

COSMIC RAY RADIO DETECTION: LATEST NEWS FROM CODALEMA

Richard Dallier

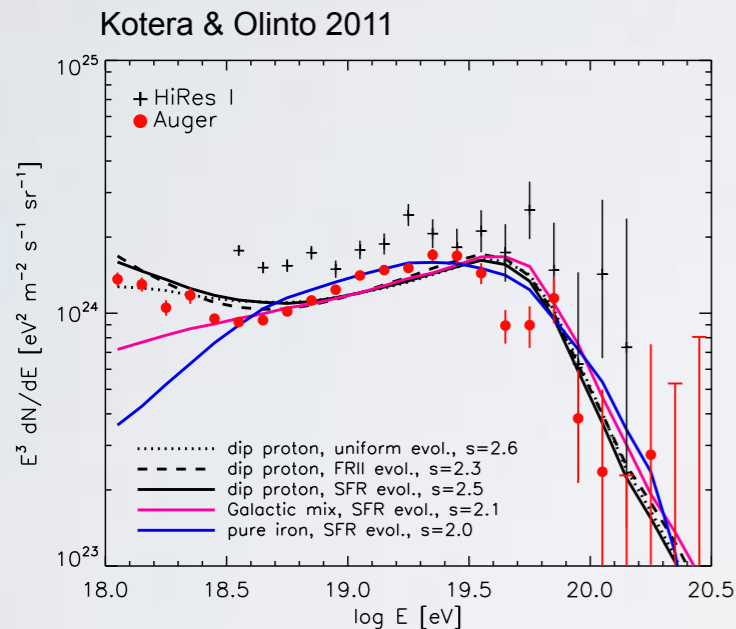
Subatech, CNRS/IN2P3 - Ecole des Mines de Nantes - Université de Nantes

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REMAINING CHALLENGES

Spectrum

Ankle: galactic/extragal. transition?
 e^+/e^- pair production depletion?
 High energy cut off: GZK ? Source acceleration limit?
 Source horizon?

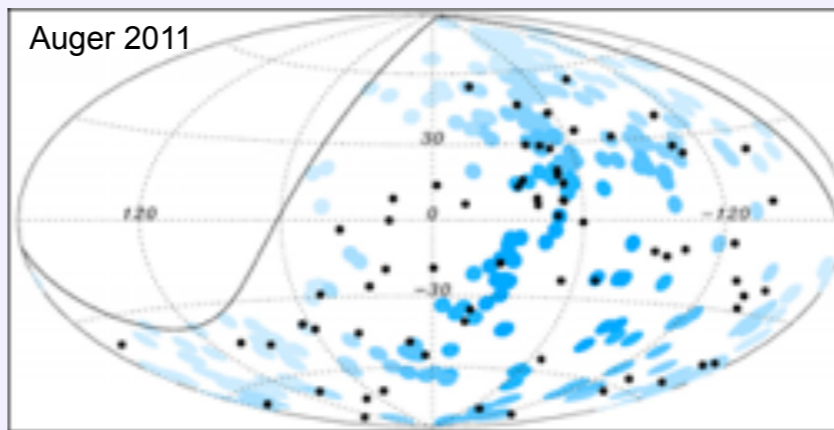


Needs

Higher statistics at high energy
 Better energy resolution
 Coverage of North hemisphere
 Measure of spectral index & **composition**

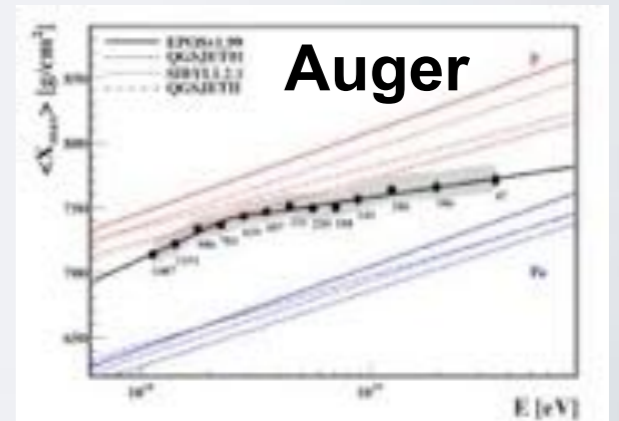
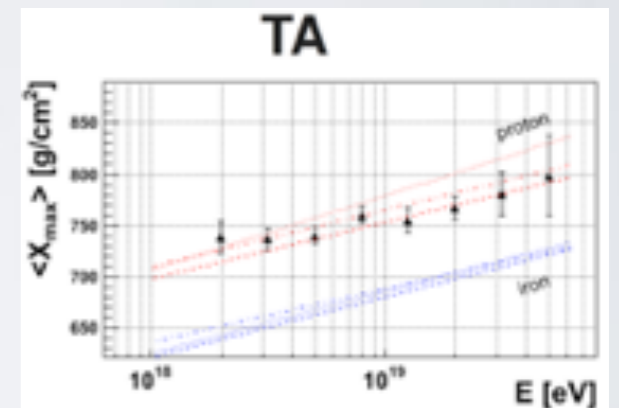
Sources

Auger : $E > 55 \text{ EeV} \Rightarrow$ Anisotropy
 HiRes/TA don't confirm !
 AGN (Auger : 3σ) ? Cen-A ?



Composition

Heavier at high energy: seen by Auger, but not HiRes nor TA!
 \Rightarrow Difference North/South sky ?
 Statistics ? Analysis method ?



WHAT ANSWERS ?

The solution would be a new giant instrument at ground

- Higher statistics at high energies:
detection surface $10 \times S_{\text{Auger}} \Rightarrow 30000 \text{ km}^2 !$
- Energy resolution, spectral index and **composition**:
more accurate measurements \Rightarrow **Multi-hybrid detection ?**
- Timeline \approx 15 years ?

Radio detection ?

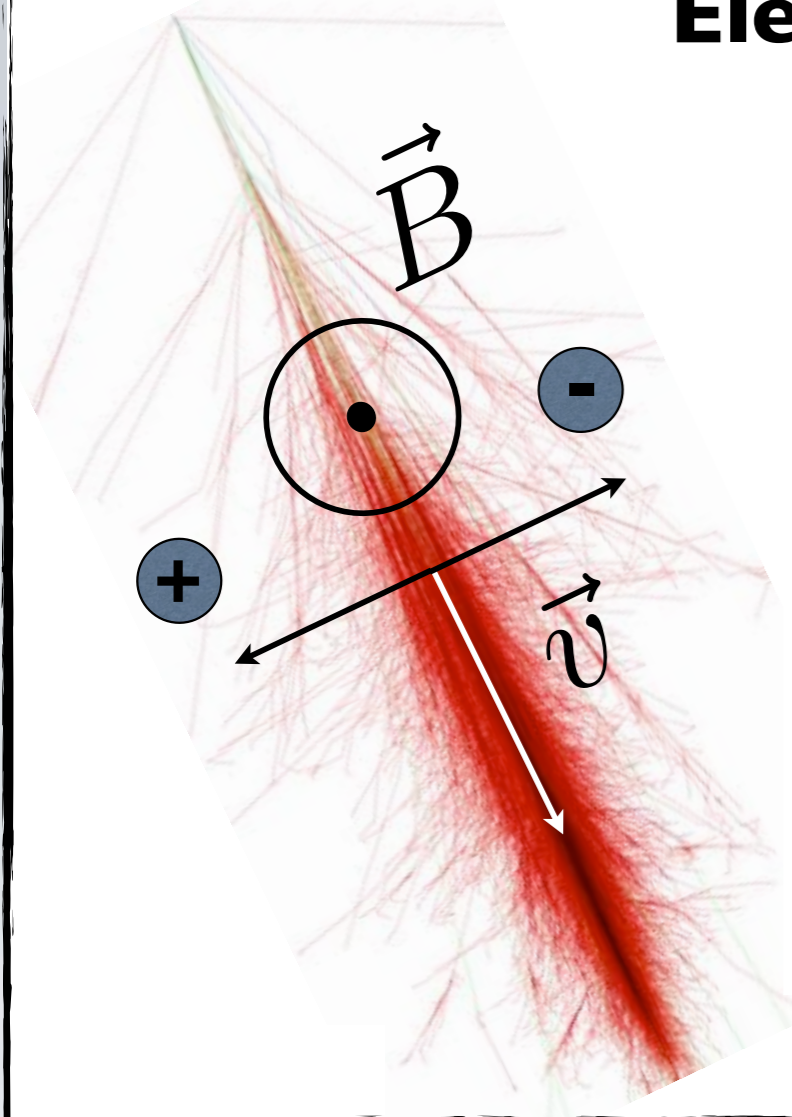
Electric field

Different approaches:

- Cerenkov radiation of negative charge excess (electron excess is ~10-20 %): Askary'an effect (1962)
- Macroscopic view: \mathbf{j} current radiation ; MGMR simulation code (Werner & Scholten)
- Microscopic view: radiation of e^-/e^+ pairs in \mathbf{B} ; codes REAS3 (Huege), SELFAS (Marin & Revenu), ZHAires (Alvarez-Muniz et al.)



Jodrell Bank 1964



$$E_{tot}(\mathbf{x}, t) = \frac{1}{4\pi\epsilon_0} \left\{ \sum_{i=1} \left[\frac{n_i q_i(t_{ret})}{R_i^2 (1 - \beta_i \cdot n_i)} \right]_{ret} + \frac{1}{c} \frac{\partial}{\partial t} \sum_{i=1} \left[\frac{n_i q_i(t_{ret})}{R_i (1 - \beta_i \cdot n_i)} \right]_{ret} - \frac{1}{c^2} \frac{\partial}{\partial t} \sum_{i=1} \left[\frac{\mathbf{v}_i q_i(t_{ret})}{R_i (1 - \beta_i \cdot n_i)} \right]_{ret} \right\}$$

Static field

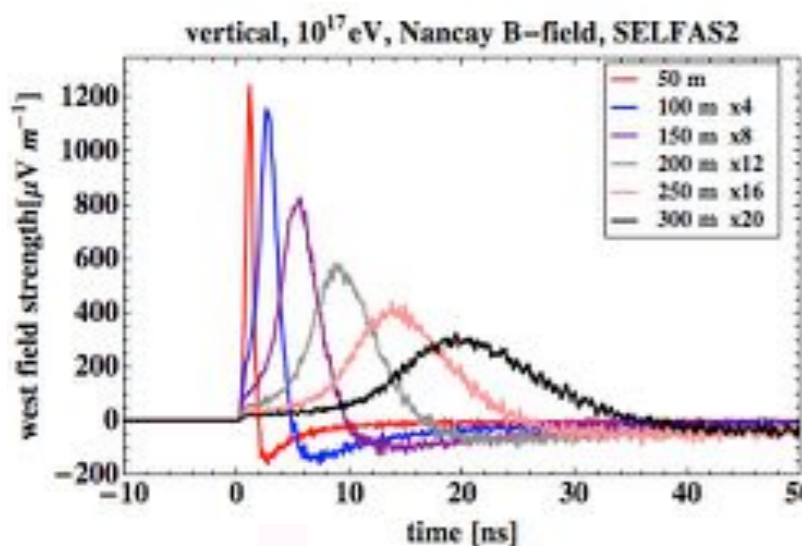
Sum of all static field contributions

Macroscopic charge variation (charge excess term)

Sum on all charges. Electron excess implies a global charge variation $Q(t) \propto N(t)$

Current variation (geomagnetic term)

Sum of currents produced by charge (e^-/e^+) drift in \mathbf{B}



Radio signal is correlated to the complete air shower development

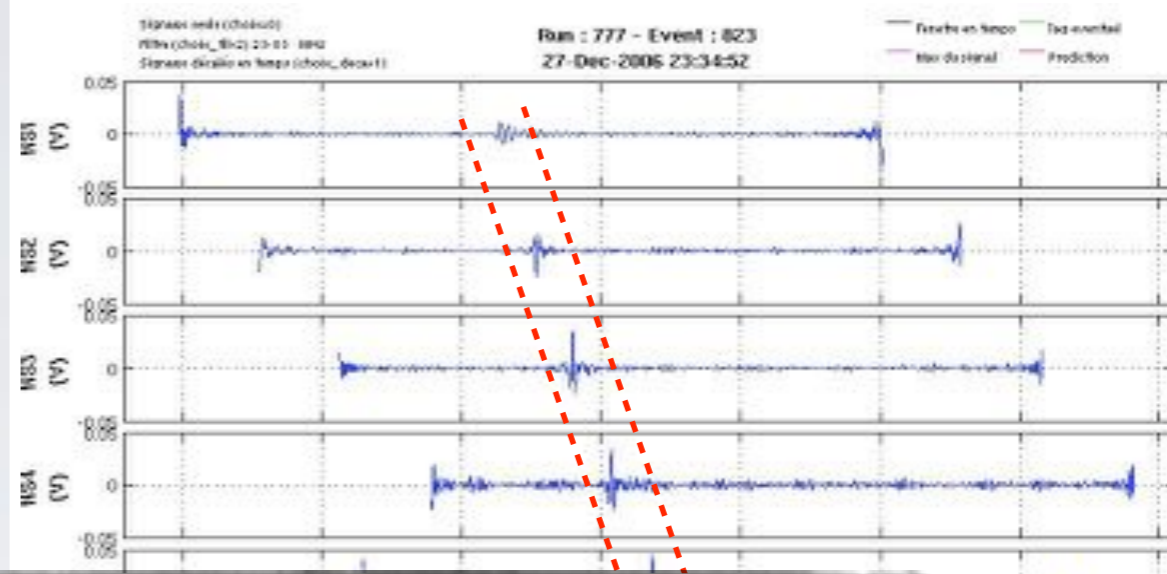
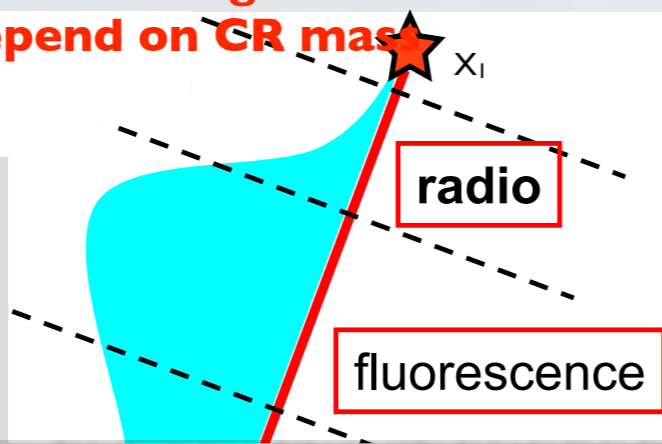
First interaction altitude and charge production maximum depend on CR mass

$$FY \propto f(t)$$

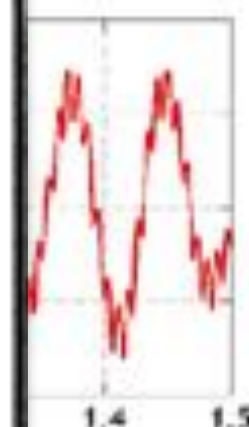
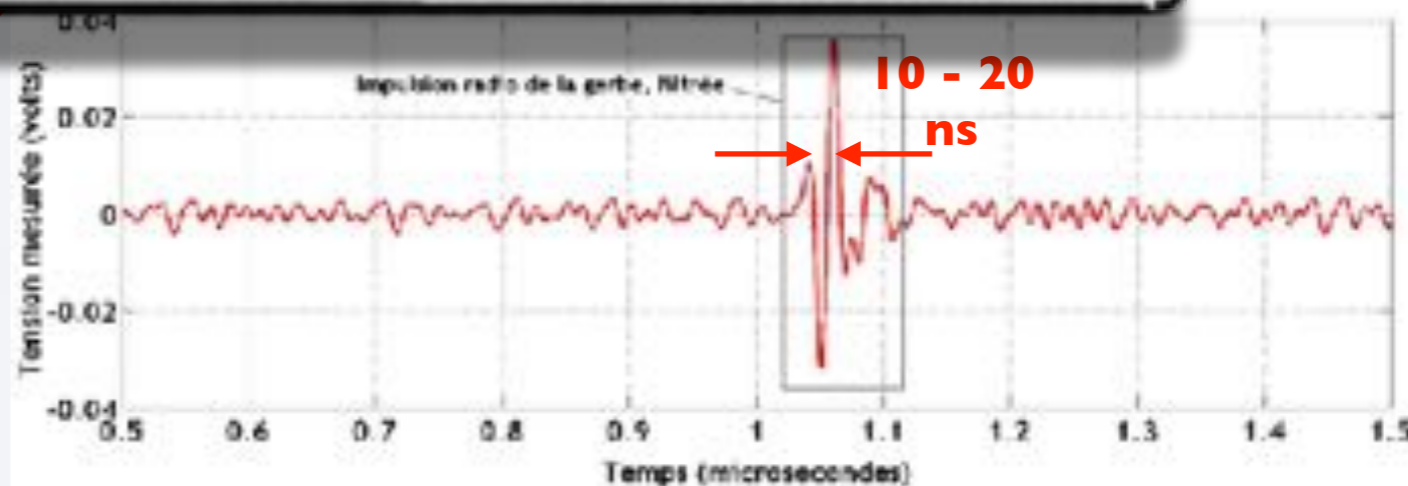
$$RY \propto \left[\frac{\partial f(t)}{\partial t} \cdot c(t) \right]$$

$$PY \propto f(t_0)$$

A. Van den Berg, 201



This is not a continuous, but a triggered observation (“snapshots” of few μs)

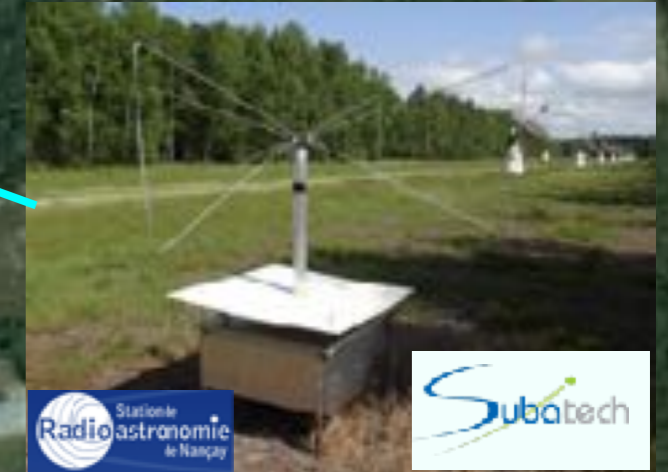


CODALEMA (NANÇAY, SINCE 2003)

1.6 km



0.1 km² - 13 particle detectors
CR validation and/or trigger



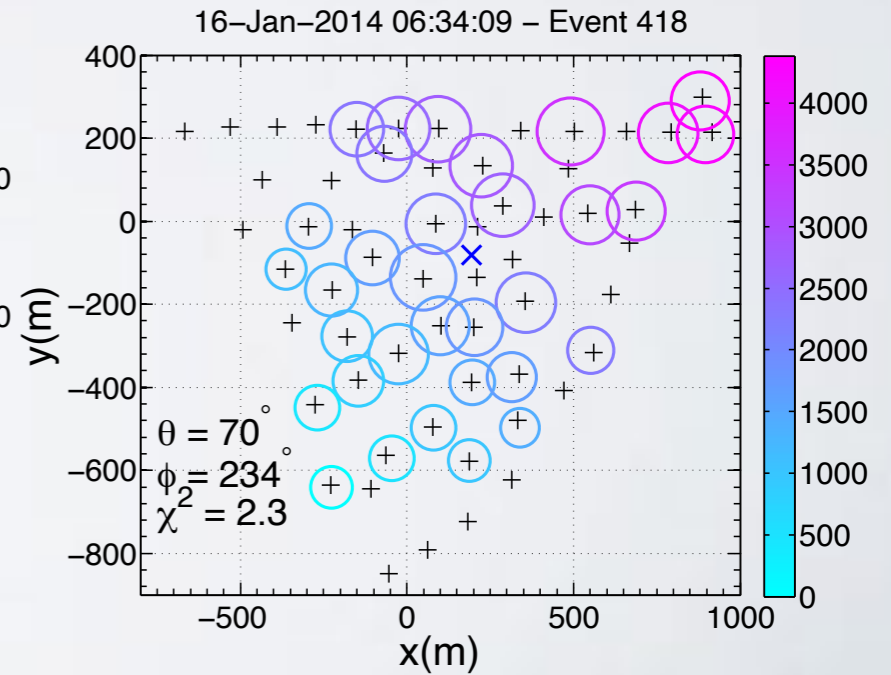
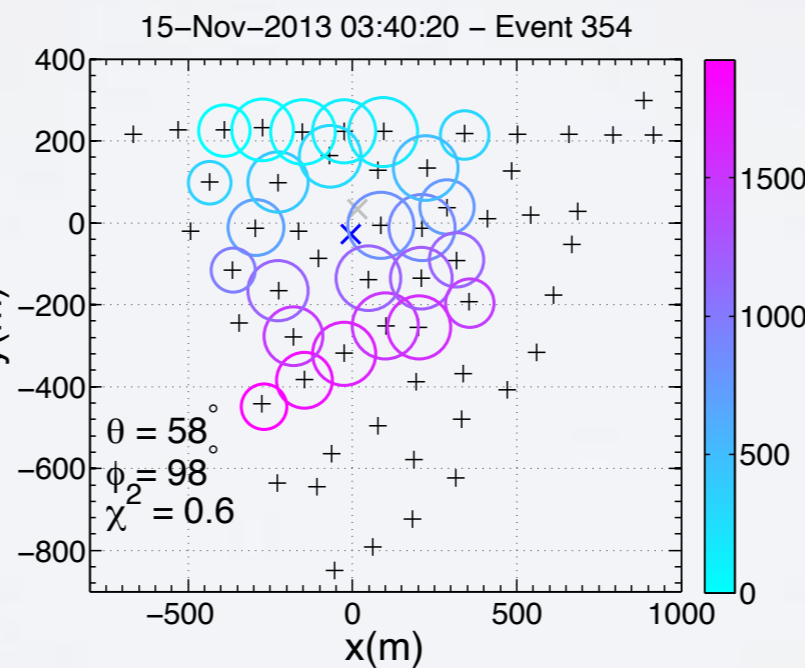
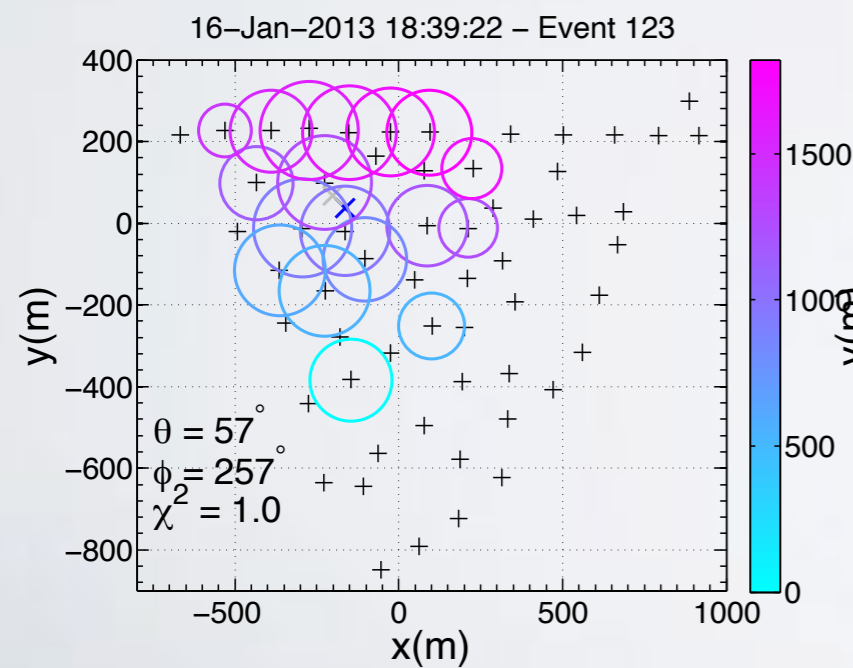
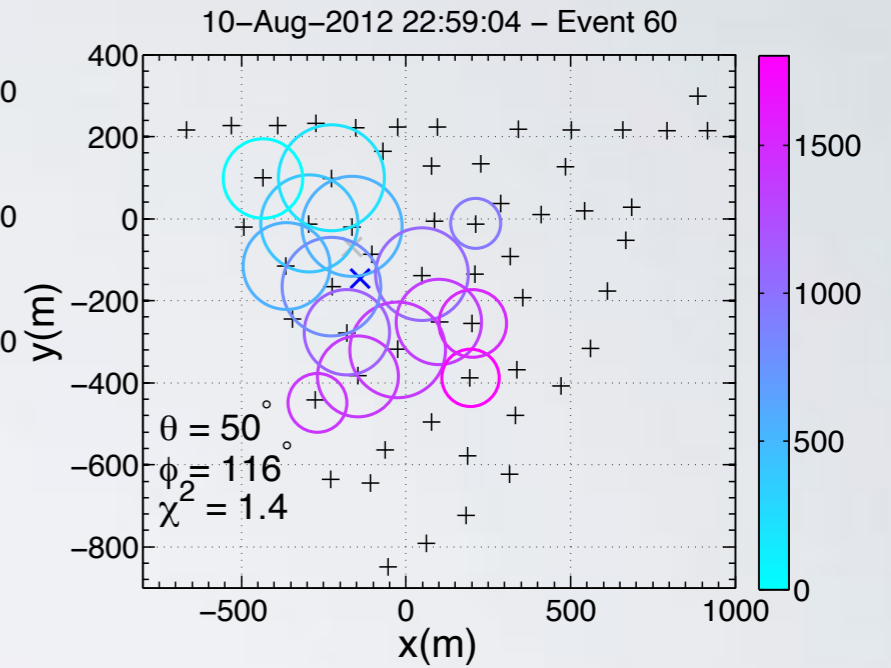
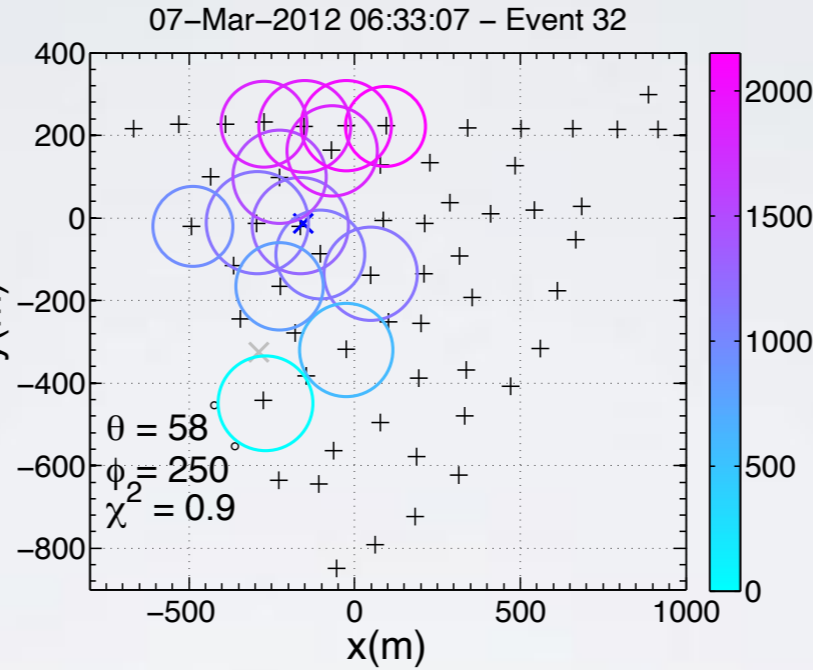
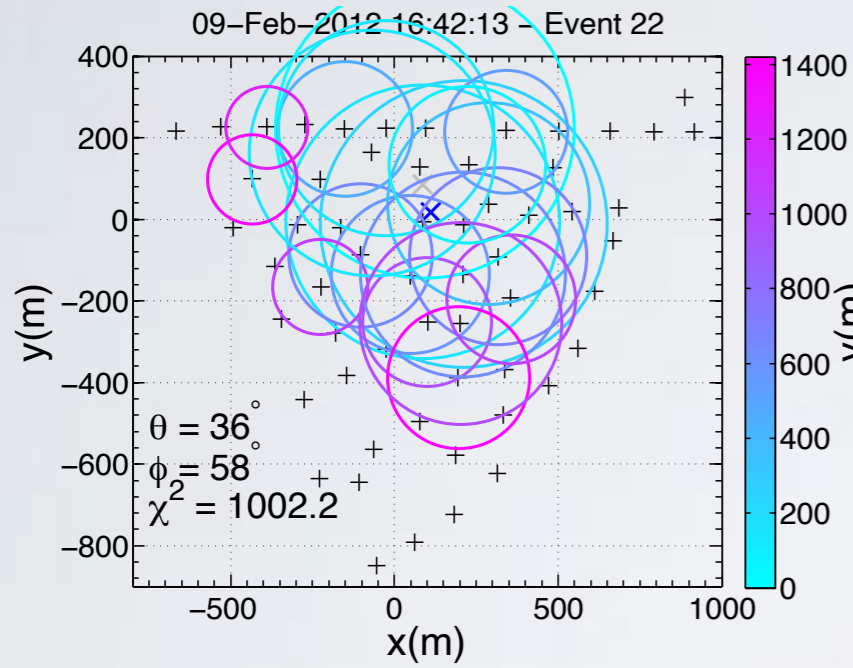
1 km² - 57 radio stations
Autonomous, radio triggering
Antenna made in Subatech,
LNA chosen for LSS



0.025 km² - 10 cabled antennas
Compact phased array, external trigger

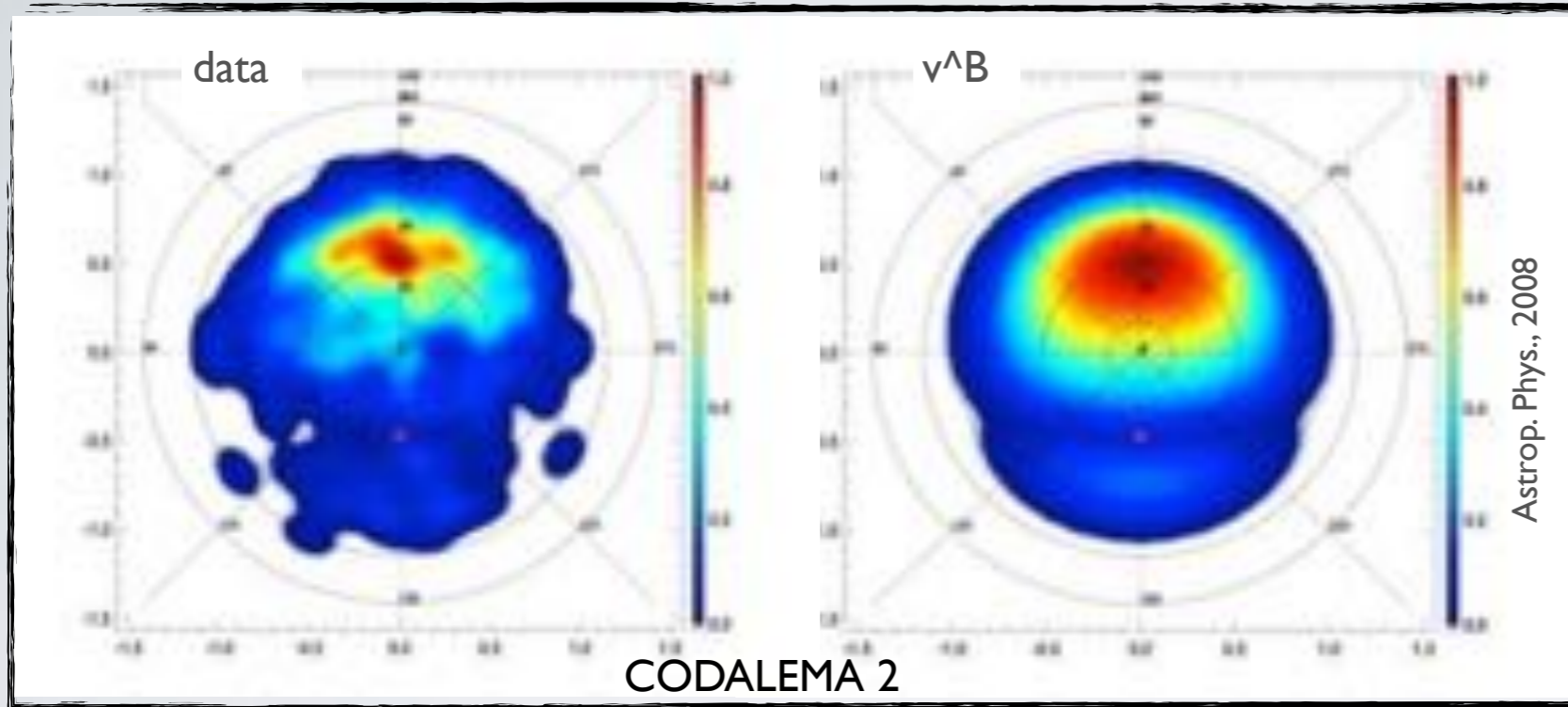
Google earth

SOME BIG EVENTS

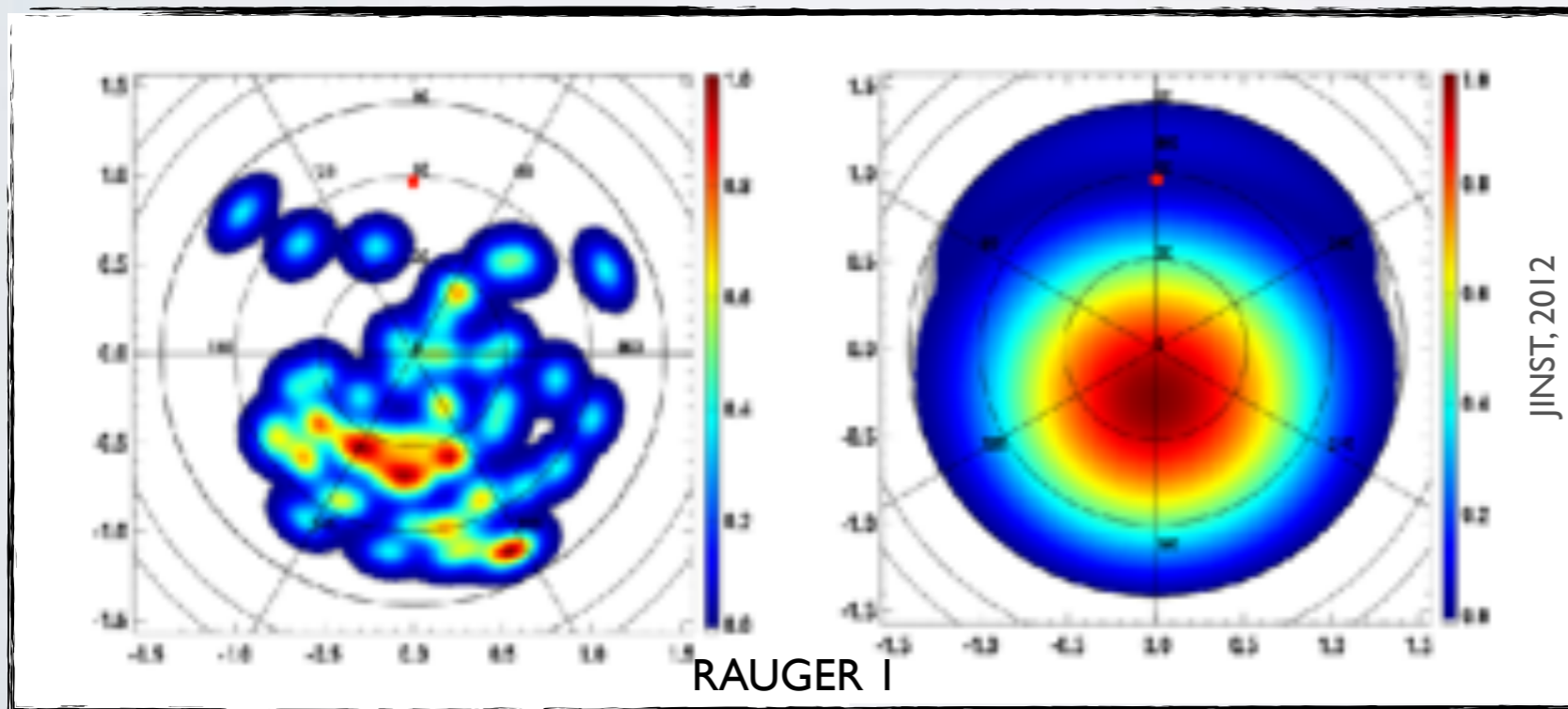
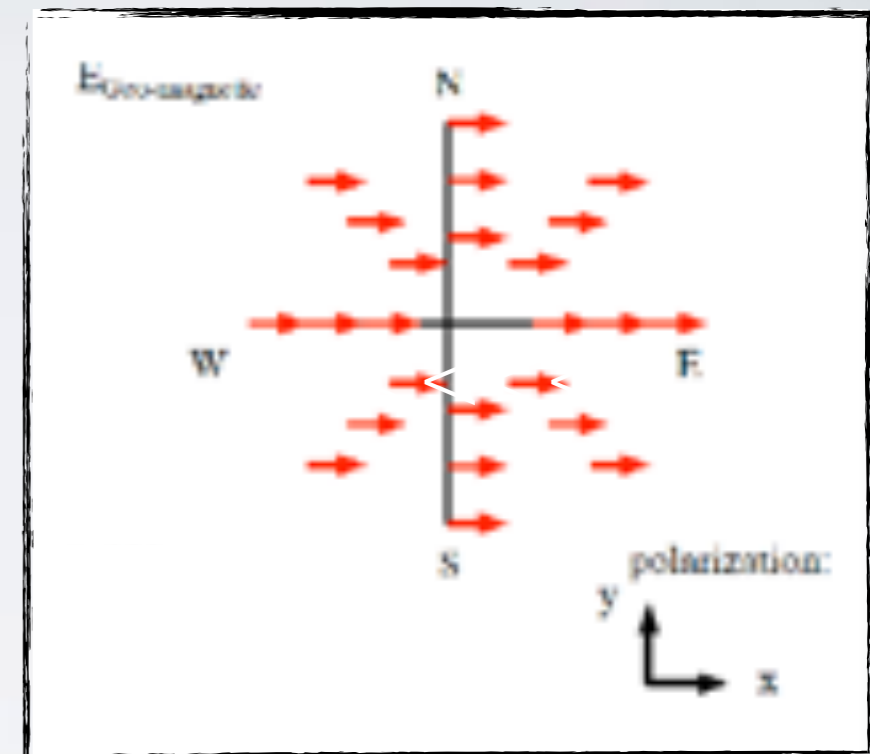


RADIO RESULTS - I

Geomagnetic contribution
 $E \propto v \wedge B$, polarization $\rightarrow f(\theta, \varphi)$



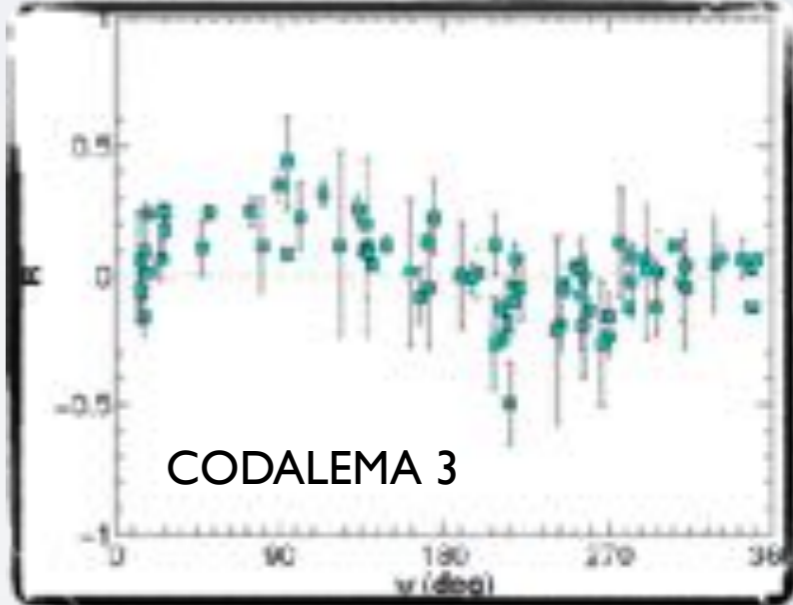
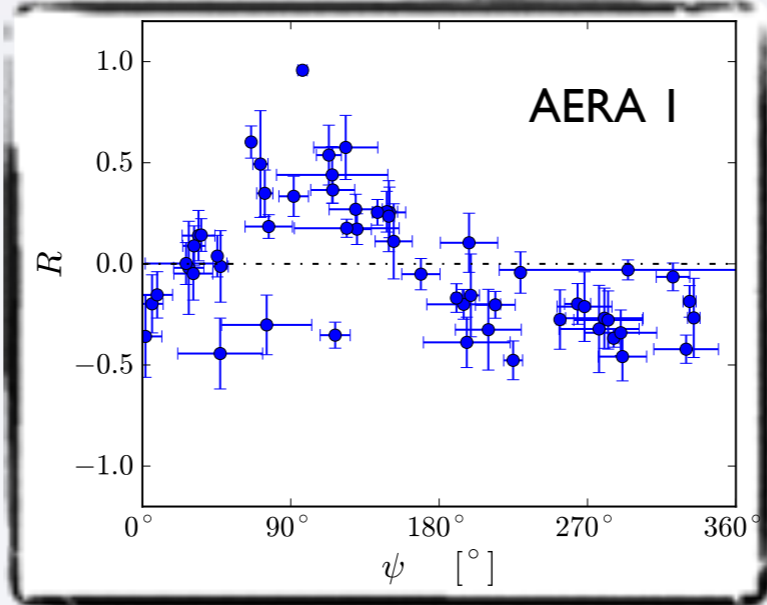
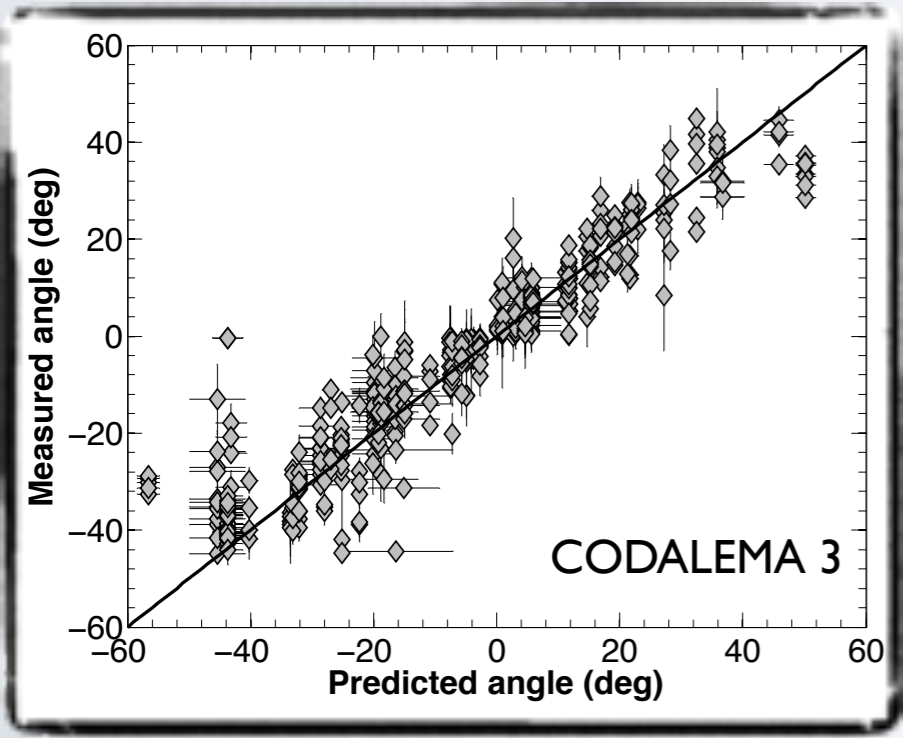
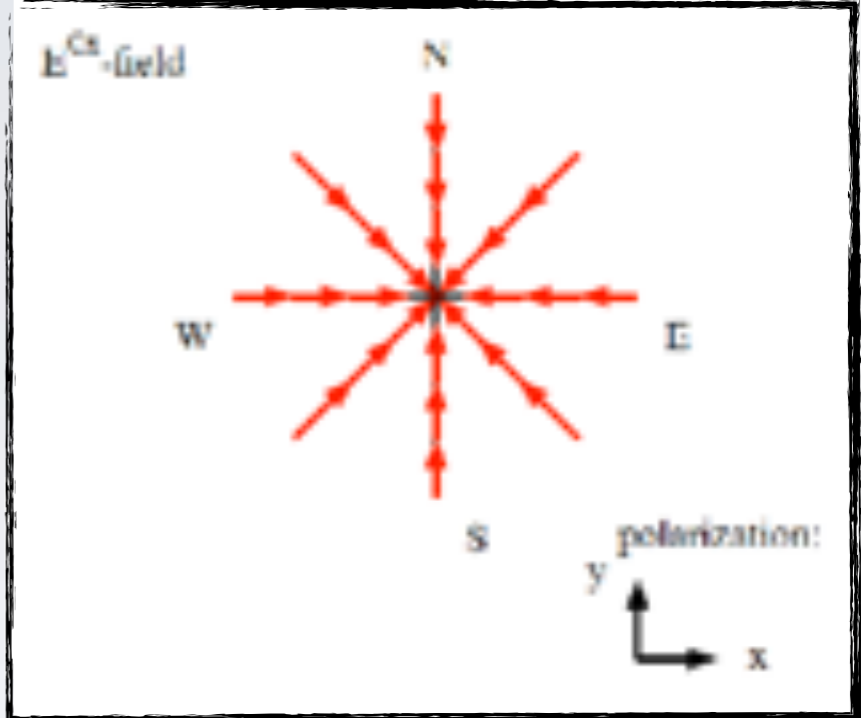
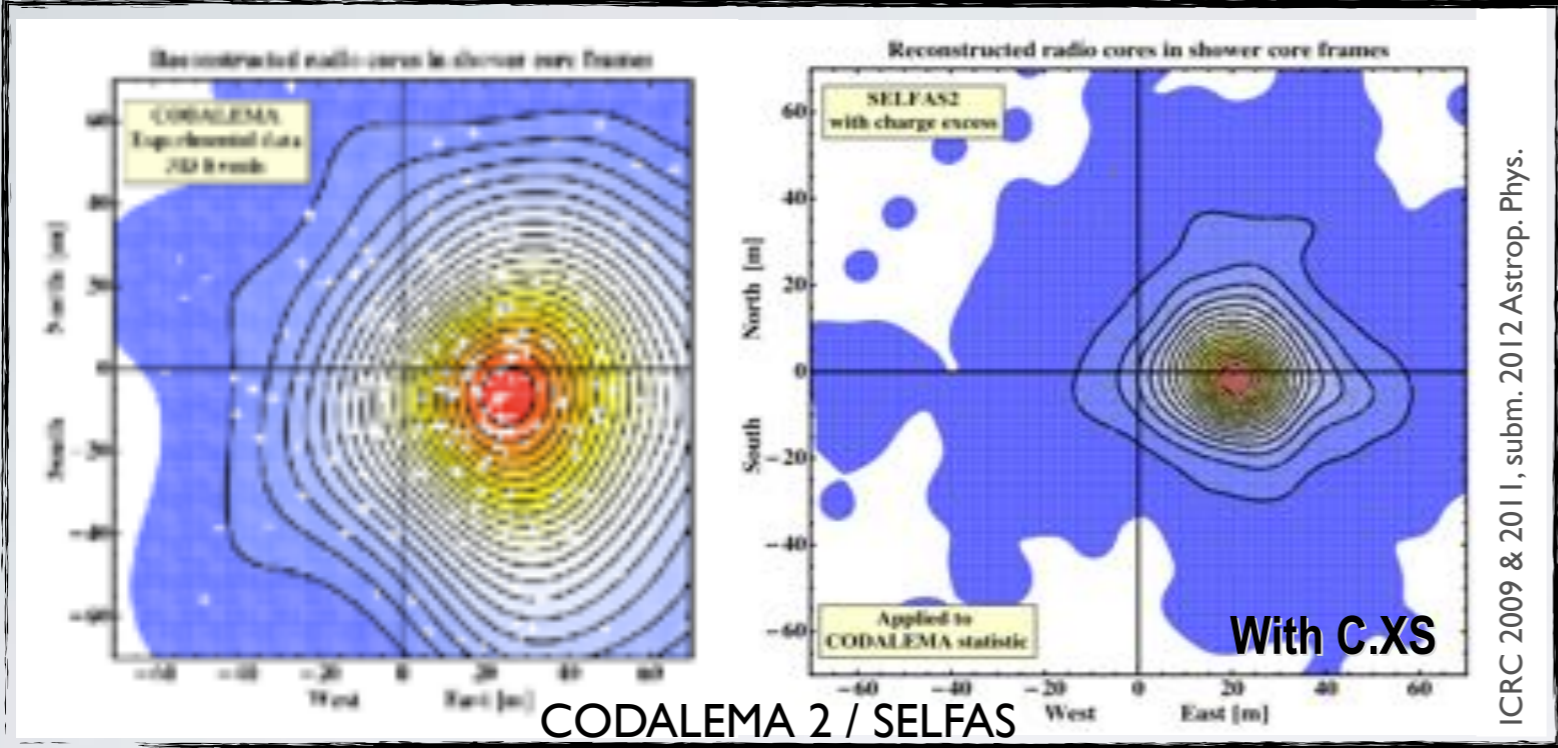
NORTH



SOUTH

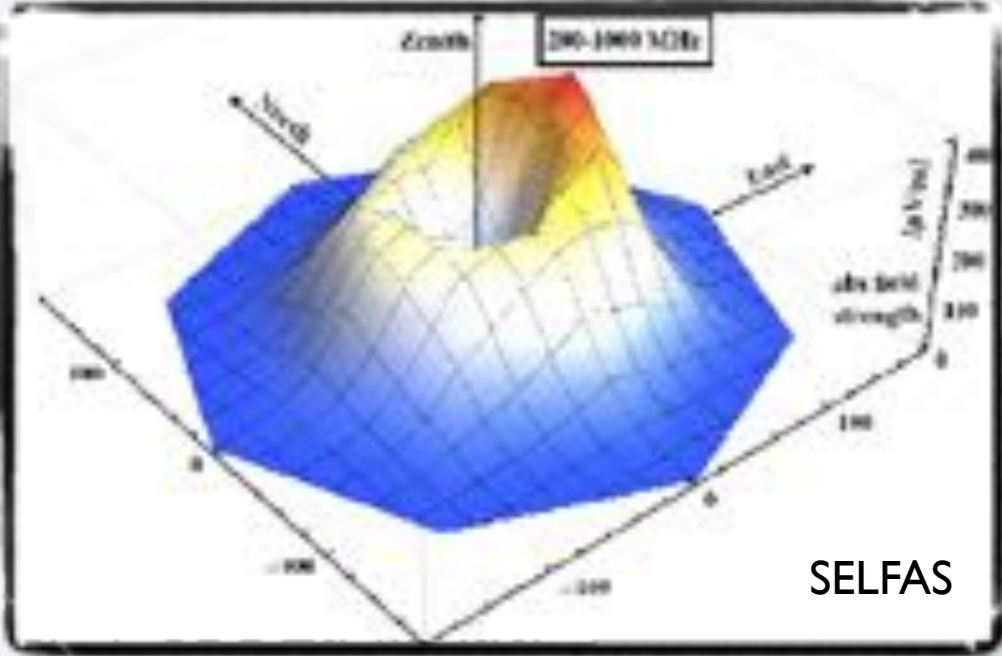
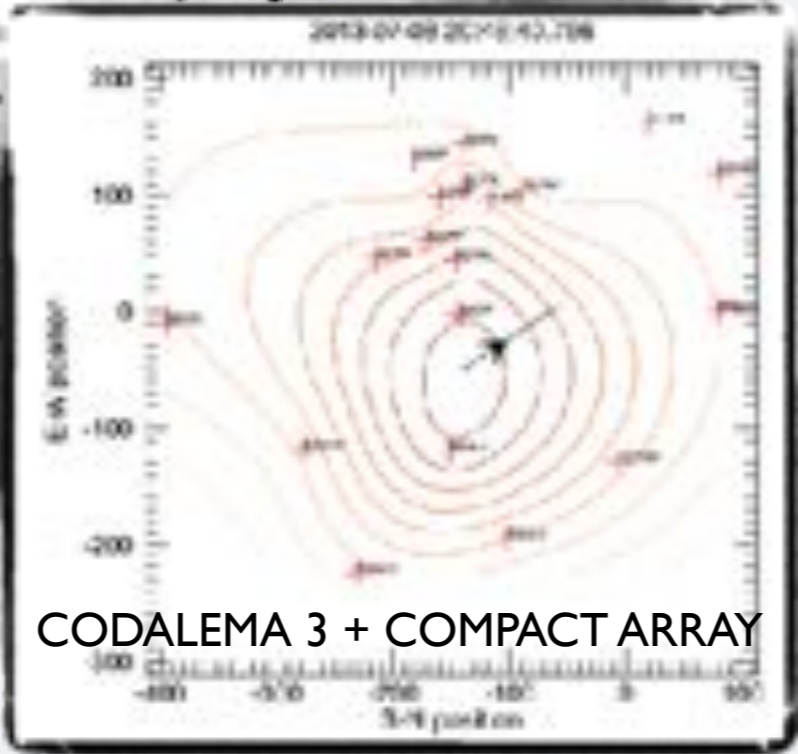
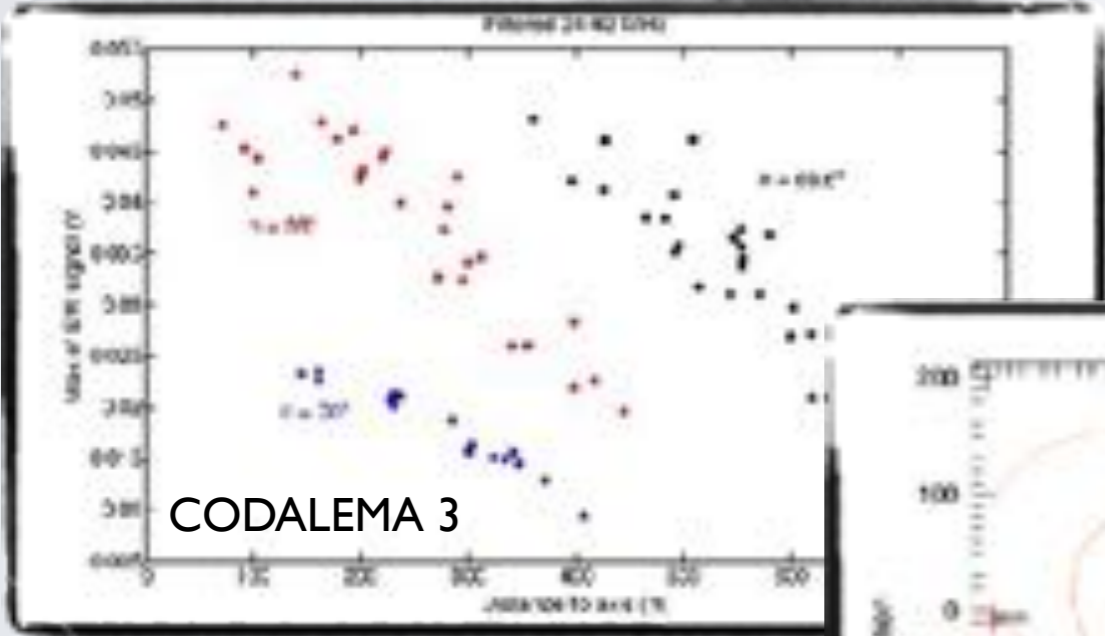
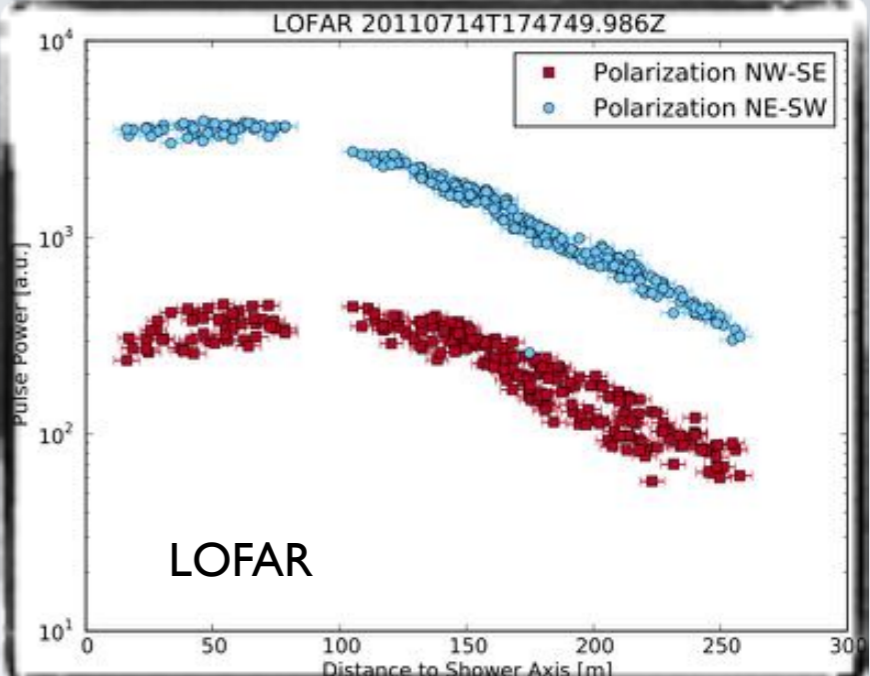
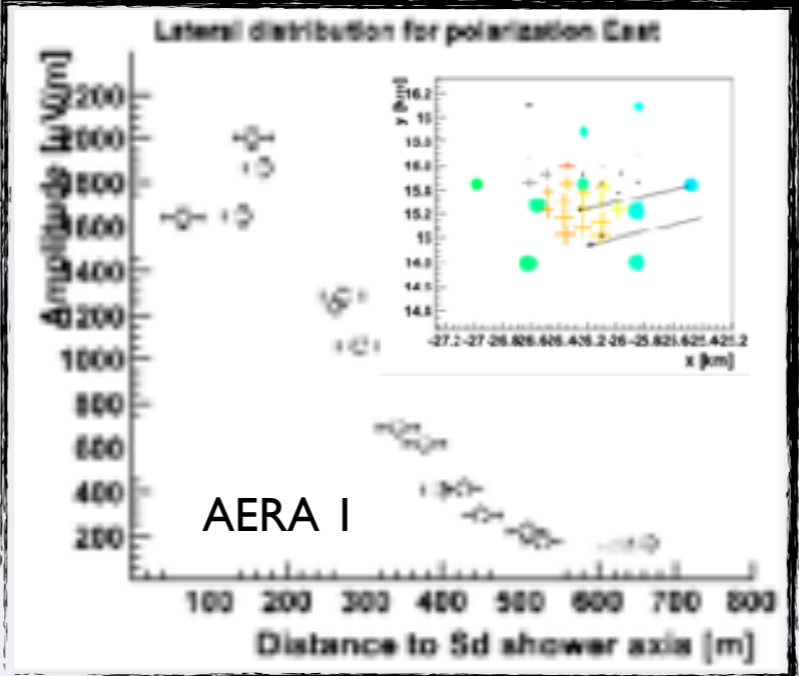
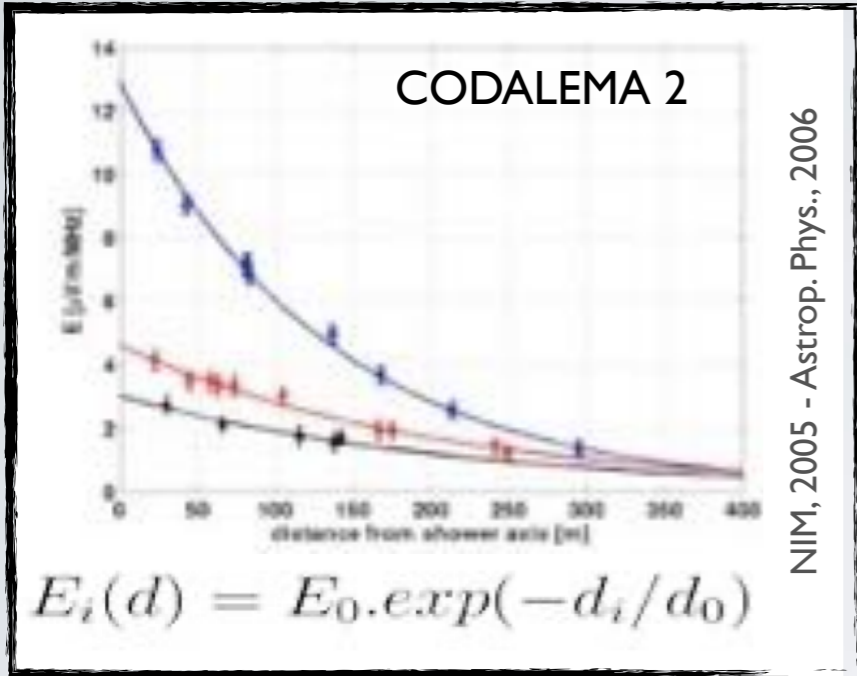
RADIO RESULTS - 2

Charge excess contribution
 2nd order, polarization → observer
 Radio core vs particle core shift



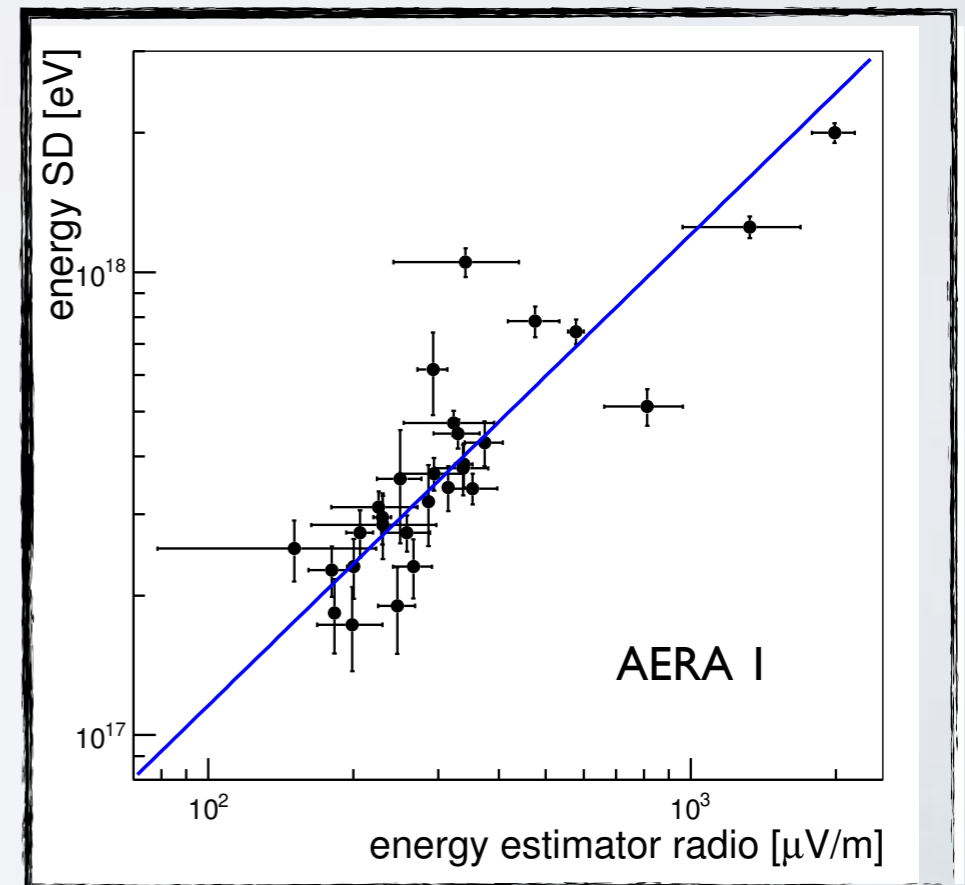
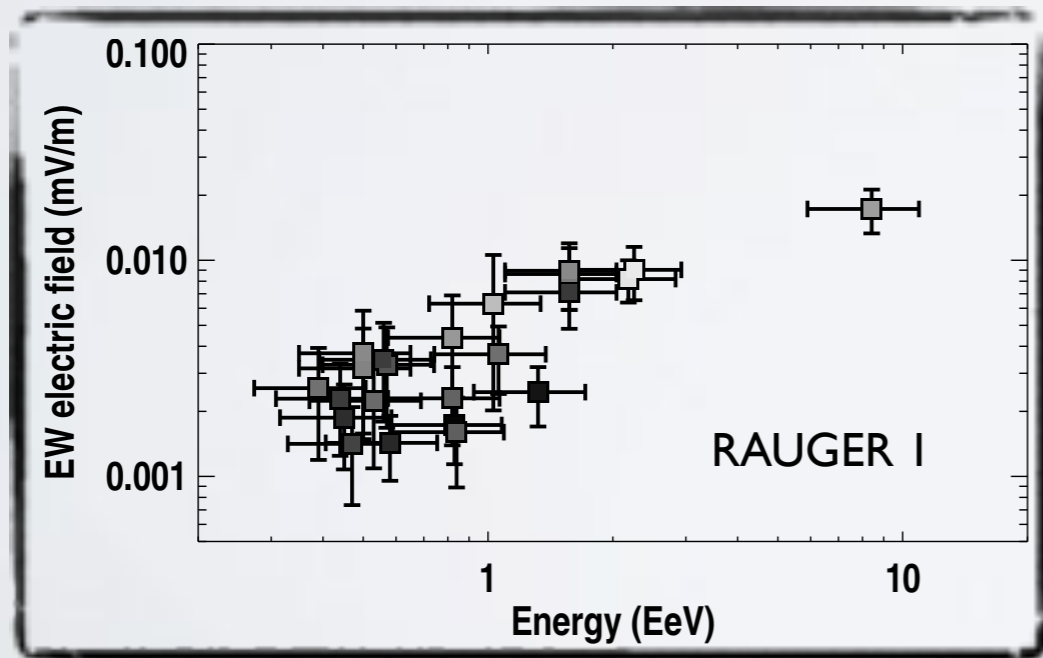
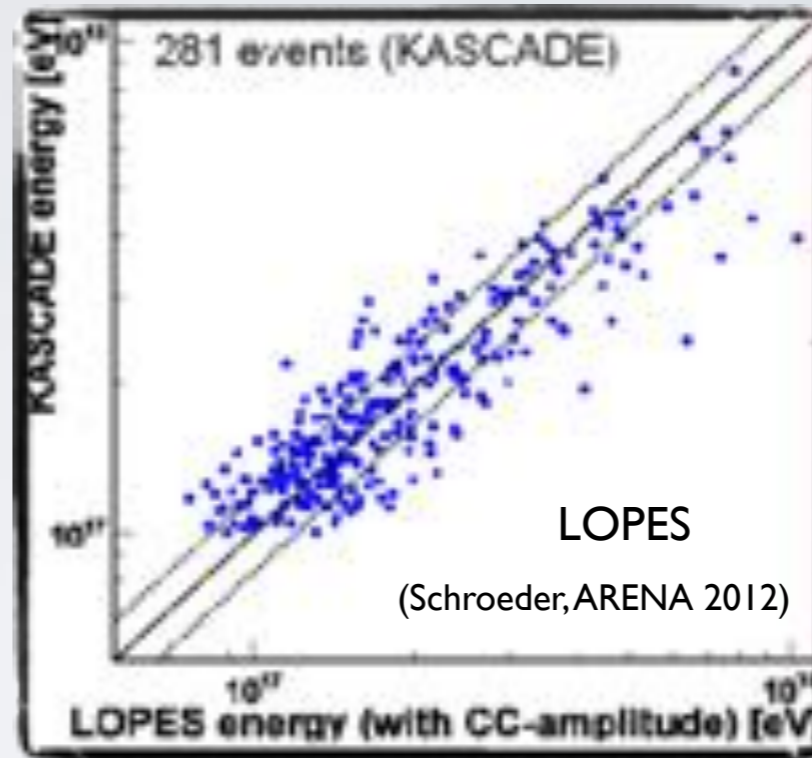
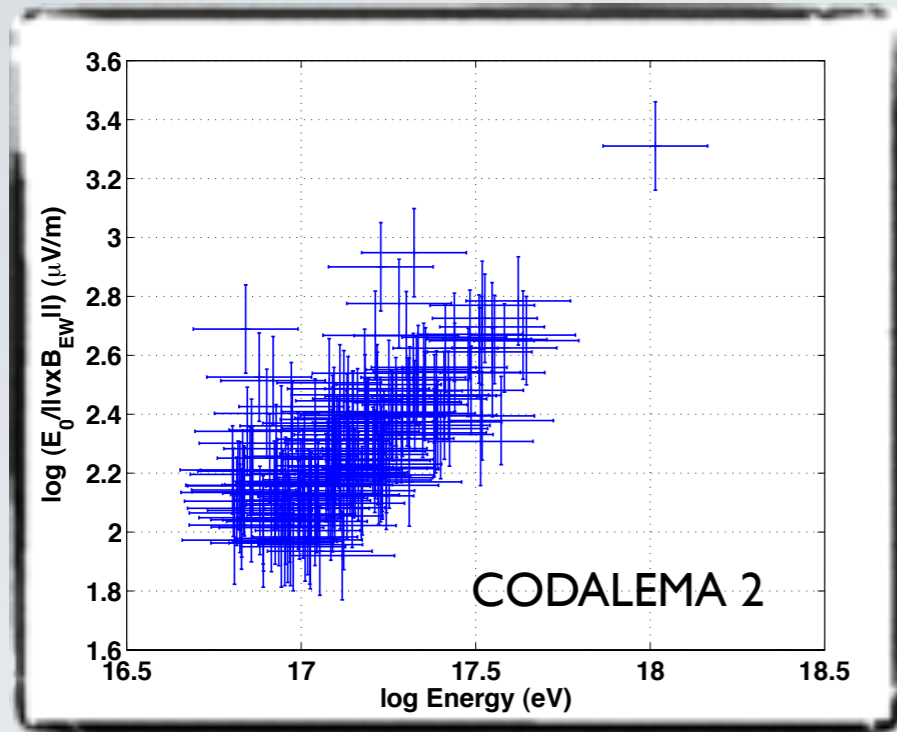
RADIO RESULTS - 3

Lateral field profile and energy correlation
 $E_0, d_0, (X_0, Y_0) - E_0 \propto E_p$



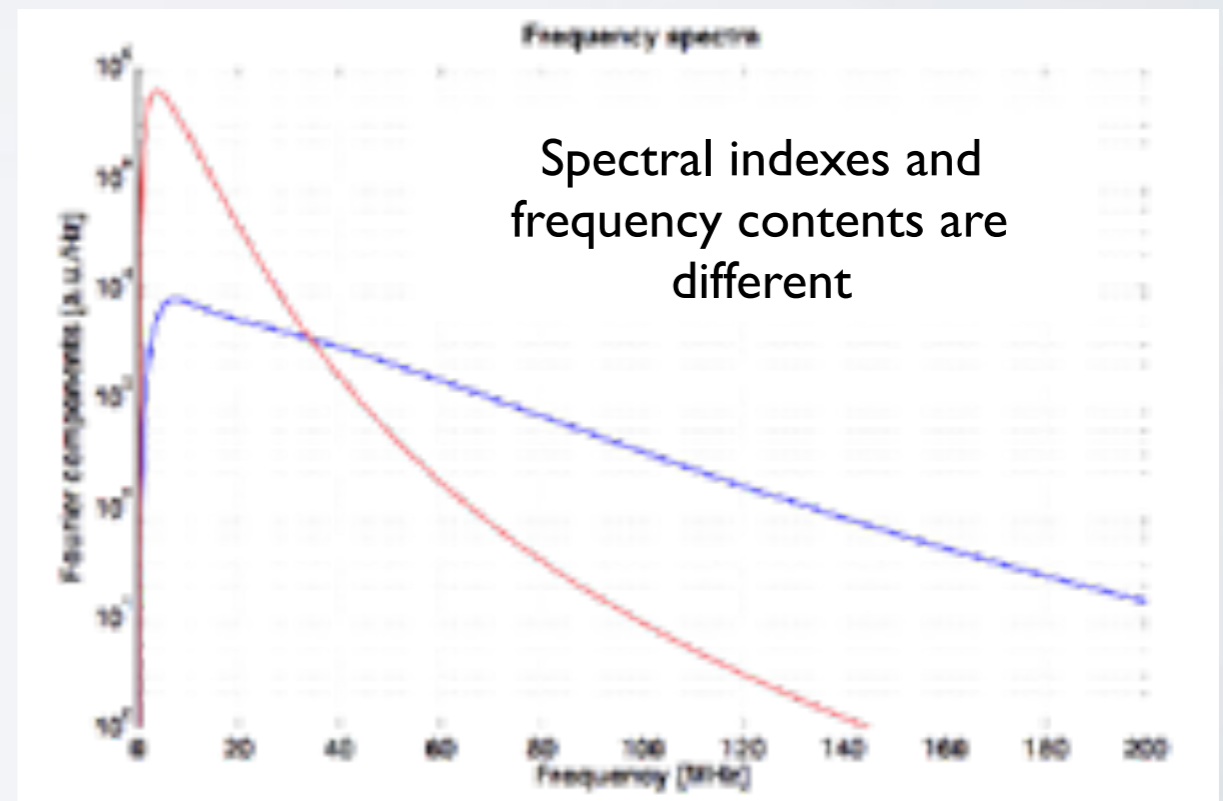
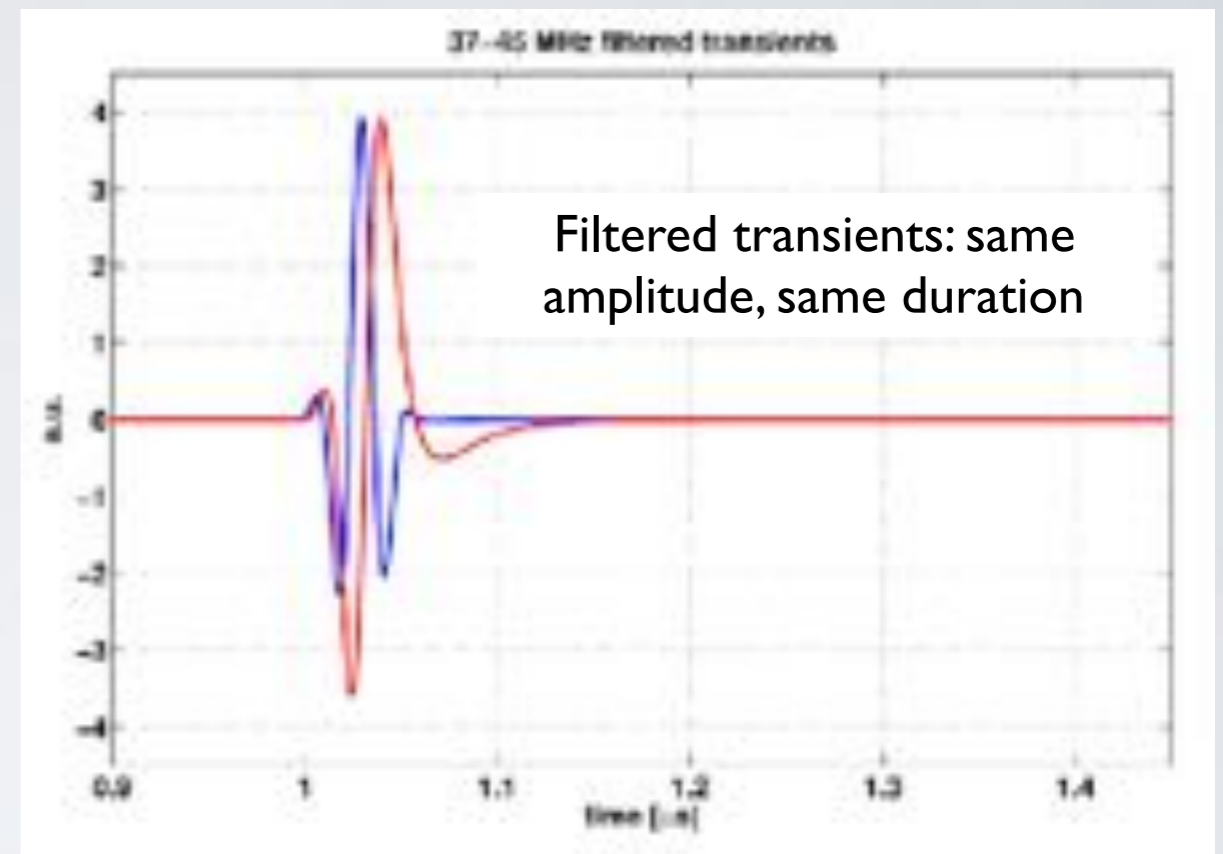
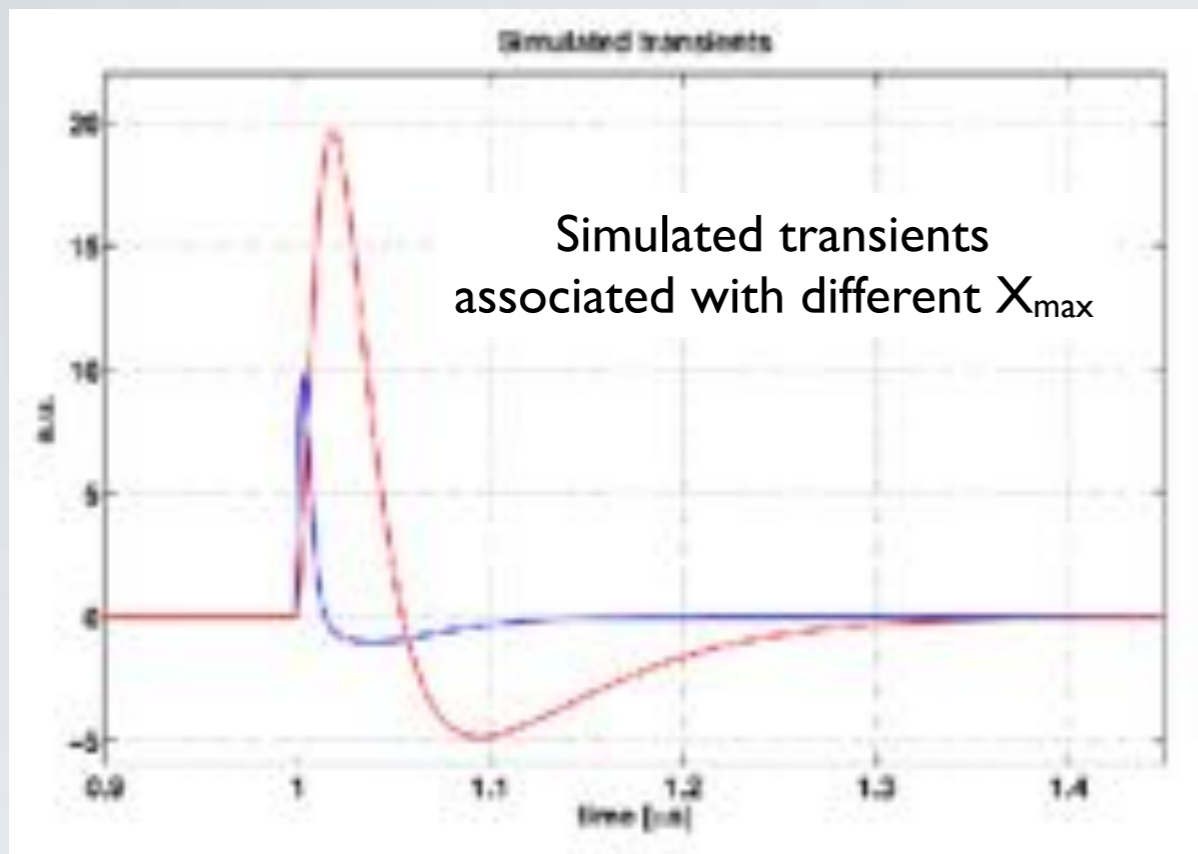
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RADIO PROSPECTS - I

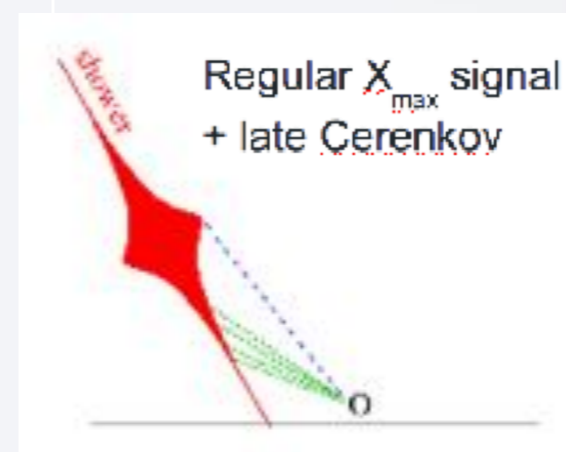
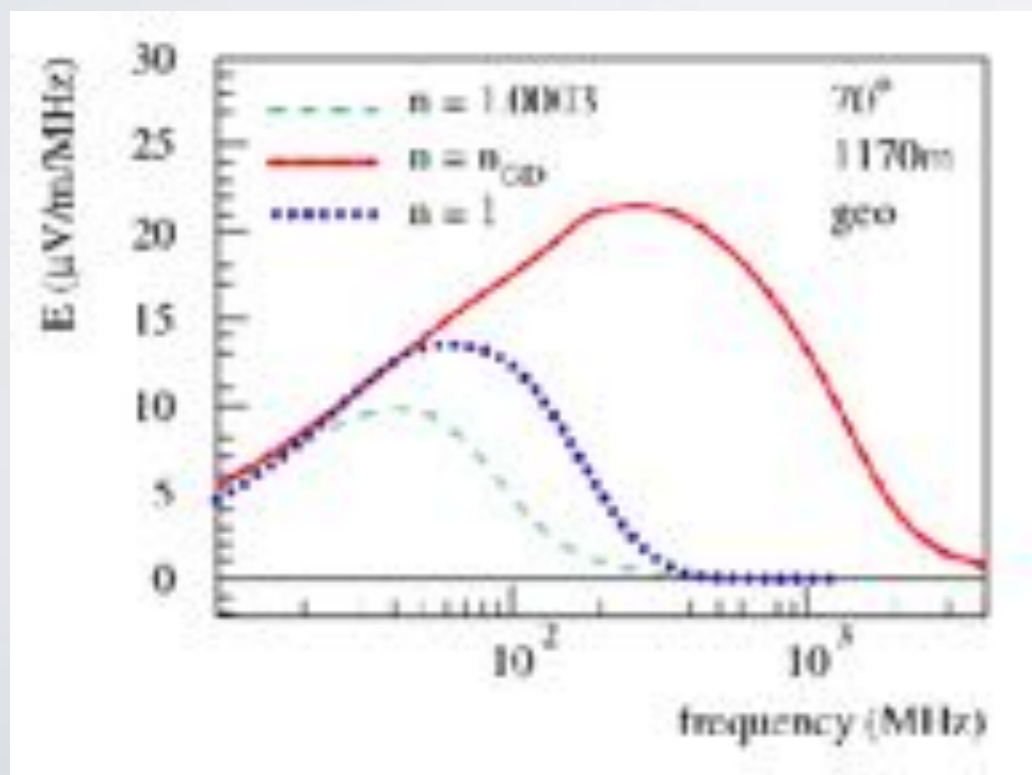
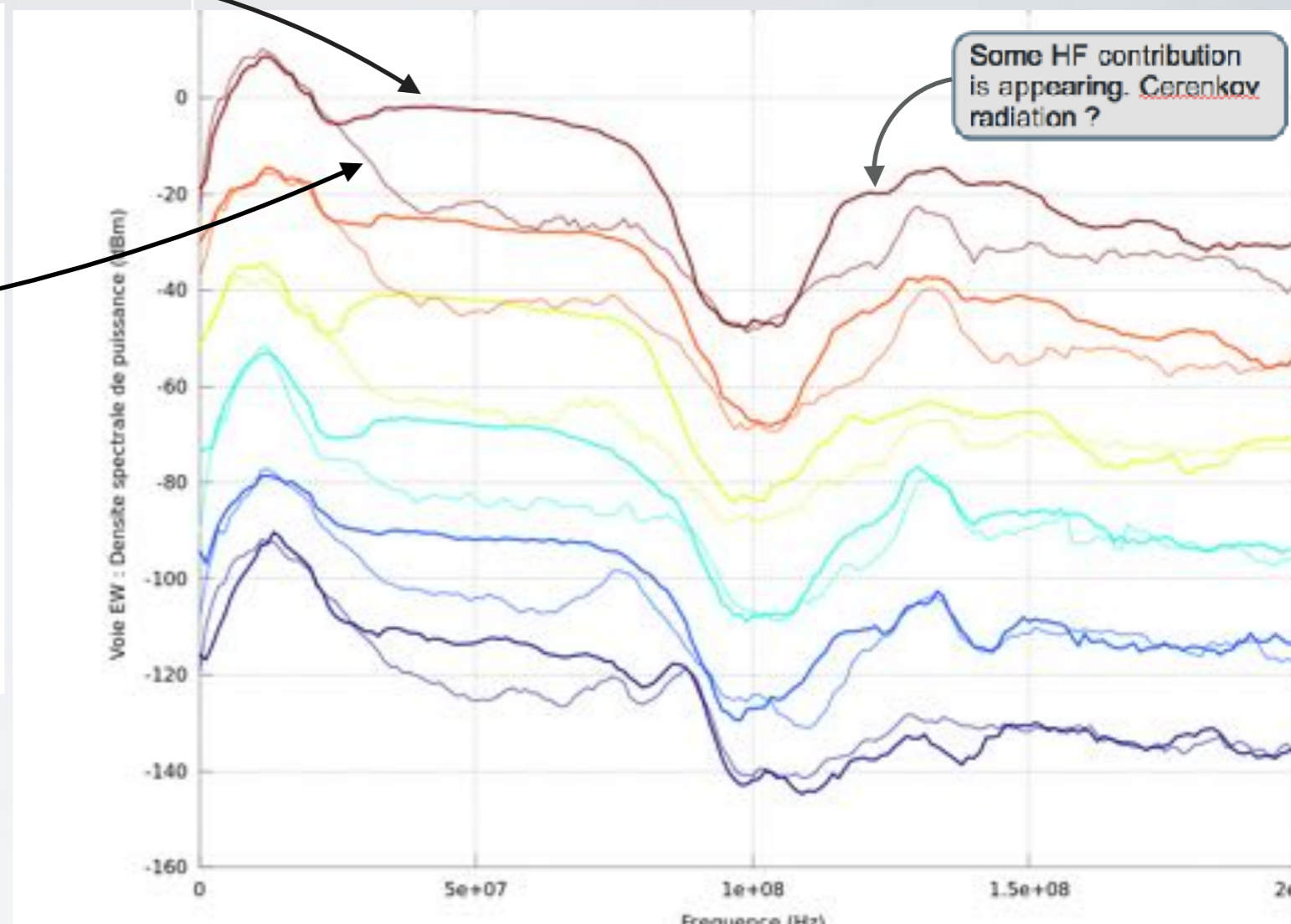
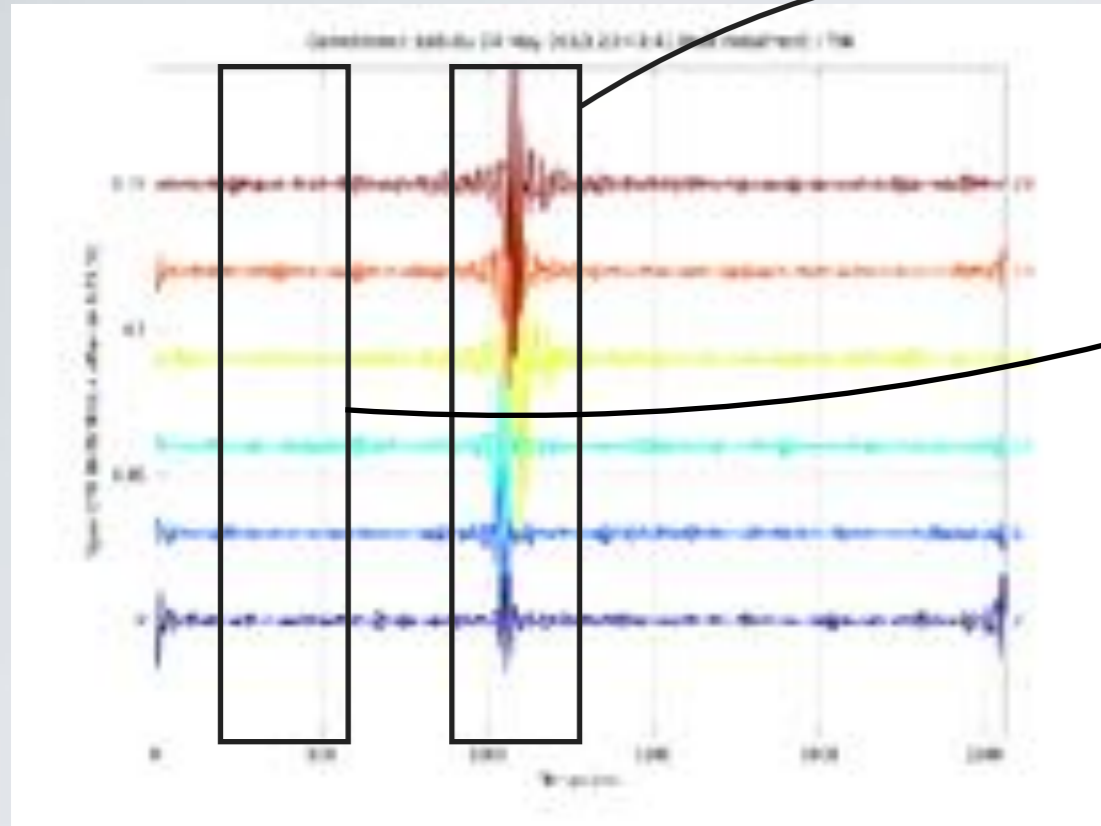
Extension of frequency range
Toward high frequencies



Different EAS features :
energy, inclination, mass (X_{\max})
Or observation conditions :
impact parameter, orientation, under/above
induces different **pulse shapes :**
Amplitude duration, bi-polarity
Filtering the signals kills the differences
Measuring the spectrum over a wide-band
preserves the sensitivity

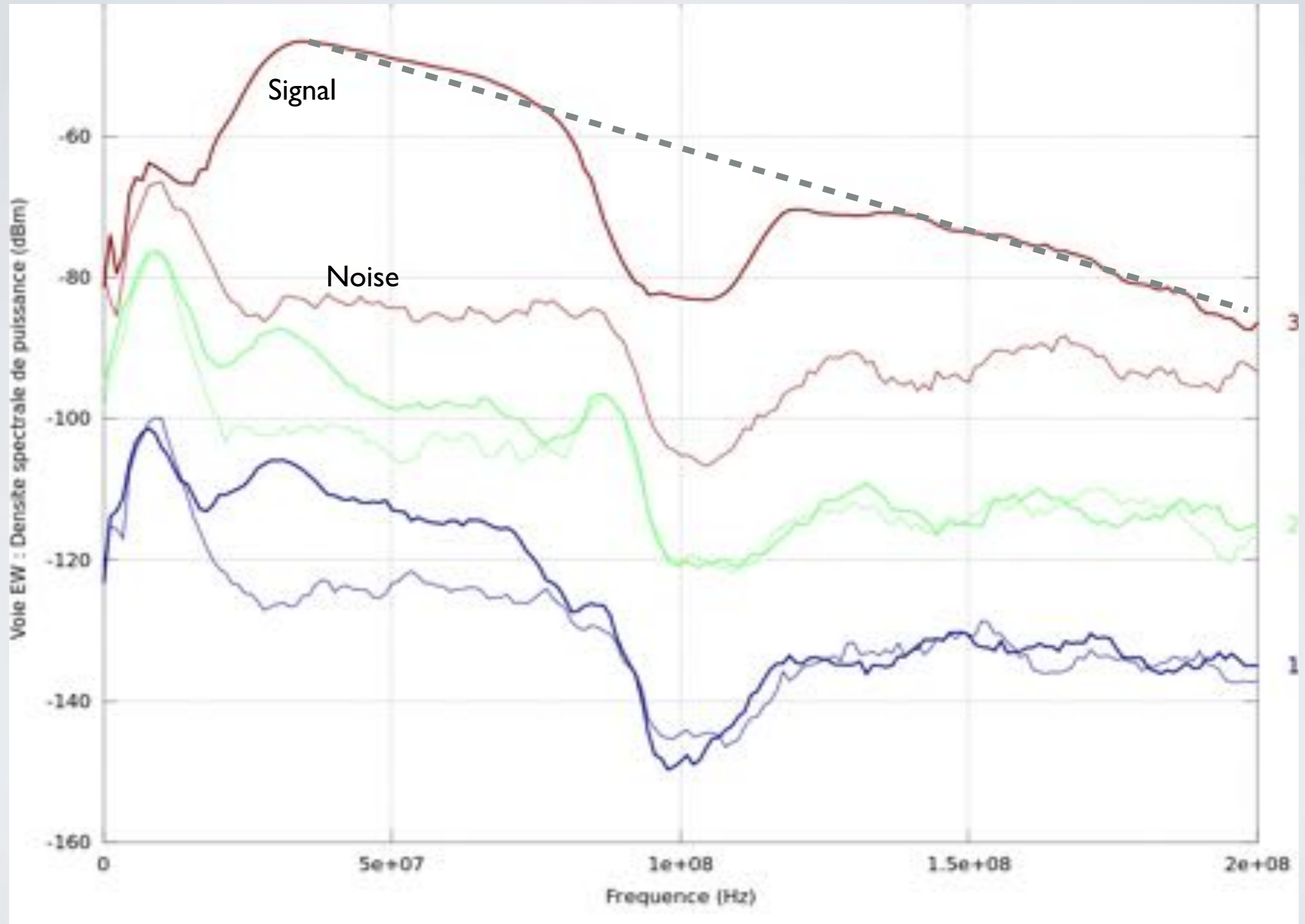
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Toward high frequencies

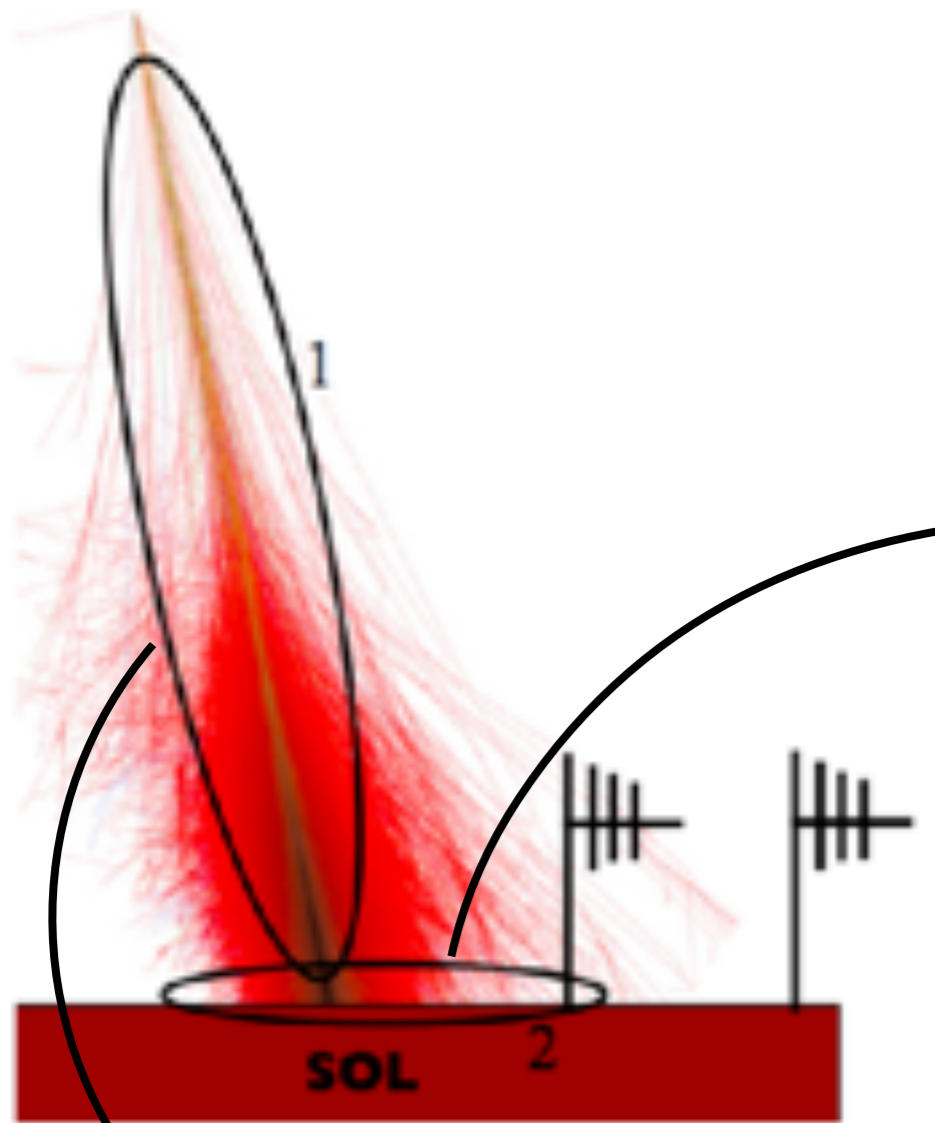


PROSPECTS - I

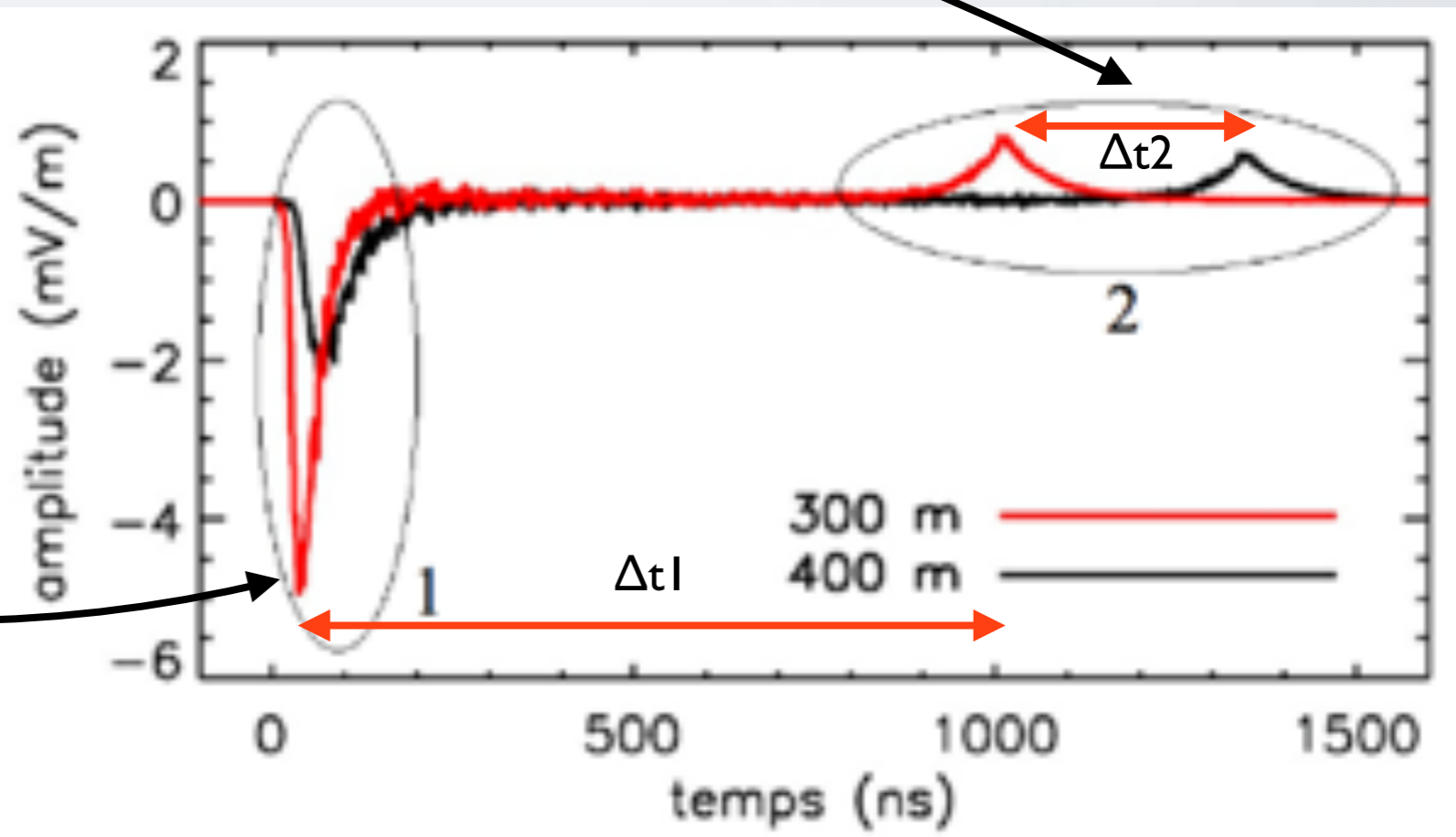
Extension of frequency range
Toward high frequencies



Sudden death of the shower

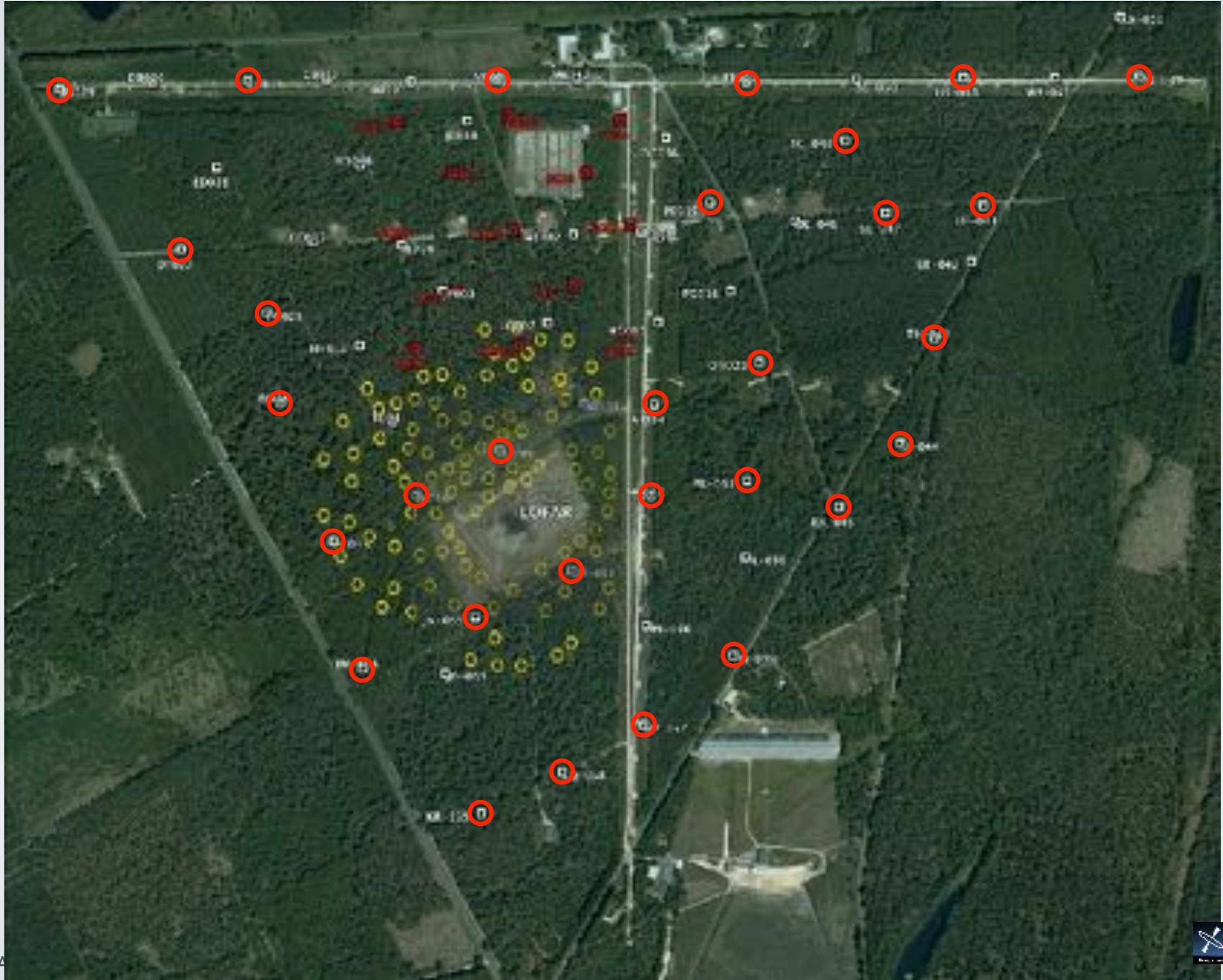


2: charges are strongly decelerated when arriving at ground, and gives “sudden death” signal. Time difference between 2 antennas gives shower’s location. The signal is produced at low frequencies (< 10 MHz).



1: charge is varying during shower’s development, and gives “main” signal. Time difference in one antenna signals gives shower’s history (nature of primary?)

CODALEMA/NENUFAR BEYOND 2015



OUTLOOK

● Ultra-High Energy Cosmic Rays

- ✓ Involves astrophysics & particle physics
- ✓ Community → needs for a new instrument
- ✓ Augmentation of statistics, **discrimination of composition**, energy resolution

● Radio detection of cosmic rays

- ✓ Key method for the future ?
 - ▶ French competence - great opportunity !
 - ▶ CODALEMA and Nançay (includes LOFAR and LSS) as a development base
- ✓ AERA : multi-hybrid on Auger - pertinence of the method, R&D difficult on site
- ✓ Still to find the composition-related radio observable
- ✓ A new way to observe very fast transients: **potential new window in radioastronomy ?**

● Links with LOFAR and SKA

- ✓ High sensor (antenna) density: very fine shower profile
- ✓ Ability to discriminate showers on radio signal only (aim of compact array @ CODALEMA)
- ✓ CODALEMA & LSS/NenuFAR: proposal INSU 2014