Multi-wavelength observation of cosmic-ray air-showers with CODALEMA/EXTASIS

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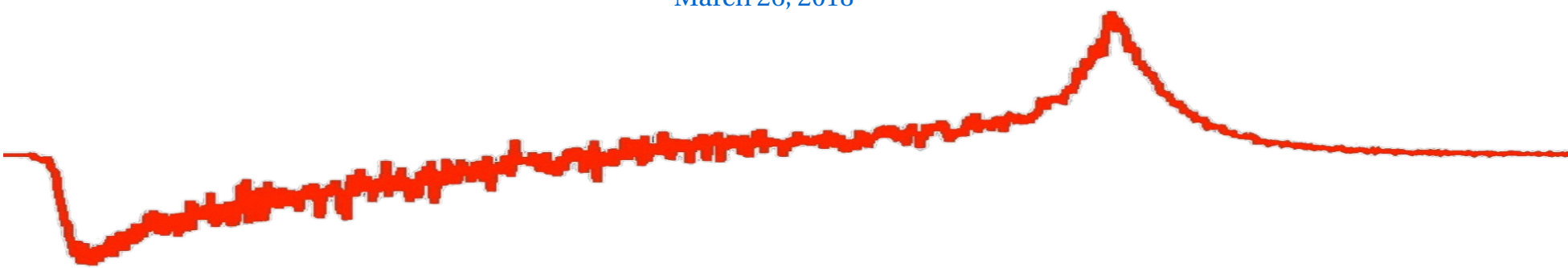
[3] Unité Scientifique de Nançay, Observatoire de Paris, CNRS, PSL, UO/OSUC, Nançay, France

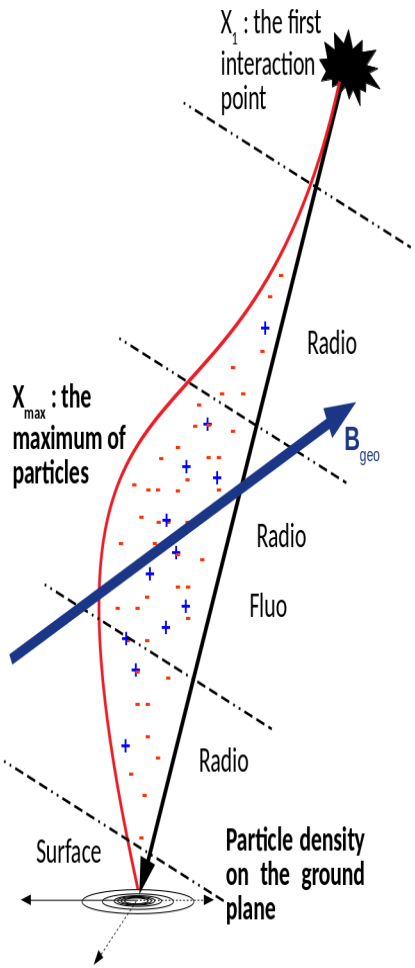
March 26, 2018



CFRCos2018

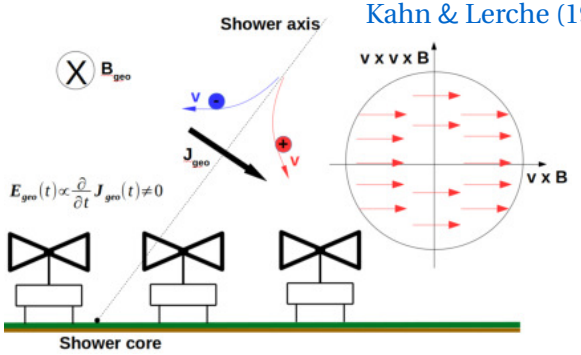
Radio-detection

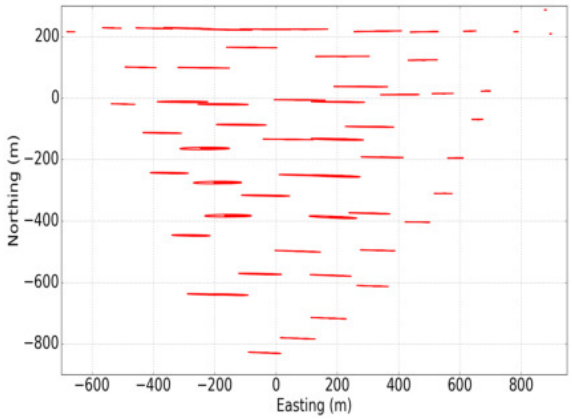
θ, ϕ, (X_{core}, Y_{core}), X_{max}, Energy



Geomagnetic mechanism

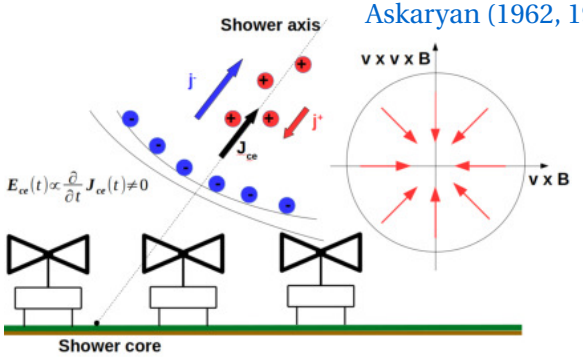
Kahn & Lerche (1967)

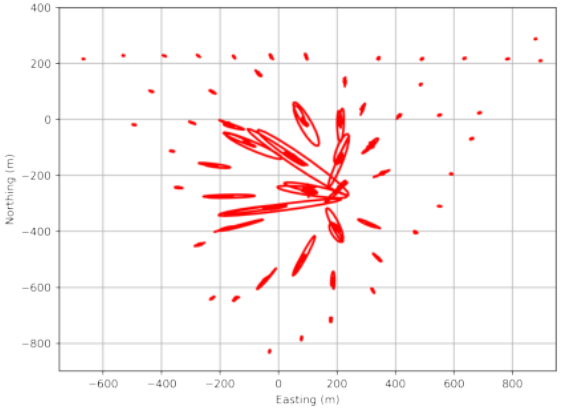




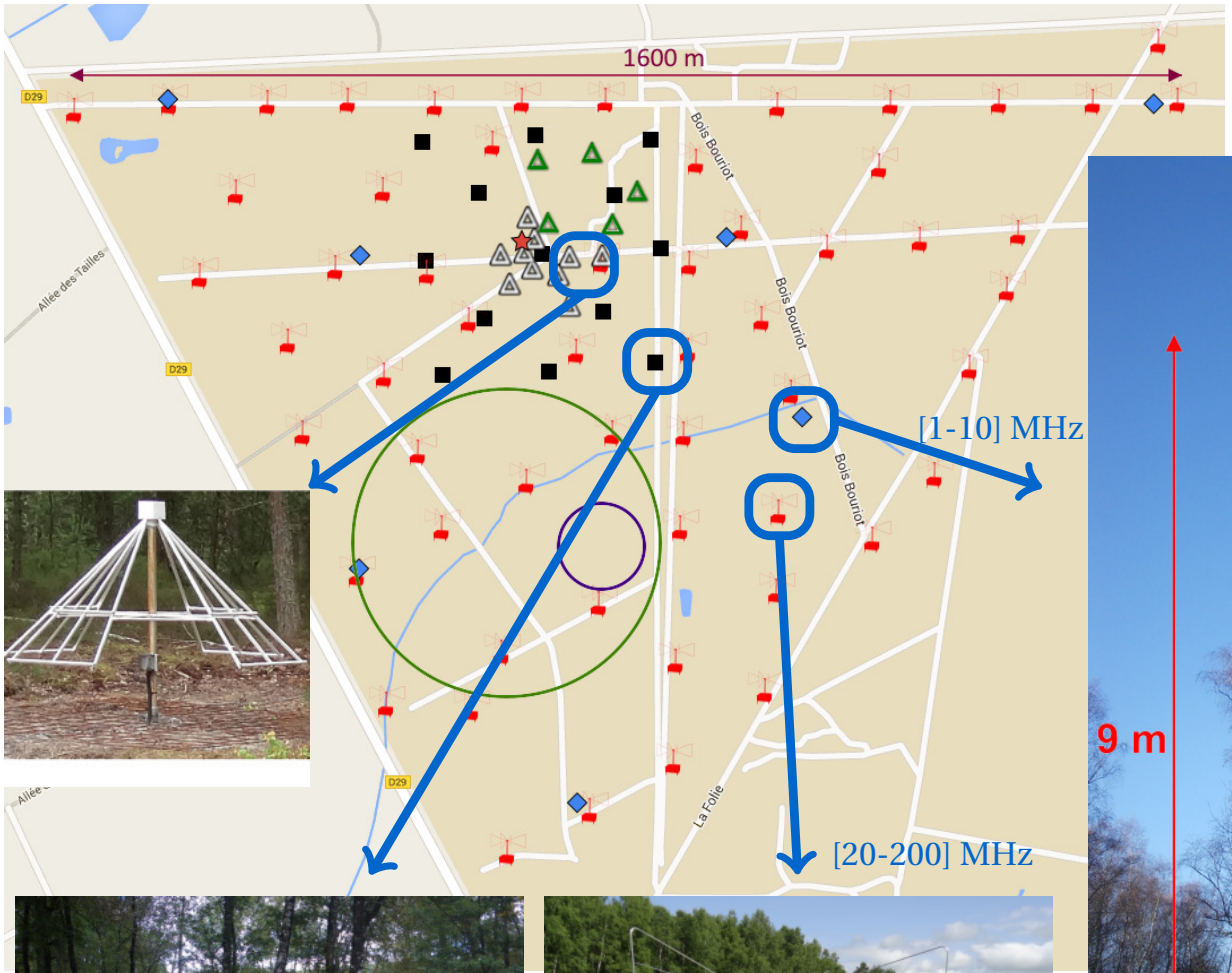
Charge excess mechanism

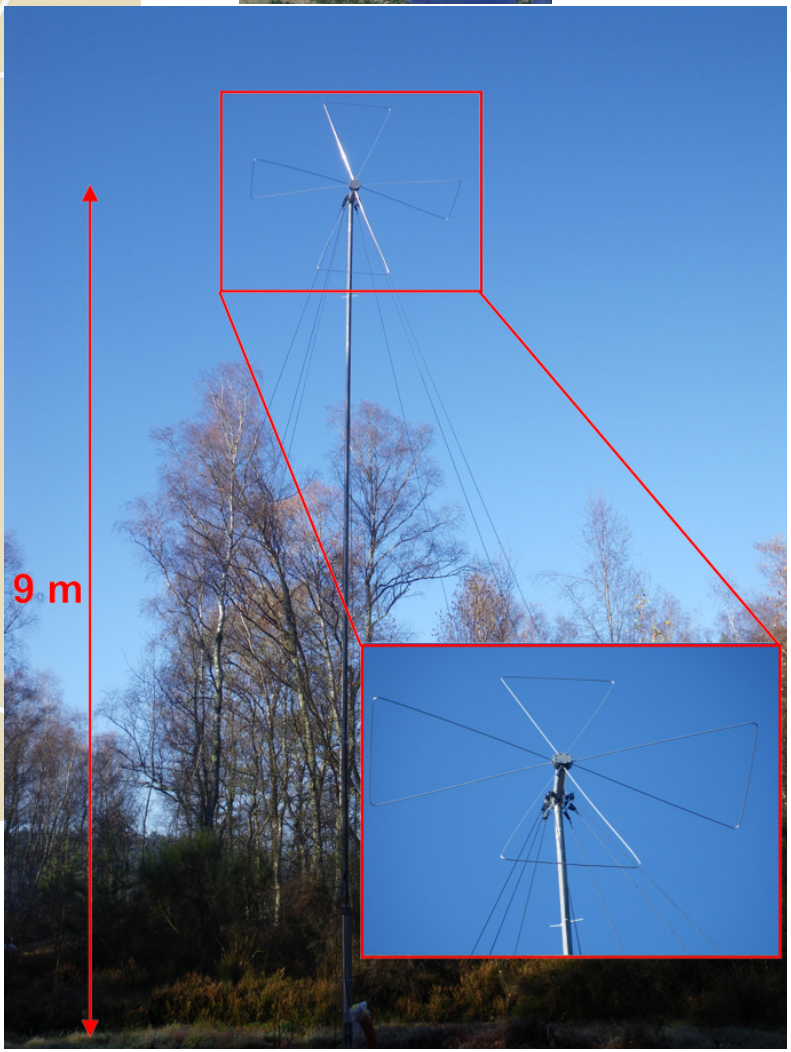
Askaryan (1962, 1965)





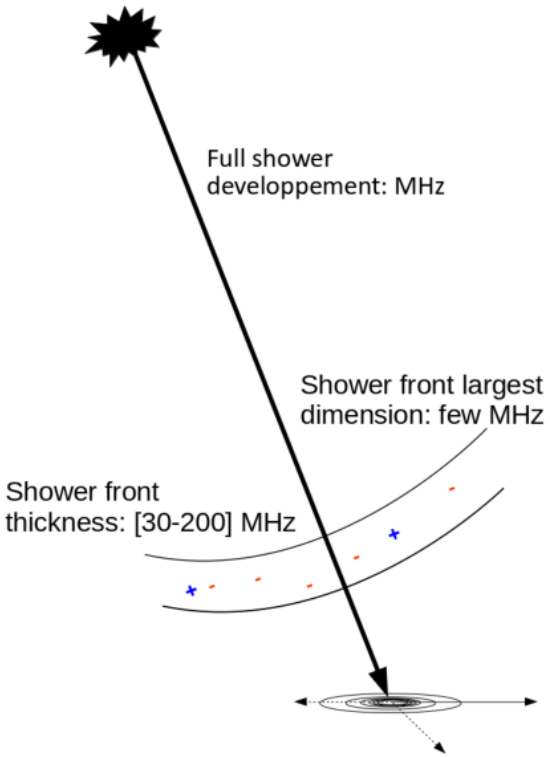
The experimental site - Nançay

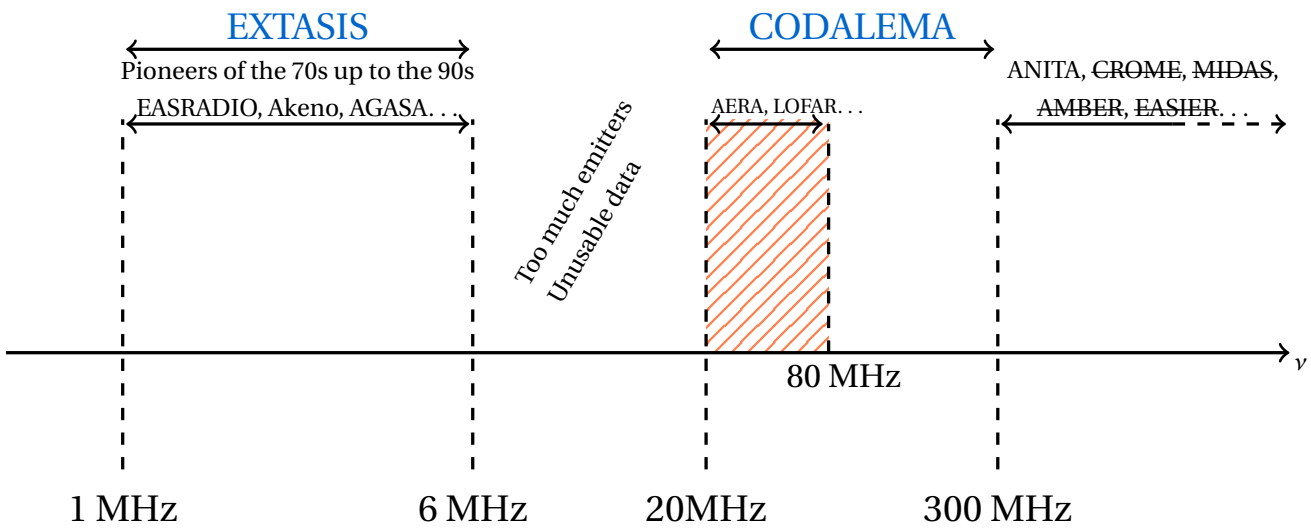




Commonly used frequency band results

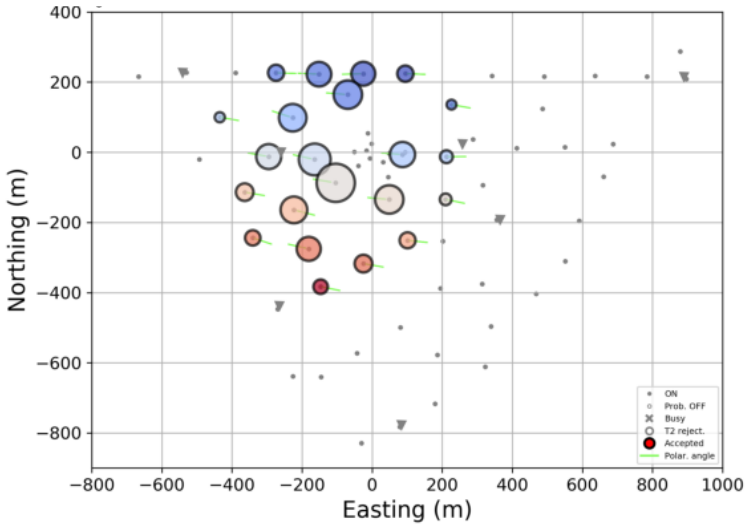
CODALEMA: [30 – 80] MHz





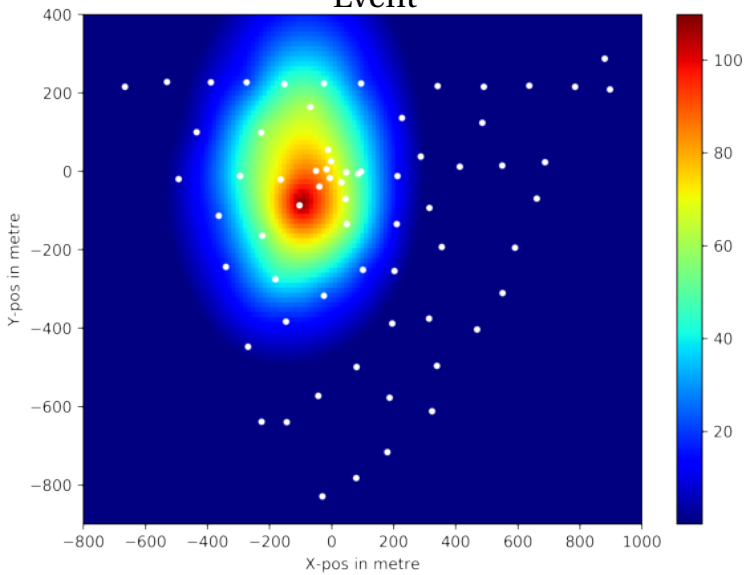
Estimating the shower parameters

Event

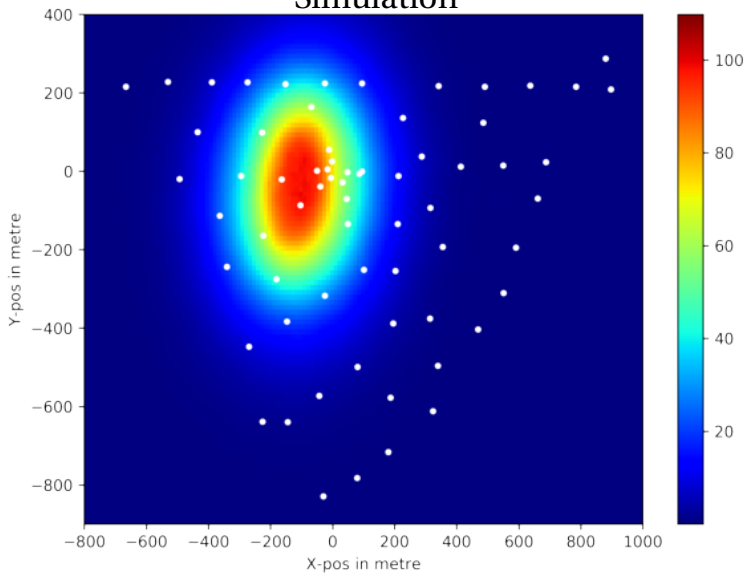


$\theta, \phi, (X_{core}, Y_{core}), X_{max}$, Energy

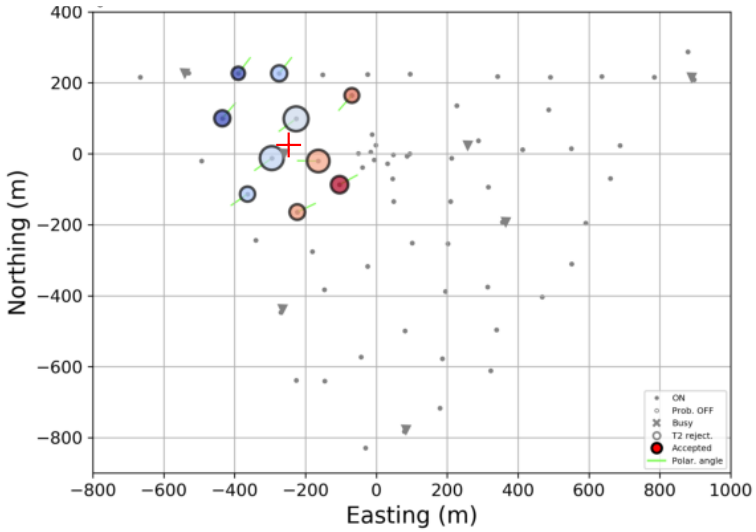
Event

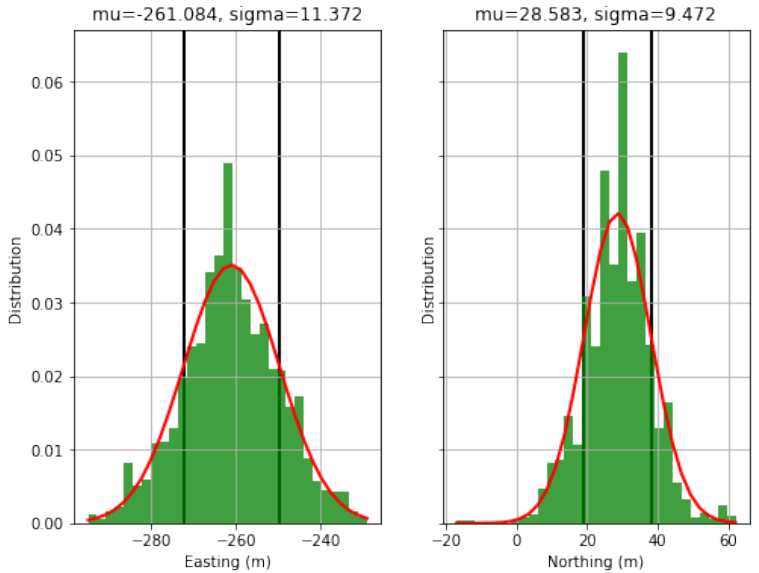


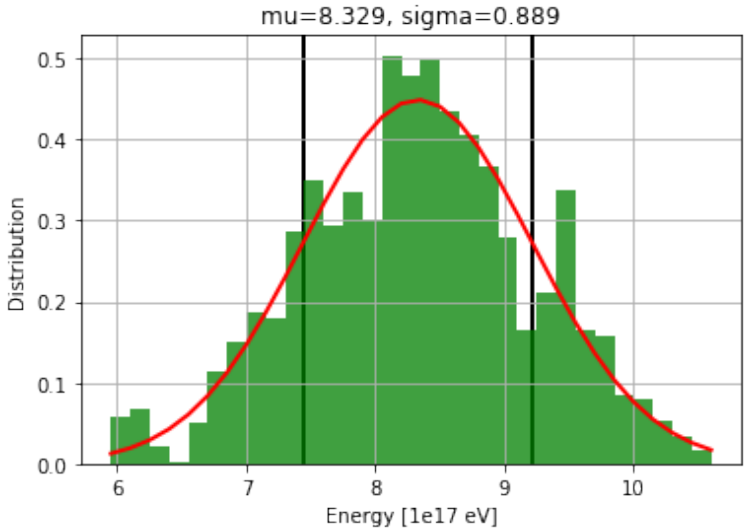
Simulation

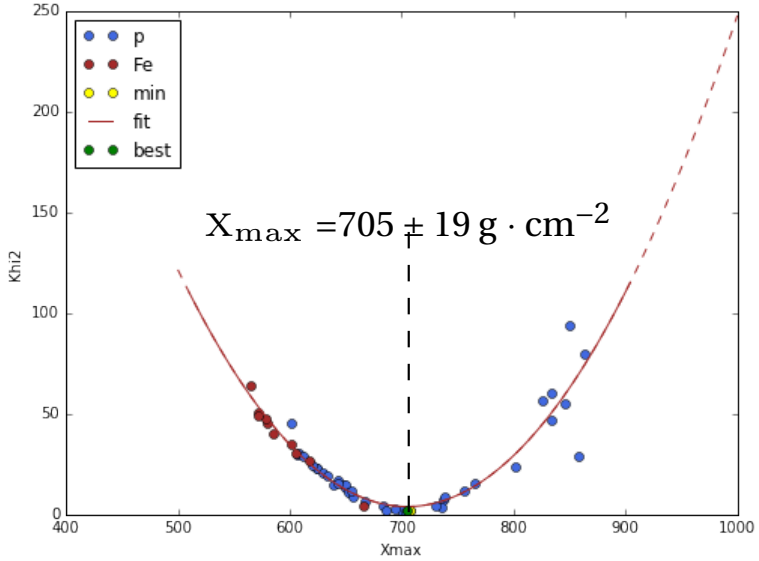


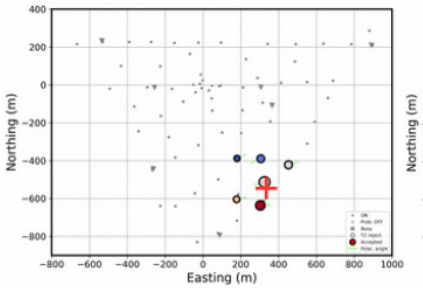
Estimating the shower parameters

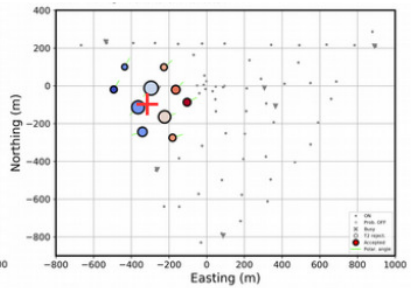


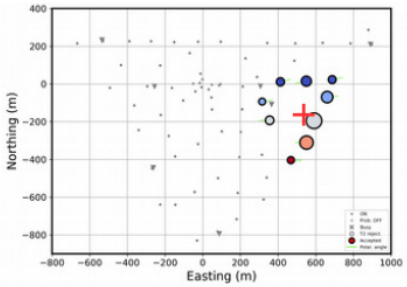


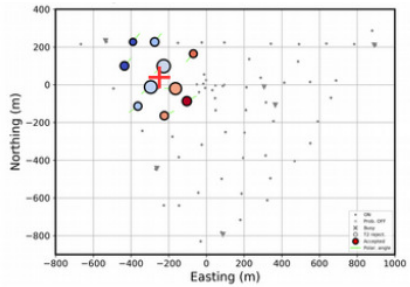




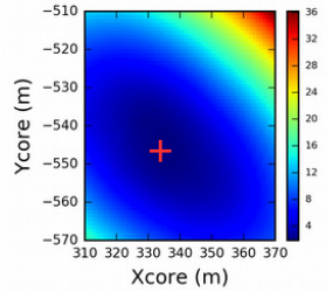


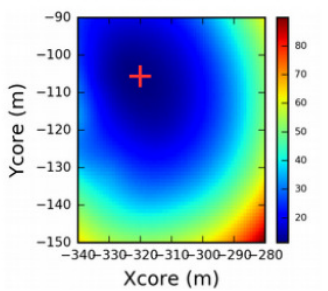


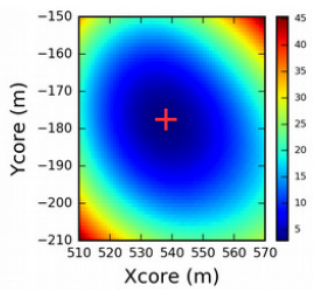


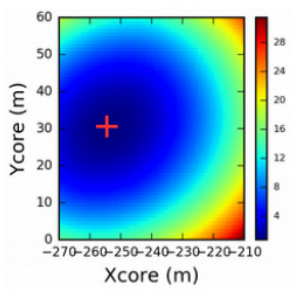


Amplitude footprint

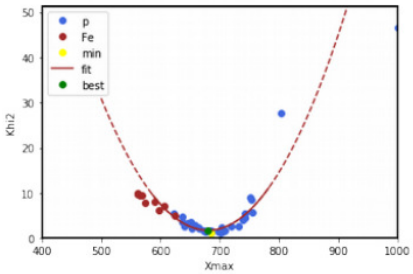


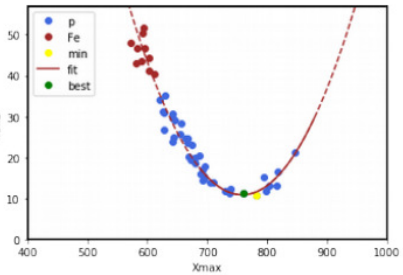


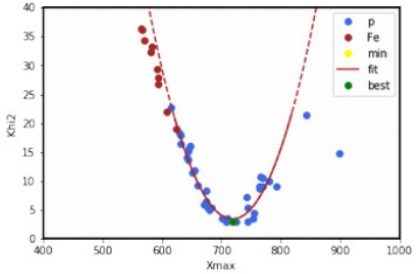


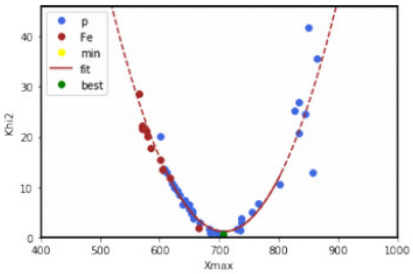


χ^2 vs core location

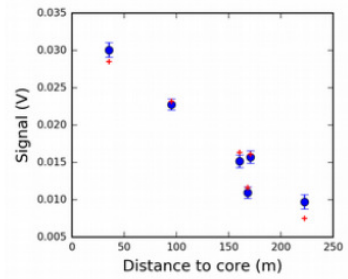


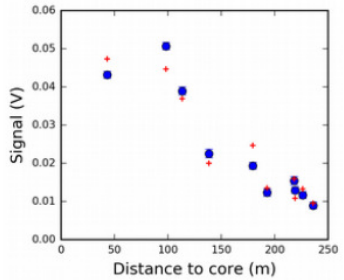


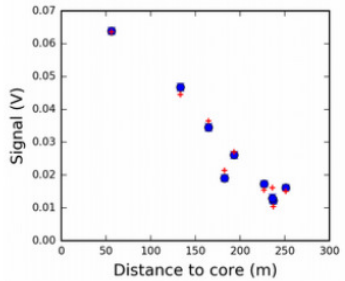


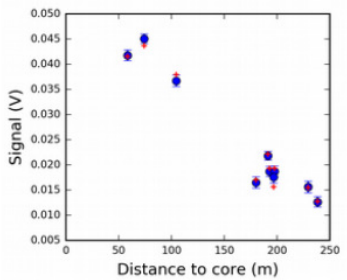


χ^2 vs X_{max}









Lateral distribution function

- Data
- SELFAS

- $X_{max} = 680 \pm 33\ g \cdot cm^{-2}$
- $X_{max} = 758 \pm 28\ g \cdot cm^{-2}$
- $X_{max} = 719 \pm 23\ g \cdot cm^{-2}$
- $X_{max} = 708 \pm 28\ g \cdot cm^{-2}$

Progress in simulation - SELFAS3

Upgrade of SELFAS with a state-of-the-art treatment of the atmosphere: F. Gaté *et al.*, Astroparticle Physics, 98:38 – 51, 2018

- USstandard: $\Delta X_{max} = 34.1\ g \cdot cm^{-2}$, $\sigma_{X_{max}} = 8.9\ g \cdot cm^{-2}$
- GDAS: $\Delta X_{max} = 0.1\ g \cdot cm^{-2}$, $\sigma_{X_{max}} = 2.4\ g \cdot cm^{-2}$

- Classically, working under "far-field" assumption: SELFAS2, ZHAireS or CoREAS
- Low frequency (<10 MHz) radio emission of EAS needs a new treatment including near-field effects (d$\sim \lambda$)
- At 1 MHz, and R =100 m: kR $\sim 2 \Rightarrow$ Near field!

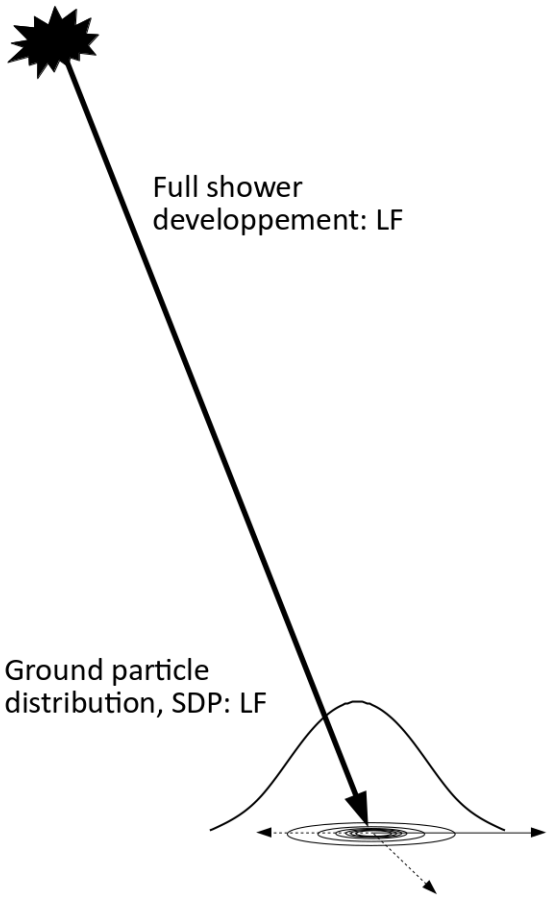
$$\mathbf{E}(\mathbf{x}, t) = \frac{1}{4\pi\epsilon} \int d^3x' \left(\left[\frac{\rho(\mathbf{x}', t_{ret})\mathbf{r}}{R^2(1 - n\beta \cdot \mathbf{r})} \right]_{ret} + \frac{n}{c} \frac{\partial}{\partial t} \left[\frac{\rho(\mathbf{x}', t_{ret})\mathbf{r}}{R(1 - n\beta \cdot \mathbf{r})} \right] - \frac{n^2}{c^2} \frac{\partial}{\partial t} \left[\frac{\mathbf{J}(\mathbf{x}', t_{ret})}{R(1 - n\beta \cdot \mathbf{r})} \right]_{ret} \right)$$

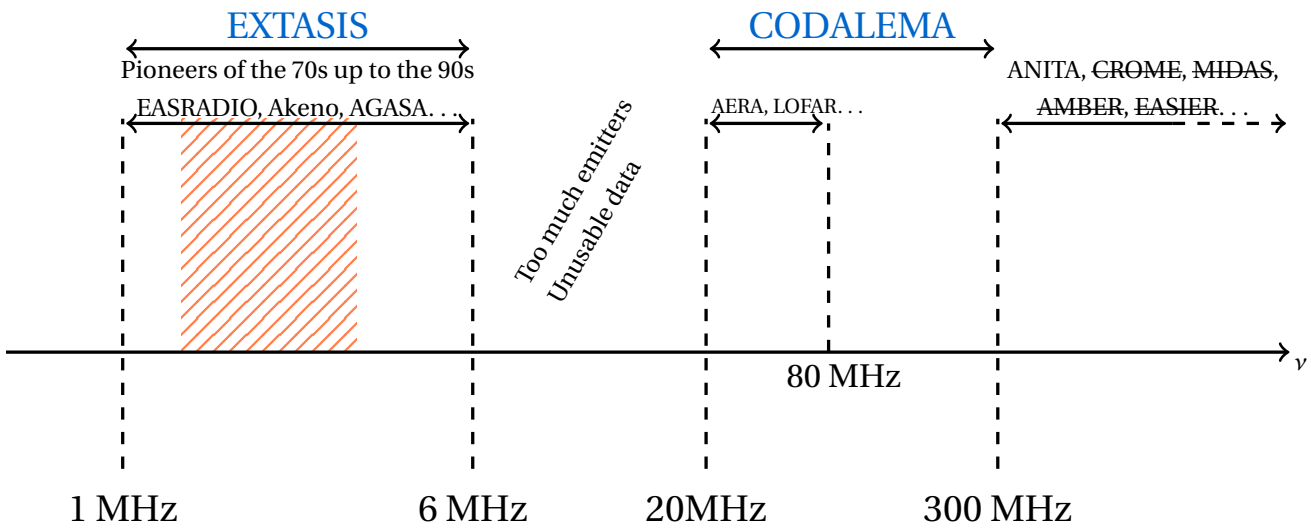
Charge must be conserved: D. García-Fernández *et al.*, arXiv:1710.11517 (submitted paper - PRD)

Other interpretations: boosted Coulombian field $\Rightarrow$ Alain Lecacheux

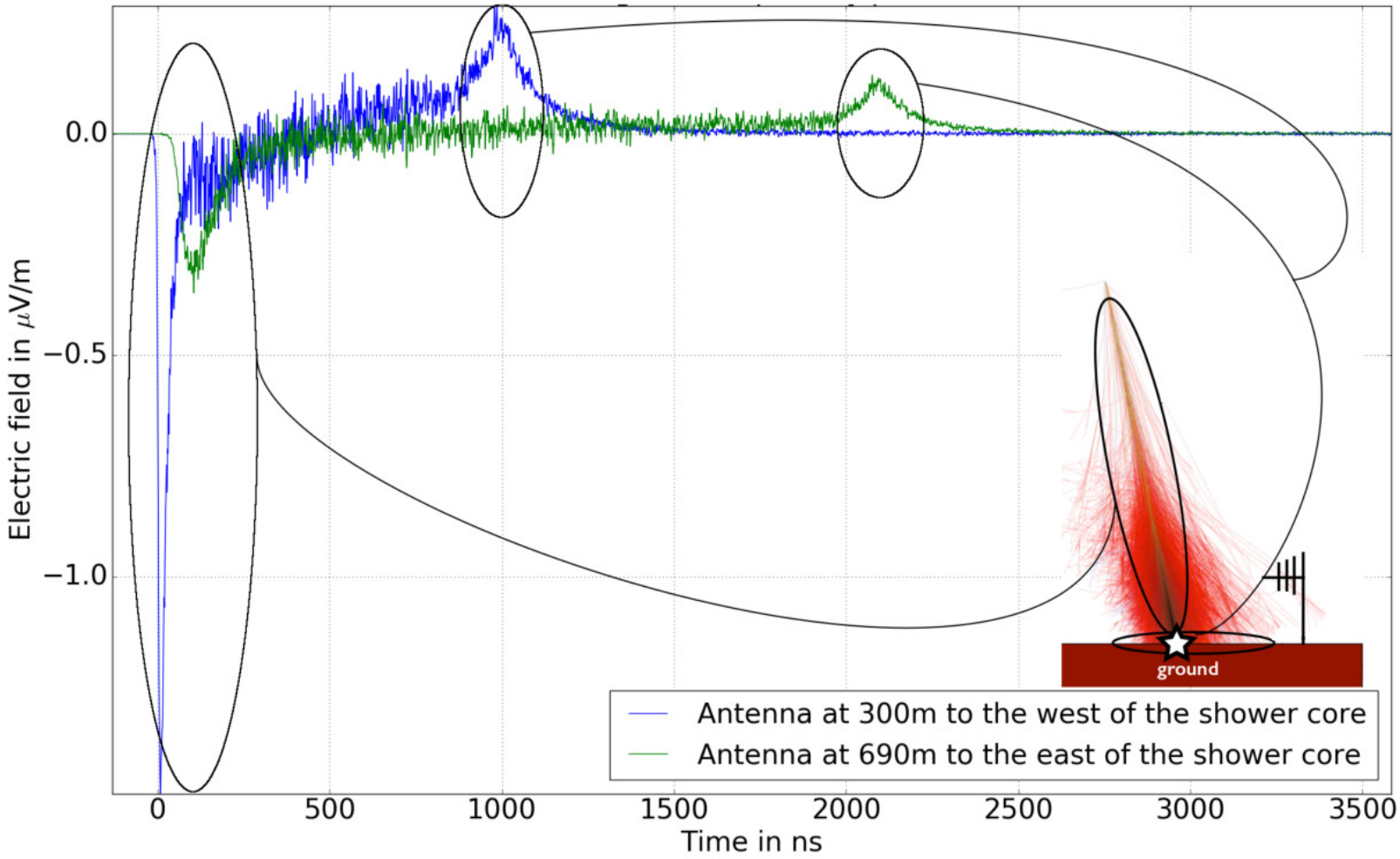
Low-frequency band results

EXTASIS: [1 – 6] MHz

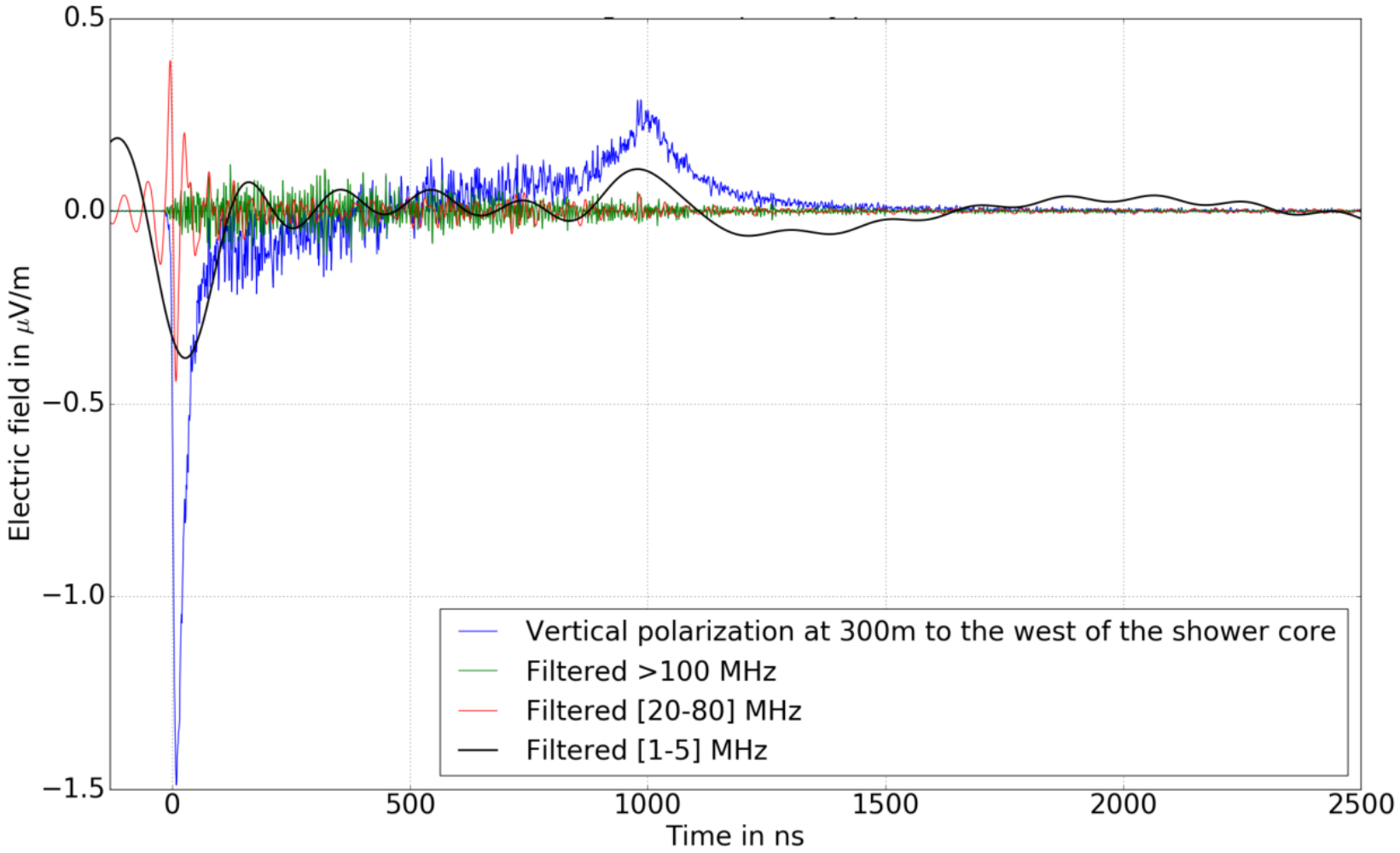




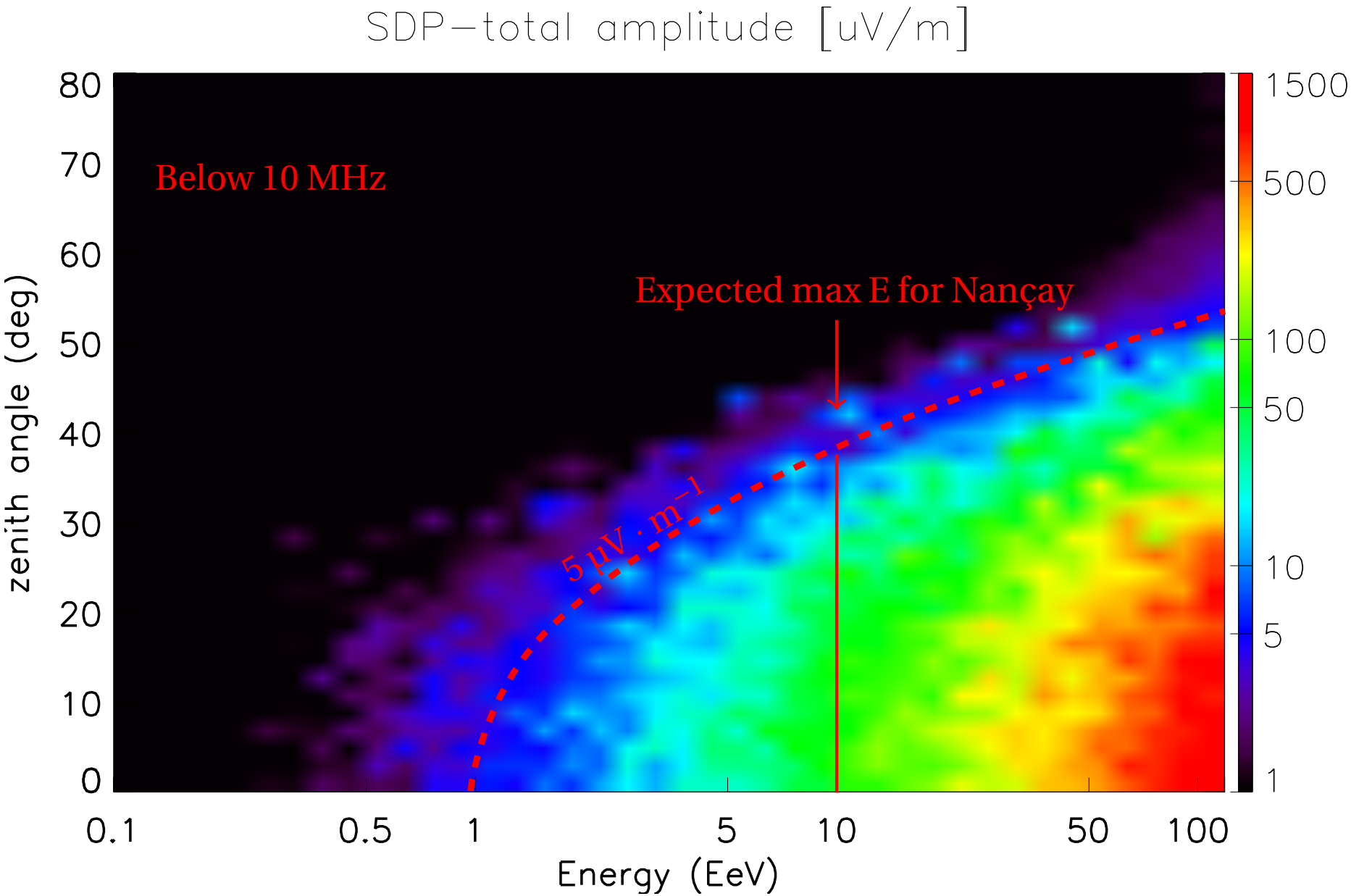
Low-frequency counterpart in the radio signal



Low-frequency counterpart in the radio signal

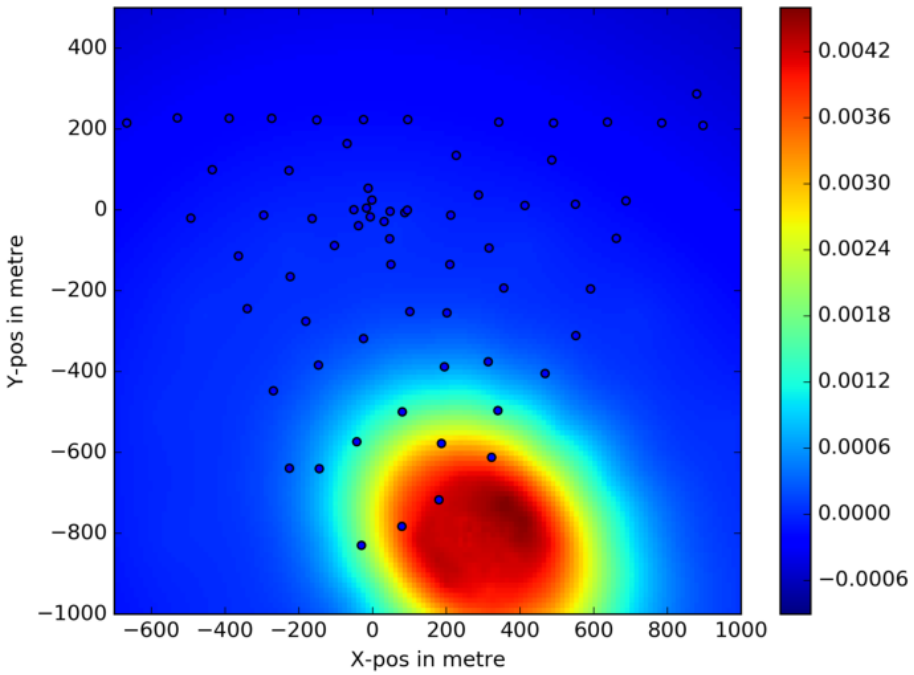


The sudden death signal

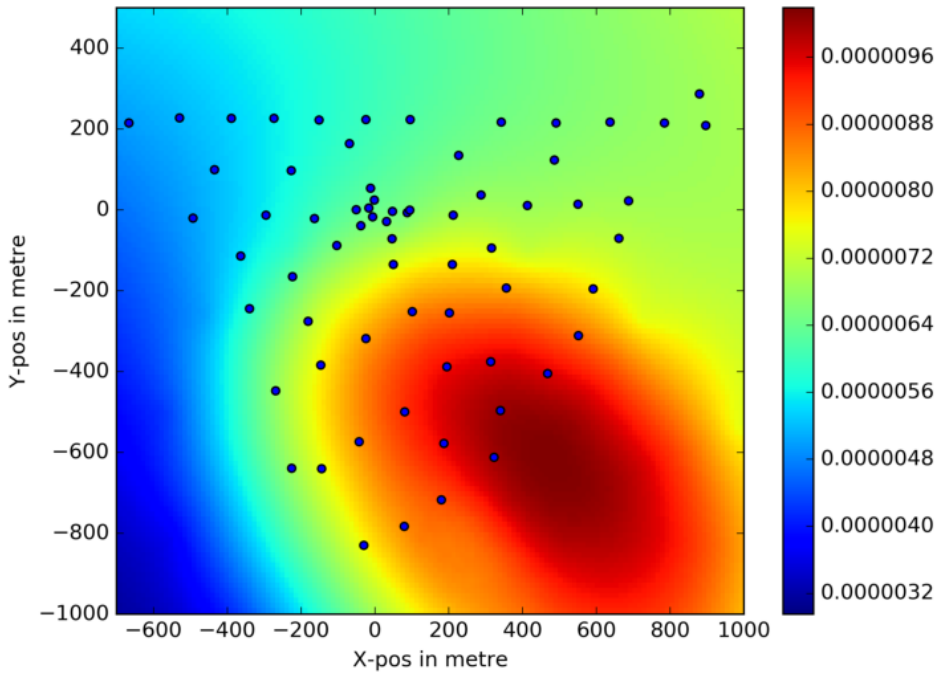


Detection range

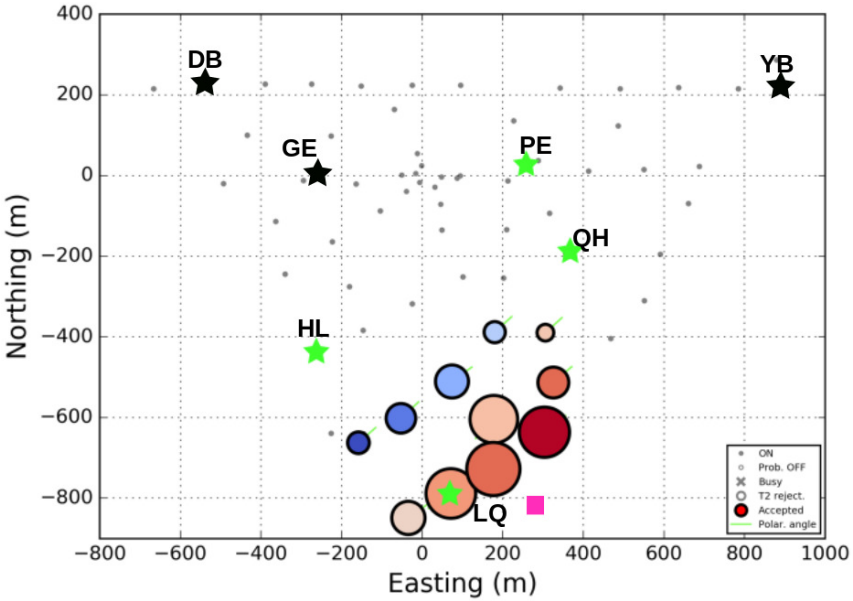
[30 – 80] MHz



[1 – 5] MHz



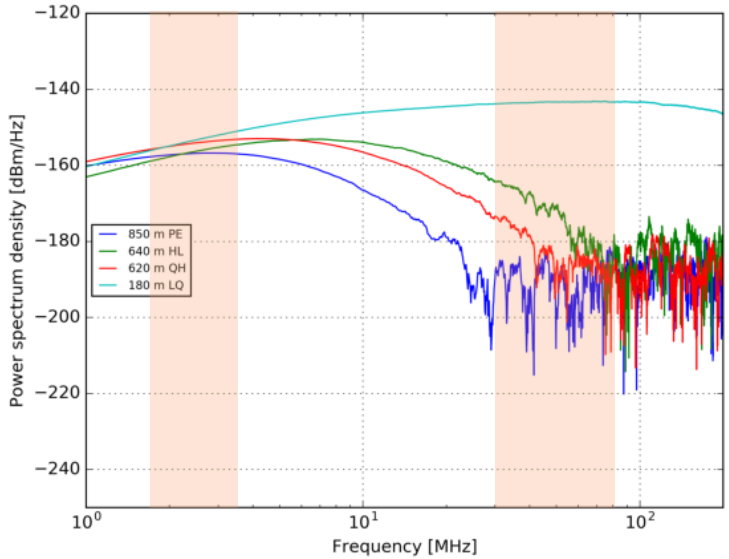
Detection



PE antenna at 850 m ⇒ only LF signal
QH antenna at 620 m ⇒ only LF signal
HL antenna at 640 m ⇒ only LF signal
LQ antenna at 180 m ⇒ HF & LF signal

Arrival directions:

- θ_{LF} =31.1°, Φ_{LF} =146.1°
- θ_{SA} =40.6°, Φ_{SA} =145.2°
- θ_{SC} =32.4°, Φ_{SC} =144.1°



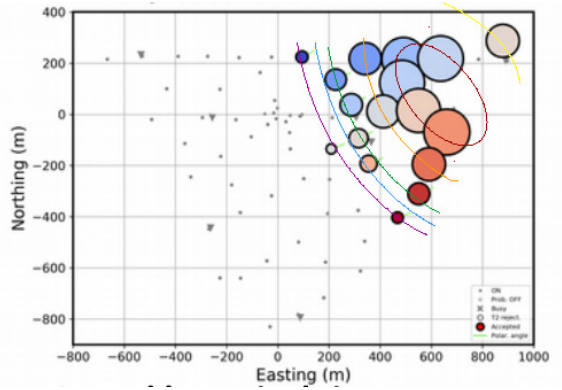
Larger detection range at low-frequency

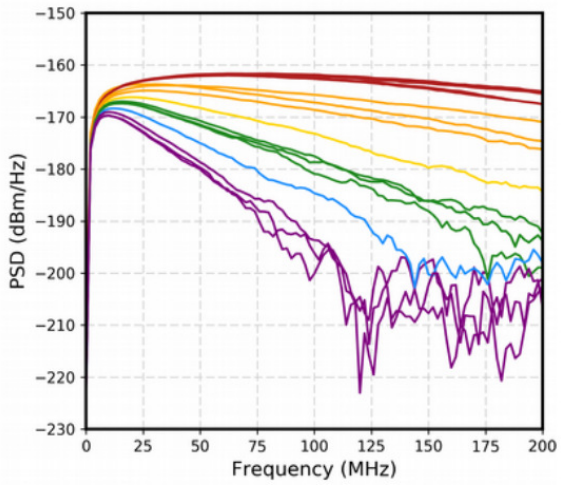
Summary

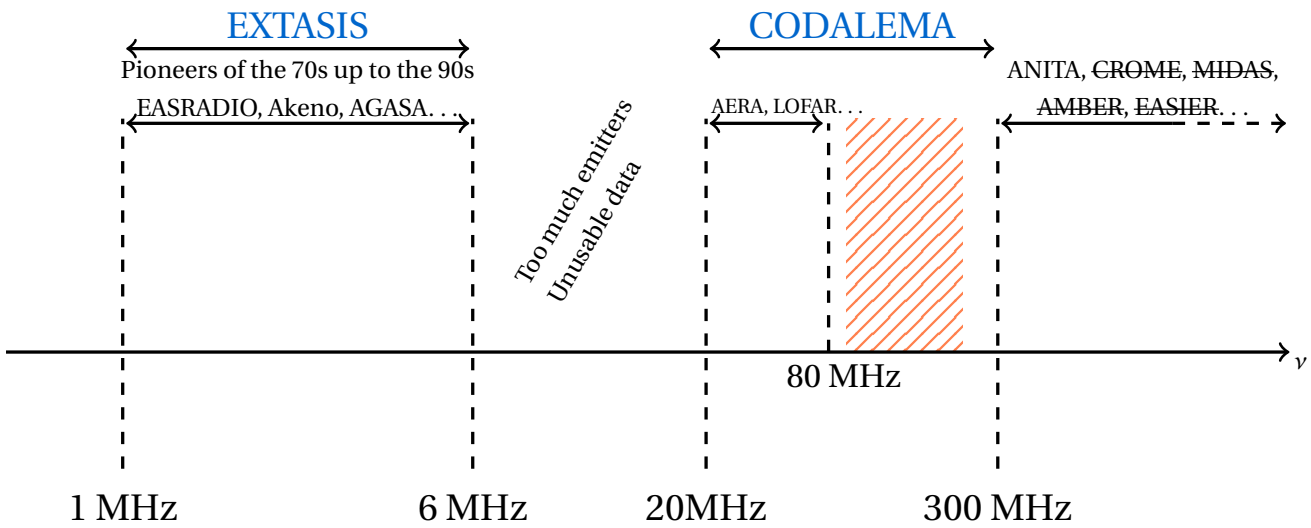
- LF counterpart of shower development detected
- Sudden death signal still not seen ⇒ Auger
- Strong correlation with atmospheric electric field
- LF signal seems not very promising (very few events, low efficiency)

High-frequency band results

CODALEMA: [120 – 200] MHz



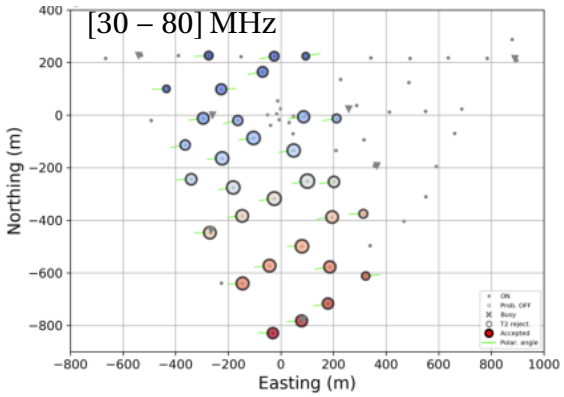


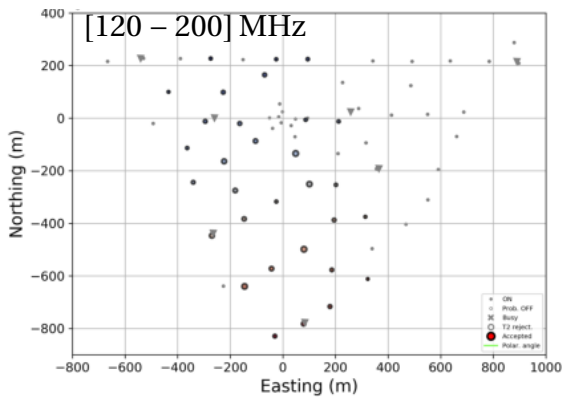


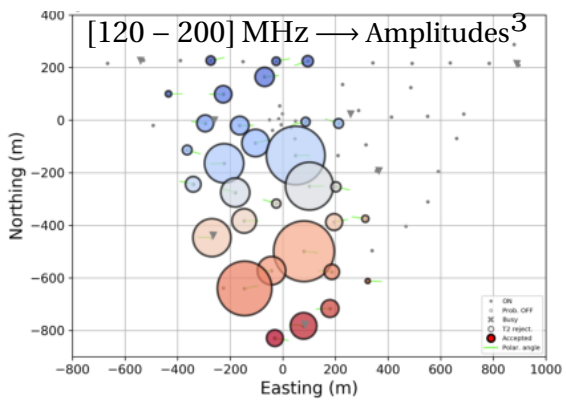
Continuity in the spectra, their content is precious ⇒ only CODALEMA can do that!

Importance of the HF signal

Inclined event





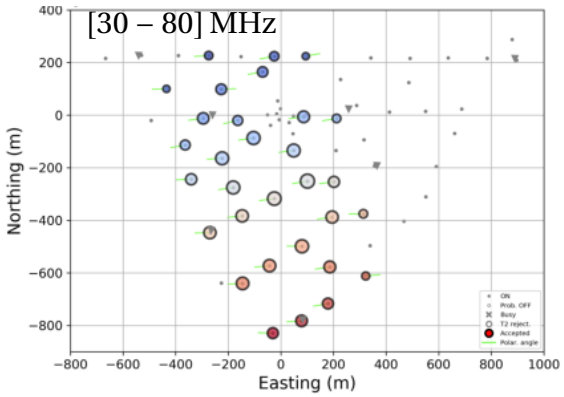


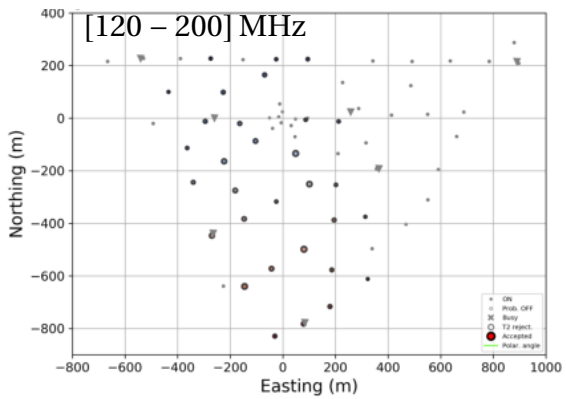
Work in progress

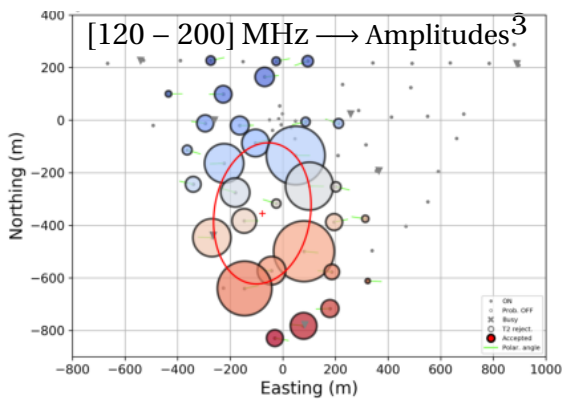
- radio-reconstruction of inclined event in [30 – 80] MHz not sensitive
- radio-reconstruction much better in the HF band: $\chi^2_{30} = 26.4$, $\chi^2_{120} = 9.2$

Importance of the HF signal

Inclined event







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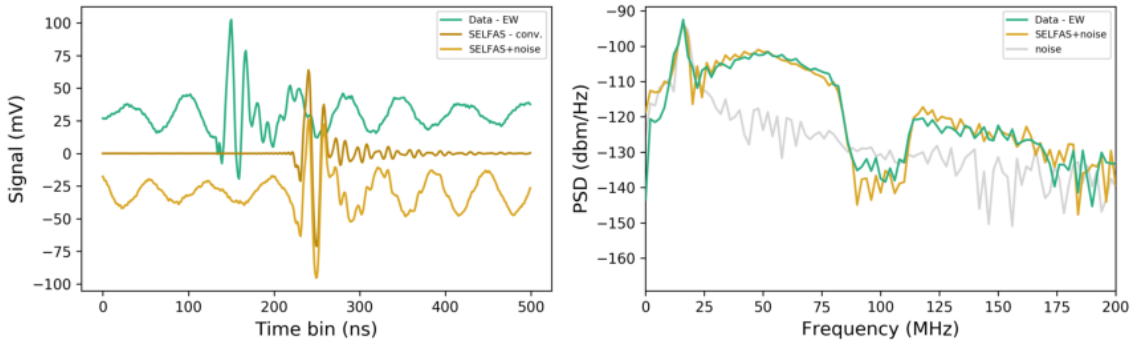
- CODALEMA/EXTASIS: routinely multi-wavelength observation of cosmic-ray air-showers in the 10^{16} – 10^{18} eV

- Instrument and simulations very well mastered, strong agreement



- Estimation of shower parameters using the radio signals: θ, ϕ, (X_{core}, Y_{core}), X_{max}, Energy
- Low-frequency signal seems not very promising
- Difficult to get shower parameters for inclined showers $\Rightarrow$ use of the HF counterpart

CODALEMA/EXTASIS are smart and powerful instruments in a unique environment, which could help as test bench for further experiments and projects

Thank you for listening !