The CODALEMA experiment

Olivier RAVEL

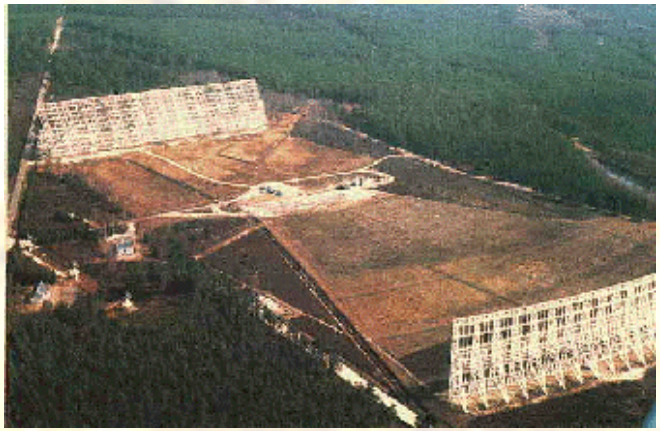
for the CODALEMA collaboration

SUBATECH, Nantes

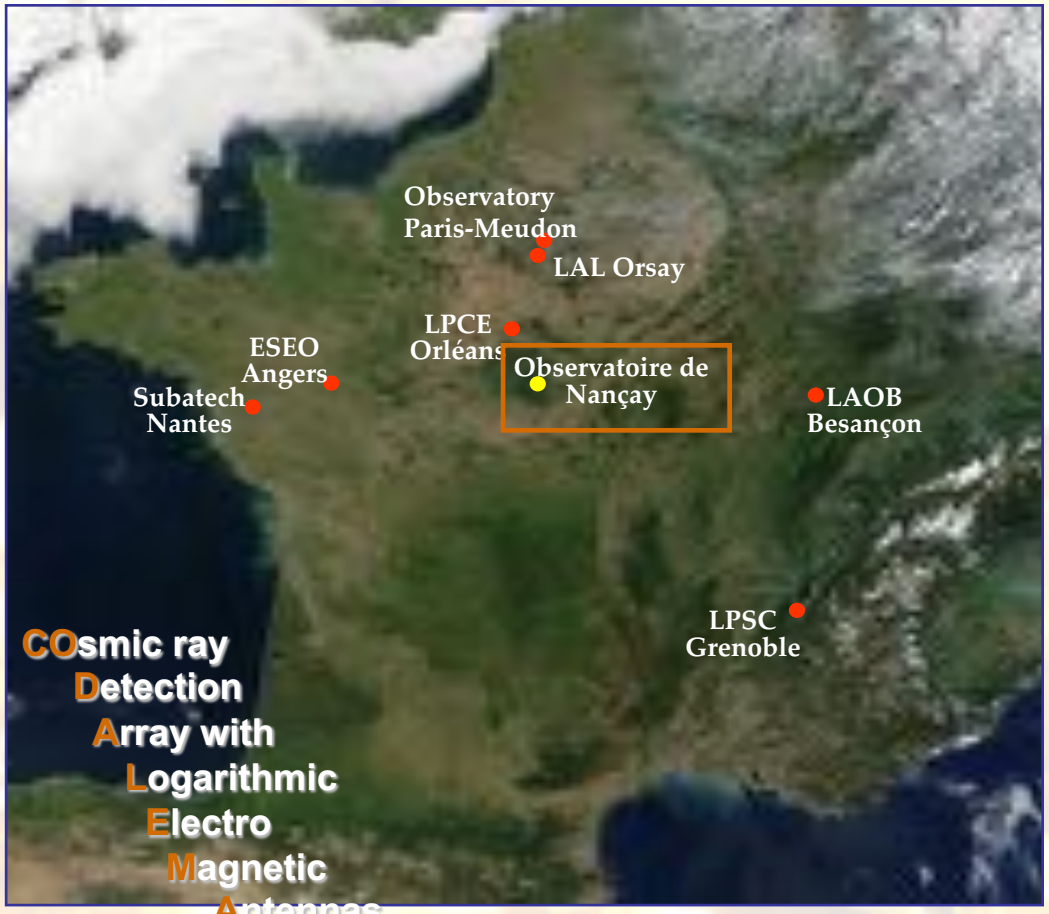
The CODALEMA collaboration

8 French laboratories

1 experimental site at Nançay (Observatoire de Paris)



Radio Telescope



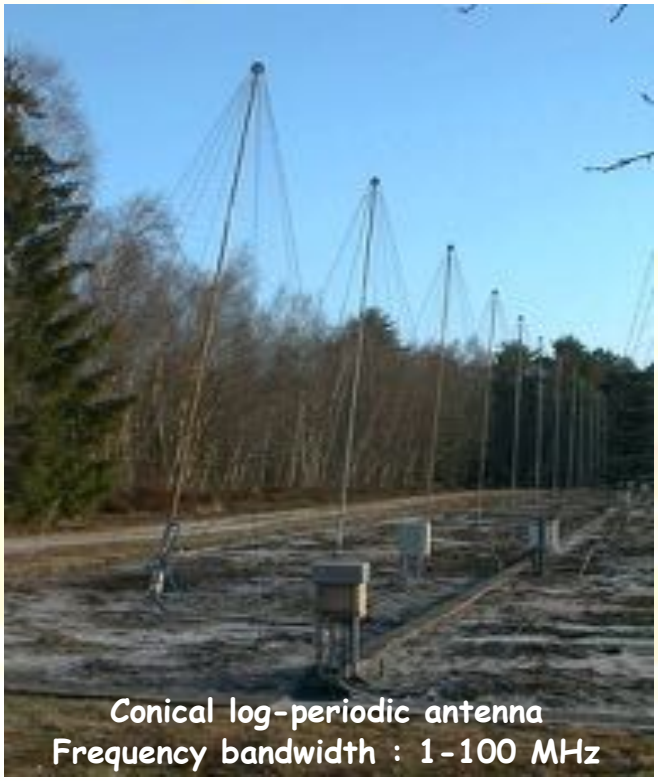
Radio detection & CODALEMA goals

- 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 (Energy, Nature)**
- 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

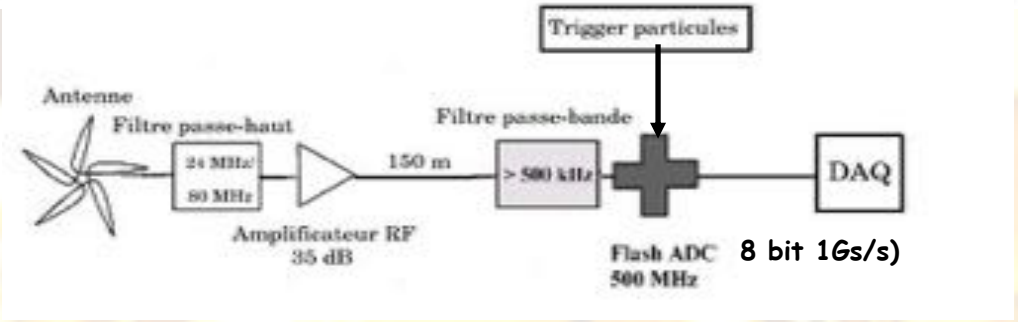
CODALEMA : stage I 2002-2005

Revival of the cosmic ray radio detection method in 2002 with the CODALEMA and LOPES experiments.

Nançay Decametric Array (DAM)



Conical log-periodic antenna
Frequency bandwidth : 1-100 MHz



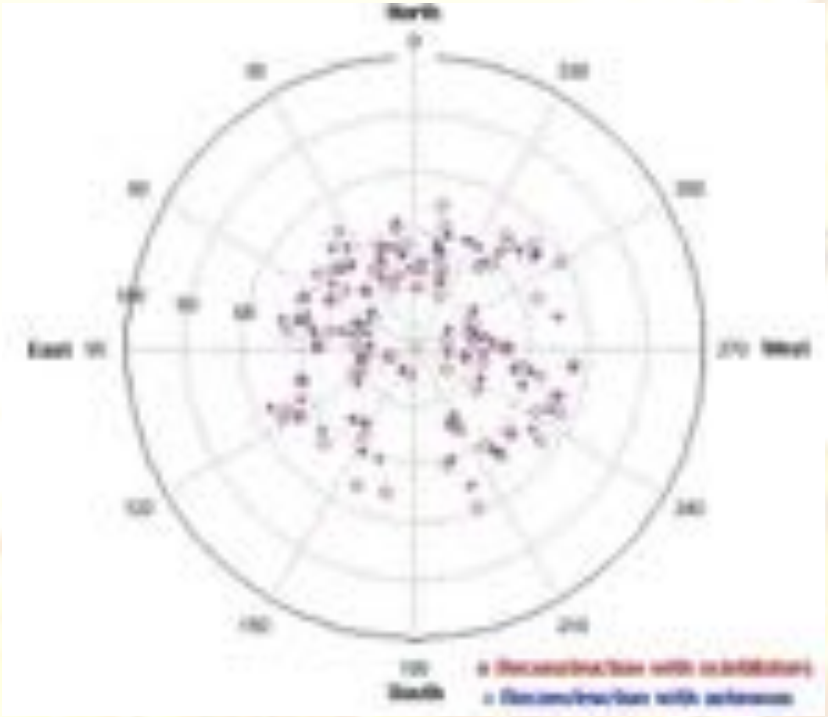
TRIGGER:

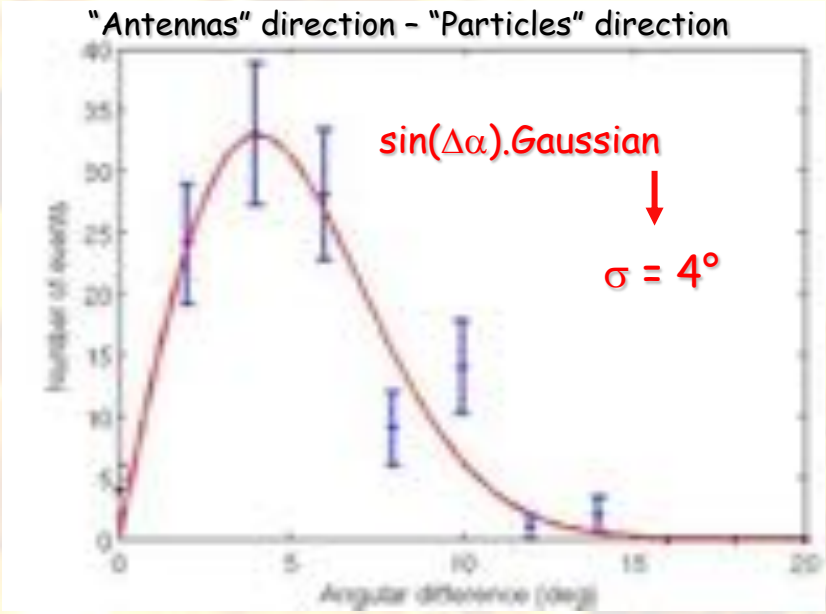
4 Stations of Scintillators (2 m^2) in time coincidences

Signal recording + Time of flight analysis

CODALEMA Stage I : main results

- **Correlation of shower arrival directions**





D. Ardouin et al. NIM A 2005

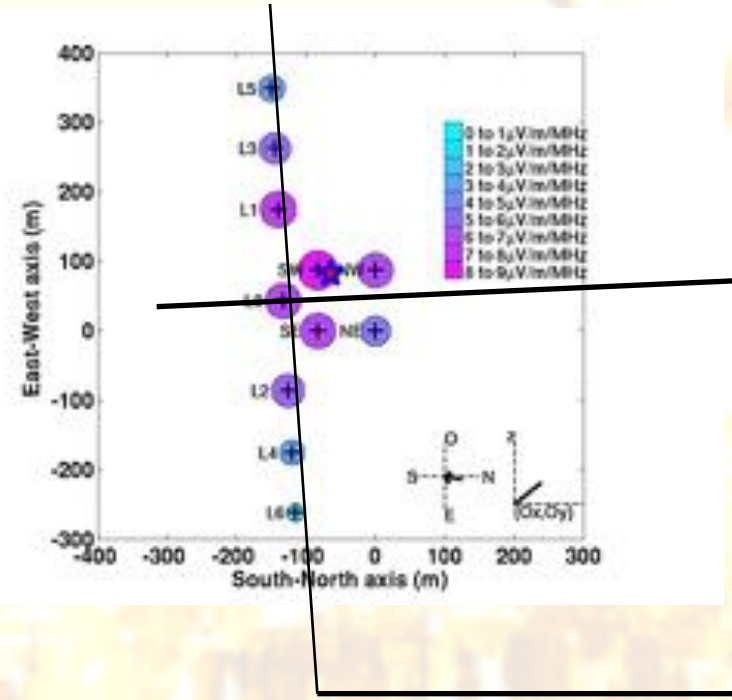
New evidence for radio-detection of cosmic ray air shower ~ 40 years after the pioneer period !

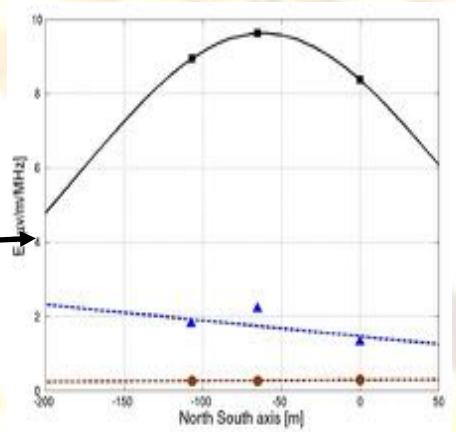
CODALEMA stage I : main results

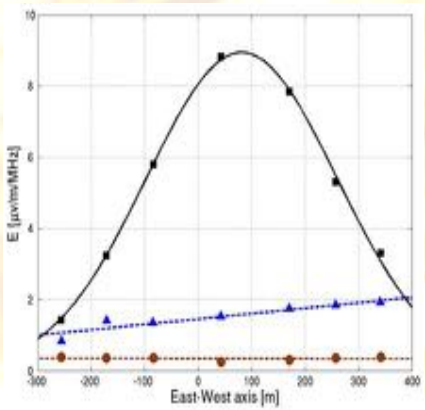
- First studies of electric field feature :

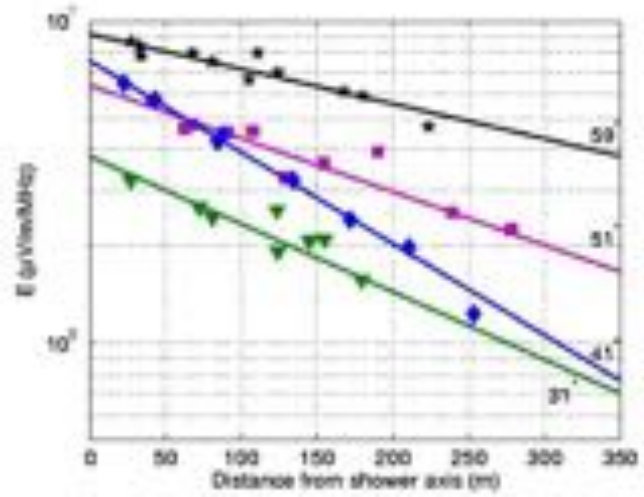
-estimation of the shower core position by radio

-first lateral distribution









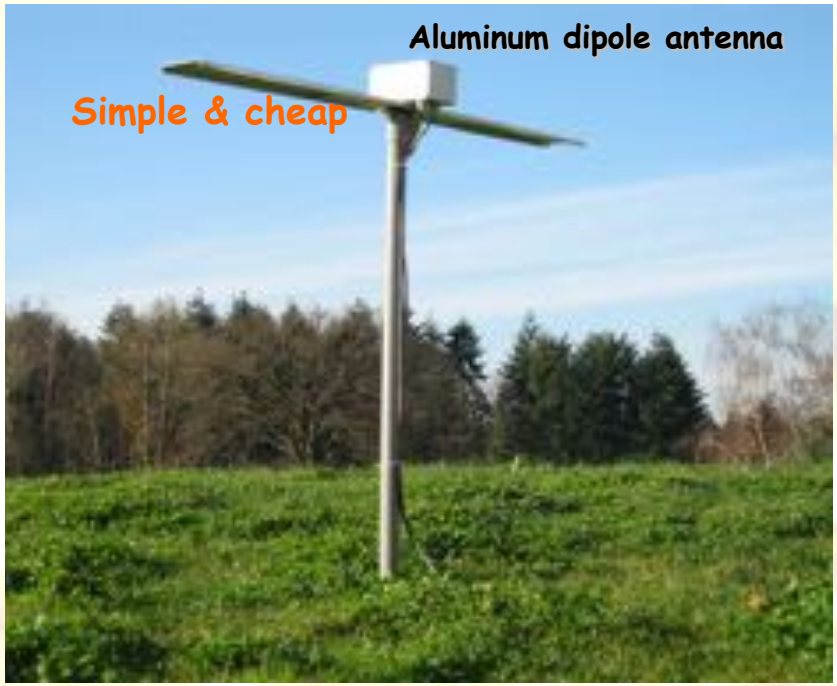
End of the stage I in 2005

-New design of antennas and extension of the antenna array

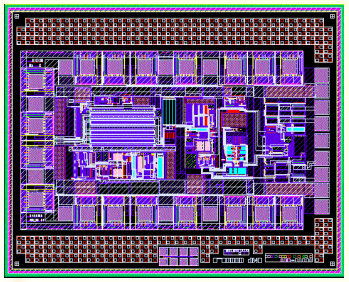
-Extension of the scintillator array => determination of the shower Energy

-New DAQ (12 bit ADC 1Gs/s)

CODALEMA active dipole



LNA CODALAMP (ASIC)



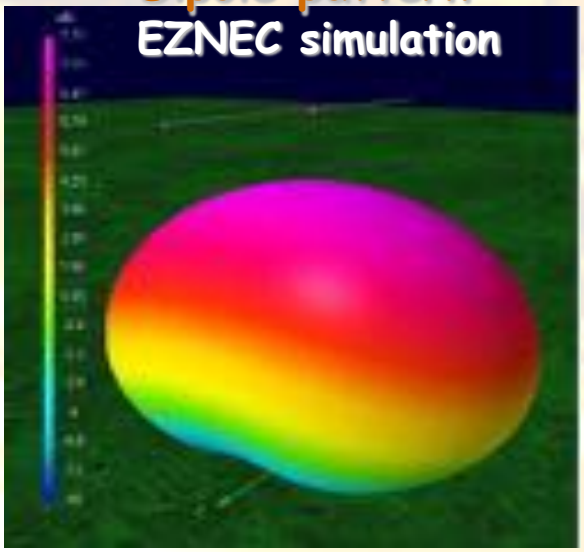
Low noise : **sensitive to Galactic noise**
Wide bandwidth : **80 kHz à 230 MHz**
High dynamic, good linearity

Data Acquisition:

- 12 bits ADC (MATAQ)
- Sampling: 1 Gs/s

See talks D.Charrier & T. Garçon

Dipole pattern



CODALEMA stage 2 : CURRENT SETUP

Nançay Observatory

3 detector arrays:

- **Antenna array**

-21 dipoles oriented *EW*
- 3 dipoles oriented *NS*

- **Scintillator array:**

17 scintillators
=> *Trigger* of the experiment
=> *Energy* determination

- **Decametric array**

18 groups of 8 Phased log-periodic antennas

Electric field map at small scale

Scintillator array (Trigger)

17 stations covering a surface of 340 x 340 m^2 with a pitch of 80 m

2 PMT per station (high and low gain) => Large dynamic 0.3-3000 VEM

R&D LPSC Grenoble

Trigger rate **1 evt/ 7 mn**

Energy threshold: **1.10^{15} eV**

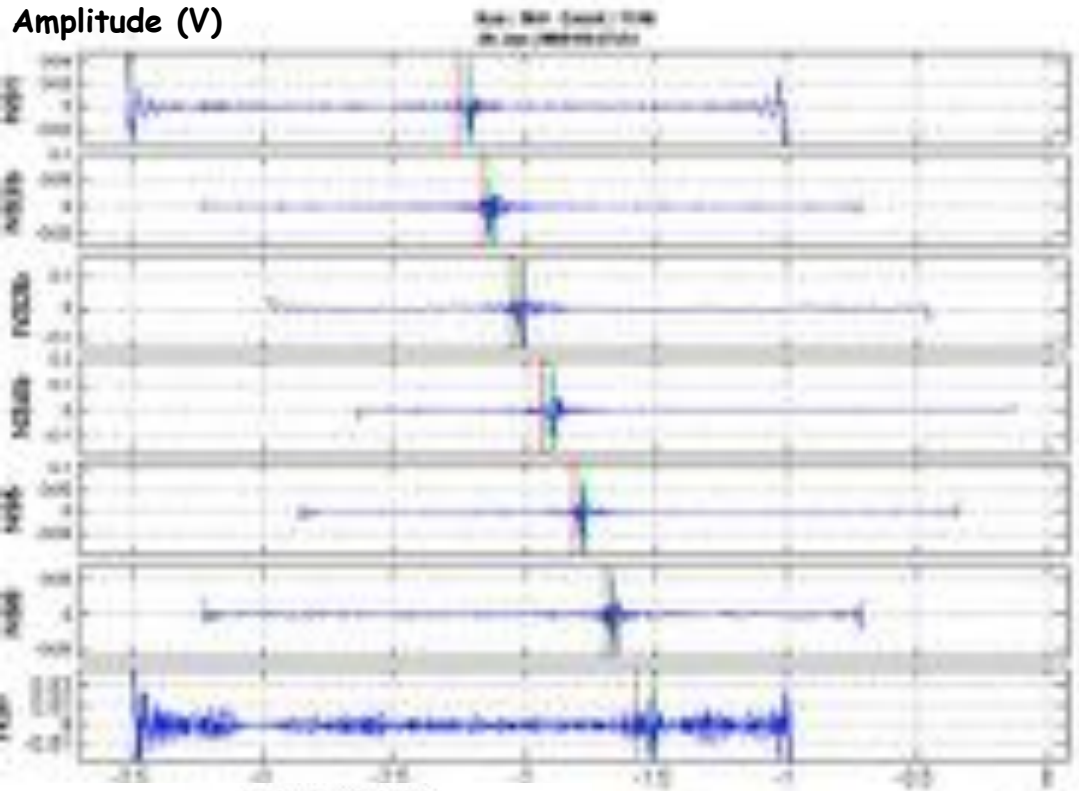
Trigger events : 5 central stations in coincidence

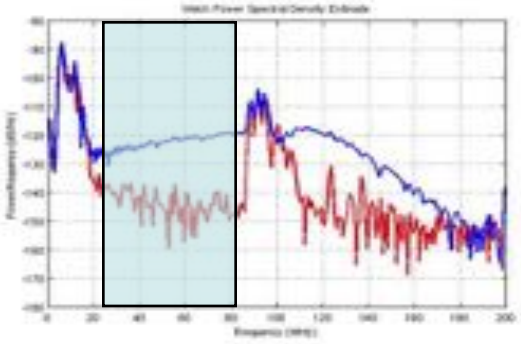
2 different classes of events :

- **Internal events:** the maximum of signal is not on the edge of the array => good particle sampling => **Correct estimate of the shower energy and the core position.**

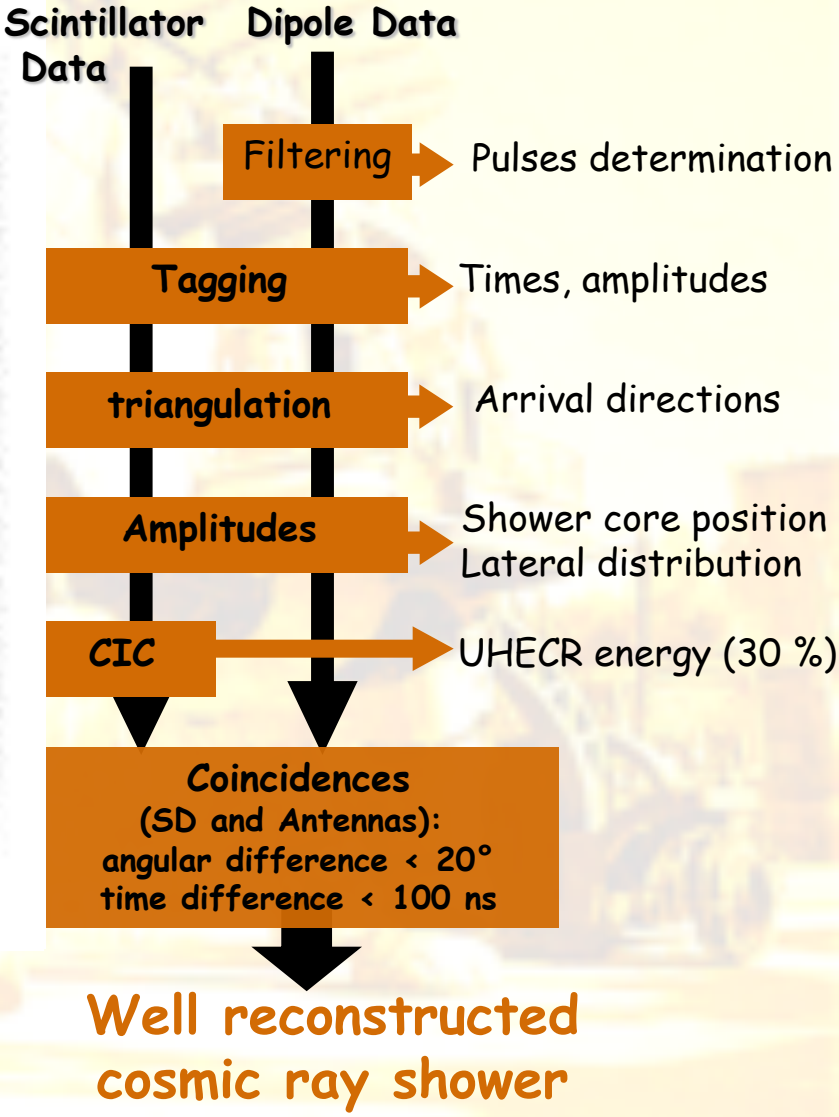
- **External events:** Particle density extrapolated outside the array :
  No confident estimate of the shower energy and the core position
  => *Events exclude from the energy analysis*

Analysis:
From raw signal to atmospheric shower…



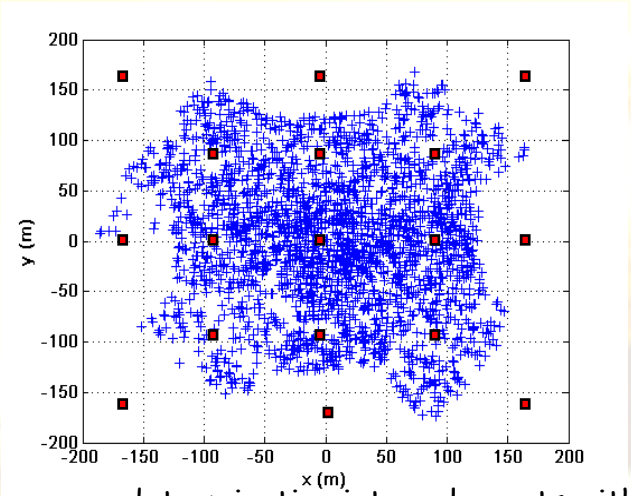


Numerical filtering
23-83 MHz



Well reconstructed cosmic ray shower

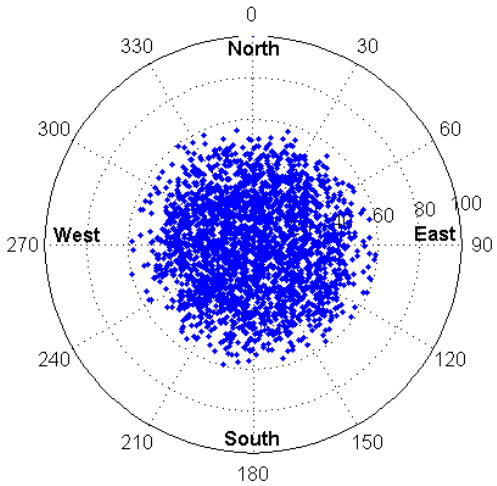
Scintillator array : Performances

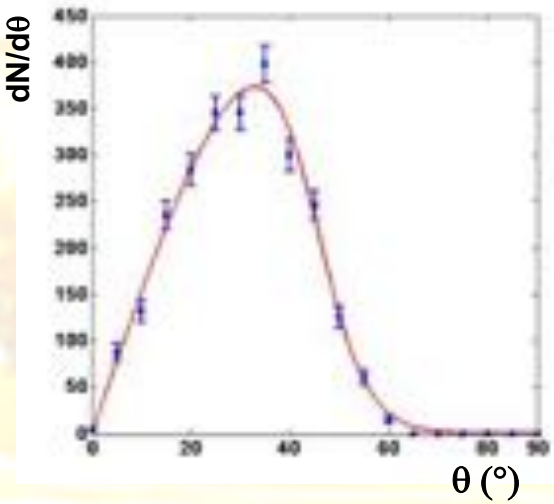


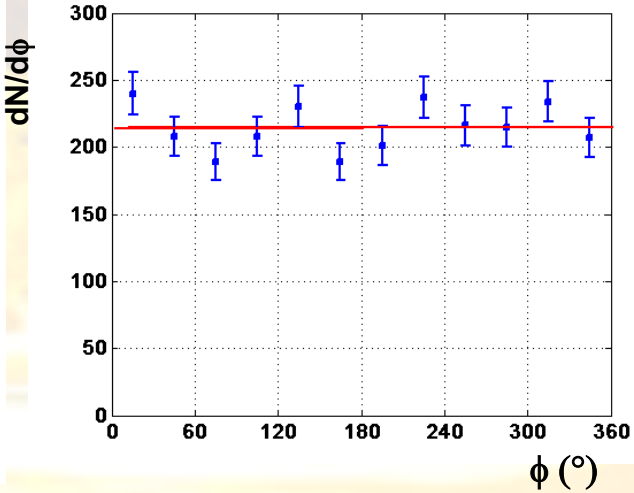
Shower core determination internal events with E > **5.10^{16}** eV

Provide important information on showers:

- Arrival direction : triangulation from the relative time of flight between the different stations
- Shower core position
- **Energy (CIC method) 30% accuracy**







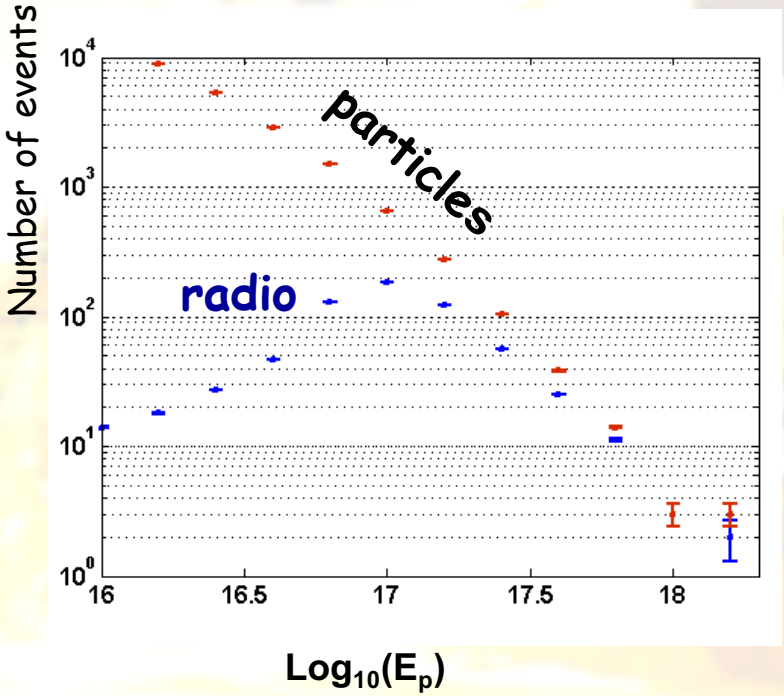
Radio detection efficiency

data taking time	~ 3 years
Trigger (SD events)	169526
Coincidences (SD and antennas)	2030
Coincidences (Internal)	450

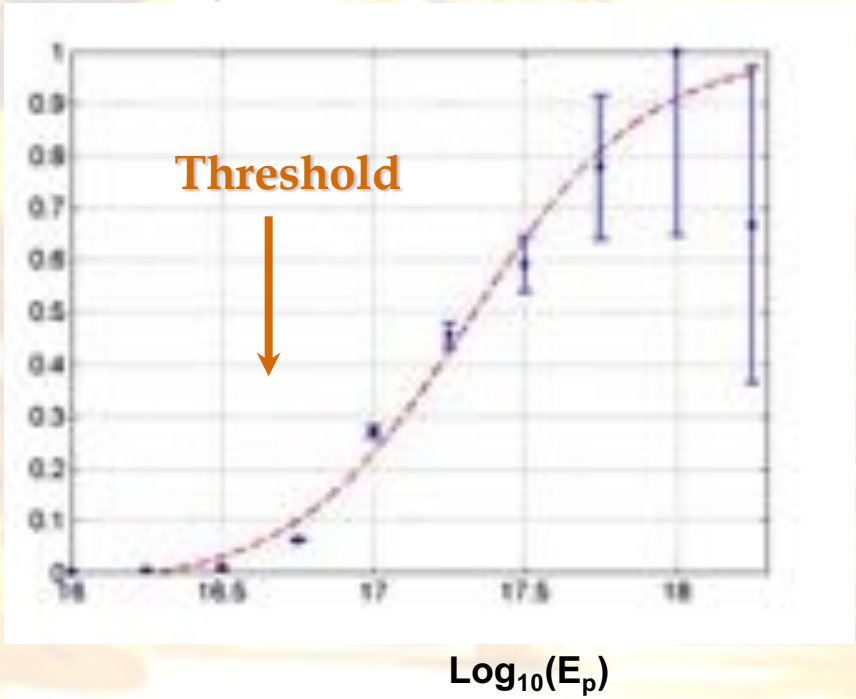
Radiodetection threshold ~ 5.10^{16} eV

Particles threshold 10^{15} eV

Energy distribution



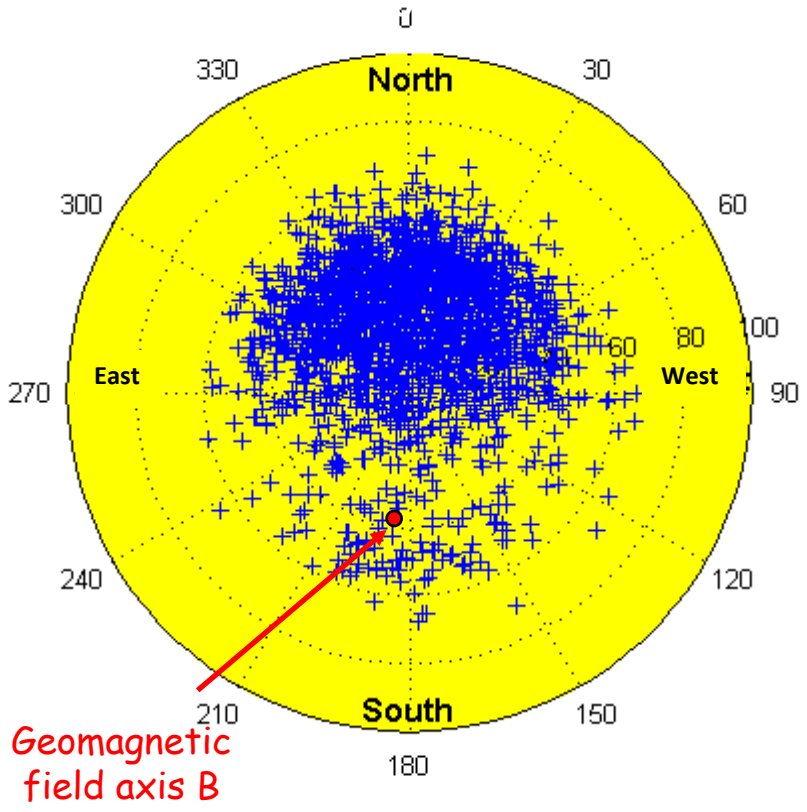
Efficiency



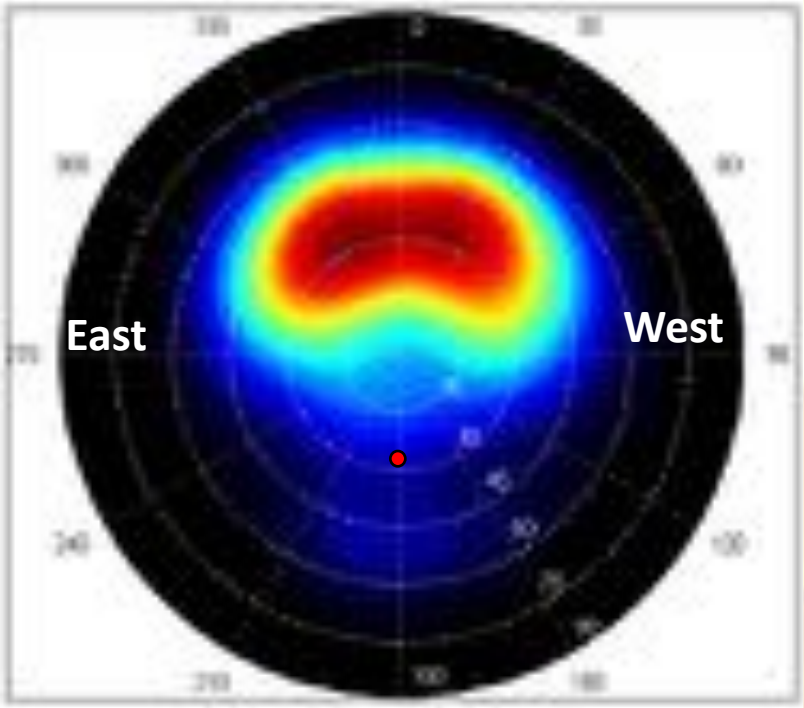
Full efficiency reached above 10^{18} eV

Shower arrival direction

scatter plot



contour Map



- **relative deficit of radio-detected events in the geomagnetic field axis area**

north/south asymmetry $N_{north}/N_{south} = 0.18$

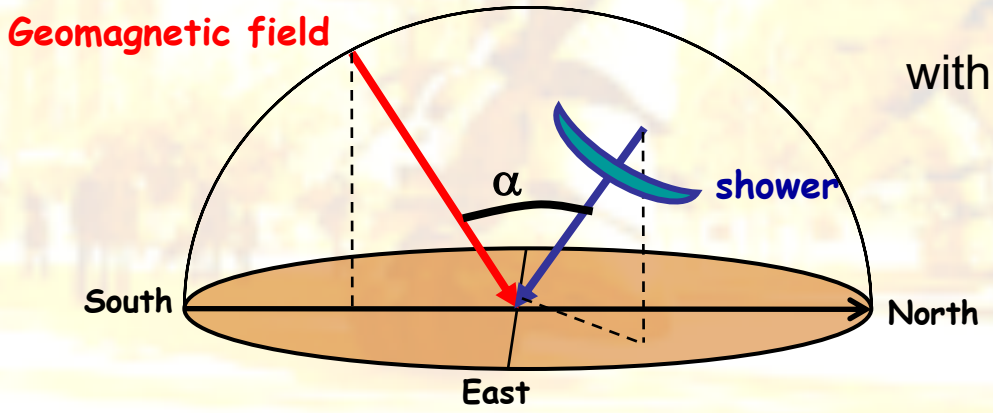
Previous result with lower statistic $N_{north}/N_{south} = 0.17$ *D.Ardouin et al. AP2009*

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



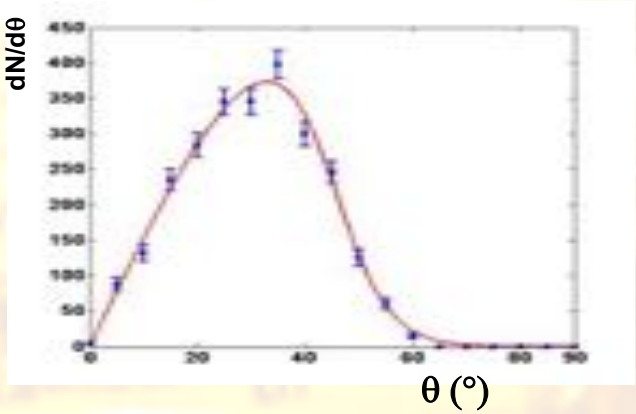
with $\theta_B = 27$ °

vxB Model : Predicted density map

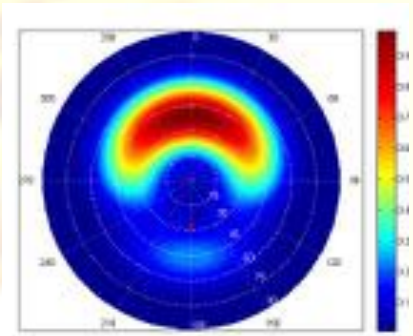
Lorentz force
E α vxB

$$\vec{E} = \begin{pmatrix} \sin\theta \,.\, \sin\varphi \,.\, \cos 27 \\ -\sin\theta \,.\, \cos\varphi \,.\, \cos 27 - \cos\theta \,.\, \sin 27 \\ \sin\theta \,.\, \sin\varphi \,.\, \sin 27 \end{pmatrix} . \begin{pmatrix} \vec{e_x} \\ \vec{e_y} \\ \vec{e_z} \end{pmatrix}$$

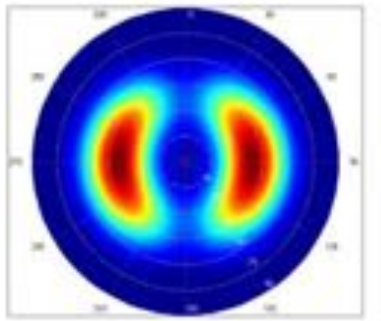
X Trigger acceptance



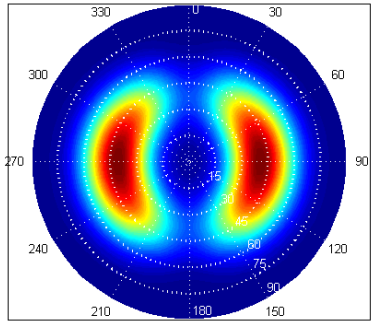
X radiation pattern



Horizontal **EW** polar



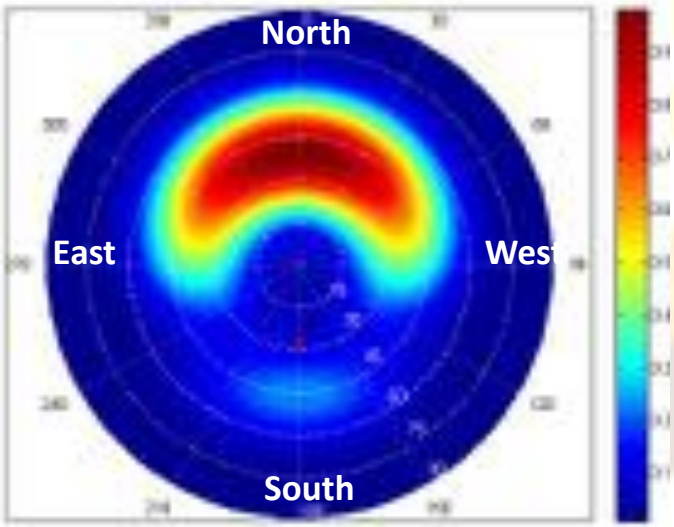
Horizontal **NS** polar



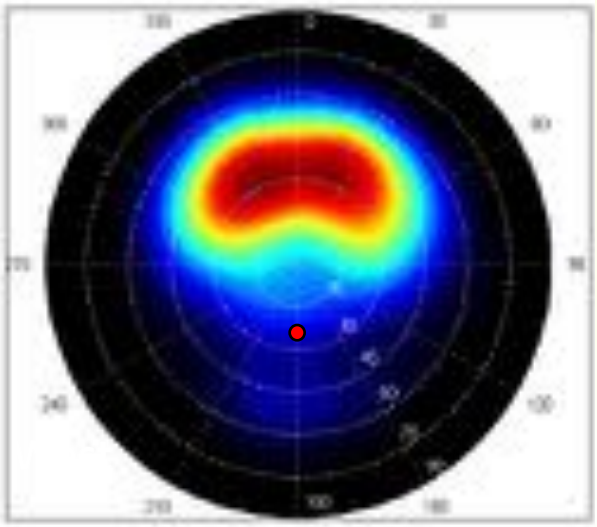
Vertical polar

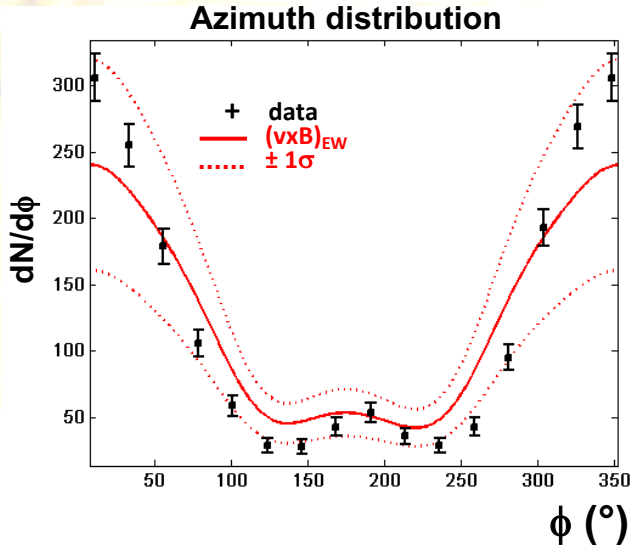
COMPARISON : MODEL vs DATA (EW polarisation)

MODEL $(vxB)_{EW}$



DATA

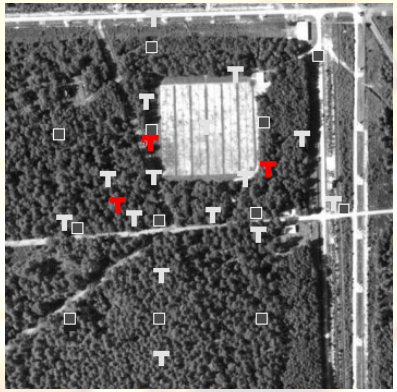




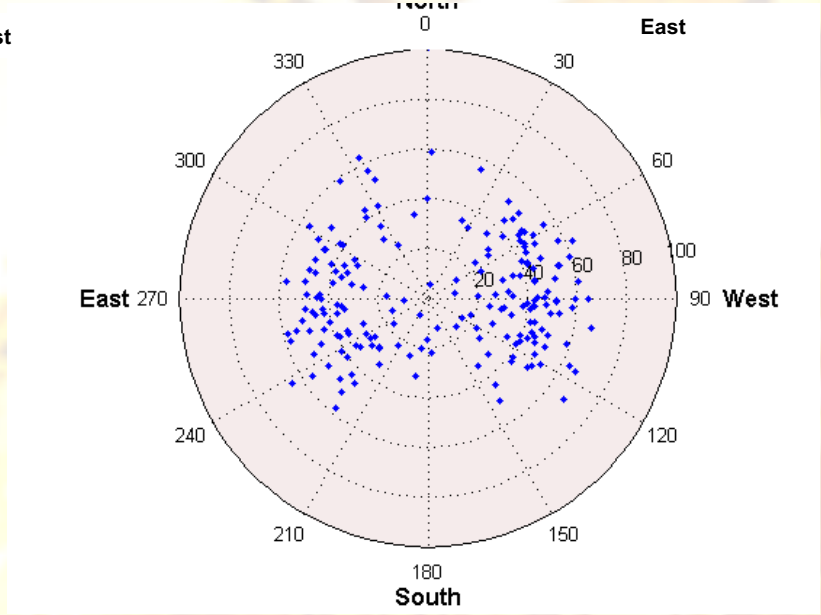
At the first order, the vxB model fits correctly the data:
notably the local maximum in the South direction ($\theta \sim 50°$)

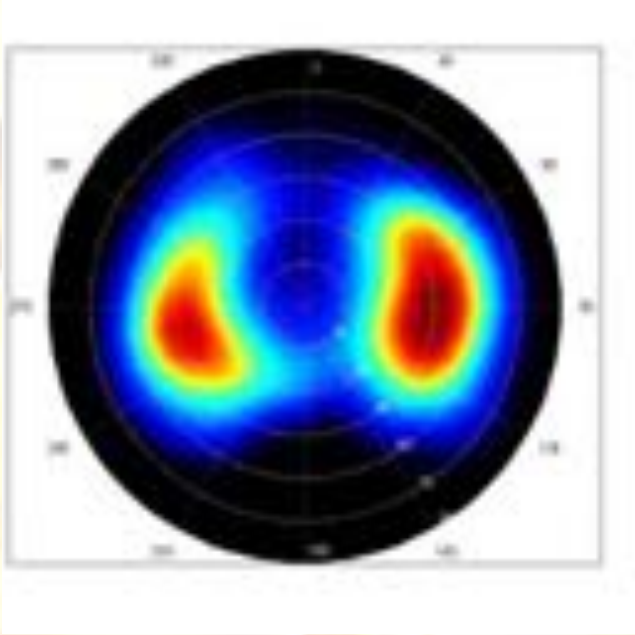
Deviations from the model could point to other emission process superimposed to the geomagnetic effect

Is the vxB model valid for the NS polarization ?



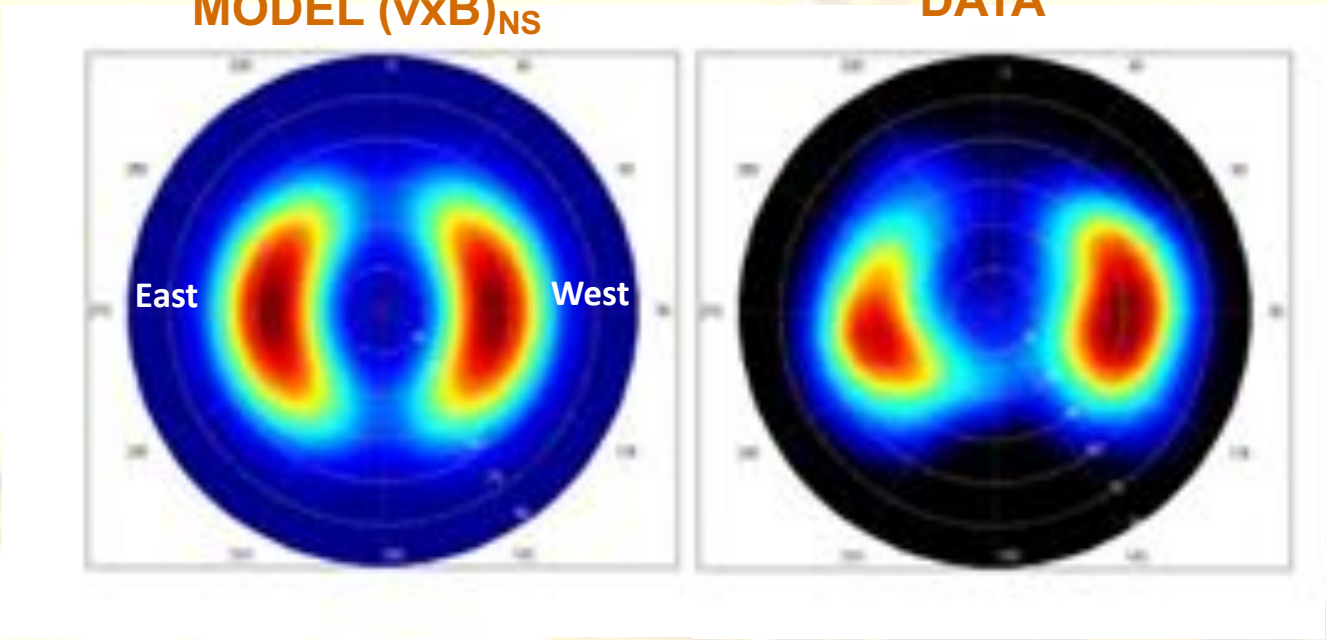
3 NS antenna in the array

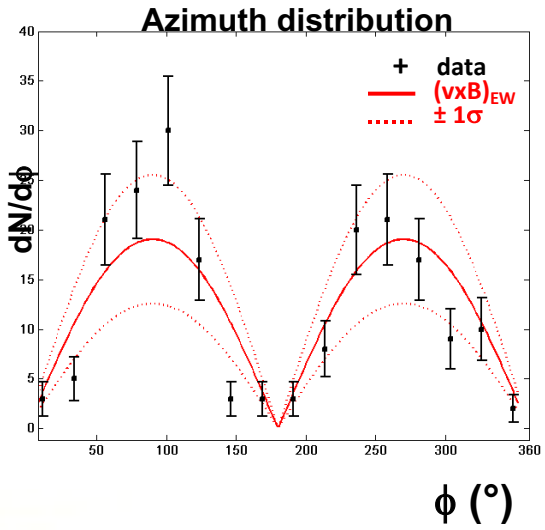




Most of the 192 events are coming from East and West directions

MODEL vs DATA COMPARISON





At first order, good agreement with the model despite the low statistic

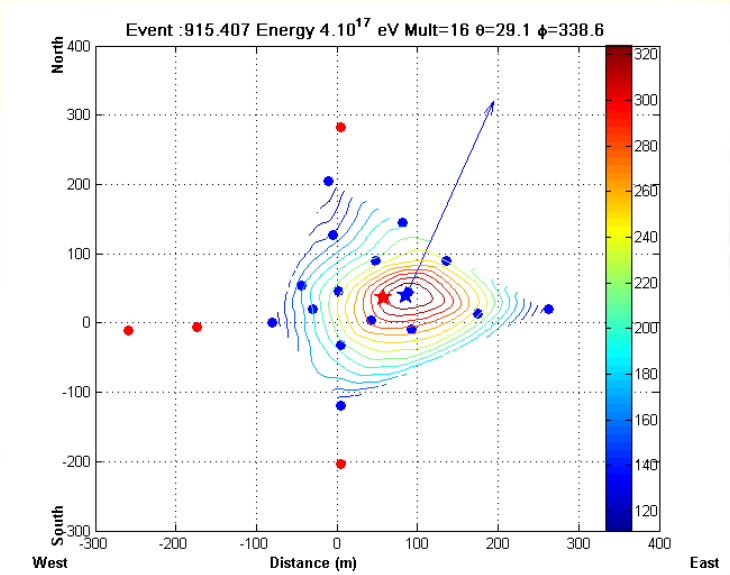
Some clues for more :

Significant asymmetry between E and W directions

Differences in the contour maps (shape)

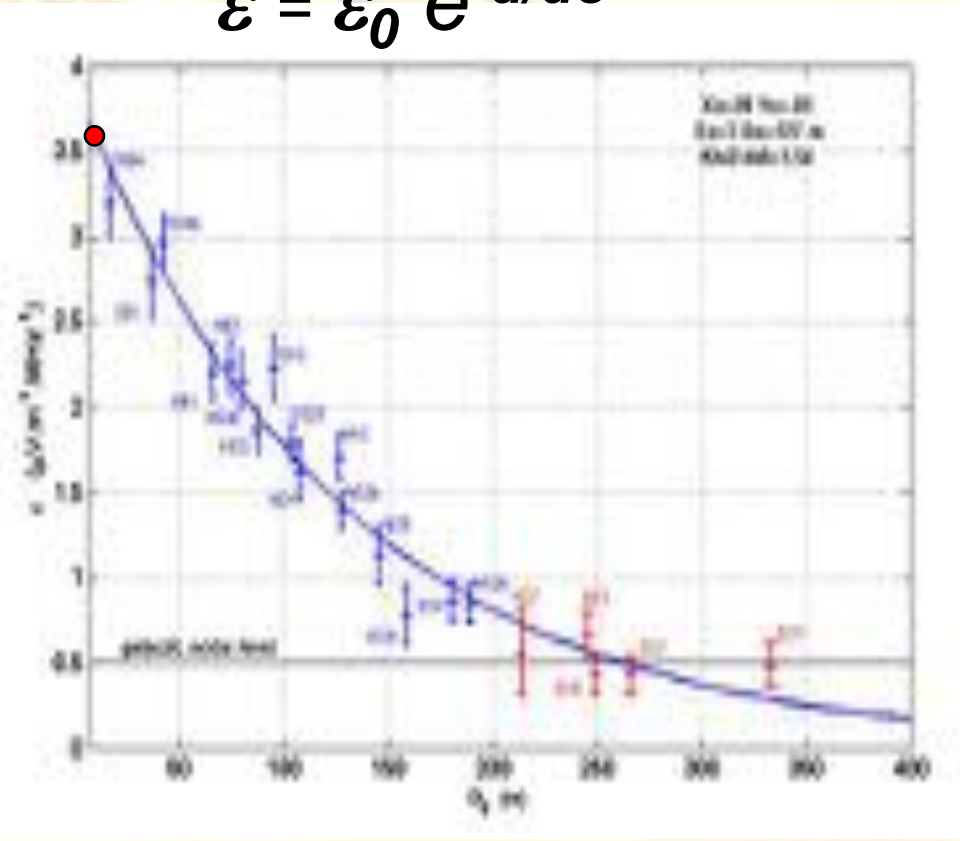
Electric Field behaviors

Ground footprint



radio Lateral Distribution Function are fitted by decreasing exponential function in the shower coordinate system

$$\varepsilon = \varepsilon_0 \, e^{-d/do}$$

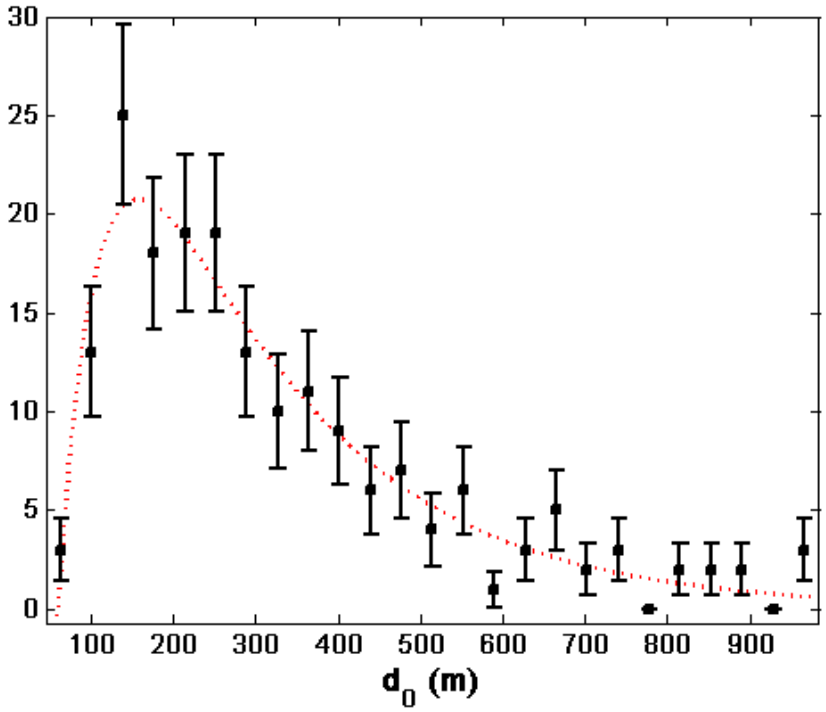


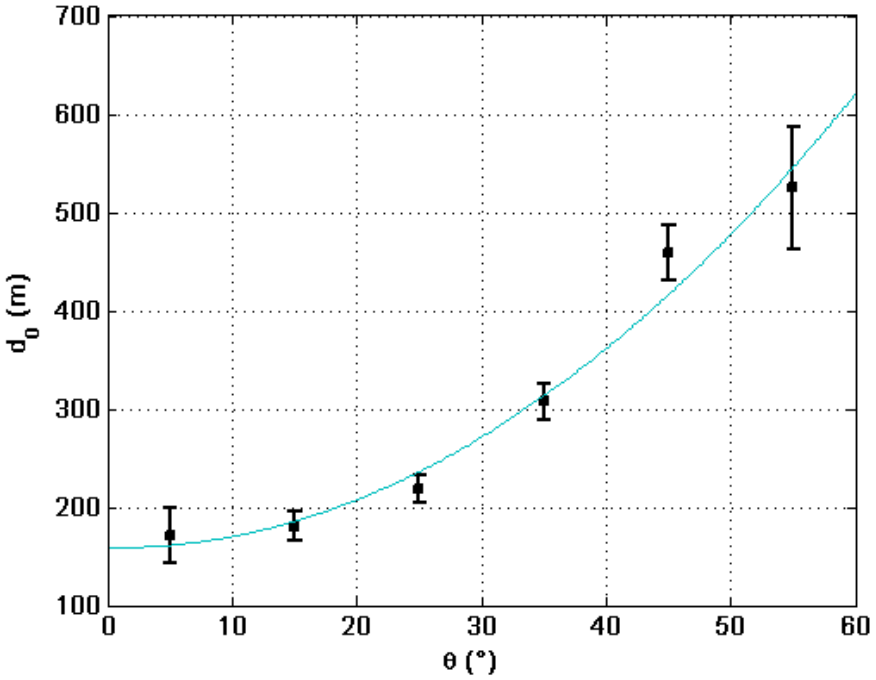
Symmetric ground patterns are observed despite the small extension of the array !

An upgraded array in both polarizations is needed : from two arms to 2D array to compare footprints with model predictions

See talks V. Marin, T Huegue

d_0 evolution





Most probable value ~ 160 m

80 % of the events with d_0 below 400 m

d_0 increases with the zenith angle

~ 500 m for θ=50°

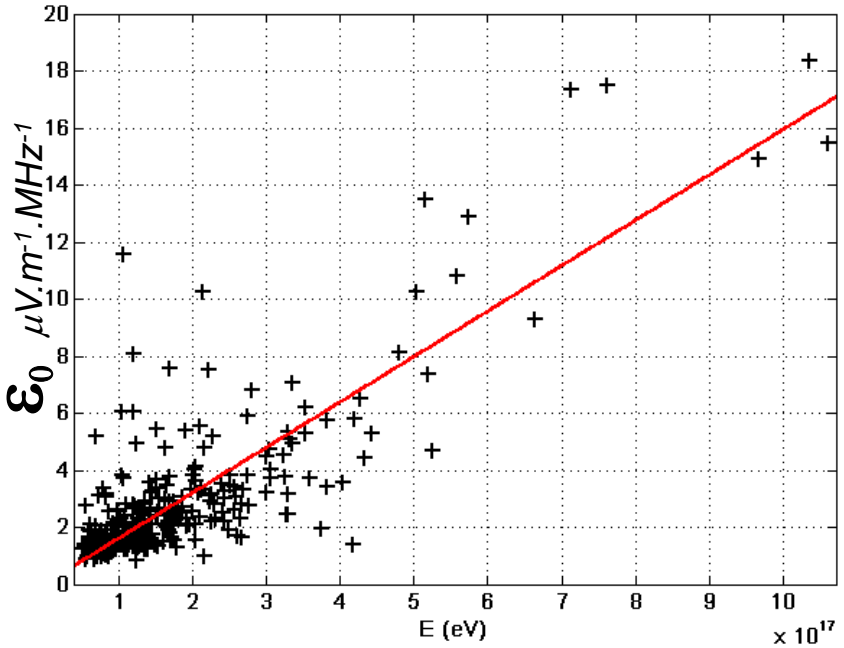
Electric field ε_0 vs Energy correlation

Event selection :

Multiplicity > 4 antennas

E > $E_{Threshold}$ = 5.10^{16} eV

$$\varepsilon_0 \propto E^{\alpha} \quad \text{with } \alpha = 1.03$$



The electric field is proportional to the primary energy.

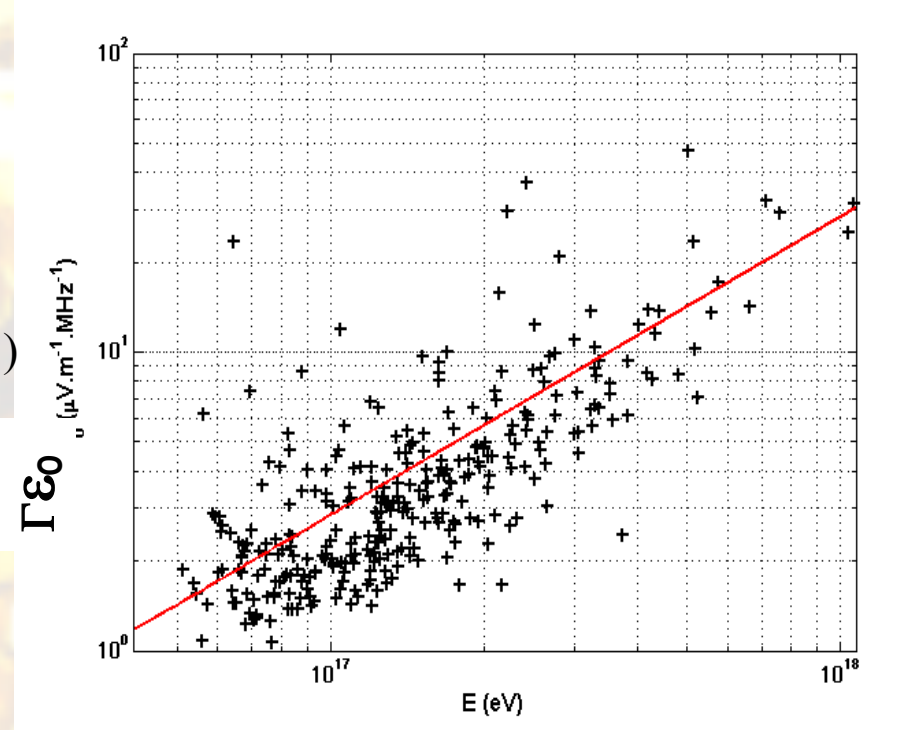
An upgraded array is needed to enrich the high energy domain : a multi-scale array

Energy calibration

Γ a correction factor to take into account the **geomagnetic effect** on the electric field.

$$\Gamma = 1/\left|v \times B\right|_{EW} = 1/(-\sin\theta.\cos\varphi.\cos\theta_B - \cos\theta\sin\theta_B)$$

Calibration **F**actor C_f



$$\Gamma\varepsilon_0 = C_f\ E\ (eV)$$

$C_f = (2.85 \pm 0.2) .10^{-17}\ \mu V.m^{-1}.MHz^{-1}.eV^{-1}$

! Nançay Magnetic field taken as unit

Conclusion

Geomagnetic effect

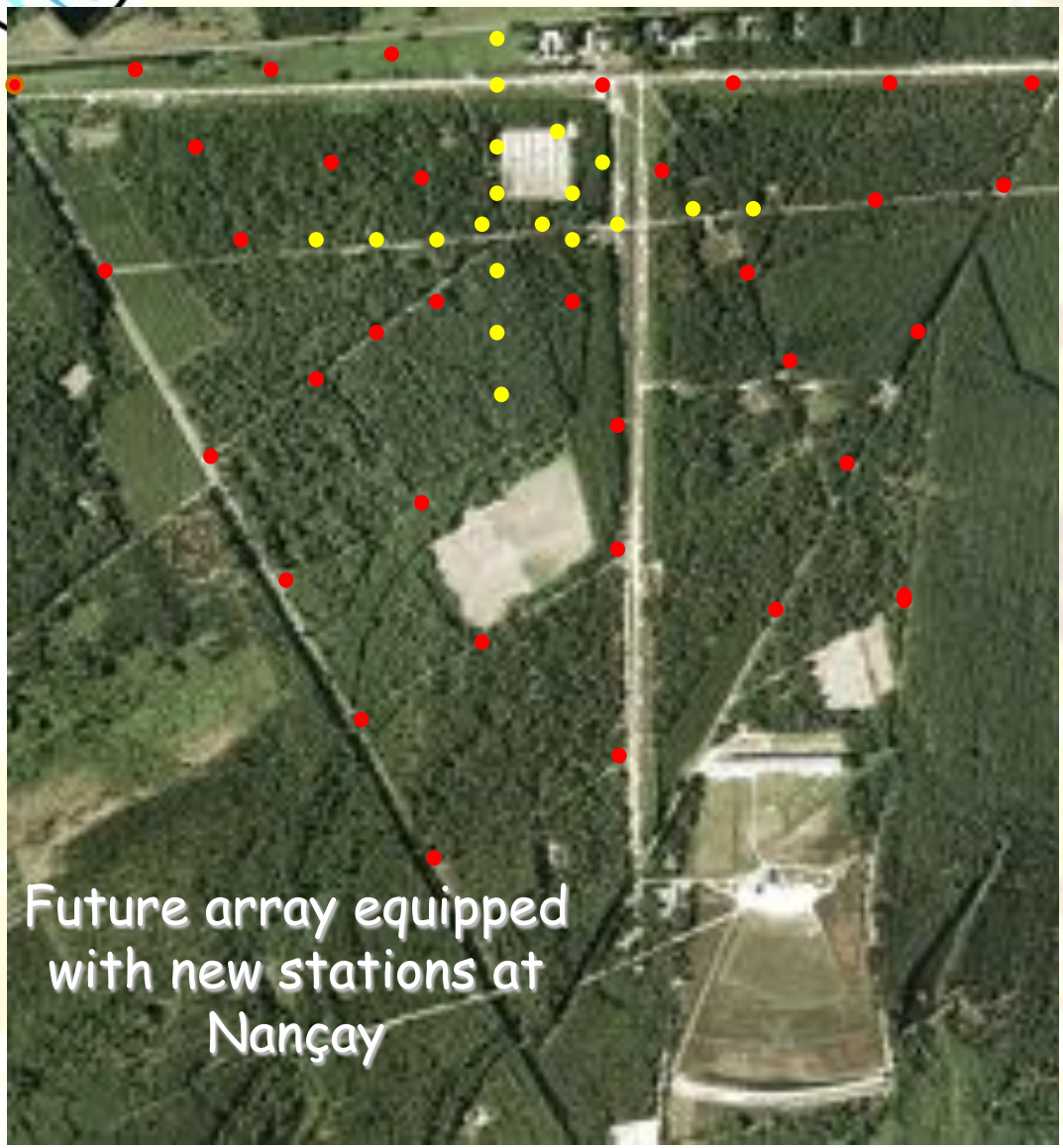
- East/West asymmetry is well interpreted with the (v x B) model
- Good agreement for North/ South polarization

Energy correlation

We observe a strong correlation between the electric field and the shower energy

The fine calibration of the energy deduce from the radio array is in progress
=> Stand alone determination of the shower energy

Perspectives



3 autonomous stations are 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). Ready in autumn
- Installation of 5 stations for tests in Argentina.

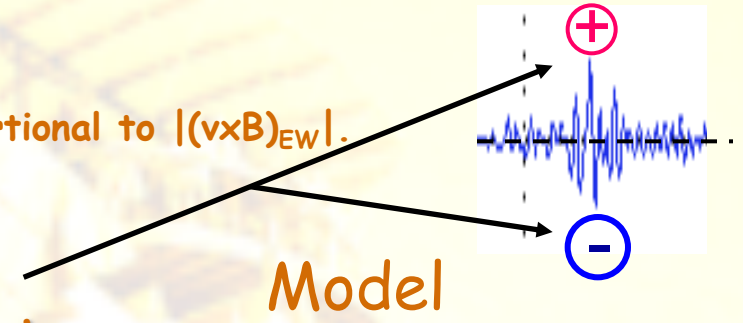
  AERA Project (AUGER)

Pulse polarity

EW polarization

C.Riviere, ICRC 2009

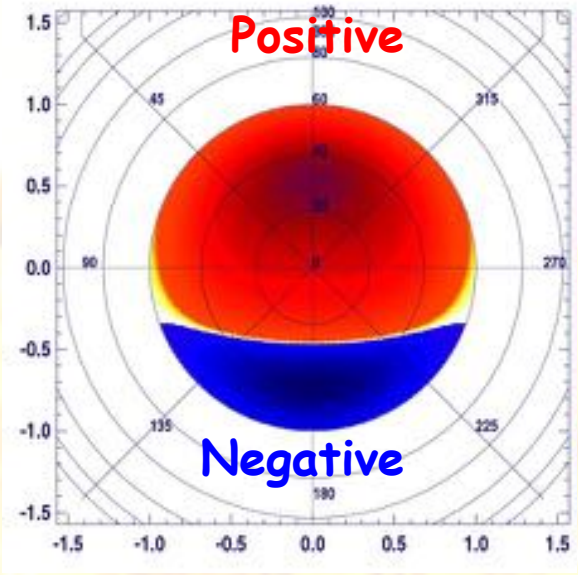
The model assumes the electric field magnitude to be proportional to $|(vxB)_{EW}|$.
Is the signal polarity given by $(vxB)_{EW}$?



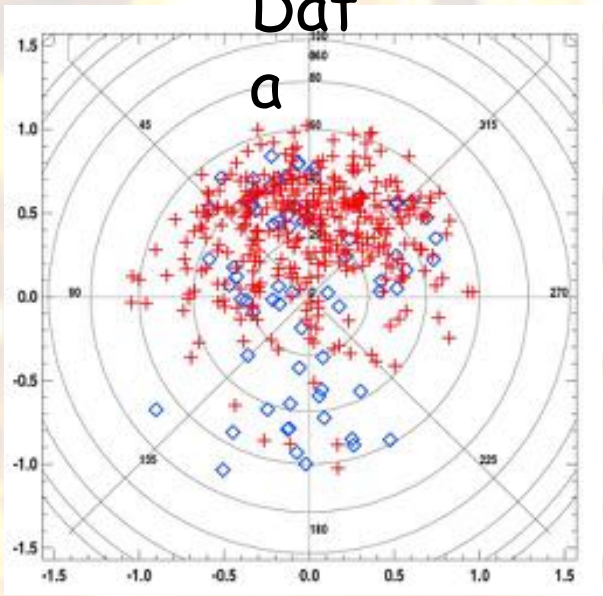
filtered dipole Signal : tags are signed

Event sign : given by the most numerous signed tags

Model



Data

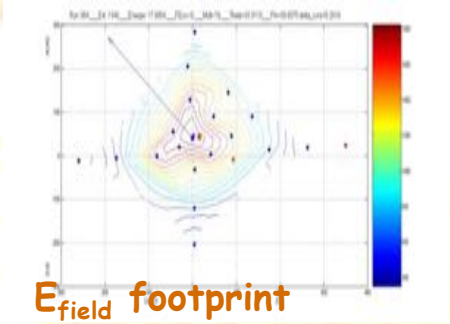


Perspectives : Physics objectives

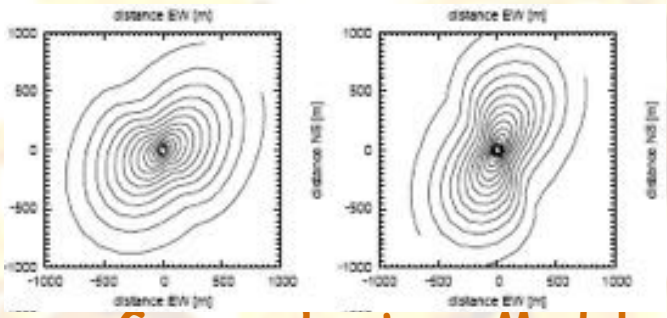
What is the geomagnetic mechanism involved in the emission process ?

- **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



E_{field} **footprint**



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 ?**

DAM result