# The Giant Radio Array for Neutrino Detection

GRAND

## The GRAND Collaboration

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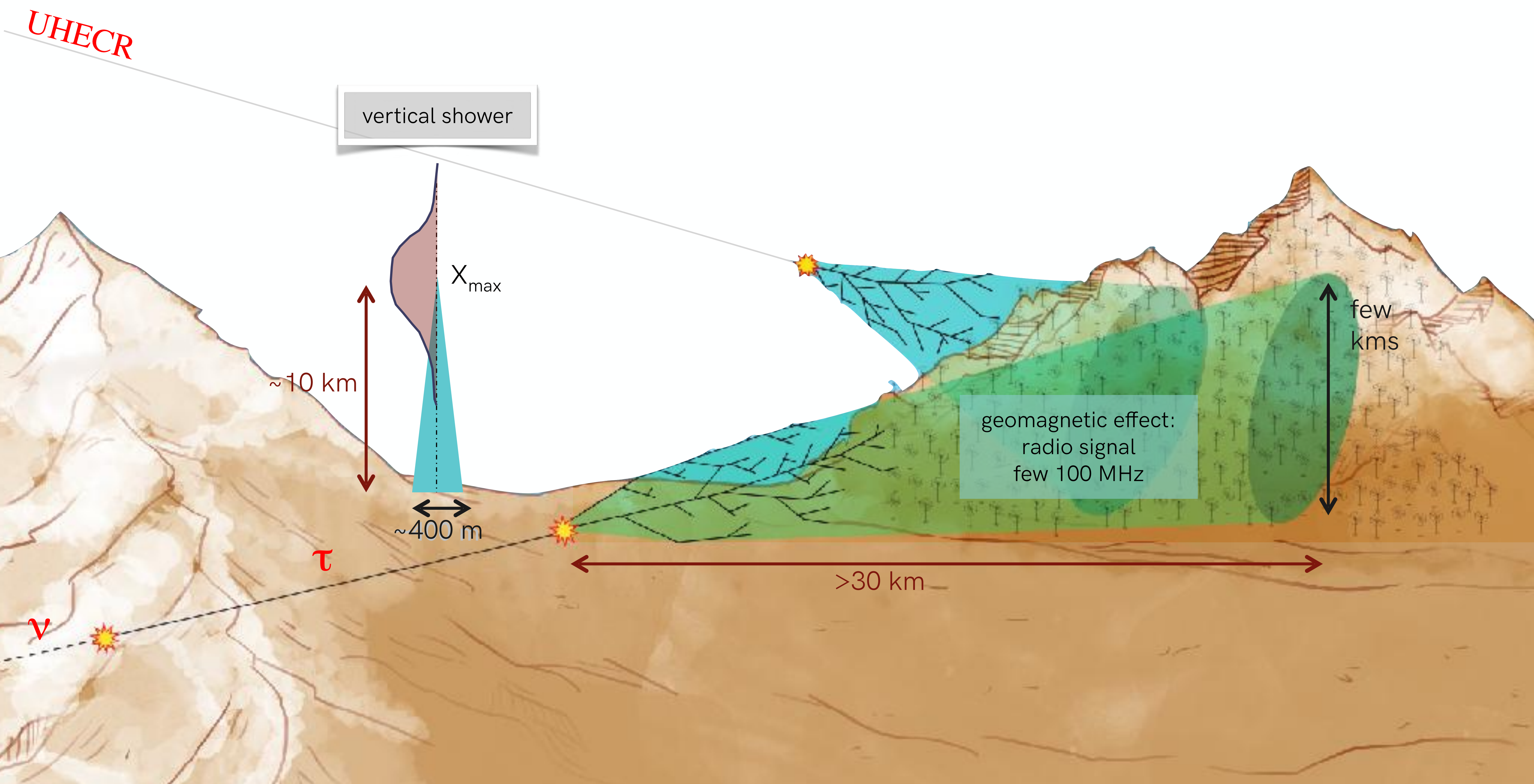
# Radio detection of ultra-high-energy air-showers

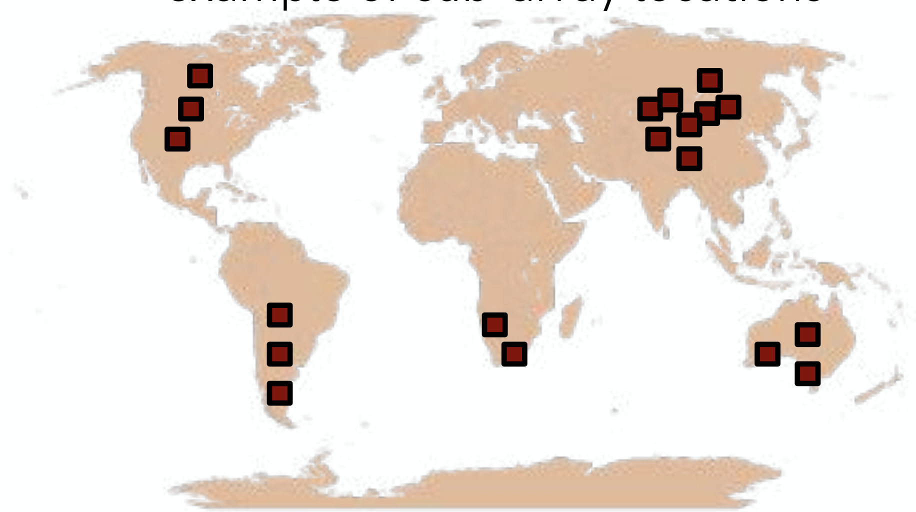



radio detection: **a mature technique**
AERA, LOFAR, CODALEMA, Tunka-Rex, TREND

radio antennas: **scalable, cheap, robust**
ideal for **giant** arrays

# The GRAND Concept

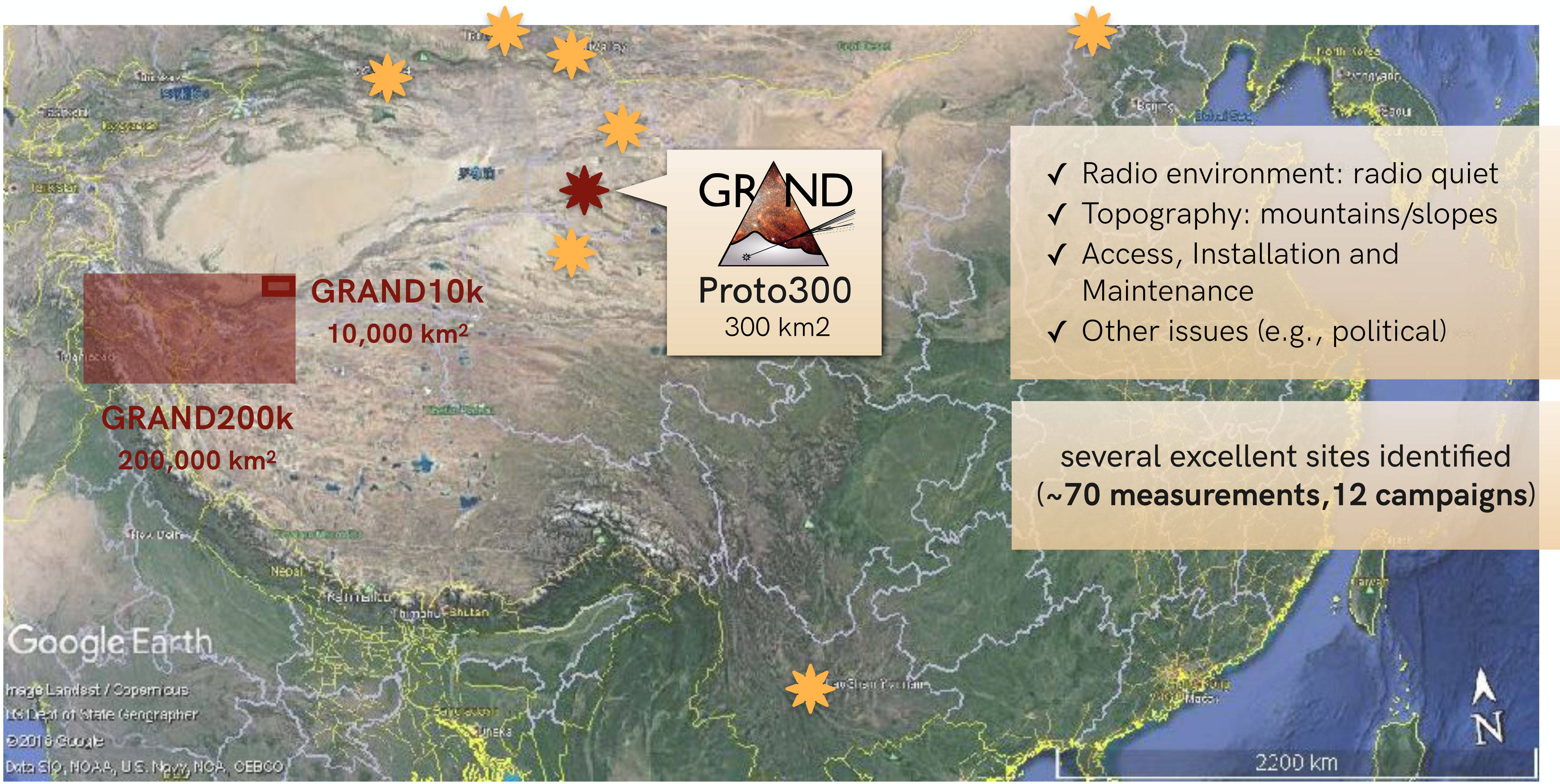
example of sub-array locations



**200'000 radio antennas over 200'000 km²**

~20 sub-arrays of 10'000 antennas

over favorable sites in China and worldwide

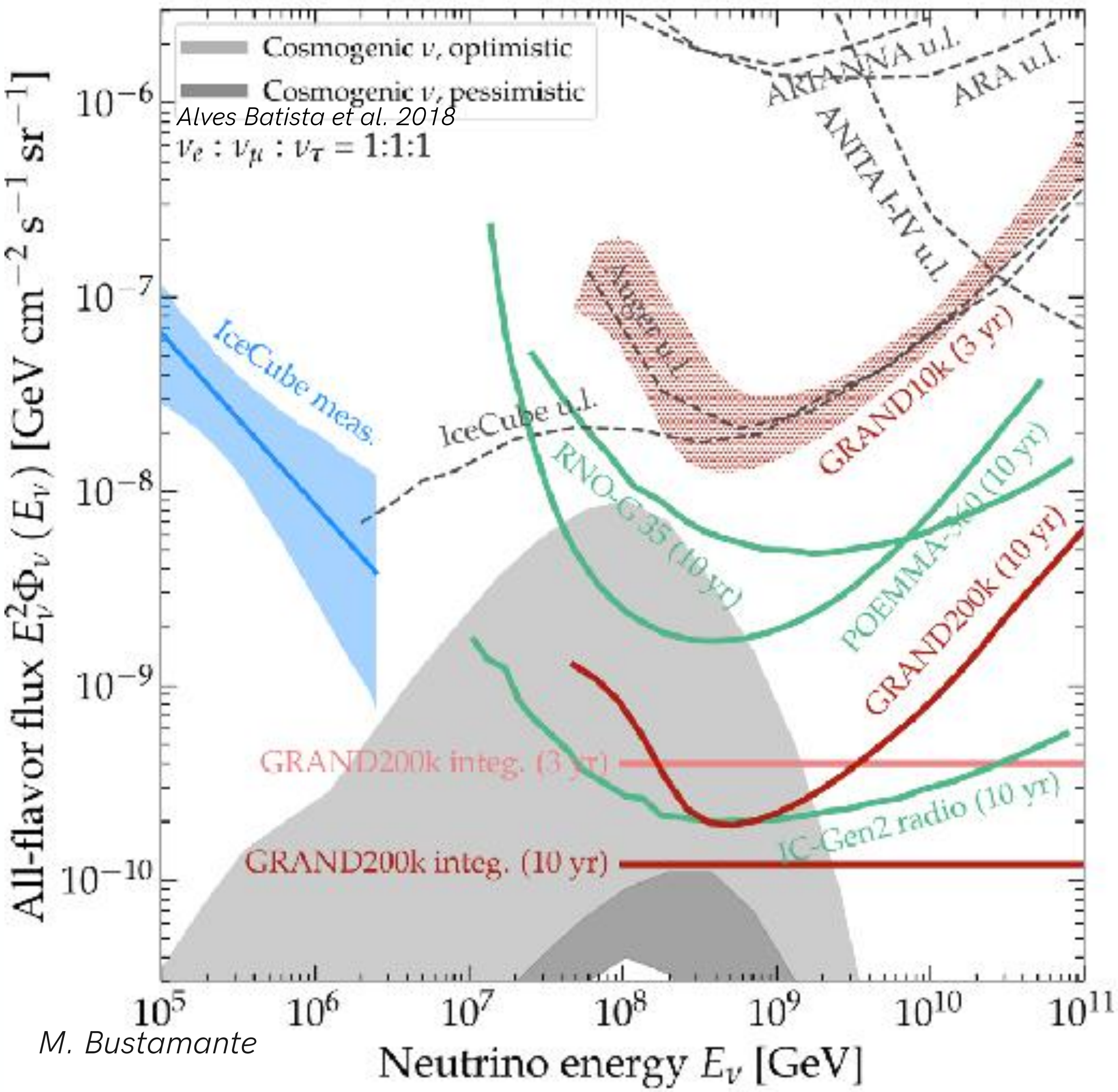


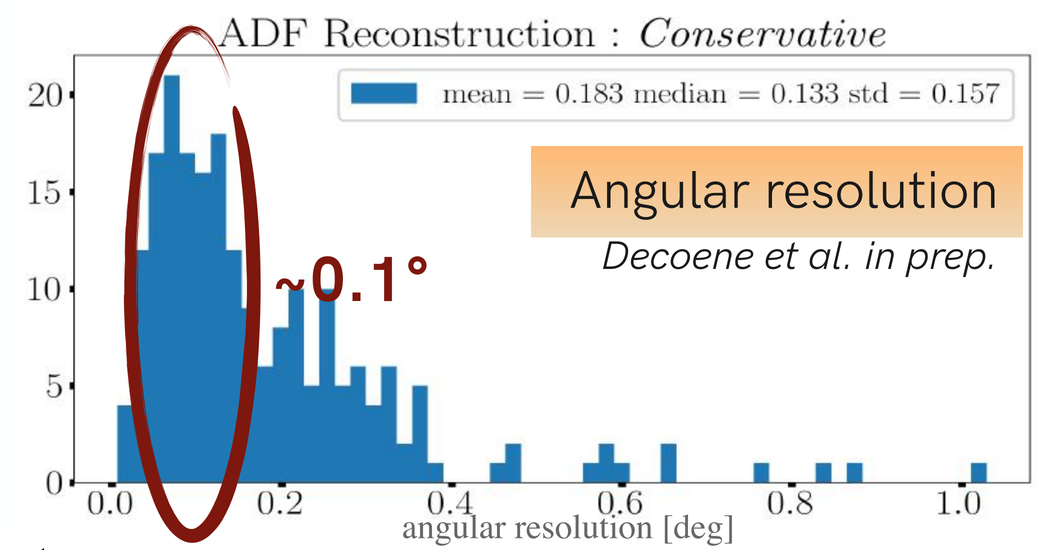

- ✓ Radio environment: radio quiet
- ✓ Topography: mountains/slopes
- ✓ Access, Installation and Maintenance
- ✓ Other issues (e.g., political)

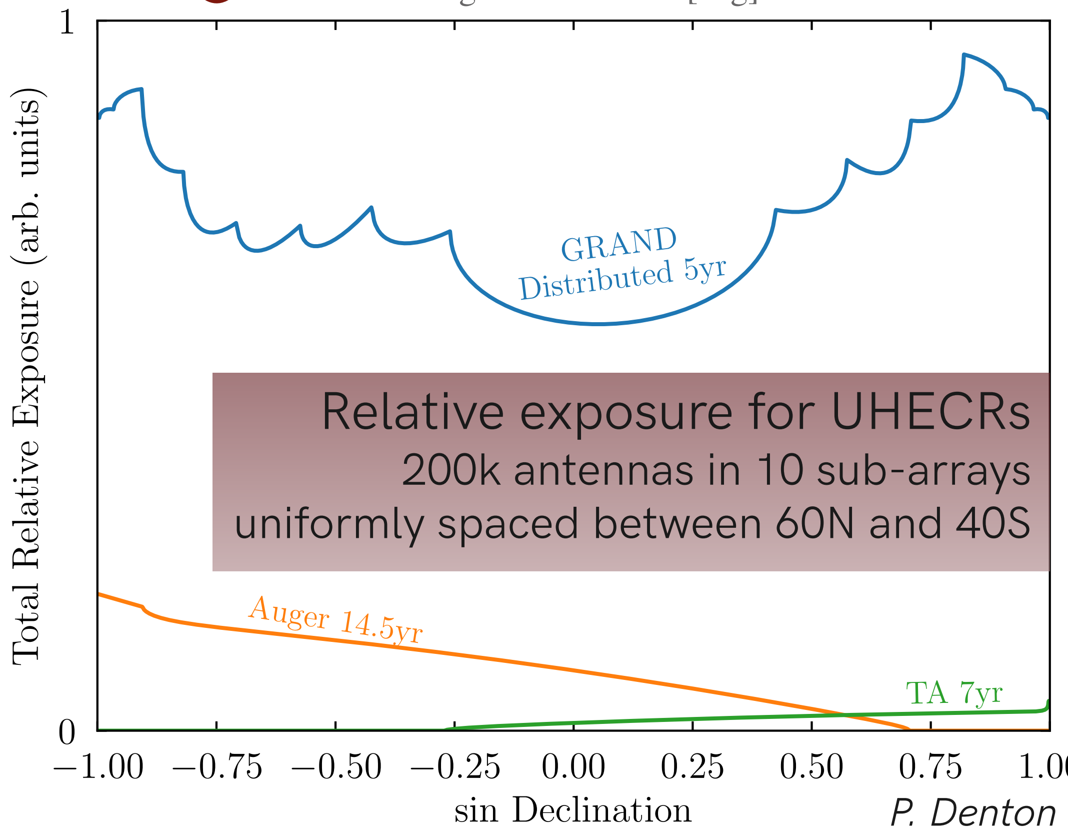
several excellent sites identified
(**~70 measurements,12 campaigns**)

# Simulated performances

*GRAND Science & Design, GRAND Coll. Science China, arXiv:1810.09994*



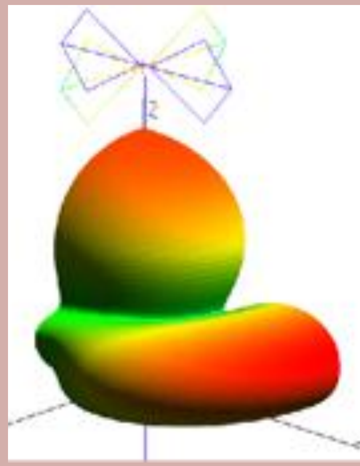

- **GRAND full sensitivity to neutrinos** ($E>10^{17}$ eV) ~4 x $10^{-10}$ GeV cm$^{-2}$ s$^{-1}$ sr$^{-1}$
- **Angular resolution** ~0.1° for GP300 & GRAND — *V. Decoene PhD 2020*
- **Energy resolution** < 10% on air-showers for GP300 & GRAND — *B. Lago & Rio GRAND team*
- **$X_{max}$ resolution** < 40 g/cm$^2$ achievable for $E>10^{19}$ eV for GRAND — *C. Guépin PhD 2019*

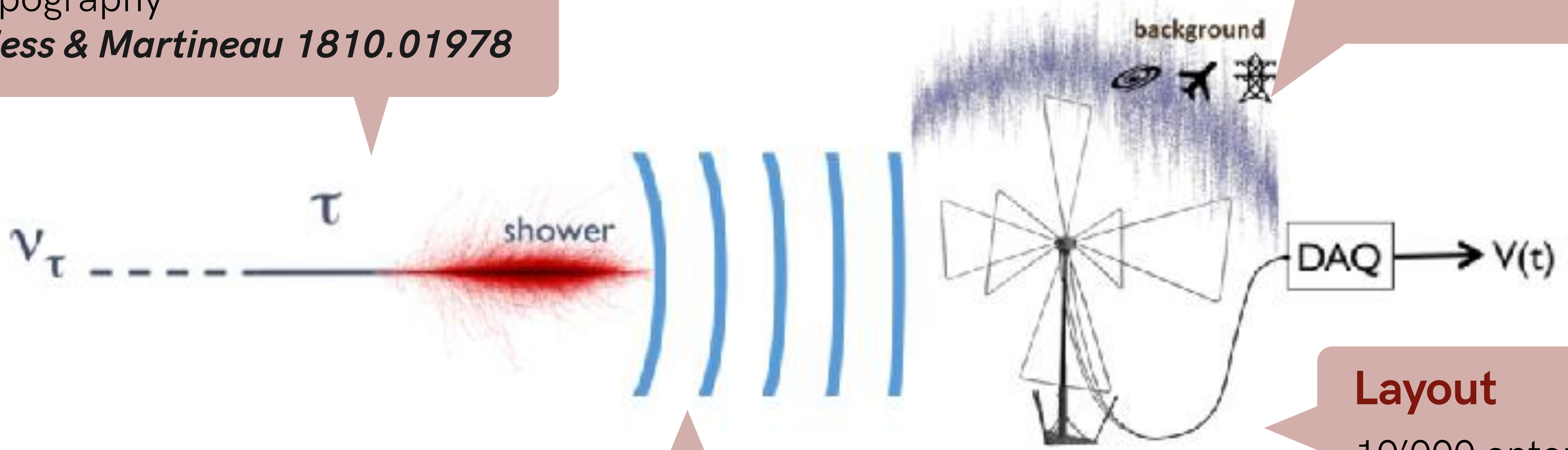
# GRAND End-to-End simulation chain

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

**DANTON**
$\nu \longrightarrow \tau$ decay
backward MC over realistic topography
***Niess & Martineau 1810.01978***

**Antenna response**
*HorizonAntenna*
h=5m, f = 50-200MHz, optimized for very inclined trajectories
Response simulated in NEC4

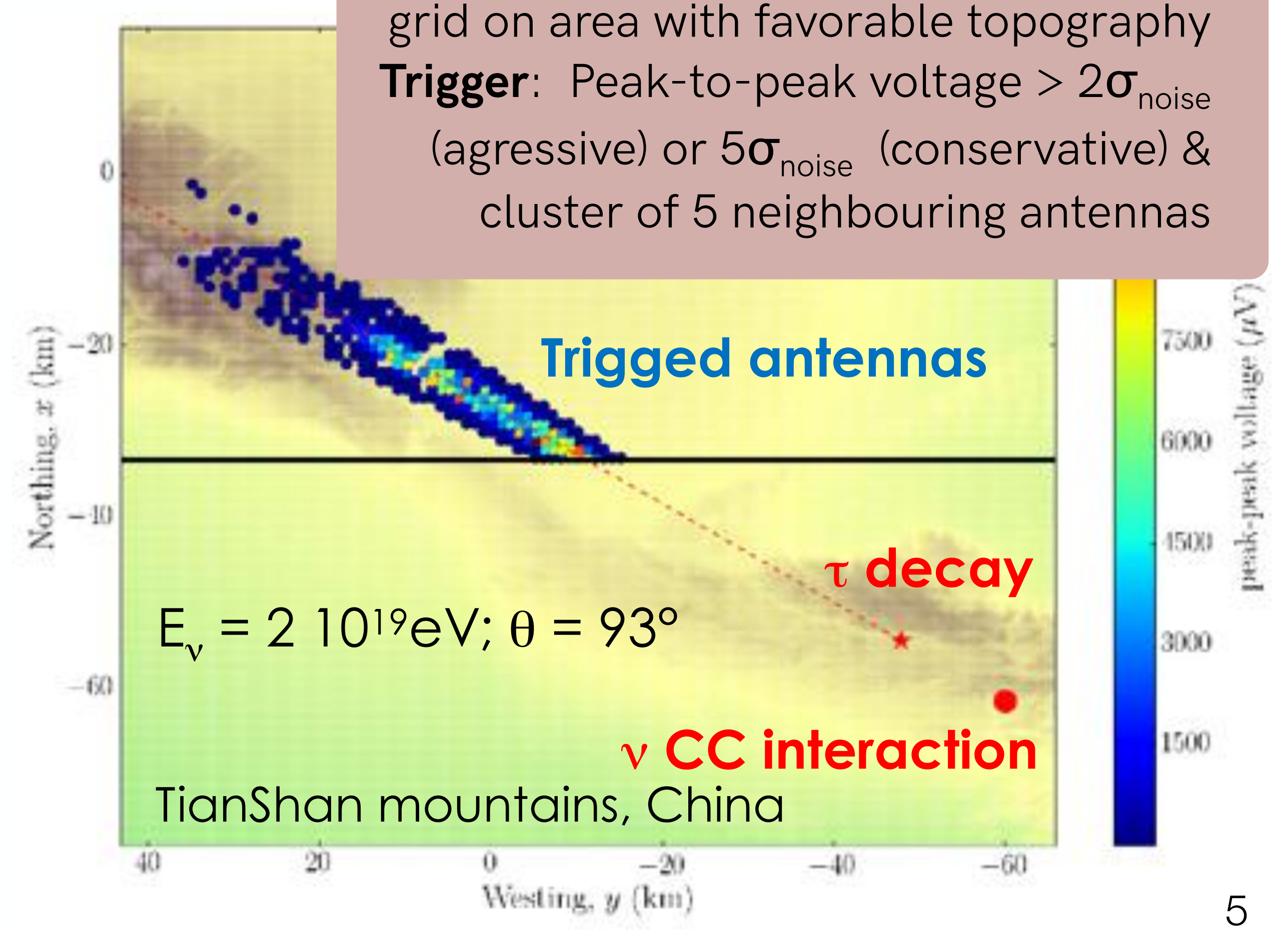





**Radio-Morphing**
semi-analytical computation of the air-shower-induced Efield transient signal.
***A. Zilles et al. 2020, 1809.04912***
***Chiche et al. ICRC 2021***

**Interpolation of radio signals**
***Tueros & Zilles arXiv:2008.06454***

**Layout**
10'000 antennas with 1 km step square grid on area with favorable topography
**Trigger**: Peak-to-peak voltage > $2\sigma_{noise}$ (agressive) or $5\sigma_{noise}$ (conservative) & cluster of 5 neighbouring antennas



# A rich science case

## UHE neutrinos

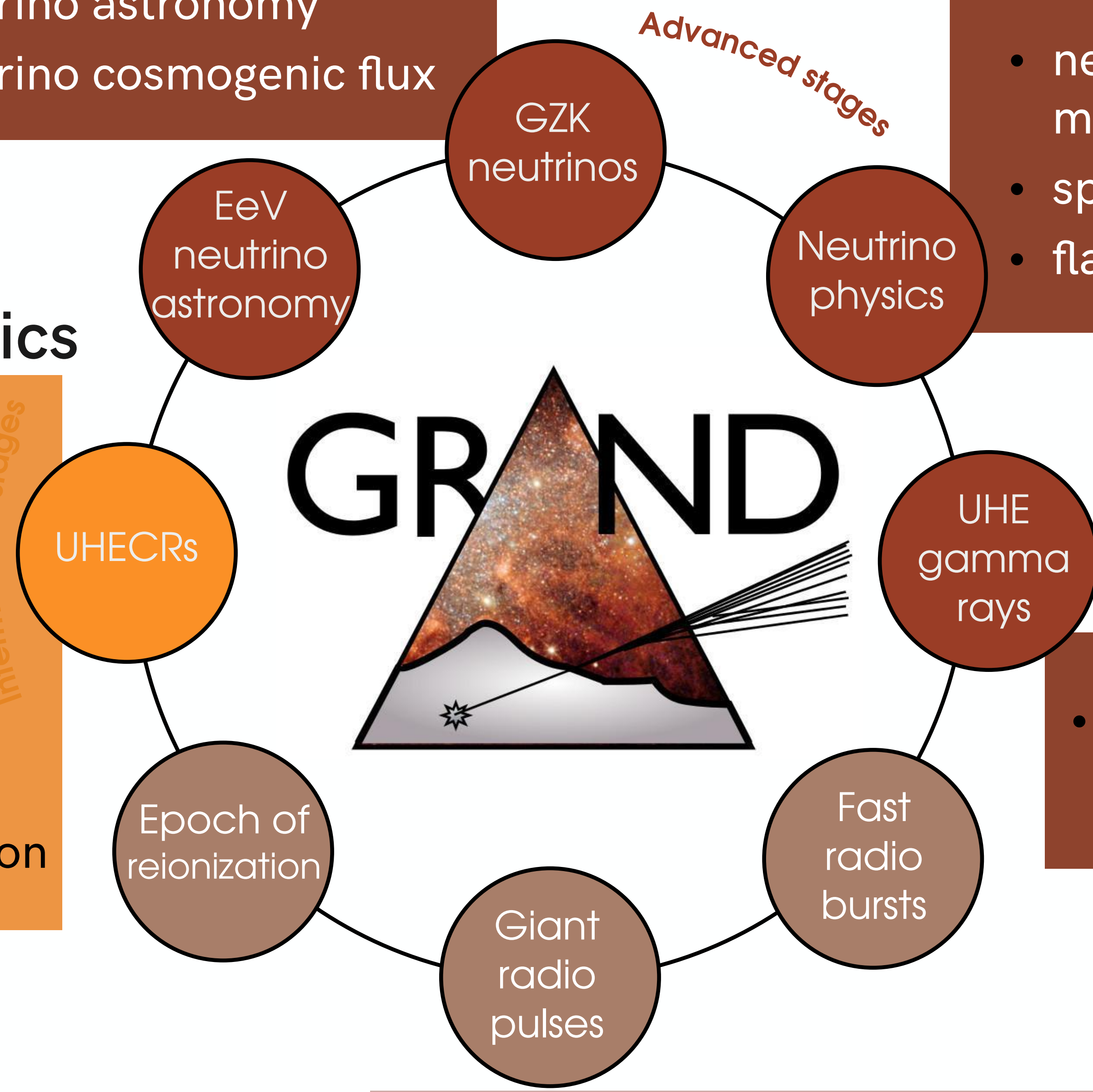
- UHE neutrino astronomy
- UHE neutrino cosmogenic flux

## neutrino physics

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

## UHECR, hadronic physics

- 20-80 times the exposure of Auger!
- GRANDProto300: transition from Galactic/ extragalactic
- hadronic physics: muon discrepancy, UHECR mass composition, p-air cross-section




## UHE gamma rays

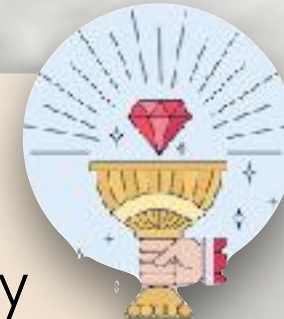
- competitive with Auger at GRANDProto300 stage

## radio-astronomy in a novel way

Early stages

- 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

# GRAND Technical Challenges



**Autonomous trigger on radio signals**

- TREND: ~32% offline identification efficiency
- Noise = ultra-dominant: rejection $1/10^8$
- Identification of signals at various trigger levels, methods to be developed *e.g., Chiche et al. submitted*
- Optimization of data collection

**Reconstruction of primary particle parameters**

- good performances for vertical air-showers
- no-man's land for inclined air-showers

**Develop new "conventional" and machine learning methods**

Need for an experimental setup to test and optimize

GRAND

**Proto300**

How to deploy/run 200k units over 200k $km^2$?
How much will it cost? Who will pay for it?

**Industrial approach!**
**low failure rates**
**deployment ~ electric poles**

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

| | GRANDProto300 | GRAND10k | GRAND200k |
|---|---|---|---|
| | 2021 | 2025 | 203X |
| **Goals** | **autonomous** radio detection of **very inclined** air-showers<br><br>**cosmic rays $10^{16.5\text{-}18}$ eV**<br>• Galactic/extragalactic transition<br>• muon problem<br>• radio transients | **1st GRAND sub-array**<br><br>• **discovery of EeV neutrinos** for optimistic fluxes<br>• radio transients (FRBs!) | sensitive **all-sky** detector<br><br>**1st EeV neutrino detection and/or neutrino astronomy!** |
| **Setup** | • 300 HorizonAntennas over 200 km$^2$<br>• Particle detectors (a la HAWC/Auger)<br>• Qinhai Province, China | • 10,000 radio antennas over 10,000 km$^2$<br>• in China | • 200,000 antennas over 200,000 km$^2$<br>• 20 sub-arrays of 10k antennas<br>• on different continents |
| **Budget** | **2 M€**<br>100 antennas already paid (China) | **13 M€** 1500€/unit<br>confident for large contribution from China | **300M€** in total 500€/unit<br>to be divided between participating countries |

# GRANDProto300: a self-standing pathfinder

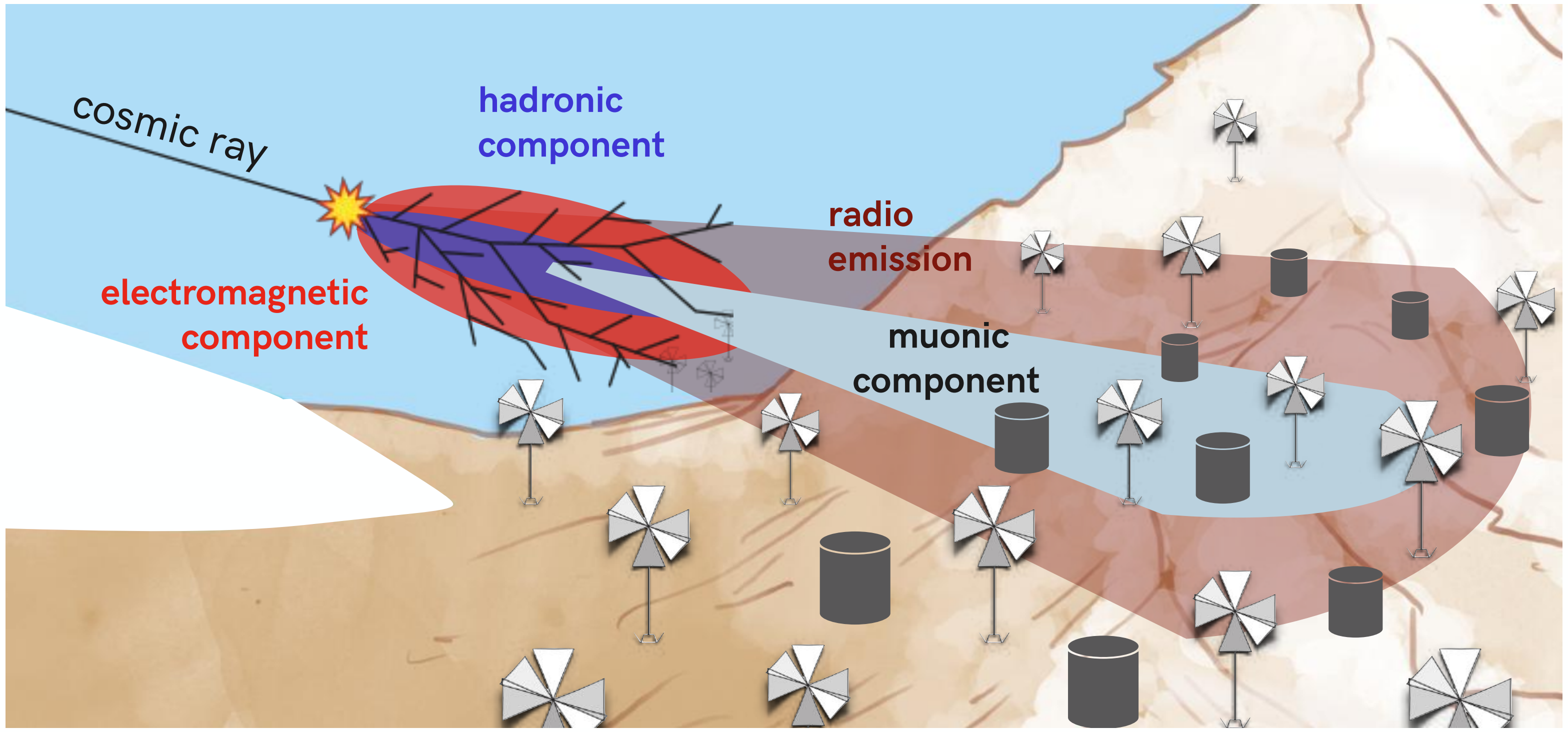
**Autonomous** detection of **very inclined cosmic rays** $E=10^{16.5}$-$10^{18}$ eV

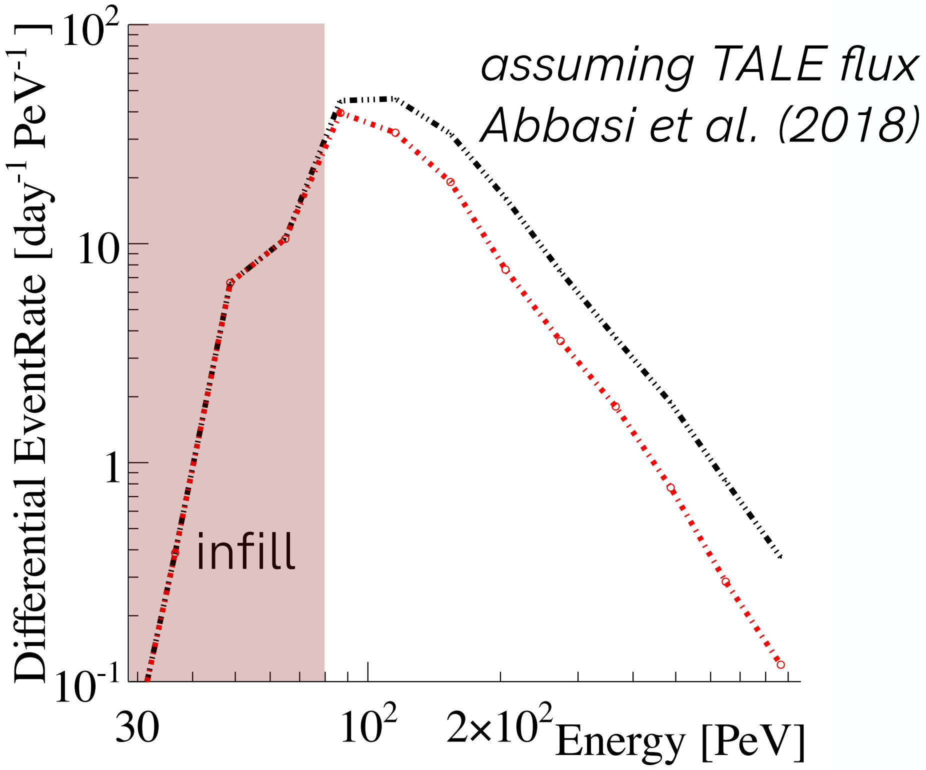
reconstructing spectrum, arrival direction & composition
validation via comparison to known results
test bench for further GRAND stages

**Proficient physics instrument** if complemented by **particle detector array**

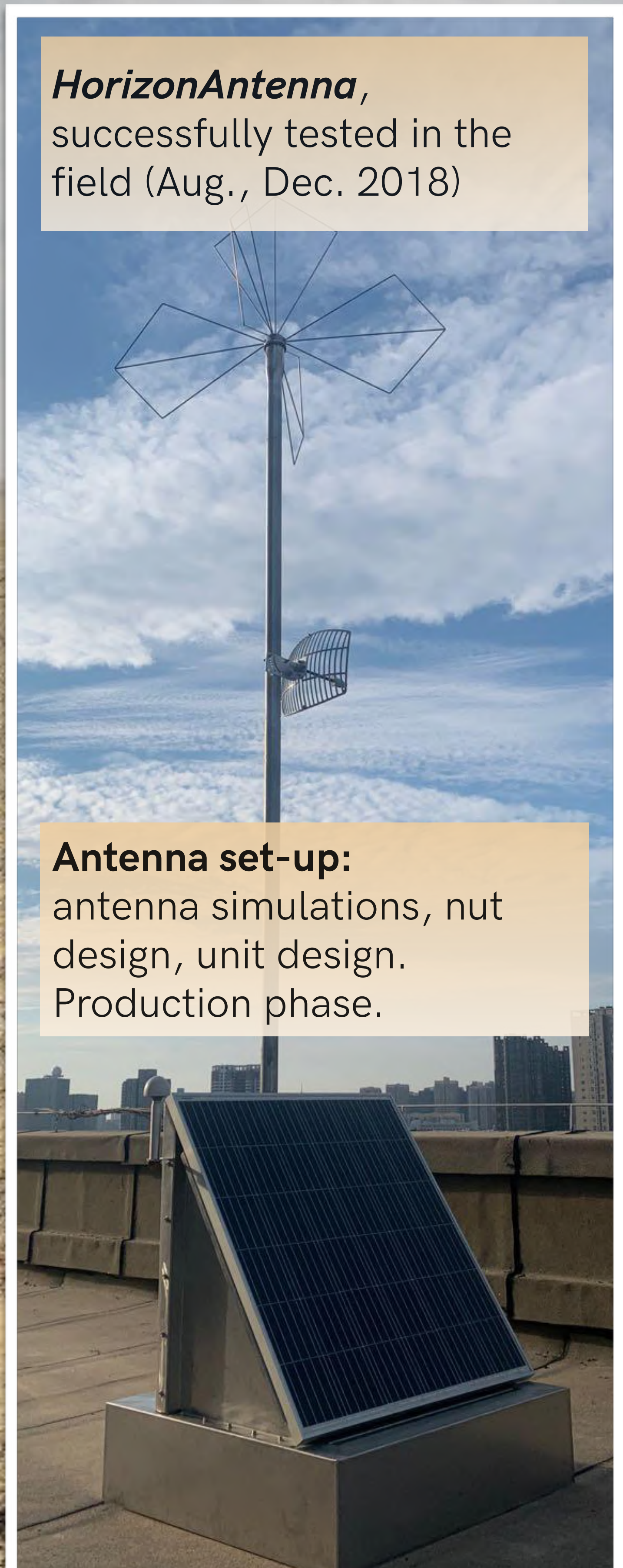
Galactic/extragalactic transition
hadronic physics (muon content in EAS)
UHE gamma-rays
Fast Radio Bursts

+ to check radio calibration at 30-200 MHz, pulse-shape analyses, Cherenkov-cone analyses



# GRANDProto300: experimental setup

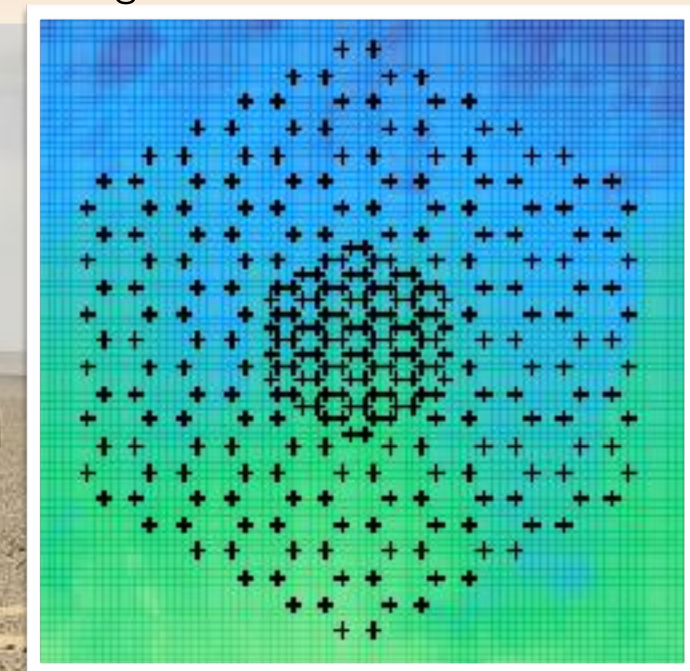


***HorizonAntenna***, successfully tested in the field (Aug., Dec. 2018)

**Antenna set-up:** antenna simulations, nut design, unit design. Production phase.

**Deployment of 13 antennas on-going in Gansu (China)**

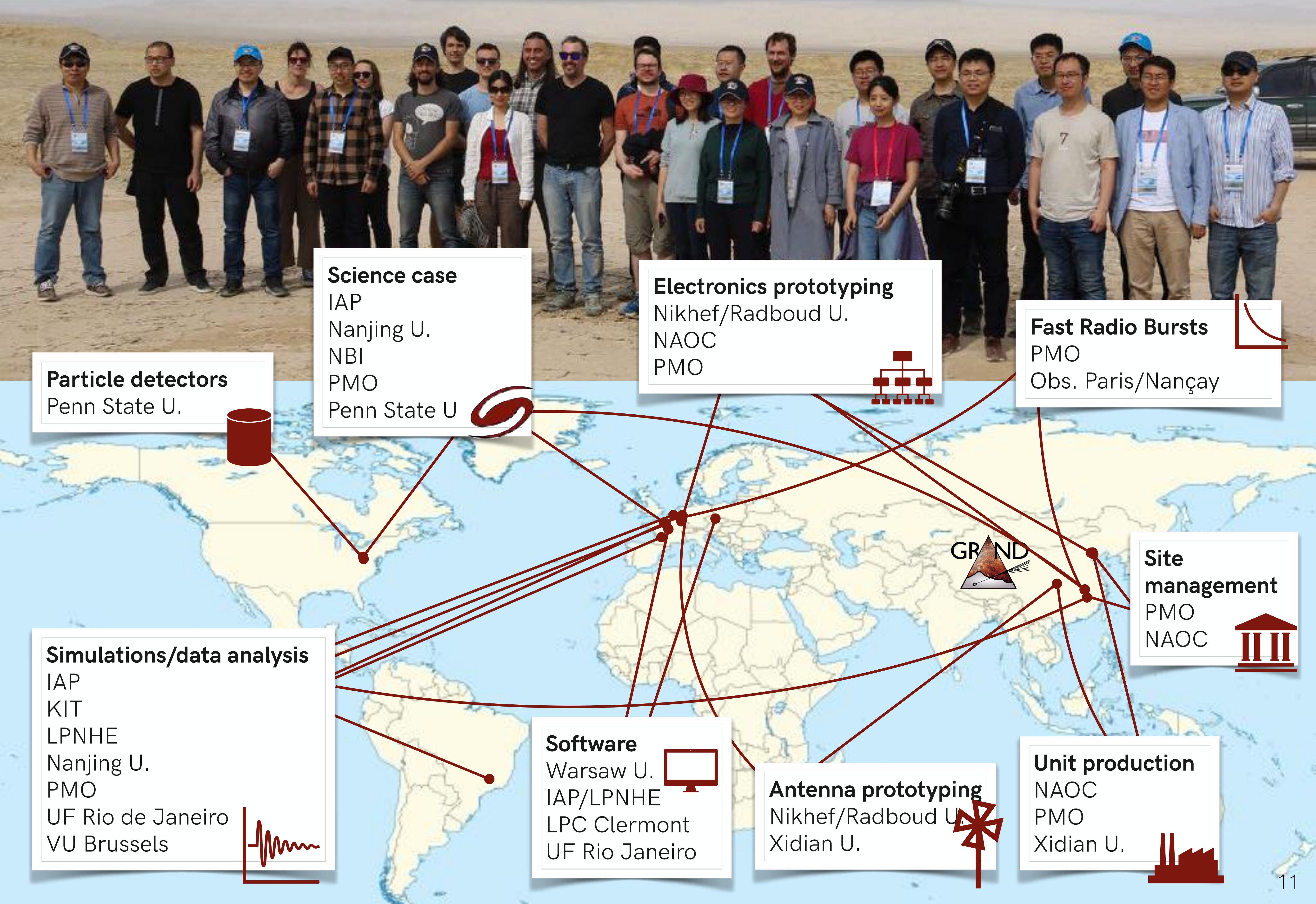
**Layout:** 300 antennas, 200km$^2$, 1km step size with denser infill Erange = $10^{16.5}$-$10^{18}$eV



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

# GRAND Today

~80 collaborators from 11 countries



# GRAND in the international community

## GRAND appears in several roadmaps

- Mid-term review of the **APPEC** strategy
- Physics briefing book: Input for the **European Strategy for Particle Physics** Update 2020, section 7.3
  http://cds.cern.ch/record/2691414
- **Nikhef** strategic plan 2017-2022 and beyond, p. 43
  https://www.nikhef.nl/strategisch-plan/
- **CNRS** Prospective INSU Astronomie & Astrophysique 2020-2025, p. 34
  https://www.insu.cnrs.fr/sites/institut_insu/files/news/2021-04/Prospective_INSU_AA_2019.pdf
- **Latin American** Strategy for Research Infrastructures for High Energy, Cosmology, Astroparticle Physics LASF4RI for HECAP https://arxiv.org/pdf/2104.06852.pdf
- White Paper in the **Decadal Survey** 2020

## Environmental responsibility

GRAND evaluates its environmental impact

One R&D goal: reduce the environmental impact of the detector

*GRAND Carbon Footprint Study*
*arXiv:2101.02049*
*arxiv:2105.04610 (Nature)*

**References:**

Website:
http://grand.cnrs.fr

GRAND White Paper
https://arxiv.org/abs/1810.09994

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

GRAND Carbon Footprint Study
https://arxiv.org/abs/2101.02049

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