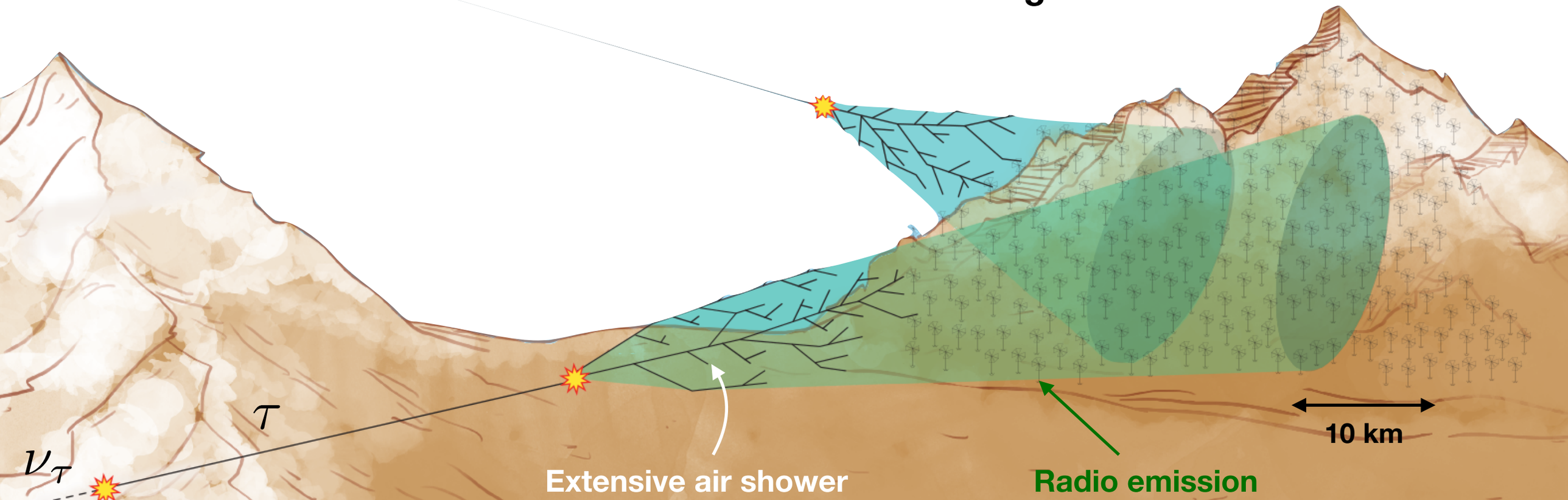
Valentin Decoene for the GRAND collaboration

The GRANDProto300 experiment

International Cosmic Ray Conference 2019

Giant Radio Array for Neutrino Detection (GRAND)

Radio detection of neutrino induced earth-skimming extensive air showers



GRAND concept:
- 200,000 antennas over 200,000 km2 = 20 sub-arrays of 10,000 km2
- in radio quiet mountainous regions around the world (half in China)
- autonomous radio detection of inclined air-showers in 50-200 MHz band

Staged approach to GRAND needed !

GRAND White Paper, GRAND coll. arXiv:1810.09994v1

From GRANDProto300 to GRAND

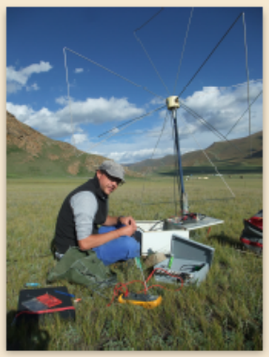
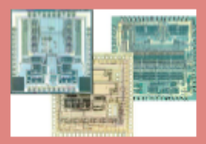
TREND +

GRANDProto300 ← **This talk**

GRANDProto35

GRAND10k

GRAND200k

	2018	2020	2025	203X
Goals	standalone radio array: test efficiency & background rejection	standalone radio array of very inclined showers (θ_z>70°) from cosmic rays (>$10^{16.5}$ eV) + ground array to do UHECR astro/hadronic physics	first GRAND subarray, sensitivity comparable to ARA/ARIANNA on similar time scale, allowing discovery of EeV neutrinos for optimistic fluxes	first neutrino detection at 10^{18} eV and/or neutrino astronomy!
Setup	35 radio antennas 21 scintillators 	• 300 HorizonAntennas over 300 km^2 • Fast DAQ (AERA+ GRANDproto35 analog stage) • Solar panels (day use) + WiFi data transfer • Ground array (à la HAWC/Auger)	DAQ with discrete elements, but mature design for trigger, data transfer, consumption	200,000 antennas over 200,000 km^2, ~ 20 hotspots of 10k antennas, possibly in different continents
Budget & stage	160k€, fully funded by NAOC+IHEP, deployment ongoing @ Ulastai	1.3 M€ to be deployed in 2020	1500€ / detection unit 	Industrial scale allows to cut down costs: 500€/unit ➔ 200M€ in total  ASIC Cost ~10M€ ➔ few 10€/board Consomption < 1W Reliability

See *GRAND: science and design* @13:45 in NU10 Wednesday 31 by *Olivier Martineau-Huynh*!

GRAND White Paper, GRAND coll. arXiv:1810.09994v1

From GRANDProto300 to GRAND

Staged approach to GRAND -> first step is GRANDProto300:
The 300 antennas prototype of GRAND (only for CRs)

GP300 main goal: validate GRAND detection principle
- **standalone radio detection (for very inclined EAS)**
- **background rejection, efficiency…**
- **event reconstruction**

GP300 = testbench:
- **different design (ARA/ARIANNA station, phased array, antenna design)**
- **new trigger methods (ML) and data transfer protocols**

Instrument for science:
- **physics of cosmic rays**
- **astrophysical phenomena**

GP300 will be both a engineering array and a standalone experiment!

Site and deployment

Site selection between August 2017 and March 2019

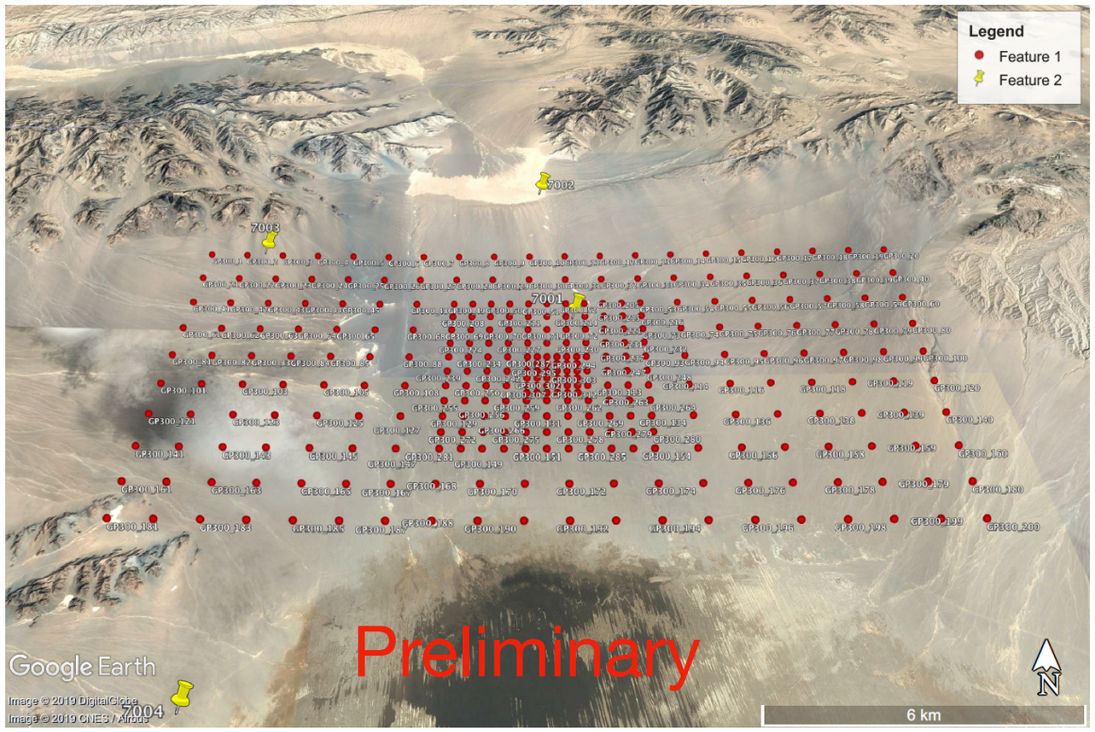
Requirements for autonomous radio detection :

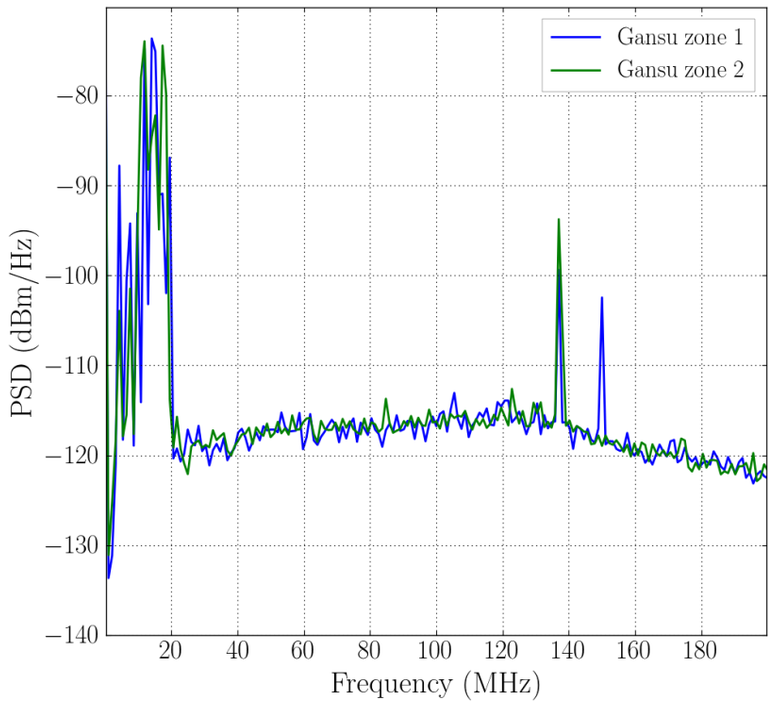
- **stationary noise power at 50-200MHz < 2x Galactic and thermal ground emission**
- **rate of transient events (above a threshold of 6x noise level) below 1kHz**

-> 6 among 9 sites comply **-> radio-quiet sites**

<u>Selected site</u>:

Lenghu QingHai province at the rim of the Tibetan plateau at a 3000m a.s.l

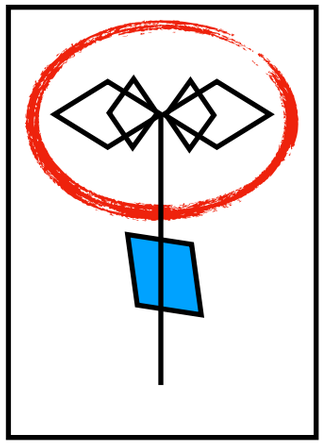




Deployment between 2020 and 2021 of about 300 detection units over 200km² at the center of a radio-protected area of 2500km²

-> long term measurements deployed this summer !

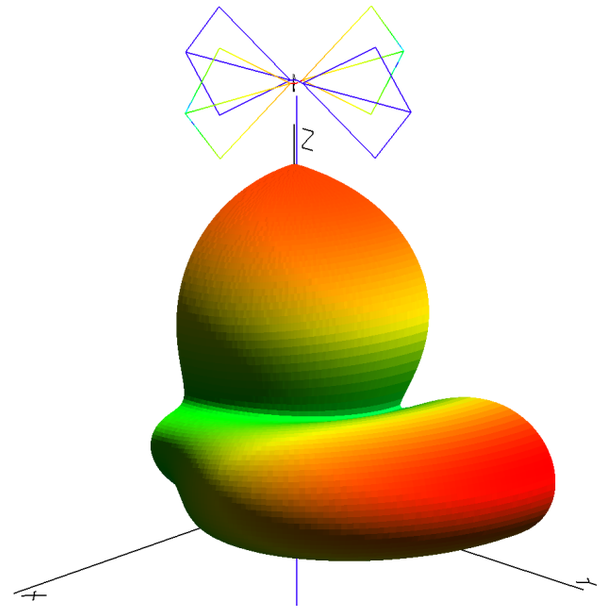
Setup: antenna units



HorizonAntenna

designed by D. Charrier and inspired from CODALEMA

active bow-tie



response simulated in NEC4: flat response -> azimuth and frequency

frequency band = 50-200MHz

-> optimized for very inclined trajectories (ground diffraction -> λ/h)

-> clear distinction of Cherenkov cone

-> optimized SNR

V. A. Balagopal et al., *Eur. Phys. J. C* 78 2 (2018)

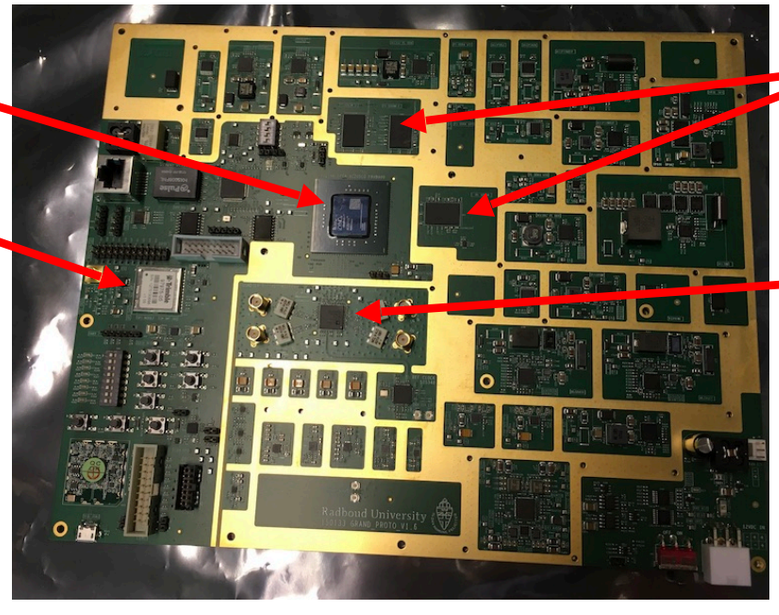
-> deployment easier for small antenna and more robust

3 polarisation measurements: x, y, z

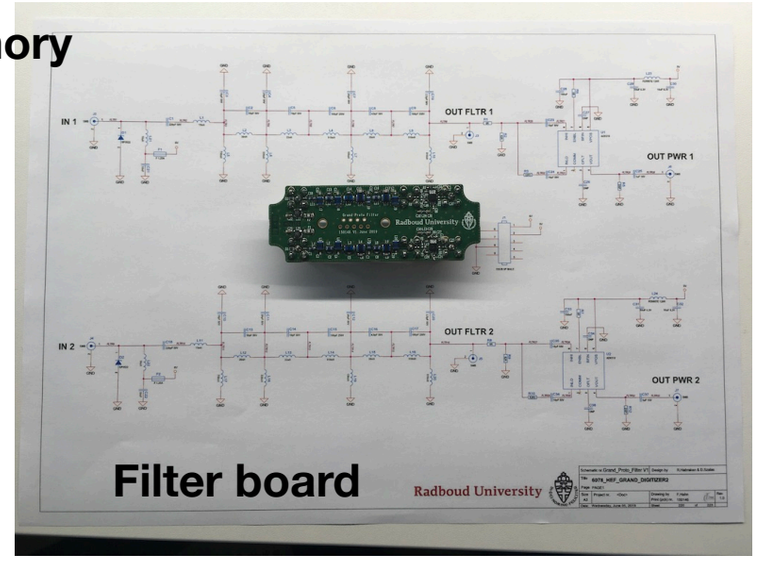
design motivated from Cherenkov cone identification and SNR studies

A. Escudie, *EPJ Web Conf.* 210 05003 (2019)

Setup: front end electronics



Radboud U.
Nijmegen



Filtering: 30-230MHz with a difference in group delay limited to 10ns -> optimised bandwidth

ADC: 14-bit (AD9694) -> 500MSPS (2W of consumption) -> above event rate

FPGA:

Zync FPGA (hardcore CPU - Xilinx XCZU5CG):
- remove narrow band sources -> background rejection
- fast trigger logic -> signal identification
- real time FFT -> monitoring and radio-astronomy

timestamps 10ns precision added to triggered ADC -> combine data from different antennas for signal identification

total consumption below 4W

Communication: WiFi Ubiquity airMAX-AC system with BULLET-AC device at the antenna side (max 8W -> ≈3W on average) -> cheap and reliable technology

Power supply: 100W solar panel -> 100% duty cycle

Detection units designed for autonomous radio-detection and efficiency!

Setup: trigger strategy and data throughput

Extrapolation from previous experiment → **Trigger strategy** → **Data throughput design**

T0
if one antenna channel > 5 σ

T1
if pulse shape analysis is positive

-> time stamps (4-Bytes) sent to DAQ

T2
if DAQ find 5 coincident T1 among the array

-> 3μs-long time traces sent to DAQ

++ FFT sums over 4096 samples in 100-200MHz every 10ms

over 300 antennas

-> TREND 95% of rejection

astro-ph/1810.03070
Astropart. Phys 110 (2019), 15

-> TREND direct extrapolations 10mHz

design for 1kHz rate →

designed for 10Hz rate →

- **at DAQ level**
- **4kB/s**
- **65kB/s at most**
- **410kB/s**
- **123 MB/s**

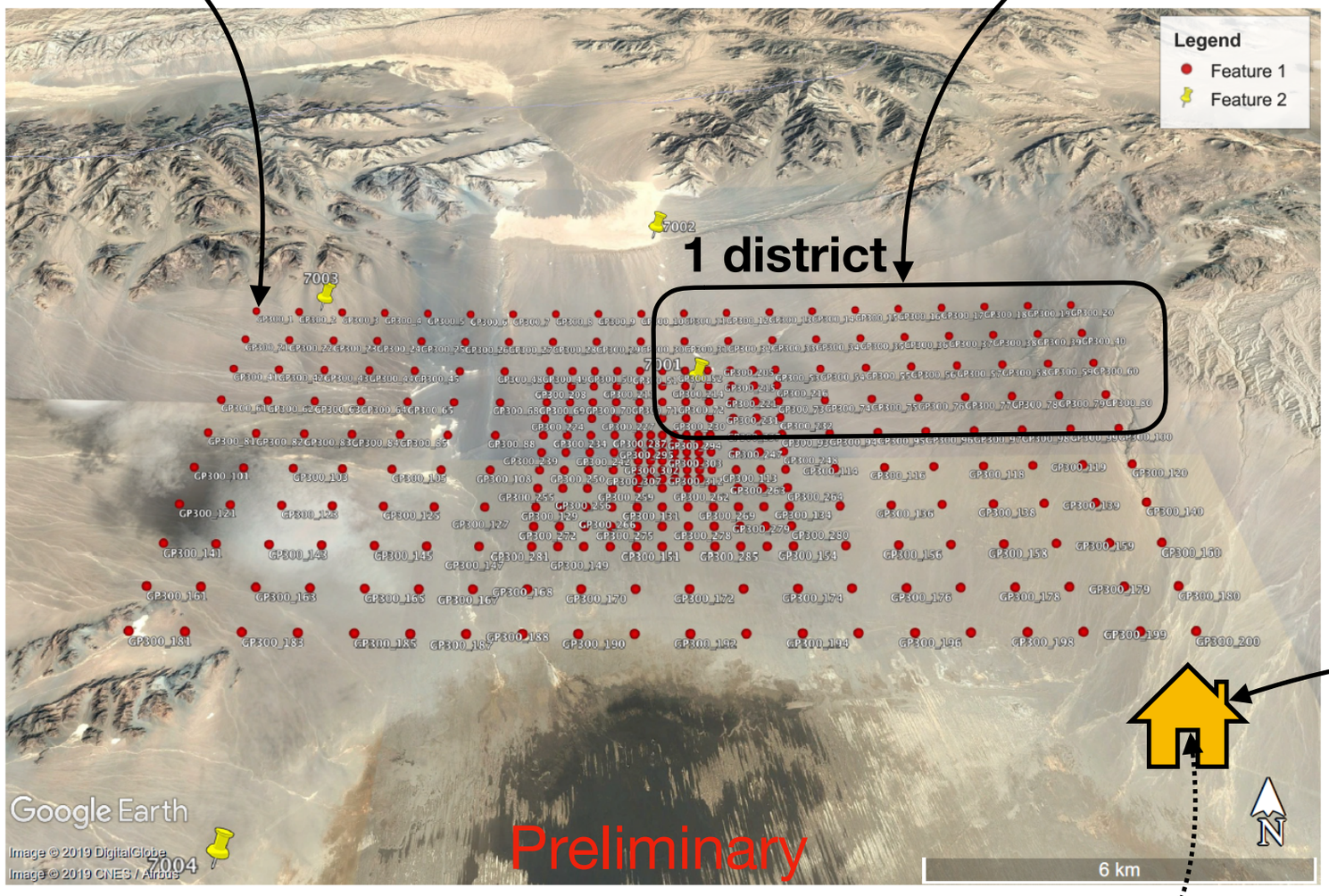
Setup: communication systems

465kB/s at most

through 1 BULLET-AC device

1 district = 37.5 MB/s
at most
through 75 BULLET-AC

x 75



Ubiquity airMAX-AC (WiFi)

ROCKET

-> 60% of its capacity

5 ROCKETs for the whole array at DAQ room

Lenghu at 90km

ethernet

Ubiquity AirFiber @2Gbps

GP300 is designed for a 100% detection efficiency in the worst estimations!

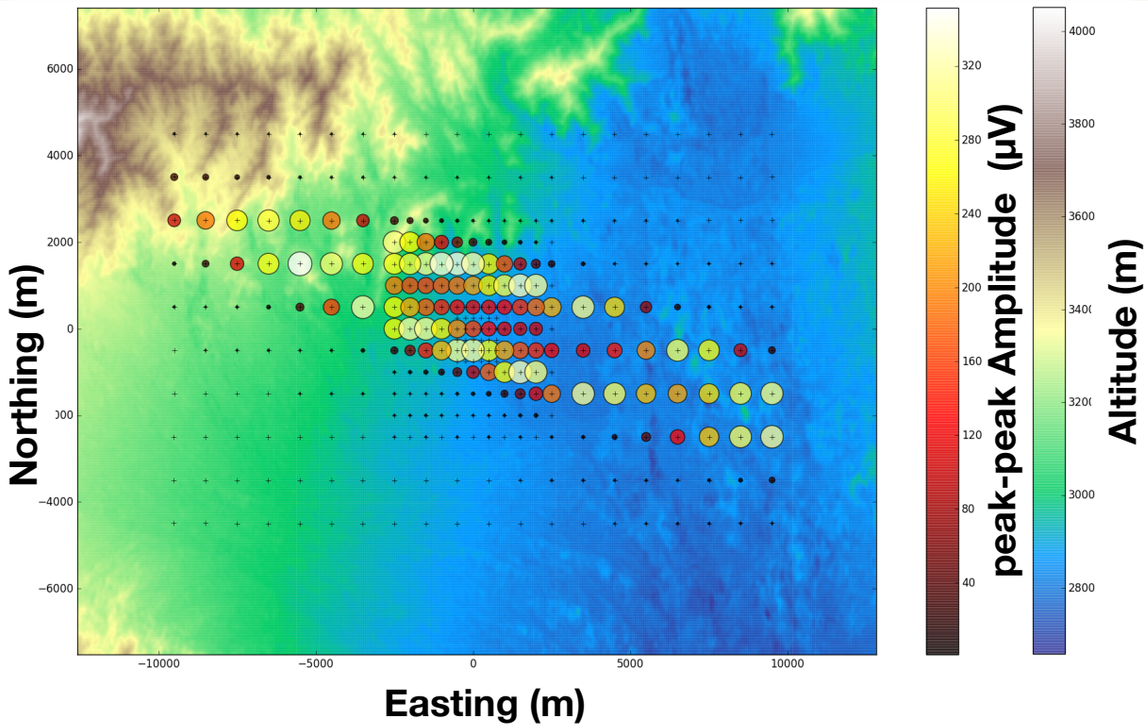
Performances: exposure

Simulation set:

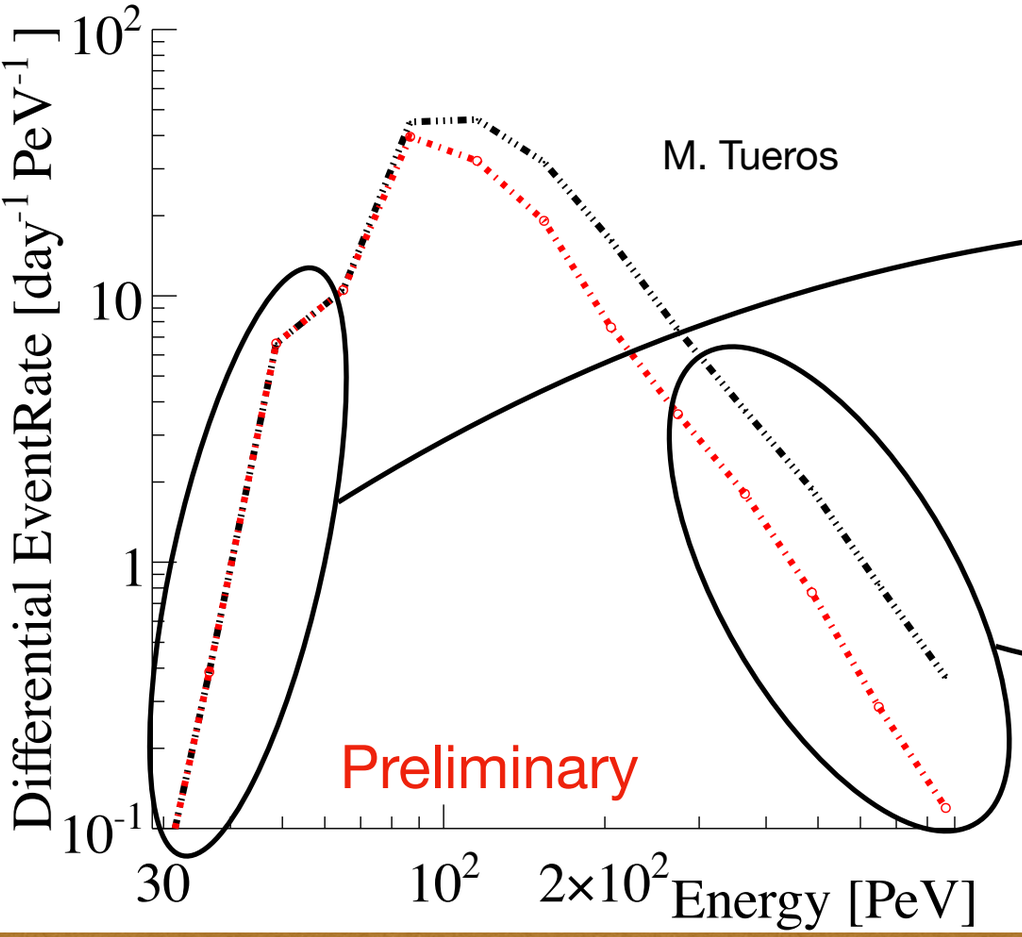
- Initial 5e6 proton events trajectories
- all azimuth and zenith [45;89.9]°
- energies from 10 and 1000PeV

Simulation:

- ZHAires (sybil2.0)
- antenna response based on the HorizonAntenna
- numerical filtering 50-200MHz -> no noise!



Trigger conditions: transient peak-peak amplitude > 75μV (5σ) for 5 antennas



Low energies stats -> infill

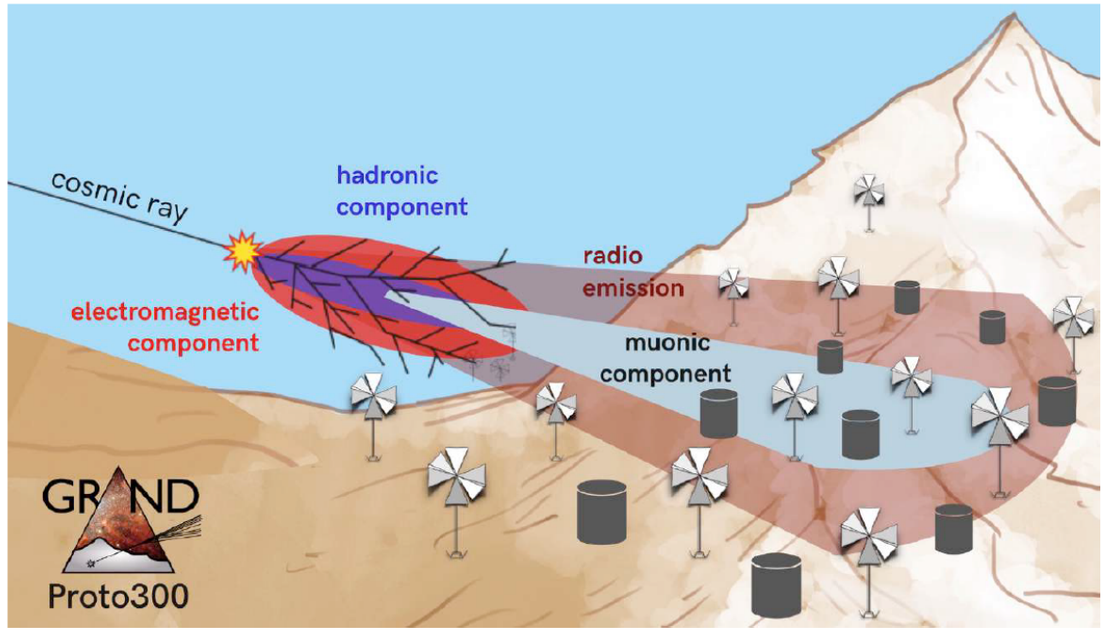
High energies stats -> 200 km² area

Assuming TALE flux

R. U. Abbasi et al., *Astrophys. J.* 865 74 (2018)

Science case: astroparticles

For inclined cosmic ray air shower only muons reach the ground E. Zas, *New J. Phys.* 7 130 (2005)



-> independent measurements of the shower component (muons and EM) with an hybrid array

E. M. Holt et al., *Eur. Phys. J. C* 79 371 (2019)

Cosmic ray physics:

- **muon content enhancement in UHE shower**
- **hadronic processes.**

A. Aab et al. (Pierre Auger), *Phys. Rev. Lett.* 116 24 (2016)

D. d'Enterria, *EPJ Web Conf.* 210 02005 (2019)

UHE gamma ray shower with zenith >65° have dominant EM component fully absorb by atmosphere before reaching the ground

-> particle detector as veto to discriminate UHE gamma rays from cosmic rays

If no gamma rays detected among a sample of 10^4 shower in 2 years

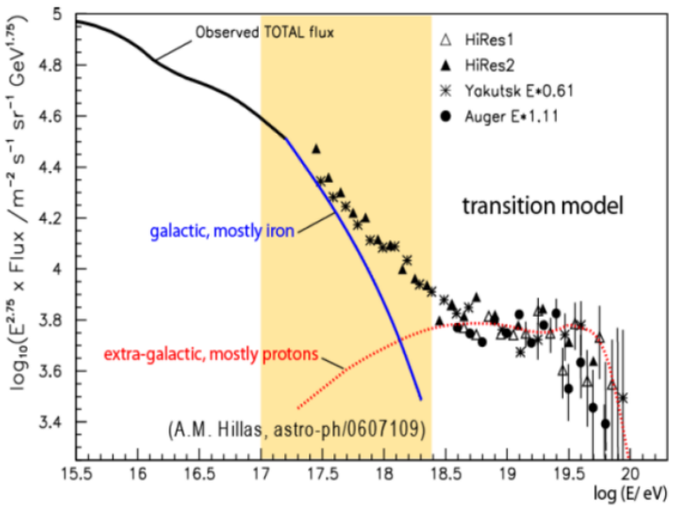
-> fraction of UHE gamma rays 0.03% at 95%CL instead of 0.1% currently.

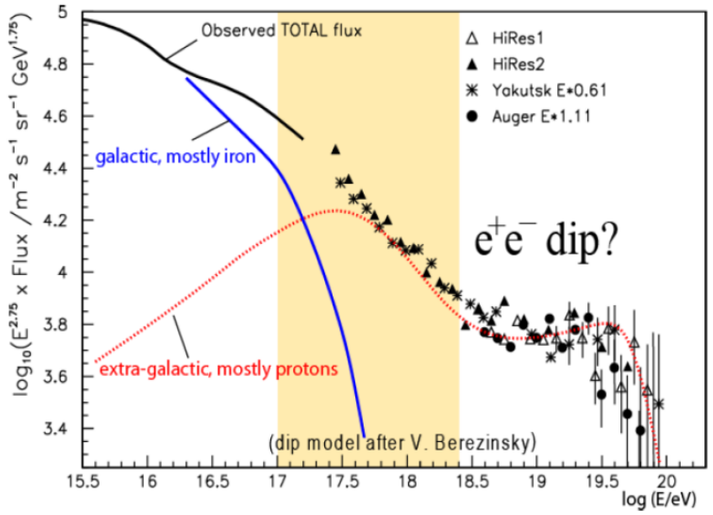
M. Niechciol (Pierre Auger), *ICRC2017* PoS 517 301 (2018)

Galactic and extragalactic transition expected between 10^{17} and 10^{18} eV

-> precise measurements of energy, composition and arrivals directions with large statistics

B. R. Dawson et al., *PTEP* 2017 12 (2017)



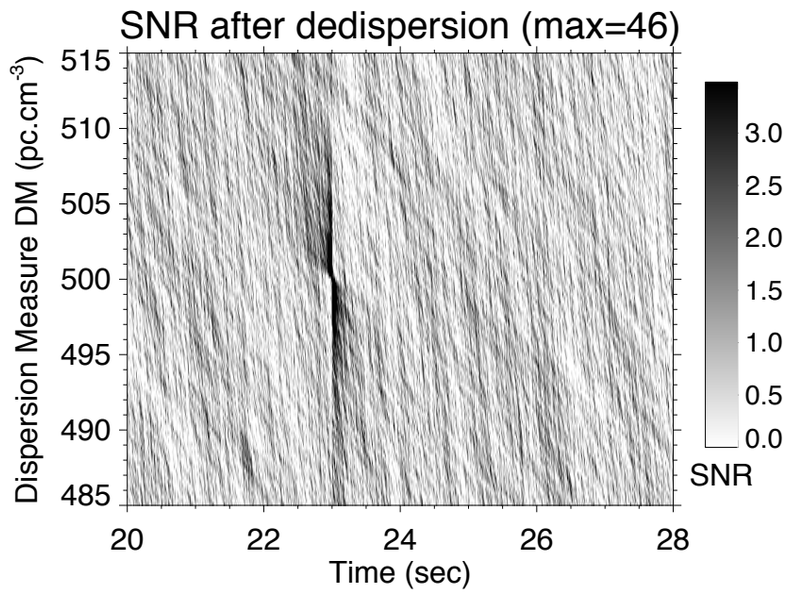


Science case: radio-astronomy

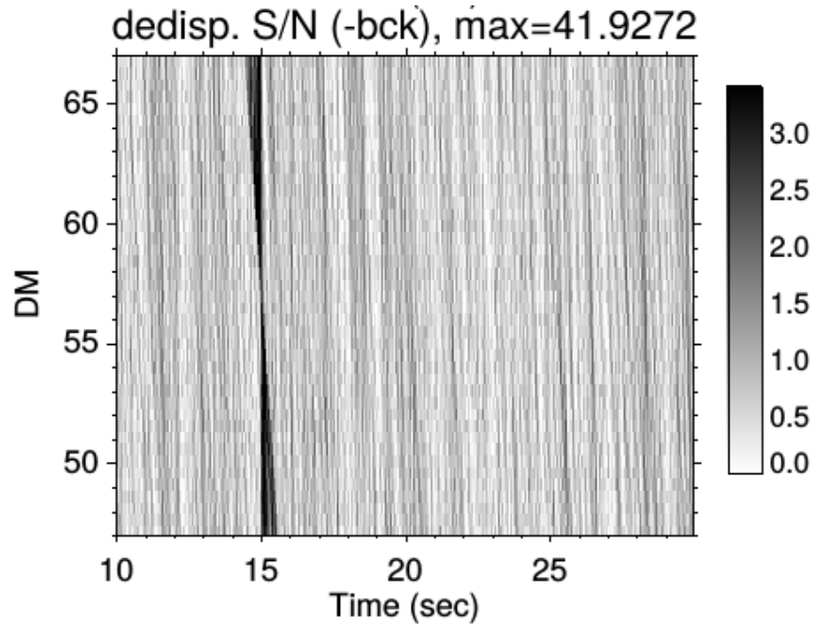
<u>Transient radio astronomy</u>: transient radio signal can bet detected using incoherent FFT sums

- **SNR $\propto$ sqrt(N_ant) not as good as a phased array** GRAND White Paper, GRAND coll. arXiv:1810.09994v1
- **But GP300 large array makes it competitive**
- **whole sky monitoring as FoV of array = FoV antenna**
- **100% duty cycle**

if Fluency above 750Jy (see ASKAP et CHIME survey)



Fast Radio Burst detection
D. R. Lorimer et al., *Science* 318 5851 (2007)



Giant Radio Pulses detection
T. Eftekhari et al., *Astrophys. J.* 829 2 (2016)

<u>Epoch of Reionization:</u>

21-cm line from the Epoch of Reionization can be measured at 10-200MHz as features in the CMB temperature.

Recent measurements has found a 500mK-deep absorption feature at 78MHz. Not in agreement with theoretical models J. D. Bowman et al., *Nature* 555 67 (2018)

GP300 might achieve 1mK with 30 antennas at 80MHz -> if precise absolute calibration done

Trending radio astronomy almost for free!

Conclusion

GRANDProto300 will be deployed in the next two years

It will be the first array designed for autonomous radio detection built on feedback from previous experiments in the field

Challenges are not underestimated!

Experimental and physical challenges offer the opportunity to develop new techniques that will be tested on field.

When working, GP300 will offer a unique opportunity to study astroparticle physics and astrophysical phenomena

Everybody is welcome to join!

+ post-doc position @Nanjin (contact: xywang@nju.edu.cn)!

http://grand.cnrs.fr/

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