Radio Detection of Cosmic-Ray-Induced Air Showers at the Pierre Auger Observatory

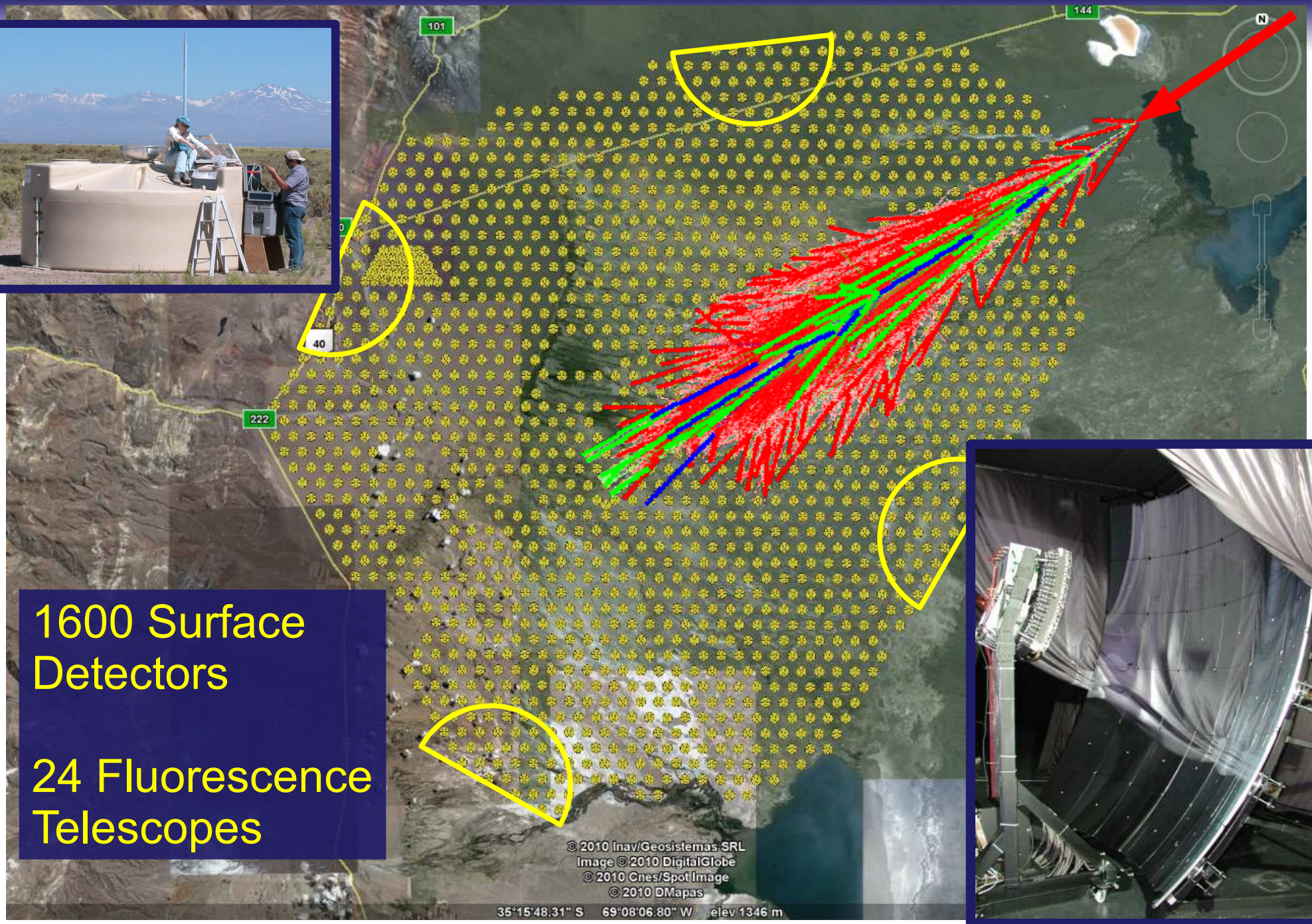
Stefan Fliescher for the Pierre Auger Collaboration
ARENA 2010, Nantes

SPONSORED BY THE
Federal Ministry of Education and Research

RWTH AACHEN UNIVERSITY

PIERRE AUGER OBSERVATORY

Overview: Pierre Auger Observatory



1600 Surface Detectors

24 Fluorescence Telescopes

Radio Emmission Processes

Geo-Magnetic-Radiation Model

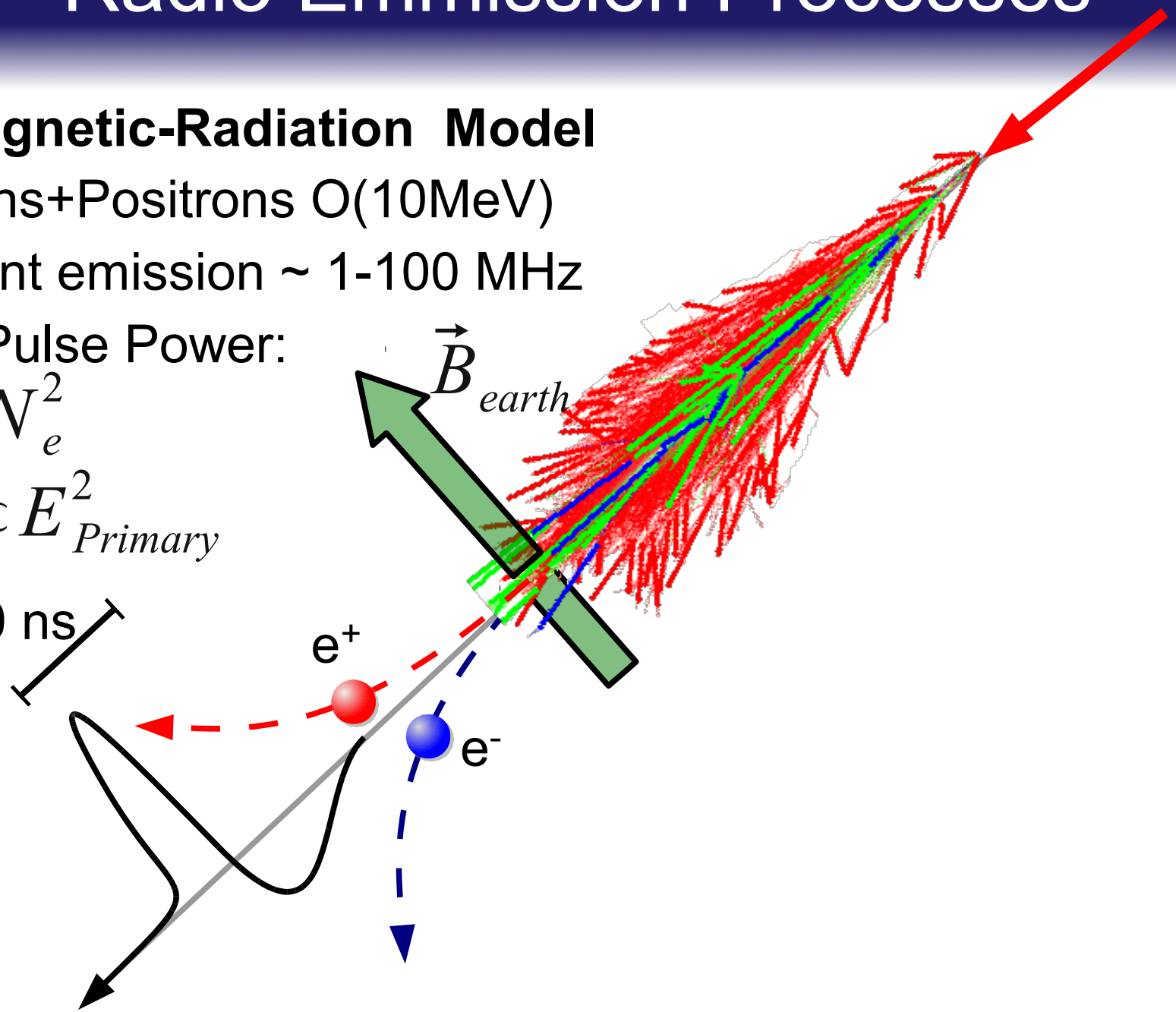
Electrons+Positrons O(10MeV)

Coherent emission ~ 1-100 MHz

Radio Pulse Power:

$$\propto N_e^2$$

$$\propto E_{Primary}^2$$



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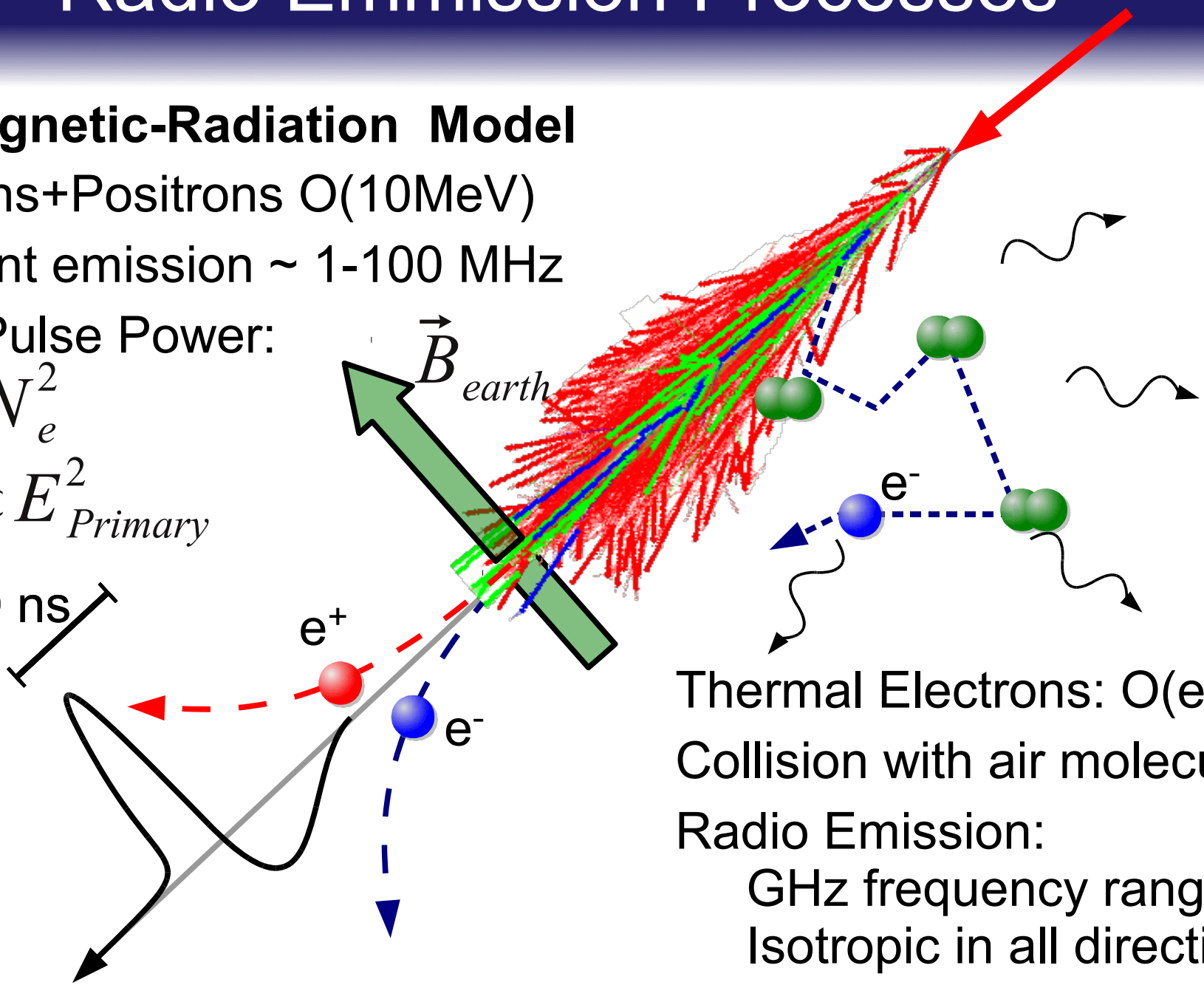


Thermal Electrons: O(eV)

Collision with air molecules

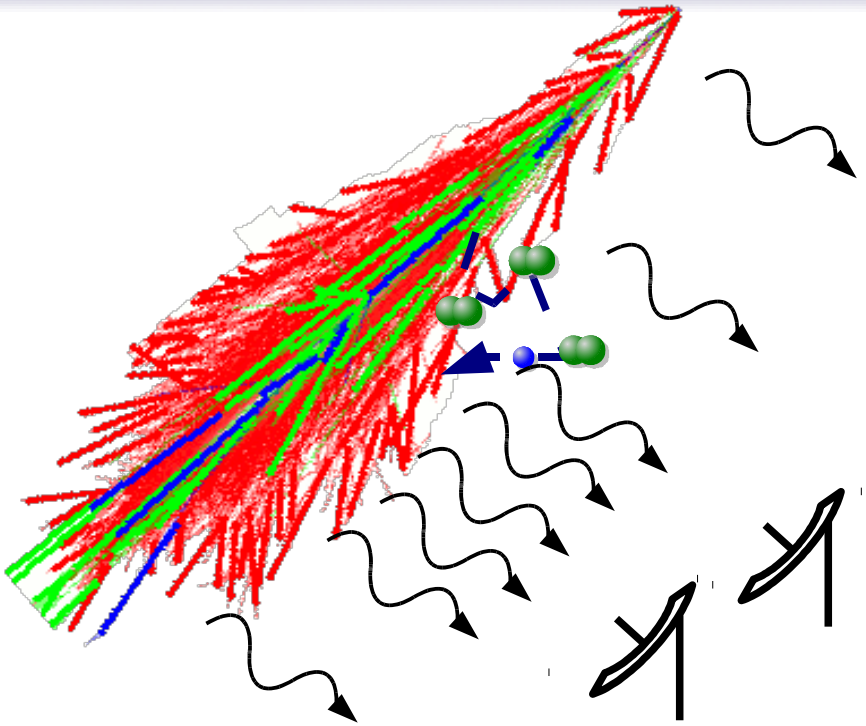
Radio Emission:

GHz frequency range

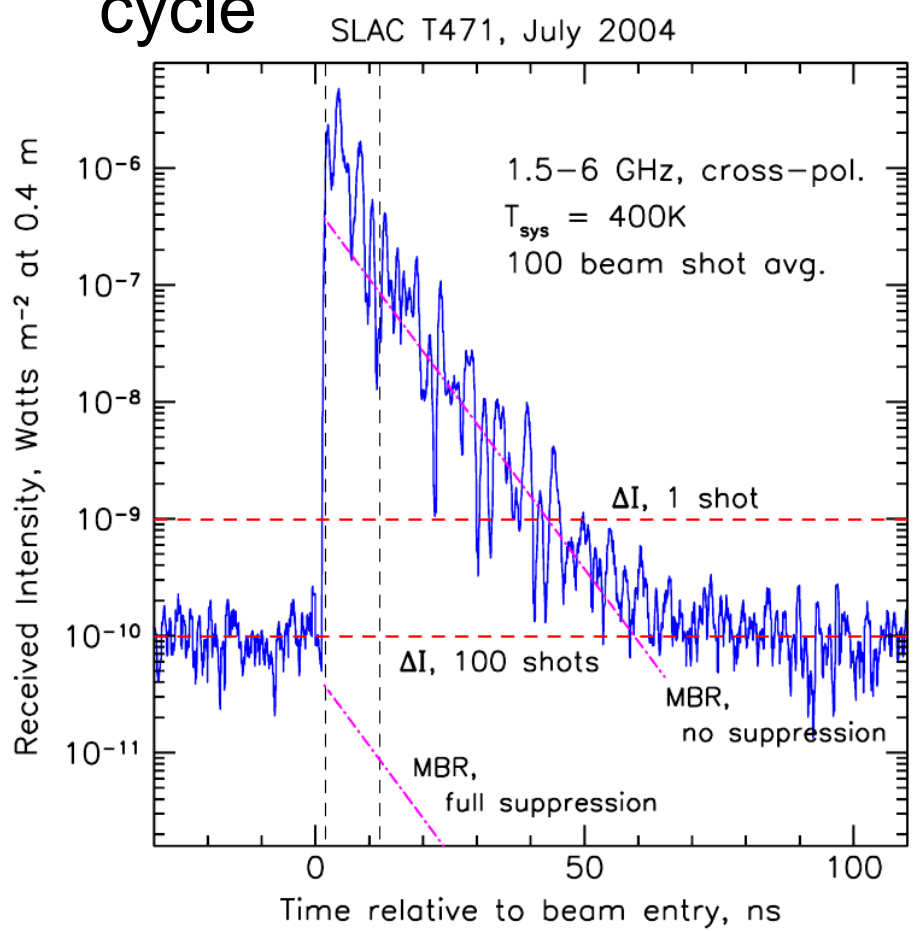
Isotropic in all directions

Molecular Bremsstrahlung

Molecular Bremstrahlung for Air Shower Detection



Watching shower evolution
→ Fluorescence Detector like measurement at 100% duty cycle



Molecular Bremsstrahlung observed at accelerator setup:
Beam on fixed target mimics airshower
(SLAC & Argonne Wakefield)

→ Phys. Rev. D 78, 032007

MIDAS & AMBER

AMBER:
Air-shower Microwave
Bremsstrahlung Radiometer

2.4 m dish
16 pixels

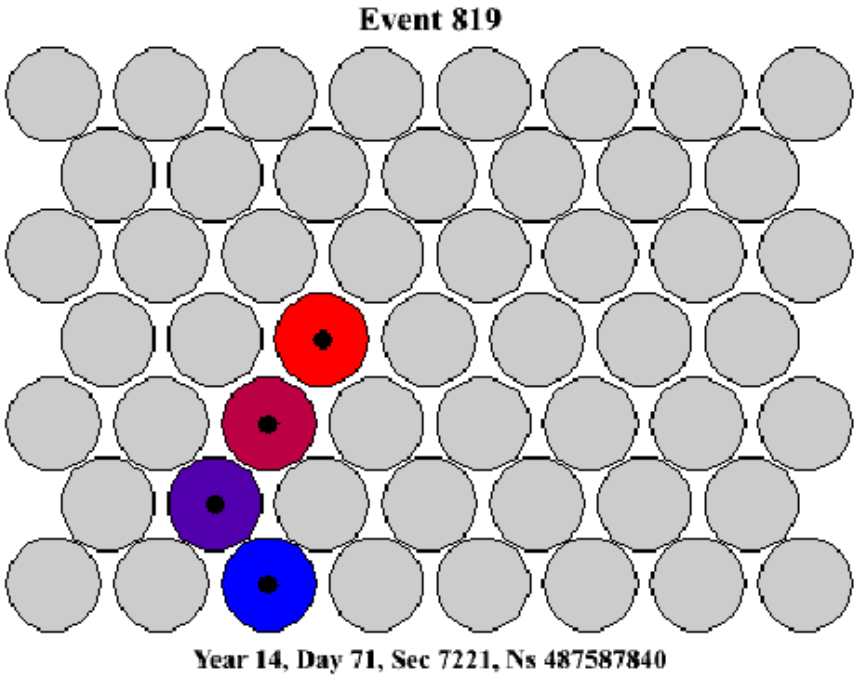
MIDAS:
Microwave Detection
of Air Showers

4.5 m dish
53 pixels

→ Talk Pedro Facal

MIDAS & AMBER

MIDAS Candidate Event



early → late

Trigger concept:

- Self triggered

Event Topology similar to fluorescence air shower detectors:

- Signal in individual camera pixels
- Timing fit downgoing events

→ Talk Pedro Facal

MIDAS & AMBER

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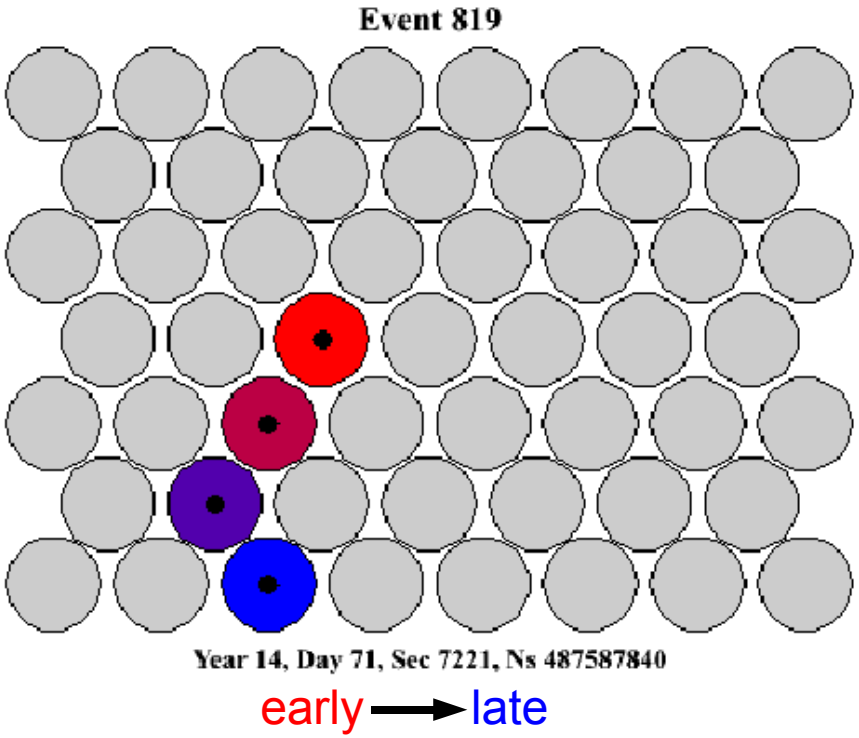

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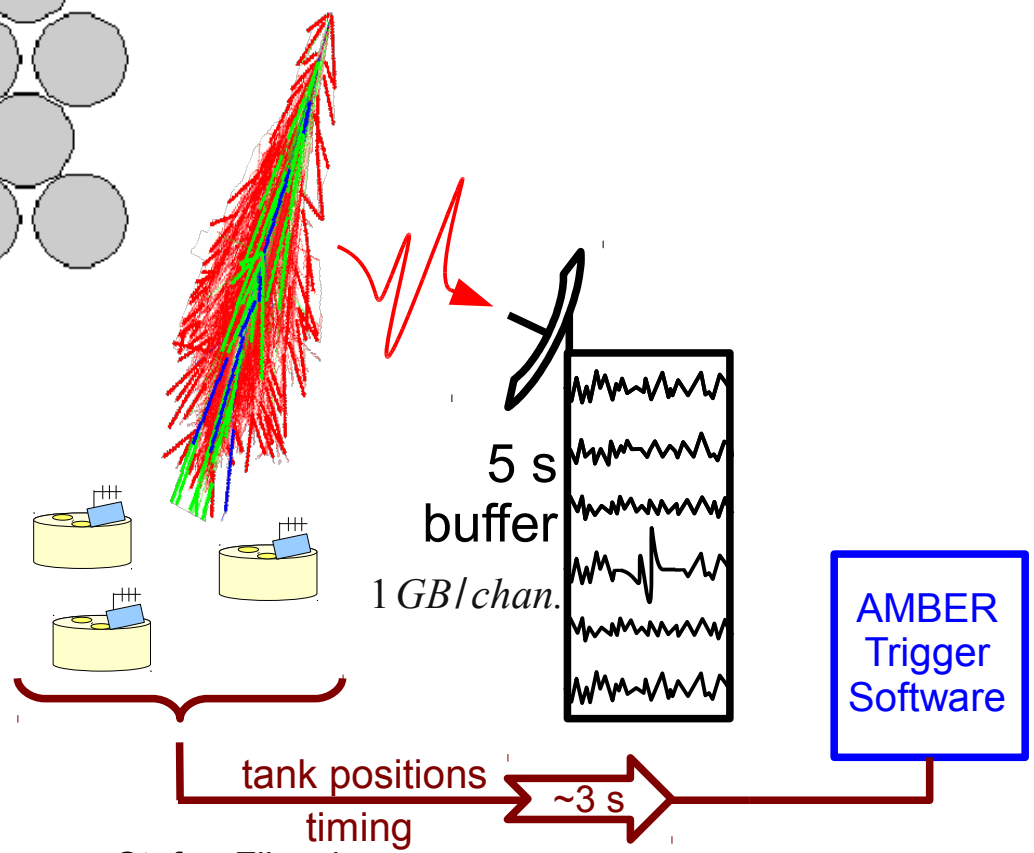

MIDAS & AMBER

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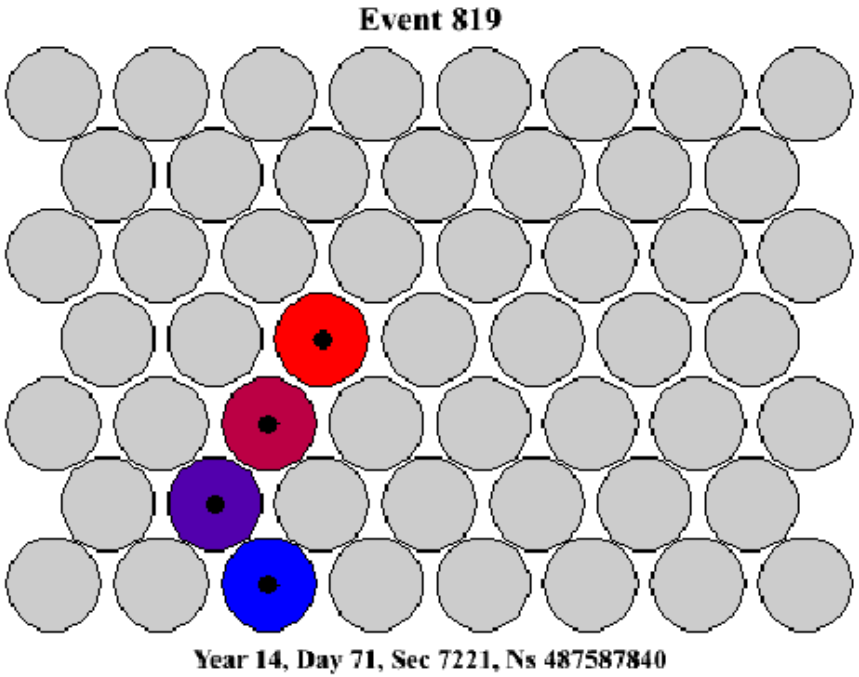

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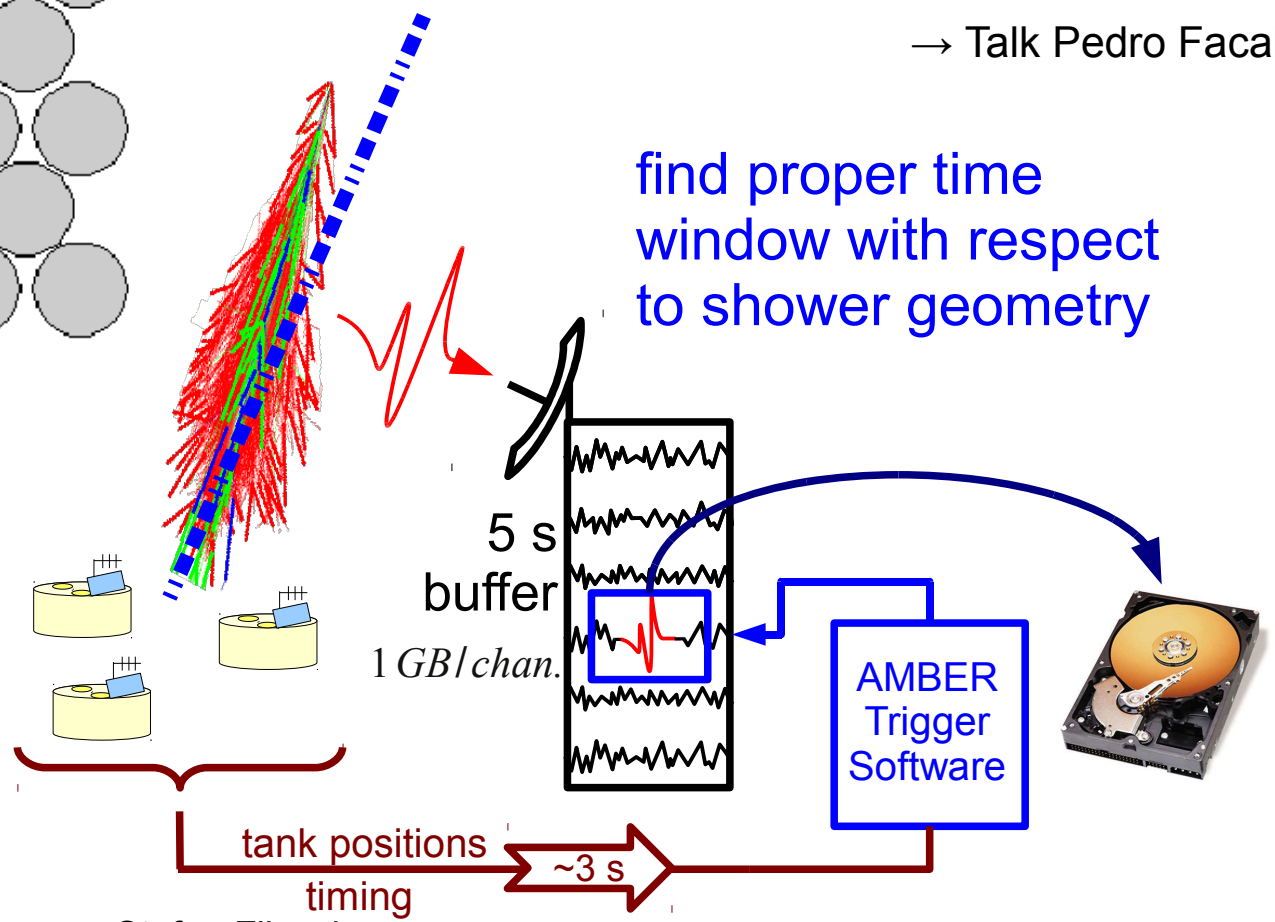

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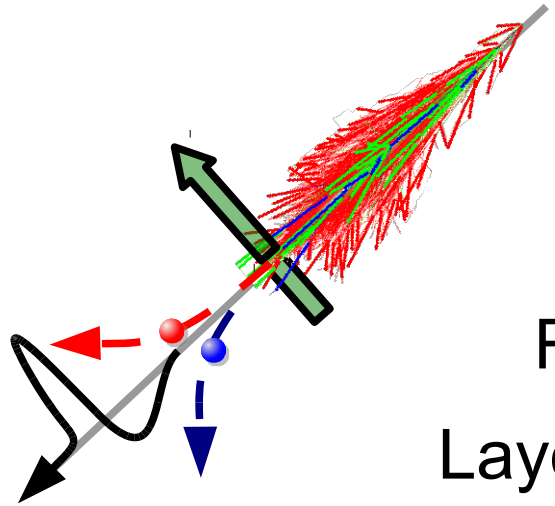
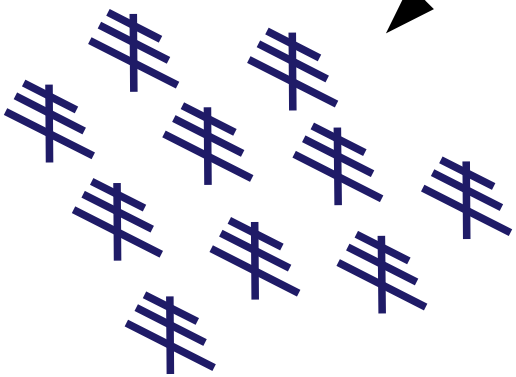
MIDAS, AMBER and AERA

MIDAS
& AMBER





Recent Radio Setups

Layout AERA

Hardware Concepts

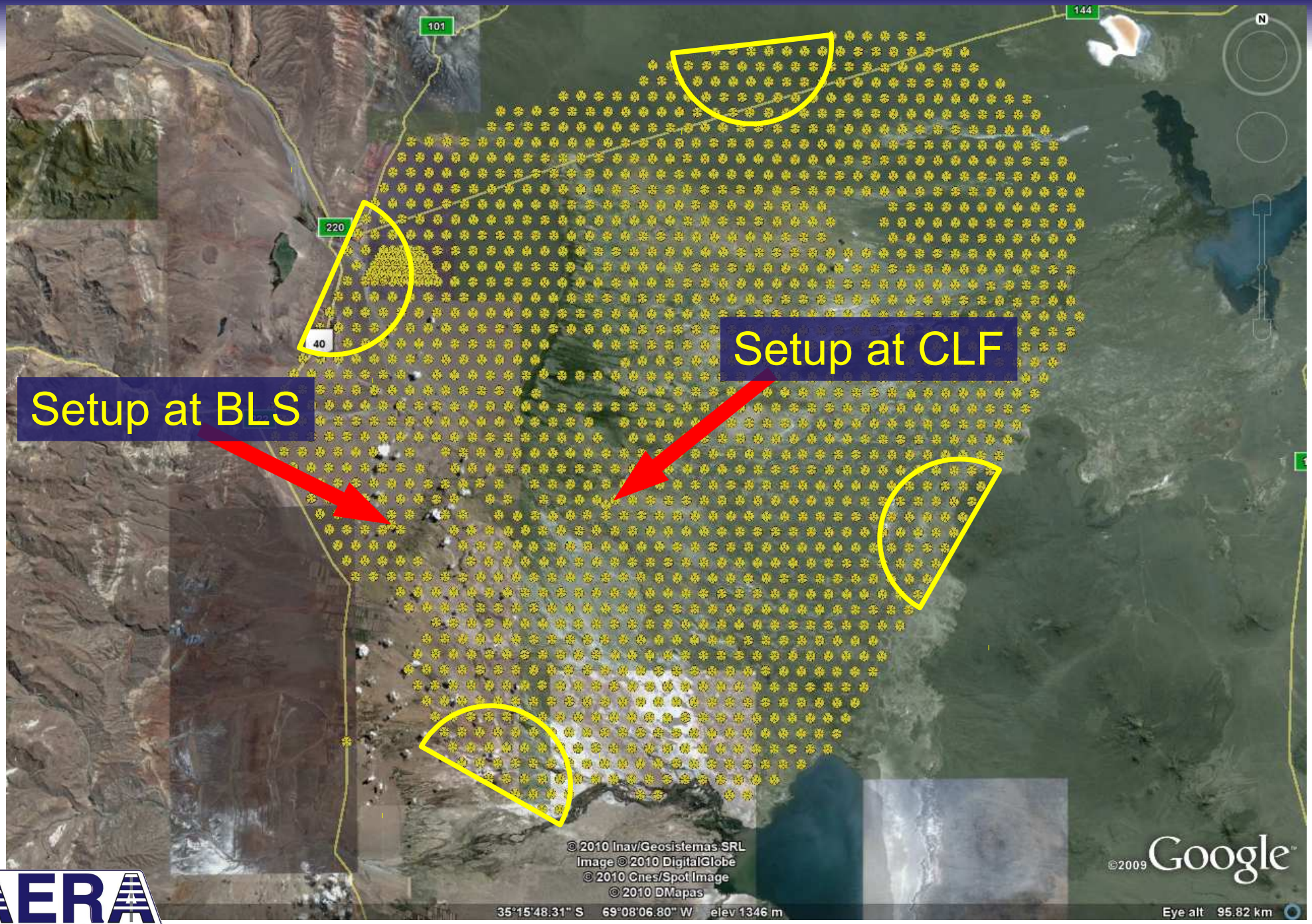
Reconstruction Software

Theoretical Models

Predictions

...

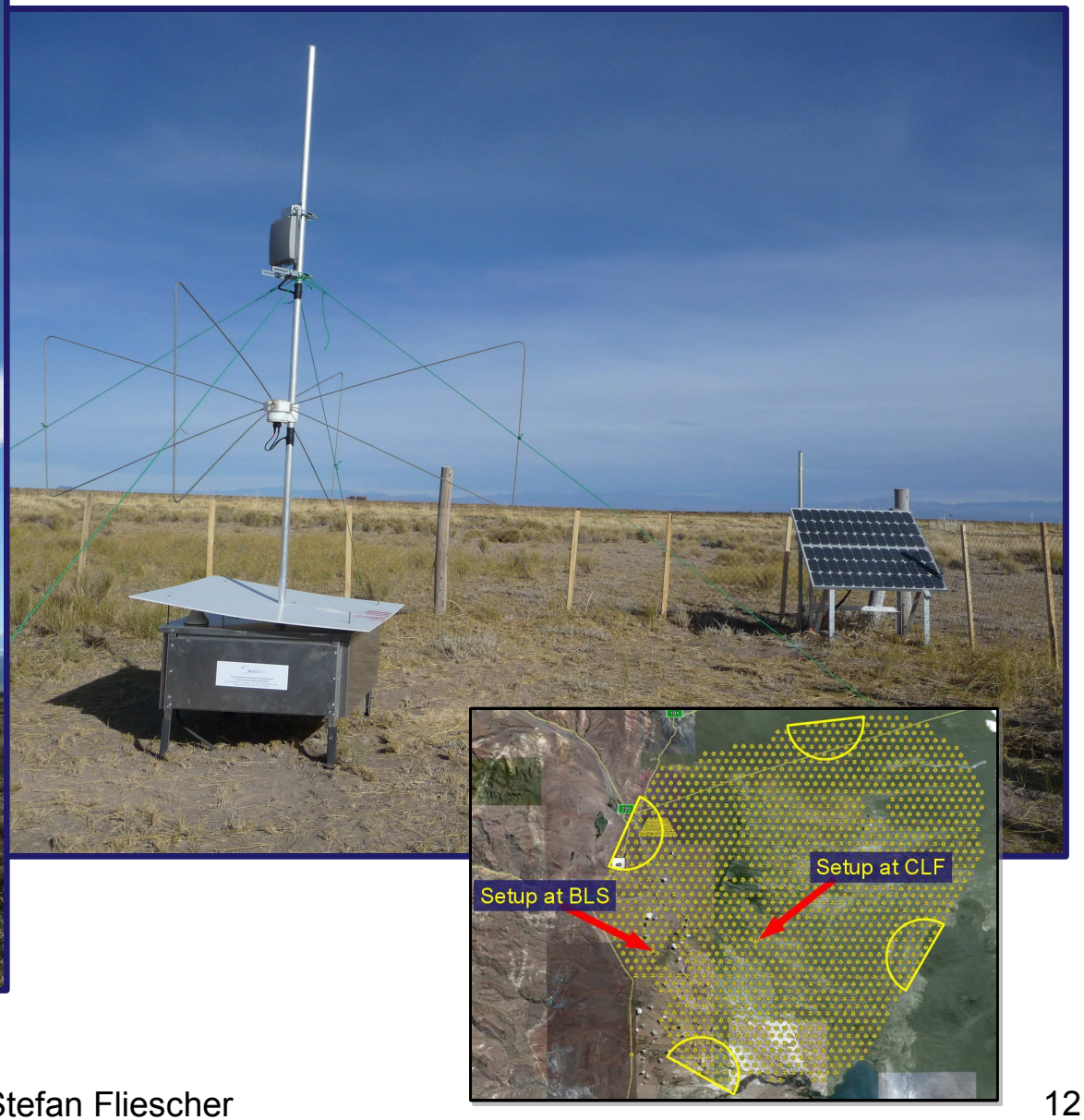
Recent Radio Setups at Auger



Recent Radio Setups at Auger

Setup at BLS

Setup at CLF



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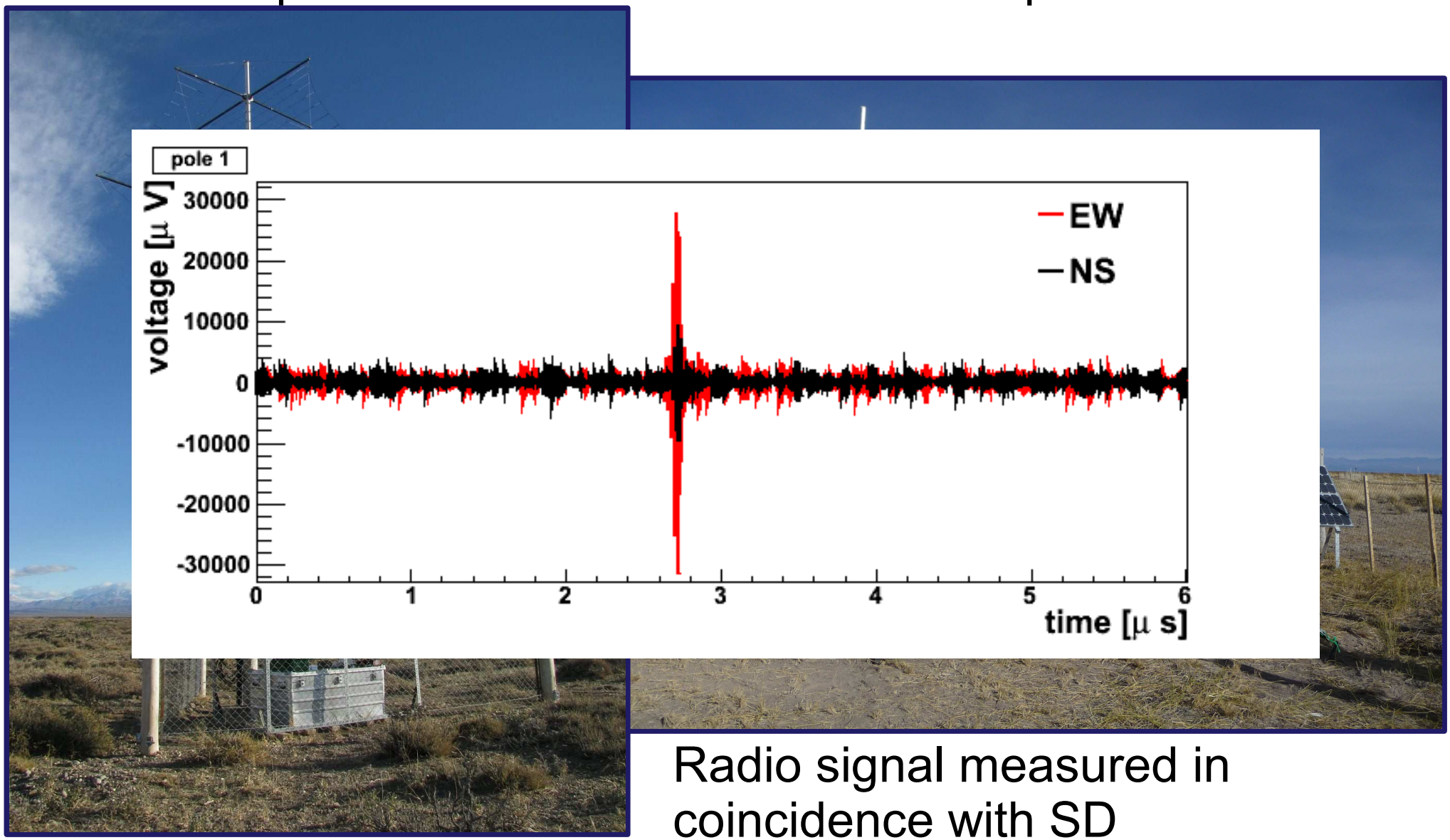
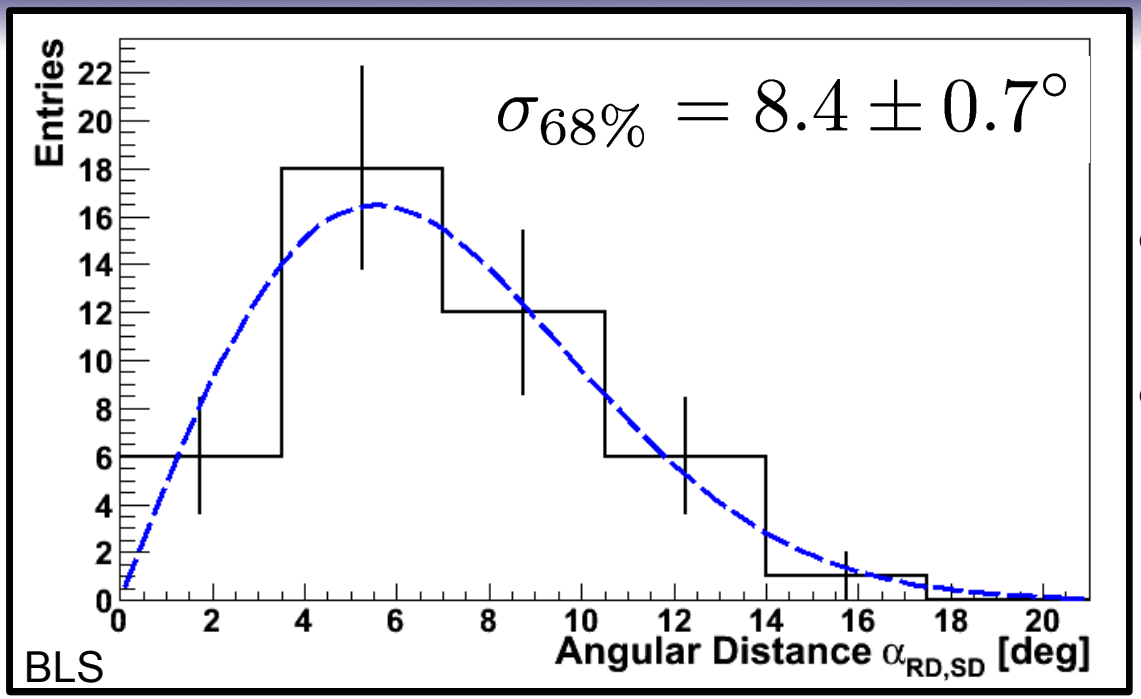


Radio signal measured in coincidence with SD

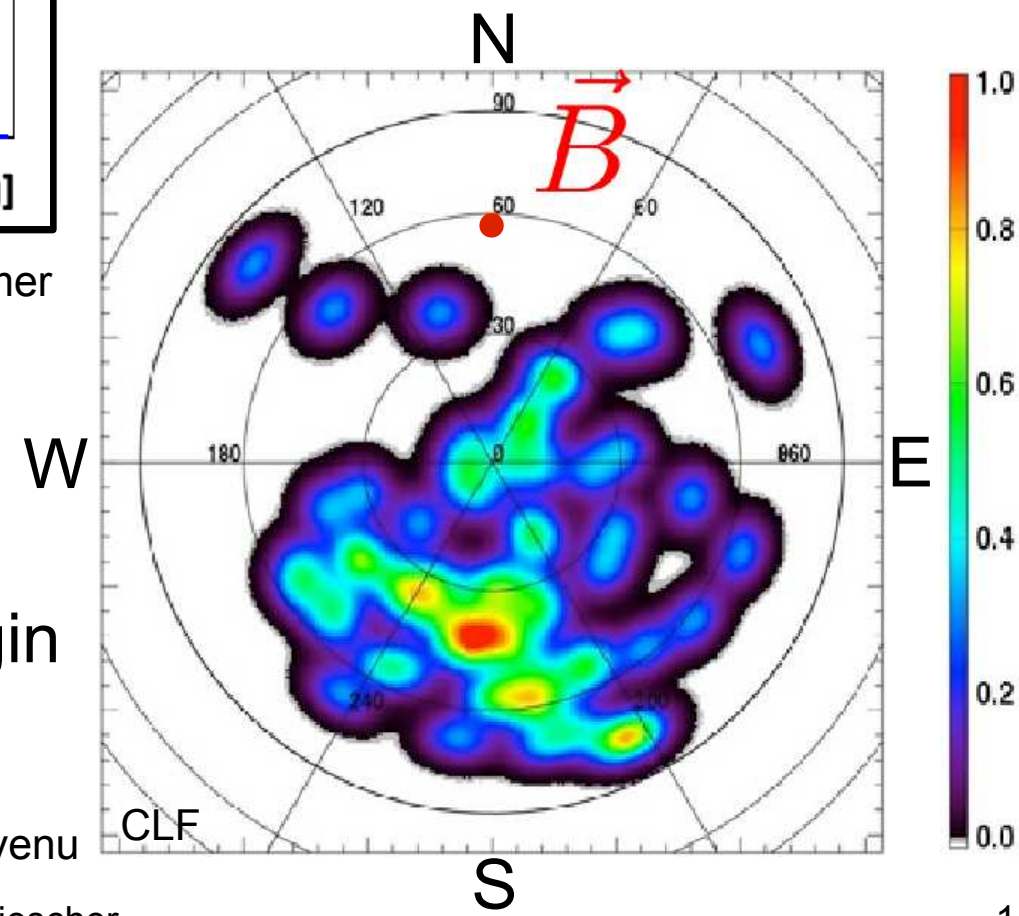
Air Shower Events in Coincidence with SD



→ Talk Harm Schoorlemmer

First radio detection performance tests:

- Scintillator triggered Radio Detector vs. SD
- 3 antennas @ 100m distance



Realize self triggered Radio Detector:

- 53/65 from south

→ Hint for geomagnetic origin

- Threefold coincidence...

→ Talk Benoit Revenu

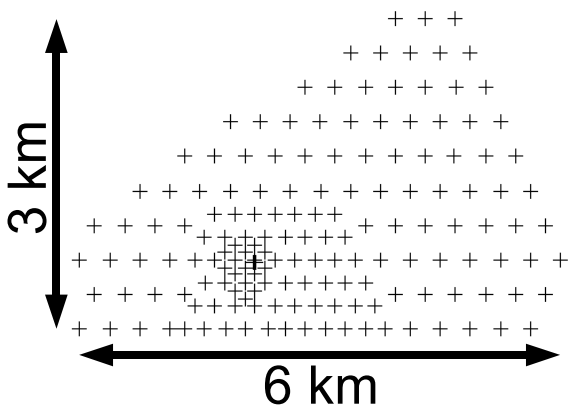
The AERA Group

Bergische Universität, Wuppertal
KIT, Campus North, IK, Karlsruhe
IMAPP, Radboud University, Nijmegen
KIT, Campus North, IPE, Karlsruhe
KVI, University of Groningen, Groningen
LPSC, Grenoble
Nikhef, Amsterdam & Nijmegen
RWTH Aachen University, Aachen
SUBATECH, Nantes
KIT, Campus South, EKP, Karlsruhe

Science Goals

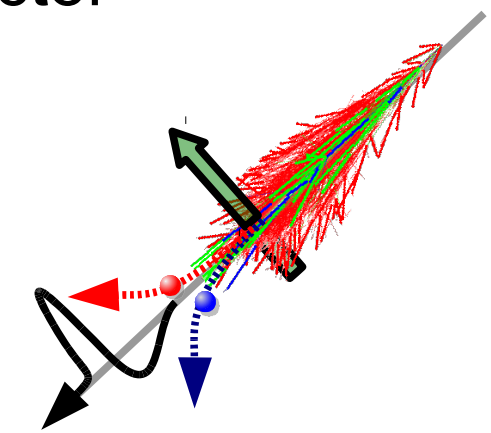
Probe the nature of cosmic rays at the transition region with a novel independent detection technique

Realize a large scale Radio Detector



Understand the details of the radio emission processes

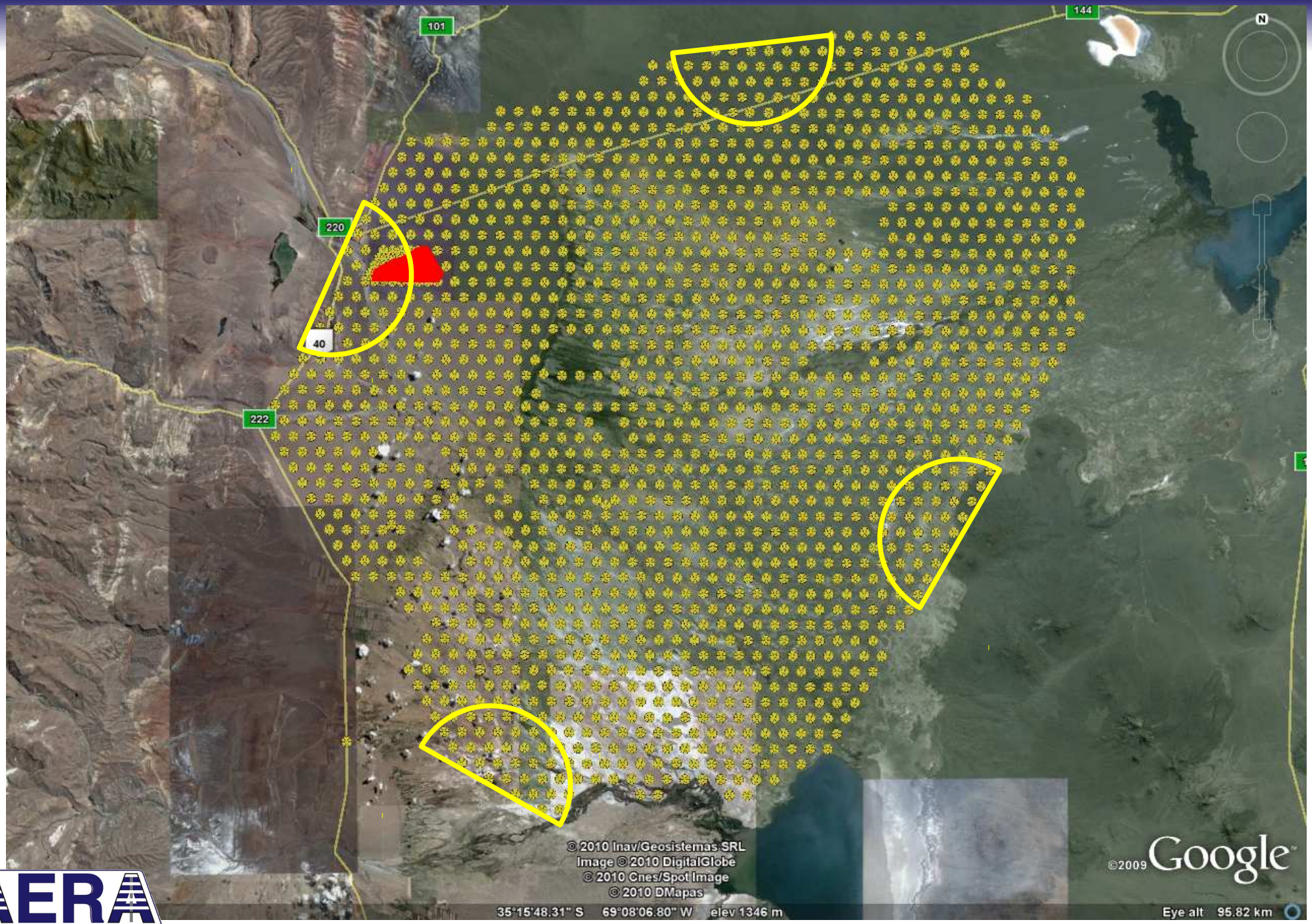
Explore the Potential of the Radio Detection Technique



Realize combined detection of air showers at Auger
„Super-Hybrid“: Radio + SD + FD

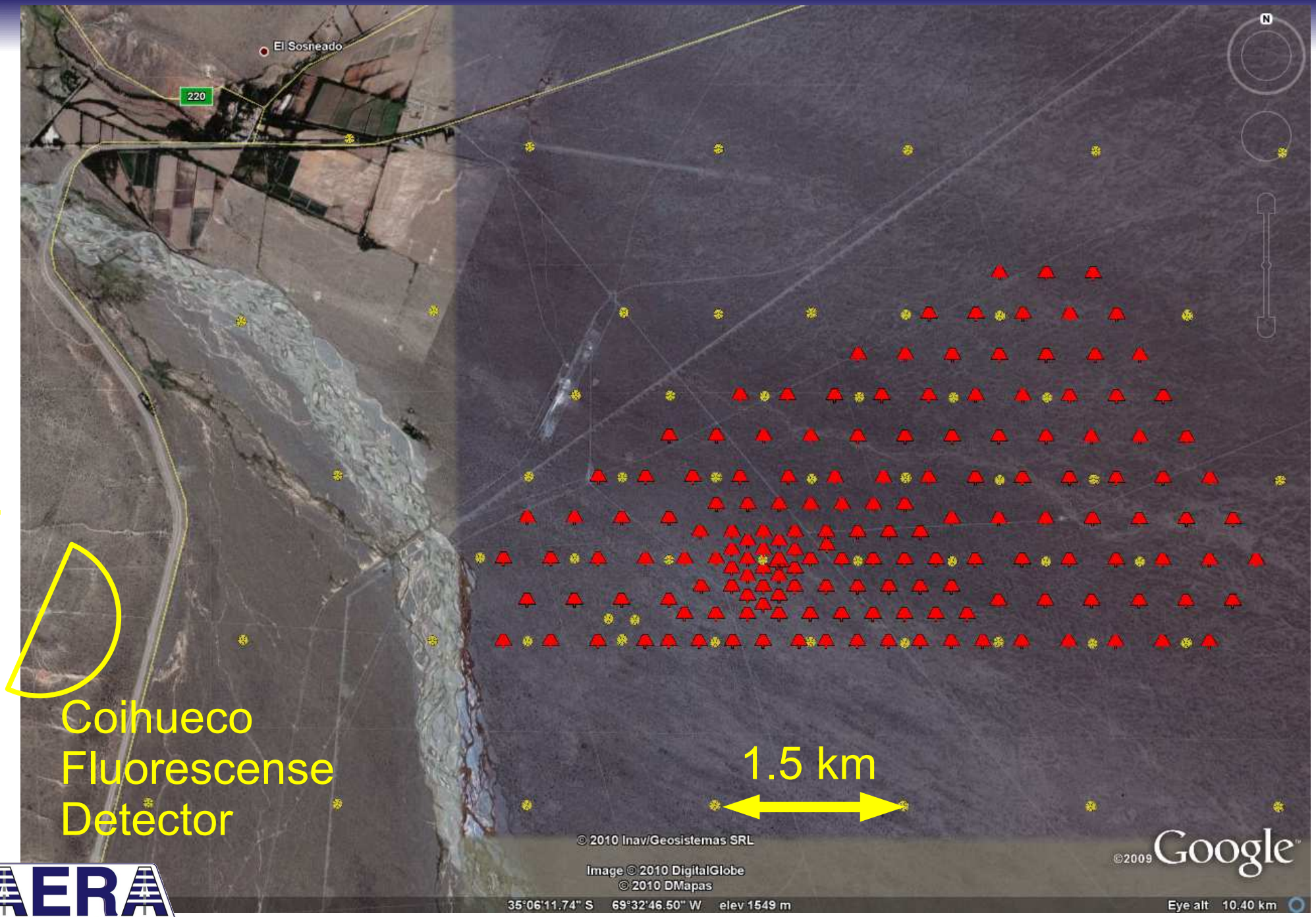
AERA
Auger Engineering Radio Array

Overview: Pierre Auger Observatory

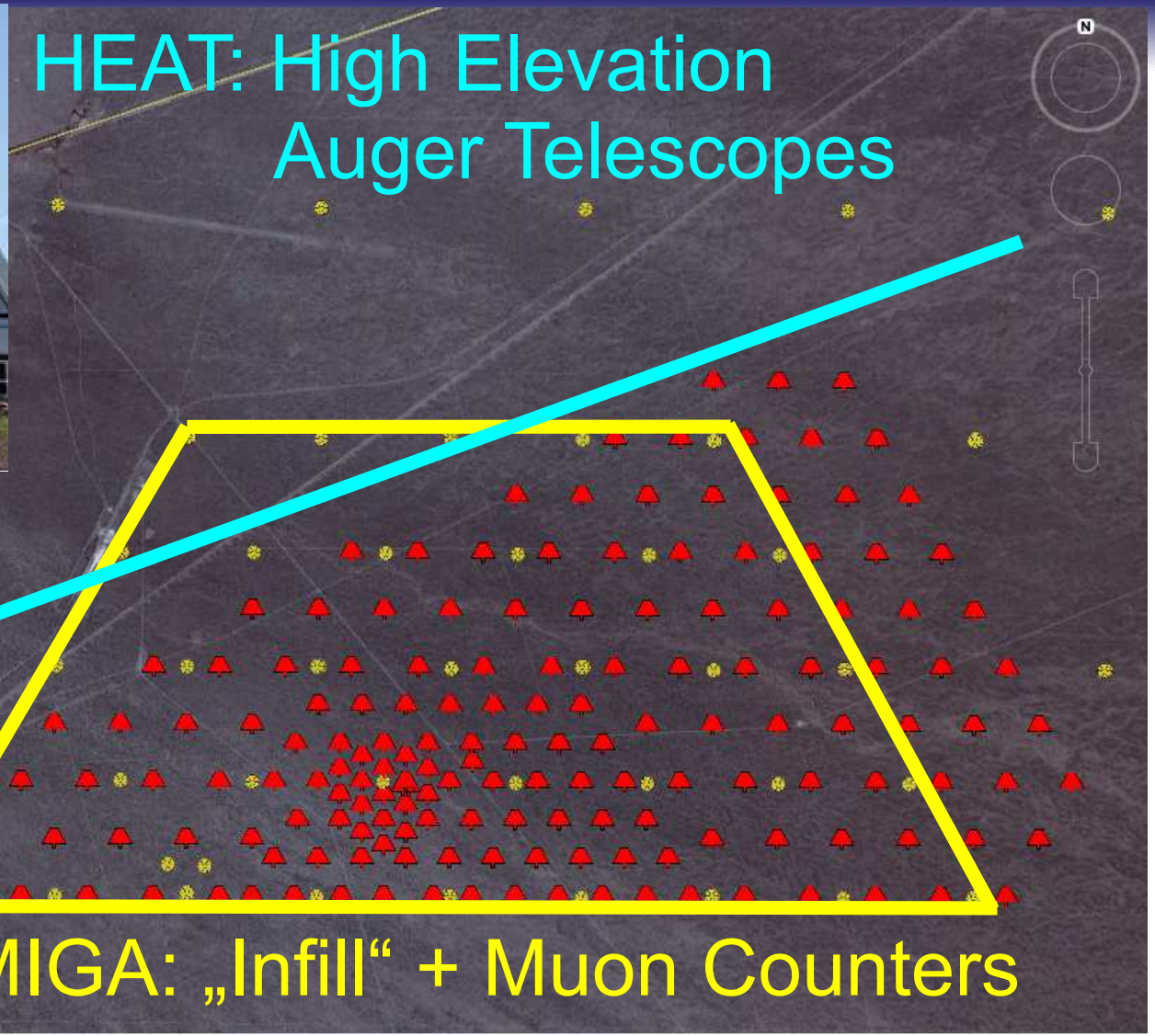


AERA Auger Engineering Radio Array

The AERA Site



AERA & Low Energy Enhancements of Auger

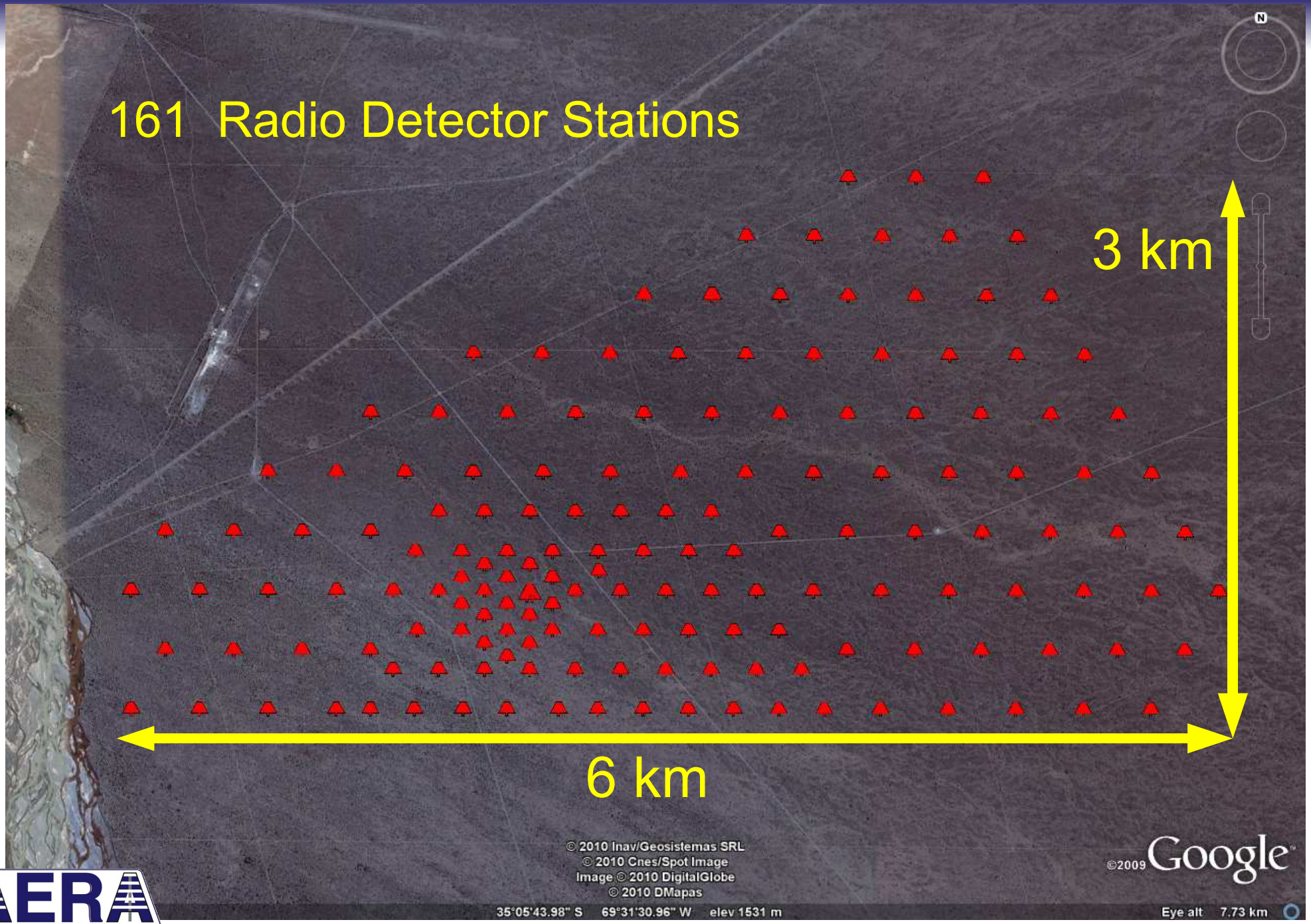


Enhancements:

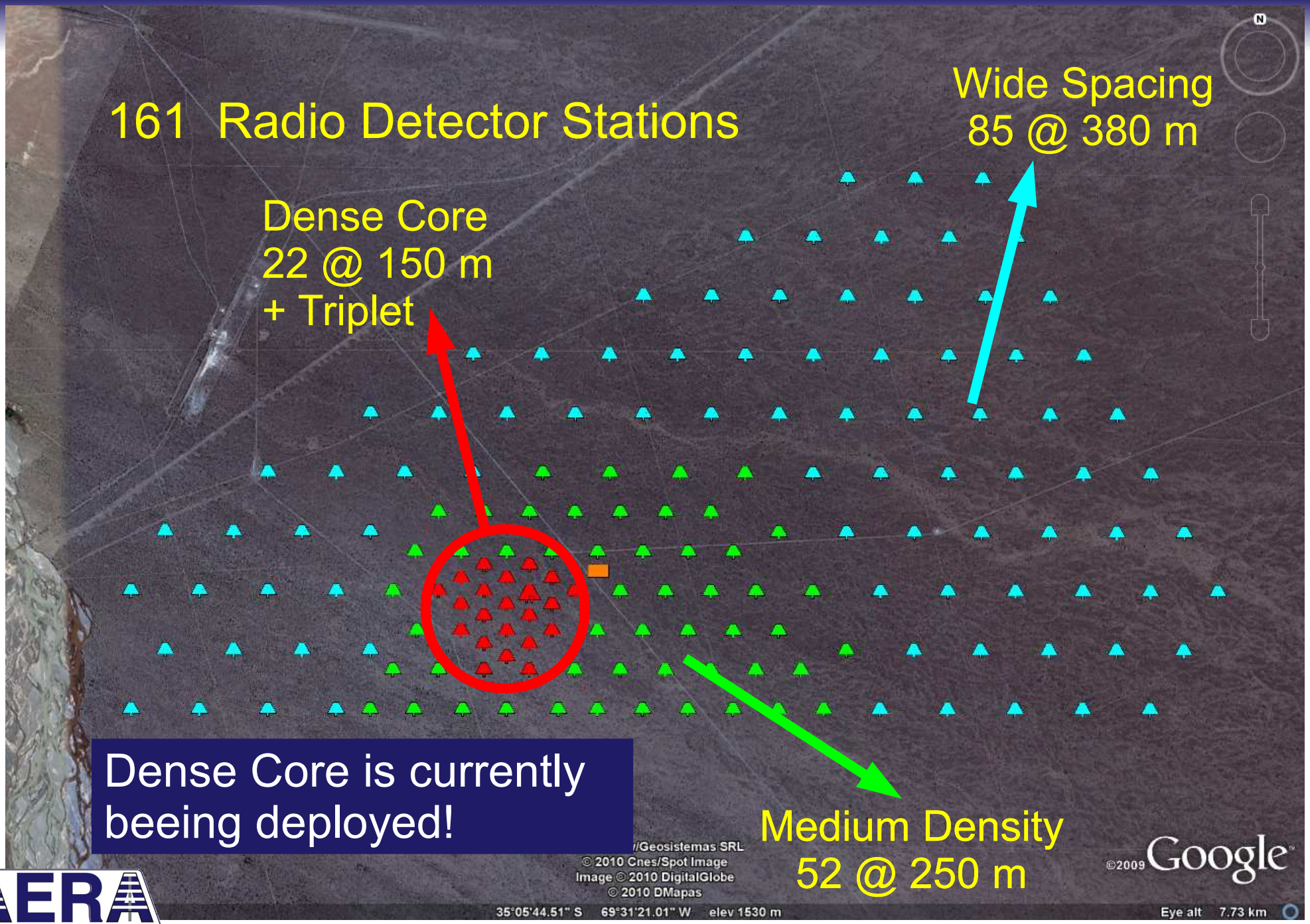
Shift energy threshold of Auger from $10^{18.5}$ to $10^{17.2}$ eV

AERA
Auger Engineering Radio Array

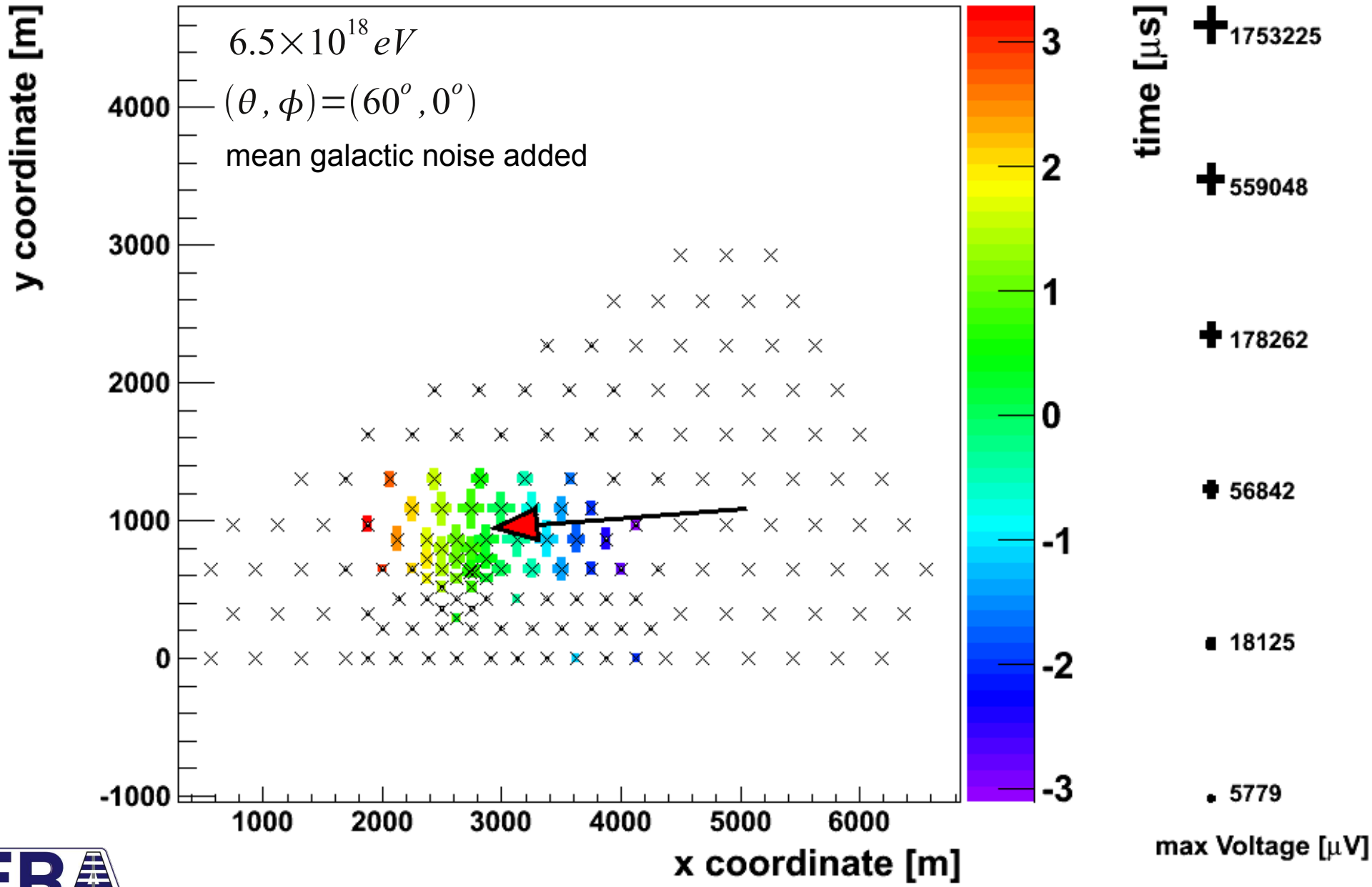
Layout of AERA



3 Stages of Deployment



Simulated Radio Event



Impressions from the AERA Site

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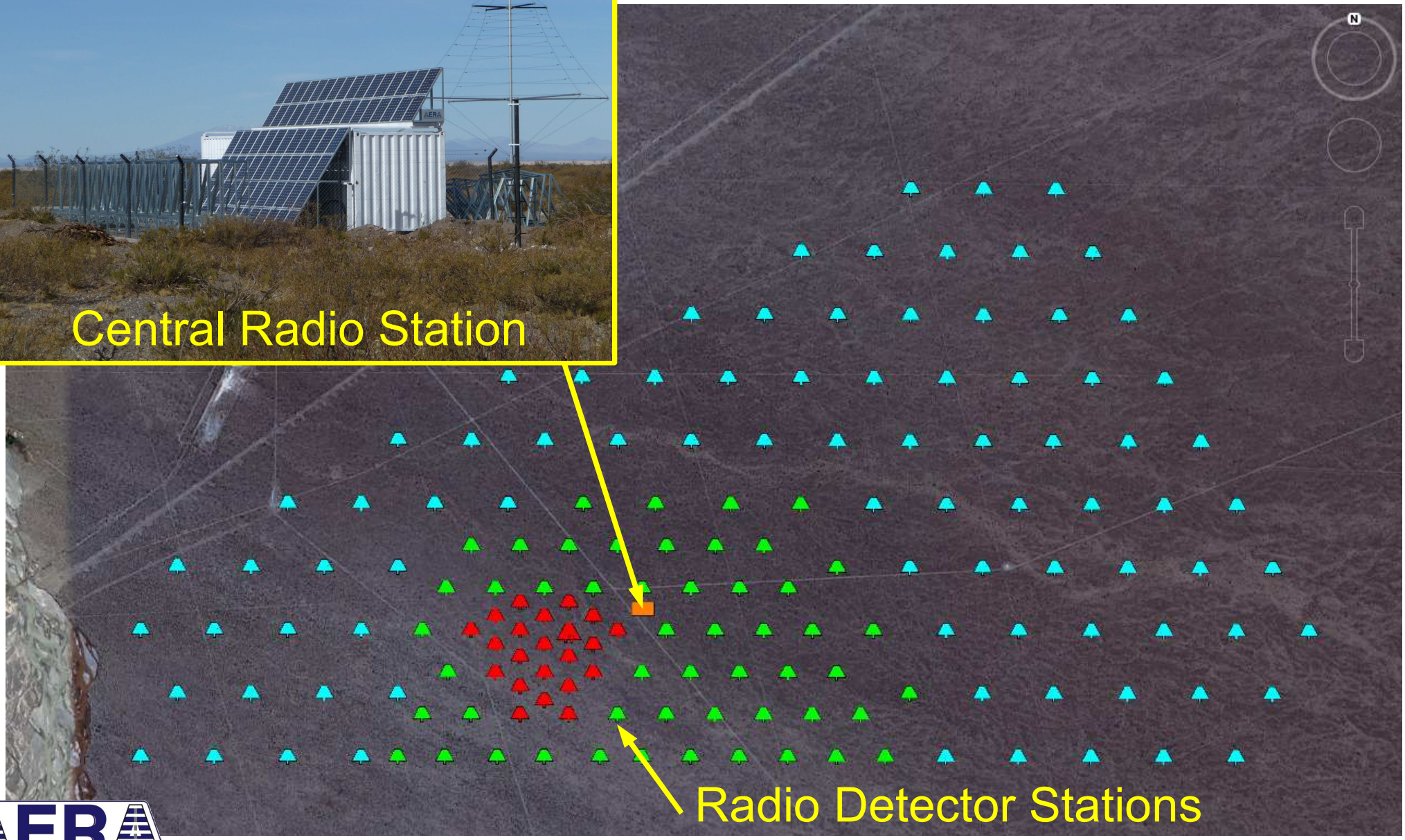
AERA Communication



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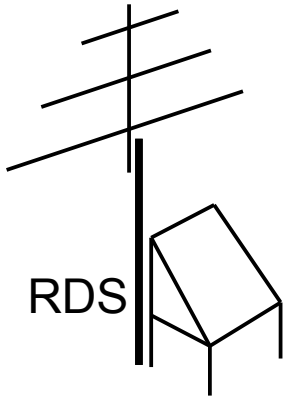
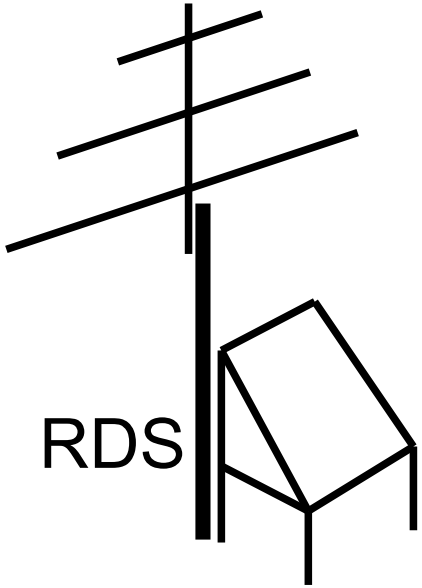
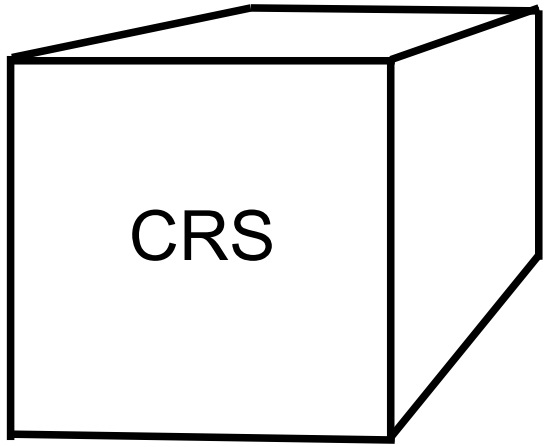


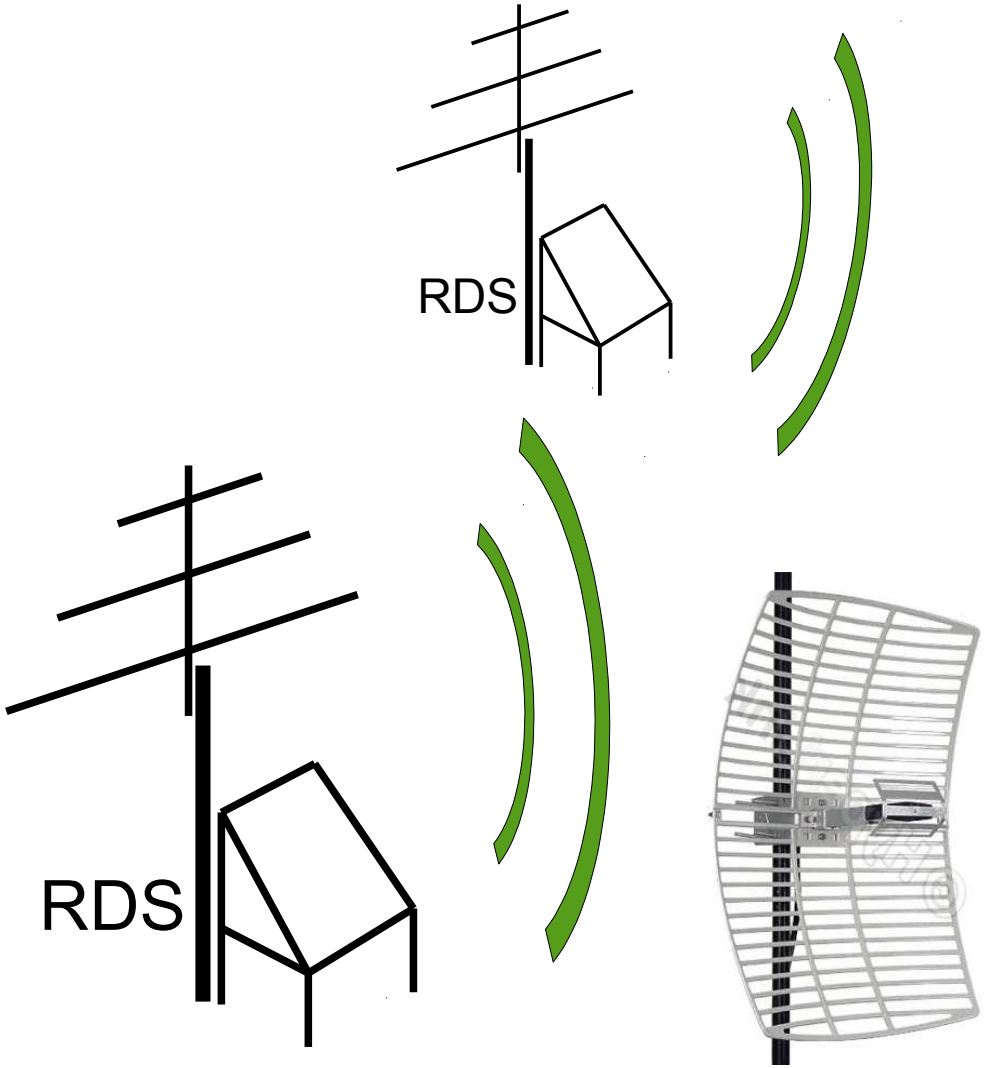


Radio Detector Stations



Central Radio Station
„Home of the DAQ“

AERA Communication



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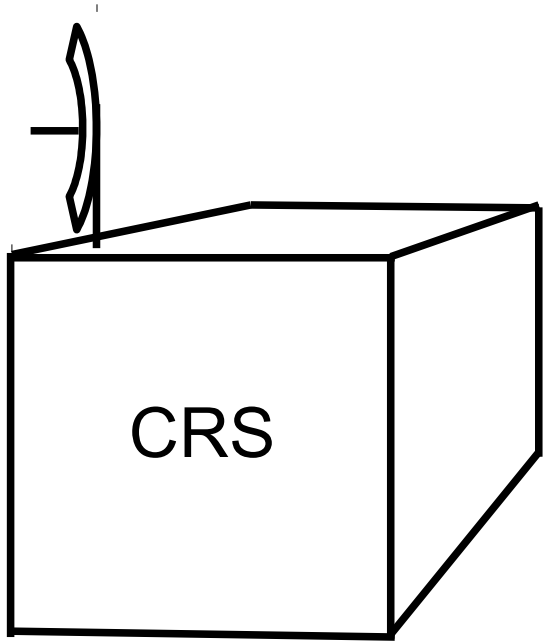


Central Radio Station
„Home of the DAQ“

Raw Data Rate and Trigger Scheme

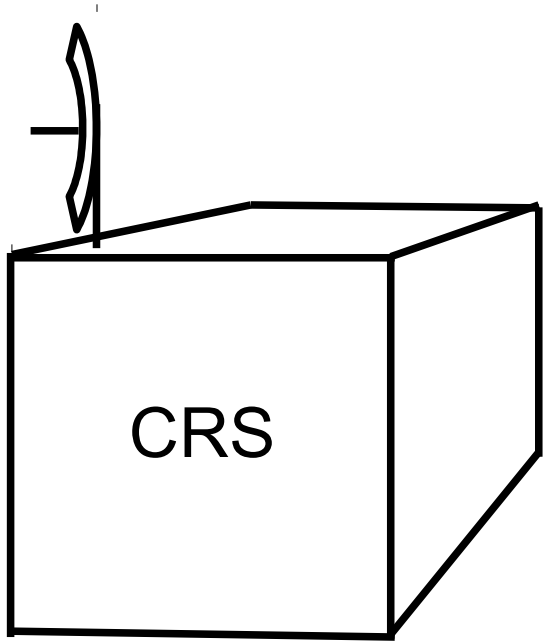
Radio **D**etector **S**tations:

Sampling frequency : 180 MHz
Number of channels : 4
Data bit depth : 12 bit

} 1.2 GB/s

Highly selective
trigger on RDS level

100-200 Hz trigger rate per RDS
Trace length: 10µs



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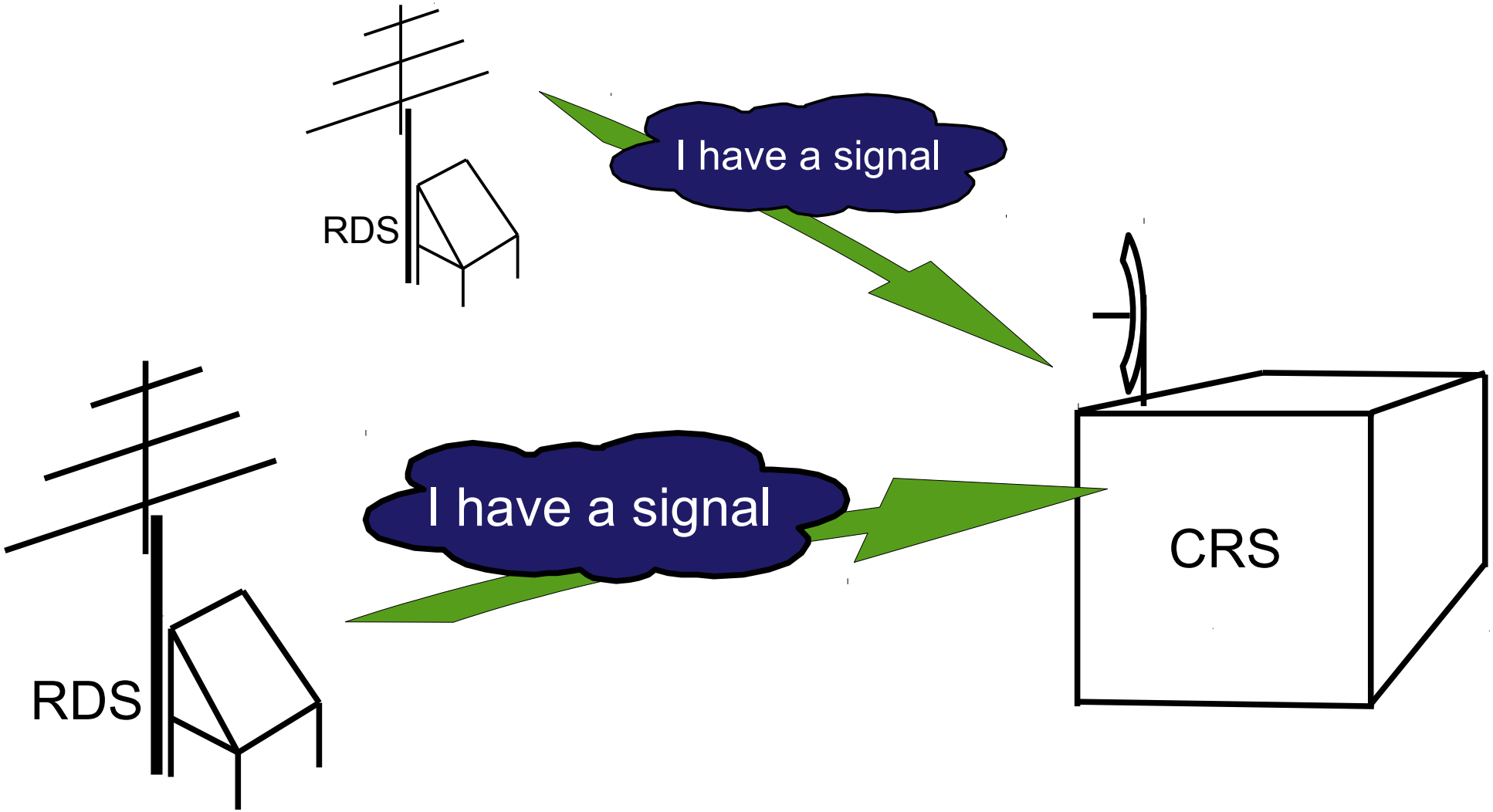

100-200 Hz tigger rate per Radio Detector Station

Central Radio Station „Home of the DAQ“

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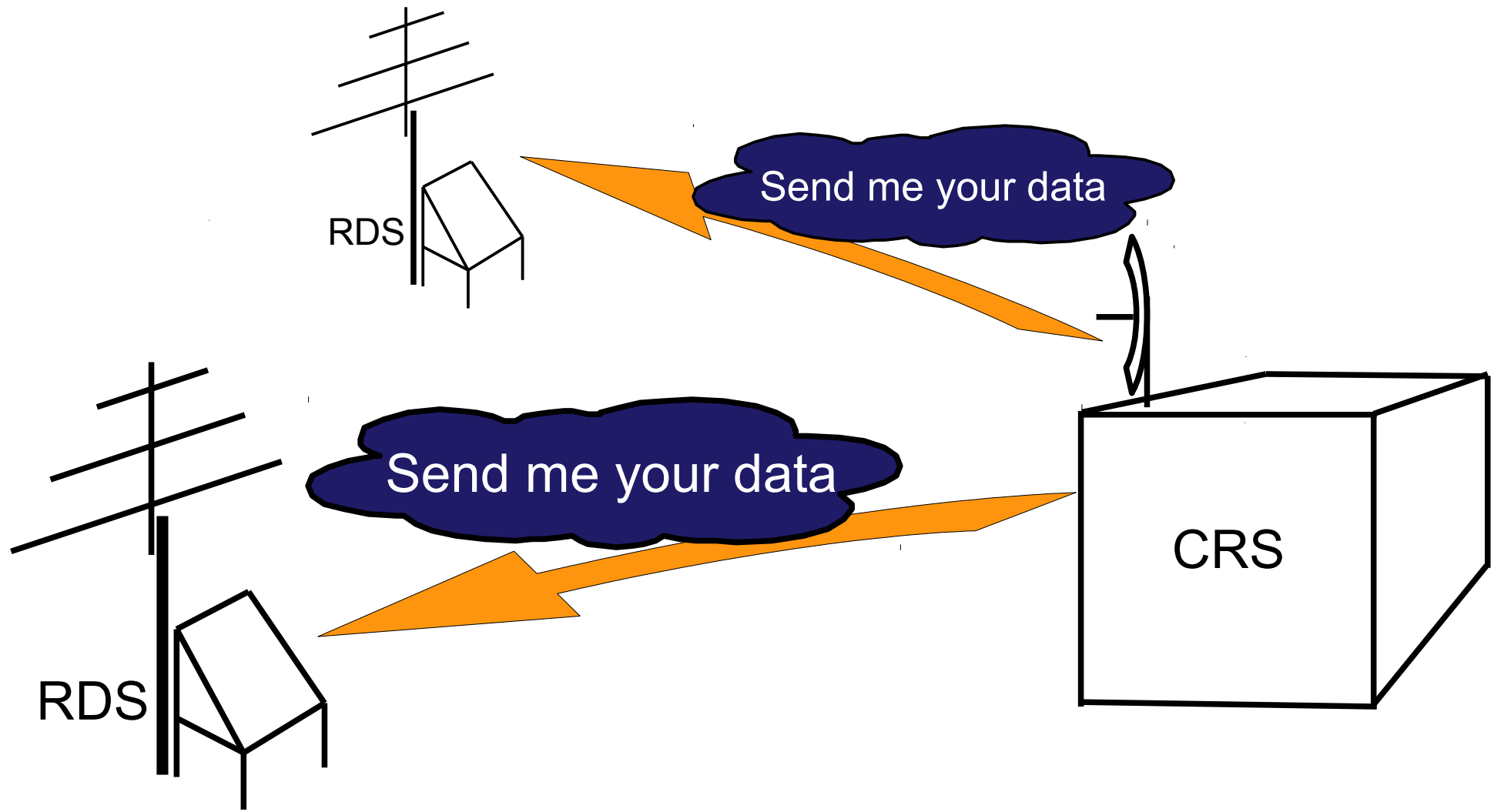

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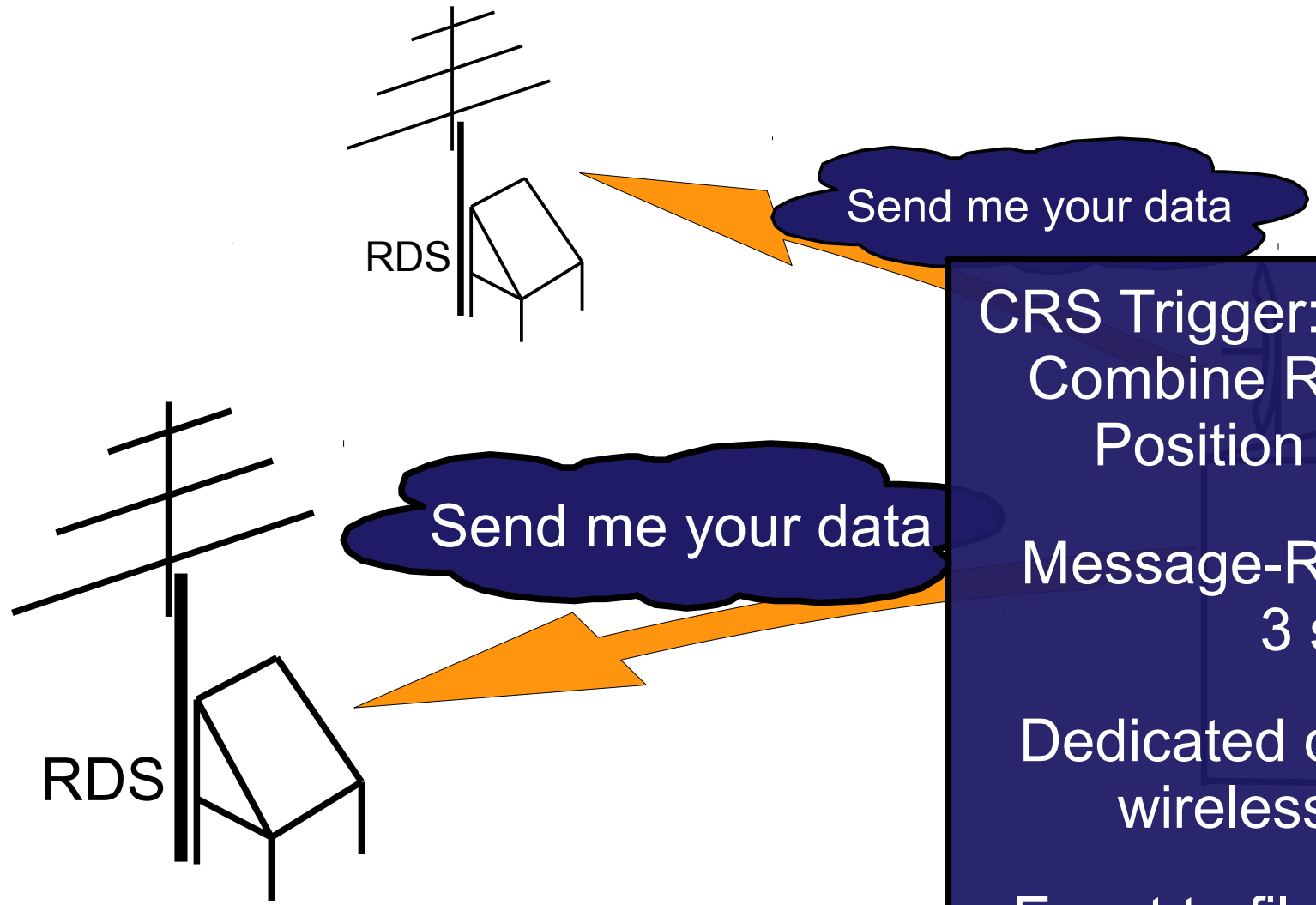


CRS Trigger:
Combine RDS triggers
Position + Timing

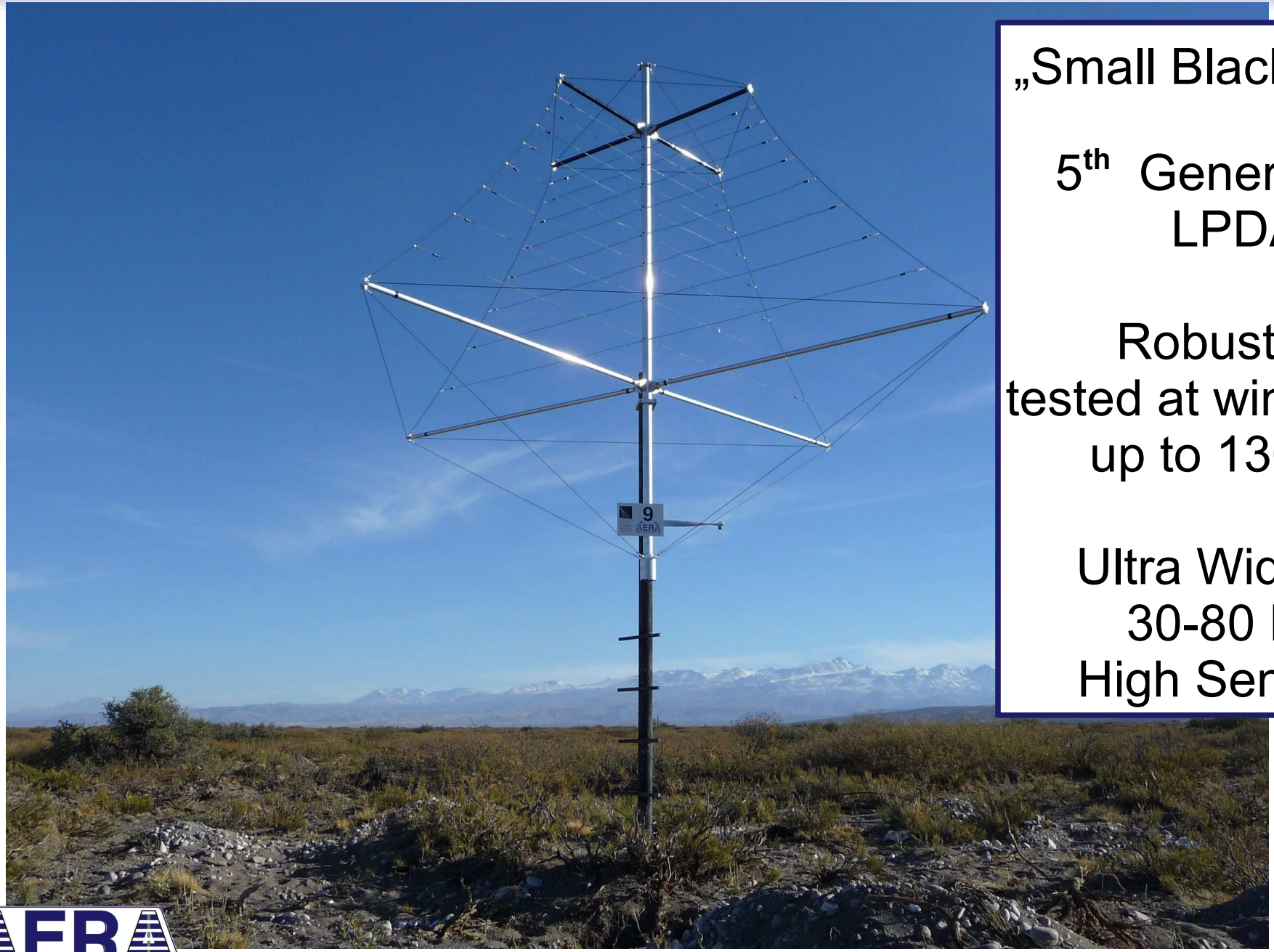
Message-Retour Time:
3 sec

Dedicated deterministic wireless network

Event to file rate : 1 Hz

100-200 Hz tigger rate per Radio Detector Station

Radio Antenna for AERA



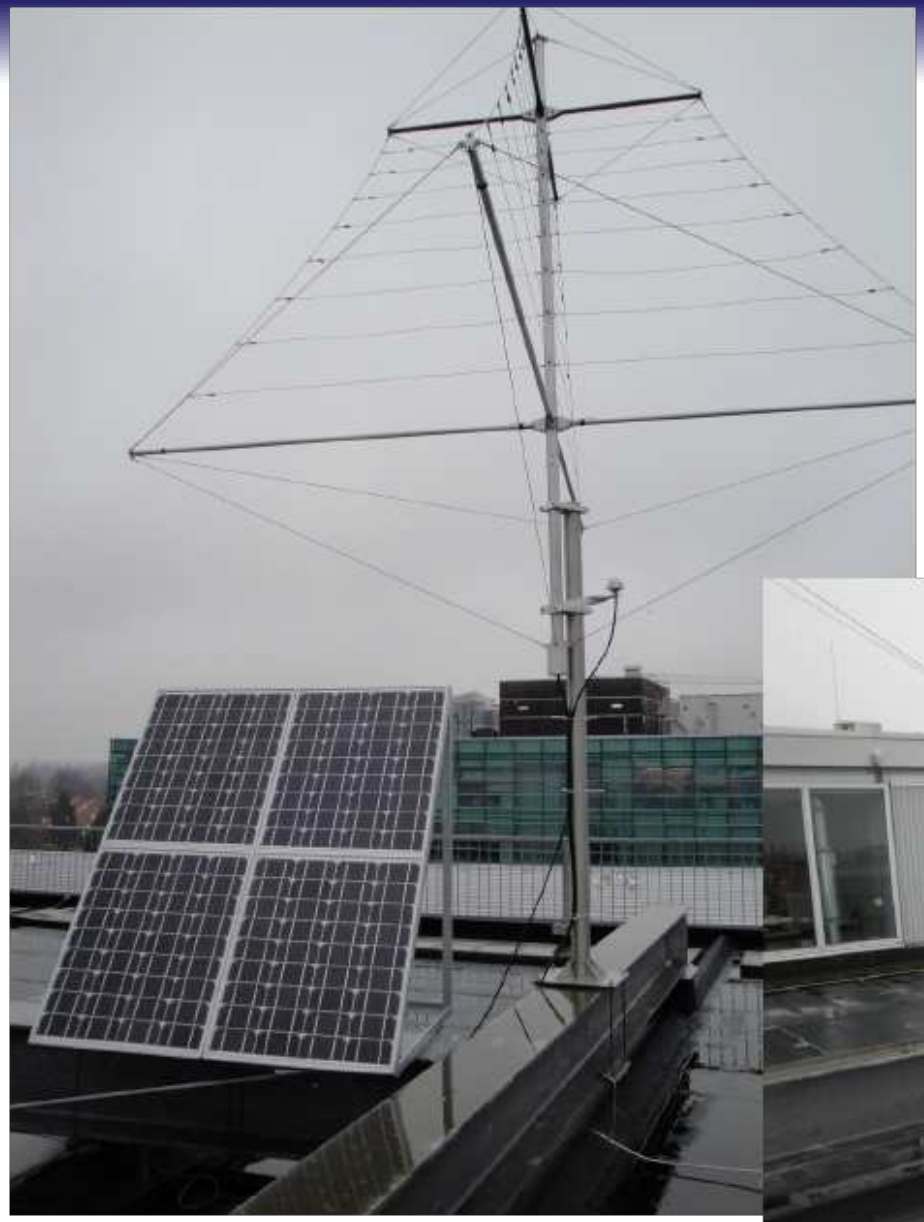
„Small Black Spider“

5th Generation of LPDAs

Robustness tested at windspeeds up to 130km/h

Ultra Wideband
30-80 MHz
High Sensitivity

Integration Test: Sample Radio Detector Station



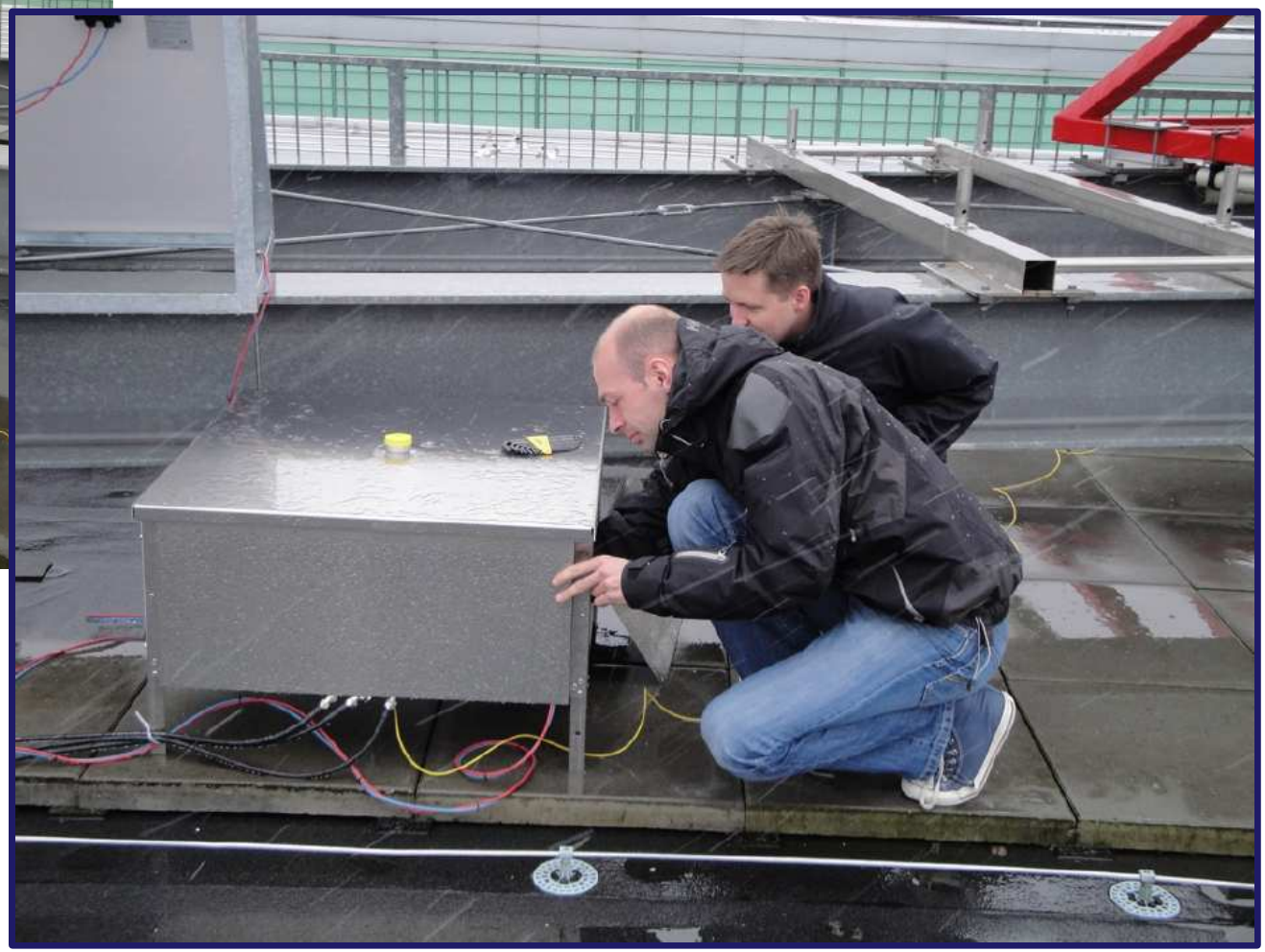
Autonomous Detector Station:

- Radio Antenna
- Low Noise Amplifier
- Readout Electronics
- Solar Panels, Batteries
- Communication, GPS

Sample station in Nijmegen (NL)

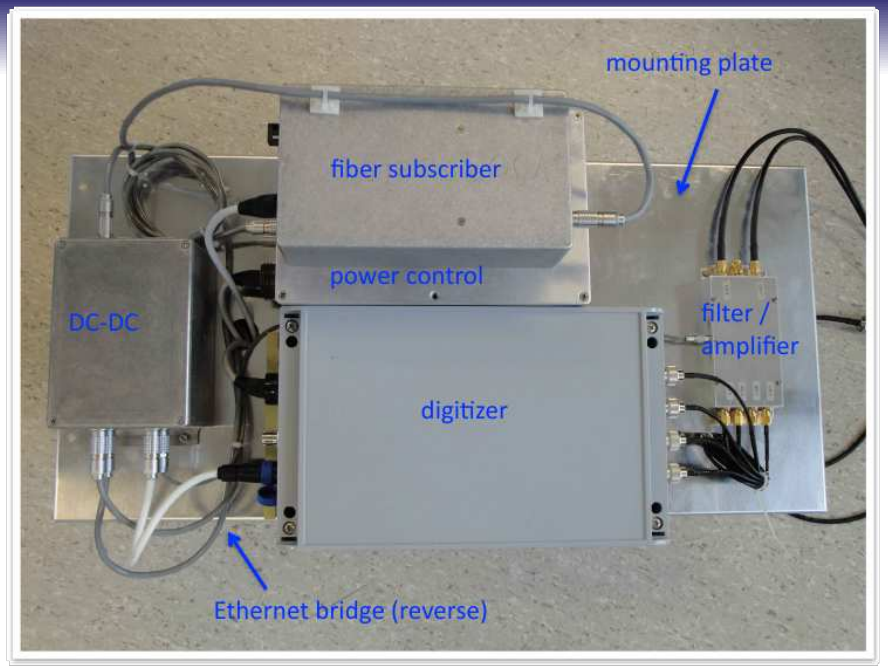
24 x for Phase 1

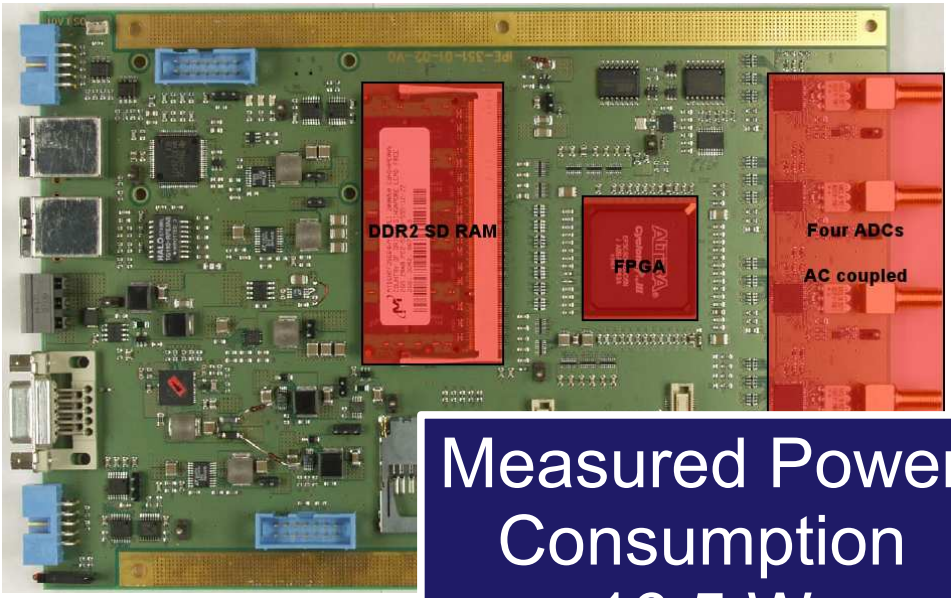
Radio Detector Station Electronics



Radio Detector Station Electronics

- Filter / Amplifier
- ADCs
- Comms
- Monitoring
- Power control
- 3 Seconds Ring Buffer





Measured Power Consumption 16.5 W

FPGA - on the fly:

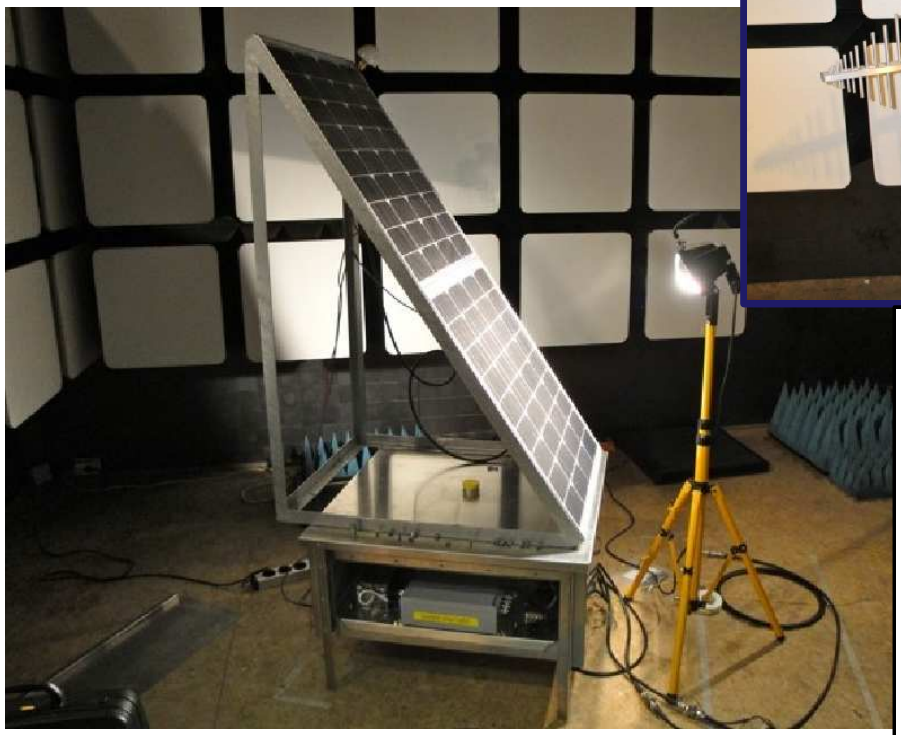
FFT
Noise Reduction
Dispersion Correction
FFT^{-1}
Trace Envelope
Signal Analysis

} Trigger Decision

→ Talk Christoph Rühle

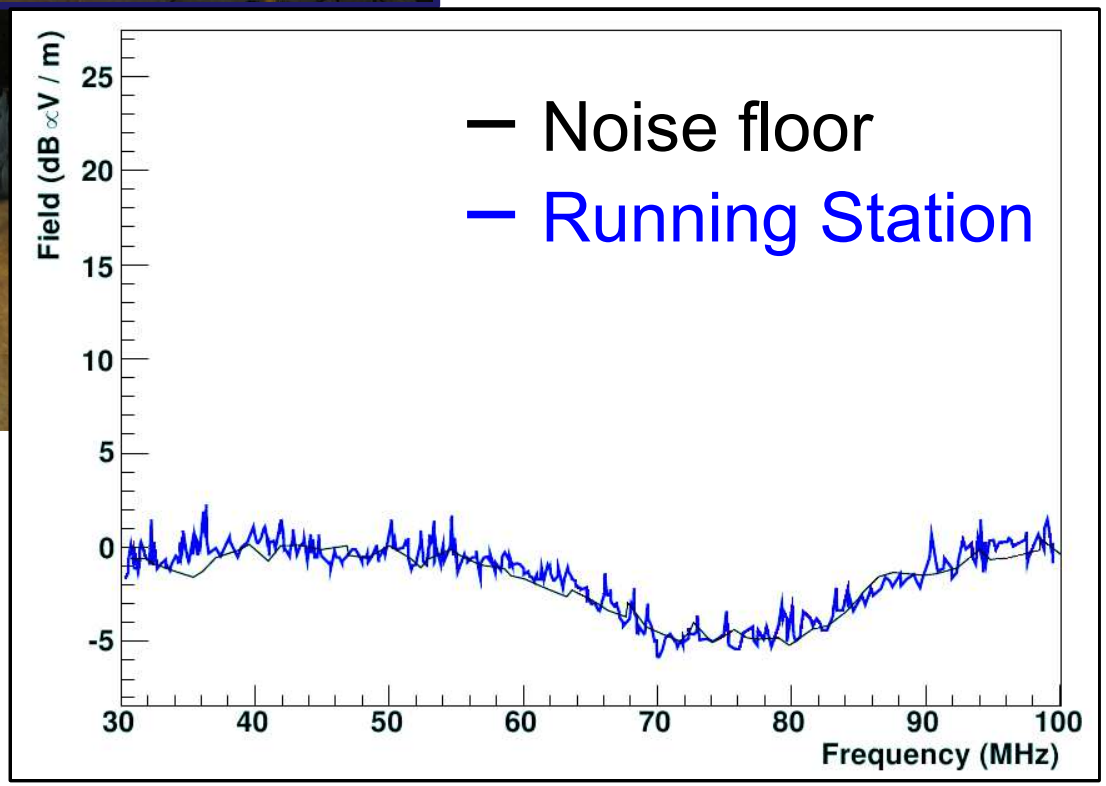
Test of Assembled Hardware Components

EMC Testing Chamber



'Radio Quietness' of the hardware:

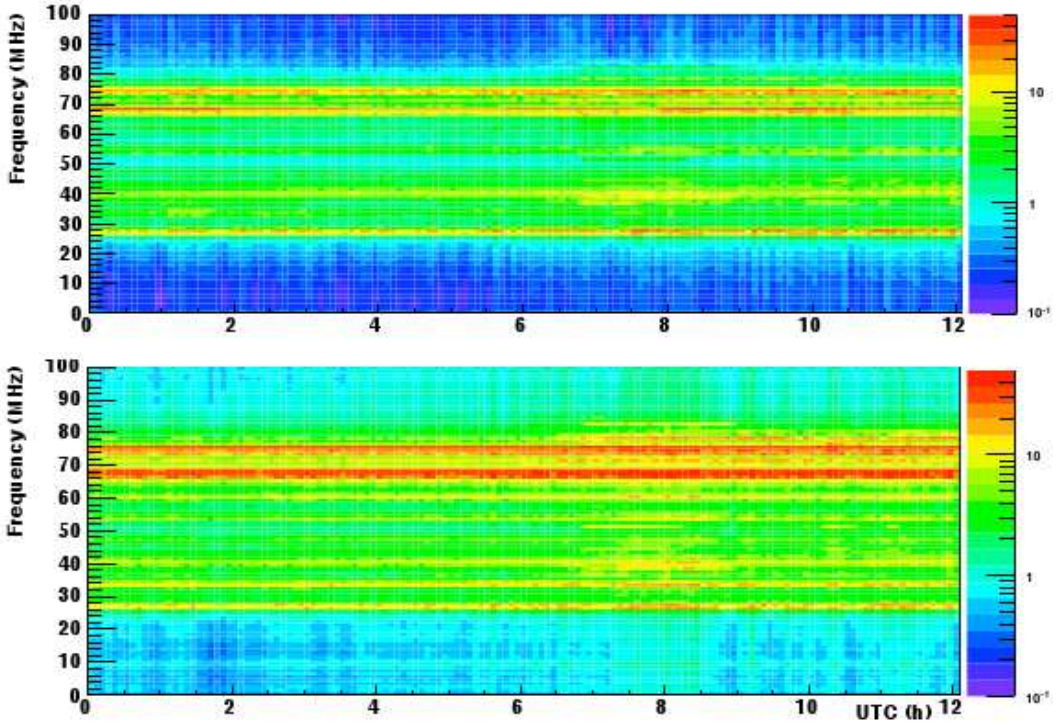
- Shielded box
- Carefully selected items



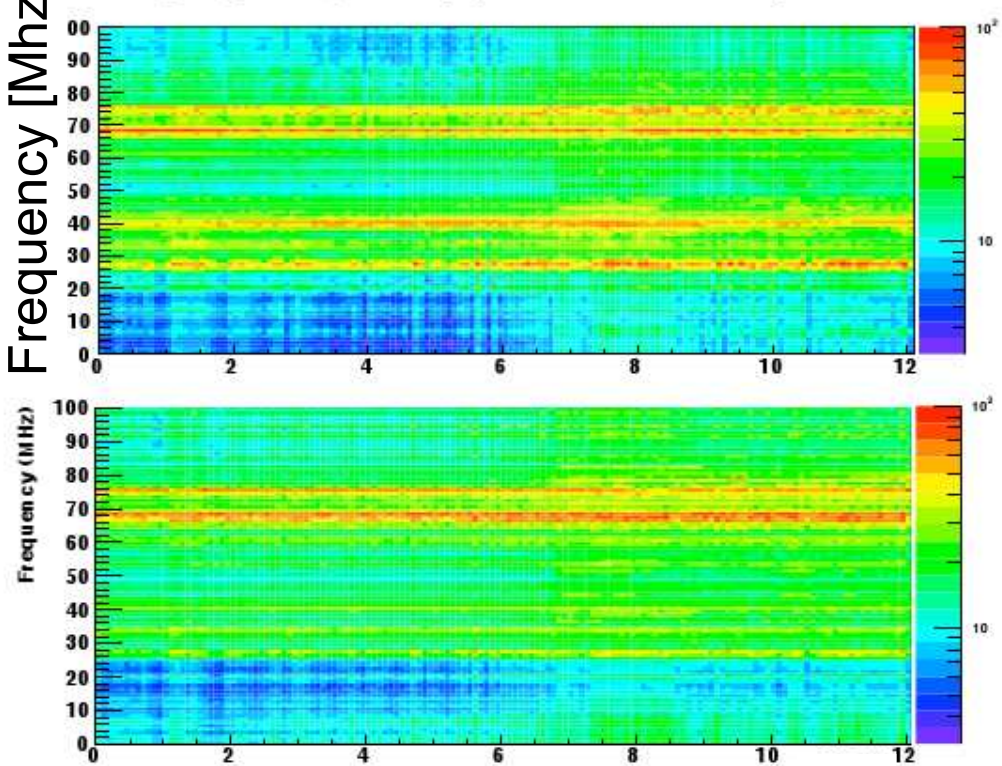
Test of Assembled Hardware Components

Take some noise data in Nijmegen

Low gain (NS upper, EW lower)



High gain (NS upper, EW lower)

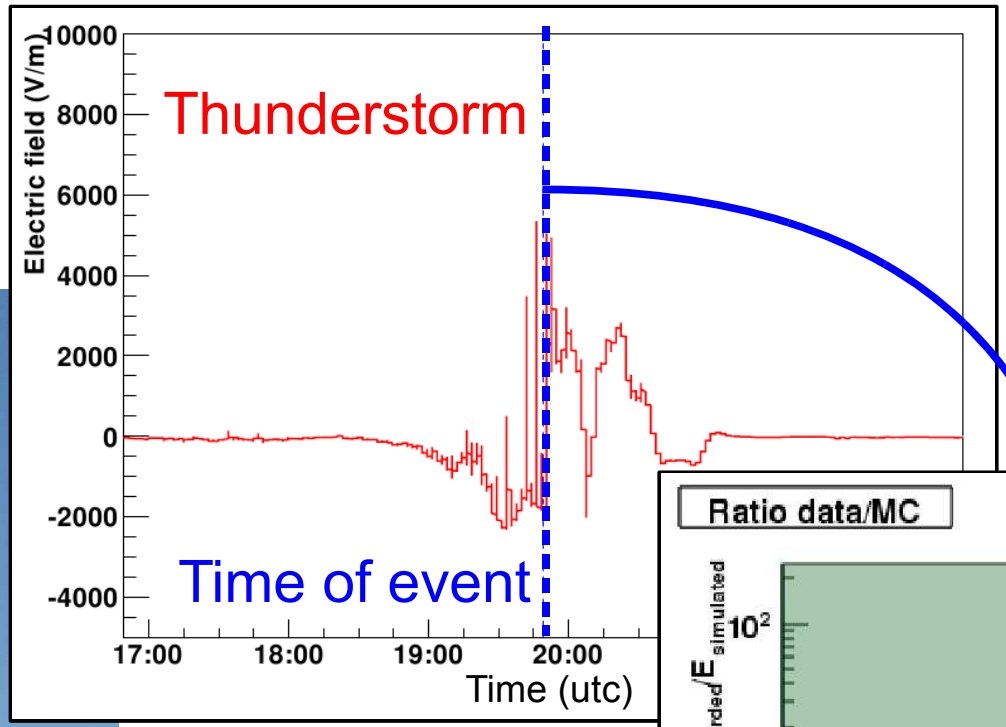


Central Radio Station

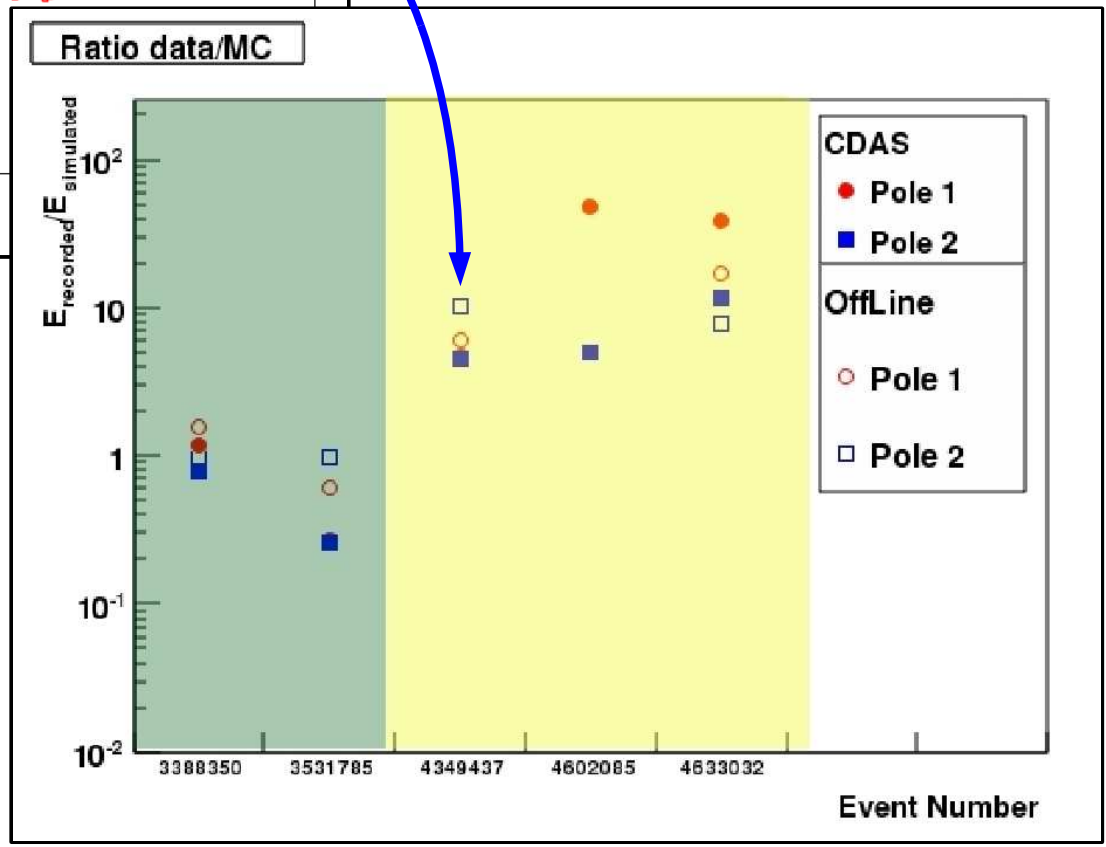
Home of...
- Data Acquisition
- Workshop
- Monitoring (Weather, Earth's elec. field, ..)

Powered with solar panels
Consumption: ~ 460 W

Weather and Earth's Electric Field Observation



How does the electric field effect radio pulse?

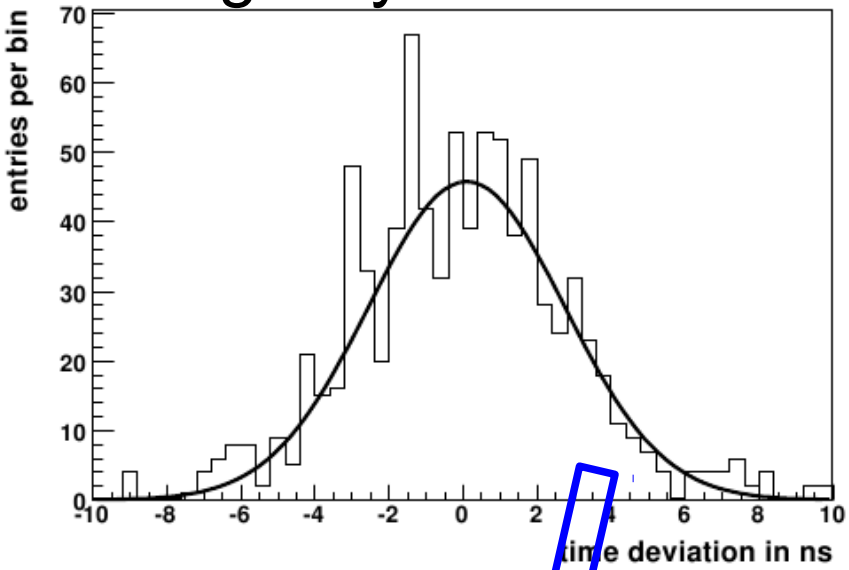


AERA Auger Engineering Radio Array

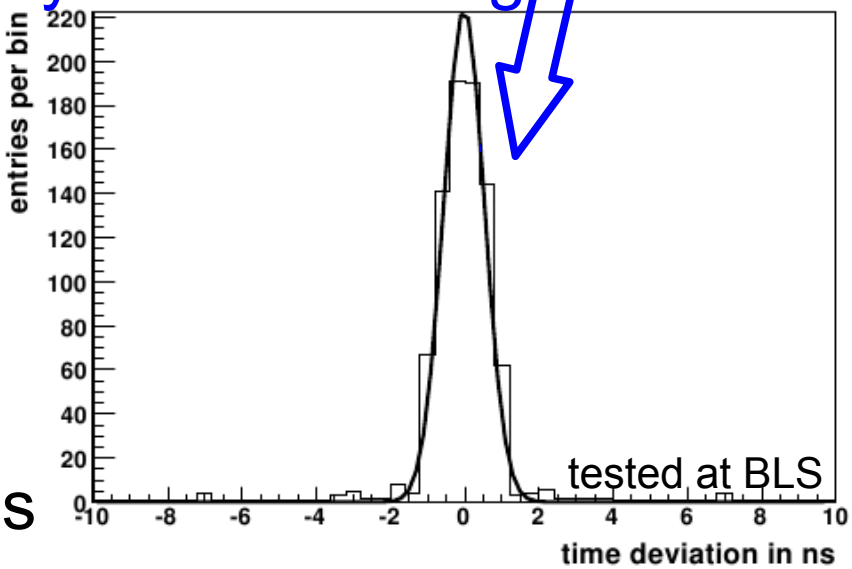
Beacon Timing

Beacon installed at Auger

GPS timing only



Apply beacon timing



Beacon timing :

Time resolution of RDS ~ 1 ns

Radio in Auger Software Framework

Auger software framework for:
- Reconstruction
- Simulation
- Calibration
- Visualization

GAP-2010-056

The radio extension of Auger Offline

Stefan Fliescher[a], Daniël Fraenkel[b], Benjamin Fuchs[d], Stefan Grebe[f,g], Tim Huege[c], Michael Konzack[d], Maximilien Melissas[d], Pietro Oliva[h], Nunzia Palmieri[d], Julian Rautenberg[h], Adrian Schmidt[e], Harm Schoorlemmer[f,g], Frank Schröder[e], Anne Stutz[i], Krijn de Vries[b].

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[a] RWTH Aachen University, Germany
[b] Kernfysisch Versneller Instituut, Netherlands
[c] Karlsruher Institut für Technologie, Institut für Kernphysik, Germany
[d] Karlsruher Institut für Technologie, Institut für Experimentelle Kernphysik, Germany
[e] Karlsruher Institut für Technologie - Institut für Prozessdatenverarbeitung und Elektronik, Germany
[f] IMAPP, Radboud University Nijmegen, The Netherlands
[g] NIKHEF Amsterdam and Nijmegen, The Netherlands
[h] Bergische Universität Wuppertal, Germany
[i] Grenoble Laboratoire de Physique Subatomique et de Cosmologie, France

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Full reconstruction ready for AERA

Key for:

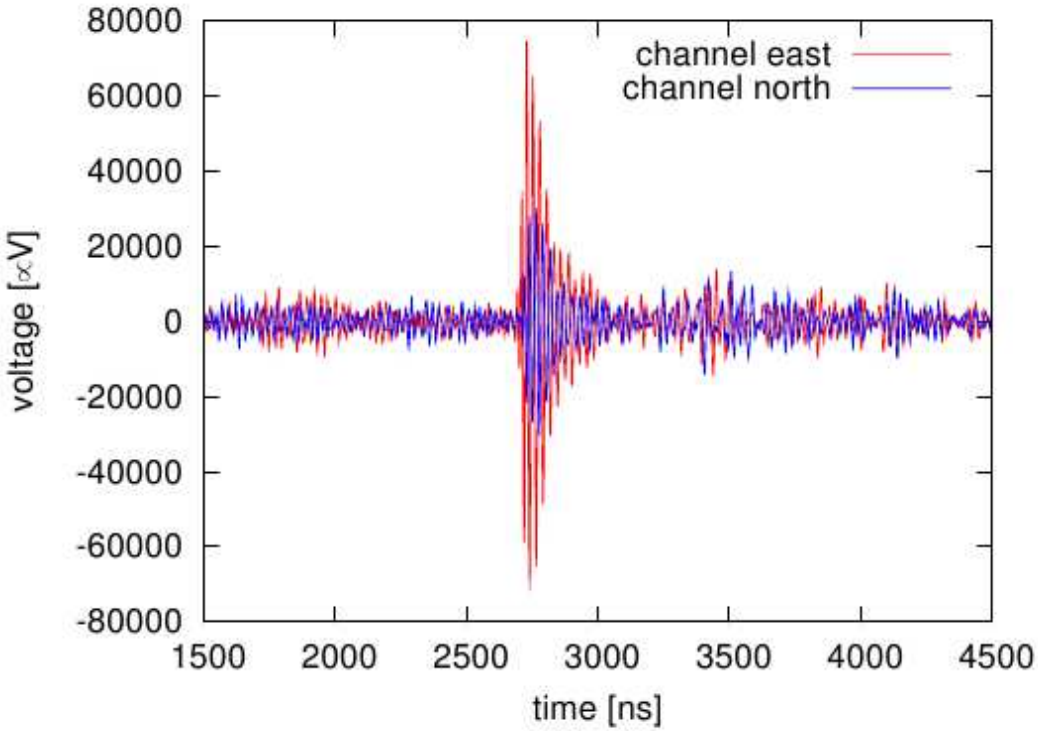
' Super-Hybrid Reconstruction '

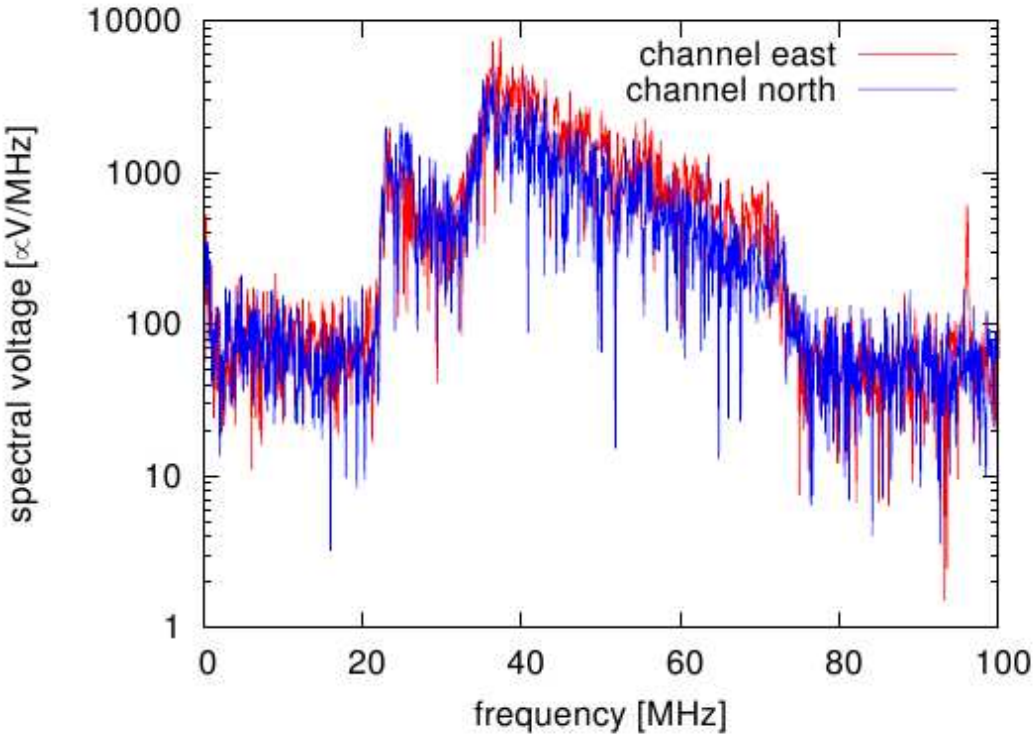
Radio Fluorescence Surface

→ Poster Daniël Fraenkel

Event Reconstruction with Radio Offline

Measured coincident radio event



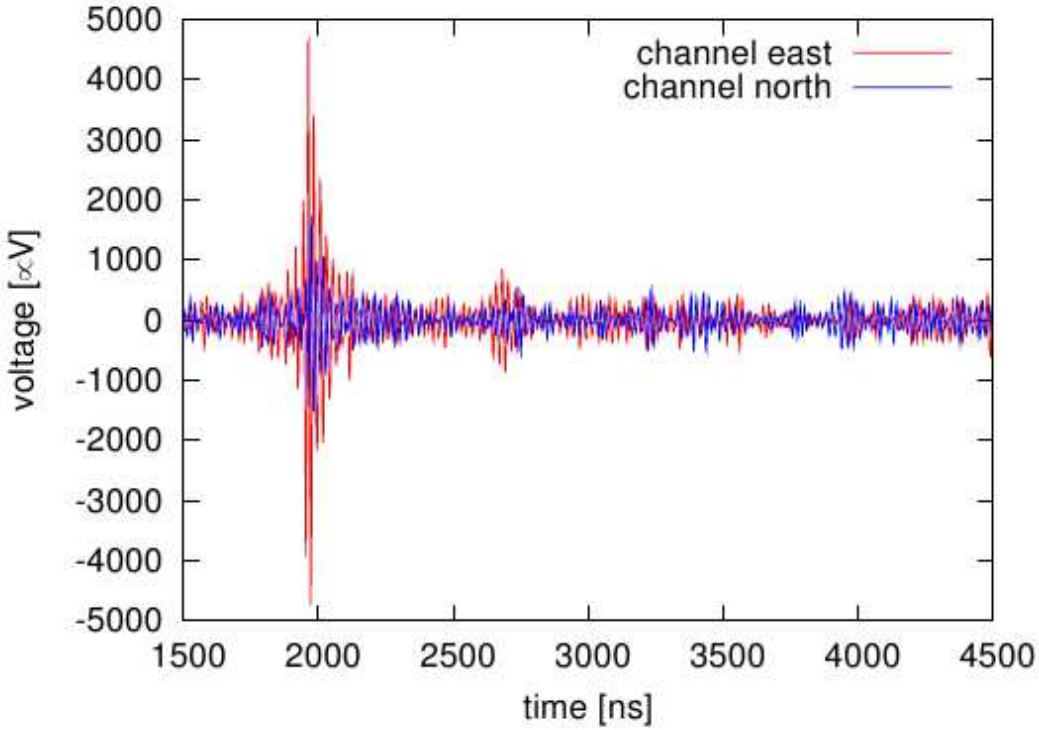


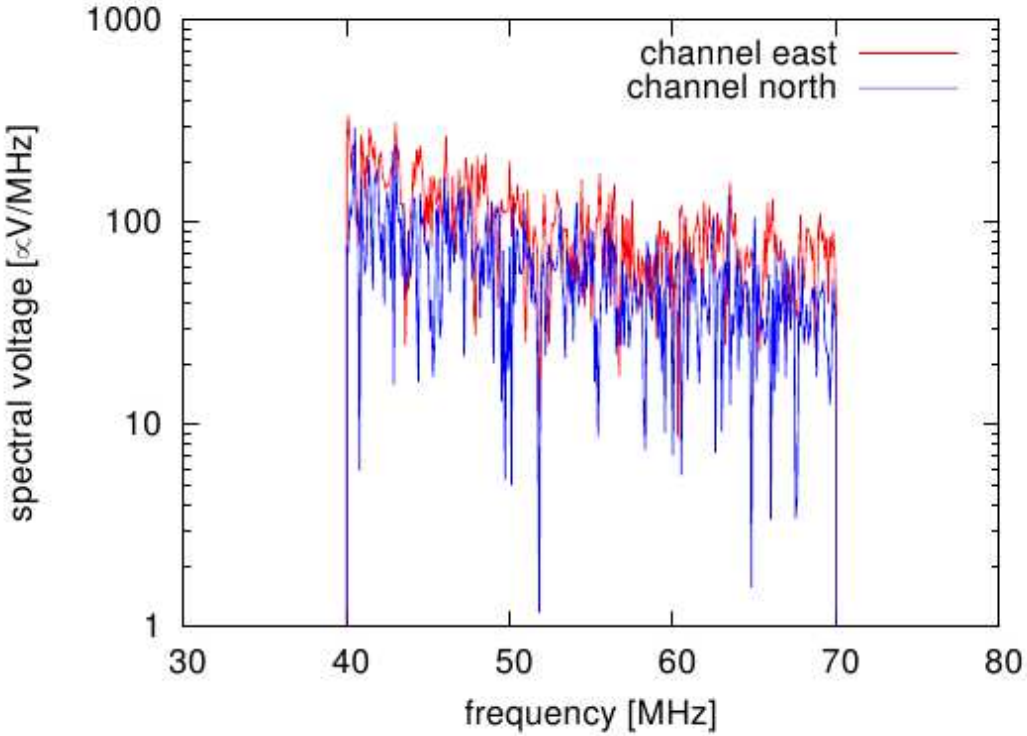
→ Poster Daniël Fraenkel

Event Reconstruction with Radio Offline

Measured coincident radio event

⇨ Remove impact of cables, filters, amplifiers





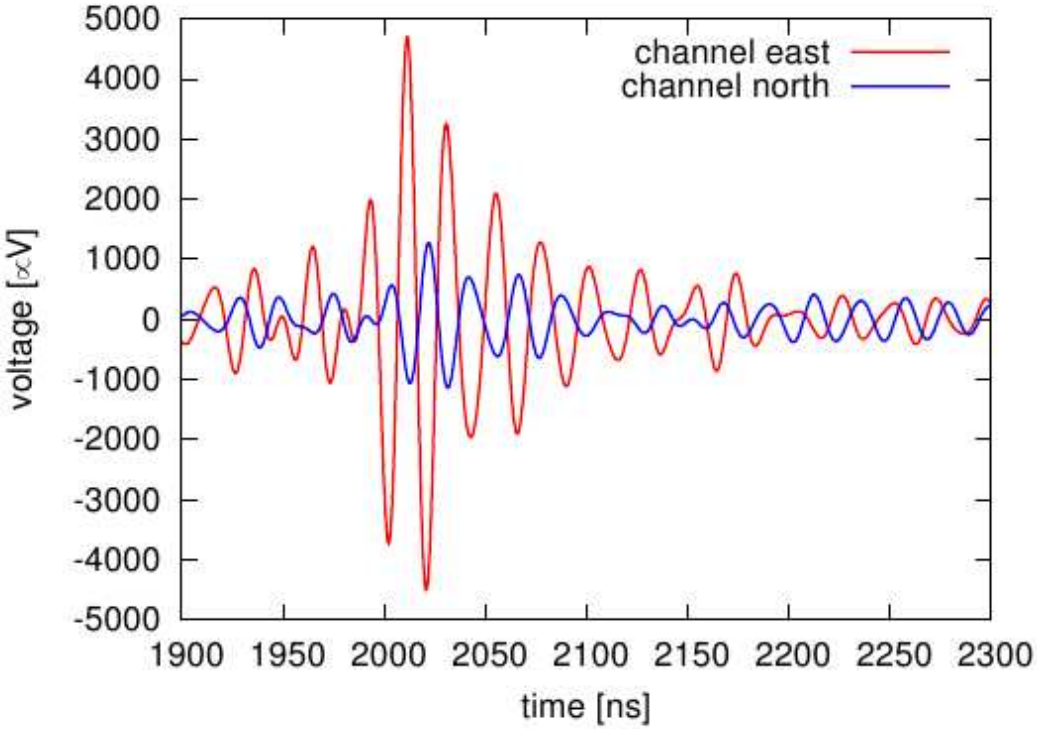
→ Poster Daniël Fraenkel

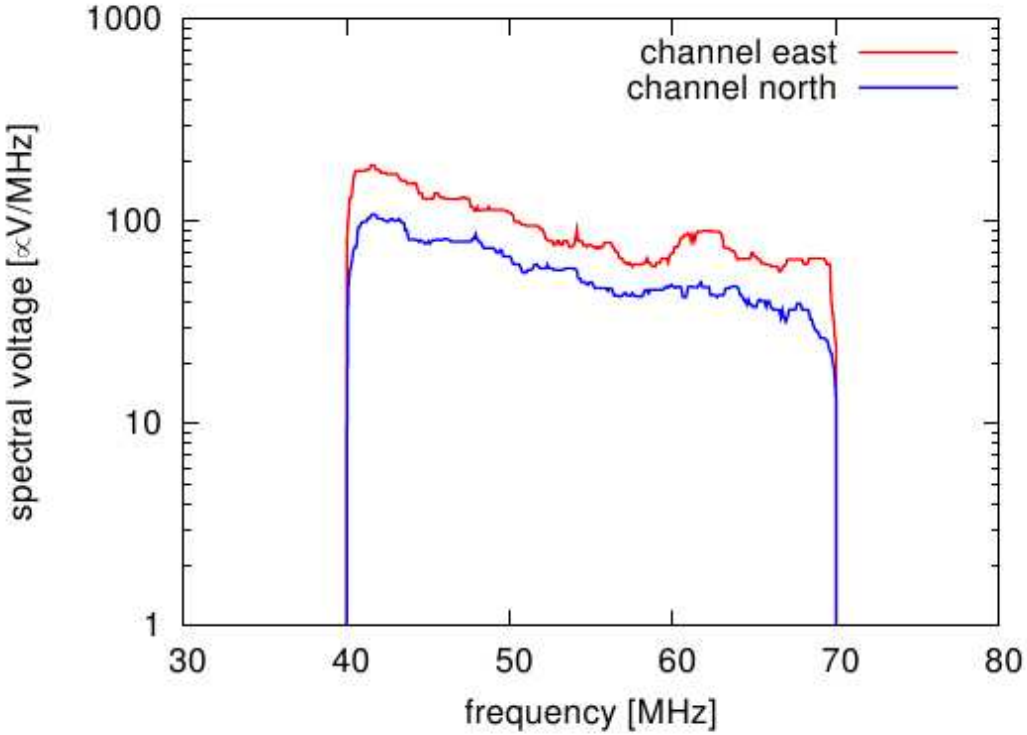
Event Reconstruction with Radio Offline

Measured coincident radio event

⇨ Remove impact of cables, filters, amplifiers

⇨ Apply median filter, do upsampling





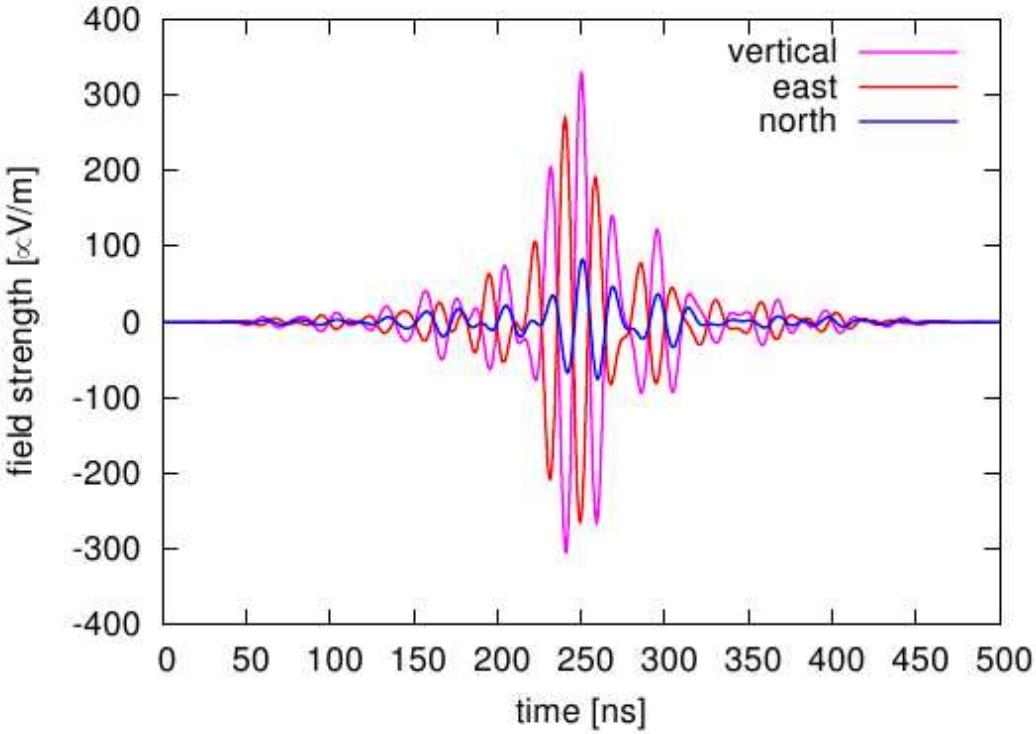
→ Poster Daniël Fraenkel

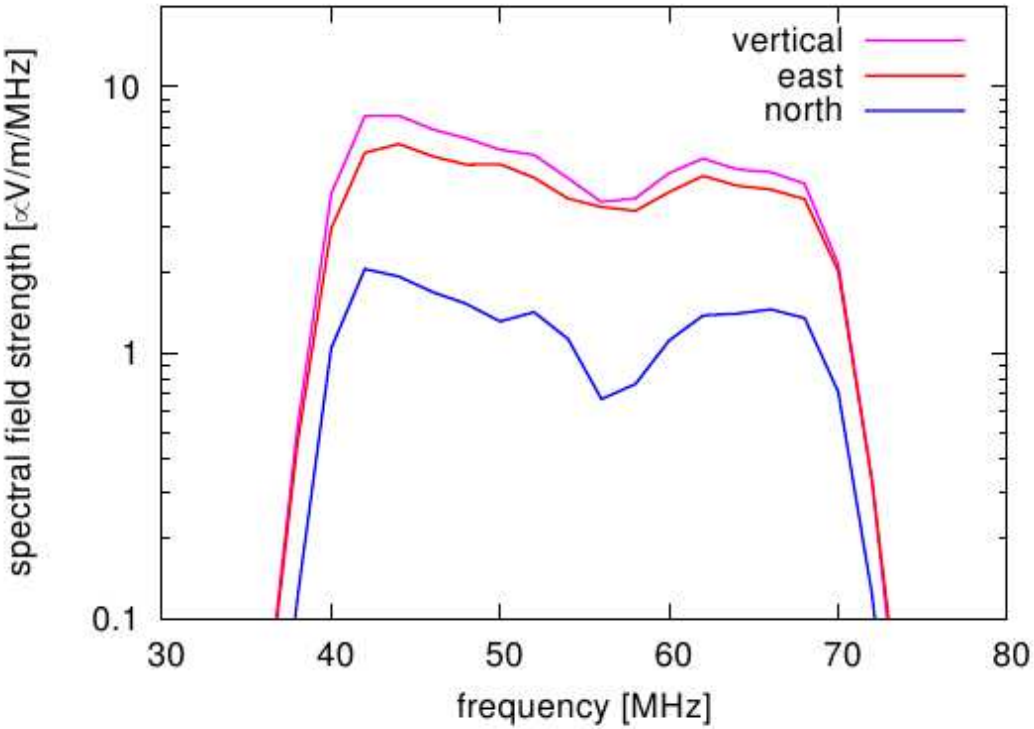
Event Reconstruction with Radio Offline

Measured coincident radio event

↳ Remove impact of cables, filters, amplifiers

↳ Apply median filter, do upsampling





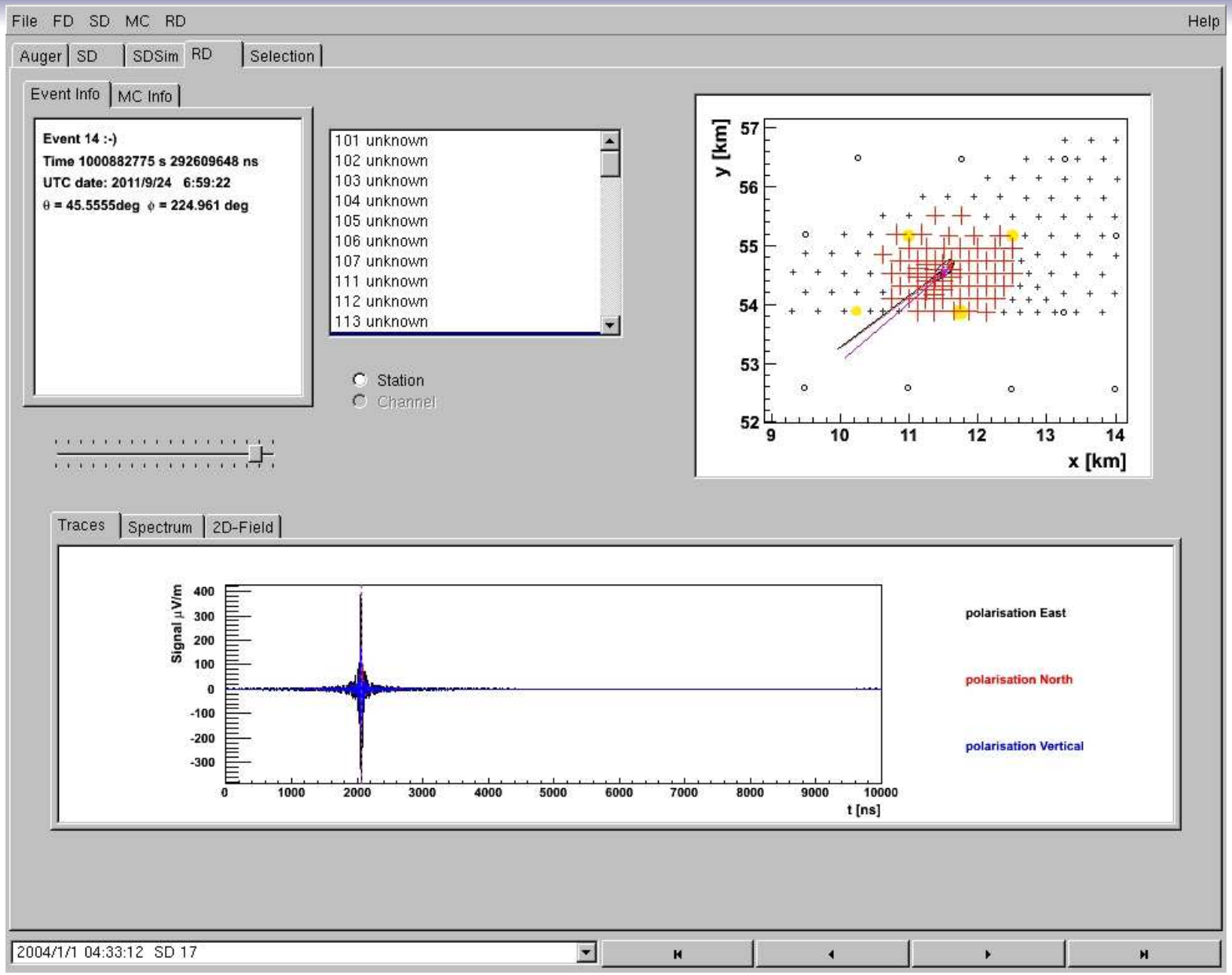
→ Poster Daniël Fraenkel

↳ Apply Hann window

↳ Remove antenna response (φ,θ,f - dependent)

↳ Reconstruct full 3D electric field vector

Event View Simulated „Hybrid Event“

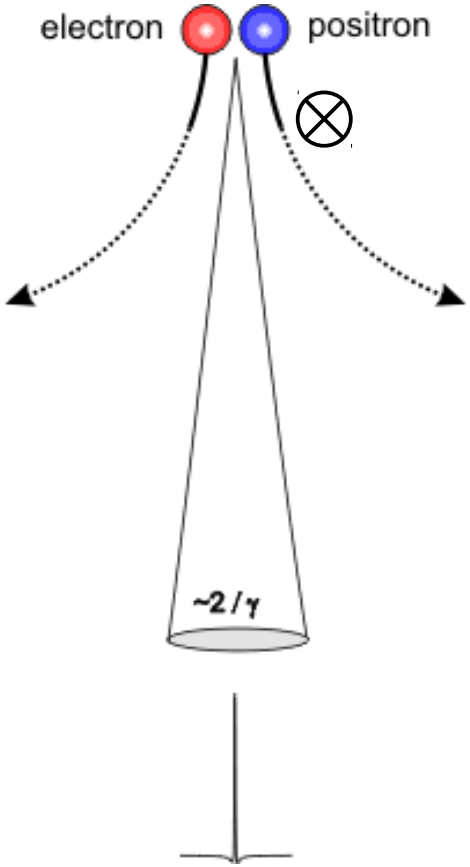


Event seen by Auger Surface Detector and AERA

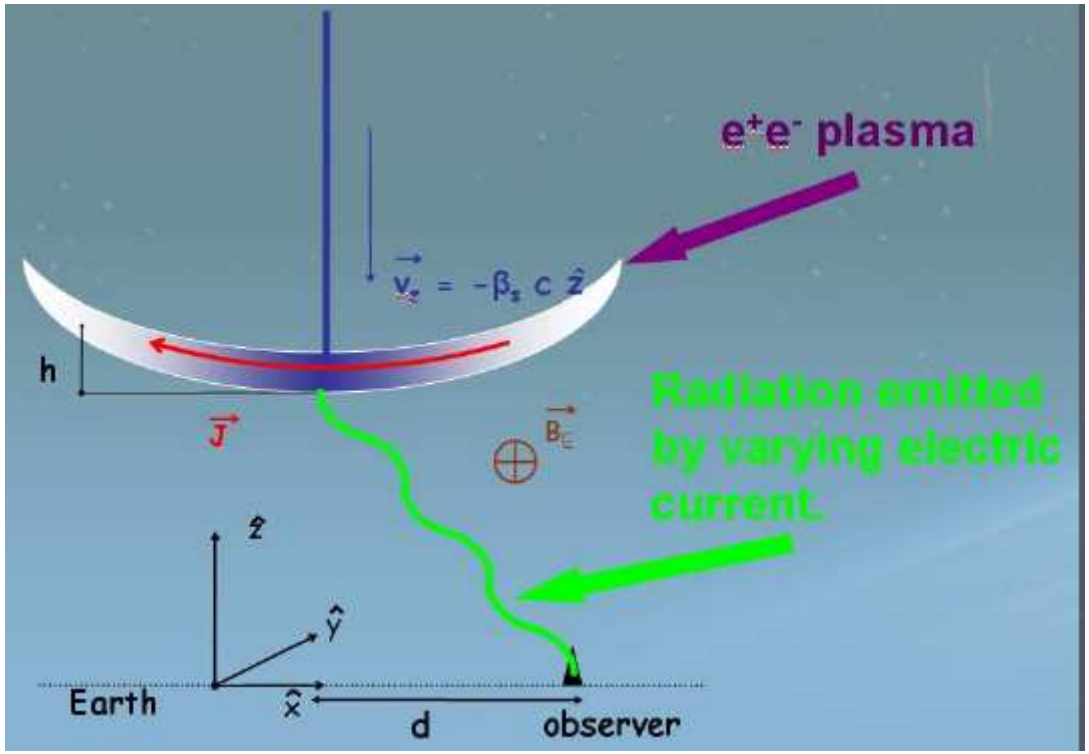
Theoretical Expectations

Charged shower particles + magnetic field of the earth...

Microscopic model



Macroscopic model



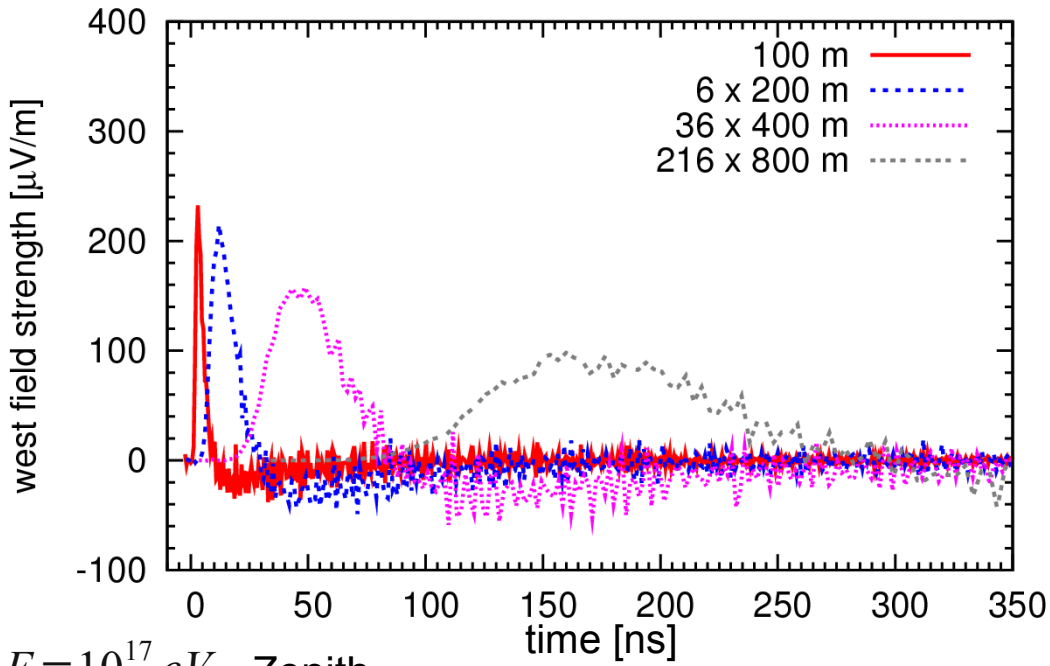
Summing contributions of individual particles

Emission from varying net current

Coherent emission at radio frequencies

Theoretical Expectations

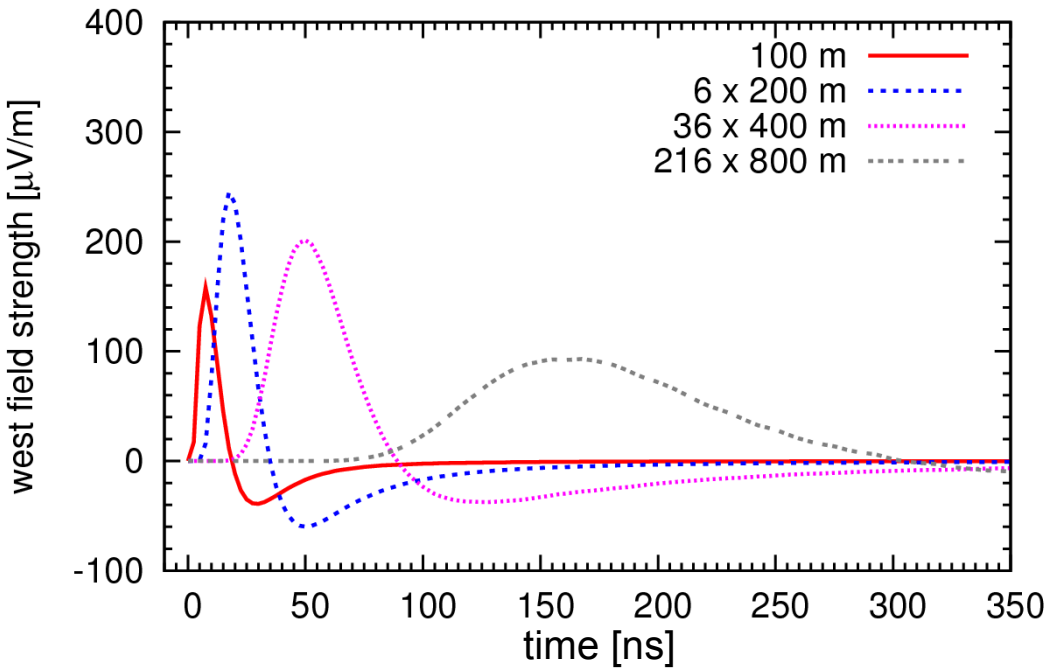
Microscopic model



$E = 10^{17}\,eV$, Zenith

REAS 3

Macroscopic model



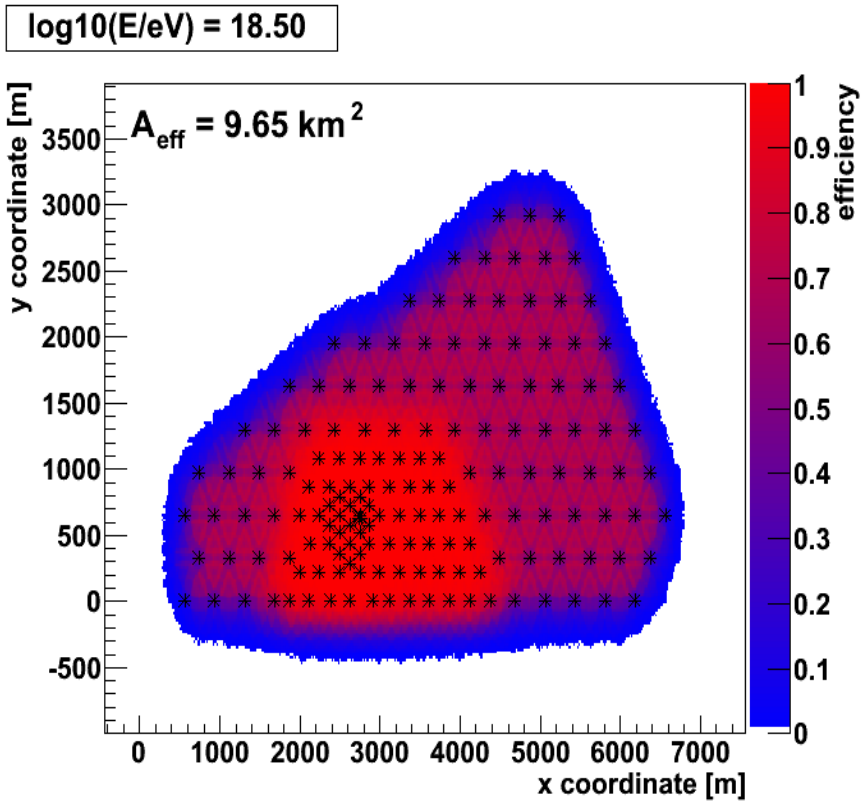
MGRM

- Similar pulse shapes
- Similar field strengths
- Dominant signal contribution:
  Radio frequencies 1-100 MHz

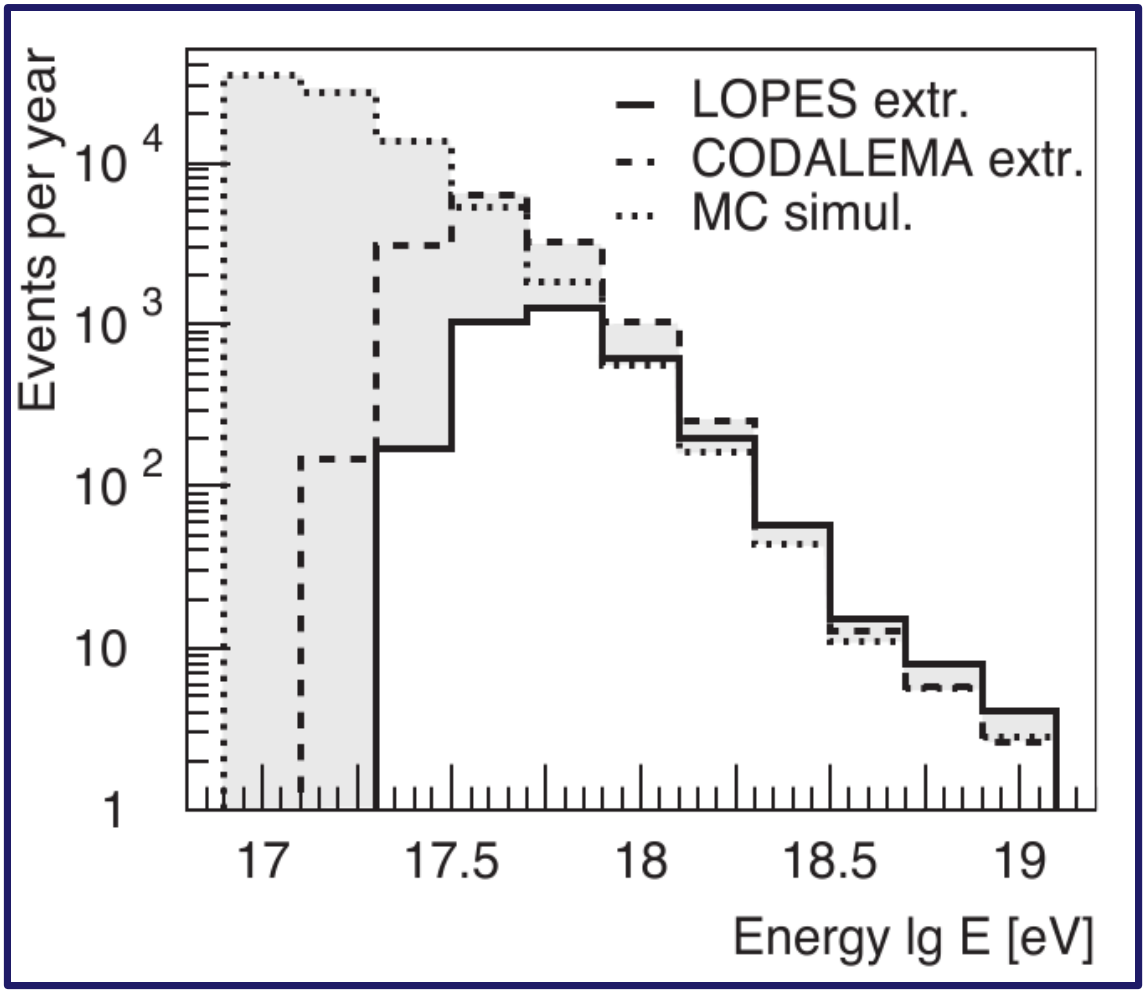
→ Talk Tim Huege

Expected Event Rate

Simulate Detection Efficieny...

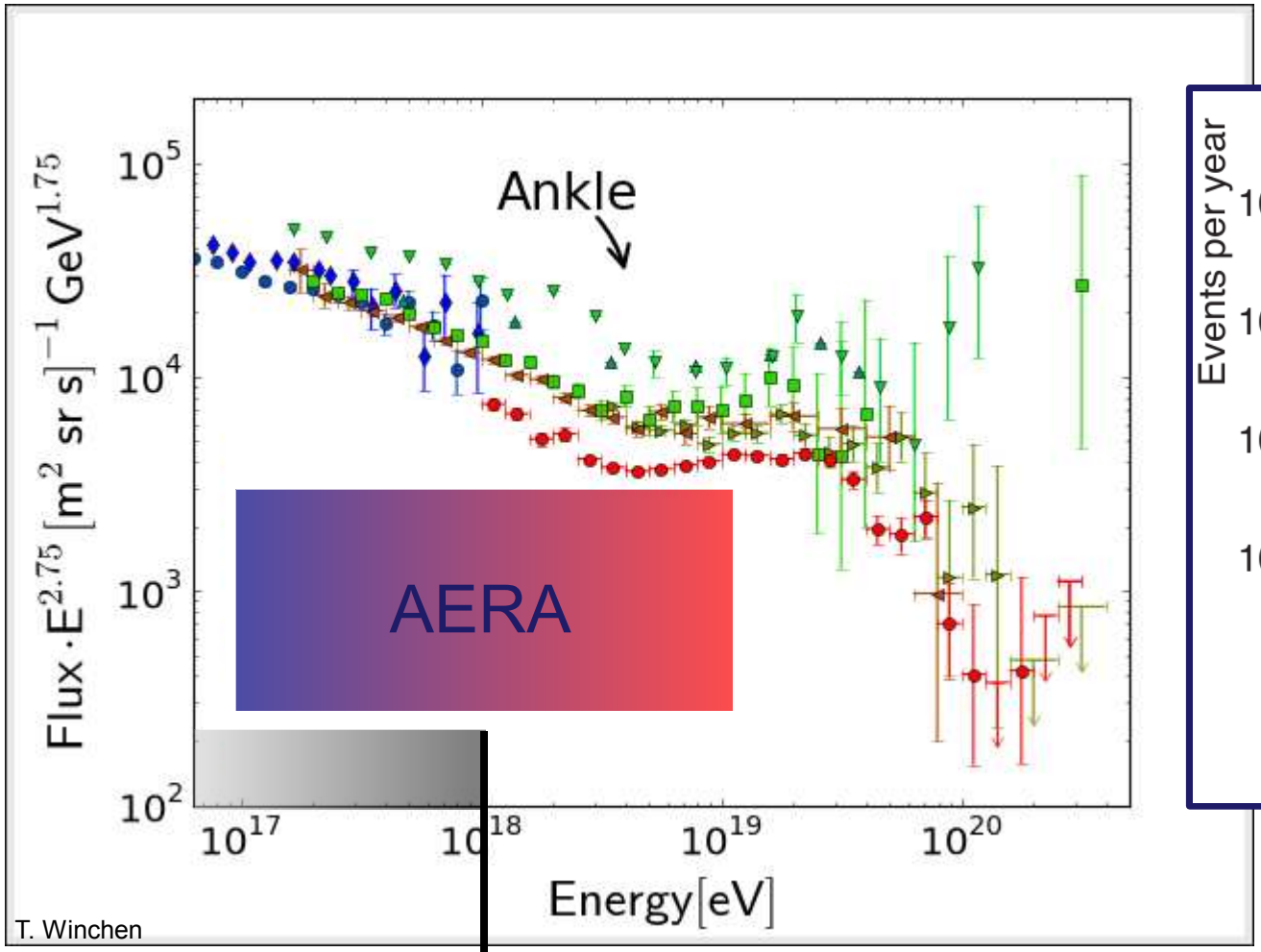


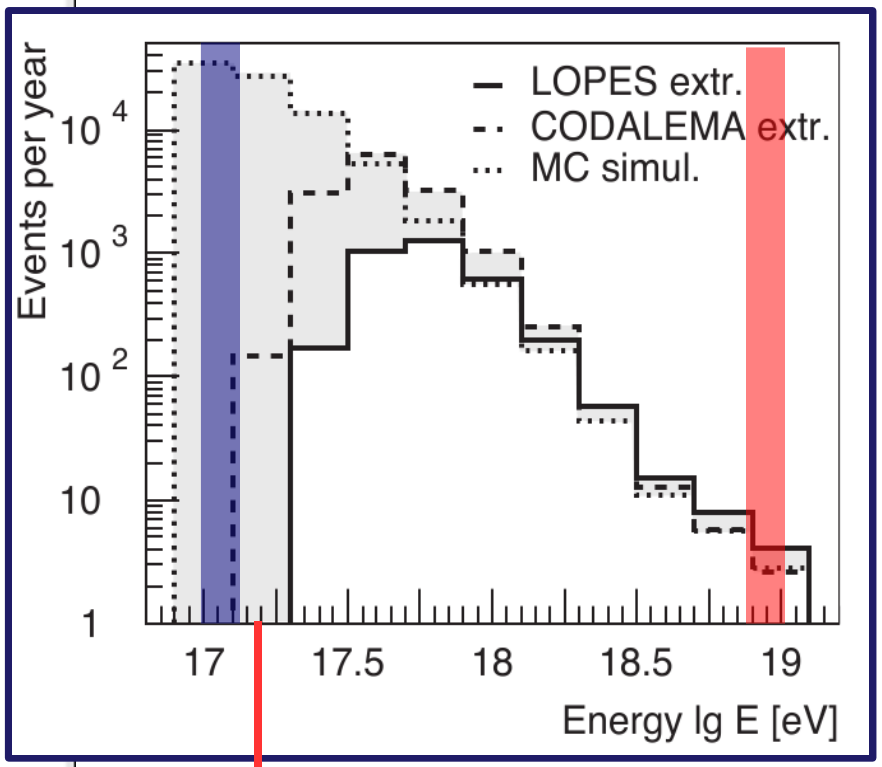
...calculate an event rate estimate



Expect several thousand air shower events per year

Expected Event Rate





Highest energies
CODALEMA & LOPES

Akeno
Kascade
Kascade Grande
Yakustk
Haverah Park
Fly's Eye
Hires I
Hires II
Auger 2009

Energy threshold
of Auger
incl. enhancements

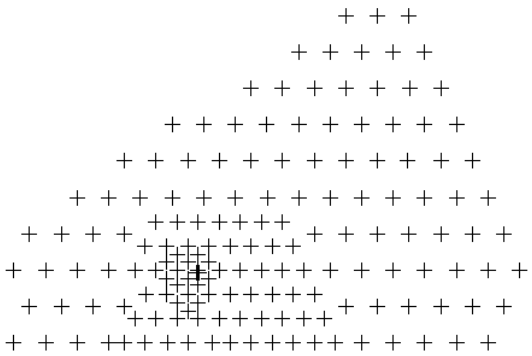
Summary & Outlook

Large Radio efforts at Auger

Midas & Amber have approval to set up at the Auger site and start first coincident measurement with SD and FD

Auger Engeneering Radio Array

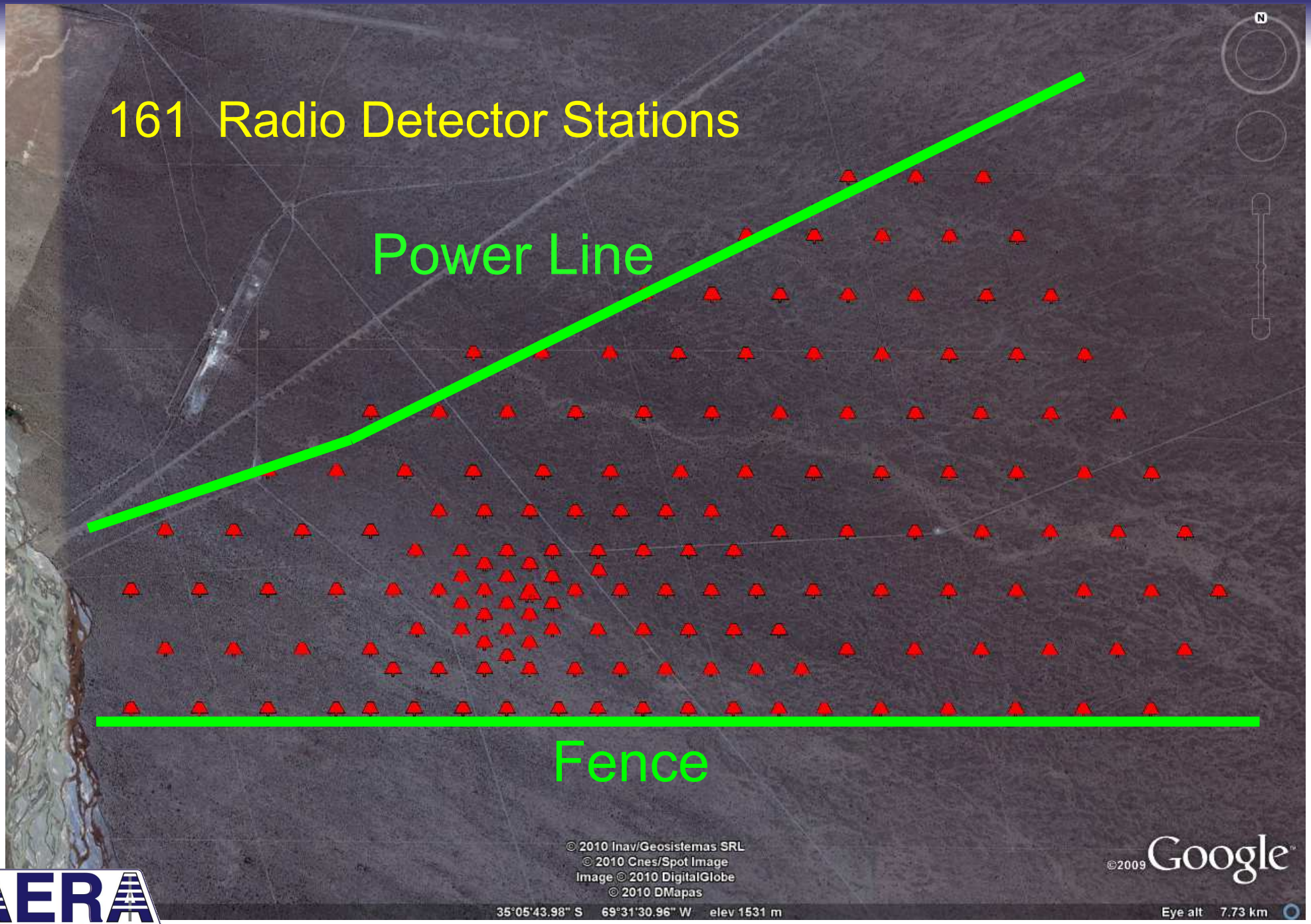
10 Institutes
161 Radio Detector Stations, 20 km²
Phase 1: 24 stations
Data taking scheduled for August



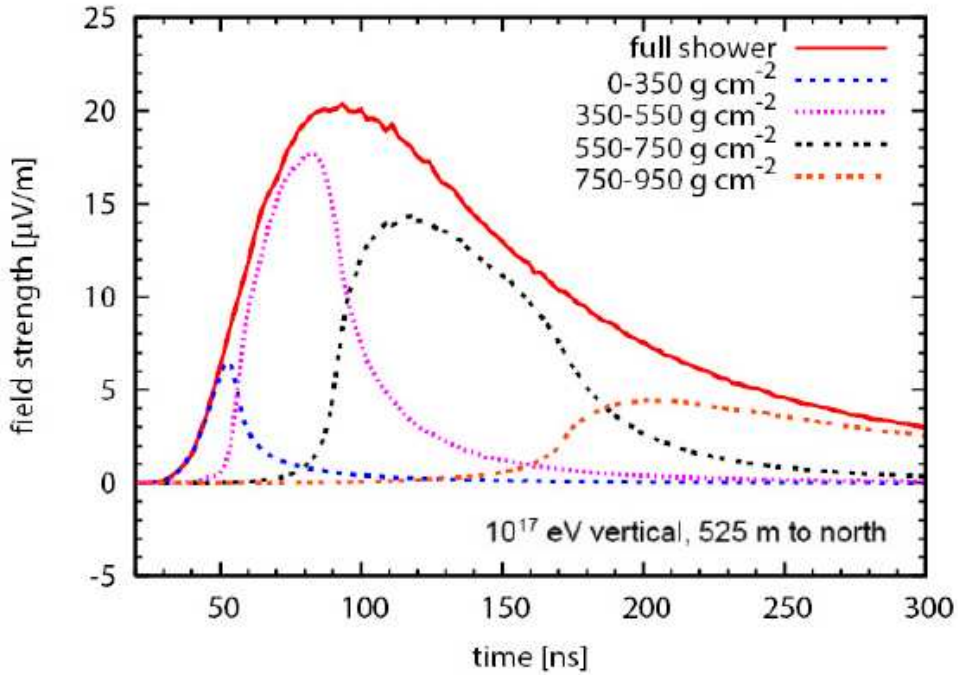
→ Details of Radio emission
→ Potential of Radio
→ Nature of cosmic ray at the transition region

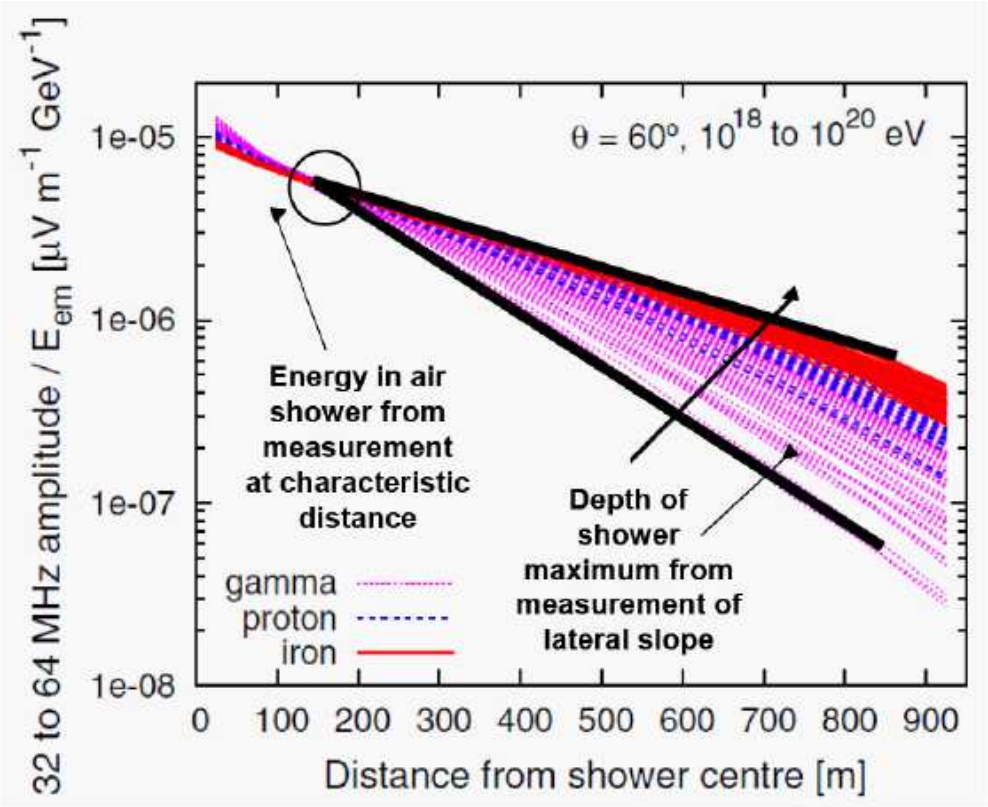
' Super-Hybrid ': Unique possiblity to study UHECRs

Layout of AERA



Some Handels on Shower Parameters





T. Huege, R. Ulrich, R. Engel, Astropart. Phys. 27 (2007) 392. T. Huege, R. Ulrich, R. Engel, Astropart. Phys. 30 (2008) 96

Recent Radio Setups at Auger