

Instead of

Neutrinos with a cosmic ray detector

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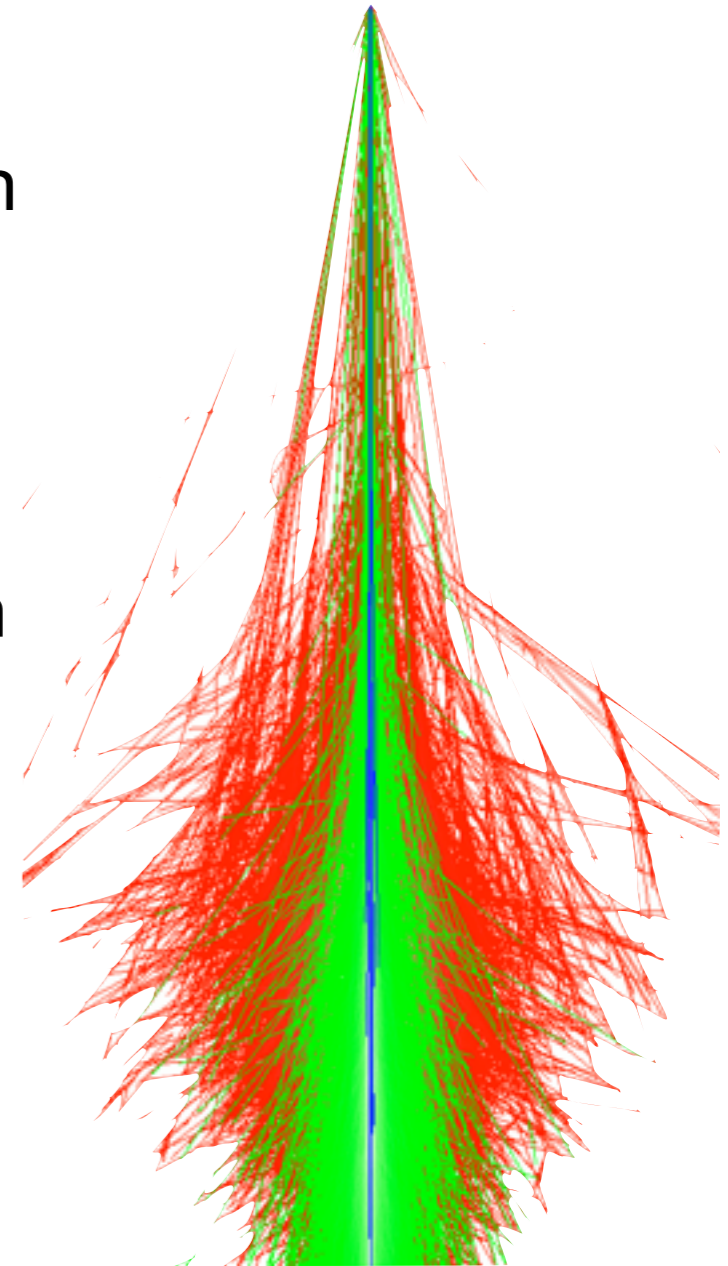
Cosmic rays with a neutrino detector

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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:
 - **Magnetic field**
(e.g. Geomagnetic field in atmosphere, dominant in air)
 - **Charge imbalance**
("Askaryan effect", dominant in ice)
 - **Relativistic compression**
(Cherenkov-like effects due to index of refraction, affects emission from both effects)



Radio emission of showers

- **(Geo-)Magnetic field**

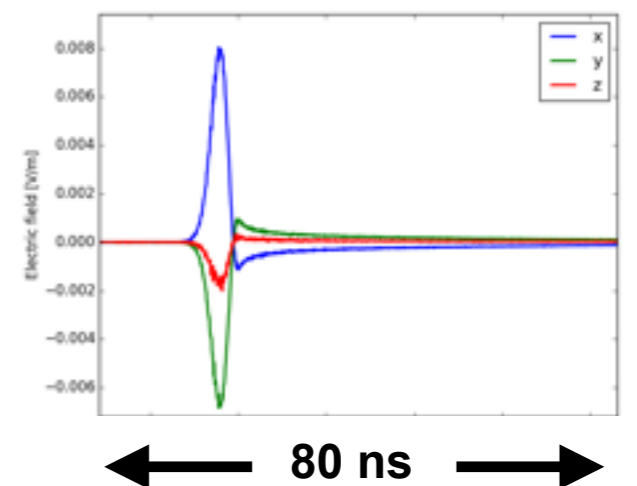
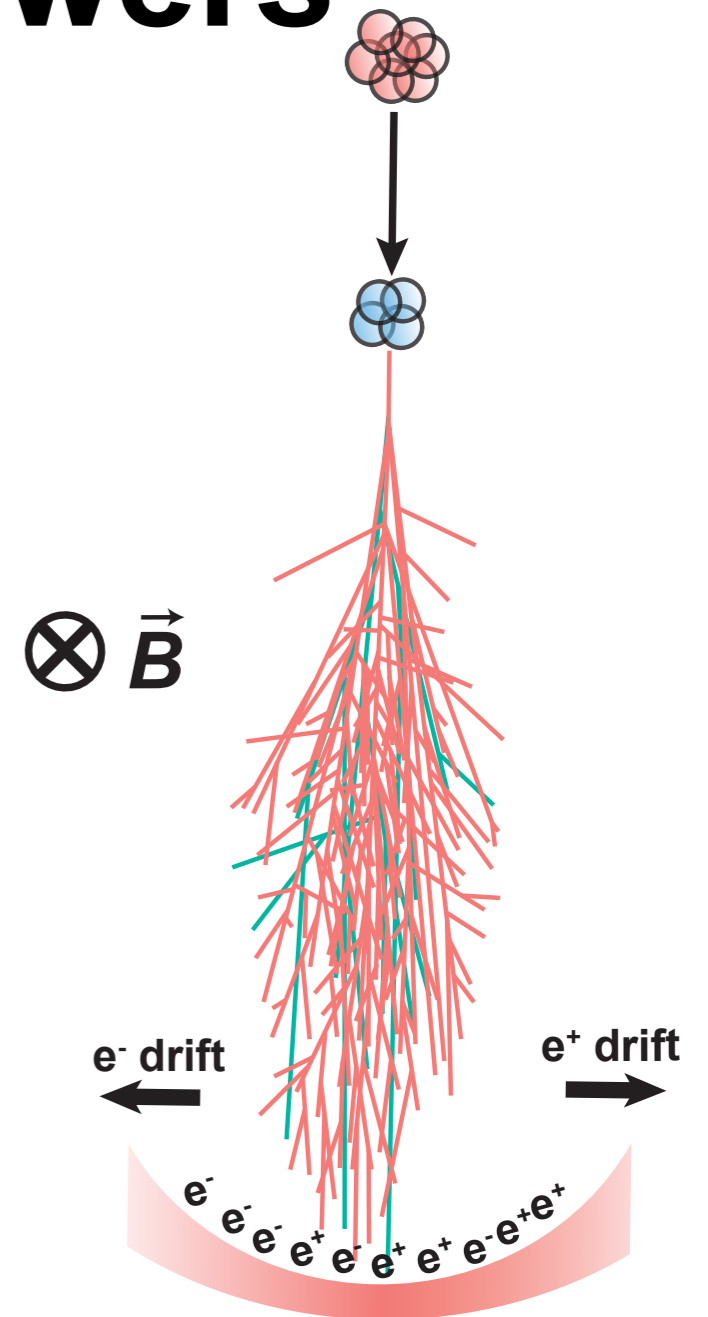
- Lorentz-force deflects particles that are created
- time-varying transverse current in shower
- electric field polarized in direction given by Lorentz-force

- **Charge imbalance (“Askaryan effect”)**

- shower accumulates electrons from medium
- time-varying current along shower axis
- electric field polarized pointing towards shower axis

- **Cherenkov-like effects, relativistic compression**

- Radiation is strongly beamed forward
- Coherence “amplifies” signal as function of frequency, Cherenkov-ring structures

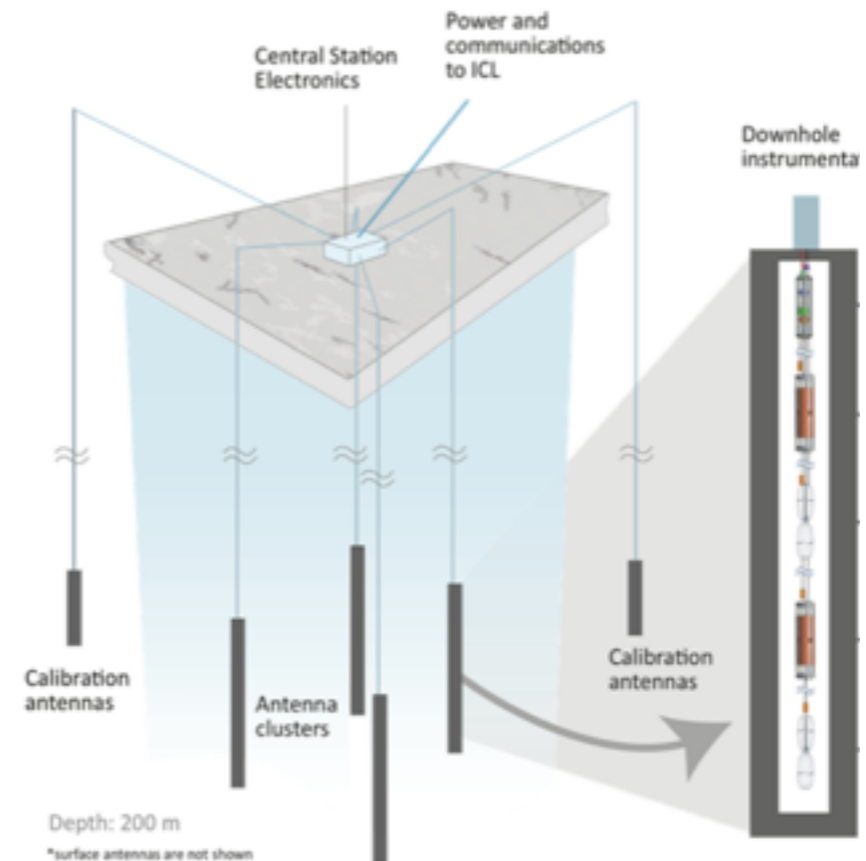


Cosmic rays for “free” in neutrino detectors

- **(almost) The same signals**
 - nanosecond pulses
 - from above instead of below
- **Use the same trigger and reconstruction algorithms**
 - energy reconstruction
 - direction reconstruction
 - ...
- **Signals needs to identified with ~100% efficiency -> background**
- **Use the signals as calibration tool**
- **Is there a cosmic ray science case?**

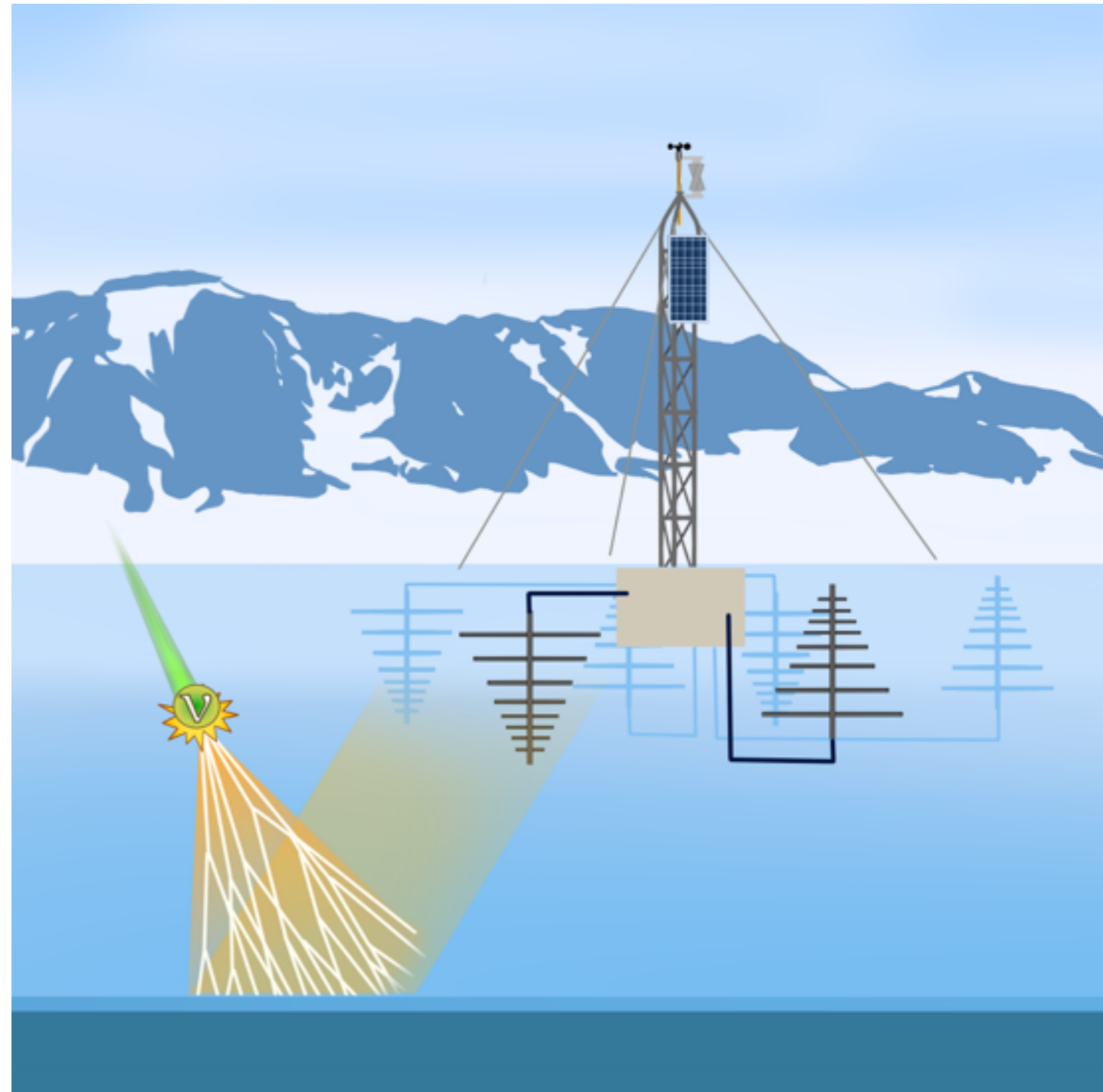
Comment on ARA

- I am more informed about ARIANNA ... my apologies
- As far as I know, no confirmed cosmic ray detection in ARA yet
- Situation at ARA might be slightly different
- Signals from above are vetoed due to noise from South Pole station
- Detectors are deep, signals from air have to propagate
- There might be a contribution from showers continuing to develop in ice, like transition radiation etc. (de Vries et al.)
- ARA is “volume”, ARIANNA is “flat”



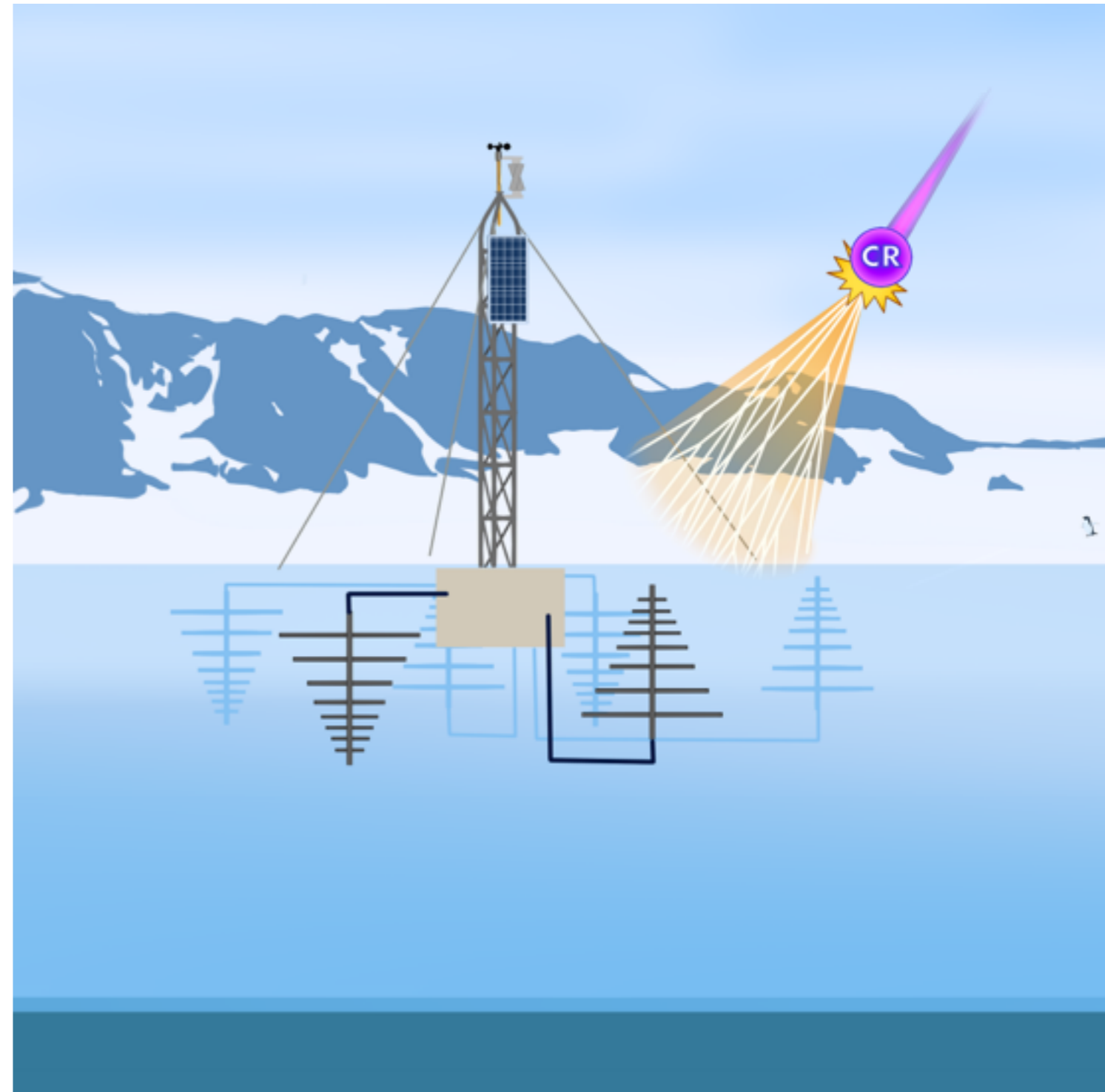
Concept of ARIANNA

- On ice-shelf: **Ice-water boundary** almost perfect reflector for radio emission
- **Independent antenna stations** can be installed at low costs on the surface
- **Real-time data transfer** via satellite
- Solar and wind power possible
- **High gain antennas** (50 - 1000 MHz) can be used to instrument a large volume
- Array of about 1000 antennas needed



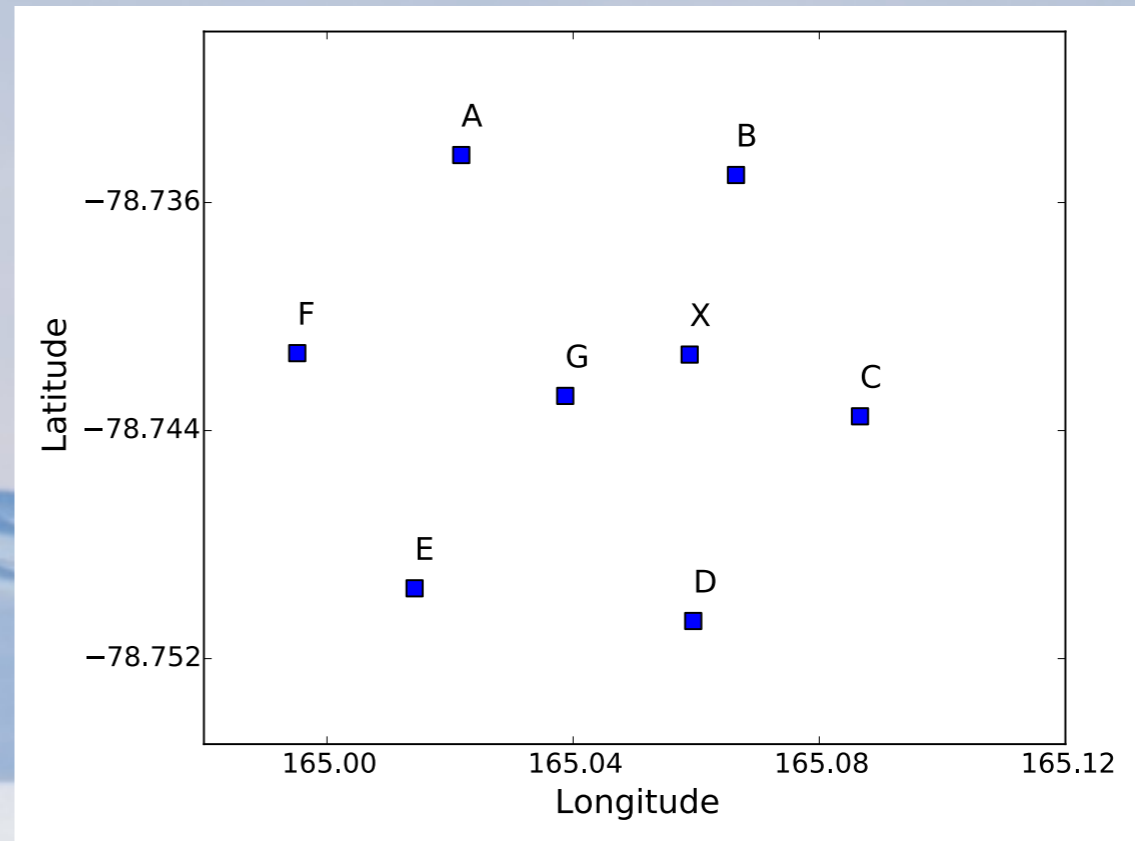
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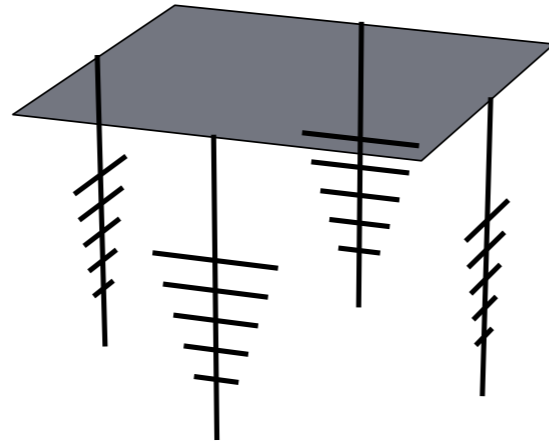
Current status of ARIANNA

First hexagonal array in operation since 2015

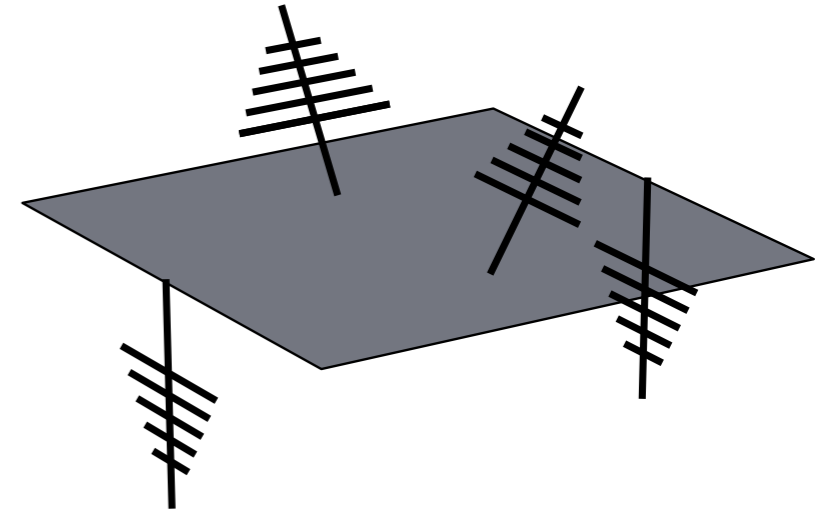


Current status of ARIANNA

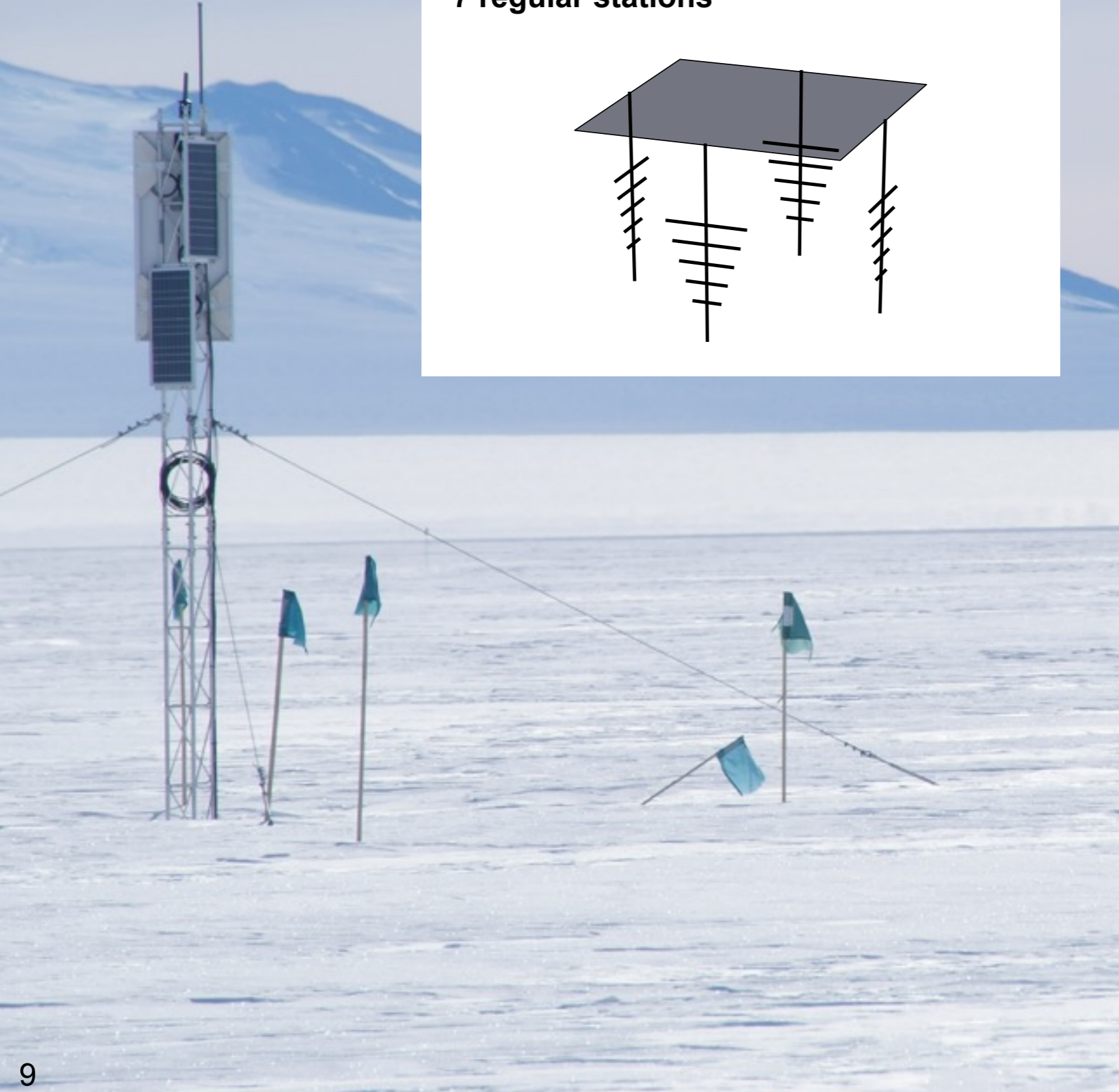
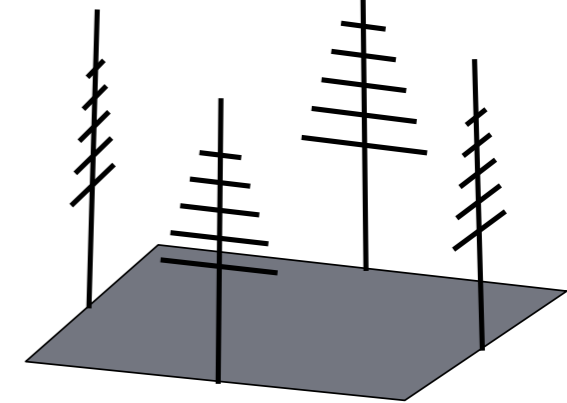
7 regular stations



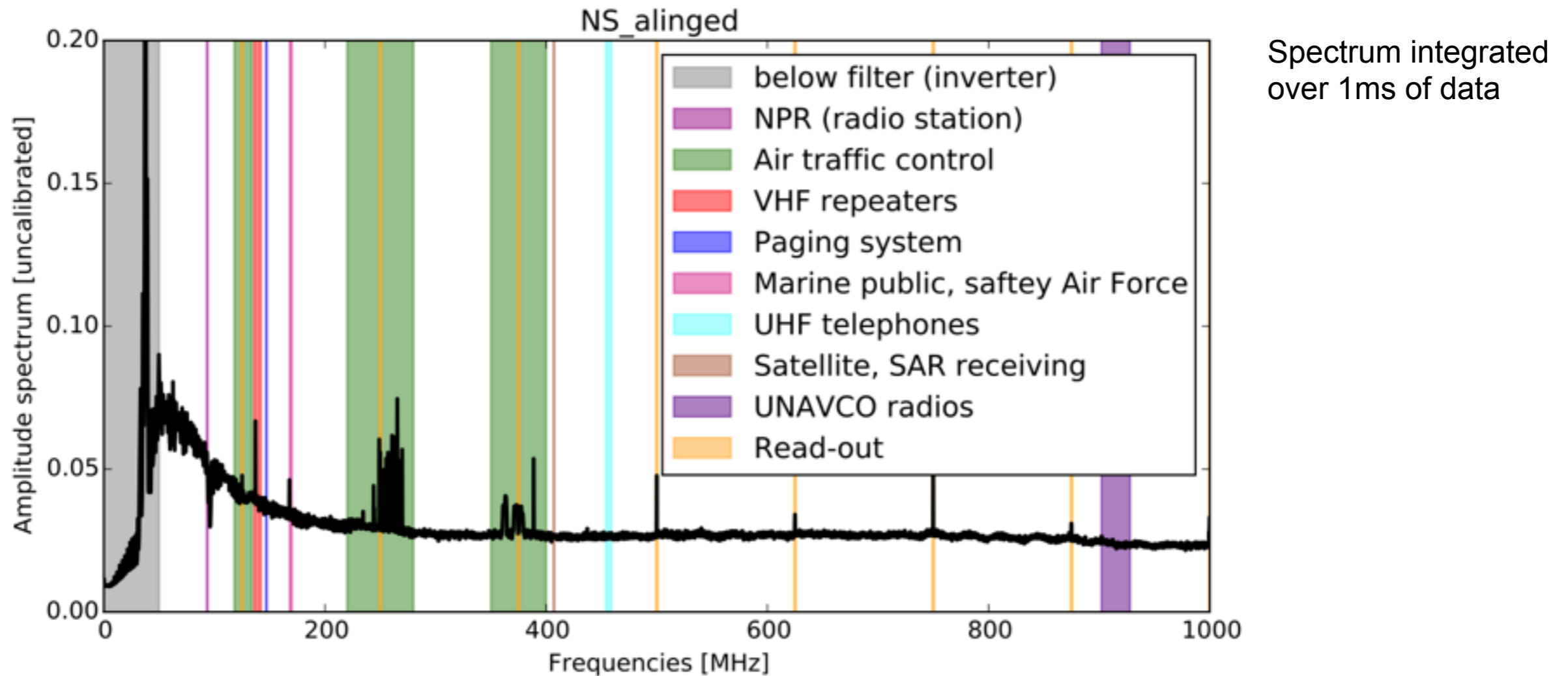
1st "Cosmic Ray" station



2nd "Cosmic Ray" station



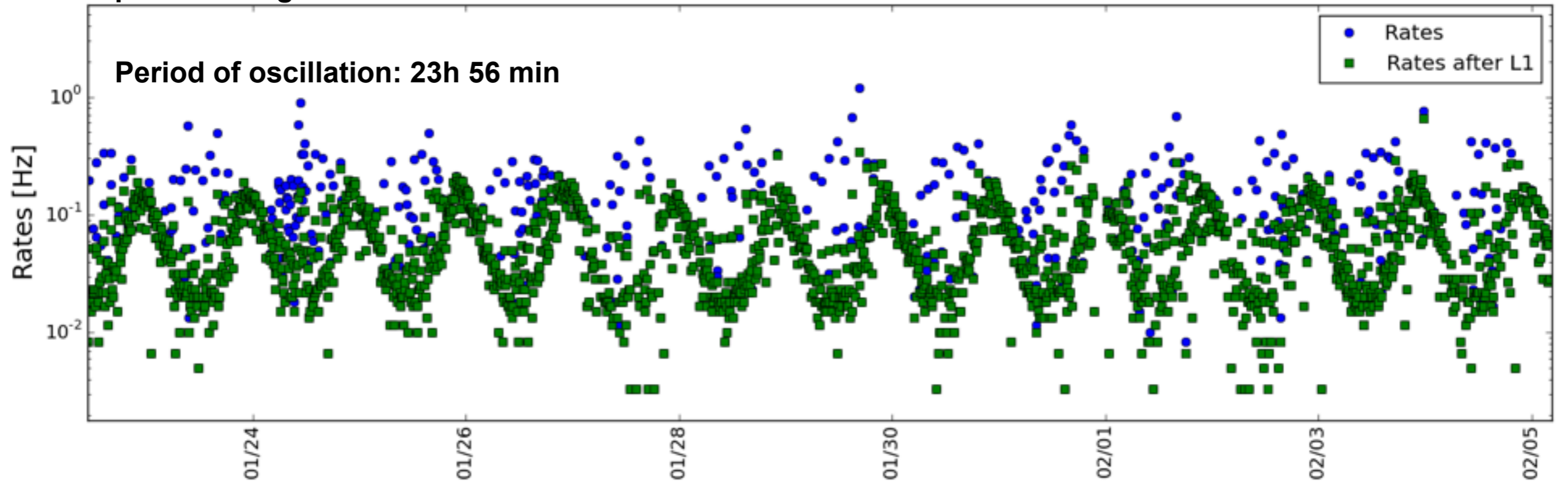
Narrow-band background



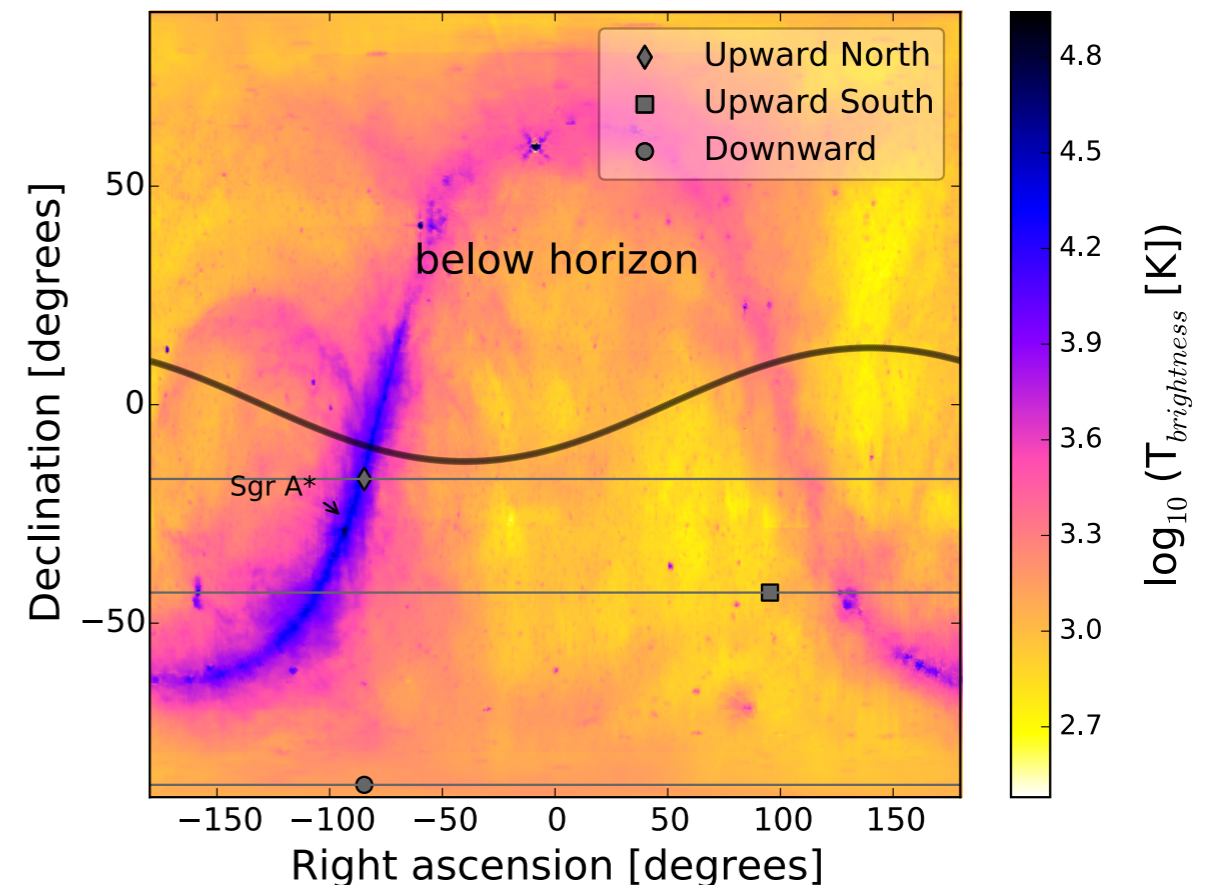
- Dedicated study with oscilloscope and upward pointing antenna 50-1000 MHz
 - **extremely quiet radio environment**
 - small, time-varying contribution of **narrowband emitters**
 - spectrum clearly dominated by Galactic noise

Galactic background

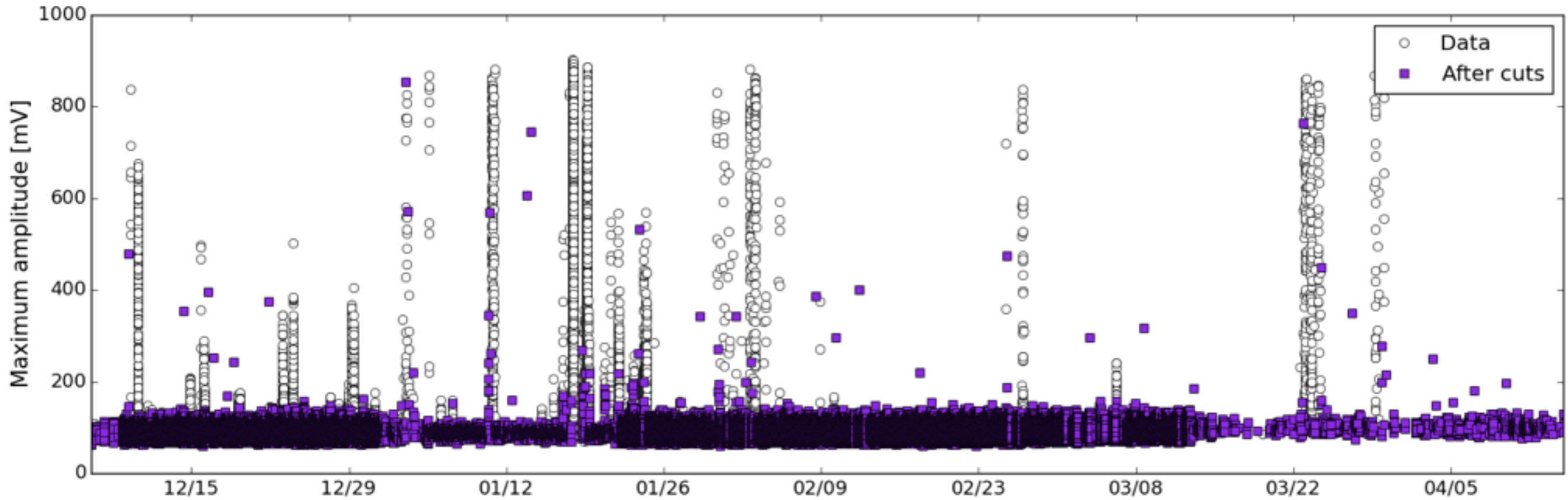
Upward facing antennas



- Irreducible background: Galactic radio emission
- ARIANNA stations reach noise floor, which is dominated by diffuse Galactic synchrotron emission

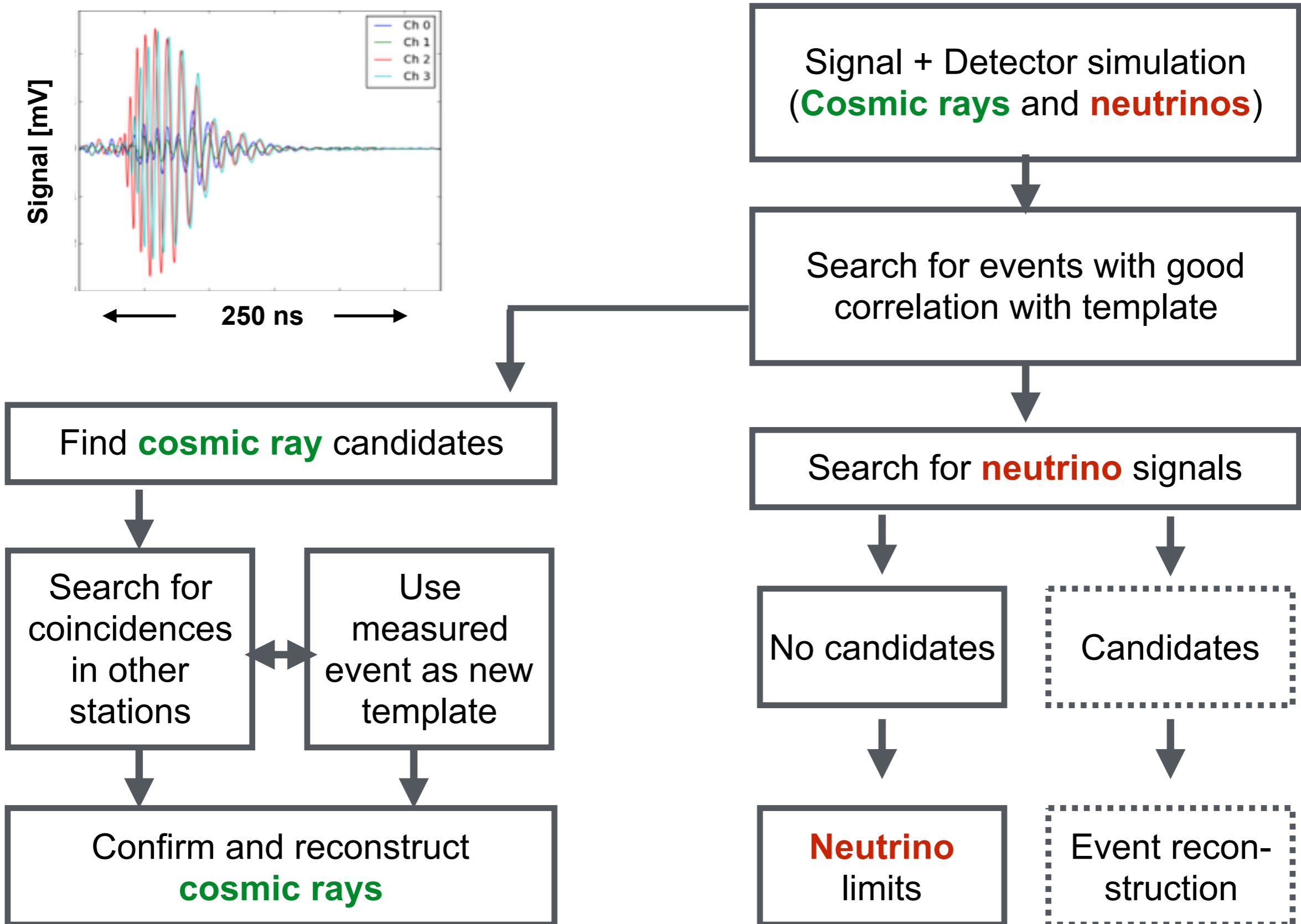
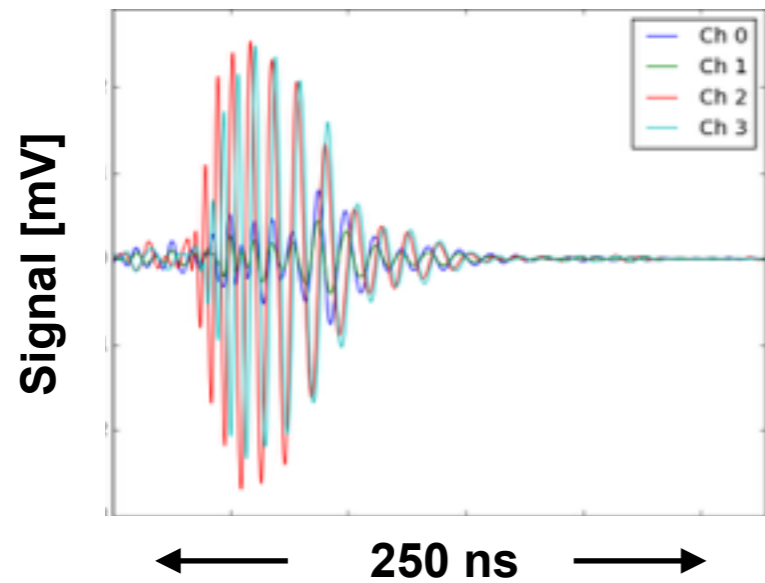


Broad-band background

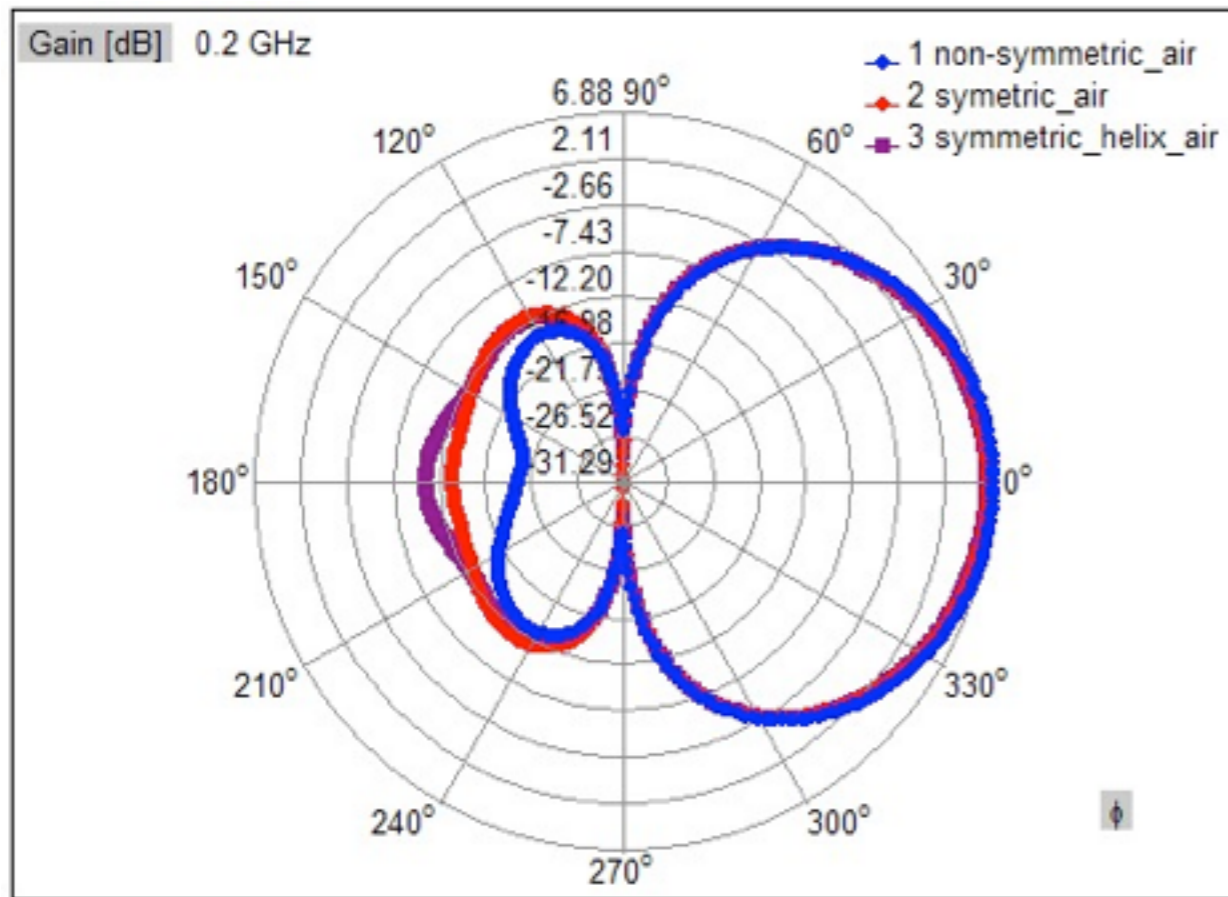


- No broad-band pulsed background, apart from:
 - During storms: either a snow or weather effect (max 7% of live-time affected), not a problem in analysis
 - Cosmic rays

Signal search strategy



Antenna simulation

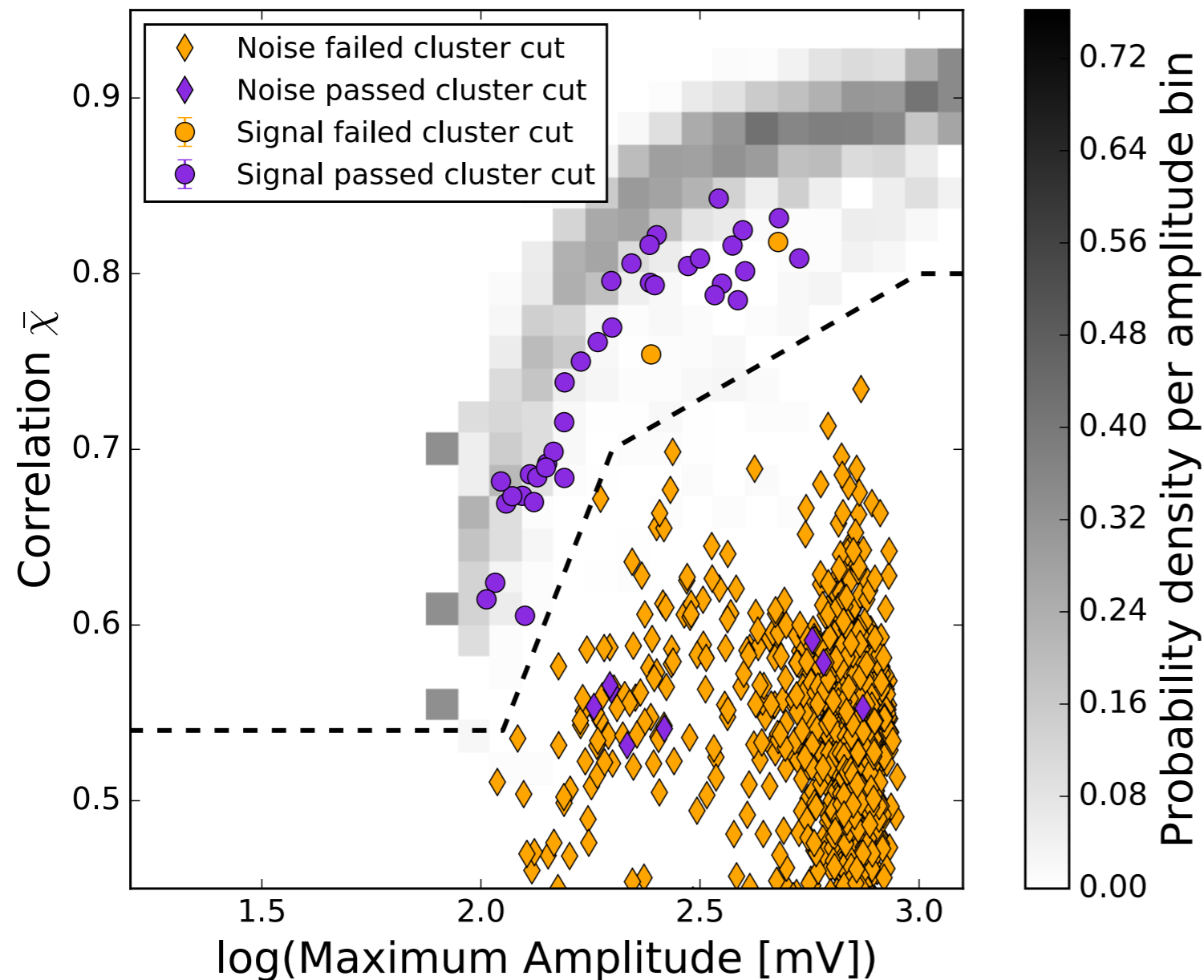


UROP project: Sky Phillips, Savannah Shively

- Signal strongly depends on antenna response
- Needed: **direction** and **frequency** dependent **gain** and **group delay** of antenna
- In-Situ measurements often difficult, calibration only as good as your calibration source
 - *No “Beam of 10^{18} eV neutrinos from the Ross ice-shelf”*
- Antenna has to be modelled in medium with accurate parameters
- WIPL-D antenna simulation software
- Complex modelling of all parameters to match measurements in anechoic chamber

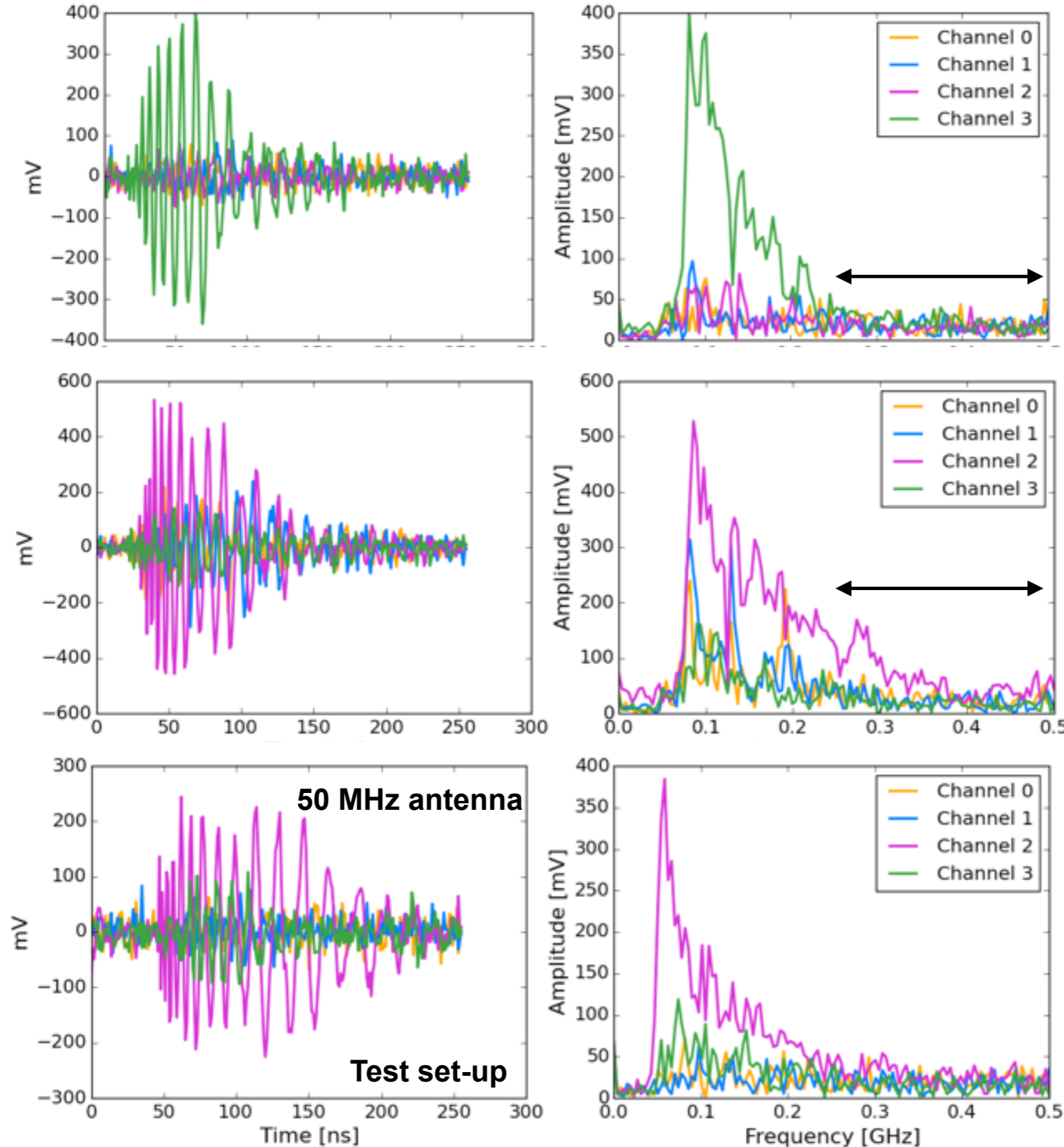
Cosmic Rays in upward antenna

All details about this analysis in arXiv: 1612.04473



- Cosmic rays in through front-lobe of LPDA have a unique characteristic
- Allows for > 99% analysis efficiency to reject noise
- Profits from large bandwidth of ARIANNA system and antenna response

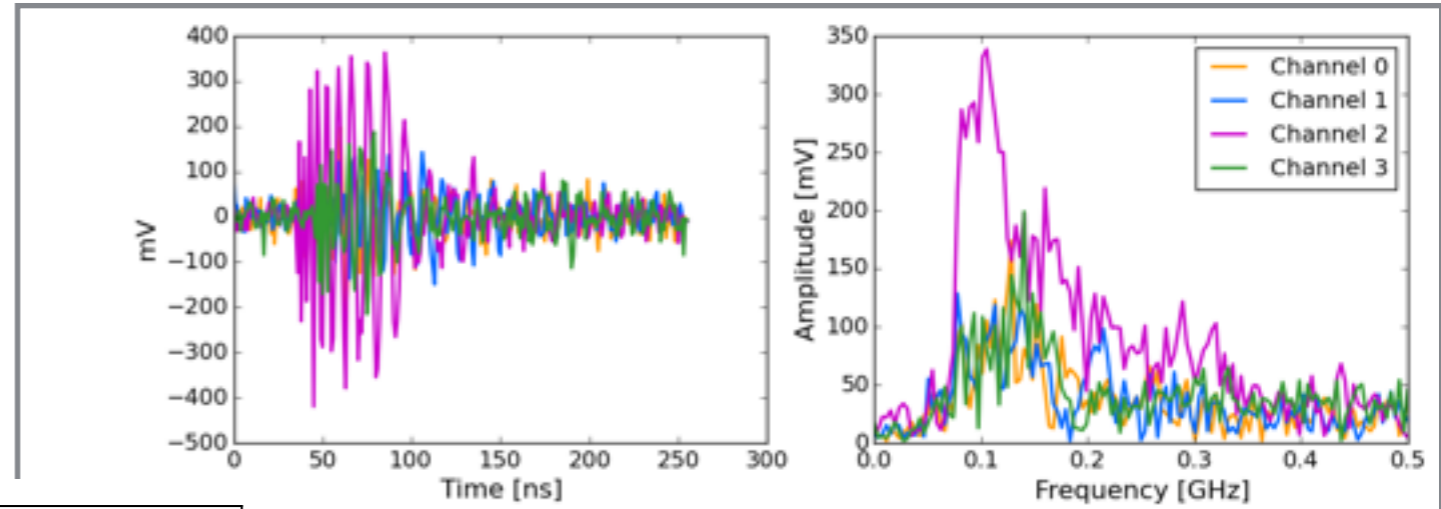
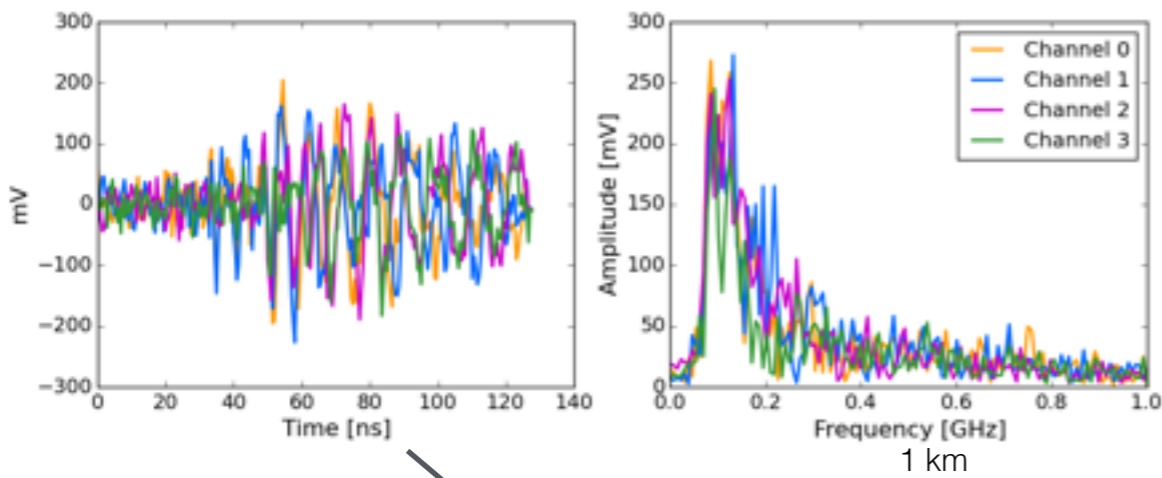
Measured air showers



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

- Signals will be interesting to study **spectral behaviour** of air shower signals

Measured air shower



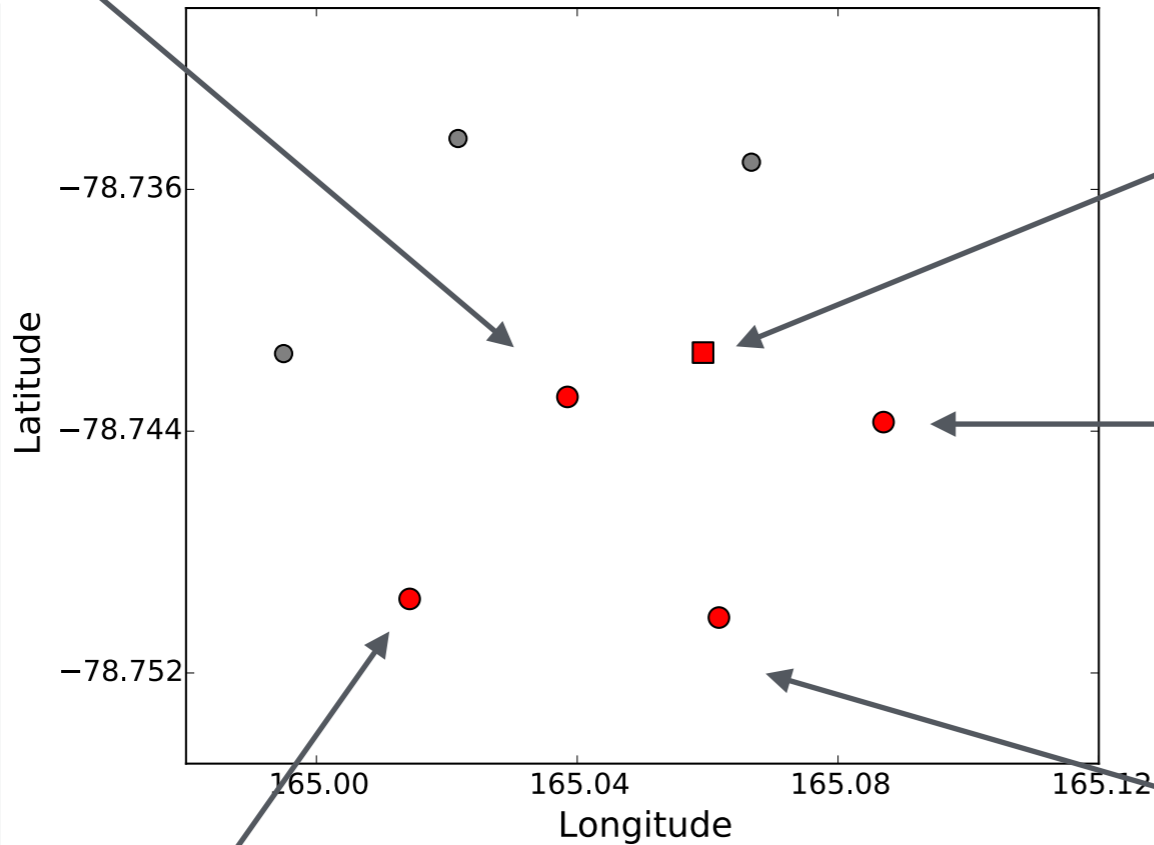
ARIANNA

Air shower detected

December 21st
2015
1450734371 UTC

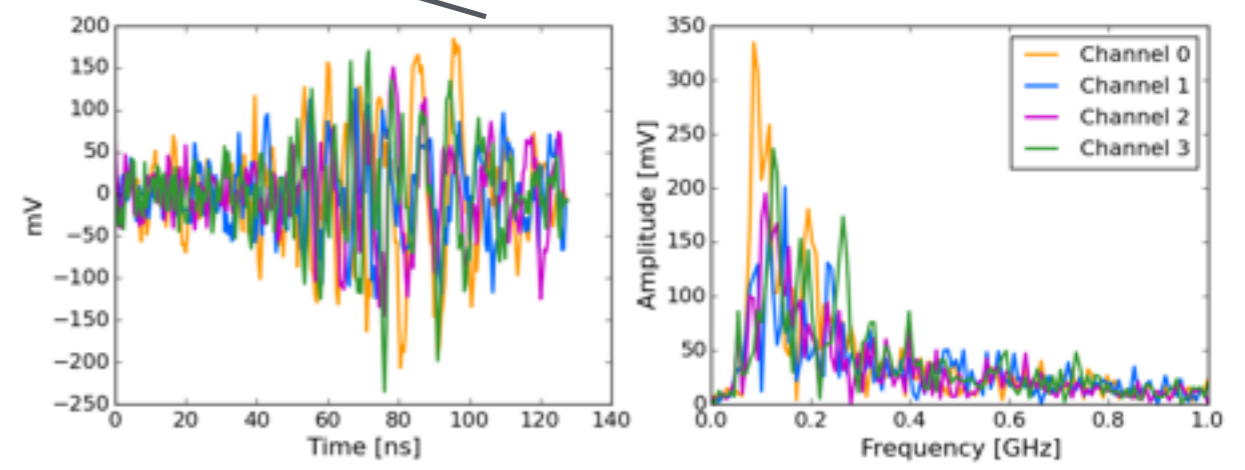
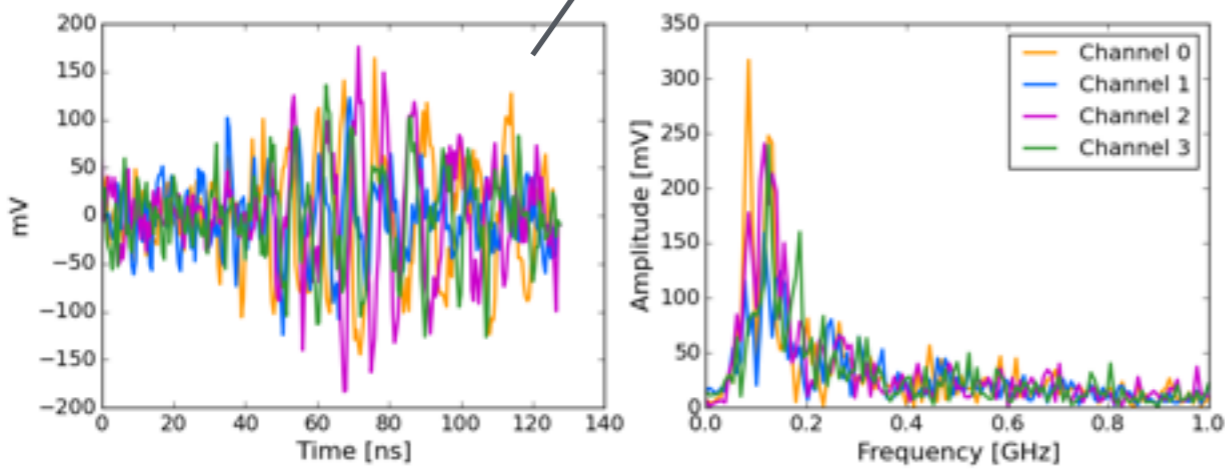
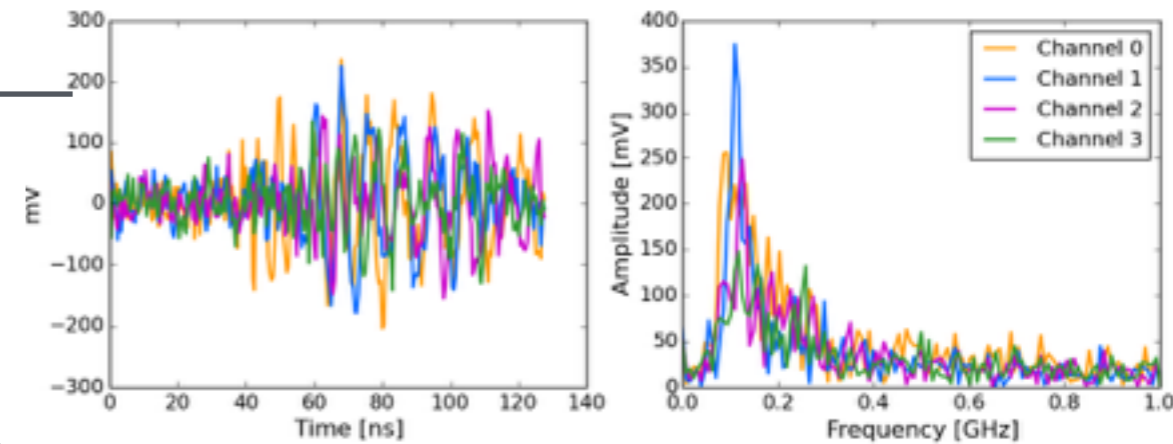
Four independent
direction
reconstructions
(after Fresnel)

Zenith = $49^\circ \pm 2^\circ$
Azimuth = $47^\circ \pm 2^\circ$

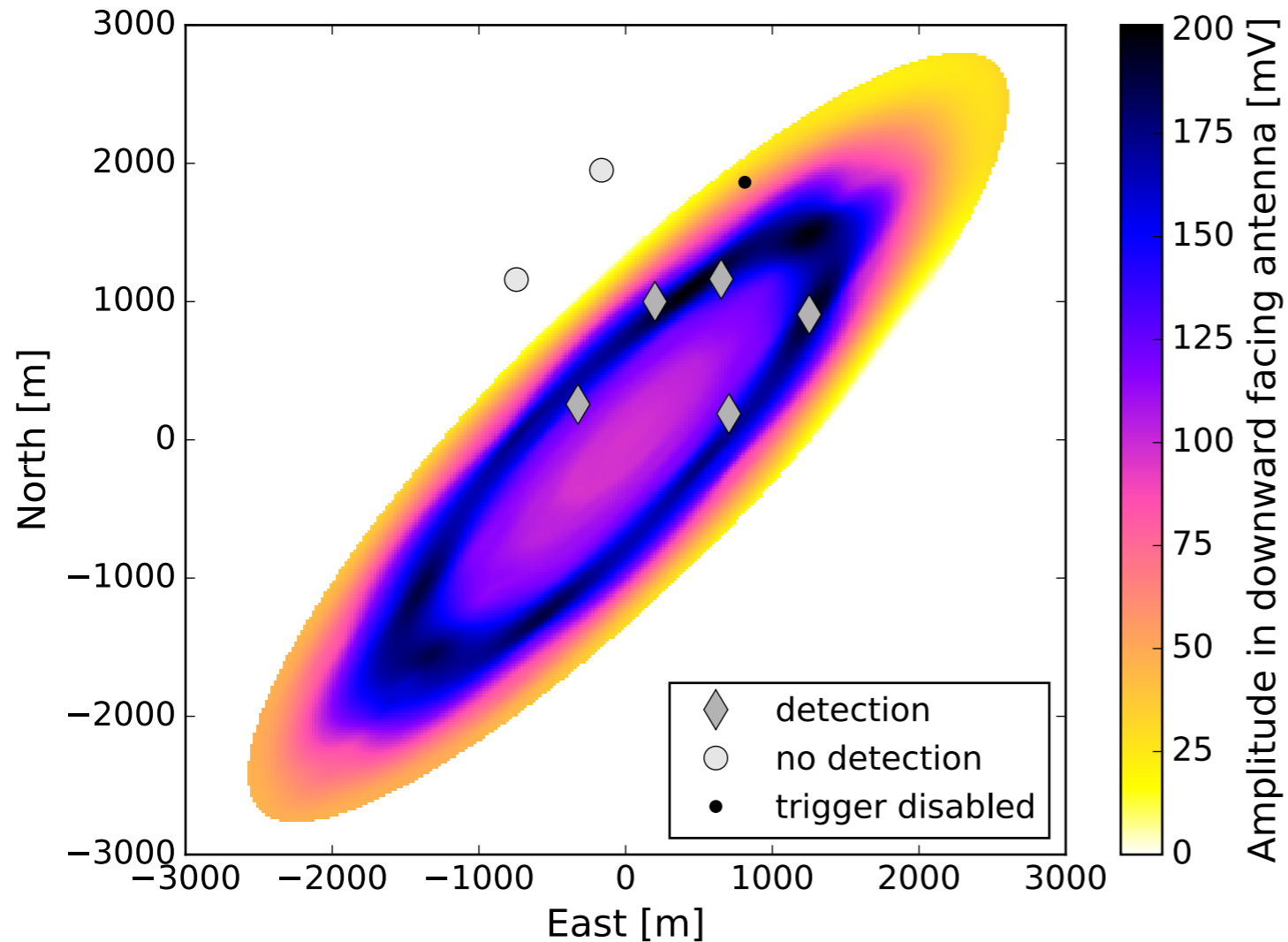


Cosmic ray station

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



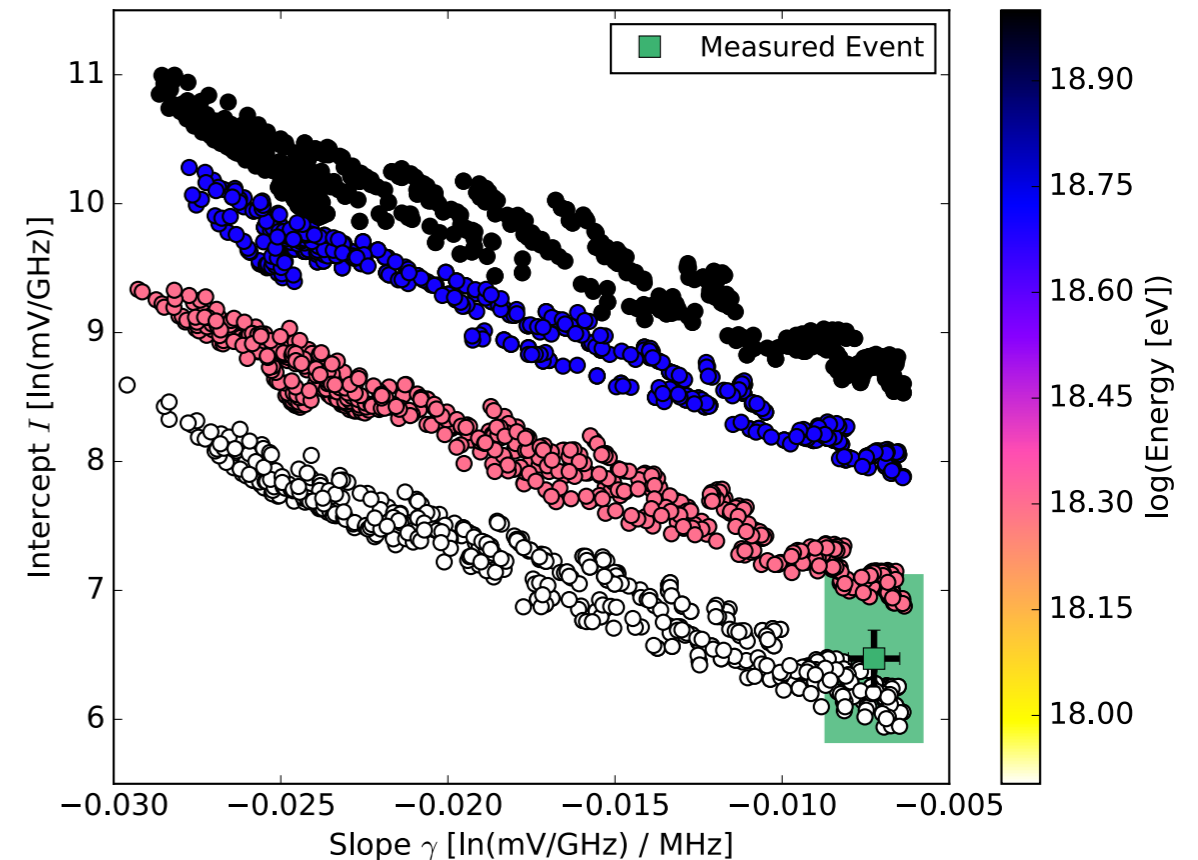
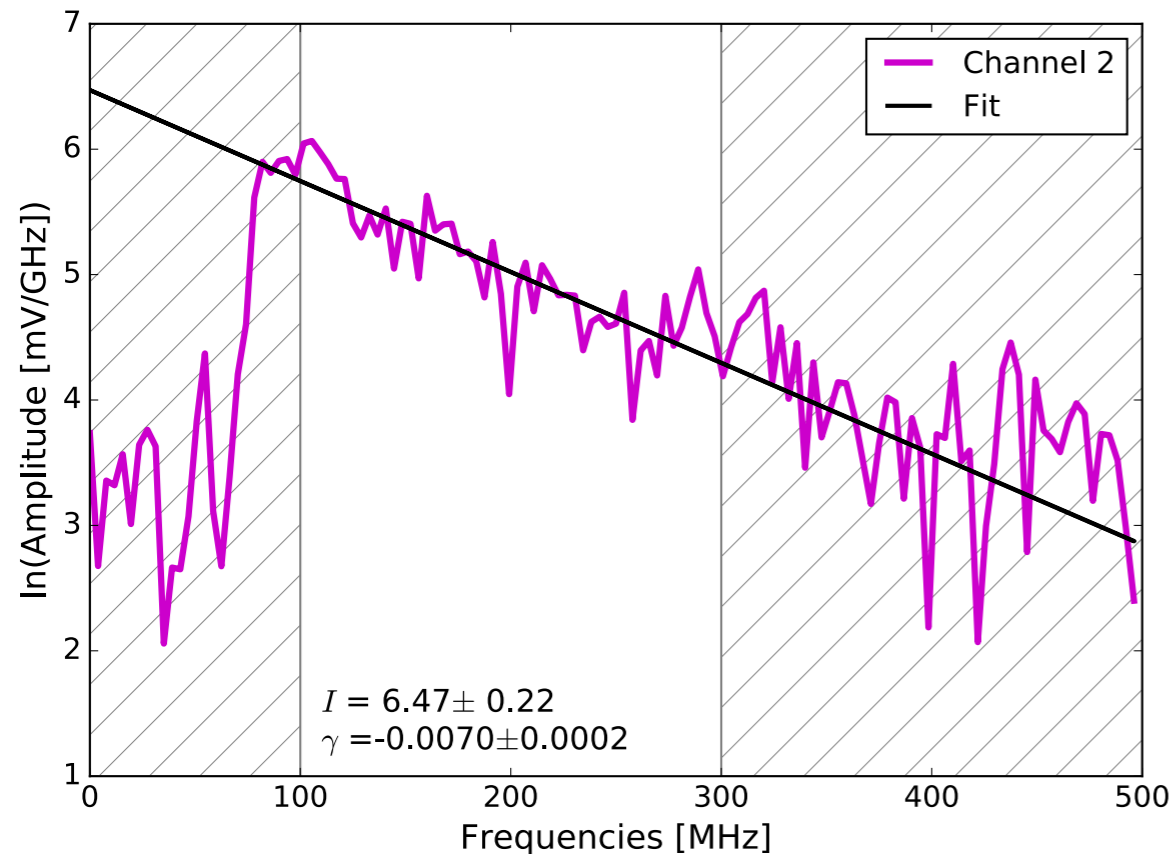
Air shower simulation



- Full detector simulation and dedicated simulations for big events
- Experiment with method as tested in LOFAR and AERA
- Use polarization information
- Fully independent reconstruction of air shower parameters

Energy reconstruction

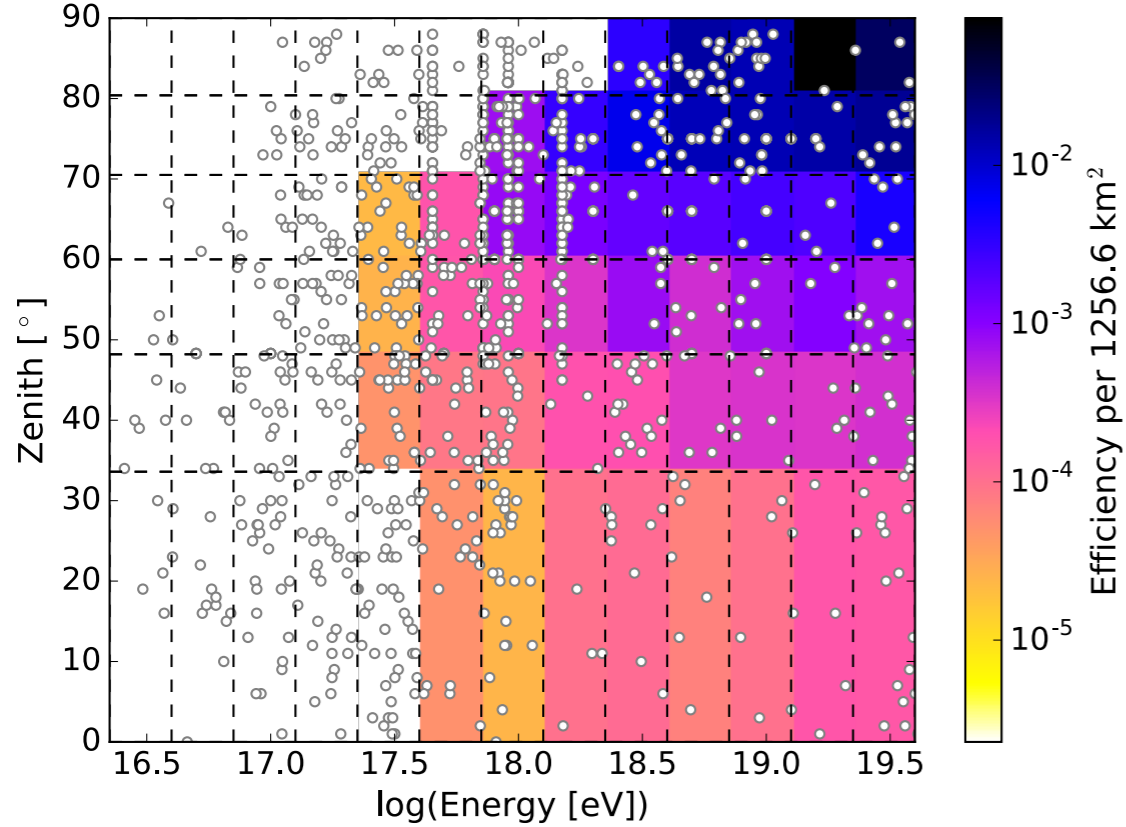
- The spectrum of the signal pulse translates to an energy and other shower parameters



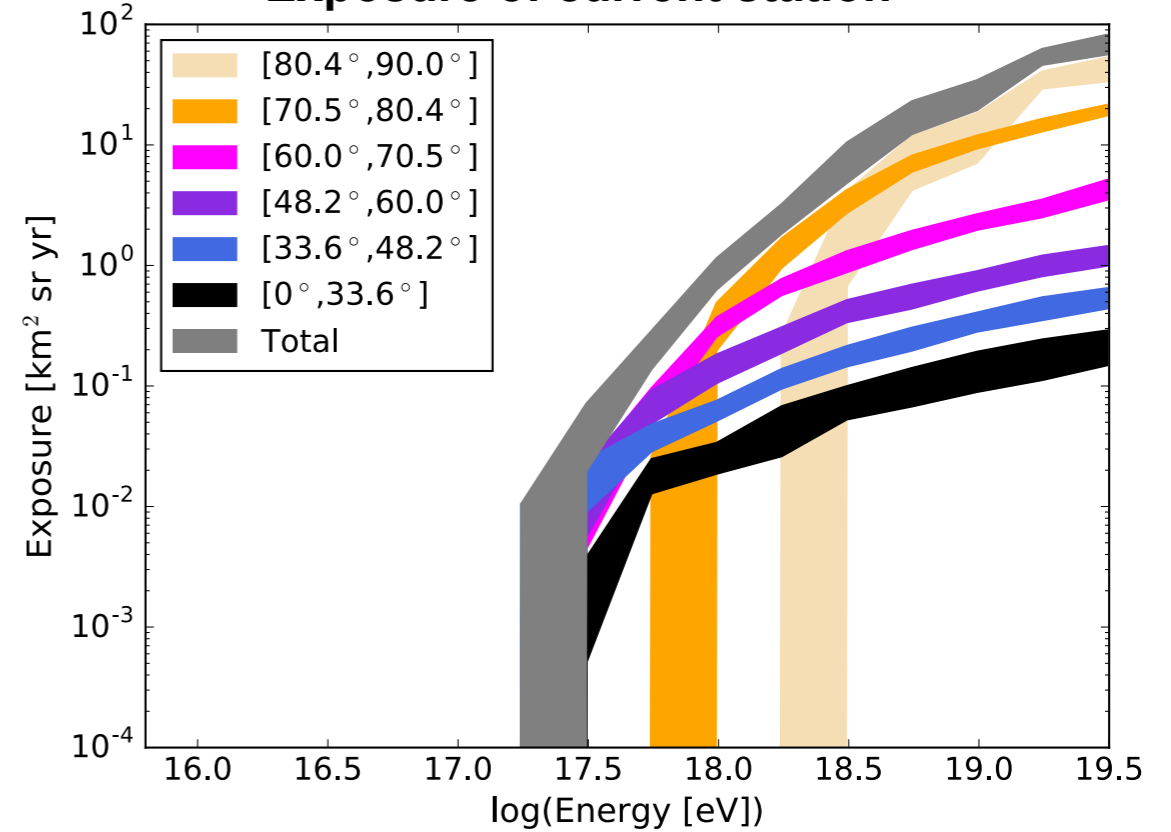
- Principle works, but needs a faster more efficient approach to work for both neutrinos and cosmic rays

Flux calculation

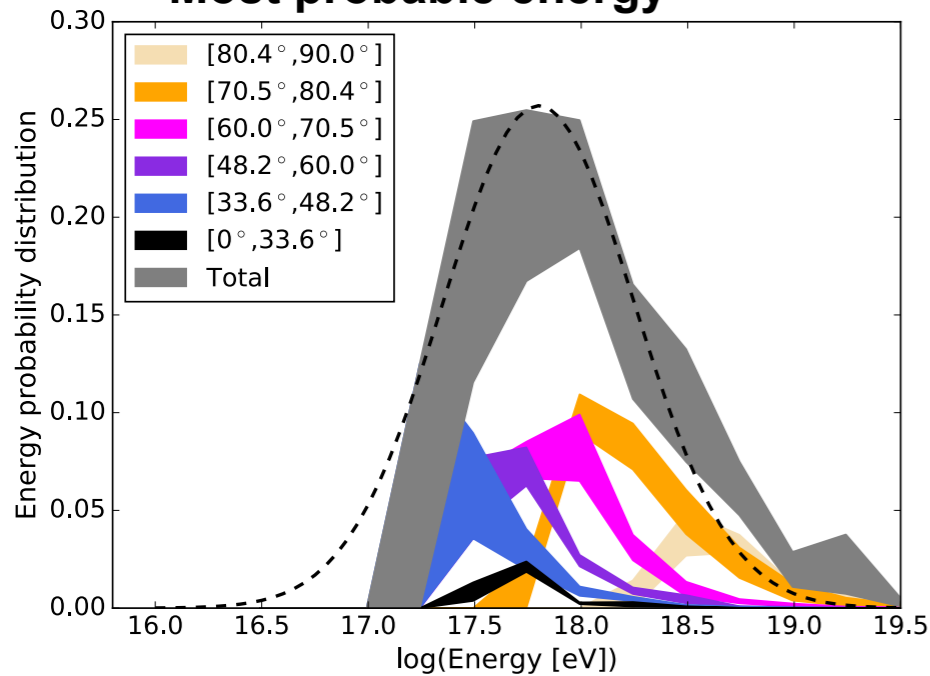
CoREAS air shower simulations
Detection efficiency per air shower



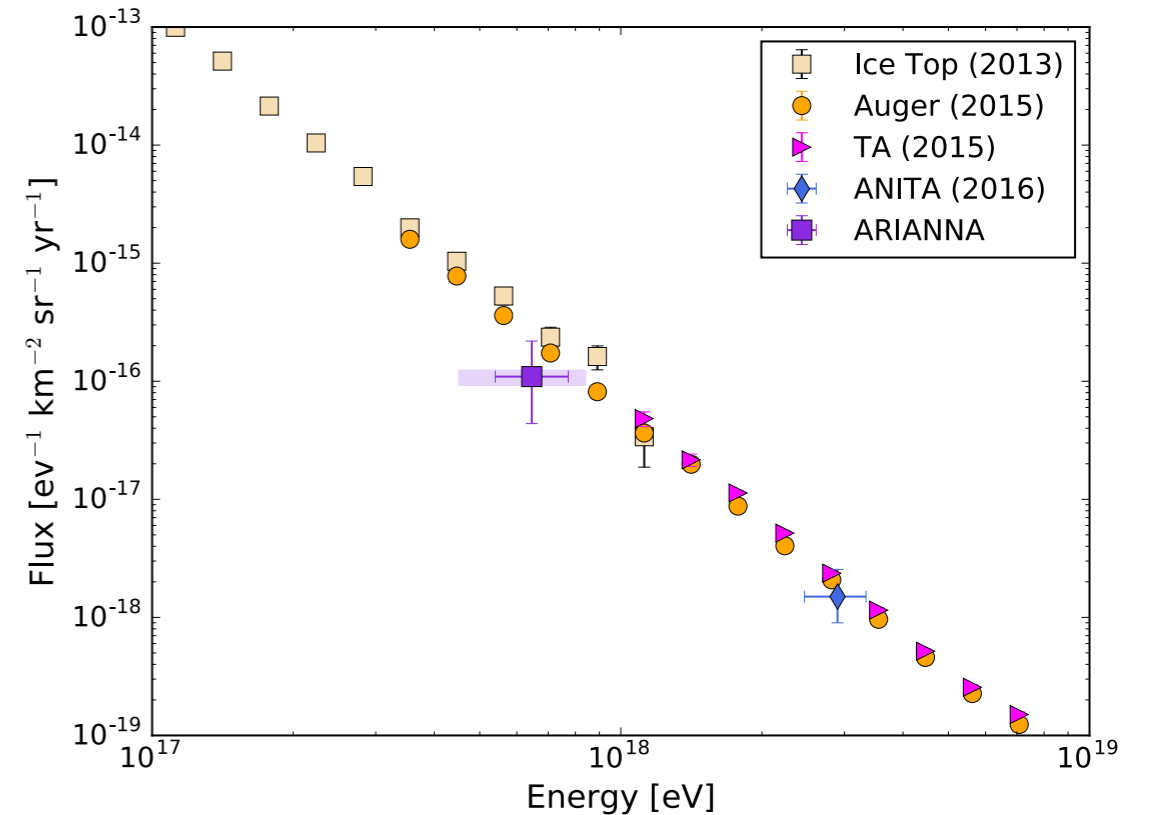
Exposure of current station



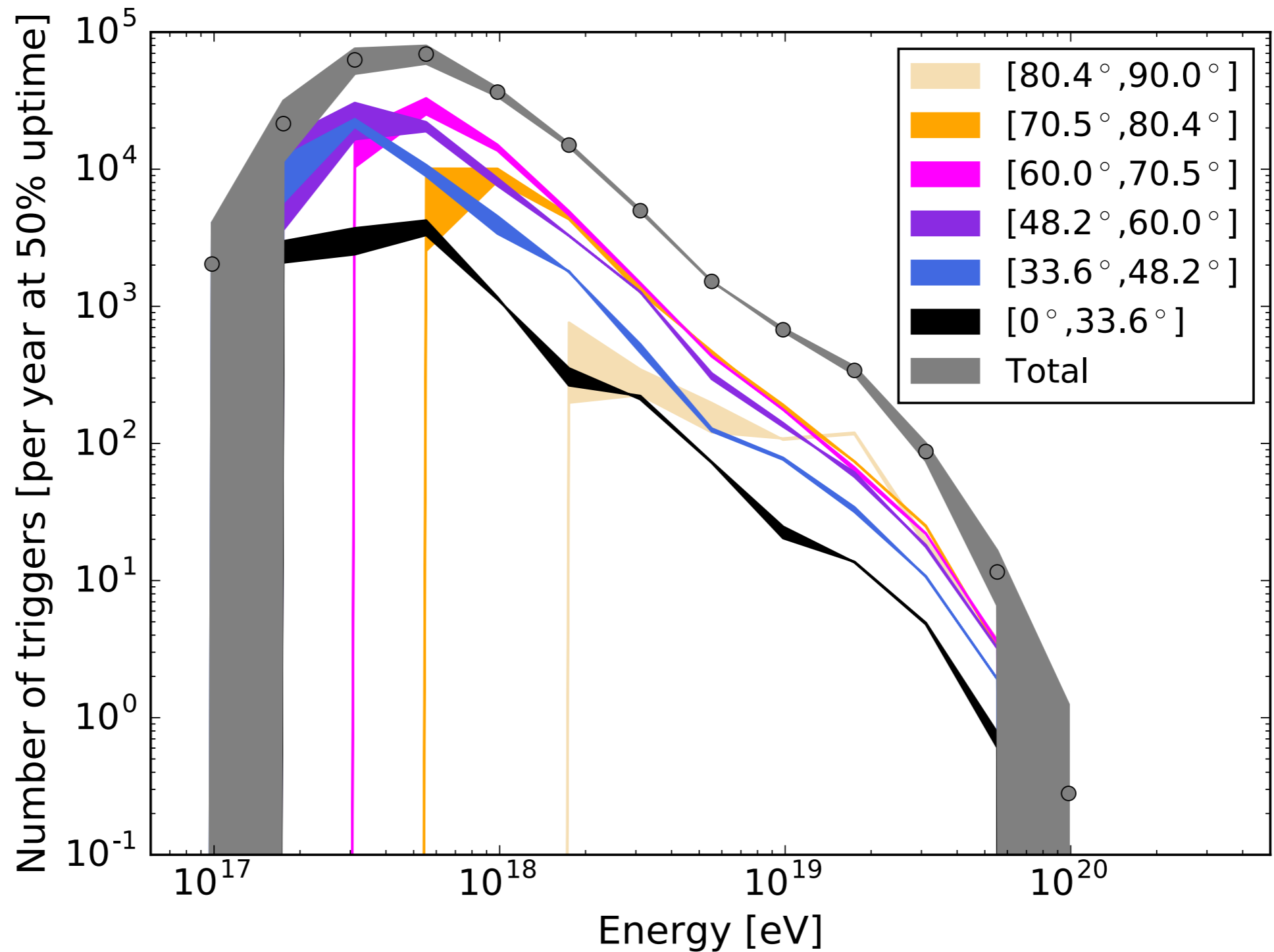
Most probable energy



Measured flux in one season

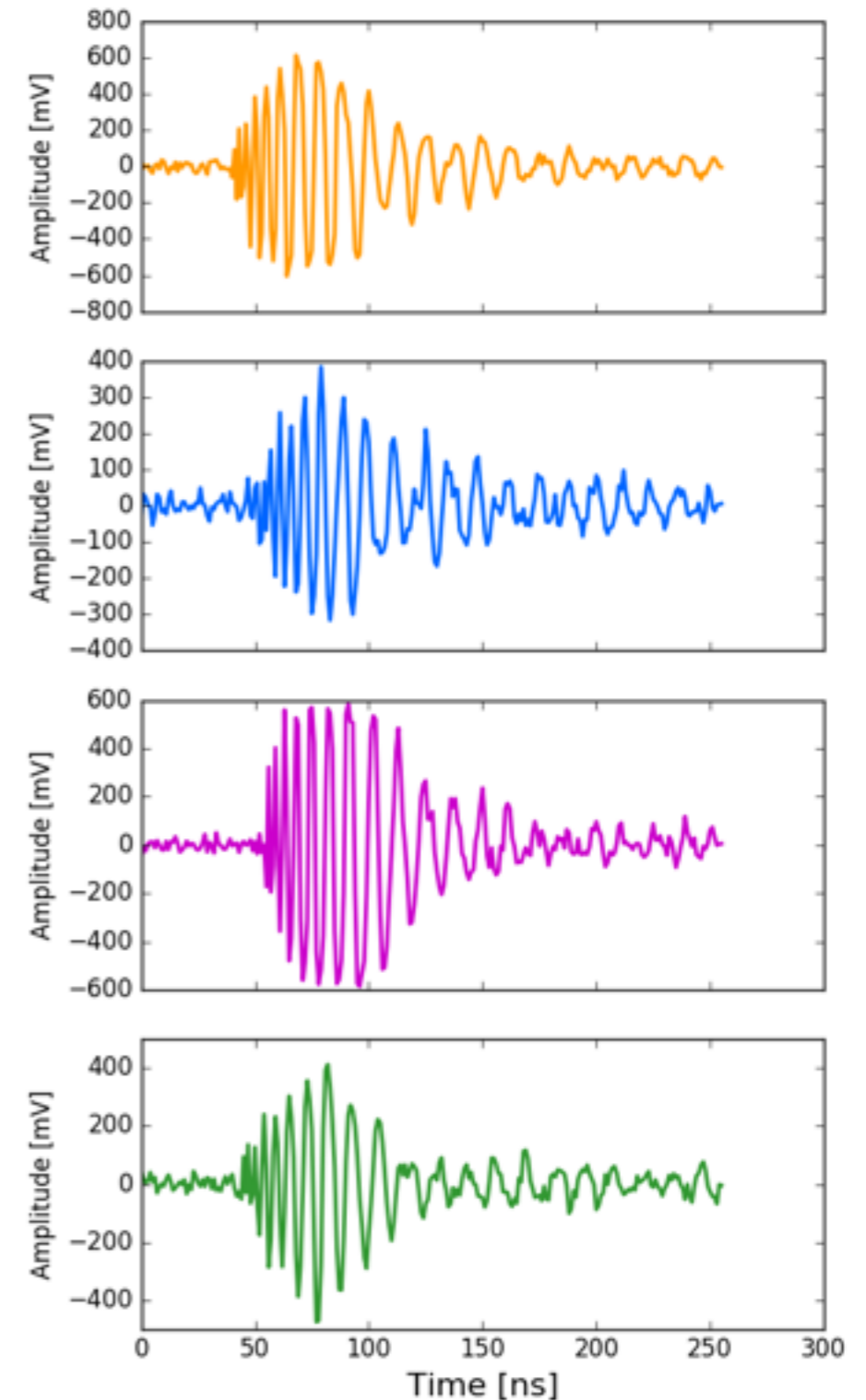
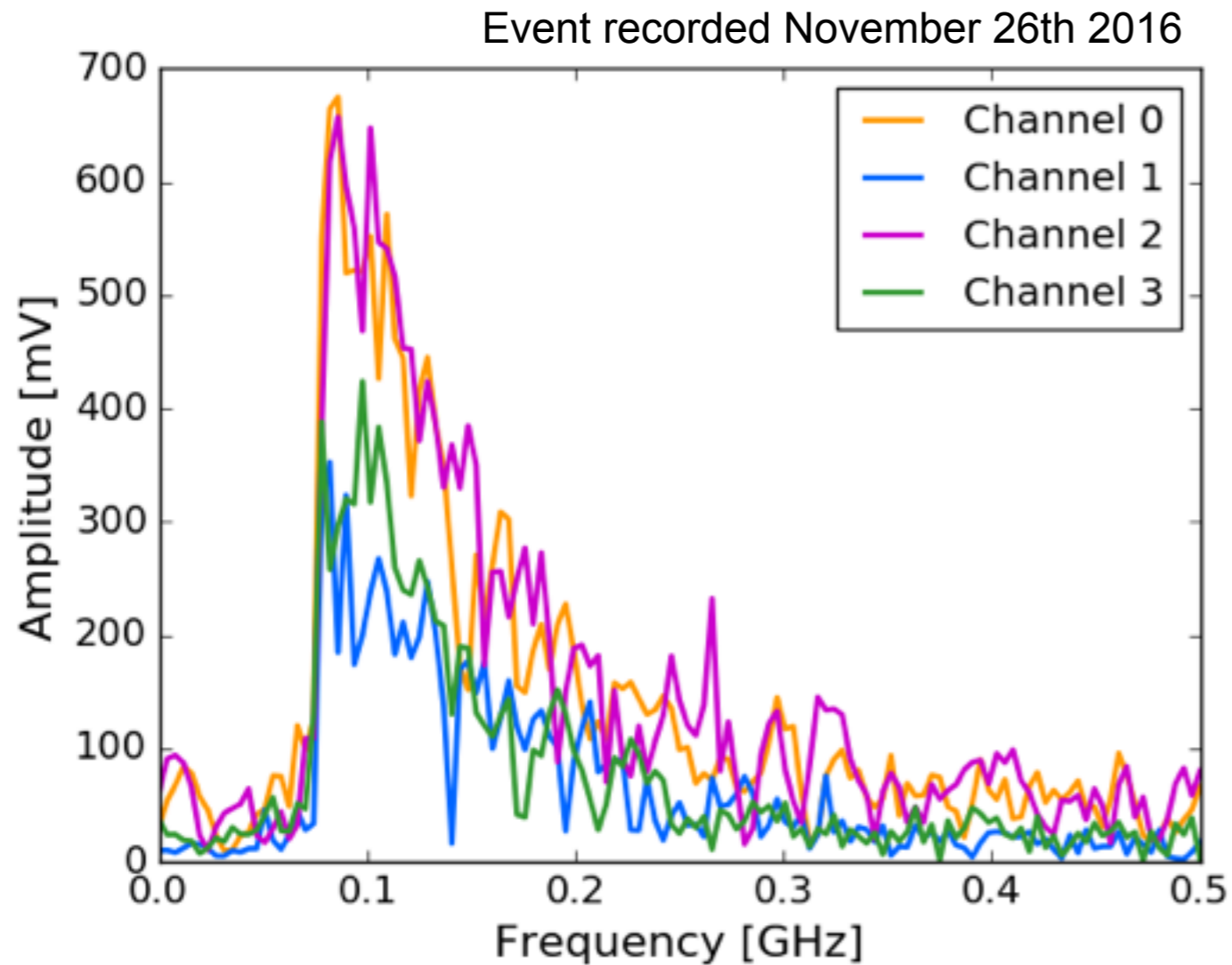


What does this mean for ARIANNA-1296?



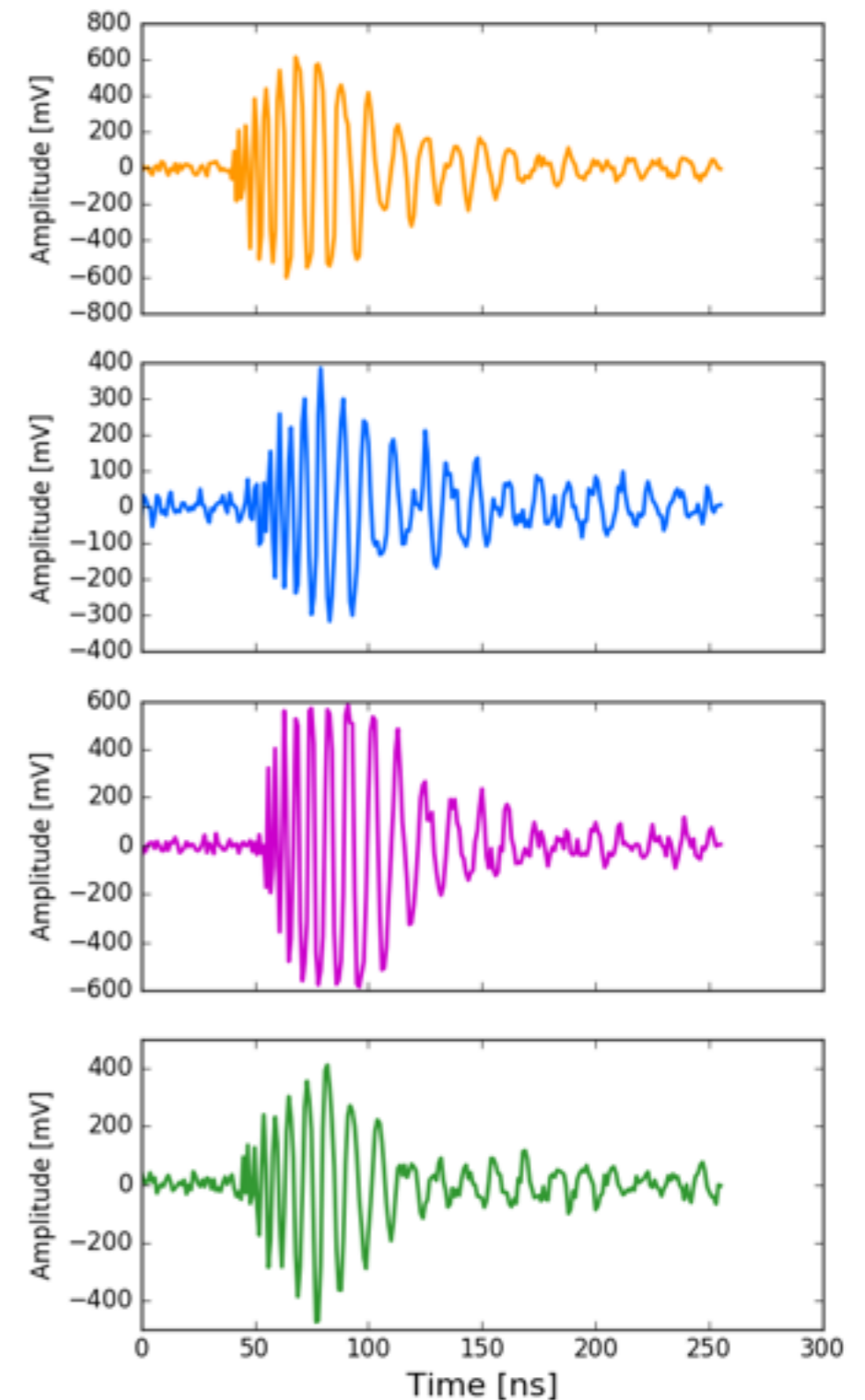
What are we doing now?

- Optimized station lay-out for cosmic rays: Four upward facing antennas, with two parallel channels



What are we doing now?

- Study how similar parallel channels are
- Develop direction reconstruction algorithms
- Study systematics
- Study polarization reconstruction
- Study energy reconstruction
- Confirmation of flux calculation
- ...



Conclusions

- Measured flux in agreement with other experiments
- Cosmic ray simulations are well understood and reproduce the measurements
- Test-bed for algorithms and calibration (we won't have neutrinos for a while)
- Potential science case from cosmic rays — not only calibration and background veto