Radio emission in extensive air showers

Workshop on Astroparticle Physics 2010, Ooty

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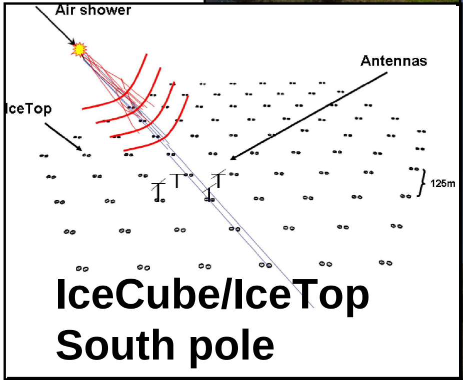
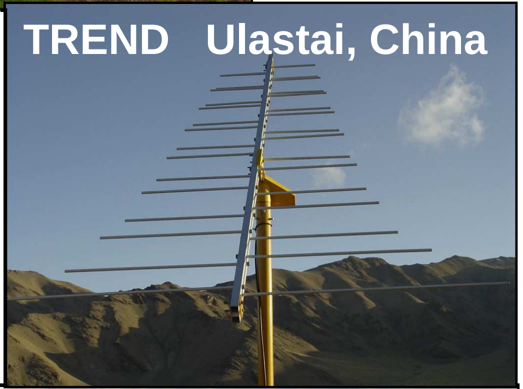
Outline

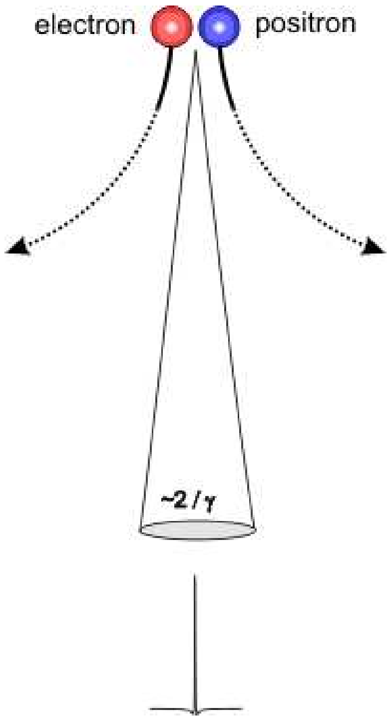
- Radio detection
- Major Radio Experiments
  - LOPES
  - CODALEMA
- Results of LOPES and CODALEMA
- Large scale applications: AERA
- Summary





Radio emission in EAS

- EAS emit pulsed radio signals:
  - Geomagnetic deflection of relativistic electrons and positrons
  - Time-variation of the number of charged particles and charge excess radiation
  - Coherent emission for frequency range below 100MHz
    (as long as shower pancake is thinner than wavelength)
- Pulses with amplitude in μV/m range, duration few ns



Radio detection: benefits

- Complementary information to particle detectors
- Nearly 100% duty cycle
- High angular resolution (< 0.5° achievable)
- Simple detectors (in particular cheap)
  → Possibillity for large scale experiments
- Applicable to very inclined (neutrino-induced) air showers

LOPES and LOFAR

- LOPES - **LO**FAR **P**rototyp**e** **S**tation
- LOFAR - **Lo**w **F**requency **Ar**ray
  - Telescope array mainly for radio astronomy
  - Most stations in the Netherlands (Europe)
  - Opening of LOFAR was on June 12th this year
  - First science results expected soon

The LOPES experiment

- Digital radio interferometer measuring in the 40-80 MHz frequency window
- Integrated with KASCADE-Grande experiment
  - Provides the trigger for LOPES
  - Provides the air shower geometry (core, direction)
  - Provides high-quality per-event air shower parameters (N_e, N_μ, …) for study of radio emission systematics
- Effective energy range $\sim 10^{16.7}$ eV to $\sim 10^{18}$ eV

The LOPES experiment

The LOPES Collaboration

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Universität Siegen, Germany
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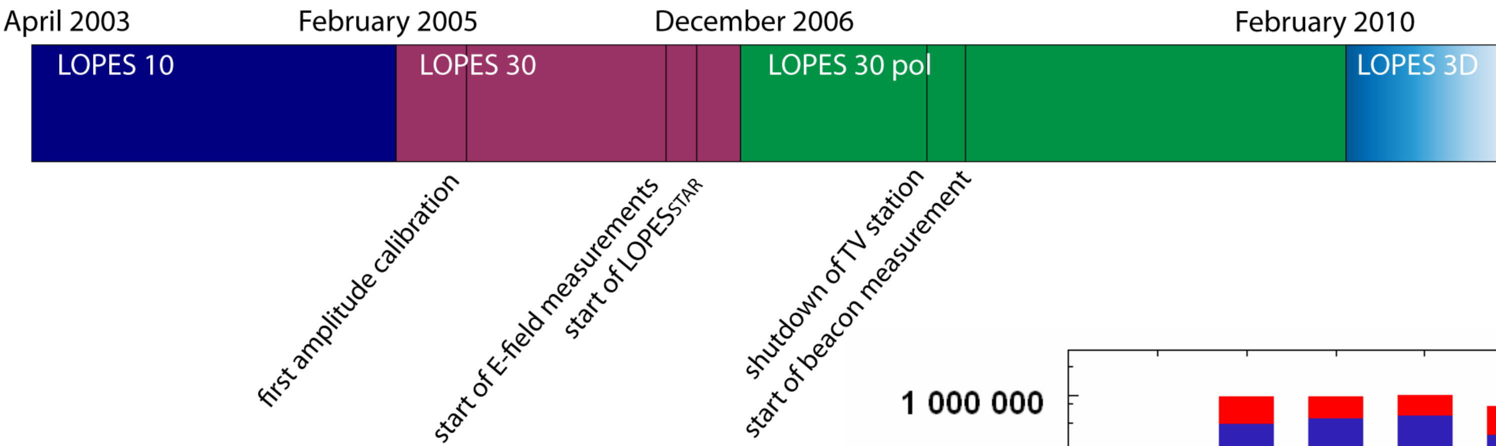
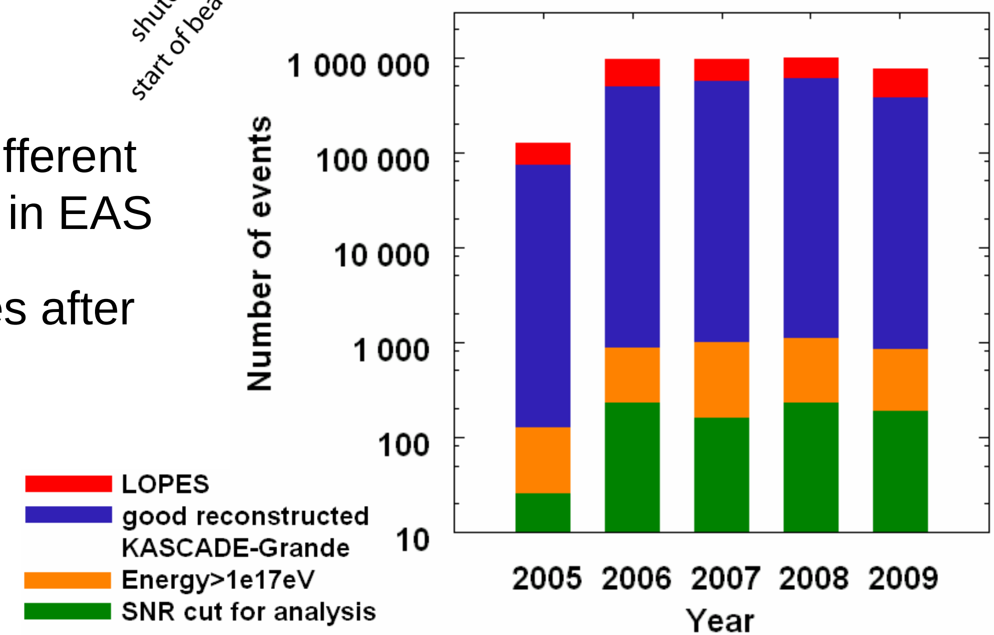
D. Kickelbick, S. Over

The LOPES experiment

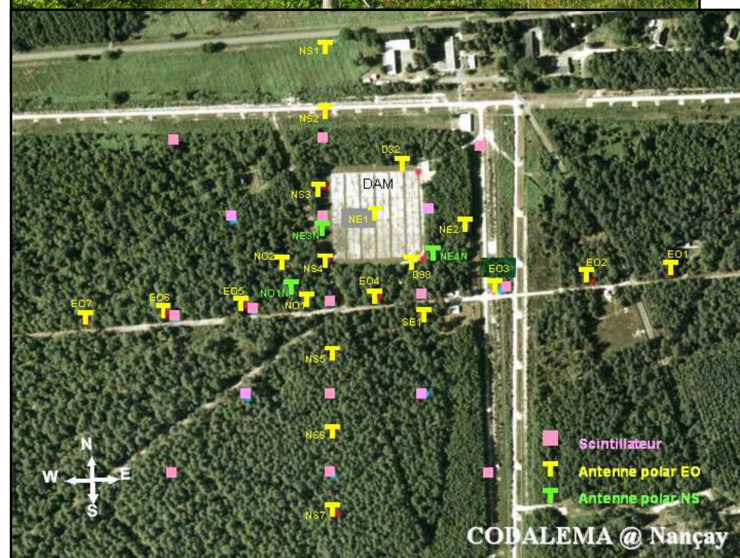


- Several setups to study different aspects of radio emission in EAS
- ~1000 events for analyses after quality cuts
- Noisy environment → Sophisticated analysis procedure required



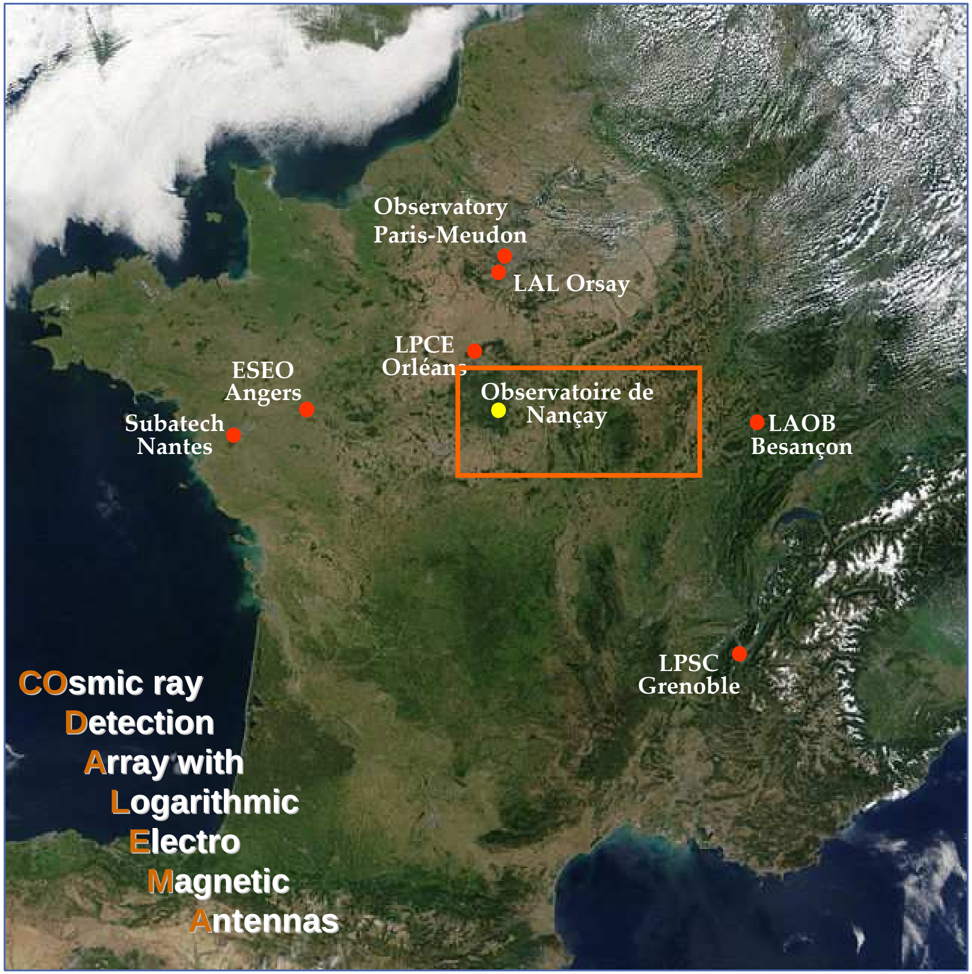
The CODALEMA experiment

- CODALEMA = **Co**smic ray **D**etection **A**rray with **L**ogarithmic **E**lectro **M**agnetic **A**ntennas
- Digital radio interferometer in the frequency range of 1-220 MHz
- Trigger and energy determination with scintillator array (since 2005)
- Effective energy range ~$5*10^{16}$ eV to ~10^{18} eV



The CODALEMA collaboration

- Located in France (Europe)
- 8 french laboratories
- 1 experimental site at Nançay (Observatoire de Paris)



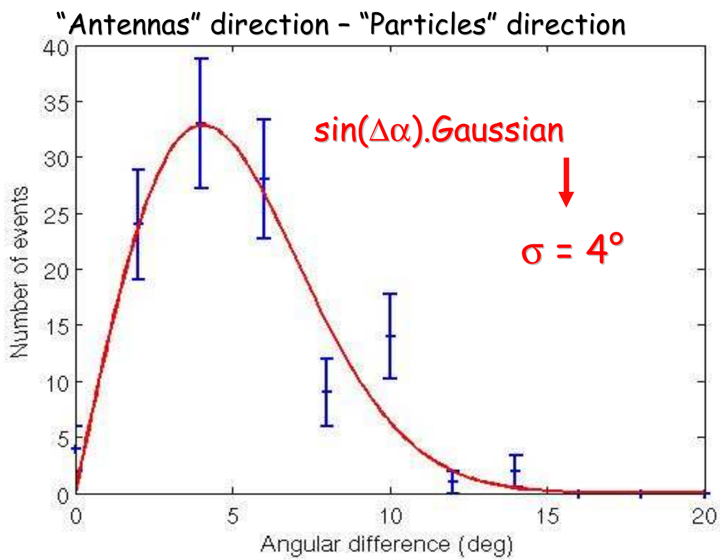
The CODALEMA experiment

- Stage 1:
  2002-2005

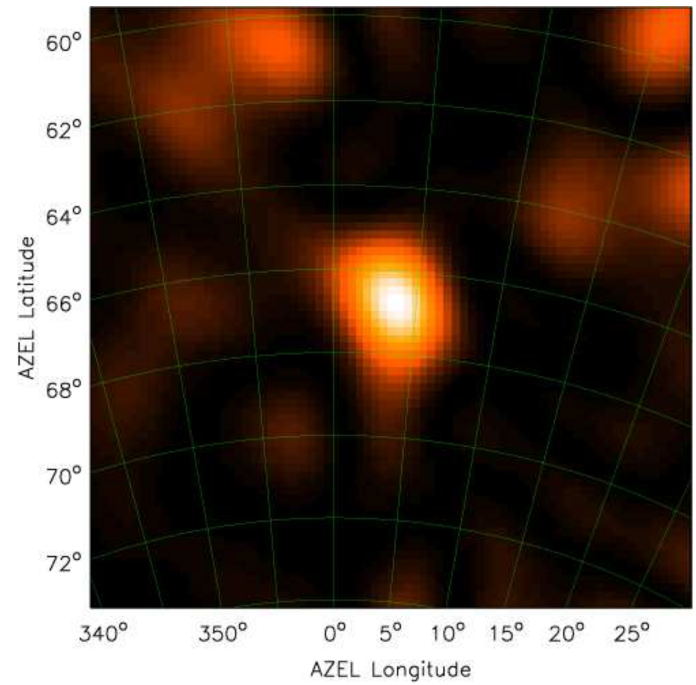
- Stage 2:
  current setup
- New antenna type: active dipole (1-220MHz)
- Extension of scintillator array
- New DAQ

Results from LOPES and CODALEMA

- LOPES 10 „proof of principle“: digital interferometry is possible
- Radio emission associated with EAS
- Reconstruction of incoming shower direction



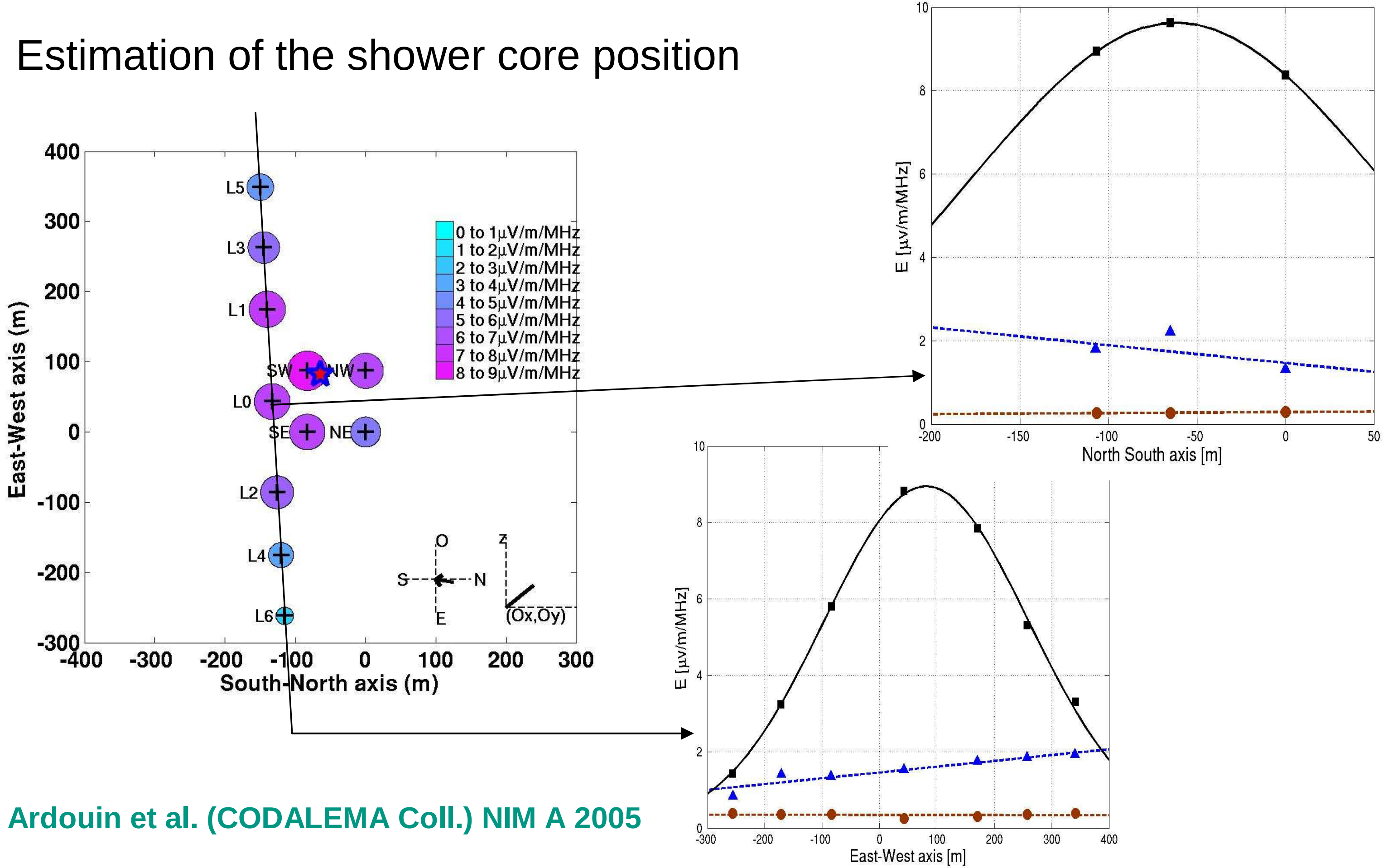
D. Ardouin et al. (CODALEMA Coll.) NIM A 2005



Falcke et al. (LOPES Coll.), Nature 2005

Results from LOPES and CODALEMA

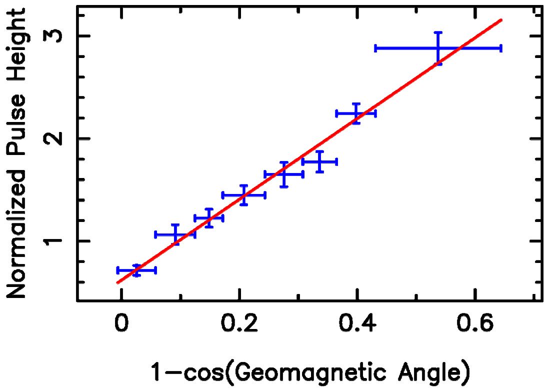
- Estimation of the shower core position

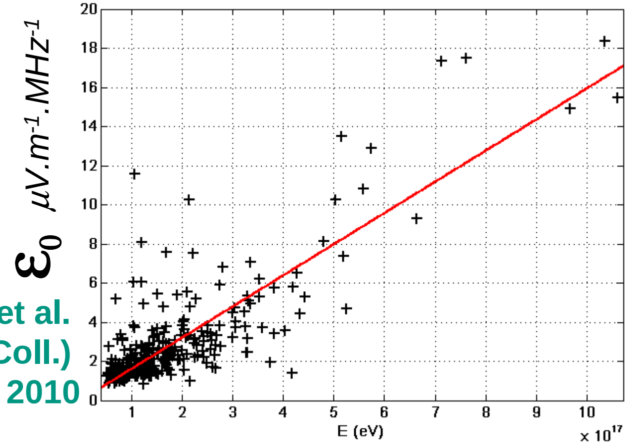


D. Ardouin et al. (CODALEMA Coll.) NIM A 2005

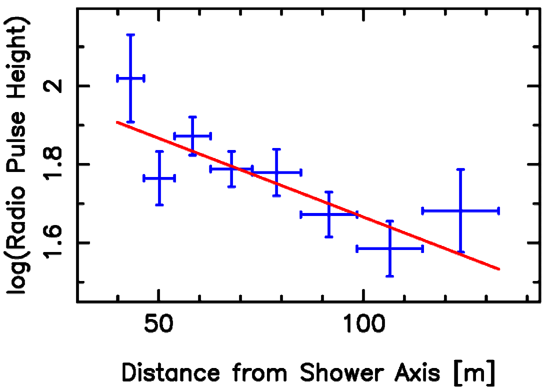
Results from LOPES and CODALEMA

- Field strength depends on primary energy, distance to shower axis and shower geometry (east-west signal)

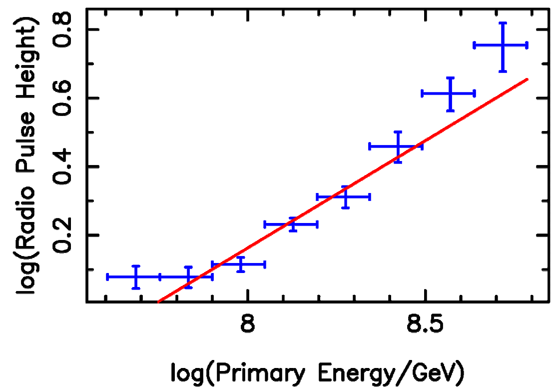




O. Ravel et al.
(CODALEMA Coll.)
ARENA 2010

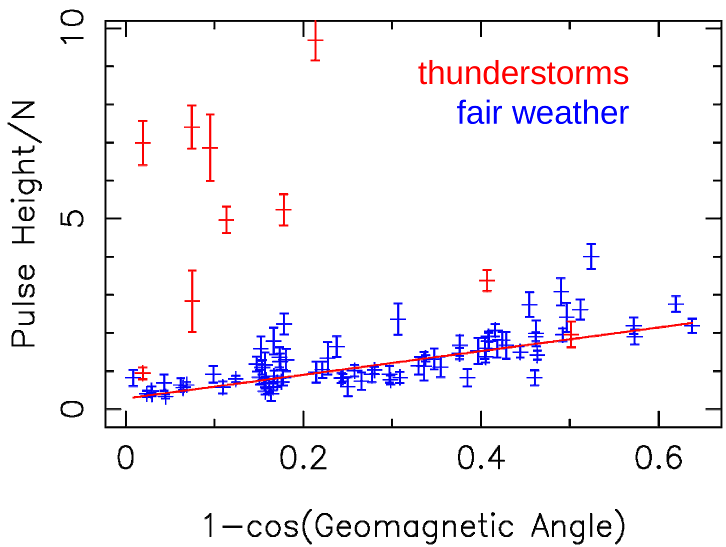


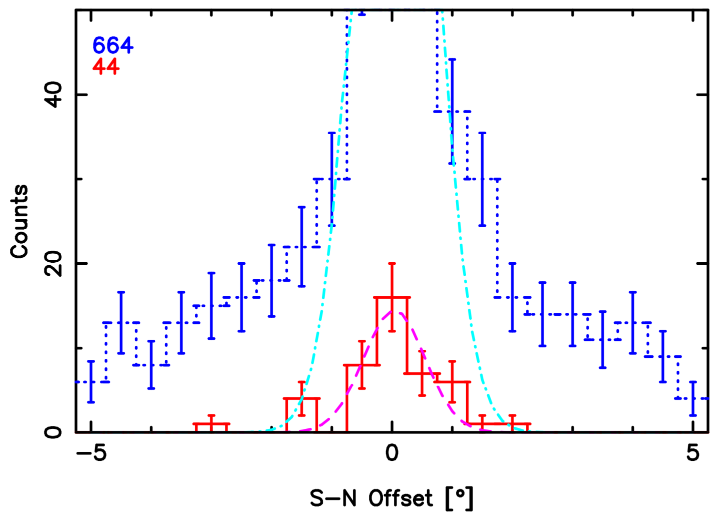
A. Horneffer et al.
(LOPES Coll.)
ICRC proc. 2007



Results from LOPES and CODALEMA

- Radio signals are amplified during thunderstorms
- Angular resolution < 1.5°, Angular resolution < 1° should be achievable





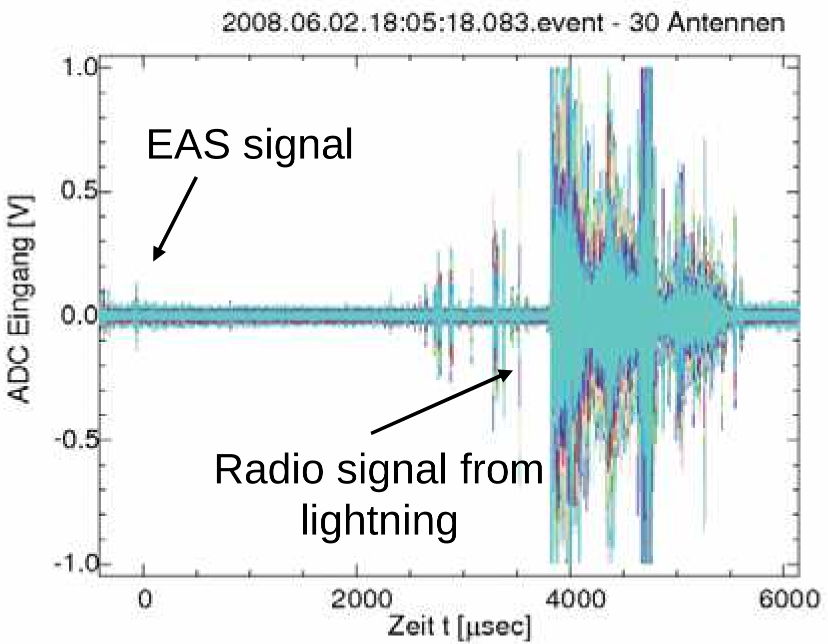
S. Buitink et al. (LOPES Coll.)
Astronomy & Astrophysics 2007

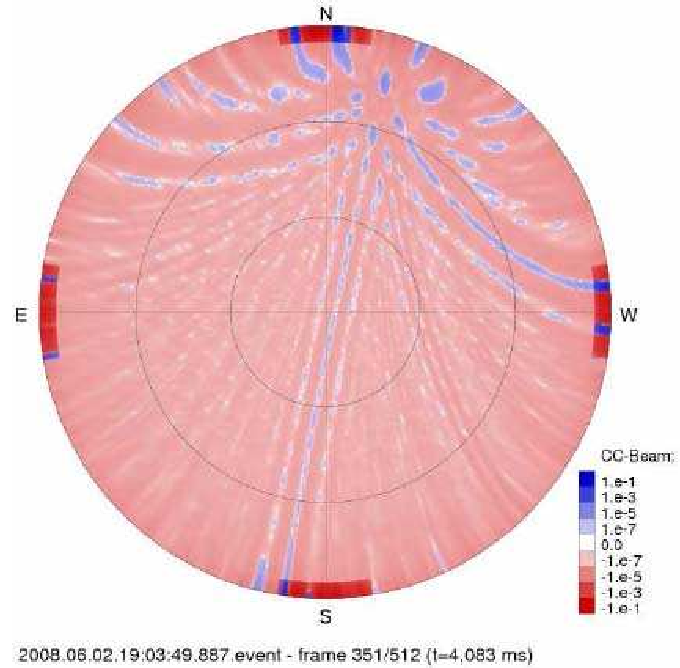
A. Nigl et al. (LOPES Coll.)
Astronomy & Astrophysics 2008

Results from LOPES and CODALEMA

- Thunderstorm analysis:
  - Measuring the atm. electric field with an E-field mill
  - During thunderstorms high atmospheric E-fields (normally ~100V/m)
  - Influence on radio emission

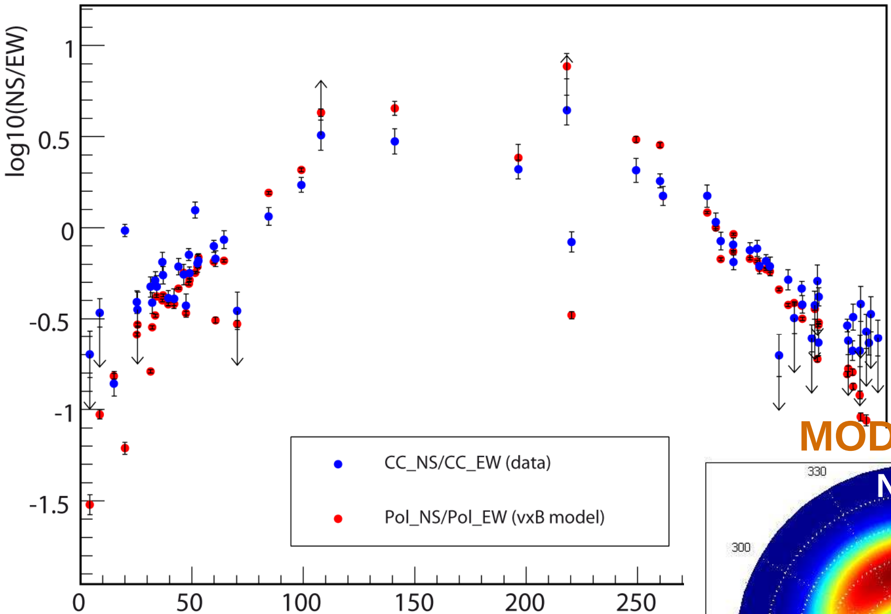
M. Ender (LOPES Coll.) FZKA report 7506





Results from LOPES and CODALEMA

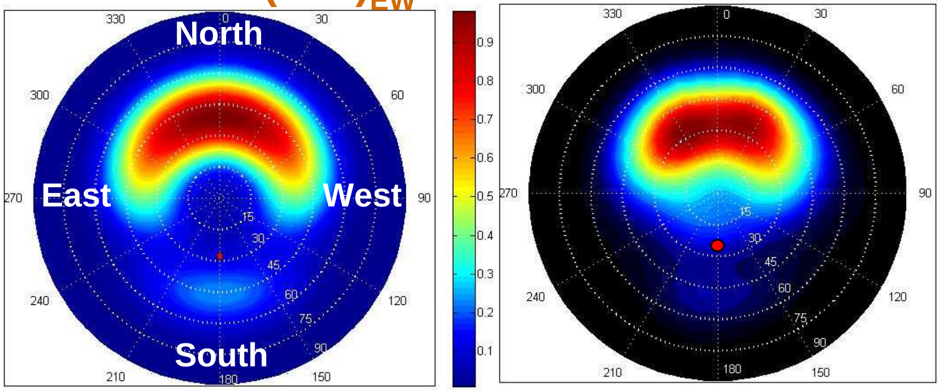
- Polarization studies: data vs. simple geomagnetic model $\vec{P} \approx \vec{v} \times \vec{B}$



K. Link et al. (LOPES Coll.)
CRIS 2010

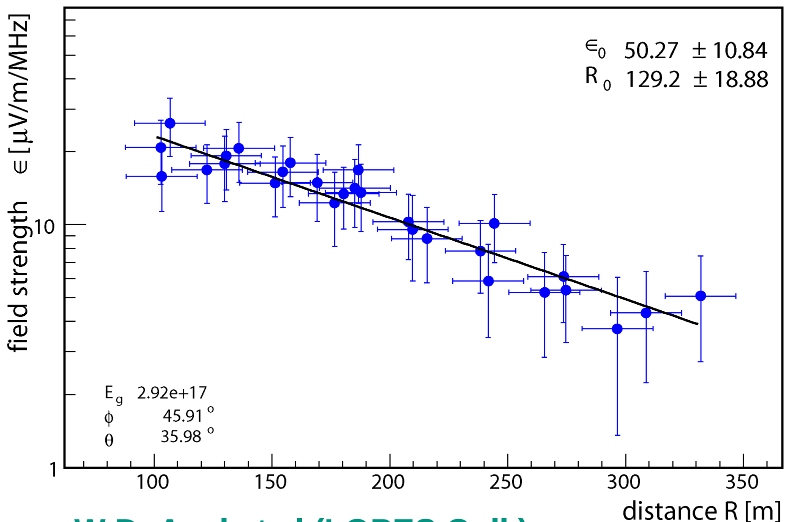
Deviations from the model could point to other emission processes

O. Ravel et al. (CODALEMA Coll.)
ARENA 2010

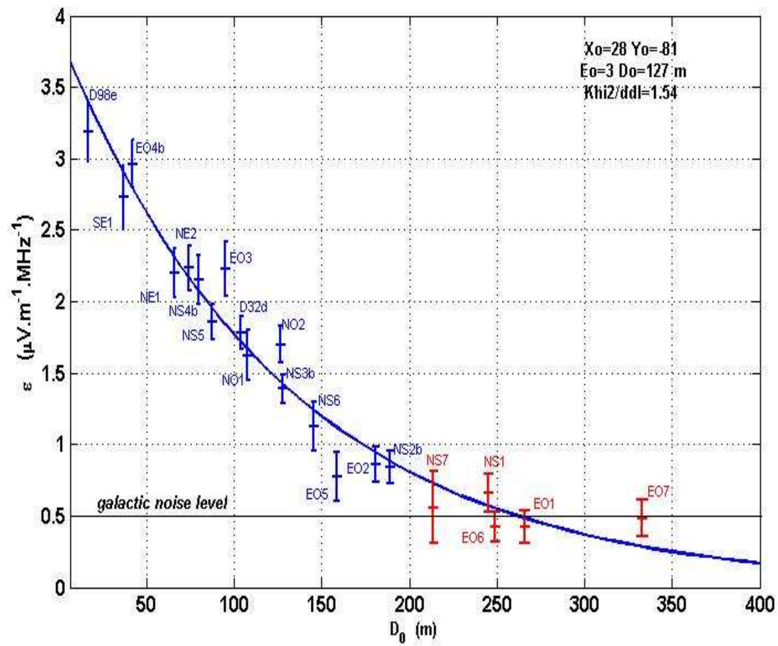


Results from LOPES and CODALEMA

- Field strength of individual antennas against distance to shower axis
- Detailed event-per-event analysis
- Fit with an exponential function $\varepsilon(R)= \varepsilon_0 \exp -(R/R_0)$
  - About 80% fit well with $R_0 \sim 160$ m

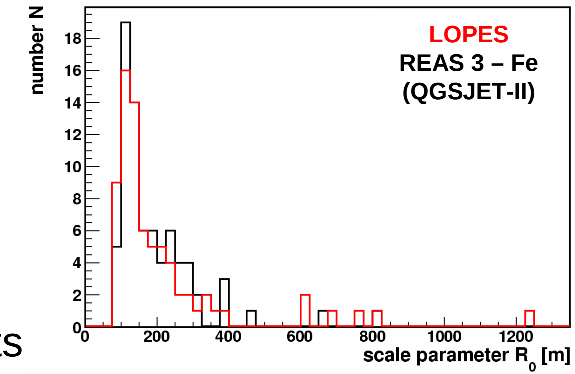


W.D. Apel et al.(LOPES Coll.)
Astroparticle Physics 2010

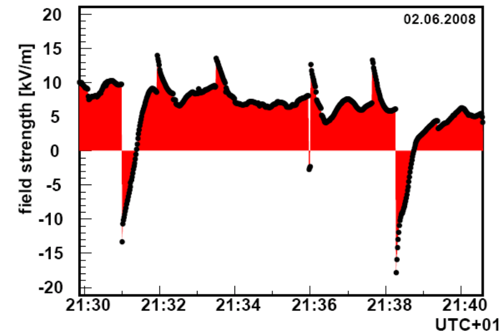


O. Ravel et al. (CODALEMA Coll.) ARENA 2010

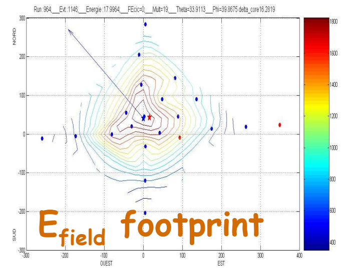
Ongoing analyses

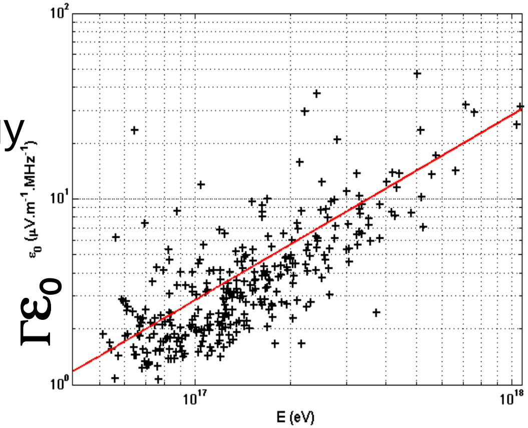


- LOPES:
  - Mass composition
  - Thunderstorm events
  - Comparison of simulations (REAS3) and data
  - …

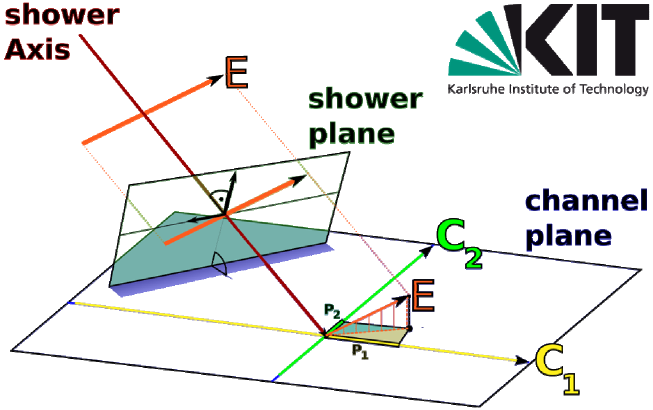


- CODALEMA:
  - Correlation of electric field and shower energy
  - Stand-alone determination of the primary energy
  - Polarization studies
  - …





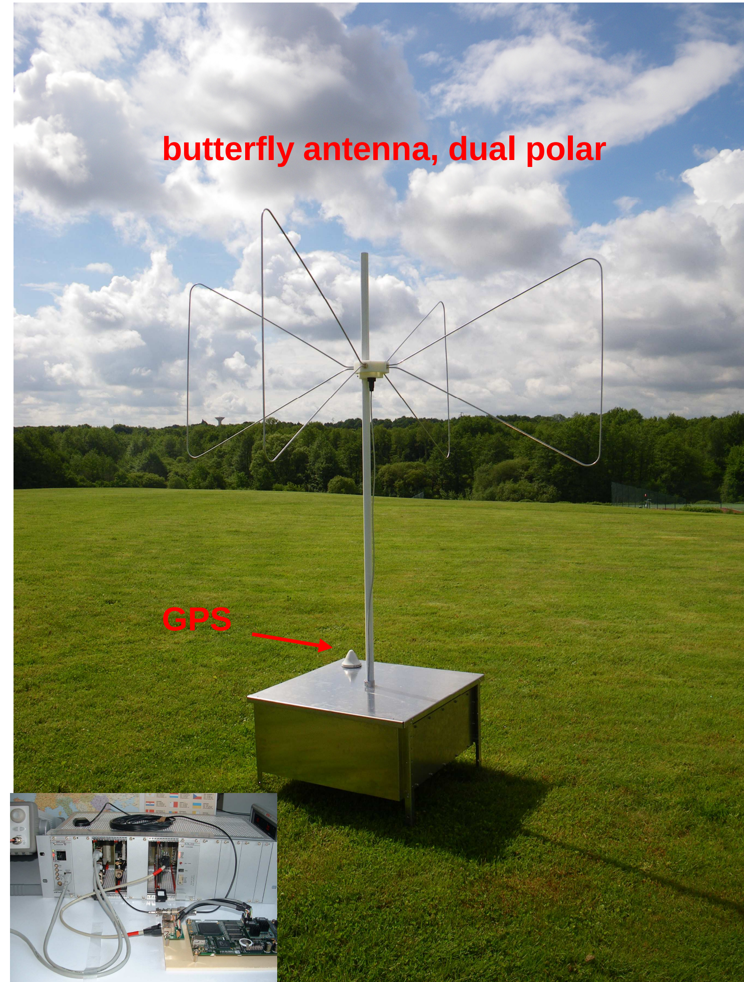
Perspectives of LOPES



- LOPES 3D:
  - 10 tripoles to measure the complete electric field vector (EW,NS,VE)
  - Stable data taking since May 2010
  - Completely calibrated
  - First analyses started
- Advantages:
  - Higher sensitivity to inclined showers
  - Improved direction reconstruction
  - Better self-trigger?
  - Check with simulations → emission models

Perspectives of CODALEMA

- Autonomous stations with new type of antenna (butterfly)
  - Three stations for testing and debugging already in the array
  - Extension of the array is planned:
    - Higher density of antennas in the center
    - Extension at larger scales
  - Testing 5 stations with butterfly antenna in Argentina



Limits of LOPES and CODALEMA

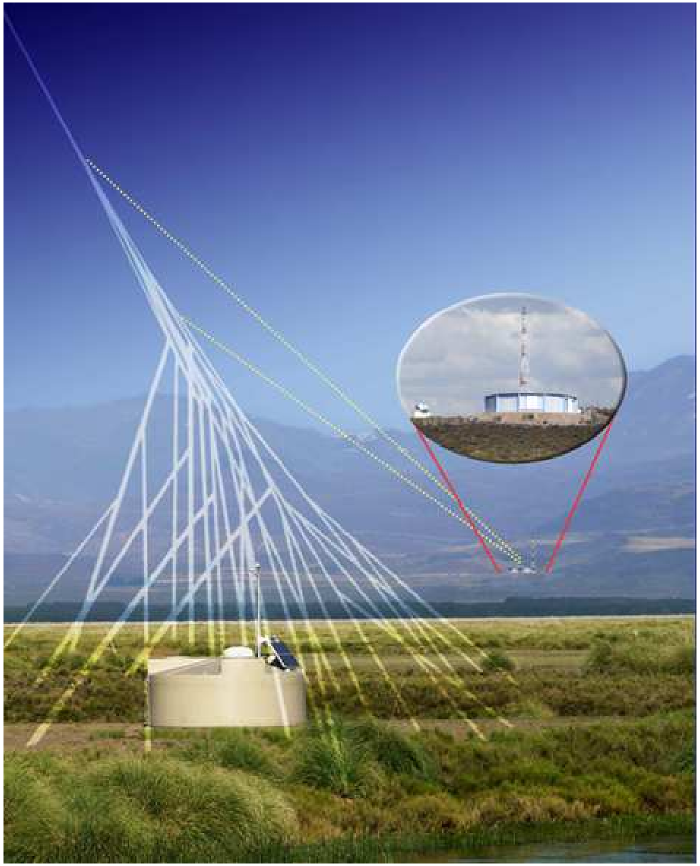
- From LOPES and CODALEMA we know:
  - Energy correlation
  - Lateral distribution
  - Geomagnetic dependence

- Limits: Both are small experiments → they run out of statistics for energies above ~10^{18} eV

- Perspective: Radio detection on large scales
  → **A**uger **E**ngineering **R**adio **A**rray at the
  Pierre Auger Observatory

AERA – Radio detection on large scales

- The Pierre Auger Observatory (cf. Talk J. Knapp)



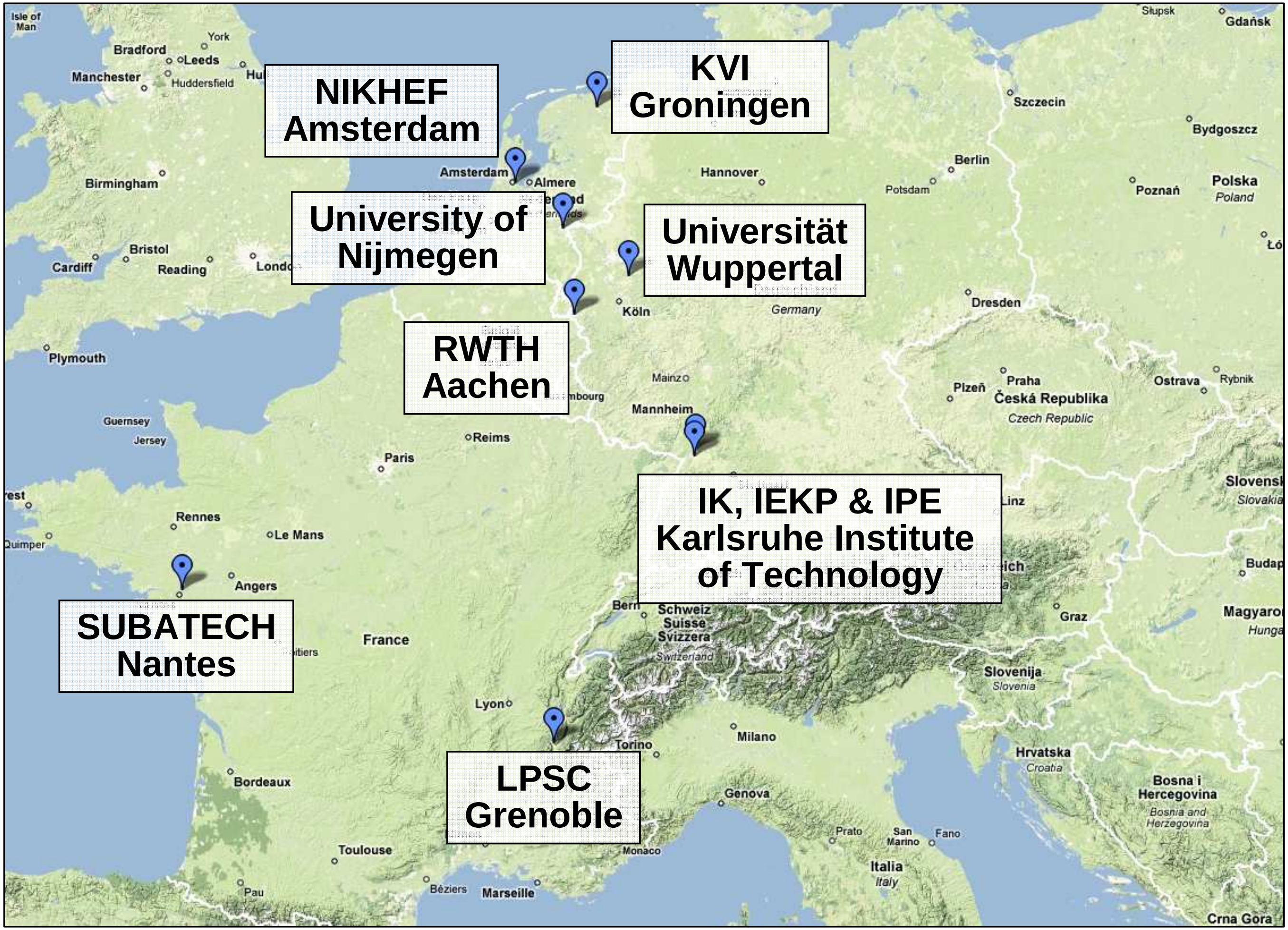
- Hybrid detection
  - 1600 water cherenkov tanks
  - 24 fluorescence telescopes
- Many advantages
  - Cross-calibration
  - Complementary information
  - General redundance
- Duty cycle of combined measurements only ~ 13%

AERA – Radio detection on large scales

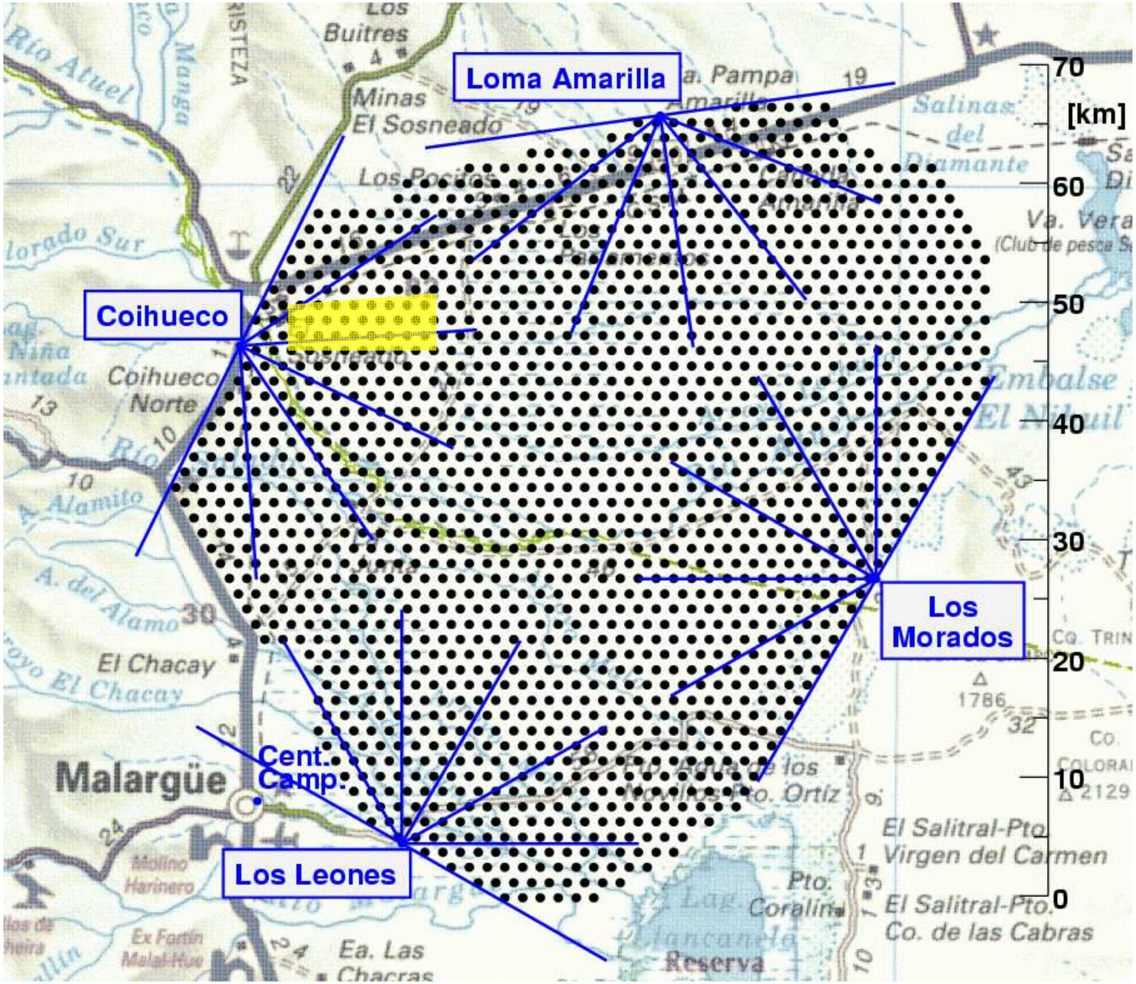
- Radio enhancement for Auger
  - Three phases
  - First phase: 24 antennas (LPDA), data taking started
  - Last Phase: up to 20 km² with ~150 antennas planned
  - Frequency range: 30-80 MHz

- Goals:
  - Study radio emission with higher energies
  - Determine primary parameters with radio measurements
  - Study transition of galactic and extragalactic cosmic rays
  - → Super-hybrid measurements

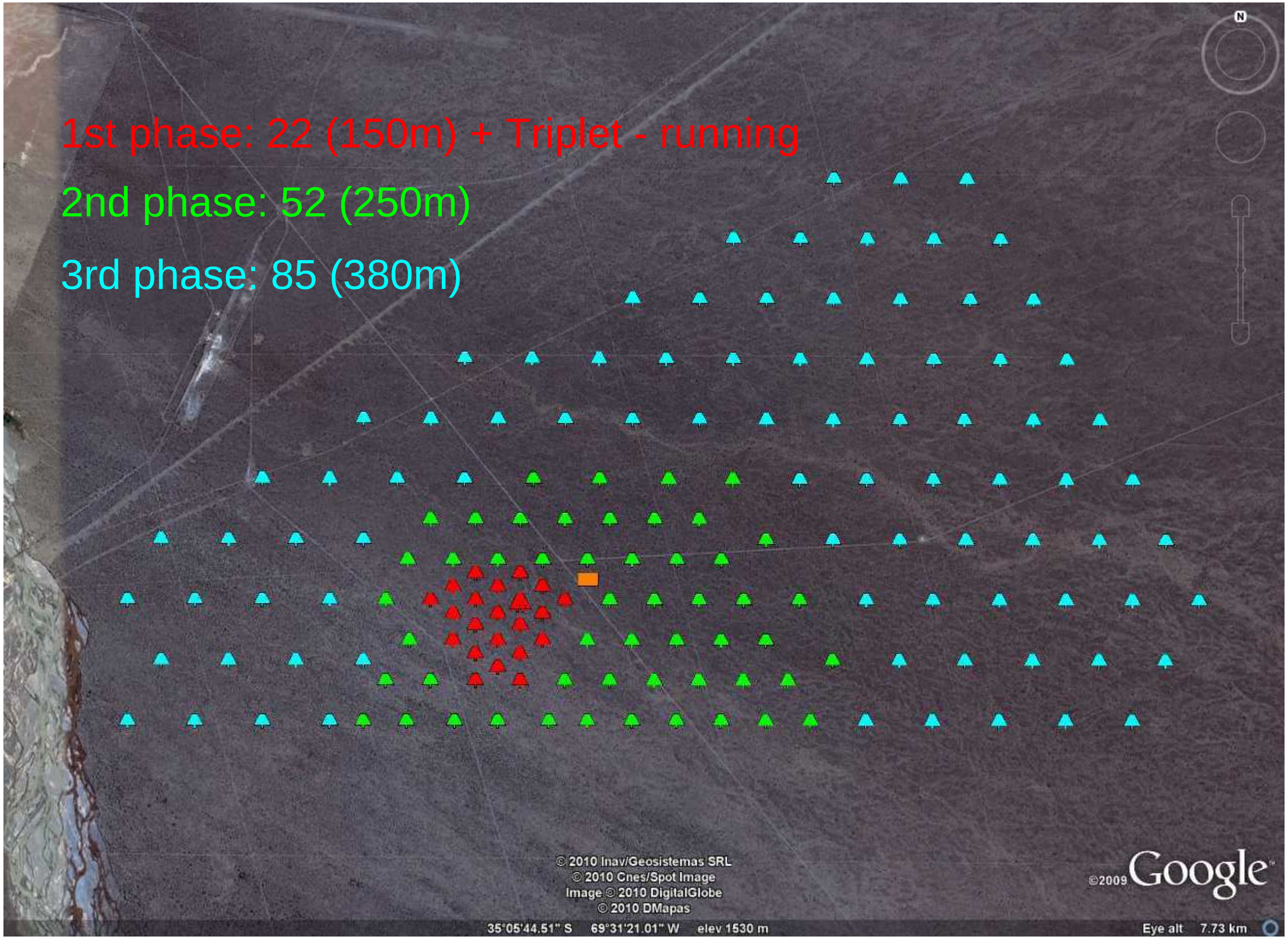
AERA – Participating groups



AERA – Radio detection on large scales



AERA – Radio detection on large scale

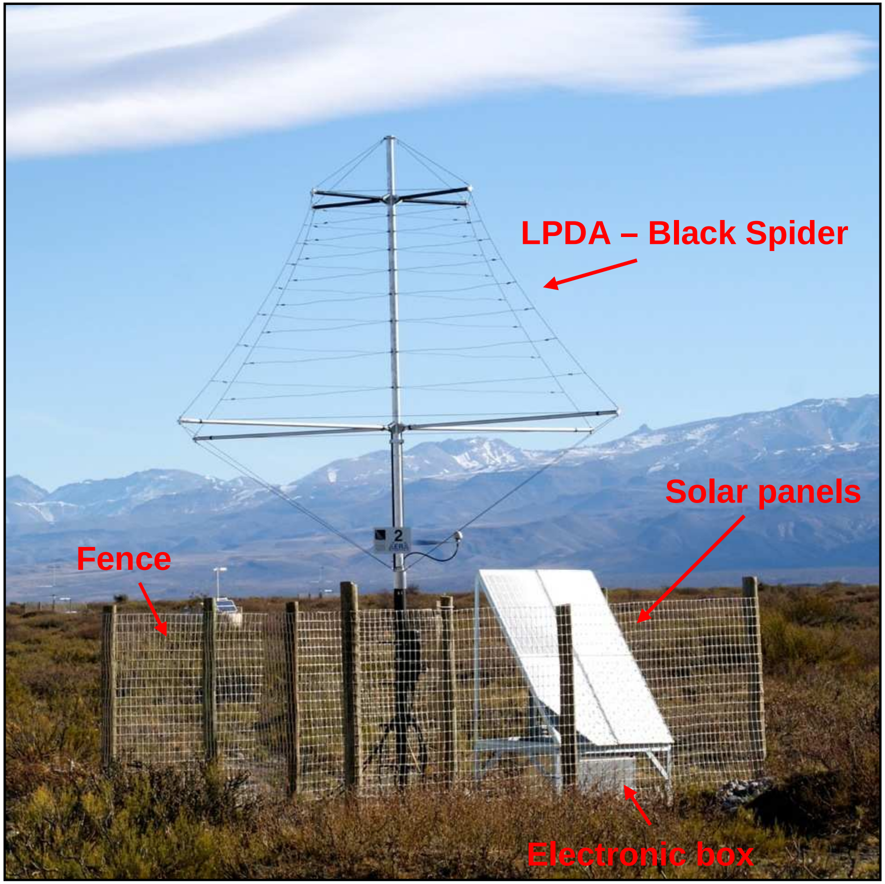


AERA – Radio detection on large scales

- Communication via Central Radio Station:
  - Data acquisition
  - Workshop
  - Monitoring (weather, …)

AERA – Radio detection on large scales

- All stations have to be autonomous:
  - Solar panels
  - Communication
  - GPS
  - Battery
- Beacon for time resolution of ~1 ns



AERA – Radio detection on large scales

- Current view over the AERA site

AERA – Perspectives

- Physics goals:
  - Calibration of the radio emission with energies above 10^{18} eV
  - Capability of the radio detection
  - Cosmic ray physics in the transition region
- Open questions:
  - Emission mechanism?
  - Influence of the primary particle?
- Challenges:
  - Self triggering
  - Noise/CR discrimination
  - Communication

Summary

- LOPES and CODALEMA show feasibility of the radio technique
- vxB model describes data well with small differences
  → main emission mechanism is geomagnetic
- Small size experiments are limited by statistics for higher energies
- Large scale applications as AERA are build for ‚super-hybrid' measurements
- Radio is a growing field with a lot of new projects (TREND, Ice Top,…)
- In transition between R&D and physics

Thank you for your attention!