Radio detection of cosmic rays at Auger observatory

Toward a super hybrid detector

Séminaire,
CPP Marseille
Le 12 Avril 2010

Maximilien Melissas IEKP

Outline

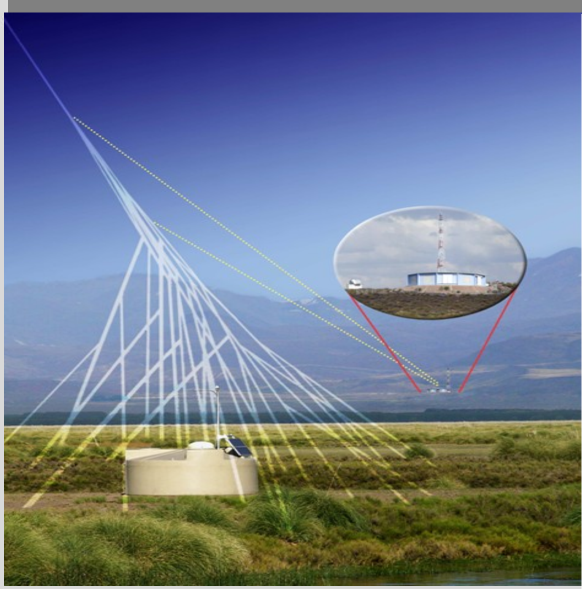
- Cosmic ray and radio-detection
- What we have up to now
- Software for Radio Analysis in the AUGER framework
- AERA

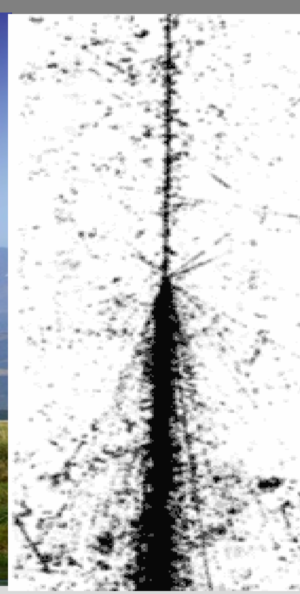
Cosmic rays and radio detection

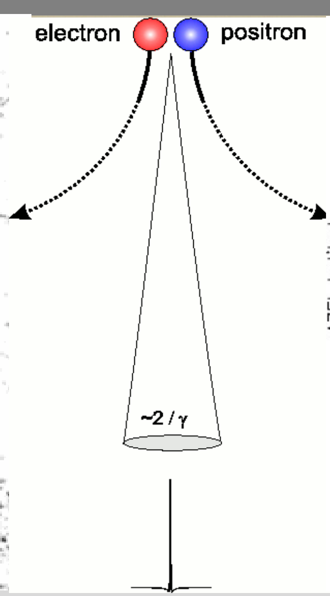
- History of cosmic rays
- Cosmic rays spectrum
- Detection principle
- Radio-detection of air showers

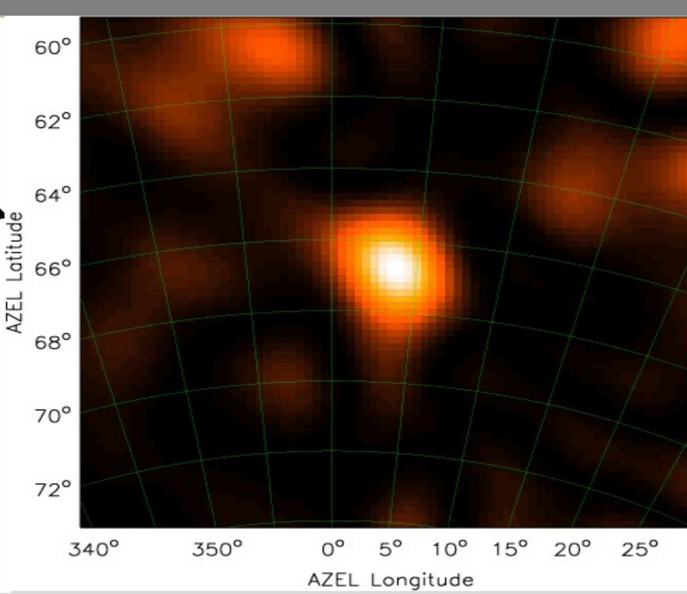
Auger Engineering Radio Array

Maximilien Melissas IEKP







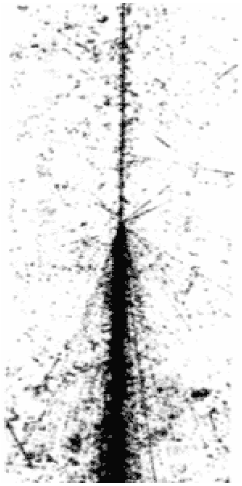


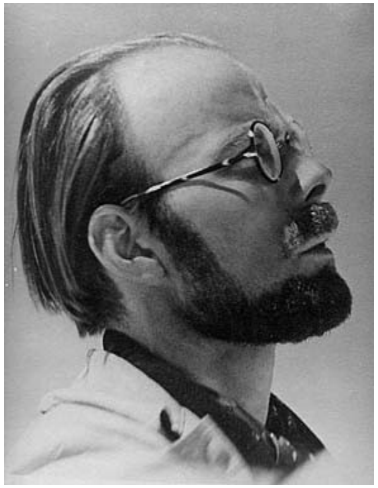
AERA Auger Engineering Radio Array

A little bit of History

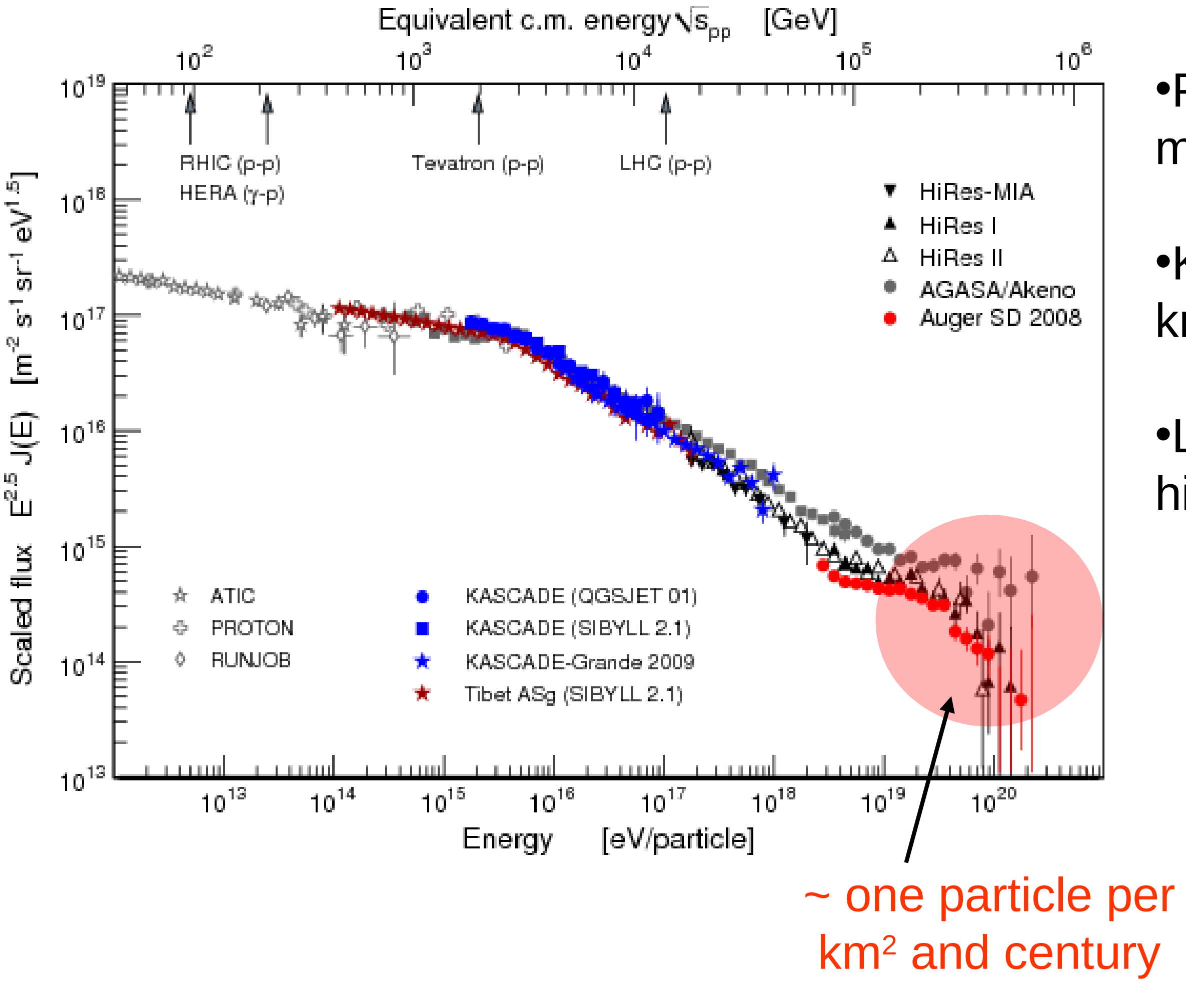
KIT Karlsruhe Institute of Technology

- 190X Electroscope experiment, show there is a natural radioactivity
- 1912 V. Hess balloon flight, radioactivity is coming from space
- 1939 Discovery of atmospheric shower by P. Auger
- 1951 : radio-astronomy (21 cm line)
- 1959 P.S. At CERN





Cosmic ray spectrum



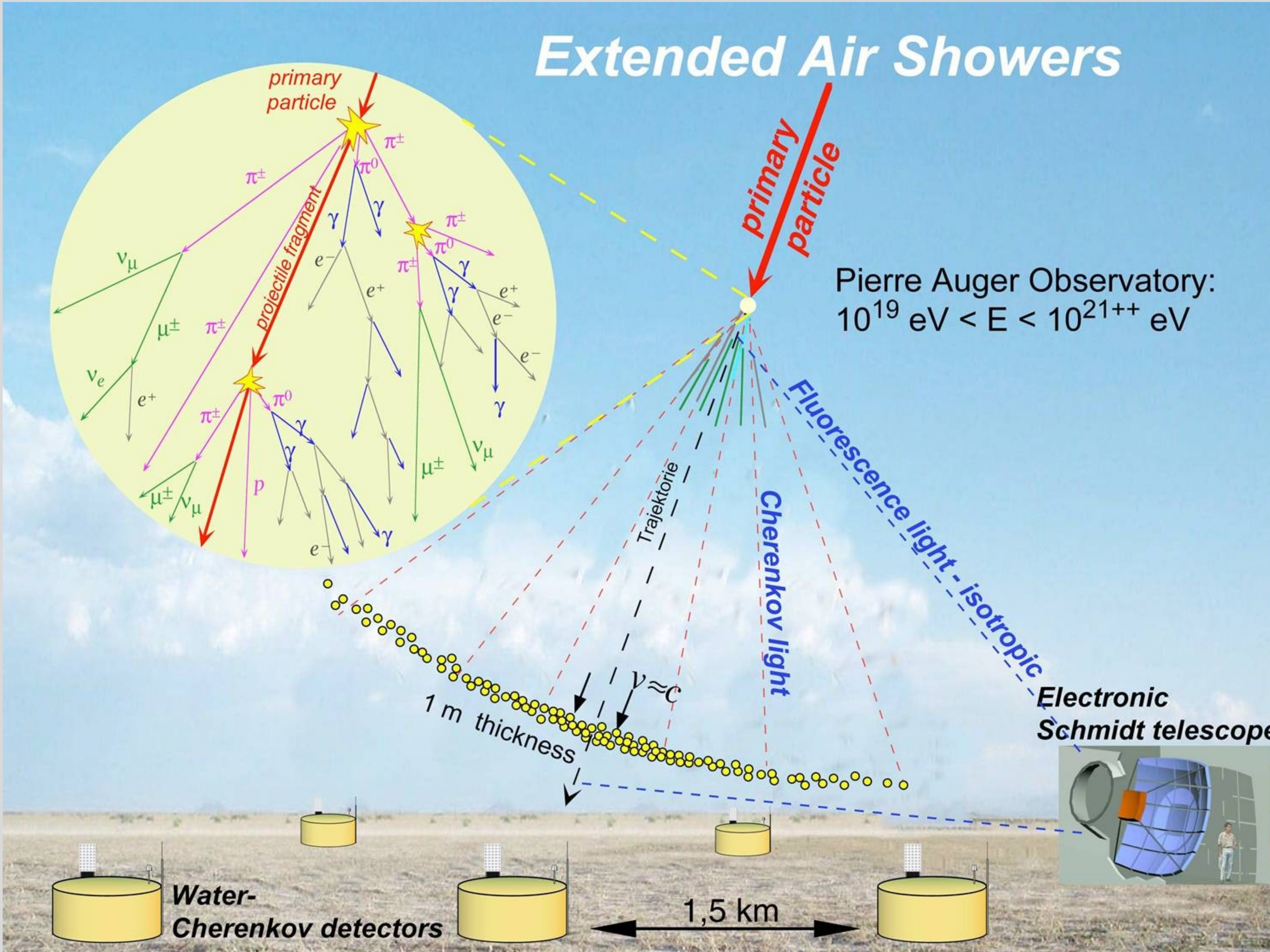
- Power law over 10 order of magnitude
- Kinks in the power law : knee and ankle
- Low energy direct method / high energy indirect method

Detection Methods (1)
Standard method

- Direct detection : AMS / Pamela/ Balloon experiment
- Surface : KASCADE-GRANDE / AUGER
- Fluorescence : AUGER-FD / E
- Cerenkov : HESS/ Celeste / V

Detection Method (2) new methods

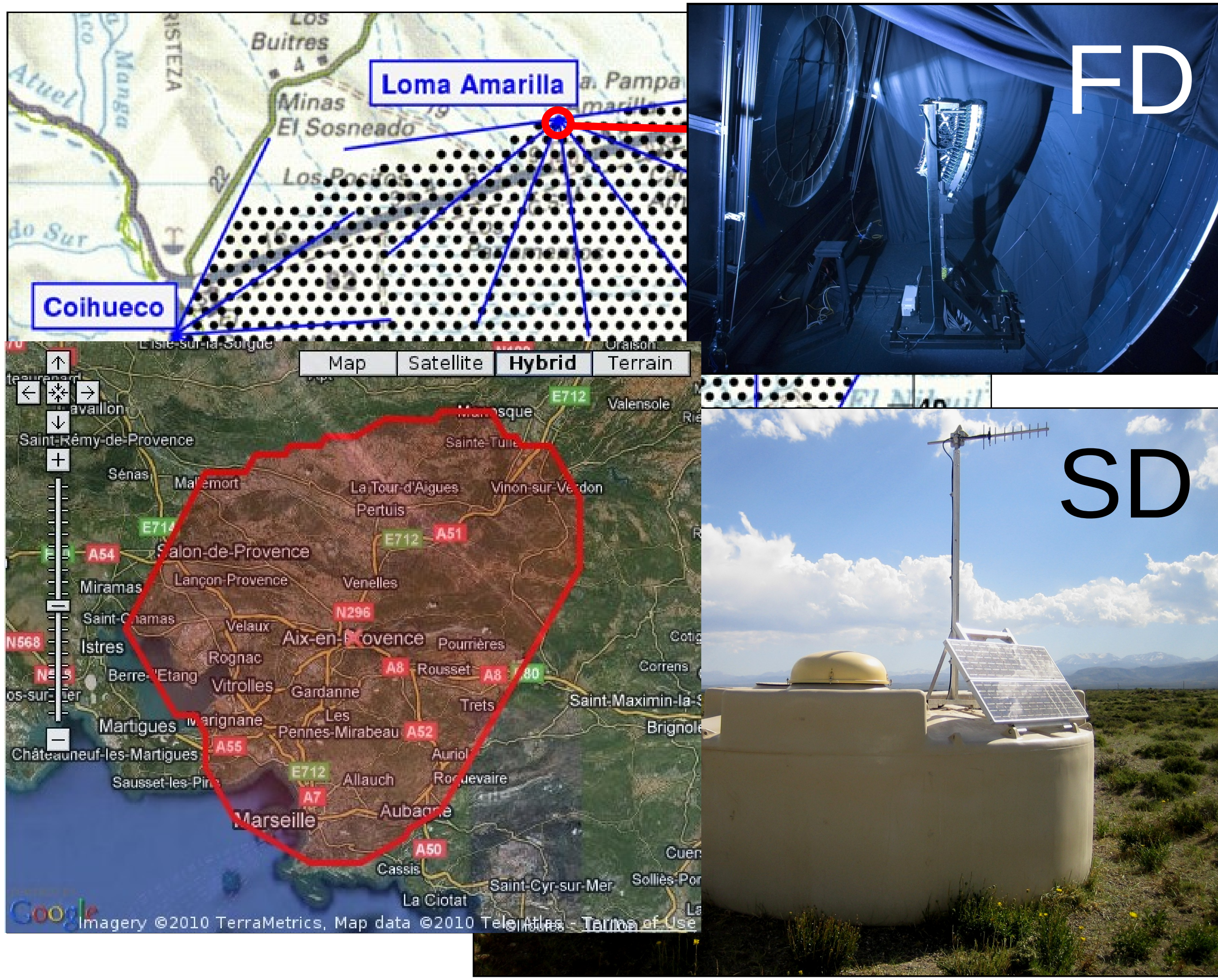
- Radio (atmosphere) : LOPES/CODALEMA/ AUGER/
- Acoustic : ANTARES/ ICECUBE
- Radio (Askarian) : ANITA, LUNASKA



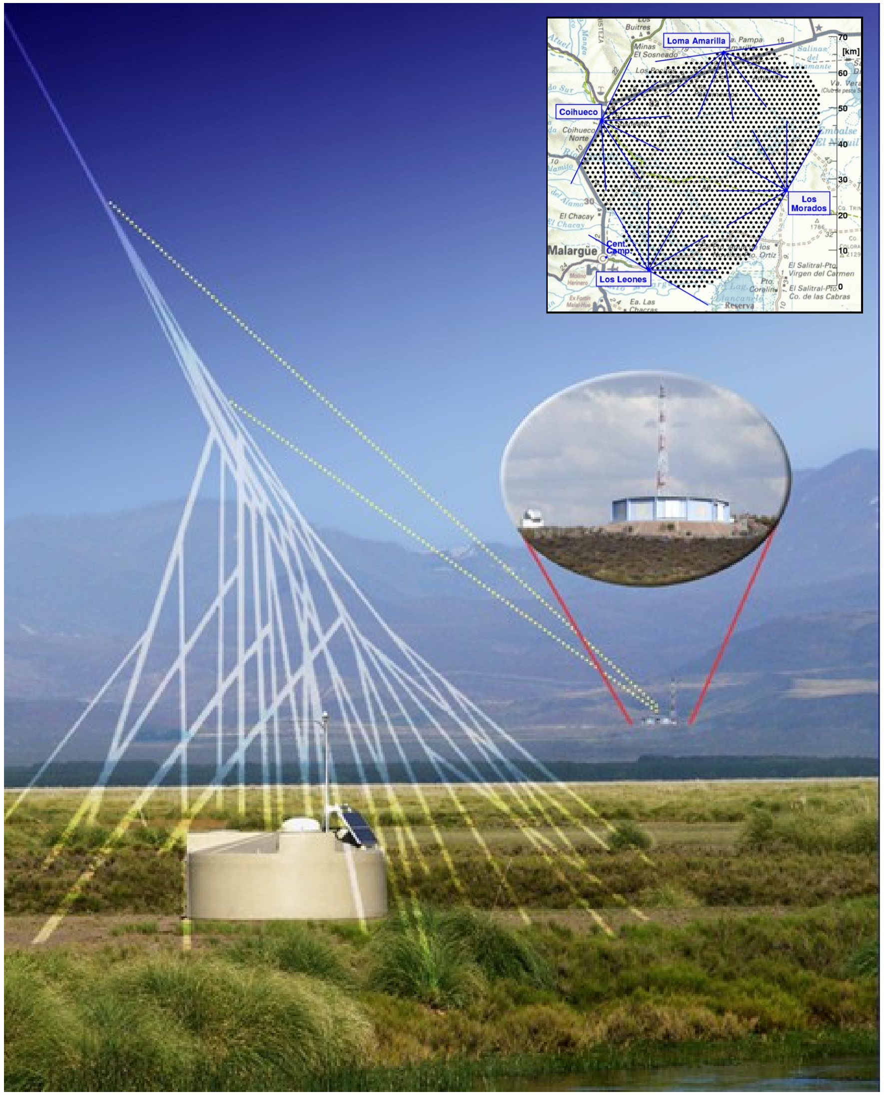
Extended Air Showers
primary particle
Pierre Auger Observatory:
10^{19} eV < E < 10^{21++} eV
primary particle
projectile fragment
$\pi^\pm$
π^0
γ
e^-
e^+
ν_μ
$\mu^\pm$
ν_e
p
Fluorescence light - isotropic
Cherenkov light
Trajektorie
$v \approx c$
1 m thickness
Electronic
Schmidt telescope
Water-
Cherenkov detectors
1,5 km

The Pierre Auger observatory

- highest energies need huge arrays
- Southern site
  - Argentina
  - 3000 km^2
  - 1600 particle detectors
  - 24 optical telescopes
- Northern site
  - planned
  - USA
  - >20000 km^2



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%

AERA
Auger Engineering Radio Array

Low-Energy extension

KIT
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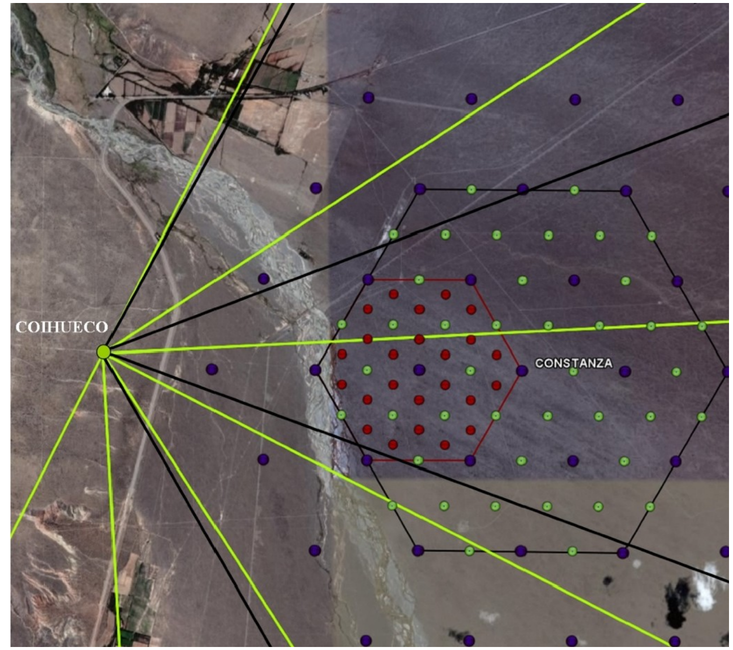
- HEAT :High Elevation Atmospheric Telescope
- Tilted clone of the FD
- In Commissioning



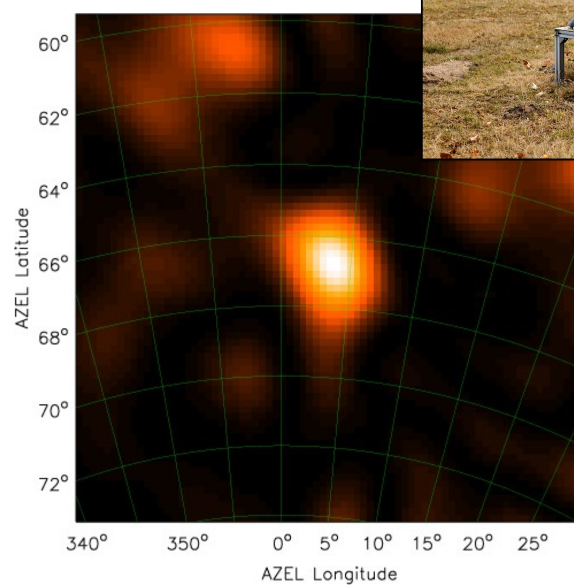
- AMIGA :
- 750m Infill array
- Underground muon counter
- Planned infill of the infill

Radio detection

- First detection of radio pulses associated with EAS in the 70's
- Since recently we have an electronic good enough to do it !
- 100% duty cycle
- Keep information about the shower history
- Good angular resolution

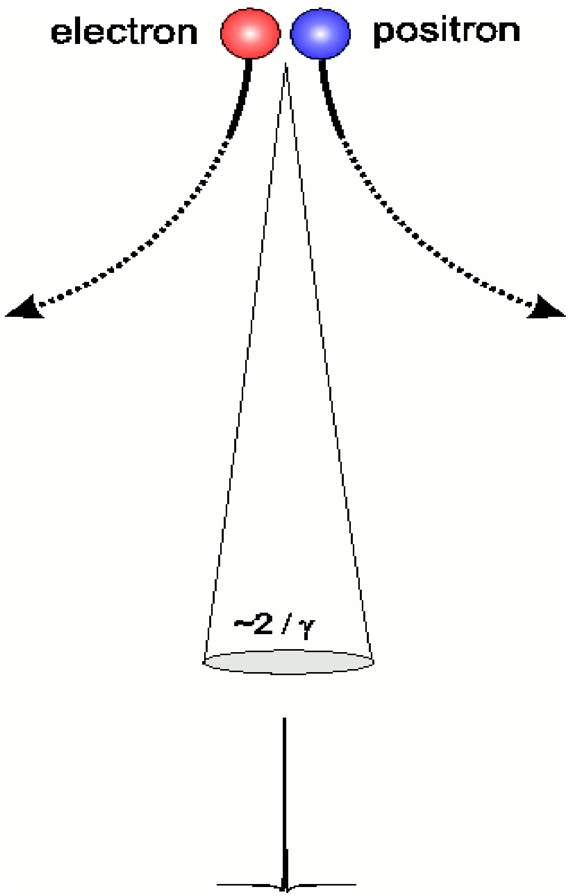
CODALEMA
dipole antenna

LOPES
dipole antenna



radio flash of a cosmic ray air shower seen by LOPES

Radio emission associated with air showers



Geo-synchrotron emission mechanism :

- e^- and e^+ generated in Cosmic Ray Extensive Air Showers are accelerated in the presence of the earth magnetic field (B) and subsequently emit short radio pulse

- Signal is coherent below 100 MHz

Karlsruhe Institute of Technology

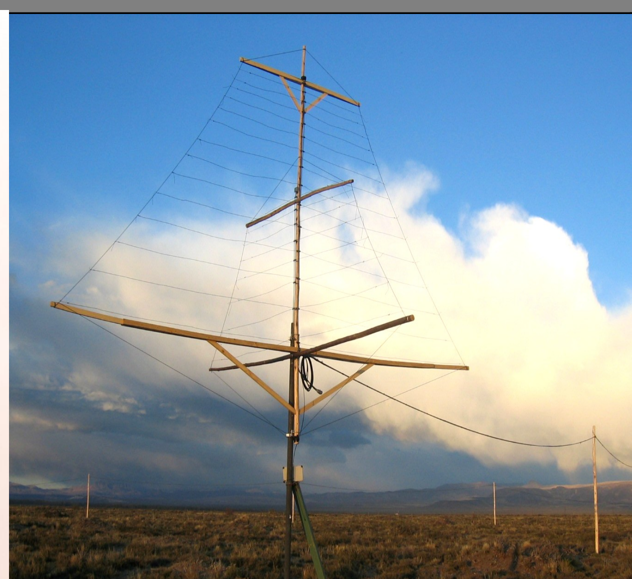
Current Status of Radio-detection at AUGER

PIERRE AUGER OBSERVATORY

- Known results from previous experiment
- Test setup at AUGER and 2007's results
- Hardware test for the next steps

AERA Auger Engineering Radio Array

Maximilien Melissas IEKP


Radio-detection rebirth

LOPES:
At KASCADE site good measurement of cosmic ray air showers
Noisy environment (research center)
Antenna taken from LOFAR
Λ-dipole

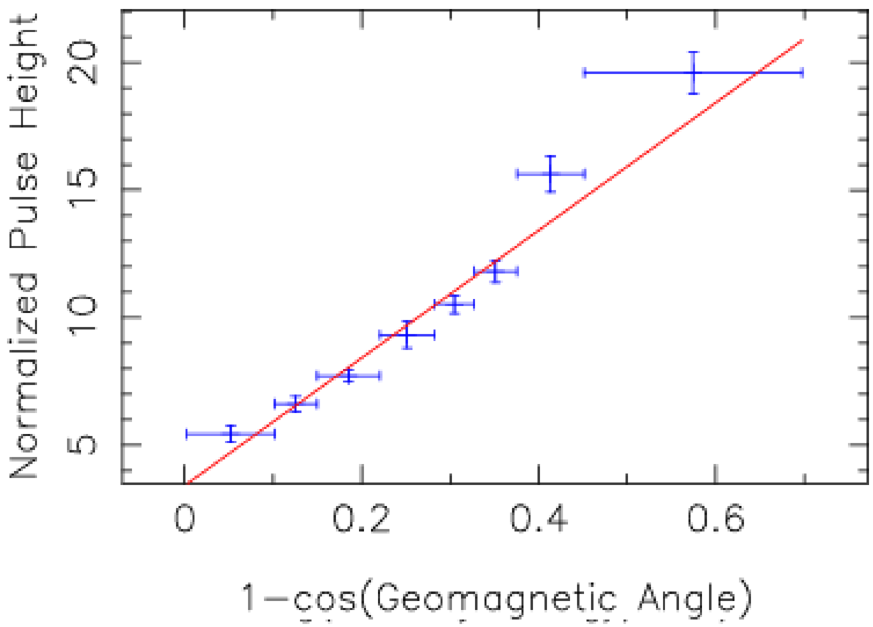
CODALEMA:
At Nancay observatory
Radio quiet
Not a cosmic ray observatory
Active dipole Antenna

Where to find a radio quiet environment and good cosmic rays measurement ?
Where to find space to go to higher energy ?
↓
AUGER

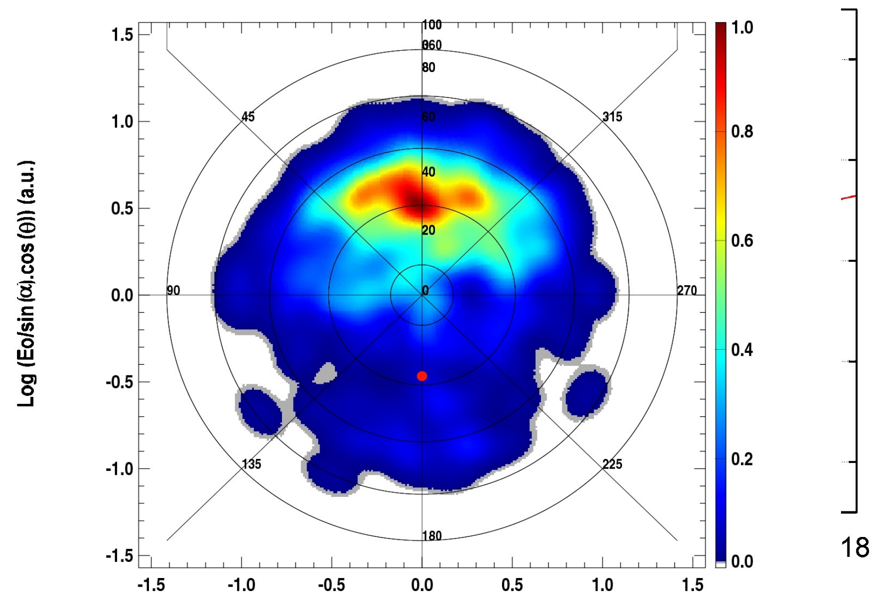


Known results

LOPES results

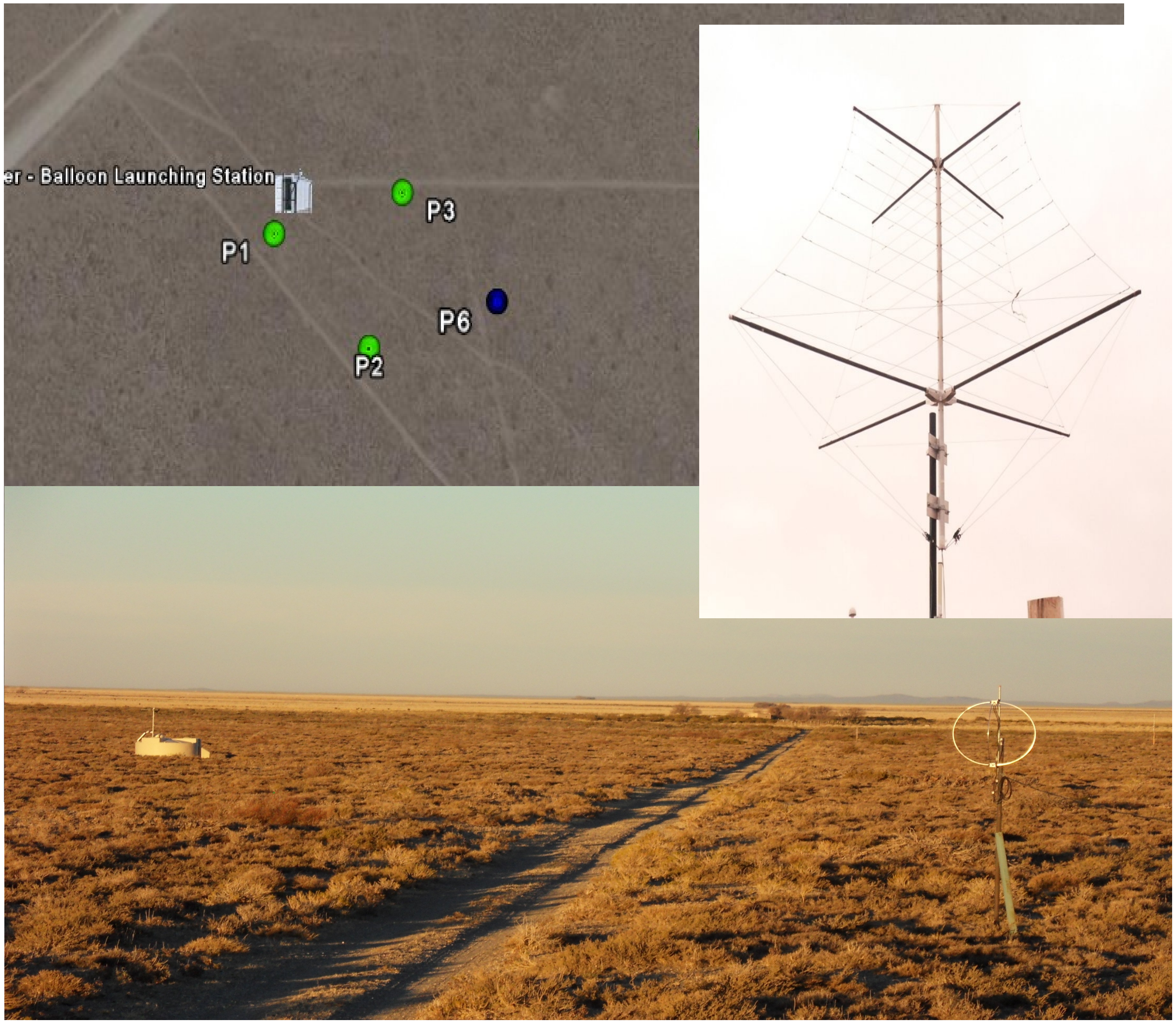


CODALEMA results



- 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

Test setup @ AUGER



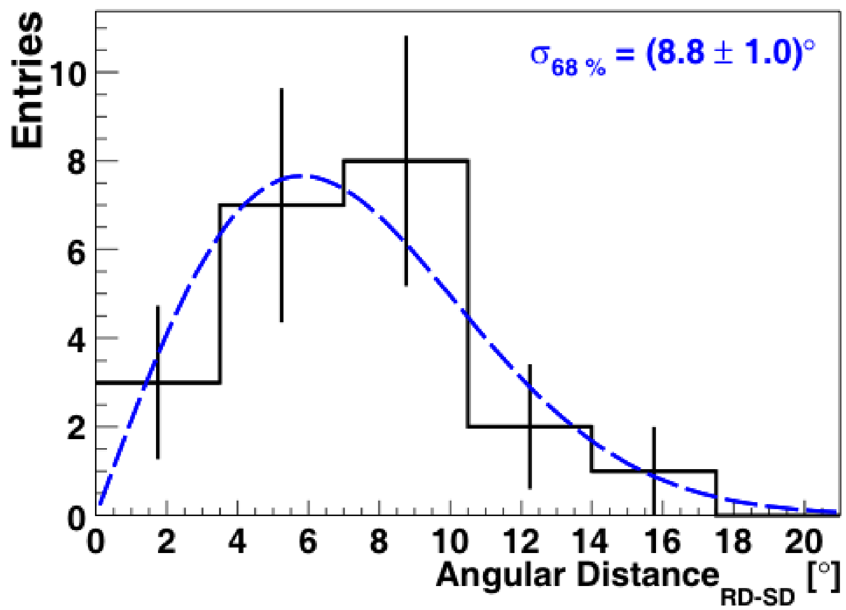
- 4 Wired poles near the BLS
- 4 MAXIMA autonomous station
- 1 infill tank *Olaia*
- Data acquisition and networking in the BLS container
- External trigger provided by scintillator

•Other radio test setup at the Central Laser Facility

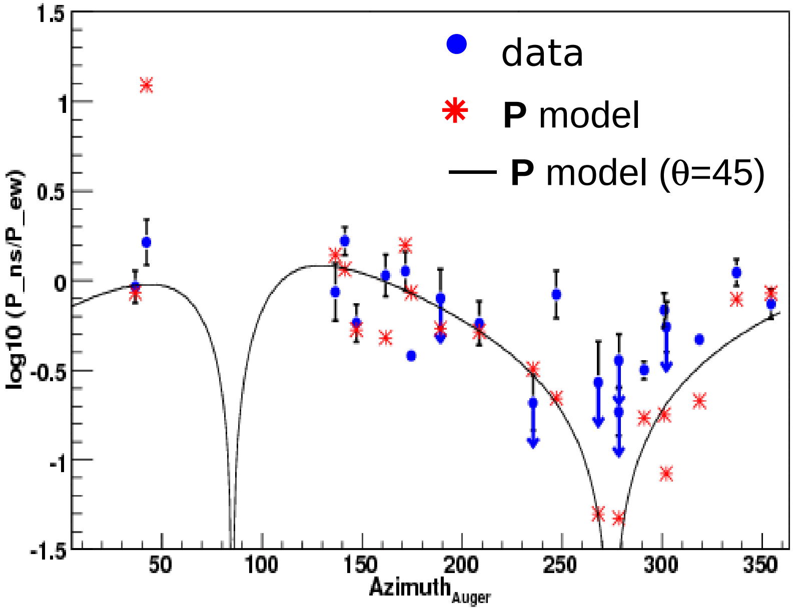
2007 : 313 events

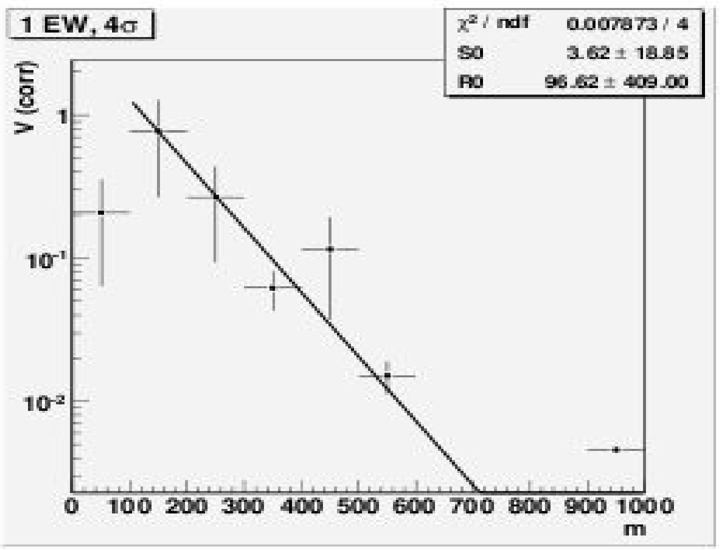
2007's datas

- Using externally triggered events, 313 where in coincidence with SD
- This events are also used as a reference set to test simulation software
- Most of these events does not pass quality cuts, i.e. 21 events with |(Direction Reconstructed)$_{RADIO}$-(Direction Reconstructed)$_{SD}$ |<20°
- 443 events including 2008



BLS's 2007 results





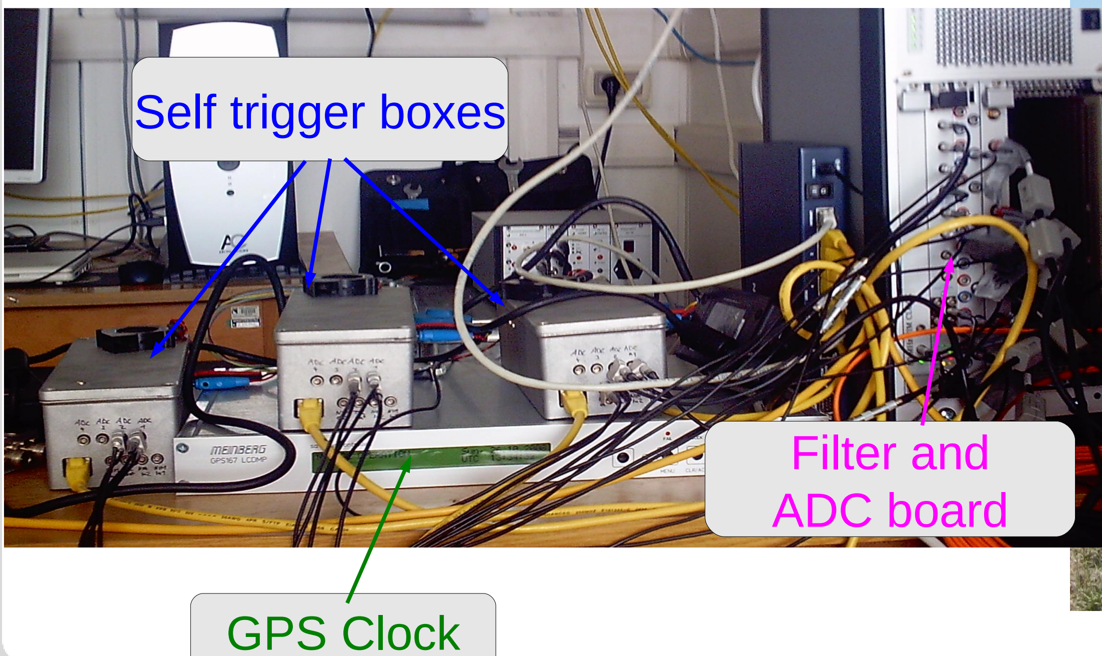
Polarization of radio signal, is consistent with simple geomagnetic model :
$$\vec{P}_i = \vec{v}_i \wedge \vec{B}$$

In agreement with geomagnetic emission mechanism

Lateral distribution measured over the BLS, has an exponential behavior

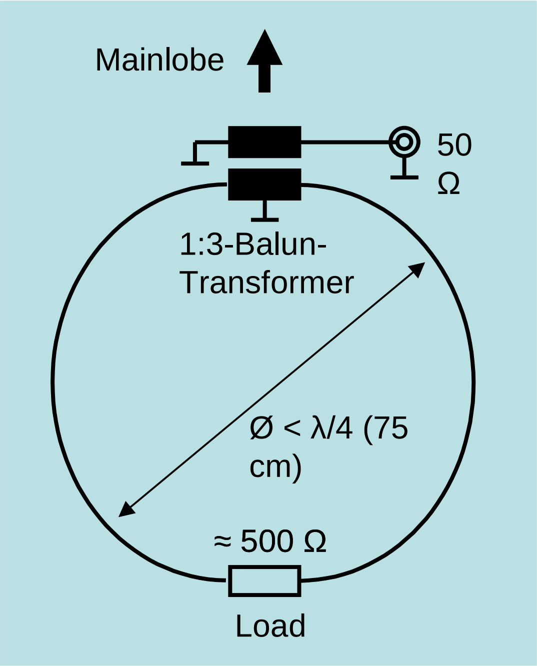
Hardware test
Self trigger and new Antenna

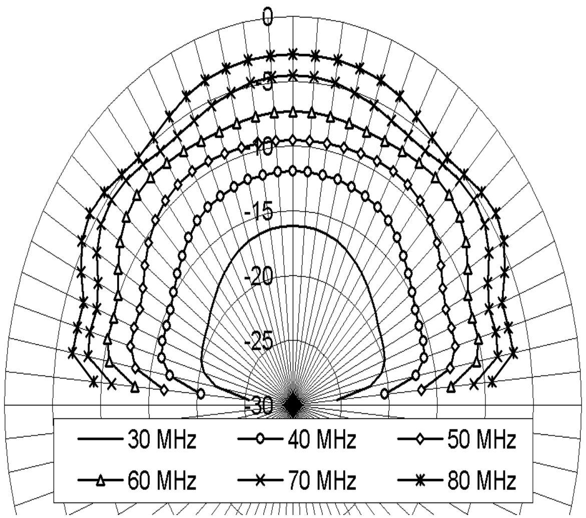
Test with a compact Antenna the SALLA,
Small **A**periodic **L**ooped **L**oaded **A**ntenna.
Also used as test bench for self triggering, we don't use the external trigger



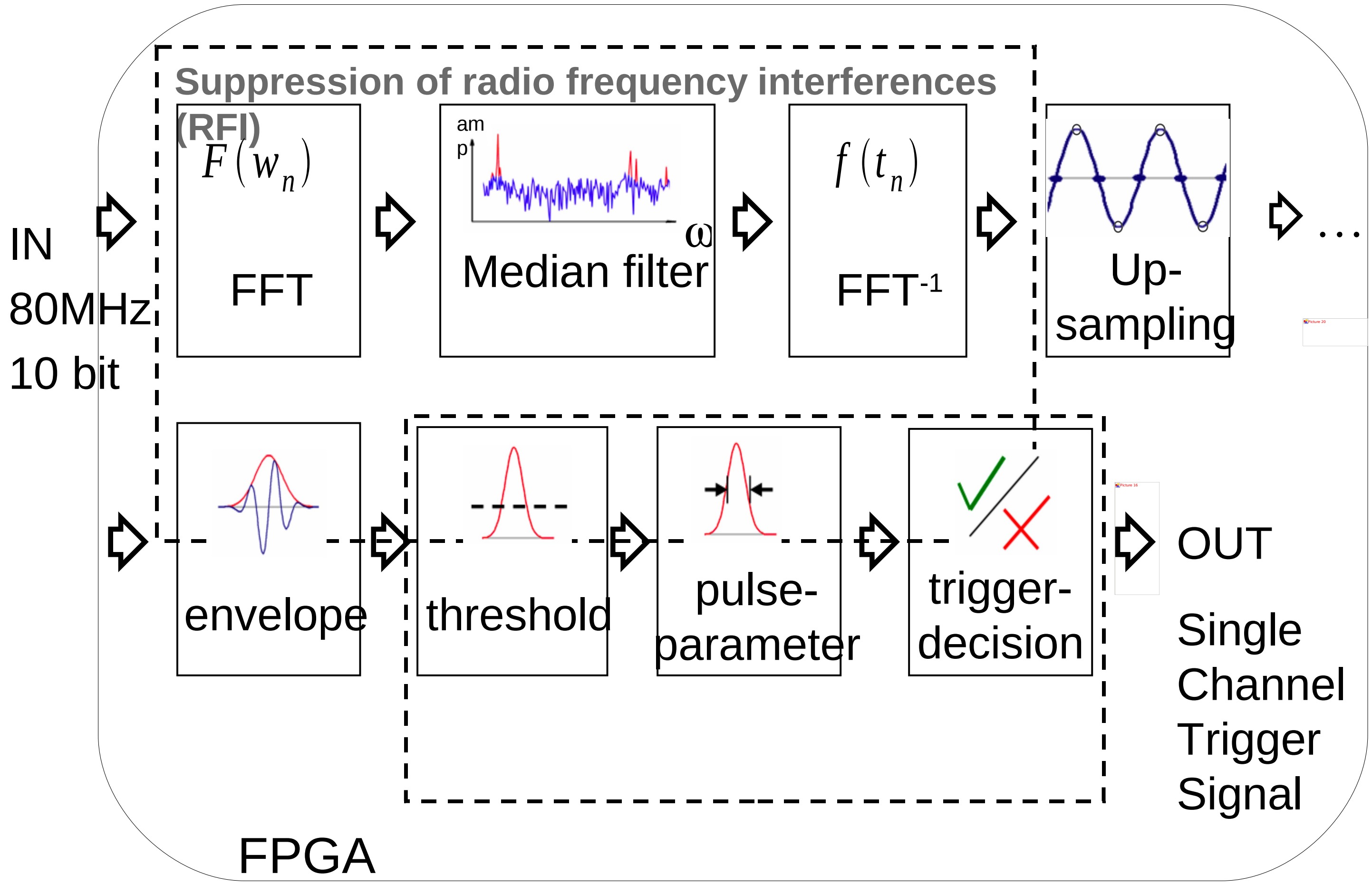
Small Aperiodic Loaded Looped Antenna

- Stable mechanical structure
- Simple construction
- Good directivity
- Smooth frequency dependency





Self trigger



- Self trigger necessary
- FPGA approach

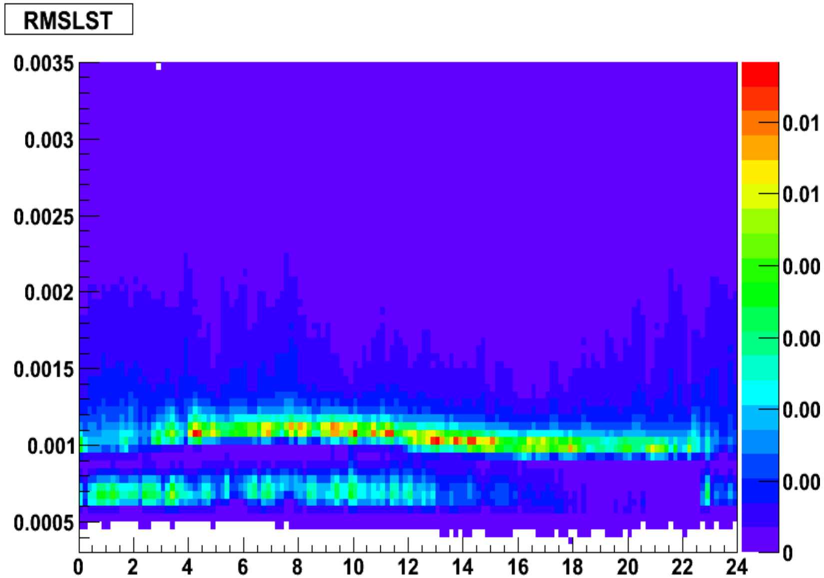
Measurement with SALLA and Self-trigger

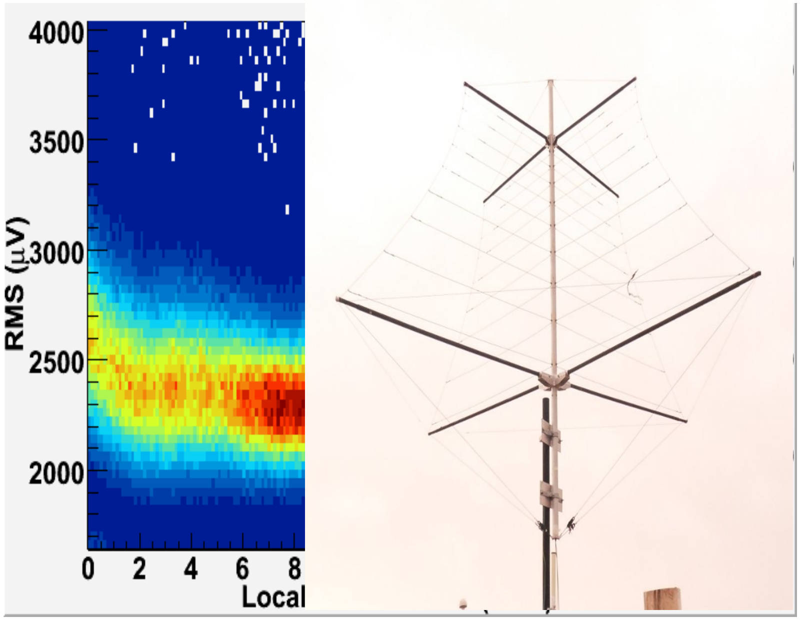
Objectives :

- Understand the noise in Argentina
- See if the SALLA is sensitive enough   for cosmic rays detection
- Test the Self trigger
- Self triggering made in case of coincidence in 3 Antennas

- A lot of self triggered events, but no coincidence with SD

Noise Measurement





- With the SALLA, no evolution of the noise level with time, antenna is not sensitive to the galactic background
- With the LPDA, the galactic background noise can clearly be seen
- LPDA antenna chosen for AERA phase 1

Radio Analysis
And software environment

- Processing of a radio signal
- Auger-OffLine
- Radio reconstruction

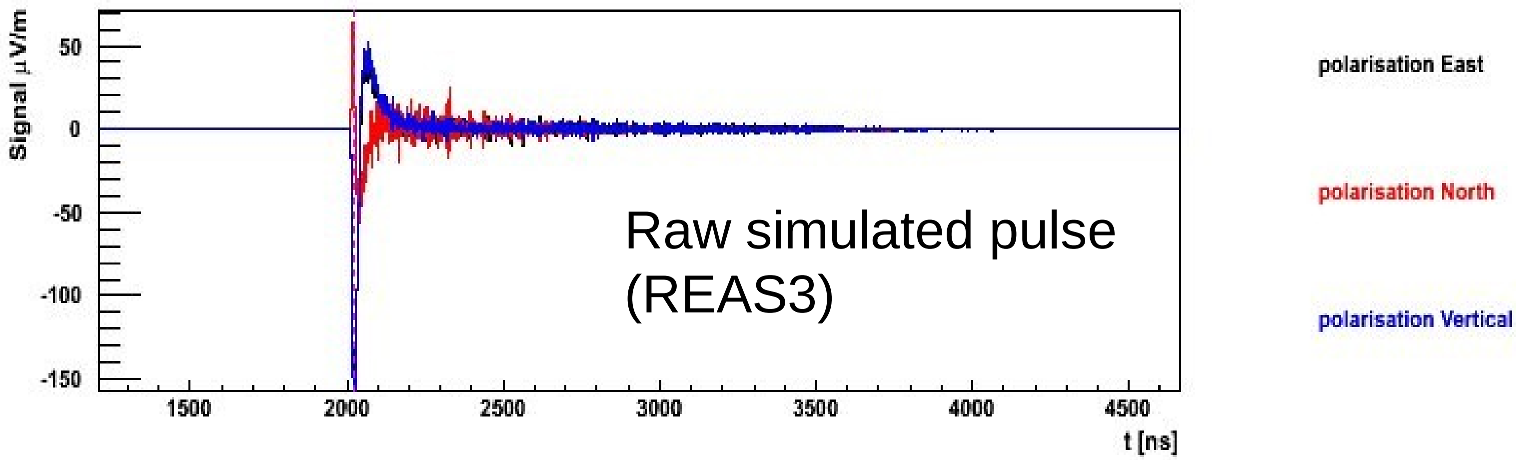
Maximilien Melissas IEKP

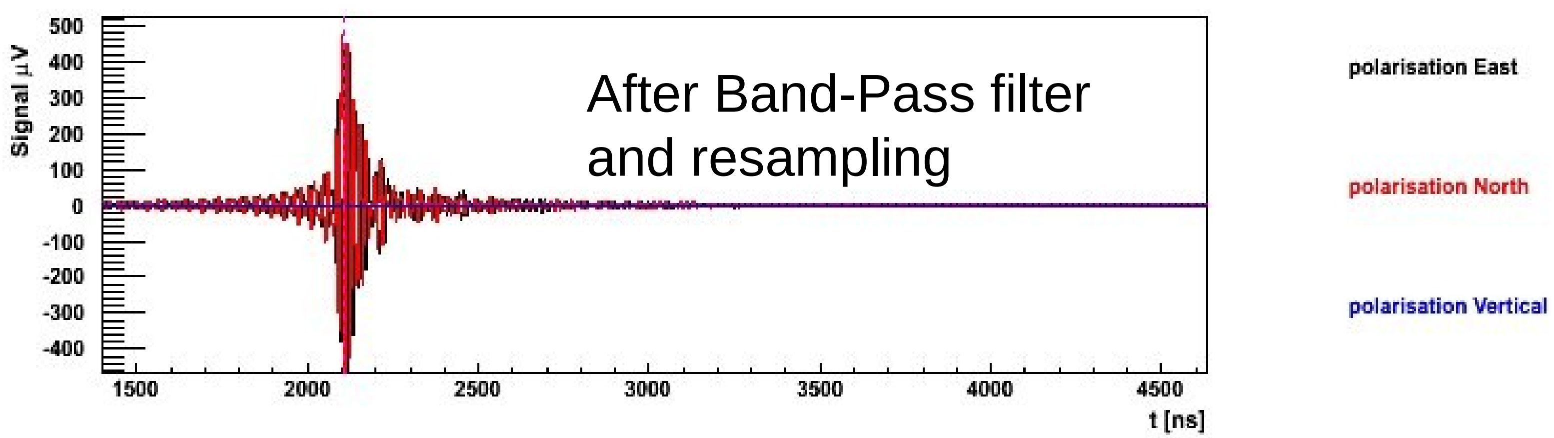
The story of a radio signal

Auger Engineering Radio Array

Karlsruhe Institute of Technology

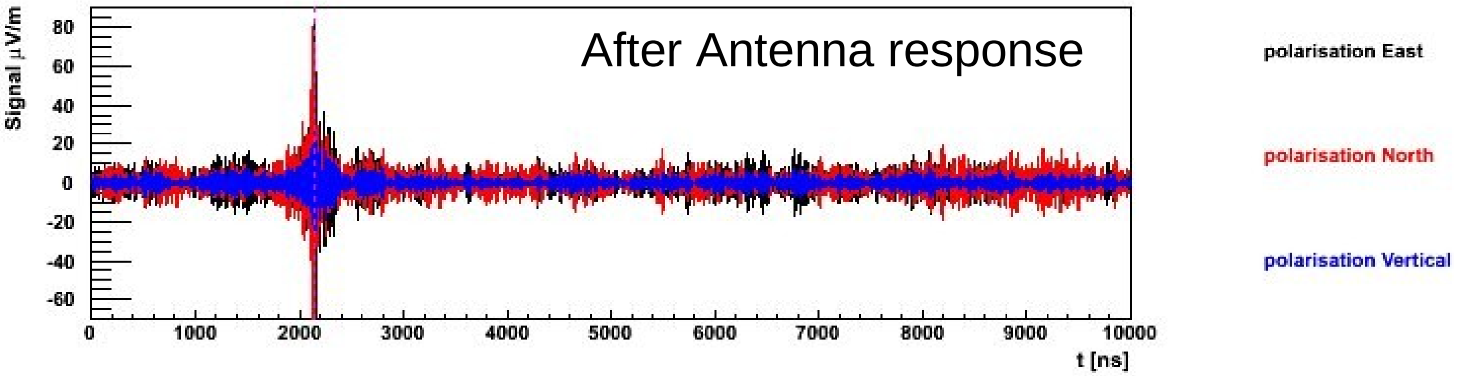
- From a raw pulse to the trace recorded by the ADC.

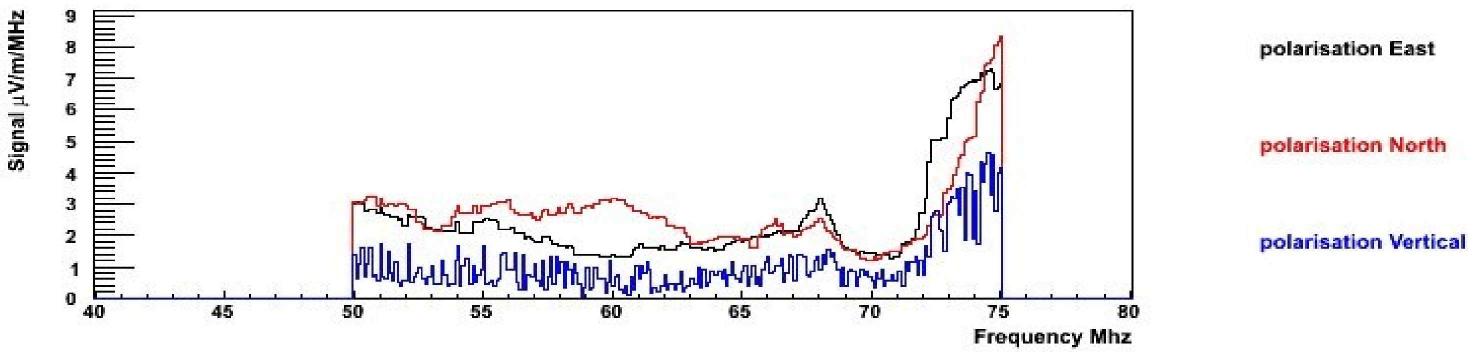




The story of a radio signal (2)

- From a raw trace to the physical field





Auger Offline analysis framework

- Modular analysis framework for Auger observatory
- Made for hybrid analysis
- Easy to configure (XML cards)
- Possibility to save DST (ADST)
- Radio has been included

Radio reconstruction with OffLine

Simulation

Open the simulation file
Associate simulated pulse to Station and channel pulse,
apply detector effect to the signal

Datas

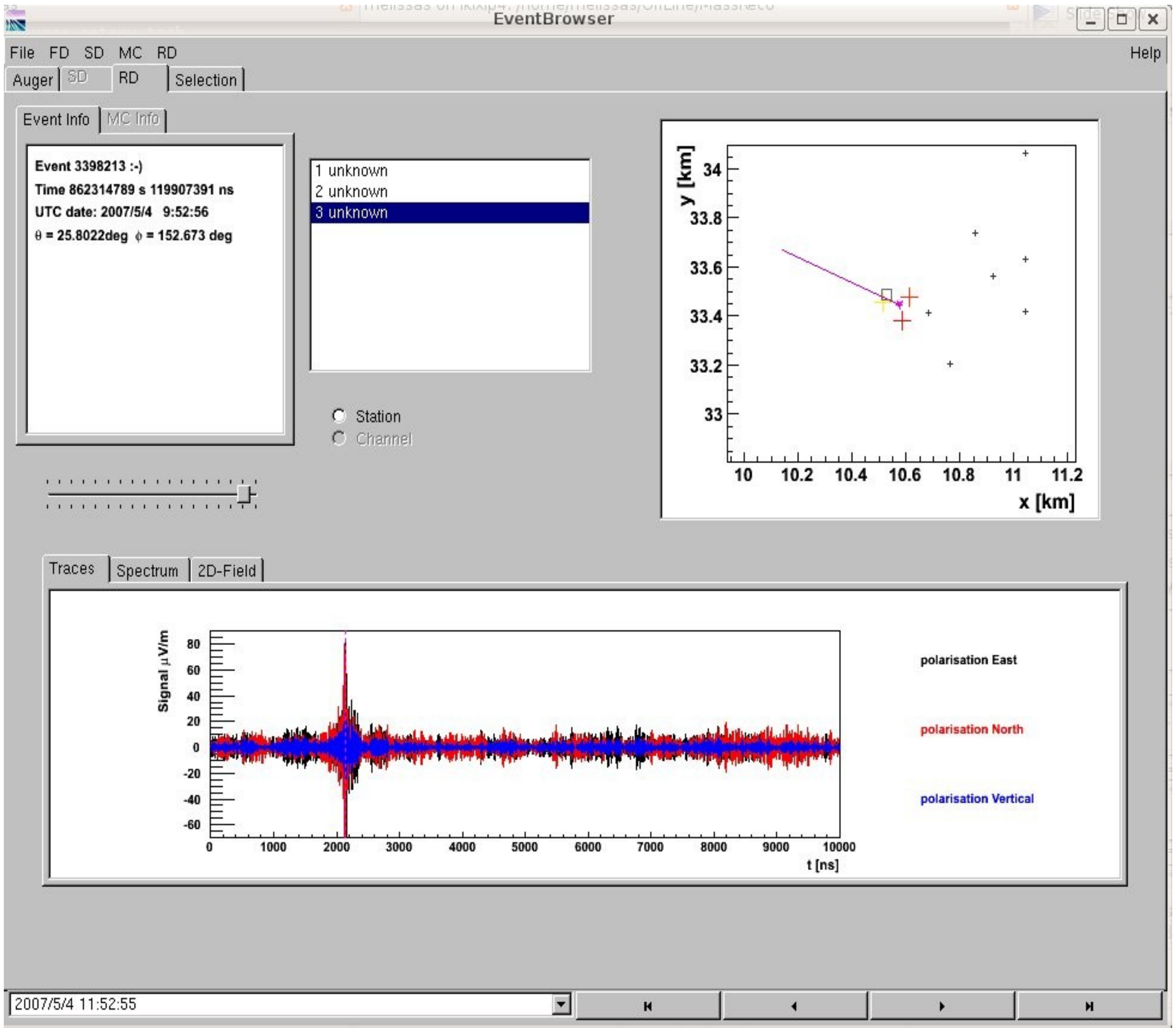
Open the data file, select the event and suppress the single frequency carrier

Up sampling to an higher time base,
Convert ADC into physical units, applying an Antenna model
find pulse and plane fit
Saving (ADST)

And much more

- Other functionalities
  - Pulse parametrization
  - Advanced time calibration
  - Parallel processing of SD/FD
  - Other Auger extension are included
  - Performant object-oriented DST (ADST) can be used for radio
- Coming functionalities
  - 3D reconstruction
  - Interferometric reconstruction
  - Merging of radio-hybrid events
  - LDF and energy estimation
  - Time varying detector description

Example event

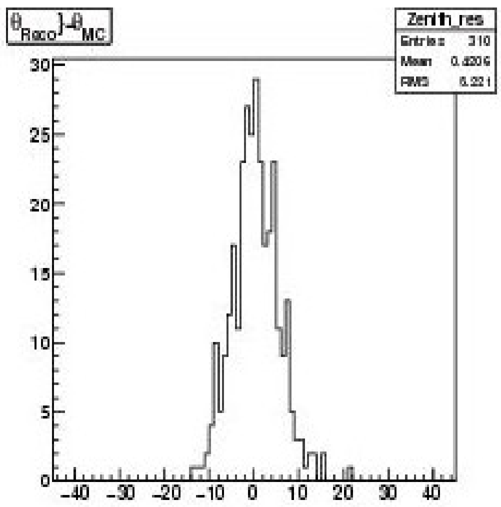


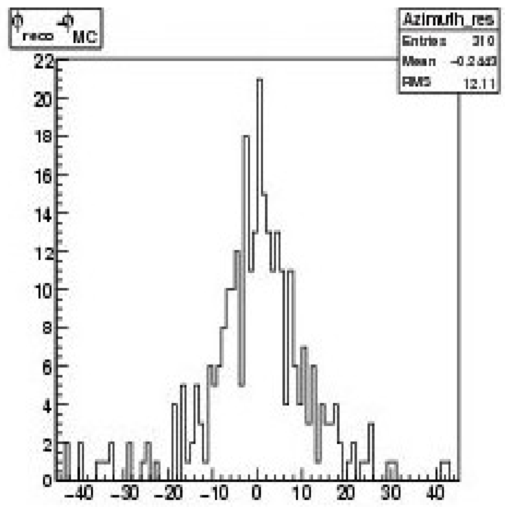
- Example radio Event
- 3 Antennas near the BLS
- 1.1 EeV

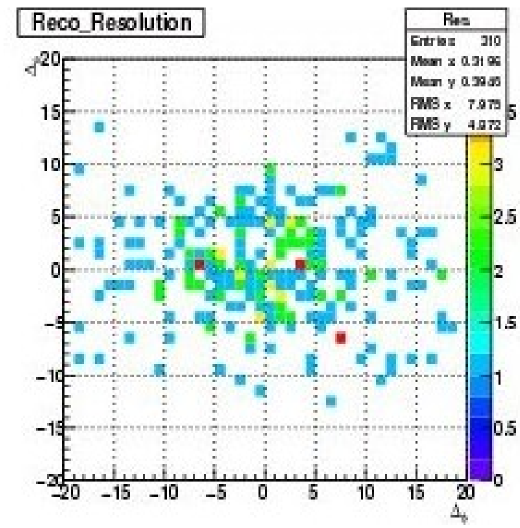
Reconstruction performance

- Difference between reconstructed angle and MC_{true} arrival direction

- Plane fit with three antennas can give a reasonable angle estimation
- With three antennas, we get a fantasist core position







Auger Engineering Radio Array

- AERA
- Planning
- Toward a super hybrid detector

Maximilien Melissas IEKP

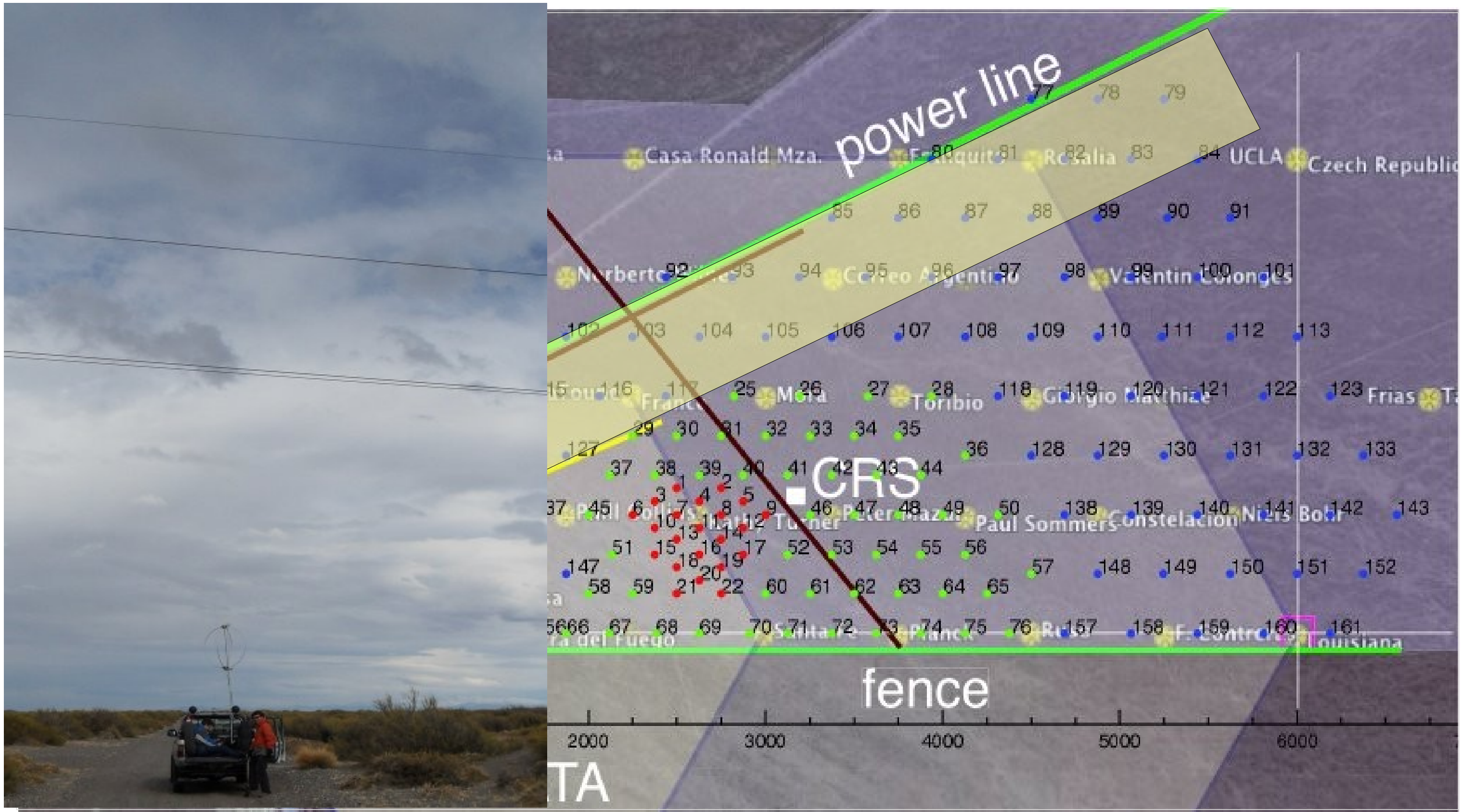
Auger Engineering Radio Array

- Current tests only with few Antennas, current experiment (LOPES/CODALEMA) are small, need to go to a larger scale to go to higher energy
- Proposal submitted to the collaboration in April 2009 and accepted
- Near Coihueco Fluorescence telescope, several extensions are in the same zone (AMIGA, HEAT)
- Planned to install 150 antennas in the infill array
- 3 differents grid size, 150m, 250m, 375m
- First Radio container should leave Europe in March.
- 20 Antennas and first operation before the summer
- ~ 20 km^2 prototype for a larger experiment

- **Physics goals:**
  - Calibration of the radio emission in air showers
  - Capability of the radio-detection method
  - Cosmic-ray physics in the transition region

AERA members

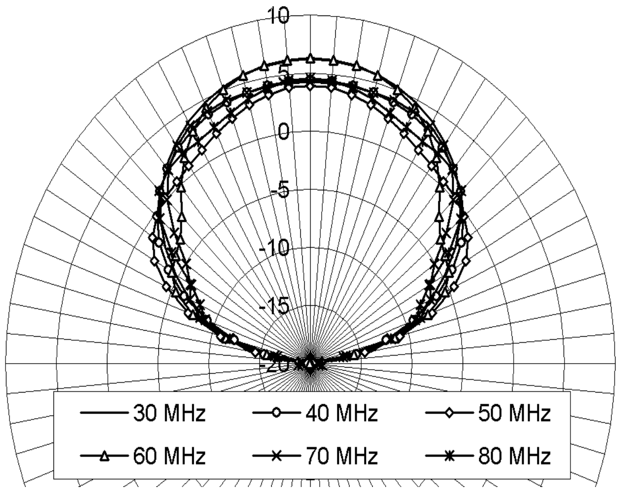
AERA layout

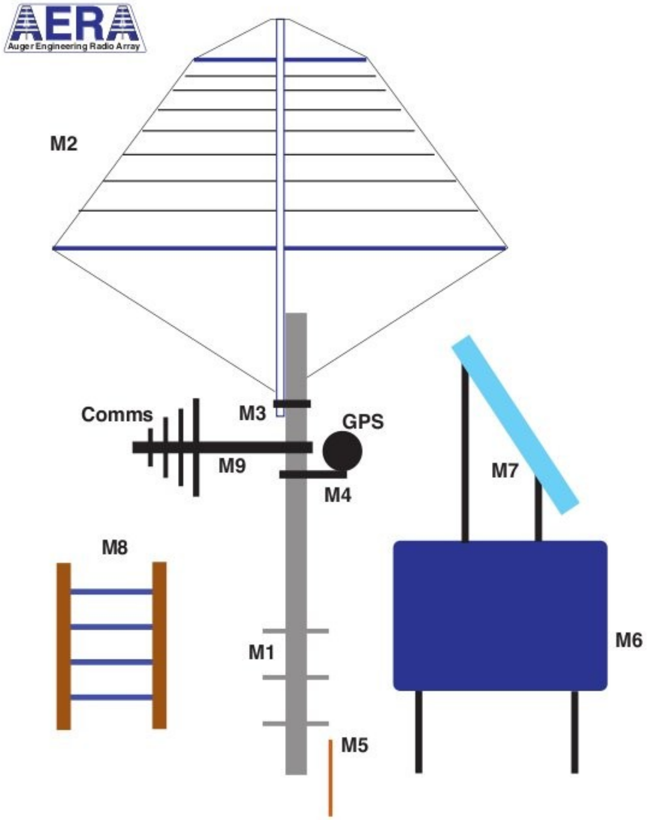


- In the infill array
- 3 Different grid size 150m, 250m,375m starting by the dense part
- 2 spaces constraint : Noise from power line, Land's owner

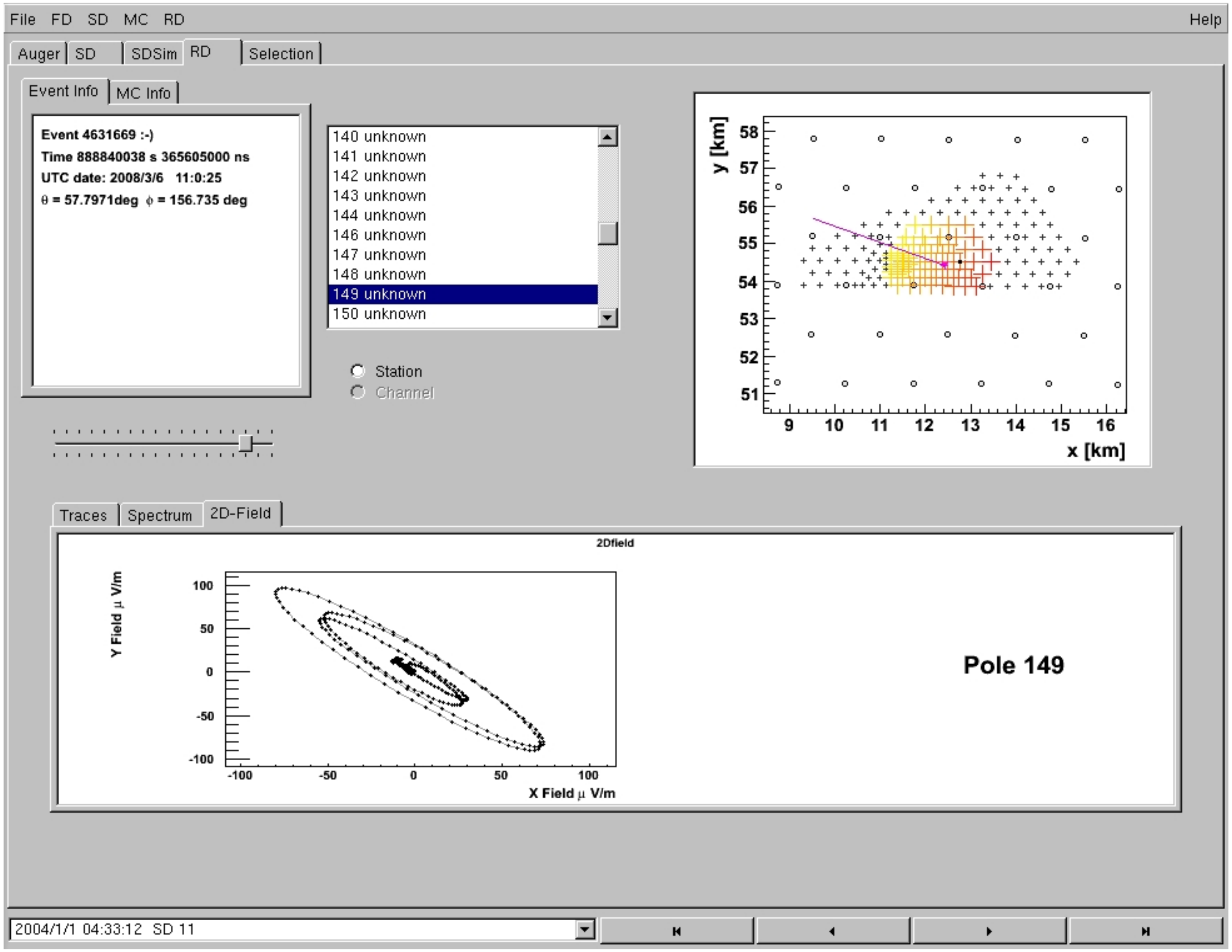
AERA Station

- For stage 1 : Antenna will be wired LPDA, a.k.a. Black spider
- For stage 1 : Wired communication (wireless protocol in development)
- For stage 1 : Simple digital trigger, more advanced trigger comes for stage 2





Example (MC) event over AERA



- 0.58 EeV
- Pure sim

Deployment timing

Prepare CRS, electric distribution in container	Spring 2010
Foundation and poles for RDS	Spring 2010
Fences around stations	Spring 2010
System integration in Nijmegen	Jan/Feb 2010
Shipment of items	March 2010
Deployment of RDSs	May-June 2010
Commissioning and initial operation	May-June 2010

Estimated performances

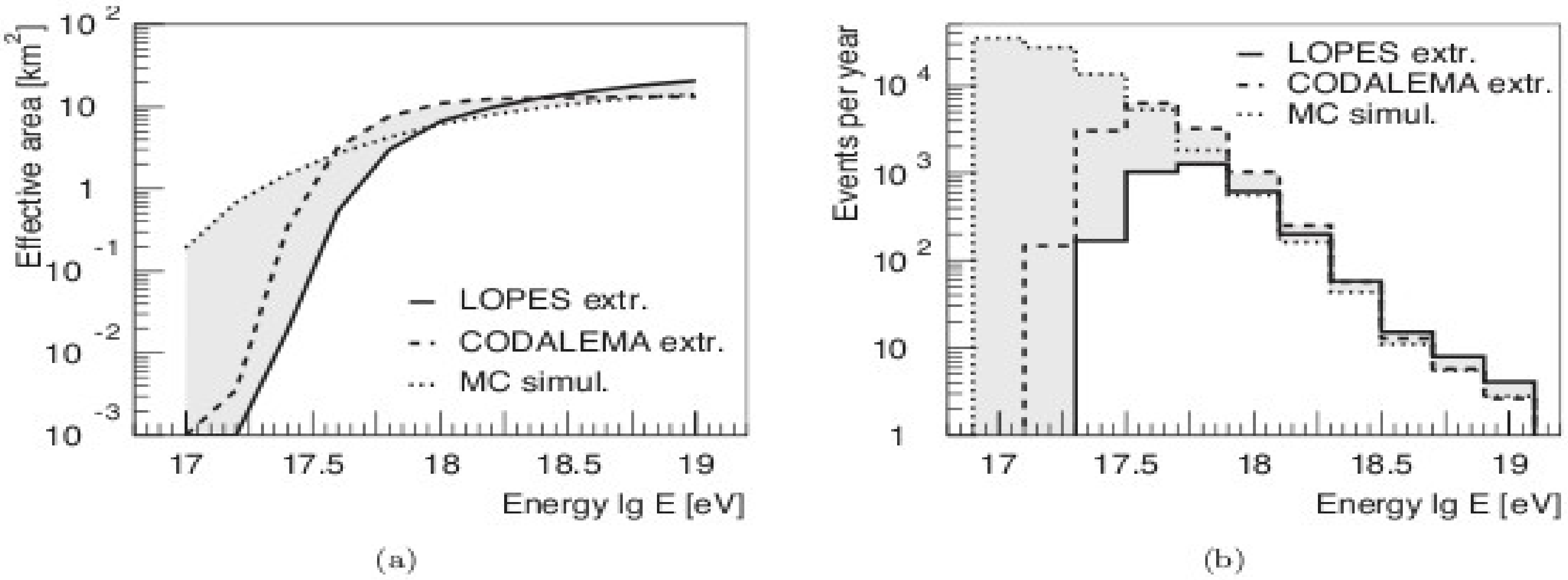


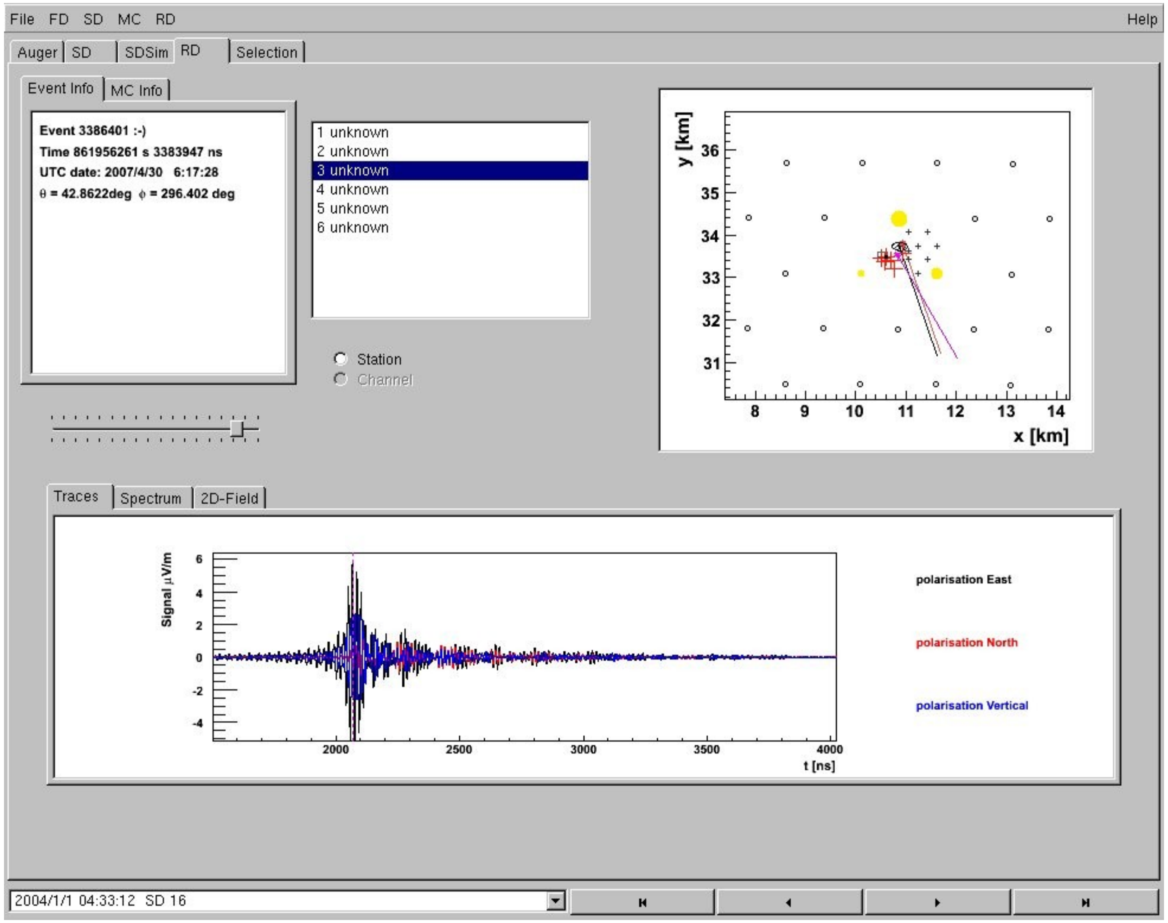
Figure 13: a: Effective area of the radio array as function of the shower energy according to extrapolations of LOPES and CODALEMA measurements as well as Monte-Carlo simulations, based on the REAS2 code. b: Expected number of events per year with zenith angle $\Theta < 60°$.

Toward a super hybrid detector

- We have well measured air-shower at the Auger site
- AERA is build at low-energy extension place, better sensitivity
- We need to compare radio events to shower parameters to understand the emission mechanism
- Radio will become an official AUGER sub-detector, and can be used for final analysis.

- No optical link between AERA and Central campus, No on-line merging.

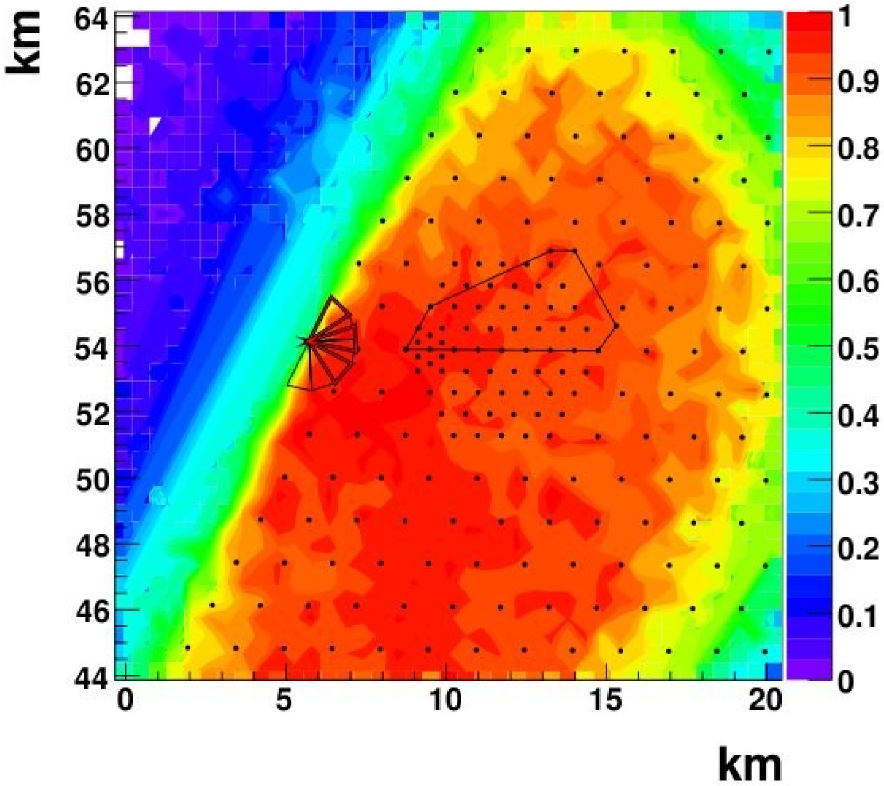
Example hybrid event



- Simulated Hybrid event over the BLS
- 6 antennas 3 SD tank
- 0.68 EeV
- Main limitation : SD sensitivity at low energy
- Auger Infill will provide us a better SD reconstruction at low energy.

Hybrid measurement range

- The Infill is efficient in AERA's range
- FD with Heat is Efficient over AERA
- 10% of the Event will be super-hybrid



Trigger efficiency for FD+HEAT 10^{18} eV Shower.

Conclusion

- Radio detection is now a working technique, but we need to improve the understanding of the emission mechanism
- Radio detection has 100% duty cycle, and keep the history of the shower.
- Self triggering is hard. No method yet to discriminate air-shower from human noise
- Human made noise is our main problem
- Analysis environment is ready
- AERA deployment starting in a few month, first light before the summer.

Outlook

- AUGER's low energy extension will be a precious input to understand radio signal
- Radio signal will be one more input to understand cosmic ray physic
- 20 km^2 in 2012, and more ?
- Cosmic ray activities in some more radio observatory (LOFAR)