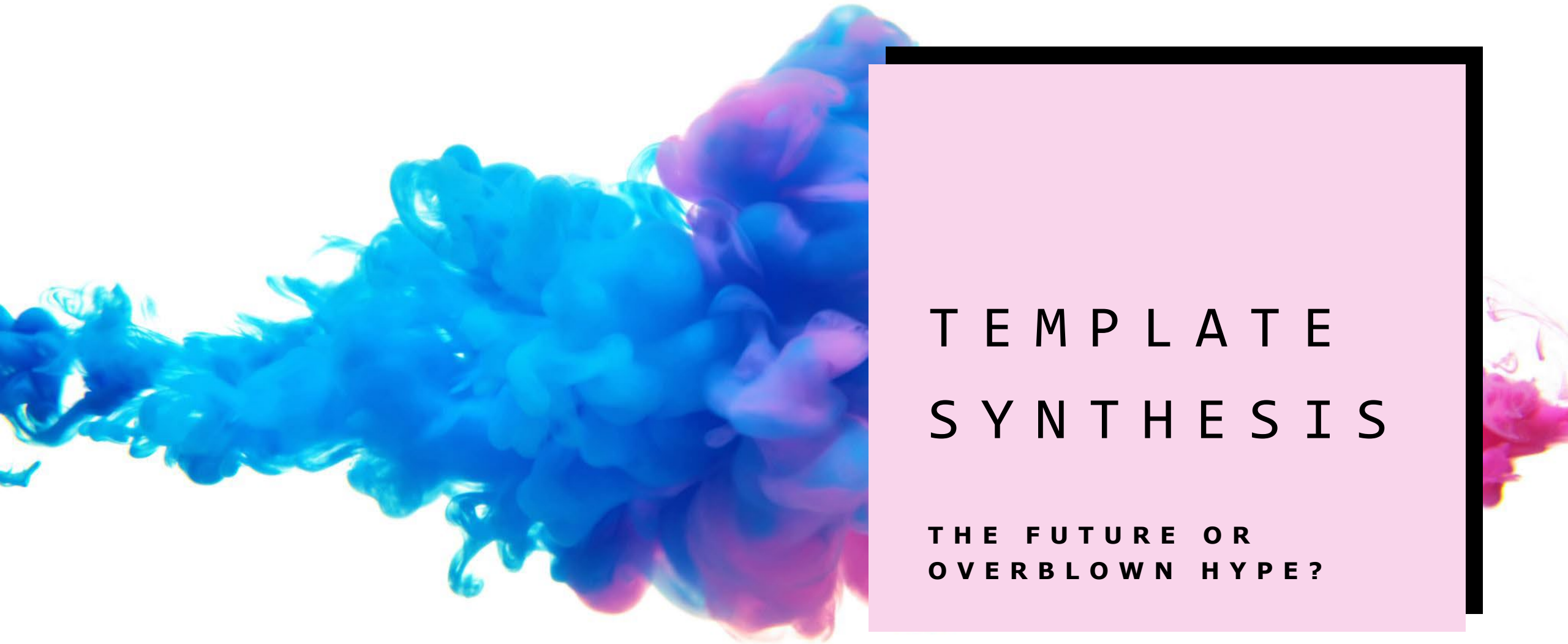


TEMPLATE SYNTHESIS

THE FUTURE OR OVERBLOWN HYPE?

WHY DO WE NEED TEMPLATE SYNTHESIS?

- Microscopic simulations of the radio emission from extensive air showers (EAS) are computationally expensive.
  - They scale with the “quality” we require
  - As well as the number of antenna’s
- Looking at the future, at LOFAR 2.0 and SKA, this approach becomes prohibitively expensive.

THE FIRST STEPS HAVE ALREADY BEEN TAKEN: FIXED GEOMETRIES

- Last year we published our first result of template synthesis, showing that the method works for vertical EAS (Arxiv: 2307.02939).
  - The synthesised electric fields agreed with CoREAS simulations within 6%, in amplitude.
- The method could easily be applied to other geometries as well.
  - At ICRC, I presented a poster which showed the results for 45 degree zenith.
  - By now, I have also tested other zenith angles (20, 30 and 40 degrees).

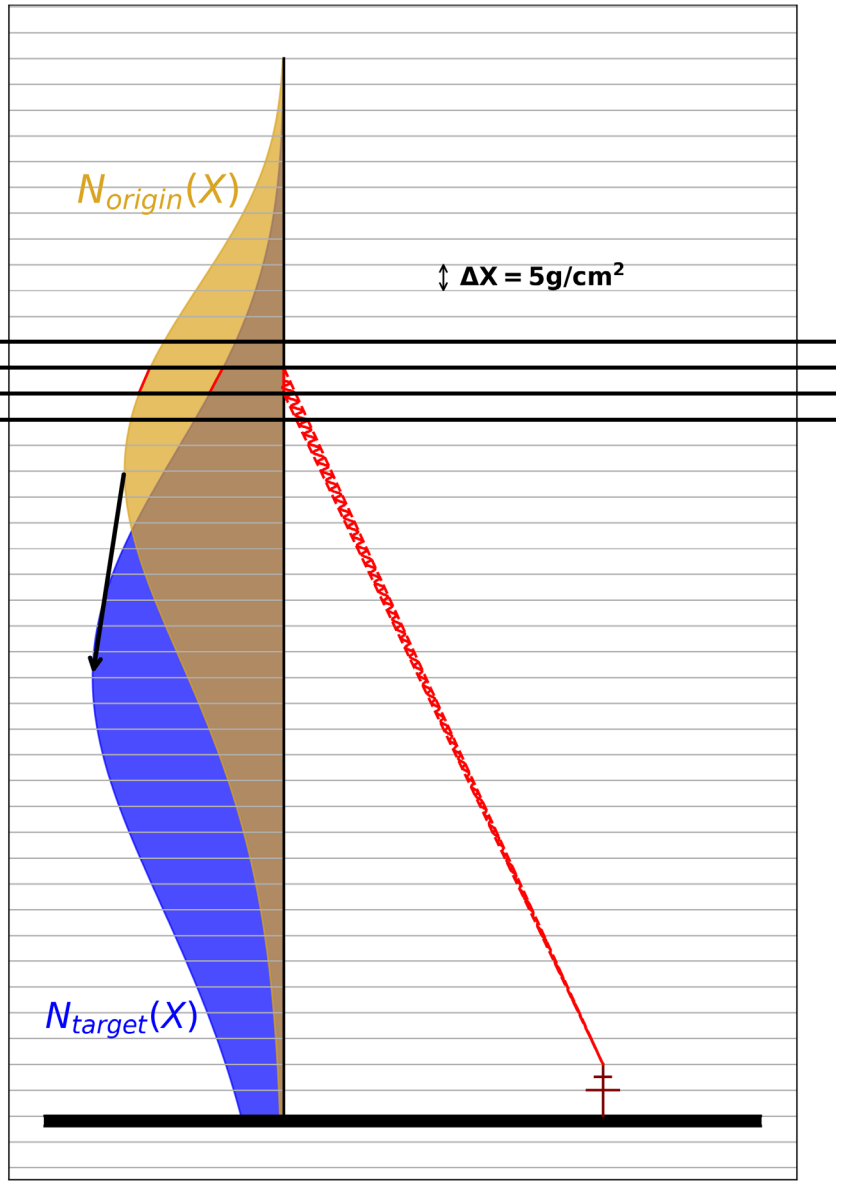


THE TEMPLATE SYNTHESIS METHOD

"DIVIDE AND CONQUER"

TEMPLATE SYNTHESIS CONSIDERS SLICES OF THE ATMOSPHERE AS POINT SOURCES

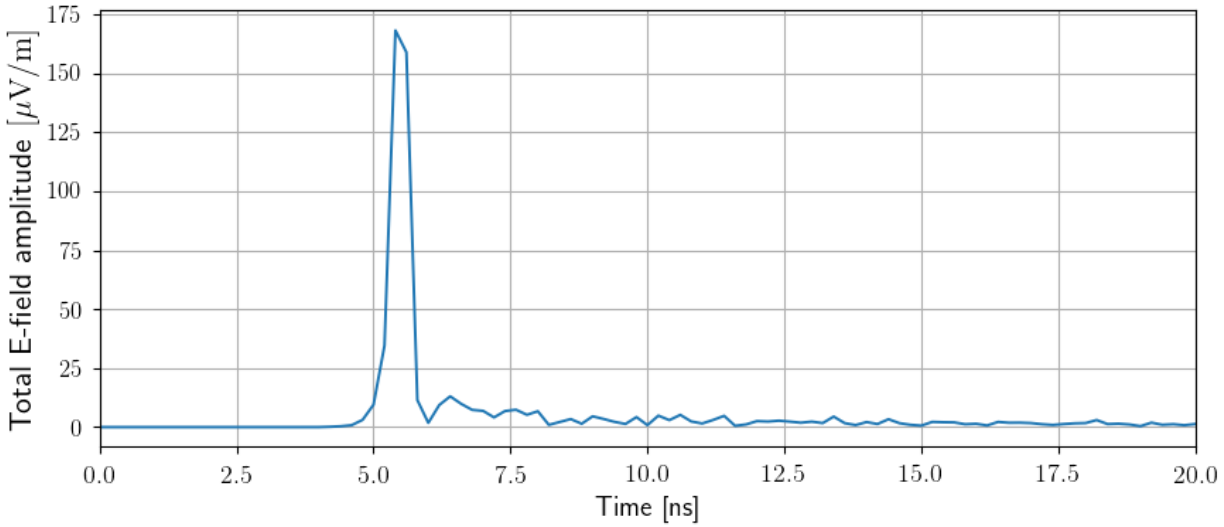
Instead of parametrizing the total emission, we look at the emission coming from atmospheric slices with constant atmospheric depth.

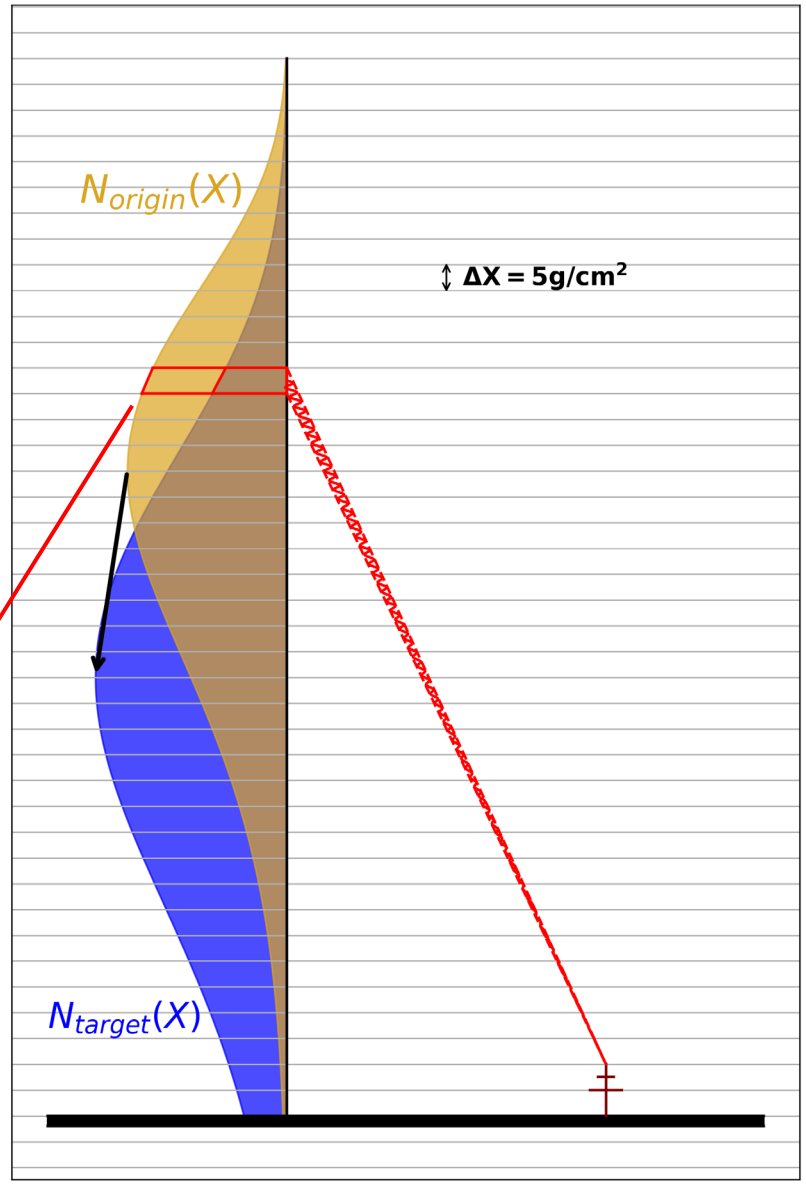


TEMPLATE SYNTHESIS CONSIDERS SLICES OF THE ATMOSPHERE AS POINT SOURCES

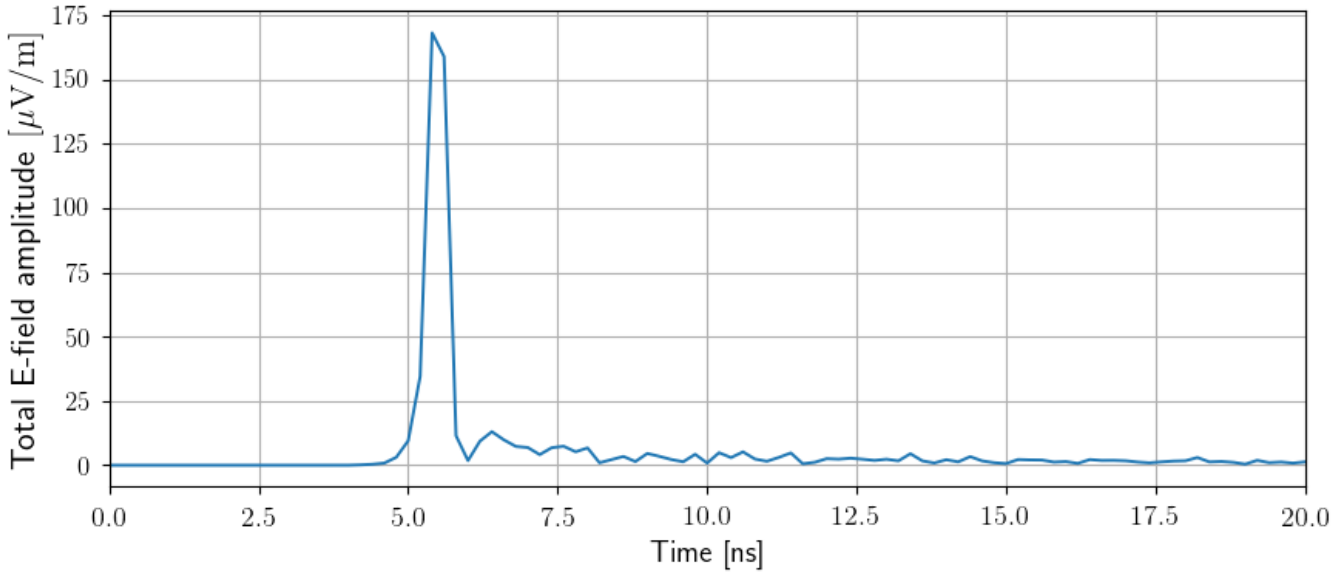
Instead of parametrizing the total emission, we look at the emission coming from atmospheric slices with constant atmospheric depth.

- The emission from a slice depends on the number of particles in it, N_slice, as well as the age of the shower in that slice.

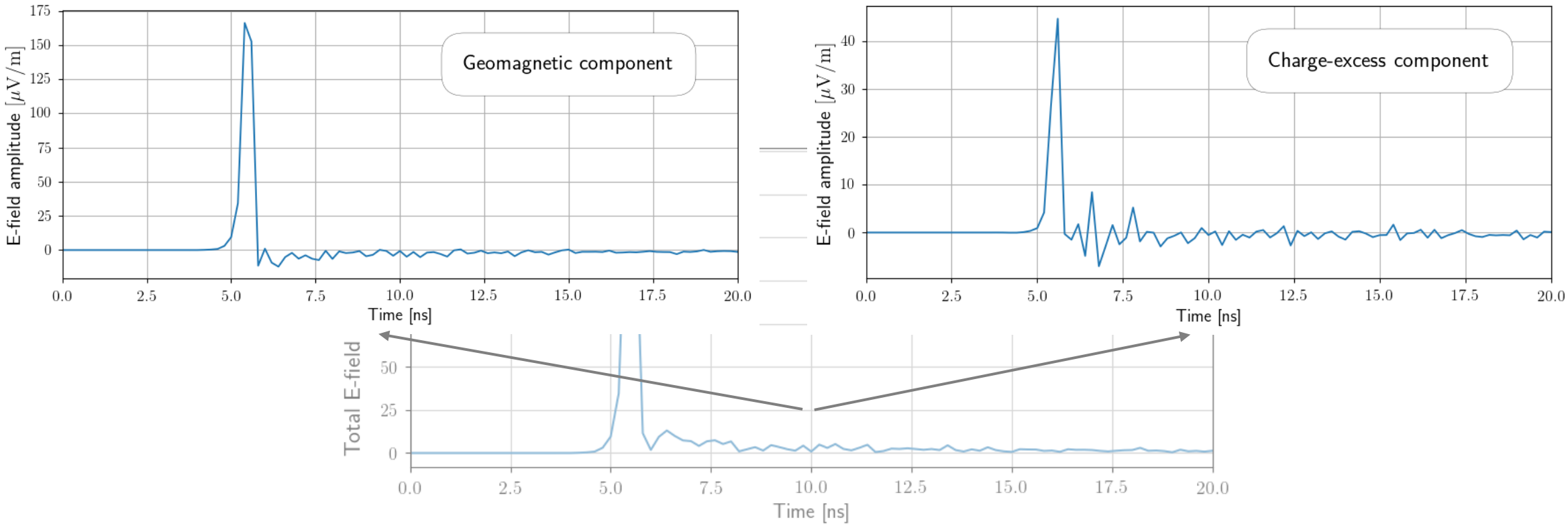




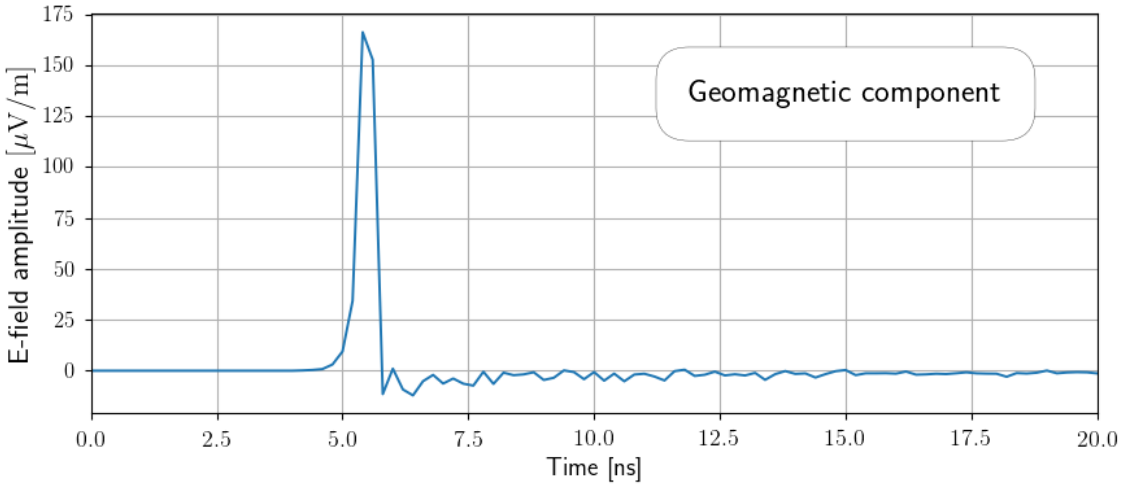
WE CHARACTERISE THE EMISSION COMING FROM EVERY SLICE, IN EACH ANTENNA

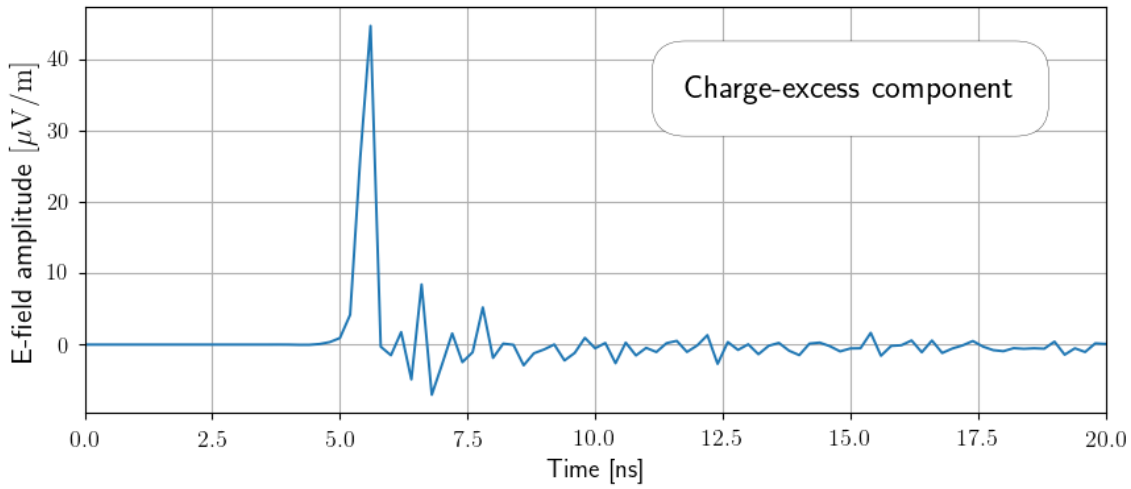


WE CONSIDER THE GEOMAGNETIC AND CHARGE-EXCESS COMPONENTS SEPARATELY

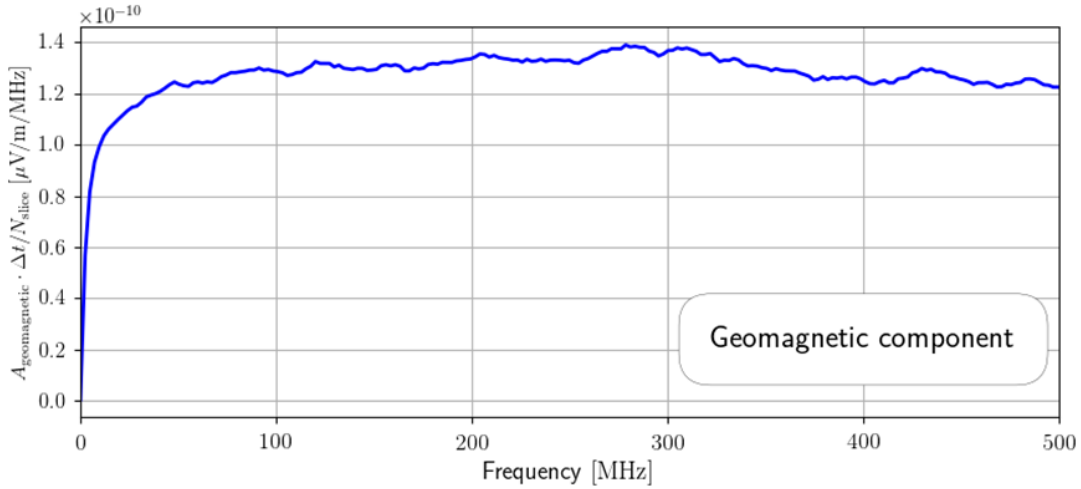


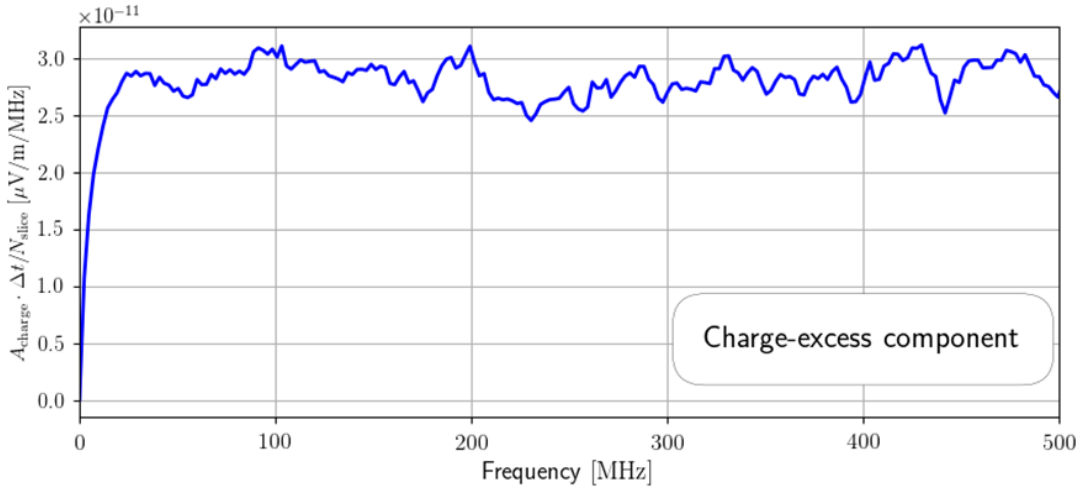
WE CONSIDER THE GEOMAGNETIC AND CHARGE-EXCESS COMPONENTS SEPARATELY





AND PARAMETRIZE THE AMPLITUDE FREQ. SPECTRUM OF EACH COMPONENT



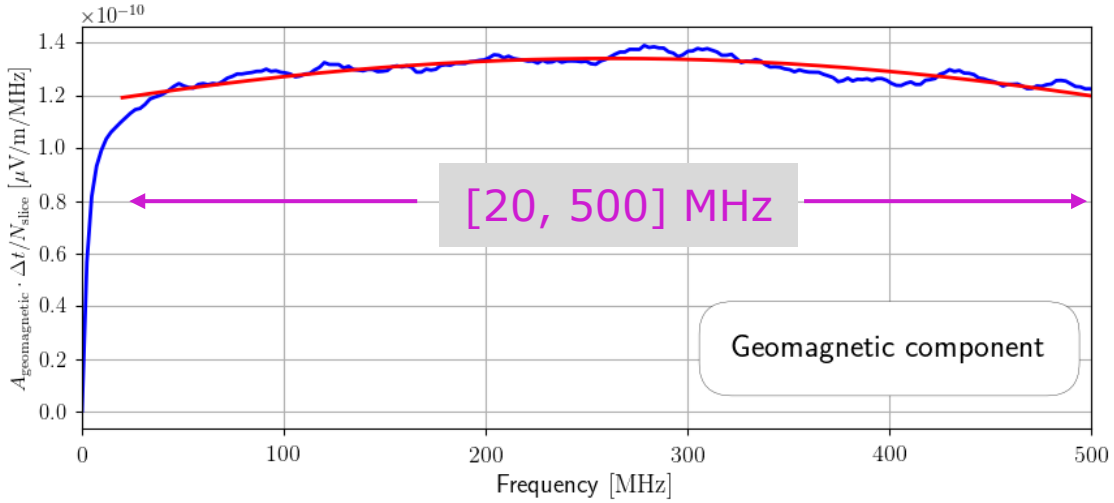


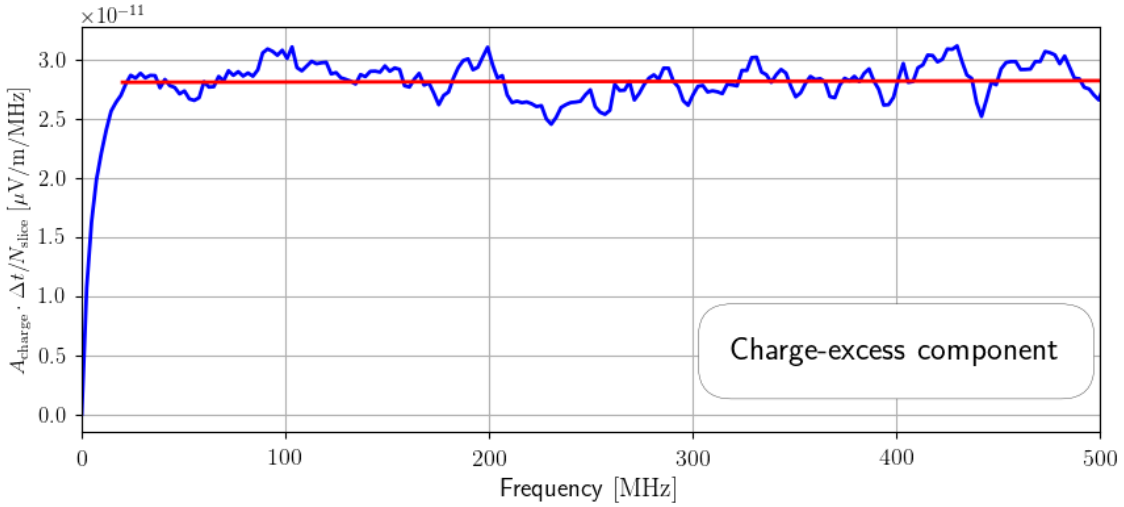
$$A(f) = |\,\mathrm{DFT}\{s(t)\}\,|$$

AND PARAMETRIZE THE AMPLITUDE FREQ. SPECTRUM OF EACH COMPONENT

$$A_{geo} = (a \cdot N_{slice}) \cdot \exp(b \cdot (f - f_0) + c \cdot (f - f_0)^2)$$

$$A_{ce} = (a \cdot N_{slice}) \cdot \exp(b \cdot (f - f_0))$$



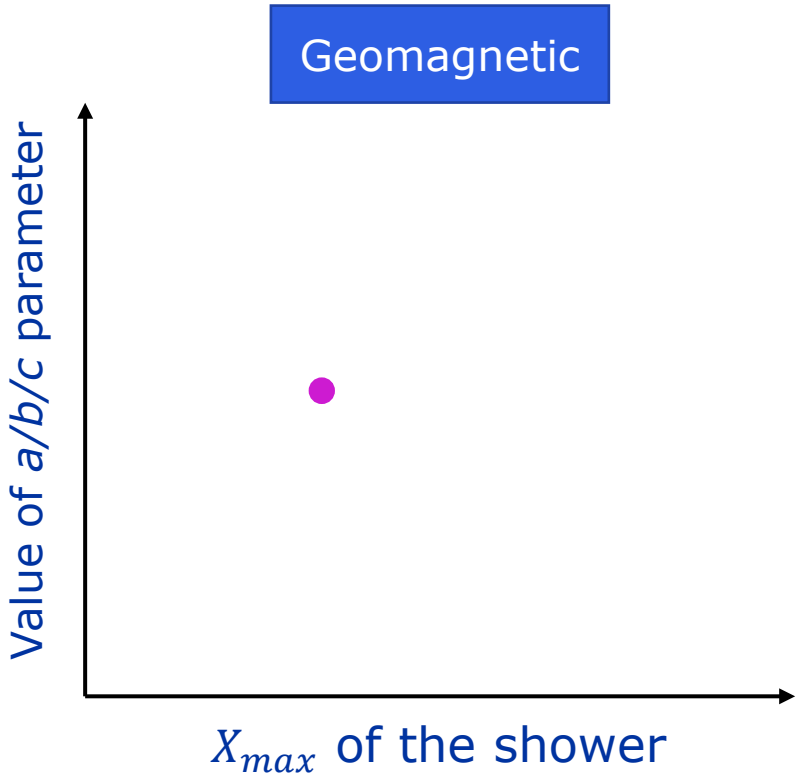


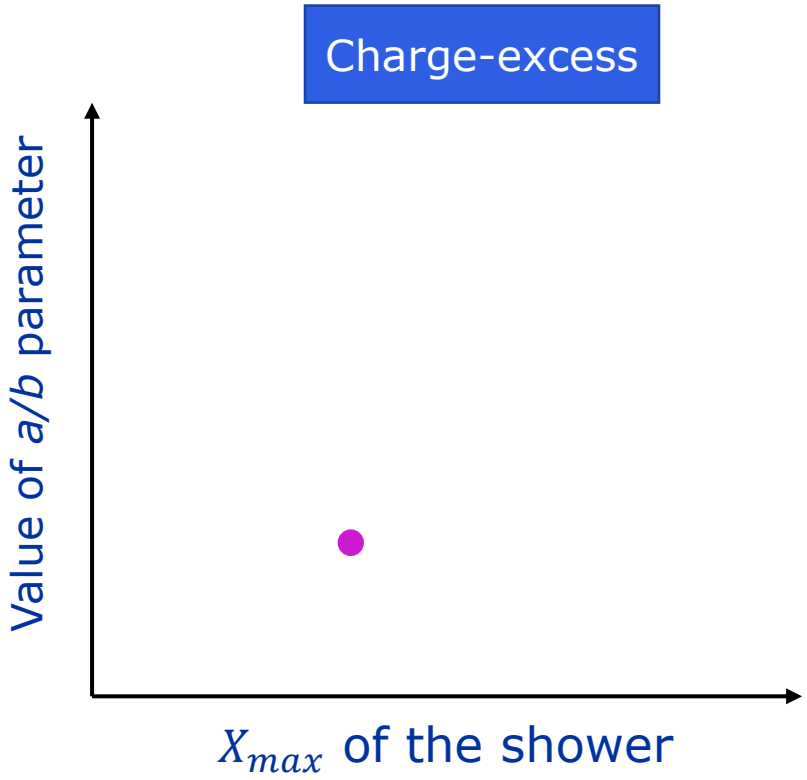
THE COEFFICIENTS ARE THE SPECTRAL PARAMETERS

$$A_{geo} = (a \cdot N_{slice}) \cdot \exp(b \cdot (f - f_0) + c \cdot (f - f_0)^2)$$

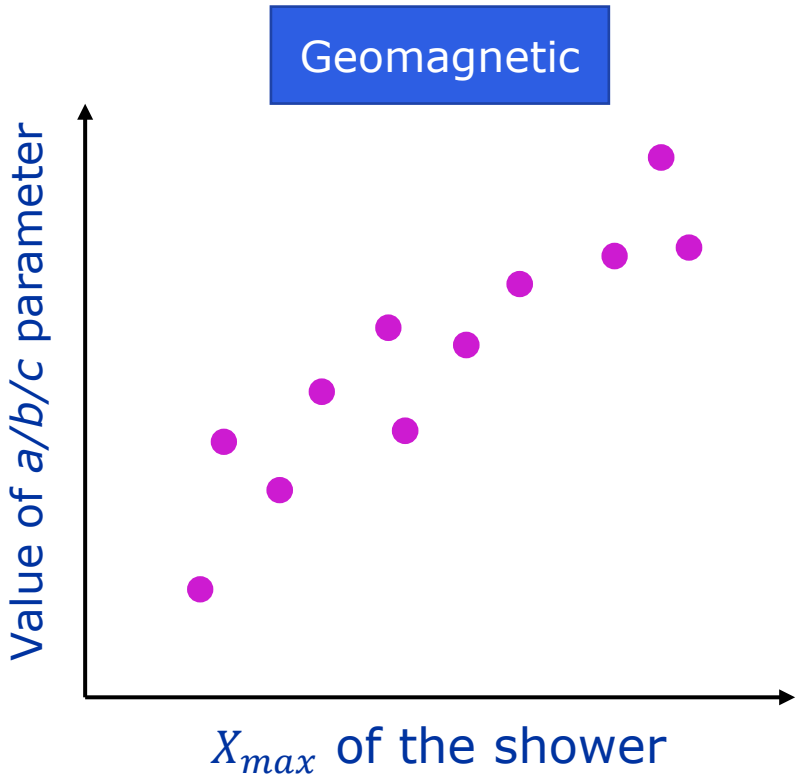
Spectral parameters

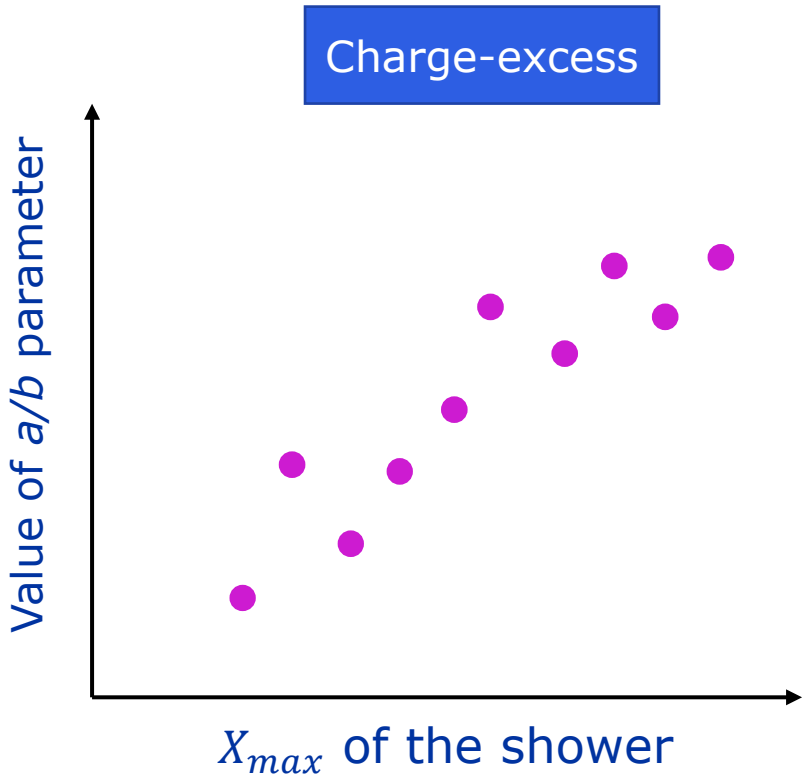
AND THEY CAN BE RELATED TO XMAX OF THE SHOWER, FOR EACH ANTENNA



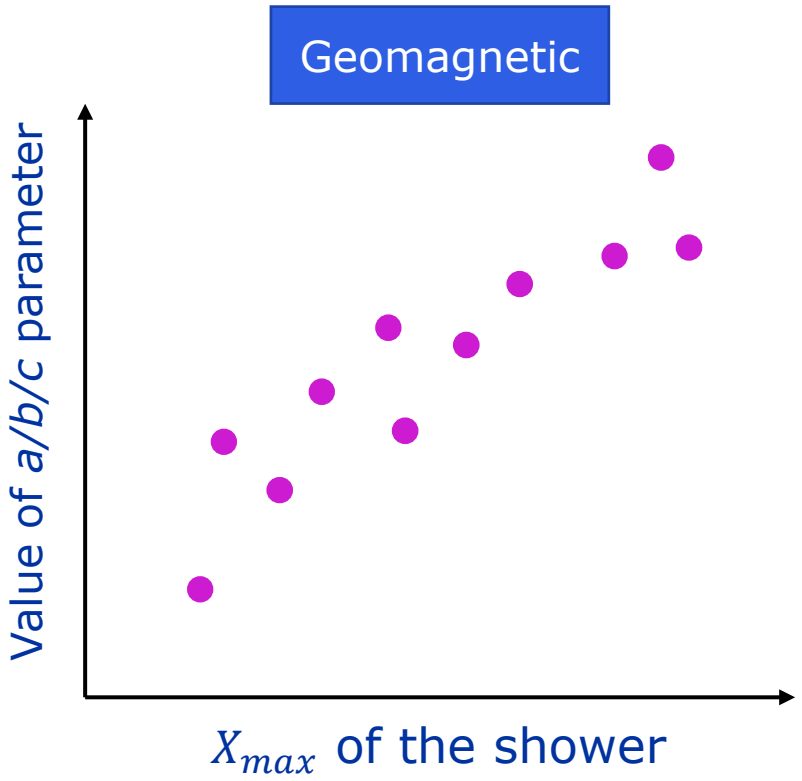


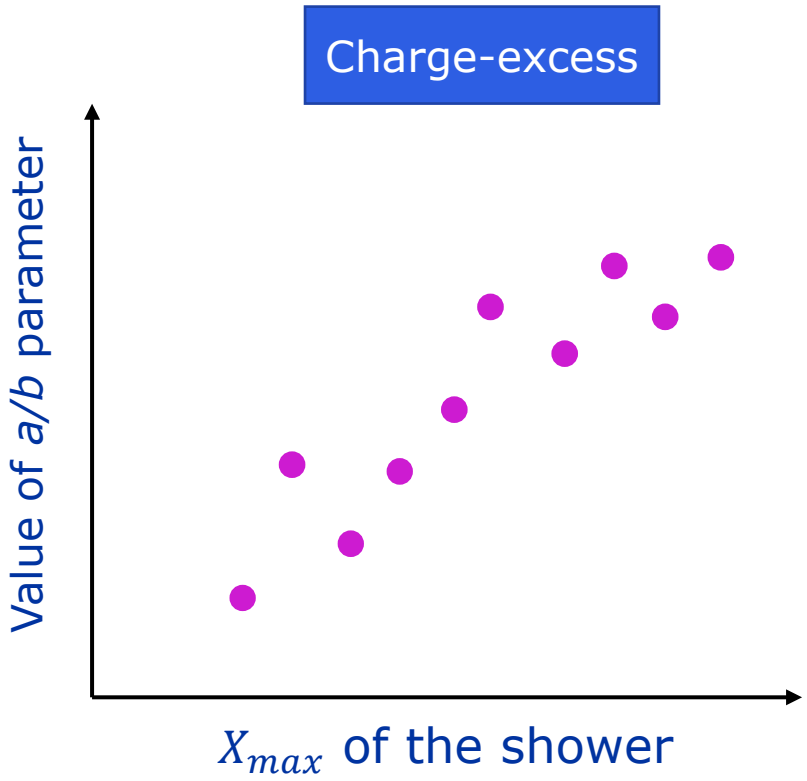
IF WE DO THIS FOR MANY SHOWERS, WE OBSERVE A CLEAR PATTERN

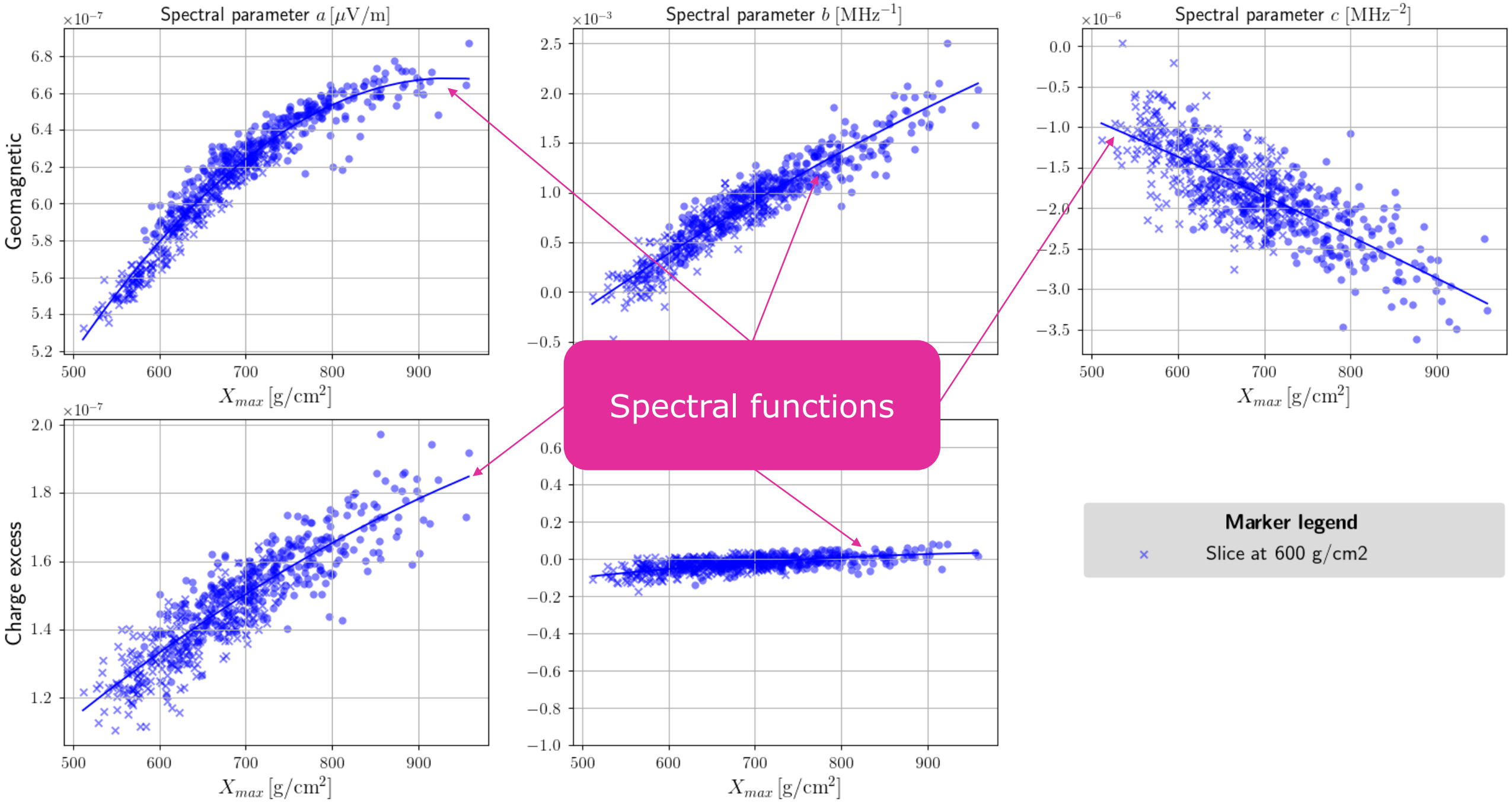




THE SPECTRAL FUNCTIONS TELL HOW THE SPECTRAL PARAMETERS VARY WITH XMAX






Spectral parameter a [μV/m]
Spectral parameter b [MHz^{-1}]
Spectral parameter c [MHz^{-2}]
Geomagnetic
Charge excess
X_{max} [g/cm^2]
Spectral functions
Marker legend
Slice at 600 g/cm2

WITH THE SPECTRAL FUNCTIONS, WE CAN RESCALE THE EMISSION FROM ANY SHOWER TO MIMIC ANY OTHER

At this point we have the spectral functions, which

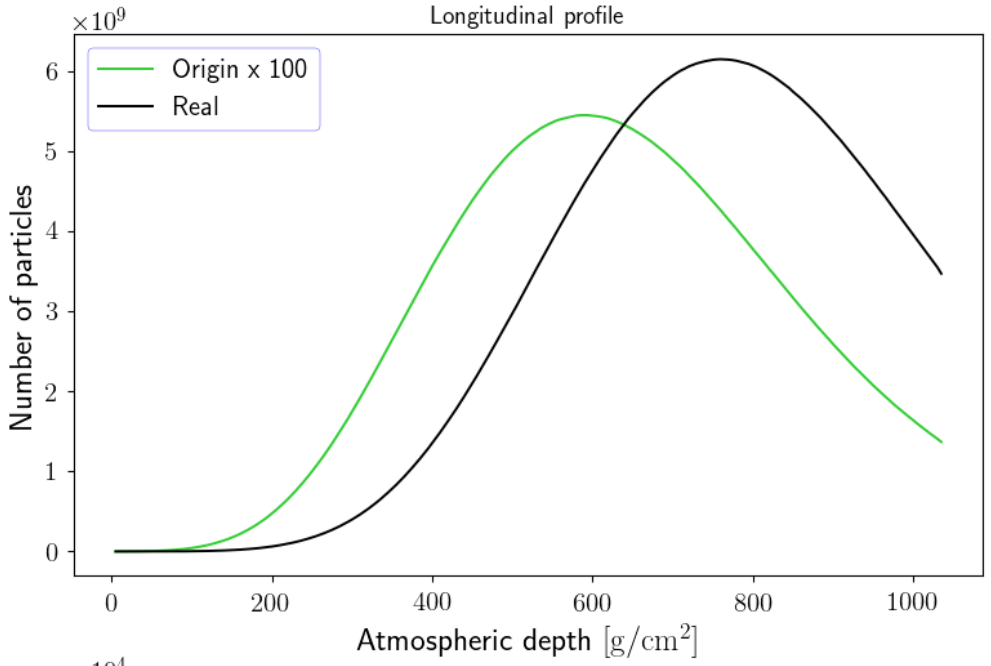
- for each simulated antenna,
- in every slice of the atmosphere present in our geometry,

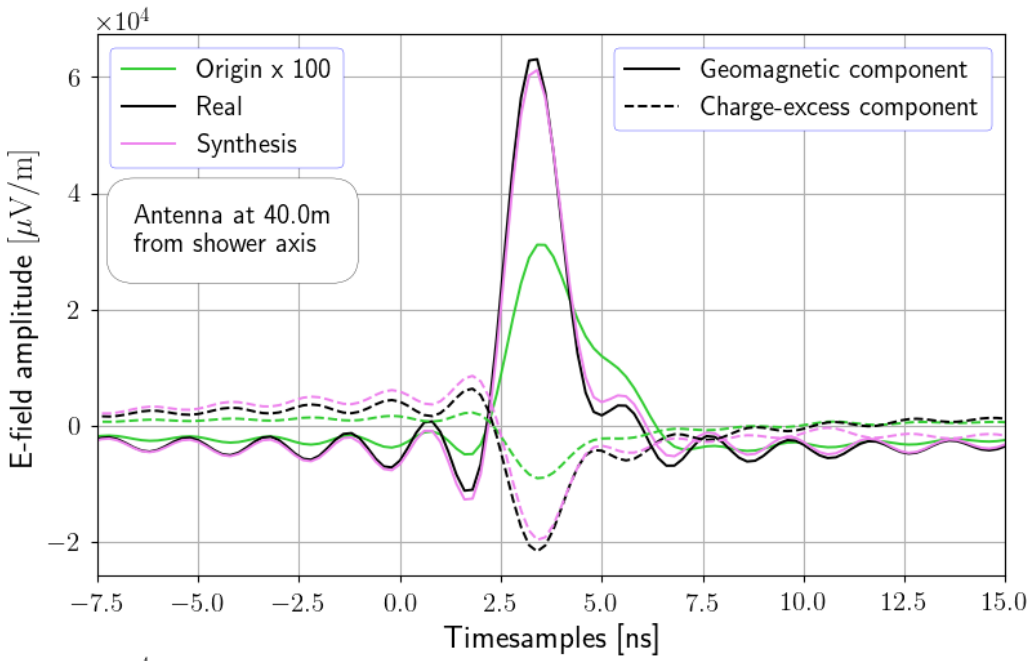
describe how the spectral parameters depend on the Xmax of a shower.

Given an input **origin** shower and a target longitudinal profile, we can now use the spectral functions to rescale the emission from the origin shower.

SOME OF THE RESULT SO FAR…





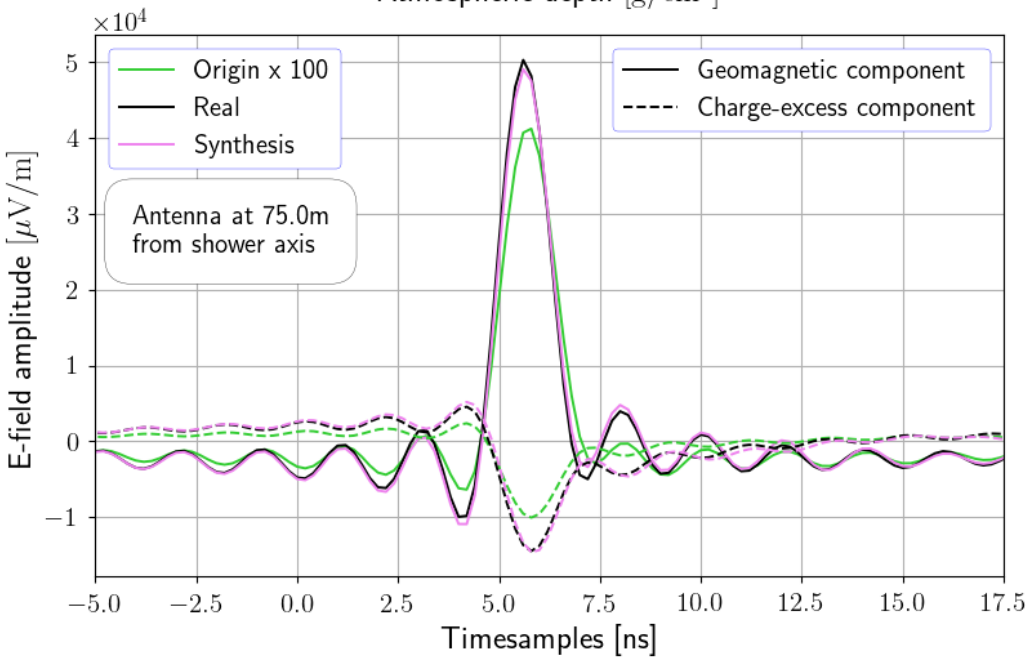


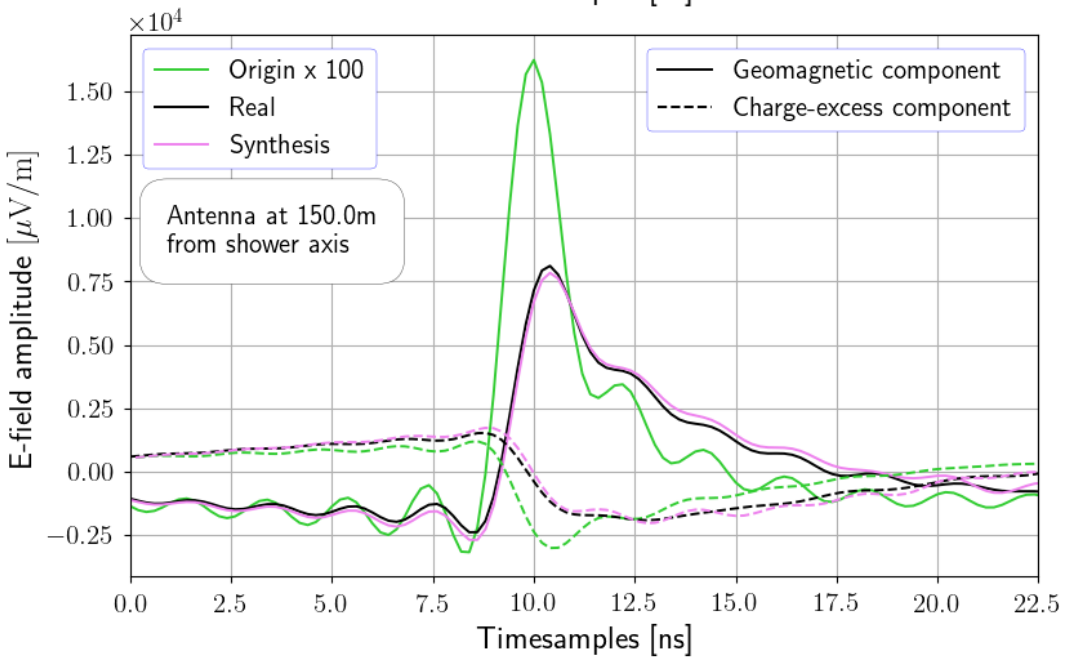
$\theta = 0°$

$\phi = 225°$

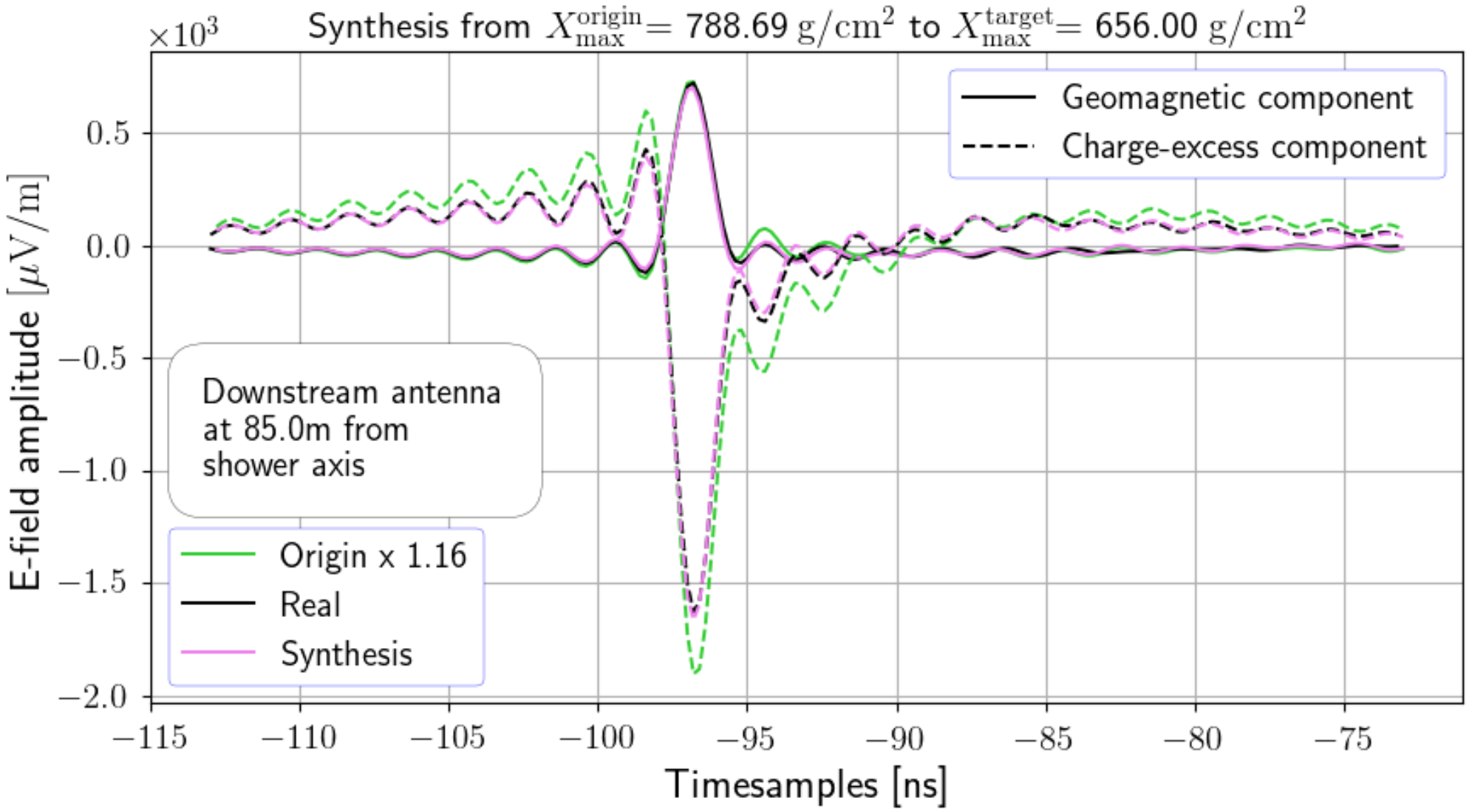
AUGER

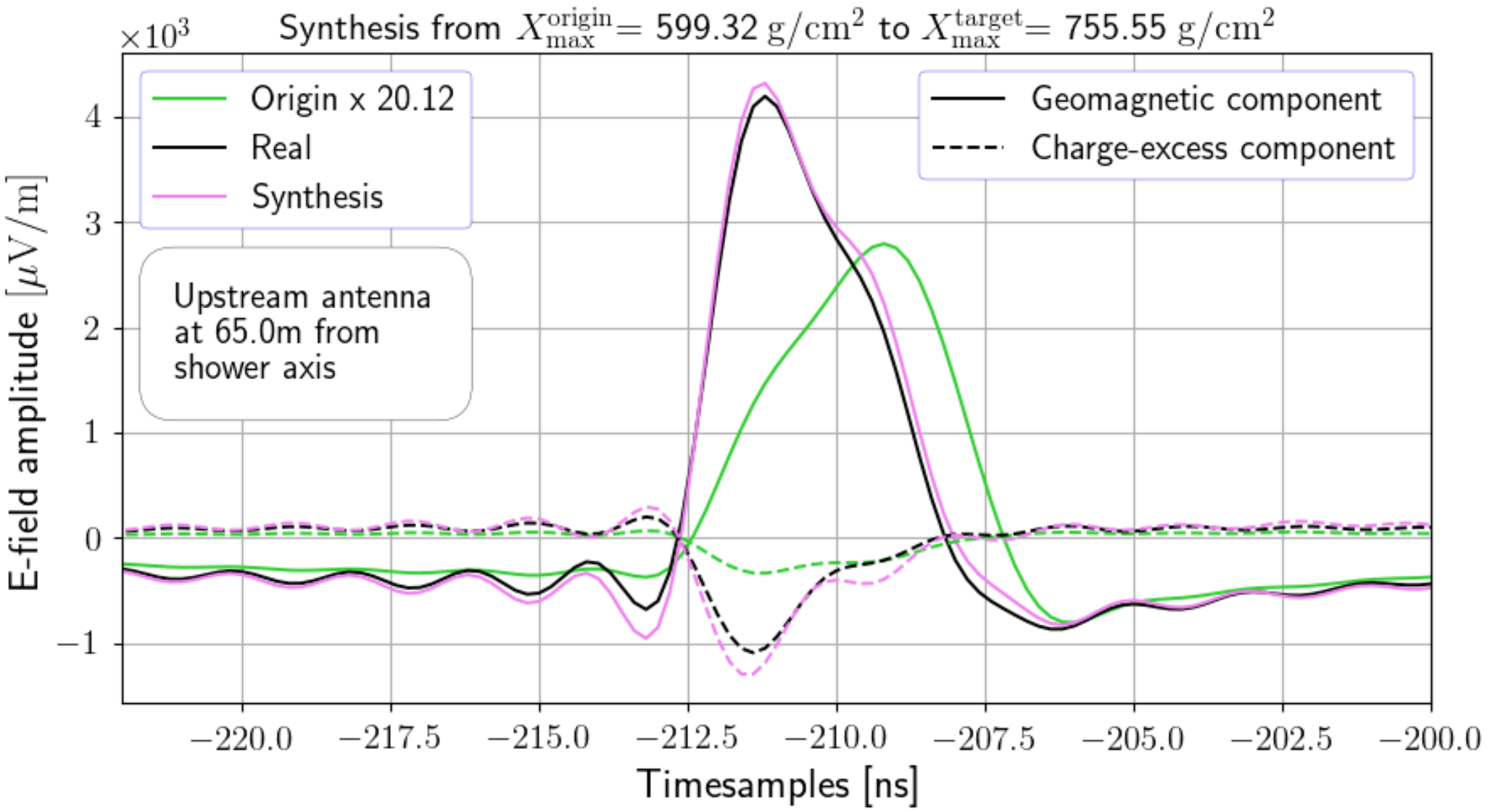
on $\vec{v} \times \vec{v} \times \vec{B}$





$\theta = 20°$
$\phi = 225°$
LOFAR
on $\vec{v} \times \vec{v} \times \vec{B}$





$\theta = 45°$

$\phi = 225°$

LOFAR

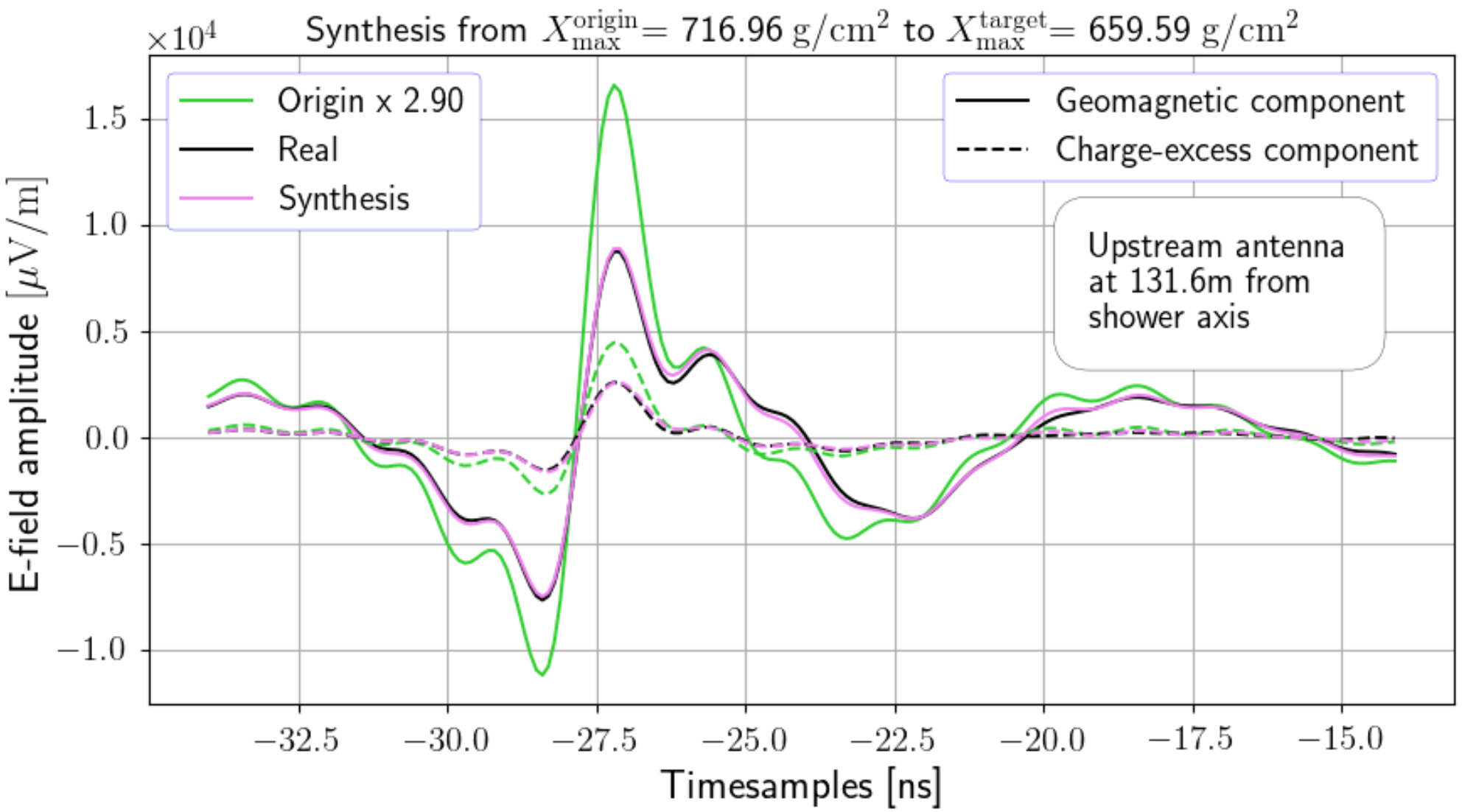
on $\vec{v} \times \vec{v} \times \vec{B}$

$\theta = 30°$

$\phi = 0°$

SKA

off $\vec{v} \times \vec{v} \times \vec{B}$

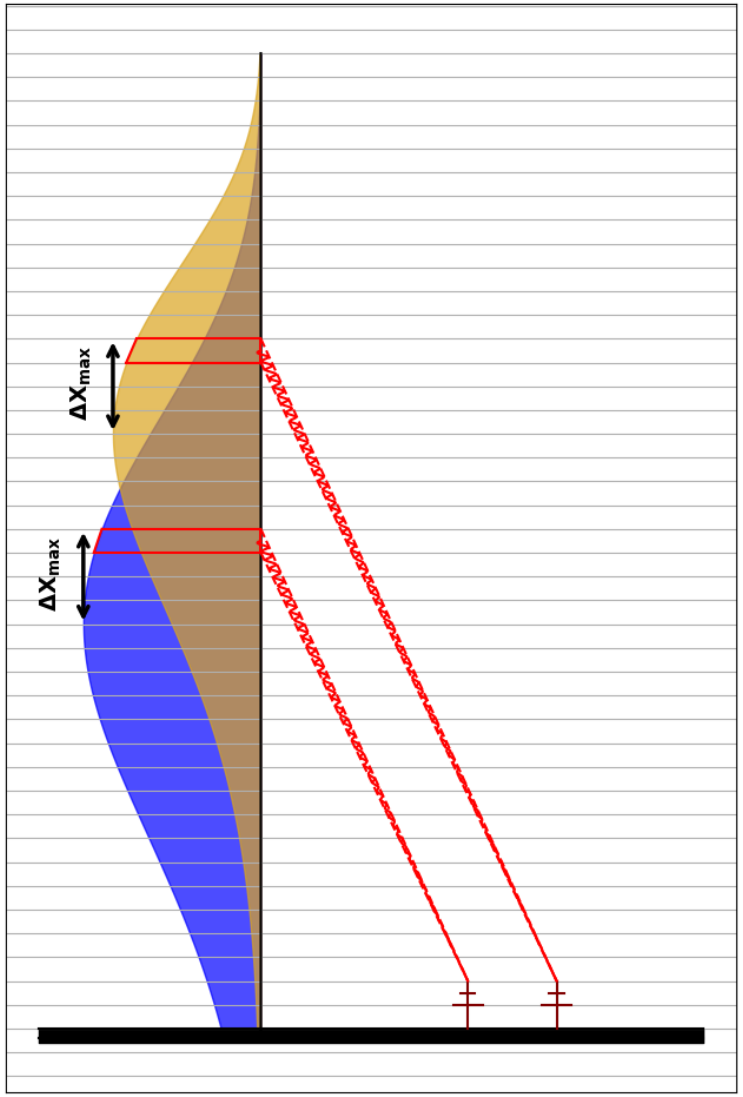


MOVING ACROSS GEOMETRIES

A GEOMETRY INDEPENDENT DESCRIPTION NEEDS TO CORRECT FOR SOME EFFECTS

Some of the important factors influencing the radio emission coming from a slice, could be

- The viewing angle
- The number of particles in the slice
- The air density at the slice
- The Cherenkov angle associated to the slice



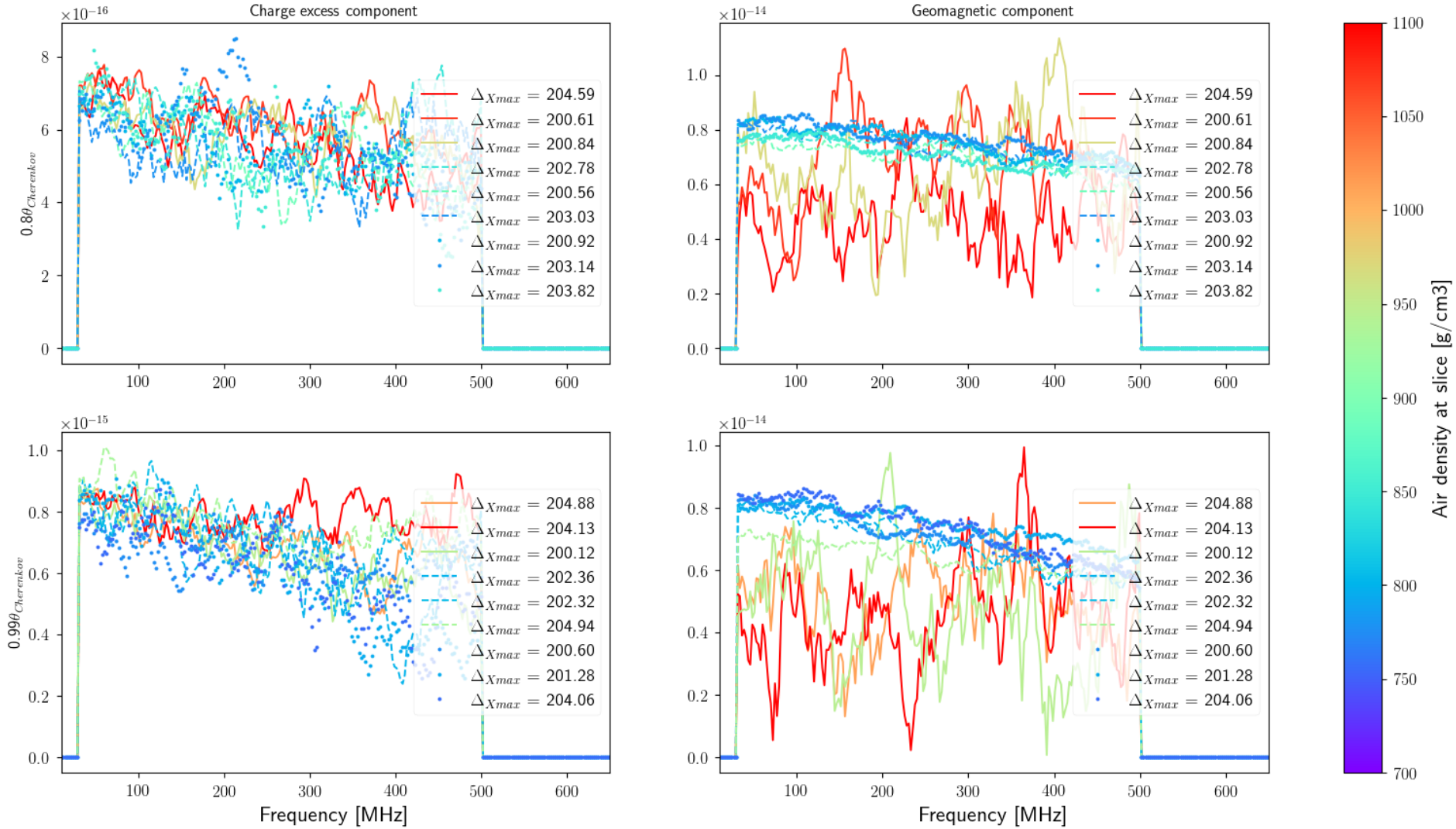
WE WANT TO COMPARE ANTENNAE WITH THE SAME "CHERENKOV VIEWING ANGLE"

- If we assume two slices with the same age (approximated by ΔX_{max}) emit similar radiation, these two antennas should see similar electric fields.
- However, the Cherenkov angle changes for both slices.
  - Consider viewing angle in units of Cherenkov angle.

TO FIND THE CHERENKOV VIEWING ANGLES WE LINEARLY INTERPOLATE FOR EVERY SLICE

- We define a fixed ΔX_{max} and a list of Cherenkov viewing angles.
- For each simulation, we find the slice that corresponds to our ΔX_{max}.
- Using the Cherenkov angle of the slice in question, we find the antenna positions corresponding to the requested viewing angles.
- From simulations we have a set of antennas on the $\vec{v} \times \vec{v} \times \vec{B}$ axis. These we interpolate linearly to the antenna positions.

THE SPECTRA *ALMOST* LINE UP



Density and magnetic intensity dependence of radio pulses induced by energetic air showers

These authors found scaling relations with density and magnetic field strength

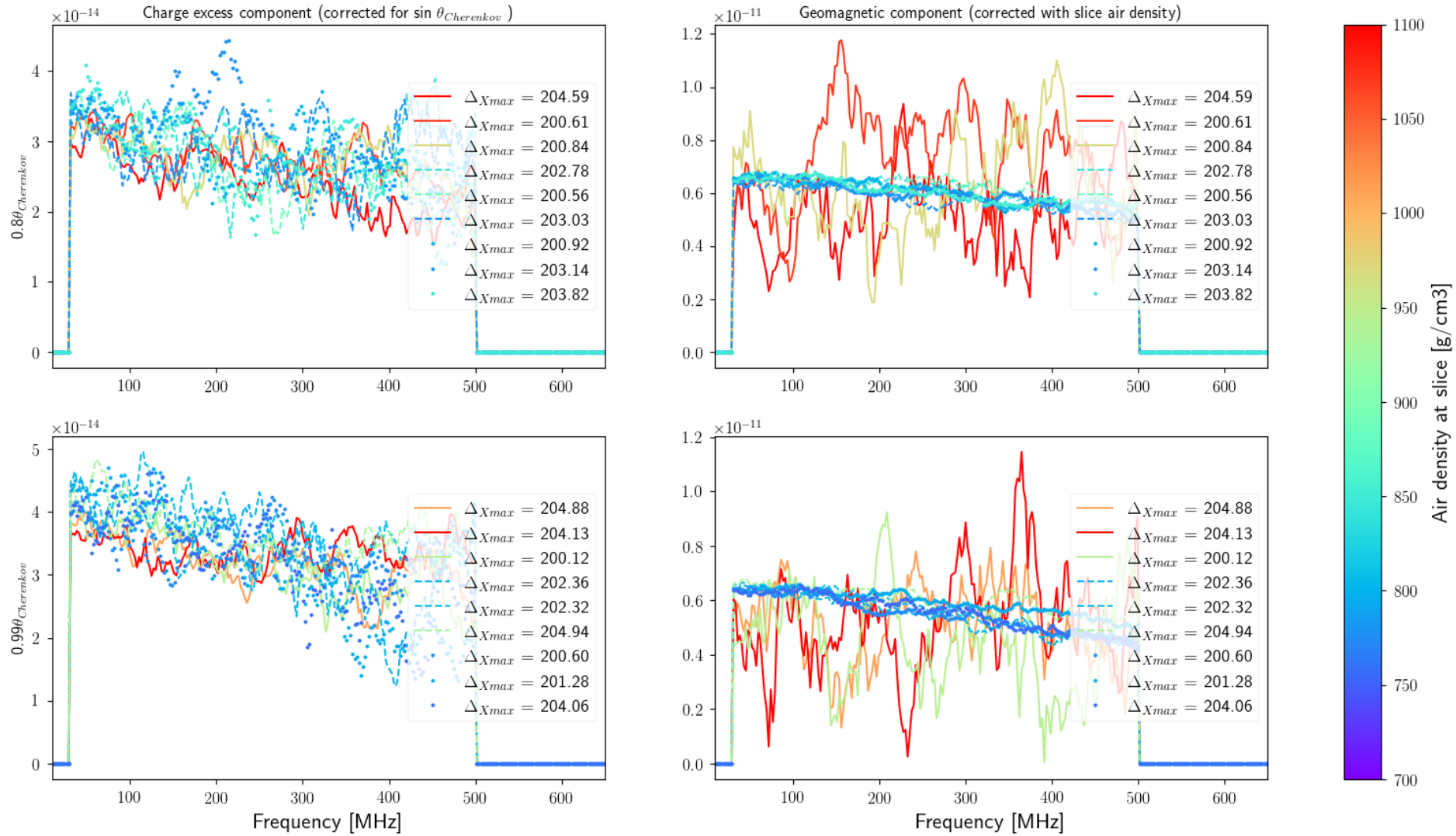
Juan Ammerman-Yebra, Jaime Alvarez-Muñiz, Enrique Zas

Instituto Galego de Física de Altas Enerxías (IGFAE), Universidade de Santiago de Compostela, 15782 Santiago de Compostela, Spain

E-mail: juan.ammerman.yebra@usc.es, jaime.alvarez@usc.es, enrique.zas@usc.es

Arxiv: 2305.11668

WE NEED TO APPLY A CORRECTION TO EACH COMPONENT



WE WANT TO SIMULATE THE ANTENNAS INSTEAD OF INTERPOLATING THEM

Interpolation

Analyse shower set with 50 degree zenith, which is already done

Complete simulation

Run simulations with different antennas per slice, to have the same Cherenkov viewing angles for every slice

Spectral functions in every slice, as a function of viewing angle


TUNE IN NEXT TIME, FOR A NEW WAVE OF UPDATES