Characteristics of high energy cosmic rays observed with CODALEMA : Evidence for a geomagnetic radio emission mechanism

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Radio detection & CODALEMA goals

- To measure the radio transient associated to the atmospheric shower produced by high energetic cosmic rays
- To understand the radio production mechanisms
- To determine key observables sensitive to the shower features and the primary cosmic particle
- 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

EXPERIMENTAL SETUP (2008)

Nancay Observatory

2 detector arrays:

- **Antenna array**

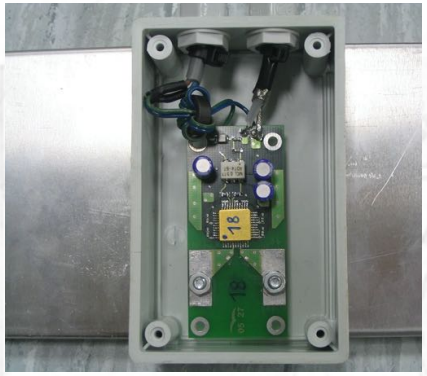
  21 dipoles
  *with **EW polarization***

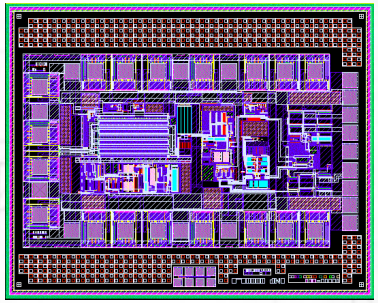
  3 dipoles
  *with **NS polarization***

- **Scintillator array:**
  17 scintillators
  ***Trigger** of the antenna array*

CODALEMA active dipole

Aluminum dipole antenna





A dedicated LNA(ASIC)

Low noise : sensitive to Galactic noise
Wide bandwidth : 80 kHz à 230 MHz
High dynamic
Good linearity

Scintillator Detector

Trigger rate: 1 evt/ 7 mins
Energy threshold: 1.10^{15} eV

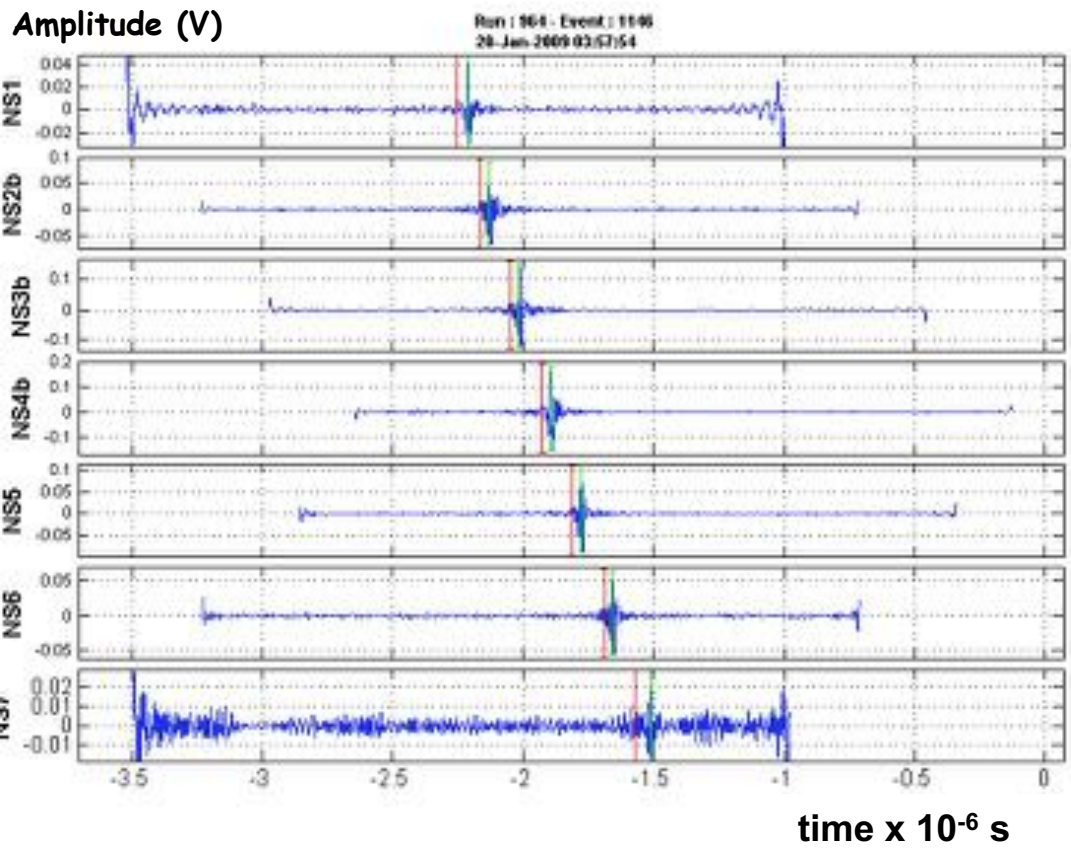
Informations on EAS:
- Arrival direction
- Shower core position
- Energy estimate (CIC method)

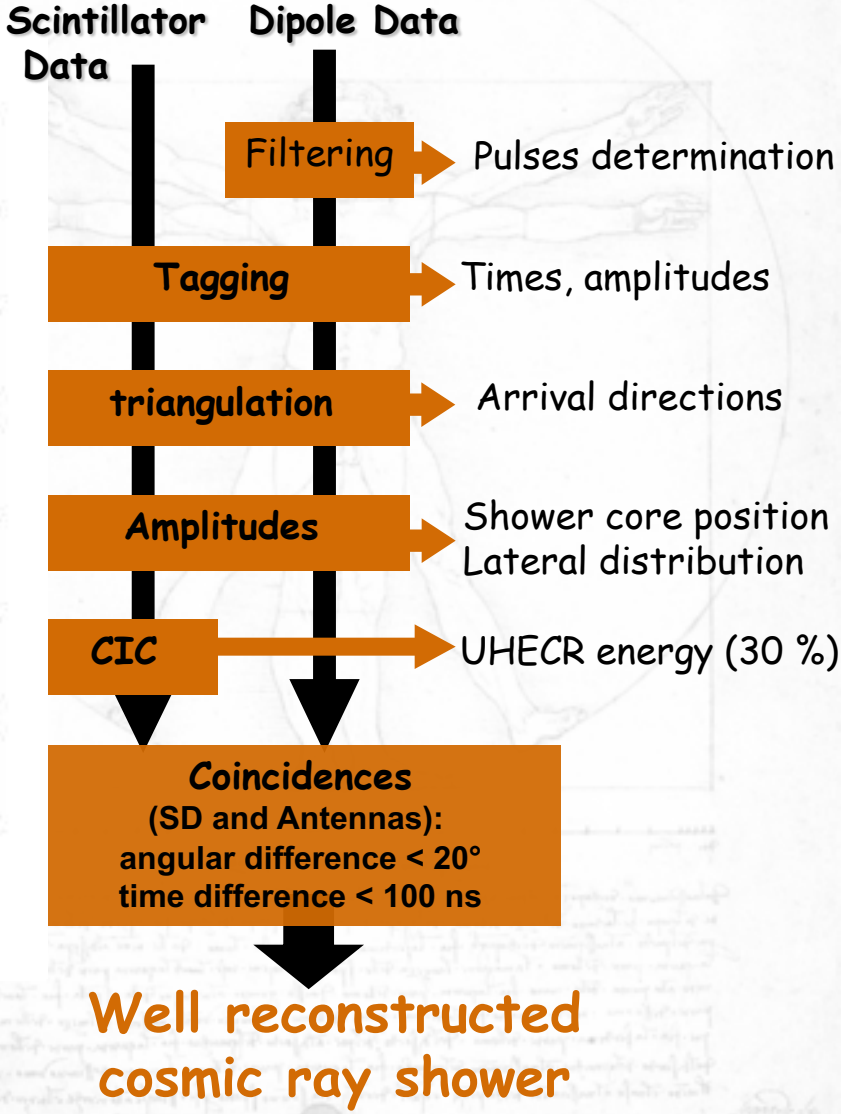
2 different classes of trigger events (5 central stations in coincidence) :

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

- External events: No estimation of shower energy and core position.

Analysis:
From raw signal to atmospheric shower…



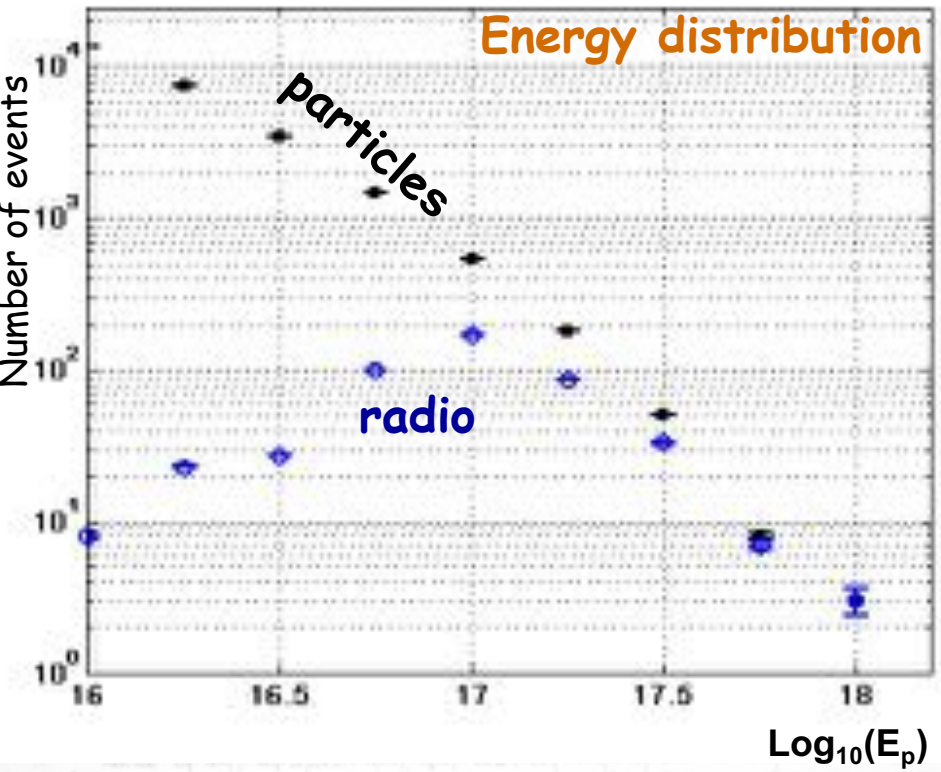


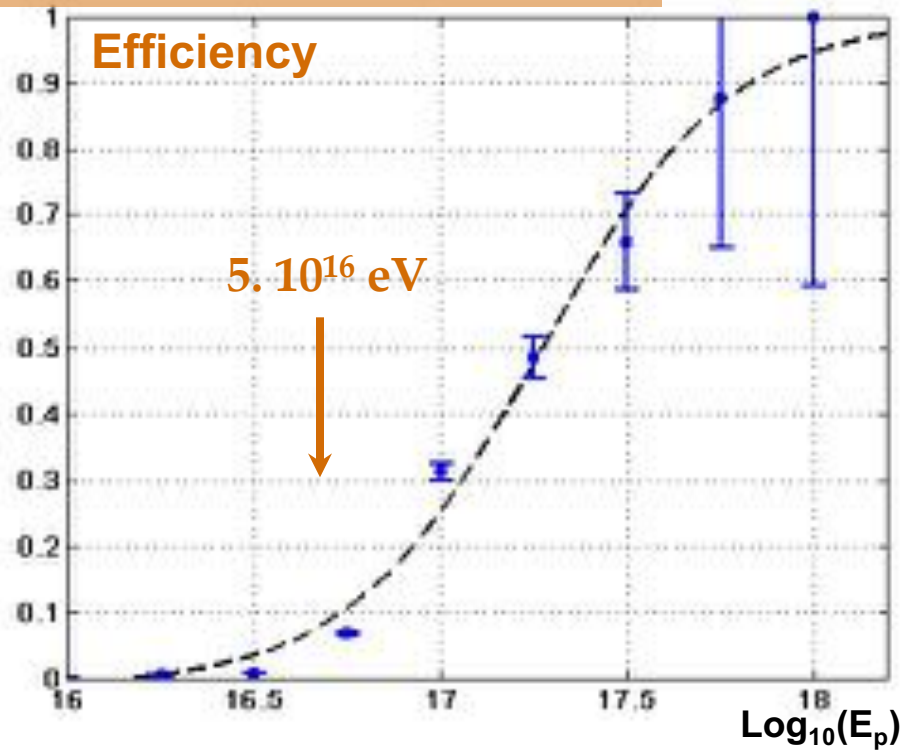
Radio detection efficiency

Radiodetection threshold ~ 5.10^{16} eV

Particles threshold 10^{15} eV

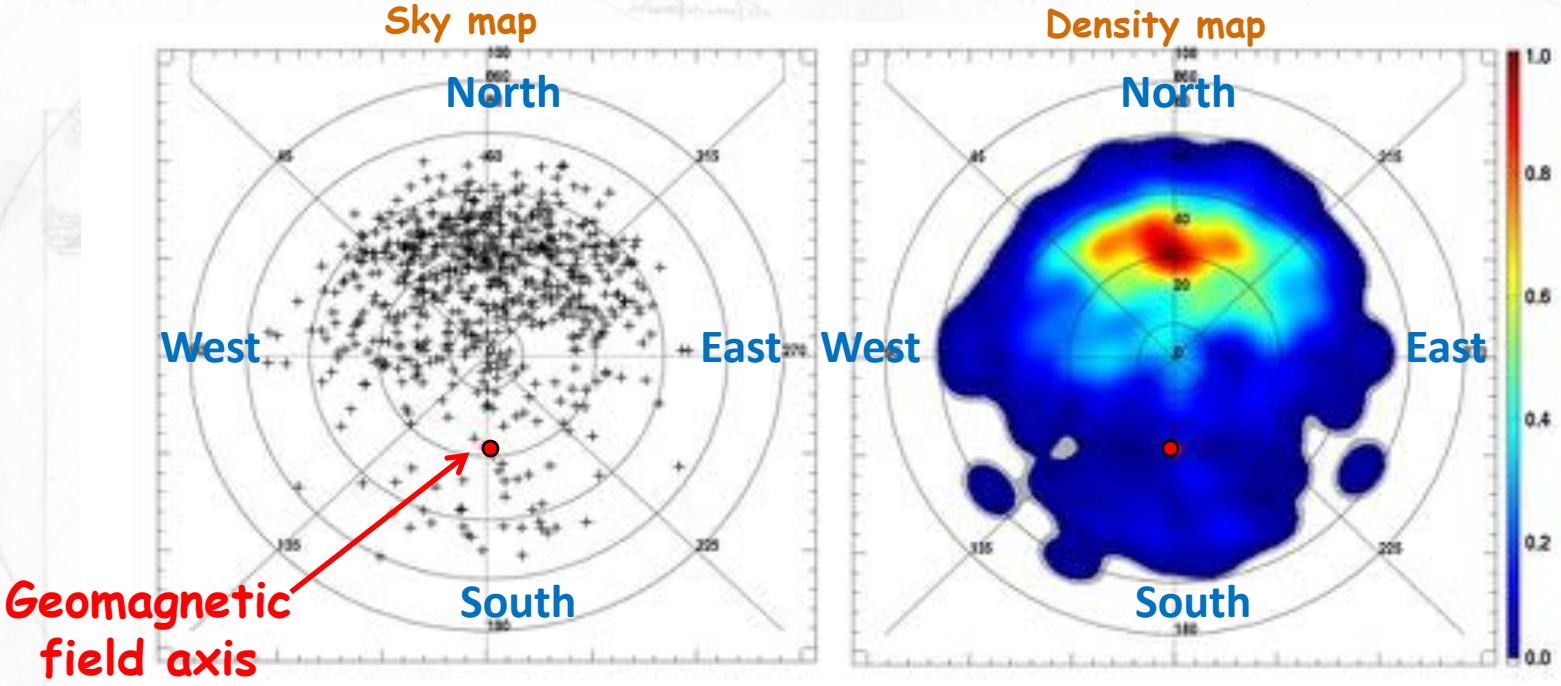
Effective data taking time	659 days
Trigger (SD events)	143795
Coincidences (SD and antennas)	1553
Coincidences (Internal)	450





Full efficiency reached above 10^{18} eV

Shower arrival direction



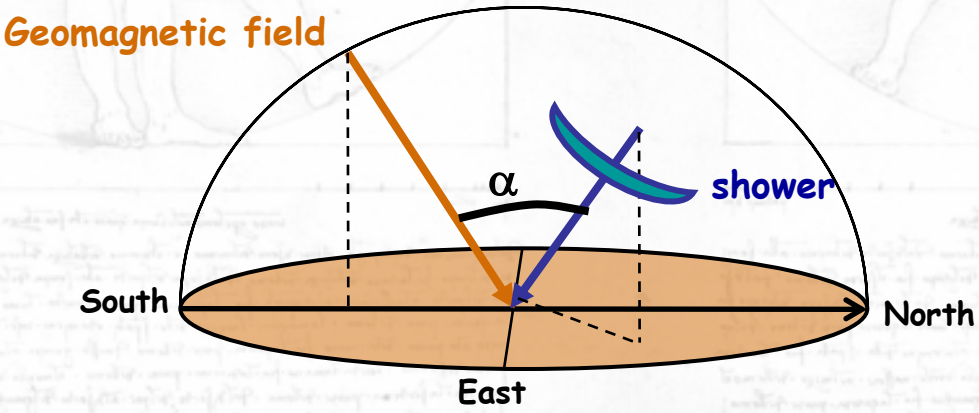
- Large north/south asymmetry, **relative deficit of events** in the geomagnetic field axis area

-For the scintillators, **the azimutal acceptance is uniform**

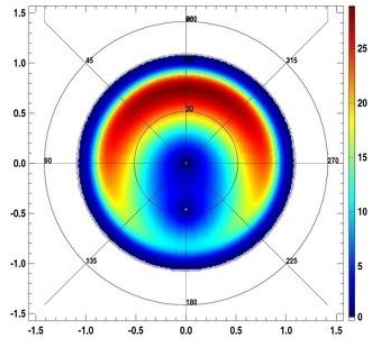
A model to understand the asymmetry

Hypothesis:

- **The electric field is proportional to the Lorentz force $E \alpha |v \times B|$**
  - Charged particles in the shower are deflected by the geomagnetic field
  - Electric field polarization in the direction of the Lorentz force :
    a linear polarization is assumed E // to **v x B**
- The number of count (ie the efficiency) depends on the electric field magnitude:
  a simple linear dependence is assumed

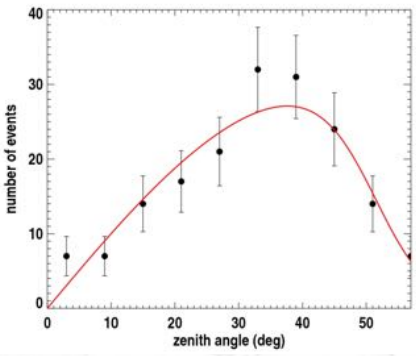


vxB Model : Predicted density map



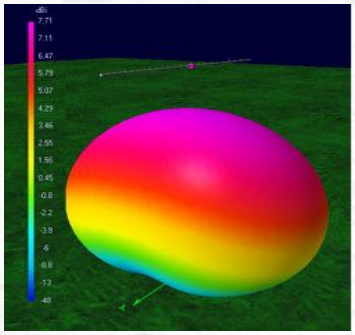
Total Lorentz force (E α sin(a))

X



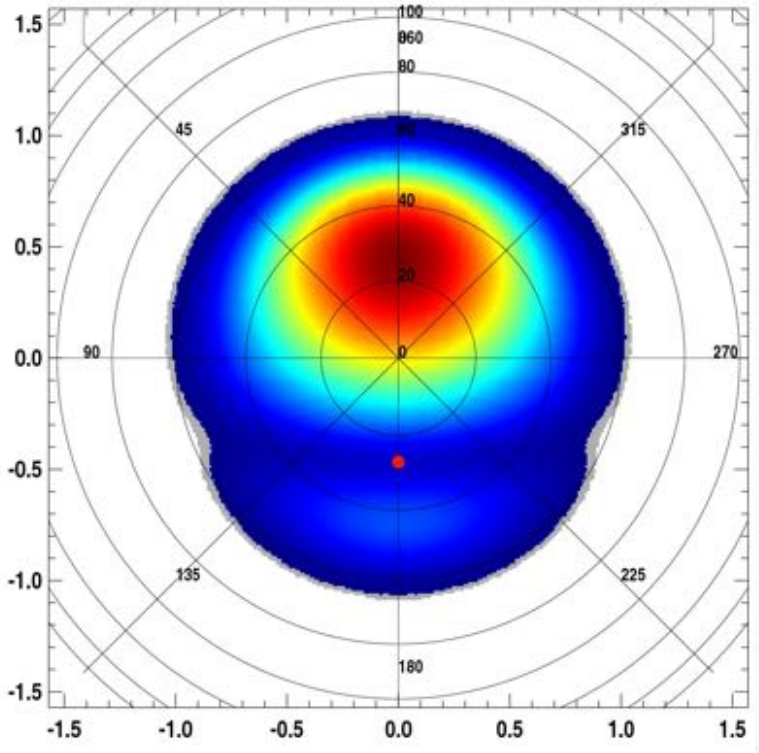
Trigger acceptance
(zenithal angle distribution)

X

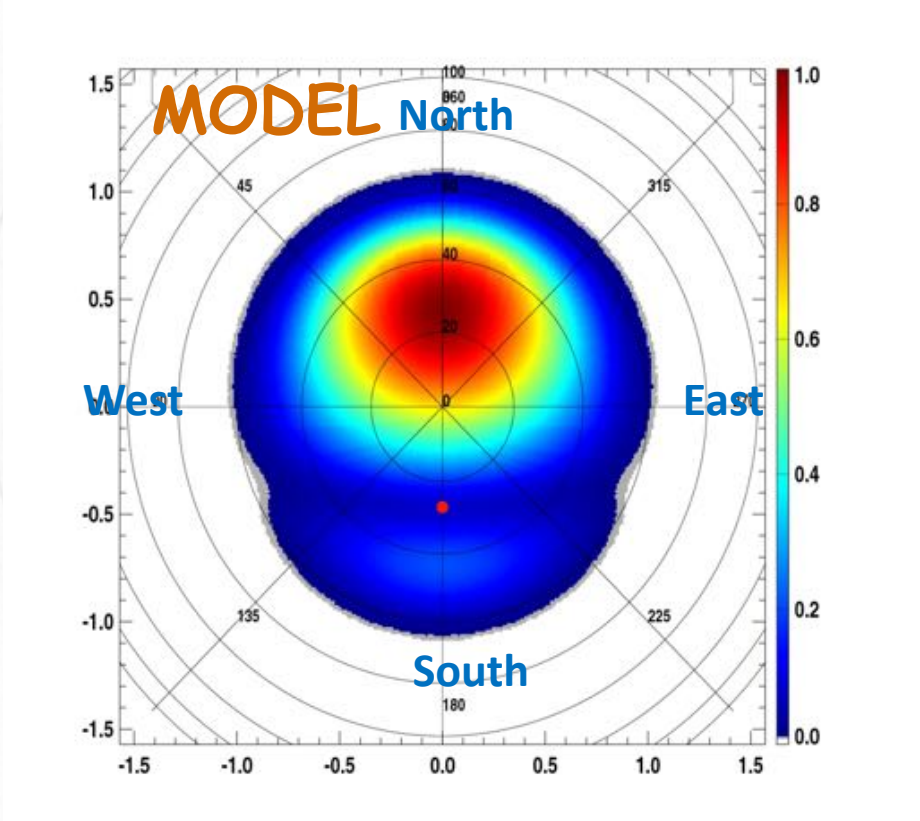


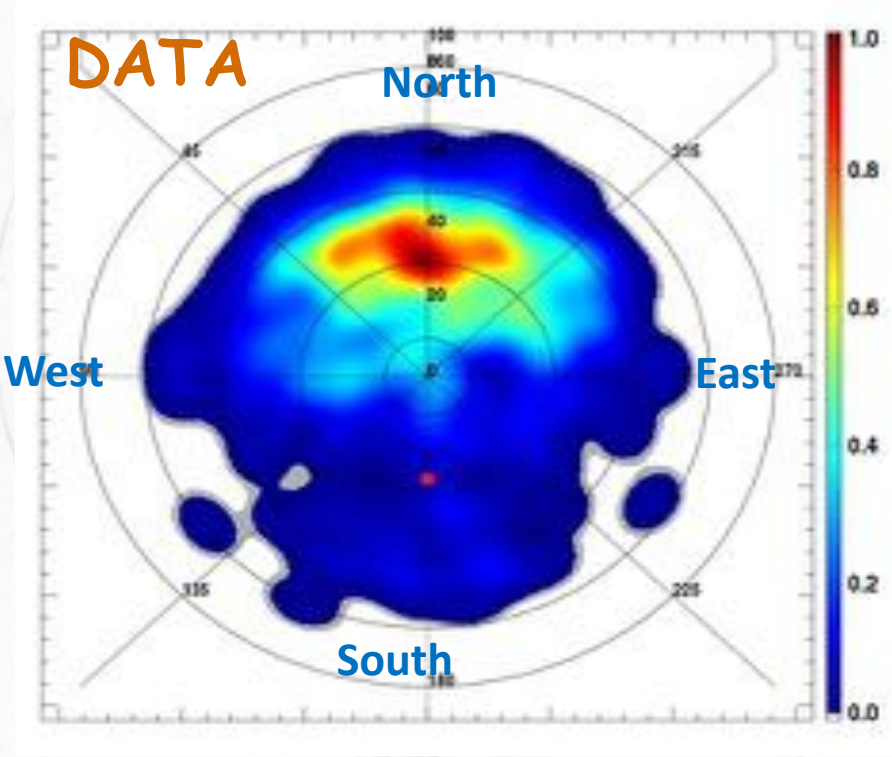
Dipole pattern
(EZNEC simulation)

Projection on East-West axis
(CODALEMA antenna polarization)

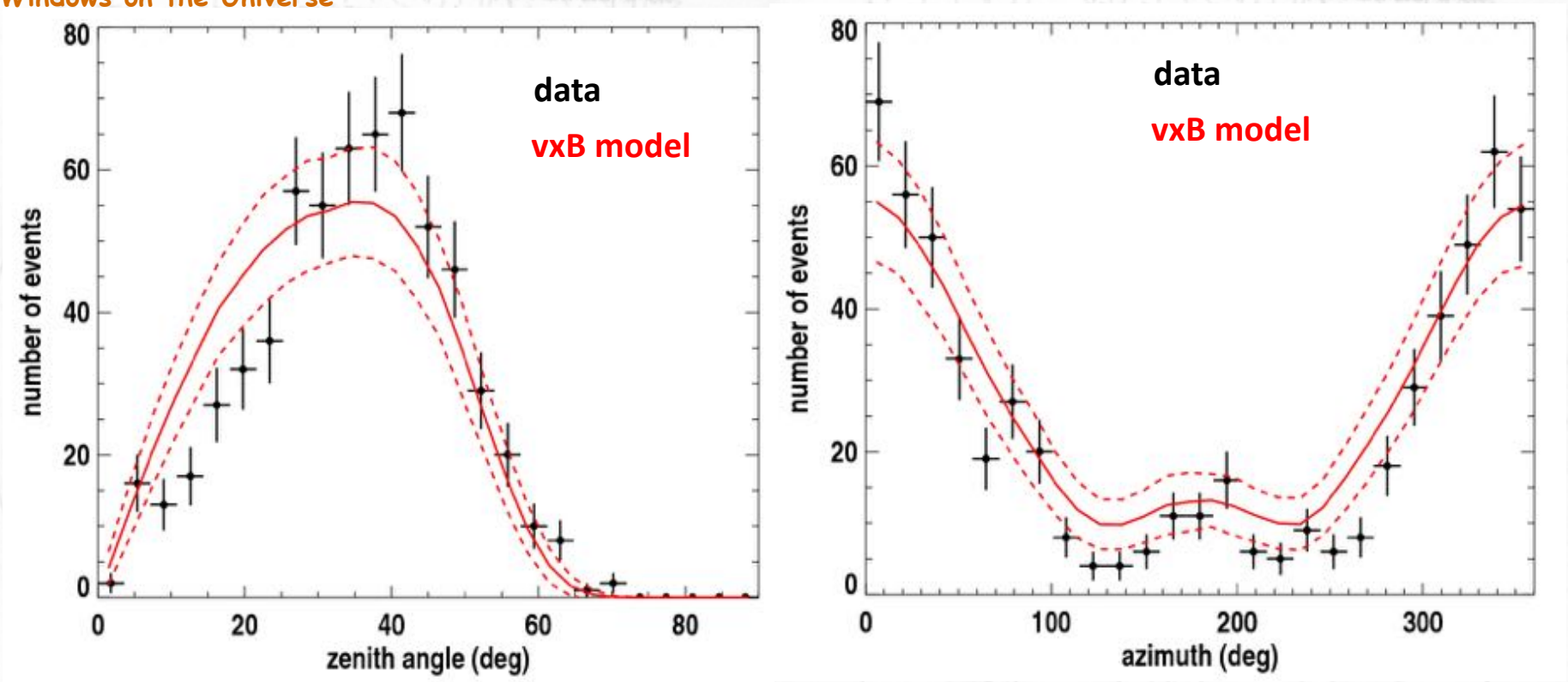


MODEL vs DATA COMPARISON





MODEL – DATA COMPARISON



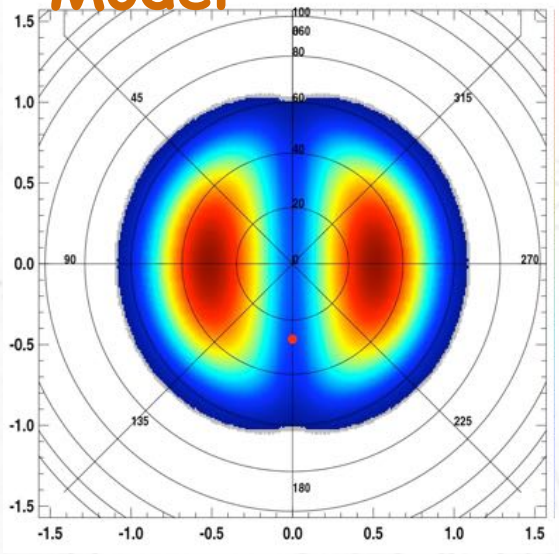
Geomagnetic vxB model fits correctly experimental data:

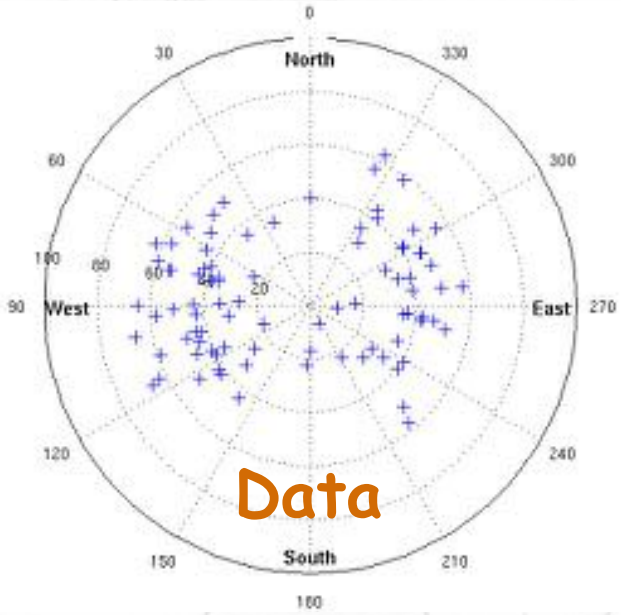
- **in zenithal angle**
- **in azimuthal angle** (notably the local maximum in the South direction)

Published in Astroparticle Physics 31 (2009) 192–200.

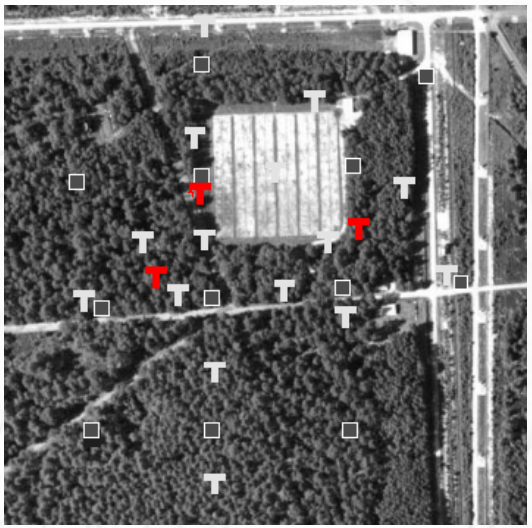
Is the vxB model valid for the NS polarization ?

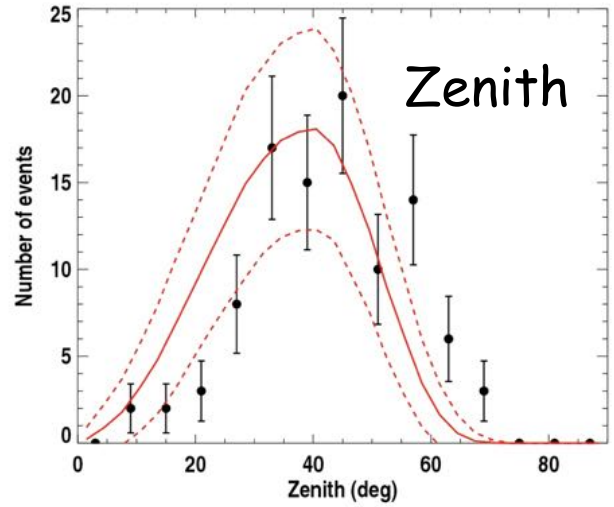
Model

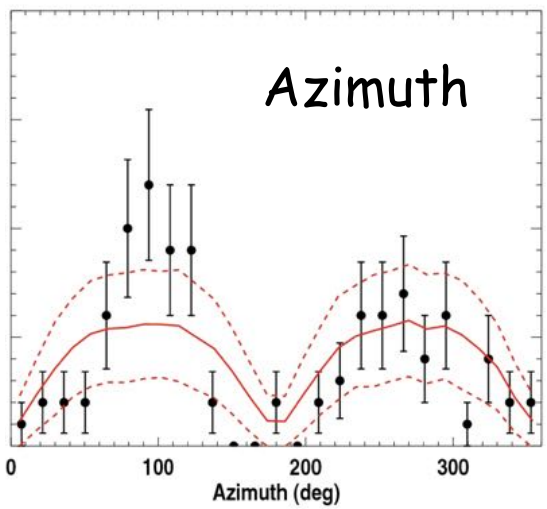




3 NS antenna in the array





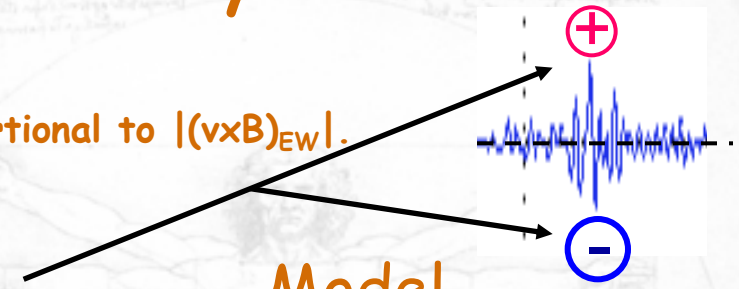


Most of the events are coming from East and West directions

The statistic is lower but at the first look : YES

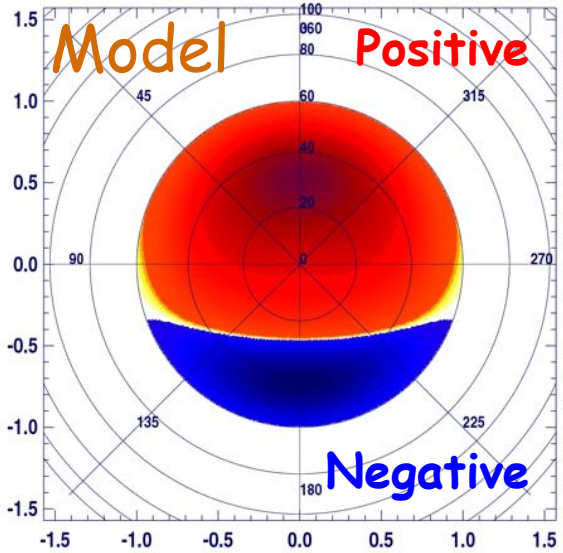
Pulse polarity

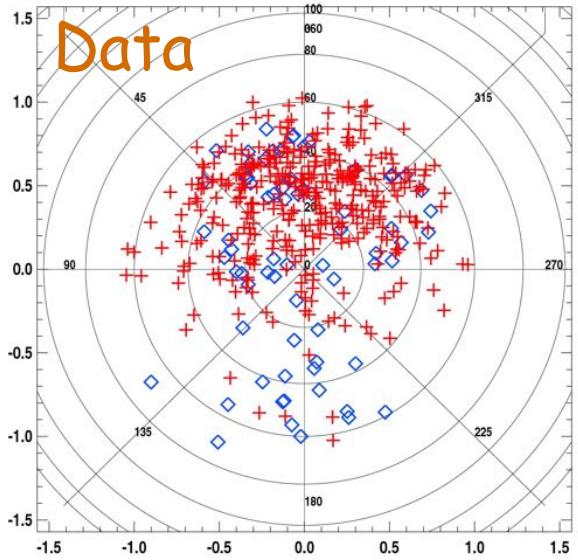
The model assumes the electric field magnitude to be proportional to $|(vxB)_{EW}|$.
Is the signal polarity given by $(vxB)_{EW}$?



filtered dipole Signal : tags are signed

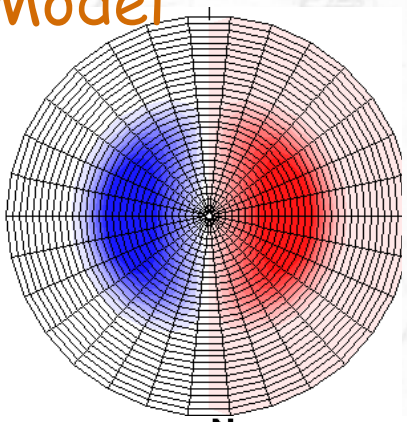
Event sign : given by the most numerous signed tags



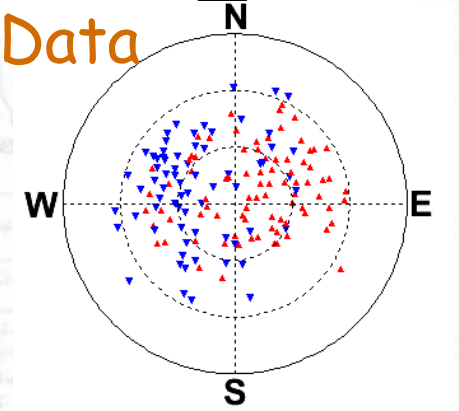


EW polarization

Model



Data



NS polarization

Conclusion

-East/West asymmetry is well interpreted with the (v x B) model

- Good agreement for North/ South polarization despite low statistic

- Good agreement on the event pulse polarity

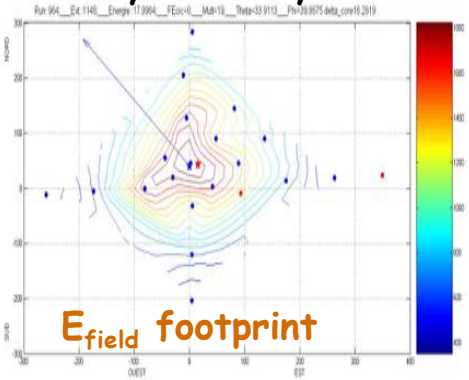
CODALEMA data demonstrate that the geomagnetic field is at the origin of the electric field radio detected by antennas

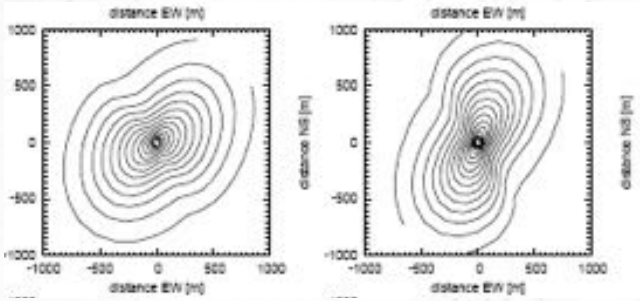
Perspectives : Physics objectives

What is the geomagnetic mechanism involved in the emission process ?

- geosynchrotron model (Huege and Falcke, 2000) ?
- transversal current model (Lasty, Scholten and Werner, 2005) ?

one way : study of the field polarization => Antenna with EW & NS polar





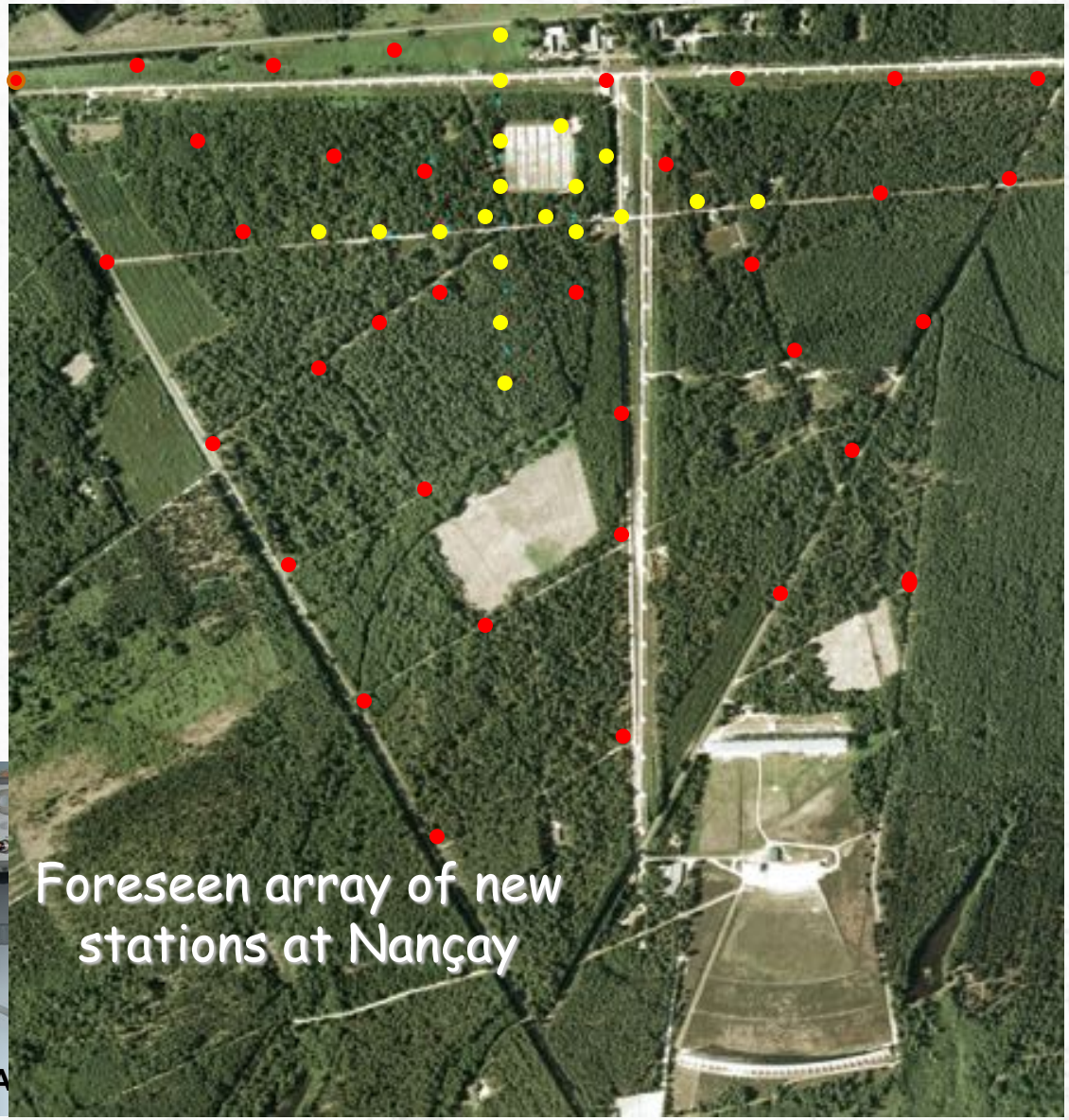
Geosynchrotron Model

- Field amplitude and primary energy correlation

(partially done in the T.Saugrin Thesis, Univ Nantes 2008, publication under preparation)

- Determination of the primary CR nature ?

Perspectives



- Installation of **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 (~1 Km^2)
- Installation for tests in Argentina.

  Participation at the AERA Project (AUGER)

The CODALEMA collaboration

8 French laboratories
(IN2P3 and INSU)

1 experimental site