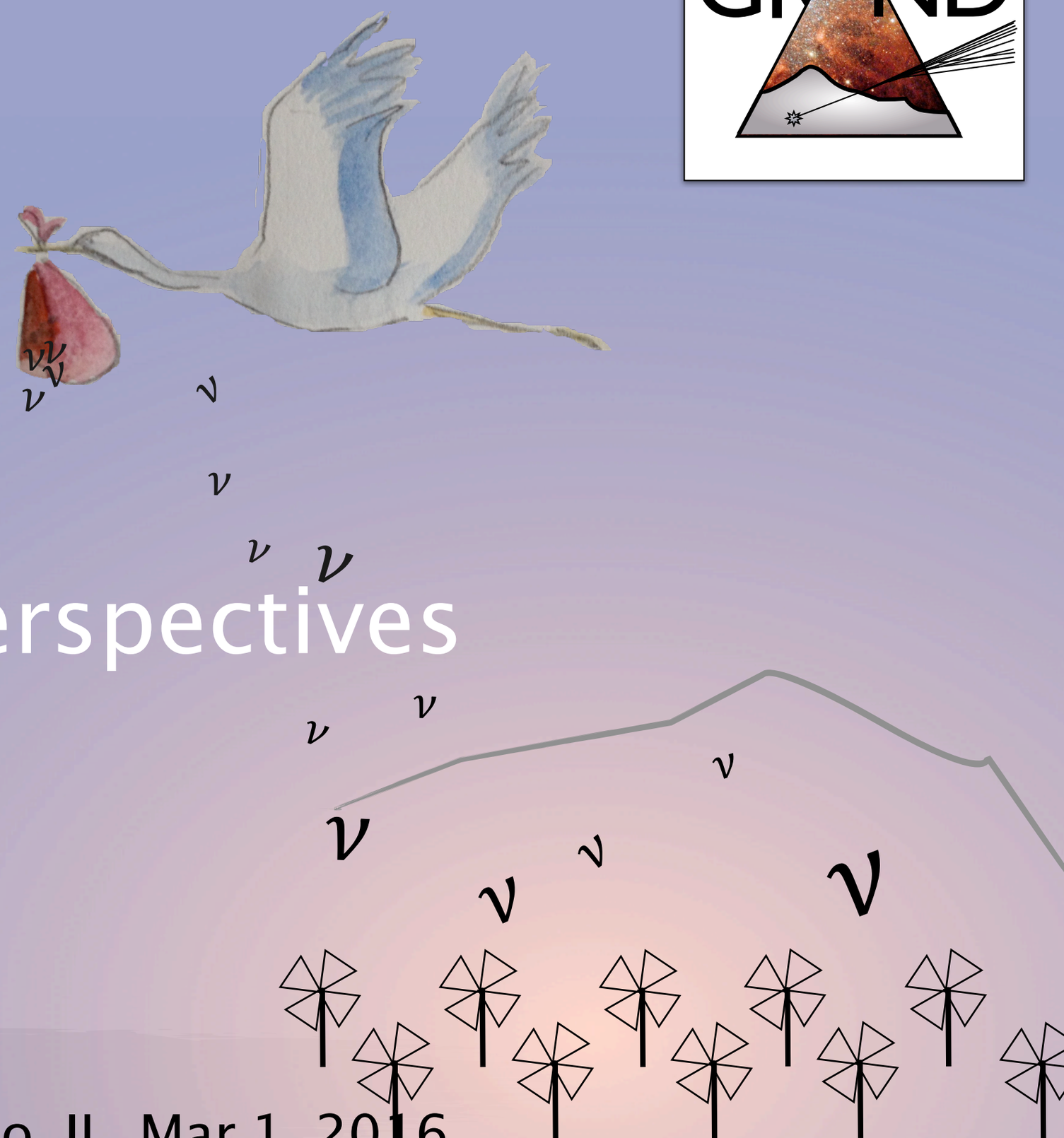
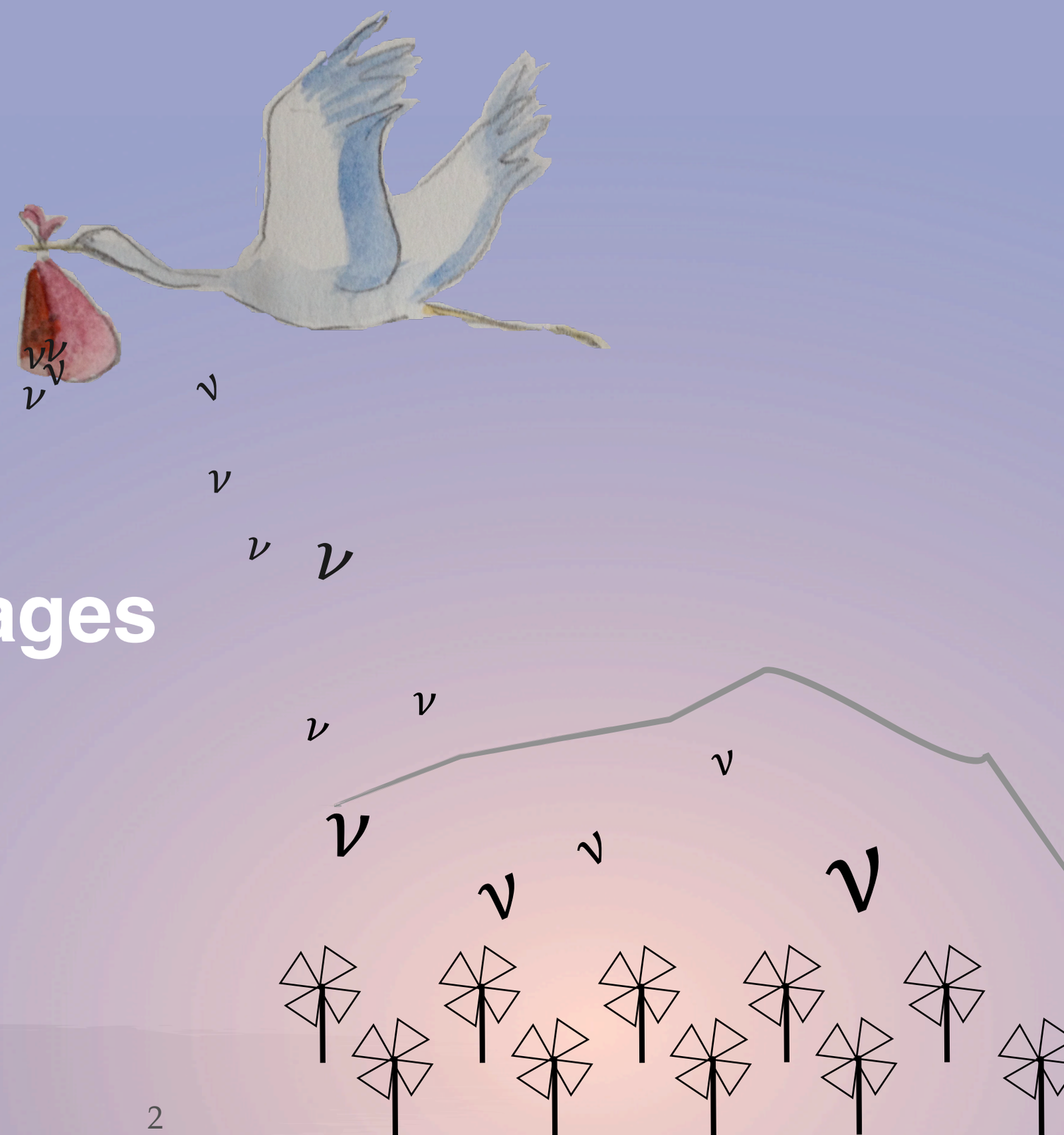
Giant Radio Array for Neutrino Detection: Present and Perspectives



Ke Fang

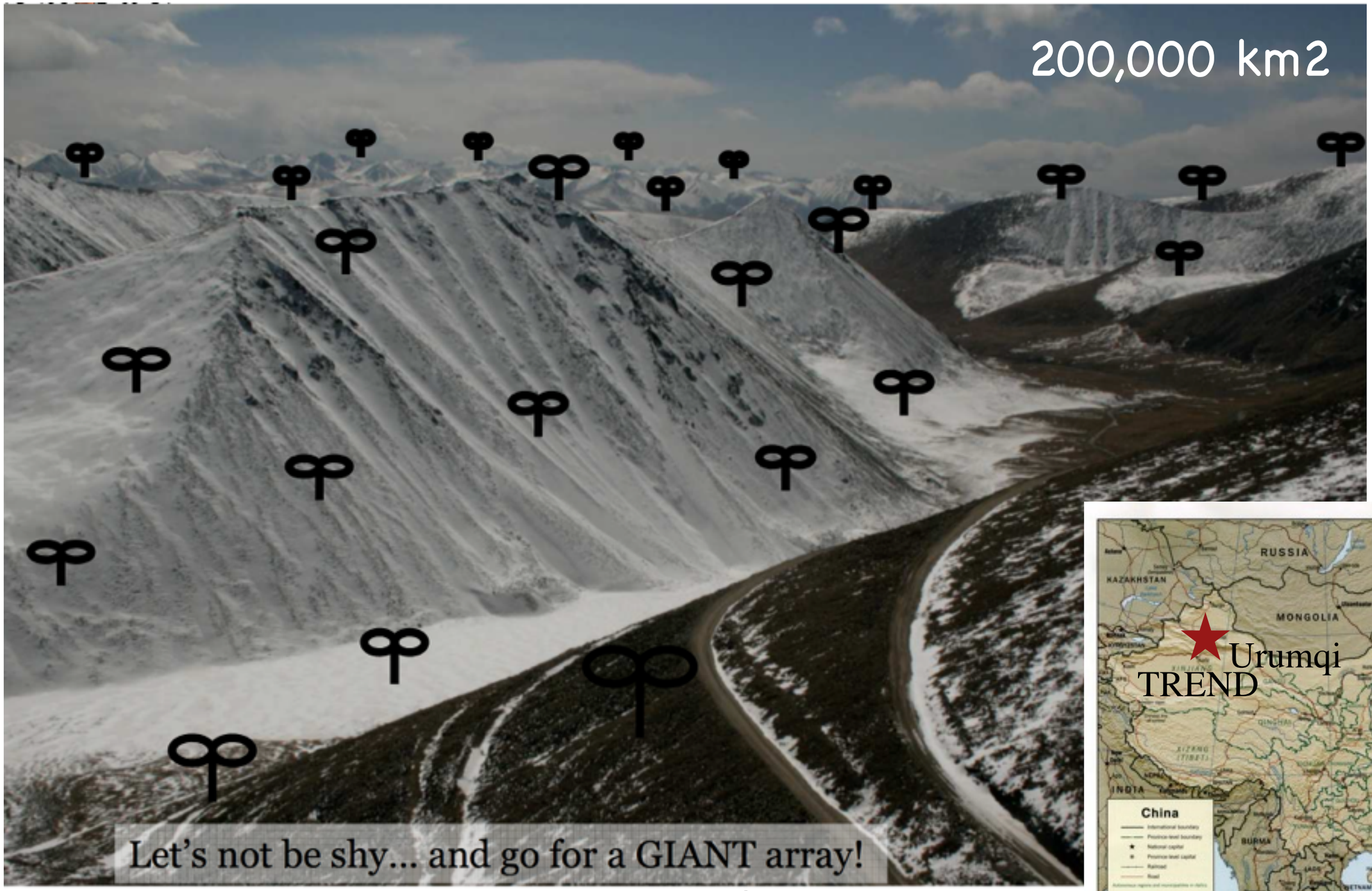
UHEAP Workshop, Chicago, IL, Mar 1, 2016

Take-home messages



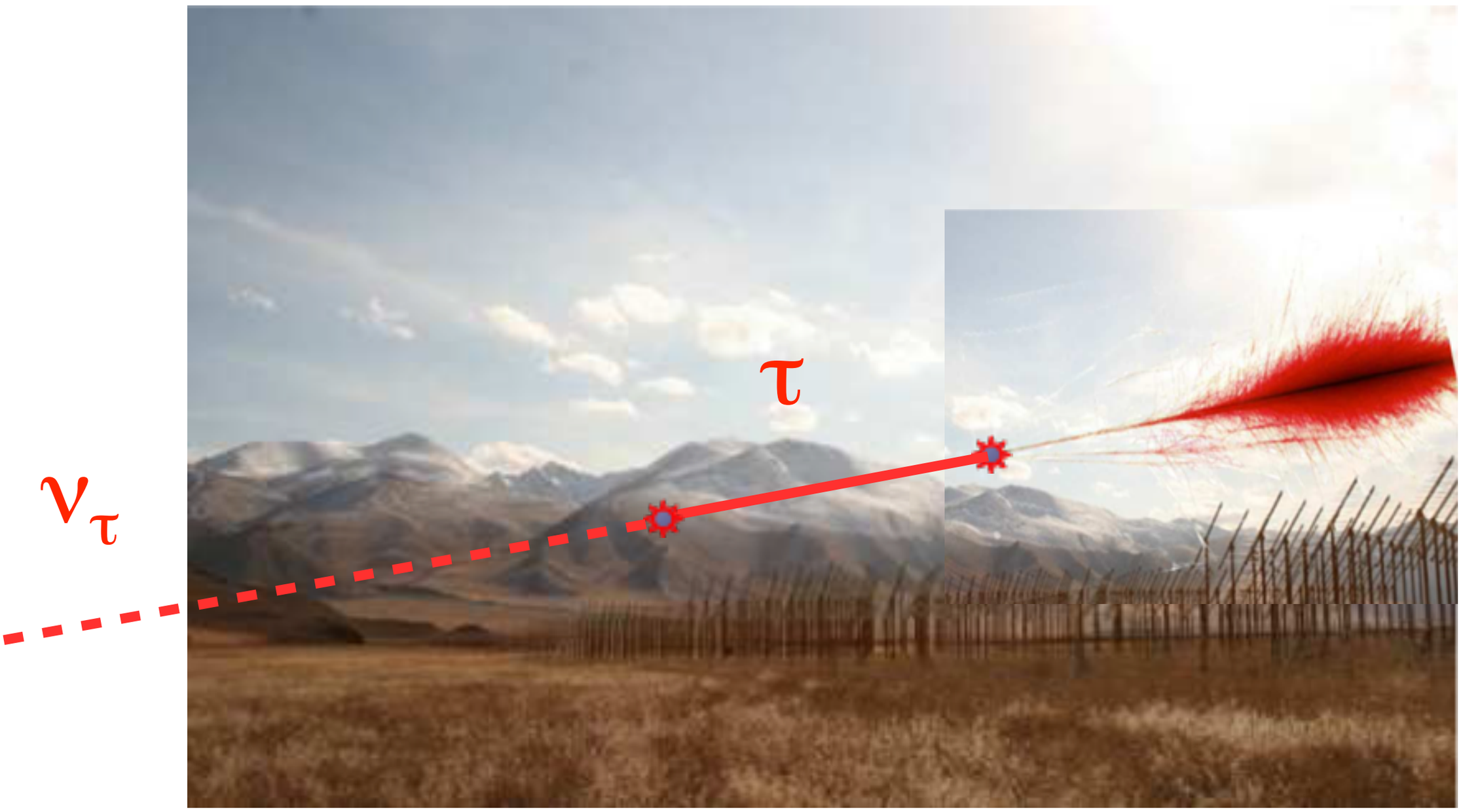
What is GRAND?

Giant Radio Array for Neutrino Detection



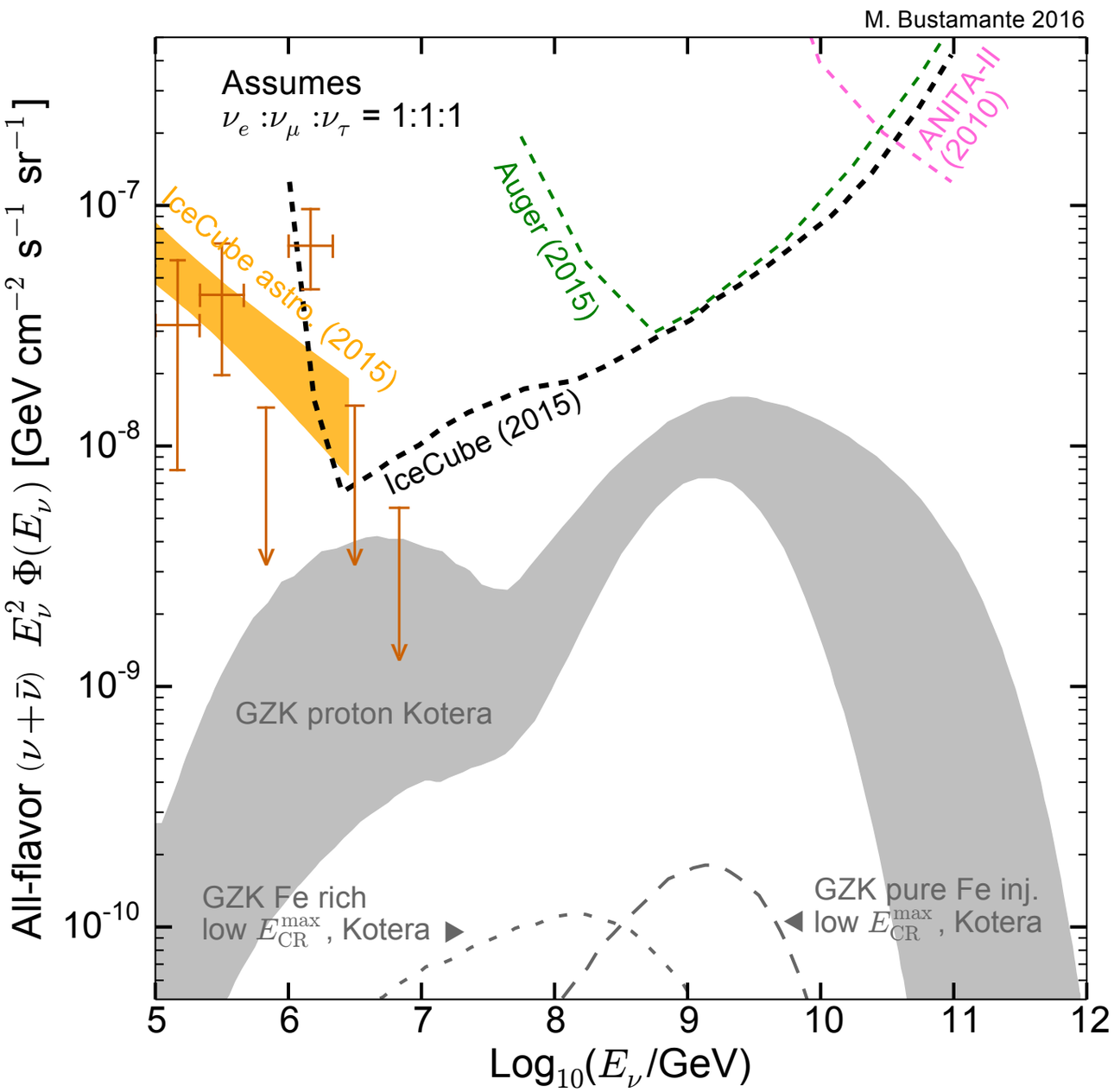
How do GRAND detect neutrinos?

Radio detection of horizontal extensive air showers of neutrino-induced tau decay



Why do we need GRAND?

Current: non-detection of EeV neutrinos

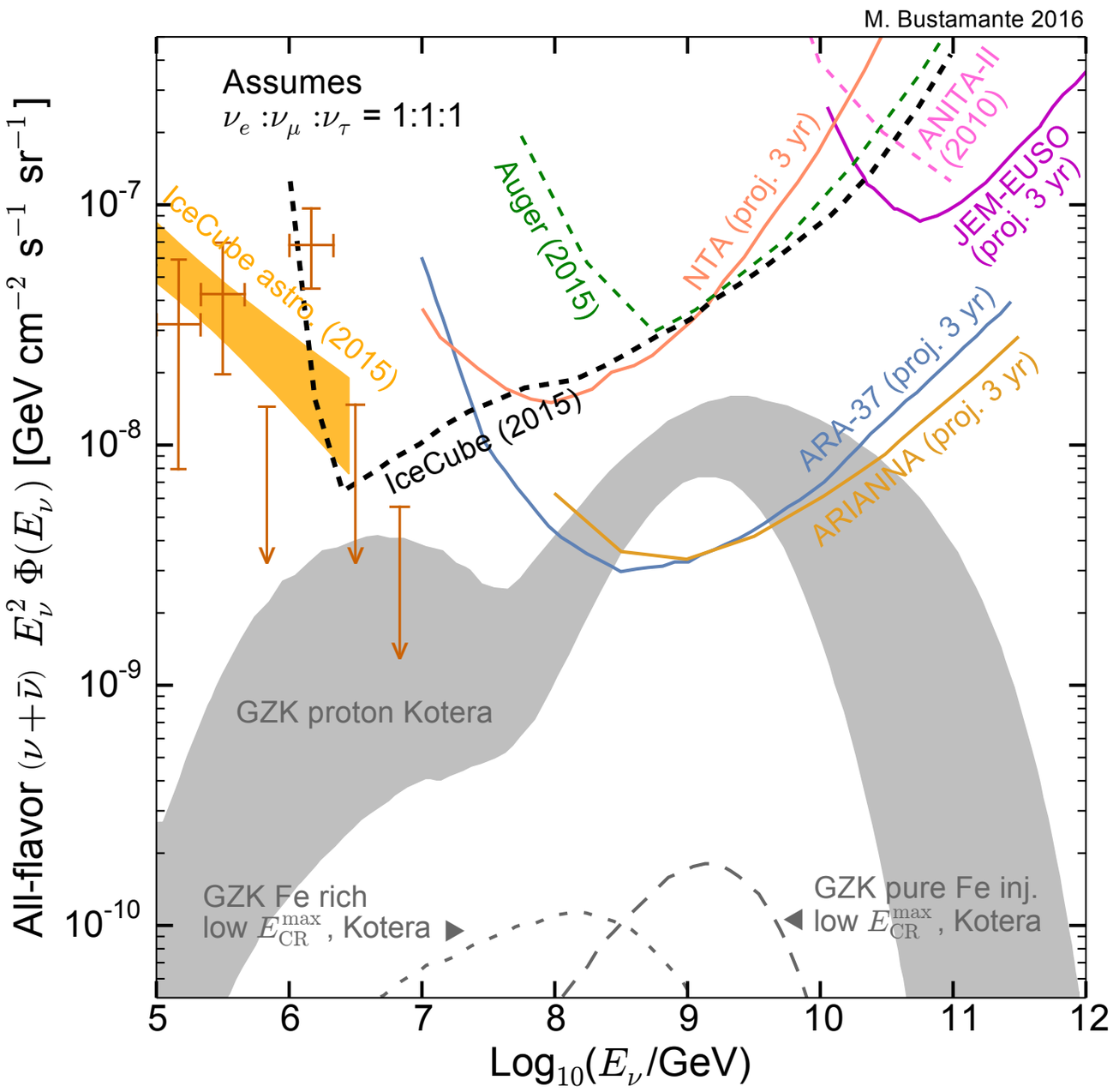


Direct probe of the highest energy sources in the Universe!

Plot by M. Bustamante

Why do we need GRAND?

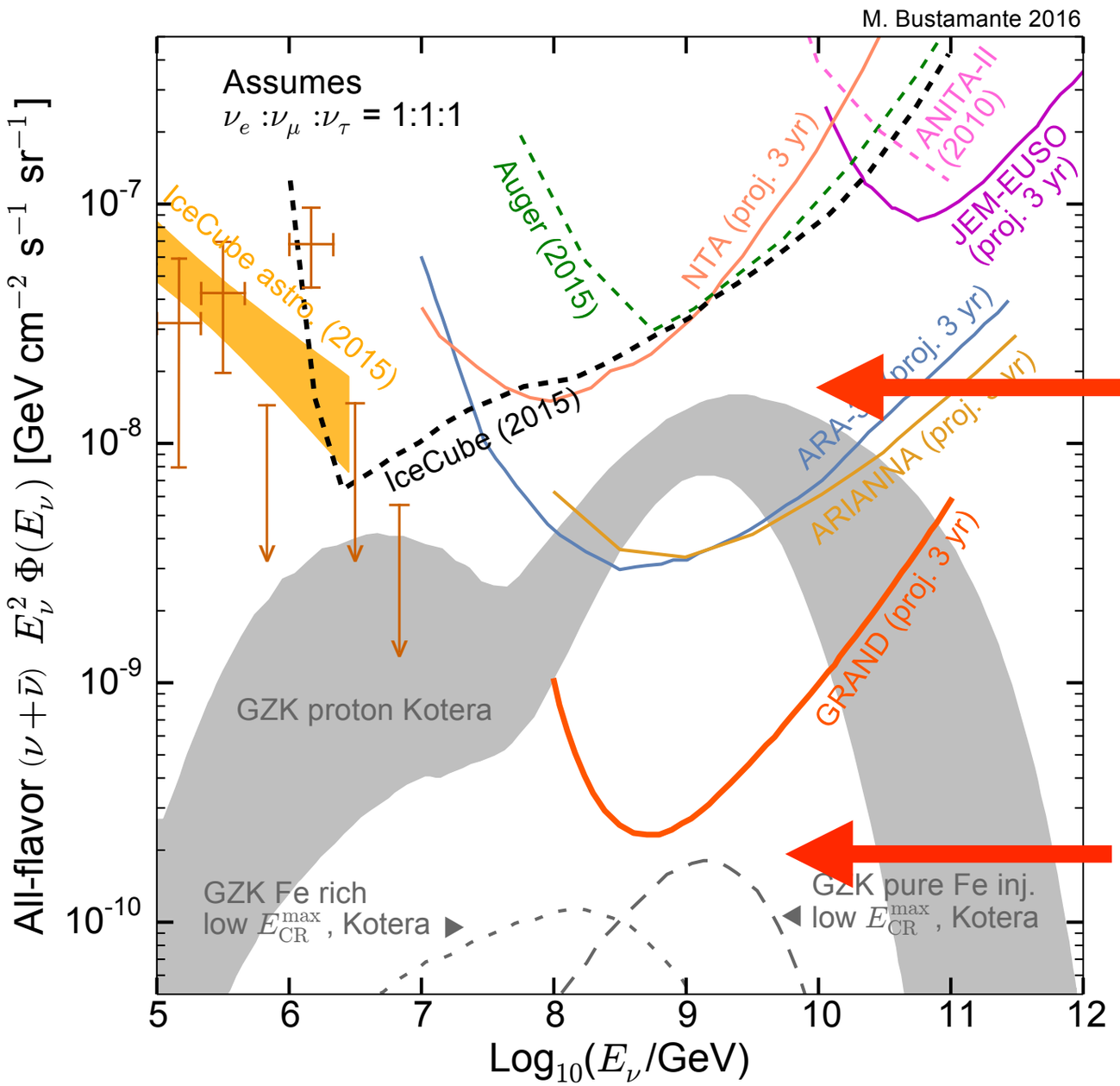
Future: sensitivity for pessimistic scenarios + statistics, statistics, statistics!



Plot by M. Bustamante

Why do we need GRAND?

Future: sensitivity for pessimistic scenarios + statistics, statistics, statistics!

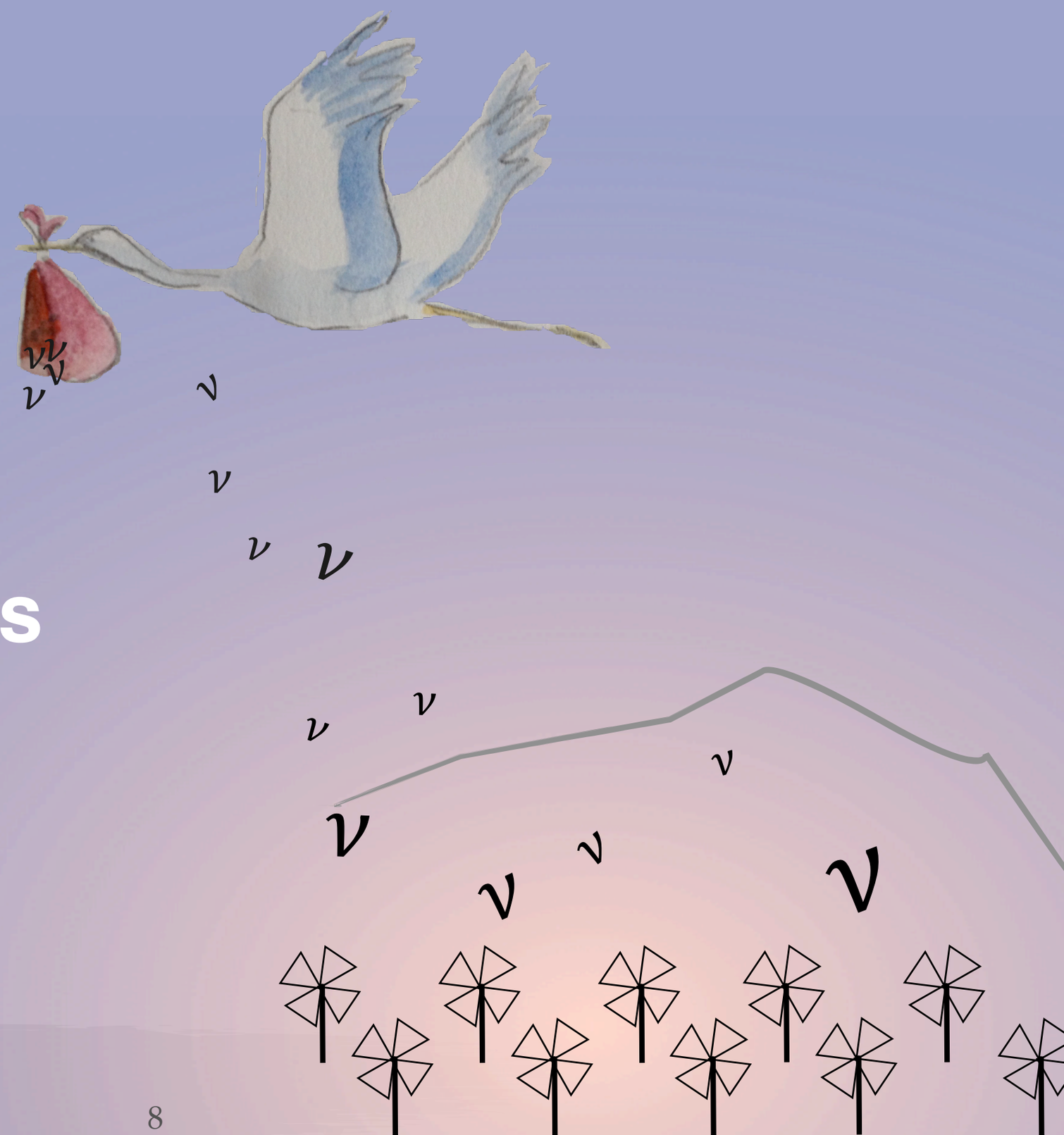


Even in optimistic cases, large statistics & great angular resolution are crucial for source searches!

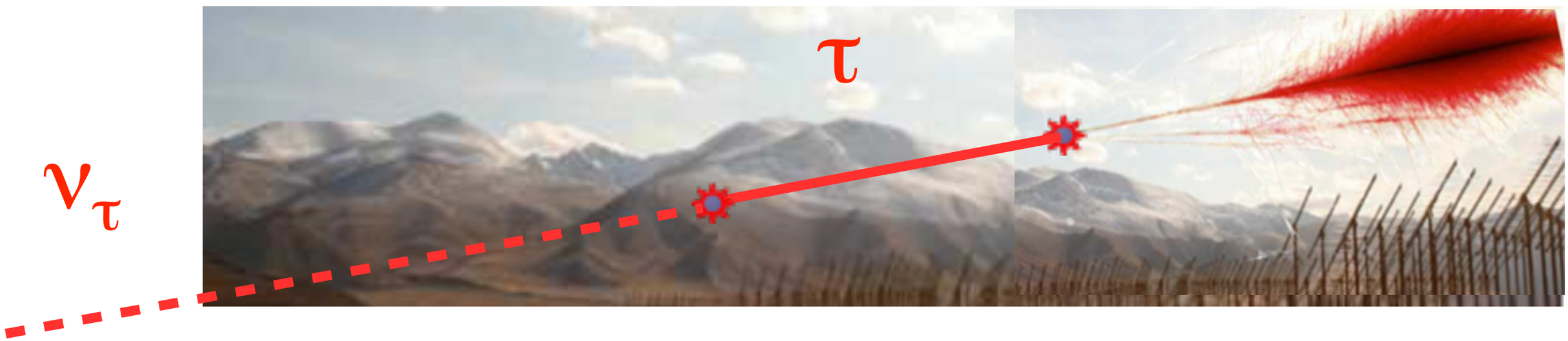
What if we were unlucky?

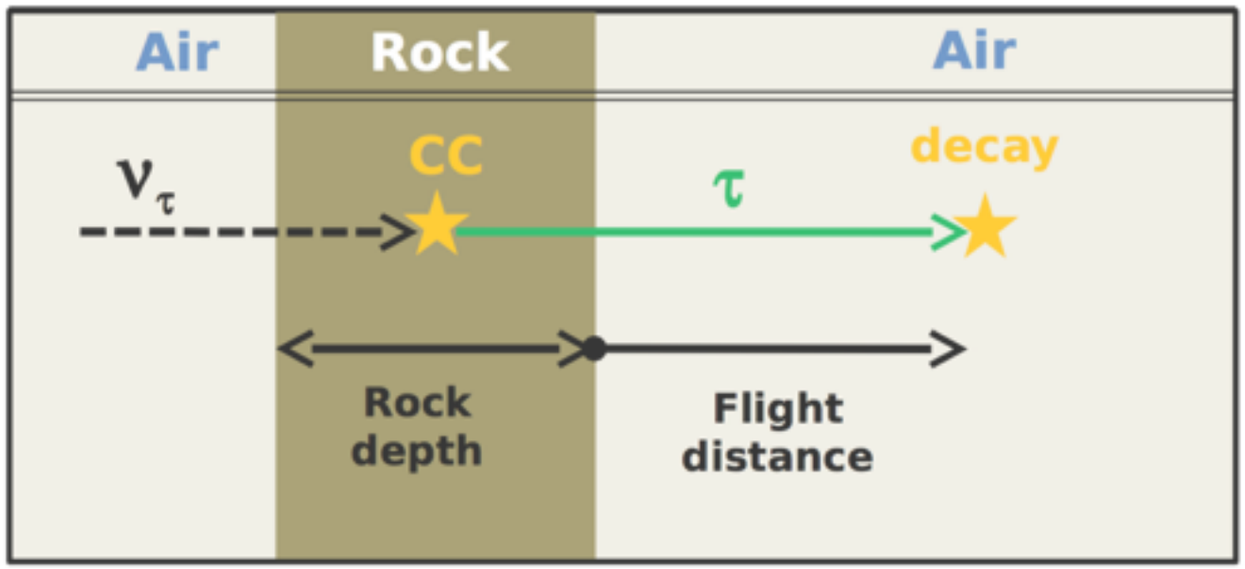
Plot by M. Bustamante

Detector details

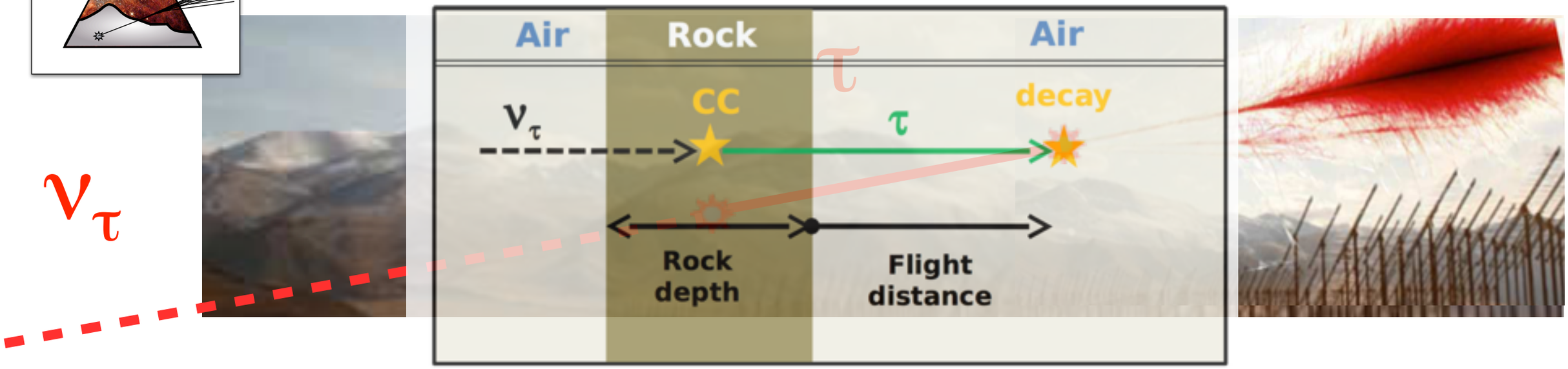


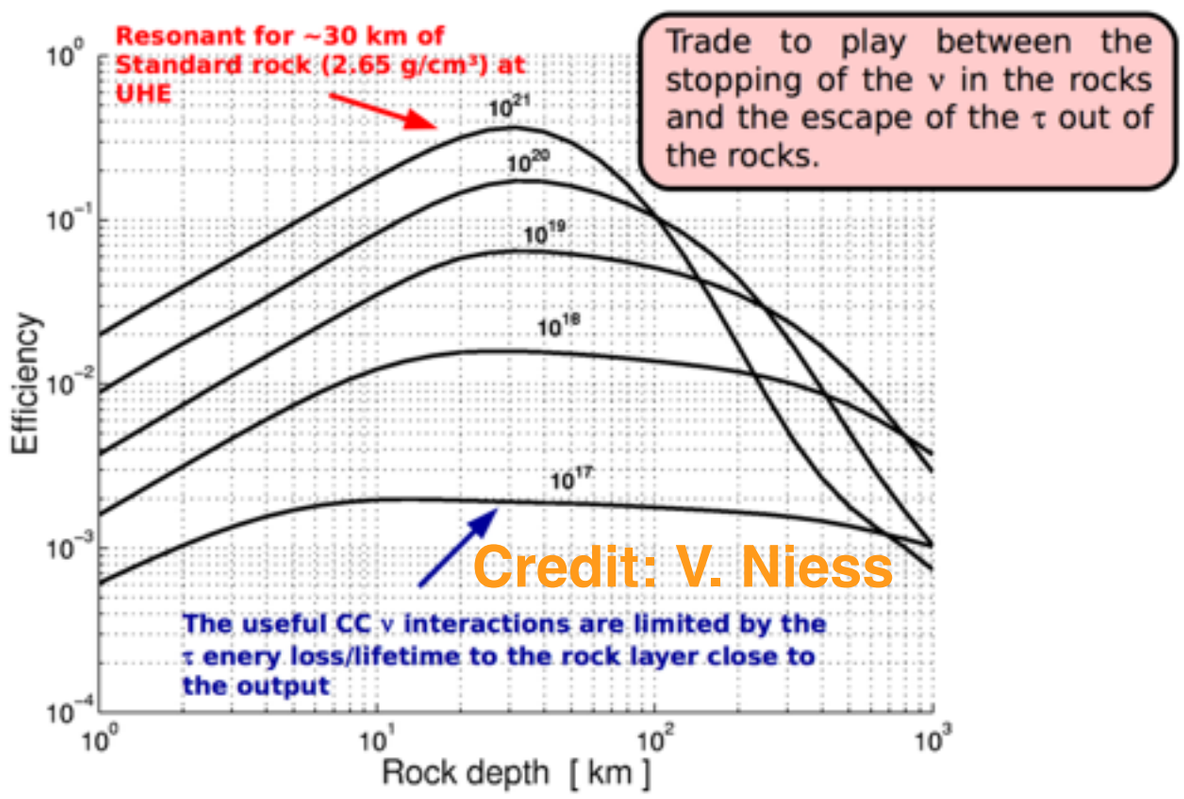
From Neutrino to Lepton





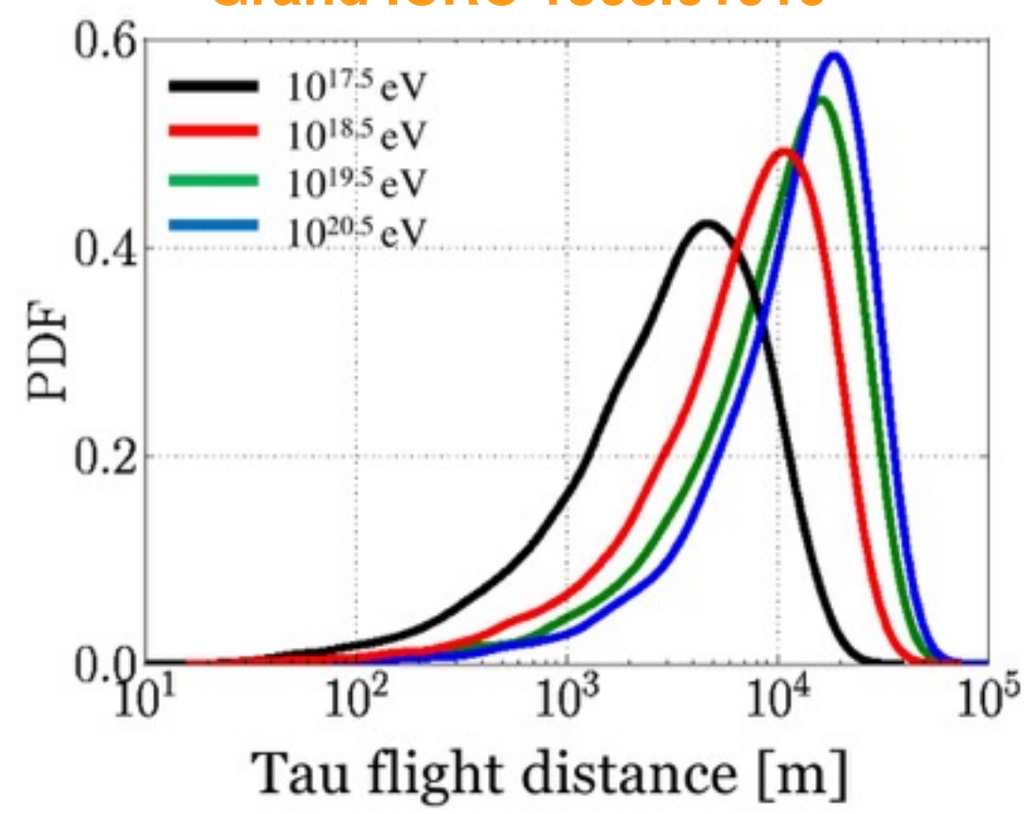
From Neutrino to Lepton





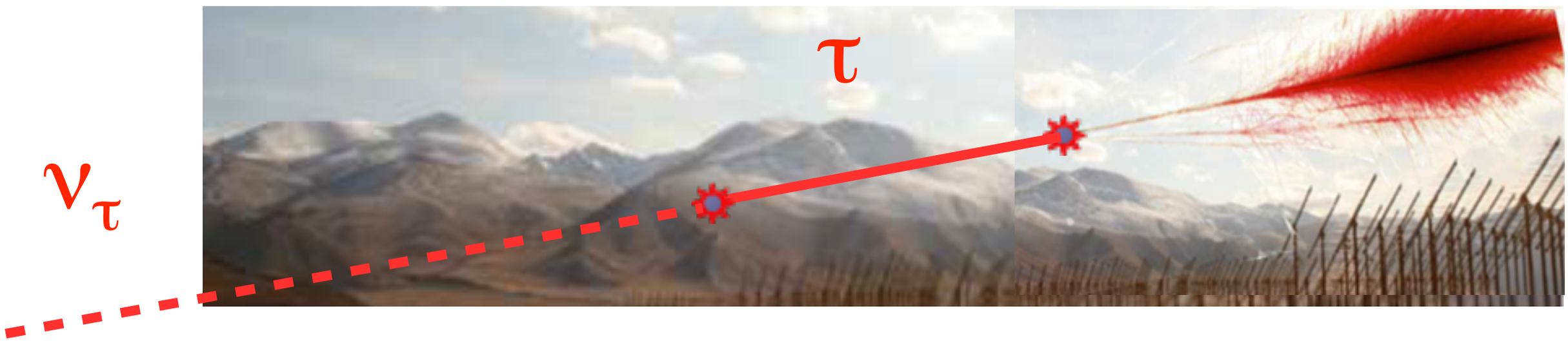
Conversion efficiency from neutrino to tau lepton decaying in the air

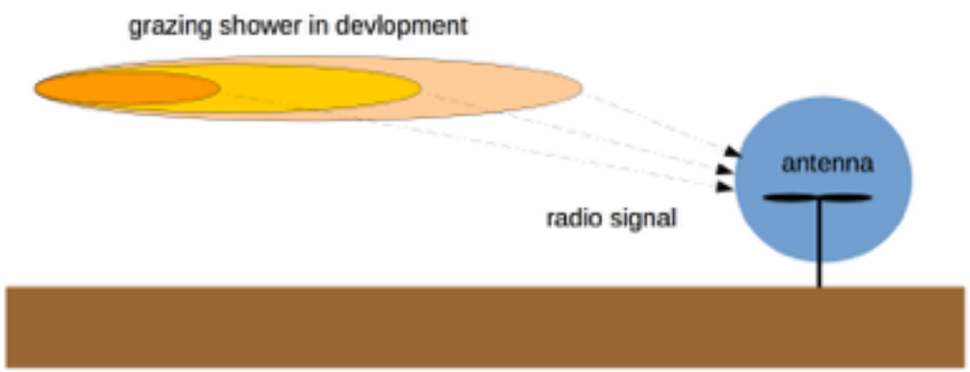
Grand ICRC 1508.01919



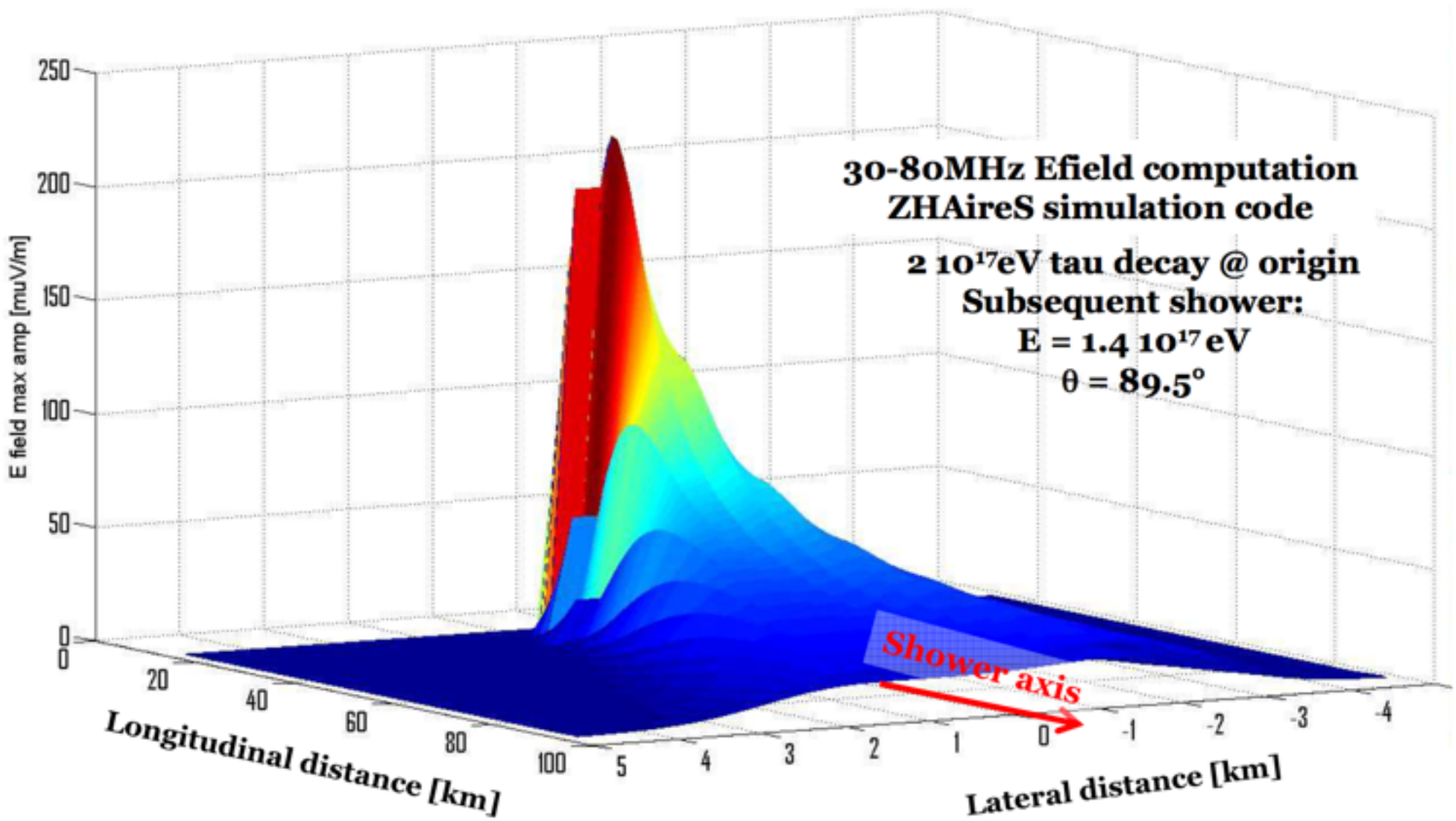
Prob. Distribution of flight distance

Extensive Air Shower



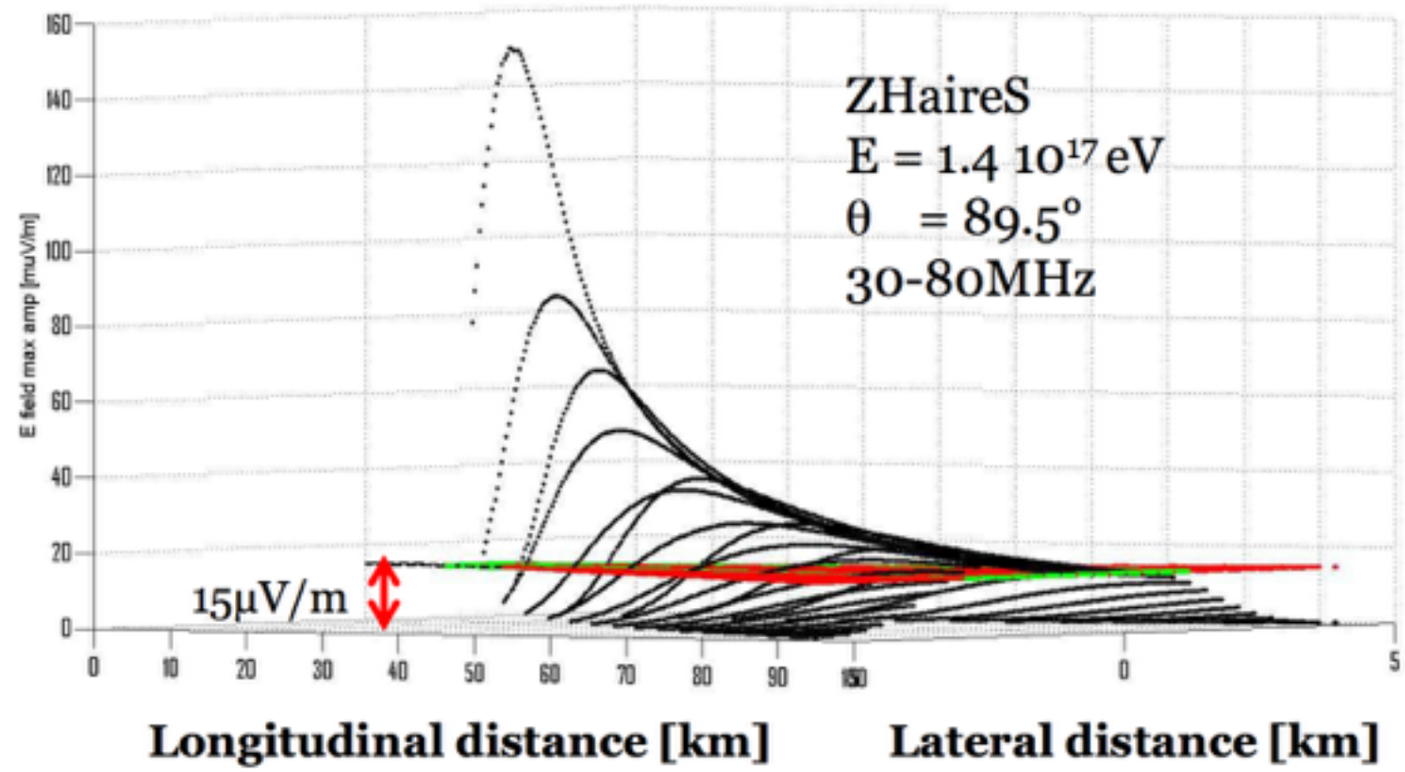


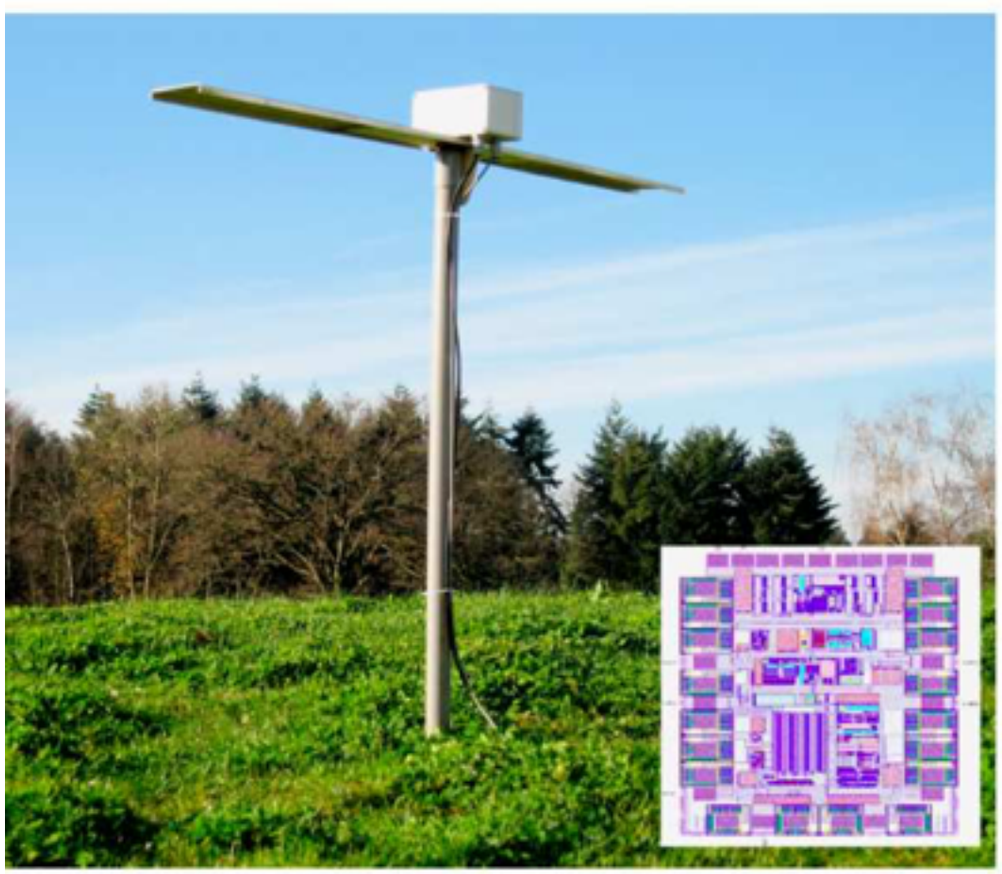
Extensive Air Shower



EAS radio detection: 30-100 MHz

Atmosphere transparent to radio waves
short waves prevent detection below 25MHz
extension of antenna to 200-300MHz possible



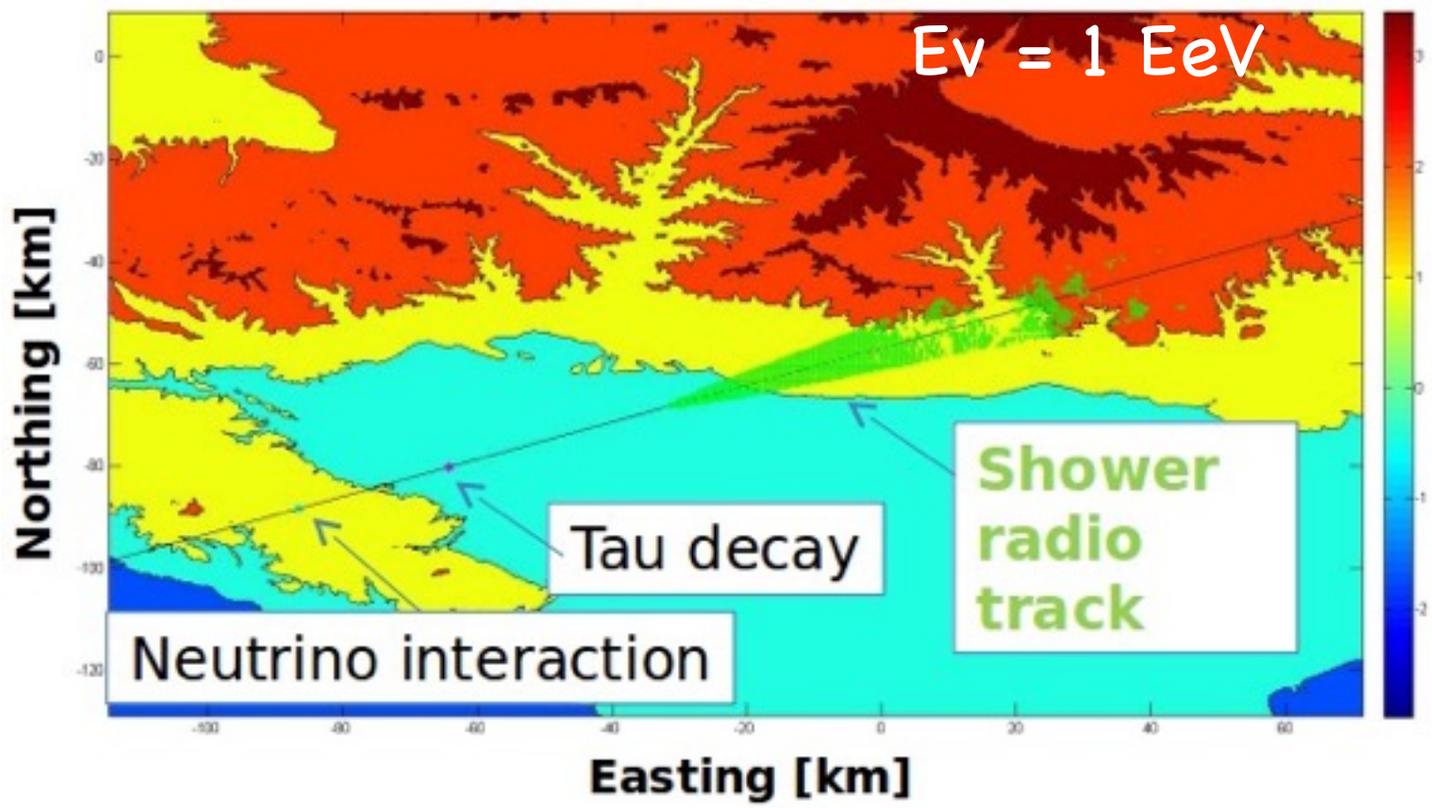


- sky noise level: rms 15muV/m
- Efield emitted by horizontal EAS still in detection range after 100 km

→ A large array of radio antennas well suited for neutrino-induced EAS!

Sensitivity Study

ν Propagation->tau Decay->EAS Development(->Radio Emission)



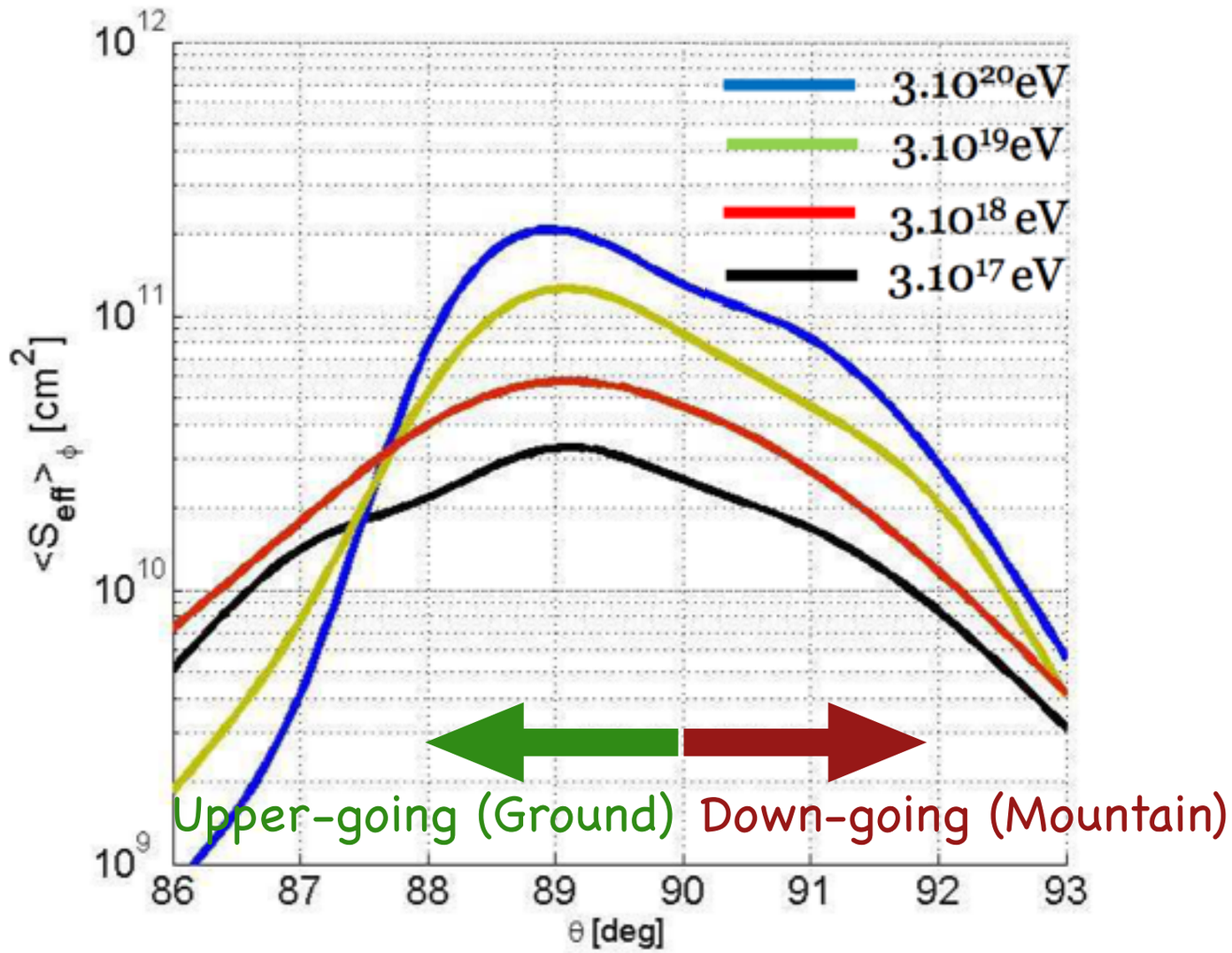
Simulation array: 90,000 antennas over 60,000 km2 with 800 m step size in Tianshan Mountain

Earth-skimming only: ±4° around the horizon

Antenna triggers if In direct view of shower + Inside a light cone of a few degrees (0.5–3°) + τ decay vertex is 14–120 km away

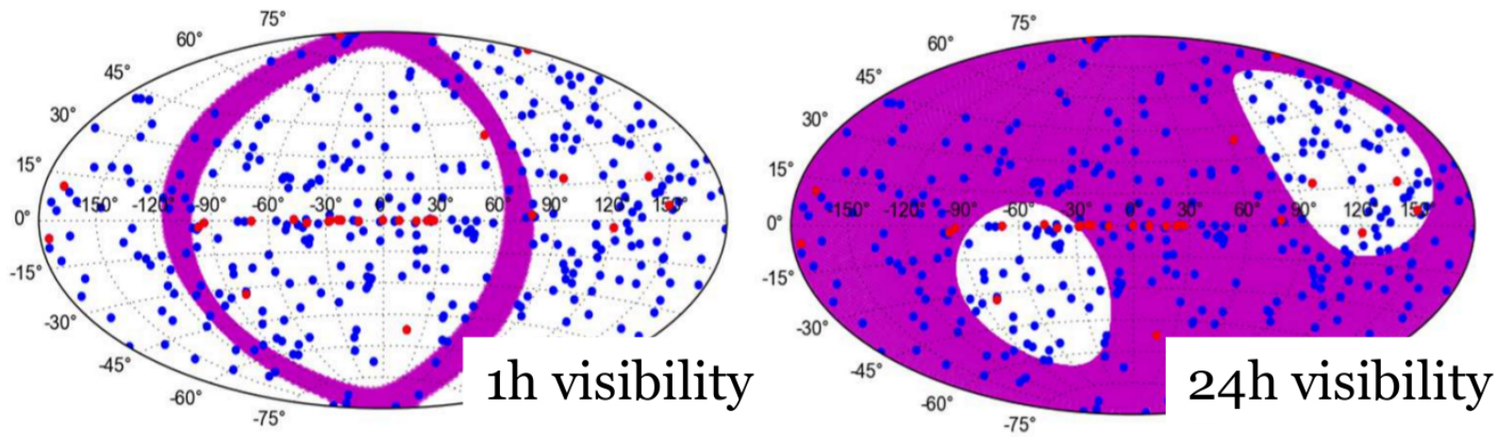
Showers detected if at least 8 antennas fired

Effective Area & Sensitivity

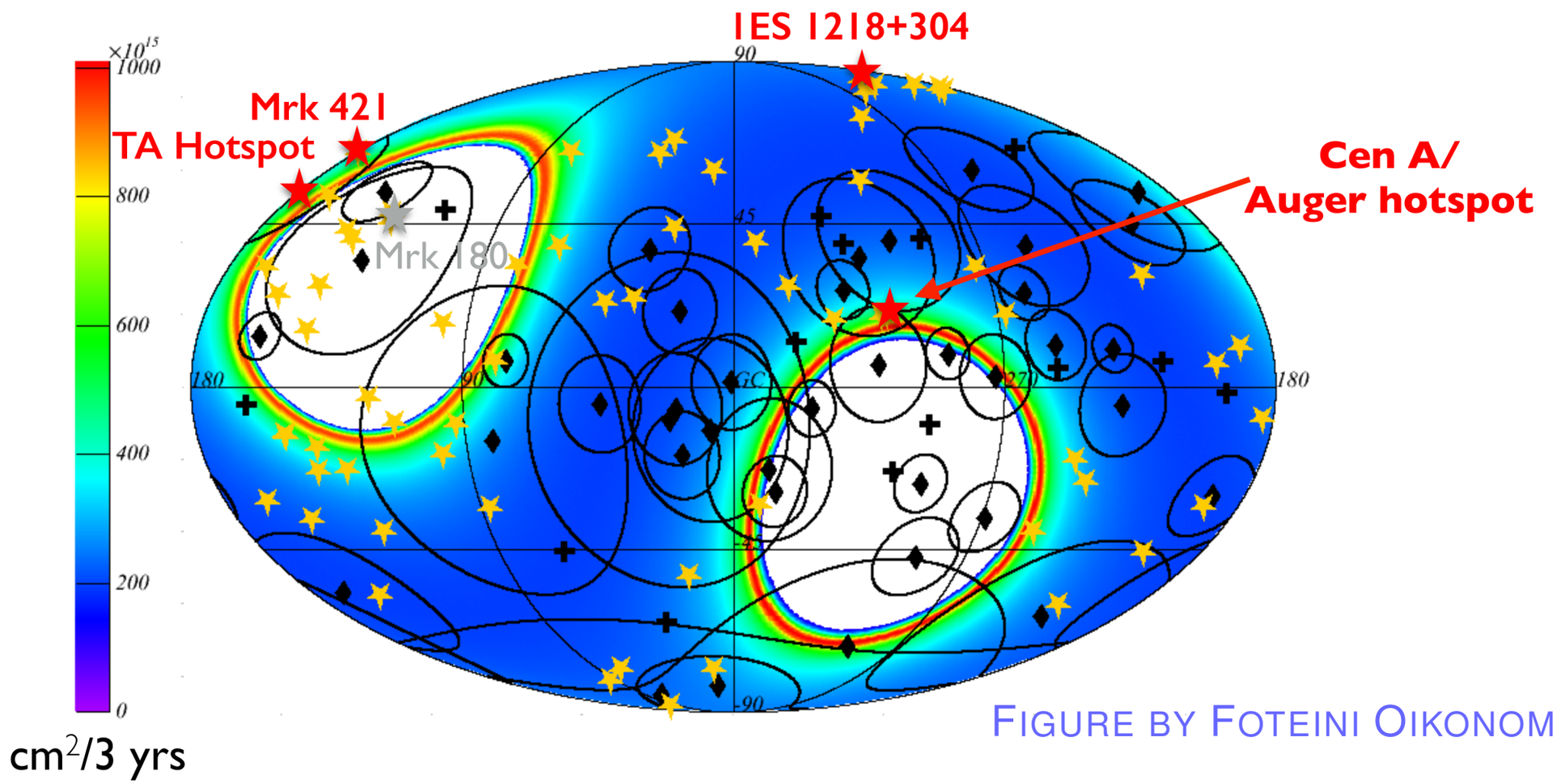


- Earth opaque for >±4° around horizontal
- Mountains are sizable targets (~40% of total)

Field Of View at 1 EeV



3-year average:

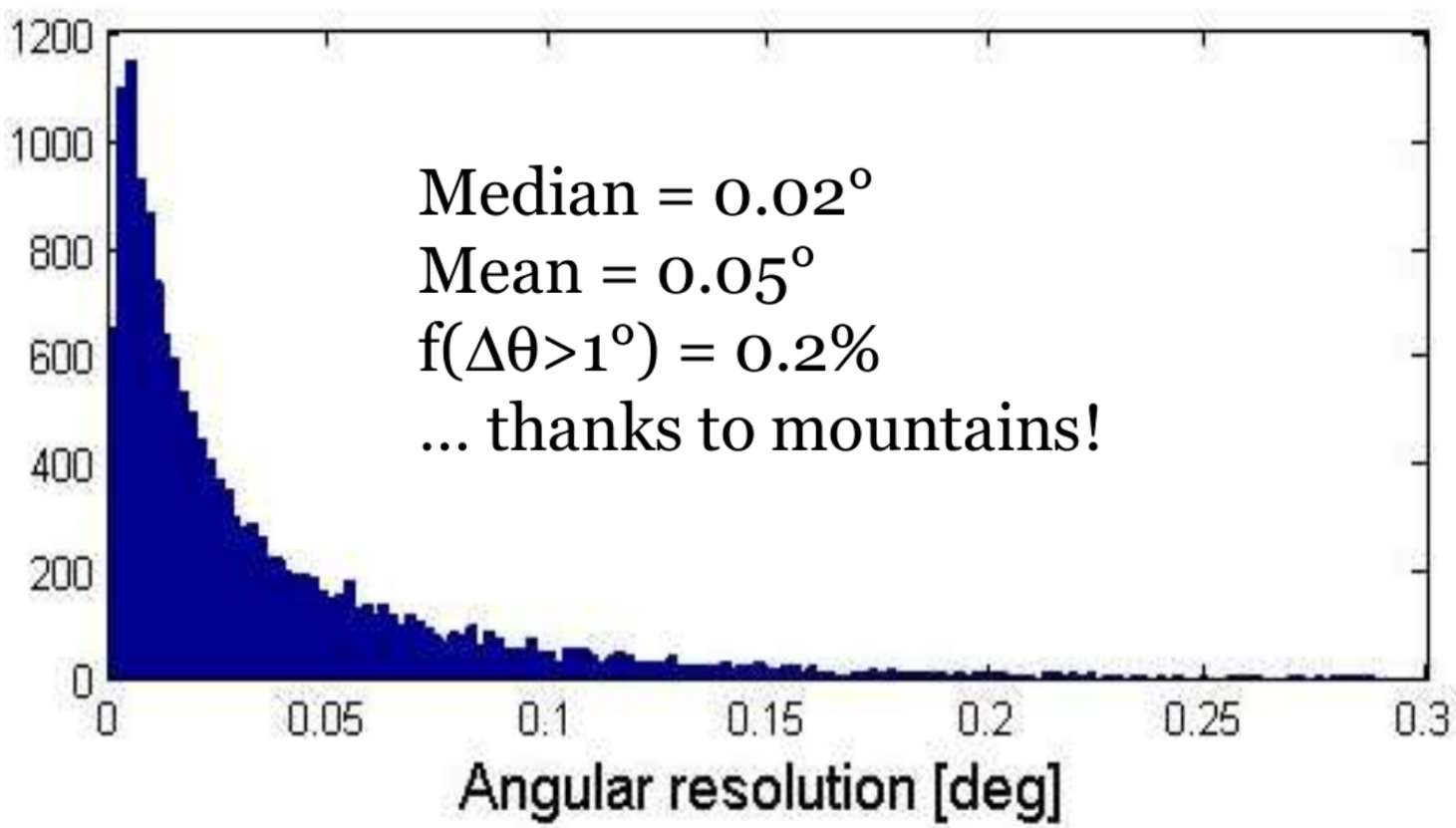


cm^2/3 yrs

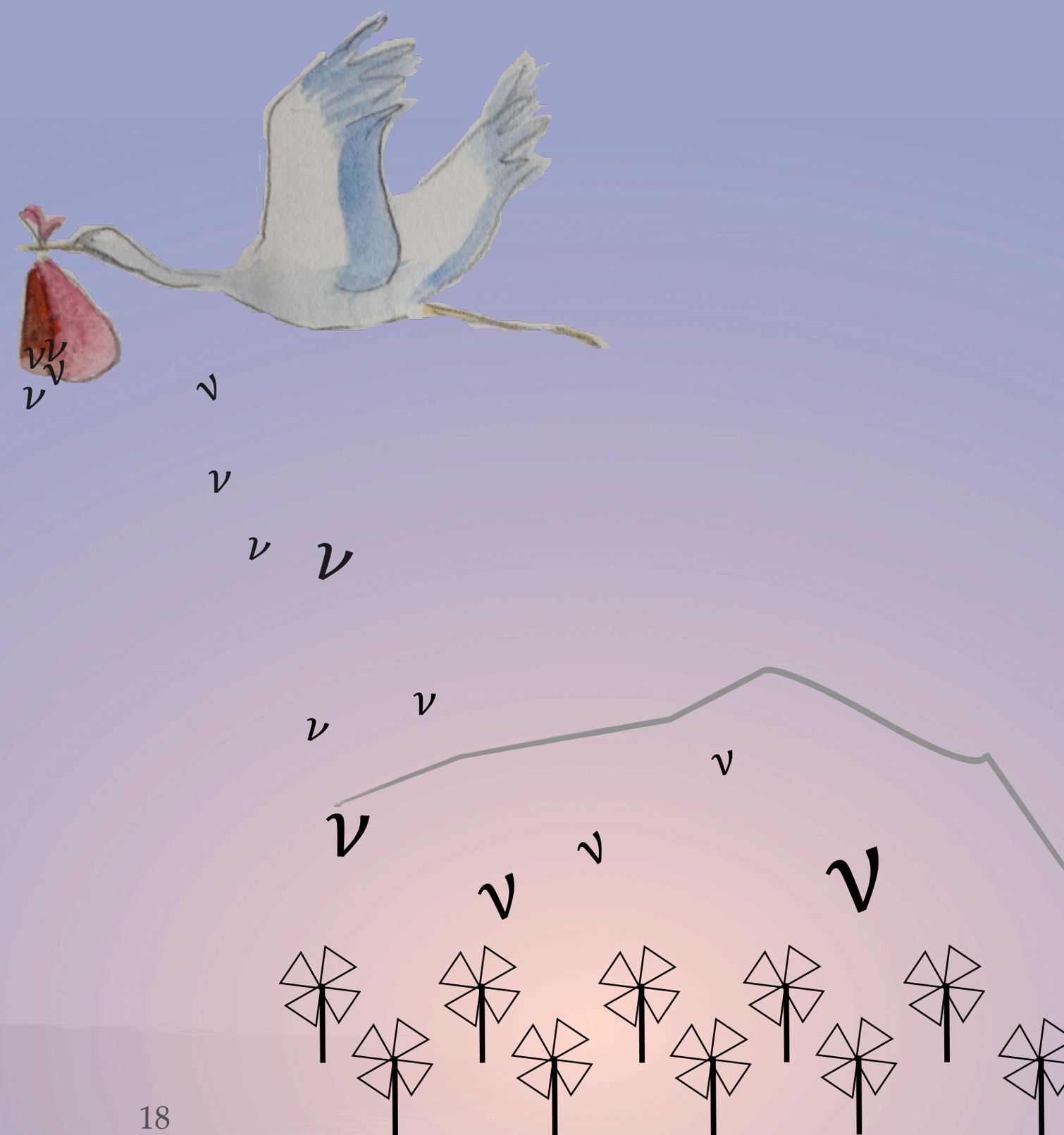
FIGURE BY FOTEINI OIKONOMOU

Angular Resolution

- Computed analytically for all detected showers following simulation by Ardouin *et al.* [1007.4359]
- Assumes 3 ns trigger timing precision
- High resolution due to extended trigger zone



Challenges



Background Rejection

Background radio signals of cosmic origin:

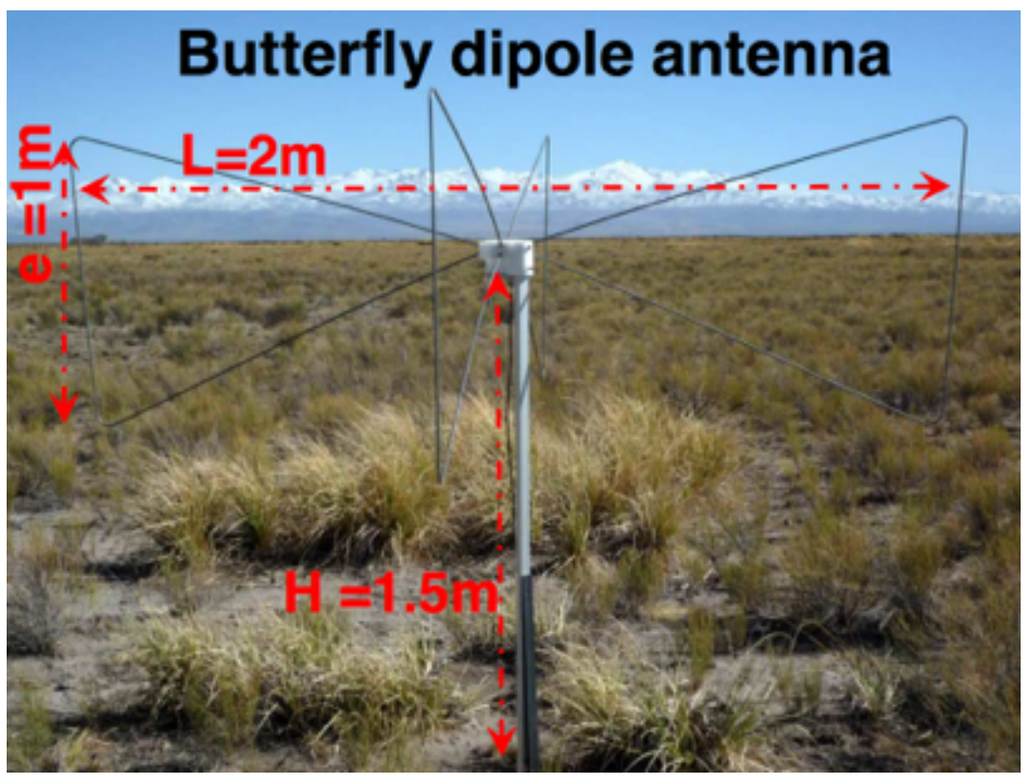
- muons: very unlikely due to longer decay time
- atmospheric neutrinos: none above 10 PeV
- UHECRs: 5-sigma cut by rejection > 1°

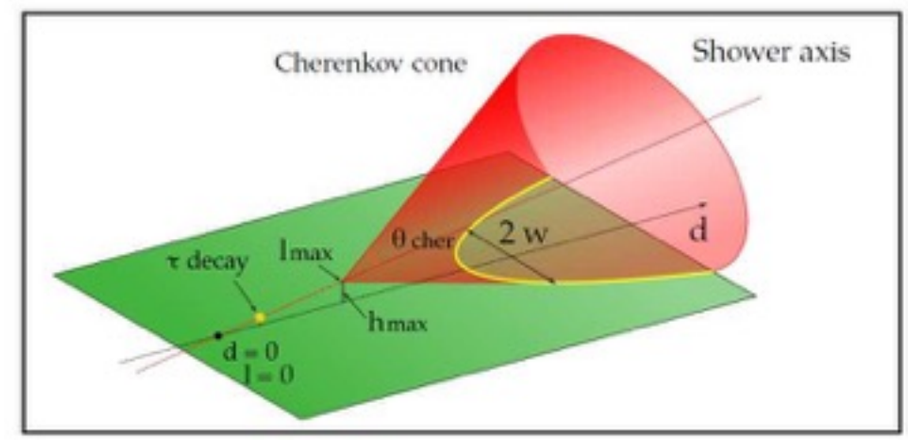
Terrestrial backgrounds: human activities, natural electric discharge in the air, thunderstorms etc: 10^8.5 events/year requires rejection factor > 10^9 —> Major Challenge!

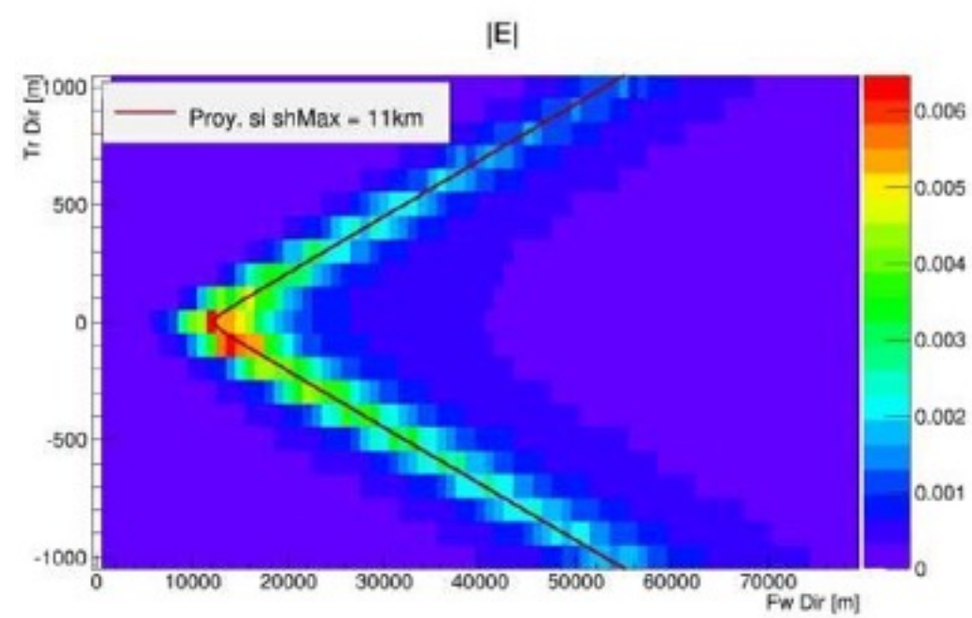
Background Rejection

EAS signatures:

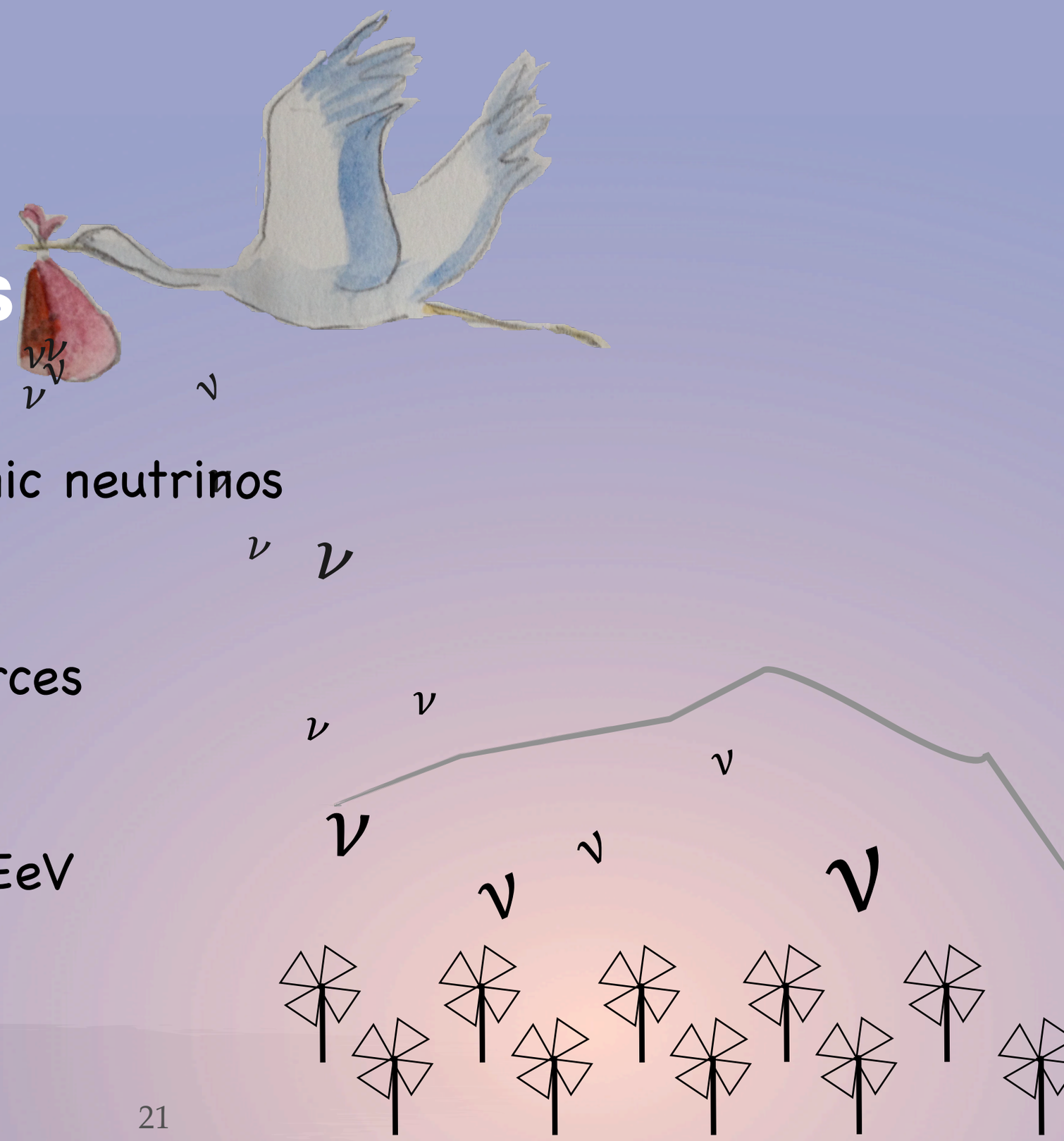
- Trigger pattern at ground (started inside array + beamed emission with flat wavefront + reconstructed source below horizon)
- Polarization pattern (perpendicular both to geomagnetic field & direction of propagation of shower)
- Cherenkov cone







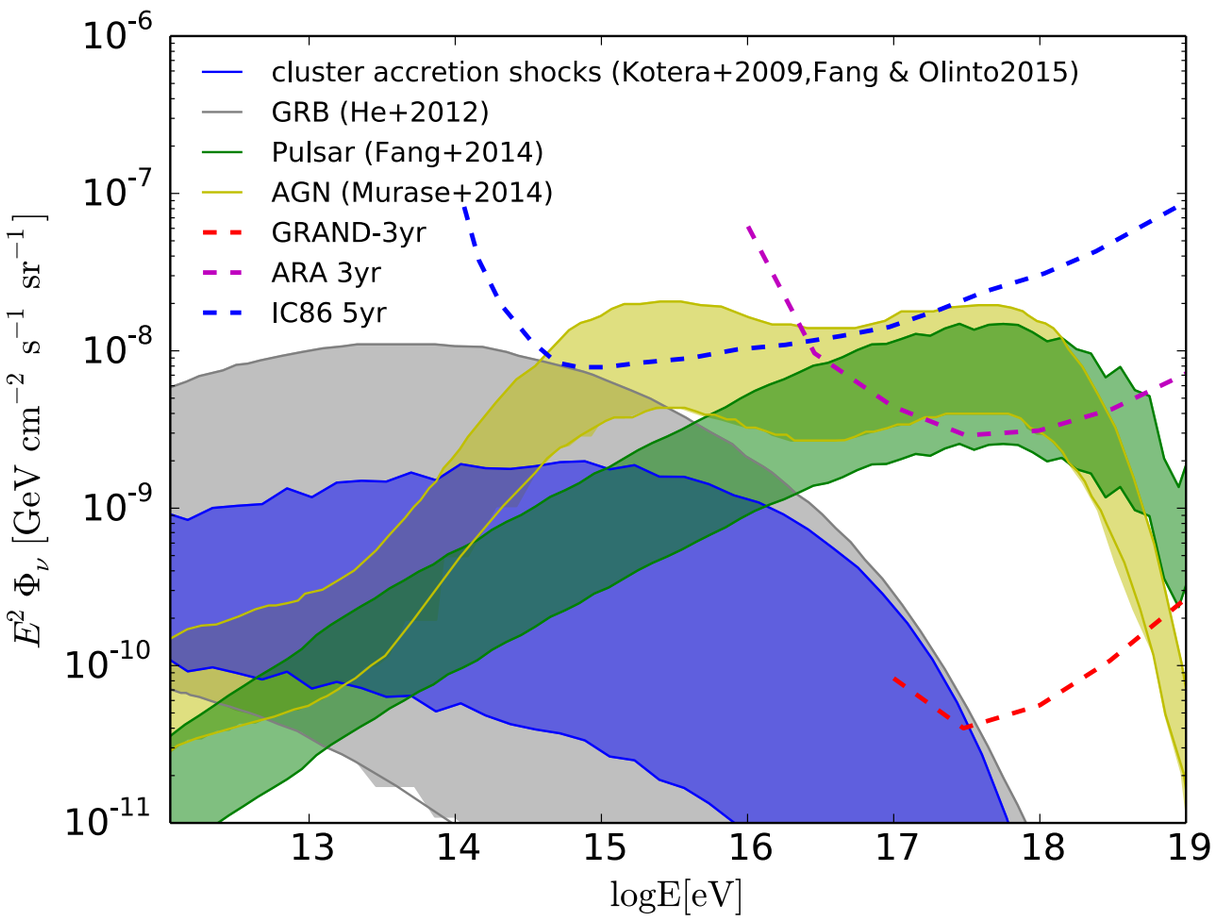
Science Objectives



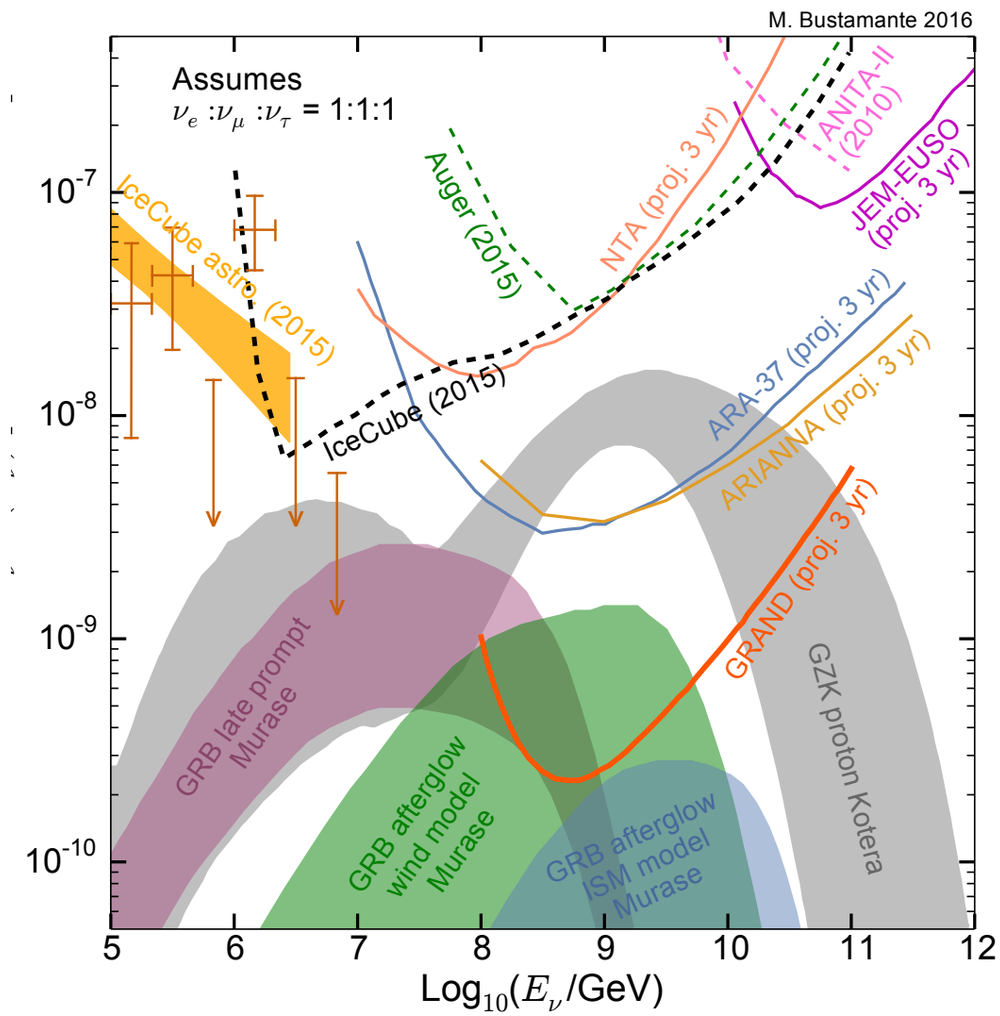
- Discovery of cosmogenic neutrinos
- Testing Source Models
- Pinpoint Neutrino Sources
- UHECR detection
- Flavor composition at EeV
- New physics
- ……

Science Cases - Testing Source Models

Blazar, Pulsar, Cluster

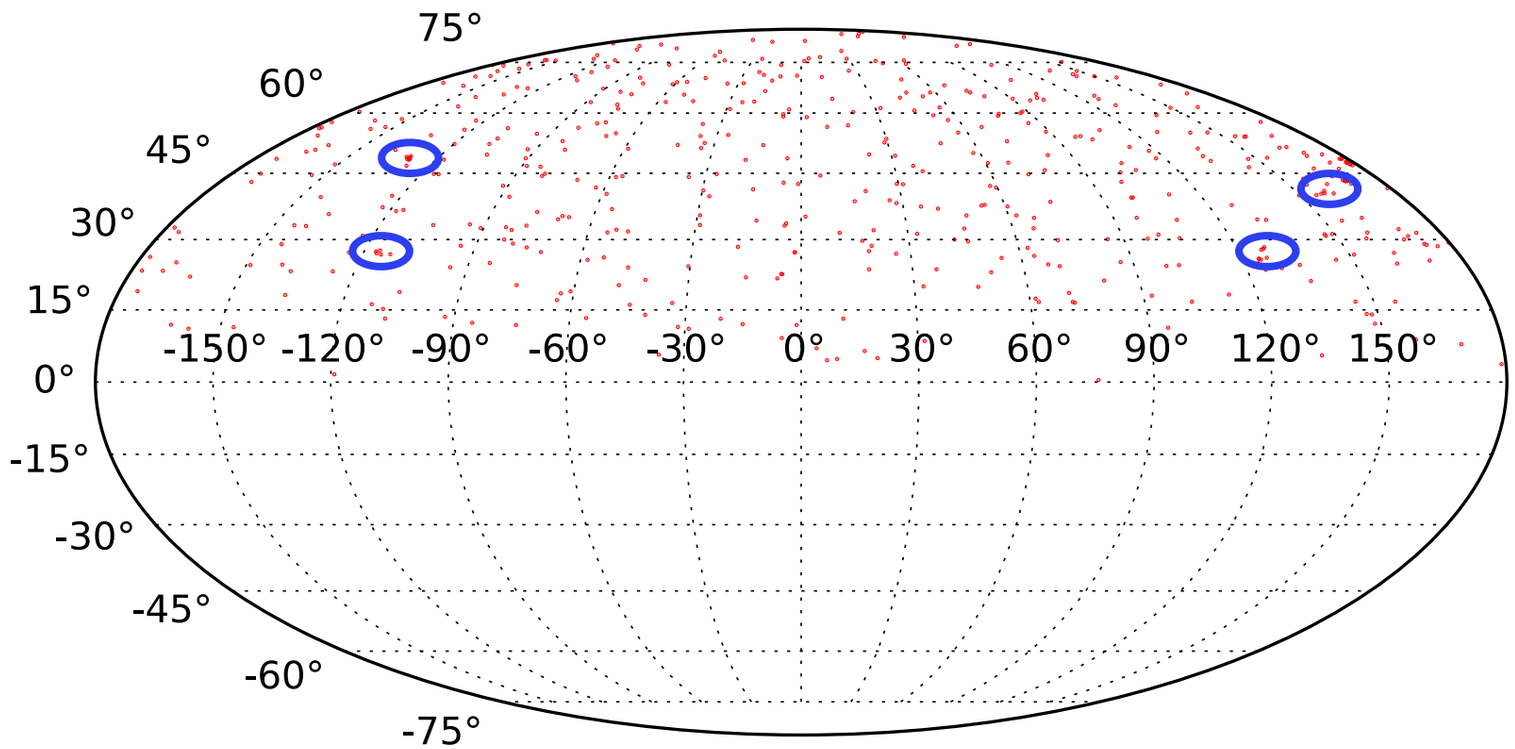


GRB



GRAND would be able to break the degeneracy!

Pinpointing Neutrino Sources



Detecting A Source On Top of the Background

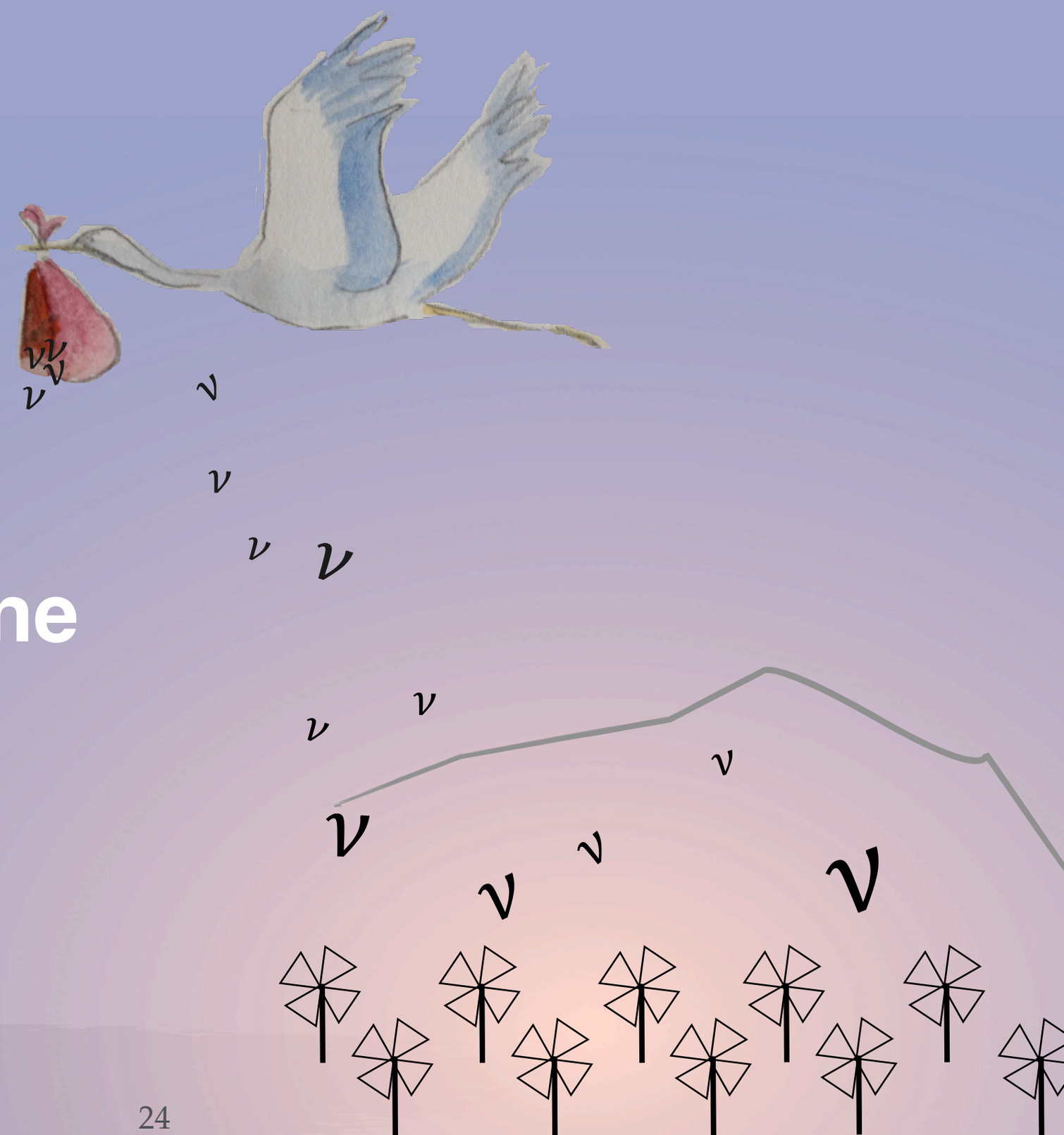
$$\bar{N} = 4.8 \times 10^{-3} \left(\frac{N_{\rm tot}}{1000}\right) \left(\frac{(0.1^\circ)^2}{5\% \times 4\pi}\right)$$

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

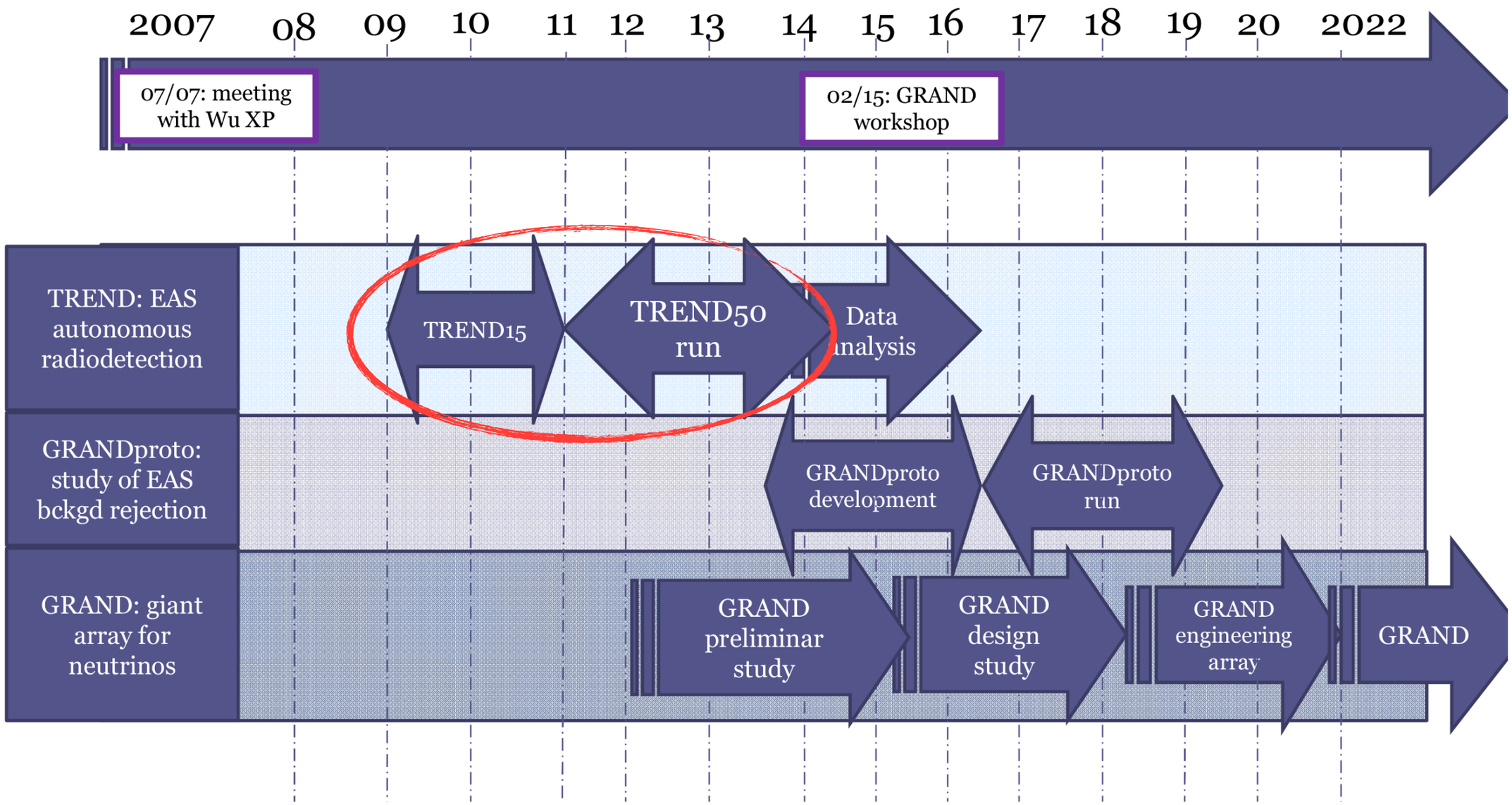
✓Doublet events —> Pinpointing the source!

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

Tentative timeline



GRAND tentative timeline



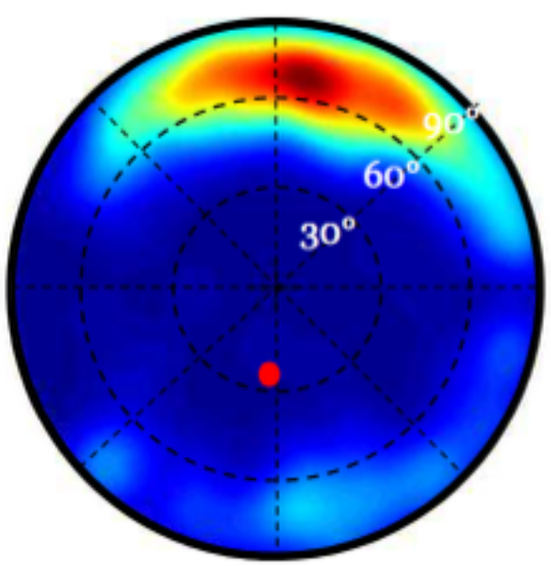
O. Martineau

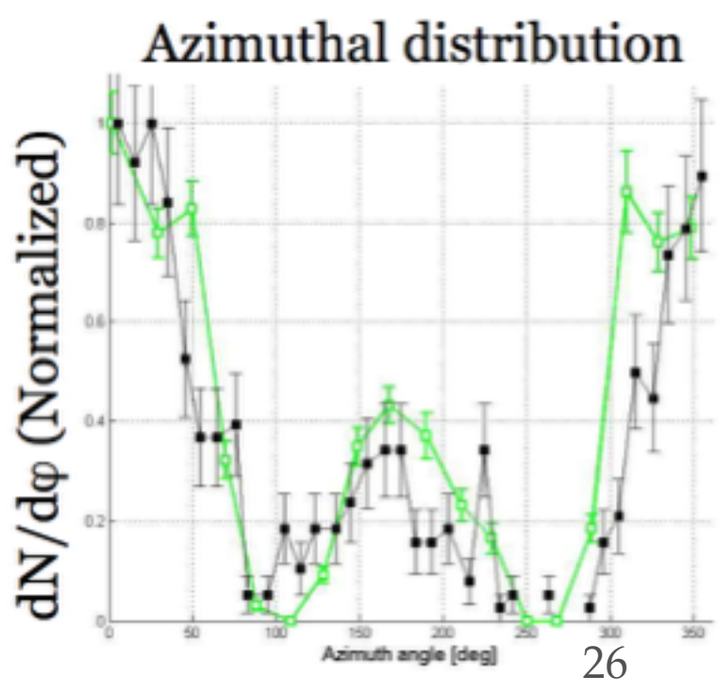
TREND: TREND 50 (2011-2014)

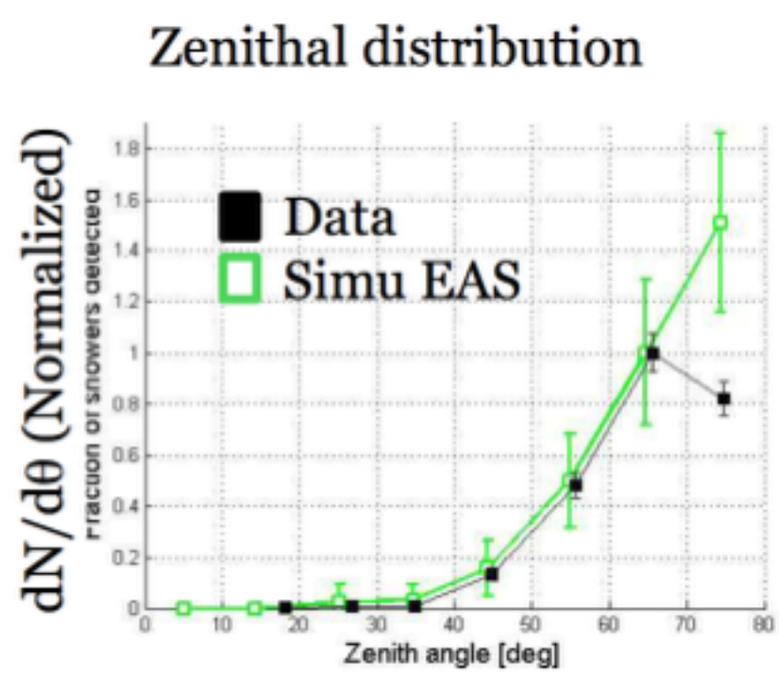
TIANSHAN Radio Experiment for Neutrino Detection

Achieved autonomous EAS detection & identification with radio antennas

Experiment by NAOC, IHEP & V. Niess, O. Martineau





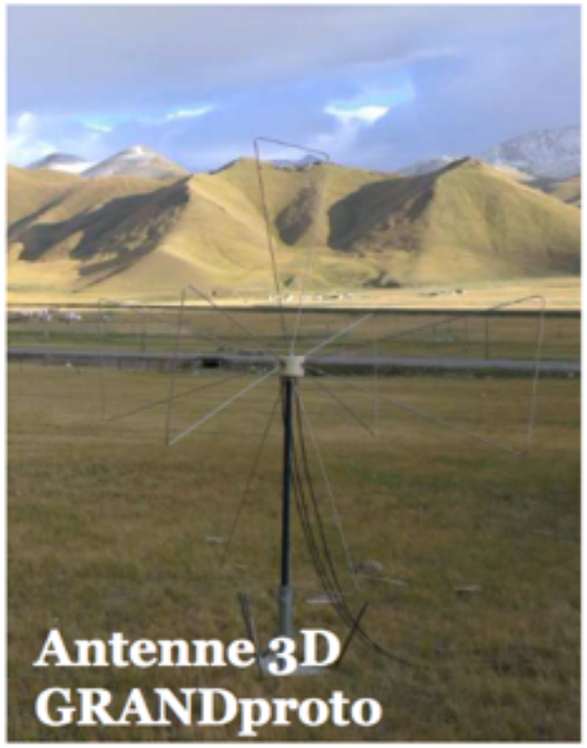


1007.4359

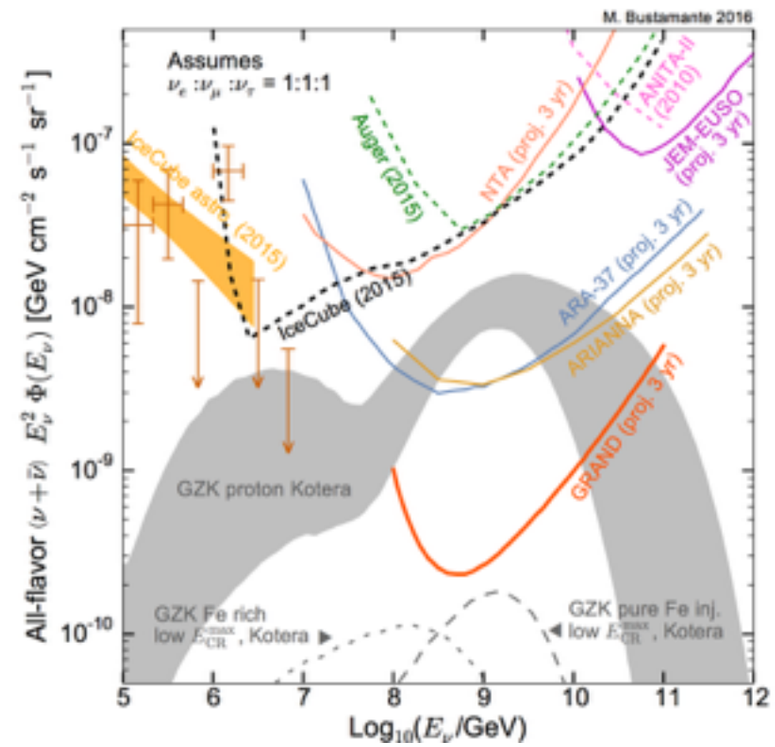
GRANDproto

EXPLORATORY setup to investigate on the potential of polarization measurement for air shower identification

- Array fully funded by NAOC & IHEP.
- Hybrid setup: 35 3-polar antennas + 24 scintillators
- 6 antennas & 6 scintillators deployed in summer 2015 to test hardware, DAQ and reconstructions to be completed in summer 2016
- Radio array electronics developed at LPNHE, to be validated on site March 2016.



Summary



Giant radio array to detect cosmogenic neutrinos even in the most pessimistic case.

Possible timeline:

2016: GRANDproto + proposal

2018: engineering array of ~1000km^2

2021: start building full array

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)
- Julia Schmid (Laboratoire AIM, Université Paris Diderot/CEA-IRFU/CNRS)
- Charles Timmermans (SUBATECH, CNRS-IN2P3, Université de Nantes)

23 people
Expertise from TREND and theory

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)

Netherlands, Belgium, Sweden:

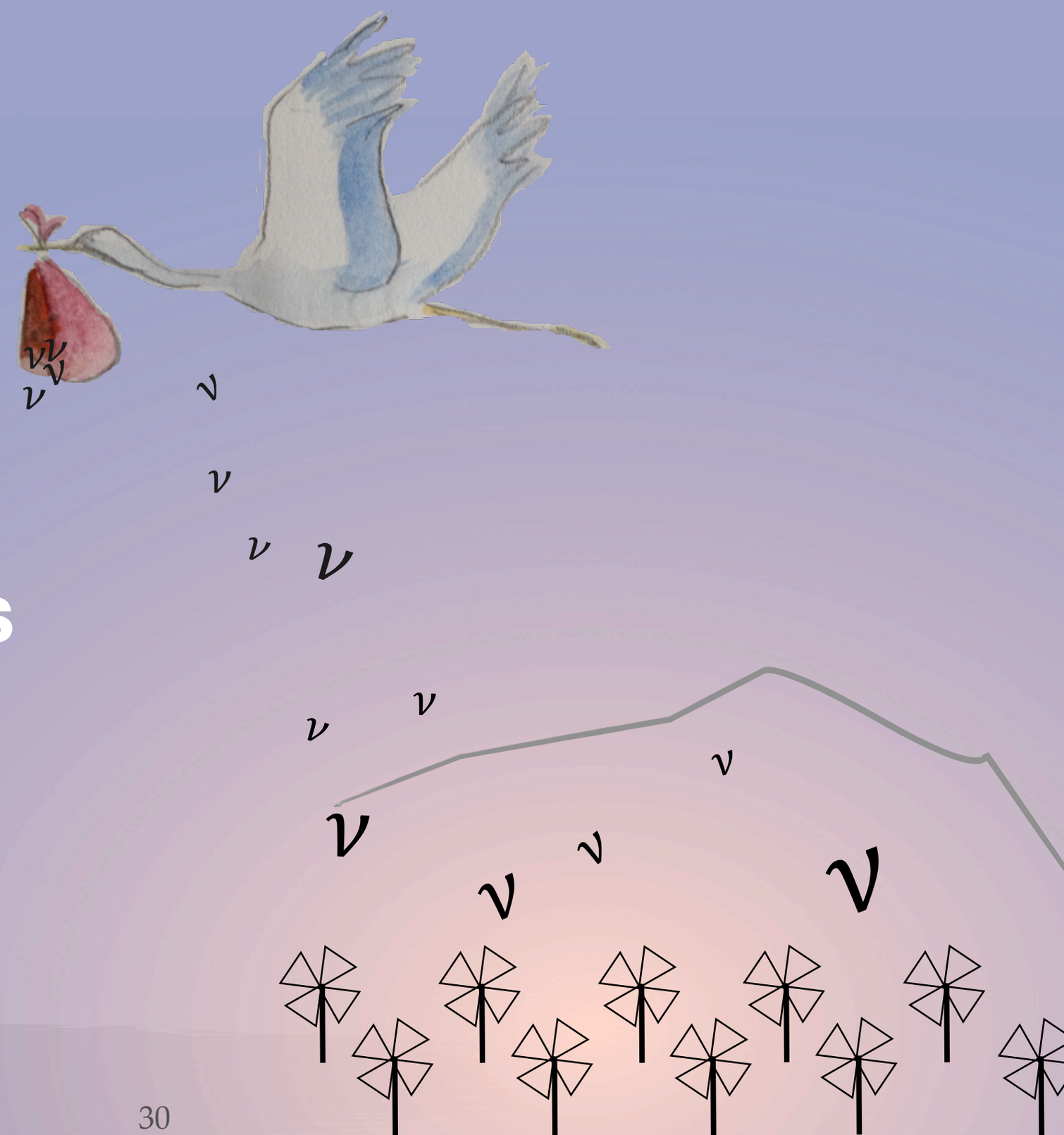
- Sijbrand De Jong (Nikhef/Radboud University, The Netherlands)
- Krijn D. de Vries (Vrije Universiteit Brussel, Belgium)
- Chad Finley (Oskar Klein Centre and Dept. of Physics, Stockholm University, Sweden)

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)

Join us!

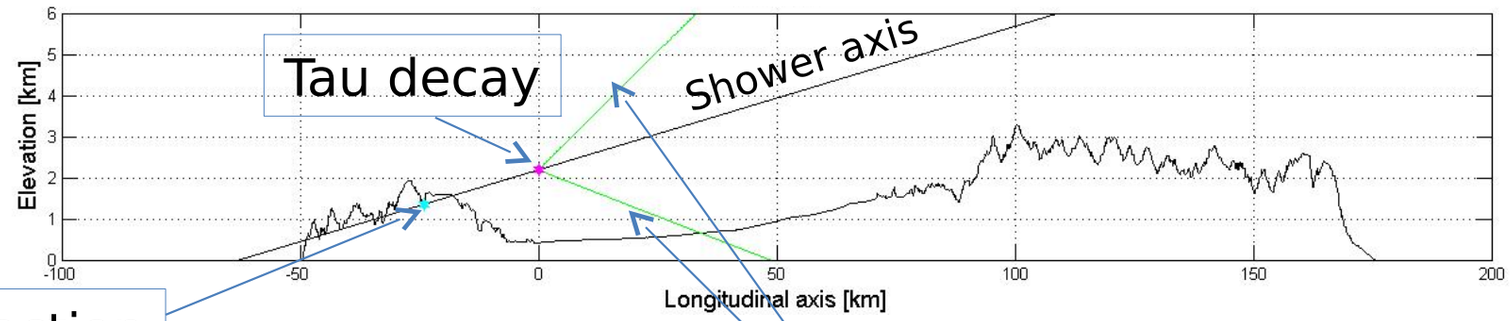
Backup Slides



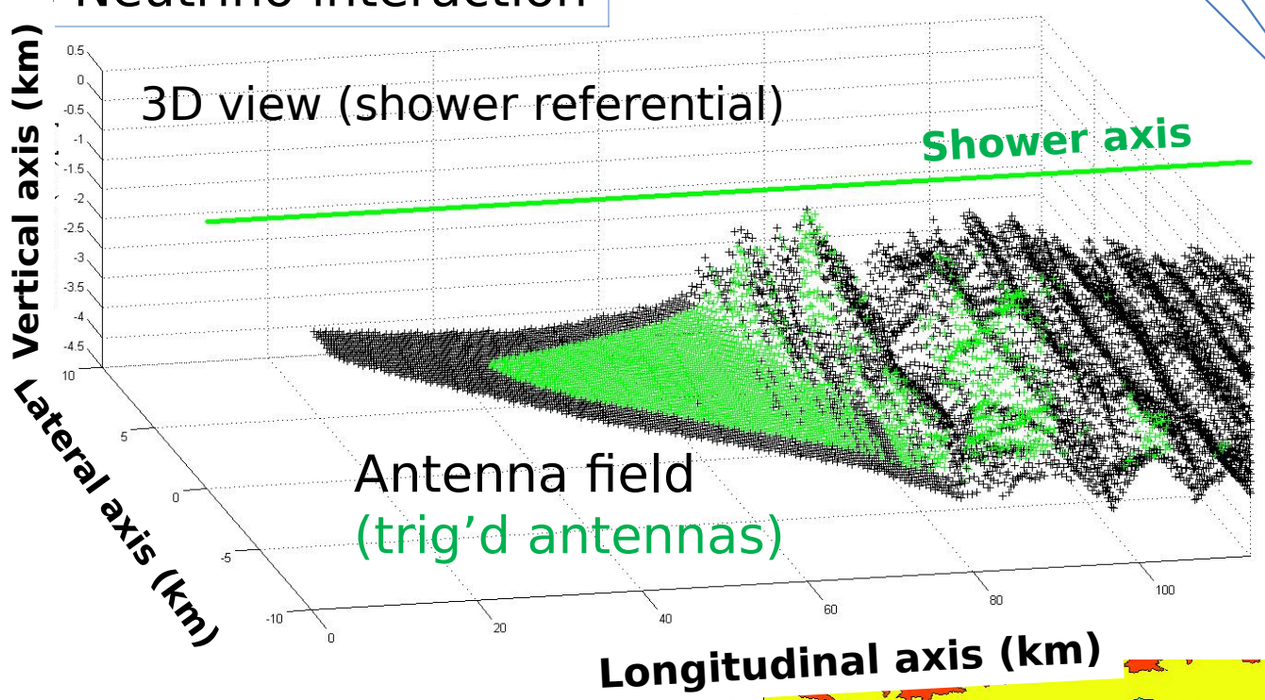
GRAND sensitivity study – simulation

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

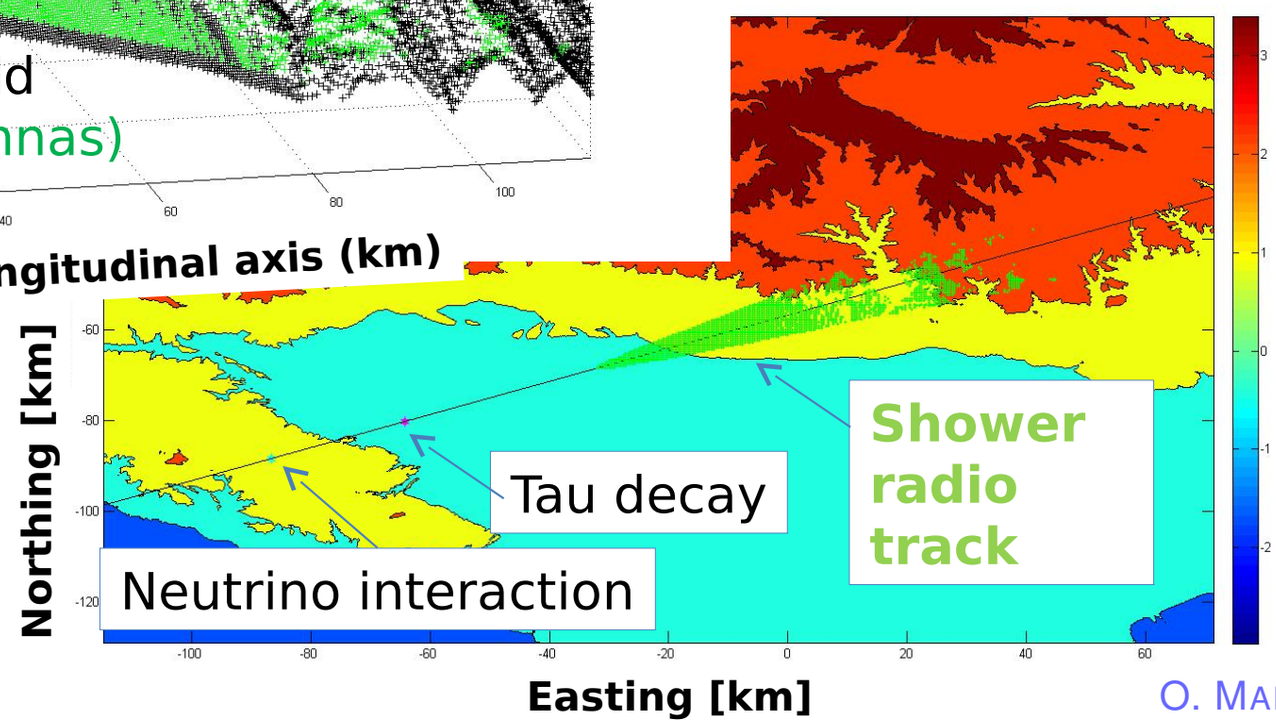
Cut view (Earth referential)



Neutrino interaction



Radio emission cone
(4.5° for E>30μV/m
@ E_{sh} = 2.4 10^{20} eV)



Top view (Earth referential)

O. MARTINEAU

Slide by M. Bustamante