# GRAND

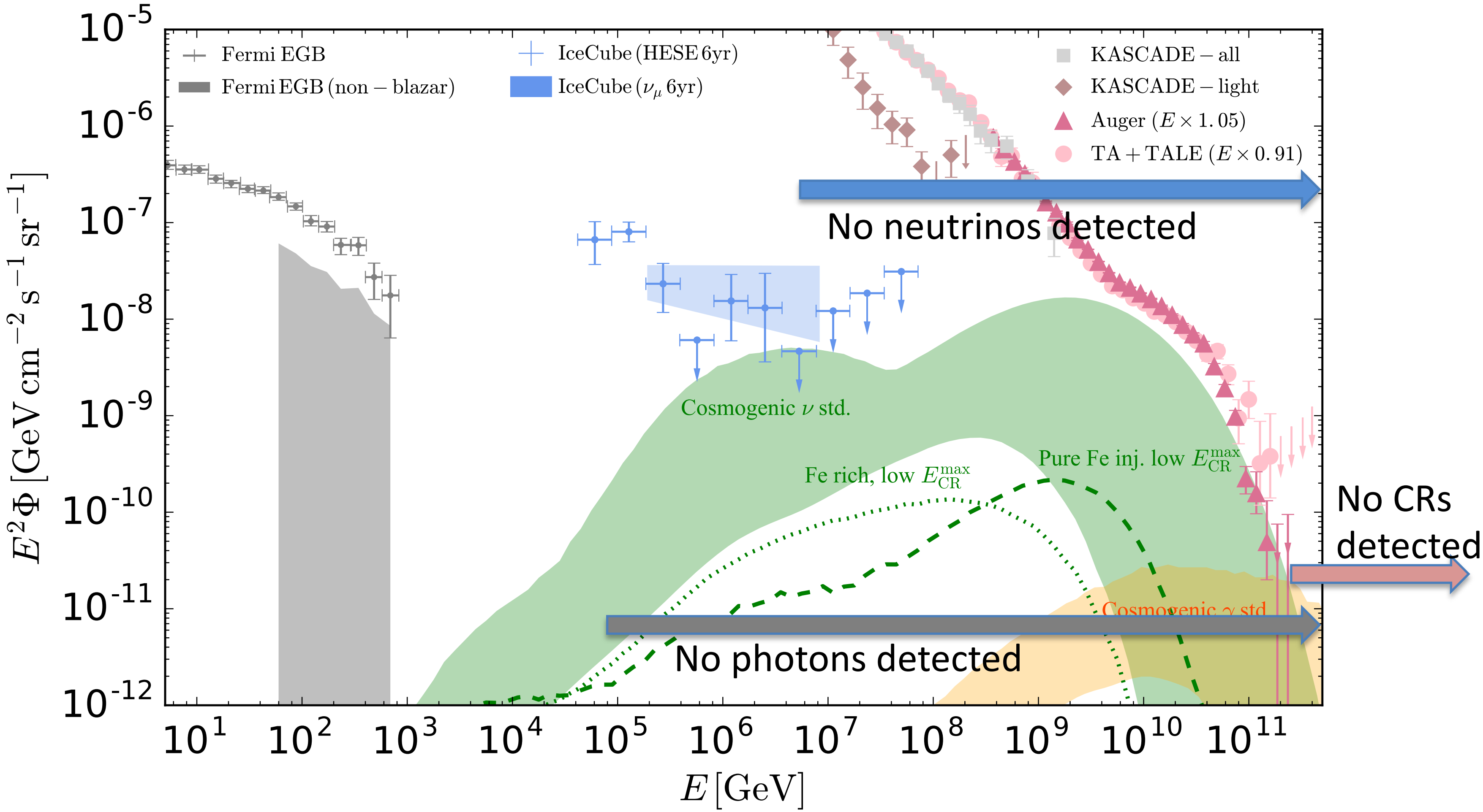
A Giant Radio Array for Neutrino Detection


Charles Timmermans

Nikhef

Radboud University Nijmegen

# The Particle multi-messenger landscape

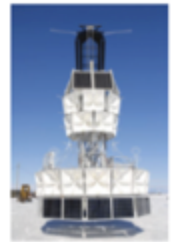


# Future project overview

complementarity,
sensitivity to
neutrino sources
**“precision frontier”**

ICECUBE
SOUTH POLE NEUTRINO OBSERVATORY

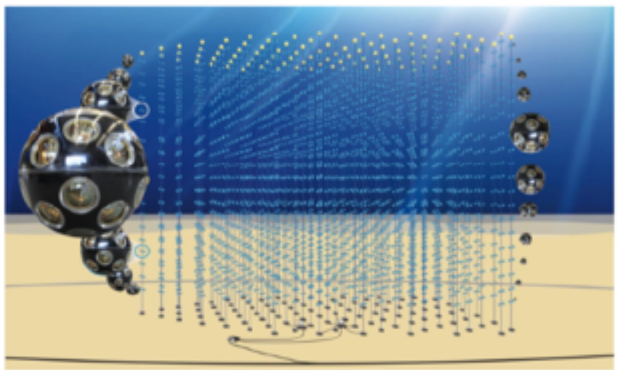
ANTARES



PIERRE
AUGER
OBSERVATORY

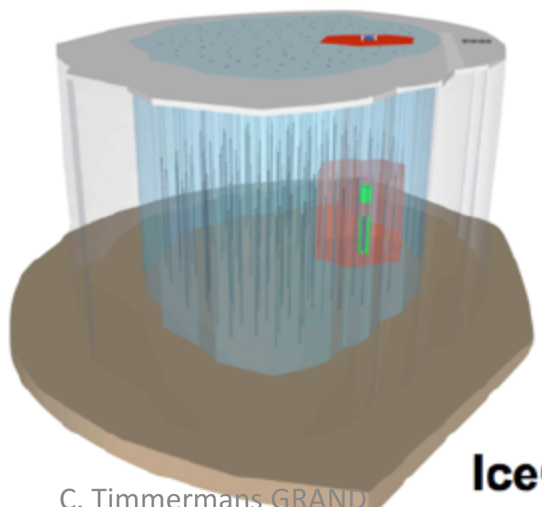
Present neutrino detectors

sensitivity at EeV
and beyond
**“energy frontier”**

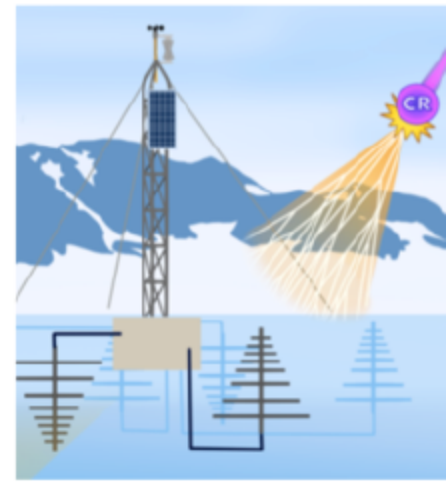


**KM3NeT, GVD**

sensitivity at
PeV energies
**“intensity frontier”**



**IceCube-Gen2**




**ARA, ARIANNA,**
**EVA, GRAND**

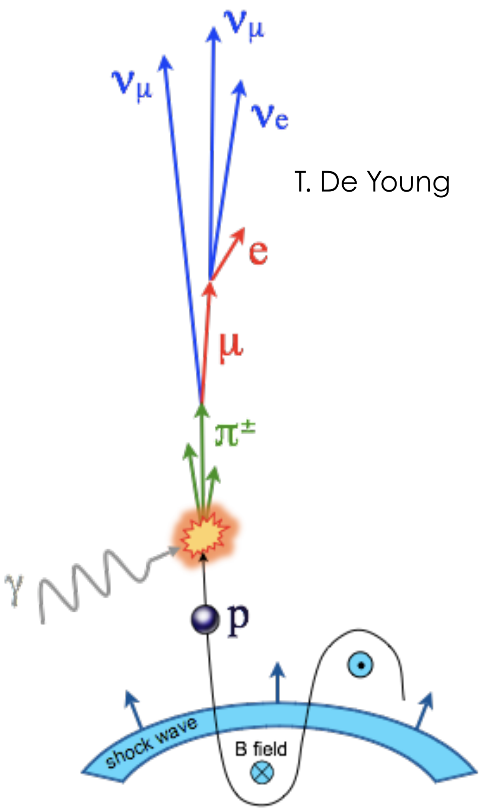
Kowalski@TeVPA2017



credit: M. Ackerman

# Origin of neutrinos and photons

## Source production




T. De Young

## Cosmogenic

$$p + \gamma_{CMB} \rightarrow p + \pi^0$$

$$\pi^0 \rightarrow \gamma + \gamma \qquad E_\gamma \sim 0.1\, E_p$$

$$p + \gamma_{CMB} \rightarrow n + \pi^+$$

$$\pi^+ \rightarrow \mu^+ + \nu_\mu \qquad E_\nu \sim 0.05\, E_p$$

$$\mu^+ \rightarrow e^+ + \bar{\nu}_\mu + \nu_e$$

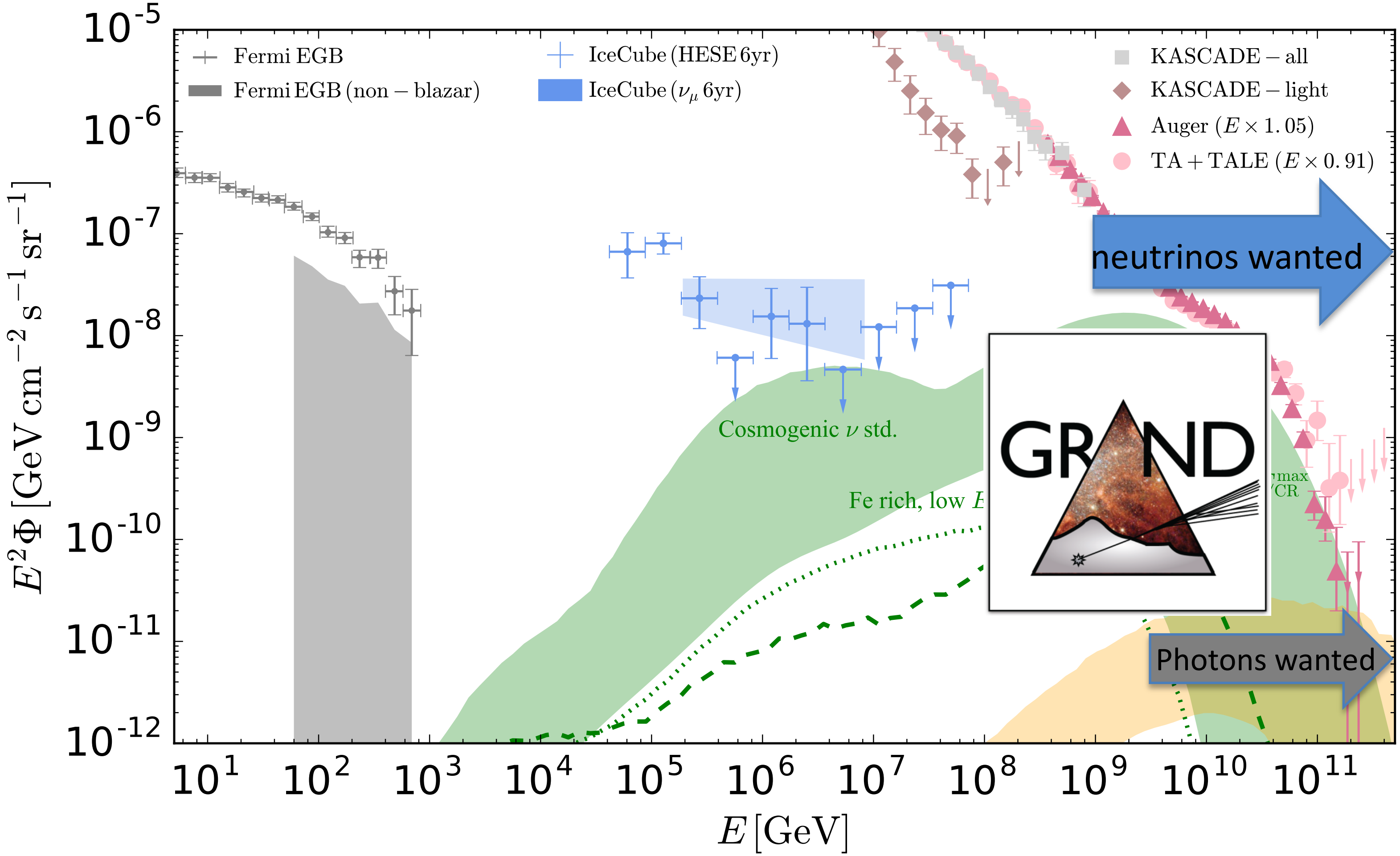
$$n \rightarrow p + e^- + \bar{\nu}_e \qquad E_\nu \sim 10^{-3} E_p$$

$$A + \gamma \rightarrow A' + p$$

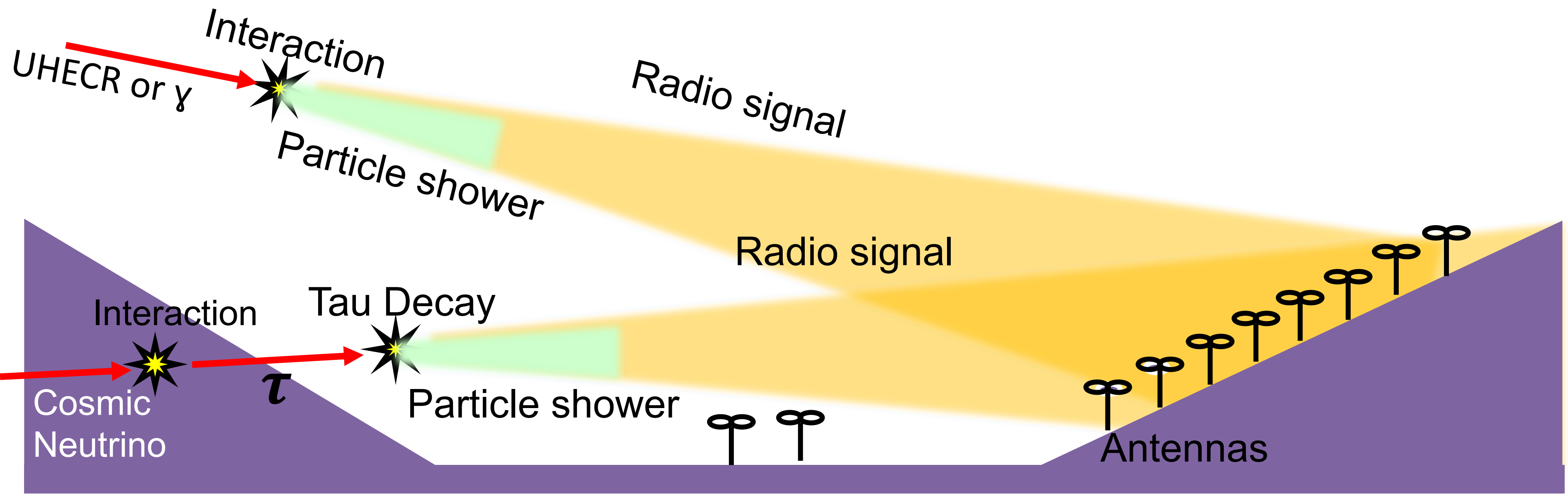
$$p + \gamma \rightarrow \nu's \qquad E_\nu \sim 0.05\, E_{nucleus}/A$$

$$p + \gamma \rightarrow \gamma's \qquad E_\gamma \sim 0.1\, E_{nucleus}/A$$

# The Particle multi-messenger landscape

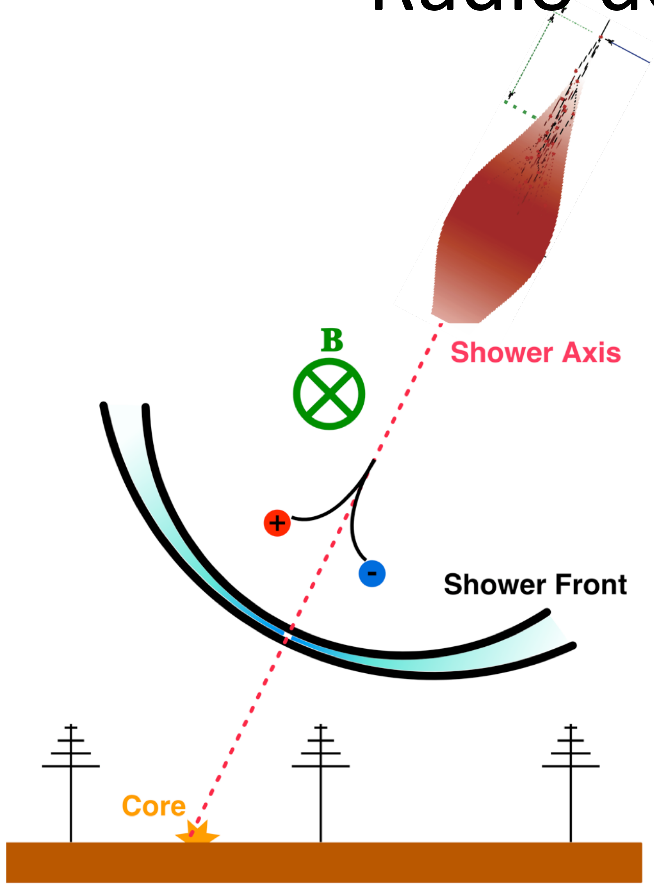


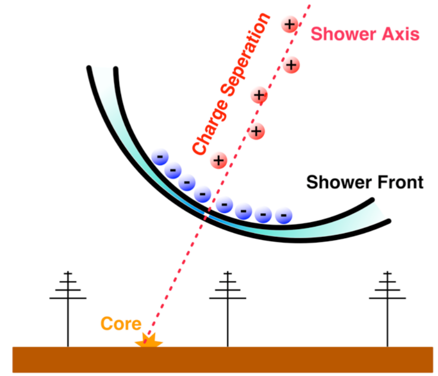
# Detection Principle for EeV (and beyond!) particles

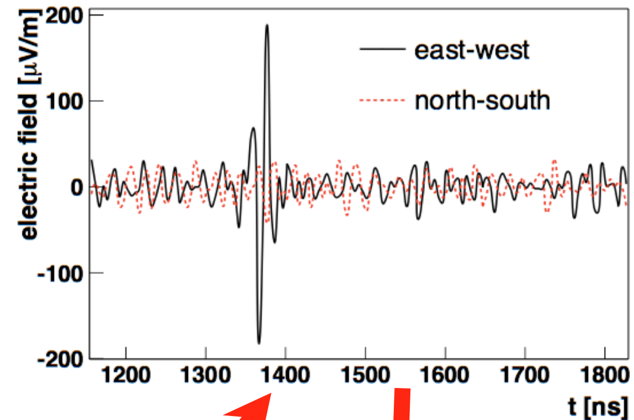



# Giant Radio Array Neutrino Detector
# GRAND

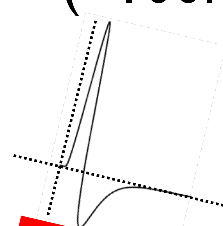
# Radio detection of air showers



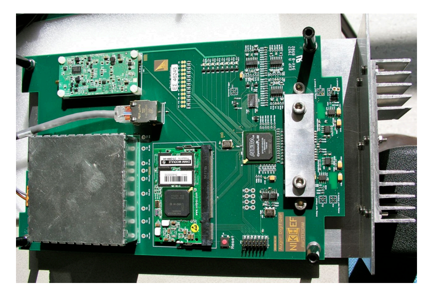



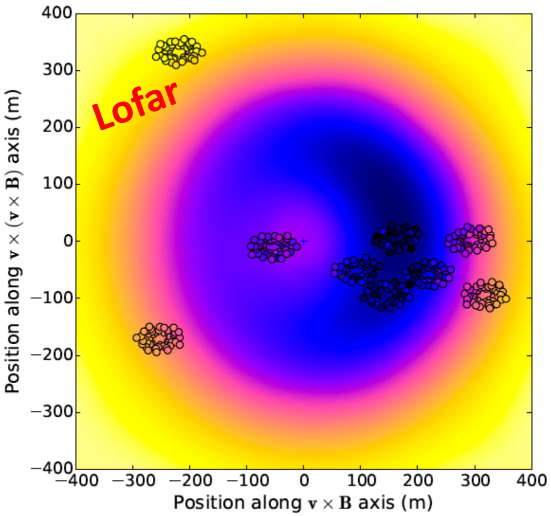

Short Pulse
(~100ns)

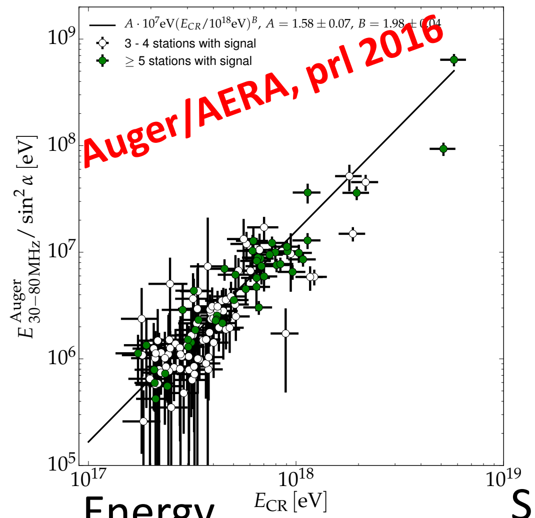


antenna
(50-200 MHz)

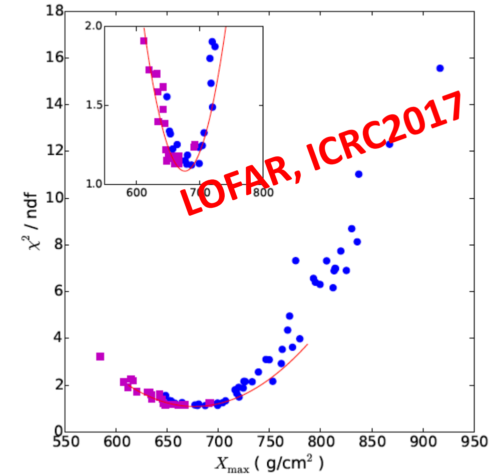


# Information from Radio Signal



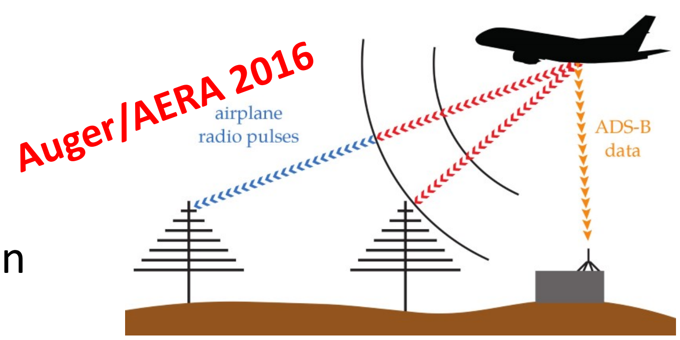



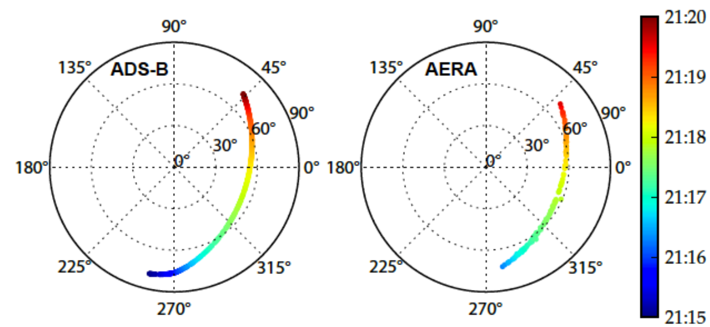

Energy



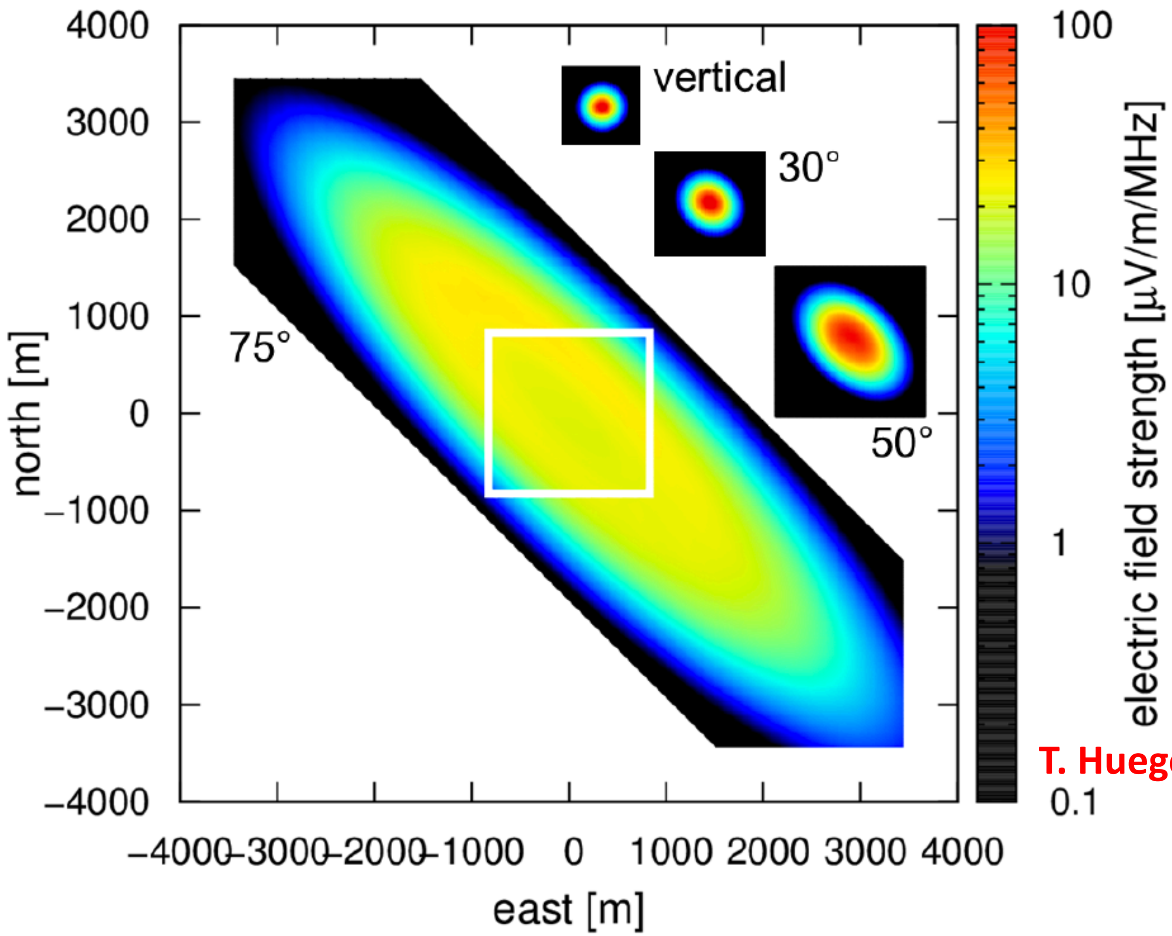

Shower depth

Direction



# Radio signal vs Zenith angle

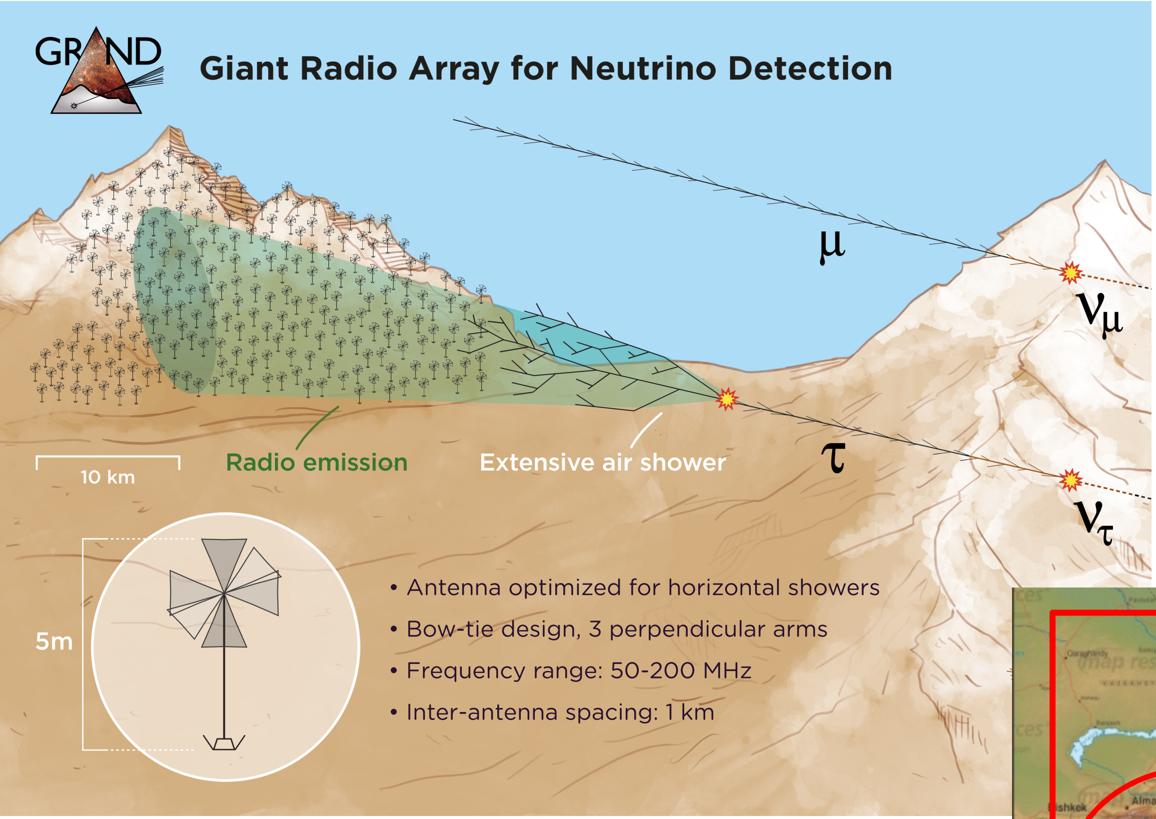


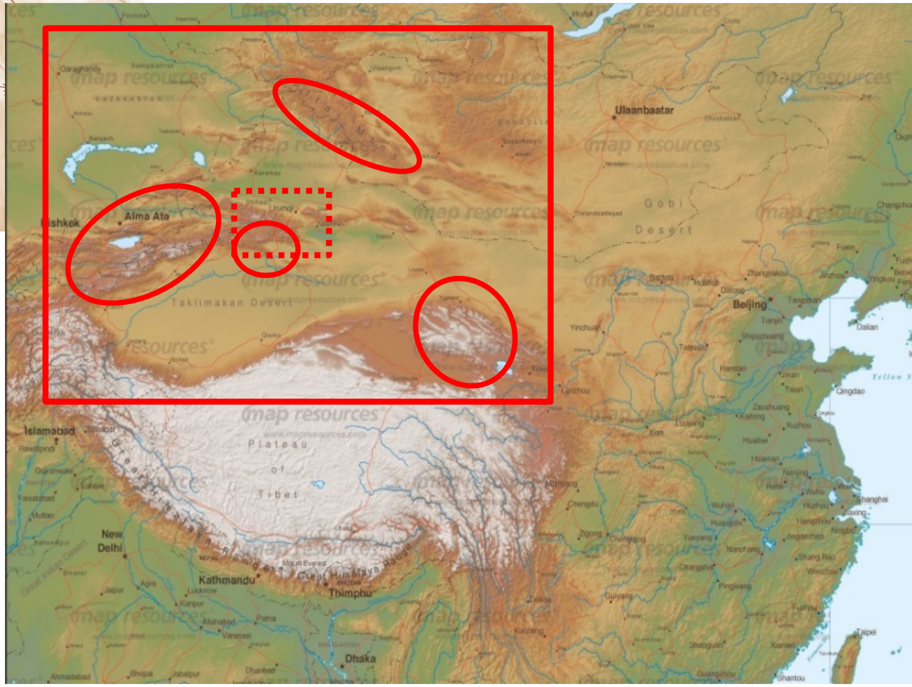

Footprint of a 5 EeV shower depending on zenith angle.

Radio can be used even in a 'sparse' array

**T. Huege, phys. Rept 2016**

# The GRAND setup

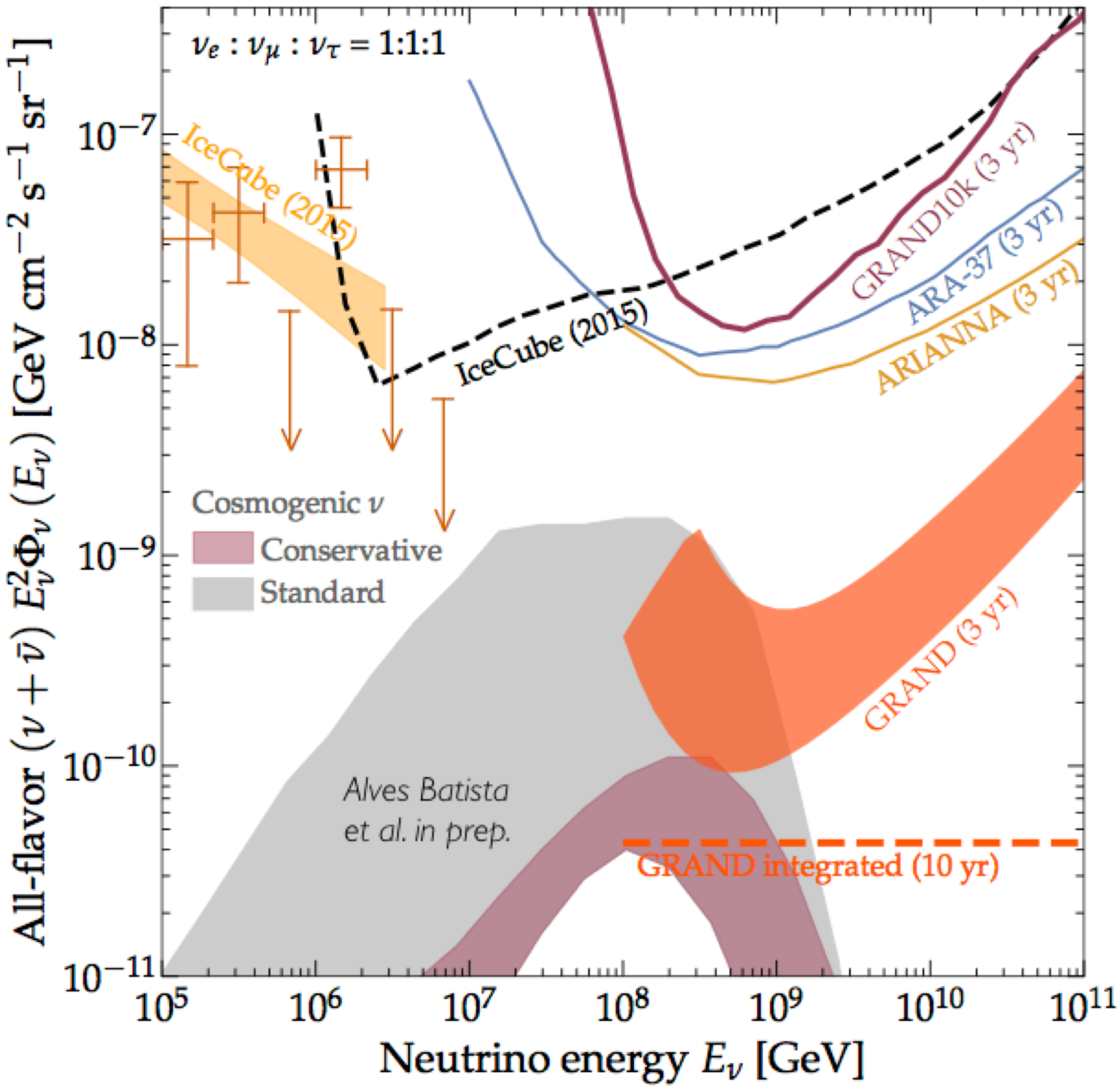



A **distributed** observatory with a total area of 200,000 km$^2$ (*eg* 20 times 10,000 km$^2$)

Location: TBD, largely in China

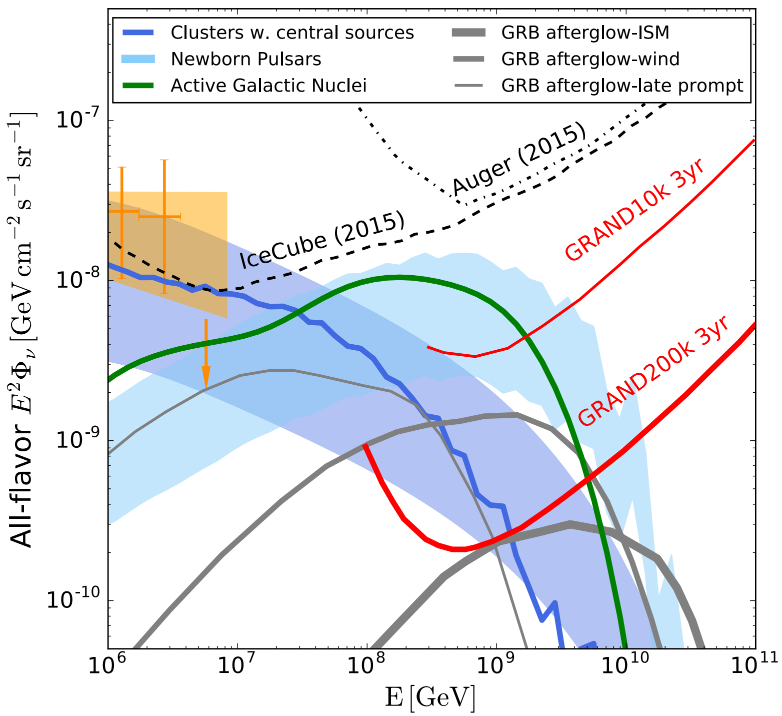
# Strong Physics Case

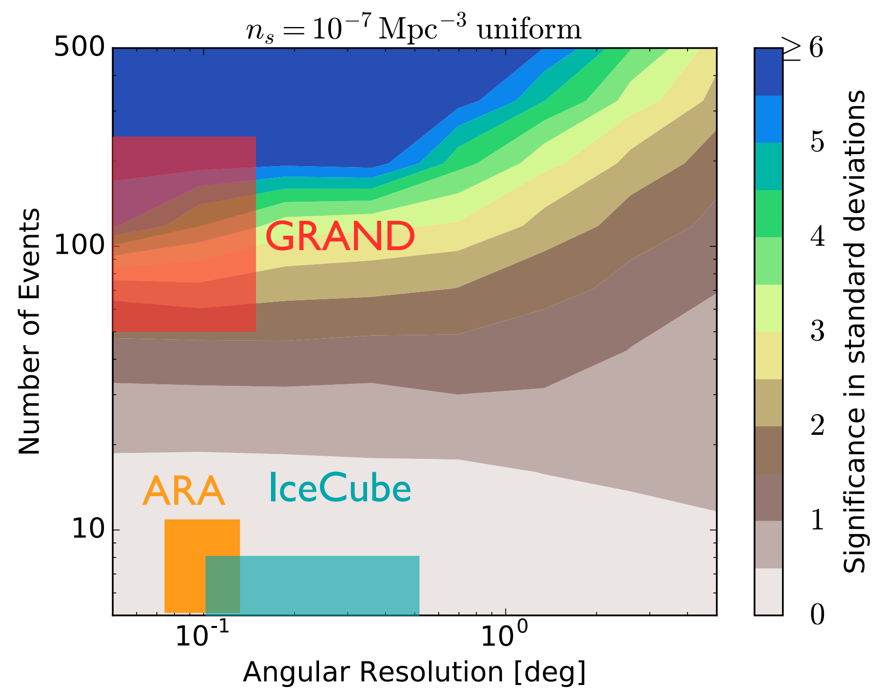


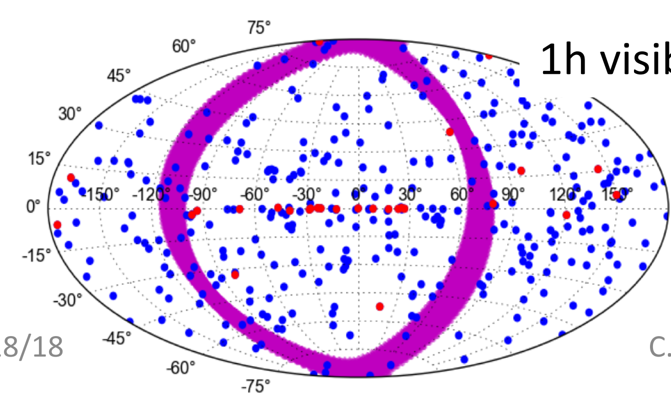

Cosmogenic neutrinos

# Strong Physics Case

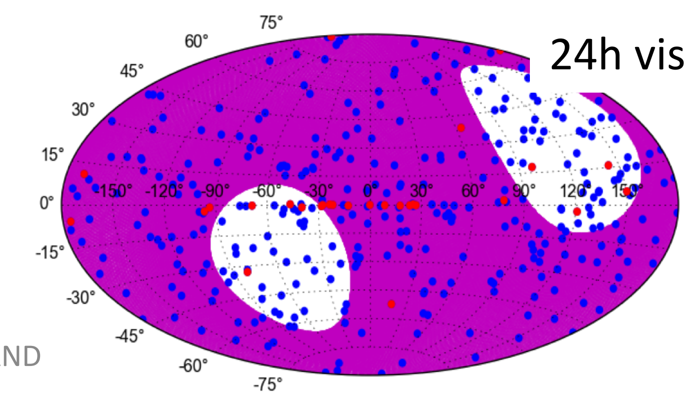
## Neutrino point sources



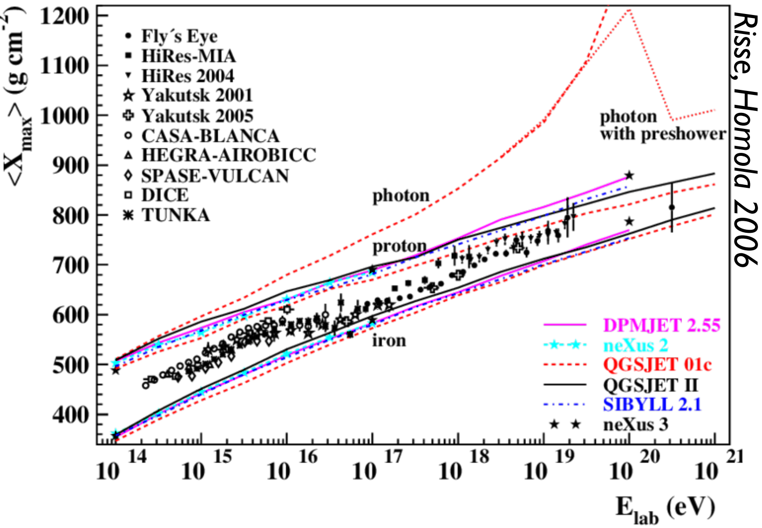



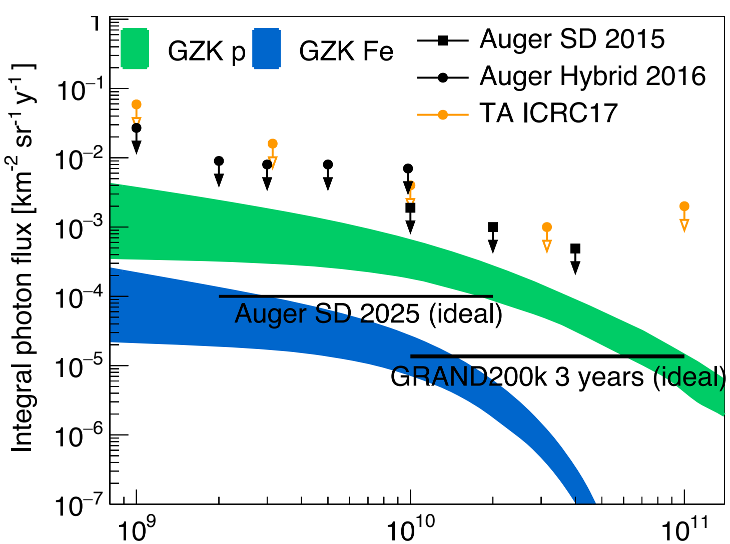
1h visibility



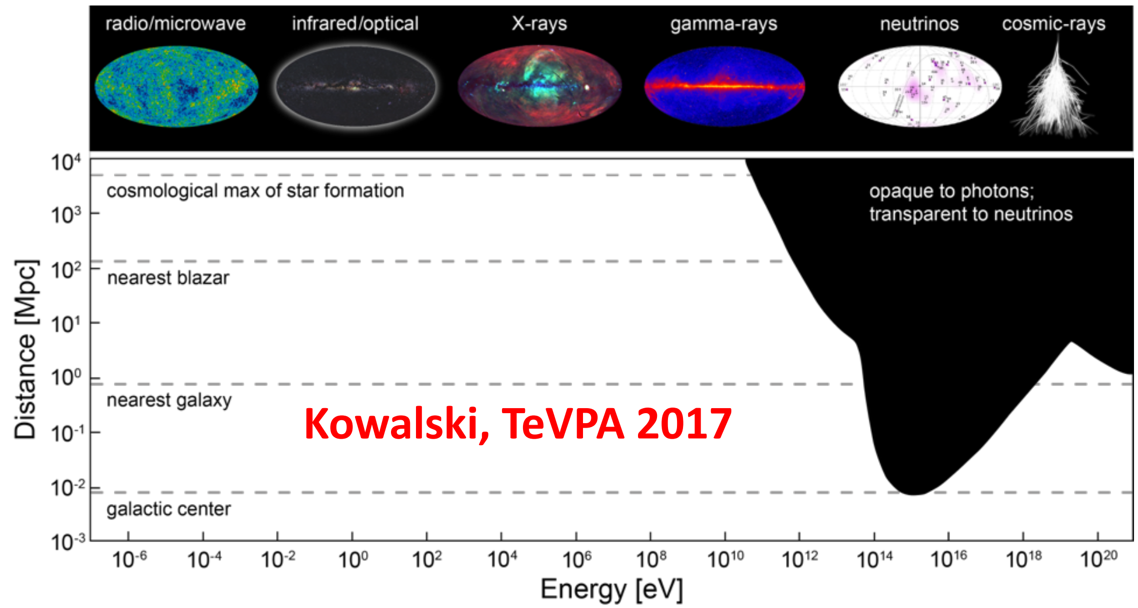
24h visibility

# Strong Physics Case



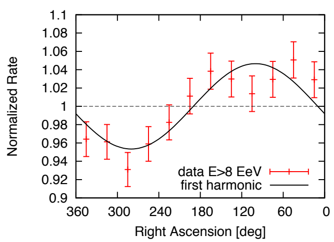



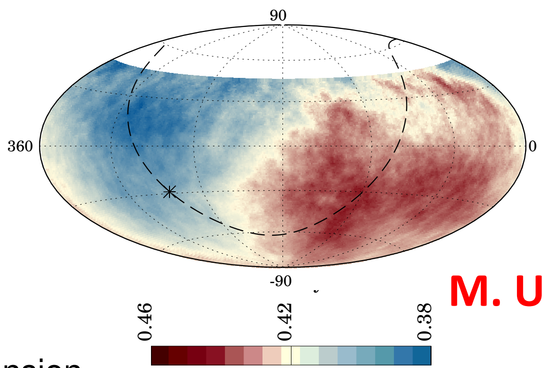

Neutrinos AND Photons: Source evolution

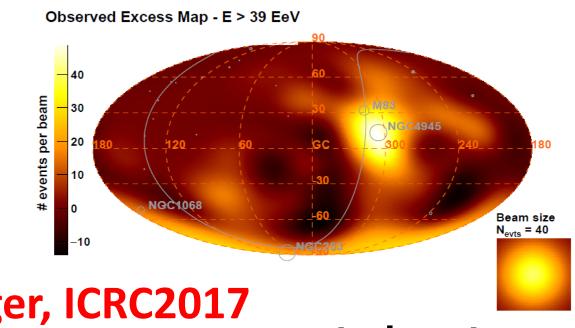


# Strong Physics Case

All of Auger UHECR data so far equals 1 year of GRAND UHECR data




M. Unger, ICRC2017

**starburst**

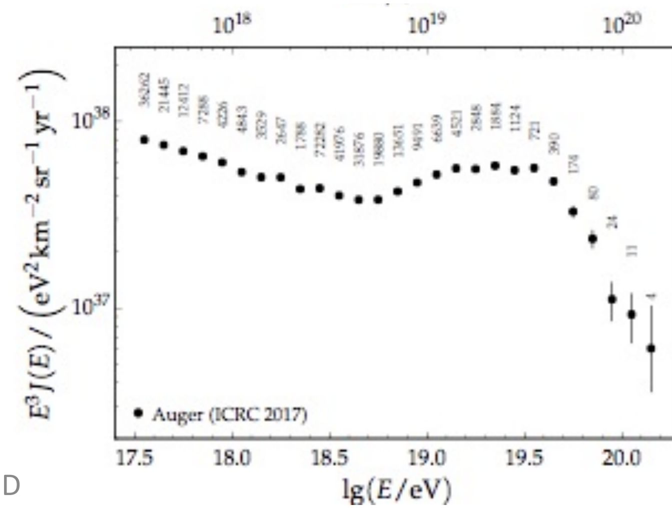
$f = 10\%,\ \psi = 13^\circ$
pre-trial* p-value: $4 \times 10^{-6}$
post-trial** p-value: $4 \times 10^{-5}$
post-trial** significance: $3.9\,\sigma$

Harmonic analysis in right ascension

| $E$ [EeV] | events | amplitude $r$ | phase [deg.] | $P(\geq r)$ |
|---|---|---|---|---|
| 4-8 | 81701 | $0.005^{+0.006}_{-0.002}$ | $80 \pm 60$ | 0.60 |
| $> 8$ | 32187 | $0.047^{+0.008}_{-0.007}$ | $100 \pm 10$ | $2.6 \times 10^{-8}$ |

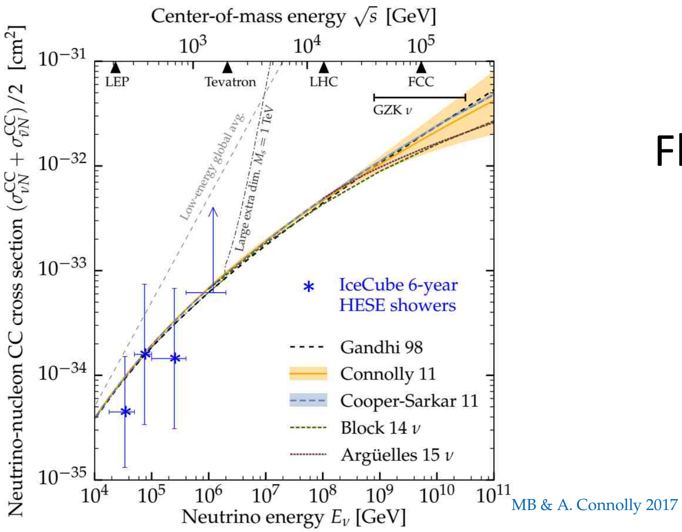
significant modulation at $5.2\sigma$ ($5.6\sigma$ before penalization for energy bins explored)

True for anisotropy, flux.
Composition studies need more simulation to estimate systematic uncertainties



# Strong Physics Case

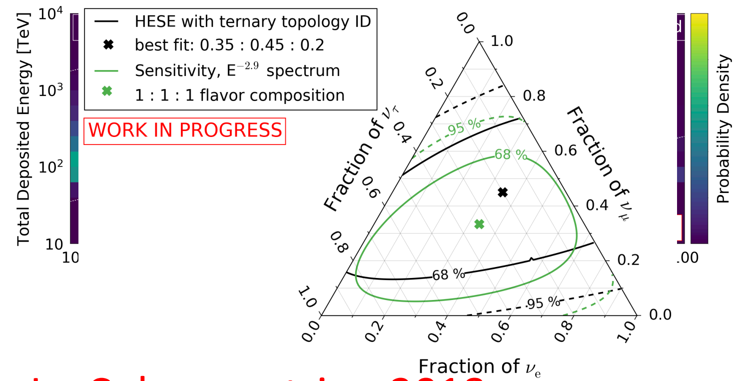
## *(New) physics*




the neutrino-nucleon cross section

**High-Energy Starting Events (HESE) – 7.5 yr**

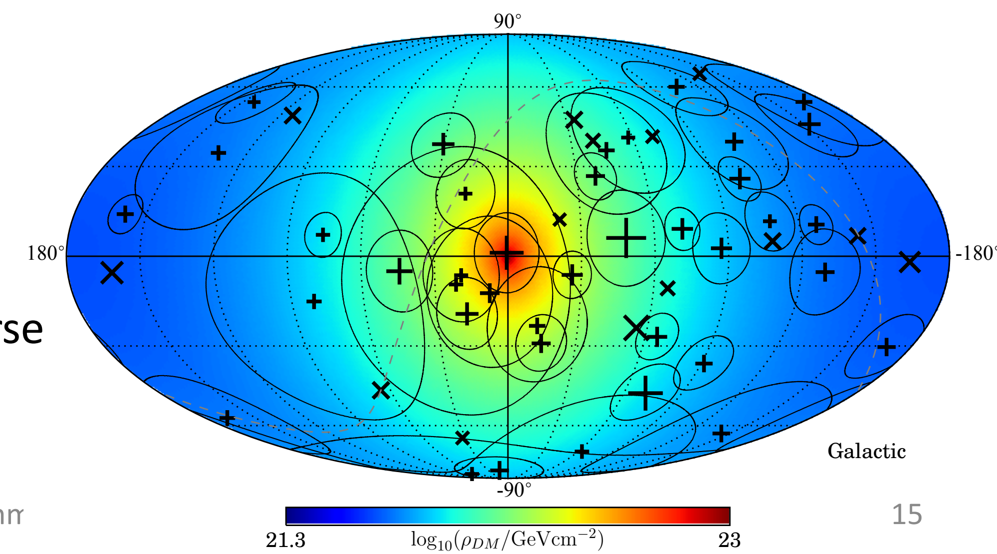
Flavor Oscillations




IceCube, neutrino 2018

Poster #174 Stachurska et al. (IceCube)
Poster #176 Meier et al. (IceCube)

dark matter interactions in the universe

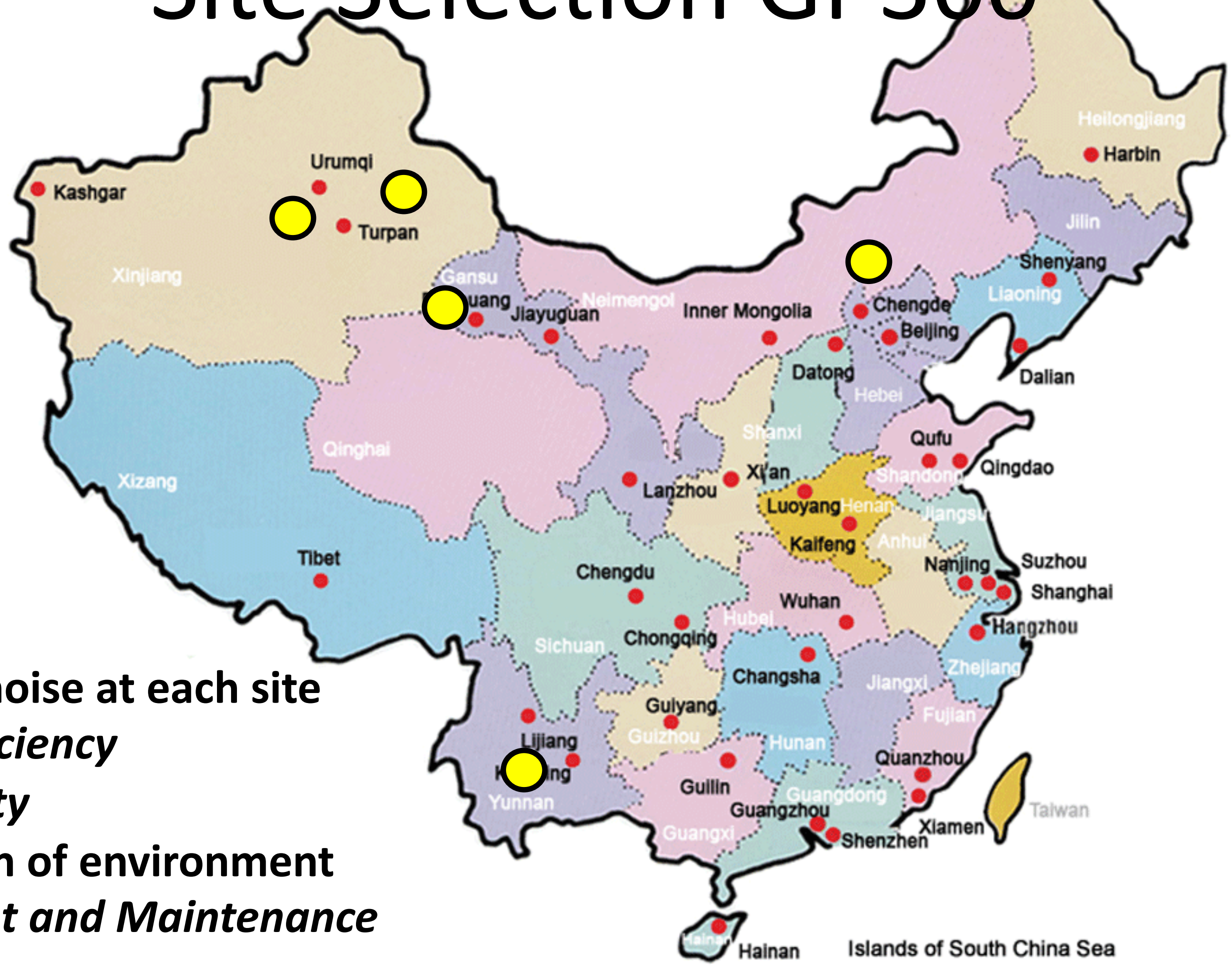


# Staging and Time line

GRANDProto300

| | GRANDProto35 (2018) | (2020) | GRAND10k (2025) | GRAND200k (203X) |
|---|---|---|---|---|
| **Goals** | **Standalone** radio detection of EAS<br><br>Very good **background rejection** | Standalone radio detection of **very inclined showers** (θ>70°) induced by high energy cosmic rays (>$10^9$ GeV) | First GRAND subarray, **sensitivity comparable to ARA/ARIANNA on similar time scale,** allowing potential 1st discovery of cosmogenic neutrinos | **First neutrino detection at $10^9$ GeV even with pessimistic fluxes and/or neutrino astronomy** |
| **Setup** | 35 radio antennas<br>21 scintillators<br> | • 300 Horizon Antennas over 300 km²<br>• Fast DAQ<br>• Solar pannels (day use) + WiFi data transfer | DAQ with discrete elements, but mature design for trigger, data transfer, consumption | 200'000 antennas over 200'000 km²<br><br>Hotspots could be in different continents |
| **Budget & stage** | 160k€, fully funded by NAOC+IHEP, deployment 2018 @ Ulastai | 1.3 M€<br>to be deployed in 2019 | 1500€ / detection unit | **Industrial scale allows to cut costs down: 500€/unit**<br>**➔ 120M€ in total** |

# Site Selection GP300




**Measure radio noise at each site**

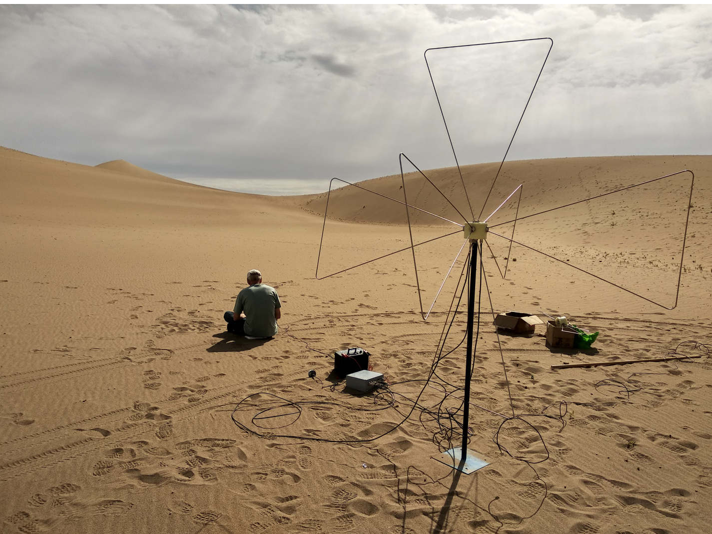
***Trigger efficiency***

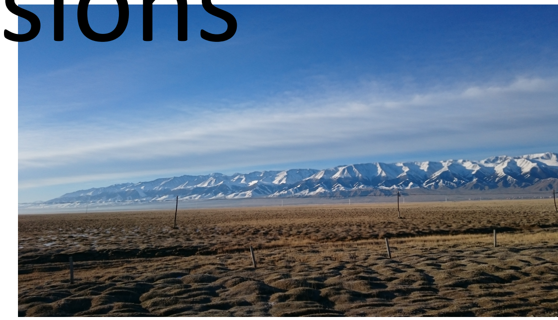
***Data Quality***

**Visual inspection of environment**

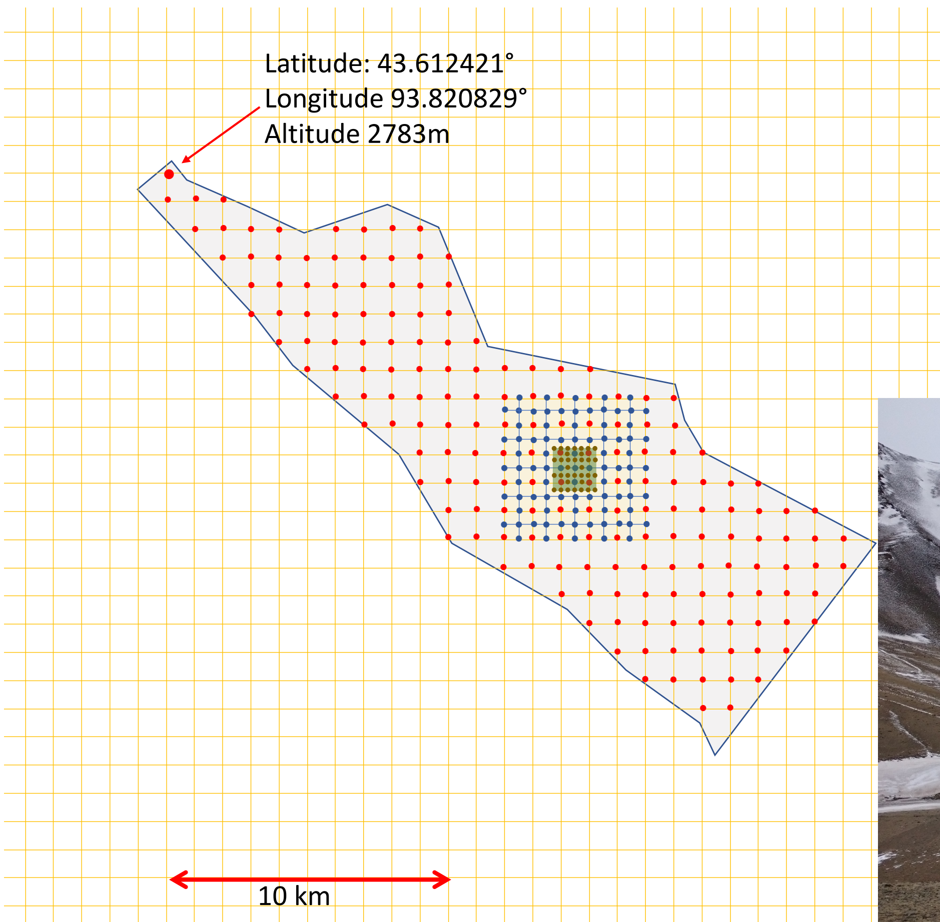
***Deployment and Maintenance***

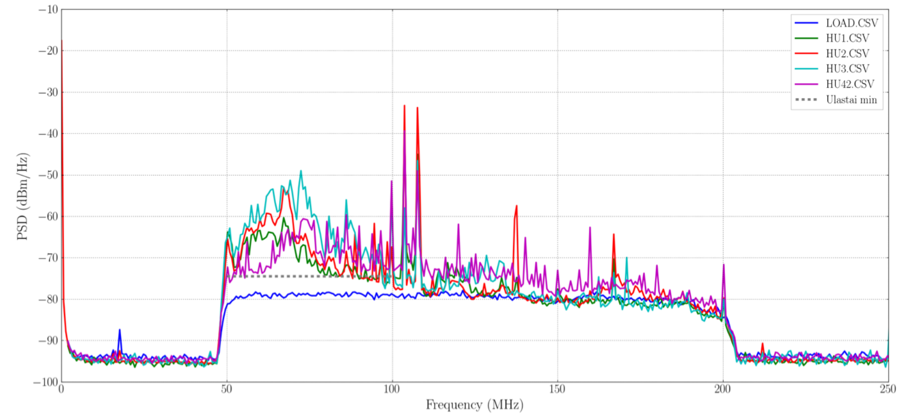
# Site Survey – Impressions



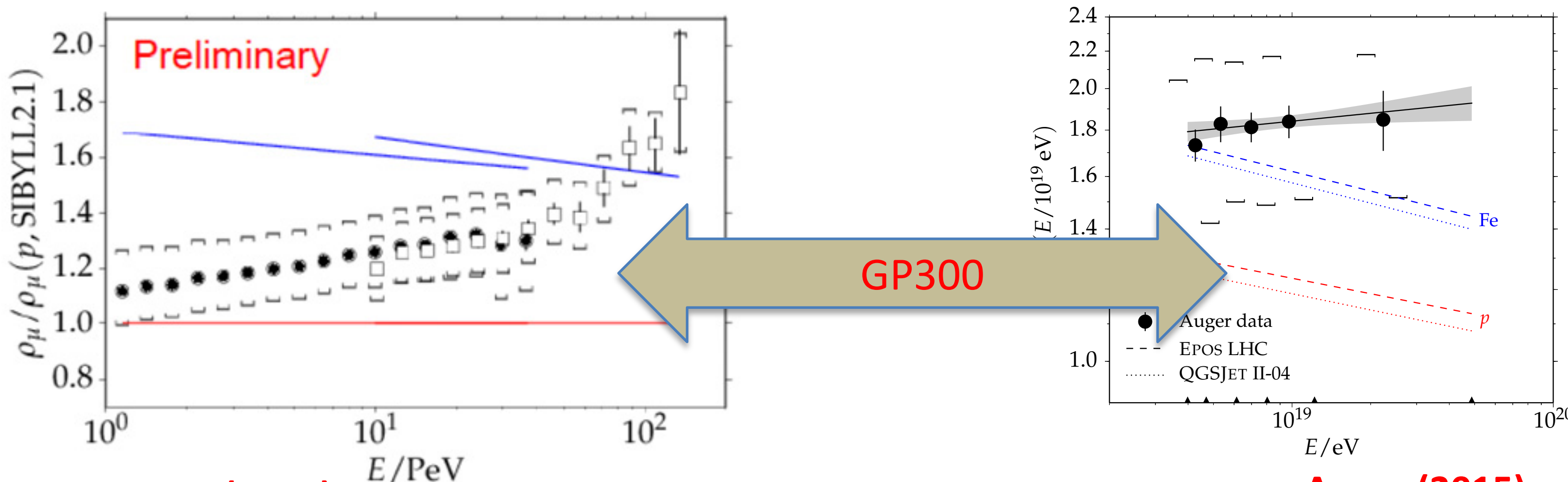


# Possible Site: Optimize setup GP300




# GP300, First (particle) physics




**Icetop (2017)**

**Auger (2015)**

Adding particle detectors on a 300 km² array

Jaime Álvarez-Muñiz[1], Rafael Alves Batista[2,3], Julien Bolmont[4], Mauricio Bustamante[5,6,7,†], Washington Carvalho Jr.[8], Didier Charrier[9], Ismaël Cognard[10,11], Valentin Decoene[12], Peter B. Denton[5], Sijbrand De Jong[13,14], Krijn D. De Vries[15], Ralph Engel[16], Ke Fang[17,18], Chad Finley[19,20], QuanBu Gou[21], Junhua Gu[22], Claire Guépin[12], Hongbo Hu[21], Yan Huang[22], Kumiko Kotera[12,23,*], Sandra Le Coz[22], Jean-Philippe Lenain[4], Guoliang Lü[24], Olivier Martineau-Huynh[4,22,*], Miguel Mostafá[25,26,27], Fabrice Mottez[28], Kohta Murase[25,26,27], Valentin Niess[29], Foteini Oikonomou[30,25,26,27], Tanguy Pierog[16], Xiangli Qian[31], Bo Qin[22], Duan Ran[22], Nicolas Renault-Tinacci[12], Frank G. Schröder[32], Fabian Schüssler[33], Cyril Tasse[34], Charles Timmermans[13,14], Matías Tueros[35], Xiangping Wu[36,22,*], Philippe Zarka[37], Andreas Zech[28], Bing Theodore Zhang[38,39], Jianli Zhang[22], Yi Zhang[21], Qian Zheng[40,21], Anne Zilles[12]

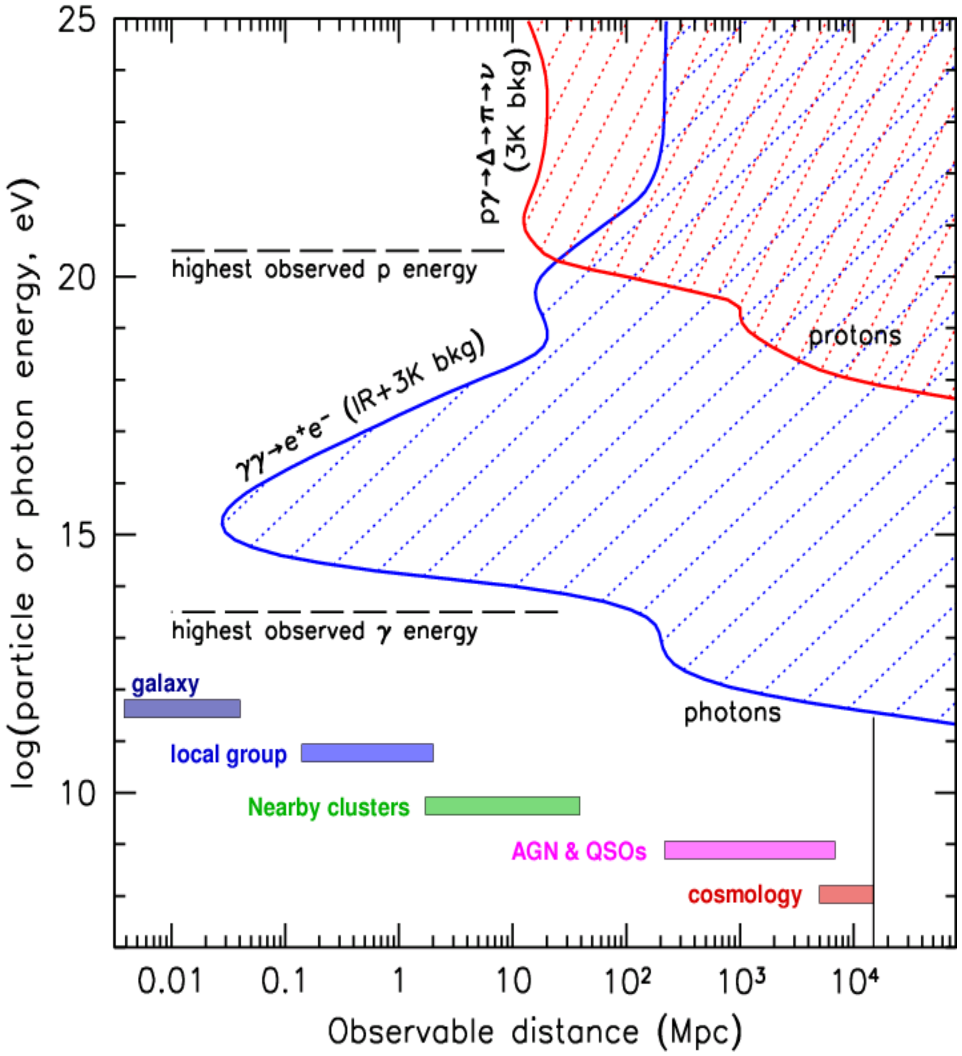
~50 scientists from 12 countries

# BACKUP

# Cosmic Horizons

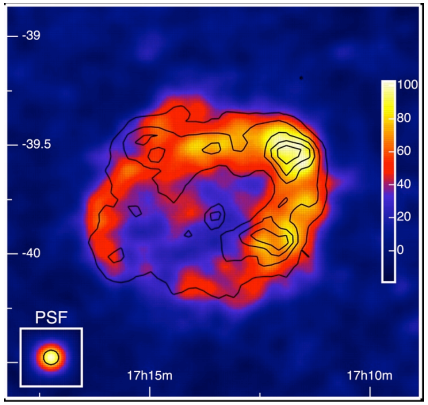
Photons have to be produced nearby (pair production)

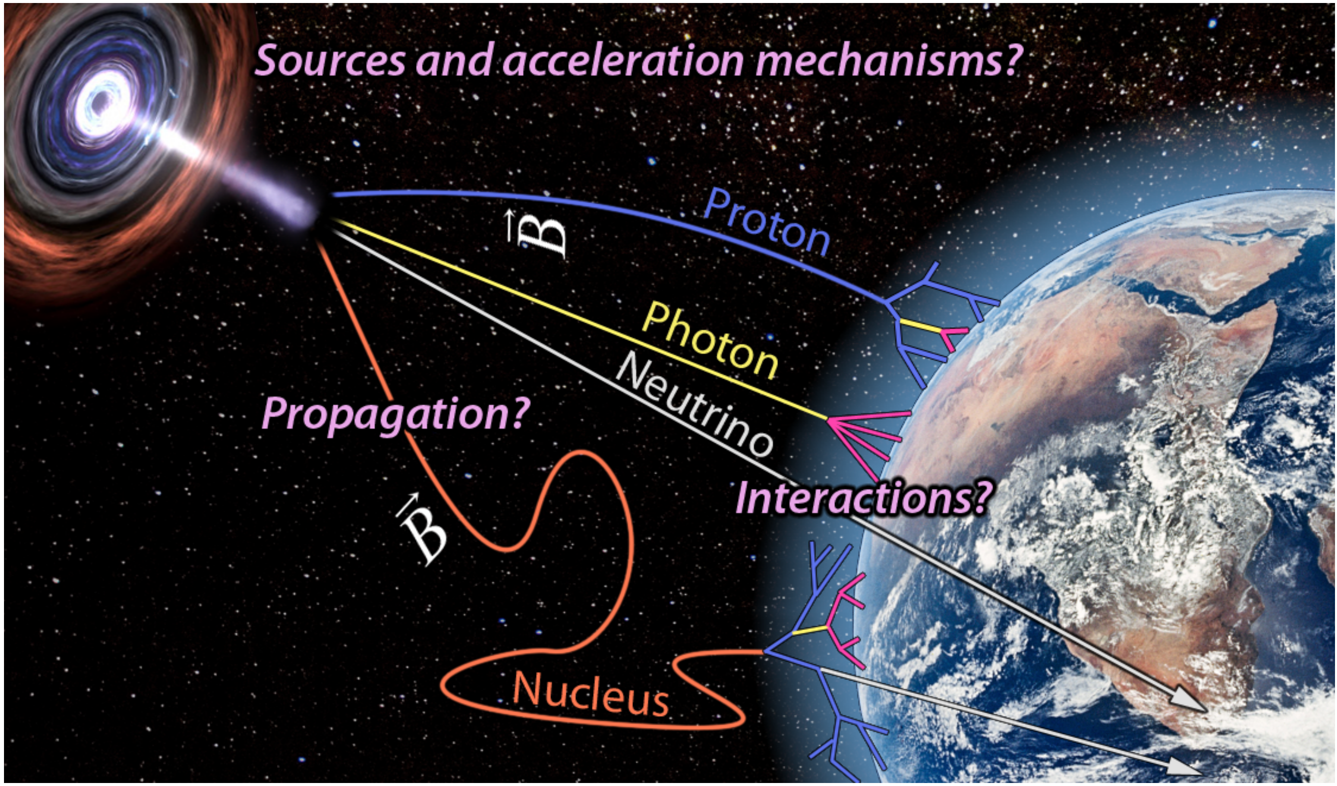
UHECR have to be produced nearby (GZK)



# Finding Acceleration sites of UHECR

1. Find light cosmic rays(p) from nearby sites (AugerPrime)
2. Find neutral particles as tracers from these sites (at low energy: ACT)

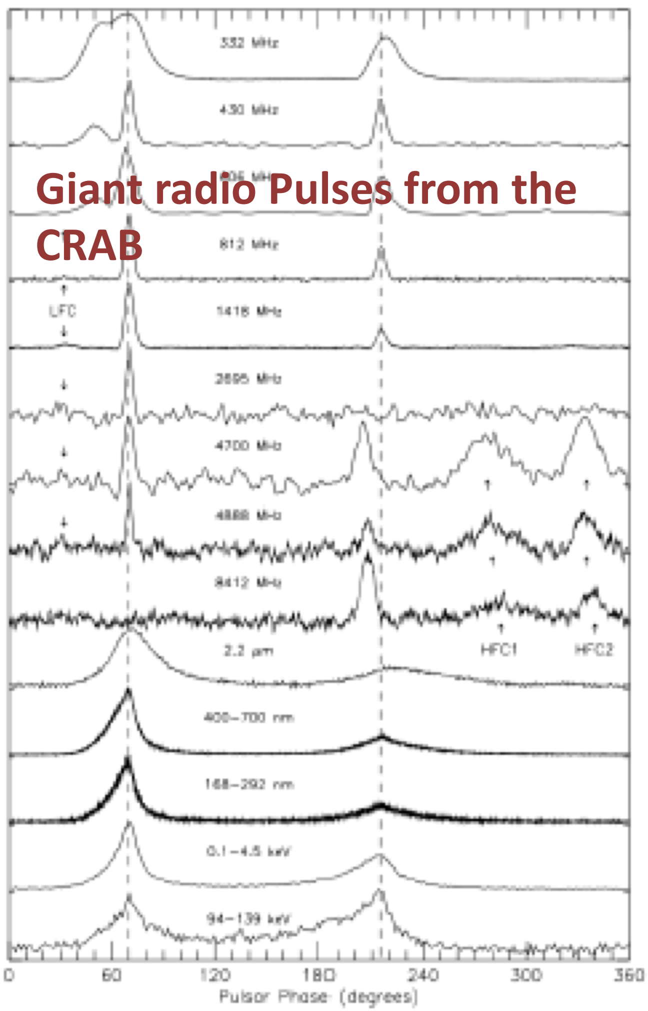



**3. Do both at the highest energies: GRAND**

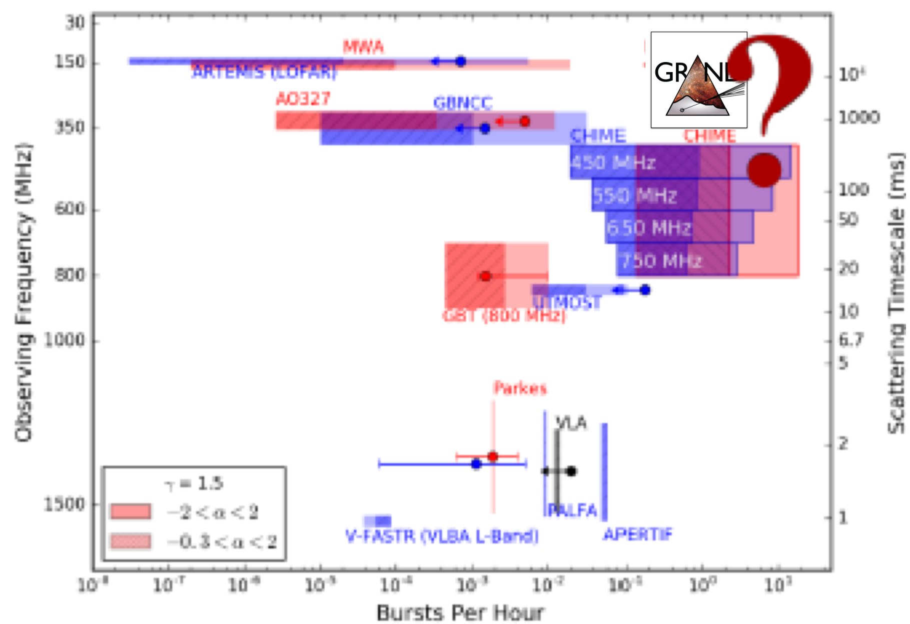
# Strong Physics Case

Giant radio Pulses from the CRAB

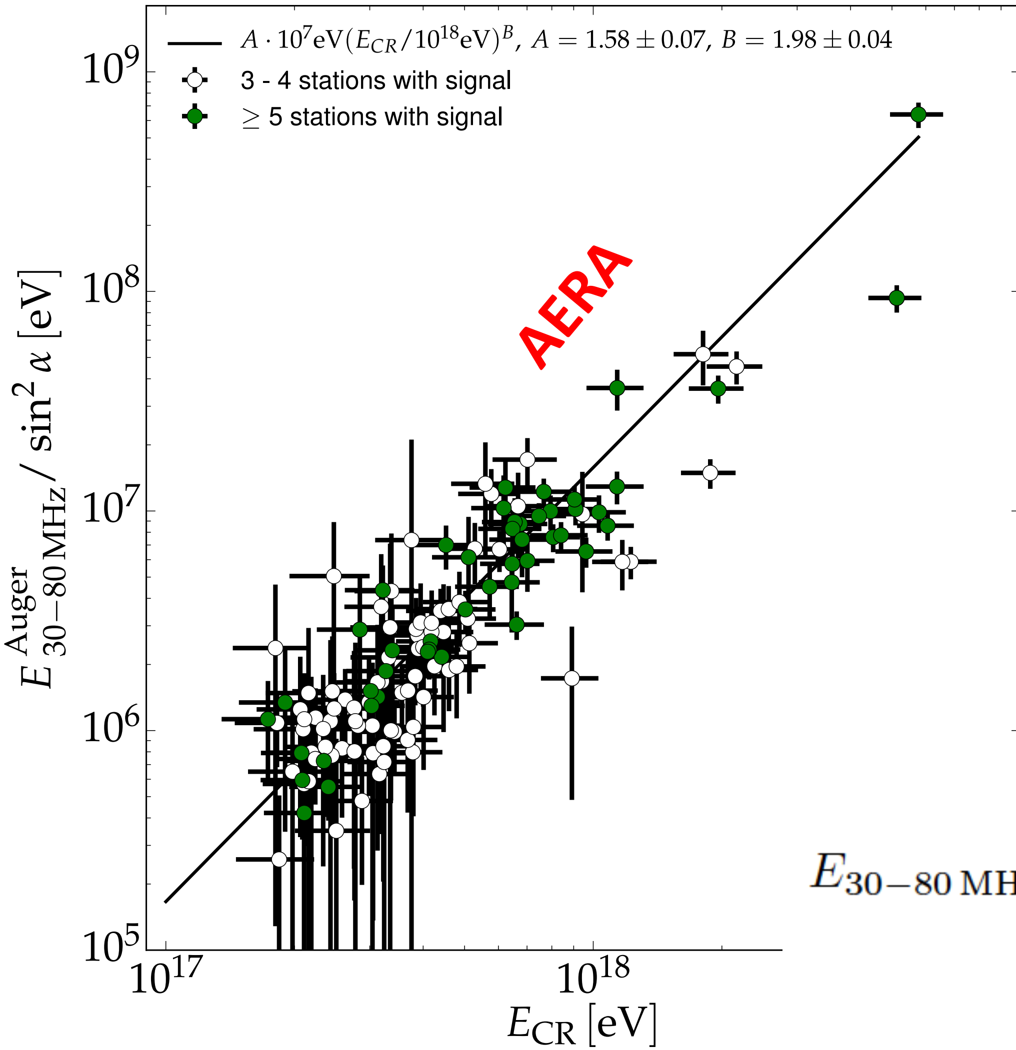


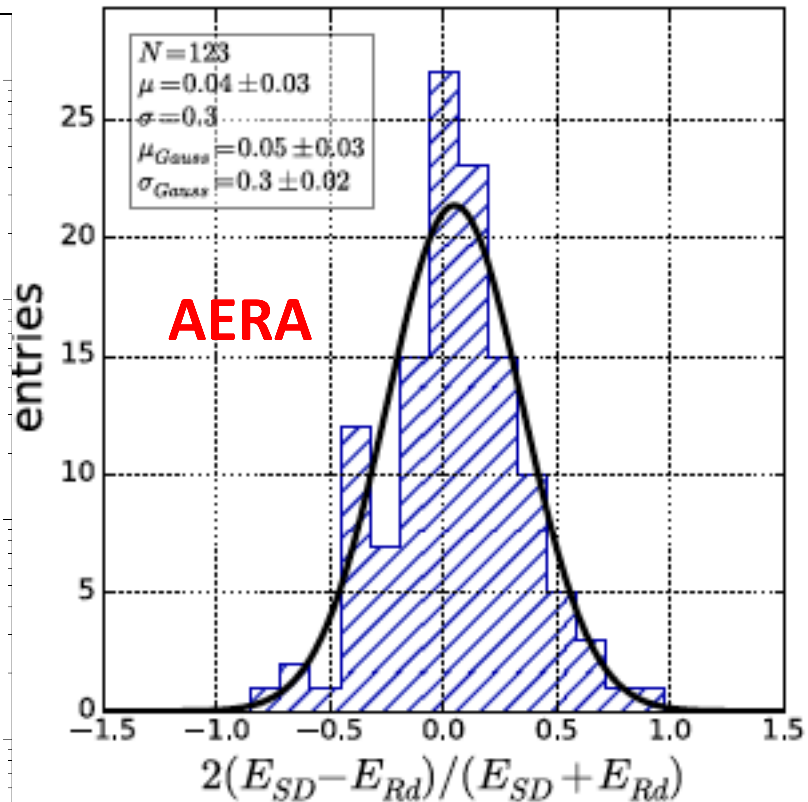

Radio Astronomy with GRAND

Fast radio bursts



# Energy resolution Radio Technique




$$E_{30-80\,\mathrm{MHz}} = (15.8 \pm 0.7\,(\mathrm{stat}) \pm 6.7\,(\mathrm{sys}))\ \mathrm{MeV} \times \left(\sin\alpha \frac{E_{\mathrm{CR}}}{10^{18}\,\mathrm{eV}} \frac{B_{\mathrm{Earth}}}{0.24\,\mathrm{G}}\right)^2.$$

# Xmax reconstruction Radio Technique