

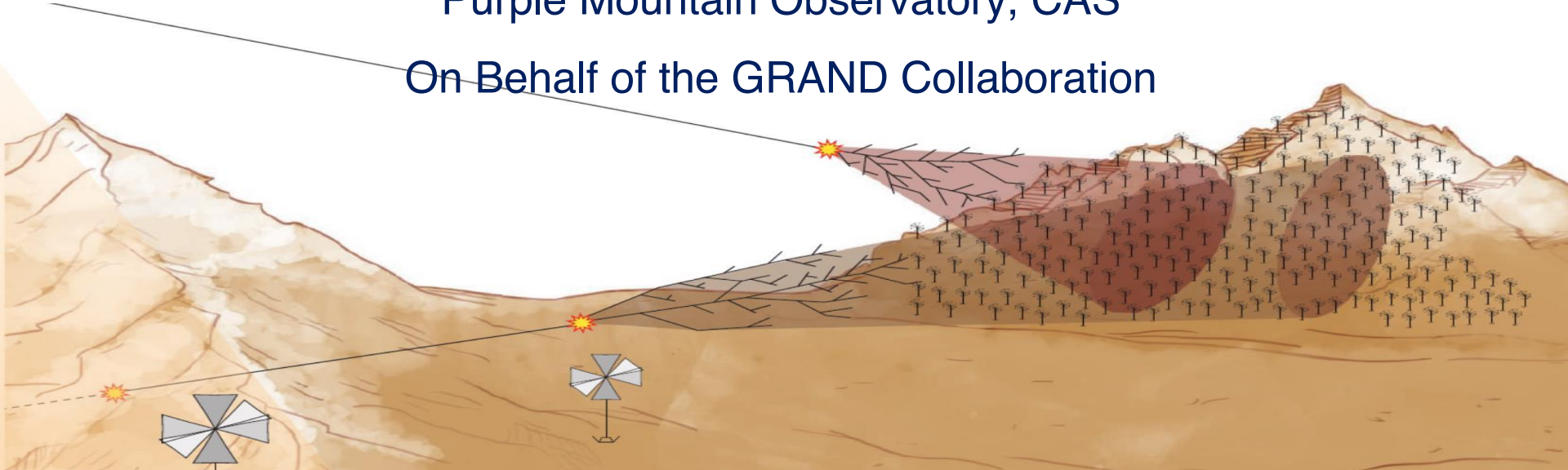


# Progress of the Giant Radio Array for Neutrino Detection (GRAND)

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On Behalf of the GRAND Collaboration



The 14th Workshop of France China Particle Physics Laboratory (FCPPL2023)  
Nov 6-10, 2023, SYSU Zhuhai Campus



UHECR

### Extensive Air Showers

- o Produced by UHE particles in the atmosphere
- o Radio emission
  - Produced by interaction with the geomagnetic field
  - Undergoes little attenuation by the atmosphere
  - Can be detected far from the shower

Radio emission

$\tau$

$U_\tau$

>30 km

<http://grand.cnrs.fr/>

Radio antennas: scalable, cheap, robust

# GRAND International Collaboration



**Particle detectors**  
Penn State U.

**Science case**  
IAP  
Nanjing U.  
NBI  
PMO  
Penn State U

**Electronics prototyping**  
Nikhef/Radboud U.  
NAOC  
PMO

**Fast Radio Bursts**  
PMO  
Obs. Paris/Nançay

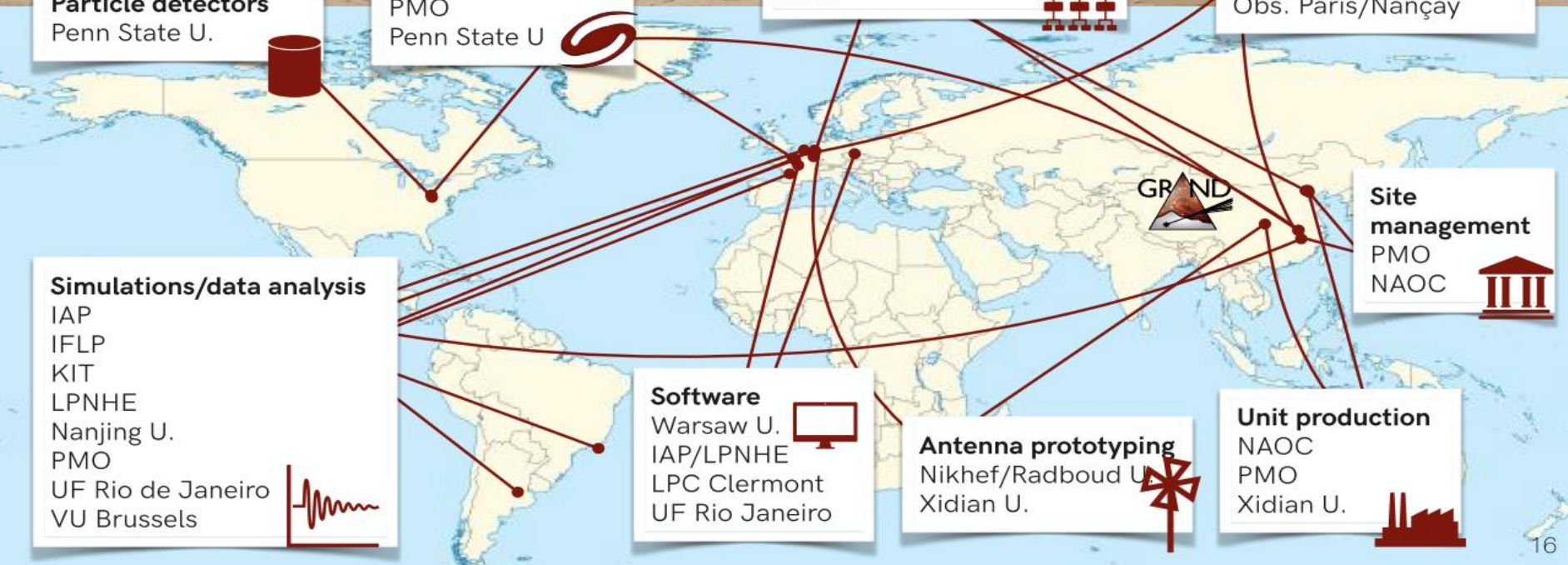
**Simulations/data analysis**  
IAP  
IFLP  
KIT  
LPNHE  
Nanjing U.  
PMO  
UF Rio de Janeiro  
VU Brussels

**Software**  
Warsaw U.  
IAP/LPNHE  
LPC Clermont  
UF Rio Janeiro

**Antenna prototyping**  
Nikhef/Radboud U.  
Xidian U.

**Unit production**  
NAOC  
PMO  
Xidian U.

**Site management**  
PMO  
NAOC



# A staged approach **with self-standing pathfinders**

	GRANDProtos	GRAND10k	GRAND200k
	2023	2028	2032 (?)
Goals	<p><b>autonomous radio detection of very inclined air-showers</b></p> <p>Cosmic rays <math>10^{16.5-18}</math> eV</p> <ul style="list-style-type: none"> <li>• Galactic/extragalactic transition</li> <li>• muon problem</li> <li>• radio transients</li> </ul>	<p><b>1st GRAND sub-array</b></p> <ul style="list-style-type: none"> <li>• discovery of EeV neutrinos for optimistic fluxes</li> <li>• radio transients (FRBs!)</li> </ul>	<p>sensitive all-sky detector</p> <p><b>1st EeV neutrino detection and neutrino astronomy!</b></p>
Setup	<ul style="list-style-type: none"> <li>• <b>GRANDProto300</b>: 300 antennas over 200 km<sup>2</sup>, GP13@Dunhuang</li> <li>• GRAND@Auger: 10 antennas for cross-calibration</li> <li>• GRAND@Nançay: 4 antennas for trigger testing</li> </ul>	<ul style="list-style-type: none"> <li>• 2 detectors of 5-10k antennas each in each hemisphere: GRAND-North (China) and GRAND-South (Argentina?)</li> </ul>	<ul style="list-style-type: none"> <li>• 200,000 antennas over 200,000 km<sup>2</sup></li> <li>• 20 sub-arrays of 10k antennas</li> <li>• on different continents</li> </ul>
Budget	<p>2 M€</p> <p>100 antennas produced funded by China</p> <p>+ ANR-DFG NUTRIG (France- Germany)</p> <p>+ Radboud University</p>	<p>13 M€</p> <p>1500€/unit</p>	<p>300M€ in total</p> <p>500€/unit</p> <p>to be divided between participating countries</p>
	From Olivier Martineau's talk at Xidian U. in Oct. 2023		



## UHE neutrinos

- UHE neutrino astronomy
- UHE neutrino cosmogenic flux

## neutrino physics

- neutrino cross-section measurements
- spectral, angular distortions
- flavor ratios

## UHECR, hadronic physics

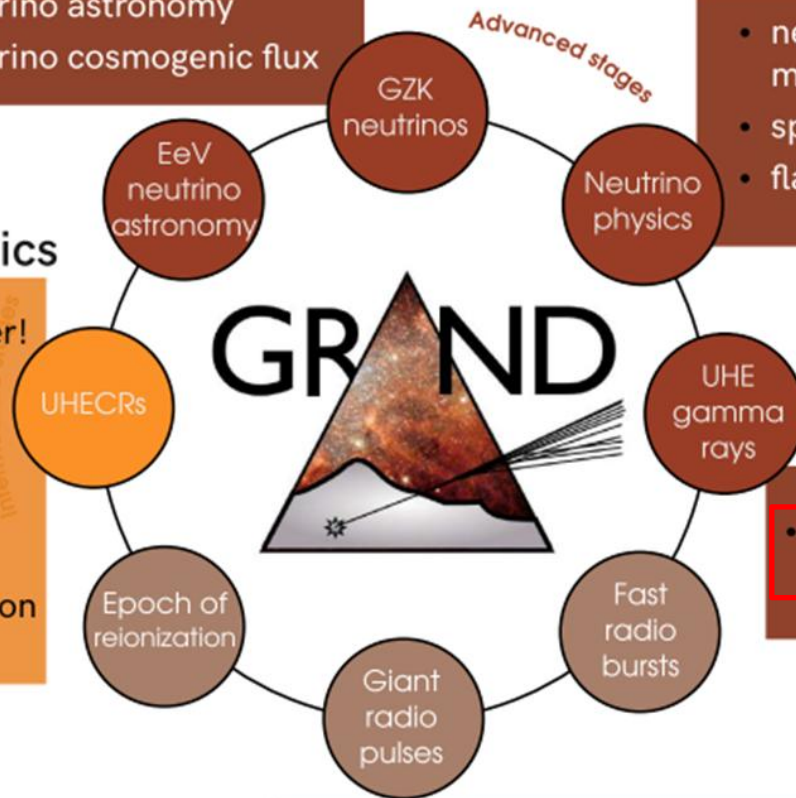
- 20 times the exposure of Auger!
- GRANDProto300: transition from Galactic/ extragalactic
- hadronic physics: muon discrepancy, UHECR mass composition, p-air cross-section

## UHE gamma rays

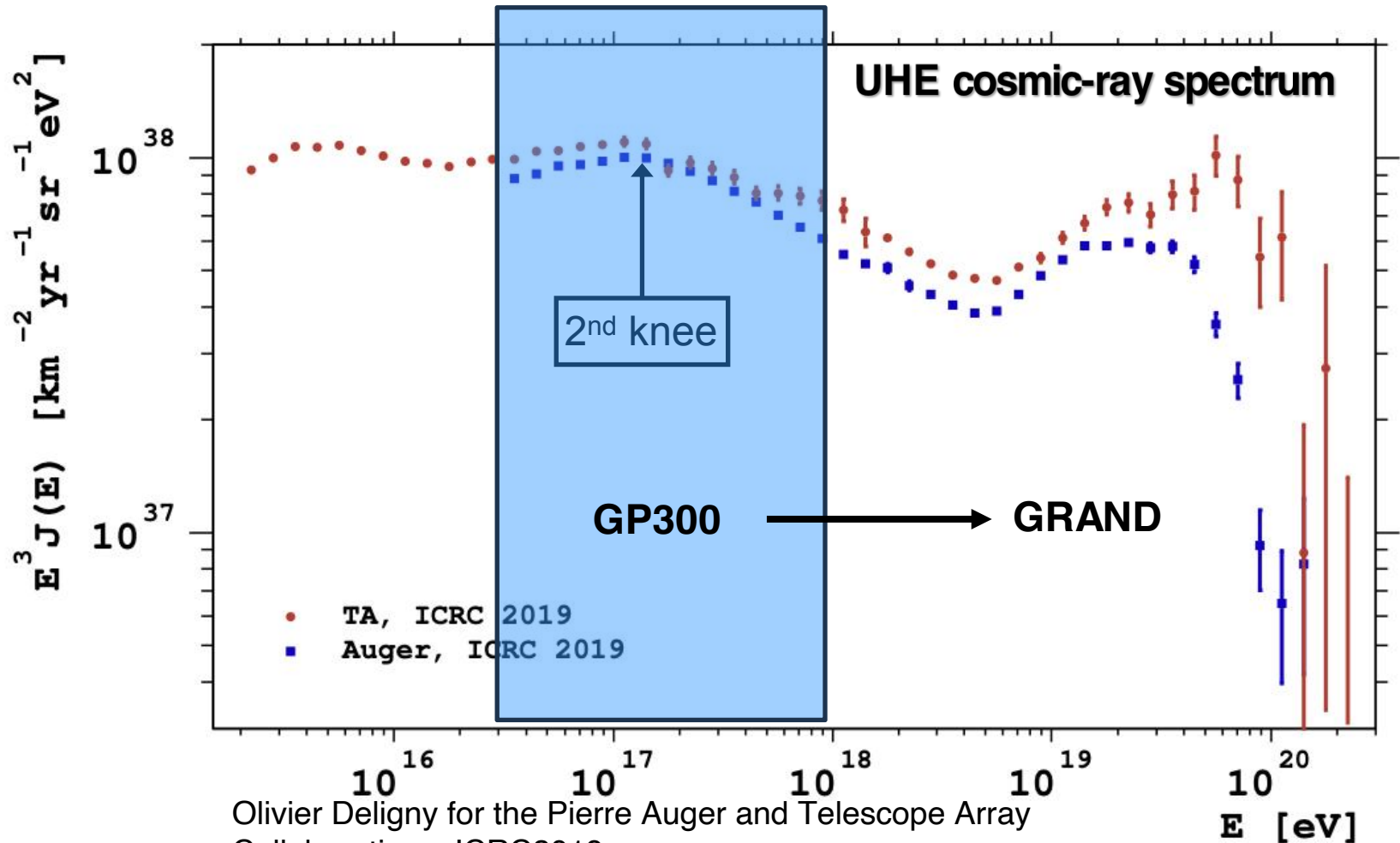
- competitive with Auger at GRANDProto300 stage

## radio-astronomy in a novel way

- unphased integration of signals: an almost full-sky survey of radio signals
- can detect FRBs and Giant Radio pulses of the Crab already at the GRANDProto300 stage



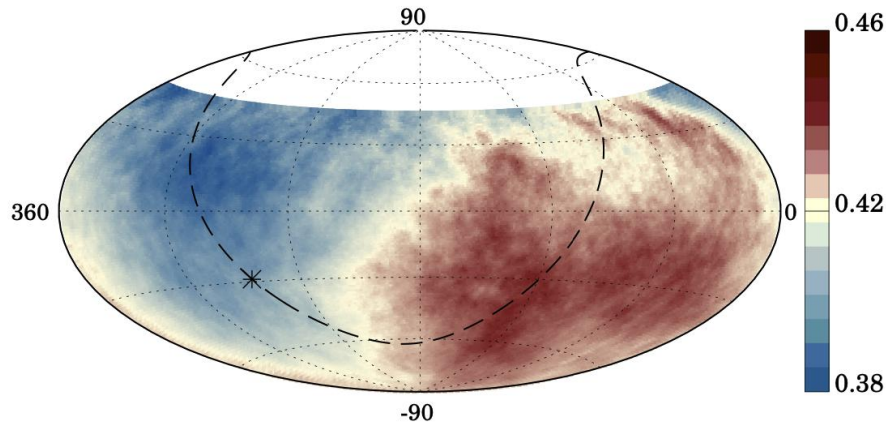
# Origin of UHE cosmic rays



- To understand observational differences between TA and Auger, confirmatory tests with more data are required
- GZK cut-off vs. the limits of particle acceleration

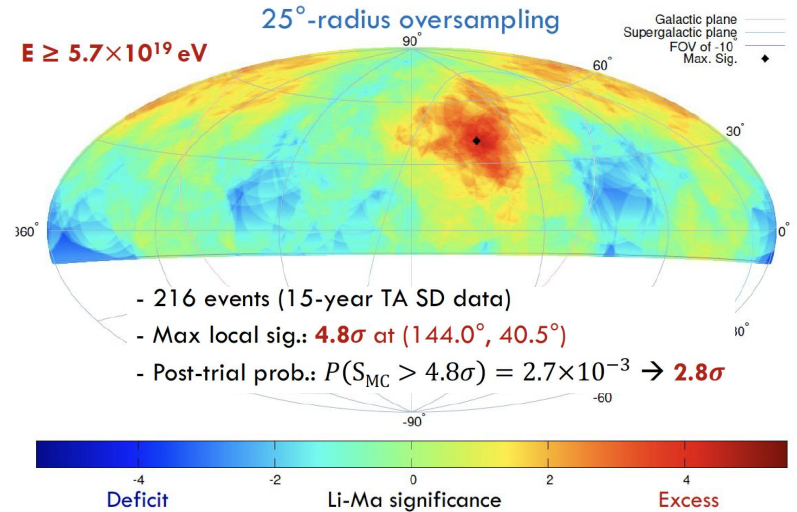


## Auger



A. Aab et al. (Pierre Auger Coll.)  
Science 357, 1266 (2017)

## TA



Jihyun Kim's talk @ ICRC2023

- $>8 \text{ EeV}$  CR anisotropy: an extragalactic origin
- $>57 \text{ EeV}$  hot spot: more data are needed to be confirmed

- GRAND can provide more precise anisotropy sky maps and confirm the hot spot
- GP300 can measure the anisotropy below EeV

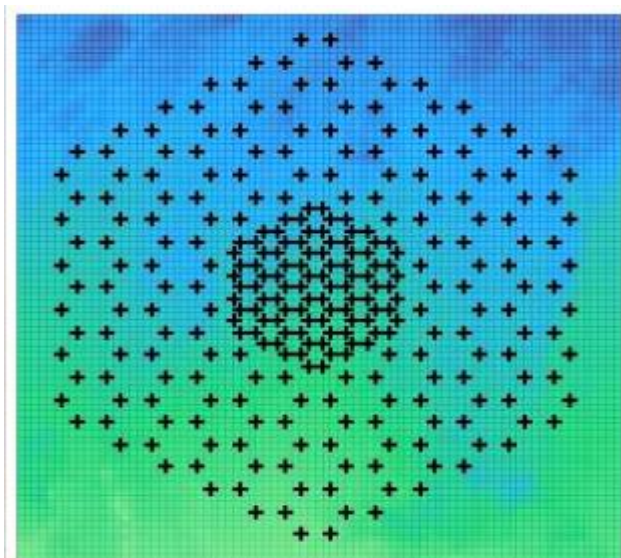


## A 300-antenna pathfinder stage of GRAND

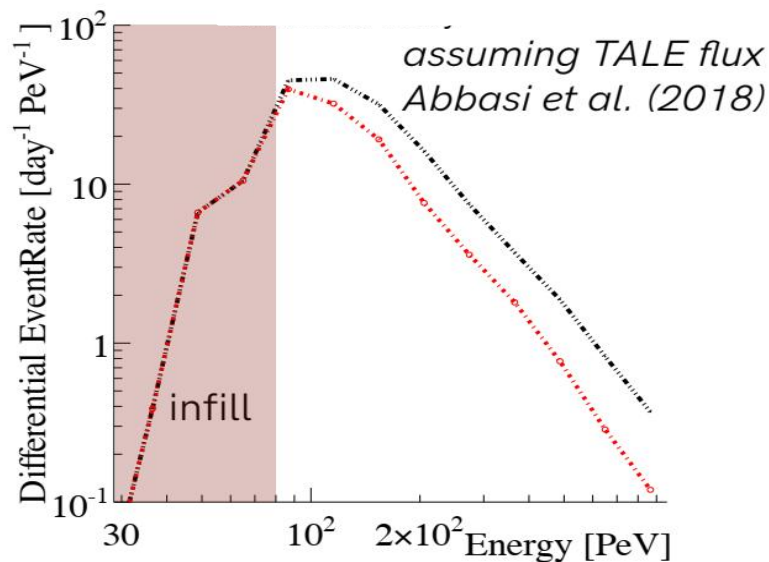
- 200 km<sup>2</sup> area
- 100 antennas ready; 23 have been deployed: 10 in Argentina; 13 in Dunhuang

## Aims to validate the GRAND as a standalone radio-detection array

- Realize the self-trigger techniques
- Algorithm for angular, energy and mass composition reconstruction
- Detection of very inclined cosmic rays with energies from 30 PeV to 1 EeV
- Study CRs in the Galactic-to-extragalactic transition energy range



**Layout:** 300 antennas, 200km<sup>2</sup>,  
1km step size with denser infill  
Erange = 10<sup>16.5</sup>-10<sup>18</sup>eV

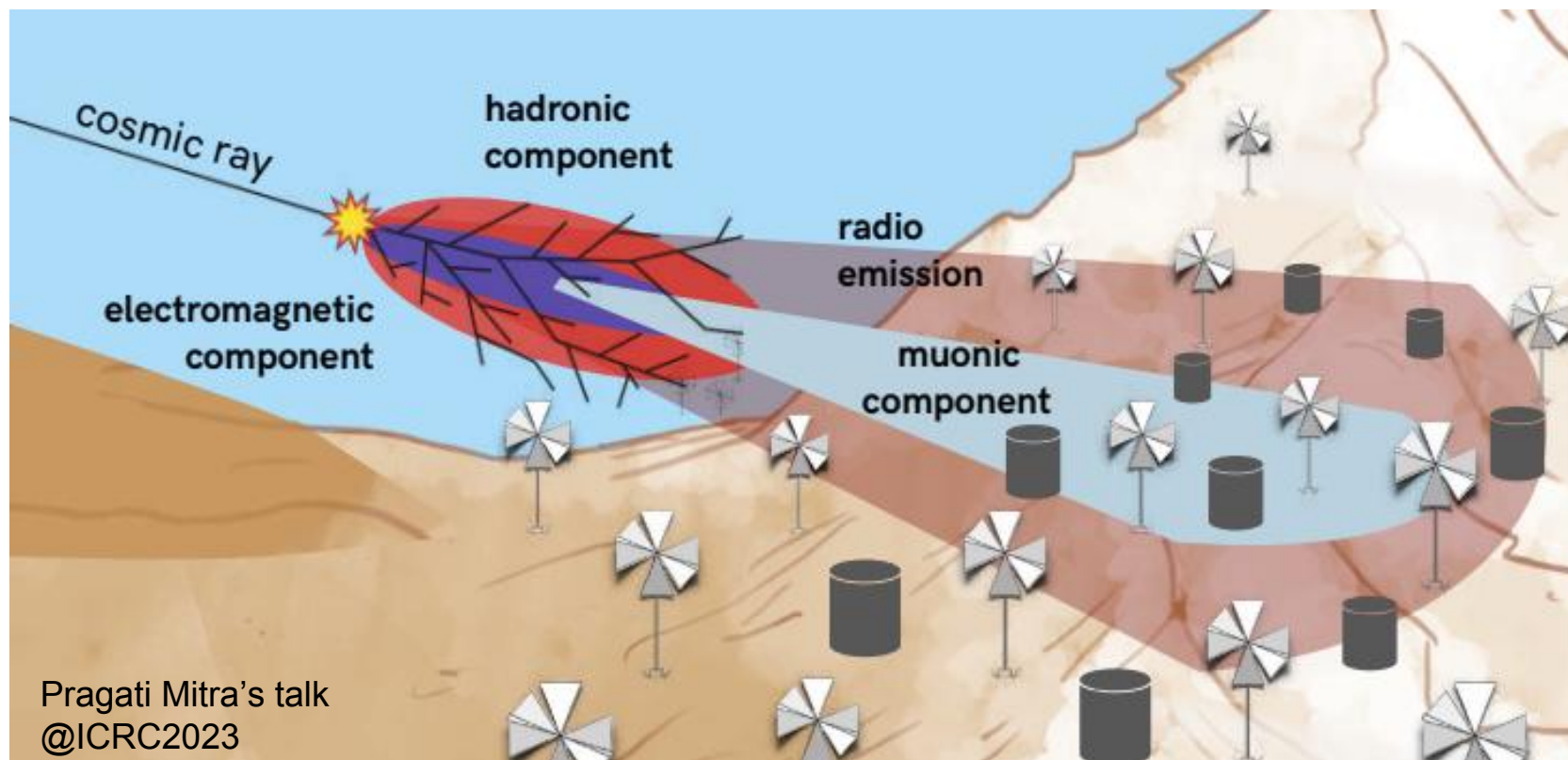


Thousands of events per day





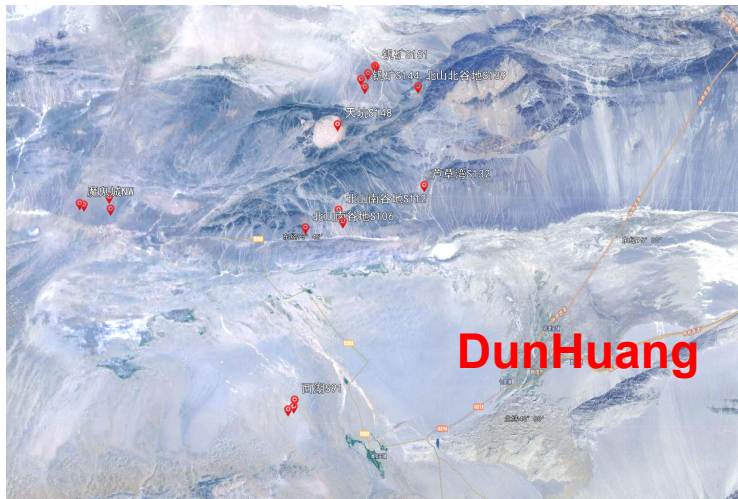
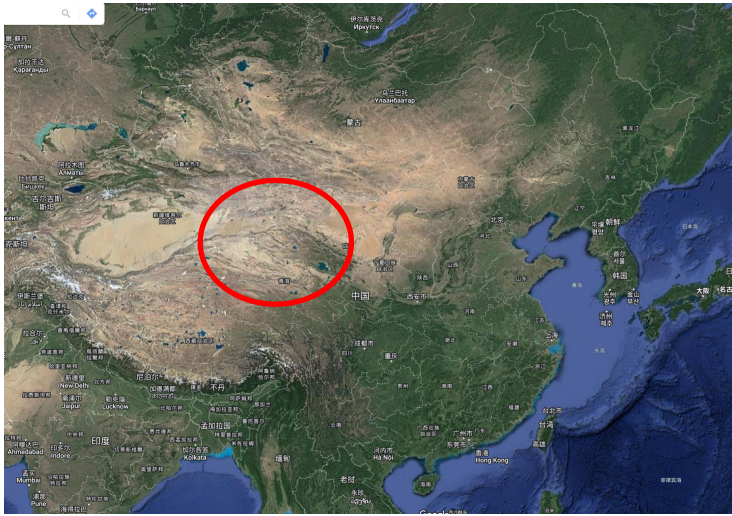
GRANDProto300 **radio array** complemented by **particle detectors**



To perform a direct separation of the two components at the detector level and study the hadronic interaction



# Site survey of GP300

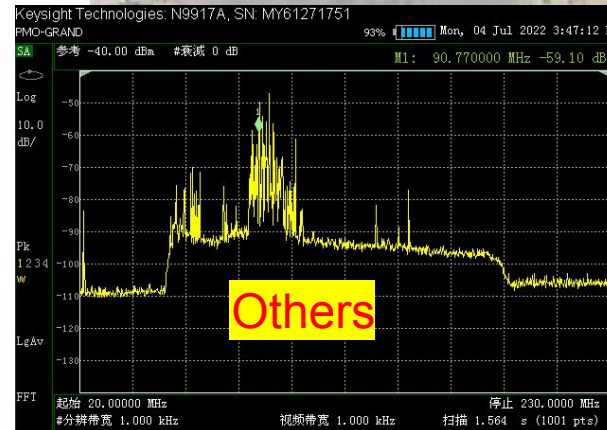
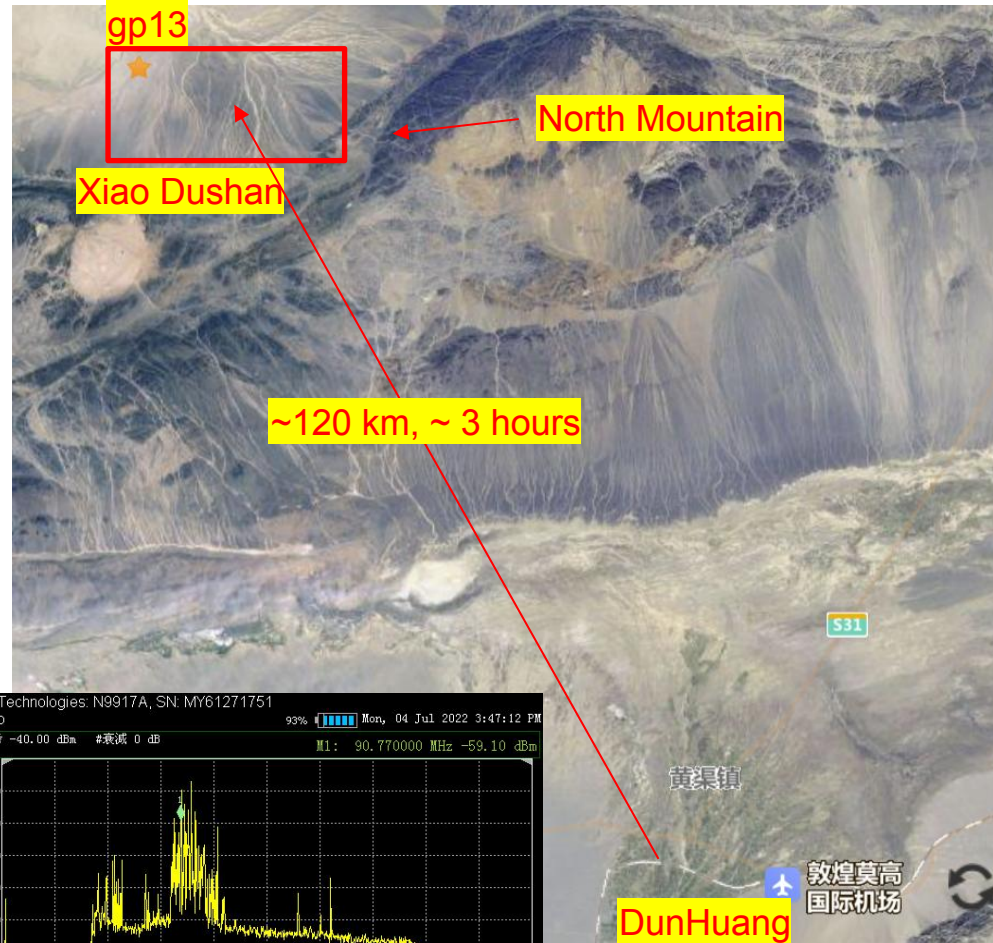


To ensure the best performance of the GP300 detector, we need a site with a very clean radio background.

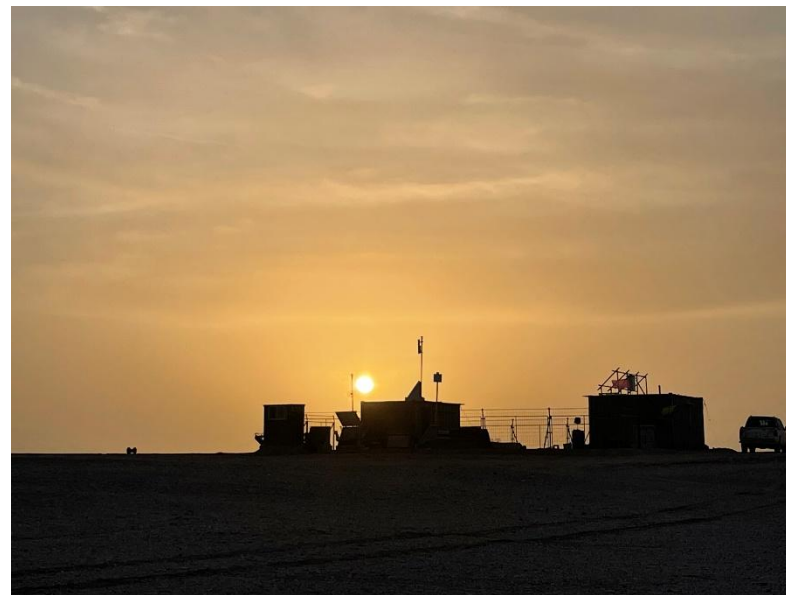
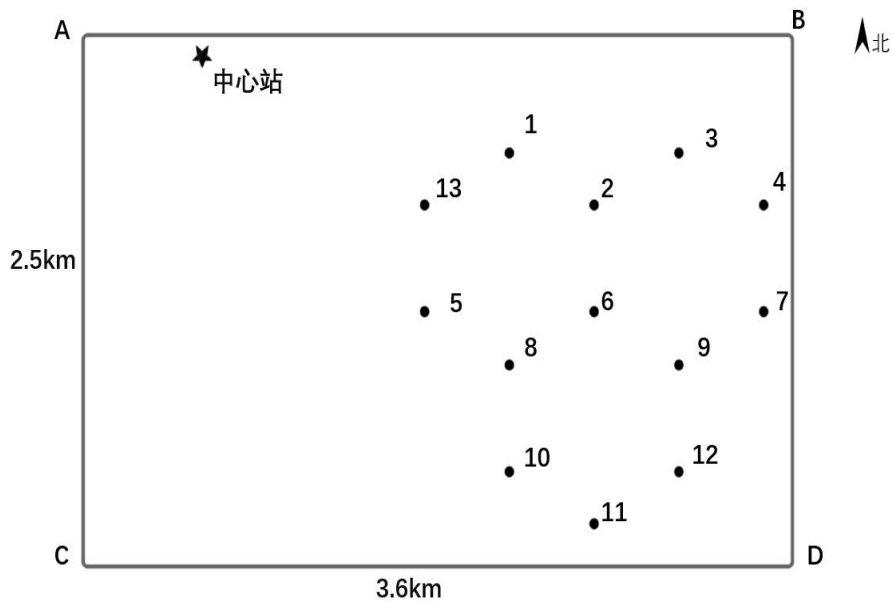
# Site of GP300



- Xiao Dushan (小独山) :  
Alt. avg. 1100m
- ~120 km from Dunhuang (敦煌), ~3 hours by car
- Low radio background



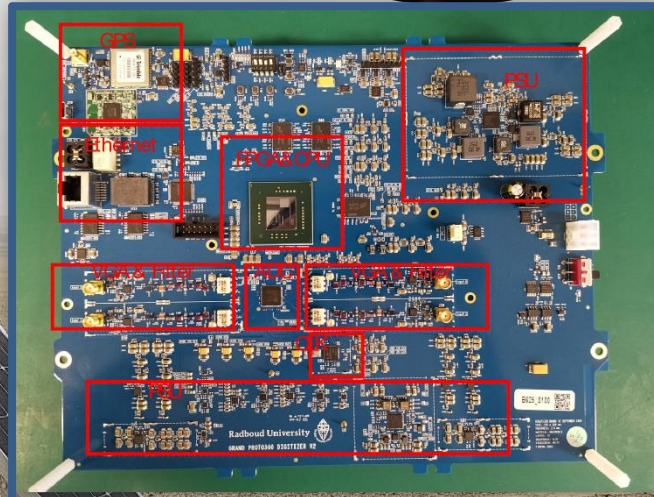
# Deployment of Gp13 in 2023





- High detection efficiency along the horizon (HORIZONANTENNA)
- Placed 3 m above the ground (to reduce diffraction of radio waves off the ground)
- Bow tie design, flat response in azimuthal angle and frequency
- Frequency range (50 MHz - 200 MHz)



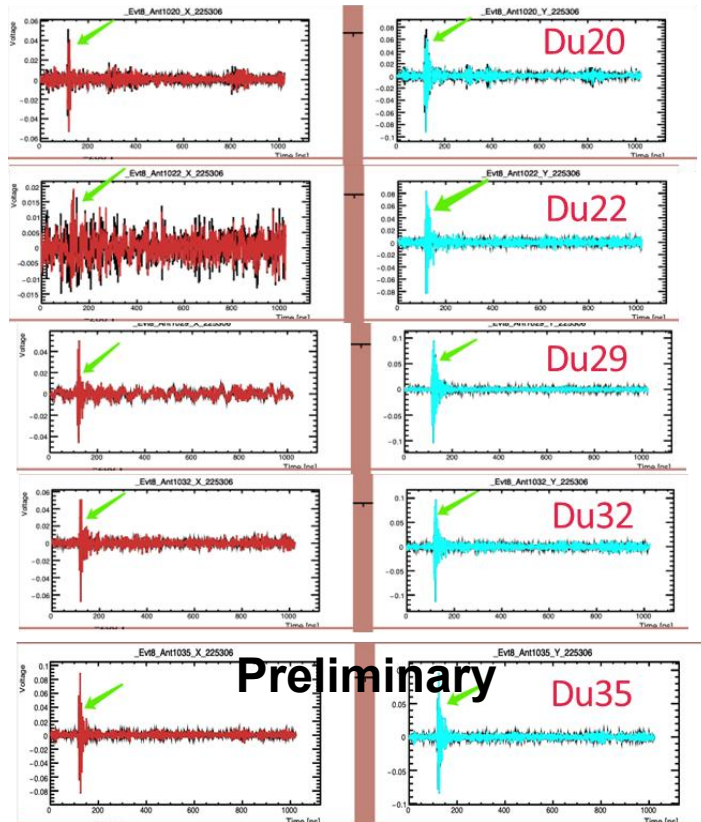


Electronic Board:  
50-200MHz analog filtering  
500 MSPS sampling FPGA+CPU  
Bullet WiFi data transfer





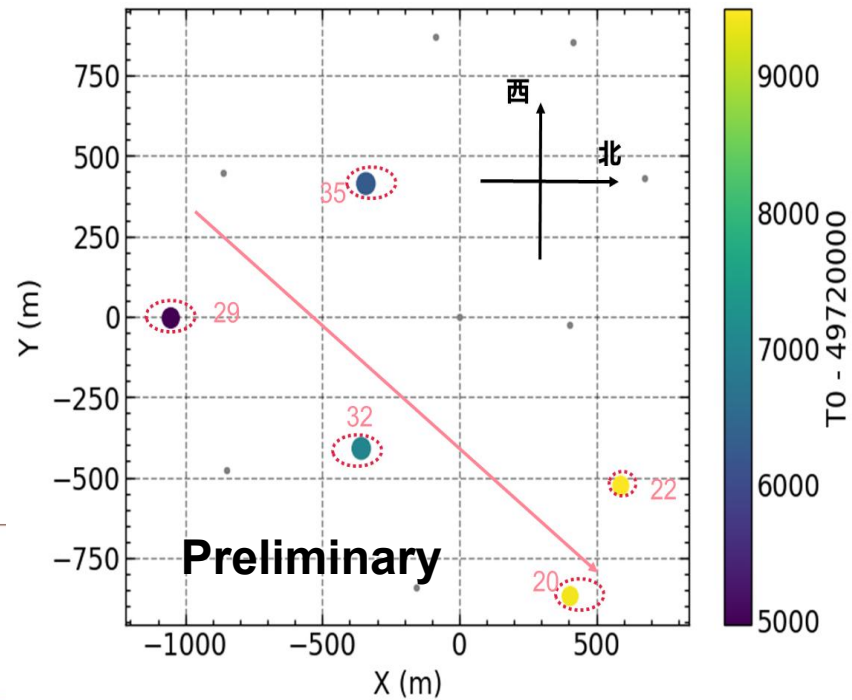
# Preliminary Result from GP13



NS

EW

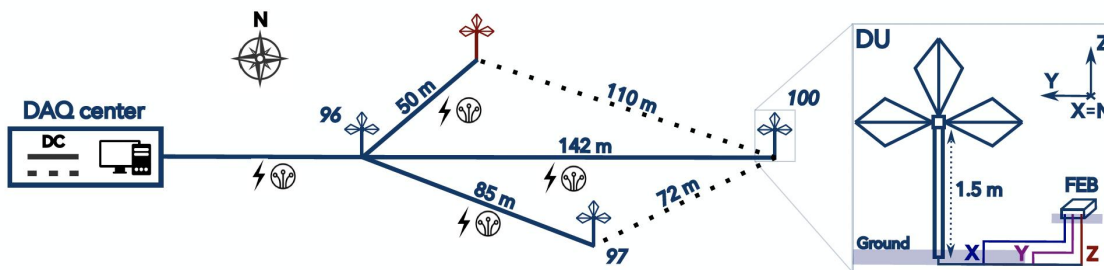
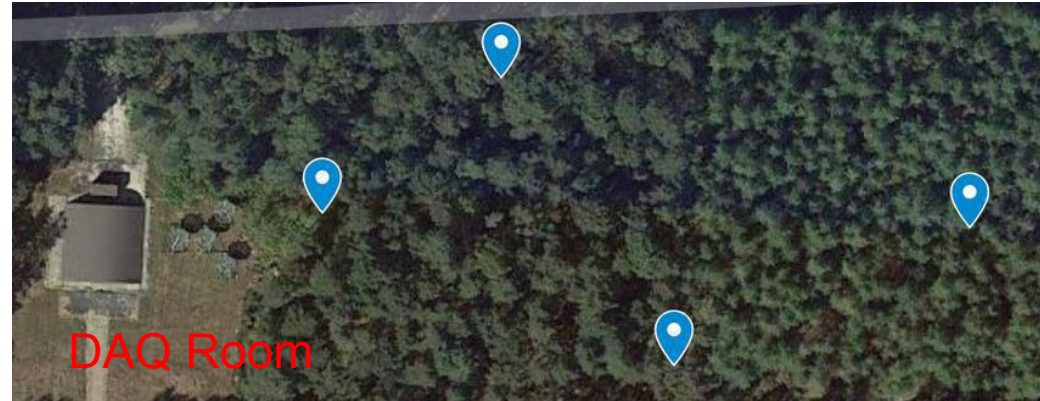
Plane wave fit  
Zenith  $71.46^\circ$   
Azimuth  $342.4^\circ$



• 5 DUs were triggered



- ❑ Hosted at the Nançay Radio Observatory, France
- ❑ Antennas were shipped from China and the rest of the equipment was funded by a joint grant between Paris (LPNHE and IAP) and Karlsruhe (KIT).
- ❑ Setup: 4 DUs have been deployed.
- ❑ Test bench for triggering and hardware





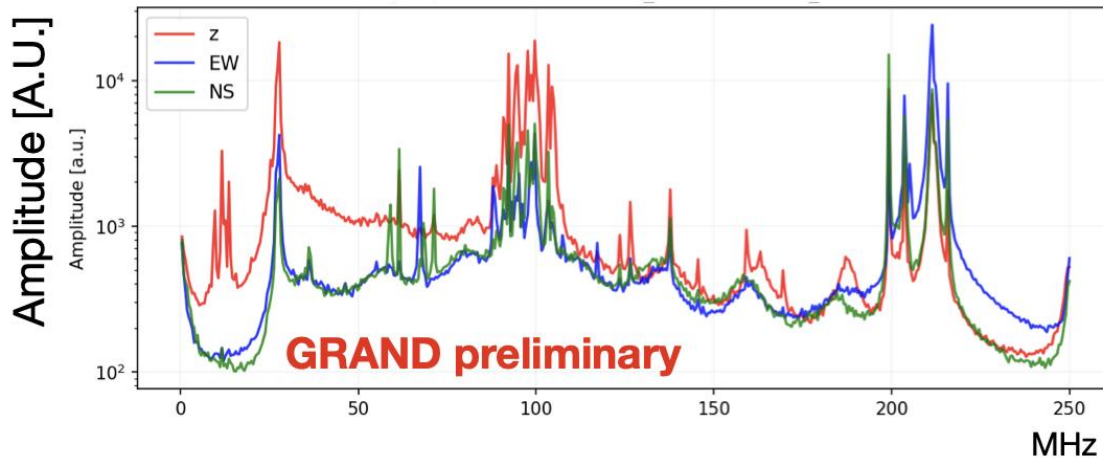


# GRAND@Auger



- Re-use part of the AERA array in the Auger experiment
- Antennas shipped from China and additional funding from Radboud U. (Netherlands), IAP and LPNHE (Paris), and Federal U. of Rio de Janeiro
- Goal: to perform an event-by-event comparison of the data with Auger
- 10 stations have been fully deployed by August 2023
- First data are now being analyzed

Plot by Beatriz de Errico



João R. T. de Mello Neto for the GRAND Collaboration  
PoS(ICRC2023)1050, ICRC2023 proceeding





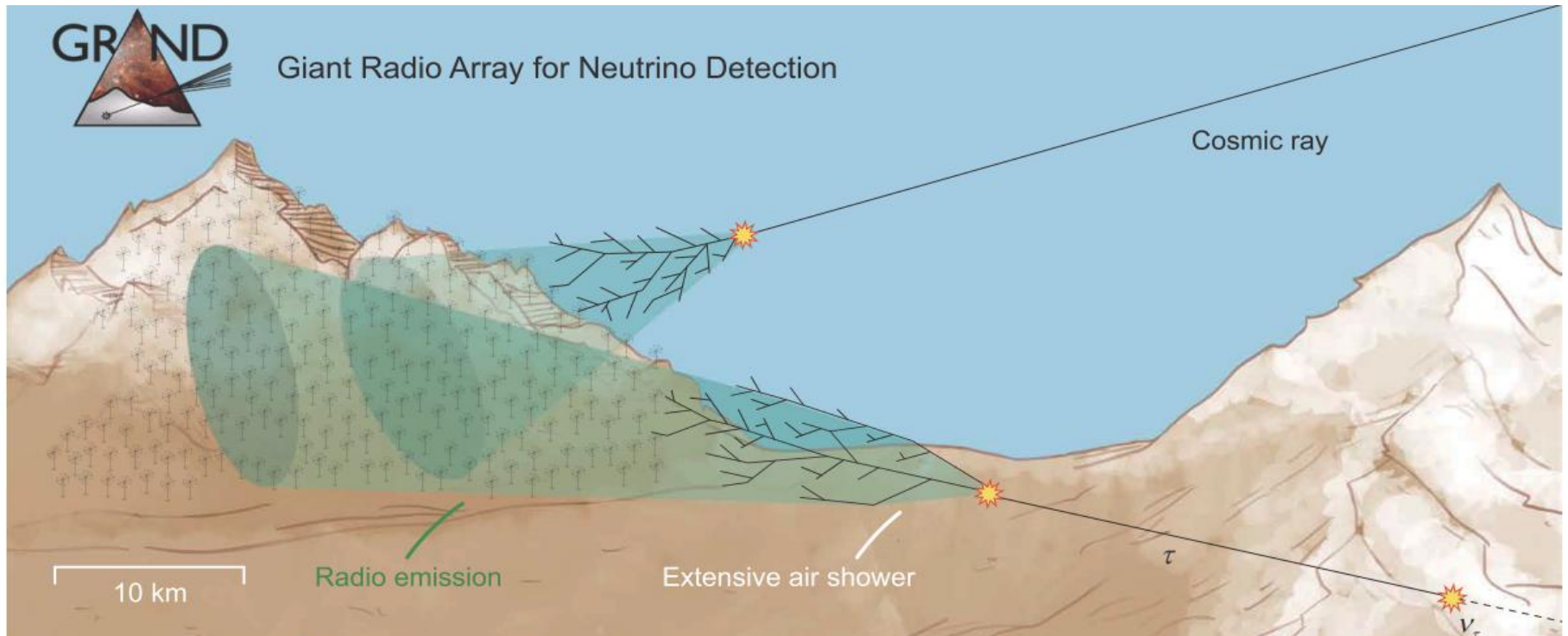
## GRANDProto300: pathfinder for autonomous radio-detection of UHECRs

- 300 detection units over 200 km<sup>2</sup>
  - Validate the detection principle for very inclined air showers
  
- Target energy range:  $10^{16.5}$  -  $10^{18}$  eV
  - Study transition between cosmic rays of Galactic and extragalactic origin
  - Study hadronic interaction by measuring electromagnetic and muonic components separately
  
- GP13 (at Dunhuang) and GRAND@Auger (10 Antennas) have been already deployed. GP100 in 2024



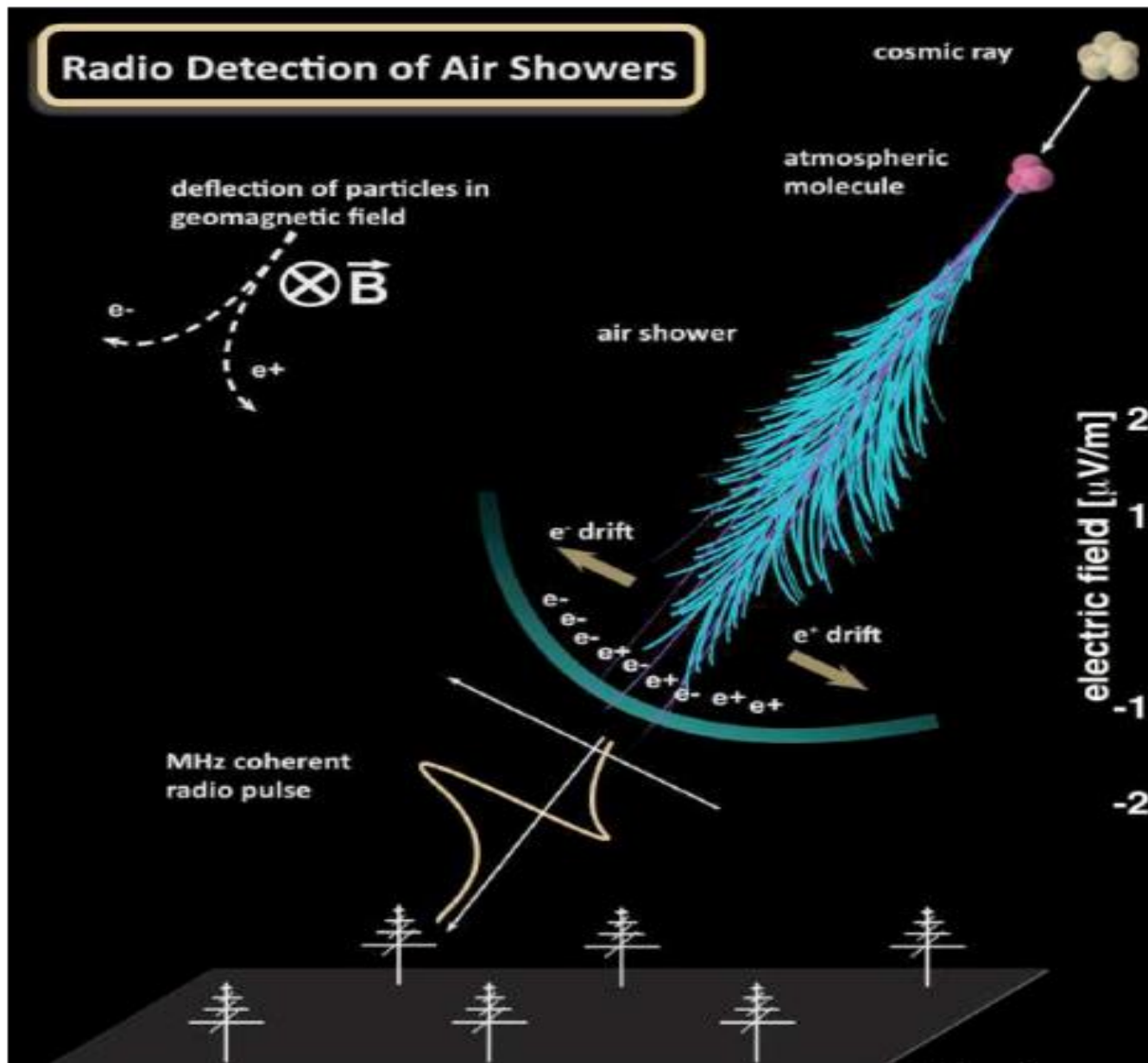
# 谢谢！

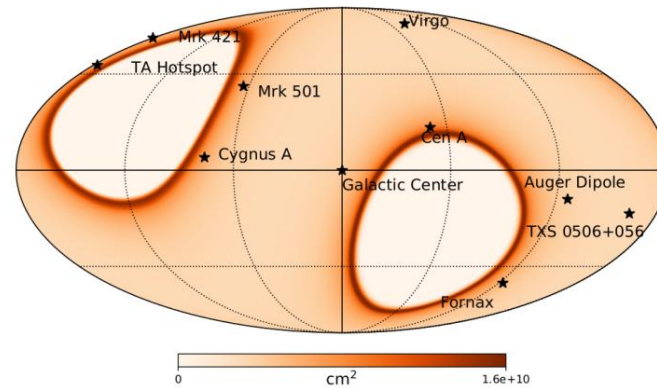
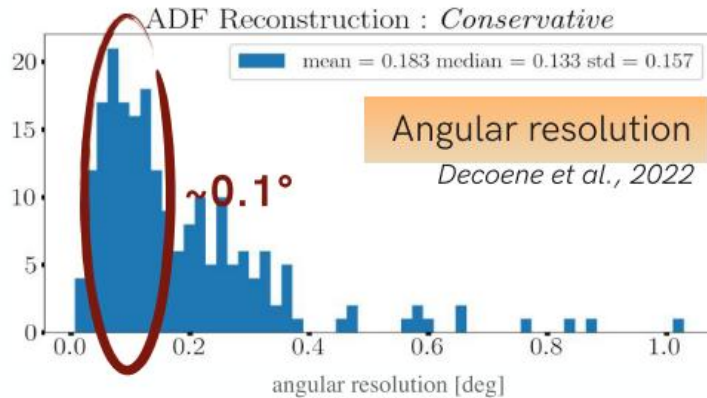
## Thank you!





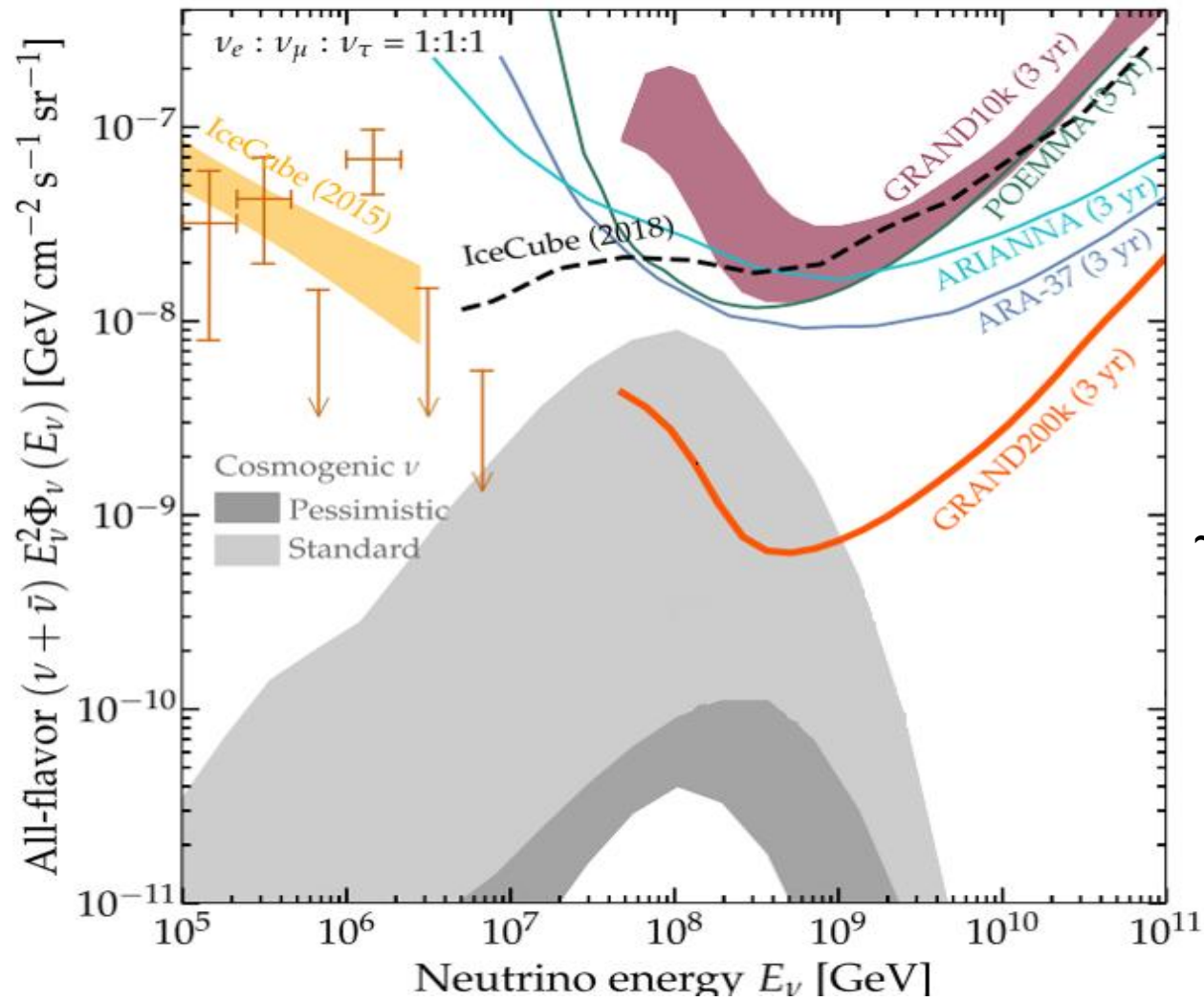
backup slides





- extensible & modularizable
- Searching for radio pulses in 50-200 MHz
- Its effective area is 10 times of Auger

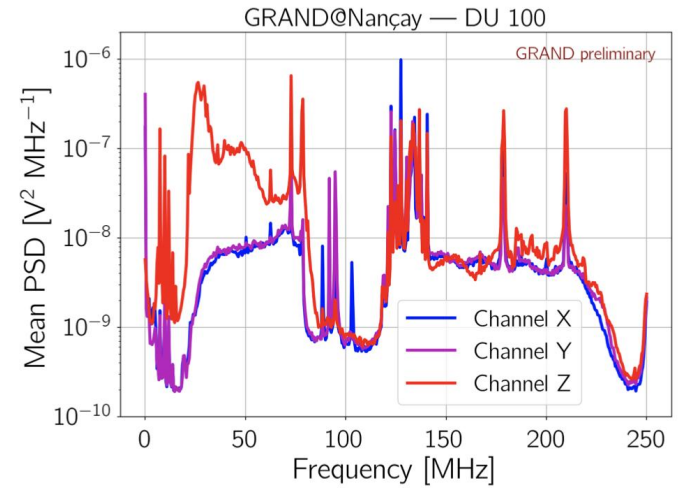
- **GRAND full sensitivity to neutrinos** ( $E > 10^{17}$  eV)  $\sim 4 \times 10^{-10}$  GeV cm<sup>-2</sup> s<sup>-1</sup> sr<sup>-1</sup>
- **Angular resolution**  $\sim 0.1^\circ$  for GP300 & GRAND *Decoene et al., 2022*
- **Energy resolution**  $< 10\%$  on air-showers for GP300 & GRAND *B. Lago & Rio GRAND team*
- **X<sub>max</sub> resolution**  $< 40$  g/cm<sup>2</sup> for  $E > 10^{17}$  eV (comparable to other methods) *Decoene et al., 2022*



$10^8 - 10^{11}$  GeV  
 $\sim 18$  events per year



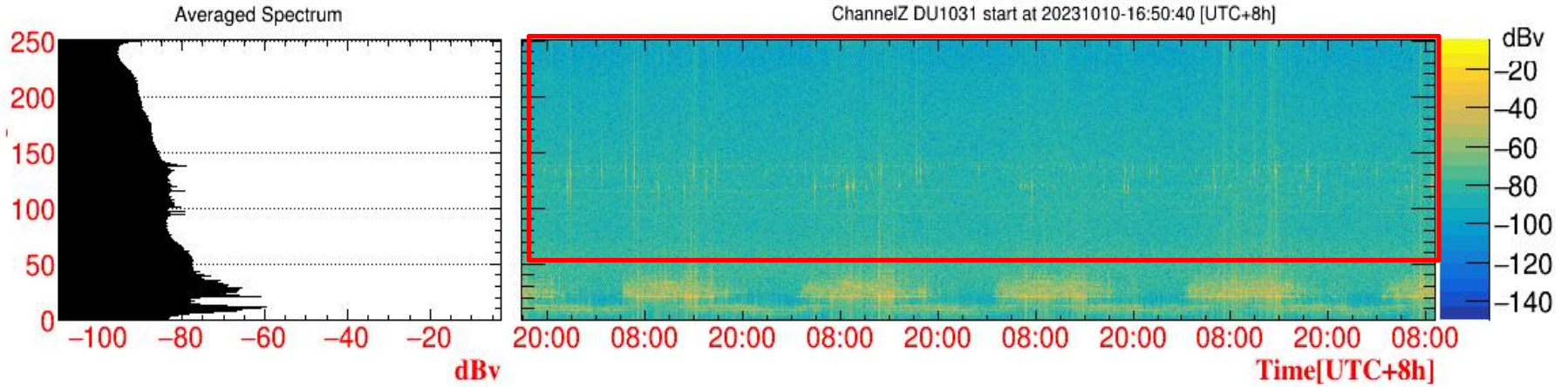
Hosted at the Nançay Radio Observatory, France  
 Antennas shipped from China and the rest of the equipment was funded by a joint grant between Paris (LPNHE and IAP) and Karlsruhe (KIT).  
 Dedicated to the first level trigger  
 Setup: 4 DUs are deployed



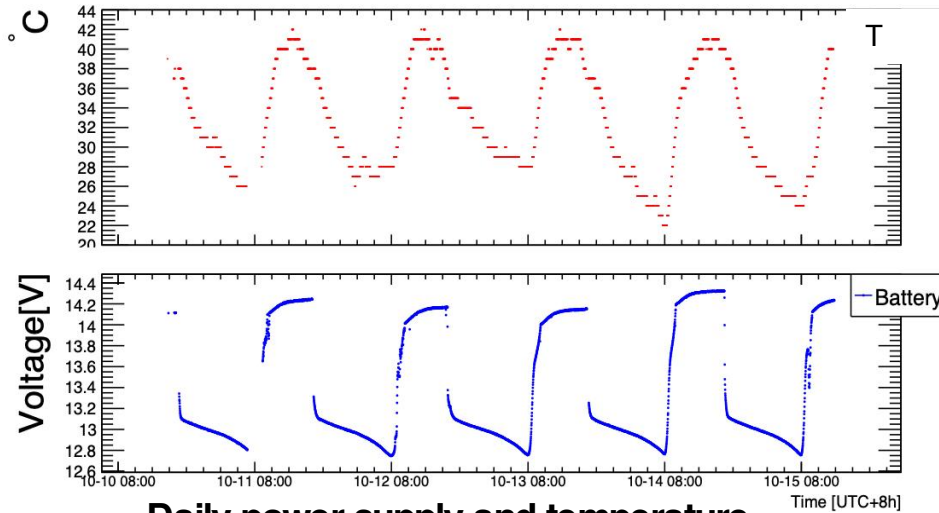




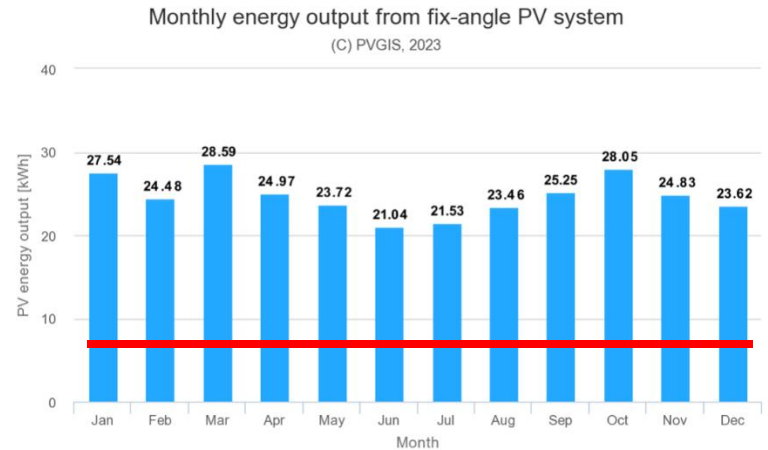
# Performance of GP13



**Radio background at 50-200MHz**



**Daily power supply and temperature**



**Sufficient energy supply from solar panel**