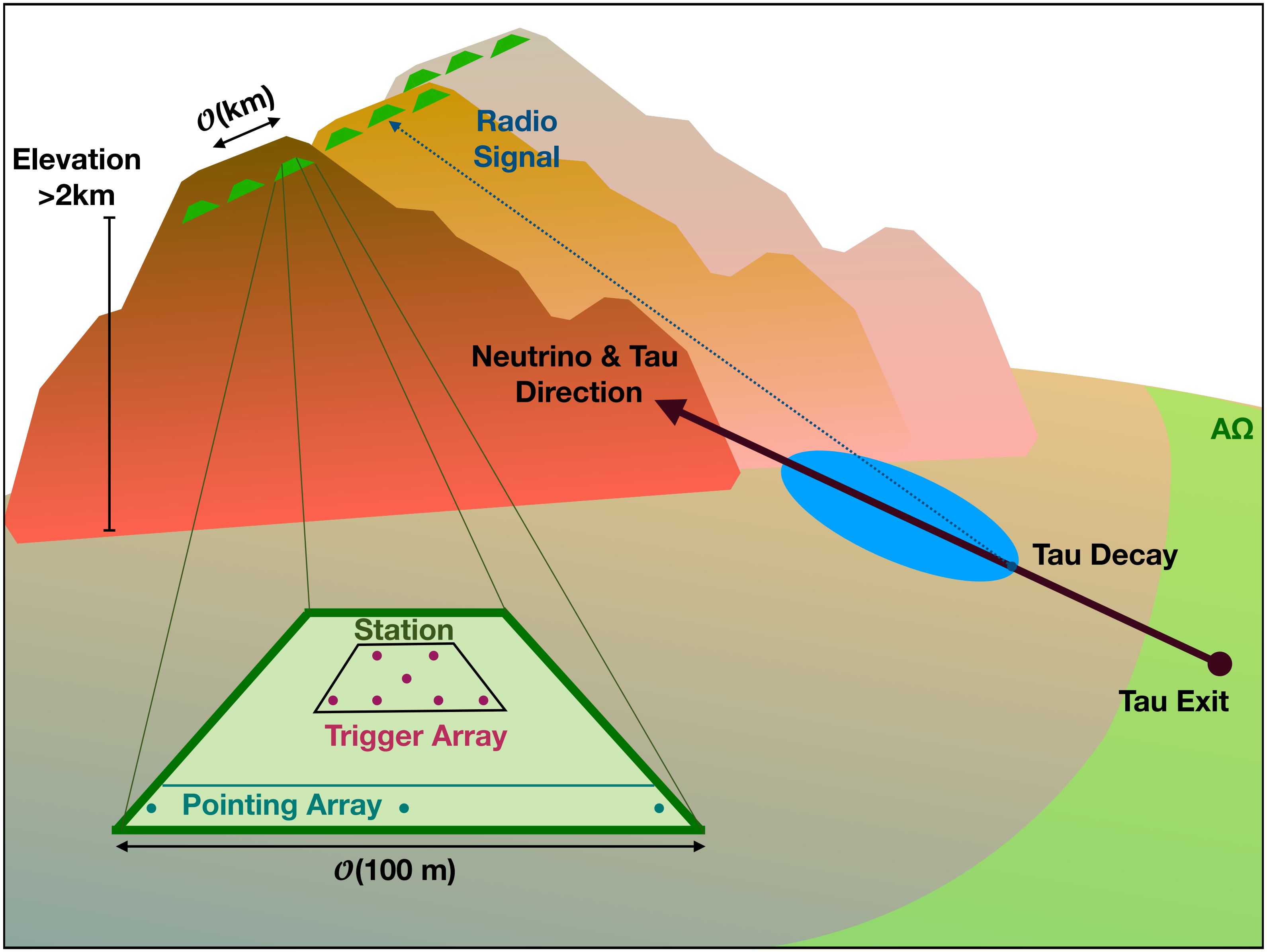
Experience with BEACON

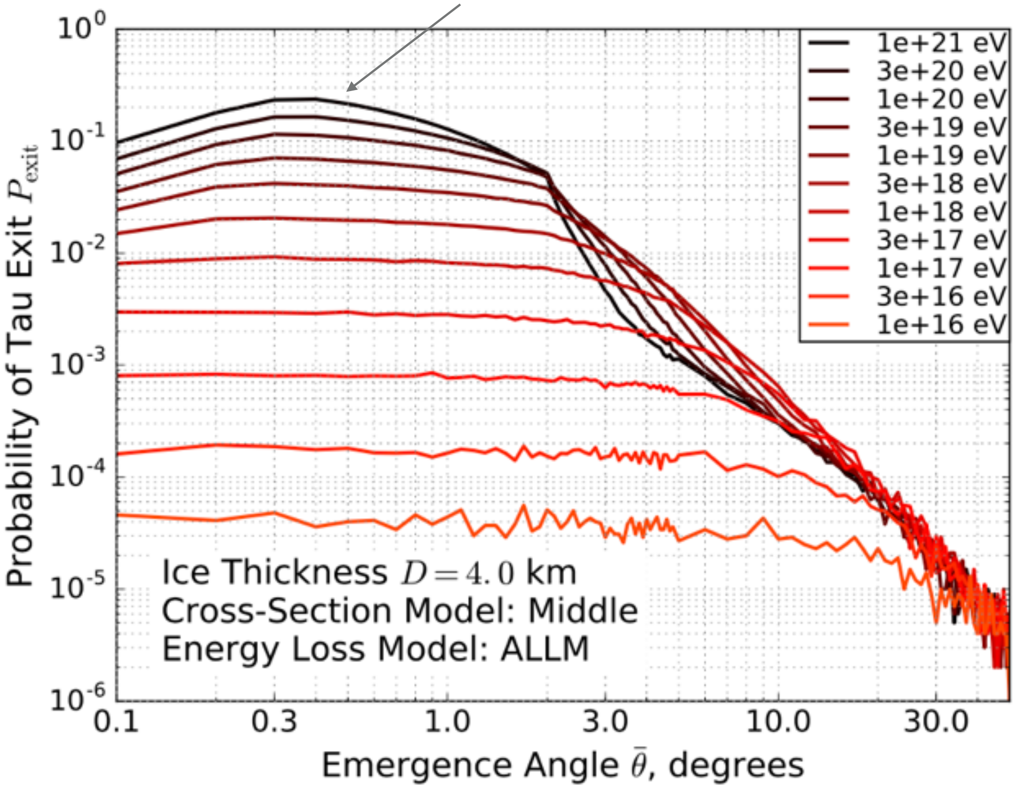
Stephanie Wissel
TAMBO Touch Base
18 October 2022



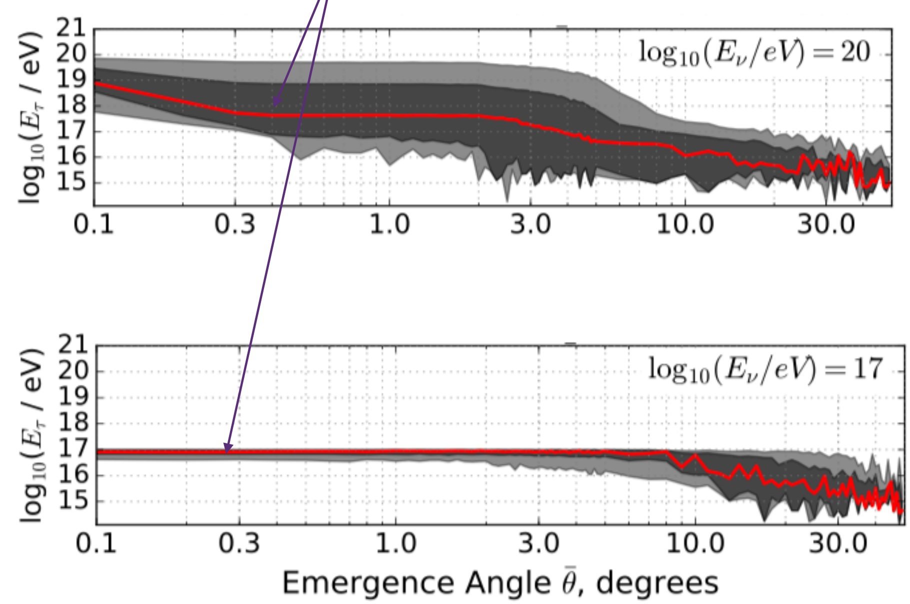
Wissel
JCAP 2020
arXiv:2004:12718

Exiting Taus

Most expected right at the horizon



Energy pile up at 10^{17} eV



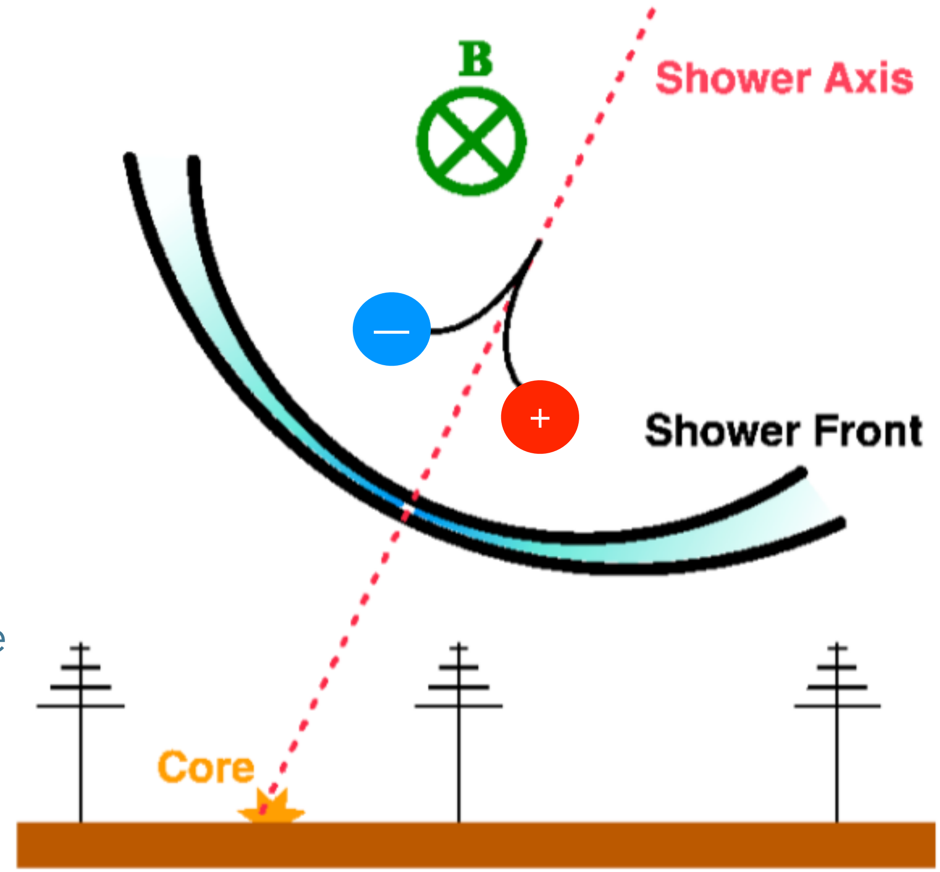
Alvarez-Muñiz, et al. PRD 2017

Radio Emission from Air Showers

- **Geomagnetic emission:** separation of positive and negative charges in shower due to Lorentz force.

$$\vec{E} \propto \vec{v} \times \vec{B}$$

- **Polarization** correlated with Earth's magnetic field
- **Impulsive** (fast and broadband)
  - Strongest at low frequencies (<100 MHz)
  - Signal peaks at Cherenkov angle at high frequencies (>100 MHz),
- Also some radially polarized emission from charge excess in the shower **("Askaryan radiation")**, but subdominant



ADVANTAGES OF THE RADIO TECHNIQUE

- Long propagation lengths – see 1-100s km away
- Strong radio signals in both ice and air
- Low cost instrumentation – $\mathcal{O}(\$1\mathrm{k})$ per channel
- Continuous data collection
- Polar ice and Earth's limb offer large natural neutrino targets

Large Detector with Minimal Instrumentation

Balloons

Mountains

In Ice

Several Options for Detector Geometries

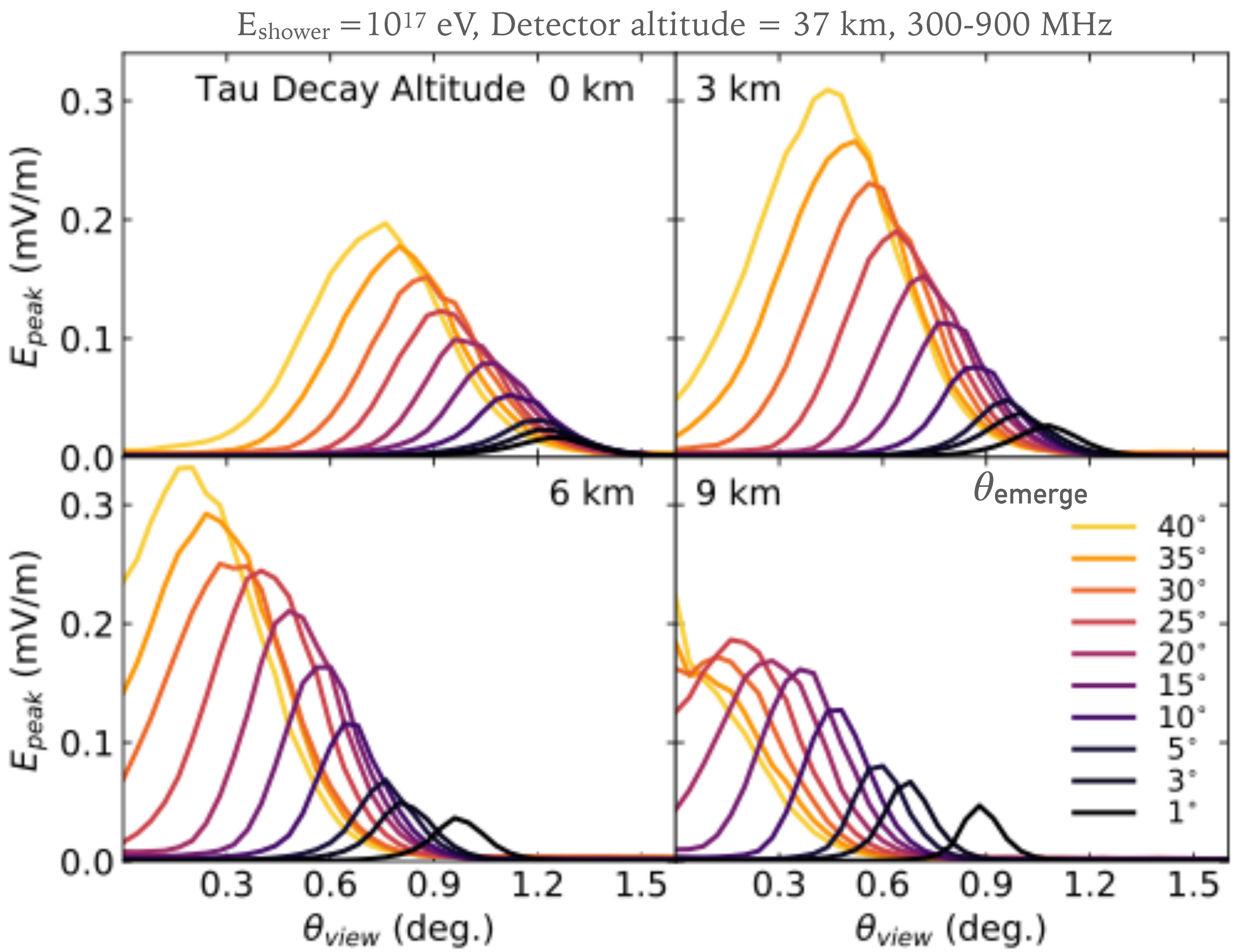
UP-GOING AIR SHOWERS SIGNAL STRENGTH

Mountain elevations

- Signal grows as shower moves closer to the detector

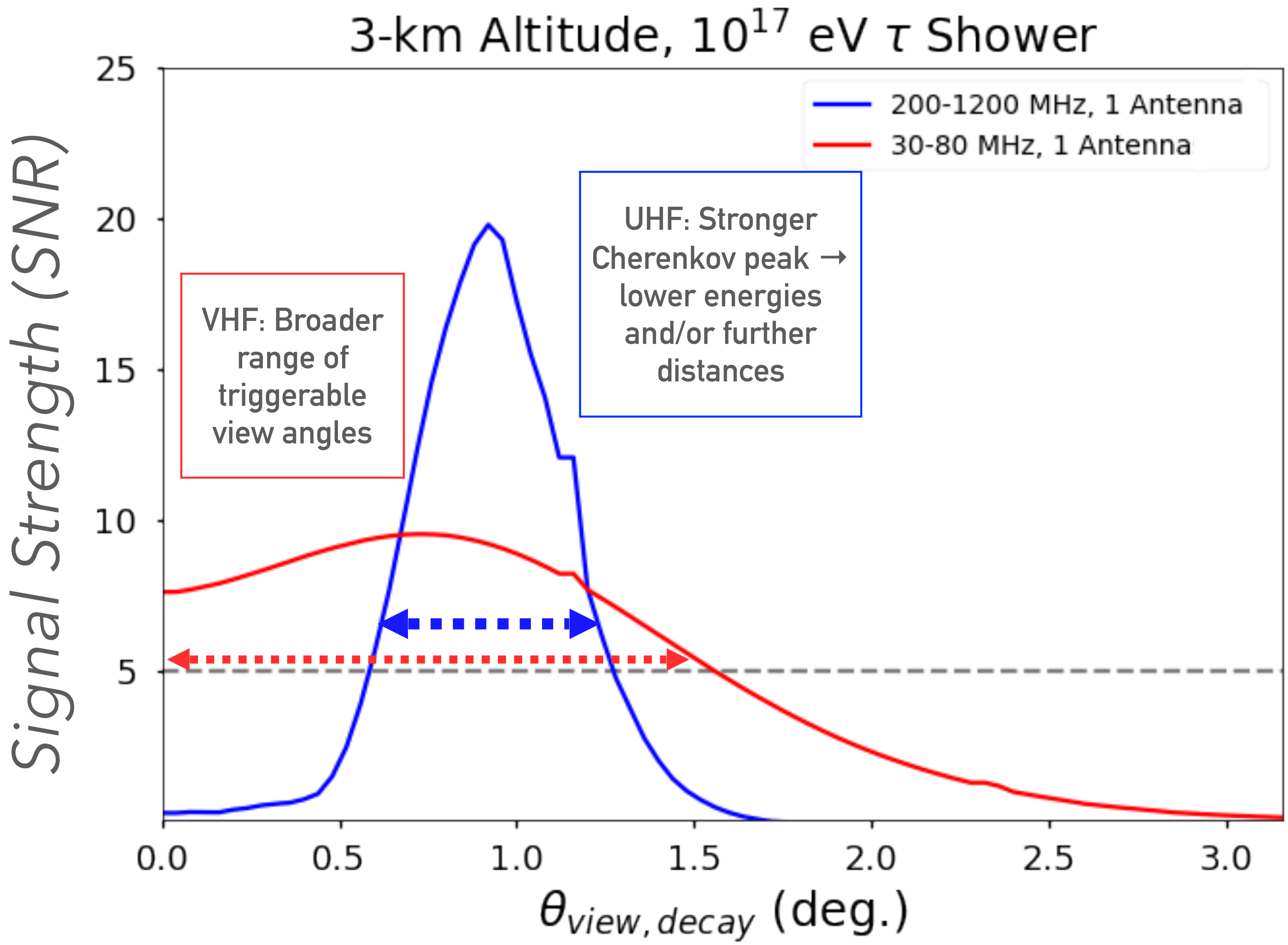
Balloon / Satellite elevations

- Signal decreases due to rarefied atmosphere



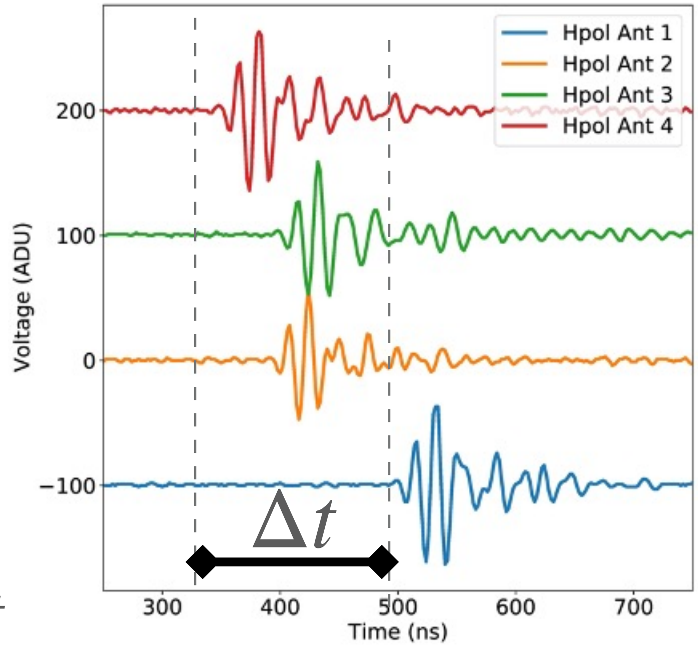
Romero-Wolf, SAW, ANITA PRD 2018

Frequency Range Matters

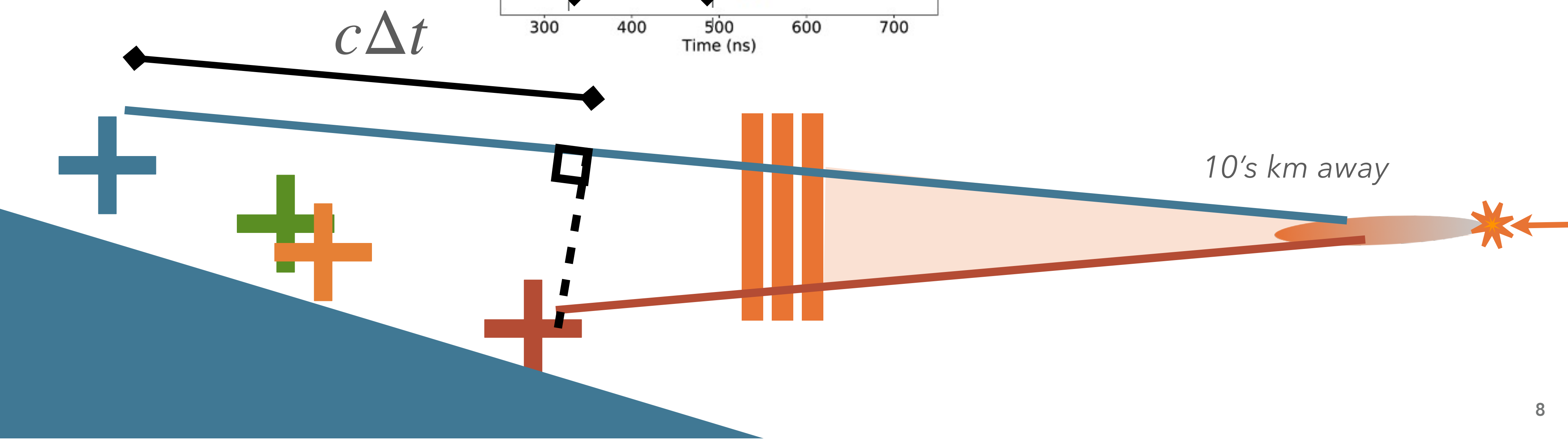


INTERFEROMETRY

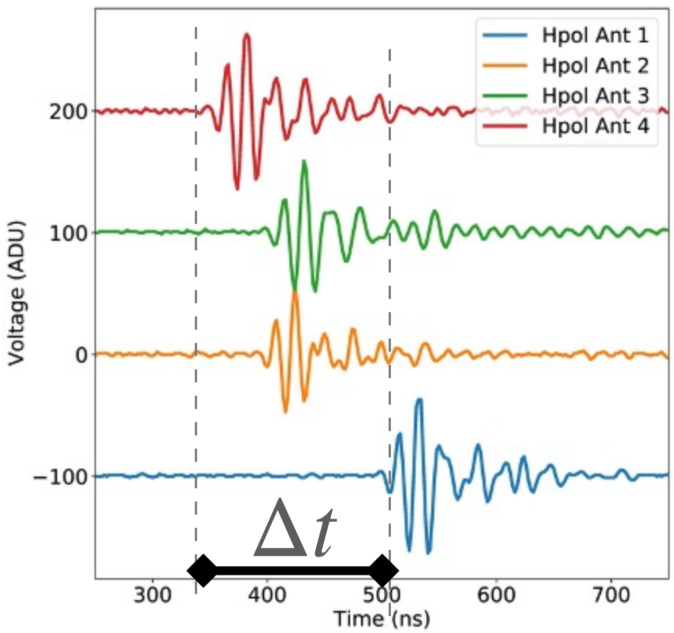
Signals arrive at different antennas delayed by the Δt determined by the path length difference



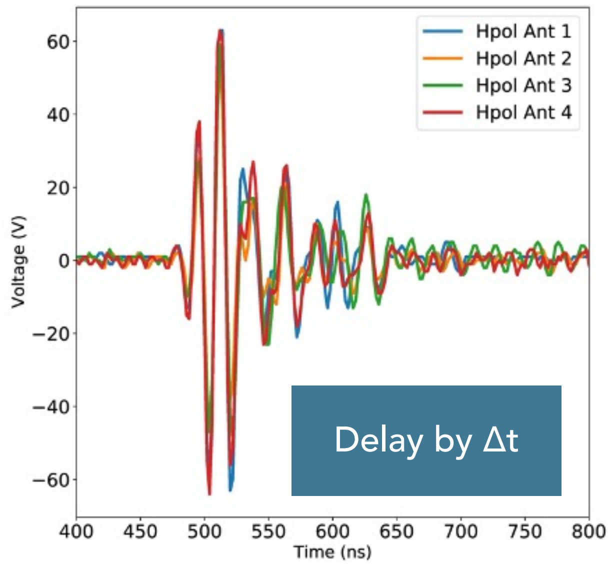
Δt's gives you direction

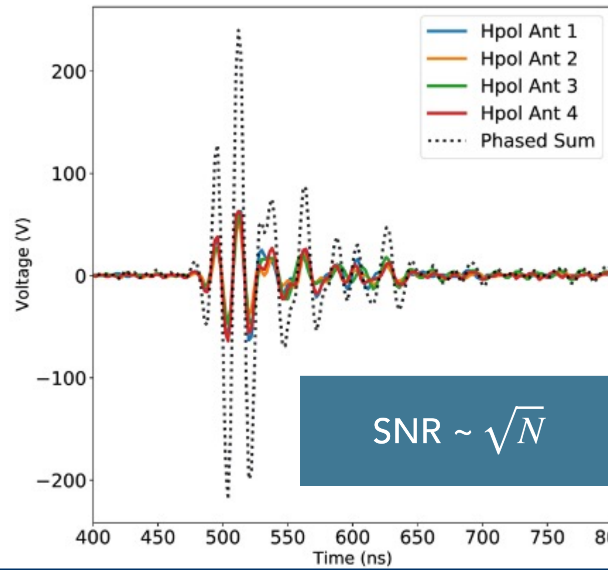


PHASED ARRAYS ON A MOUNTAIN

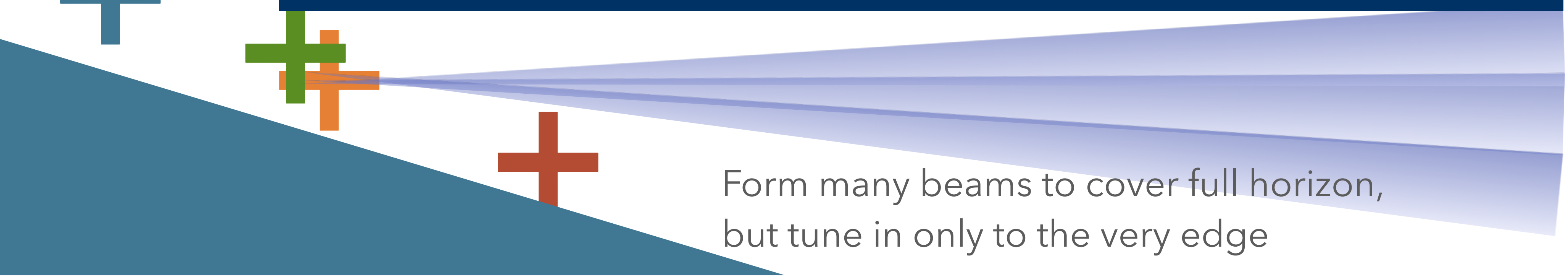


"Phasing" increases SNR





Tunable field of view



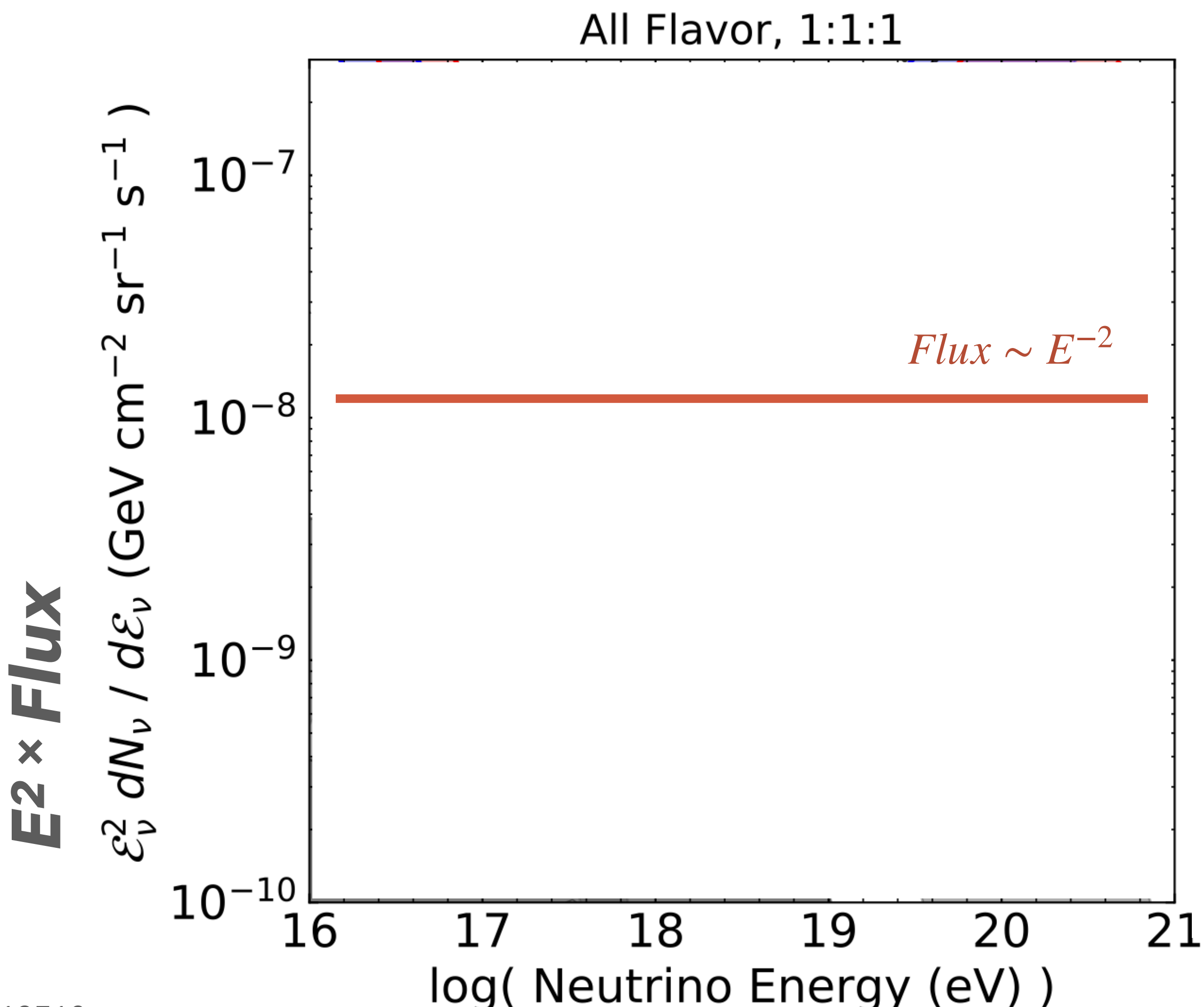
Form many beams to cover full horizon,
but tune in only to the very edge

Advantages of the BEACON Concept

- **Phasing**
  - Coherently summing signals in an array improves SNR by a factor of $\sqrt{N_{antennas}}$
  - Pointing allows for directional rejection of noise and a low trigger threshold

- **High elevation mountain ranges**
  - Increased viewing area
  - Multiple independent antenna arrays can be built to linearly improve the sensitivity

BEACON IS AN EFFICIENT DESIGN



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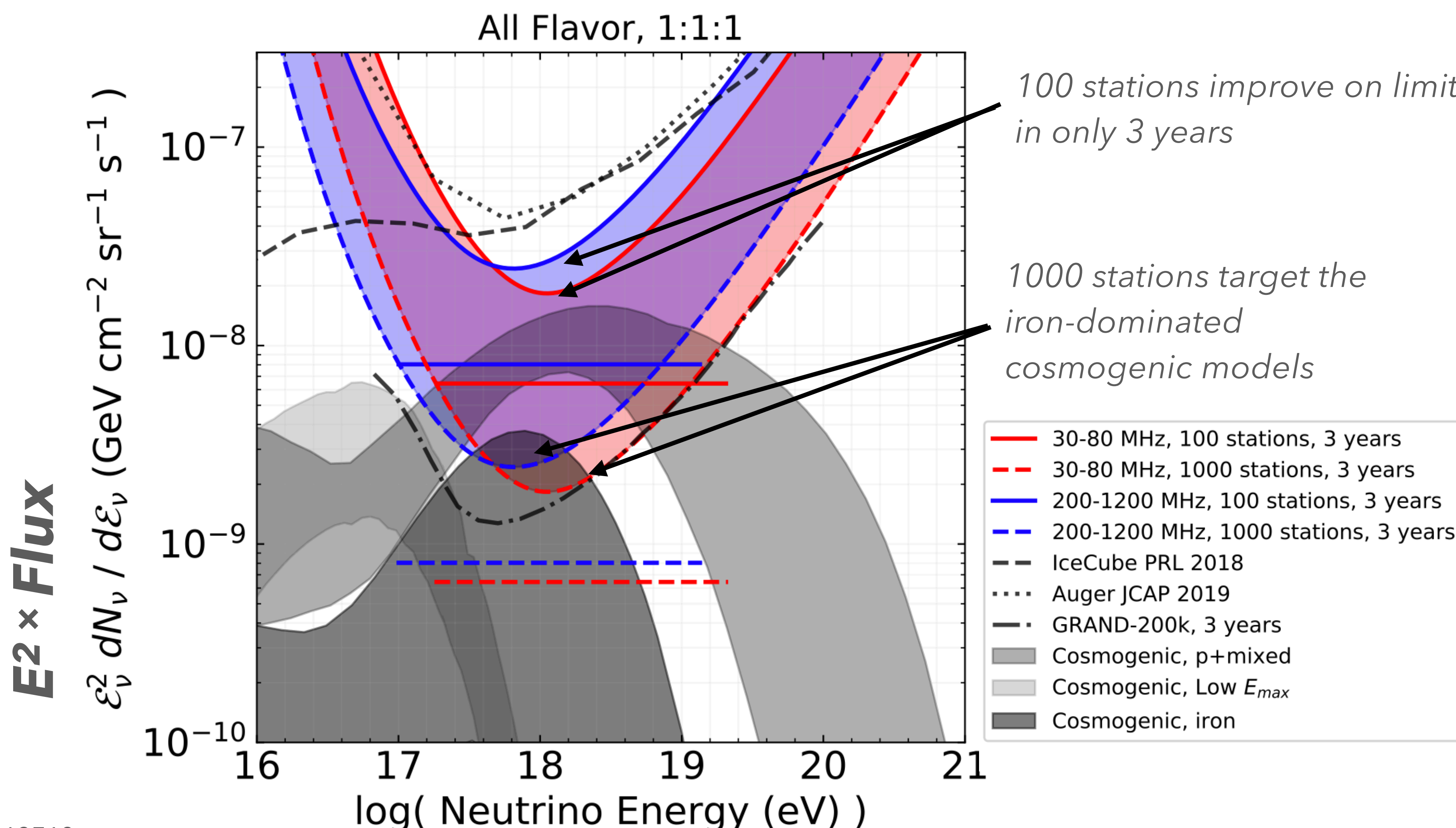

100 stations improve on limits in only 3 years

1000 stations target the iron-dominated cosmogenic models

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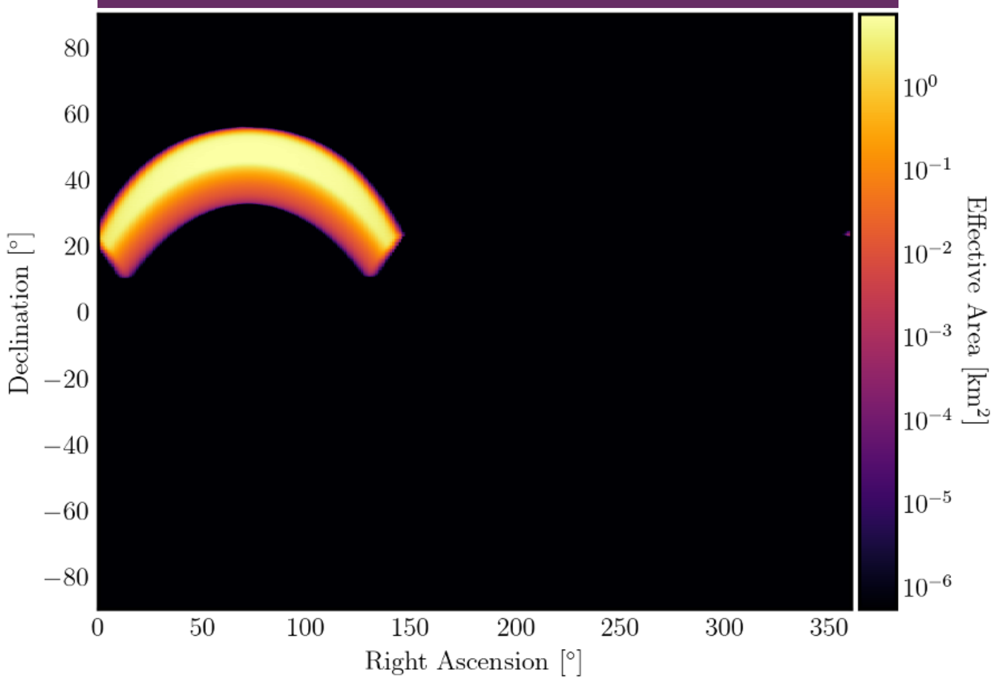
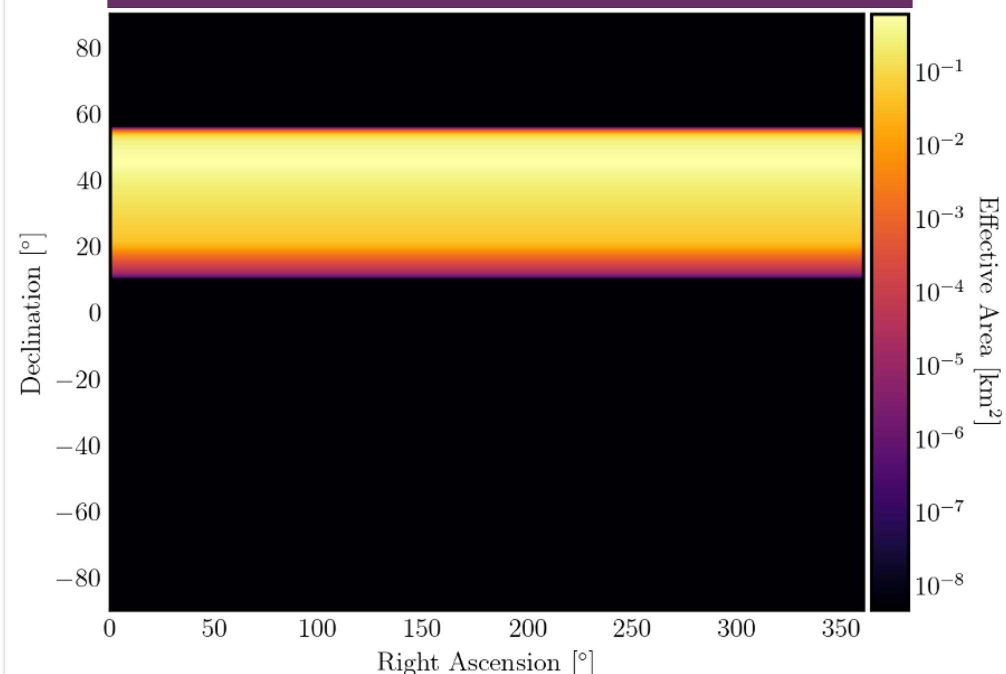
BEACON Field of View

- Need multiple sites, so could build up complete sky coverage with sites around the world, including Colcha Valley

Instantaneous

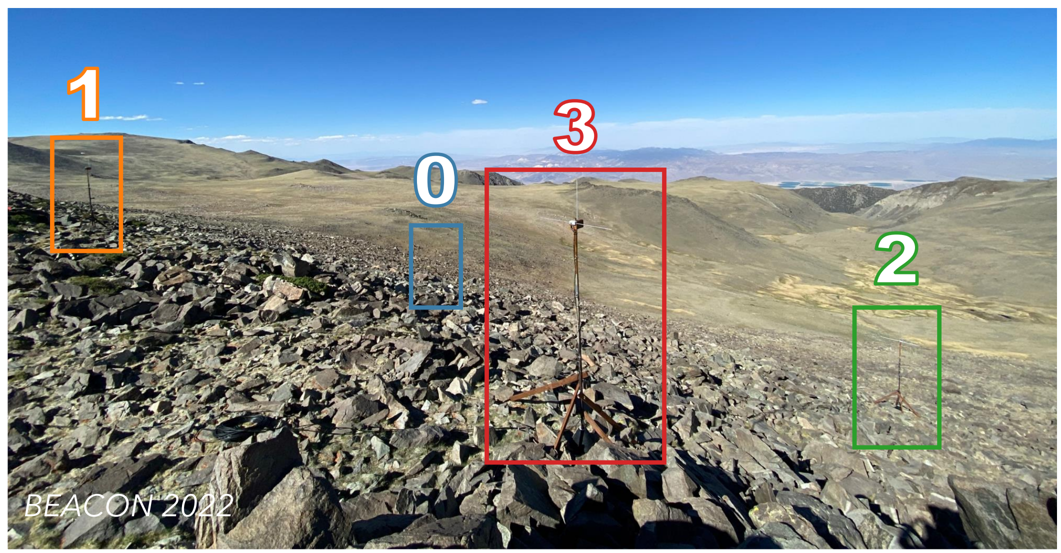


Averaged over a day



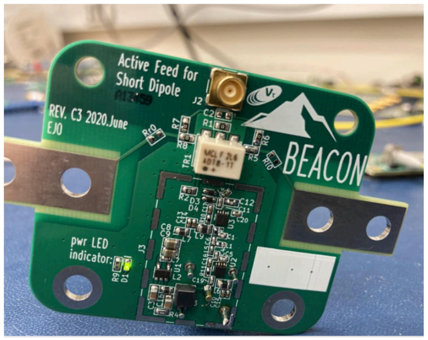
BEACON Prototype Array

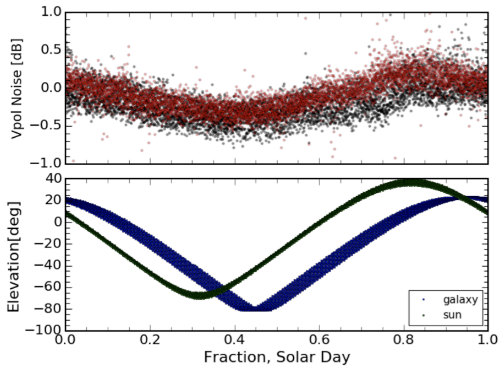
- Prototype at the White Mountain Research Station has been running since 2018 at 3.8 km
- Goals:
  - validate sensitivity estimates with cosmic ray search
  - test phased arrays at high elevation
  - manage backgrounds and operate continuously

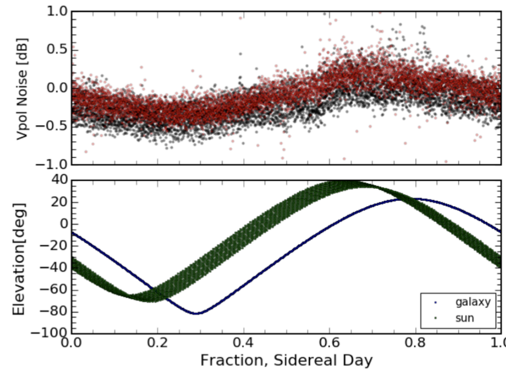


Hardware

- Custom design dipoles. Vpol and Hpol, mounted12 ft above the ground



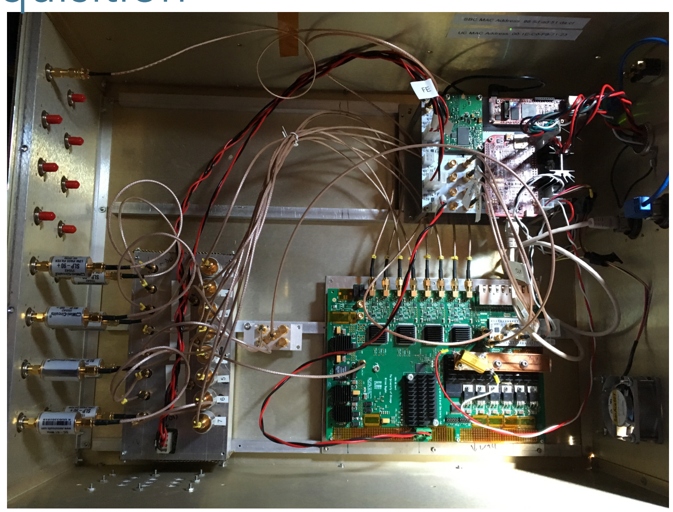




Antennas track galaxy, esp b/c temperature (sun elevation) should be anti-correlated with signal chain gain

- Phased array trigger and data acquisition

based on ARA phased array, Oberla NIM 2018



Single board computer for control, GPS, power

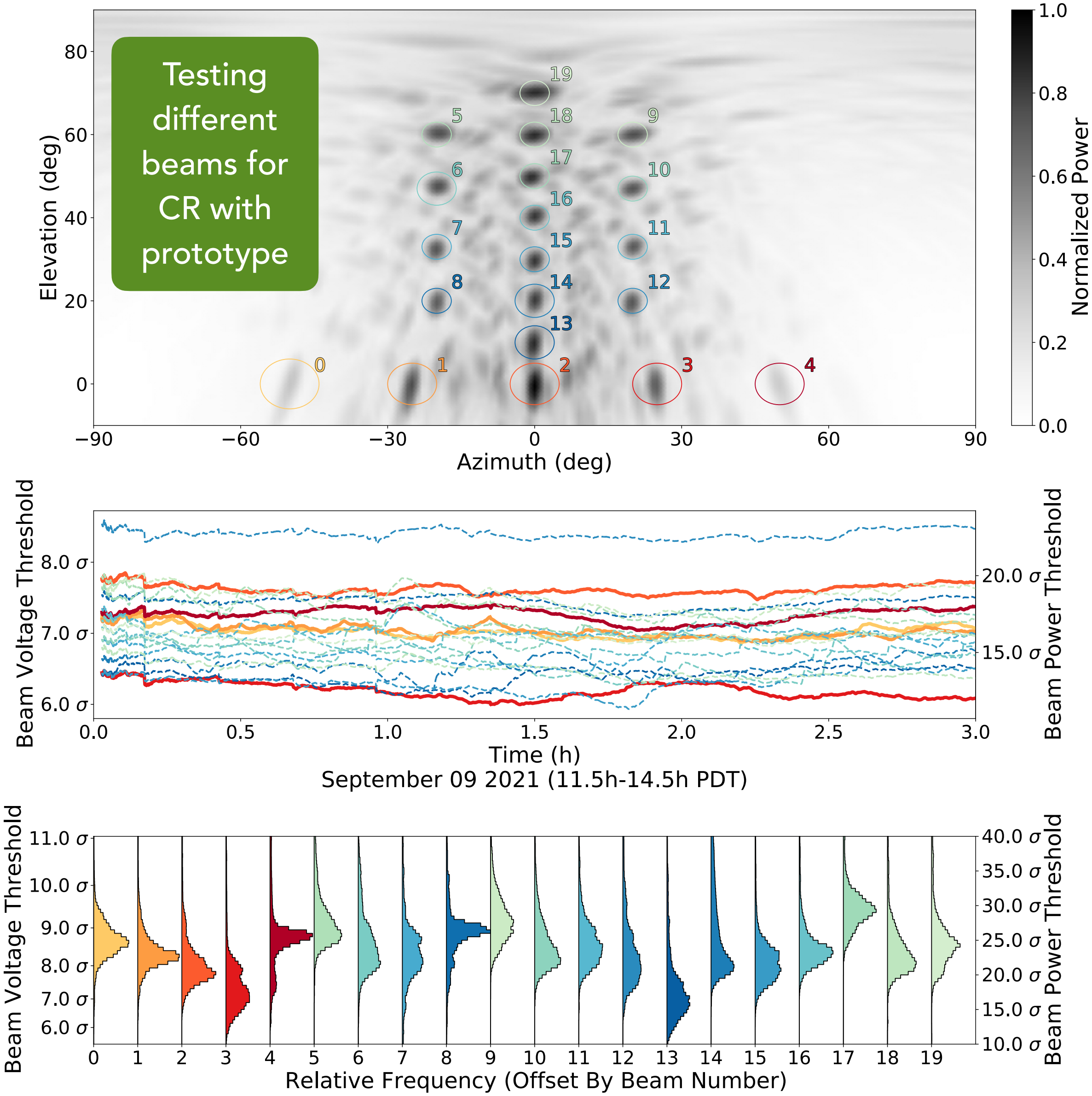
8-channel 7-bit digitizer & interferometric trigger

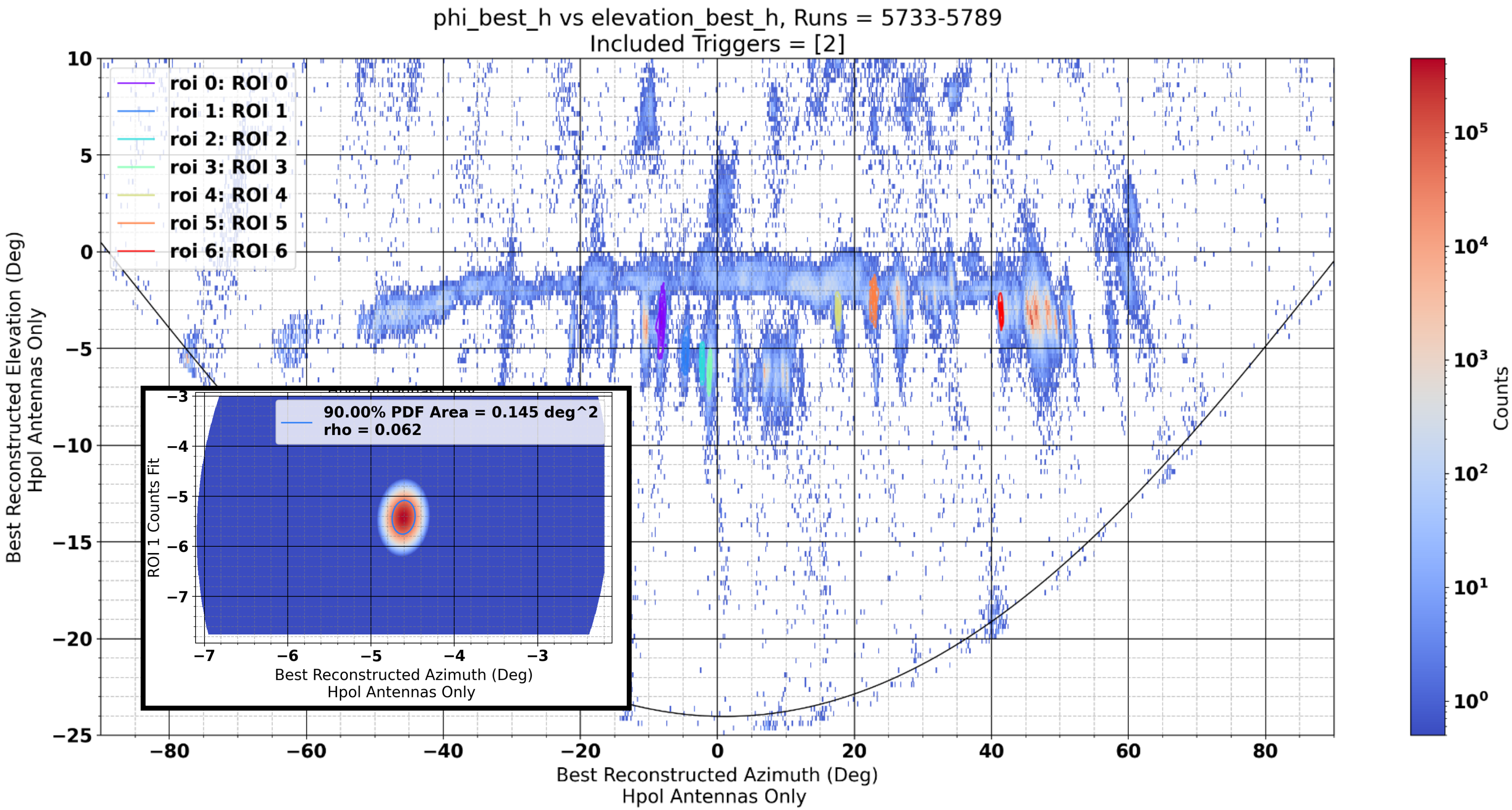
Second stage amps + filters

- WMRS Observatory provides 2kW power, (nearly) continuous networking ~ Gb/day

BEAMFORMING *IN SITU*

- Form beams that cover your full solid angle
  - Full scale BEACON would fill the solid angle near horizon, down weighting
- Noise-riding threshold automatically adjusts the thresholds in "noisy beams" so the backgrounds do not dominate

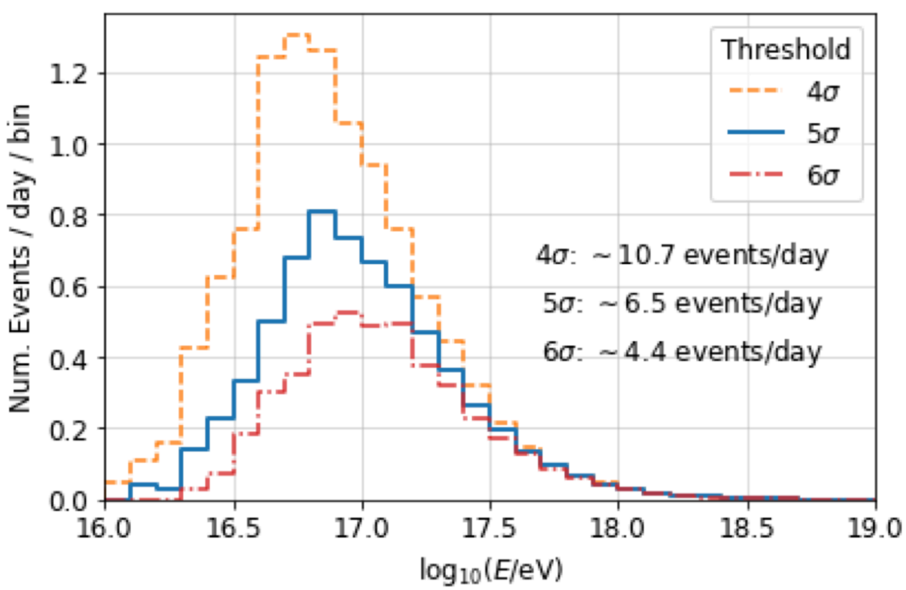



phi_best_h vs elevation_best_h, Runs = 5733-5789
Included Triggers = [2]
roi 0: ROI 0
roi 1: ROI 1
roi 2: ROI 2
roi 3: ROI 3
roi 4: ROI 4
roi 5: ROI 5
roi 6: ROI 6
Best Reconstructed Elevation (Deg)
Hpol Antennas Only
Best Reconstructed Azimuth (Deg)
Hpol Antennas Only
Counts
90.00% PDF Area = 0.145 deg^2
rho = 0.062
ROI 1 Counts Fit
Best Reconstructed Azimuth (Deg)
Hpol Antennas Only

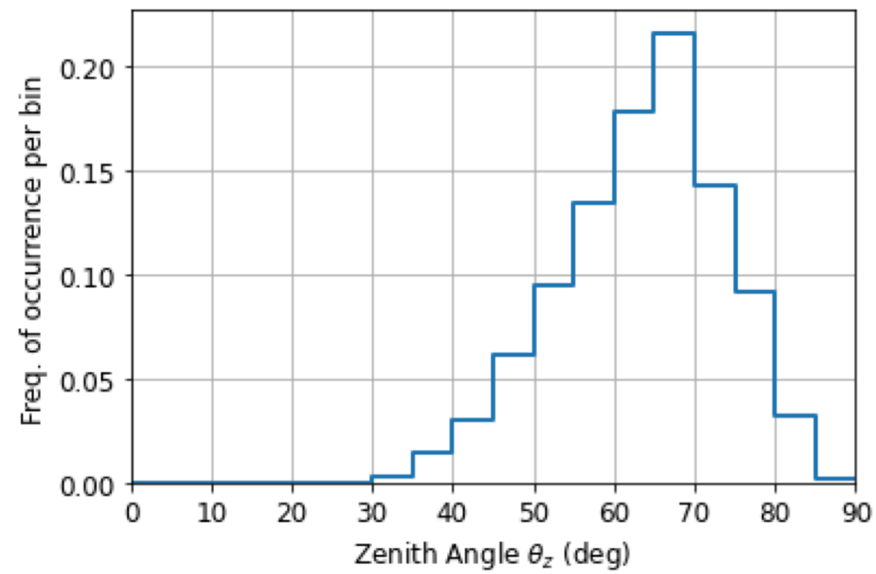
D. Southall

Cosmic Rays help Validate the Performance

- Cosmic ray rate depends strongly on instrument threshold



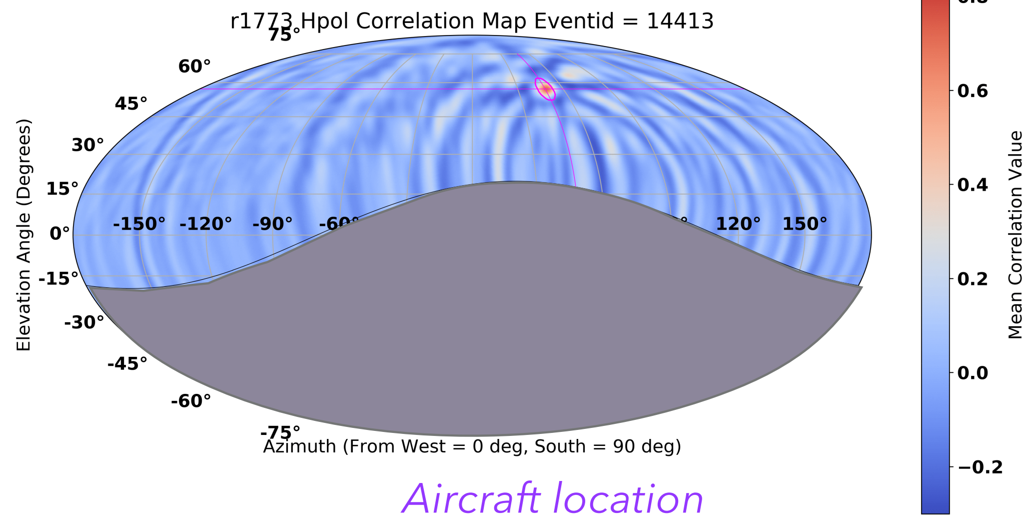
- Expect predominated inclined showers due to antenna orientation and elevation (3.8 km)



Advances Toward Efficient Triggering on Air Showers

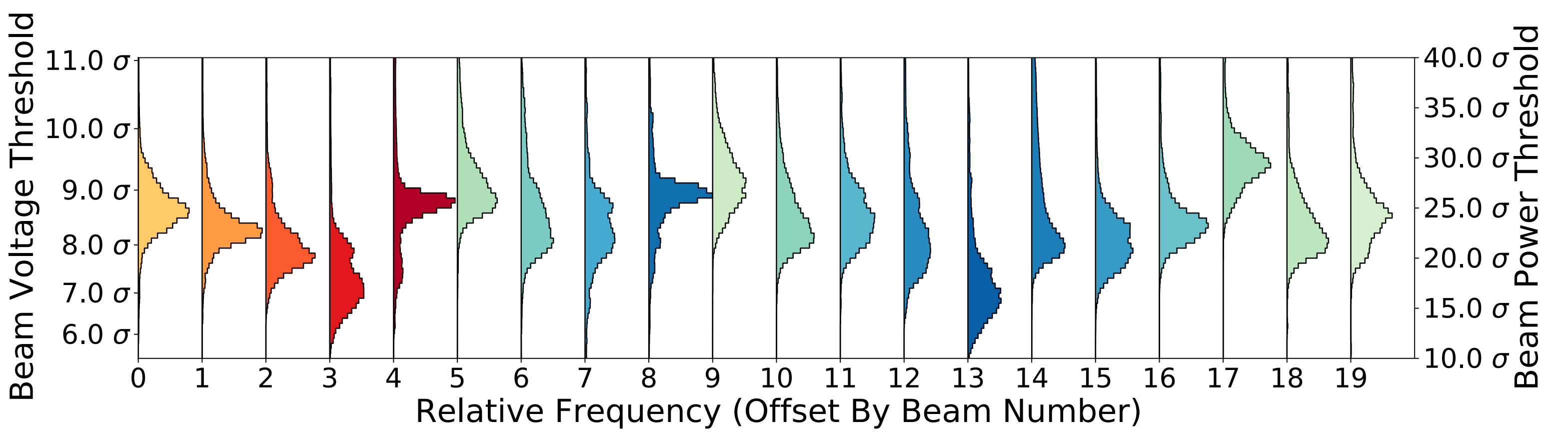
- Need to demonstrate that we can trigger on **(1) impulsive signals** with **(2) thresholds** comparable to 5 x thermal noise level in voltage

1. **Impulsive triggers**: Reflected RFI off airplanes

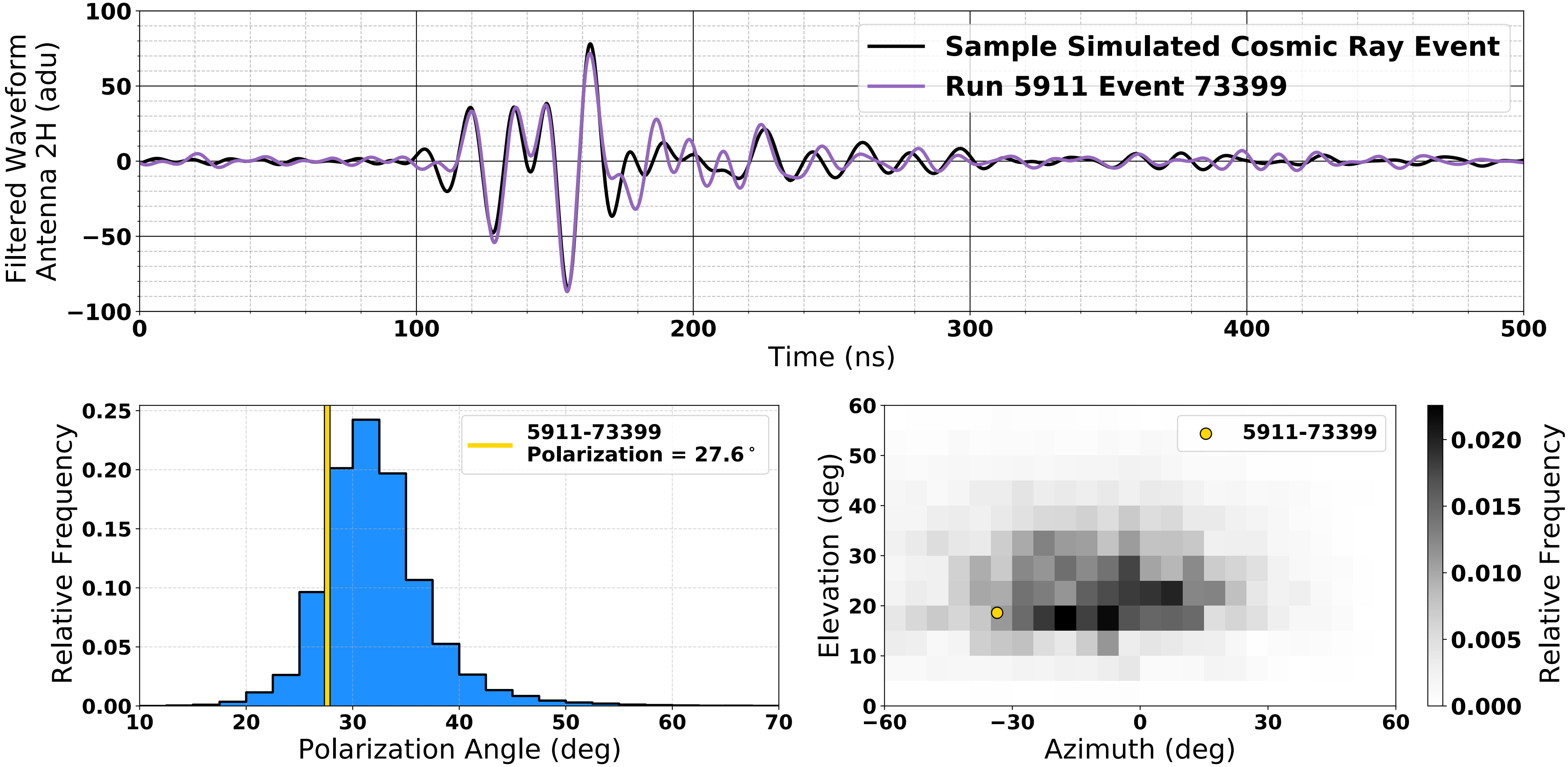


Aircraft location

2. **Thresholds**: Many beams at thresholds ***approaching*** level assumed in neutrino sims



PROMISING CR CANDIDATE



WHAT'S NEXT?

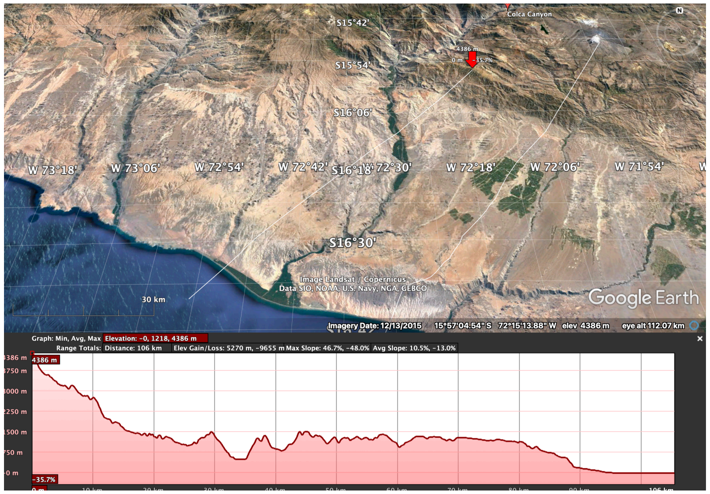
- Ongoing cosmic ray search in three years of data
- Full scale hardware
- Exploring new sites
  - Survey in Delta Utah this weekend
  - Other sites? Colca Canyon?
  - Refine models with topography

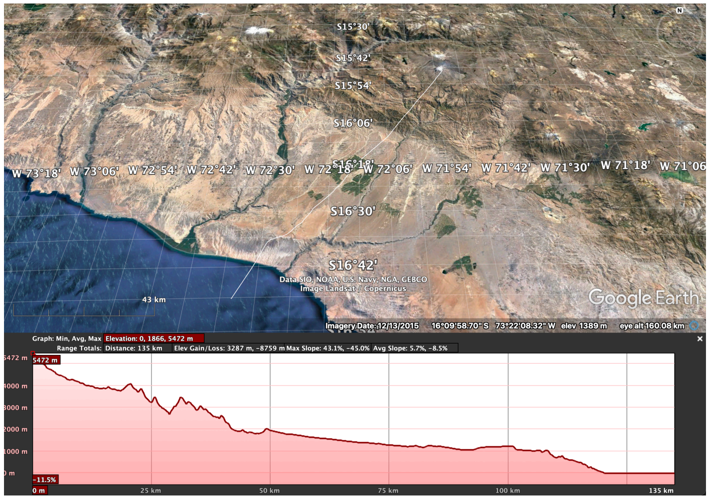
WHAT ABOUT TAMBO AND BEACON?

- Both do *big science* with *big experiments*.
- My suspicion is that combined techniques will make the most compelling science case
- Independent techniques, independent but somewhat overlapping energy bands → good handle on systematics

Colca Canyon

- Site requirements for BEACON:
  - >2 km elevation
  - Clear view to the horizon
  - RF quiet
  - Align the array where geomagnetic peaks (perpendicular to magnetic field) magnetic field
- Several ridges near Colca Canyon that look to the sea. Could be quite beneficial.



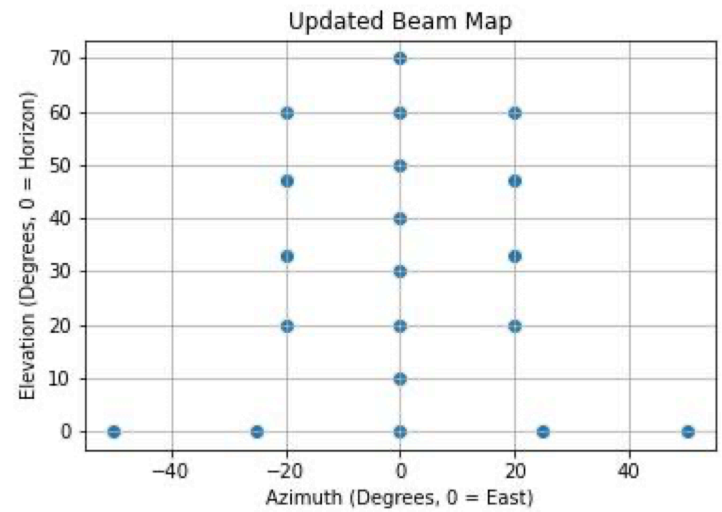


Bonus Slides

MANAGING RFI FROM A HIGH SITE

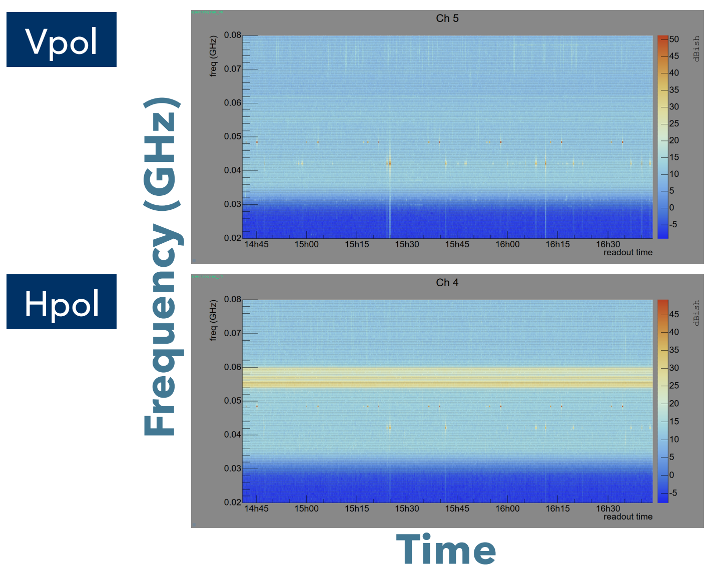
➤ 1. Use phased beams to mask out RFI

Beams at the trigger level adjust their thresholds based on the beam-level trigger rates



➤ 2. Find an RF-quiet site! Many options…

WMRS is okay & good test for CR triggering



McGill Arctic Research Station (MARS) is ***quiet (!!)*** *& near a high altitude mountain*