A study of radio frequency spectrum emitted by high energy air showers with LOFAR

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on behalf of the Cosmic Ray Key Science Project

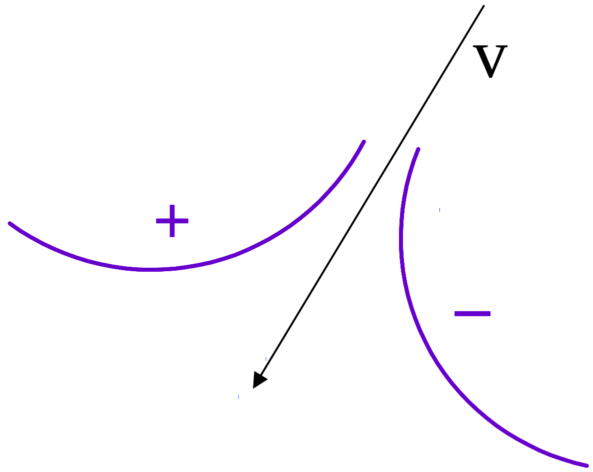
LOFAR Science Workshop, Zandvoort aan Zee, April 5th 2016

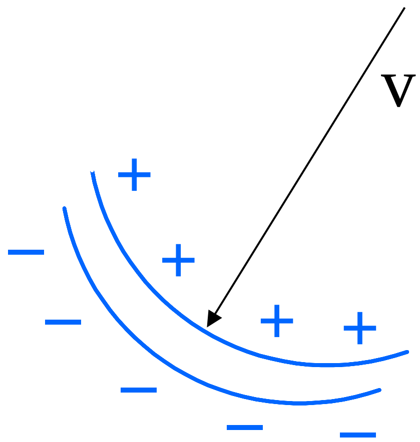
Cosmic ray radio emission

→ **Geomagnetic synchrotron emission**

→ **Charge excess emission (Askarian effect)**

negative charge excess produced in the shower front





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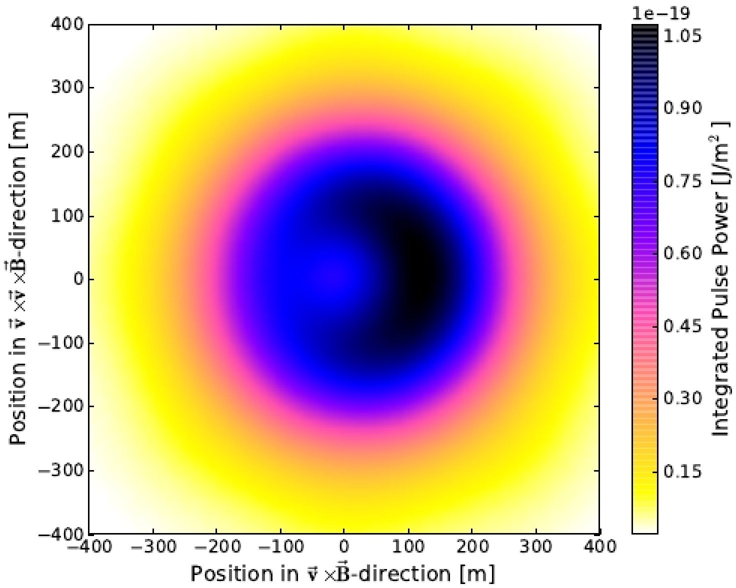
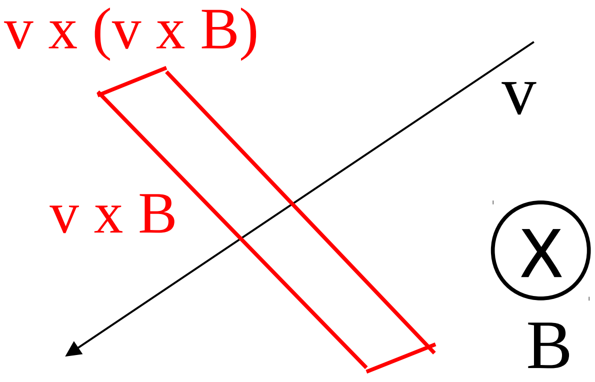
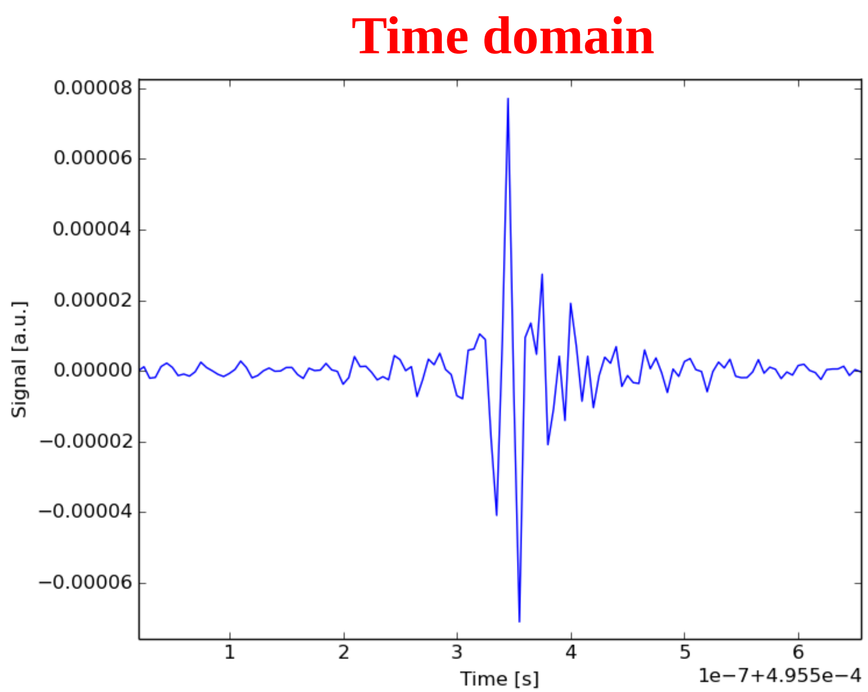


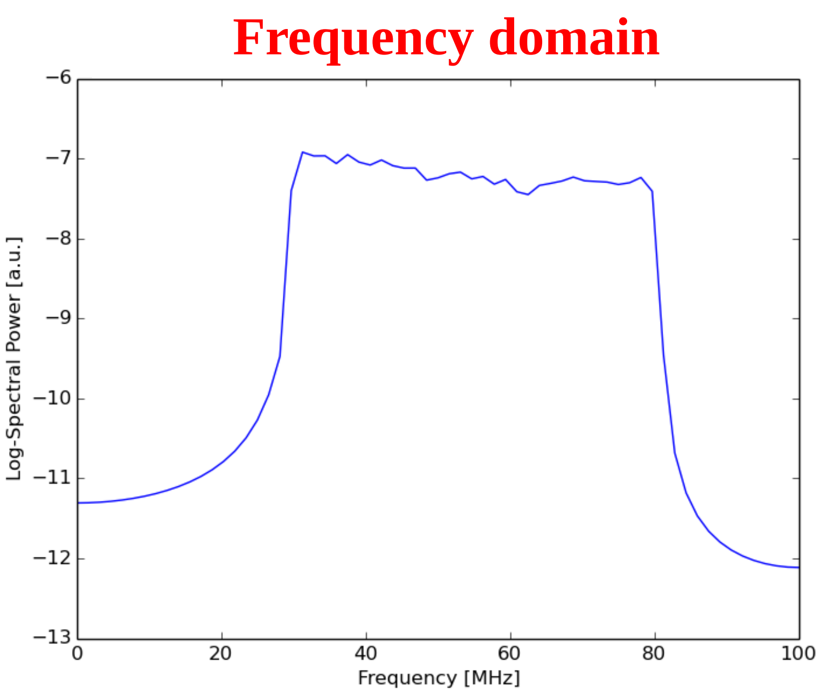


v = shower axis

B = Earth magnetic field vector

Frequency spectrum study



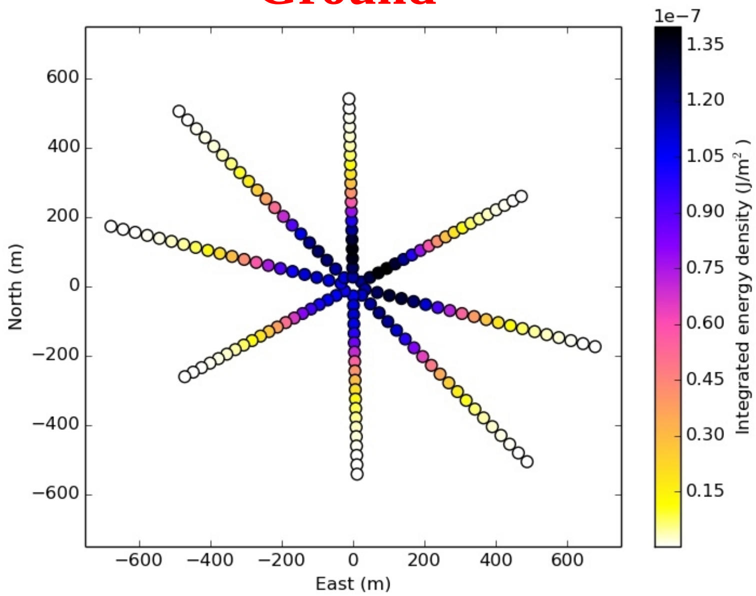


- **Is it possible to extrapolate information about primary particles by studying radio signals in the frequency domain ?**

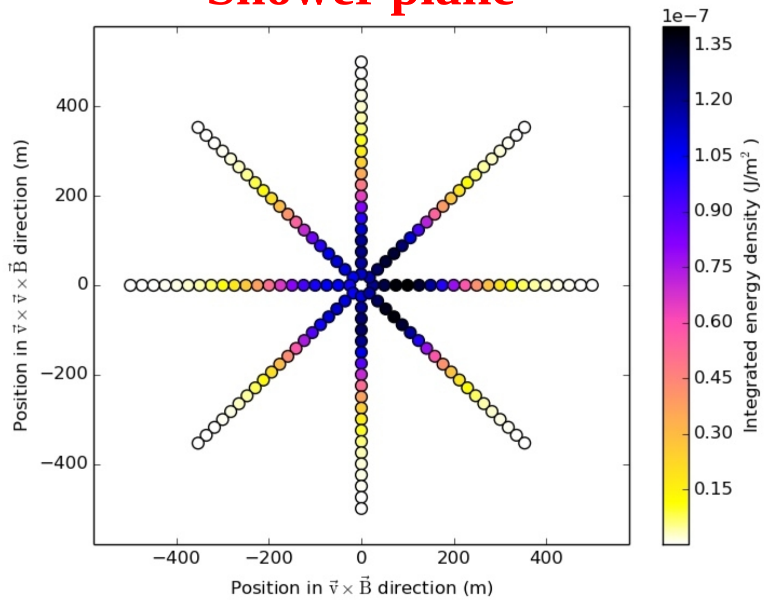
- **Set of simulated showers initiated by PROTONS and IRON nuclei (initial parameters: energy and arrival direction from real data)**

Frequency spectrum study

Ground



Shower plane



- **Is it possible to extrapolate information about primary particles by studying radio signals in the frequency domain ?**

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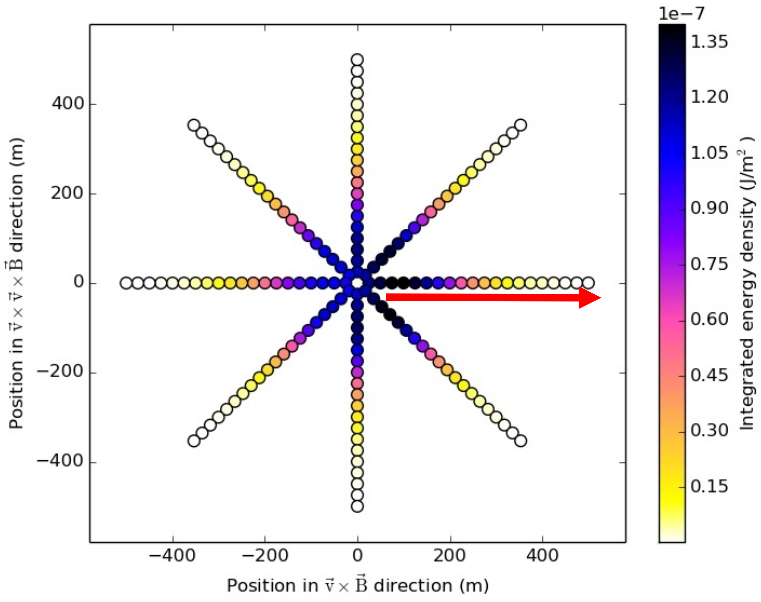
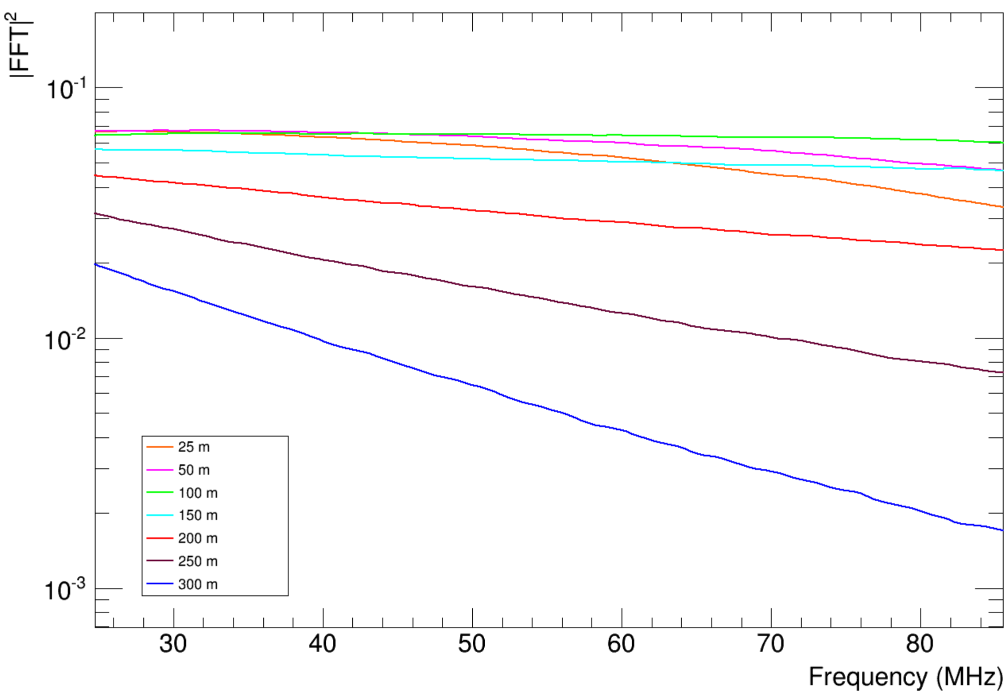
Frequency spectrum study: simulations



How does the frequency spectrum change as a function of distance to the shower axis ?

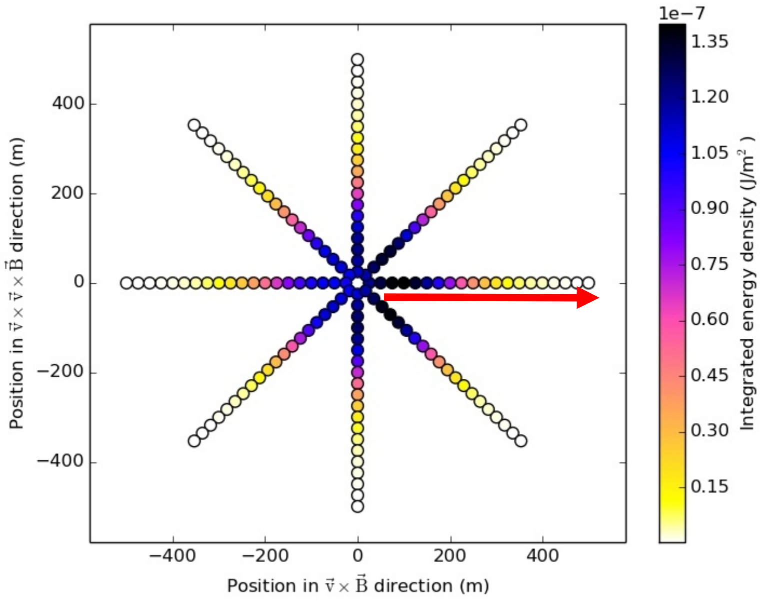


Particle type: **PROTON**

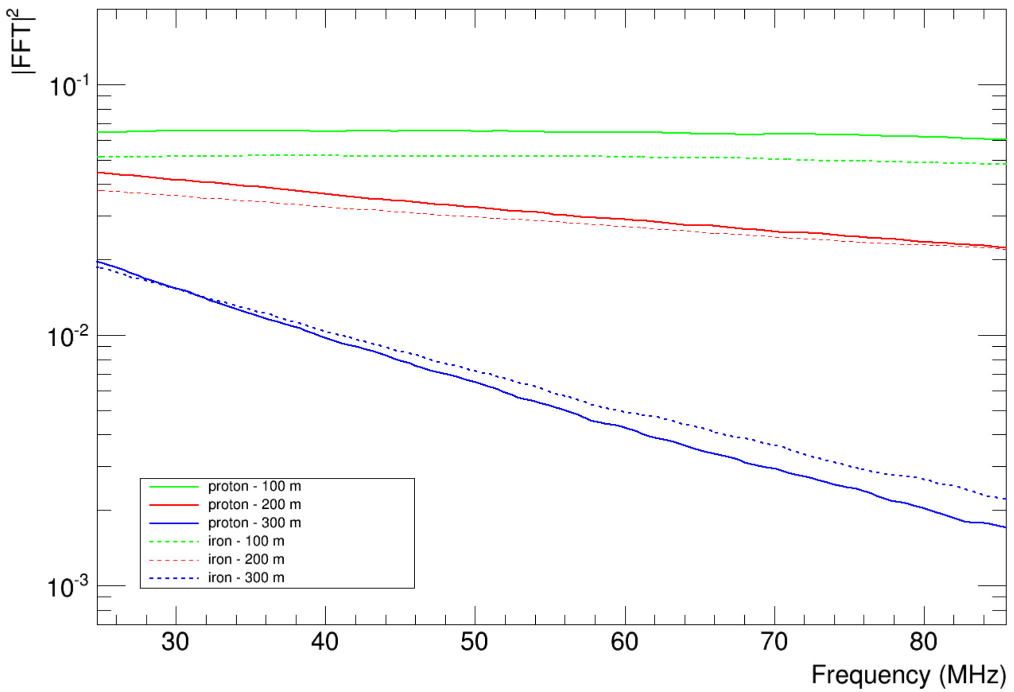
Energy = **$1.7 \cdot 10^{17}$ eV**

$[\theta, \varphi]$ = **[45.25°, 304.2°]**

Frequency spectrum study: simulations



How does the frequency spectrum change as a function of distance to the shower axis and mass composition ?



Particle types:

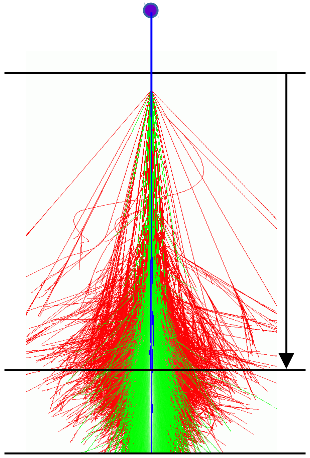
PROTON → X_{max} = **764.43 g/cm²**

IRON → X_{max} = **715.34 g/cm²**

Energy = **$1.7 \cdot 10^{17}$ eV**

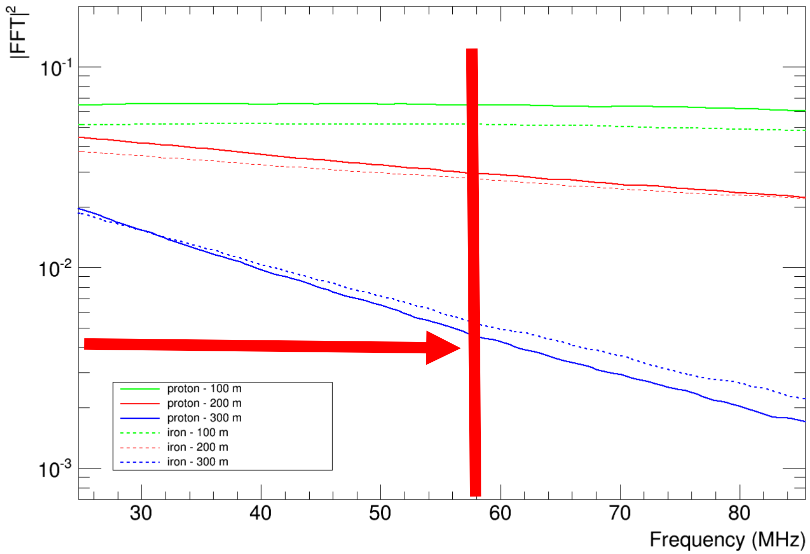
$[\theta , \varphi]$ = **[45.25° , 304.2°]**

Frequency spectrum study: simulations



→ X_{max} increases with energy

→ for a fixed energy,
$X_{max}(p) > X_{max}(Fe)$



- **Finding a variable which describes the frequency spectrum :**

  → **frequency of the 50th percentile**

  → **parameters of a fitted function**

Comparison simulations – real data

Distribution of the **50th percentile frequency**:

Background → simulations

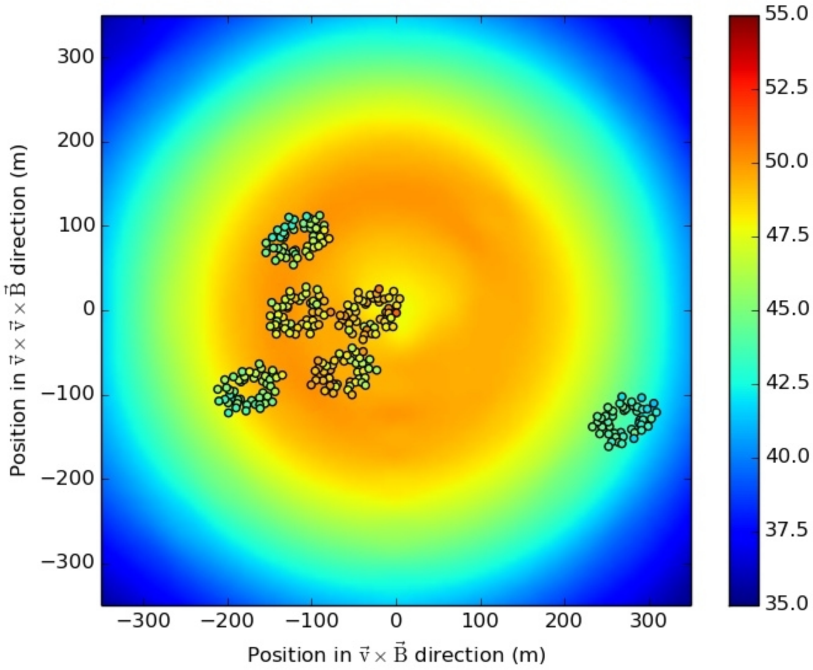
Circles → antennas of LOFAR stations

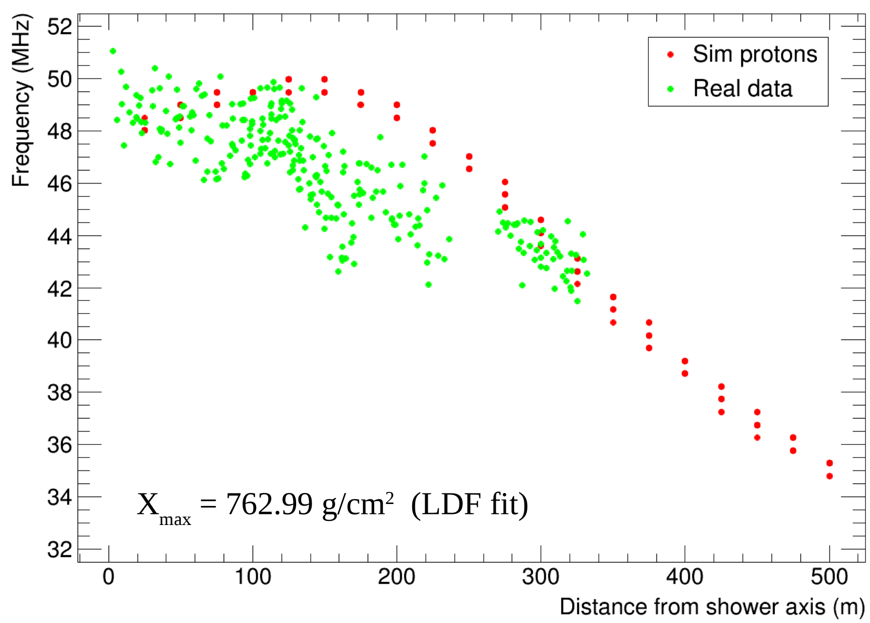
Simulations INFO:

Energy = **$1.7 \cdot 10^{17}$ eV**

Arrival direction [θ , φ] = **[45.25° , 304.2°]**

PROTONS → X_{max} = **660.24 g/cm²**





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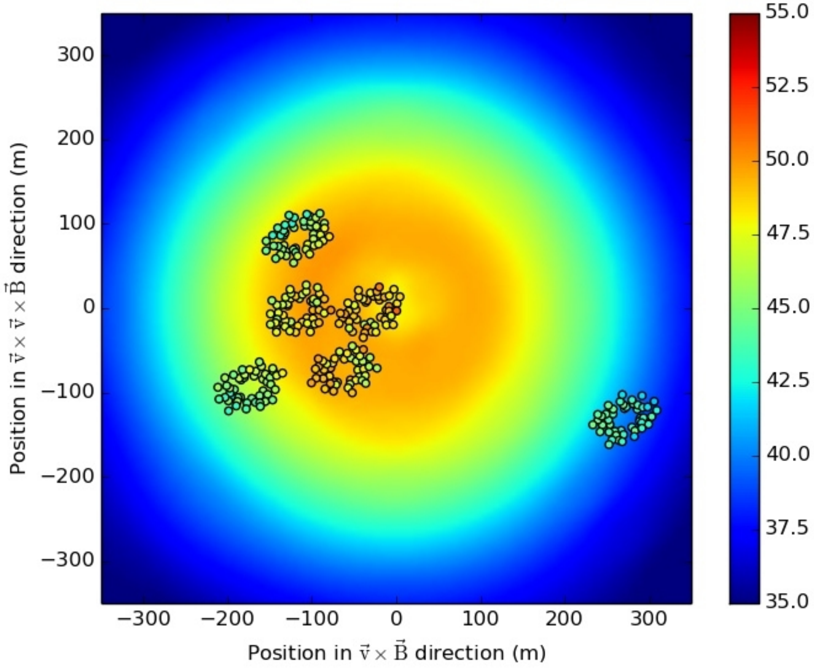
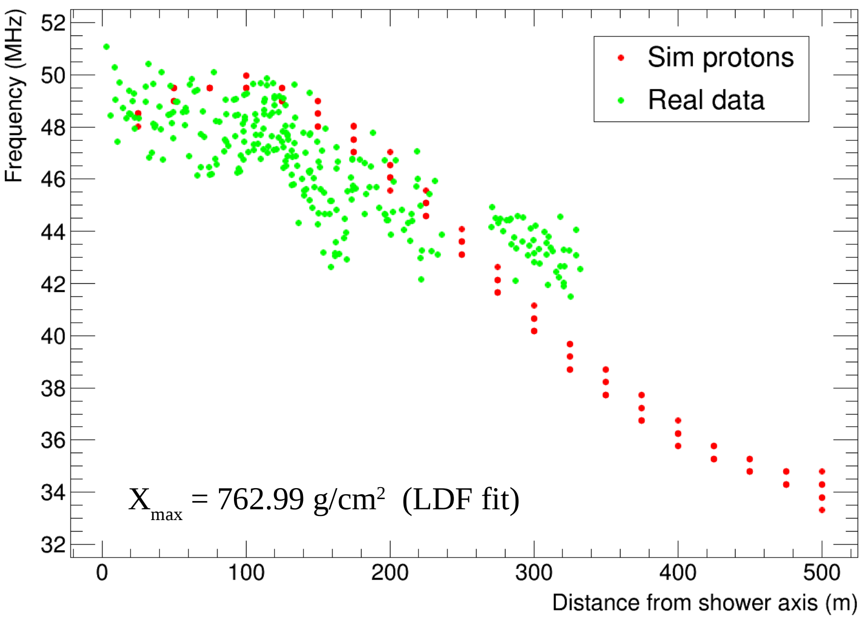
Energy = **$1.7 \cdot 10^{17}$ eV**

Arrival direction [θ , φ] = **[45.25° , 304.2°]**

PROTONS → X_{max} = **907.20 g/cm^2**





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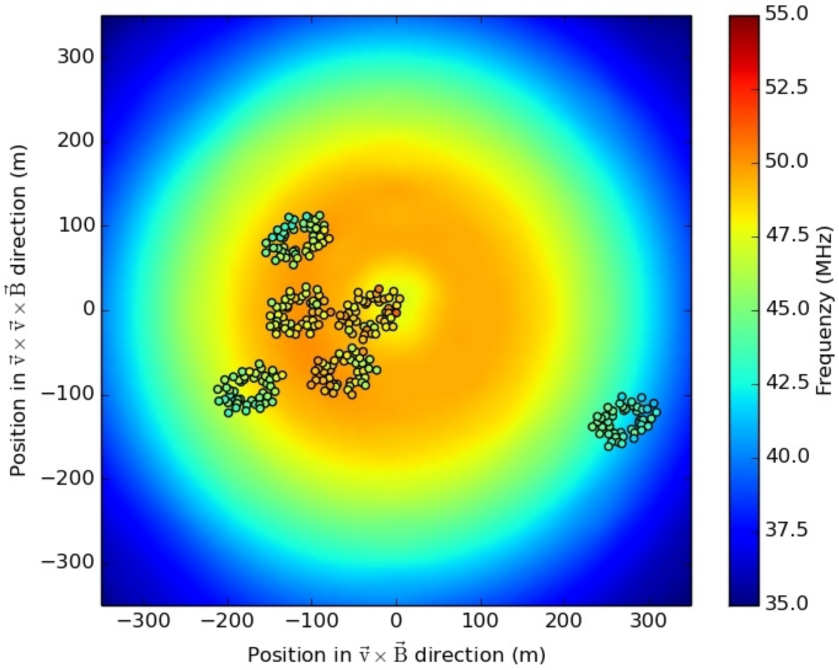
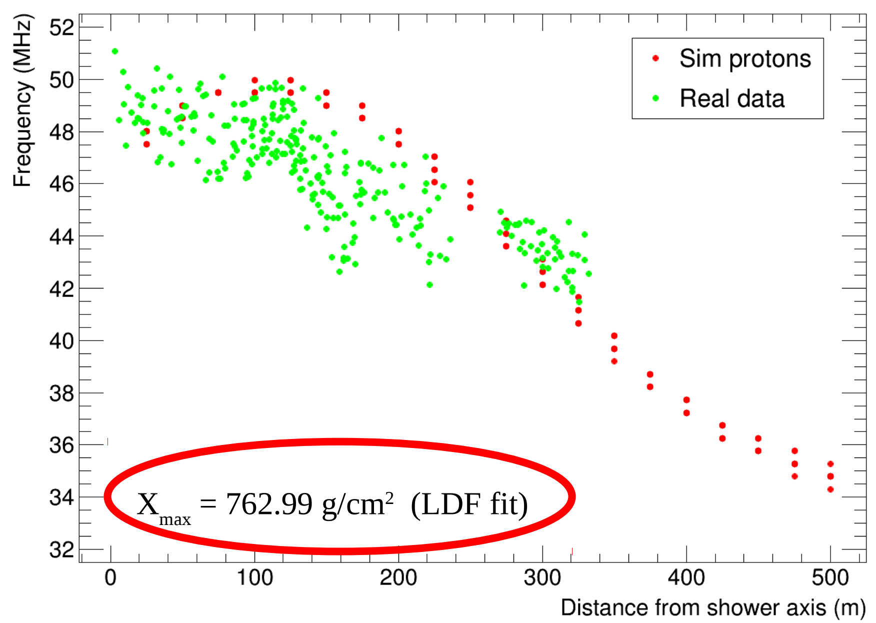
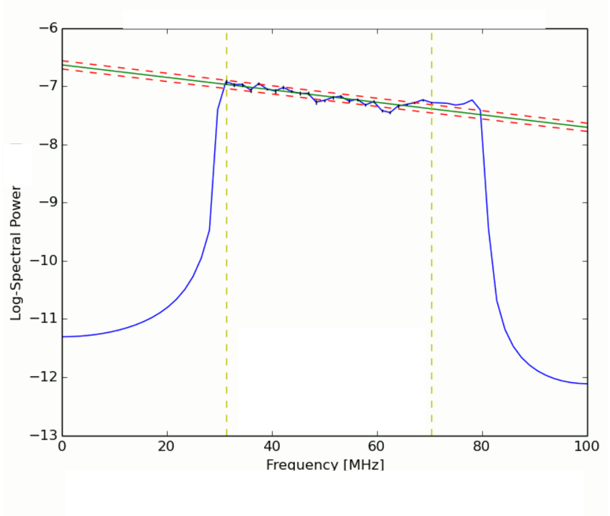




Analysis on real data

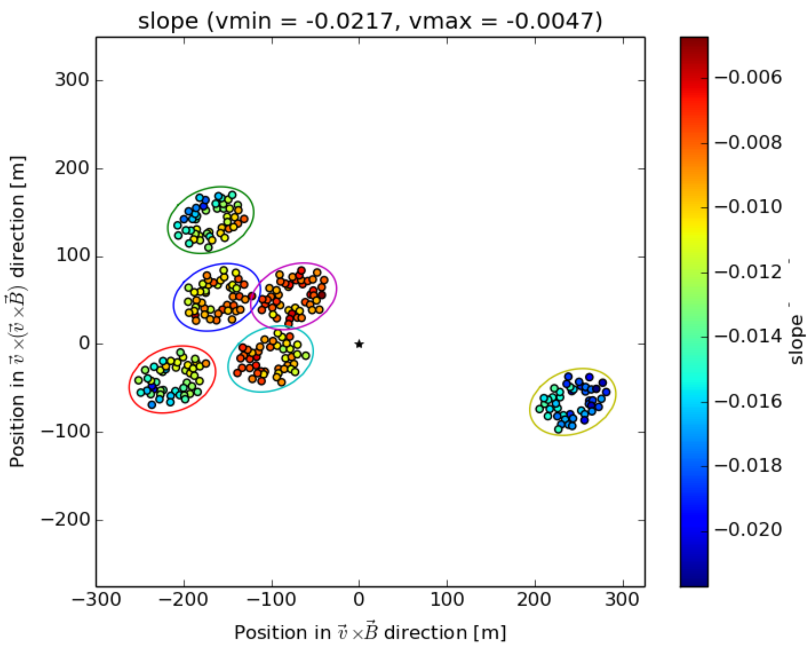


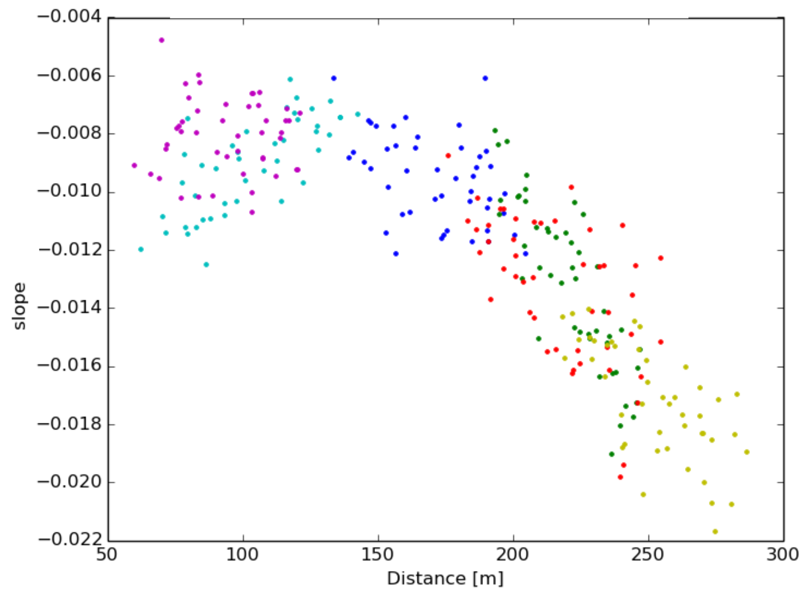
Study the parameters of a fitted function

Log(FFT) = a + b · frequency

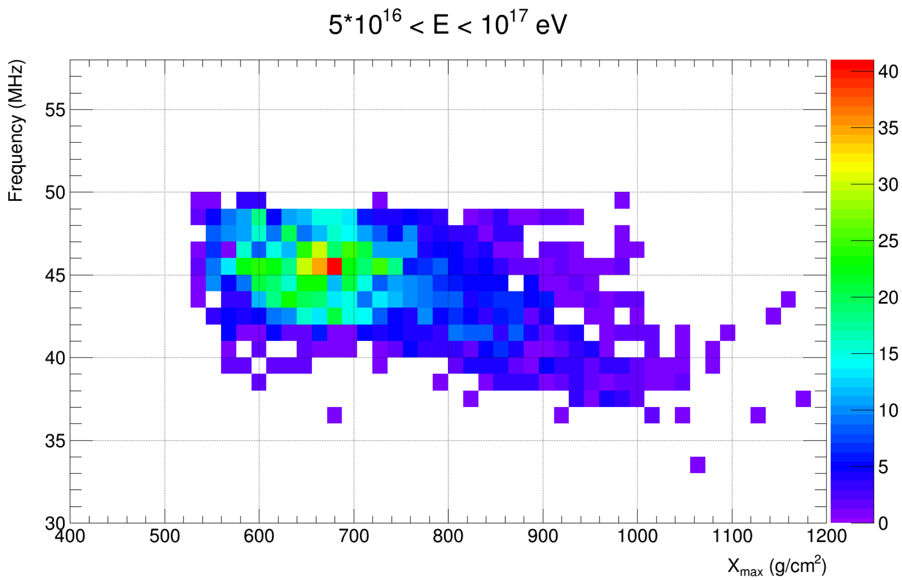
Energy = **$1.7 \cdot 10^{17}$ eV**

Arrival direction [θ , φ] = **[45.25° , 304.2°]**

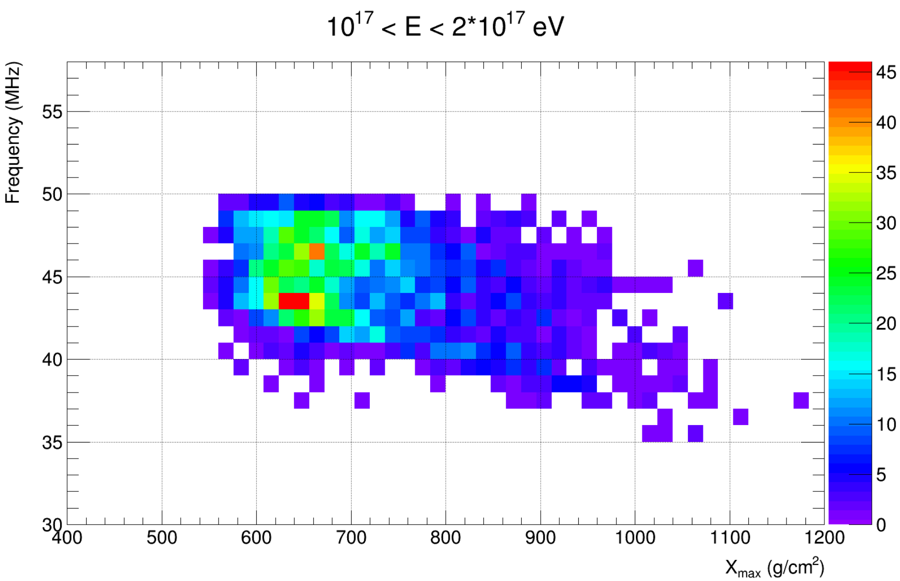


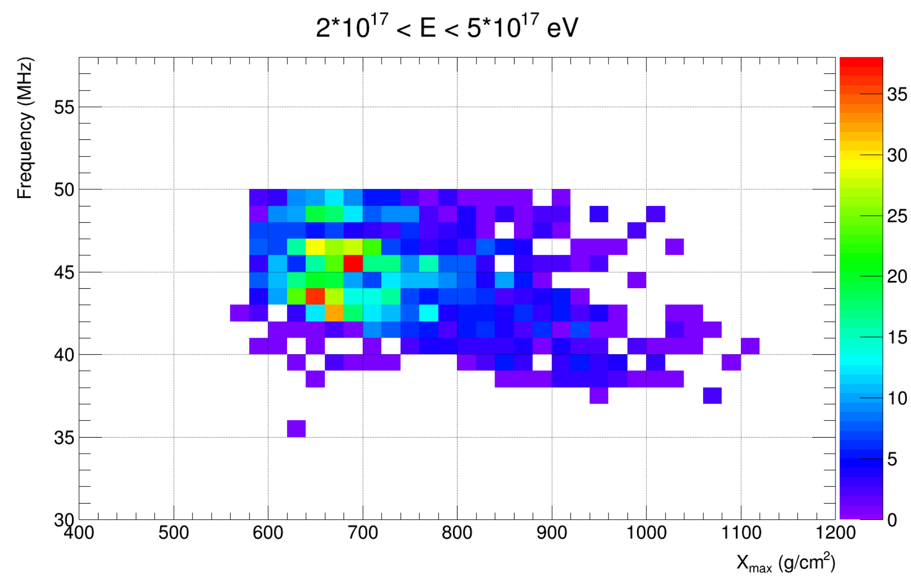


Simulation study: X_{max} dependence?



Distribution of the 50th percentile frequency (30 – 70 MHz) as function of X_{max} for PROTONS at 200 m from the shower axis





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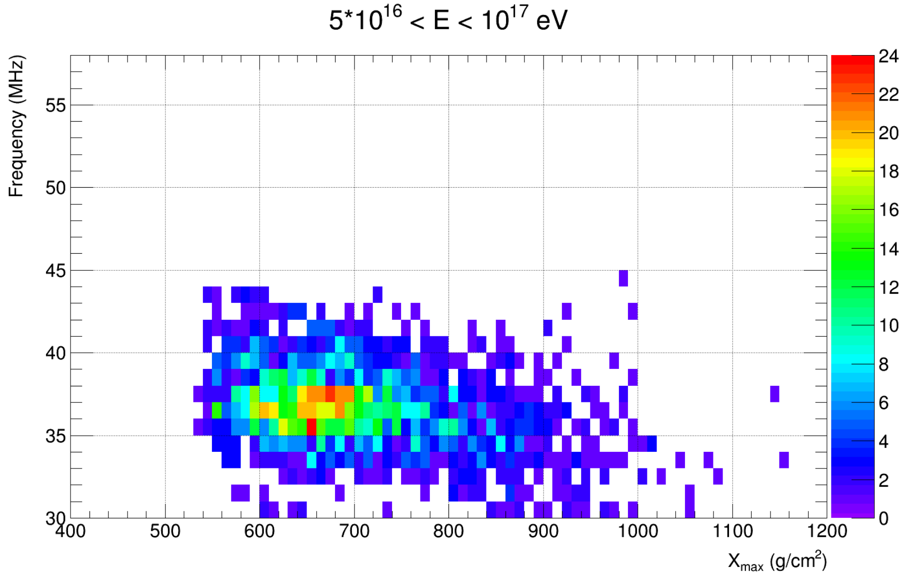
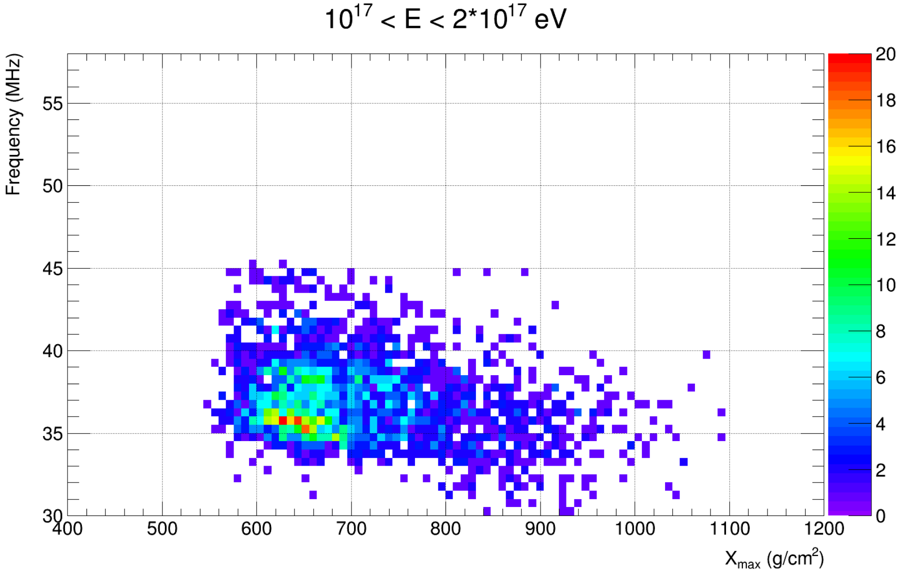
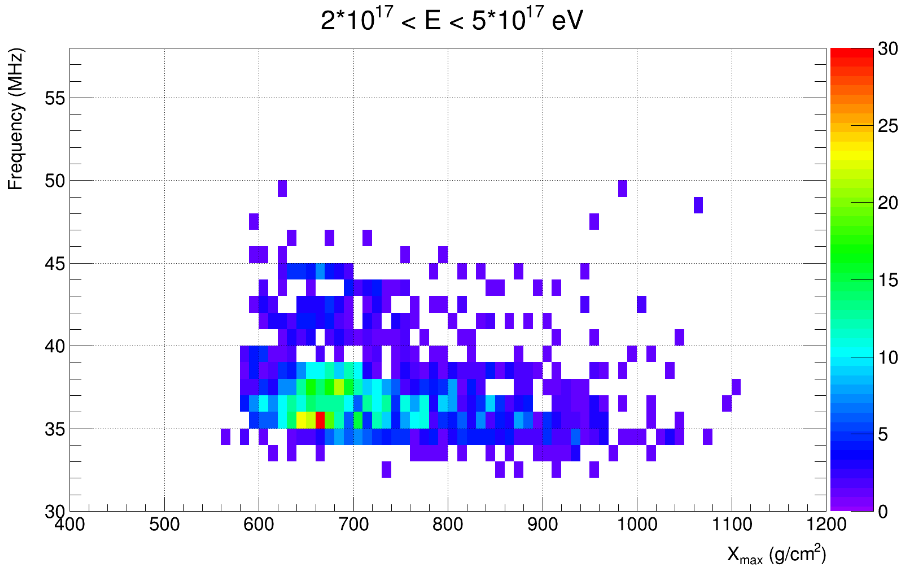


Distribution of the 50th percentile frequency (30 – 70 MHz) as function of X_{max} for PROTONS at 350 m from the shower axis





Conclusions and outlook

- Study of the frequency spectrum on simulated events and real data
- the percentile method allows to find :

  → a strong dependence of the frequency spectrum as function of distance to the shower axis

  → a slight dependence on X_{max}

- WORK in PROGRESS :
  → analysis on simulations and real data by studying the fitted function of the FFT and comparison with results obtained by using the percentile method

Spare slides

Comparison simulations – real data

Distribution of the **50th percentile frequency**:

Background → simulations

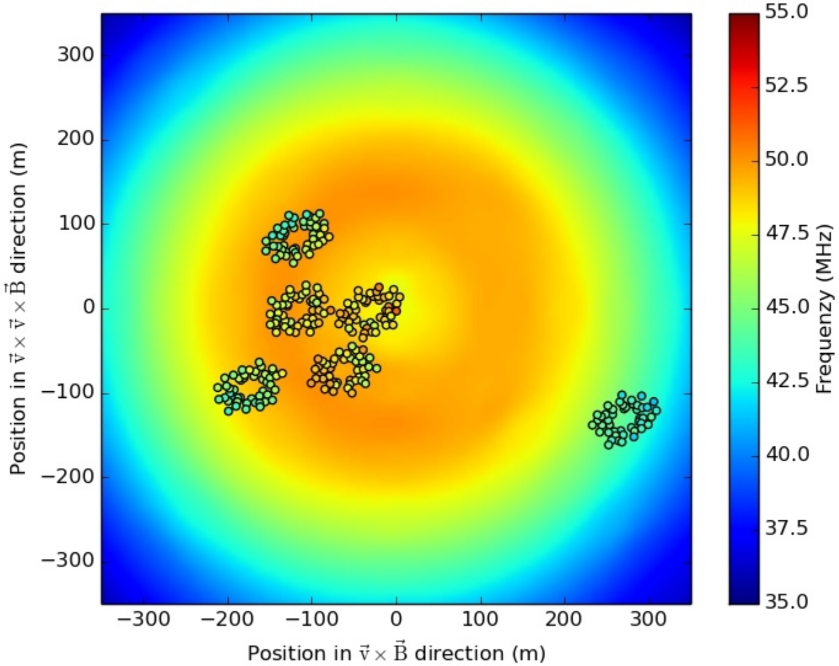
Circles → antennas of LOFAR stations

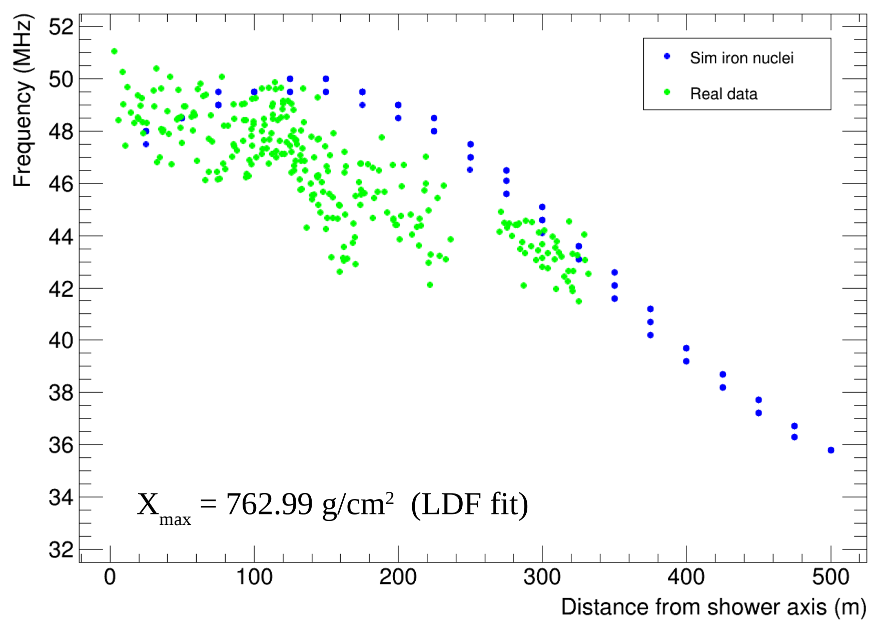
Simulations INFO:

Energy = **$1.7 \cdot 10^{17}$ eV**

Arrival direction [θ , φ] = **[45.25° , 304.2°]**

IRON → X_{max} = **616.37 g/cm²**





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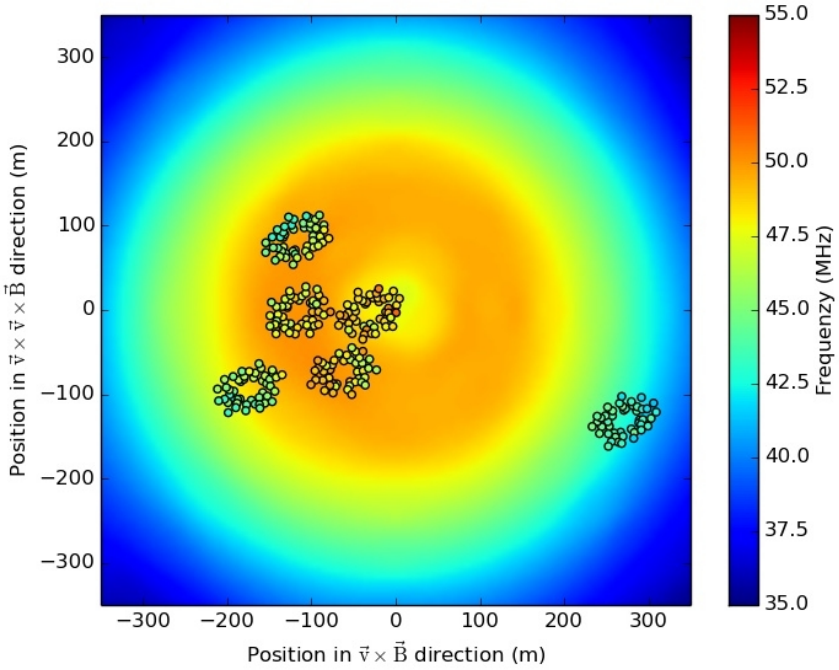
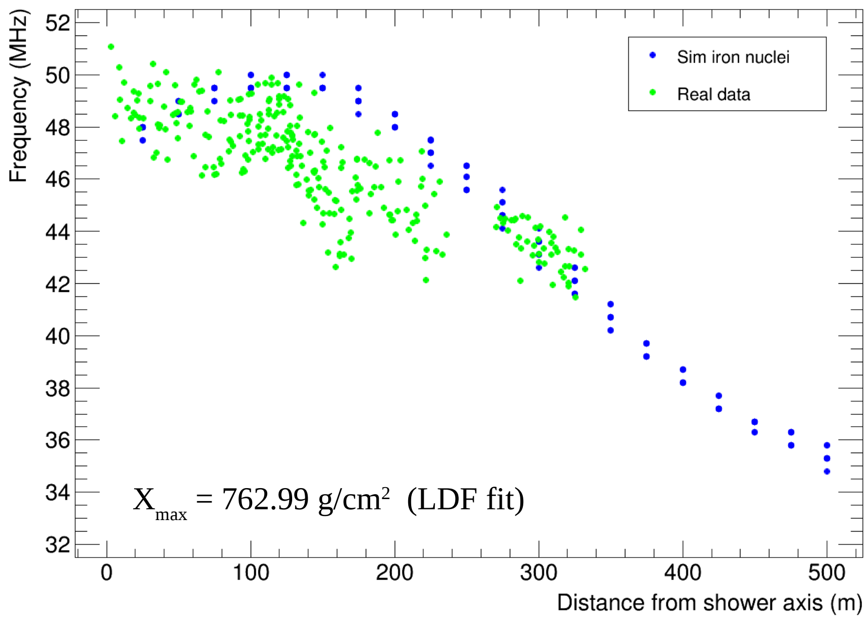
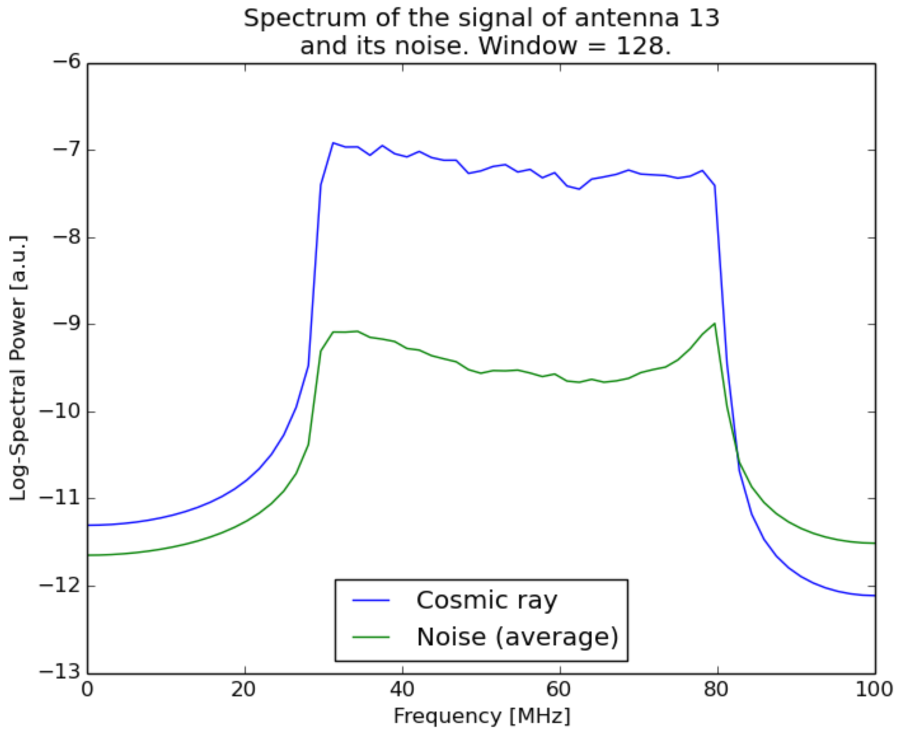
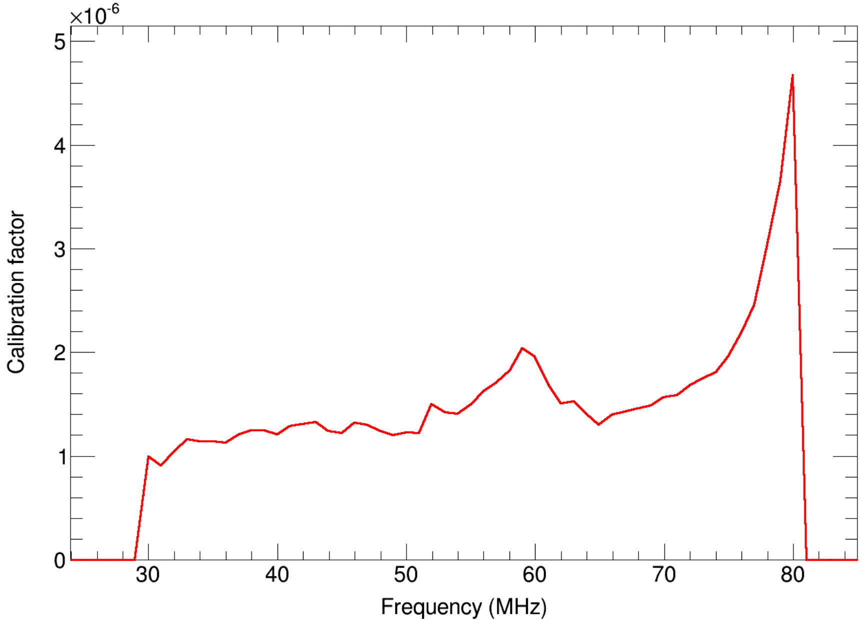





Spectrum of the signal of antenna 13
and its noise. Window = 128.
Log-Spectral Power [a.u.]
Frequency [MHz]
Cosmic ray
Noise (average)


×10^-6
Calibration factor
Frequency (MHz)