HELLENIC OPEN UNIVERSITY

School of Science & Technology

ASTRONEU
Physics Laboratory
School of Science and Technology
Hellenic Open University
Parodos Aristotelous 18, Hellenic Open University Campus, Building D, Postcode 26335, Patra, Greece

Results and Prospects of the Hellenic Open University air shower array

Stavros Nonis, Antonios Leisos, Apostolos Tsirigotis

Physics Laboratory, School of Science and Technology

Hellenic Open University

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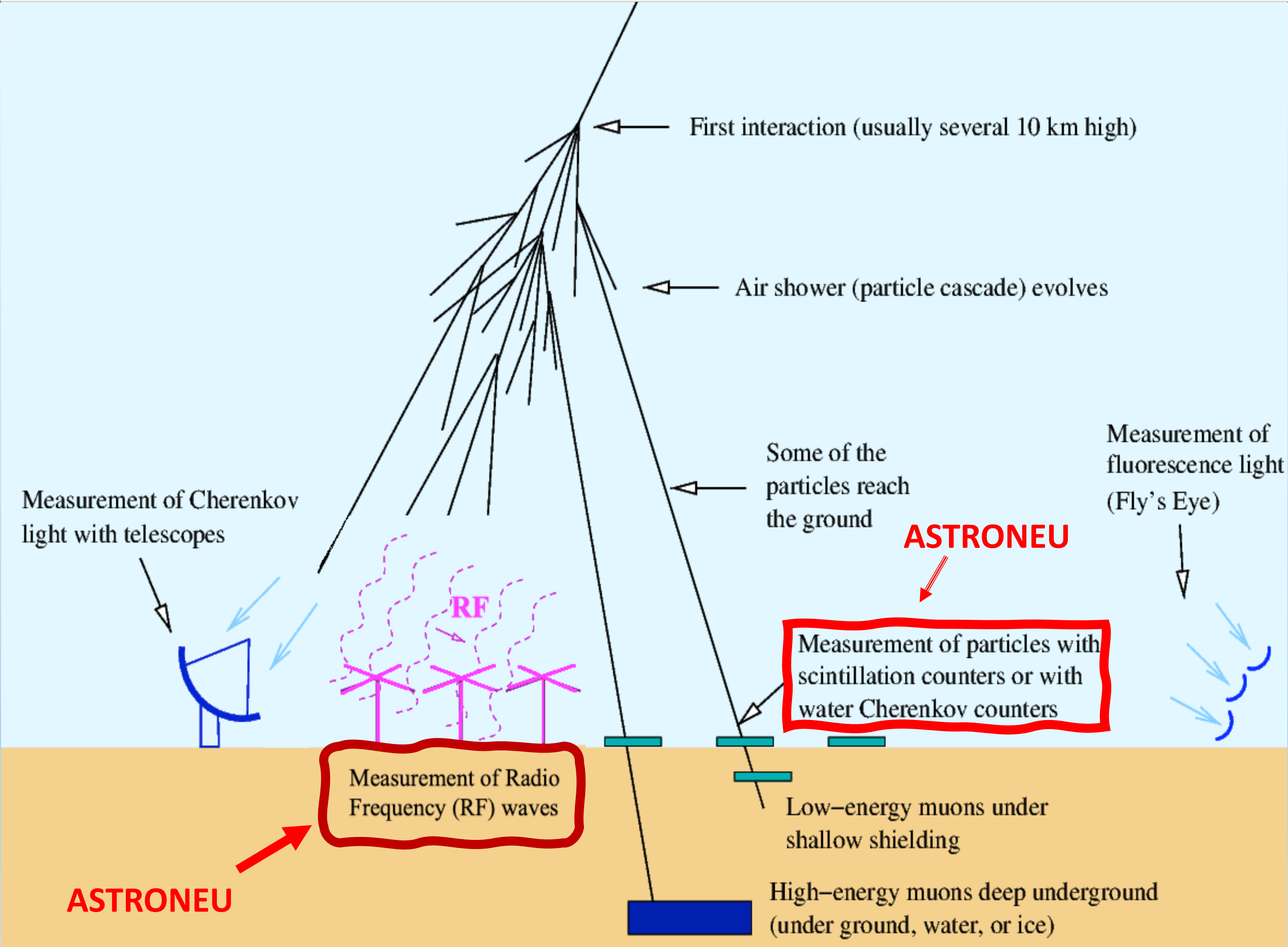
Outline

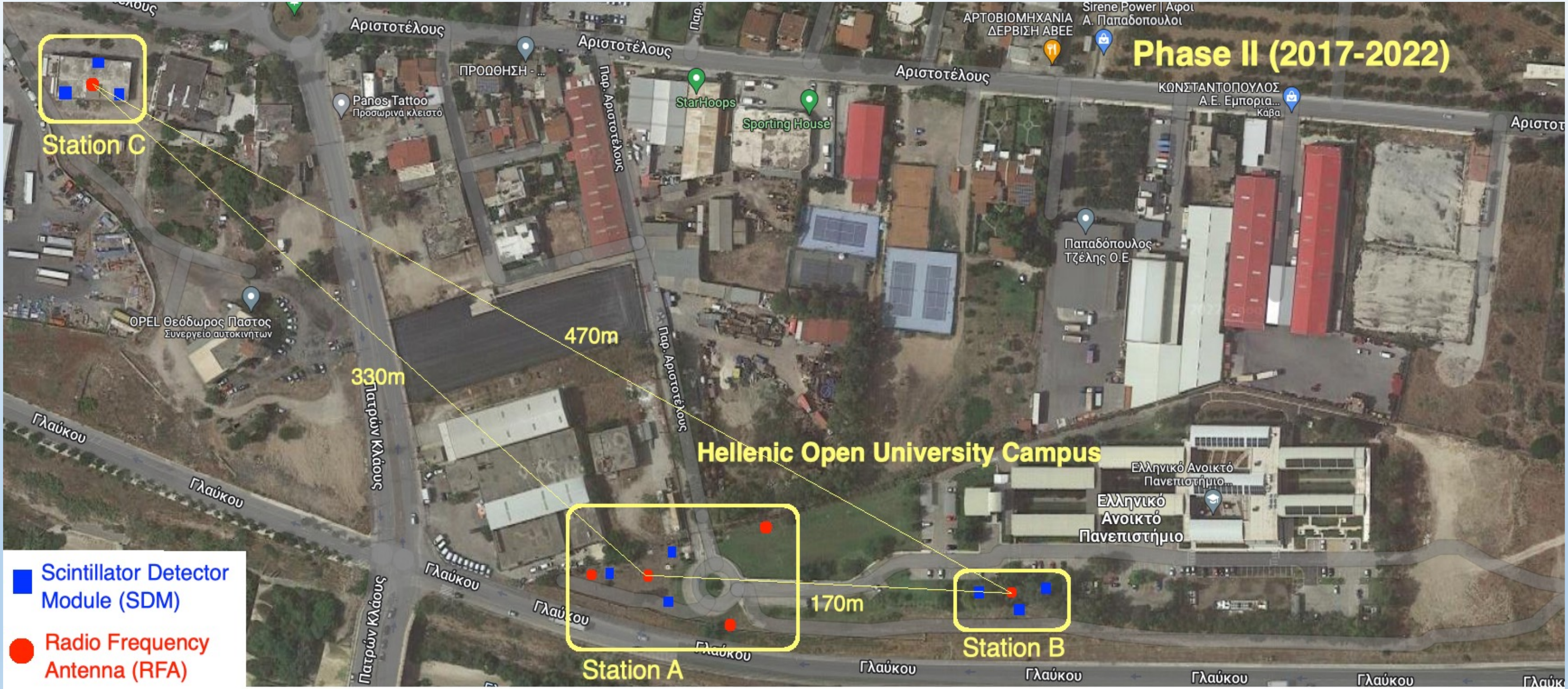
- ASTRONEU Array Status report
  - Cosmic Rays detection with ASTRONEU
  - Instrumentation
  - Performance
- Results from ASTRONEU array
- μNet-Educational Activities with ASTRONEU & μCosmics
- ASTRONEU array expansion
- Conclusions & Prospects

Extensive Air Shower (EAS) Detection with ASTRONEU



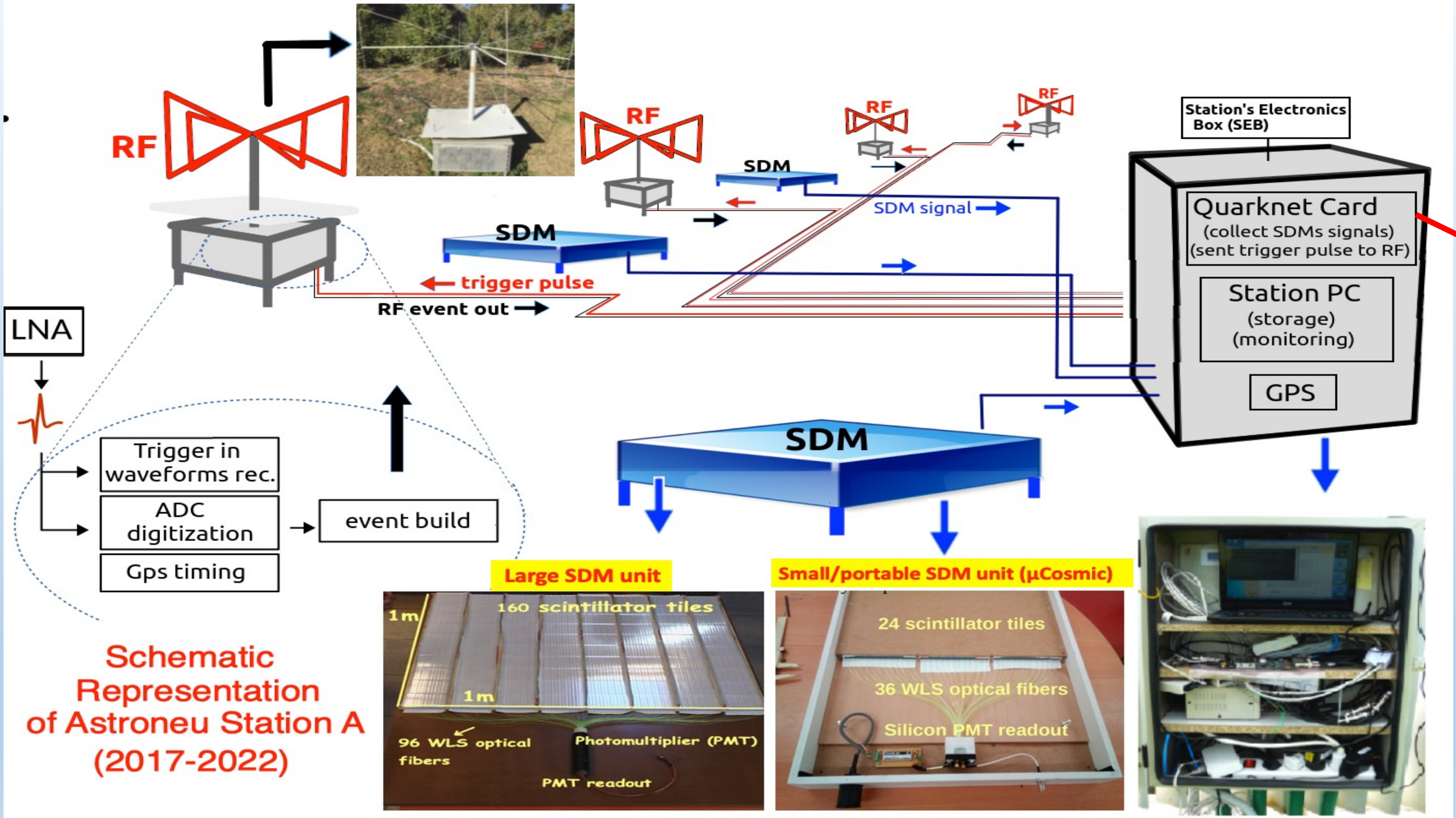
- High energy (> 10^{15} eV) cosmic rays induce extensive showers in atmosphere (EAS)
- Two main shower components:
  - Charged particles (e.g. μ, e)
  - Radiation (γ)
    - Light (Cherenkov, fluorescence)
    - Radio Frequency (RF)
- Hybrid EAS detection with ASTRONEU:
  - Particles with scintillation counters
  - RF with antennas

Experimental Site – Array Dimensions



Layout of the Astroneu array during the second phase of operation (2017-2022). 3 more RFA were installed at station A. The blue rectangular boxes indicate the position of the SDMs while red circles the position of the RFAs.

Station Setup

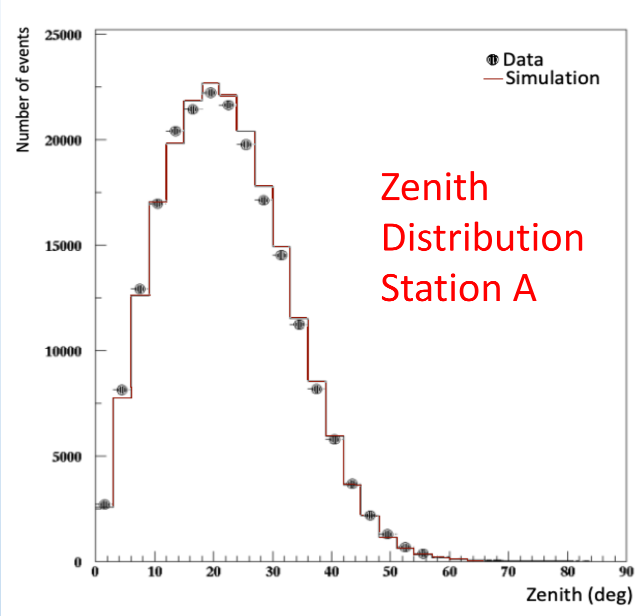


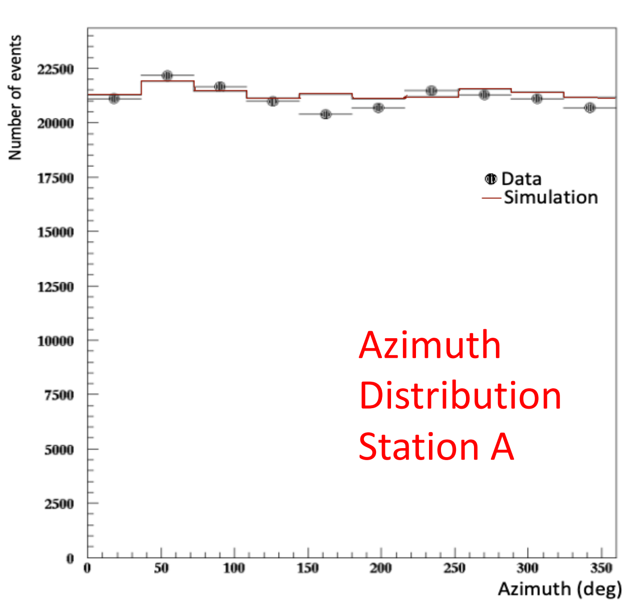
Schematic Representation of Astroneu Station A (2017-2022)

Quarknet (Fermilab)

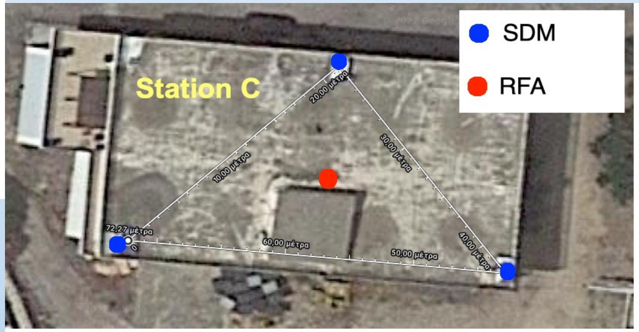
Schematic of the electrical and electronic connections between the station's electronics box (SEB), the SDMs and the RFA

Station's Performance (SDM only) - Single Station





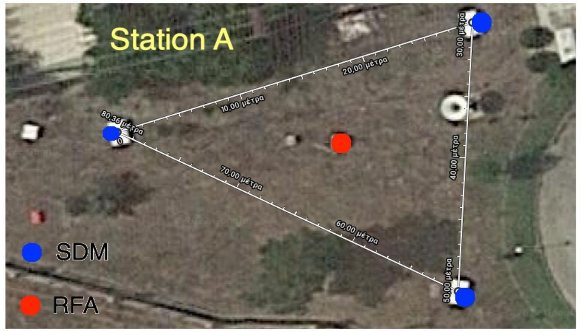
station	Event Rate (hr^{-1})	σ_θ (deg)	σ_ϕ (deg)	ω_{median} (deg)	E_{th} (TeV)
A	17.5	3.3	10.4	3.3	20
B	11.5	6.0	14.8	5.5	30
C	18.9	3.7	11.2	3.6	20
$A \cap B$	0.15	3.6	9.5	2.9	$5 \cdot 10^3$

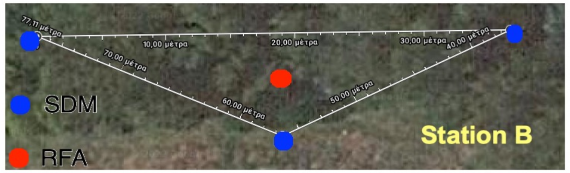


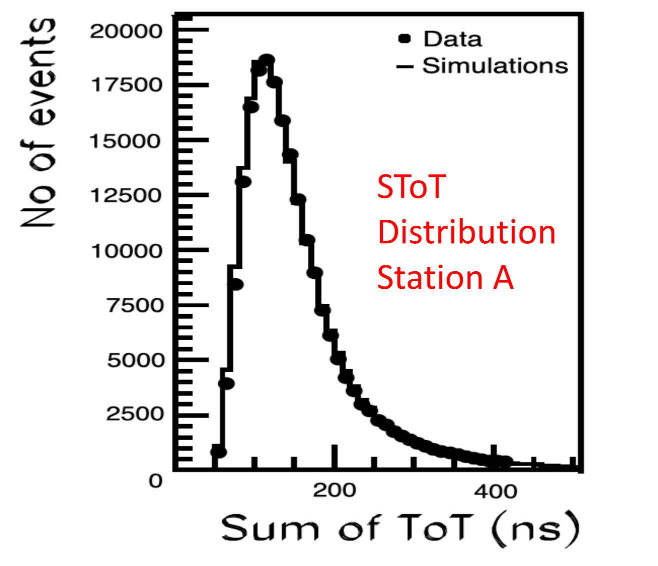
Different Stations Geometries

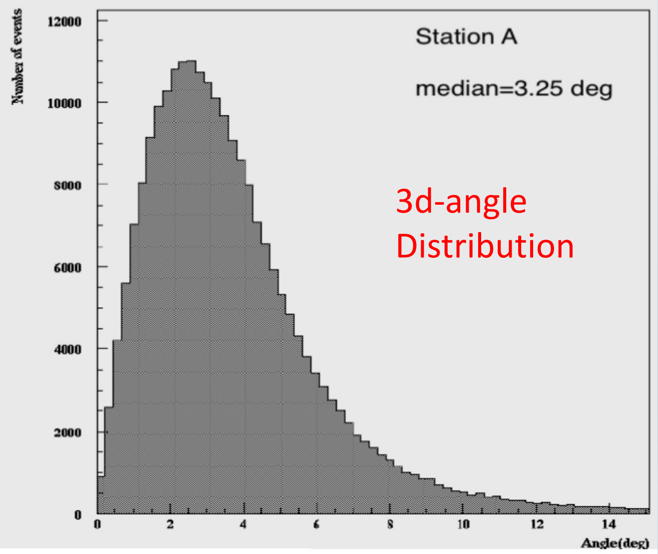
↓

Different Performance









T. Avgitas *et* al 2020 *JINST* **15** T03003
A. Leisos et al 2021 *New Astronomy* **82** 101448

RF Events Selection – Simulations

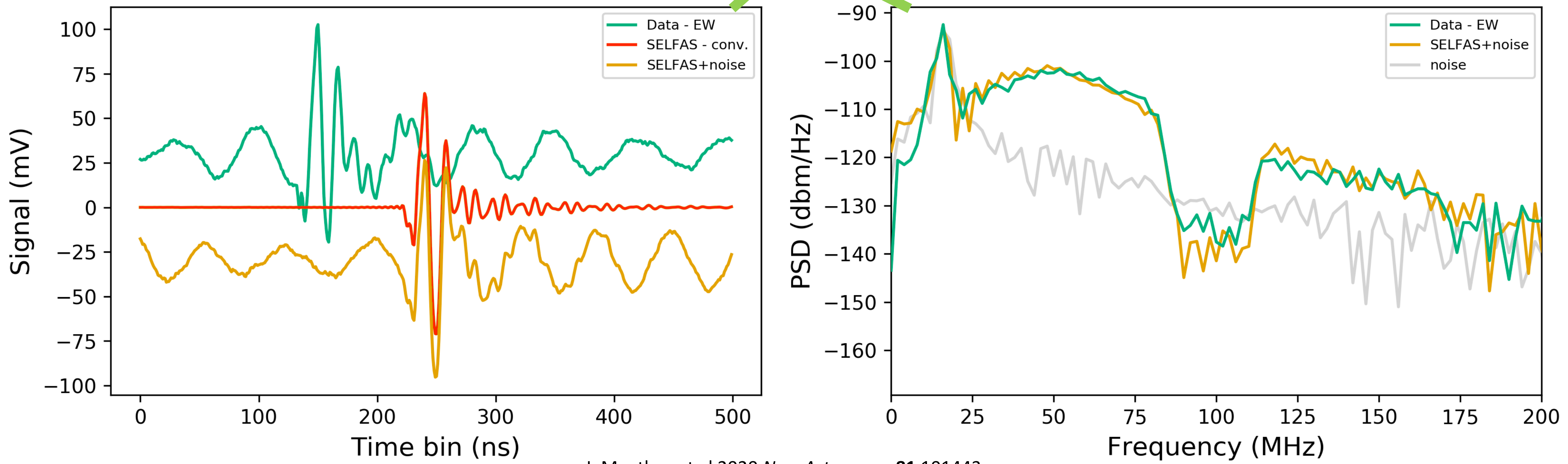
RF offline analysis

- Filtering in range 30-80 MHz
- Signal to Noise Ratio (SNR)
- Signal Rise Time
- Signal Polarization
- Signal Power Spectrum

RF signal Simulations

- Antenna Model
- MC signal simulation (SELFAS)
- Nearby EM environment (background noise)

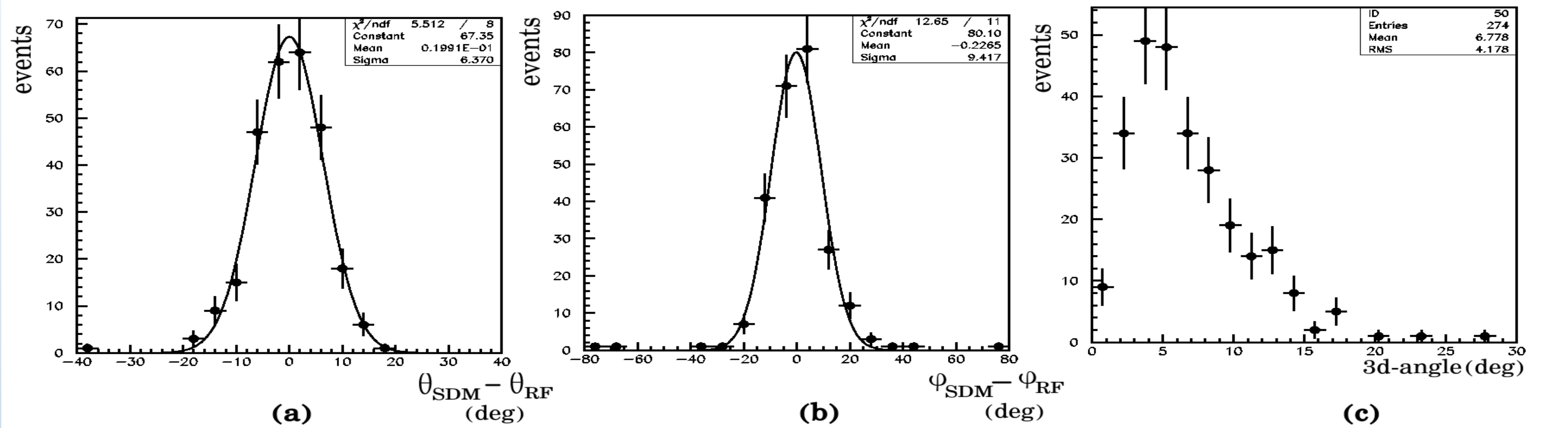
RF Data and Signal Simulations very Strong Agreement



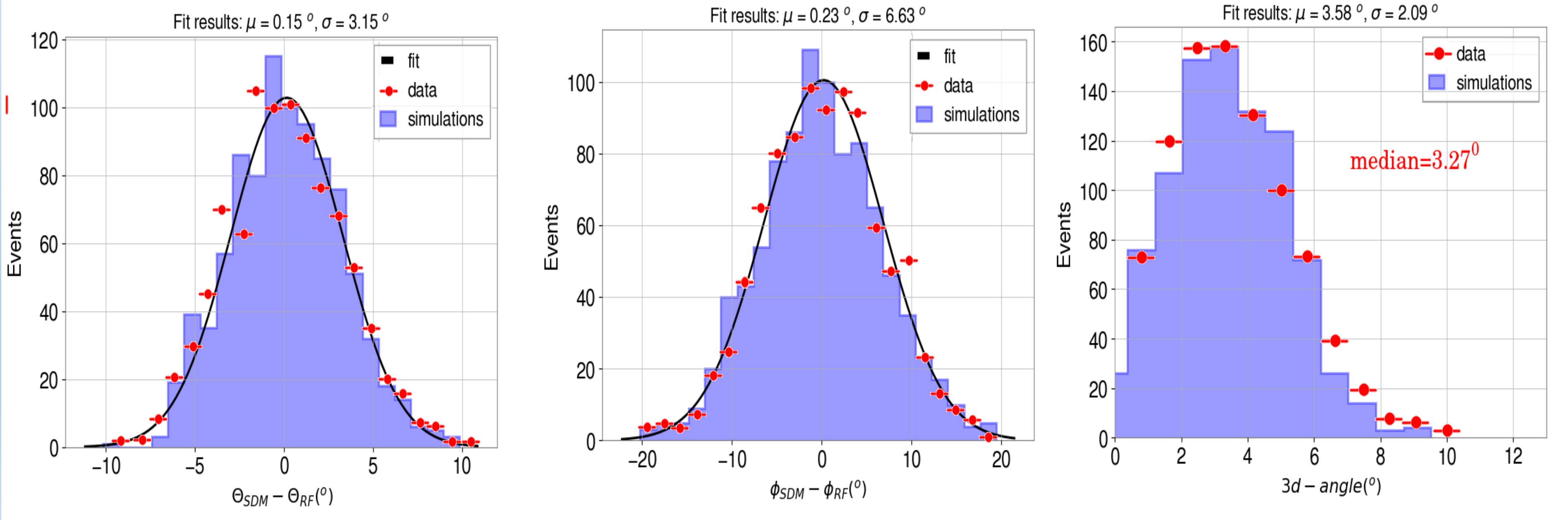
I. Manthos et al 2020 *New Astronomy* **81** 101443

Astroneu Results SDM + RF

Comparing EAS axis reconstruction results between SDMs and RFAs (using spectrum RF timing)



The distributions θ_{SDM}-θ_{RF} (left) ϕ_{SDM}-ϕ_{RF} (middle) using the SDM timing and the RF spectrum. The distribution of the angle between the shower direction using SDM data and the RF spectrum (3d-angle) (right).



The distributions of the difference θ_{SDM} - θ_{RF} (left) and $\phi_{SDM} - \phi_{RF}$ (middle). The distribution of the 3d-angle (right) as estimated using the SDM and the RF timing data.

S. Nonis et al 2020 Phys. Scr. 95 084007
S Nonis et al 2021 J. Phys.: Conf. Ser. 2105 012018

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Astroneu Results RF only

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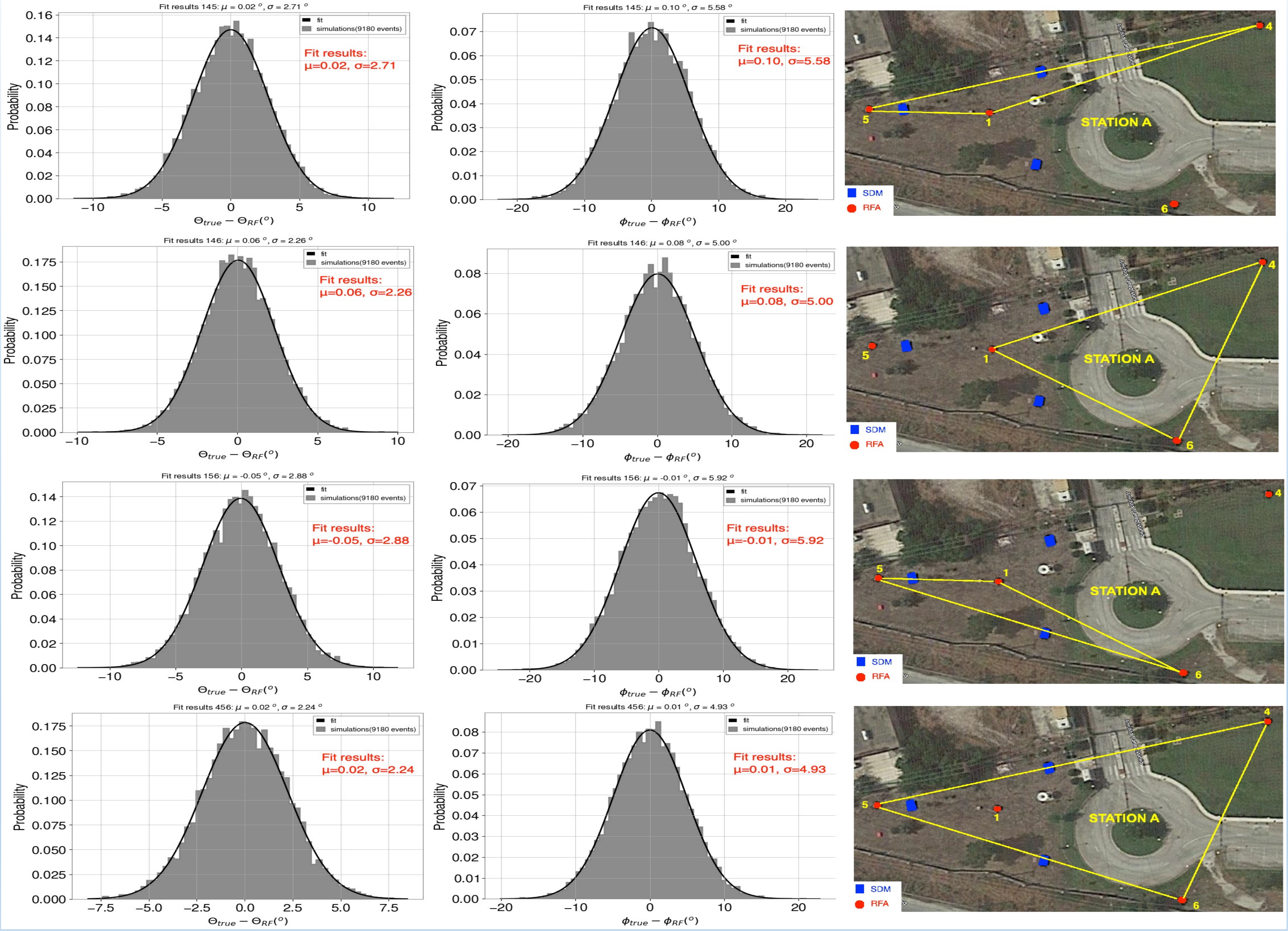
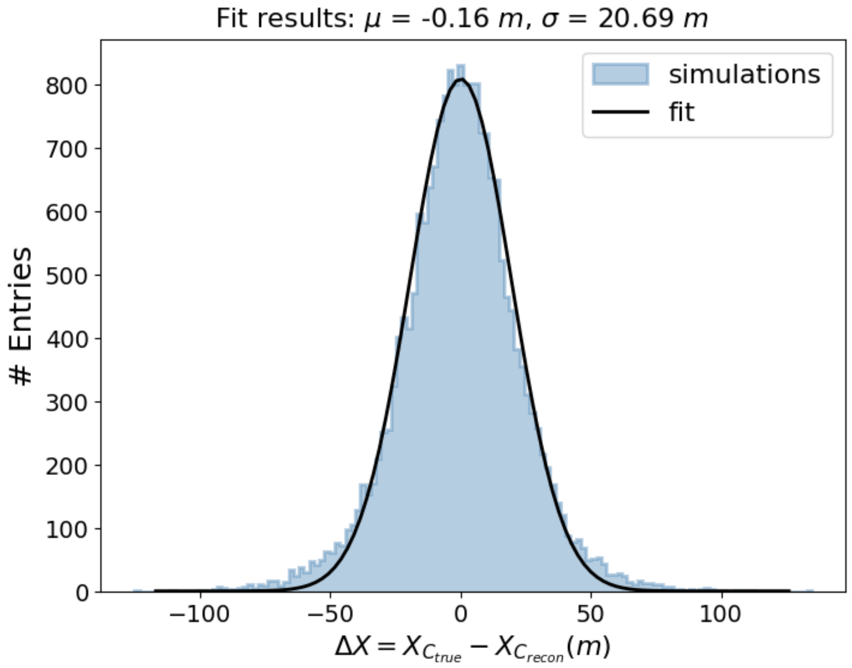


- Reconstruction of the shower axis direction using 3 of the 4 RF antennas
- Study of the effect of the array geometry on reconstruction efficiency
- The formations 145 and 156 (obtuse triangles) less efficient than 146 and 456 (approximately equilateral triangles)

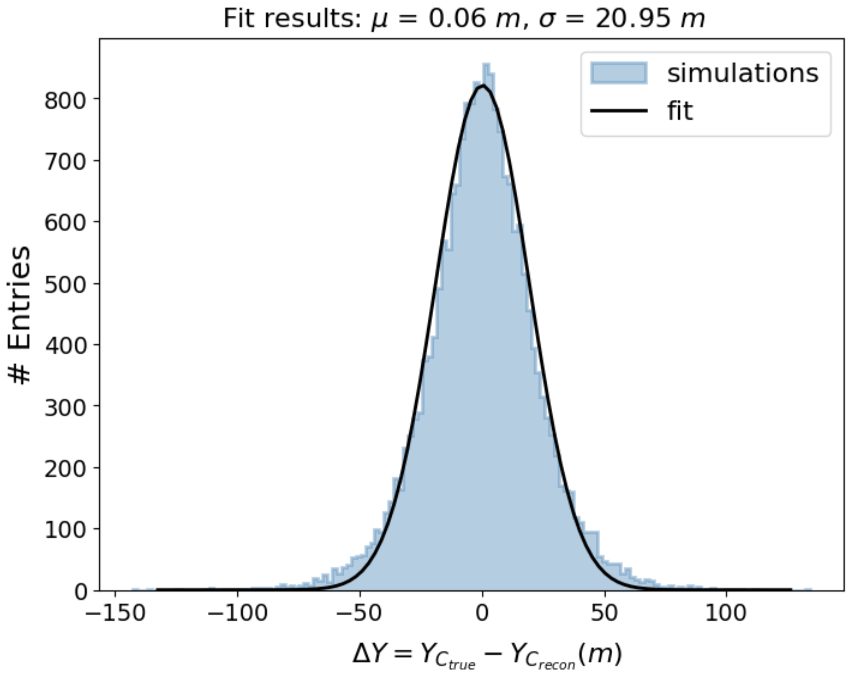
Astroneu Results RF only

EAS Core Reconstruction (work in progress)

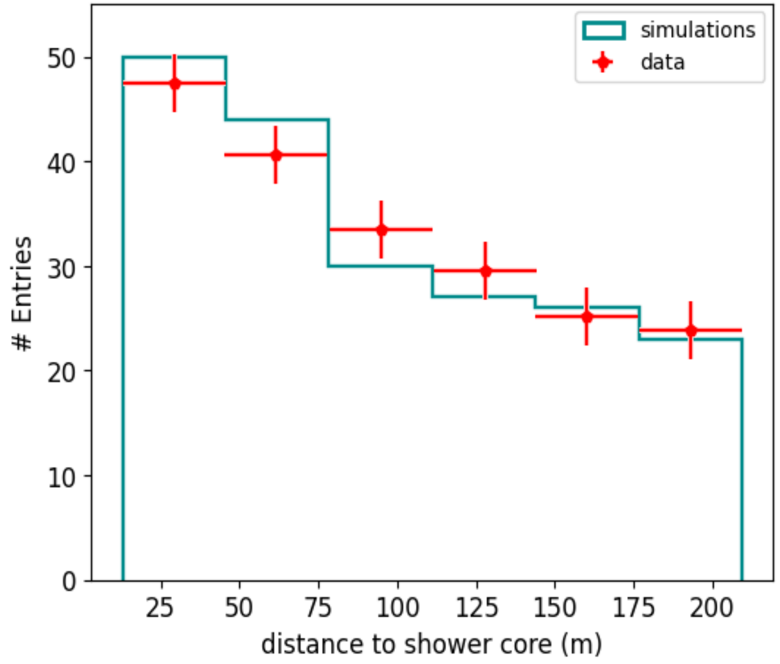
- EAS core reconstruction using the RF signal and simulations.
- The measured electric field map in the ground is compared with a simulated one reconstructed for a dense virtual antenna array.
- Comparing core results between RFAs and simulations (no SDMs data for core reconstruction)



The distribution of the difference $X_{core-true} - X_{core-recon}$ between the true and the reconstructed X coordinate of the core position.



The distribution of the difference $Y_{core-true} - Y_{core-recon}$ between the true and the reconstructed Y coordinate of the core position.



The distribution of the distances from the shower core for the data (red points) and simulations (histogram).

Astroneu Results RF only

Charge Excess to Geomagnetic Ratio (CGR) - Results (preliminary)

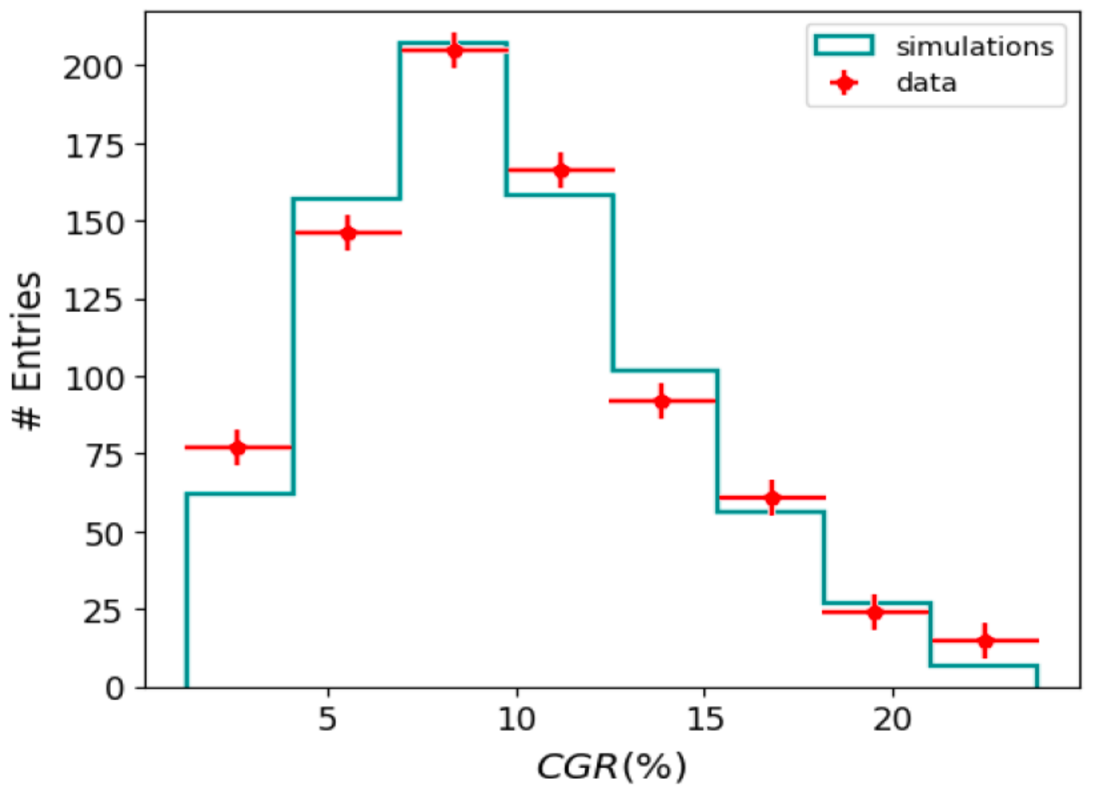
The motions of secondary e^- /e^+ in EAS creates the RF electric field. Two dominant contributions

- Geomagnetic (polarized in the direction of the Lorentz force - independent the point of observation)
- Charge Excess (polarized radially to shower axis)

The relative amplitudes $|E_{ch}|/|E_{geo}|$(=CGR) can be measured using the RF data of two polarizations (EW & NS) and the shower core position

	$d \in [0, 50m]$	$d \in (50, 100m]$	$d \in (100, 150m]$	$d \in (150, 200m]$
$\theta_{sh} \in [0, 15^0]$	8.1%	13.15%	17.14%	19.23%
$\theta_{sh} \in (15, 30^0]$	6.96%	10.76%	12.50%	14.92%
$\theta_{sh} \in (30, 45^0]$	5.16%	7.08%	8.74%	10.76%
$\theta_{sh} \in (45, 60^0]$	4.13%	6.56%	8.62%	10.45%

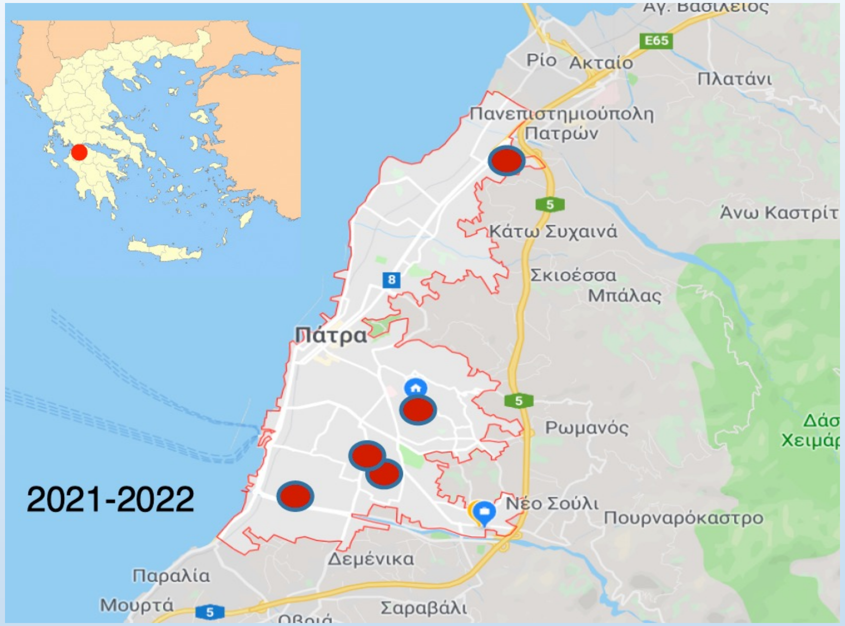
- The mean values of CGR for different zenith angle and distance to shower core value regions.
- The measured CGR values range from 3% (inclined shower near the core) to 24% for almost vertical showers at large distances (150-200 m).



Distribution of the CGR as determined from data (red points) and simulations (histogram).

μNet-Educational Activities with ASTRONEU & μCosmics

- Small SDM (μCosmics) construction
- Calibration – Study the SDM response to single atmospheric muons (MIPs)
- Detector Timing Synchronization (Pulse arrival time information adjustment)
- Shower Reconstruction-Data Analysis (Event rates, Zenith & Azimuth distributions)
- Geometry Studies (How reconstruction results depend on the detector deployment geometry)
- Muon Telescopy (studying the characteristics of atmospheric muon flux)
- 2021-2022: deployed and operating at 5 High Schools of Patras
- 2023: full operation involving more than 50 schools and 1000 students per year



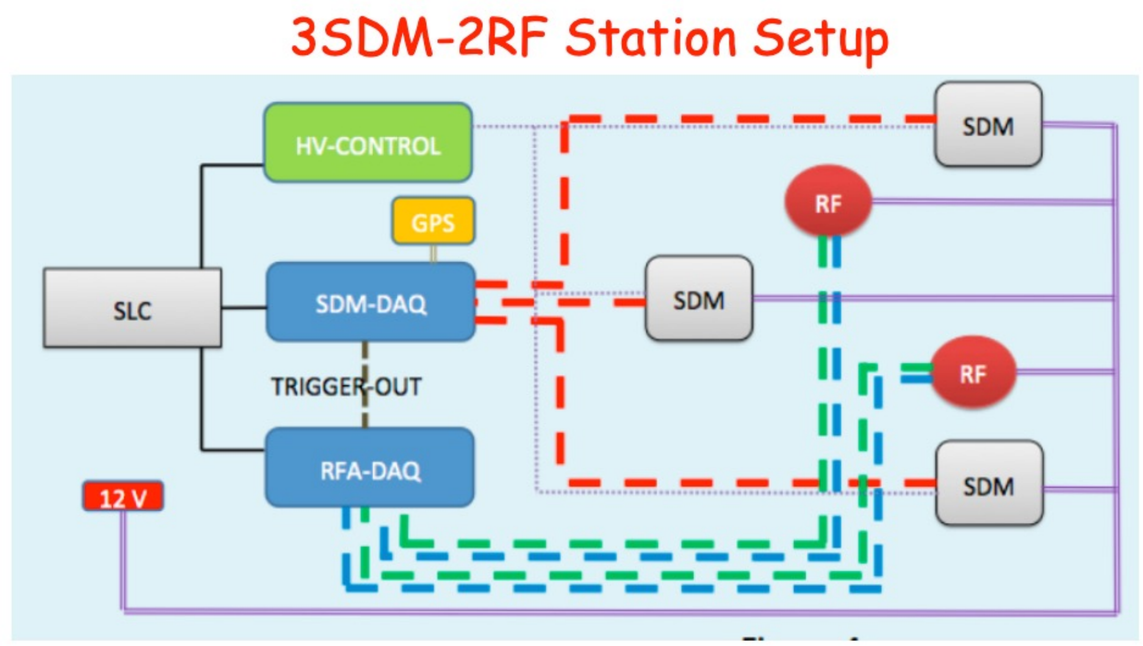
M Petropoulos *et al* 2020 *Phys. Educ.* **55** 055005
https://doi.org/10.1142/S0217751X20440224

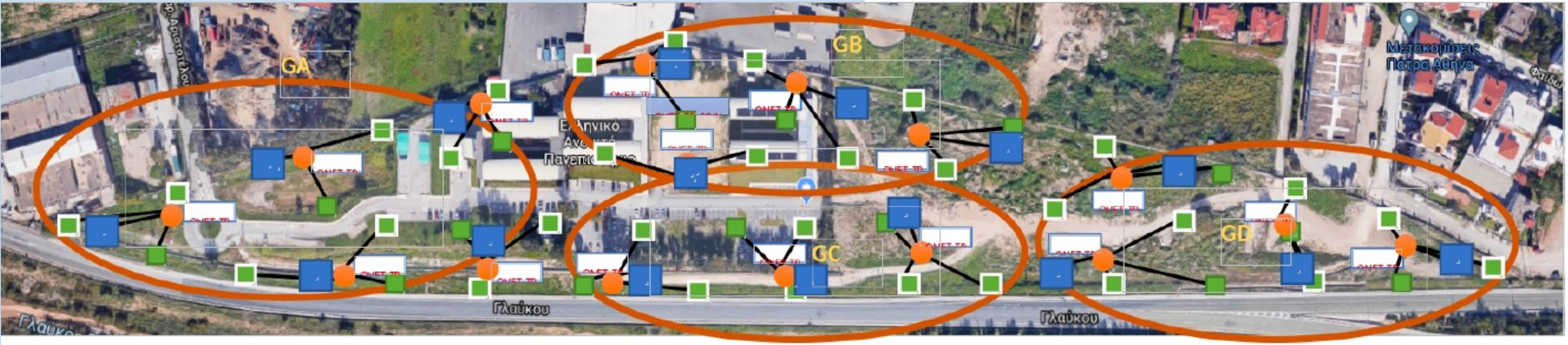
ASTRONEU array expansion

Plans to expand ASTRONEU array on HOU campus with small SDMs and RF antennas:

- 16 stations
- 3 Scintillator Detector Modules (SDMs) per station
- 2 RF antennas per station (3SDM-2RF)
- Electronics for independent SDM and RF DAQ
- Will be in operation by 2023

A G Tsirigotis *et al* 2020 *Eng. Res. Express* **2** 025027





Conclusions & Prospects

- The developed Astroneu array has well known response to air showers.
- RF detection in environment with strong electromagnetic noise is possible even with small scale hybrid (Particle + RF detection) arrays.
- The RF pulse from a single antenna combined with MC simulations can give access to the cosmic ray arrival direction.
- Reconstruction the shower core using the RF signal and simulations
- Charge Excess to Geomagnetic Ratio (CGR) measurements
- Building a new low cost RF antenna and the corresponding LNA from the HOU astroparticle group.
- Expand the Astroneu array with more particle detectors and RF antennas - More accurate predictions and extended RF studies.
- Study the possibility for an RF only self-triggered detector array in an EM-noisy urban environment (efficient new methods for noise rejection)

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
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https://doi.org/10.1142/S0217751X20440224
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