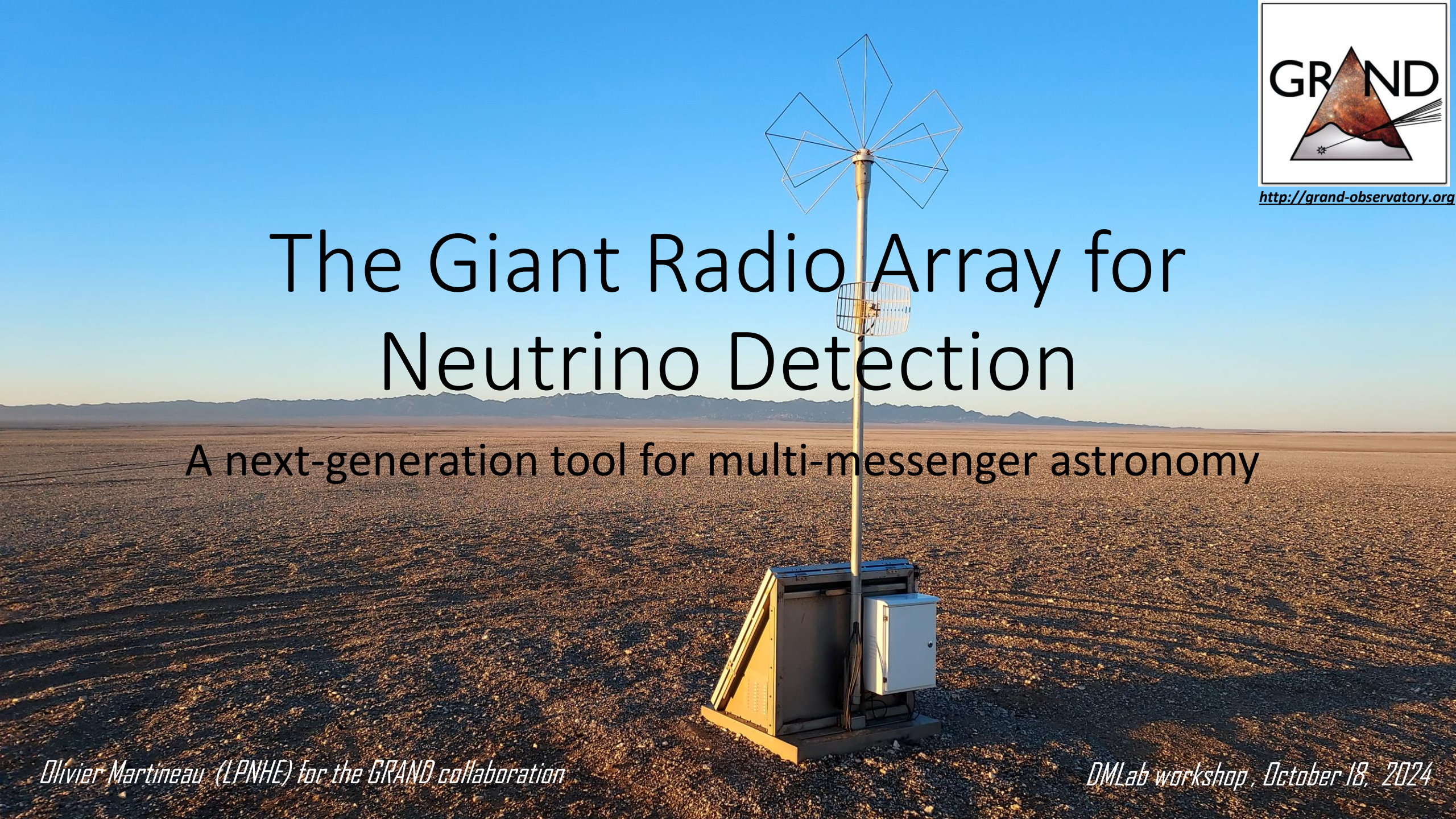


The Giant Radio Array for Neutrino Detection

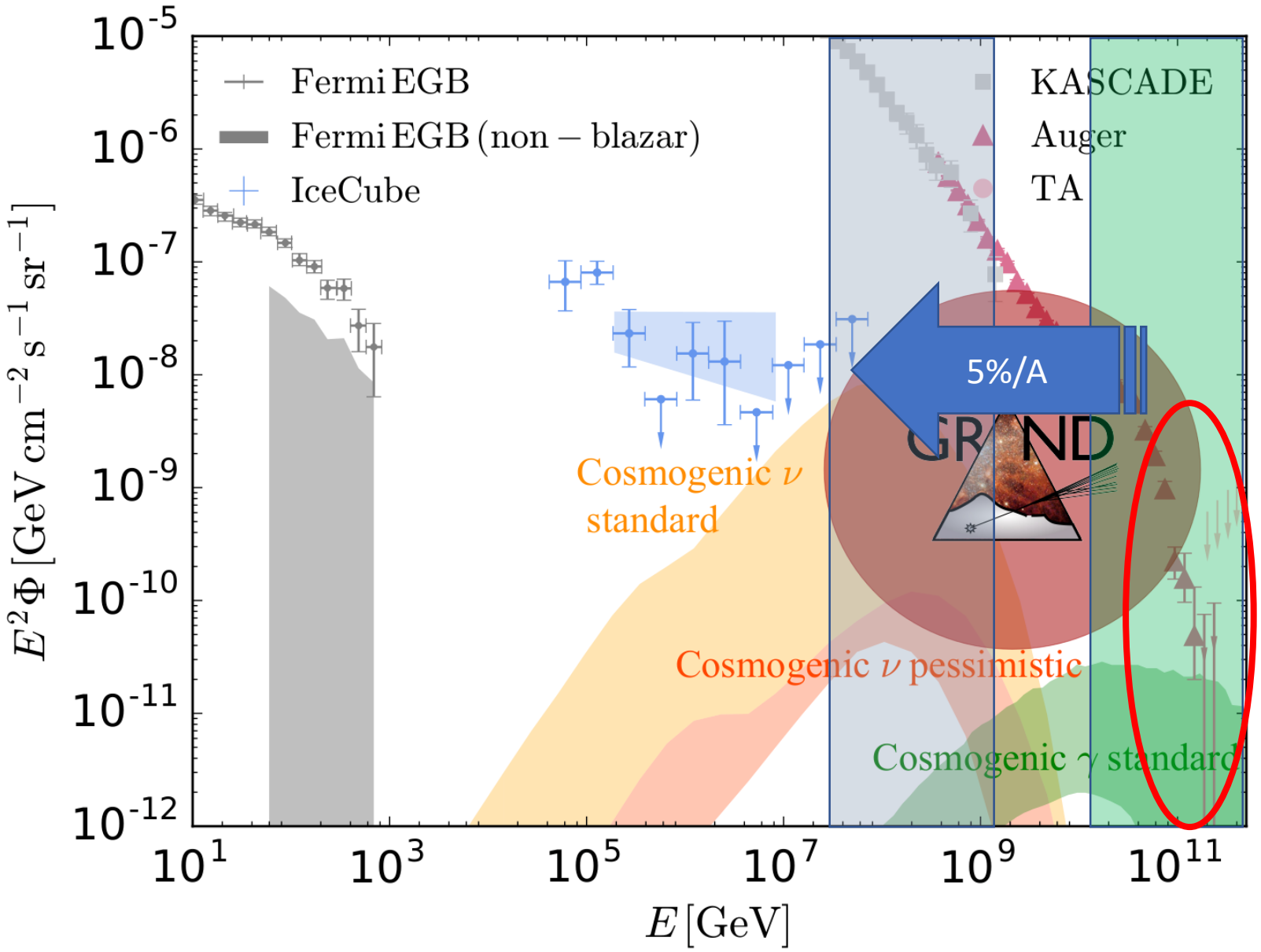
A next-generation tool for multi-messenger astronomy

http://grand-observatory.org

Olivier Martineau (LPNHE) for the GRAND collaboration

DMLab workshop, October 18, 2024

The New Frontier of the cosmic landscape



UHECR sources still not know!
Challenges:
Charge + mixed composition
EAS physics…
UHE neutrinos as a powerful indirect probe?

Understanding the violent Universe?

Neutron star mergers

Magnetars (AXP/SGR)

Young pulsars

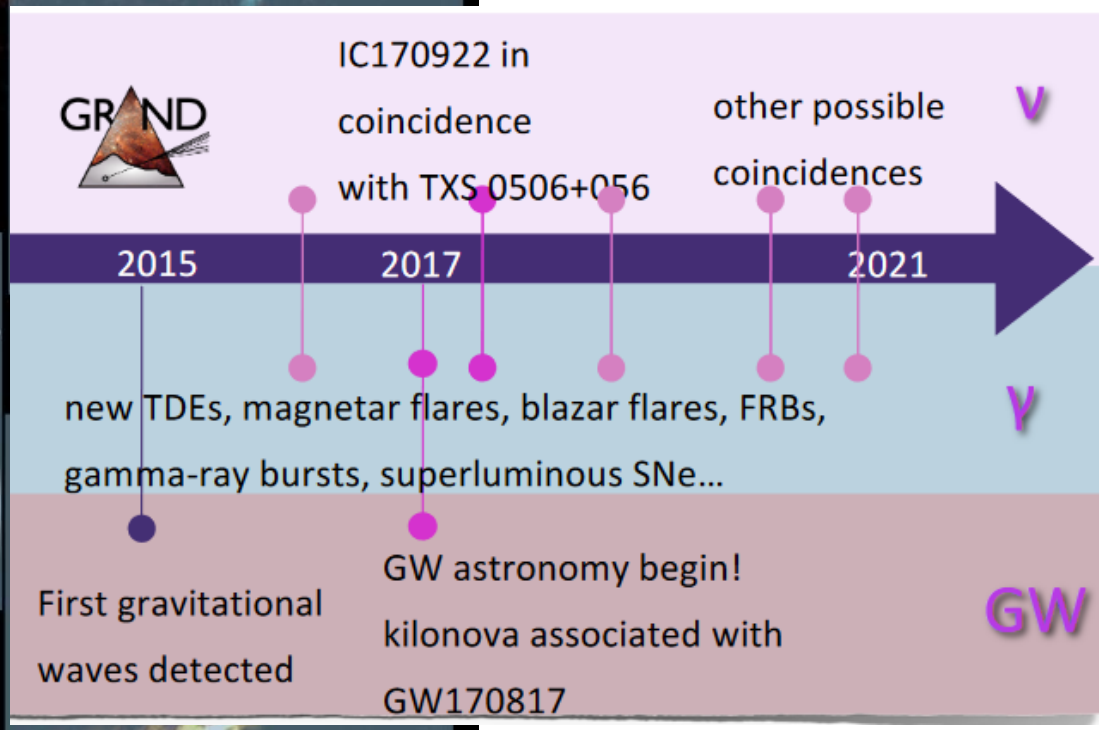
AGN/Blazars
flares, time-variabilities

Long Gamma Ray Bursts

Black hole mergers

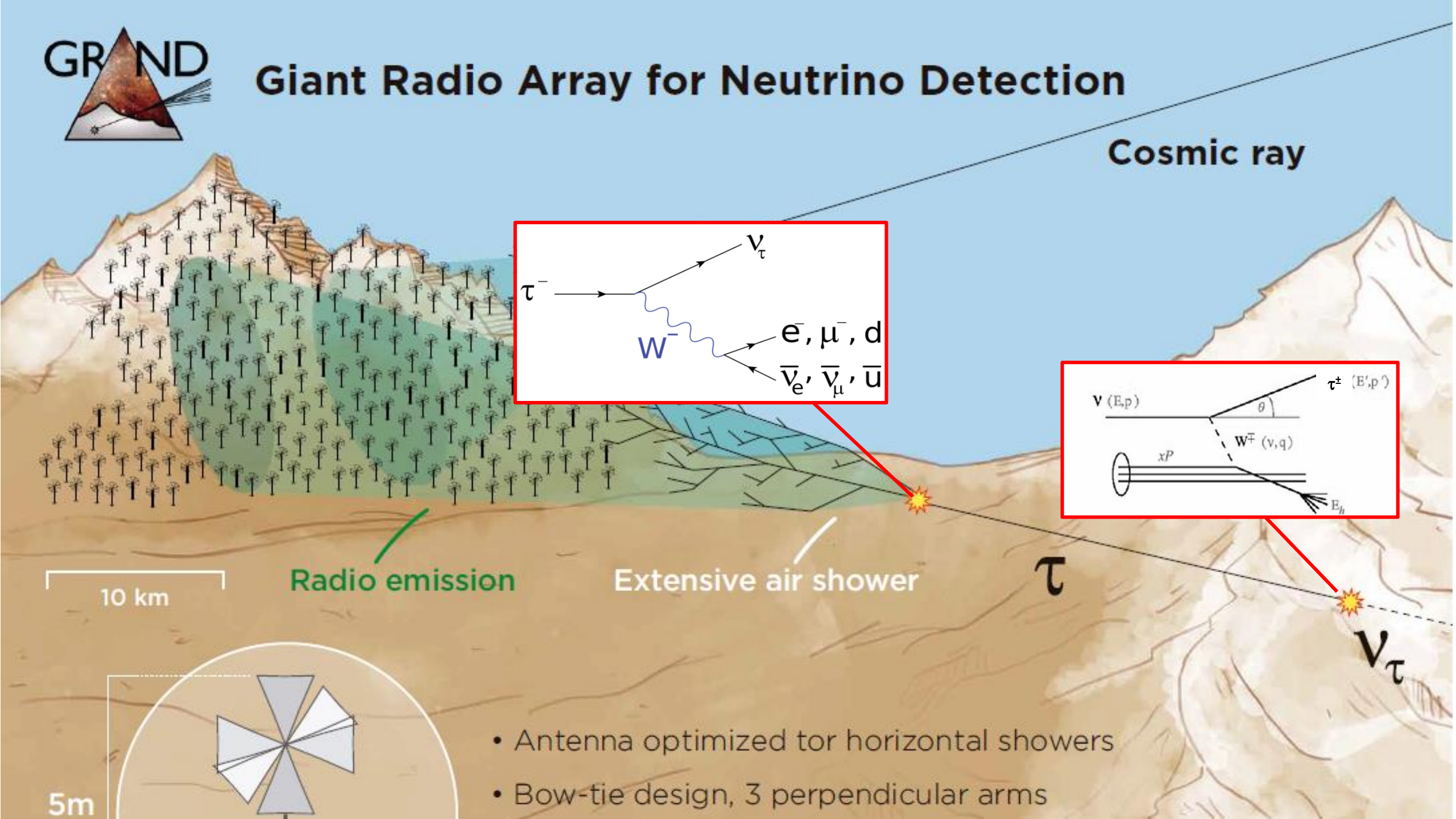
Tidal disruption events

Superluminous Supernovae



Slide by K. Kotera

Giant Radio Array for Neutrino Detection



- Antenna optimized tor horizontal showers
- Bow-tie design, 3 perpendicular arms

The GRAND Collaboration

16 Member & Associate Institutes represented at the Board

- 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

- Nanjing University
- National Astronomical Observatories, Chinese Academy of Sciences (NAOC)
- Purple Mountain Observatory (PMO)
- Xidian University

- 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

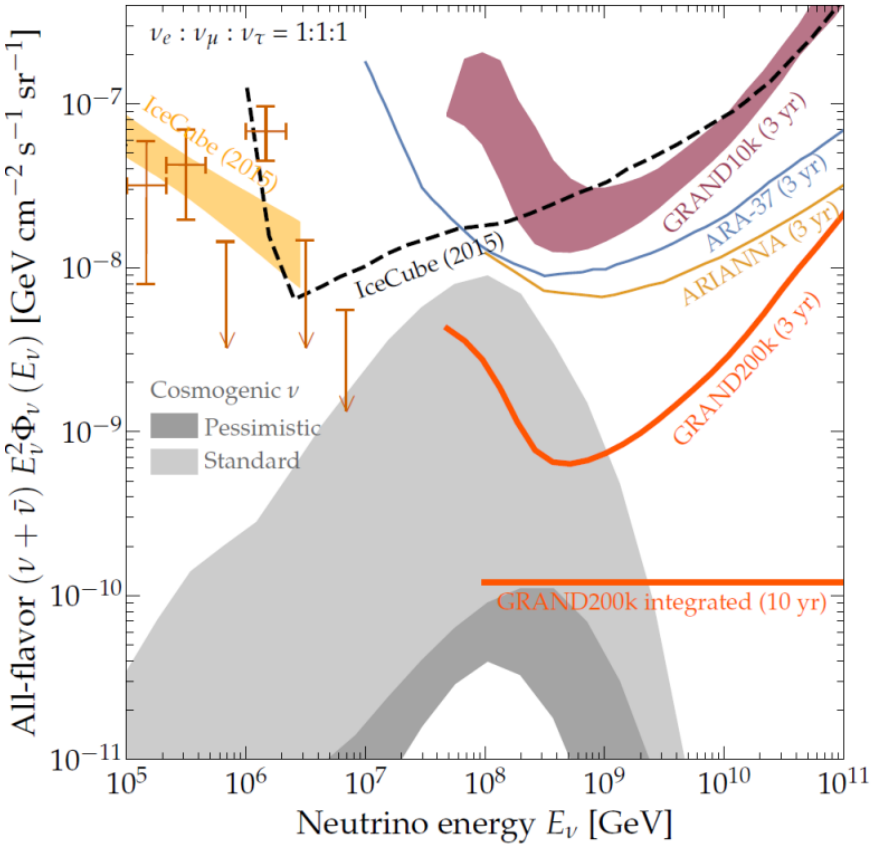
Co-spokespersons: K. Kotera (IAP), Wu XiangPing (NAOC) & O. Martineau (LPNHE)

Nanjing Collaboration Meeting @ Purple Mountain Observatory, May 2024

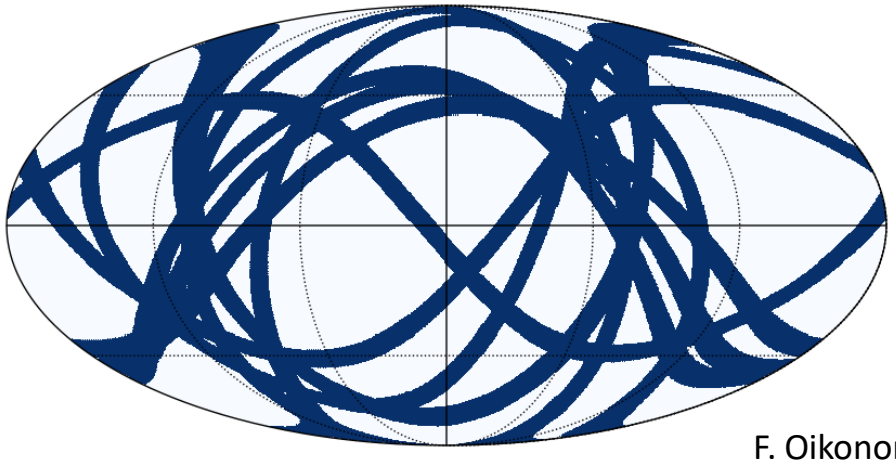
GRAND proposal

A network of o(20) subarrays of o(10000) antennas with sparse density (1/km²) at various favorable locations around the world (« hotspots »)

Alvarez-Muniz et al., The GRAND collab,
Sci. China-Phys. Mech. Astron. 63, 219501 (2020)
arXiv:1810.09994
GRAND simulation and analysis library: `grandlib` arXiv:2408.10926

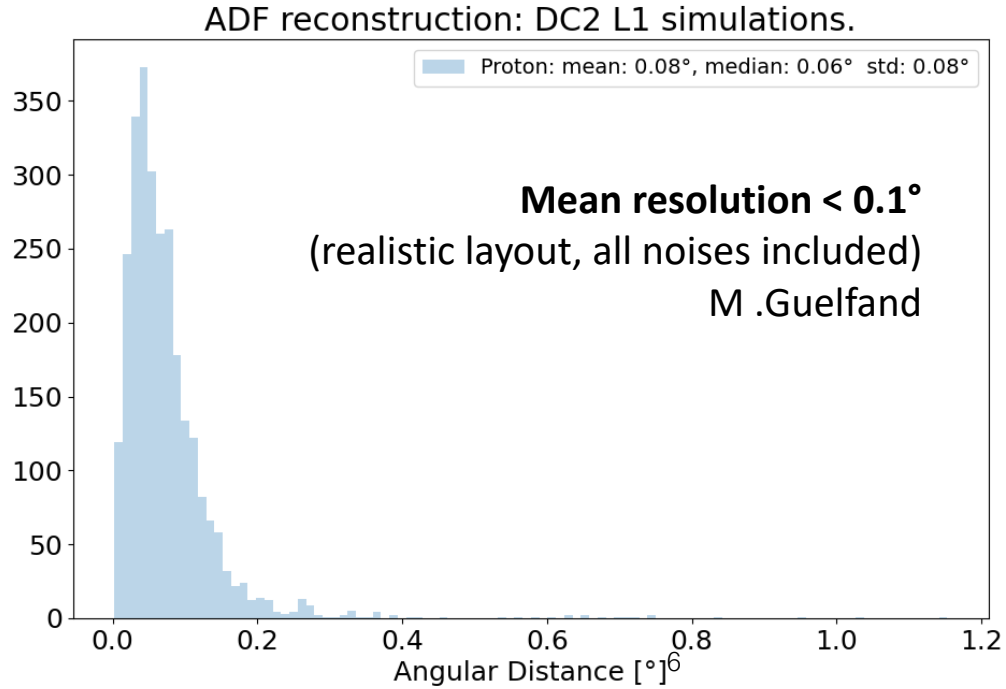


GRAND is the most competitive proposal for the detection of UHE neutrinos (cosmogenic and transient)



F. Oikonomou

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



Mean resolution < 0.1°
(realistic layout, all noises included)
M .Guelfand

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/extragalactic transition • muon problem • radio transients	**1st GRAND sub-array** • discovery of EeV neutrinos for optimistic fluxes • radio transients (FRBs!)	sensitive all-sky detector **Neutrino astronomy!**
Setup	• **GRANDProto300**: 300 antennas over 200 km² • GRAND@Auger: 10 antennas for cross-calibration • GRAND@Nançay: 4 antennas for trigger testing	• 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: status

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

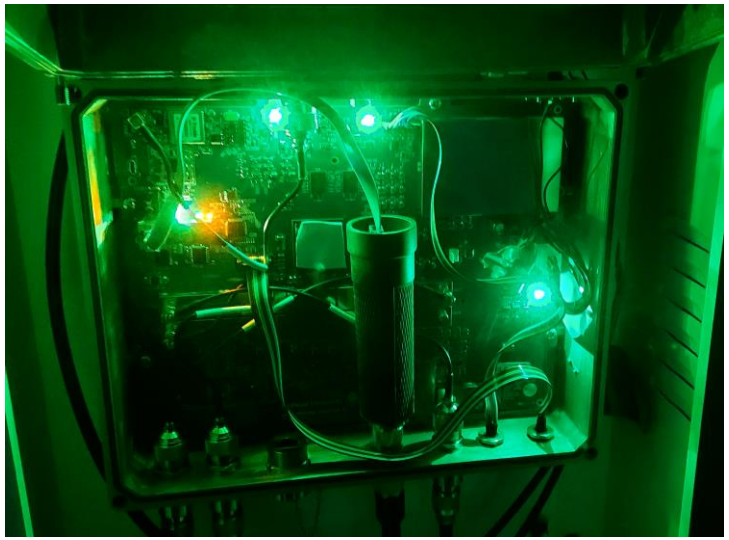
Deployed Feb 2023

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 (LPNHE)

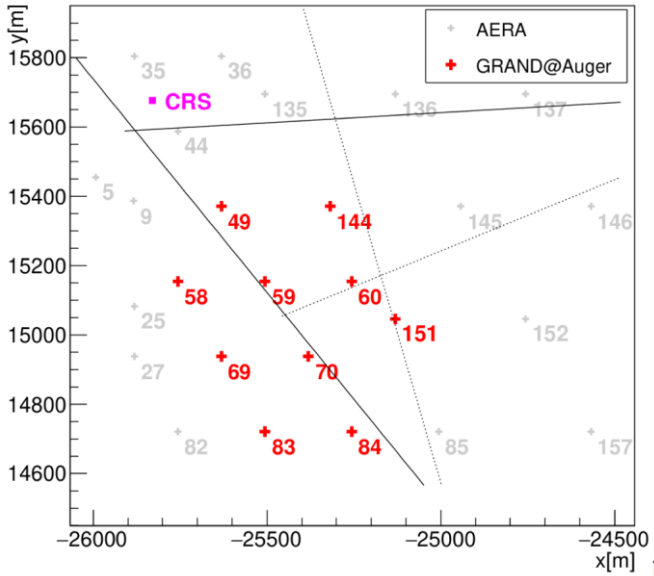
Deployed Oct 2022



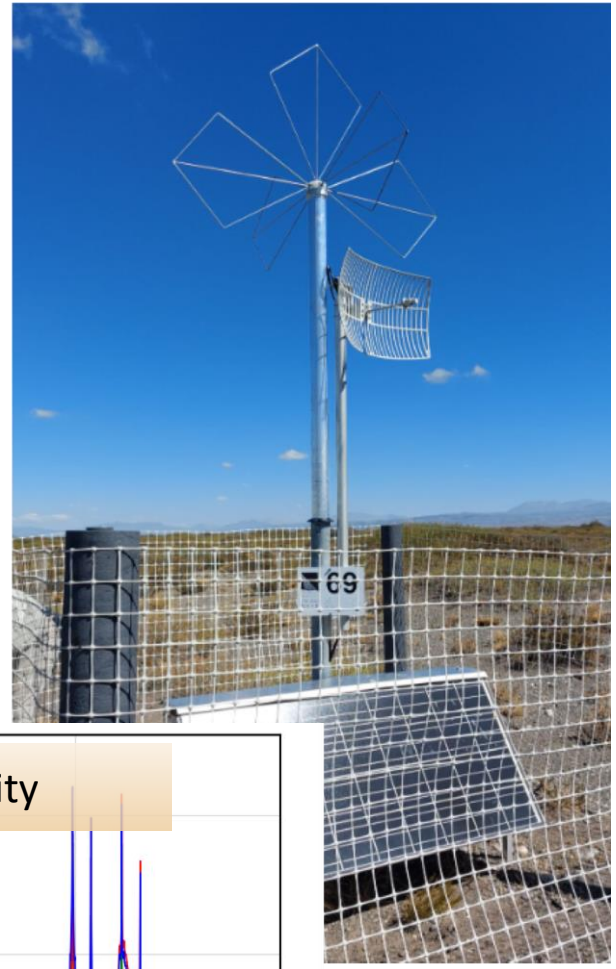
50-200MHz analog filtering,
Electronics:
500MSPS sampling
FPGA+CPU
Bullet WiFi data transfert

Prototypes: GRAND@Auger

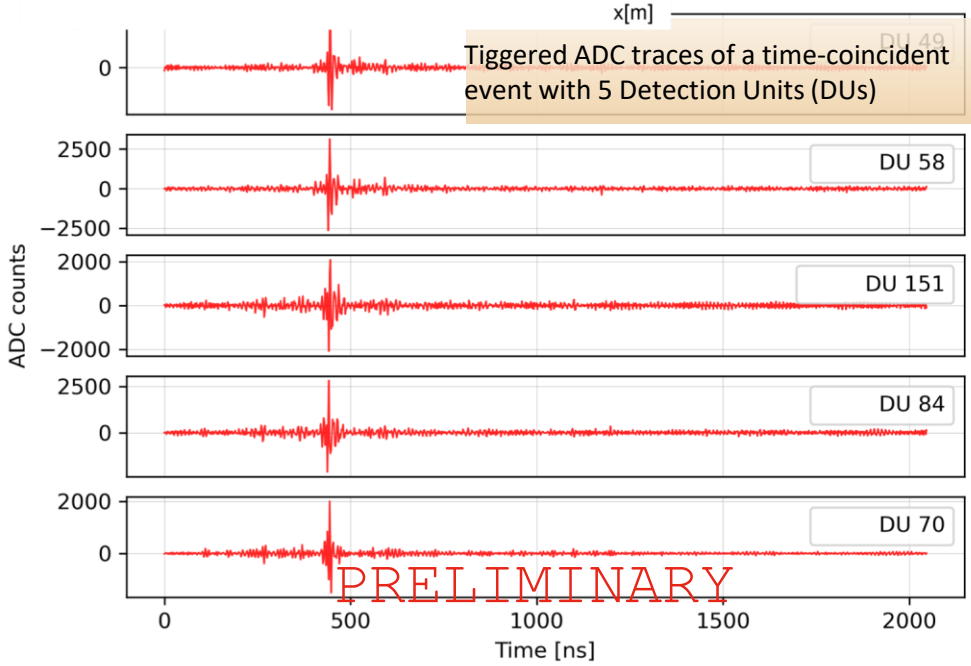
GRAND Coll. in prep.



- Cross-calibration with Auger detectors
  1 coincident event/day expected
- 10 antennas deployed
  Auger mechanical structure + infrastructure
- Hardware tests: set-up stability
- Firmware tests, trigger / transient detection



Tiggered ADC traces of a time-coincident event with 5 Detection Units (DUs)



Power Spectrum Density

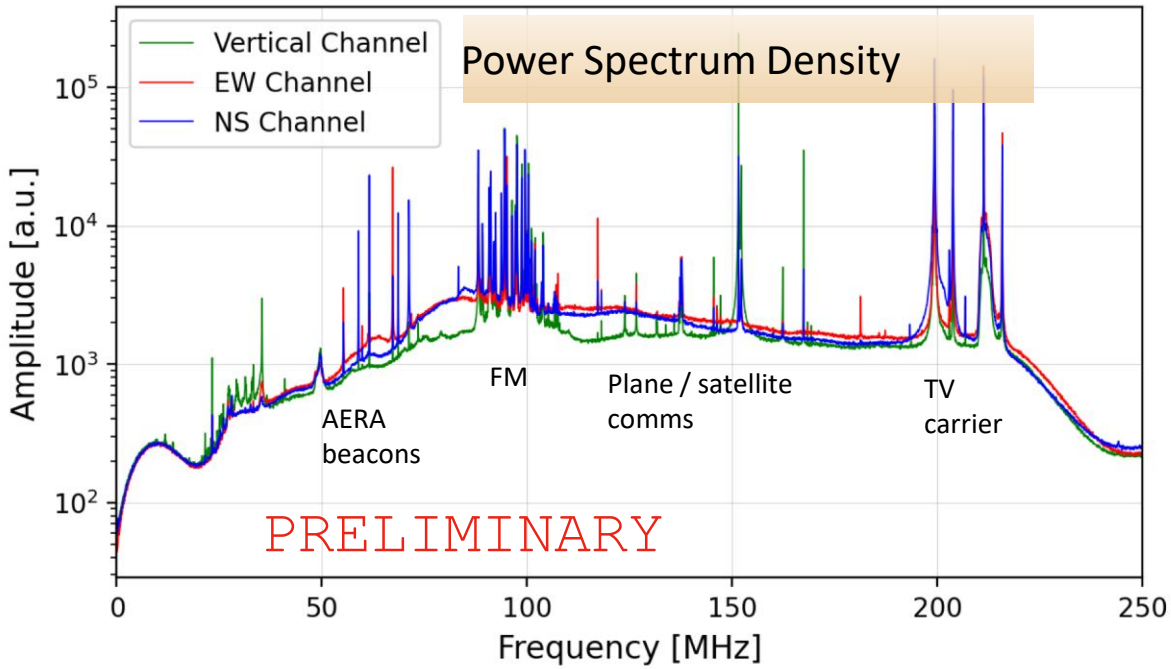
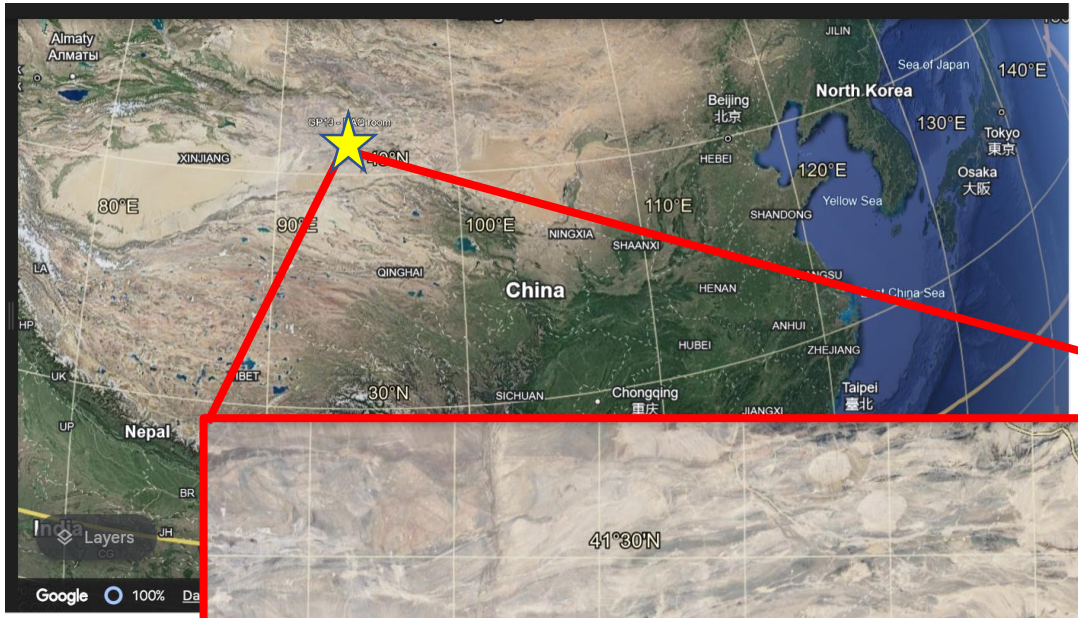
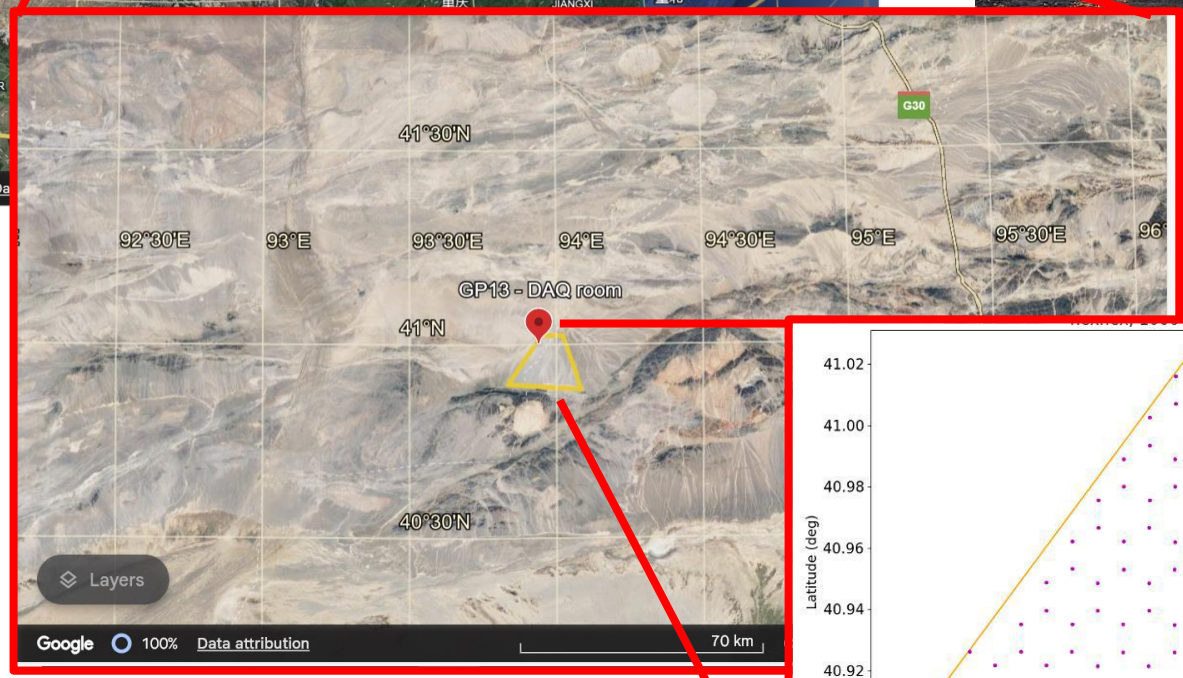
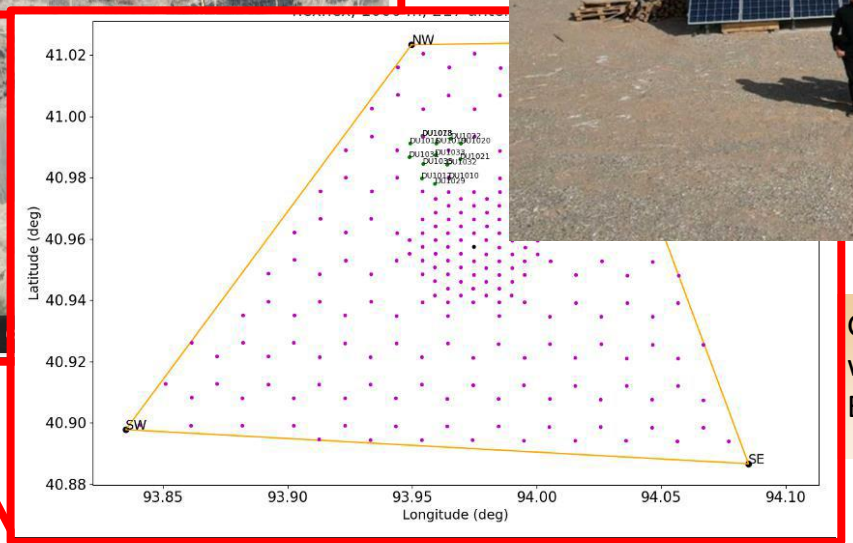


Figure 11: Triggered ADC traces in the NS polarization of a time-coincident

GRANDProto300 in Xiao Dushan







The Gobi desert

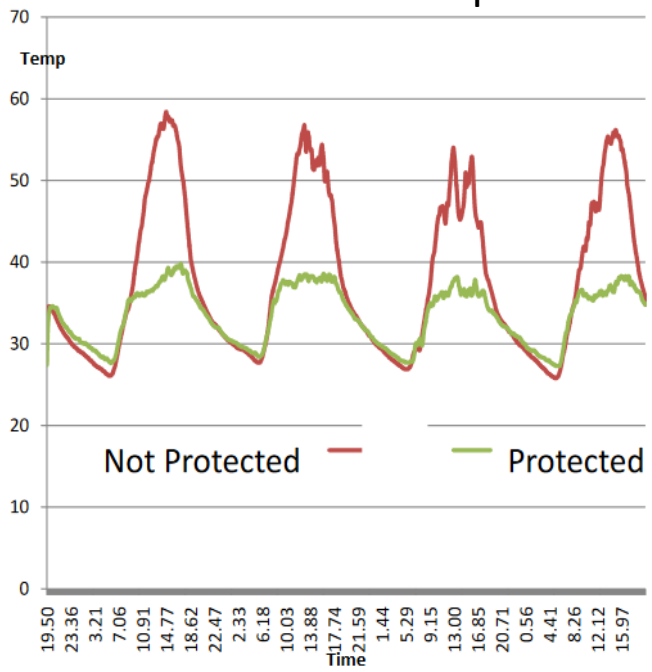
The DAQ room (and living quarters)

GP300: 300 antennas, 200km^2, 1km step size with denser infill (TBC)
Erange = $10^{16.5}$-10^{18}eV

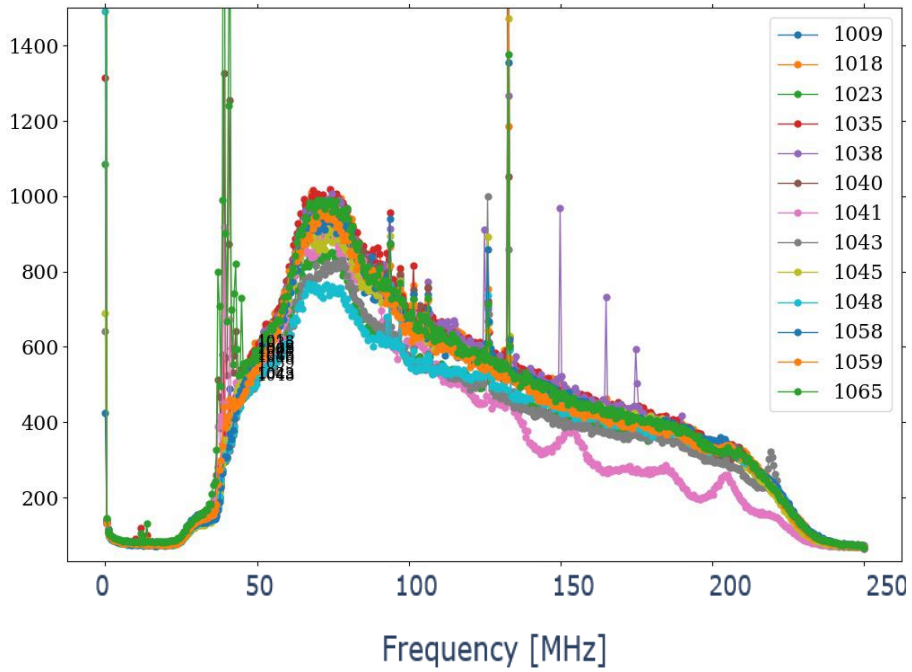
GRANDProto300 in Xiao Dushan

- 13 antennas deployed in Feb 2023 for design validation (Xidian U. & Purple Mountain Observatory)
  - Thermal regulation ➔ OK
  - Control of radio self-emission ➔ OK
  - Trigger / transient pulse detection ➔ OK
  - Data collection efficiency/ setup stability ➔ in progress
  - Amplitude Calibration ➔ in progress

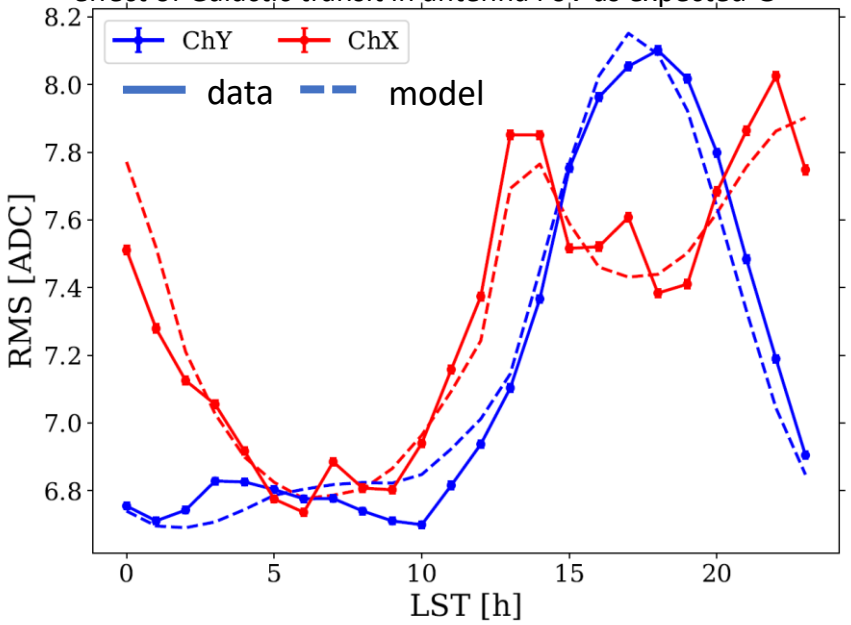
Front End Board Temperature



GP13 Y arm frequency spectra Sep 2024

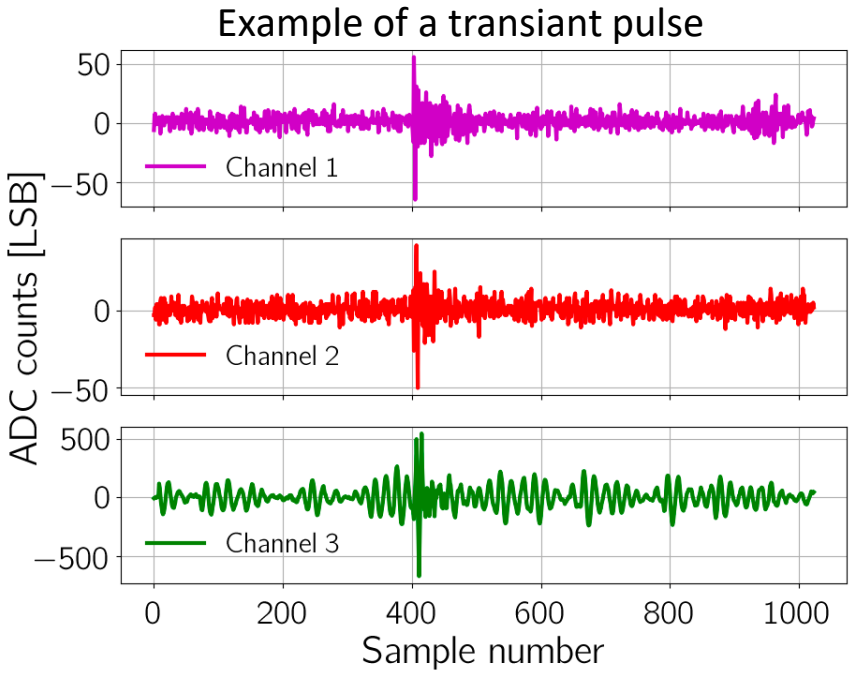


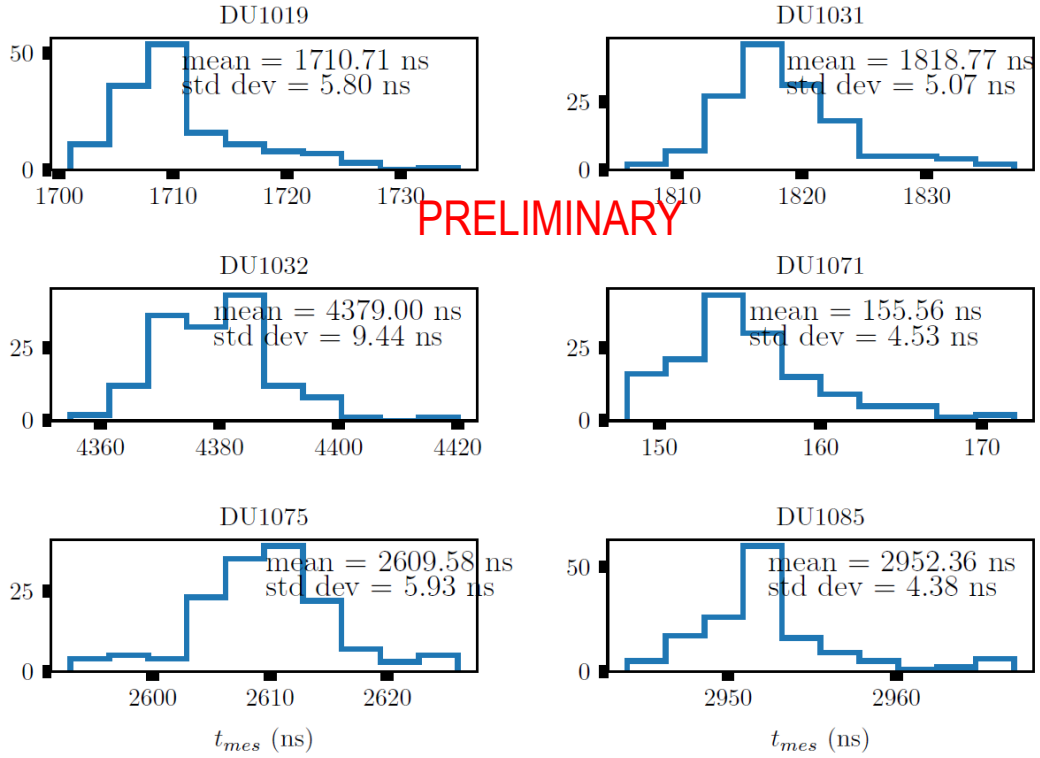
Baseline noise level over 24h:
effect of Galactic transit in antenna FoV as expected ☺

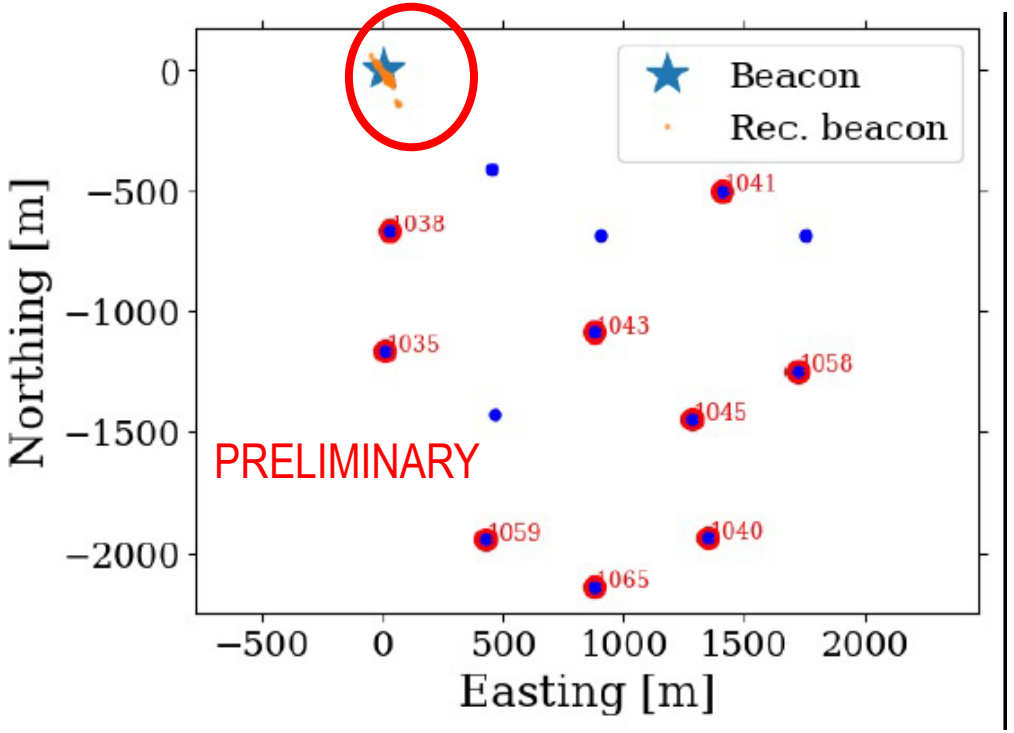


GRANDProto300 in Xiao Dushan

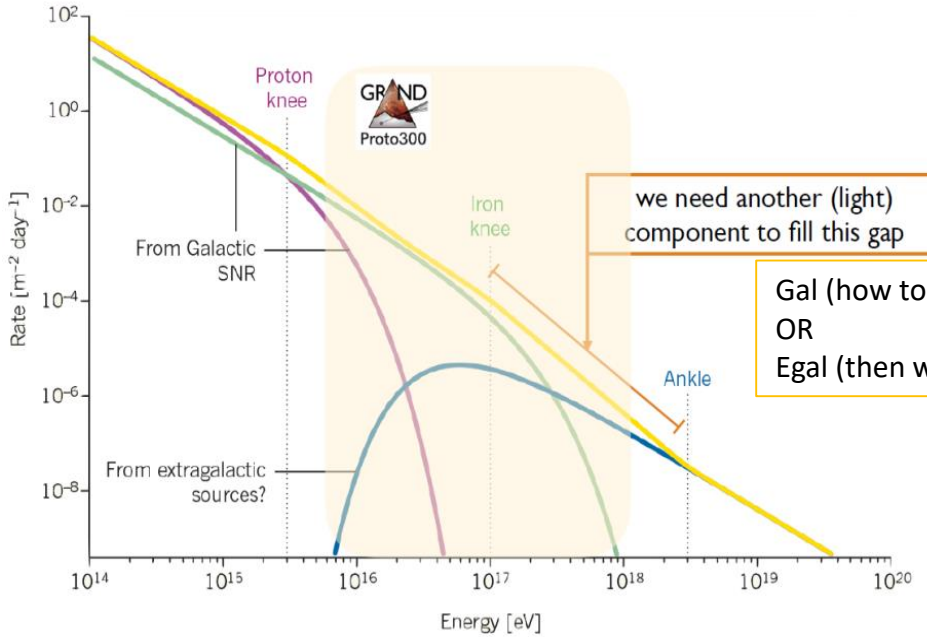
- Trigger, timing & reconstruction validation
  - Done with beacon source
  - **Timing resolution ~5ns** allows for ~10m resolution on source position
- Next steps:
  - **Deployment of 70 more units** in second half 2024
  - First air showers early 2025? ☺
  - **Then plenty of physics!**





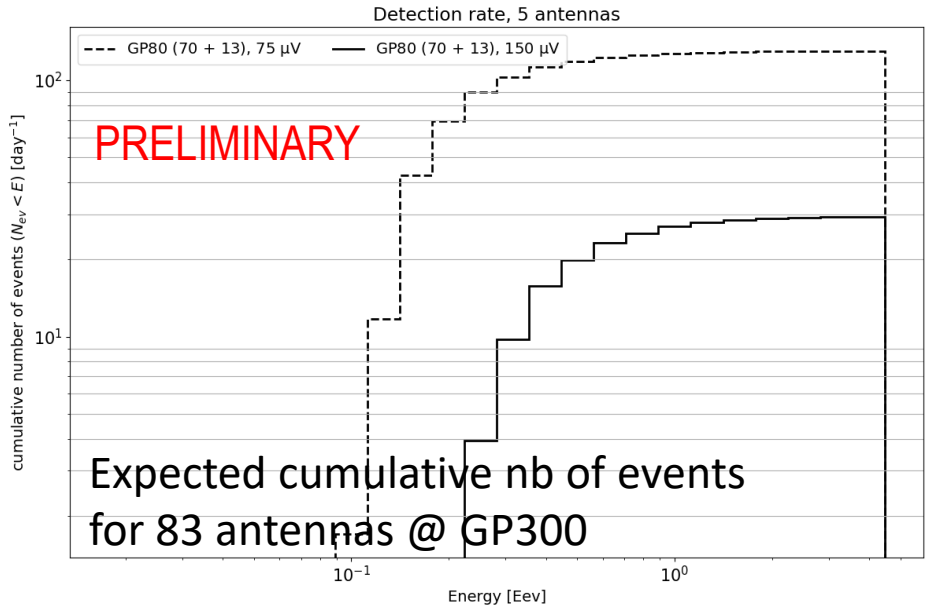


Gal-EGal transition



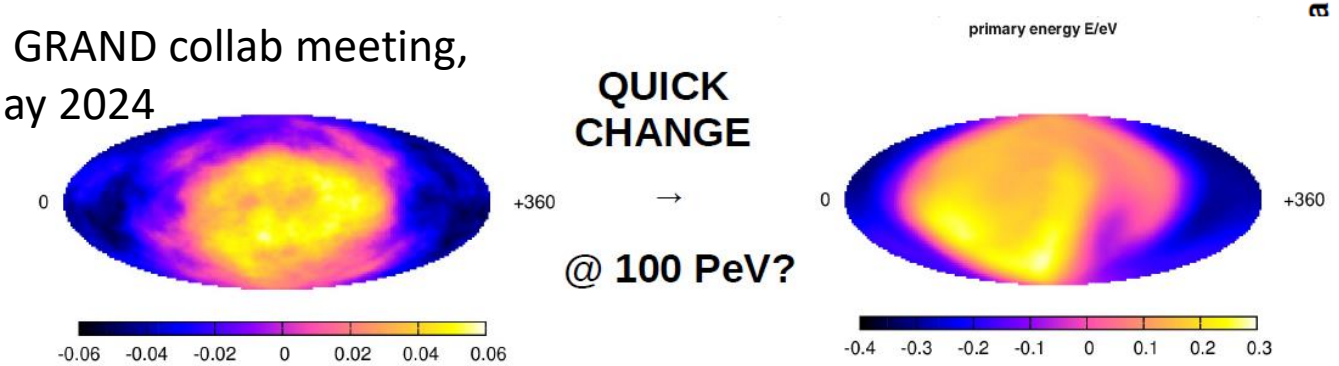
Gal (how to reach EeV?)
OR
Egal (then what with heavy??)

Plots by R. Batista

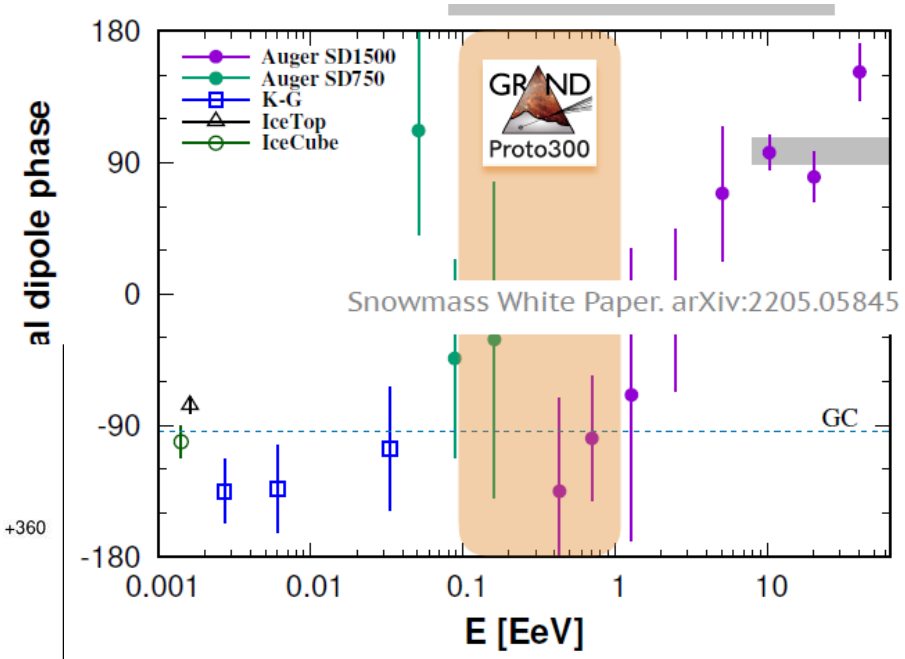


Expected cumulative nb of events for 83 antennas @ GP300

G. Giacinti, GRAND collab meeting, Nanjing, May 2024



Bian & Giacinti, In prep. (2024)



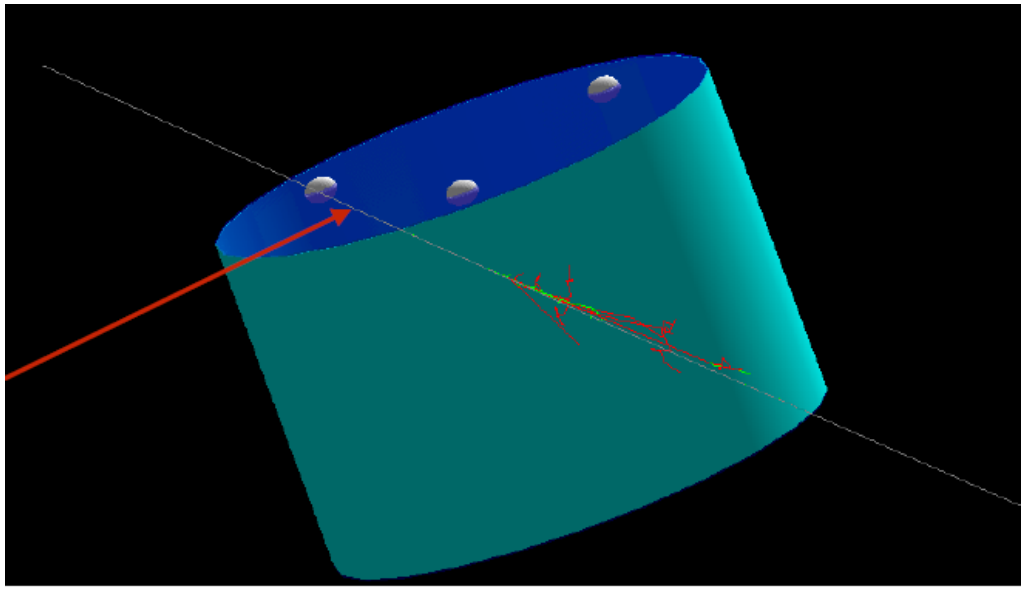
GP300 excellent angular resolution (~0.1°) & large statistics (100 of EAS/day) may be decisive!

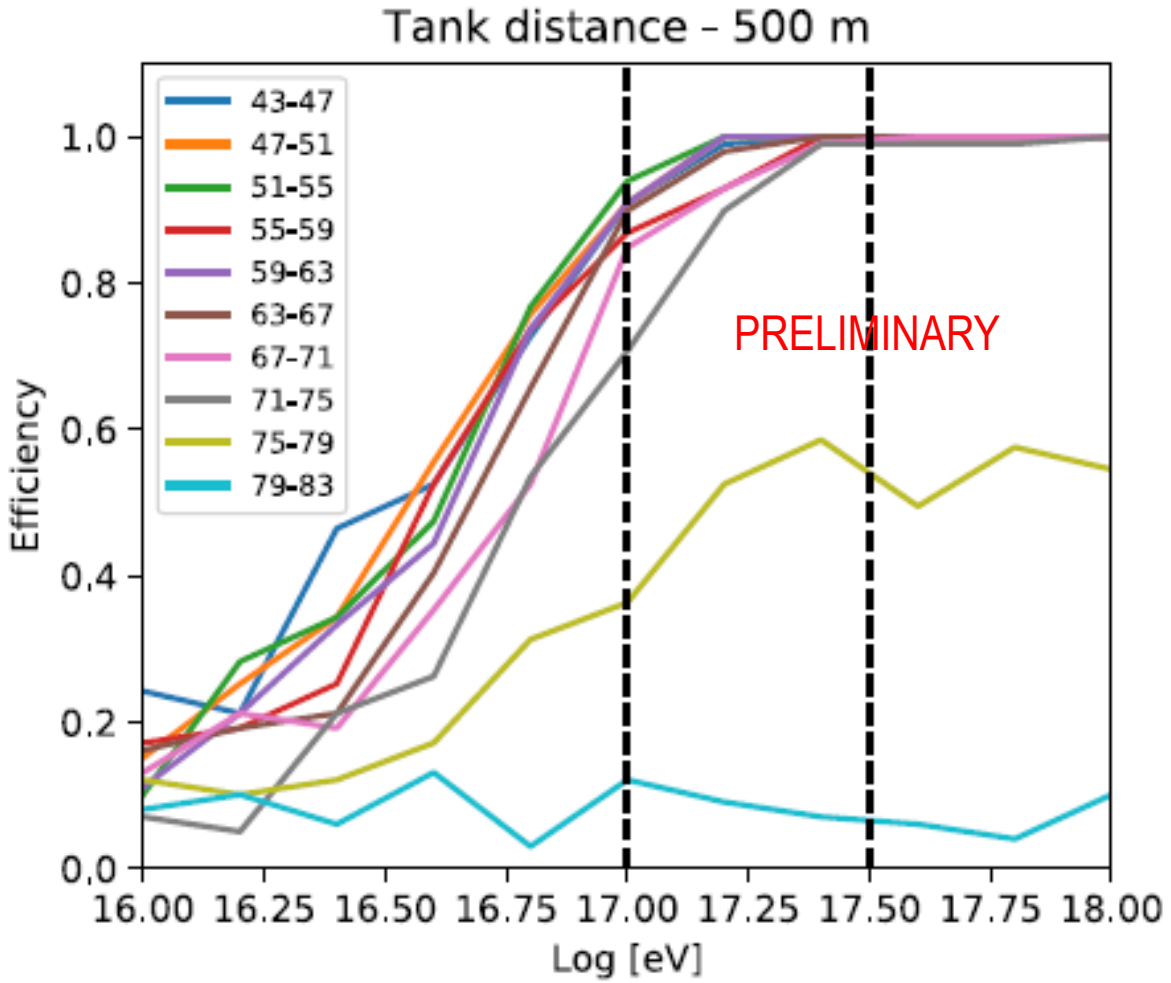
Physics with GP300?

- Completing the GP300 radio detector with an (independant) particle detector array (after 2025)?
  - Simulations assuming 300 tanks *a la* AUGER

(B. Zhang, Penn State)

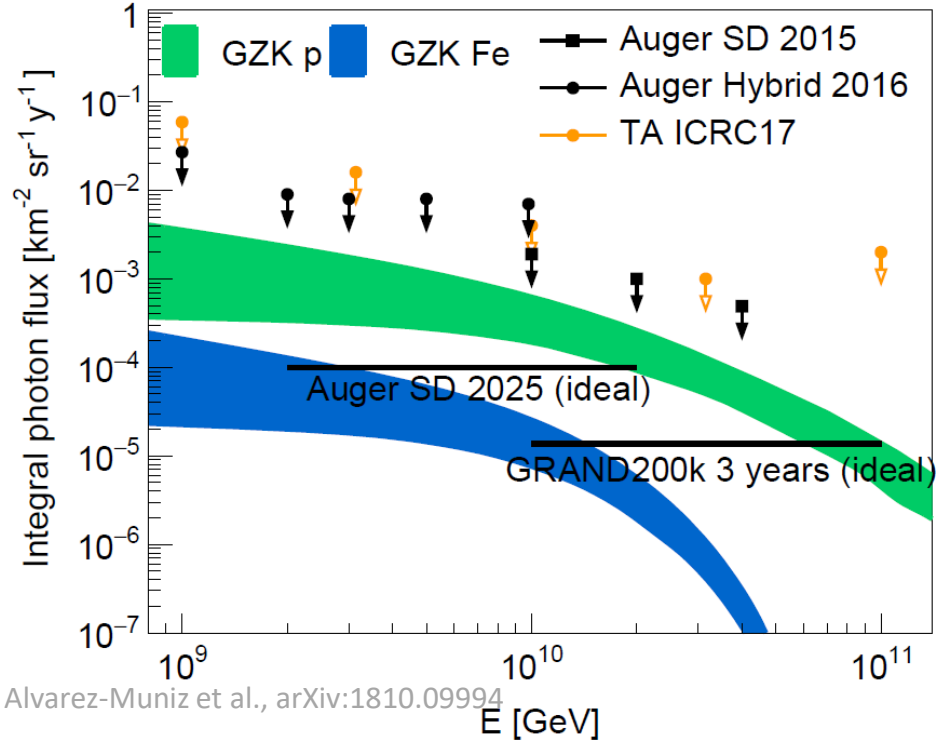
➔ **ε>20% for E>10^{16}eV & θ<75° ☺**



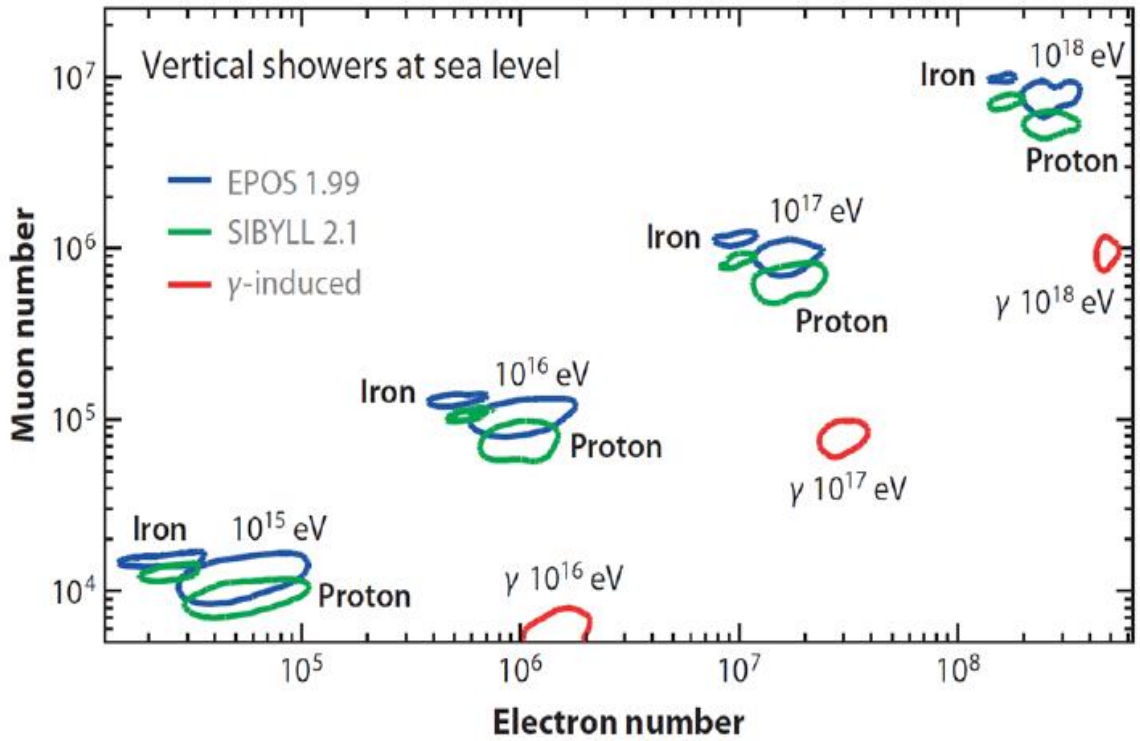


Gamma ray astronomy

- GP300: very clean separation of hadronic/γ primaries **with ground array**
- Later stages: large effective area may allow to reach sensitivity comparable to (better than?) Auger in the 10^{17} -10^{18} eV range.



Alvarez-Muniz et al., arXiv:1810.09994



Engel et al., Annual Rev of Nuclear and Part. Science 61, 467 (2011)

➔ Probe for cosmogenic γ

➔ UHE gamma ray astronomy???

New trigger methods for autonomous radio arrays

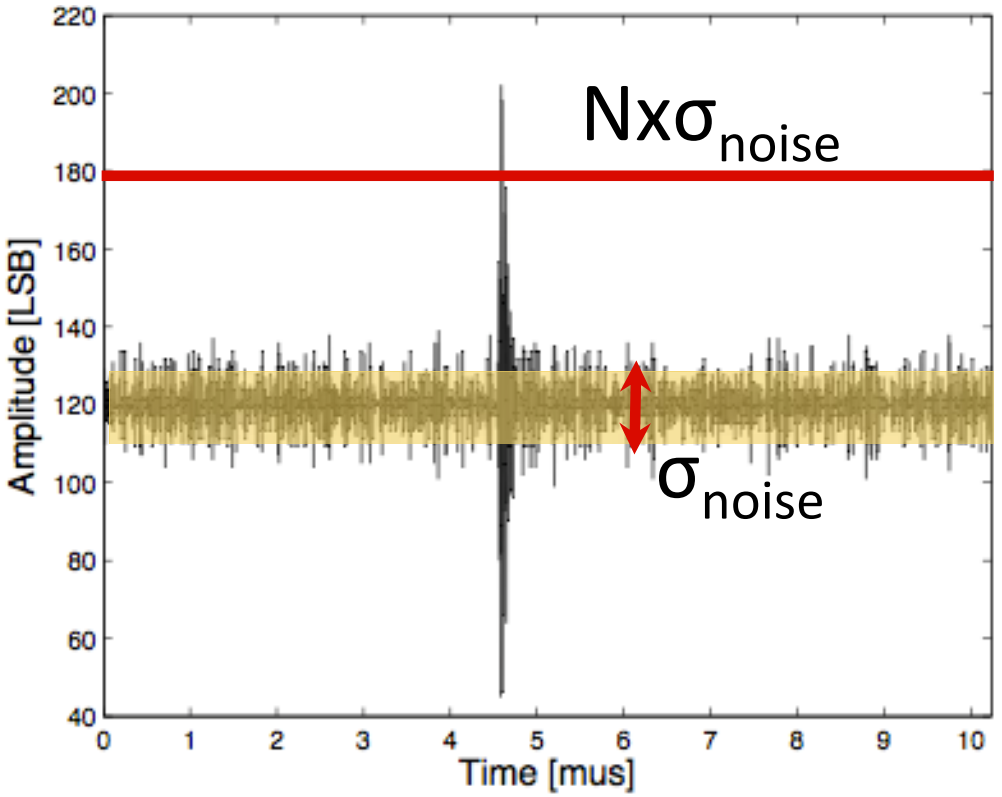
- At present (including GP300), only standard methods for triggering:
  - L1 @ unit level: (mostly) signal-over-threshold

  EAS signal known from simulation, background continuously measured
  - L2 @ DAQ level: select causal coincs between L1s (GPS timetags)

  Background is mostly waves rather than random coincs
  - Full time trace collected

  Huge data volume (~10kBy/trigger), while offline treatment reduced to few infos (trig time, amplitude, polar)…

A TREND event

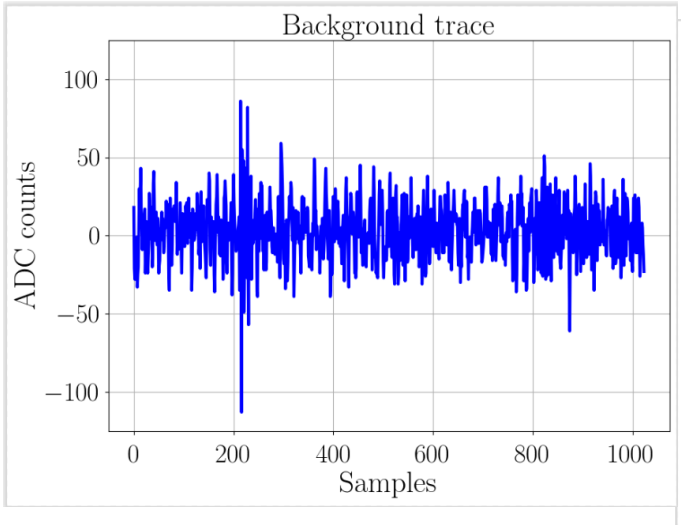


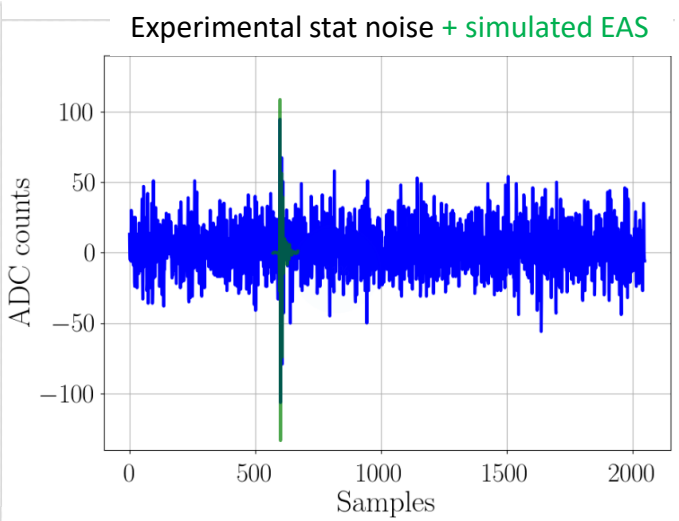
GP300: large volumes of data ➔ Large bandwidth needed ➔ WiFi ➔ High cost, high power consumption, low range

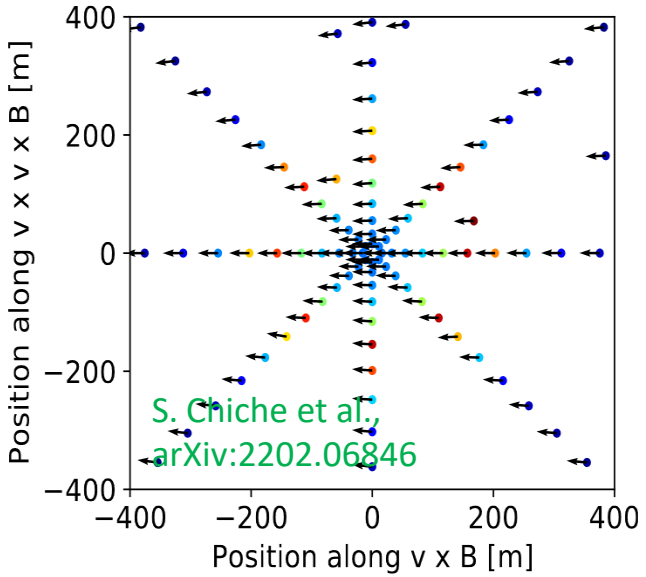
Need for a low-rate, low-power, low-price solution for giant arrays (e.g. GRAND10k)

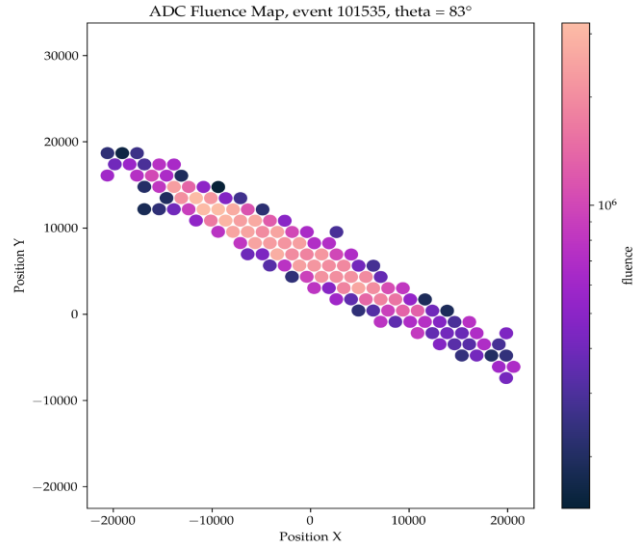
✻NUTRIG (*LPNHE + IAP + KIT) ANR+DFG funded

- L1 trigger (LPNHE lead)
  - Developing innovative methods for
    - Signal identification (ie fighting against transient noise) ➔ improve purity
    - Signal extraction (ie fighting against stationnary noise) ➔ improve threshold
  - Specific constraints:
    - Online treatment (ie faster that data rate)
    - « Frugality »: low power & limited CPU
    - Noise variability: large range of background pulses, not-so-stationnary baseline conditions
- L2 trigger (KIT lead): use EAS signatures
- Data format (LPNHE + IAP + KIT):
  - Optimize balance between data volume and quality using offline (blind) analysis based on reduced info.









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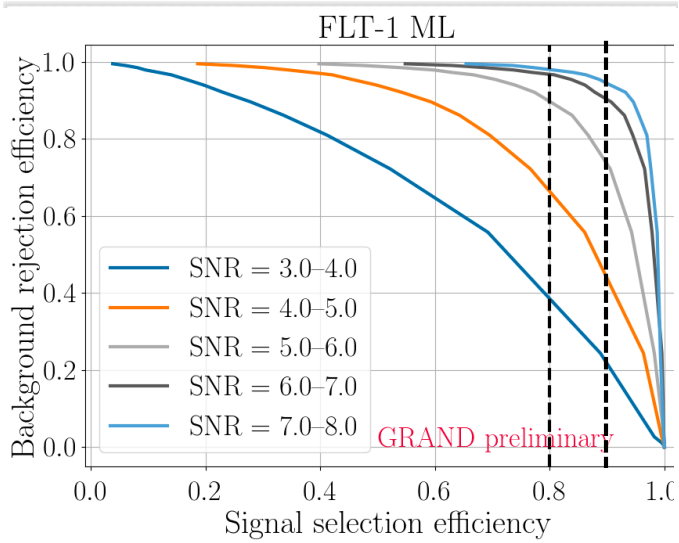
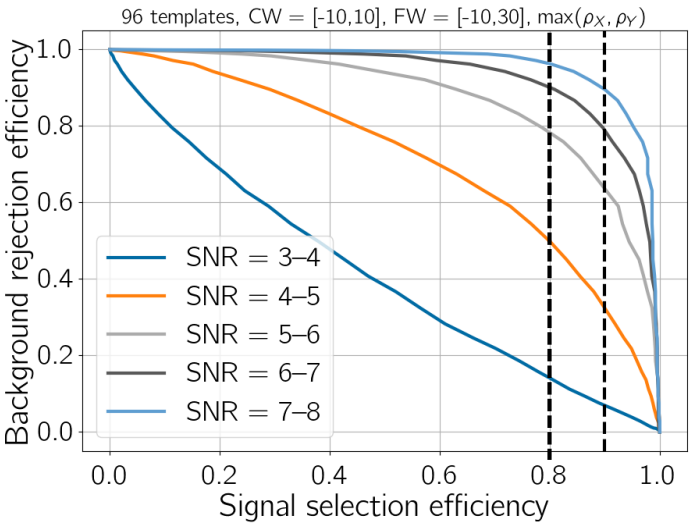
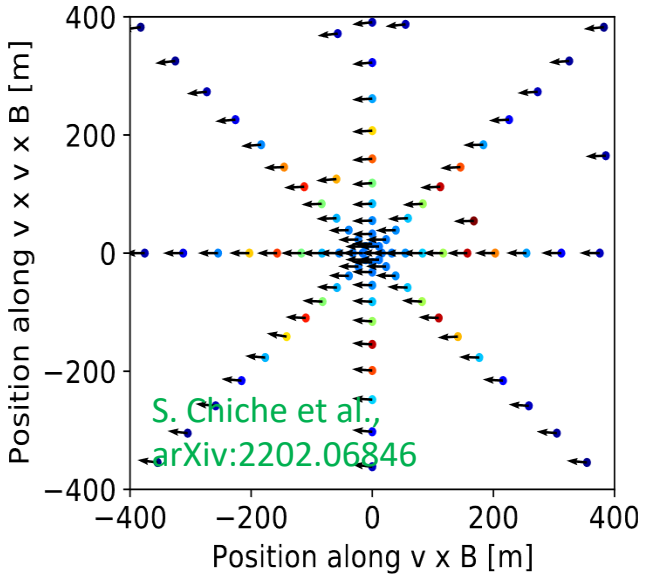
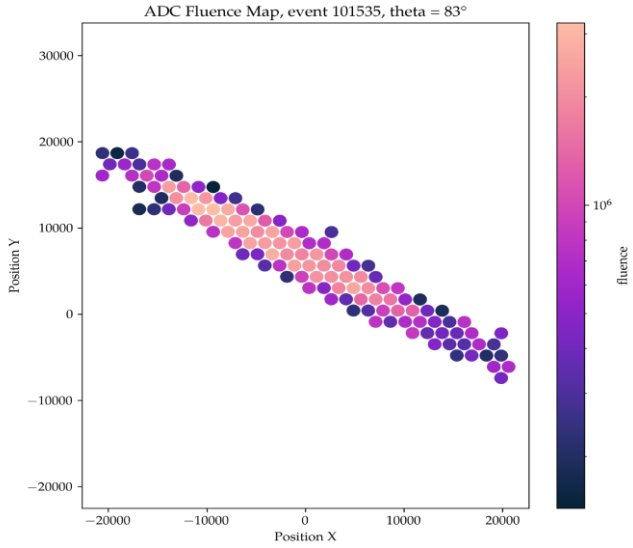
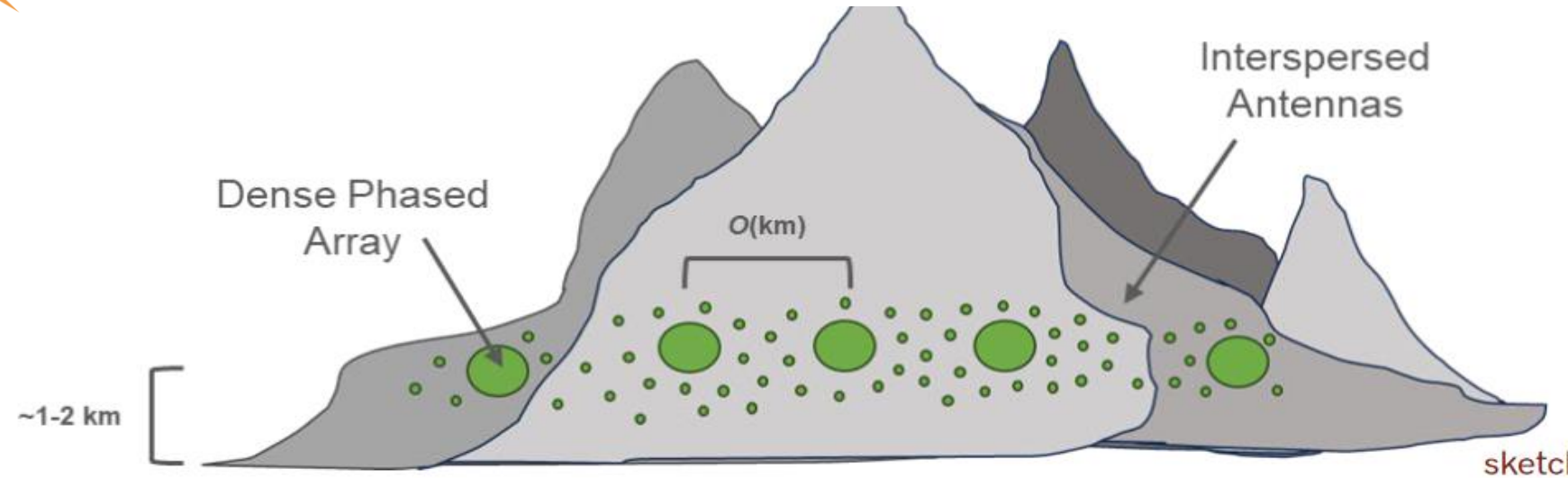








HERON (ERC Synergy proposal 2024)
(IAP + LPNHE + Penn State + Santiago de Compostella)



sketch by Andrew Zeolla
GRAND Analysis Forum Meeting - May 2024

- **BEACON-type: phased stations**
  low energy threshold for triggering
- **GRAND-type: interspersed antennas**
  autonomous trigger + also triggered externally by phased stations,
  use offline interferometry (via reference beacon transmitter), for reconstruction + RFI rejection
- **High gain antennas** design for individual antennas, focused at the horizon, mostly low frequencies (30-80 MHz), for minimal energy threshold —> to be developed within general GRAND framework
- **~1000m elevation**
  for aperture + sensitivity at low-energies

S. Wissel, et al., *Sensitivity of BEACON to Ultrahigh Energy Neutrinos*, PoS ARENA2024 (2024) 058.