From the observation of UHECR radio signal in [1-200] MHz to the composition: CODALEMA/EXTASIS status report

Antony Escudie[1]

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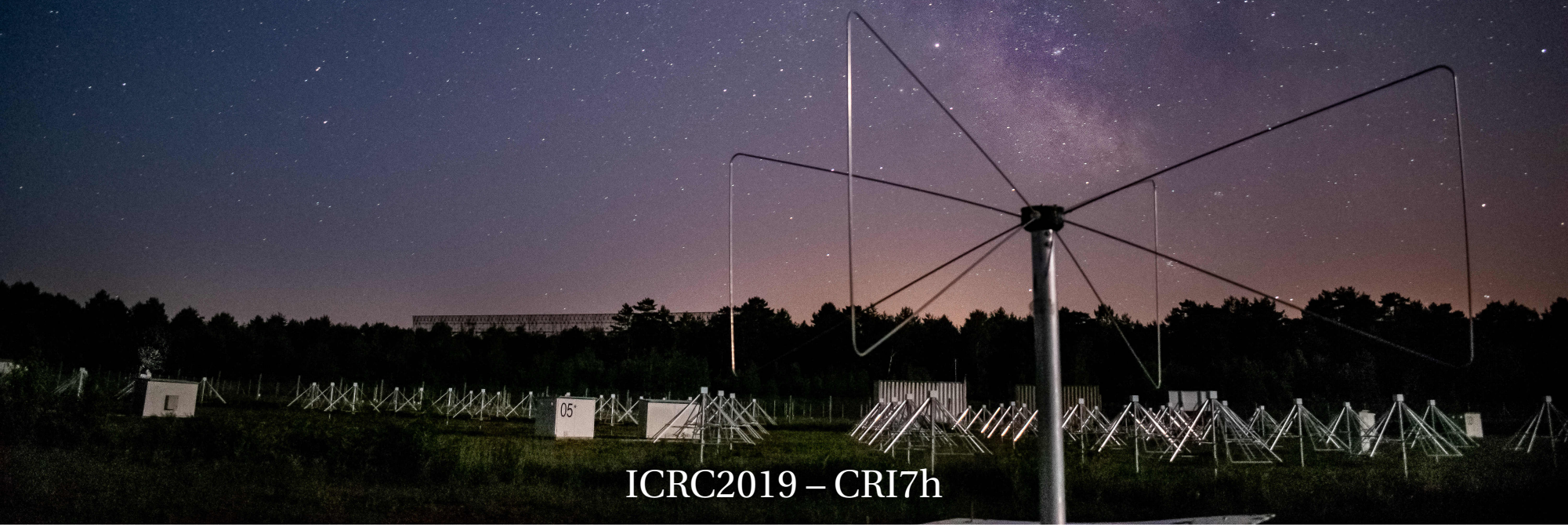
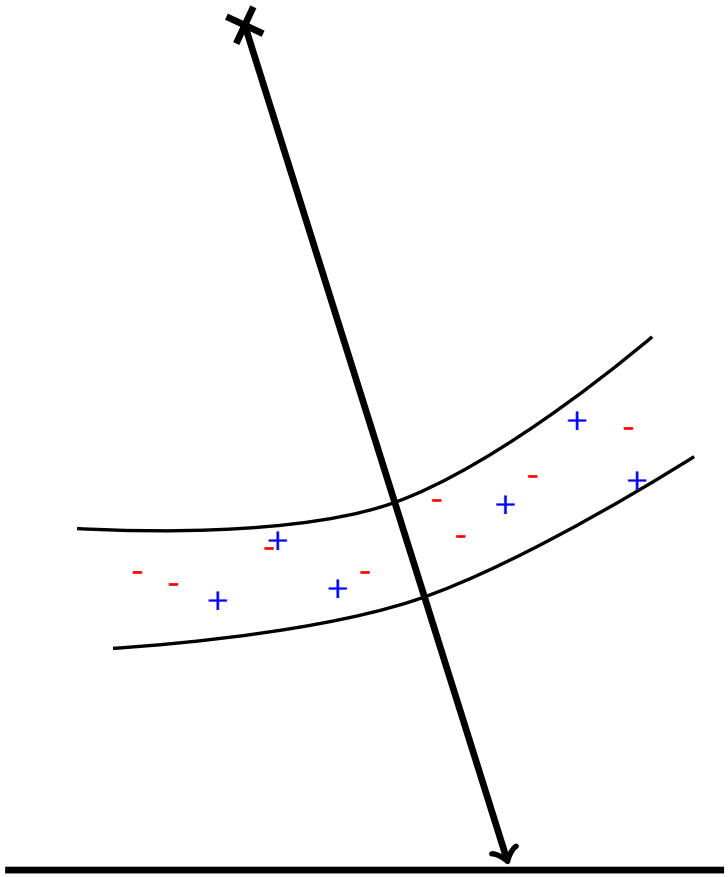
[3] Unité Scientifique de Nancay, Observatoire de Paris, CNRS, PSL, UO/OSUC, Nançay, France

July 22, 2019



ICRC2019 – CRI7h

Radio-detection of cosmic-rays



- A primary CR arrives in the atmosphere, and creates an extensive air shower (EAS)
- Charged particles (e^+/e^-) in the EAS create electric field (geomagnetic + negative charge excess mechanisms)

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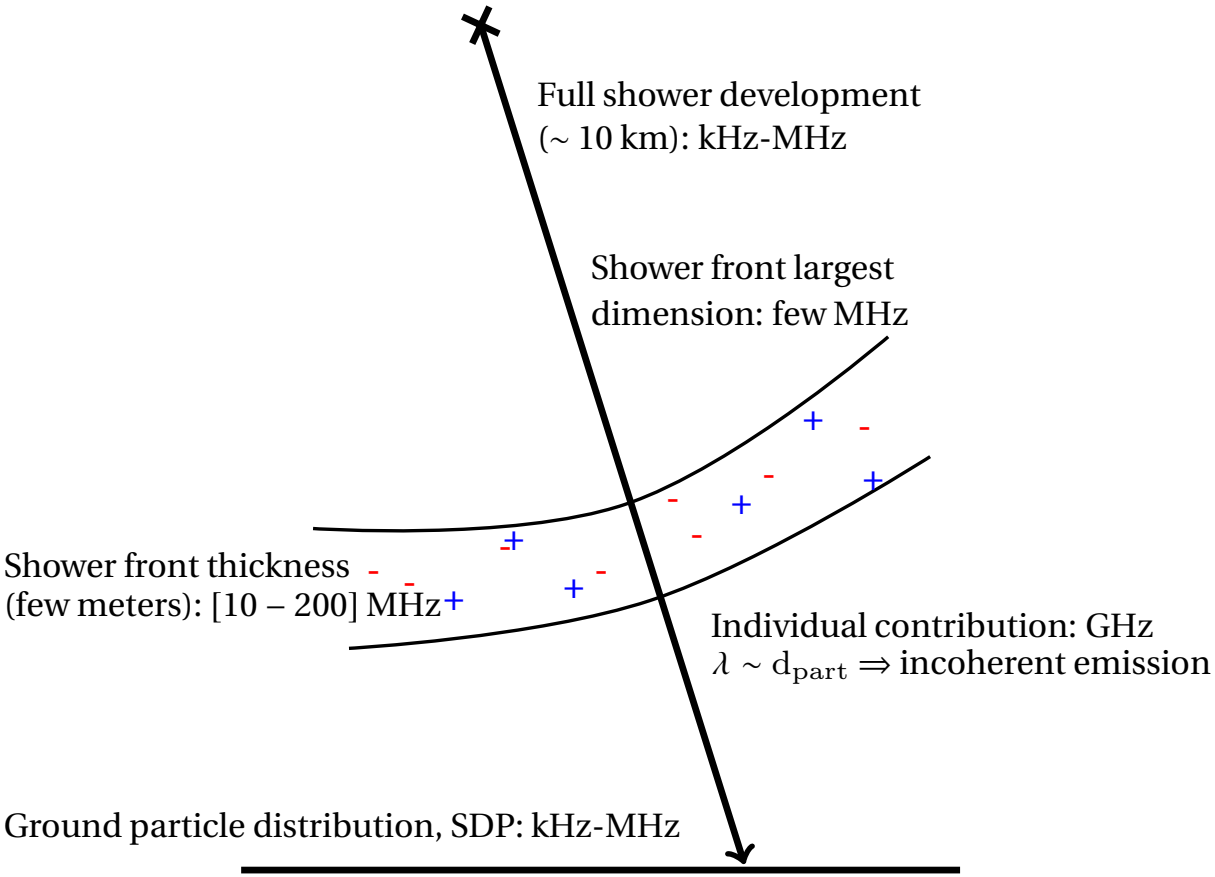

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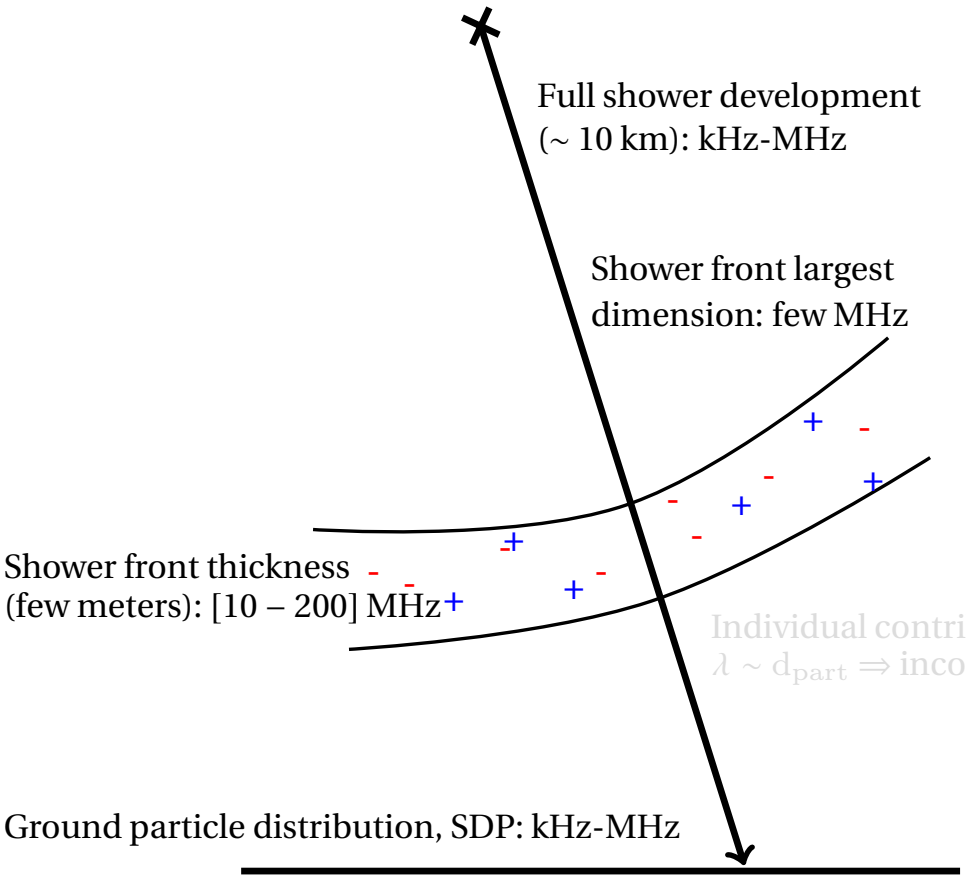

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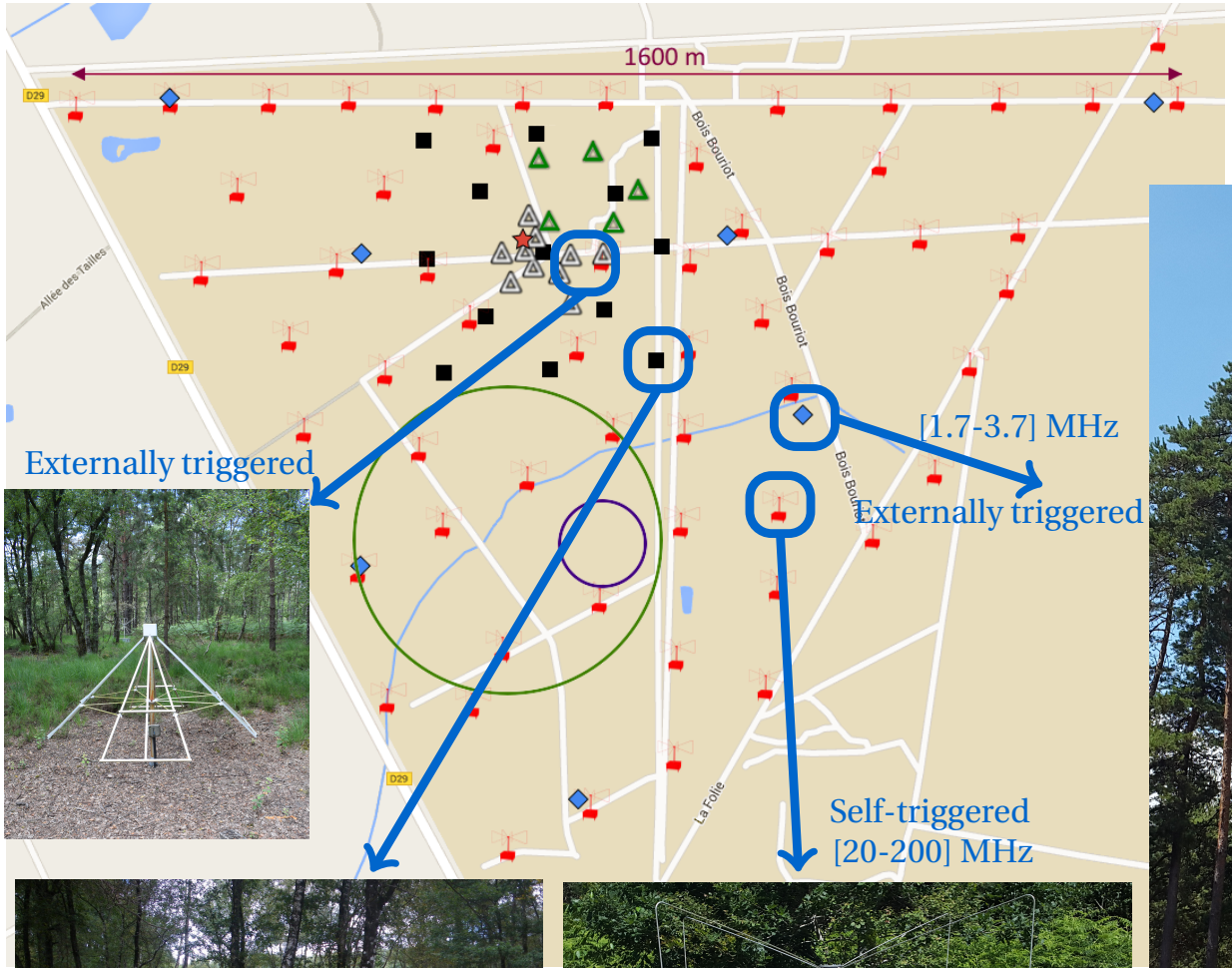
- Charged particles (e^+/e^-) in the EAS create electric field (geomagnetic + negative charge excess mechanisms)
- Electric field is measured (usually above 20 MHz)

- Arrival direction (θ, ϕ), core position, composition (X_{max}), energy
- Different frequencies probe different properties of the shower

The experimental site - Nançay Observatory



Externally triggered

[1.7-3.7] MHz

Externally triggered

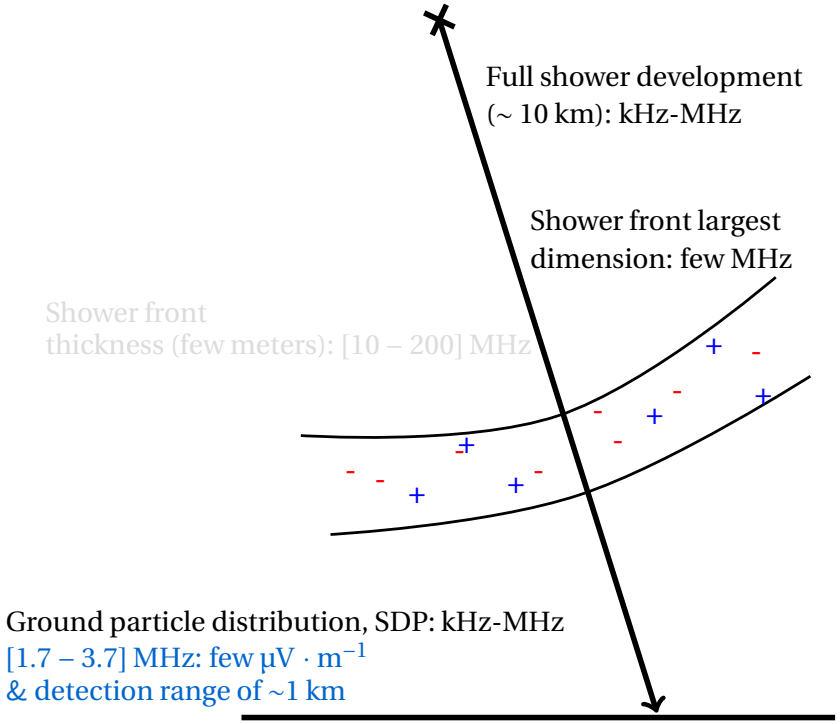
Self-triggered
[20-200] MHz

EXTASIS status report

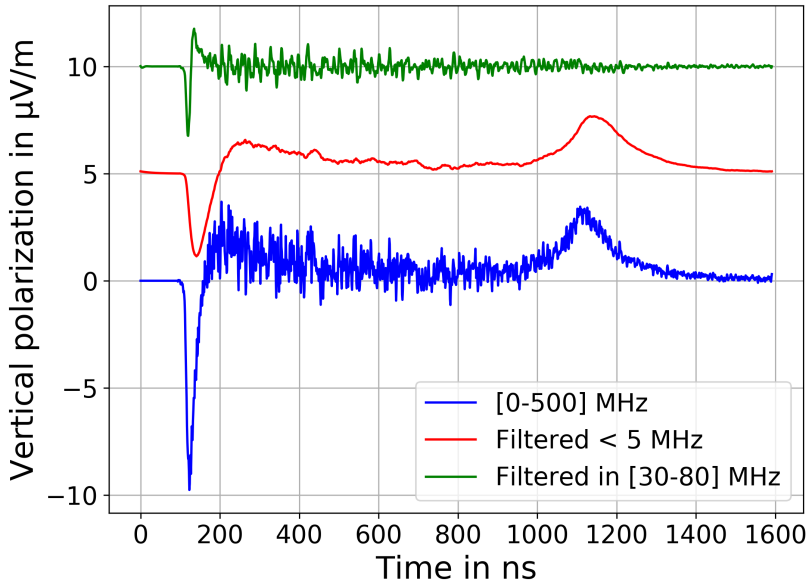
[1.7 – 3.7] MHz

Published in Astroparticle Physics, *Radio detection of cosmic rays in [1.7-3.7] MHz: the EXTASIS experiment*, **Astroparticle Physics, 113:6 - 21, 2019**

What we are trying to detect...



SELFAS simulation of vertical proton at 10^{18} eV observed in the vertical polarization



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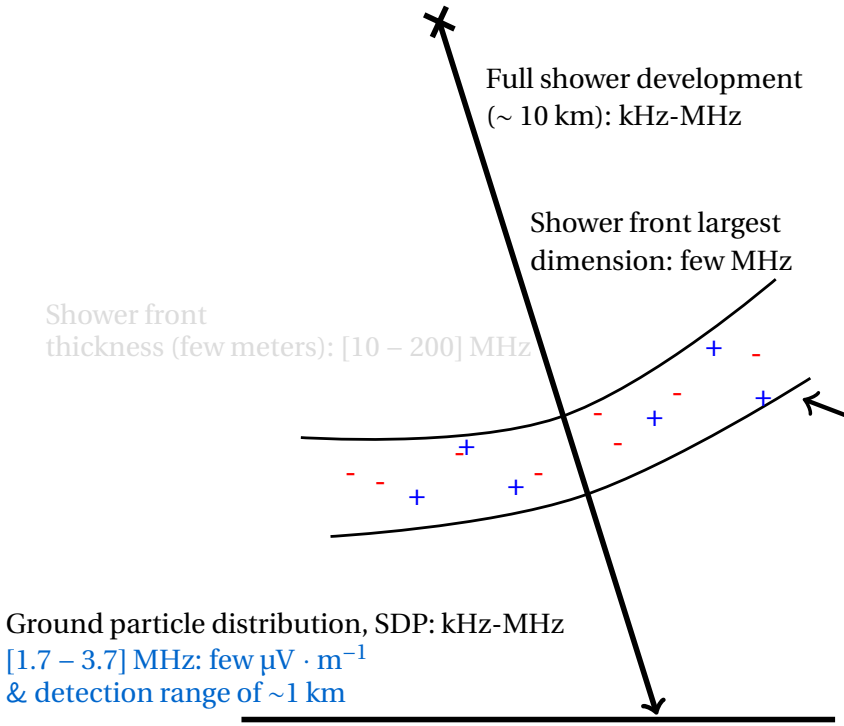

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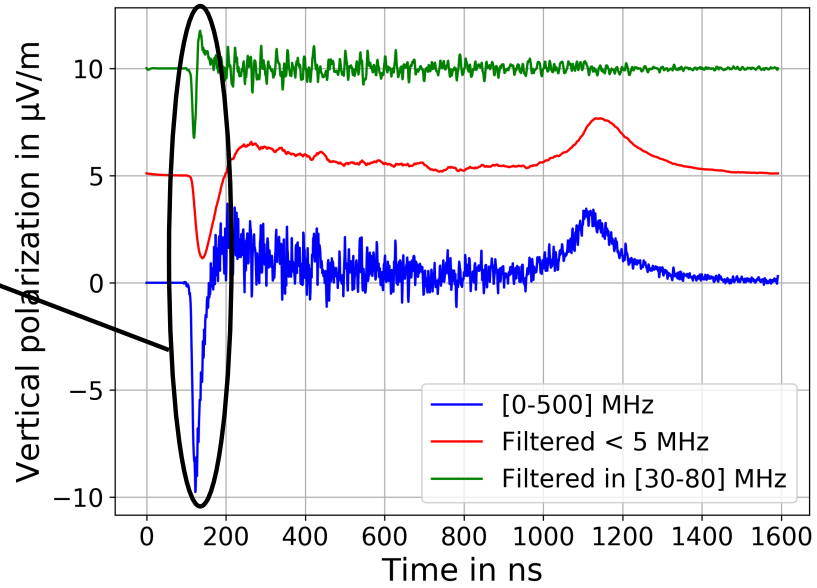

- Shower development counterpart

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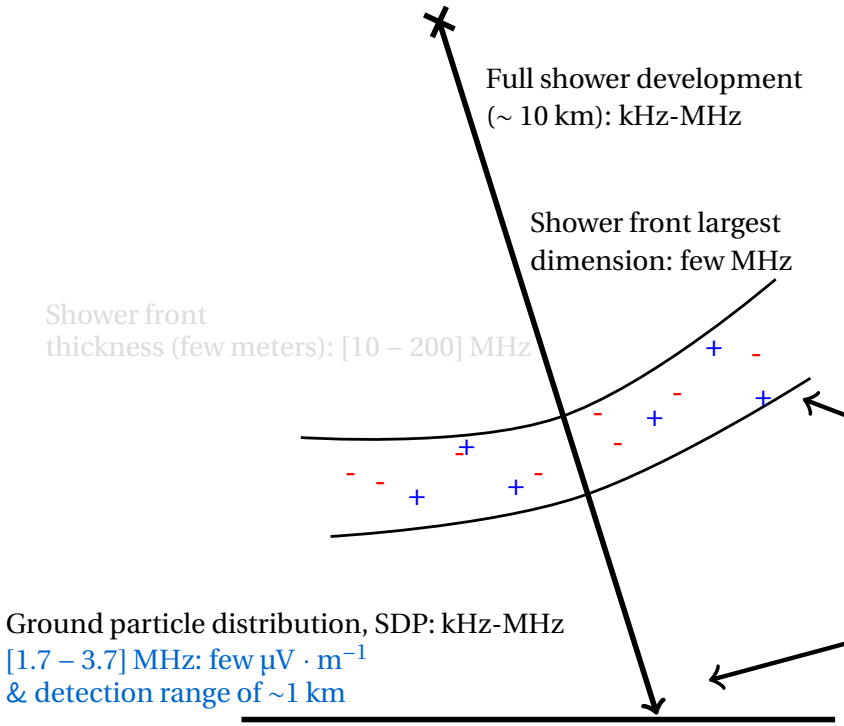

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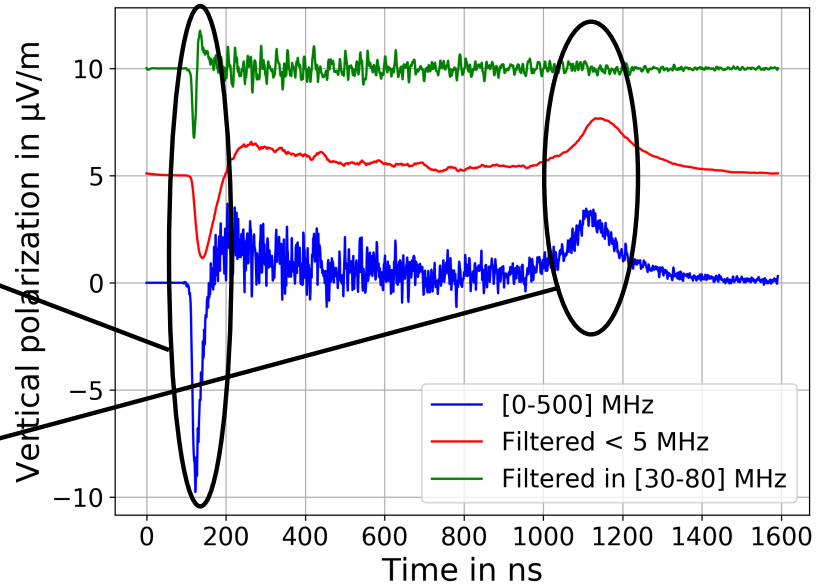
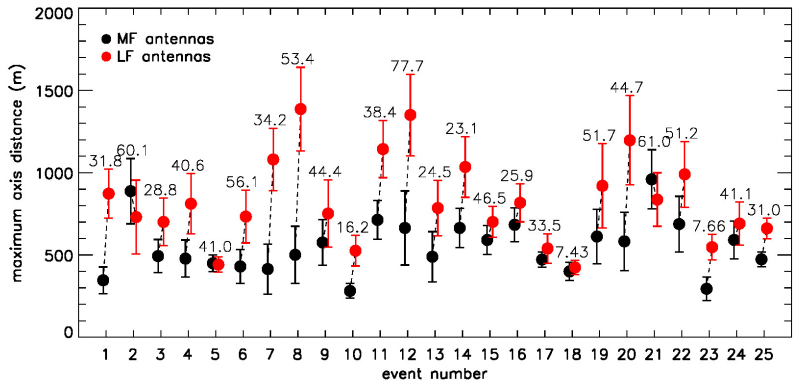
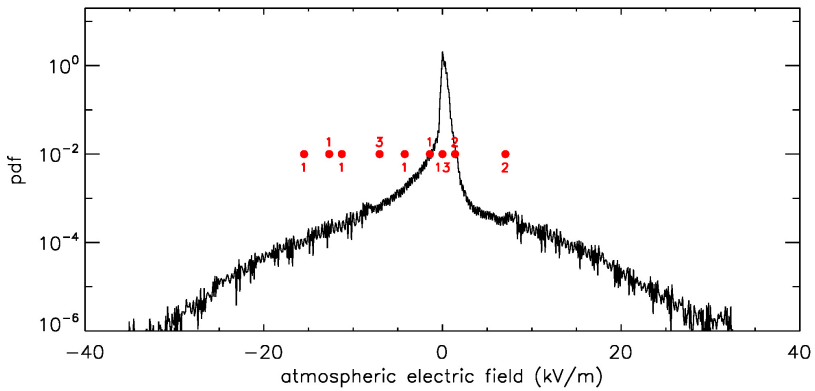


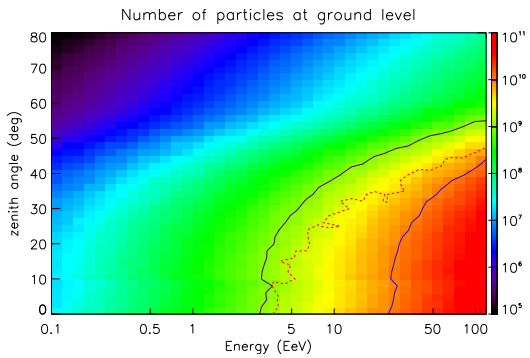
- Shower development counterpart
- Sudden Death (SDP) counterpart: due to the sudden disappearance of the charged particles on the ground

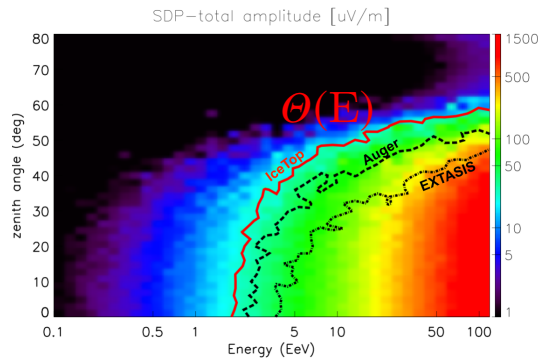
Summary of the results obtained in the LF band

- 25 LF events observed over 2 years in correlation with cosmic-ray events
- Only one reconstructible LF event: detection threshold of $23 \pm 4\ \mu V \cdot m^{-1}$
- Detection range at LF larger than at MF confirmed
- Harsh atmospheric noise conditions hamper the LF detection
- Strong correlation with the atmospheric electric field
- SDP: higher altitude sites much more favourable: Auger ($3000\ km^2$) ~ 2600 detectable showers per year, GRAND ($200\ km^2$) ~ 350 detectable showers per year



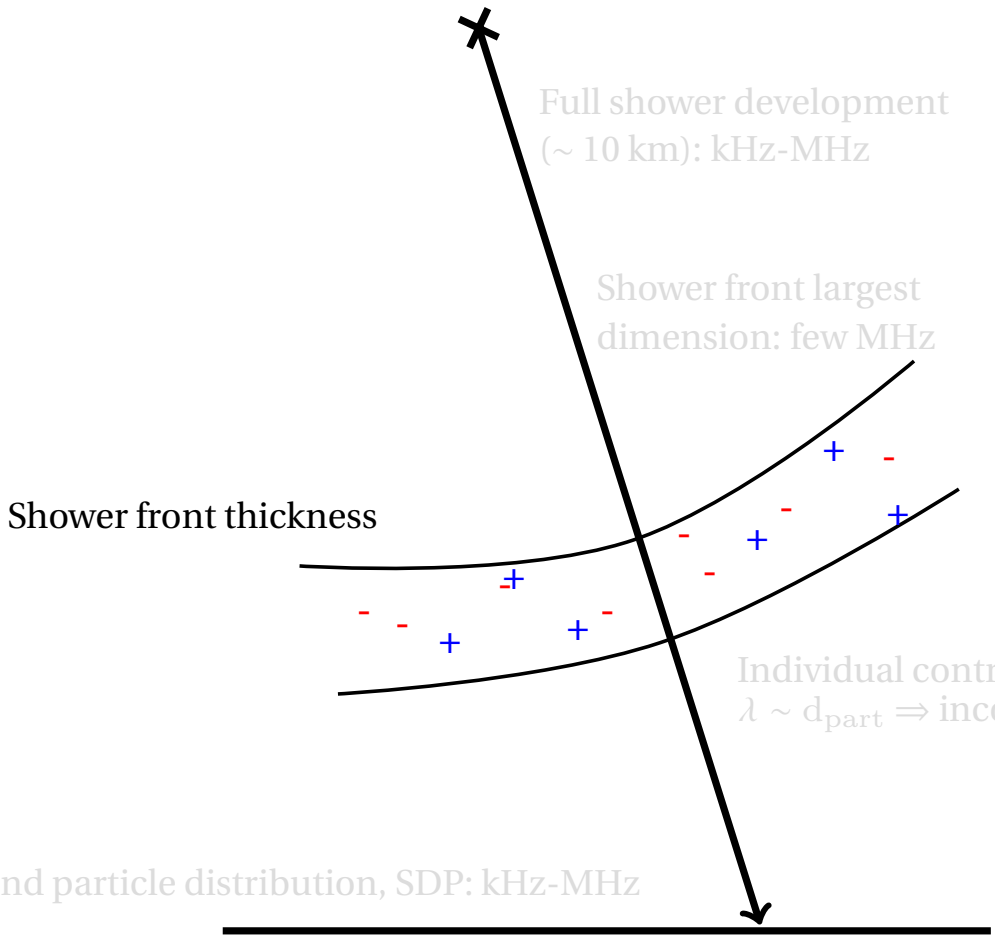




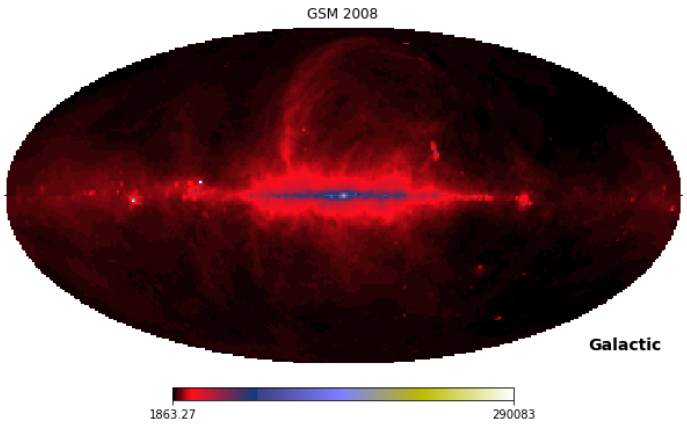


CODALEMA status report

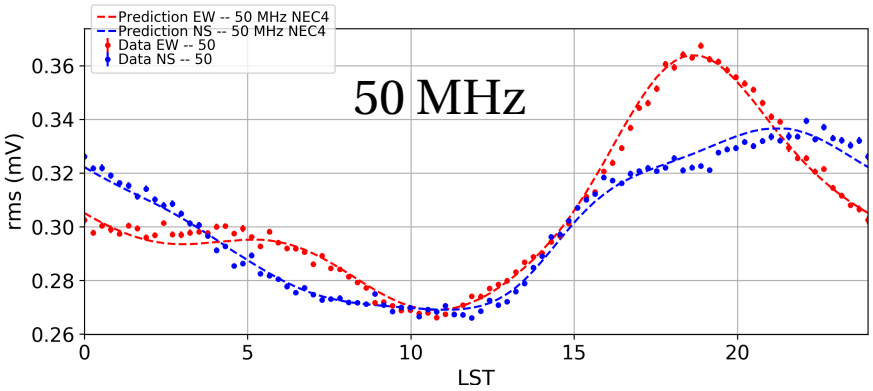
[20 – 200] MHz

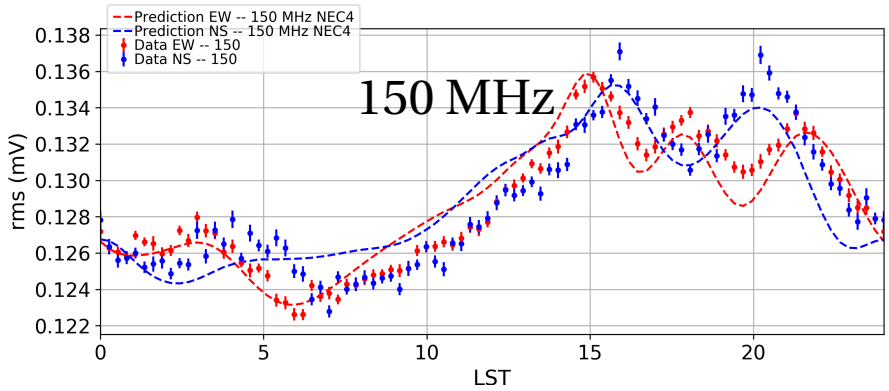


Calibration of the radio antennas



- Use of the Galactic radio emission as a source for the calibration of the radio detectors of CODALEMA
- Galactic model: GSM (*arXiv0802.1525*)
- NEC4: Antenna model + nearby environment (elec. crate, ground)





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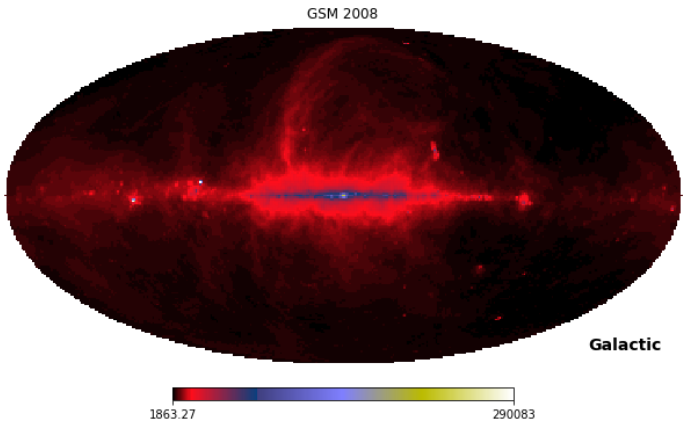

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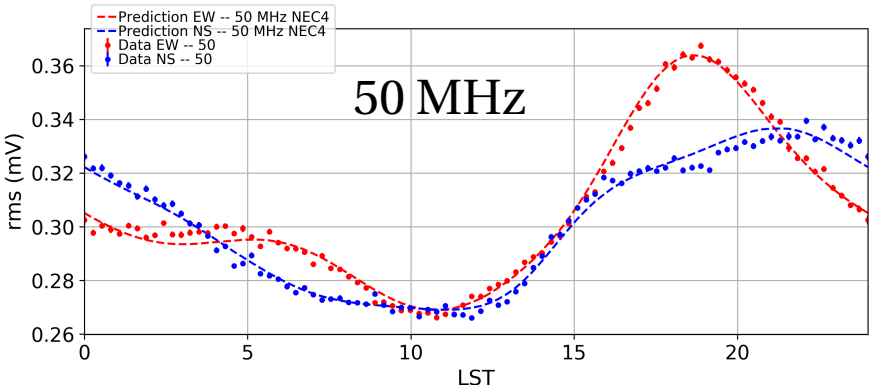

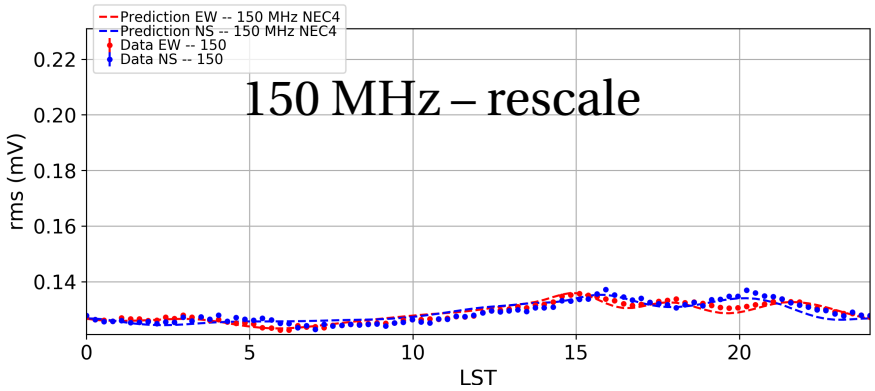

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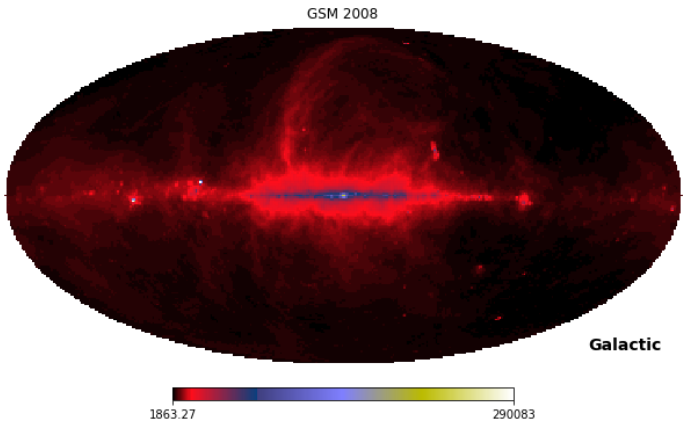

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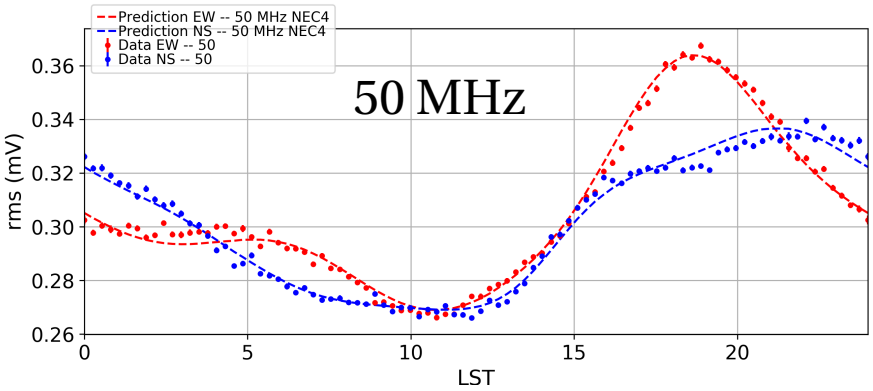
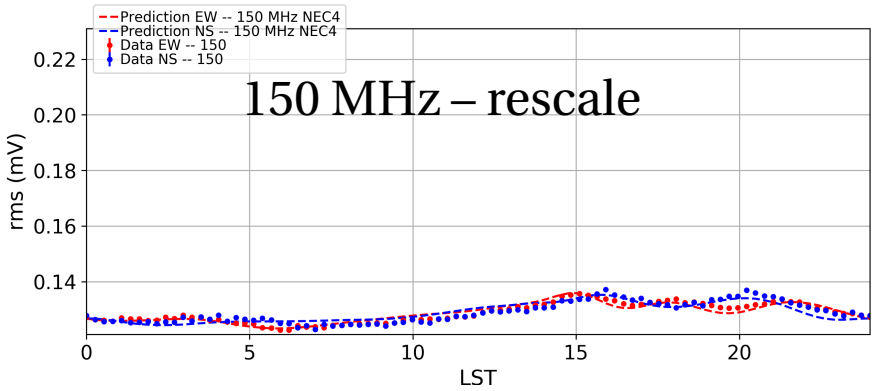
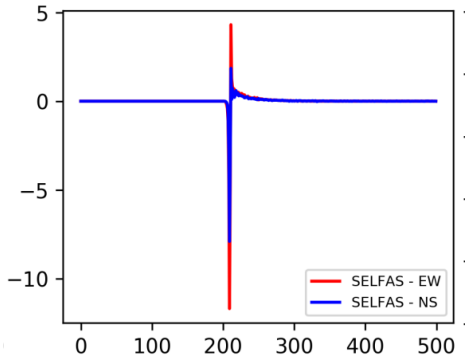
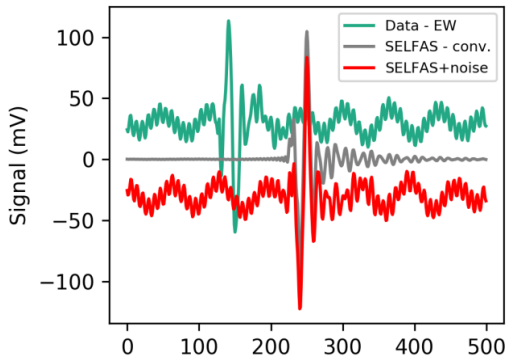
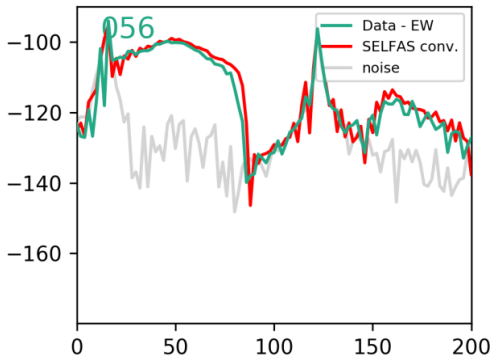




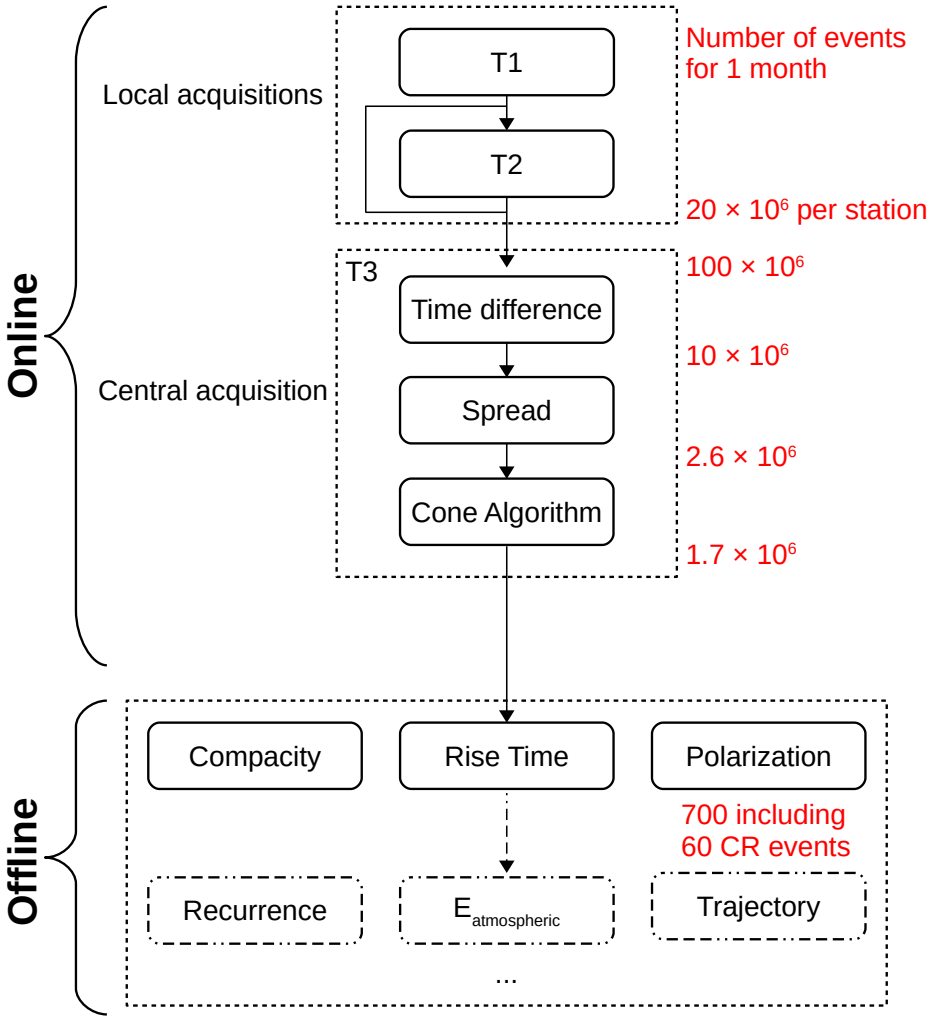


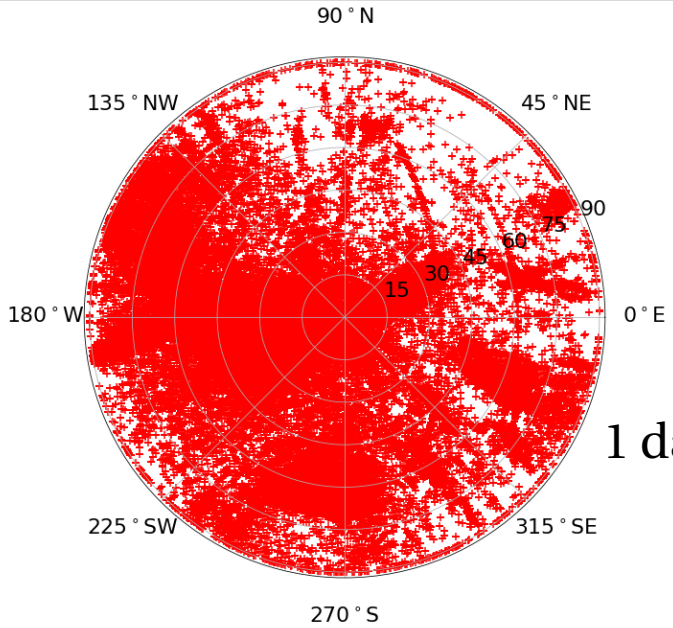




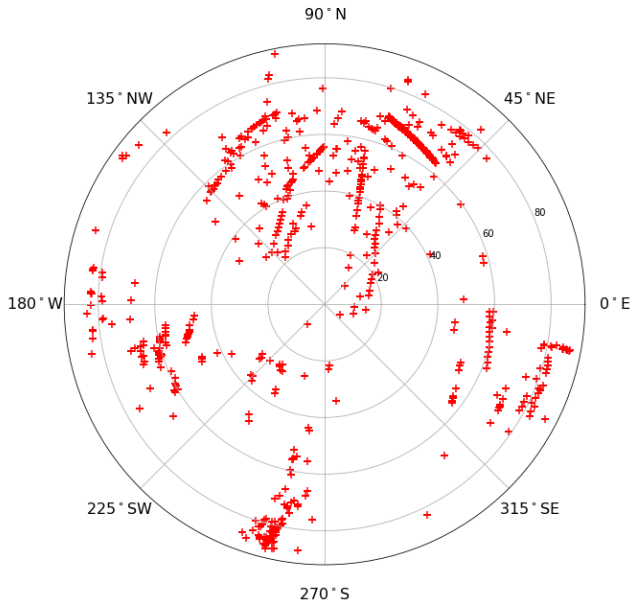
- Instrument and simulations very well mastered, strong agreement on [1-200] MHz

Selection of events



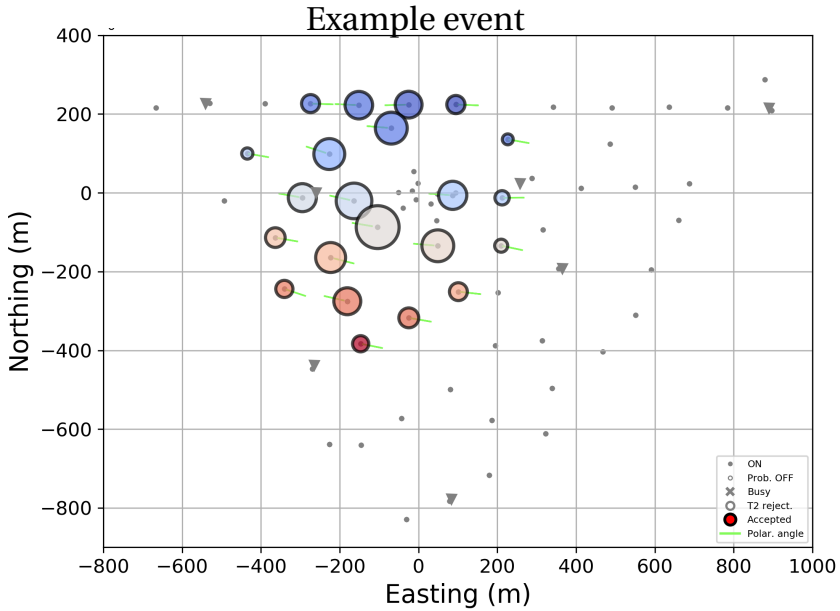


1 day !

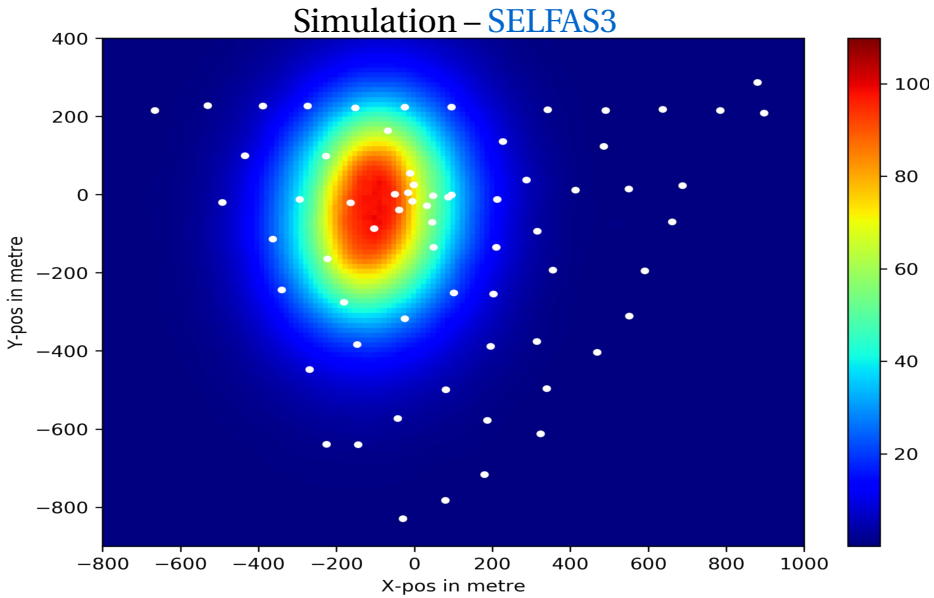


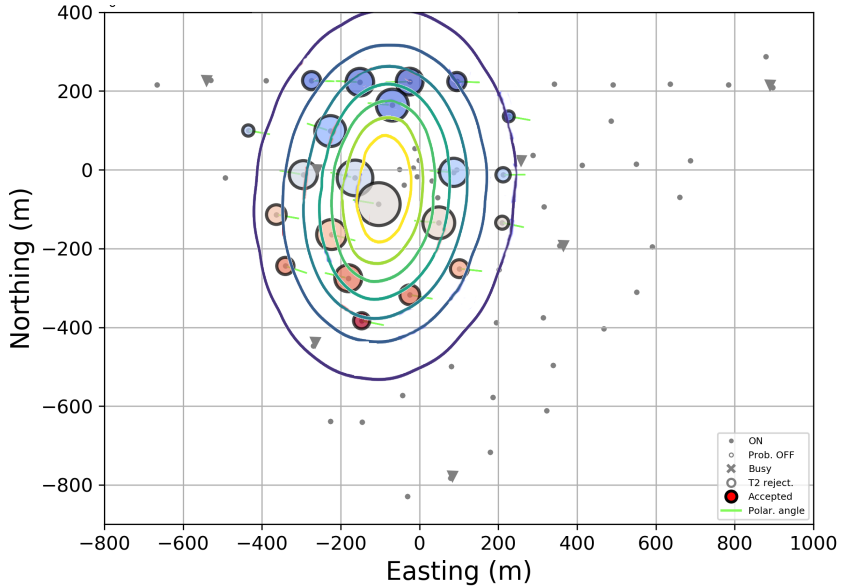
⇒ 5 orders of magnitude reduction, able to get rid of particle detectors !

Estimating the shower parameters



- θ, ϕ reconstructed using arrival times
- Core position, composition (X_{max}) and energy reconstructed trough MC simulations
- Generalized method: decoupling both polarizations (no more quadratic sum) and use of [120 – 200] MHz band





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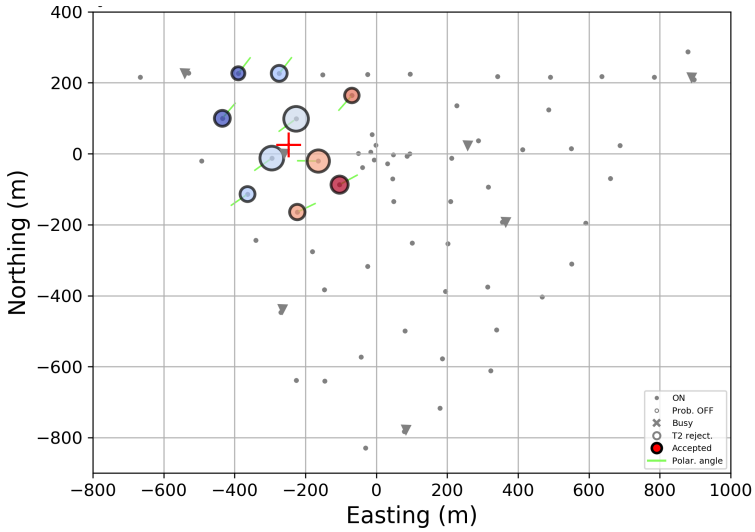

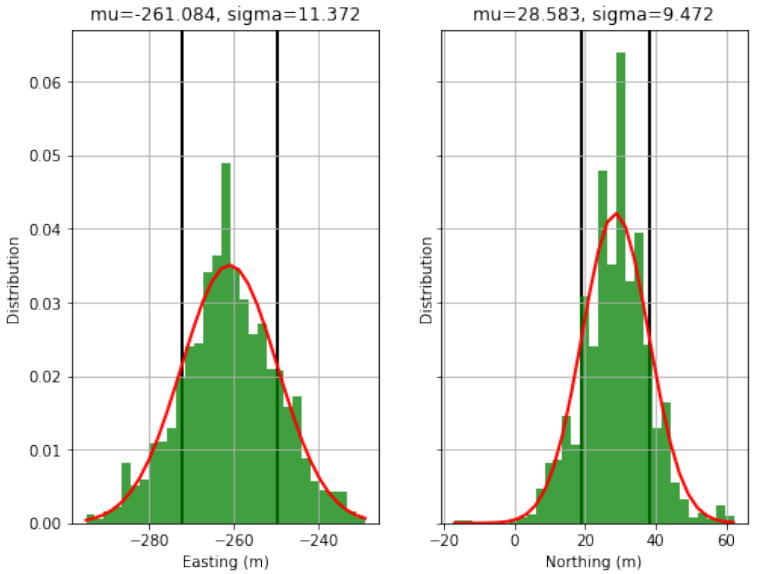

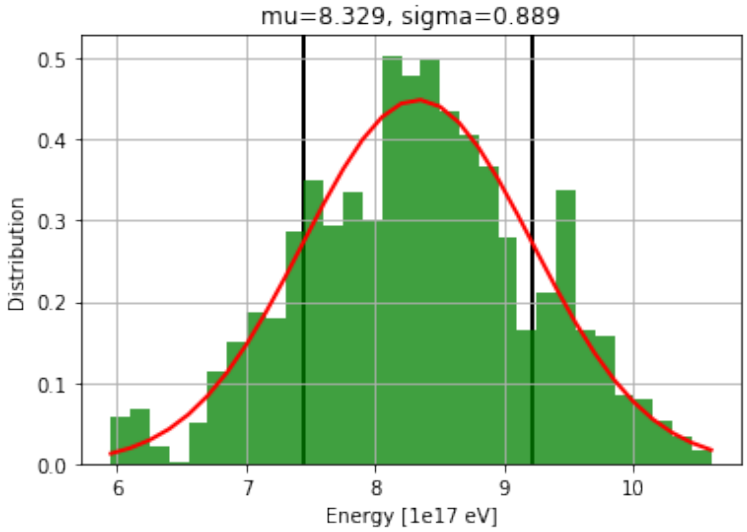

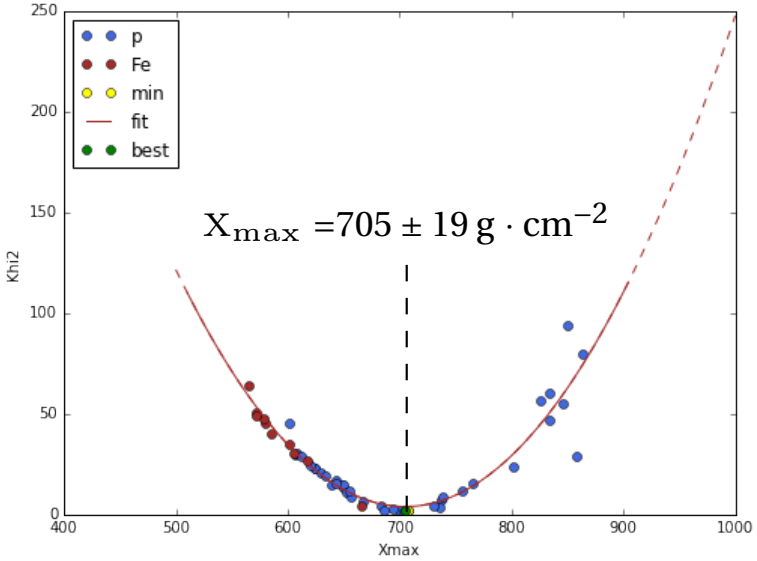

Estimating the shower parameters

- E_{radio} compares well with $E_{particles}$ within the scintillator array acceptance and resolution: E_{radio} deduced from simulations seems reliable
- A large batch of radio events (294 events) has been collected over a large energy window
- $\Rightarrow$ Towards mass composition with CODALEMA

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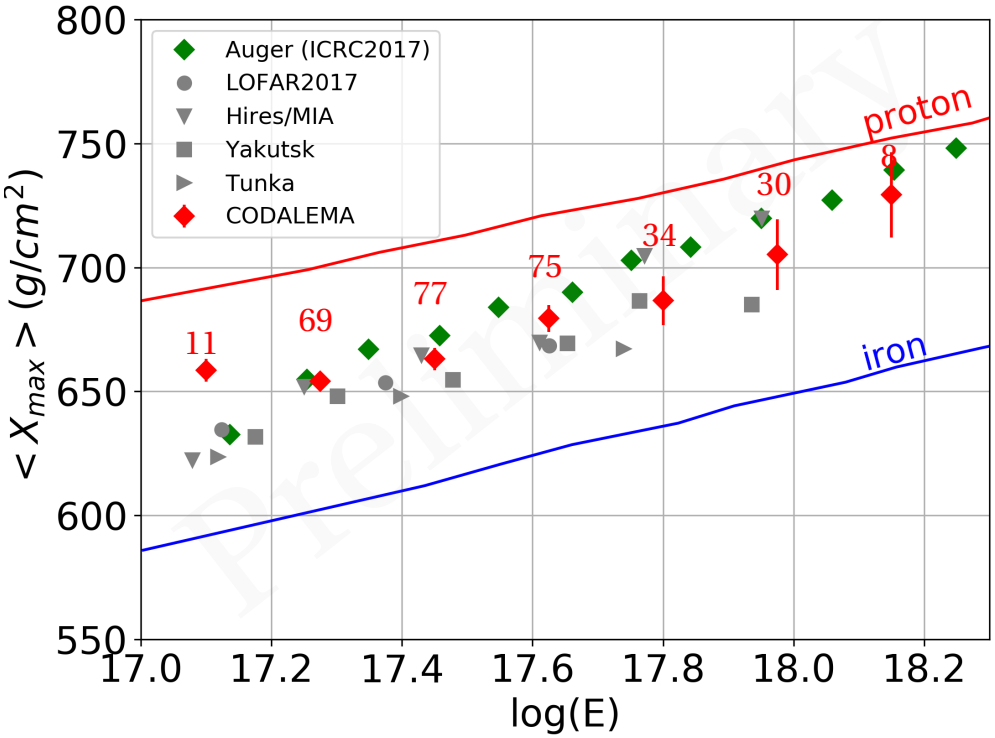
- $\Rightarrow$ Towards mass composition with CODALEMA
- CODALEMA in agreement with other experiments in $\log_{10} E \in [17.0 - 18.2]$
- Lighter composition with increasing energy
- Mass component proportion available soon, work in progress

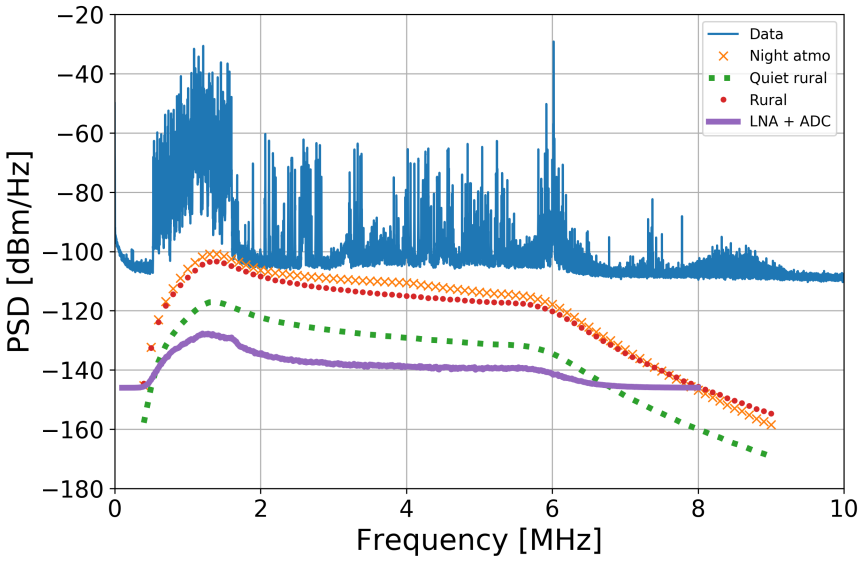


- CODALEMA&EXTASIS: very wide [1.7-3.7] + [20 – 200] MHz, routinely multi-wavelength observation of cosmic-ray air-showers in 10^{16} – 10^{18} eV, self-triggered stations in [20 – 200] MHz
- Instrument and simulations very well mastered, strong agreement
- Estimation of shower parameters using the radio signals (θ, ϕ, (X_{core},Y_{core}), X_{max}, Energy) in [20 – 200] MHz, using both polarizations independently $\Rightarrow$ CR composition from CODALEMA in agreement with other experiments
- Low-frequency band:
  - Signal seems not very promising, only 25 events over 2 years + strong correlation with E_{atm}
  - Detection range larger
  - SDP: higher altitude sites, Auger? GRAND?

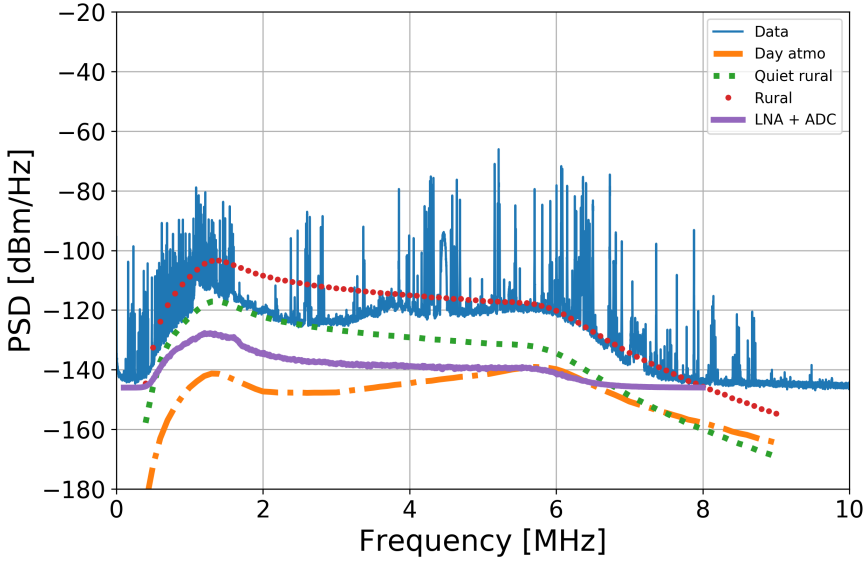
Thank you

Back-up

Atmospheric noise

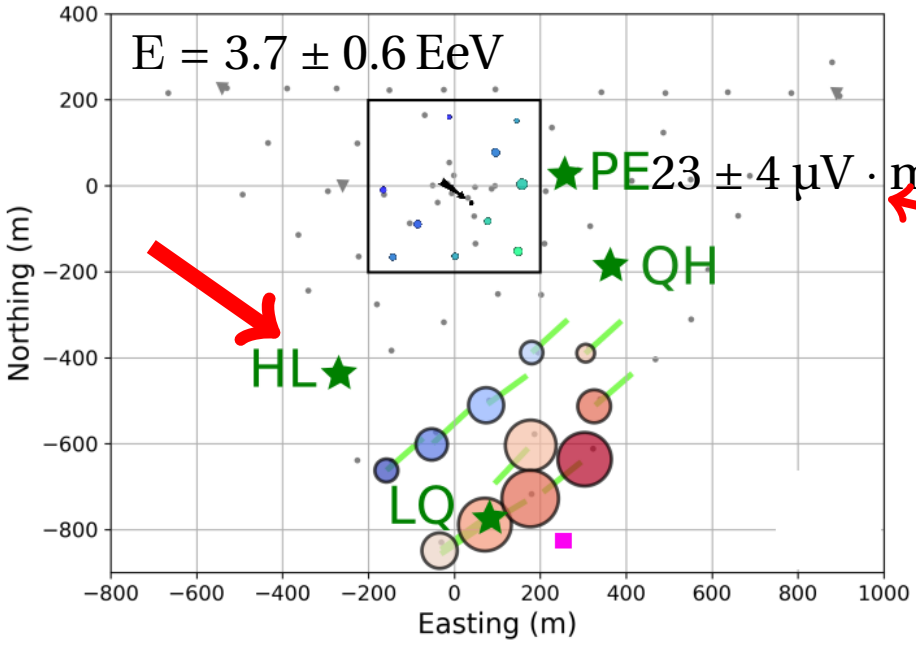


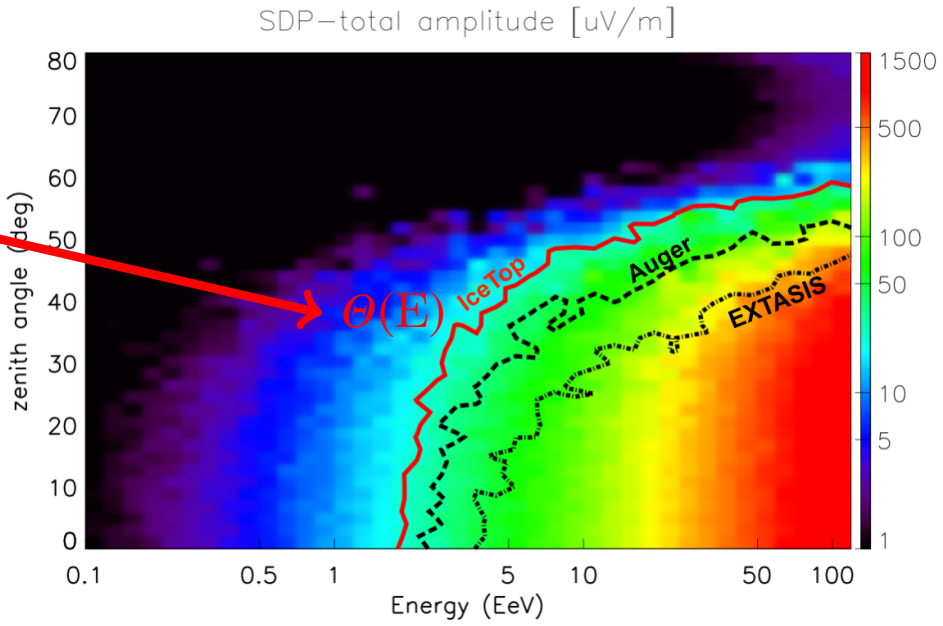
Nighttime PSD.

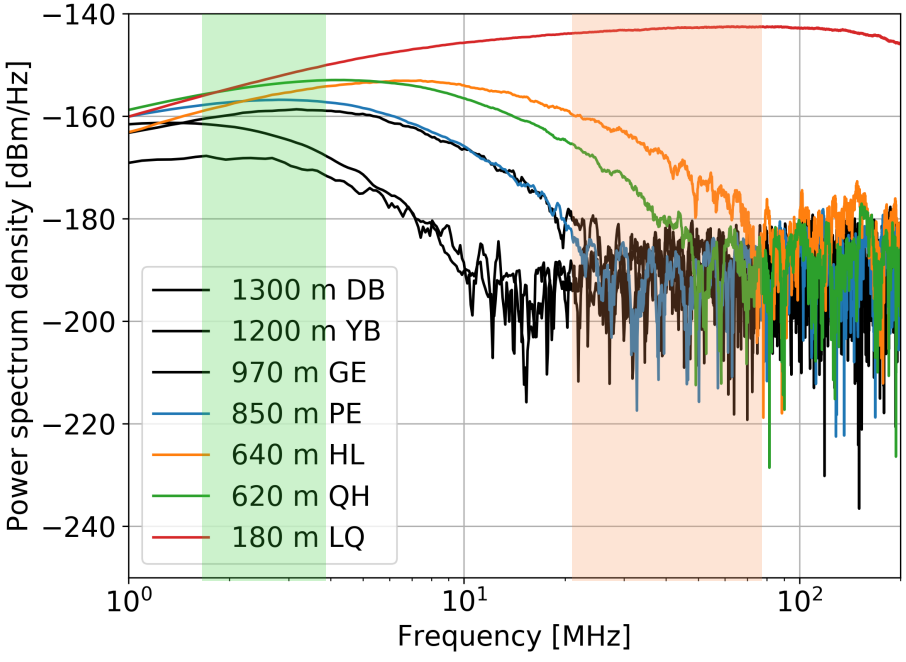


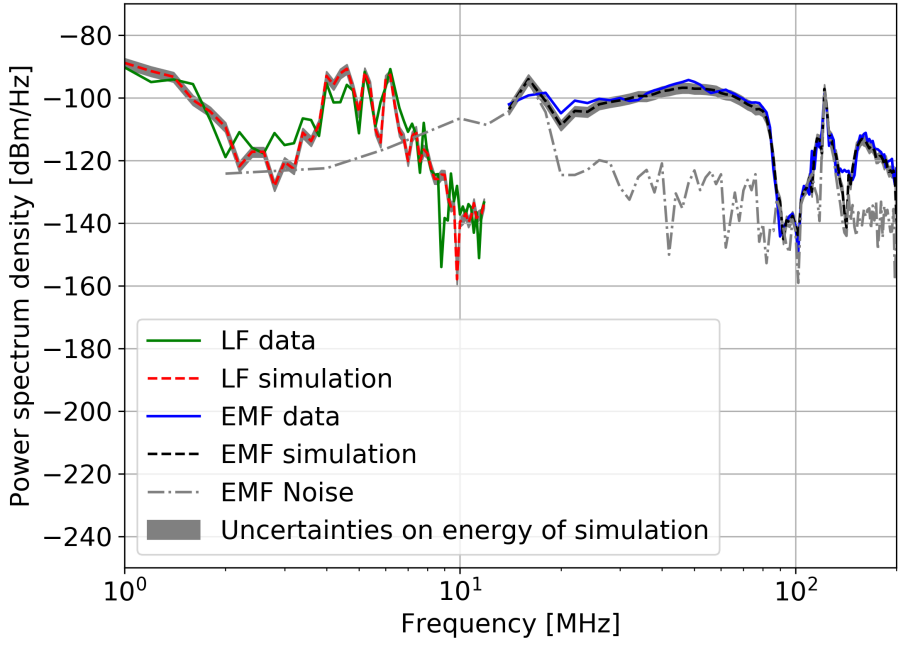
Daytime PSD.

- Dominated by atmospheric and man-made noises (not the Galactic one)
- Atmospheric noise lower during day than night $\Rightarrow$ duty cycle ≤ 50 %
- Analysis band: [1.7 – 3.7] MHz

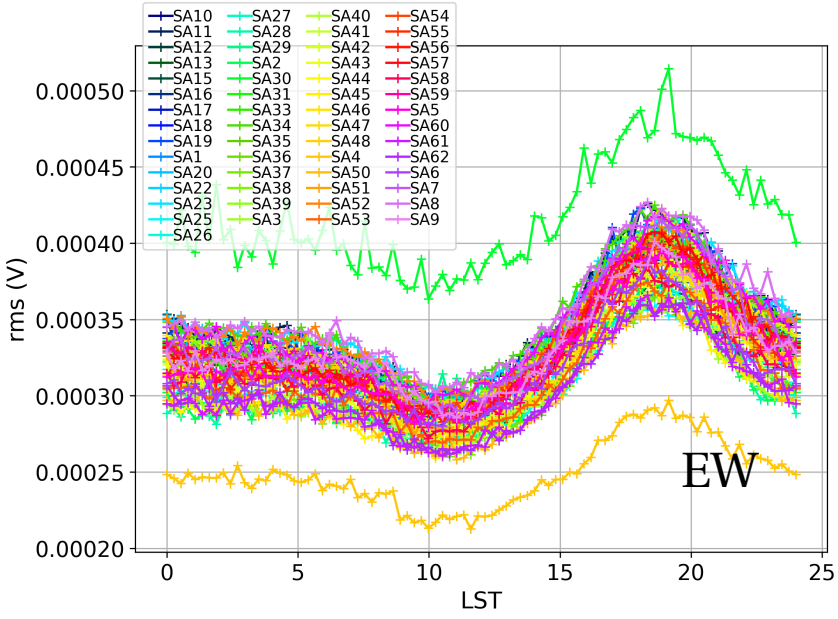

E = 3.7 ± 0.6 EeV
PE23 ± 4 μV · m⁻¹
QH
HL
LQ
Northing (m)
Easting (m)

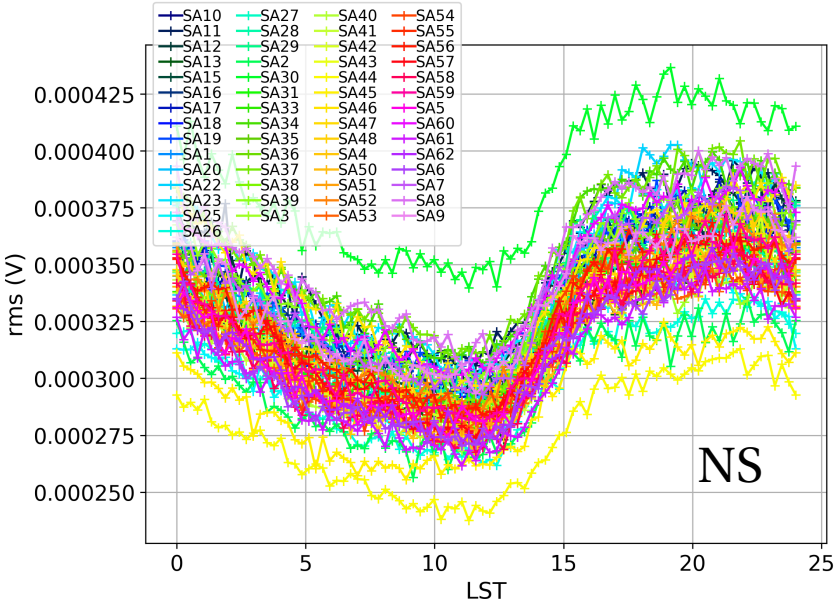

SDP−total amplitude [uV/m]
Θ(E)
IceTop
Auger
EXTASIS
zenith angle (deg)
Energy (EeV)

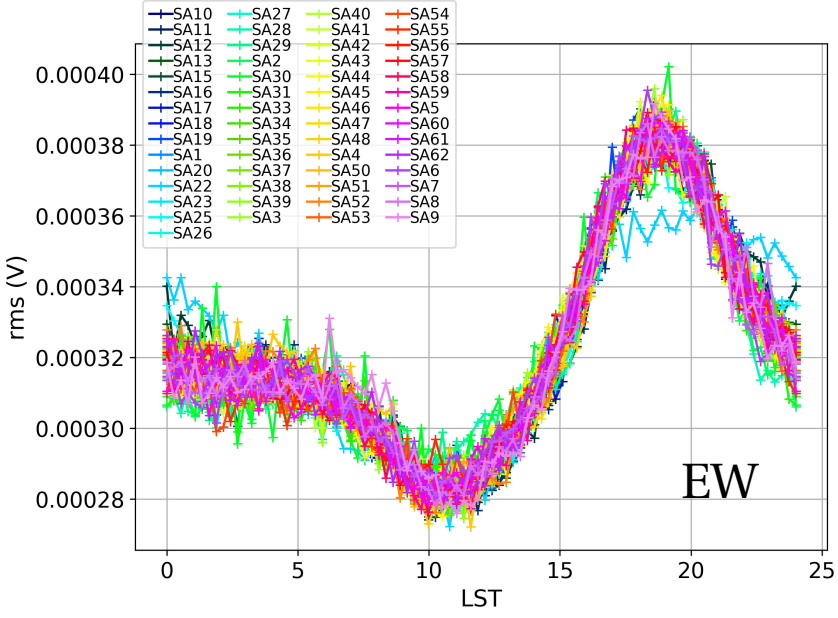

1300 m DB
1200 m YB
970 m GE
850 m PE
640 m HL
620 m QH
180 m LQ
Power spectrum density [dBm/Hz]
Frequency [MHz]

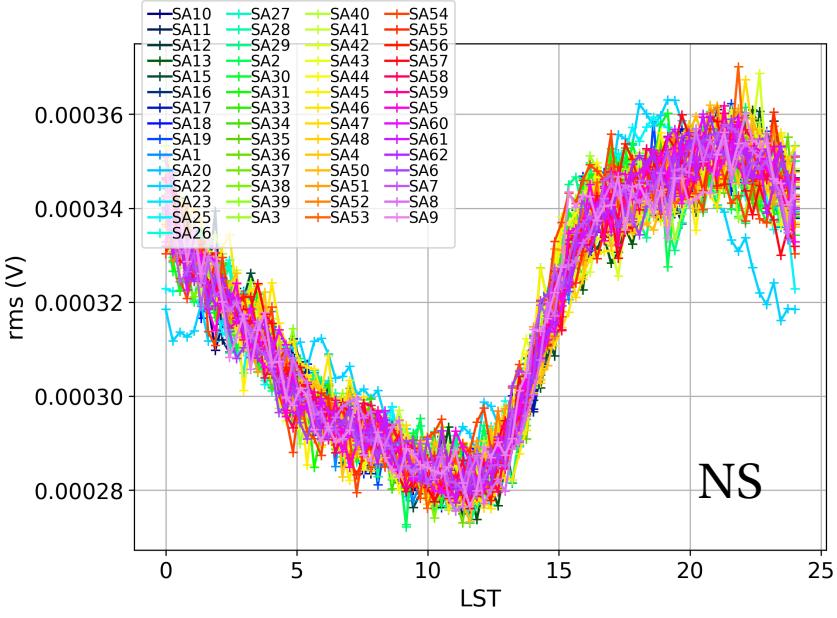

LF data
LF simulation
EMF data
EMF simulation
EMF Noise
Uncertainties on energy of simulation
Power spectrum density [dBm/Hz]
Frequency [MHz]

Calibration of the SA

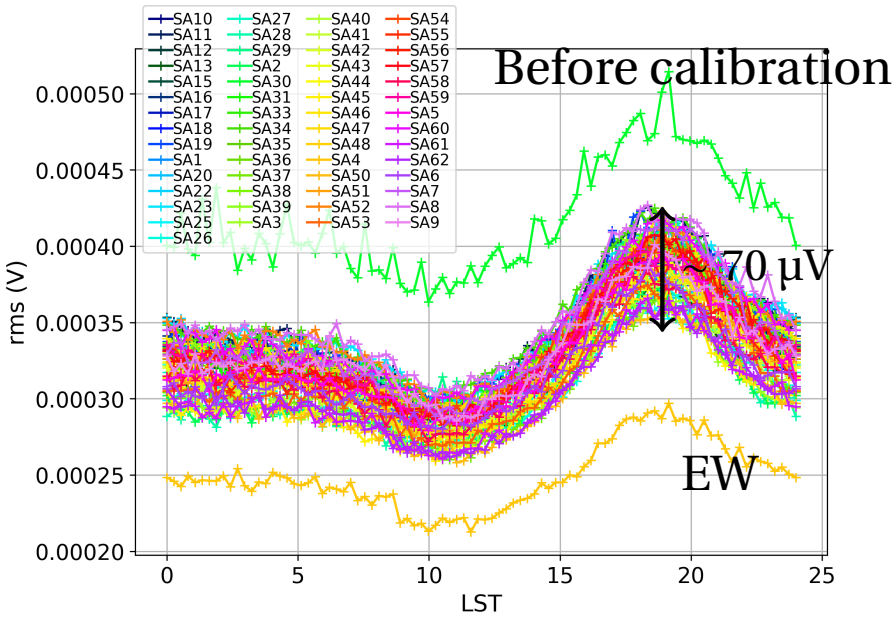


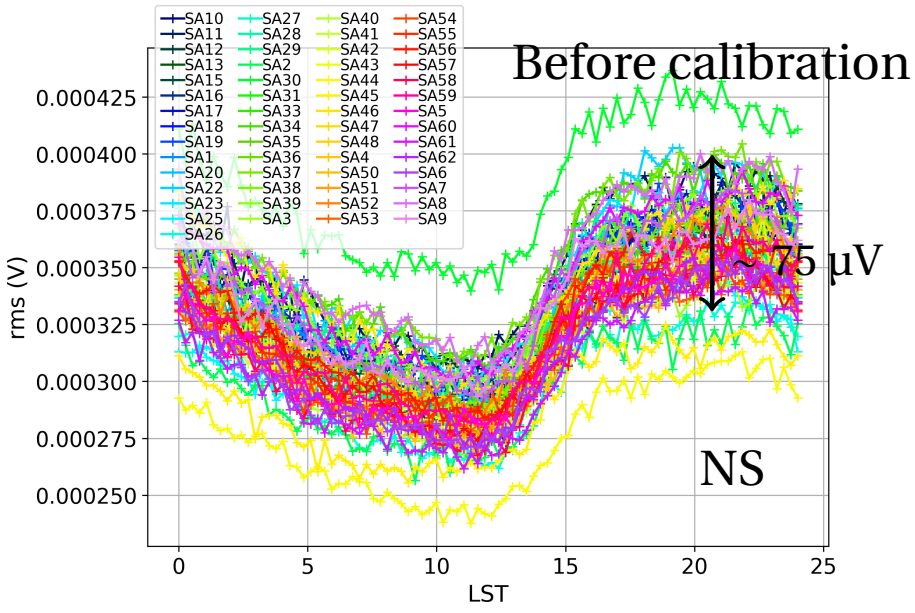


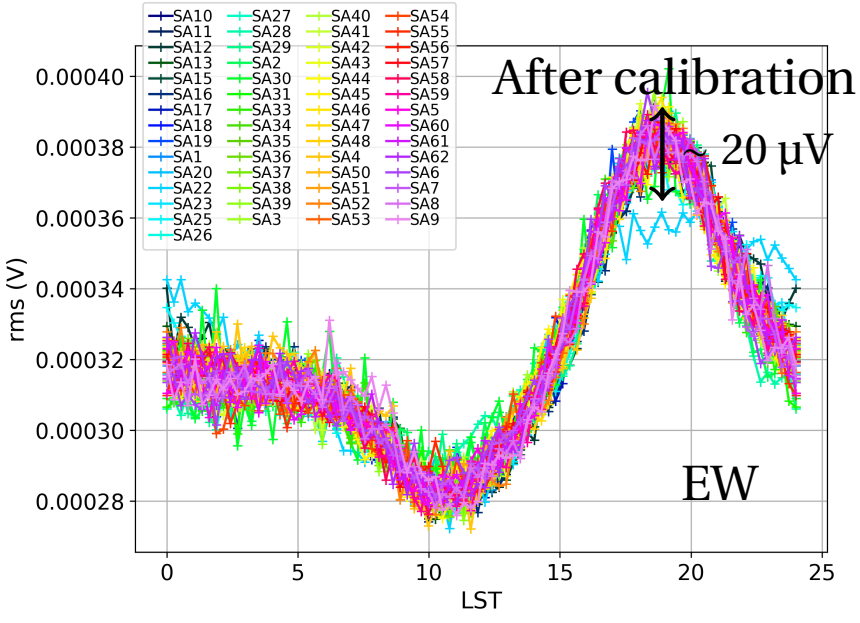


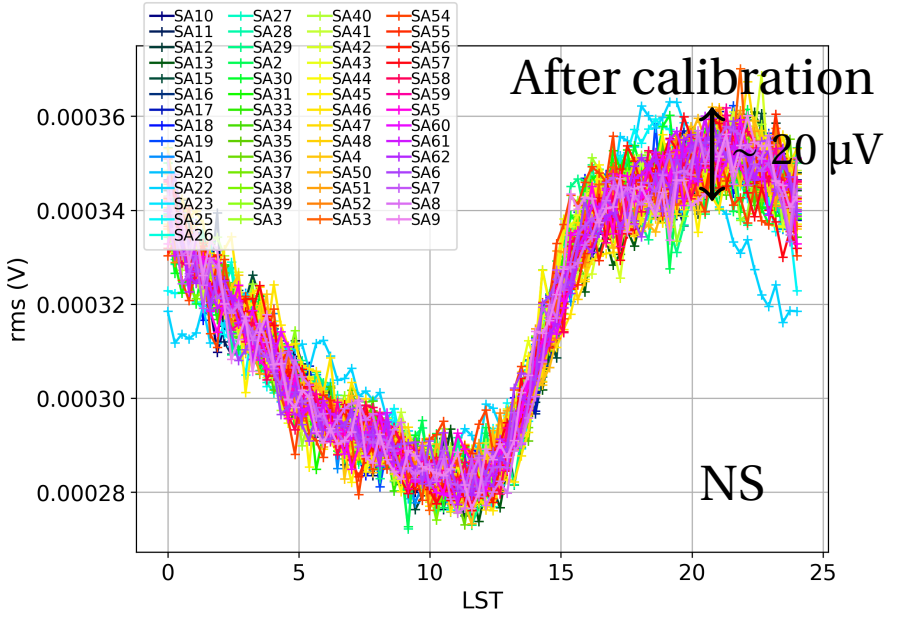


Calibration of the SA







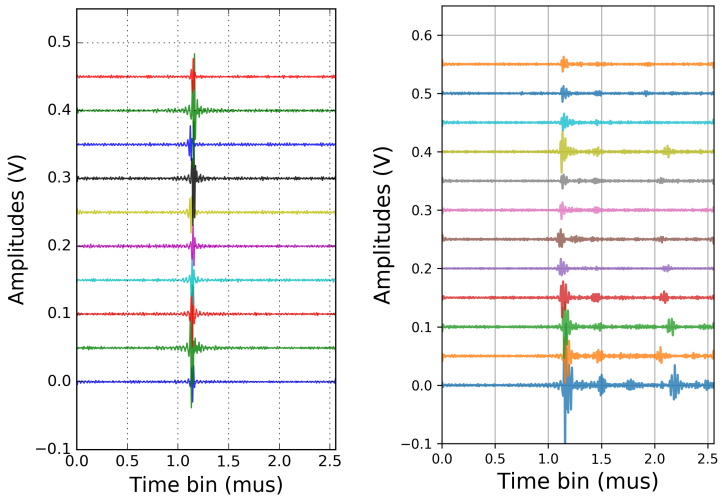


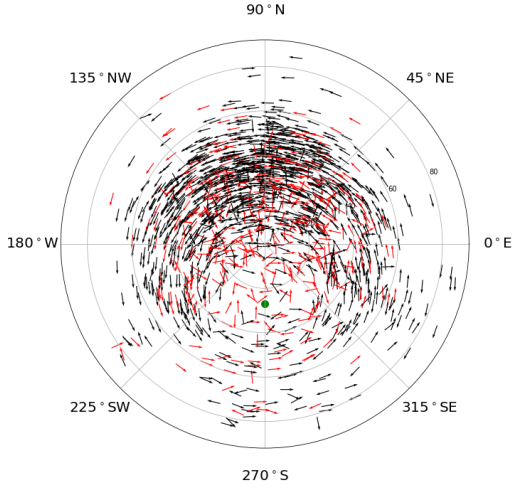
- Rise time: ~ 10 nanoseconds

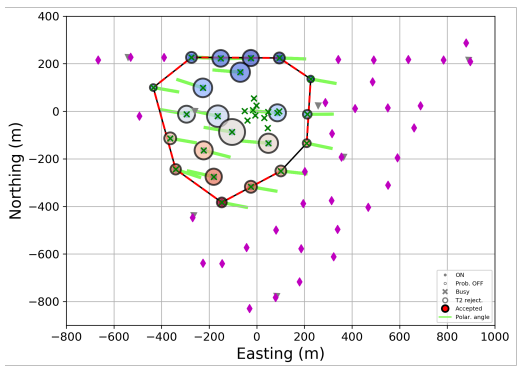
- Polarizations: relative contribution of both mechanisms + fortuitous, presence of abnormal atmospheric electric field

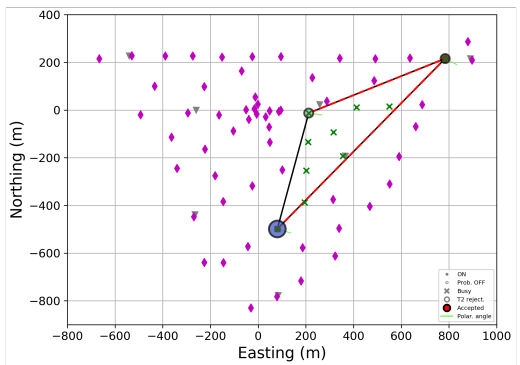
- Compacity: regular pattern at ground for showers

- Test: 1 704 838 events recorded over 1 month ⇒ 701 (0.04 %) events selected, no cosmic ray event rejected (58 remaining)



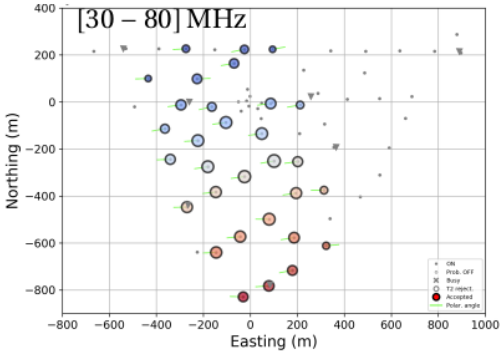


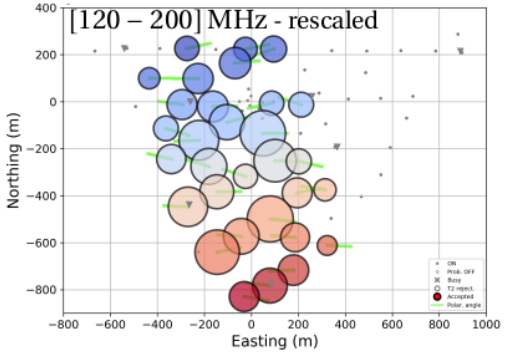


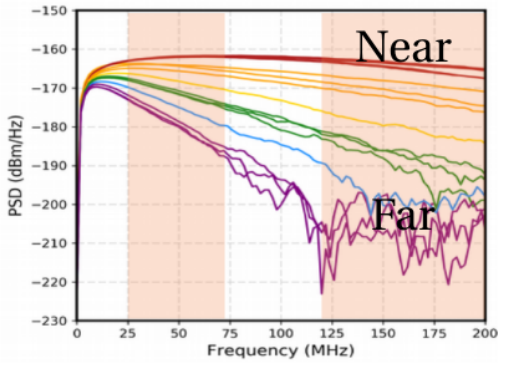


Importance of the [120 – 200] MHz region

Inclined event ($\theta = 55°$)







Work in progress

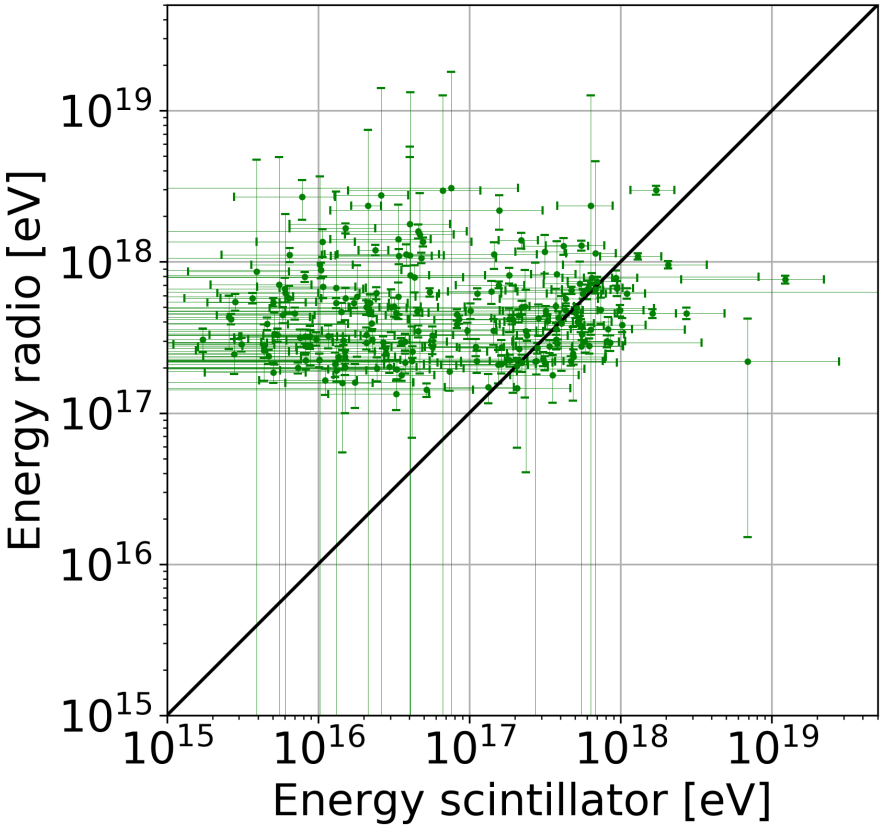
Radio-reconstruction of inclined event in [30 – 80] MHz difficult

Radio-reconstruction much better including the HF band: $\chi^2_{[30-200]} = \chi^2_{[30-80]}/3$

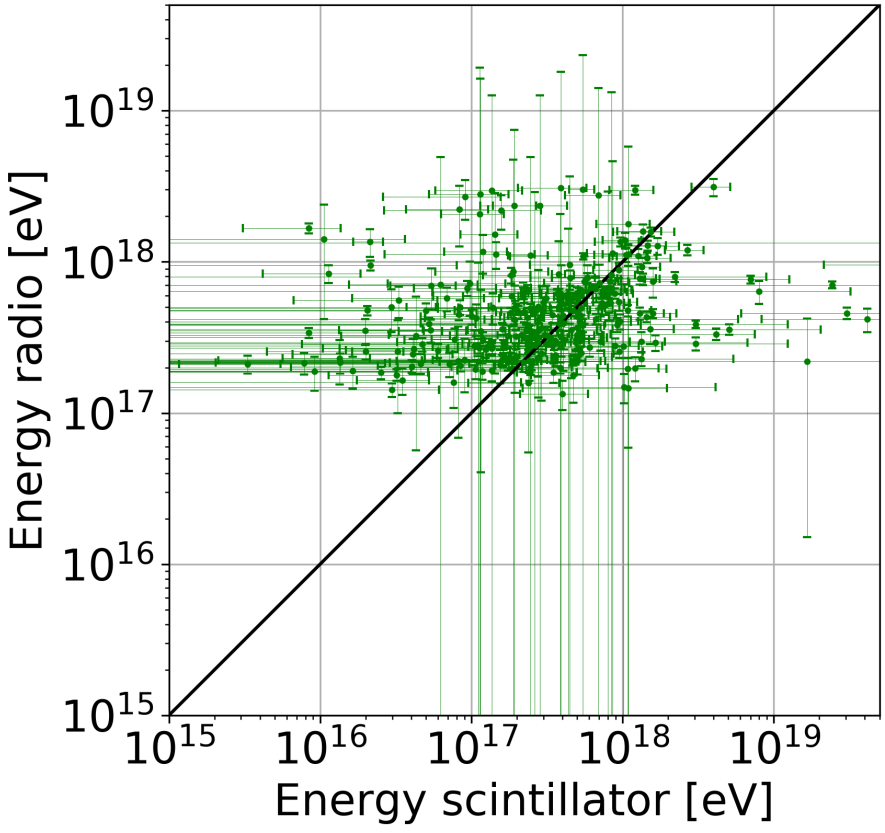
Continuity in the spectra, their content is precious ⇒ only CODALEMA can do that!

One-to-one correlation between E_{radio} and $E_{particles}$

$E_{particles}$ with (X_c, Y_c) particles

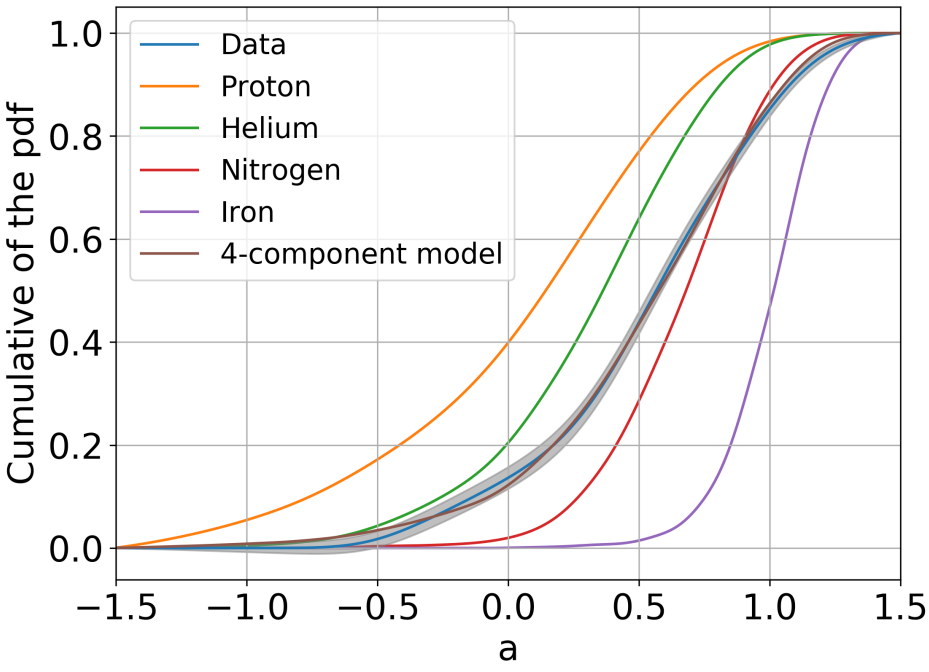


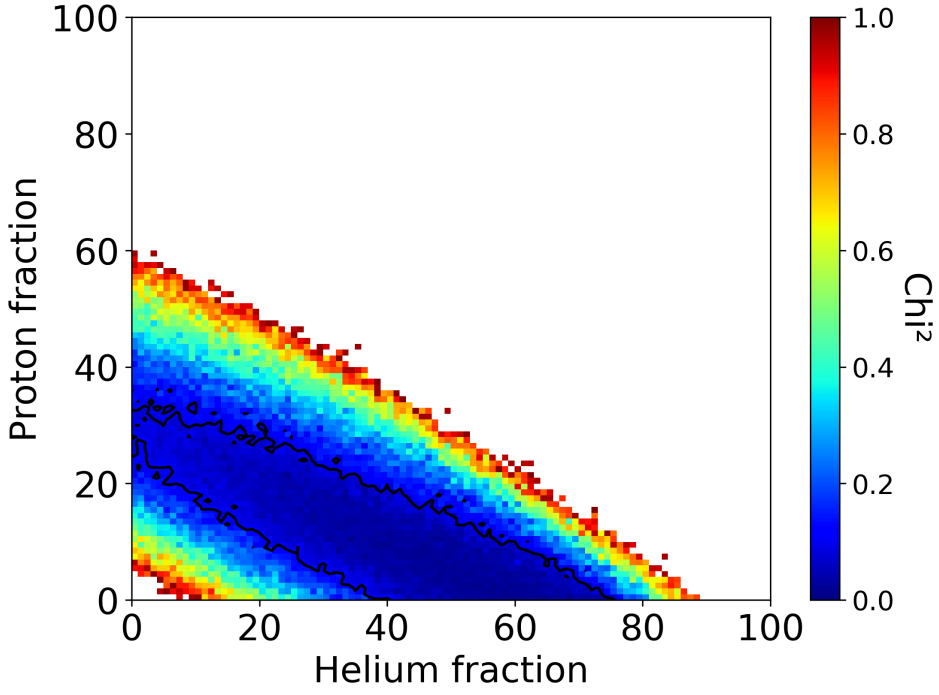
$E_{particles}$ with (X_c, Y_c) radio



Mass component proportion

Analysis "*a la LOFAR*", Nature vol-531, 2016





- $a = \frac{\langle X_{max}^{proton} \rangle - X_{max}}{\langle X_{max}^{proton} \rangle - \langle X_{max}^{iron} \rangle}$
- Use of EPOS-LHC
- Four component model tested: best fit with 1 % Protons, 50 % Helium, 33 % Nitrogen and 16 % Iron
- Systematic uncertainties and improvement of the statistical analysis in progress