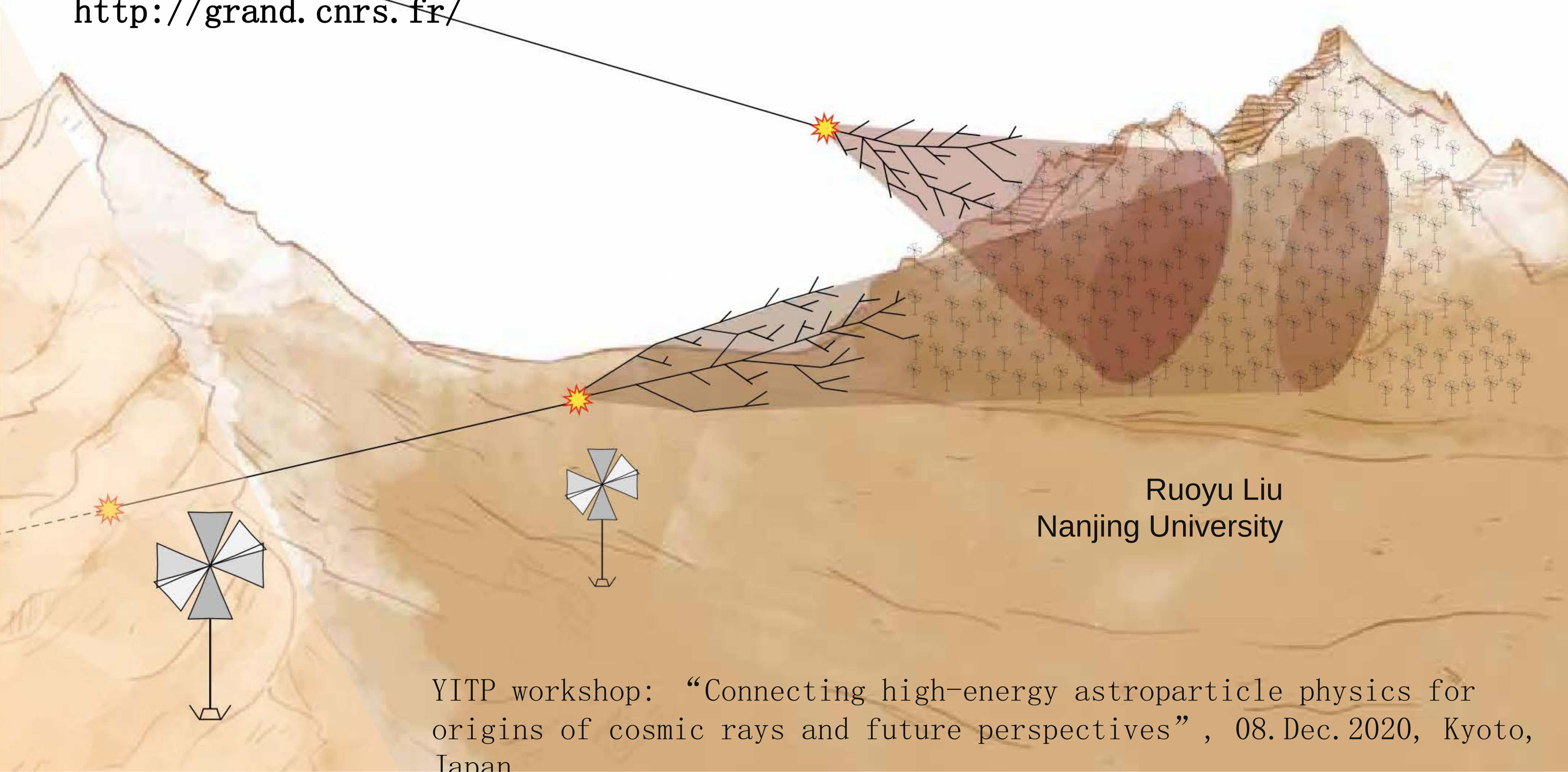
The Giant Radio Array for Neutrino Detection

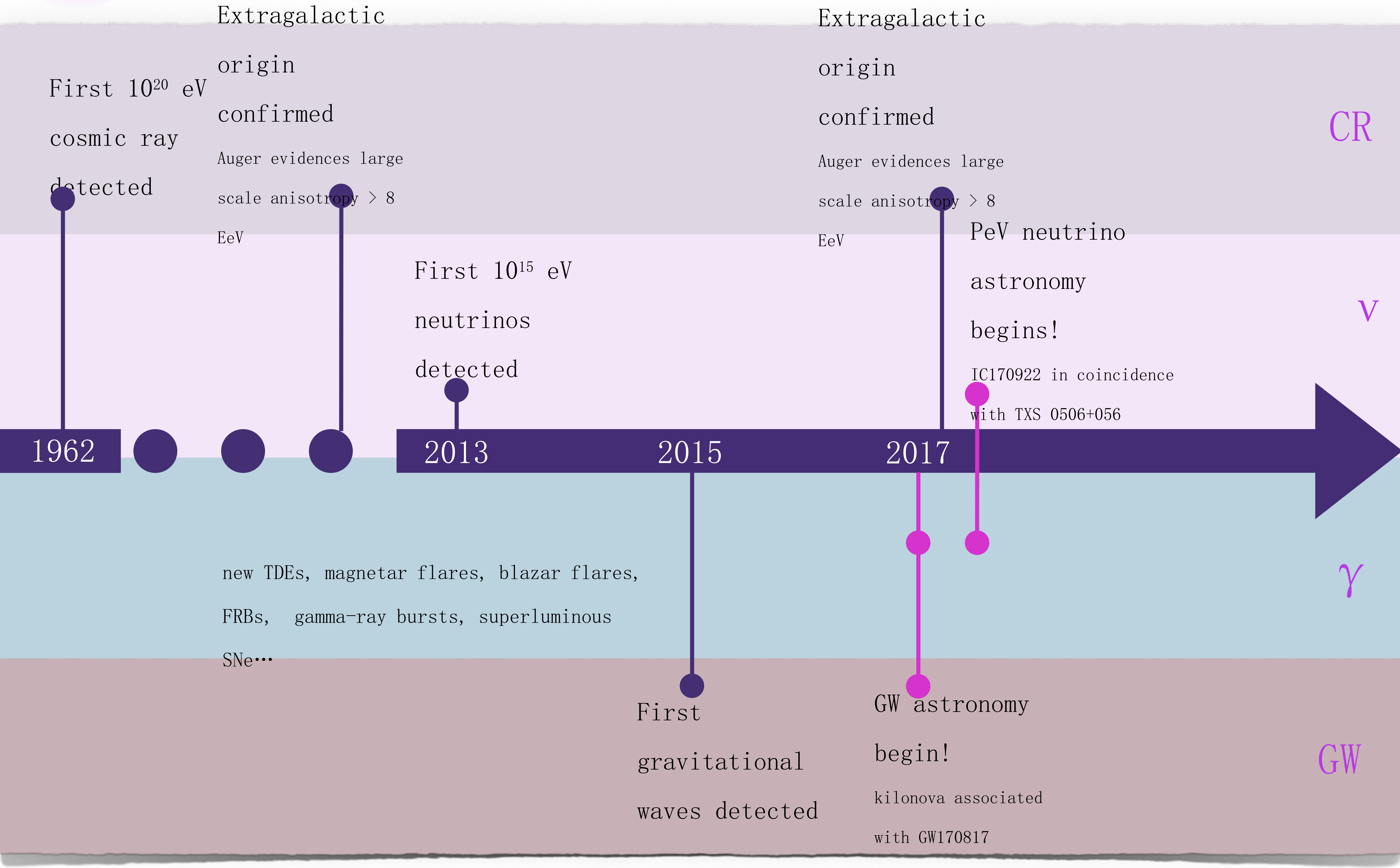
http://grand.cnrs.fr/



Ruoyu Liu
Nanjing University

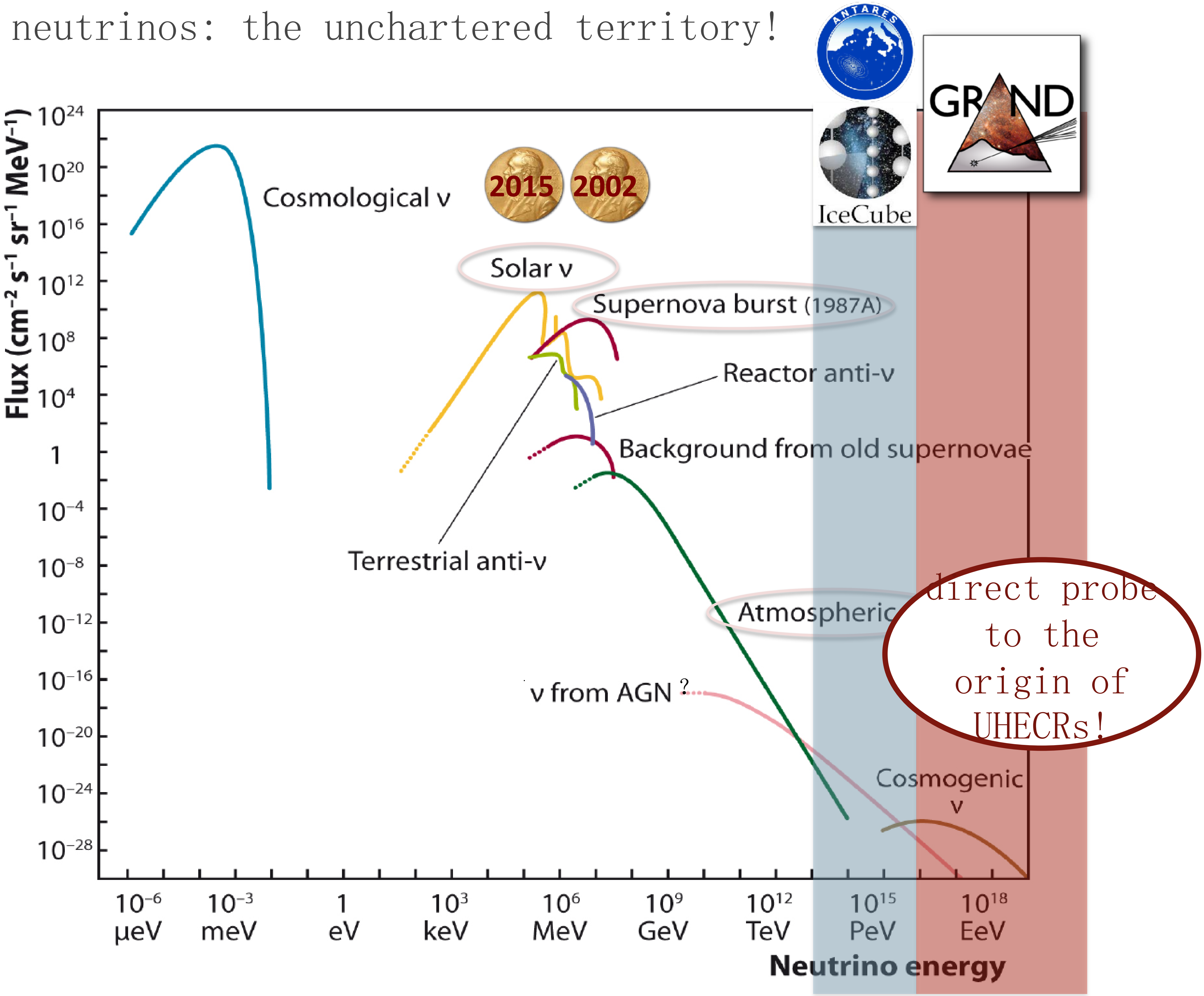
YITP workshop: “Connecting high-energy astroparticle physics for origins of cosmic rays and future perspectives”, 08.Dec.2020, Kyoto, Japan

Exciting times!



And we still don’t know the origin of UHECRs

UHE neutrinos: the unchartered territory!



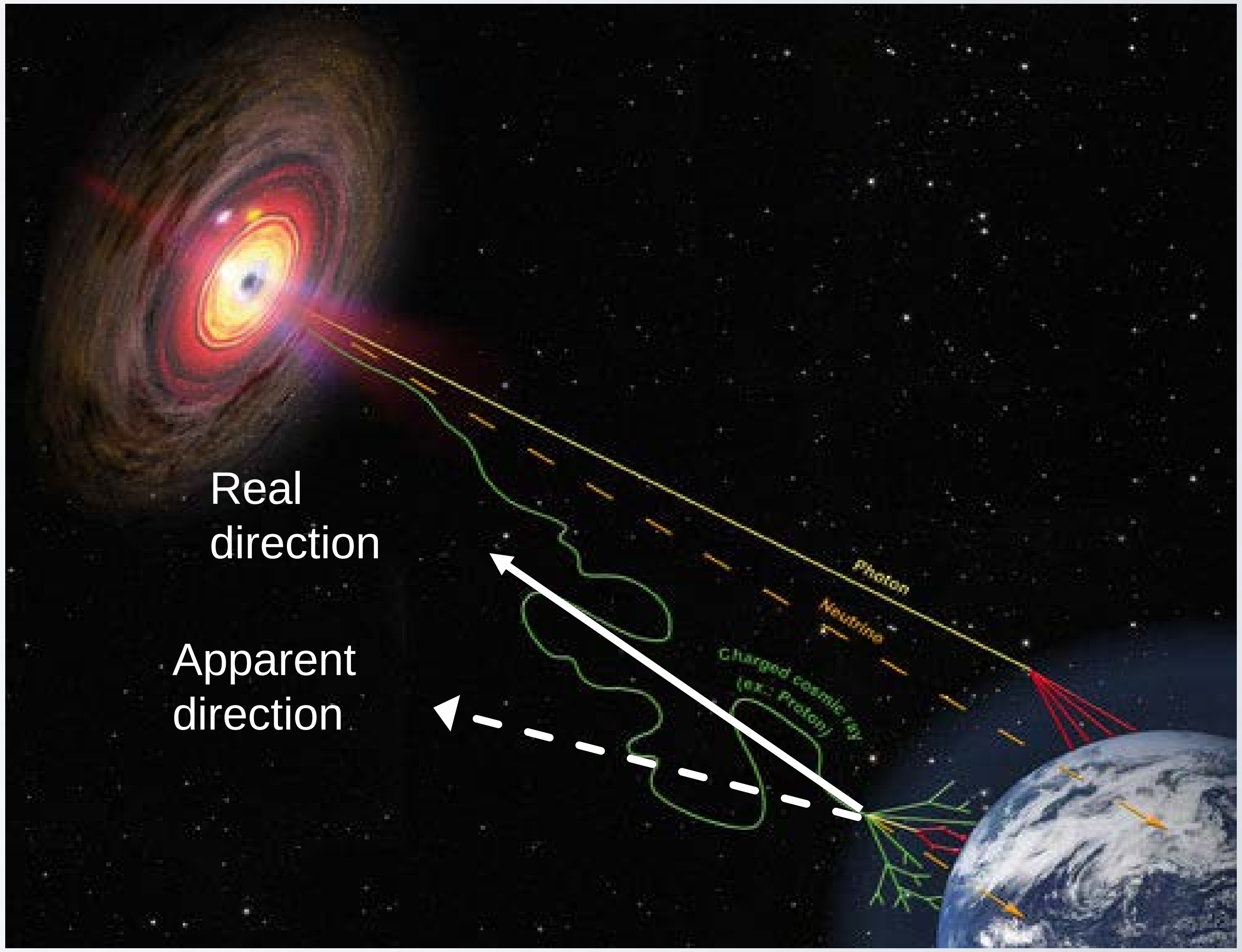
Production of ultrahigh-energy neutrinos

$$p+\gamma/p \rightarrow \pi^0 \rightarrow 2\gamma$$
$$\rightarrow \pi^+ \rightarrow \mu^+ + \nu_\mu, \quad \mu^+ \rightarrow e^+ + \nu_e + \bar{\nu}_\mu$$
$$\rightarrow \pi^- \rightarrow \mu^- + \bar{\nu}_\mu, \quad \mu^- \rightarrow e + \bar{\nu}_e + \nu_\mu$$

$E_\gamma \sim 10\%\ E_{CR}/A$
$E_\nu \sim 5\%\ E_{CR}/A$

Target:
Baryons: ISM, ICM
Photons: source radiation, cosmic radiation (CMB/CIB)

CR: deflection due to IGMF, GMF
Gamma: absorption
Nu: neutral, transparent, small cross section



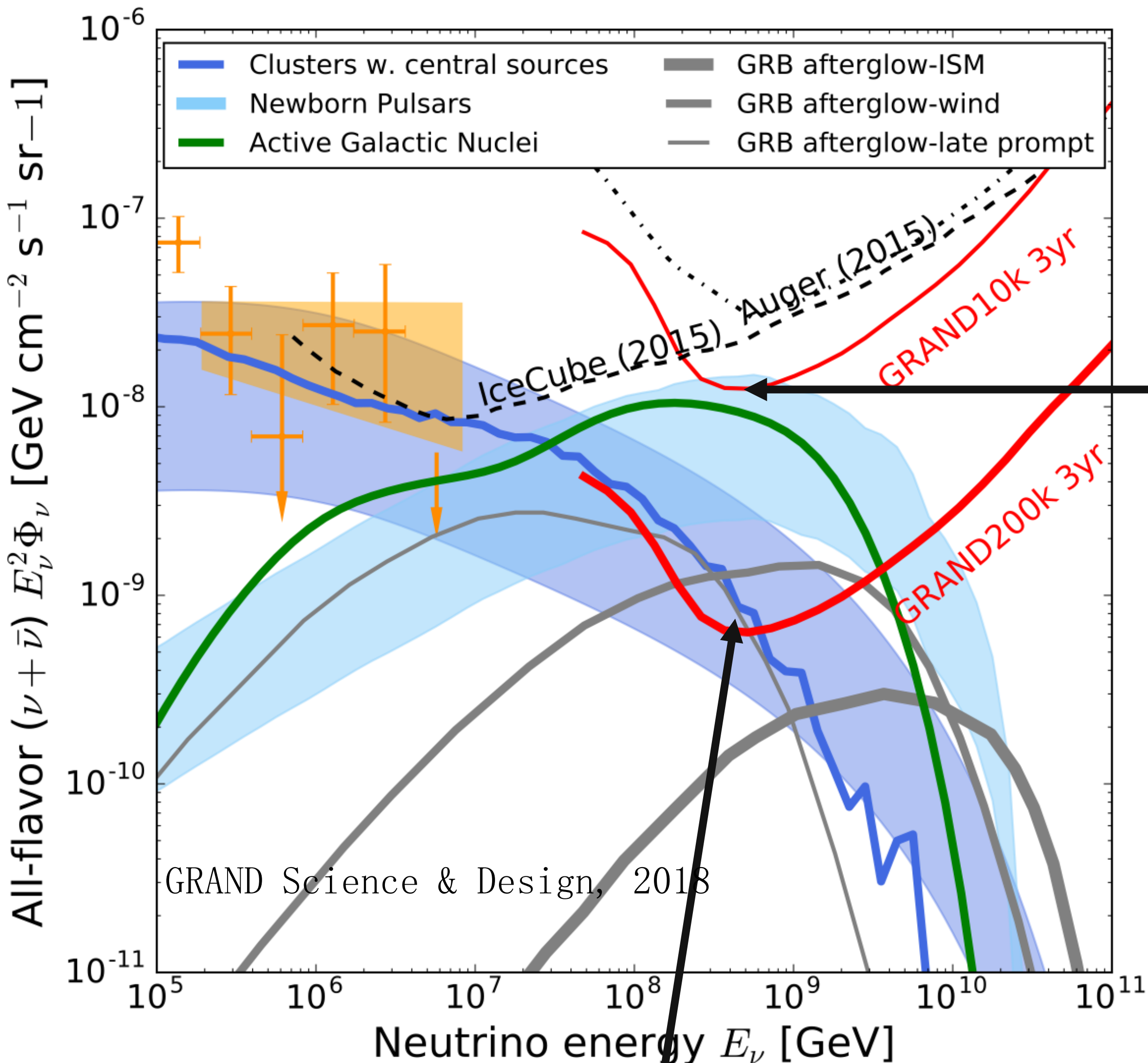
What we can aim to do with future observatories

cosmogenic: guaranteed

direct from source: likely more abundant

pessimistic scenarios of cosmogenic neutrinos = good!

low background for source neutrinos

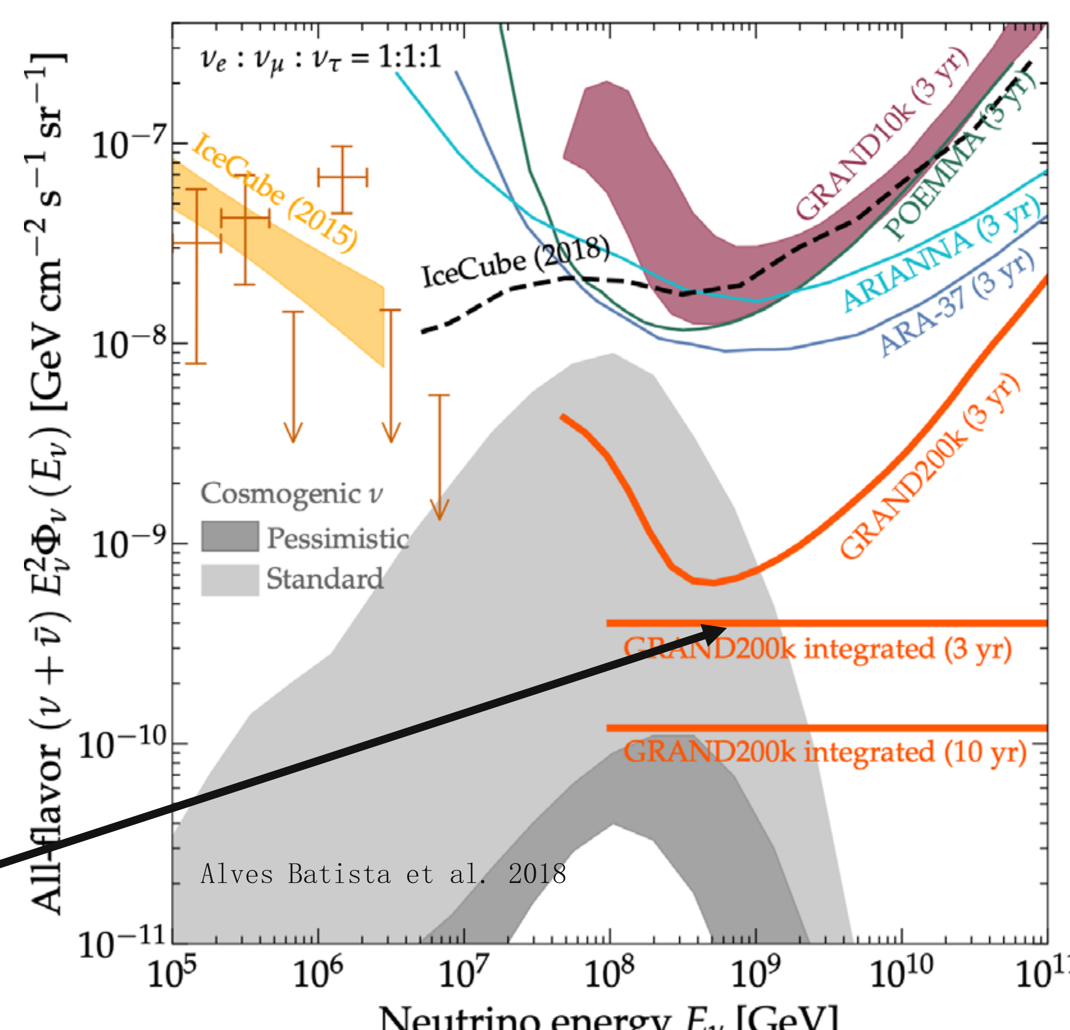


detect the first EeV neutrinos

detect EeV neutrino point sources

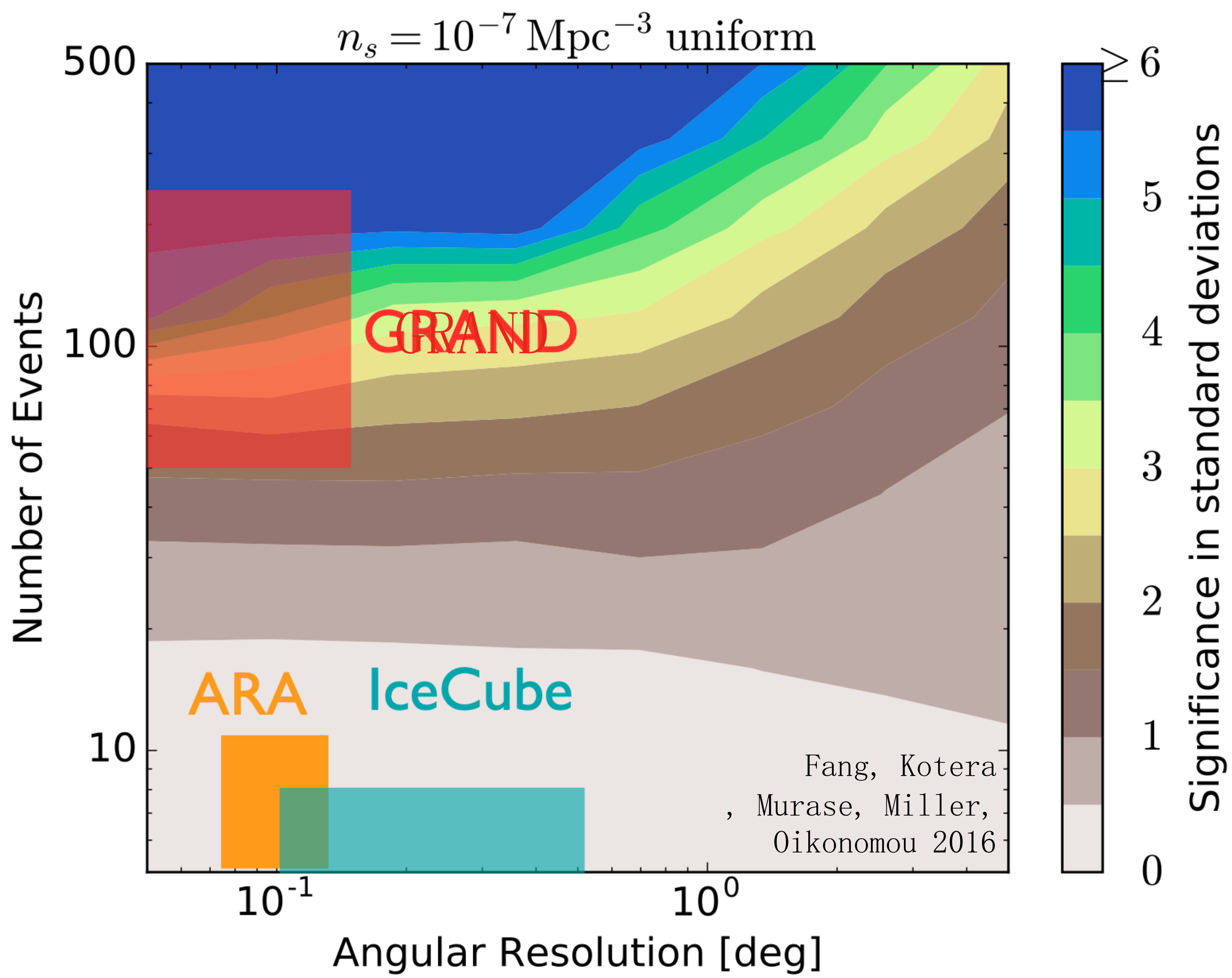
100s of events
~0.3° angular resolution

detect cosmogenic neutrinos



Can we hope to detect very high-energy neutrino sources?

Neutrinos don't have a horizon: won't we be polluted by background neutrinos?



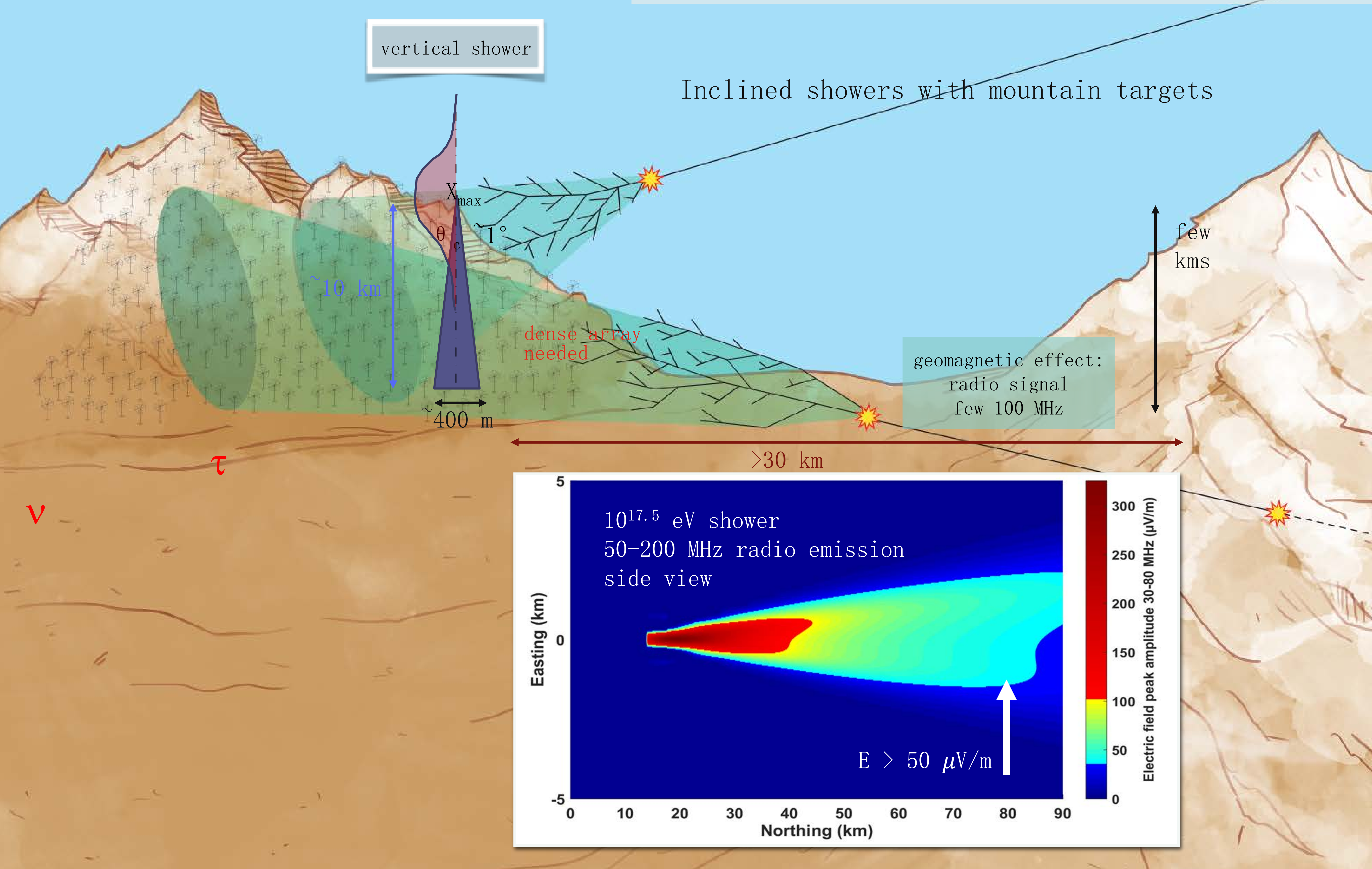
boxes for experiments assuming neutrino flux: 10^{-8} GeV cm^{-2} s^{-1}

YES if
- good angular resolution (< fraction of degree)
- number of detected events > 100s

The GRAND Concept

radio detection: a mature and autonomous technique
AERA, LOFAR, CODALEMA/EXTASIS, Tunka-Rex, TREND

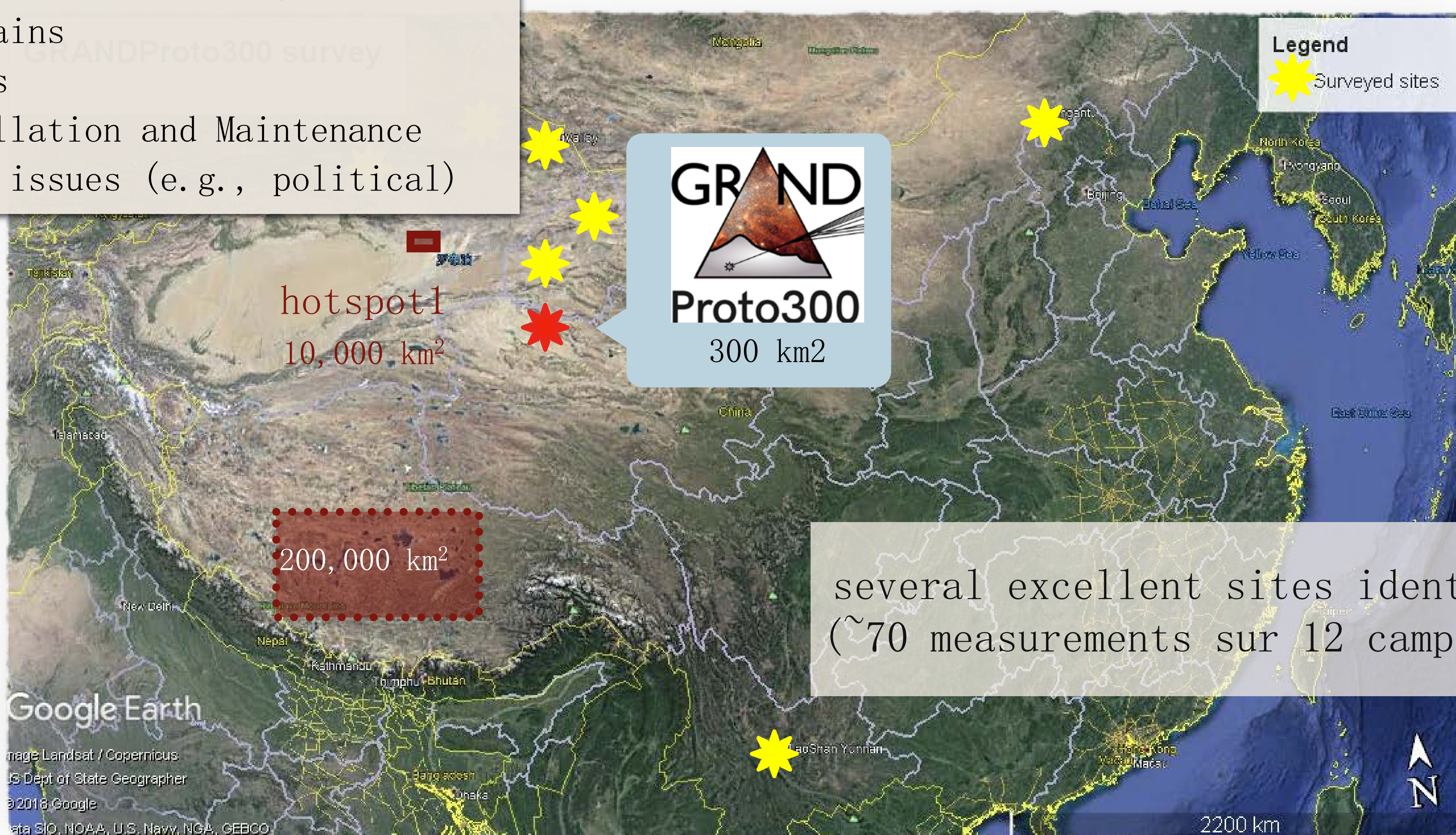
radio antennas cheap and robust: ideal for giant ar



The GRAND Concept

200’000 radio antennas over 200’000 km^2
~20 hotspots of 10’000 antennas
over favorable sites in China and worldwide

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



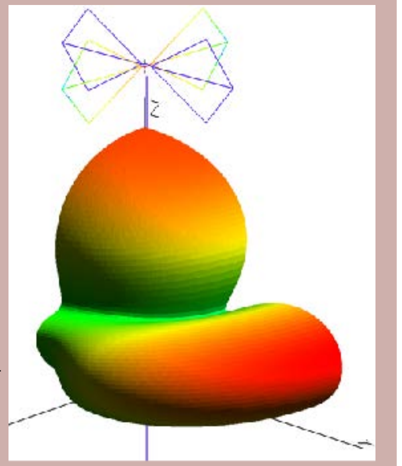
several excellent sites identified
(~70 measurements sur 12 campaigns)

GRAND End-to-End simulation chain

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

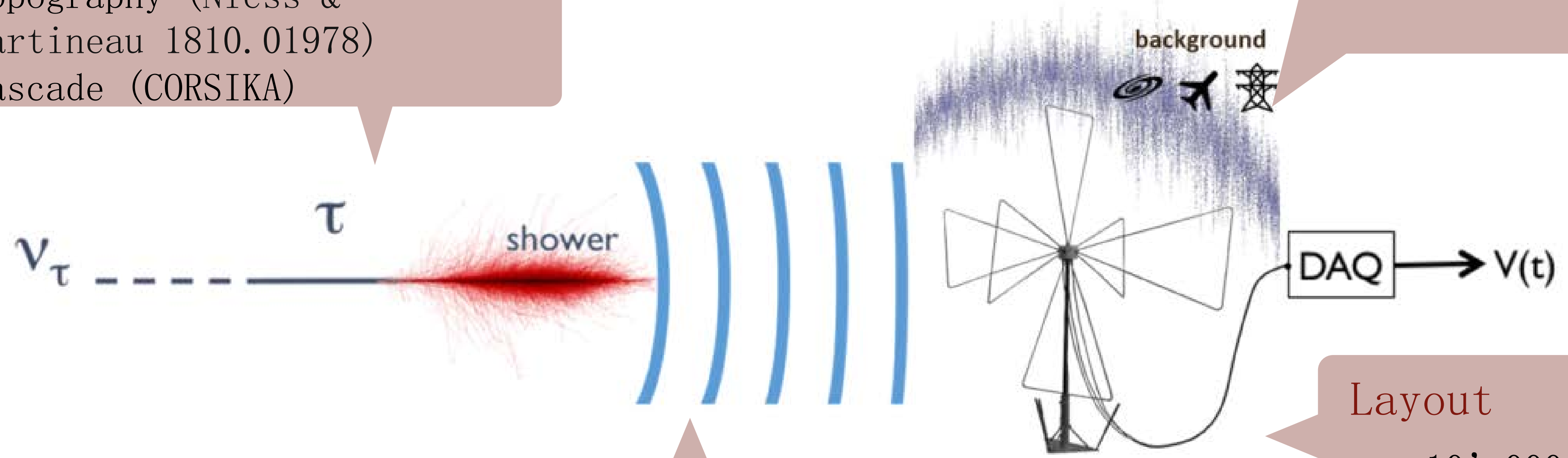
Antenna response

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



Shower Development

ν —> τ decay (DANTON)
backward MC over realistic topography (Niess & Martineau 1810.01978)
Cascade (CORSIKA)



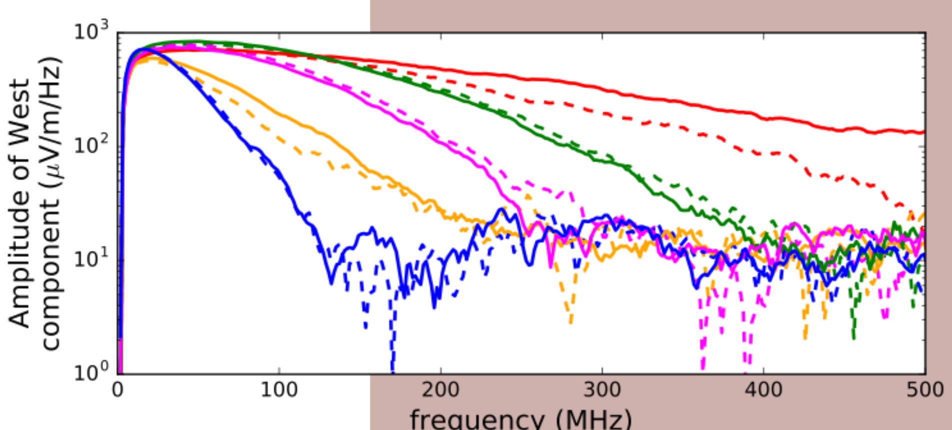
Layout

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

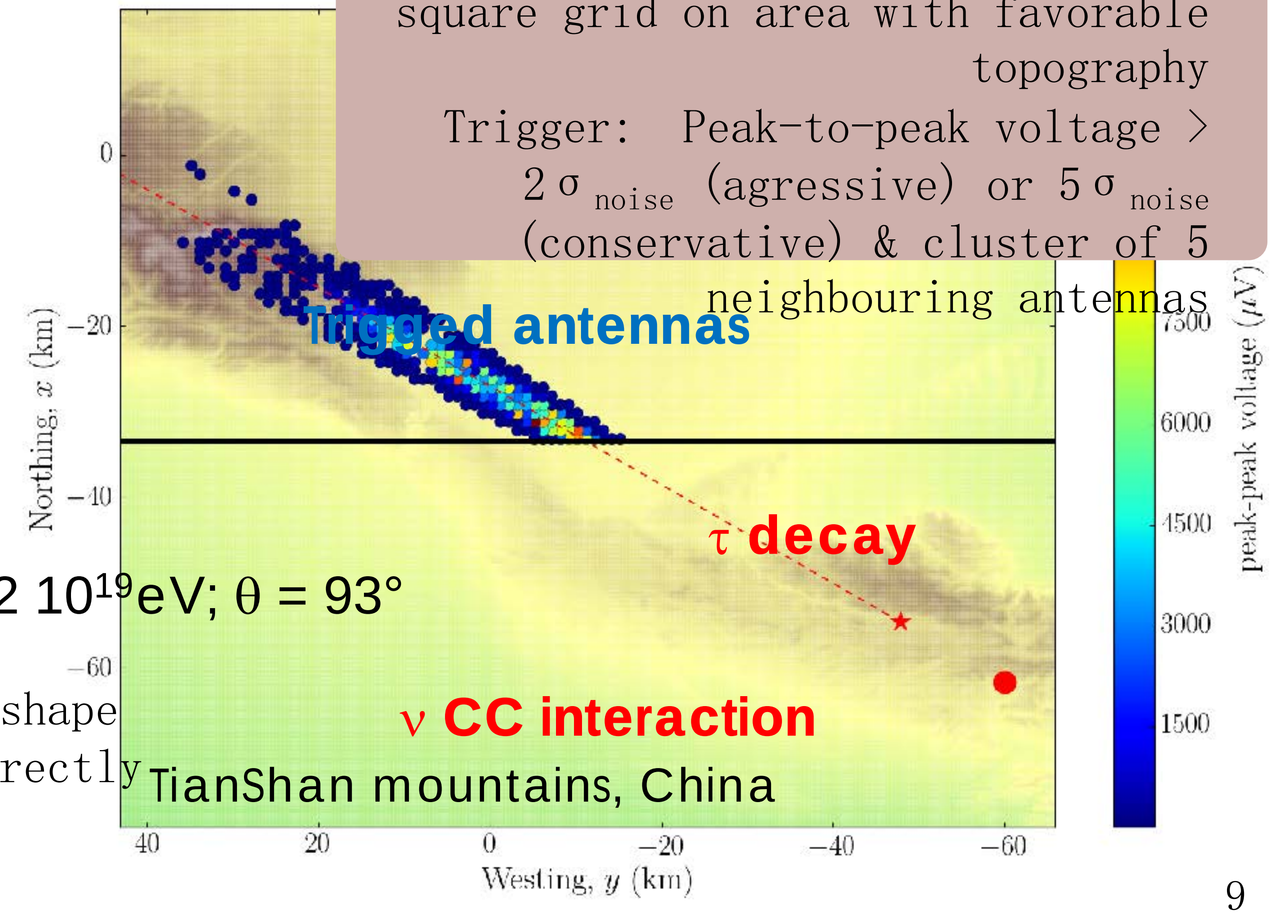
Radio emission

Radio-Morphing: semi-analytical computation of the air-shower-induced Efield transient signal.
A. Zilles et al., Astropart. Phys 114 (2020), 1809.04912
Coreas



amplitude + pulse shape + polarization correctly reproduced!

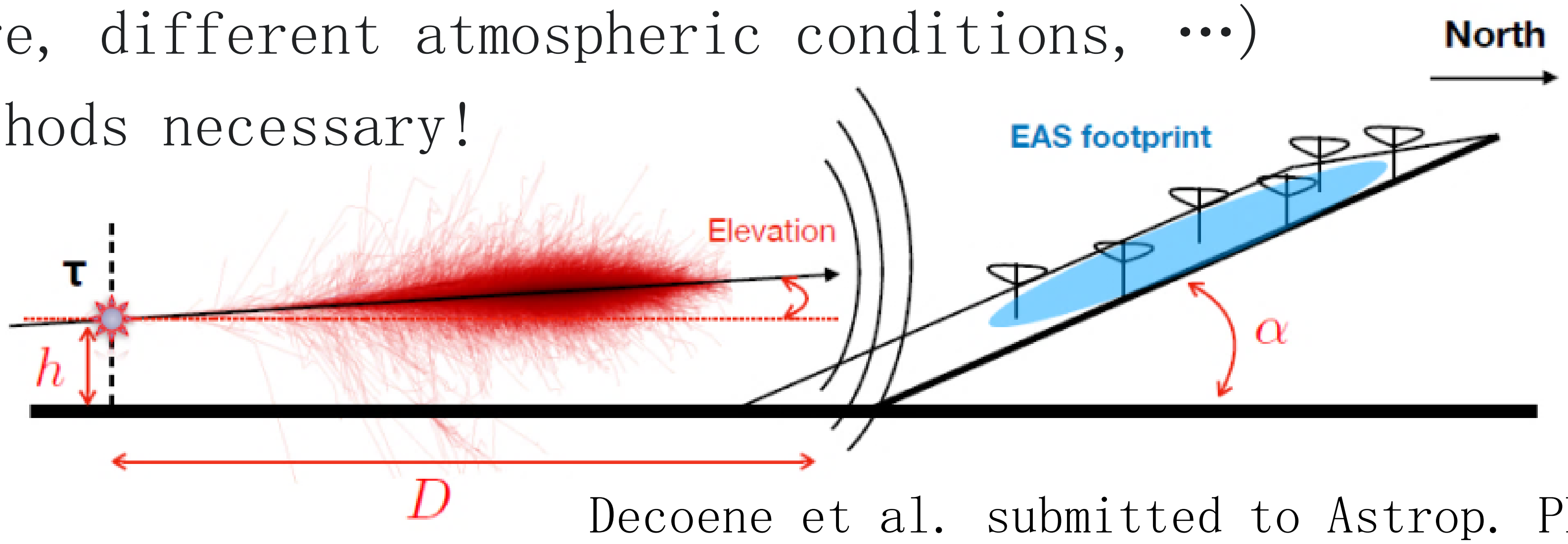
E_ν = 2 10^{19} eV; θ = 93°



Air-shower parameter reconstruction

- Main issue: additional asymmetries for very inclined showers cannot be ignored (different shower age, different atmospheric conditions, …)

➔Dedicated reconstruction methods necessary!



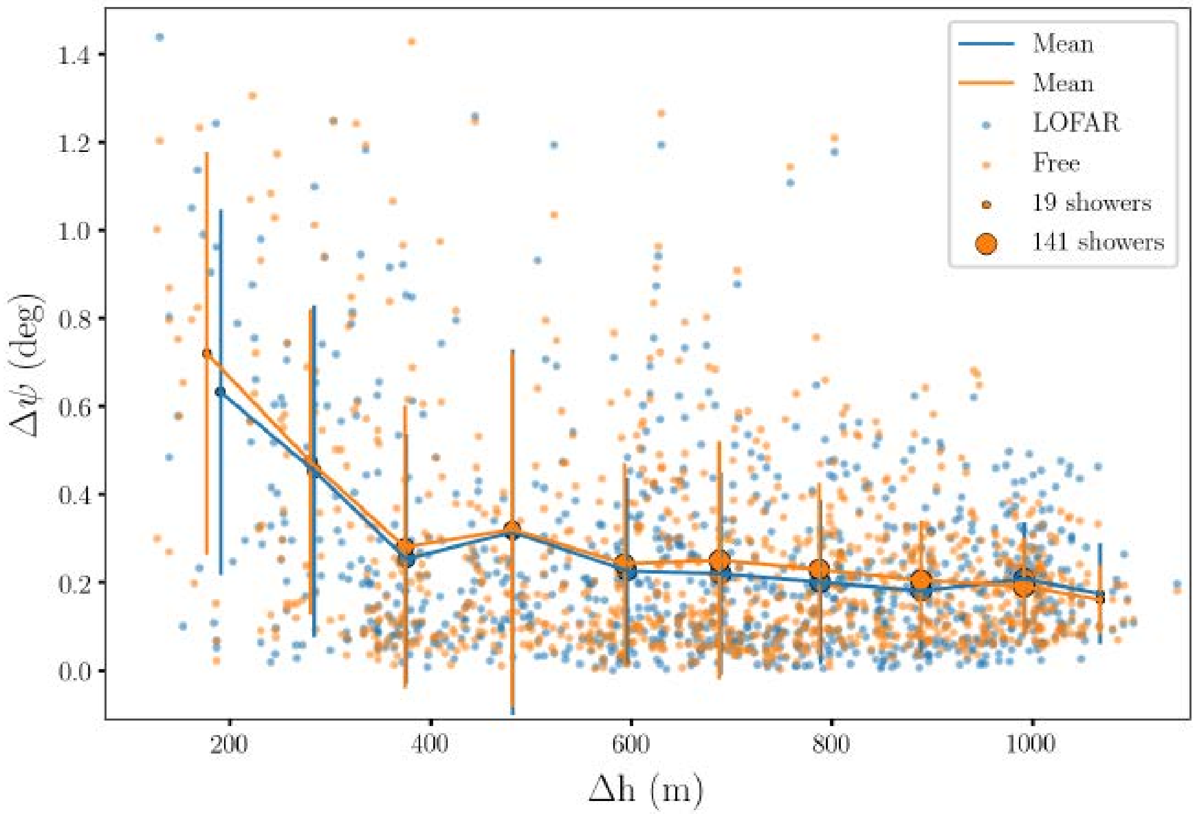
Decoene et al. submitted to Astrop. Phys.

- Standard methods do not perform that bad, thanks to very large footprint & topography... Encouraging!

Angular resolution

- GRAND like toy-model array (slant array of fixed slope) Decoene et al. submitted
- Hyperbolic fit Corstanje et al. 14
- GPS resolution & noise included

➔ Δψ ~ 0.2° for Δh>400m



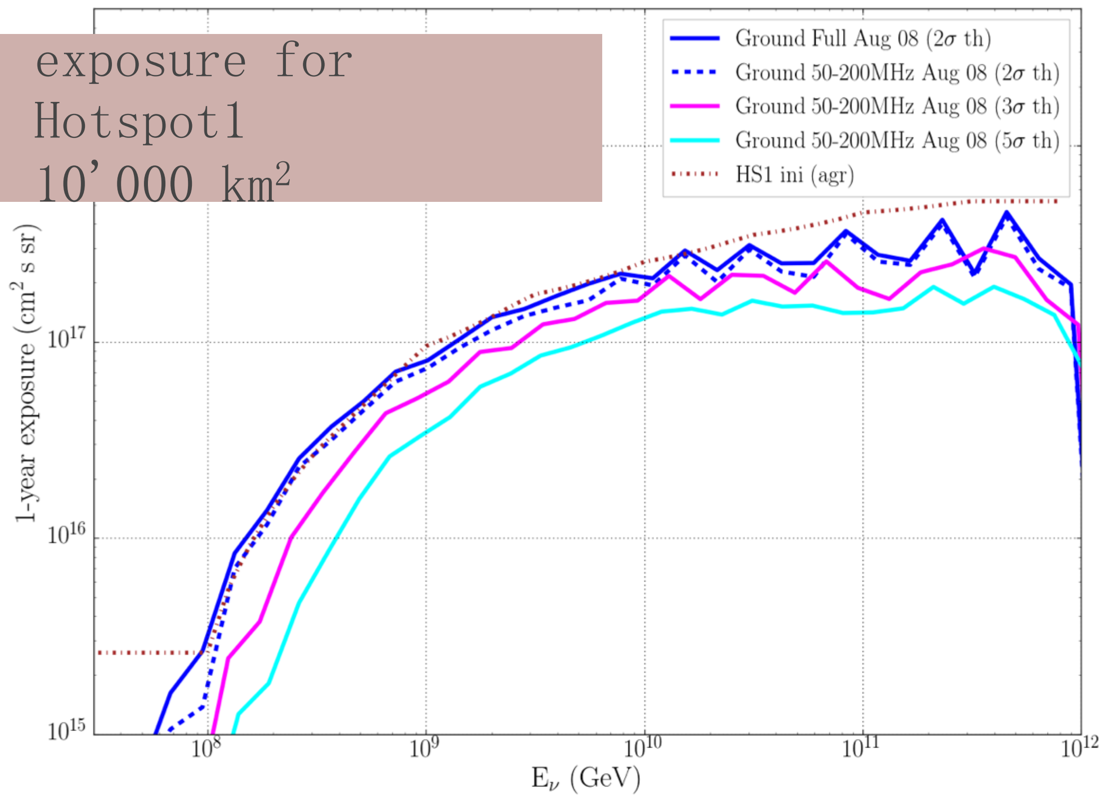
X_{max}

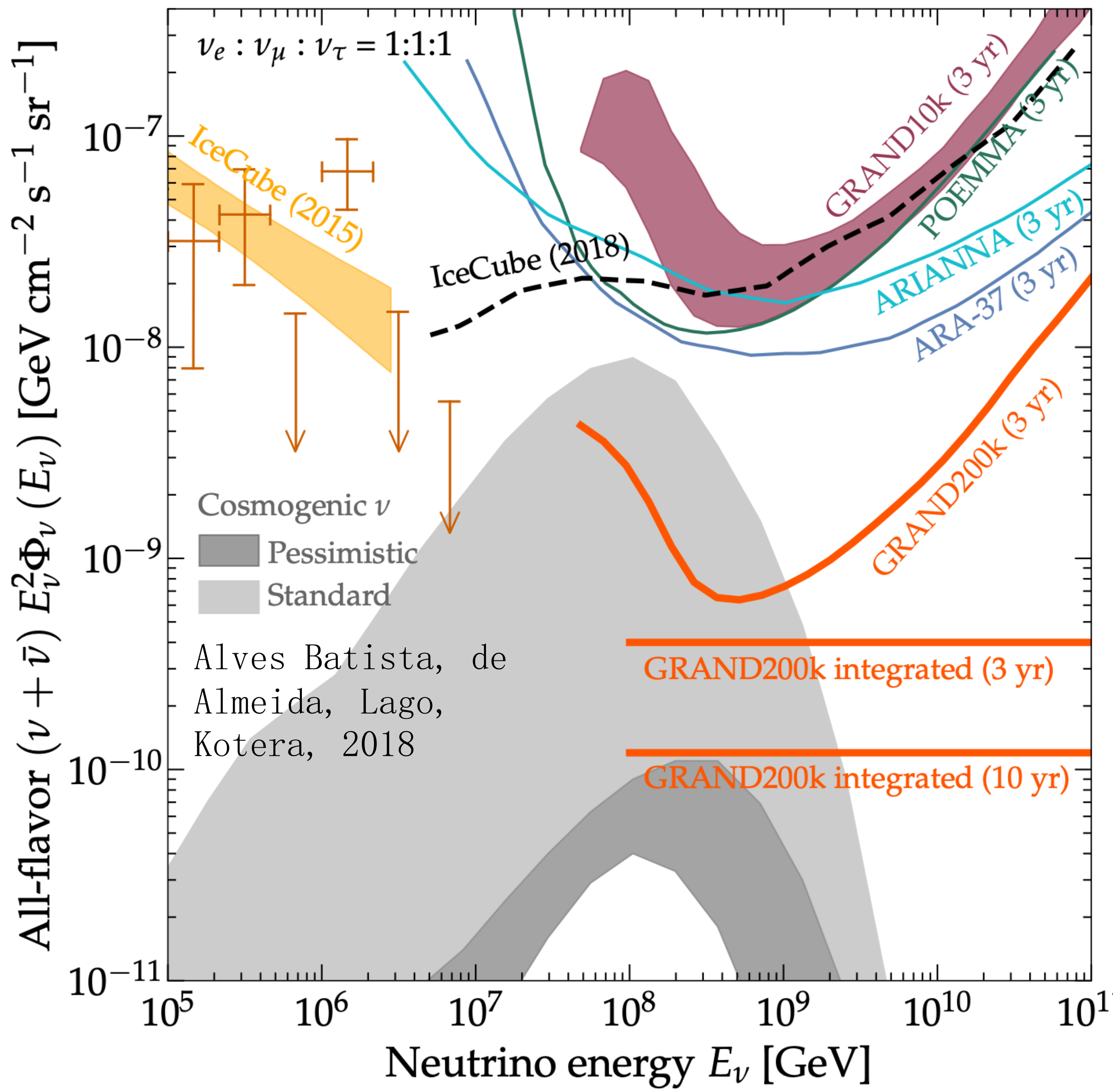
- applying LOFAR method Buitink et al. 14 yields ~40g/cm² (provided E and x_{core} known)

Simulated performances

GRAND Science & Design, GRAND Coll.
Science China, https://arxiv.org/abs/1810.09994

exposure for
Hotspot1
10'000 km^2





- GRAND full sensitivity (E>10^{17} eV): ~4×10^{-10} GeV cm^{-2} s^{-1} sr^{-1}
- angular resolution: ~0.1-0.3° for GP300 also achievable for Hotspot1
- X_{max} resolution: < 40 g/cm² achievable for E>10^{19} eV with GP300 & further stages

A rich science case

UHE neutrinos

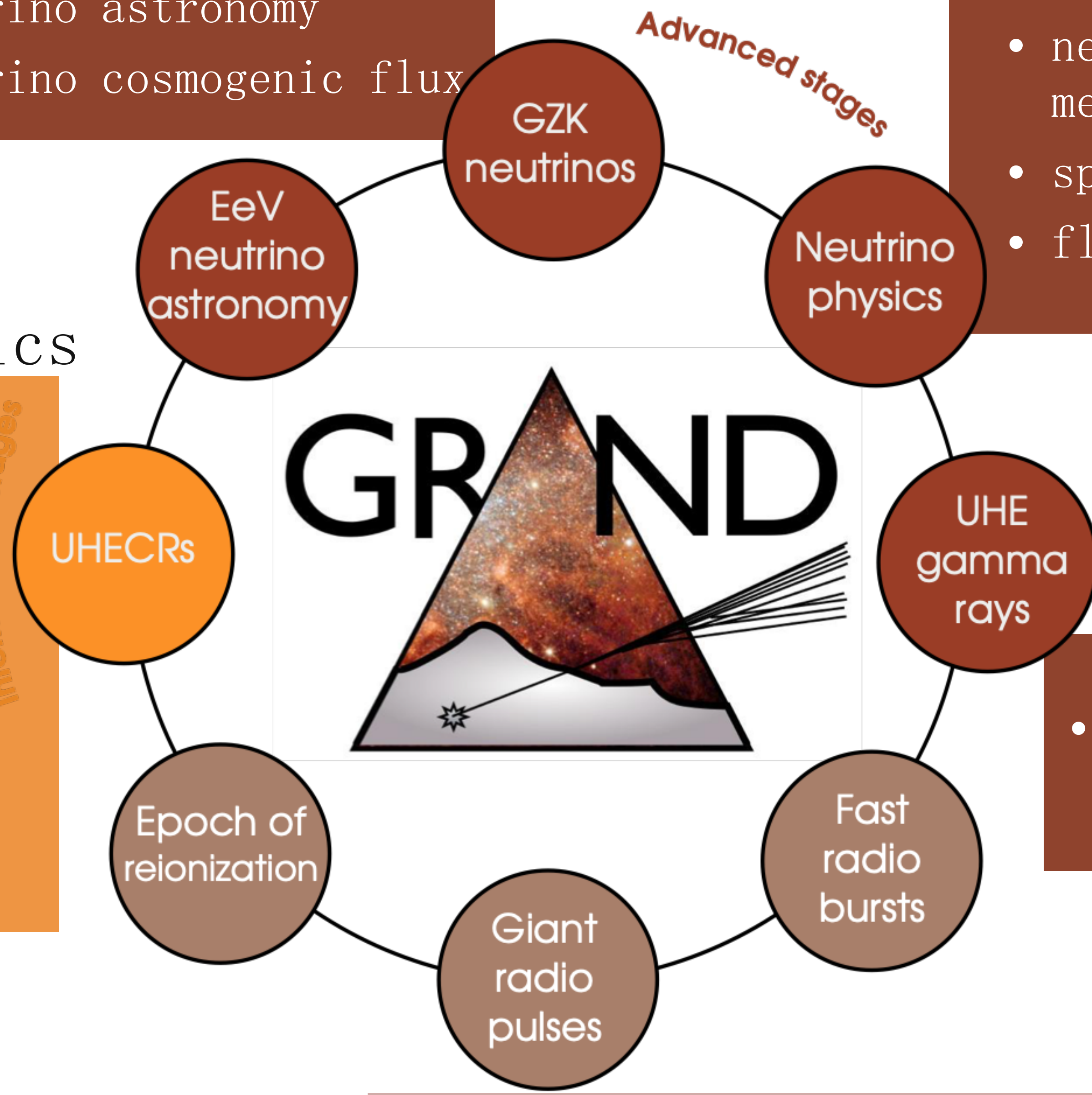
- UHE neutrino astronomy
- UHE neutrino cosmogenic flux

neutrino physics

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

UHECR, hadronic physics

- 20 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

A staged approach with self-standing pathfinders

	GRANDProto300	GRAND10k	GRAND200k
	2021	2025	203X
Goals	autonomous radio detection of very inclined air-showers cosmic rays $10^{16.5-18}$ eV - Galactic/extragalactic transition - muon problem - radio transients	1st GRAND subarray - discovery of EeV neutrinos for optimistic fluxes - radio transients (FRBs!)	1st EeV neutrino detection and/or neutrino astronomy!
Setup	• 300 HorizonAntennas over 200 km² • Particle detectors (a la HAWC/Auger) • Western China	• 10'000 radio antennas over 10'000 km² • in China	• 200,000 antennas over 200,000 km² • 20 hotspots of 10k antennas • on different continents
Budget	1.3 M€ fully funded (China)	1500€ /detection unit 13 M€ mostly secured (China)	Industrial scale allows to cut down costs: 500€/unit 150M€ in total to be divided between participating countries, e.g.: China 35% US 10% Germany 15% France 10% Netherlands 5% Brasil 5% Others: 20%

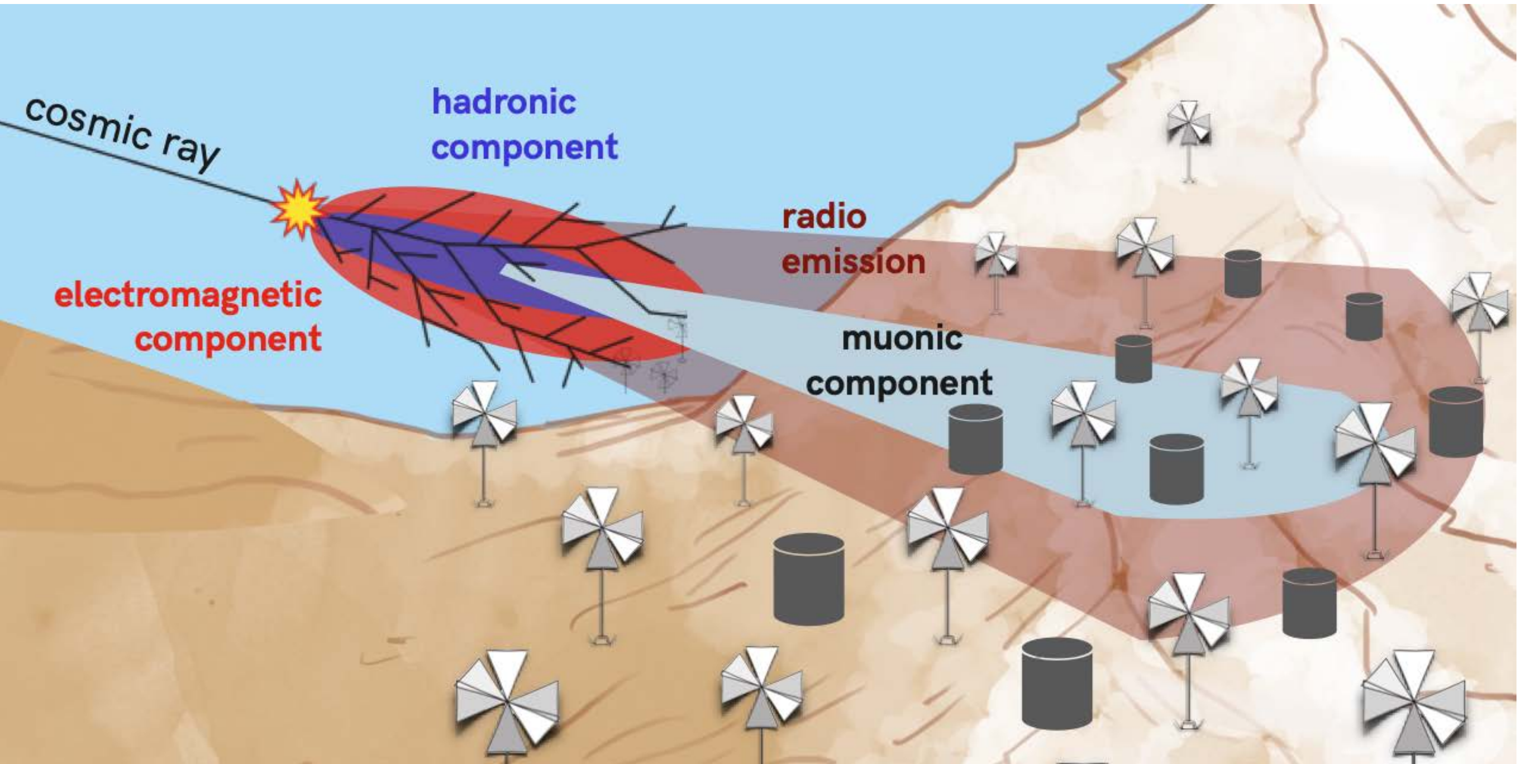
GRANDProto300 (GP300)

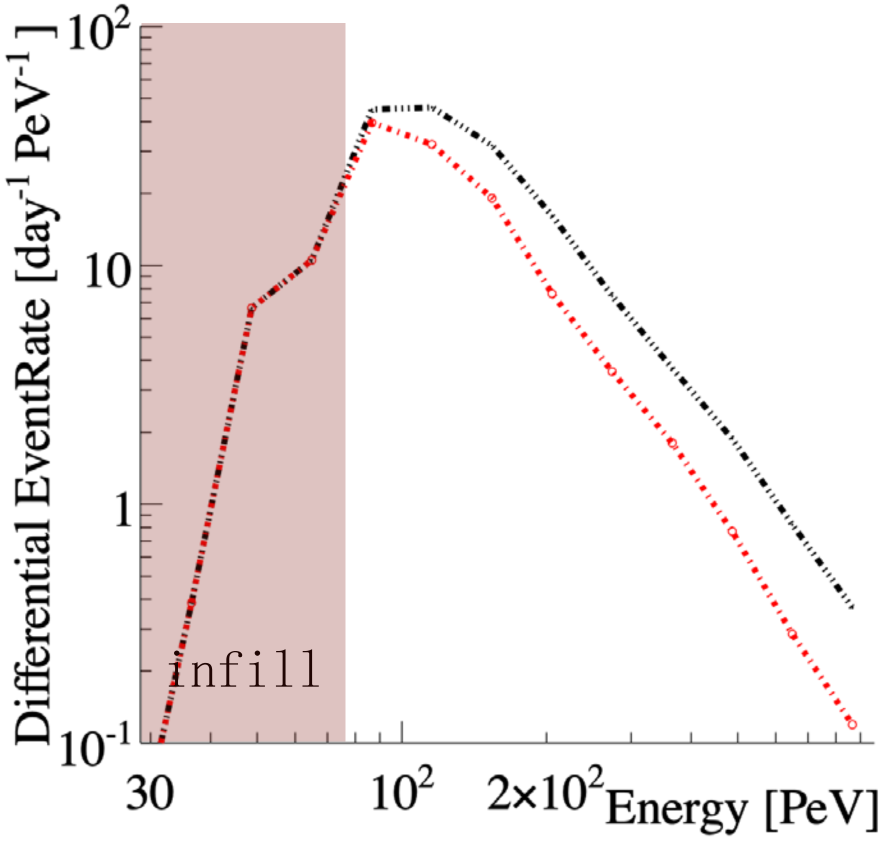
GRANDProto300: a self-standing pathfinder

- 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 array of particle detector
  Galactic/extragalactic transition
  hadronic physics (muon content in EAS)
  UHE gamma-rays
  Giant Radio Pulses from Crab pulsar
  Fast Radio Bursts

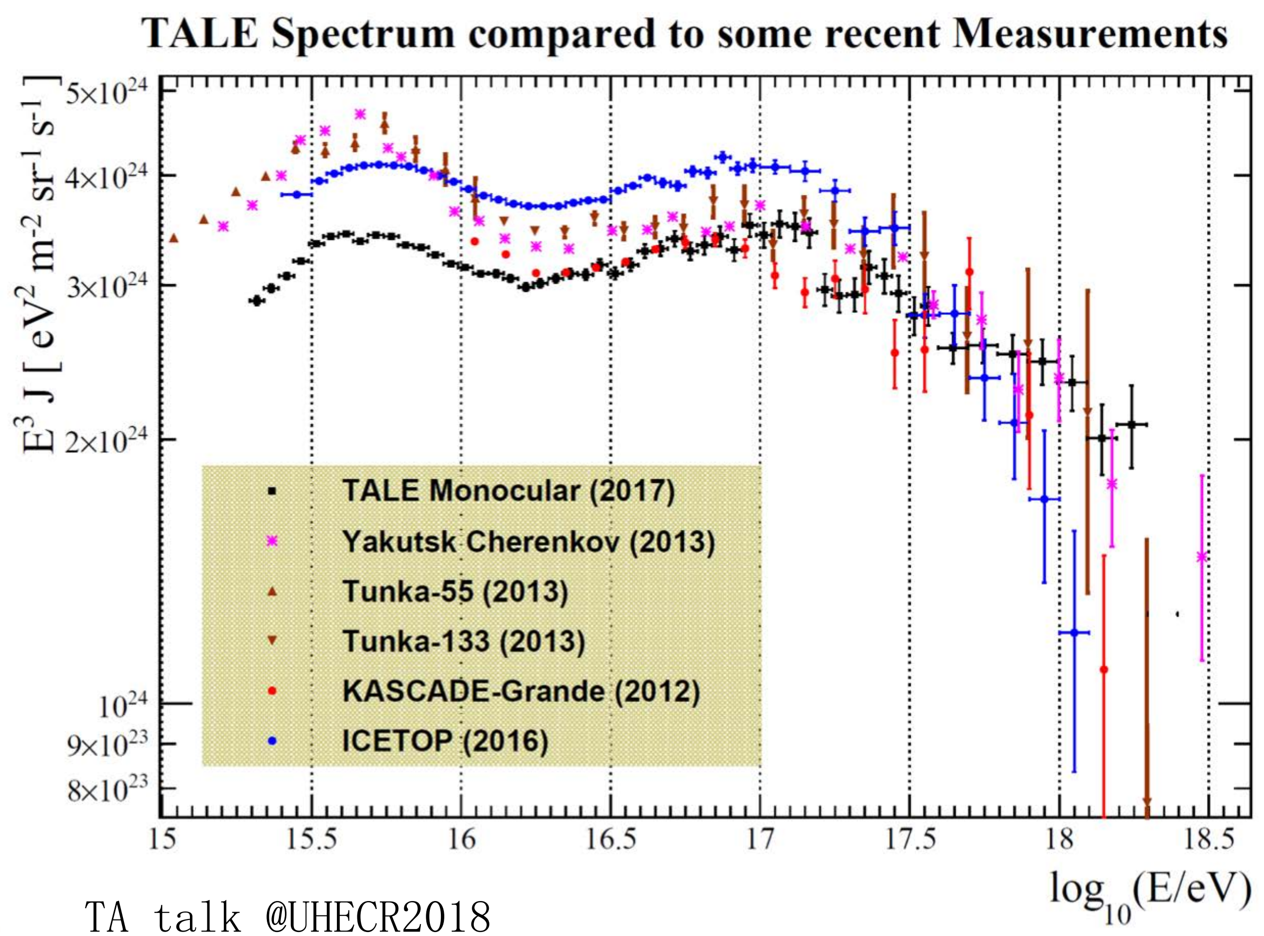
assuming TALE flux
Abbasi et al. (2018)



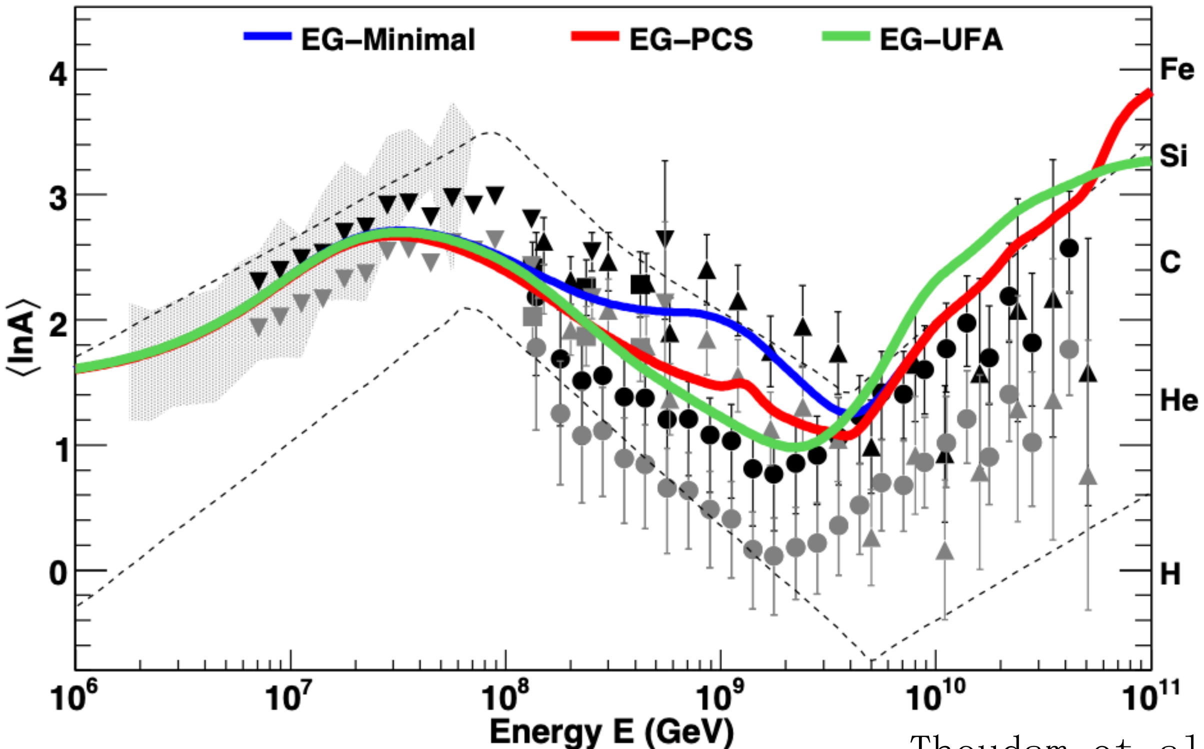


The Galactic to extragalactic transition region

- bumpy spectrum
- emerging and vanishing mass elements?
- most theory models fit because of systematic uncertainties
- experimental gap around 10^{17}eV
- a single setup covering $10^{16.5-18}$ eV?

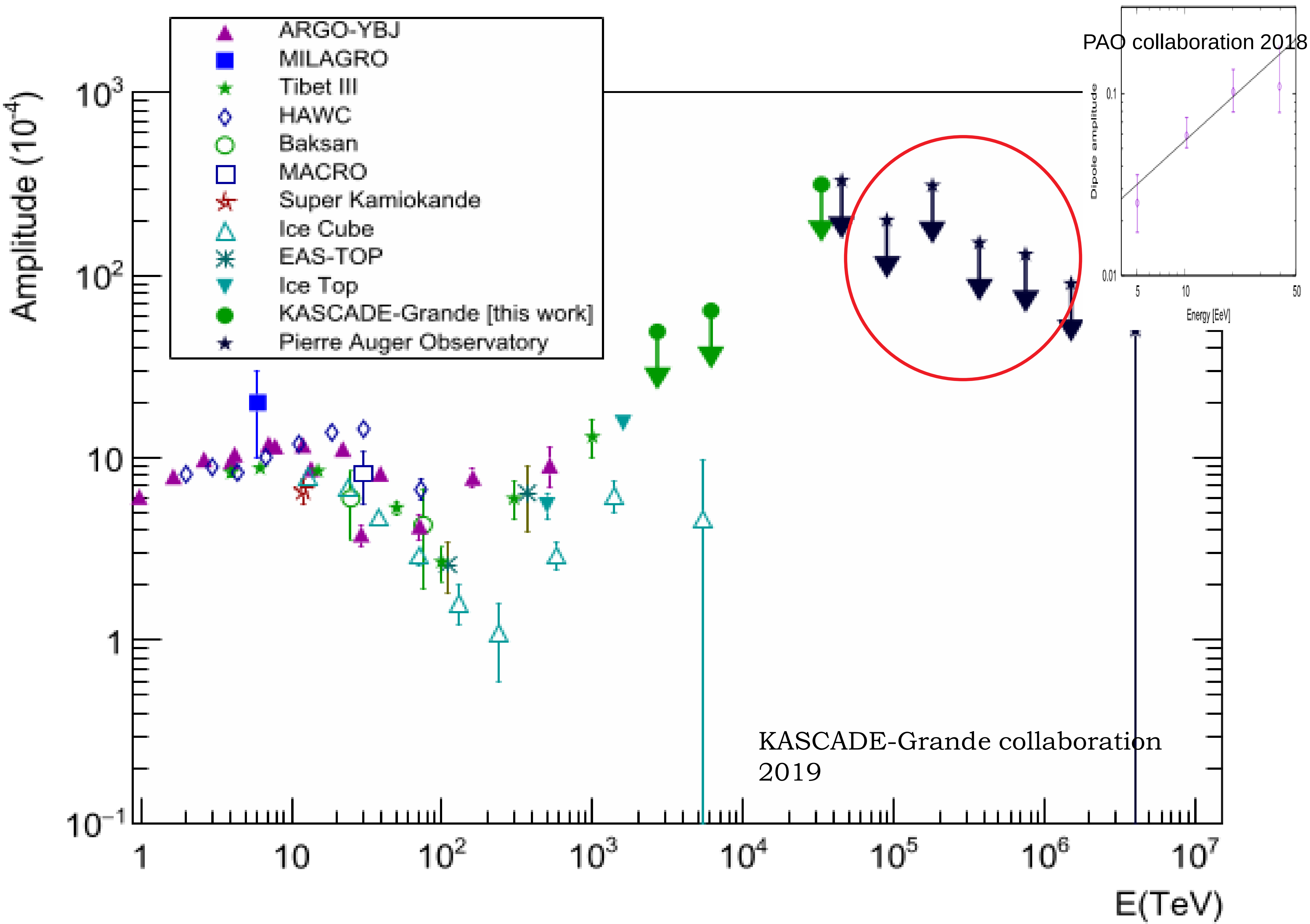


TA talk @UHECR2018



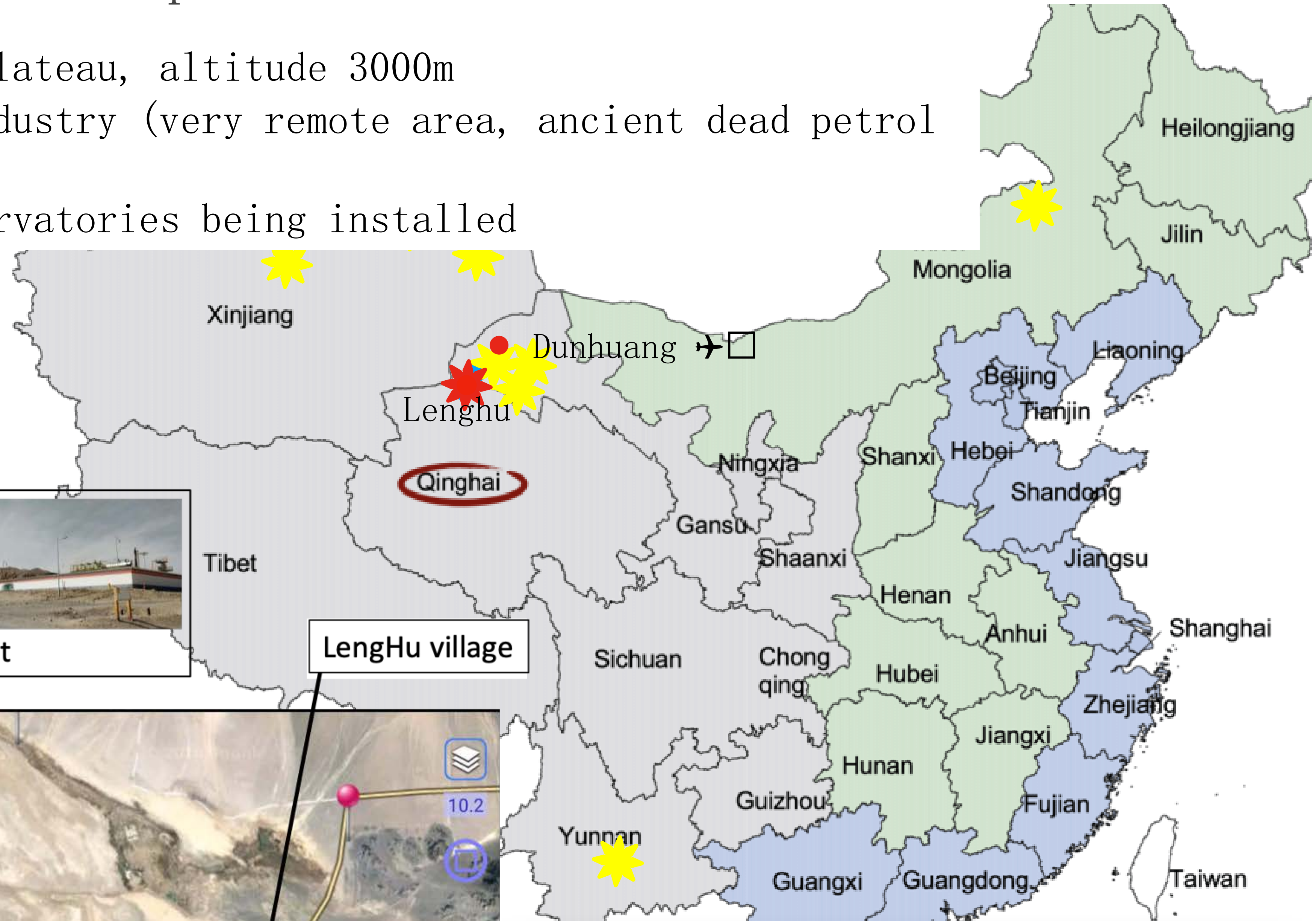
Thoudam et al. 2016

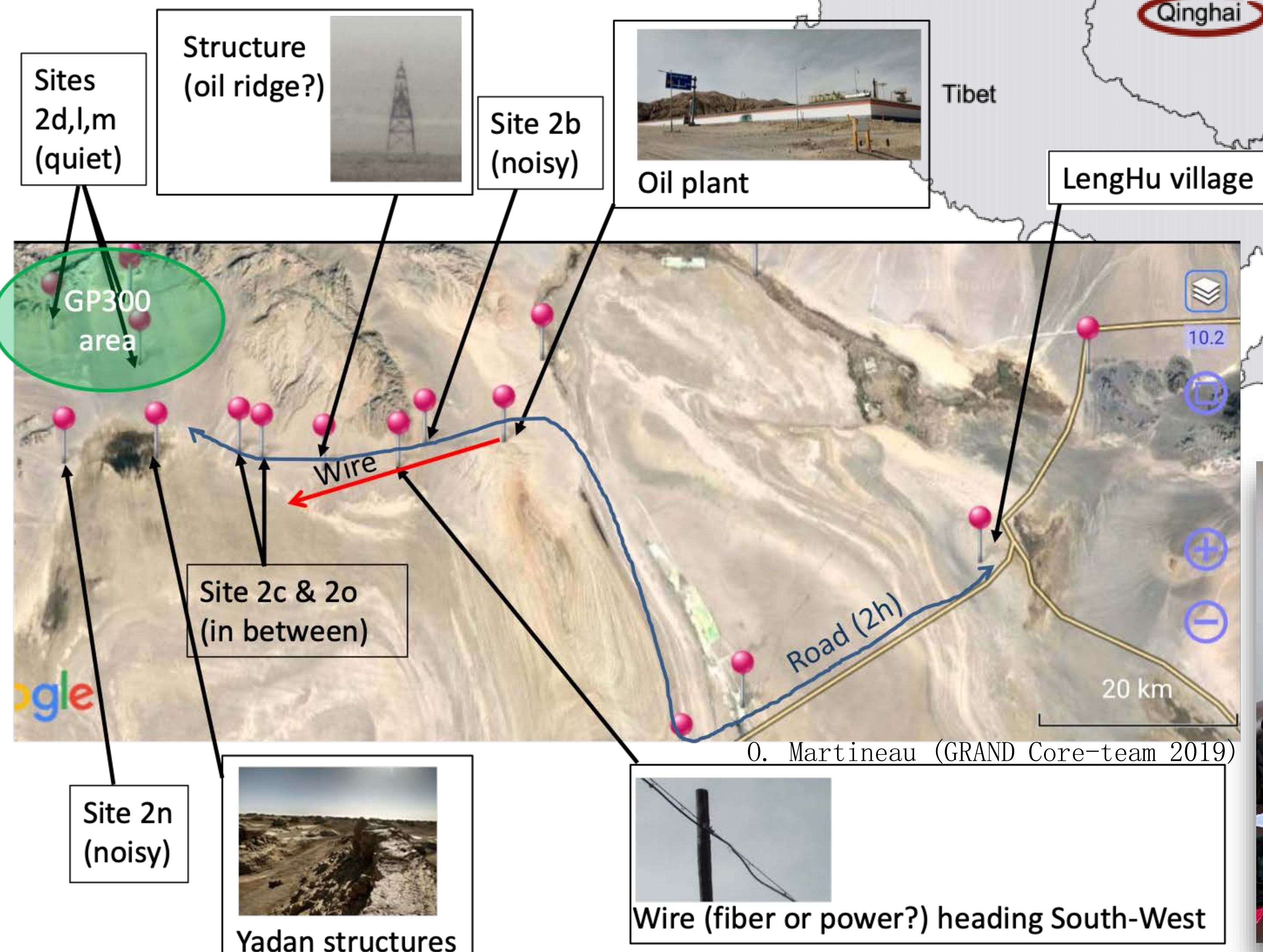
CR Dipole Anisotropy



GRANDProto300 site example

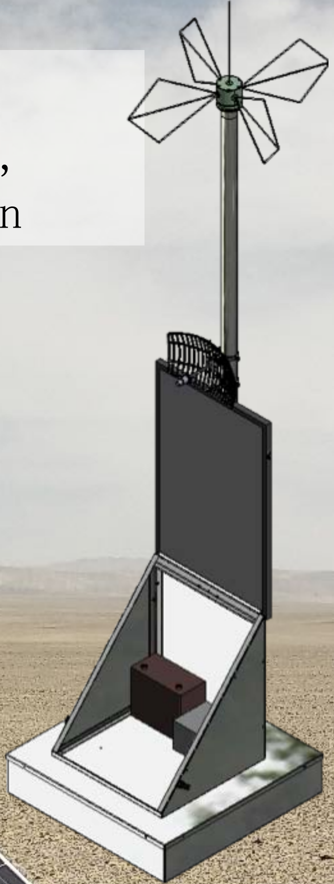
- on the verge of Tibetan plateau, altitude 3000m
- no long-term plans for industry (very remote area, ancient dead petrol industry)
- several astronomical observatories being installed





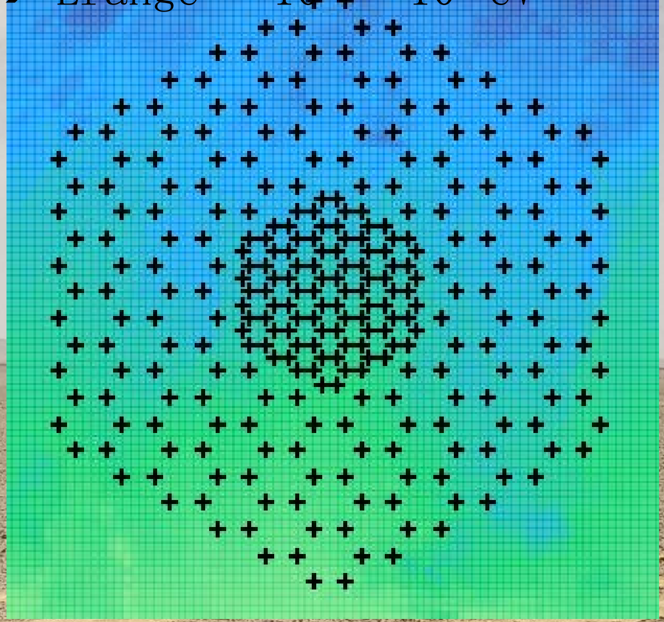
GRANDProto300: experimental setup

Antenna set-up:
antenna simulations, nut design, unit design. Entering production phase.



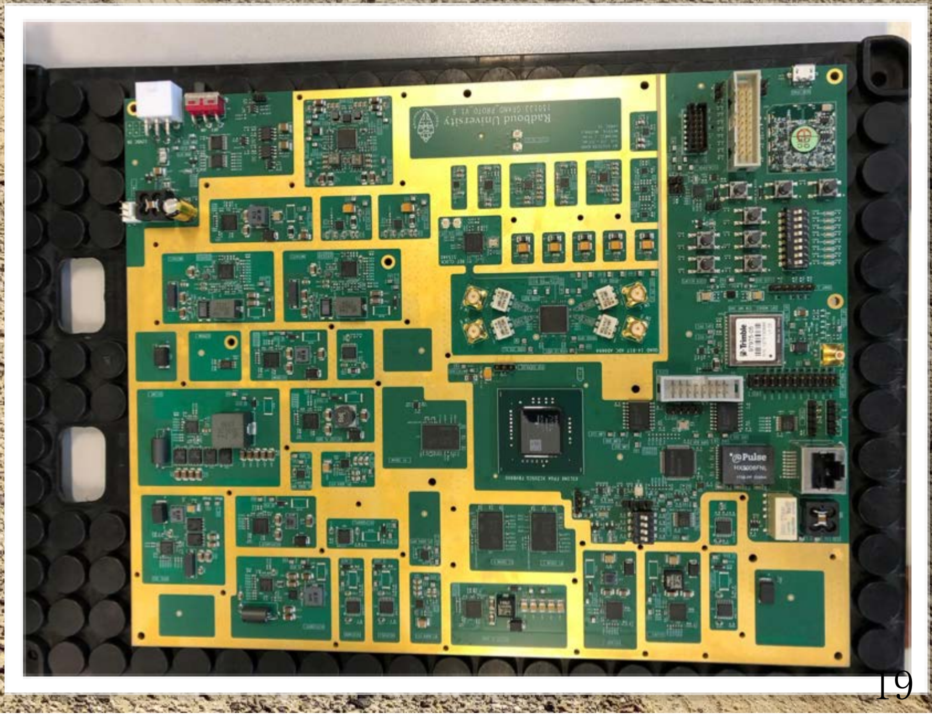
Layout: 300 antennas, 200km², 1km step size with denser infill

➔ Erange = $10^{16.5}$–10^{18}eV



HorizonAntenna successfully tested in the field (August, December 2018)

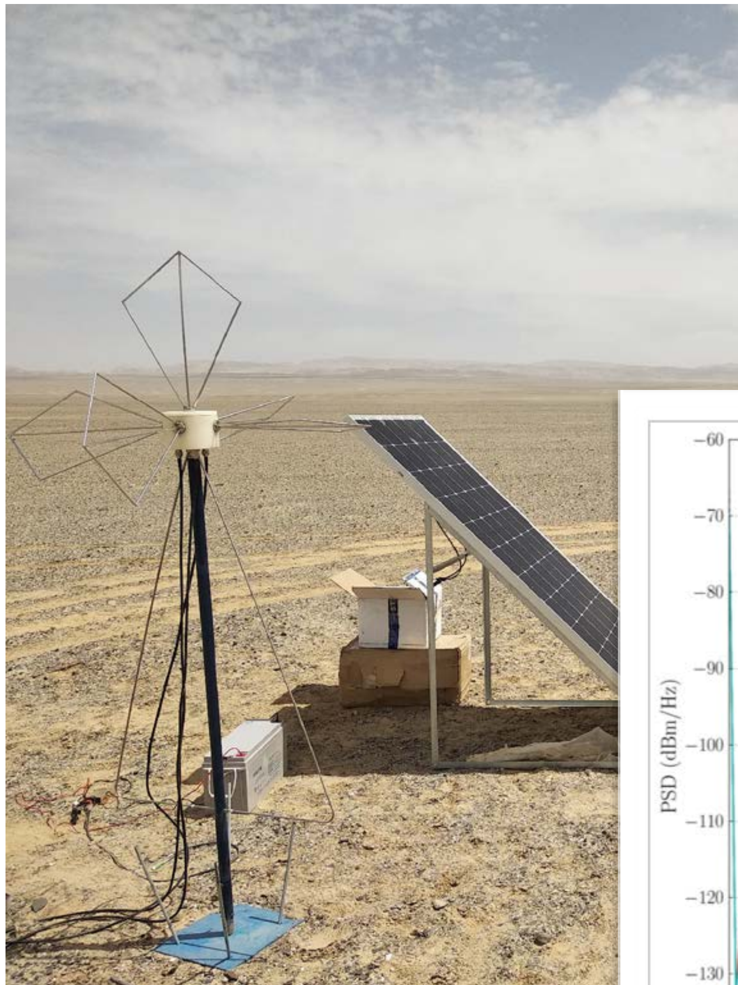
Electronics:
50-200MHz analog filtering,
500MSPS sampling
FPGA+CPU
Bullet WiFi data transfert

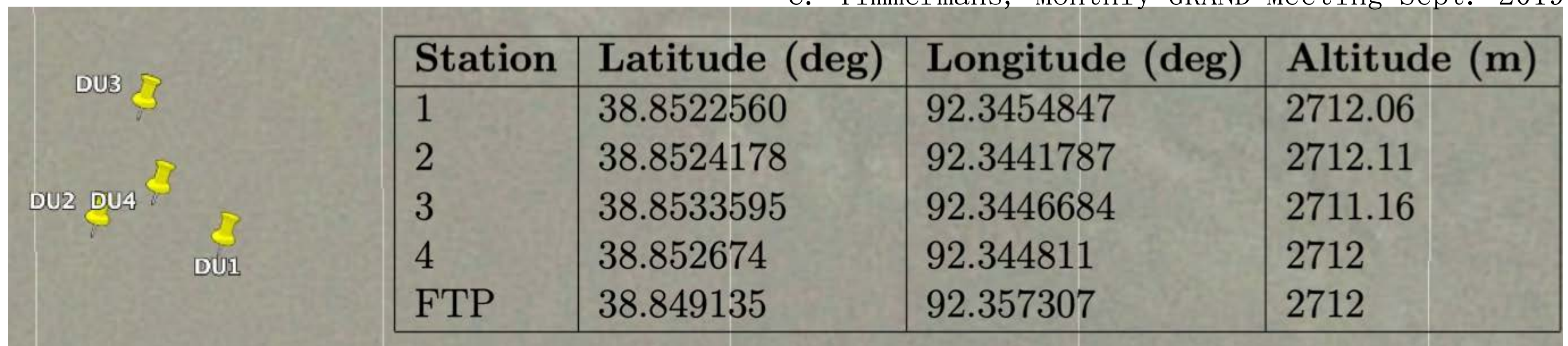


Site: Search still in progress, slower convergence due to Covid+Chinese administration

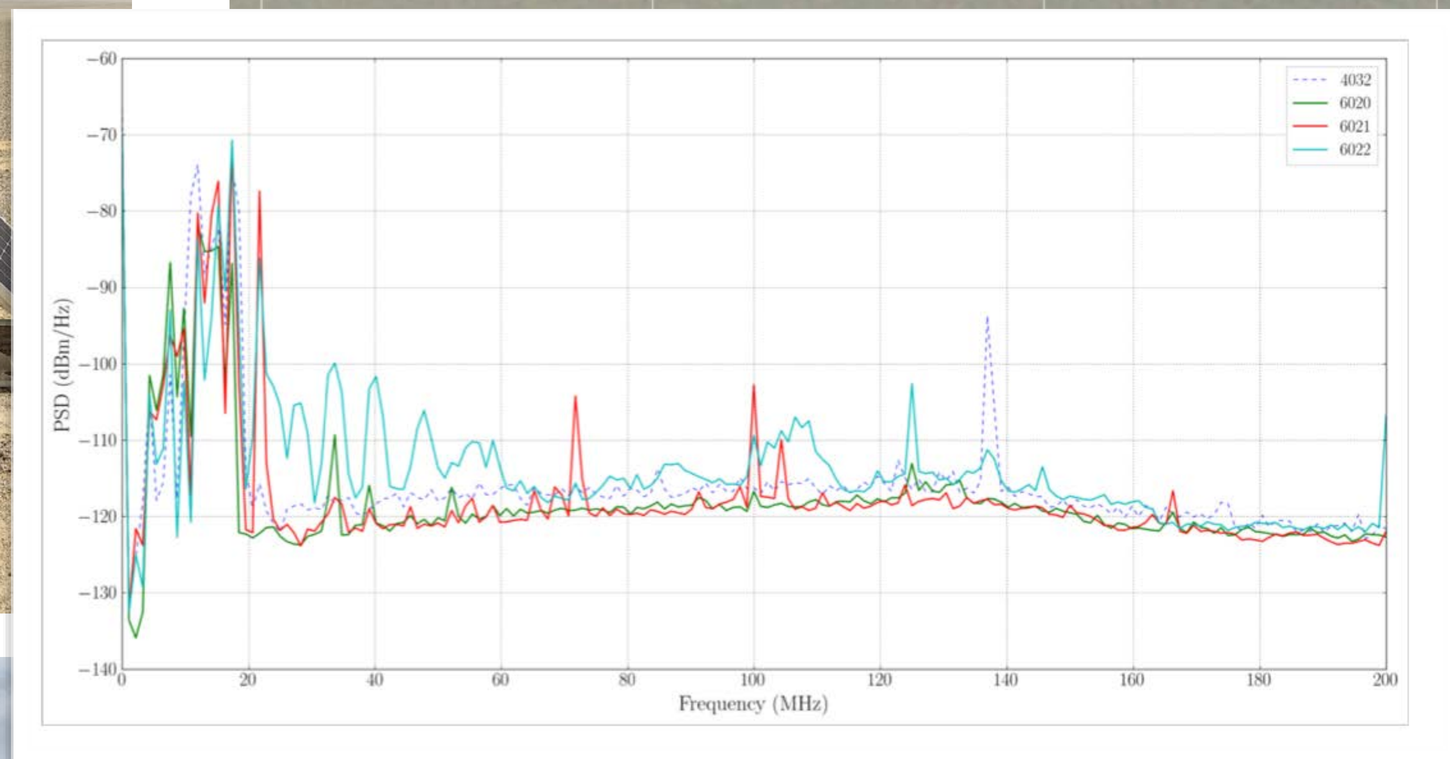
GRANDProto300 long-term monitoring: started this summer!

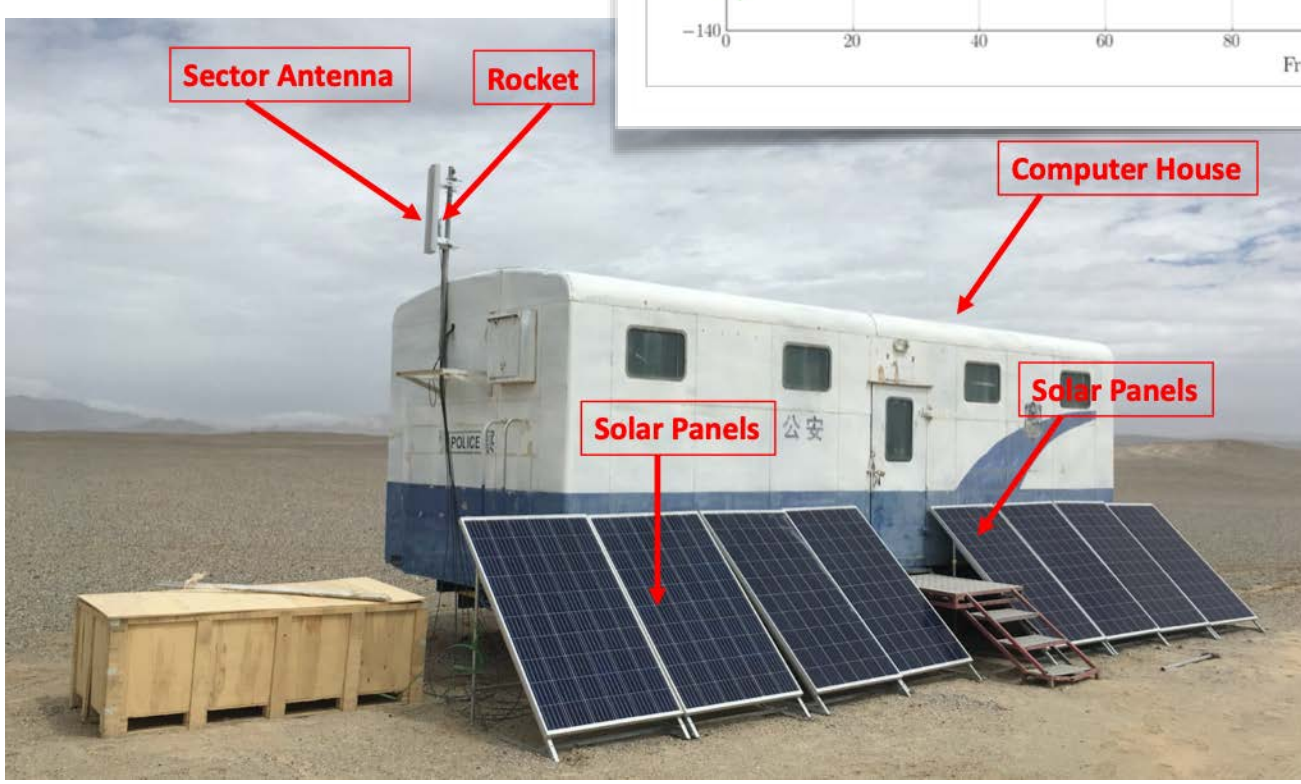
C. Timmermans, Monthly GRAND Meeting Sept. 2019





Station	Latitude (deg)	Longitude (deg)	Altitude (m)
1	38.8522560	92.3454847	2712.06
2	38.8524178	92.3441787	2712.11
3	38.8533595	92.3446684	2711.16
4	38.852674	92.344811	2712
FTP	38.849135	92.357307	2712

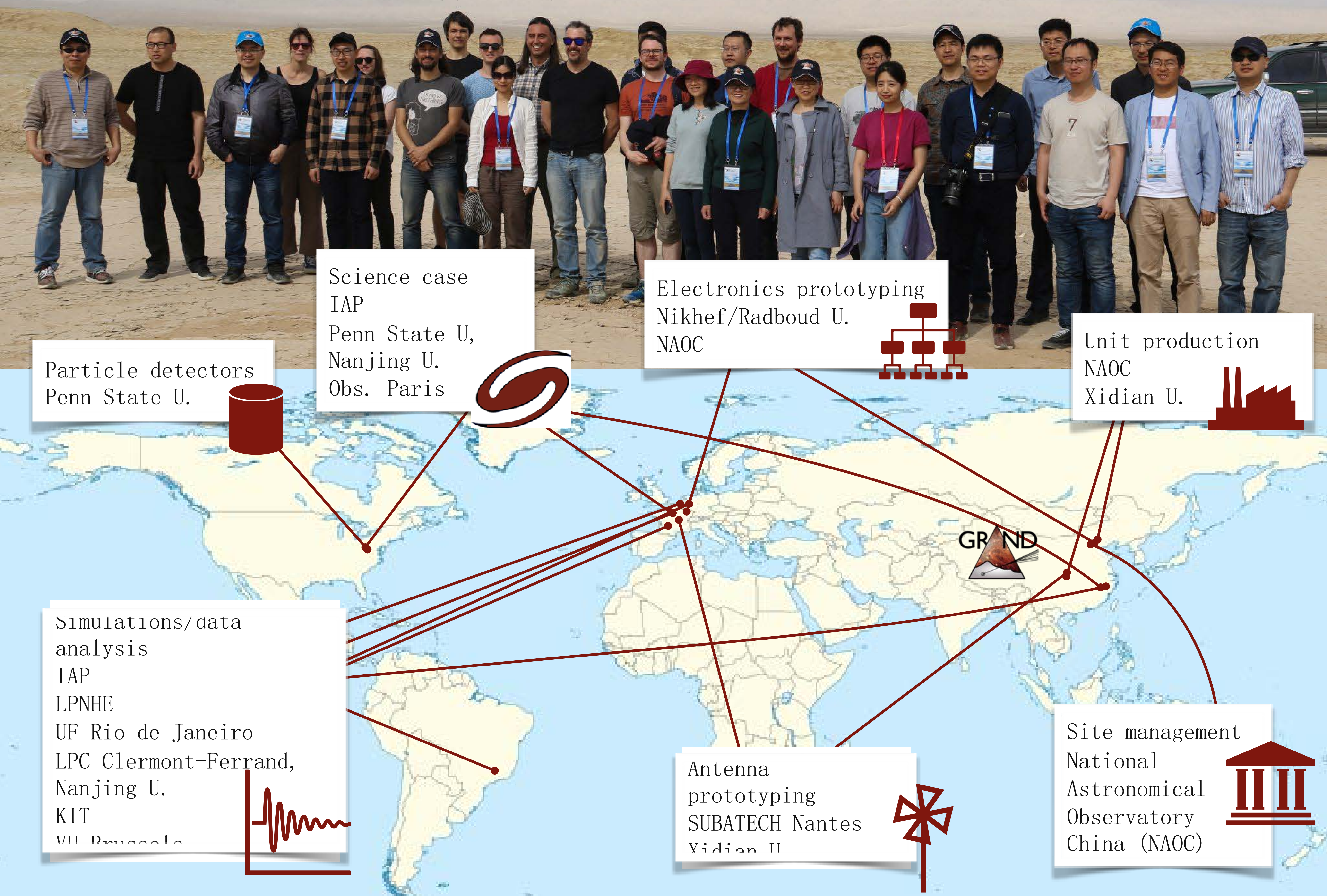




- overall excellent electromagnetic conditions
- noise rate dominated by self-induced noise
- in 24 hours: only 15 events triggered by all 3 stations
- new tests within next months with low-noise equipment

GRAND Today

~60 collaborators from 10 countries



Particle detectors
Penn State U.

Science case
IAP
Penn State U,
Nanjing U.
Obs. Paris

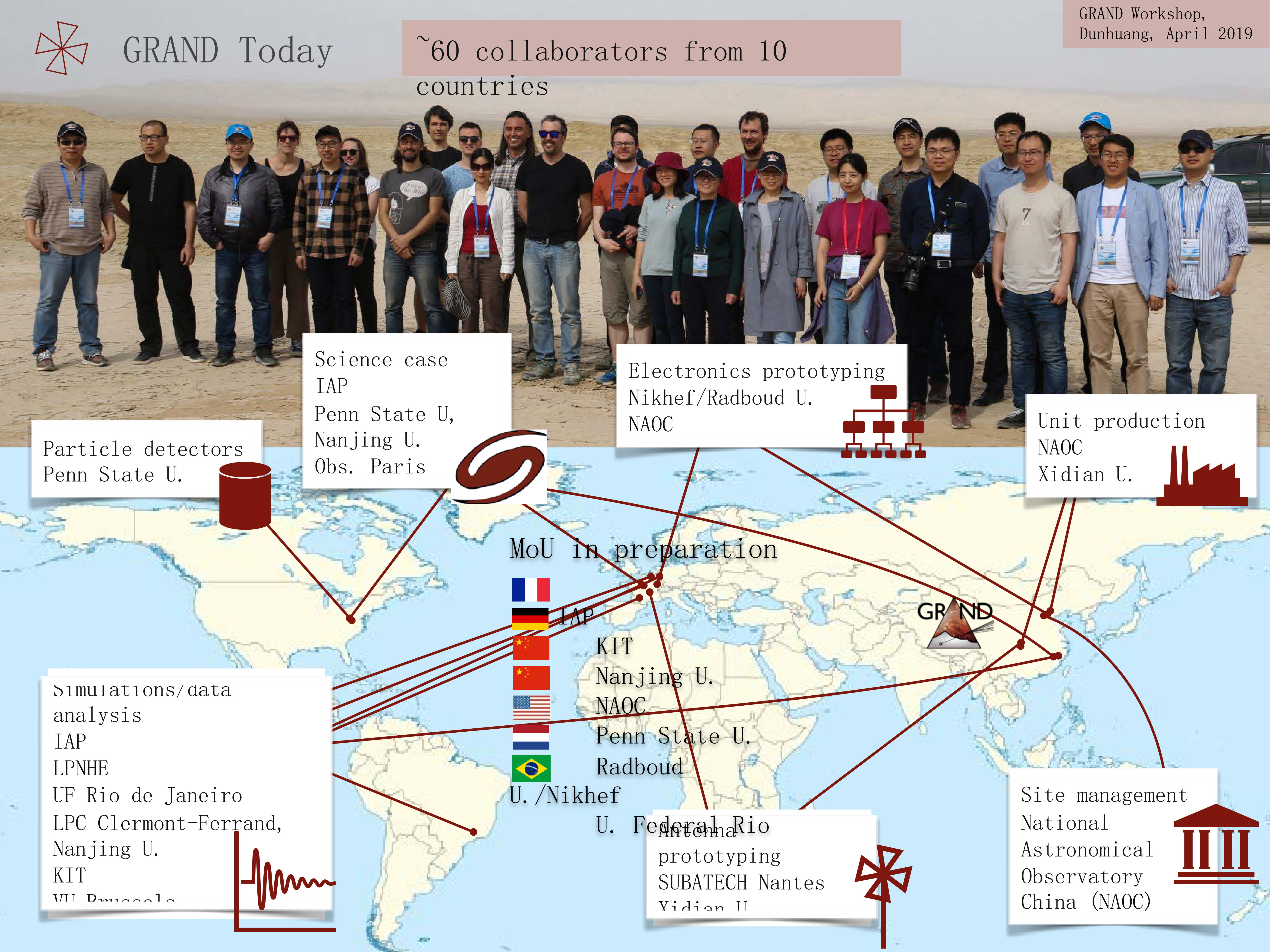
Electronics prototyping
Nikhef/Radboud U.
NAOC

Unit production
NAOC
Xidian U.

Simulations/data analysis
IAP
LPNHE
UF Rio de Janeiro
LPC Clermont-Ferrand,
Nanjing U.
KIT
VU Brussels

Antenna prototyping
SUBATECH Nantes
Xidian U.

Site management
National Astronomical Observatory China (NAOC)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~60 collaborators from 10 countries
GRAND Workshop, Dunhuang, April 2019
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MoU in preparation
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NAOC
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Nanjing U.
KIT
Antenna prototyping
SUBATECH Nantes
Site management
National Astronomical Observatory China (NAOC)

References:

Website:
http://grand.cnrs.fr

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

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

join us and bring your ideas!

kotera@iap.fr

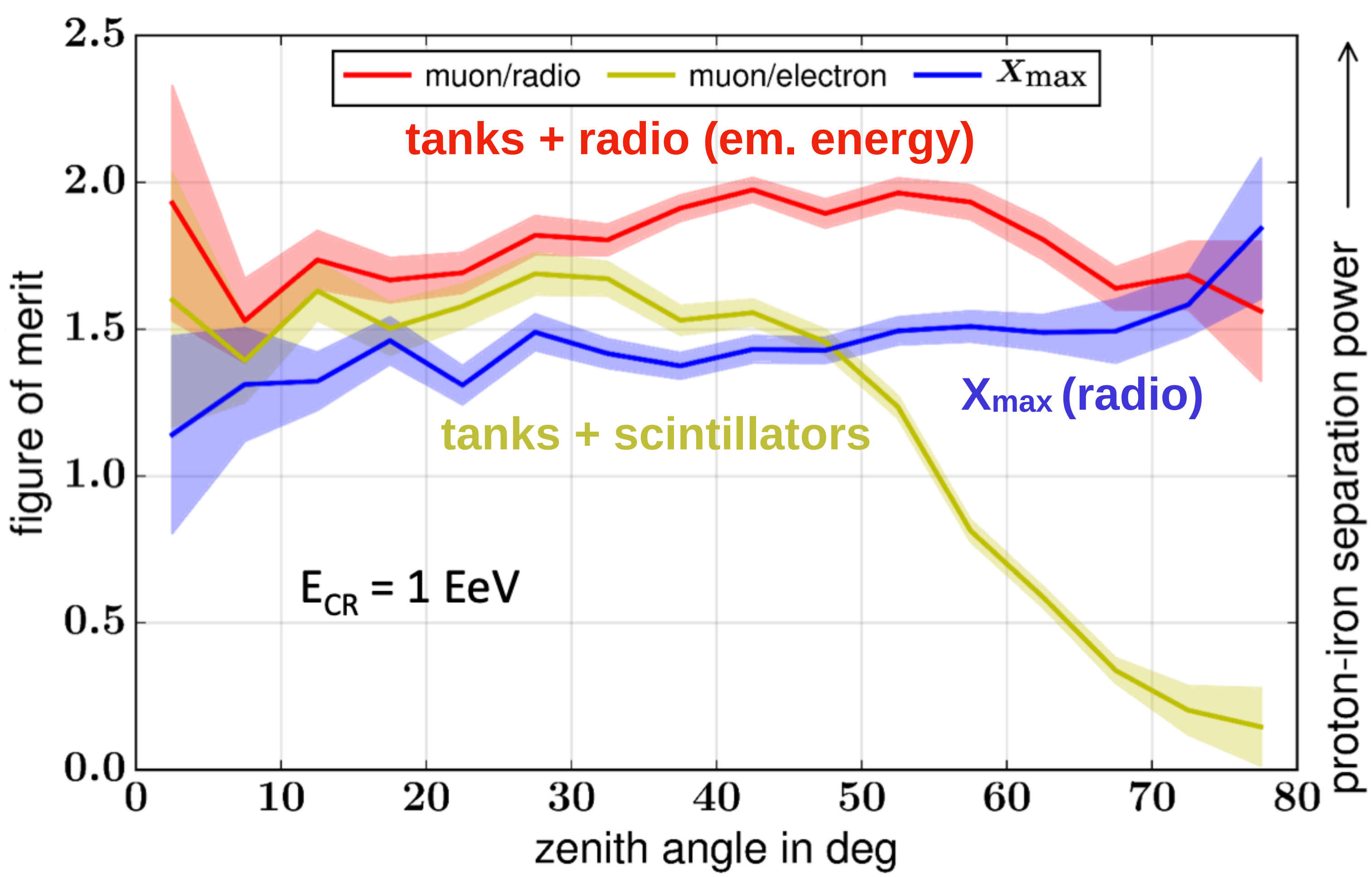
How to reach an exquisite accuracy on mass composition?

- a single setup covering $10^{16.5-18}$ eV?

Yes, and combining radio + muon detectors
—> best for inclined showers (>60°)
—> add also standalone radio measurement of X_{max}

for exquisite accuracy!

radio self trigger —> no dependency on the primary nature for trigger efficiency (ex : light primaries inducing muon-poor showers)



Ewa Holt PhD thesis