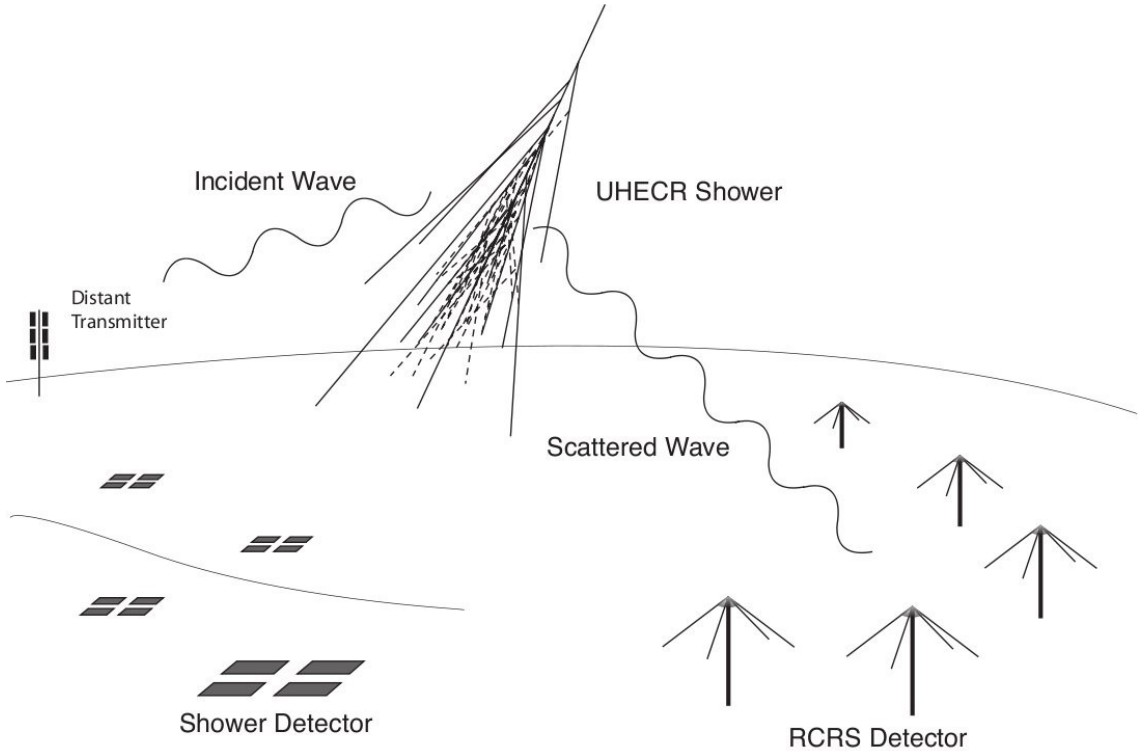
Radar Detection of UHECR Air Showers at the Telescope Array



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The TARA Project

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(BNL, Kansas, Nebraska, NIPR, ICRR, Utah, Utah State)

and the Telescope Array Collaboration

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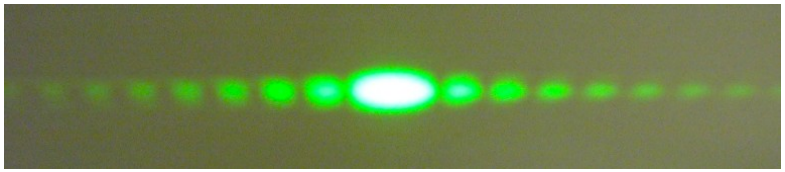
Salt Lake City TV stations KUTV, ABC4

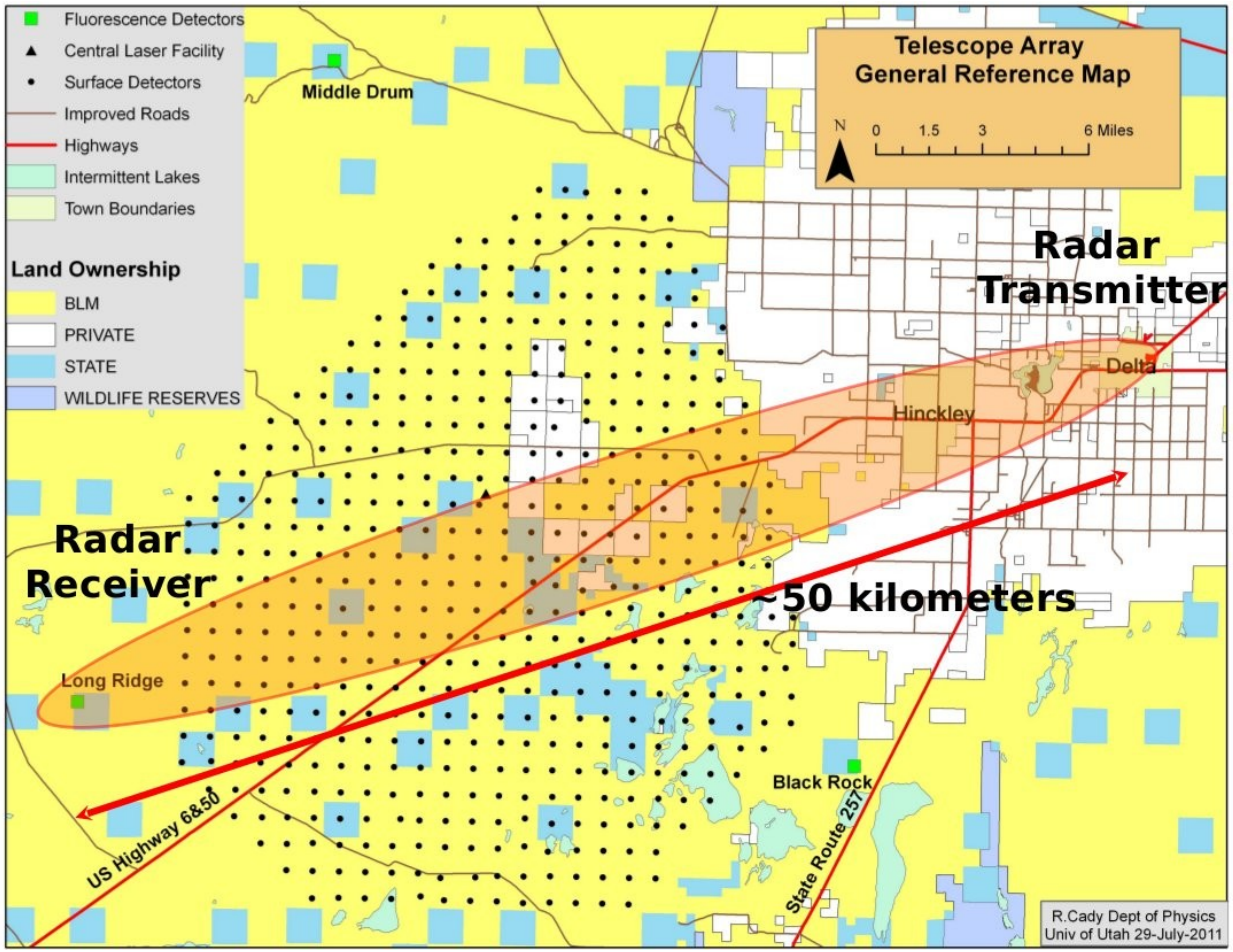
Bistatic Radar at Telescope Array

- Air shower plasma should reflect low-VHF (~50 MHz) radiation (Blackett and Lovell, 1941).
- **BUT** most scattered power is in the forward direction:



Two-station ("bistatic") radar preferable!

- Low-cost remote sensing technique?
- Investigating at Telescope Array with donated analog television equipment.



Station WF2XHR: Transmitter

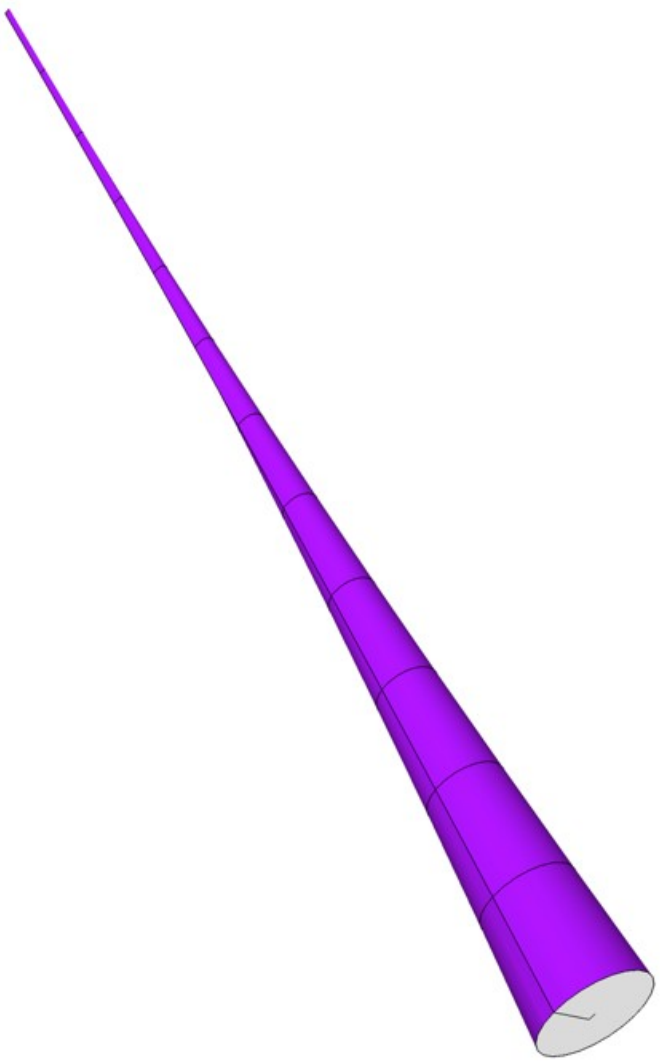
“Channel 2” transmitter donated by KUTV-2, broadcasting 54.1 MHz sine wave at 2 kW.

Antenna mast and 6-meter Yagi broadcasting towards Telescope Array observatory

Receiver Station at “Long Ridge”

- Array of log-periodic antennas (low-VHF)
- Software-defined radio receivers
- Triggering:
    - Fluorescence Detector, readout at 12.5 Ms/s.
    - Self threshold trigger, readout at 6.25 Ms/s.

What do we Expect?



- Shower segments contribute to received power according to *bistatic radar equation*:

$$P_R = P_T \times \left(\frac{G_T}{4\pi R_T^2}\right)\sigma \times \left(\frac{G_R}{4\pi R_R^2}\right)\left(\frac{\lambda^2}{4\pi}\right)$$

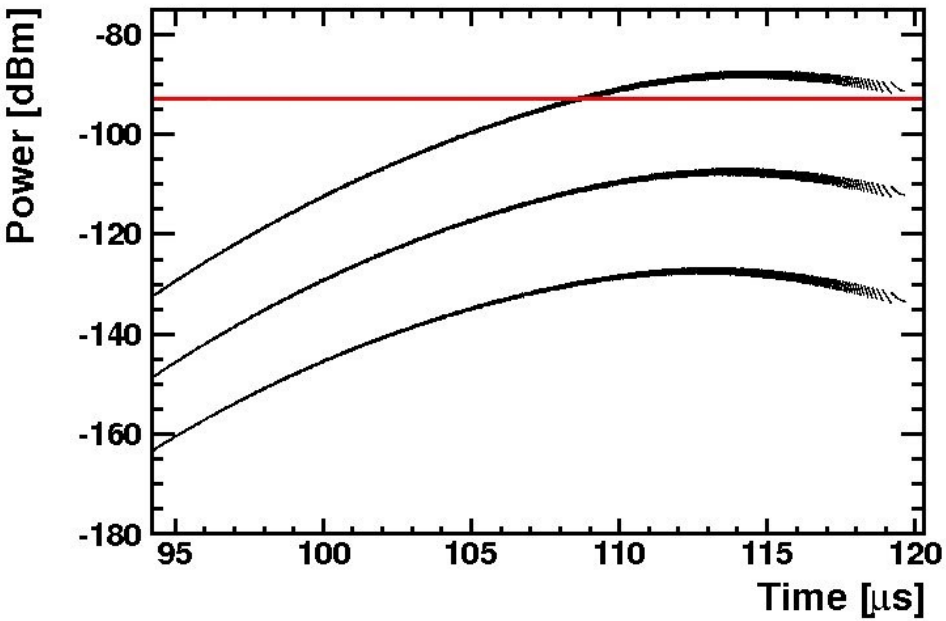
- Add amplitudes to take into account phasing:

$$V = \sqrt{P \cdot Z_i} sin(\omega t - \phi)$$

- Details: Poster #1315, *Forward Scattering Radar for Ultra High Energy Cosmic Rays*

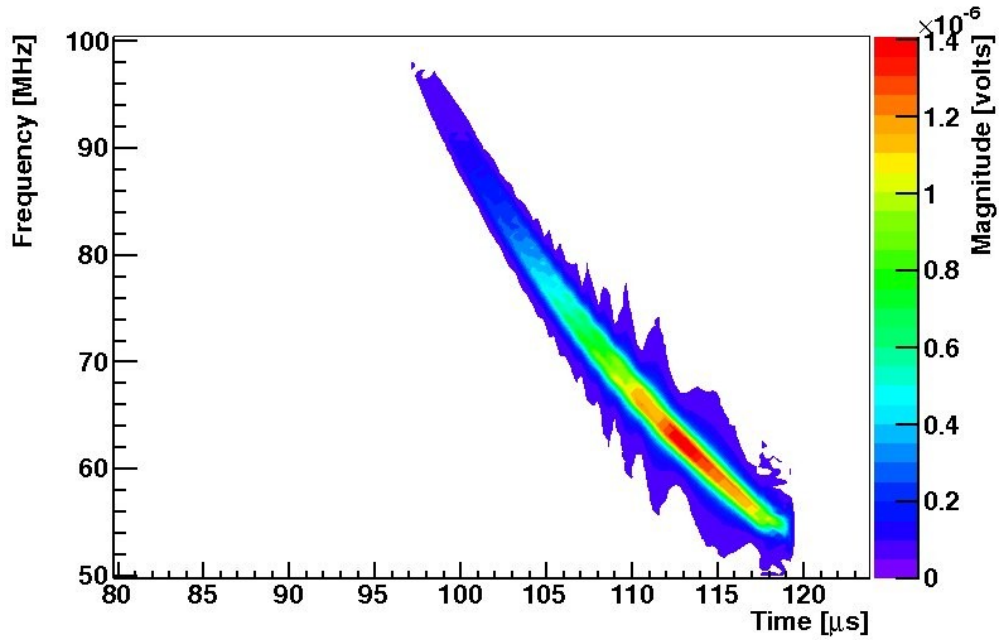
Signal Characteristics

Signal-to-Noise, 2 kW TX



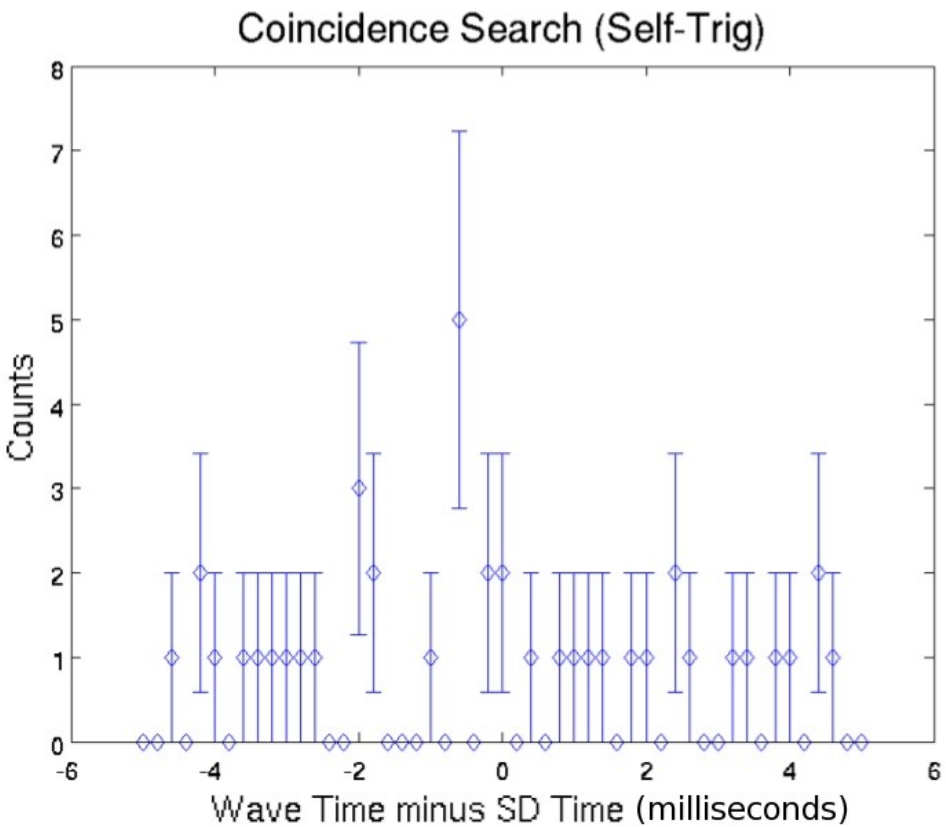
- Prediction for received power for 10^{18}, 10^{19}, 10^{20} eV showers, 30 deg from zenith, ideal TA geometry and current antenna gain.
- Horizontal line: Galactic noise floor (4 MHz B.W.)

Phase Modulation



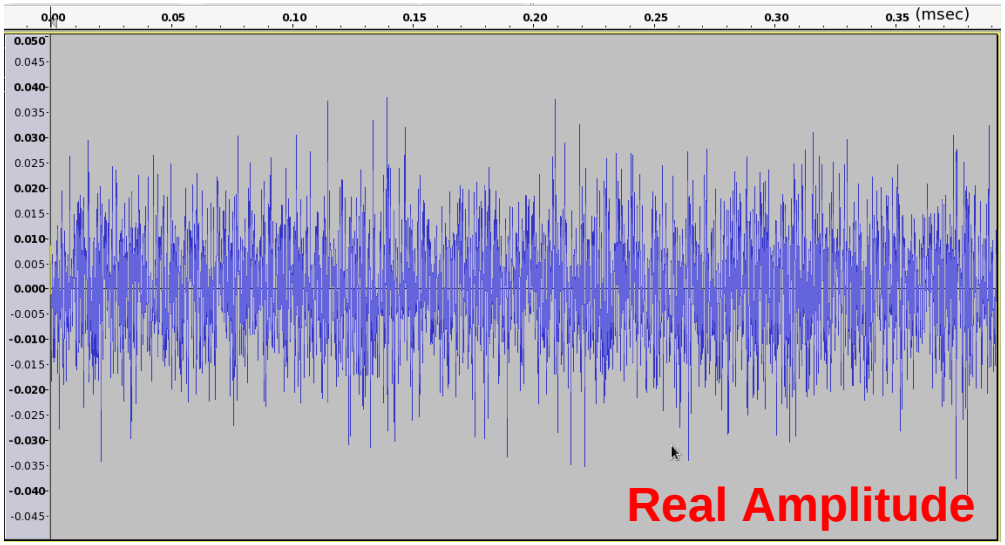
- Predicted signal for 10^{19} eV shower, 30 deg from zenith; frequency vs time.
- Rapid movement of “target” produces Doppler-like frequency shift.
- “Chirp” = Unique signature for air shower echoes!

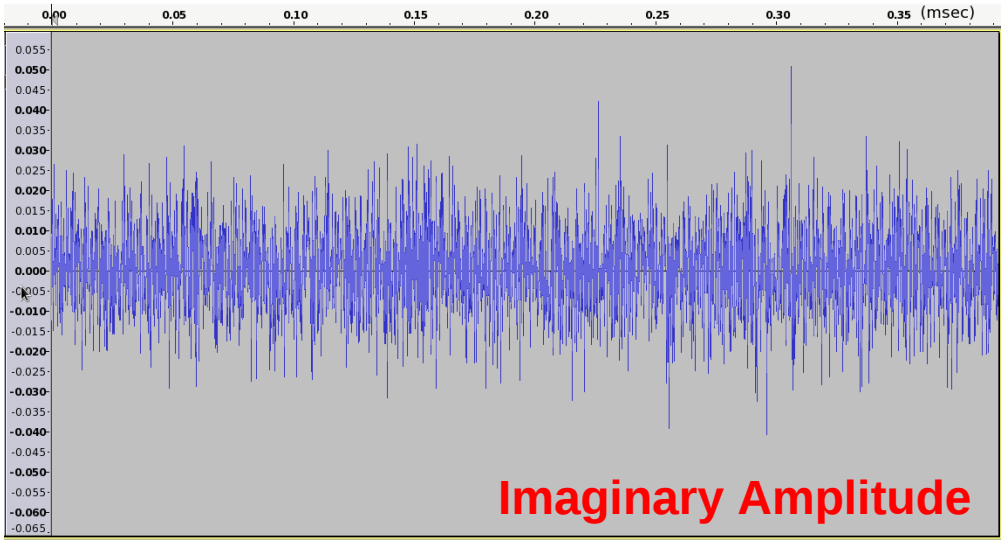
SD/Self-triggered Radar Coincidence Search, ~3 Months Data at 2 kW



- Event timing good to 100 microseconds
- Self-trigger rate ~1 Hz
- ~6k Surface Detector events > 1 EeV.
- No coincidences above background seen (or expected).

Fluorescence-triggered Coincidence Search, ~3 Months Data at 2 kW





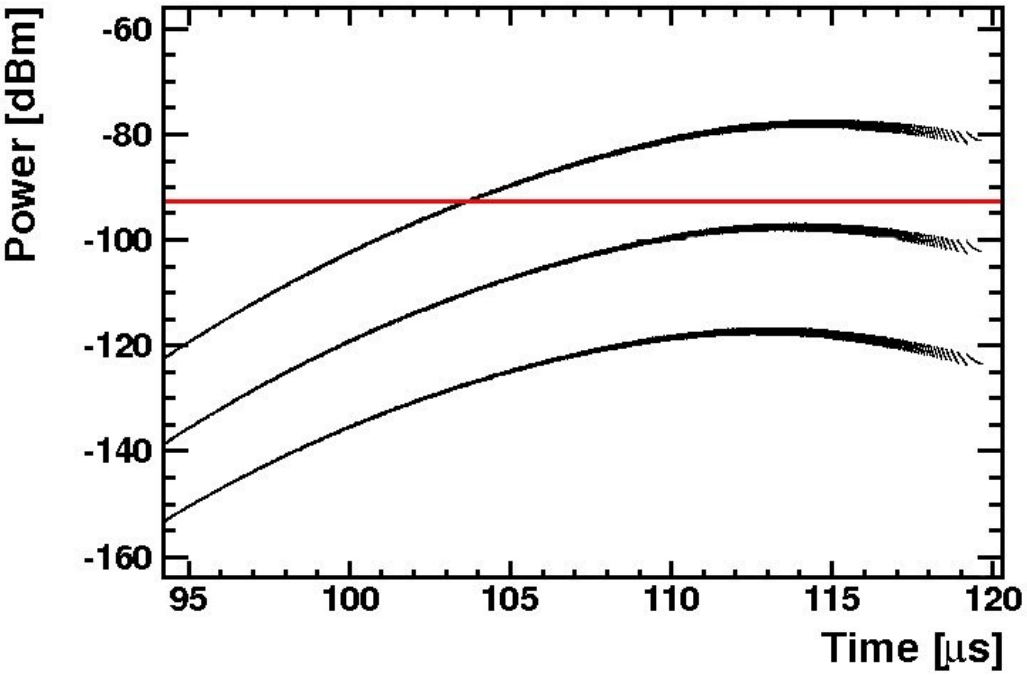
- Timing good to 100 microseconds.
- FD-trigger rate ~2 Hz
- Search waveforms corresponding to good hybrid triggers for activity.
- No activity above background seen (or expected).

15 EeV Event, near "1st diffractive maximum"

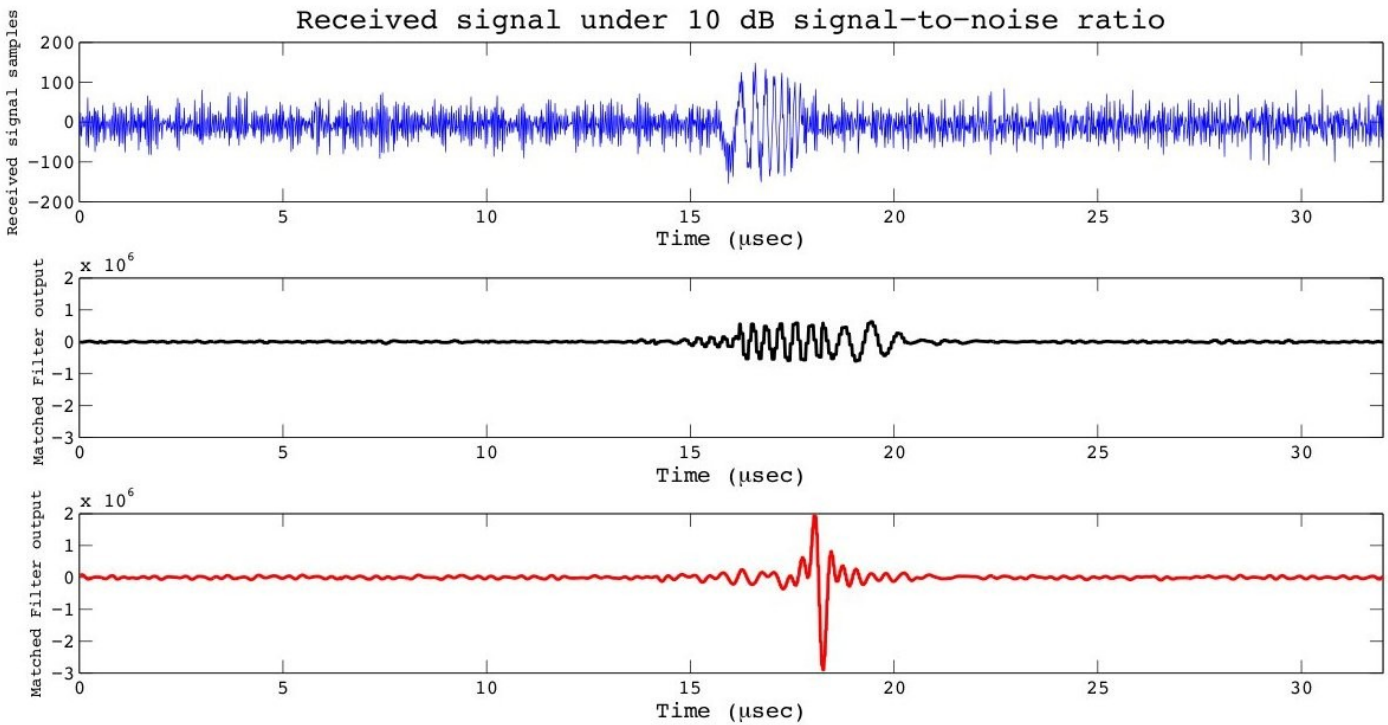
Upcoming Enhancements...

* Factor of 20+ increase in transmitter (TX) power (US-NSF/MRI)
* High-gain TX antenna; another factor of ~10
* Smart triggering:
  - Real-time “matched filter” comparison of waveform to chirp expectation (FPGA)
  - detection for S/N < 1...

Signal-to-Noise, 20 kW TX



Matched Filter Performance: Lab



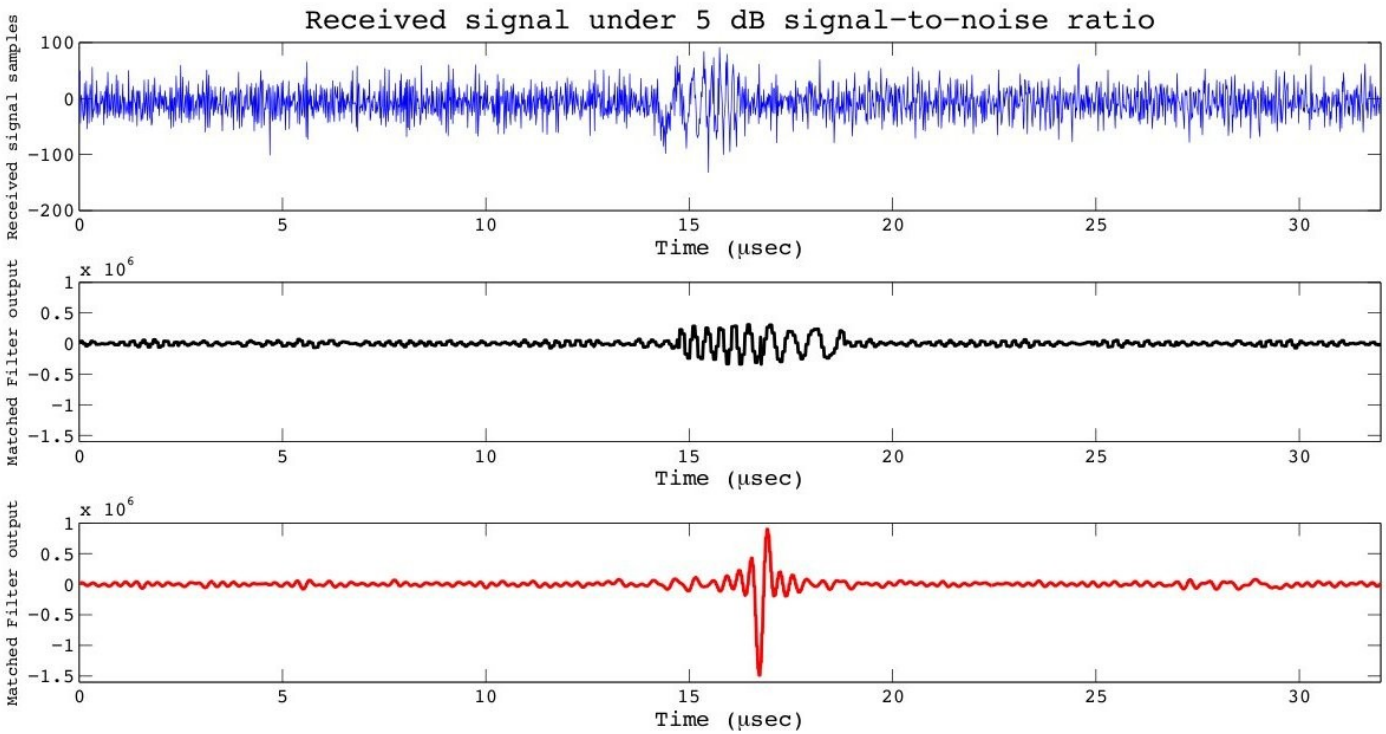
Input 3.5 MHz/microsec "chirp"

1 MHz/microsec filter output

3.5 MHz/microsec filter output

10 dB SNR

Matched Filter Performance: Lab



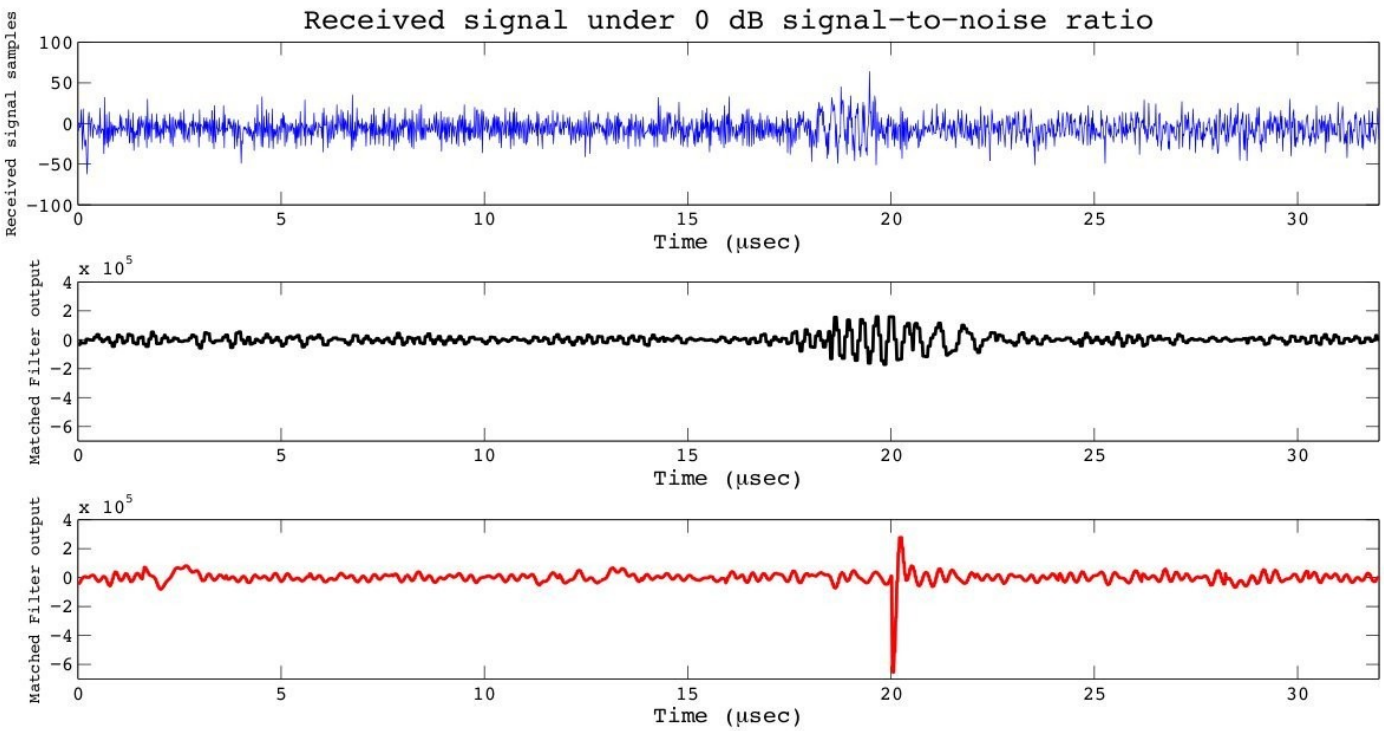
Input 3.5 MHz/microsec "chirp"

1 MHz/microsec filter output

3.5 MHz/microsec filter output

5 dB SNR

Matched Filter Performance: Lab



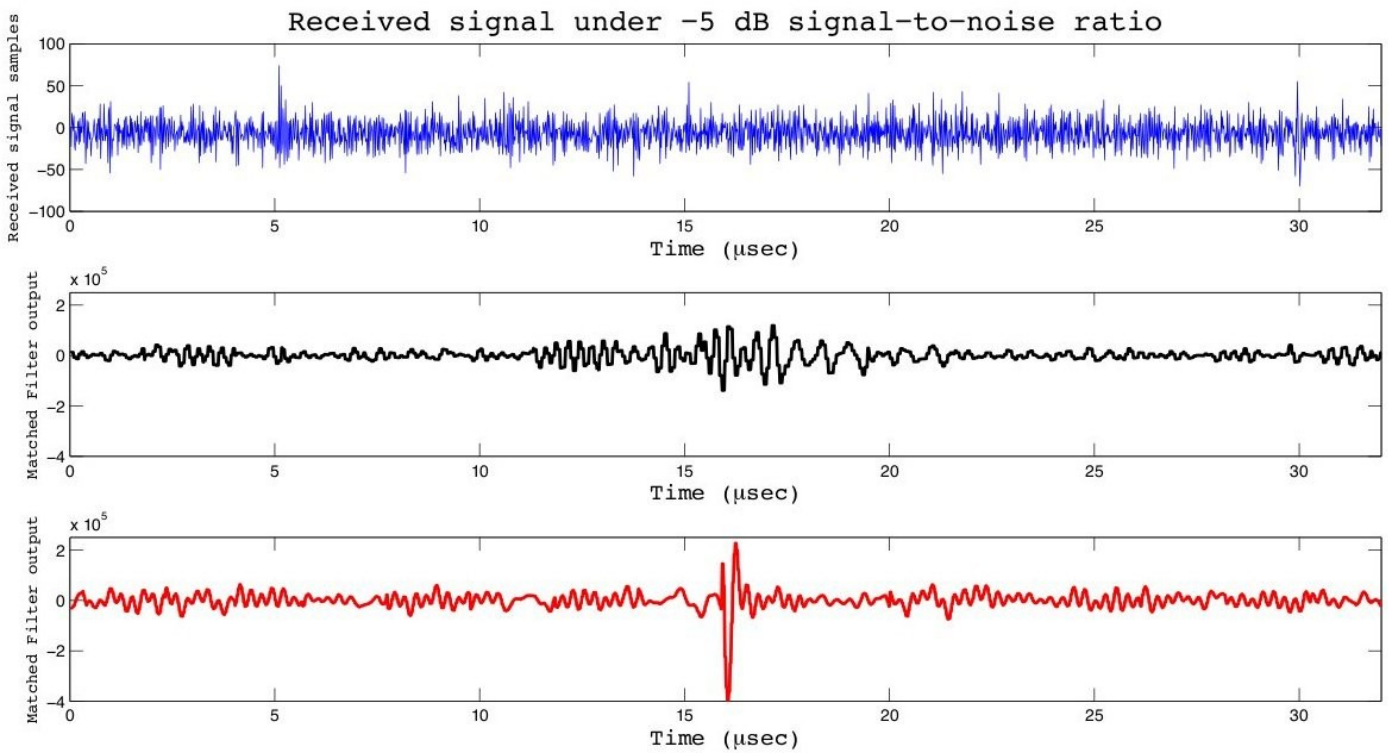
Input 3.5 MHz/microsec "chirp"

1 MHz/microsec filter output

3.5 MHz/microsec filter output

0 dB SNR

Matched Filter Performance: Lab



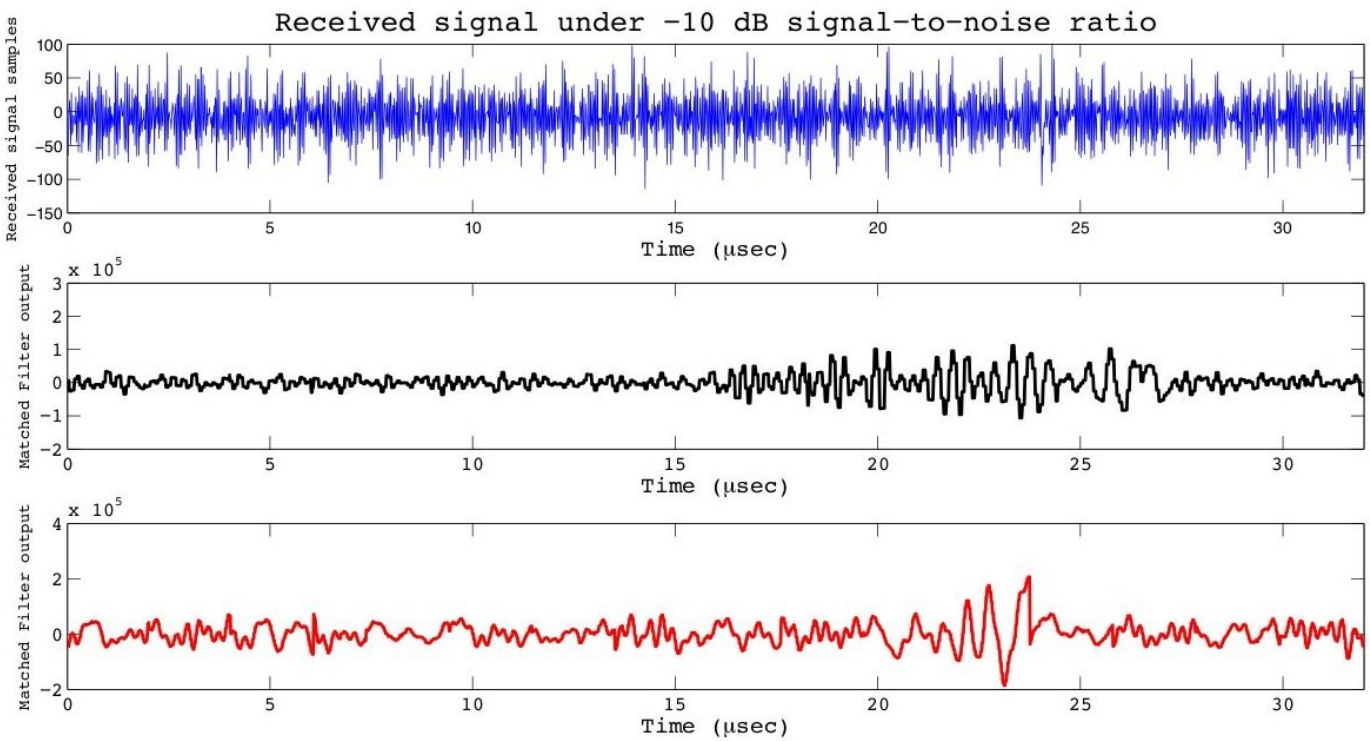
Input 3.5 MHz/microsec "chirp"

1 MHz/microsec filter output

3.5 MHz/microsec filter output

-5 dB SNR

Matched Filter Performance: Lab



Input 3.5 MHz/microsec "chirp"

1 MHz/microsec filter output

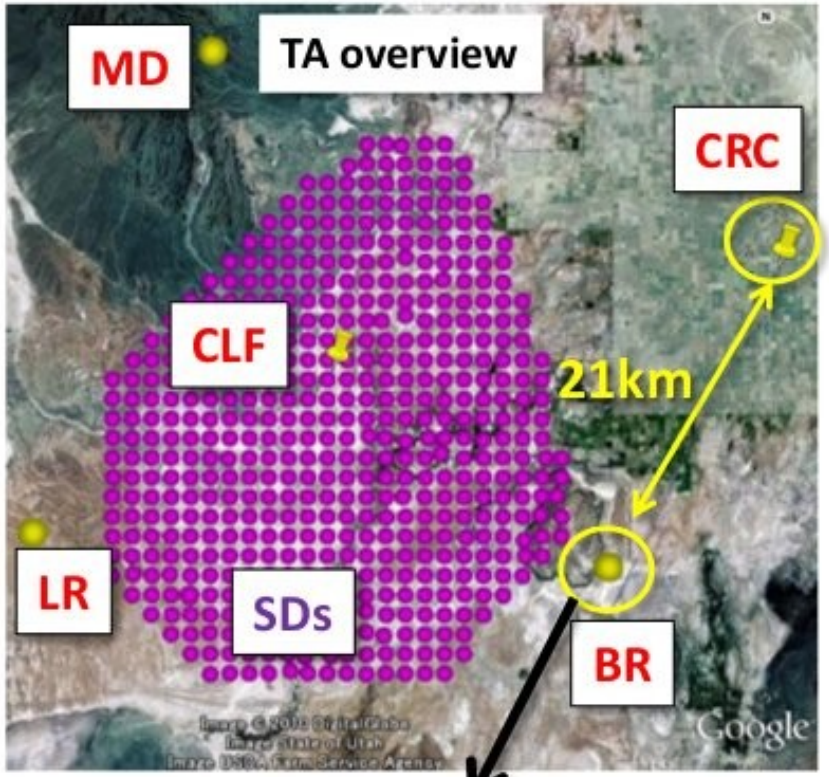
3.5 MHz/microsec filter output

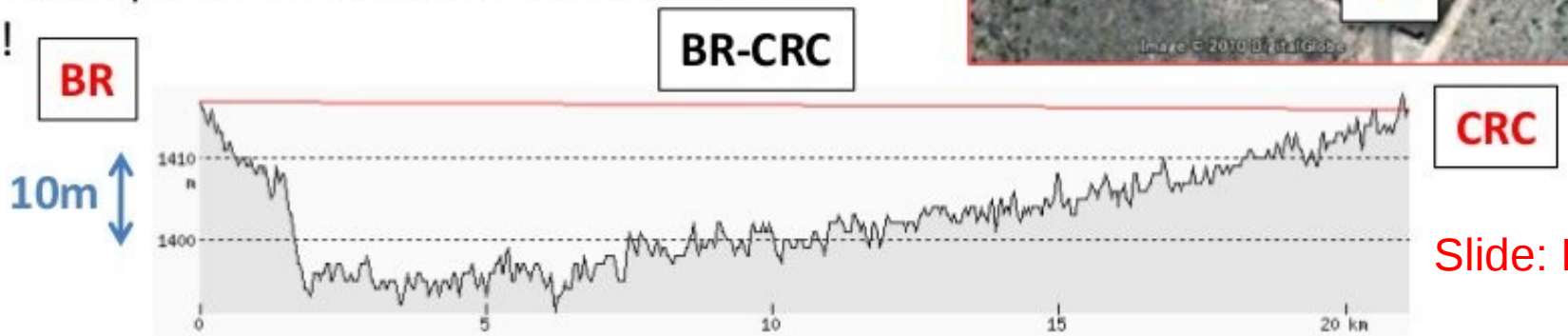
-10 dB SNR

ELS observation

Observation for the reflected radio from ELS shower to confirm the method

- Set the observer to the roof of BR station
- Radio path: CRC - ELS - BR
- Receiver : Five-element Yagi antenna
  - Design is fixed (see other file)
- Also we can measure the cross-section
  - Distance: CRC-BR >> ELS-BR
  - Can measure the power of coming radio from CRC by seeing to CRC
  - Cross-section is obtained by the ratio of detected power: seeing to ELS / seeing to CRC
- For this test, E-Plane of trans. wave should be vertical.
- Geometry b/w BR and CRC is better for radio transmission.
- The direction b/w BR-CRC and BR-ELS is almost 90 degrees !!





Slide: D. Ikeda

Conclusions

- Search for radar echoes of UHECR EAS in progress at Telescope Array (**TARA**).
- Upgrades to transmitter power (> 40 kW), transmitter antenna, smart triggering DAQ should bring us above detection threshold.
- Potential remote sensing technique; enhanced aperture for future UHECR studies.