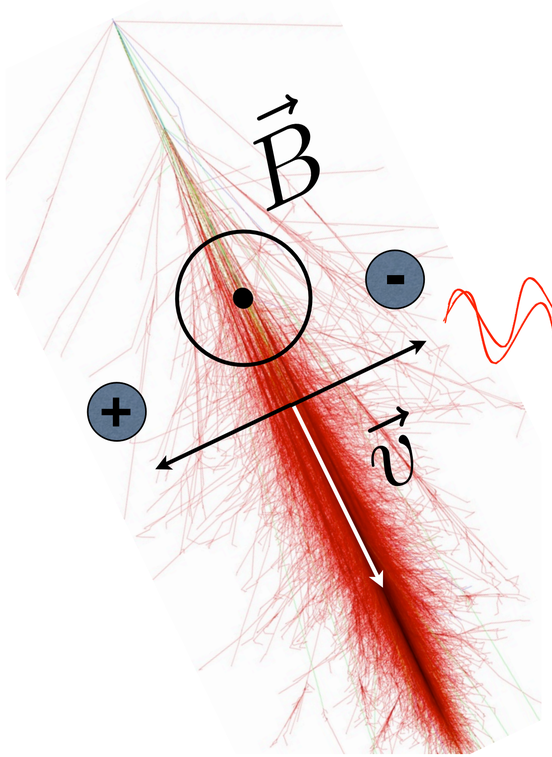
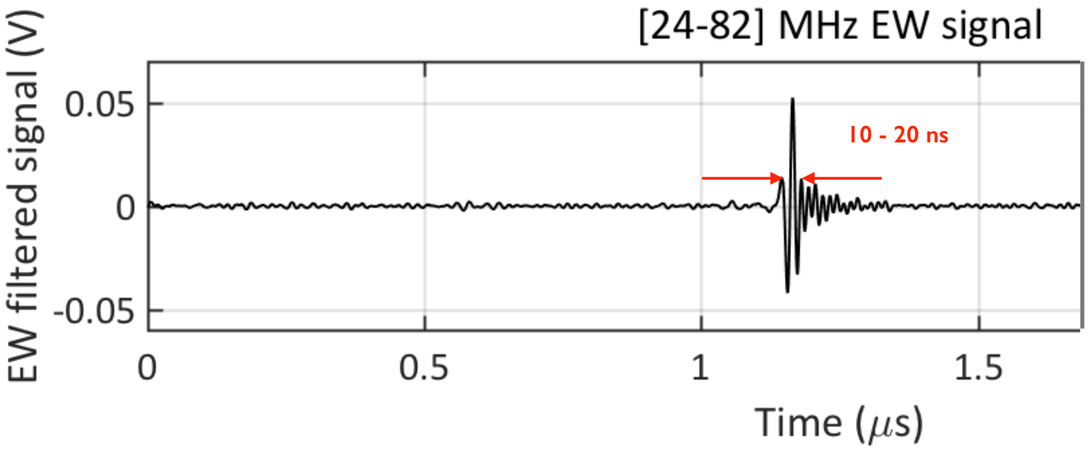
Multi-scale and multi-frequency studies of cosmic ray air shower radio signals at the CODALEMA site

R. Dallier, J.L. Béney, H. Carduner, D. Charrier, L. Denis, F. Gaté, A. Lecacheux, V. Marin, L. Martin, B. Revenu, D. Torres Machado





Motivations

To explore new or neglected ways of exploitation of the radio signal emitted by EAS

Successes

Simulation codes: very good understanding of the emission mechanisms

Properties of EAS: arrival direction, energy, mass-sensitive observables

At least 10 ground experiments of radio detection of UHECR currently operated in the world + neutrino search + SWORD…

Lacks

Determination of X_{max}: seems needing high antenna density (contradictory with high energies)

Covering large areas: standalone detectors, but either reject parasitic transients (self-triggering) or use scintillators (slave mode)

Detection range in classical [30-80] MHz band too short (sensitivity too low)

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Solutions ?

Look at high frequencies ?

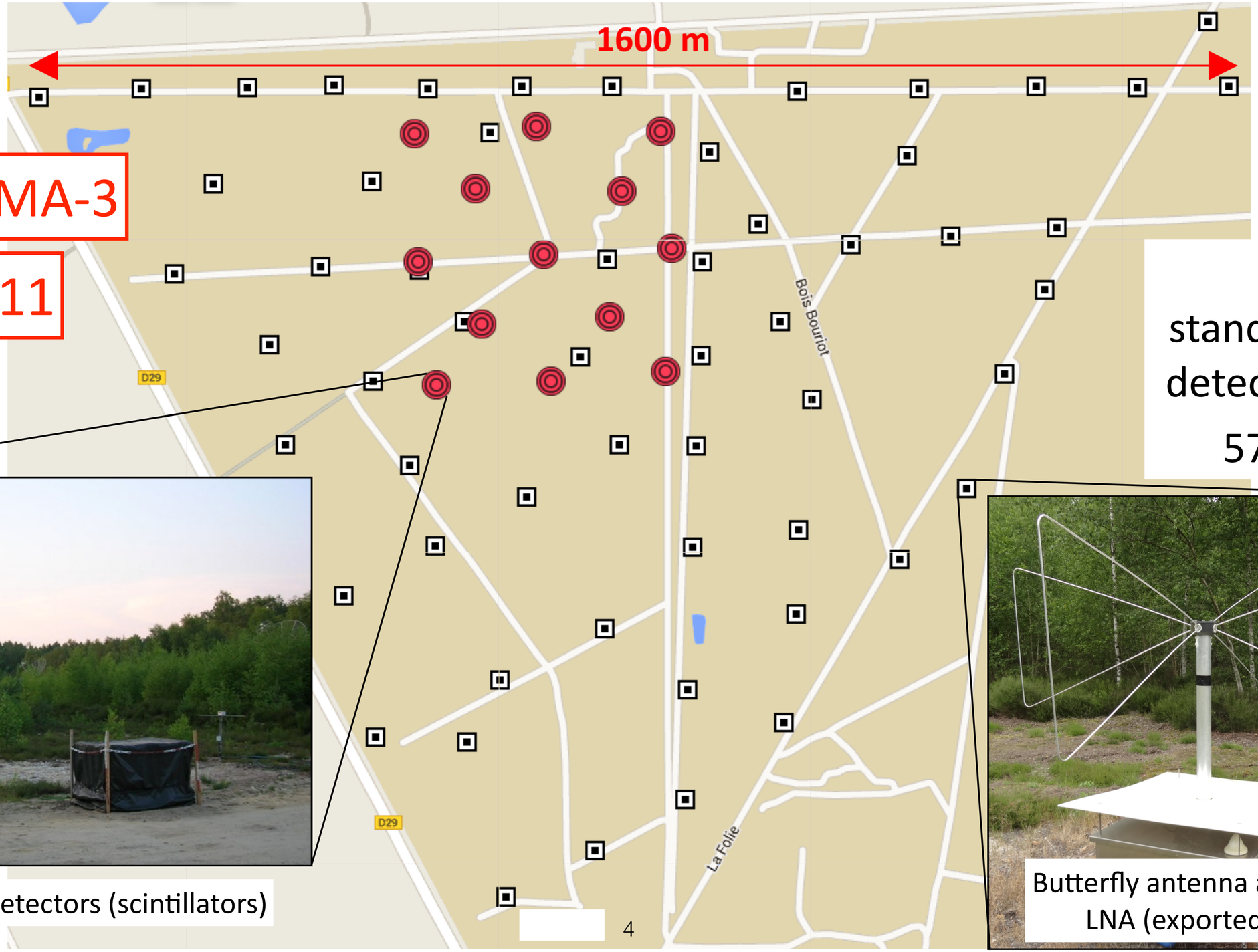
Very selective, composite radio trigger with several antennas (increased sensitivity) ?

Look at low frequencies ?

3-polarization detection ?

CODALEMA-3

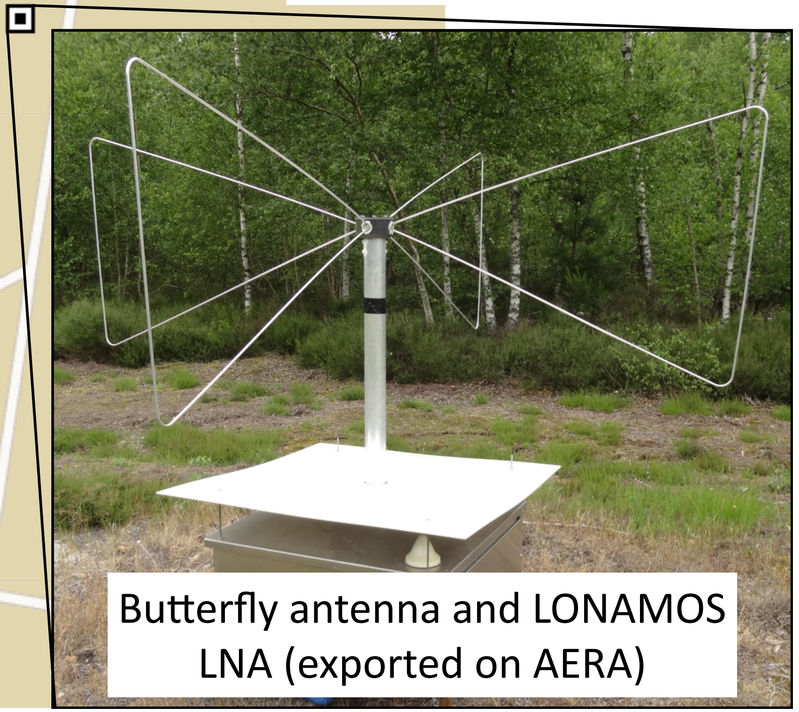
Since 2011



CODALEMA standalone radio detection station

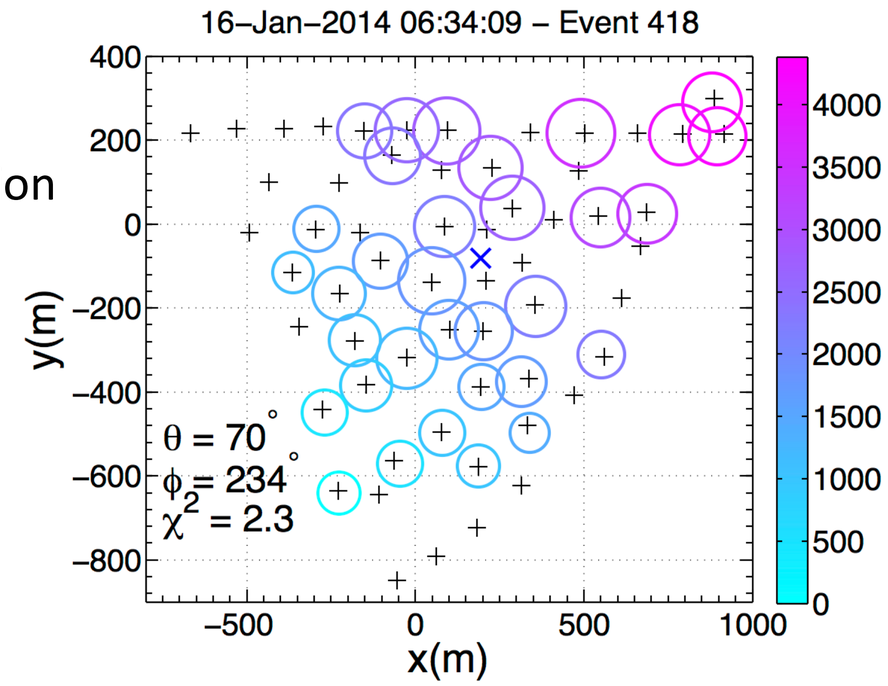
57 over 1 km^2

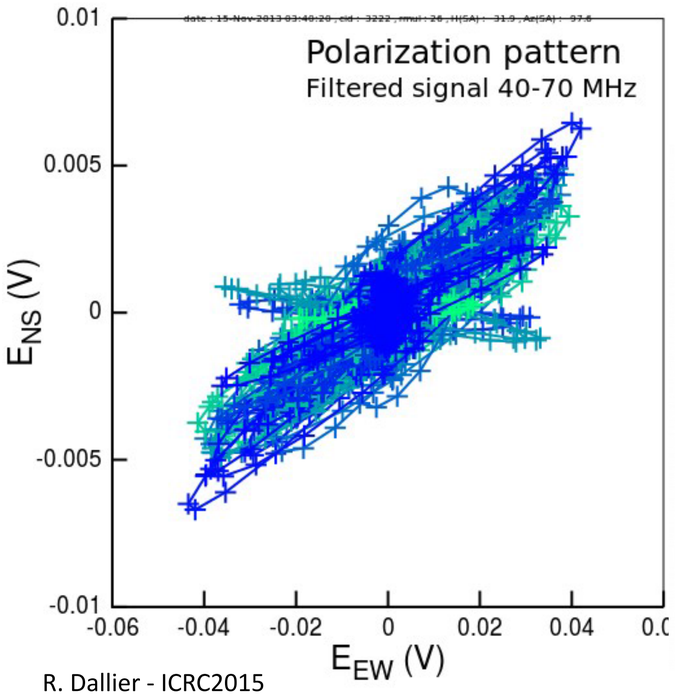
13 particle detectors (scintillators)



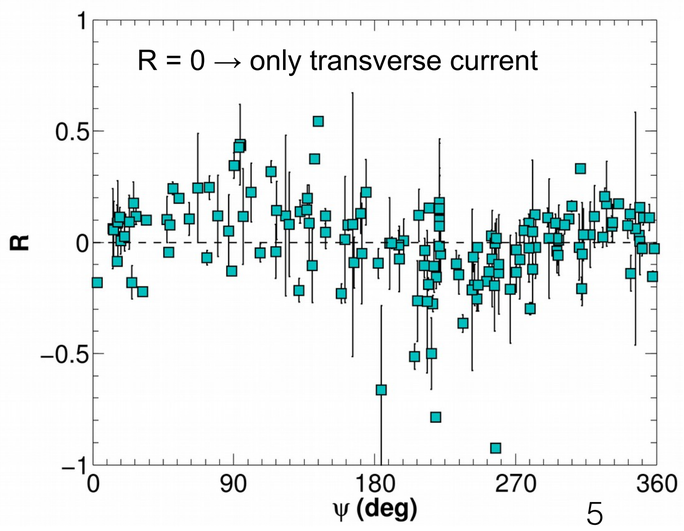
Butterfly antenna and LONAMOS LNA (exported on AERA)

Event reconstruction

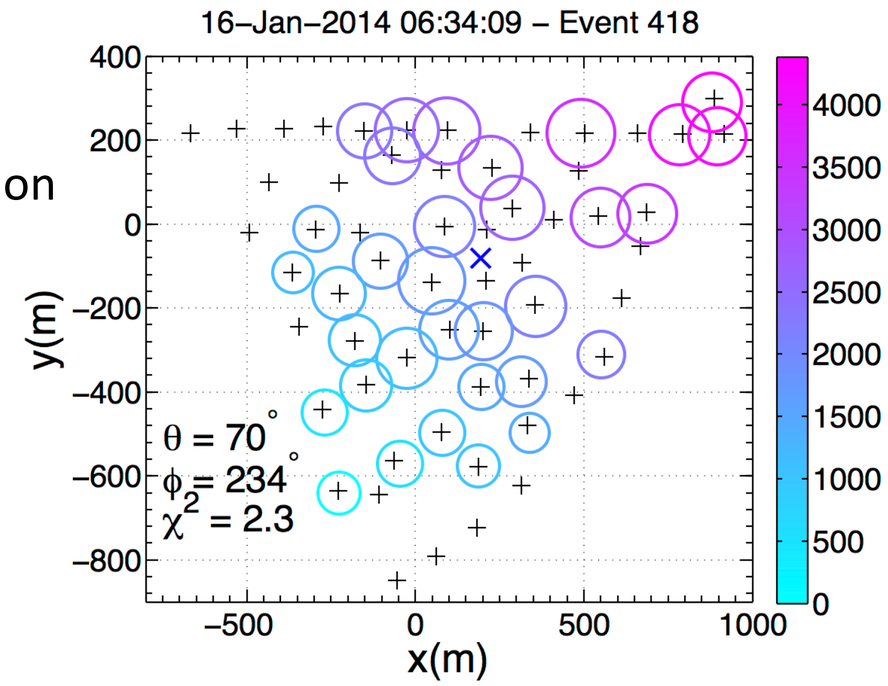


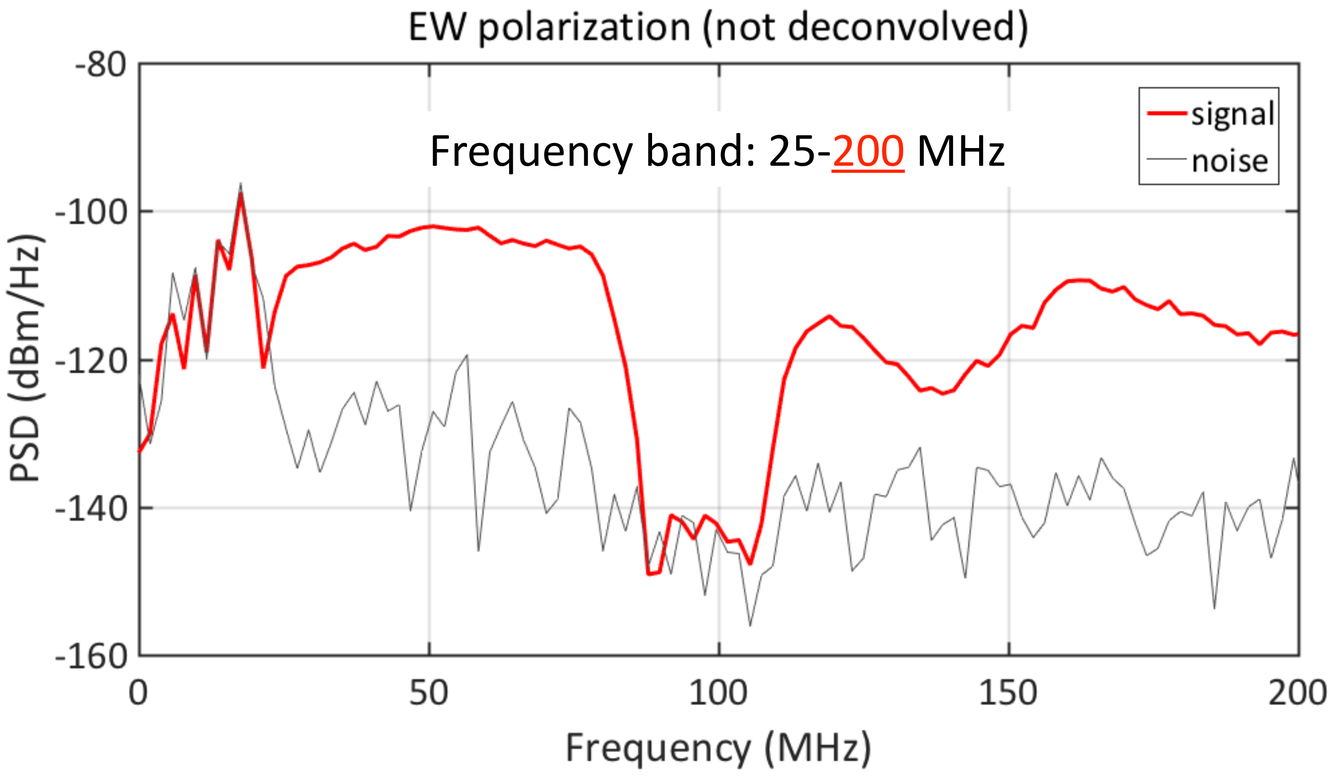


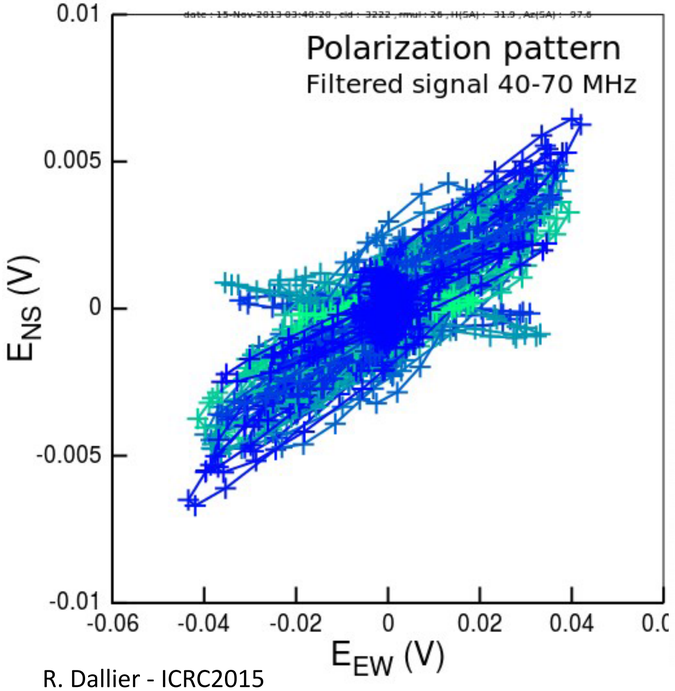
Polarization studies
Charge excess contribution



Event reconstruction







Polarization studies

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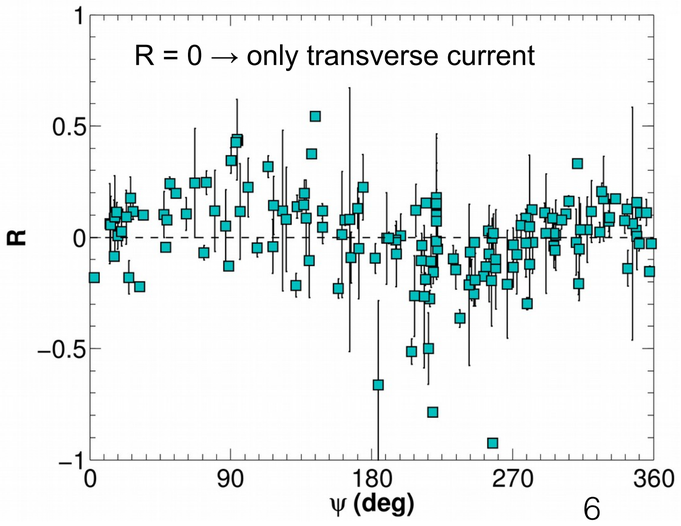
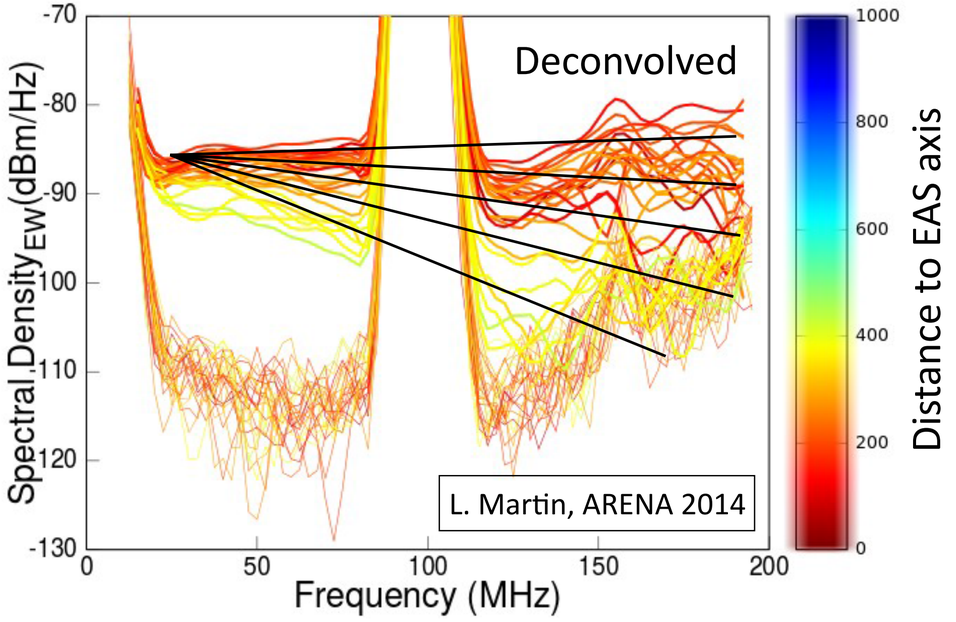
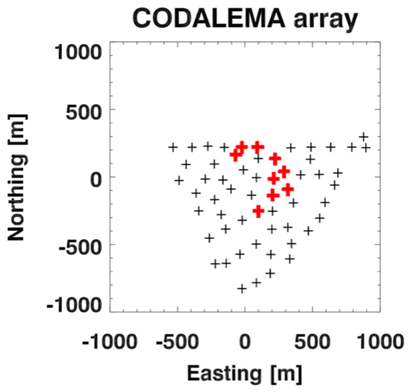
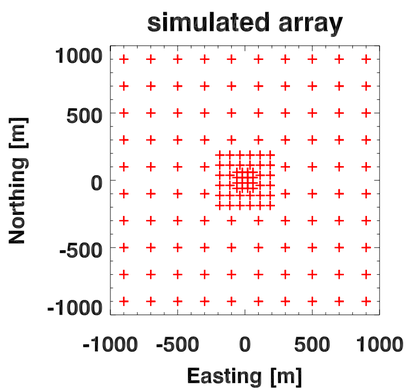
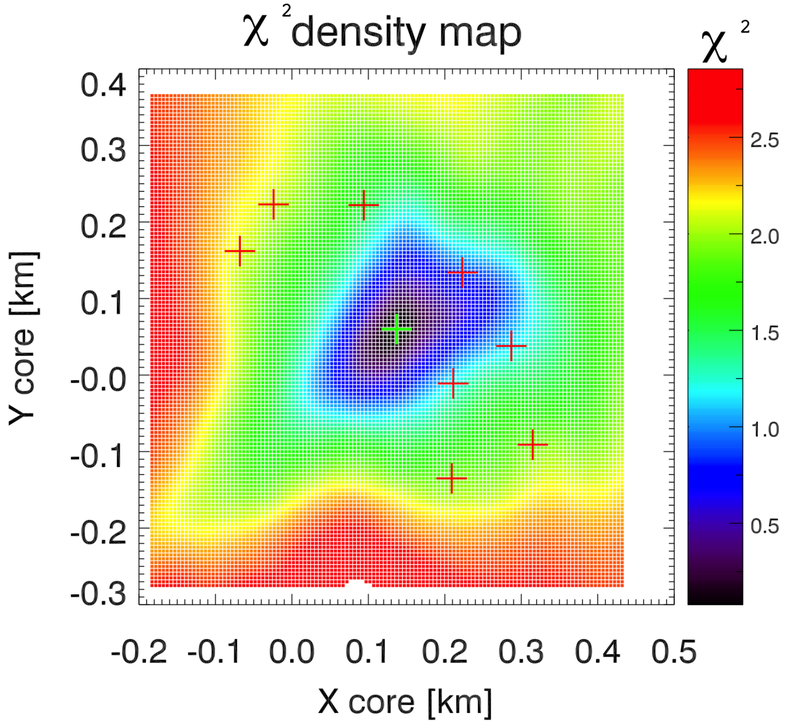
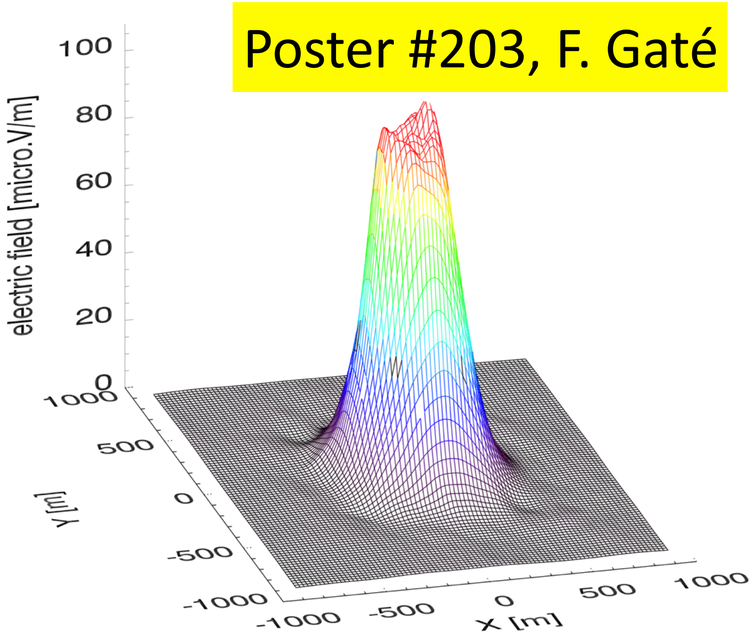








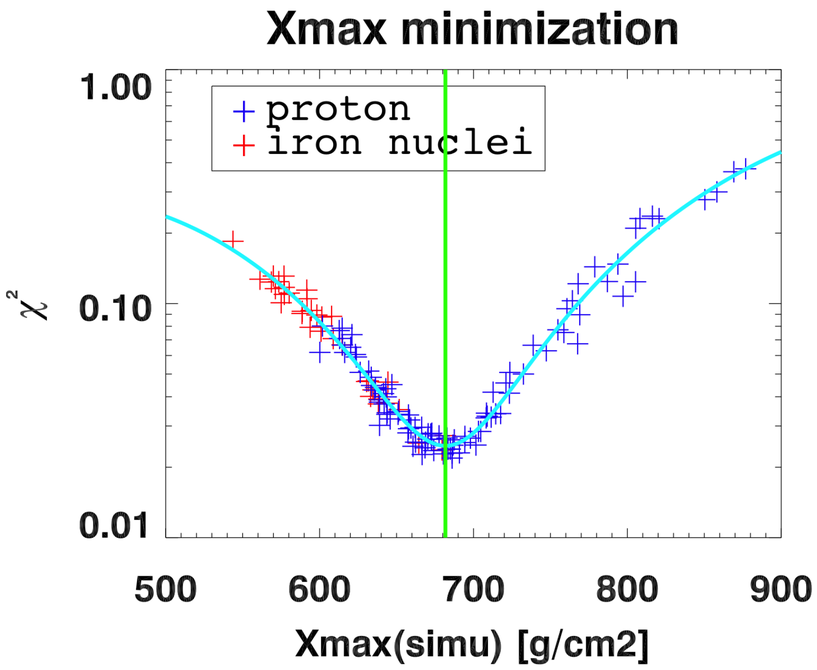




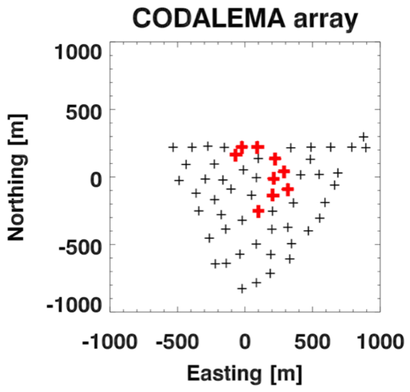
Poster #203, F. Gaté

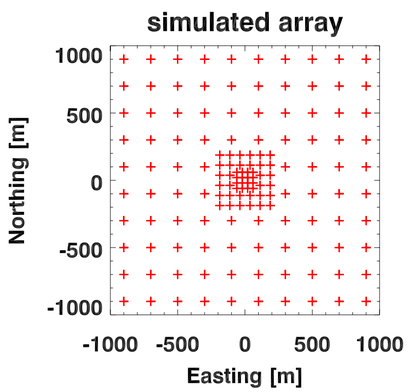
SELFAS simulation

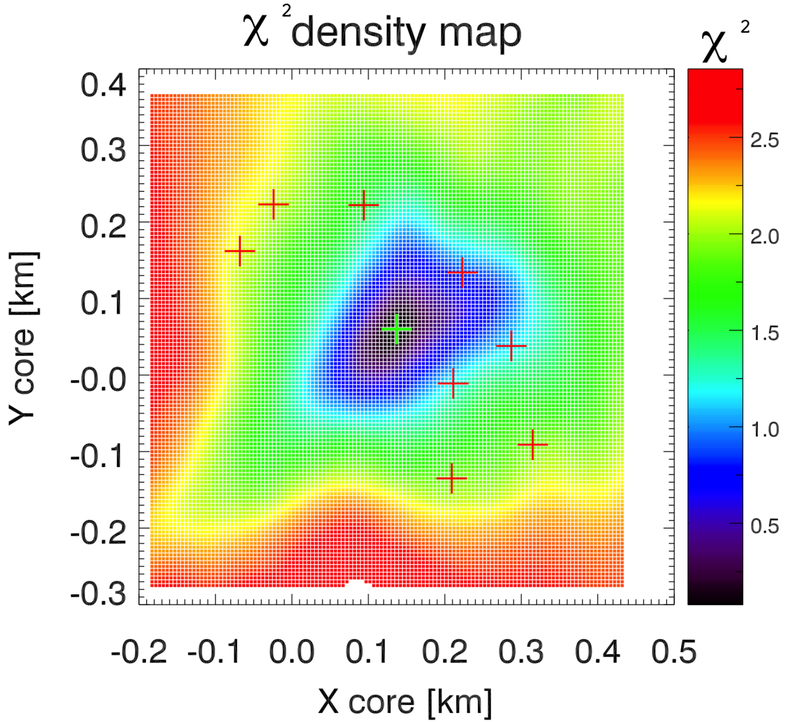
- Search for best core position
- Search for best 2D-LDF match
- Recover EAS parameters

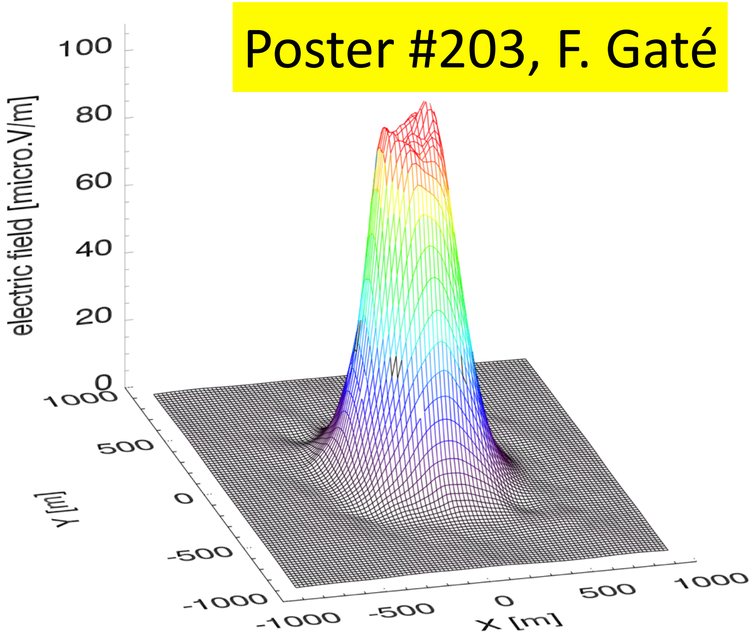


X_{Max} = 673 ± 26 g/cm^2
X_{core} = 80.2 ± 9 m
Y_{core} = -10.5 ± 8 m
E = (2 ± 0.7) 10^{17} eV









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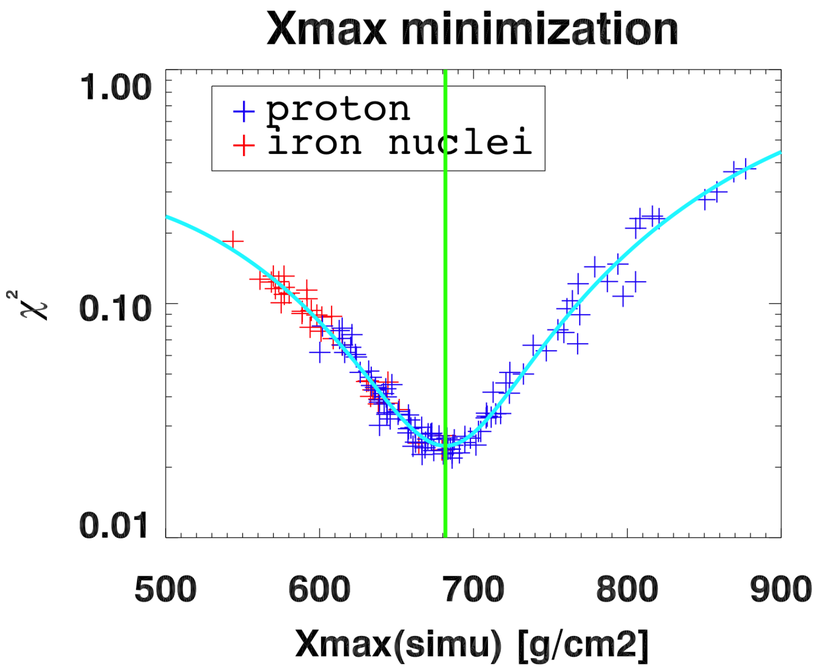
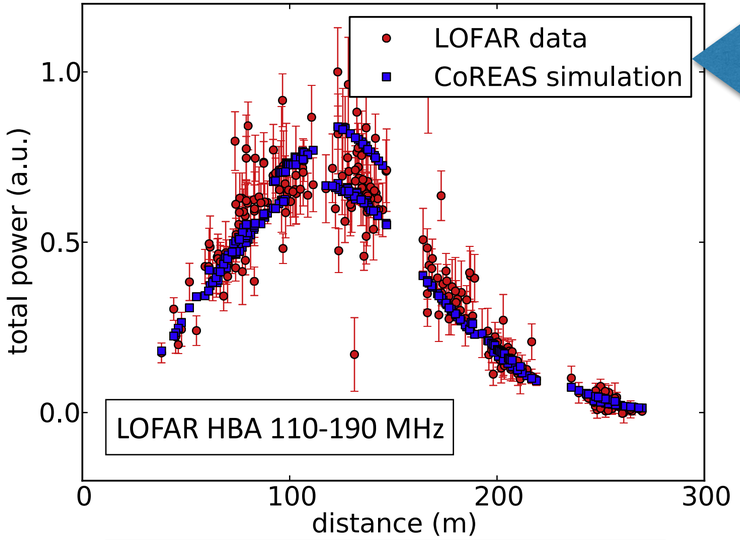




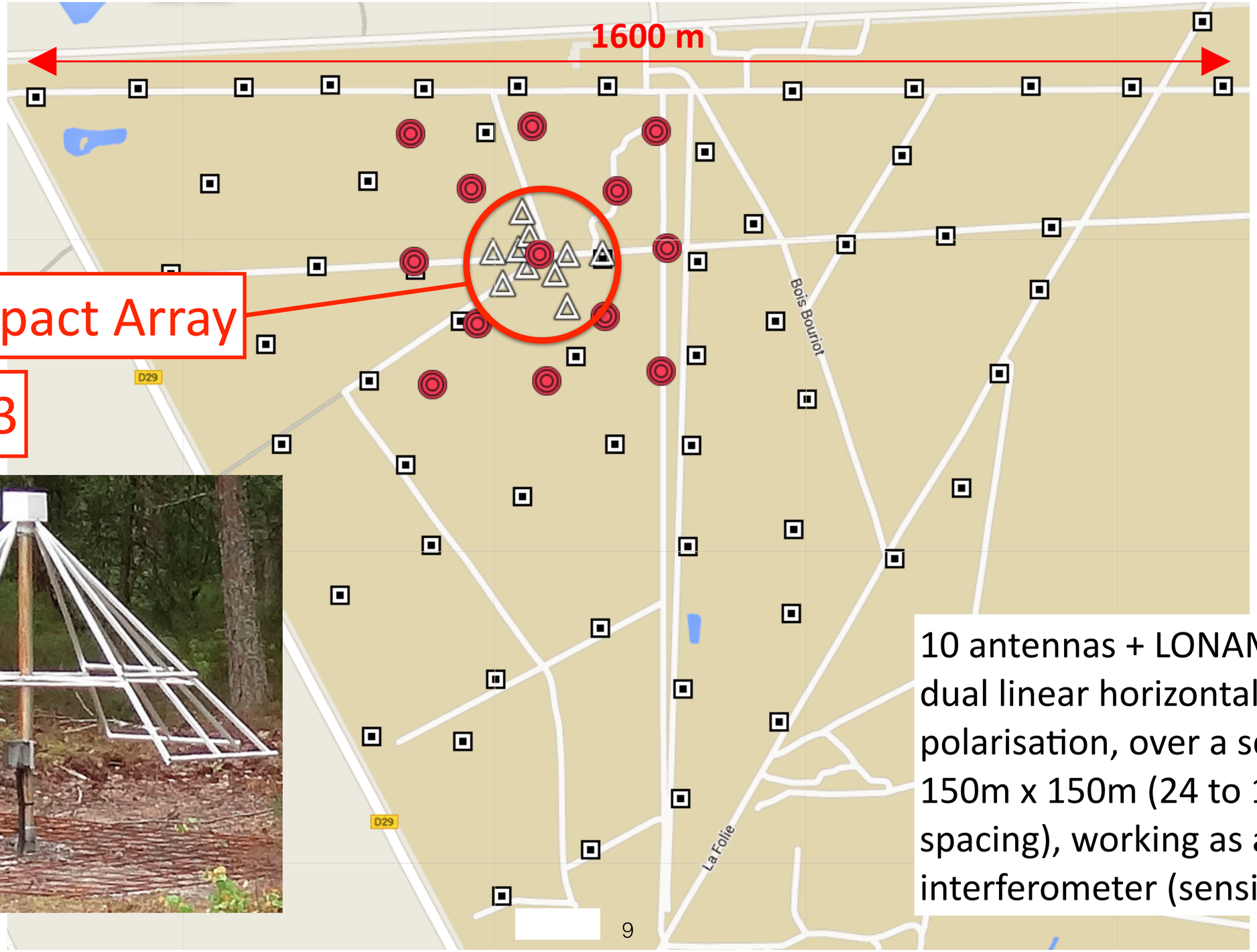
A. Nelles et al., Astropart. Phys. 65 (2015)

LOFAR HBA observation of Cherenkov ring at 100 m from axis > 110 MHz

The instantaneous [25-200] MHz band covers both the LBA and HBA bands of LOFAR (not usable at the same time): filtering band can be selected depending on antenna location vs. axis. Could compensate a lower antenna density over a larger area (in progress)

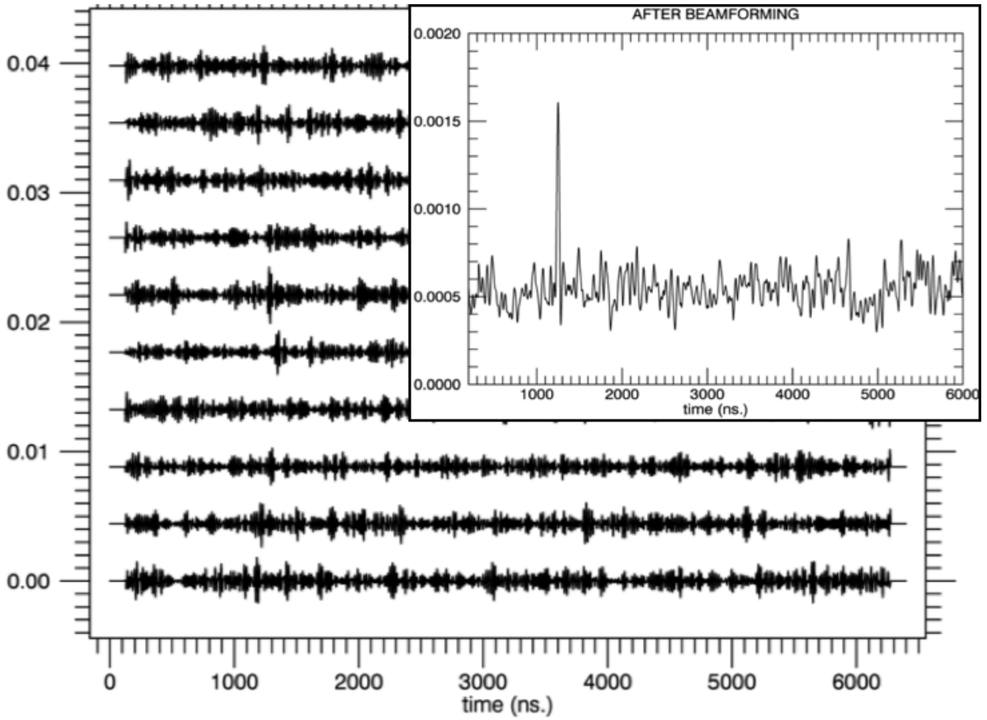
The Compact Array

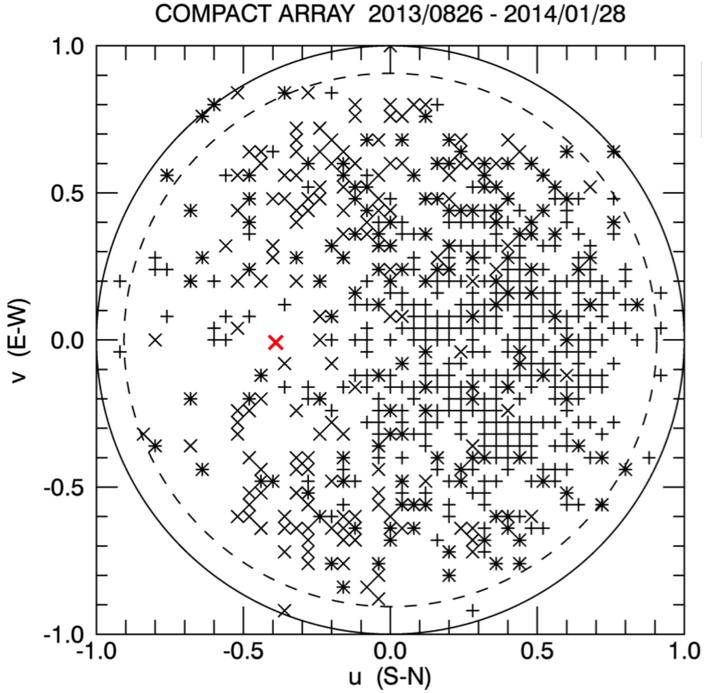
Mid-2013



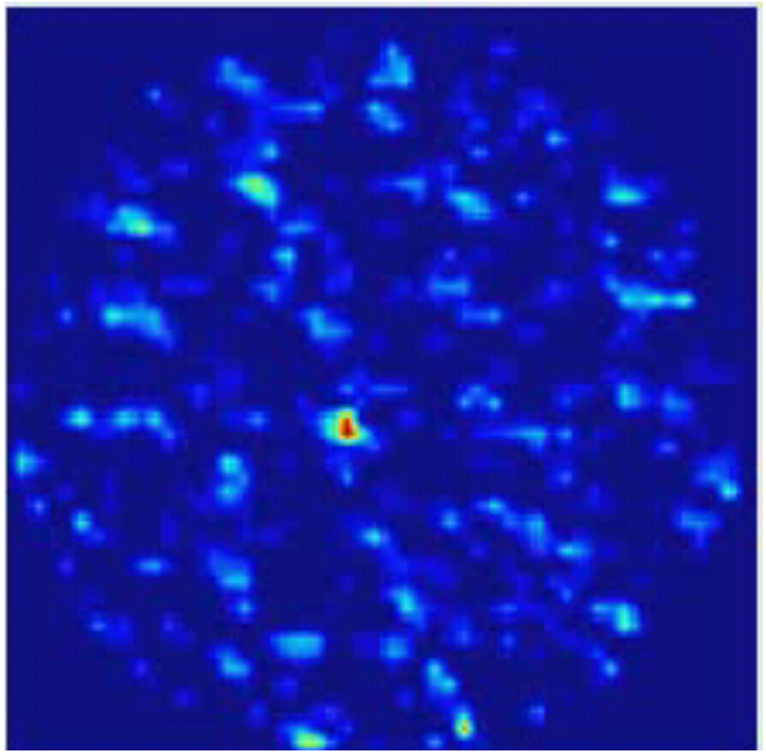
10 antennas + LONAMOS LNA, dual linear horizontal polarisation, over a square of 150m x 150m (24 to 146m spacing), working as an interferometer (sensitivity x $\sqrt{10}$)

Aim: testing a composite trigger, able to detect and select online the EAS events by testing in real time all sky directions at once





SD triggered mode: offline reconstruction of 1000 events out of 80000 triggers

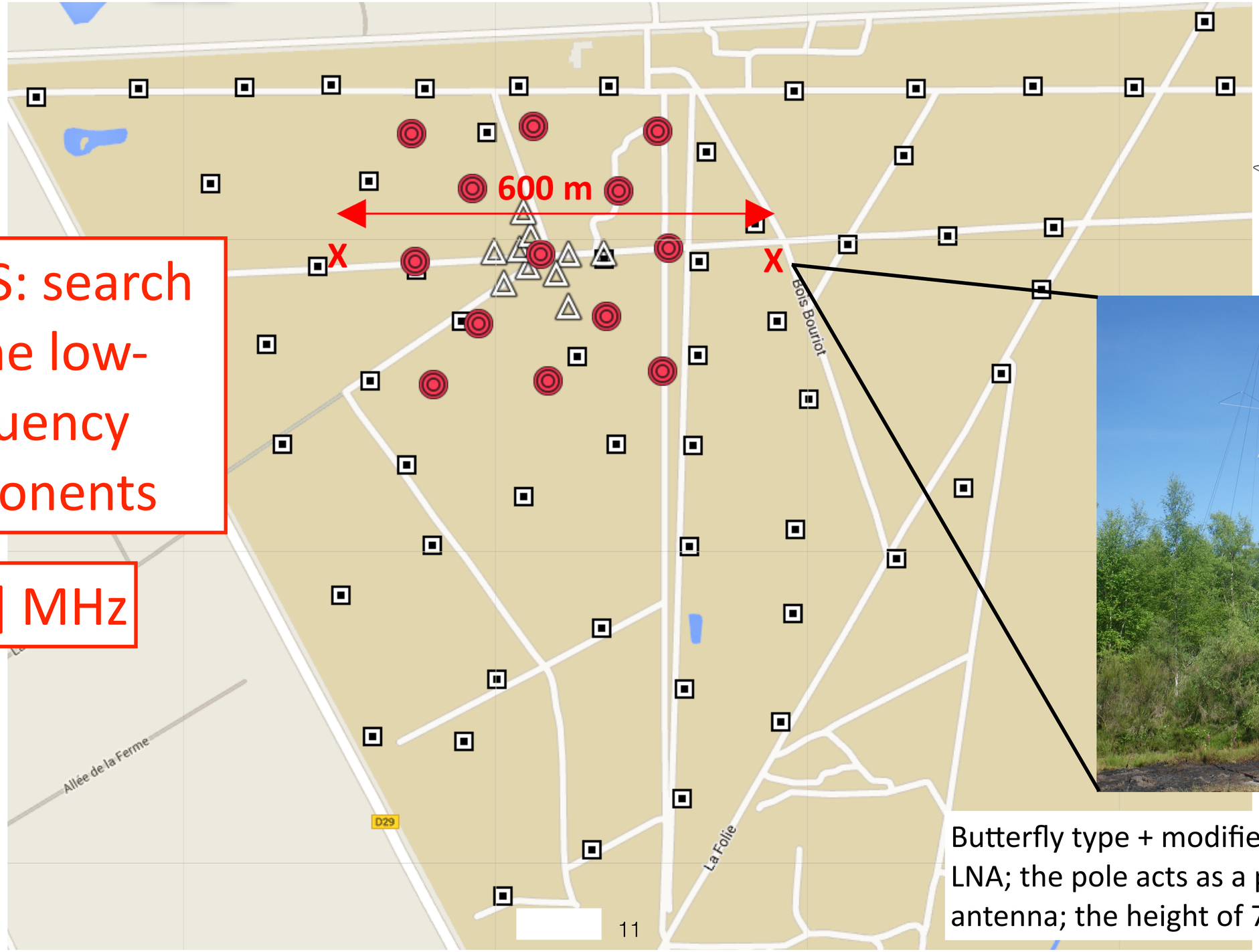


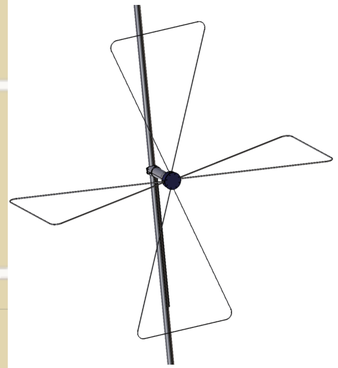
Two observing modes:

- ☑ SD triggered (20 channels, 6 µs snapshot), [10-200] MHz
- ☐ Self detecting mode (in progress), [30-80] MHz
  - continuous sampling of (up to) 8 channels, in circular polarisation @100 MHz
  - real-time software (using GPU 5 Tflops)
  - for each successive time-window corresponding to the array time aperture (500 ns): generate ~2000 beams in sky (~2° apart) via beamforming, and search for beam(s) containing signal above some intensity threshold

EXTASIS: search for the low-frequency components

[2-5] MHz

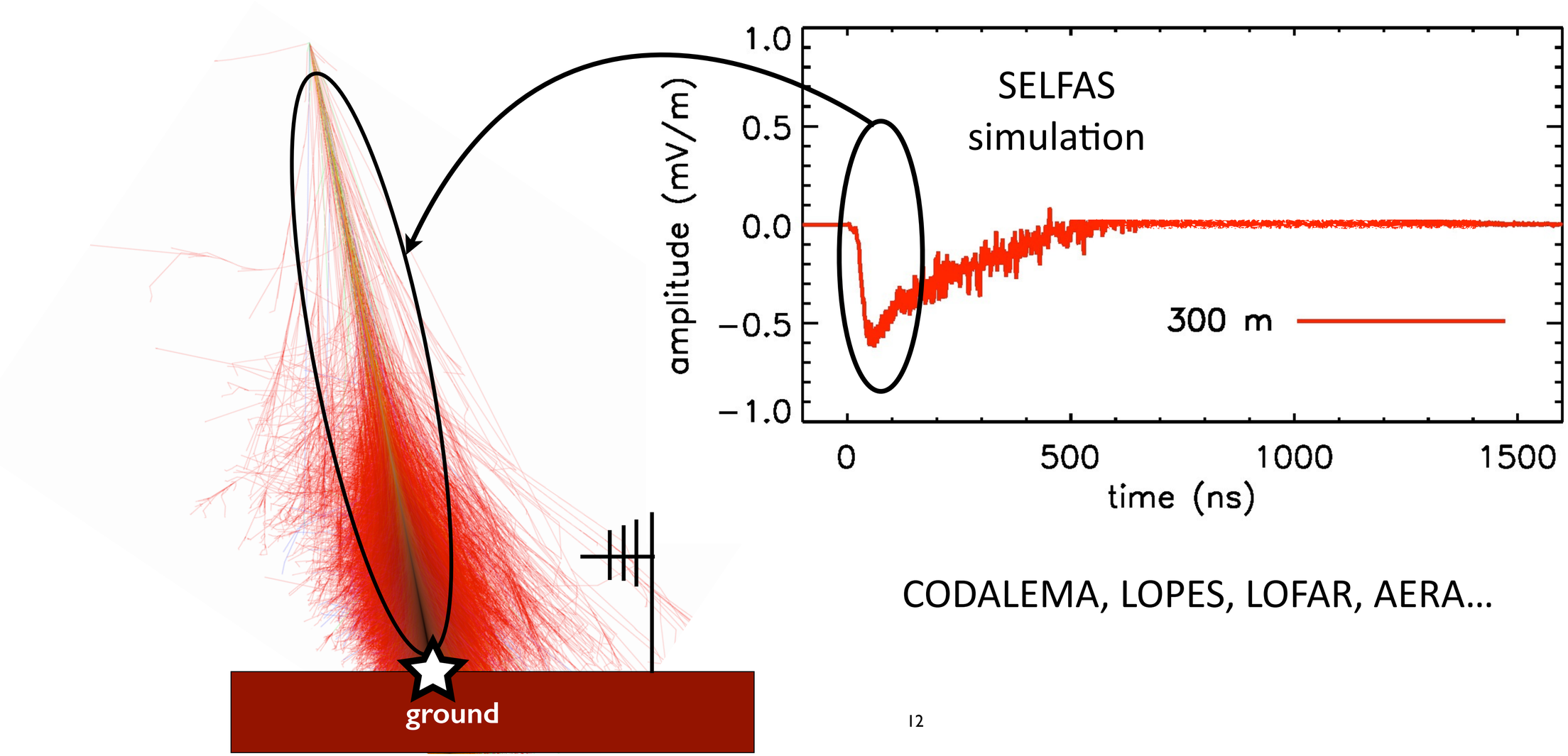




Butterfly type + modified LONAMOS LNA; the pole acts as a part of the antenna; the height of 7 m is optimized

EXTASIS: the low-frequency components

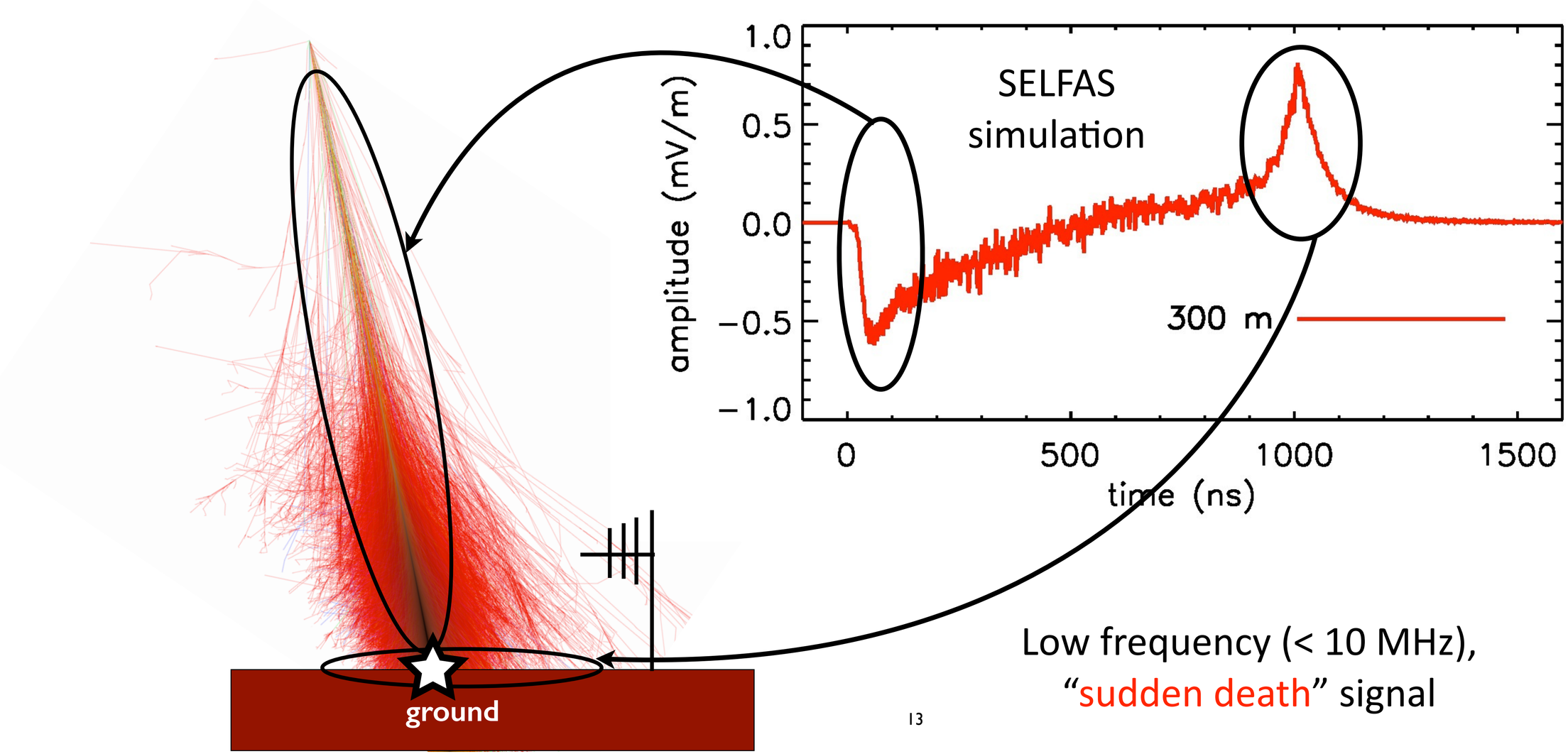
The “classical” signal (here vertical polarization, full band)



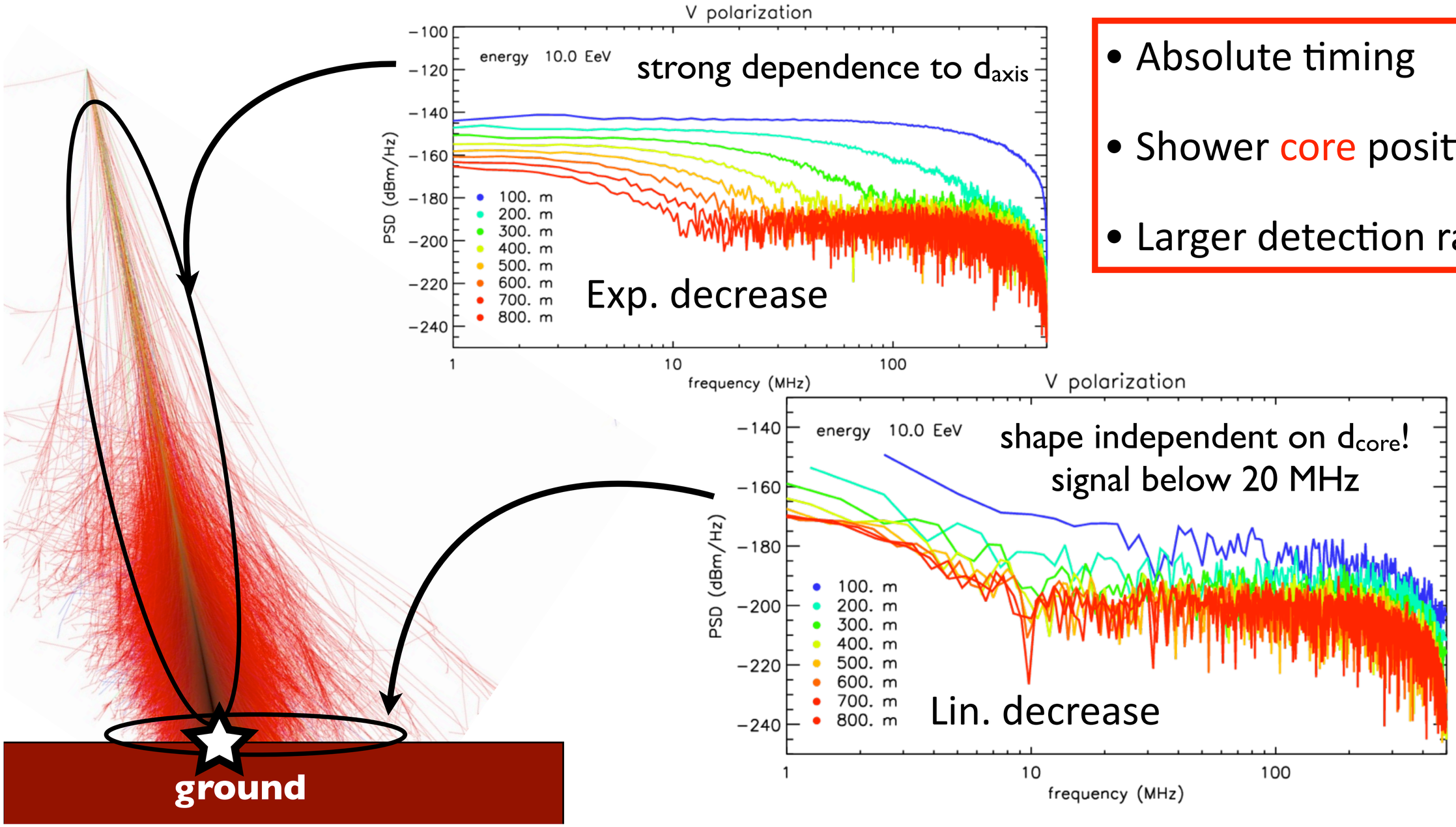
CODALEMA, LOPES, LOFAR, AERA…

EXTASIS: the low-frequency components

And the expected “new one” (still vertical polarization, full band)

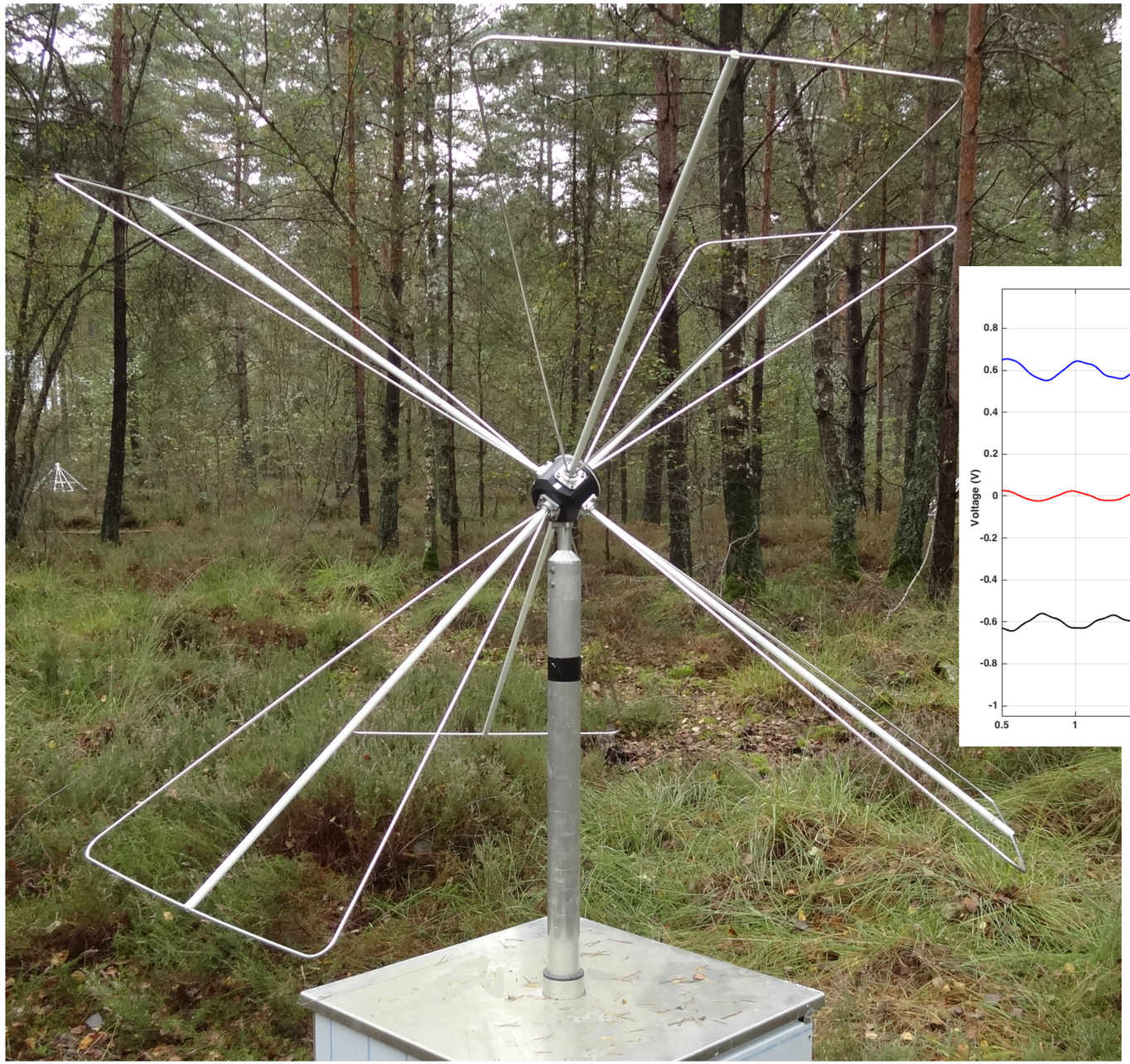


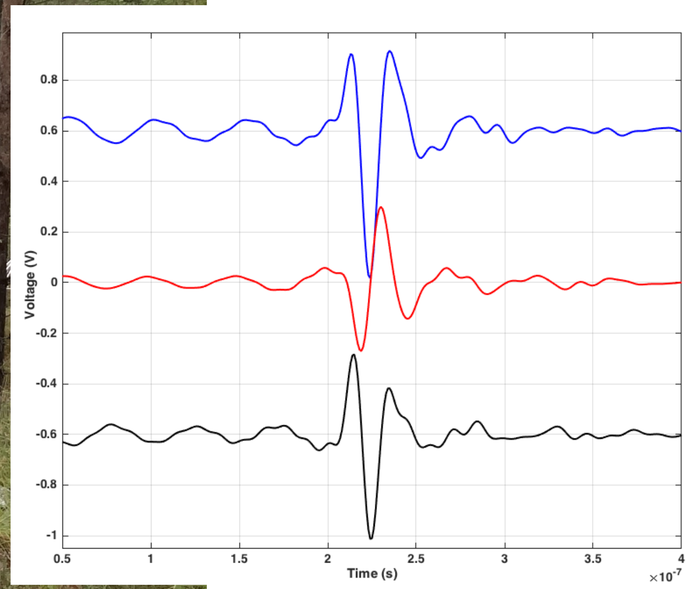
Low frequency (< 10 MHz),
“sudden death” signal



- Absolute timing
- Shower core position
- Larger detection range

B. Revenu, ICRC 2013





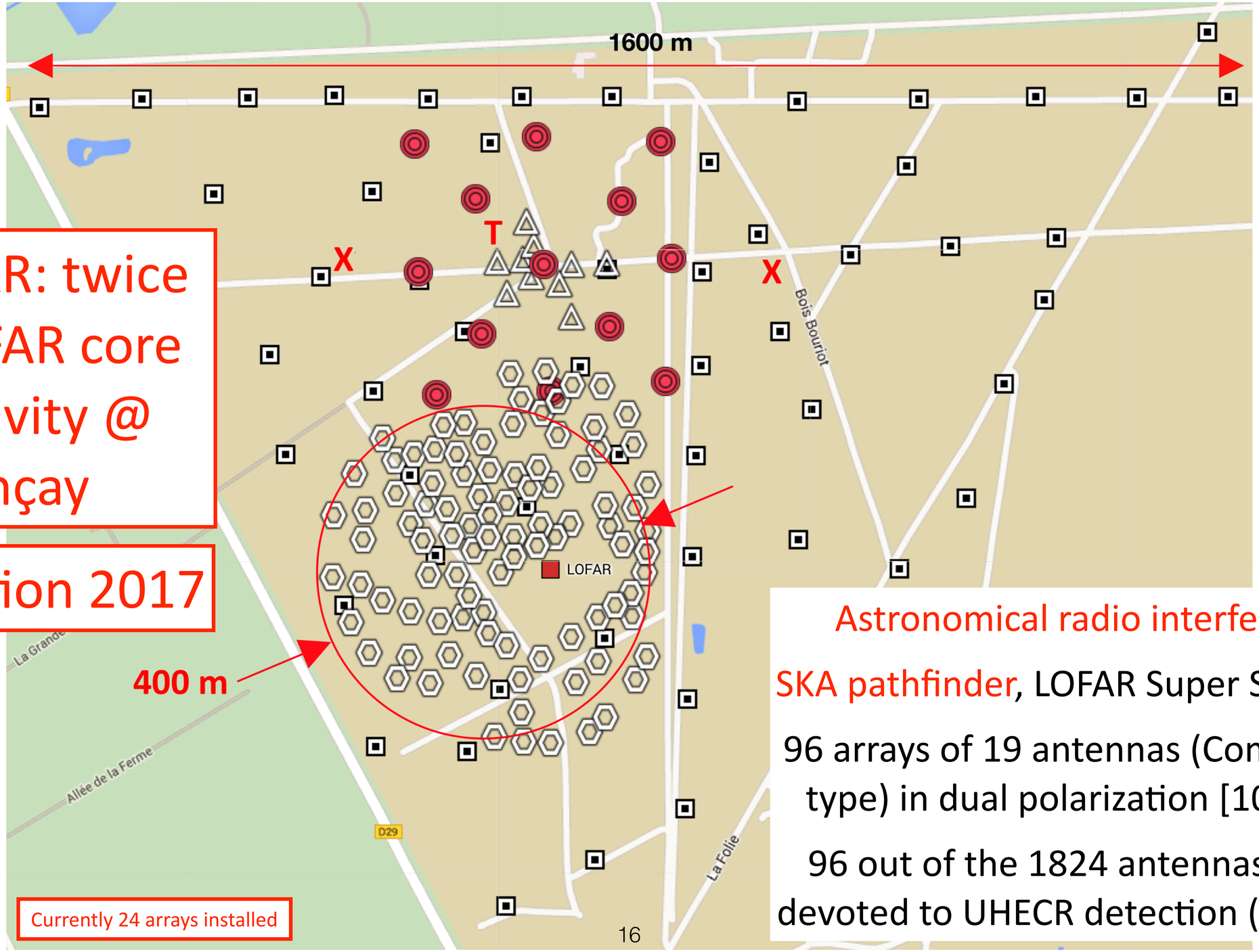
A newly designed 3-Polarization antenna

Aim: testing the "far-field" hypothesis (no longitudinal E-field component)

End 2014

NenuFAR: twice the LOFAR core sensitivity @ Nançay

Completion 2017



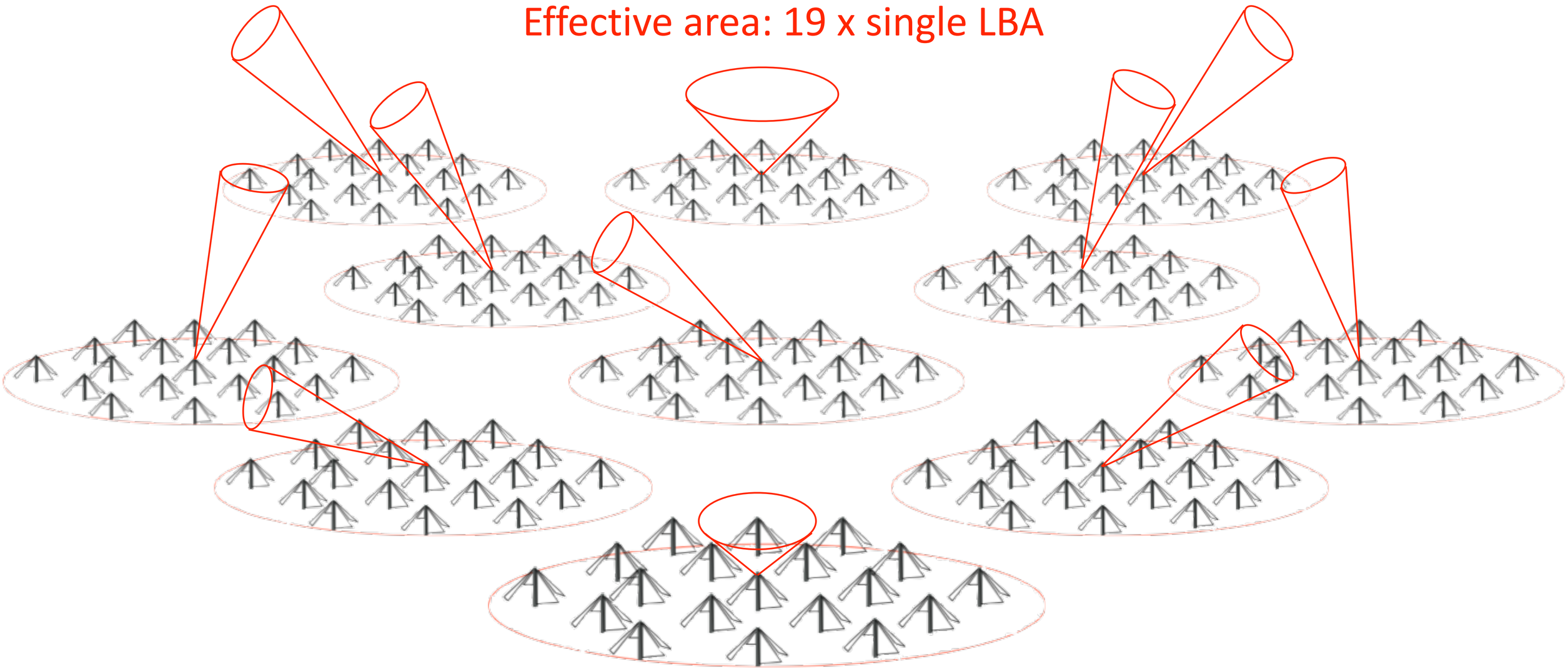
Astronomical radio interferometer

SKA pathfinder, LOFAR Super Station (LSS)

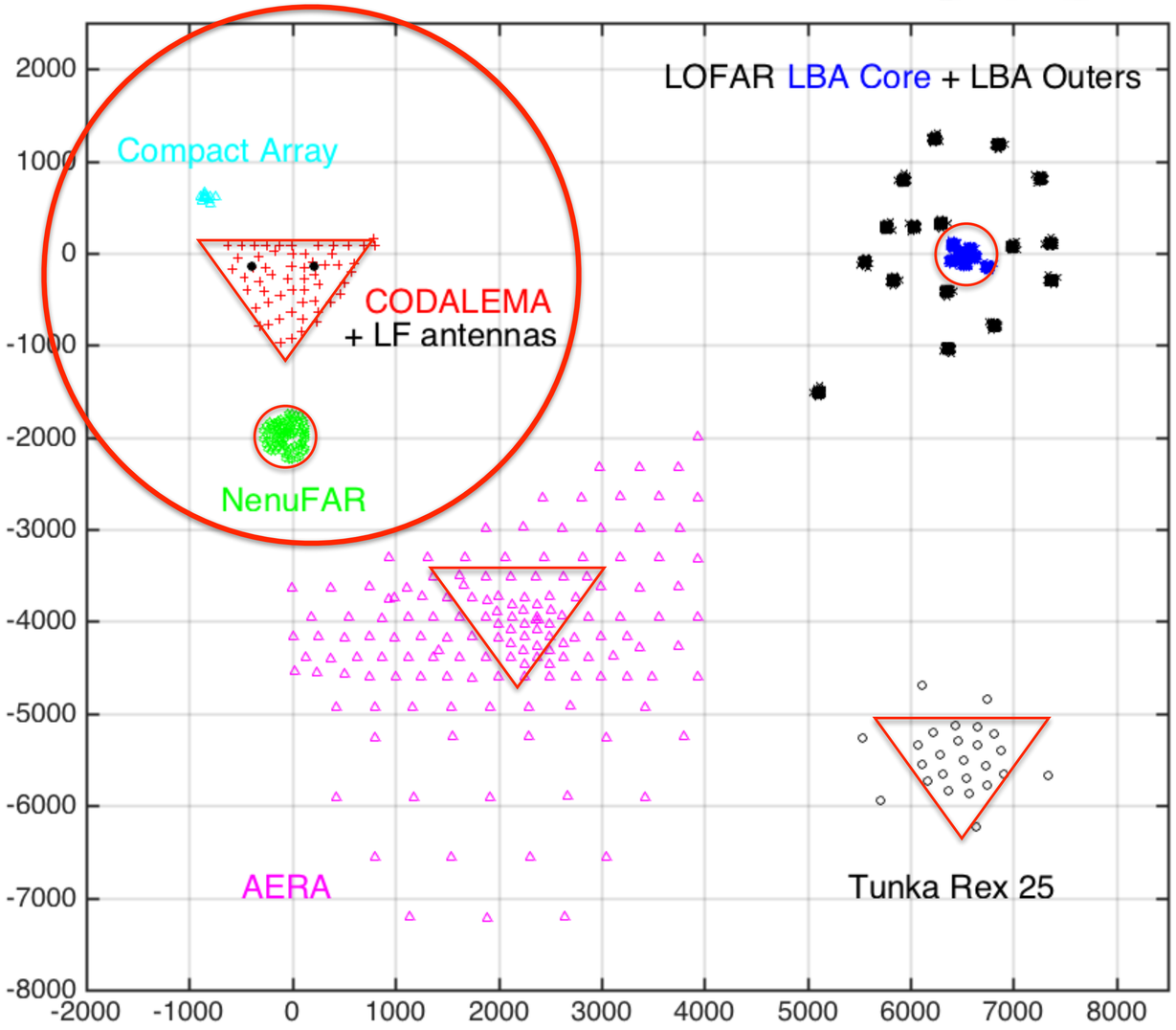
96 arrays of 19 antennas (Compact Array type) in dual polarization [10-80] MHz

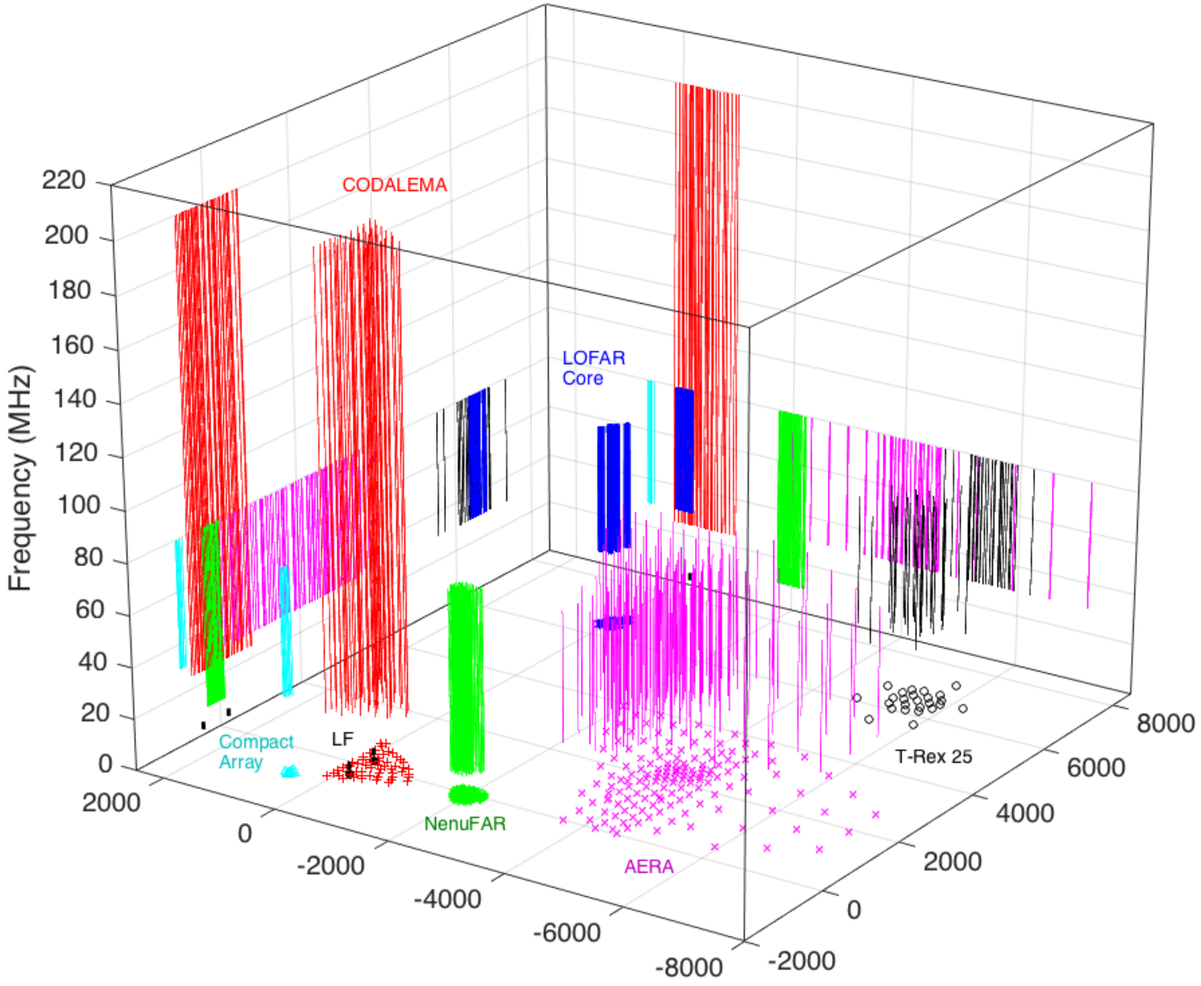
96 out of the 1824 antennas (1/array) devoted to UHECR detection (ext. trigger)

Another possible use in dedicated observation mode (not 100% of time): phasing each mini array in different directions, the whole covering all the sky, externally triggered ("Compact Array" mode)



Nançay facilities: a swiss-knife for UHECR radio detection





- Unique wide frequency band (2 - 200 MHz)
- Multi-scale antenna densities
- Test bench for future projects (SKA, see T. Huege's talk on saturday)
- **Anyone interested is welcome !**