# Radio detection of extensive air showers

# The CODALEMA project

**COsmic ray Detection Array with Logarithmic ElectroMagnetic Antennas**

**The CODALEMA collaboration: 3 french institutes – 8 laboratories**

**SUBATECH Nantes (IN2P3, 2002)**

**Obs. de Paris-Meudon-Nançay (INSU, 2002)**

**LAL Orsay (IN2P3, 2004) - ESEO Angers (2004)**

**LPSC Grenoble (IN2P3, 2005)**

**LAOB Besançon (INSU, 2006) - LPCE Orléans (INSU, 2006)**

**+ support of the Lab. of Auger-France for the tests @ Auger-South**

**Objectives and perspectives:**

- **Cosmic Ray Physics @ E > $10^{16}$ eV**
- **Neutrino or Gamma showers**
- **Solar bursts, giant pulsar pulses, atmospheric effects**

**Phase 1 (2002-05):** Enlightenment of the method

**Phase 2: (2006-08):** Energy calibration from $10^{16}$ to $10^{18}$ eV

**NEXT PHASE (2009…):** Setting on a giant detector

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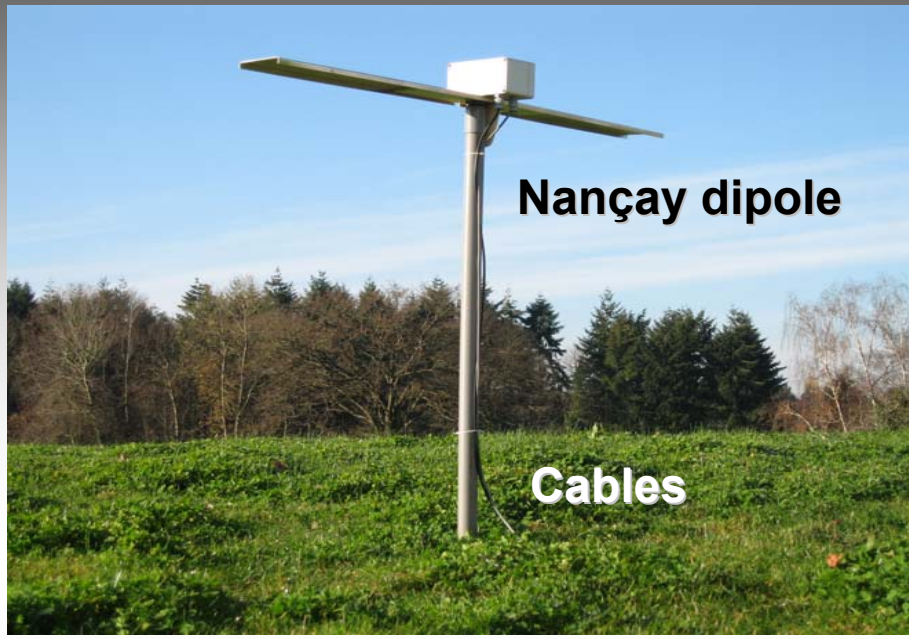
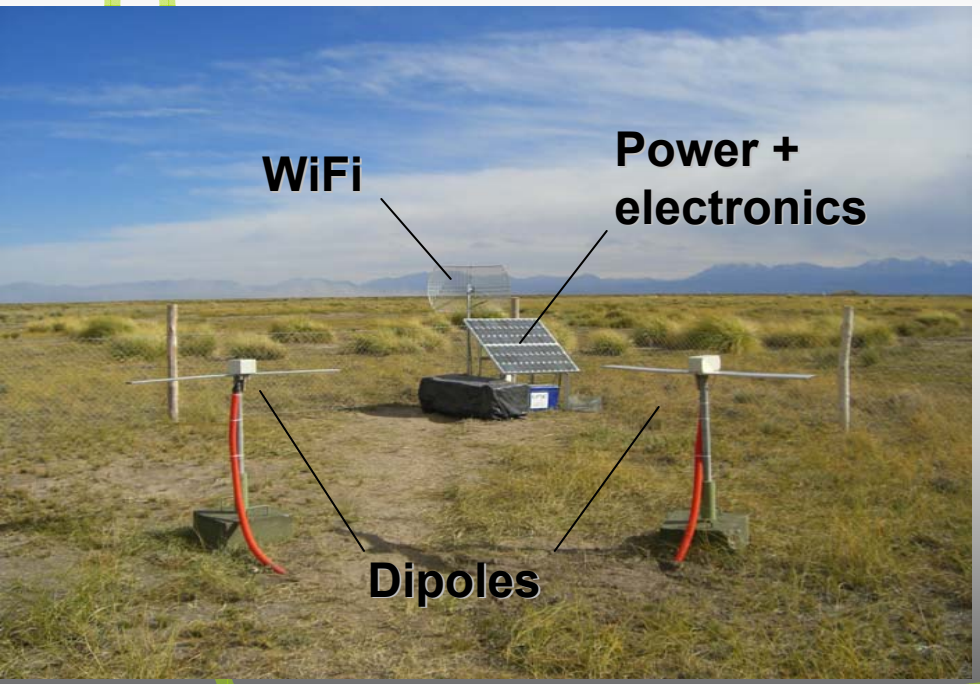
# A multi-site experiment

**Nançay @ $10^{16}$ - some $10^{17}$ eV**

16 dipoles

+ 13 particle detectors




**Auger @ $10^{17}$ - some $10^{18}$ eV**

3 autonomous stations in phase 1

+ coincidences with SD

**But also:**

- ARAGAT (Armenia) in 2007
- YangBaJing (Tibet) in 2008??

# Nançay (2006-2008)

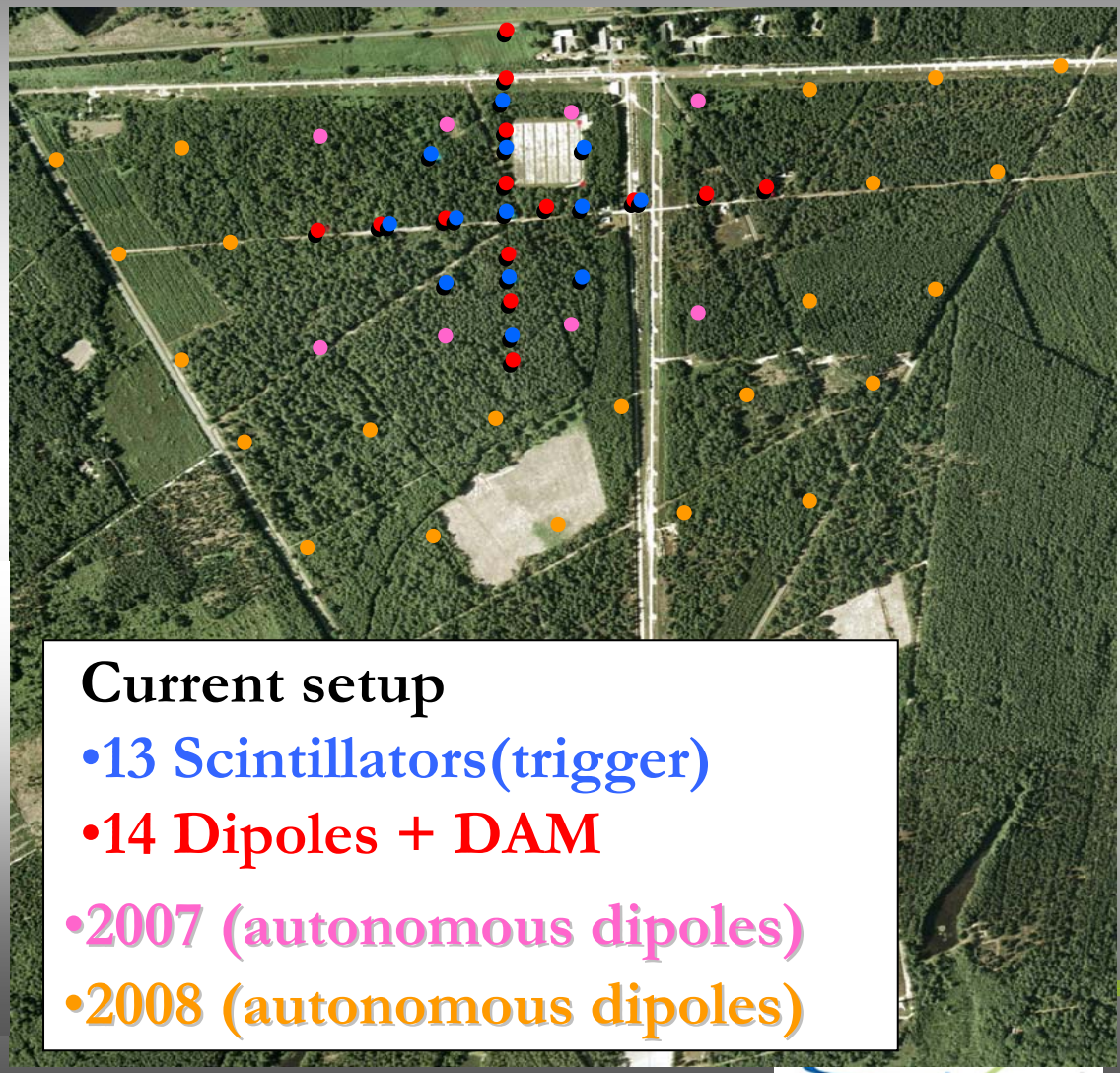
**Status: data taking for energy calibration**

## At end of the ANR (2008)

**Setup of a 1 km² engineering array for a future giant radio-detector**

## Autonomous dipoles:

- Trigger
- Data taking (ADC MATACQ 12 bits, Full Bandwidth 0-250 MHz)
- Time tagging
- Data transmission
- Power supply





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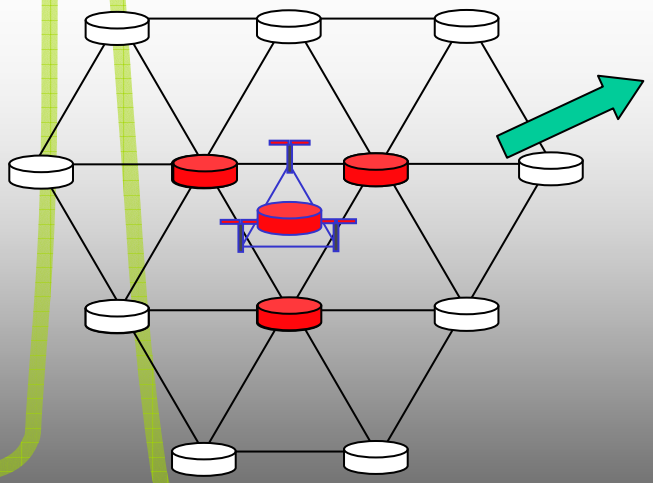
# Auger (~ 2007)

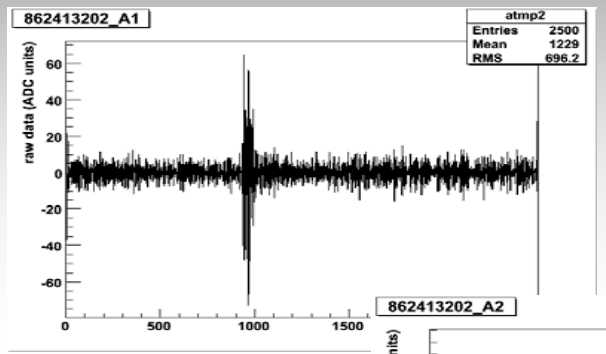
## Radiodetection tests @ > $10^{18}$ eV in coincidence with Auger

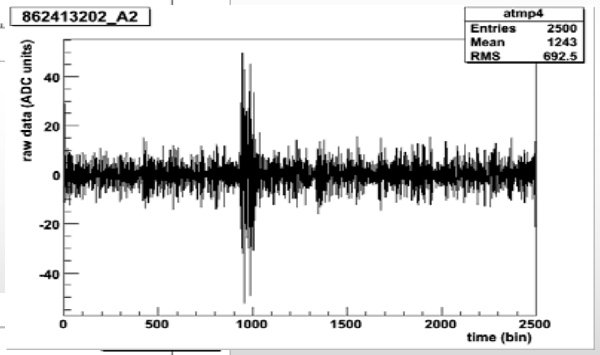
- 3 autonomous, self-triggered broad band dipoles
- Off-line coincidences with SD
- Electric field extension
- Energy calibration @$10^{18}$ eV

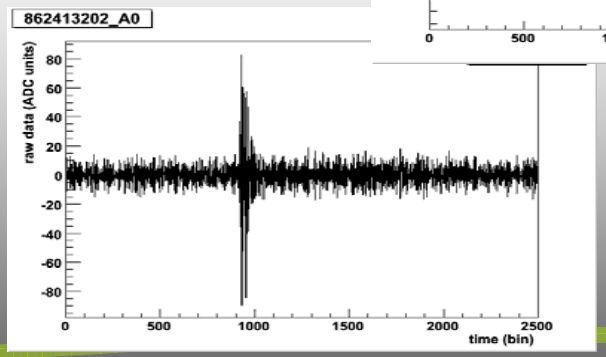
## In Acquisition since Nov. 2006



CLF @ 900 m

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# Theory: current

- **Microscopic geosynchrotron:**
  Tim Huege, Karlsruhe

- **Monte-Carlo:**
  CORSIKA, AIRES models (LAL, LPSC)

- **Macroscopic description (calorimetry) :**
  with simple laws ⇒ semi-analytical models ?
  (SUBATECH, Obs. de Paris, O. Scholten (KVI))

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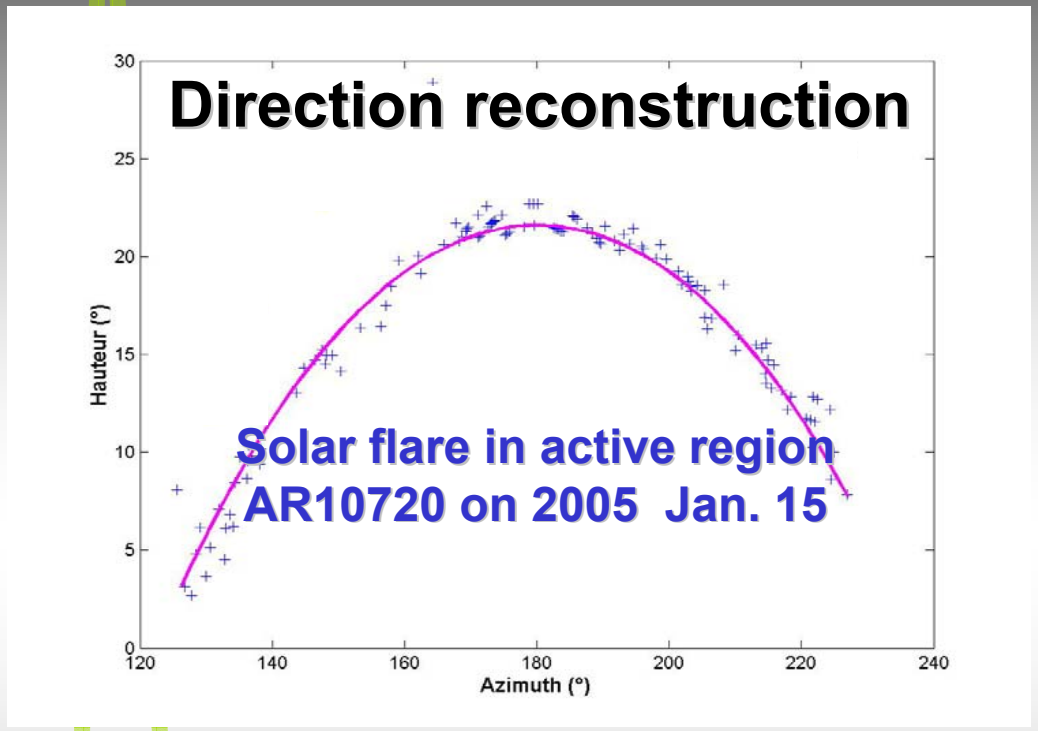
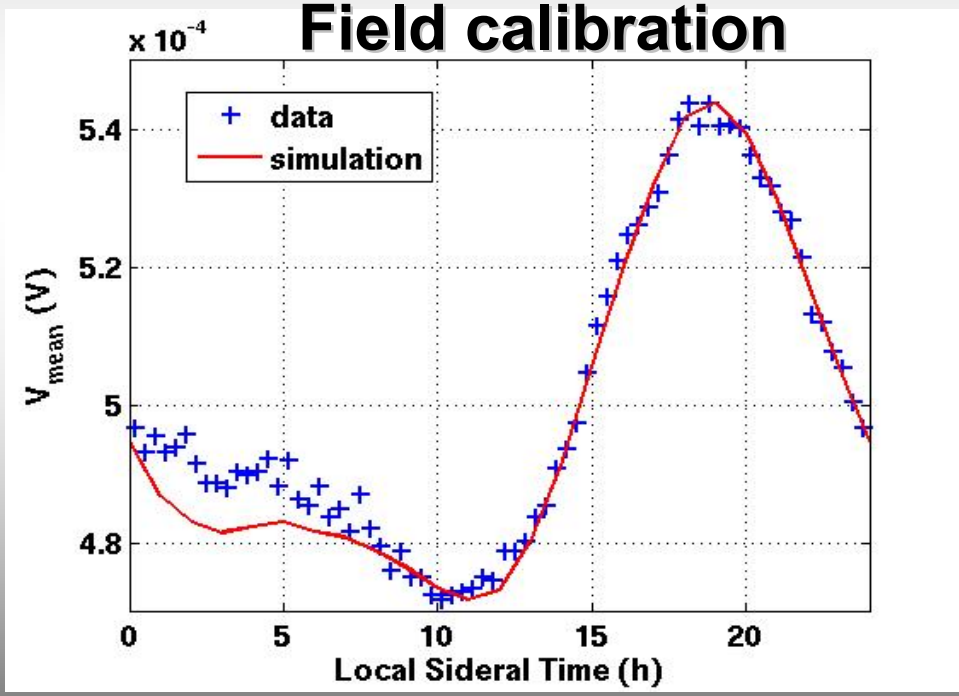
# Radiodetection performances




**Angular Resolution**

$\sigma = 0.74$ °




**With Galactic background radio signal**

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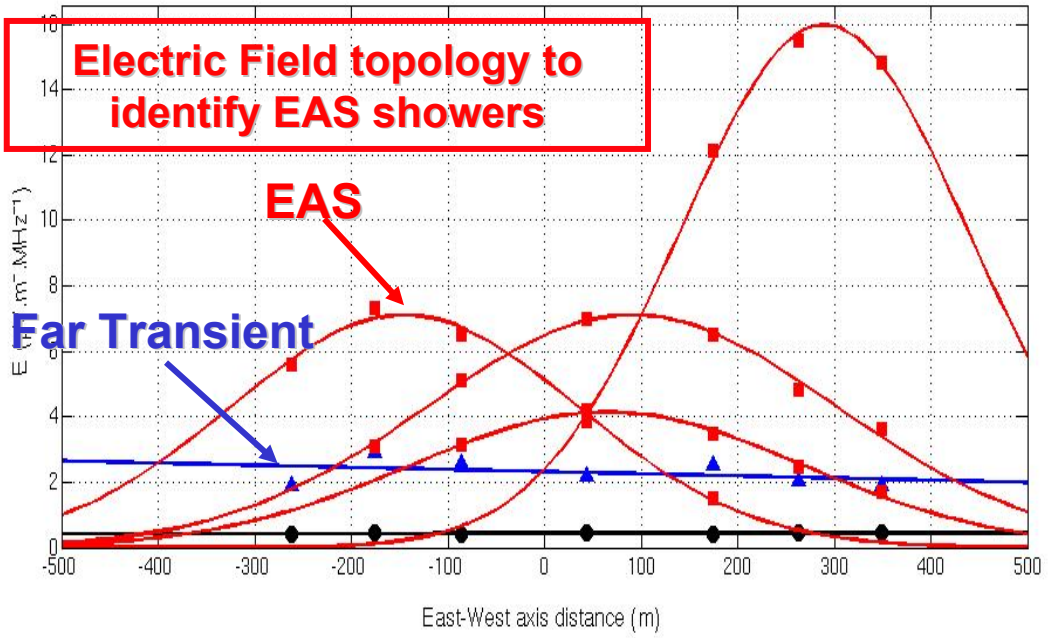
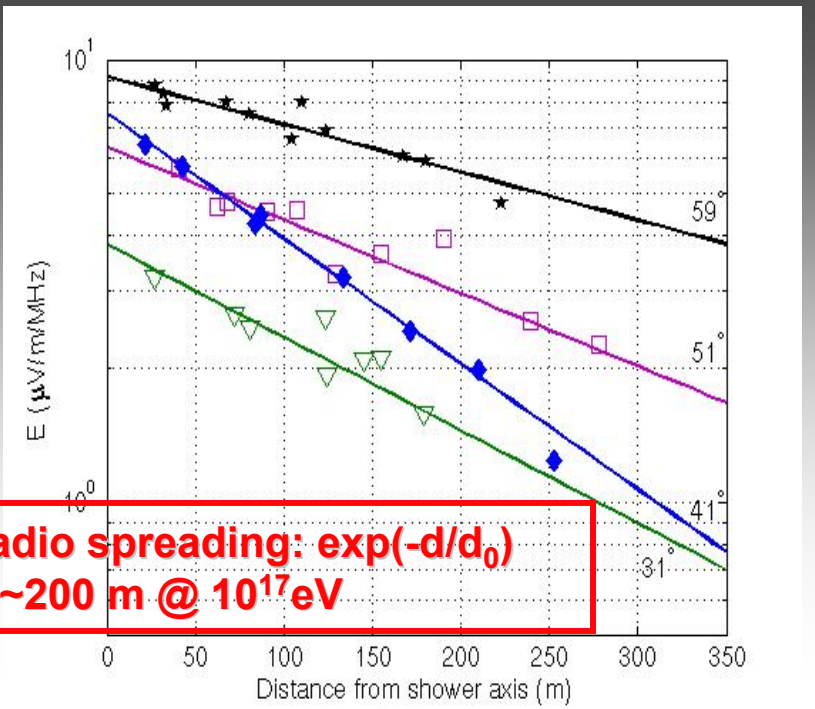
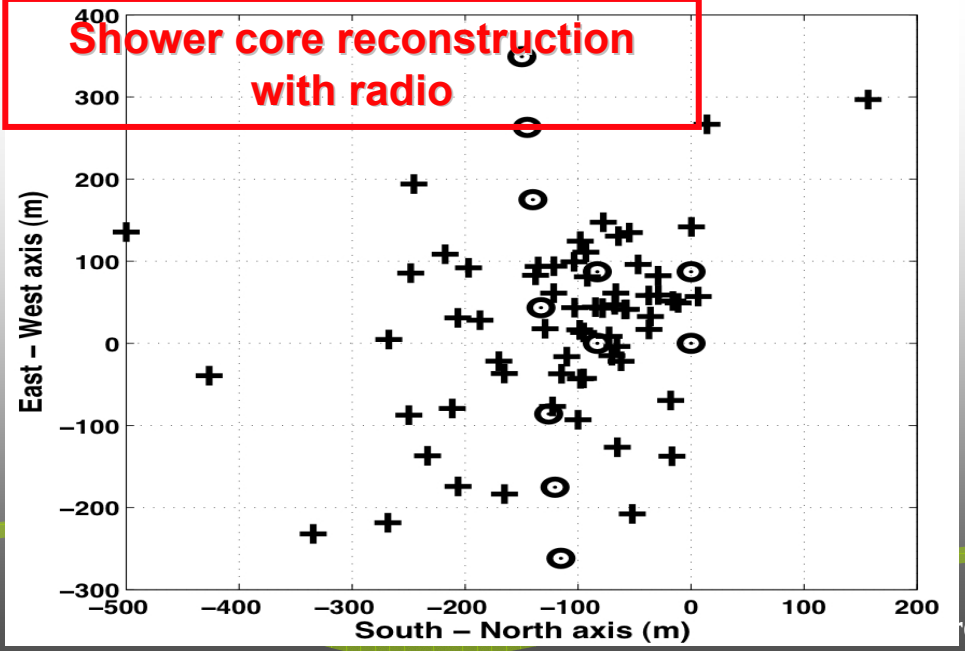
## Electric Field topology to identify EAS showers



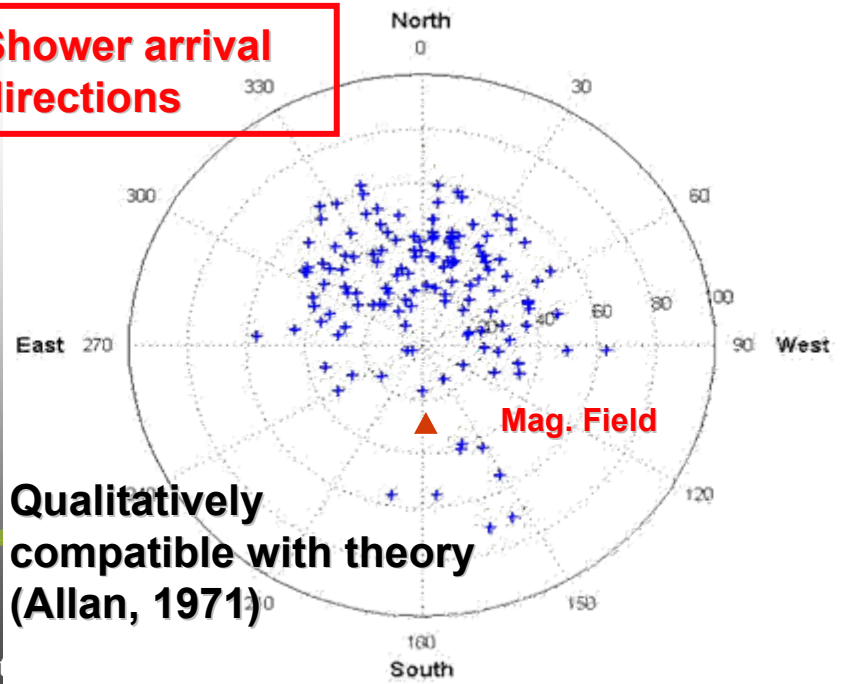




**Radio spreading: $\exp(-d/d_0)$**
**$d_0$~200 m @ $10^{17}$eV**

## Shower core reconstruction with radio

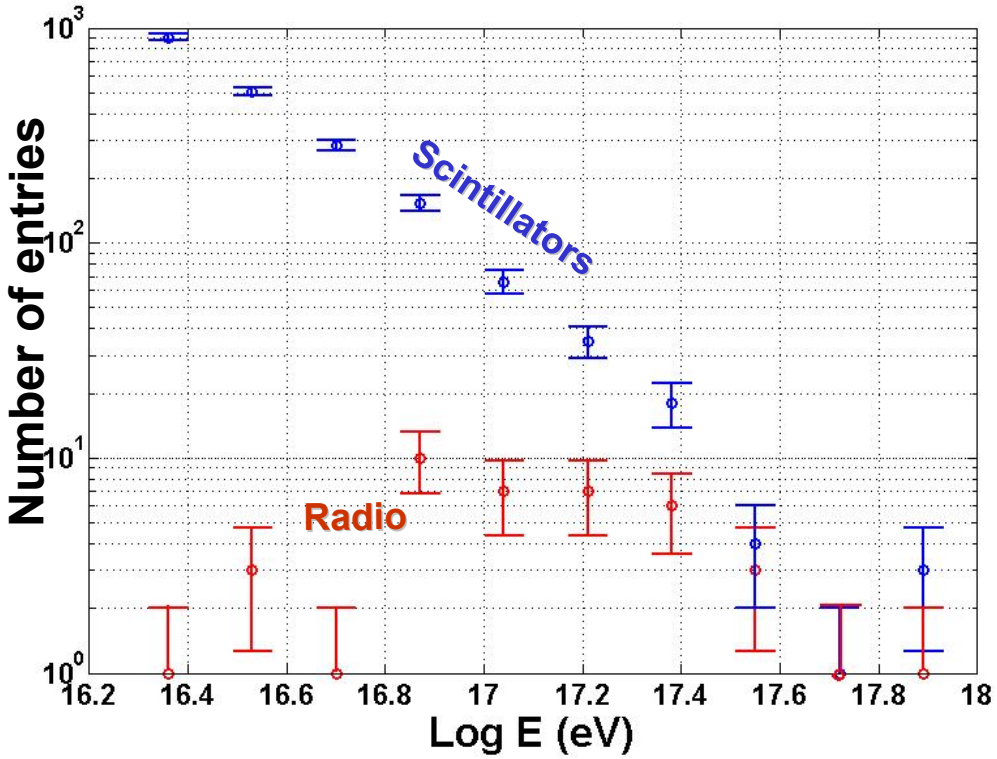


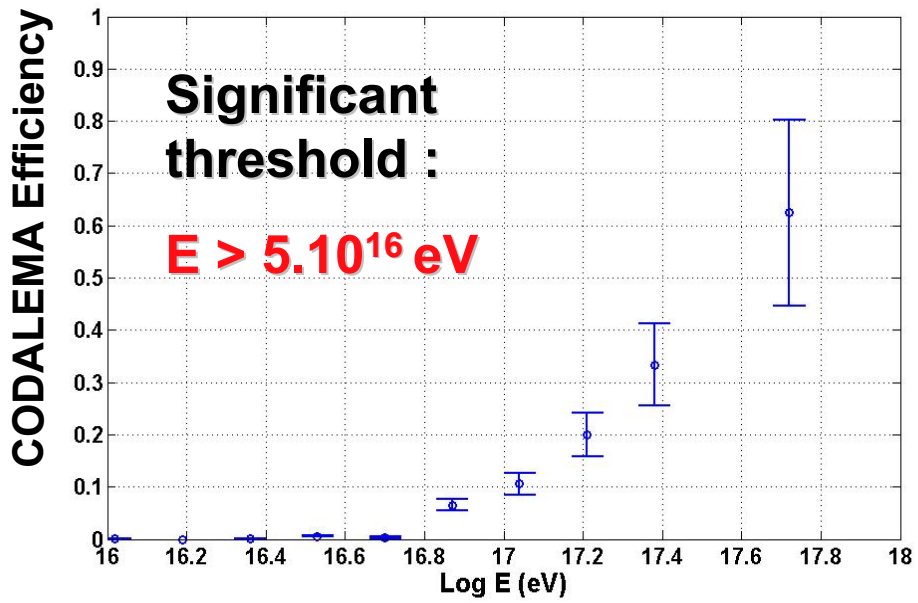

## Shower arrival directions




**Qualitatively compatible with theory (Allan, 1971)**

# Energy distribution and detection efficiency




Ravel, ICRC 2007
Bellétoile, HEP 2007

(Histogram not corrected for the acceptance)

- Factor ~2: only East-West polarisation of the electric field
- Factor ~2: geomagnetic effect ⇒ ~½ sky

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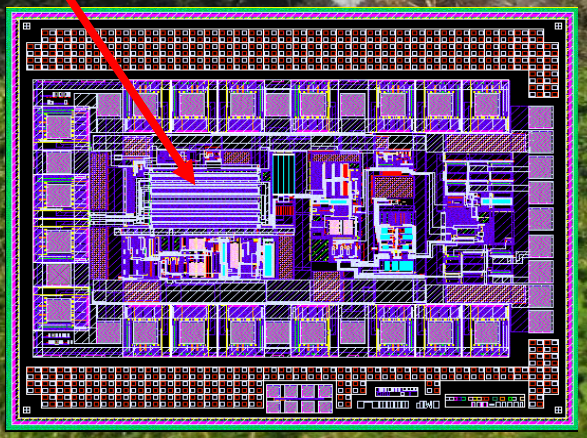
# Next: autonomous station

Dipole antenna in aluminium

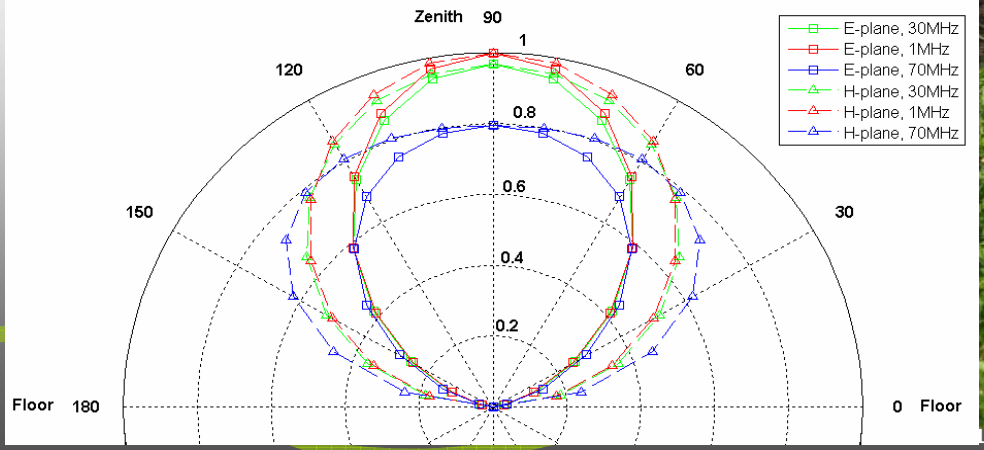
Full Bandwidth (0-250 MHz)

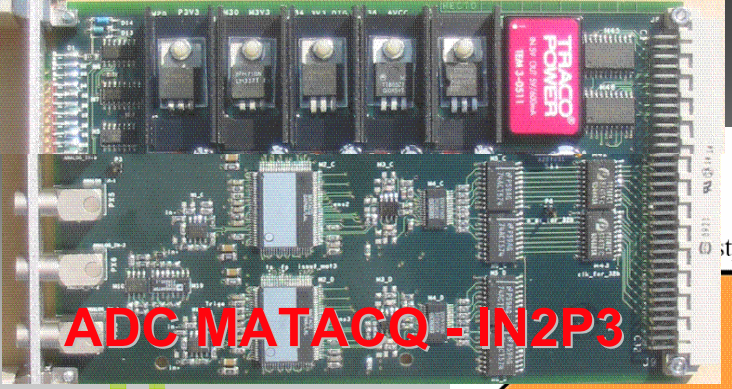
Low Noise Amplifier (ASIC) designed at SUBATECH



## Constant directivity

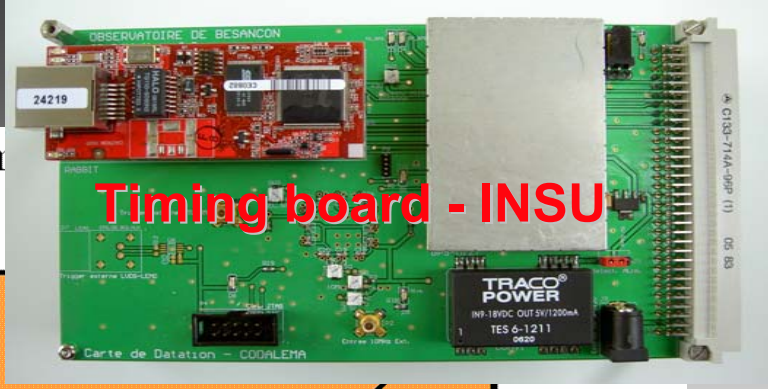
Normalised gain in E and H plane versus the Elevation angle






Châssis Codalem

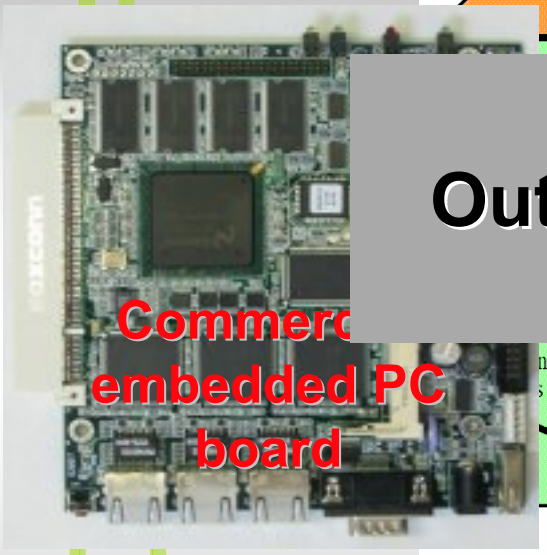
style Schroff G64 (réf 23007-010)

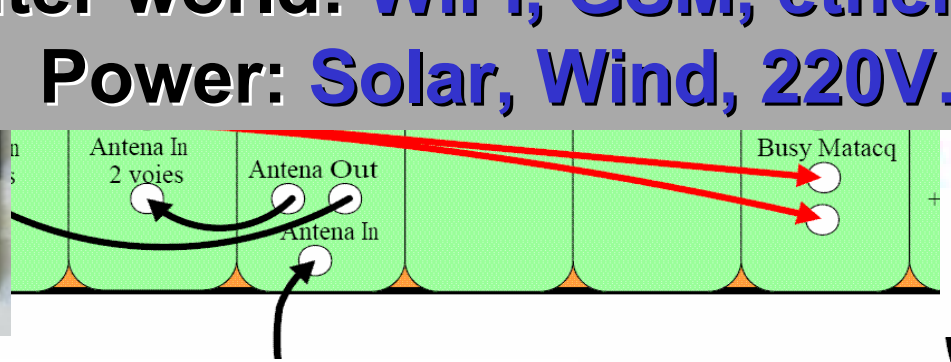


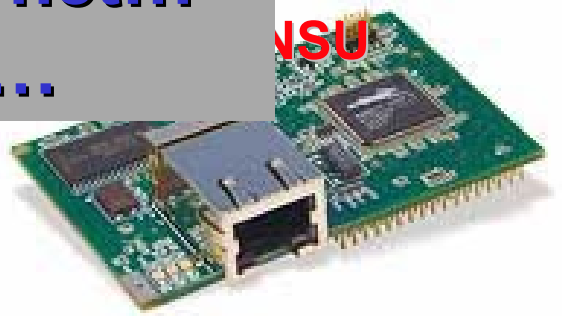

# Versatile solutions

## Outer world: WiFi, GSM, ethernet…

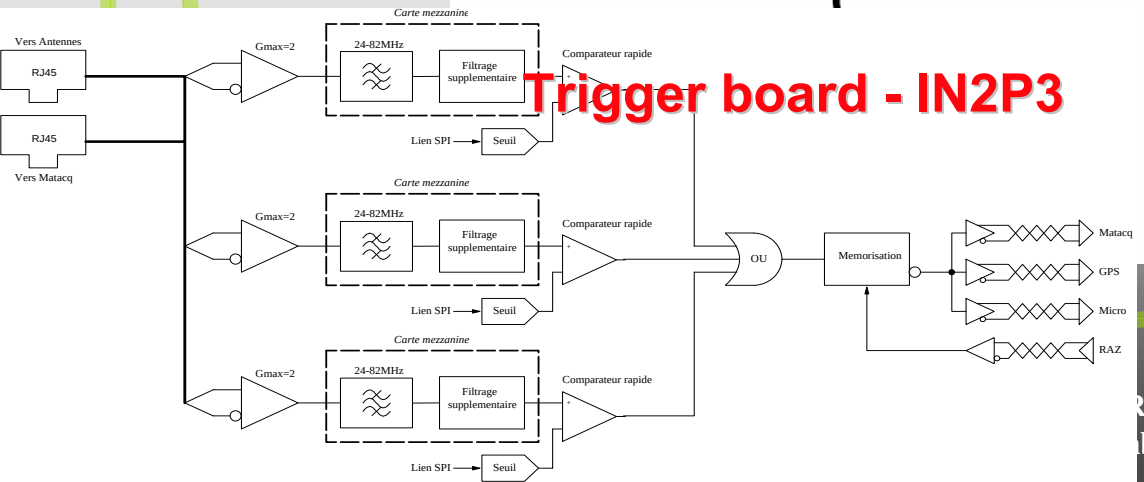
## Power: Solar, Wind, 220V…




Cartes: 2 unités de large




Connexion en face avant

Connexion backplane (que l'on peut mettre aussi en face avant)

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boration

# Next: steps towards a large array

- Energy calibration
- Pitch of antenna array
- Detection technic and analysis method will be ready at end of 2008 for the construction of an engineering array (some $km^2$)

**Phase 2 of Radio @ Auger South? (North?)**

**Europa: Nançay? LOFAR?**

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# Human power and work plan

| TOTAL ETP<br>Phys./Ing./Tech./<br>Post.-Doct./ Doct. | 2007<br>Nançay 20+2 Ant.<br>& RAuger phase 1 | 2008<br>Nançay 20+20 Ant. &<br>end RAuger phase 1 | 2009<br>Engineering array 10X10<br>Km² ?100 Ant.? | 2010… |
|---|---|---|---|---|
| @ CODALEMA<br>NANCAY | 9 / 3.5 / 1.9<br>/ 2 / 3 | 8 / 3.1 / 1.3<br>/ 1? / 3? | 12?/ 6? / 6?<br>/ 2? / 3? | …. |
| @ CODALEMA<br>AUGER | 1.5 / 0.4 / 0.8<br>/ 0 / 1 | 1.5 / 0.1 / 0.5<br>/ 0? / 0? | | |
| GOALS | Radio-detection tests and settings<br>Conception of the autonomous stations | | Production & Construction of the engineering array | |

# Resources and expenses

**@ Nançay**

2003-05: 120.5 k€ (AP IN2P3 + PI astroparticules 2004)

2006-08: ANR 590 k€ (equip. 258.2, fonct. 331.8) (reste 1/3 pour 2008)

**@ Auger**

2006: pris sur ANR SUBATECH 2006 25 k€ + LPSC 10 k€ (reste 0)

2007: IN2P3 2007 15k€ + Fond propre SUBATECH 15 k€ (reste 0)

**For 2008-10:** Région Pays de Loire 380 k€ for the engineering array (Auger, Nançay?)

# Publications

**With referees** 3 NIM, 1 Astro-Part. Phys

**With Conf. Comity** 21 proceedings.

# Organization chart

**P.I., scientific coordinator:** P. Lautridou, SUBATECH/IN2P3
Technic coordinator, Nançay: L. Denis, Nançay/INSU
Technic coordinator, Auger: R. Dallier, SUBATECH/IN2P3

**+** each group head (7): **collective decision structure**

# Work Packages

IN2P3

| | |
|---|---|
| SUBATECH: | Dipoles, FEE, trigger, telecom, embedded PC, analysis, theory |
| LPSC: | Particle detectors, acquisition, analysis, theory |
| LAL: | ADC, analysis, theory |

INSU

| | |
|---|---|
| LAOB: | Timing electronics |
| LPCE: | Atmospheric physics |
| Obs. Paris-Nançay: | DAM, Nançay infrastructures, RF filters, ethernet, data transmission, analysis, theory |

Private engineer school ESEO: Signal processing

**+ Support** of **Auger-France labs** for tests @ Auger

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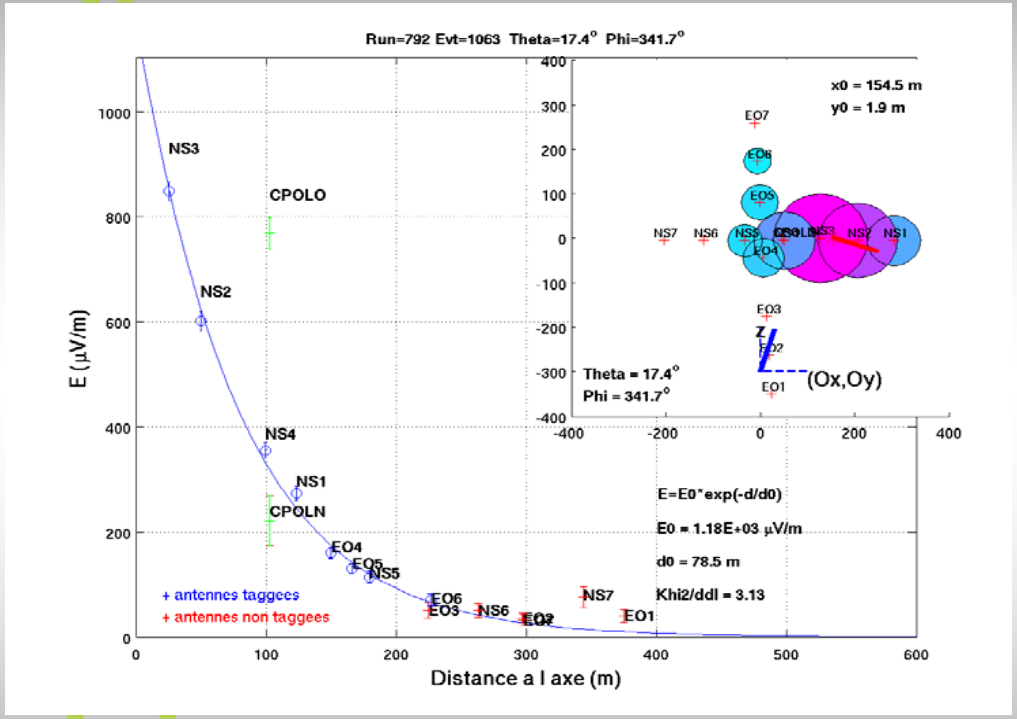
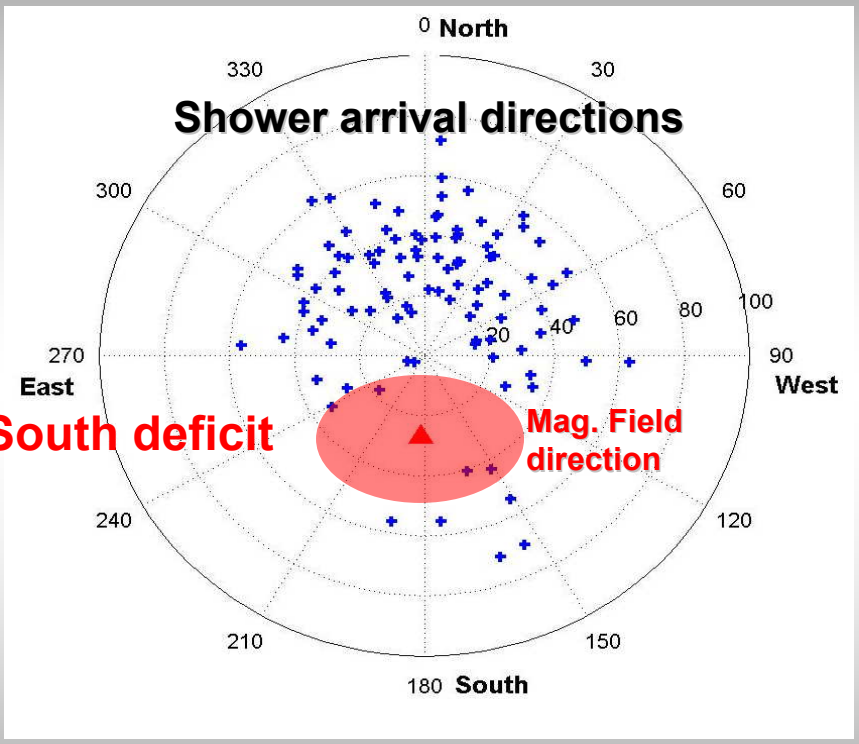
# Conclusion

**2009: choice of radio-detector and method for an engineering array (~20 km² ?)**

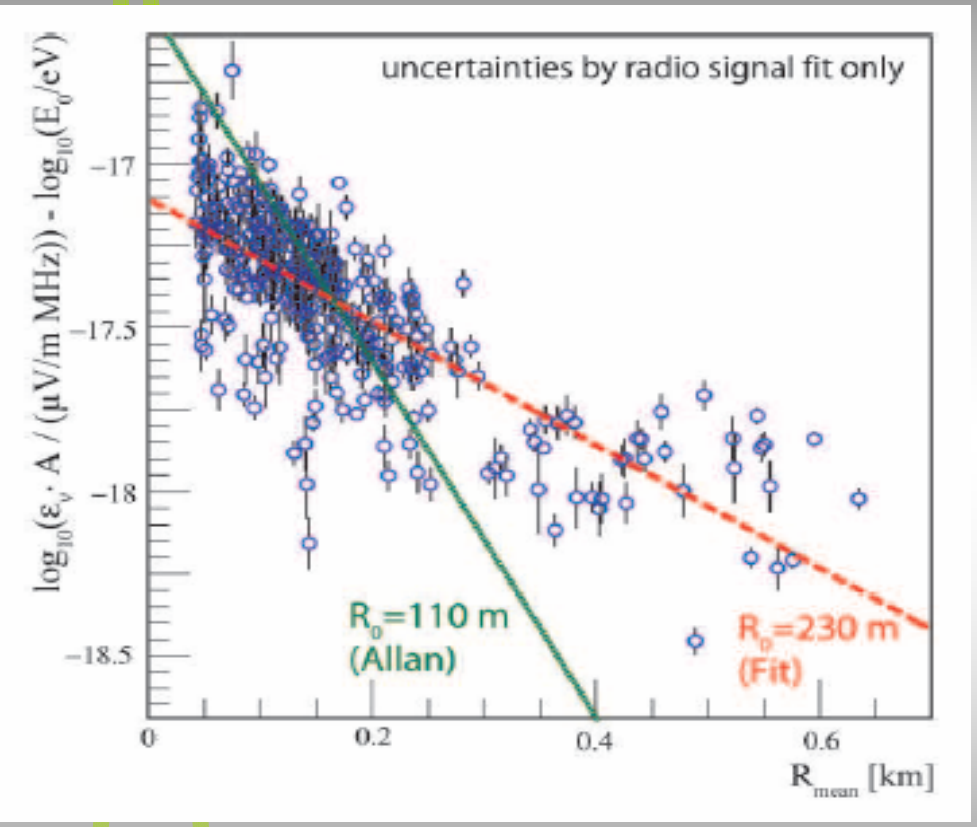


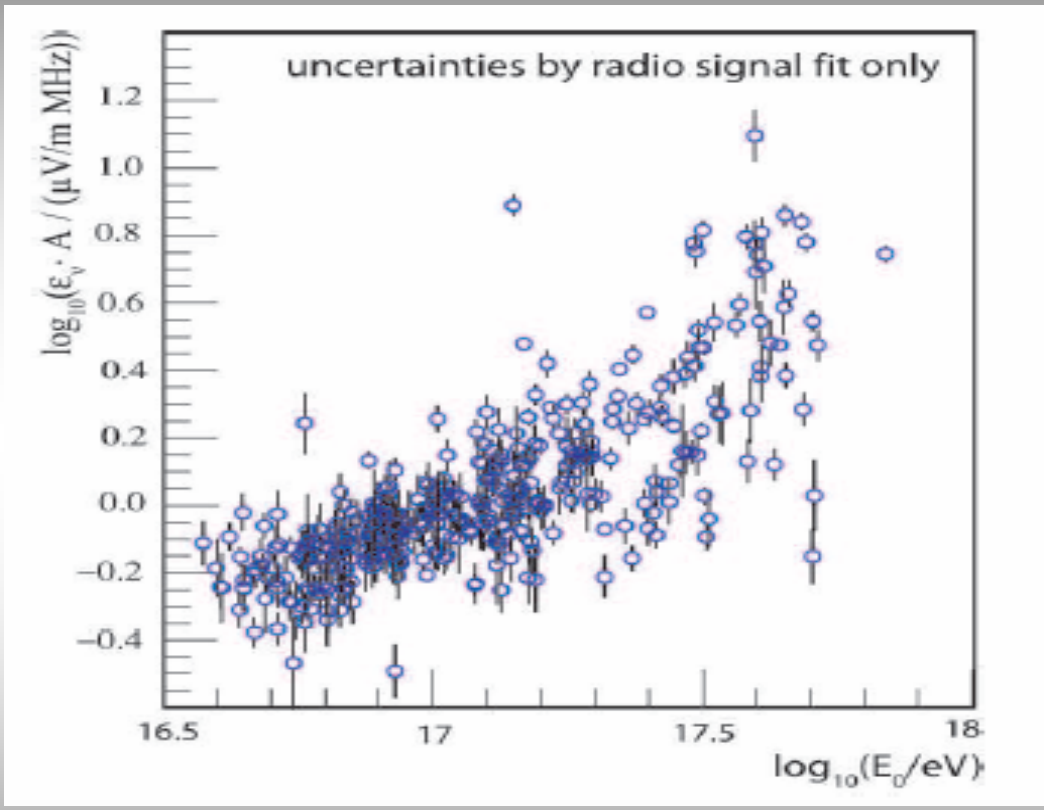

**GOAL: to keep our scientific and technic pole position**

- by being the first to build and exploit a km² engineering array
- based on our developed technology
- to be leader in the construction of a further giant antenna array

# LOPES 10: Results with KASCADE-Grande




Correlation of the radio pulse height with the mean distance of the shower axis




Correlation of the radio pulse height with the primary energy of the shower

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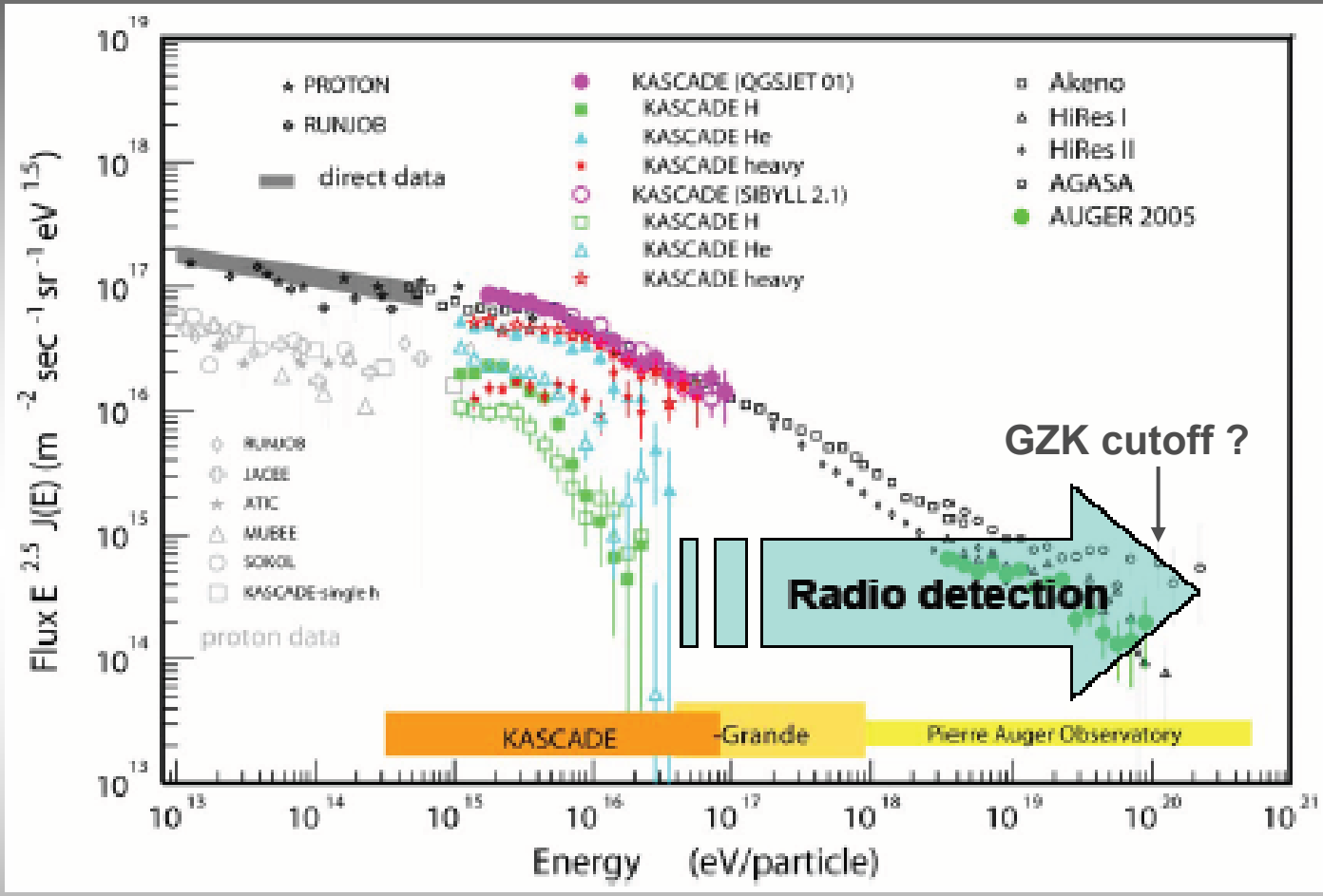
# UHECR studies

**Problematic of**
**ORIGINE**
**&**
**NATURE**
**of the cosmic rays**

**Radio-detection:**
**longitudinal development, macroscopic observables, long range detection, high acceptance, inclined showers, cheap, high duty cycle…**




**Complementary to hybrid techniques**
Fluorescence, surface particles detectors

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# 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)**

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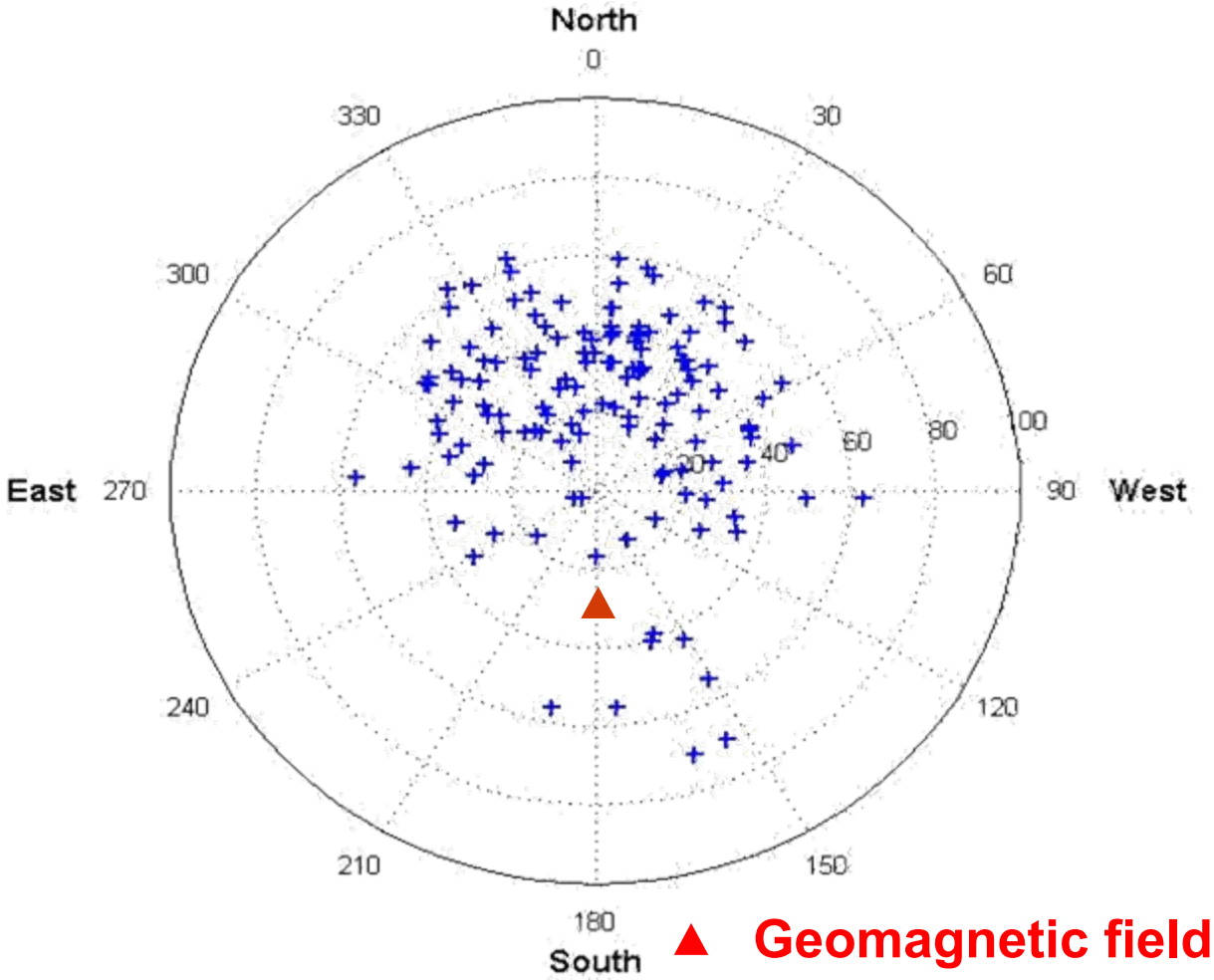
# Geomagnetic effect

## For unknown energy

**Arrival direction of radio-detected showers**

**Explicit deficit in the South direction**

**Few events near geomagnetic field vector**




▲ Geomagnetic field
θ = 27 °, φ =180°





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# Effect on radio efficiency

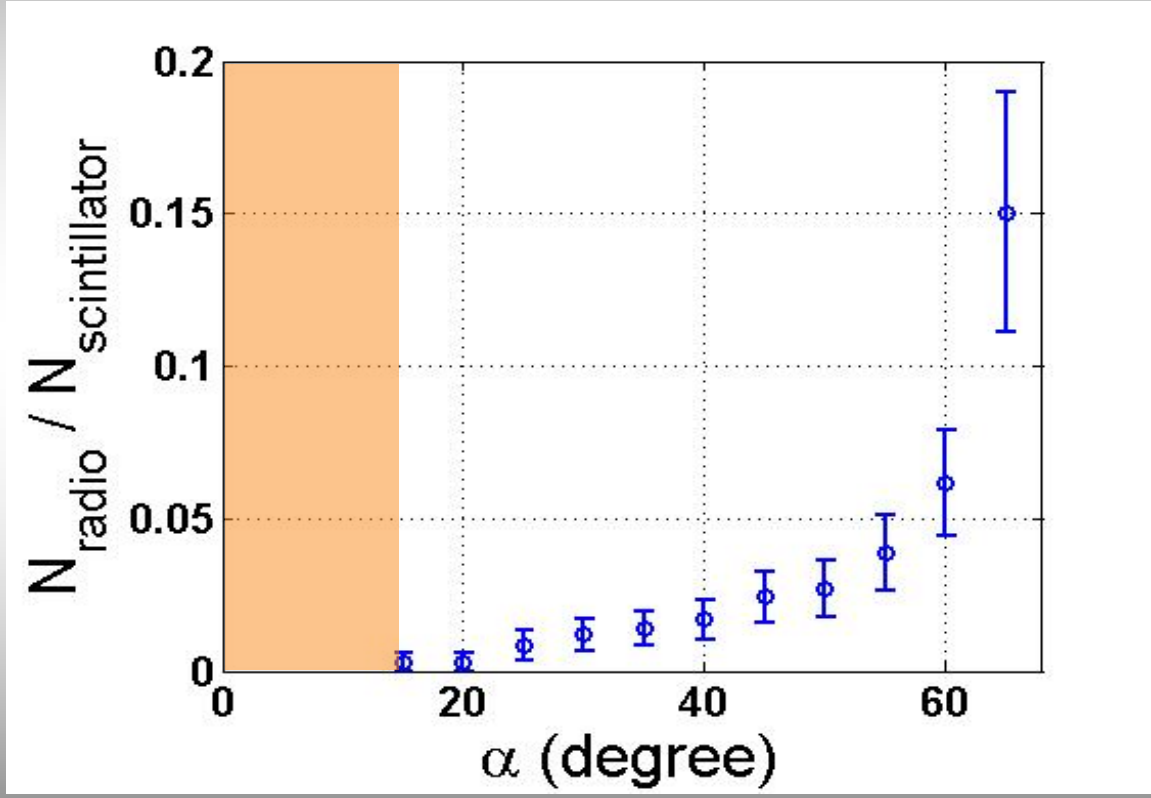
**Ratio radio-particles as a function of α**

**Rising function of α**

**No event for α below 15°**

**Qualitatively compatible with theory (Allan, 1971)**

**For unknown energy**

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# Effect with the energy

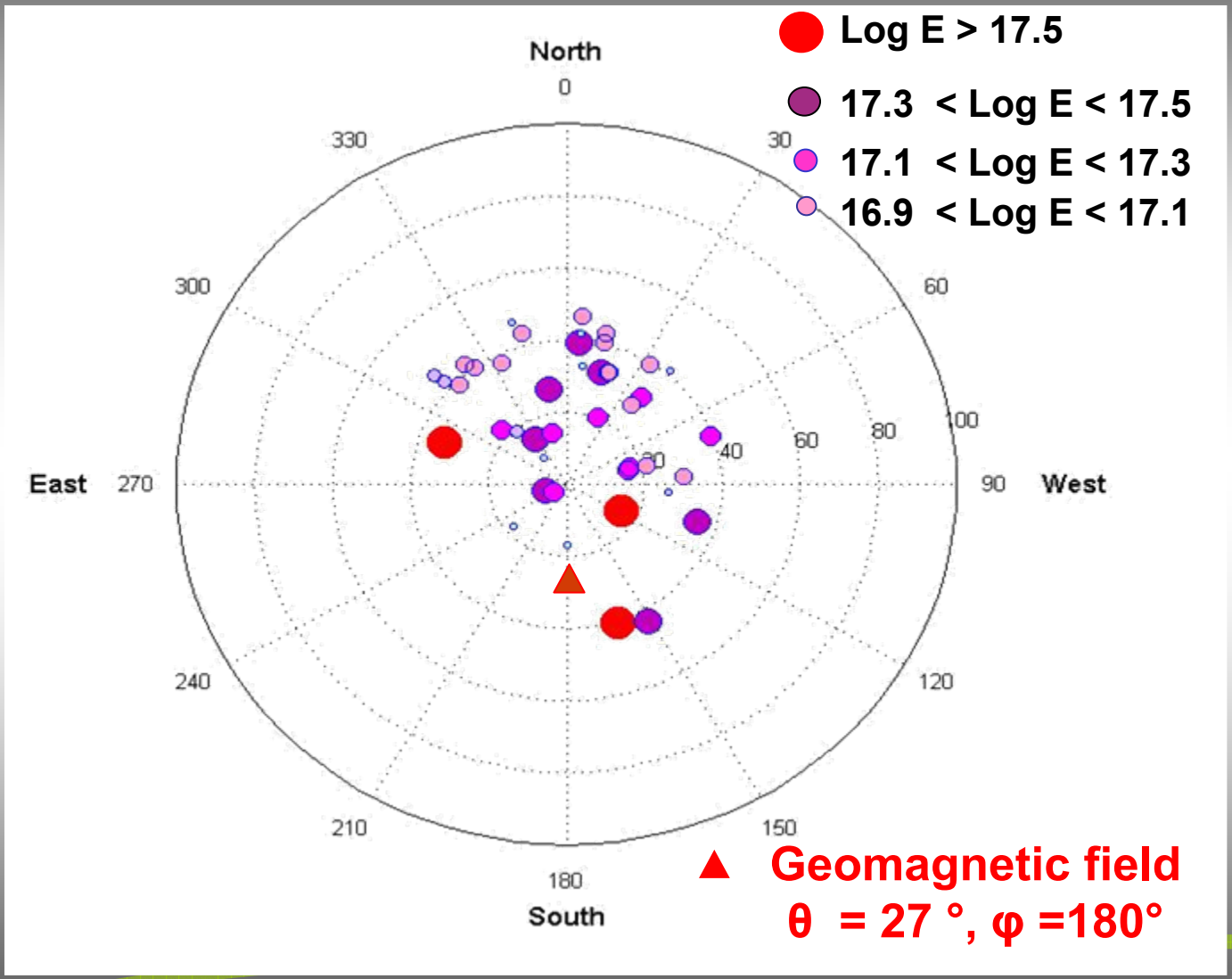
**Energy known**

**for « internal showers »**

**(CIC method, precision 30 %)**

**43 internal showers**

**Showers from South were more energetic**





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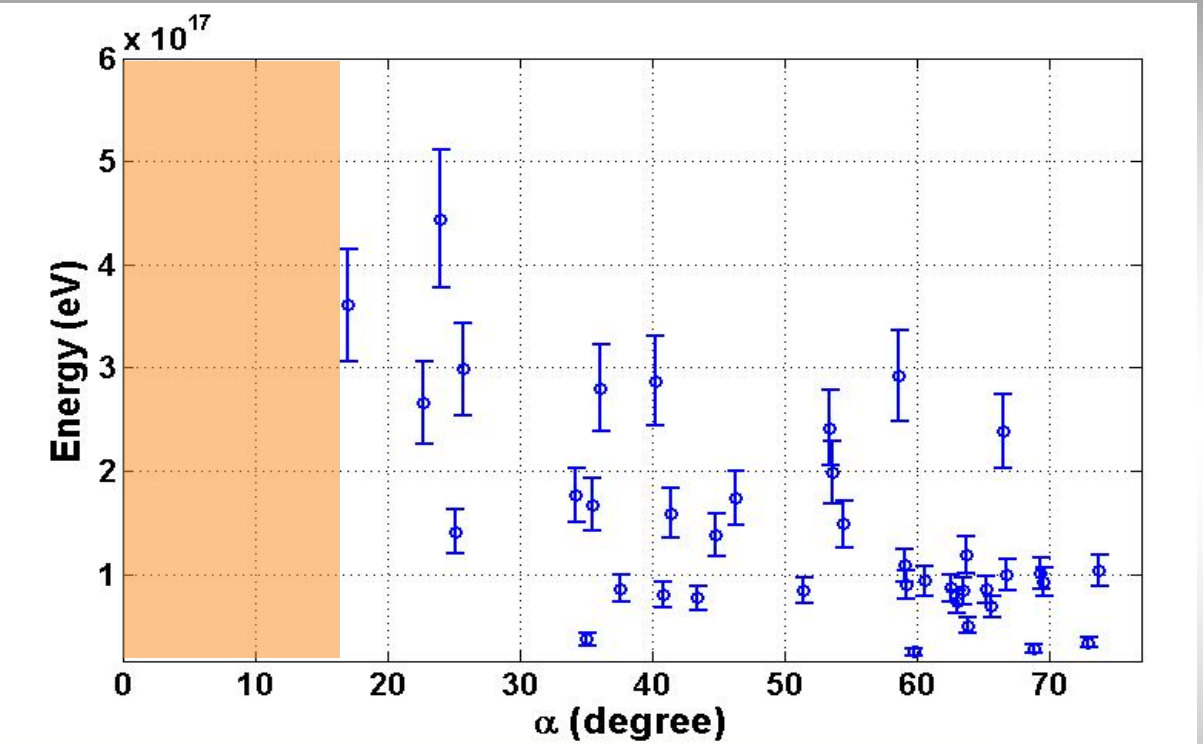
# Effect with the energy

## 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**

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# Summary of main results

**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 → Ongoing 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)**

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