Geomagnetic effect observed by the Codalema experiment

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SUBATECH

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Outline

- The CODALEMA experiment
- Some examples of radio signals
- Radio detection efficiency and angular asymmetry
- Interpretation in terms of a geomagnetic effect
- Hardware developments
- Upgrades

CODALEMA goals

- To measure the radio signal associated to the atmospheric shower produced by highly energetic cosmic rays reaching the Earth

- To revisit a technique unsuccessfully explored 40 years ago by :
  - understanding the radio production mechanisms
  - Identifying key observables correlated to the air shower and the primary cosmic particle features

- To develop a detection technique competitive with conventional surface detectors in terms of :
  - Quality of data (sensitivity, resolution)
  - Efficiency and duty cycle
  - Simplicity, robustness and COST

The CODALEMA collaboration

8 French laboratories (IN2P3 and INSU)

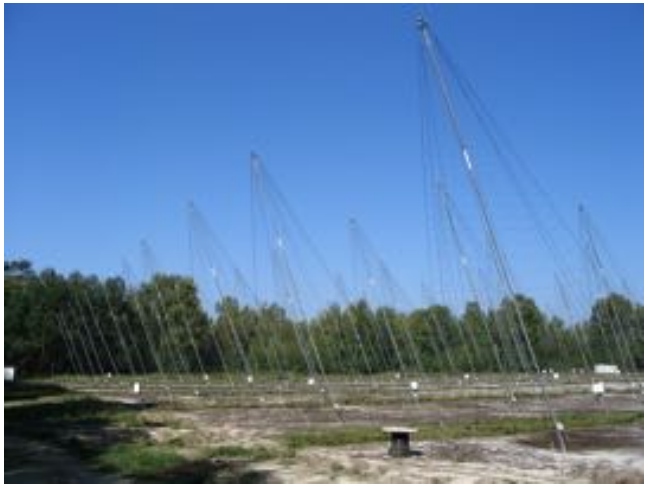
1 experimental site

2002 : first tests with logarithmic antennas

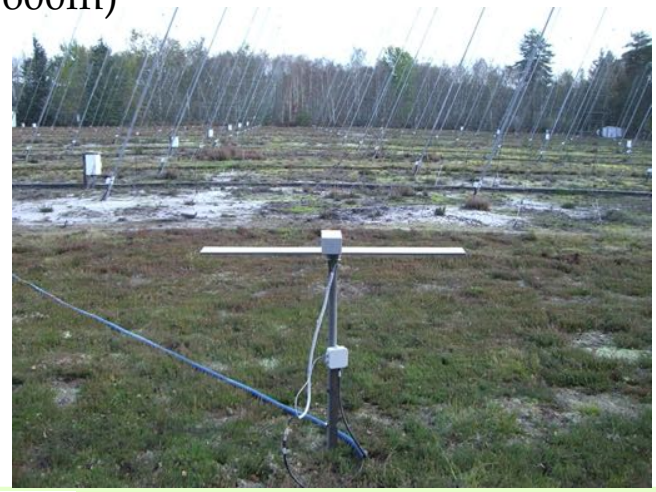
2009 : large arrays routinely taking data

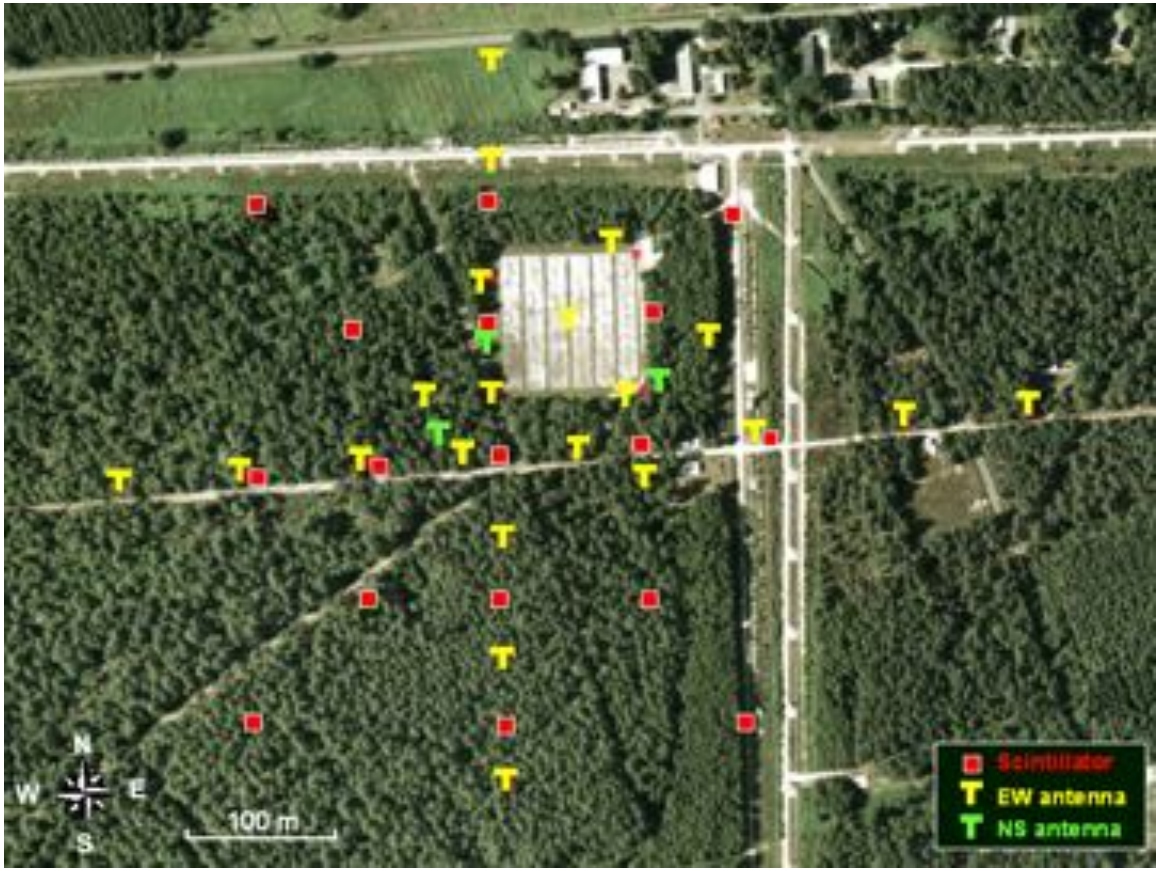
Experimental setup : 3 instruments

The Decametric array (DAM) : 144 log-periodic antennas (80x80 m²)



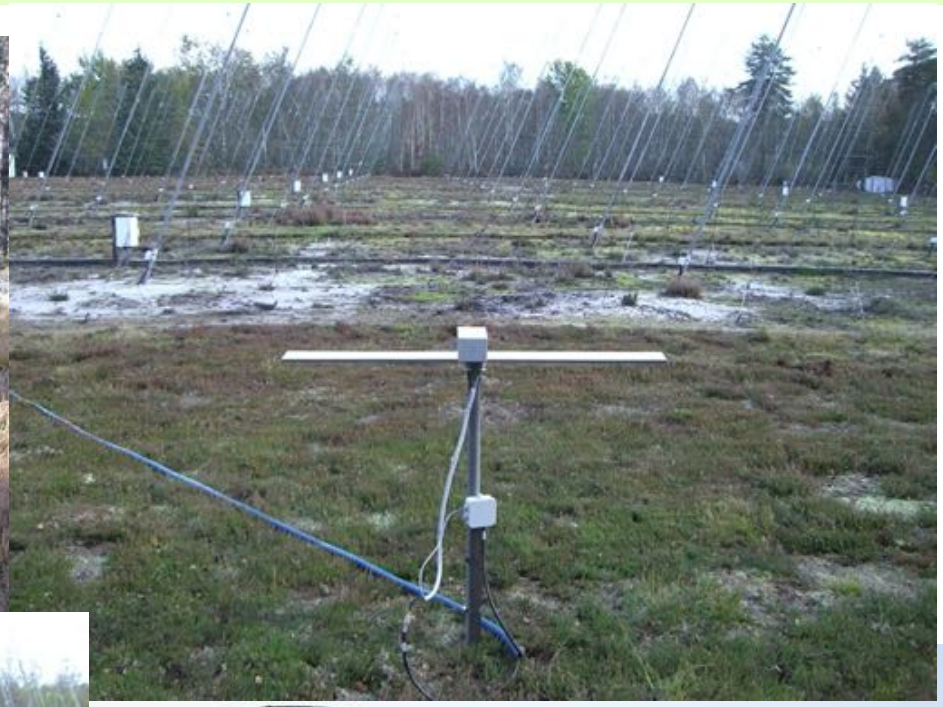
24 dipole antennas (two arms of 600m)





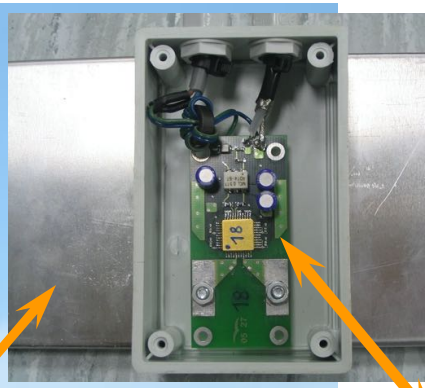
17 Surface Detectors (340x340 m²)

Some pictures



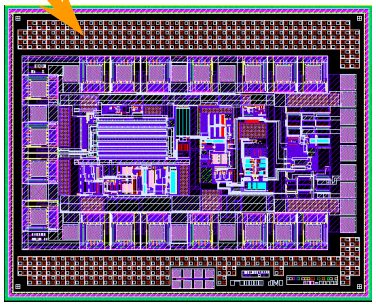
The CODALEMA short active dipole

Simple
and cheap

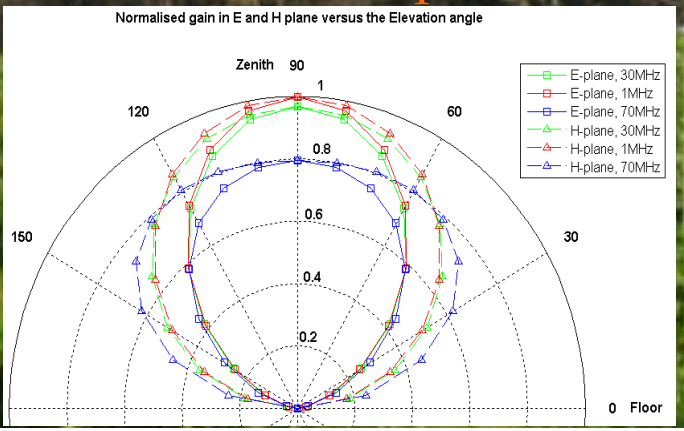


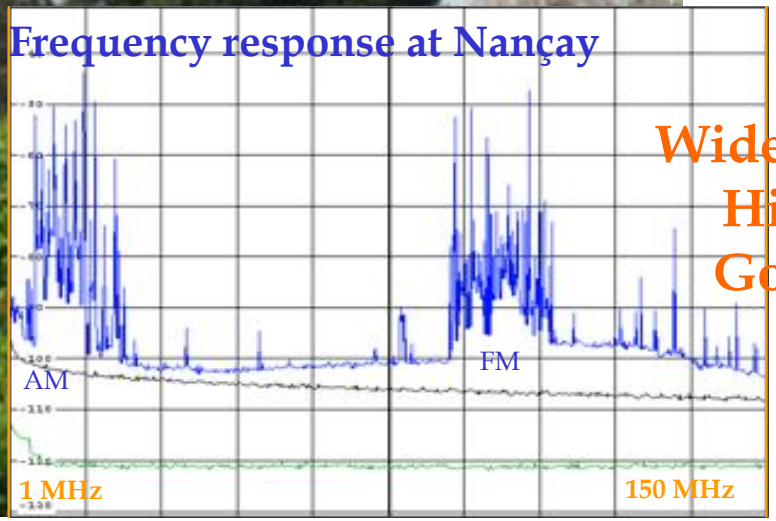
Aluminum dipole antenna

A dedicated
LNA(ASIC)



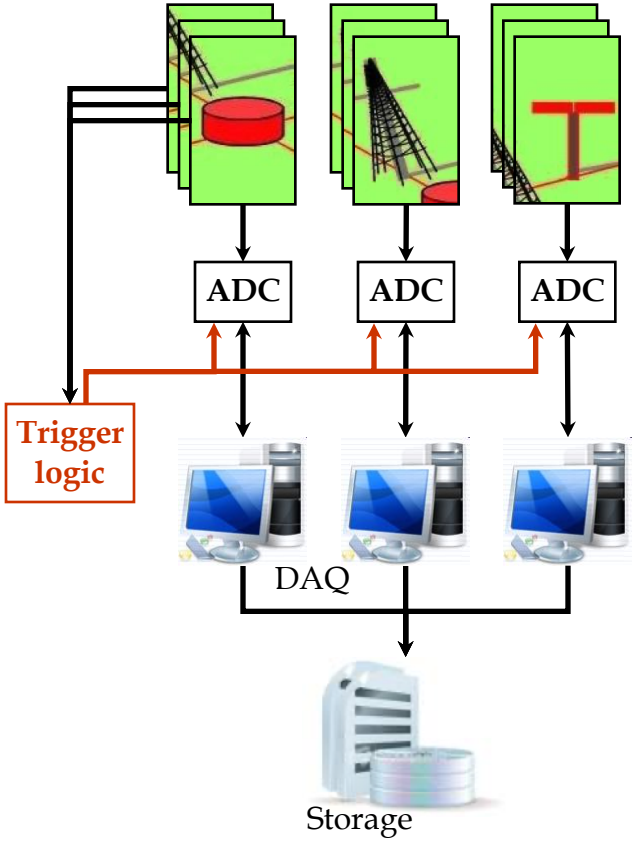
Smoth radiation patterns





Low noise
Wide bandwidth
High dynamic
Good linearity

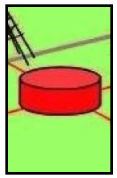
Trigger and data acquisition



- Trigger logic : Custom board allowing to remotely change :
  - threshold values
  - coincidence conditions
- MATACQ ADC : 300 MHz, 12bits, 1GS/s, 2500 samples, 4 channels, VME or GPIB
- Slow trigger rate :
  - GPIB reading
  - LabVIEW for DAQ and monitoring

Coincidence of the 5 central SD :
Trigger rate of ~200 events/day

Data processing



SD Antennas

Filtering → Corrected signals

Tagging → Times, amplitudes

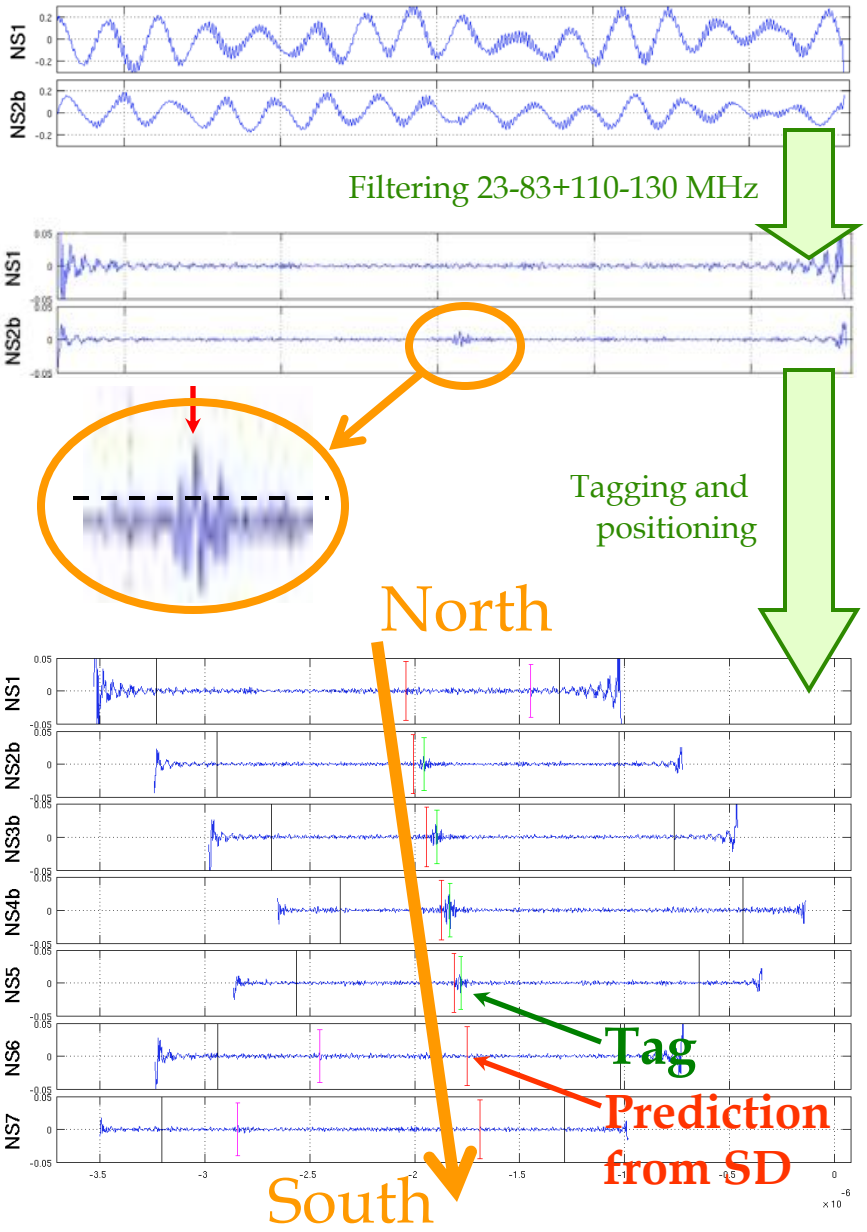
Positioning* → Arrival directions

Amplitudes → Shower core position, Lateral distribution

CIC → UHECR energy

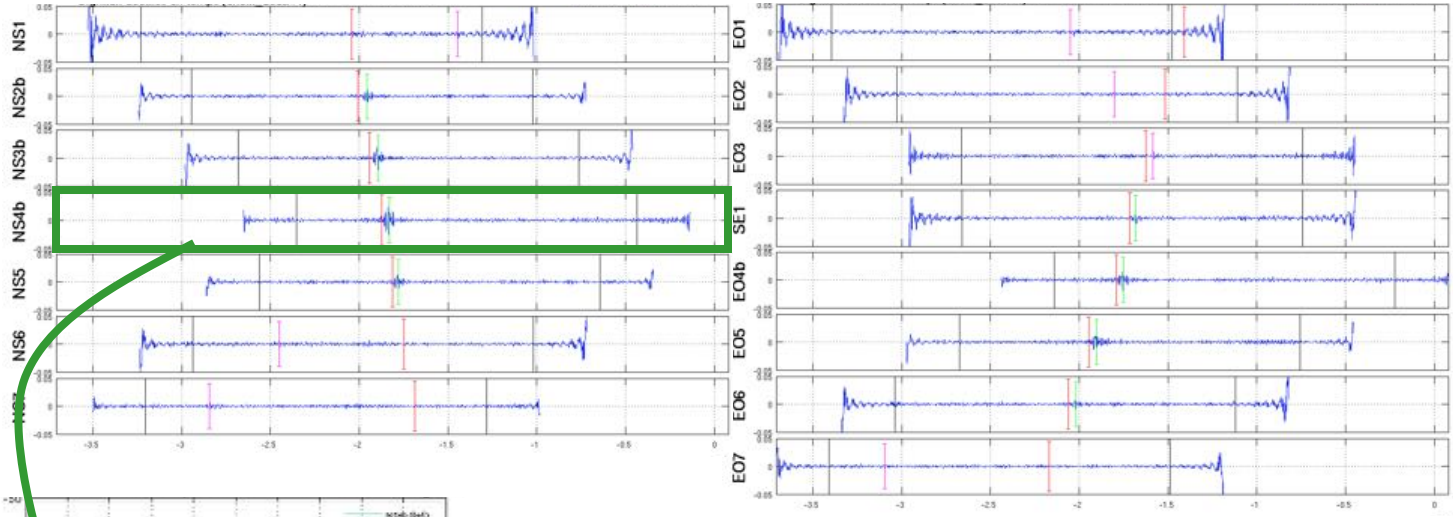
Coincidences

Selection of well reconstructed UHECR



*** positioning** by computing the **time difference of arrival** (**TDOA**) of the signal received by three or more SD/antennas.

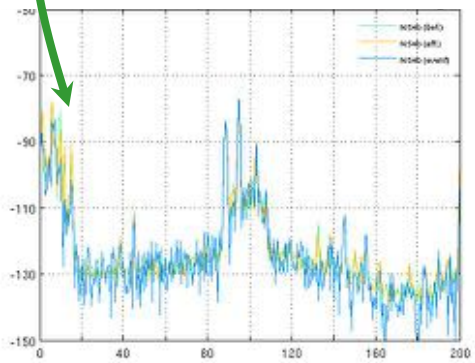
Measured data : some examples



Time signals

Pulses restricted to some antennas

Variations in the lateral distribution of amplitudes

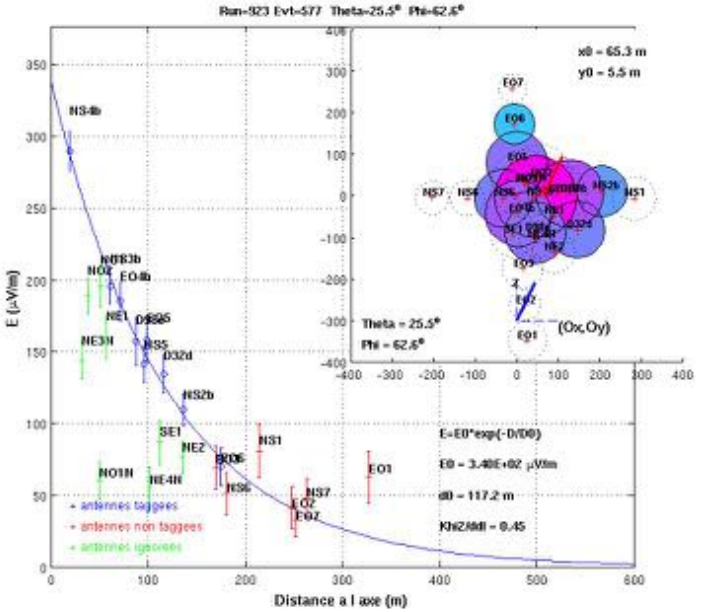


Frequency spectrum

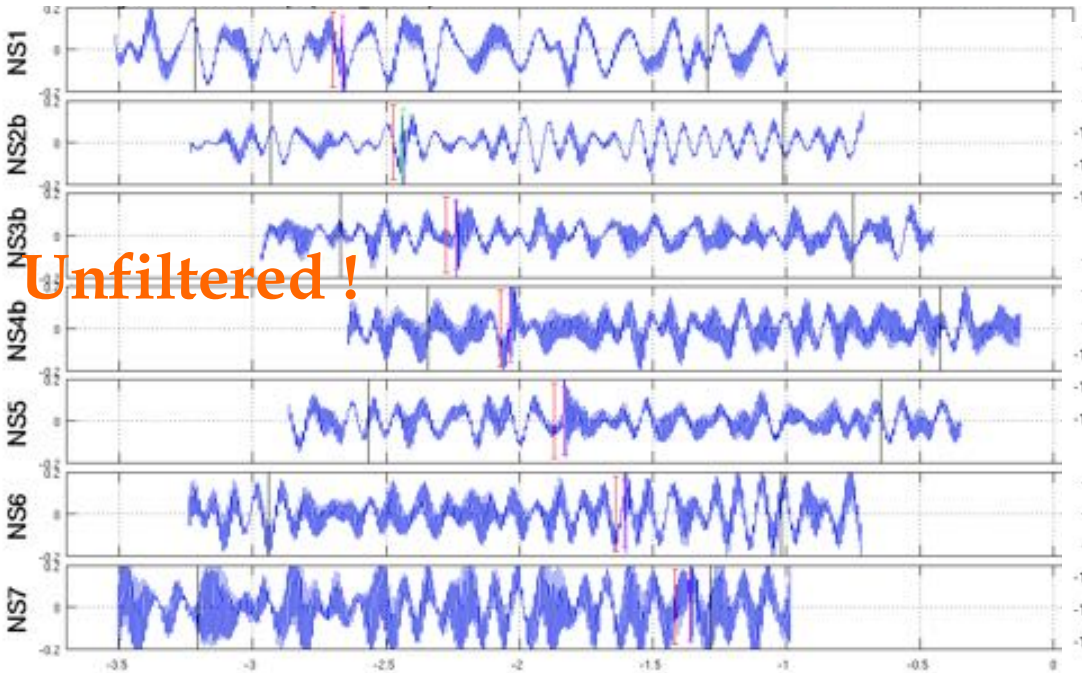
Not that much besides the AM and FM bands

Low energy event :

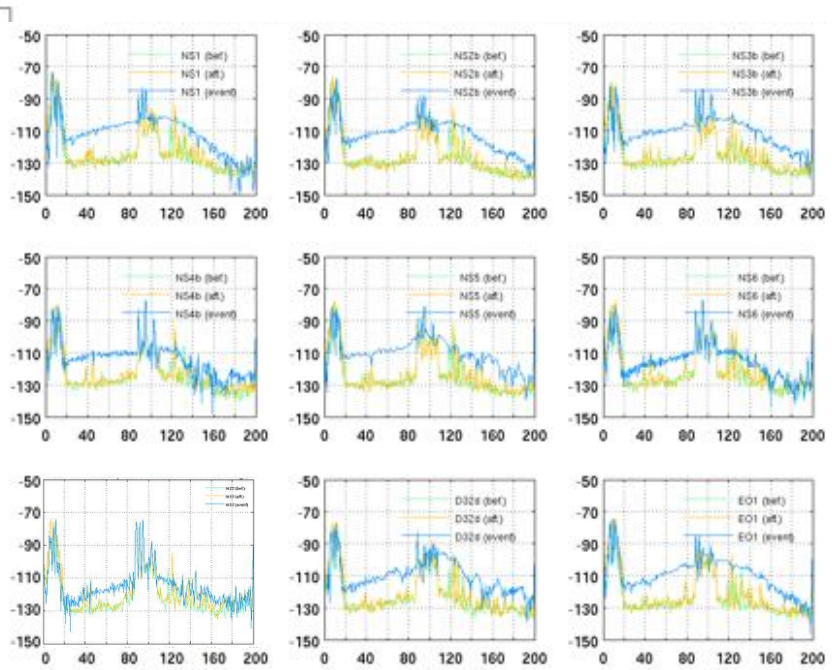
- Clear transient signal in filtered time series
- No clear contribution in the frequency domain



Measured data : some examples

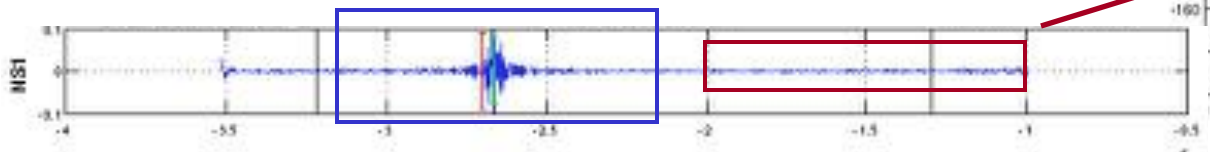


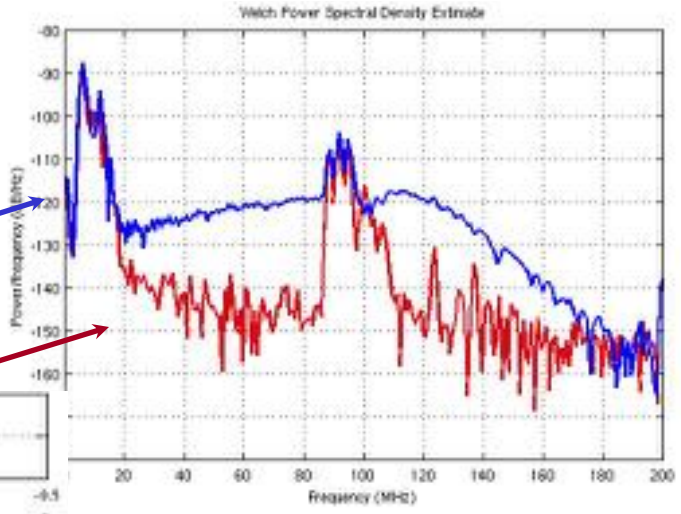
Unfiltered !



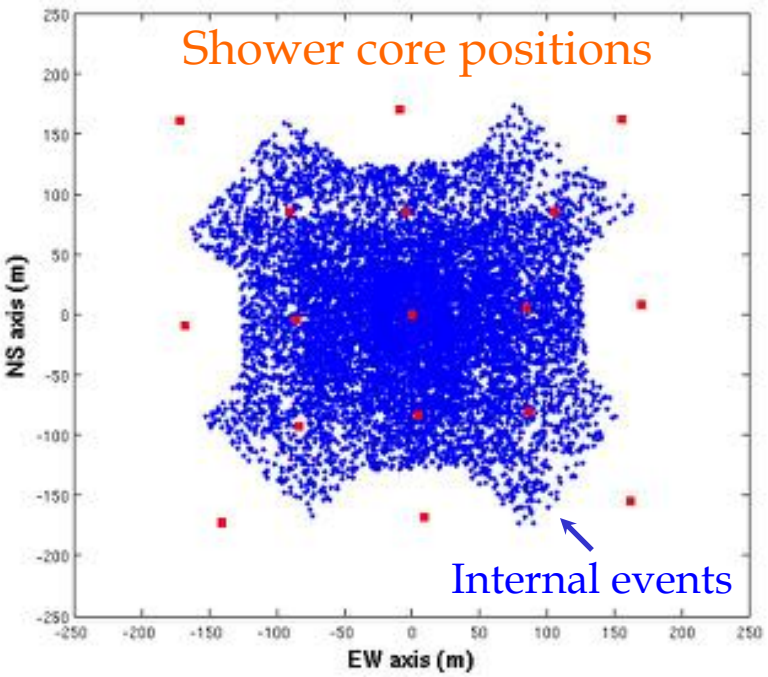
Very large event :

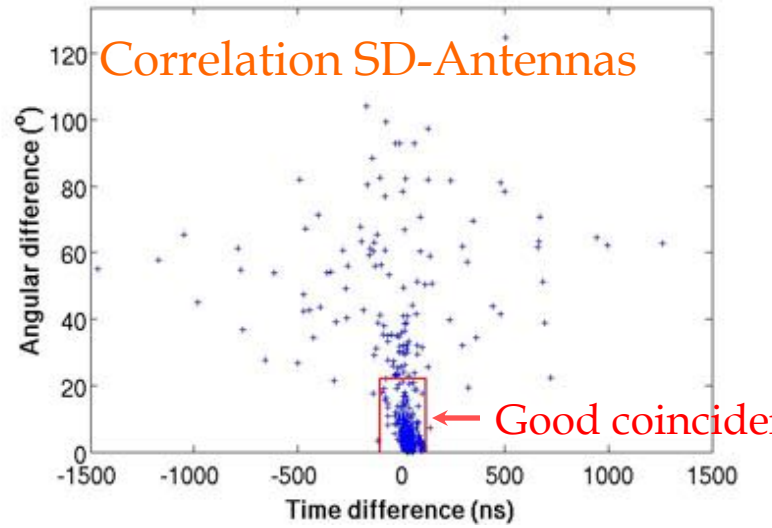
- Transient signal in raw data
- Large contribution in the spectrum





Event selection





Information on the shower :

- arrival direction
- shower core position
- Energy estimate (CIC method)

2 classes of SD events for the analysis

Internal events : Station with the maximum signal not on one edge of the array. Correct estimate of shower energy and core position.

External events : Unreliable estimate of shower energy and core position. Correct arrival direction.

Coincidences (SD and Antennas):

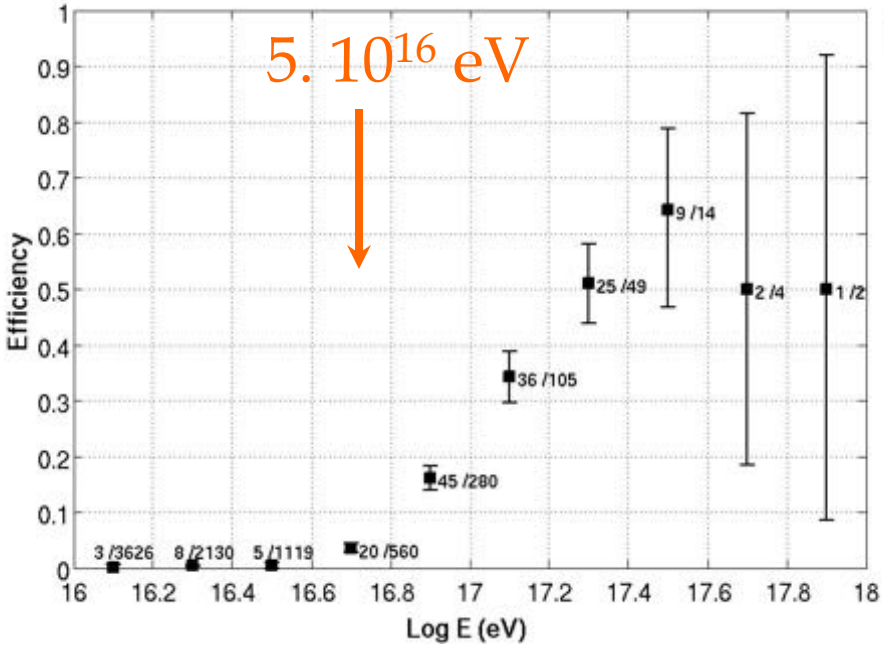
angular difference < 20°

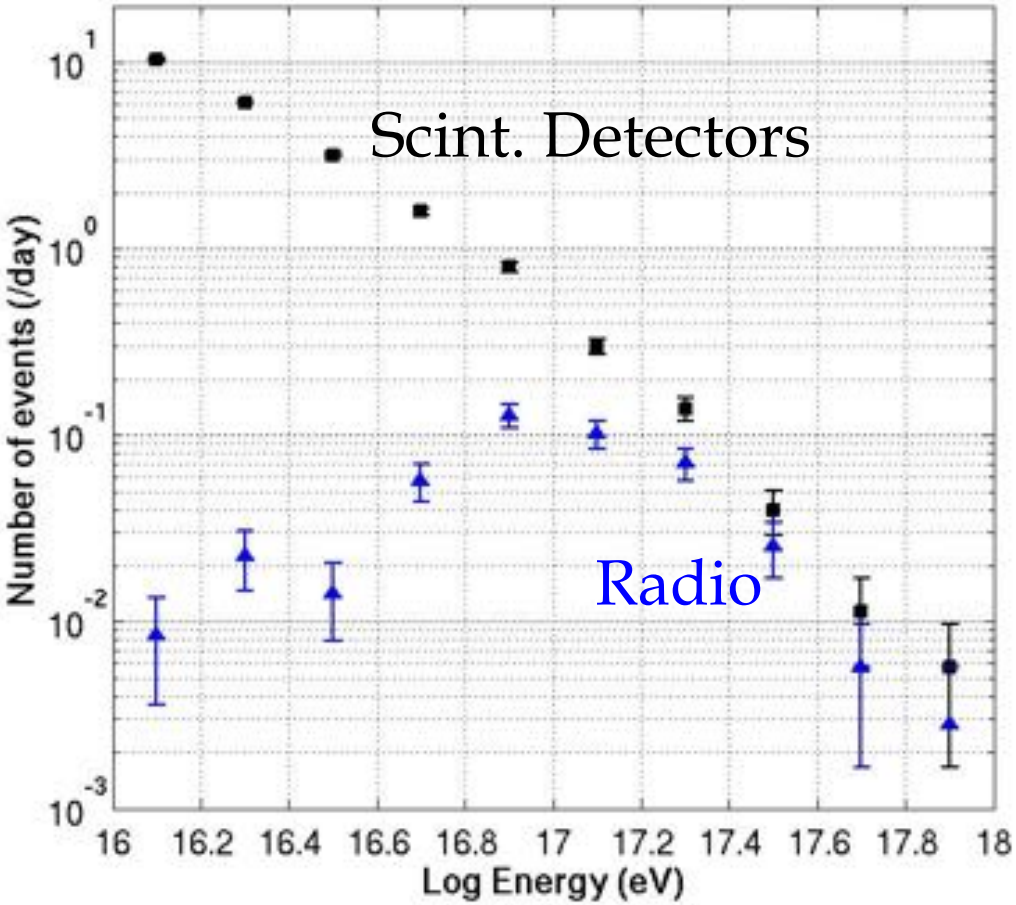
time offset < 100 ns

Radio detection efficiency

Effective data taking time	355 days
Trigger (SD events)	61500
Reconstructed antenna events	750 (2.1/day)
Coincidences (SD and antennas)	620 (1.7/day)
Coincidences (Internal)	157 (0.4/day)

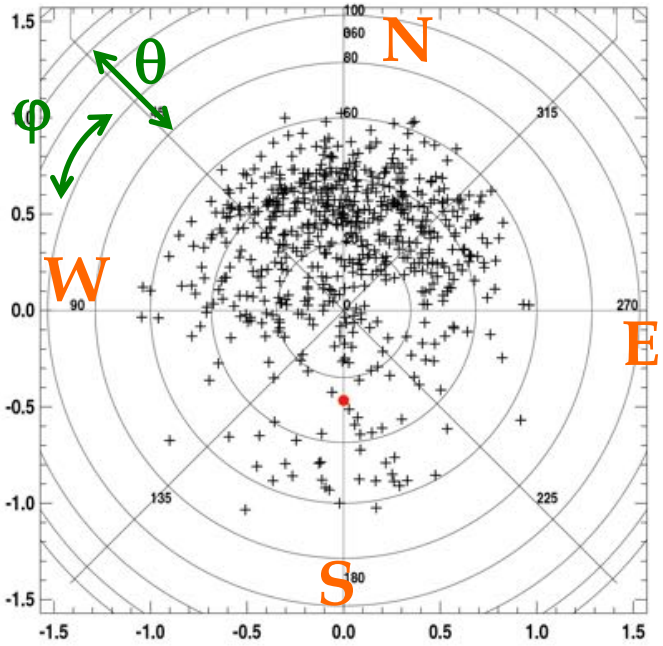
Extend the SD array !





CODALEMA is performing radio measurements at the detection threshold → E_{th}~5. 10^{16} eV
Full efficiency is not observed

Observed azimuthal asymmetry

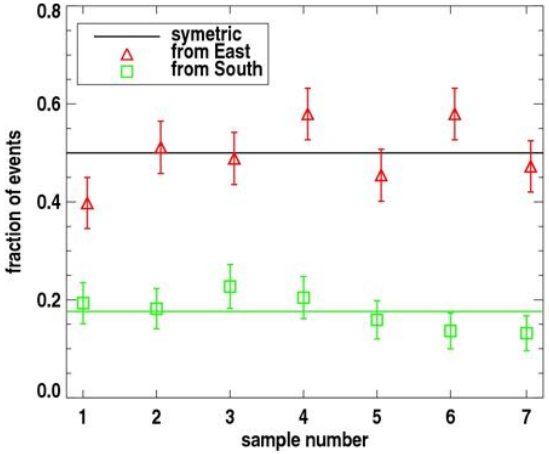


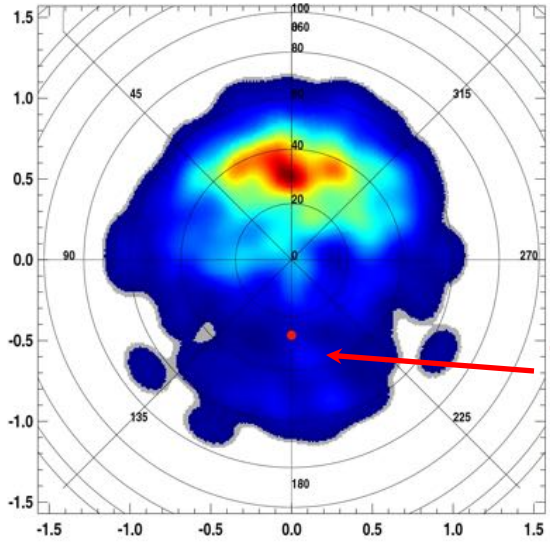
The deficit is clearly in the southern region :

$N_{south}/N_{total} = 0.17$

The SD azimuthal distribution is flat : not a trigger effect

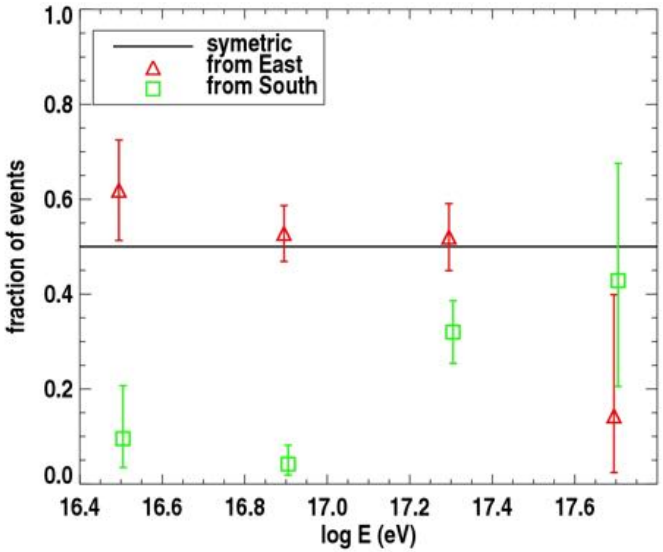
Independent subsets of events give similar results





Geomagnetic field direction

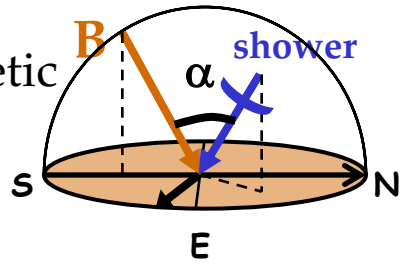
Larger effects on smaller energy events



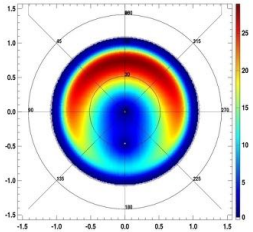
A toy model to understand the asymmetry

Hypothesis:

- The electric field is **proportional** to the Lorentz force $E \alpha |v \times B|$
  - Charge particles in the shower are deflected by the geomagnetic field (At Nançay : +q toward East and –q toward West)
- Electric field polarization in the direction of the Lorentz force :
  a linear polarization is assumed E // to $v \times B$
- The number of count (ie the efficiency) depends on the electric field magnitude :
  a simple linear dependence is assumed



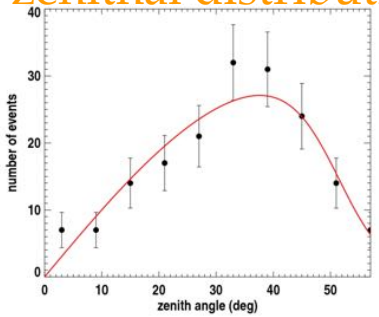
Predicted covering map:

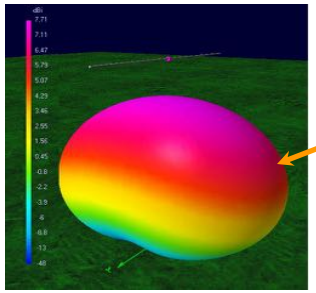


Total Lorentz force ($E \alpha \sin(\alpha)$)

X Trigger acceptance
(zenithal angle distribution)

SD zenithal distribution

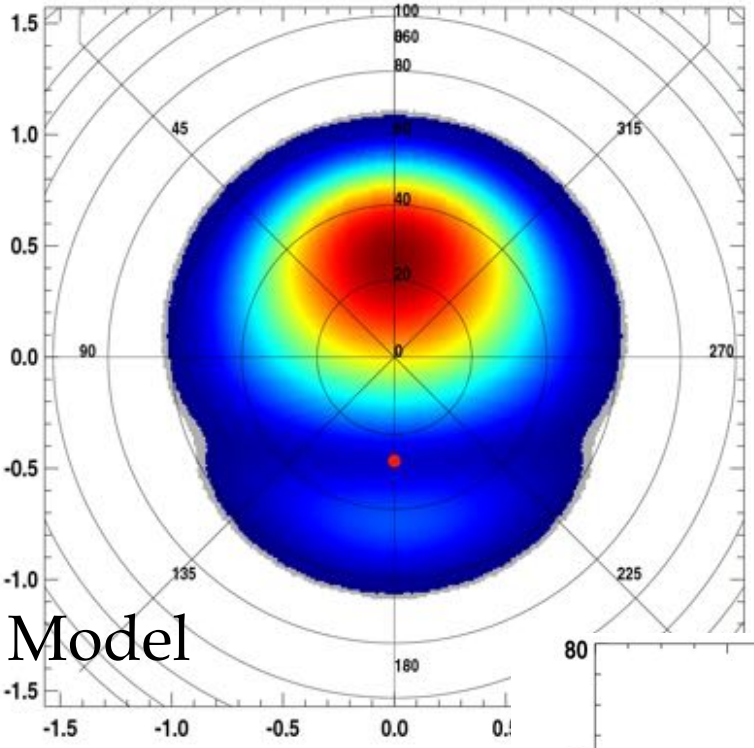


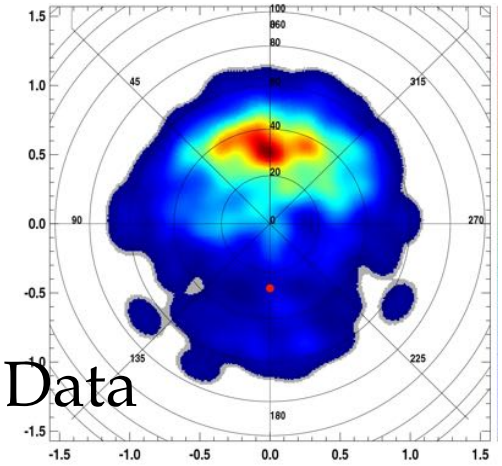


X Antenna lobe
(EZNEC simulation)

X Projection on East-West axis
(CODALEMA antenna polarization)

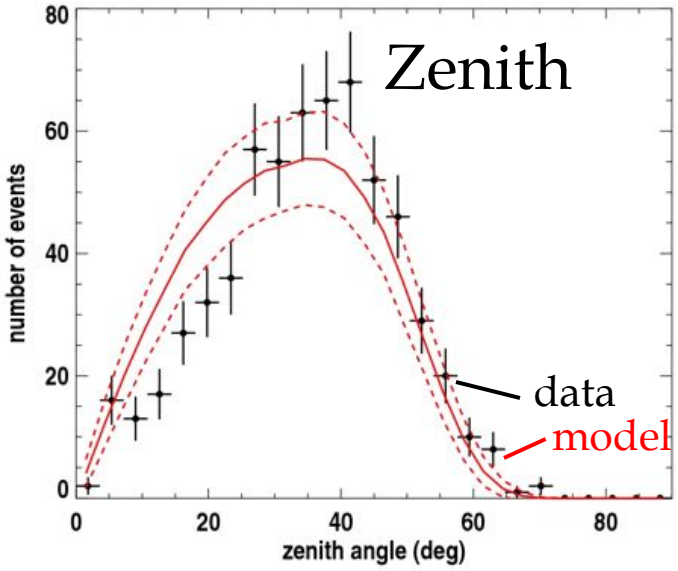
Azimuthal asymmetry : comparisons

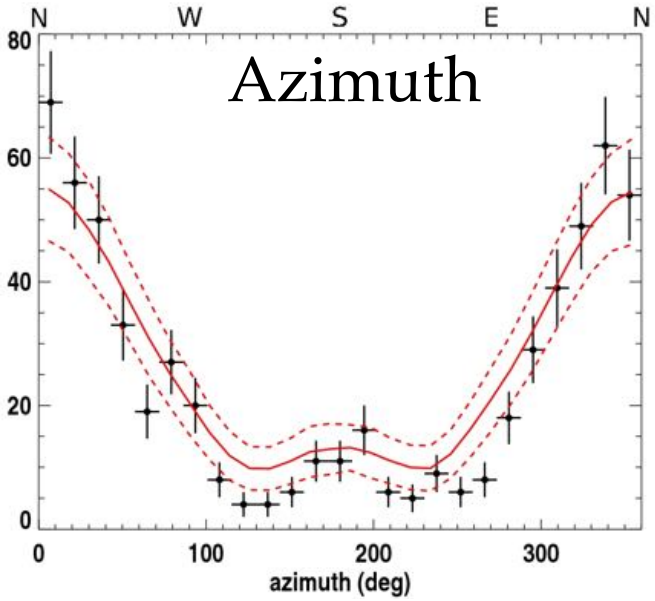




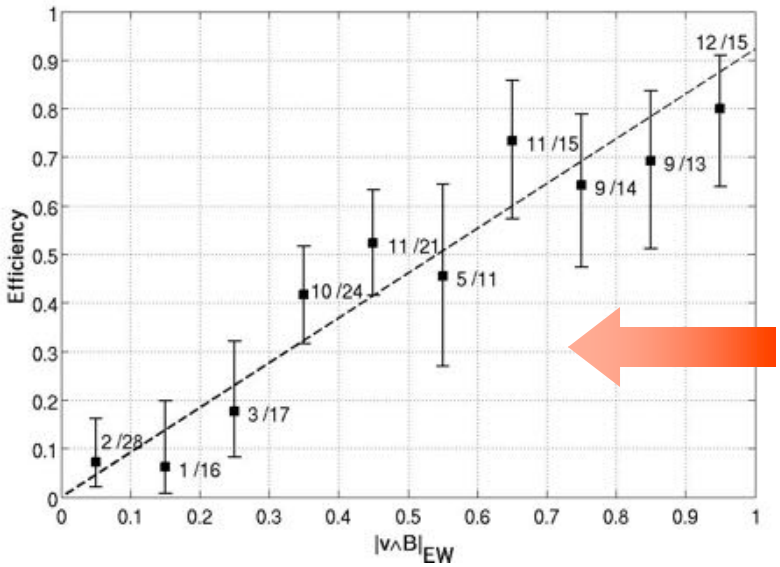
The model reproduces quite well the observed distributions :

- The maximums and local maximum
- The minimums





Asymmetry : understanding the efficiency

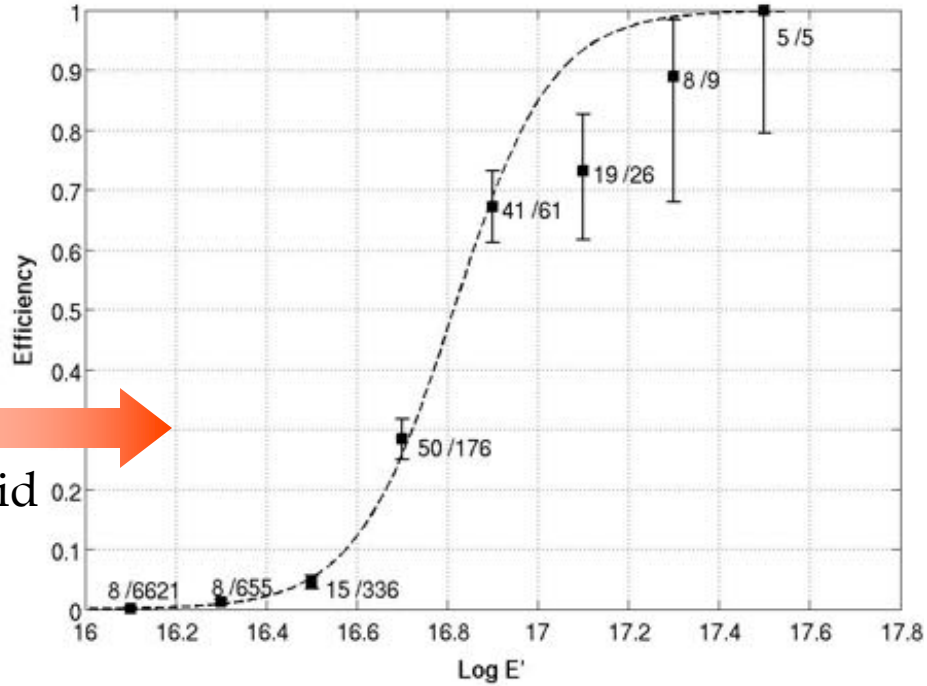


At 10^{17}eV and Nançay, the efficiency scales linearly with $|vxB|_{EW}$: Assumption of detection proportional the field amplitude is OK

$E' = E \,.\, |(vxB)_{EW}|$

Energy weighted by the cross product. Efficiency tends to reach 100%

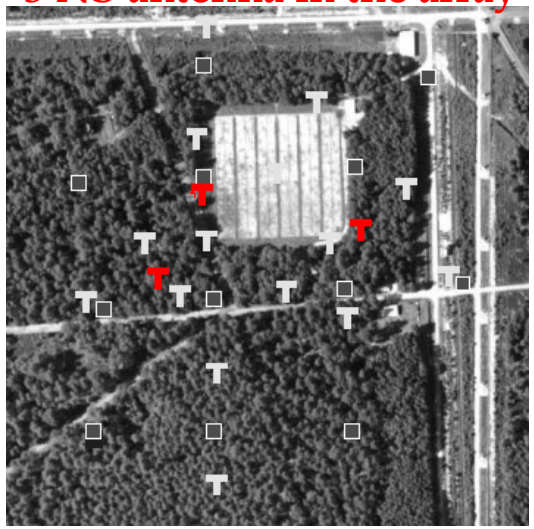
This linearity is probably only valid at threshold. Must be different at other energies.

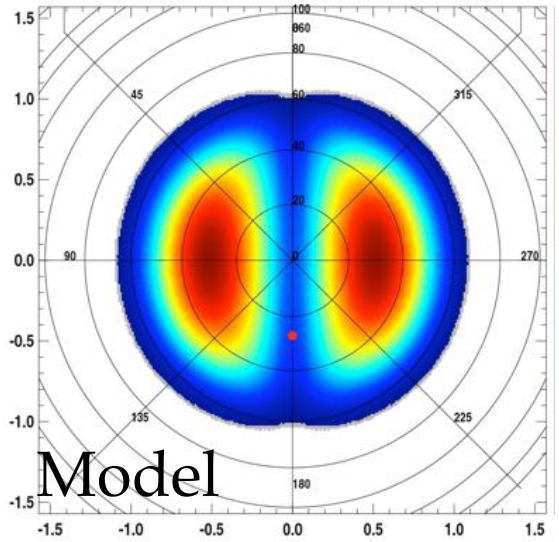


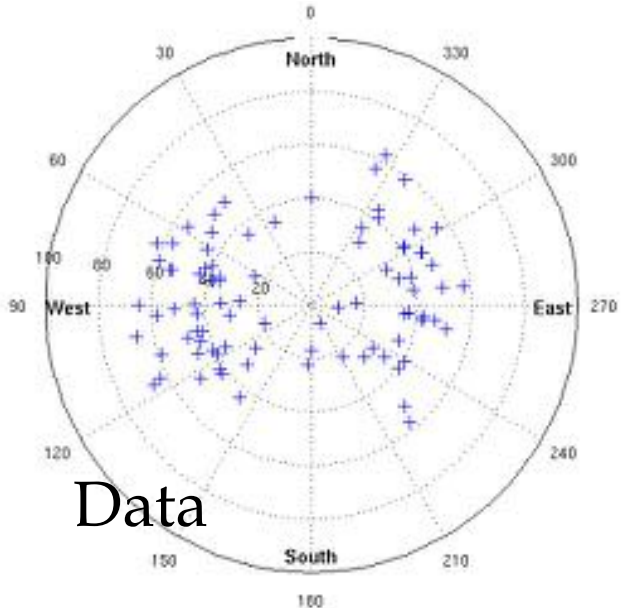
Measuring the NS polarization

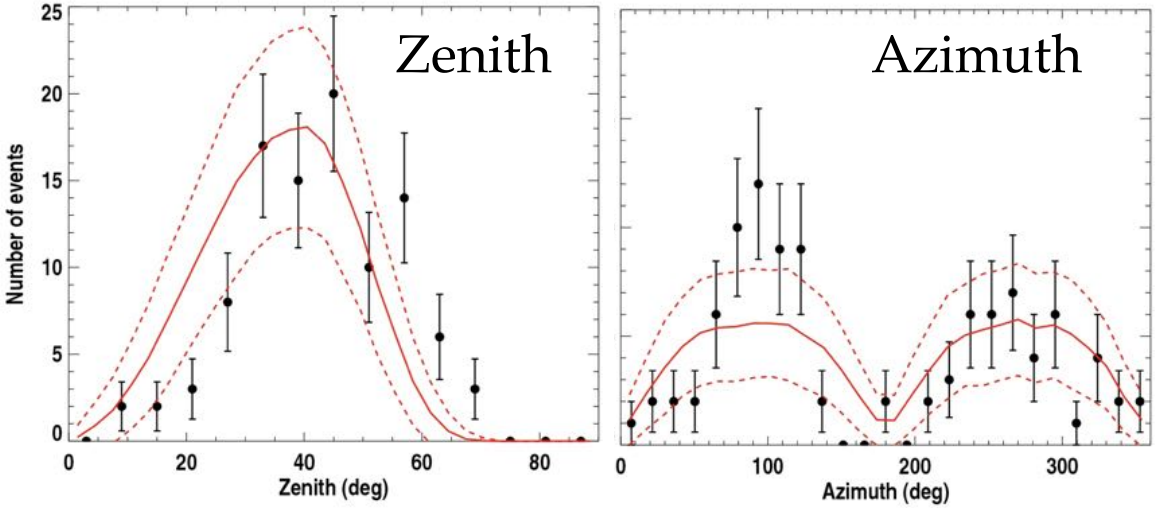
Is this picture valid for the NS polarization ?

3 NS antenna in the array







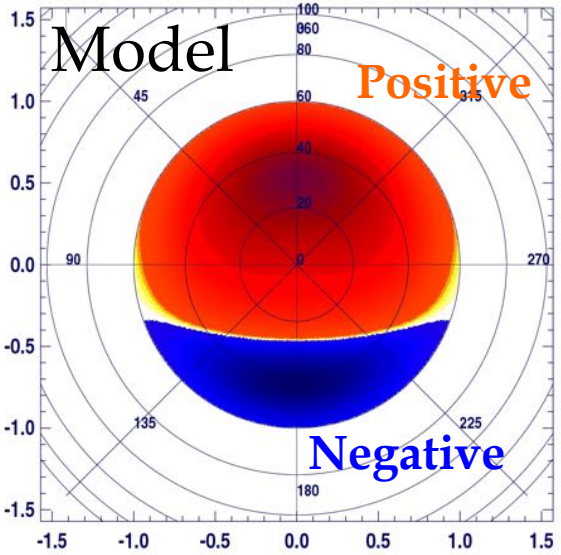


The statistic is lower but at the first look : YES

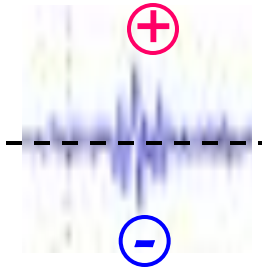
Most of the events are coming from East and West directions

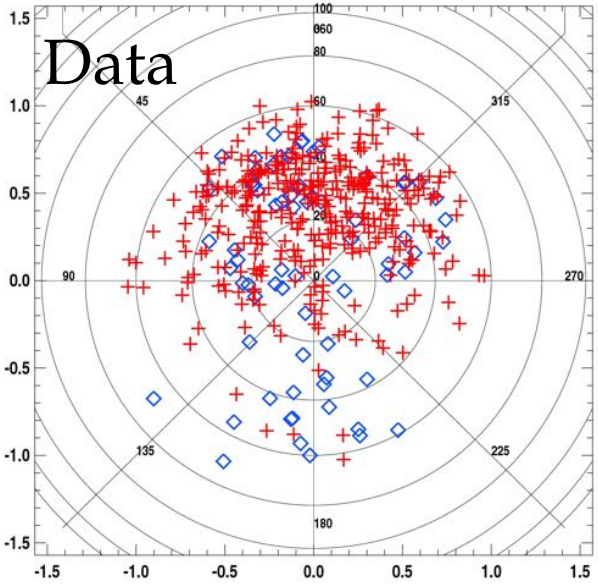
Signal polarity

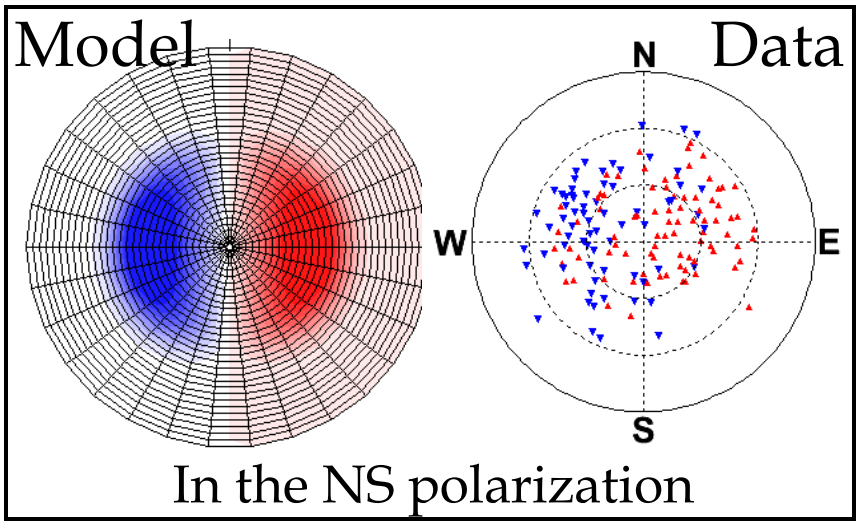
The model assumes the electric field magnitude to be proportional to $|(vxB)_{EW}|$.
Is the signal polarity given by $(vxB)_{EW}$?



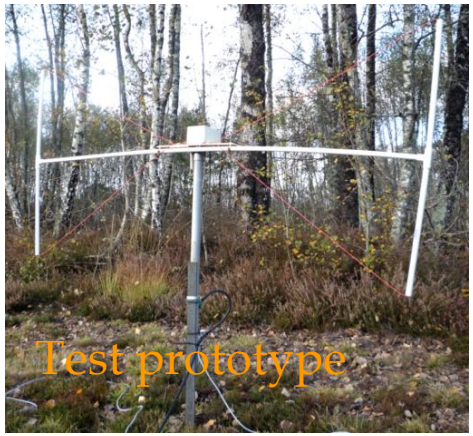
Event Signal :
antenna tag are signed
Event sign : given by the majority of signed tags



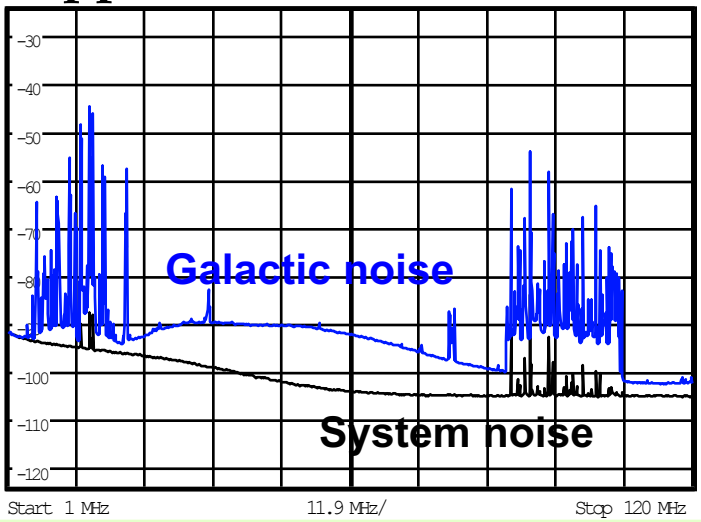




CODALEMA upgrade : improving the antenna



Measurement with a prototype
Simplified half antenna (one polar.)
Improved sensitivity (galactic noise dominated) and **stronger radio-diffusion suppression**



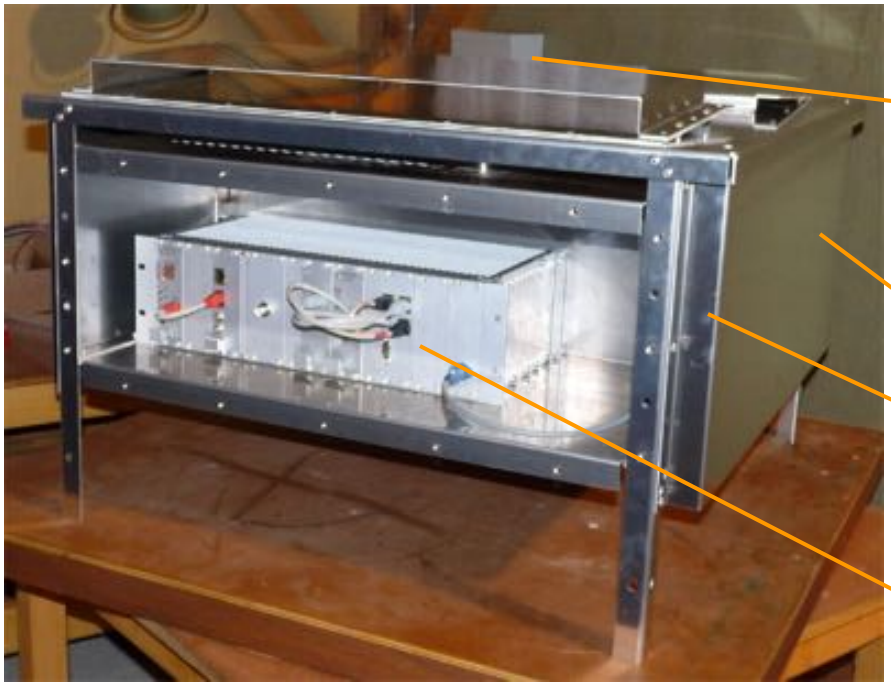
New prototype more suited for : robustness, easy production, 2 polar. measurements

CODALEMA upgrade : autonomous station

French efforts to develop an **autonomous** system :

- first prototypes were built with commercial material and existing Auger electronics : in used at Radio Auger (first cosmic events self triggered on radio signal)
- development of a custom made new system is under test at CODALEMA and soon at Radio Auger

Autonomous in terms of power, trigger, DAQ, coms.



Support for the antenna (top)

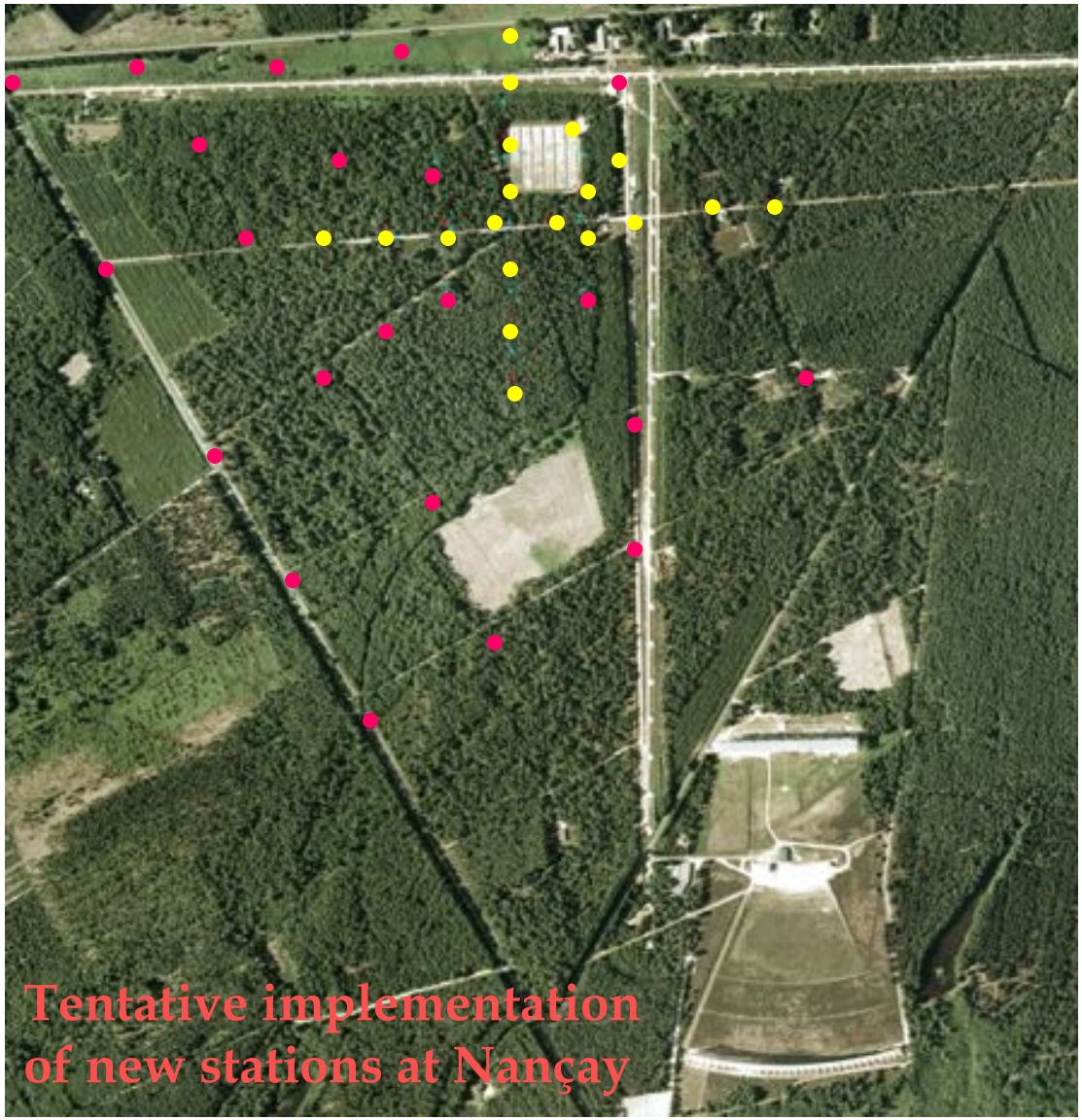
Batteries (back)

Metallic box for protection and electric shielding

Electronics crate (front)

New electronic crate

Foreseen upgrades of the antenna array



Replacement of the existing dipole antennas by butterfly antennas.

Installation of (semi)-autonomous station in the current array for testing and debugging

Extension of the current array

–Higher antenna density at the center

–Extension at larger scales

Installation for testing in Argentina