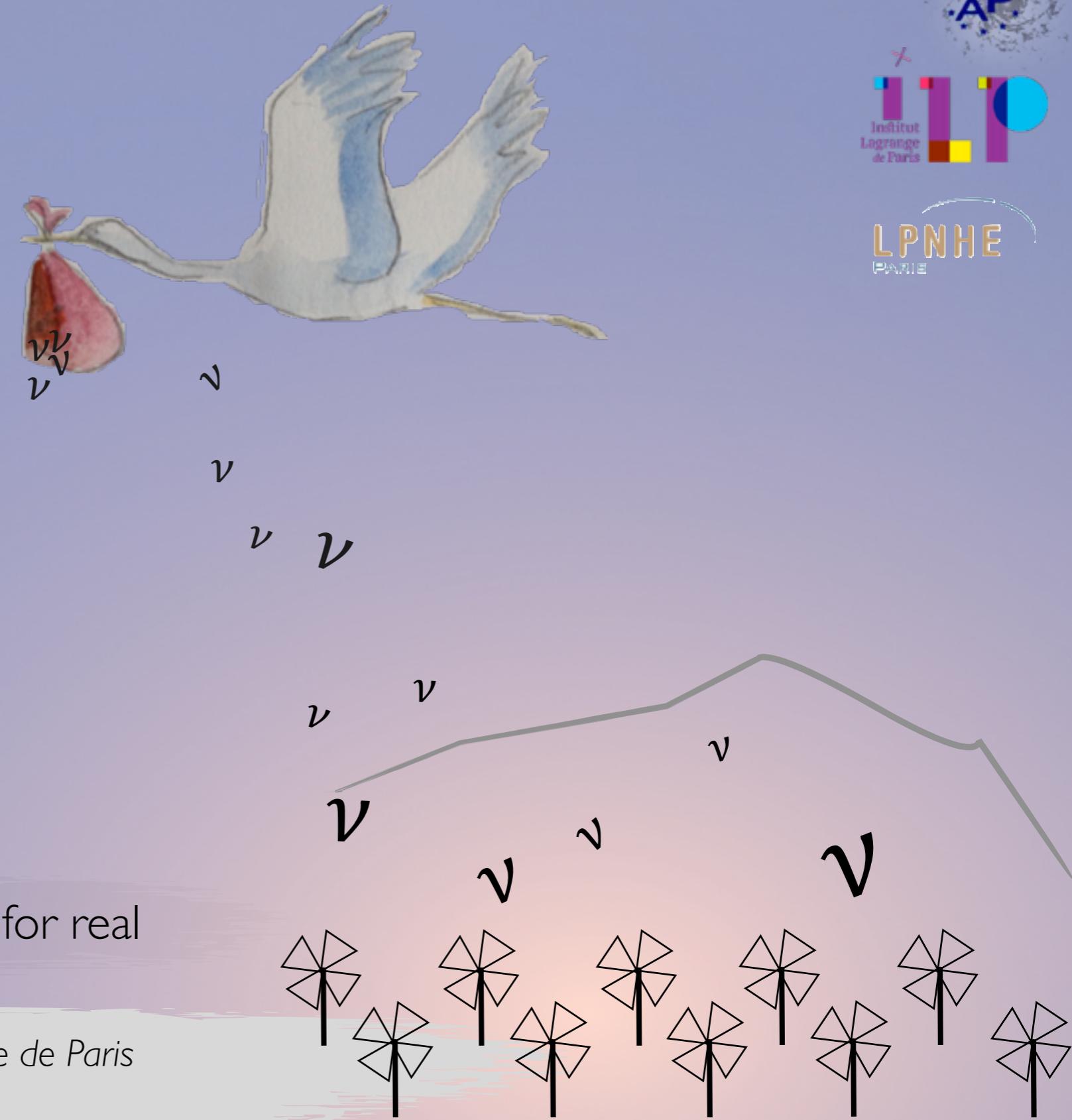


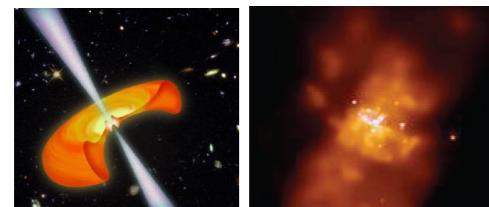
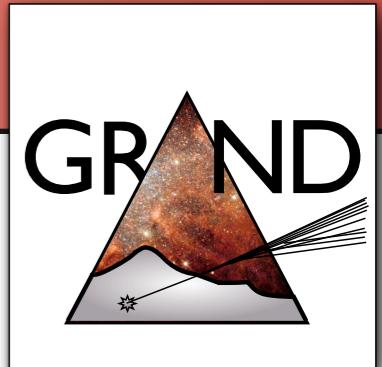


# Proposal for a **Giant** **R**adio **A**rray for **N**eutrino **D**etection

High-energy neutrino astronomy for real

Kumiko Kotera - Institut d'Astrophysique de Paris  
FCPPL Workshop 31/03/16





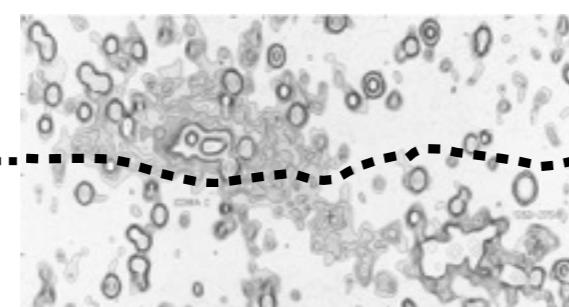
## Physics of the sources?

Most violent sources

gamma-ray bursts,  
pulsars, magnetars,  
AGN...

acceleration

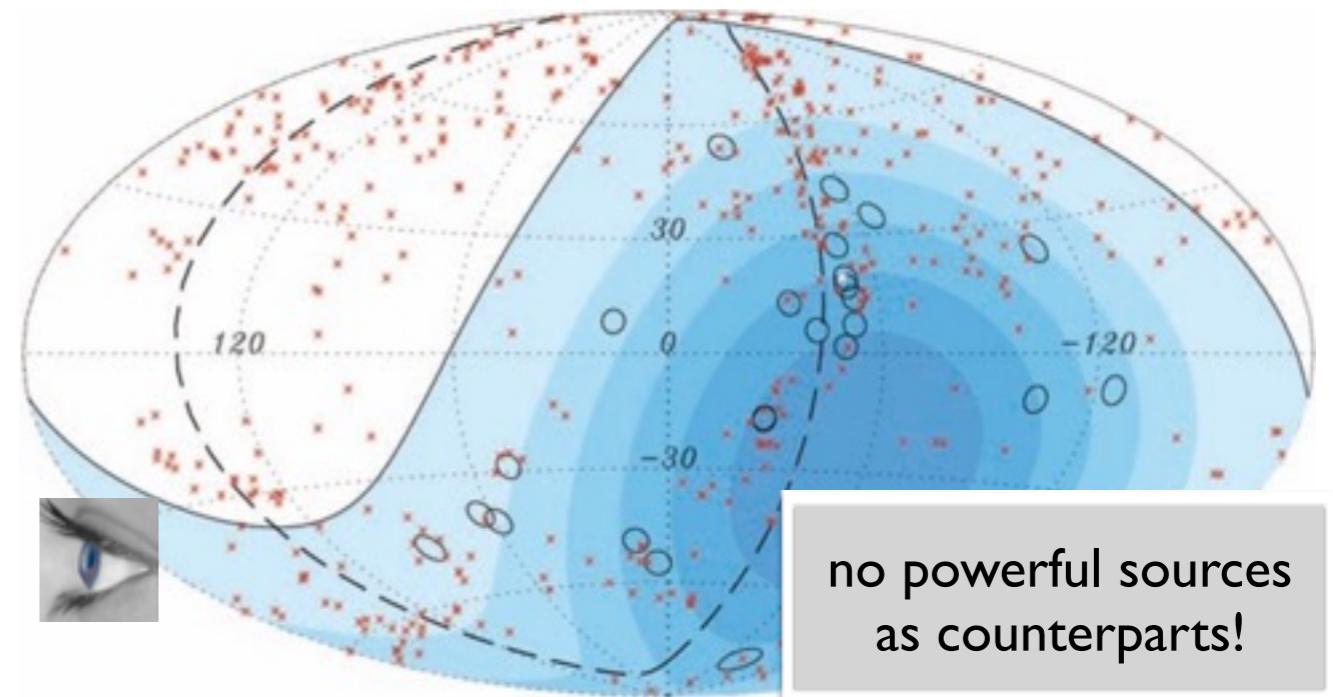
UHECR



interactions on baryonic and  
photonic backgrounds

at the source

neutrinos

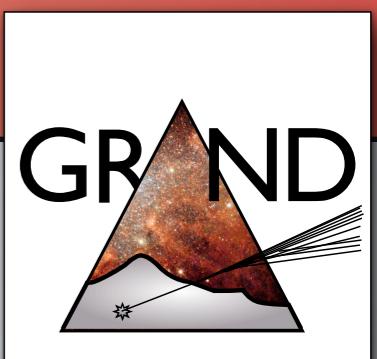


## Extragalactic magnetic fields?

deflection : spatial decorrelation  
time delay : temporal decorrelation if transient source

- ▶ neutrinos are not deflected by magnetic fields
- ▶ neutrinos allow us to see farther in the Universe
- ▶ neutrinos allow us to see deeper in objects
- ▶ clear hadronic acceleration signature

# The guaranteed cosmogenic neutrino flux

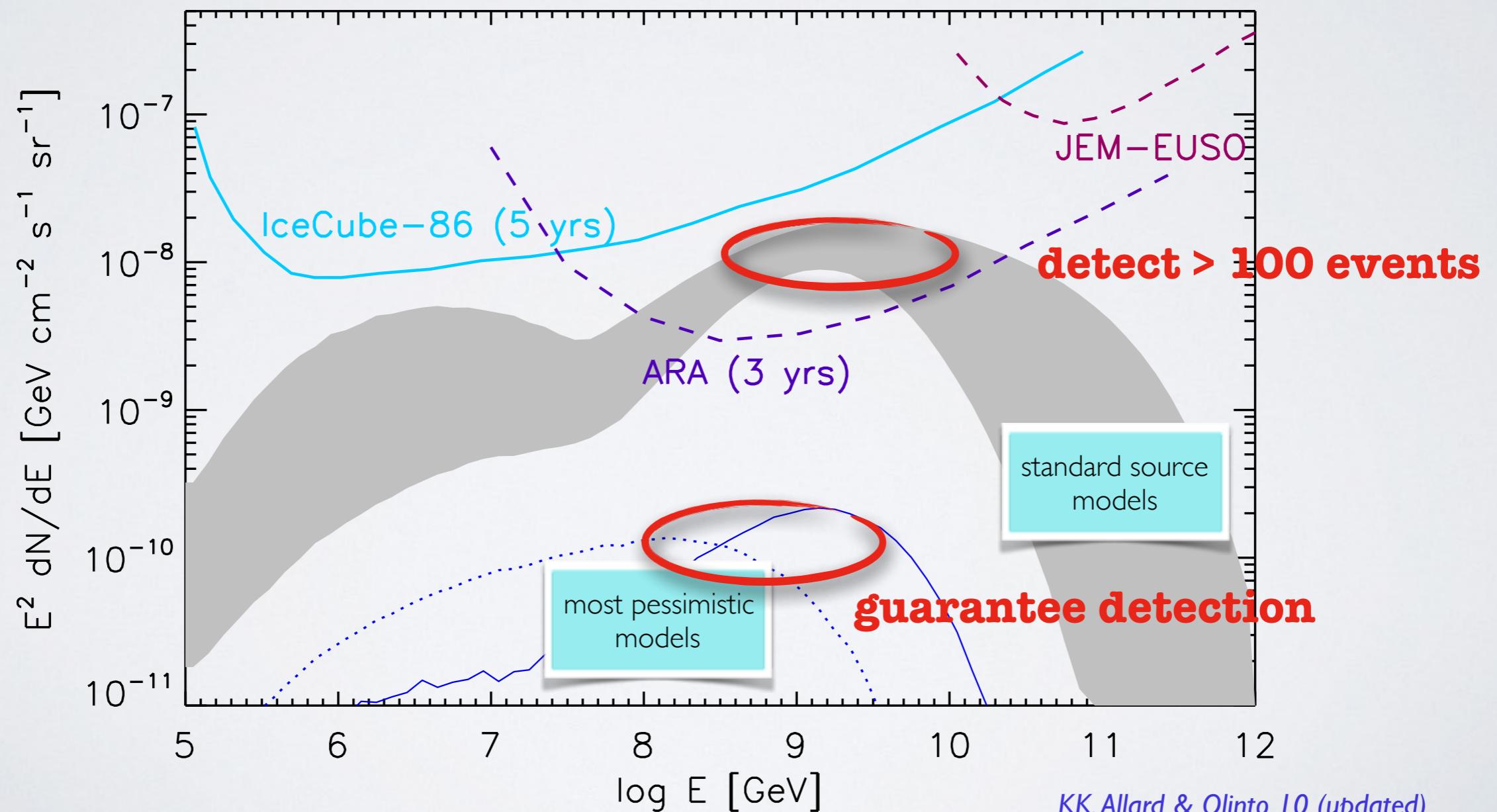


UHECRs sunt *ergo* cosmogenic neutrinos sunt

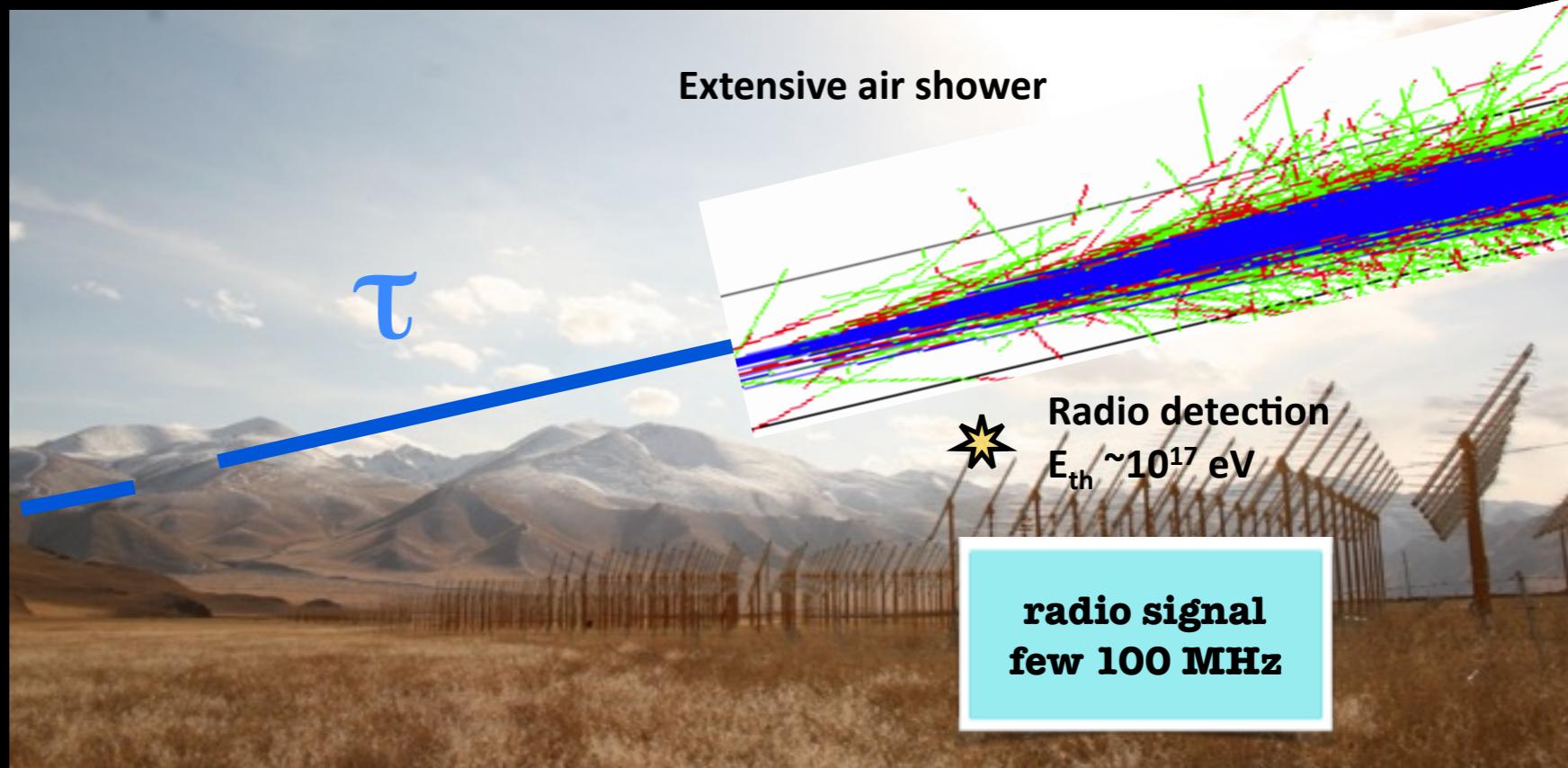
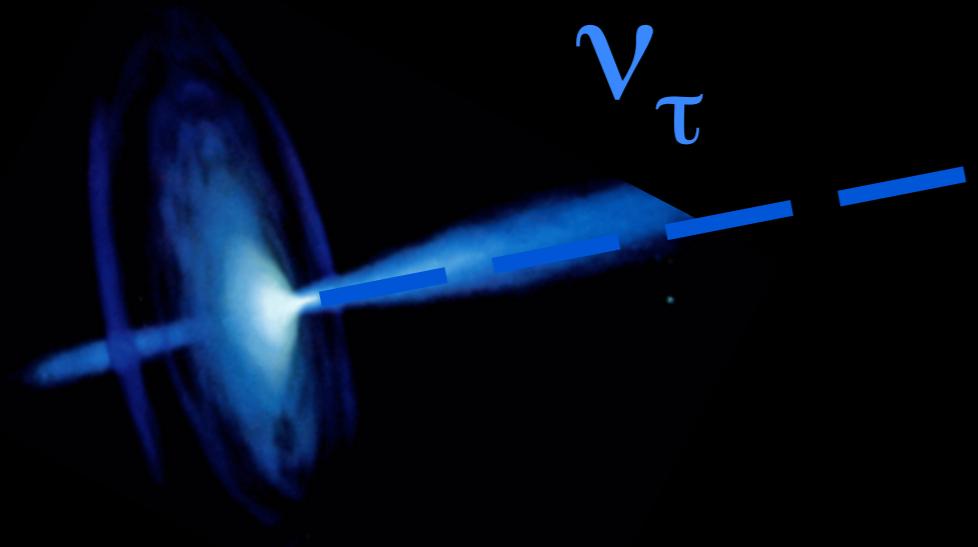
UHECRs exist hence **cosmogenic neutrinos** exist

neutrinos produced when UHECRs interact  
with the cosmic photon backgrounds

**Let's be ambitious**

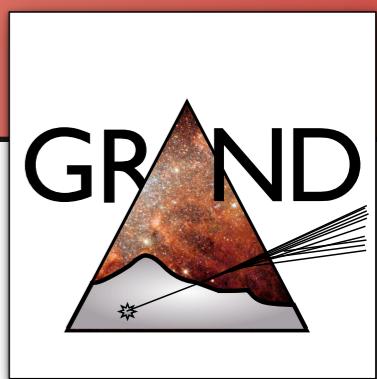


# GRAND neutrino detection principle

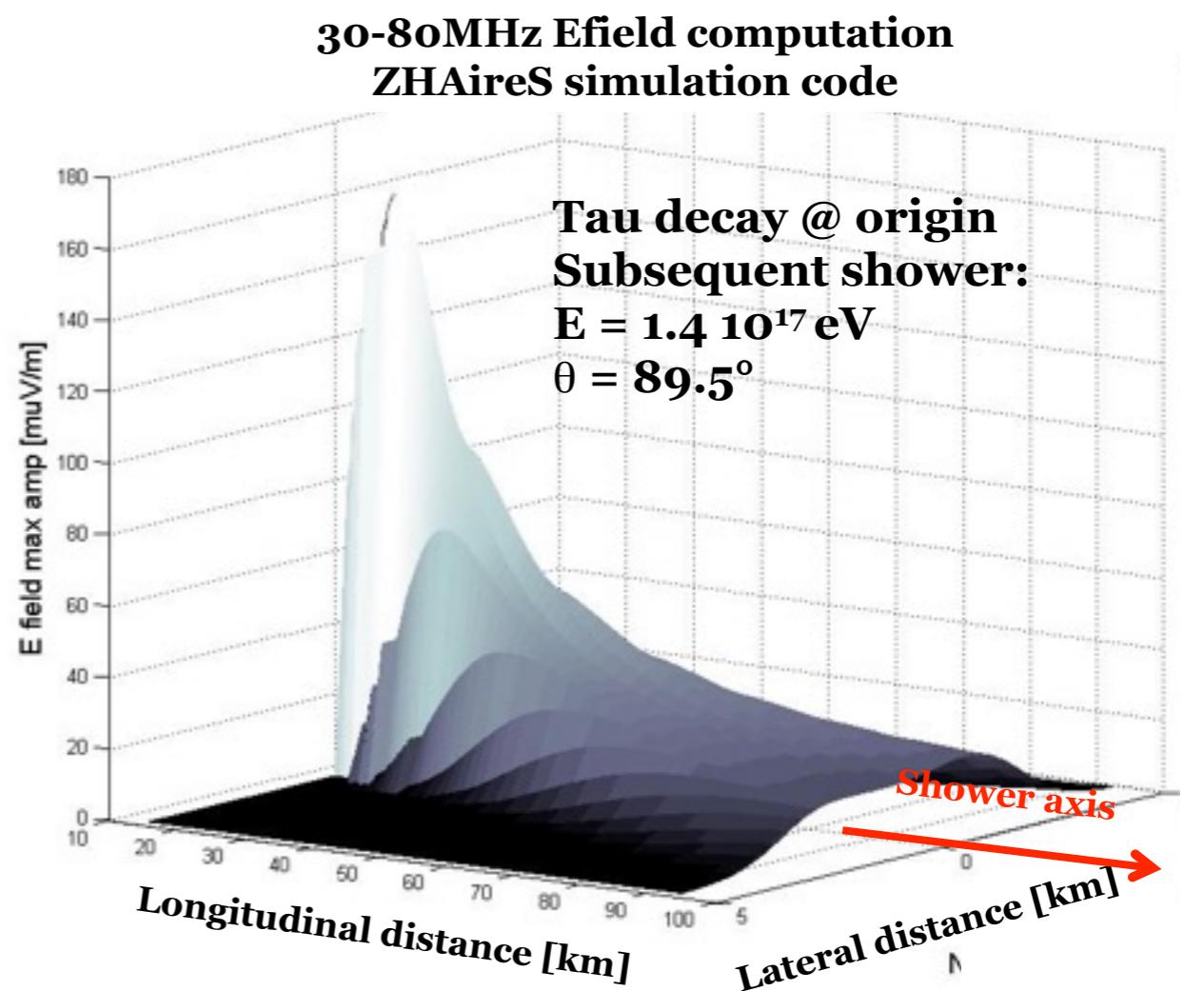


- Earth + mountains as target for neutrino interaction  
*Fargion et al. (2000), Bertou et al. (2001)*
- Radio detection of subsequent Extensive Air Shower (good at large zenith angles) on a HUGE array [  $\text{o}(100'000 \text{ km}^2)$  ]

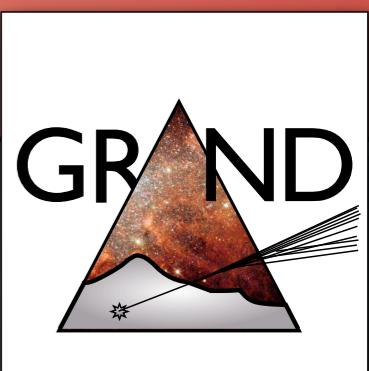
# EAS radio detection



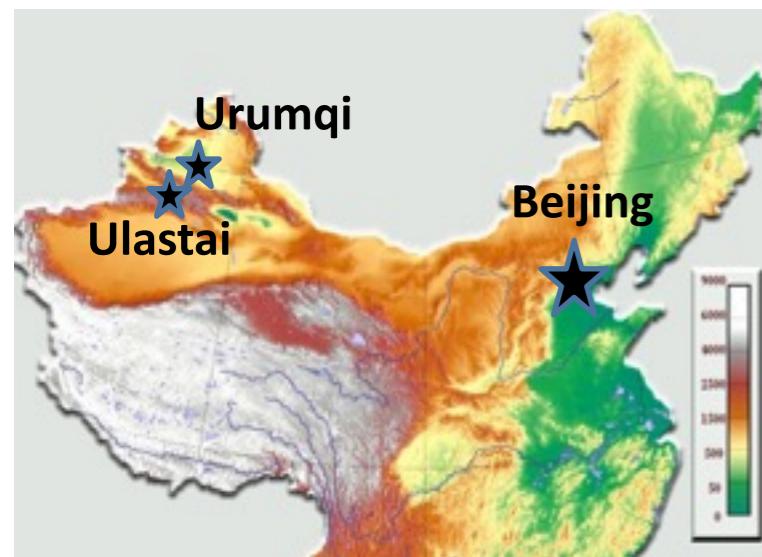
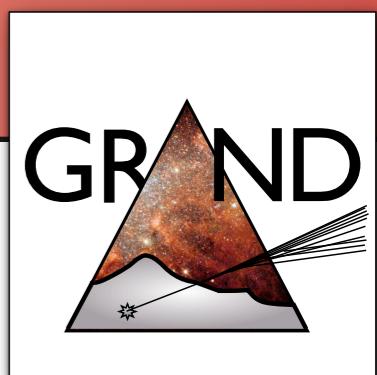
- ▶ Radio antennas are well-suited for very large arrays:
  - ▶ They are simple detectors
  - ▶ Extensive technical development
- ▶ Atmosphere transparent to radio
- ▶ Emission from horizontal EAS of  $\gtrsim 2 \cdot 10^8$  GeV still detectable 100 km away from interaction vertex
- ▶ Short waves prevent detection below 25 MHz
- ▶ Sky noise level:  $15 \mu\text{V m}^{-1}$  for 30–100 MHz



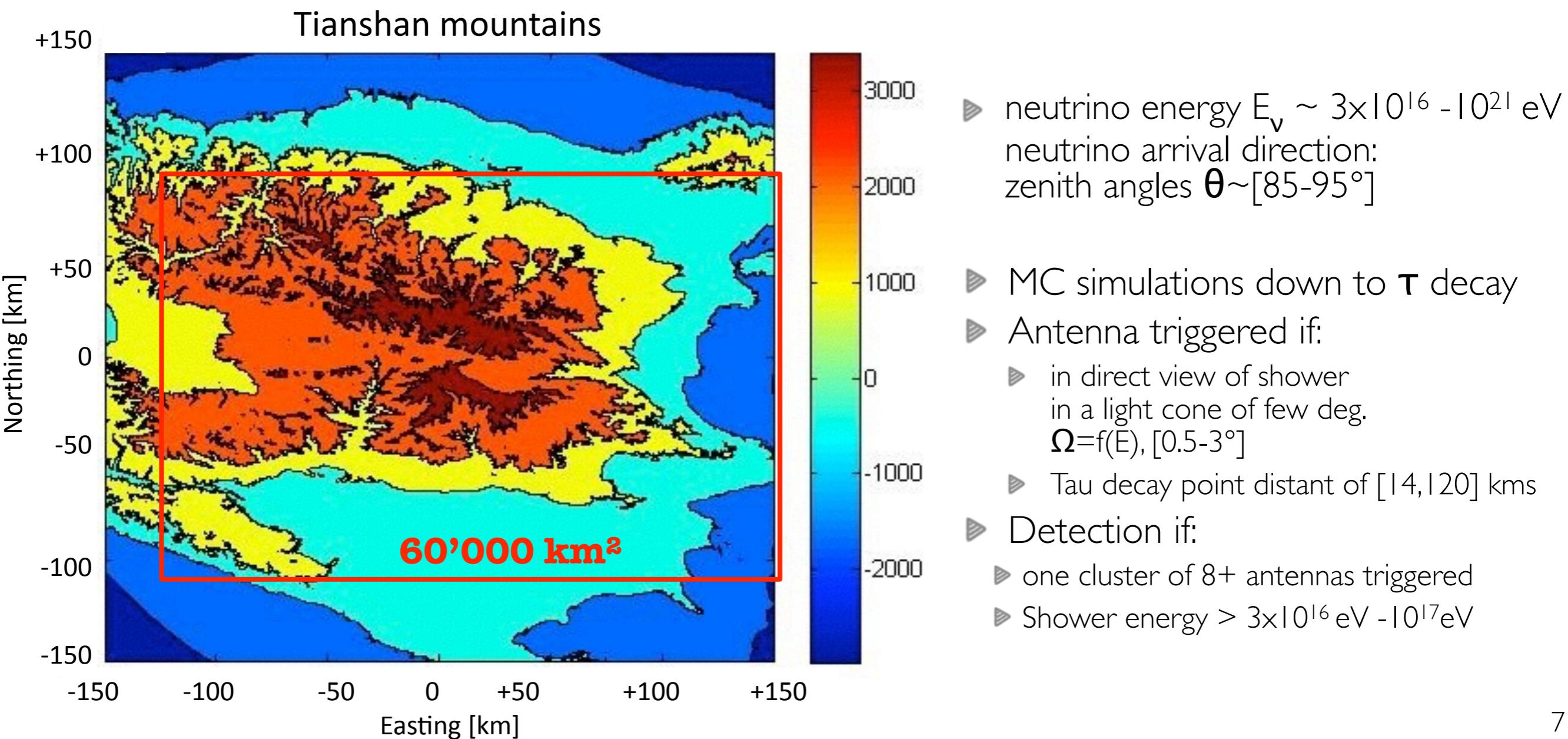
Let's not be shy... and go for a GIANT array!



# GRAND $\nu$ sensitivity preliminary study (toy setup)



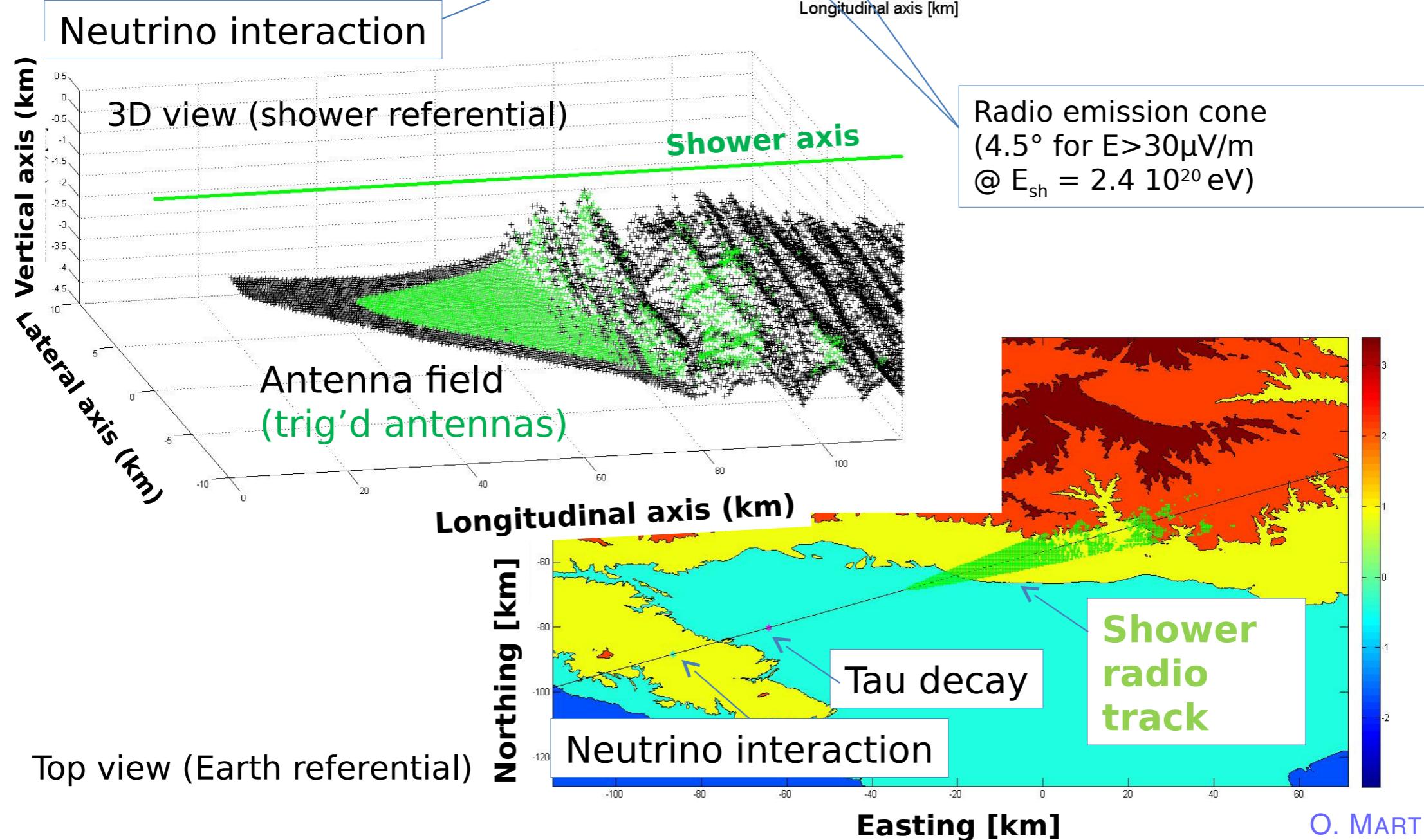
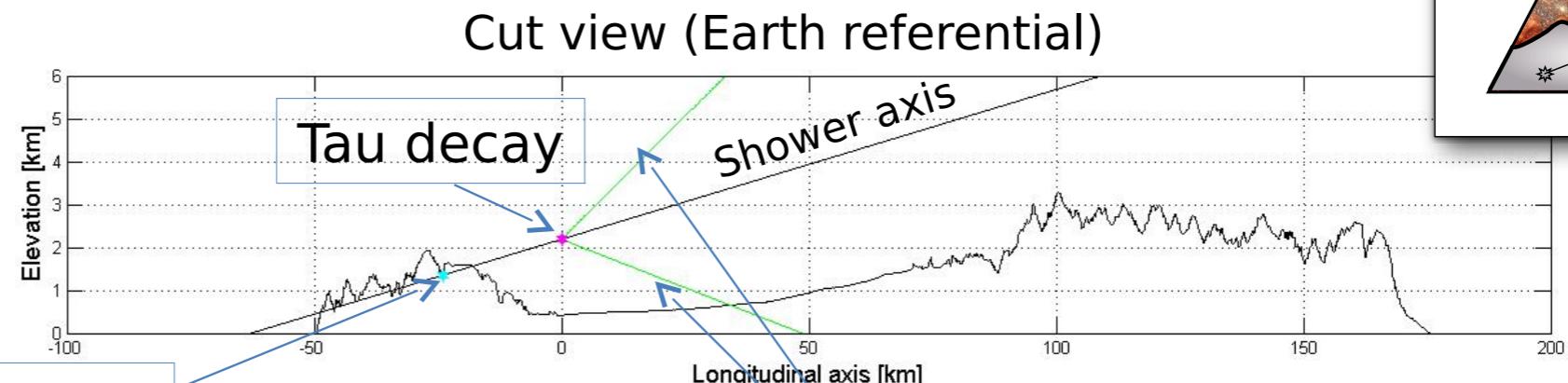
90'000 antennas  
deployed over 60'000 km<sup>2</sup>  
in Tianshan mountains (Western China)



# GRAND $\nu$ sensitivity preliminary study (toy setup)

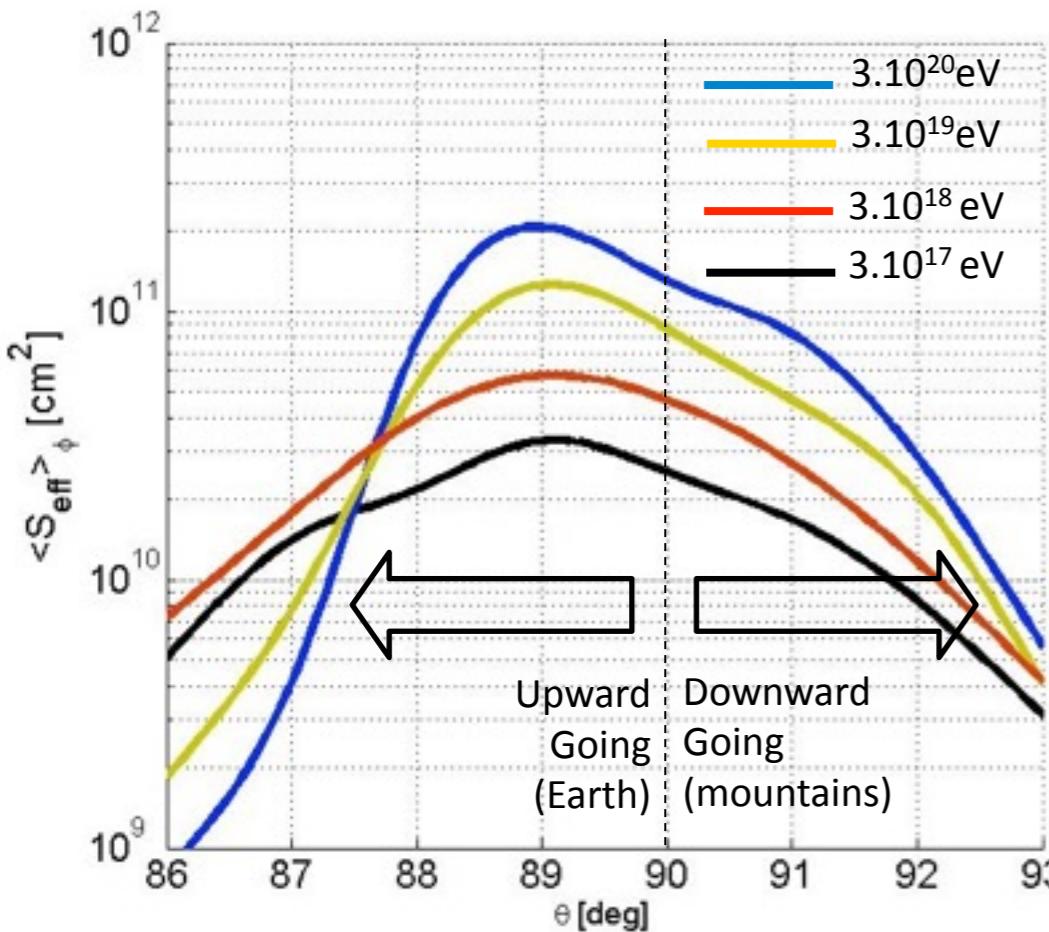
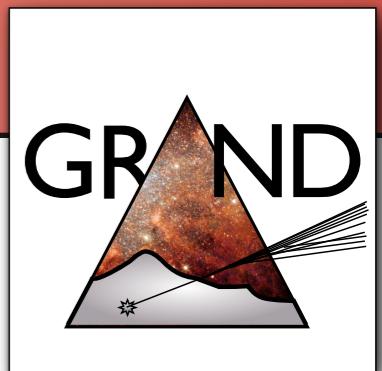


3  $10^{20}$ eV neutrino  
 2.4  $10^{20}$ eV shower  
 $\theta = 88^\circ$   
 2114 antennas  
 triggered



O. MARTINEAU

# GRAND $\nu$ sensitivity preliminary study (toy setup)

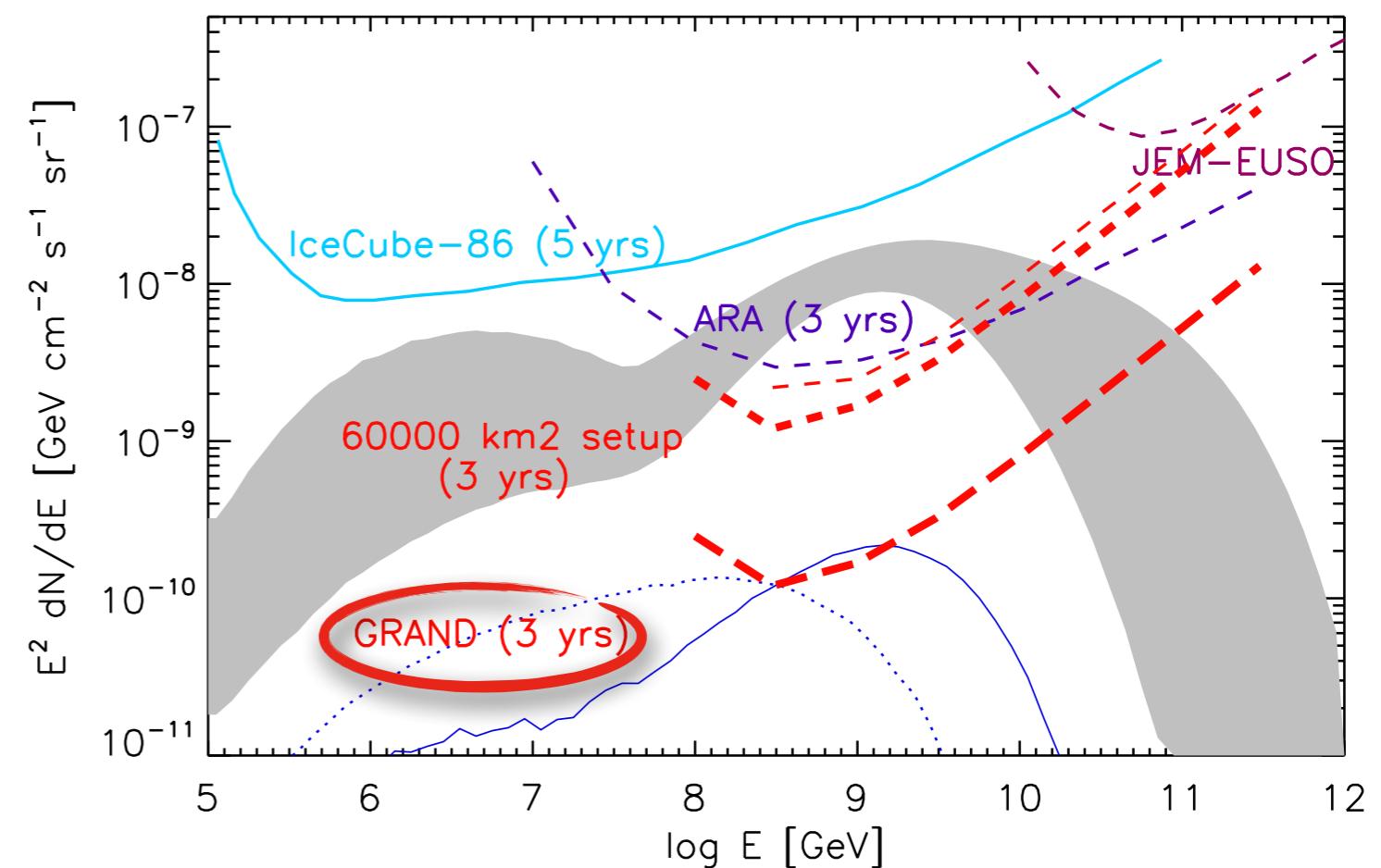


**envisioned GRAND**

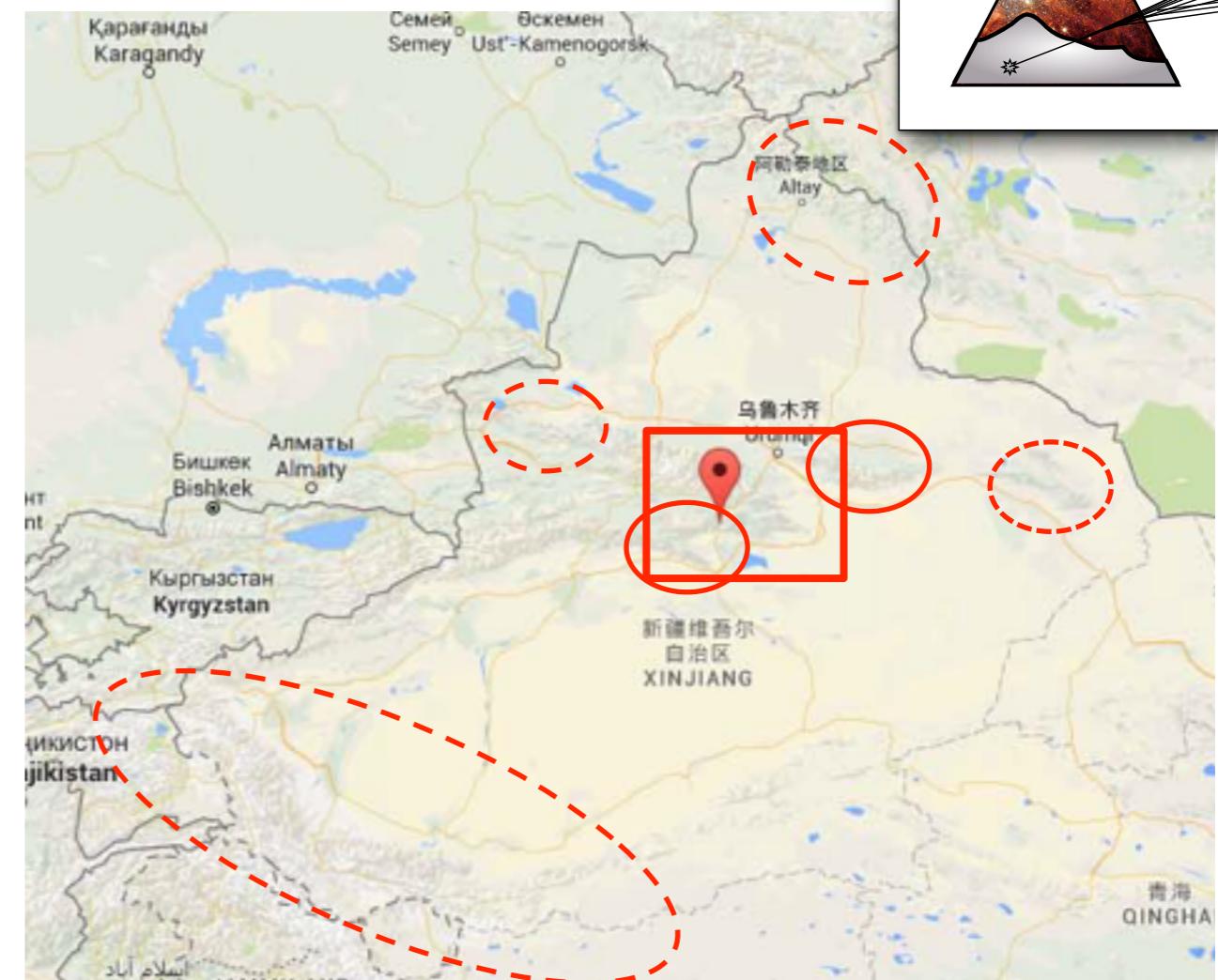
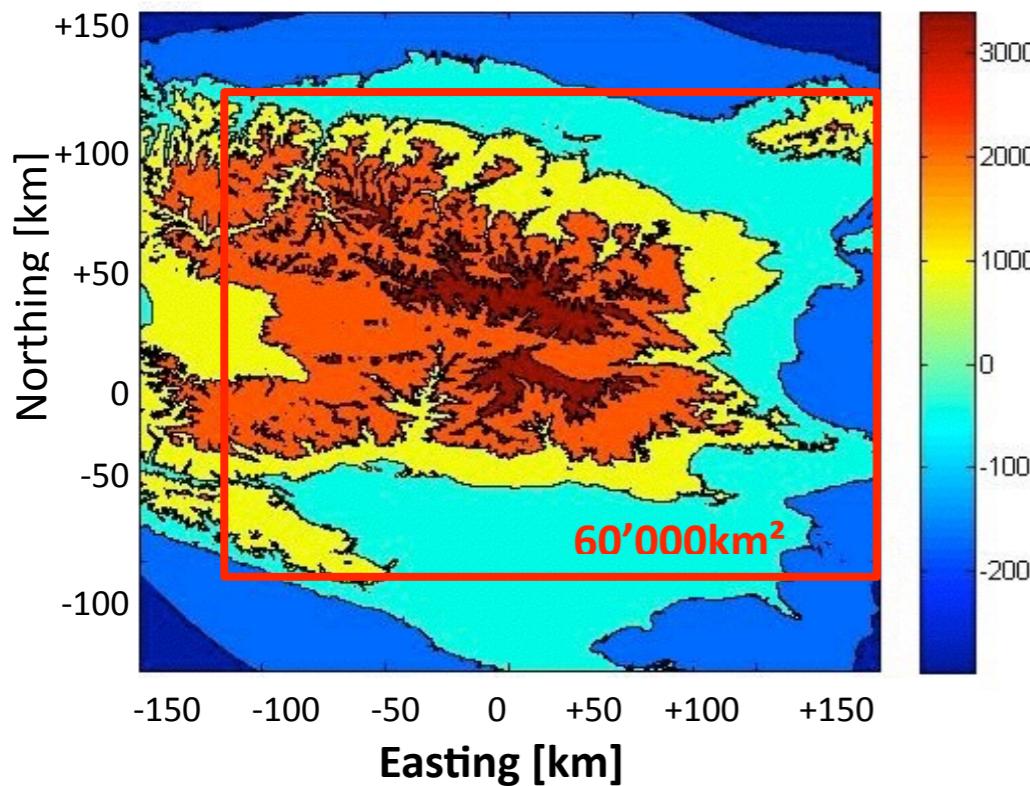
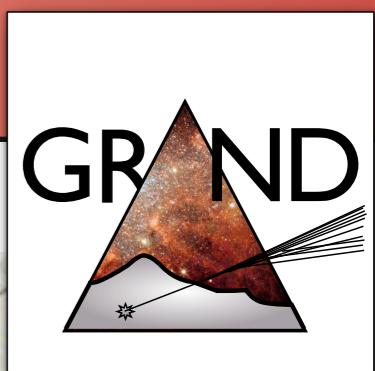
- ▶ ~ Horizontal trajectories
- ▶ Mountains are sizeable targets
- ▶ Earth becomes opaque at higher energies

## Toy setup:

factor 3 to 10 better sensitivity  
compared to ARA for  $E_\nu \sim 10^{17}$ - $10^{19}$  eV

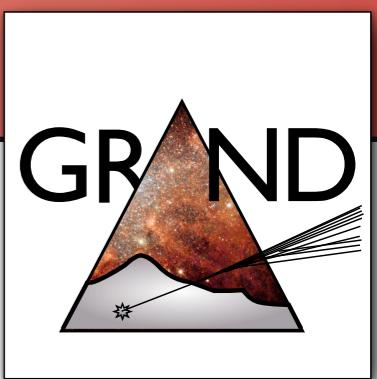


# GRAND 200'000 km<sup>2</sup> layout

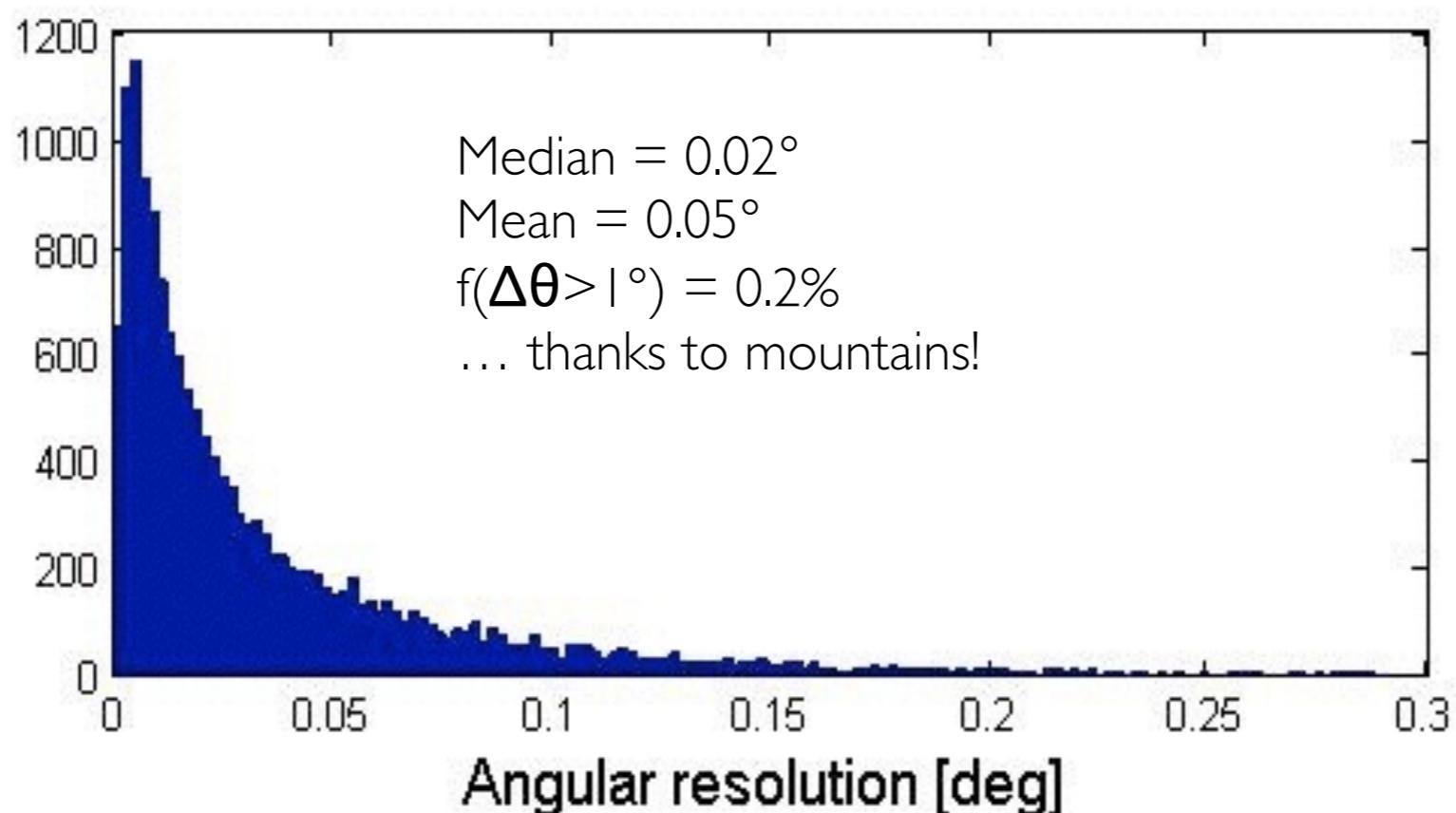


- ▶ “Hotspots” with event rates well above average
- ▶ Possible strategy: deploy sub-arrays on hotspots only [size =  $\text{o}(10'000 \text{ km}^2)$ ?]  
Total detection area  $\times 3$  ( $\sim 200'000 \text{ km}^2$ ) should result in  $\times 10$  in sensitivity
- ▶ Sub-arrays could be separated by large distances...  
and very well be on different continents!
- ▶ Strategy to be validated/refined through MC

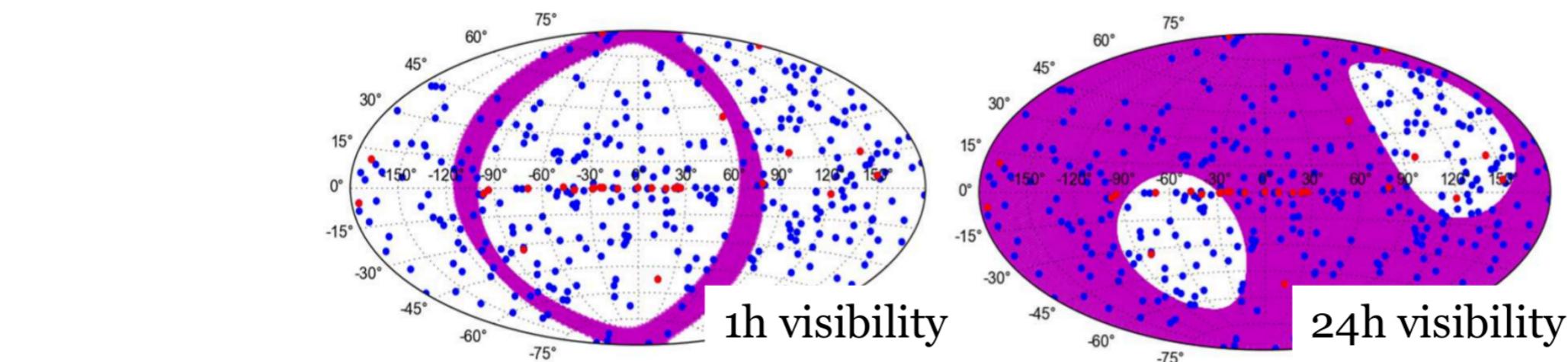
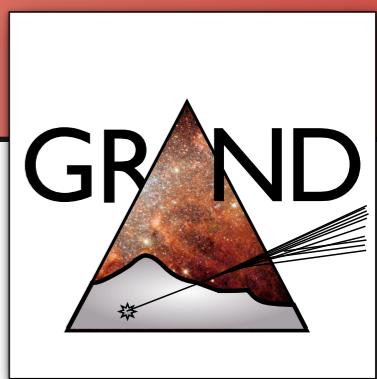
# Angular resolution



- ▶ Computed analytically for all detected showers in simulation from Arduouin et al., arxiv/1007.4359
- ▶ Assumes 3 ns trigger timing precision
- ▶ High resolution due to extended trigger zone



# Field Of View at 1 EeV



3-year average:

Figure by J.-P. Lenain

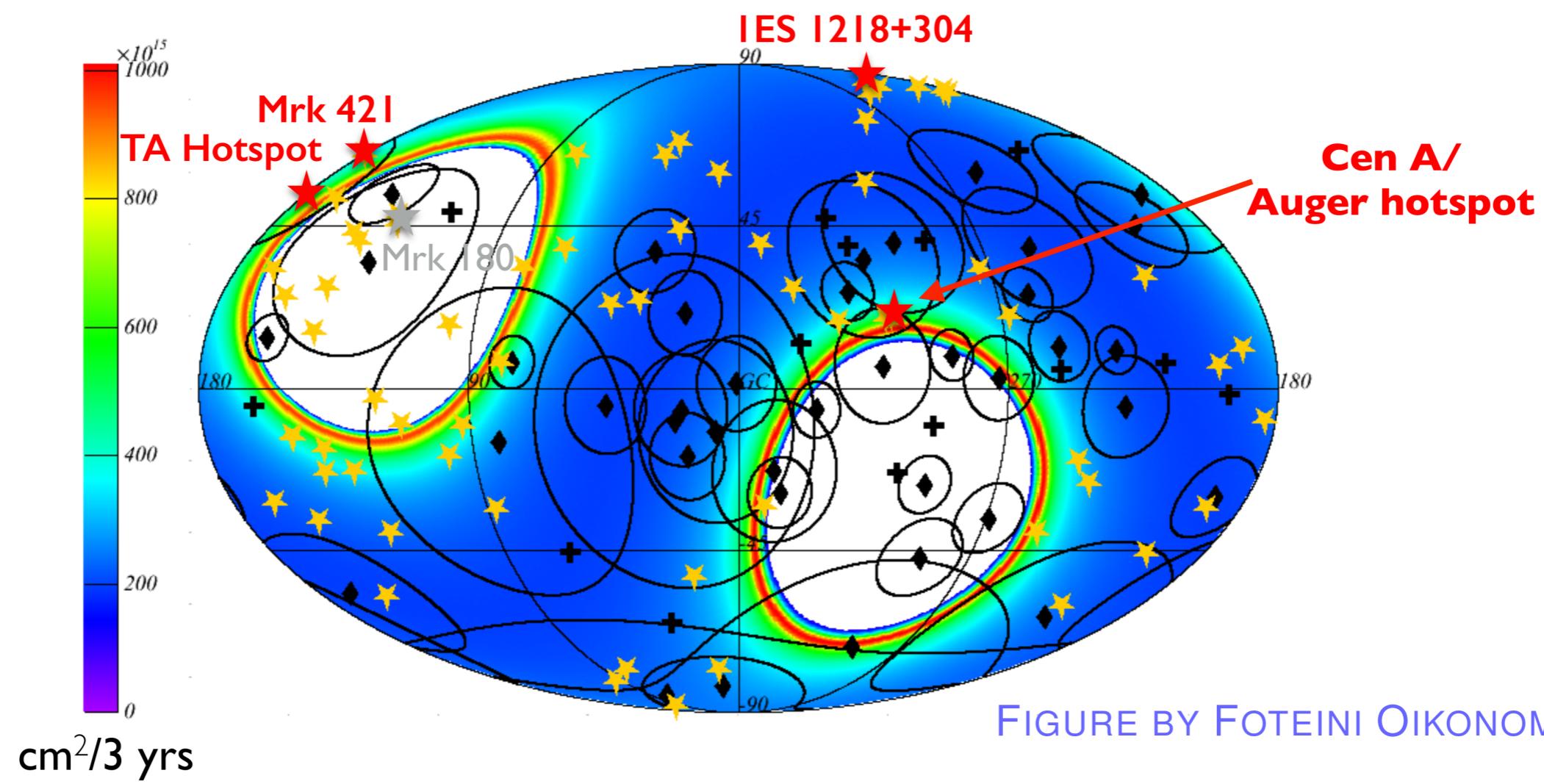
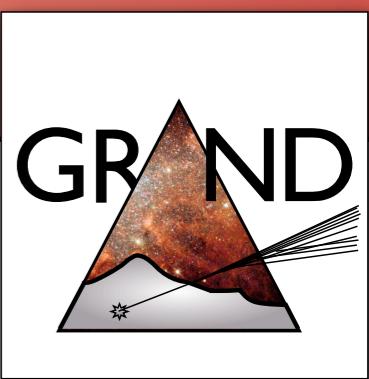
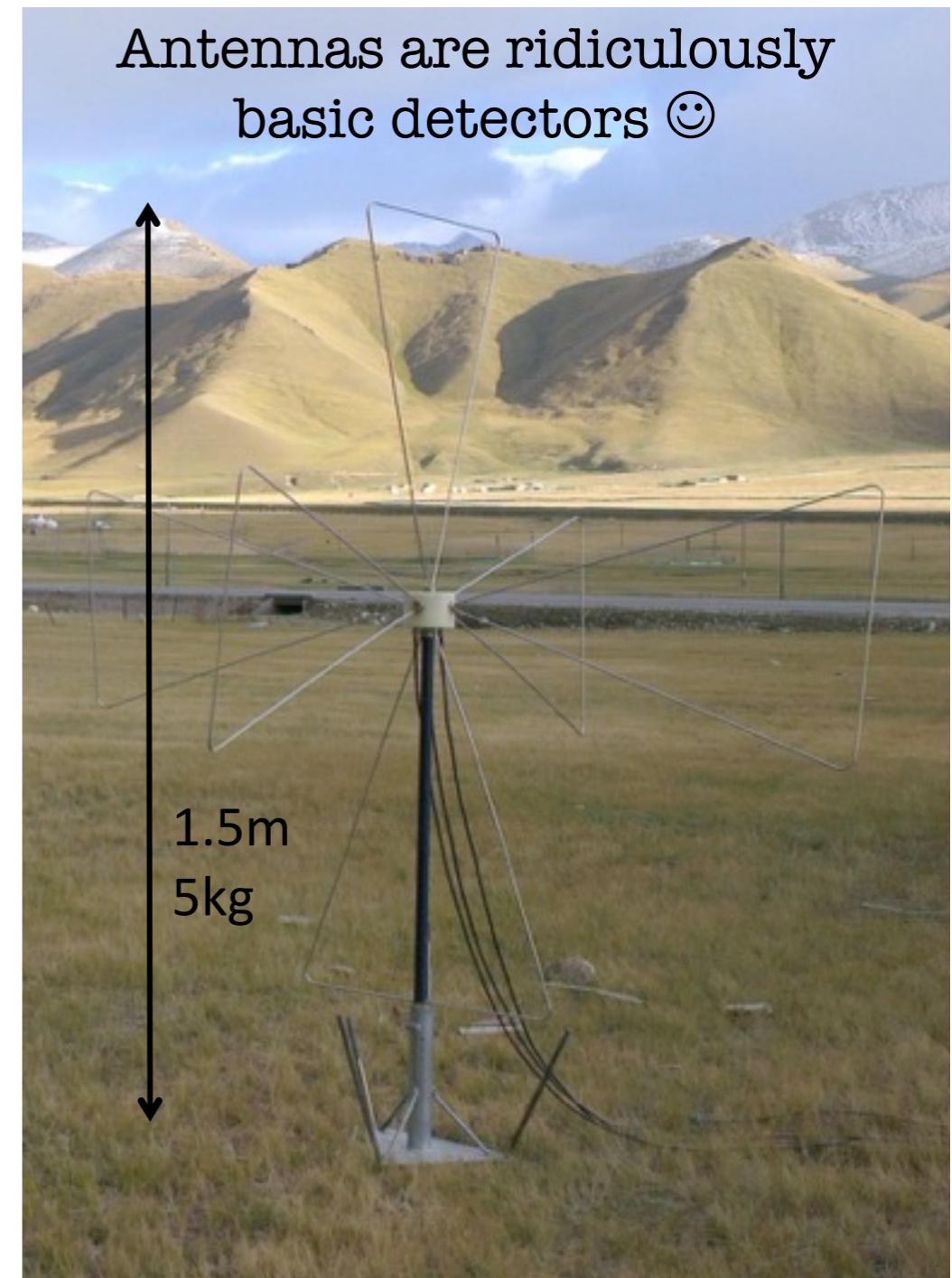


FIGURE BY FOTEINI OIKONOMOU

# Challenges: antenna deployment



- ▶ How realistic/affordable is it to deploy, run & maintain a 200'000 antenna array?
- ▶ Possible answer: keep it as basic as possible!
  - ▶ Basic (analog) trigger (T0) on transient signal
  - ▶ Record 4 words/trigger  
[Max amplitude × 3 channels + trig time by GPS]
  - ▶ Rely on commercial solutions for electronics & data transfer
- ▶ <1W & <200\$ / antenna achievable.
- ▶ ... Probably not as crazy as it first sounds!



# Challenges: background rejection

HE muons

*Chirkin (2004)*:  $3 \times 10^{-6}$  decays/yr over full array above  $10^{16}$  eV

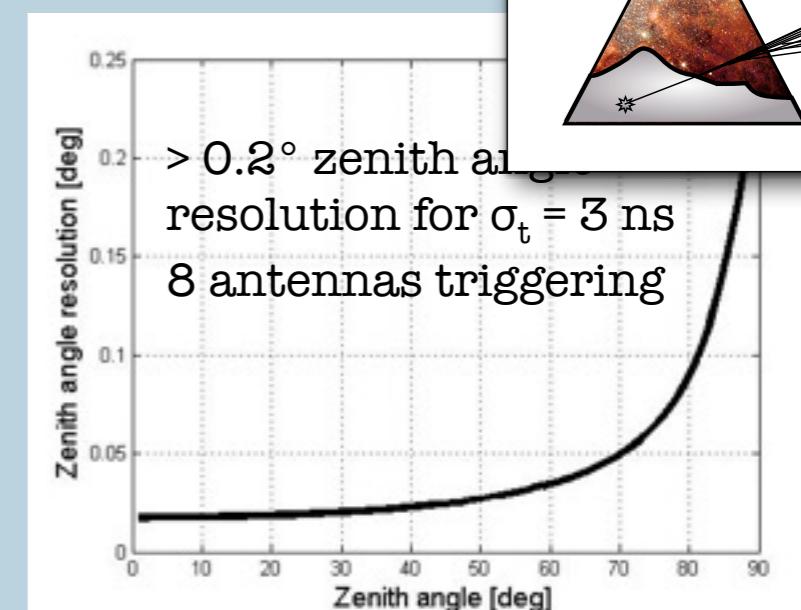
atmospheric neutrinos

negligible  $> 10^{16}$  eV



standard cosmic ray air-showers

- Cut  $1^\circ$  below horizon (mountains!)
- $1^\circ \rightarrow 5\sigma$  for  $0.2^\circ$  angular resolution  
 $\rightarrow 5 \times 10^{-7}$  suppression factor
- Affects marginally detection efficiency:  
 $< 10\%$



terrestrial background

from the TREND experiment  
(2009-2014, *Martineau et al. 2010*):  
 $\sim 3 \times 10^8$  events/year (?)

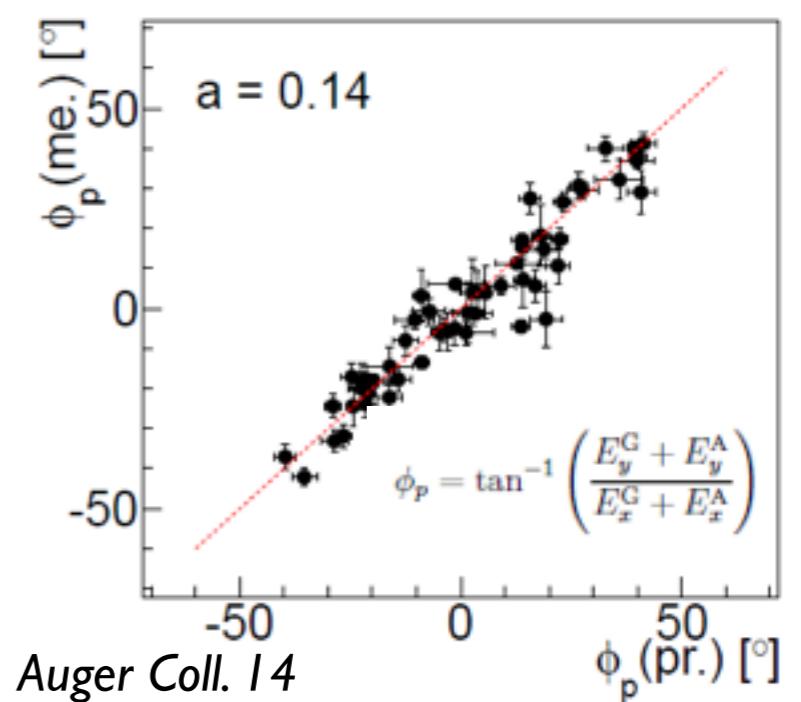
**Terrestrial background  
 $3 \times 10^8$  events/year (?)**

- Neutrino signal:  
0-100 events/year



Rejection factor:  
 $R \sim 10^9$

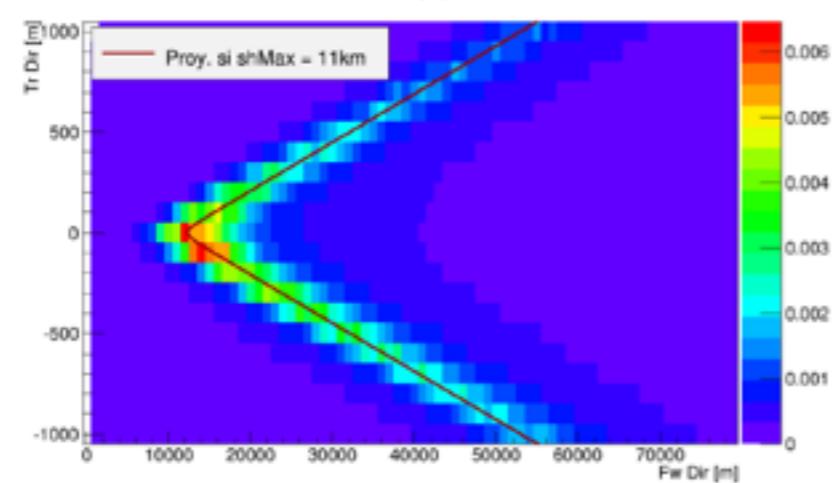
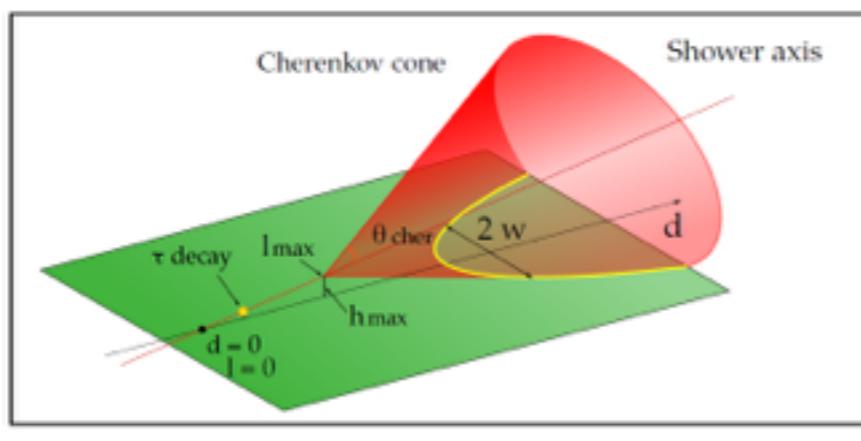
Discriminating parameters  
Trigger pattern at ground? Polarisation?



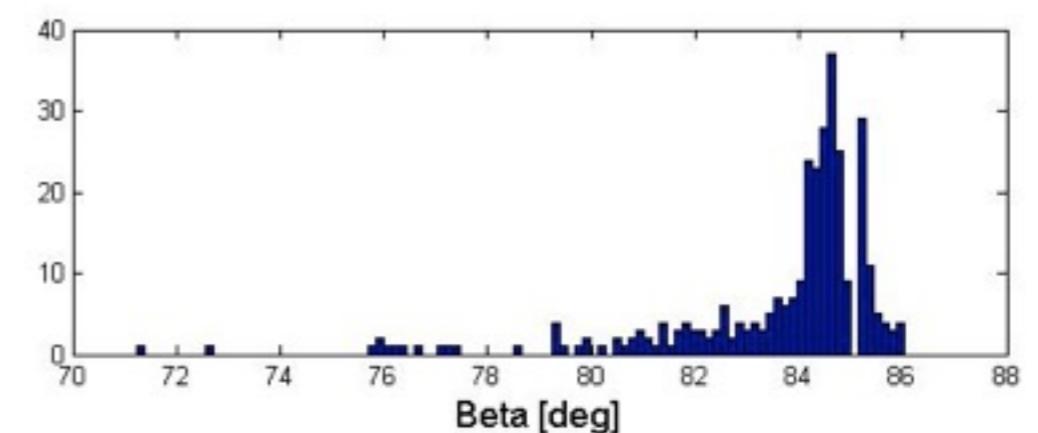
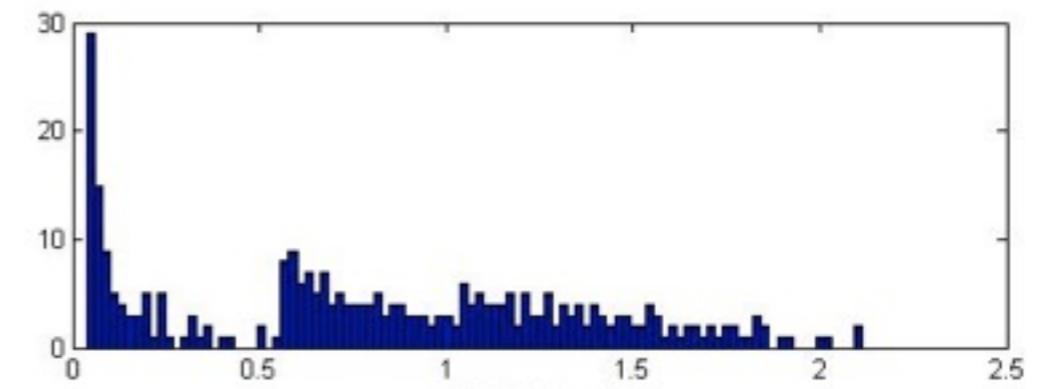
# Challenges: background rejection



- Extensive Air Shower signatures
  - Trigger pattern on ground  
(beamed emission with flat wavefront & lateral drop)
  - Cherenkov cone
  - Polarization: perpendicular to  $B_{\text{geo}}$  & direction of shower propagation

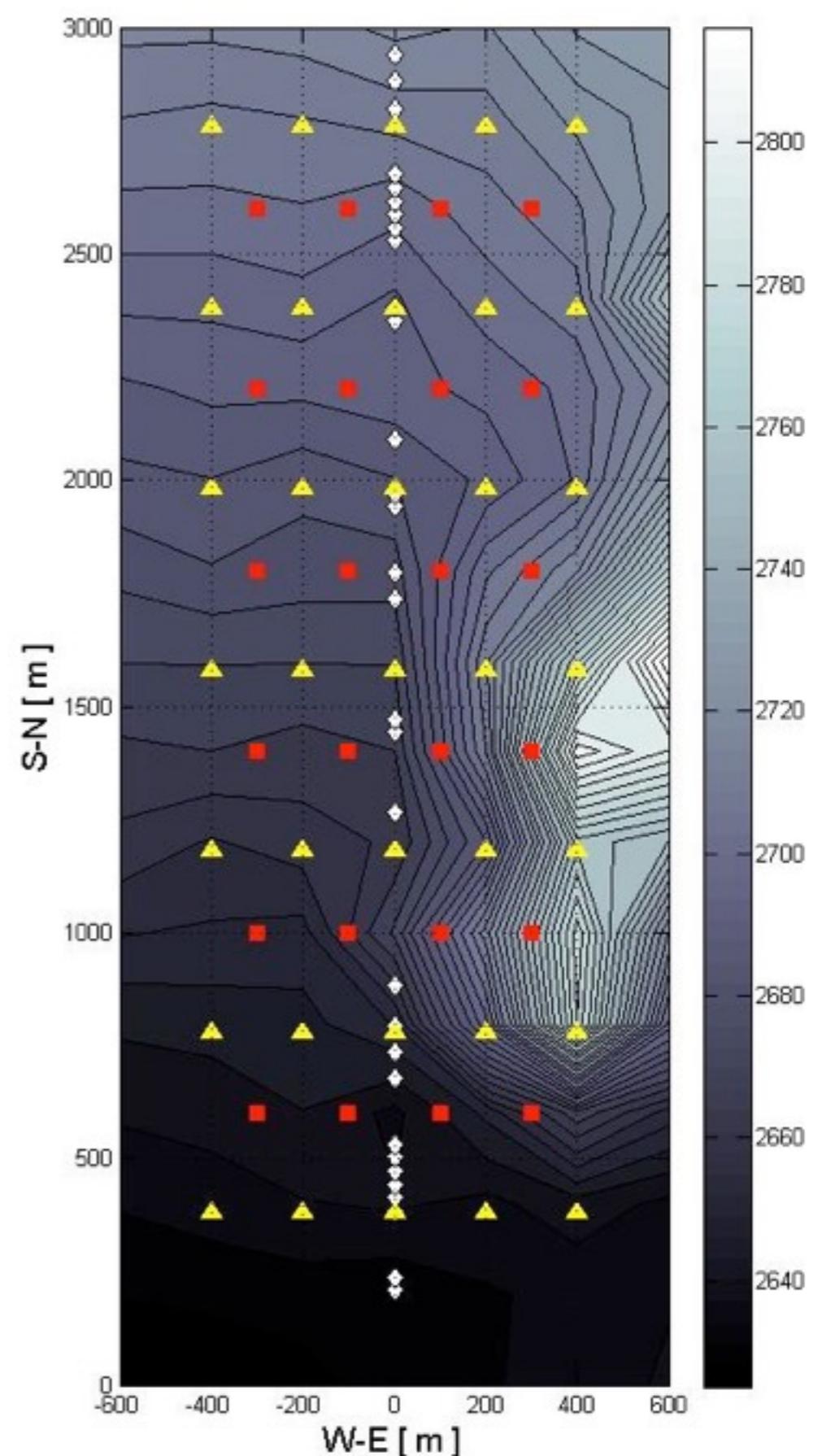


**Polarization angles on all triggered antennas**

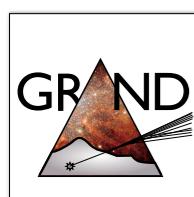
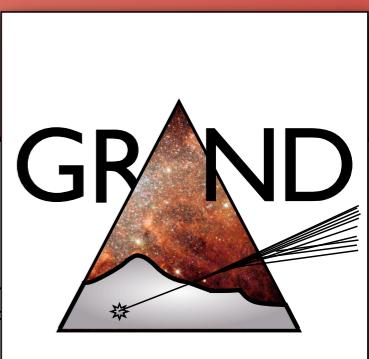


# GRANDproto (talk by Olivier Martineau)

- ▶ Hybrid setup with 35 3-polar antennas + 24 scintillators
- ▶ Target: (standard) air showers coming from North with  $40^\circ < \theta < 70^\circ$
- ▶ Principle: select radio candidates from polar info, use scintillator array as a cross-check  
--> qualitative determination of rejection factor
- ▶ Deployment on-going, to be completed before June 2016
- ▶ Proposal to perform similar tests @ AUGER-AERA

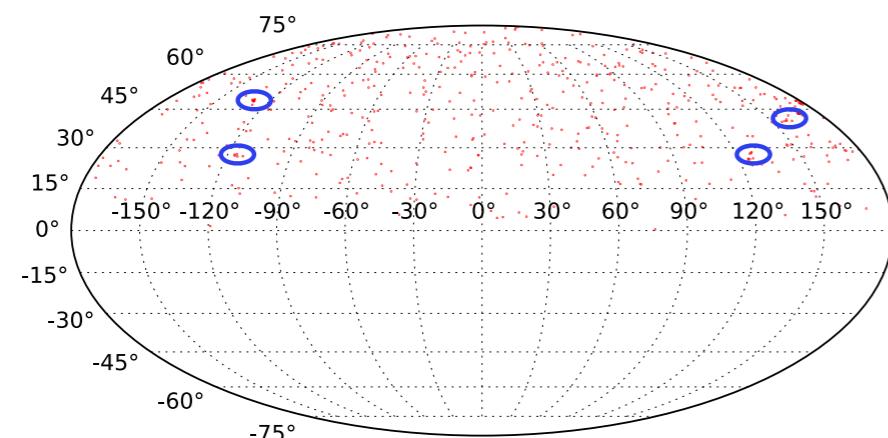


# Neutrino astronomy and other Science Cases with GRAND



## Pinpointing Neutrino Sources

by K. Fang



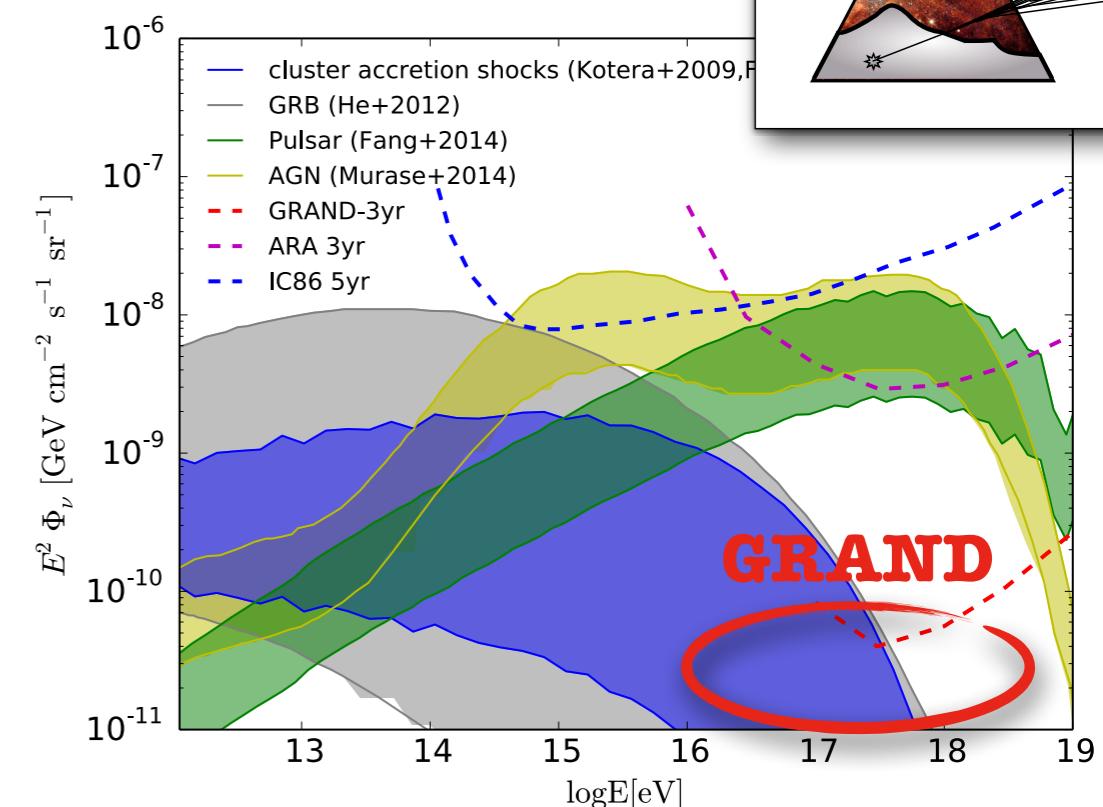
Detecting A Source On Top of the Background

$$\bar{N} = 4.8 \times 10^{-3} \left( \frac{N_{\text{tot}}}{1000} \right) \left( \frac{(0.1^\circ)^2}{5\% \times 4\pi} \right)$$

With 0.1 deg resolution, a doublet has a p-value 1e-5 to be from different sources => 4.2 sigma detection

✓ Doublet events → Pinpointing the source!

✓ With  $> 10^{-6} \text{ Mpc}^{-3}$  source number density, doublets are guaranteed with ~1000 events



expected neutrino fluxes directly from sources

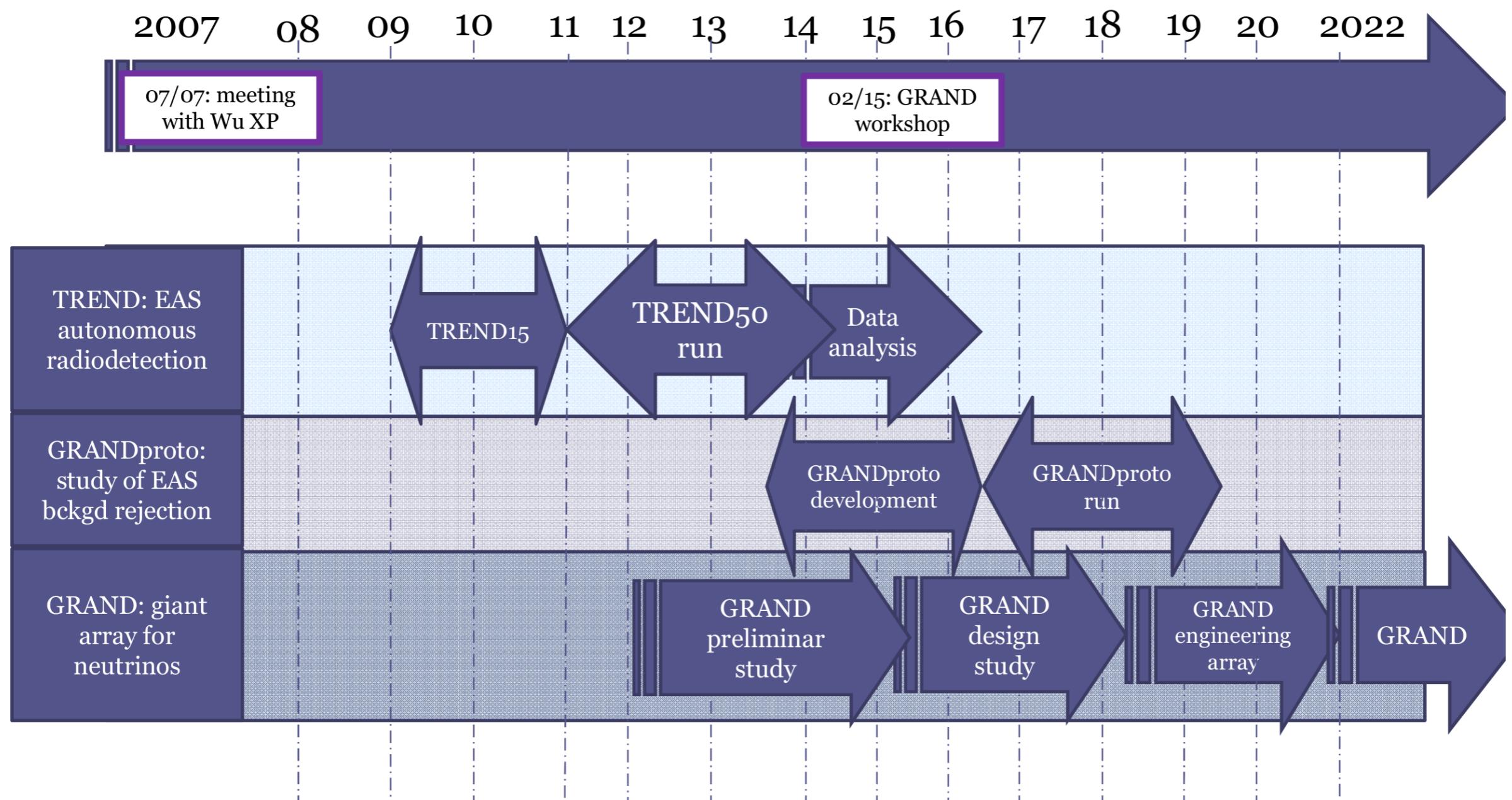
by K. Fang

23

- ▶ ν sensitivity + angular resolution <0.1° would launch neutrino astronomy @ VHE
- ▶ Huge effective area + performances for EAS reconstruction: great tool for UHECR physics above  $10^{19} \text{ eV}$
- ▶ Epoch of reionization (?)
- ▶ Fast Radio Bursts (?)

Science case to be defined in more details!  
Work in progress.

# Tentative Timeline



# The GRAND team



## France:

- ▶ Olivier Martineau-Huynh (LPNHE, CNRS-IN2P3, Universités Paris VI & VII)
- ▶ Kumiko Kotera (Institut d'Astrophysique de Paris)
- ▶ Didier Charrier (SUBATECH, CNRS-IN2P3, Université de Nantes)
- ▶ Valentin Niess (Clermont Université, Université Blaise Pascal, CNRS-IN2P3)
- ▶ Nicolas Renault-Tinacci (Institut d'Astrophysique de Paris)

## China:

- ▶ Zhaoyang Feng (Key Laboratory of Particle Astrophysics, Institute of High Energy Physics)
- ▶ Quanbu Gou (Key Laboratory of Particle Astrophysics, Institute of High Energy Physics)
- ▶ Junhua Gu (National Astronomical Observatory)
- ▶ Hongbo Hu (Key Laboratory of Particle Astrophysics, Institute of High Energy Physics)
- ▶ Zhen Wang (Key Laboratory of Particle Astrophysics, Institute of High Energy Physics)
- ▶ Xiangping Wu (National Astronomical Observatory)
- ▶ Jianli Zhang (National Astronomical Observatory)
- ▶ Yi Zhang (Key Laboratory of Particle Astrophysics, Institute of High Energy Physics)

## Netherlands, Belgium, Sweden:

- ▶ Charles Timmermans (Nikhef/Radboud University, The Netherlands)
- ▶ Krijn D. de Vries (Vrije Universiteit Brussel, Belgium)
- ▶ Chad Finley (Oskar Klein Centre and Dept. of Physics, Stockholm University, Sweden)
- ▶ Sijbrand De Jong (Nikhef/Radboud University, The Netherlands)

## USA:

- ▶ Mauricio Bustamante (Center for Cosmology and AstroParticle Physics, The Ohio State University)
- ▶ Ke Fang (University of Maryland)
- ▶ Jordan Hanson (Center for Cosmology and AstroParticle Physics, The Ohio State University)
- ▶ Kohta Murase (Pennsylvania State University)
- ▶ Foteini Oikonomou (Pennsylvania State University)

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