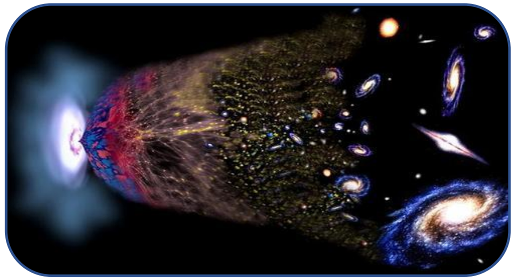
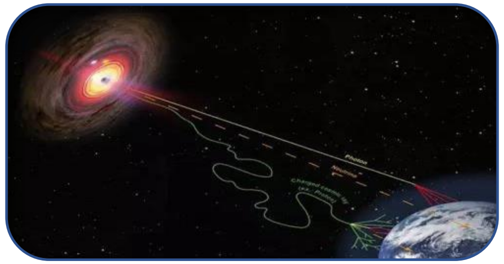
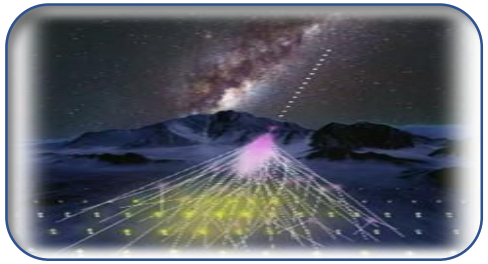
16th France-China Particle Physics Network/Laboratory workshop (FCPPN/L 2025)


Introduction to GP300-the path finder of GRAND (The Giant Radio Array for Neutrino Detection)

July 23th 2025

PENGFEI Zhang(张鹏飞);

Cooperators：YI Zhang（张毅）；YAN Huang（黄滟）etc.

（Xidian University，zhangpf@mail.xidian.edu.cn)

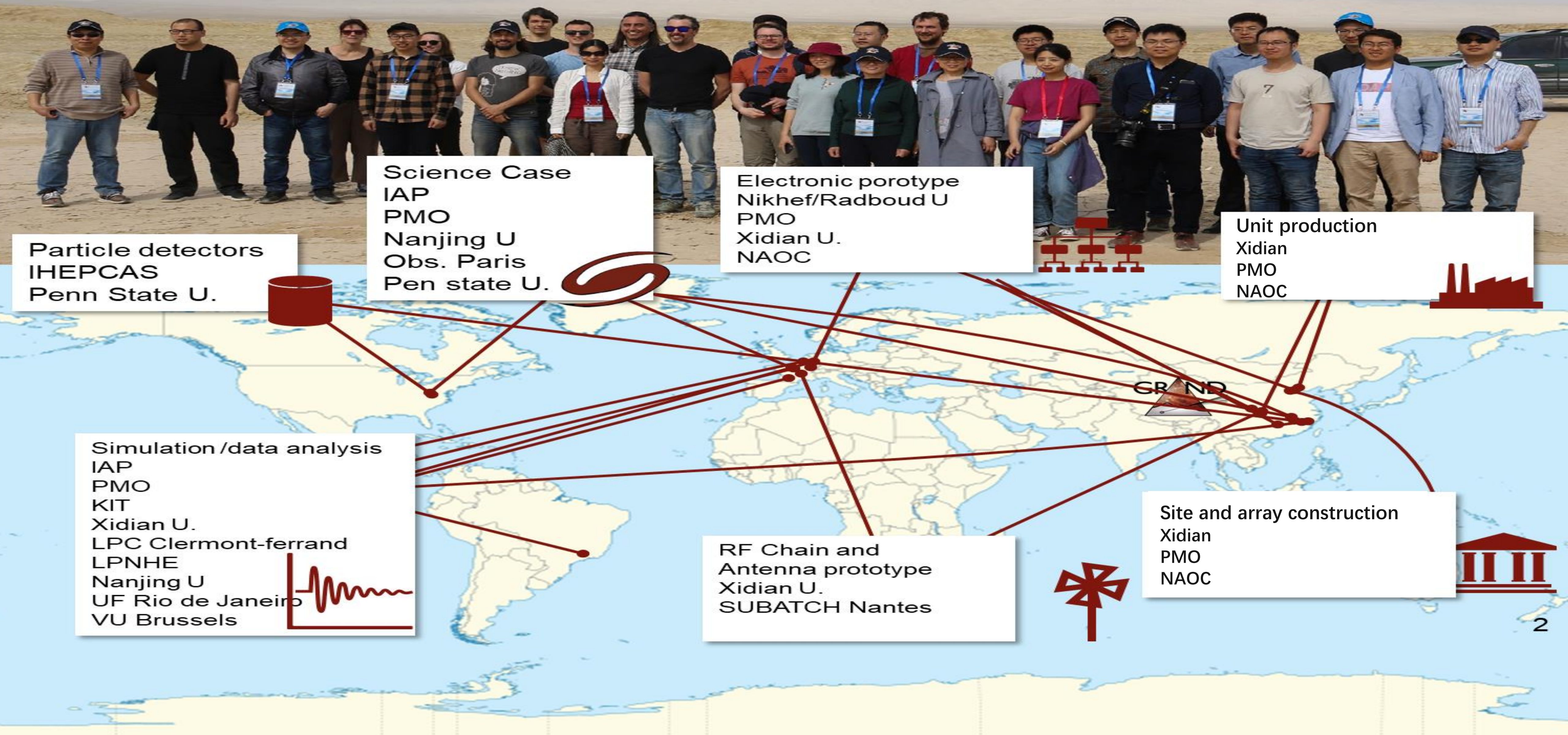
On behalf of GRAND International Cooperation Porject


西安电子科技大学
Xidian University

Thanks :

119 members & 14 countries: Argentina, Belgium, Brazil, China, Czech Republic, Denmark, France, Germany, Greece, Japan, Netherlands, Norway, Poland, USA

GRAND Workshop, Dunhuang, April 2019



GRAND Collaboration

16 Member & Associate Institutes represented at the Board

- Purple Mountain Observatory (PMO)
- Xidian University
- National Astronomical Observatories (NAOC)
- 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)

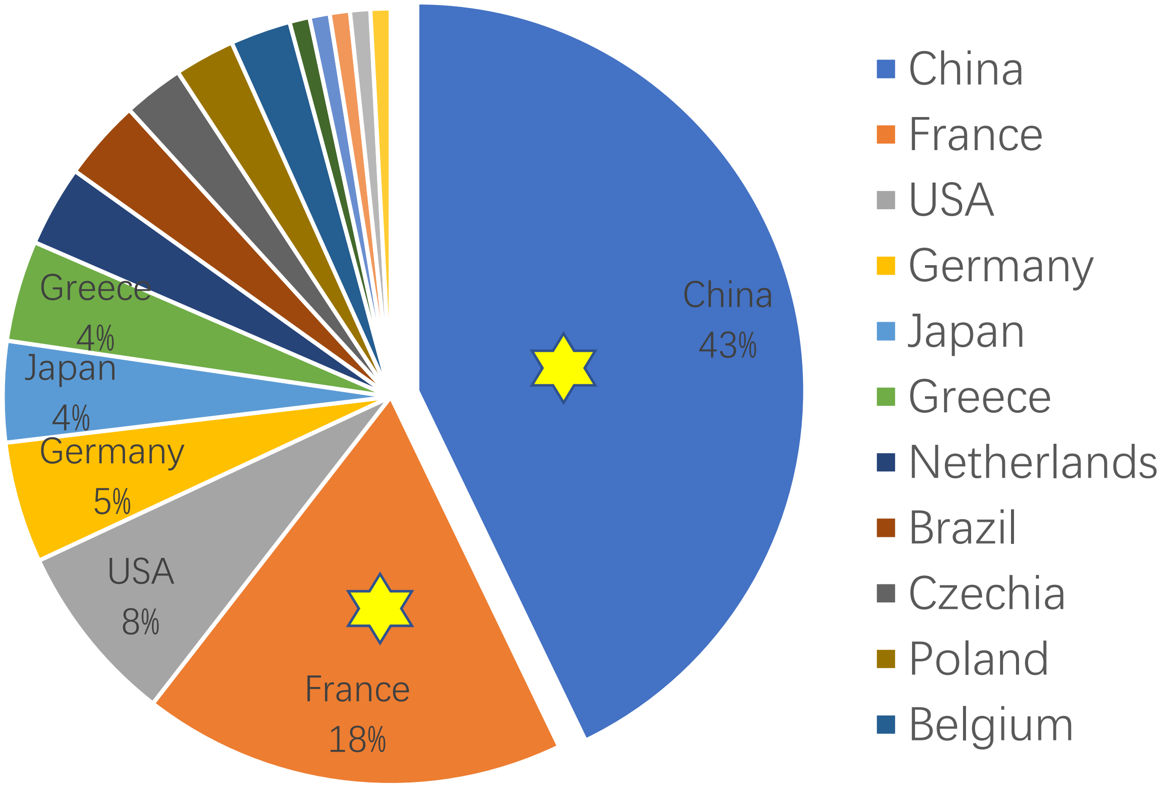
- Universidade Federal do Rio de Janeiro (UFRJ)

119 members 14 countries: Argentina, Belgium, Brazil, China, Czech Republic, Denmark, France, Germany, Greece, Japan, Netherlands, Norway, Poland, USA

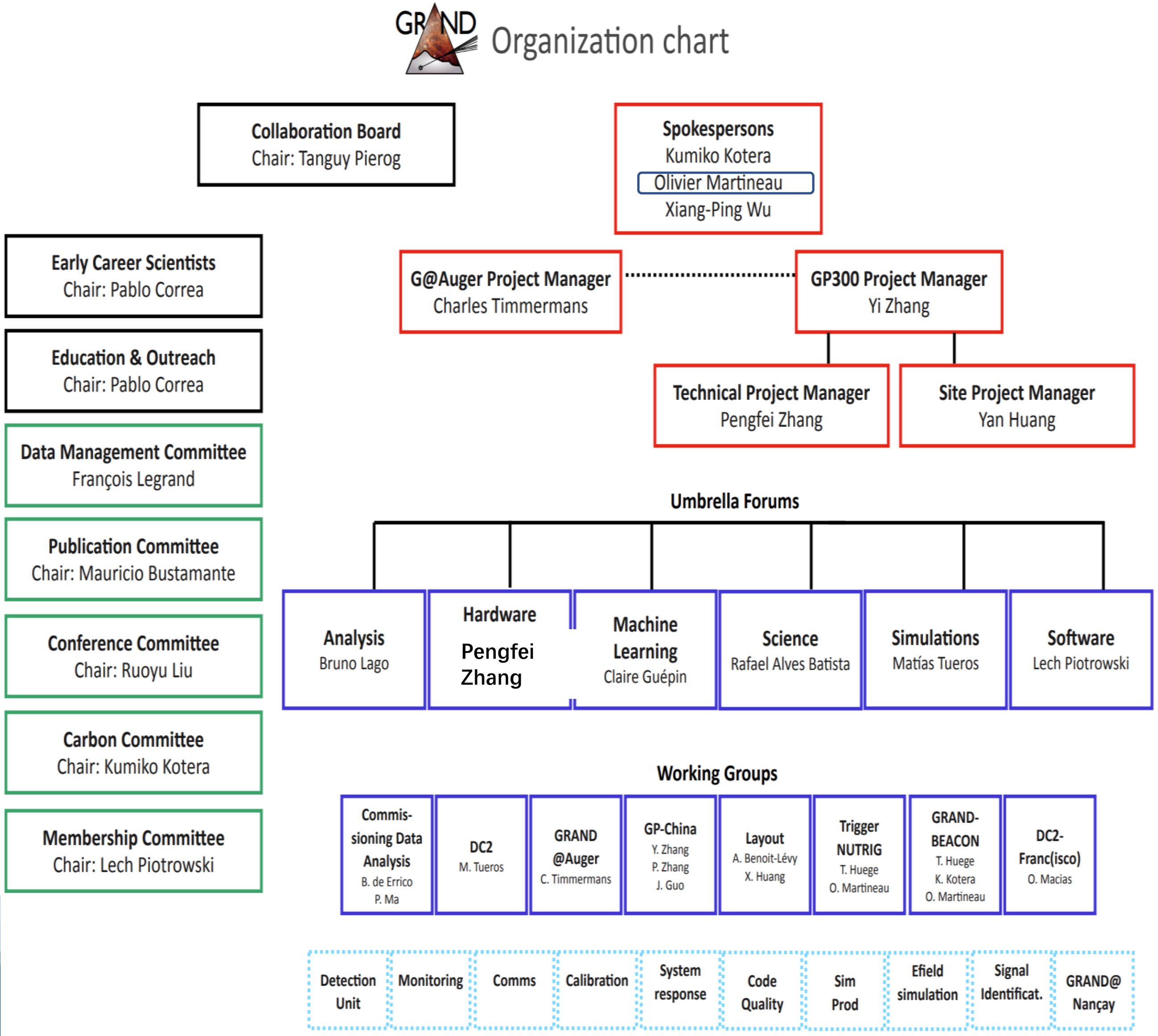
GRAND Collaboration Meeting in Nanjing @ Purple Mountain Observatory, May 2024

119 members & 14 countries: Argentina, Belgium, Brazil, China, Czech Republic, Denmark, France, Germany, Greece, Japan, Netherlands, Norway, Poland, USA

西安电子科技大学 Xidian University



From the author list members



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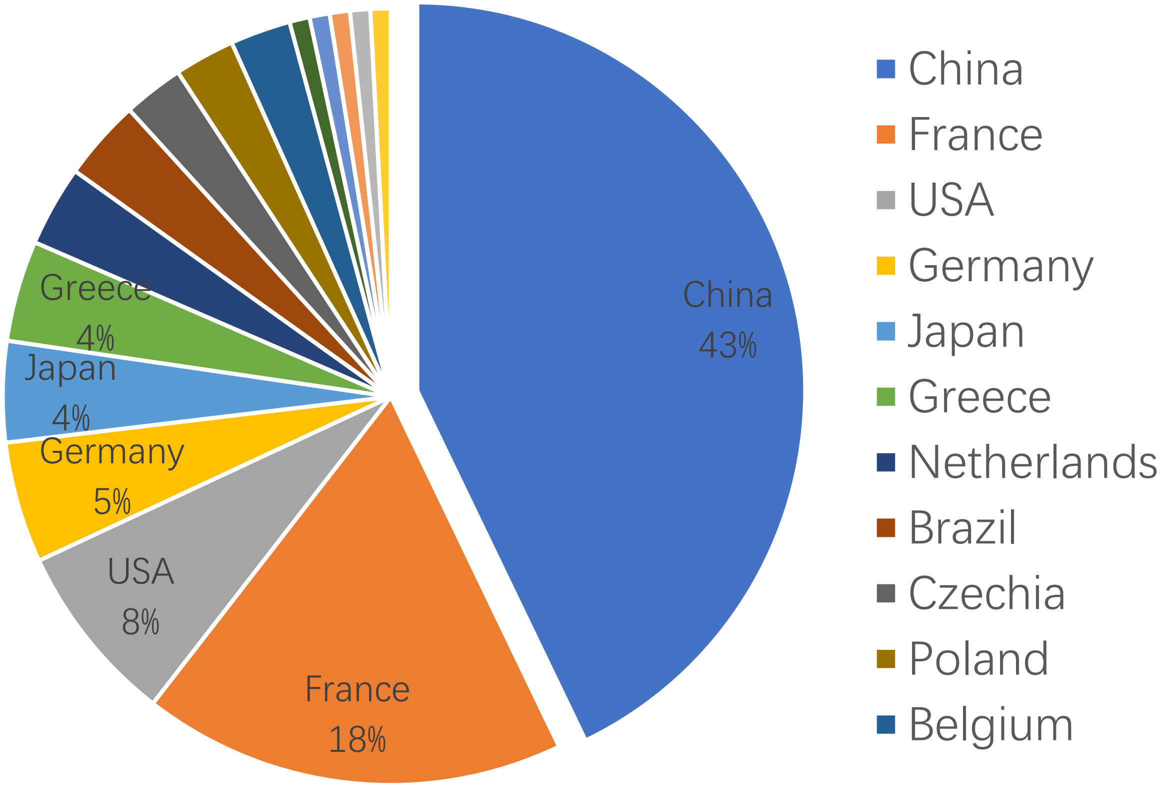
西安电子科技大学 Xidian University



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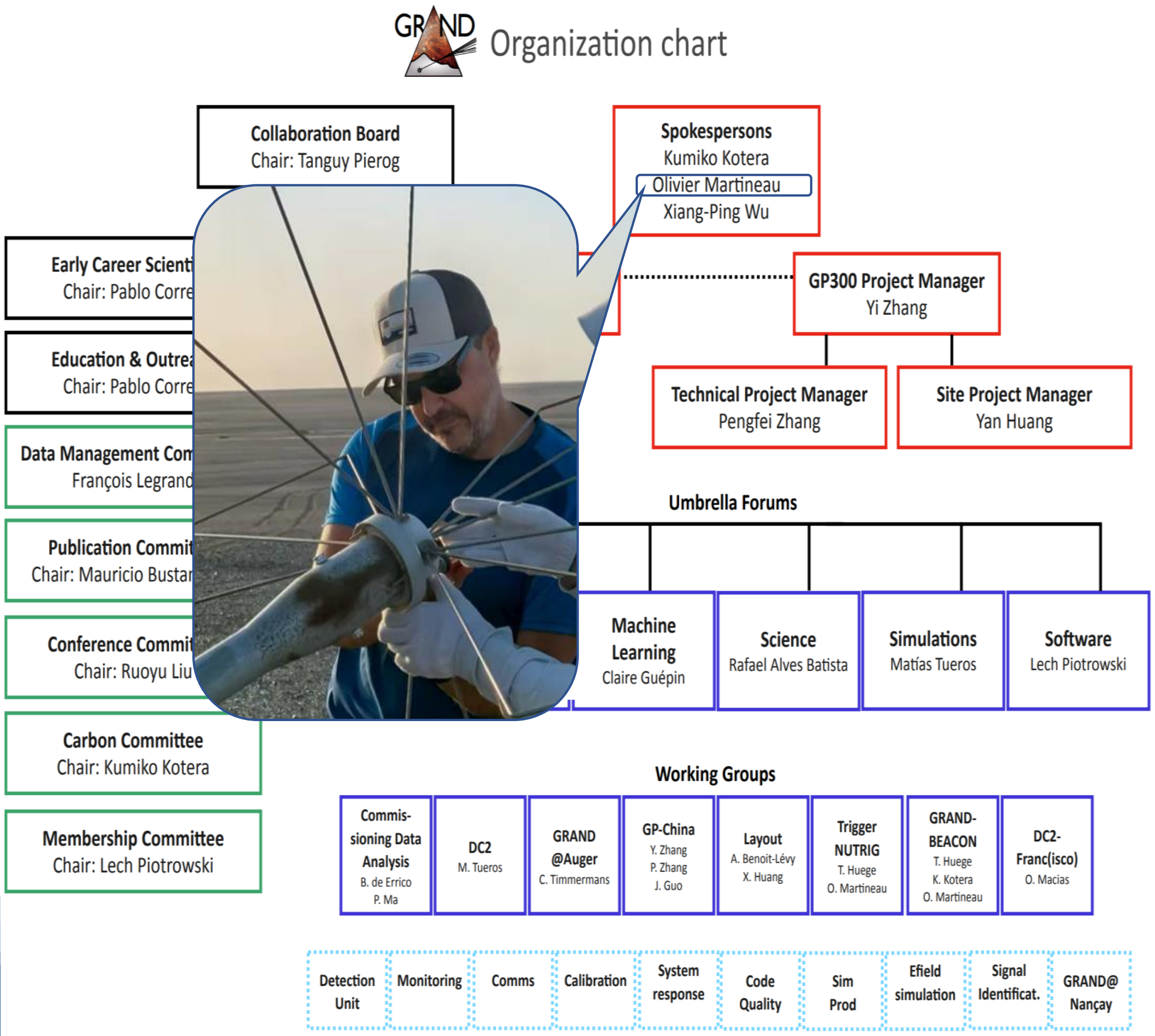

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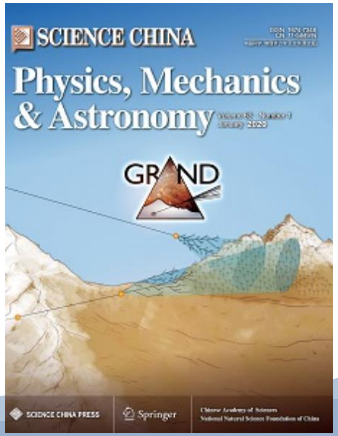
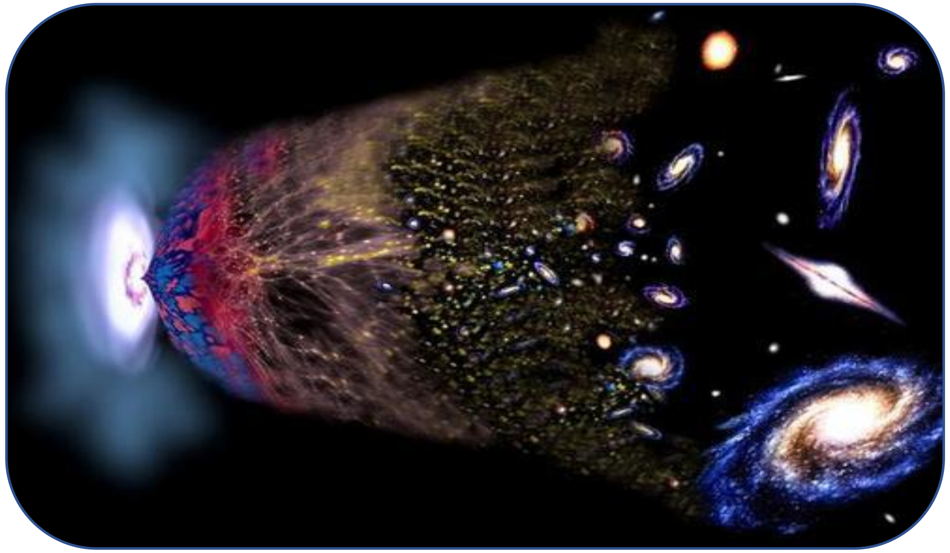
- Background : The motivation \ scientific targets
- Strategy and the Desired detection capability: Detection target \Angular resolution\Energy
- Plan: Schedule of the project

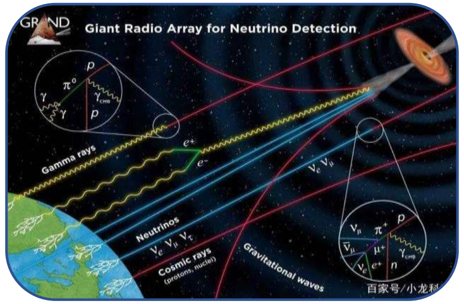
◆GP13->65->300->10,000->200,000（From Path finder to Giant Array）

- Hardware design \test\fabrication\installation\calibration ;
- Firmware and soft development \ test \ and application;
- Simulation pipe line and the related problem ;
- Data process and some Preliminary observation results

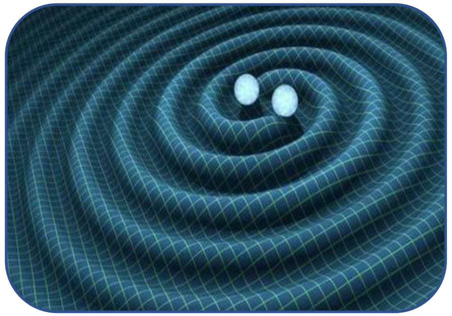


Background: Multi-Message detection



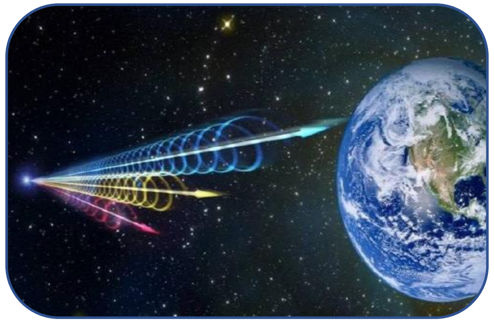


◆ Particles

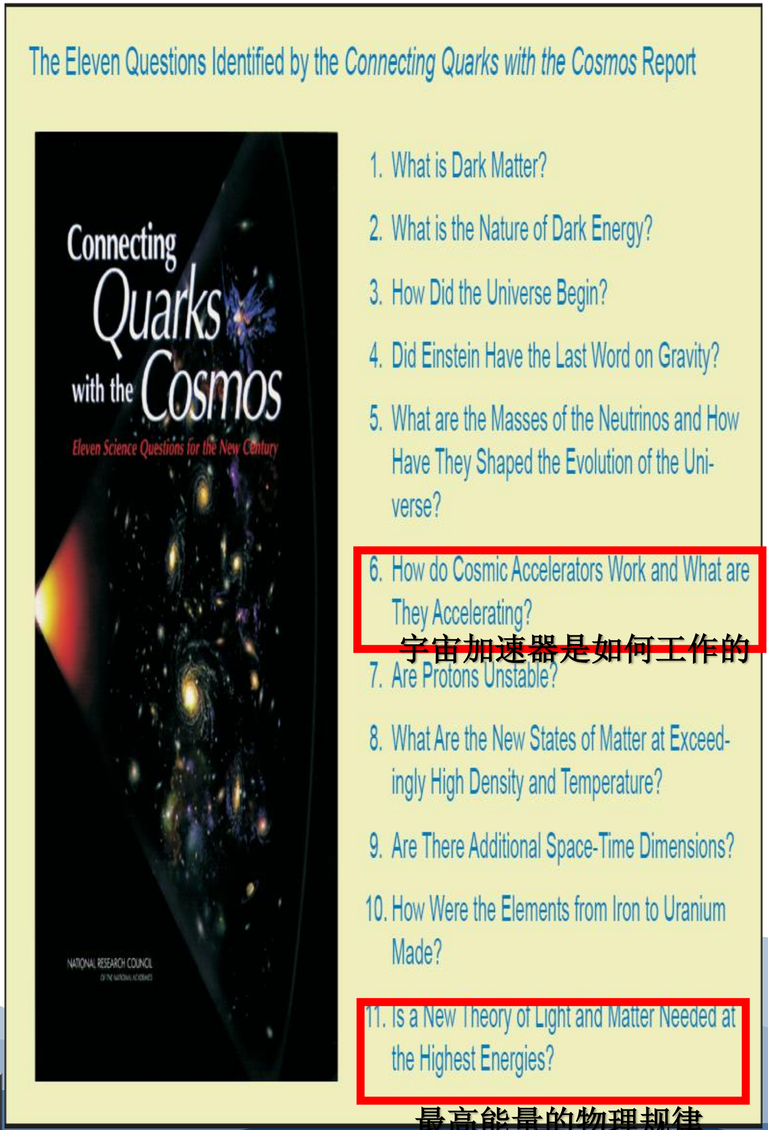


◆ Gravitational wave

◆ Light



◆ Radio



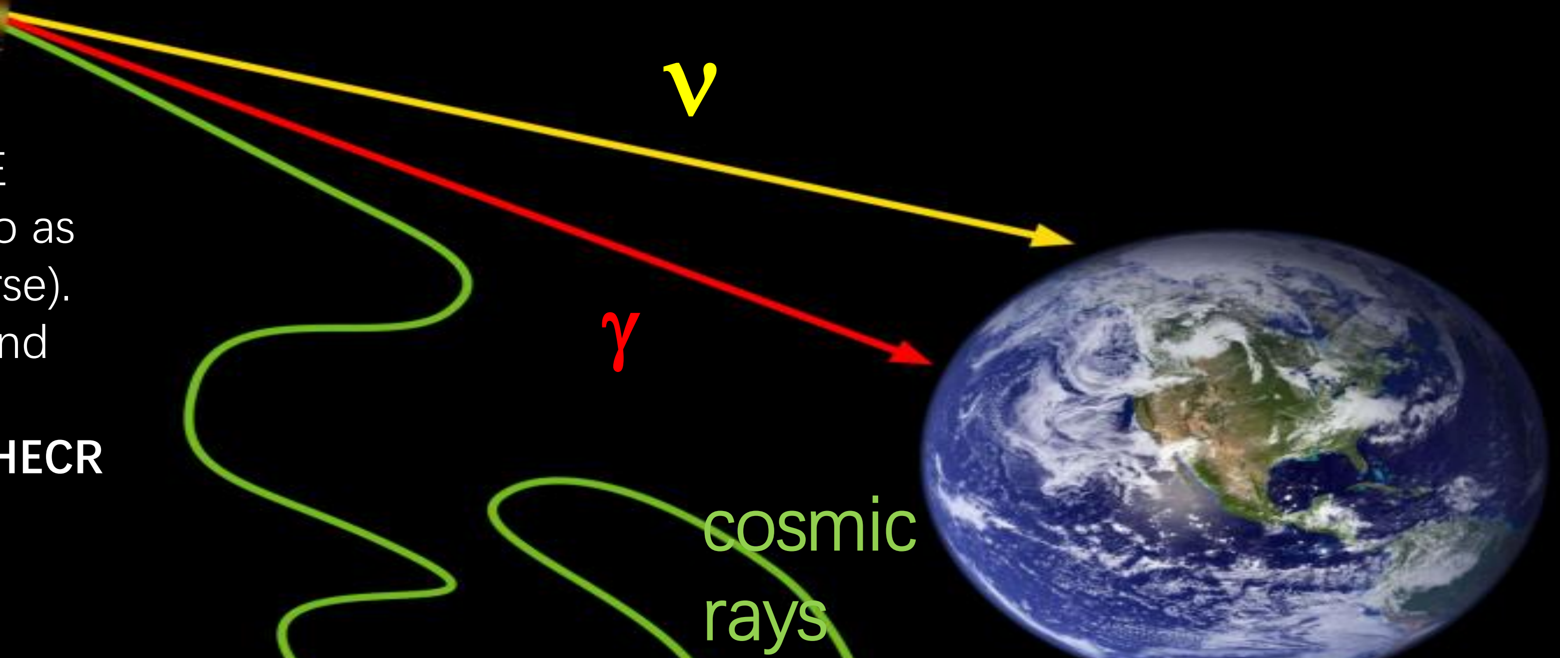
宇宙加速器是如何工作的

最高能量的物理规律

□UHECR & Neutrino

Background: Why neutrino?

UHECRs are charged particles ➔ deviate from source during travel in space because of magnetic fields.
Neutrinos are neutral ➔point back to their sources .
+ very weak interaction probablity: very distant sources can be seen!
➔ **Very clean probe of the violent phenomena in the Universe**



Sources of UHECRs <u>must</u> also produce UHE neutrinos with energy ~10^{18}eV. (UHECRs do as well, during their propagation in the Universe).
➔ Very tight link between UHE neutrinos and UHECRs
➔ **Neutrinos are key element to solve UHECR mystery.**

Neutrino is a very important tool for physics:

Background: Why radio detection?

- **Particle detector array**

✓ All-weather work

◆ Only one profile of the cosmic ray shower is observed, and the energy resolution and composition identification ability are limited.

- **Atmospheric fluorescent telescope**

✓ Similar to calorimeter to measure cosmic ray atmospheric shower process, it has better energy resolution (~10%) and composition identification ability.

◆ Only ~10% duty cycle

- **Radio detection array**

✓ Low cost

✓ All-weather work

✓ Good energy resolution (~10%) and composition identification ability

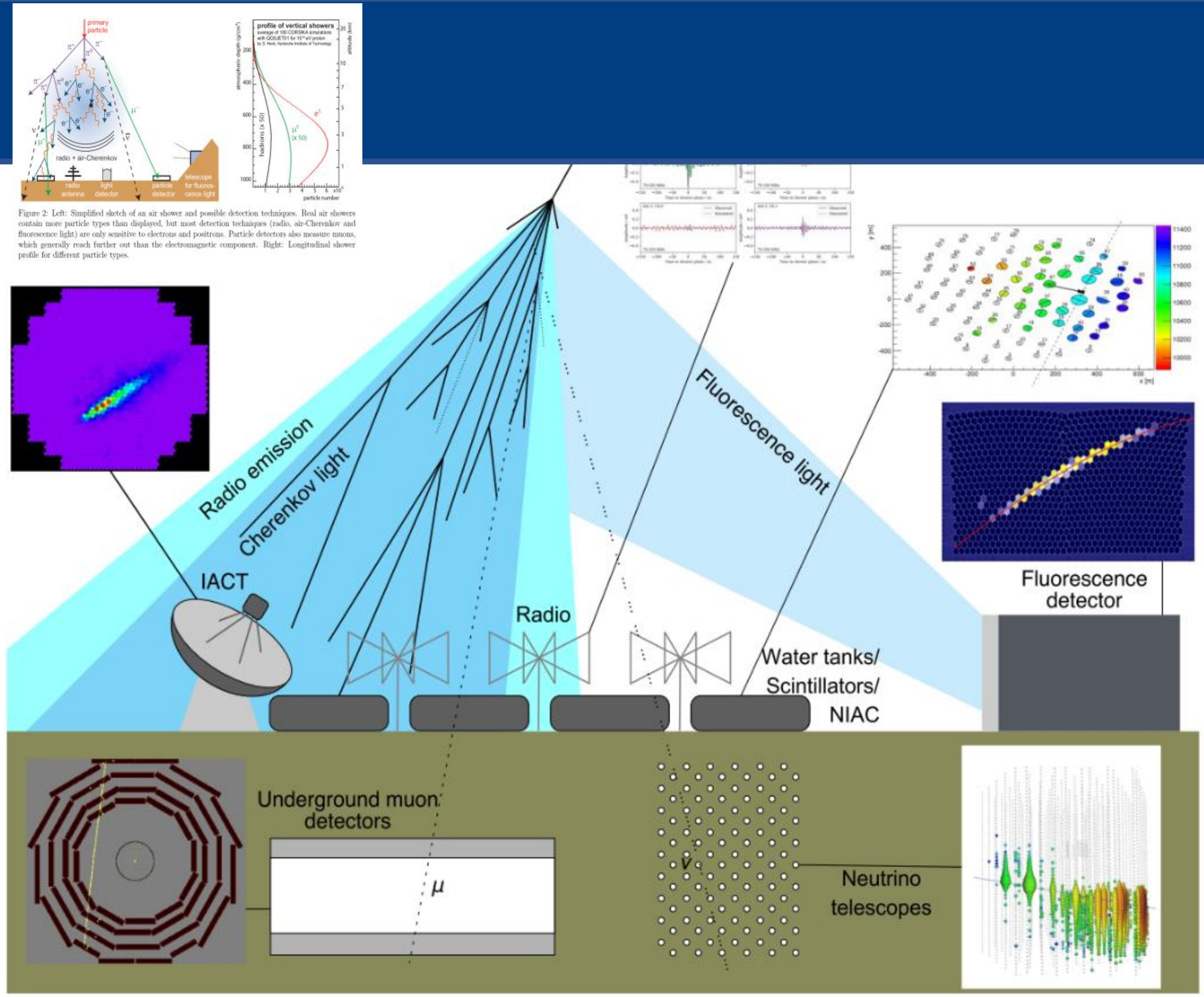
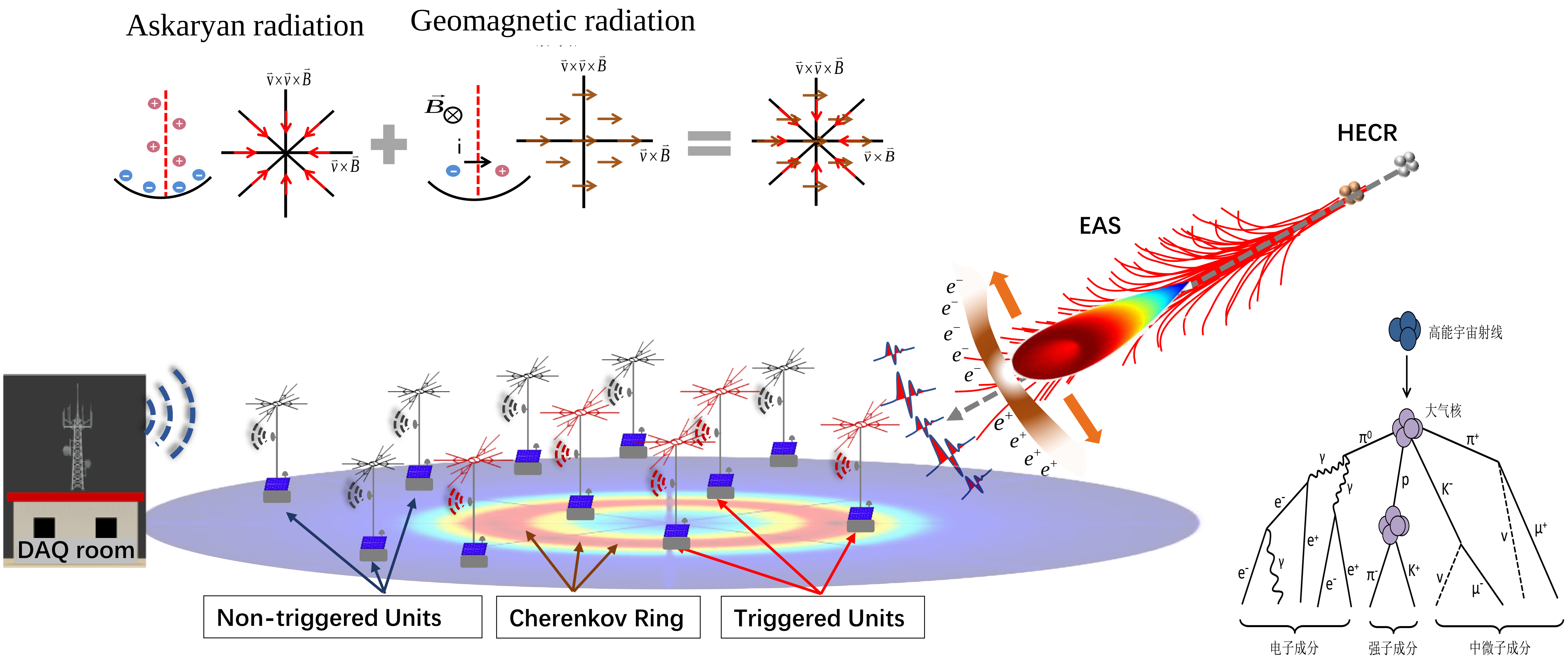


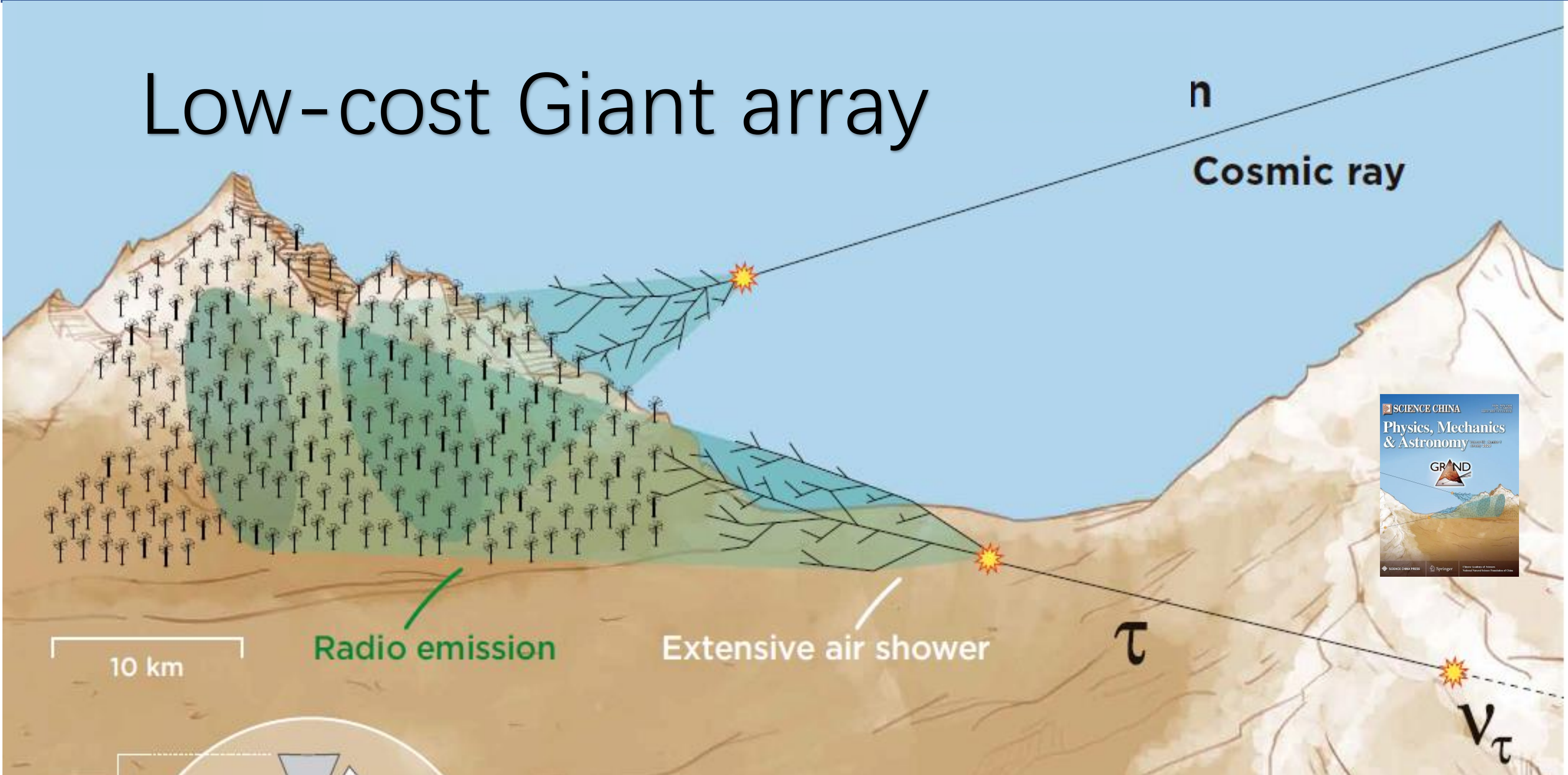
Figure 6.1: Schematic of indirect CR detection methods for EAS. Surface and underground particle detectors measure electromagnetic particles and muons. Imaging (IACT) and non-imaging (NIAC) air-Cherenkov detectors as well as radio antennas provide a measurement of the electromagnetic shower component when located in the footprint of the shower, while fluorescence light detectors can observe the shower development from the side (pictures from Refs. [105, 771–775]

http://dx.doi.org/10.1016/j.ppnp.2016.12.002

Background: Radio Detection of EAS （From UHECR or UHECN）



Background: From CR to Neutrino, and why "Giant array"



Background: Detection target of GRAND from CR to Neutrino

UHE neutrinos

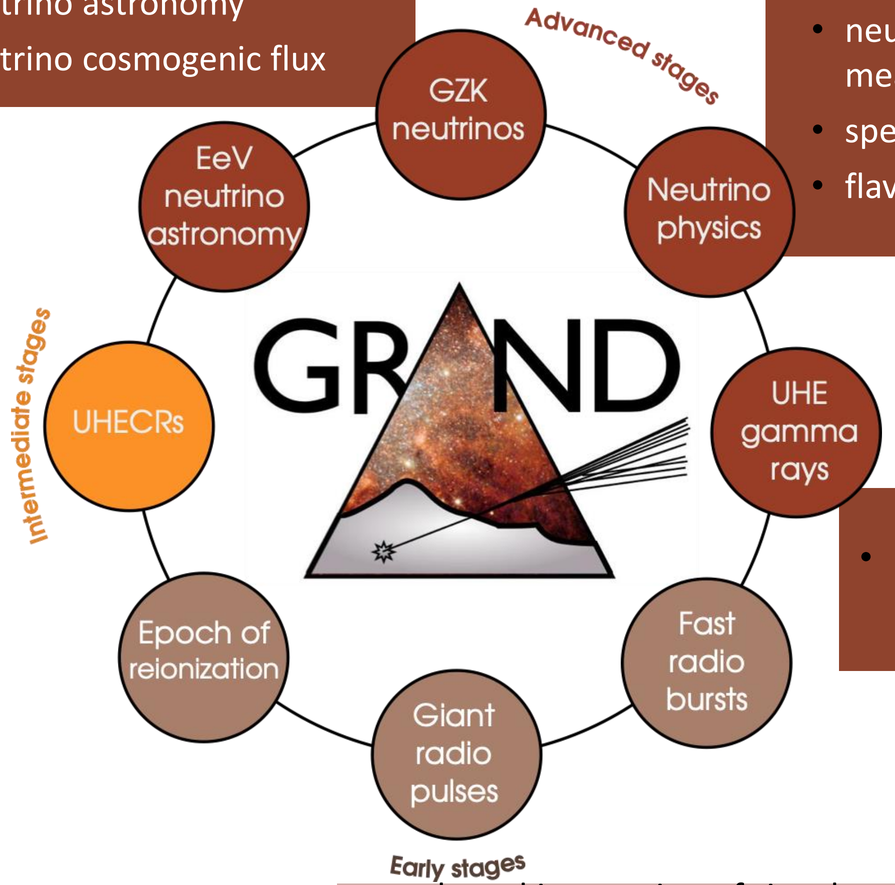
- UHE neutrino astronomy
- UHE neutrino cosmogenic flux

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

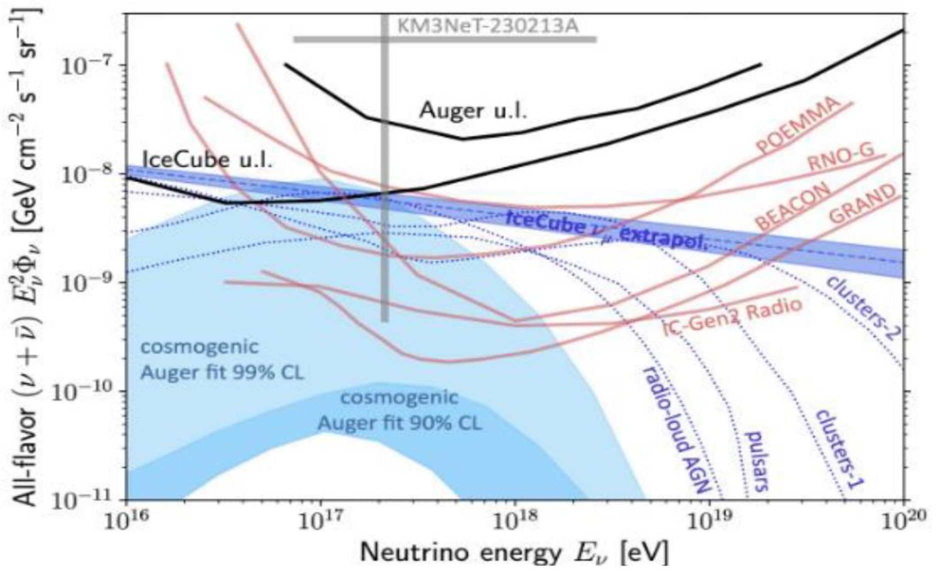
Target of GRAND

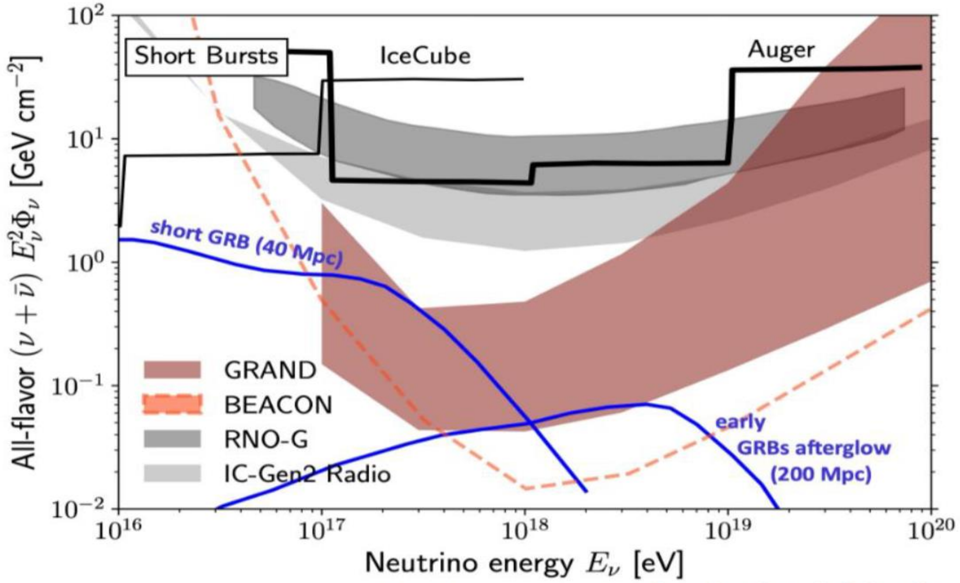
GRAND proposal

GRAND goal: reach**10-10GeV/cm^2/s/sr** sensitivity range for diffuse neutrino fluxes)

End-to-end simulation
➔**baseline GRAND design = network of o(20) subarrays of o(10000) antennas with sparse density(1/km^2) at various favorable locations around the world («hotspots»)**
Alternatives being studied to reduce size for same performances

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



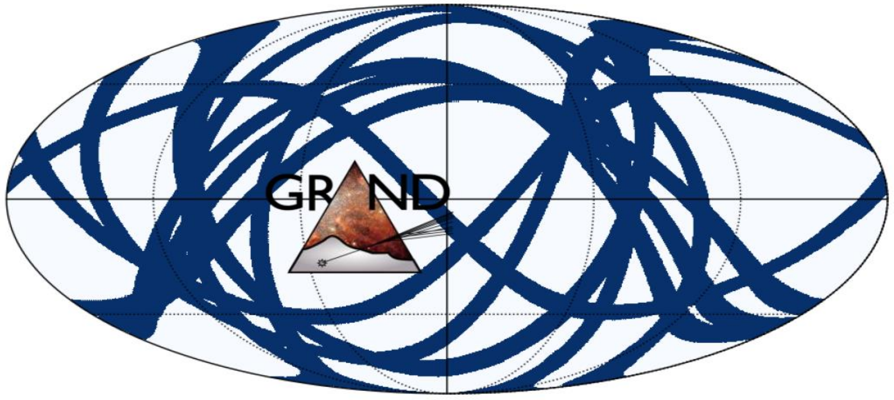


K. Kotera et al., 2504.08973

Target of GRAND

Expected performances

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

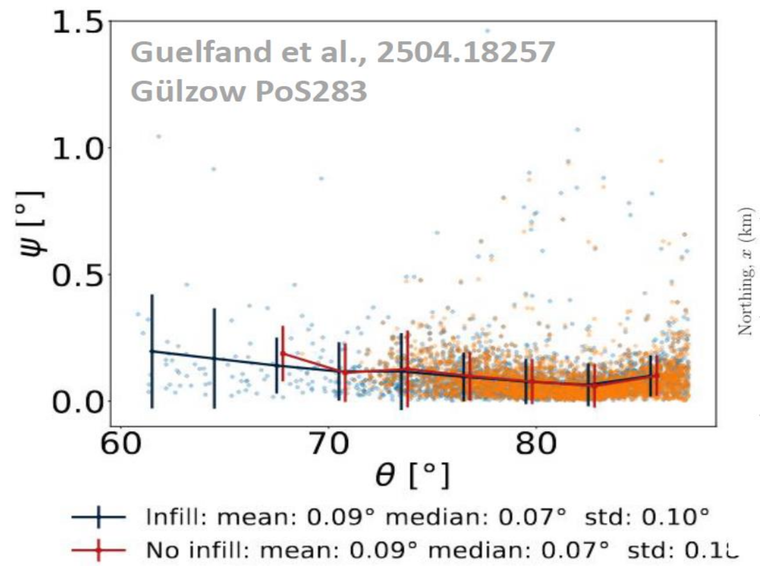


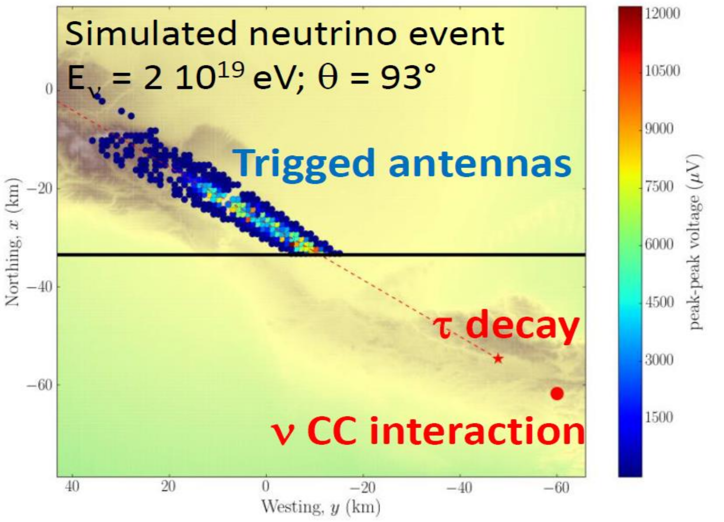
instantaneous FoV: 45% of sky
(for 10 random* site locations between 40S and 60N)

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.	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	$2°\times10°$	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	$2°\times10°$	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

Guépin, Kotera, Oikonomou, 2023



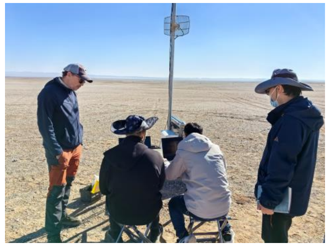


Schedule

A staged approach with self-standing pathfinders

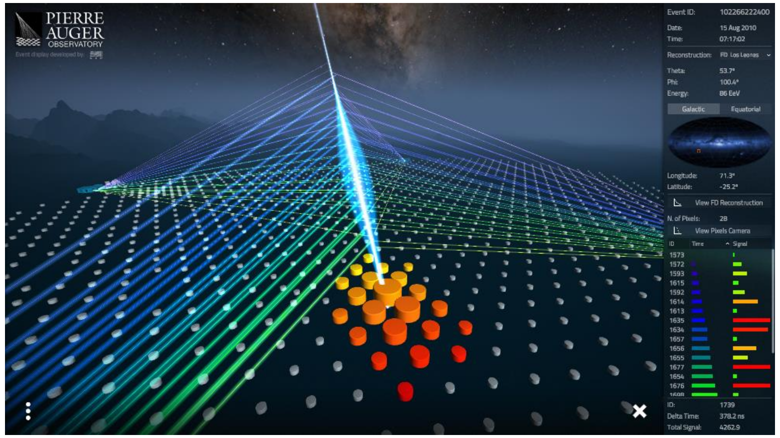
	GRANDProtos	GRAND10k	GRAND200k
	2023	2028	203x
Goals	**autonomous radio detection of very inclined air-showers** Cosmic rays $10^{16.5\text{-}18}$ eV • Galactic/extrag • muon problem • radio transients	**1st GRAND sub-array** • discovery of EeV neutrinos for	sensitive all-sky detector **Neutrino astronomy!**
Setup	• **GRANDProto30** over 200 km² • GRAND@Auger cross-calibratio • GRAND@Nança trigger testing		ennas 0 km² ys of 10k antennas continents
Budget	2 M€ 100 antennas p Funded by Chin + ANR-DFG NUTRIG (France- Germany) + Radboud University		total 500€/unit to be divided between participating countries

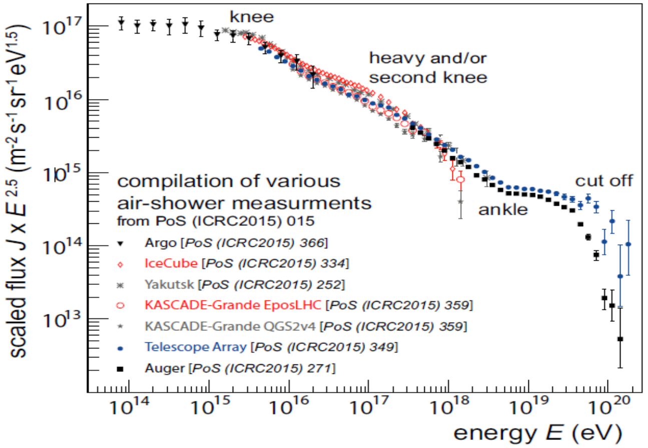
About 10M RMB hardware investment From China until now (NAOC PMO XIDIAN)

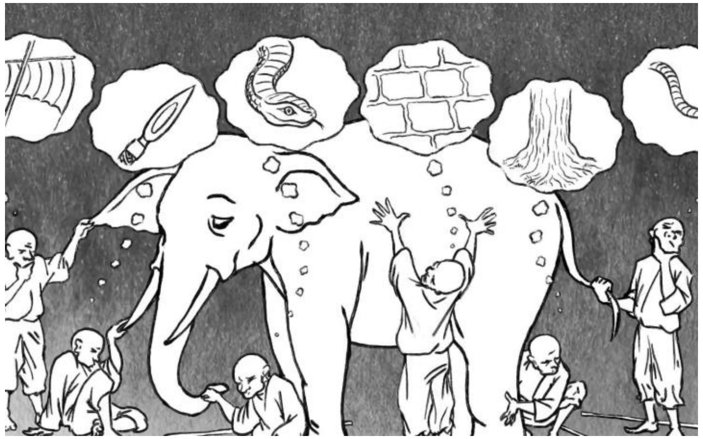


Necessary of Giant Self-triggered detection radio array

西安电子科技大学 Xidian University







https://www.auger.org/news/scientific-highlights/343-the-pierre-auger-observatory-open-data

Question and Problem

- High-energy cosmic ray sources and acceleration mechanisms in Galactic and extragalactic.
- Correlation between high-energy cosmic rays and active galactic nuclei
- About GZK
- Magnetic Fields and Interstellar Matter (ISM)

AUGER and HiRes Telescope Array

Comprehensive and Complete Event Data

- Giant detection array.
  - Low-cost
  - Sparse array
  - Full time operation
  - Self-triggered

Mass， Energy，Incident angle

Design of Self-triggered detection system

- Units functions:
  - Wide working frequency band
  - High speed ADC and data processing
  - Long distance communication
  - Autonomous Time Maintenance
  - Self-power supply
  - Self-triggered

Path finder： Self-triggered system

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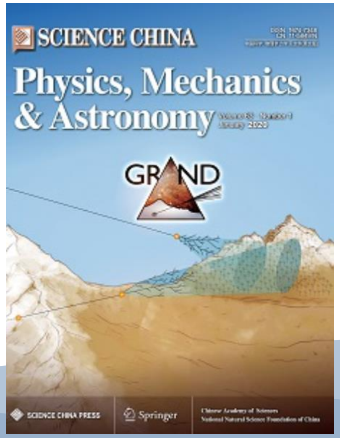

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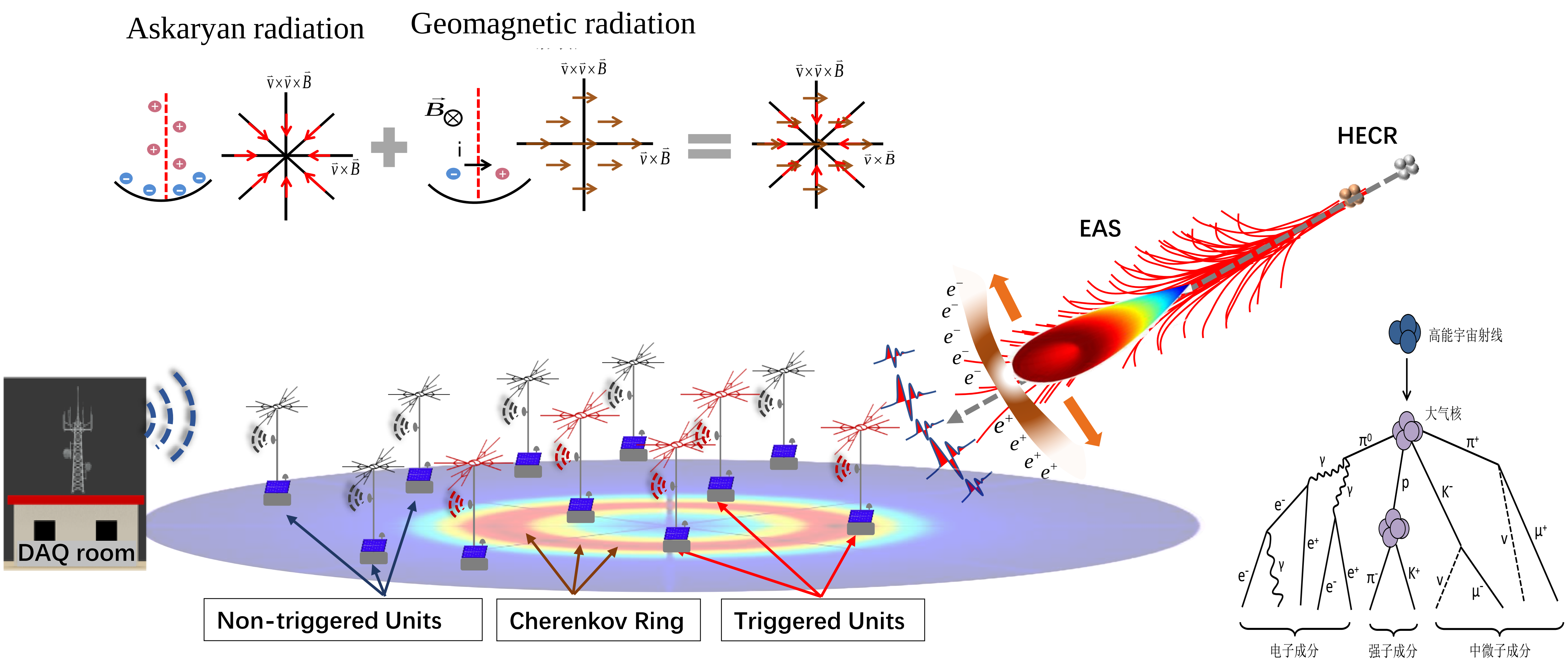
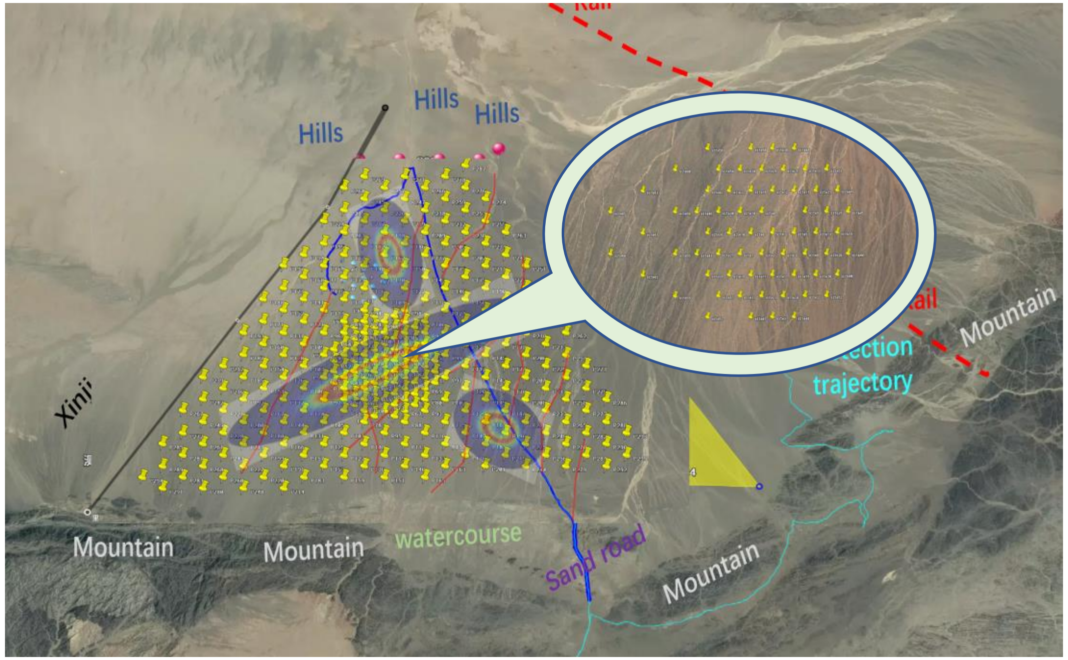


The GP65 system : Three-Level Architecture of GP65

Xidian University

- 3 Level structure of GP65

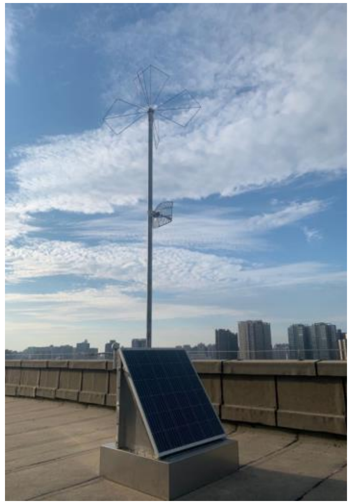


- (Hardware Firmware. software)

Units
- Antenna and RF Chain
- FEB board
- Solar and power supply
- Mechanical and thermal protection
- GPS Time
- Wifi communication system

Center station
- Wifi Rocket
- DAQ system
- Solar and power supply
- Monitoring system and Living security
- Microwave communication system

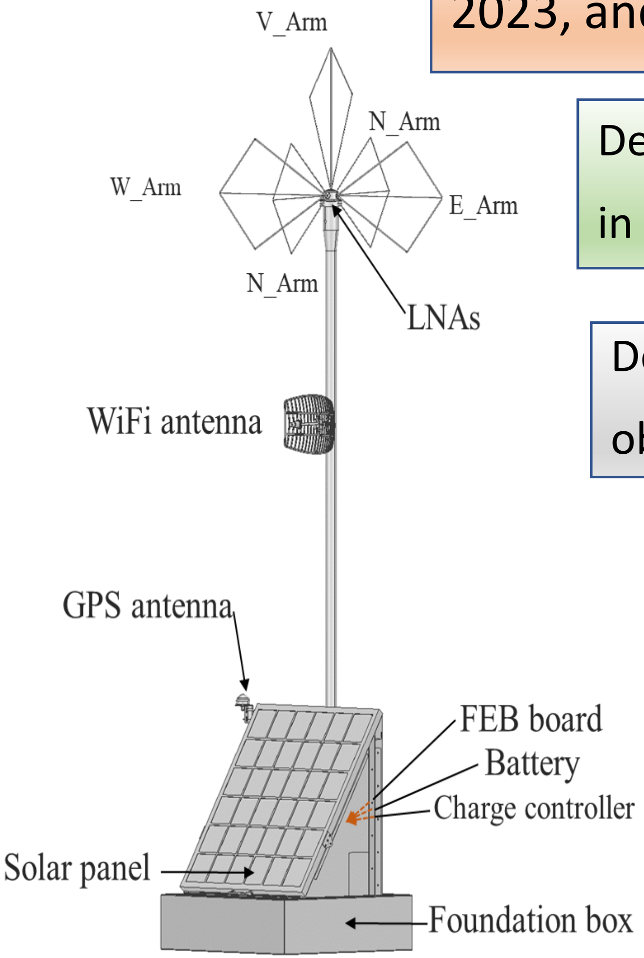
PMO data server
- Internet access
- Data data storage and management
- Data access authorization and distribution



The GRAND Prototype [Dunhuang (China), Auger (Argentina), Nancay (France)]

Xidian University

GRANDProto300 & other prototypes: experimental setup



Deployment of 13 antennas in Gansu (China) 2023, and 65 in 2025, and 200 more later

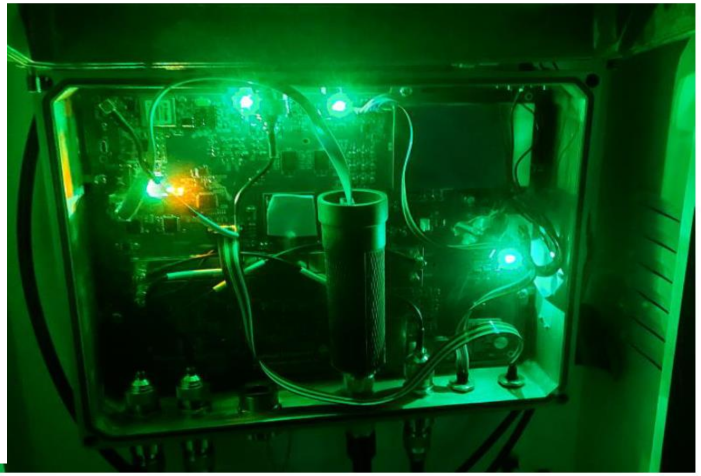
2021（Xidian）
Deployed Feb 2023
Updated 2025

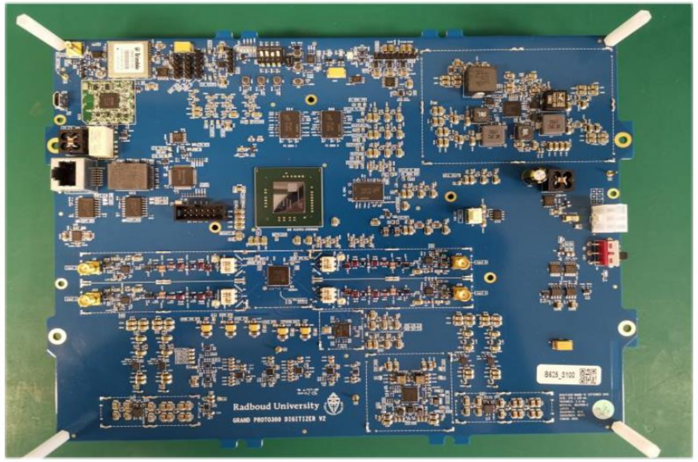
Deployment of 10 antennas on the Auger site in Malargüe, Argentina(cross-calibration)

Deployed Aug 2023

Deployment of 4 antennas in Nançay radio observatory (France)for trigger test(LPNHE)

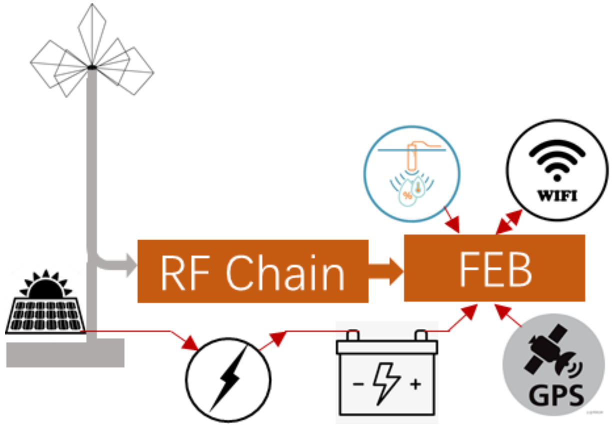
Deployed Oct 2022

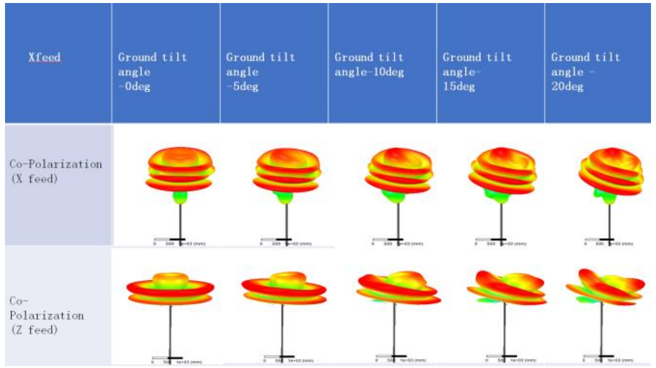


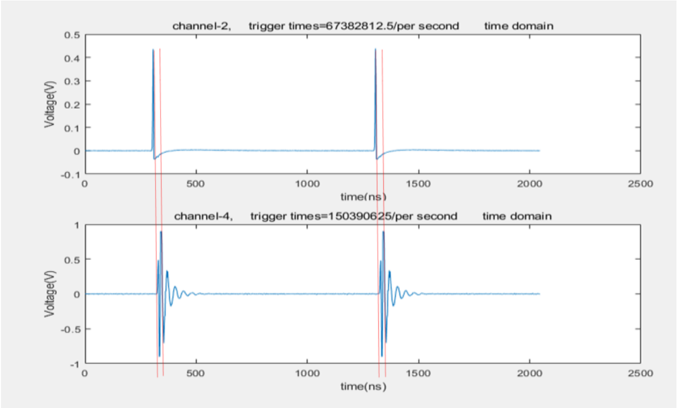


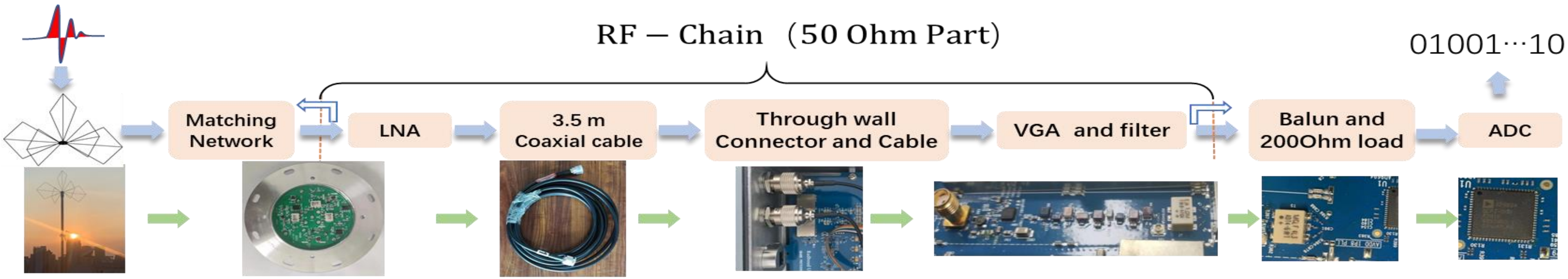
50-200MHz analog filtering,
Electronics:
500MSPS sampling
FPGA+CPU
Bullet WiFi data transfert

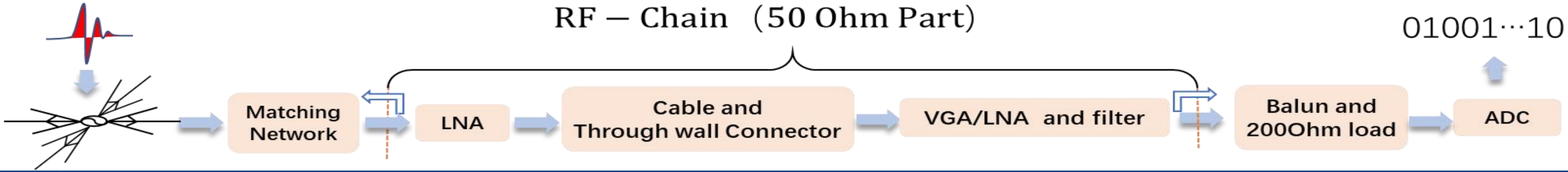
Detection units and RF Chain of GP65



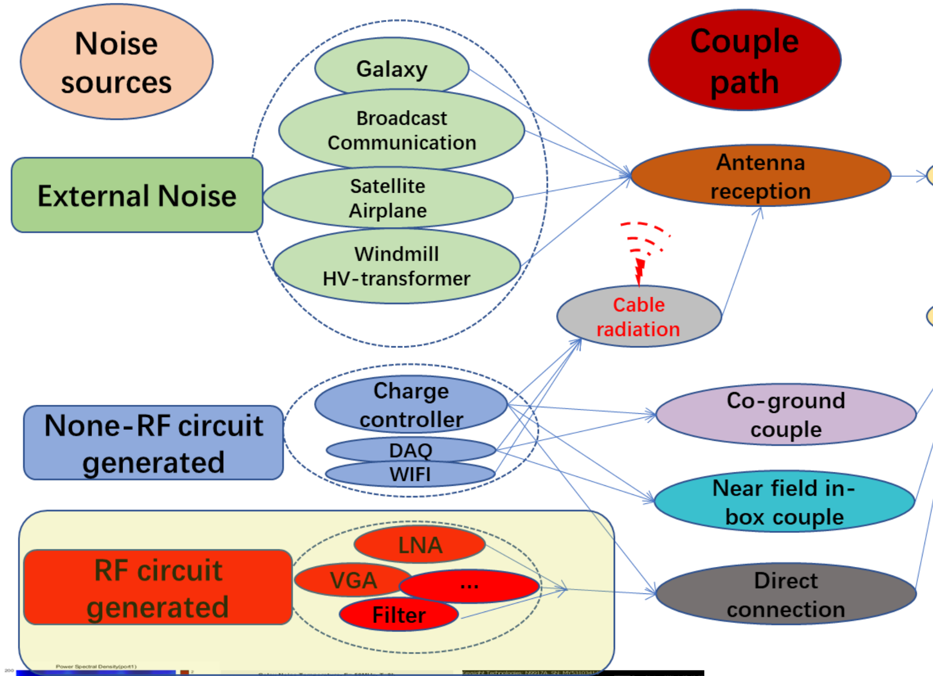


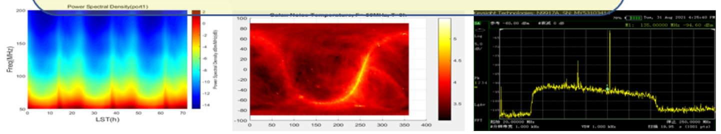


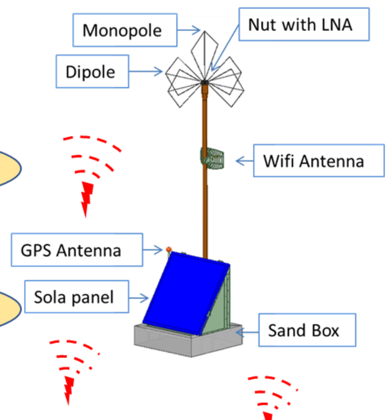


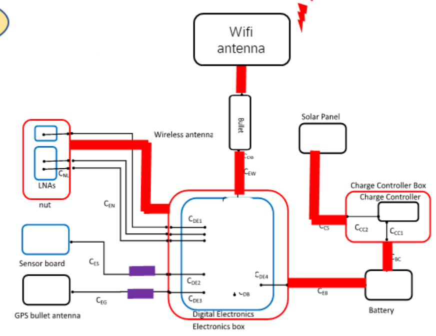


Noise suppress and RFI rejection

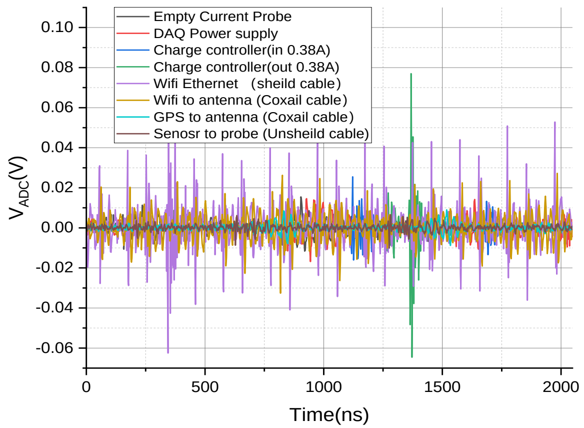


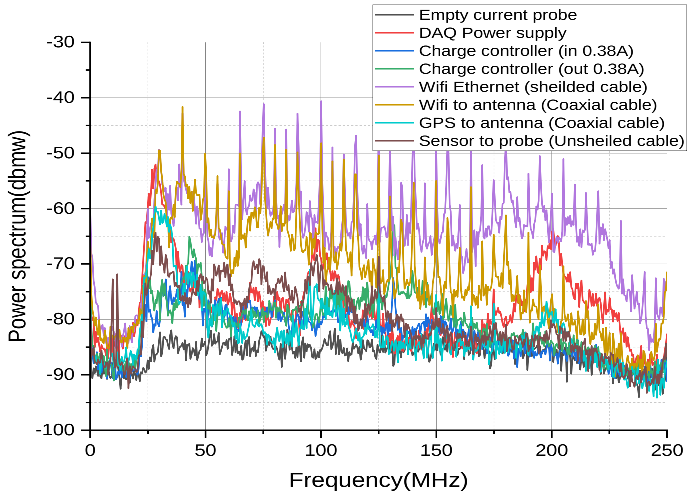


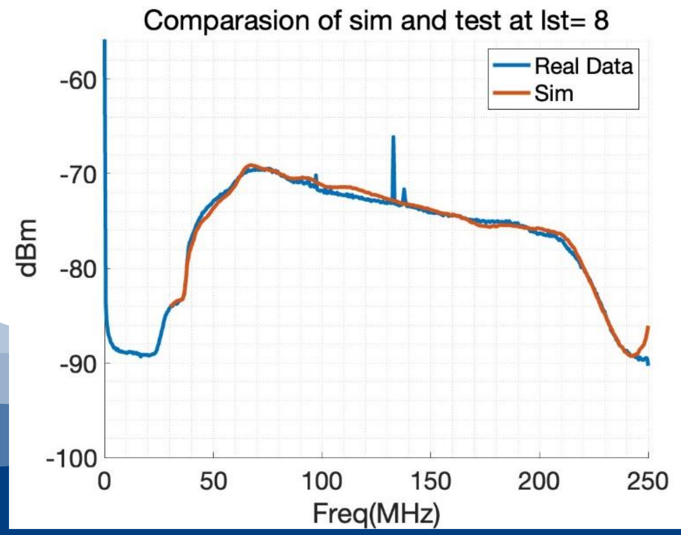




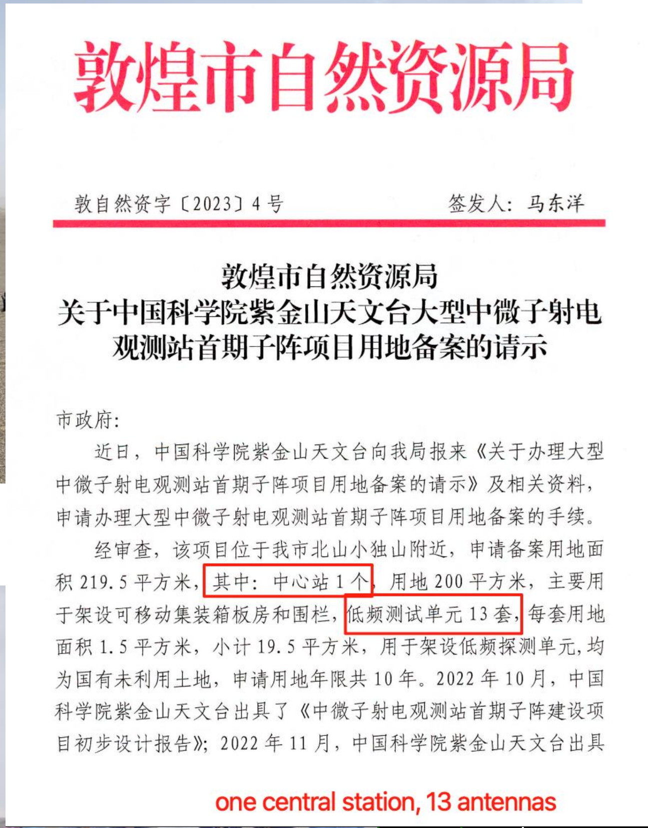
Source	Magnitude (RMS/ADCUnit) (0~250MHz) /(50~200)	Time domain		Frequency domain		Process
RF-Chain AD sample	12	Random noise		Random noise Within 50~200MHz		/
Power supply cable (Probe test)	30 (12)	Modulation noise		Bump：35MHz,110MHz ,190MHz		Filter(DC pass) 10MHz~500MHz, 60dB suppression
Charge controller (Probe test)	38(34)	Pulse（pair, 600ns）：width: 150ns		Wide band spectrum		Filter(DC pass) 10MHz~500MHz, 60dB suppression
Wifi Unsheilded Ethernet cable (Probe test)	400(320)	Strong Random noise		Wide band spectrum 20~120MHz 125~135MHz		replace
Wifi sheilded Ethernet cable (Probe test)	100(90)	Periodic noise		Wide band spectrum Peaks		Shield
Wifi Coaxil cable (Probe test)	65(43)	Periodic noise		Wide band spectrum Peaks		Filter (HF pass) 0~500MHz: 60dB suppression 5~5.5GHz 0.5dB insetloss
Laptop Couple To powersupply	150	Modulation noise		Bump: 35MHz,95MHz ,190MHz		/
GPS cable	15(10)	Pulse（pair）600ns（period）, 150nswidth (test without charging systerm)		Big bump 30MHz(?) Small bump 90/200MHz		/
Sensor	13(5)	Small Pulse		small bump 30~130MHz		/







Engineering work: Site survey : (NAOC /Xidian/ PMO/SAO) 2018-2022



敦煌市自然资源局

敦自然资字〔2023〕4 号　　签发人：马东洋

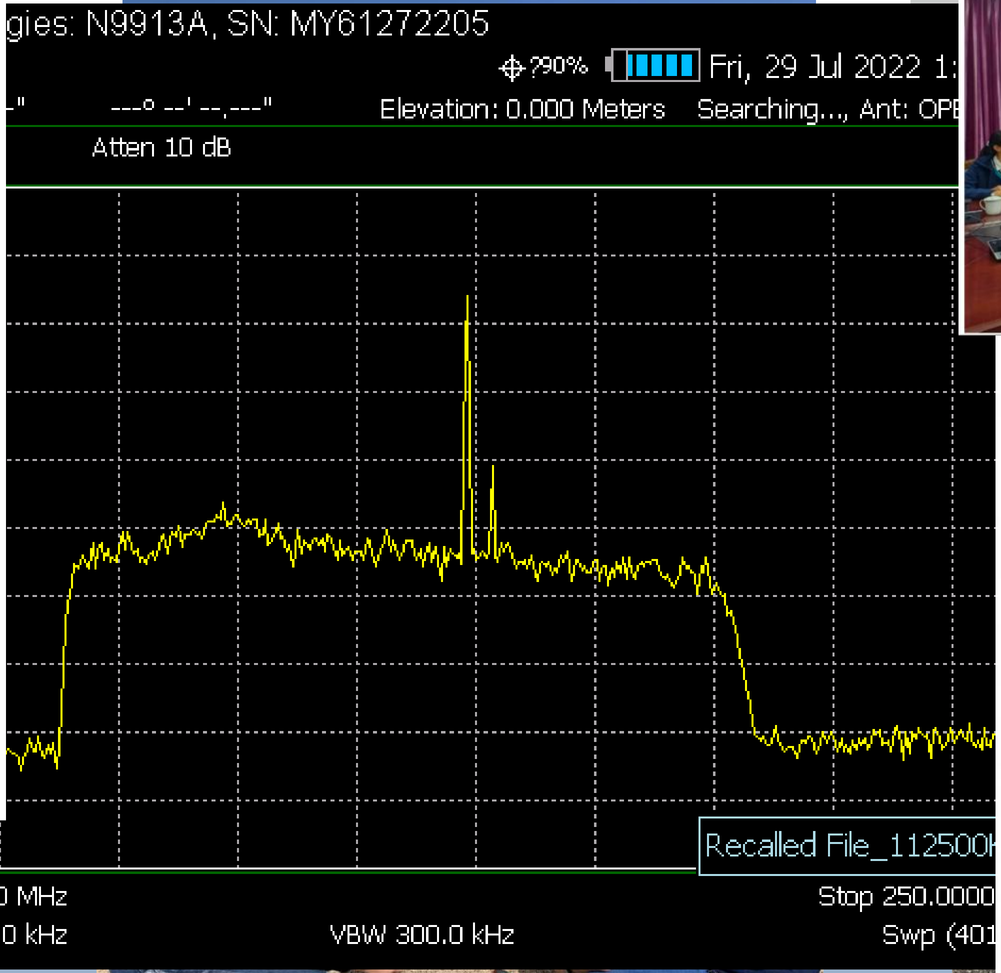
敦煌市自然资源局
关于中国科学院紫金山天文台大型中微子射电观测站首期子阵项目用地备案的请示

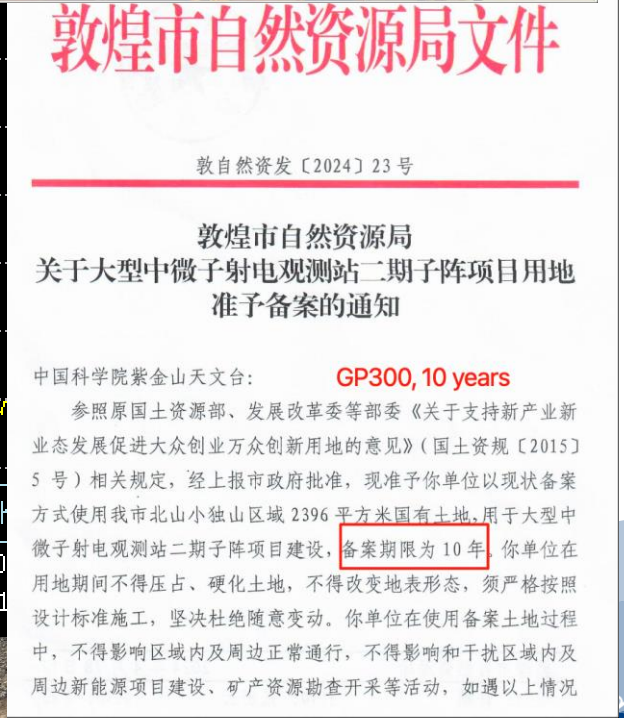
市政府：

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





敦煌市自然资源局文件

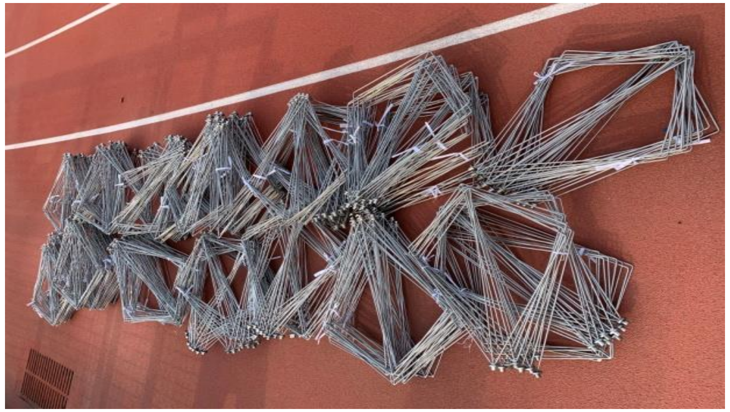
敦自然资发〔2024〕23 号

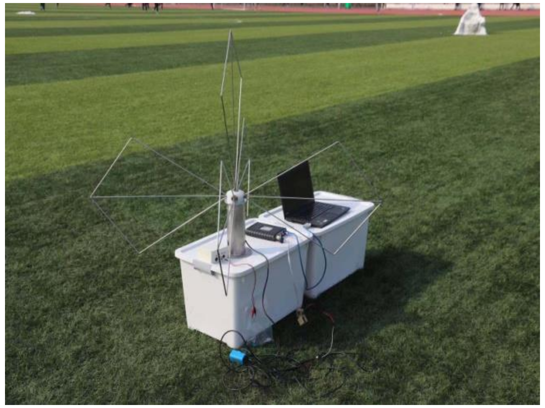
敦煌市自然资源局
关于大型中微子射电观测站二期子阵项目用地准予备案的通知

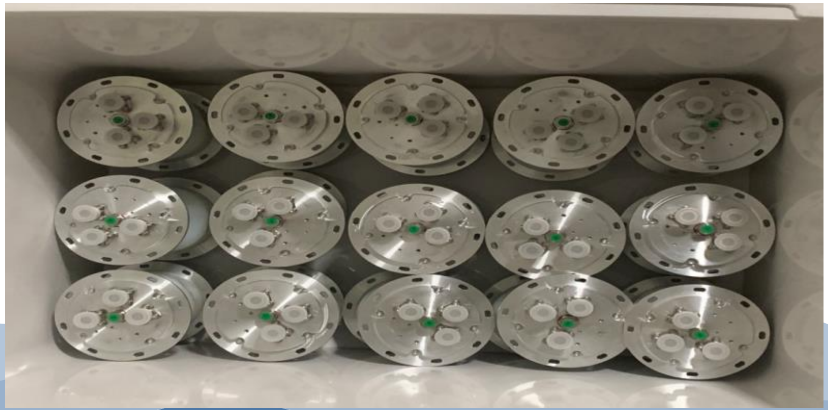
中国科学院紫金山天文台：　　GP300, 10 years

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

Engineering work: Design Fabrication and Test（2019-2023， Xidian）

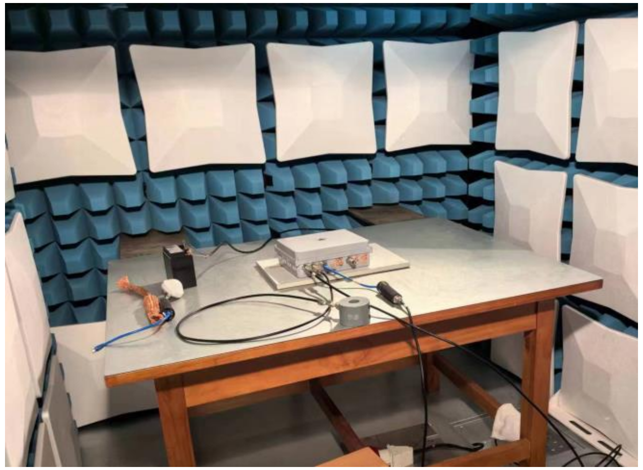


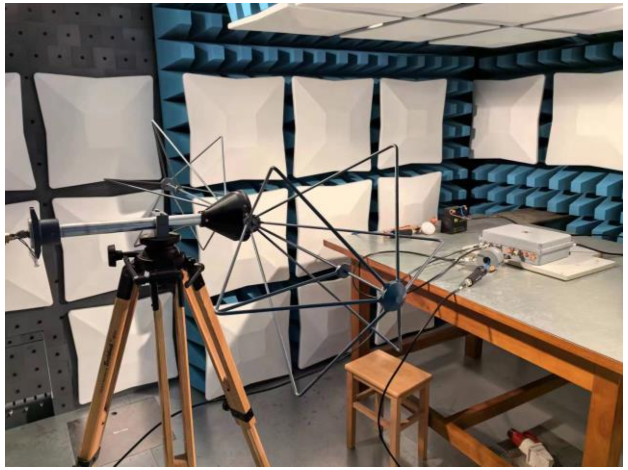



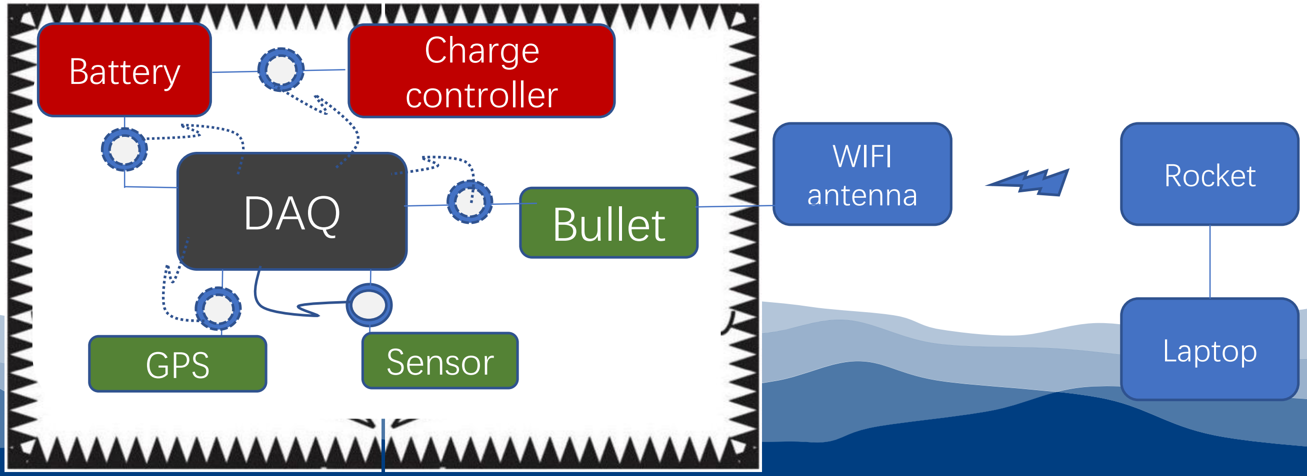



Engineering work: Noise suppress and RFI Rejection（Xidian)

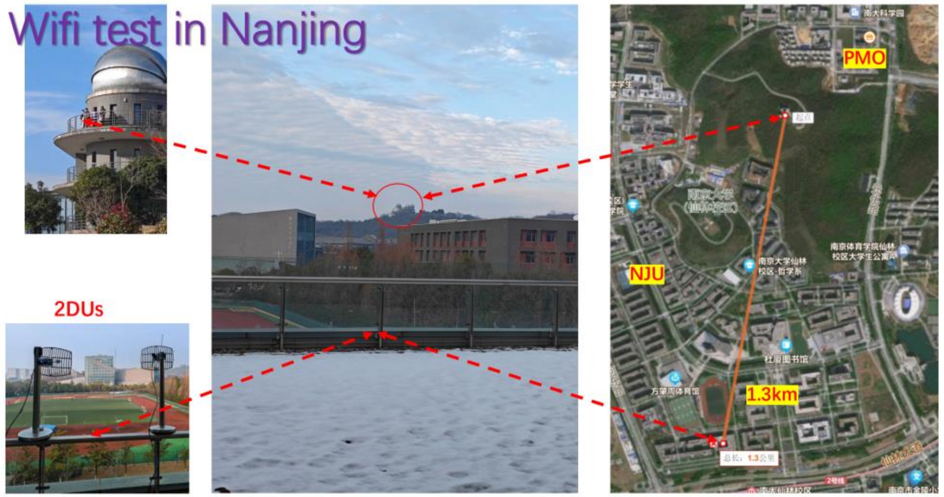
- Test 2   Indoor EMC chamber: test system



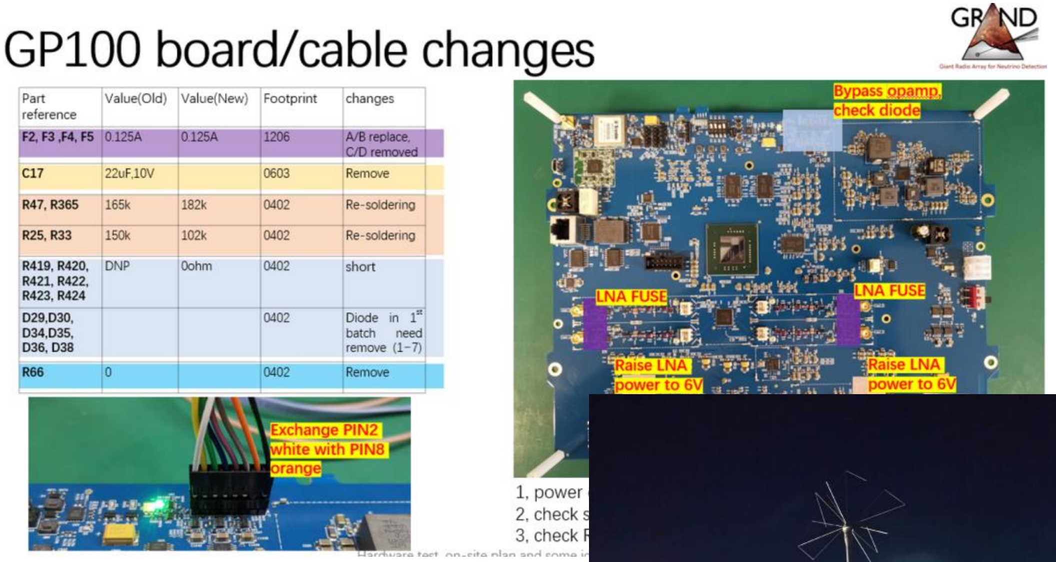




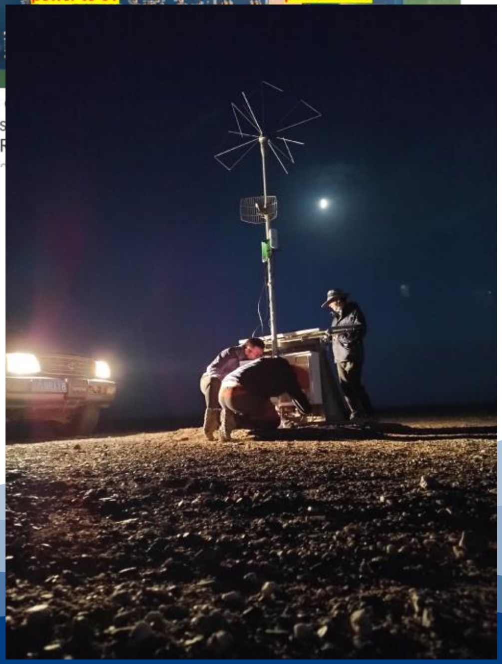
(Powerful contribution from PMO) Site survey\ Firm ware debug test\Software development test\Communication system test\Simulation work \Data manage\Reconstruction work



Thanks to Xing Xu, Chao Zhang, Wei Liu, Pengxiong Ma, Ruoyu Liu and Qiuhui He in this experiment.

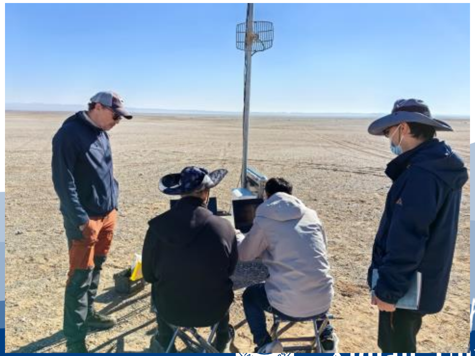


Part reference	Value(Old)	Value(New)	Footprint	changes
F2, F3 ,F4, F5	0.125A	0.125A	1206	A/B replace, C/D removed
C17	22uF,10V		0603	Remove
R47, R365	165k	182k	0402	Re-soldering
R25, R33	150k	102k	0402	Re-soldering
R419, R420, R421, R422, R423, R424	DNP	0ohm	0402	short
D29,D30, D34,D35, D36, D38			0402	Diode in 1st batch need remove (1-7)
R66	0		0402	Remove

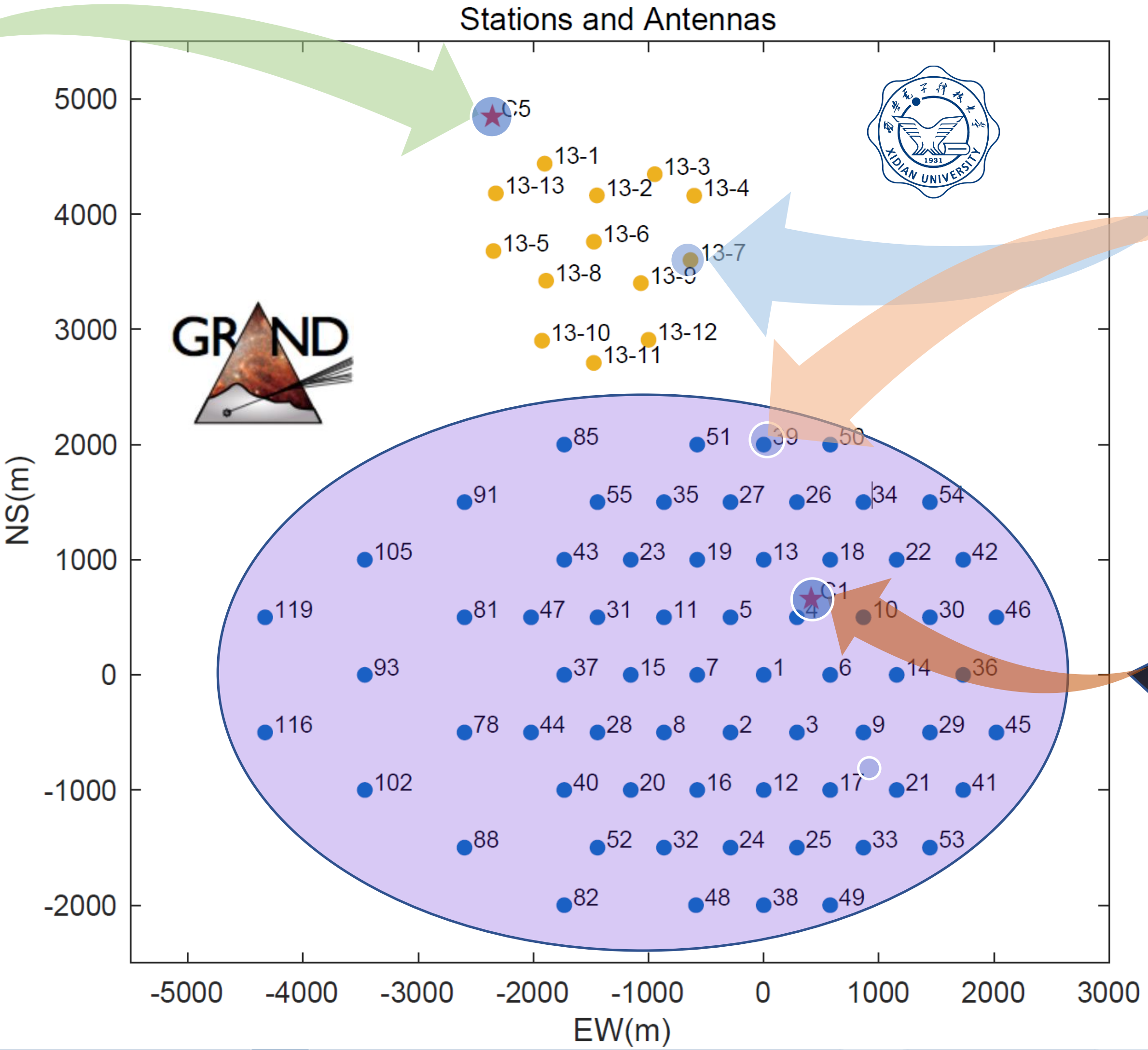


Engineering work: Construction of GP13 and Center station

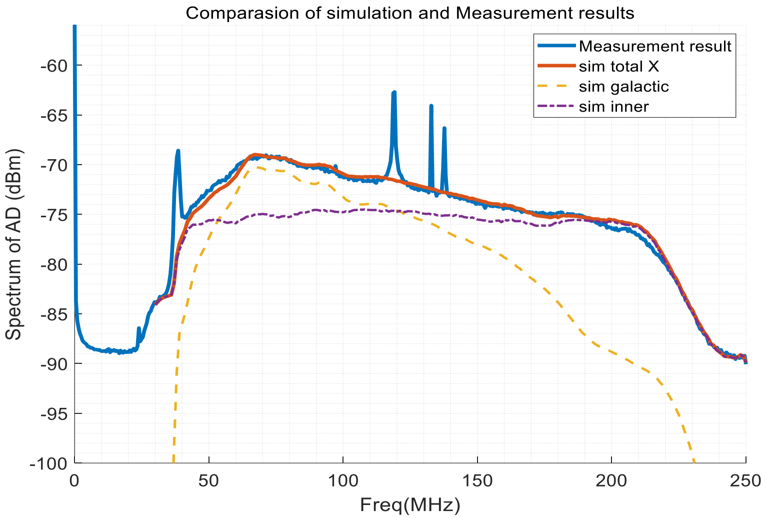
- Thanks to GP-13 working team

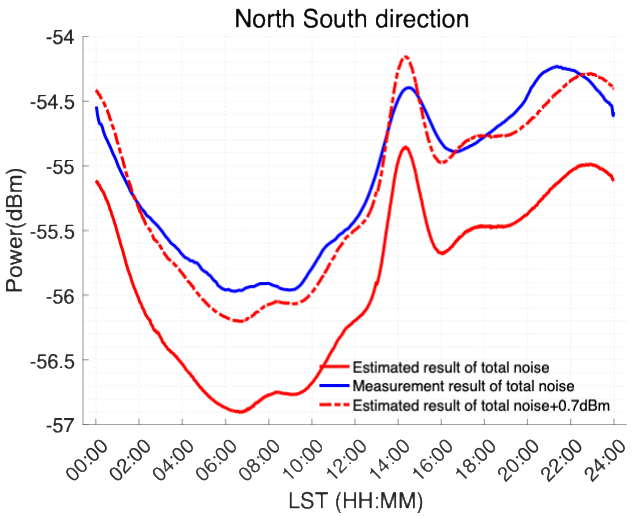


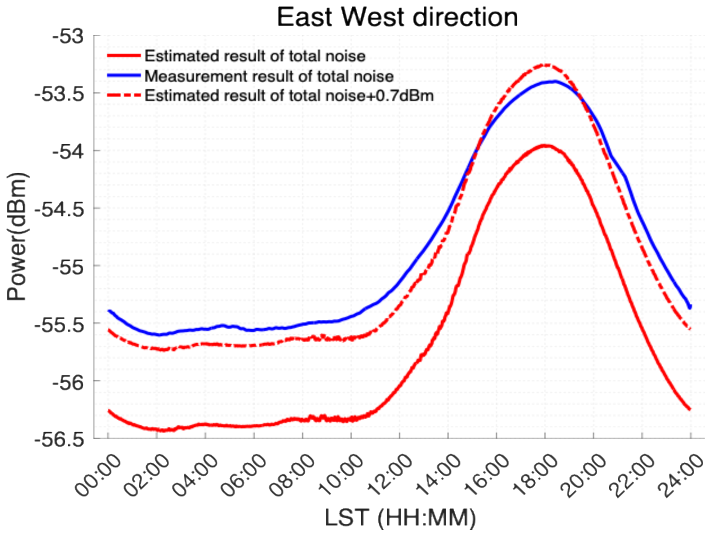
Statues of Xiaodushan（Dunhuang China） site

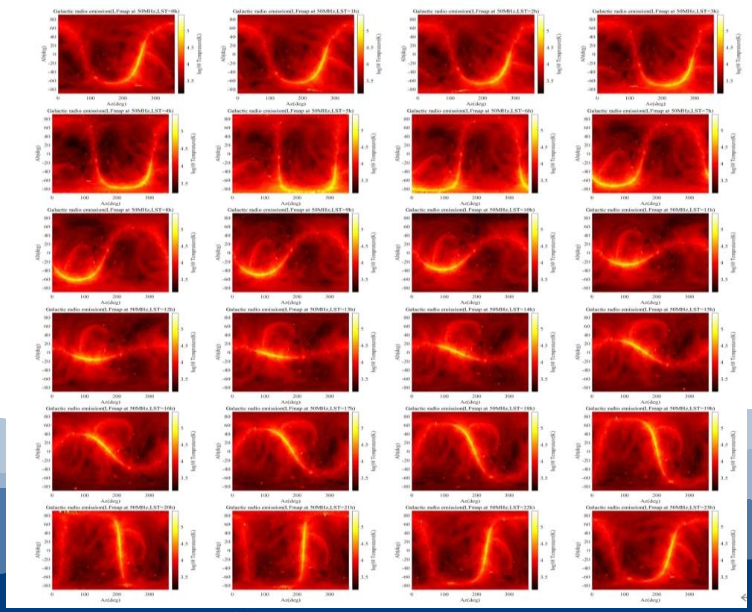


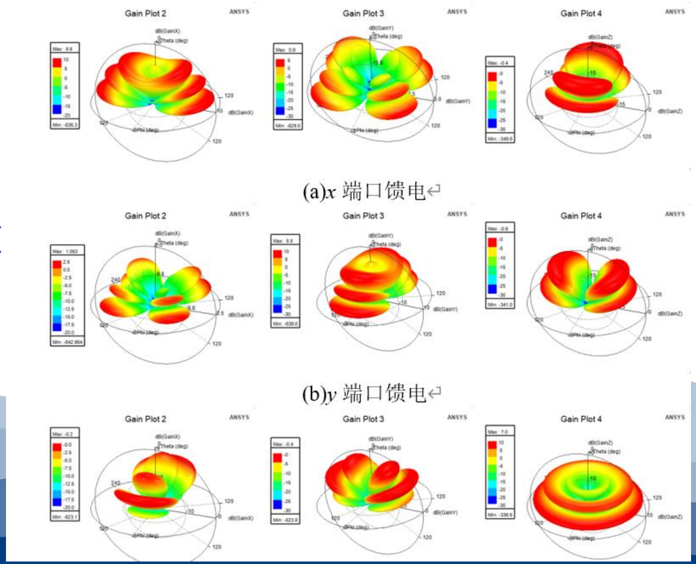
Galactic noise simulation and test

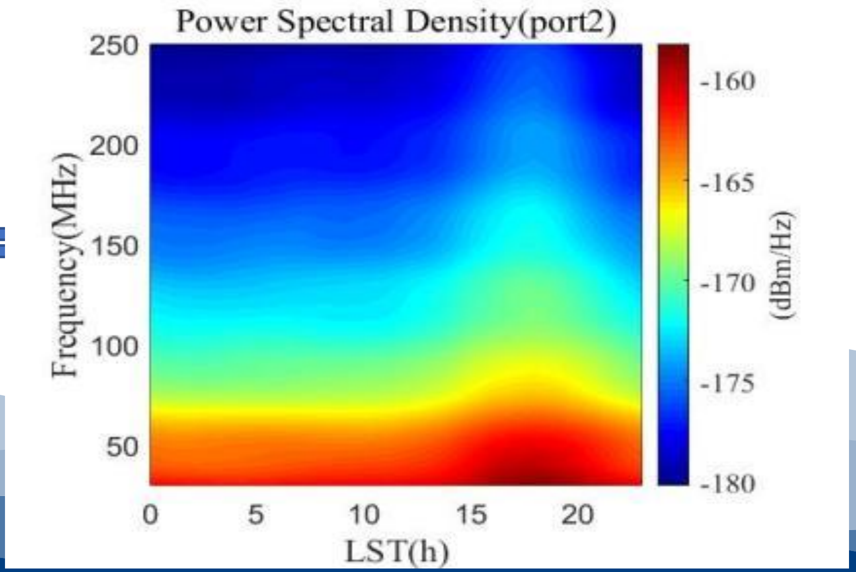




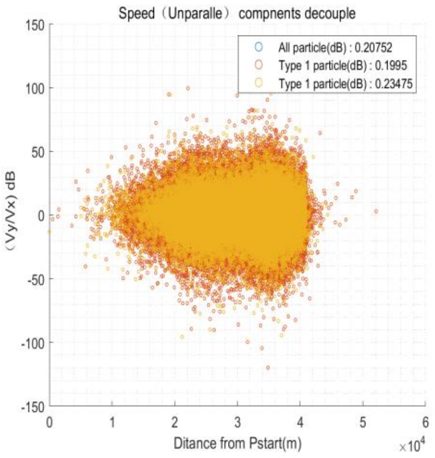


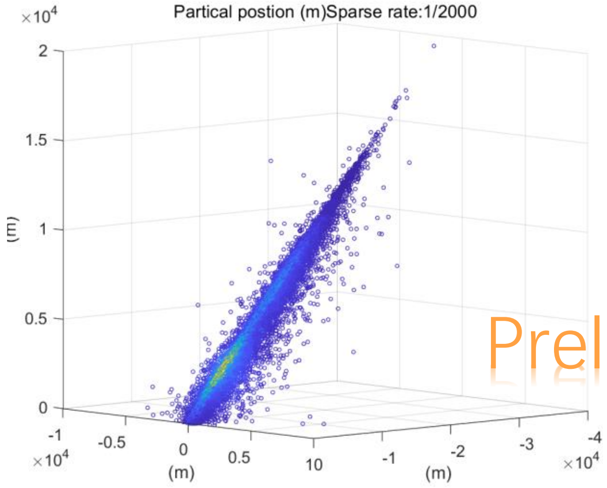


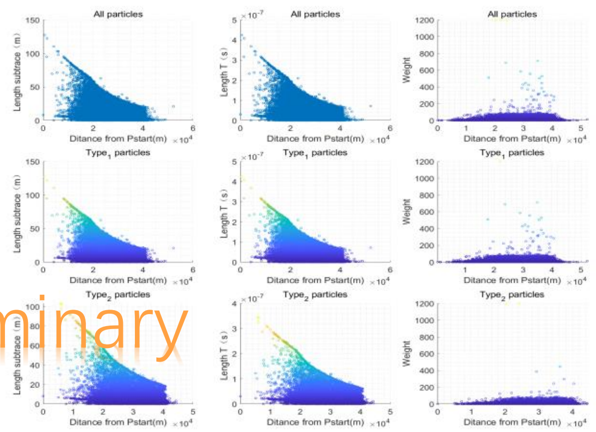




EAS simulation improvement and system simulation tool development

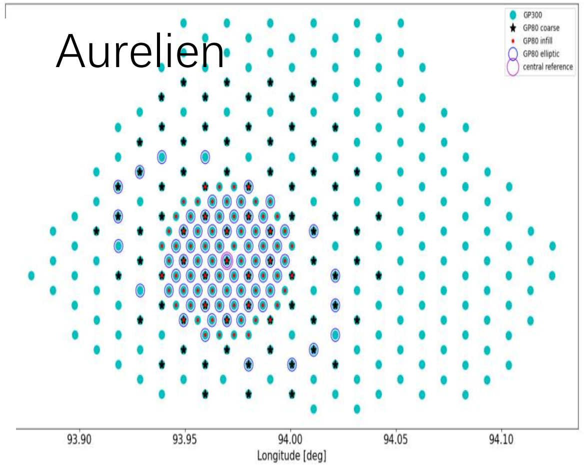


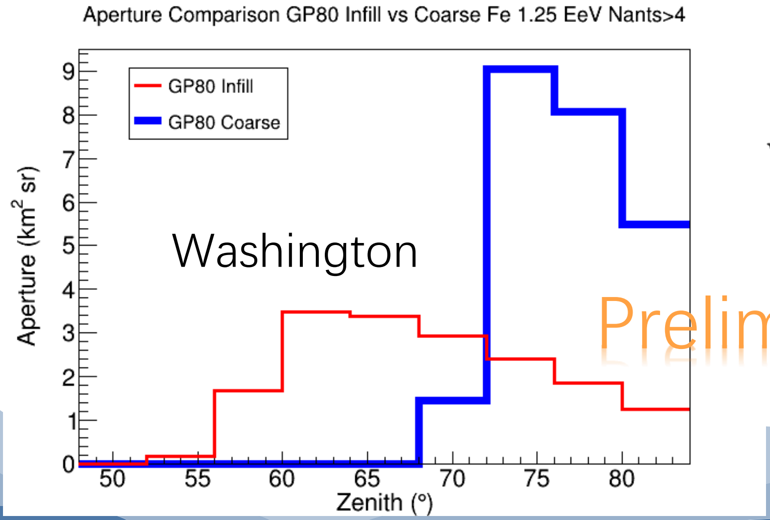




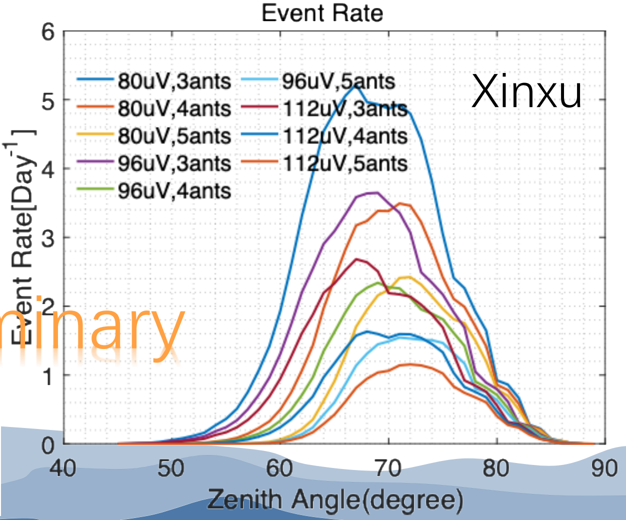
FuFu yang FuFu yang FuFu yang

Aurelien

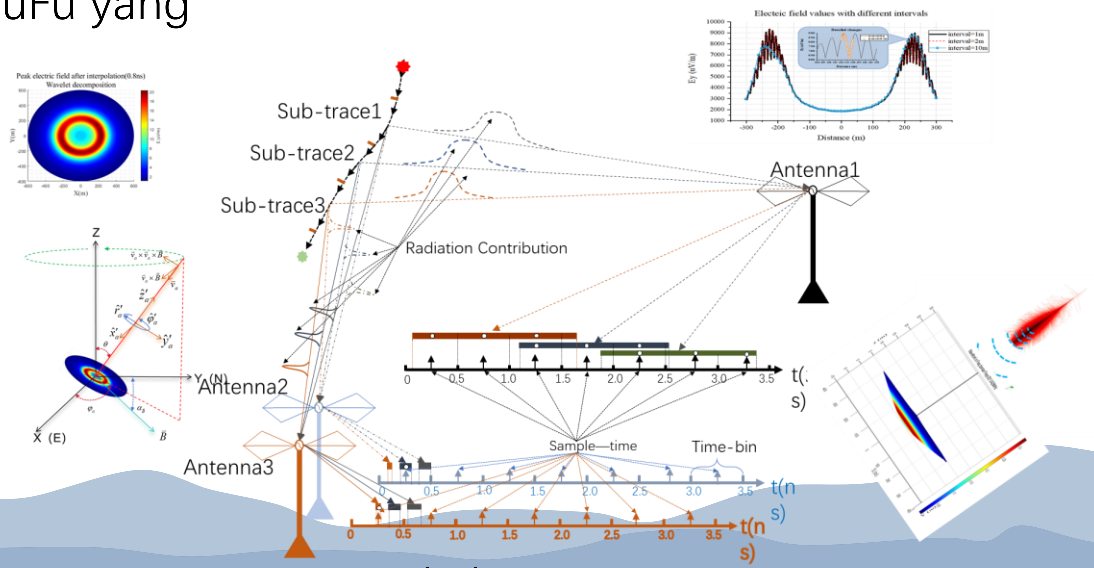




Washington

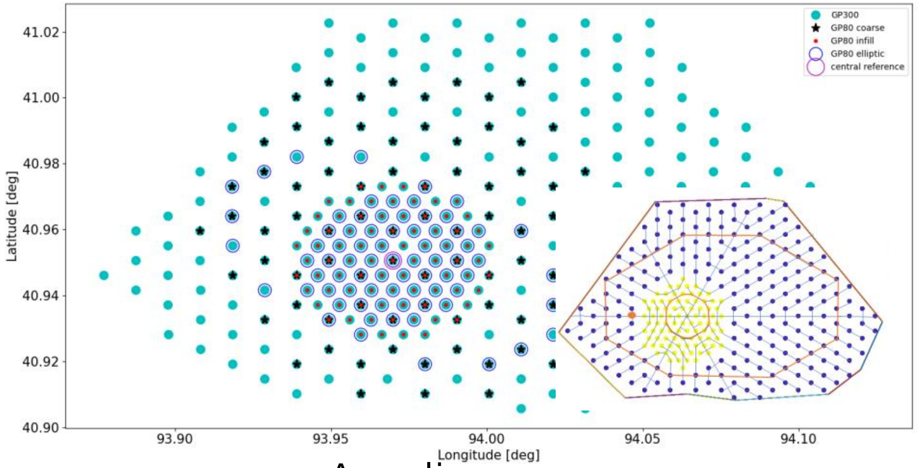


Xinxu



Jia le wang

Trigger, layout based event number estimation and time calibration



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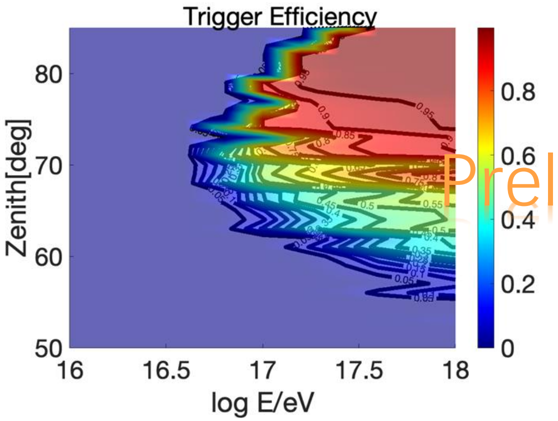
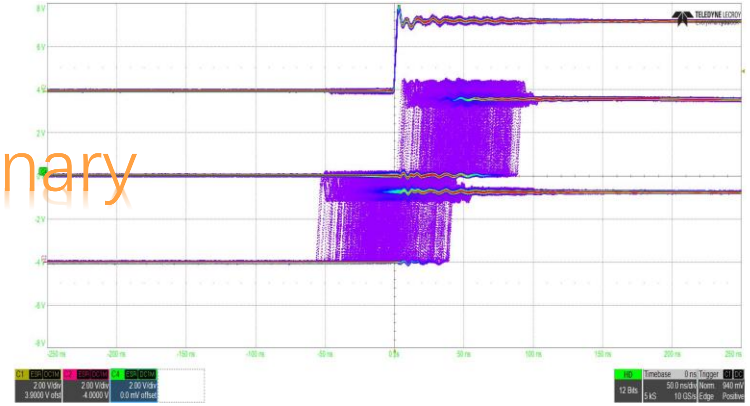
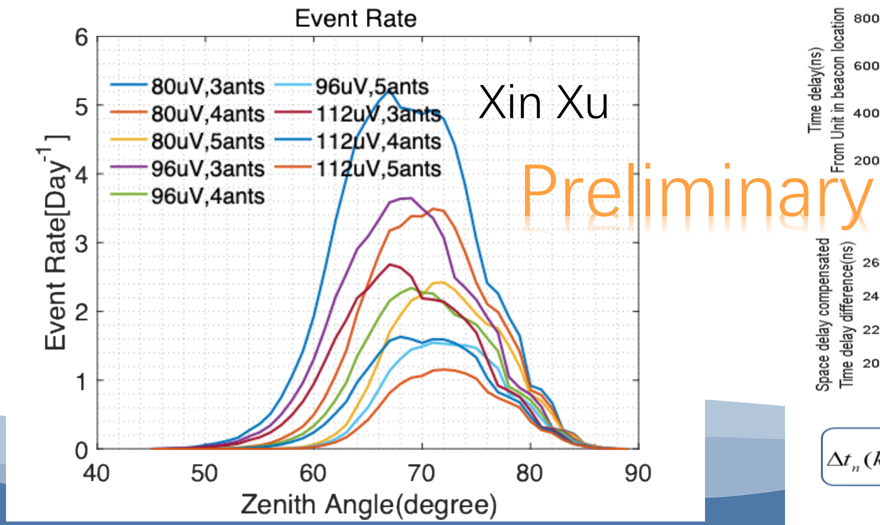


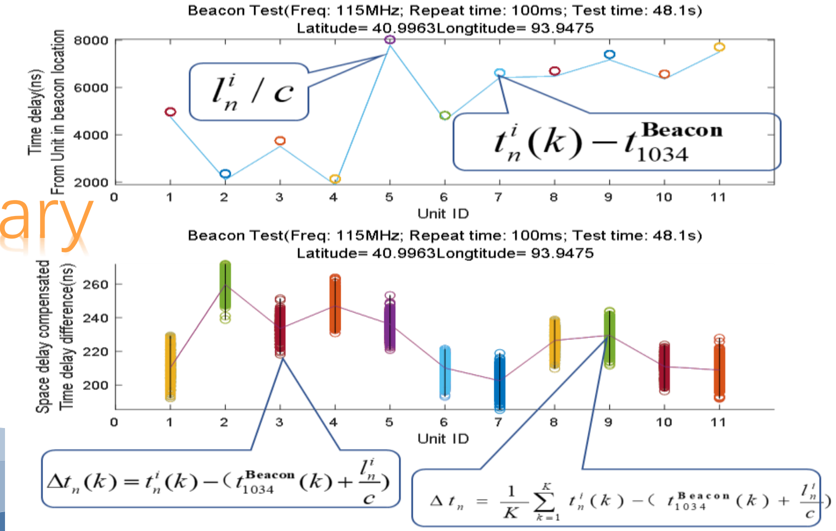
Xin Xu



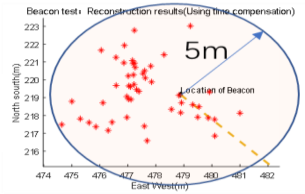
Xing Xu

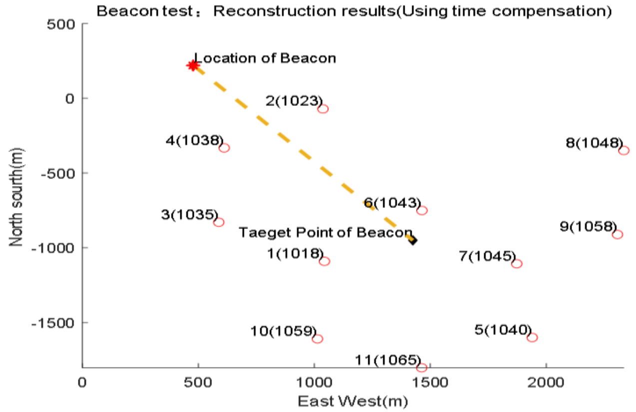


Xin Xu



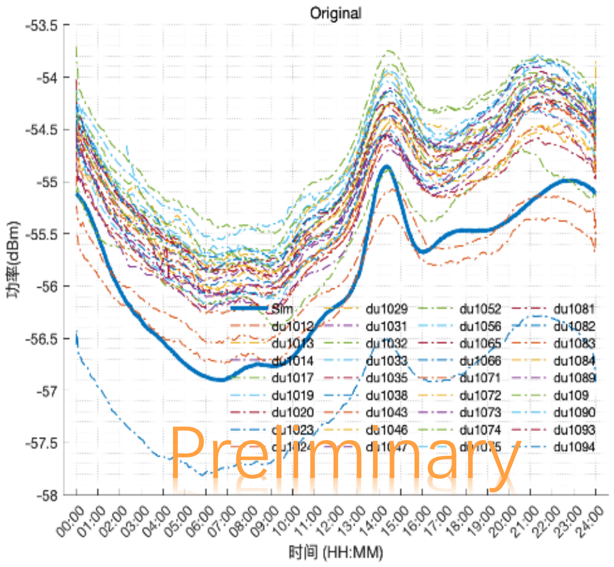
Xidian

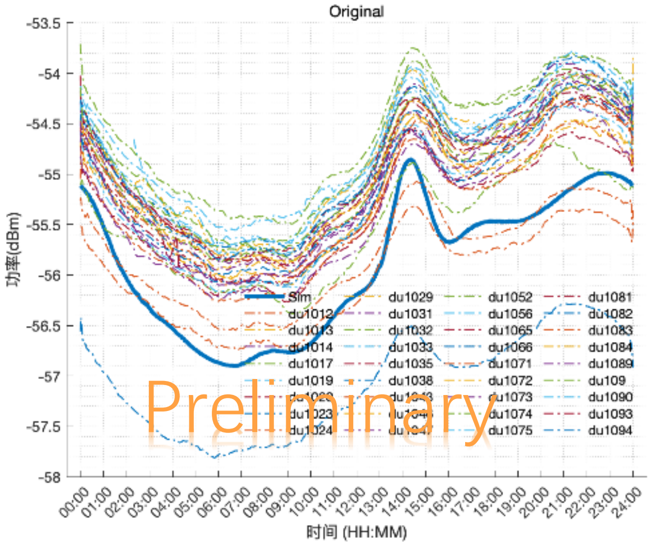


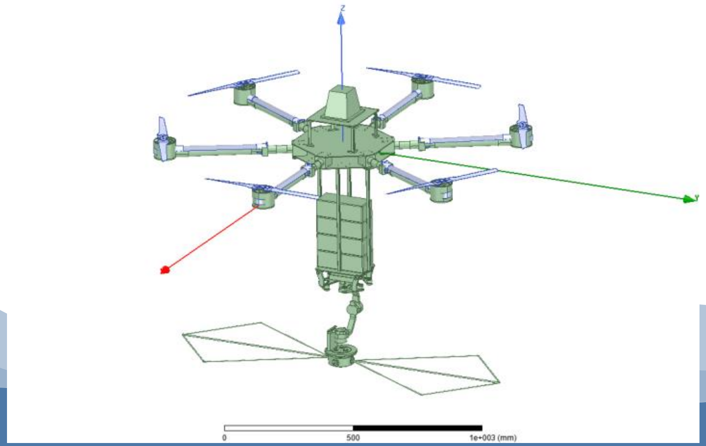


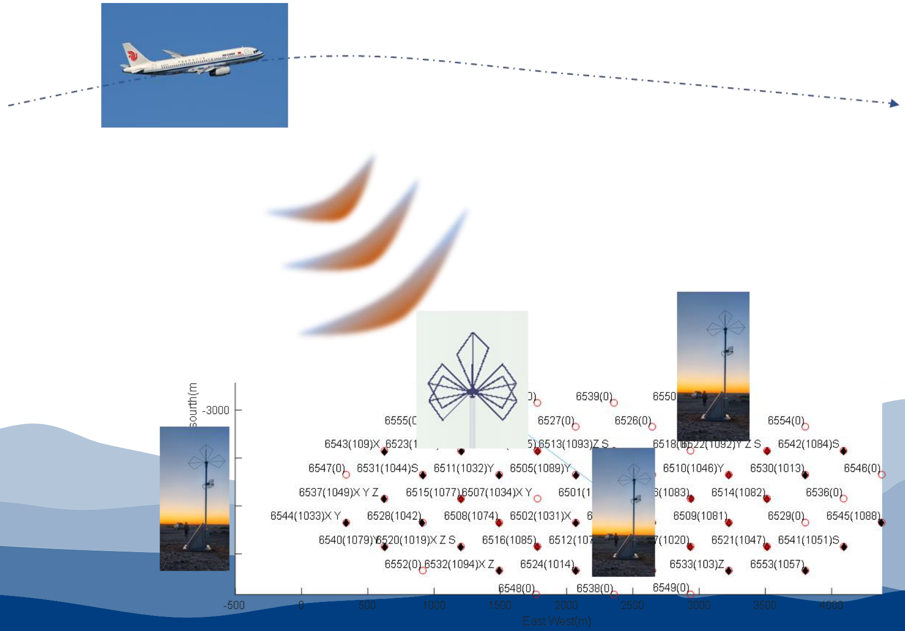
Preliminary Study on Calibration：time, Gain, Pattern

西安电子科技大学
Xidian University





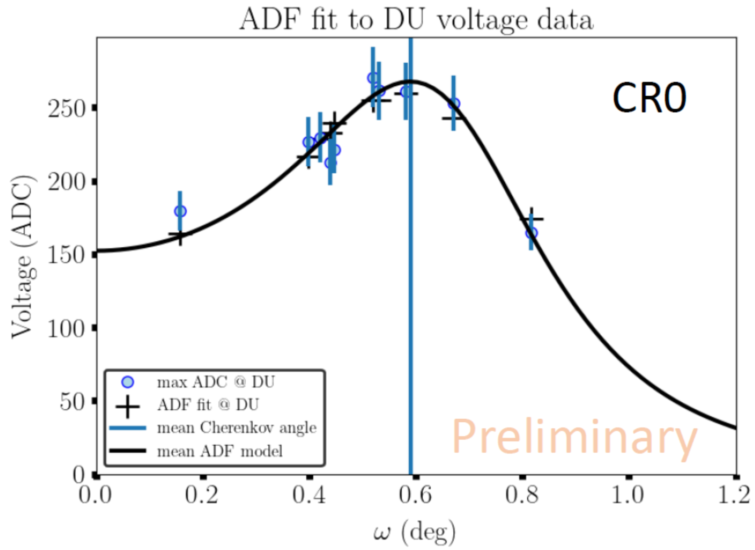




GRANDProto300: first cosmic-ray candidates

Selection pipeline for CR candidates applied over 12/24 – 03/25 GP300 data

➔ 41 candidates (GP300 cosmic ray talk, Jolan Lavoisier, PoS314)



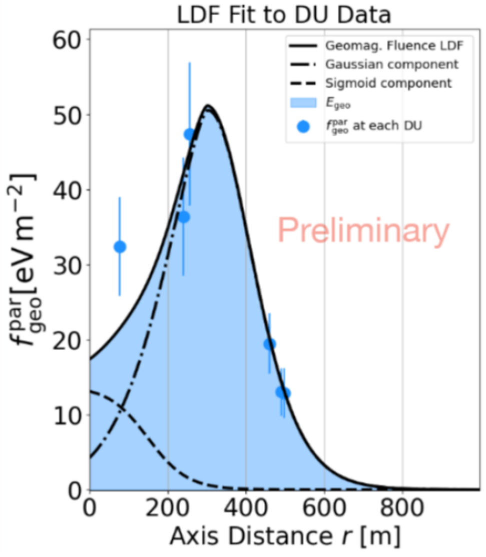
Reconstructed Efield from antenna response deconv. (K. Zhang's talk PoS447)

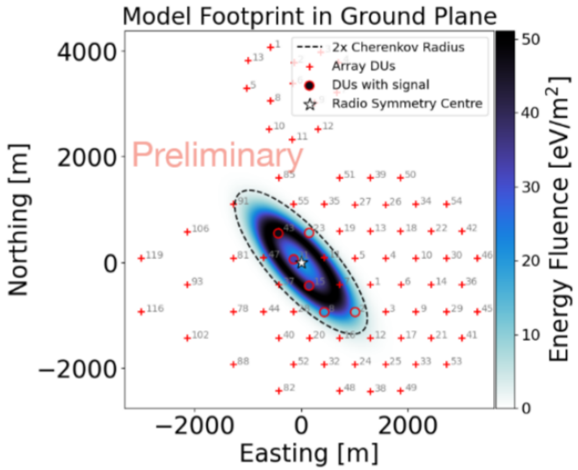
3 independent methods for amplitude analysis:

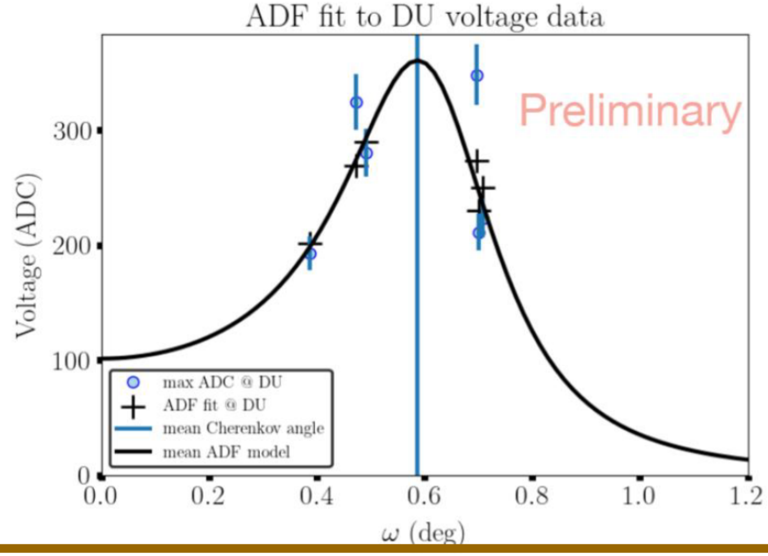
- Lateral Distribution Function on Efield (Lukas Gülzow PoS283),
- Angular Distribution Function on Voltage (Marion Guelfand PoS278)
- GNN on Voltage (Arsène Ferrière PoS253)

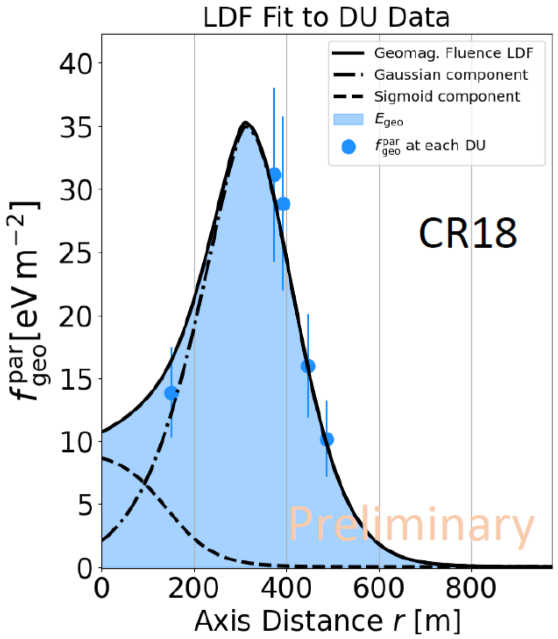
➔ "CR-like" amplitude profiles (Cherenkov enhancement)

Cosmic-Ray Candidate 31



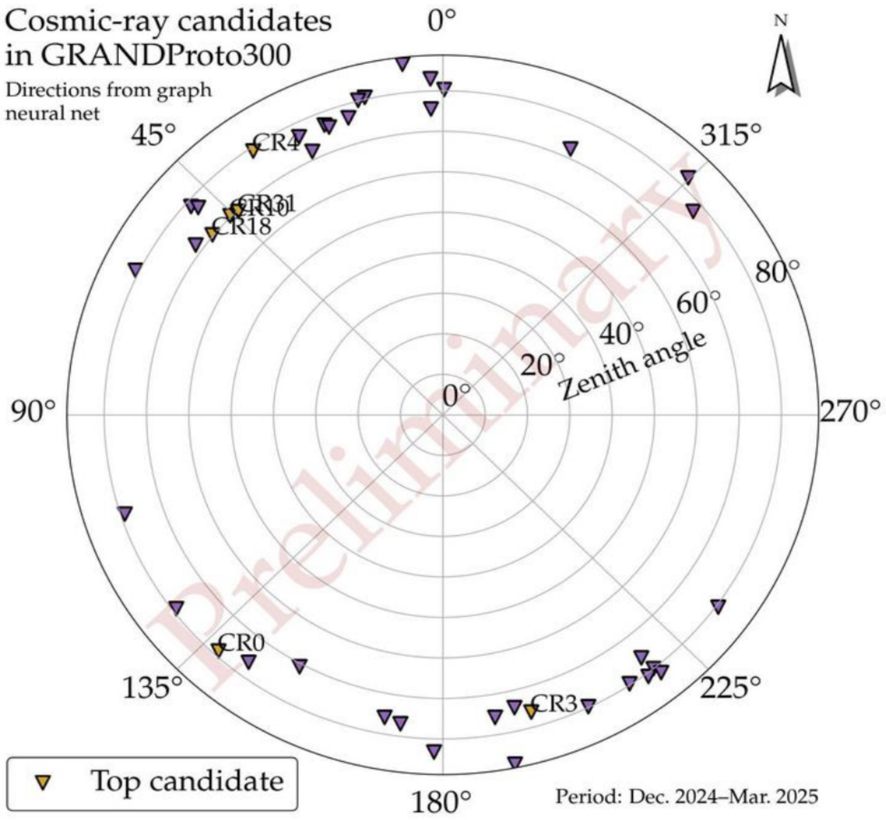






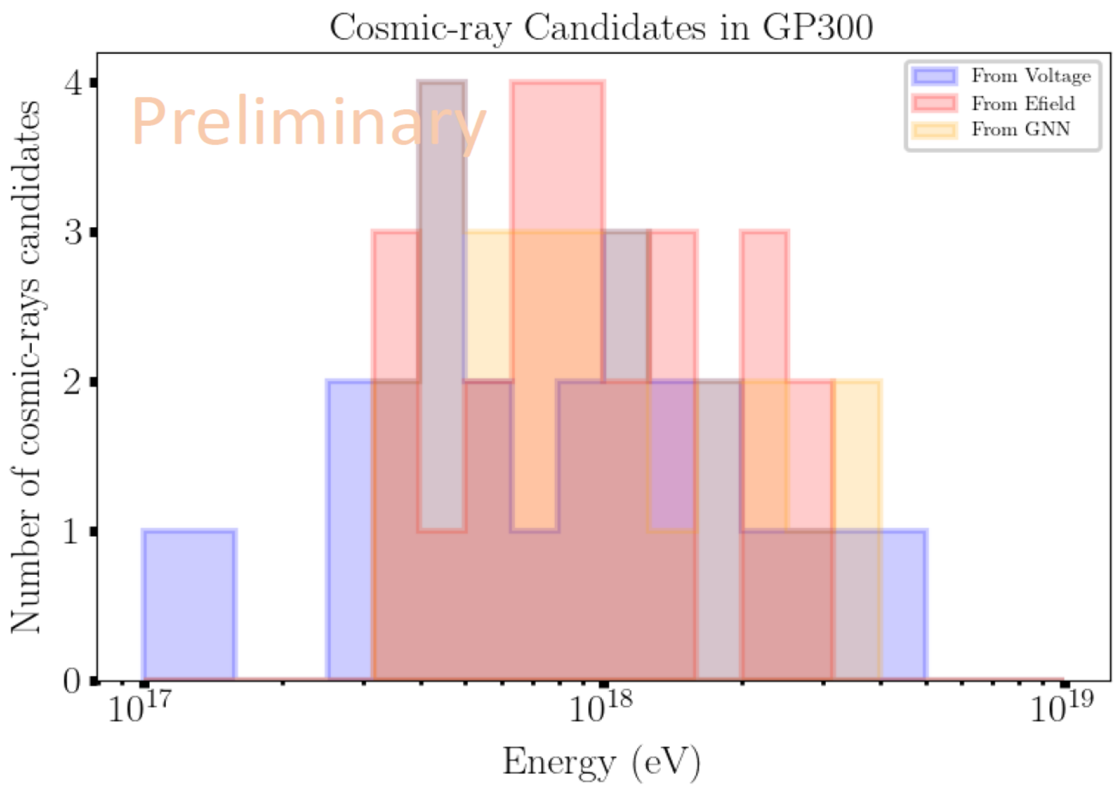
GRANDProto300: first cosmic-ray candidates

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)



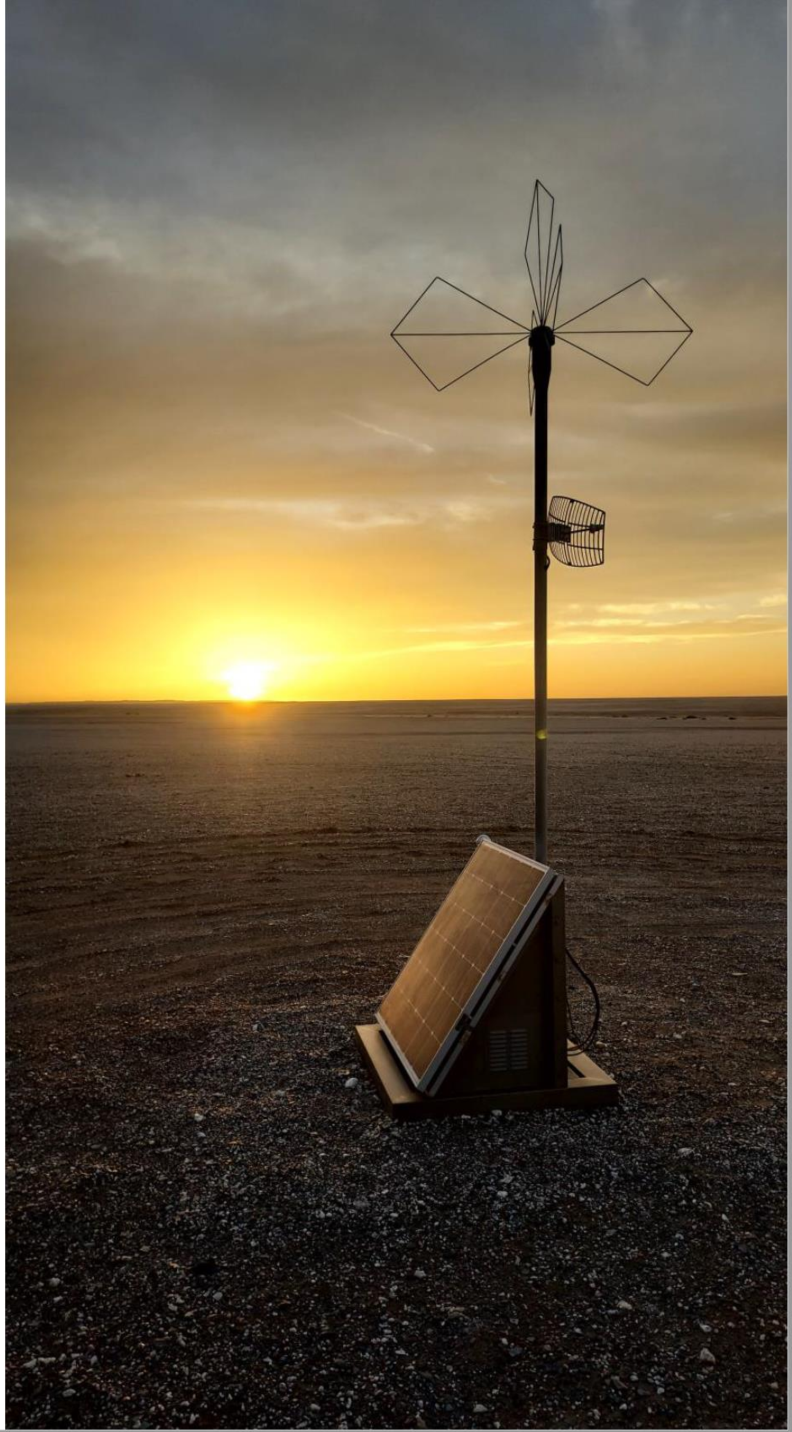
Disclaimer: **GP300 now in commissioning phase**. Efficiency and purity not known yet for CR detection process. Only validating HW, DAQ and reconstruction for now!

Next steps

Coming months:
✓ Optimize HW, DAQ & CR selection procedures
➔ start Physics run @ G@A and GP300
with nominal rate of few 10s CRs/day
✓ Build energy spectrum, arrival direction distribution, nature of primary
✓ Extend analysis to horizontal events (q>85°)
➔ Validate detection principle of GRAND
➔ Do CR physics around the Galactic-Extragalctic transition

In 1-3 years
✓ Complete GP300
✓ Increase stat, refine methods and analysis (horizontal events)
✓ Test GRAND10k design with improved HW & trigger/DAQ

Later:
Deploy GRAND10k on 2 sites in 2 hemispheres and **start neutino search**



Thank you for your time and attation!

Questions and Comments please !