GPS Time Synchronization and Radio Detection for Ultra High Energy Cosmic Rays

March 21st, 2019, HamSCI at CWRU

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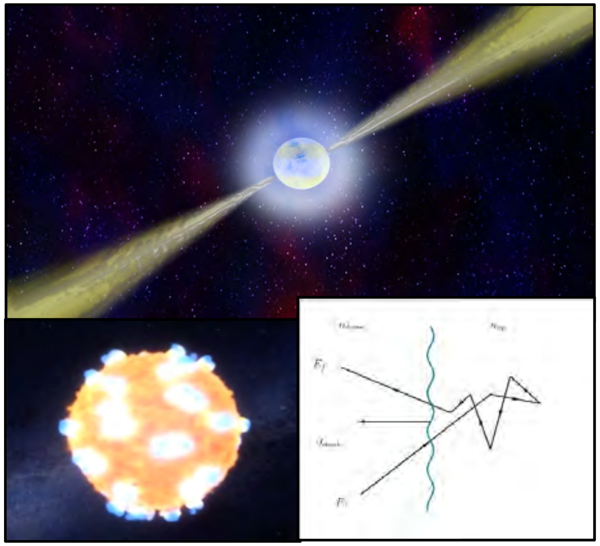
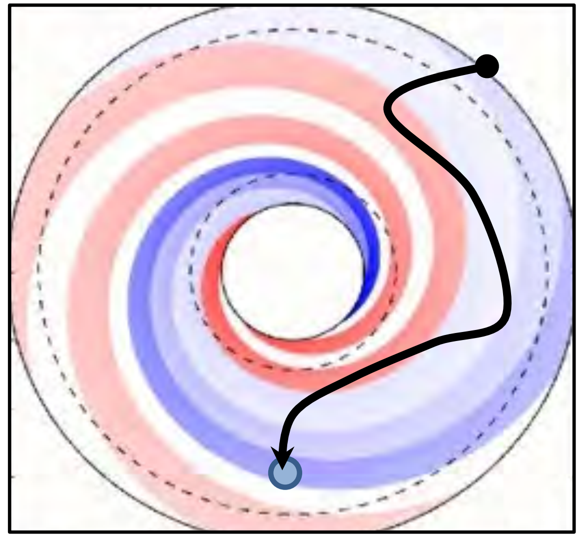
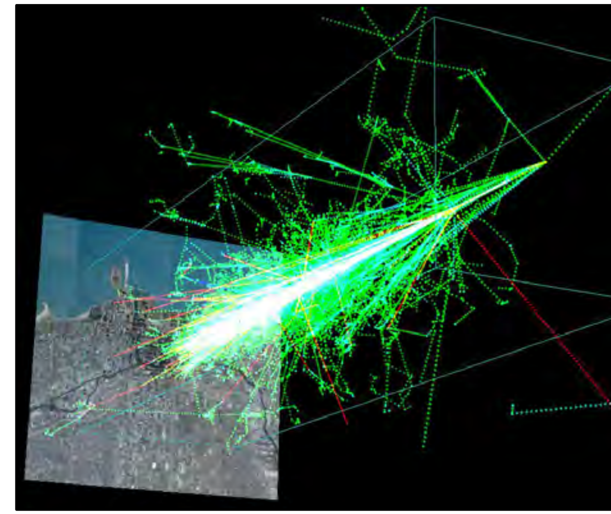
Department of Physics

Ultra High Energy Cosmic Rays: Introduction







Injection/Acceleration:
- Supernovae /Accretion /Remnants
- Fermi Acceleration
- Inductive Acceleration
- Exotic Decays

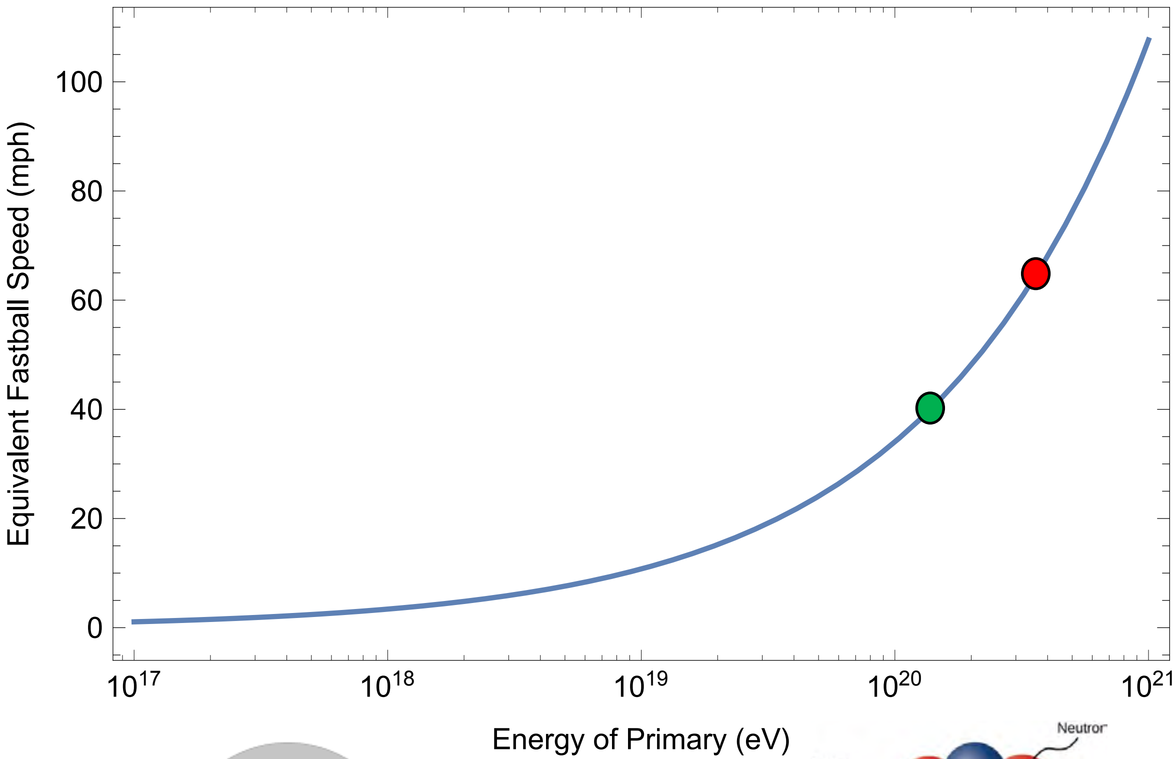
Transport (Chap. 7)
- Galactic and Extragalactic Magnetic Fields
- JFQ17 Model
- GZK/Photo-disintegration

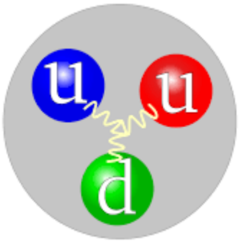
Arrival (Chap. 4, 5 and 6)
- Extensive Air Showers
- >LHC Energies
- Water Cherenkov /Scintillation /Fluorescence Detection

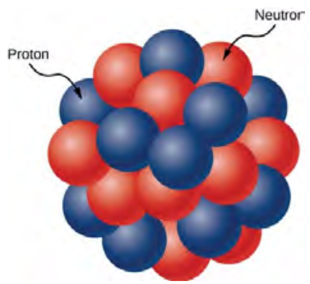
LHC: Large Hadron Collider
GZK: Greissen-Zatsepin-Kuz'min limit
JFQ17: Janson-Farrar-Quinn Magnetic field model

CASE WESTERN RESERVE UNIVERSITY EST. 1826
think beyond the possible

Ultra High Energy Cosmic Rays: An Everyday Connection







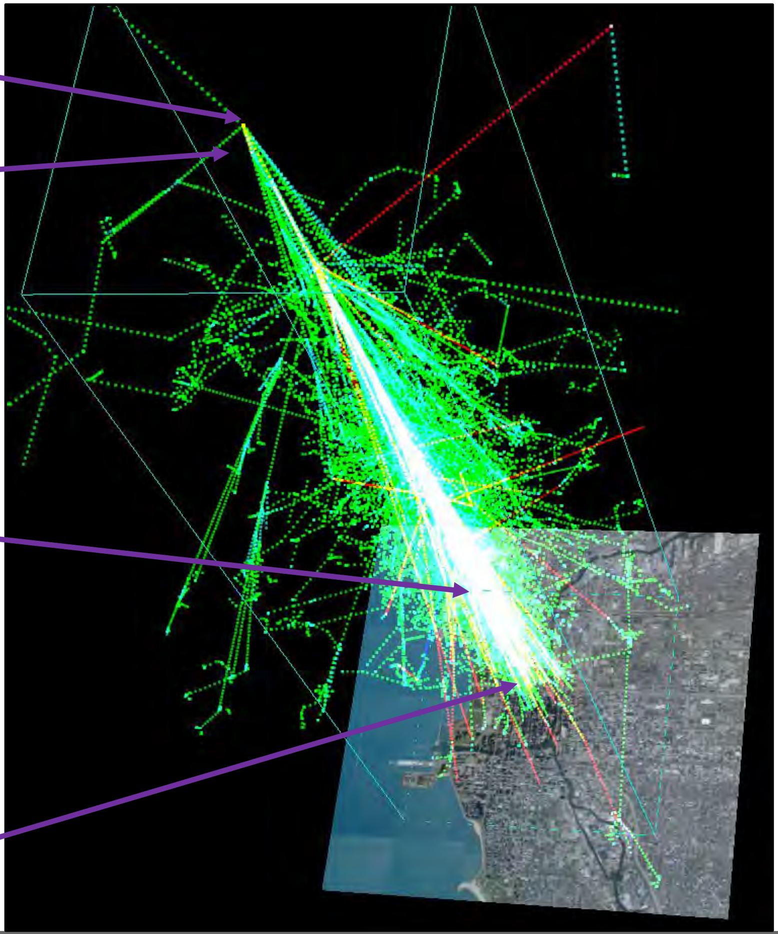
Ultra High Energy Cosmic Rays: Extensive Air Showers

“Primary”

First Interaction:
>LHC energies (~100 TeV CM)
>Zoo of exotic mesons and baryons

X_{max}:
>Maximum of particle production, reaches equilibrium between production and absorption
>Pions, electrons, photons, muons, K_{long}

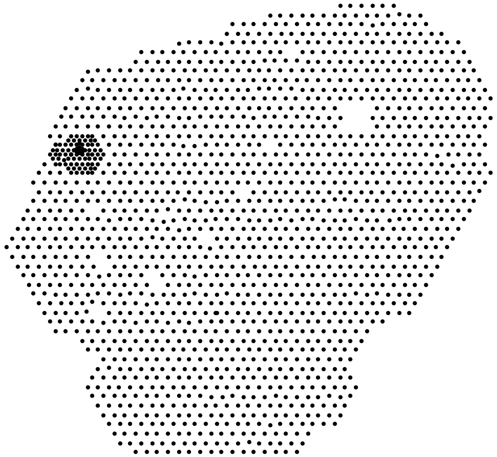
Detection:
>Signal generated by scintillation, Cherenkov
>Electrons, photons and muons



10^{20} eV proton-induced shower over Chicago

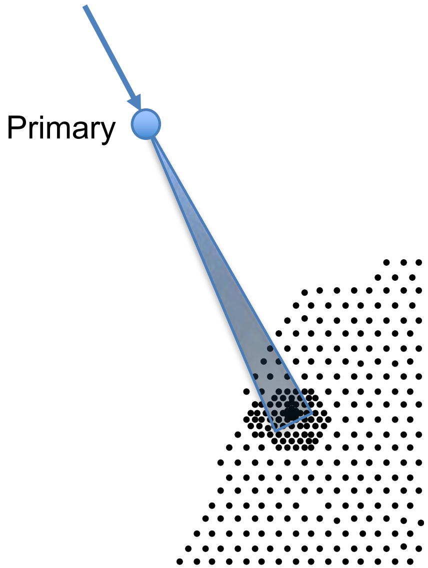
CM: Center of Mass
TeV: 10^{12} eV electron volts

Pierre Auger Observatory

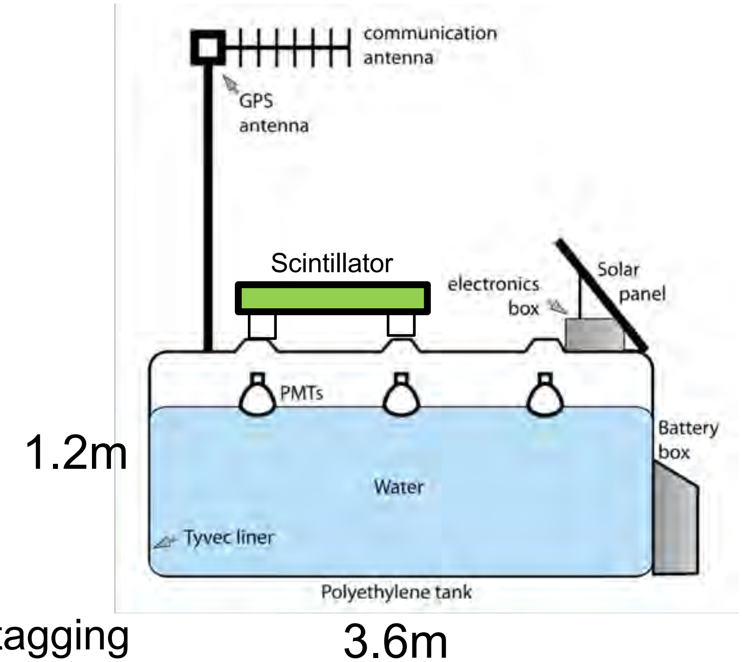


- Science Goal: Understanding the origin and nature of Ultra High Energy Cosmic Rays (UHECRs, 10^{18} eV+)
  - Astrophysics and astronomy of sources
    - Composition dependence
    - Exotics and UHE γ, ν
  - Particle Physics in atmosphere
- 1660 Water Cherenkov Detector stations in a 1.5km regular triangular grid
- 24 Fluorescence telescopes at 4 sites
- Smaller Infill and Engineering Array
- Undergoing upgrade to AugerPrime

Timing High Energy Air Showers



Time particles passing through each detector to triangulate arrival direction, record shower front as it passes
>Requires precise timing synchronization



AugerPrime Surface Detector Station:
Photomultiplier Tubes, 120 Mhz ADCs + time-tagging
Run by Upgraded Unified Board (UUB)

- GPS Timing, <2ns precision PPS
- 8.5ns Time-tagging accuracy

Radio Communications Network (~200bps), Solar Panel and Lead Acid Batteries

GPS Testing for AugerPrime

- When we found the original choice of GPS (i-Lotus M12M) would be on back order and possibly not be reproducible, we had to test a new GPS unit (SSR-6Tf)
- Reconfigured our in-house time-tagging module (next section) to test each model against:
  - An atomic clock *(Absolute Timing)*
  - An identical unit *(Relative Timing)*
  - An identical unit with temperature modulation *(Temperature Testing)*

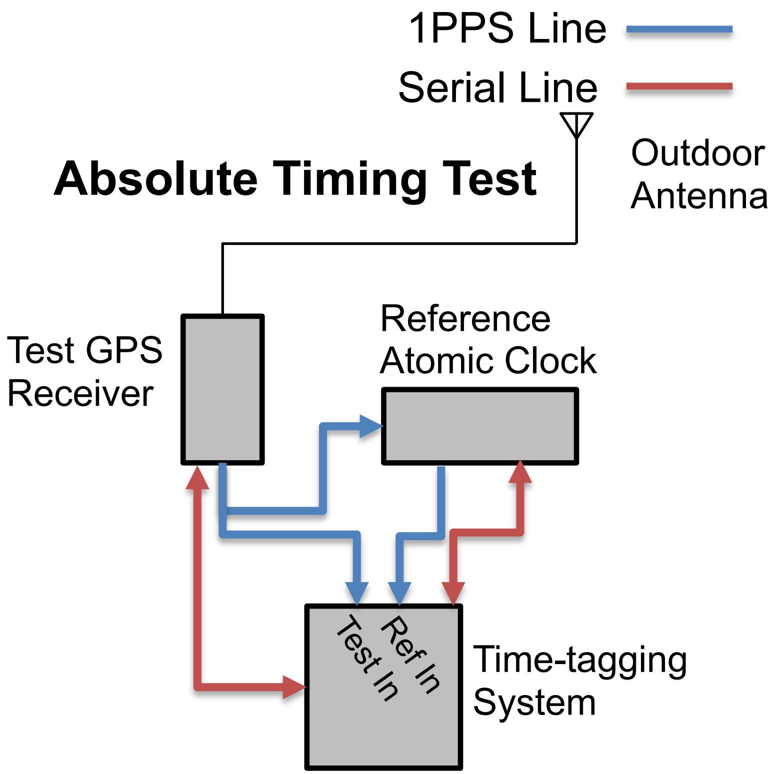
VS.

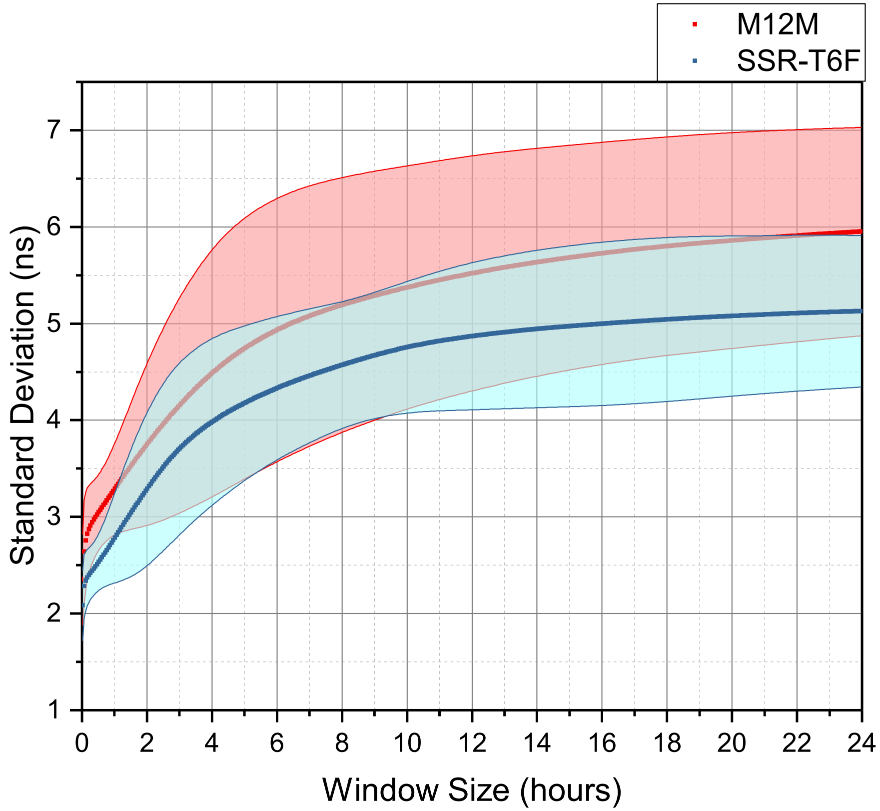
i-Lotus M12M

Synergy SSR-6Tf

AugerPrime GPS Testing: Absolute Timing

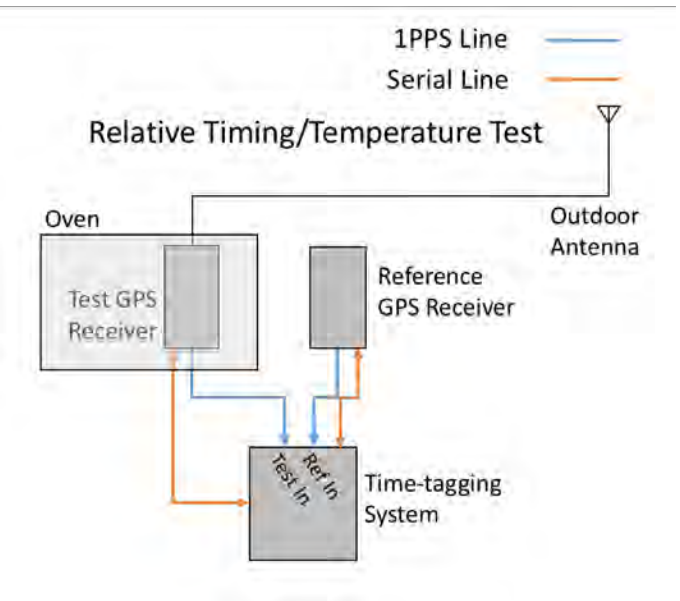
Absolute Timing: The accuracy of a timing source against a GPS second (in this case provided by a Rubidium atomic clock)

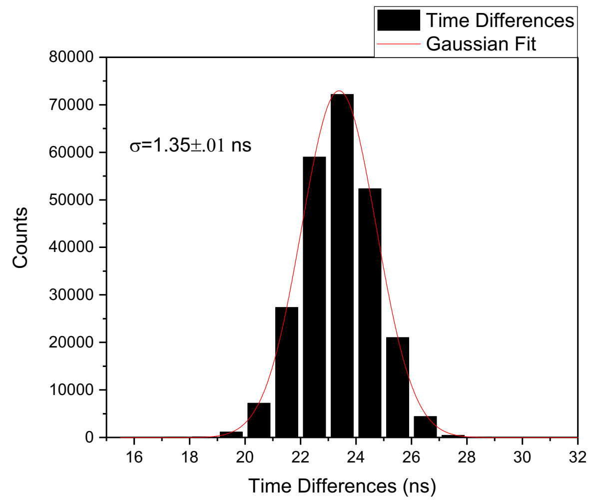




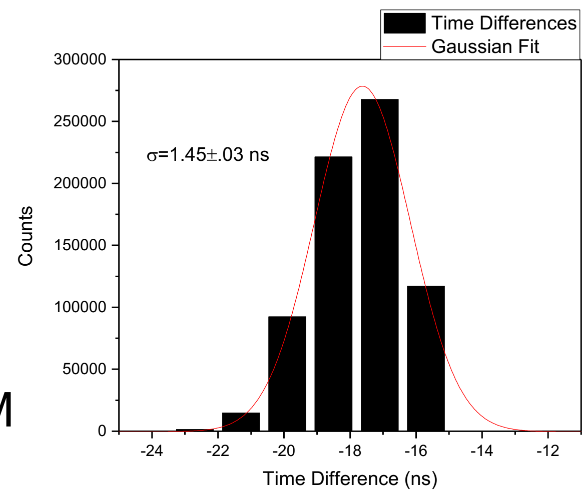
AugerPrime GPS Testing: Relative Timing

Relative Timing: The accuracy of a timing source against an identical timing source





SSR-6Tf

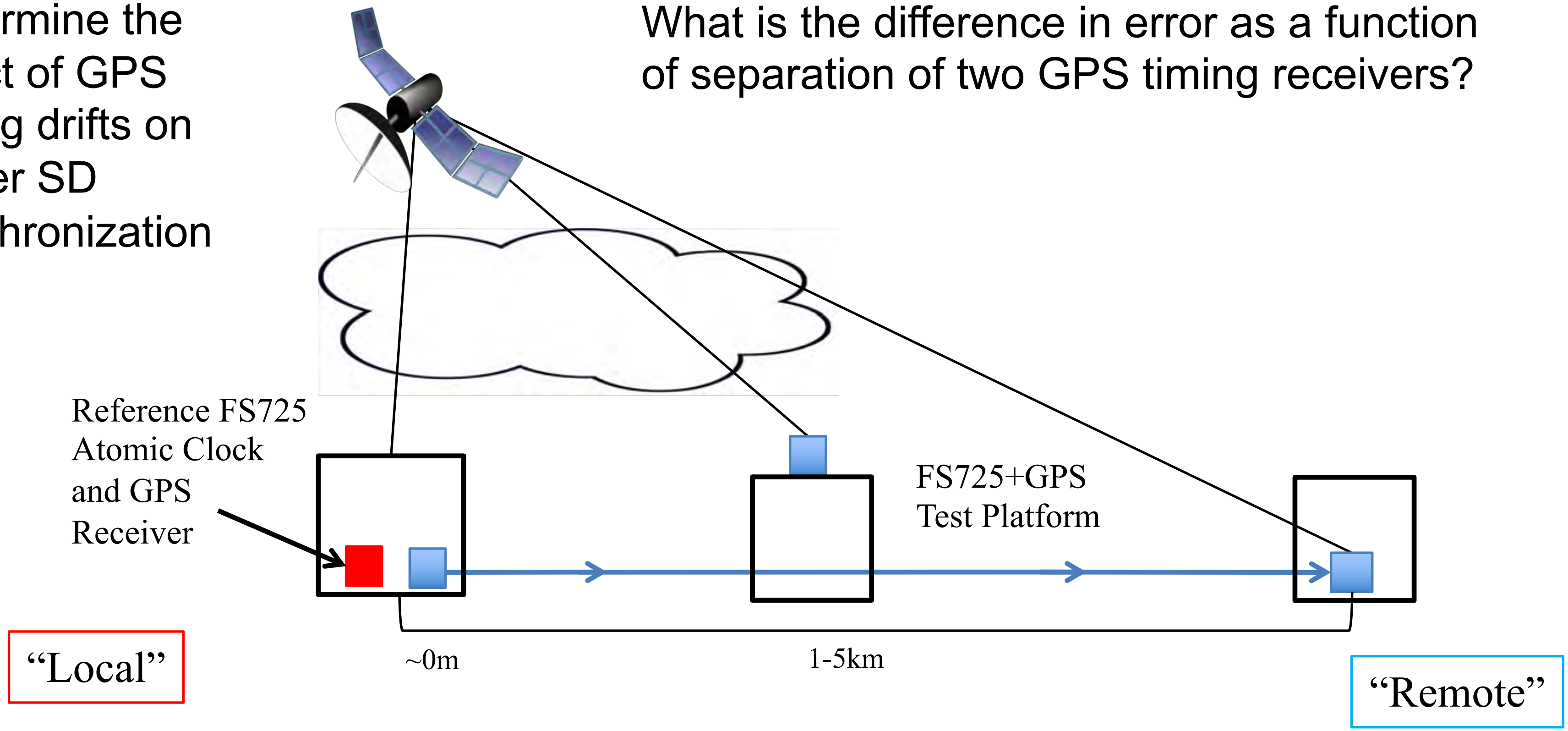


M12M

Spatial Correlation of GPS Timing Drifts

Motivation: Determine the effect of GPS timing drifts on Auger SD synchronization

What is the difference in error as a function of separation of two GPS timing receivers?

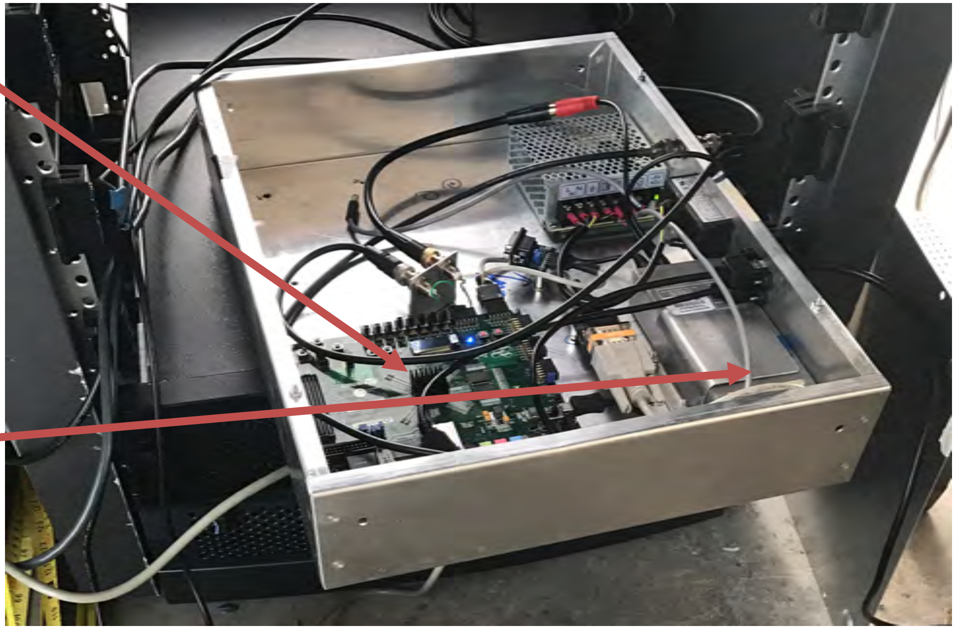


Timing Instrumentation Module

AKA 'TIM'

Hardware consists of:

- ZedBoard driven by Zynq SoC/FPGA
    - Telemetry handling for GPS, time-tagging and peripherals on SoC
    - Can be configured to output over USB or RS-232
    - 750 Mhz Time Tagging System
- M12M/SSR-6Tf GPS Receiver
- Power Supply and Fuse Box



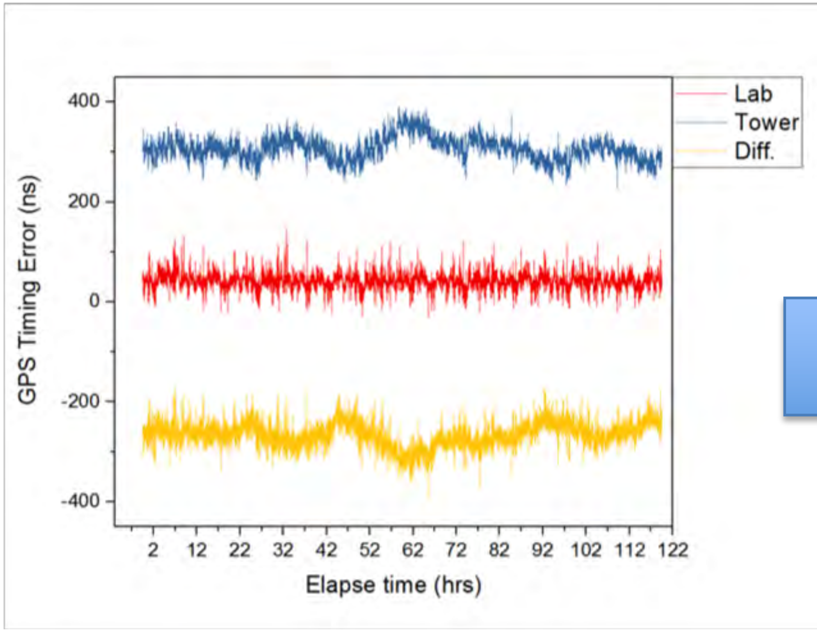
Key Points:

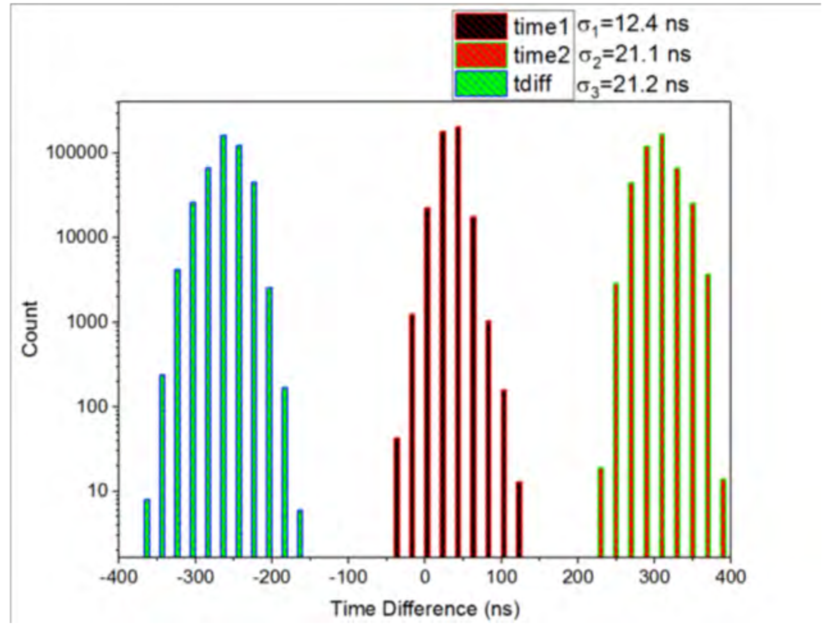
Reliable, precise, portable and flexible time-tagging for astrophysics applications in the field or in the lab

Applications:

1. Spatial Correlations of Timing Errors
2. Auger@TA
3. TIM@CTA

Spatial Correlation of GPS Timing Drifts: Method

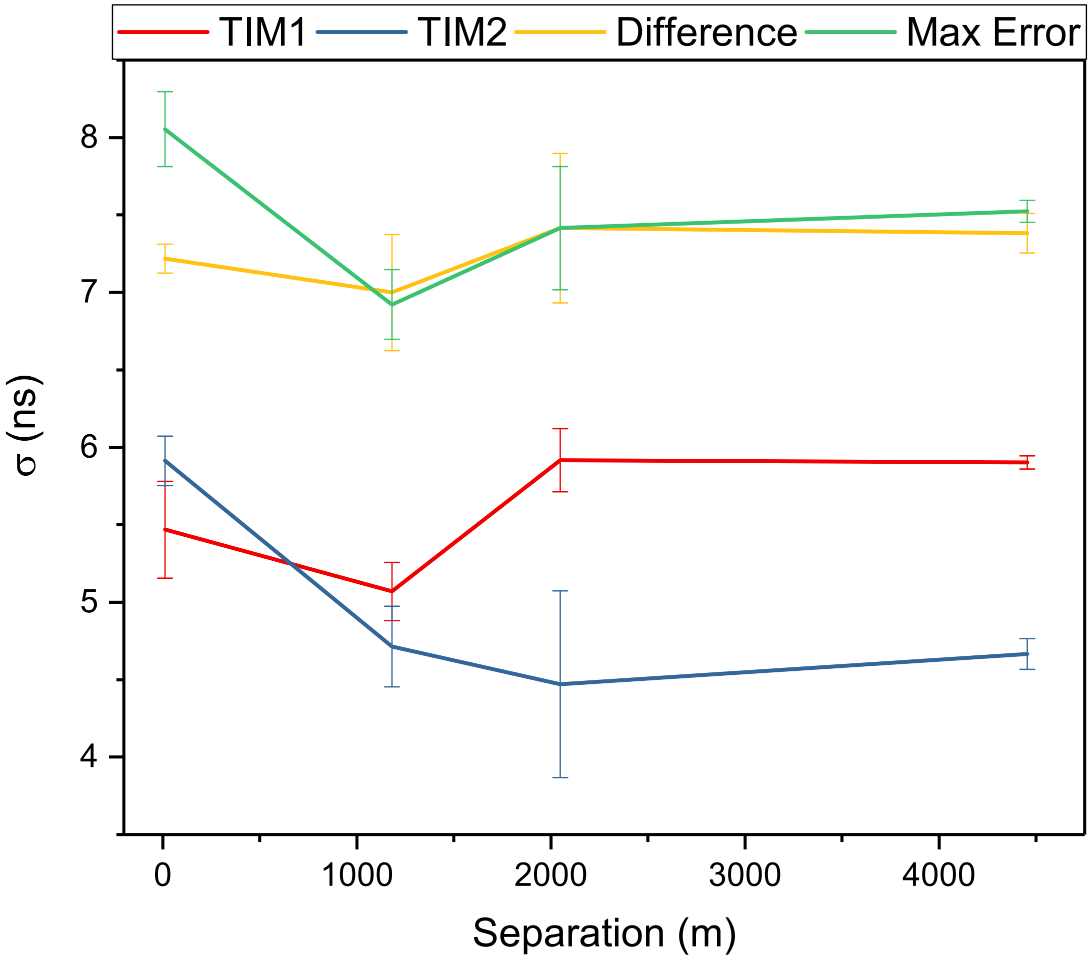




Basic method:

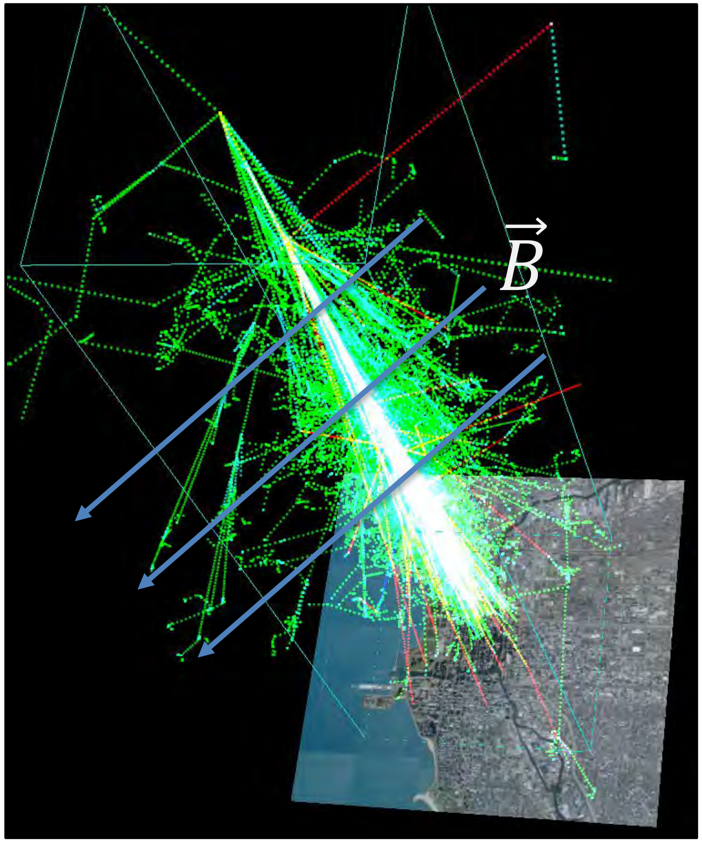
1. Set up TIM in two locations of predetermined separation
2. Take data for 1.5-2 weeks
3. Look at the standard deviation of each time stream
4. See if standard deviation of differences is less than time streams standard deviations added in quadrature

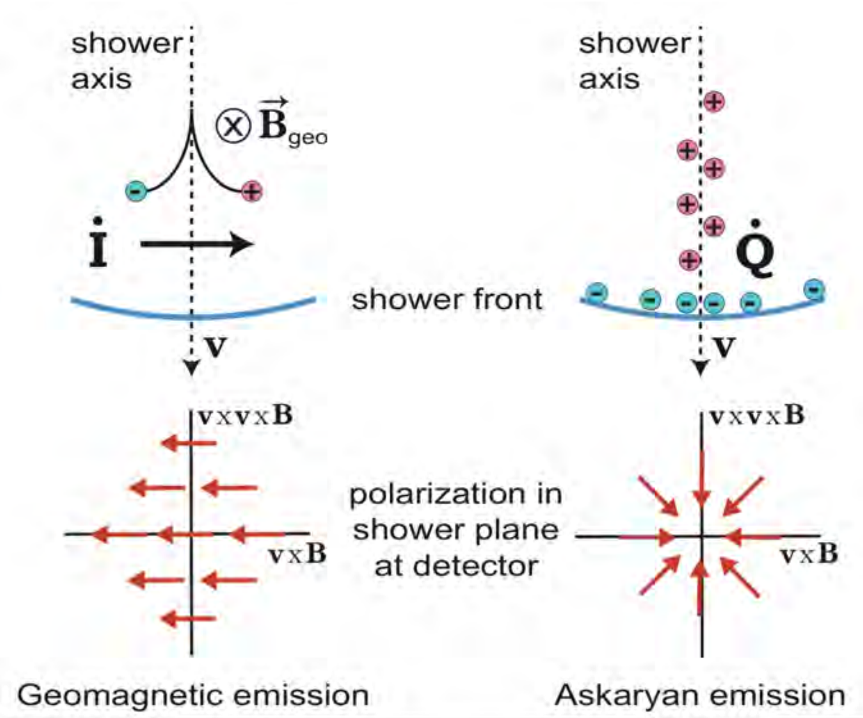
Spatial Correlation of GPS Timing Drifts: Results



If σ of difference is less than Max Error, the time streams are not independent (i.e. are correlated)

And now for something completely different…



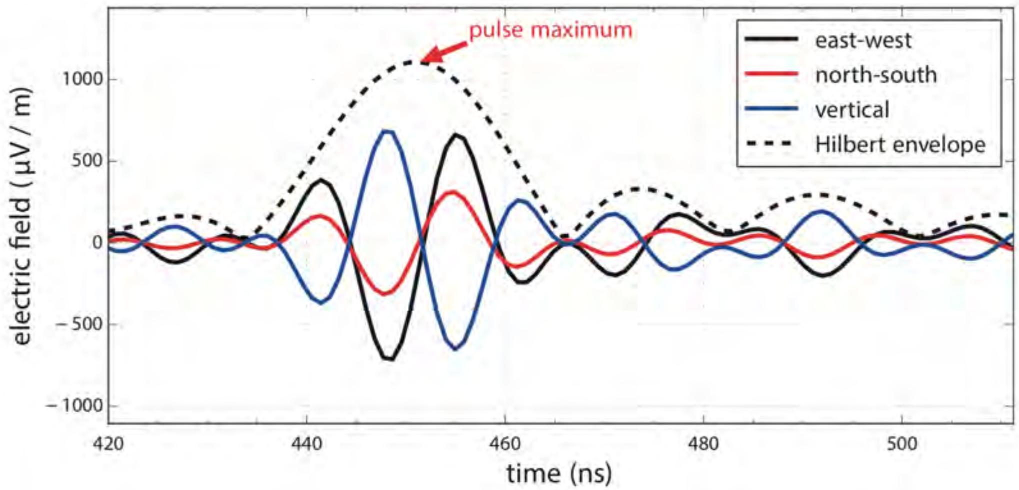


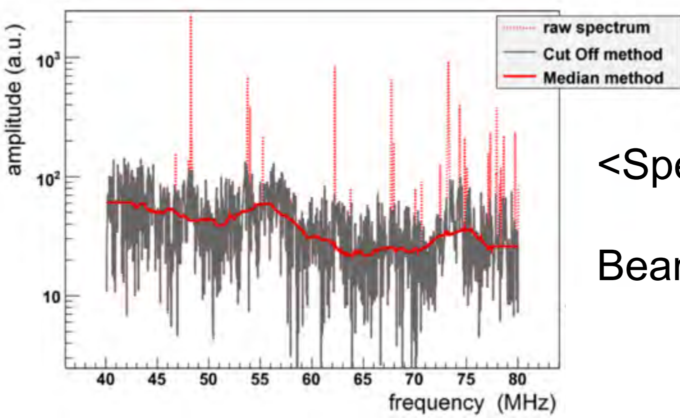
Produces Radio Emission!

Back to that ~17J Cosmic Ray Shower

Radio Detection of UHECRs

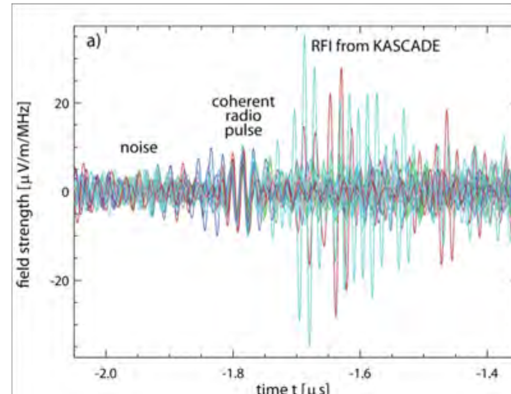
(c) LPDA at AERA





<Spectrum (for reference)

Beamforming example>



Thanks for Listening!

- First part of the talk-- my thesis work, soon to be available from the High Energy Astrophysics group's website: **hea.cwru.edu**
- Second part of the talk– figures from my colleague Frank Schroeder's excellent review on radio UHECR detection (Karlsruhe Institute of Technology and University of Delaware):

Radio detection of Cosmic-Ray Air Showers and High-Energy Neutrinos

published by *ELSEVIER* in *Progress in Particle and Nuclear Physics* 93 (2017) 1-68

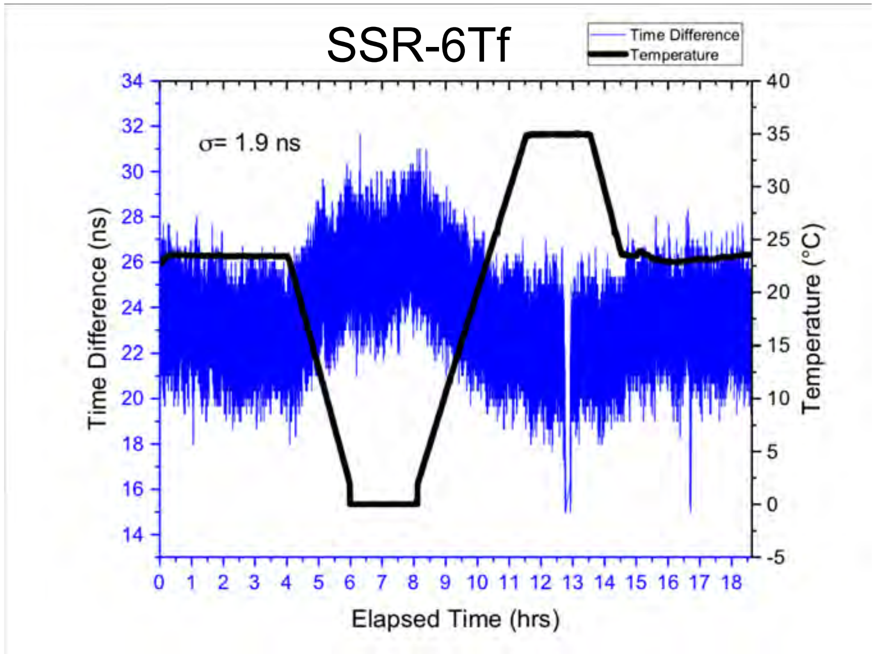
http://dx.doi.org/10.1016/j.ppnp.2016.12.002

Frank G. Schröder[1]

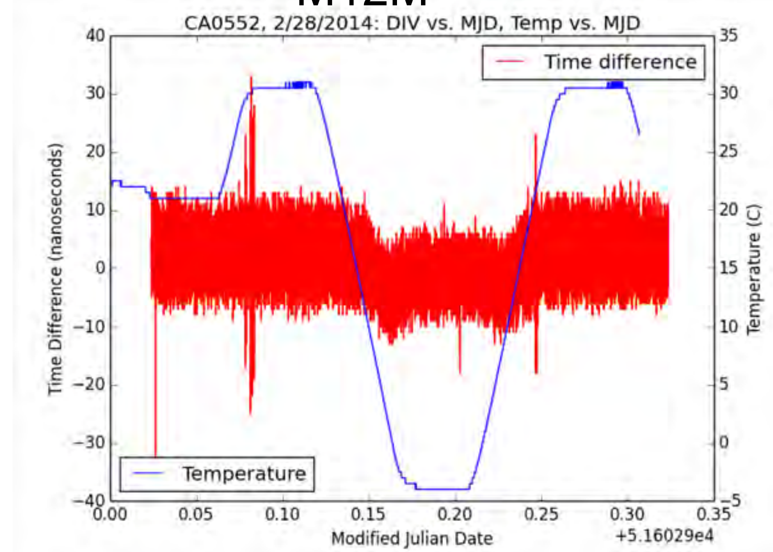
And thank you to Nathaniel, David, the Case HAM club, NJIT and all others who helped put this together.

[BACKUP] GPS Temperature Testing

Temperature Testing verifies that the precision timing of the receivers is not affected by the rapid temperature changes in the desert



M12M



AugerPrime GPS Testing Conclusions:

Recommended SSR-6Tf based on performance and future availability

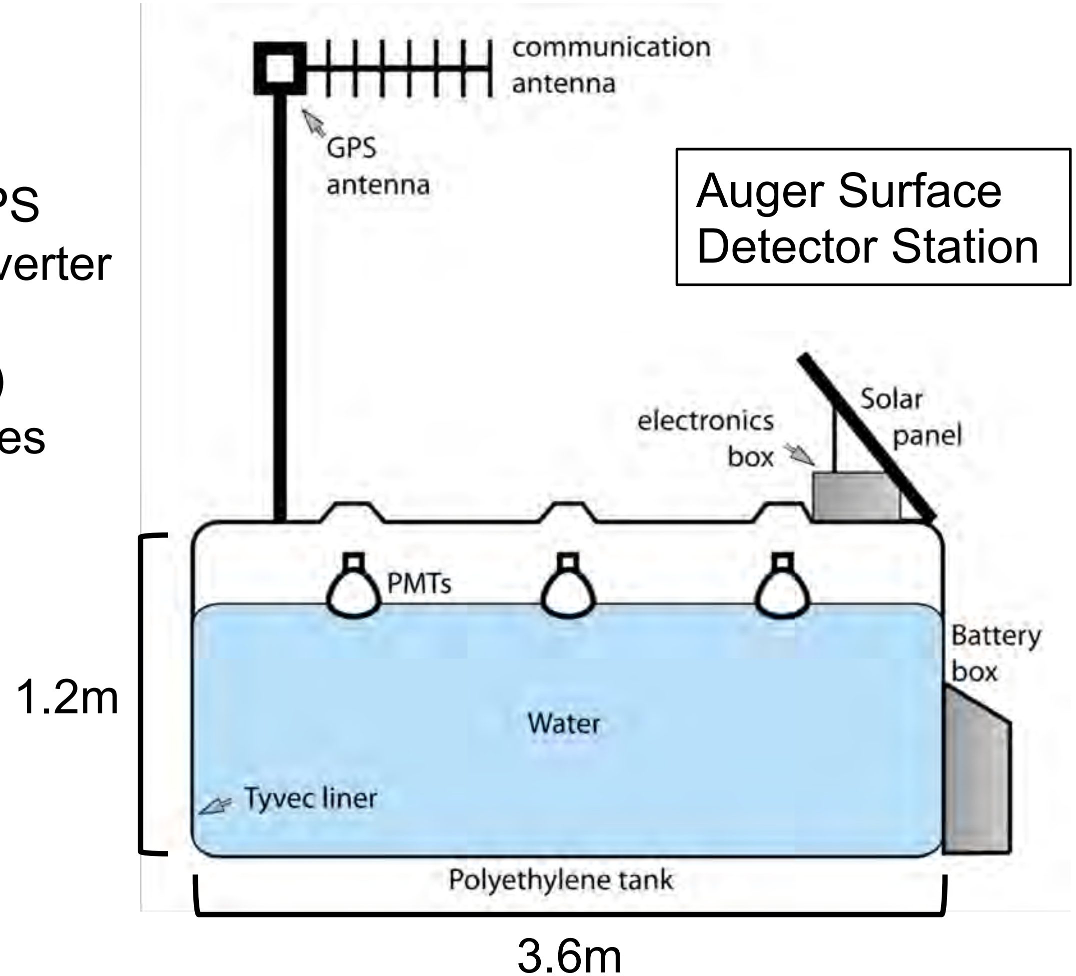
[BACKUP] AugerPrime upgrade: Surface Detector

1660 Detector Stations
3 Photomultiplier Tubes
Upgraded Unified Board (UUB)

- GPS Timing, <2ns precision PPS
- 120 Mhz Analog-to-Digital Converter
- 8.5ns Time-tagging accuracy

Radio Communications (~200bps)
Solar Panel and Lead Acid Batteries

Upgrade with scintillator



PMT: Photomultiplier tubes