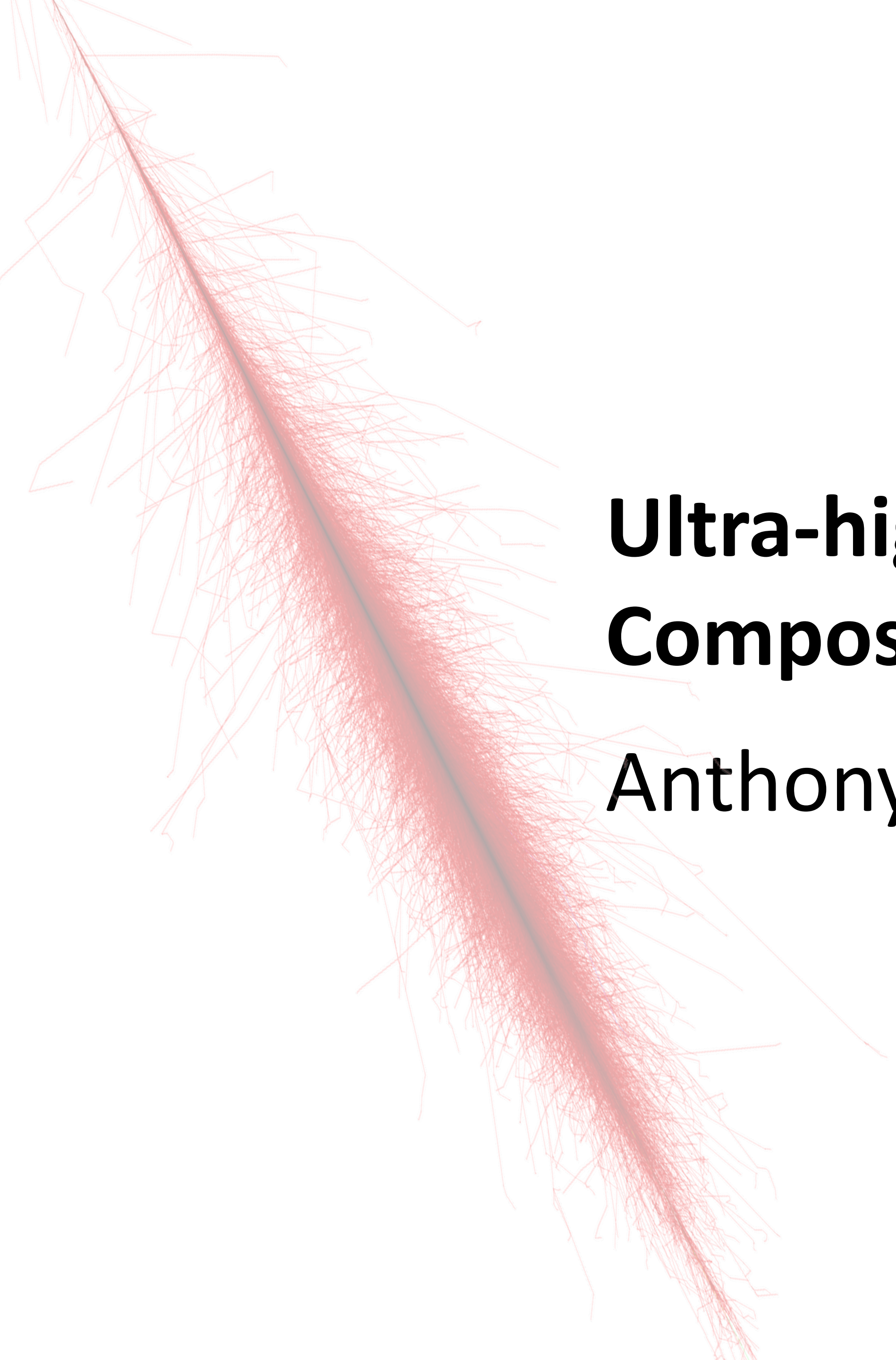


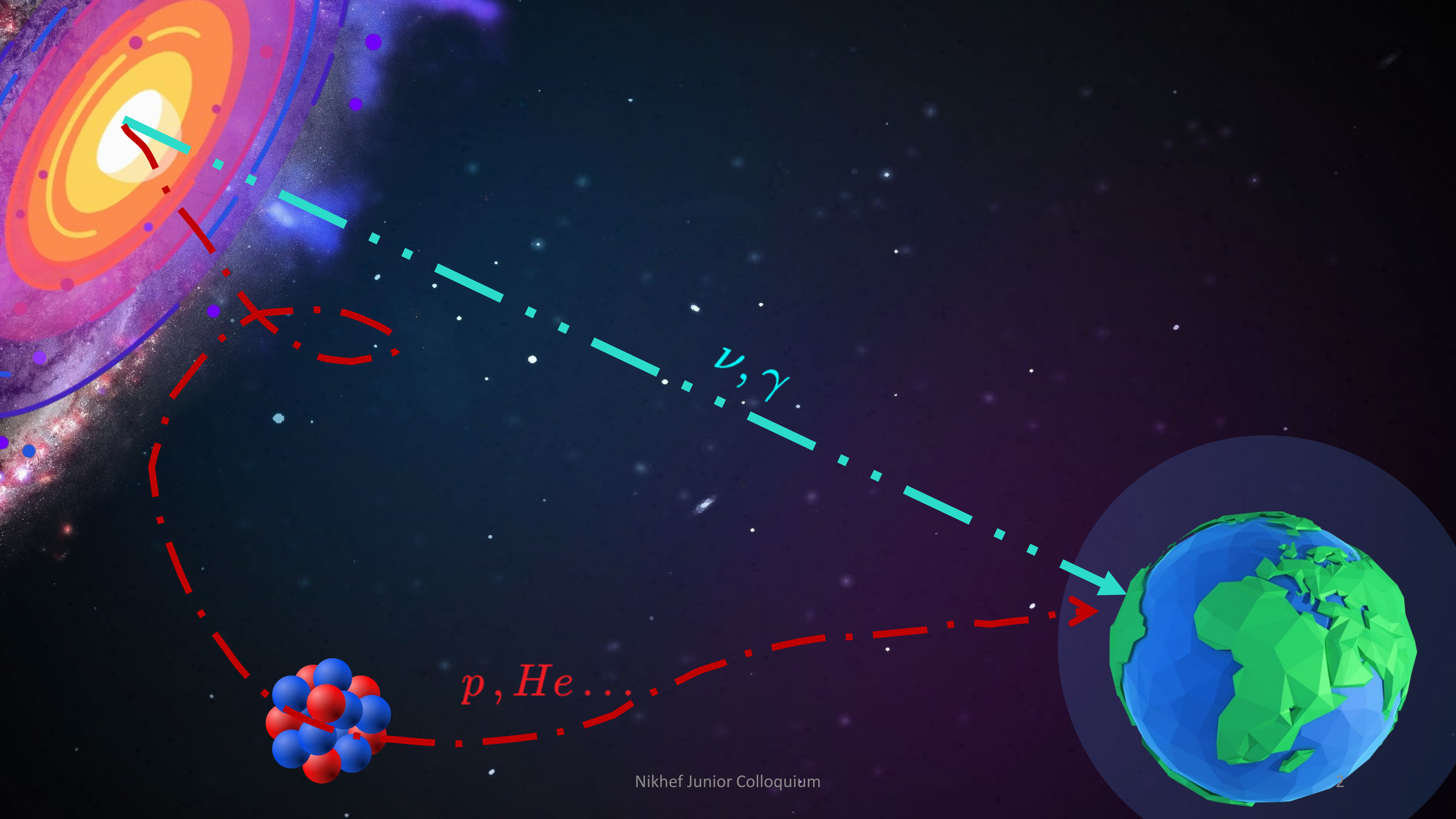
Radbound University

Ultra-high Energy Cosmic Rays Mass Composition Using Radio

Anthony Bwembya

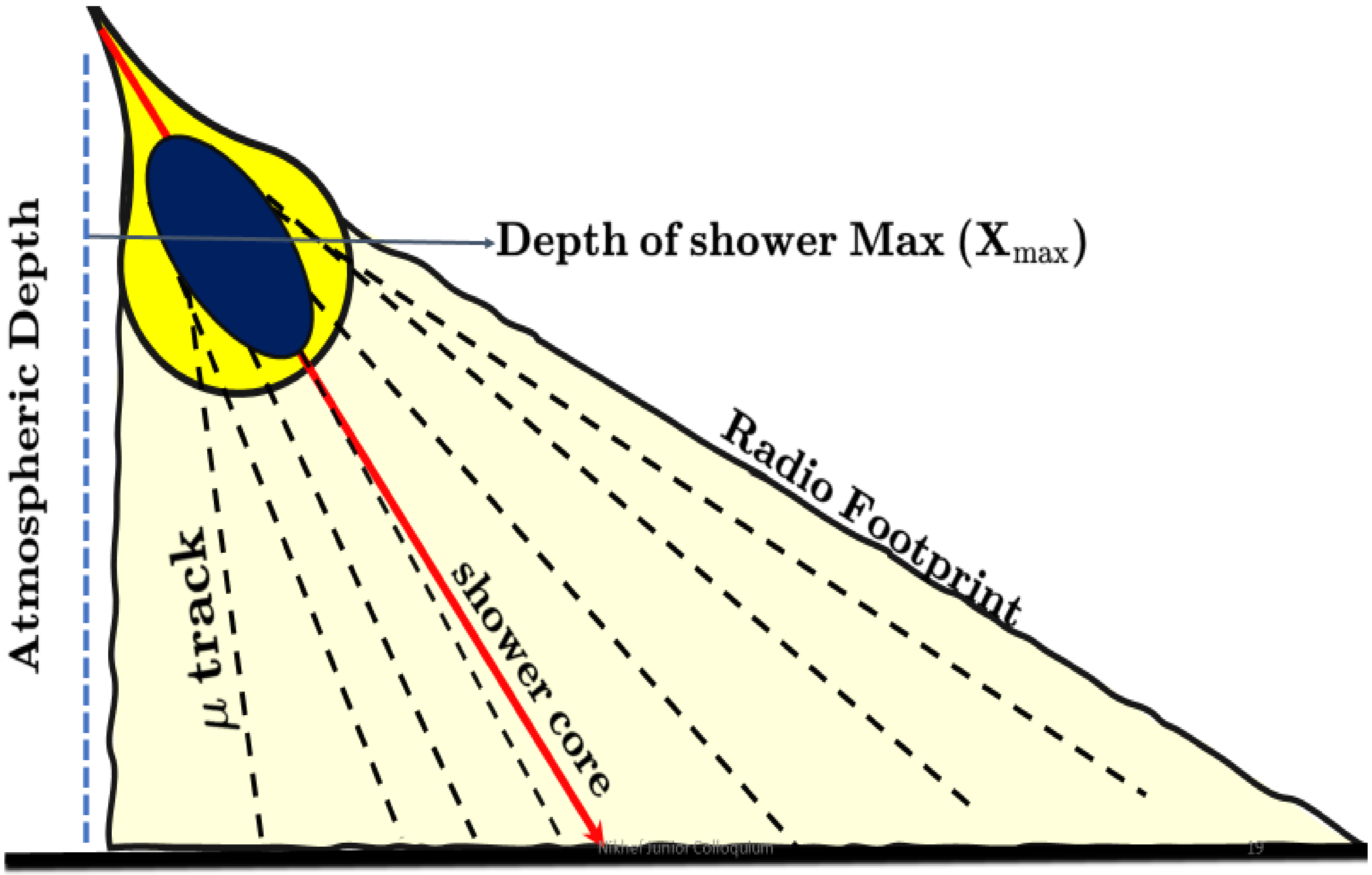
Nikhef

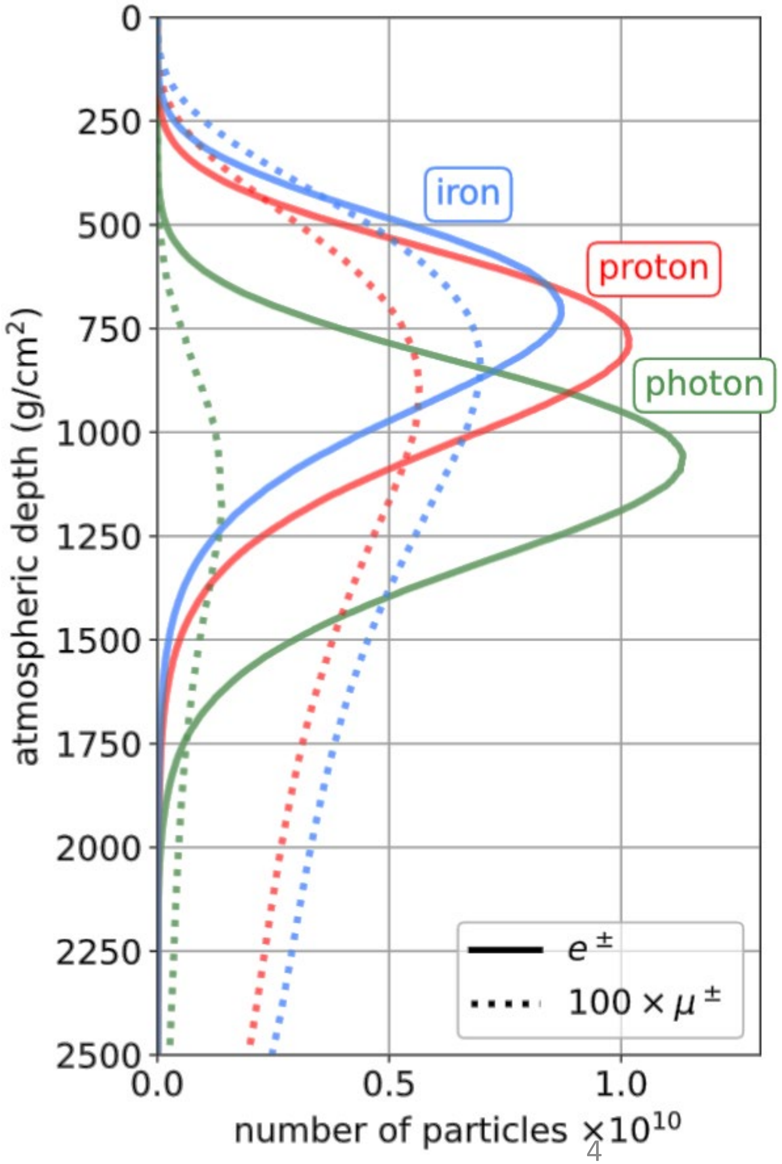
PIERRE AUGER OBSERVATORY


ν, γ
$p, He \ldots$

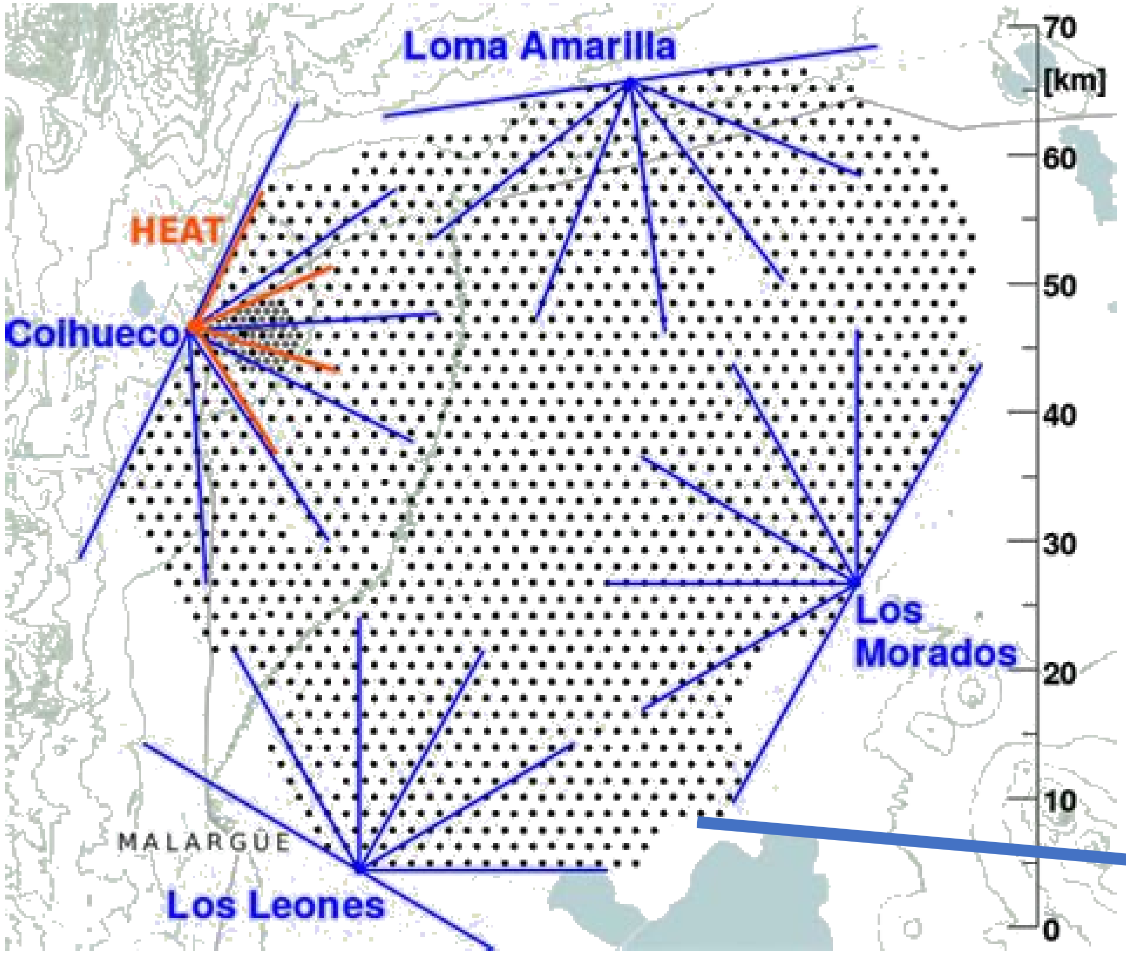
- The particle then interacts in the atmosphere and creates a cascade of particles

Extensive Air showers (EAS):



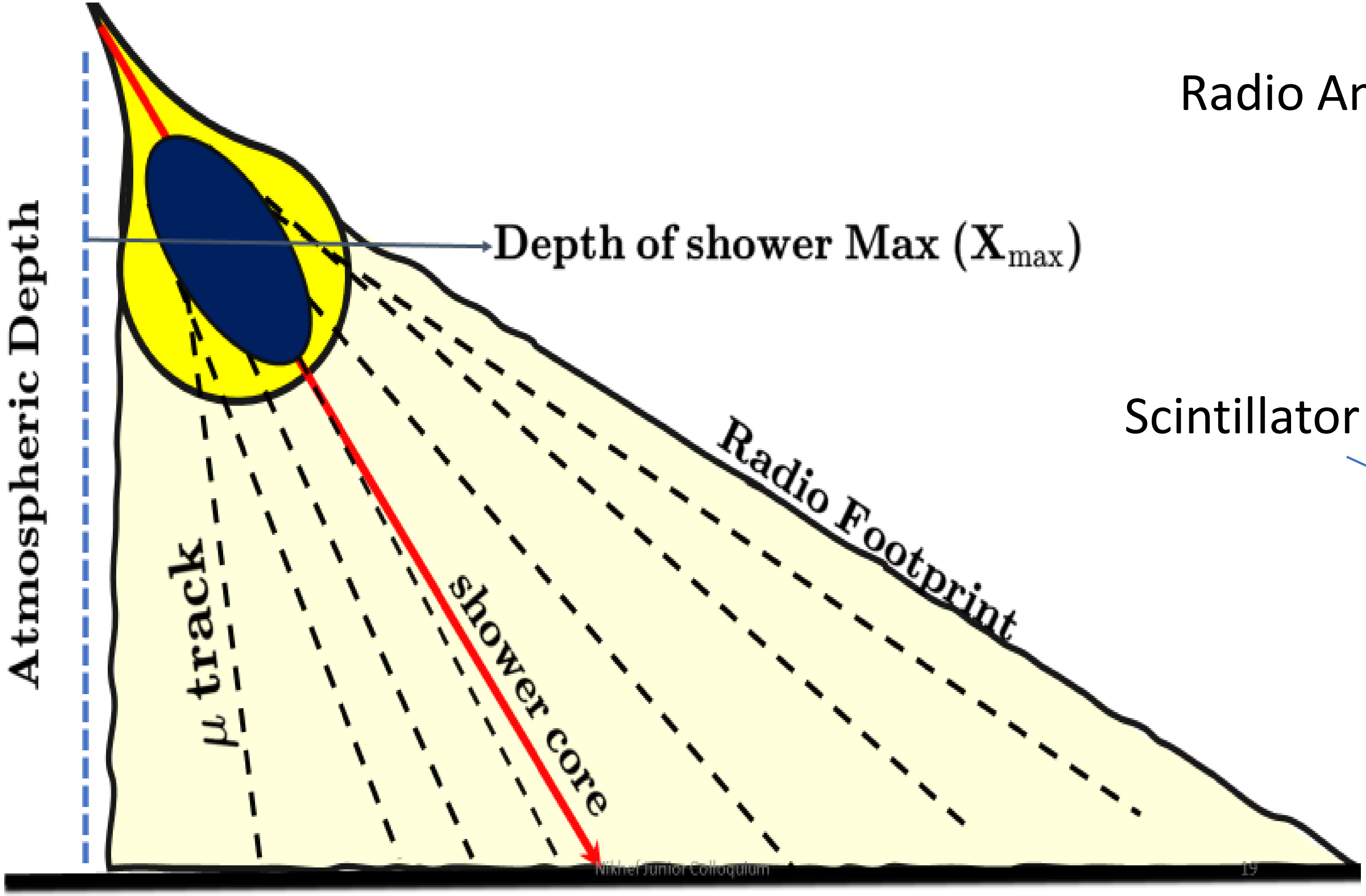


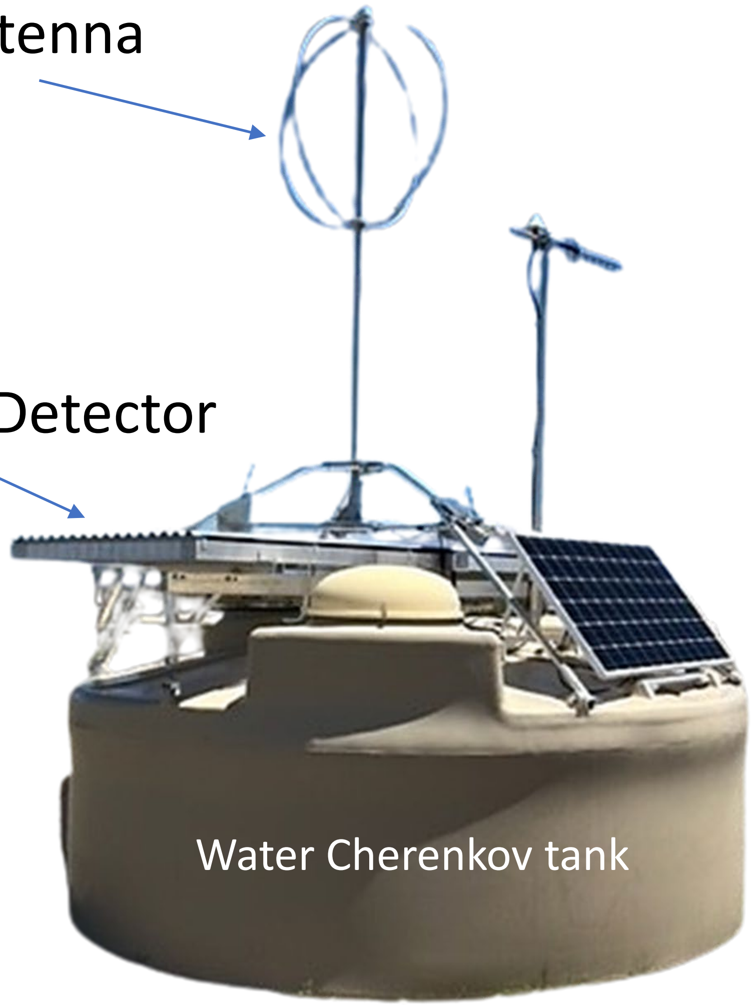
Pierre Auger:



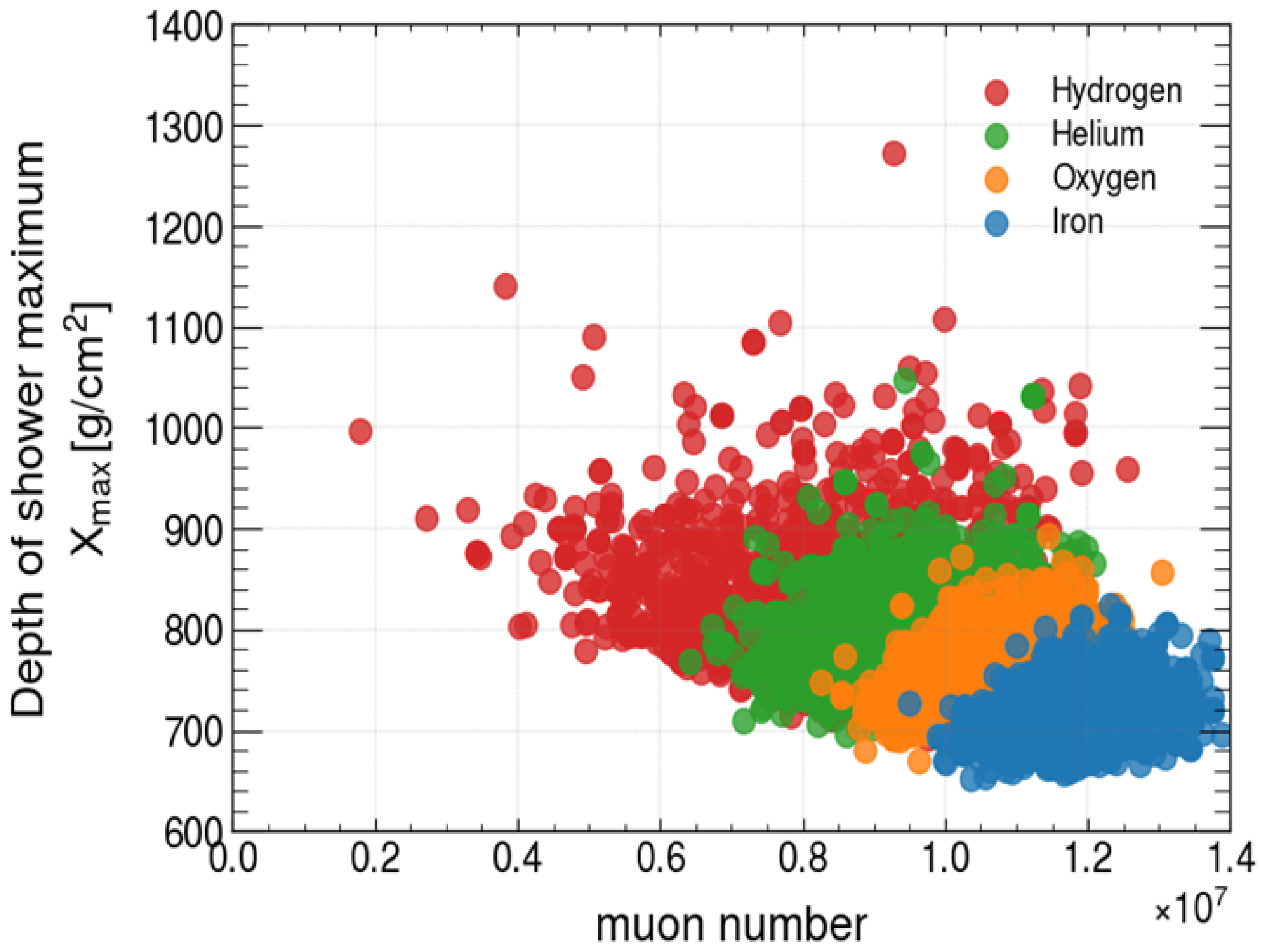
- The observatory covers 3000 Km^2 in the area and comprises 1660 detector stations.
- Spaced 1.5 km apart.
- It is located in the Argentinian pampas.
- Currently undergoing an upgrade to >> **Auger Prime**

The Pierre Auger Prime:





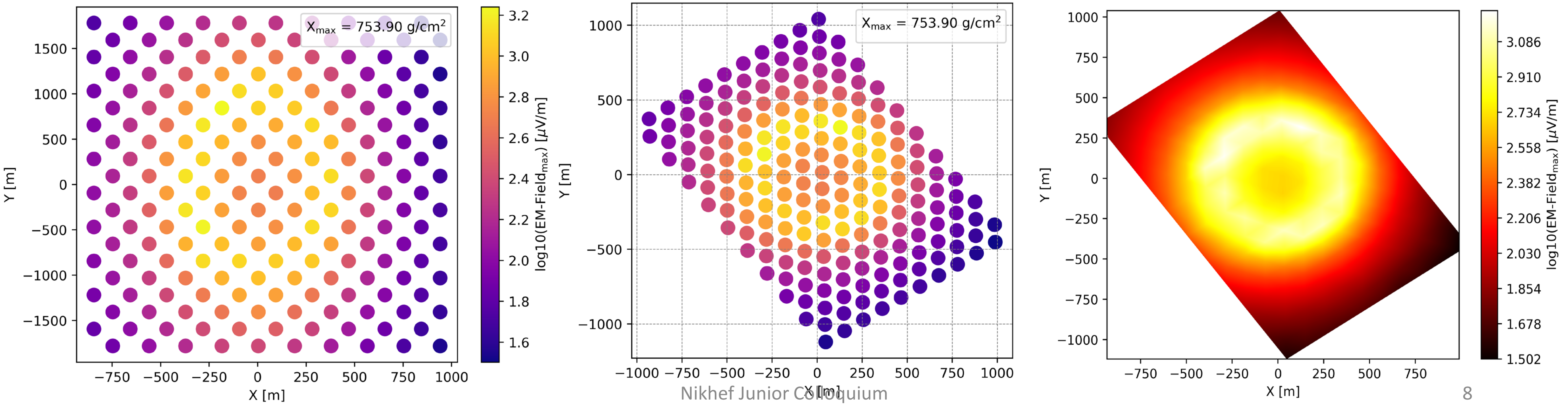
Why measure X_{max}?



- X_{max} is used in constraining the mass of cosmic rays.
- Measuring both X_{max} and the number of muons can give us a good separation of primaries

X_{max} With Radio:

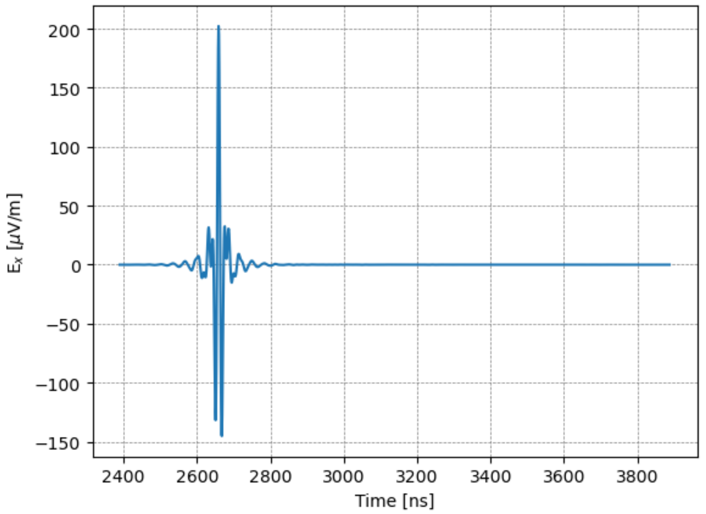
- Using Radio X-max is done through the measurement of the footprint.
- The Cherenkov ring is an important feature in the footprint.
- The radio footprint can be in a 2D plot with either the amplitude or spectral index plotted as a function of distance from the core.

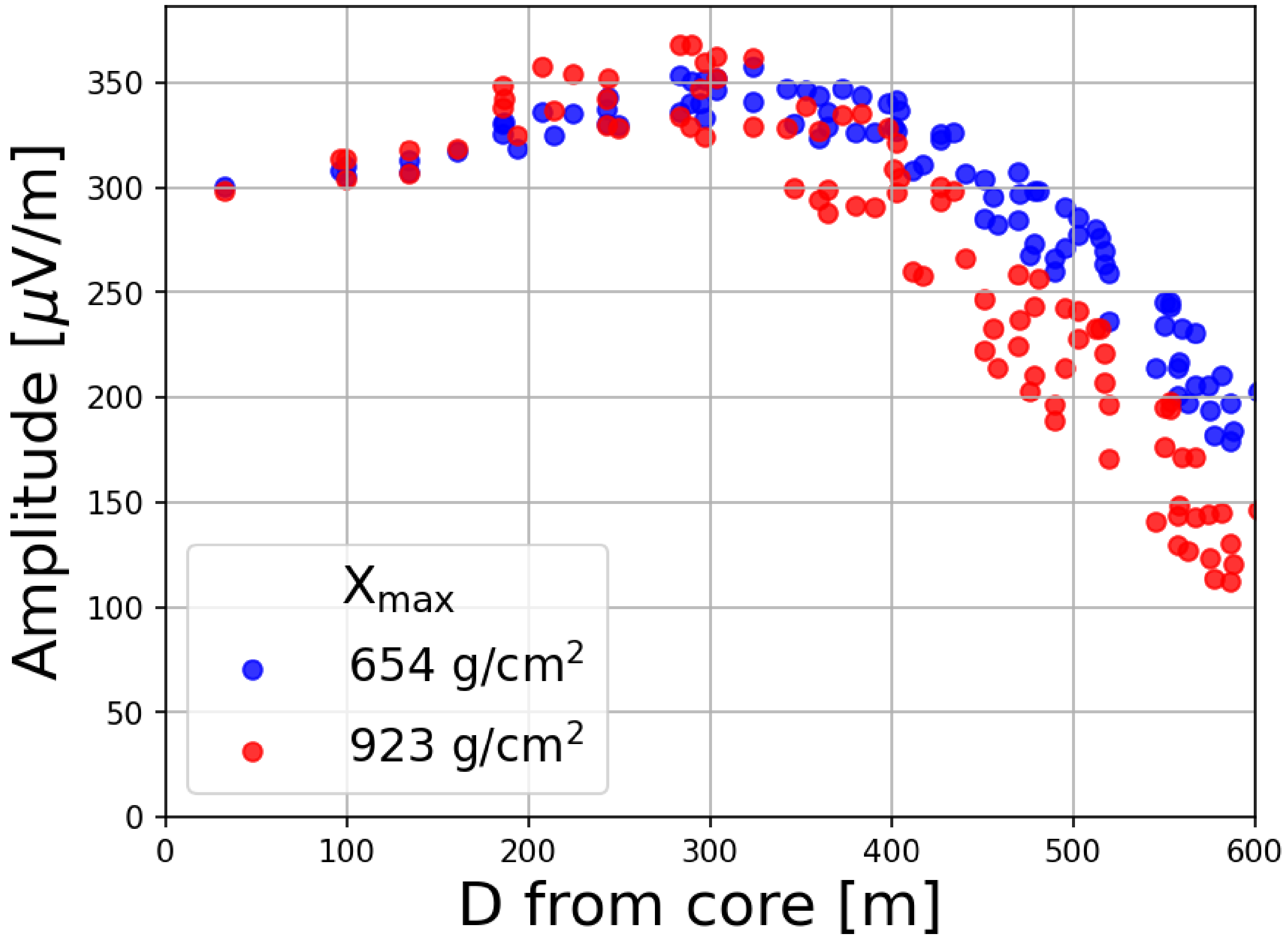


Longitudinal Distribution Function(LDF):

- This LDF has X_{max} dependence.

- Plotting the maximum amplitudes in the footprint as a function of the antenna distance to the shower core.



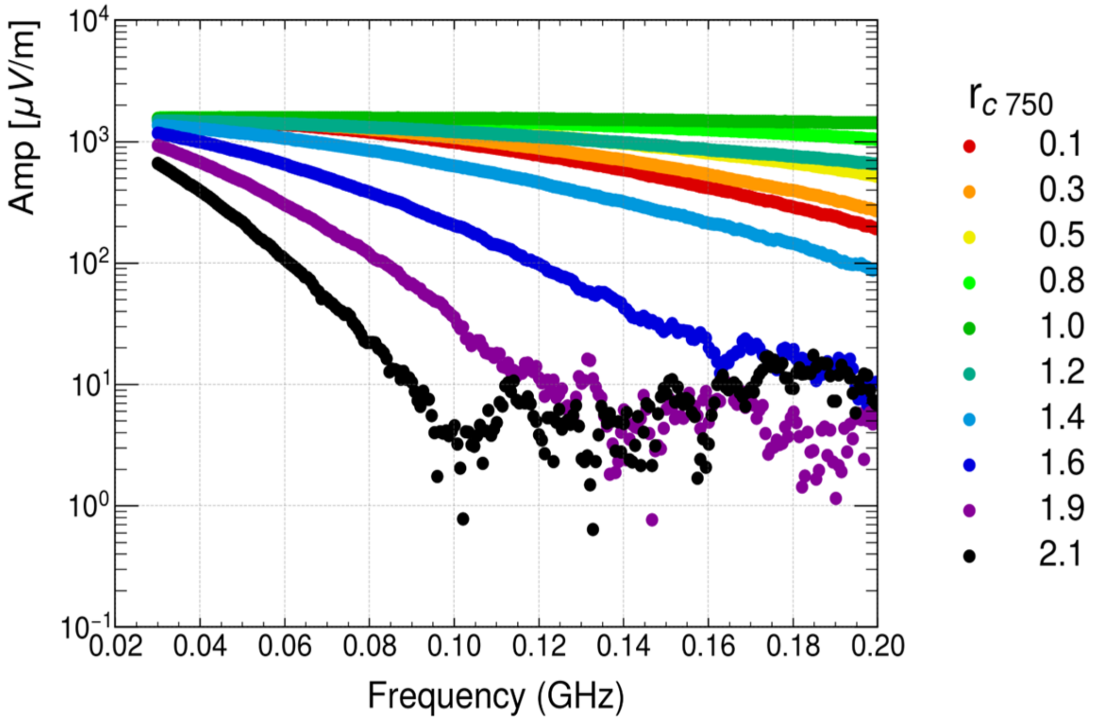


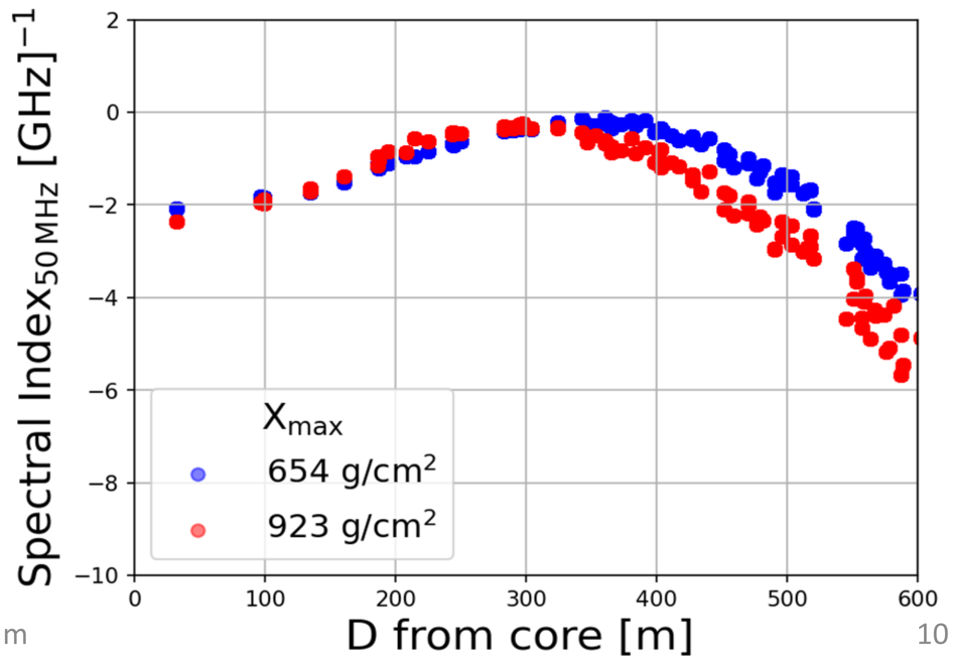
Distribution of the slope:

- We calculate the spectral distribution by fitting the frequency spectrum with a polynomial.

$$S(\nu - \nu_0) = a_1(\nu - \nu_0)^2 + a_2(\nu - \nu_0) + a_3$$

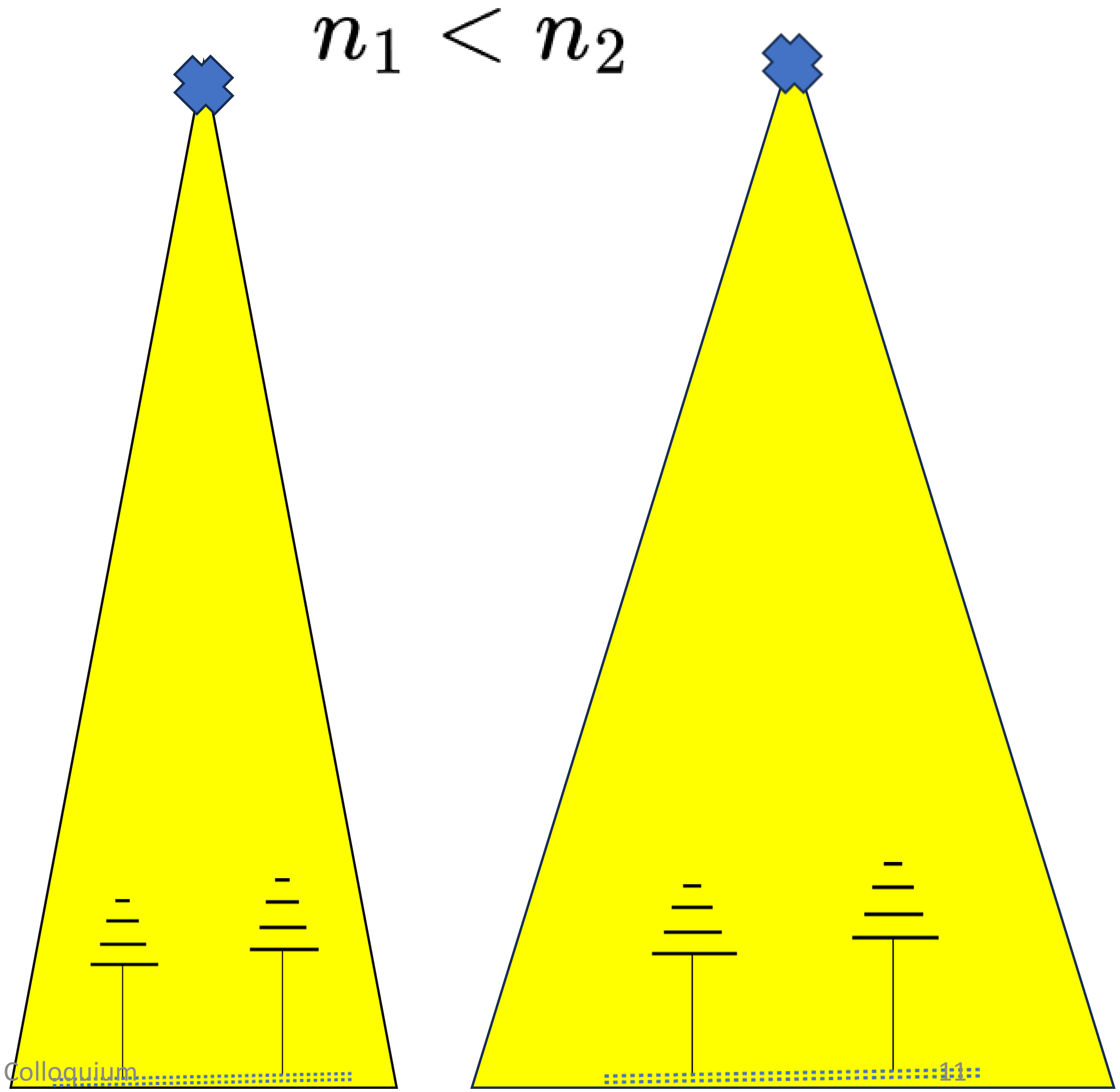
$$b = \frac{1}{\ln(10) \cdot S(\nu - \nu_0)} \left(\frac{d}{d\nu} S(\nu - \nu_0) \right)\Bigg|_{\nu_0} = \frac{a_2}{\ln(10) \cdot a_3}$$





However:

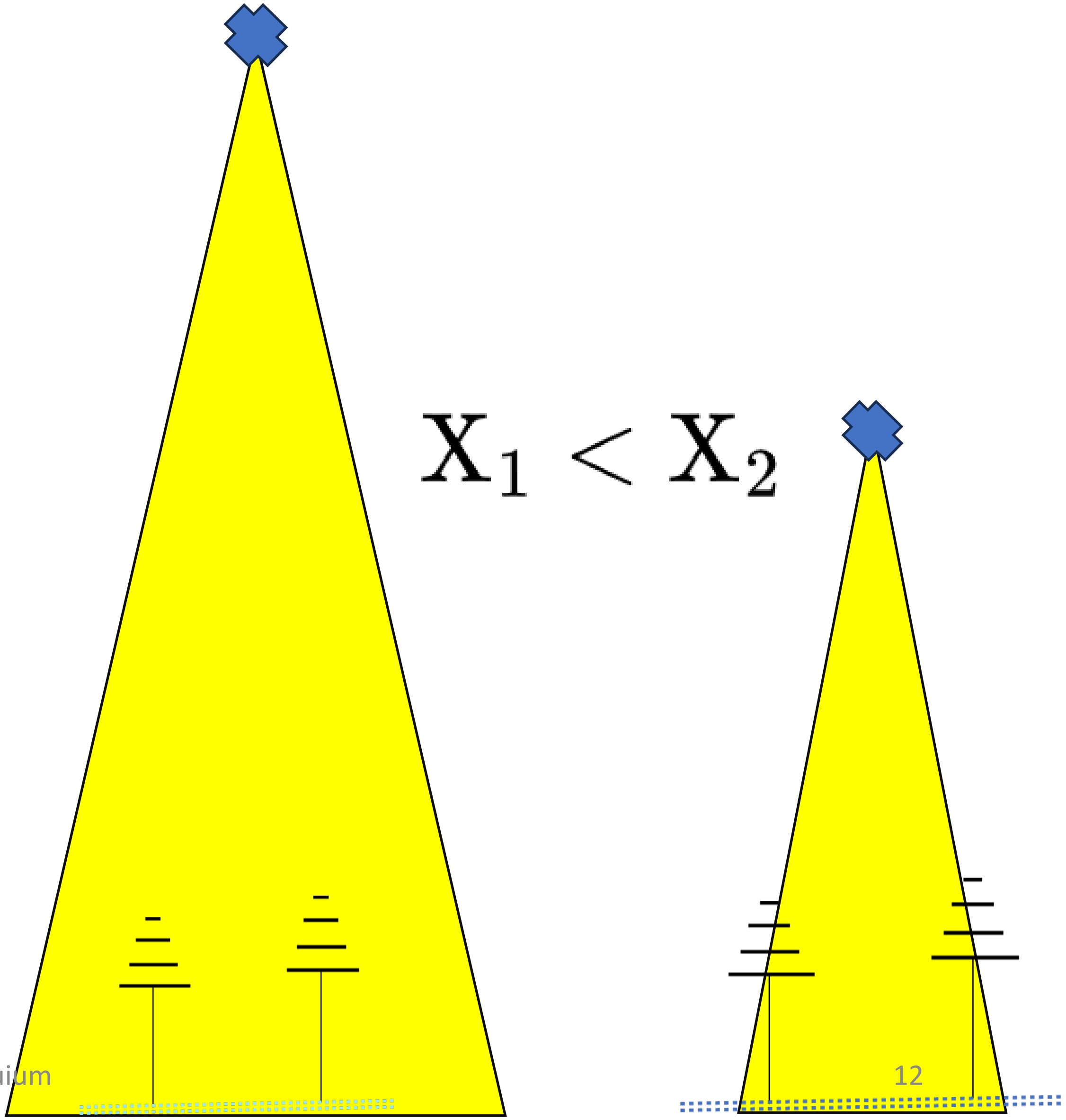
- The refractive index in the atmosphere is not constant
- *n* increases as a function of depth in the atmosphere due to changes in density.



Depth effect:

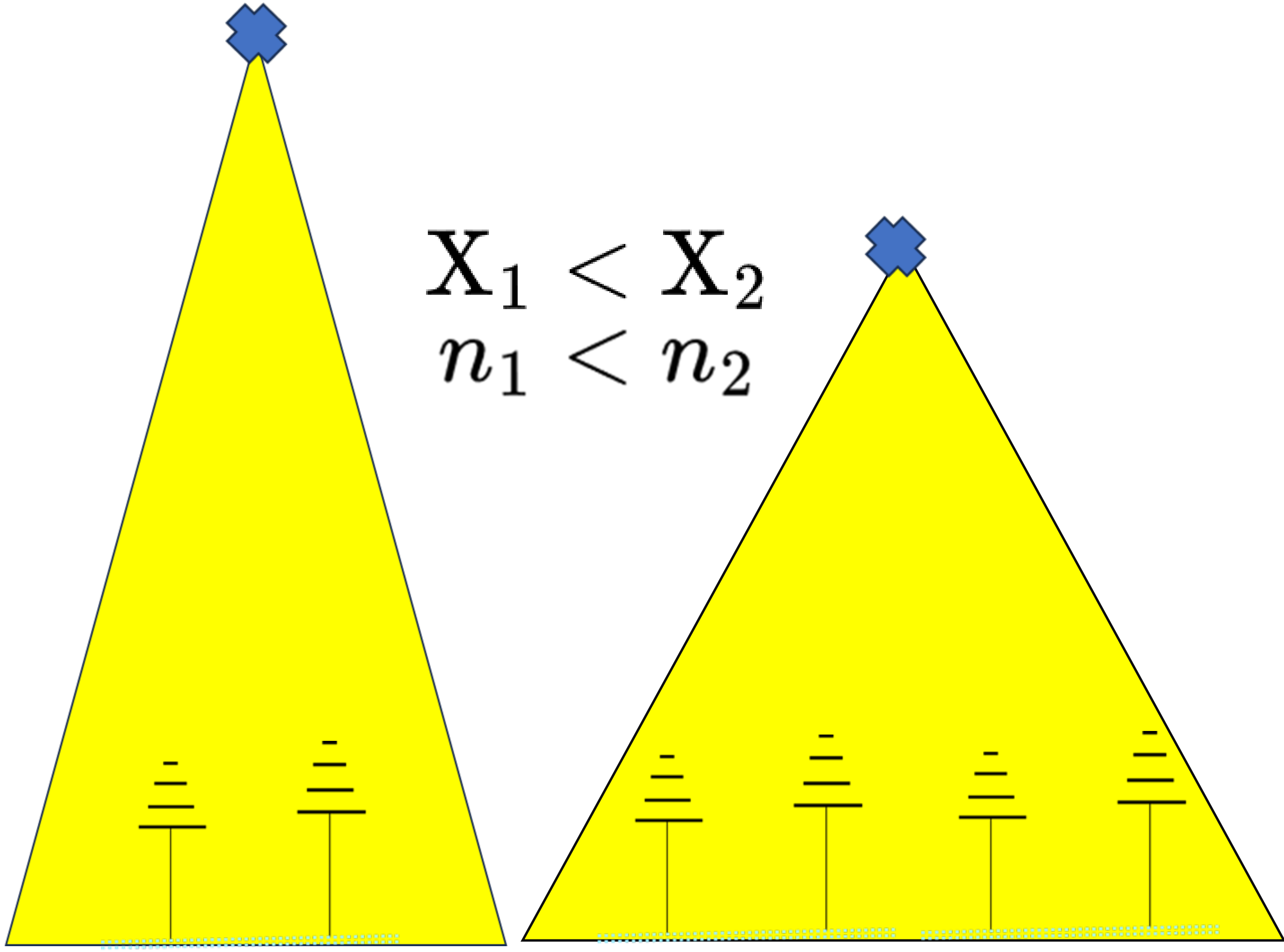
- Also, because the radio emission is a diverging beam, the projection on the ground is larger the further the emission point is from the ground

- Typically the case for vertical showers.

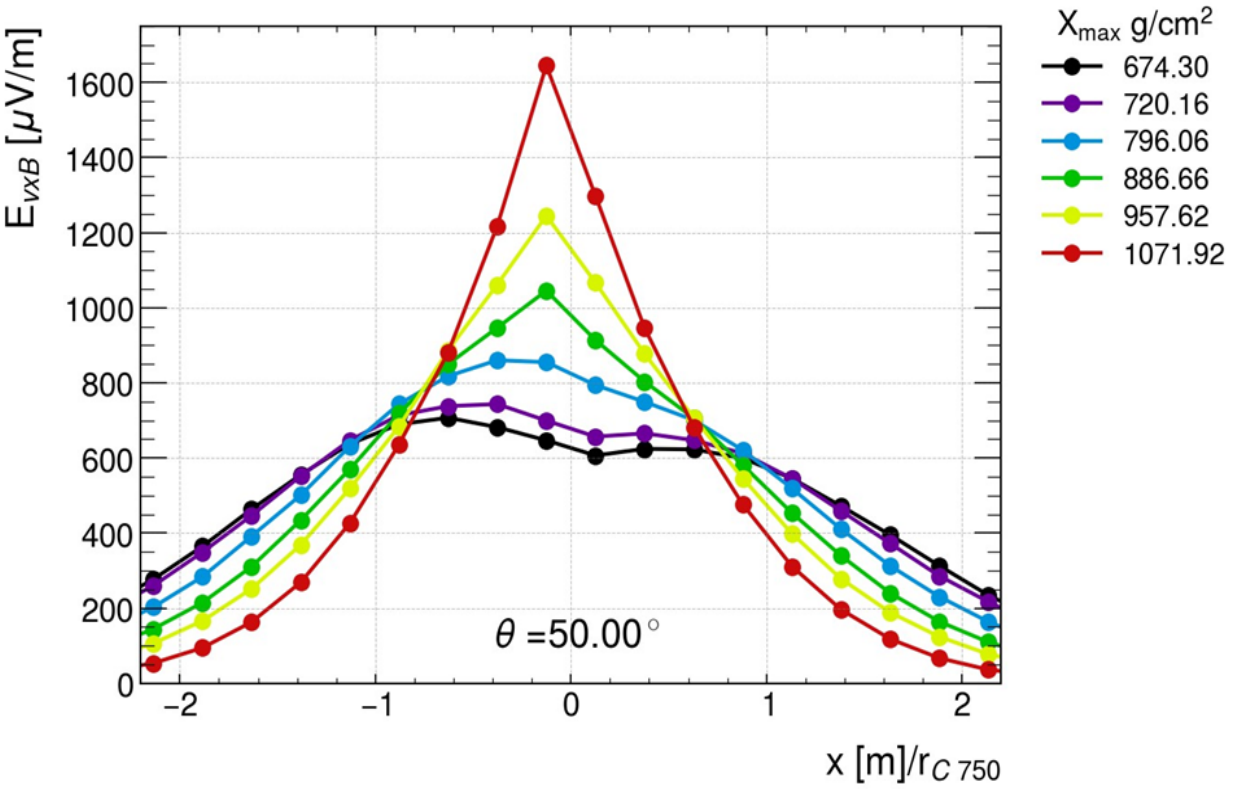


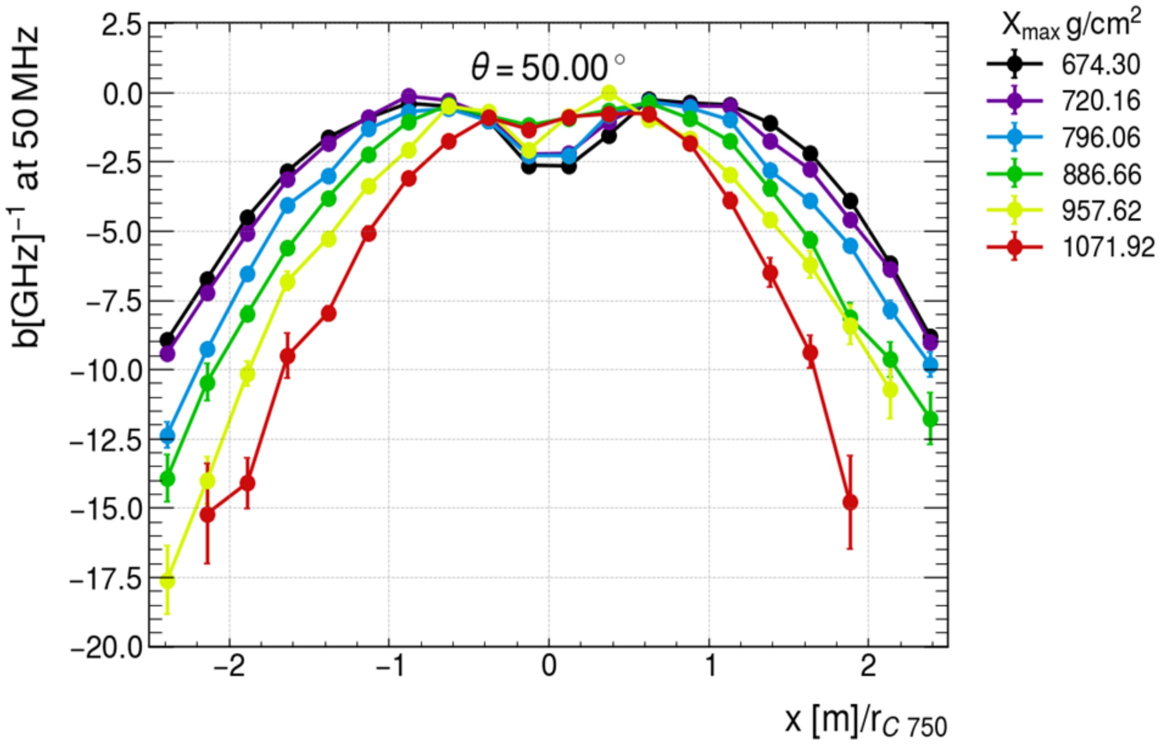
A mix:

- For distances far enough from the ground, the footprint of the deeper shower can be larger.
- This happens for nearly inclined showers.



For Zenith angles [0,82°]:

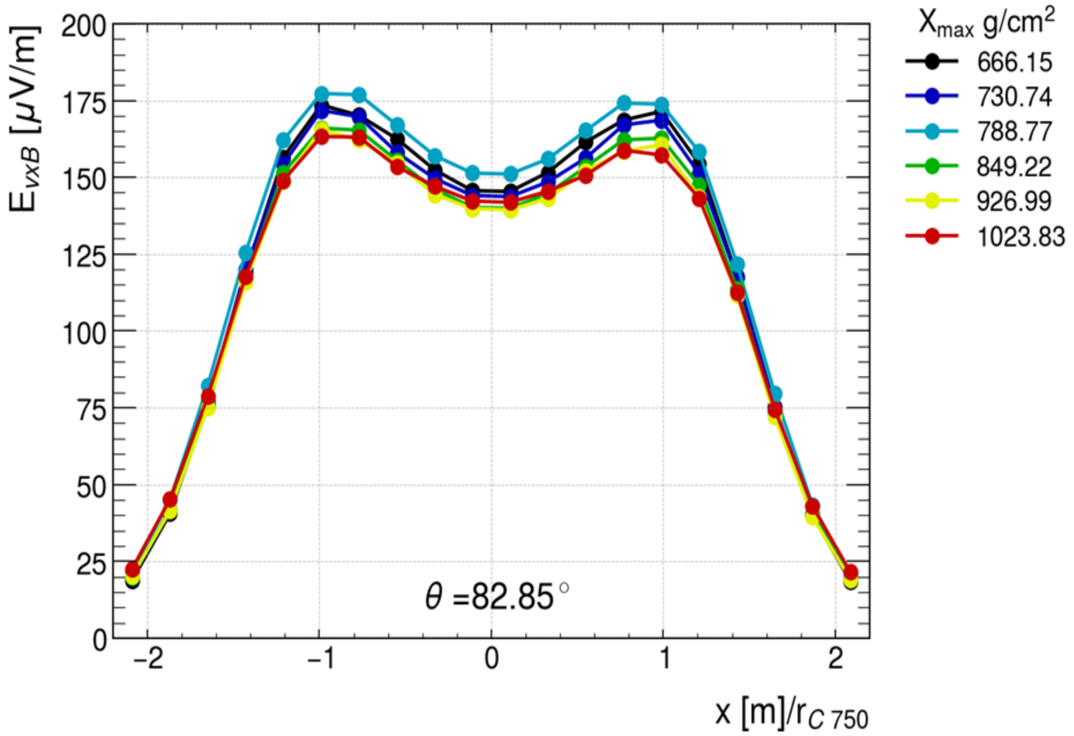


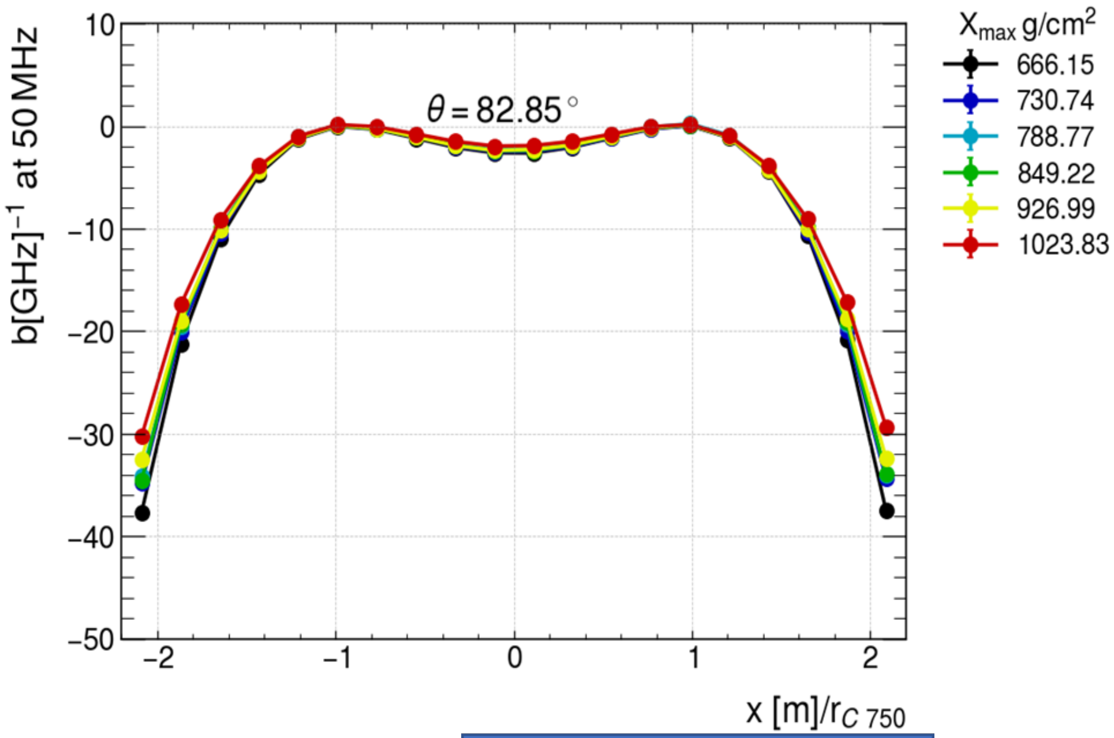


r_c=125 m

Magic/horror Angle:

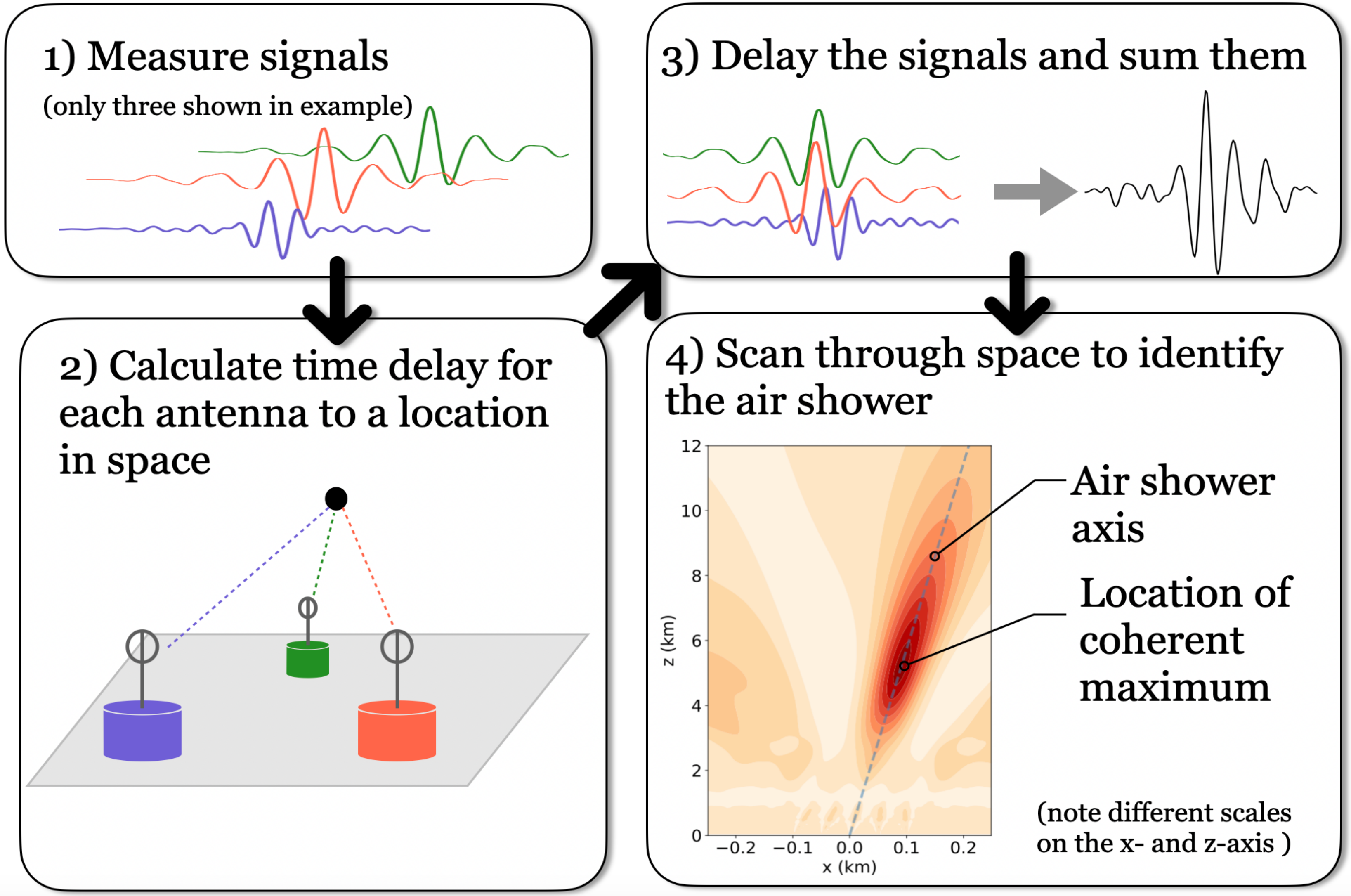
- From 82 - 86 degrees
- In this angle range the two effects, distance and refractive index cancel out.





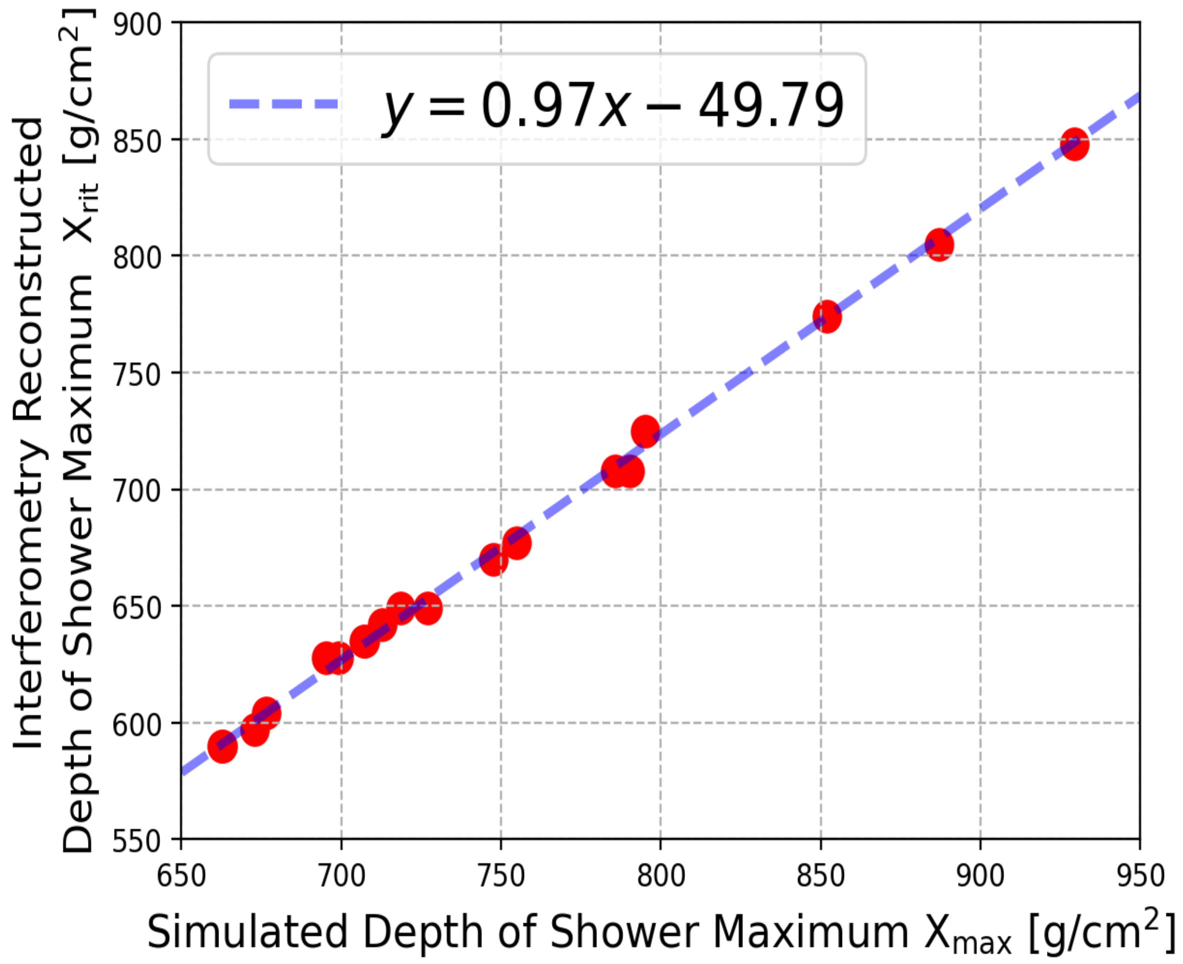
r_c=1045 m

Interferometry:



Interferometry:

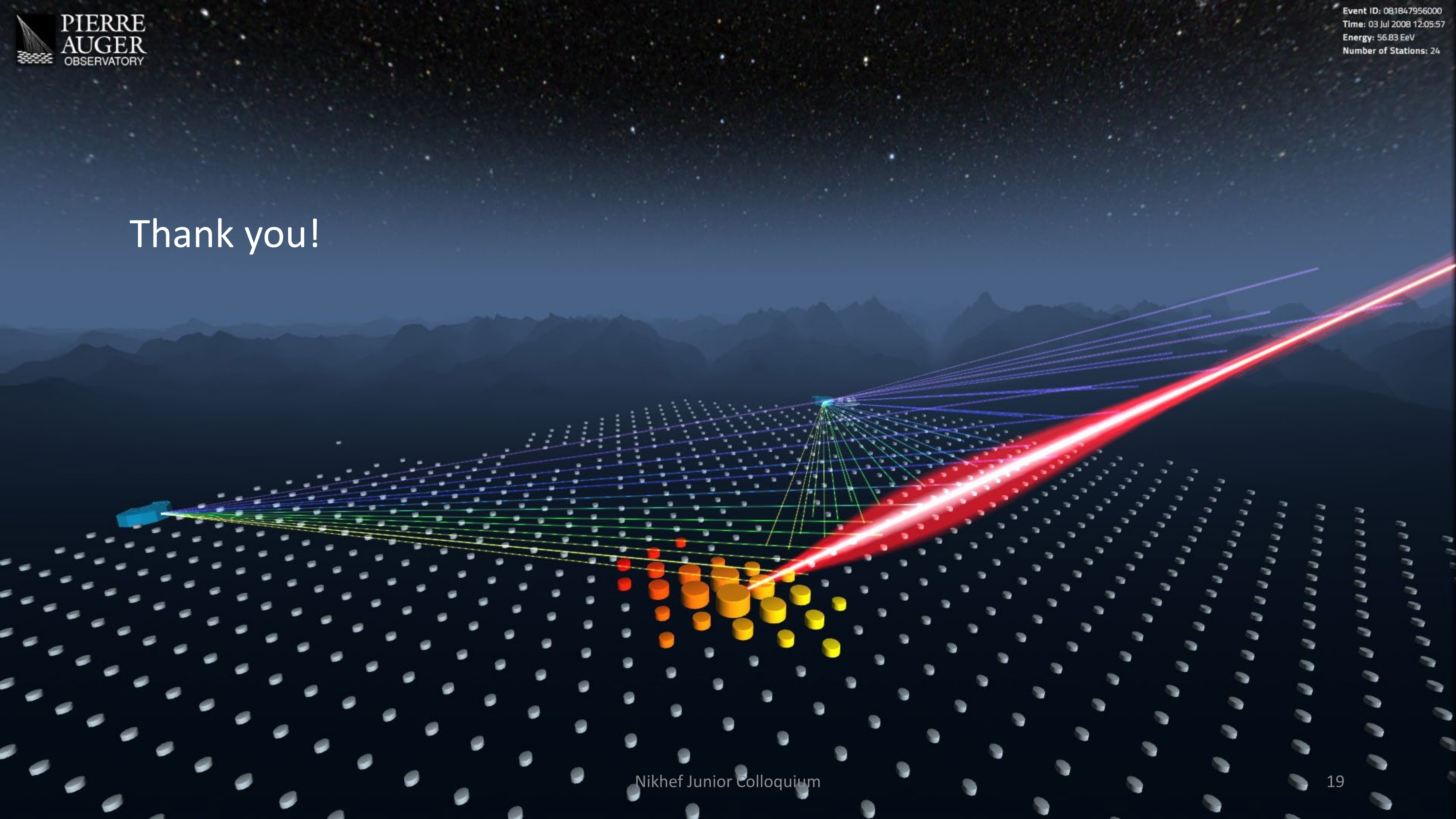
- The large footprints for inclined showers
- So even at these angles where traditional methods don’t work
- Radio interferometry works just fine.
- Provided the timing uncertainty between detectors is < 5ns
- Accurate up to 7g/cm^2



Summary:

- LDF and Spectral slope are good for measuring Xmax for zenith angles less than 82^0.
- No X_{max} dependency above 82^0
- For nearly horizontal showers interferometry would be better suited
- Timing accuracy greater than 5ns

This is where I'd put the QR code of the paper …


PIERRE AUGER OBSERVATORY
Event ID: 081847956000
Time: 03 Jul 2008 12:05:57
Energy: 56.83 EeV
Number of Stations: 24

Thank you!