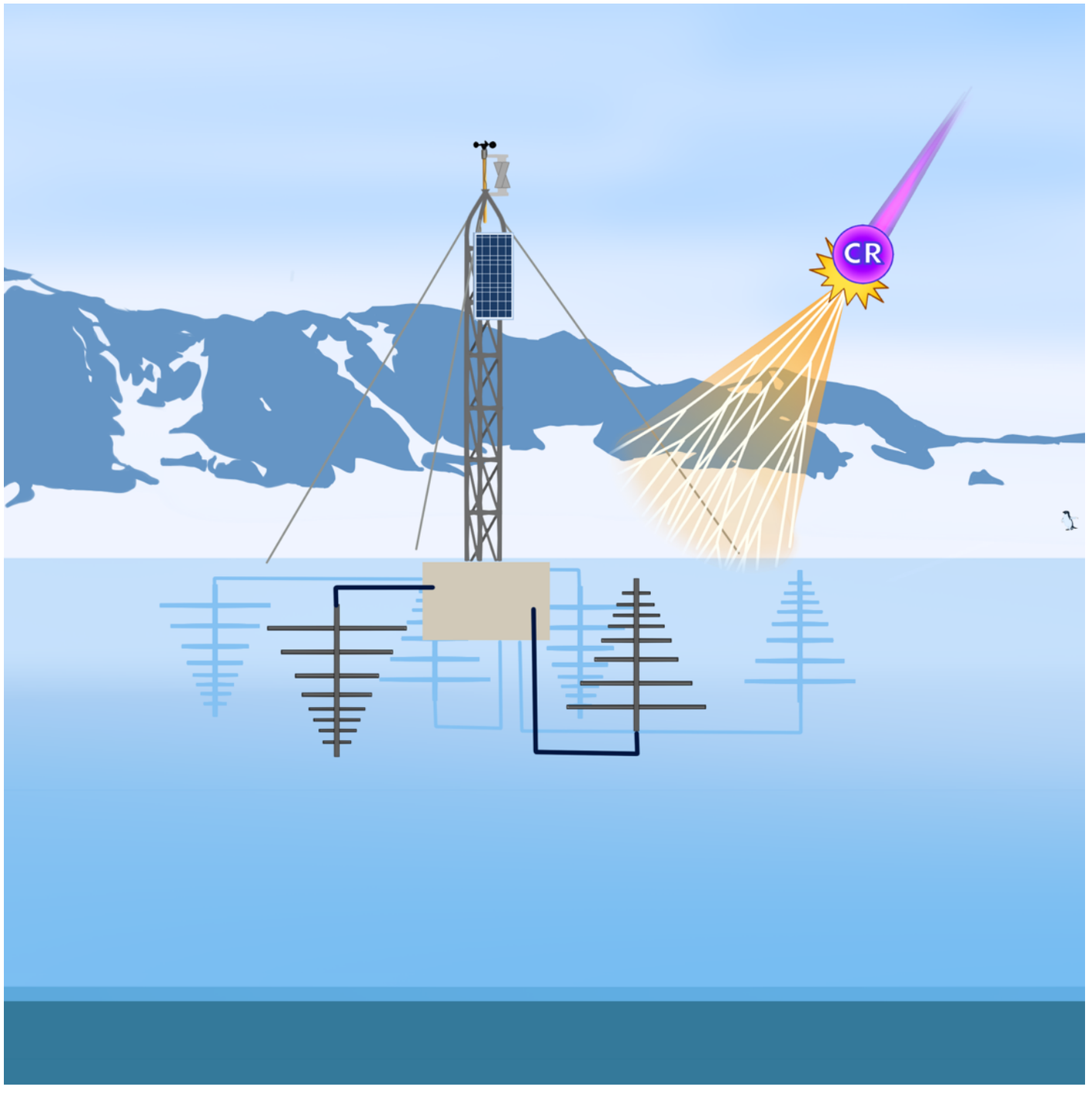
ARIANNA

- **Independent antenna stations** can be installed at low costs
- **High gain antennas**
- Solar and wind power making the stations fully autonomous
- **Real-time data transfer** via satellite or long-range wifi
- On ice-shelf: **Ice-water boundary** almost perfect reflector for radio emission in addition to direct signals from neutrinos

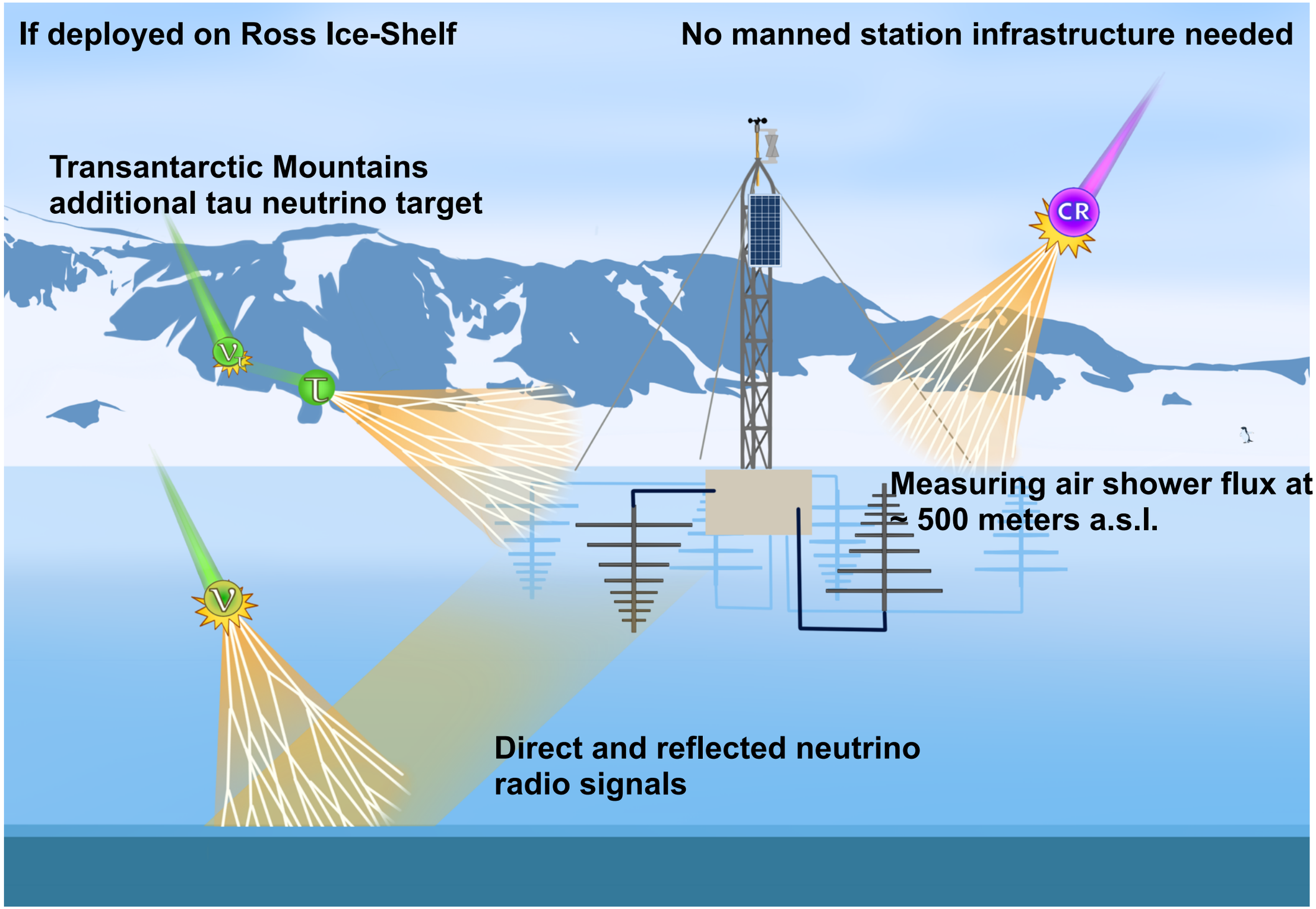


Concept of ARIANNA

- **Independent antenna stations** can be installed at low costs
- **High gain antennas**
- Solar and wind power making the stations fully autonomous
- **Real-time data transfer** via satellite or long-range wifi
- Surface deployment: ARIANNA array would also be very large cosmic ray / gamma ray array

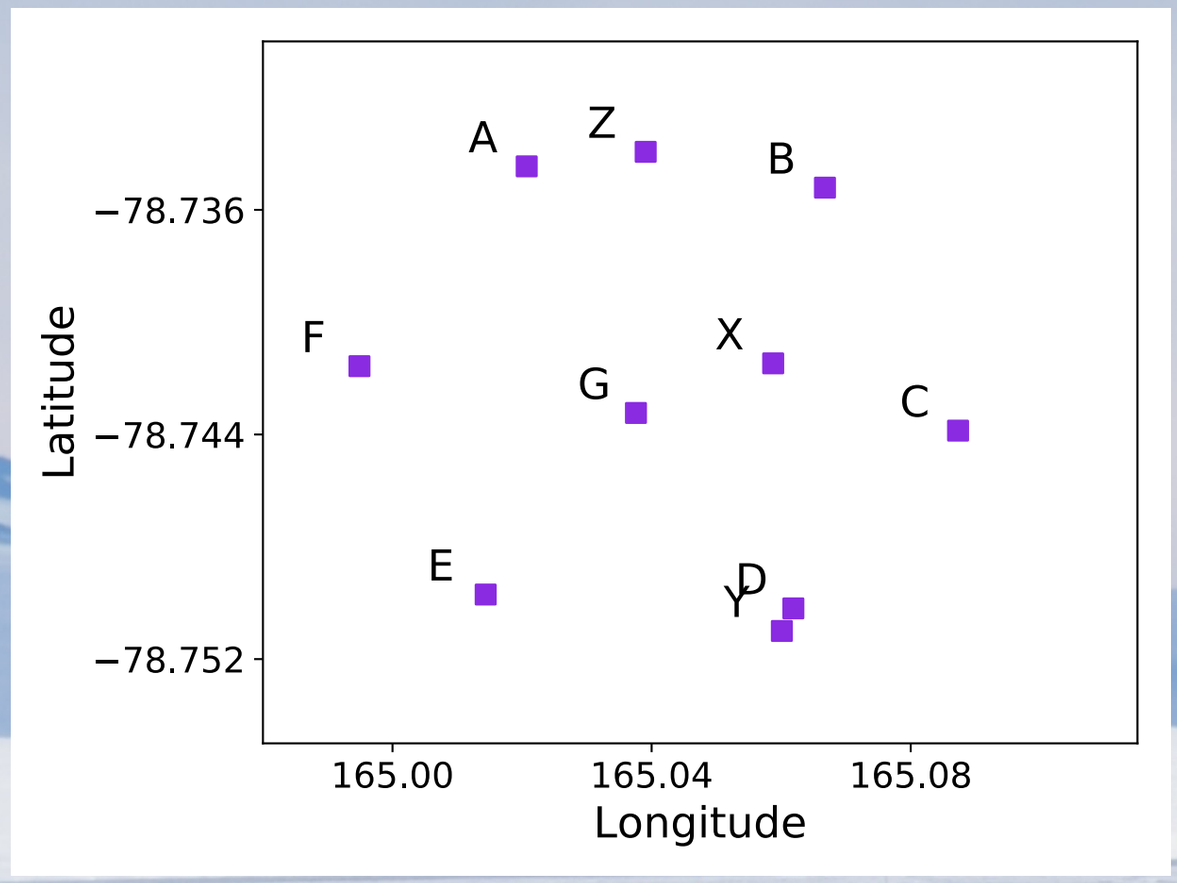


ARIANNA


If deployed on Ross Ice-Shelf
No manned station infrastructure needed
Transantarctic Mountains
additional tau neutrino target
CR
Measuring air shower flux at
~ 500 meters a.s.l.
Direct and reflected neutrino
radio signals

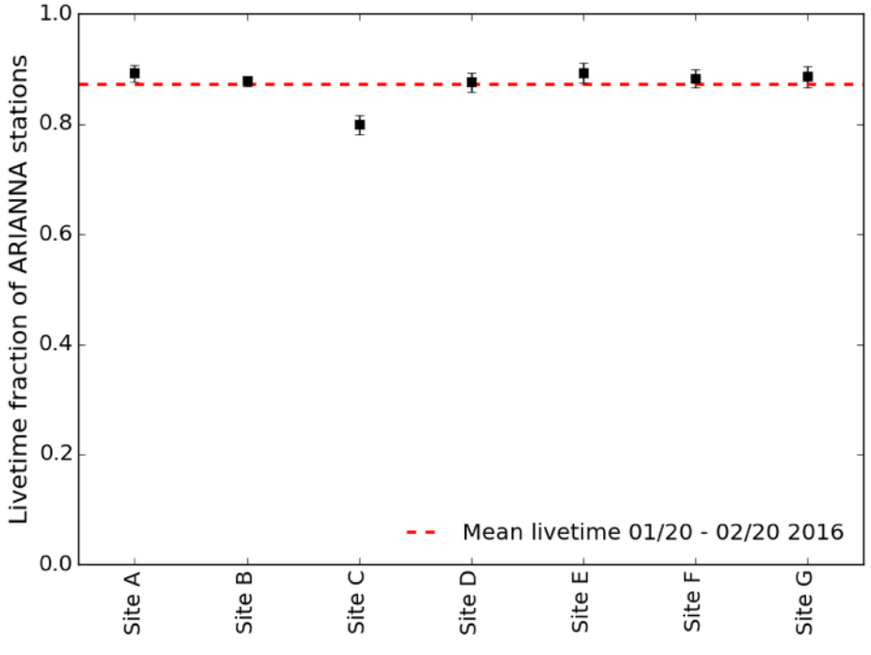
Current status of ARIANNA - HRA

First hexagonal array in operation since 2015



Hardware

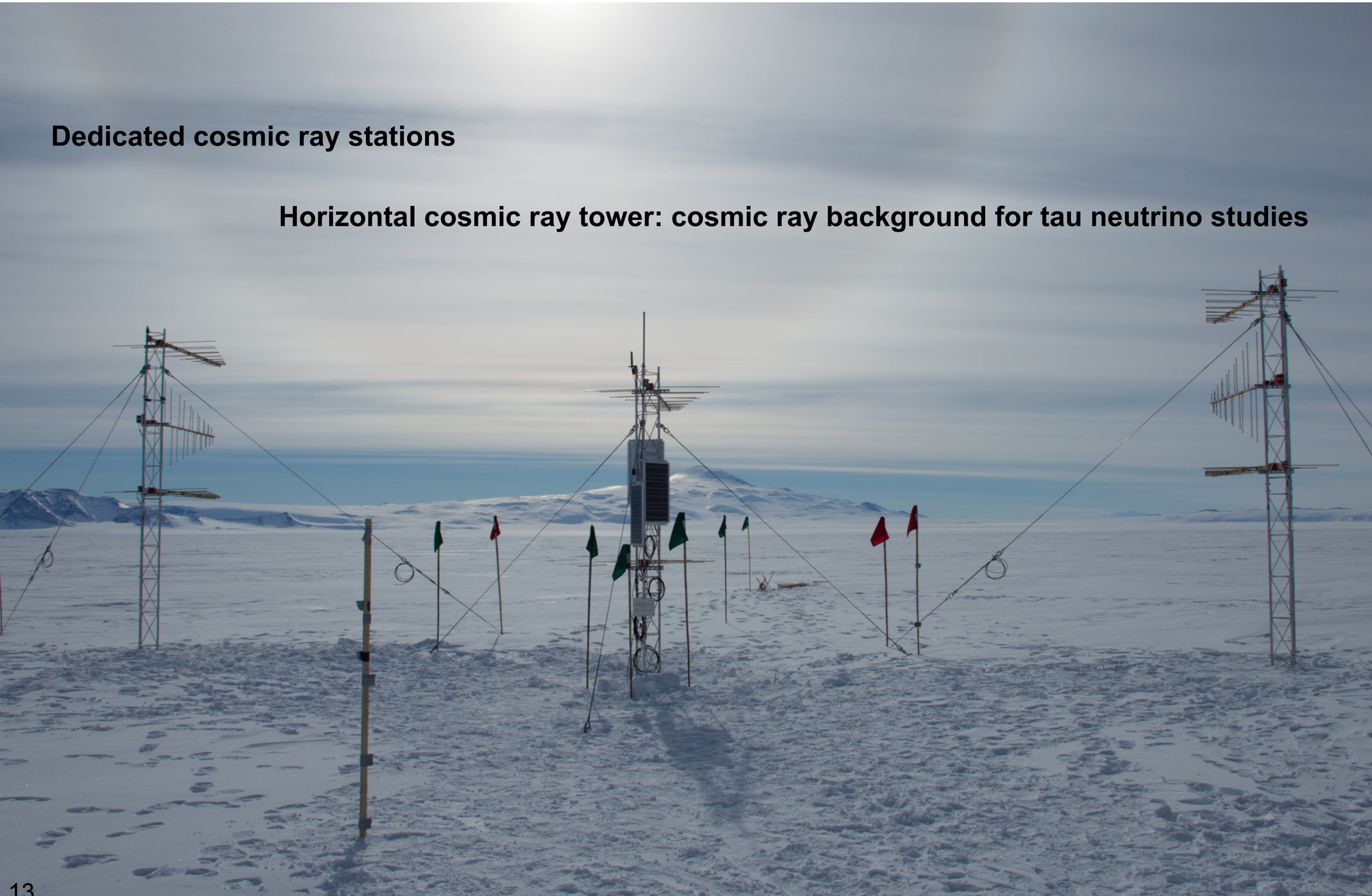
- Very low-power customized DAQ boards (< 1 Watt)
- 1 GHz (or 2 GHz) sampling, 256 ns (or 128 ns) per triggered waveform
- 4 and 8 channel/antenna systems deployed
- Long-range wifi (AFAR relay via McMurdo station) and satellite communication (Iridium), real-time data transfer
- Online real-time monitoring
- 8 stations running reliably with same hardware since 2014/2015 in Moore's Bay, other stations since 2012



New this season

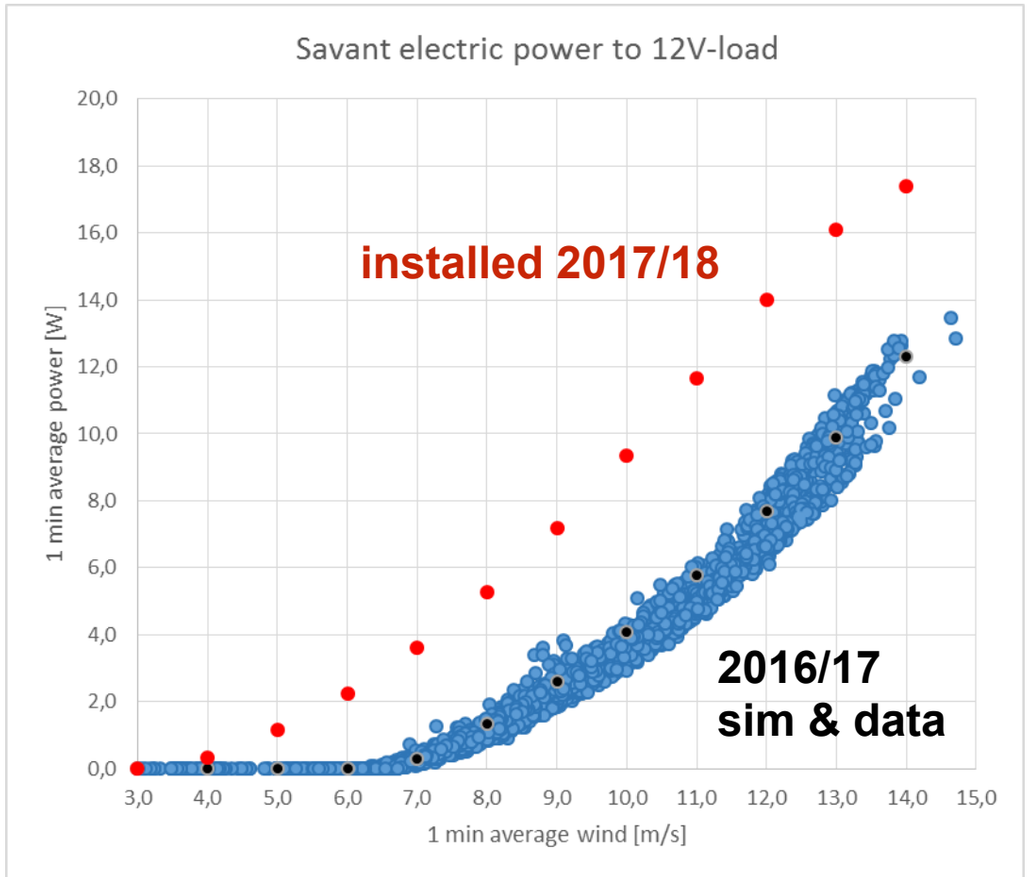
Dedicated cosmic ray stations

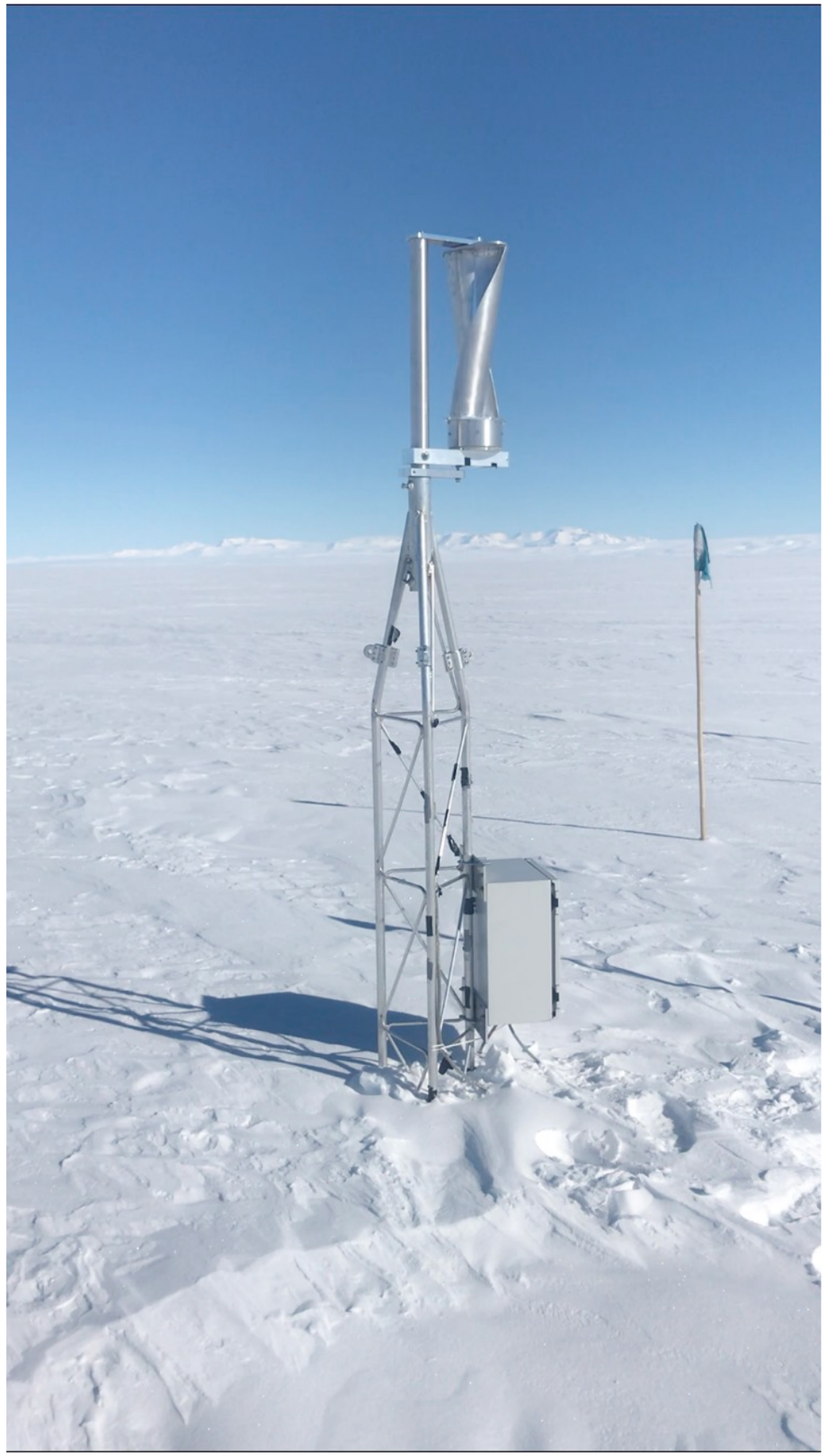
Horizontal cosmic ray tower: cosmic ray background for tau neutrino studies



Power systems

- Since 2015: Solar powered with 20 Amph $LiFePO_4$ batteries for buffering
- Custom windgen developed in Uppsala (Bernhoff, Hallgren)
- First prototype, survived the winter and took data, since this season a slightly updated one, attached to a station

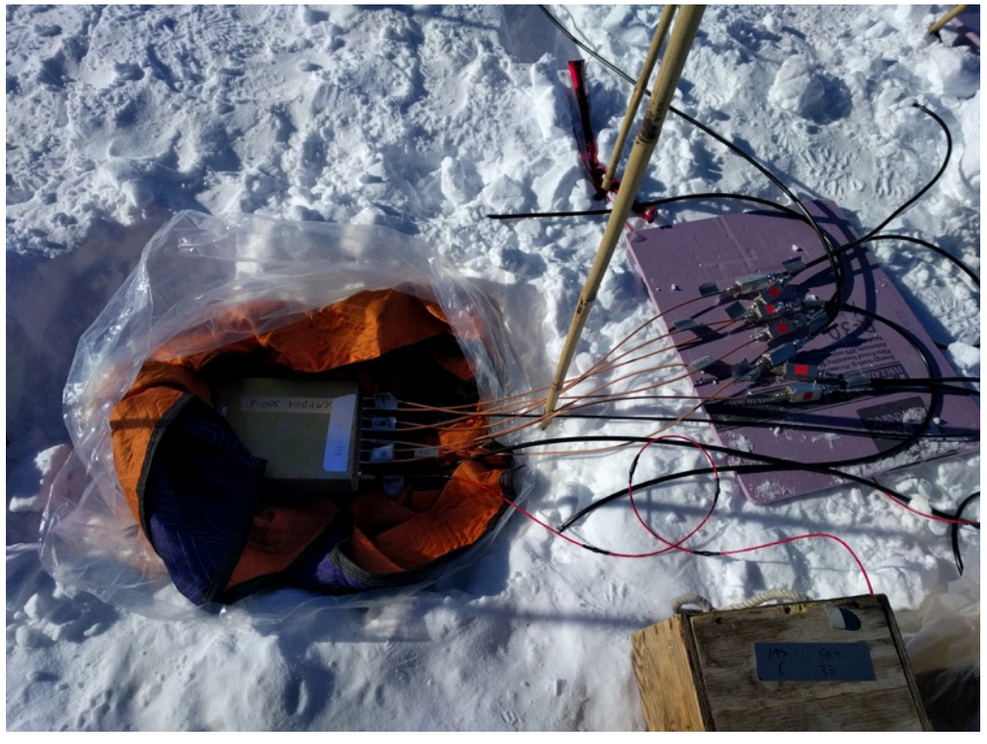




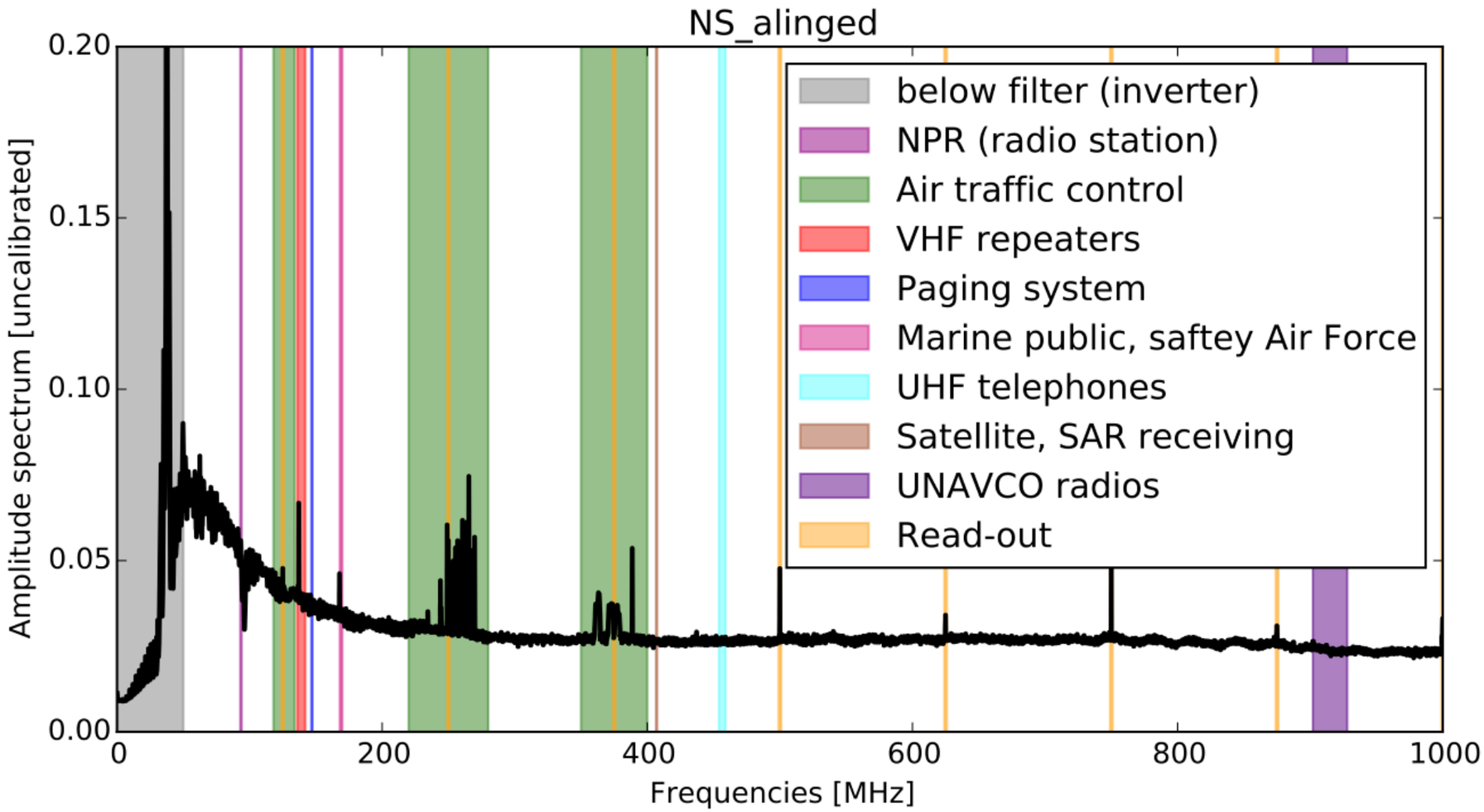
ARIANNA @ South pole

- The deeper ice at lower temperatures might have advantages for the ARIANNA concept

- Questions to be answered:
  - Interference background at surface?
  - Survival of hardware at lower temperatures
  - Dealing with power from station instead of independent power
  - Station available for borehole tests with pulser (*data is being analyzed as we speak)



Radio noise background

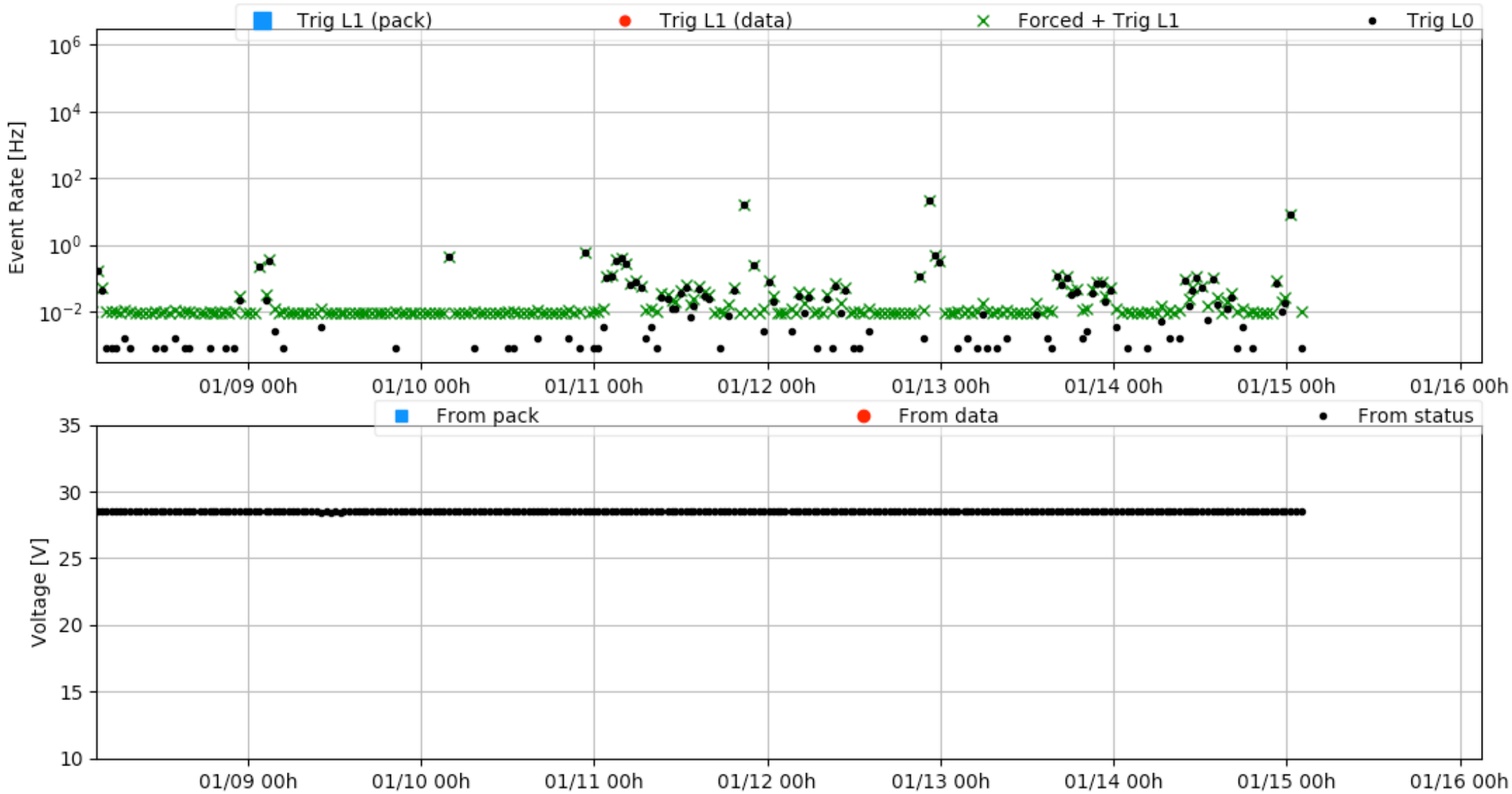


Spectrum integrated over 1ms of data

- **Extremely quiet radio environment at Moore's Bay**
- Small, time-varying contribution of **narrowband emitters**
- Spectrum clearly dominated by Galactic noise
- In addition: very little transient broadband sources

What about South Pole?

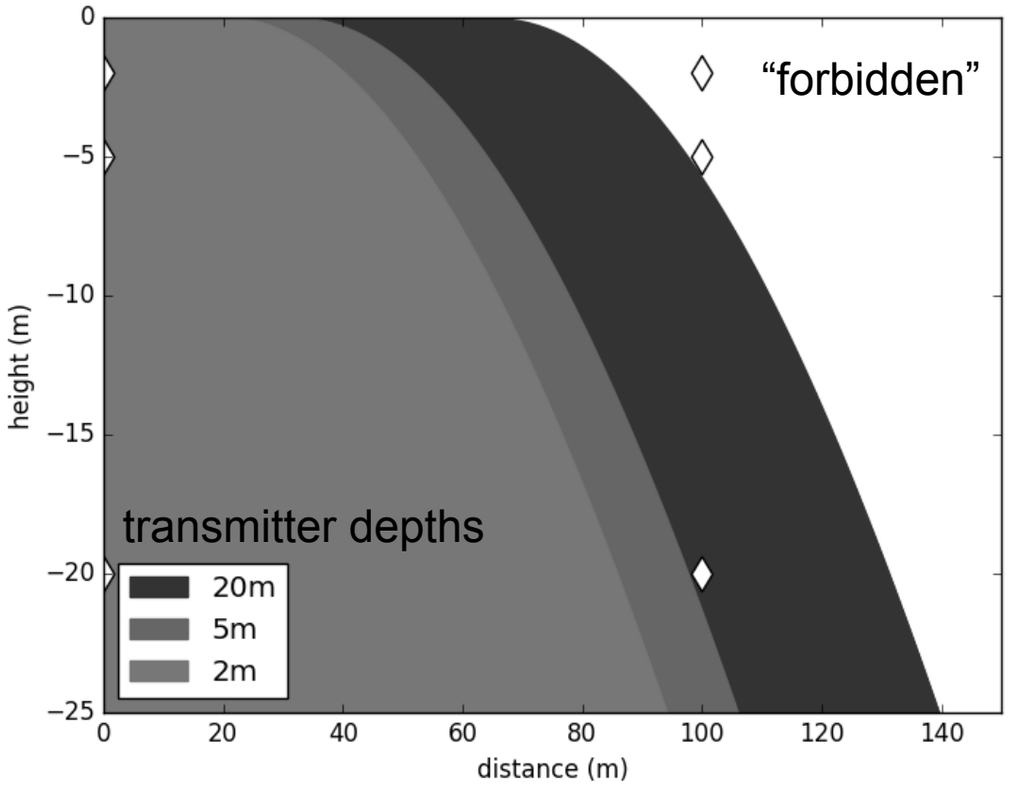
Online Monitoring of station at South Pole



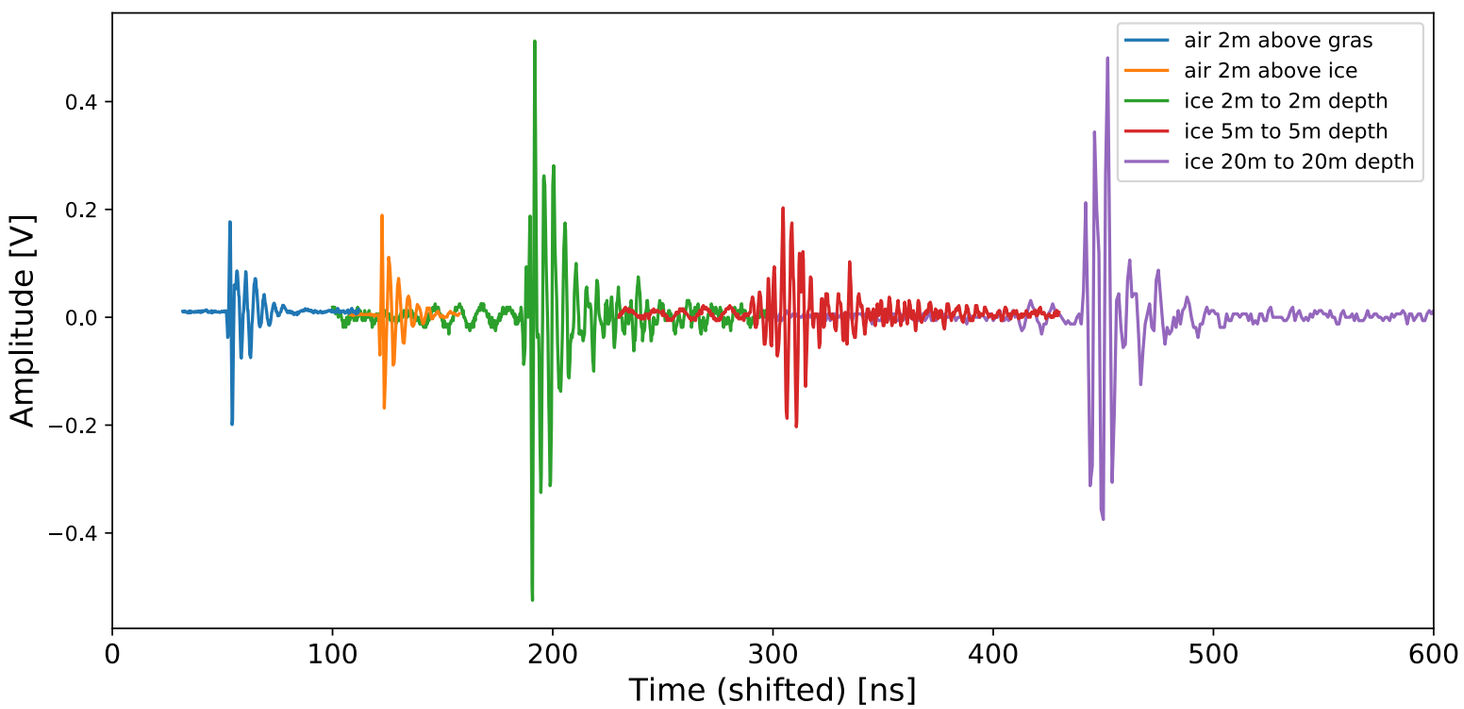
- While station is open, many bursts of pulsed interference
- Site less good (in summer), let's wait for the winter

Signal propagation

Paper in prep.



- Polar ice has a density gradient with depth
- Classically, signals will be bent downwards, leading to “forbidden” regions
- However, at many locations (Moore’s Bay, South Pole, Greenland, …) radio signals observed in “forbidden” regions



- Ice is layered, not smooth gradient
- Density fluctuation lead (also classically) to ray trapping and horizontal propagation

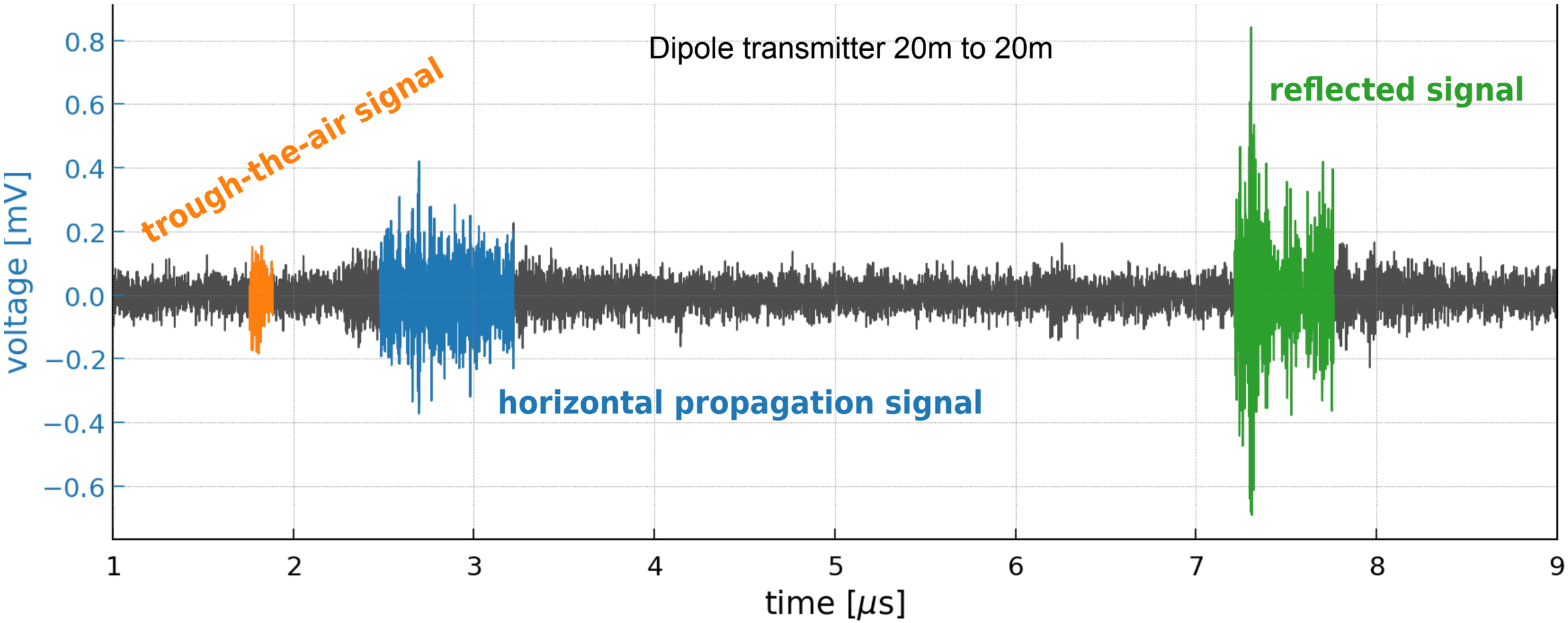
Understanding crucial for future neutrino arrays

See also poster
C. Glaser

Signal propagation

Paper in prep.

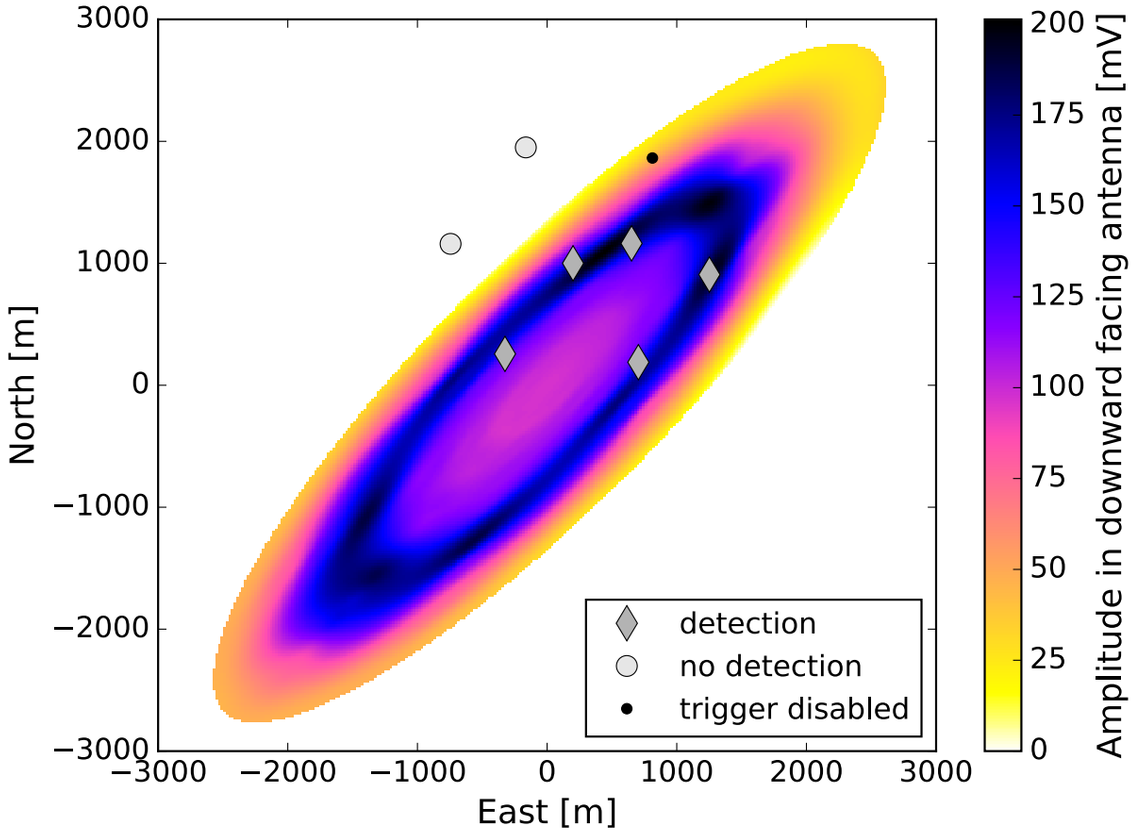
- Additional evidence for several multi-path propagations



- Understanding of ice propgation is coming together

- However, still anecdotal evidence, so additional studies like in borehole (2000 m) at South Pole have to have highest priorities

Cosmic Rays

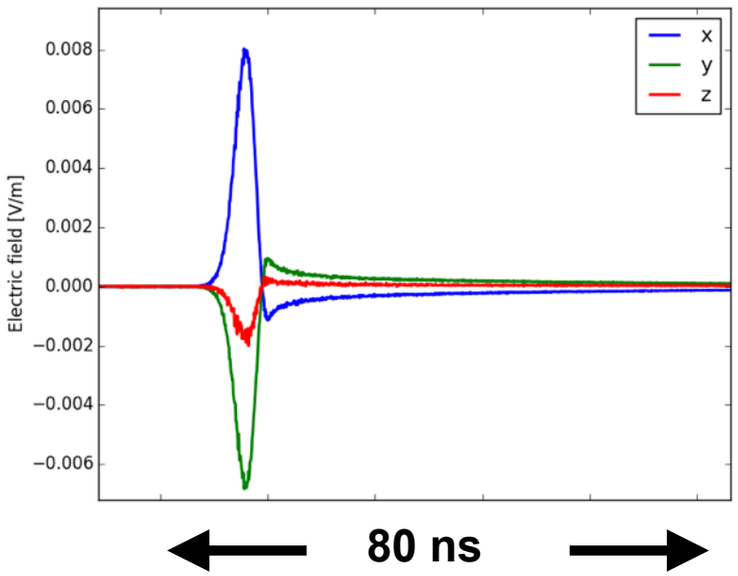


- The most “important” background
- Since emission mechanisms is the same, signals are expected to be very similar to neutrino signals

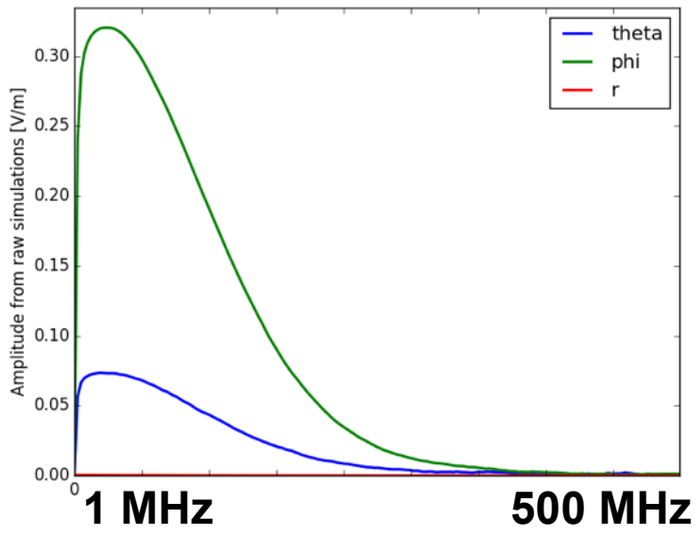
- Two stations have been equipped with upward pointing antennas
- One station has been equipped with antennas out of the snow pointing towards the mountain
- Air showers will be used as **calibration source** for the energy, arrival direction reconstruction and as **proof of principle for detection method**

Cosmic Rays

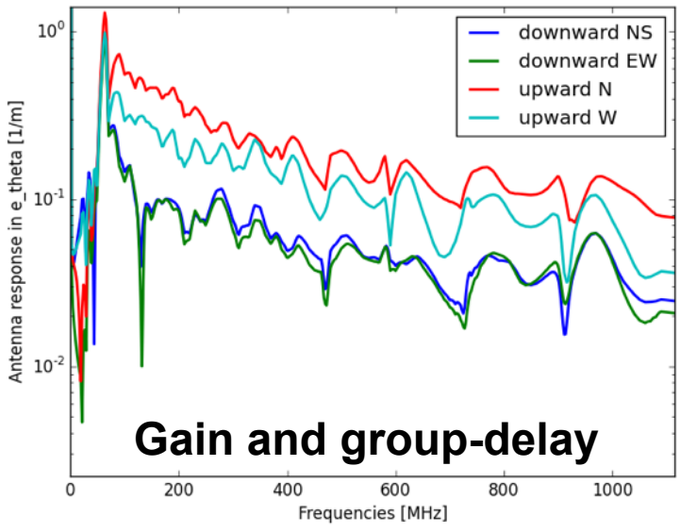
Raw electric field pulse



Raw electric field spectrum



Antenna response

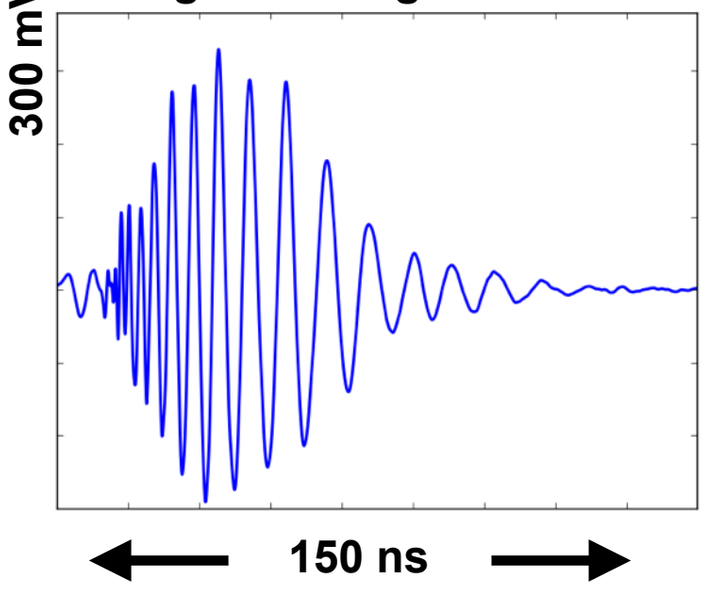


- Air shower signals through front-lobe of LPDA have a **unique characteristic**

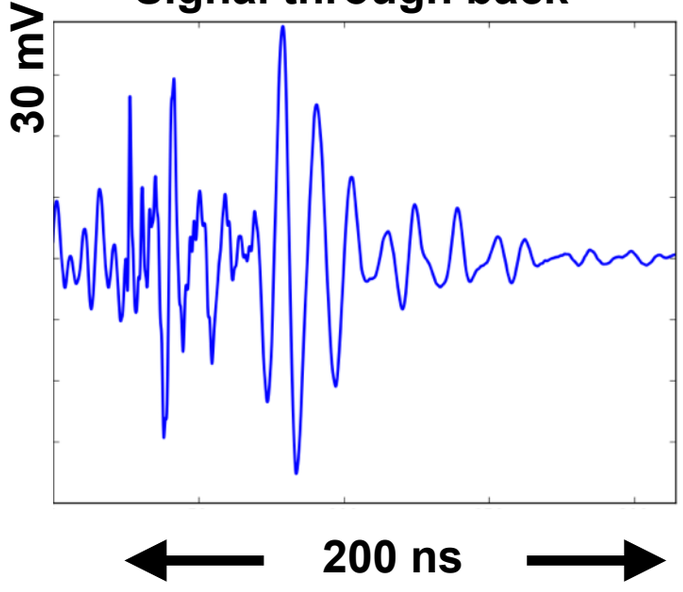
- High frequency chirping followed by lower frequencies

- Due to short broadband pulses and group delay of antenna and amplifier

Signal through front

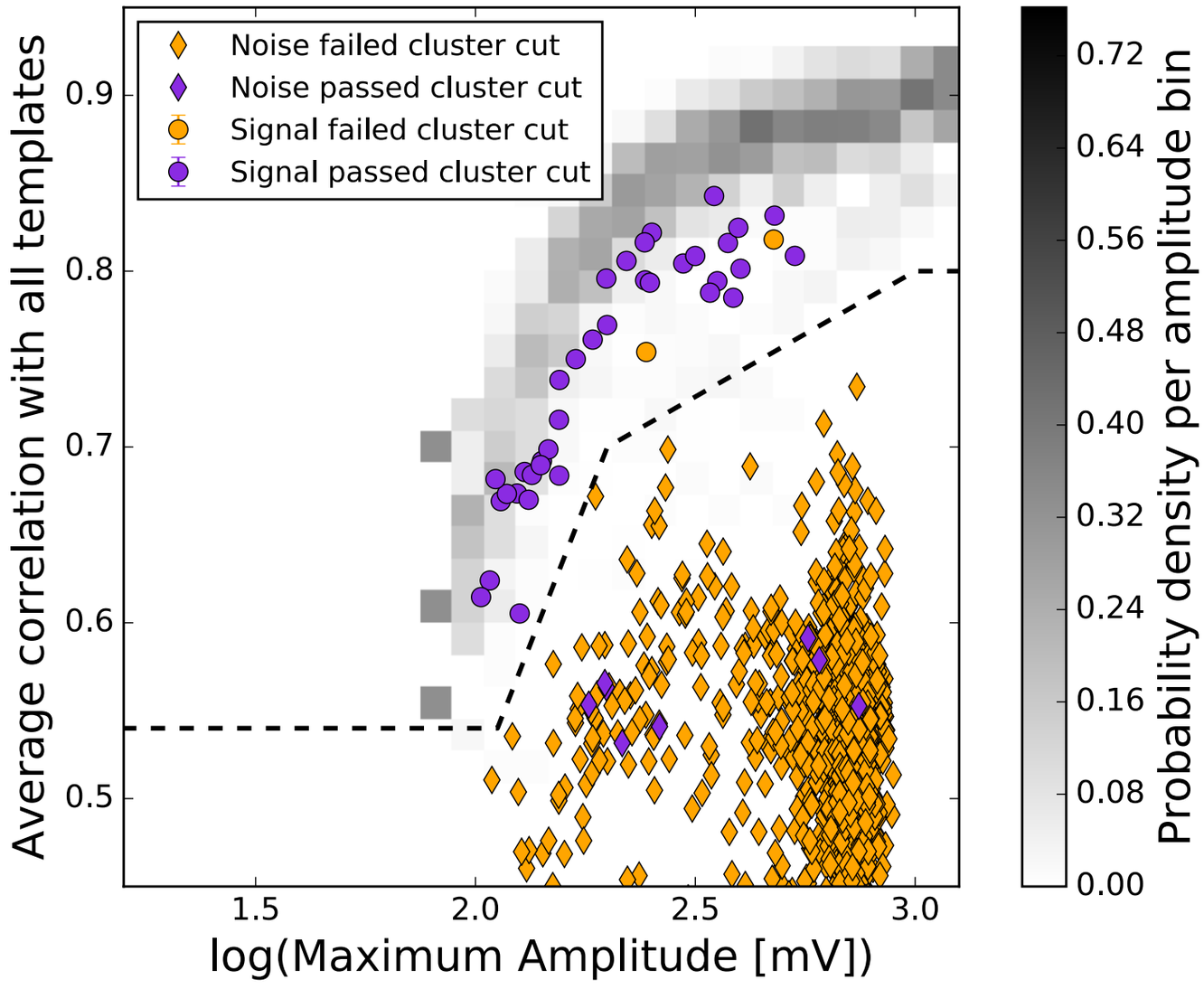


Signal through back



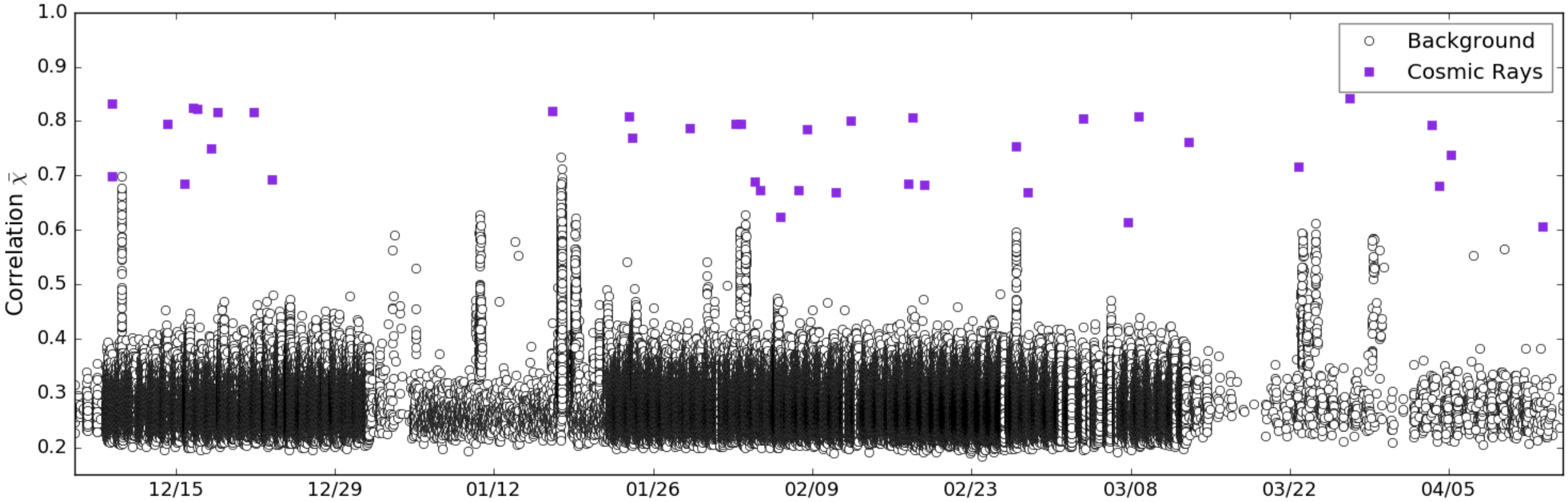
Cosmic Rays 2016

- Analysis on one station as proof of principle
- One road: devise cluster cut to remove noisy periods: 7% loss in livetime
  - Other option: Cut on simulation expectation, 0.001% loss in efficiency



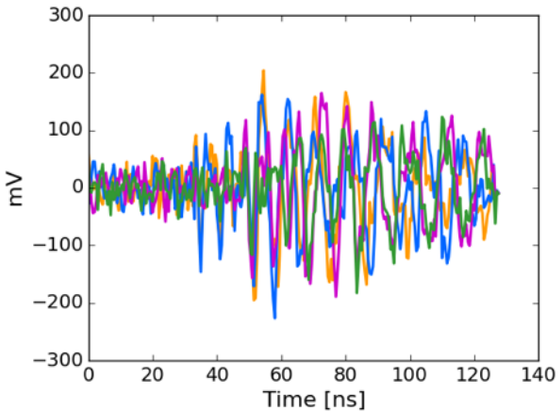
- Cosmic ray search at ARIANNA: **one cut analysis**

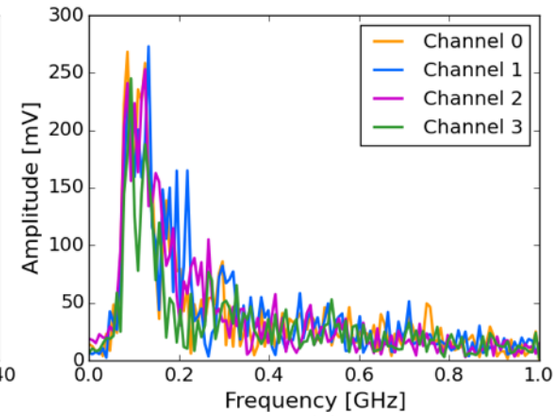
Cosmic Rays Overview



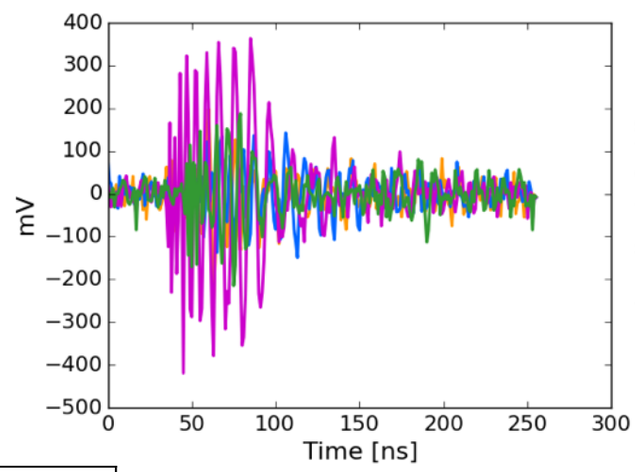
- Find correlation with one simulated signal template
- Distinct set of isolated events with high correlation
- Overlap of 25 events in high amplitude set and high correlation set

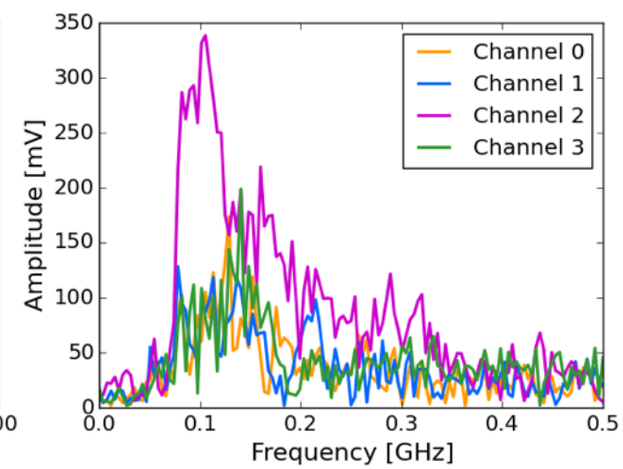
Measured air shower





1 km





Cosmic ray station
Upward pointing channels 2,3
Better low-frequency resolution
Signal detection in forward direction

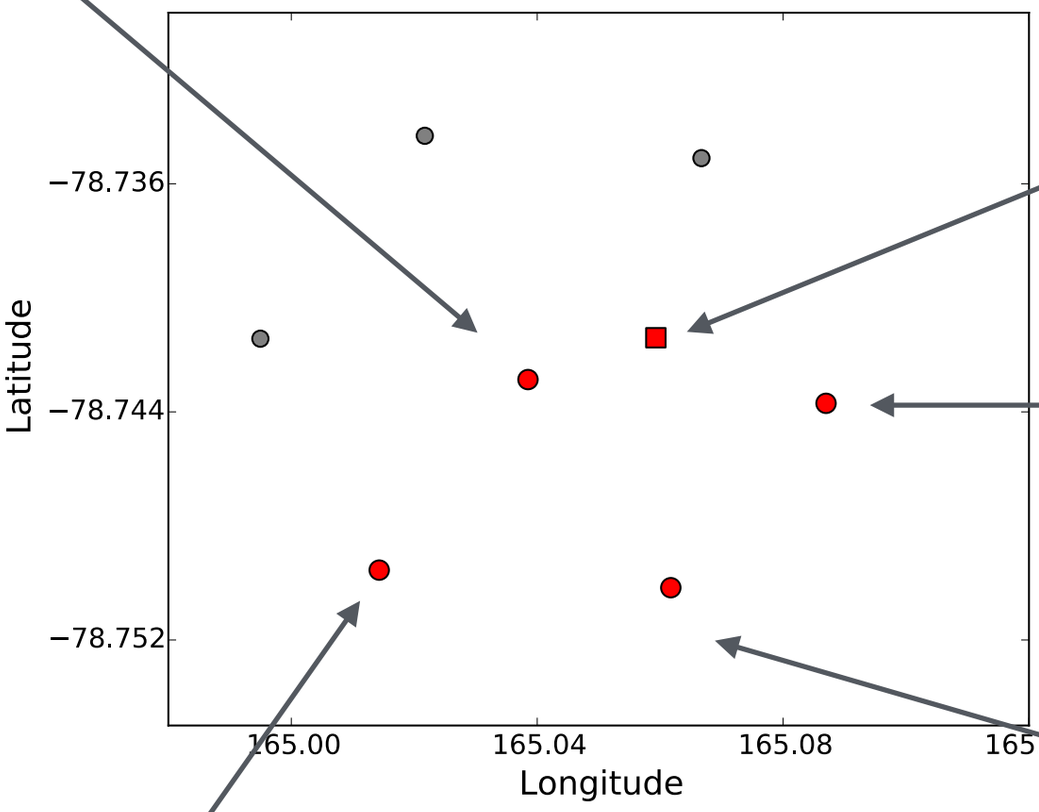
ARIANNA

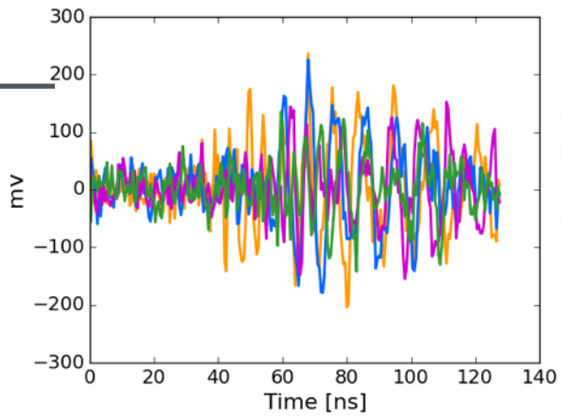
Air shower detected

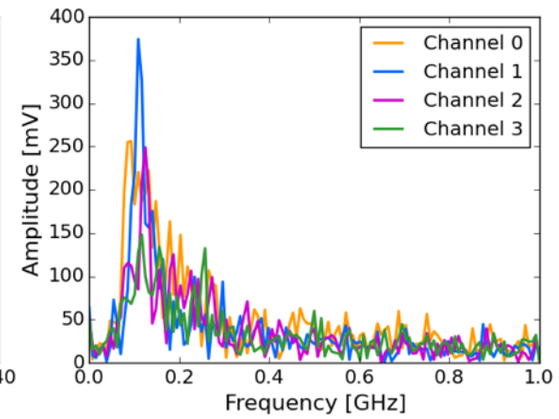
December 21st 2015
1450734371 UTC

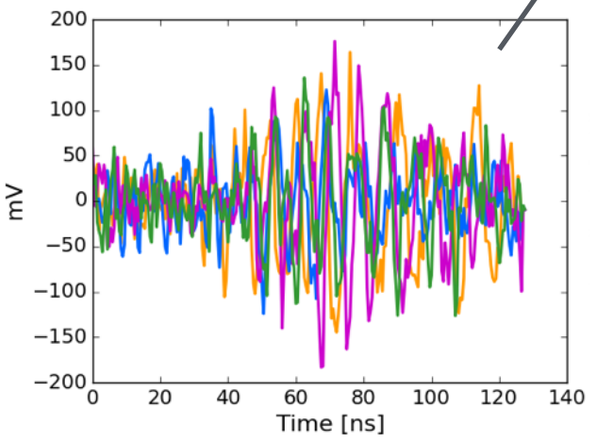
Four independent direction reconstructions (after Fresnel)

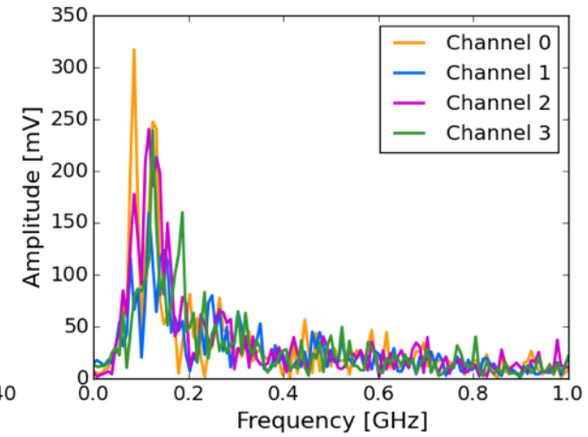
Zenith = 49˚ +/- 2˚
Azimuth = 47˚ +/- 2˚

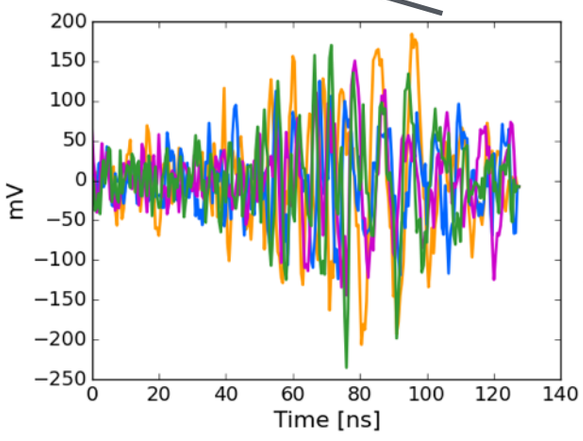


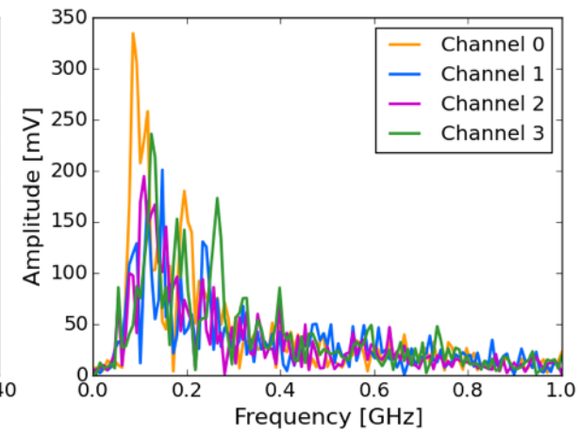




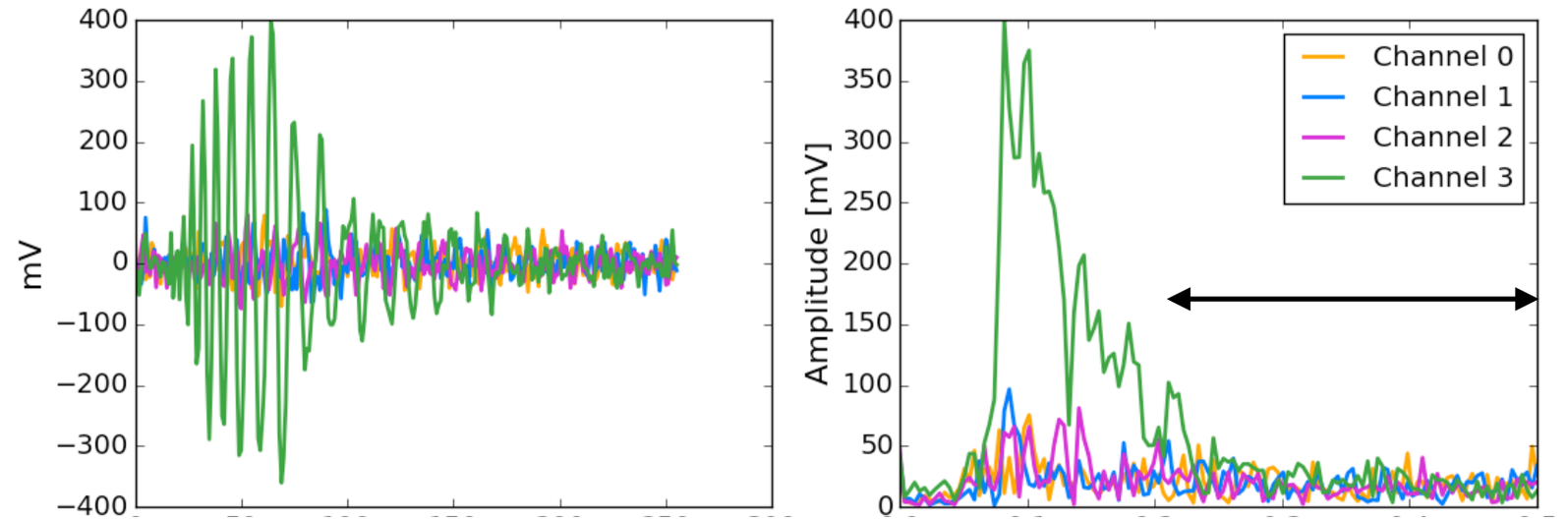


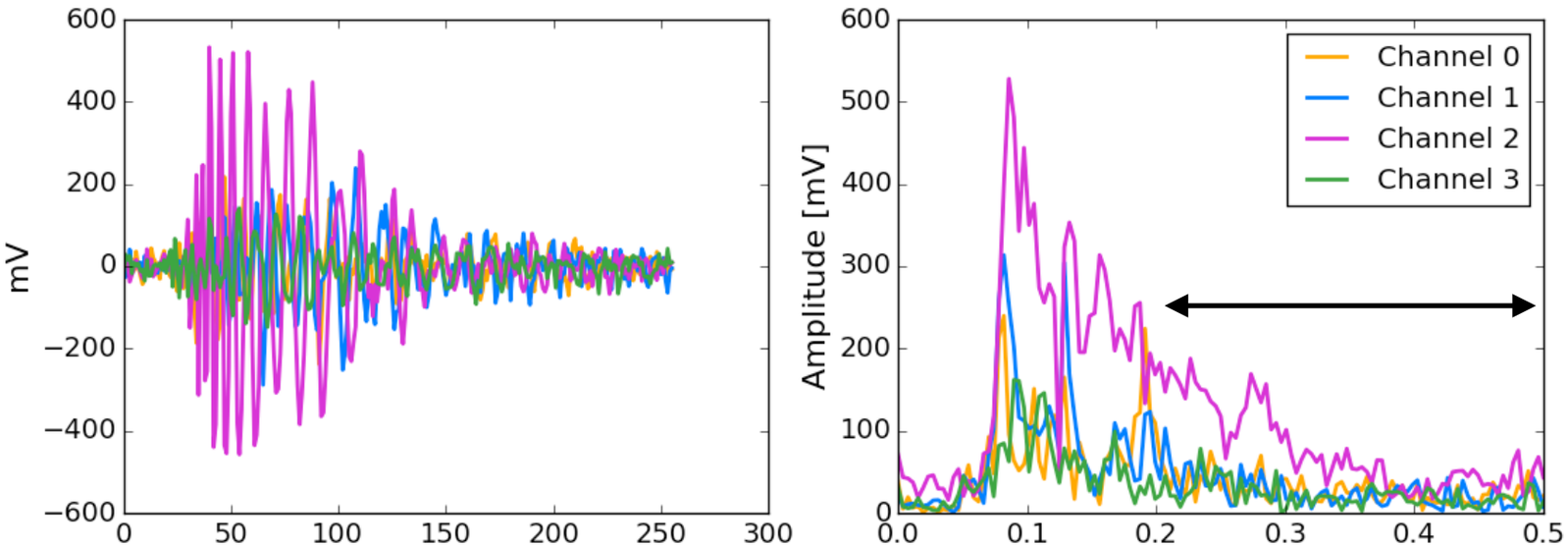


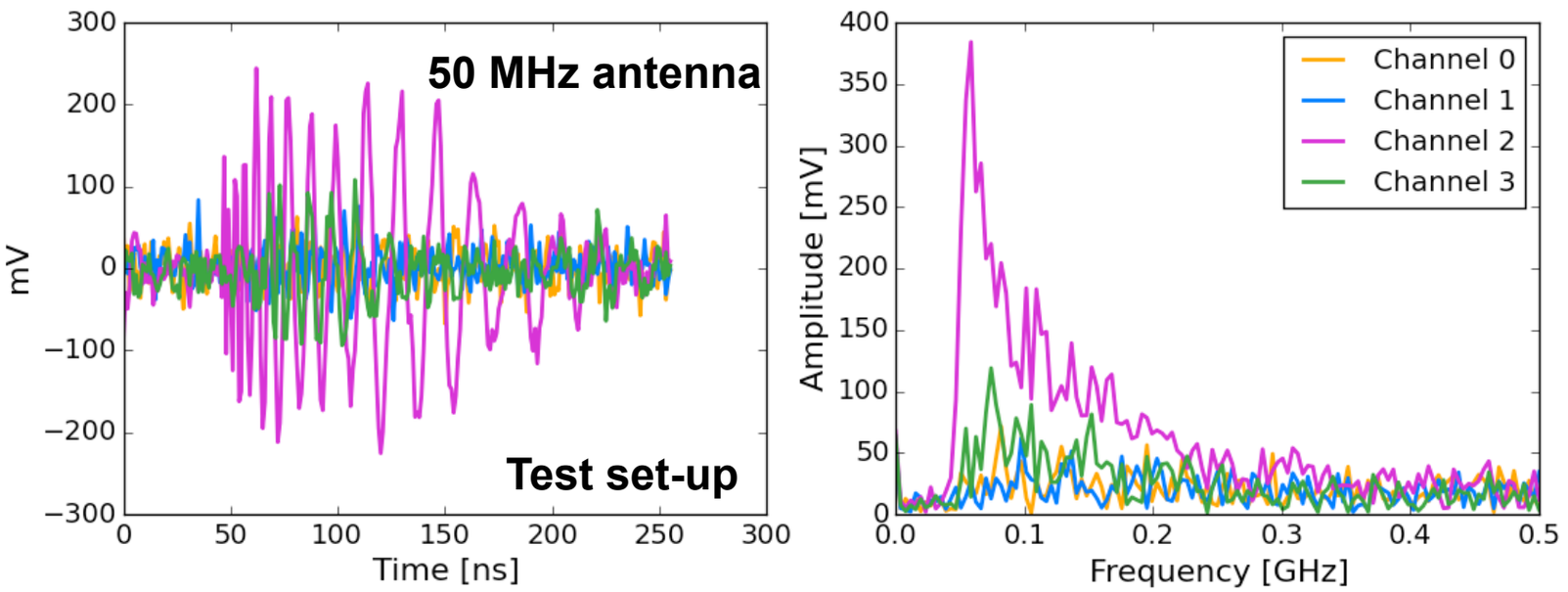




Measured air showers



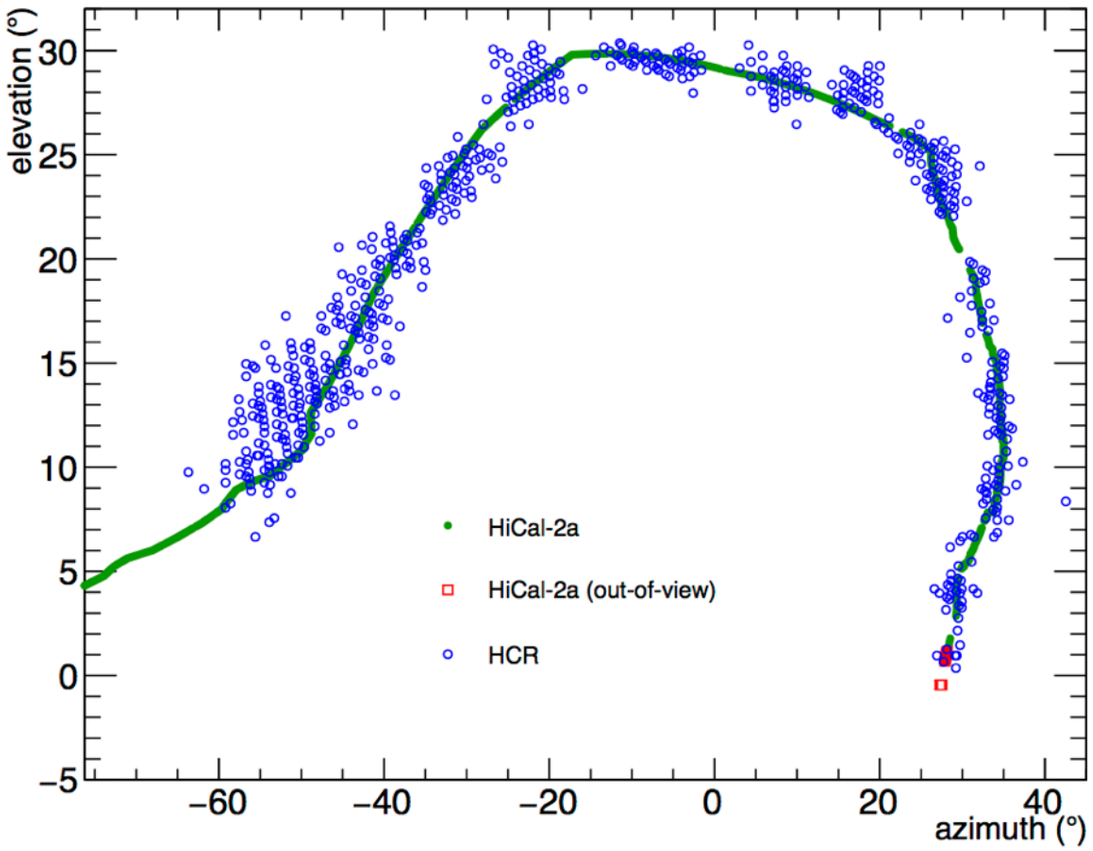




- ARIANNA is only experiment that directly measures air showers from 50 - 500 MHz with no significant filtering against RFI

- Slope of the frequency spectrum can be used without restriction

Horizontal-cosmic ray station



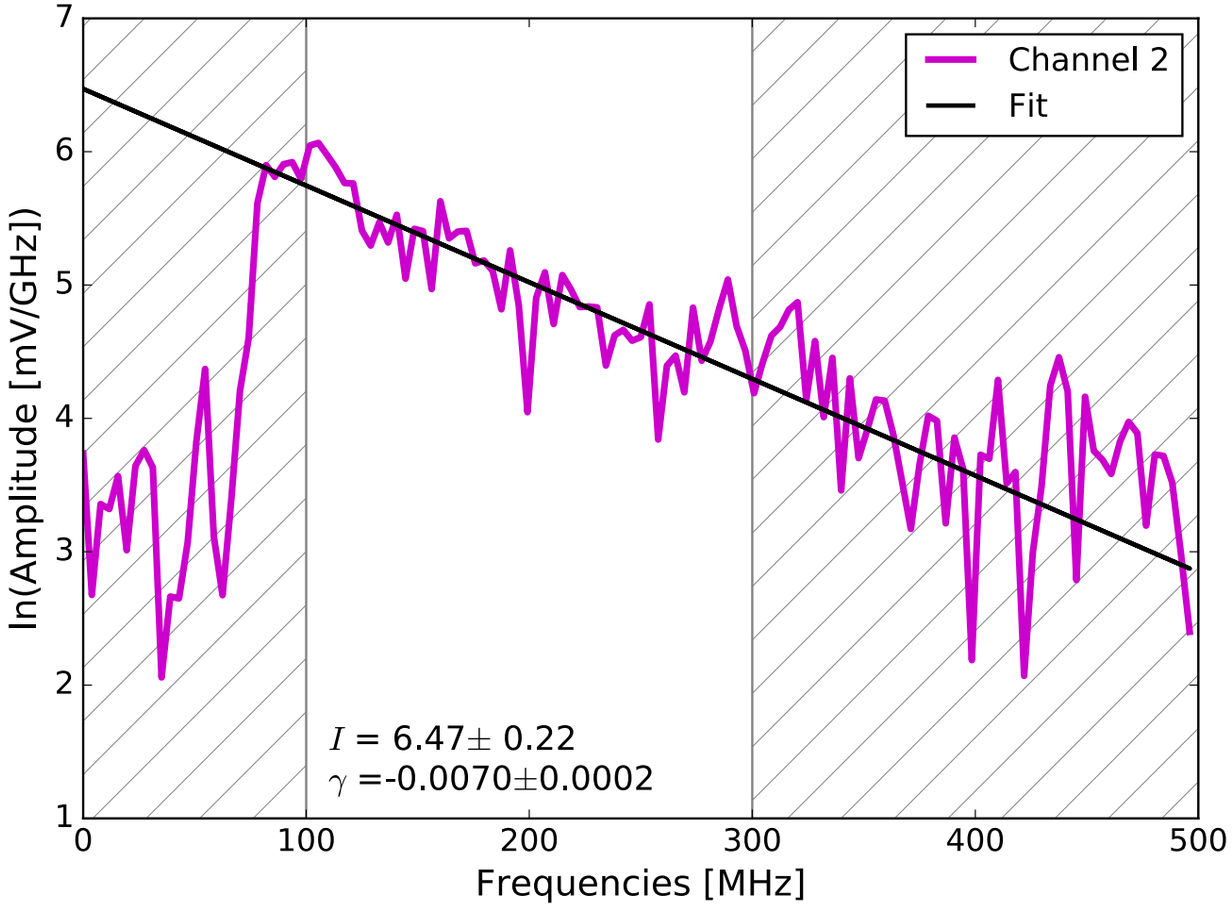
- If air shower radio signal is observed coming out of the mountains: tau neutrino
- Collaboration with TAROGE (analysis thanks to S. Wang)
- Use cosmic rays as proof-of - principle, no mis-reconstruction to mountain allowed

- Observation of ANITA HiCal calibration pulser
- Angular reconstruction to few degrees
- New layout of HCR this seasons, larger lever arm, improvement of angular reconstruction expected

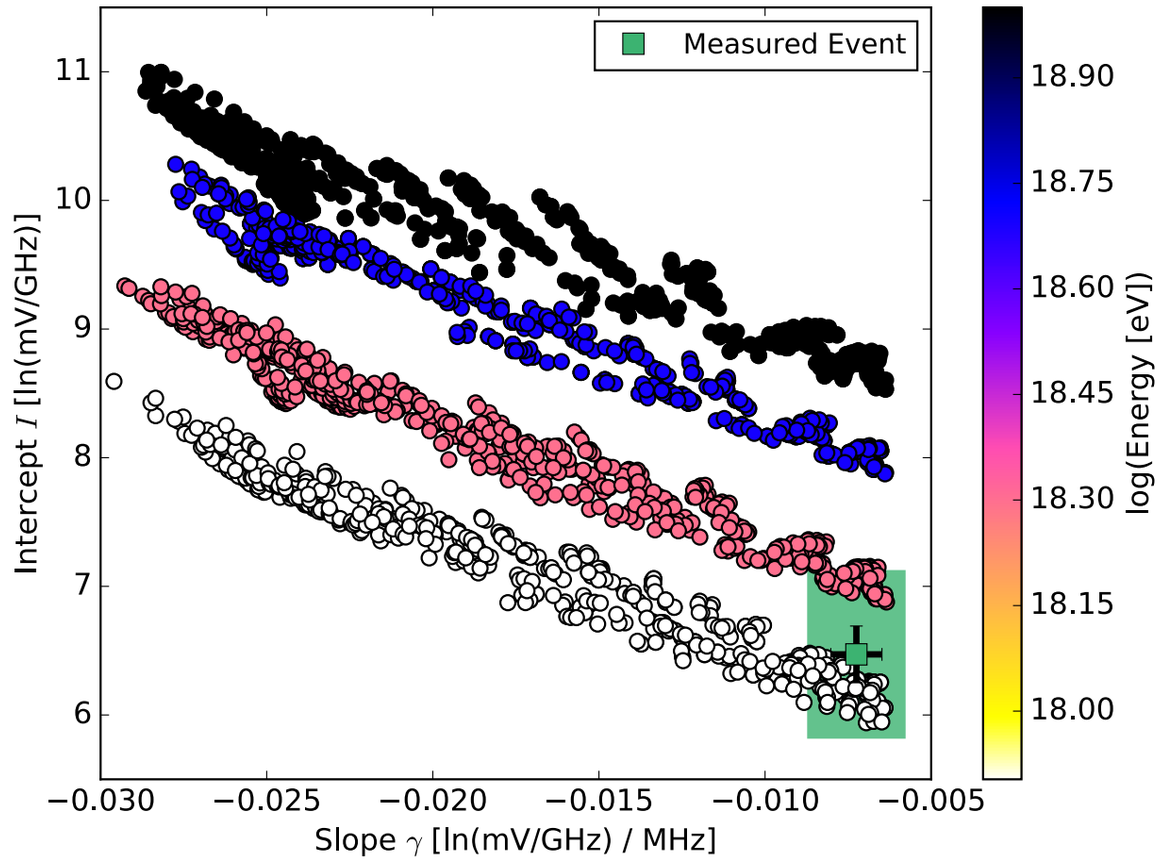
Energy reconstruction

- The spectrum of the signal pulse translates to an energy and other shower parameters

- Example for a single event:

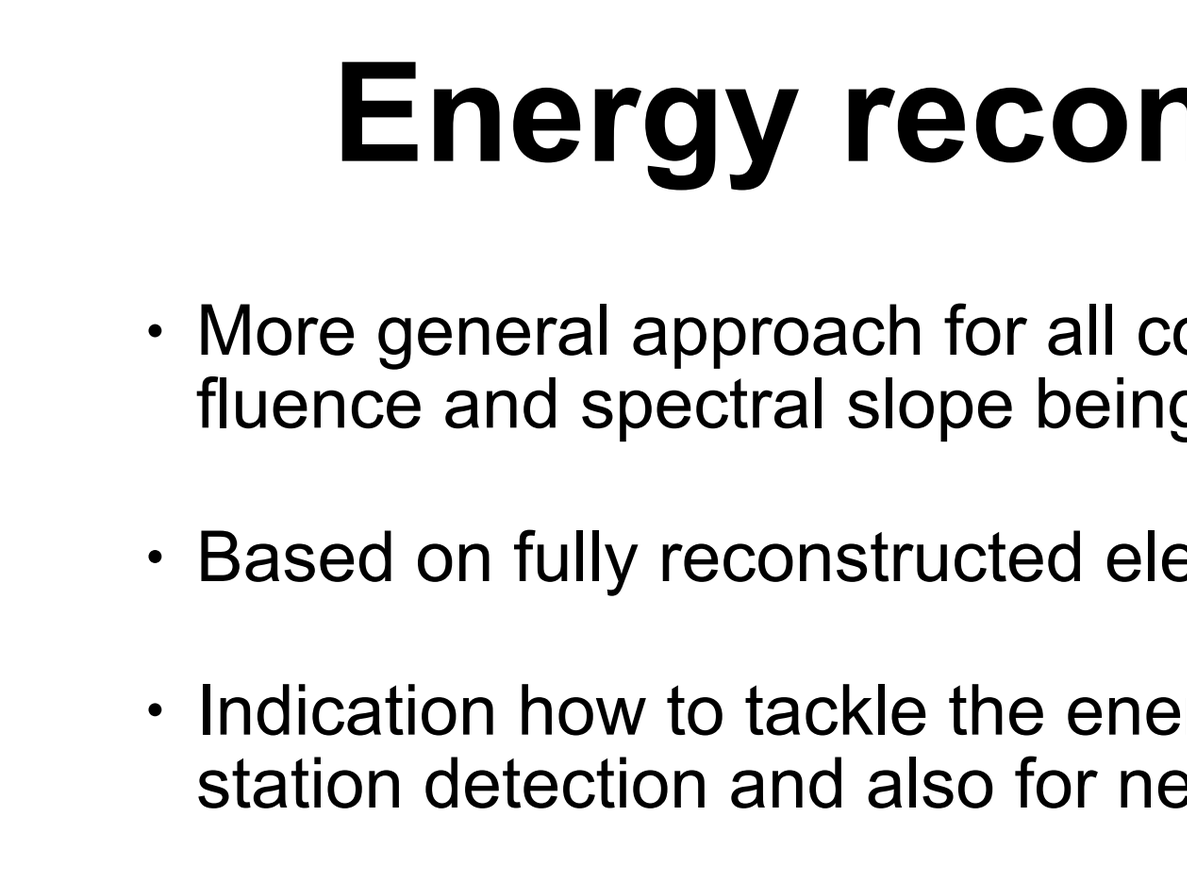


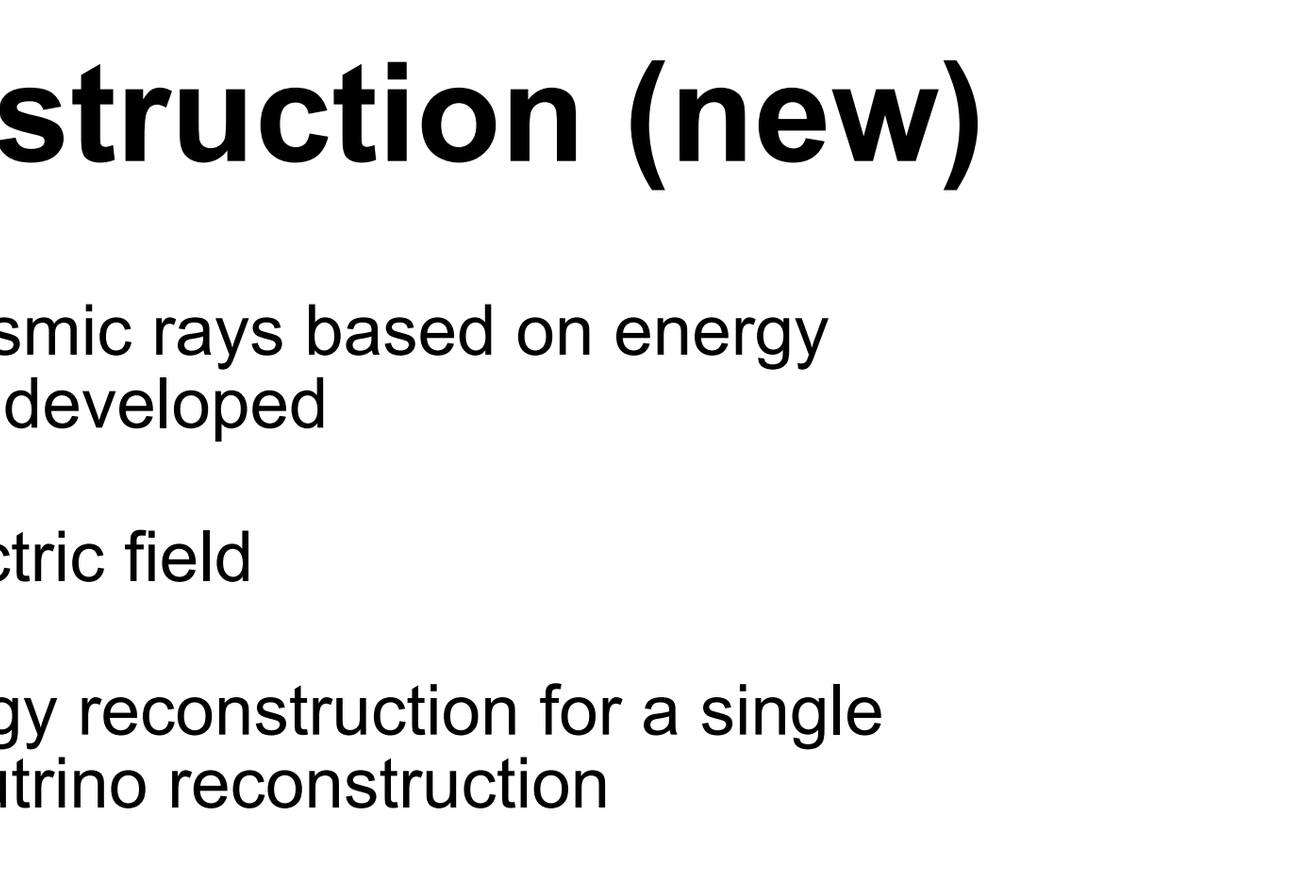
Astro.Part.Phys, 90, 50-68, 2017



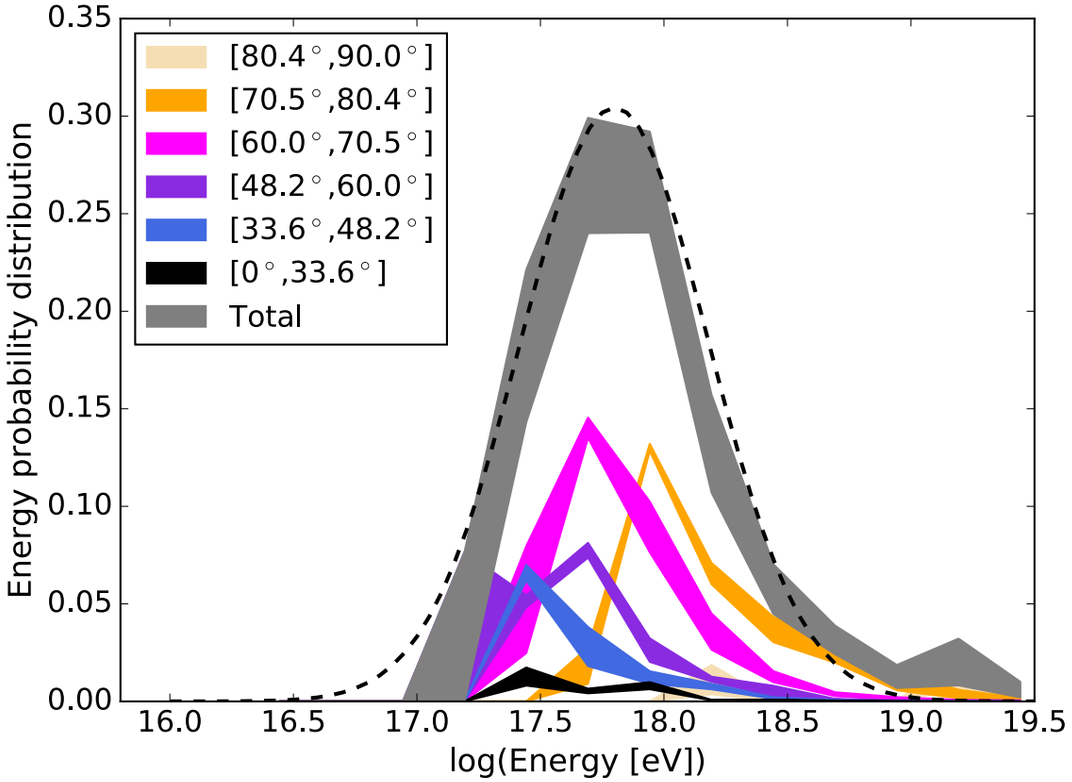
Energy reconstruction (new)

- More general approach for all cosmic rays based on energy fluence and spectral slope being developed
- Based on fully reconstructed electric field
- Indication how to tackle the energy reconstruction for a single station detection and also for neutrino reconstruction

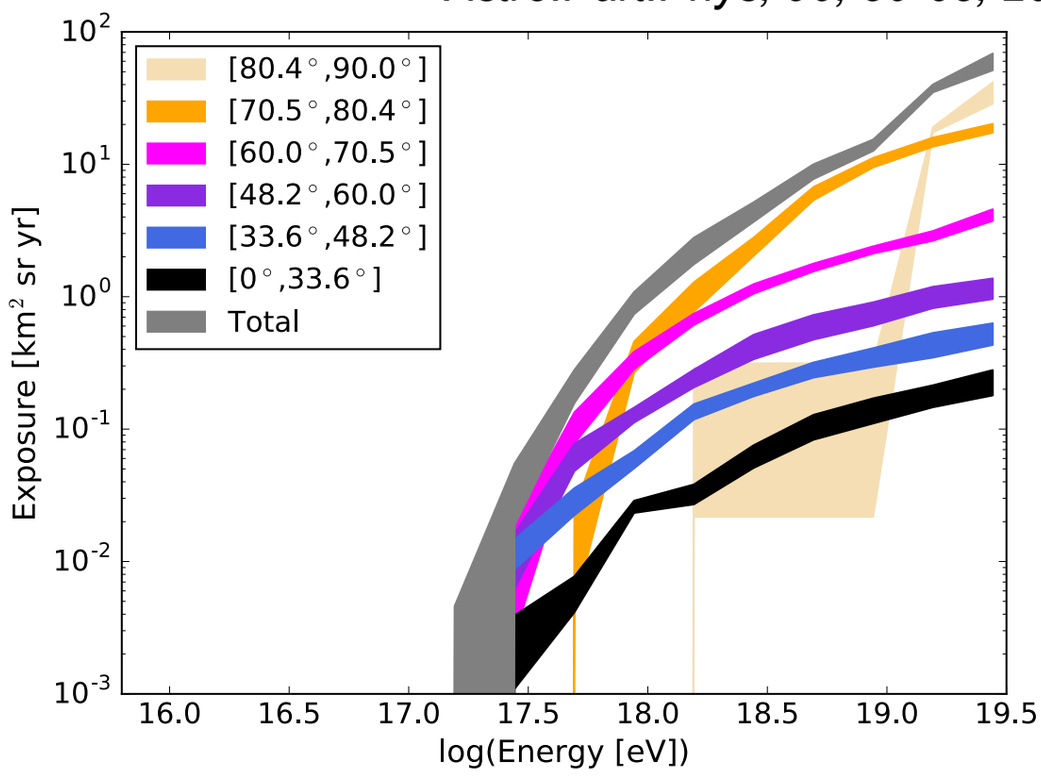




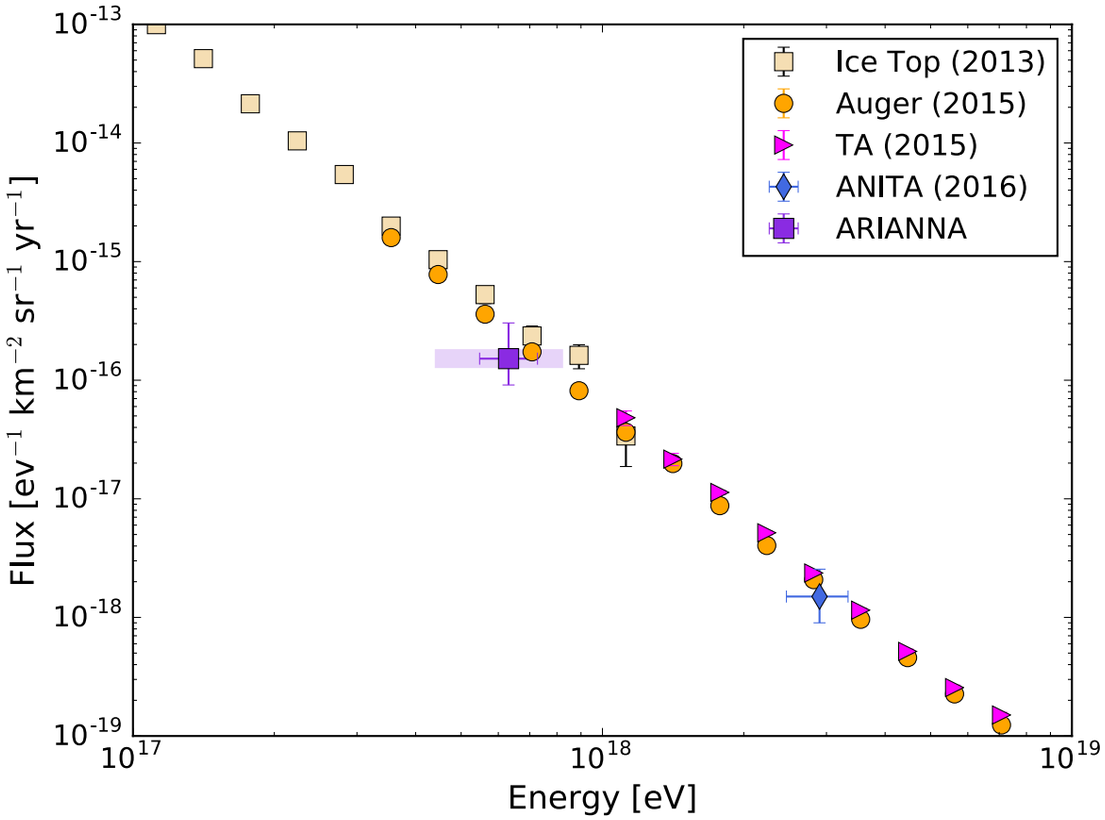
Flux calculation



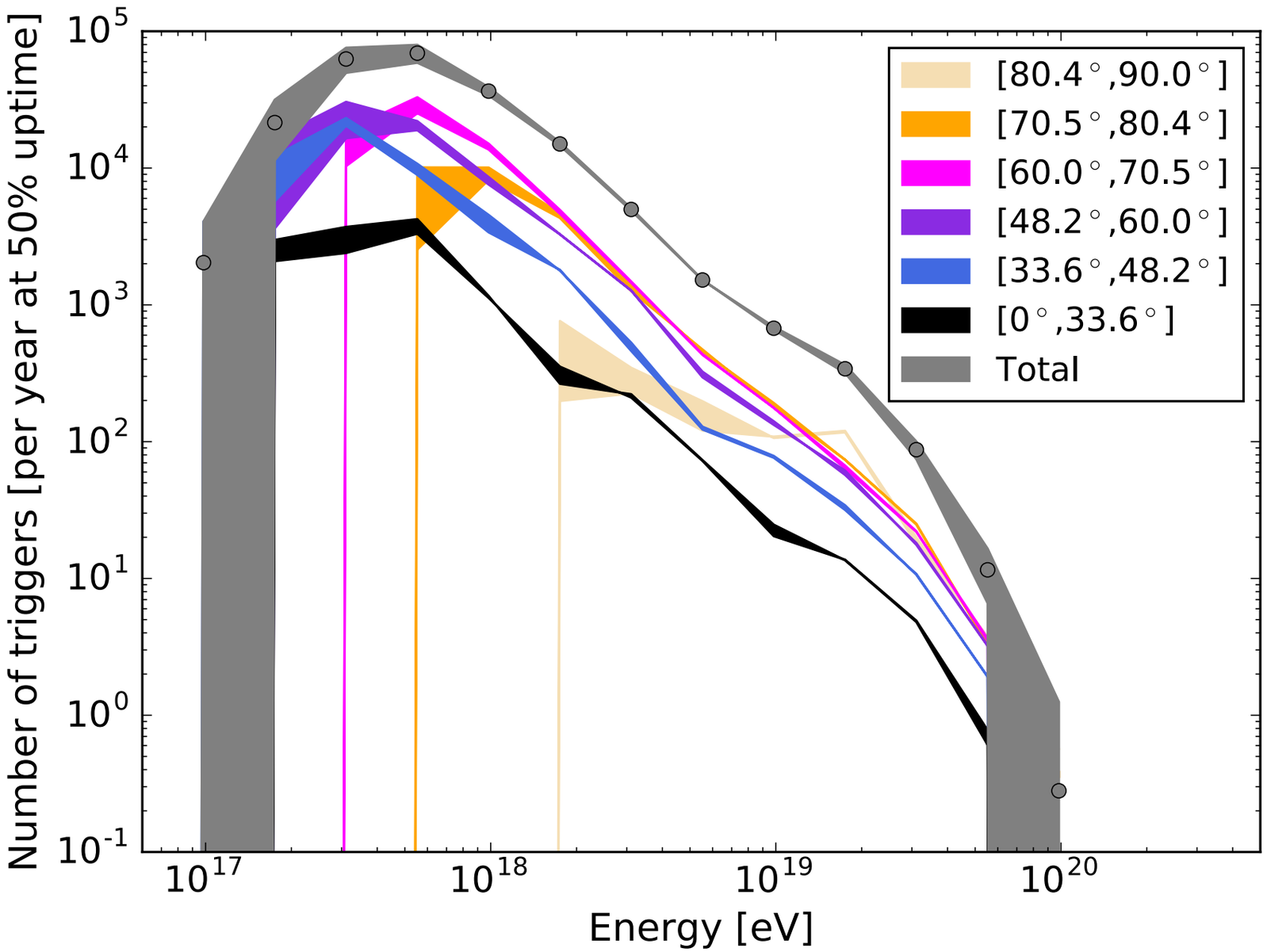
Astro.Part.Phys, 90, 50-68, 2017



- Use simulations to:
  - calculate most probable energy
  - with livetime calculate exposure
- Combine with number of events to flux
- In good agreement with literature



ARIANNA-like array with 1000 stations

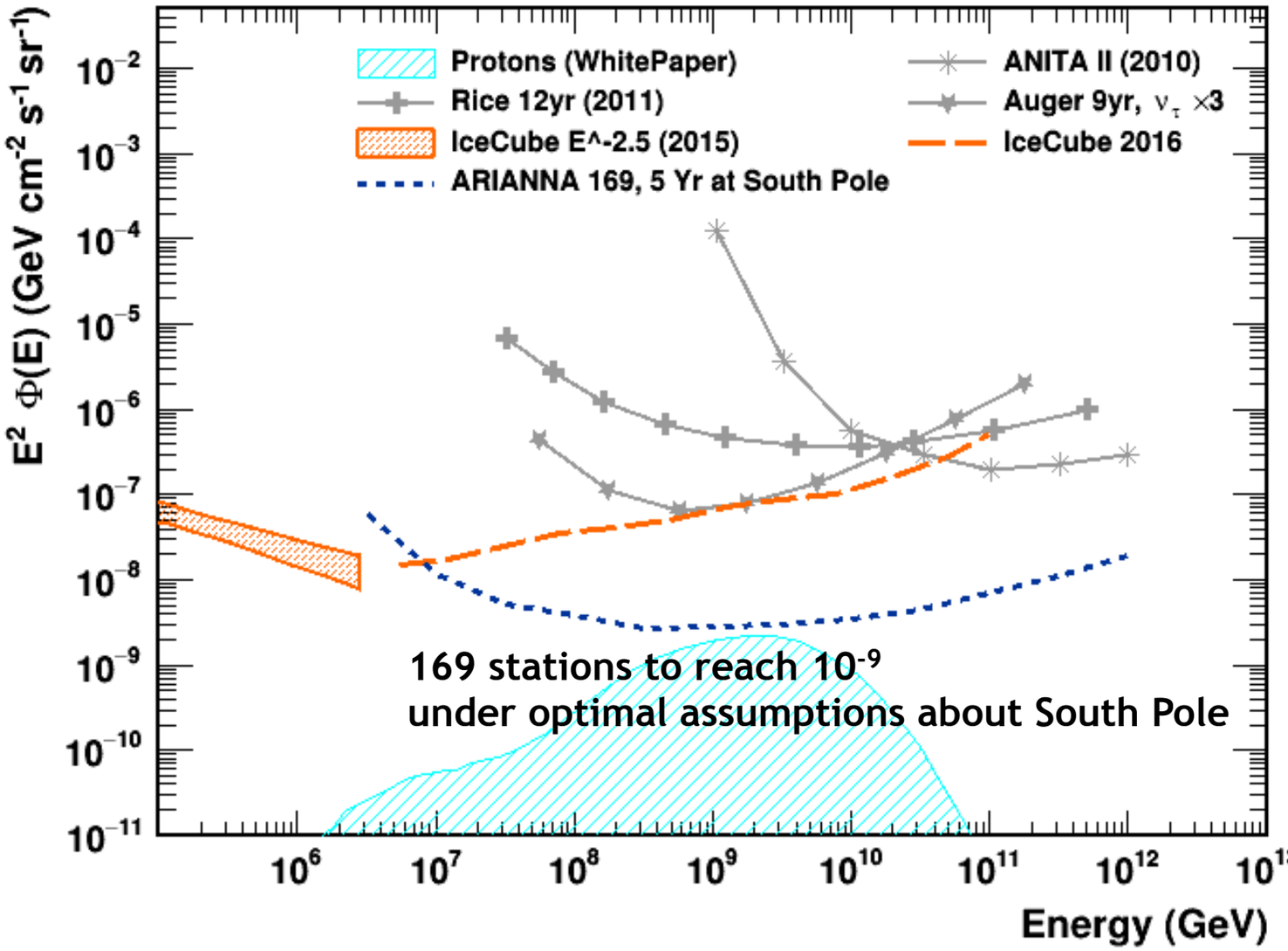


- A surface array with ARIANNA stations would also be a relatively large cosmic ray detector

Sensitivity to diffuse neutrino flux

- Basically a function of money: stations are independent so sensitivity scales linearly with number of stations deployed (and time operational)

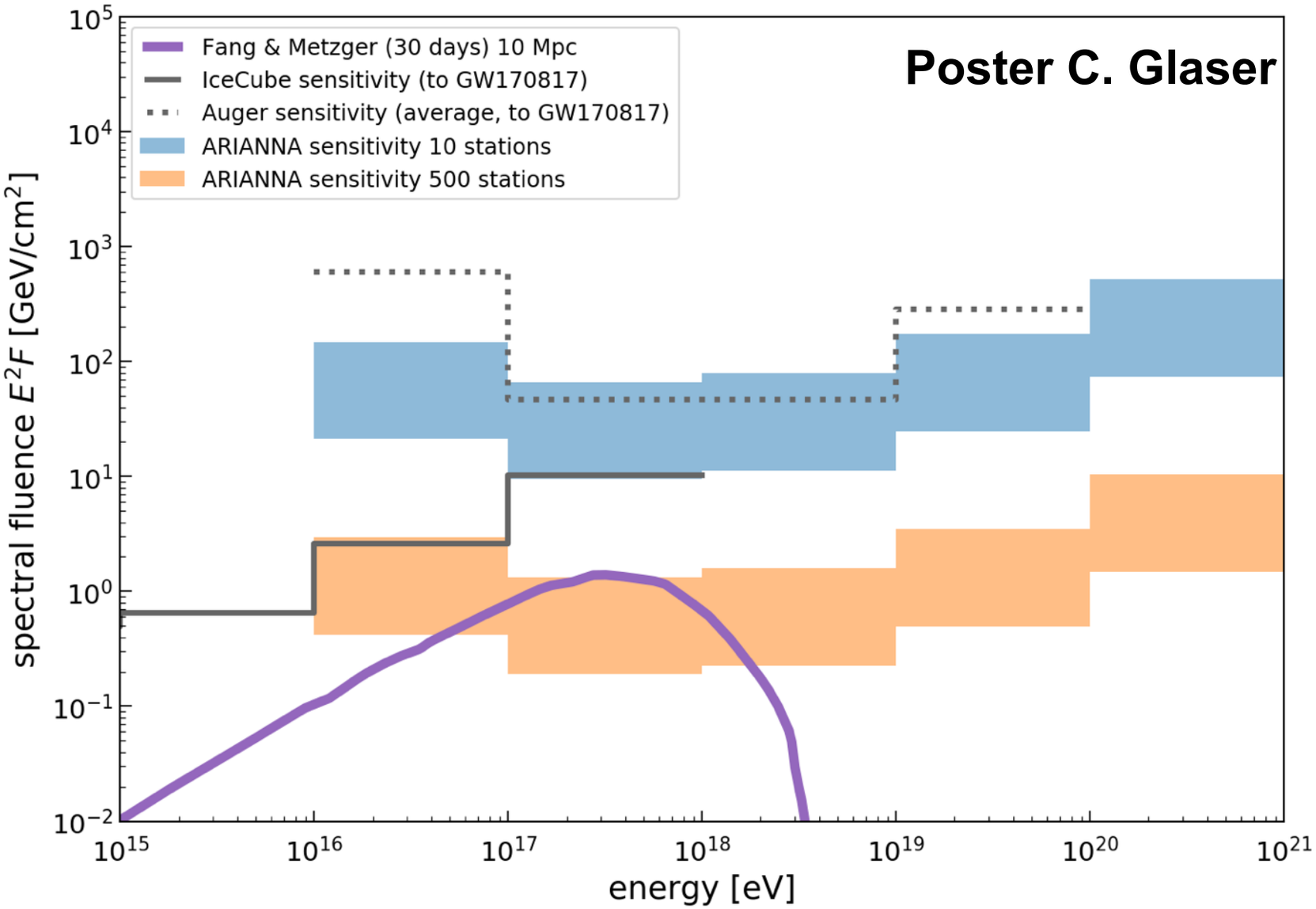
- "Uncertainties": ice propagation, analysis efficiency, antenna choice, …



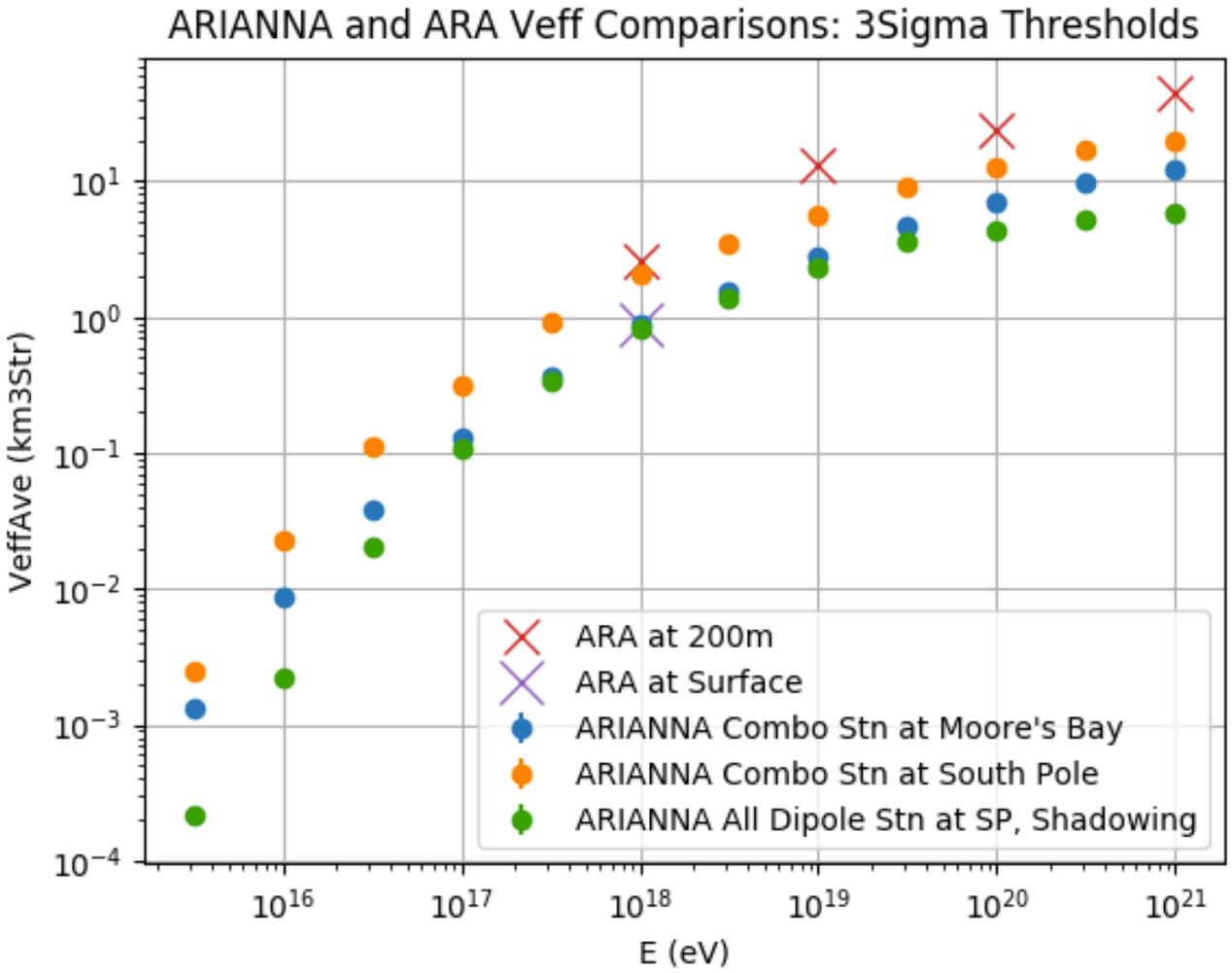
5 years ontime
South pole ice
No reflection
Amy Conolly's ν-tot cross-section
Horizontal Prop, L=500m
Analysis eff =0.8 (same as Moore's Bay)
169 stn, 0.9 nonoverlap
Grid spacing=1.5km

Sensitivity to explosive events

- Could ARIANNA contribute to seeing a GW counterpart?
- Not yet, but surprisingly (?) sensitive already in current set up of 10 stations
- Unfortunately, the GW detection happened in polar winter …



Outlook - Neutrino simulation



- Signal simulation softwares are not at a quality where they should be
- Team from ARA and ARIANNA working on update
- ShelfMc and ARASim agree in principle at the same simple set-up

- Complexer signal propagation not implementable
- Impossible to change aspects of detector configuration
- …
- New software effort is currently being started (for all dense media)

Outlook - Large neutrino array

- ARIANNA hardware has been running reliably and would be ready for a large array
- Neutrino community needs to merge to proposed one joint array
- **Open questions:**
  - Go deep, stay shallow?
    - **Signal propagation (high priority)**, antenna types, …
  - Where? South Pole vs. Moore's Bay vs. anywhere else?
    - Ice, radio interference background, infrastructure, …