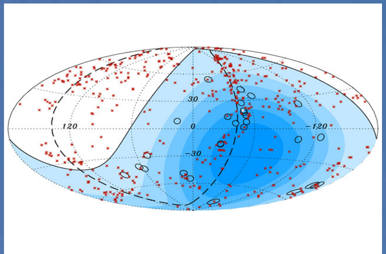
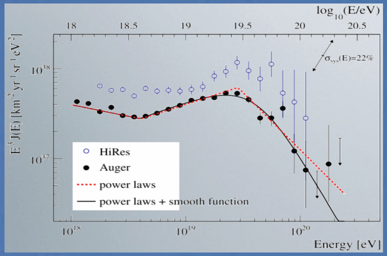
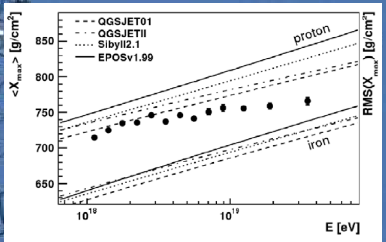
Toward the autonomous radiodetection of UHECR with CODALEMA

P. Lautridou for CODALEMA @ RICAP2011

Auger data







What Challenges for UHECR ?

- Sources
- Energy limit
- Composition

=> Current limitations due to flux & detectors...

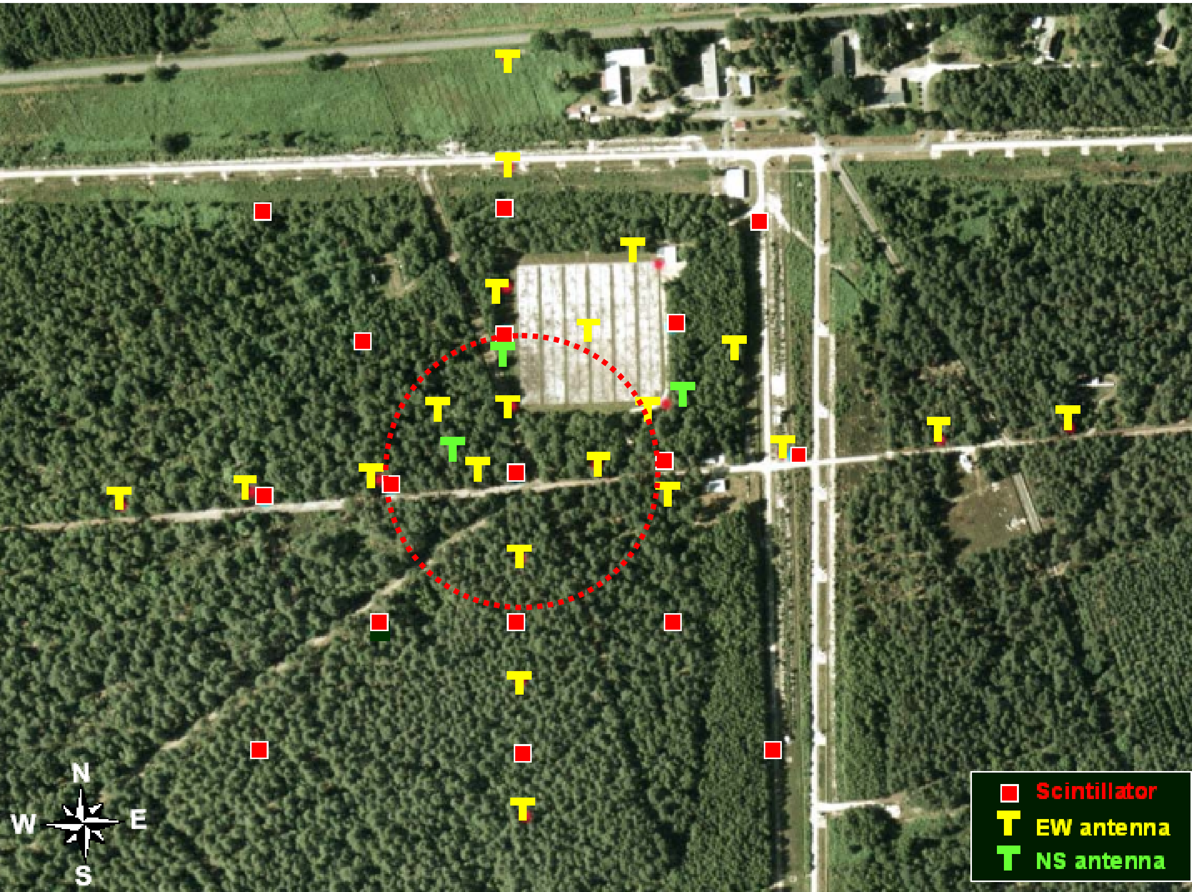
=> What could bring radiodetection ?

- Surface
- Duty cycle
- Primary composition
- Cost, …

Since 2003 many points raised by CODALEMA & LOPES, in a high complementarity

CODALEMA 2006-11 @ Nançay

Temporal + frequency approaches + Trigger considerations @ 10^{17} eV



Radio arrays

-24 dipole antennas

cross: 600 m x 500 m

21 ant. in E-W polarization

3 ant. in N-S polarization

-Decametric Array

18 blocs of 8 phased log-spiral antennas

Operating in transient mode

12 bits ADC
@ 1 GSample/s

Particle array

17 scintillator stations : square 350 m x 350 m

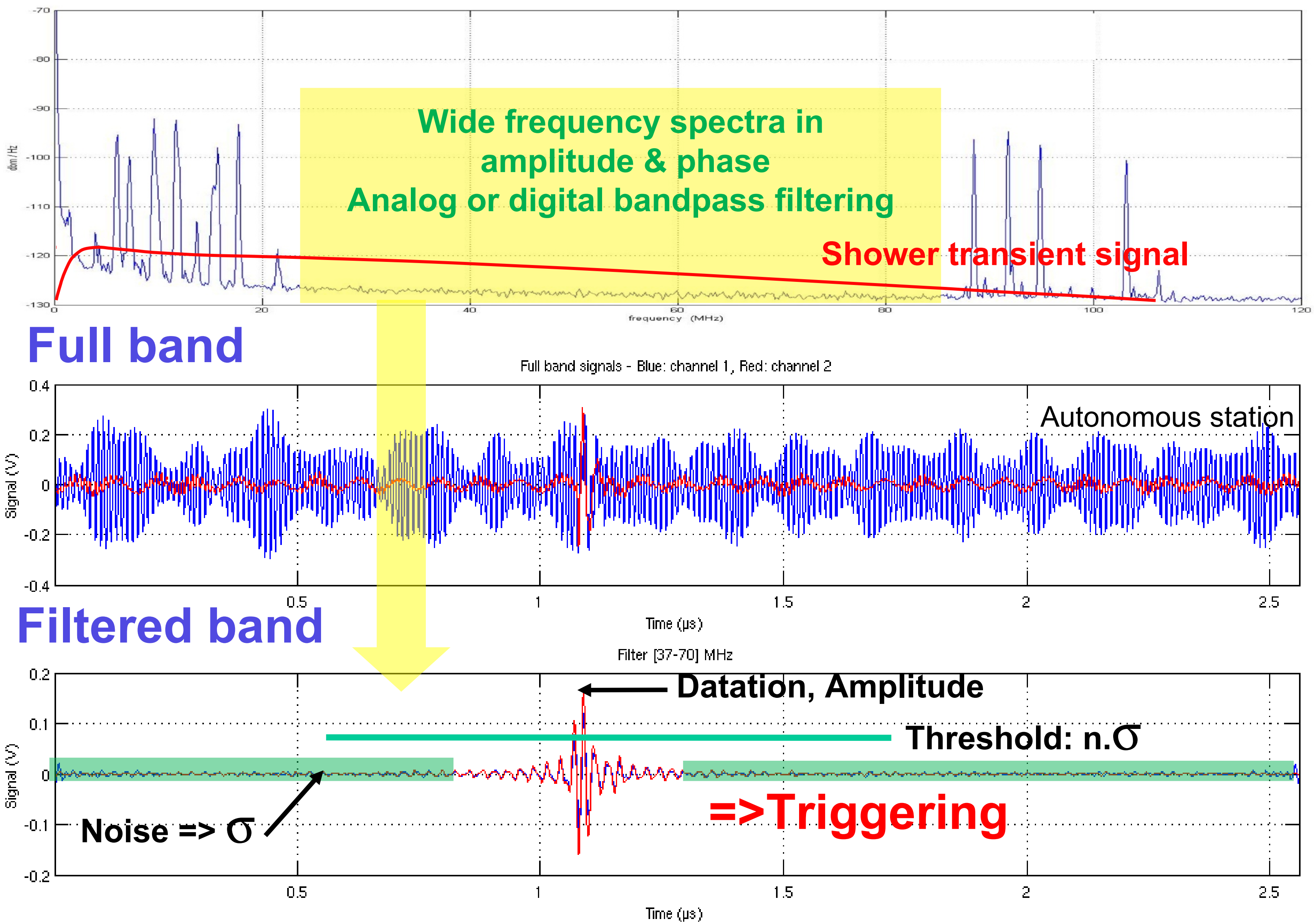
Trigger : the 5 central particle stations

Internal Showers : higher signal in central stations

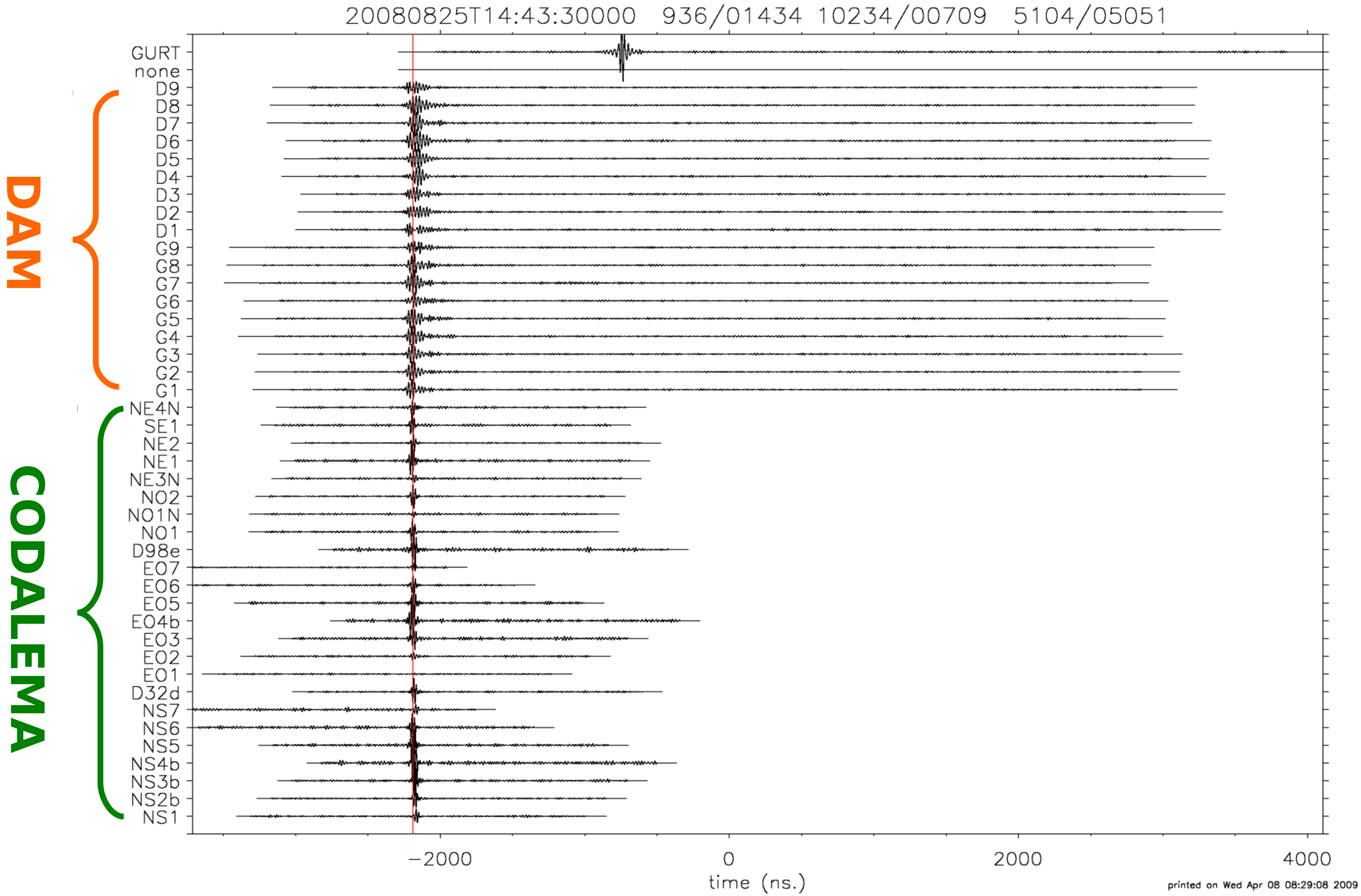
Core Position + Direction + Energy (via CIC method)

Method of transient recognition

Transient signal in noise: from sensor, RFI, broadcasting, galactic signal etc.



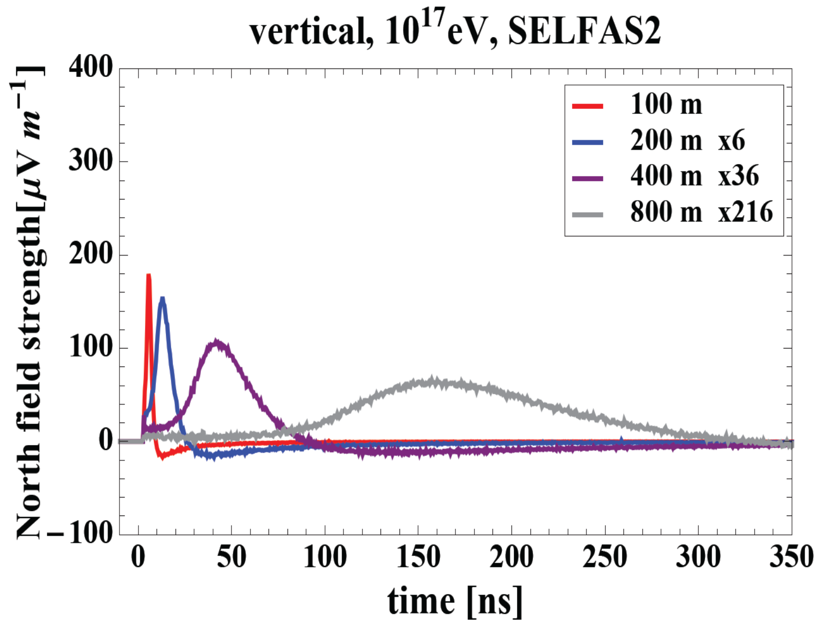
CODALEMA radio-event



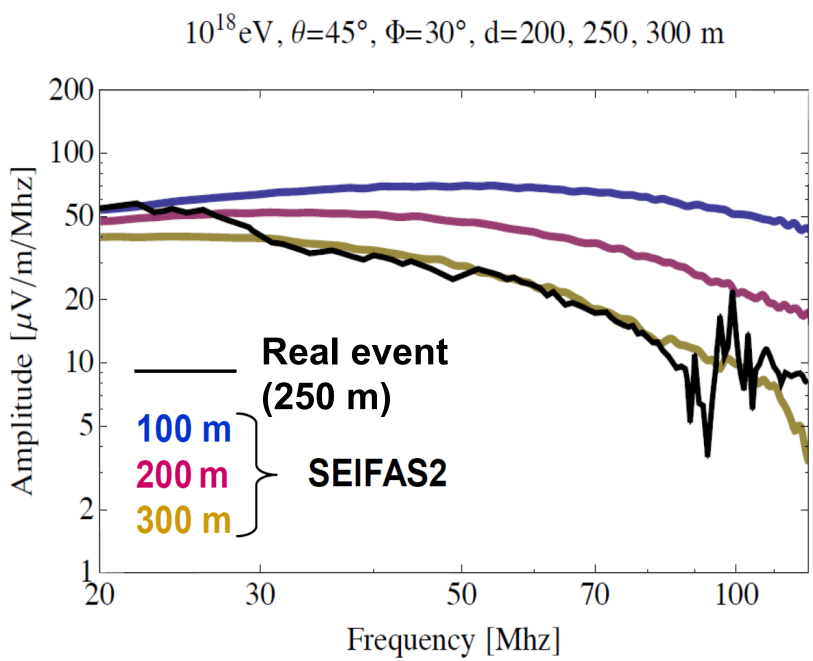
Signal features with the SEIFAS2 model

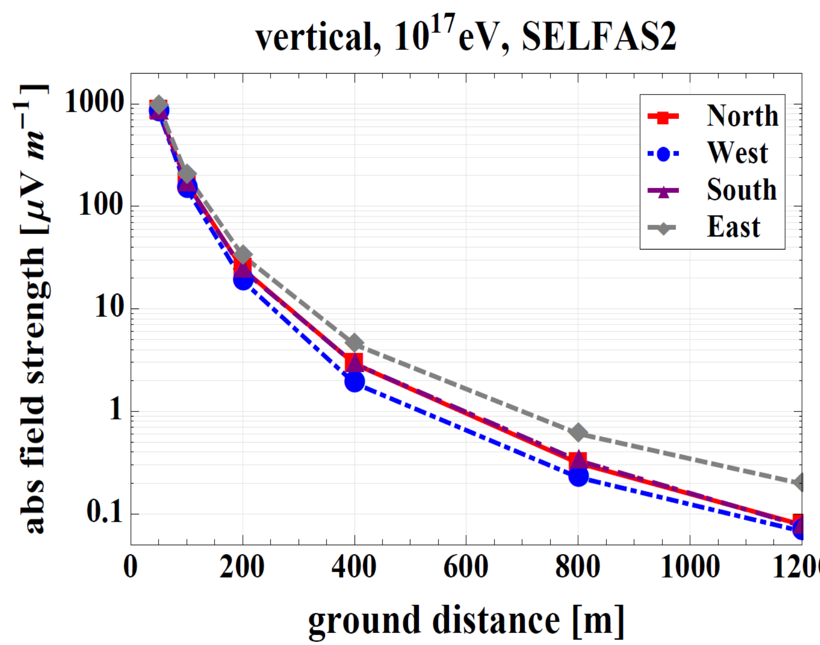
Signal features in agreement with the other models

Field amplitude: from µV/m to mV/m
Transient duration: from ns to µs
Frequency spectrum: broad band emission from MHz to few hundred MHz

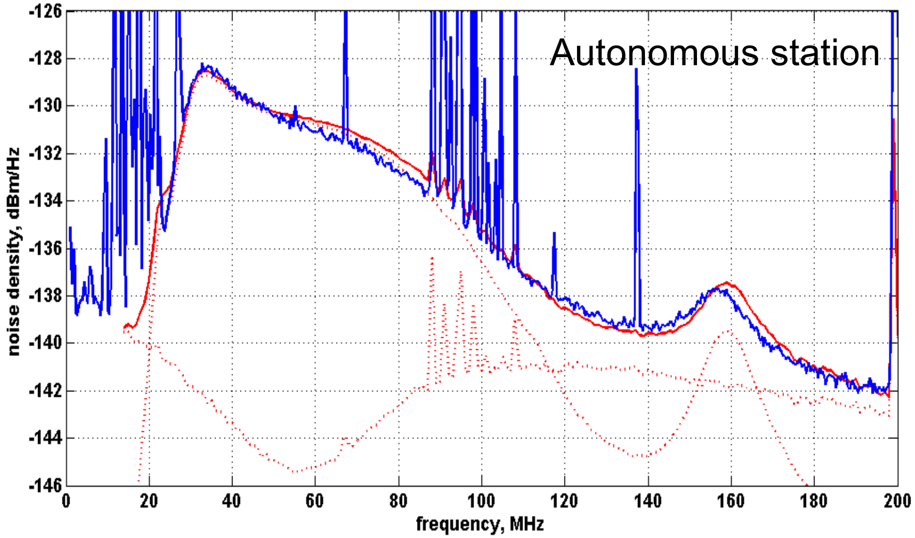


Deconvolution of the antenna response for a real event





Signal deconvolutions



... LNA noise (antenna disconnected)

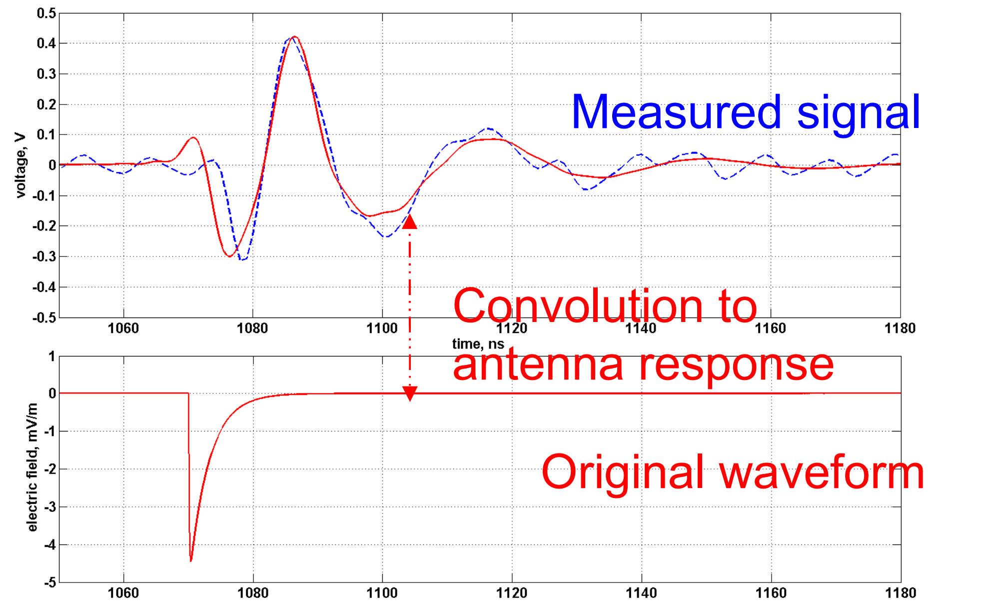
- - Simulated Galactic signal

__Simulated Galactic signal + LNA

__Measurement

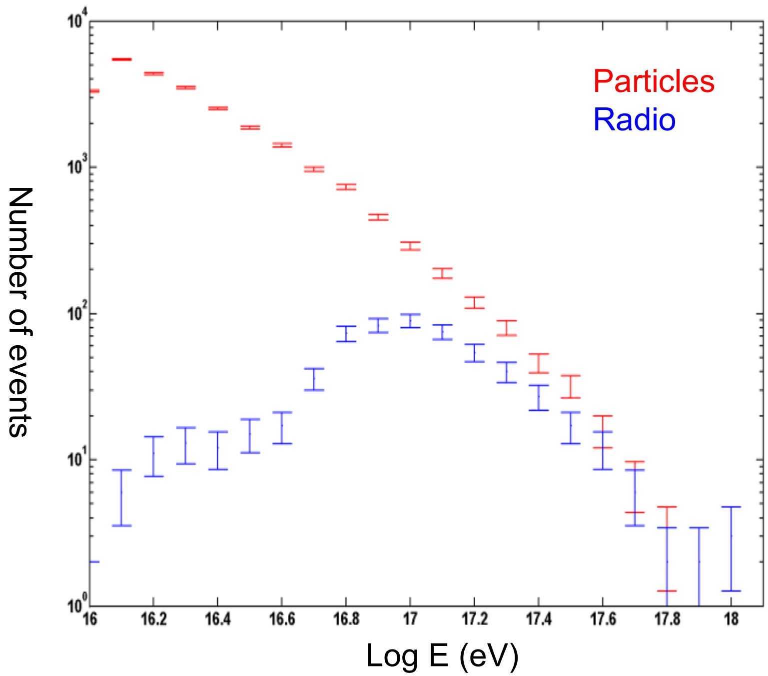
Simulation of the signal waveform

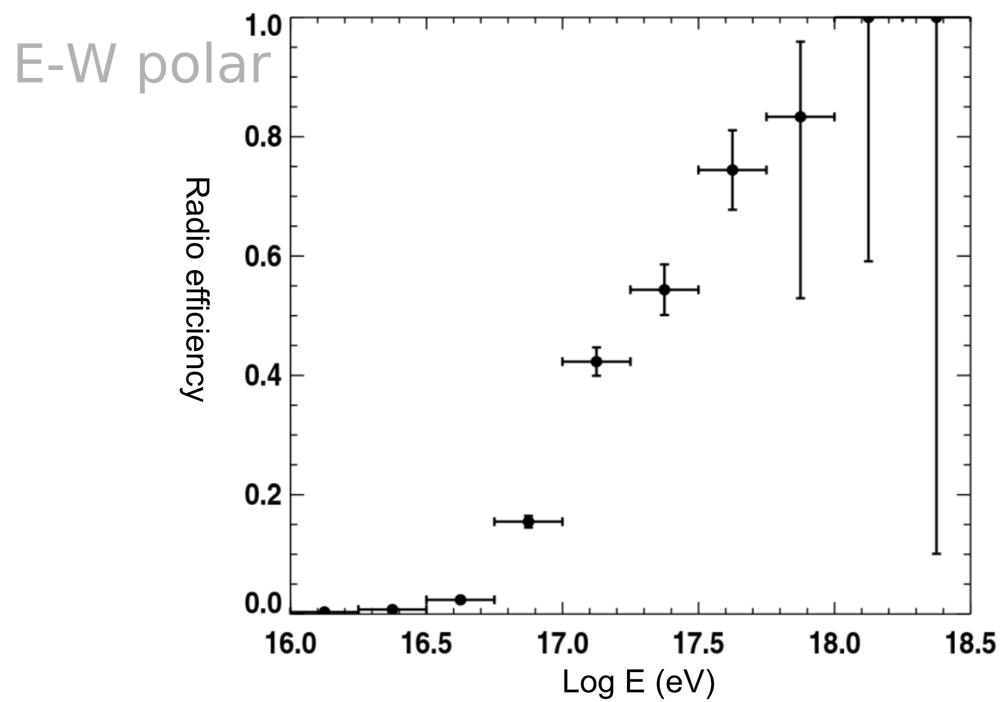
In principle could enable to describe the shower with a single antenna (amplitude => energy, duration => distance, polarization => direction)…



=> Could finger the true methodological interest of the method ?

Detection efficiency





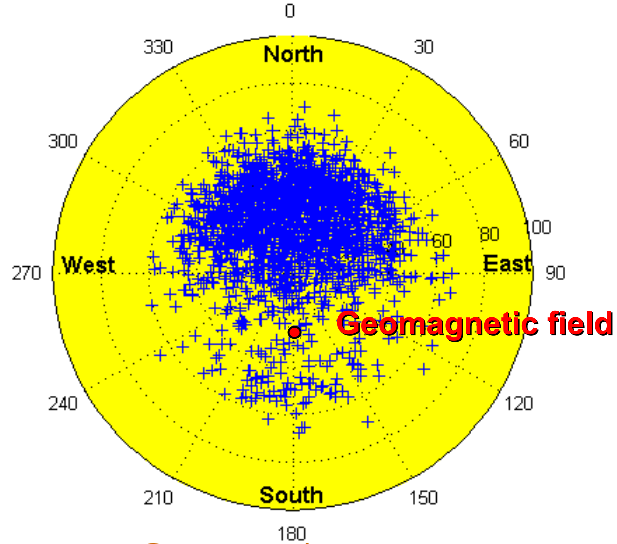
Full efficiency reached @10^{18} eV with E-W polarization

⇒Expected improvements: using E-W + N-S states of polarisation (x2) + better antenna lobes (x1.5) + better SNR (x3)

⇒ Detection threshold mainly attributed to the mechanism of emission

Emission mechanism

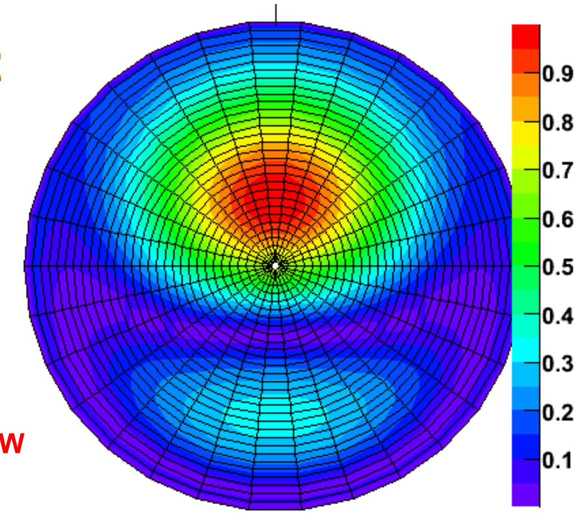
North



E-W polarization
Data

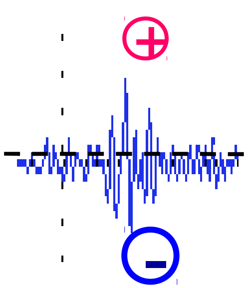
=>Geomagnetic effect
highlighted at detection threshold

=> Field Strength ~ $|VxB|_{E\text{-}W}$

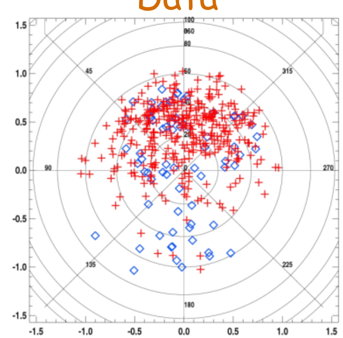


CODALEMA toy-model
(also SELFAS2, AIRES)

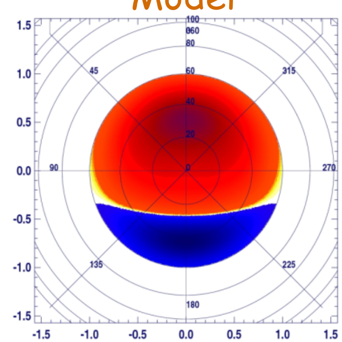
- Corresponding pattern observed in N-S polarization
- Corresponding pattern observed at Radio-Auger (opposite geomagnetic field direction)



Data



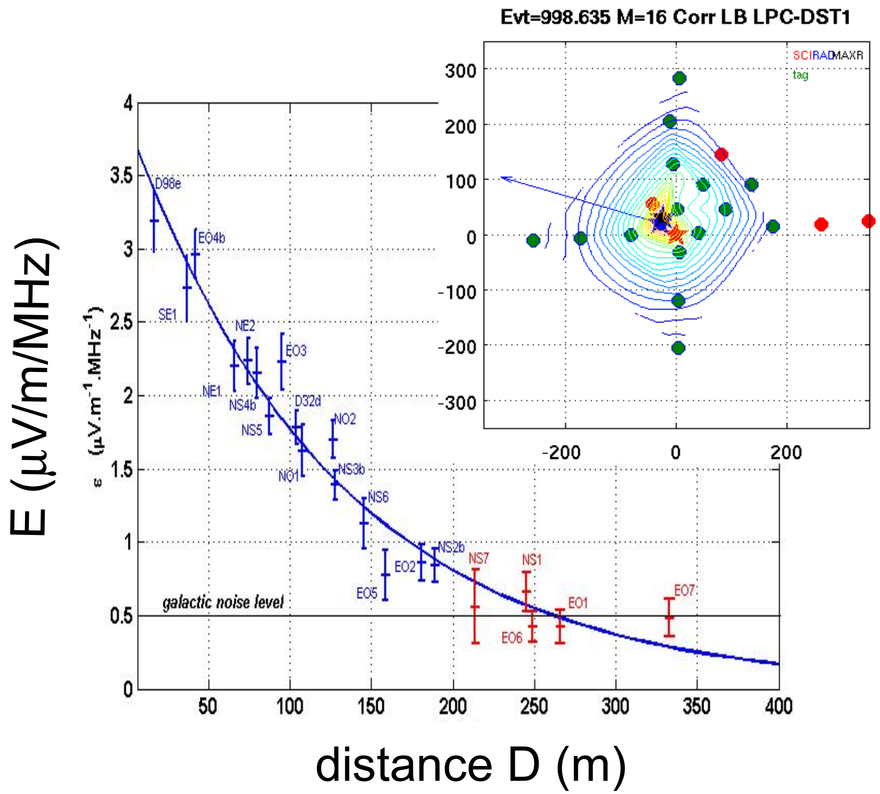
Model



E-W polarization

- Pulse polarity consistent with the model in both polarizations E-W and N-S

Energy calibration



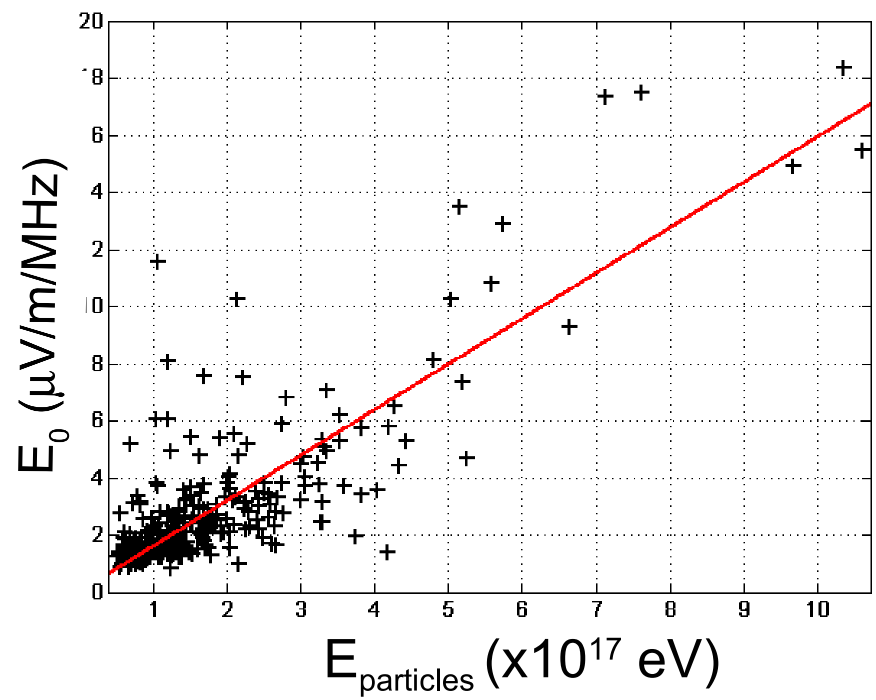
Interpretation of the lateral field distribution within the formalism of ALLAN :

$E = E_0.\exp(-D/D_0)$

=> After fit: E_0, D_0, core position

- Full development of the shower seen by radio => differs from particle detectors on ground (S_{1000} @ Auger)

=> E_0 as energy estimator for radio ?



=>$E_{radio} = E^{\alpha}_{particles}$ with $\alpha \sim 1.03$

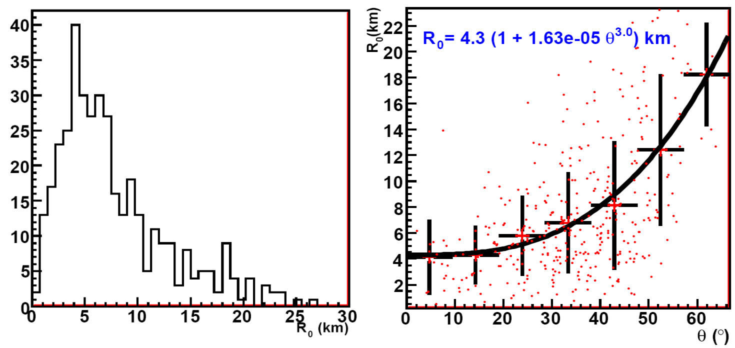
=> Coherent emission dominant

=> What energy resolution ?

With $\sigma(E_{particles})$~30% => $\sigma(E_{radio})$<20% ?

Energy estimation with radio seems relevant...

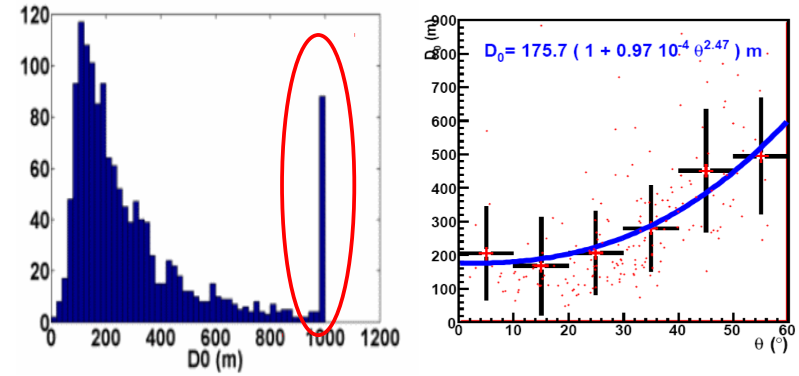
New issues

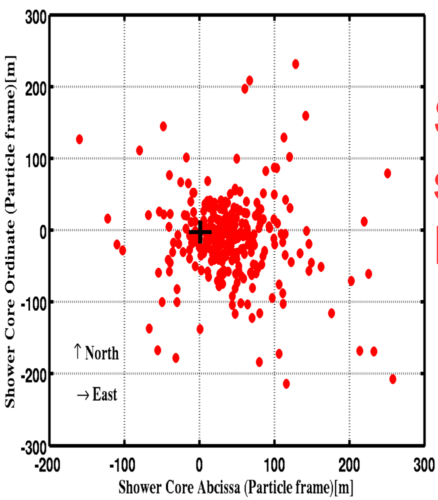


Curvature R_0 correlated to Xmax ?

=> Estimation of energy and composition ?

Slope D_0 due to a geometrical effect ?



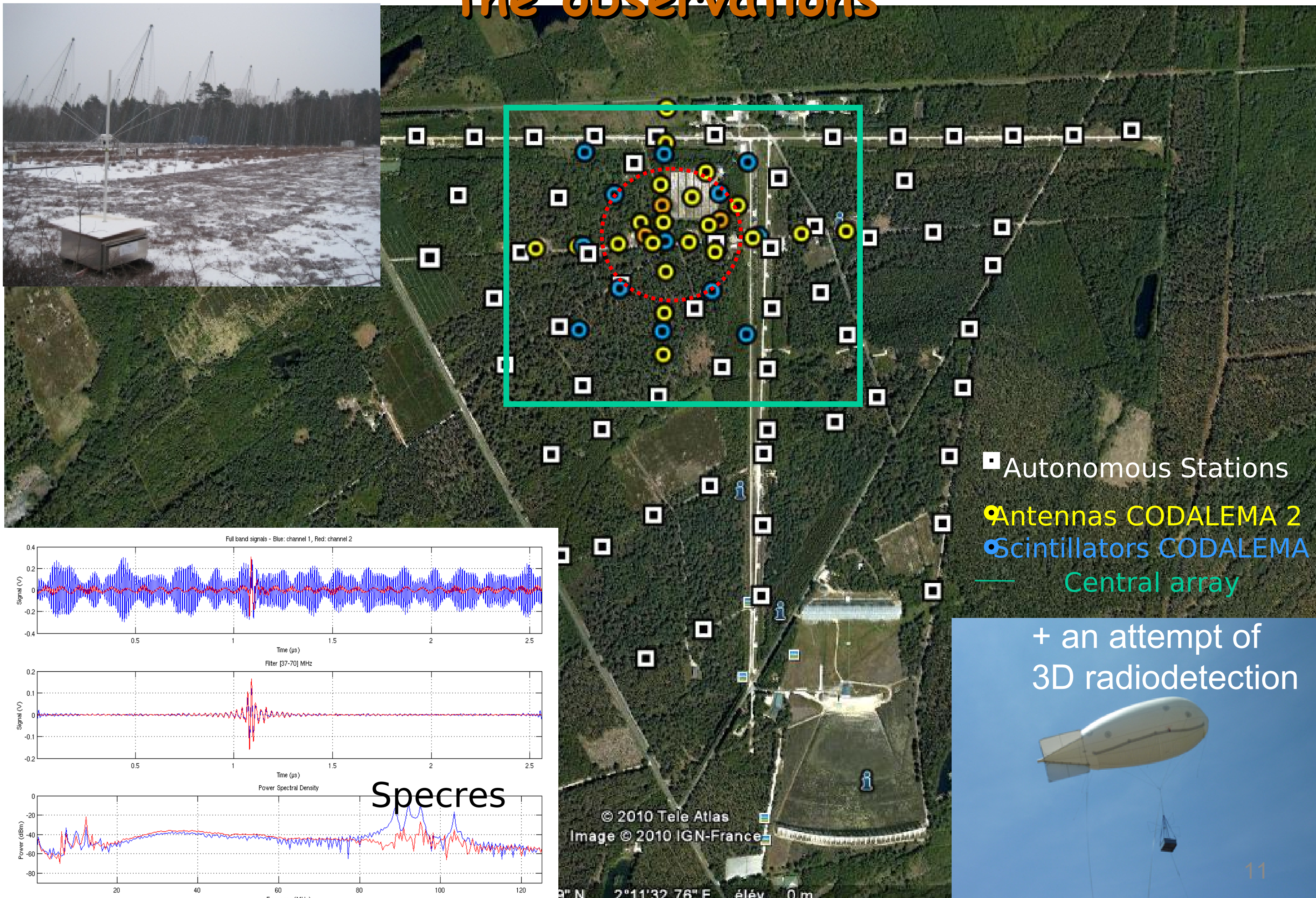


Shower footprint shifted to the EAST !

+ detected events near the geomagnetic axis !

=> Needs interpretations ...

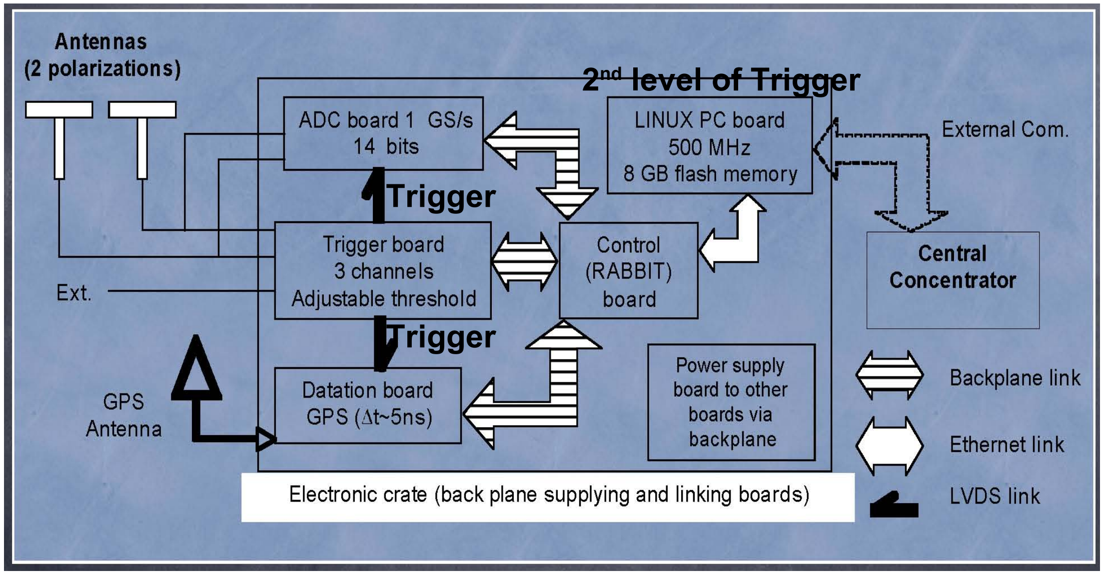
CODALEMA 3 : a multi-scale array to refine the observations



The CODALEMA stand-alone station

Guidelines

- Min-bias detection of showers
- Avoid exchanges between stations for the triggering
- Simplify communication to the outside world
- Ensure RFI self-immunity



+ Use part of previous the CODALEMA hardware
(ADC, LNA, Antenna design)

+ Open solutions for

- Com.: WiFi (@ PAO), GSM, 3G, Ethernet (embedded mini-switch @Nançay),…
- Power: Solar (@ AUGER), Wind, 220V (embedded 220-12V transformer @ Nançay)…

A modular design

First stand-alone operational detector

Based on

dedicated LNA

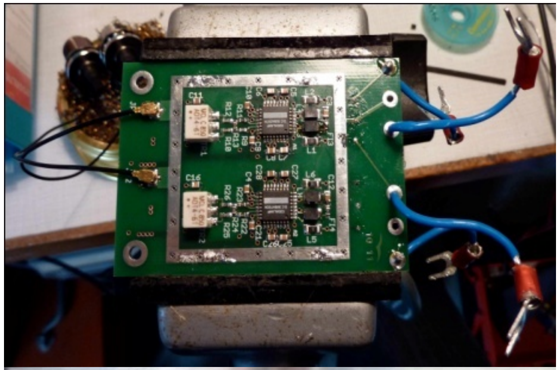
Bw: 80kHz - 200MHz

Input noise: < 1nV/√Hz (30MHz - 200MHz)

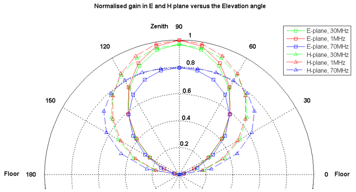
Max input dyn.: 24mVp-p

C_{in} = 9pF

Consumption : ¼ W



Radiator



2 polarization states

- **1 ADC board :** 14 bits waveform, 1GS/s, 2.5 μs
- **1 dating board :** GPS timing resolution: < 5 ns
- **1 trigger board :** 1st level of trigger: @ galactic threshold
- **1 PC board :** 2nd level of trigger in embedded PC + Data management + 8GB flash memory

(+ 1 Alim. board, 1 Bus board)

- Acq. rate: 25 evt/s
- Native Bandwidth : 1-200 MHz
- Effective Bandwidth : 20-150 MHz
- Consumption: 20 W

Implementation of 2nd level of trigger

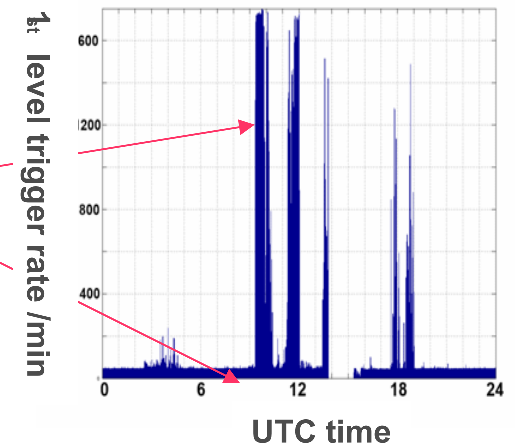
based on processing in the embedded PC
(In quiet environment => 1st trigger level)

1st trigger level (hard)		2nd trigger (soft)
based on analog filtering in the trigger board Waveform digitization in ADC	Send to CPU → ← Threshold	based on waveform analysis through PC processing Data storing in SSD

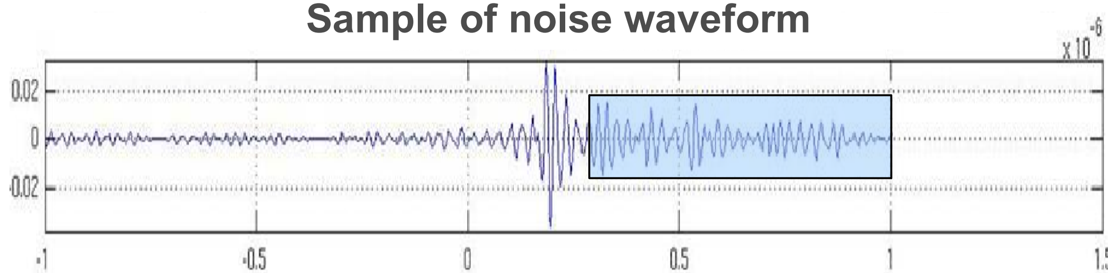
Allows multiple strategies of rejection :
- Max of amplitude
- Standard deviation
- Signal duration
- …

Only speed constraints

RFI Burst
RFI emitter (T=1.23s)

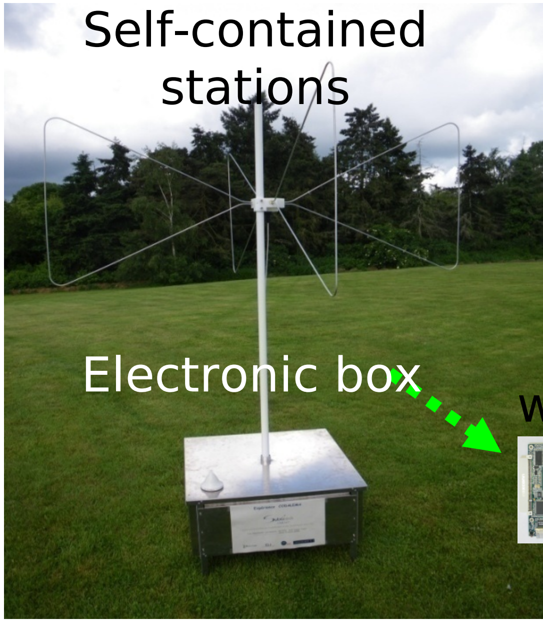


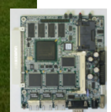
Sample of noise waveform



=> Allows easy reprogramming & Possible rejection factor > 99%

New mode of data communications





with Local PC

DATA LINK to OUTER WORLD

Data & program transferts (board & parameter initialisations)

Transactions based on intermittent exchanges (every hour or day…)

Wake up the com. process

- Multiple trigger levels
- Processings
- Event buffering in Local Memory (several days of storage)
- Data sending

Central Data server

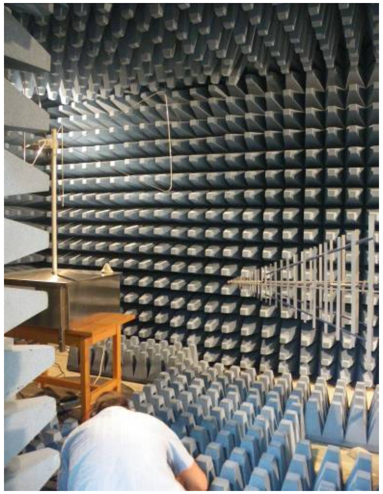
- Select station coincidences from Dating-Tab
- Only recovery of interresting data

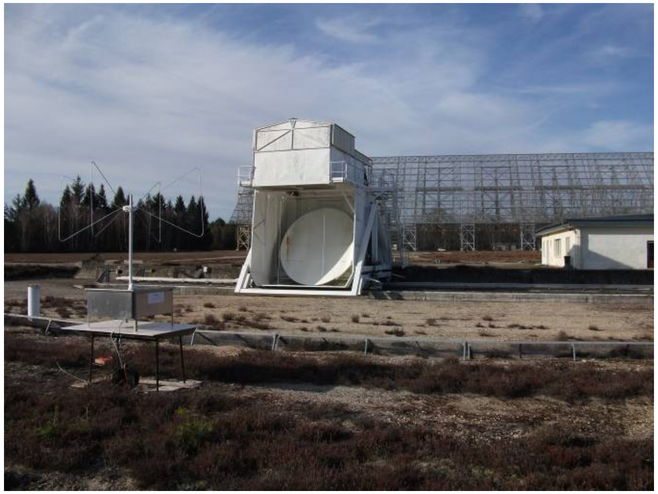
=> Relaxation of communication constraints

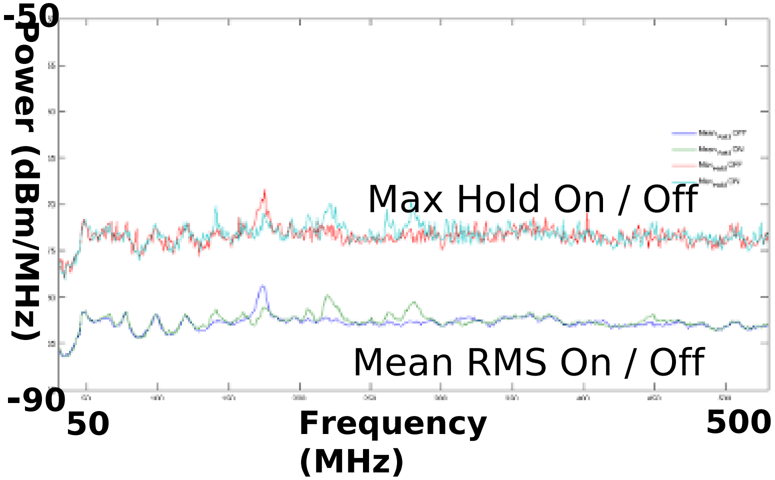
Electromagnetic compatibility (EMC)

Tests of noise produced by the autonomous station - Antennas @ 1 m of the electronic box (0.8 nV.Hz$^{-1/2}$)

Anechoic chamber, radioheliograph and radiotelescope measurements @ Nançay







- **No noise radiated between 10 MHz and 4 GHz**
- **No self-induced triggering**

Evolution of the sensor concepts from 2002 to 2009

Sensitivity

Compactness

Log-Spiral Antenna (2005)
Circular polarization
Diameter = 5m
Heigh = 6m

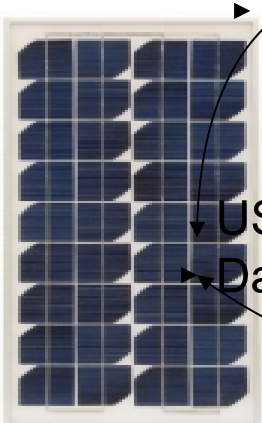
Active Short
Fat Dipole (2006)
length = 1.21m
Height = 1m
50E/Antenna

Self-Contained
Radio Station (2008)
2 polar.
f_{middle} ~ 65 MHz Length =
3.22m Height = 1.40m
3KE/Station
@ Nançay 1st station in 2009
@ Auger 1st station in 2010

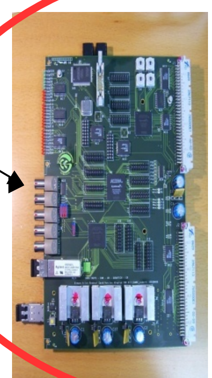
Designed for radiodetection studies !
… but probably not suitable for giant arrays (10000 km^2)…

Toward a next generation of stand-alone stations fully based on mainstream technologies

Consumpt.<2.5 W (5V*0.5A)
WIFI/3G...
Processing
Storage > 16Go
Cost<200E



USB link
Data & power



ADC
+ Trigger
+ GPS dating

All in radiator head

Power source: 10W (12V)
Surface 40*25cm
Cost <60E

Cost objective < 800 E/station

Consumption < 5 W

Mecanics < 10 kg

No civil engineering

Conclusion

=>Analysis and detection methods in a phase of detailed studies (see also LOPES results)

=>More detailed interpretation of observations needed
+ theoretical developments are various… and in great progress...

=>Autonomous radiodetection now a reality (see also AERA)

=>EAS radio detection not far from being ready for intensive use...
First ideas for the futur are being...

Thank you for your attention