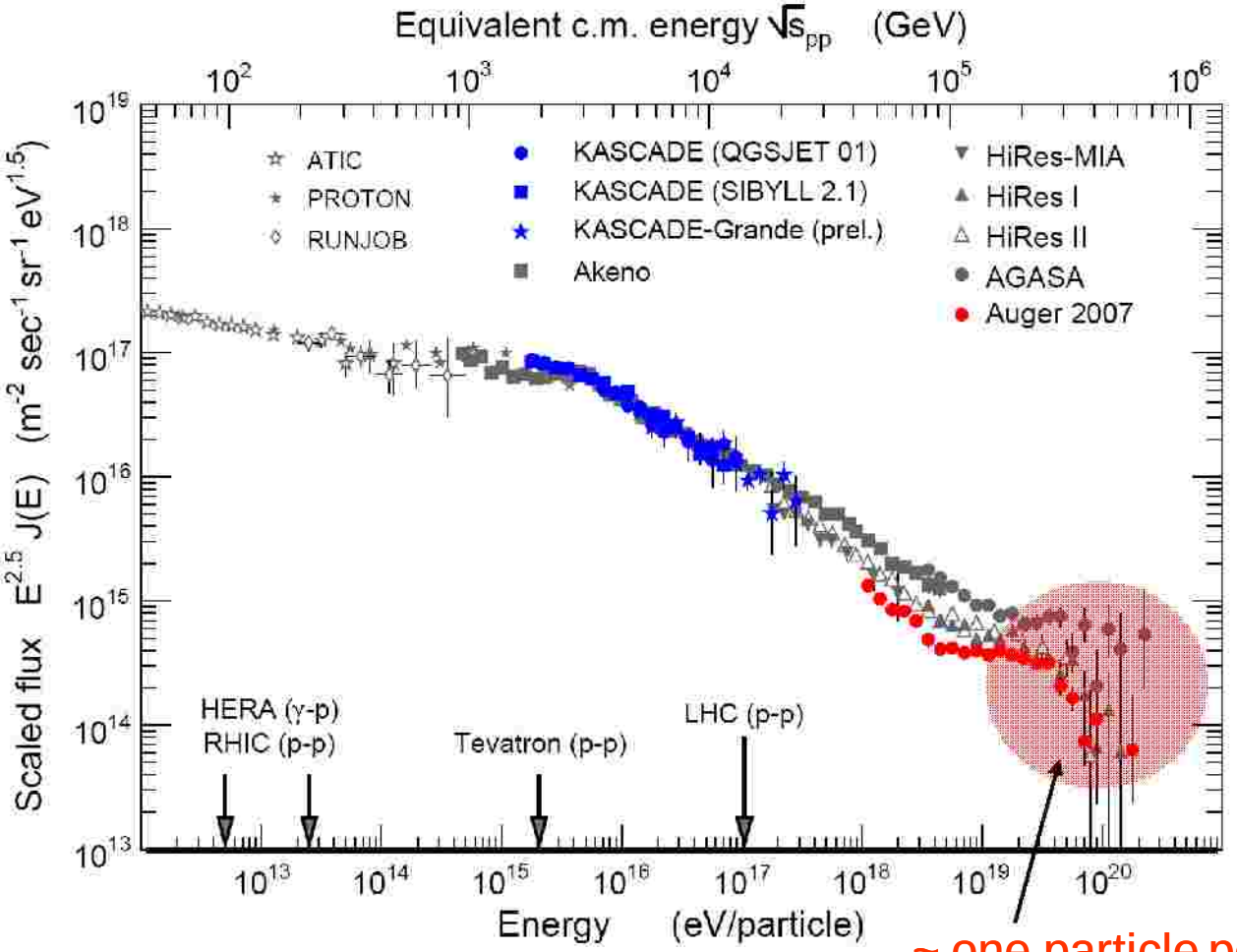
Radio Detection of Cosmic Rays in the Pierre Auger Observatory

Tim Huege (KIT)
for the Pierre Auger Collaboration

Forschungszentrum Karlsruhe in der Helmholtz-Gemeinschaft
Universität Karlsruhe (TH) Research University · founded 1825

(Ultra) High Energy Cosmic Rays

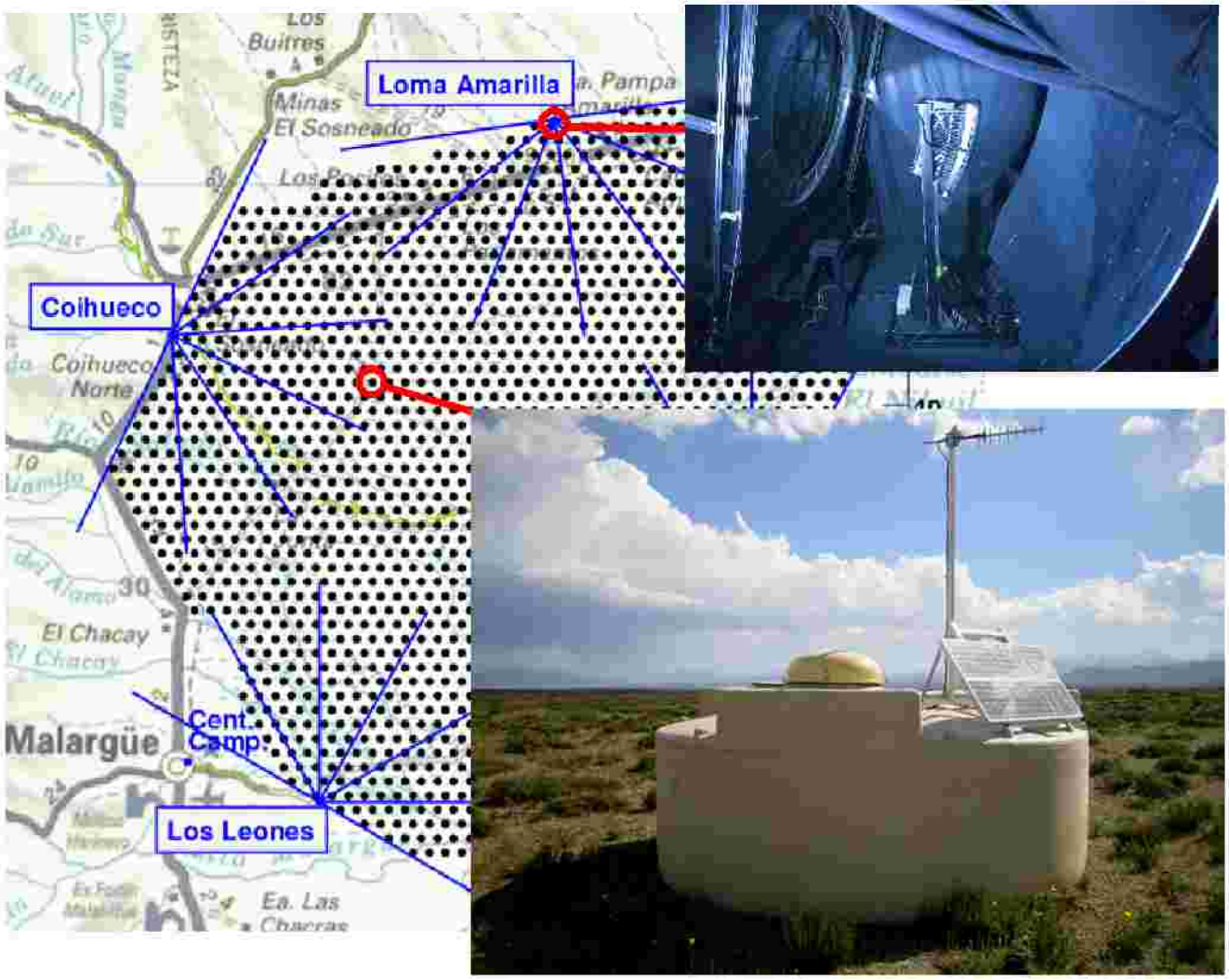
- cosmic rays are observed over many decades in energy
- the sources of the highest-energy CRs are unclear
- statistics are very low at the highest energies



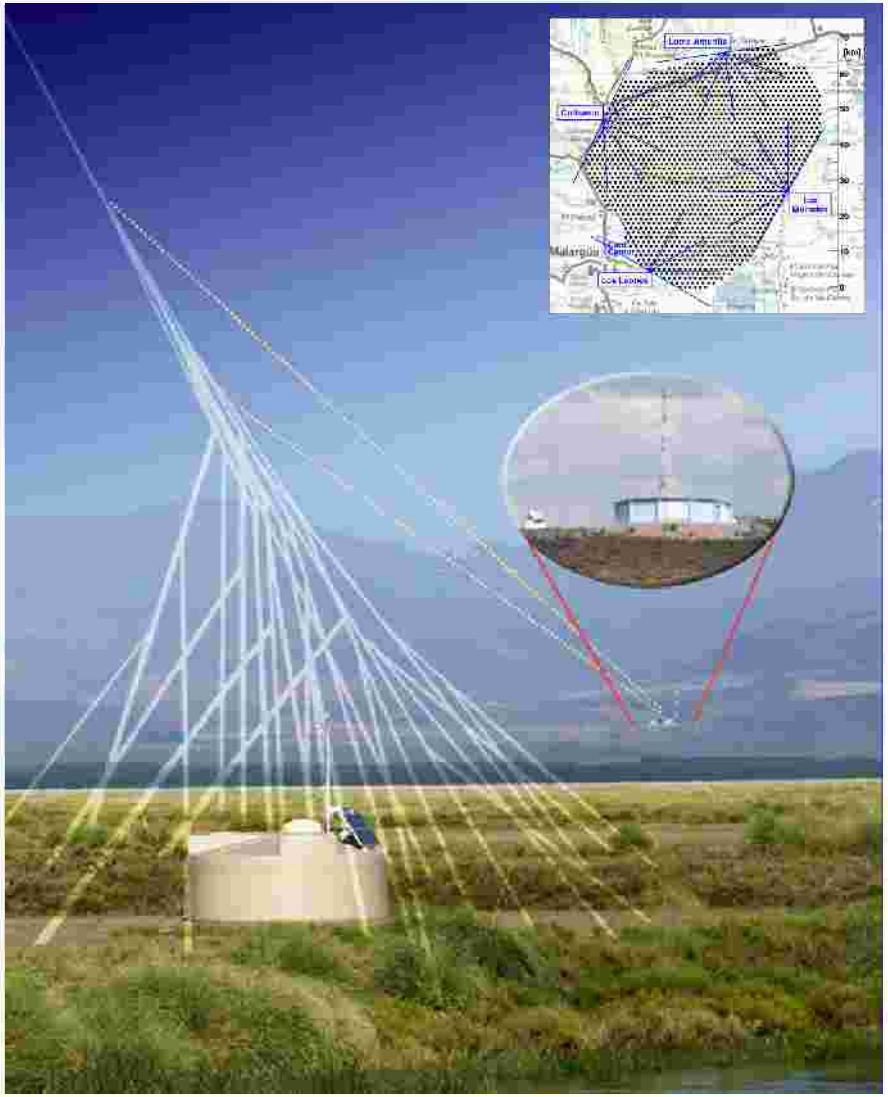
~ one particle per km^2 and century

The Pierre Auger Observatory

- highest energies need huge arrays
- Southern site
  - Argentina
  - 3000 km²
  - 1600 particle detectors
  - 24 optical telescopes
- Northern site
  - planned
  - USA
  - >20000 km²



Hybrid detection in Auger



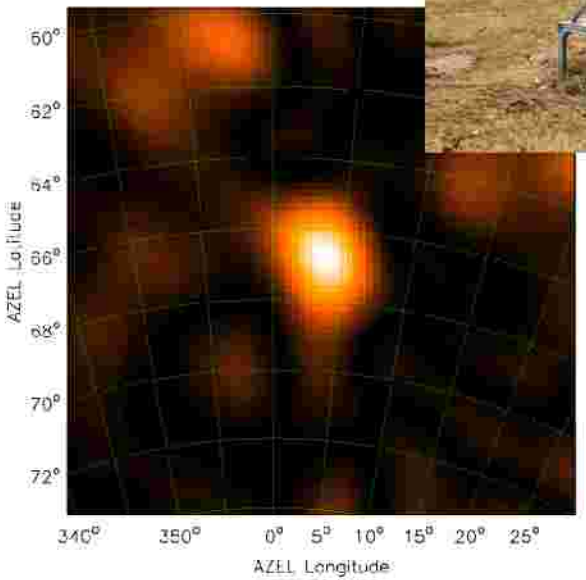
- hybrid detection
  - particle detectors
  - fluorescence telescopes
- many advantages
  - cross-calibration
  - general redundance
  - minimisation of model dependence (energy scale)
- duty cycle of combined measurements only ~13%

Novel technology: radio detection

- **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

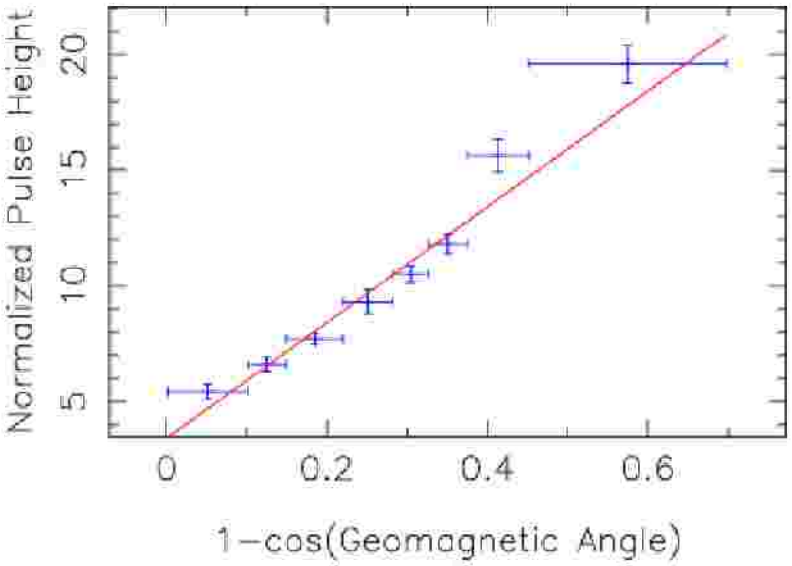
LOPES
dipole antenna



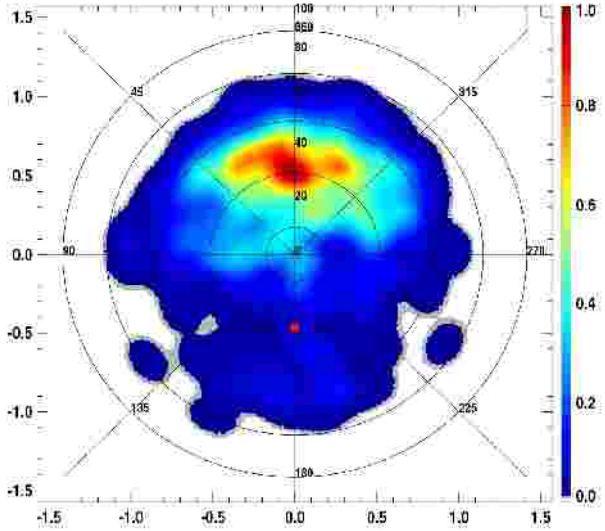
radio flash of a cosmic ray air shower seen by LOPES

Radio detection up to 10^{18} eV

LOPES results



CODALEMA results



- **from LOPES and CODALEMA we know:**
  - **radio amplitude drops exponentially with lateral distance**
  - **radio amplitude scales linearly with particle energy**
  - **radio amplitude is strongly correlated with „geomagnetic angle“**
- **problem: LOPES and CODALEMA are small experiments, run out of statistics at ~ 10^{18} eV**

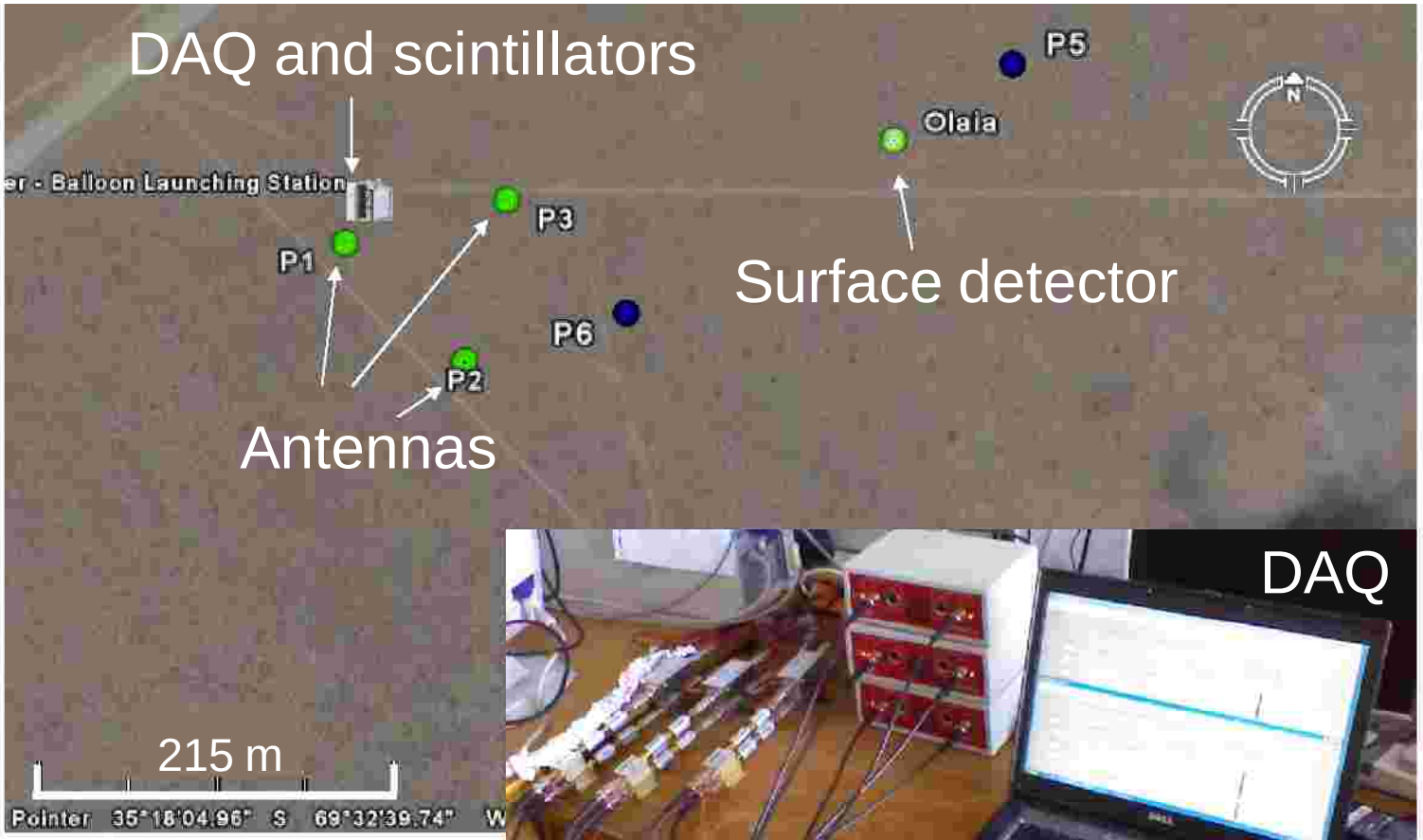
Large scale radio detection in Auger

- so far only small experiments (<0.5 km²)
- 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

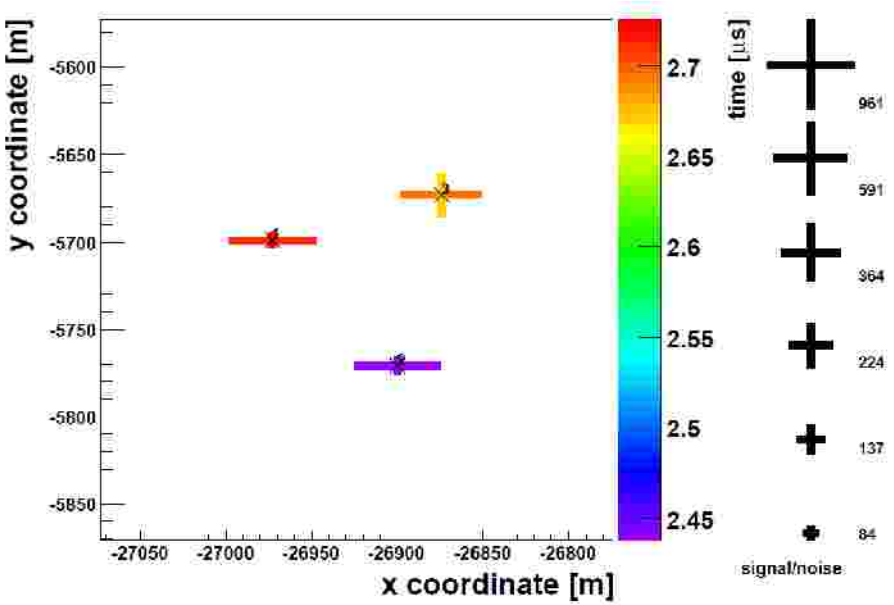
- many technological challenges
  - decentralized array organisation
  - autonomous, self-powered detector stations
  - wireless communication between stations
  - self-triggering on radio signals
  - robustness (cows, strong winds, …)
- R&D so far with a number of small test cells operating in various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

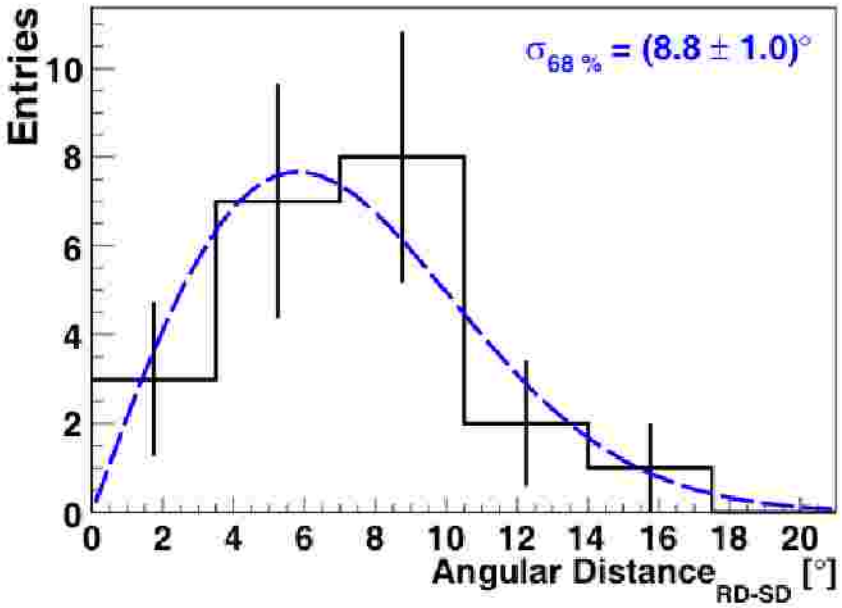
Externally triggered measurements at BLS



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

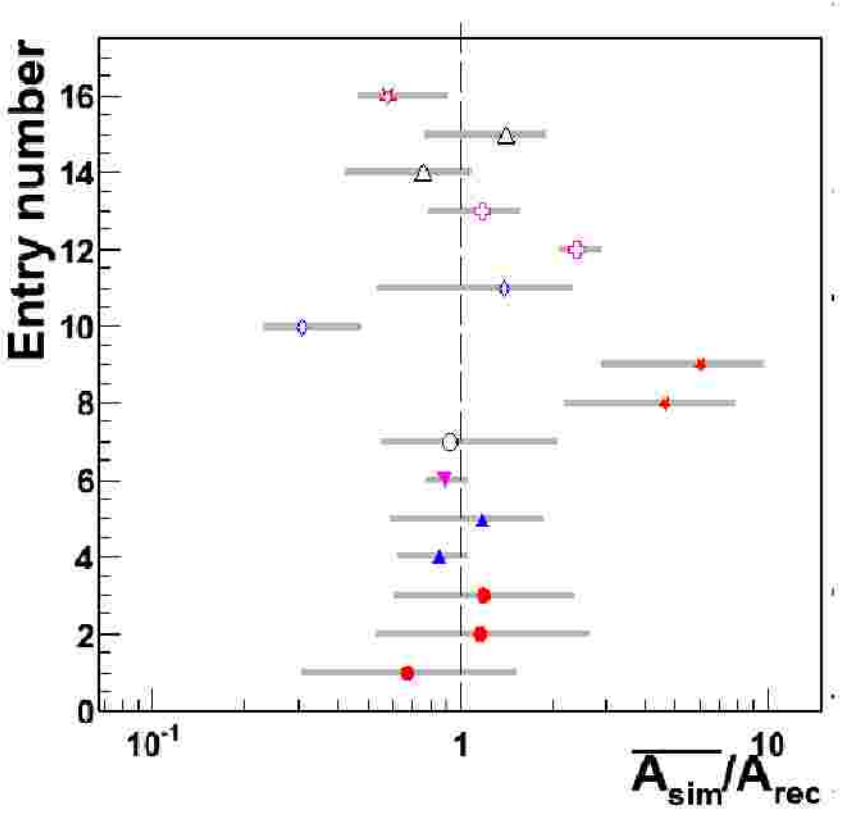
Results of measurements near BLS



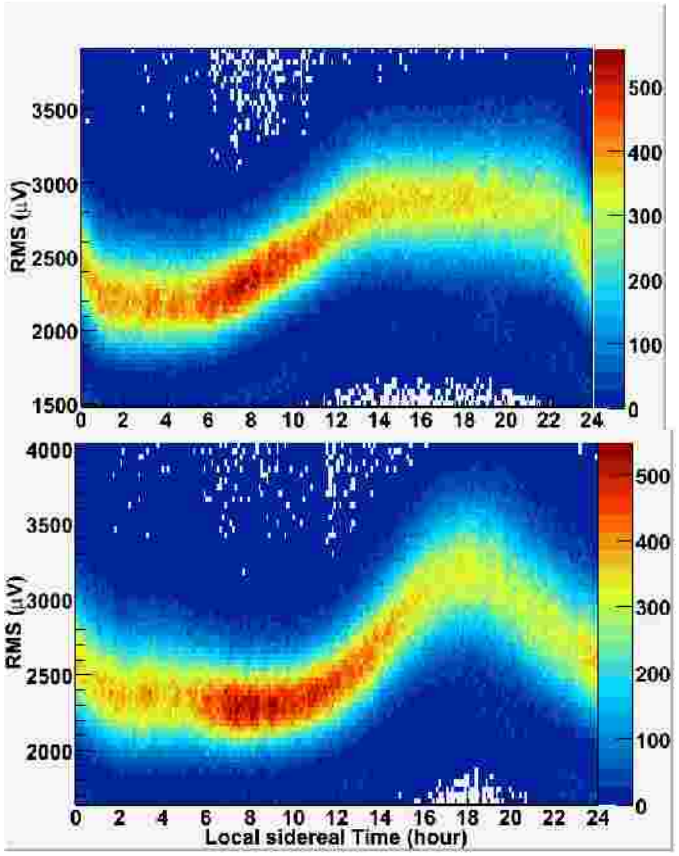


- **>25 coincident events between Auger SD and all 3 radio antennas**
- **signal usually seen in both antenna polarisations**
- **directions reconstructed with SD and radio are compatible**
- **angular resolution limited by GPS-only timing**

Further results from BLS measurements

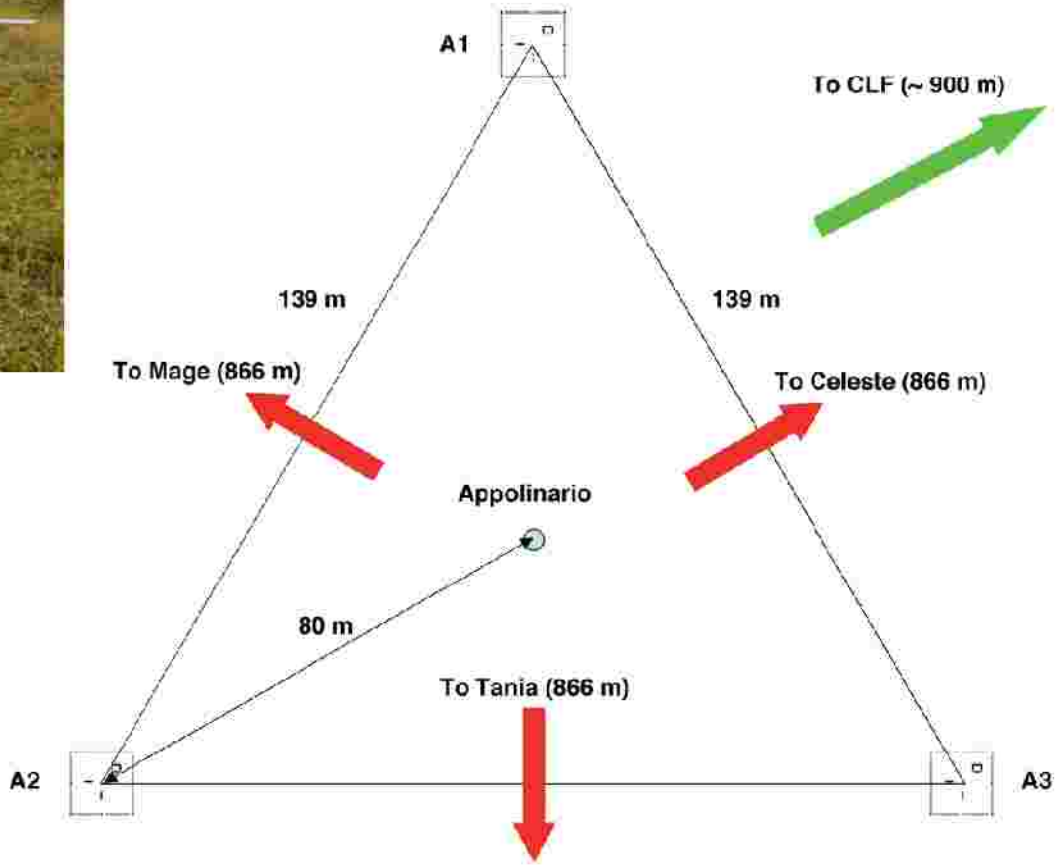


- full event and detector simulation chain (CORSIKA, REAS2, RDAS)
- fair agreement within (relatively large) uncertainties



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

Self-triggered measurements near CLF

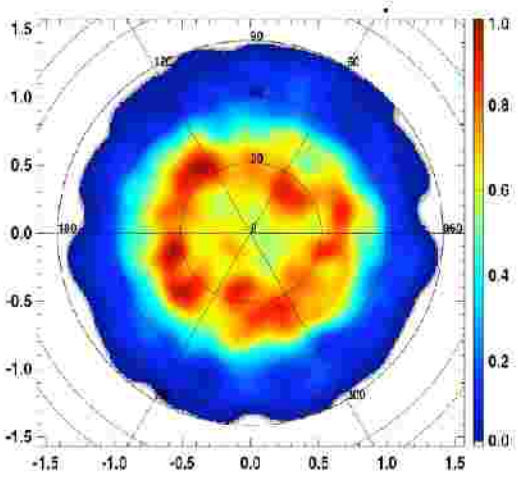


- 3 autonomous stations
  - solar-powered
  - dual-polarisation
  - wireless data link
  - self-triggered on radio signals (50-70 MHz)

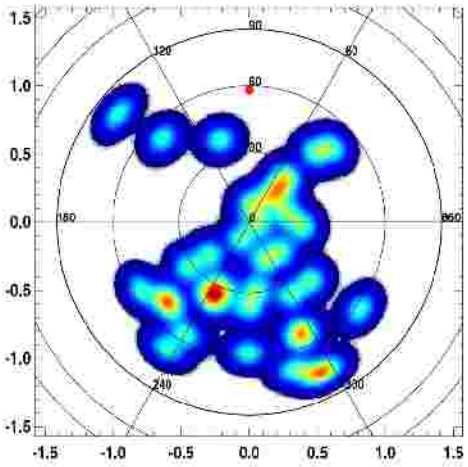
Results of measurements near CLF

- detectors have successfully self-triggered on radio pulses
- found 36 self-triggered radio events coincident with SD events
- 72% of the radio-triggered events come from south
  - threshold effect
  - confirmation of geomagnetic radio emission mechanism

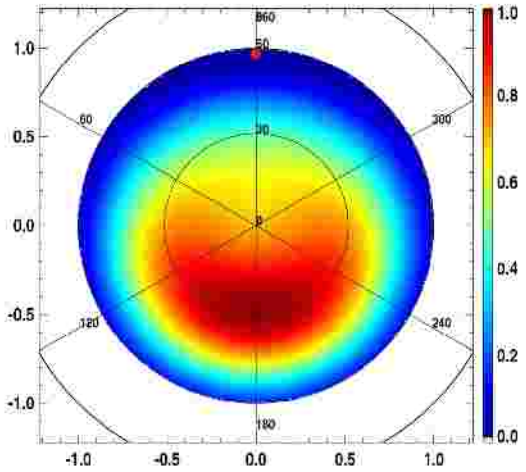
SD events



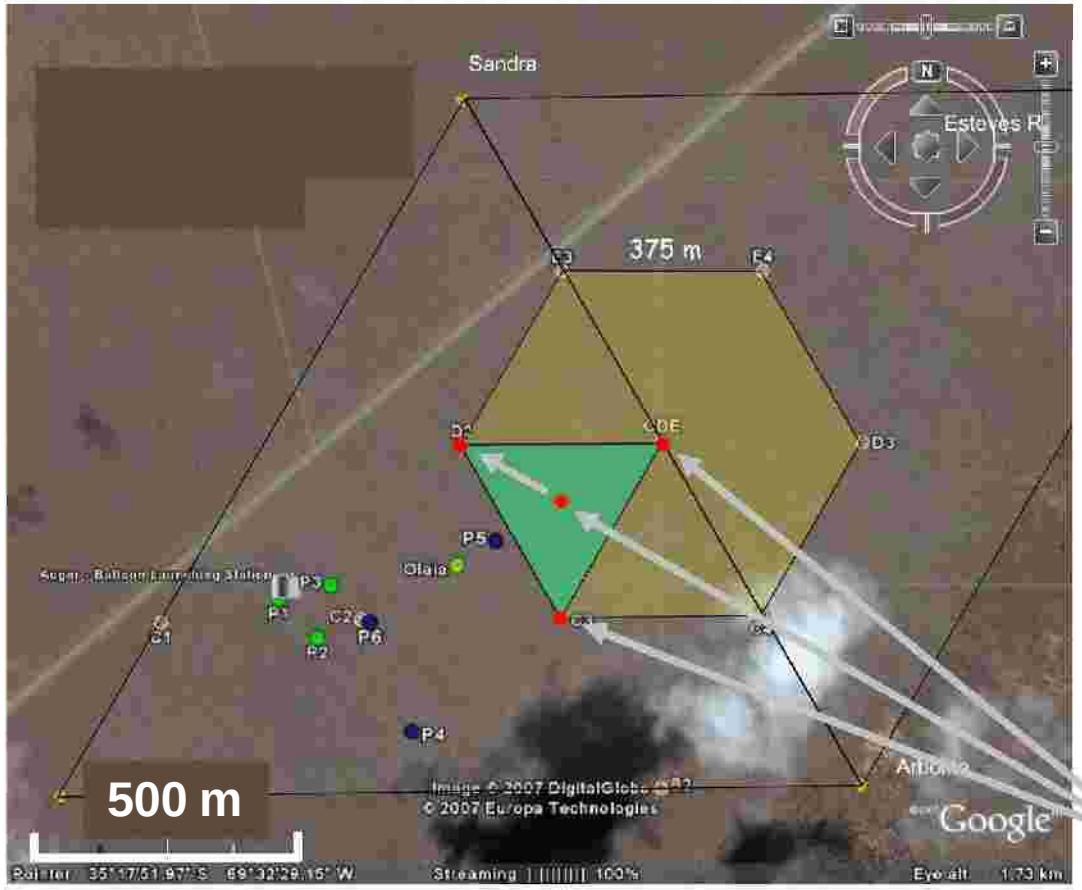
Radio events



v x B model



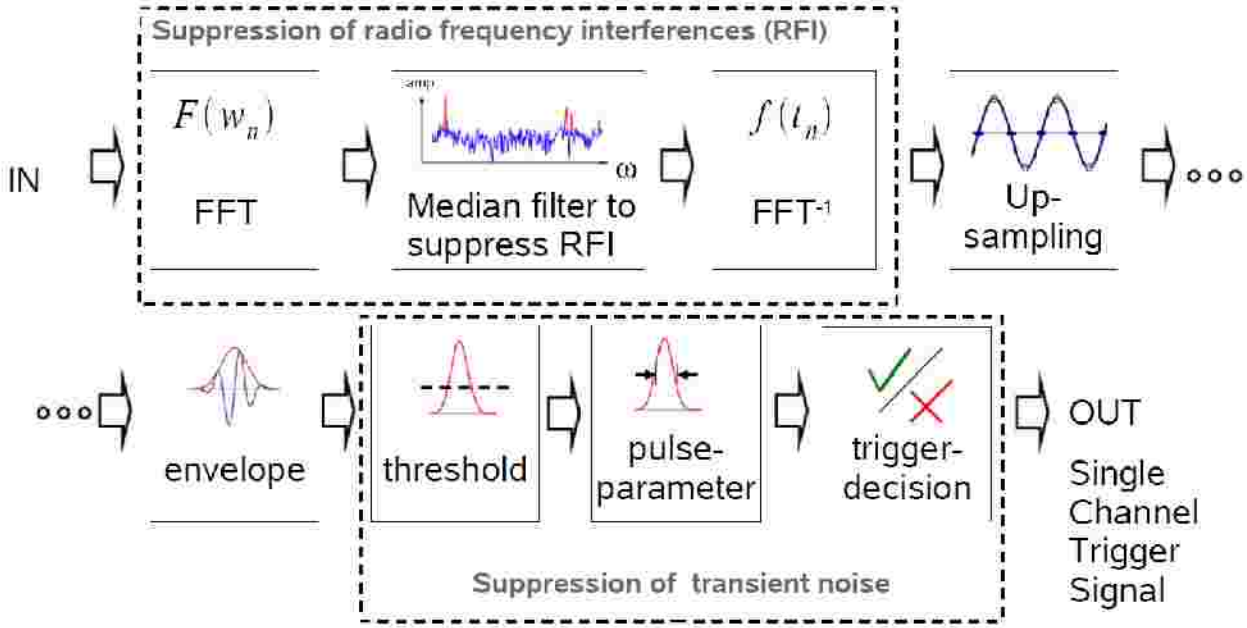
Self-triggered setup at BLS: MAXIMA



- 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

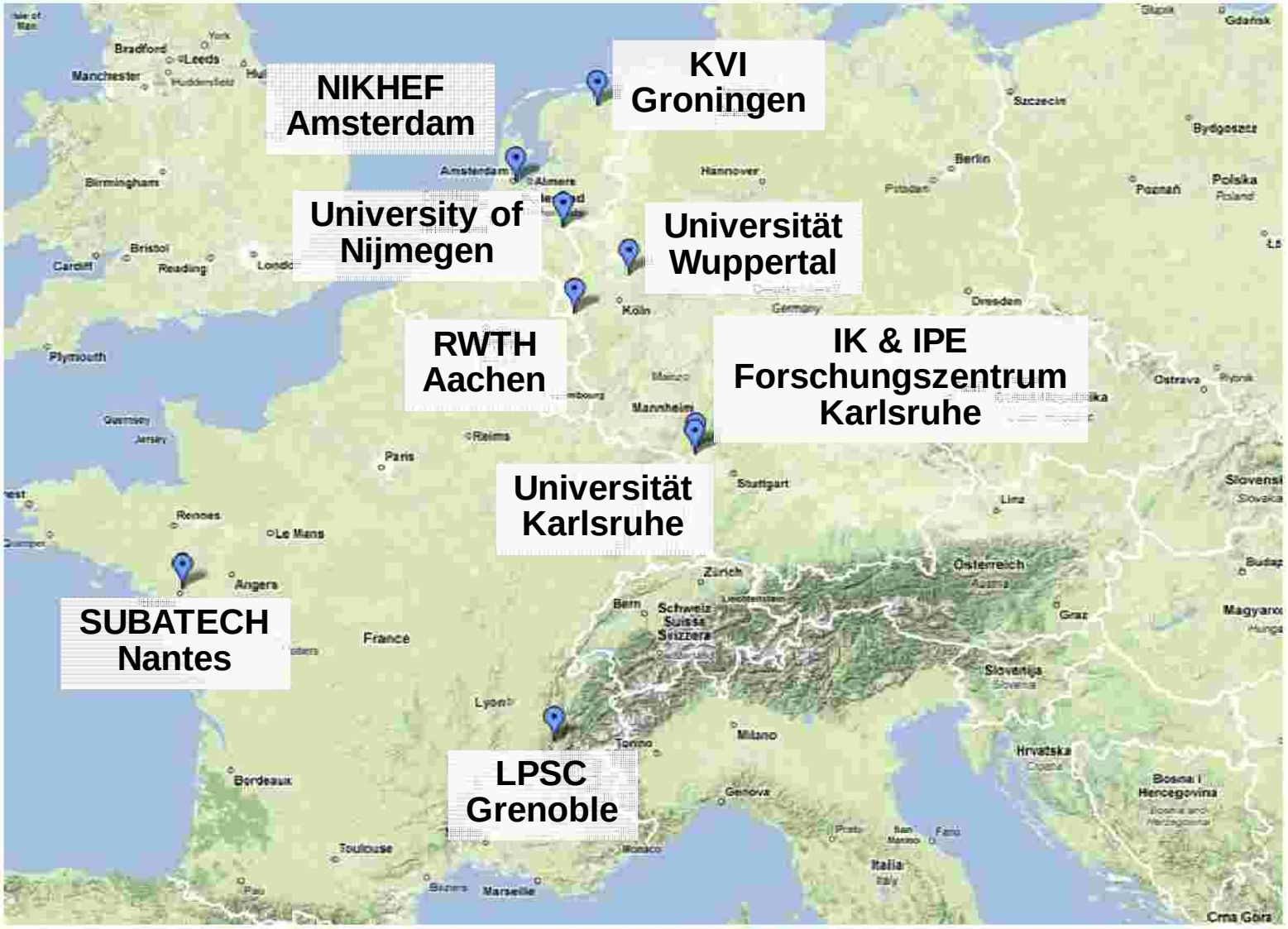


- **tests of a new antenna design (SALLA)**
- **test of a sophisticated self-trigger implemented on an FPGA**
  - **real-time RFI suppression for 40-80 MHz band**
  - **real-time pulse characterisation (after upsampling, enveloping)**
  - **trigger decision depending on pulse parameters**

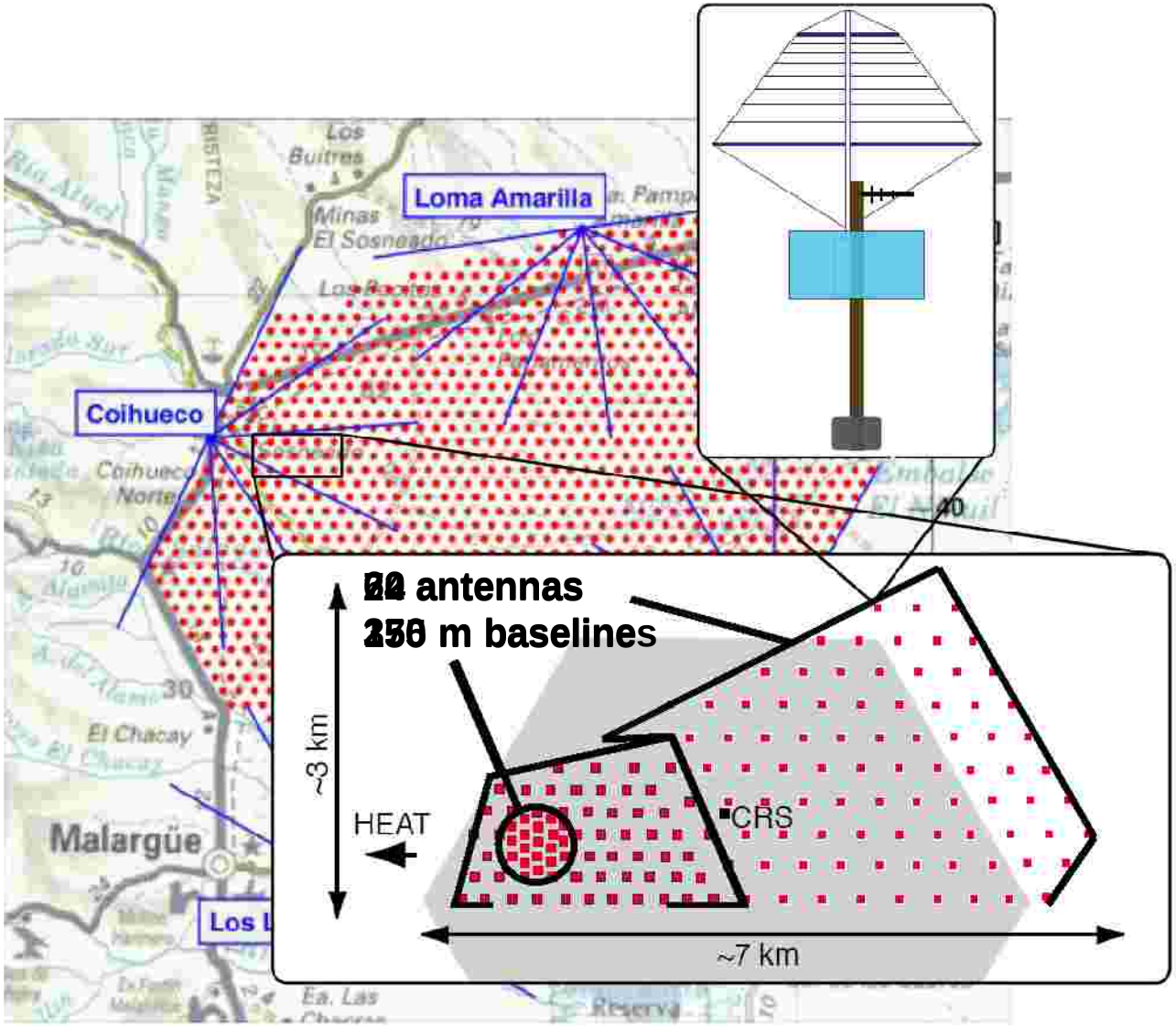
The Auger Engineering Radio Array

- 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

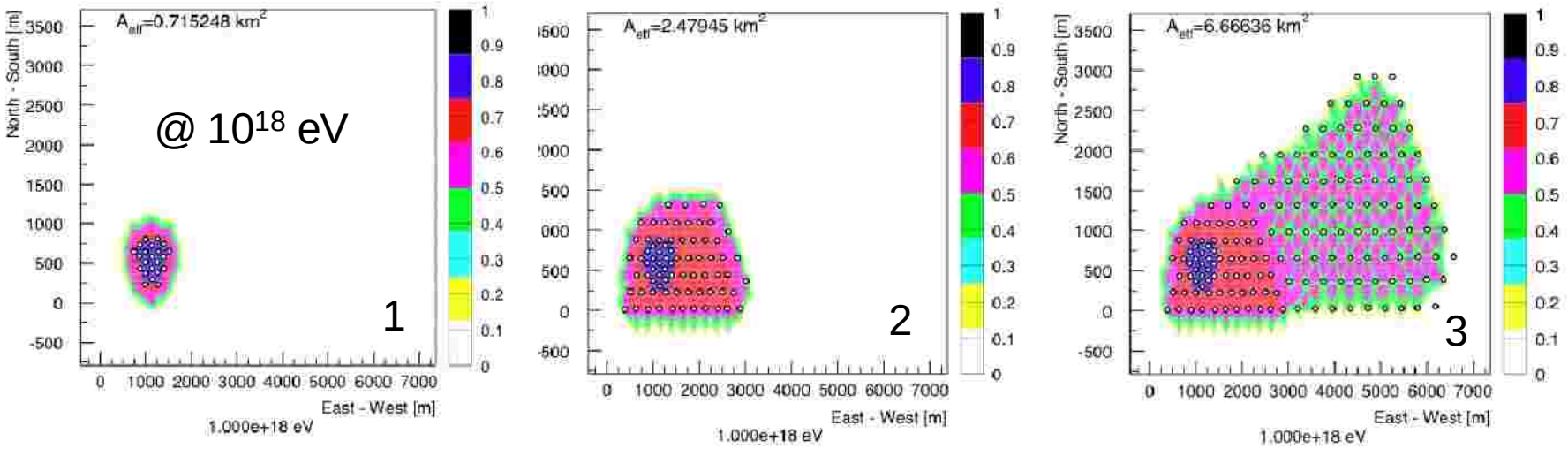


Planned configuration of AERA

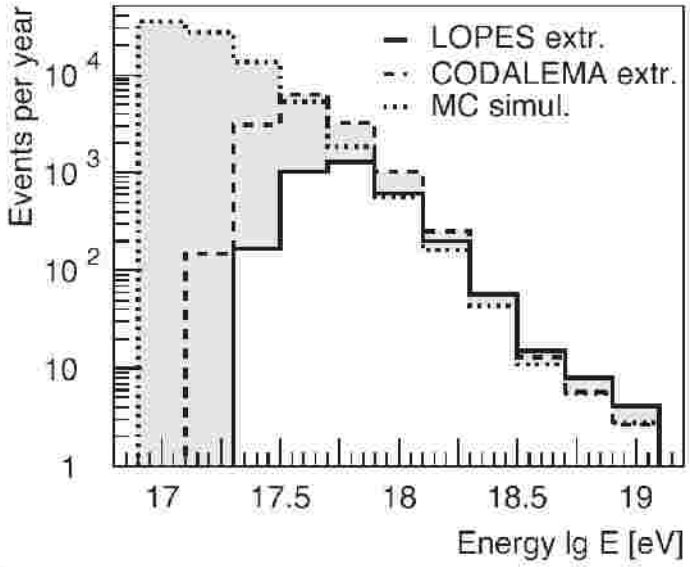


- autonomous stations
- solar-powered
- wireless links
- 30-80 MHz
- 4 channels
- 200 MS s^{-1}
- 12 bit ADCs
- ring buffer for ~3 seconds
- first stage: LPDA antennas

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



Summary

- radio detection of cosmic rays has been studied very successfully by CODALEMA and LOPES
- its real potential lies in the application to ultra-high energy cosmic rays
- within Auger, we develop the radio detection technique for this large-scale application
- prototype tests have been very successful
- 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

Extensive air showers

- cosmic ray interacts with nucleus in the atmosphere
- cascade of secondary particles evolves
  - grows up to billions of particles before it declines again
- hadronic interactions at extremely high energies
  - Monte Carlo simulations
  - considerable model uncertainties