ES12 - KP Radio Gamma in a 

Objective: attempt to detect ultra-short radio transients generated by atmospheric air showers initiated by *very high energy gamma photons.*

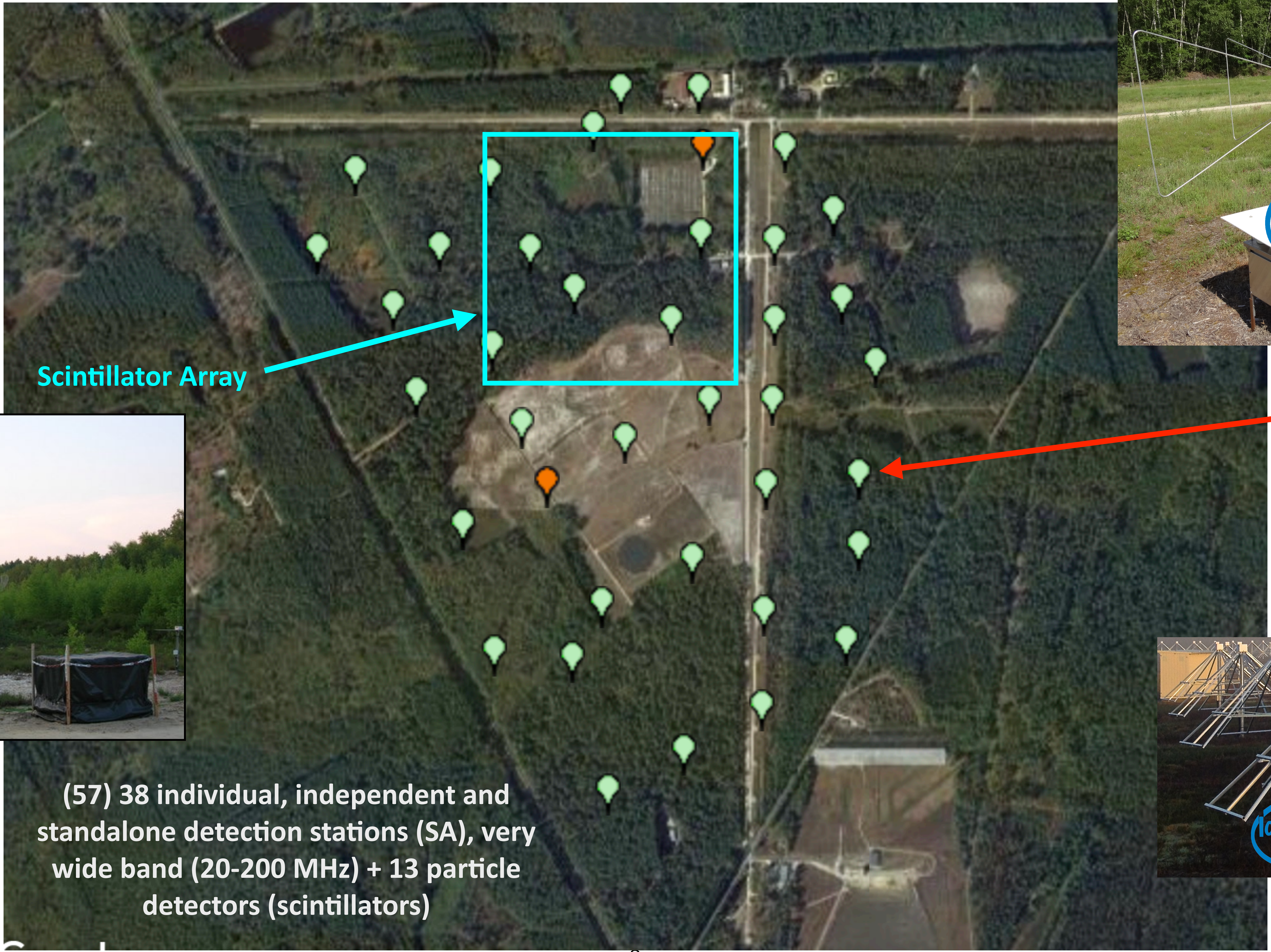
Interest (1): current gamma ray telescopes are “limited” to photon energies up to few hundred TeV: radio signals should trace energies from few hundred TeV (search for possible *PeVatrons* in our Galaxy, strongly expected to be sources of *ultra-high energy cosmic rays* (UHECR). This would be a major detection!

Interest (2): current gamma ray telescopes have a duty cycle of ~15 %: a radio-telescope can in principle observe during 100 % of the time.

Programme derived from our experience with CODALEMA on the detection of UHECR (charged nuclei) induced air shower signals. Currently mainly *R&D and proof-of-principle* for the technique.

CODALEMA

TRADEMARK
SINCE 2002



Standalone
Antenna

(57) 38 individual, independent and standalone detection stations (SA), very wide band (20-200 MHz) + 13 particle detectors (scintillators)

Cosmic Rays

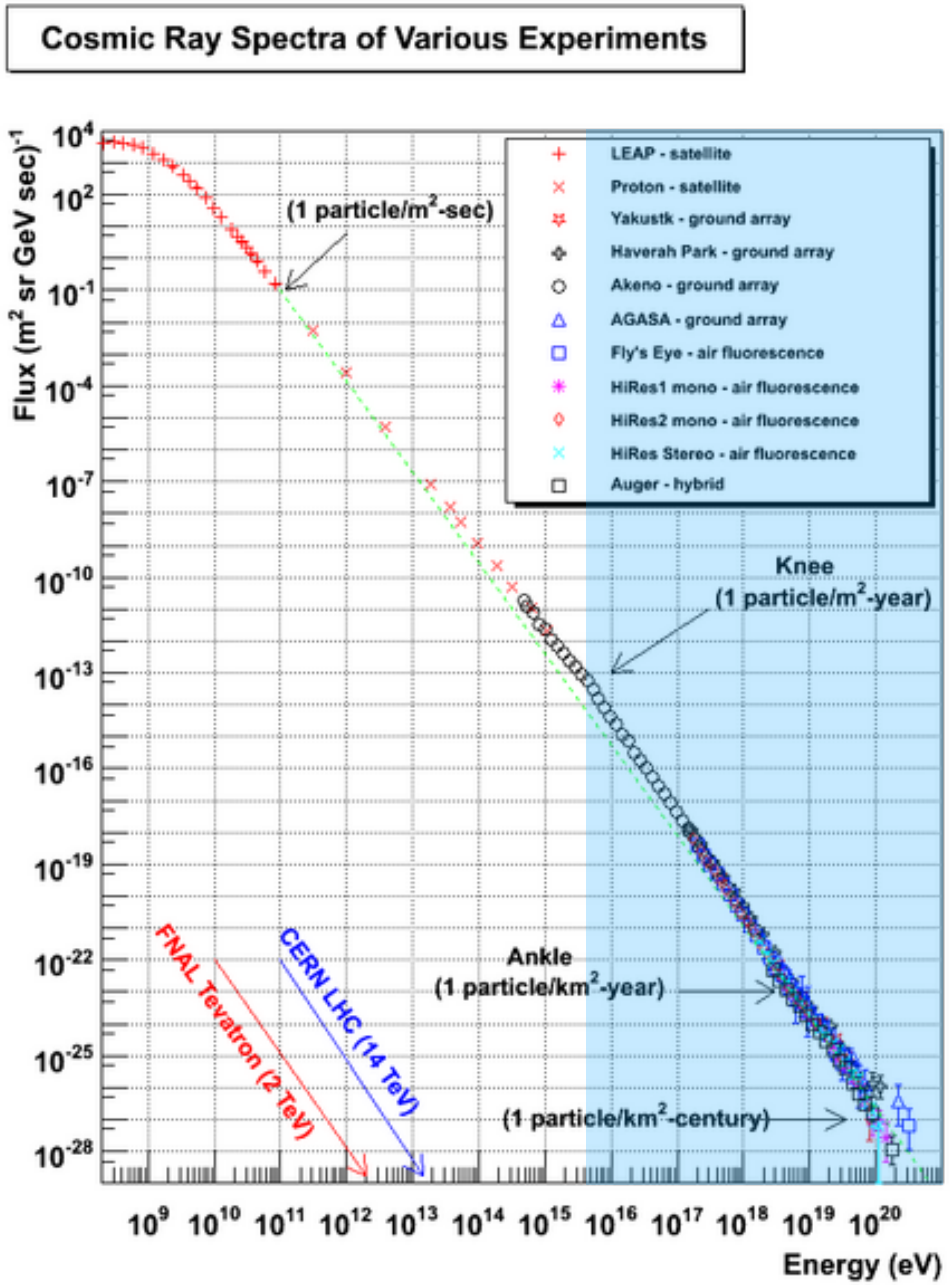
- Cosmic rays are charged particles
- At high energies, only nuclei (from p+ to Fe)

- On Earth, their flux is coherent over 32 orders of magnitude and more than 10 orders of magnitude in energy

- Ultra High Energy Cosmic Rays (UHECR) deal with E ≥ 10^{16} eV and up to 10^{20} eV (~10^{6} x Energy @ LHC, CERN)

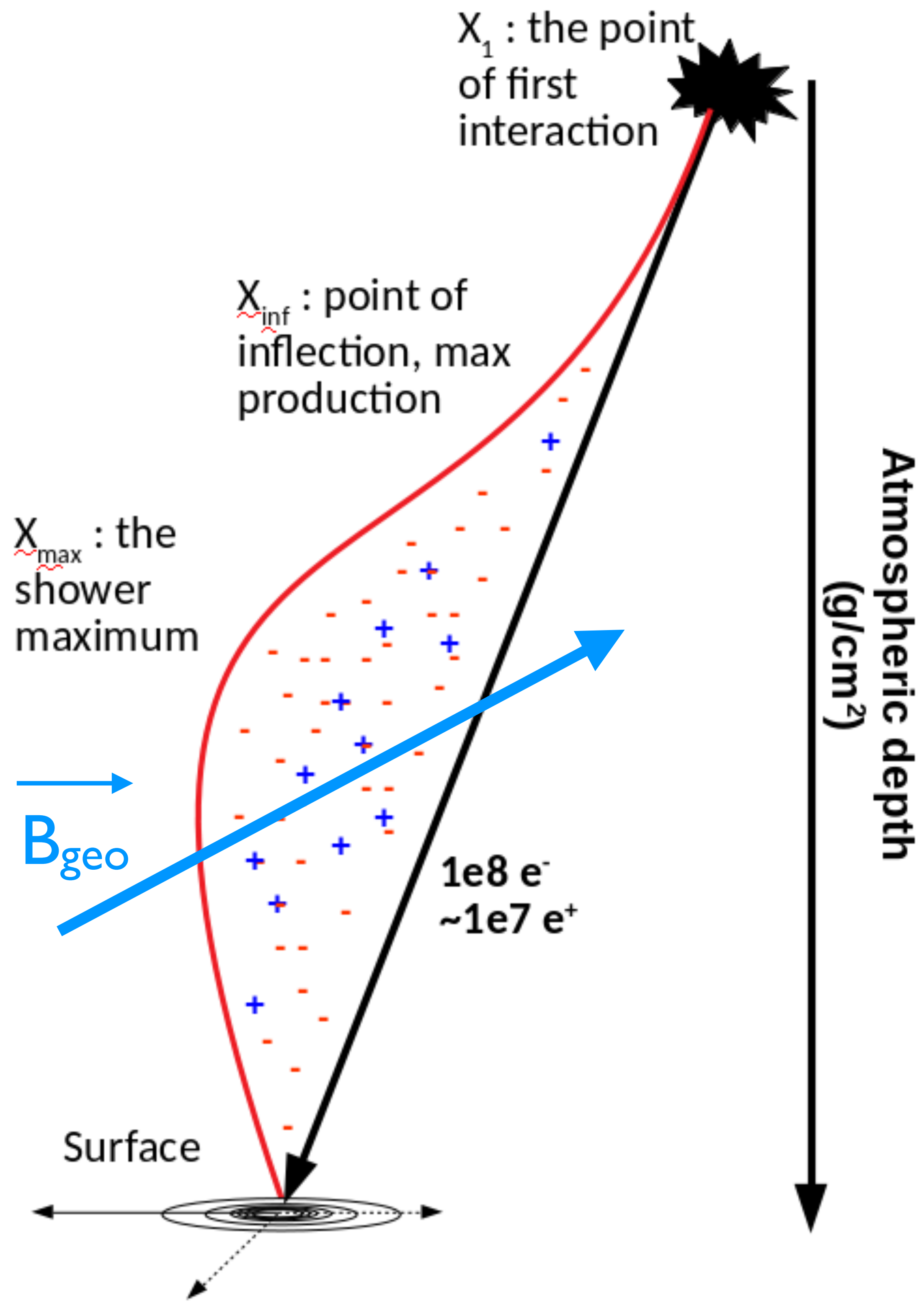
- They are the progenitors of very high energy gamma rays and neutrinos in the vicinity of their sources (still unknown)

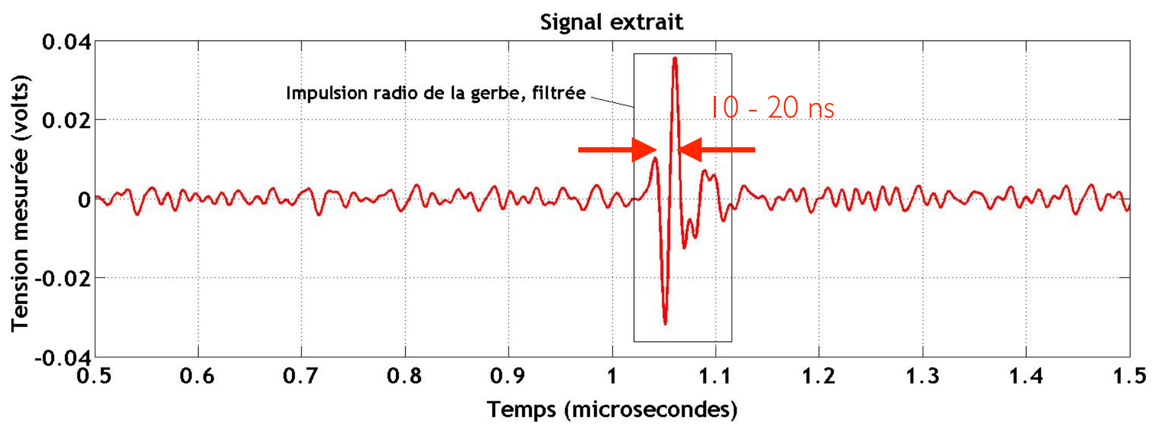
- Btw: gamma photons are not expected to exceed ~10^{15} eV (PeV)

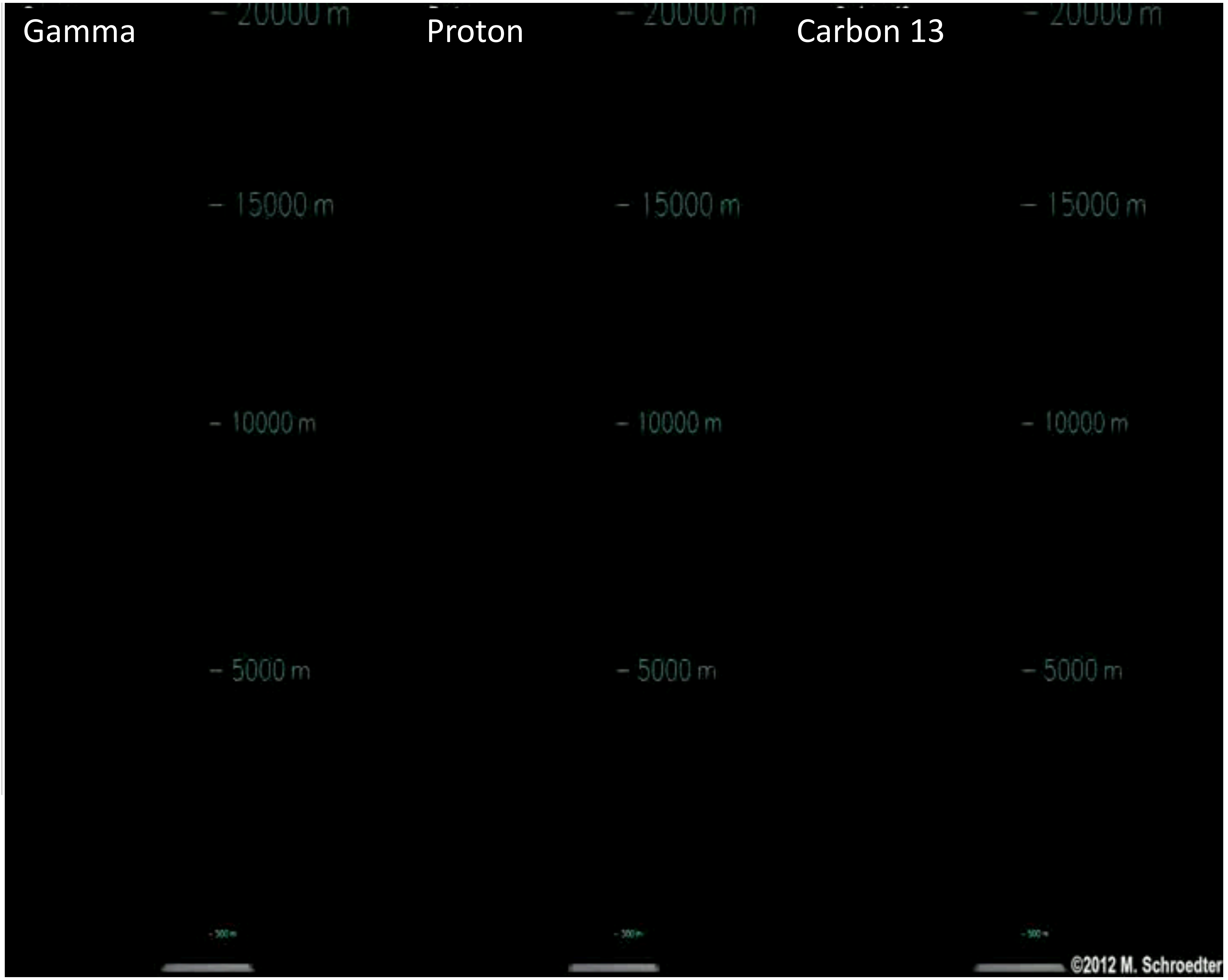


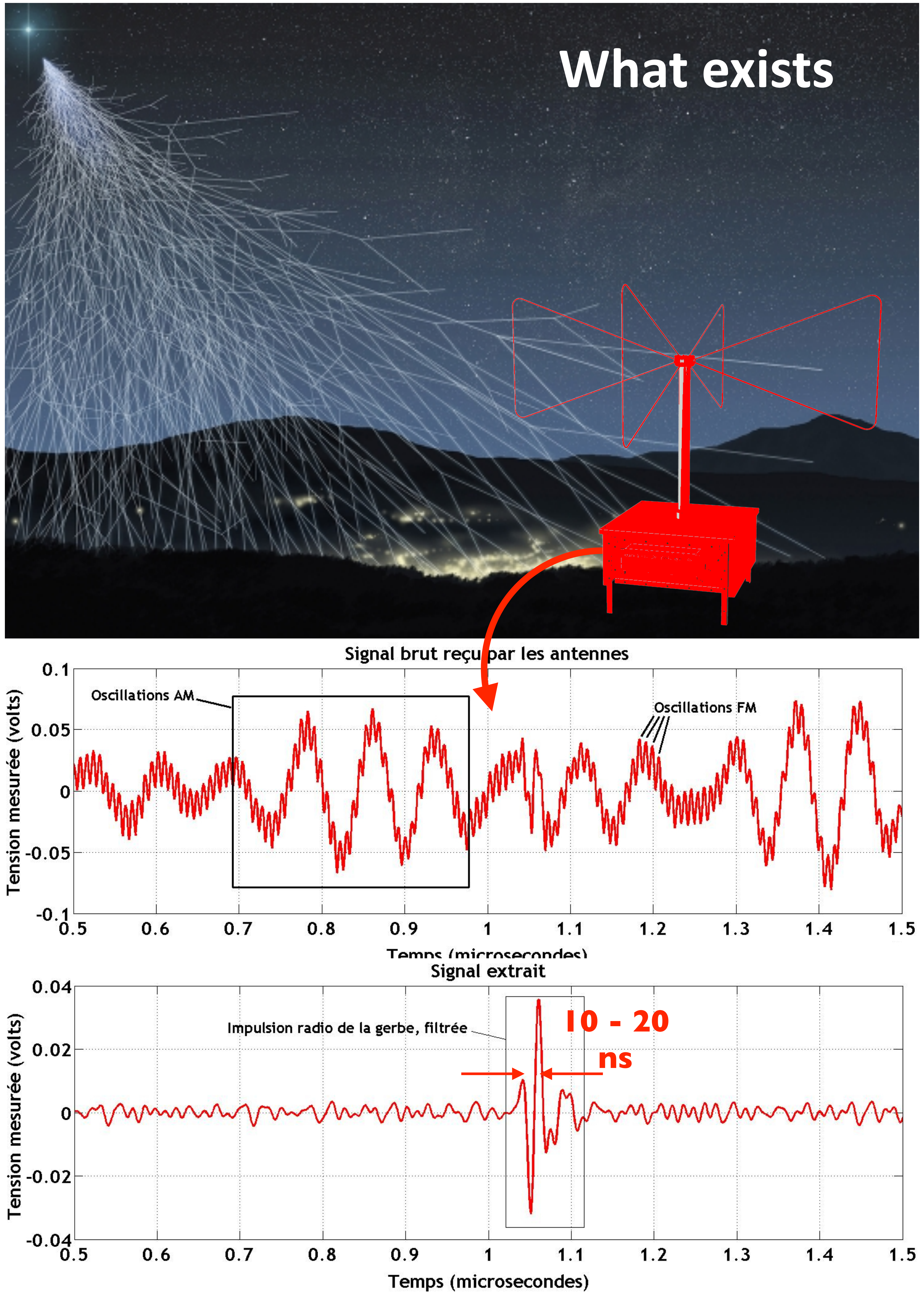
Cosmic Ray and Gamma Air Showers

Looking for θ, Φ, (X_{core}, Y_{core}), X_{max} (nature), Energy









CODALEMA & Cosmic Rays: detection of the radio pulse emitted by the secondary particle shower (lasting *few tens of ns*)

Analogue trigger electronics

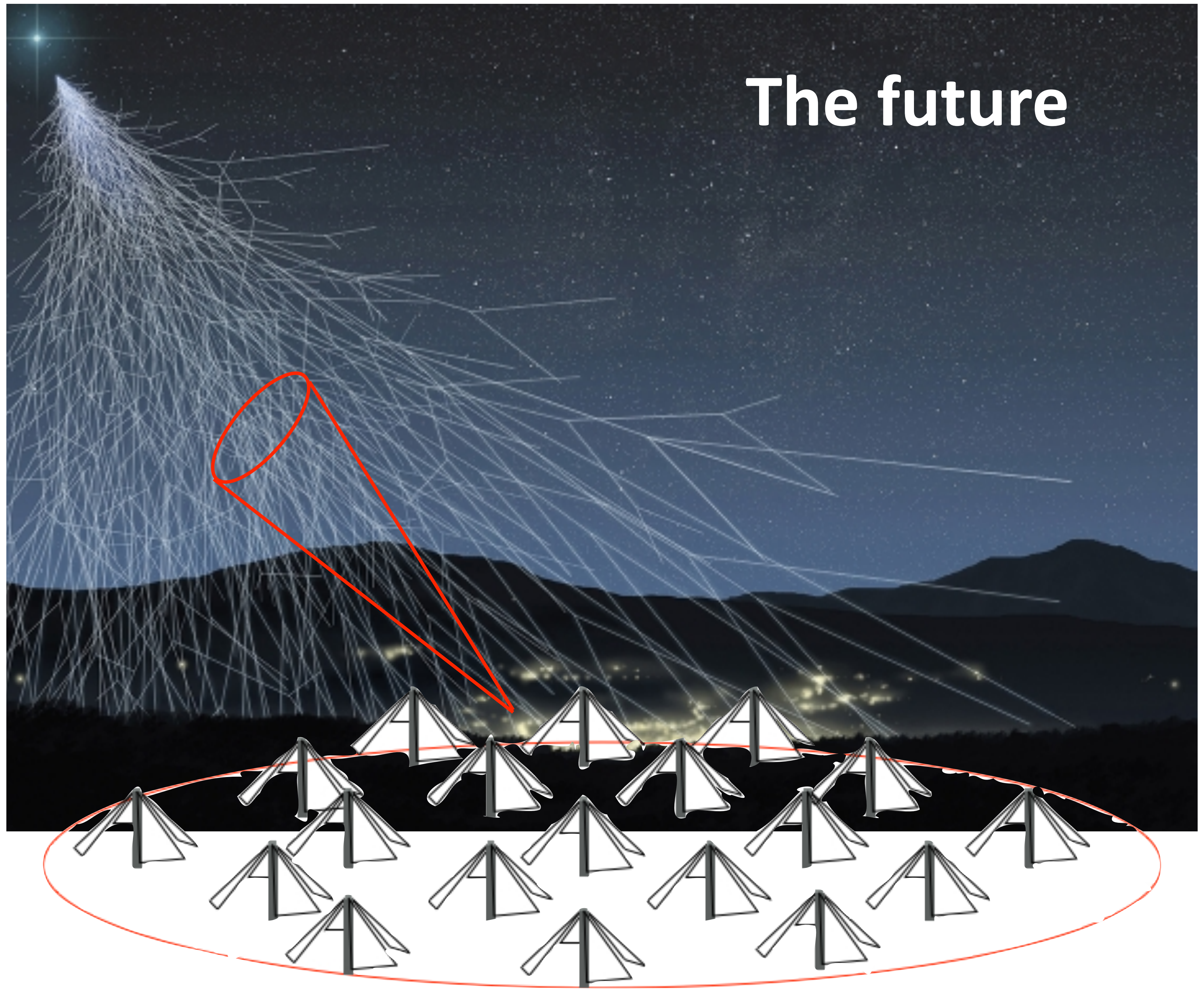
Recording of 2.5 µs snapshots (GPS dated) at 1 GS/s
We work in time domain!

The information on the shower and the primary comes from the electric field profile on the ground, on several stations.

Size of CODALEMA allows addressing UHECR energies E ≥ $10^{16.5}$ eV and up to 10^{18} eV

We don't know where the signal is coming from, we have to observe the whole sky (individual, wide antenna lobe)

But what if we knew where the shower was coming from beforehand?



Gamma photons: source is known *a priori* (HAWC, HESS, MAGIC, VERITAS…)

The γ also produce a similar shower but with energy lower than for UHECR (~1/10th) thus lower electric field (~1/100th)

Increase detection sensitivity = to phase several antennas = 1 or more MA, and to point toward the sources

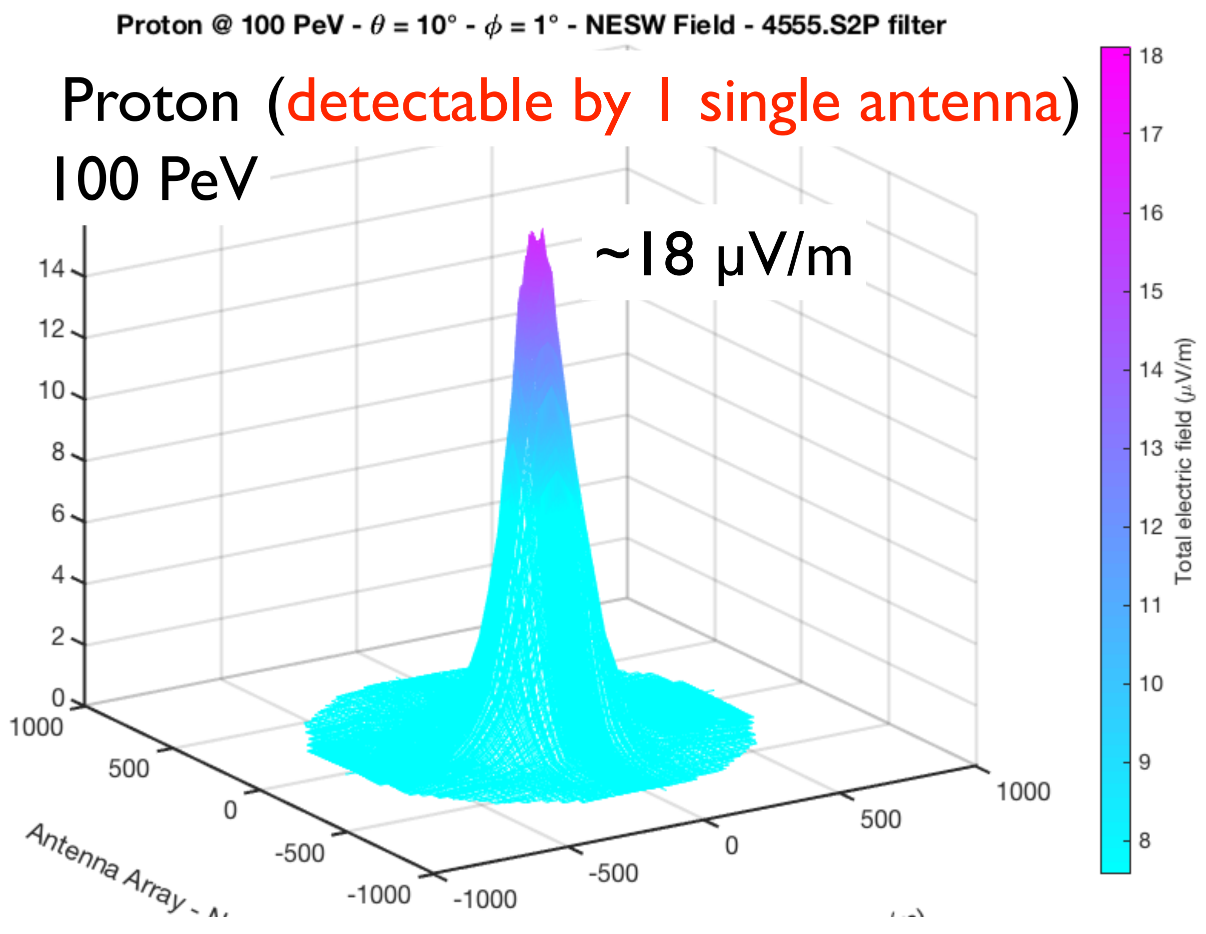
Trigger

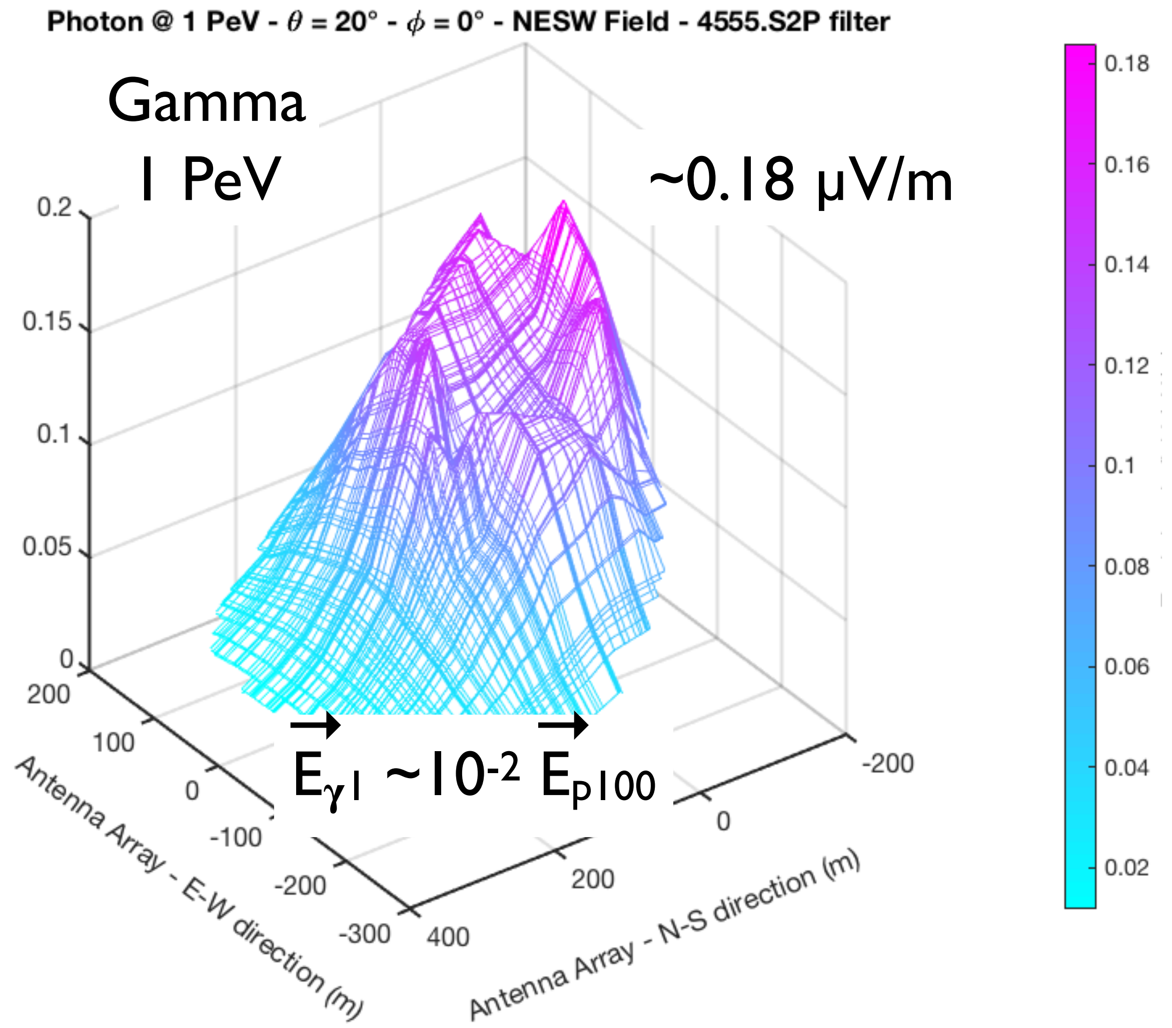
How to do it ?

That is THE question

Trigger the reading of the TBBs of the whole NenuFAR array to obtain the $\vec{E}$ footprint on the ground, reconstruct the photon energy as with the SA array

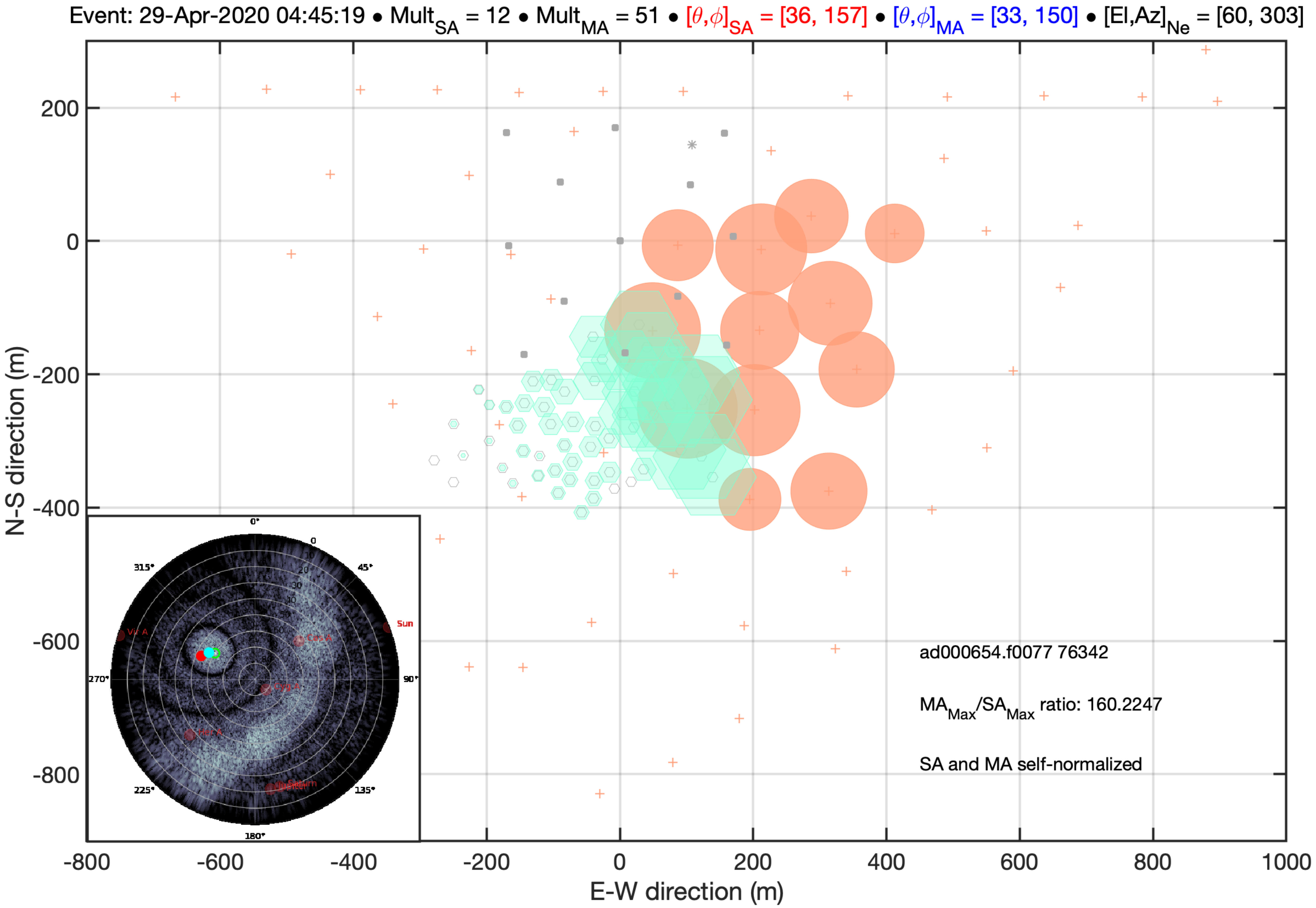
First use of the Transient Buffer Boards (TBB) of NenuFAR



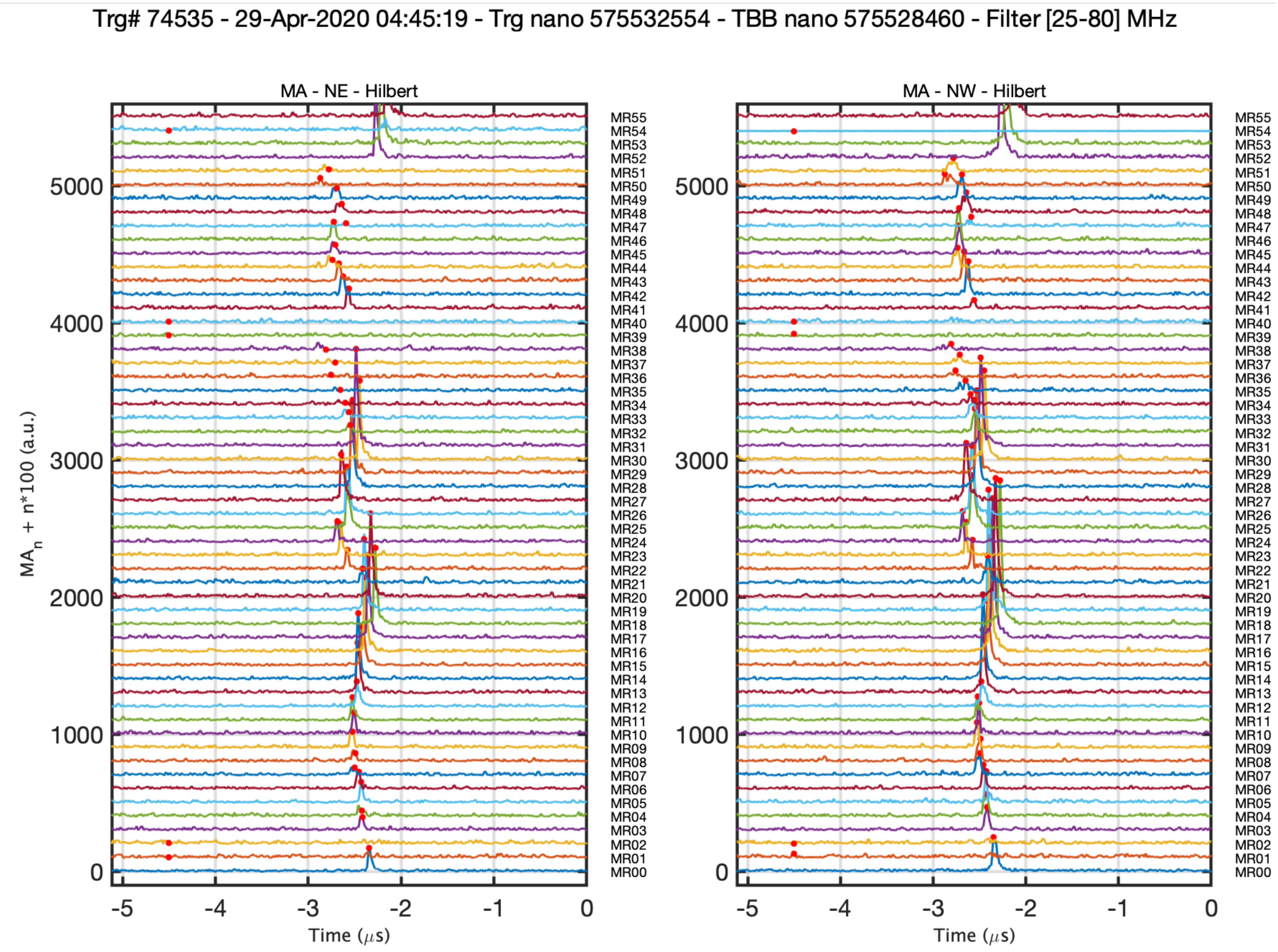


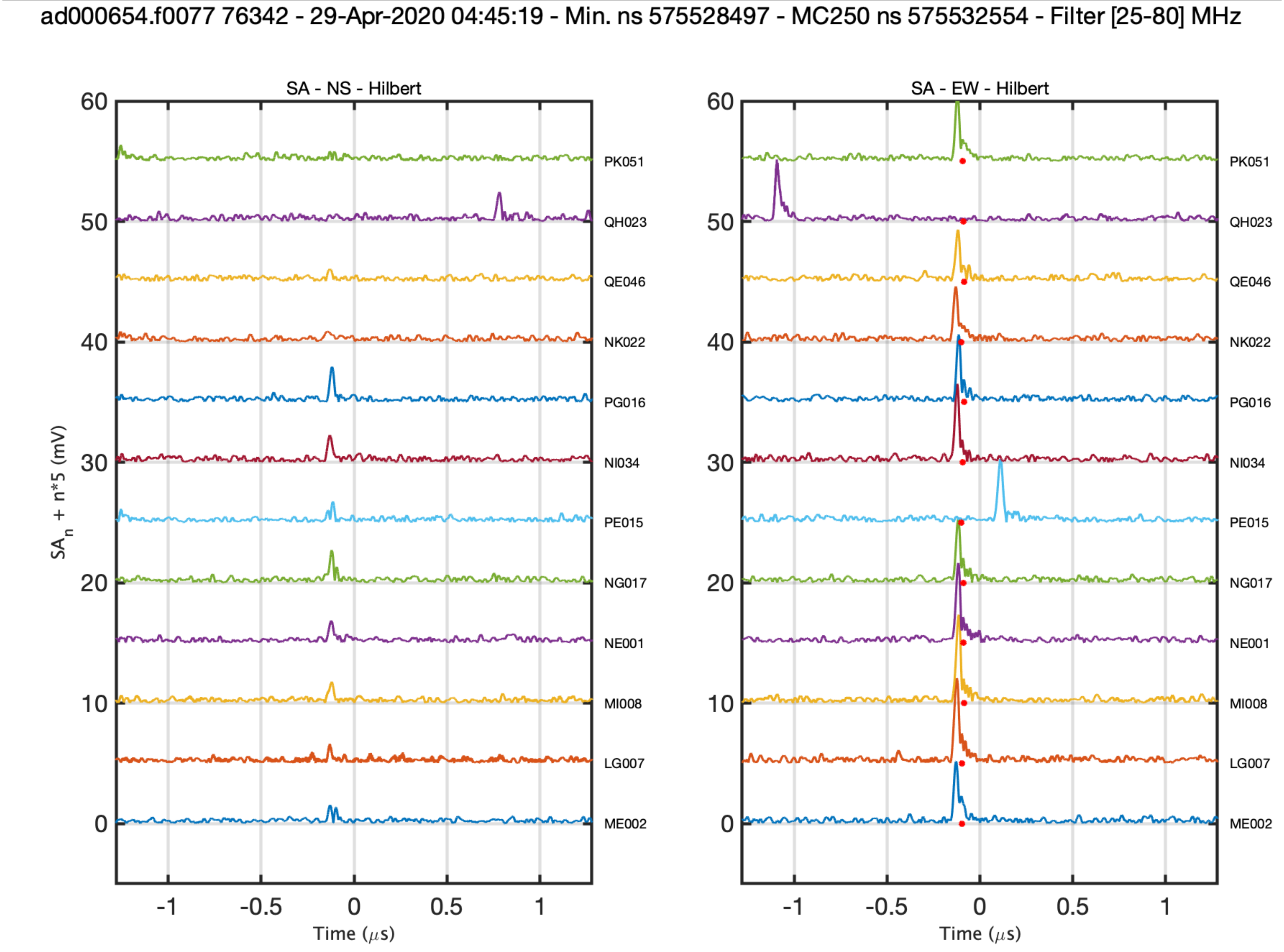
Electric field profile @ ground

An example: cosmic ray event seen by CODALEMA and NenuFAR on scintillator trigger by chance in the NenuFAR pointing direction



TBB





CODALEMA

A new receiver: RadioGAGa

Radiodétection des Gerbes Atmosphériques Gamma

Goal

- coherent, online summation of the signals of 8 identical polarisations of 8 (or 16) mini-arrays in the analogue pointing direction (identical for all mini-arrays concerned as fixed by the observation parameters), or 2 summations of 4 (or 8) signals combining the identical polarisations of 4 (or 8) mini-arrays if necessary

- and thus track the object by adapting the digital phase shifts for summation throughout the observation

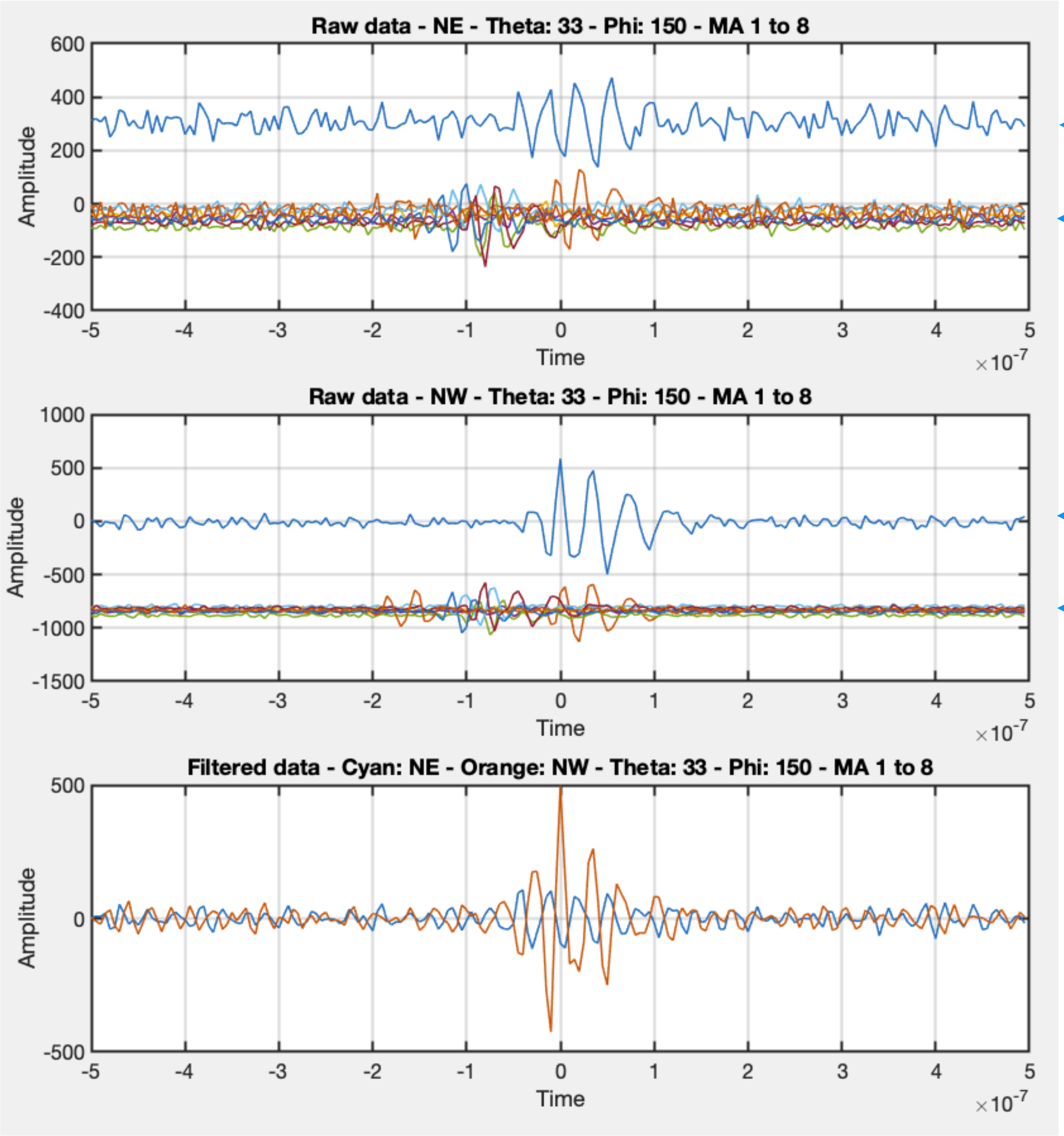
- set up configurable and cumulative trigger conditions on the sum of the signals (threshold in ADC level; time windowing for analysis of the amplitude of the noises before/after the sought-after pulse; rise time of the pulse signal; if two polarisations, then ratio of the sums on each polarisation; finally, decision of the trigger based on a combination of criteria)

- send by UDP a logical trigger on the other TBBs of NenuFAR after trigger decision

Work by Thomas, Cédric and Christophe + ALSE on HPAPB cards initiated at the end of 2020, in the final implementation phase
Possibility of chaining 2 or more HPAPB boards to increase the number of MA used in the trigger

Sum of little affected MA (especially NW pol.)

Sum of very affected MA



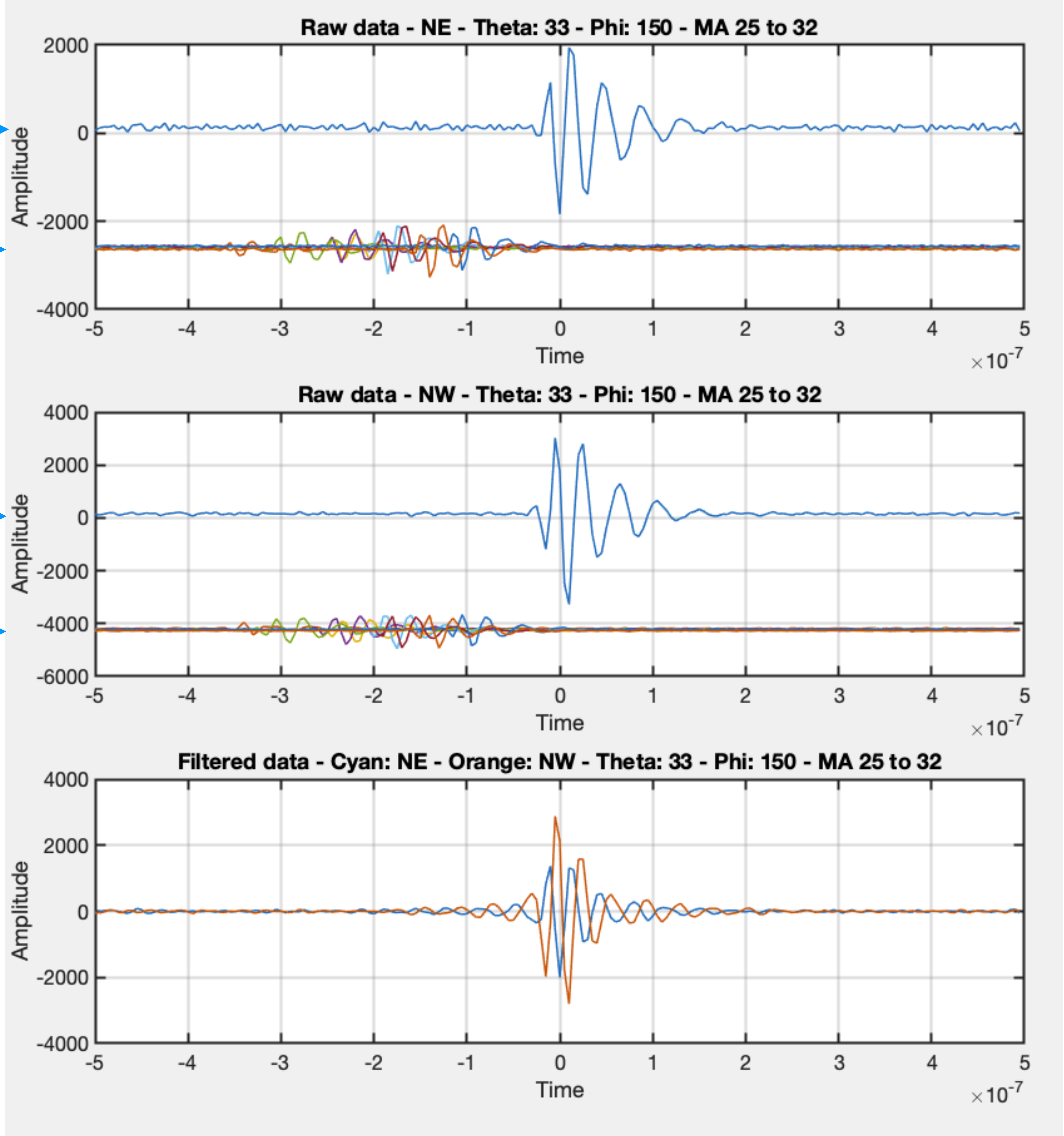
Sum

Raw signals

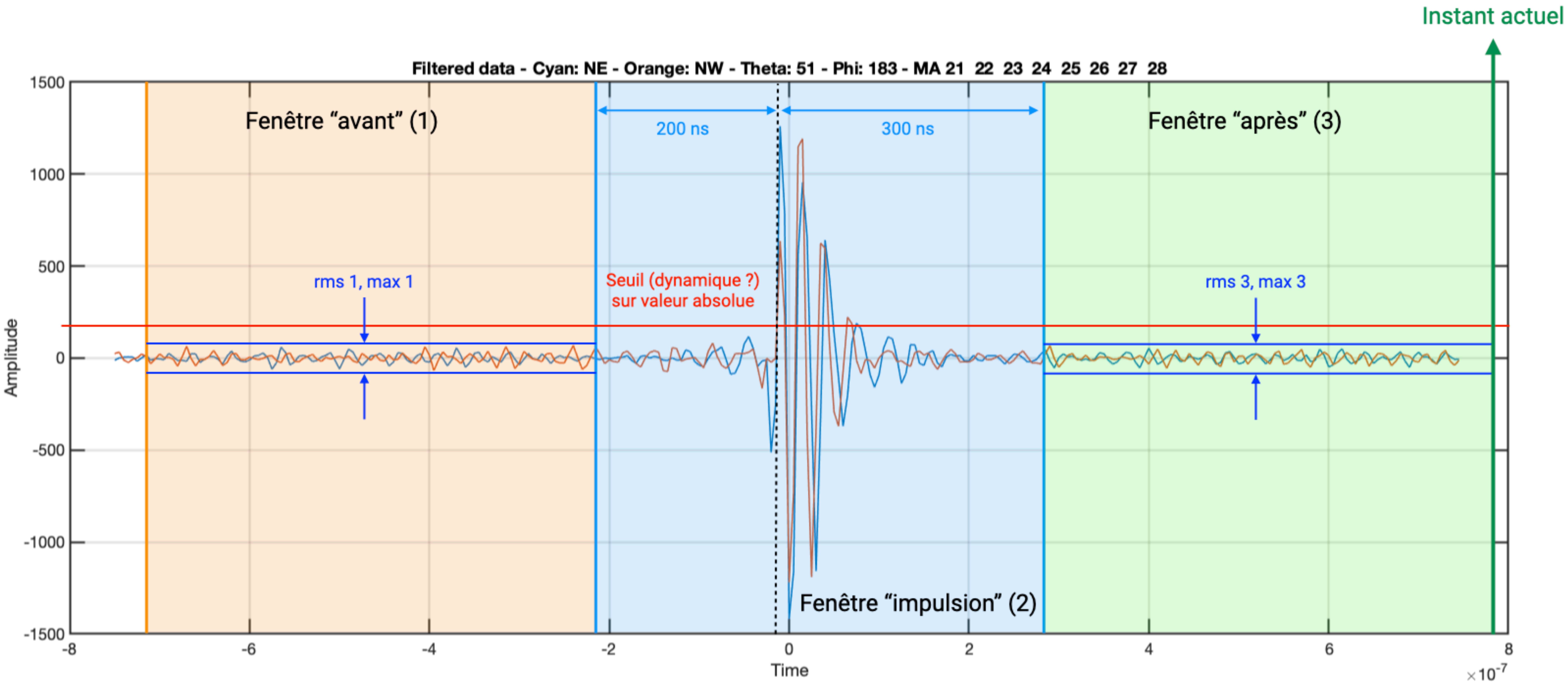
Sum

Raw signals

Sum of filtered signals (2 polars)

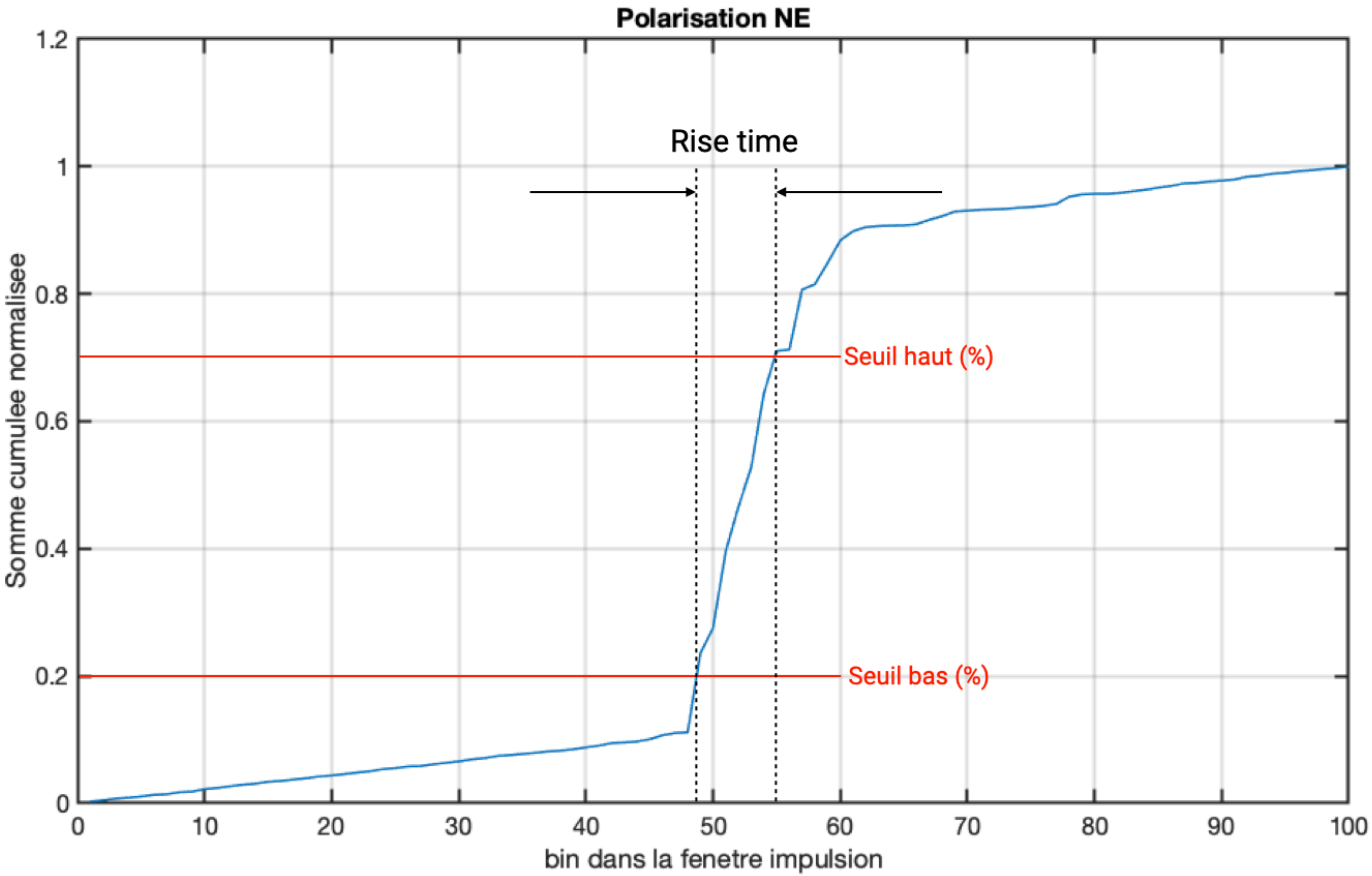


Parameters of the RadioGAGa trigger specifications (inspired by the CODALEMA trigger)



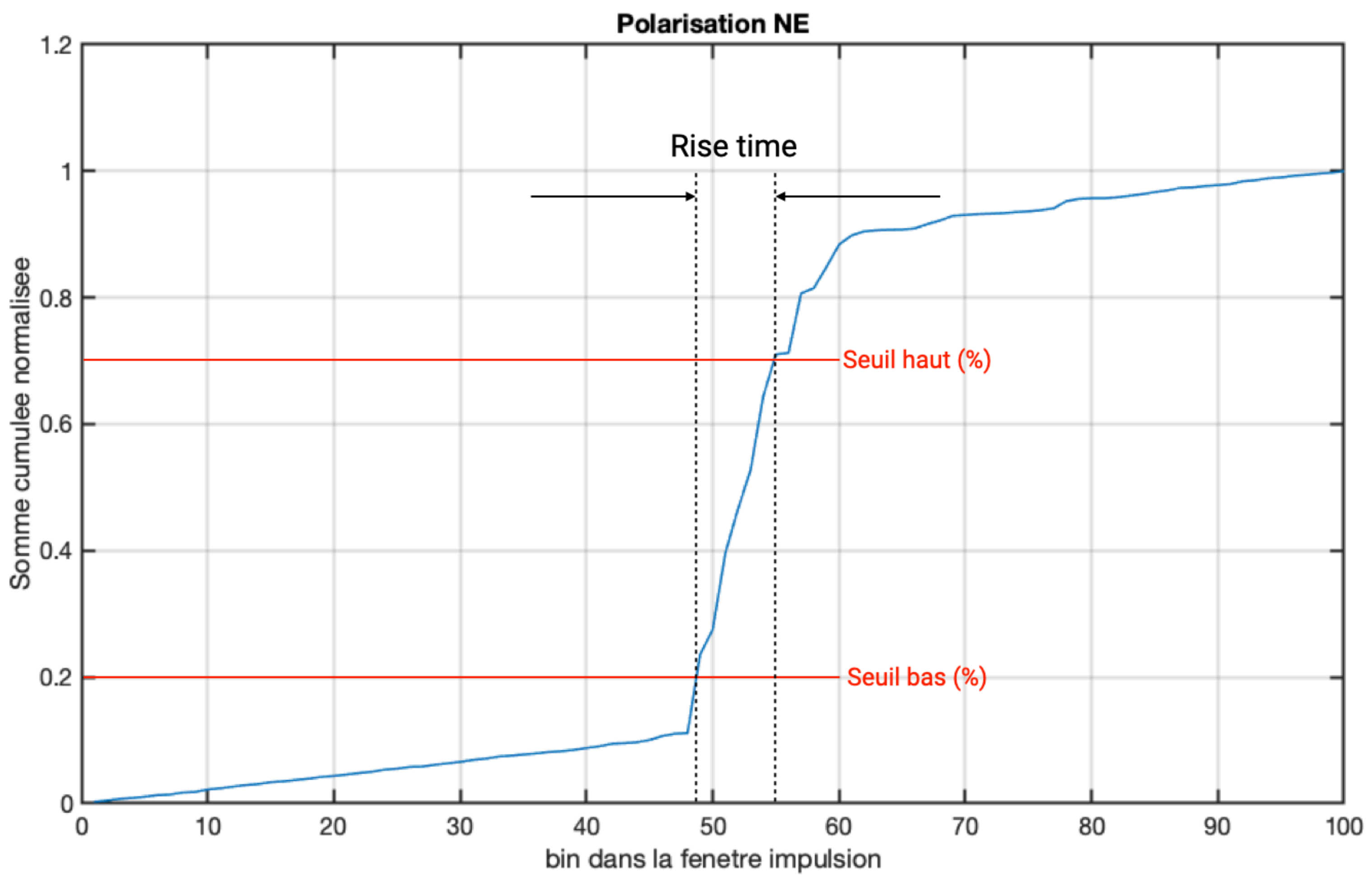
Paramètres à calculer sur chaque fenêtre (sur le signal filtré puis somme cohérente) : max(valeur absolue), rms, mean, rise time + *rapport des signaux de chaque polarisation (bin à bin) si option possible*

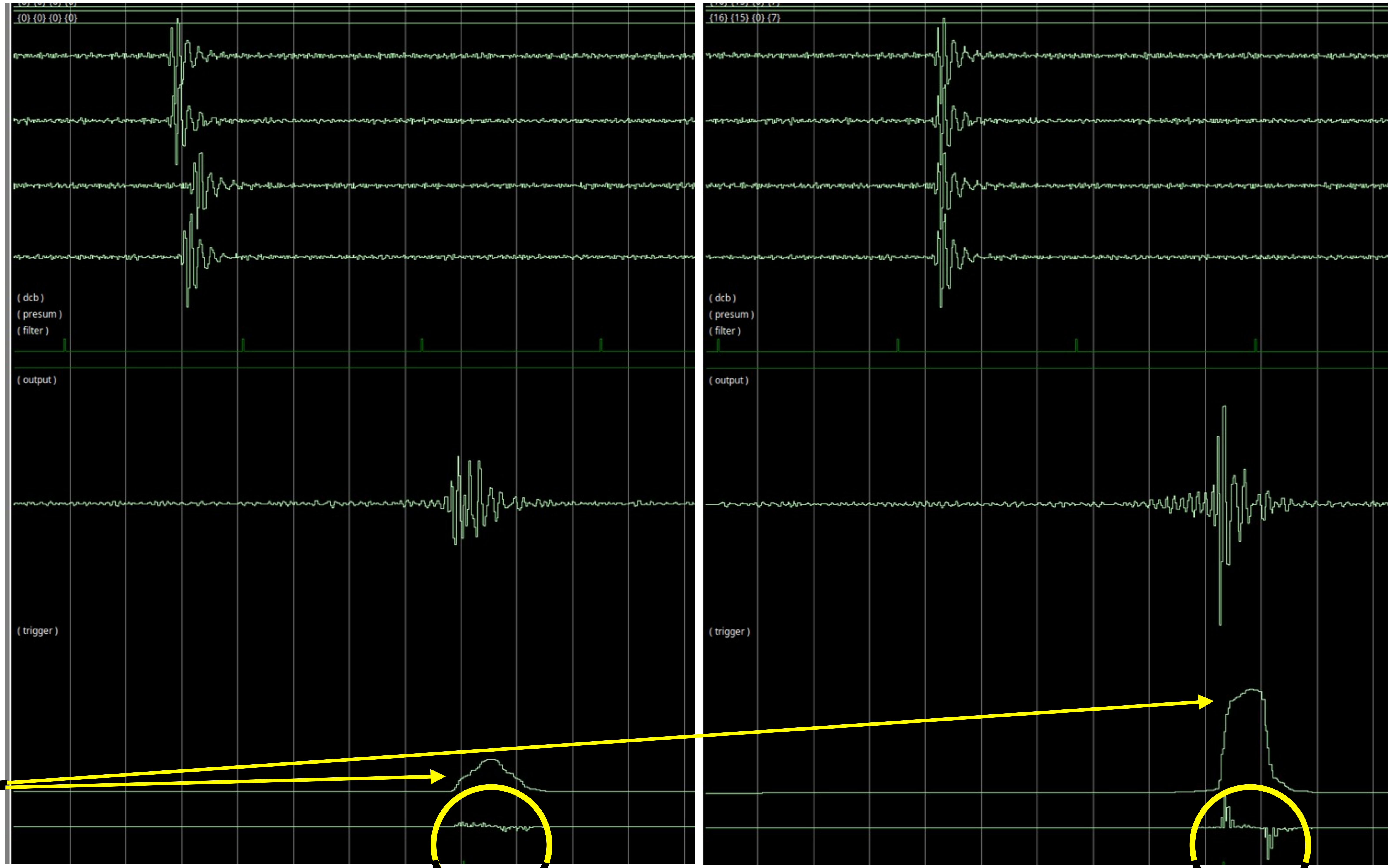
Most discriminating criterion: the rise time of the signal
(calculated on the cumulative sum of the square of the signal)



VHDL implementation in the FPGA of HPAPB boards (Thomas Berthet)

TB - Réunion technique NenuFAR France 21/10/2021



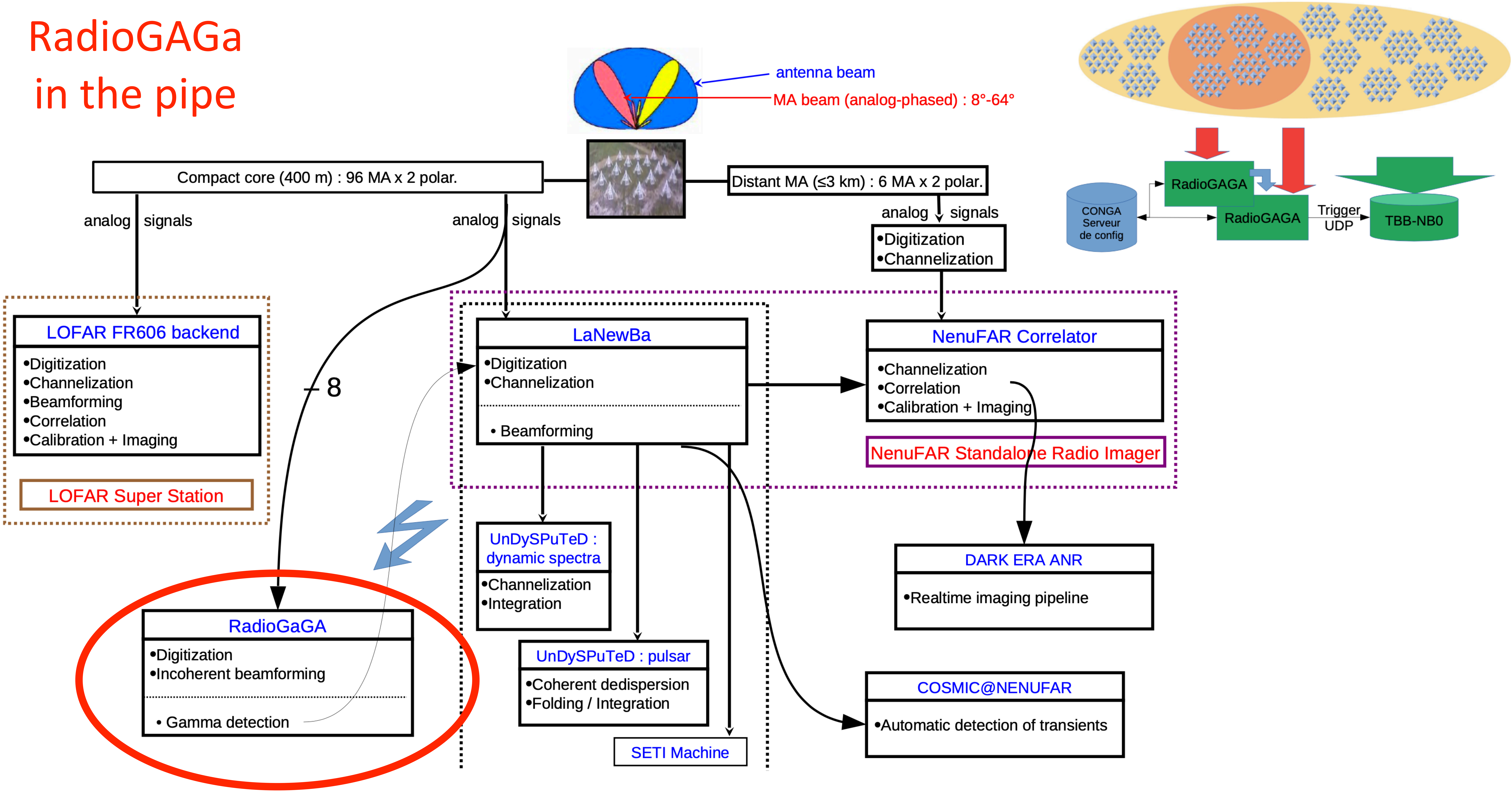


Cumulative sum over sliding window

Non-phased signals, low derivative

Phased signals, very strong derivative

RadioGAGa in the pipe



Already available

- ☑ TBB mode: raw waveforms over (currently) 10 μs extracted online from the 5 s memory (duration adjustable offline). Needs a trigger signal (yet UDP, analogue/digital possible?).

Soon available

- ☐ TBB mode: full memory (5s) extracted from all MA, at different day and night times, with different pointing directions
  ➡ Goal: to analyse repetitive RFI coming from (mainly) horizon, to estimate their strength, their occurrence frequency and tentatively to localise them.
- ☐ RadioGAGa trigger: combination of time signals and selection regarding several criteria. See with Thomas Berthet whether it can (easily) be modified following special needs.

If anyone is interested in these uses or to help analysing 5s TBB data…

ES12 - KP Radio Gamma

Semester #6 Early Science phase

- Sources to be observed:

- Crab nebula (TauA) - Right Ascension 5:34:31.884 - Declination 22:0:52.1640

- HAWC source 2HWC J1825-134 - Right Ascension 18:25:36 - Declination -13:22:12.0000

- HAWC source 2HWC J2227+610 - Right Ascension 22:27:50.3 - Declination 61:2:60.0000

The main sources pointed to in this KP are selected as 3 of the 4 HAWC sources visible in the Northern Hemisphere with the harder energy gamma-ray spectrum and the highest flux (see A. U. Abeysekara et al. (HAWC Collaboration), Phys. Rev. Lett. 124, 021102, 2020). The Crab nebula is known to have emitted the most energetic gamma ever detected (450 TeV, TIBET). Recently, the spectrum of J1825-134 has been clarified by the HAWC Collaboration with improved statistics (A. Albert et al., arXiv:2012.15275 [astro-ph.HE], 2021), and it no longer shows a high energy cut-off (>200 TeV), making this source particularly interesting for the search for gamma-rays. This is also the case for J2227+610, which has recently been identified as a possible PeVatron in the Galaxy, and appears of paramount interest for gamma-ray observatories. For this semester, which will see the implementation of the RadioGAGa trigger with the dedicated HPAPB card (which was intended for the previous semester but not yet realised), we have therefore chosen to concentrate our observations on these three sources alone. The Crab pulsar (in the field of view of TauA) is also observed in conjunction with the ES03 Pulsars programme (i.e. unlike the other sources in the ES12 programme which only use TBB data, the UnDysPuTed receiver is configured for ES03 observations in conjunction with the acquisition of the TBB signals from ES12).

+ TBB record on each ES03 observation + same on ES04 and ES05 (Transients and FRB)
+ Since 2021-10-21: all current MR TBB are recorded (0 to 79)