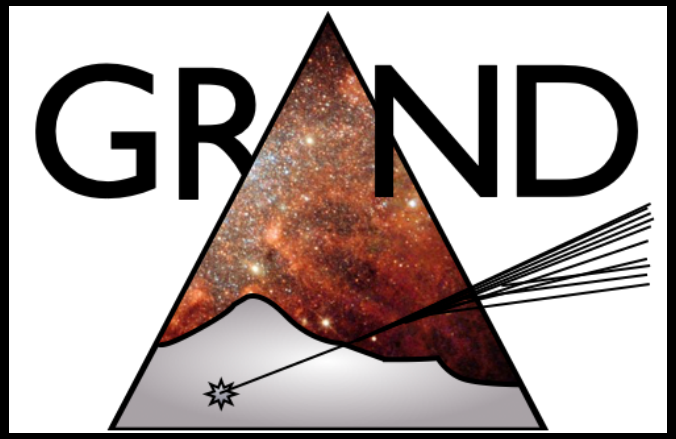

GRAND: Progress and Prospects

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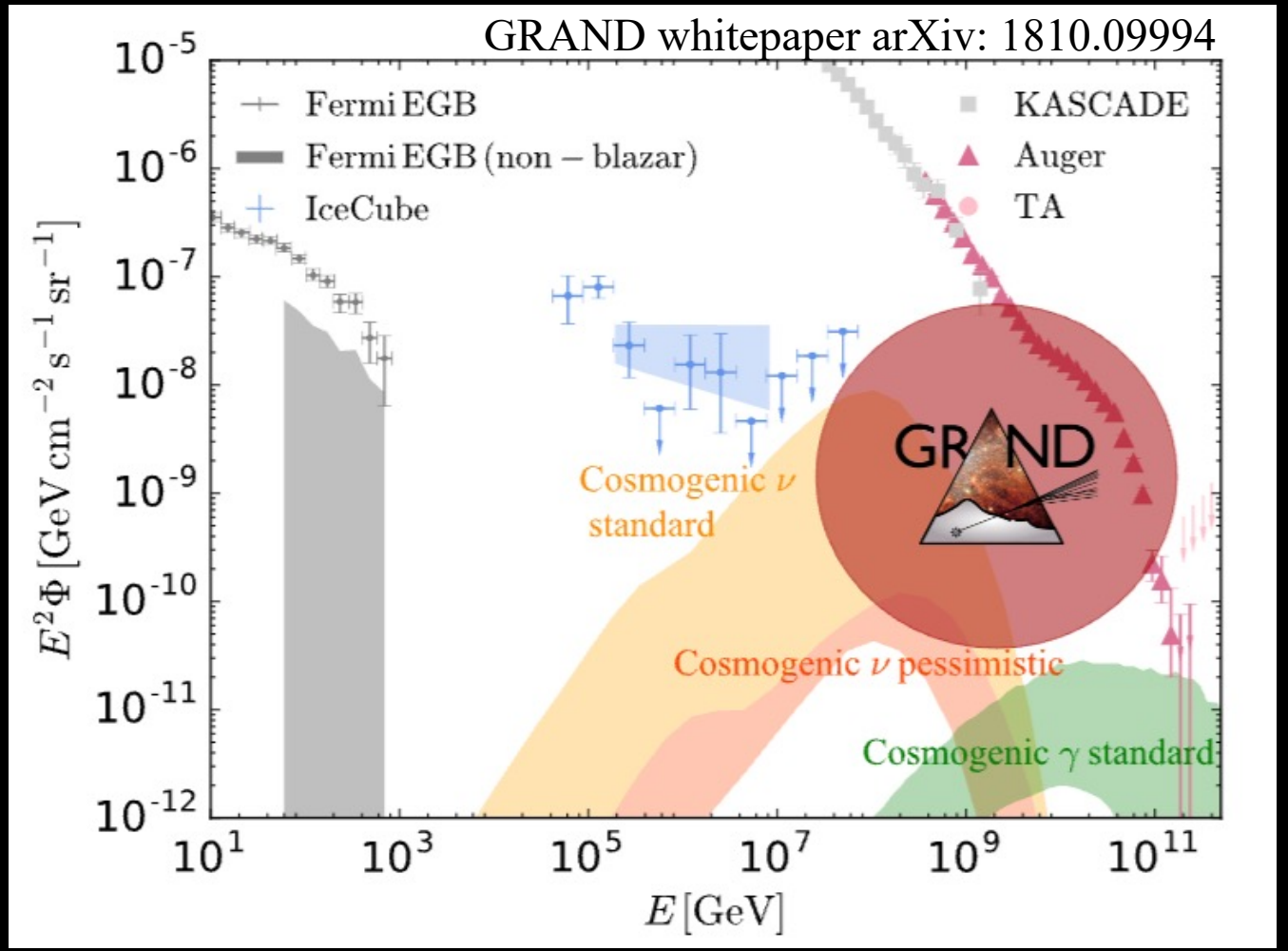
for the GRAND collaboration
tianxs@stu.pku.edu.cn

Neutrino physics in Vietnam 2025
2025.07.24

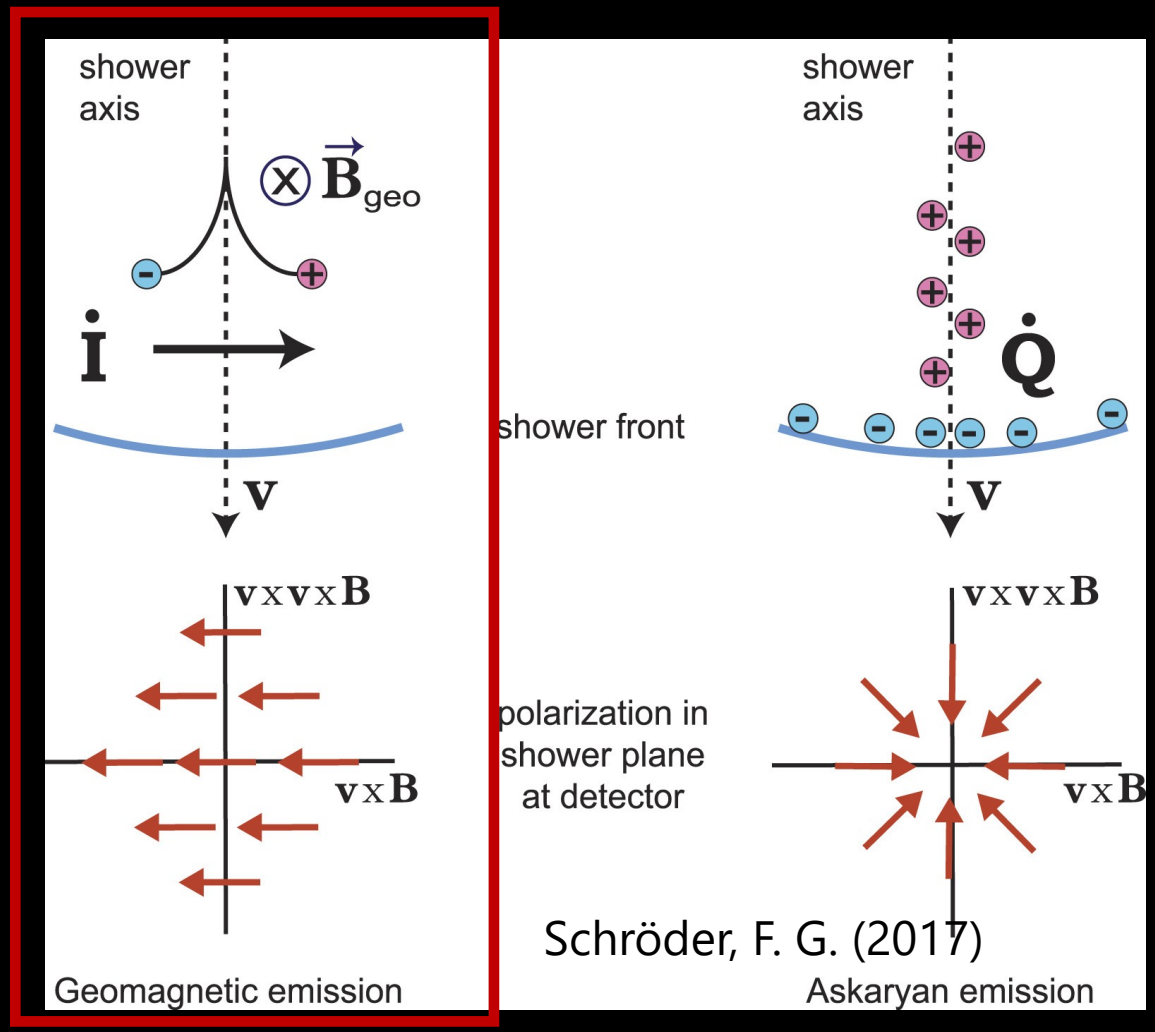
Ultra-high-energy neutrino

- GRAND targets neutrinos ≥ 100 PeV of astrophysical origin.
- UHE neutrinos originate from UHECRs interacting with ambient gas/photons.
- Diffuse background encapsulates the composition and evolution of the UHECR sources.
- UHE ν sources can trace back to the UHECR sources.



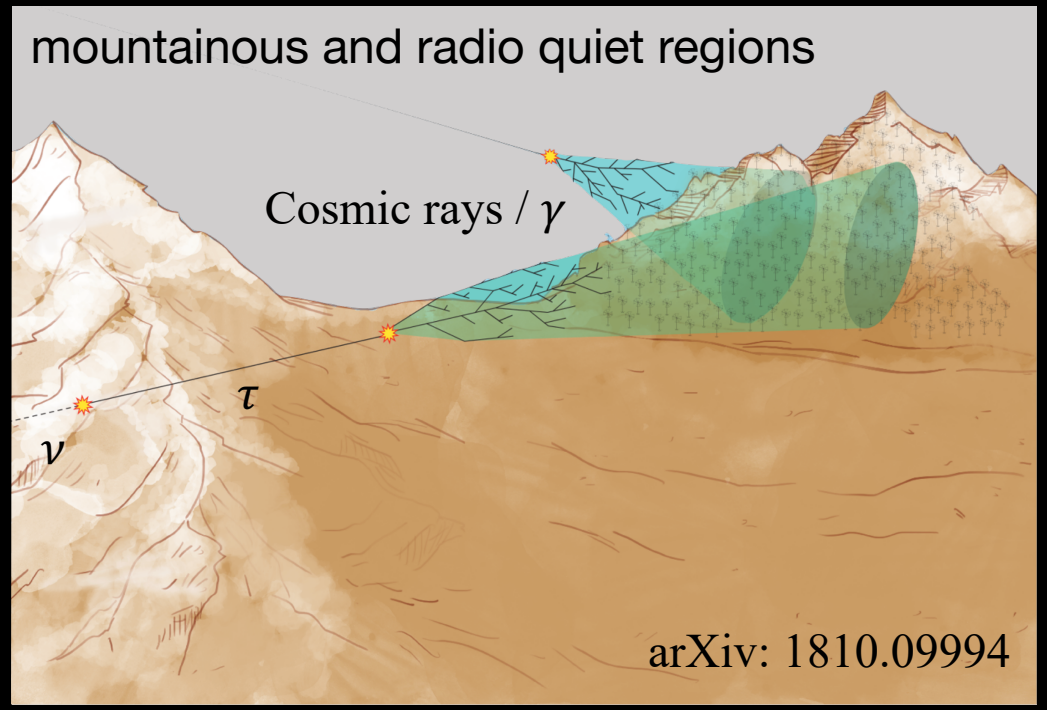
Radio Detection of Air Showers

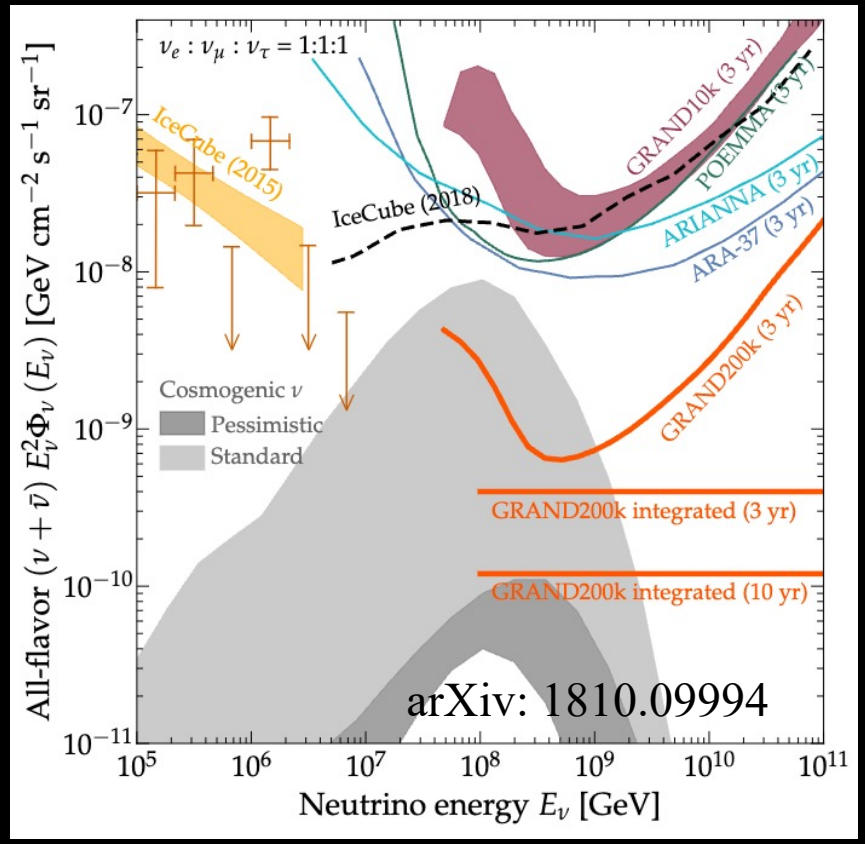
1. The source: the geomagnetic effect (deflection of $e^{\pm}$ in the geomagnetic field)
2. The medium: atmosphere is transparent for radio waves.
3. The detector, radio antenna is cheap, robust, scalable, and easy to deploy over a large area.



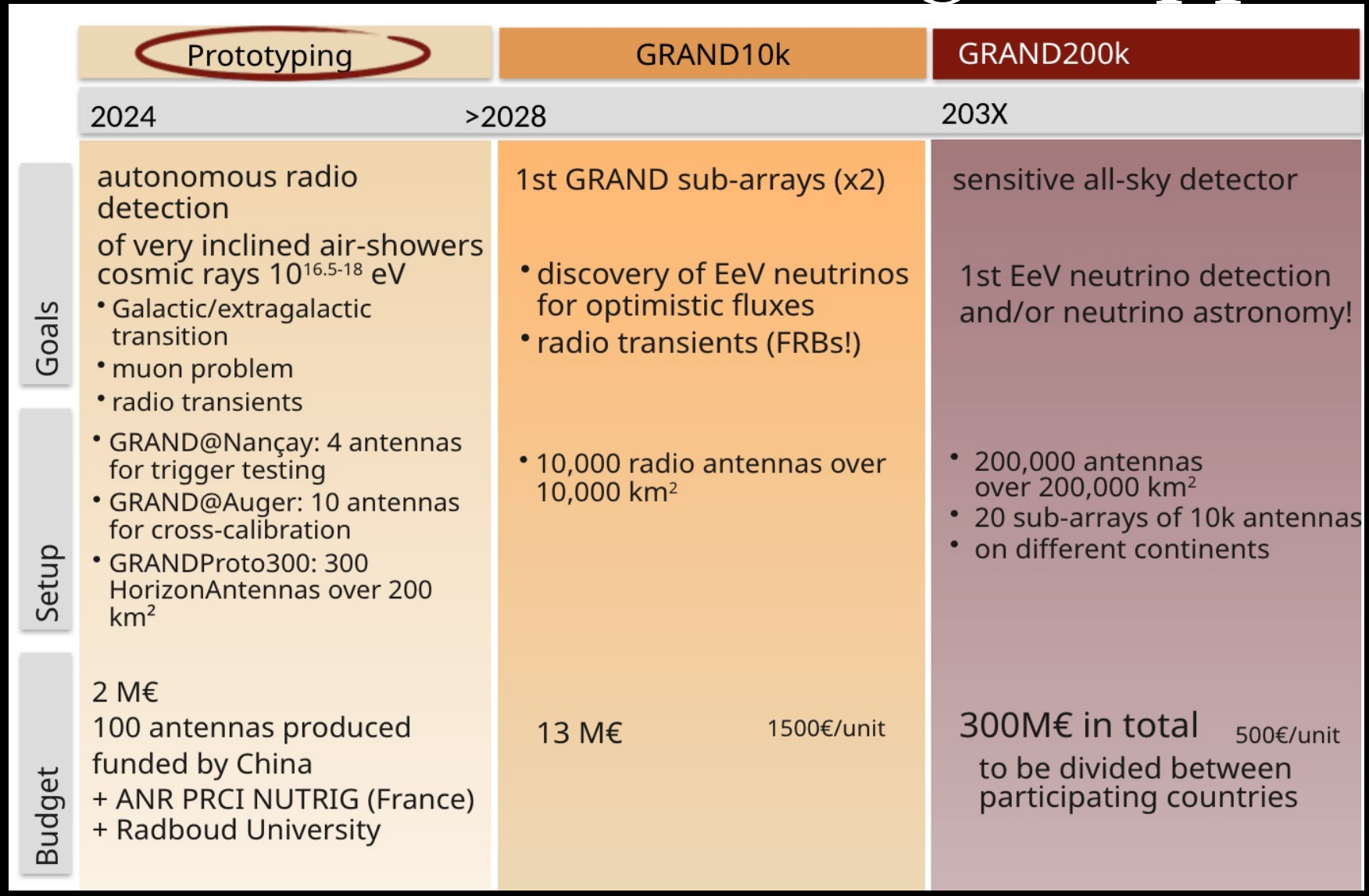
GRAND Concept

- Giant Radio Array for Neutrino Detection
- Multi-messenger observatory of 20x10k radio antennas at different locations ~200k km^2



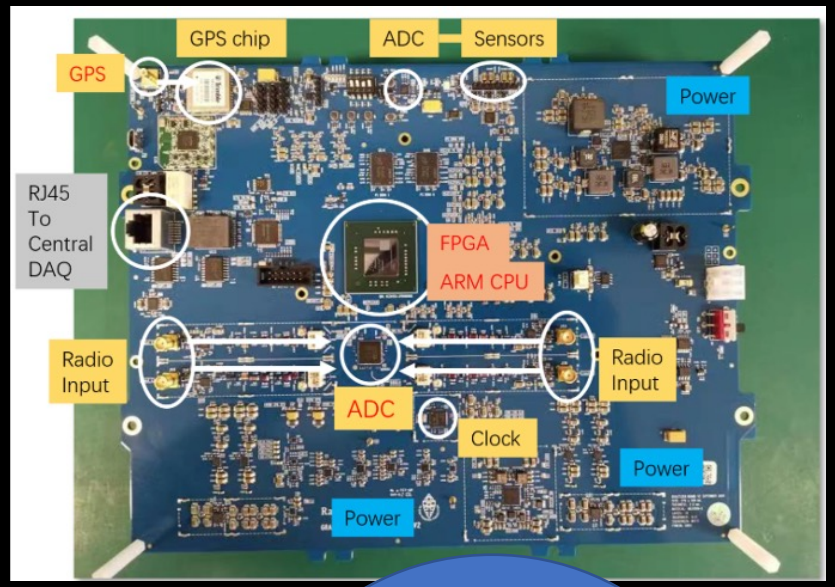


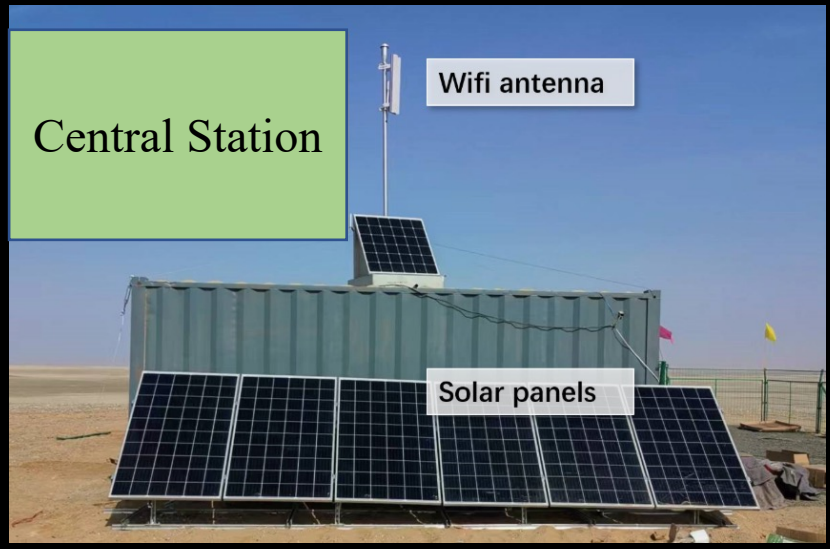
GRAND timeline – a staged approach



Prototype Design

- Antenna array + central station
- Multi-level trigger





Antenna output

ADC: 500 MHz sampling
Band: 50-200 MHz

DU

FPGA → CPU

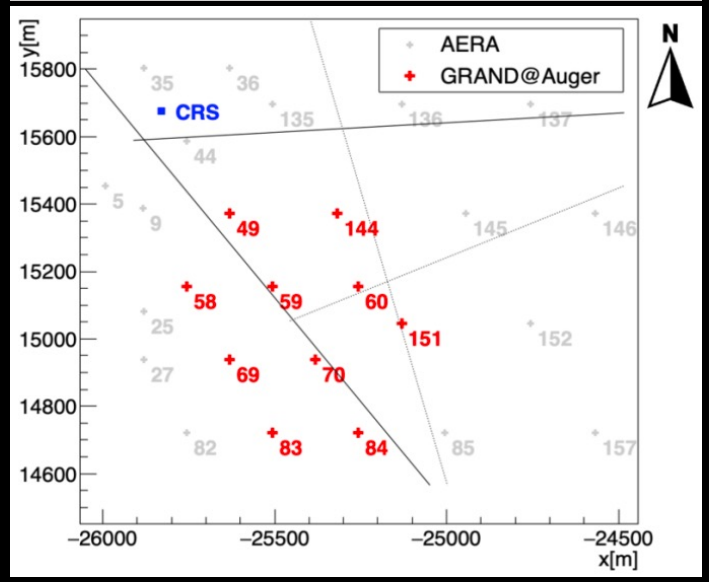
L1 L2

Triggered Event

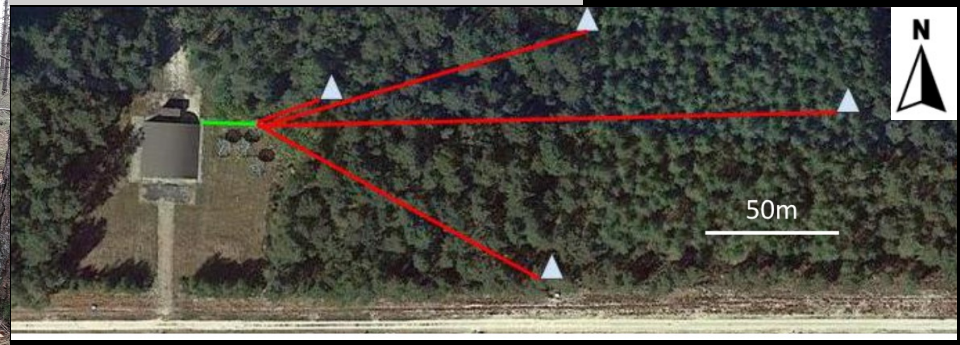
Central Station L3

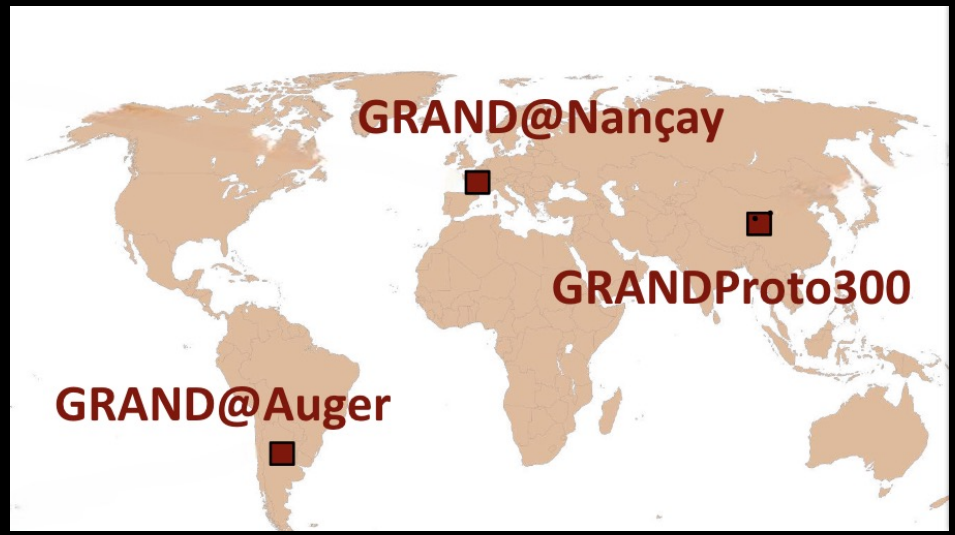
Prototype Arrays

GRAND@Auger, 10DUs
Cross-calibration with Auger SD

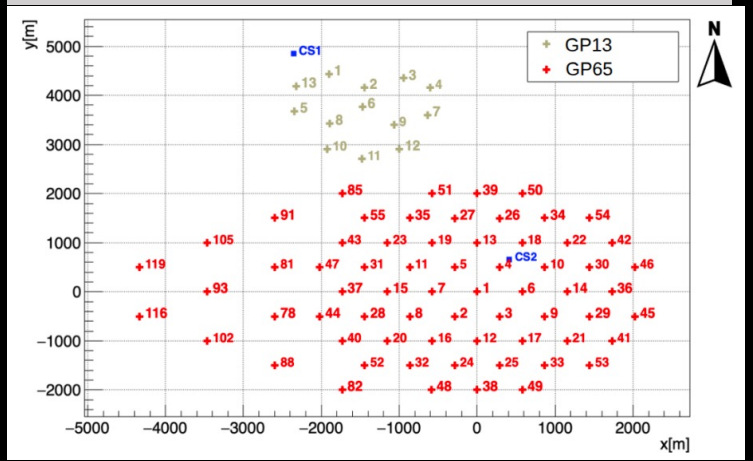


GRAND@Nançay 4DUs
Trigger test



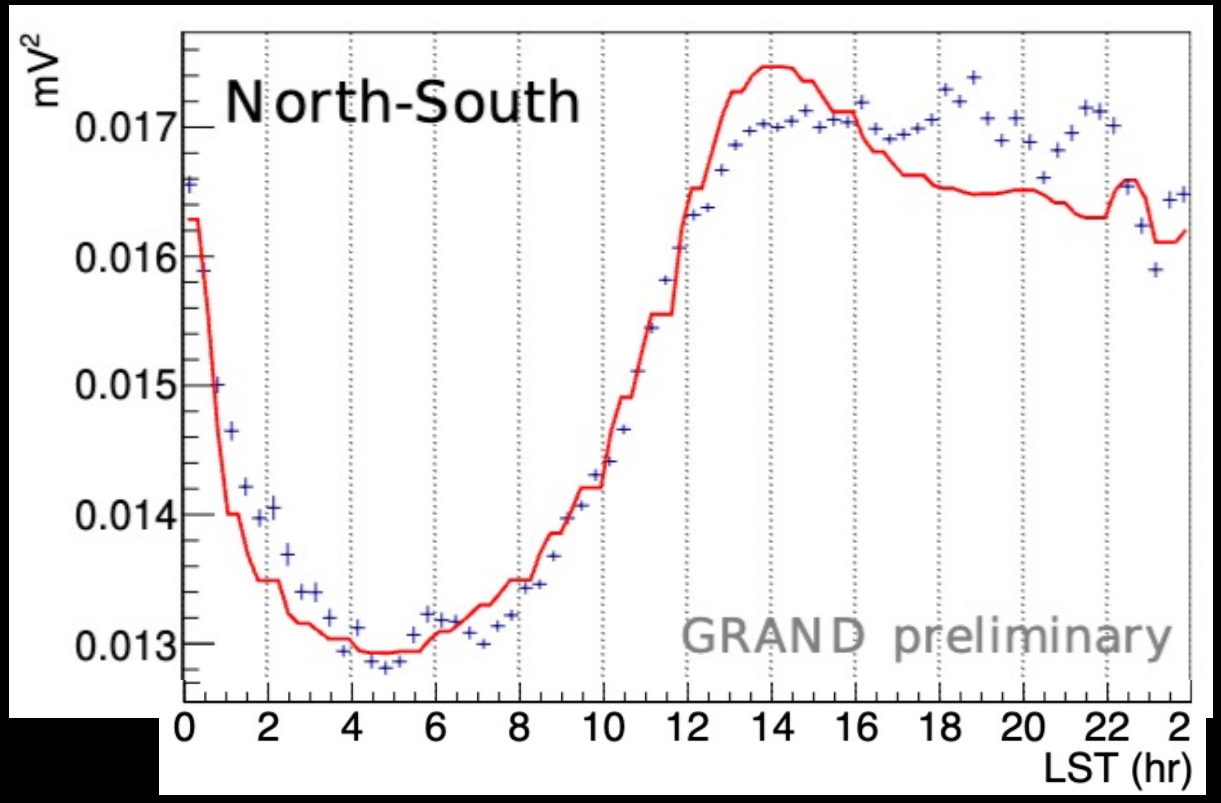


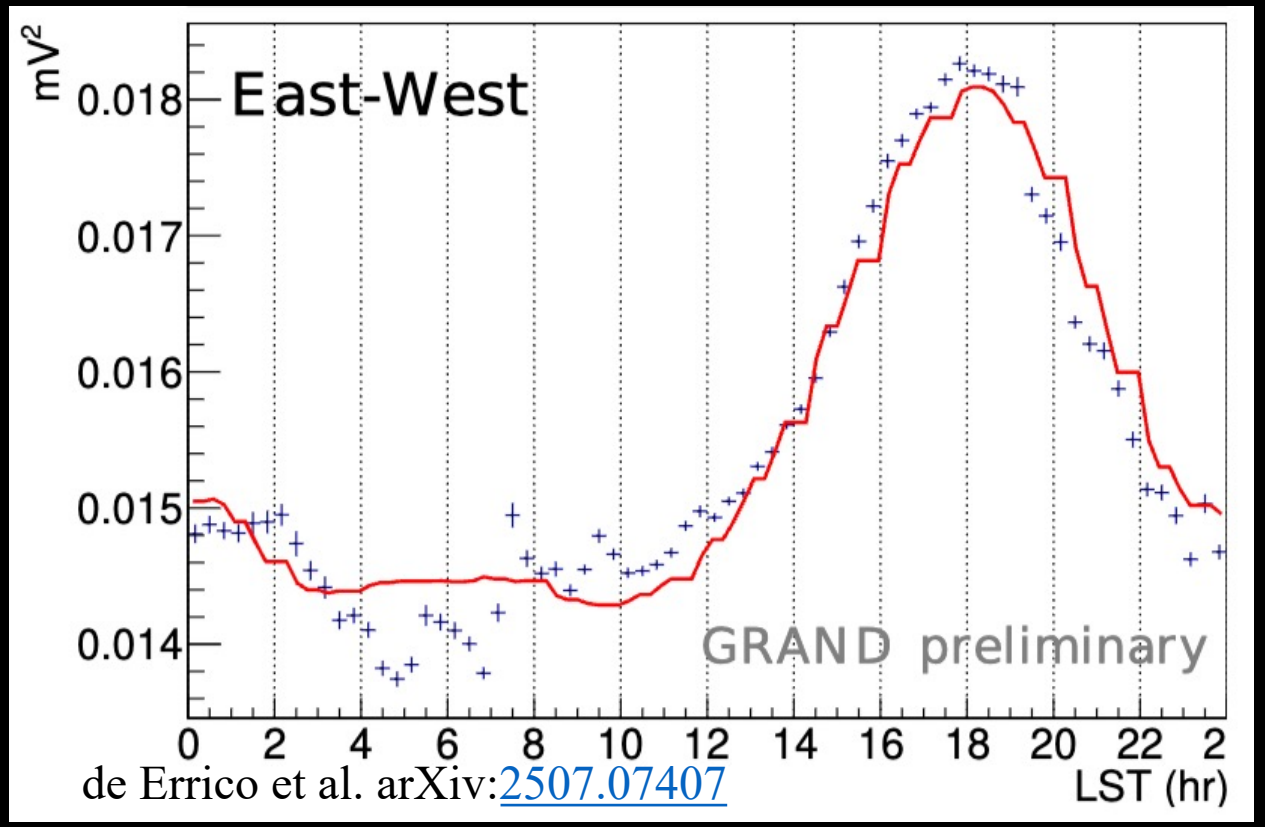
GP300 300 DUs (65 deployed)
Radio self-trigger on EAS



GRAND@Auger: Galactic background

- Galactic radio background in 100-200MHz at Malargüe, Argentina.





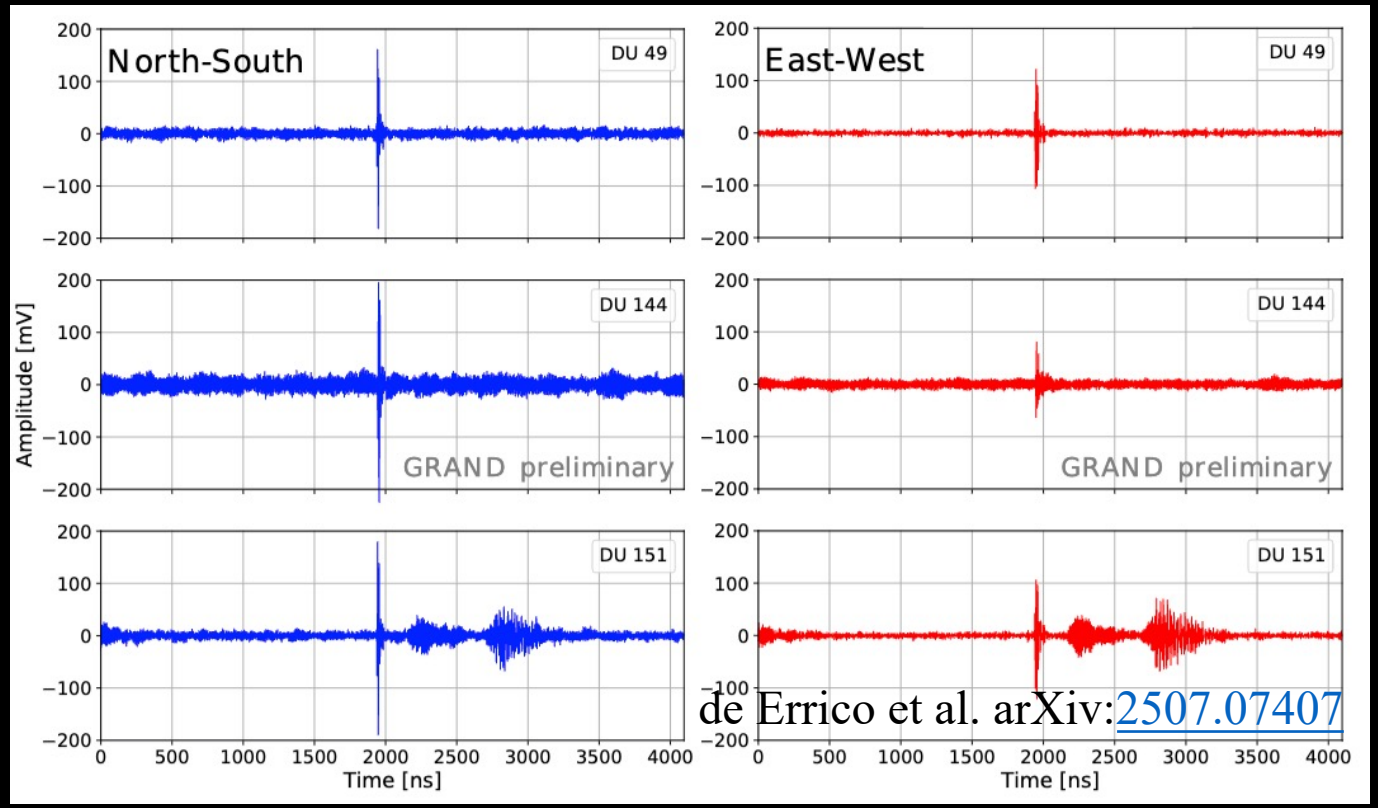
de Errico et al. arXiv:2507.07407

GRAND@Auger

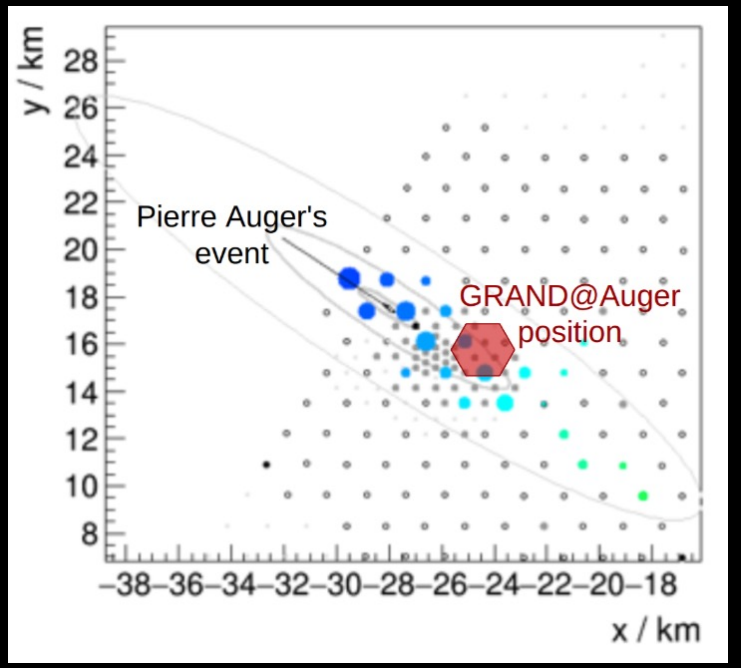
The first coincident event with PAO surface detector:

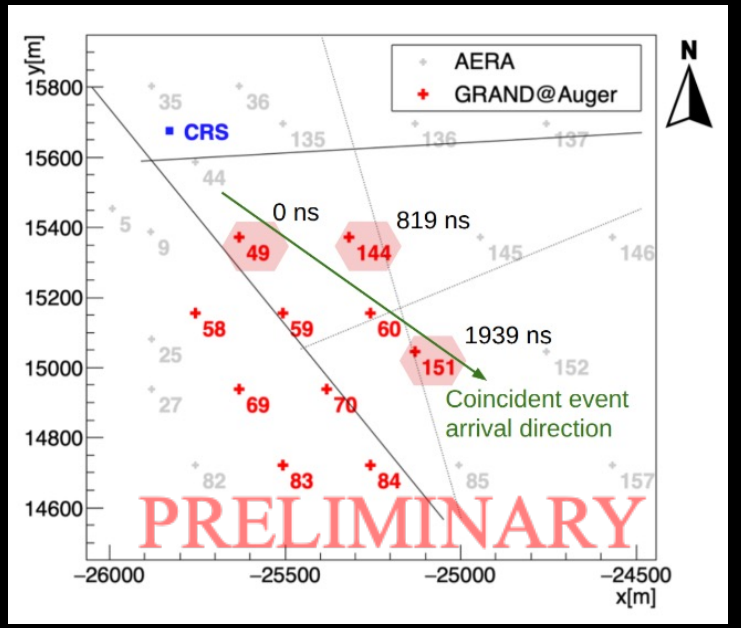
1. Reconstructed direction ✅
2. Event time ✅

$E_{\mathrm{rec}} = 1.39\times10^{19}$ eV



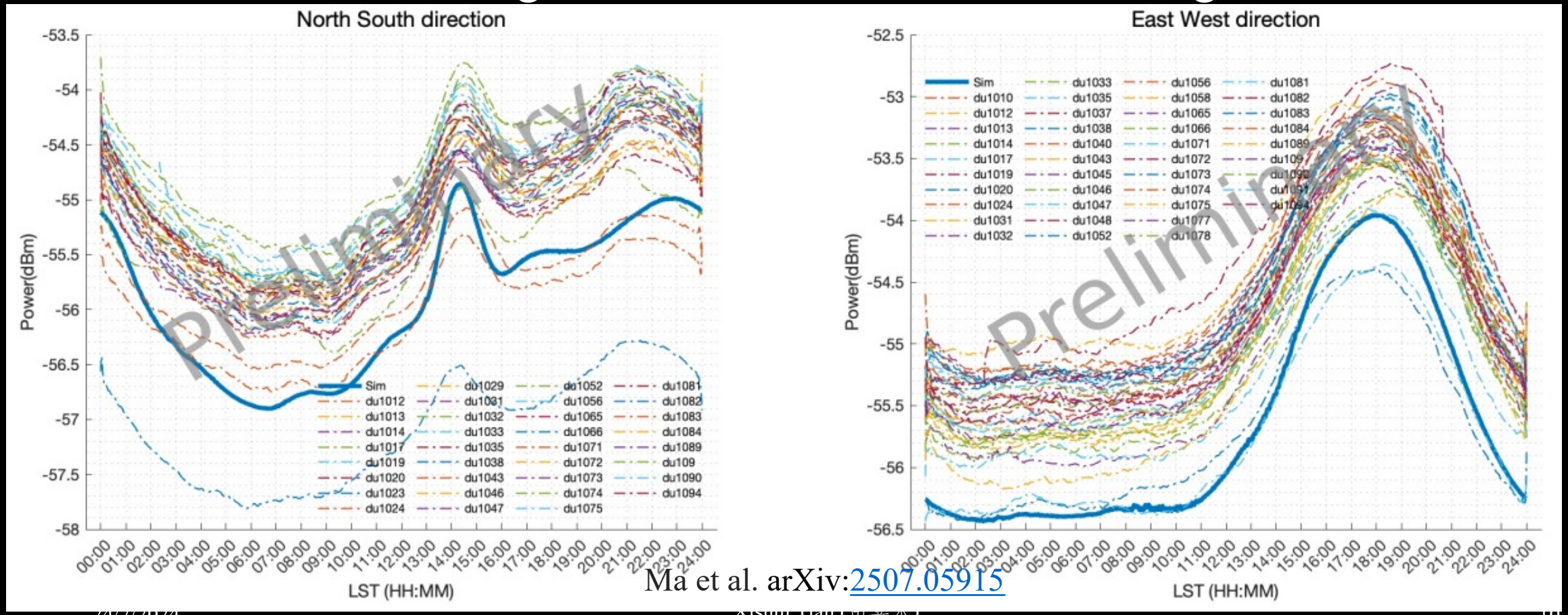
de Errico et al. arXiv:2507.07407





GP300: Galactic background

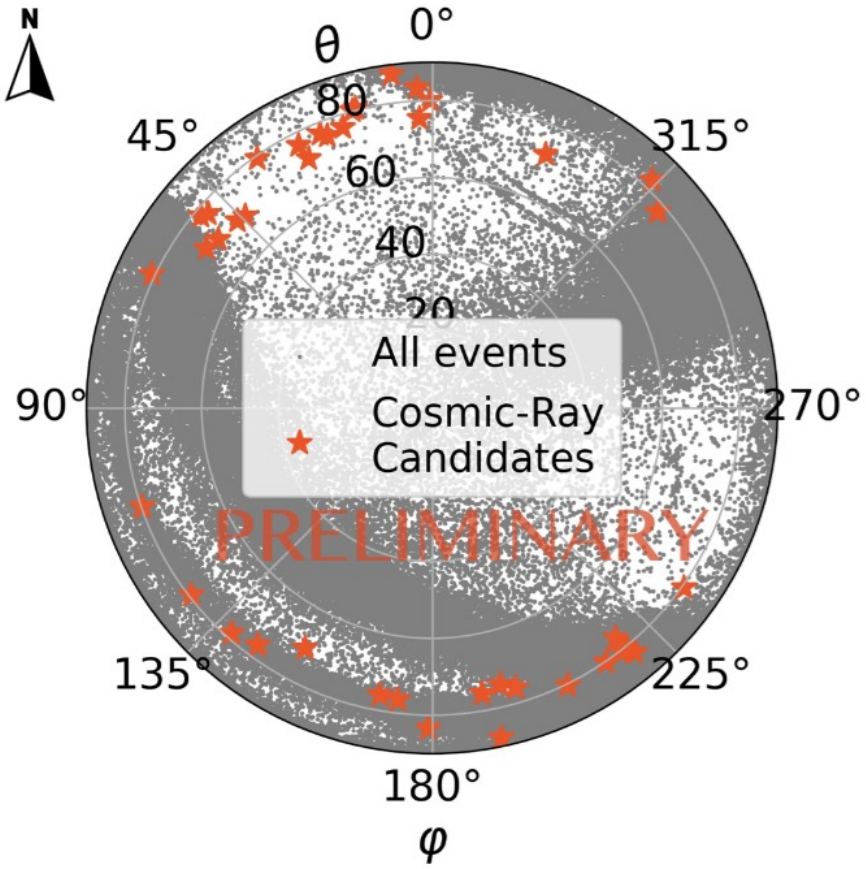
- Galactic radio background in 60-80MHz at Dunhuang, China.



Ma et al. arXiv:2507.05915

GP300: selection of cosmic rays

- First cosmic-ray candidate events by standalone radio trigger



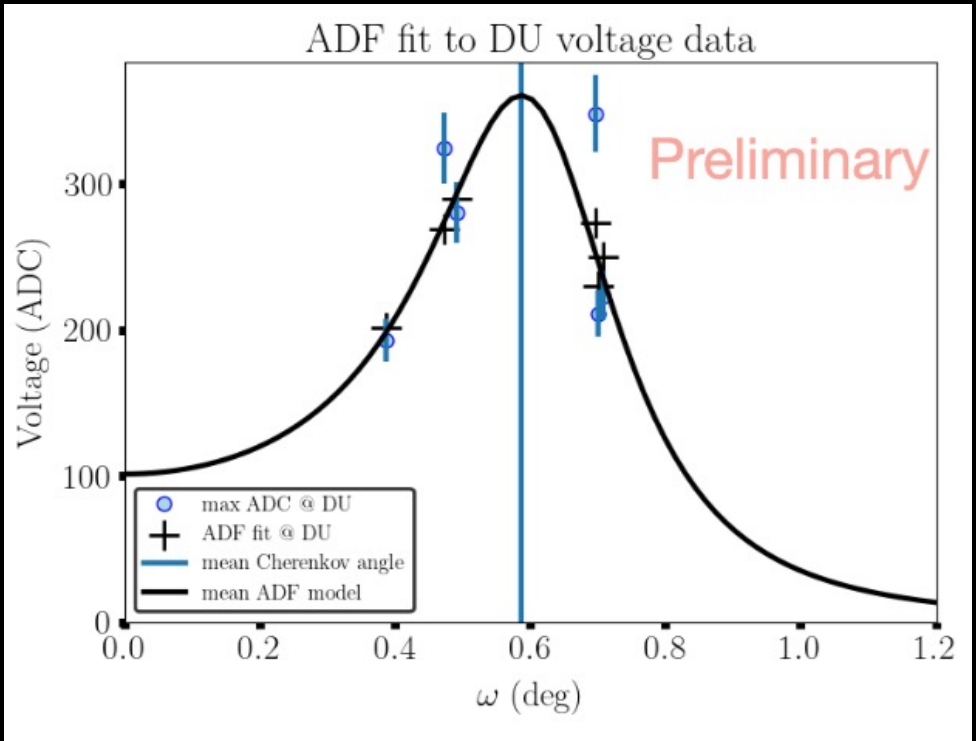
	Cut Parameters	Cut efficiency
Clustering	$\Delta t \leq 5\,\mathrm{s}$ $\Delta\vartheta \leq 5°$	79 %
Polarization	$\mathbf{e_V} \cdot \mathbf{e_B} < 0.25$	22 %
Nb of DUs	$N_{DU} \geq 5$	50 %
Zenith	$\theta \in [66°, 88°]$	56 %
PWF error	$\mathrm{err_{PWF}} < 0.5°$	31 %
SNR	$\mathrm{SNR_Y} \geq 5$	58 %
RMS	$\mathrm{RMS}_{X,Y}(50-80\,\mathrm{MHz}) < 2\,\mathrm{mV}$ $\mathrm{RMS}_X(160-225\,\mathrm{MHz}) < 1\,\mathrm{mV}$ $\mathrm{RMS}_Y(160-225\,\mathrm{MHz}) < 3\,\mathrm{mV}$	85 %
Full pipeline		7×10^{-5} %

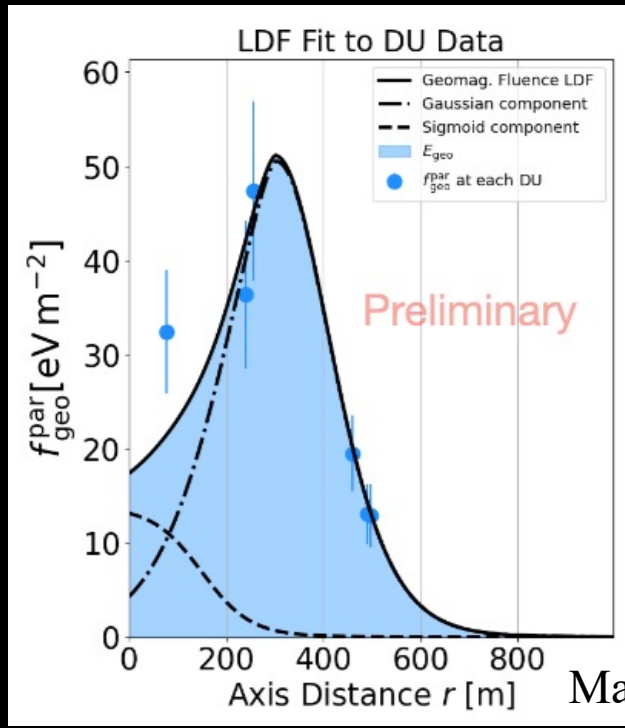
Lavoisier et al. arXiv:2507.06695

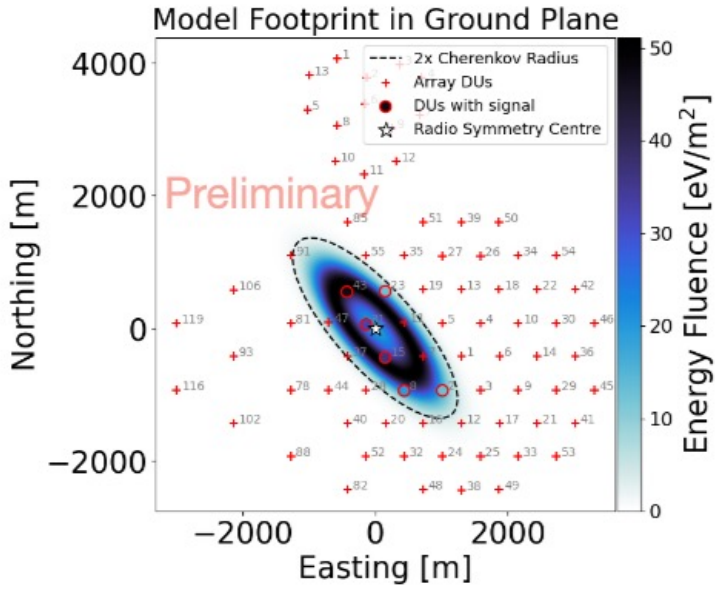
GP300: reconstruction of CR candidates

The Cherenkov ring is clearly seen. → Shower origin established

- Angular distribution function
- Lateral distribution function







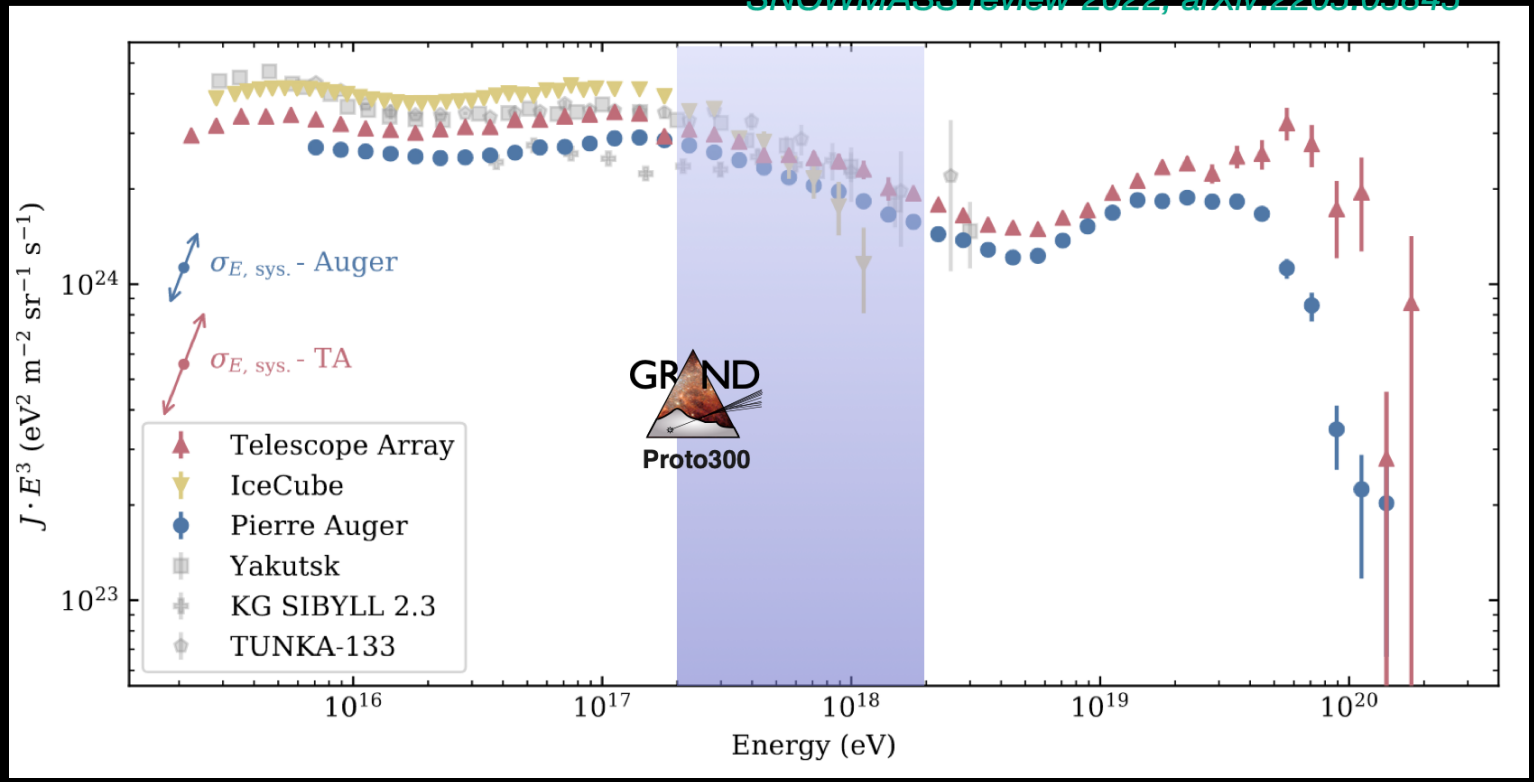
Martineau-Huynh et.al arXiv:2507.07260

GRANDProto300

1. Official approval for 200km^2 for GP300 in Dunhuang, China.
2. To measure CRs around $\mathcal{O}$(100 PeV)-$\mathcal{O}$(1EeV).

Study the galactic to extragalactic transition of CRs.

SNOWMASS review 2022, arXiv:2205.05845



Summary

1. GRAND's main goal is to observe the UHE ν with radio antennas.
2. Three prototype arrays are being deployed:
   GP300: Dunhuang, China
   GRAND@Auger: Argentina
   GRAND@Nançay: France
3. Cosmic rays have been observed at GP300 and GRAND@Augar.
4. GP300 will continue to measure CRs of 100 PeV-1 EeV.

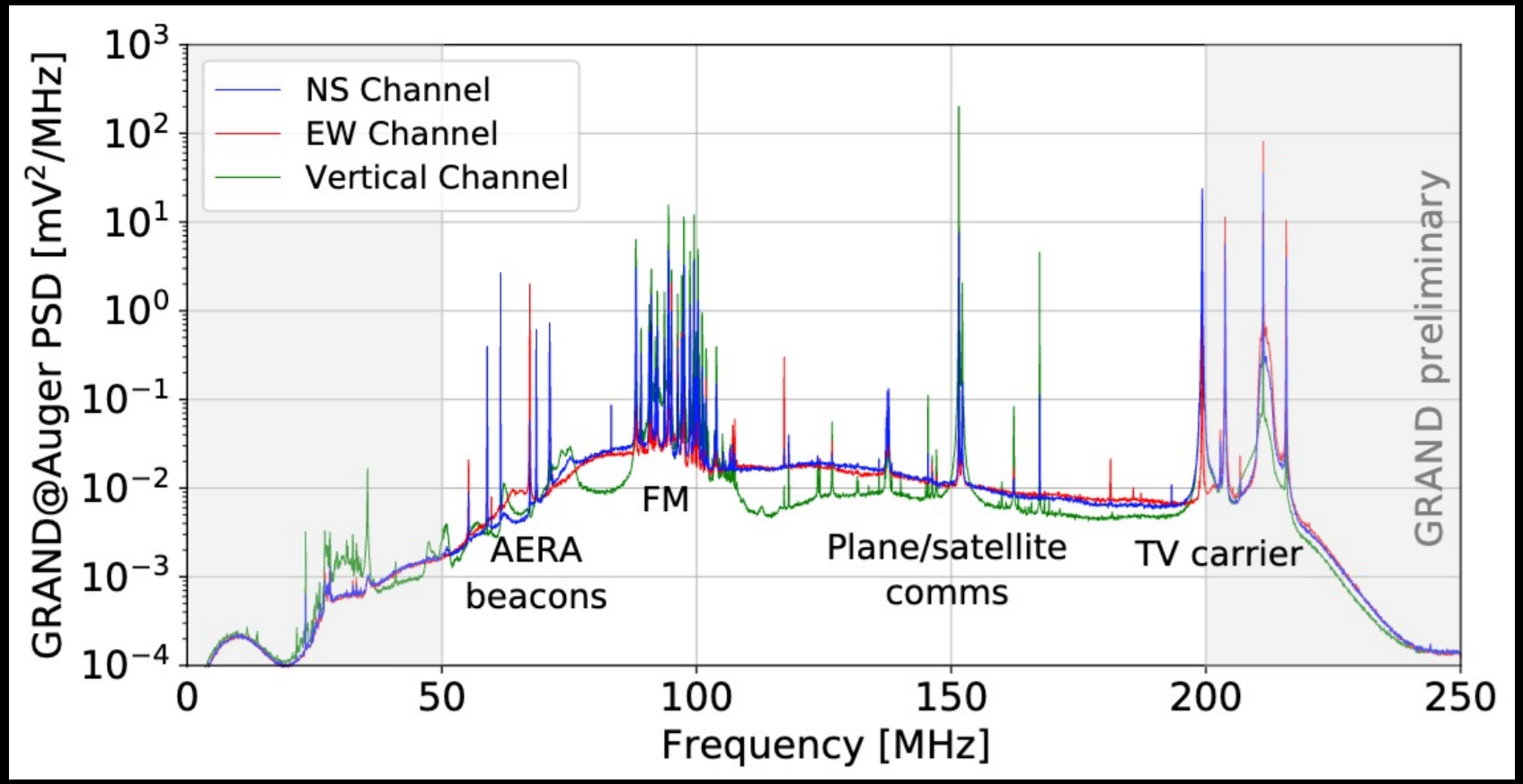
References:
Website: http://grand-observatory.org
GRAND Whitepaper: https://arxiv.org/abs/1810.09994
GRAND ICRC2025: https://arxiv.org/html/2507.09585/
GRANDlib: https://arxiv.org/abs/2408.10926
https://github.com/grand-mother

GRAND Collaboration Meeting @Warsaw, June 2025

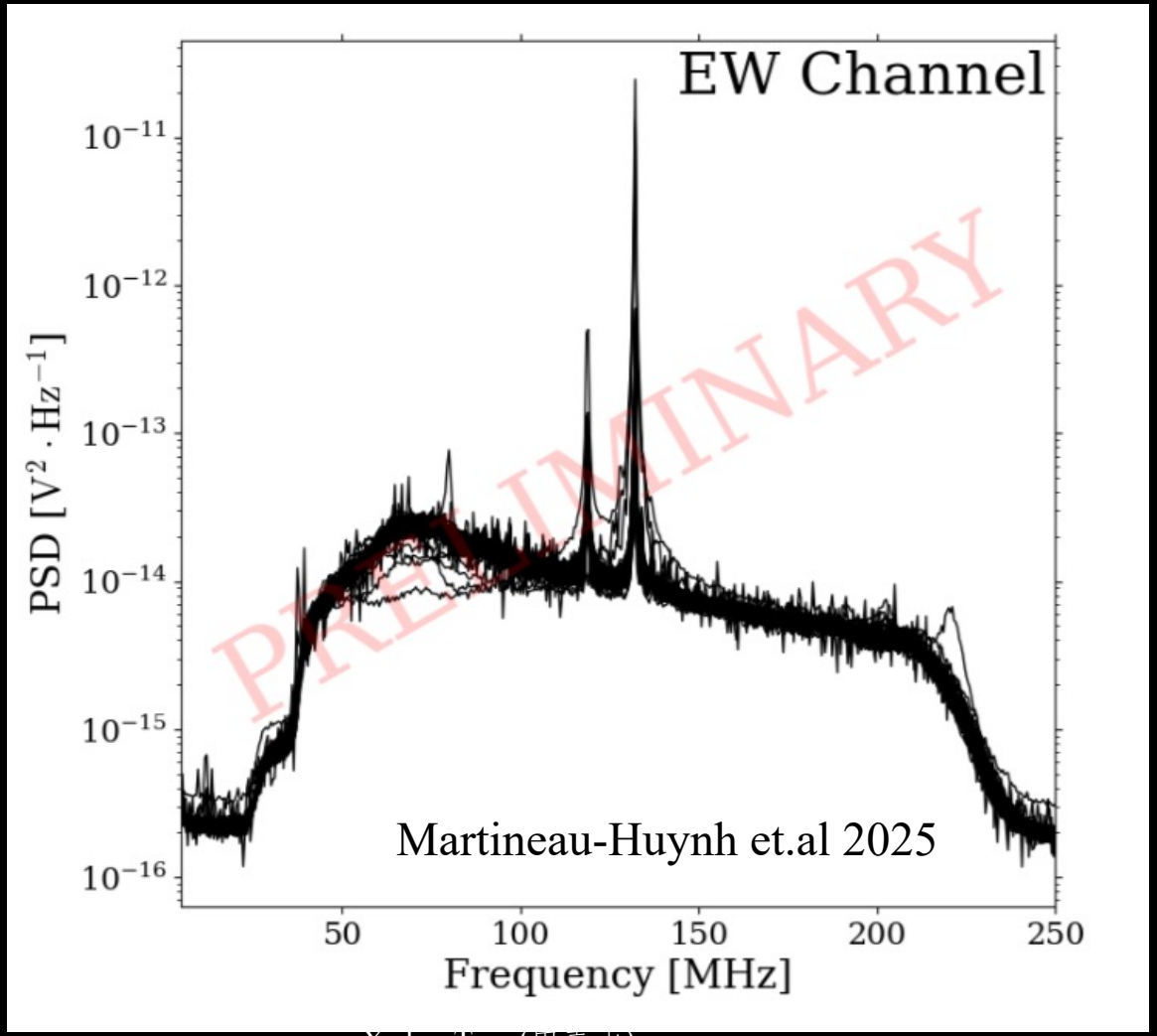
Backup

GRAND@Auger: periodogram

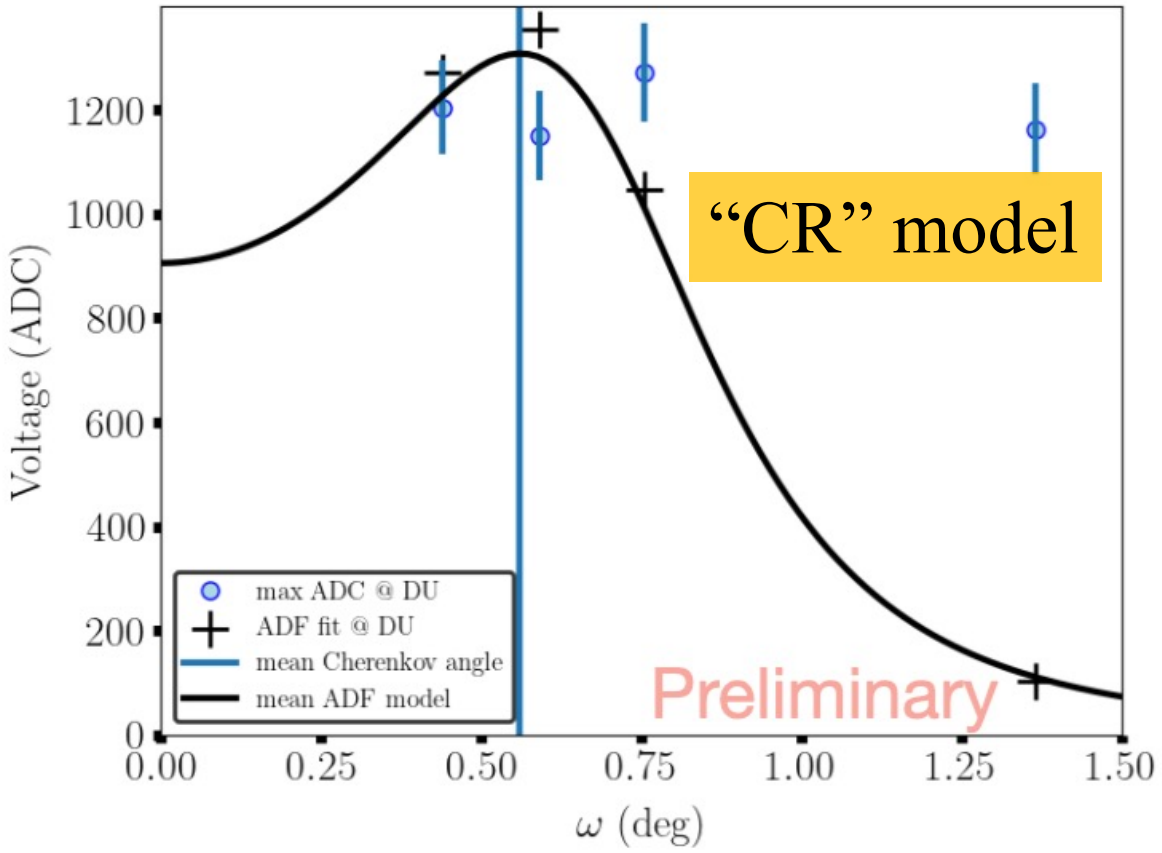
Known noises at Malargüe, Argentina.



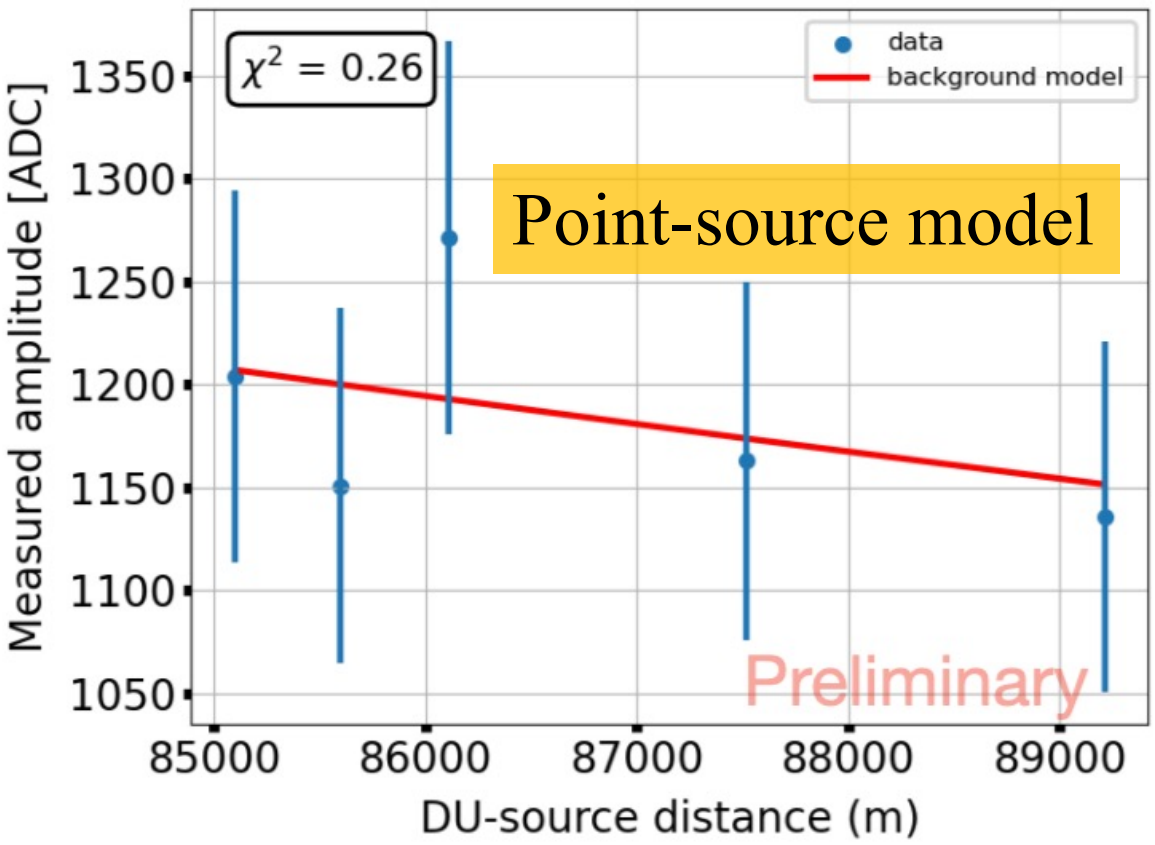
GP300 spectrum: data vs. simulation



ADF for noise events

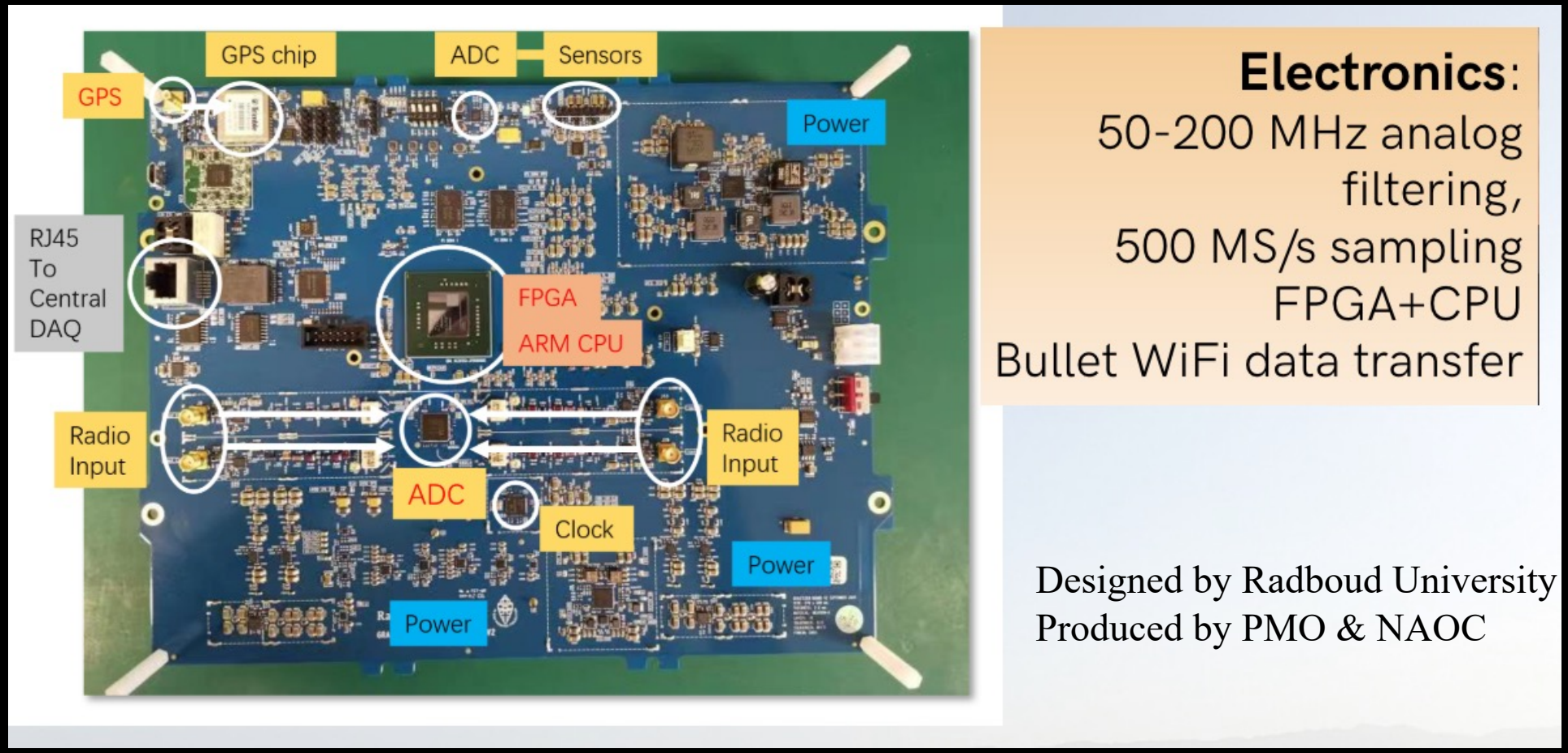


"CR" model



Point-source model

Frontend Board of Prototype

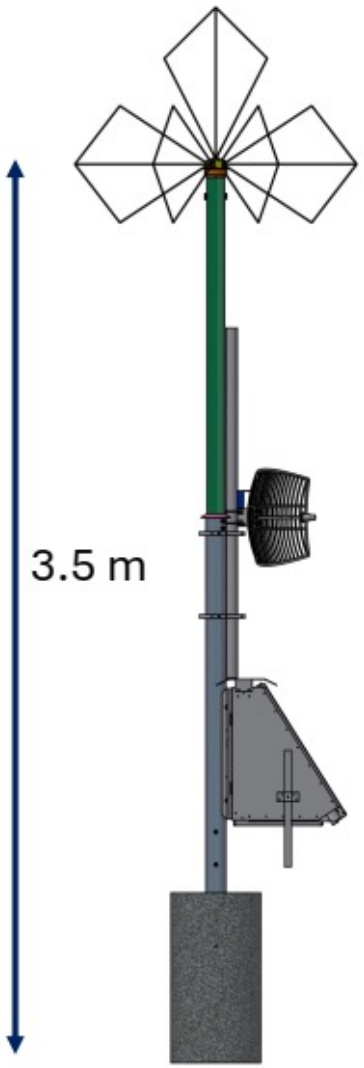


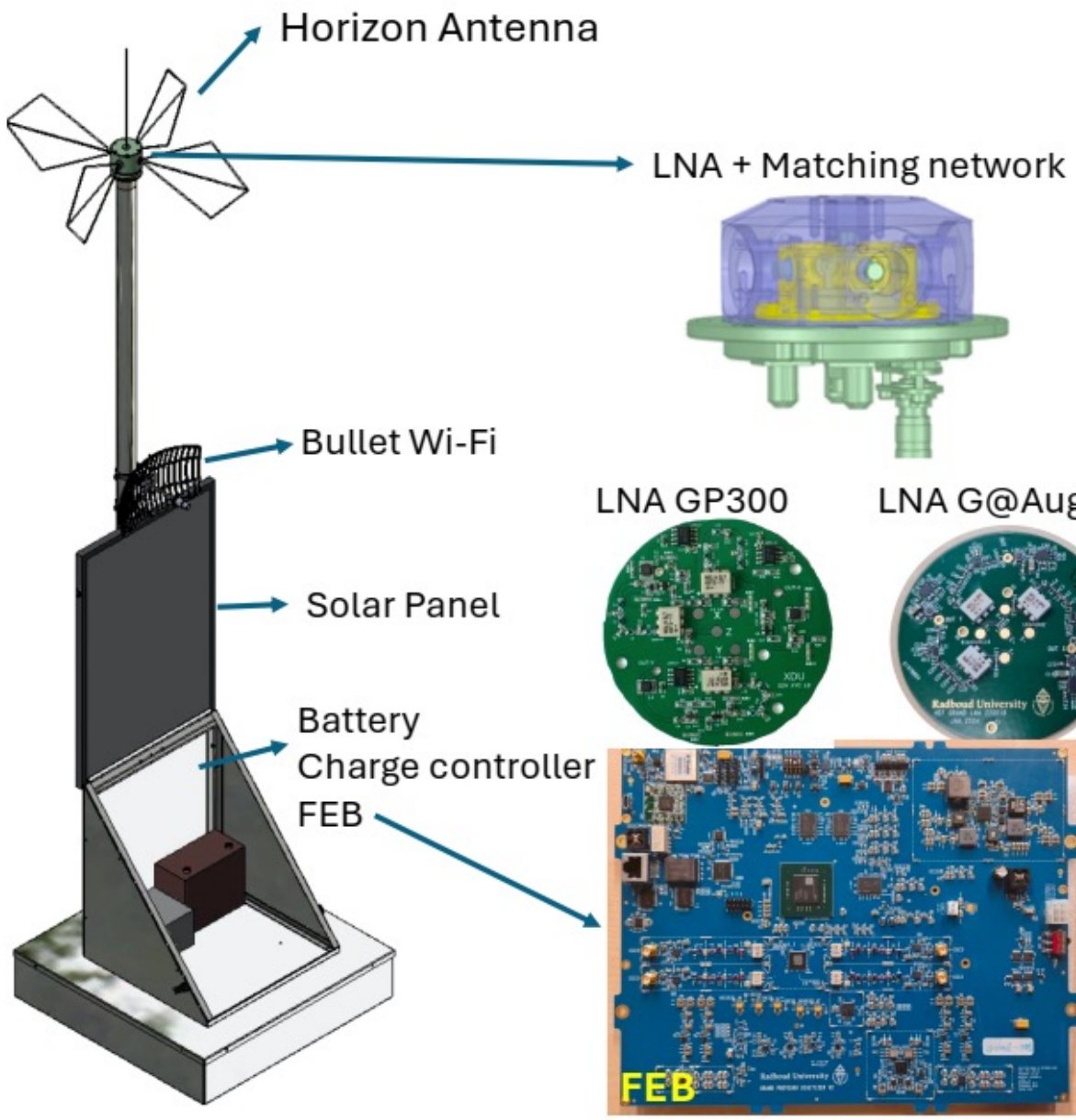
Electronics:
50-200 MHz analog filtering,
500 MS/s sampling
FPGA+CPU
Bullet WiFi data transfer

Designed by Radboud University
Produced by PMO & NAOC

GRAND Detector Unit

- Horizon Antenna
  - 3 arms: x (N-S), y (E-W): 2 x 65 cm, z (Vertical) : 65 cm
  - Fixed at 3.5 m above ground
- LNA + Matching network enclosed in antenna hub.
- Solar Panel – Battery – Charge Controller.
- Front-End Board electronic: ADC 500MS/s,14 bits, FPGA + 4 CPUs
- Data transmission through a Wi-Fi antenna to central DAQ.
- Trigger algorithm:
  - Unbiased trigger mode every 10 s.
  - L1 trigger detects transient pulses above fixed threshold.
  - L2 trigger: searches for coincidences between DUs within a time window.





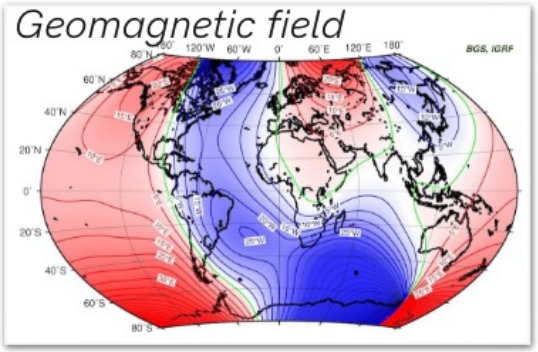
Software pipeline: GRANDlib

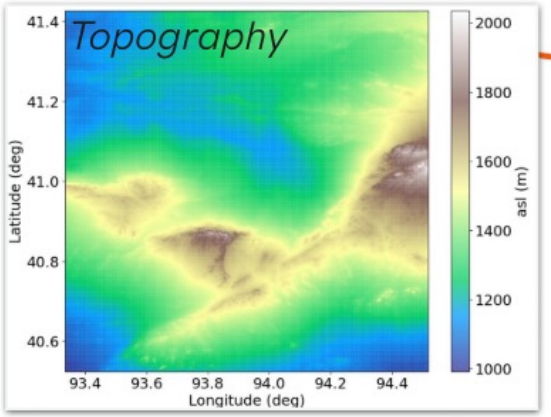
https://github.com/grand-mother/grand

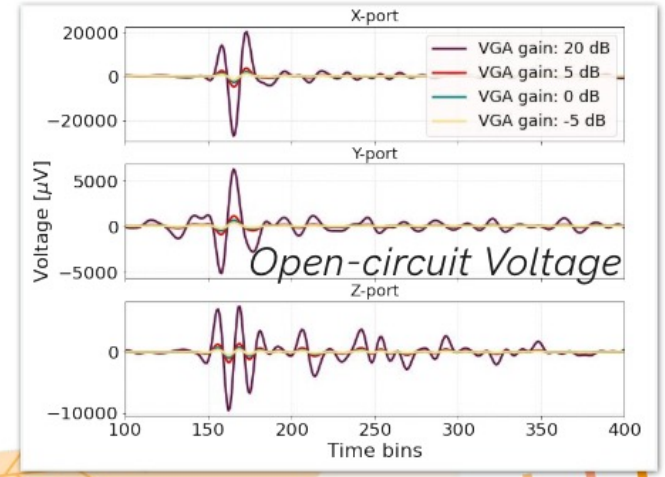
Python offline software package for the GRAND collaboration
Tool to manage and analyze data

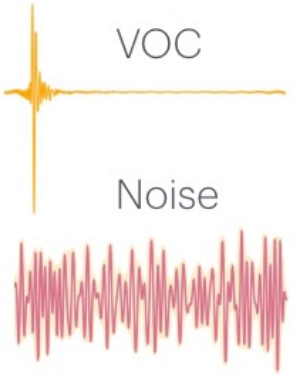
GRAND Coll. in prep.

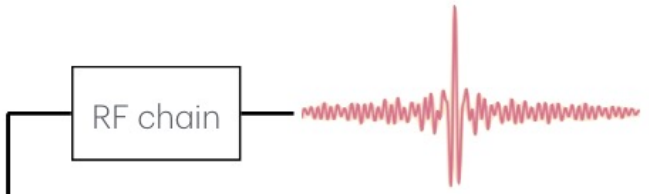
PRELIMINARY FIGURES

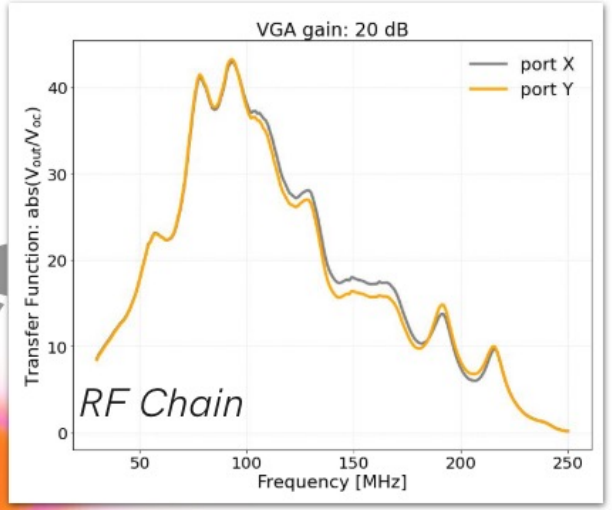


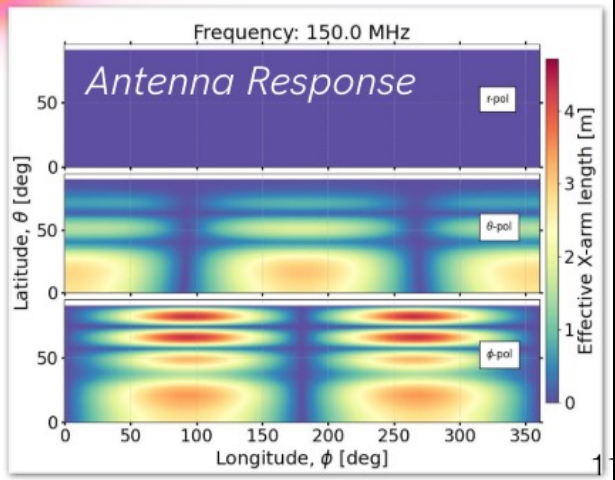








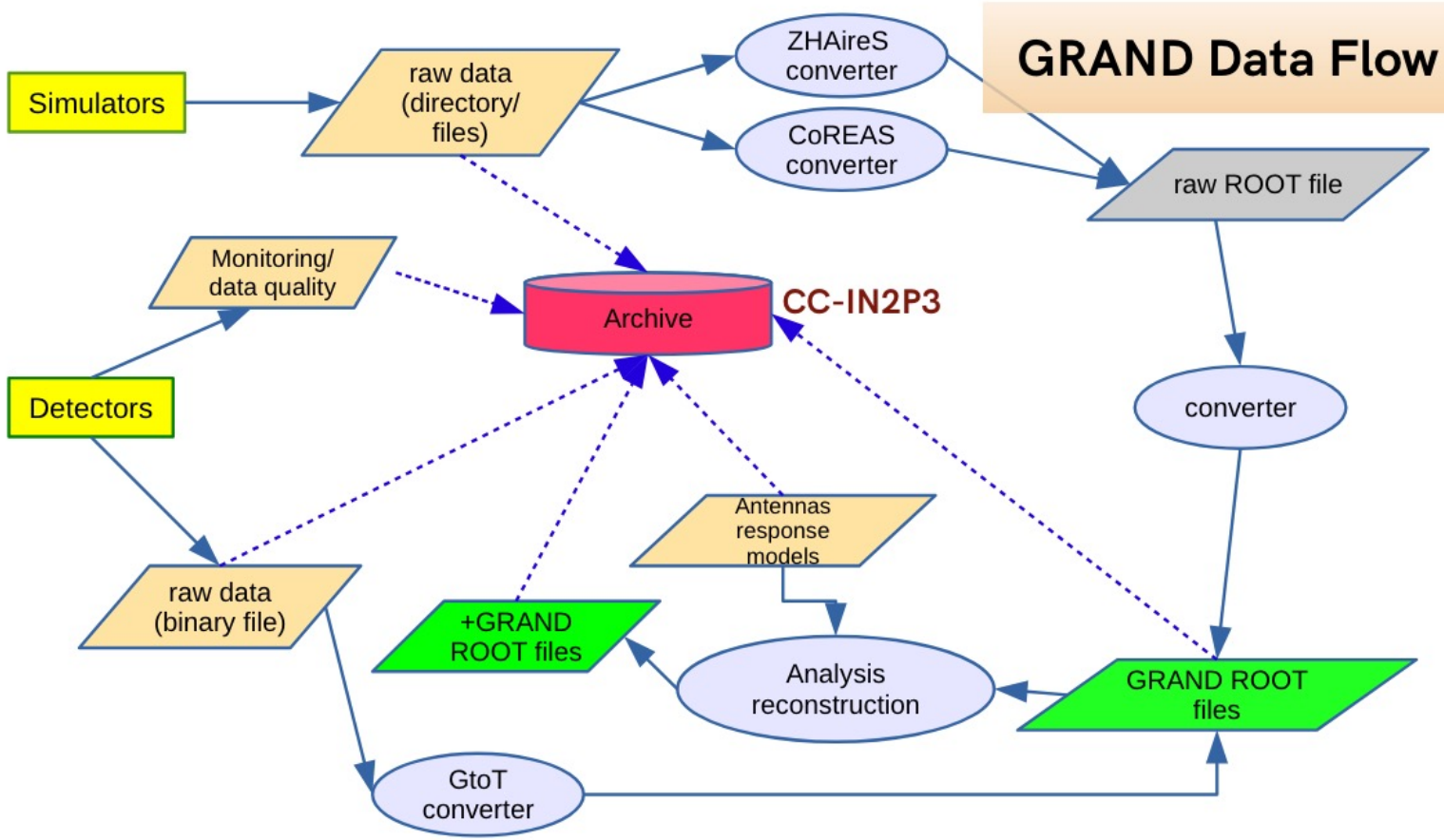




- User friendly tool. No need to install ROOT
- Modules for coordinate systems, topography and geomagnetism
- Includes galactic noise and RF chain parameters
- Standard code for signal processing
- Tools to store data in a standard file format and manage them
- Refer to grand/examples for example scripts

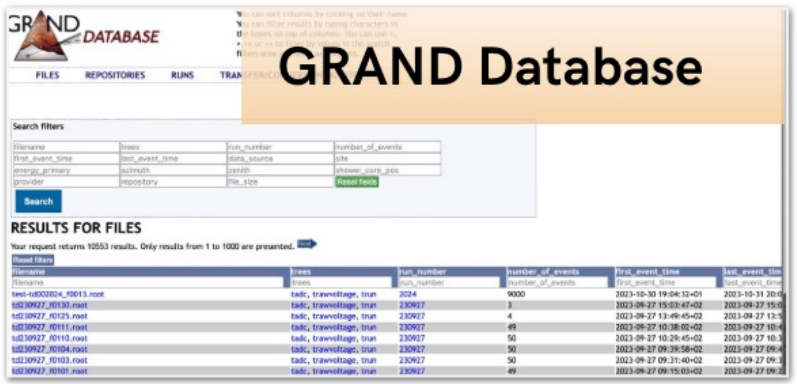
Software pipeline: data flow & online monitoring

GRAND Data Flow

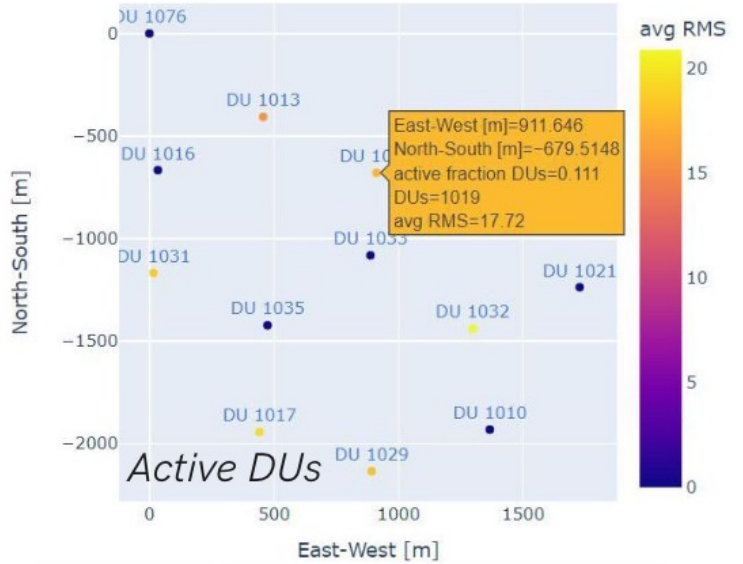


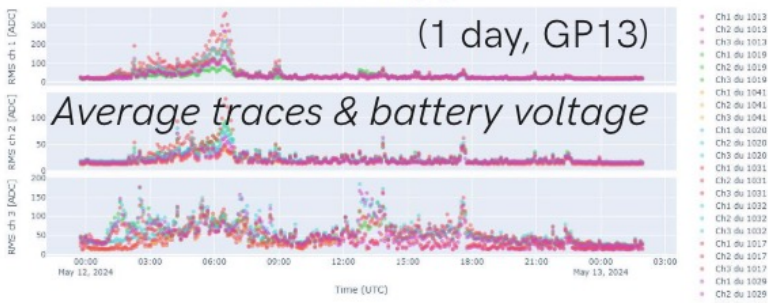
- Automatic/semi-automatic transfer from GRAND@Auger/GP300
- Automatic conversion to GRANDRoot format
- Recorded into GRAND Database, storage at **CC-IN2P3** (Lyon, France)

GRAND Database



GRAND Data Online Monitoring





- Battery & Temperature levels
- RMS levels
- Traces and Frequency domains
- Transient rate, coincidences