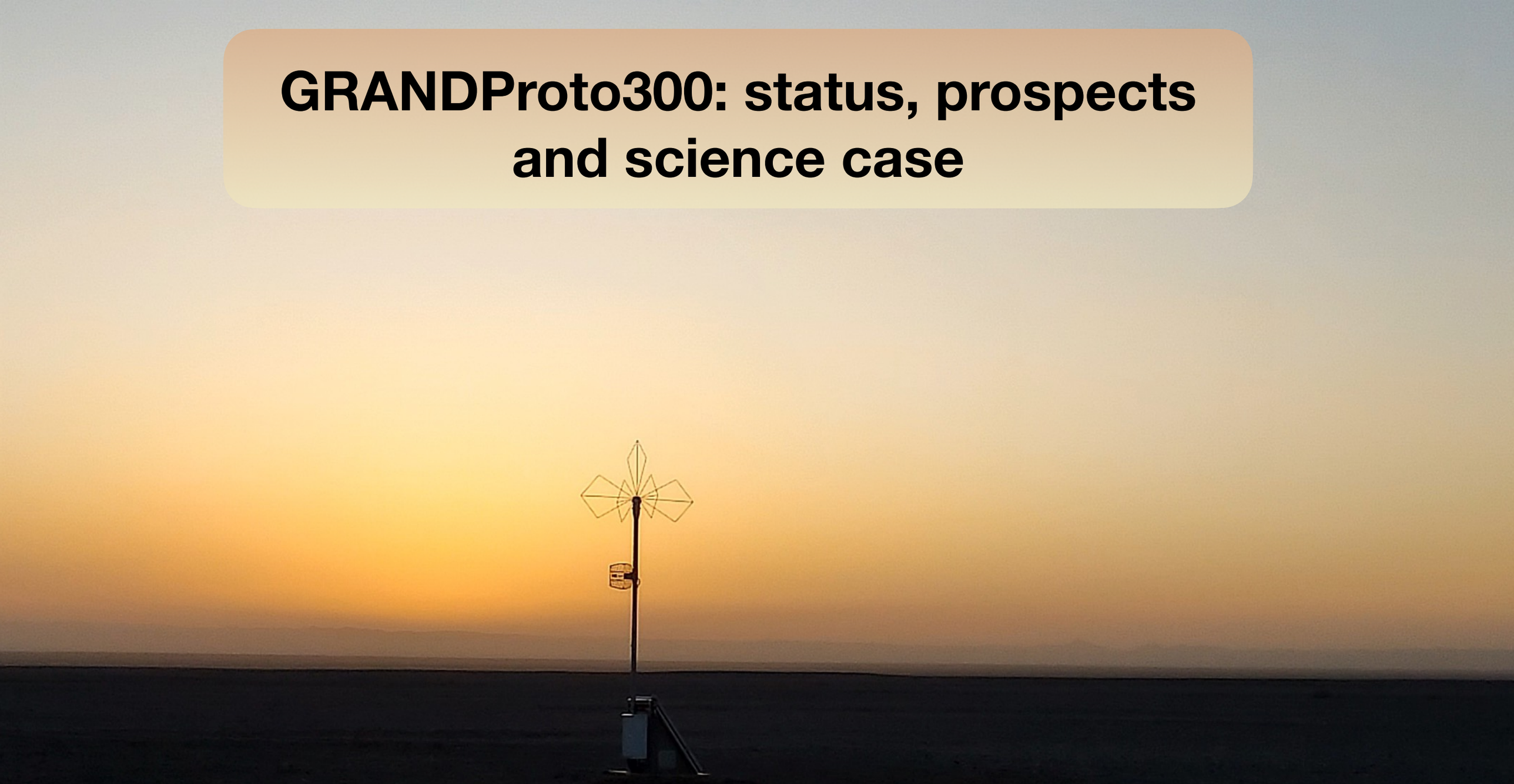
GRANDProto300: status, prospects and science case



ARENA 2024

Simon Chiche - for the GRAND collaboration

GRANDProto300 in Xiao Dushan

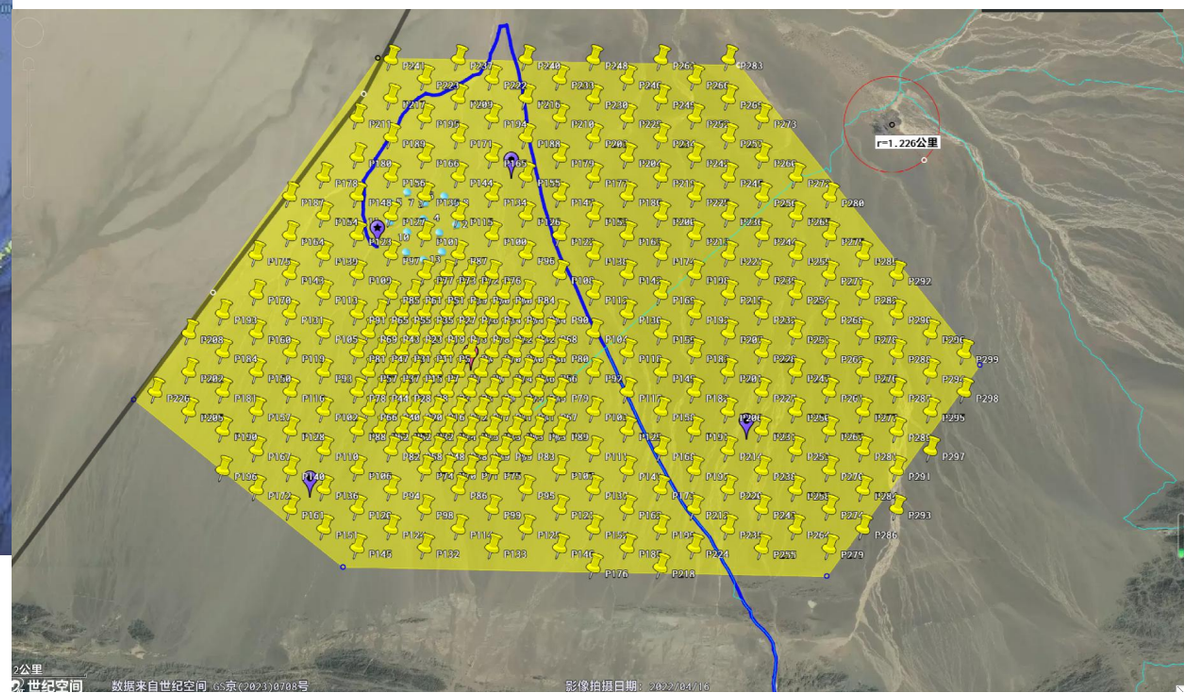
GRANDProto300: A radio array of $\mathcal{O}(300)$ antennas over 200 km^2

Located in Xiao Dushan in the Gansu province (China)

Flat solid ground in mountainous area

Low radio background

Average altitude of ~1100m above sea level



The deployment site has been officially approved!

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

- Hexagonal grid
- Sparse array (1k step) with denser infill (577 m step)
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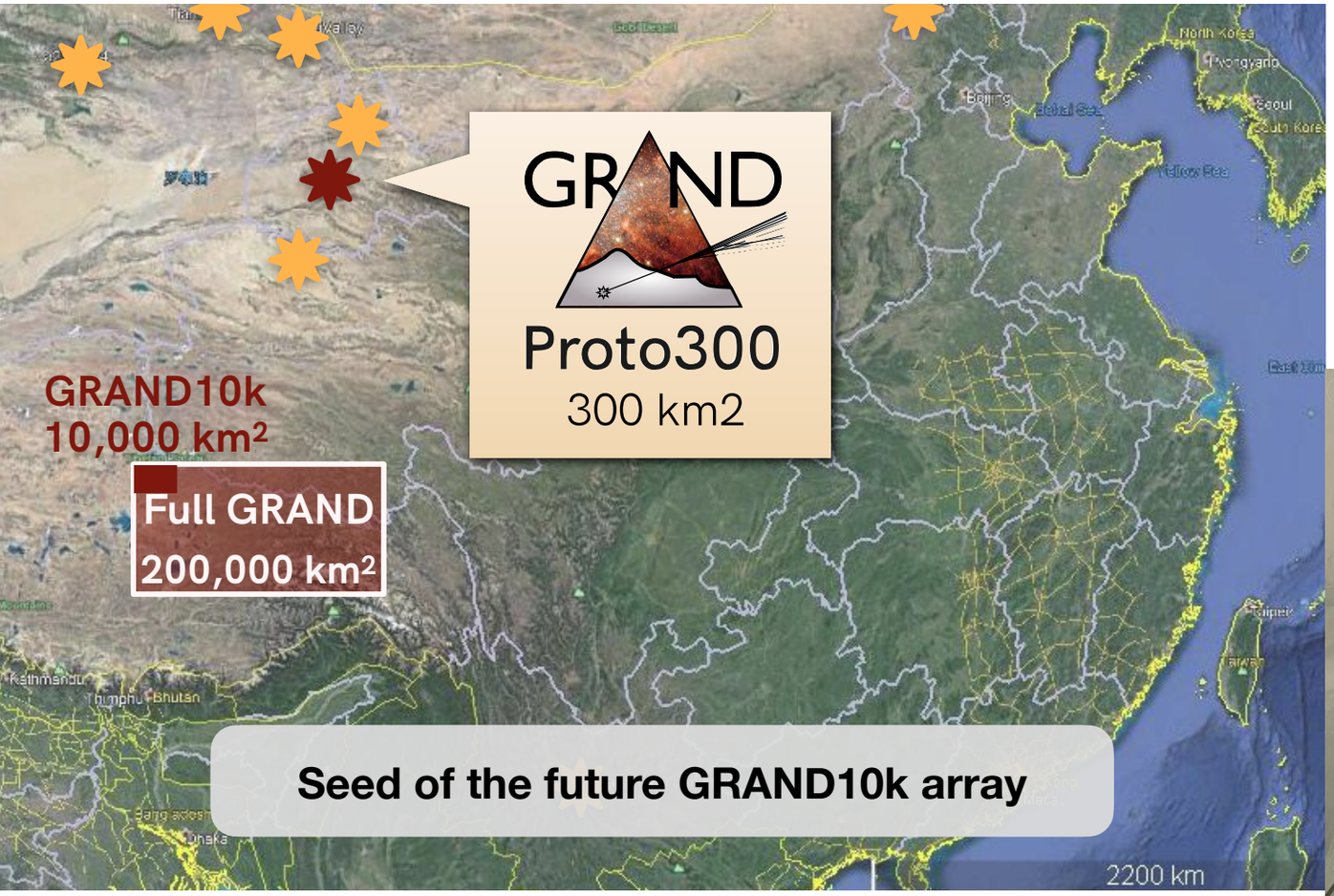

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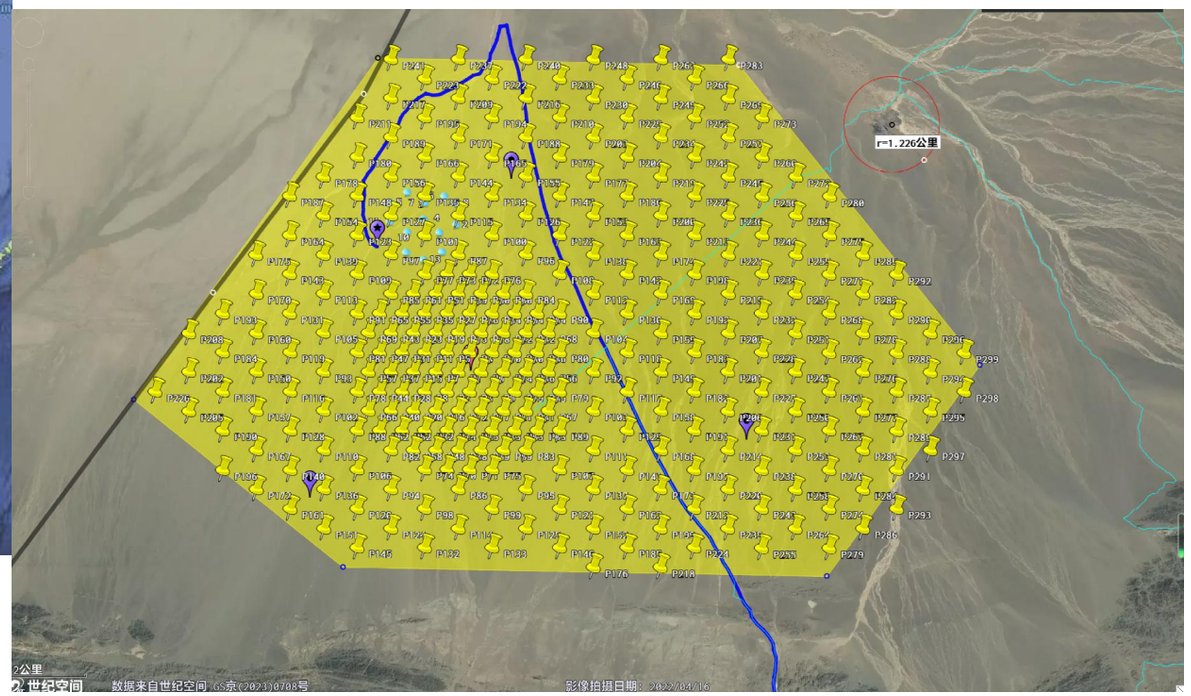

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GRANDProto300 aims at tackling several challenges to validate GRAND detection principle

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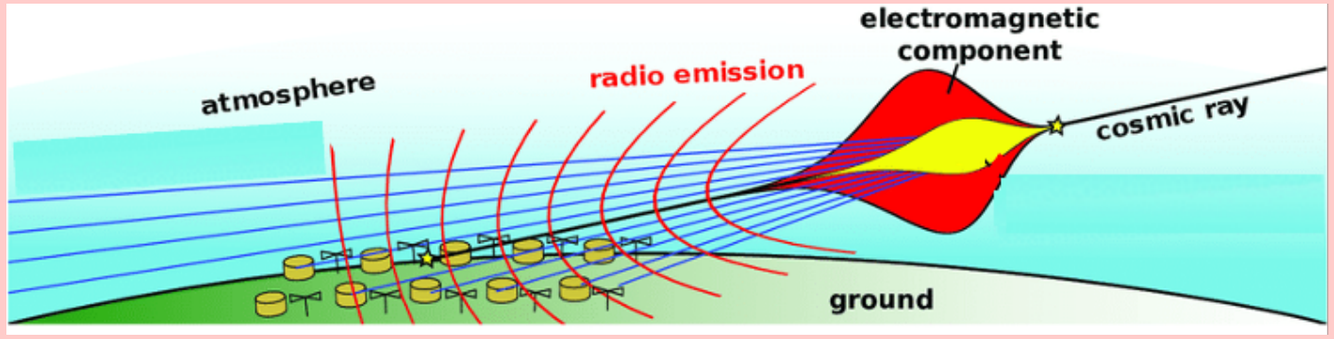
Reconstruction of inclined air showers (Oscar Macias / Lukas Gülzow presentations)

- Inclined air showers are challenging (asymmetries, reflections, …)

- Detection of very inclined showers with a sparse array: unchartered territory

- Reconstruction algorithms need to be tested

(Schröder 2017)



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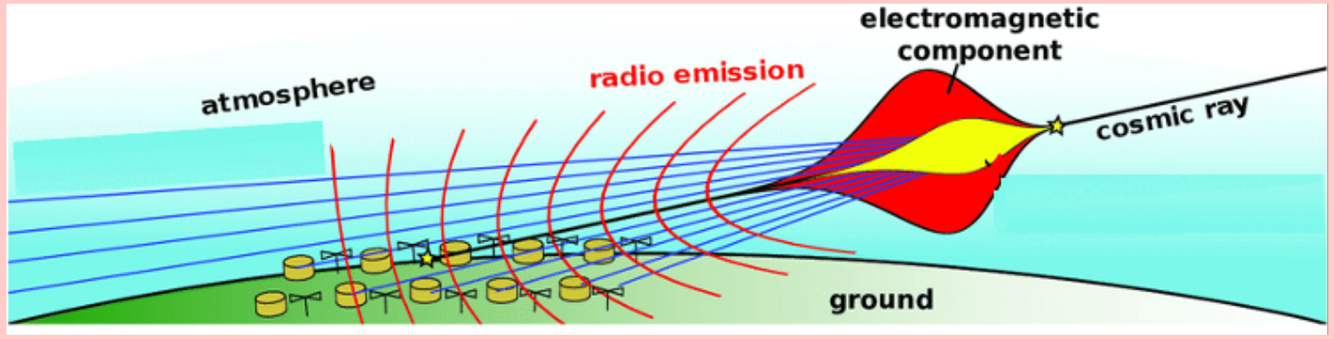
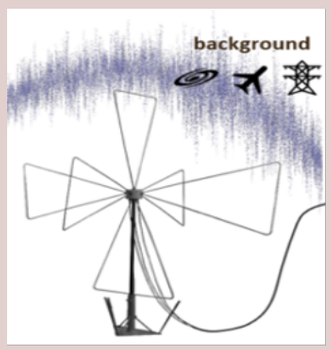


Autonomous radio detection

- GRAND aim to achieve radio detection without external triggers



- Requires to identify air shower signals among the various backgrounds

- Several approaches possible: Neural networks, polarisation signatures, template fitting… (Chiche et al. [arXiv:2202.06846], Le Coz et al. [ARENA2022])

Jelena's talk, Pablo's talk

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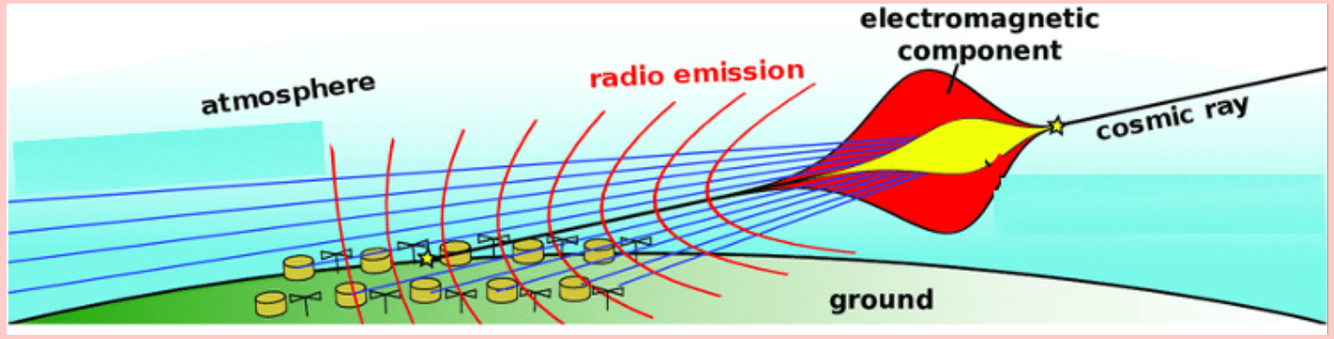

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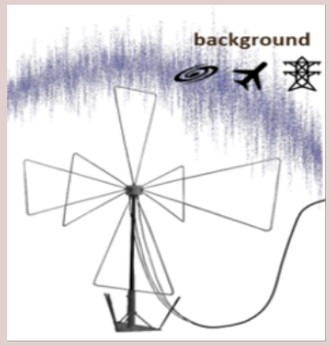

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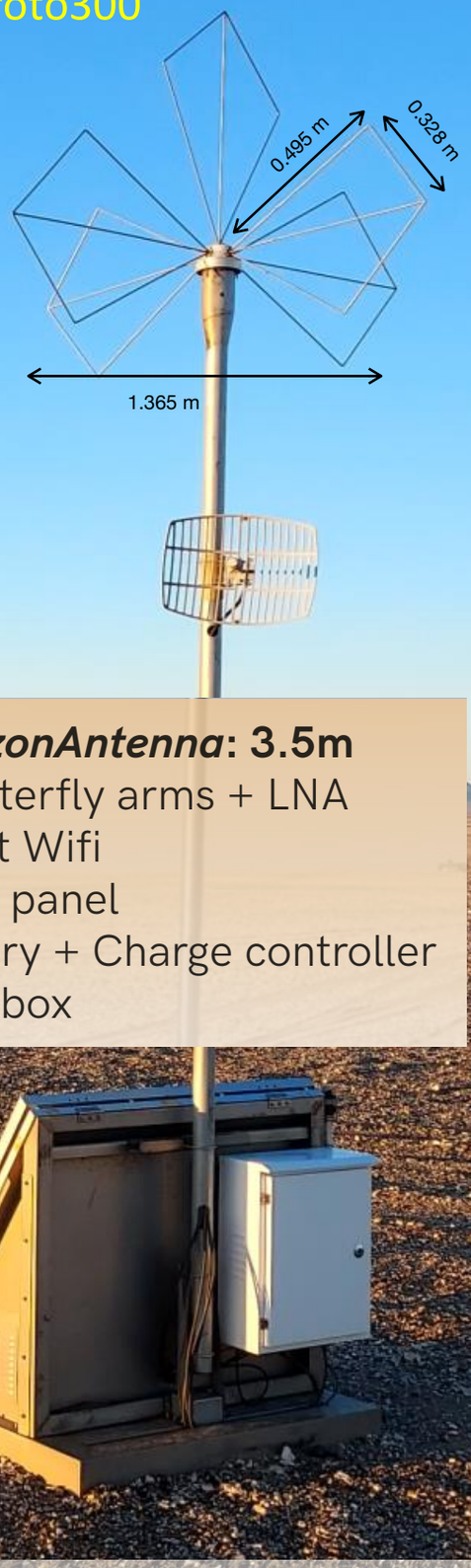
Hardware monitoring

Hardware needs to be tested in experimental conditions (antenna and electronics design, reliability, ….)

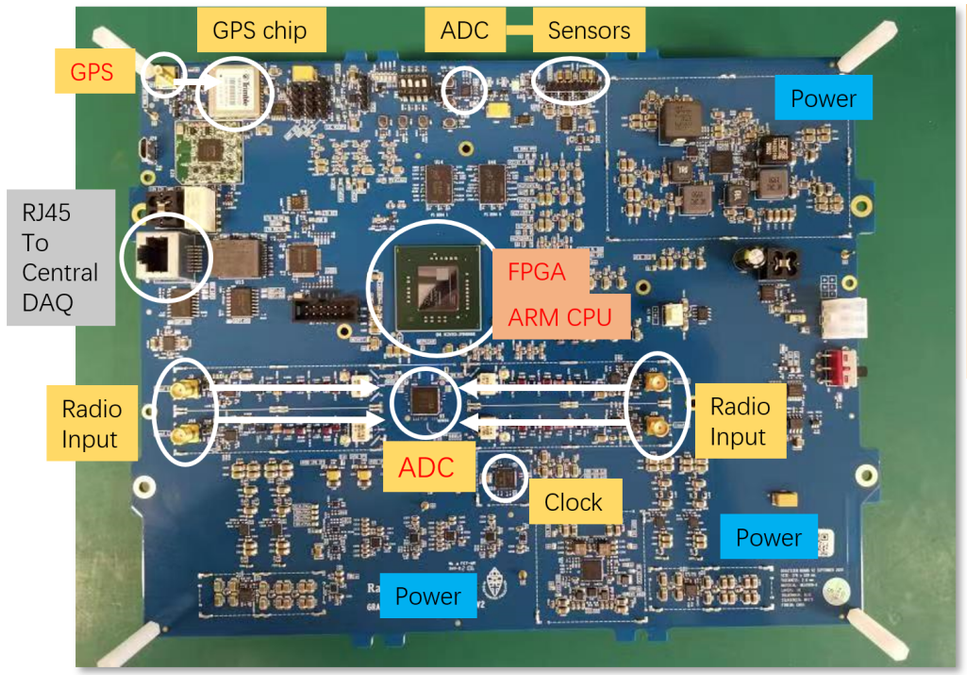
Will allow to scale the experiment to the future stages

Detector overview

One GRANDProto300 detection unit



***HorizonAntenna*: 3.5m**
3 butterfly arms + LNA
Bullet Wifi
Solar panel
Battery + Charge controller
DAQ box

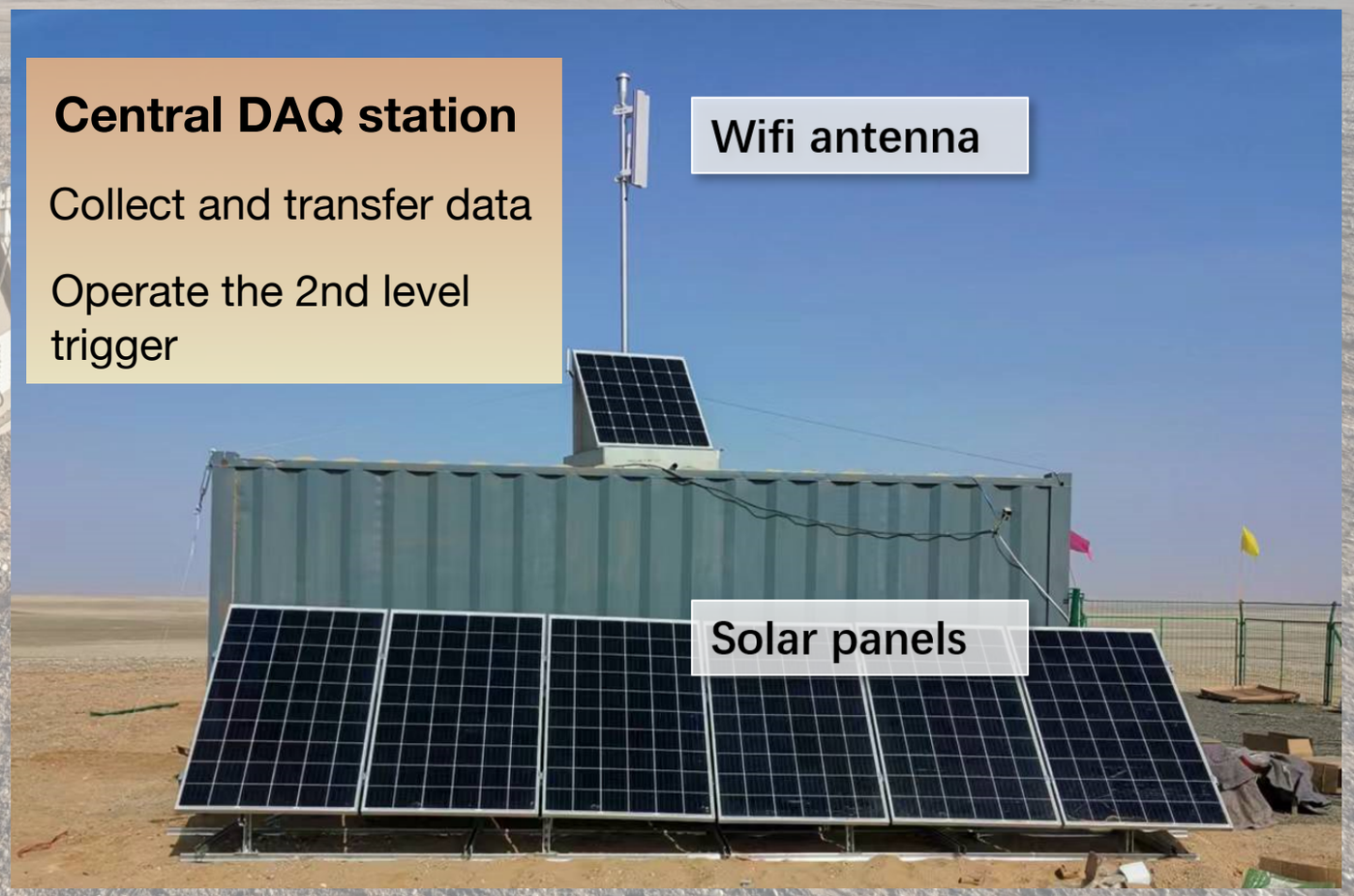


Electronics:
50-200 MHz analog filtering,
500 MS/s sampling
FPGA+CPU
Bullet WiFi data transfer

Central DAQ station

Collect and transfer data

Operate the 2nd level trigger



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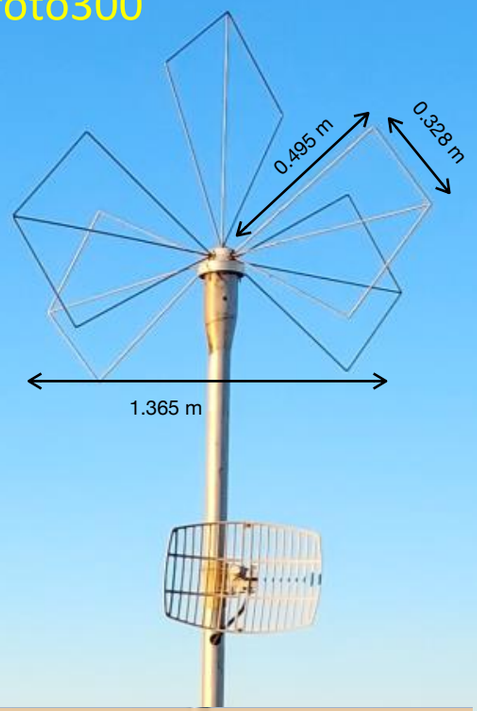

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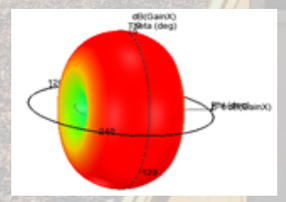
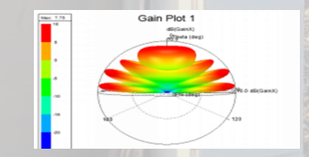
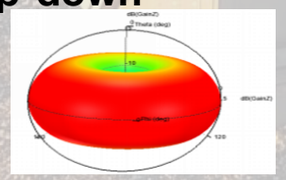
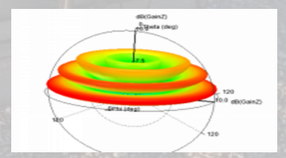
North-south

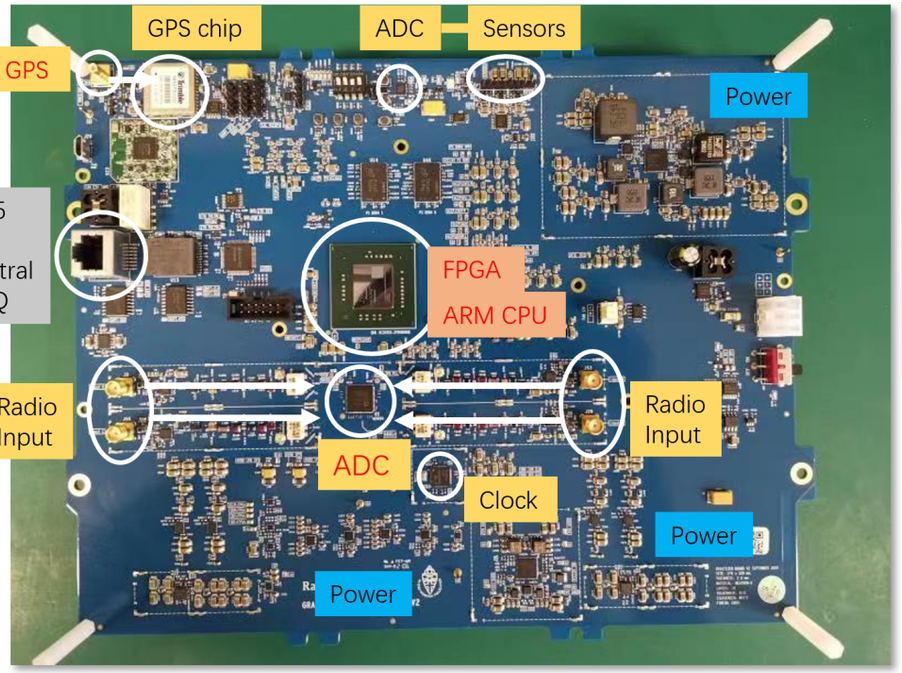




Up-down







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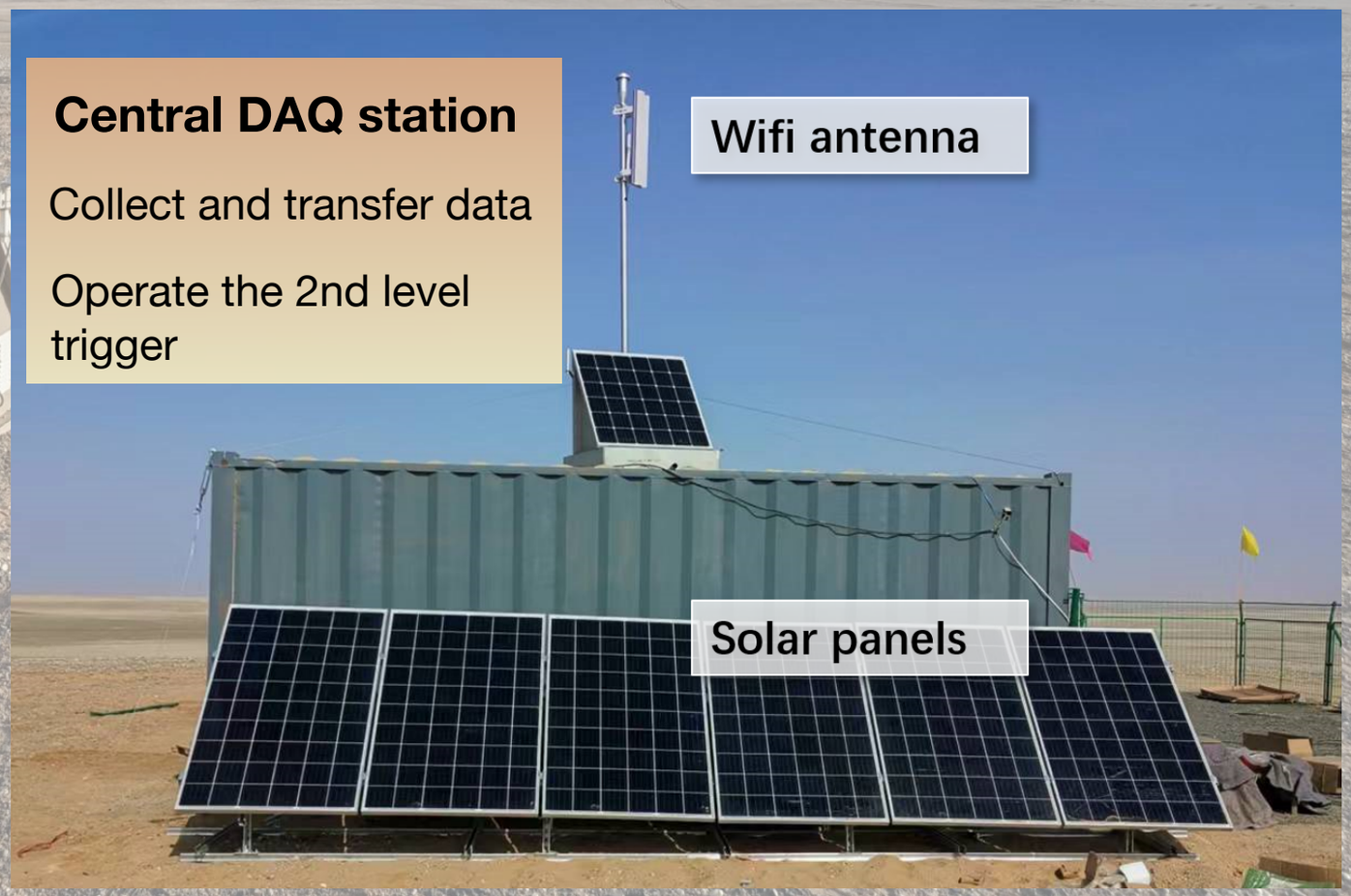
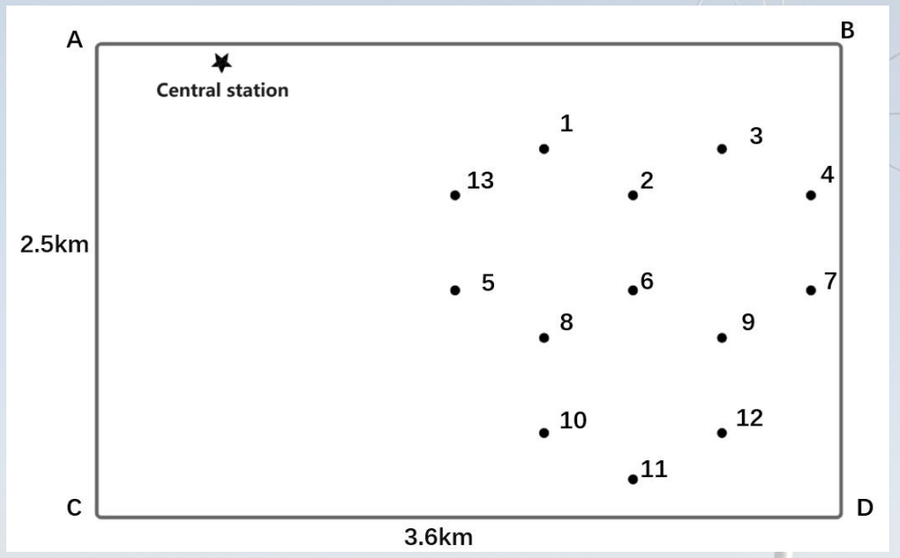


Current status of GRANDProto300

GP13 commissioning

13 antennas deployed in February 2023 in Xiao Dushan!



First data were taken and processed

Tests of the equipment were performed

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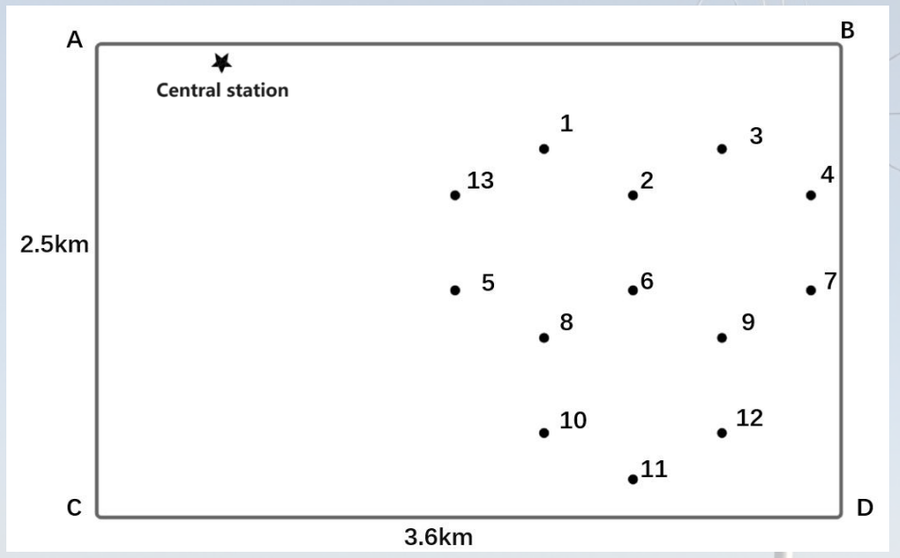

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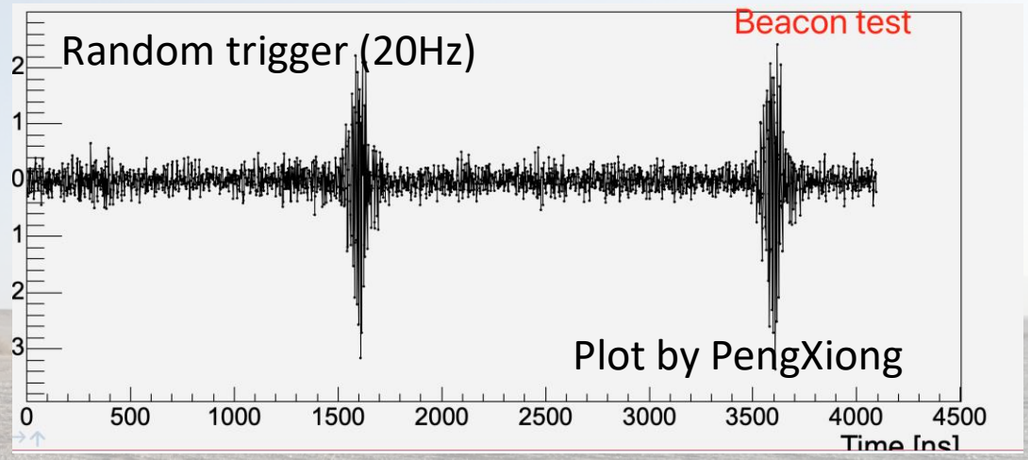

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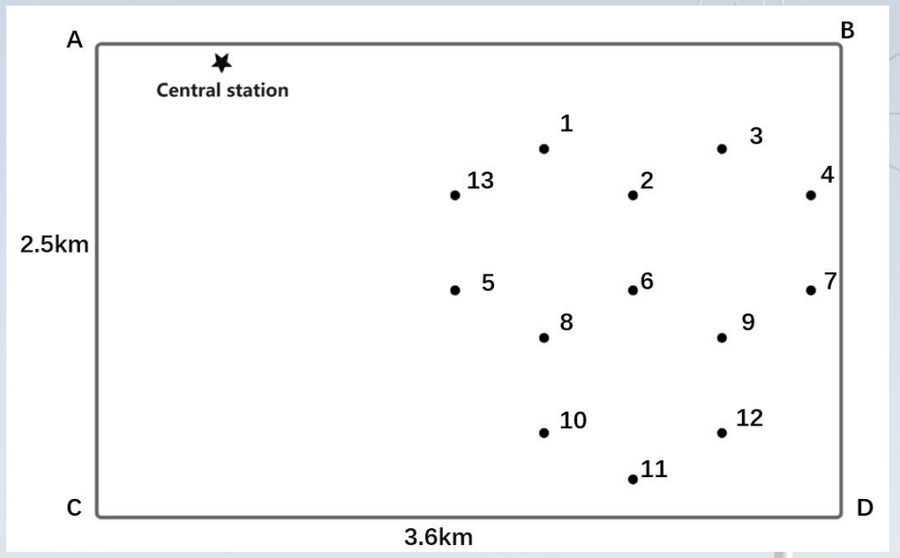

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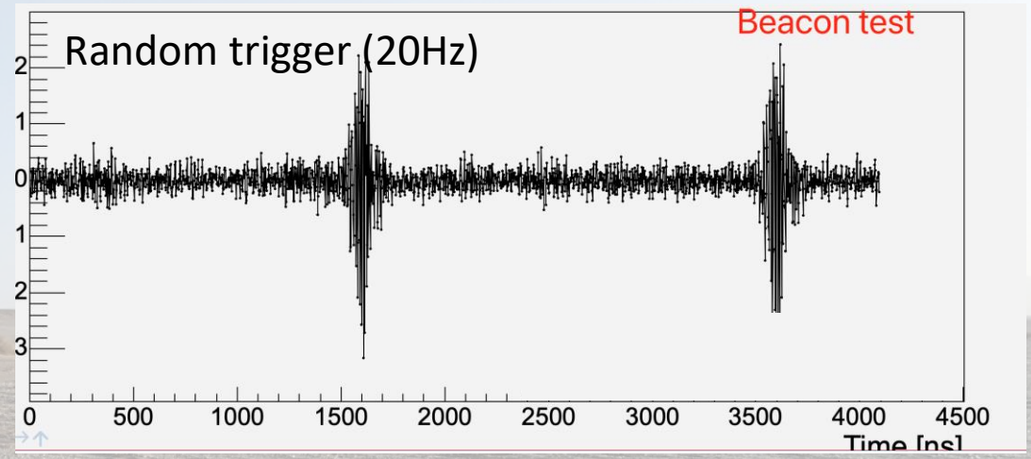
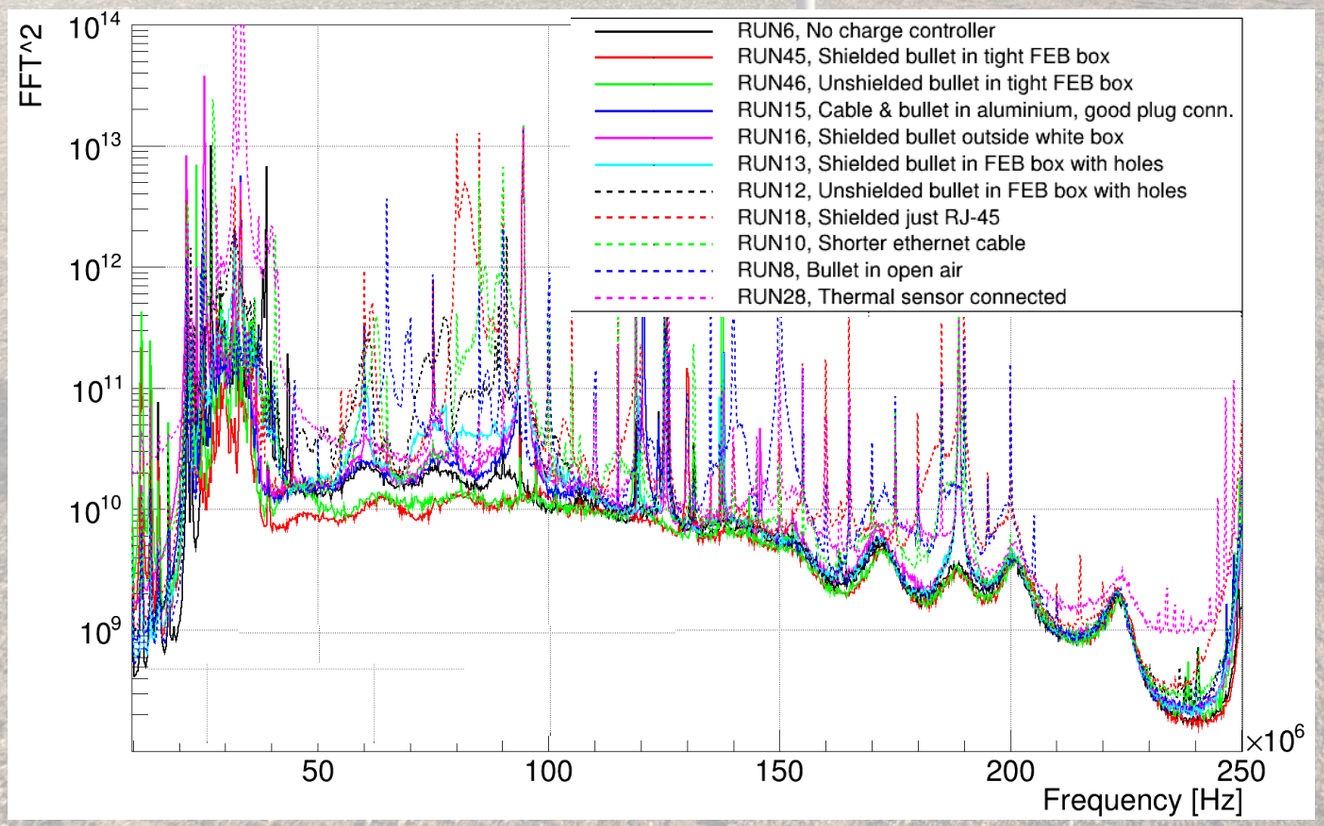




~40 data acquisitions to test the influence of various parameters

All components radiate

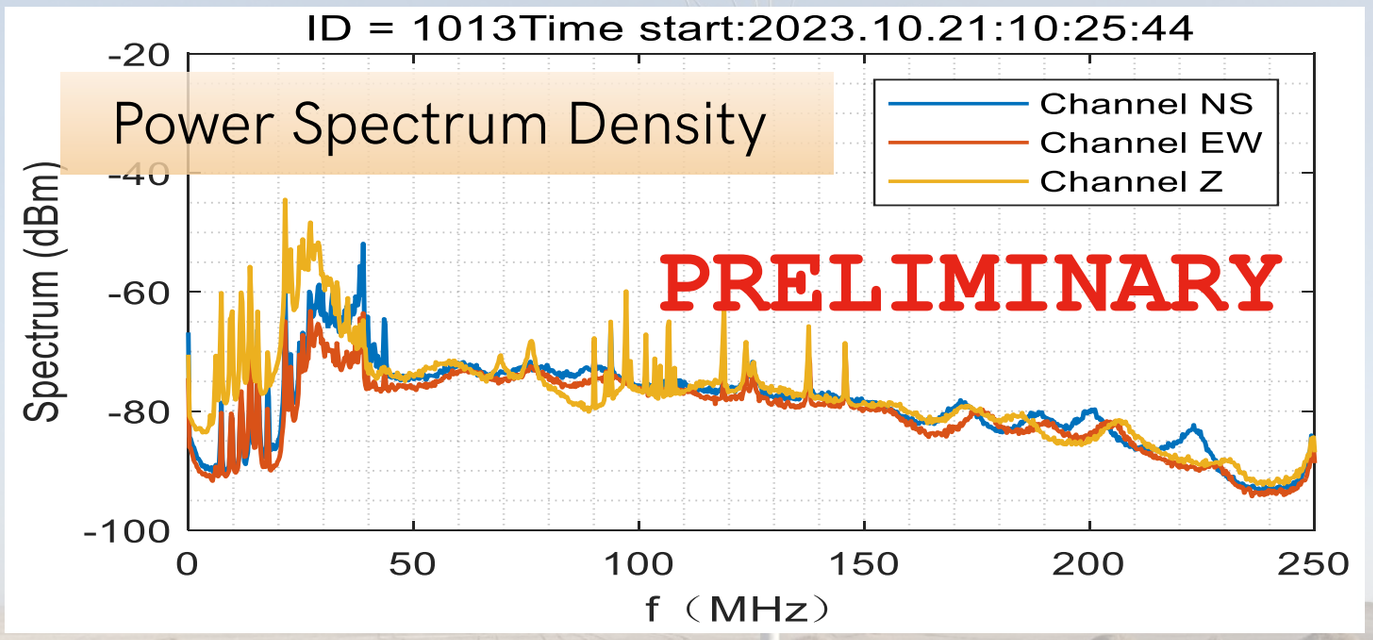
Initially, heating issue with the LNA and the front-end board

Now all the components are shielded and the heating issue is solved!

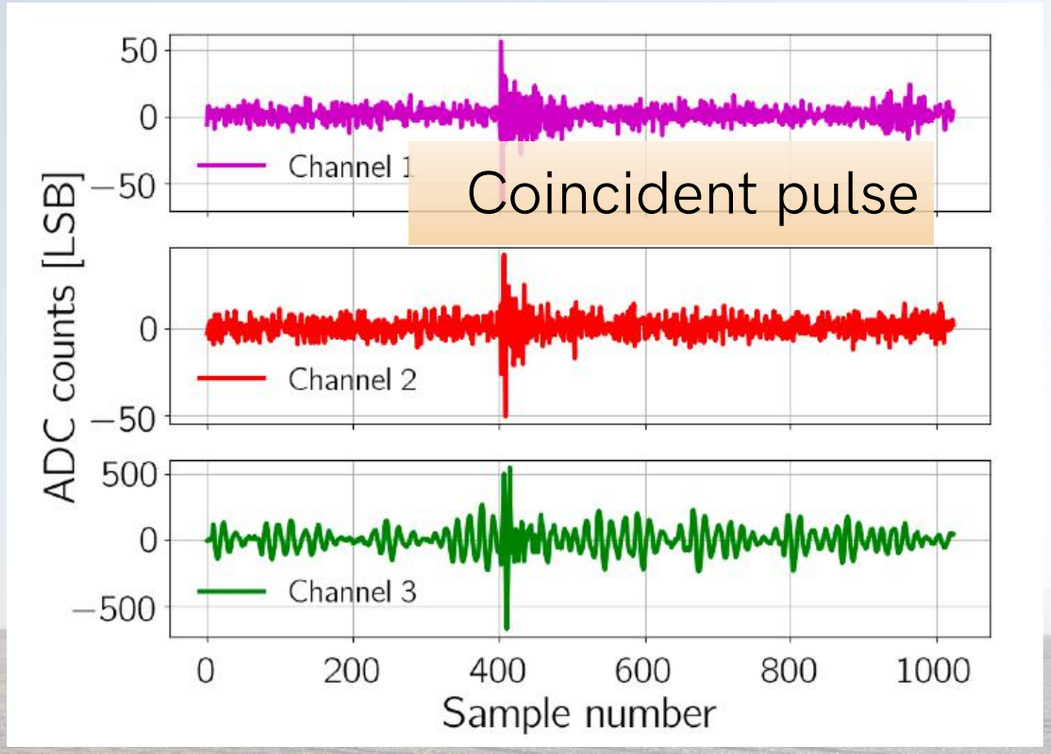
Data from GP13

Current data are encouraging!

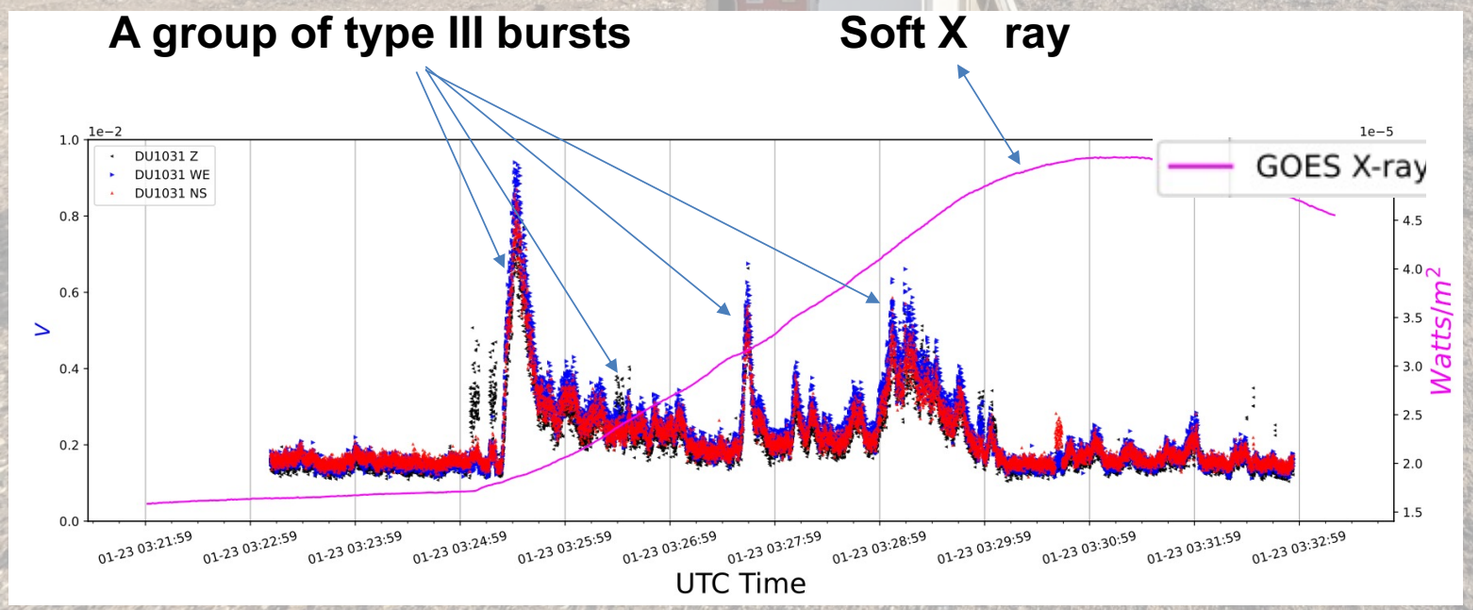
Power Spectrum Density



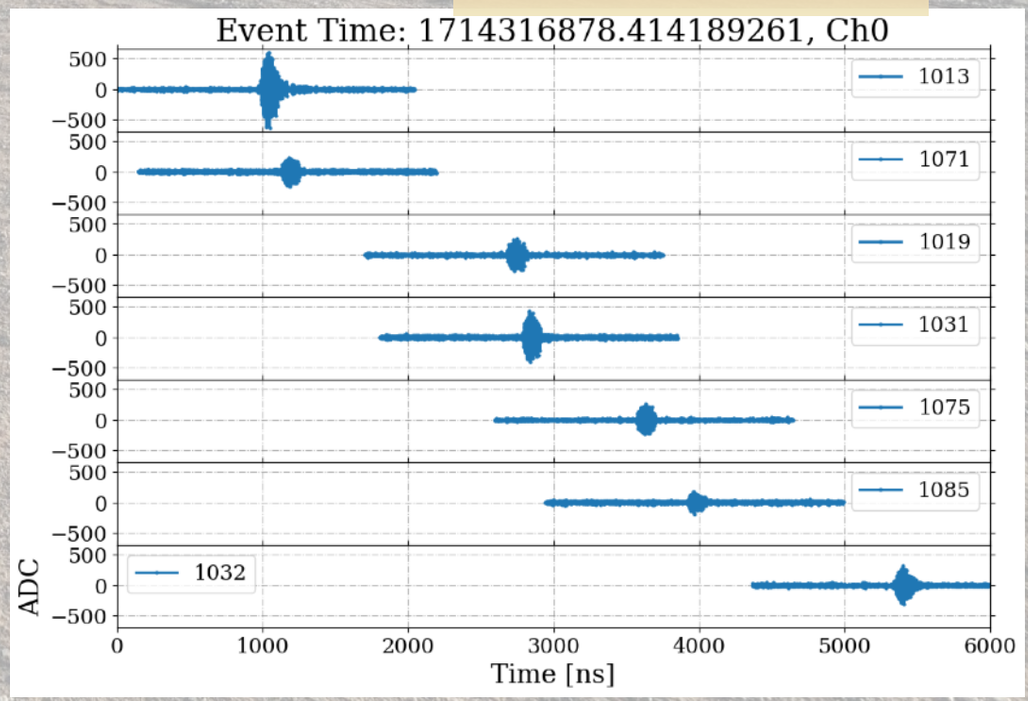
Coincident pulse



Solar flares



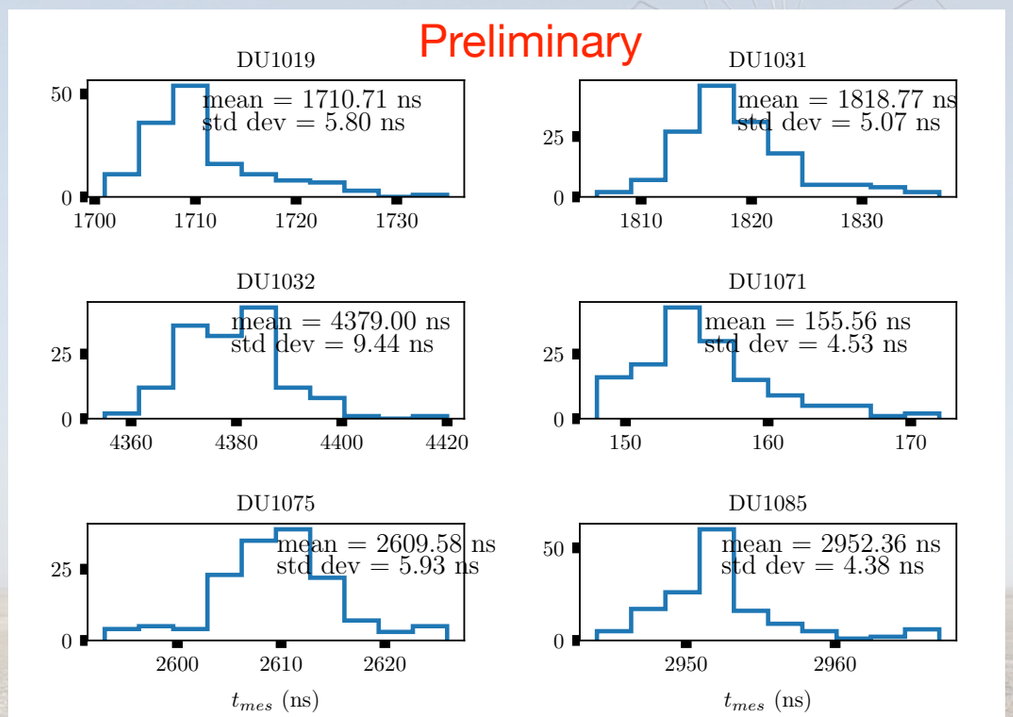
Coincident triggers

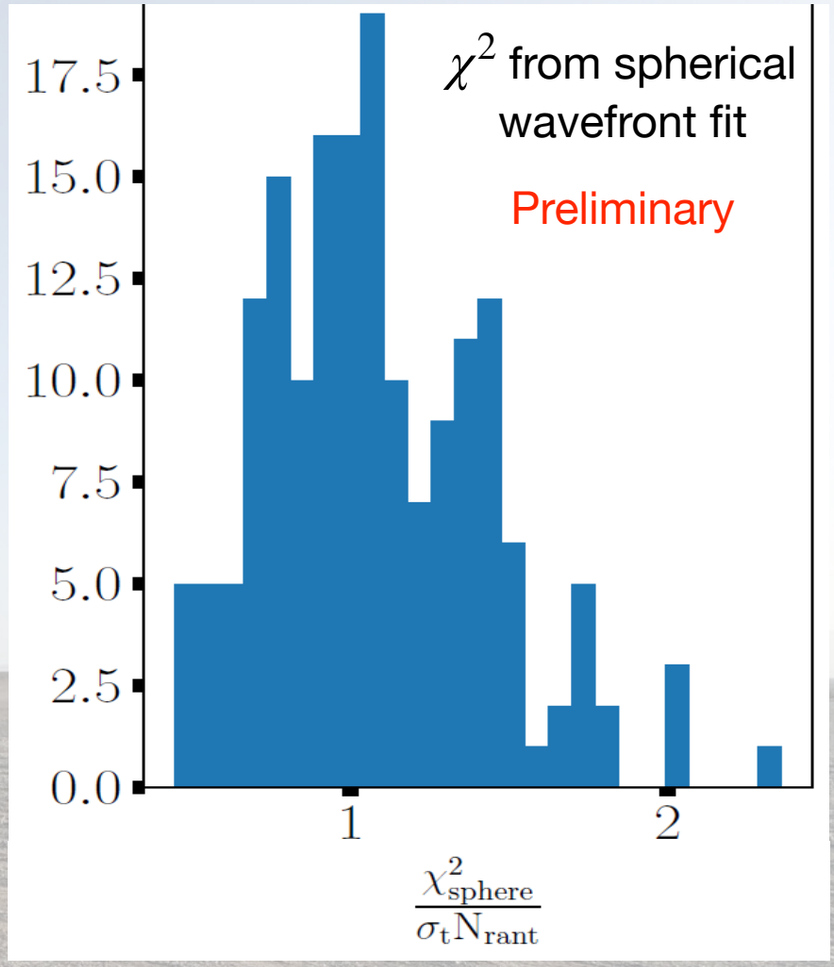


Beacon reconstruction

The beacon position was reconstructed from trigger times at the antenna level

Timing resolution of ~ 5 ns!





Preliminary

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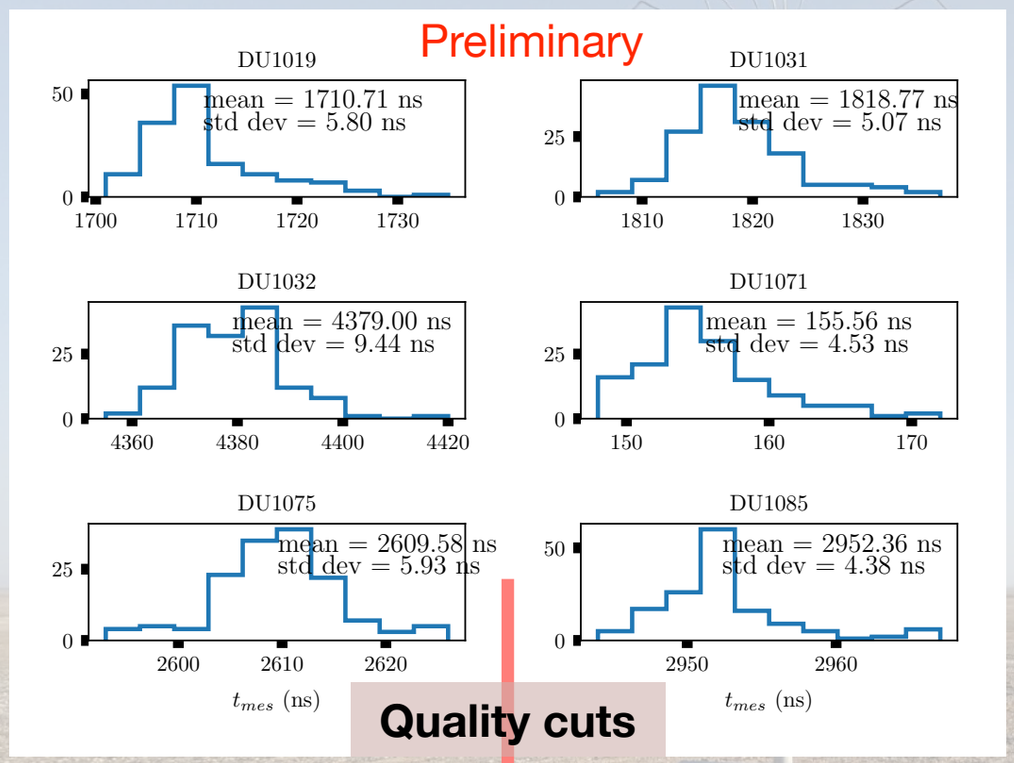
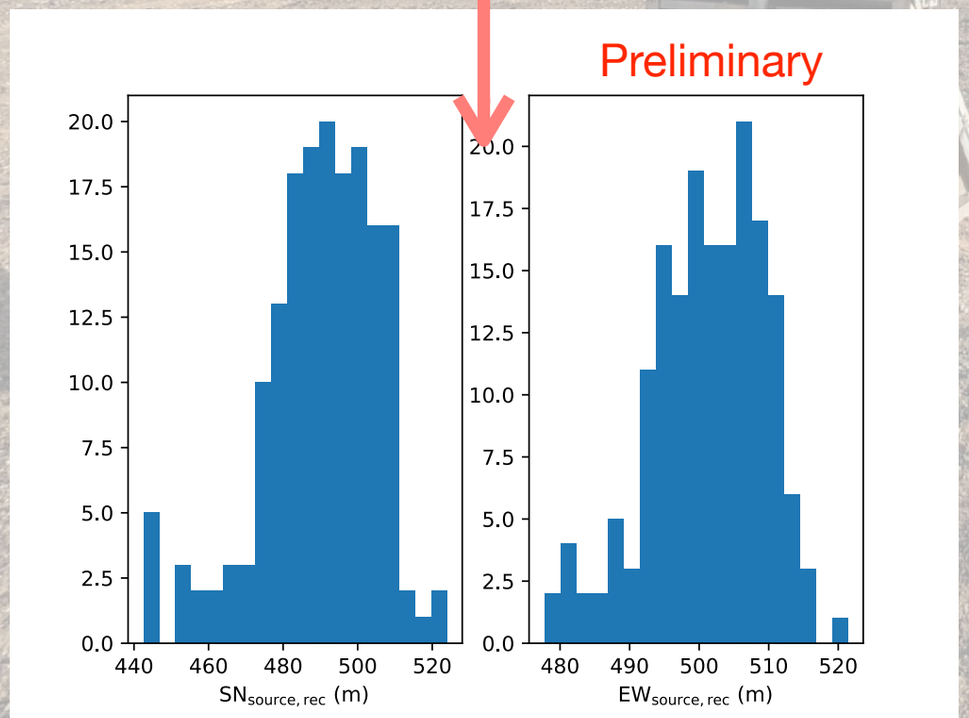
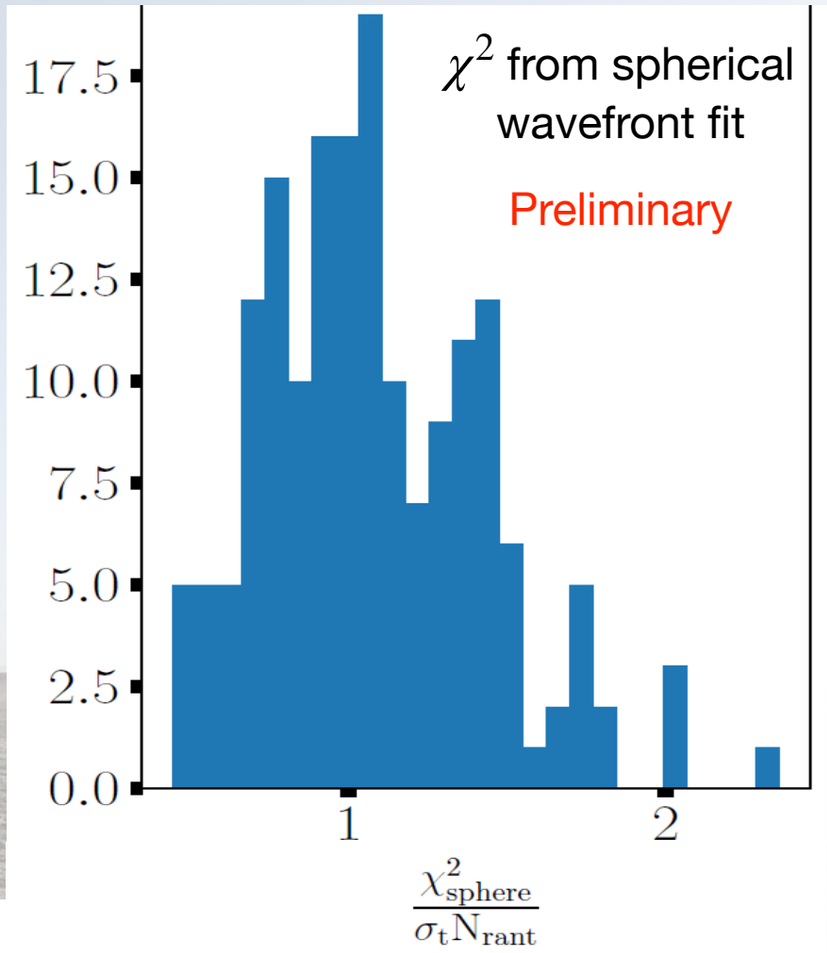
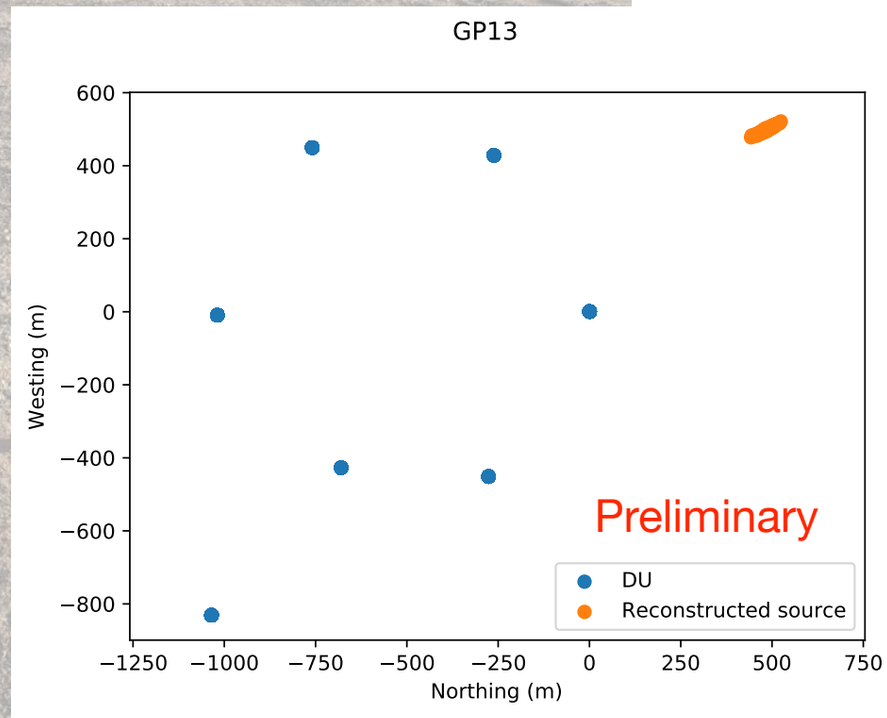


Quality cuts







Next stages

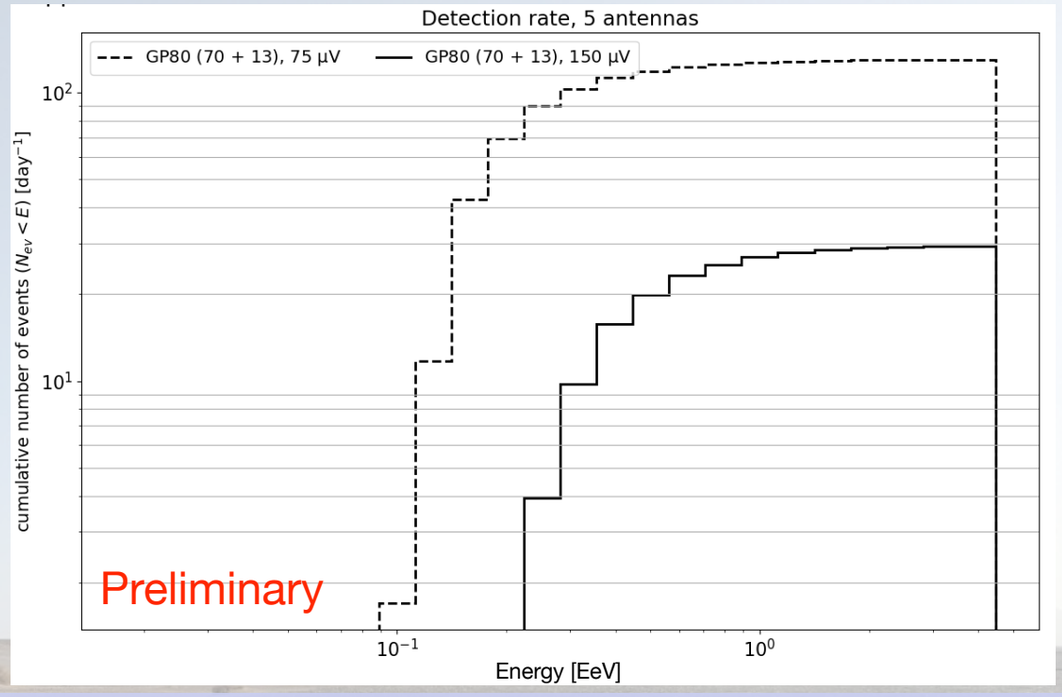
GP80 **70 additional antennas to be deployed in Fall 2024**

Requirements by then

- Firmware needs to be upgraded
- Improved communication between DUs and DAQ
- Reconstruction of the arrival direction from a known source

Expected achievements

- Reconstruction of the first cosmic-ray events



With 83 antennas (70 + 13 antennas, no infill) and conservative trigger: **~30 cosmic rays EAS/day** between ~ **2.10^{17} and 2.10^{18} eV**

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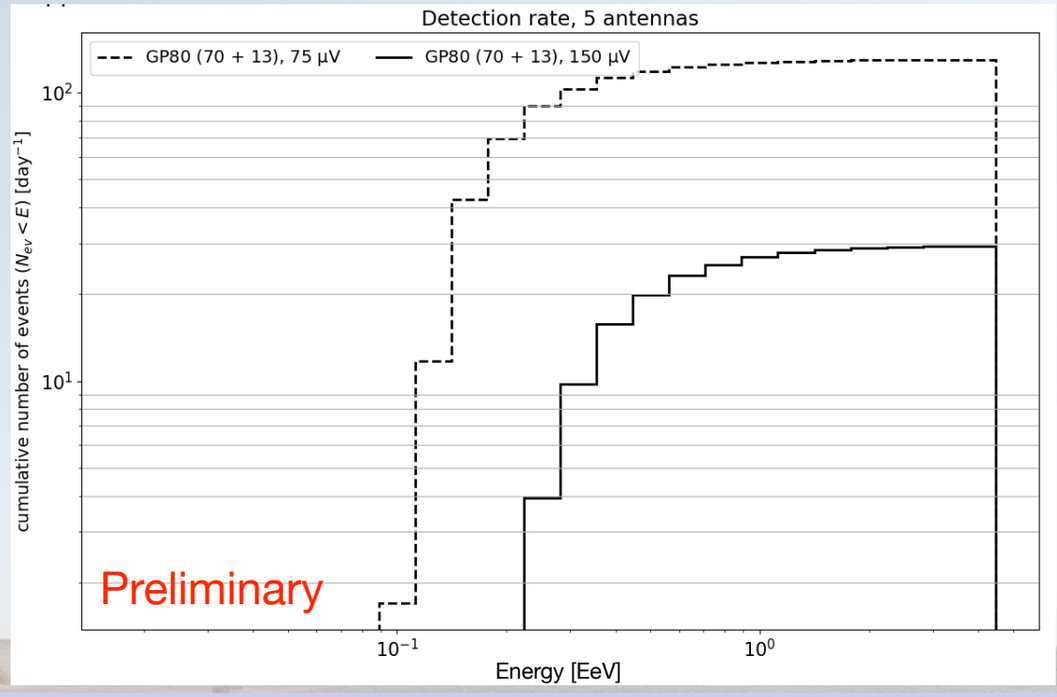

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GP300

~2026: full array of $\mathcal{O}(300)$ antennas over 200 km^2 (+ surface detectors?)

Cosmic-ray, gamma-ray and radio astronomy science

Validation of GRAND detection principle

GRAND10K

~2030s: extension to the first GRAND sub-array with $10\,000$ antennas (Kumiko's talk)

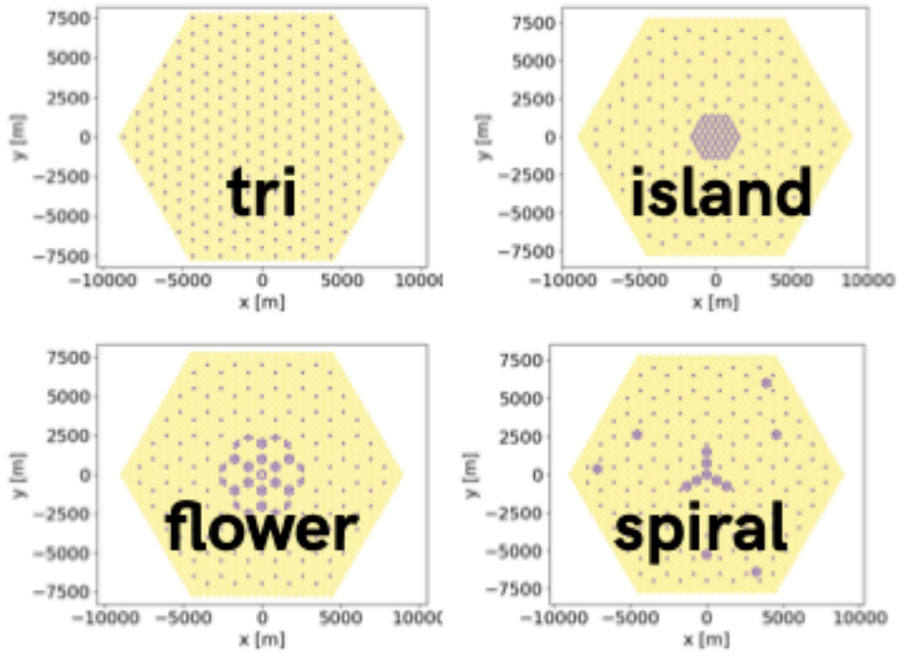
Expected performances

Layout and expected trigger rate

Benoit-Lévy, Kotera, Tueros, 2024 (arXiv: 2401.01267)

Explored: Geometrical pattern, step size, ...

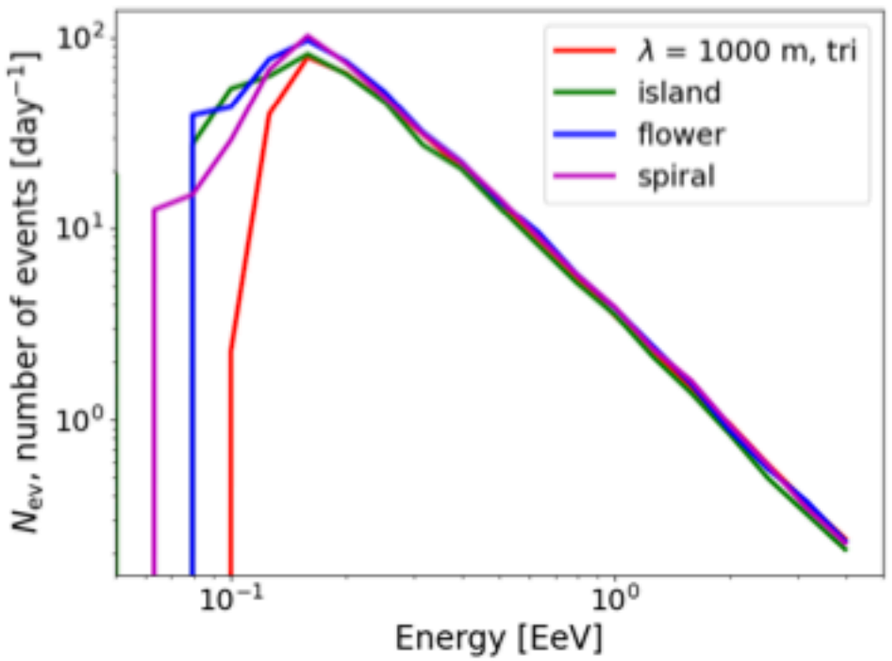
Adding an infill

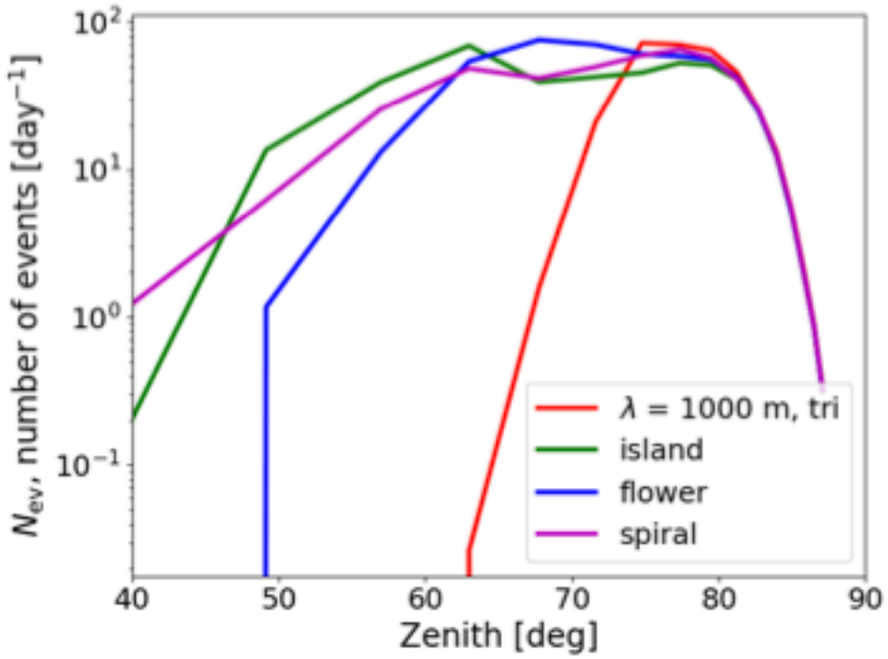


geometry	step size of coarse λ [m]	N_{antenna}	N_{ev} [day^{-1}]	$N_{\text{ev}}/N_{\text{antenna}}$ [day^{-1}]
hex	1000	150	192.38	1.28
tri	1000	241	321.77	1.33
island	1000	240	438.40	1.83
flower	1000	264	476.43	1.80
spiral	1000	235	441.15	1.88

more efficient to have infill than dense array

tri geometry: marginal gain
for large number of antennas required





~250 antennas
surface = 204 km^2
N_{trig} = 5, V_{trig} = 75 muV

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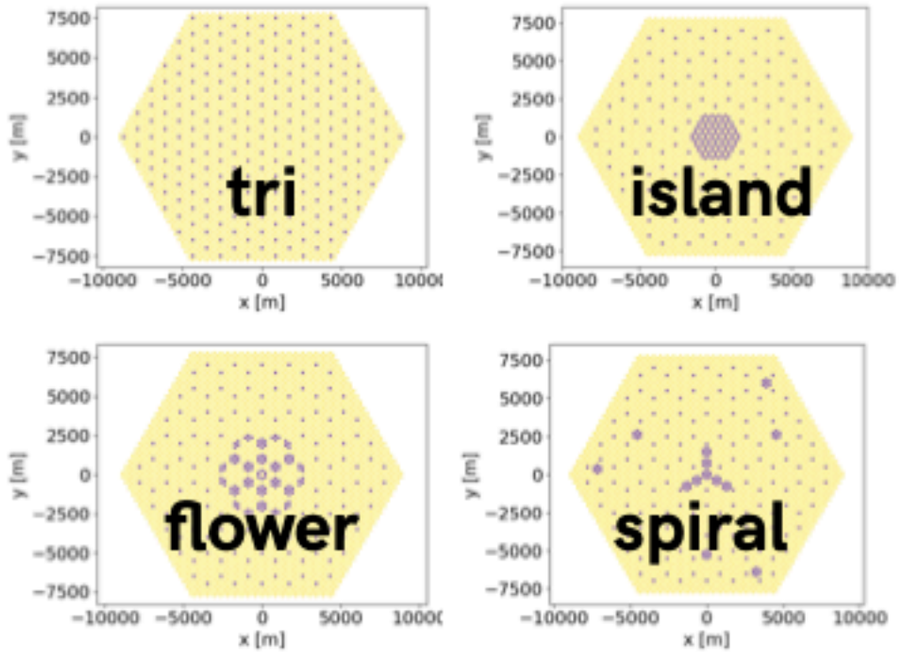

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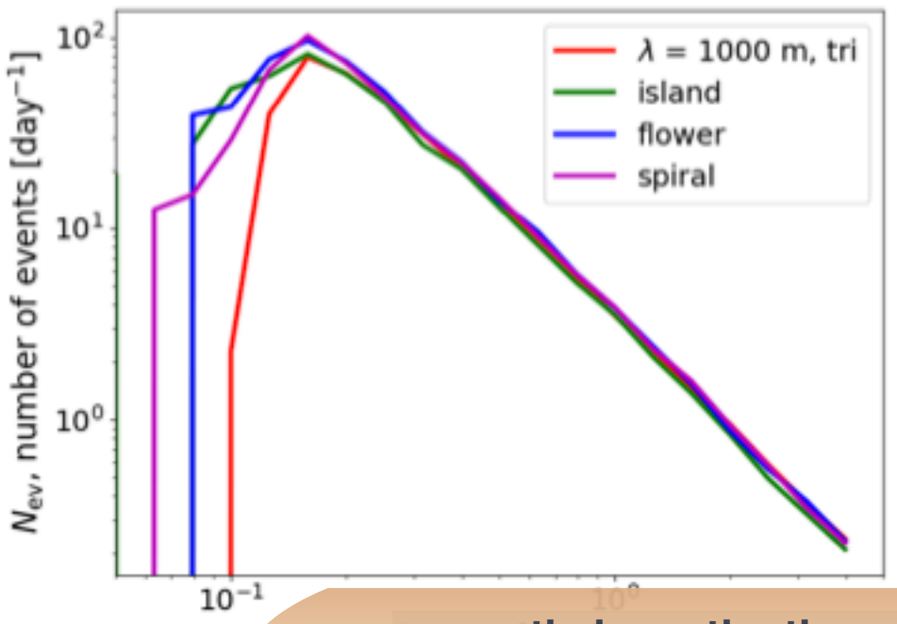

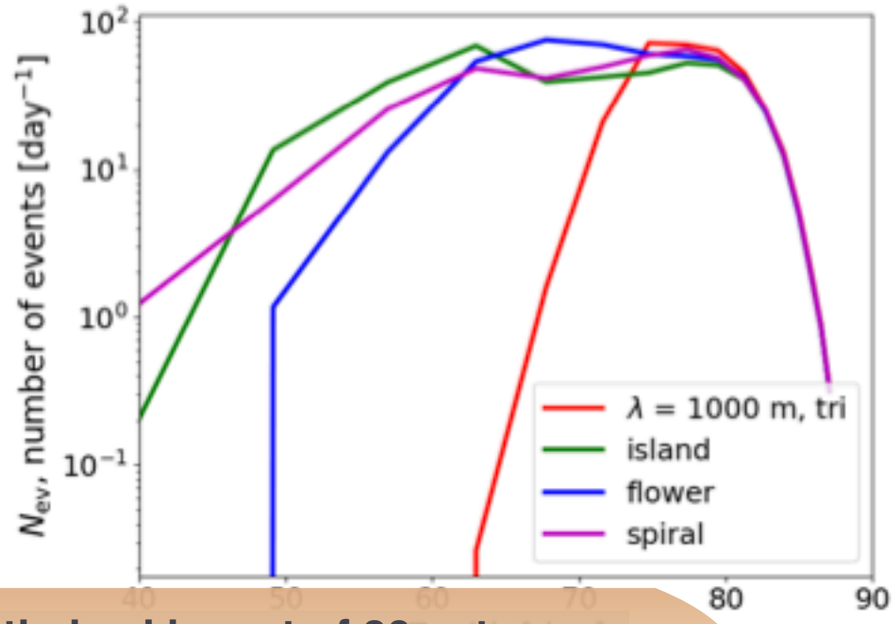

~250 antennas
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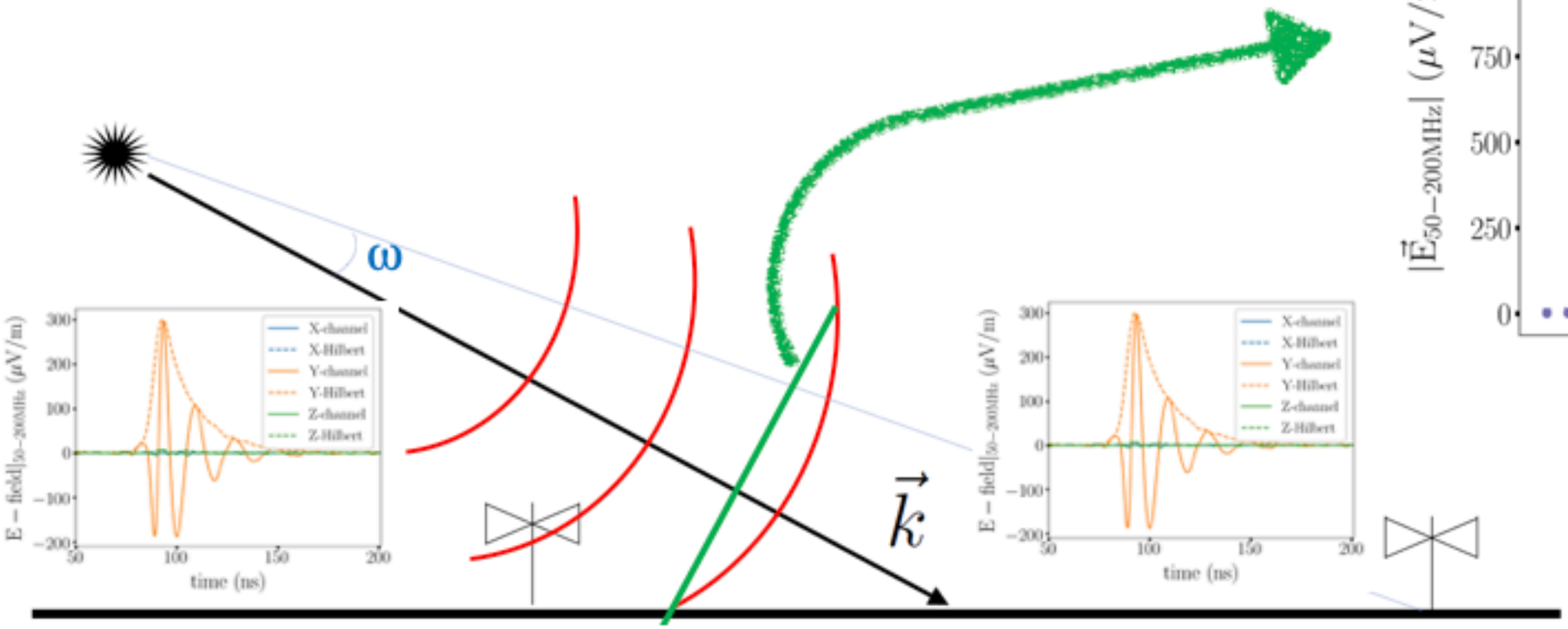
currently investigating optimized layout of 80 antennas for good reconstruction performances of very inclined EAS

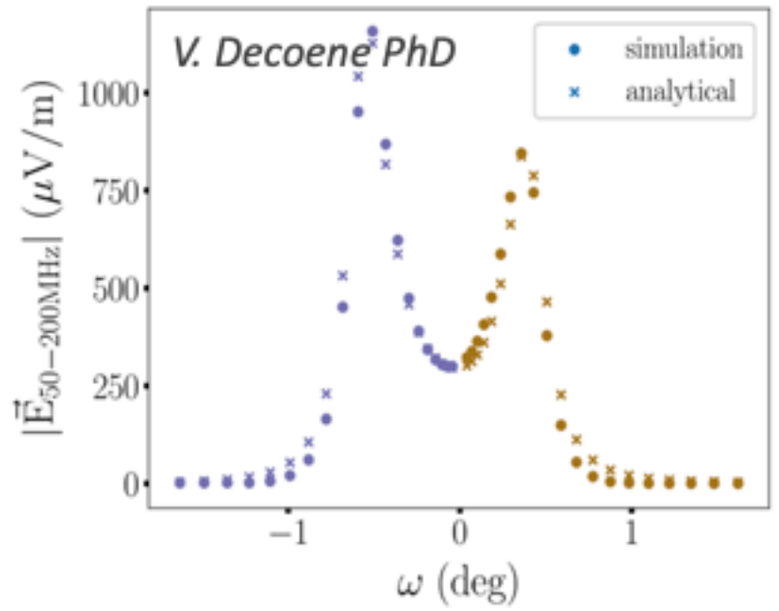
X_{max} and angular reconstruction

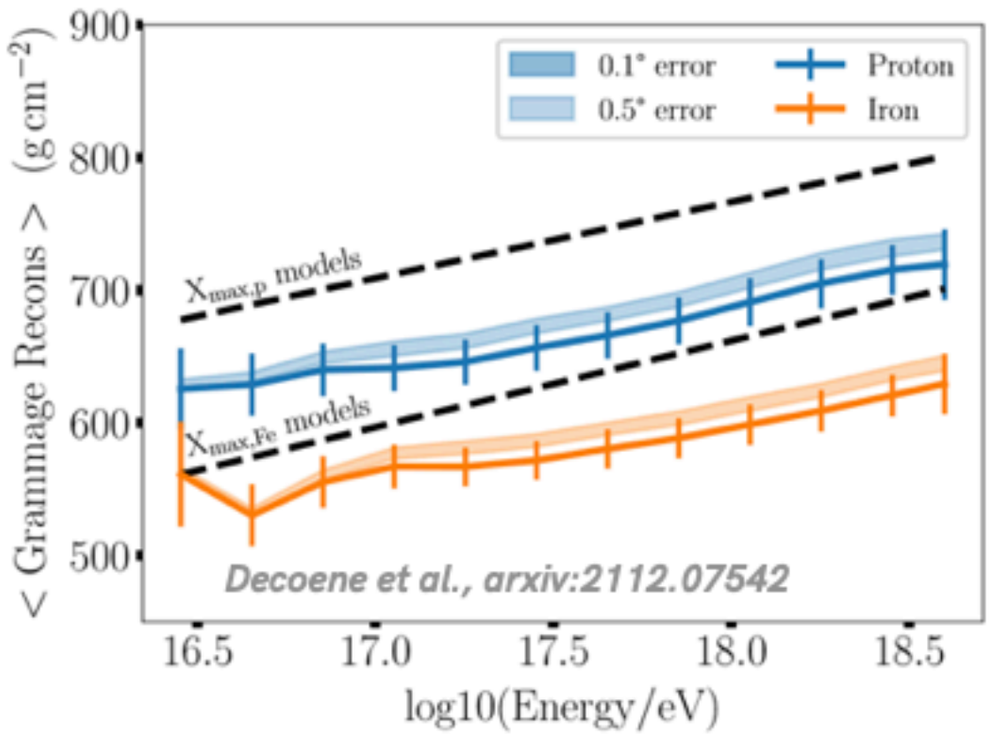
(Oscar's presentation)

Center of spherical fit
of trigger times
⇔ radio emission source

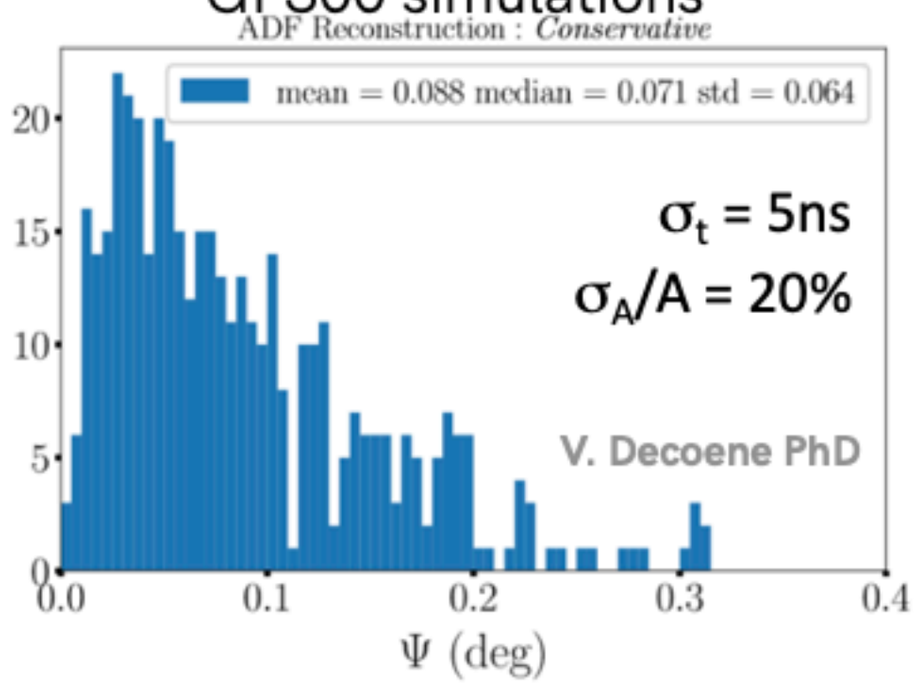


Analytical description of amplitude distribution



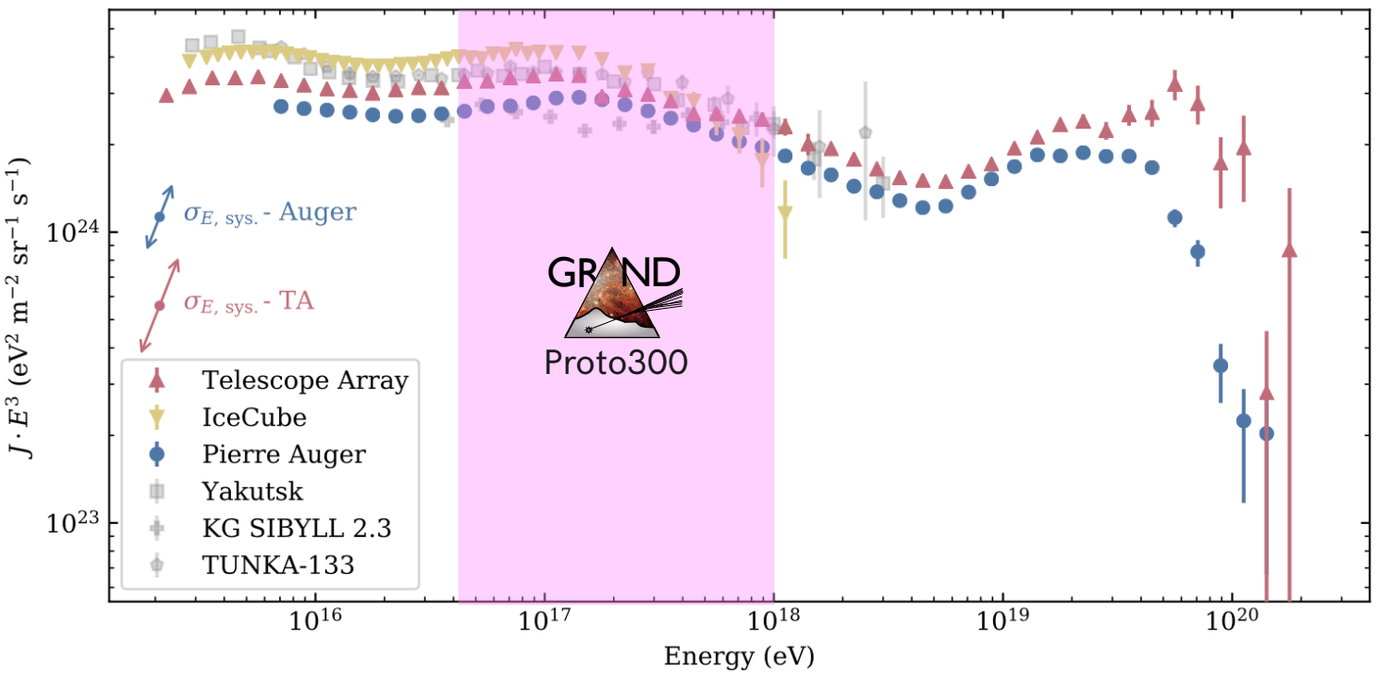


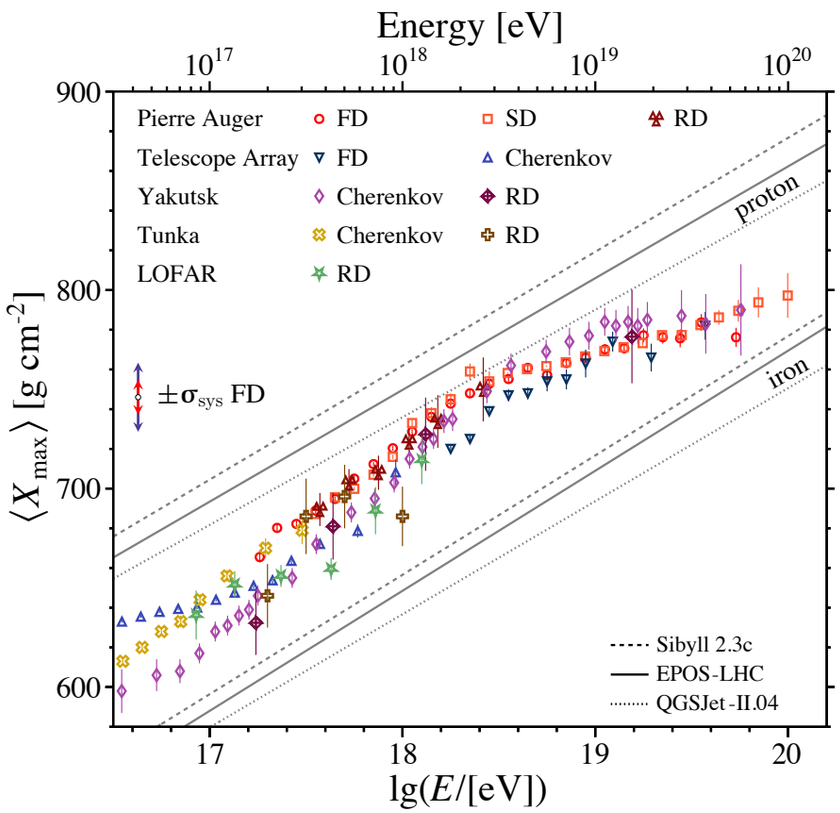
GP300 simulations

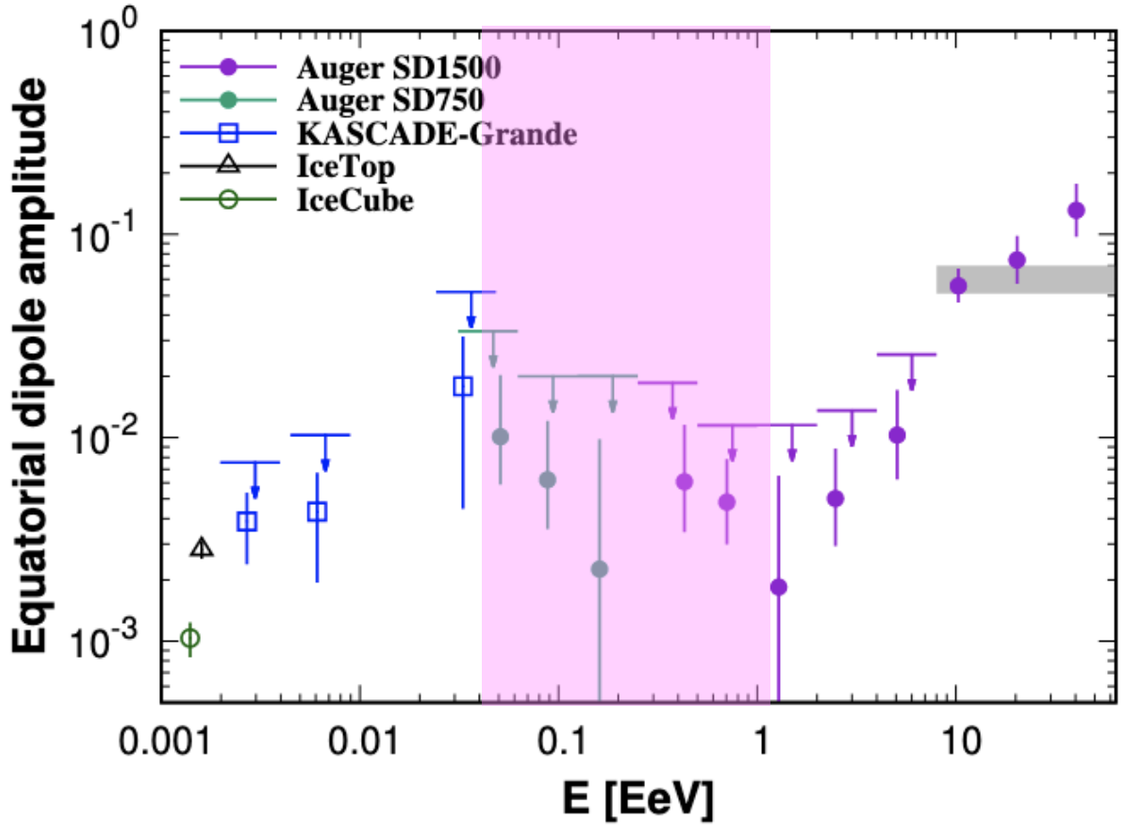


GRANDProto300 science case

Galactic to extragalactic transition







SNOWMASS review 2022, arXiv:2205.05845

- Composition between knee and second knee?
- Several breaks in TA's spectrum
  (mixed composition?)
- We need **more statistics** and **a better** $\mathbf{X}_{\mathrm{max}}$ **resolution** between $10^{16.5}$ eV and 10^{18} eV

GRANDProto300 will increase the statistics and perform independent cross-checks from pure electromagnetic measurements

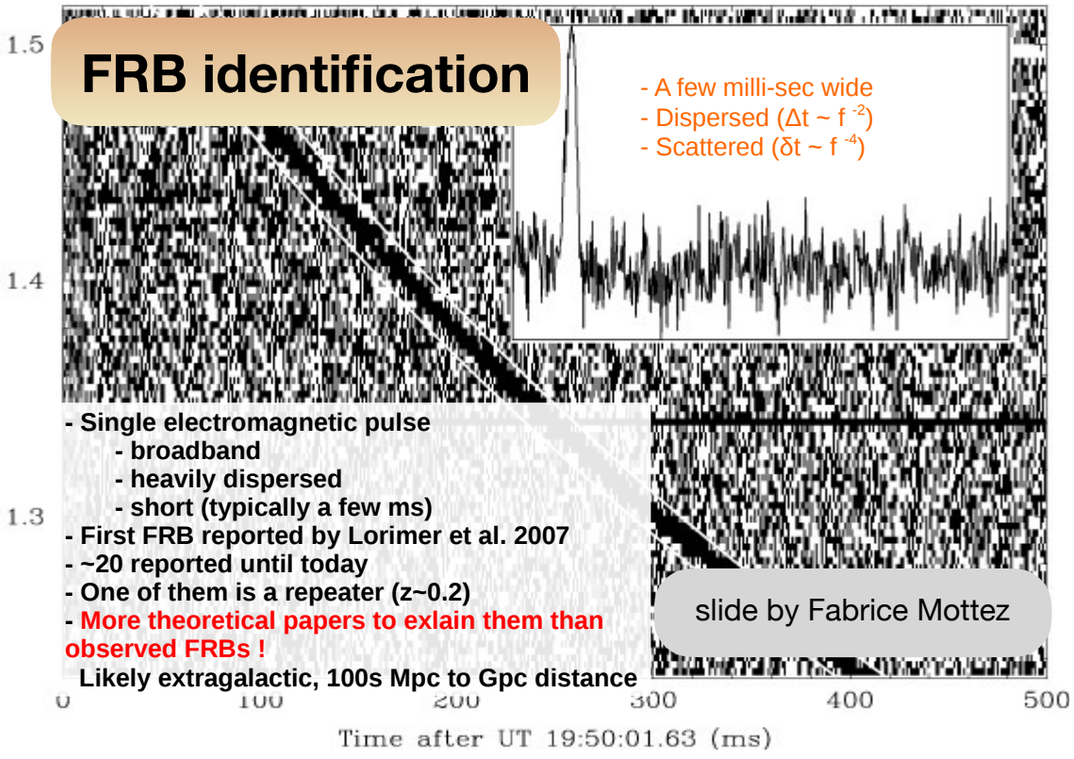
Fast radio bursts

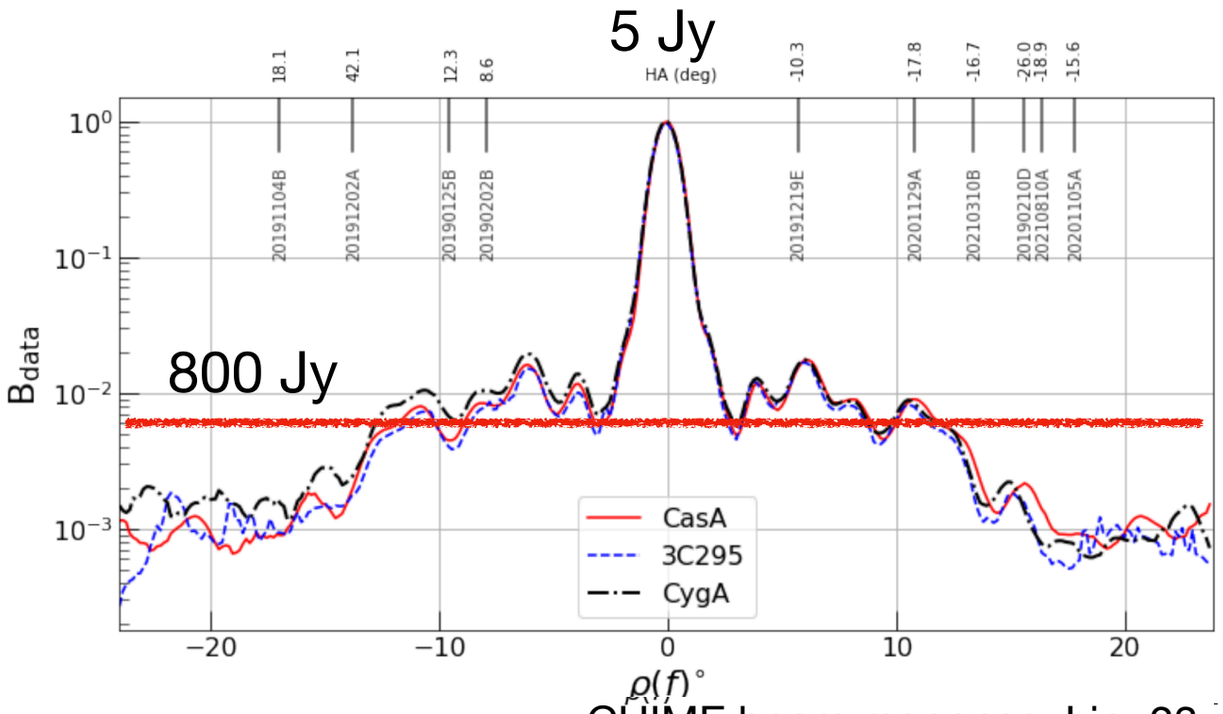
Fast radio bursts: Powerful transient radio pulses with a typical duration of a few ms

• Most FRB detectors have an angular resolution of a few arcmin^2

• GRAND will have a large field of view and high sensitivity: **well suited to do FRB searches**

• 2 possible approaches:
(1) unphased sum of signals (large FOV nearby FRBs)
(2) Beamforming (higher sensitivity)





CHIME beam response: Lin+23

• Beamforming: Sensitivity $\propto \sqrt{N_{\rm ant}}$

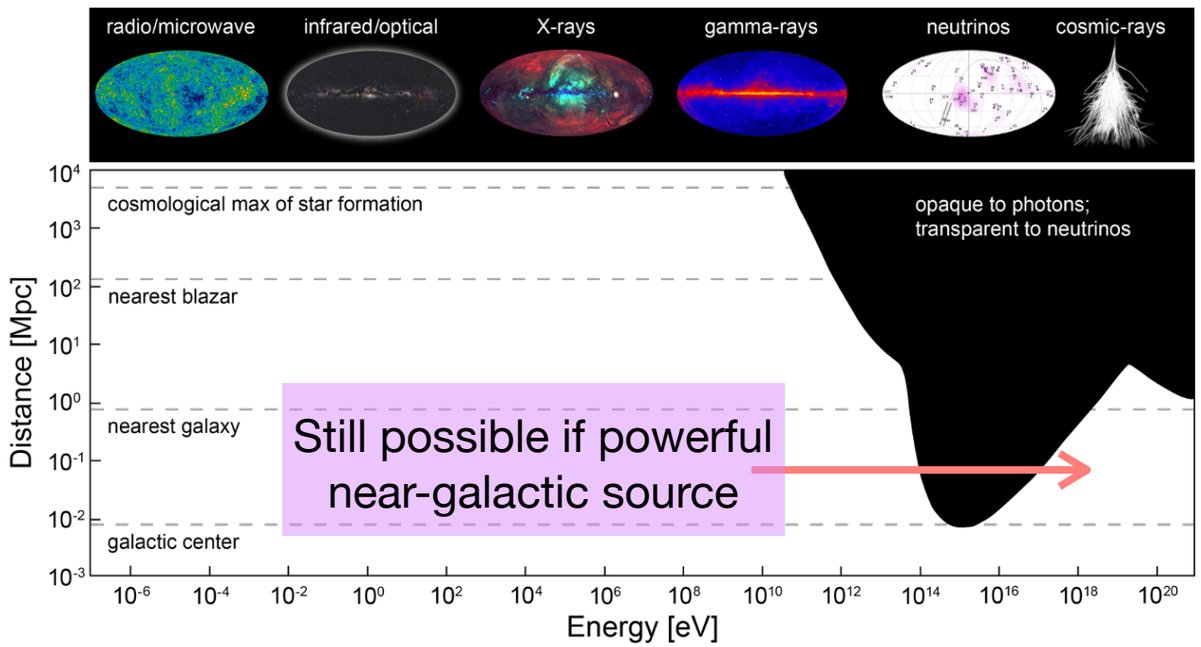
• GP300 detection threshold for a $10\,\sigma$ observation: $\sim 800\,\mathrm{Jy}$

• GP300 could potentially see **1 FRB/month**

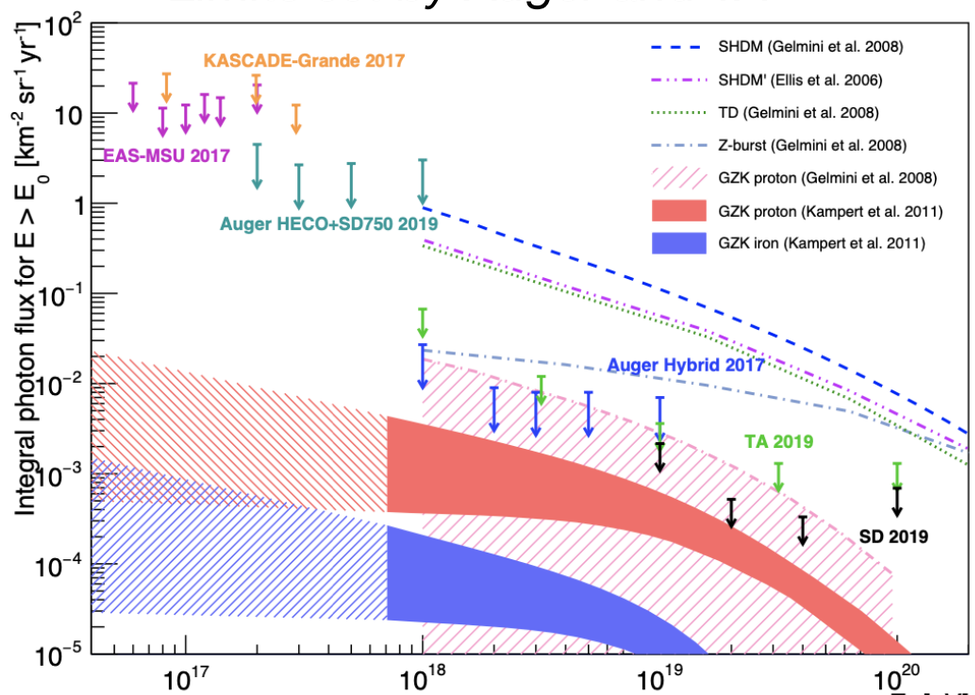
Ultra-high-energy gamma-rays

Ultra-high-energy gamma-rays ($E > 10^{17}\,\mathrm{eV}$) are guaranteed to exist

Yet, observation is challenging



Limits set by Auger and TA



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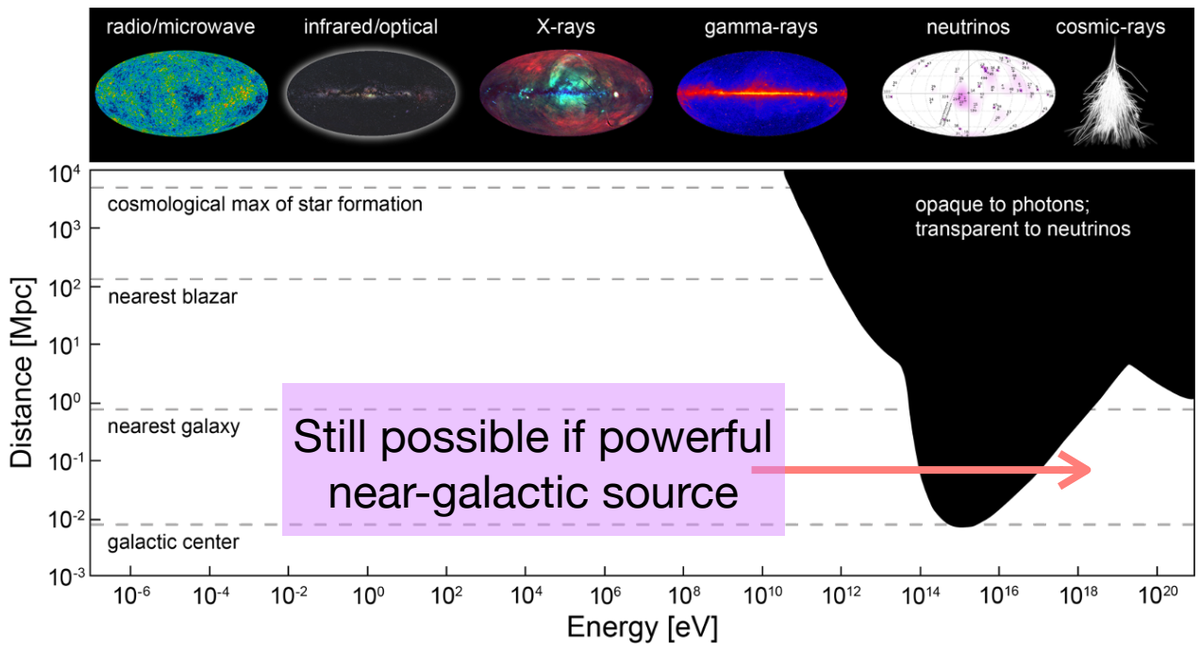

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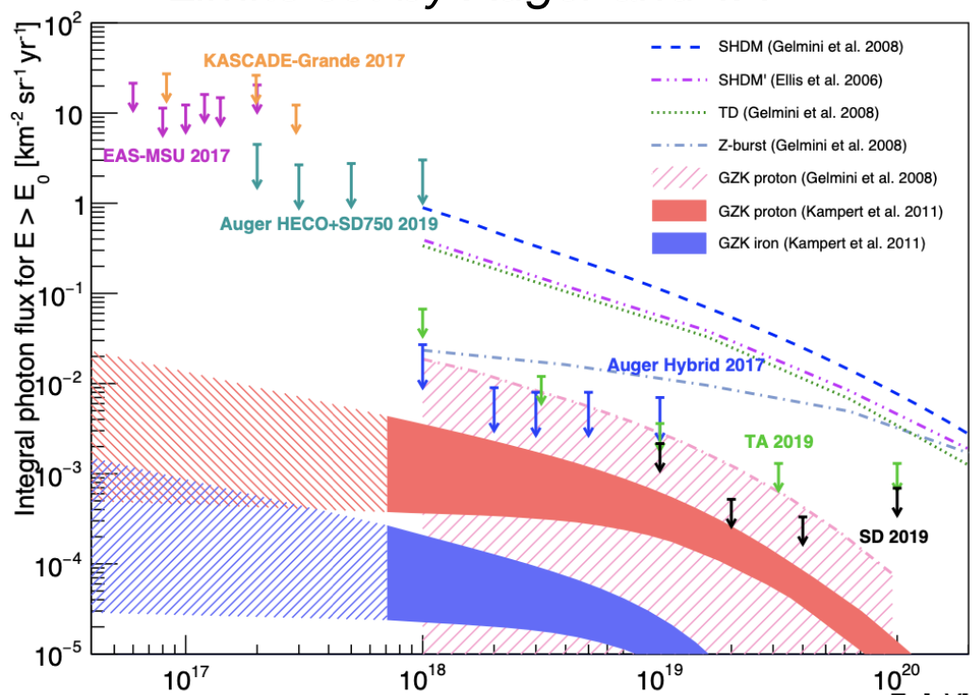

GP300 could be one of the most sensitive UHE γ-ray experiment if completed with surface detectors

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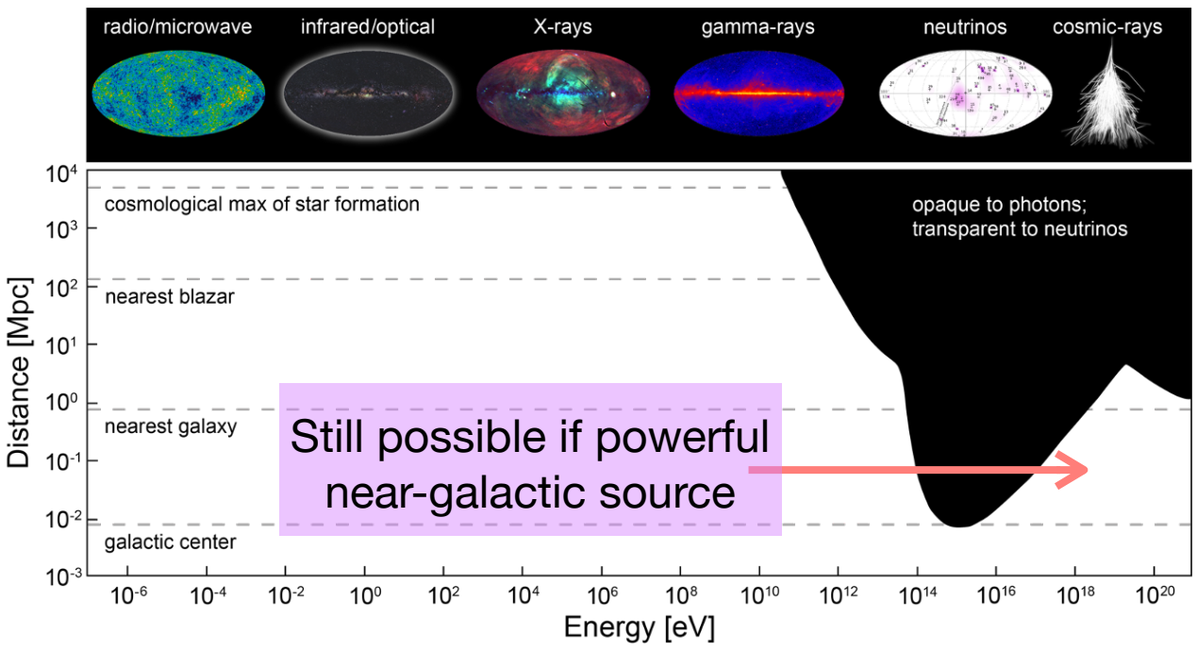

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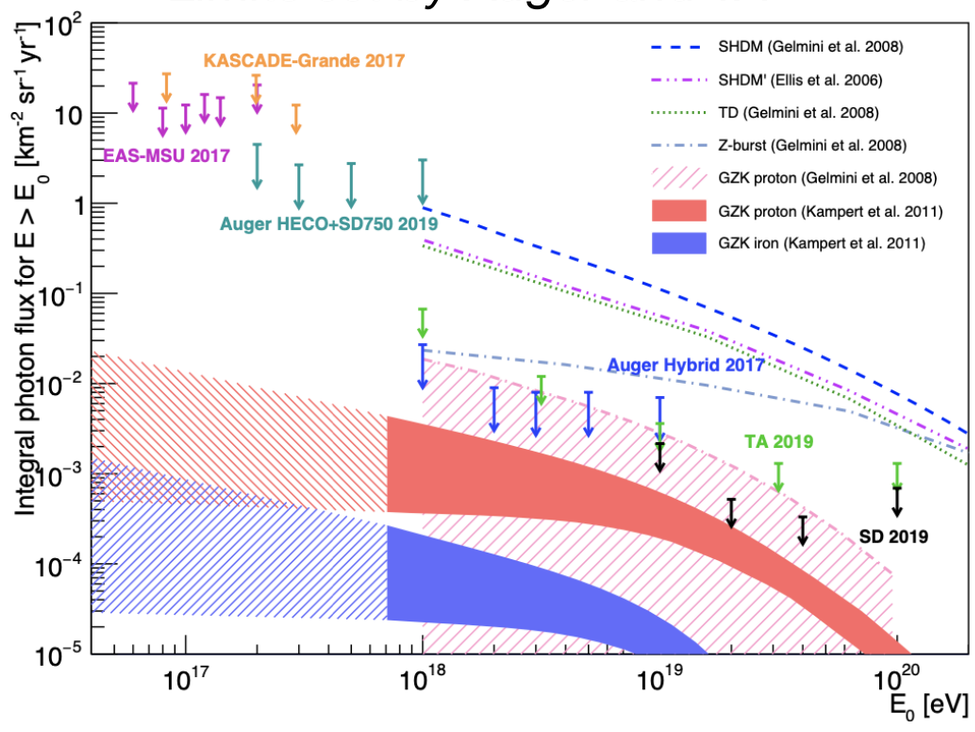
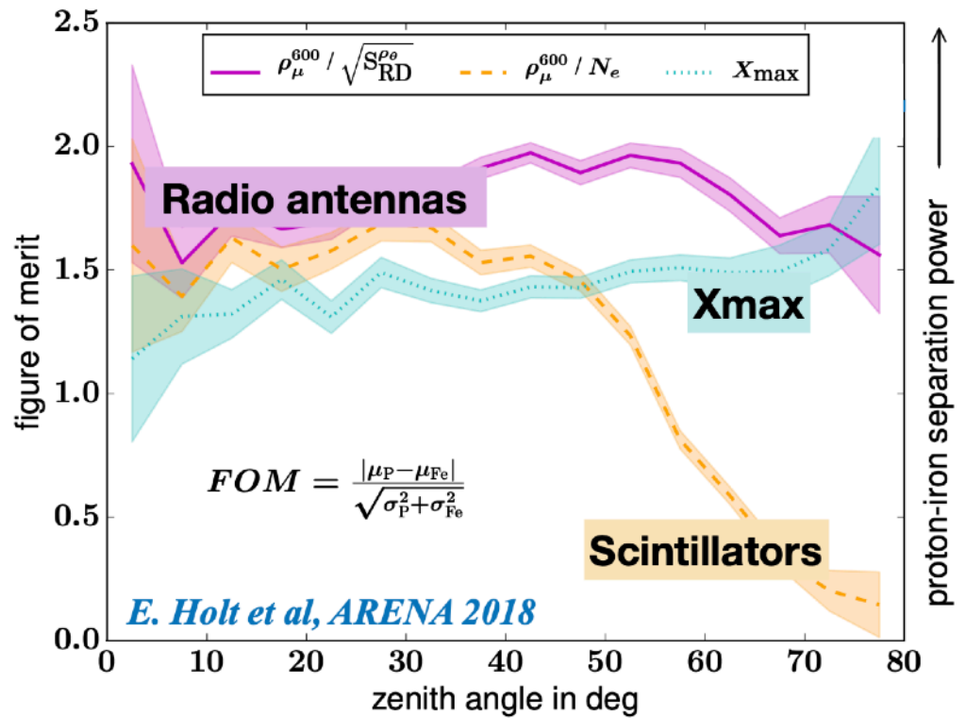


GP300 could be one of the most sensitive UHE γ-ray experiment if completed with surface detectors

- EM/μon ratio is one of the best observables for mass composition studies
- Radio antennas measure the EM energy
- For inclined showers, surface detectors yield a precise measurement of the muon content



Summary

GRANDProto300: radio array of 300 antennas in the Gobi desert detecting cosmic-rays (and gamma-rays?) between $10^{16.5} - 10^{18}\,\mathrm{eV}$

13 antennas were deployed and 83 should be deployed by Fall 2024

First data were taken and reconstructed events should follow!

Successful collaboration meeting in Nanjing! (May 2024)