Simulations studies for the RF performance of the Astroneu II Array

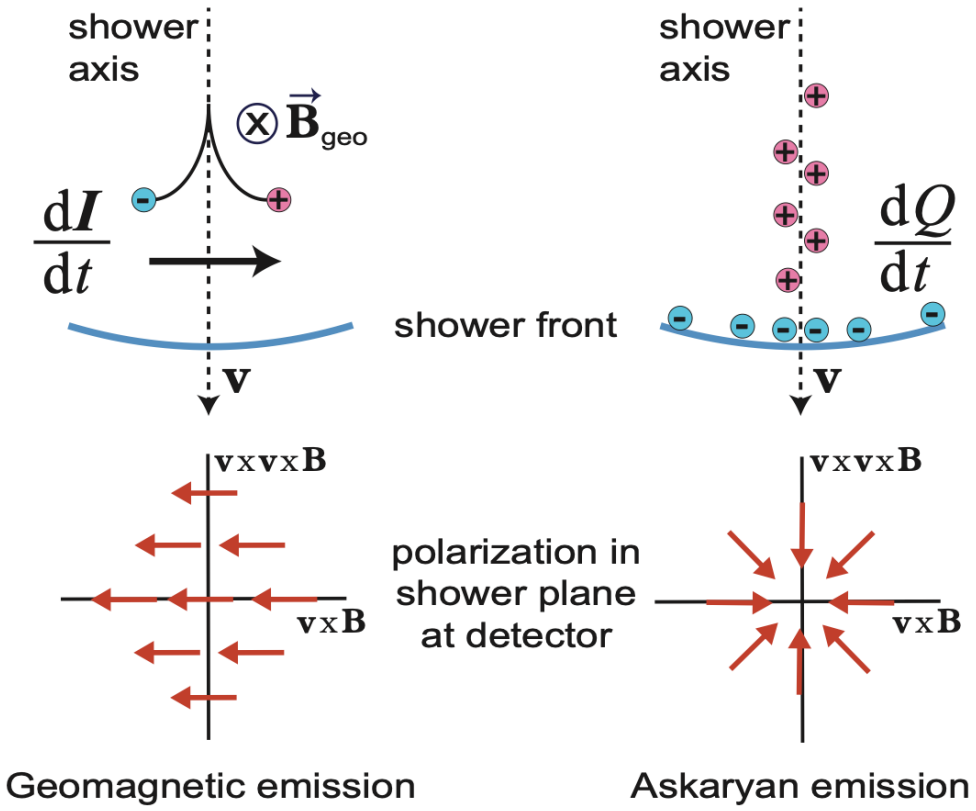
Stavros Nonis on behalf of the ASTRONEU collaboration

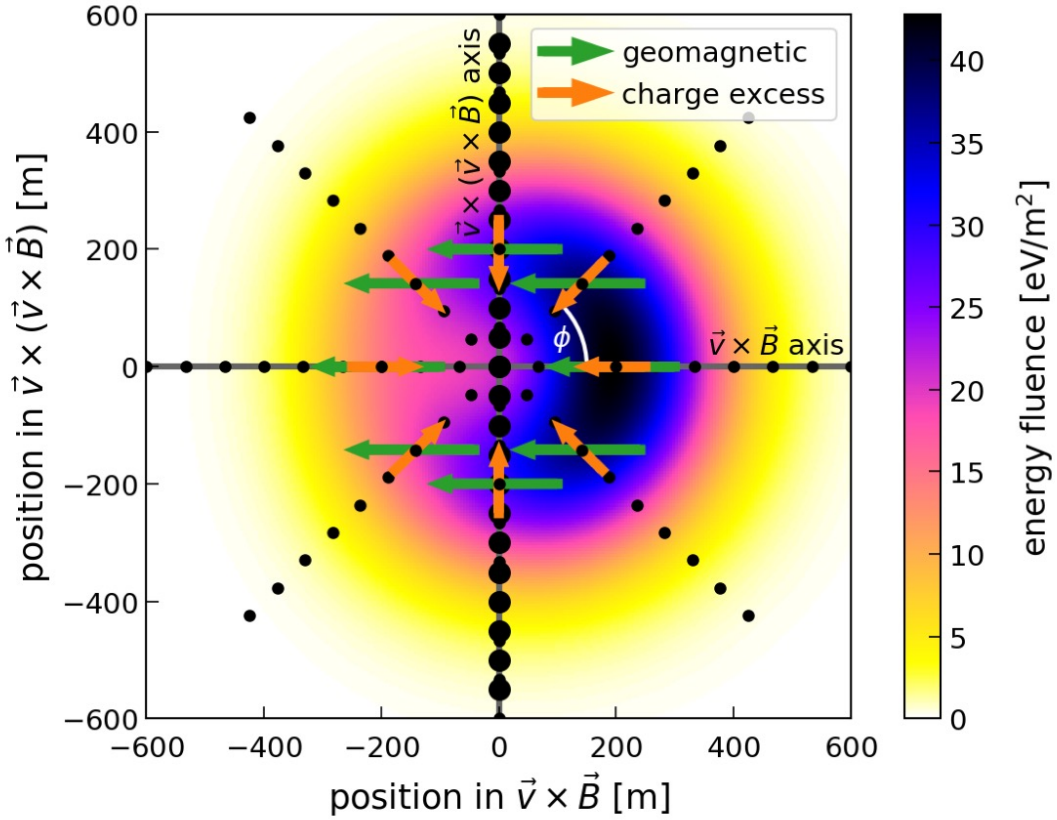
HEP 2023 - 40th Conference on Recent Developments in High Energy Physics and Cosmology, Ioannina, Greece, 5-8 April 2023

Outline

- ➔ Radio Emission from Extensive Air showers
- ➔ Astroneu Array I & II
- ➔ Simulations Sample
- ➔ Event Selection & Analysis
- ➔ Results
- ➔ HOU contribution to the GRAND experiment
- ➔ Summary – Conclusions

Radio Emission from Extensive Air showers





1st order: geomagnetic radiation

➔ Electrons/positrons deflected in Earth magnetic field B

➔ Polarized into direction of Lorentz force

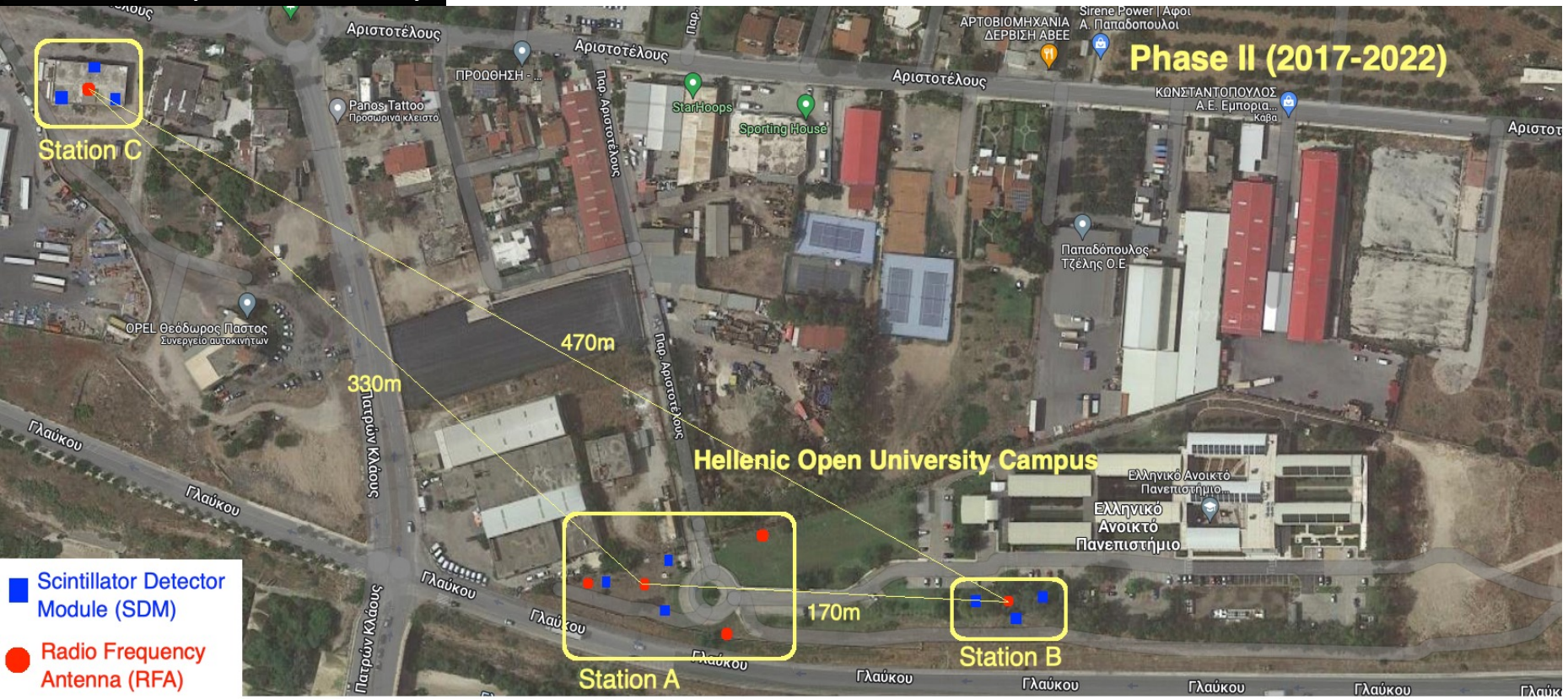
➔ E-field strength ∝ $sin\alpha$ (α: geomagnetic angle)

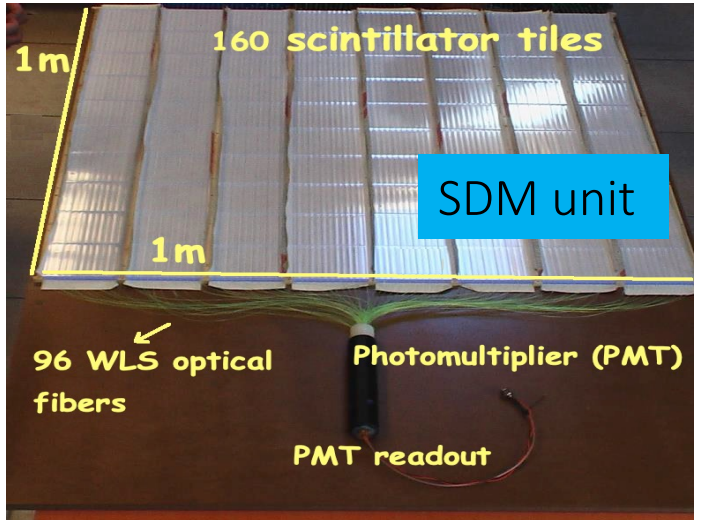
2nd order: charge excess / Askaryan effect

➔ Time varying net charge excess

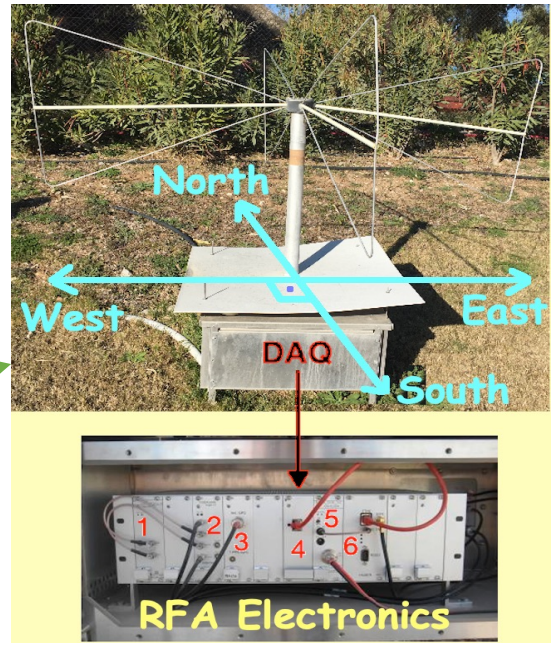
➔ Radially polarized towards shower axis

ASTRONEU I

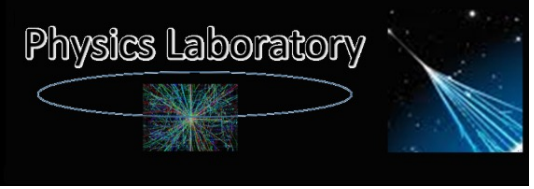




Antenna



- ➔ 3 Stations
- ➔ 3 SDMs in each Station
- ➔ 1-4 Antennas in each Station



ASTRONEU I

HELLENIC OPEN UNIVERSITY

ASTRONEU Array Description

The Astroneu Extensive Air Shower array, 2020 *JINST* **15** T03003

Detection of the RF component and RF signal Analysis

Hybrid Detection of High Energy Showers in Urban Environments, Universe 2019, 5(1), 3

Studies for high energy air shower identification using RF measurements with the ASTRONEU array, EPJ Web of Conferences 210, 05010 (2019)

Cosmic Ray RF detection with the Astroneu array, New Astronomy, Volume 81, 2020

Angular reconstruction of high energy air showers using the radio signal spectrum, 2020 Phys. Scr. 95 084007

Performance of the RF detectors of the Astroneu Array. Universe 2023, 9, 17.

- RF Signal Analysis
- Electric Field Reconstruction
- RF Power Spectrum
- RF Emission Mechanisms

Performance and Detector developments

Detection of high energy showers by the Astroneu extensive air shower array, New Astronomy, Volume 82,2021

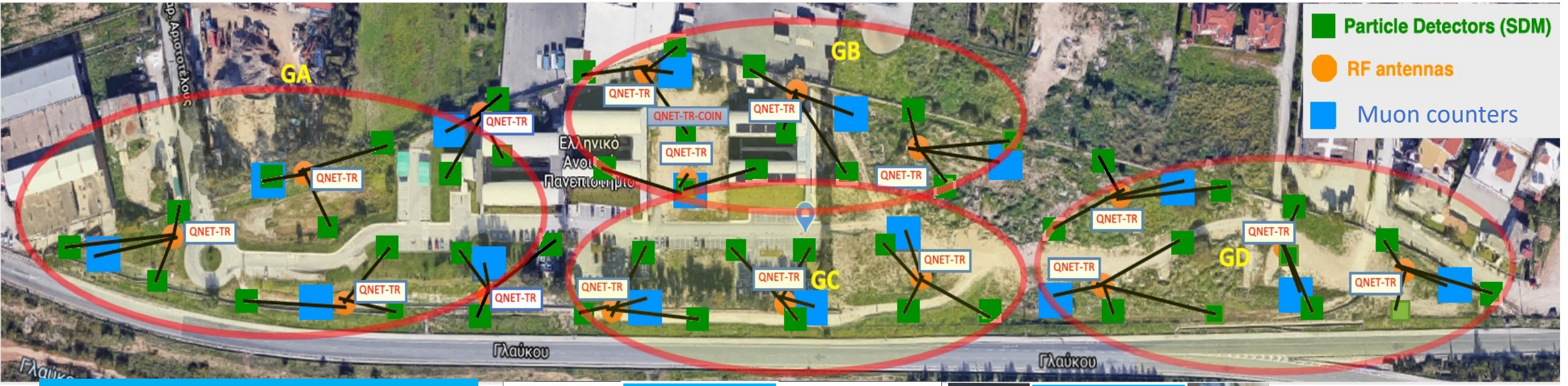
A 100 ps multi-time over threshold data acquisition system for cosmic ray detection, 2018 Meas. Sci. Technol. 29 115001

A low cost hybrid detection system of high energy air showers, 2020 *Eng. Res. Express* **2** 025027

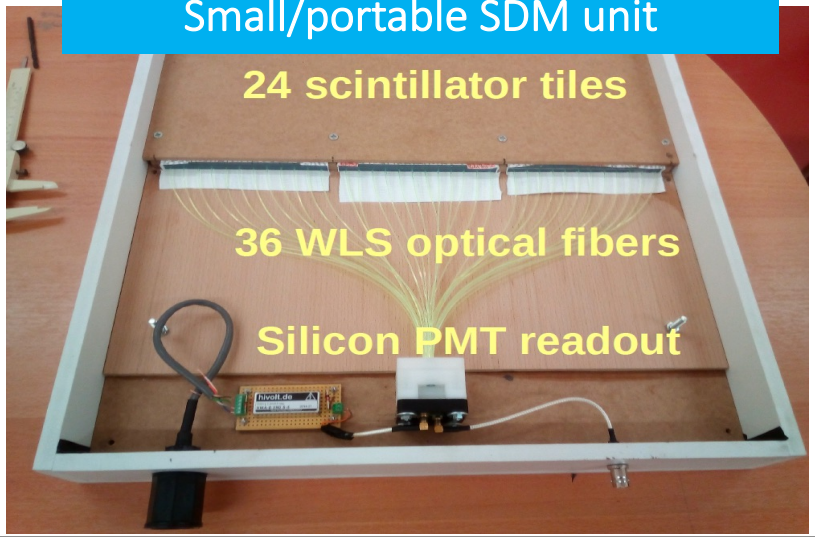
Operation and performance of a pilot HELYCON cosmic ray telescope with 3 stations, arXiv:1801.04768

- Detector Performance
- DAQ developments
- Detector Design

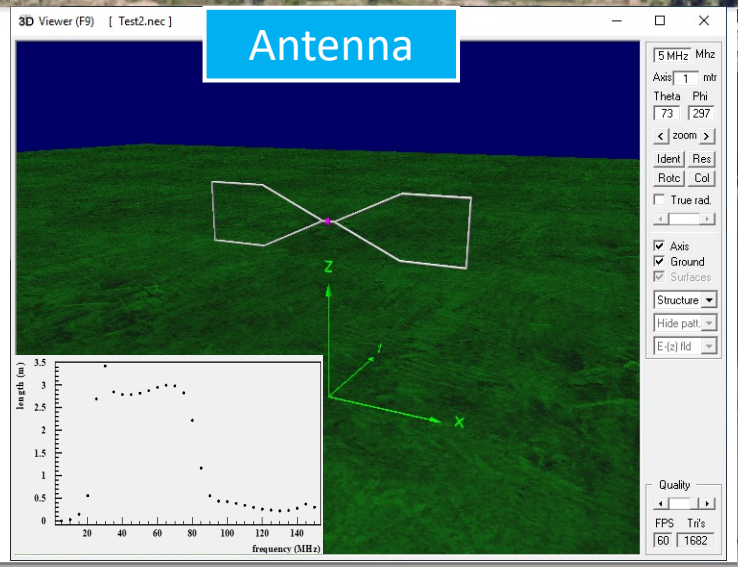
ASTRONEU II



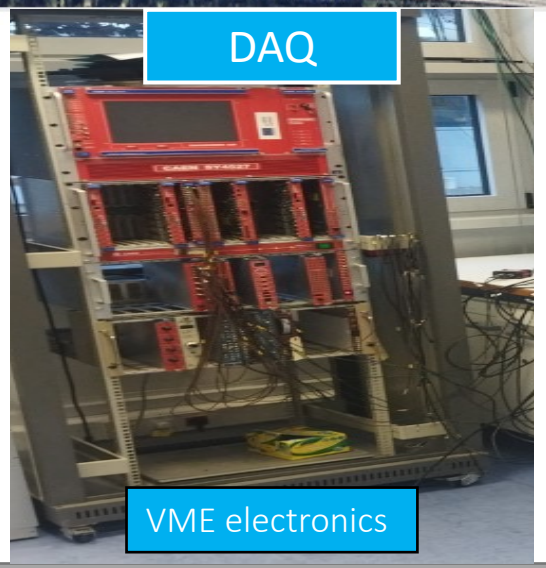
Small/portable SDM unit



Antenna



DAQ



- 16 Stations
- 3 SDMs
- 1 Muon Counter
- 1 RF Antenna

The simulation Sample

Physics Laboratory
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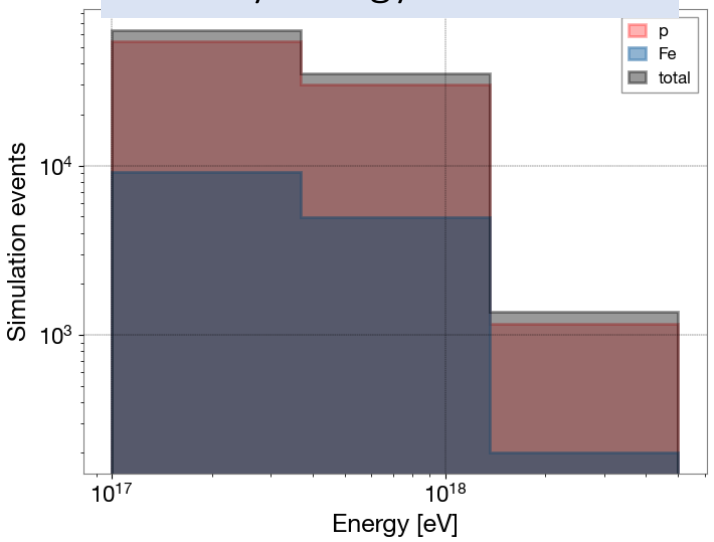
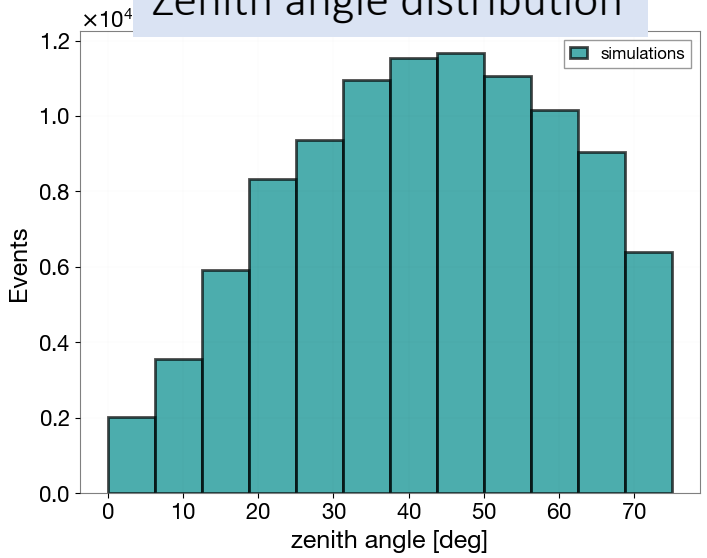
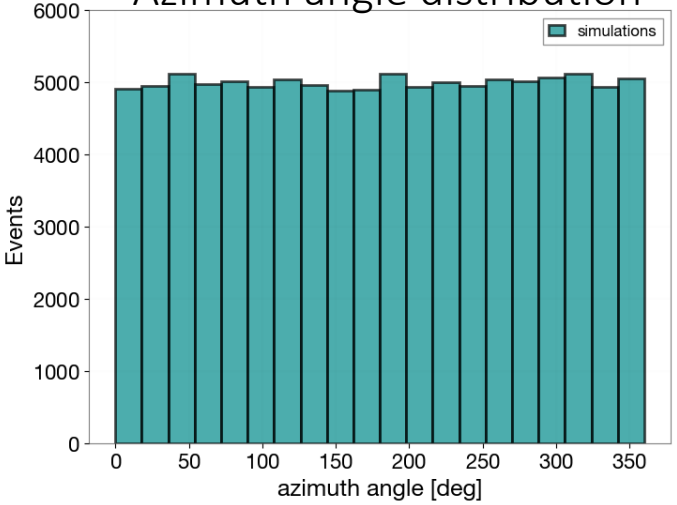
Primary Energy distribution



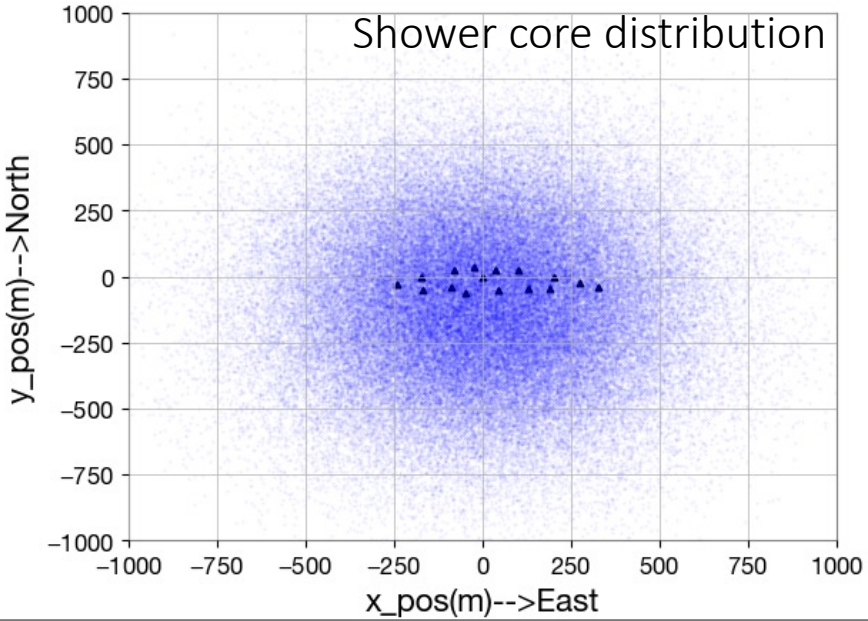
Zenith angle distribution



Azimuth angle distribution

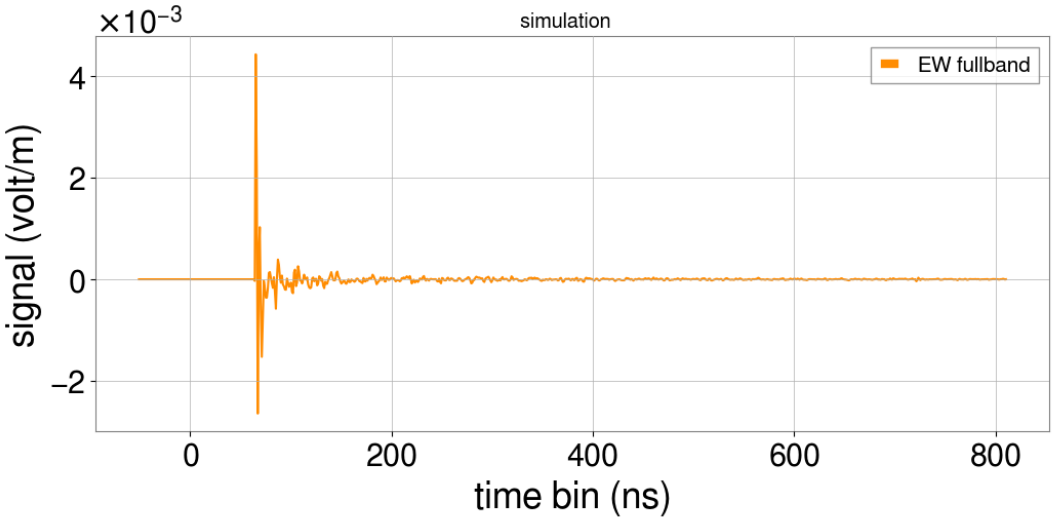


Shower core distribution

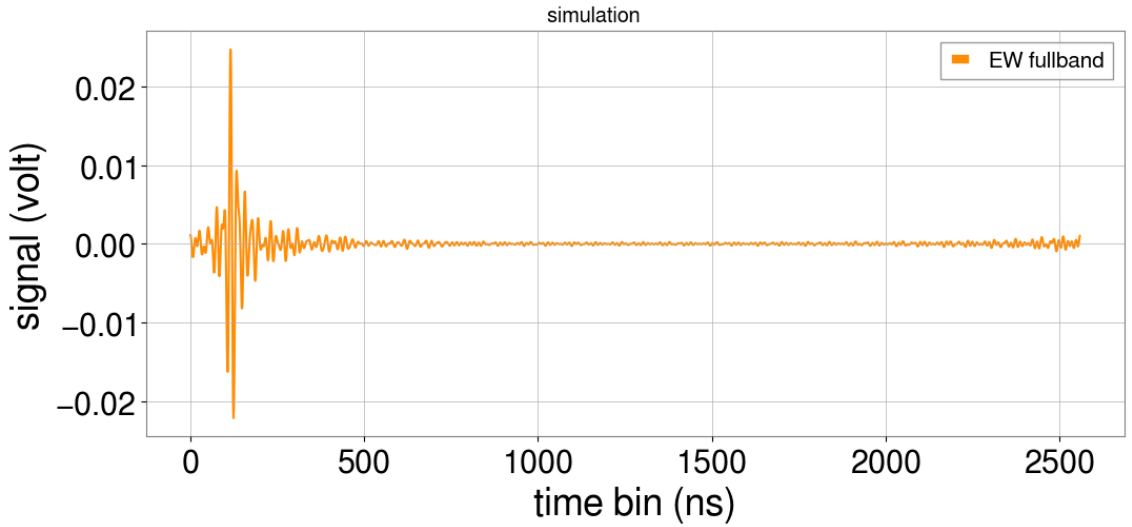


- ➔ Corsika simulation Package
- ➔ Coreas for the RF simulation
- ➔ 10^5 simulated events
- ➔ Energy $10^{17} - 5 \cdot 10^{18}\ eV$
- ➔ Primary proton, Fe
- ➔ Zenith angle (θ) distribution according to $sin\theta \cdot cos\theta$
- ➔ uniform distribution for the azimuth angle (ϕ)
- ➔ shower core position is distributed in a circular area of radius $\sim 500m$ around the array (area$\sim 1.1\ Km^2$)

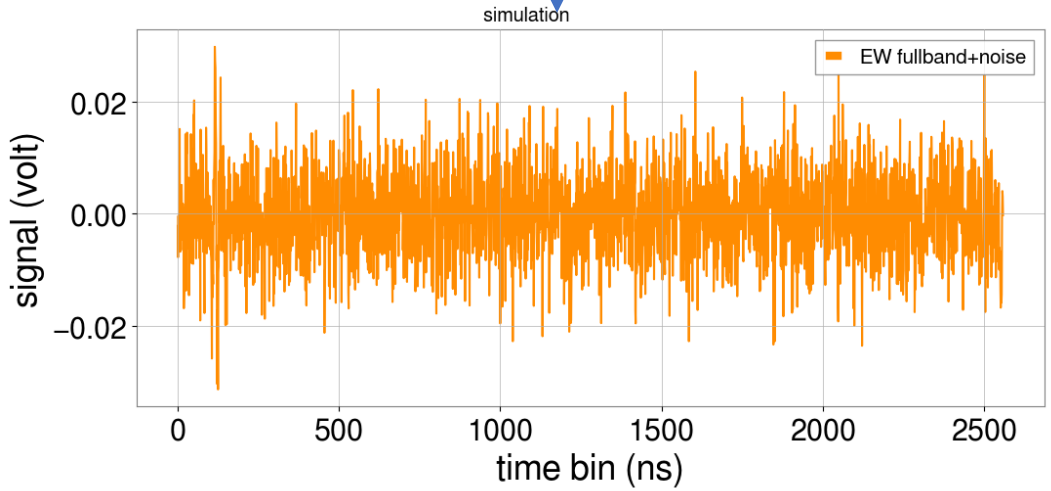
Building an Event



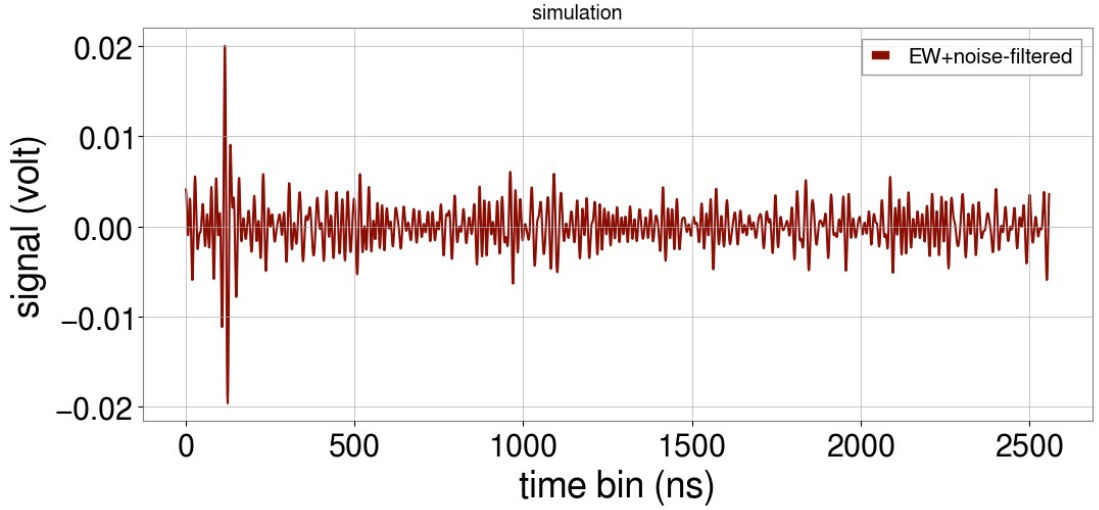
Convert from E-field to induced Voltages in the antenna



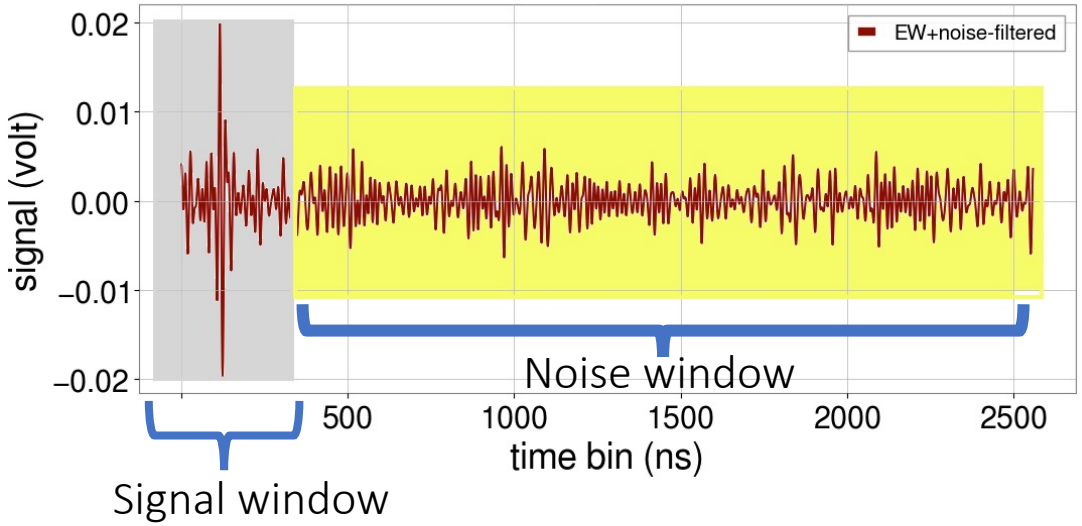
Add background noise



Filtering Algorithm keep frequencies 30-80 MHz

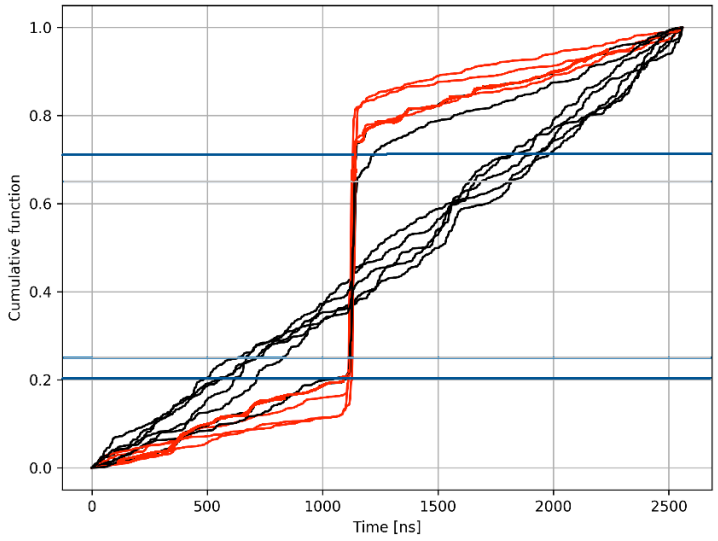


Event Selection



➔ Signal to noise ratio algorithm 1

$$SNR = \frac{\frac{1}{200} \cdot \left(\sum_{j=i-100}^{i+100} V_j^2 \right)}{\frac{1}{2360} \cdot \left(\sum_{j=1}^{i-100} V_j^2 + \sum_{j=i+100}^{2560} V_j^2 \right)} \geq 6$$



➔ Rise Time Algorithm 2

$$C(k) = \frac{\sum_{j=i-128}^{j=i-128+k} V_j^2}{\sum_{j=i-128}^{i+128} V_j^2}$$

Rise Time = R_t = C(0.7)-C(0.2)$\leq 28ns$

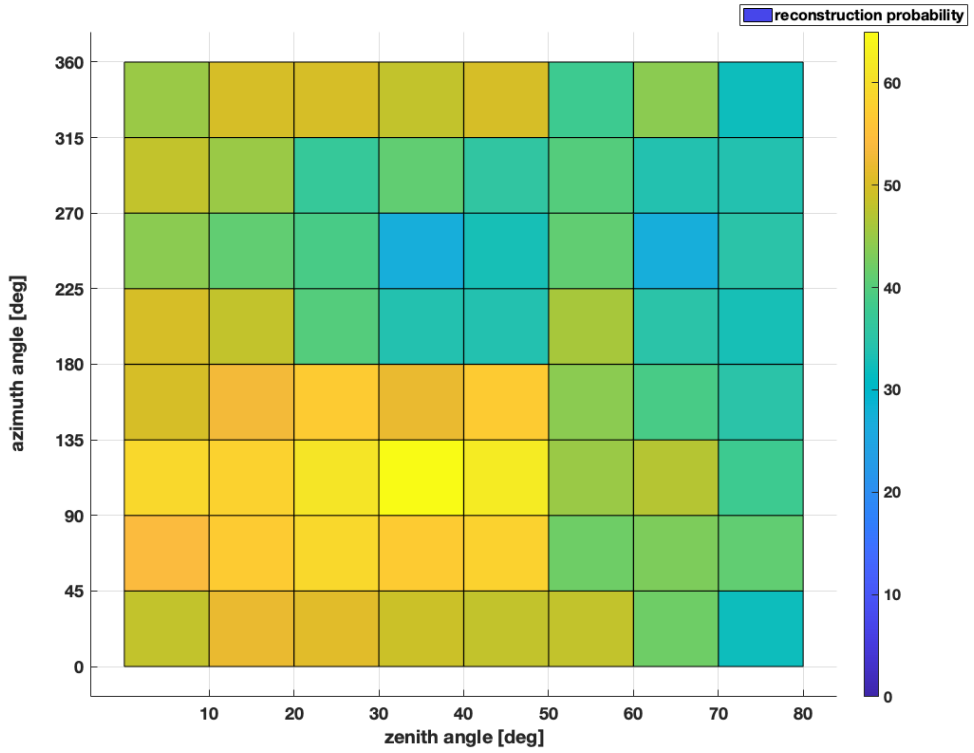
➔ Polarization Algorithm 3

$$p = \frac{\sqrt{Q^2 + U^2 + V^2}}{I} > 0.85$$

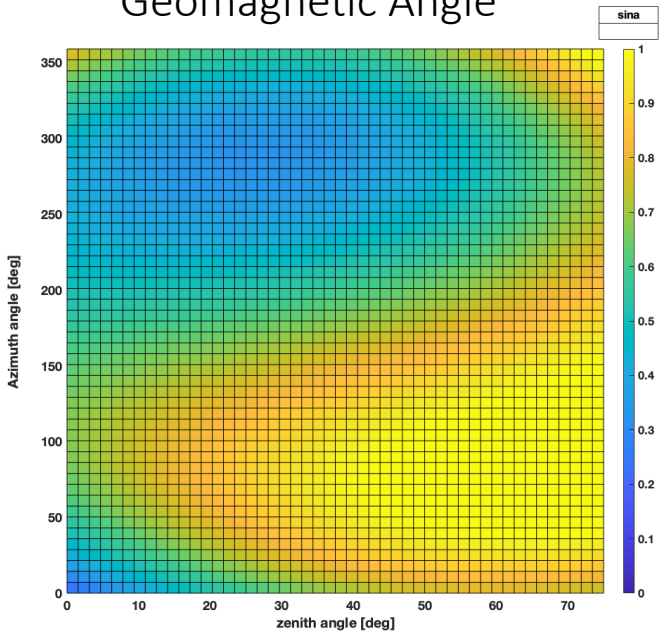
p : Degree of polarization

RESULTS

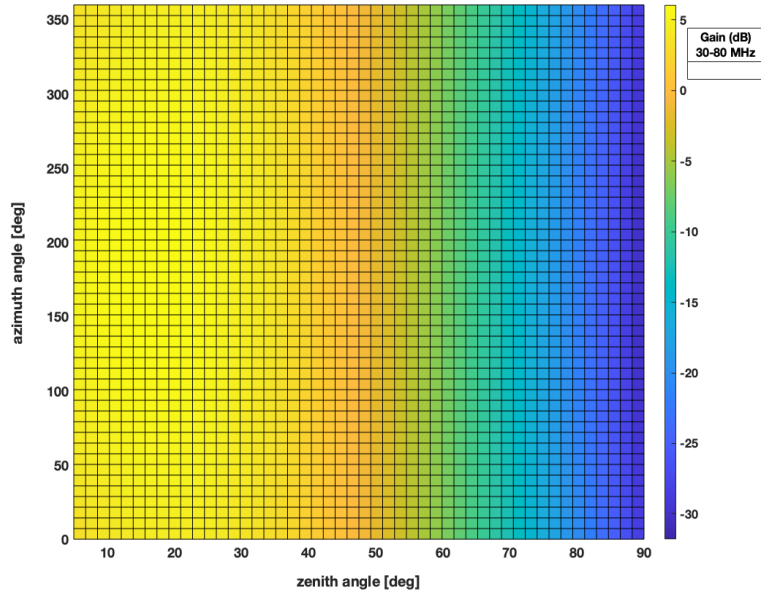
Reconstruction probability with respect to zenith and azimuth angles



Geomagnetic Angle



Antenna Gain

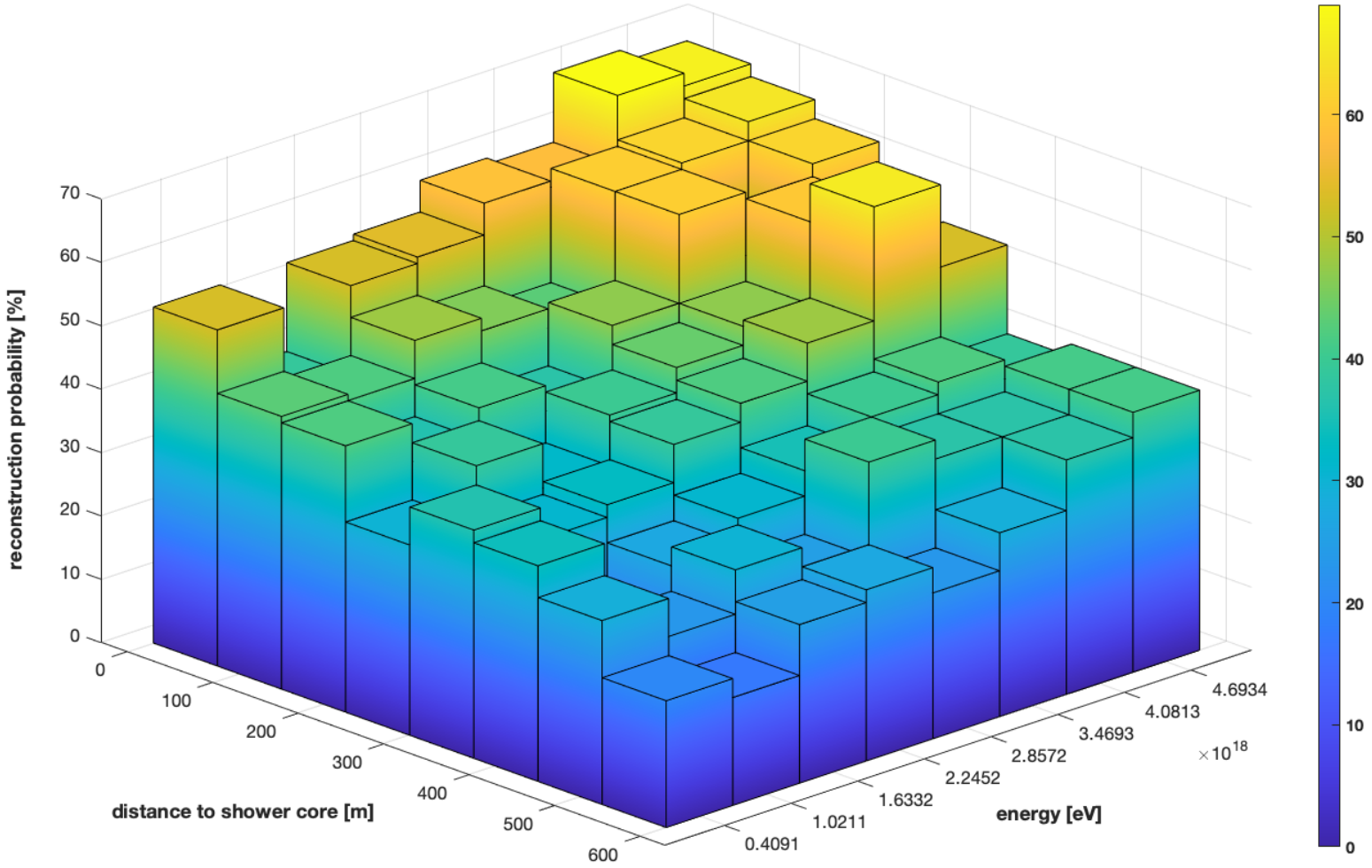


➔ Results compatible with the geomagnetic angle variation and the antenna gain

Successful event reconstruction ➔ At least 5 signals (antennas) pass the criteria

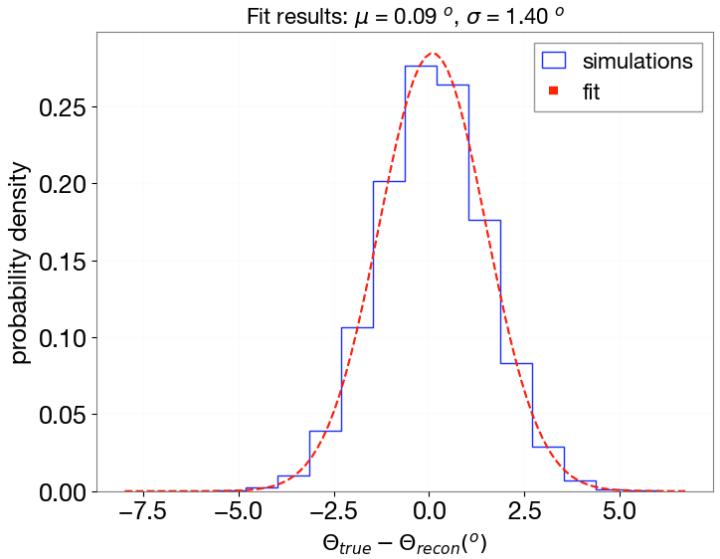
Reconstruction probability = Number of events successfully reconstructed / total number of events in the bin

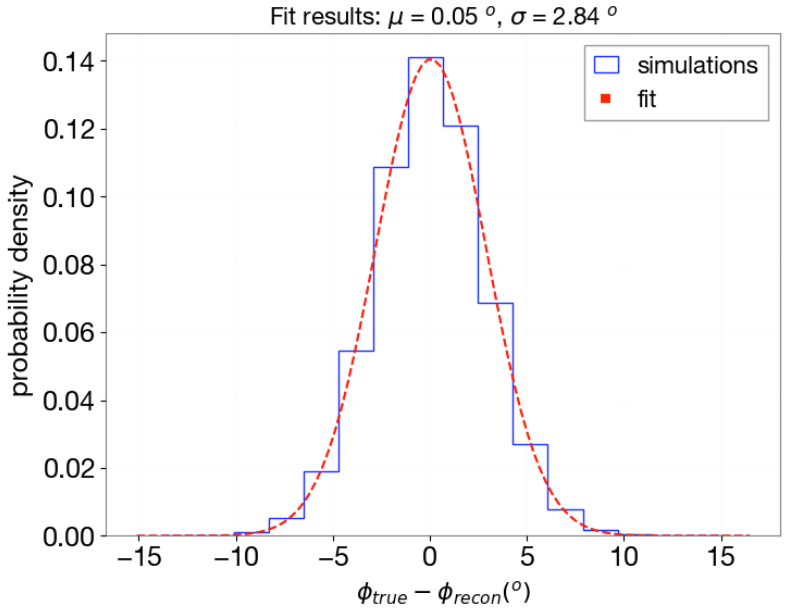
RESULTS

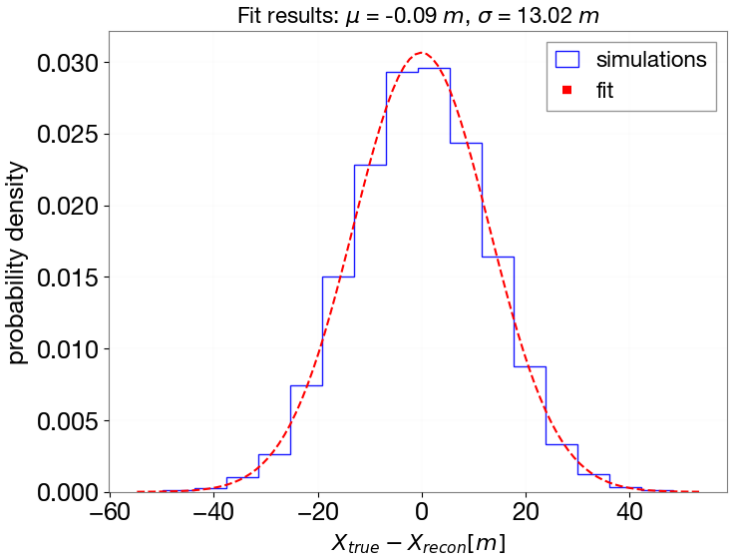


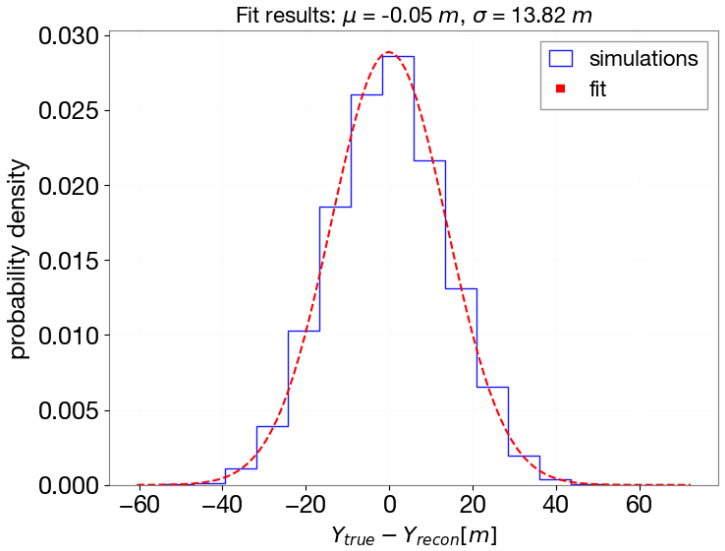
➔ Reconstruction probability for different distance to shower core and energy bins

RESULTS







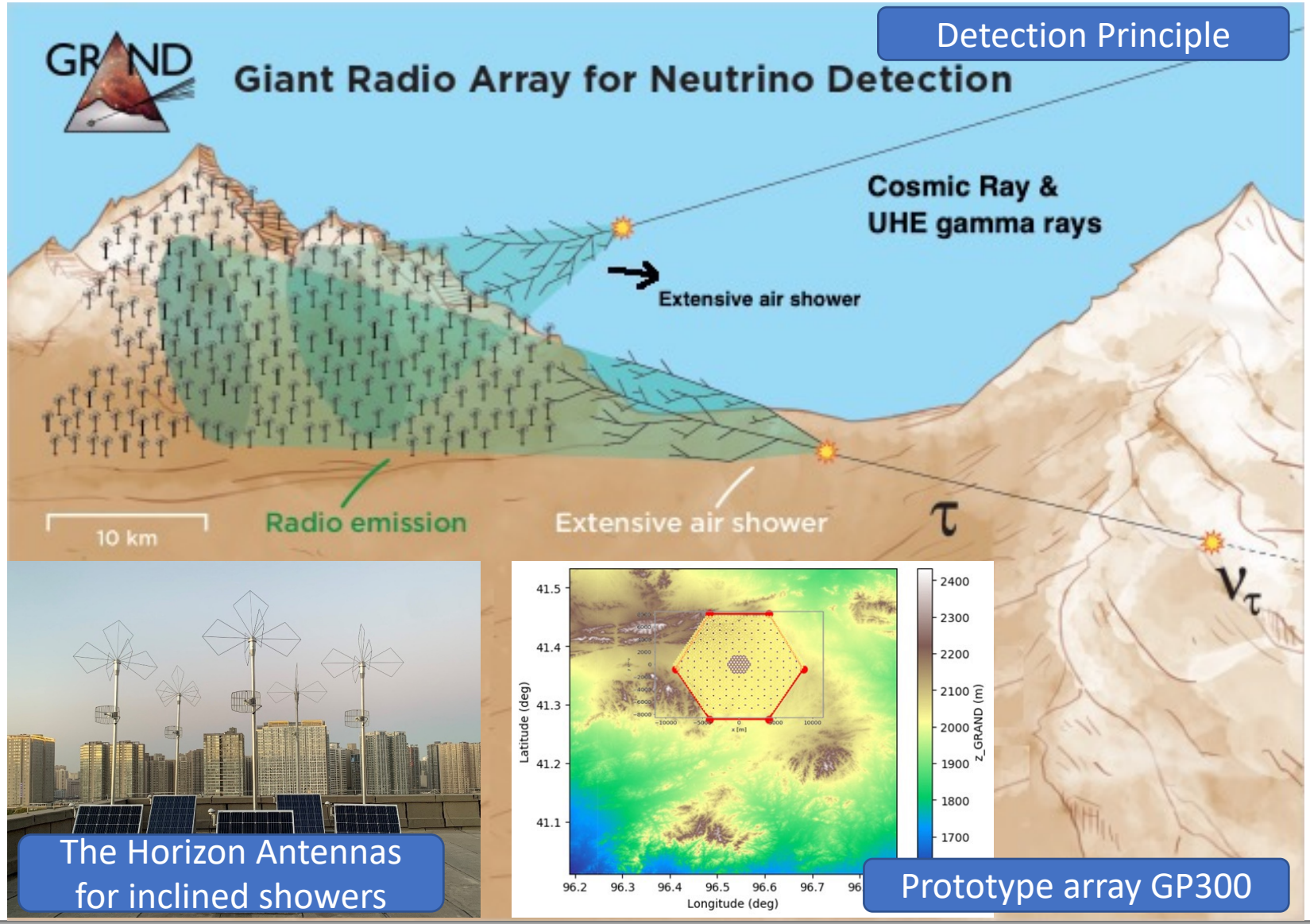


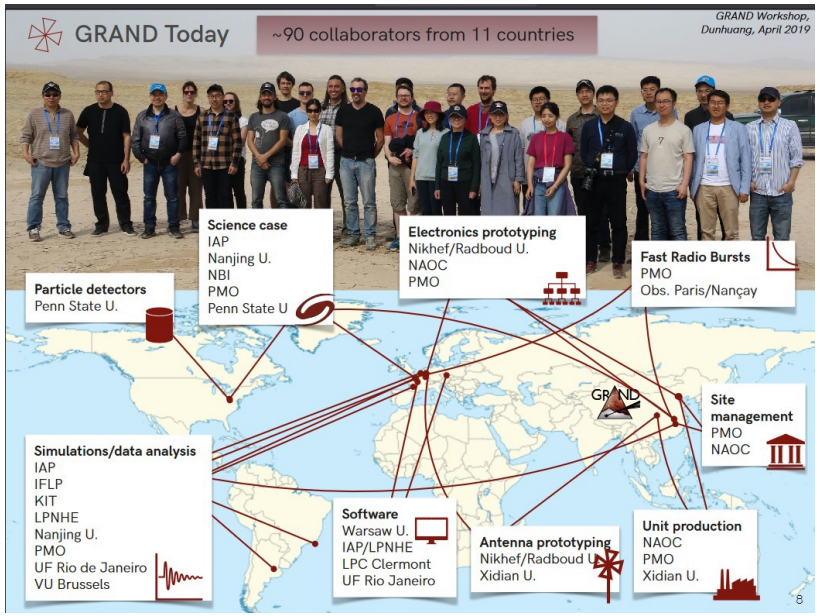
➔ The resolution in estimating the zenith and azimuth angles

➔ The resolution in estimating the the shower core position

The GRAND experiment

The Physics Laboratory of HOU part of the GRAND collaboration





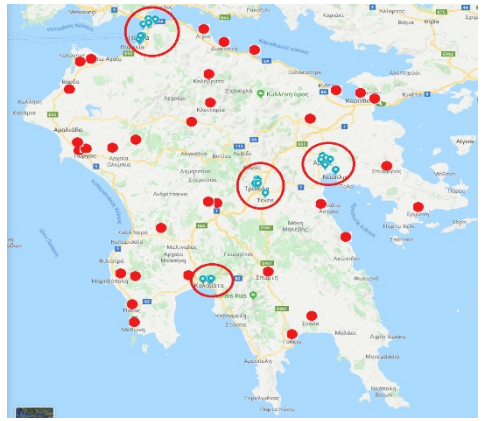
The Horizon Antennas for inclined showers

Prototype array GP300

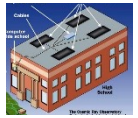
Candidate Installation Locations

Educational cosmic ray telescopes

Int. Journal of Modern Physics A Vol. 35, No. 34n35, 2044022 (2020), https://doi.org/10.1142/S0217751X20440224

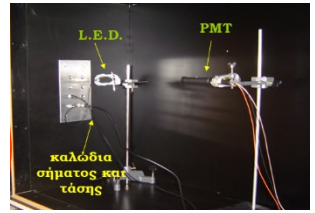


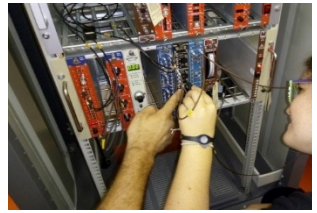


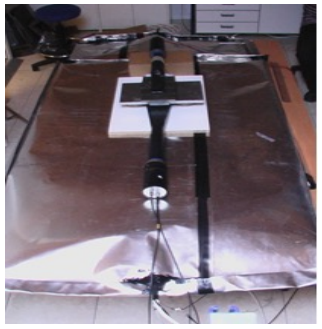


µCosmics detectors at high schools

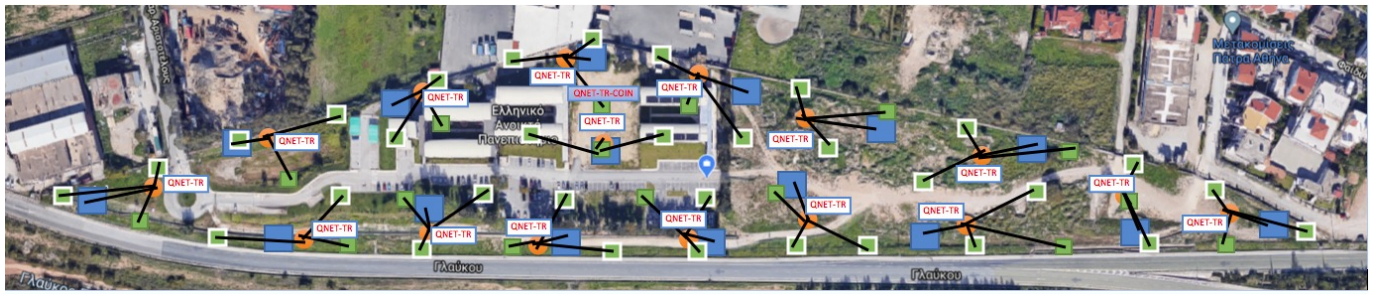
µNet







Remote operated experimental setups of the HOU Physics Lab



Utilization of the detection stations deployed at the HOU university campus

Summary - Conclusions

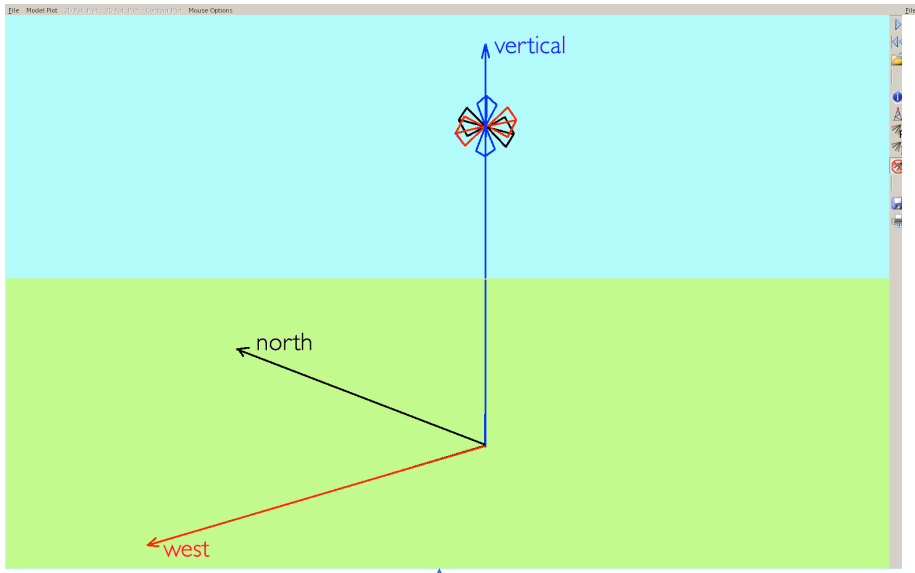
- Simulation study for the RF performance of the new Astroneu II array in estimating the shower parameters (direction, core, energy, X_{max}).
- A sufficient large detection probability (considering the area electromagnetic background) in a wide range of shower directions (even in inclined shower up to 75 degrees).
- Effective detection area of the order of 1 Km^2 around the center of the array in the energy range $10^{17} - 5 \cdot 10^{18}$ eV.
- Very good resolution in estimating the shower direction and core.
- Studies in progress in order to specify the resolution in estimating the energy and the X_{max}.
- A testbench for the GRAND experiment (antenna characterization, software and analysis algorithms development, DAQ tests etc).

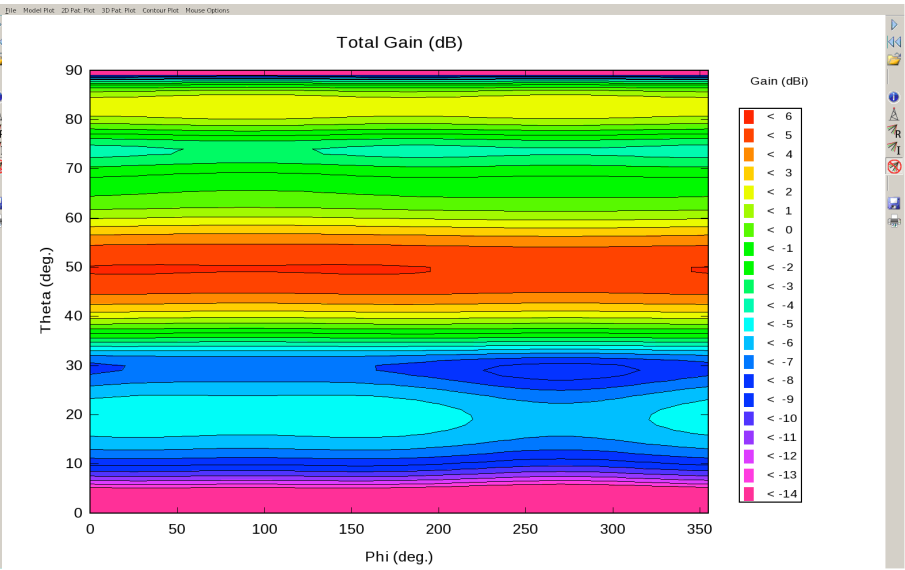
Back Up

The GRAND experiment

The HOU contribution to the GRAND experiment

- ➔ Simulations for the antenna characteristics (gain, effective length)
- ➔ Electric field reconstruction from the voltages induced in the antenna dipoles.
- ➔ Shower simulation for studies of the array performance in the different stages of development.





NEC model for the horizon antenna

Horizon antenna gain

Mass MC production

Performance studies

Thank you for your attention !

Publications

https://doi.org/10.1088/1748-0221/15/03/T03003
https://iopscience.iop.org/article/10.1088/1361-6501/aadc48
https://doi.org/10.3390/universe5010003
https://doi.org/10.3390/universe5010023
https://doi.org/10.3390/universe5010004
https://doi.org/10.1051/epjconf/201921005010
https://doi.org/10.1051/epjconf/201818202072
https://doi.org/10.1134/S0020441220060202
https://arxiv.org/abs/1801.04768
https://doi.org/10.1016/j.newast.2020.101448
https://doi.org/10.1016/j.newast.2020.101443
https://doi.org/10.1088/2631-8695/ab9126
https://doi.org/10.1088/1361-6552/ab921b
https://doi.org/10.1088/1402-4896/ab9f79
https://doi.org/10.1142/S0217751X20440224
https://doi.org/10.3390/universe9010017