GRAND and latest progress of its prototype array

GP300 & GRAND@Auger

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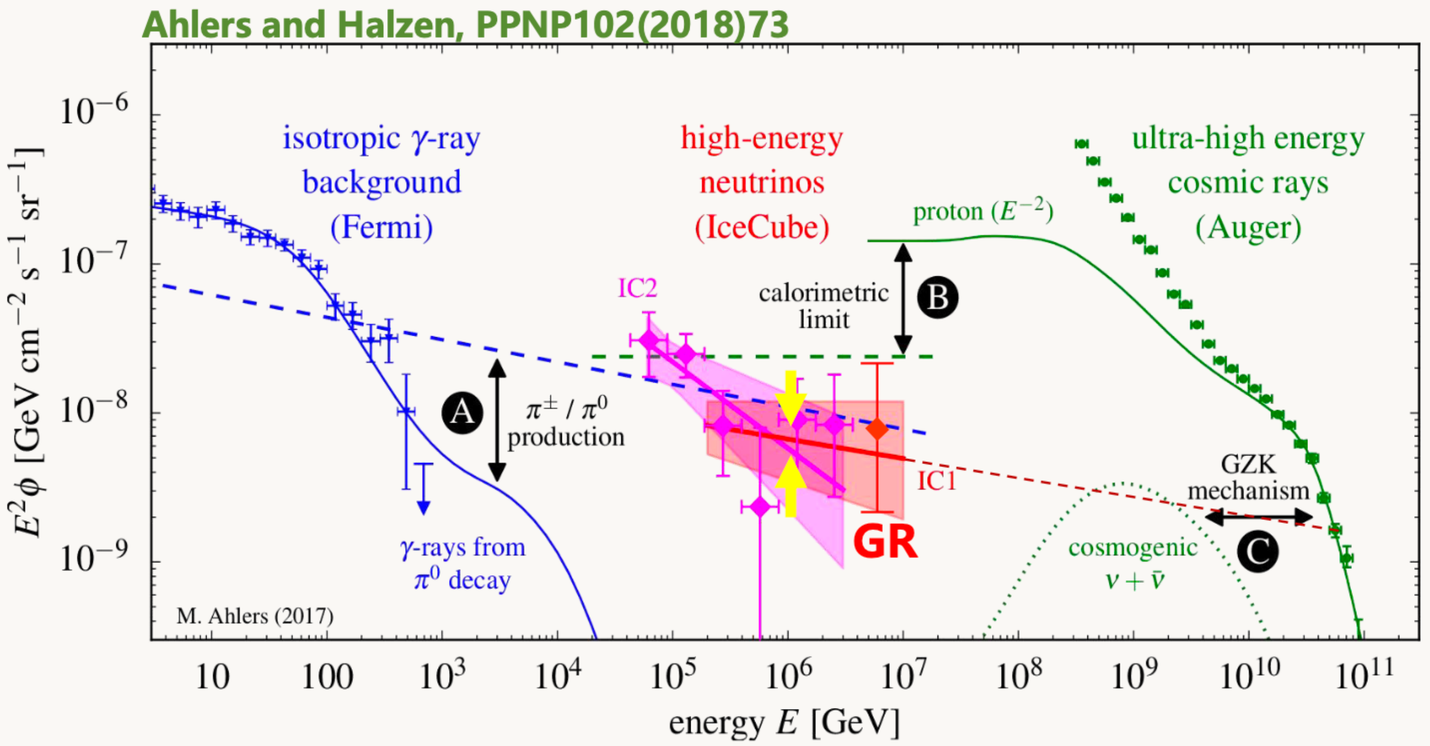
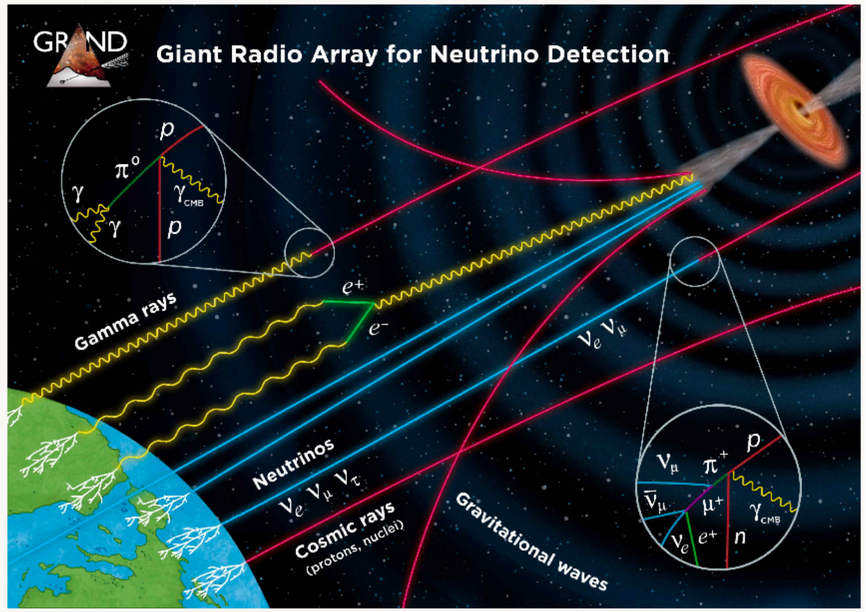
mapx@pmo.ac.cn
Purple mountain observatory, CAS.

2.Nove.- 7.Nove. 2025
TeVPA2025@Spain

Neutrinos: the power probe of the ultra-energy cosmic





1) **UHE CR tracing:** deflected by magnetic field. the GZK horizon
2) **UHE Gamma rays:** Interaction with the CMB. They cascade down to low energy.
3) **UHE neutrinos:** Universe transparent, beyond the GZK horizon, difficult for detection.

Adapted from Huang's slide at TAUPA2025

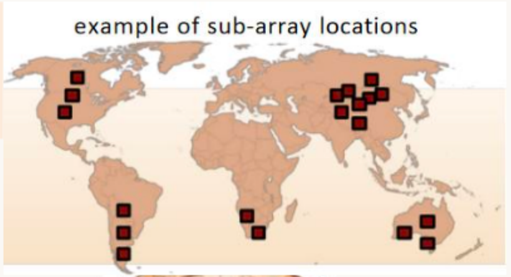
GRAND Concept

10 years from paper to prototype array.

UHECR

Investigate the origin of UHE CRs and neutrinos.

200k radio antennas array over 200'000 km² in several sub-arrays at favorable sites worldwide



Radio emission:

Undergoes little attenuation in the atmosphere;
Can be detected far from the shower.

X_{max}

~10 km

~400 m

few kms

geomagnetic effect:
radio signal
few 10s to100s MHz

τ

>30 km

ν

☺ Radio detection is a well-established technique proven by AERA, LOFAR, CODALEMA, Tunka-Rex, TREND

☺ **Scalable, cheap**, robust, ideal for giant arrays

☺ Exellent angular resolution

☹ Self-triggering efficiency may not be very high

☹ Huge area (radio-quiet) is required: $2*10^5$ km^2 ~ the land of entire UK...

GRAND Collaboration

16 Member & Associate Institutes represented at the Board

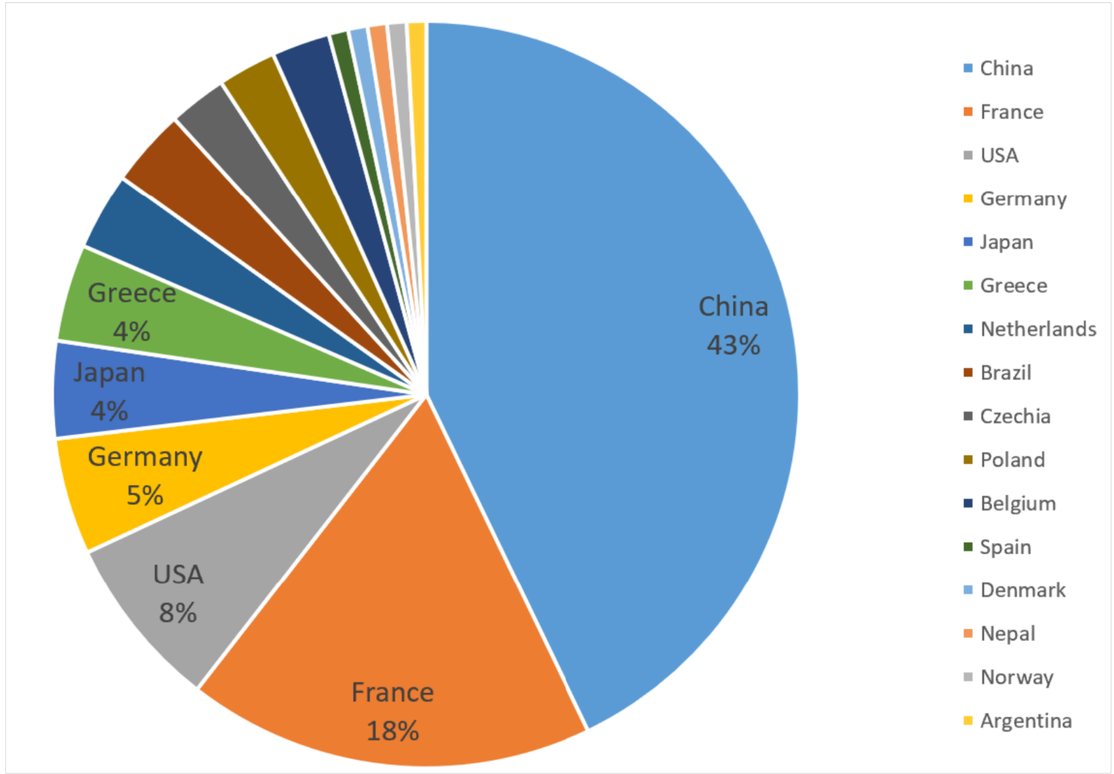
- Purple Mountain Observatory (PMO)
- National Astronomical Observatories (NAOC)
- Xidian University
- Nanjing University
- China University of Geoscience University (Wuhan)

- Hellenic Open University (HOU)
- Institut d'astrophysique de Paris (IAP)
- Institute of Physics of the Czech Academy of Sciences (FZU)
- Inter-University Institute for High Energy at Vrije Universiteit Brussel (IIHE-VUB)
- Karlsruhe Institute of Technology (KIT)
- Laboratoire de Physique Nucléaire et des Hautes Energies (LPNHE)
- Laboratoire Univers et Particules de Montpellier (LUPM)
- Radboud University
- University of Warsaw

- Pennsylvania State University (PSU)
- San Francisco State University (SFSU)

- Universidade Federal do Rio de Janeiro (UFRJ)

119 members 16 countries: Argentina, Belgium, Brazil, China, Czech Republic, Denmark, France, Germany, Greece, Japan, Nepal, Netherlands, Norway, Poland, Spain, USA



Author's national affiliations by July 2025

Sciences with GRAND

1) Radio astronomy (early stages)
- full-sky survey of radio signals
- FRBs and giant radio pulses from Crab with GP300

2) UHECRs (intermediate stages)
- 20 times the exposure of Auger (final setup)
- GP300: transition from galactic to extragalactic
- hadronic physics: muon discrepancy, UHECR mass composition, p-air xsec

3) Neutrinos, gamma rays (advanced stages)
- Cosmogenic neutrino flux
- Neutrino astronomy at EeV
- Competitive with Auger at GP300 stage

4) Neutrino physics (advanced stages)
- nu Xsec at EeV
- new physics effect

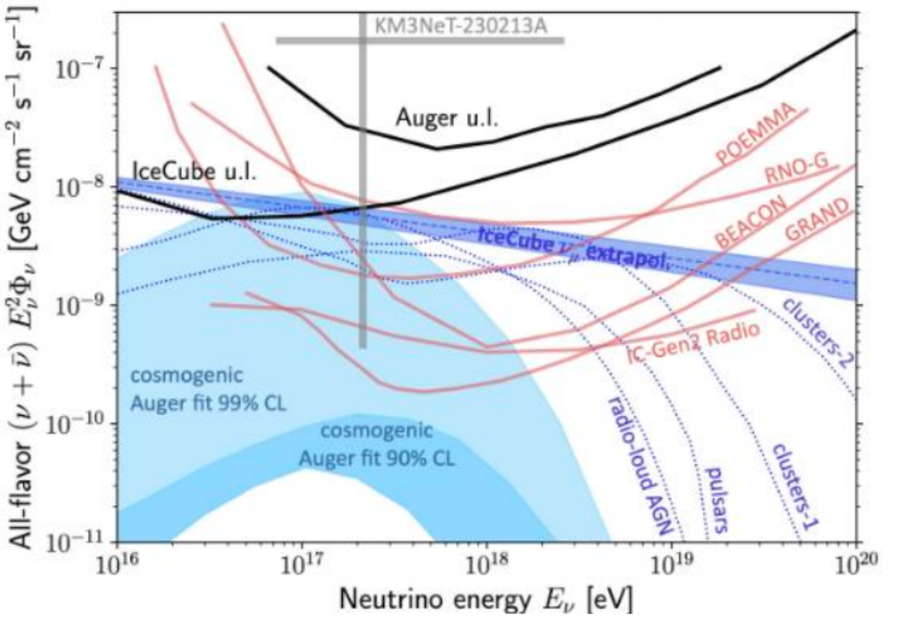
GRAND proposal

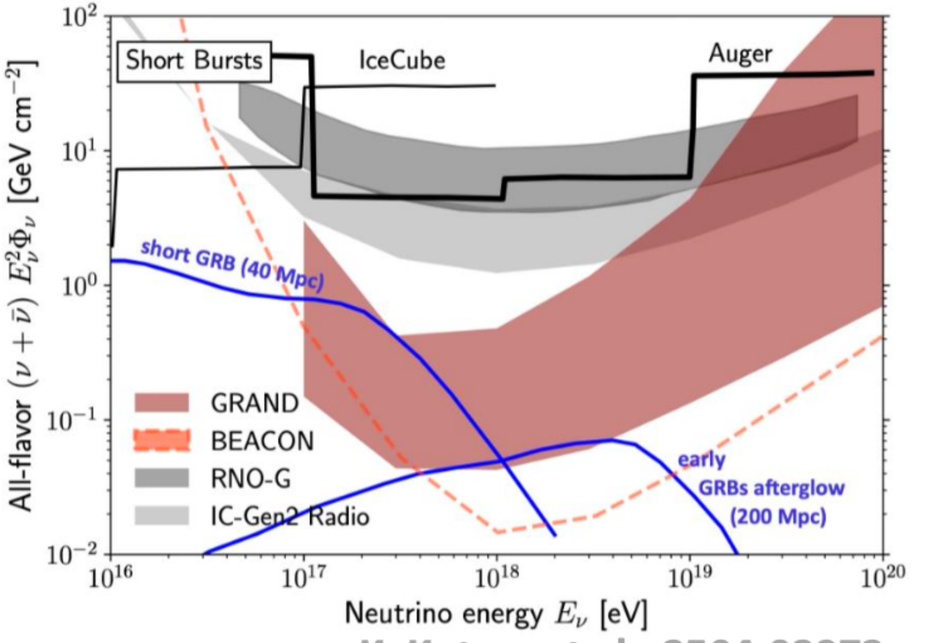
GRAND goal: reach **10^{-10} GeV/cm²/s/sr** sensitivity range for diffuse neutrino fluxes

End-to-end simulation (GRAND collab, 1810.09994)
➔ **baseline GRAND design = network of o(20) subarrays of o(10000) antennas with sparse density (1/km²) at various favorable locations around the world (« hotspots »)**

Alternatives being studied to reduce size for same performances
➔ GRAND-BEACON talk, Kumiko Kotera, PoS1078 ICRC2025

Sensitivity of full GRAND array allows to detect **cosmogenic neutrinos** for standard hypothesis AND hunt for **transient sources**.



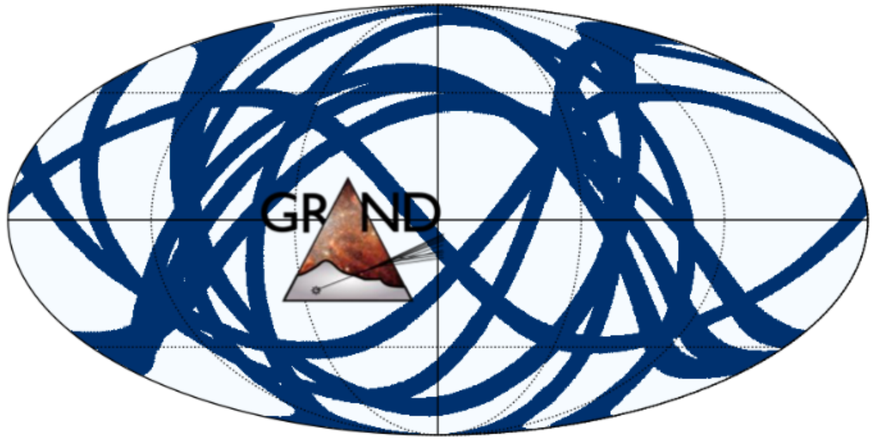


K. Kotera et al., 2504.08973

Adapted from Olivier's slide at ICRC2025

Expected performances

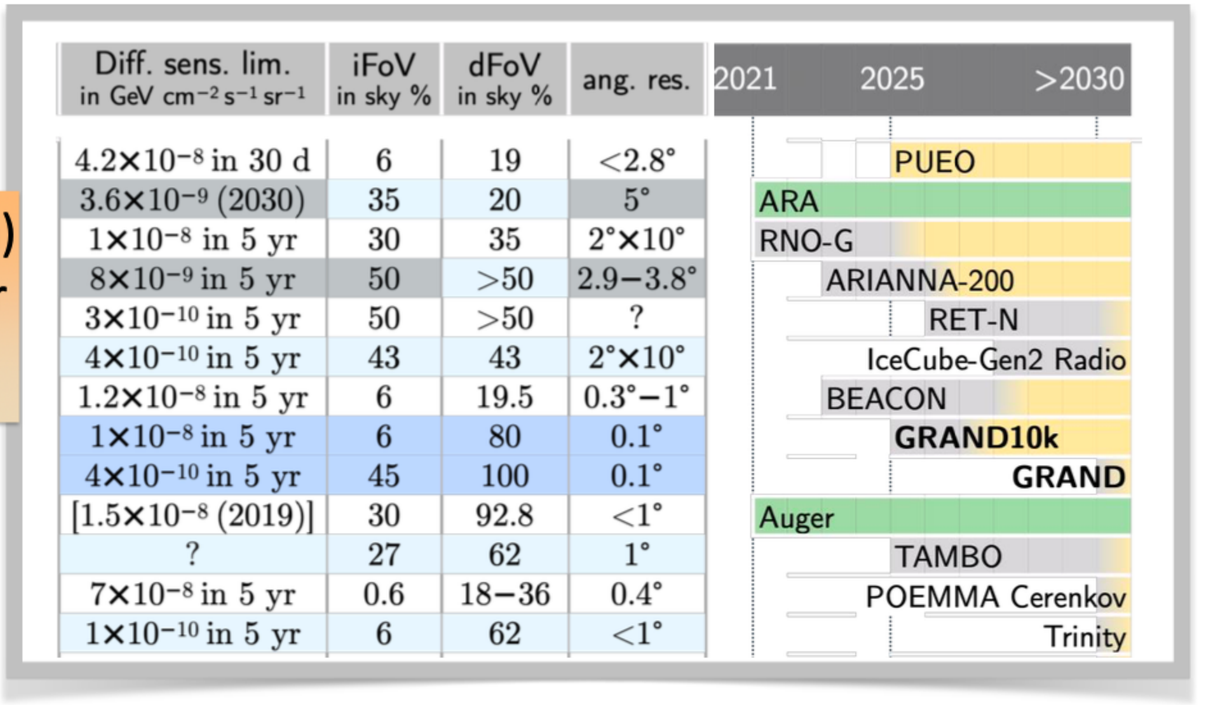
Limited efficient zenith range (few degrees below horizon)
BUT full azimuth sensitivity + multiple locations allows for half-sky instantaneous field of view.



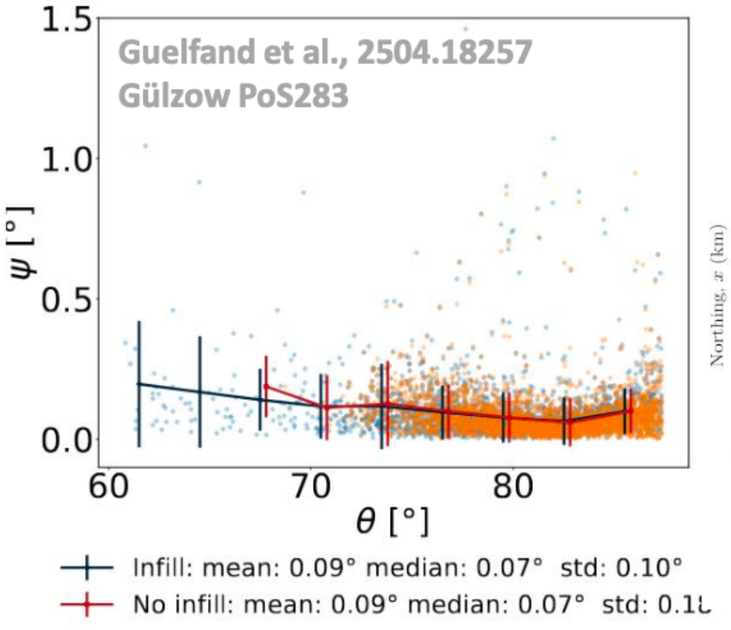
instantaneous FoV: 45% of sky
(for 10 random* site locations between 40S and 60N)

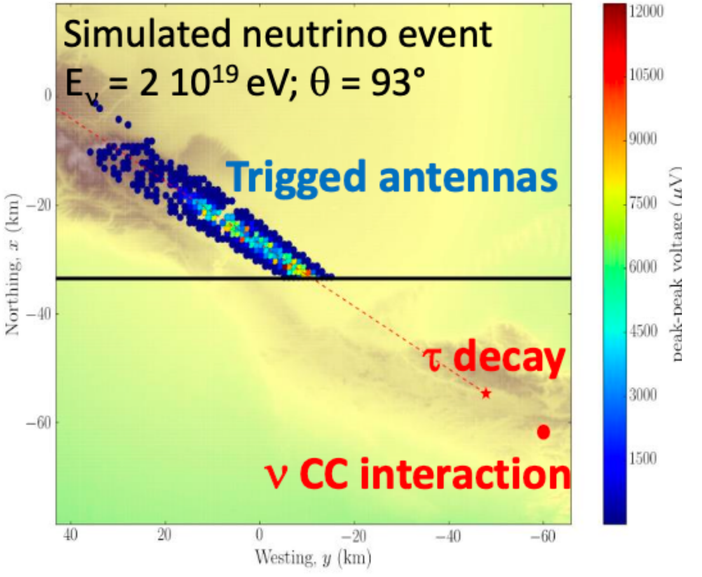
Very long radiofootprints allow for excellent angular resolution (0.1° on simulated cosmic-rays, TBC on neutrinos)

Diff. sens. lim. in GeV cm^{-2} s^{-1} sr^{-1}	iFoV in sky %	dFoV in sky %	ang. res.
4.2×10^{-8} in 30 d	6	19	$<2.8°$
3.6×10^{-9} (2030)	35	20	5°
1×10^{-8} in 5 yr	30	35	$2°\times10°$
8×10^{-9} in 5 yr	50	>50	$2.9-3.8°$
3×10^{-10} in 5 yr	50	>50	?
4×10^{-10} in 5 yr	43	43	$2°\times10°$
1.2×10^{-8} in 5 yr	6	19.5	$0.3°-1°$
1×10^{-8} in 5 yr	6	80	0.1°
4×10^{-10} in 5 yr	45	100	0.1°
[1.5×10^{-8} (2019)]	30	92.8	$<1°$
?	27	62	1°
7×10^{-8} in 5 yr	0.6	18−36	0.4°
1×10^{-10} in 5 yr	6	62	$<1°$



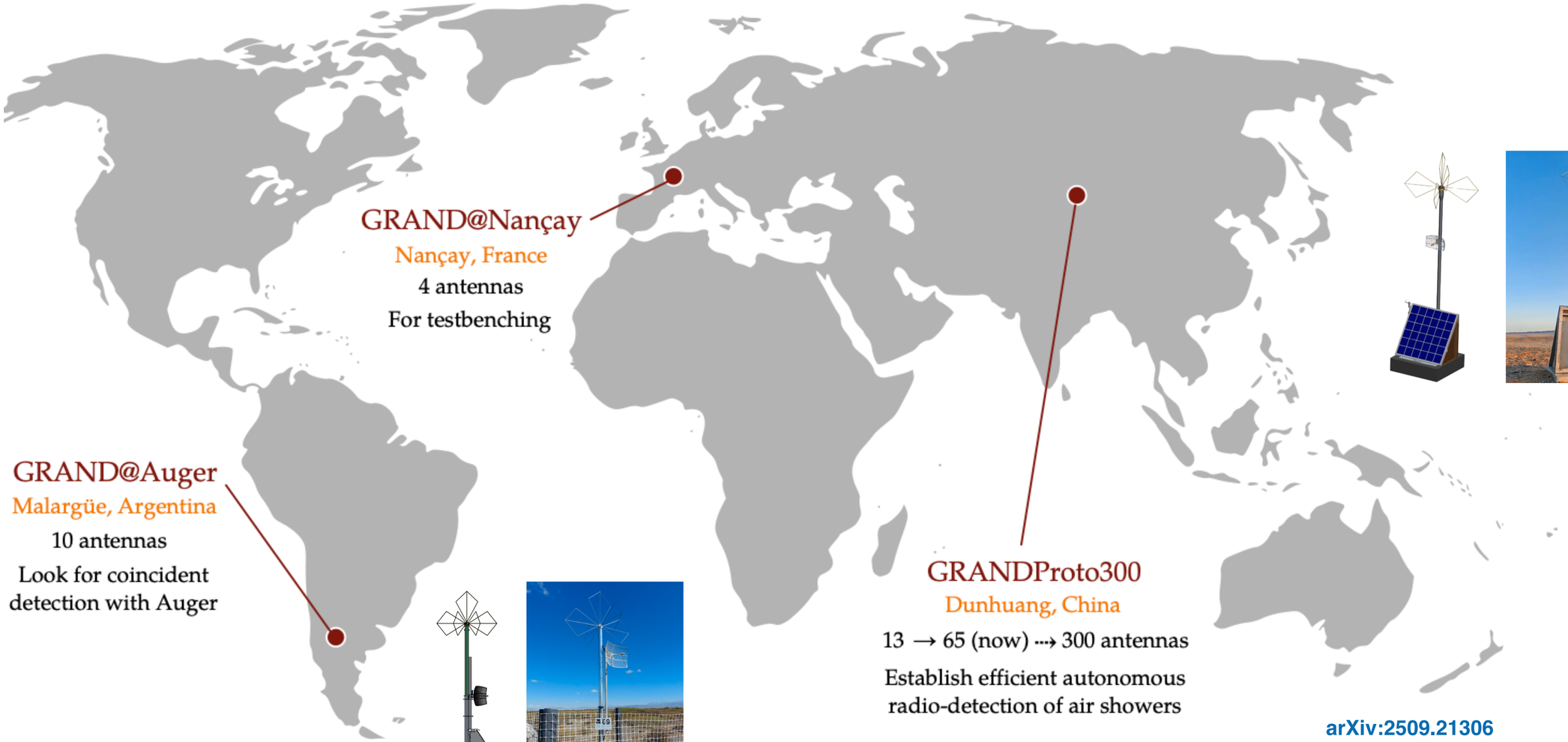
Guépin, Kotera, Oikonomou, 2023





Adapted from Olivier's slide at ICRC2025

Three prototype arrays



GRAND@Nançay
Nançay, France
4 antennas
For testbenching

GRAND@Auger
Malargüe, Argentina
10 antennas
Look for coincident detection with Auger

GRANDProto300
Dunhuang, China
13 → 65 (now) ⇢ 300 antennas
Establish efficient autonomous radio-detection of air showers

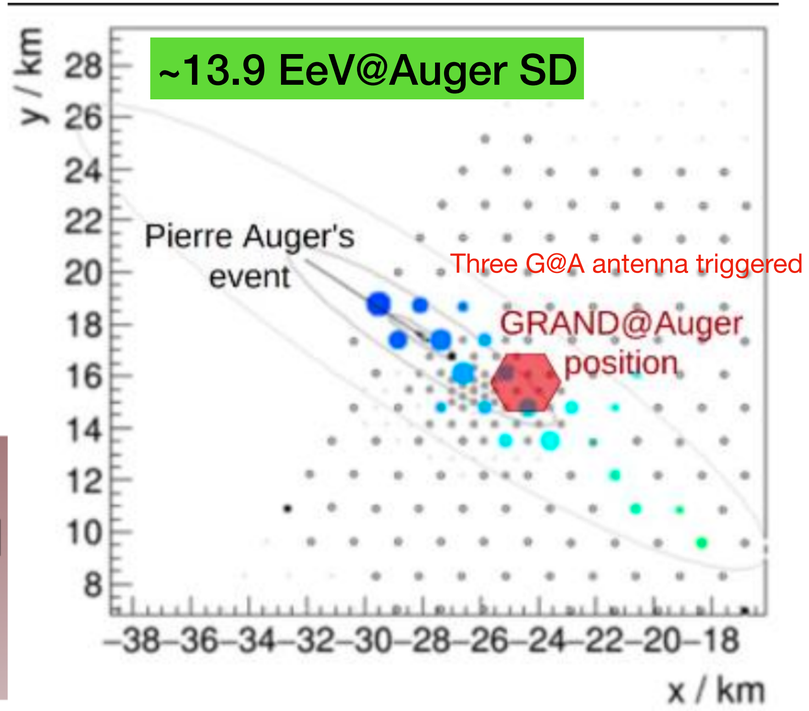
arXiv:2509.21306

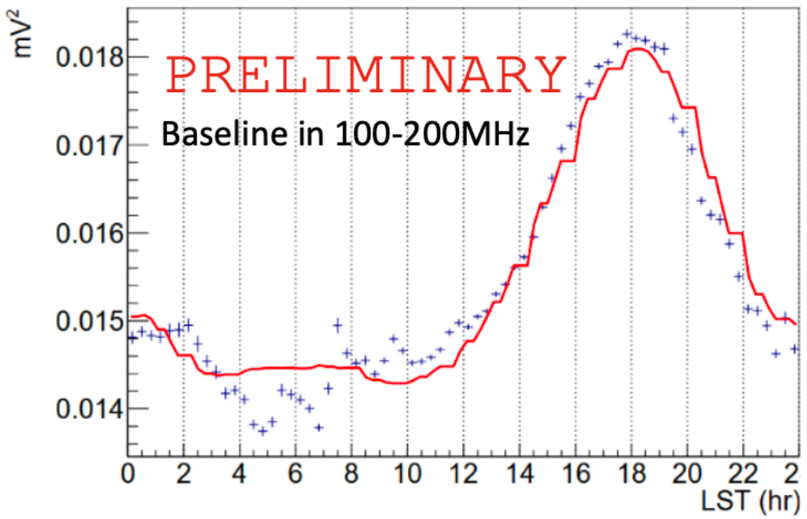
Prototypes: GRAND@Auger

Objective: coincident detection with Auger
➔ measure efficiency, purity, recons perfs

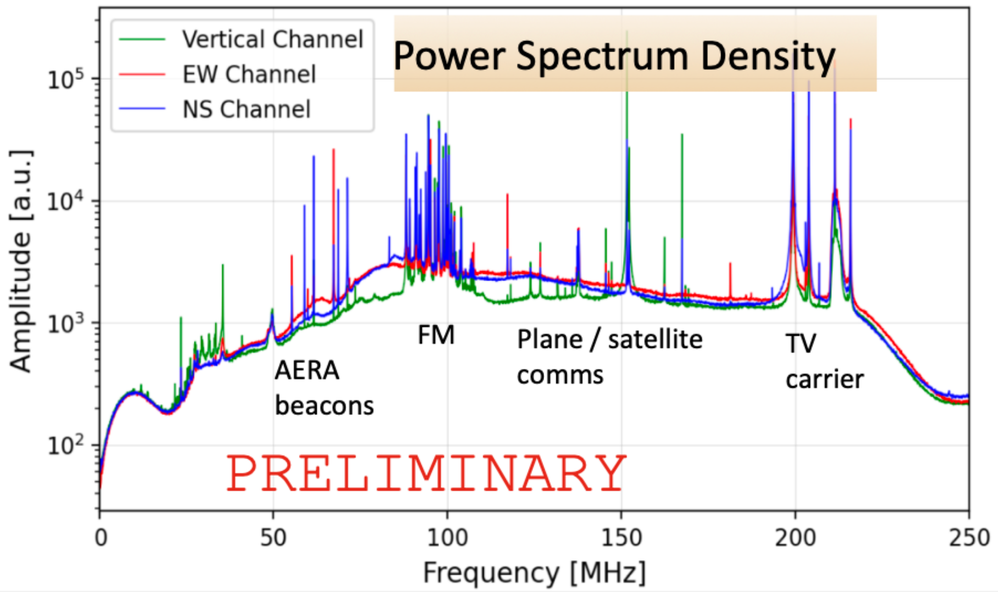
Status: 10 antennas deployed with Auger mechanical structure + infrastructure

Results:
- Galactic transit observed in 100-200MHz band
- Event observed on 3 DUs in time + direction coincidence with 1.4×10^{19} eV Auger event

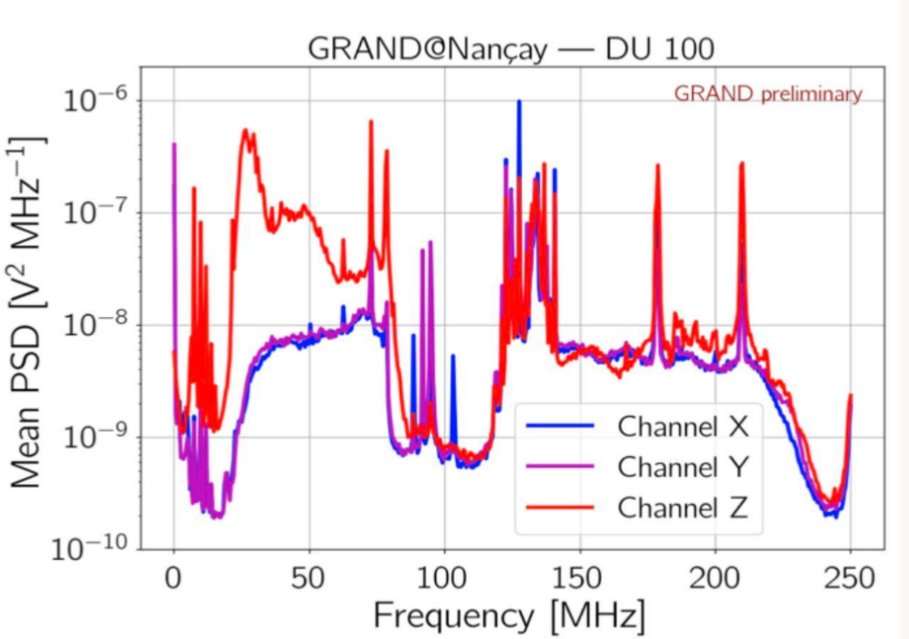




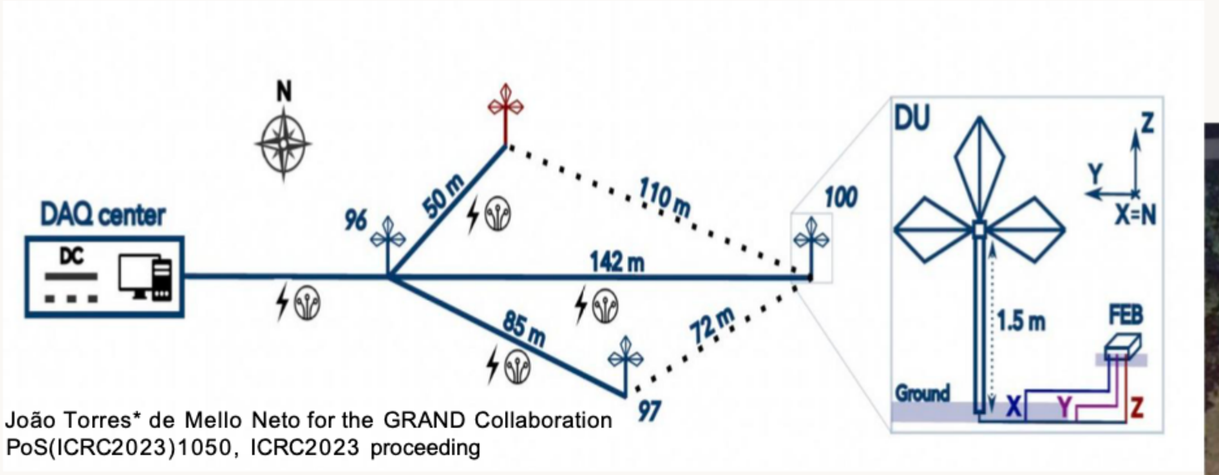
Adapted from Olivier's slide at ICRC2025



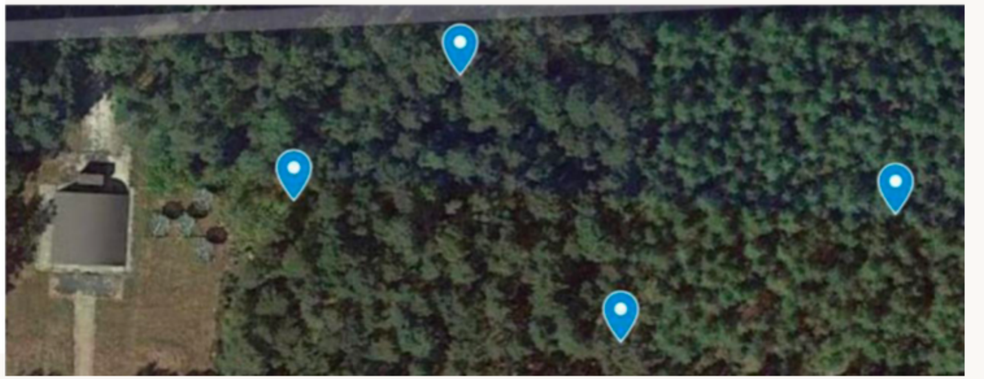
GRAND@Nançay



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



João Torres* de Mello Neto for the GRAND Collaboration
PoS(ICRC2023)1050, ICRC2023 proceeding



GP300: one 300-antenna array for demonstration

Site survey

敦煌市自然资源局

敦自然资字〔2023〕4号　　签发人：马东洋

敦煌市自然资源局
关于中国科学院紫金山天文台大型中微子射电观测站首期子阵项目用地备案的请示

Approval from local government

市政府：

近日，中国科学院紫金山天文台向我局报来《关于办理大型中微子射电观测站首期子阵项目用地备案的请示》及相关资料，申请办理大型中微子射电观测站首期子阵项目用地备案的手续。

经审查，该项目位于我市北山小独山附近，申请备案用地面积219.5平方米，其中：中心站1个，用地200平方米，主要用于架设可移动集装箱板房和围栏，低频测试单元13套，每套用地面积1.5平方米，小计19.5平方米，用于架设低频探测单元，均为国有未利用土地，申请用地年限共10年。2022年10月，中国科学院紫金山天文台出具了《中微子射电观测站首期子阵建设项目初步设计报告》；2022年11月，中国科学院紫金山天文台出具

one central station, 13 antennas

13-antenna, Feb 2023

Locating the first detection unit.
Feb. 2023

敦煌市自然资源局文件

敦自然资发〔2024〕23号

敦煌市自然资源局
关于大型中微子射电观测站二期子阵项目用地准予备案的通知

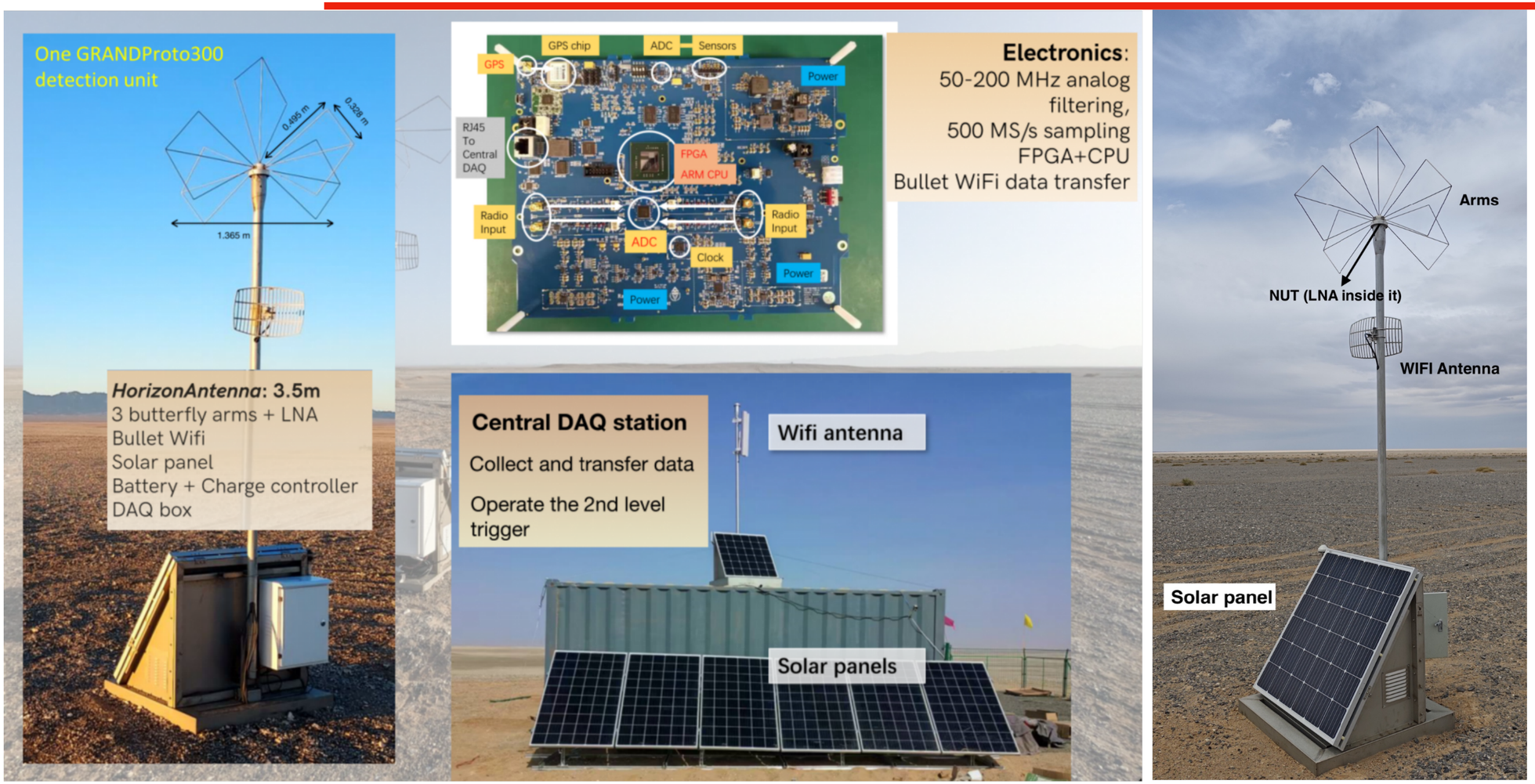
Approval from local government

中国科学院紫金山天文台：　　GP300, 10 years

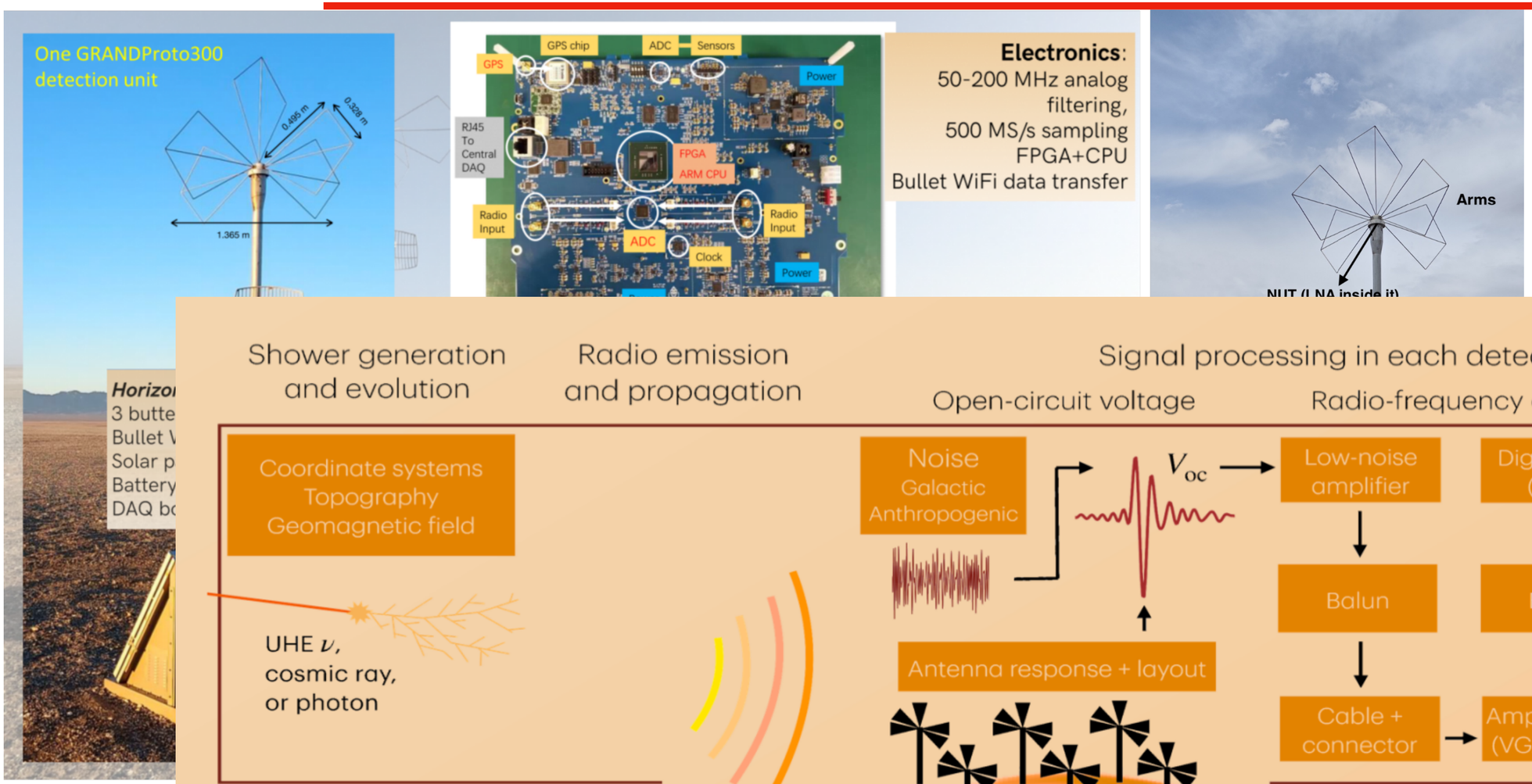
参照原国土资源部、发展改革委等部委《关于支持新产业新业态发展促进大众创业万众创新用地的意见》（国土资规〔2015〕5号）相关规定，经上报市政府批准，现准予你单位以现状备案方式使用我市北山小独山区域2396平方米国有土地，用于大型中微子射电观测站二期子阵项目建设，备案期限为10年。你单位在用地期间不得压占、硬化土地，不得改变地表形态，须严格按照设计标准施工，……

GP300, April 2024

Hardware: detection unit (DU), software development

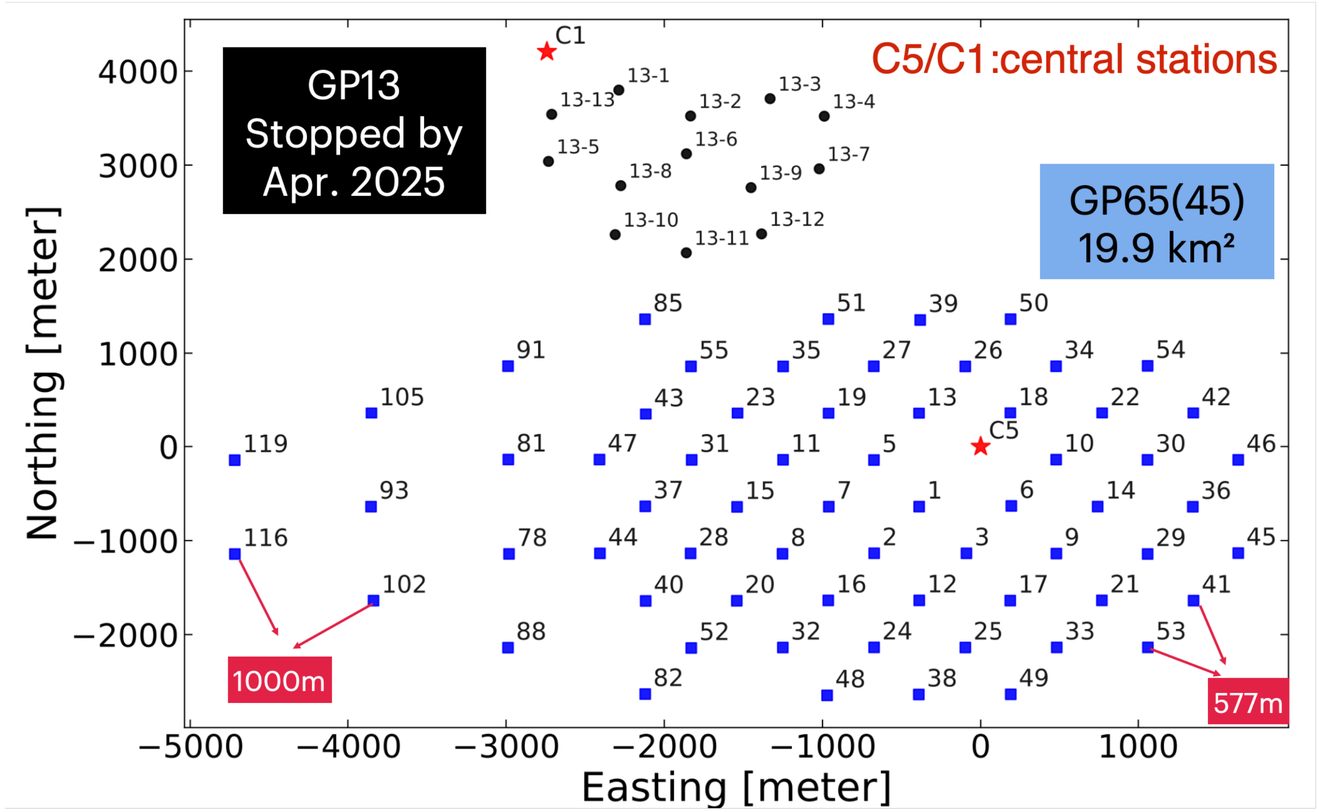


Hardware: detection unit (DU), software development



GP300: Deployment

GP13 (March 2023—> GP45 (Sep. 2024) —> GP65 (April 2025)



RFI suppression

- Noise shielding was main task in past two years.

  (1) Charge controller, AM band, satellite and planes ranging from 118MHz to 140MHz. FEB power supper, Ethernet and sensor cables.

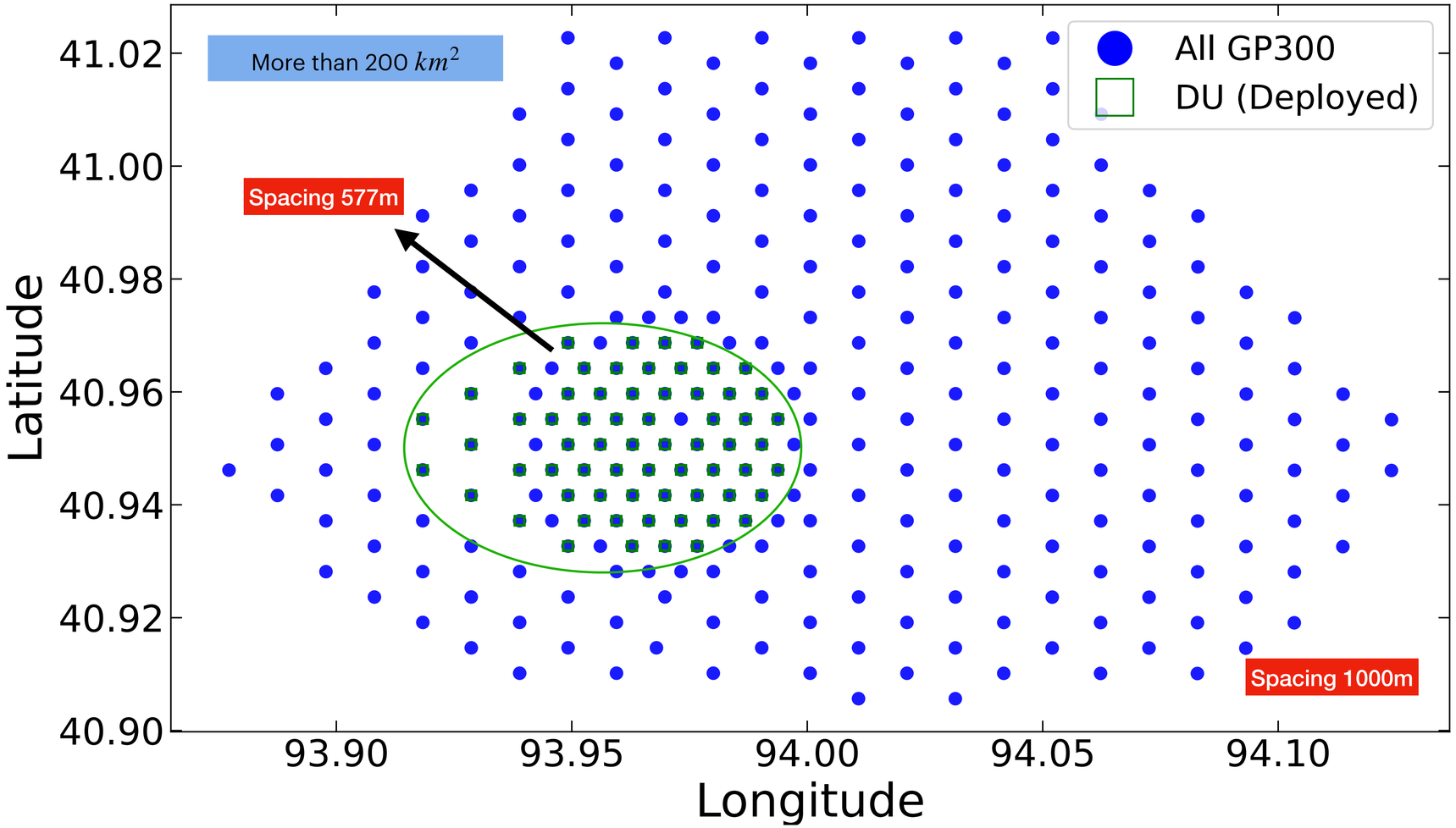
  (2) One strong RFI source above 150MHz, transformer station ~13 kilometers far away.

Thermal issue

- Improved FEB box cooling by diffusion through copper dissipators.
- Better ventilation of DU base to ensure reasonable temperature for battery
- Modified LNA configuration for temperature independent gain.

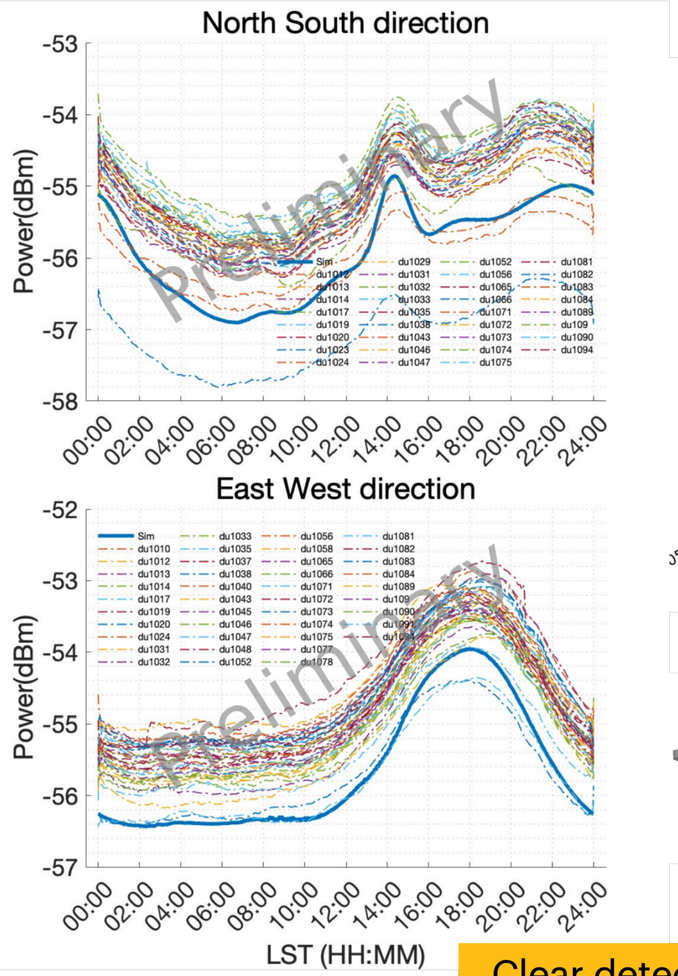
Staged deployment allowed for optimal DU performance today

GP300: Deployment

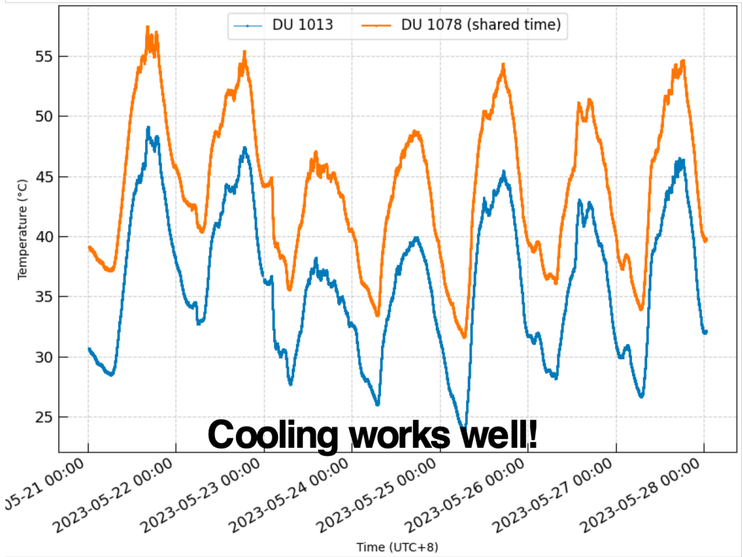


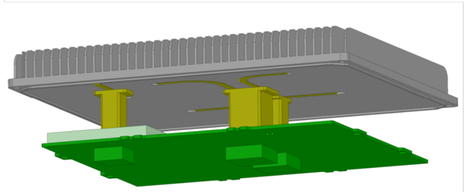
Will be completed in coming five years.

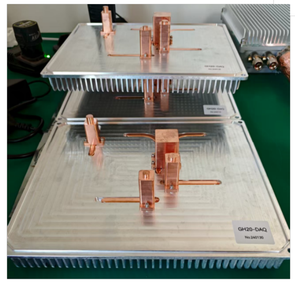
Performance of DUs from GP300



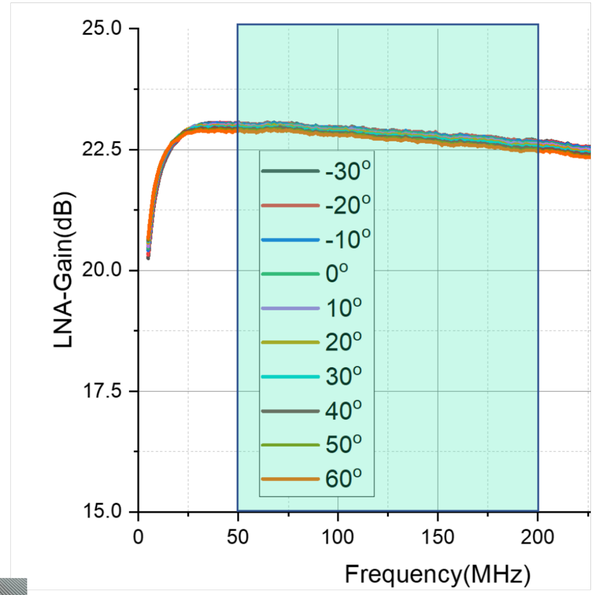
Temperature inside FEB box







Temperature dependence of LNA's gain

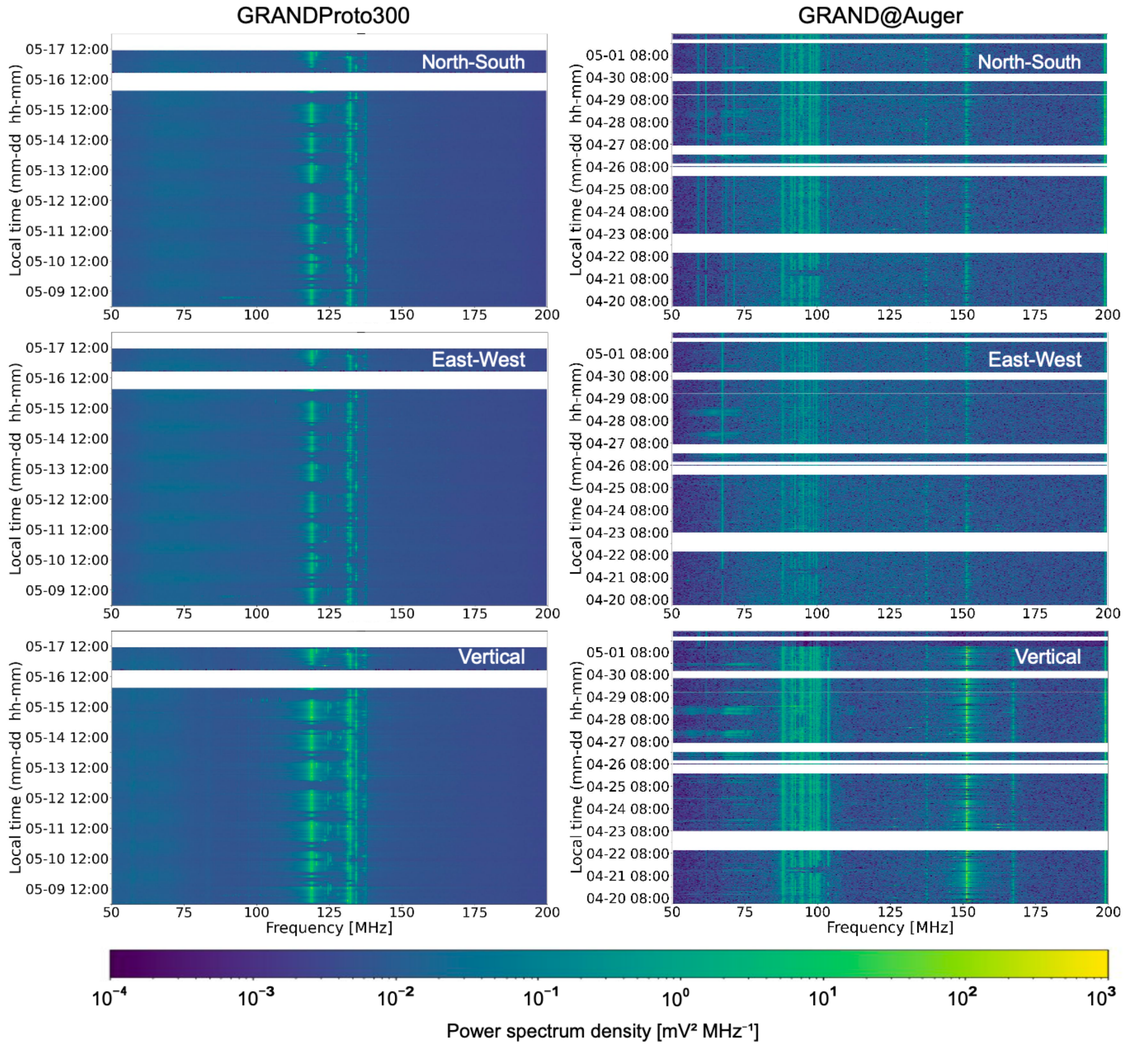


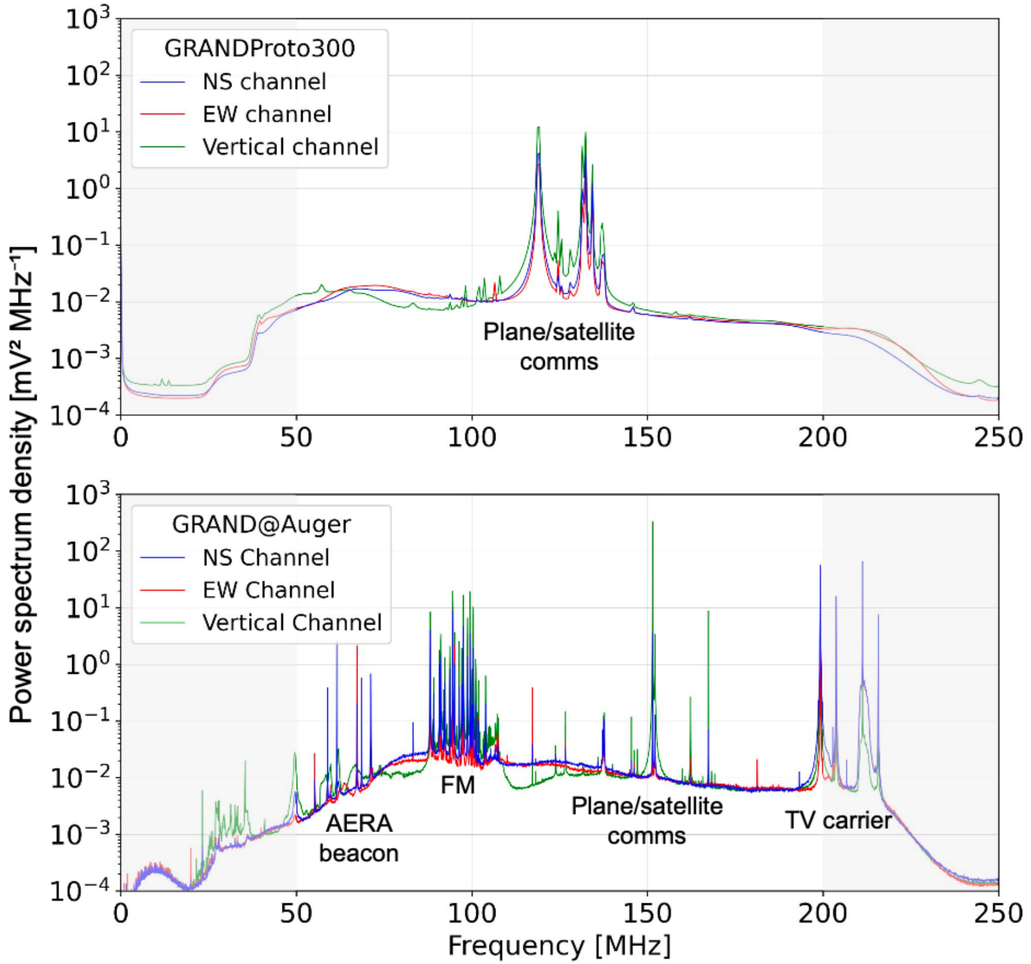
LNA's very weak temp. dependence.

Clear detection for the transient of our Galaxy across the sky of GP300.

Spectrum

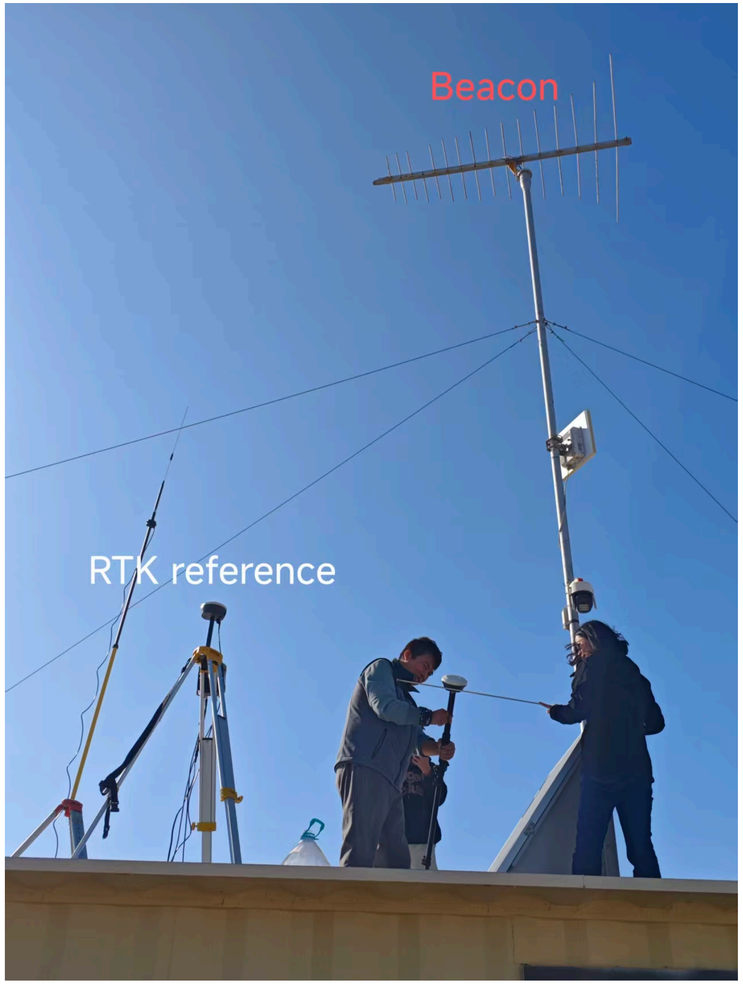
Prototype paper of GRAND arXiv:2509.21306

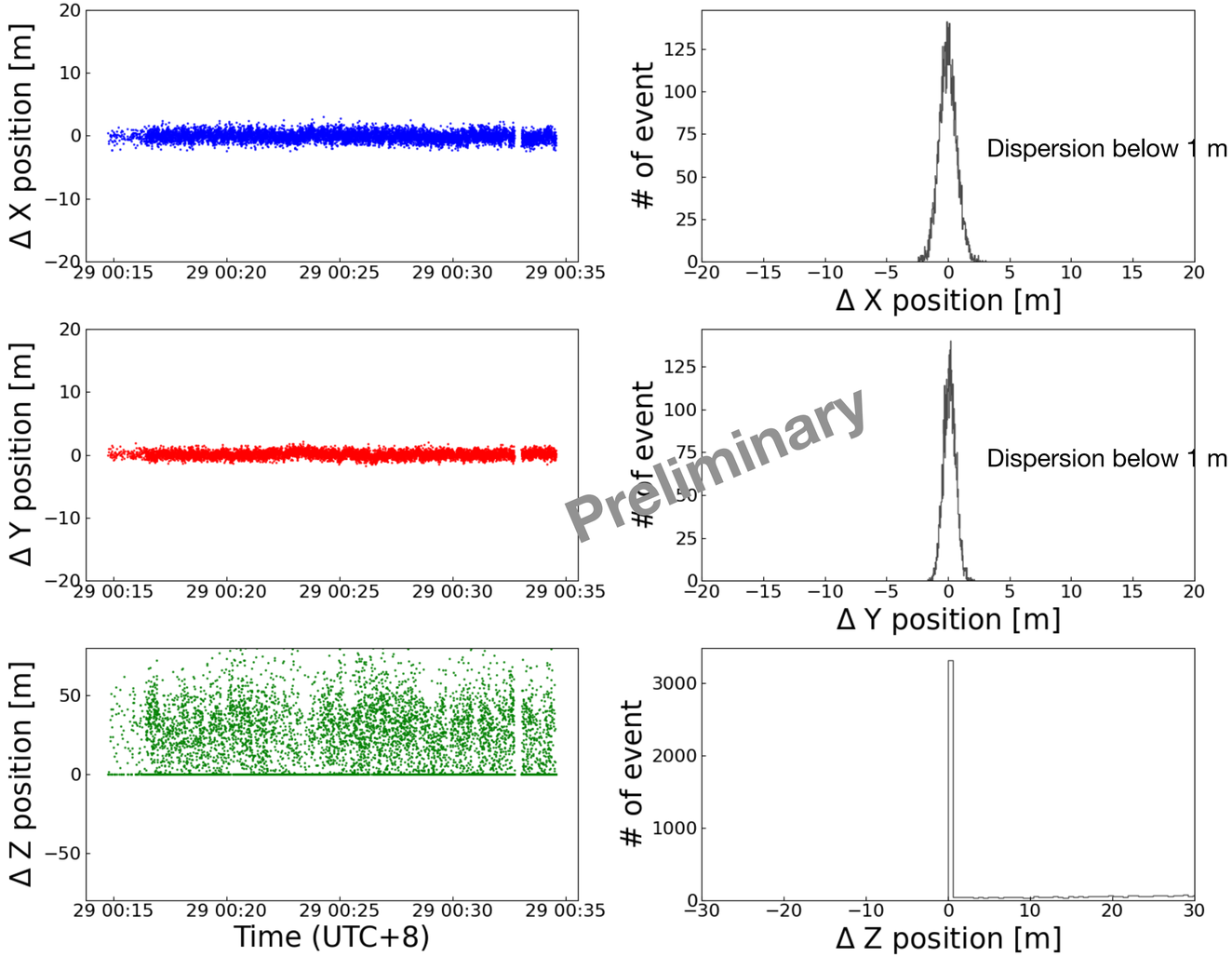




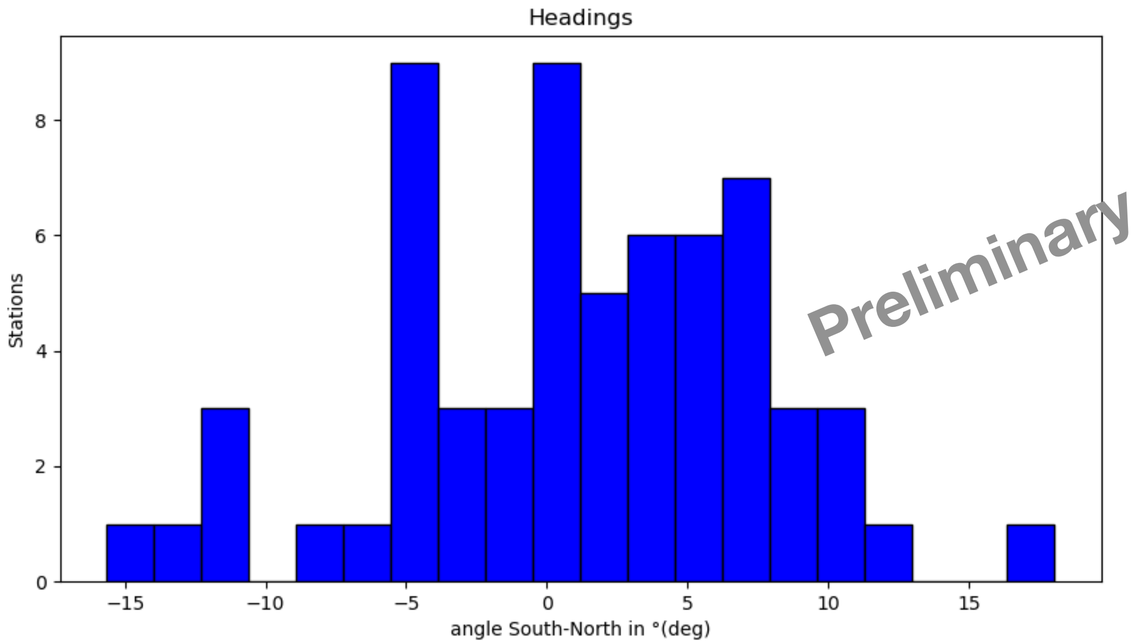
GP300 will be the largest radio array with self trigger mode.

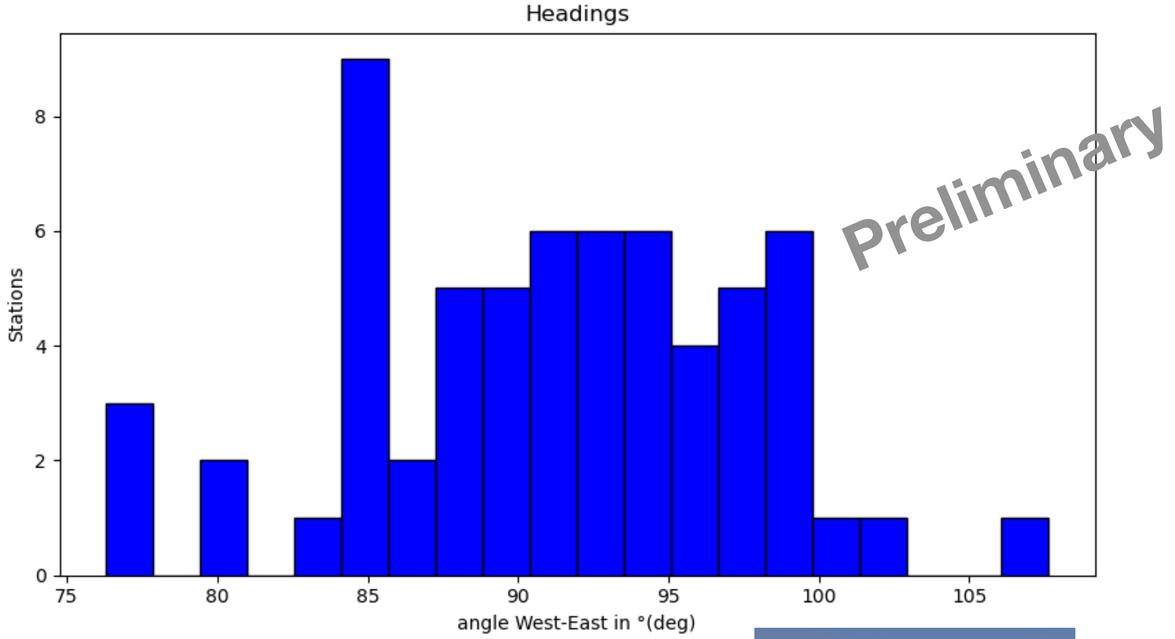
Positioning with RTK(Real-Time Kinematic) and Timing with Beacon





Positioning with RTK(Real-Time Kinematic) and Timing with Beacon



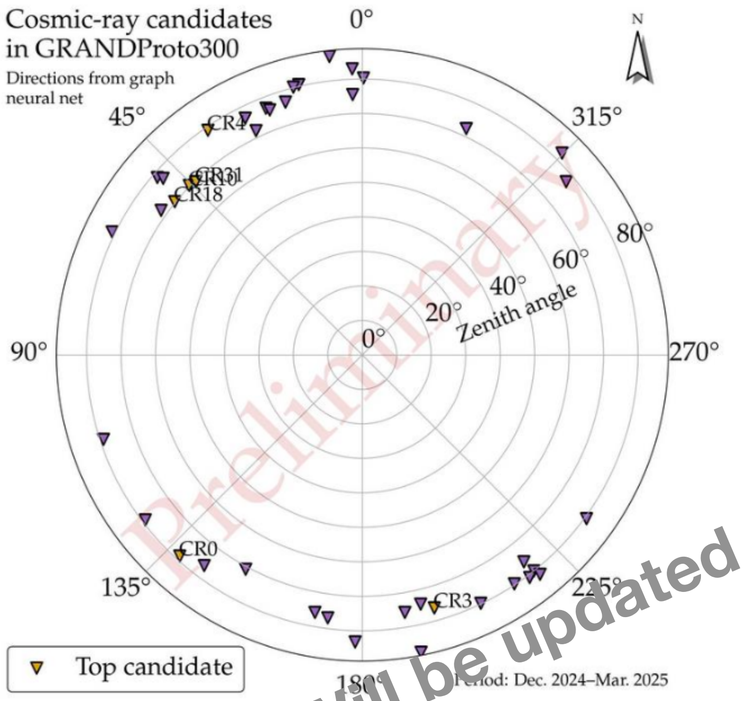


This enables us to do precise measurement

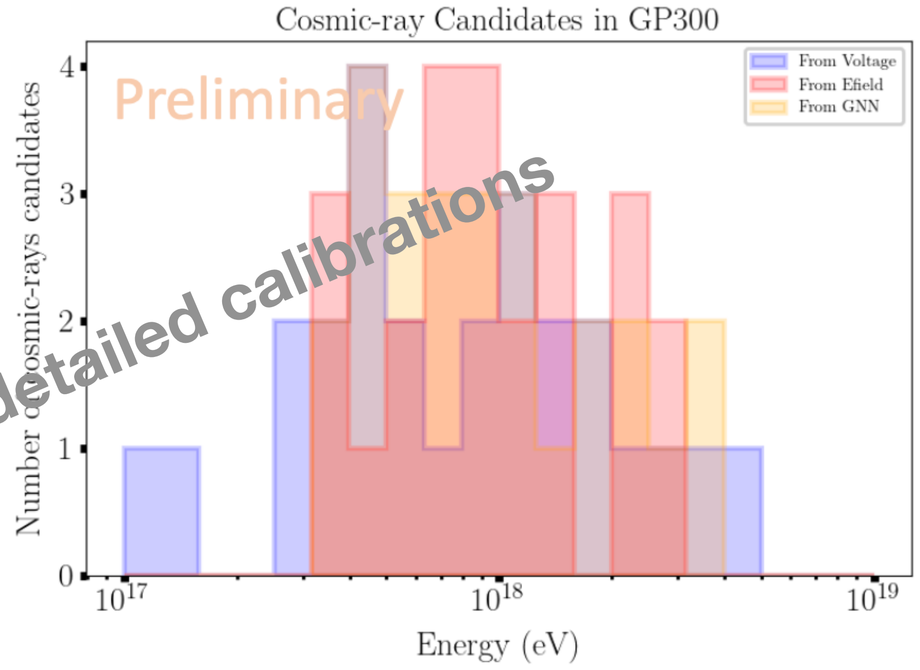
Credits: Fred & Kumiko

GP300: cosmic ray candidates

Direction of arrival consistent among 3 methods, … and with expectations from EAS



Energy spectrum for 26 candidates with
- ✓ Reconstructed Efield for 5+ DUs
- ✓ LDF error < 10^{20} eV
- ✓ ADF χ^2 /ndf < 25 (see PoS278) ICRC2025

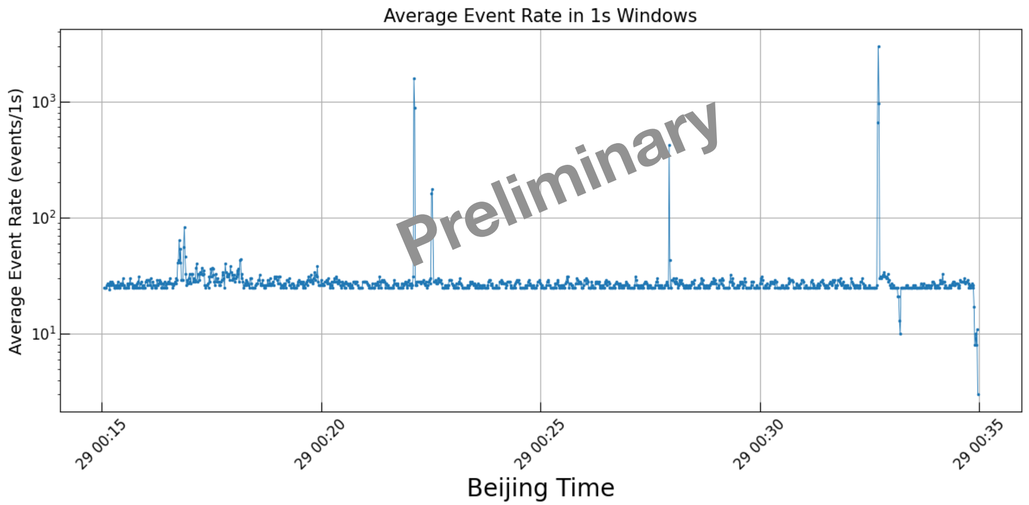


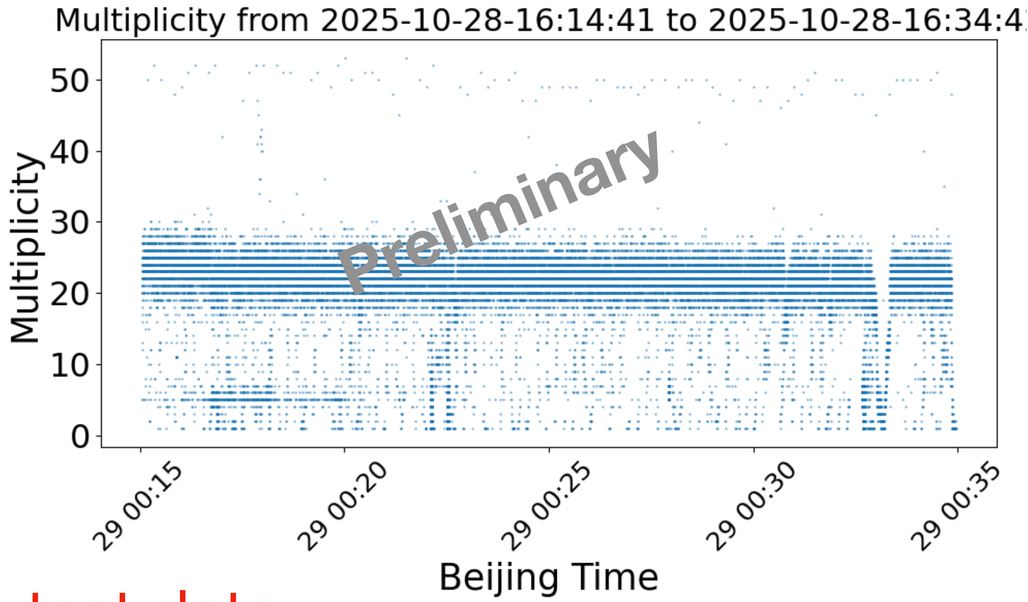
Will be updated with detailed calibrations

Disclaimer: **GP300 now in commissioning phase**. Efficiency and purity not known yet for CR detection process. Only validating HW, DAQ and reconstruction for now!

Latest status of GP300

DAQ is undergoing optimization and becomes much reliable.

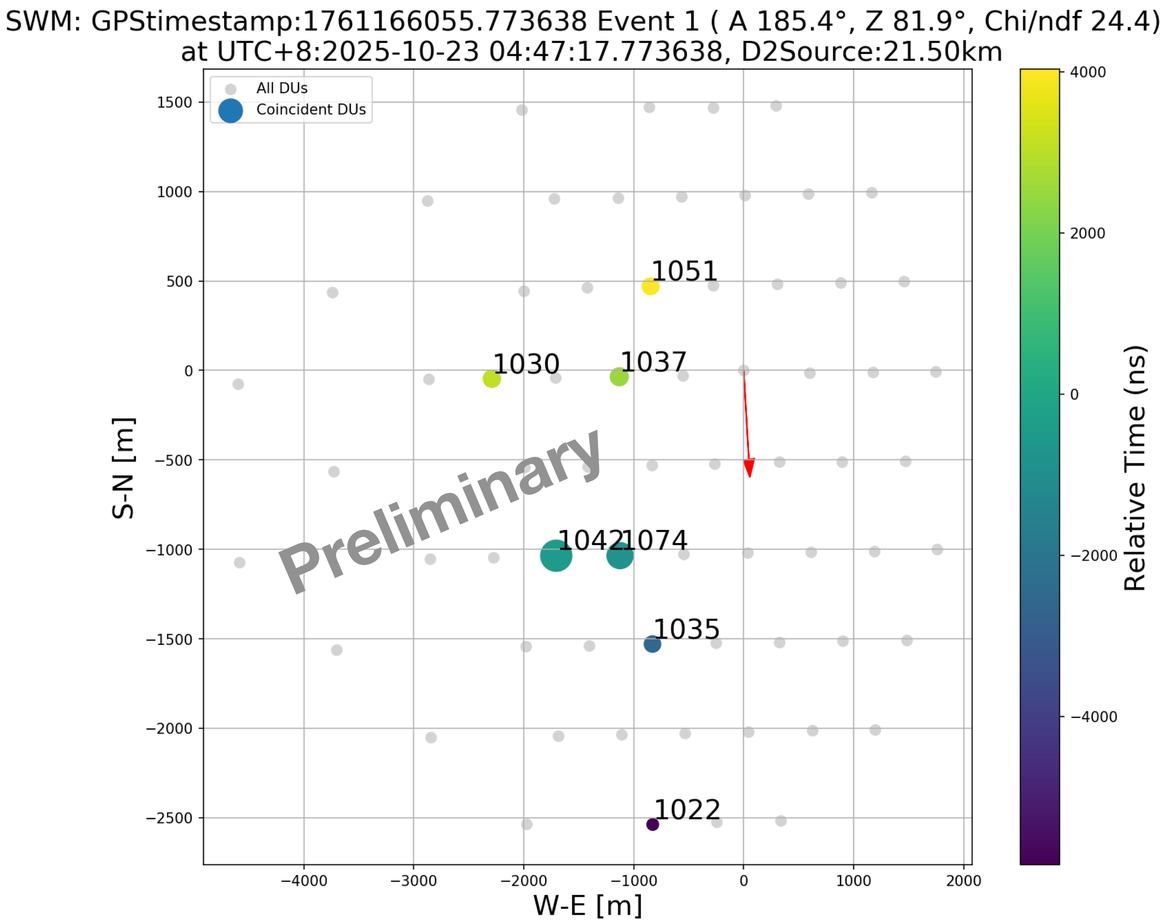


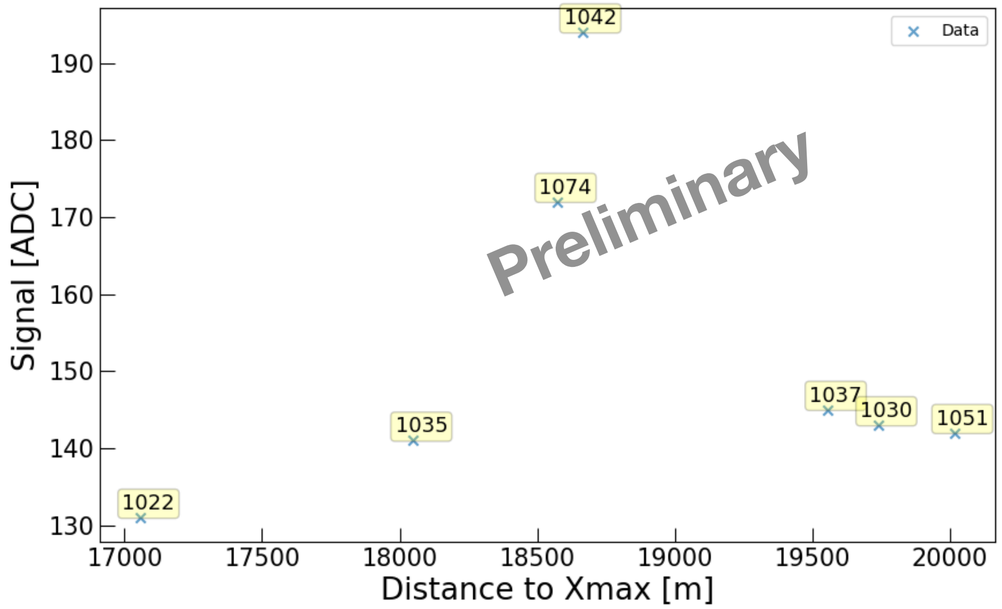


25Hz Beacon test data

- Significant progress achieved with respect to a few months ago.

New CR candidates

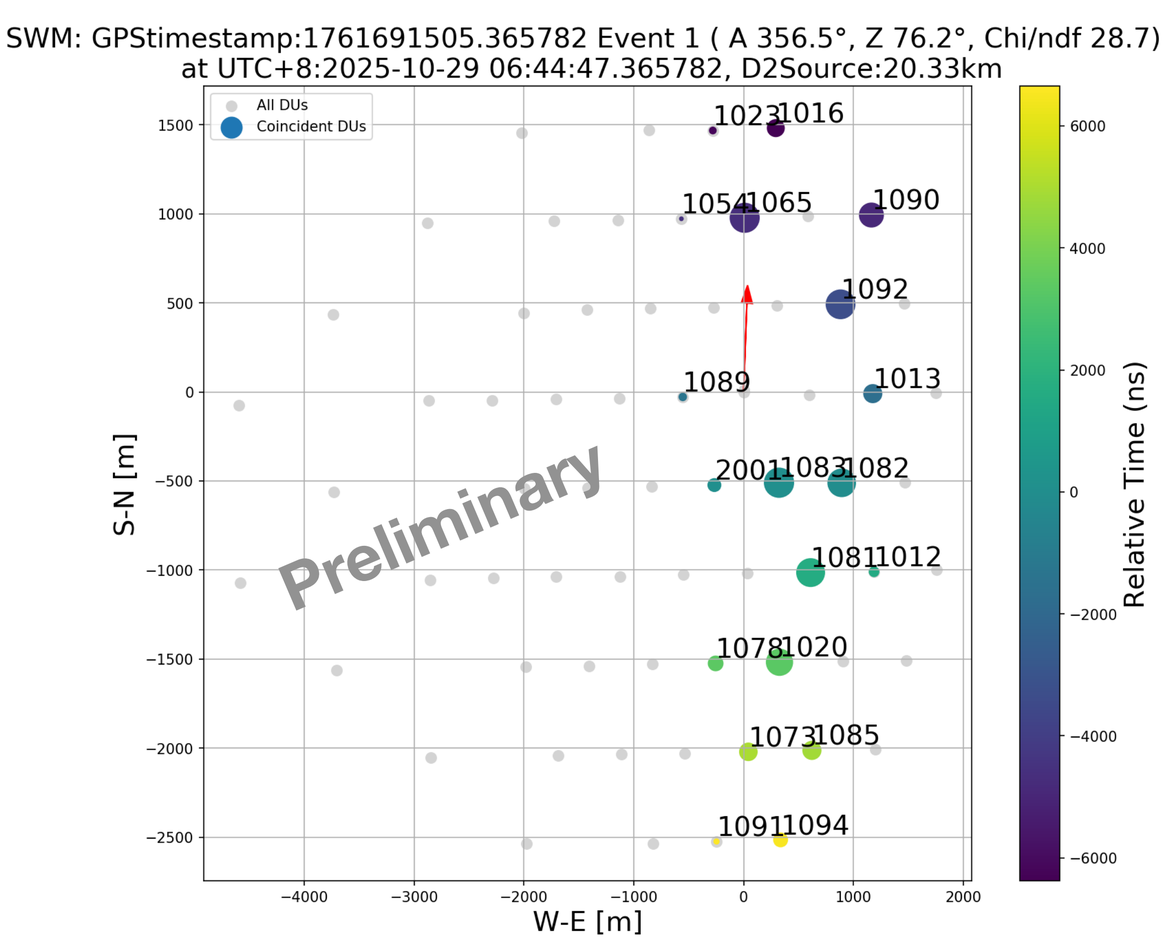




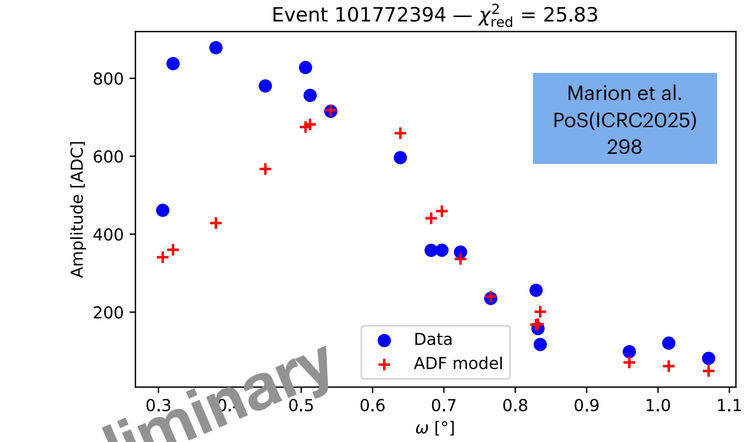
A CR event with sharp part of C-ring and missing of the other part?

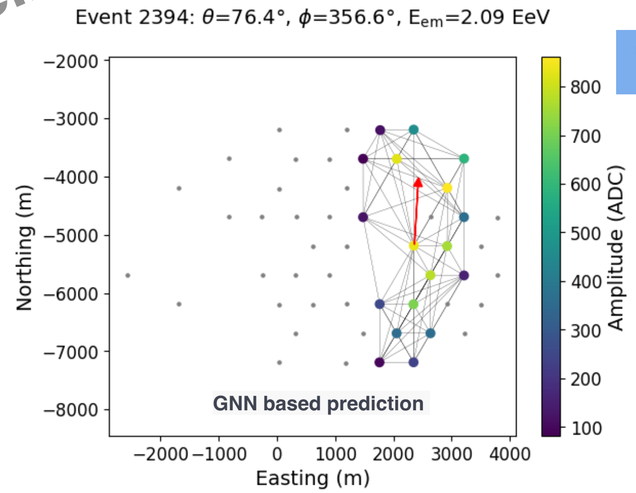
Disclaimer: we are still undergoing the optimization from many aspects, particularly DAQ, no clear efficiency estimation so far.

New CR candidates



One of ~ EeV CR candidates





GNN method, Arsène et al. PoS(ICRC2025) 253

Disclaimer: we are still undergoing the optimization from many aspects, particularly DAQ, no clear efficiency estimation so far.

Summary

- **HERON has benn selected by ERC (14M euros), which combines the concept of Beacon and GRAND together.**
- **GP300's funding from China is under reviewing.**

Coming 24 months:

✓ Optimize HW, **DAQ & CR selection procedures (optimized mask method for background)**

➔ Physics run 65-antenna of GP300 and G@A with nominal rate of few 10s CRs/day

✓ Build energy spectrum, arrival direction distribution, chemical mass of primary

✓ Extend analysis to horizontal events (z > 85°)

➔ Validate detection principle of GRAND

➔ Study CR physics around the Galactic-Extragalactic transition [~100 PeV - EeV]

In 2-5 years

✓ **Step-by-step Complete GP300 project.**

✓ **Increase statistics, refine methods and analysis (very inclined/horizontal events)**

✓ **Test GRAND10k design with improved HW & trigger/DAQ.**

Towards the Giant Radio Array for Neutrino Detection (GRAND): the GRANDProto300 and GRAND@Auger prototypes

GRAND Collaboration

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arXiv:2509.21306


Thank for your attention
latest filed trip last week.