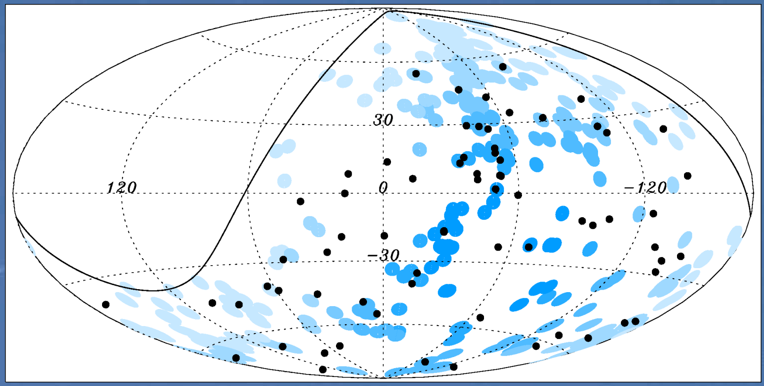
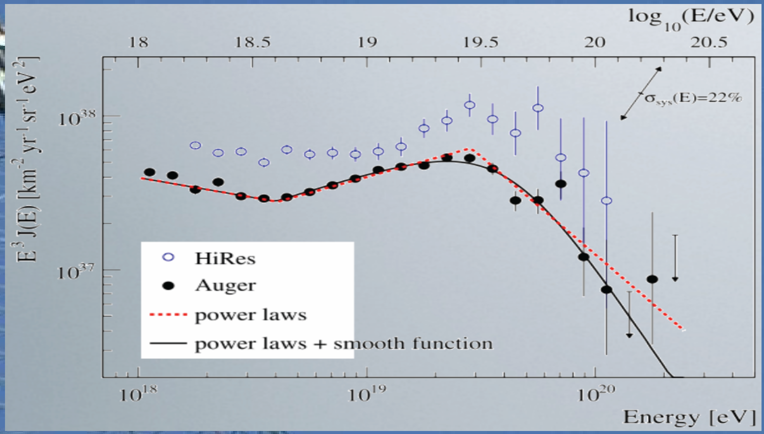
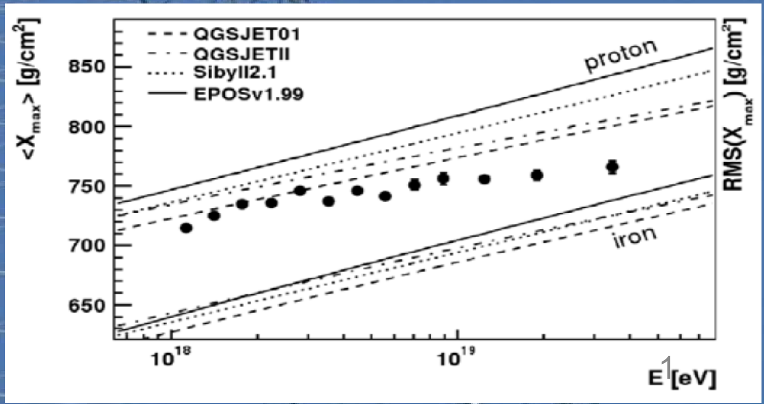
# Radiodetection (of UHECRs from ground)

**P. Lautridou Marseille 06/04/2011**

Auger data 2010




## What Challenges ?

- **Current limitations due to flux & detectors...**
  - Sources
  - Energy limit
  - Composition

## => How to ?

- **Surface, duty cycle, primary composition, cost, ...**

## => What could bring radiodetection ?

# The development of the radiodetection

**1962:** **Article** of Askaryan

**1964:** **First experiment** (Weekes et al.) + emission mechanism (Jelley et al.)

**Early 70:** **Method neglected** (problems of interpretation + success of other techniques) (review of Allan)

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**End 90:** **Revival for detection in dense materials** (neutrinos in ice, salt, sand)
+ proof of principle with accelerator (Saltzberg et al.)
+ detection attempt of EAS @ CASA-MIA (Green et al)
+ P. W. Gorham

**In 2002:** **Experiment LOPES @ KASCADE => Frequency analysis**
**Experiment CODALEMA @ Nançay => Waveform analysis**
H. Falcke et al., Nature, May 19, 2005, P. Lautridou et al. NIM A555, 2005

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**Prospectives from 2006: AERA @ PAO, TREND @ 21CMA (neutrinos), + balloon, ice - In 2007 mechanism of molecular bremstralung: MIDAS, EASIER, AMBERS…**

**=> More than 14 experiments underway around world…**

**=>Multi-sites, multi-antennas, multi-analysis, multi-Messengers**

# Models

**Since 2002, a temporal + frequency approach for modelisations & detection + Trigger considerations**

**•Monte-Carlo: microscopic approaches**

**Spectrum analysis in frequency space**

REAS3: Corsica shower model + geosynchrotron

ReAIRES: Géomagnétic effect

**•Semi-analytical: macroscopic approaches**

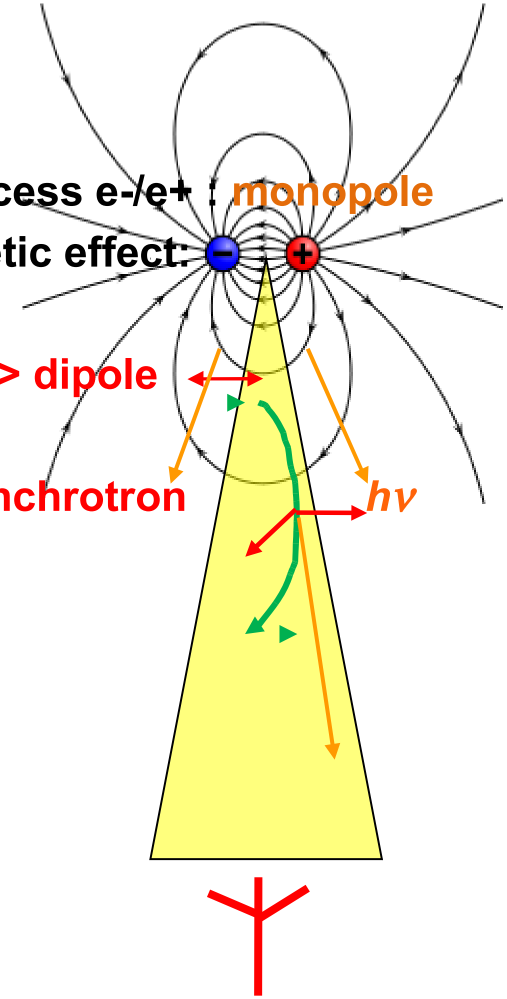
**Waveform analysis in time space**

MGMR: Simple description of showers
+ Transverse + Dipole currents

SELFAS2 : geosynchrotron

+ **Several toy models: test of specific points**

- Charge excess, Coulomb boost emission, Air index,
- Cerenkov, Wire model, Compton Inverse model, etc.

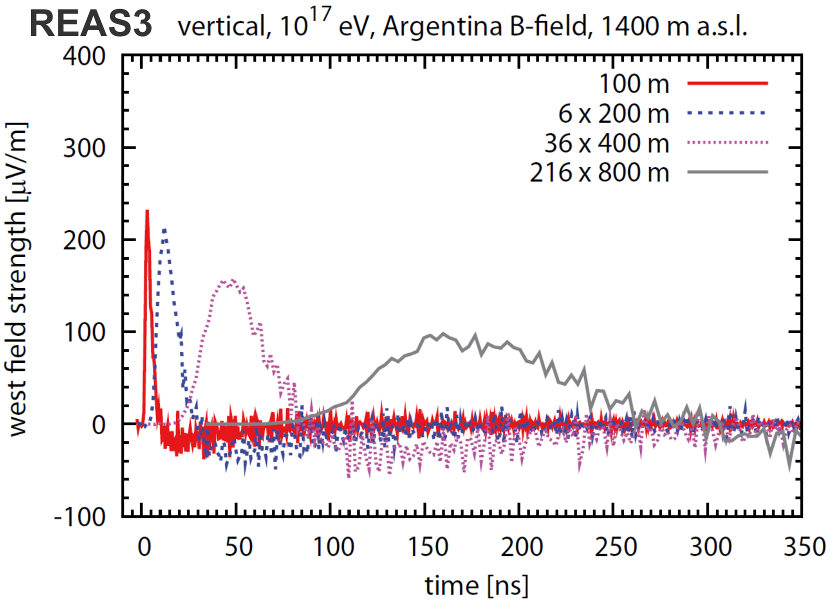


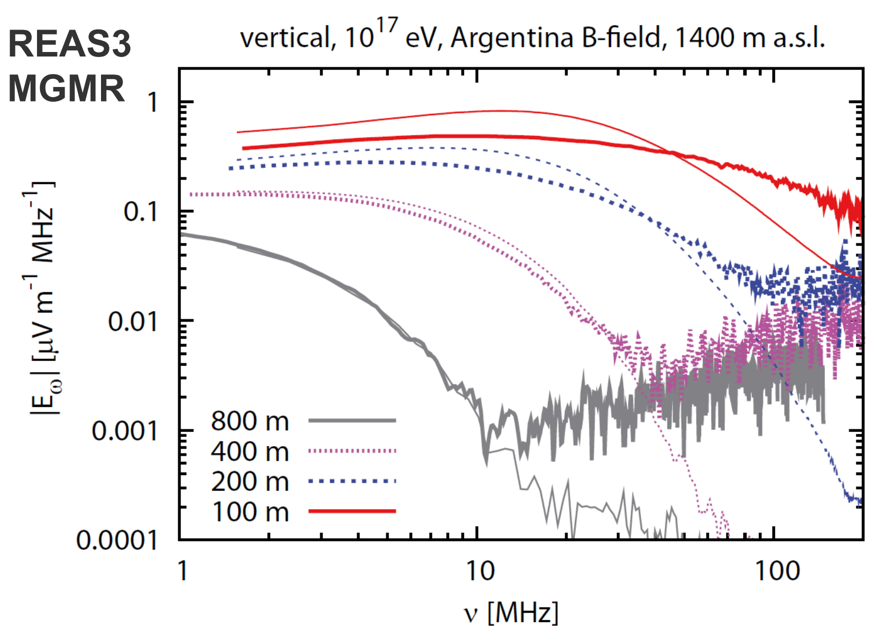

**⇒Toward a convergence of the theoritical predictions**
**⇒But some experimental results not fully described**

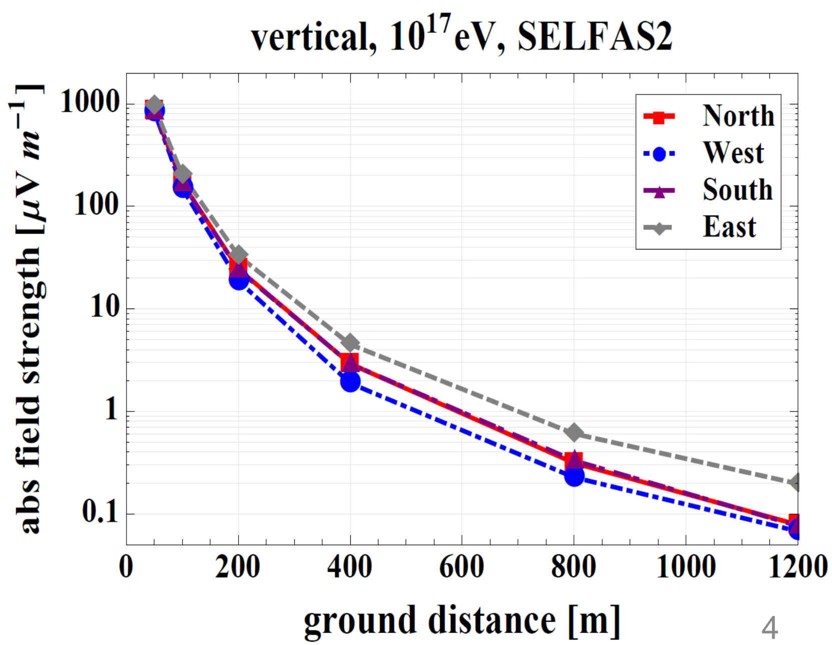
# Models: Results

## Signal features firmly established

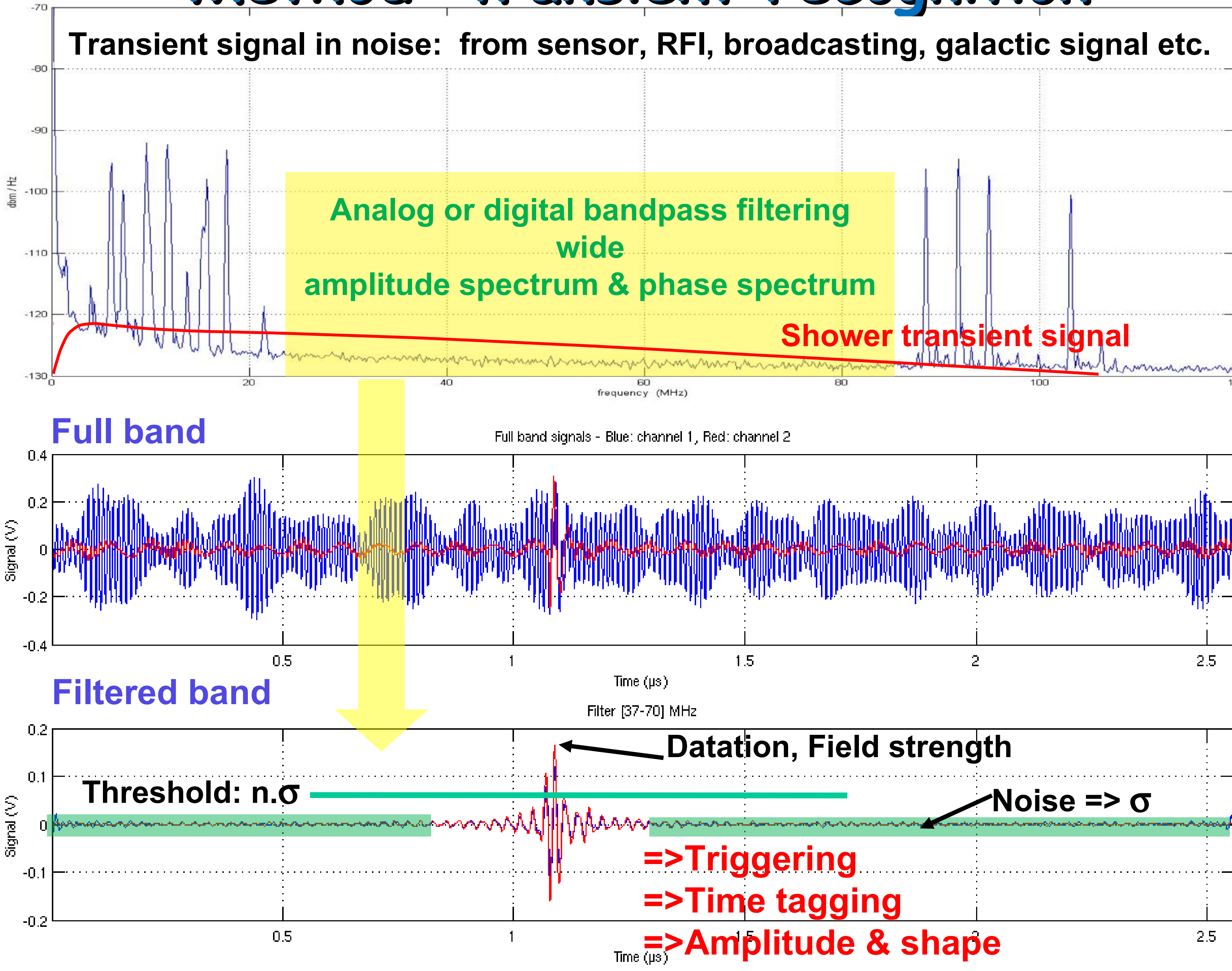
**Field amplitude:** from µV/m to mV/m
**Transient duration:** from ns to µs
**Frequency spectrum:** broad band emission from MHz to few hundred MHz
**Shape :** longitudinal development
**Arrival time**



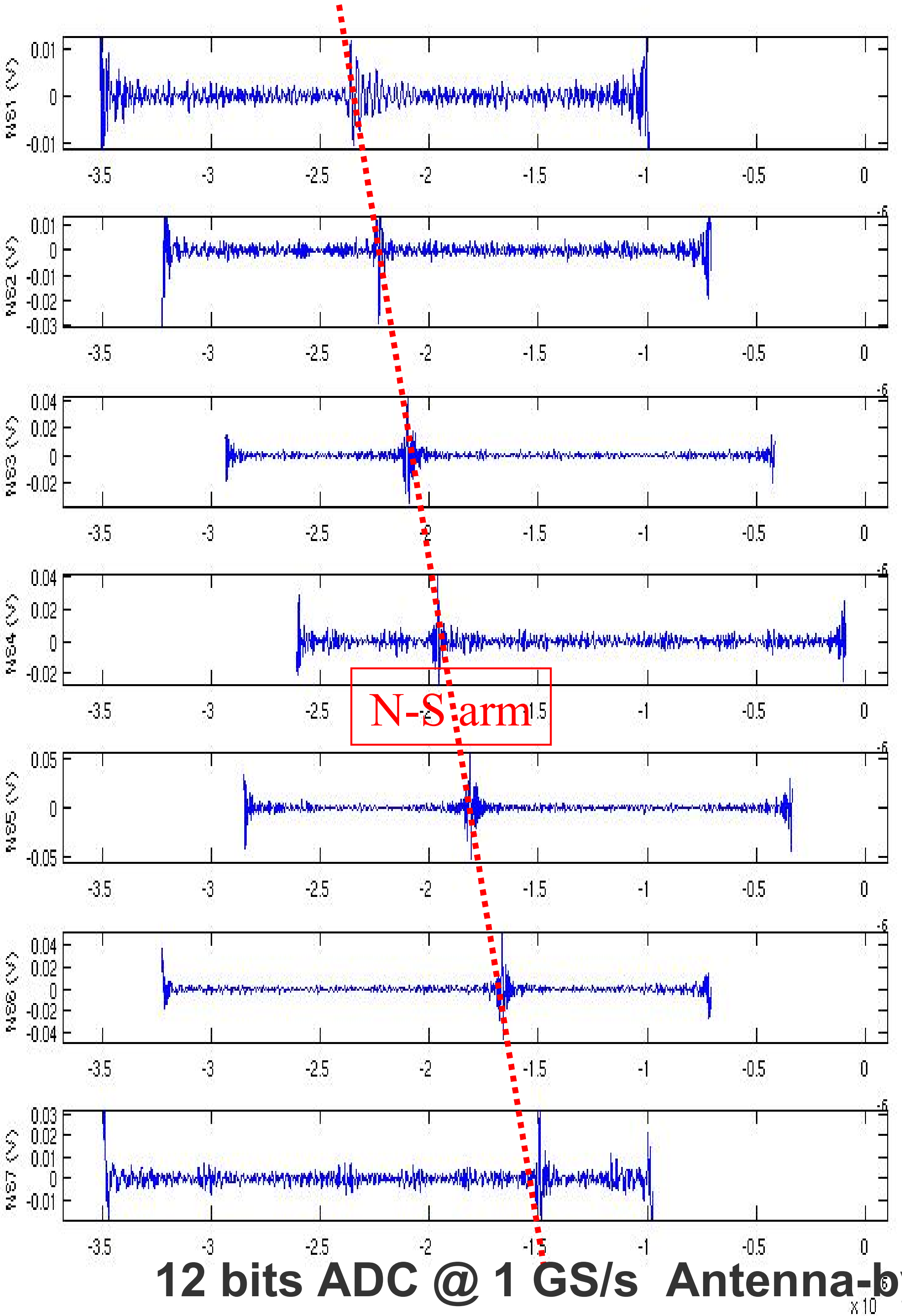



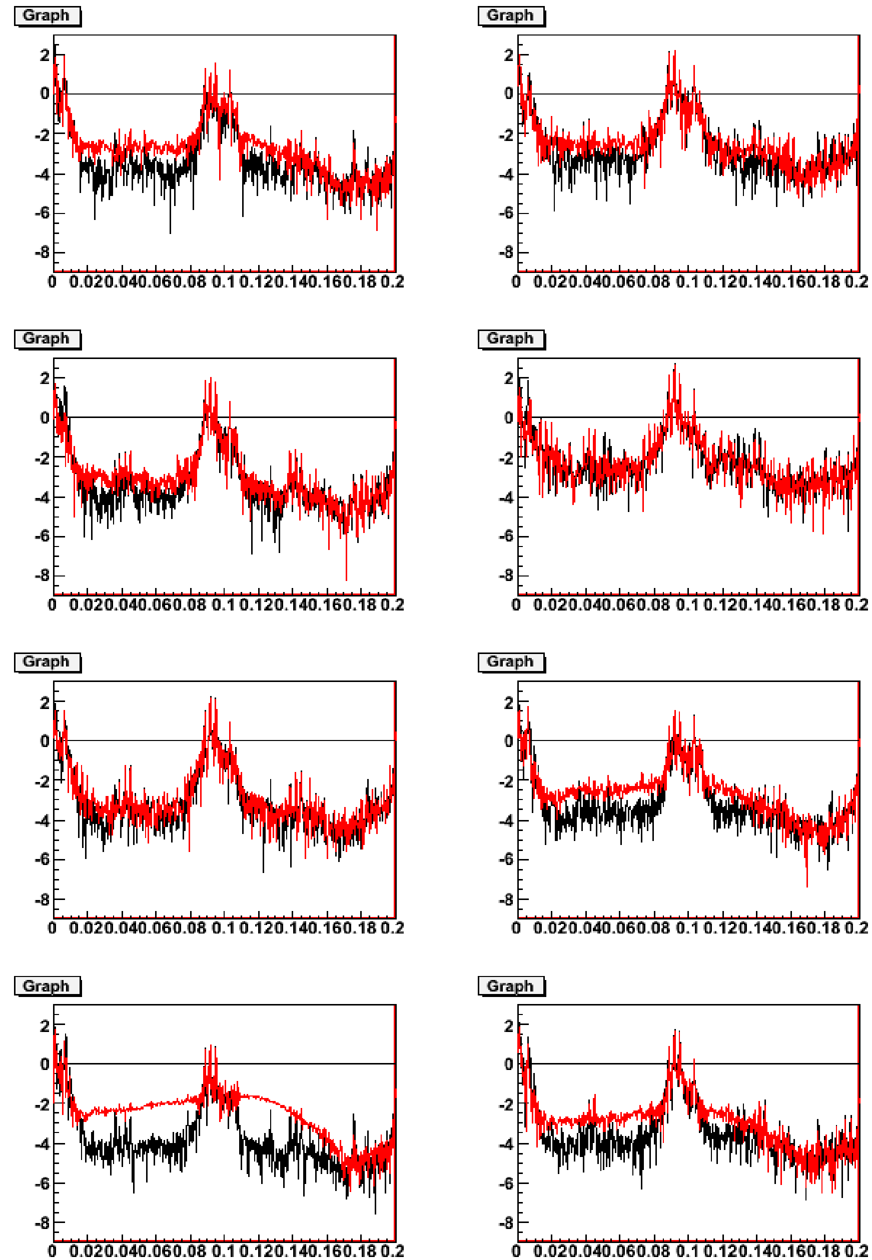



# Method: transient recognition



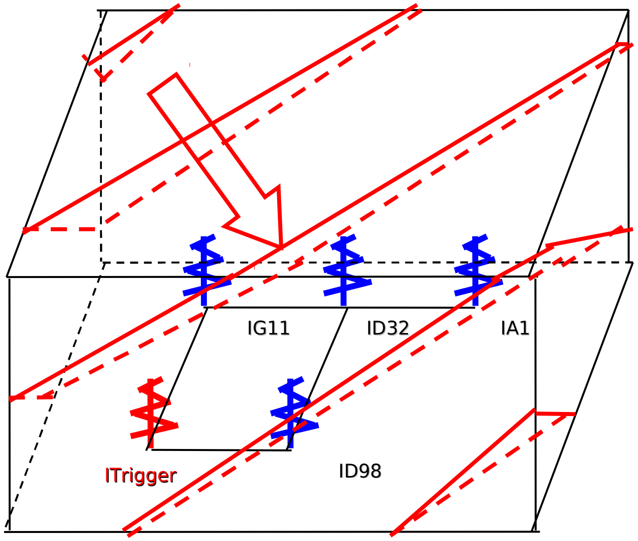
# A shower event in E-W pol. @ E~$10^{17.5}$ eV (23-130 MHz) CODALEMA



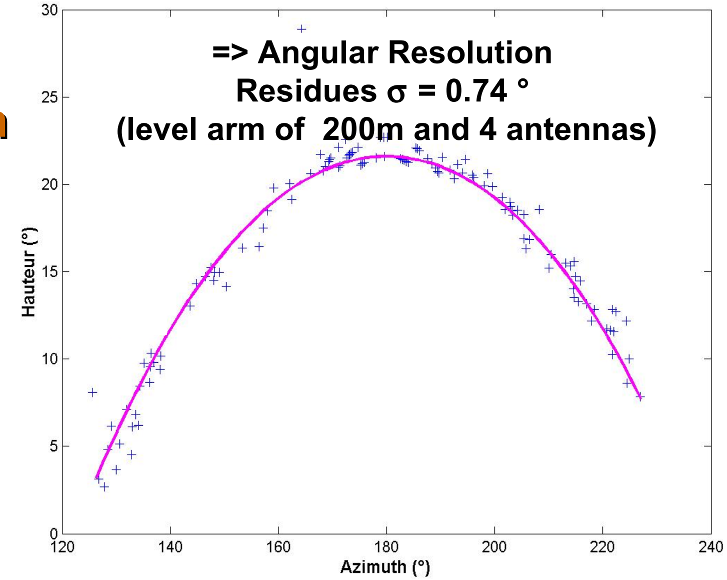

**12 bits ADC @ 1 GS/s Antenna-by-antenna & Event-by-event analysis**

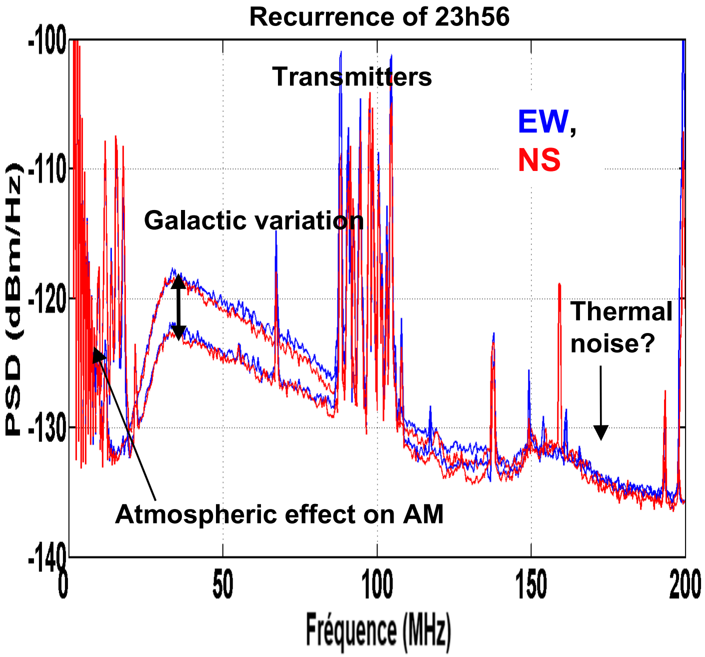
# Method: calibration




In
arrival direction
=>using solar
flares

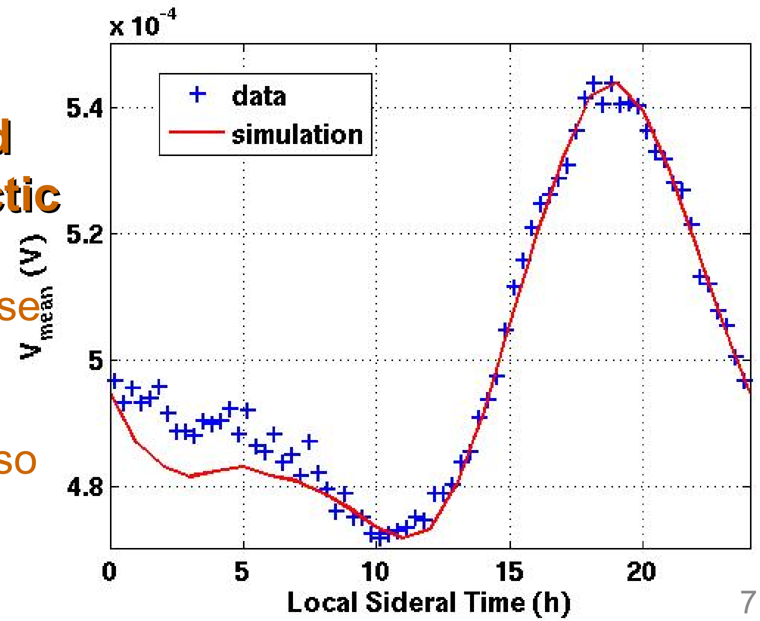
(with beacon also LOPES)



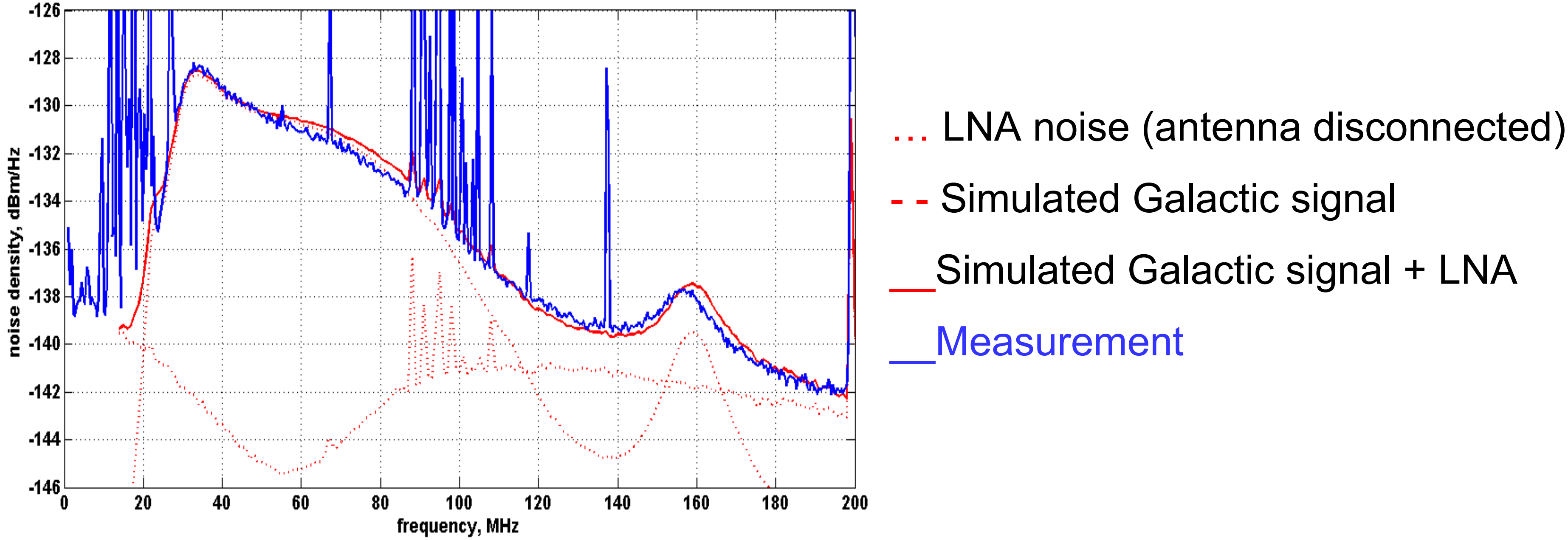




In
electric field
=>using galactic
signal
(Irreductible noise reached)

(with beacon also LOPES )

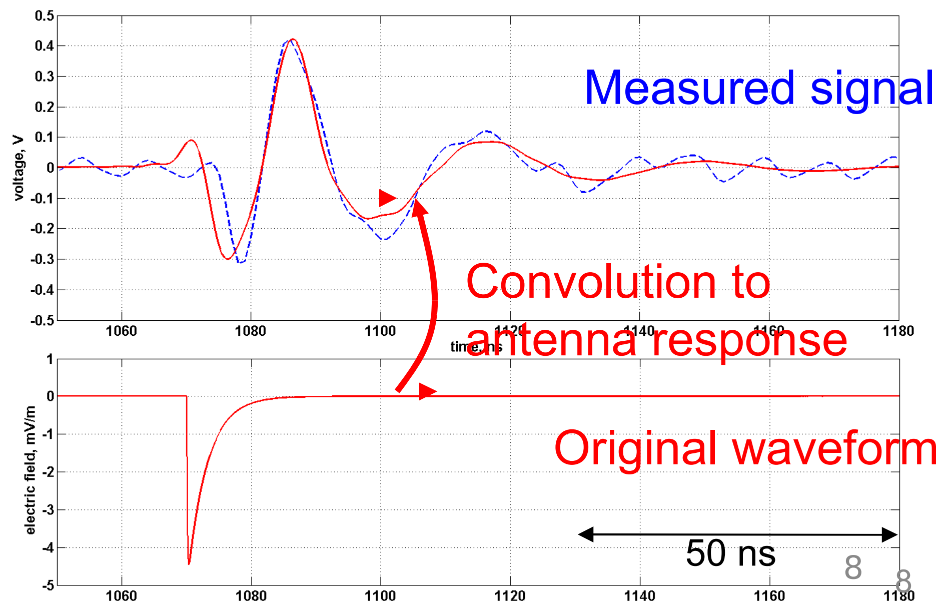


# Method: toward full signal deconvolution




**Simulation of the signal shape in the temporal space**

⇒In principle could fully describe the shower with a single antenna (amplitude ~ energy, duration ~ distance, polarization ~ direction)…





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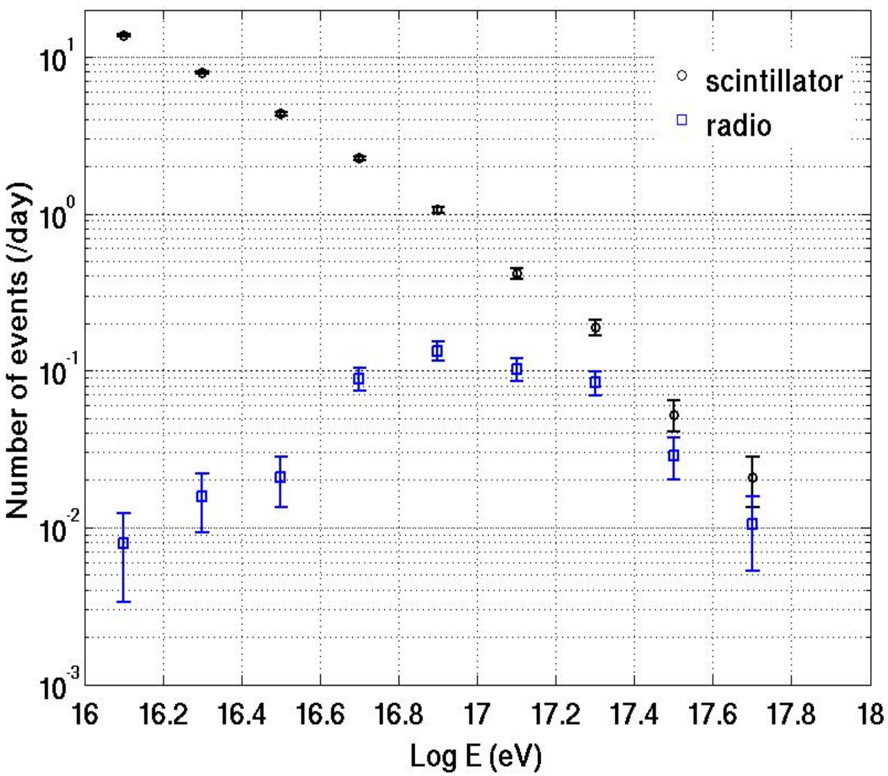
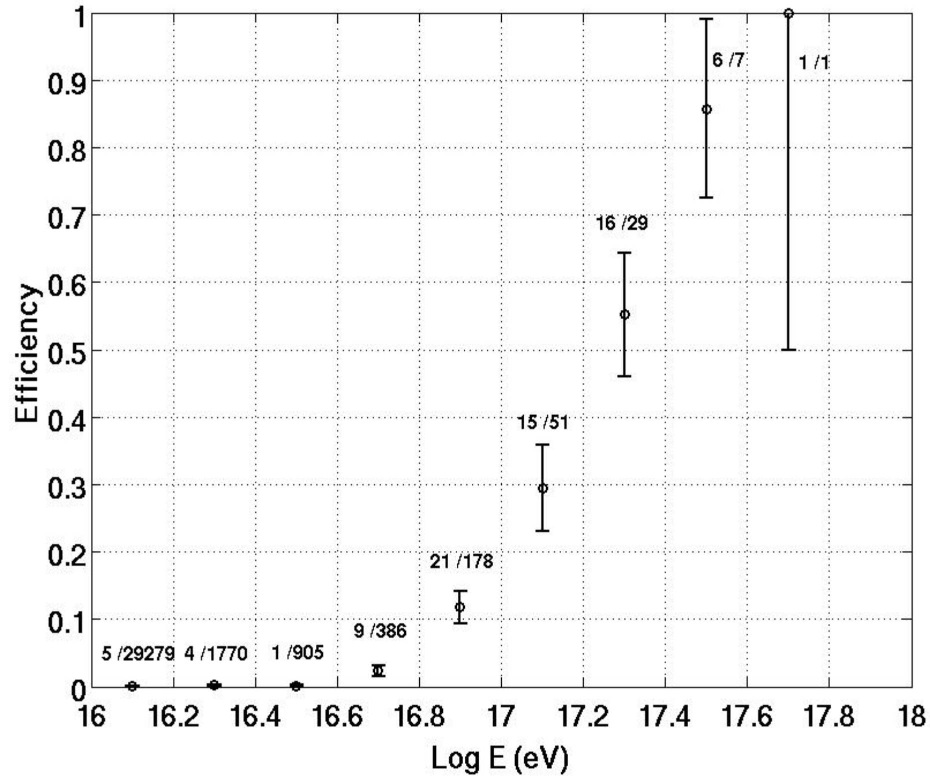
# Results: detection efficiency



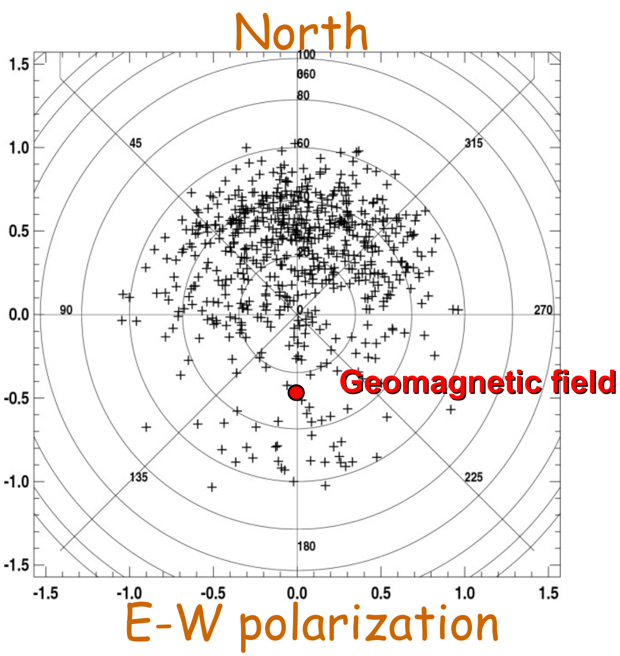




**Full efficiency reached @10$^{18}$ eV with E-W polarization**

**⇒Expected improvements (x10) using the detection of the full states of polarisation + better antenna lobes + better SNR**

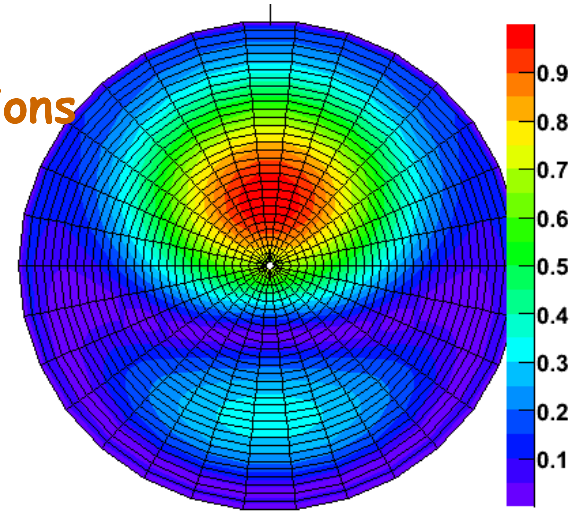
⇒ Detection threshold mainly attributed to the mechanism of emission

# Results: emission mechanism

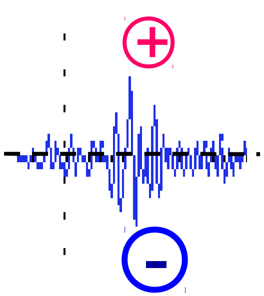


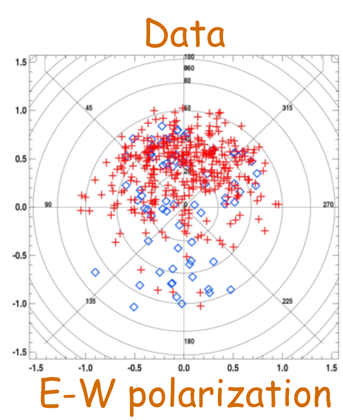

=>Detection at threshold correlated to arrival directions
=>GEOMAGNETIC EFFECT

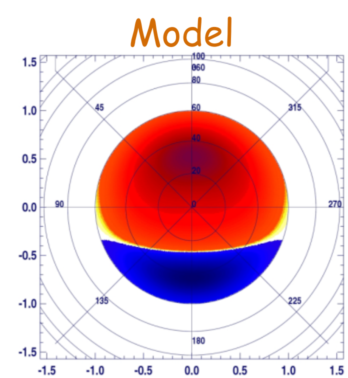
**CODALEMA toy-model & AIRES calculations:**
**Field Strength ~ $|VxB|_{E-W}$**



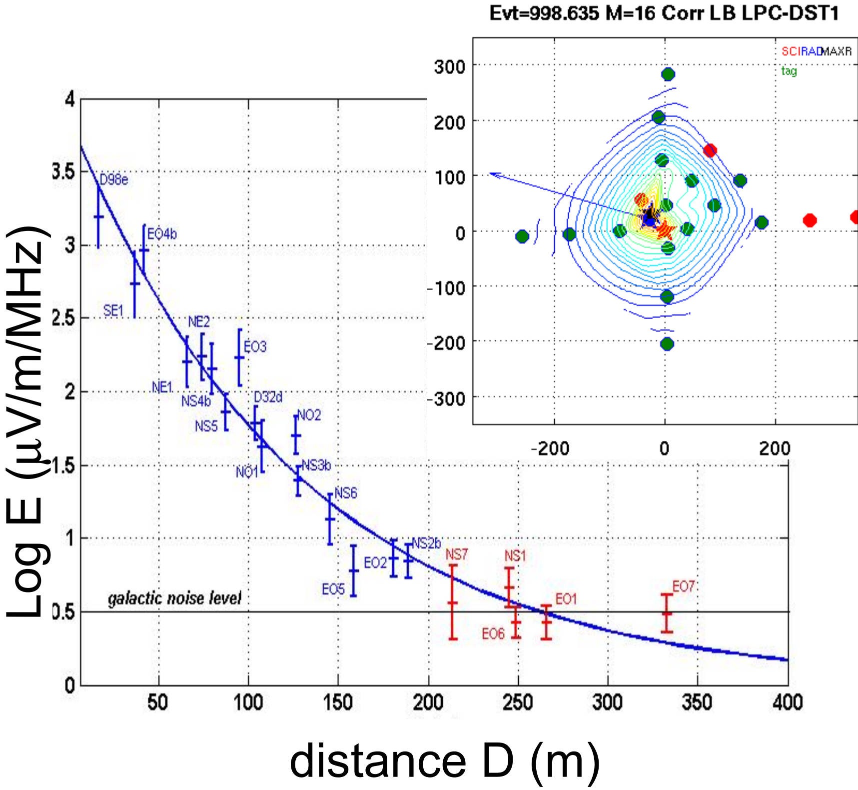

- Corresponding pattern observed in N-S polarization
- Corresponding pattern observed at AUGER (opposite geomagnetic field direction)
- Pulse polarity consistent with the model in both polarizations E-W and N-S



# Results: energy calibration

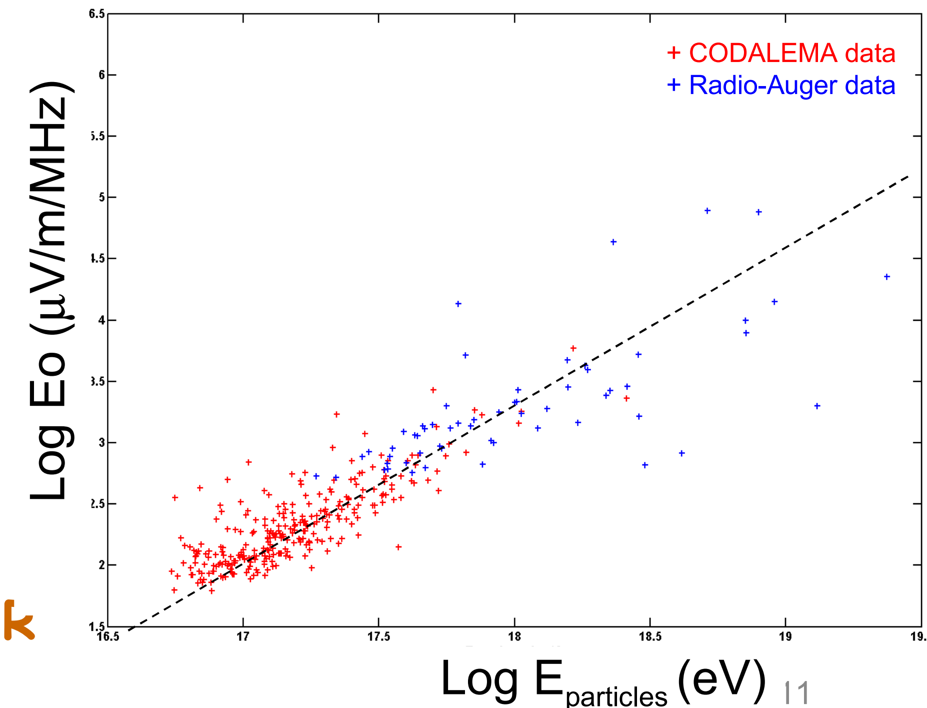



Interpretation of the lateral field distribution with the ALLAN formula:

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

=> After fit: $E_0$, $D_0$, core position

=> $E_0$ as energy estimator for radio ?




$\mathbf{E_{radio} = E^{\alpha}_{particles}}$ with $\alpha \sim 1.\pm0.1$

=> almost full coherence reached

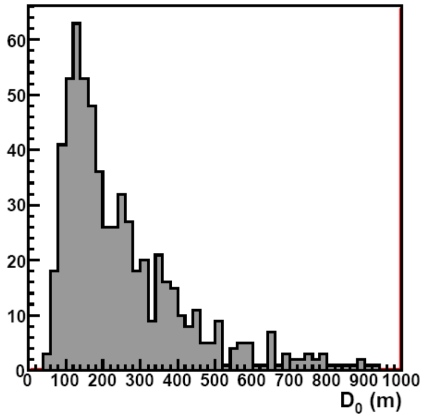
(with $\sigma_{particles} \sim 30$ % => $\sigma_{radio} \sim 15$ % ?)

**Expected improvements with E-W+ N-S detection and with better SNR & deconvolution controls**

# Primary composition

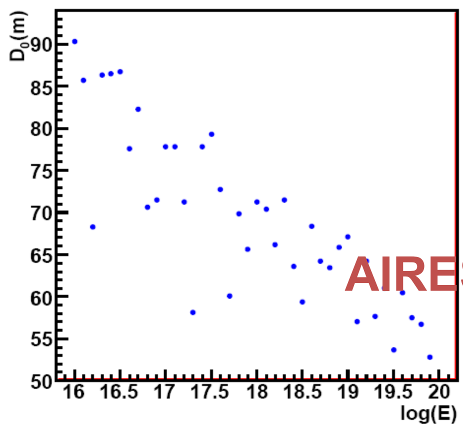
(currently under investigation)

**Following the REAS3 model:**

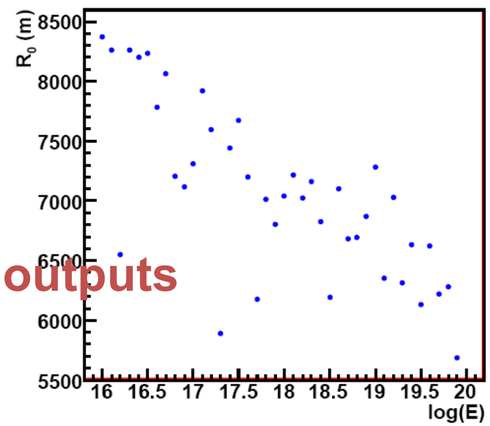


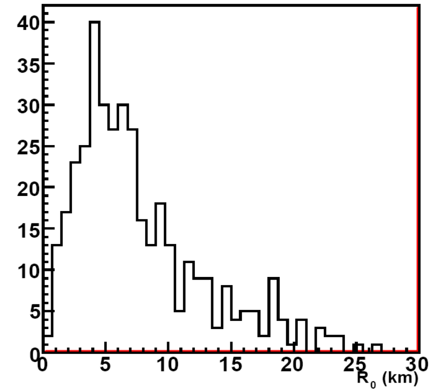

Slope $D_0$

**$D_0$ sensitive to Xmax**



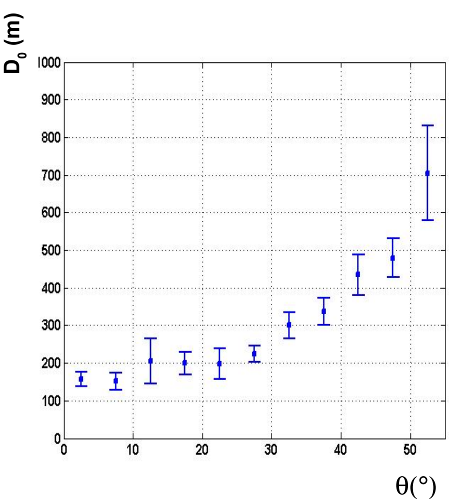

AIRES outputs



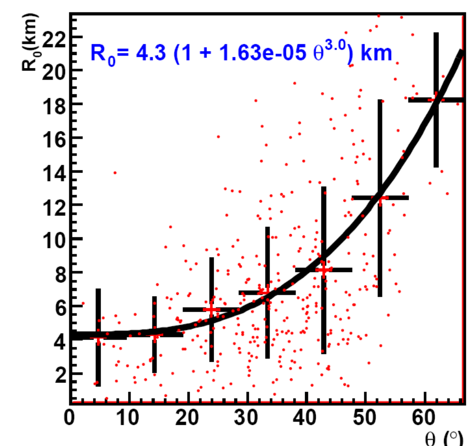

Curvature $R_0$

**$R_0$ sensitive to Xmax**




**⇒Variabilities well observed but…**

**CODALEMA & LOPES must gain in accuracy on these observables**



# Robustness of the method

**From 2008 various points raised by LOPES & CODALEMA**
**=> High complementarity**

## Environment effect

- Near environments on the antennas (electrical conductors): < 10%
- Stormy conditions: duty cycle > 80%
- Frequency BW: 24-82 MHz well determined

## Impacts on the observables (at low SNR)

. Versus Signal/Noise: flattens $D_0$ by < 10%, Increase $E_0$ by < 5%

. Frequency window: $D_0$, $E_0$ < few %

- Time calibration: accuracy < 1 ns => using beacon
- Passband filters dispersion: $D_0$, $E_0$ < 5%
- Sampling frequency: >> 10 * frequency BW
- Absolute fied strengh : < 35 % using beacon

## Conception and test of Autonomous stations

# Evolution of the sensor concepts from 2002 to 2009

Self-Contained
Radio Station (2008)
2 polar.
$f_{middle}$ ~ 65 MHz
Length = 3.22m
Height = 1.40m
3KE/station

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

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

AERA
Log periodic (2009)
2 polar.
Diam = 6m
Heigh = 6m
Digital trigger

LOPES 3D (2009)
Thin dip. 3 polar.
1 m2

LOPES 2D (2005)
V shape dip. 2 polar.
Diameter = 2m
Heigh = 1.5m

# The CODALEMA stand-alone station

**First stand-alone operational detector**

Based on

dedicated LNA

Bw: 80kHz - 200MHz

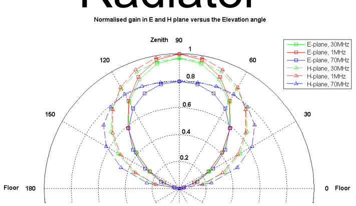
Input noise: < 1nV/√Hz (30MHz - 200MHz)

Max input dyn.: 24mVp-p

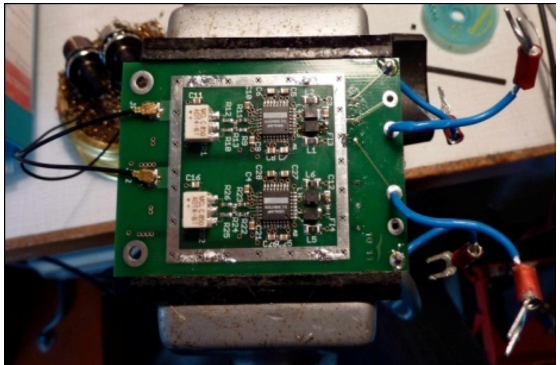
$C_{in}$ = 9pF

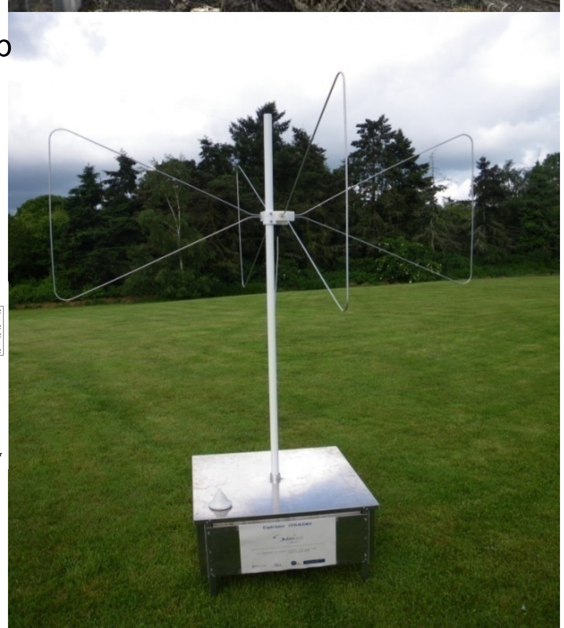
Consumption : ¼ W

Radiator




2 polarization states





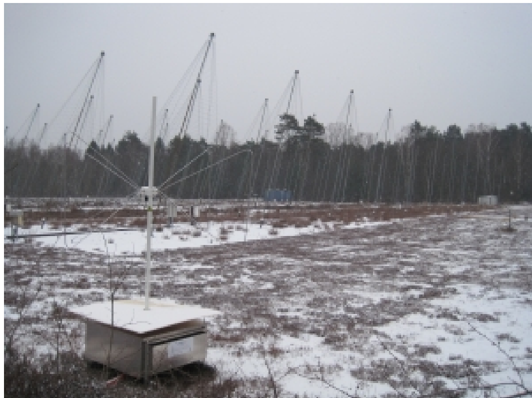
- Waveform 14 bits, 1GS/s, 2.5 μs
- GPS timing resolution: < 5 ns
- Trigger: @ galactic threshold
- Acq. rate: 25 evt/s
- Local Memory (1 day of run)
- pre-processing (including higher trigger level)
- Transactions based on intermittent exchanges of data (every hours, day…)
- External triggercapacities

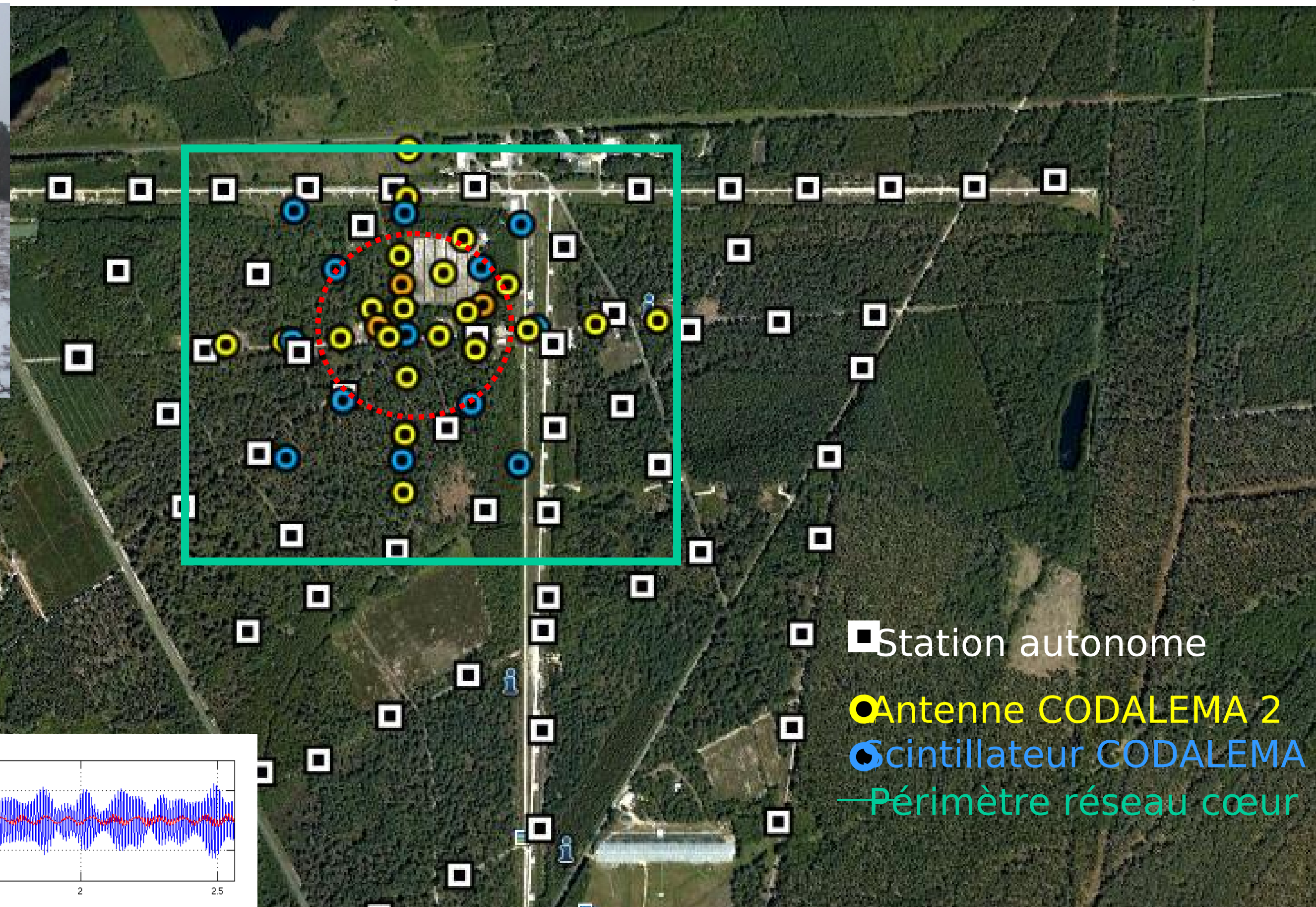
**+ Open solutions for**

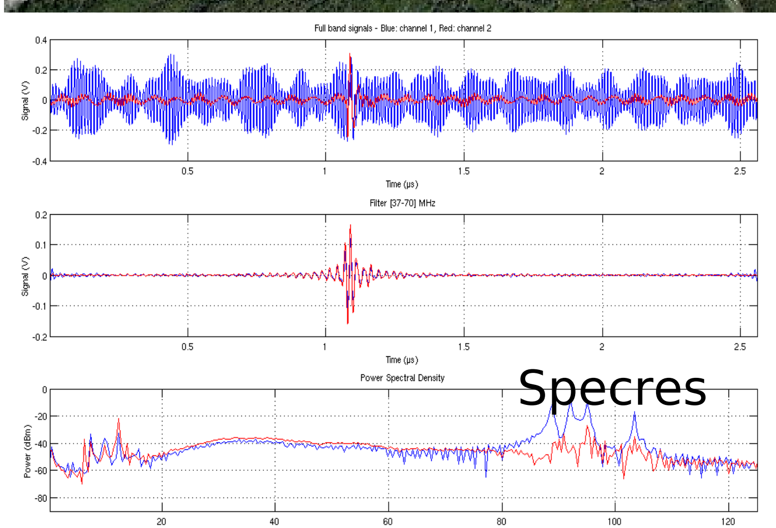
- Outer world: WiFi (@ PAO), GSM, 3G, Ethernet (enbedded mini-switch @Nançay),…
- Power: Solar (@ AUGER), Wind, 220V (enbedded 220-12V transformer @ Nançay )…

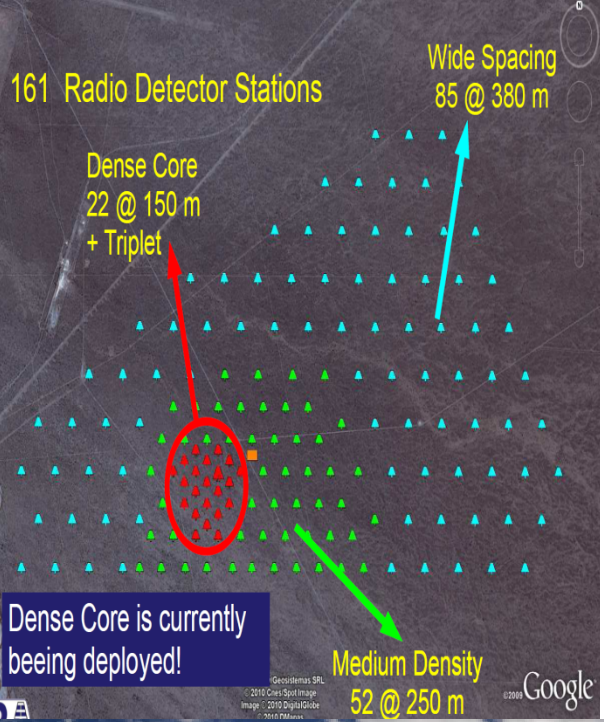
Consumption: 20 W

# CODALEMA 3 : concept of multi-scale array



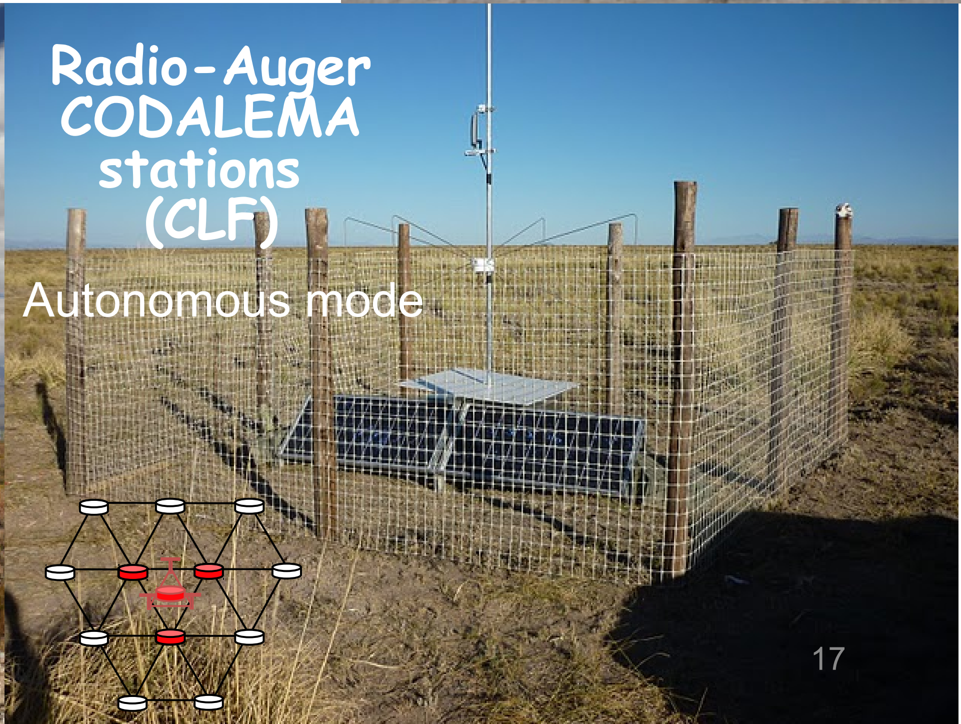


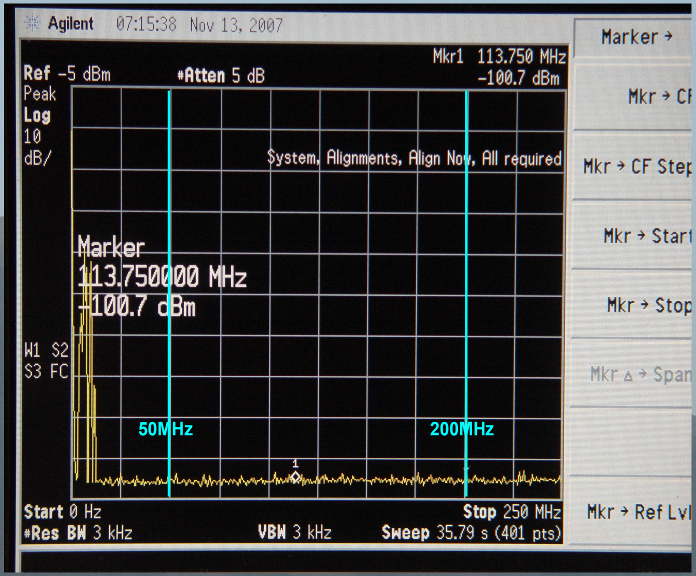



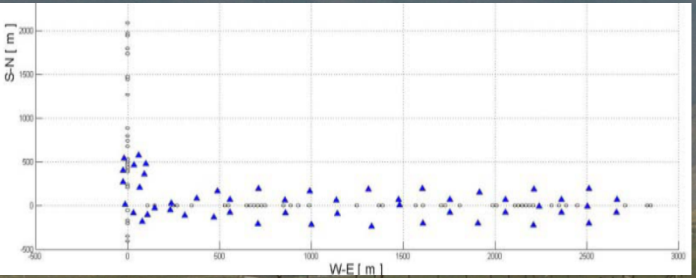

# Radiodetection developements @ AUGER

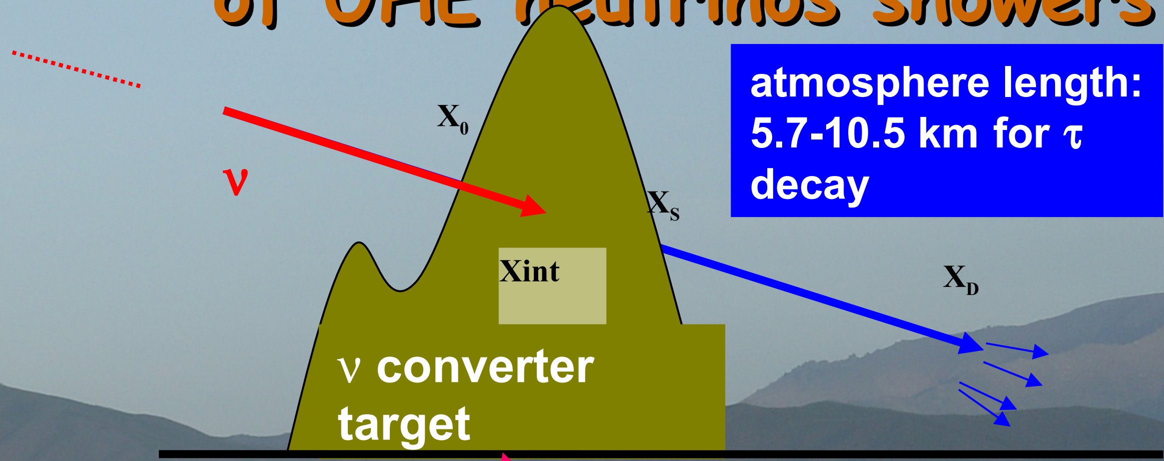




# TREND @ 21CMA:observation bench of UHE neutrinos showers



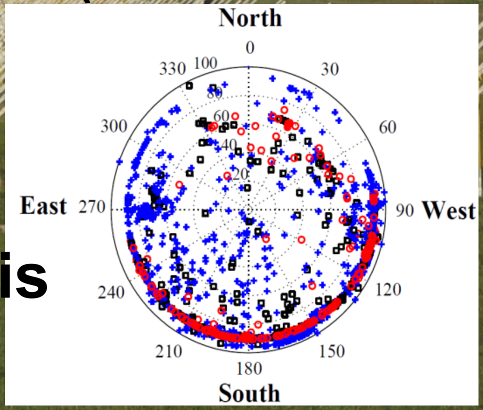



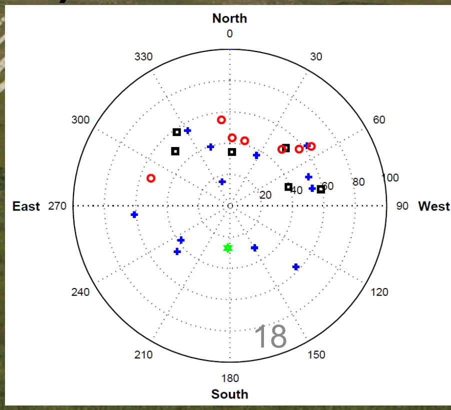




**atmosphere length: 5.7-10.5 km for τ decay**

Target & shield volume :
20 000 km$^3$

**10287 (50-200 MHz)**
**log- periodic antennas**
**2 arms (4km NS +3km EW)**




- **Bench test for a different technique of detection & analysis**
- **Inclined showers**

# Molecular Bremsstralhung

**Geo-Magnetic-Radiation Model**

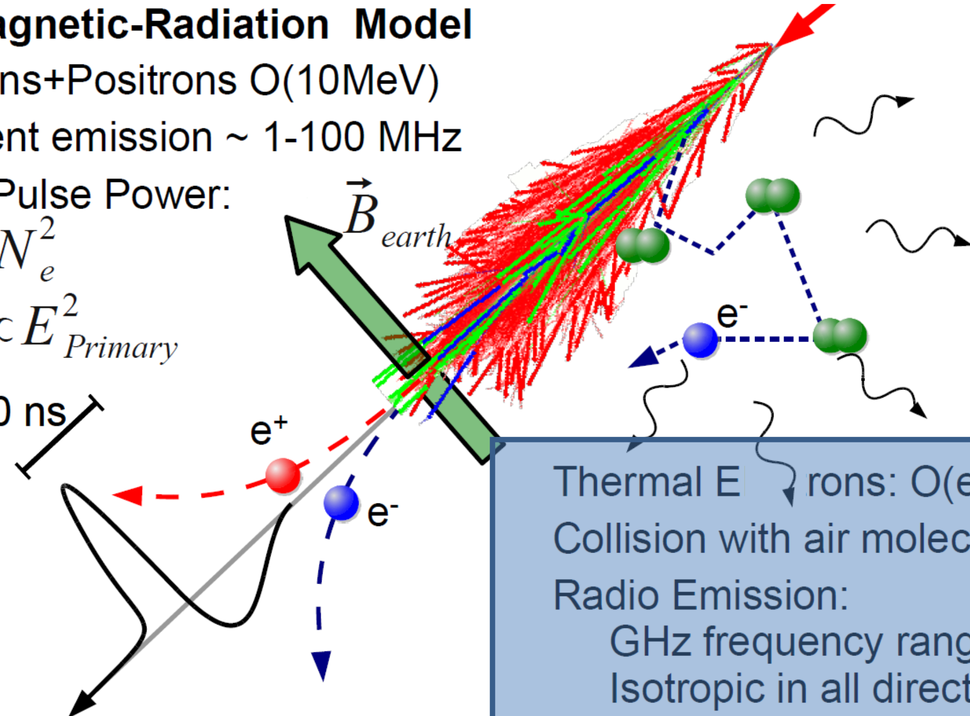
Electrons+Positrons O(10MeV)

Coherent emission ~ 1-100 MHz

Radio Pulse Power:

$\propto N_e^2$

$\propto E_{Primary}^2$




Thermal E rons: O(eV)

Collision with air molecules

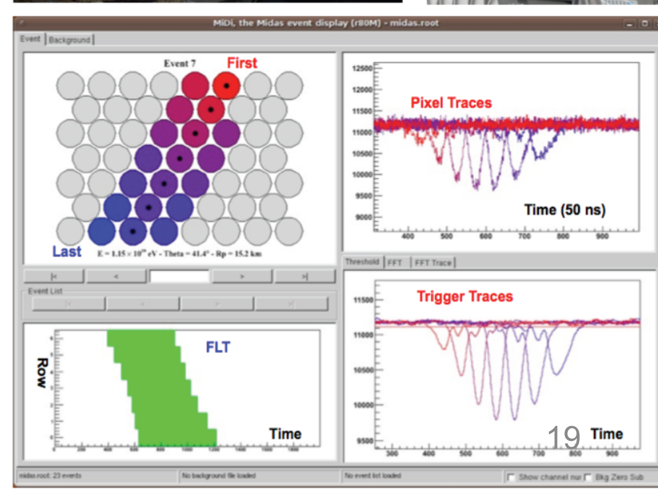
Radio Emission:

GHz frequency range

Isotropic in all directions

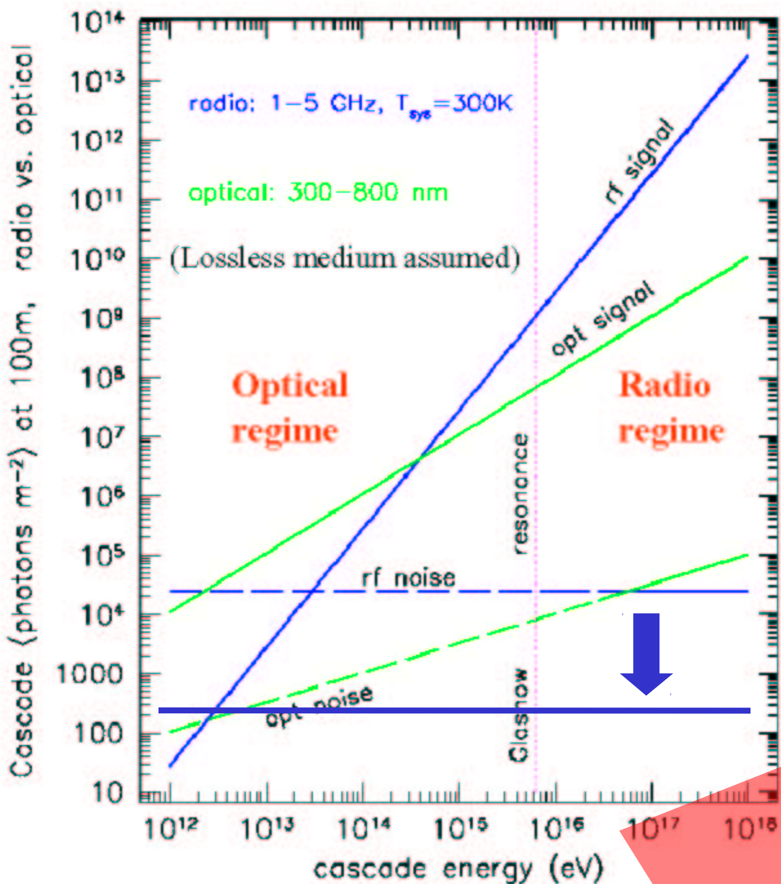
**Molecular Bremsstrahlung**

Imager
MIDAS – AMBER
(AUGER)




GHz Power detector
EASIER
(AUGER)

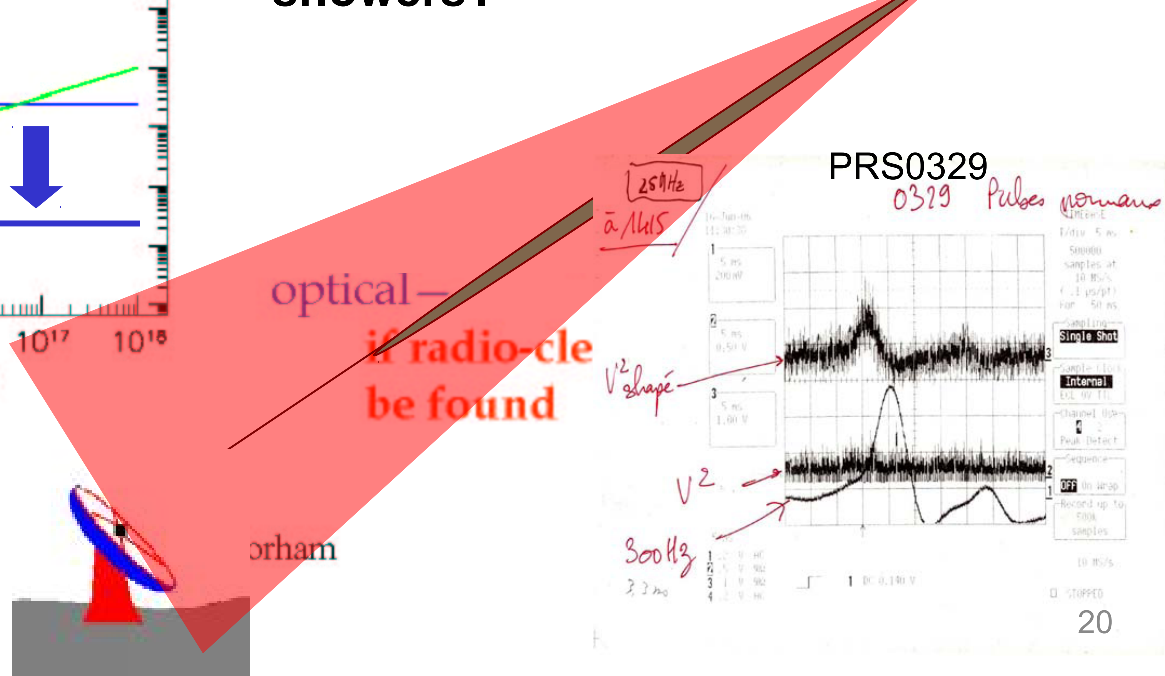
# Radiodetection « à la HESS » @ $10^{12}$ eV ?




Radiotelescope with beamforming
( < mn of arc @ RT de Nançay)

Detection of the radio Č transient
Trigger et waveform analysis
High duty cycle

Recognition of hadronic showers?

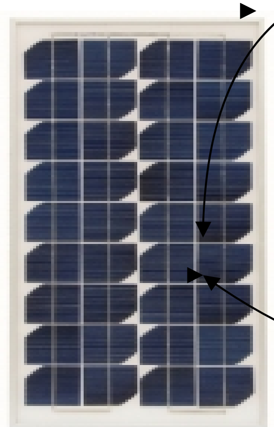



Fréquency ~ 1 GHz
Floor = 3 K°
⇒Tsys ~ 20 K°

Current design for radiodetection studies not suitable for giant arrays (10000 km2)

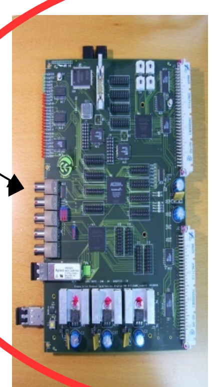
# Toward a second generation of stations: fully based on mainstream technologies

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



USB link

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



ADC
+ Trigger
+ GPS dating

All in radiator head

**Cost objective < 800 E/station**

**Consumption < 5 W**

**Mecanics < 10 kg**

**no civil engineering**

# Epilogue

=>Analysis and detection methods are in stage of stabilization and have entered in a phase of detailed studies (see also LOPES results)

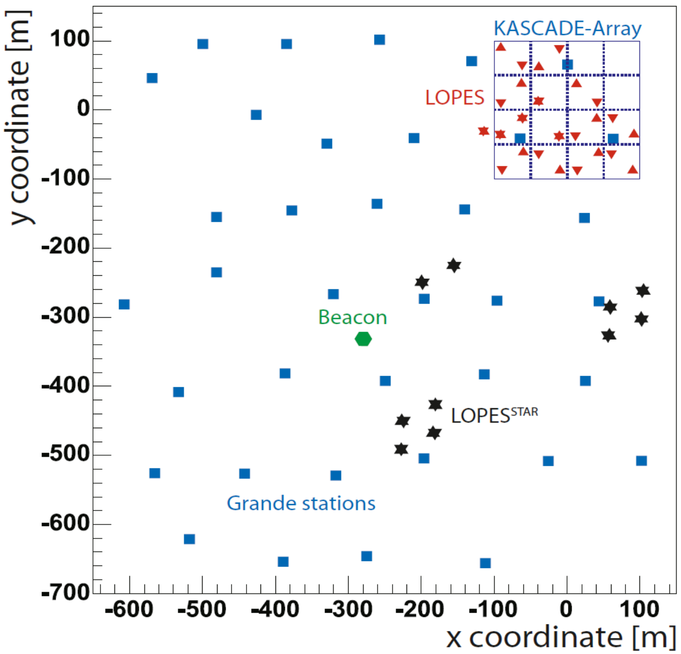
=>Theoretical developments must now be conducted at the end...

=>EAS radio detection is not far from being ready for intensive use...

=>The crippling handicap of the 60's is lifted…

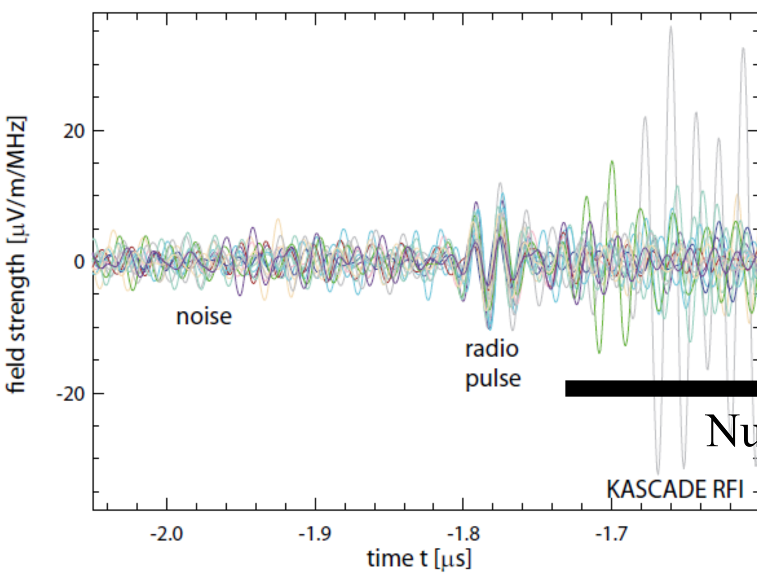
Thank you for your attention

# LOPES/10/30/Star/3D

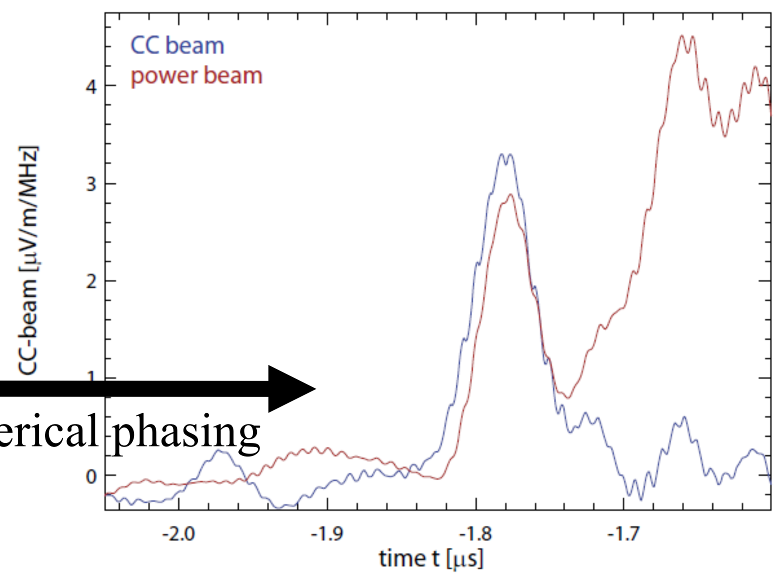



**Trigger + shower**
**Features: KASCADE**

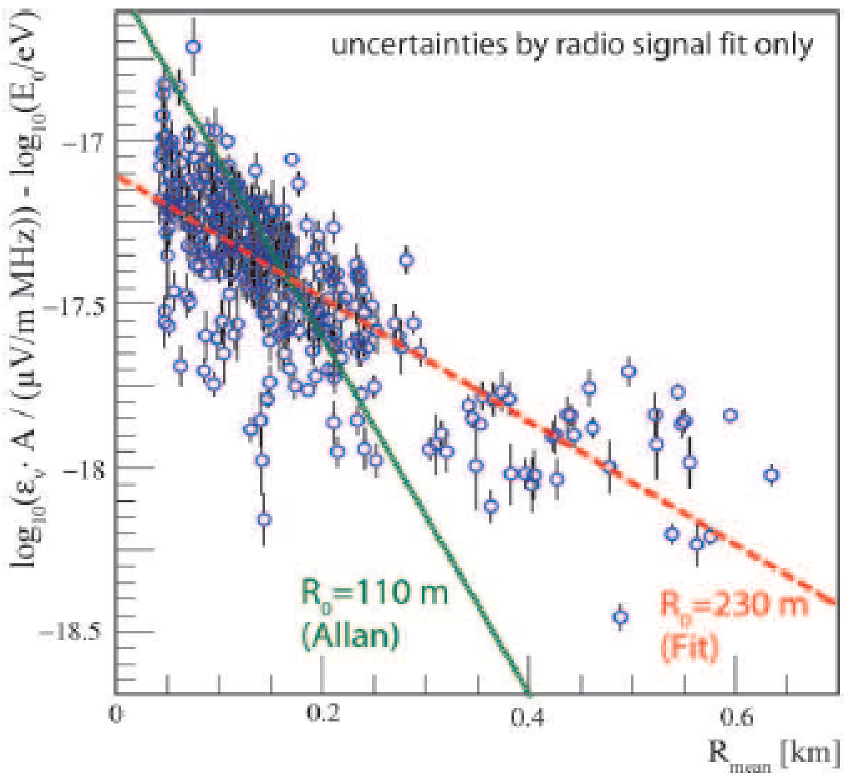
Bandwidth: 40-80 MHz
Sampling: 80 MS/s



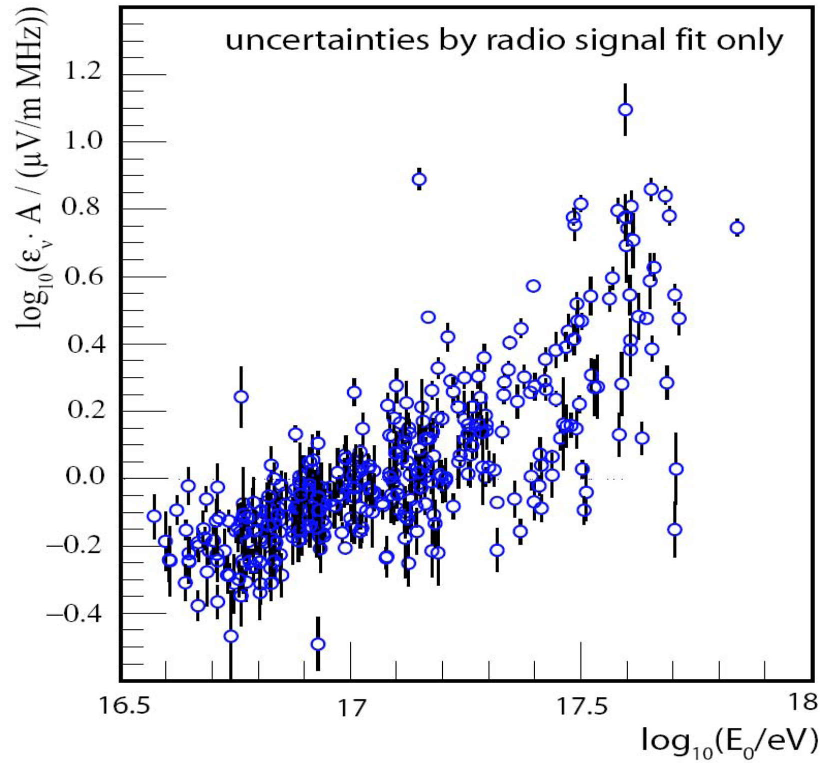

Numerical phasing



# 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

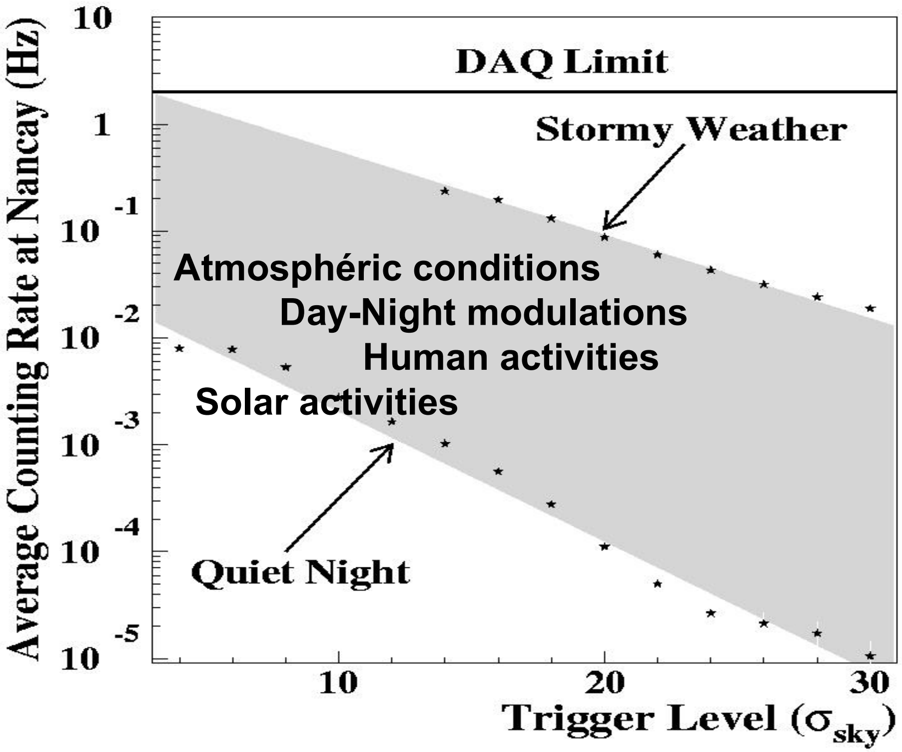
$$\varepsilon_{est,E_p} = (12 \pm 1.8)\left[\frac{\mu V}{m\ MHz}\right](1 + (0.1 \pm 0.03) - \cos(\alpha))\cos(\theta)$$
$$\times \exp\left(\frac{-R_{SA}}{(200 \pm 45)m}\right)\left(\frac{E_p}{10^{17}\,eV}\right)^{(0.91 \pm 0.07)}$$



Norm
consi
MC si

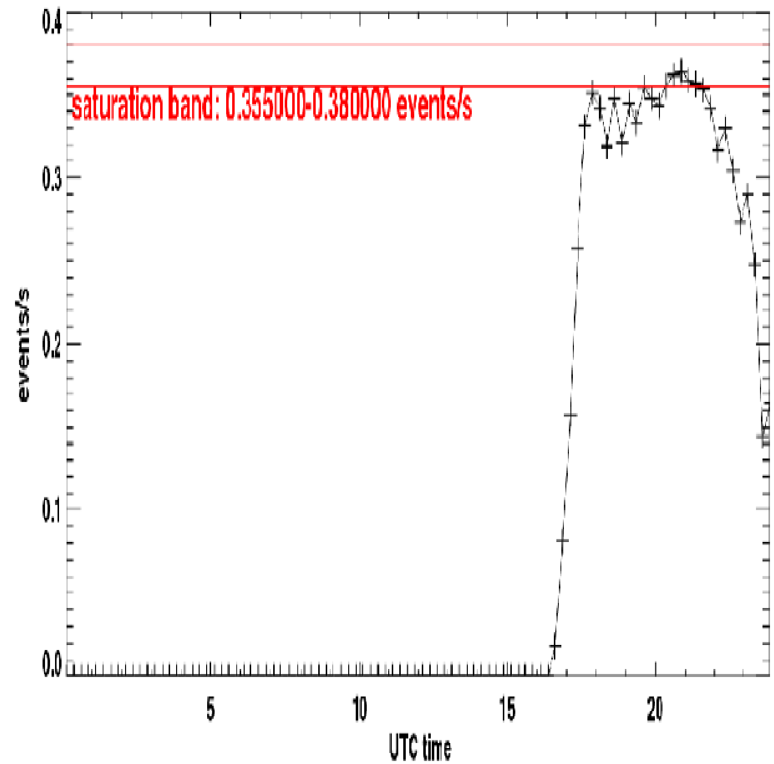
# Trigger capability & Transient background

**2004 : Trigger rate in 33-65 band with 1 antenna @ Nancay**




=> Triggering with antenna is possible in stand alone mode

**2006 : Trigger rate in 50-70 band with 1 antenna @ PAO**



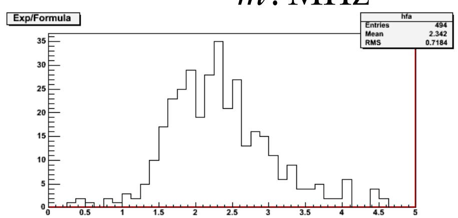

Trigger Rates depend of the site (& of the frequency band) …

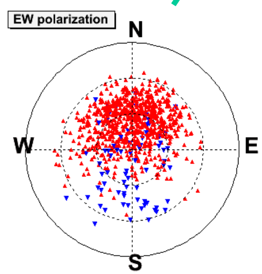
Orage 80% cycle utile (garcon)

# From CODALEMA results to the simulations codes for detection setups => overall parameterization

$$E = E_0 \left(\frac{\mu V}{m\,.\,MHz}\right) .\, \Delta\nu\,(MHz)\,.\,\frac{E}{10^{17}\,(eV)}\,.\,\frac{-\beta \times B}{|\beta|.|B|}\,.\,\frac{|B|}{47\,(\mu T)}\,.\,F(\theta)\,.\,\exp\left(\frac{-d}{D_0(\theta,\nu)}\right)\,(\mu V/m)$$

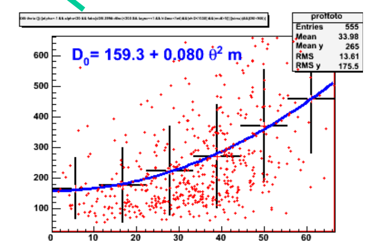
$$E_0 = 2{,}3\ \frac{\mu V}{m\,.\,MHz}$$




$$F(\theta) = \cos\theta$$

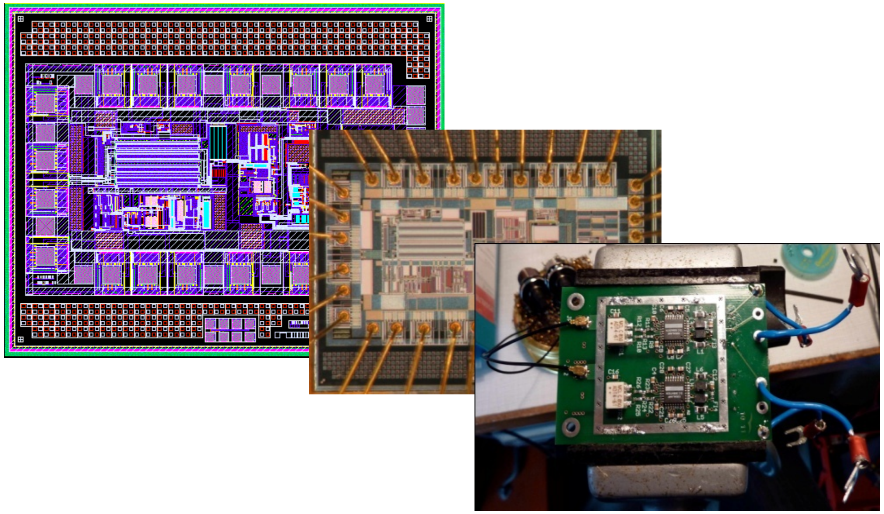
for 'historical' reasons. Need statistics @ high zenith angle to refine.




## ⇒Applied to radio-detection networks (CODALEMA, AERA…)

**Effects of array pitch, shape, magnetic field, altitude, detection threshold, acceptance, multiplicity, bandwidth, polarisation…**

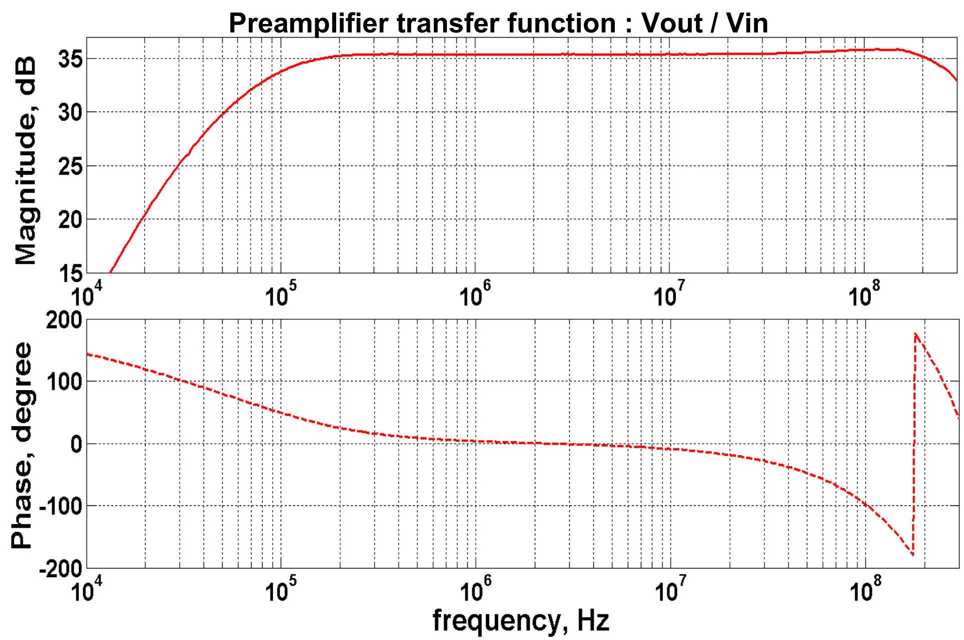
# The ASIC LNA of CODALEMA



**A large band FE ampl.**

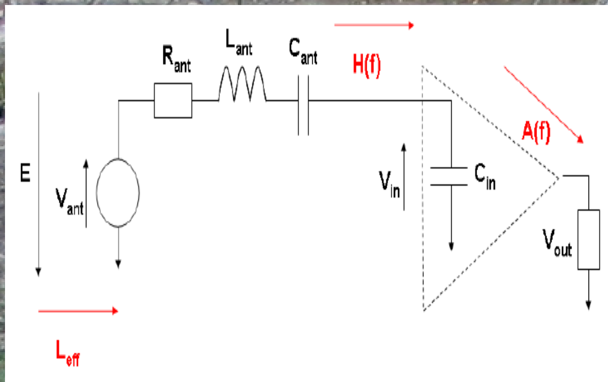
Design independant (as possible) from the antenna in ASIC based on

- High input inpedance
- Differential Output



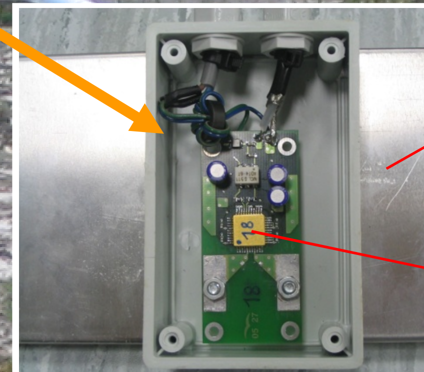

- Bw: 80kHz(limited by the output transformer) to > 200MHz
- Preamp.input noise: Less than 1nV/√Hz from 30MHz to 200MHz
- Max input dyn. : 24mVp-p
- $C_{in}$ = 9pF
- Consumption : ¼ W

=> New planned developments: more optimized @ low frequency + in AMS BiCMOS 0.8 micron + adjustable gain from 48 to 55 dB




# With flat active dipole antenna

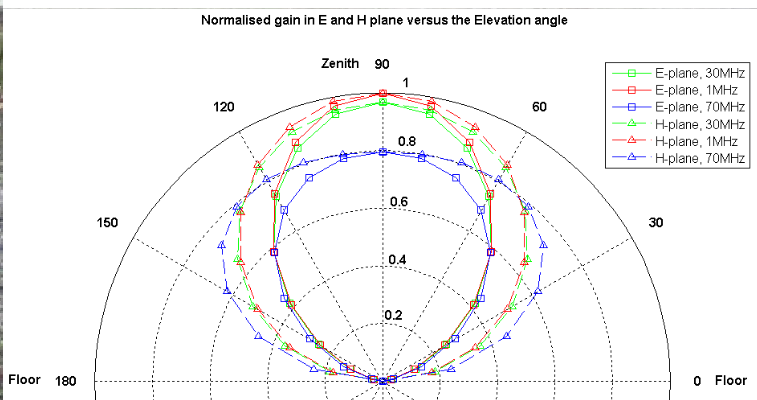
(Performances also determined by the matching Radiator-LNA, inputs filters, PCB design…)

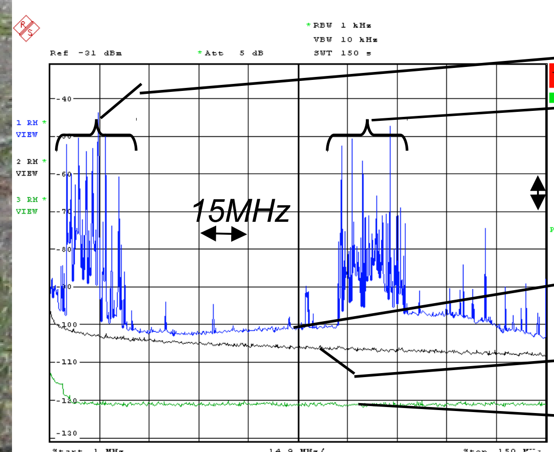



Constant directivity, No side lobes from 100kHz to 70MHz

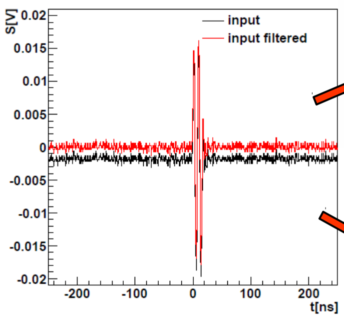
-H-plane: half beamwidth=120°

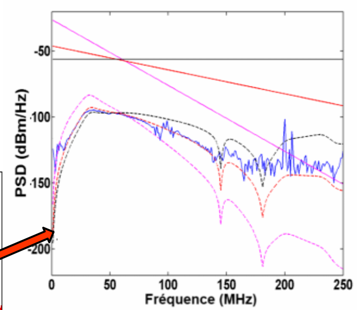
-E-plane: half beamwidth=90°

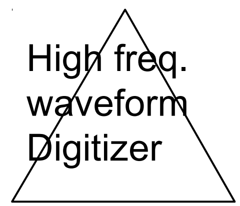


# Waveform captures…



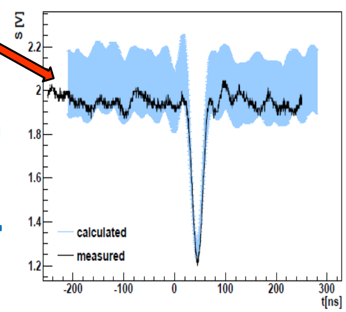



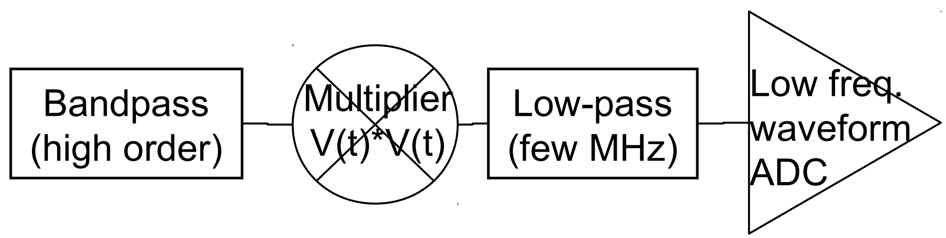




- Least distorded waveform,
- Allows frequency studies
- High time and amplitude resolutions

Apparent simplicity of electronics

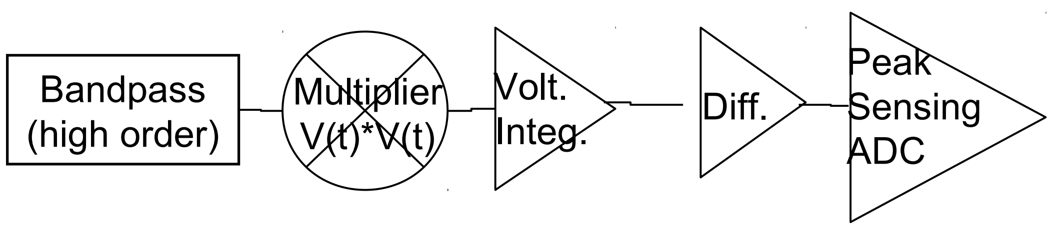
- but… High data flux & power consumption, Technologic traps…




- Low power
- Allows dating
- but …no frequency !

Can be also a trigger technics !




- Perfectly mastered
- Irreductible data flux (1 word/evt !)
- High integration
- Cheaper technology