Radio-detection of UHECR with the CODALEMA experiment

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for the CODALEMA collaboration

CODALEMA setup

Scintillator array :
13 detectors

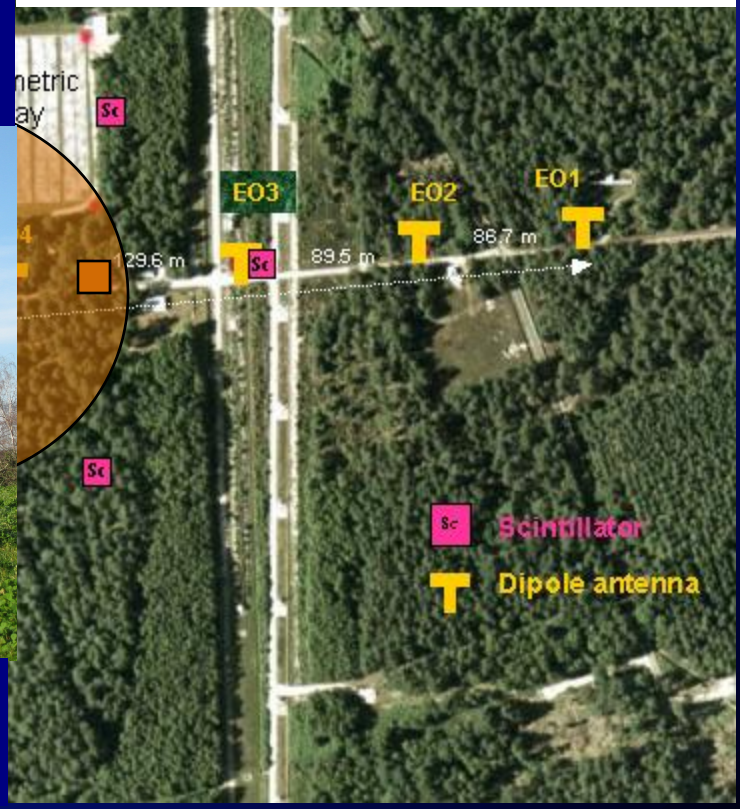
Trigger : 5 central scintillators in coincidence

Internal air showers :
Energy with 30 % of uncertainty

Antenna :
Short Active Dipole

Antenna array :
14 detectors
Cross shape
612 m x 473 m

East West polarisation of the Electric field



Transients in coincidence

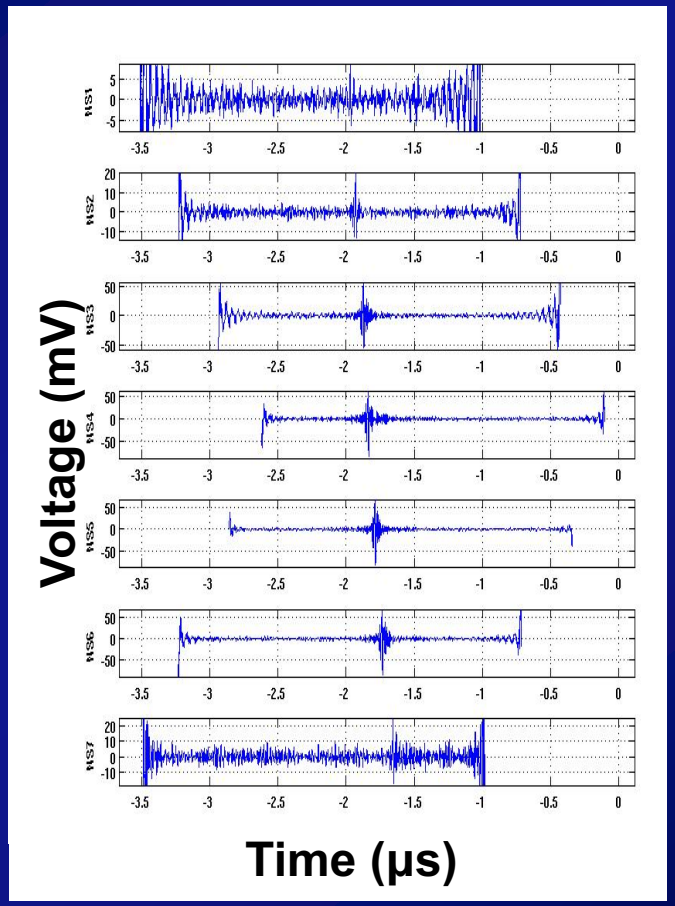
Waveform recorded as a function of time

- Δf=500MHz
- f_e=1GHz
- 12 bits ADC
- T_{obs}=2.5µs

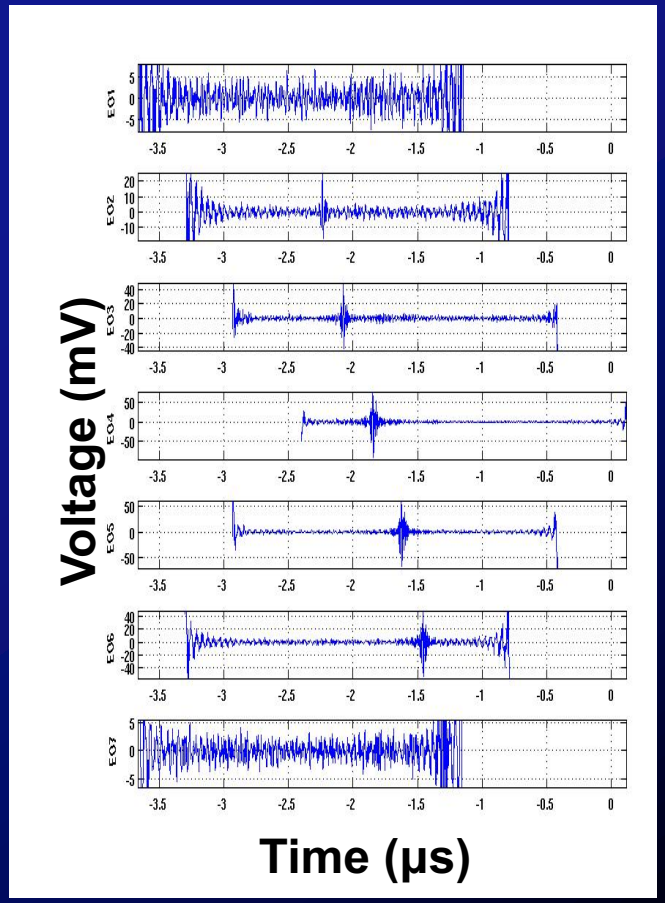
Offline processing

- Numerical filter 24-82MHz
- Transient detection

North-south axis



East West axis



Radio-detected EAS

To validate a candidate :

Time difference

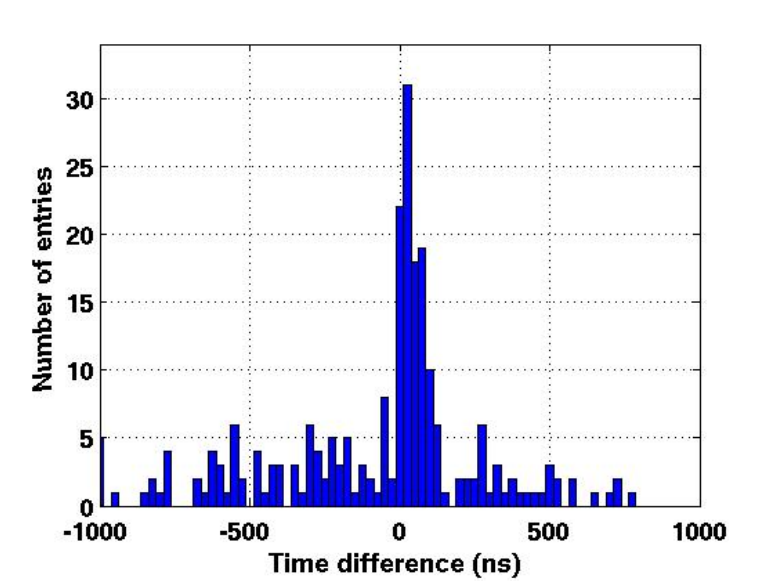
Between wave and particle

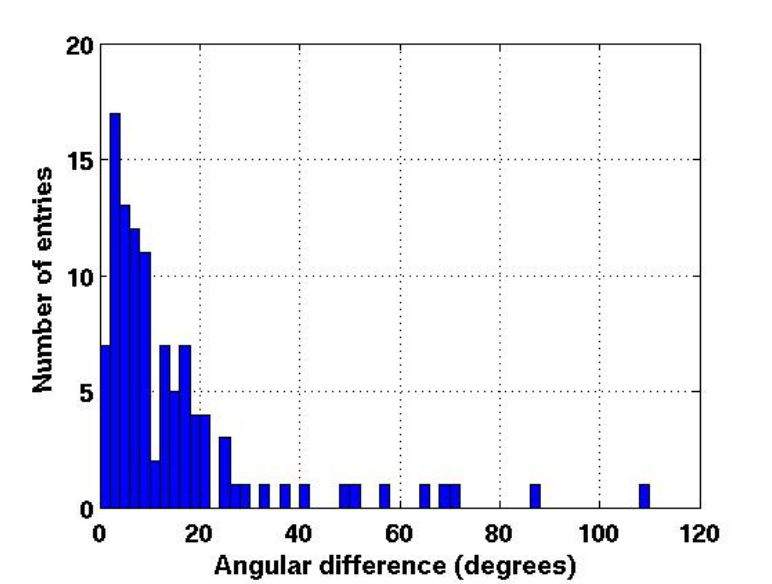
$\Delta t < 200$ ns

Angular difference

Both reconstructed independently !

$\Delta < 20°$





EAS radio-detected

Some numbers

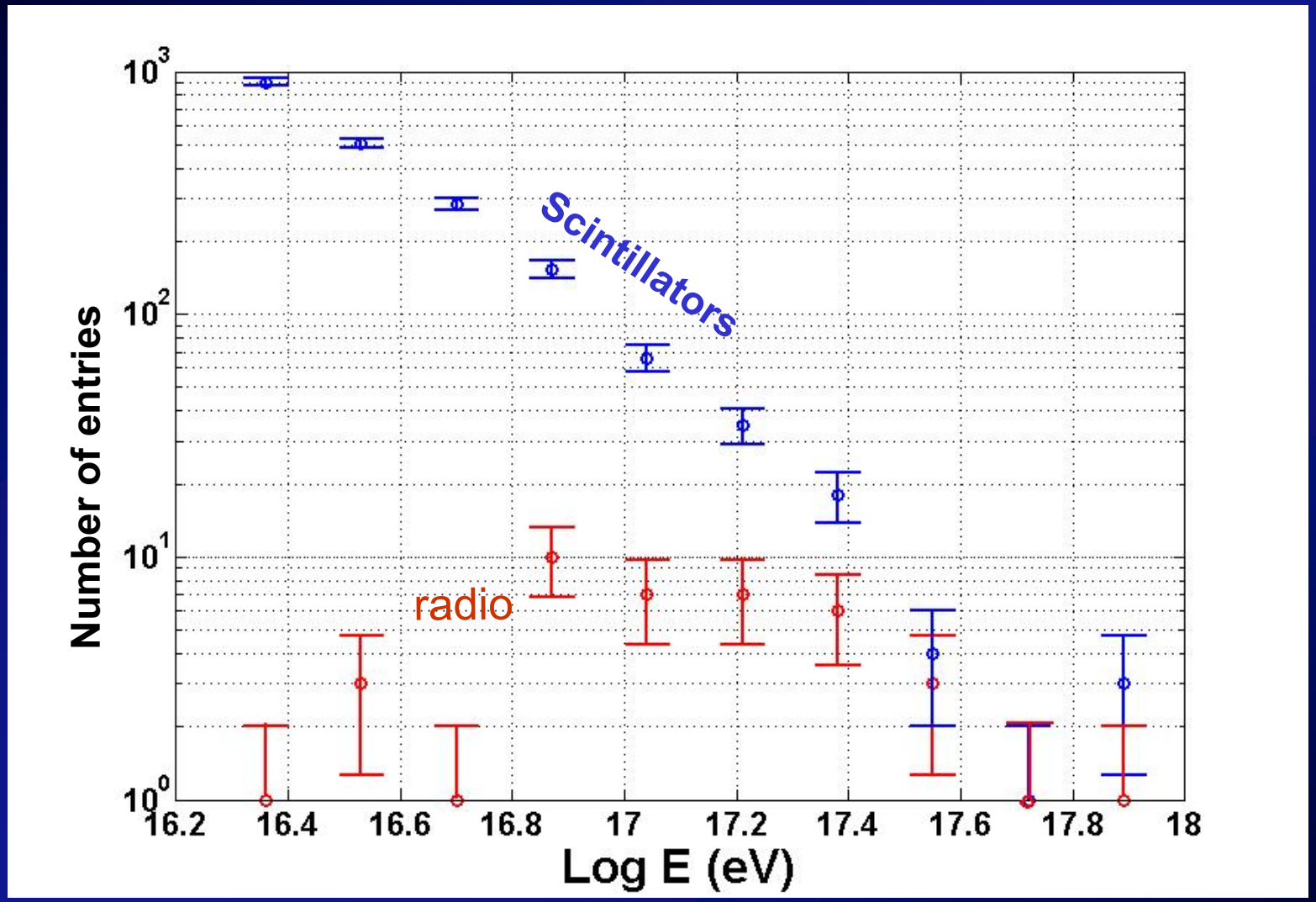
New setup under operation since December 2006

- **170 effective days of data taking**
- **613 transient radio waveforms reconstructed**
- **141 EAS radio-detected**

0.8 events / day

- **43 Internal shower (energy known)**

Energy distribution



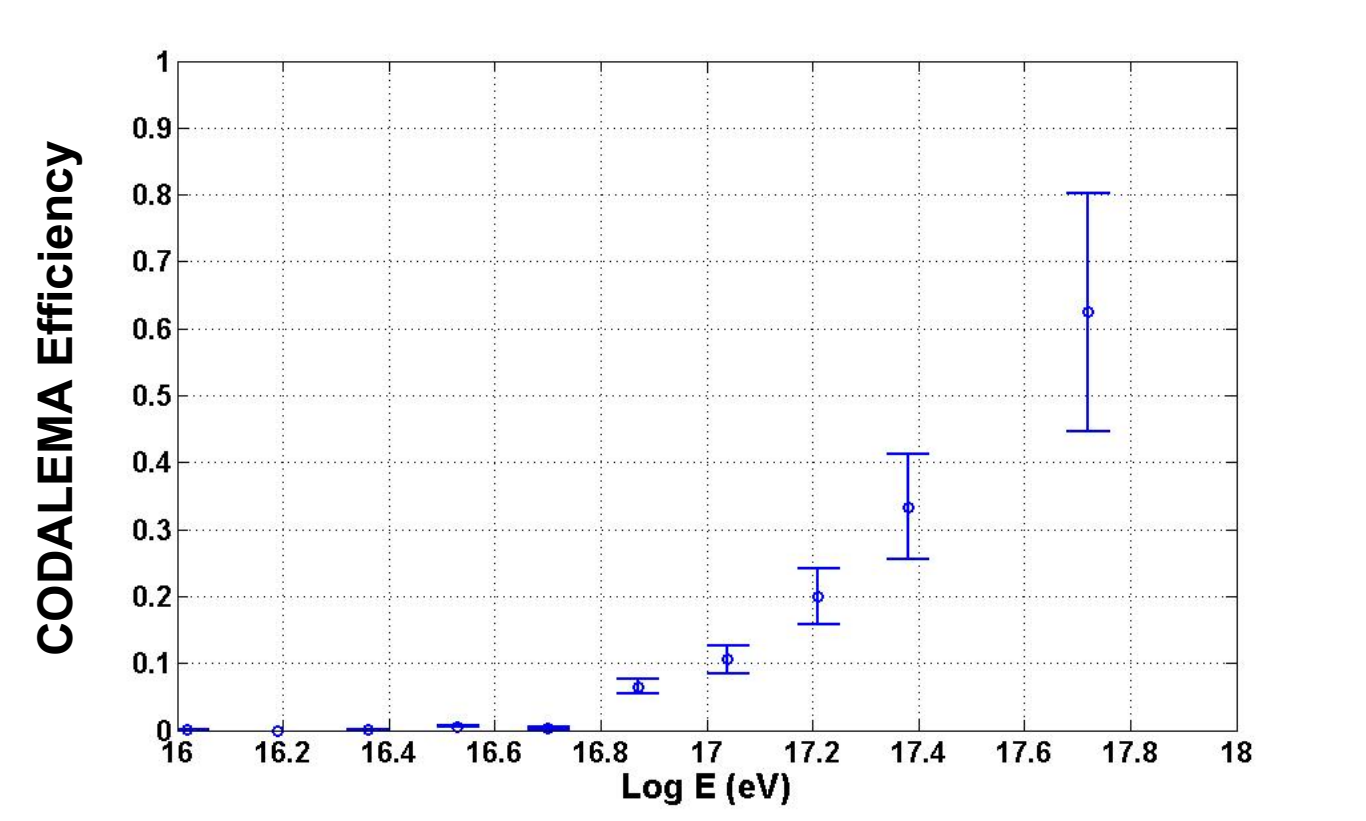
Histogram not corrected for the acceptance

Radio-detection efficiency

As a function of energy

Significant threshold :

$E > 5.10^{16}$ eV



Only East-West polarisation of the electric field

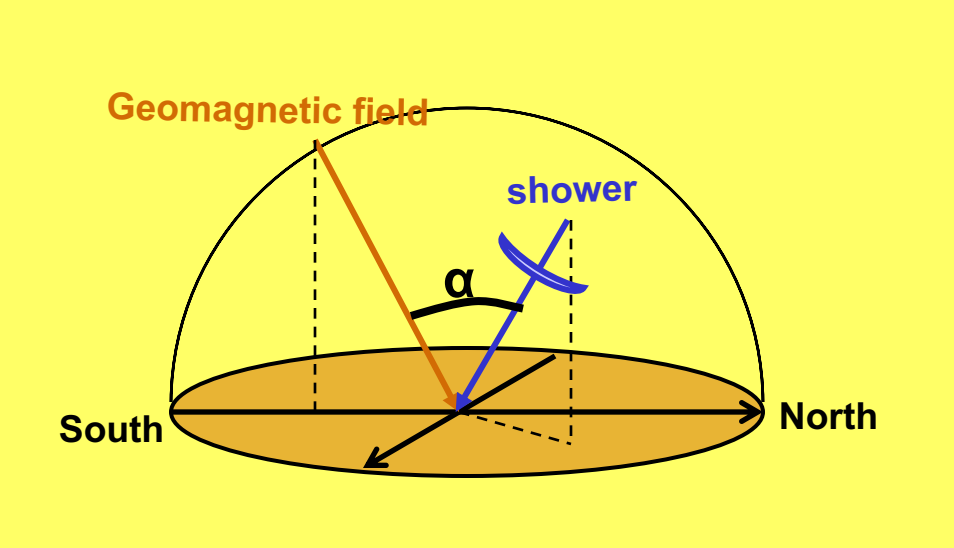
Search for geomagnetic effect

Allan *et al.* Nature 227, 1970

$$\varepsilon_\nu = 25.[\frac{E_P}{10^{17}}].sin\alpha.cos\theta.exp(\frac{-b}{b_0(\nu,\theta)})\,\mu V/m/MHz$$

Lorentz Force :

F = q . V ^ B



α : angle between Geomagnetic field and cosmic ray arrival direction

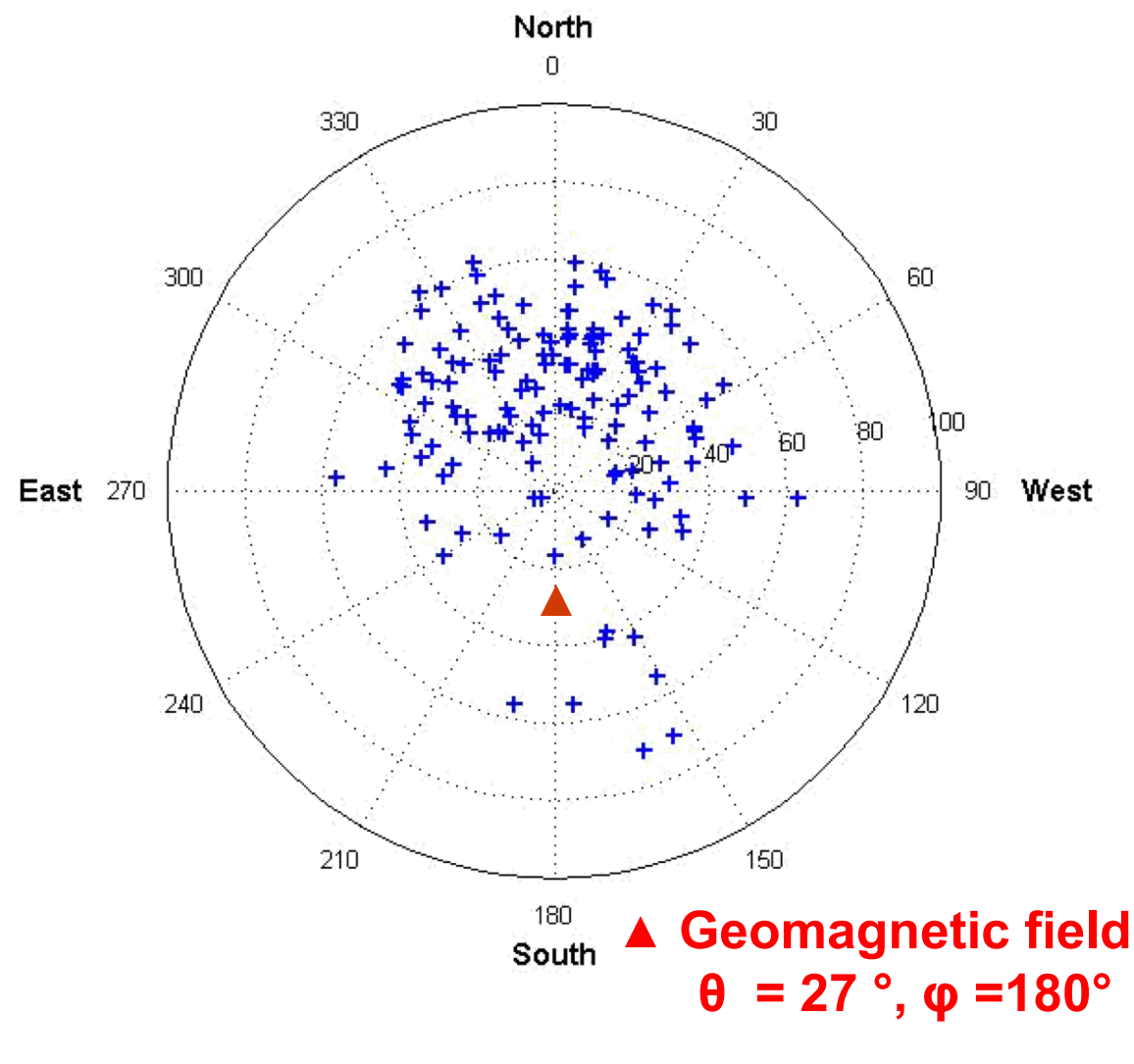
Effect on arrival direction

For unknown energy

Arrival direction of radio-detected showers

Explicit deficit in the South direction

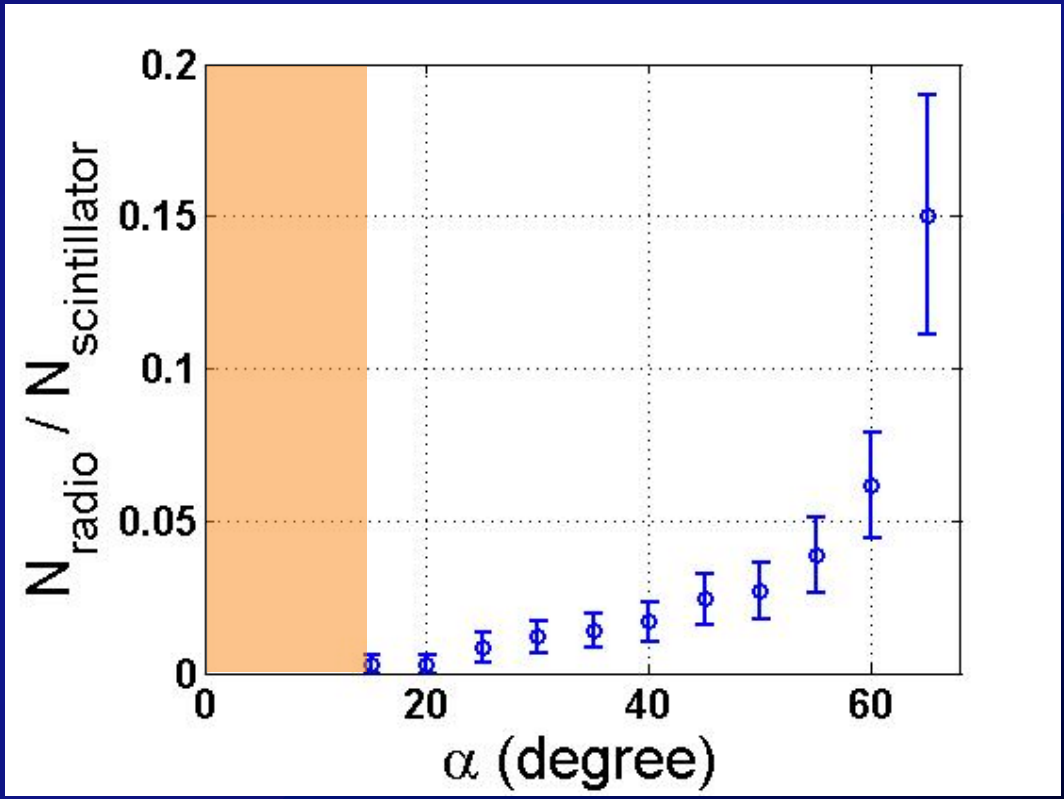
Few events near geomagnetic field vector



Effect on radio efficiency

Ratio radio-particles as a function of α

For unknown energy



Rising function of α

No event for α below 15°

Qualitatively compatible with Allan

Effect with the energy

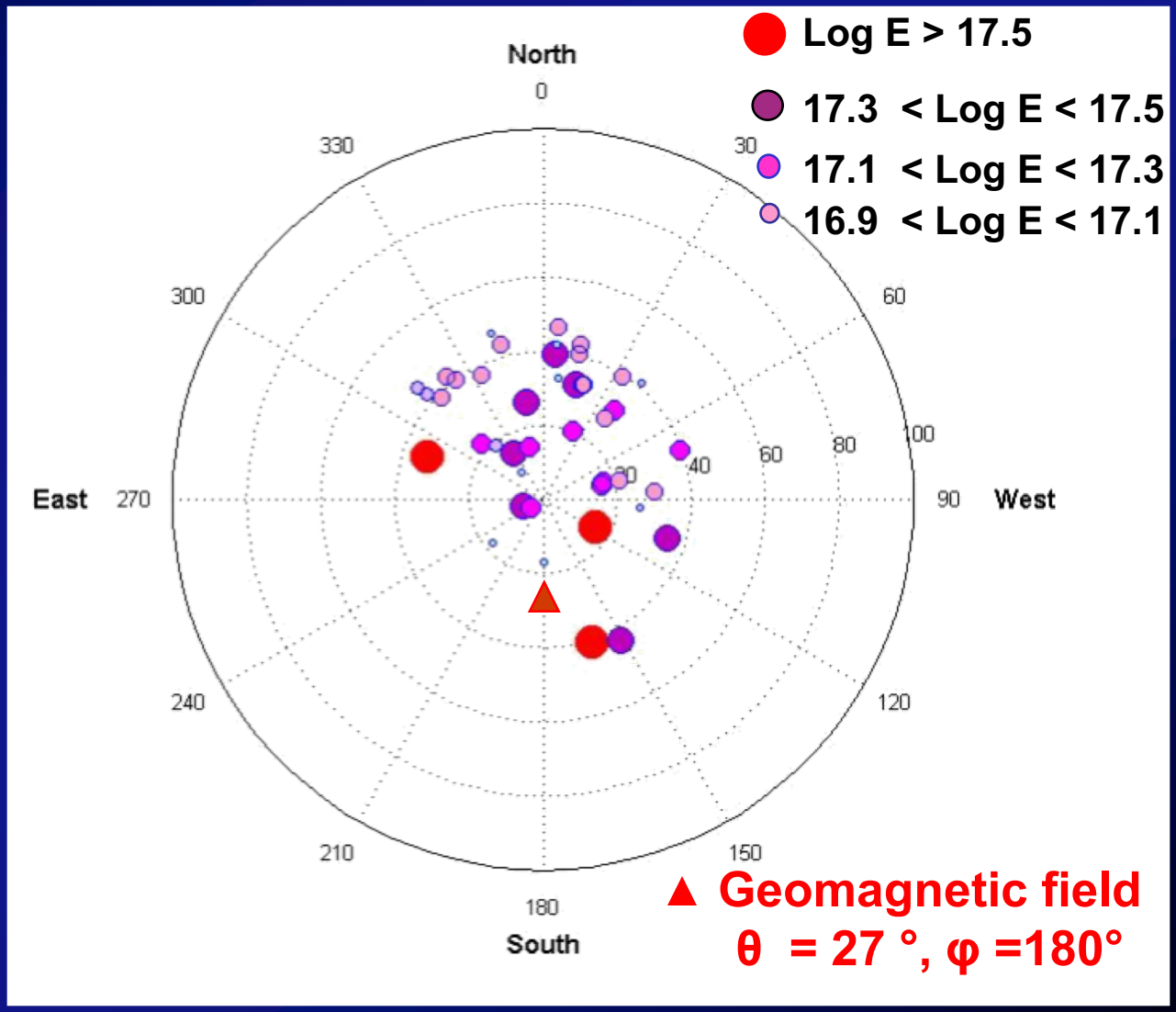
Energy known

for « internal showers »

(CIC method, precision 30 %)

43 internal showers

showers from south were <u>more energetic</u>

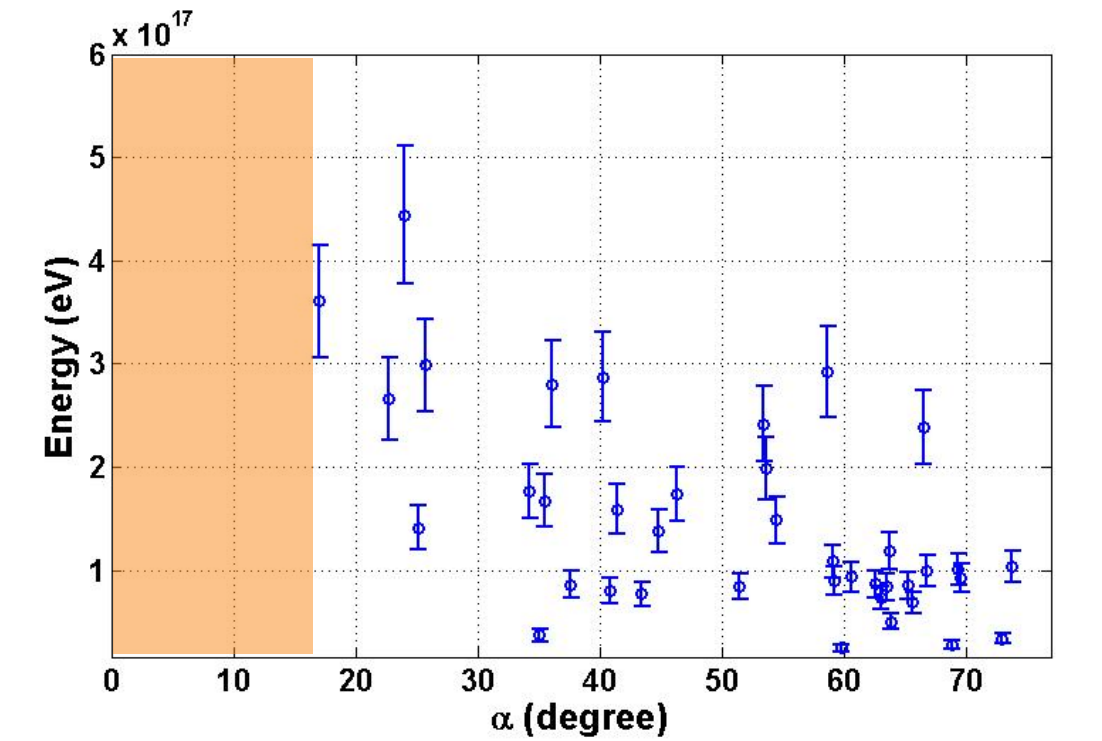


Effect with the energy

Energy as a function of α

Deficit of low energy event for small α

Low counting rate for small α



Evidence for a geomagnetic effect in the radio emission process

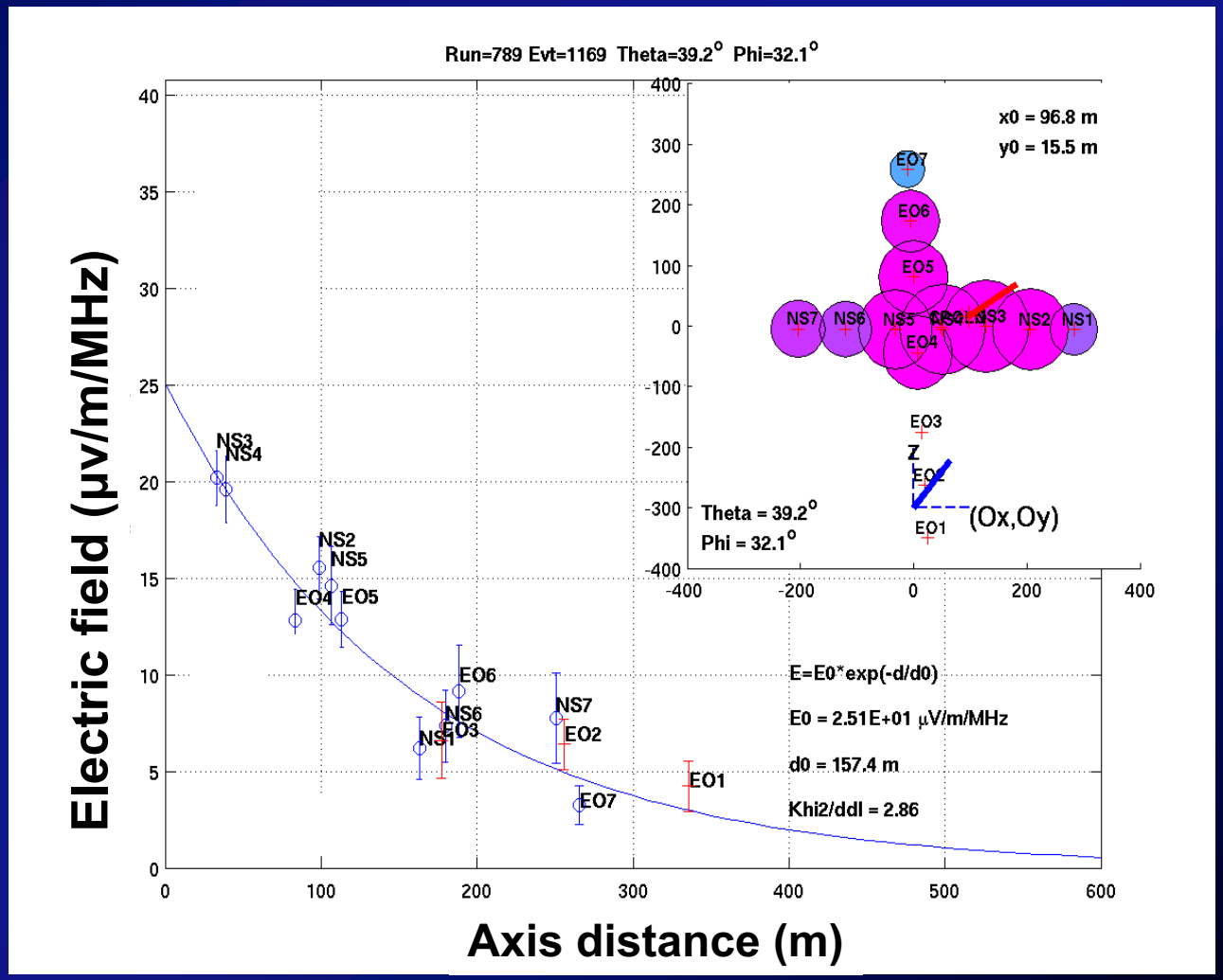
Electric field topology

Exponential dependence

$$\varepsilon = \varepsilon_o \exp(-d/d_o)$$

$$E = 2x10^{17}\ eV$$

$$\varepsilon_o = 25\ \mu V/m/MHz$$



Electric field topology

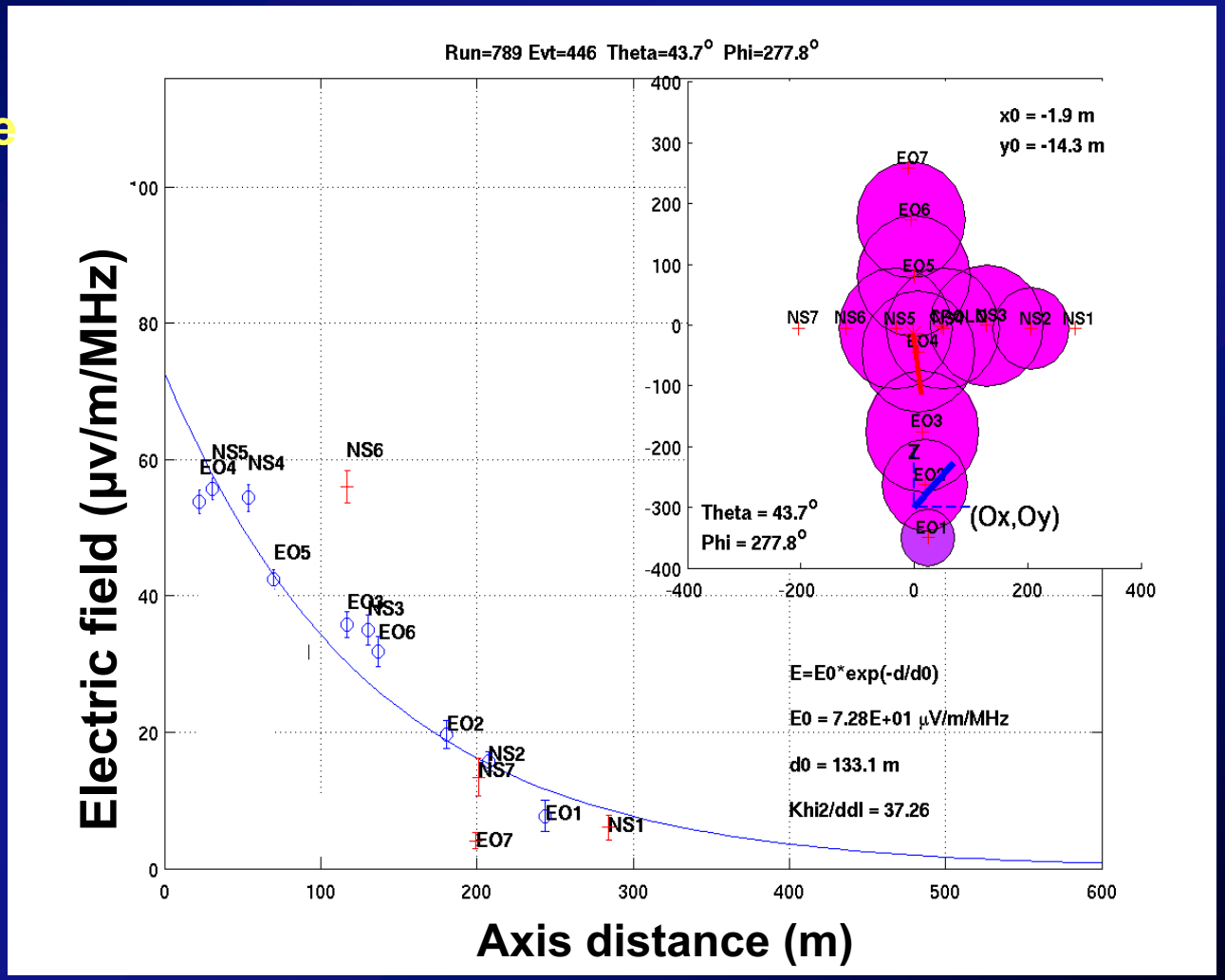
Exponential dependence

$$\varepsilon = \varepsilon_o \exp(-d/d_o)$$

$E = 8x10^{17}$ eV

ε_o = 73 µV/m/MHz

More statistic needed to correlate ε_o and Energy



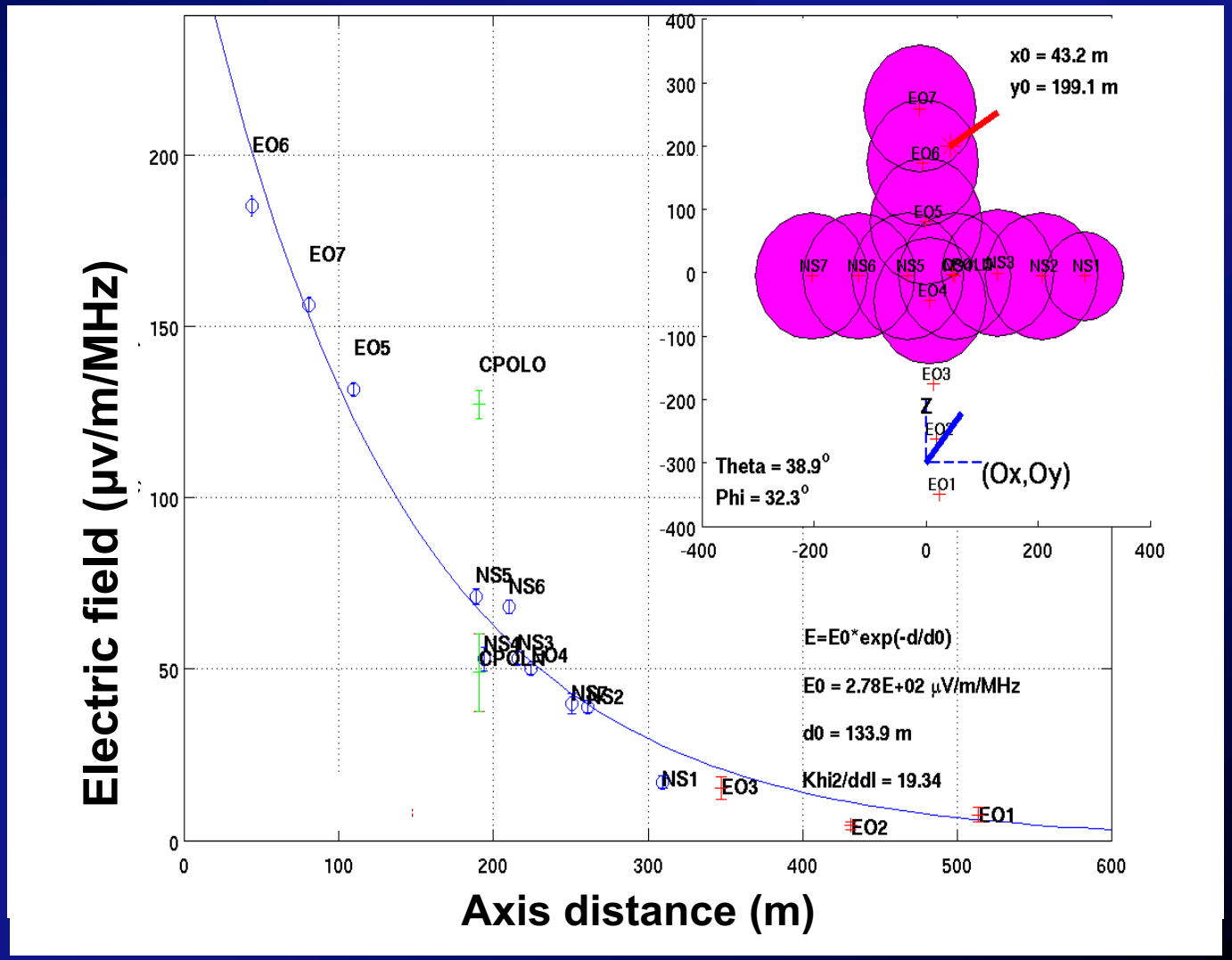
Electric field topology

"Giant event"
($E > 10^{18}$ eV)

ε_o = 278 µV/m/MHz

HUGE electric field !

Unfortunately not internal



Conclusion

CODALEMA radio detection efficiency increases with energy

Evidence for a Geomagnetic effect

radio-detection deficit close to the Geomagnetic field direction

- effect on the radio-detection efficiency around 10^{17}eV
- constraint on the emission process

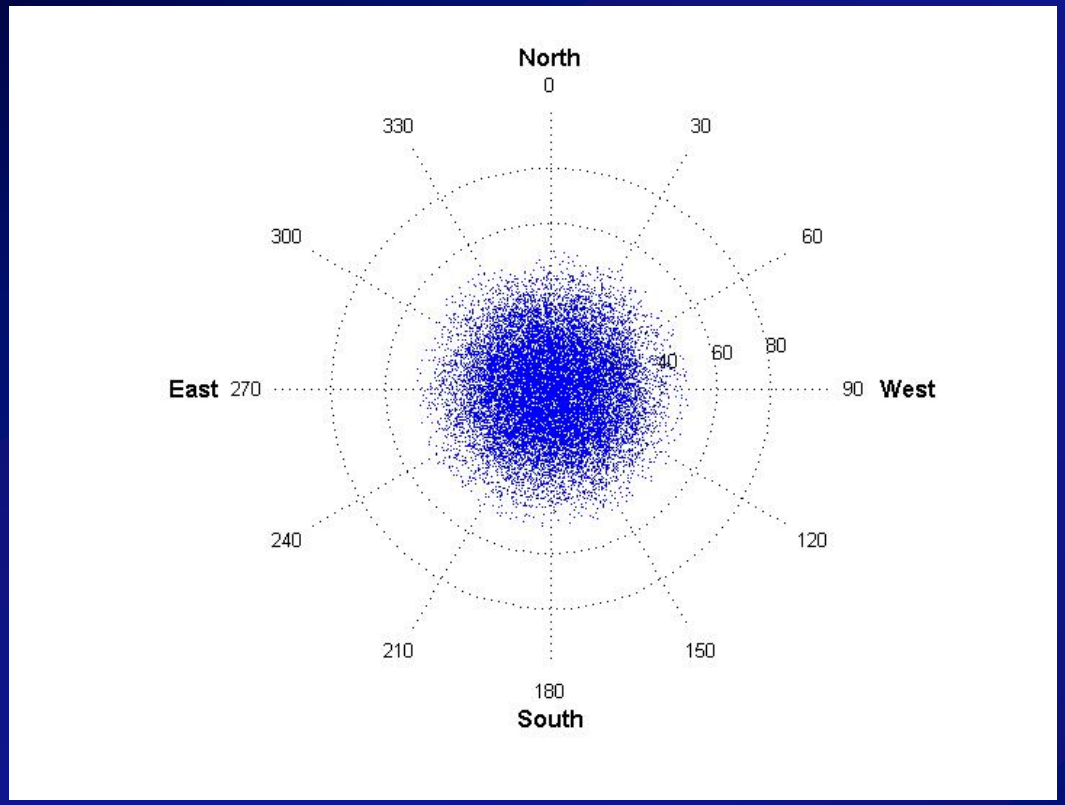
Detection of all polarization → On going effort

At the present time, we do not see clear correlation between the cosmic ray Energy and the measured electric field

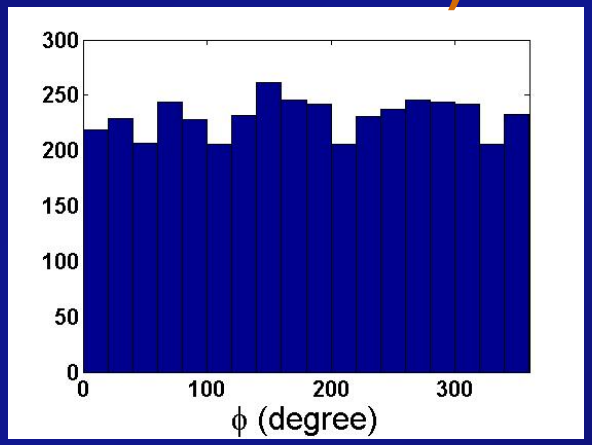
- Larger autonomous antennas array (in 2008 @ Nançay)

Scintillator distributions (internal showers)

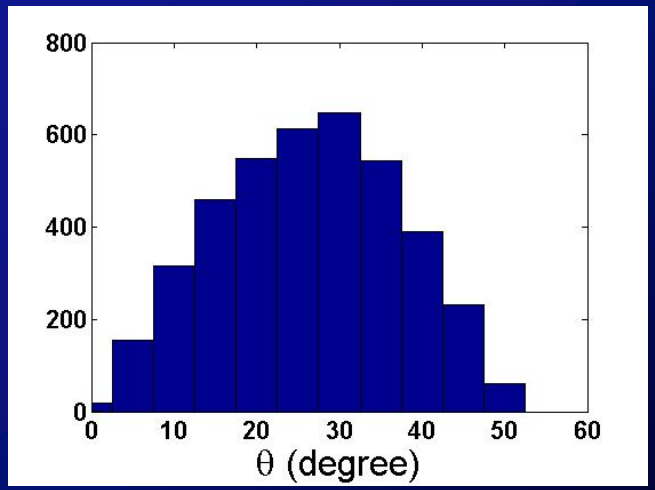
Shower arrival directions calculated with the **scintillator data**



Energy threshold for scintillator array ~ **10^{15} eV**



Azimutal distribution



Zenithal distribution
Limited at $\theta < 50°$