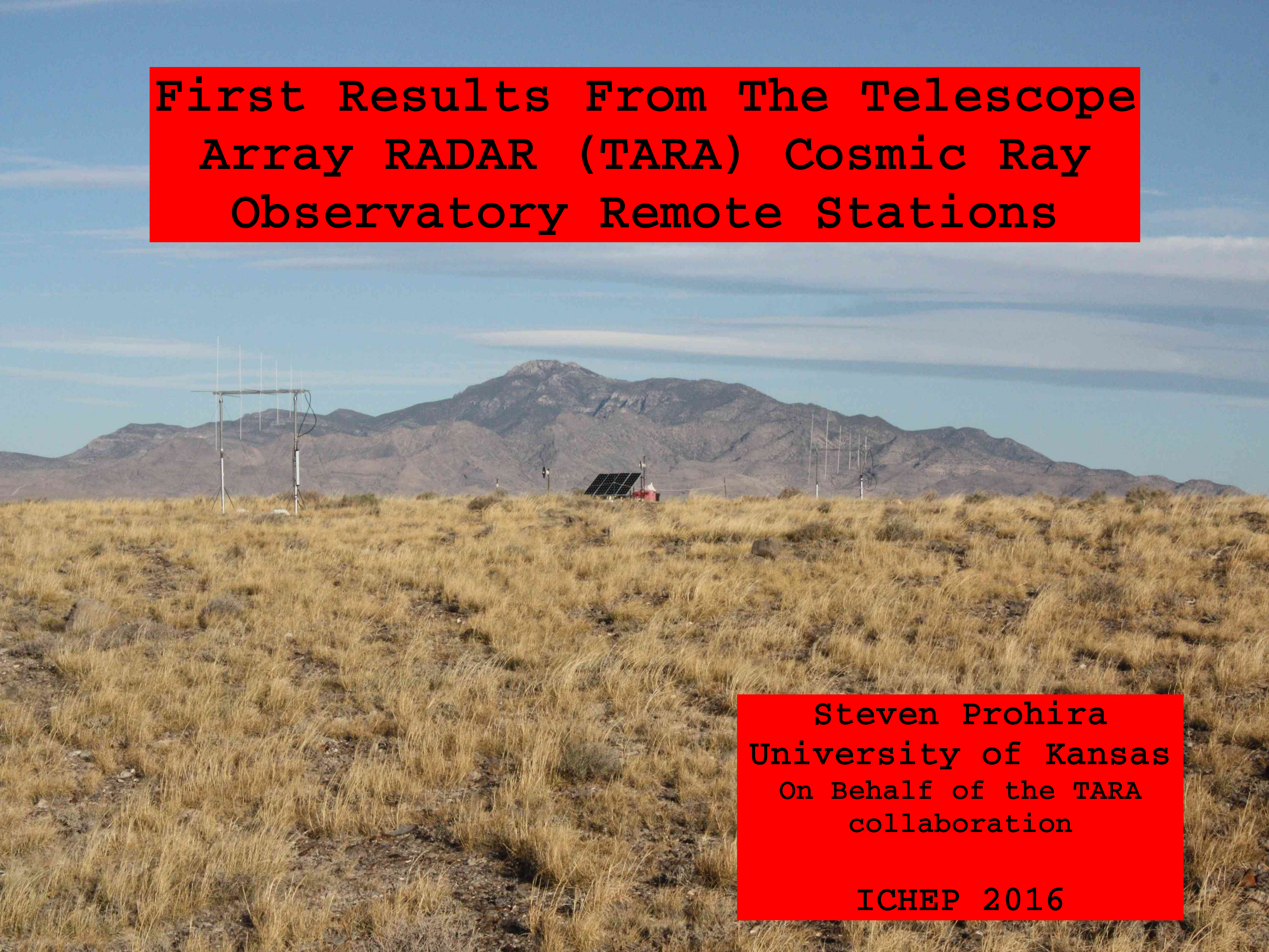
First Results From The Telescope Array RADAR (TARA) Cosmic Ray Observatory Remote Stations



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Outline

- Telescope Array RADAR (TARA)
- The Remote Stations-Motivation
- Deployment/Decommission
- Trigger System
- System sensitivity (Galaxy Check)
- Self-Coincident analysis
- Telescope Array (TA) coincidences
- Future work.

Telescope Array RADAR (TARA)

- Extensive Air Showers (EAS) from UHECR may form ionized column dense enough to reflect sounded RF.
- Co-located with the Telescope Array (TA) surface detector, TARA attempts to detect these echoes.
- Bi-Static RADAR configuration

The TARA transmitter array.

TARA main detector

- Two techniques:
  - Florescence Detector(FD) triggers
    - Analysis by I.Meyers et.al. Reports <u>no signal</u>
    - Preprint: arXiv:1603.05217
    - Submitted to Atropart. Phys
  - Match Filter trigger
    - Analysis ongoing.
- Main Theory Question: what is the actual Radar Cross Section (RCS)?
    - I.Meyers, et. al. (above) places first RCS upper limit at ~10 cm^2 (optimal geometry, 100EeV)

Canned formula:

$$P_r = P_t \frac{G_r}{4\pi R_r^2} \sigma_{eas} \frac{G_t \lambda^2}{16\pi^2 R_t^2}$$

The Remote Stations

- Desired a more isolated, noise-free location

- Initially located 4 km from main detector on Long Ridge.
  (more on this later)

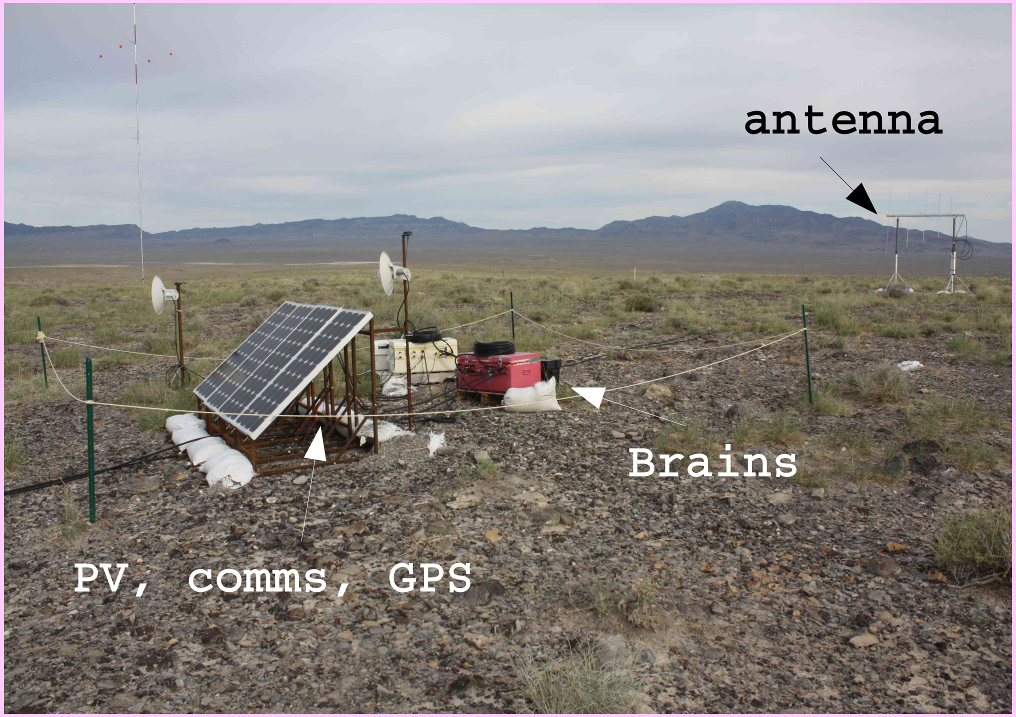
- Fully autonomous

- Different trigger scheme.

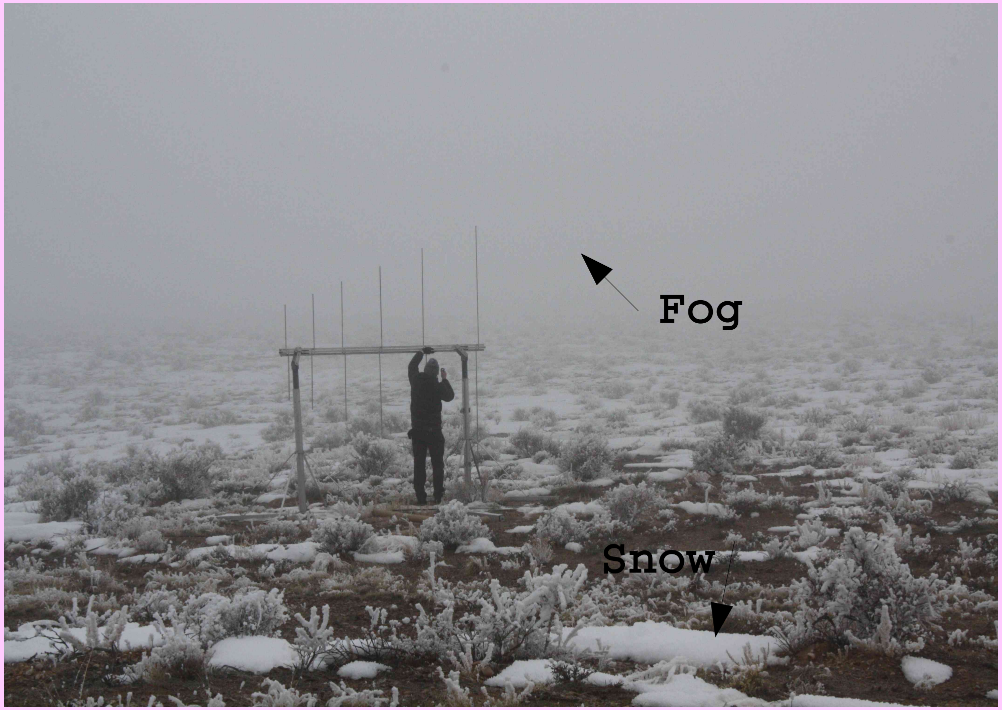
- Custom hardware and firmware

RS deployment/decomission

Deployment 1:
Summer 2014-Summer 2015



Deployment 2:
Winter 2016-present



First Deployment had hardware issues.

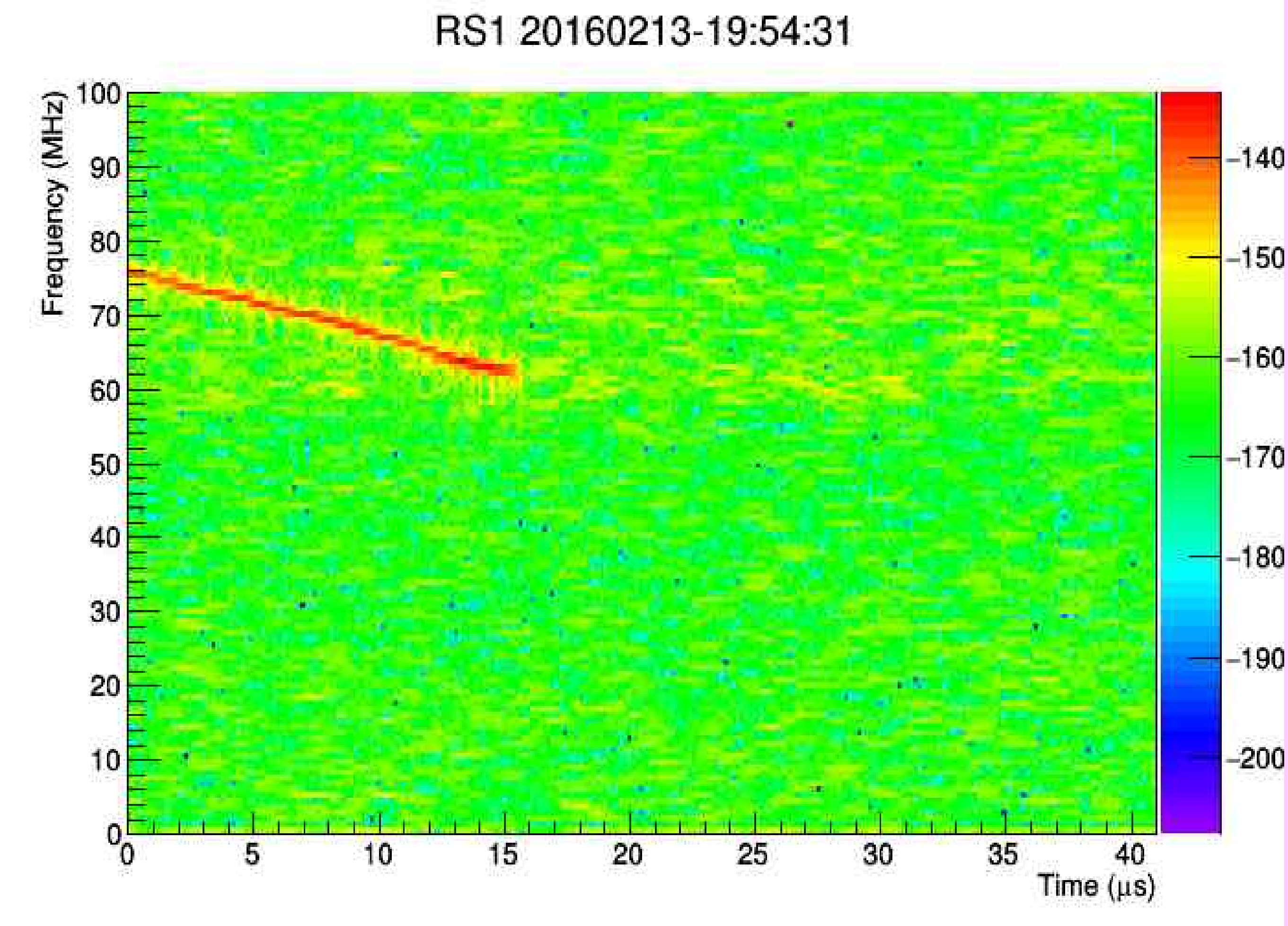
Second deployment had new firmware trigger, but poorer location

Chirps

Bi-static configuration results in Doppler shifted reflected signal, O(10μs) in duration.

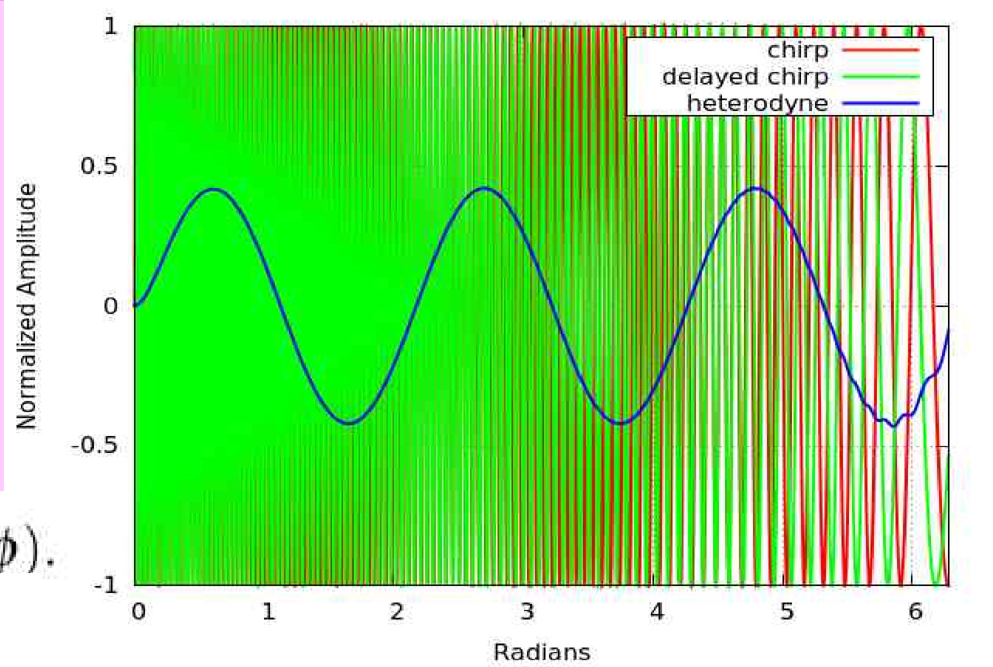
"chirp"

We exploit the chirp in our trigger scheme.



Remote Station Trigger

- Custom Firmware trigger
  - Xilinx Spartan 6 FPGA



Heterodyne method:

-Generally: extract a modulation by mixing two signals

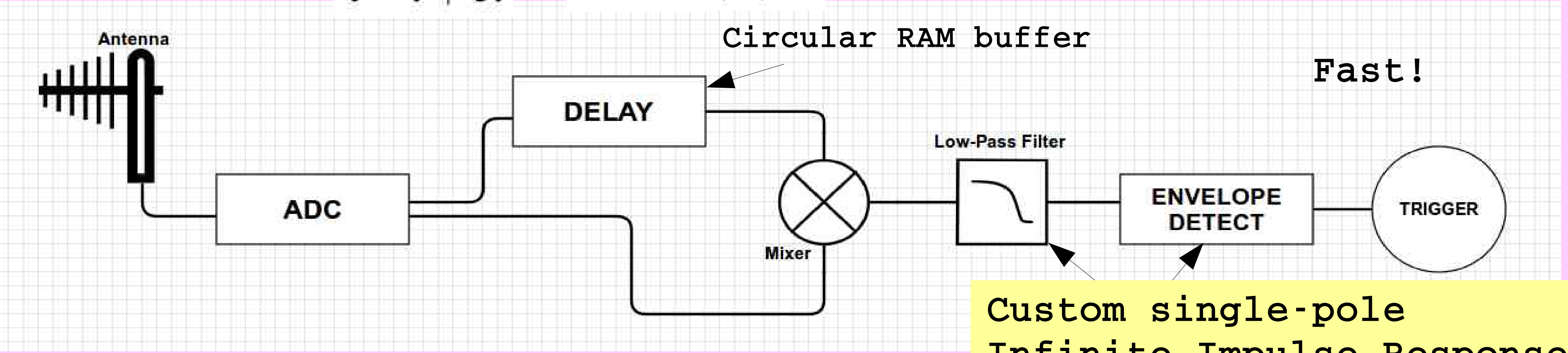
-Here: the two signals are the same, but one is offset in time.

2 signals: $2cos\theta cos\phi = cos(\theta - \phi) + cos(\theta + \phi).$

$$\theta = \omega t + \kappa t^2 \quad and \quad \phi = \omega\tau + \kappa\tau^2,$$

$$\tau = t + \delta t$$

$f_{mono} = 2|\kappa|\delta t.$



Custom single-pole Infinite Impulse Response time-domain filter

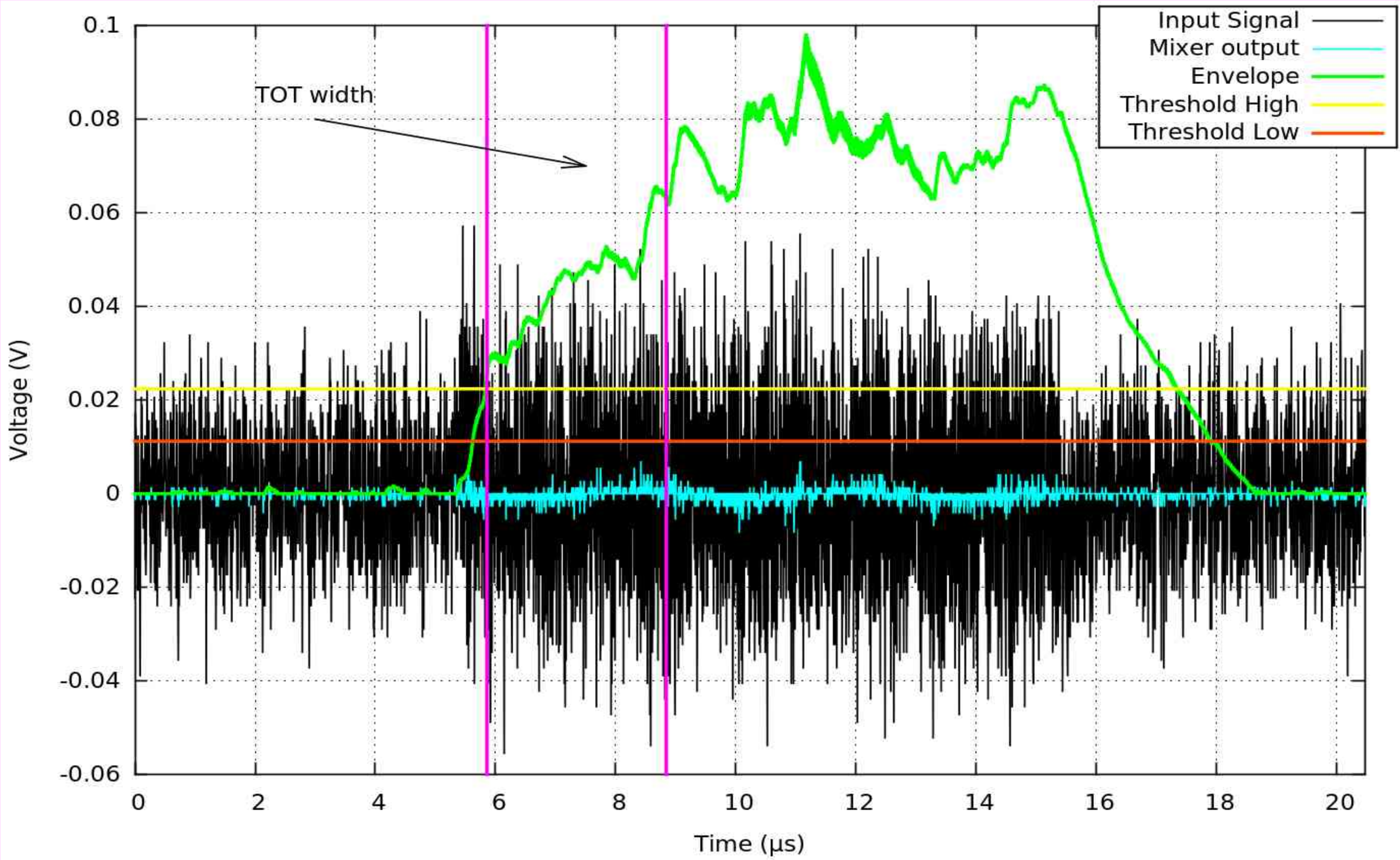
Trigger

Here a test chirp is embedded in Gaussian noise. (black)

The signal is heterodyned and filtered (blue)

Envelope detection results in the green trace, which we trigger on.

Must rise above high trigger and stay above low trigger for TOT duration.

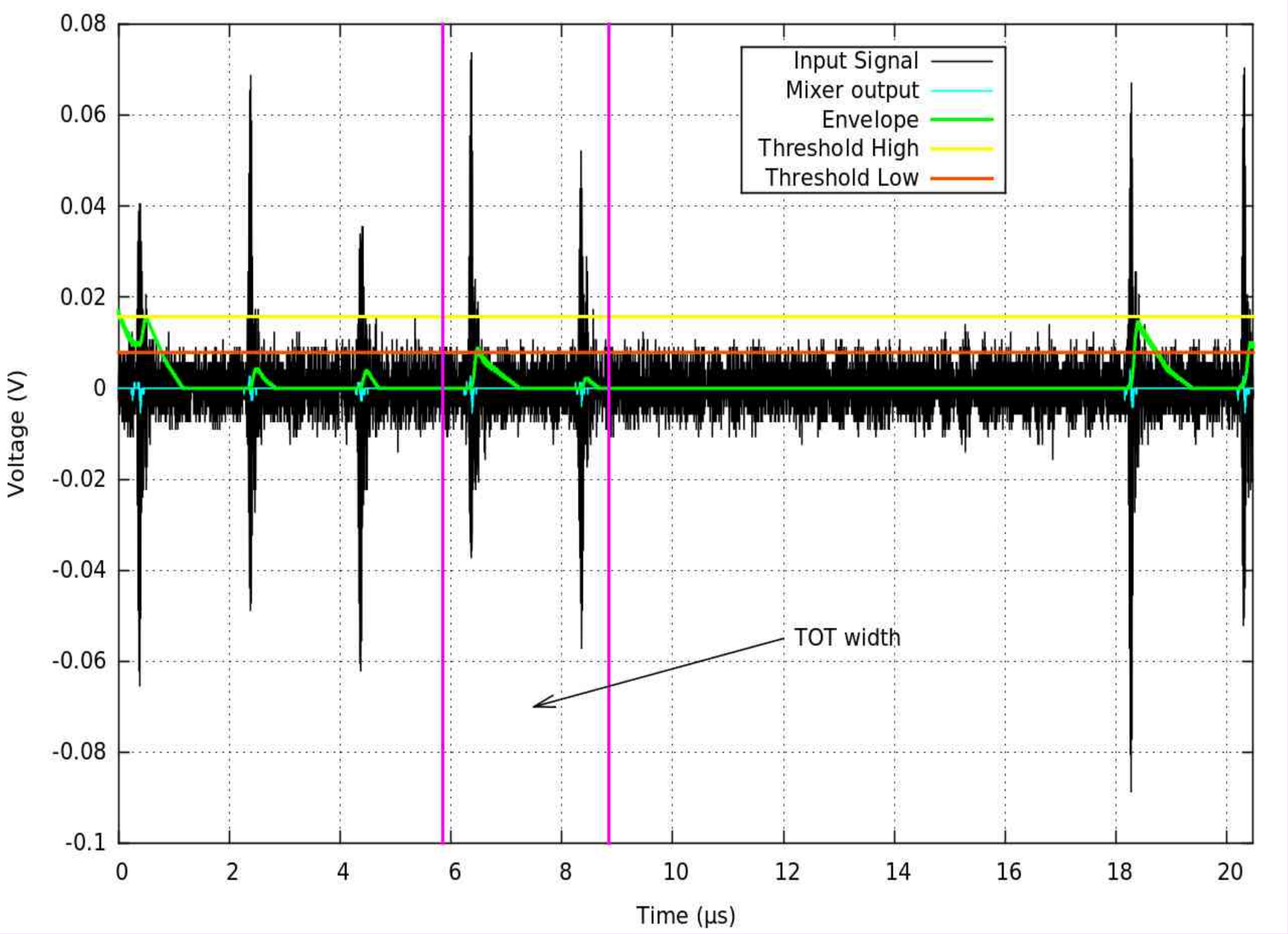


All 'in firmware' traces

Trigger

Here we see relatively high amplitude, incoherent time transients.

Well rejected.

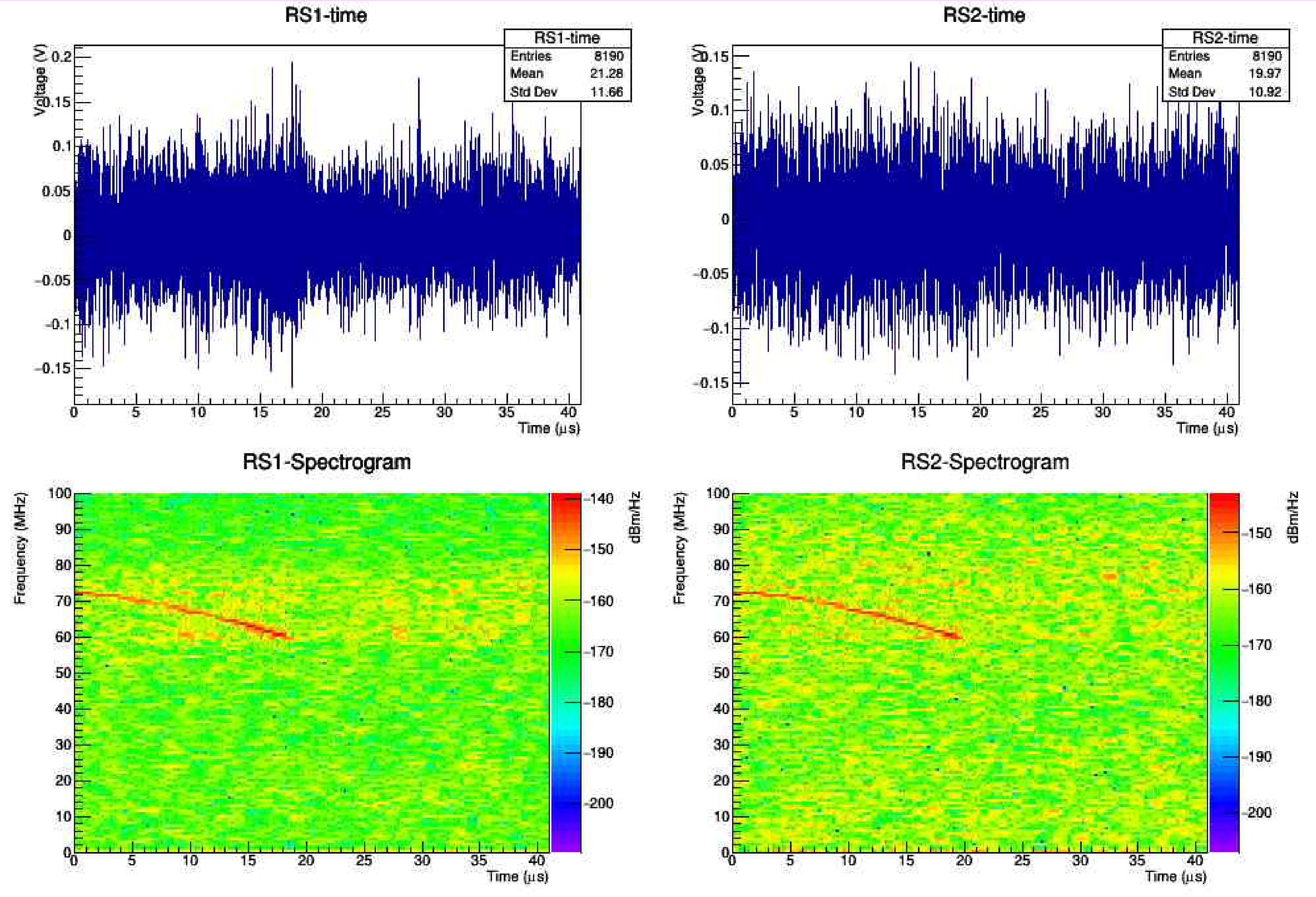


Chirp Calibration Unit(CCU)

CCU sends out a chirp every minute.

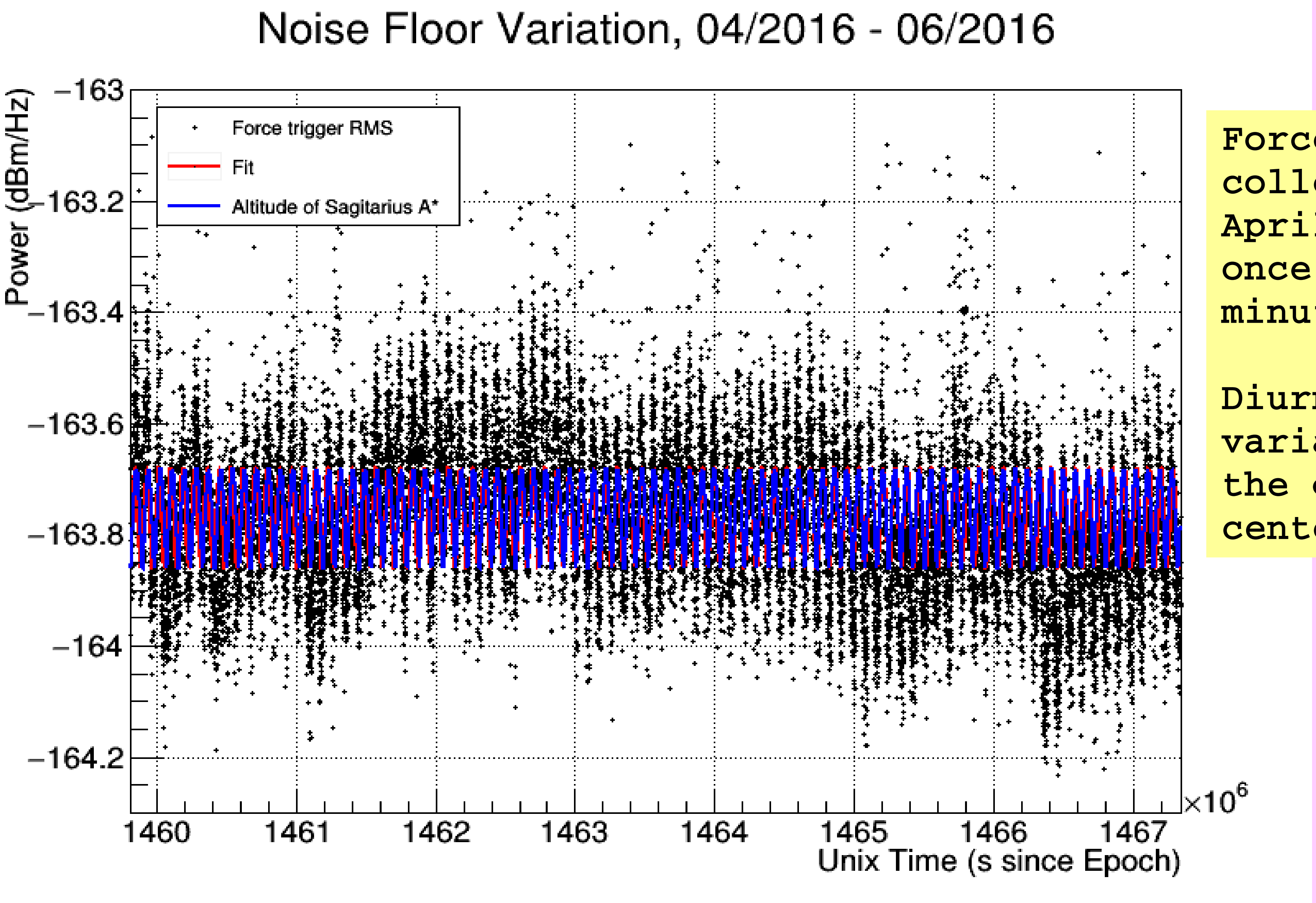
Attenuated output to level of noise.

Here captured in both stations in the field. 2016-02-17-12:26 UTC



If this were an actual event, would correspond to an RCS of $\sim 1m^2$

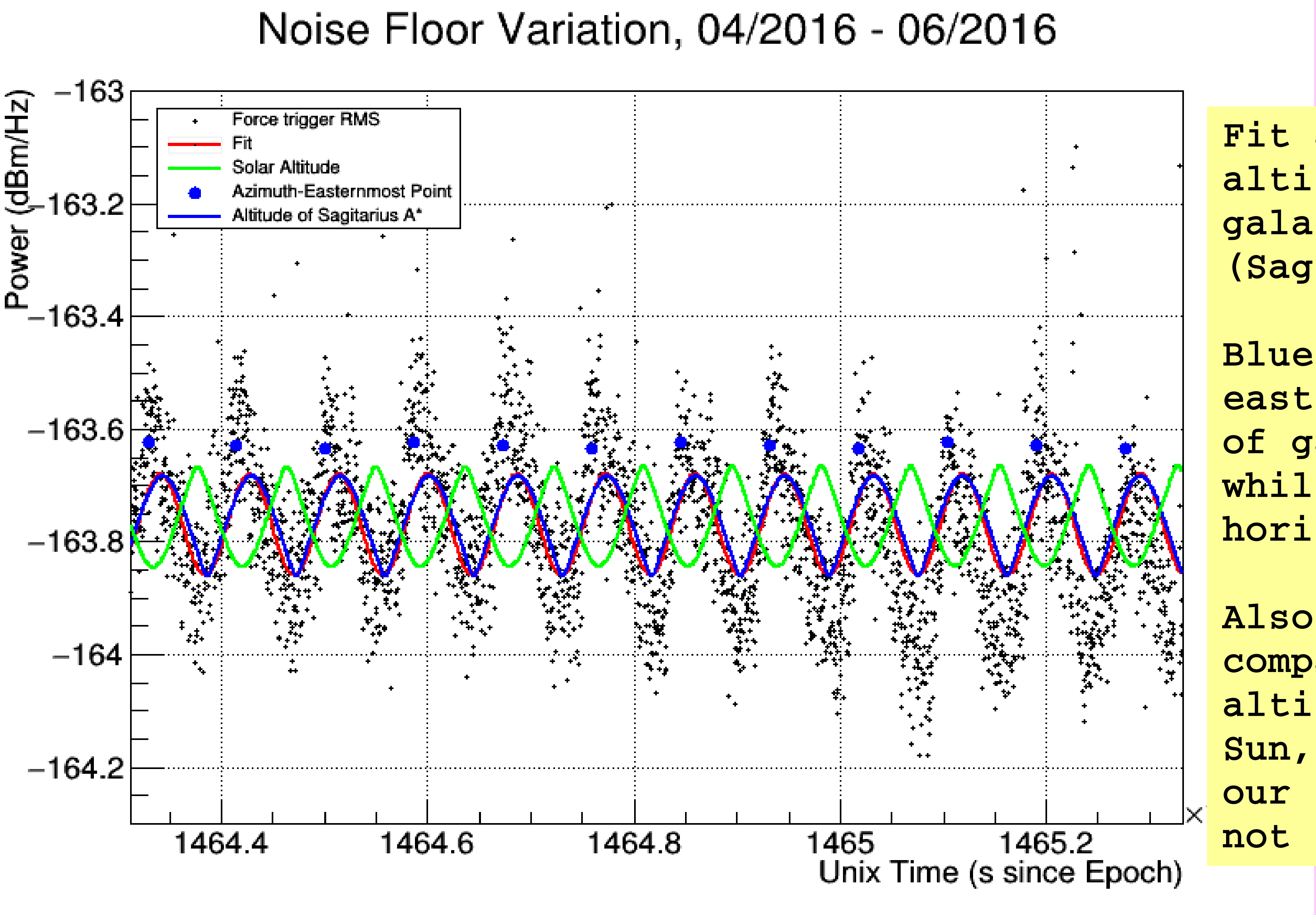
System Sensitivity-Galaxy Check



Force triggers collected from April to July, once every six minutes

Diurnal variation tracks the galactic center!

System Sensitivity- Galaxy Check



Fit agrees with altitude of galactic center (Sagittarius A*)

Blue dots indicate easternmost point of galactic center while above the horizon

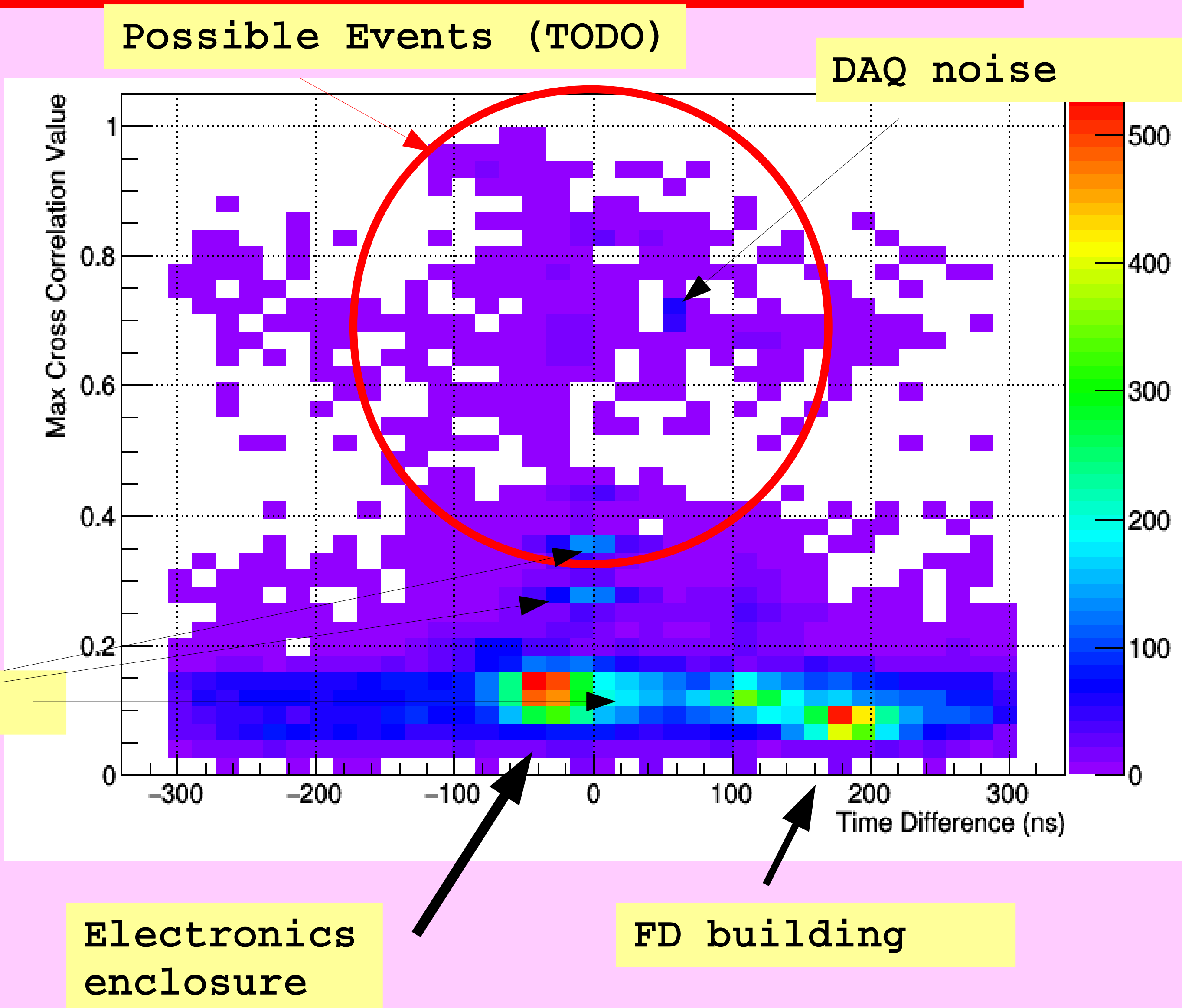
Also shown for comparison is the altitude of the Sun, indicating our fluctuation is not solar-thermal.

Initial Results-Self-coindiences

- With two stations we can "point" to noise sources, in part because they are restricted to the ground plane (at least the hot ones)

Pointing:
+200ns->270° in ?
-200ns->90° in ?

Cross correlation finds highly similar events



Initial Results- TA coincidences

- Preliminary timestamp comparison between TARA and TA events yields no direct coincident events.

- However:
  - During our 6 week run time, TA was offline for 1 week.
  - No events in the TA data set over 60EeV.
  - Our detection volume is larger- possible events not detected by TA (unlikely)

Conclusions/TO-DO

- **Preliminary analysis (self-coincident, and TA coincidence) yields <u>no events.</u>**
- **Detailed analysis is needed on event-per-event basis to chirp-hunt**
- **Monte Carlo-existing particle-level MC based on CORSIKA**

Thanks!

- Thanks to the TARA collaboration for excellent Transmitter runtime, maintenance, and in-the-field assistance, the TA collaboration for data and network access, and Dave Besson and Dr. Sam Kunwar for the first RS implementation paper, from which I draw heavily: https://arxiv.org/pdf/1504.00779.pdf

BACKUP

Bi-Static RADAR

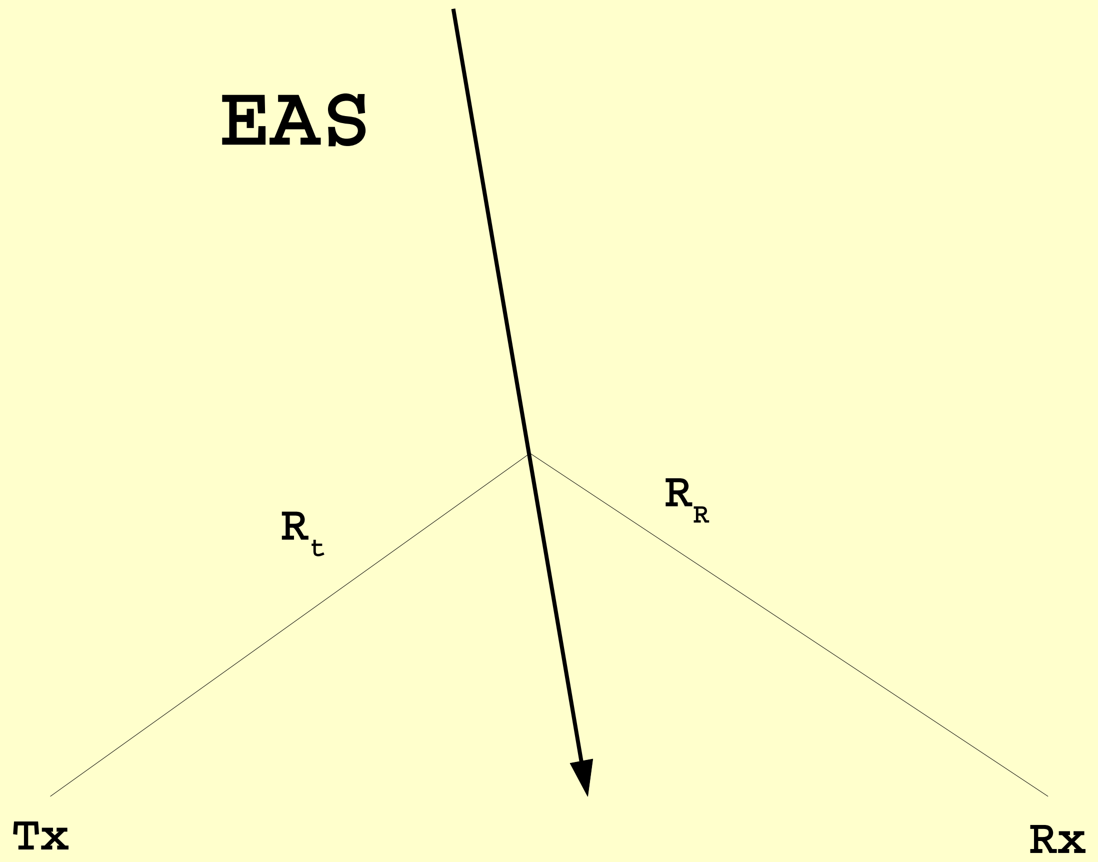
Separation of TX and RX along some baseline.

Doppler shift of scattered field is minimized.

TARA baseline ~35km
TARA frequency: 54MHz

Expected Doppler shift: ~100MHz down to 54MHz

$$f = \frac{1}{\lambda}\frac{d}{dt}[R_T + R_R]$$



Trigger Efficiency

Benchtop trigger efficiency as a function of RCS, for a 40kW transmitter, and a baseline of 40km.

Made by sweeping amplitude of sig-gen chirp into actual trigger path. Input amplitude converted into RCS by above parameters.