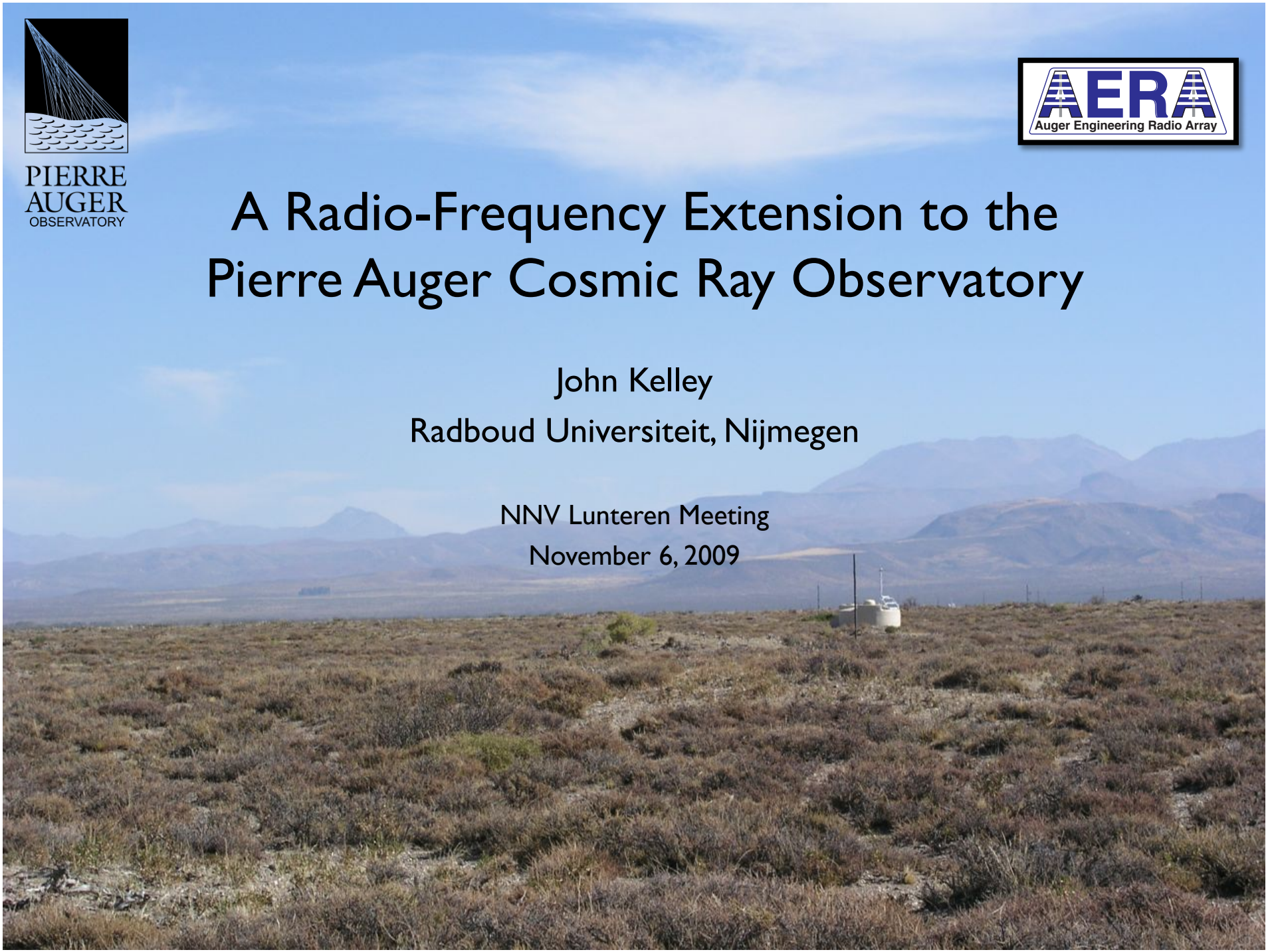


A Radio-Frequency Extension to the Pierre Auger Cosmic Ray Observatory

John Kelley

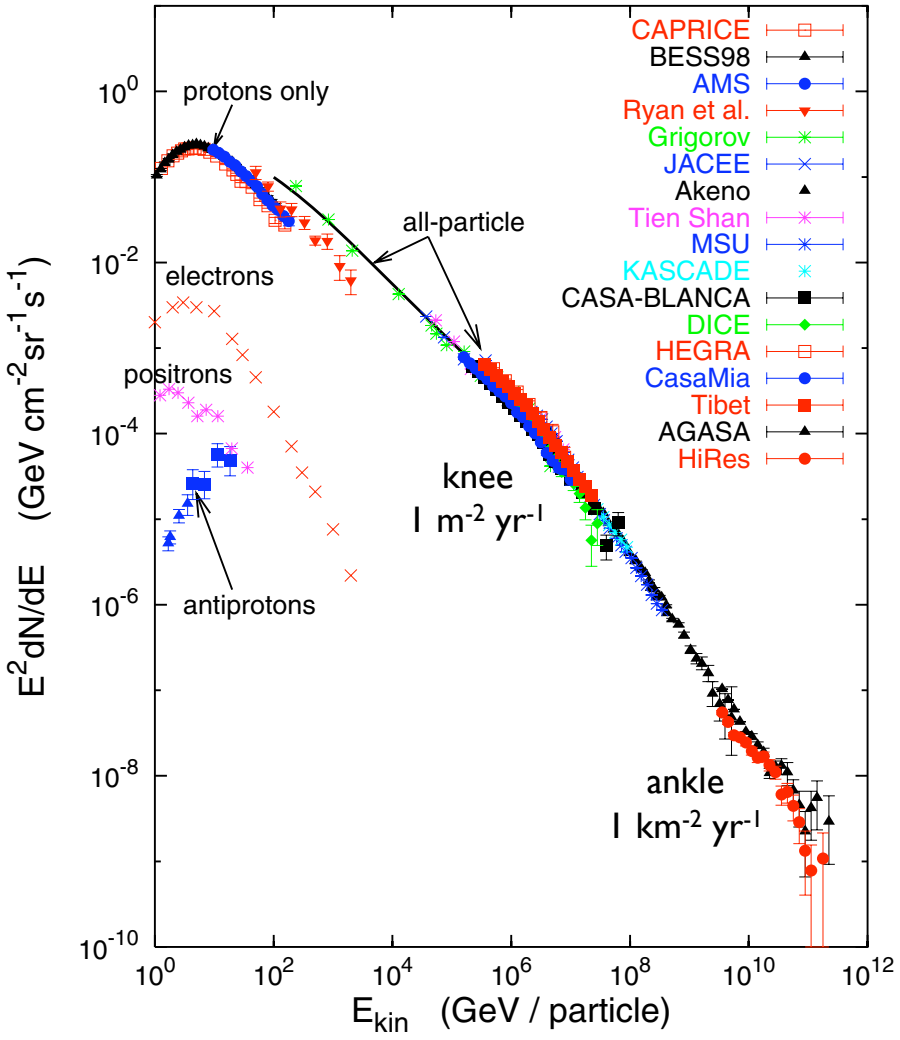
Radboud Universiteit, Nijmegen

NNV Lunteren Meeting

November 6, 2009

Cosmic Ray Spectrum

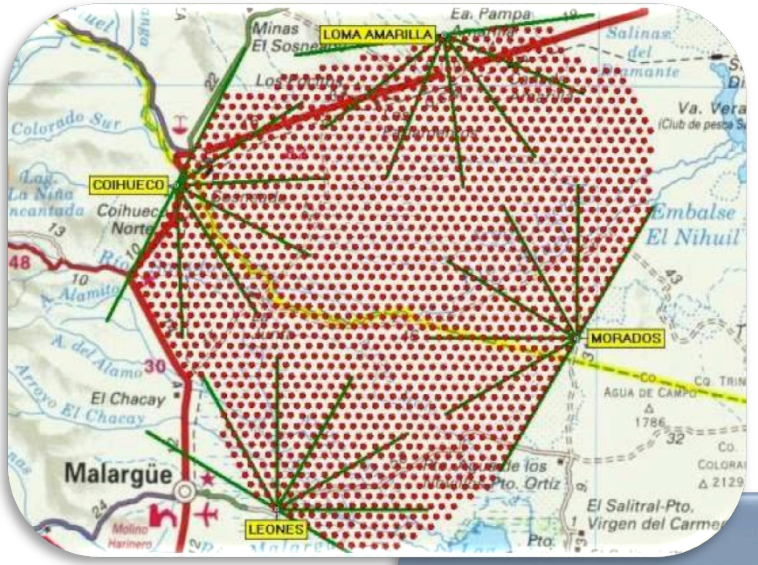
- Charged particles with steep power law spectrum
- Low flux at high energy: detect via extensive air showers
- "Ankle": transition from galactic to extragalactic sources?
- Composition: protons vs. heavy nuclei?



Gaisser 2004

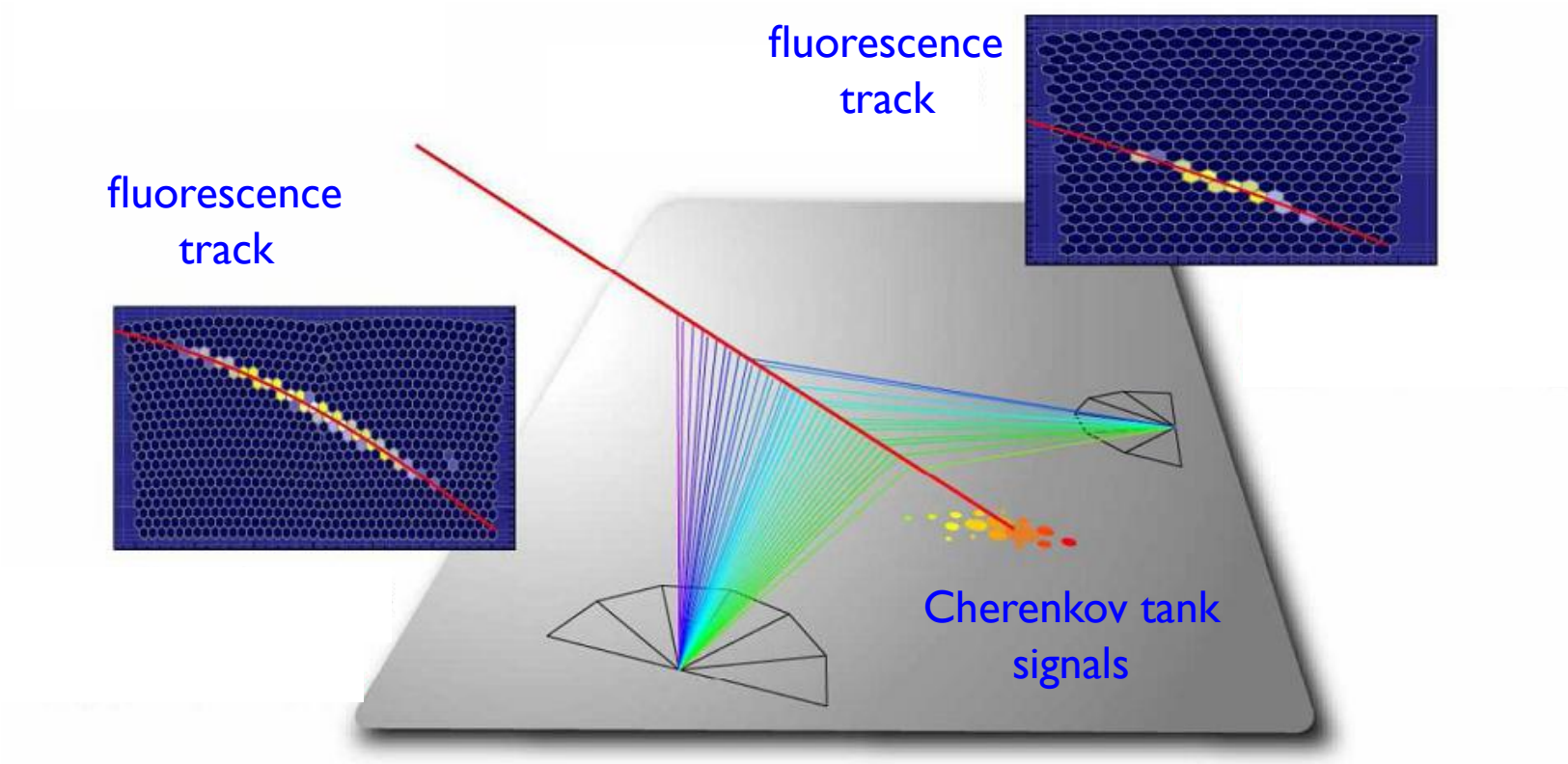
Pierre Auger Observatory

- Hybrid air shower detector
- Southern site (3000 km^2) in Argentina completed 2008
- Northern site (21000 km^2) planned for Colorado, U.S.A.



Auger South

Hybrid Detection

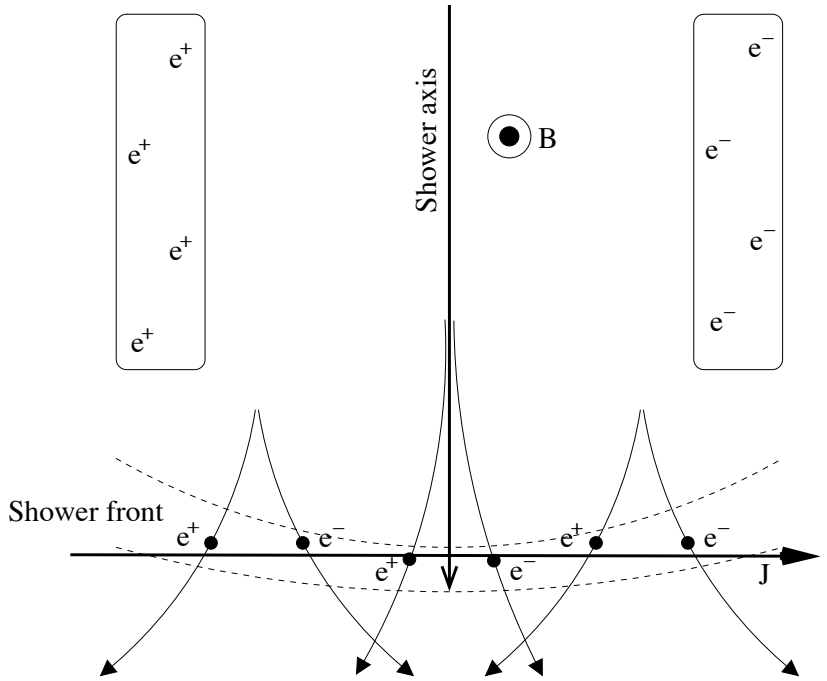


Hybrid observation: powerful, but duty cycle of fluorescence detectors ~10%

Further enhance array with a high duty cycle, calorimetric detection method…

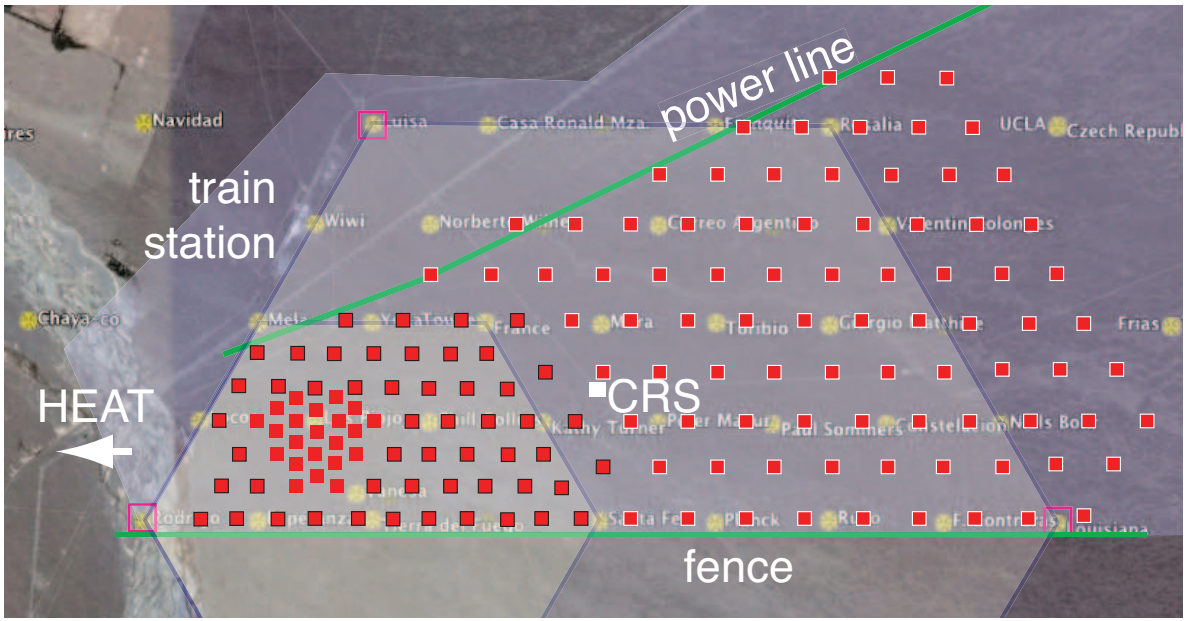
Radio Emission from Air Showers

- Separation, acceleration of e^+, e^- in geomagnetic field
  - secondary: charge excess, moving dipole
- Broadband radio pulse (width ~50 ns)
- Emission is coherent up to 100 MHz
  - RF power scales as $(E_{primary})^2$
- Observed by LOPES, CODALEMA, MAXIMA detectors
  - geomagnetic asymmetry verified
  - larger experiment needed to verify details of emission



Auger Engineering Radio Array

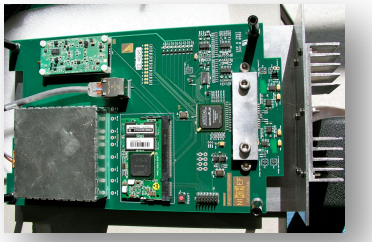
- AERA: Auger Engineering Radio Array
- 20 km^2 extension to southern site (at infill array)
- Phase I: 25 stations, early 2010 (total: 150)



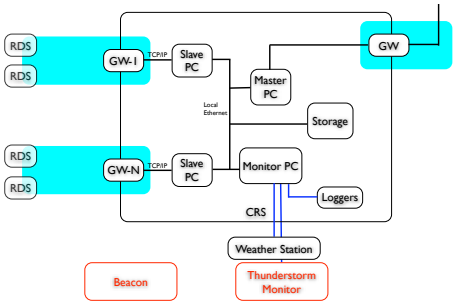
Radio Detection Station

- Autonomous, solar power
- LPDA antenna, 30-80 MHz bandpass
- Local digitizer and trigger
- Multi-station coincidence via central DAQ

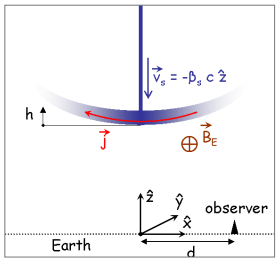
AERA Netherlands Activities



Digital Electronics

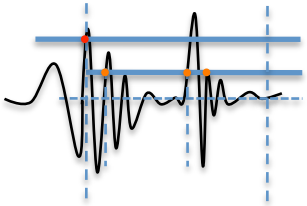


DAQ



Theory & Simulation

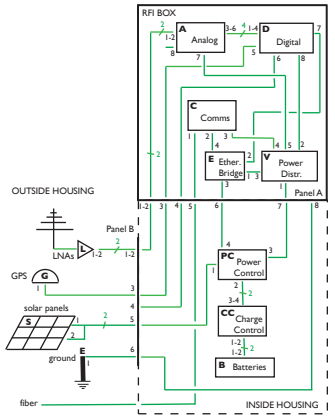
talk by Krijn de Vries



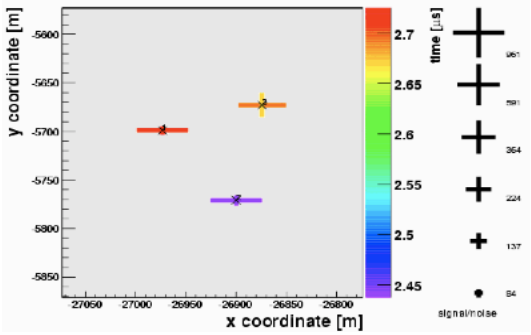
Self-Triggering

talk by Stefan Grebe

PV System

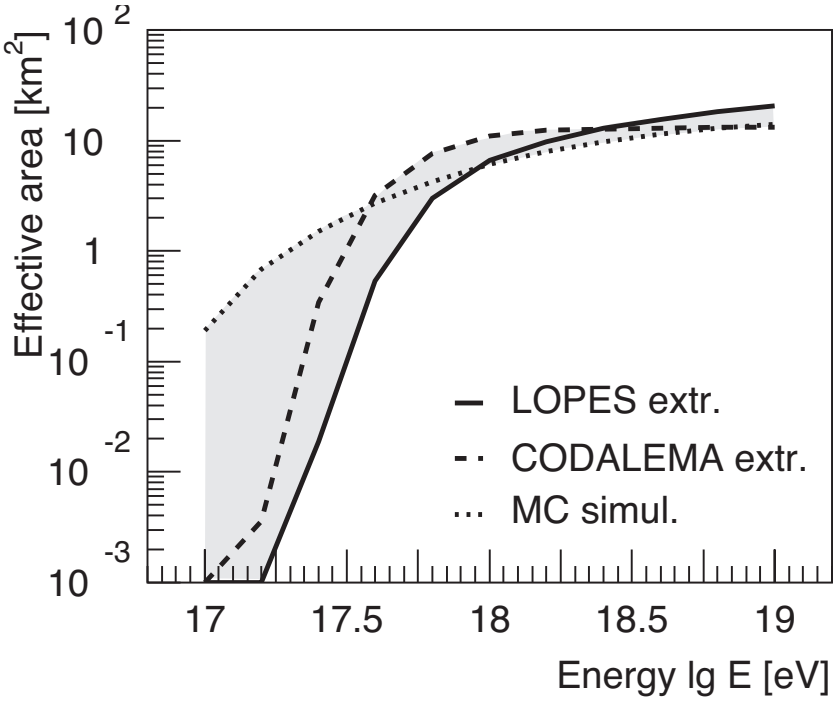


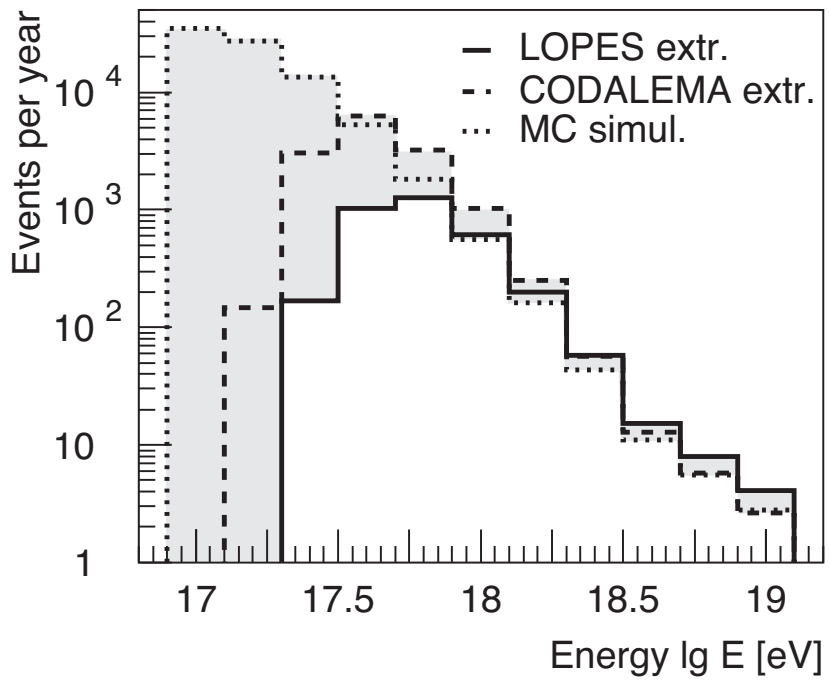
System Integration



Reconstruction

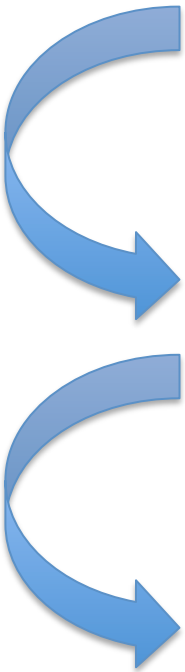
Expected Event Rates





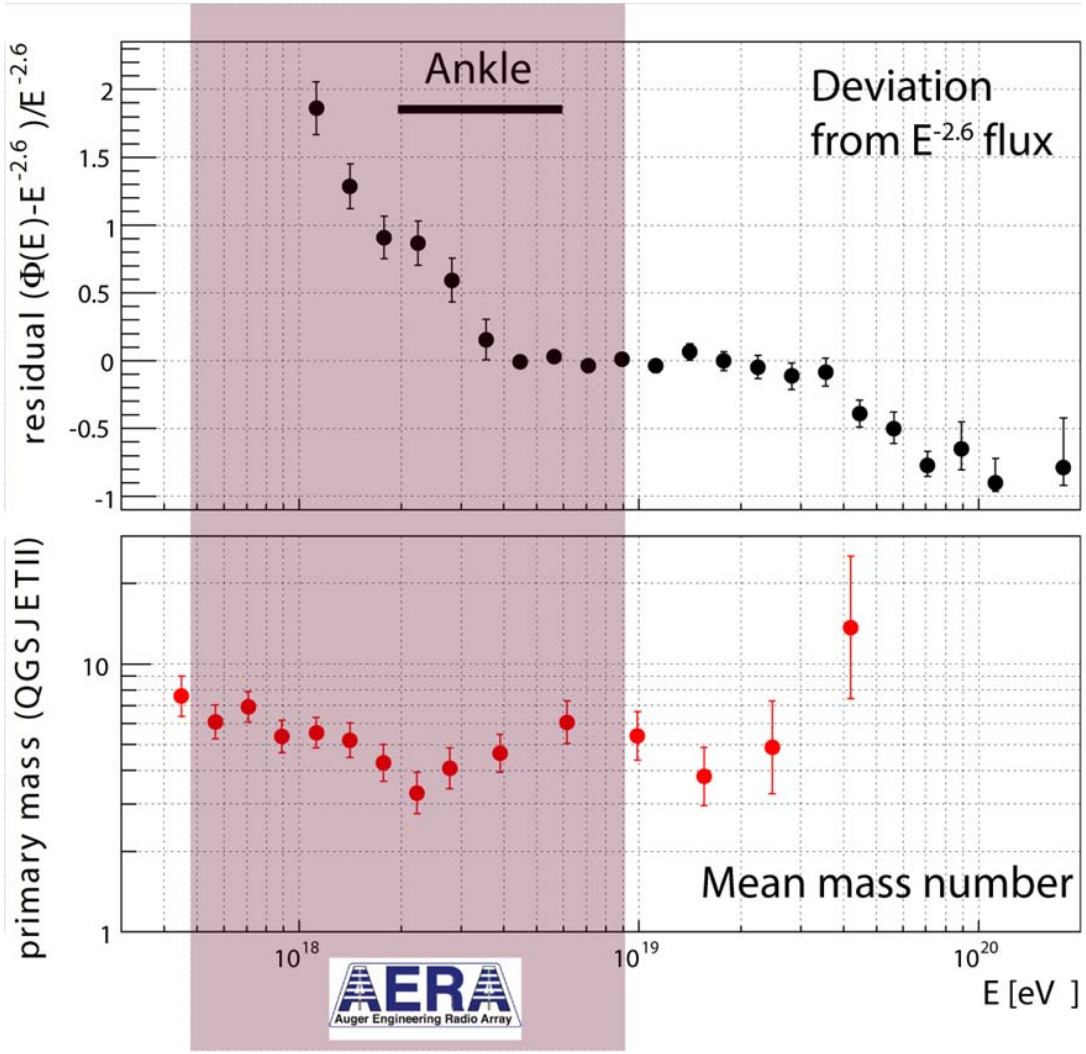
~5000 events / year with E > 3 x 10^{17} eV
~800 events / year with E > 1 x 10^{18} eV

AERA Science Program



- Detailed calibration of radio signal
  - self-triggering
  - coincidences with other Auger components
  - full understanding of all RF emission mechanisms
- Resolution of radio technique
  - energy and direction
  - composition via shower maximum, lateral distribution
- Composition of ankle region
  - galactic to extra-galactic transition
  - super-hybrid measurements

AERA Physics



Radio will open a new window onto cosmic ray physics!

Thank you!

Czech Republic	Argentina
France§	Australia
Germany§	Brazil
Italy	Bolivia*
Netherlands§	Mexico
Poland§	USA
Portugal	Vietnam*
Slovenia	
Spain	
United Kingdom	

PIERRE AUGER OBSERVATORY

*Associate Countries

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S. J. de Jong
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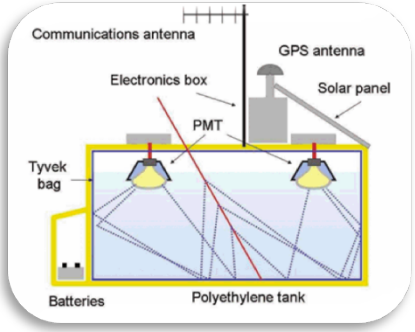
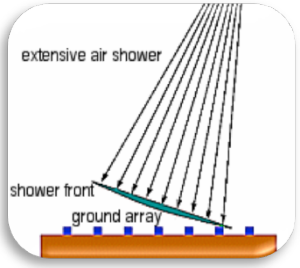
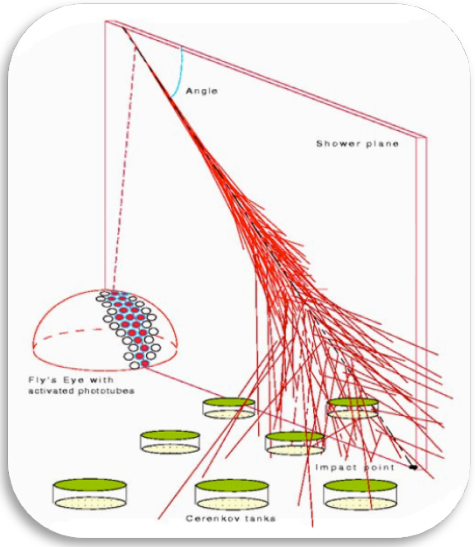
H. Schoorlemmer

Air Shower Detection

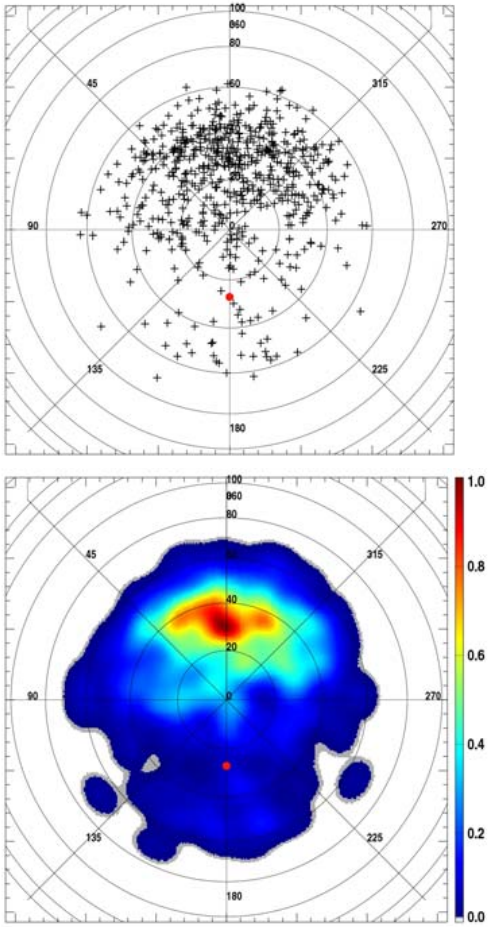






- Water (or ice) Cherenkov tanks
  - detect EM shower front on ground
  - near-100% duty cycle
- Fluorescence telescopes
  - follow Nitrogen fluorescence as shower develops
  - good for calorimetry, measurement of shower maximum (particle ID)
  - duty cycle is ~10%

Geomagnetic Origin



Ardouin *et al.* 2009

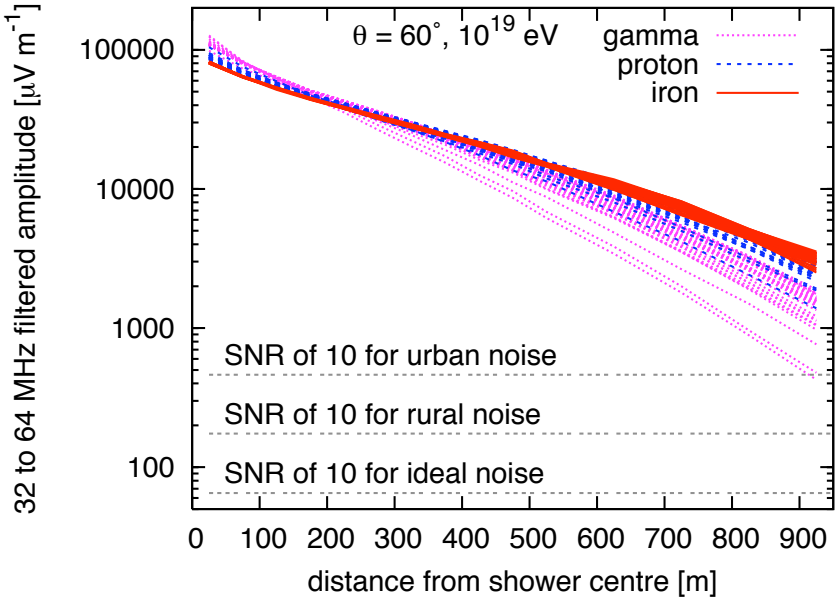
- Simplification: geomagnetic origin implies

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

- Asymmetry confirmed with LOPES, CODALEMA experiments

Composition

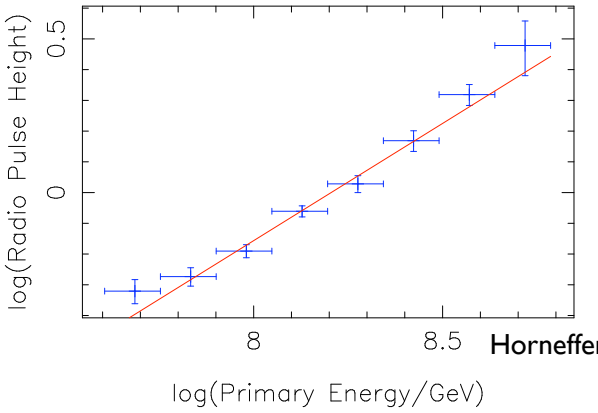
- Primary composition by:
  - lateral distribution
  - reconstruction of shower front curvature
- Simulations only at this point: need larger array, more events!



Huege *et al.* 2008

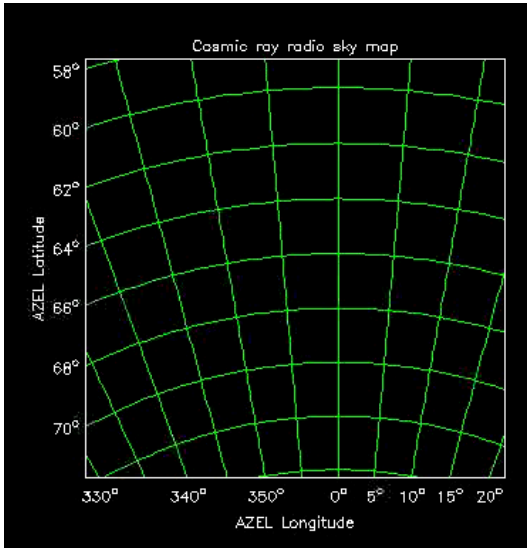
Coherence and Imaging

- Radiation is coherent below ~100 MHz
  - E field ~ primary energy



Horneffer *et al.* 2006

- Offline beam-forming!
  - image radio pulse in 5D: space, time, and frequency
  - angular resolution ~ 1°



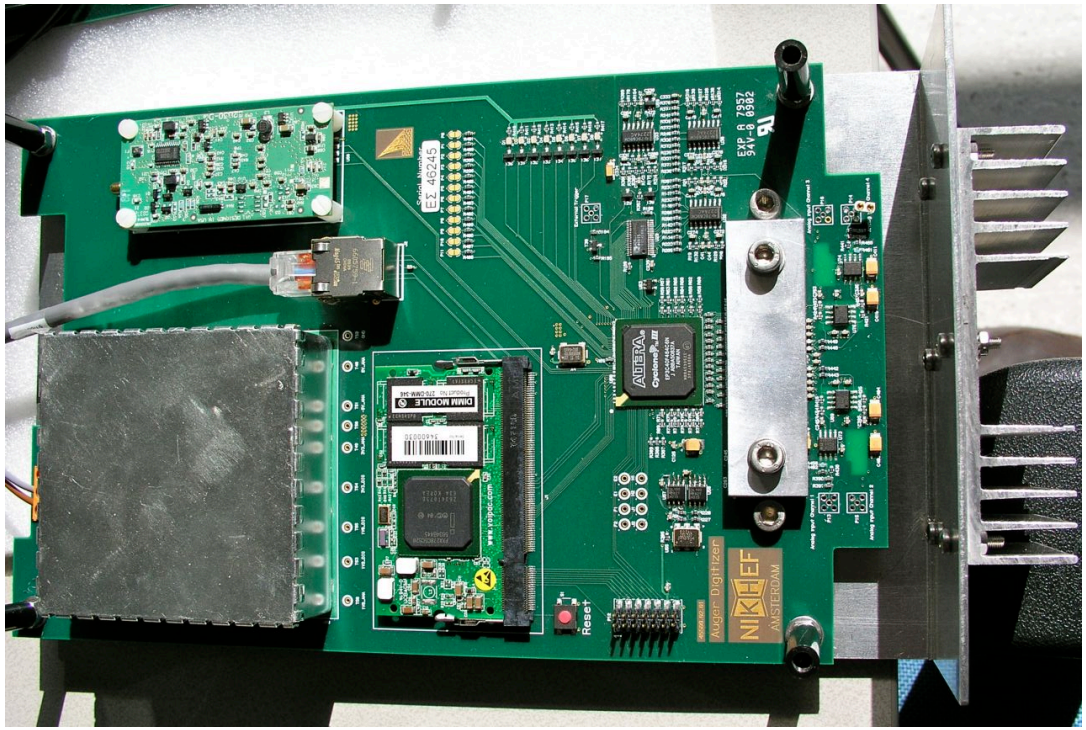
Digital Electronics (NIKHEF and RU)

GPS receiver (timestamping)

Cyclone III FPGA (triggering & readout)

Ethernet (to comms)

DC/DC conv. (shielded)



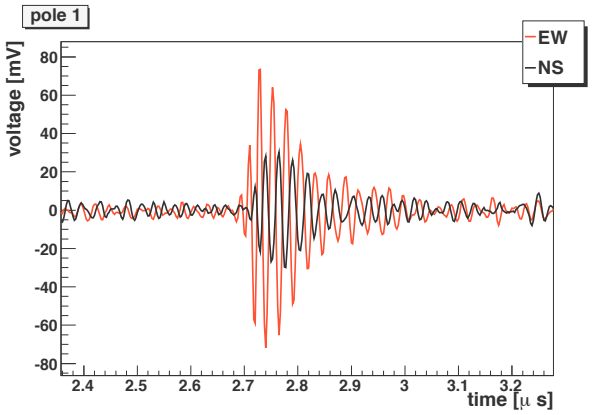
4 channel, 200 MHz ADCs

XScale-based PC board (running Linux)

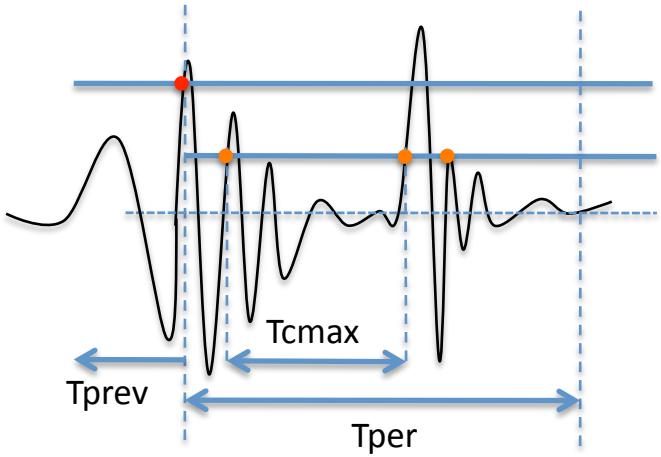
serial interface

Self-Triggering

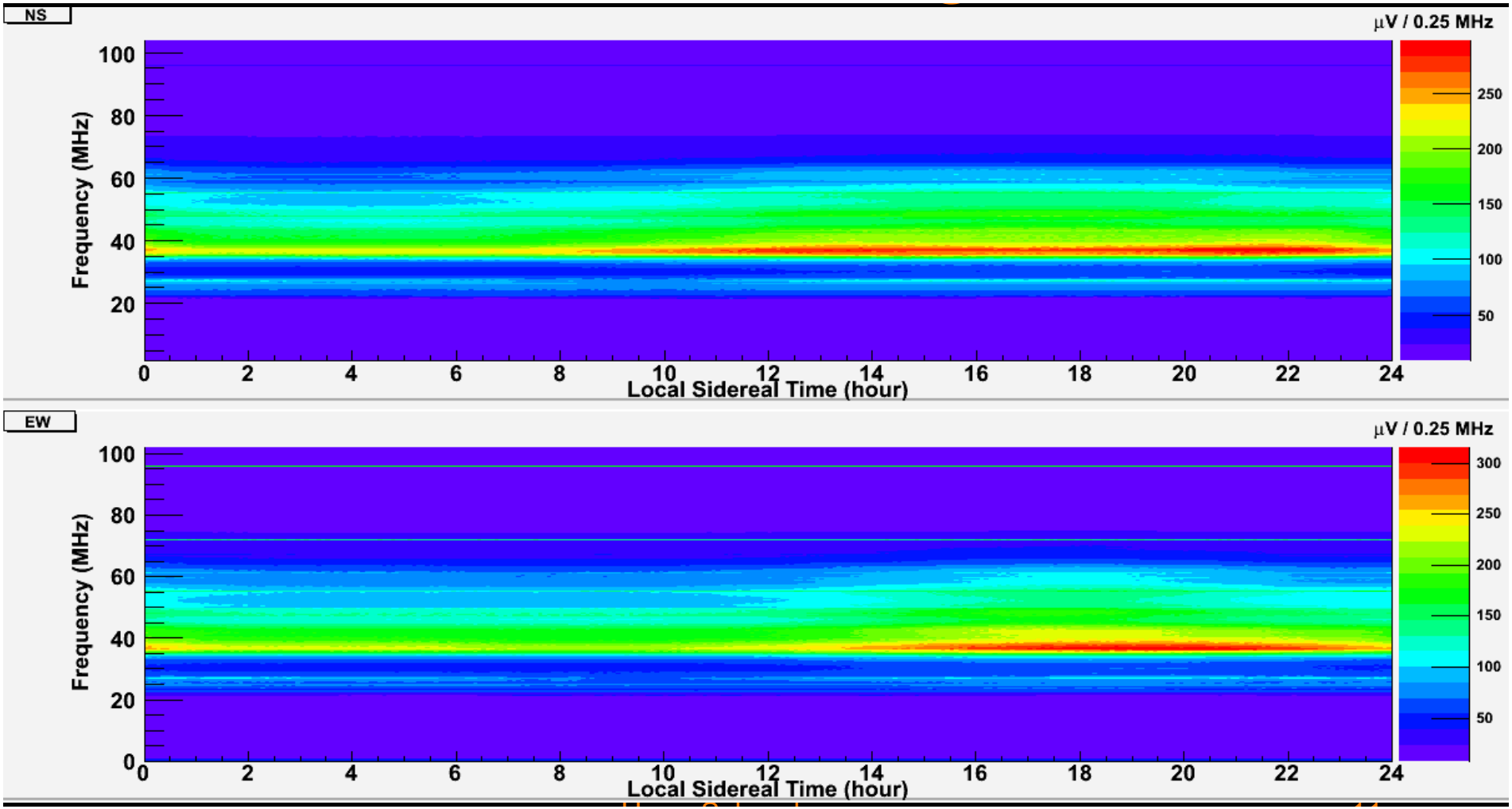
- Technological challenge: impulsive RFI
- Current algorithms focus on time-domain analysis
- New techniques under development:
  - power detection circuit
  - periodic veto (e.g. 50 Hz)
  - wavelet filtering



BW-limited pulse

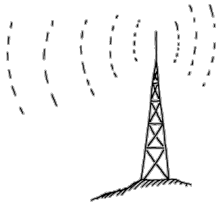


Calibration Techniques (I)



Calibration Techniques (II)

beacon



station (reference)

station

Phase difference from CW beacon (2+ freq.)

O(5 ns) from GPS to sub-nanosecond timing

Also: solar flares, lightning

simulated timing error