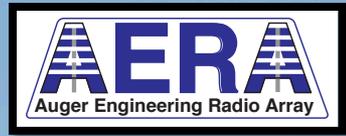




PIERRE  
AUGER  
OBSERVATORY



# Data Acquisition, Triggering, and Filtering at the Auger Engineering Radio Array

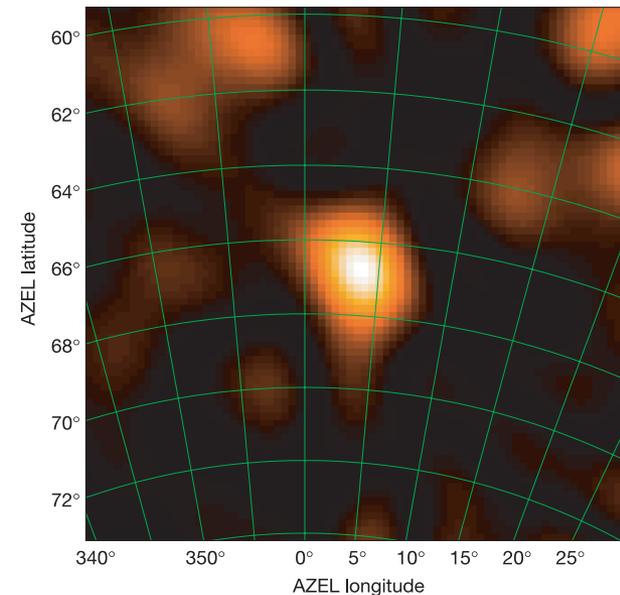
John Kelley for the Pierre Auger Collaboration  
Radboud University Nijmegen  
The Netherlands

VLVnT II Workshop  
Erlangen, Germany  
October 12, 2011



# Radio Air Shower Detection

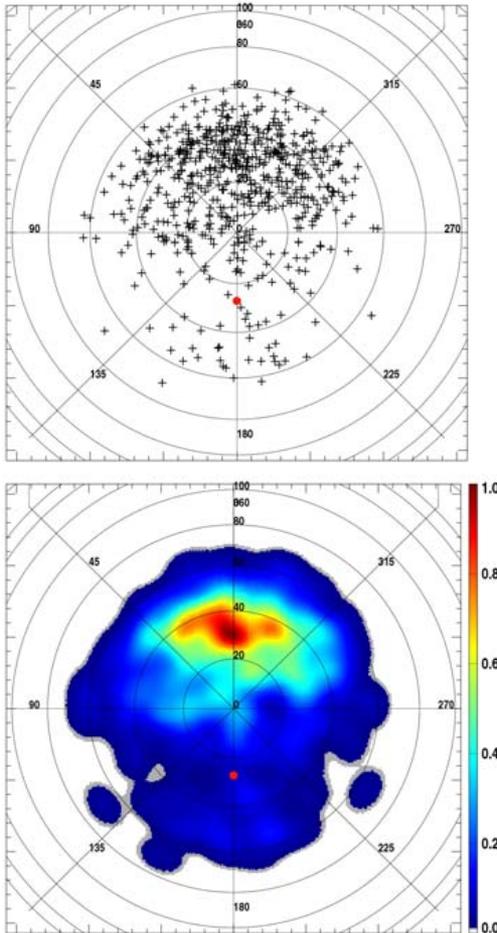
- Renaissance in radio detection of air showers
  - high duty cycle
  - access to shower development
- Existing or planned extensions at CR / neutrino experiments:
  - KASCADE-Grande + LOPES
  - IceCube + RASTA
  - TREND
  - ANITA
  - Pierre Auger Observatory + AERA
- Radio poses unique technical challenges



Falcke et al., Nature **435** (2005)

# Radio Emission from Air Showers

CODALEMA skymap



Ardouin *et al.*, *Astropart. Phys.* **31** (2009)

- Coherent pulse (MHz frequencies) of primarily geomagnetic origin

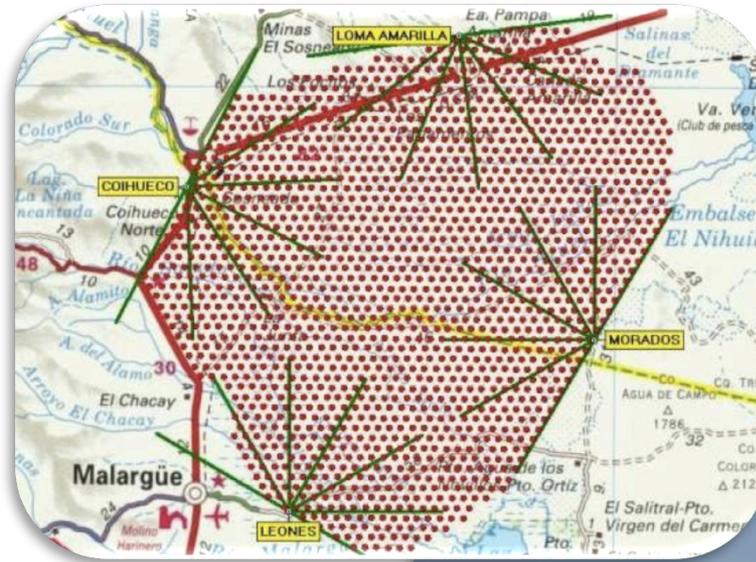
- Simplification:

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

- Asymmetry confirmed with LOPES, CODALEMA experiments
- Full story is actually more complicated...

# Pierre Auger Observatory

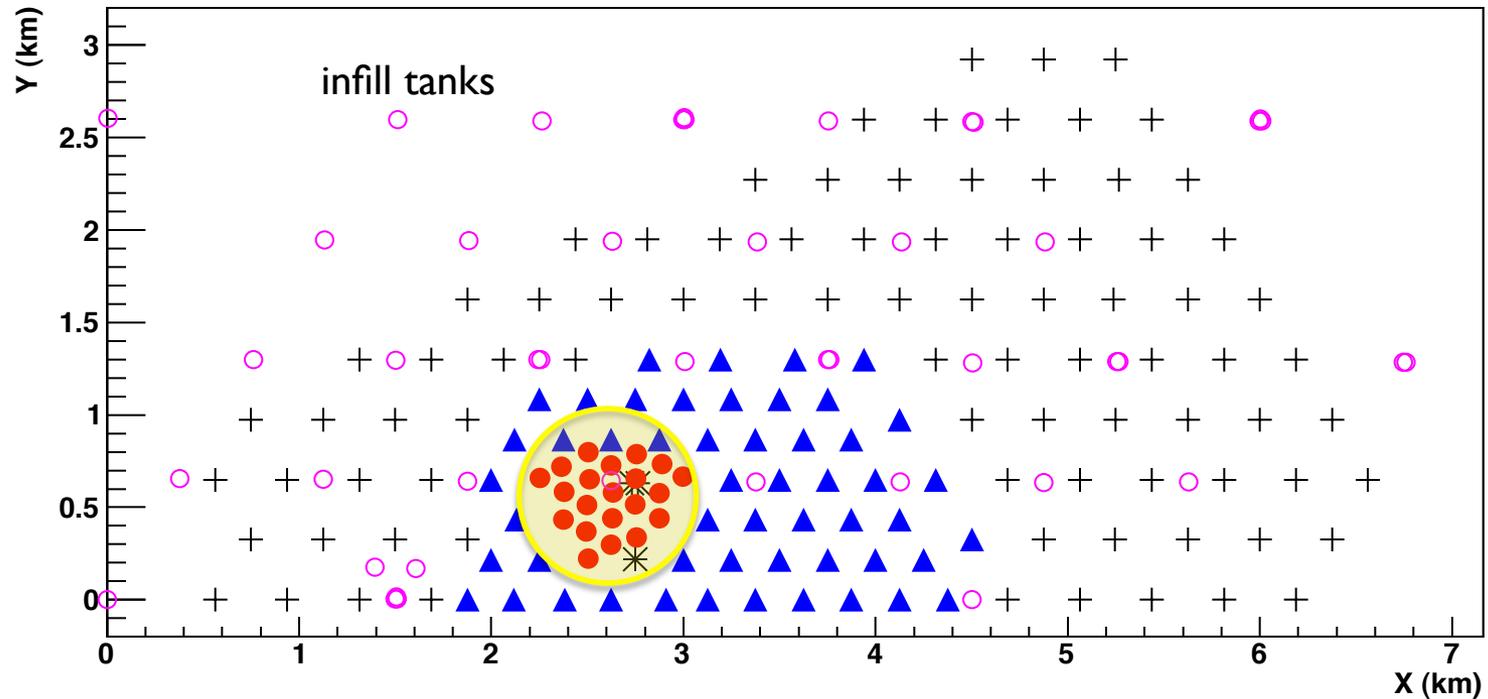
- Hybrid cosmic ray air shower detector
- Southern site (3000 km<sup>2</sup>) in Argentina completed 2008
- Energy threshold:
  - $E > 10^{18}$  eV full array
  - $E > 10^{17}$  eV infill array



Auger South

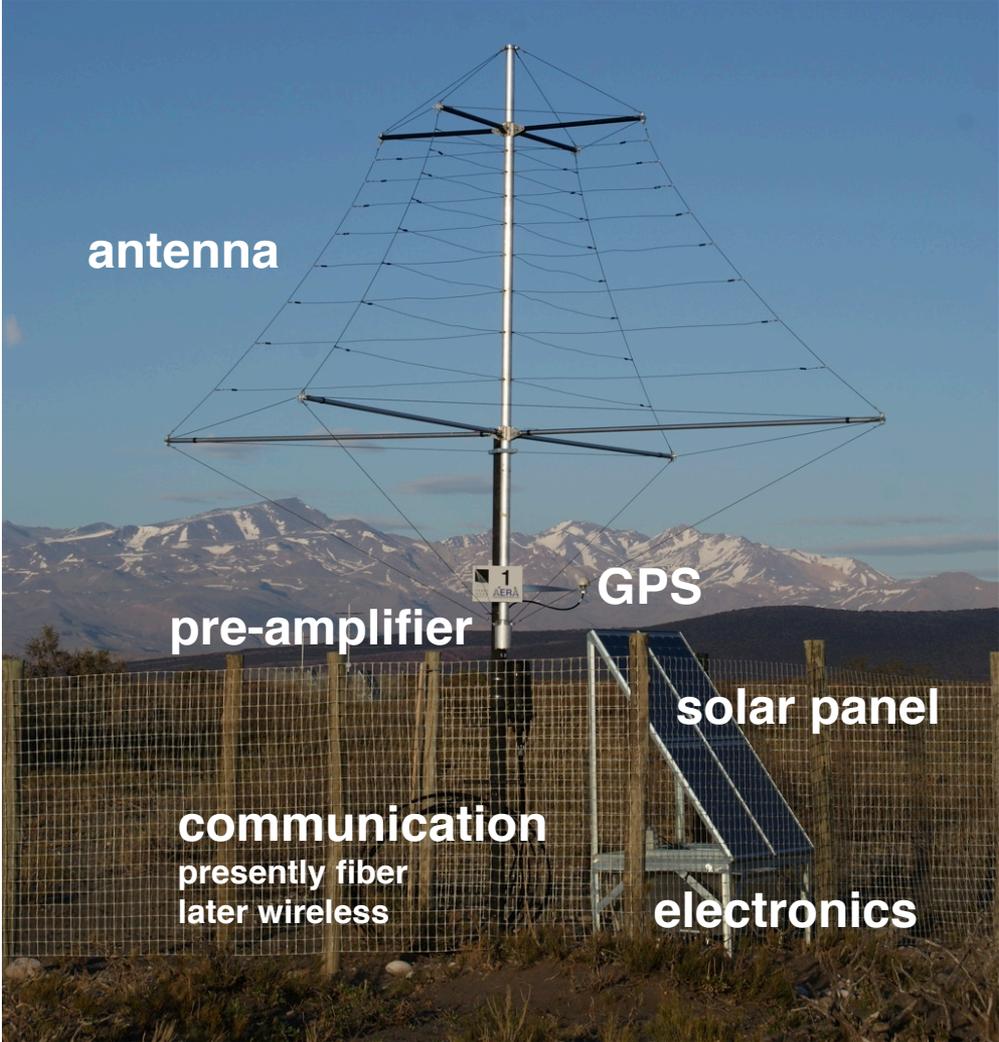


# Auger Engineering Radio Array



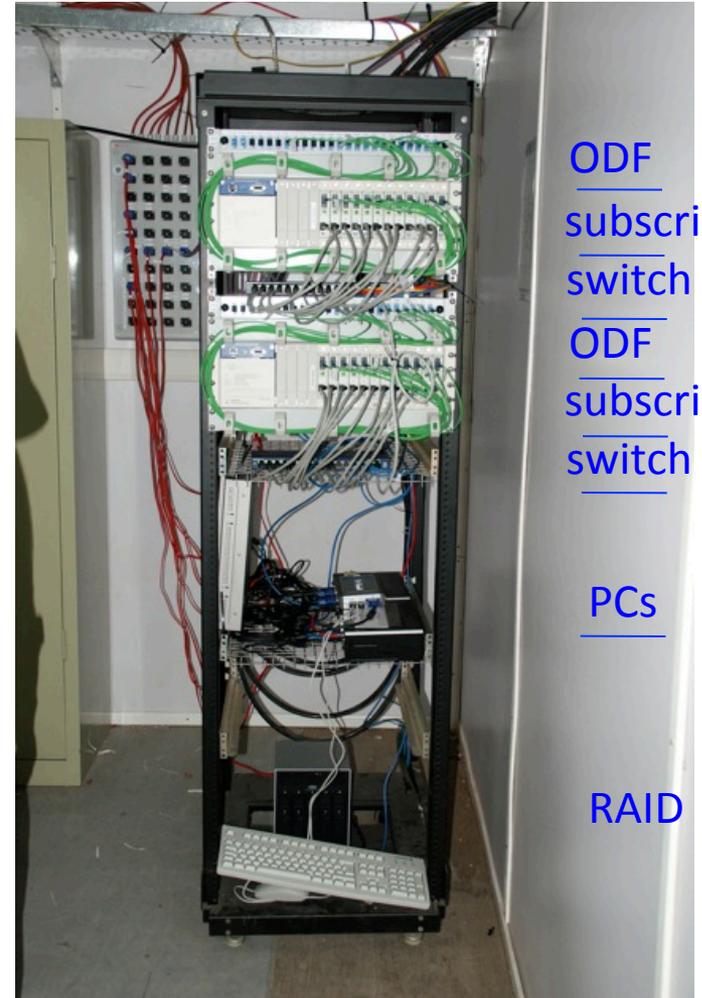
- 20 km<sup>2</sup> extension to southern site: 160 radio detector stations
- 2010-11: deployed dense core (23 stations)

# AERA Station



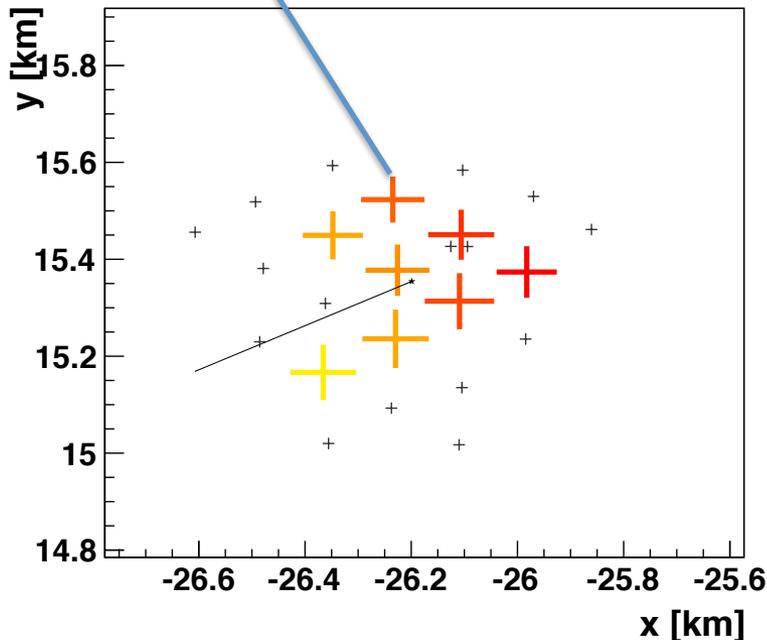
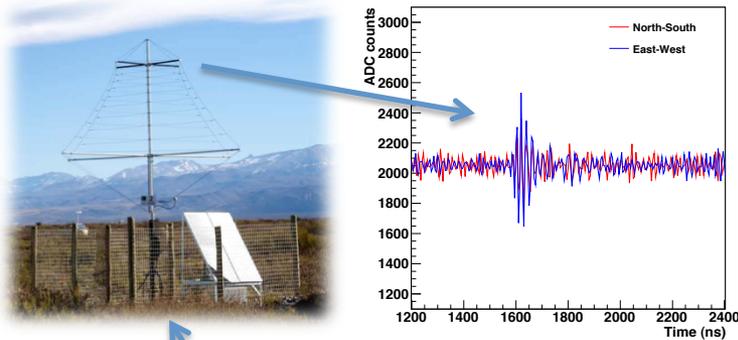
# Central DAQ Container

---



ODF  
subscribers  
switch  
ODF  
subscribers  
switch  
PCs  
RAID

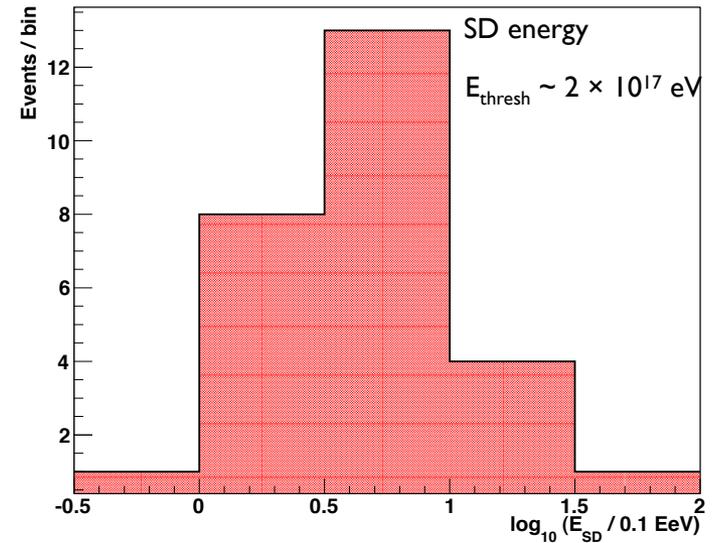
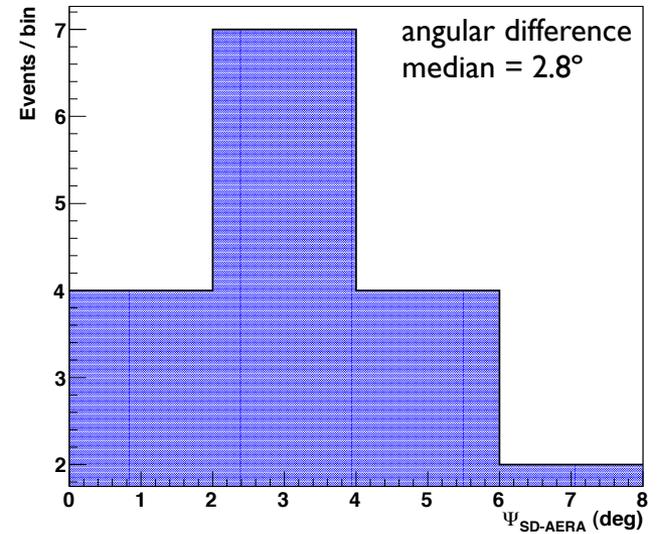
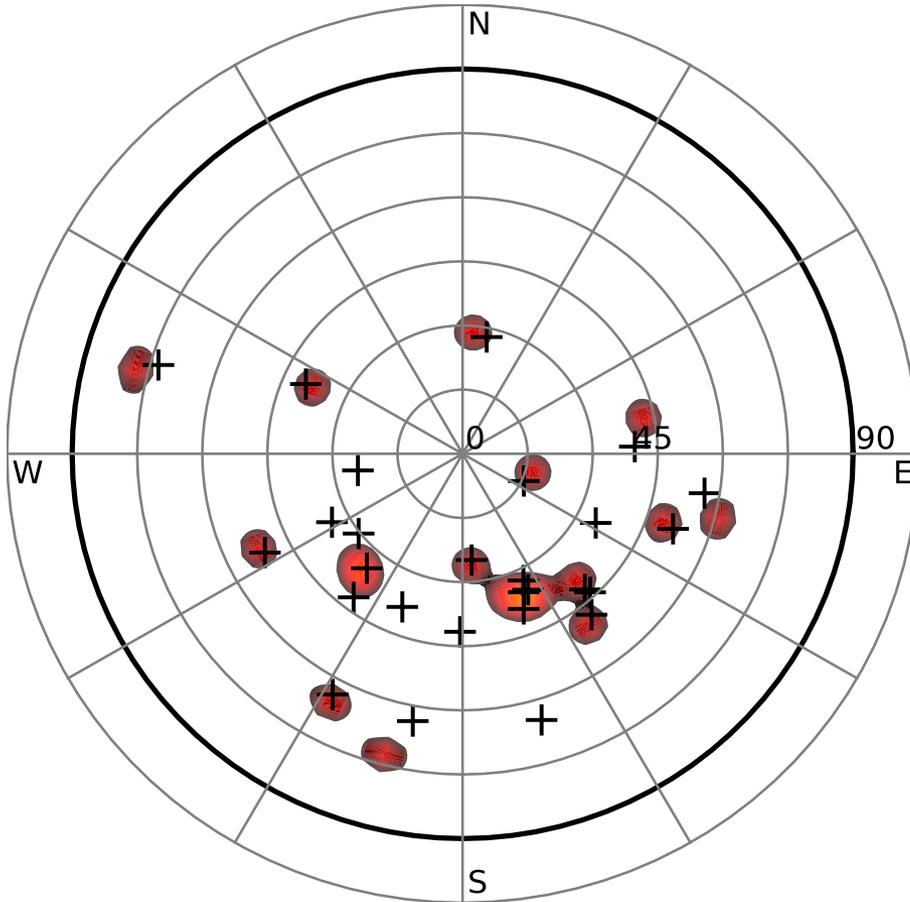
# Hybrid Self-Triggered Cosmic Rays



- First hybrid cosmic ray detections in mid-April  
– coincidences with SD
- First super-hybrid event at end of April  
– radio, SD, and FD

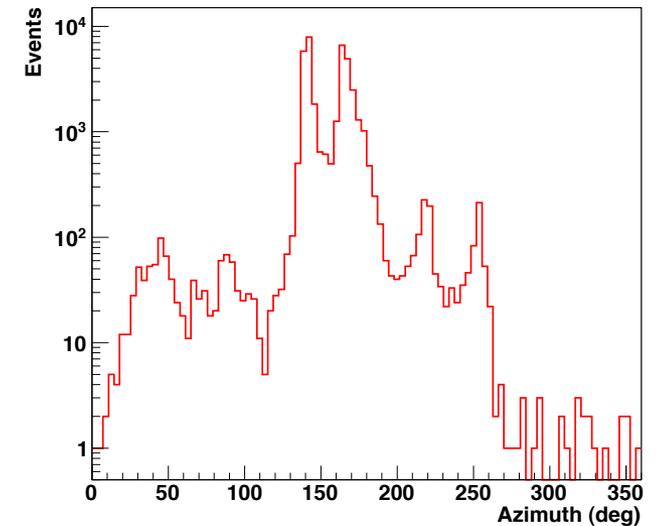
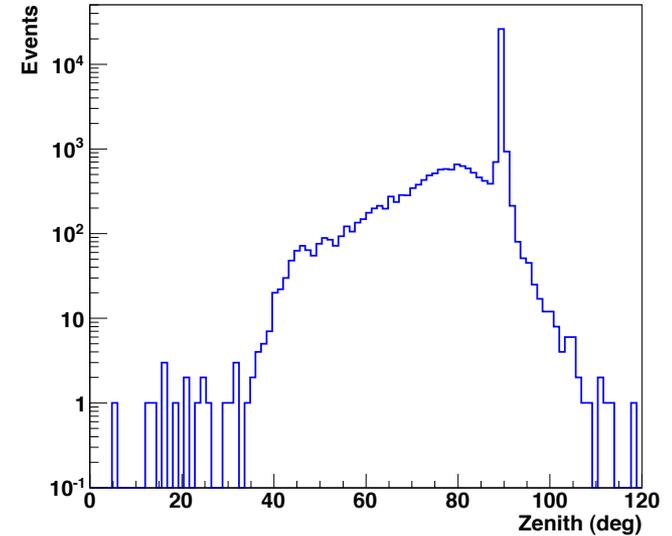
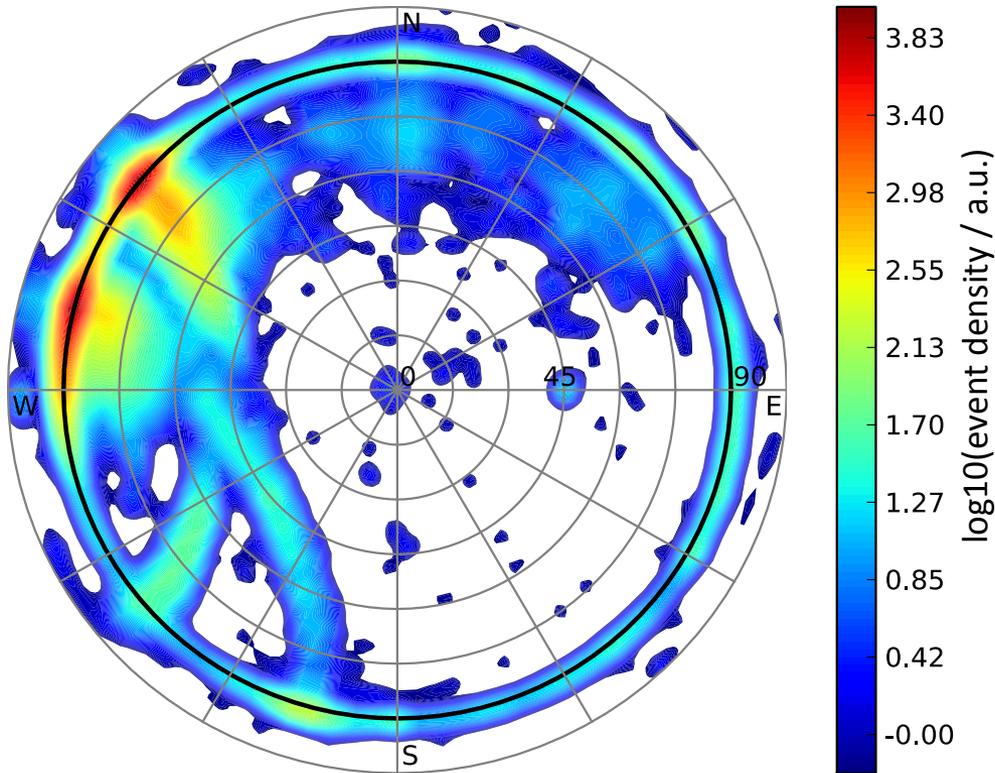
# Hybrid Events

27 events: 0.3 to 0.9 per day



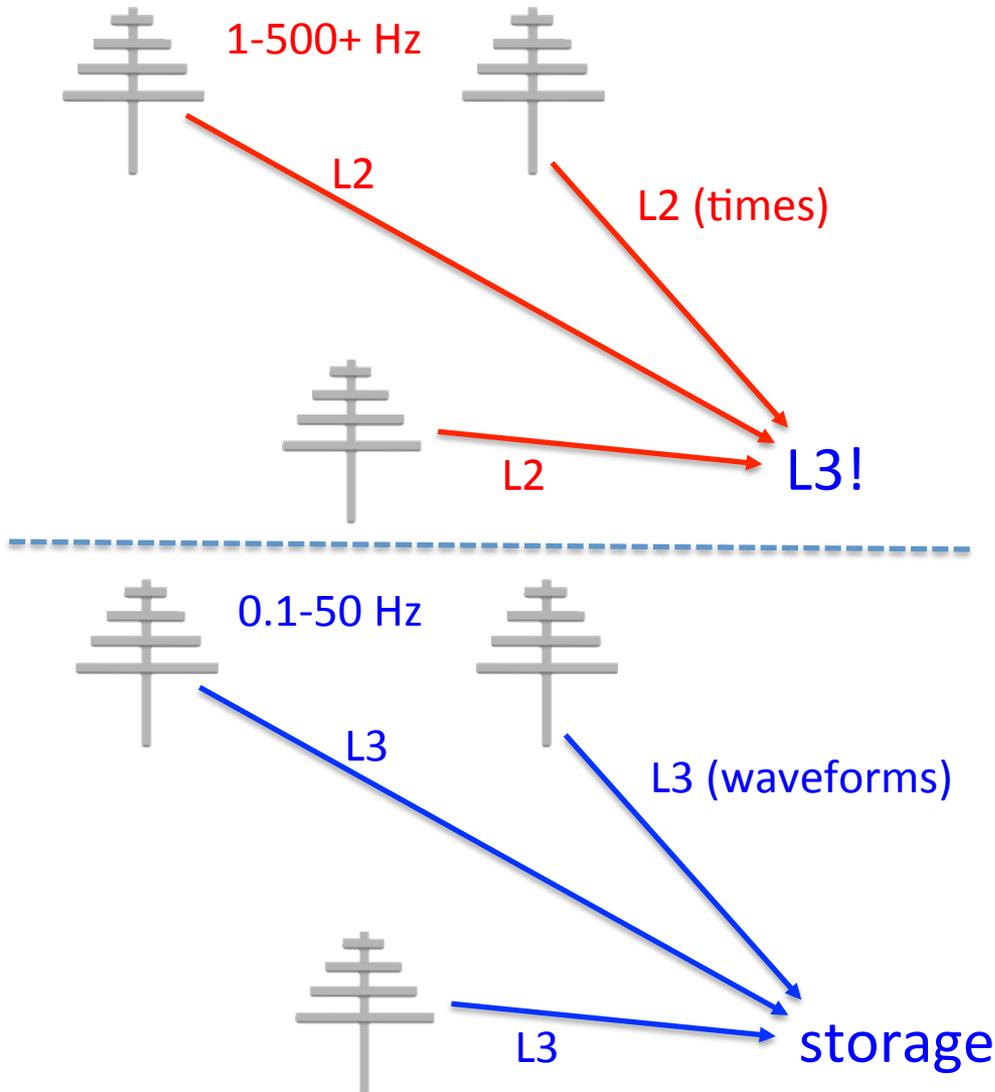
# Raw Data (2.5 hours)

Run 2116 : GPS 16 Mar 2011 17:30:12 - 19:51:48 (39617 events)



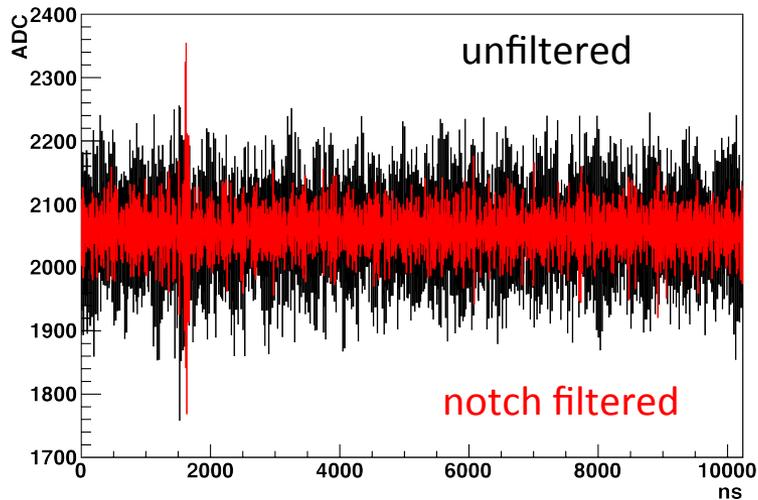
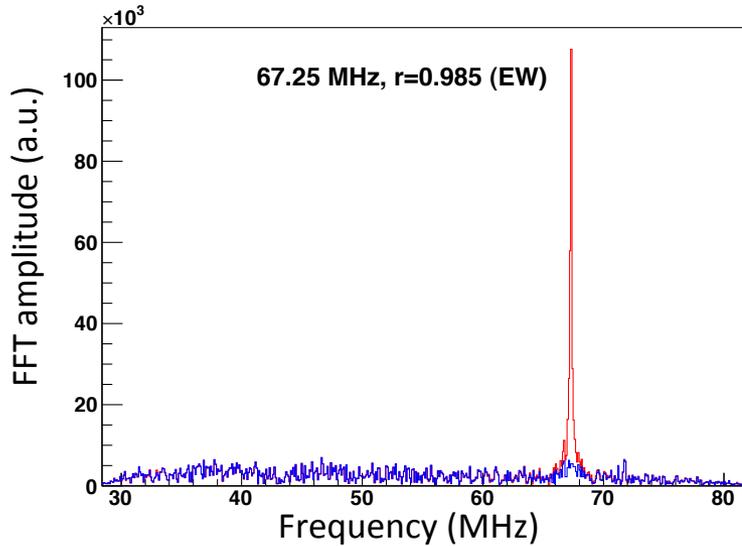
“Level 3” trigger rate: 0.1-50 Hz  
Compared to coincidence rate:  $10^6$  to  $10^7$ !

# DAQ Topology



- L1: low-level station trigger (FPGA)
- L2: high-level station trigger (CPU)
  - send timestamps to central DAQ
- L3: multi-station coincidence (central DAQ)
  - request event waveform data from stations
- At each stage: opportunity for filtering / data reduction

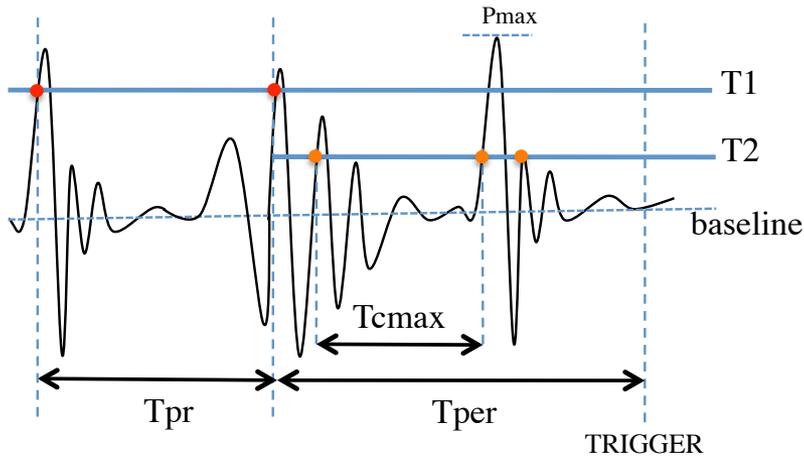
# Level I: Increase Signal-to-Noise



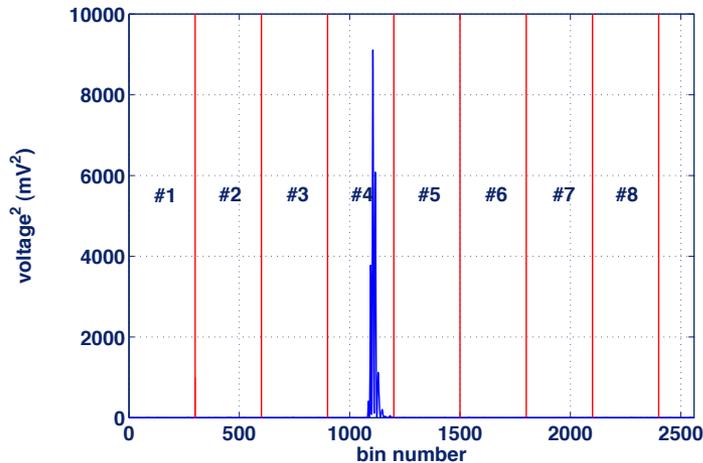
- Remove narrowband transmitters
- IIR notch filter **implemented**
- Median filter (FFT + rolling median + iFFT) **implemented**
- Matched filter **development**

$$\text{transfer } H(f) = \frac{\text{signal } |S(f)|^2}{\text{noise } |N(f)|^2 + |S(f)|^2}$$

# Level I: Smart Trigger

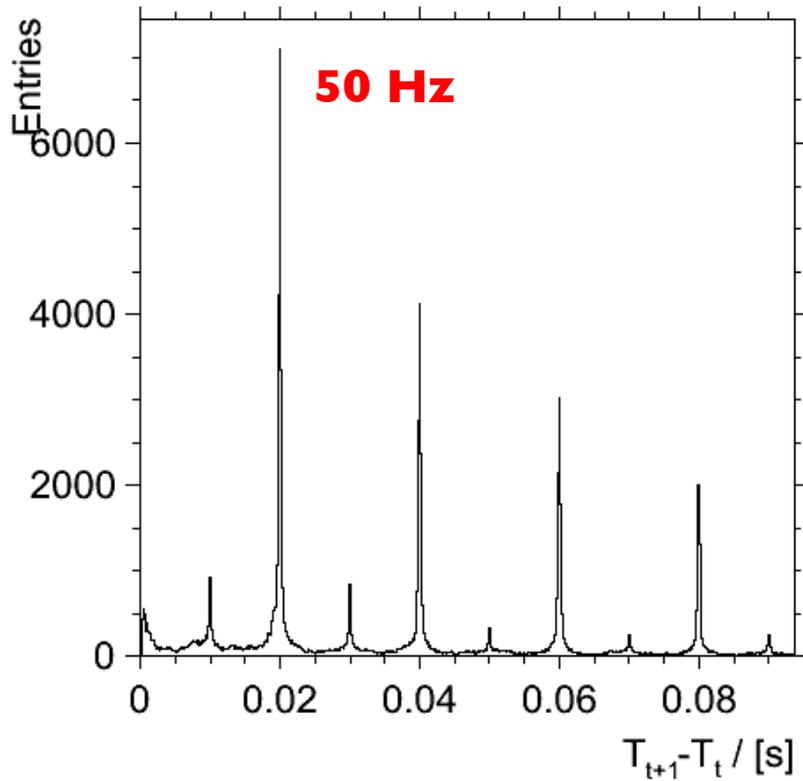


- Eliminate non-bandwidth-limited pulses
- Second “noise threshold” implemented
- Integrated power in time windows development

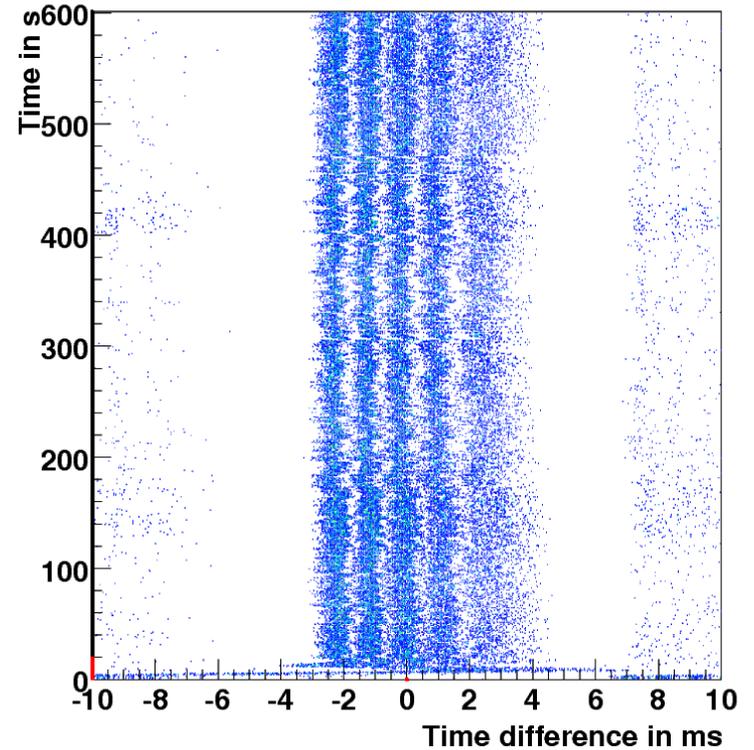
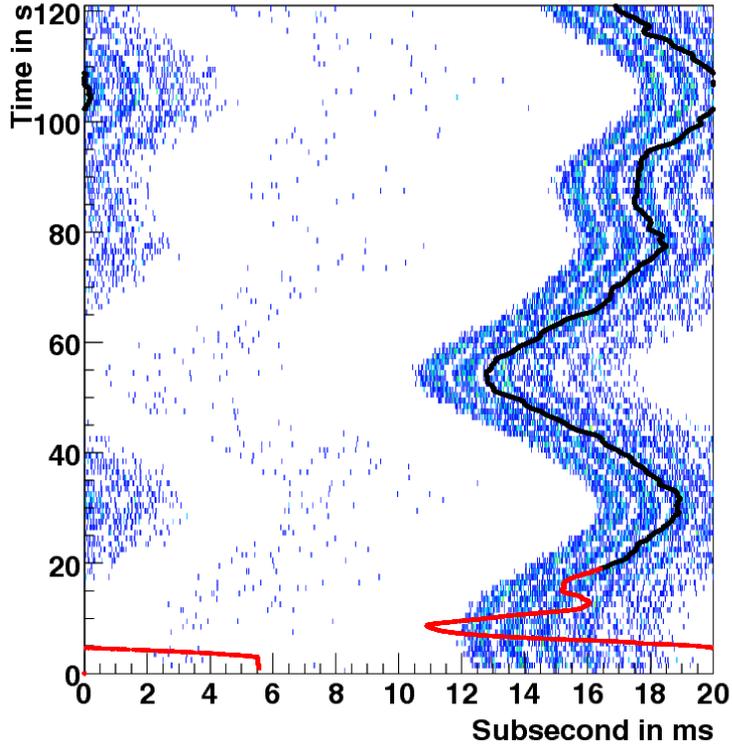


$$E_k = \sum_{i=1}^{300} v_i^2$$

# Periodicity as Noise Indicator



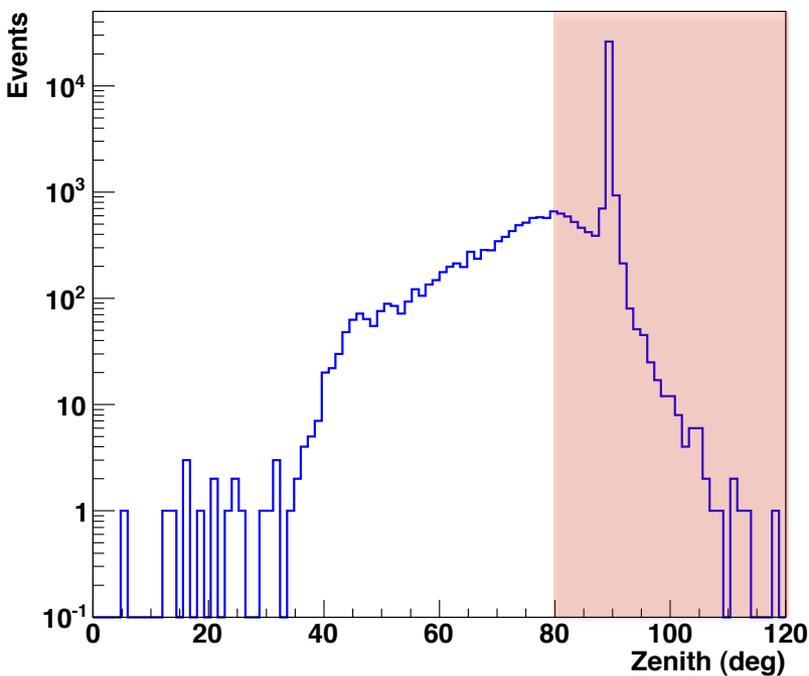
# Level 2: Periodic Veto



Track 50 Hz drift (power line load) with digital PLL

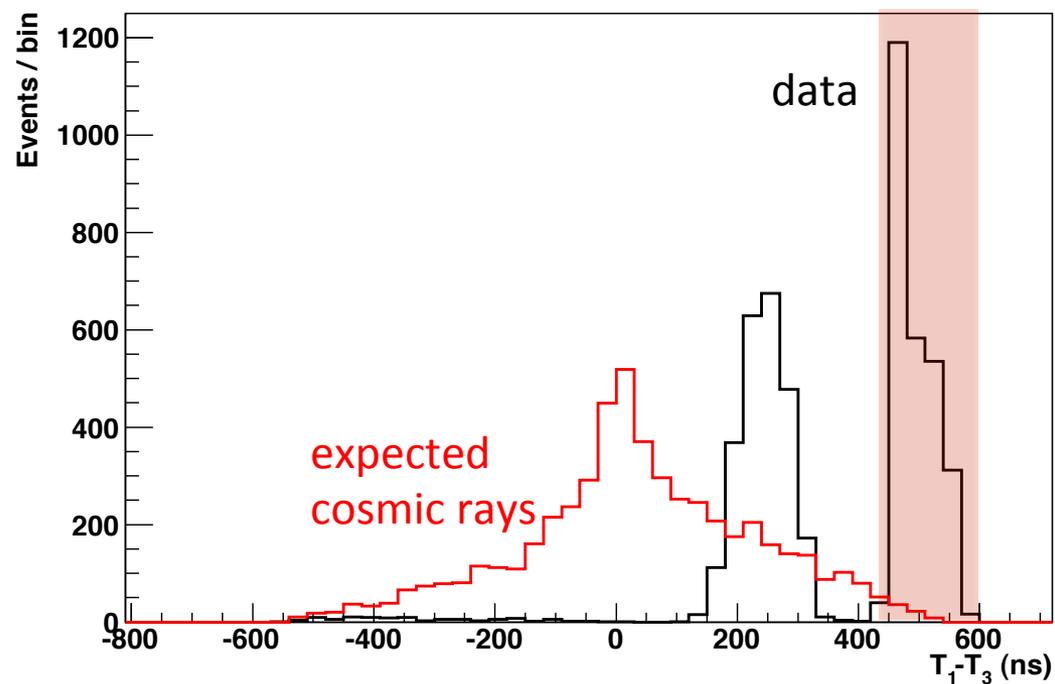
field testing

# Level 3: Direction



Full directional reconstruction:  
veto hotspots or entire horizon

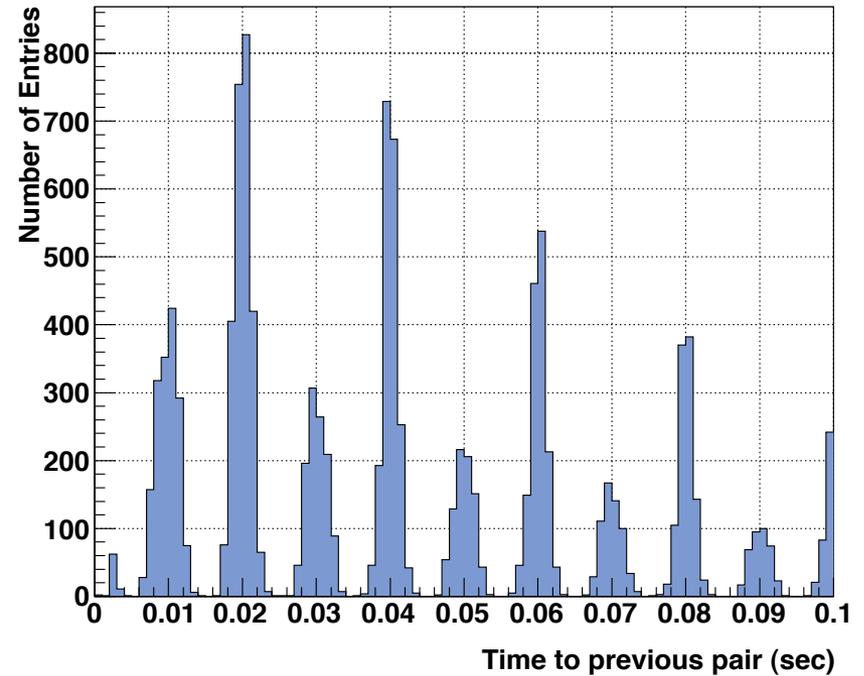
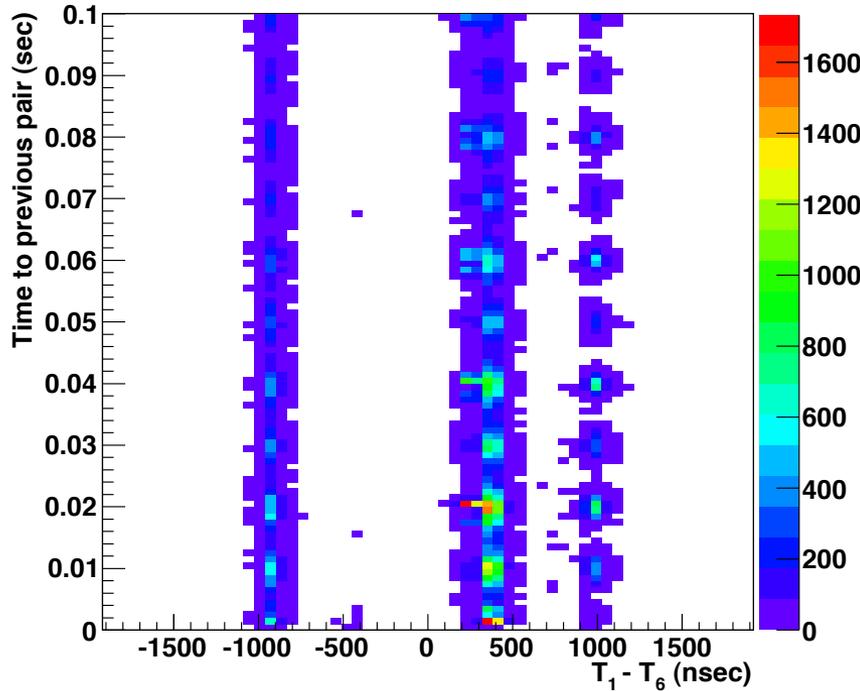
implemented



Trigger time pairs: can still veto hotspots

implemented

# Direction and Periodicity

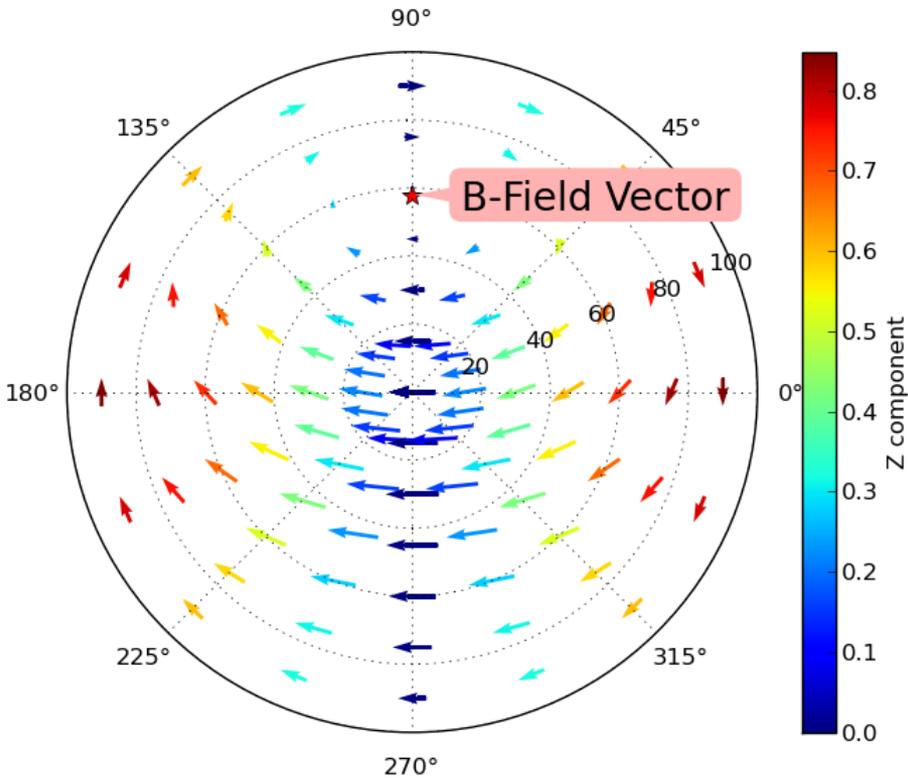


Combine time-pair hotspots and 50 Hz information!

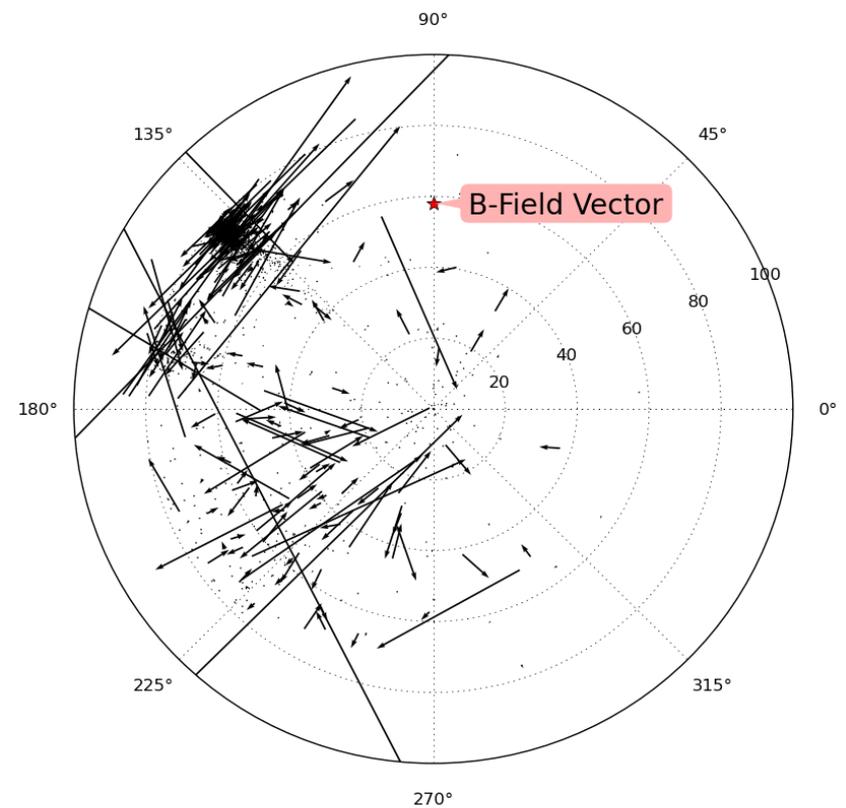
development

# Polarization for Offline Event Selection

development



predicted for pure geomagnetic emission



man-made noise

# Communications Development



- Fiber too expensive: need low-power, medium- to high-bandwidth wireless

- Fully custom TDMA wireless
  - 5.5 Mbit/s, 2.5W
  - 180 subscribers / sector
  - can optimize protocol to DAQ

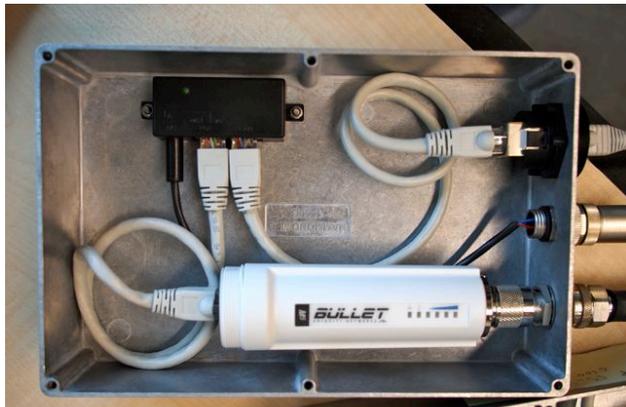
field testing

- Commercial 802.11n + TDMA
  - 150 Mbit/s, 3W
  - 80-100 subscribers / sector (?)
  - no access to MAC layer

field testing

- Distributed protocol design
  - stations find coincidences themselves

development



# Summary

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- Radio detection of air showers is maturing
  - a number of cosmic ray and neutrino experiments actively exploring radio
  - super-hybrid observations underway
  - challenges for data acquisition and background rejection
- But... many ways to distinguish air showers from man-made noise
  - pulse characteristics
  - periodicity / direction
  - polarization
- Solutions will get us to a large-scale radio air shower array!

A landscape photograph showing a radio telescope array in the foreground, consisting of several tall masts with horizontal arms. The array is situated in a field of dry, brownish vegetation. In the background, there are large, rugged mountains with significant snow cover. The sky is a pale, hazy blue, and a full moon is visible in the upper right quadrant. The overall scene is captured during the "blue hour" of twilight.

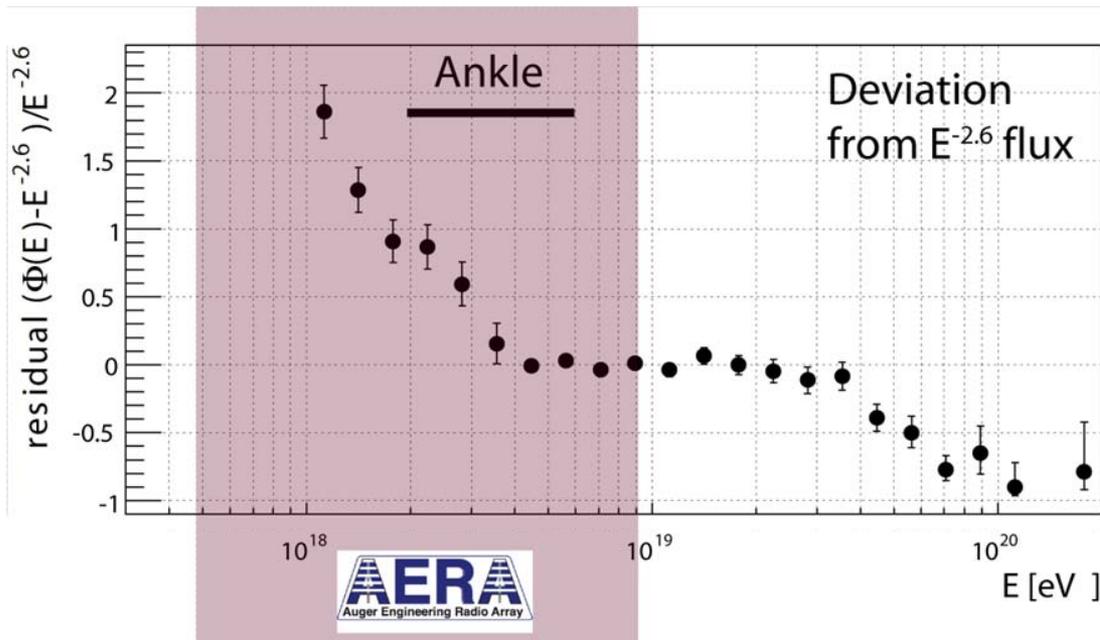
Thank you!

14.10.2011

J. Kelley, VLVnT11

# Backup slides

# AERA Physics Program



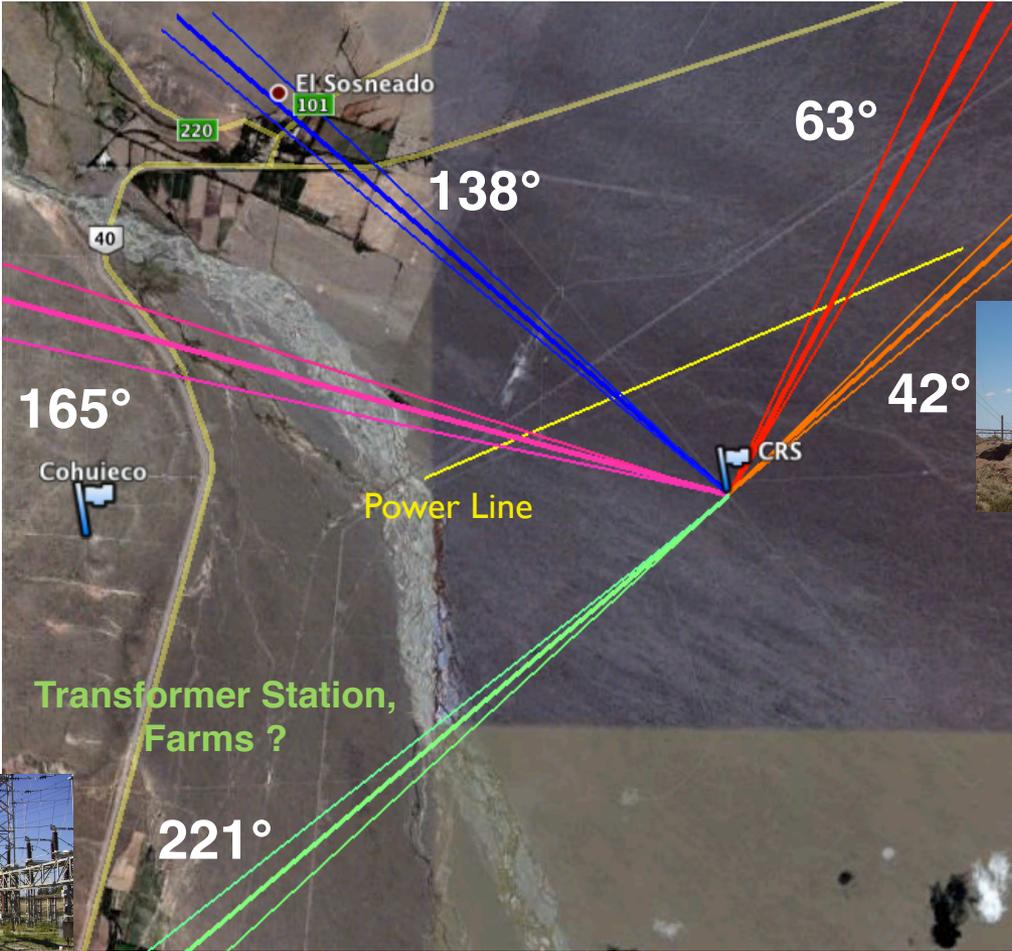
1. Full understanding of all radio emission mechanisms
2. Potential of radio technique for primary energy and mass determination
3. Composition of ankle region; understanding Galactic to extra-galactic transition
4. ... scale up!

# Direction of Noise Sources

El Sosneado, Communication Tower ?

Farms, Oil ?

???



El Diamante ?



Antennas at El Diamante

