Karlsruhe Institute of Technology

Auger Engineering Radio Array

PIERRE AUGER OBSERVATORY

Radio Detection of Cosmic Rays in the Pierre Auger Observatory

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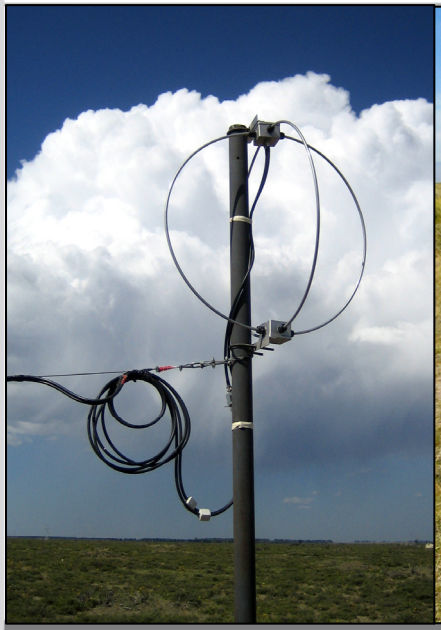
for the Pierre Auger Collaboration

Forschungszentrum Karlsruhe in der Helmholtz-Gemeinschaft

Universität Karlsruhe (TH)
Research University · founded 1825

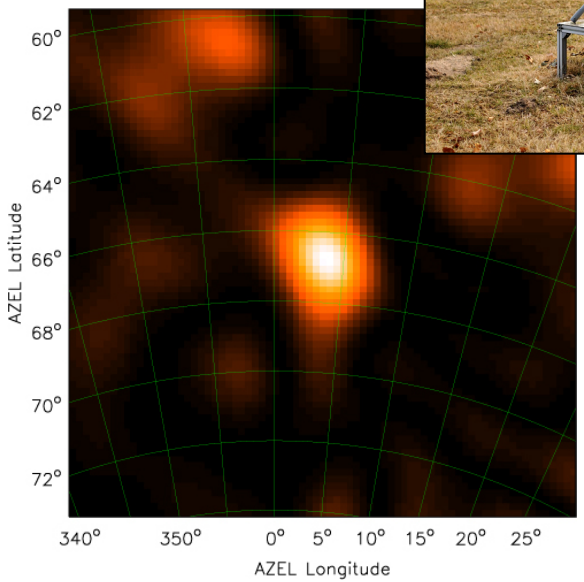


Radio detection of EAS

- **cosmic ray air showers emit pulsed radio signals**
  - **geomagnetic deflection of relativistic electrons and positrons (geosynchrotron, transverse currents)**
  - **coherent in frequency range <100 MHz**
- **ideal complement for existing detection techniques**
  - **24 hours/day operation (10 x fluorescence), ideal for hybrid operation with particle detectors**
  - **large collecting area for moderate cost**
  - **high angular resolution (source localisation)**
- **has been studied with CODALEMA and LOPES experiments up to energies of ~10^{18} eV**

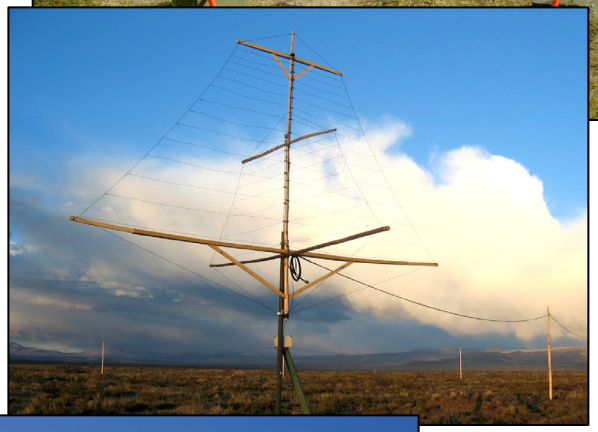
CODALEMA
dipole antenna

LOPES
dipole antenna



radio flash of a cosmic ray air shower seen by LOPES

Large scale radio detection in Auger

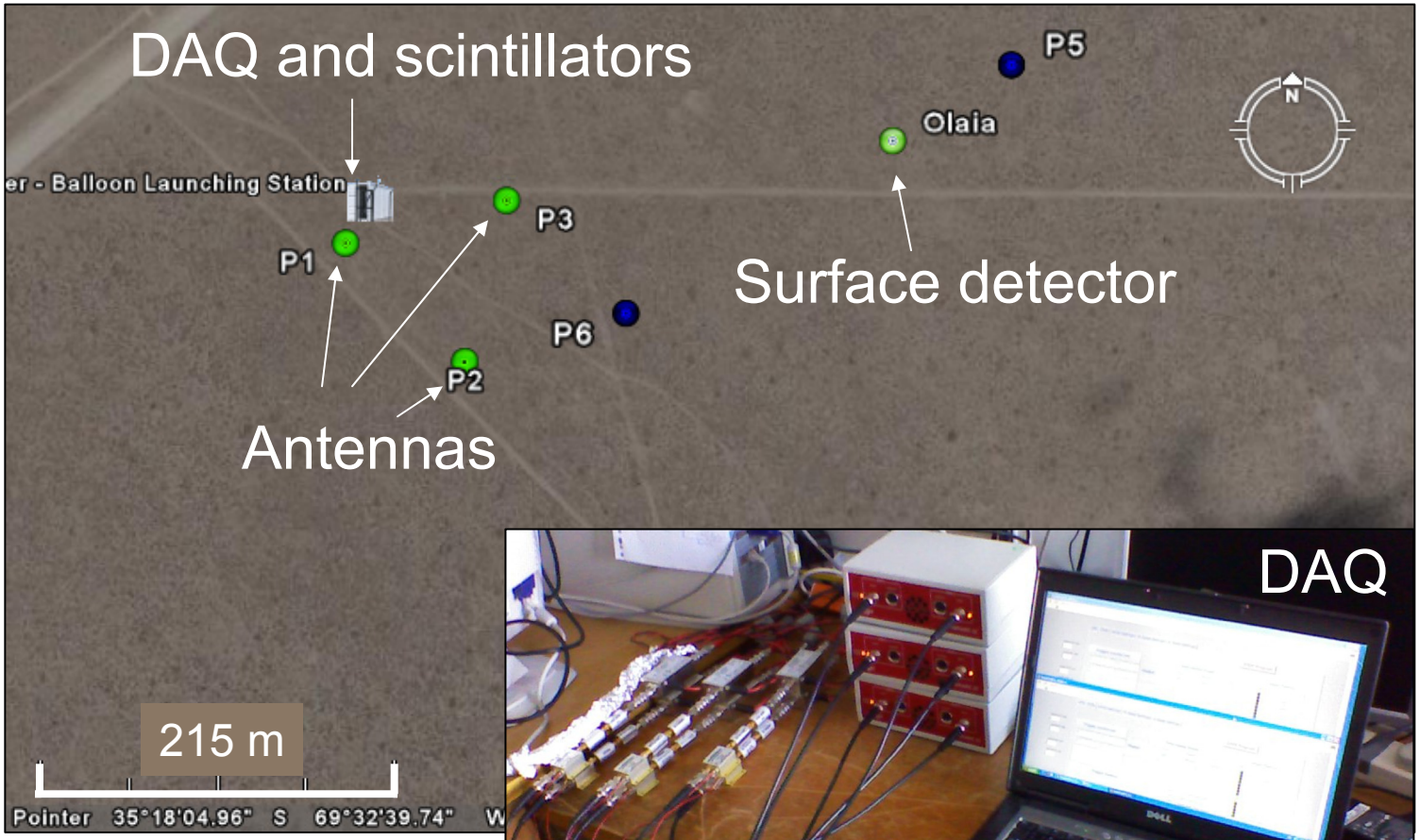


- so far only small experiments (<0.5 km^2)
- radio detection is most interesting for ultra-high energy cosmic rays
- develop large-scale application

- R&D in the Pierre Auger Observatory
  - allows hybrid analysis together with particle and fluorescence detectors
  - in Argentinian pampa has very good radio noise conditions

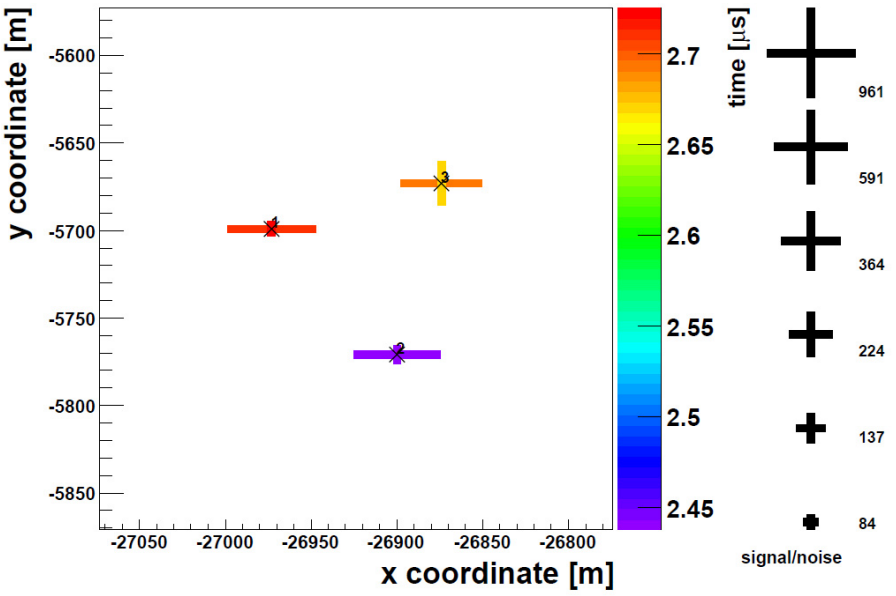
- many technological challenges
  - decentralized array organisation
  - autonomous, self-powered detector stations
  - wireless communication between stations
  - self-triggering on radio signals
  - robustness (cows, strong winds, …)
- R&D so far with a number of small test cells operating in various configurations

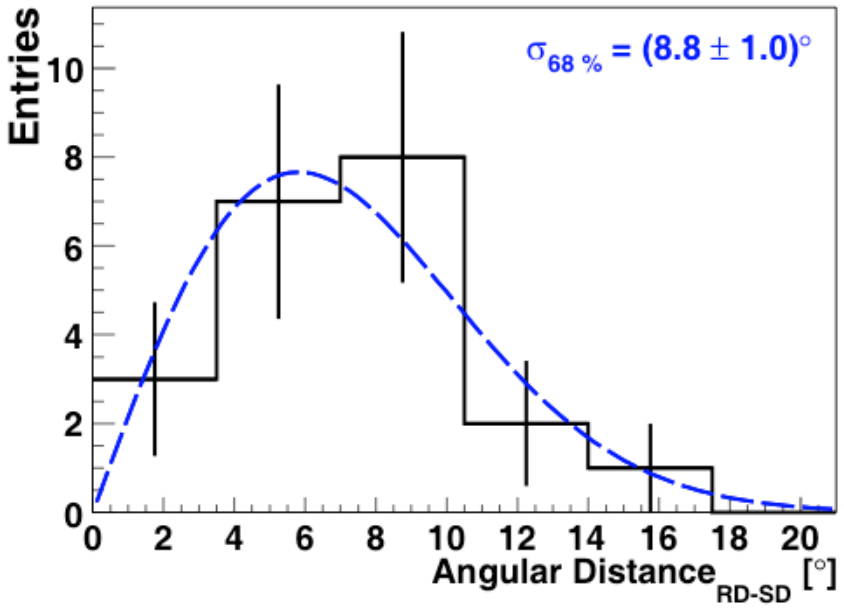
Externally triggered measurements at BLS



- **Two scintillators provide external trigger. “Offline” search for coincidences with Auger SD.**

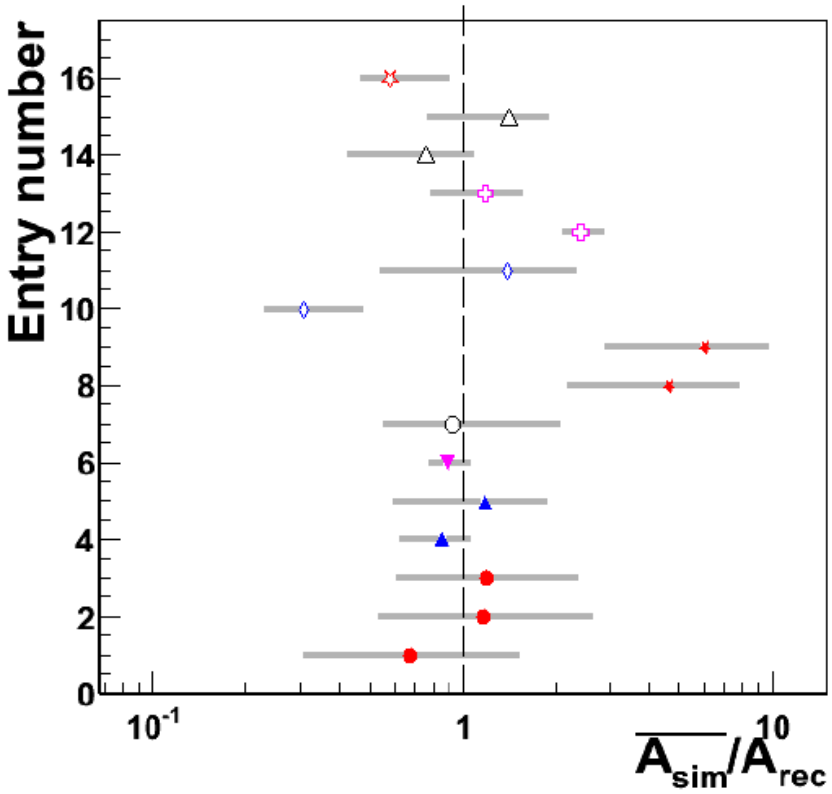
Results of measurements near BLS



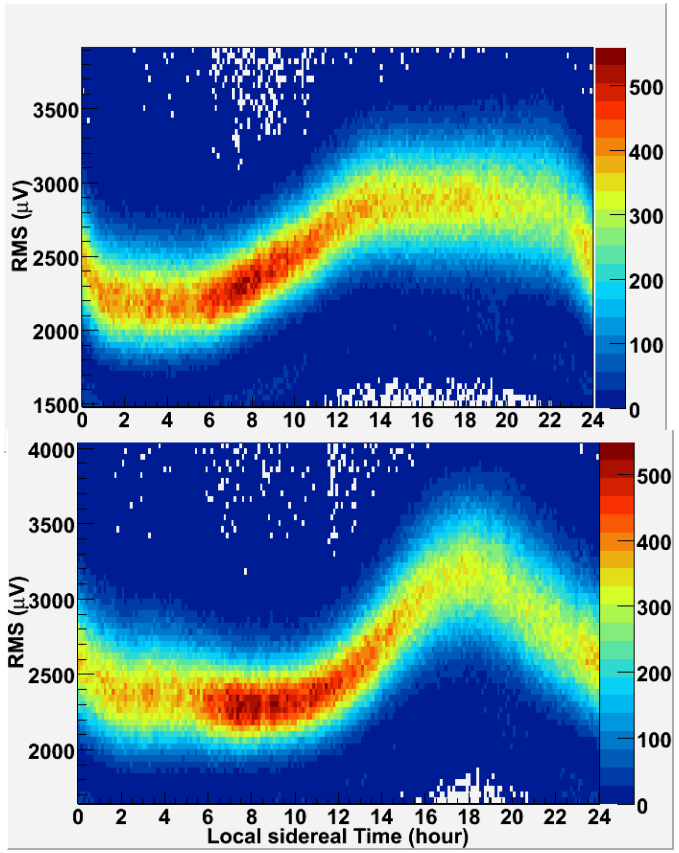


- >25 coincident events between Auger SD and all 3 radio antennas in 2007 (about same number in 2008, not discussed here)
- signal usually seen in both antenna polarisations
- directions reconstructed with SD and radio are compatible
- angular resolution limited by GPS-only timing

Further results from BLS measurements



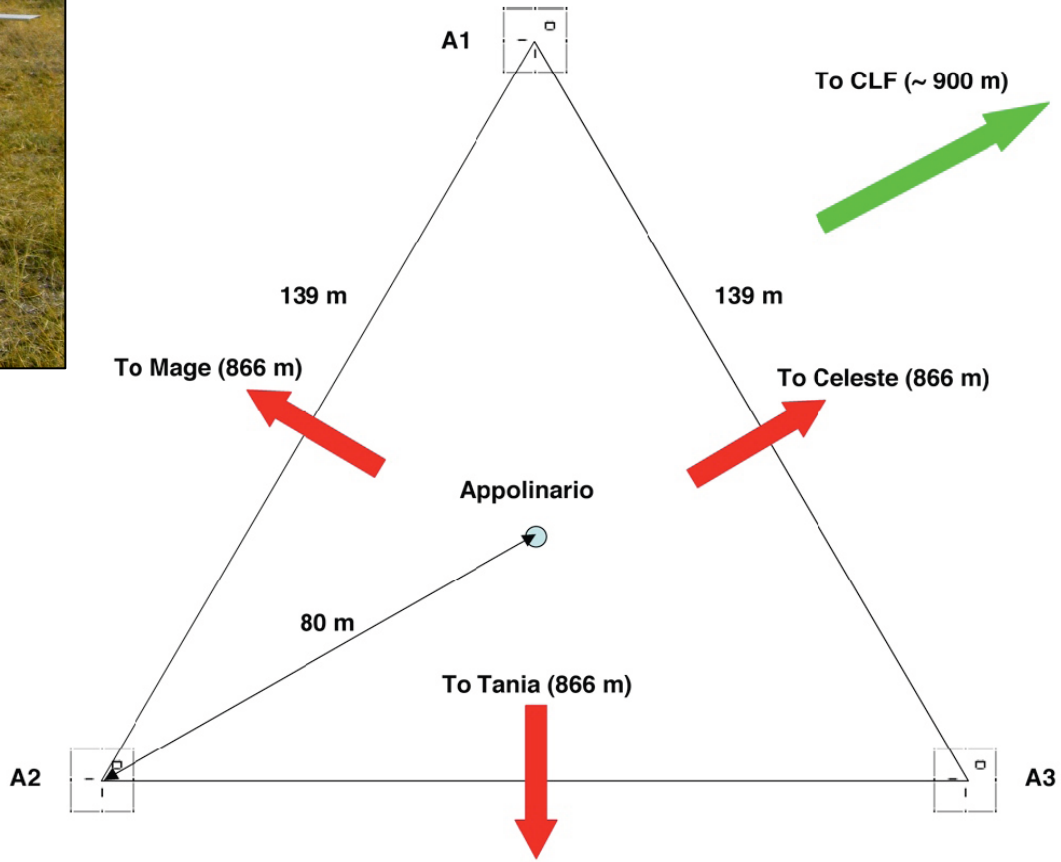
- full event and detector simulation chain (CORSIKA, REAS2, RDAS)
- fair agreement within (relatively large) uncertainties



- radio noise in both polarisations shows passage of Galactic centre
- can be used for amplitude calibration and antenna diagnosis

Self-triggered measurements near CLF

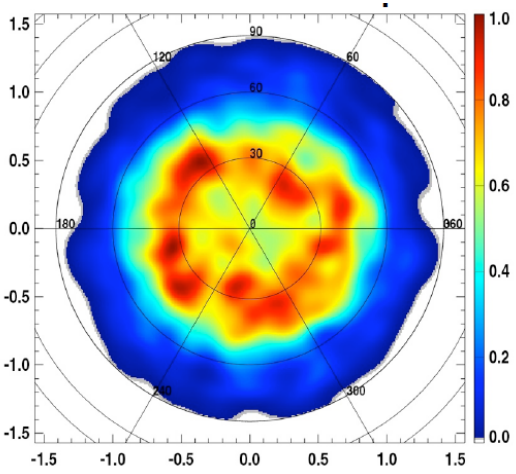
- 3 autonomous stations
  - solar-powered
  - dual-polarisation
  - wireless data link
  - self-triggered on radio signals (50-70 MHz)



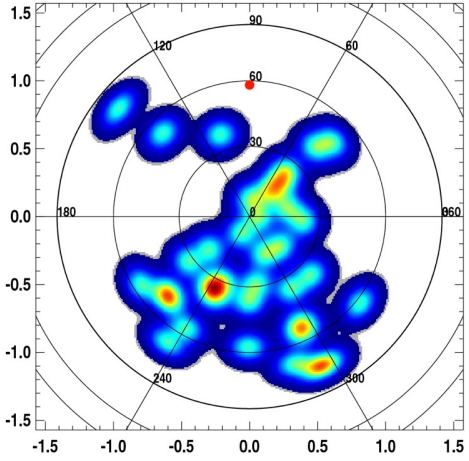
Results of measurements near CLF

- detectors have successfully self-triggered on radio pulses
- found ~60 self-triggered radio events coincident with SD events
  - only one three-fold coincidence so far, though
- ~70% of the radio-triggered events come from south
  - threshold effect
  - confirmation of geomagnetic radio emission mechanism

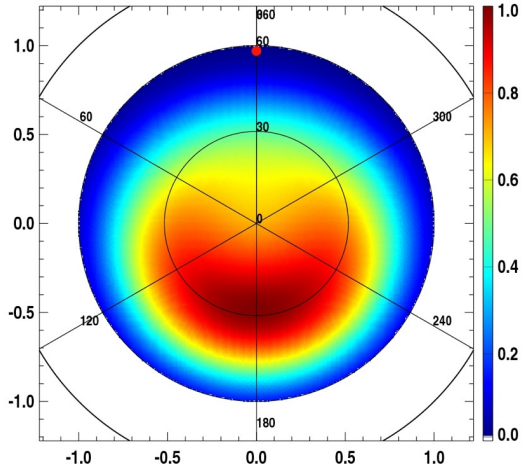
SD events



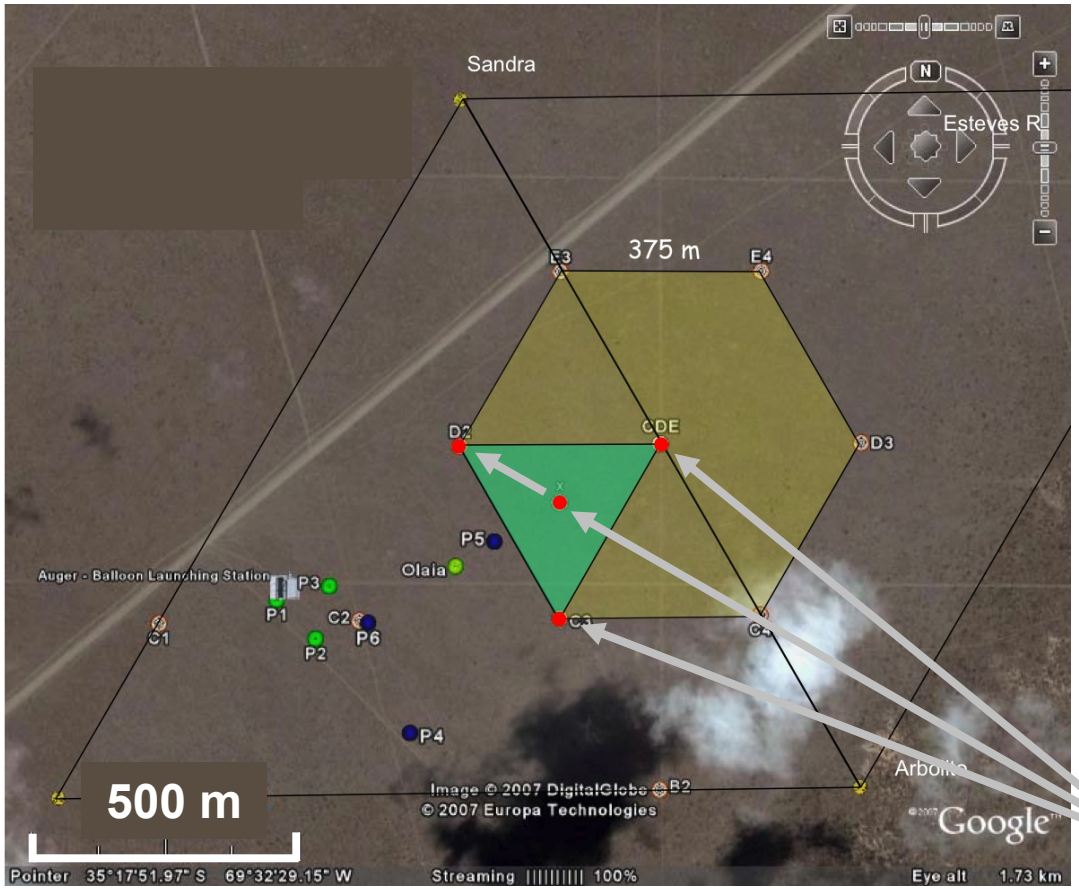
Radio events



v x B model



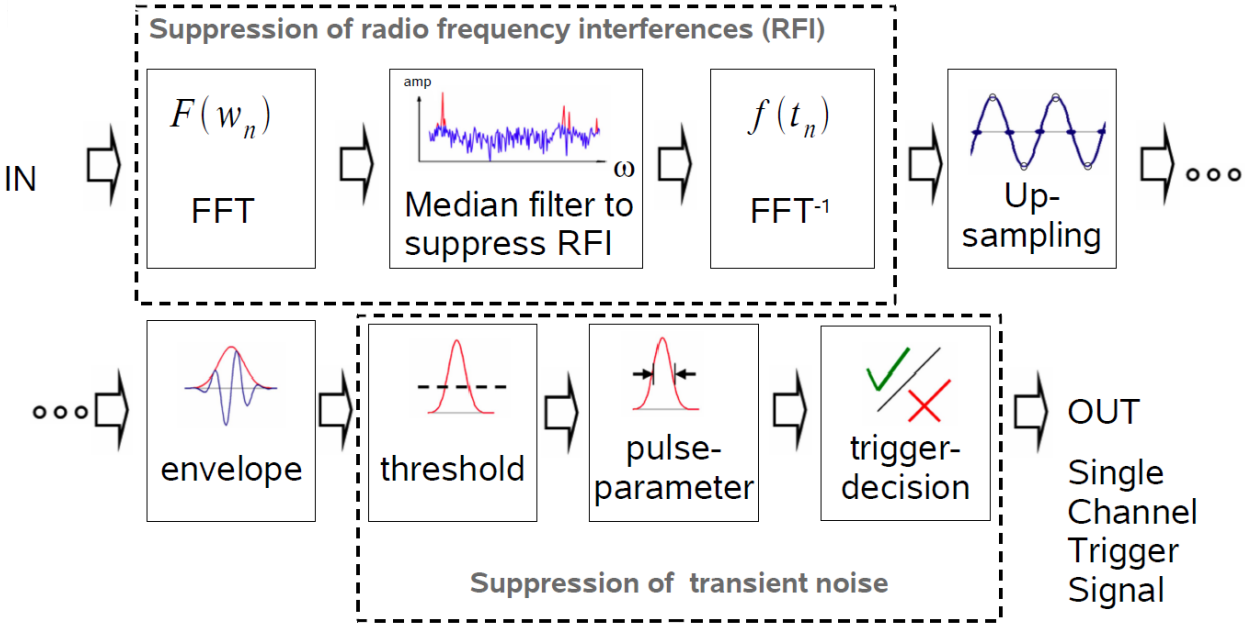
Self-triggered setup at BLS: MAXIMA



- autonomous stations
- LPDA antennas
- solar-powered
- wireless comms
- self-triggered

- collecting valuable experience for larger array under realistic conditions

FPGA self-trigger tests at BLS

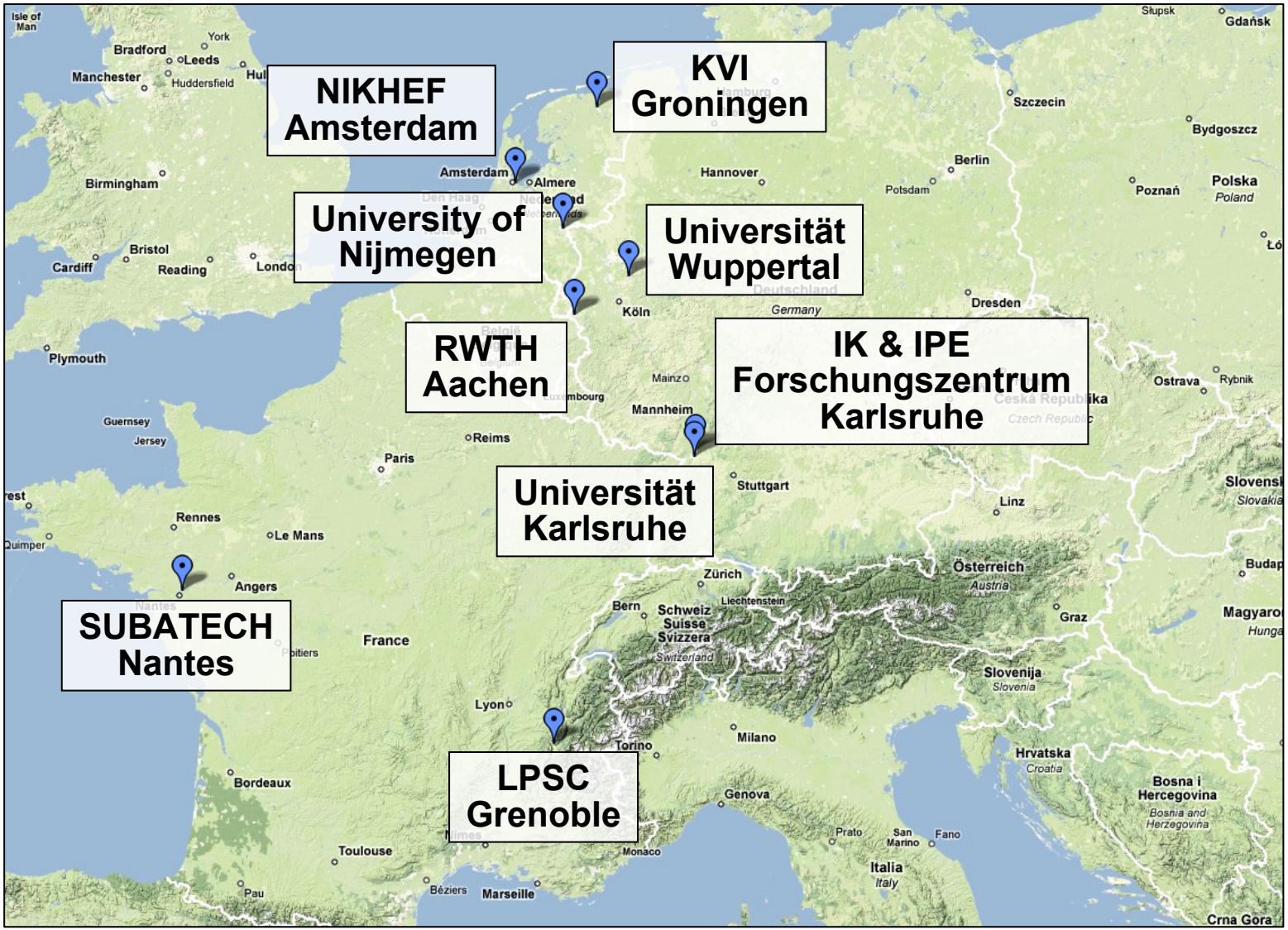


- tests of a new antenna design (SALLA)
- test of a sophisticated self-trigger implemented on an FPGA
  - real-time RFI suppression for 40-80 MHz band
  - real-time pulse characterisation (after upsampling, enveloping)
  - trigger decision depending on pulse parameters

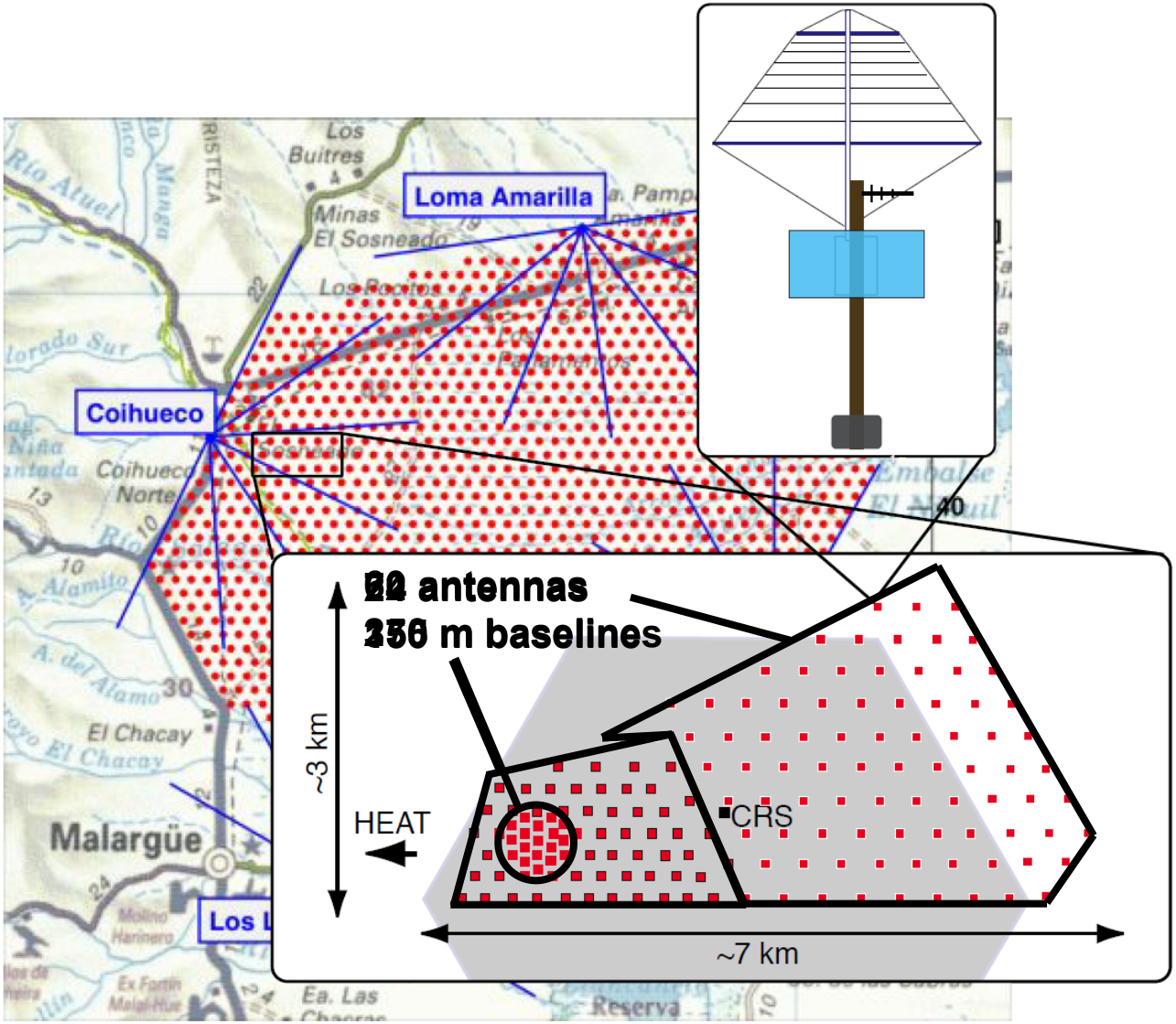
The Auger Engineering Radio Array

- small-scale tests have been concluded successfully
- next step: ~20 km^2 radio array with ~150 antennas
  - prototype experiment for large-scale radio detection
- super-hybrid measurements
  - co-located with HEAT (high-elevation fluorescence telescopes)
  - co-located with AMIGA (SD infill and muon counters)
- science goals of AERA
  1. study and understand in detail radio emission above $10^{17.5}$ eV
  2. evaluate capabilities of large scale radio detection wrt.
     - cosmic ray energy
     - cosmic ray mass
     - cosmic ray arrival direction
  3. perform cosmic ray measurements in the region of transition from galactic to extragalactic sources
     - energy spectrum
     - mass composition

Institutions participating in AERA

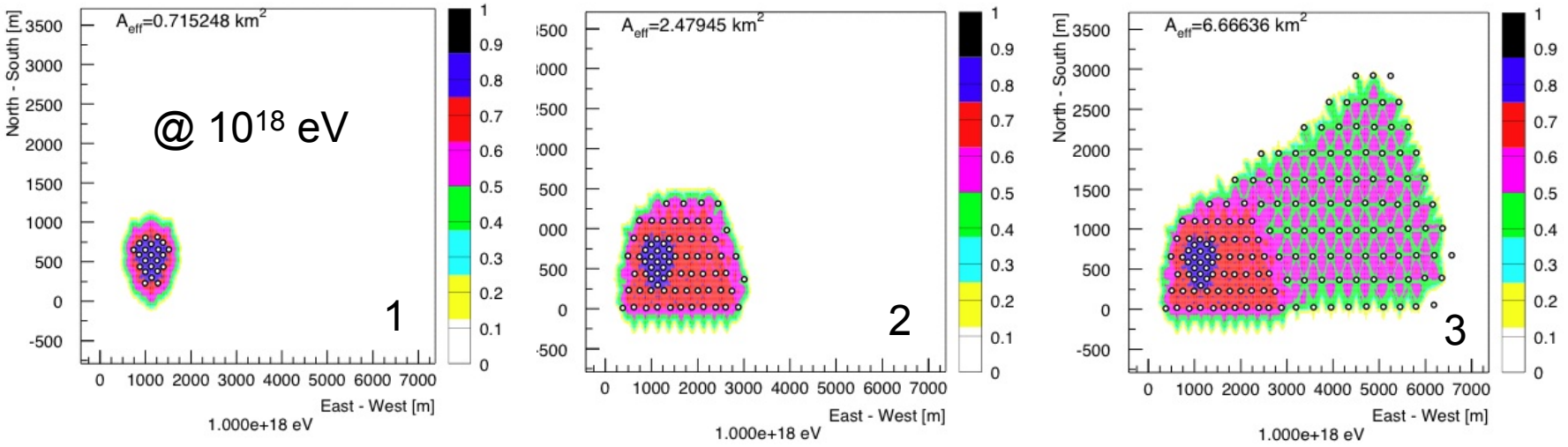


Planned configuration of AERA

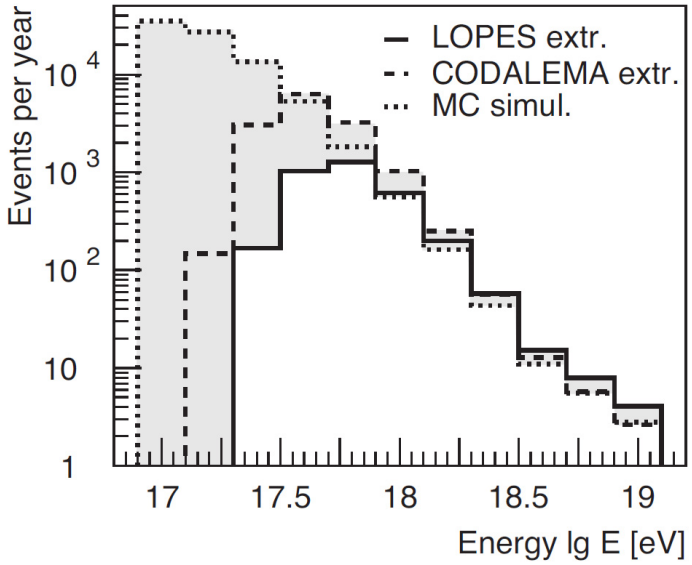


- autonomous stations
- solar-powered
- wireless links
- 30-80 MHz
- 4 channels
- 200 MS s^{-1}
- 12 bit ADCs
- ring buffer for ~3 seconds
- first stage: LPDA antennas

Projected array performance

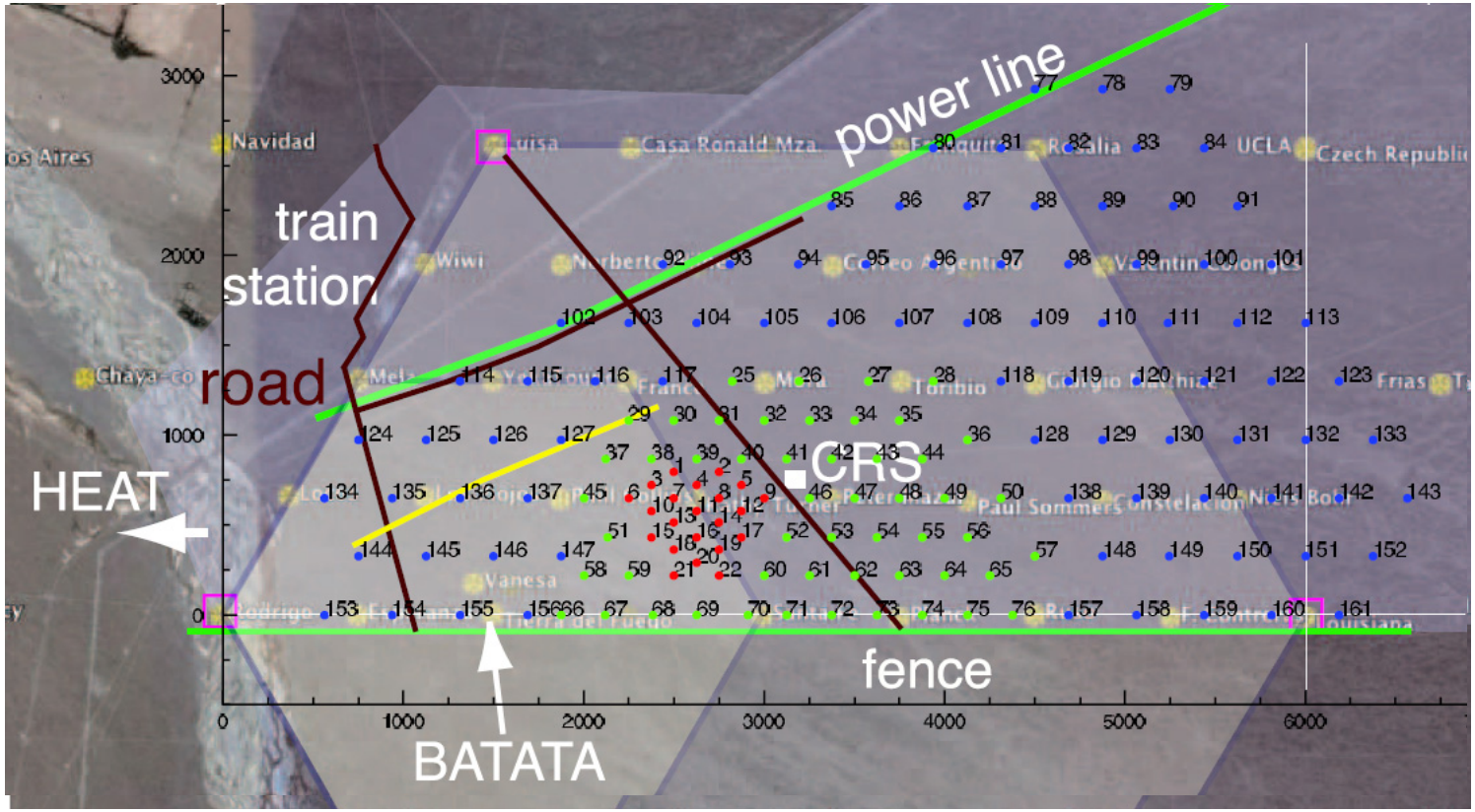


- array will be set up in three stages
- 24 antenna stations in first phase
  - parallel R&D for later upgrades
- event rates have been projected based on different data
  - complete array will see ~1000 events per year at energies >10^{18} eV
  - small baseline region will reach 100% efficiency at energies of ~1-2 10^{18} eV
  - complete array will reach 100% efficiency at energies of ~ 4-5 10^{18} eV



Shift of core position

- new measurements showed that there is significant noise background up to ~600 metres from the power line
- core position for first 24 antennas has been shifted



Deployment schedule

- first container is being shipped right now
  - will arrive in Malargüe mid-April (if all goes well)
- deployment of first 24 antennas should be finished in July
- then evaluate phase one of AERA and plan upgrades

Radio analysis: Auger Offline

- **full-blown analysis pipelines for experimental data and simulations**

Experimental Data

1. read file (MAXIMA, Ka-BLS)

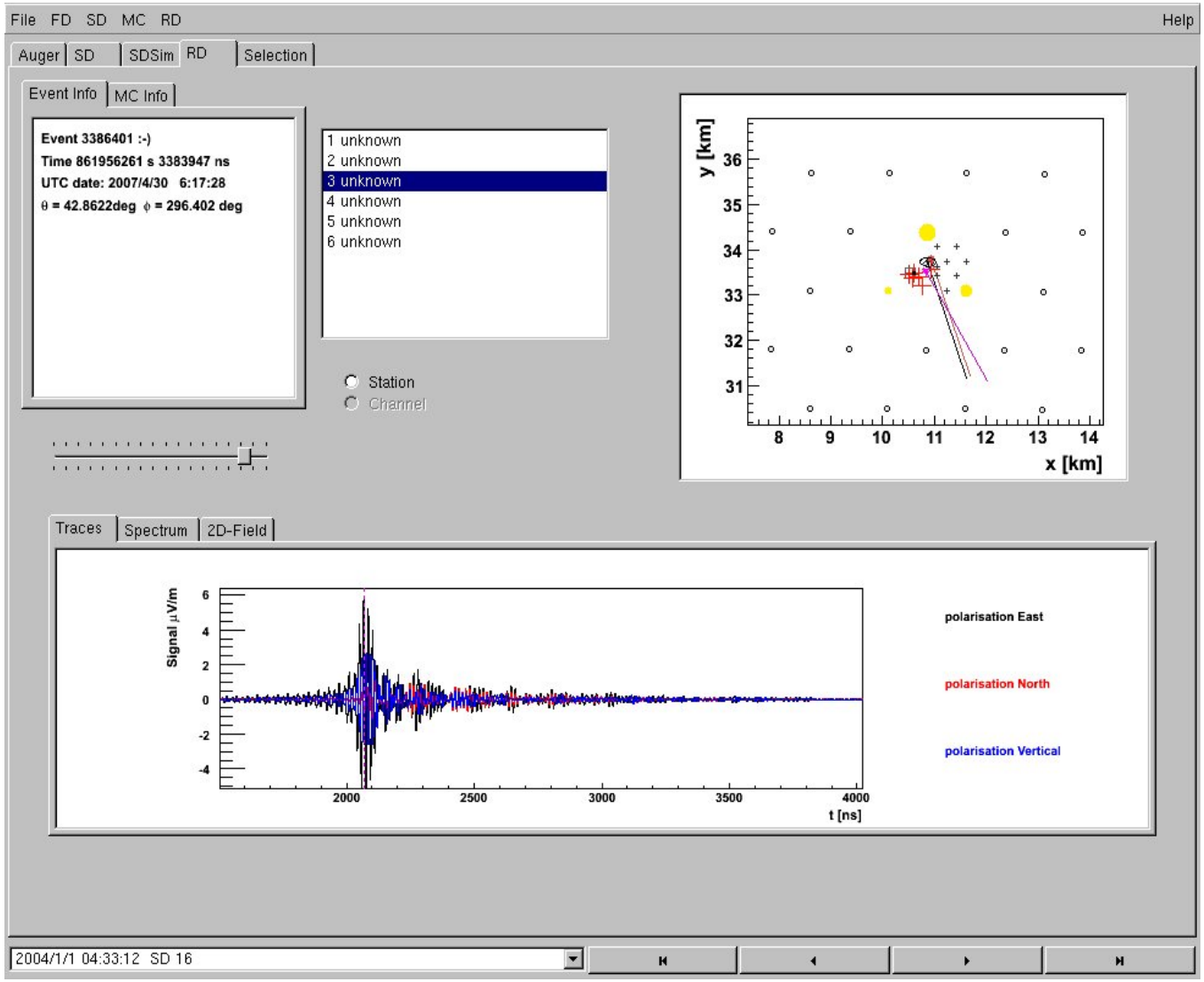
Simulations

1. read file (REAS, MGRM)
2. fold in antenna response
3. add continuous radio noise
4. fold in electronics response
5. resample to given time-base

6. correct for electronics response
7. suppress narrow-band noise
8. up-sample data (physical interpolation)
9. reconstruct physical e-field vector using correct antenna characteristics
10. do an iterative plane fit direction reconstruction
11. write out reconstruction results to ADST files

Radio analysis: hybrid events

- prepare everything for combined analysis of SD, FD and radio



Summary

- within Auger, we develop radio detection on large scales
- prototype tests have been successful
  - Argentinean environment very favourable
  - self-triggering remains a challenge
- this year, we will begin setting up the AERA engineering array
  - area of 20 km^2
  - ~150 antennas
  - ~1000 events/year at energies >10^{18} eV
  - super-hybrid measurements
  - pave the way for large-scale application