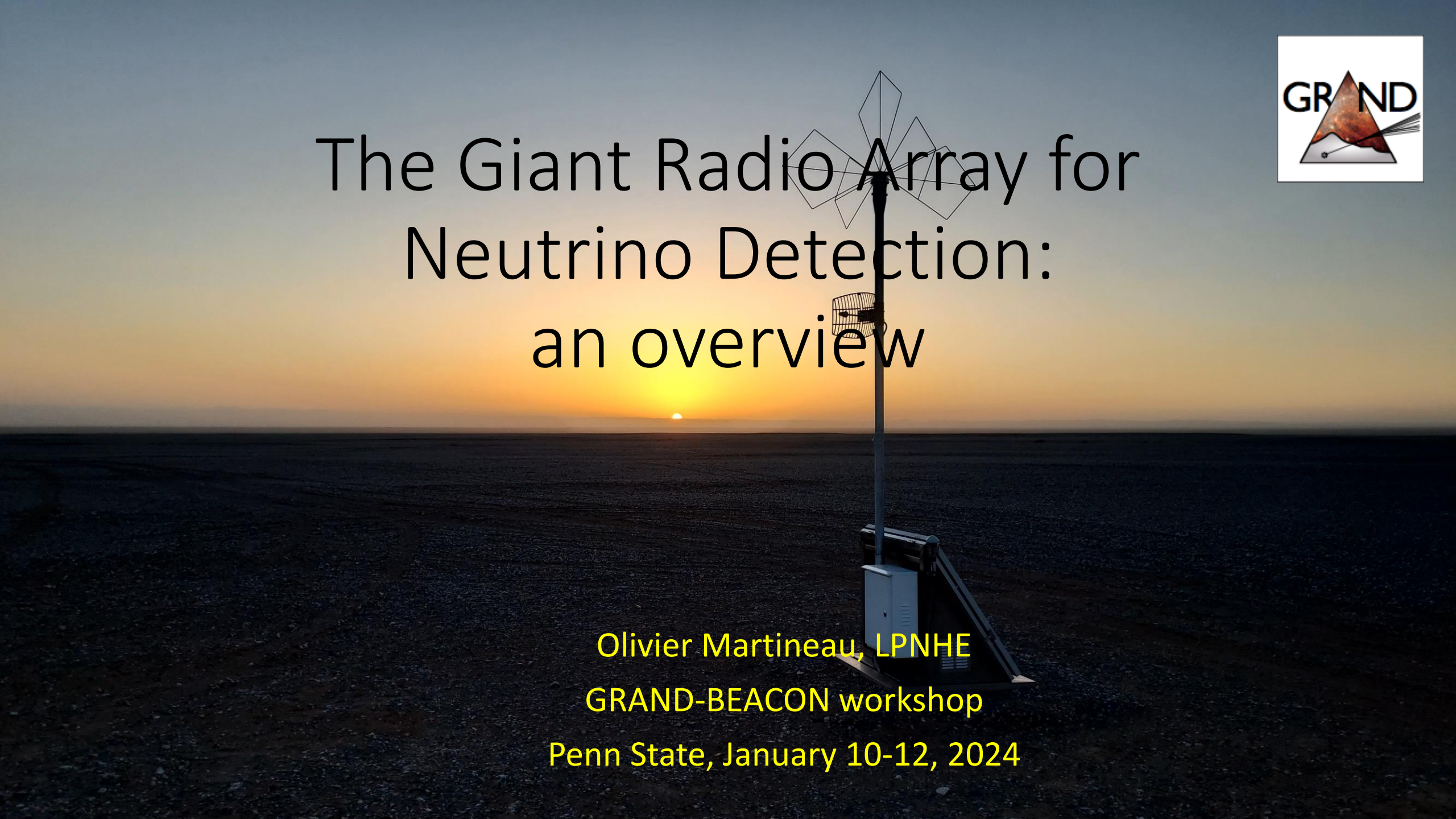


The Giant Radio Array for Neutrino Detection: an overview

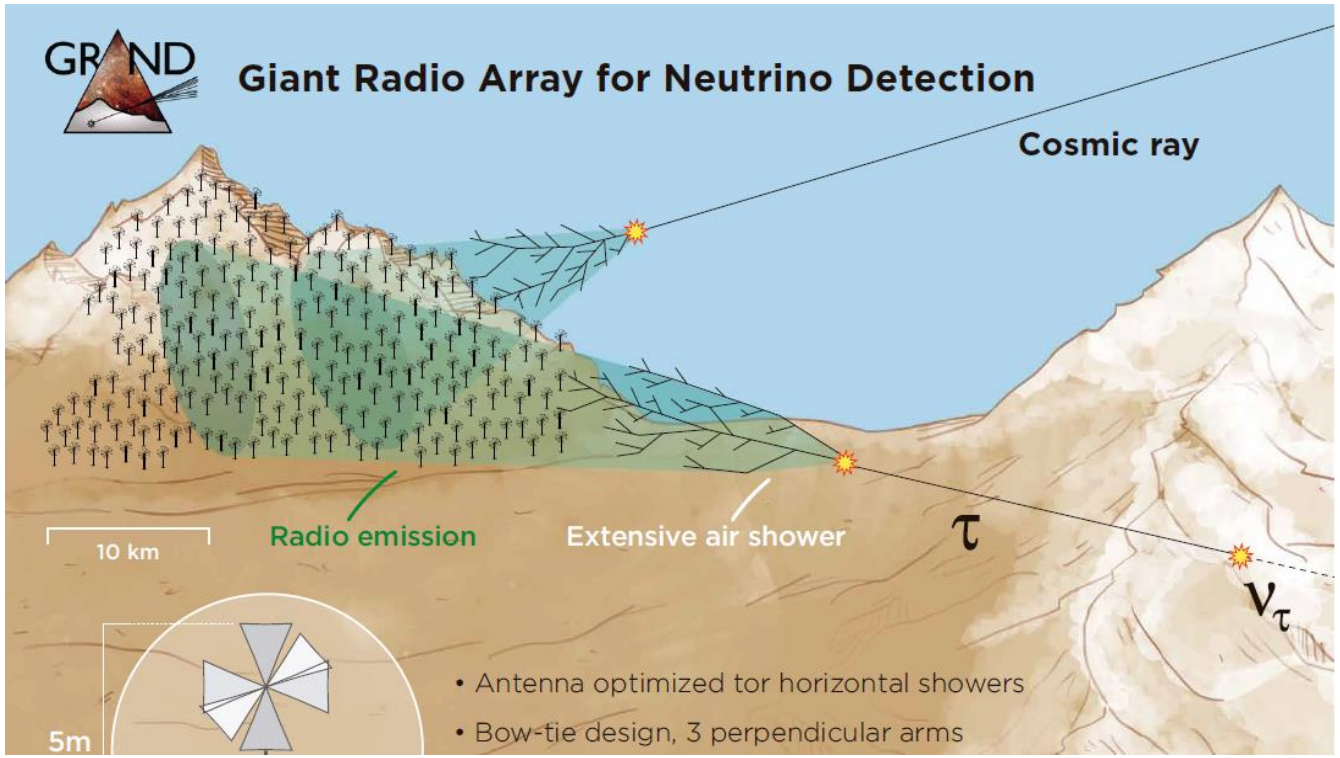
Olivier Martineau, LPNHE

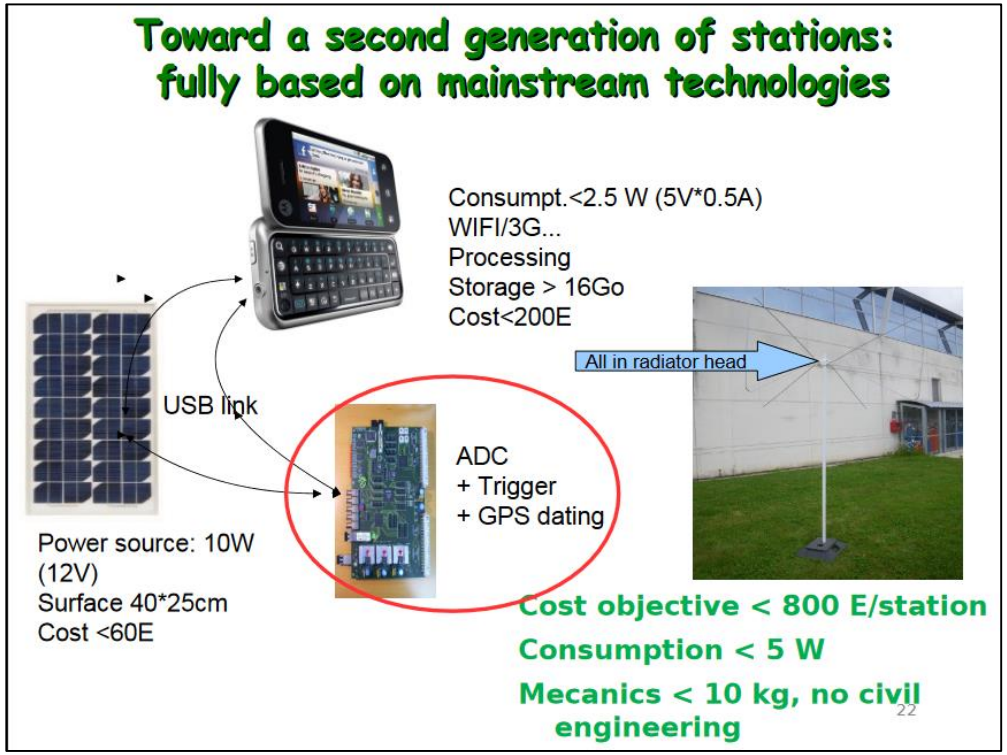
GRAND-BEACON workshop

Penn State, January 10-12, 2024

GRAND in a nutshell

Pascal Lautridou (2011)





- Very low UHE neutrino fluxes ⊗ very indirect EAS production mechanism

➔ Very rare events

➔ Very large effective area

➔ **Very cheap detection system ⊗ very large area: GRAND**

GRAND proposal

- Large effort for end-to-end simulation (2015-2018)

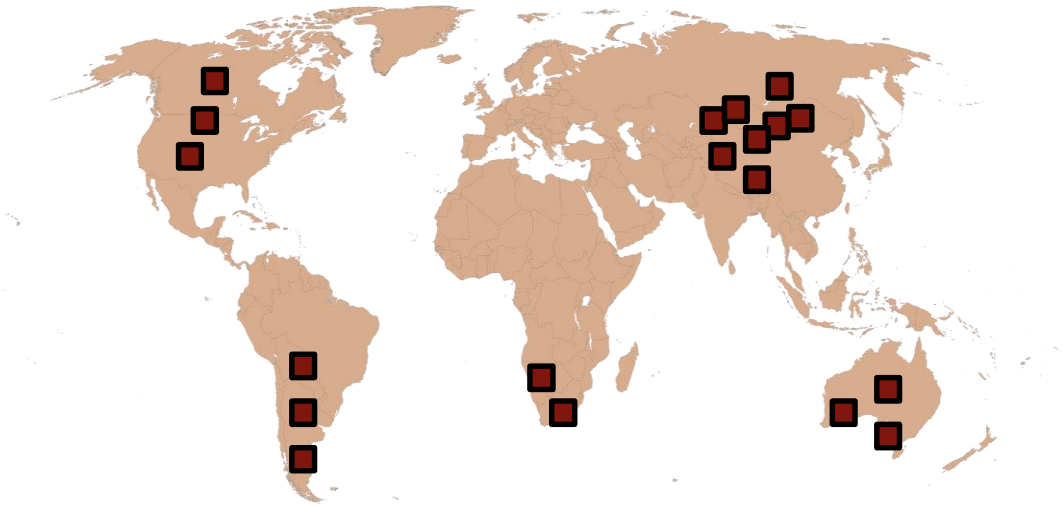
DANTON Niess & Martineau-Huynh arXiv:1810.01978

RadioMorphing Zilles et al. arXiv:1811.01750

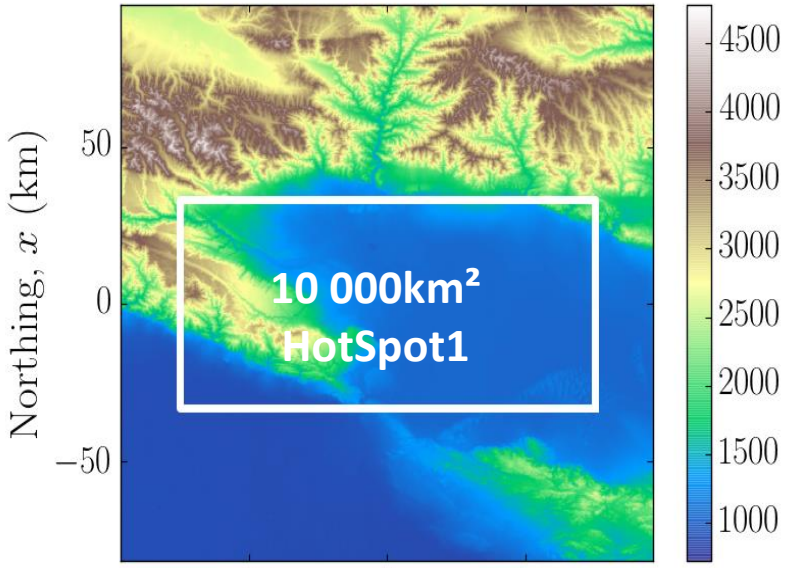
on a 10’000 antennas hotspot (GRAND10k)

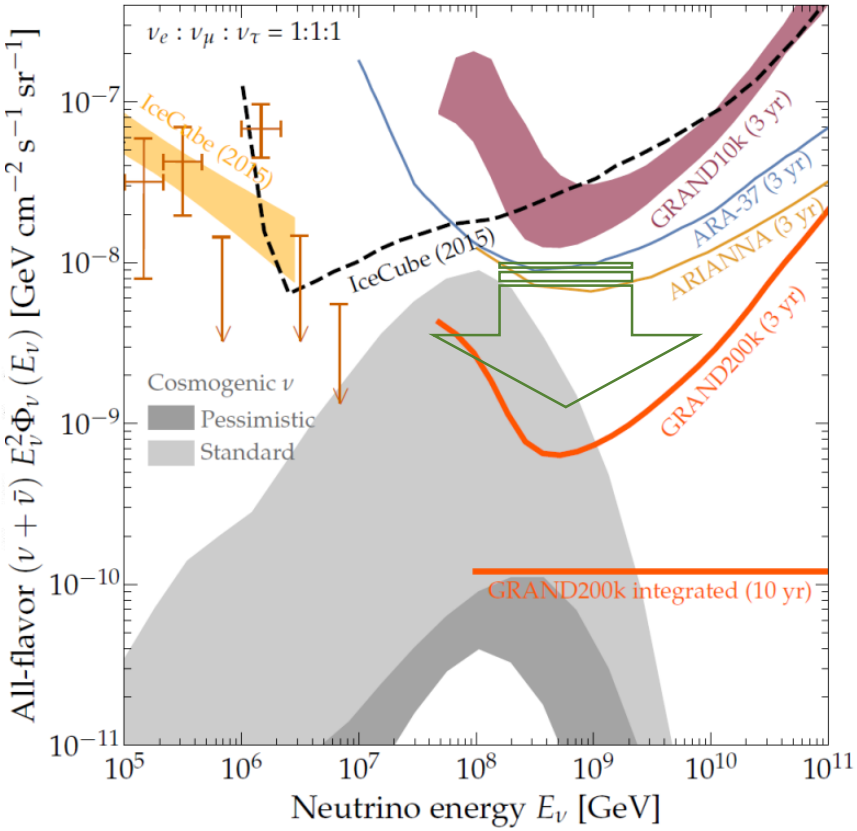
➔Sensitivity in IceCube2015 range.

- **Go for x20!! ➔ Network of o(20) subarrays of o(10000) antennas with sparse density (1/km²) at various favorable locations around the world (« hotspots »)**
- Sensitivity of full array good enough for GRAND to detect cosmogenic neutrinos for standard hypothesis



Alvarez-Muniz et al., The GRAND collab, Sci. China-Phys. Mech. Astron. 63, 219501 (2020) arXiv:1810.09994





Improving ν sensitivity?

- **Role of topography: up to x3** (see eg Decoene et al., arXiv:1903.10466)
- **Trigger threshold** improvement could surely allow to increase effective area,

  BUT probably by factor of a few only (at least for $E_\nu \geq 10^{17}$eV)
  - GRAND sims: **5σ ➔ 3σ: A_{eff} x 1.6; 5σ ➔ 2σ: A_{eff} x 2.5**
- Bottom line: ν-induced EAS are seldom!... And we already detect a significant fraction with standard trig (TBC).
  - **GRAND sims : factor ~2-3 between full efficient & 2σ threshold**
  - Pieroni PhD with similar results

➔ **Discuss more at « effective area » session!**

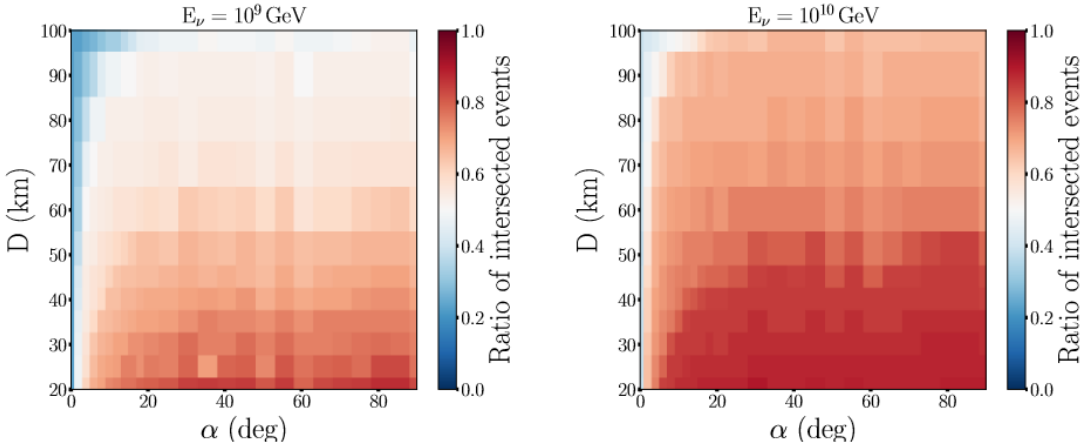
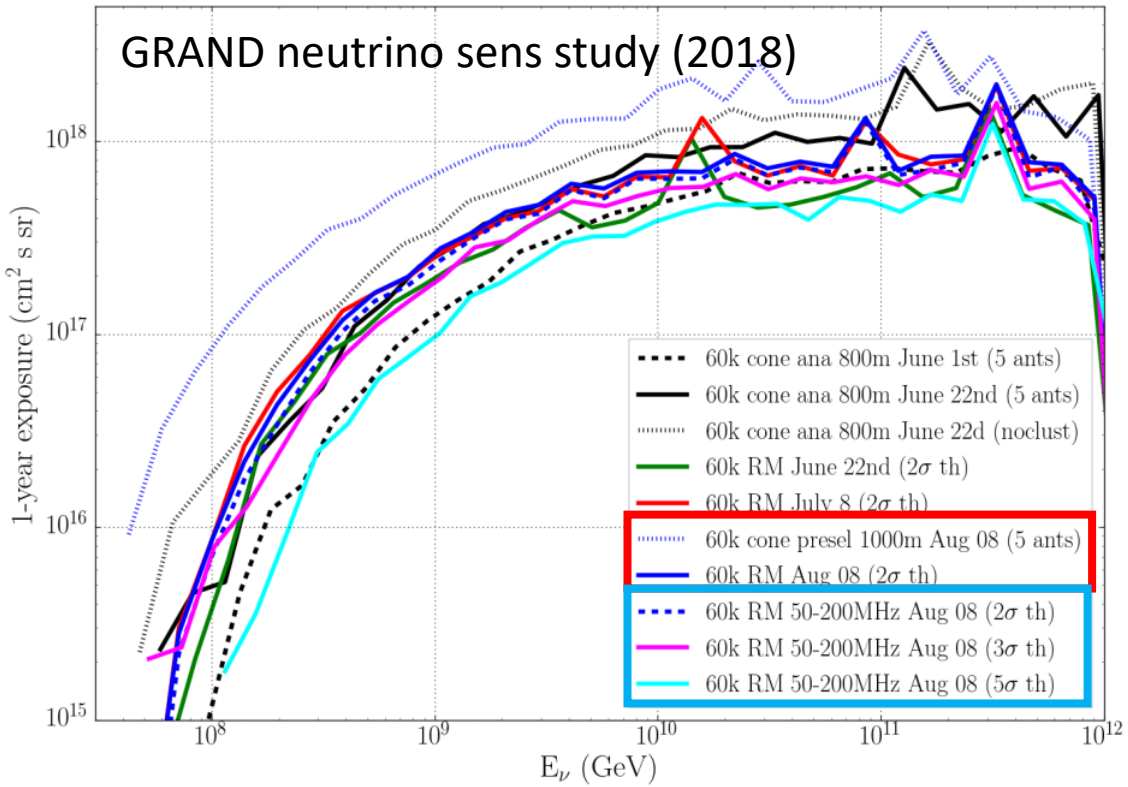
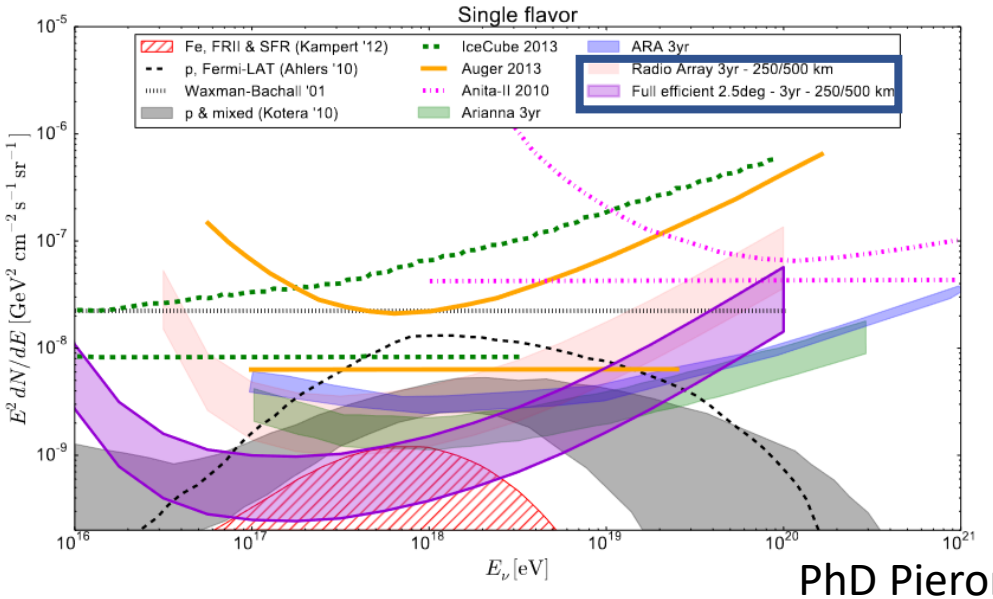


Figure 12: *Left:* Fraction of events intersecting the detection area as a function of distance D and slope α for the simulation set with a primary neutrino energy of 10^9 GeV. *Right:* Same for a primary neutrino energy of 10^{10} GeV.

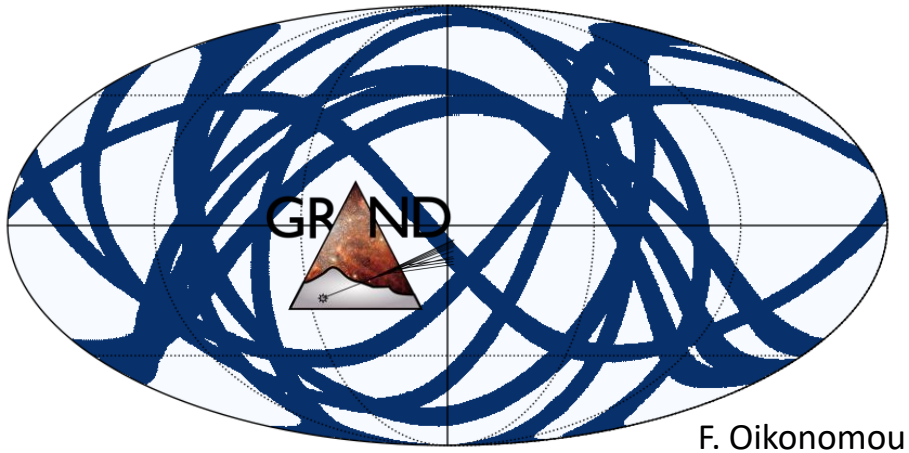




PhD Pieroni (2015)

Figura 11.28: Se agrega como banda violeta a la figura 11.27 el límite diferencial al 90 % C.L. que presentaría un detector 100 % eficiente entre 90° y 92.5°, con un tamaño de entre 250 km y 500 km de lado y para 3 años de medición. Esta banda permite formar una idea los límites que tiene la detección de neutrinos con SD de antenas de radio.

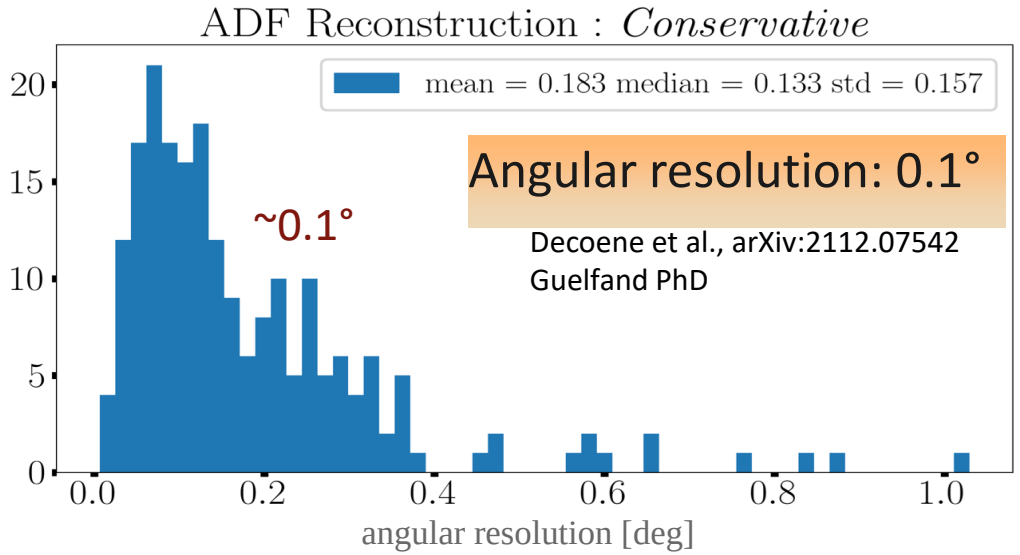
GRAND performances



F. Oikonomou

instantaneous FoV: 45% of sky

(for 10 random* site locations between 40S and 60N)



2021 / 2025 / >2030	Diff. sens. lim. in GeV cm^{-2} s^{-1} sr^{-1}	iFoV in sky %	dFoV in sky %	ang. res.
PUEO	4.2×10^{-8} in 30 d	6	19	$<2.8°$
ARA	3.6×10^{-9} (2030)	35	20	5°
RNO-G	1×10^{-8} in 5 yr	30	35	$2°\times10°$
ARIANNA-200	8×10^{-9} in 5 yr	50	>50	$2.9–3.8°$
RET-N	3×10^{-10} in 5 yr	50	>50	?
IceCube-Gen2 Radio	4×10^{-10} in 5 yr	43	43	$2°\times10°$
BEACON	1.2×10^{-8} in 5 yr	6	19.5	$0.3°–1°$
GRAND10k	1×10^{-8} in 5 yr	6	80	0.1°
GRAND	4×10^{-10} in 5 yr	45	100	0.1°
Auger	$[1.5\times10^{-8}$ (2019)]	30	92.8	$<1°$
TAMBO	?	27	62	1°
POEMMA Cerenkov	7×10^{-8} in 5 yr	0.6	$18–36$	0.4°
Trinity	1×10^{-10} in 5 yr	6	62	$<1°$
Ashra-NTA	2×10^{-10} in 5 yr	30	>50	0.1°

adapted from Guépin et al. Nature Phys. Rev. 2022

A competitive proposal for the detection of UHE neutrinos

A staged approach with self-standing pathfinders

	GRANDProtos	GRAND10k	GRAND200k
	2023	2028	2032 (?)
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-array** • discovery of EeV neutrinos for optimistic fluxes • radio transients (FRBs!)	sensitive all-sky detector **1st EeV neutrino detection and neutrino astronomy!**
Setup	• **GRANDProto300**: 300 antennas over 200 km² in Gobi desert • GRAND@Auger: 10 antennas for cross-calibration • GRAND@Nançay: 4 antennas for trigger testing & setup validation	• 2 detectors of 5-10k antennas each in each hemisphere: GRAND-North (China) and GRAND-South (Argentina?)	• 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 + ANR-DFG NUTRIG (France- Germany) + Radboud University	13 M€ 1500€/unit	300M€ in total 500€/unit to be divided between participating countries

GRANDProto300 & other prototypes: experimental setup

The HorizonAntenna:
3 butterfly arms + LNAs

WiFi antenna connected to bullet

Deployment of 13 antennas in Gansu (China), to be completed by 70 more in 2024, and 200 more later

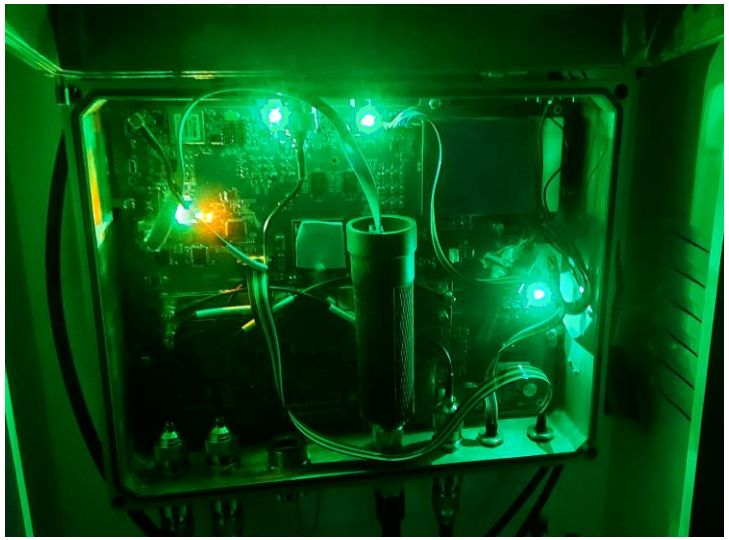
Deployed Feb 2023

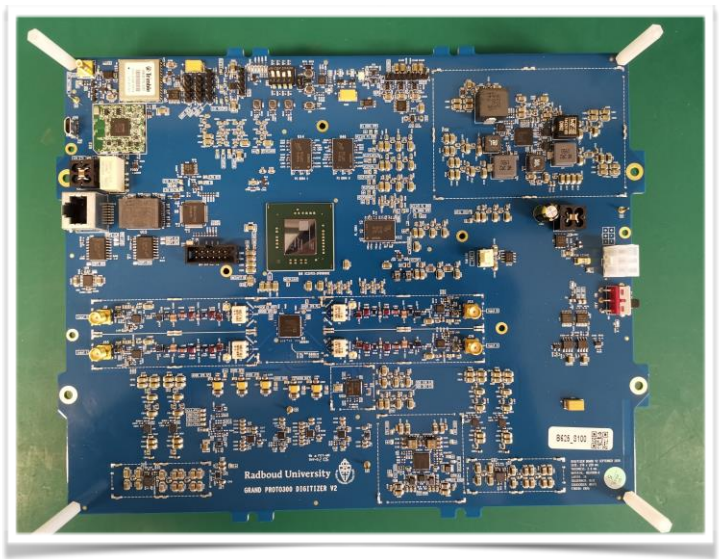
Deployment of 10 antennas on the Auger site in Malargüe, Argentina (cross-calibration)

Deployed Aug 2023

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

Deployed Oct 2022

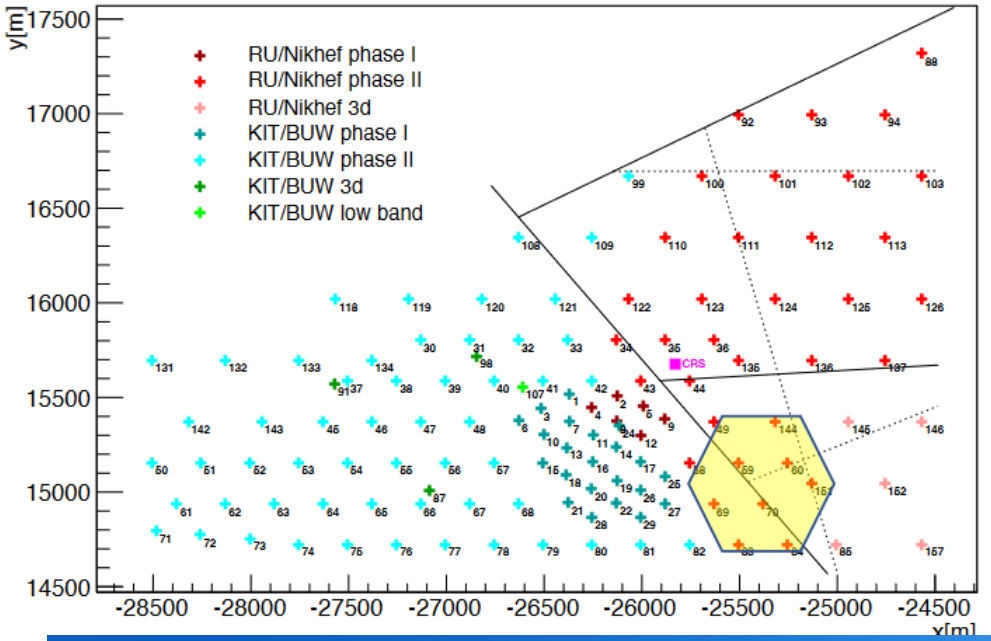


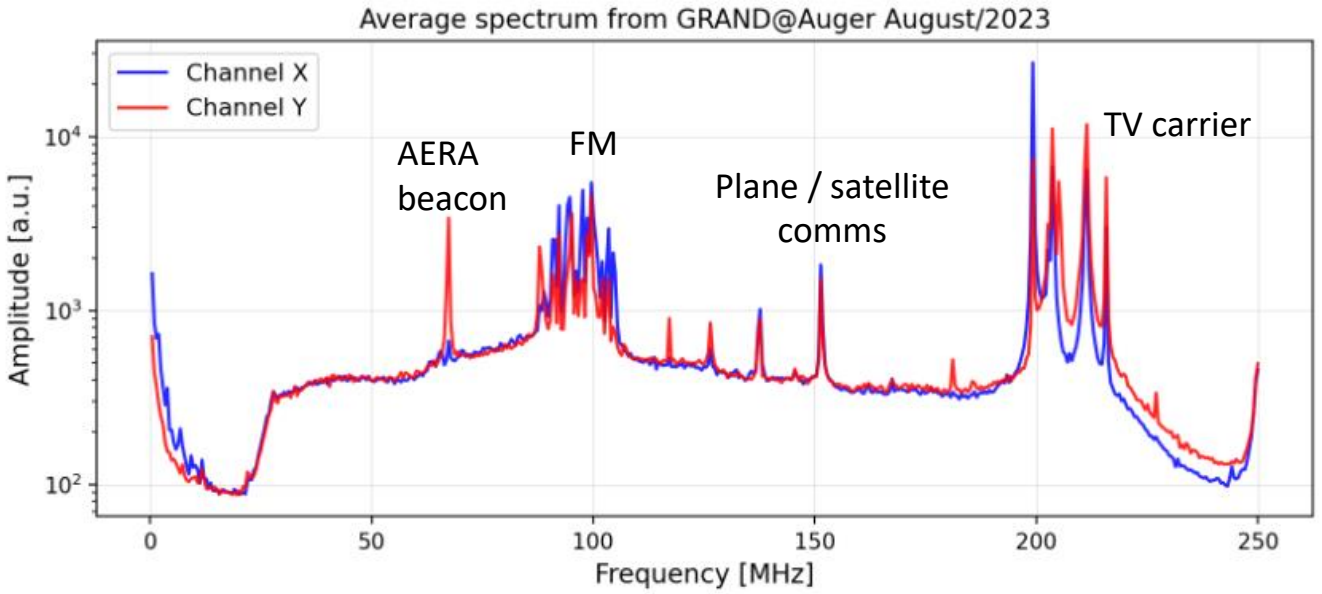


50-200MHz analog filtering,
Electronics:
500MSPS sampling
FPGA+CPU
Bullet WiFi data transfert

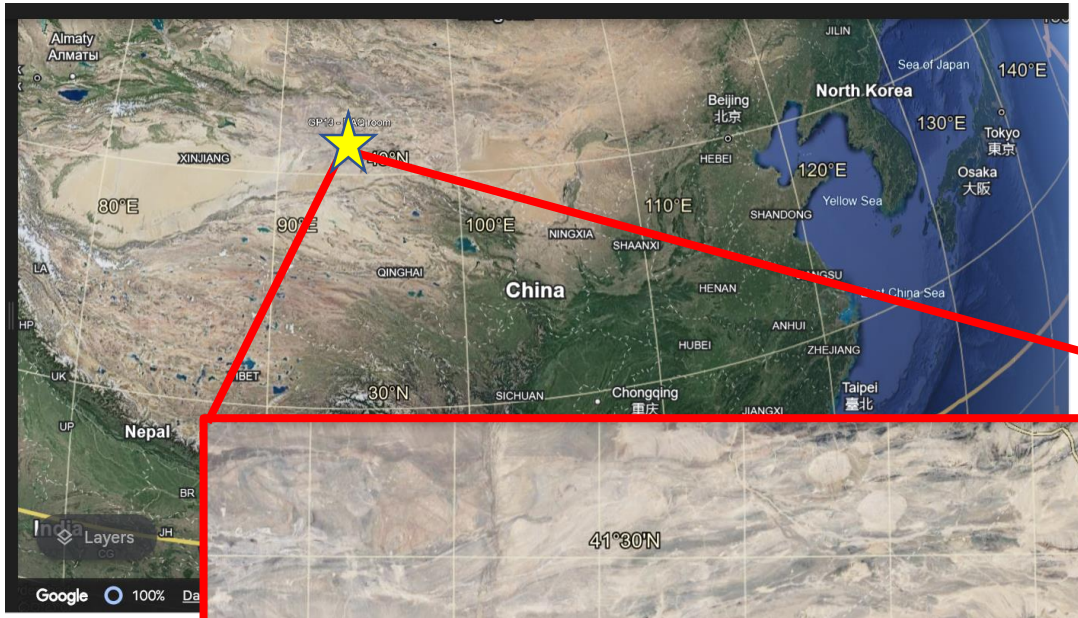
GRAND @ Auger

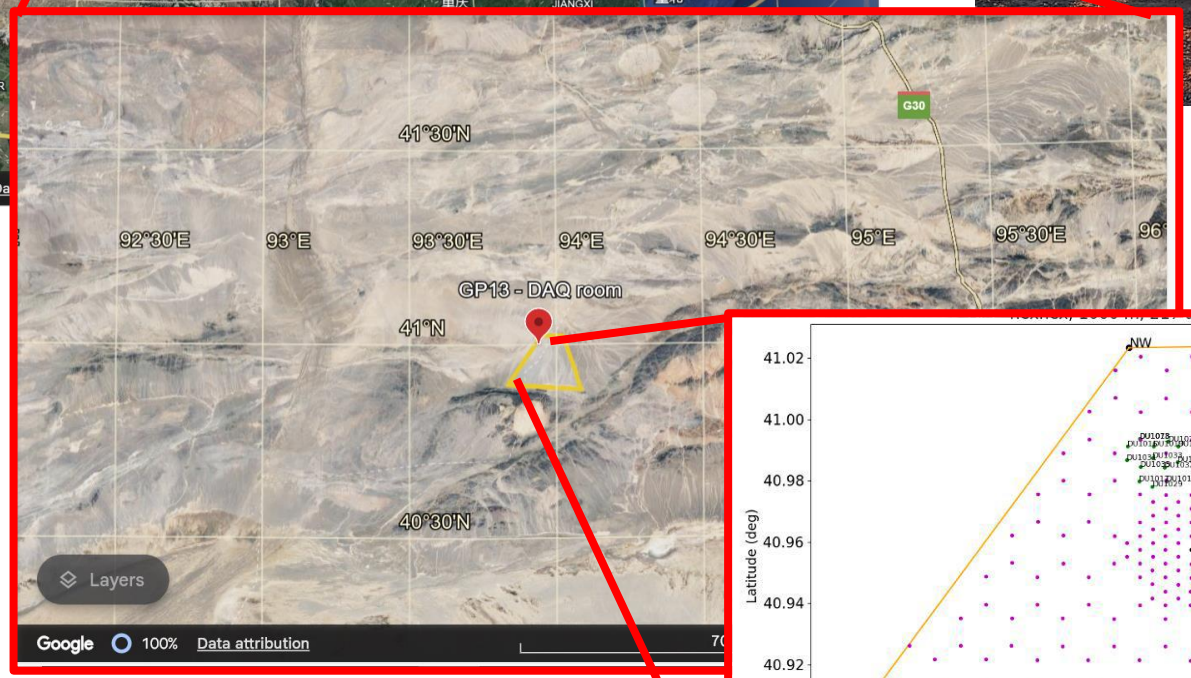
- 10 GRAND detection units at location of AERA antennas, using Auger infrastructure.
- Run autonomously & offline comparison with Auger data
- Expected rate: **~1 EAS/day in coinc with Auger**
- Present status: commissioning

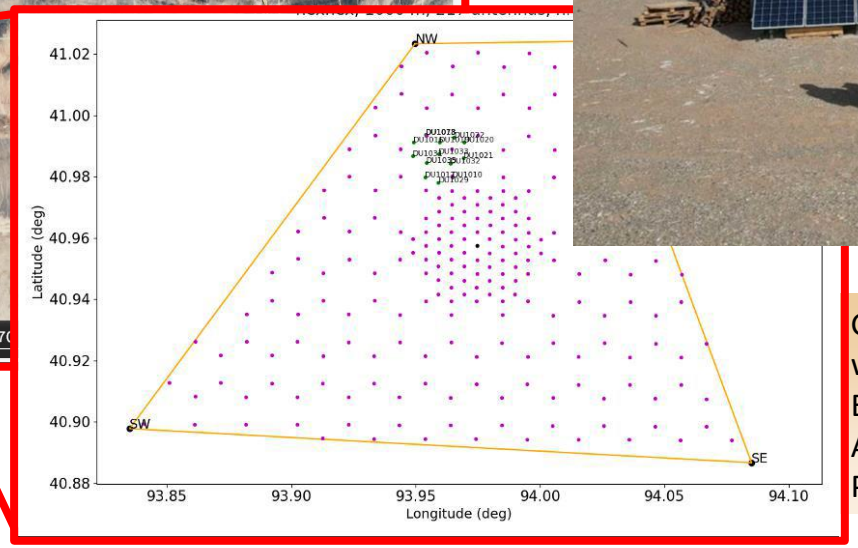




GRANDProto300 in XiaoDuShan



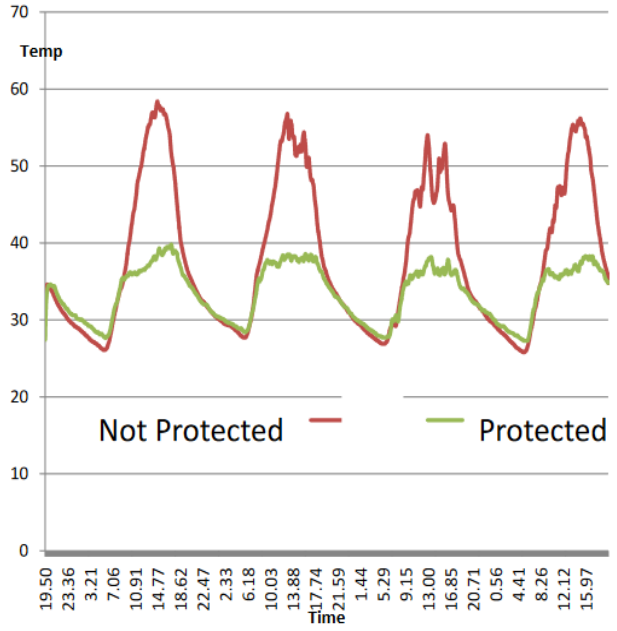


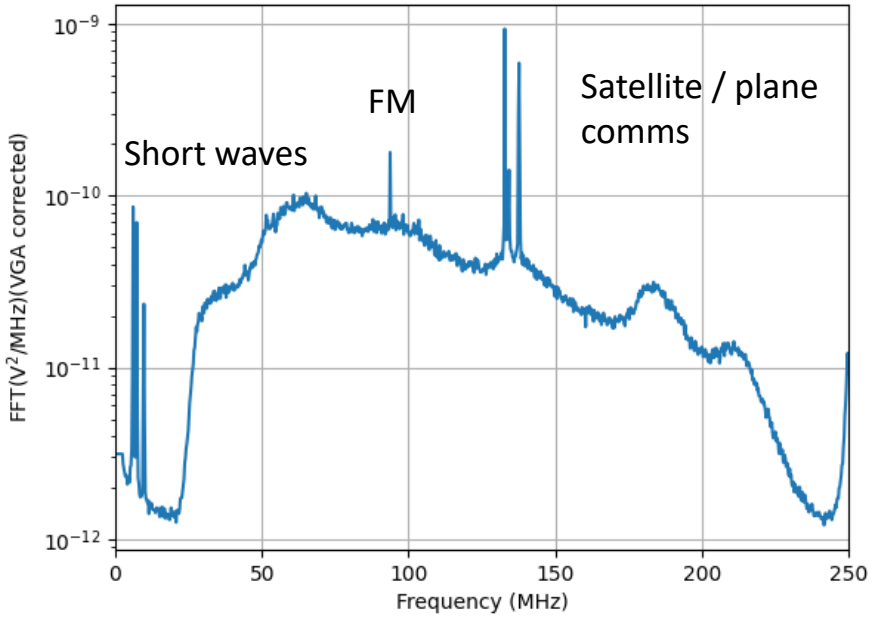


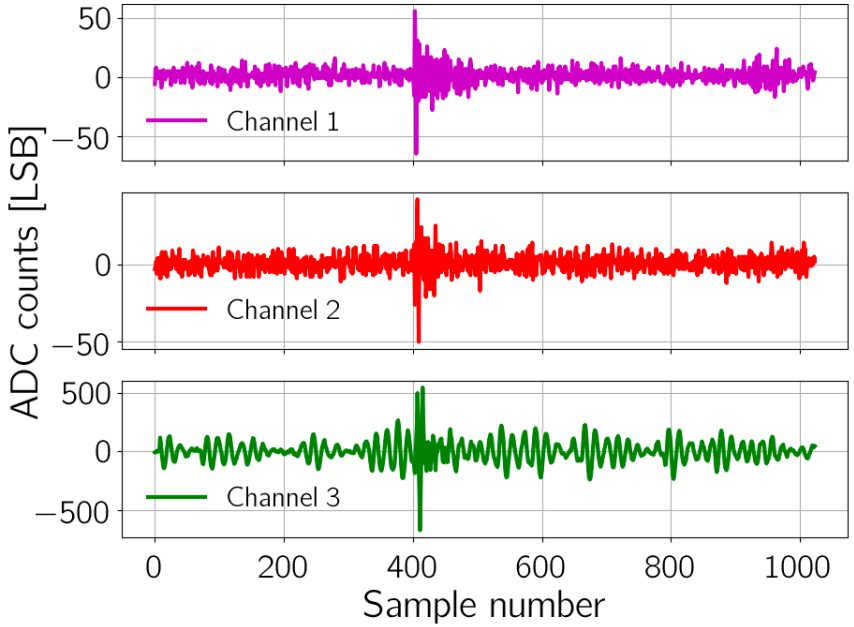
GP300: ~300 antennas, 200km², 1km step size with denser infill
Erange = $10^{16.5}$-10^{18}eV
AT present 13 antennas
Plan for 80 at summer 2024

GRANDProto300 in XiaoDuShan

- 13 antennas deployed in Feb 2023 for design validation (Xidian U. & Purple Mountain Observatory)
  - Thermal regulation ➔ OK
  - Control of radio self-emission ➔ OK
  - Reconstruction of coincident pulses ➔ OK
  - Trigger ➔ in progress

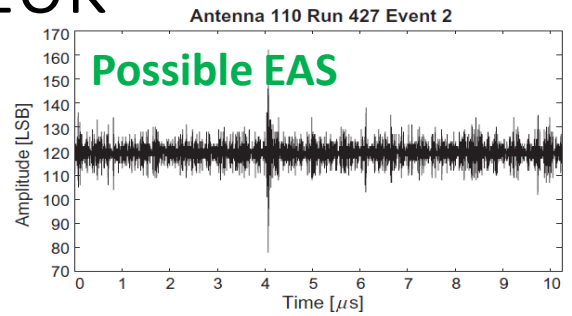


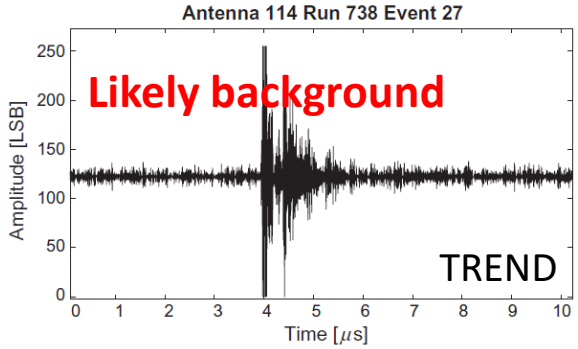


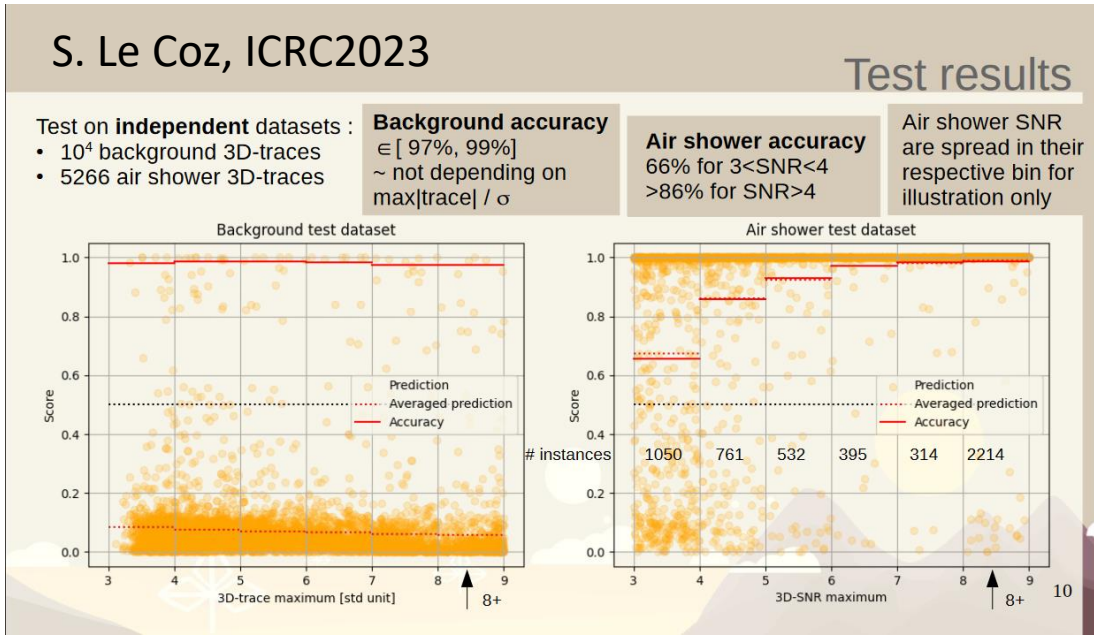


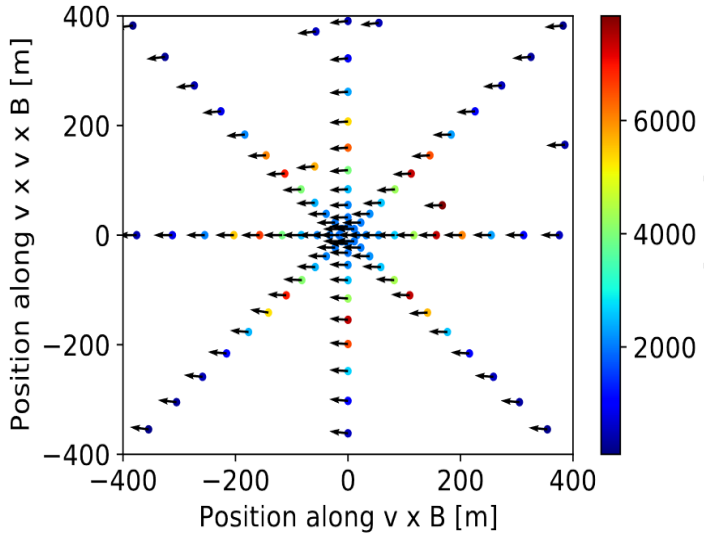
R&D for GRAND10k

- Working towards a cheap, robust & frugal system:
  - less mechanics
  - less cables
  - Cheaper SoC/FPGA
  - less power consumption
  - less data transfer
- To be tested on GP300 starting 2024-26
- Trigger as key parameter ➔ **NUTRIG project** (KIT & Paris): working towards a pure, efficient and scalable methods to trigger over giant arrays, based on specific signatures of signal & background.
  - First Level Trigger @ Detection Unit
  - Second Level Trigger @ Central DAQ

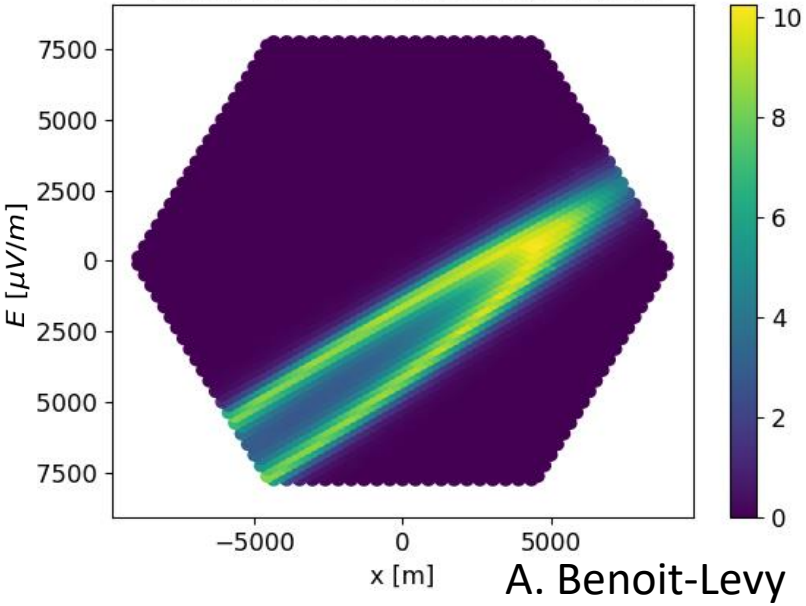








S. Chiche



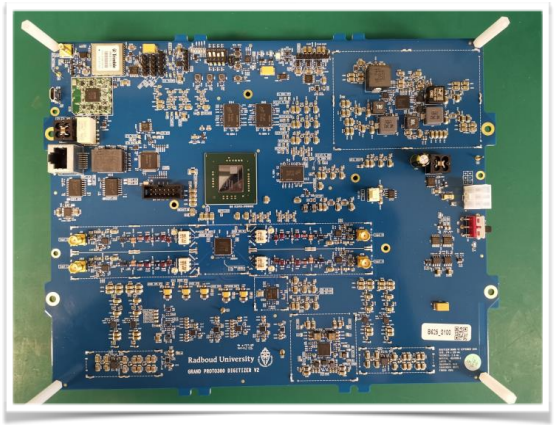
A. Benoit-Levy

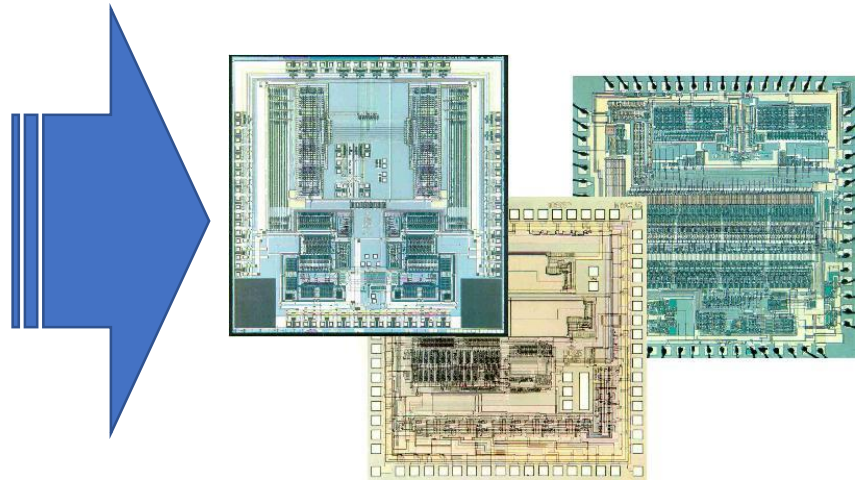
The GRAND200k detector (design freezed in 2030?)

- As basic/robust/cheap as possible
  - 5W/unit ➔ xx solar pannel
  - 500€/unit (including deployment)
- **Apply industrial/validated/off-the-shelf solutions**
- Many unknowns to be worked out in the next 5+ years

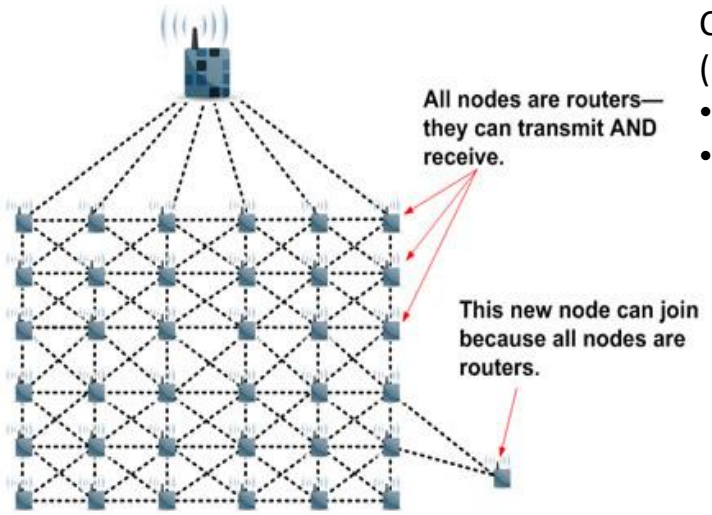
  (but that is what we love ☺) :
  - Antenna design/power supply
  - Trigger strategy?
  - Comms?
  - Information saved?
  - Logistics?
  - Political aspects?
  - Design tailored to different sites/scie cases?

Electronics: going for ASICs?





Mechanics:
going for utility poles?



Comms: gooing for SmartMesh? (DustTechnologies)
- 2.4GHz band.
- 400By/s on the shelf, 4kBy/s in R&D stage

(Personnal) conclusion

- GRAND designed as a network of giant radio arrays.
- Staged approach, now into prototype phase (2024 as moment of truth)
- Detection unit as simple (ie cheap) as possible to achieve **very large detector area**
- Driver: even the best radio detector can only detect neutrino-induced EAS which exist, and those are very seldom!

- BUT
  - Very happy to be proved wrong at this workshop!
  - GRAND can be a versatile network presently in its early stage of design
    ie combined with other technics / adapted to other designs.