The Status and Perspectives of Giant Radio Array for Neutrino Detection (GRAND)

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China University of Geosciences (Wuhan)
on behalf of the GRAND Collaboration

2025Aug@TAUP西昌

Collaboration

16 Member & Associate Institutes represented at the Board

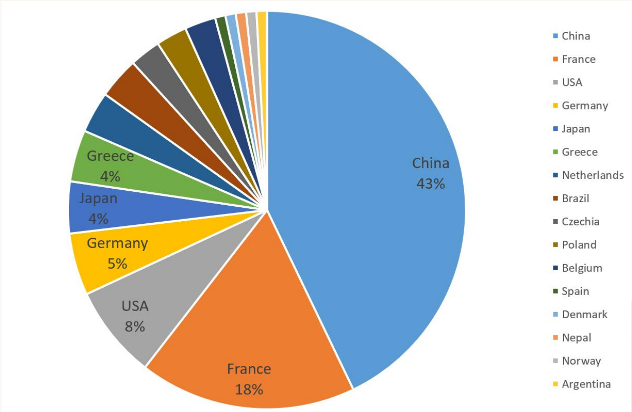
- **Purple Mountain Observatory (PMO)**
- **National Astronomical Observatories (NAOC)**
- **Xidian University**
- **Nanjing University**
- **China University of Geosciences (Wuhan)**

- **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**

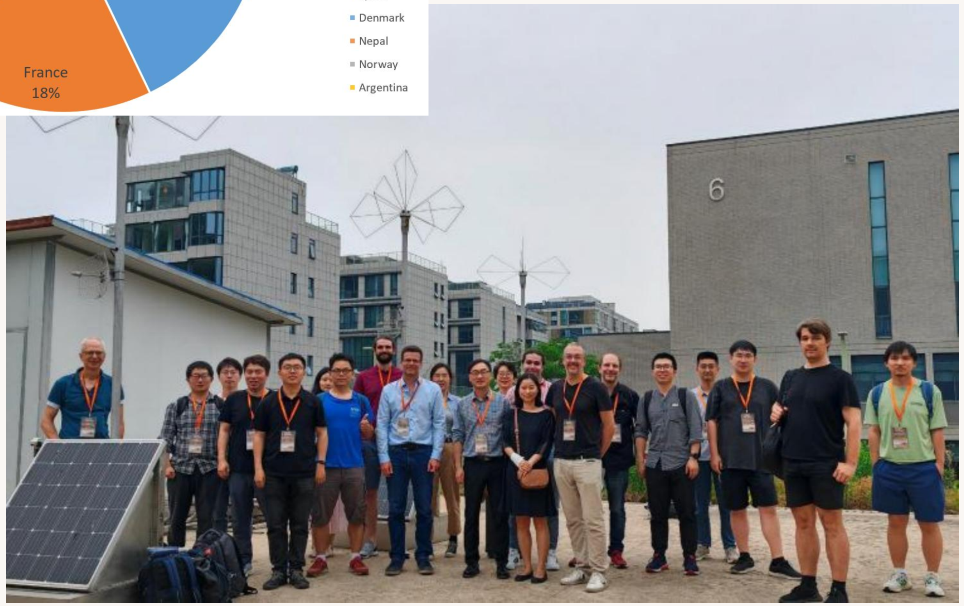
- **Pennsylvania State University (PSU)**
- **San Francisco State University (SFSU)**

- **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

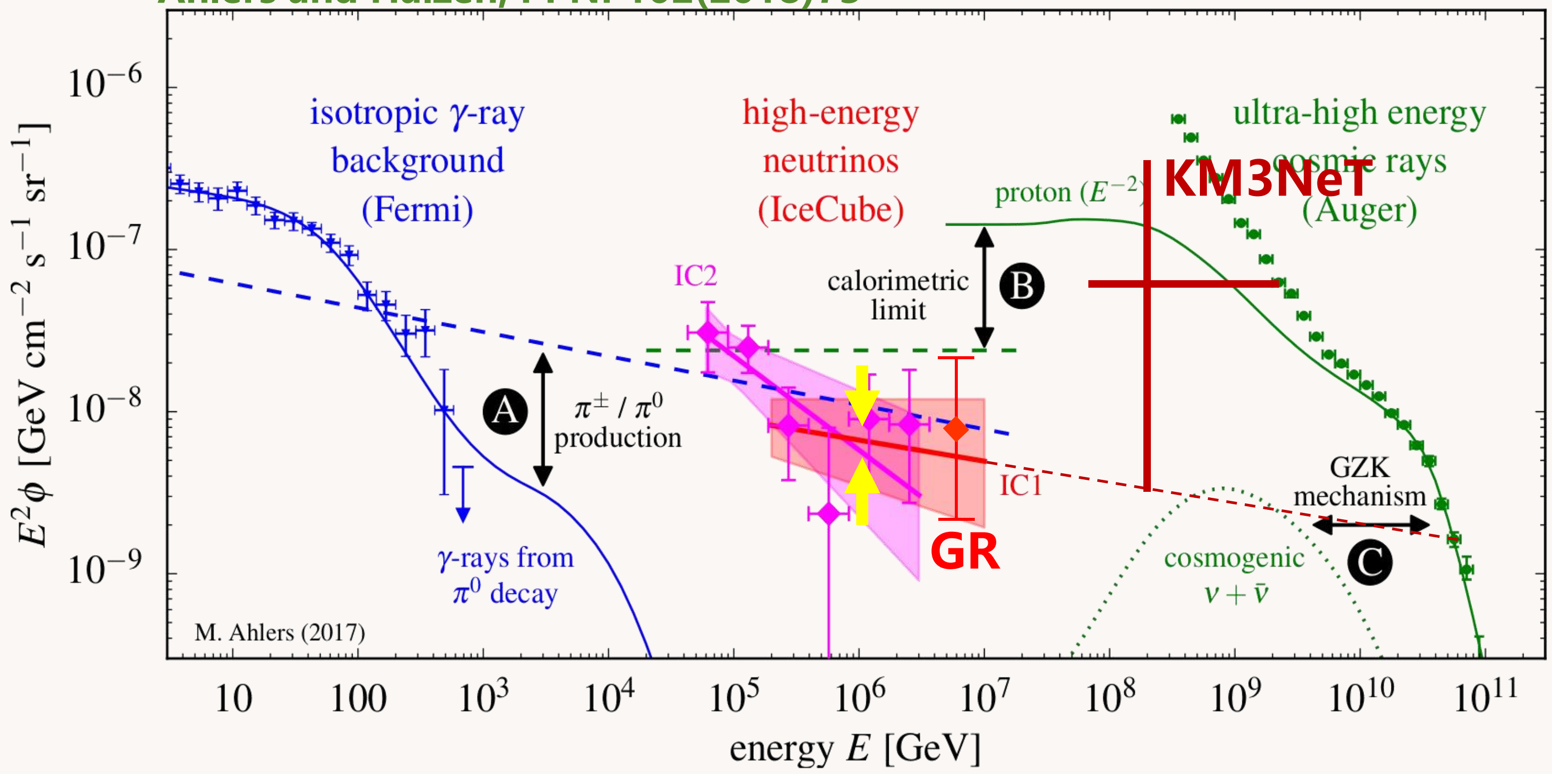


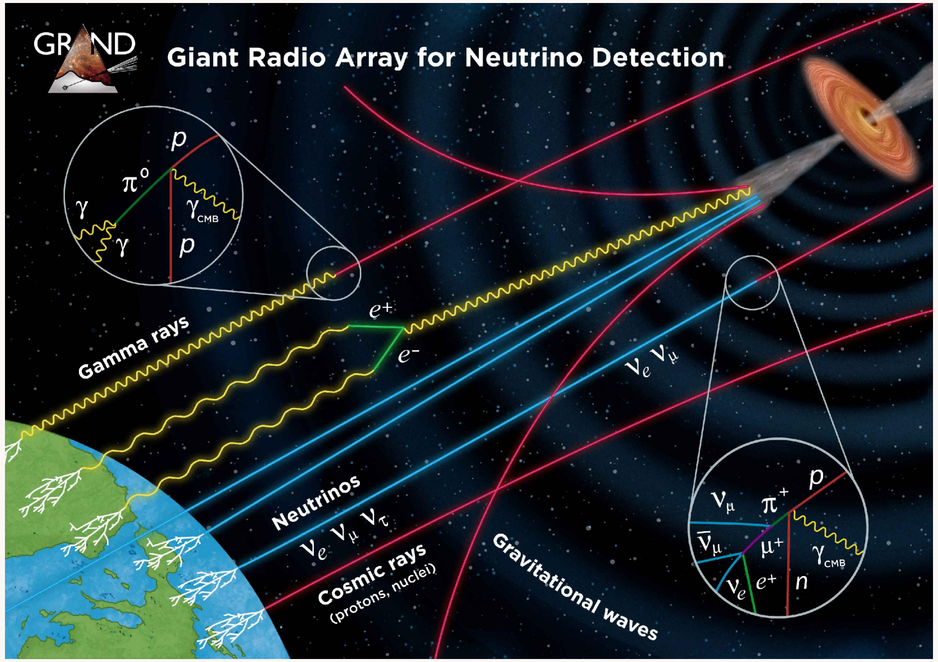
GRAND Collaboration Meeting @ PMO, Nanjing, China - May 2024



Cosmic Rays and Neutrinos

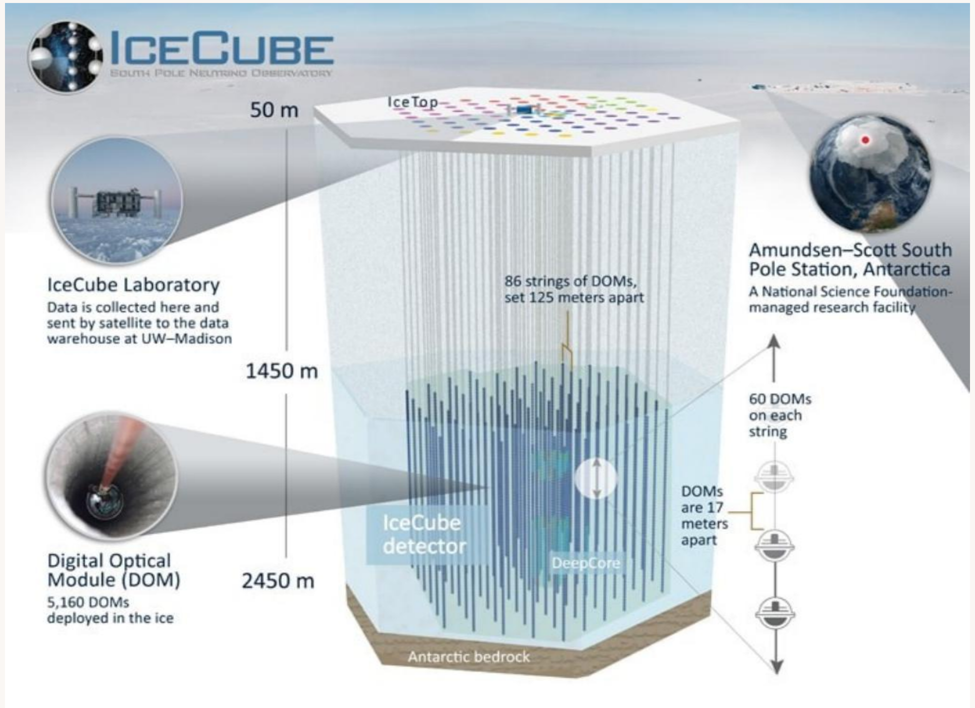
Ahlers and Halzen, PPNP102(2018)73

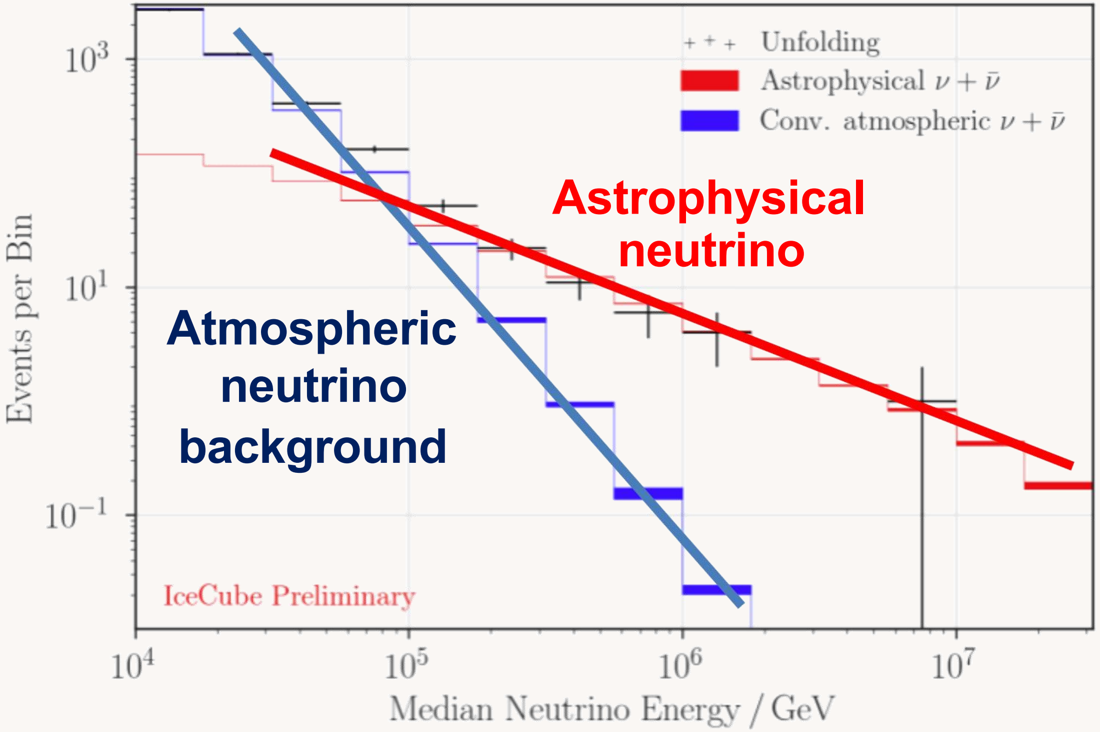


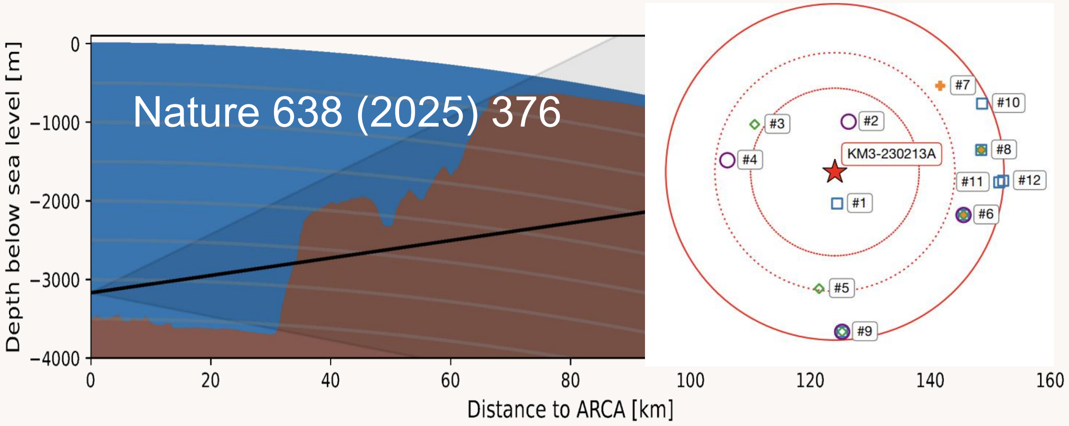


1) **UHE CR tracing:** deflected by magnetic field. the GZK horizon
2) **UHE Gamma rays:** Interaction with the CMB. They cascade down to low energy.
3) **UHE neutrinos:** Universe transparent, beyond the GZK horizon, difficult for detection.

UHE Neutrinos

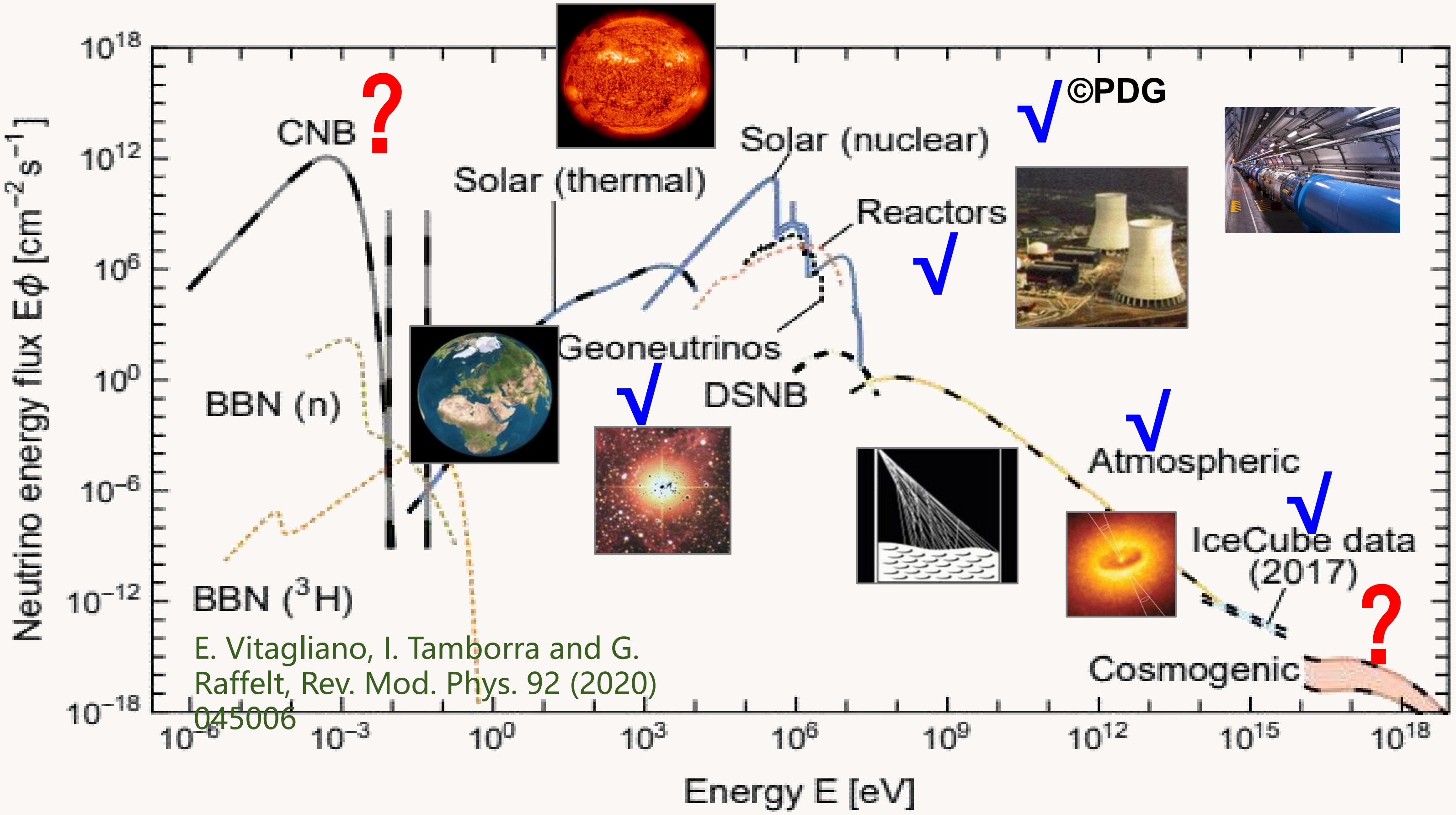


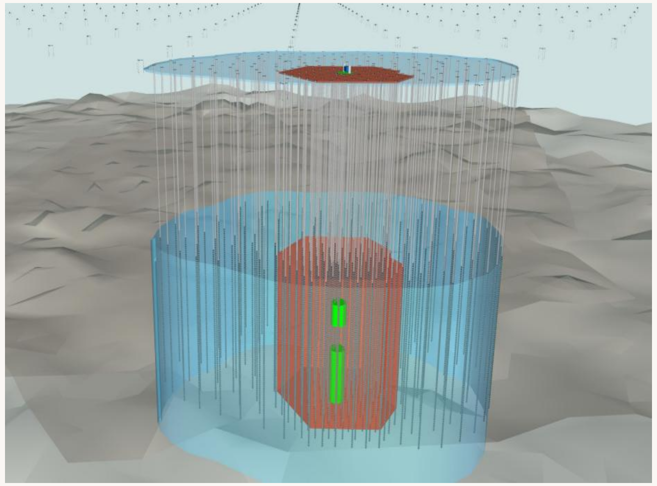


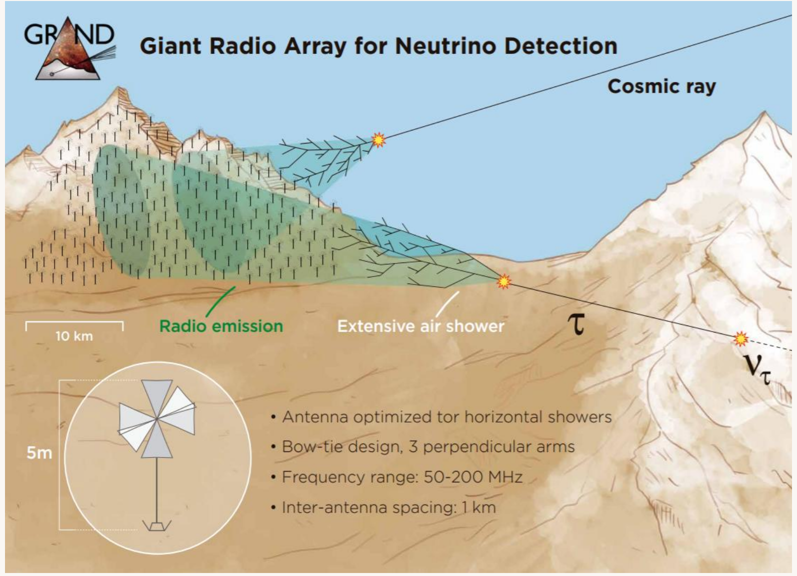


- IceCube first detected the high- energy neutrinos of extraterrestrial origin in 2013.
- Hard to identify neutrino sources due to the limited sensitivity and angular resolution.
- Origin of the 220 PeV event of KM3NeT is not yet identified.

UHE Neutrinos





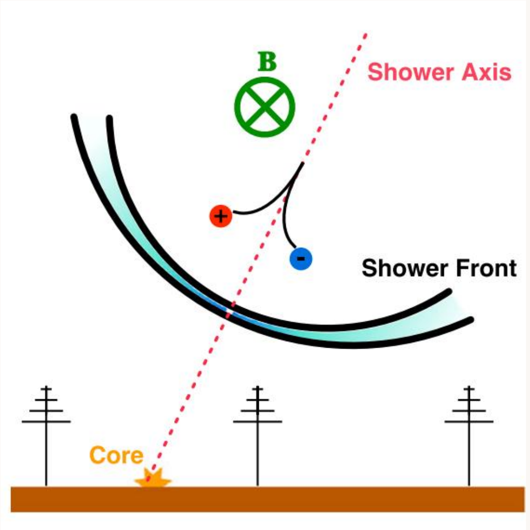


- $p+\gamma_{\rm CMB} \rightarrow p\ (\text{or } n) + \text{n}\pi$ **Very efficient for Ep ~ 50 EeV**
- $p+\gamma_{\rm CMB} \rightarrow \Delta^+(1232) \rightarrow p+\pi^0 (\text{or } n+\pi^+)$ $(p_{\rm p}+p_\gamma)^2 > (M_{\rm n}+M_\pi)^2$
- $\pi \rightarrow \nu + \ldots$ $E_\nu \approx \mathcal{O}$ **(1 EeV)** **COM energy is only 1 GeV**

CR+CMB (CIB) = Guaranteed EeV neutrino flux

V. S. Berezinsky, G. T. Zatsepin, PLB 28 (1969) 423

Radio Detection



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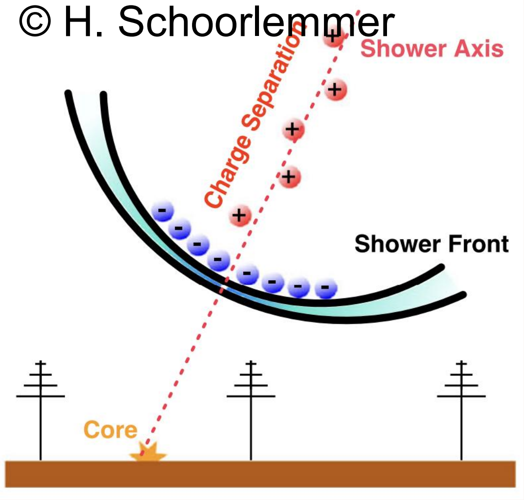


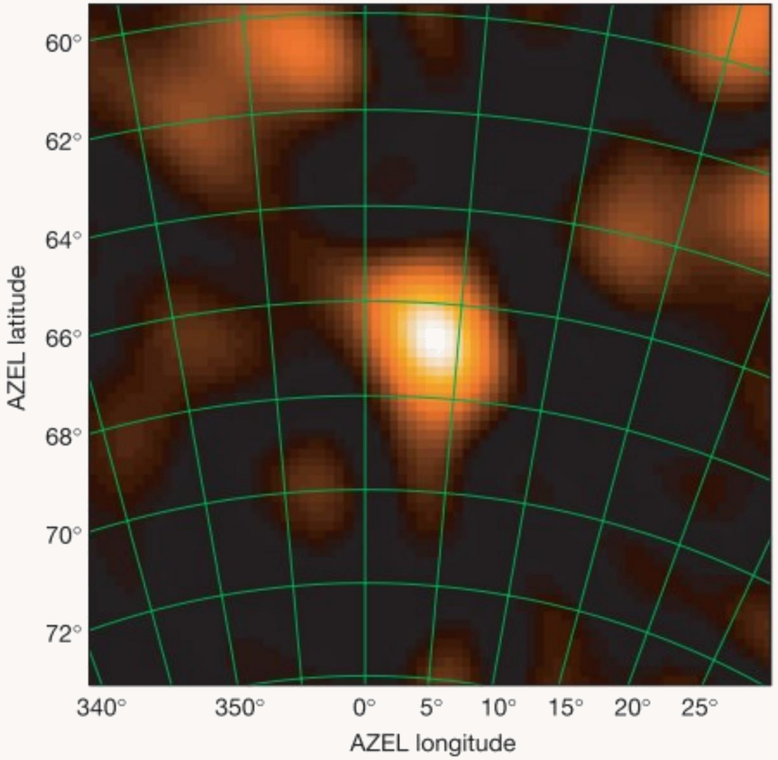
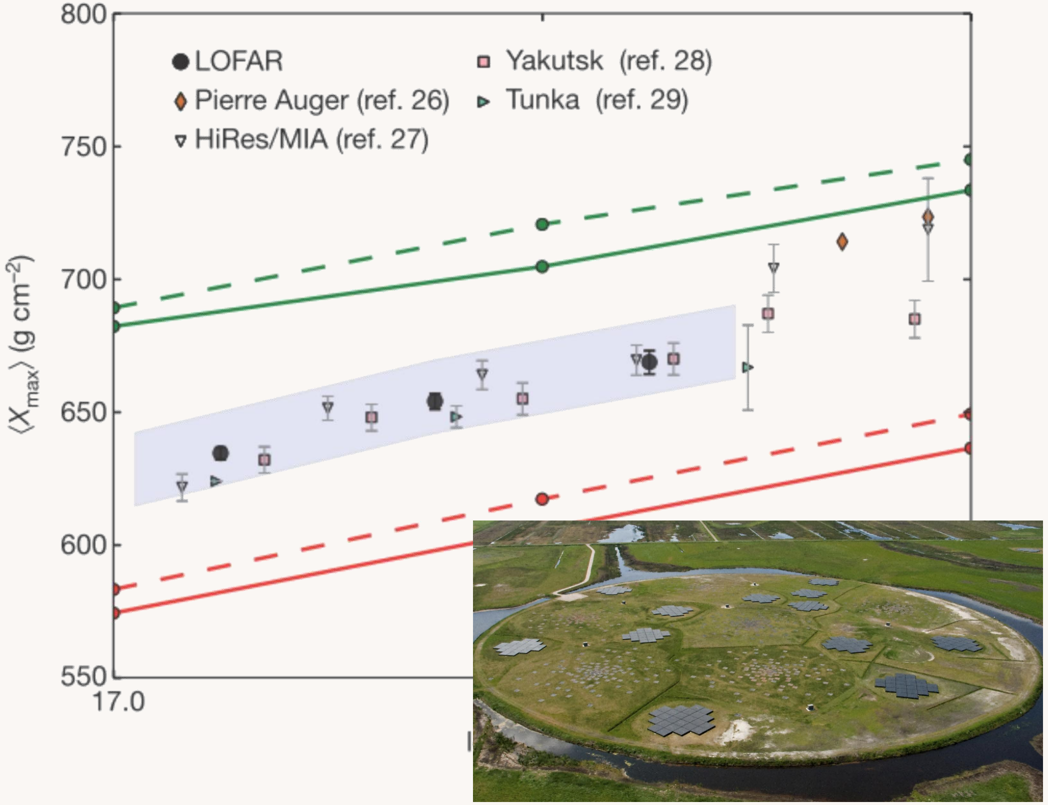
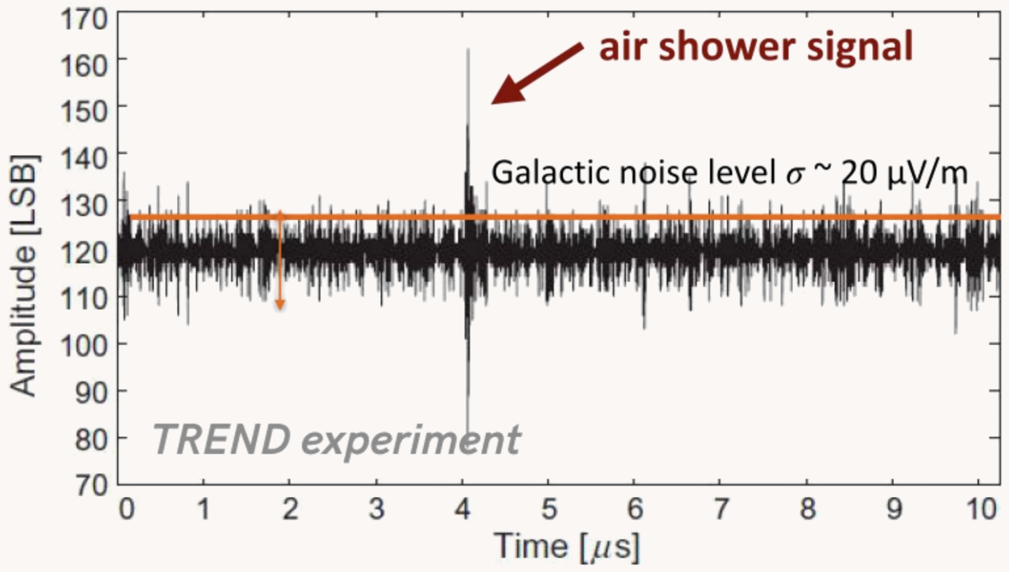


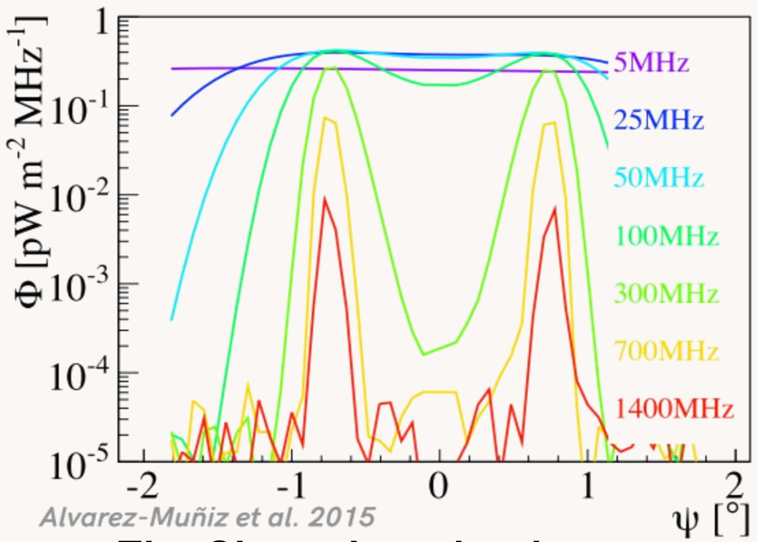
Image of an air shower using radio signals, LOPES, Nature 435 (2005) 313



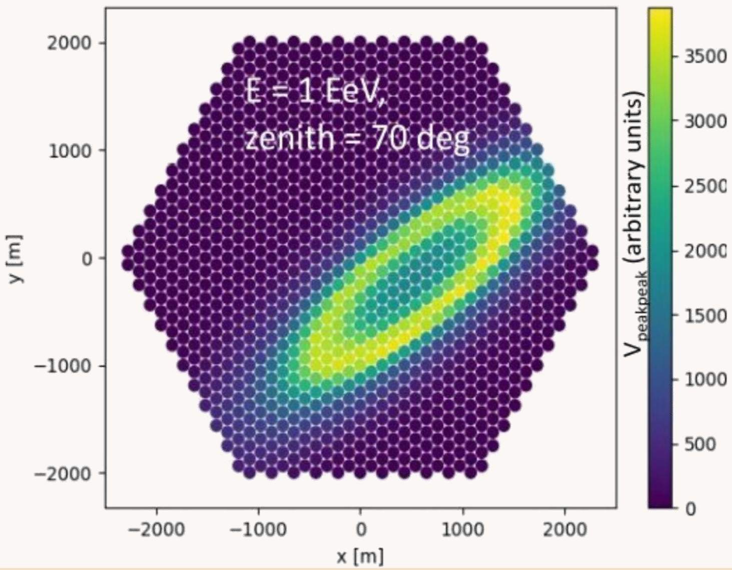
Xmax with high precision, 16 g/cm^2, LOFAR, Nature 531 (2016) 70

Radio Detection





The Cherenkov ring becomes more significant with >50MHz



- Frequency range: 50-200 MHz (C-ring)
- Transient pulses, duration: <~ 100 ns
- Amplitude of detectable signals at unit level: > 3-5 above stationary Galactic background
- Amplitude scales linearly with particle energy
- Self-triggered is made possible
- Paves the way for GRAND

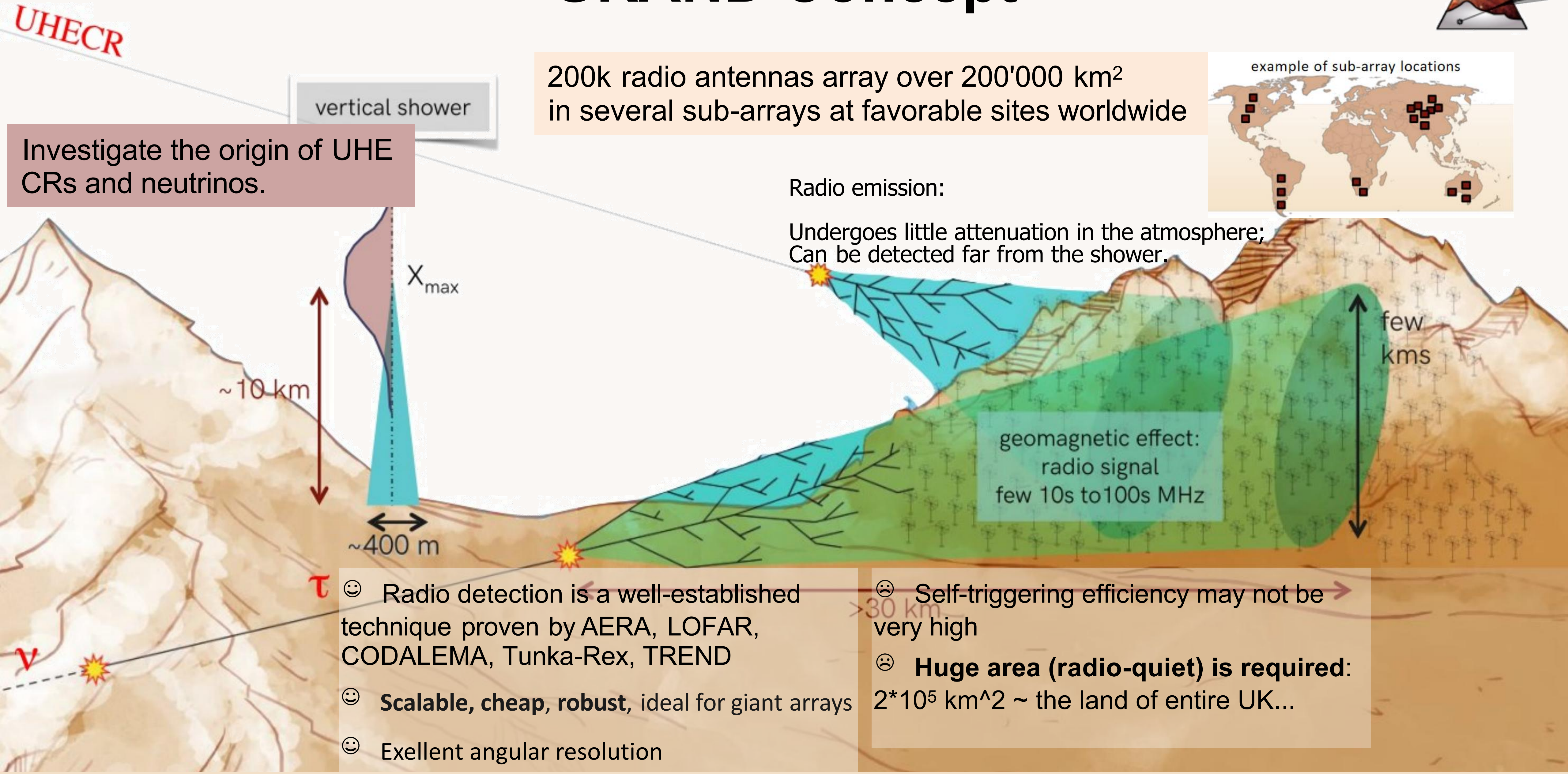
GRAND Concept

200k radio antennas array over 200'000 km^2
in several sub-arrays at favorable sites worldwide

Investigate the origin of UHE CRs and neutrinos.

Radio emission:

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



☺ 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...

Science Case

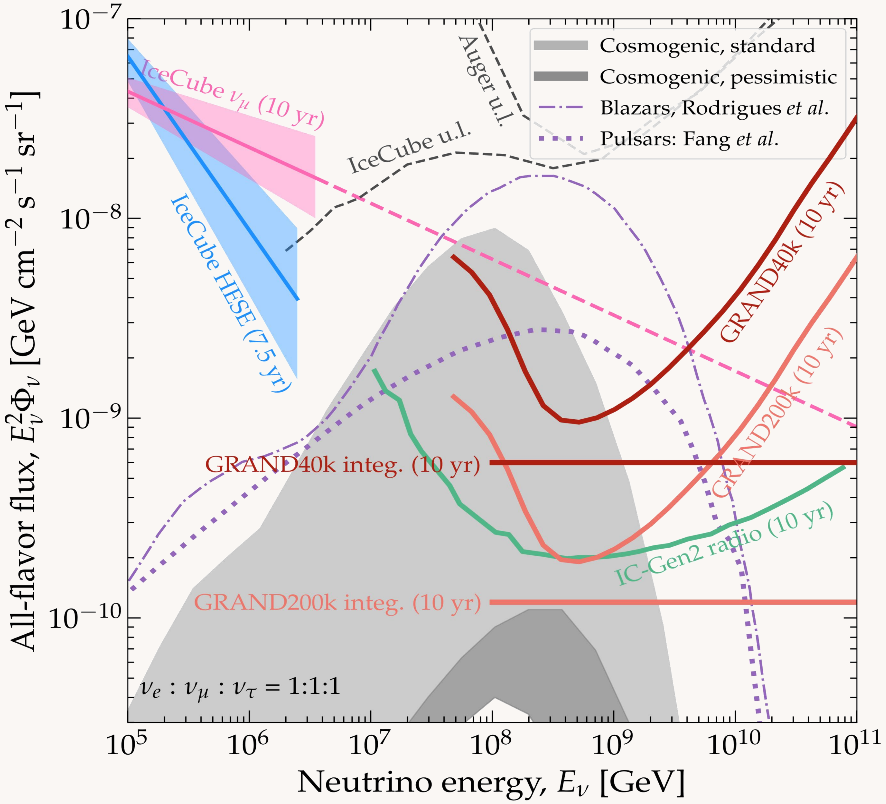
1) Radio astronomy (early stages)
- full-sky survey of radio signals
- FRBs and giant radio pulses from Crab with GP300

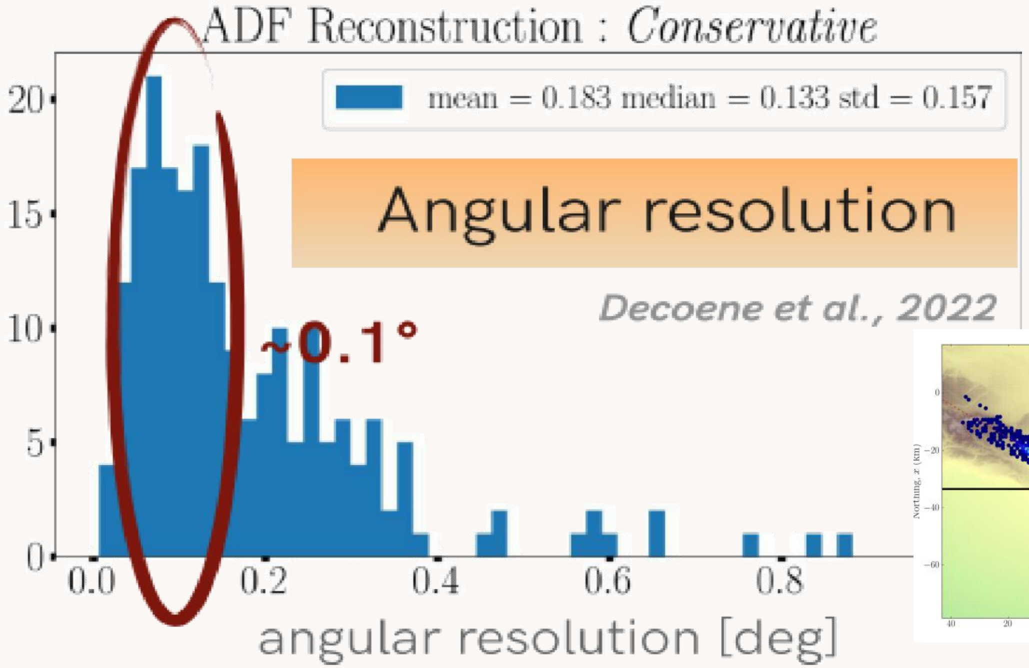
2) UHECRs (intermediate stages)
- GP300: transition from galactic to extragalactic
- hadronic physics: muon discrepancy, UHECR mass composition, p-air xsec

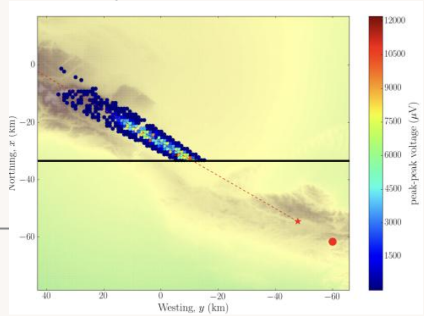
3) Neutrinos, gamma (advanced stages)
- Cosmogenic neutrino and gamma flux
- Neutrino astronomy at EeV
- Competitive with Auger at GP300 stage

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

Expected Sensitivity for Neutrinos



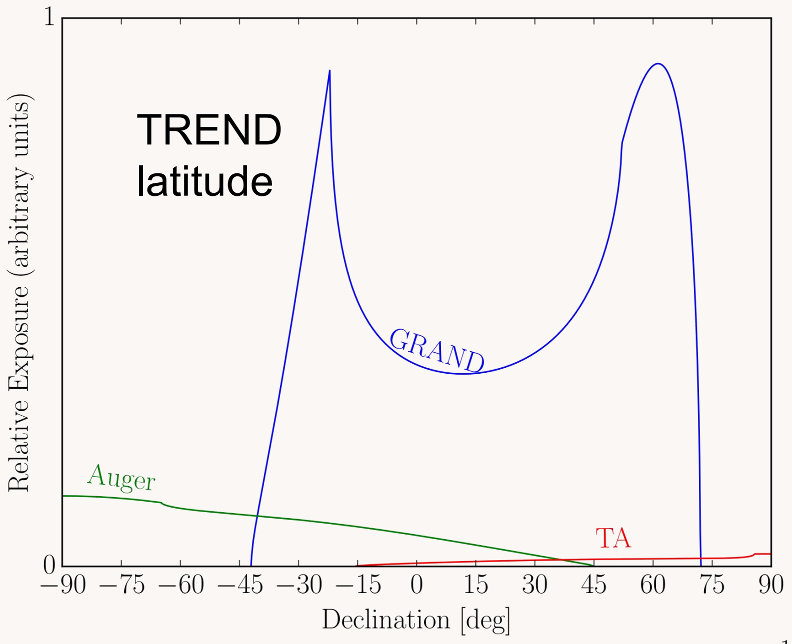


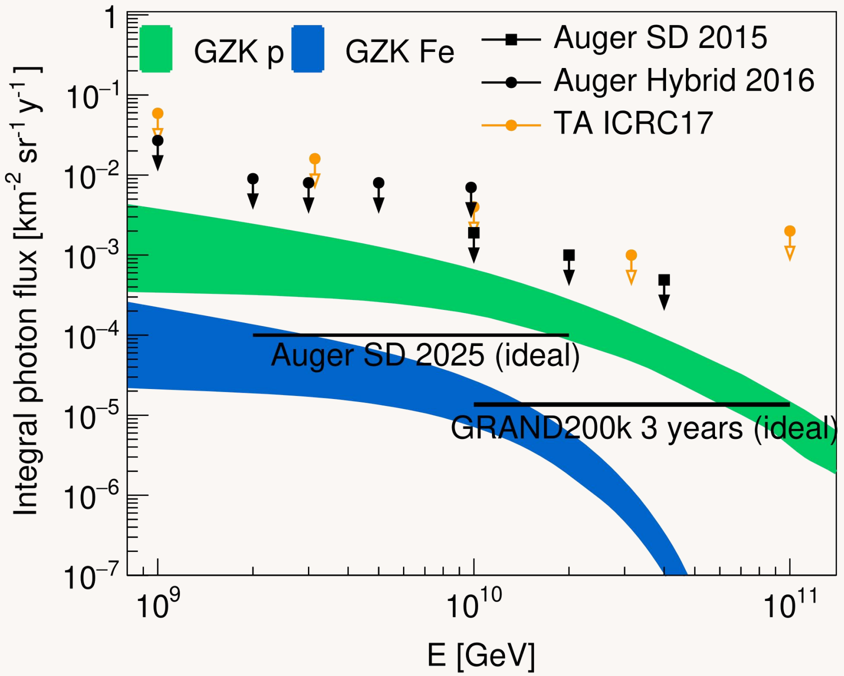


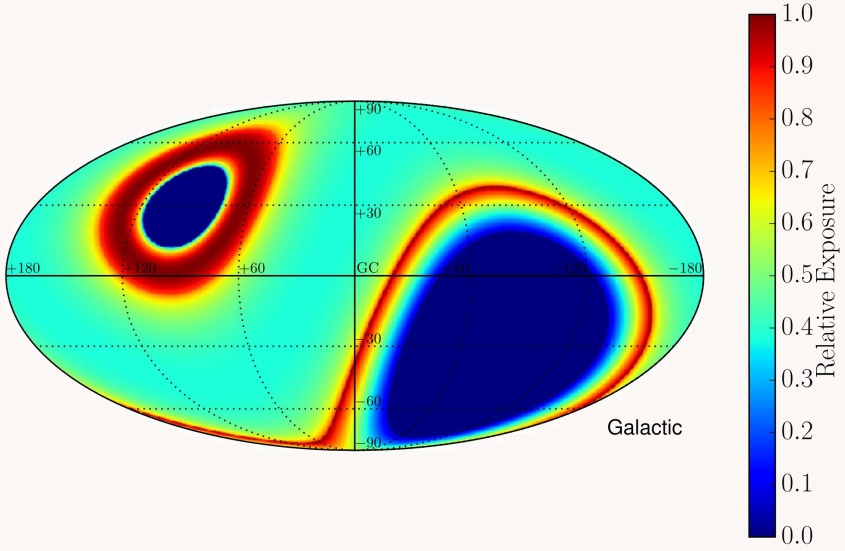
Diff. sens. lim. in GeV cm^{-2} s^{-1} sr^{-1}	iFoV in sky %	dFoV in sky %	ang. res.	2021 / 2025 / >2030
4.2×10^{-8} in 30 d	6	19	<2.8°	PUEO
3.6×10^{-9} (2030)	35	20	5°	ARA
1×10^{-8} in 5 yr	30	35	2°×10°	RNO-G
8×10^{-9} in 5 yr	50	>50	2.9−3.8°	ARIANNA-200
3×10^{-10} in 5 yr	50	>50	?	RET-N
4×10^{-10} in 5 yr	43	43	2°×10°	IceCube-Gen2 Radio
1.2×10^{-8} in 5 yr	6	19.5	0.3°−1°	BEACON
1×10^{-8} in 5 yr	6	80	0.1°	**GRAND10k**
4×10^{-10} in 5 yr	45	100	0.1°	**GRAND**
[1.5×10^{-8} (2019)]	30	92.8	<1°	Auger
?	27	62	1°	TAMBO
7×10^{-8} in 5 yr	0.6	18−36	0.4°	POEMMA Cerenkov
1×10^{-10} in 5 yr	6	62	<1°	Trinity

- With 200k antennas, GRAND can achieve an unpredented sensitivity to diffuse neutrino flux @ EeV.
- For usual flux models, the rate can read 1-18 event per year.

Expected Sensitivity for CR and Gamma







- The site is assumed at latitude 43.
- The final setup of GRAND200K with 20 sites will have a much wider coverage

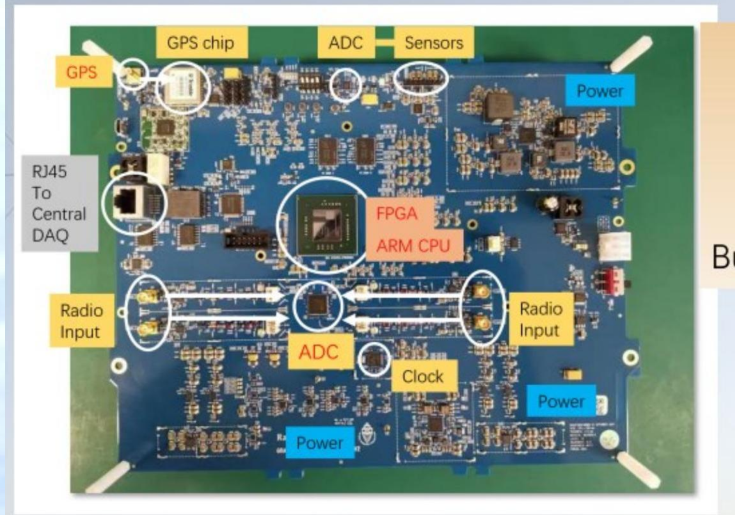
Timeline

	Prototyping	GRAND10k North/South	GRAND200k
	2023	2028	203X
Goals	**autonomous** radio detection of **very inclined** air-showers **cosmic rays $10^{16.5\text{-}18}$ eV** • Galactic/extragalactic transition • muon problem • radio transients	**1st GRAND sub-arrays** • **discovery of EeV neutrinos** for optimistic fluxes • radio transients (FRBs!)	sensitive **all-sky** detector **1st EeV neutrino detection and/or neutrino astronomy!**
Setup	• **GRAND@Nançay**: 4 antennas for trigger testing • **GRAND@Auger**: 10 antennas for cross-calibration • **GRANDProto300**: 300 HorizonAntennas over 200 km²	• 10,000 radio antennas over 10,000 km²	• 200,000 antennas over 200,000 km² • 20 sub-arrays of 10k antennas • on different continents
Budget	**2 M€** 100 antennas produced funded by China + Radboud University + ANR-DFG PRCI NUTRIG (France-Germany) + CNRS INSU (IAP, MITI)	**13 M€** 1500€/unit	**300M€** in total 500€/unit to be divided between participating countries

Detector

For more on the prototype technology, please check Sei Kato's talk ☺

1. Highly efficient along the horizontal direction
2. Placed 3.5 meters above the ground to minimize diffraction
3. bow-tie design for a flat response in azimuthal angle

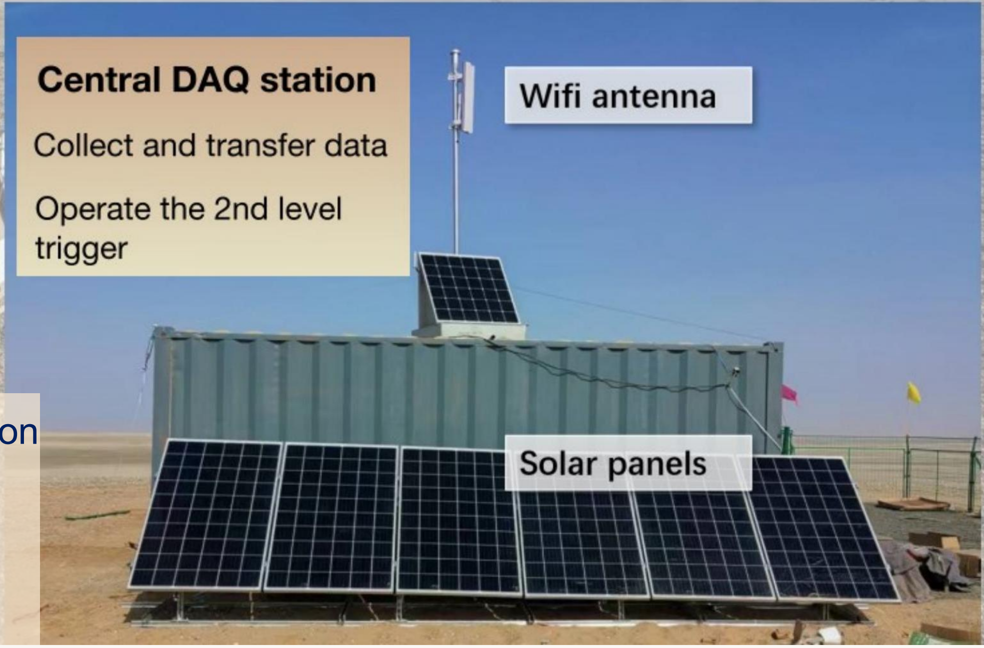


Electronics:
50-200 MHz analog filtering,
500 MS/s sampling
FPGA+CPU
Bullet WiFi data transfer

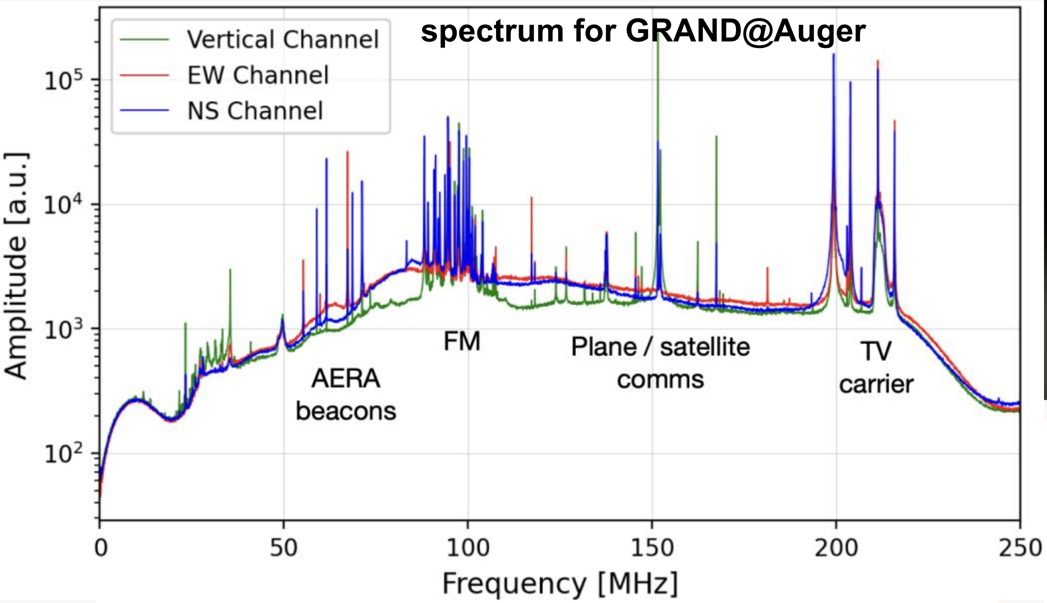
Central DAQ station

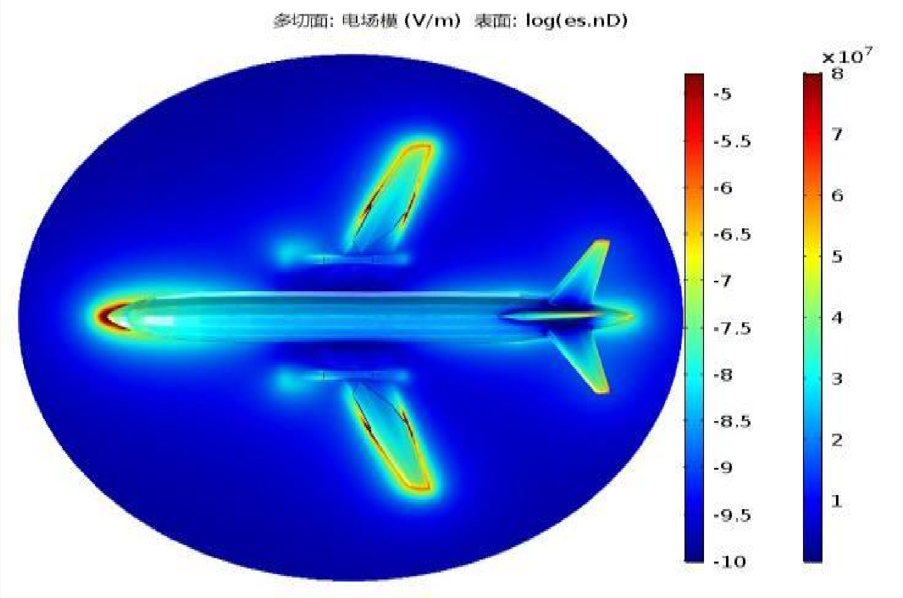
Collect and transfer data

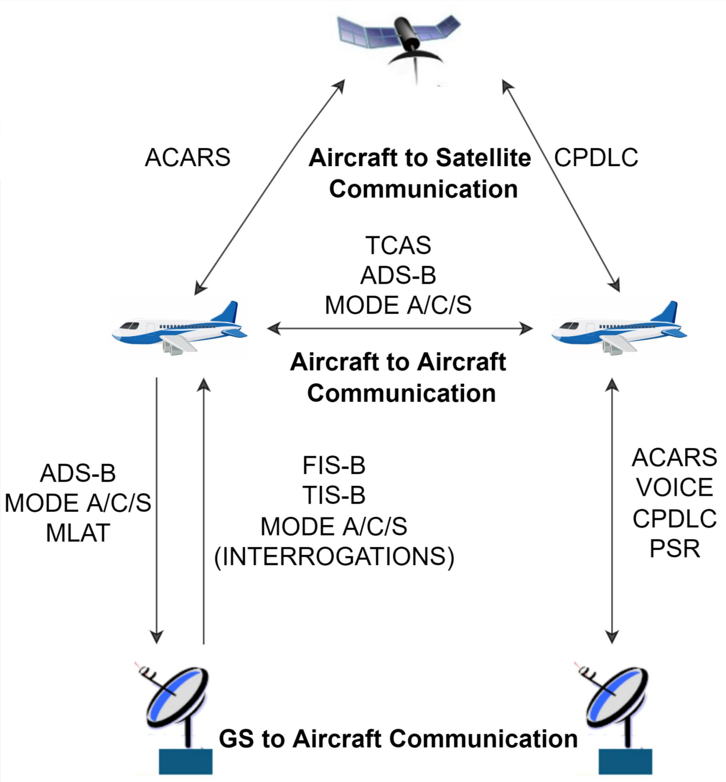
Operate the 2nd level trigger



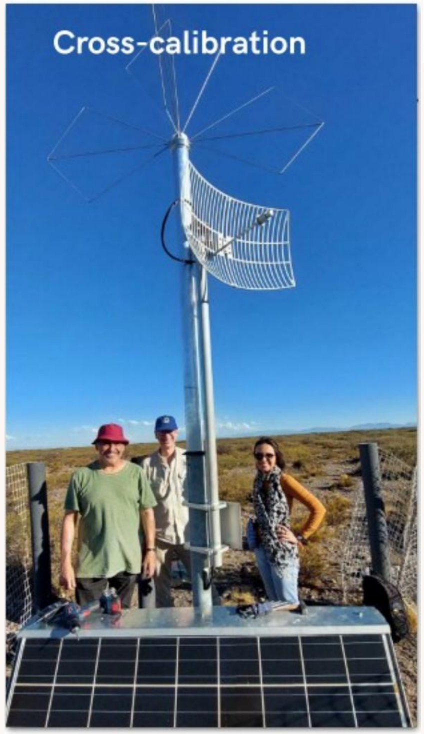
Possible Background





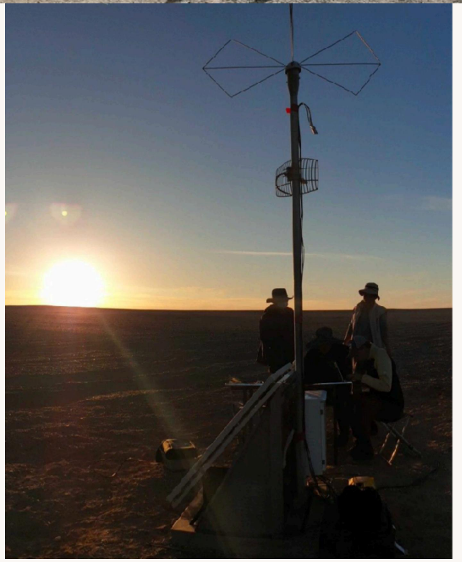


Prototypes

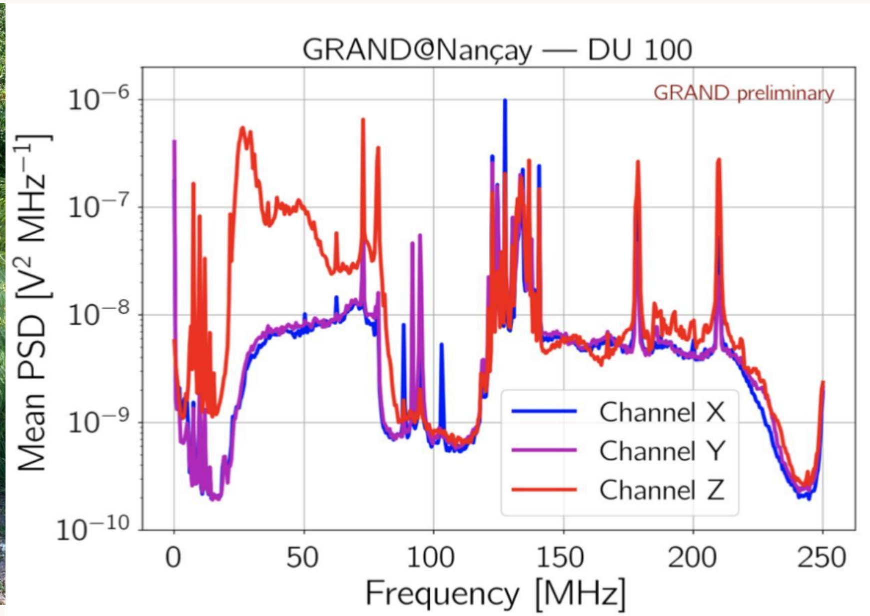


Commissioning phase

Deployment on 3 sites and first experimental data obtained!



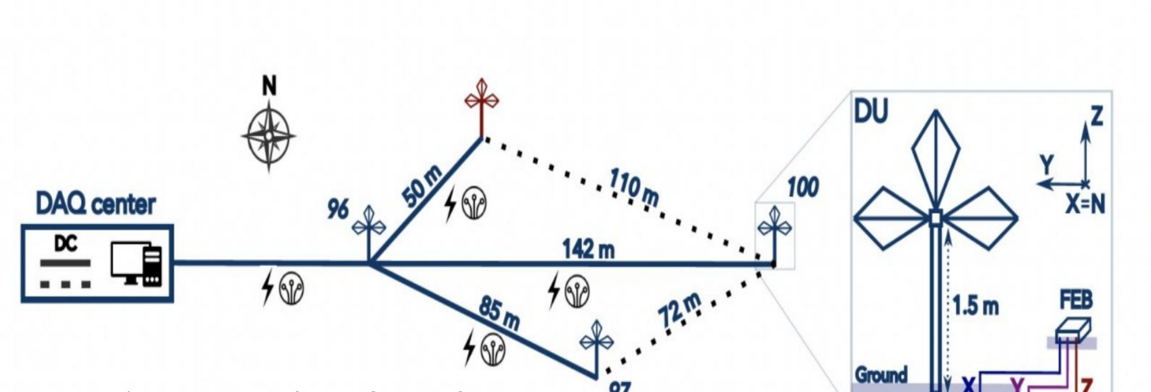
GRAND@Nançay



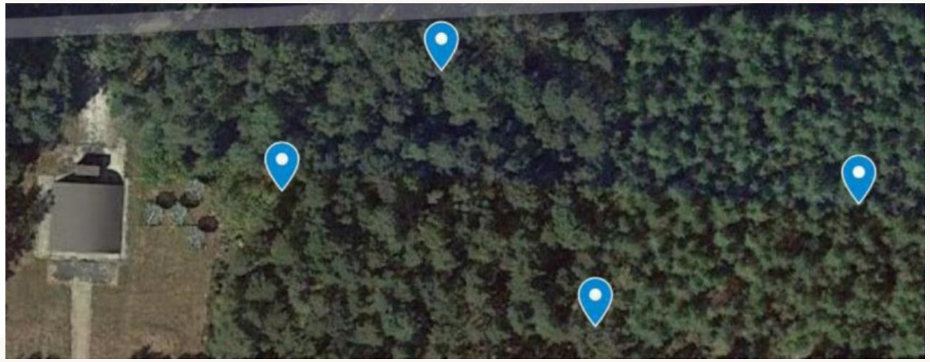
- **Hosted at the Nançay Radio Observatory, France,** 4 DUs have been deployed.

- **Test bench for triggering and hardware**

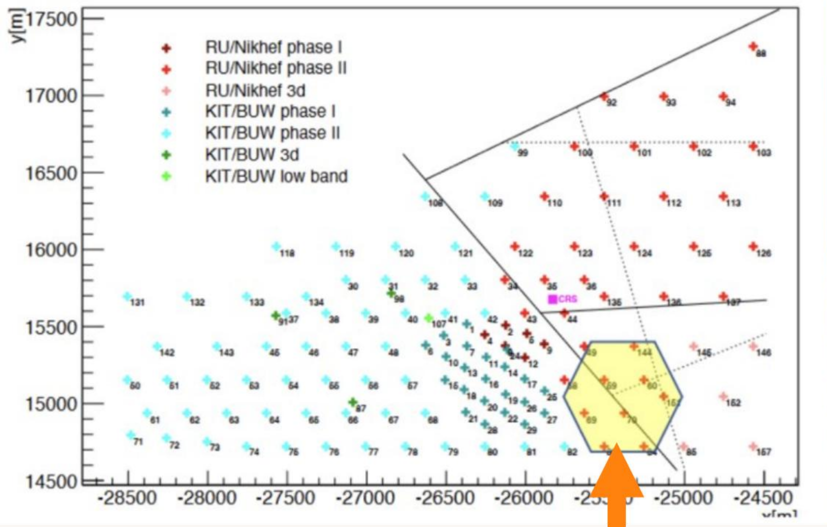
- Antennas were shipped from China and the rest of the equipment was funded by the ANR- DFG grant between Paris (LPNHE and IAP) and Karlsruhe (KIT)



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

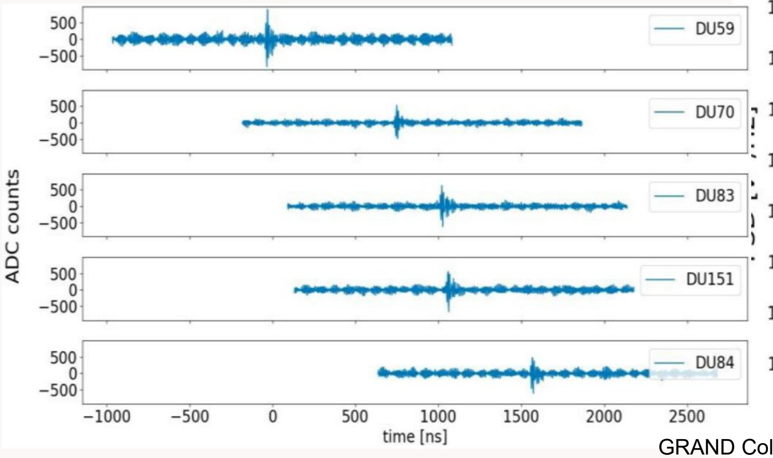


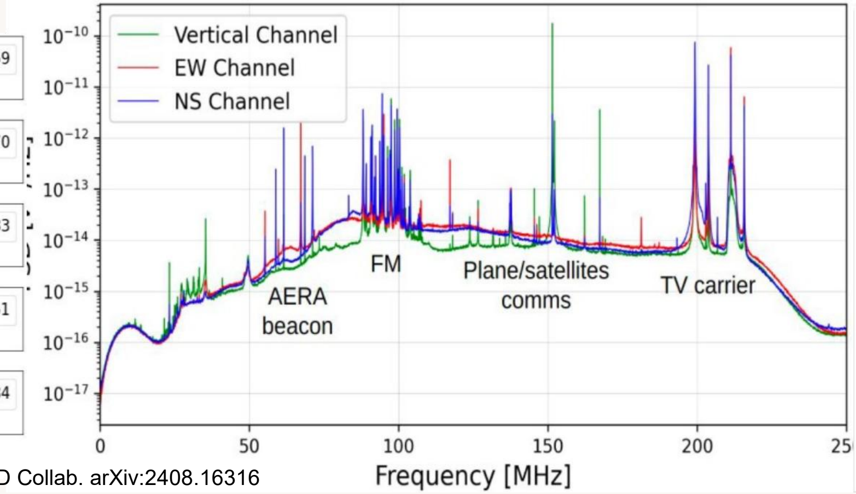
GRAND@Auger



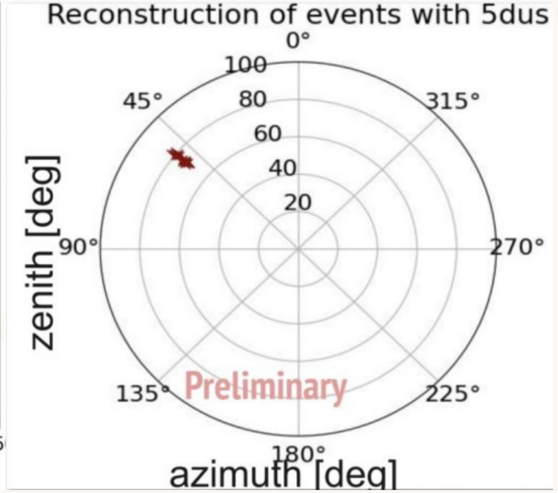
- 10 antennas deployed
- Auger mechanical structure + infrastructure
- Cross-calibration with Auger detectors
- Hardware tests, Firmware tests
- Online coincidence search at central DAQ (L3 triggering)
- ~ 1 event/day expected

GRAND@Auger

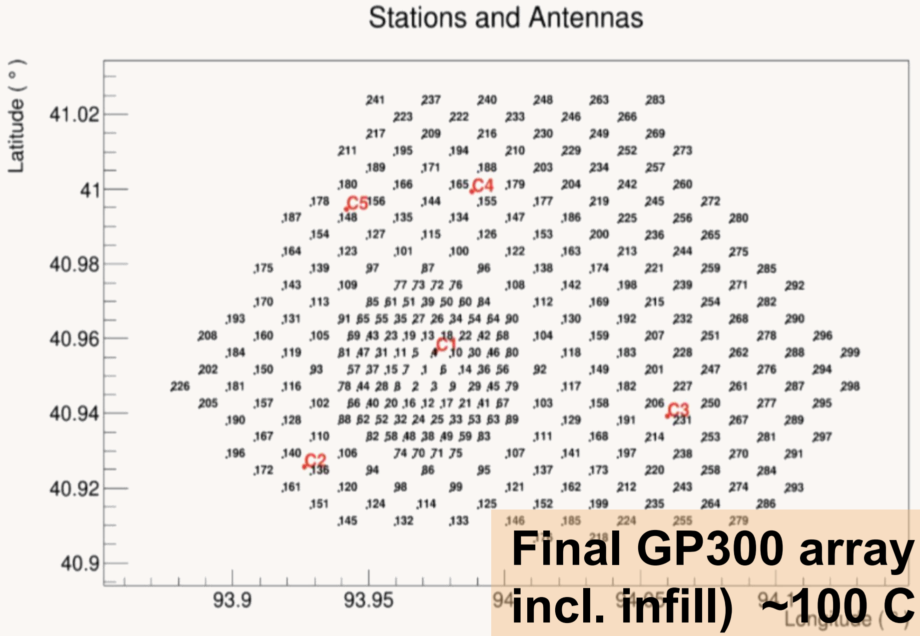


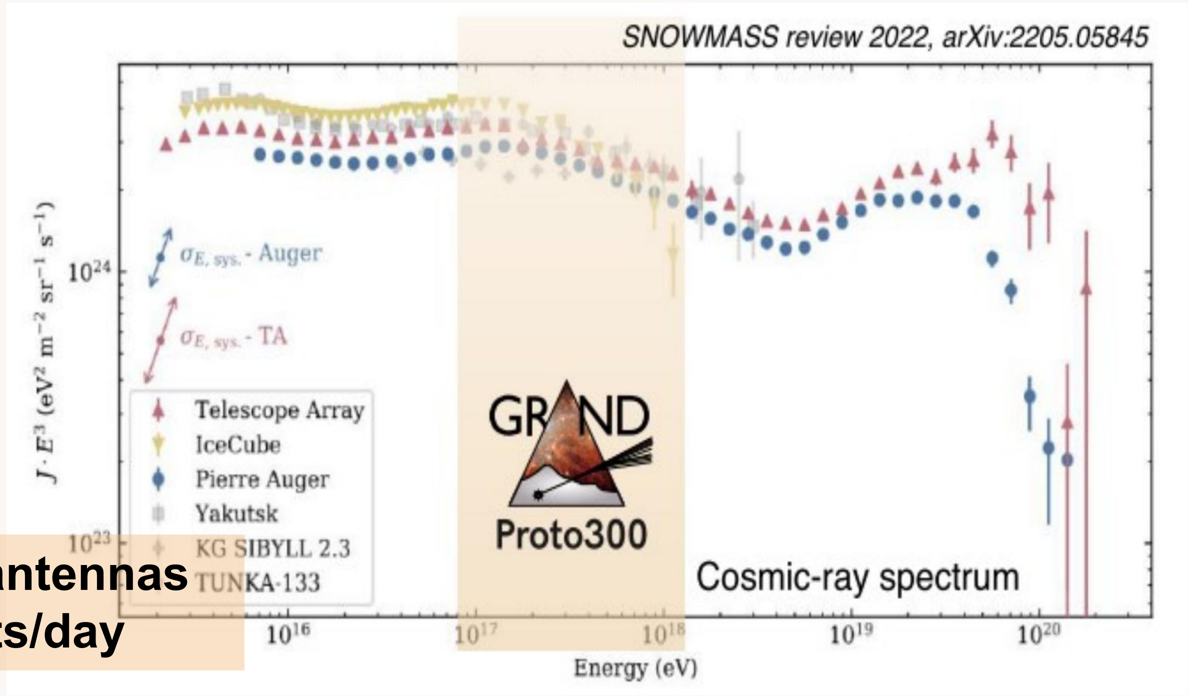


GRAND Collab. arXiv:2408.16316



GRANDProto300 (GP300)





Final GP300 array (~300 antennas incl. infill) ~100 CR events/day

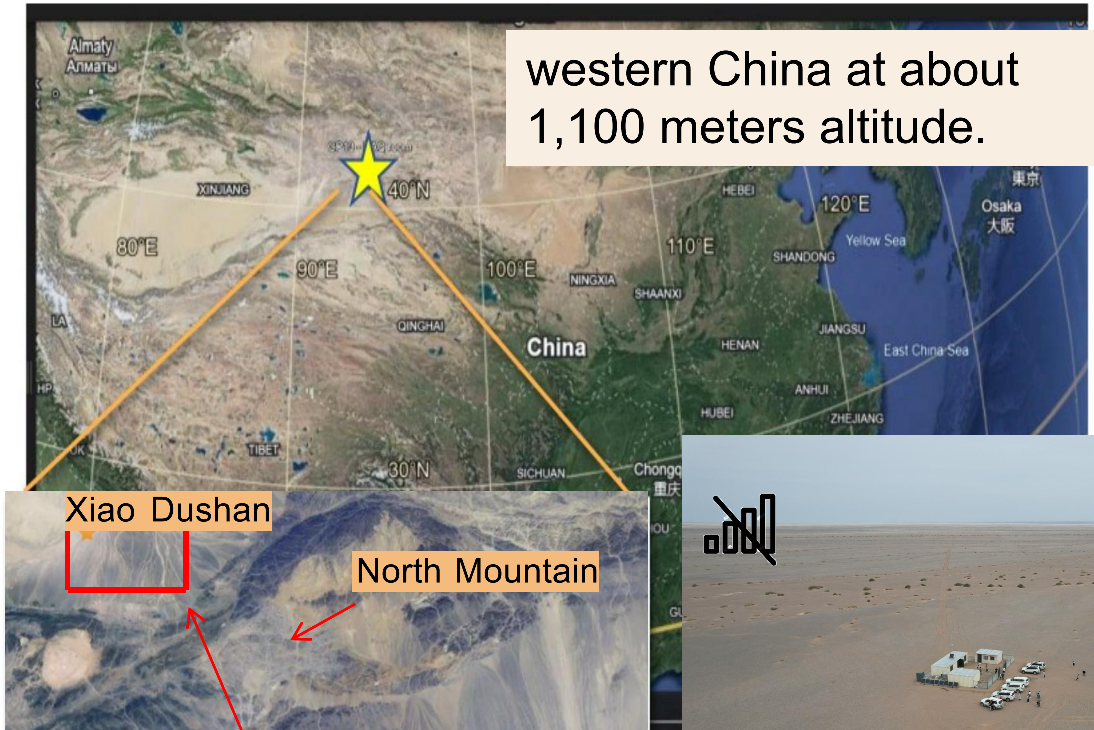
Aims to validate the GRAND as a **standalone** radio detection array

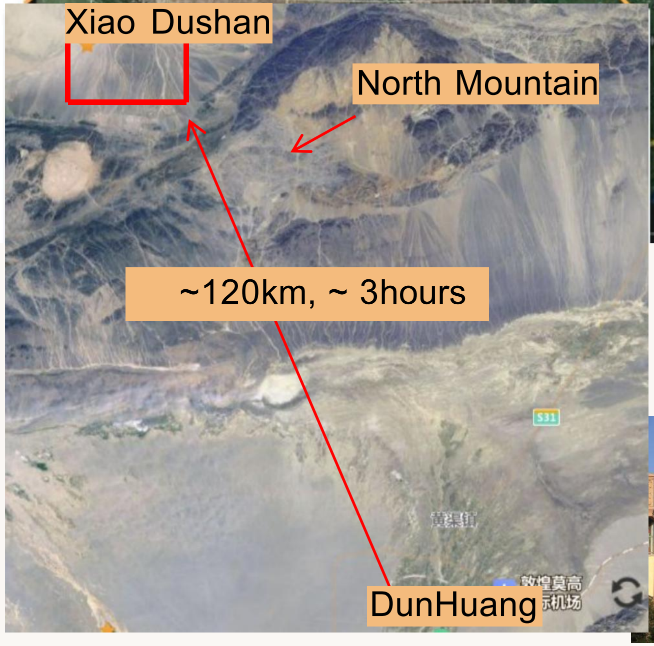
- **Realize the self-trigger techniques**; test bench for further GRAND stages
- **Algorithm** for angular, energy and mass composition reconstruction;
- Detection of very inclined cosmic rays with energies from 30 PeV to 1 EeV;
- **Study CRs in the galactic to extragalactic transition energy range.**

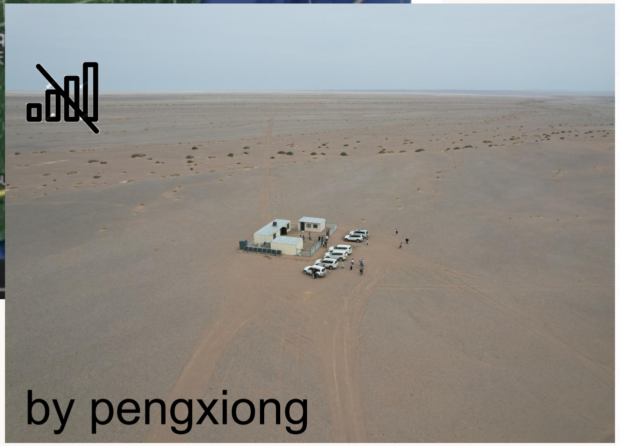
A 300-antenna pathfinder stage of GRAND

- **200 km^2 area;**

GP300 Location







敦煌市自然资源局文件

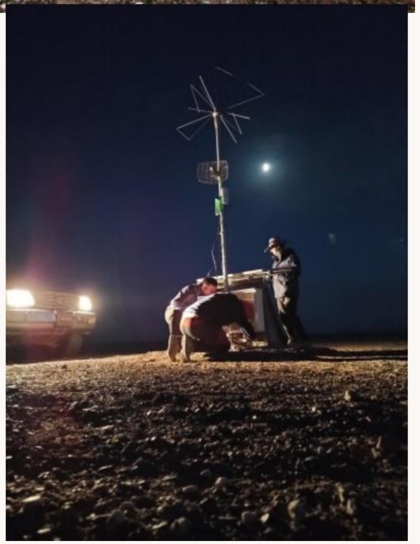
敦自然资发〔2024〕23 号

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

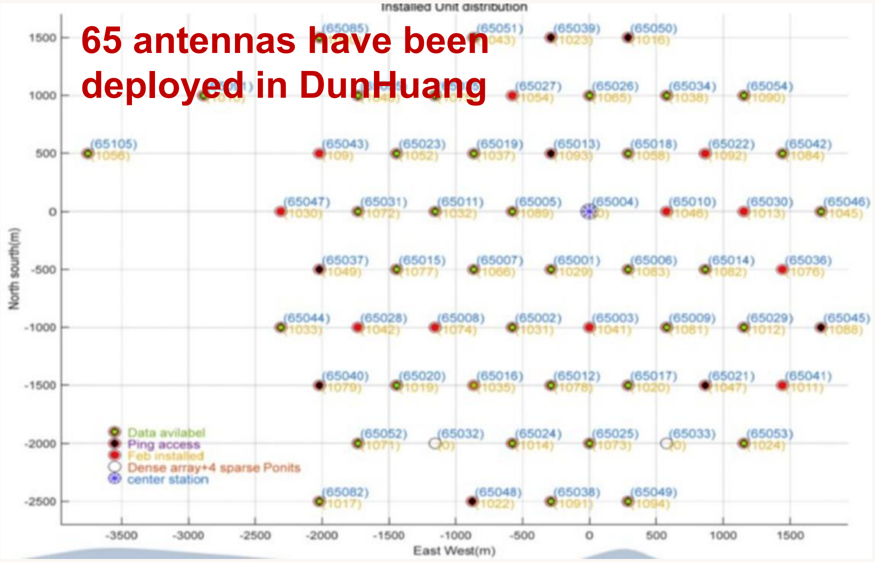
中国科学院紫金山天文台：　　**GP300, 10 years**

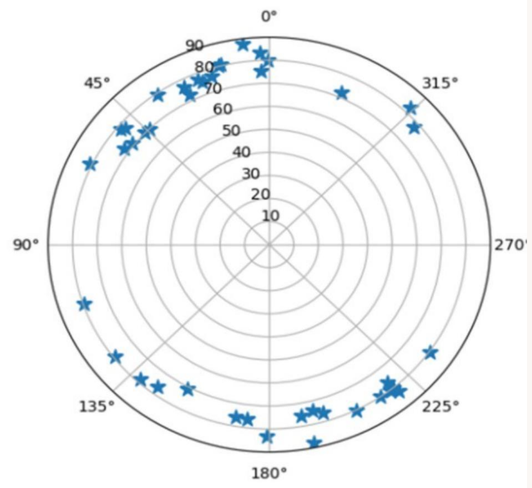
参照原国土资源部、发展改革委等部委《关于支持新产业新业态发展促进大众创业万众创新用地的意见》(国土资规〔2015〕5 号)相关规定，经上报市政府批准，现准予你单位以现状备案方式使用我市北山小独山区域 2396 平方米国有土地，用于大型中微子射电观测站二期子阵项目建设，备案期限为 10 年，你单位在用地期间不得压占、硬化土地，不得改变地表形态，须严格按照设计标准施工，坚决杜绝随意变动。你单位在使用备案土地过程中，不得影响区域内及周边正常通行，不得影响和干扰区域内及周边新能源项目建设、矿产资源勘查开采等活动，如遇以上情况

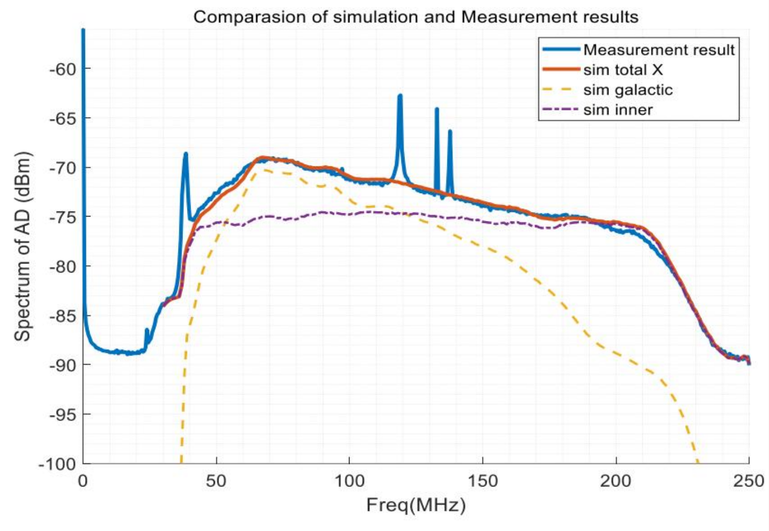
GP300 Construction

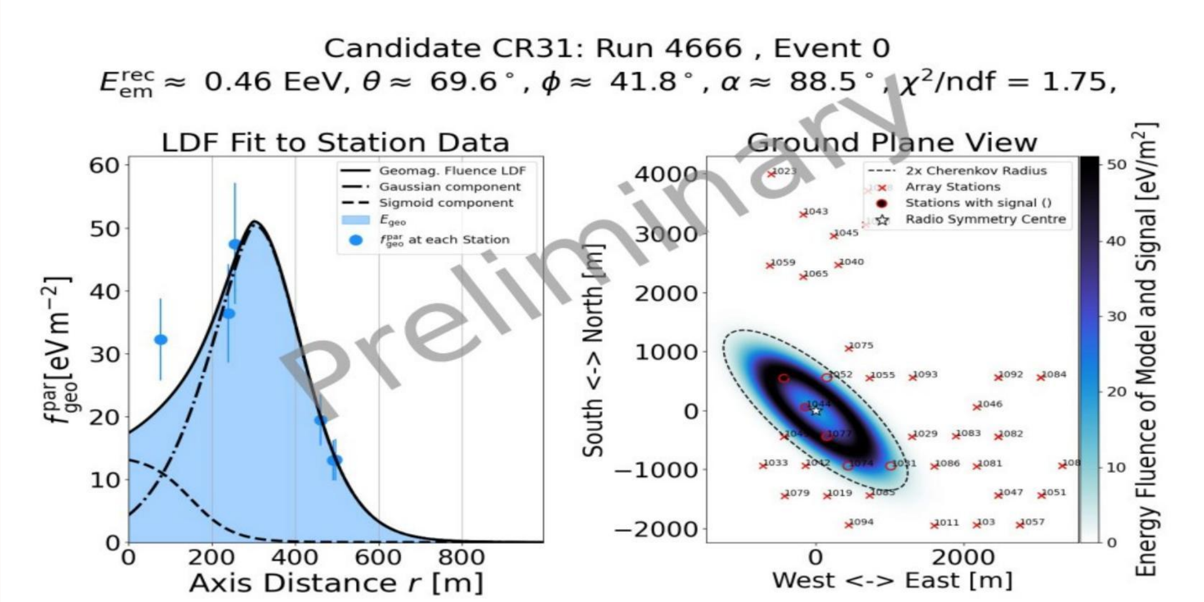


GP300 Science









Using the Autonomous Radio-detection technique, we have already identified ~40 CR candidates with successful reconstruction in the commissioning phase.

GP300 Animals

Summary

GRAND key features:

⭐ One of the largest UHE neutrino observatories: excellent sensitivity, large FoV, 0.1 degree angular resolution

⭐ Scalable design using radio antennas with autonomous triggering

⭐ Rich science case: radio astronomy; UHE cosmic rays; UHE neutrinos@EeV; UHE gamma rays

Prototype Stage:

☕ Three Prototypes: GRAND@Nançay, GRAND@Auger, GRANDProto300

☕ 65 antennas were deployed at GP300

☕ Radio astronomy and cosmic rays with GP300

Stay tuned
谢谢！ Thank you!