Radboud University

# Search for ultra-high energy neutrinos with the Pierre Auger Observatory

## Current status and ongoing efforts

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22nd Course of ISCRA, Erice

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S. Saffi

# Production

## Cosmogenic neutrinos

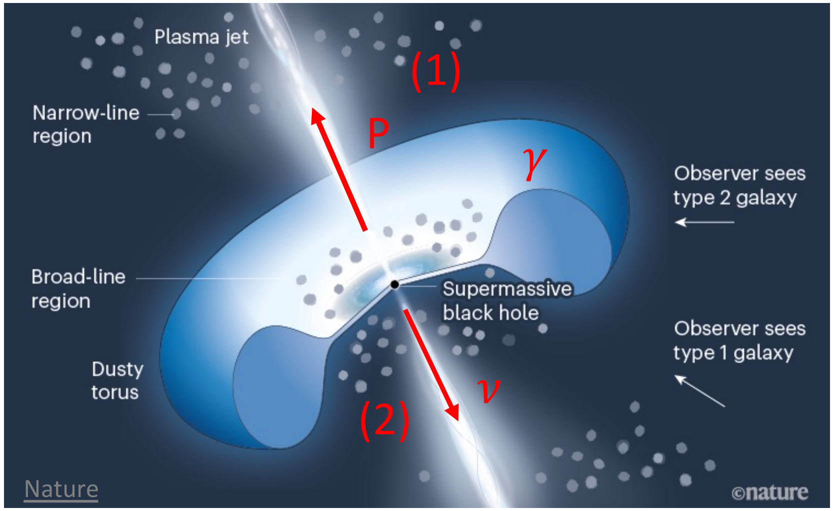
$$p + \gamma_{CMB} \rightarrow \Delta^+ \rightarrow p + \pi^0$$
$$p + \gamma_{CMB} \rightarrow \Delta^+ \rightarrow n + \pi^+$$

$$\pi^+ \rightarrow \mu^+ + \nu_\mu \rightarrow e^+ + \nu_e + \bar{\nu}_\mu + \nu_\mu$$
$\nu_e : \nu_\mu : \nu_\tau = 1:2:0$ (source) $\rightarrow 1:1:1$ (Earth)

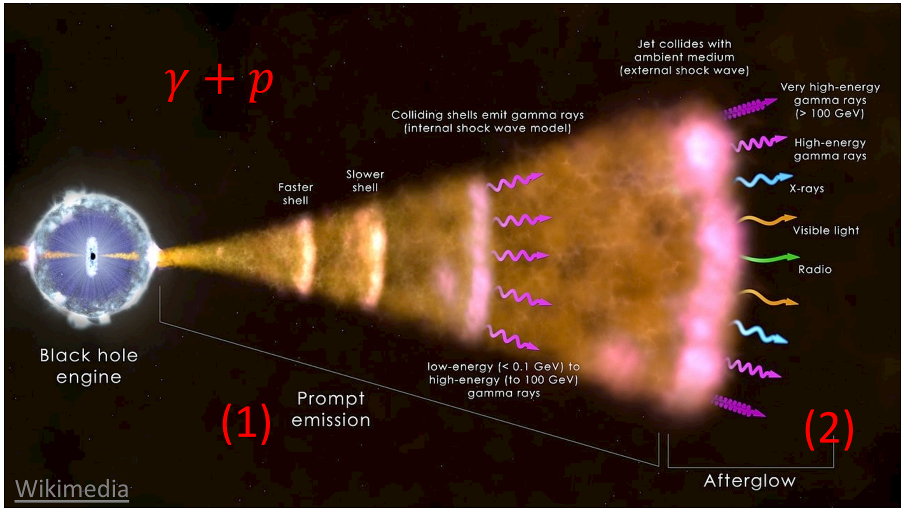
$$(A, Z) + \gamma_{CMB} \rightarrow (A-1, Z-1) + p$$
$$(A, Z) + \gamma_{CMB} \rightarrow (A-1, Z) + n$$

$$E_p > 5 \times 10^{19}\, eV \rightarrow E_\nu \sim 10^{18} eV$$

## Astrophysical Neutrinos




(1) AGN jet model, (2) AGN core model




(1) Prompt neutrinos

(2) Afterglow neutrinos


Mohit Saharan (m.saharan@science.ru.nl)

# What can we learn?

Neutrinos point back to the source → Source identification

UHE neutrino flux can tell us about:

- Distribution of CR sources with redshift (time) →
  - No evolution
  - Star formation rate
  - AGN (FRII)
  - Strong GRBs

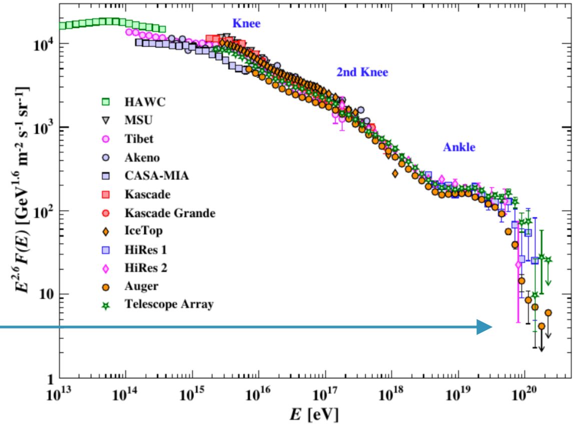
- Primary composition

$$\nu_{Fe}^{Flux} = \sim \frac{1}{10} \nu_{p}^{Flux}$$

→ Constraints:

- neutrino production models
- CR acceleration models
- Flux suppression due to GZK effect or due to maximum rigidity of the sources?

- Cosmological evolution model of the universe

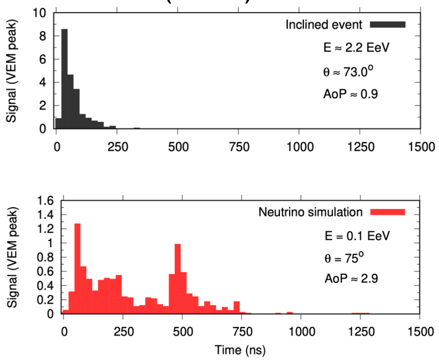


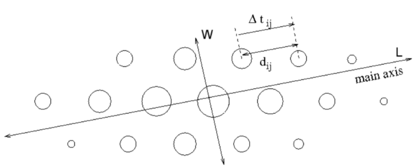

PTEP 2020.8 (2020), p. 083C01

CR sources beyond 100 Mpc

# Identification with the Water Cherenkov Detector

JCAP10(2019)022



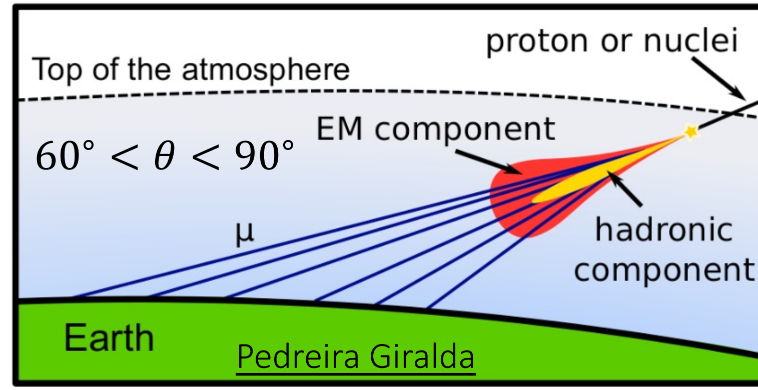

- CR primaries interact early in the atmosphere
- Sharp signal in the WCD (due to muons)

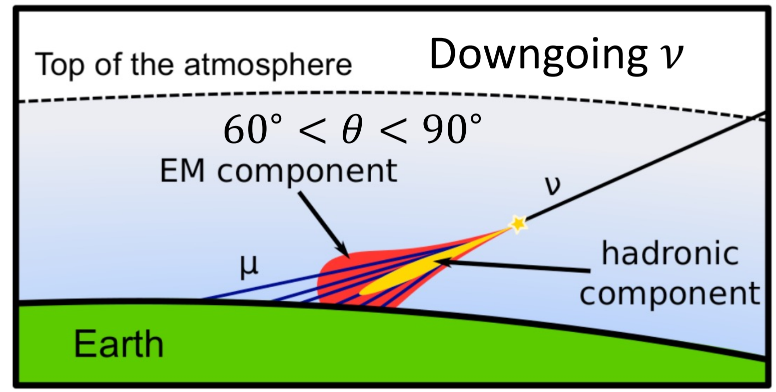
- DG $\nu$: Interact deep in the atmosphere
- Long signal in WCD (due to the electromagnetic component)

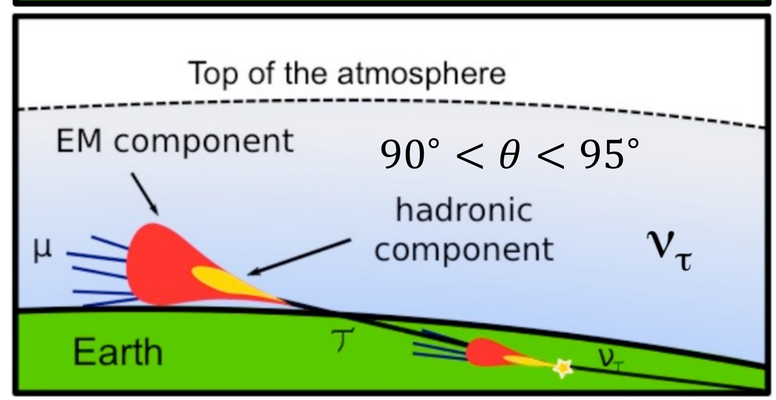
- ES $\nu_\tau$: Highest interaction probability → most sensitive channel

Selection criteria:

- signal arrival time
- # stations
- $\theta_{rec}$
- Footprint pattern
- A variable related to time spread of the signal in WCD

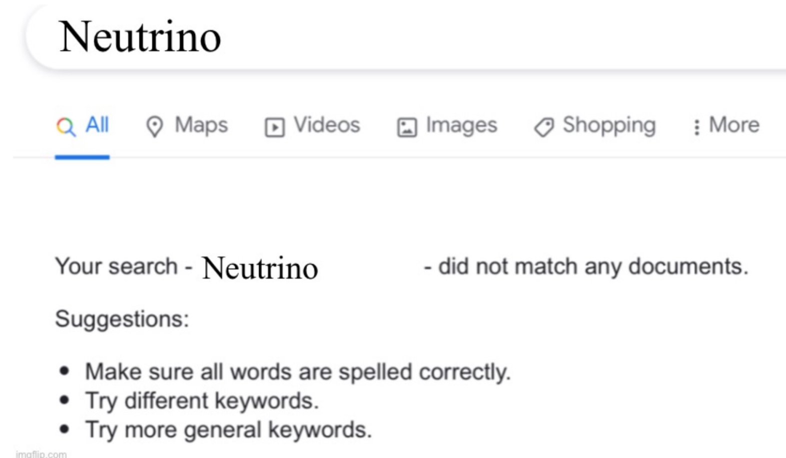


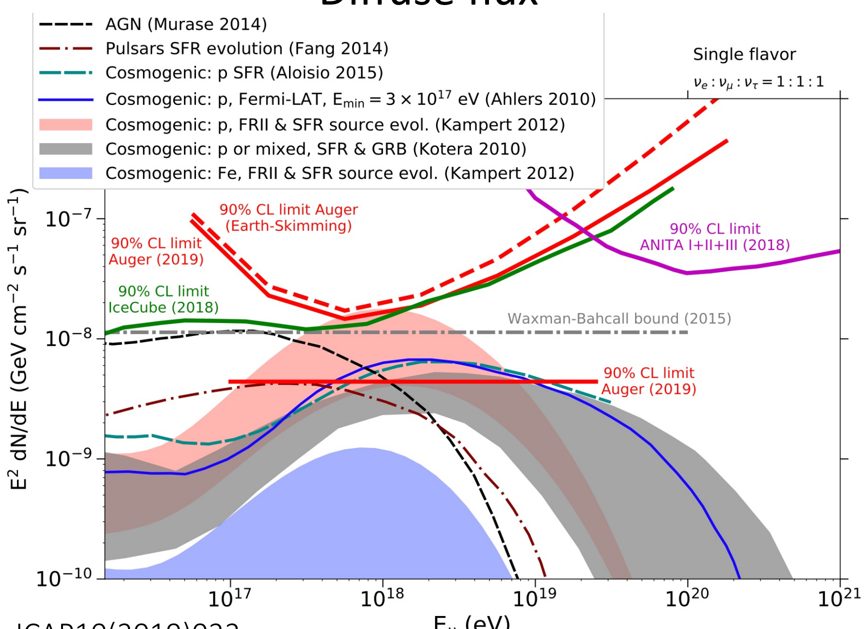
# Searches so far

- No neutrinos detected




- Limits:

## Diffuse flux

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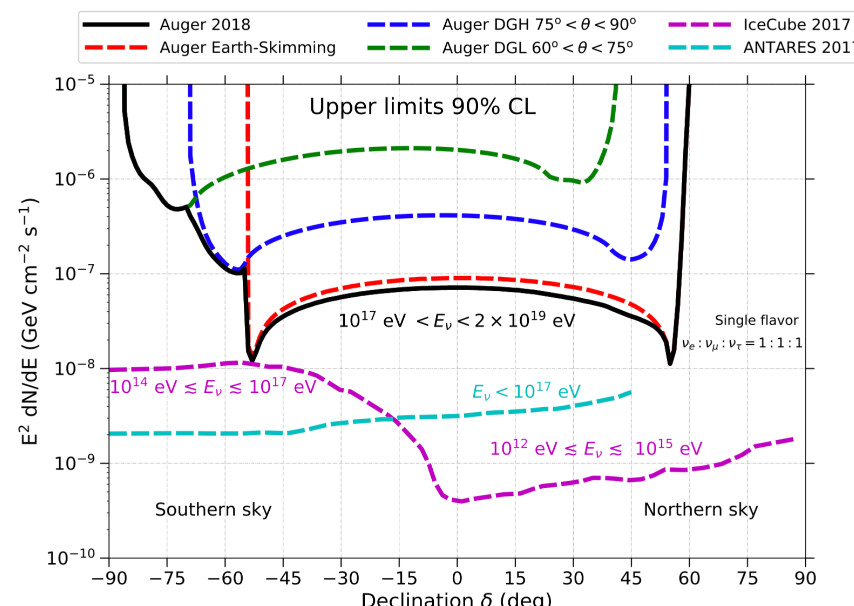
## Point-like sources

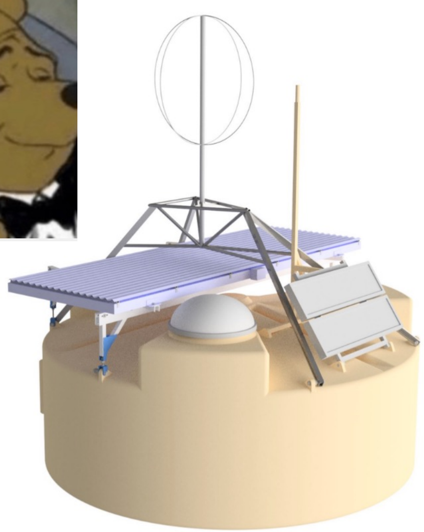


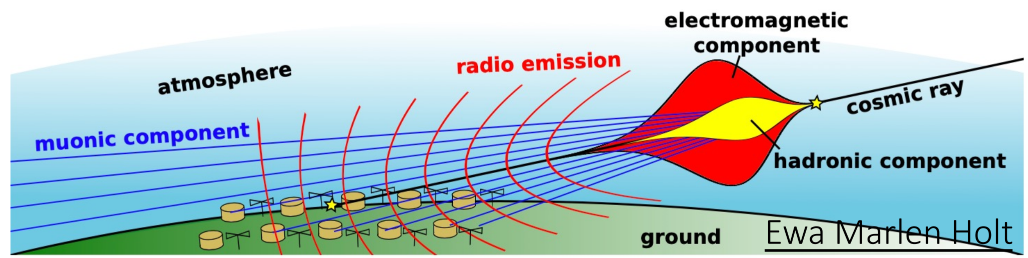

JCAP11(2019)004

# AugerPrime Radio Detector

### Existing online triggers (WCD)

- T1 (station level)
- T2 (station level)
- T3
  - Coincidence in three or more stations
  - Send WCD and RD data to Central DAQ System

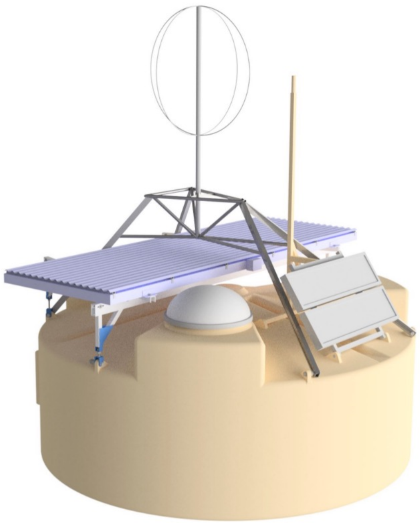



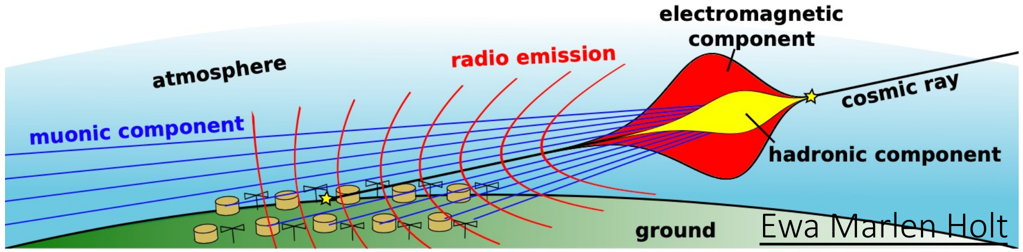



### Expected additional information with RD

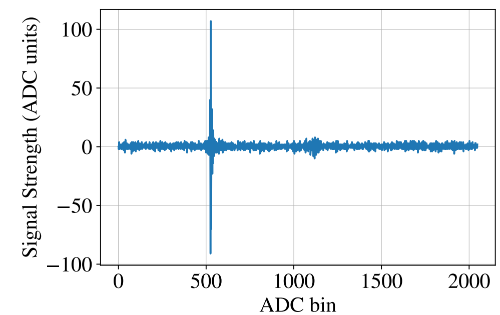
- Sensitivity to distant $\nu$ showers (EM component)
- Discrimination from hadrons
- Radio wavefront and LDF -> shower age

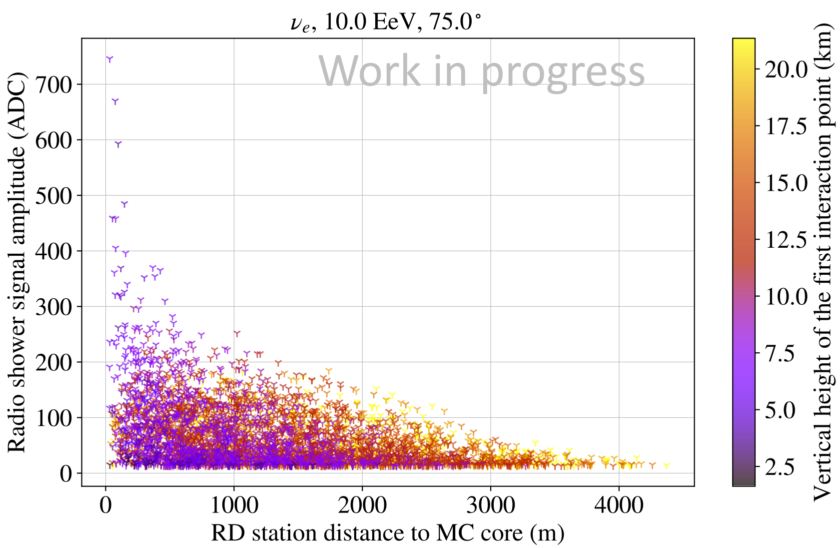
# AugerPrime Radio Detector and the $\nu_e$

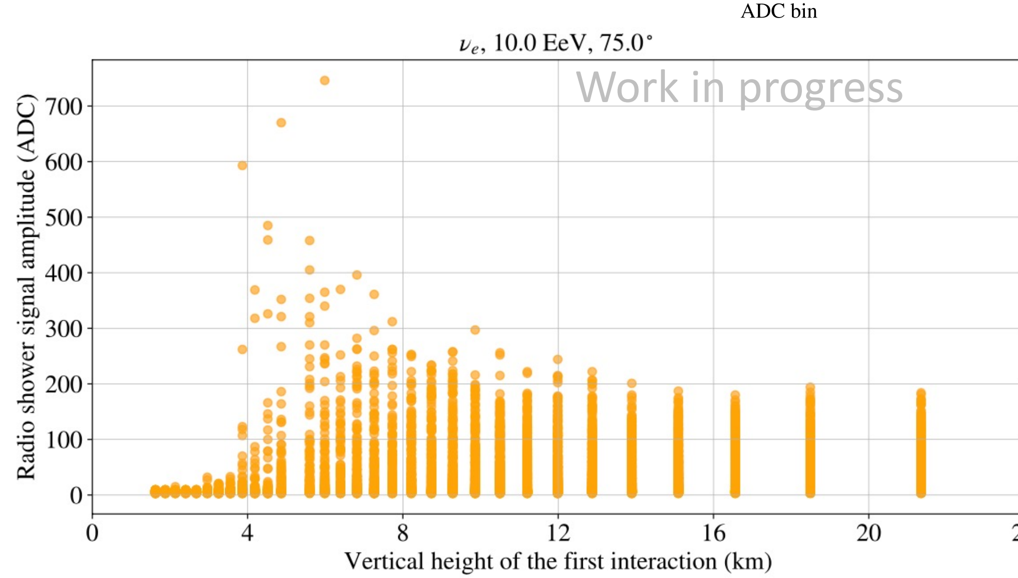




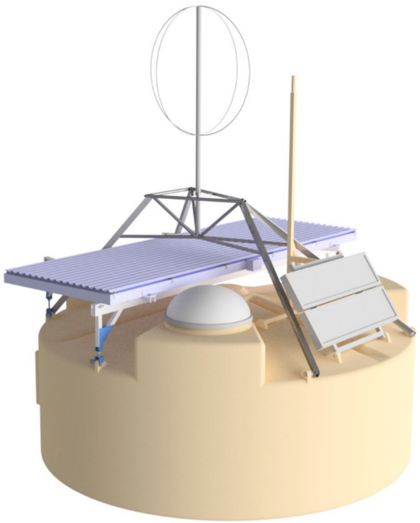

Preliminary study with test simulations

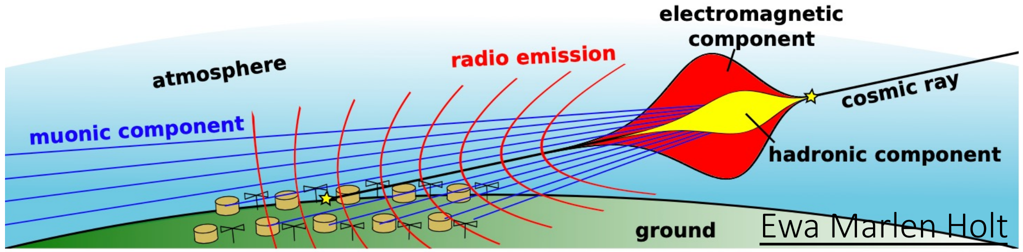


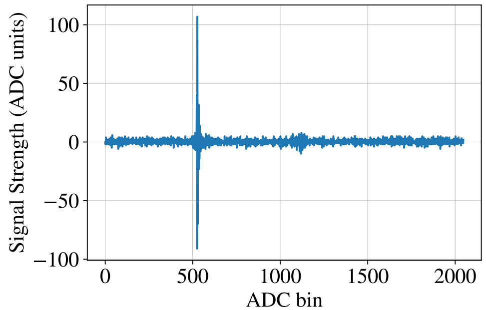
# AugerPrime Radio Detector and the $\nu_e$

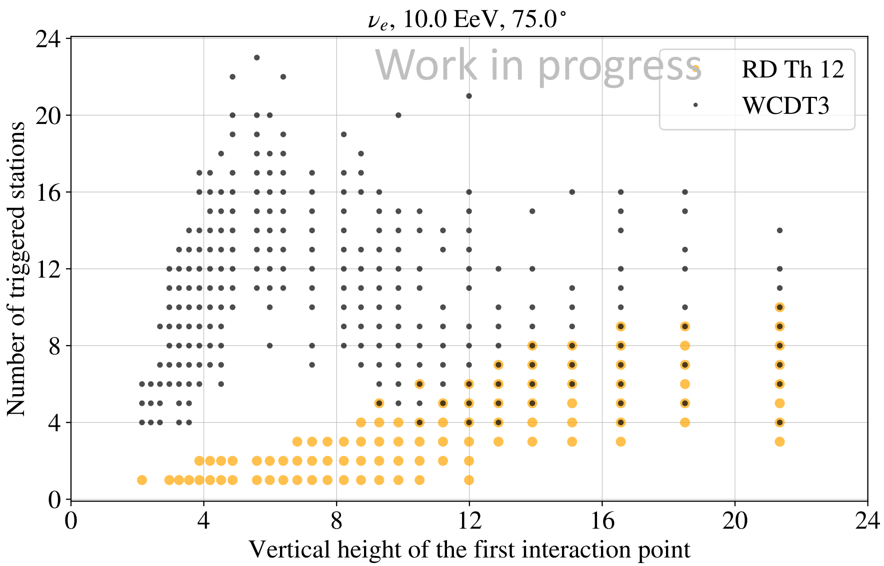


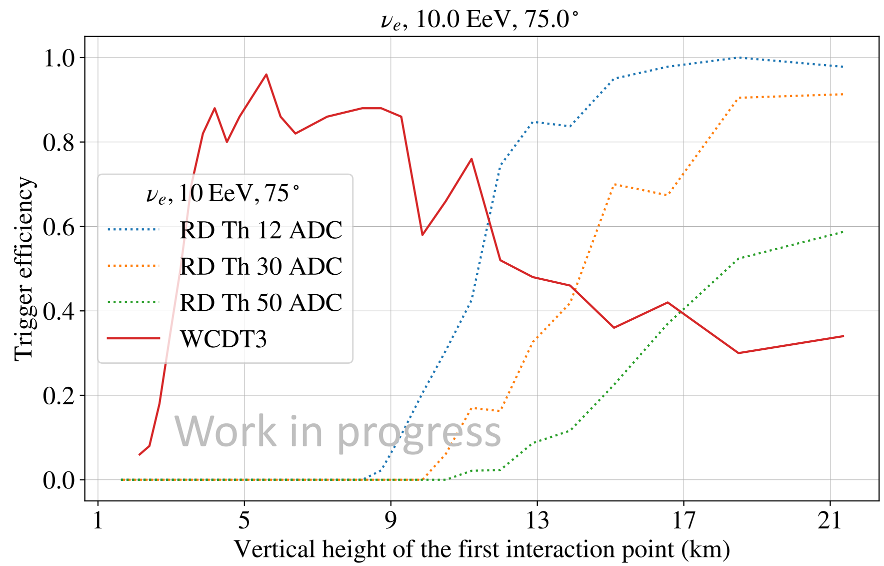



Preliminary study with test simulations

- RD Trigger = 3 Stations above Th.
- Trig. Eff. = # trig. events / # sim. events



# All that glitters is not gold (but it could be) …


We've got issues to solve

- T1 rate limit ~ 100 Hz
- T2 rate limit ~ 20 Hz
- ~ 2 Hz available at both levels
- Simulation of the detector response, new electronics, radio signal arrival time, …
- Zenith dependent antenna response
- Limited computing power available onboard
- …


# The path ahead…

Deployment

Simulations with radio emission

Calibration

Trigger development

Search!

# Some toys for you … 😊

- https://c-glaser.de/physics/radiotools/
- https://www.c-glaser.de/physics/geoceLDF/

By Christian Glaser

## Welcome to radiotools's documentation!

Contents:

- helper
- plthelpers
- coordinatesystems

### default coordinate system and units

The radiotools package uses the 'Auger' coordinate system: A zenith … indicated the zenith and a zenith angle of 90 deg points towards the … azimuth angle counts from East counterclockwise, e.g., phi = 270 d…

Unless explicitly specified in a function, the following default units …

- length: meter
- time: second
- energy: eV
- angle: radian
- mass: grams

## Indices and tables ¶

- Index
- Module Index
- Search Page



## geoceLDF 1.0.0 documentation

WELCOME TO GEOCELDF'S DOCUMENTATION!

Contents

### Welcome to geoceLDF's documentation!

A parametrization of the spatial distribution of the energy fluence in the 30 - 80 MHz band as a function of radiation energy and distance to the shower maximum. The energy fluences of the geomagnetic and charge-excess emission processes are parametrized separately.

The most important function is LDF_geo_ce which provides the parametrization as a function of radiation energy and distance to Xmax only. However, also other parametrizations with more free parameters are provided. Please refer to the documentation of each function for more information.

`LDF.LDF_ce`(*x, y, sigma, k, E, dxmax=None*)

parametrization of the charge-excess LDF as a function of E, sigma and k. If dxmax is provided, the …

**Parameters:**

- **x** (*float or array*) – x position in vxB-vx(vxB) frame
- **y** (*float or array*) – y position in vxB-vx(vxB) frame
- **sigma** (*float*) – width of LDF function
- **k** (*float*) – k parameter of LDF

**Returns:**

**Return type**

## coordinatesystems

*class* `coordinatesystems.cstrafo`(*zenith, azimuth, magnetic_field_vector=None, site=None*)

class to performe coordinate transformations typically used in air shower radio detection

the following transformations are implemented:

From the cartesian ground coordinate system (x: East, y: North, z: up) to

- to the vxB-vx(vxB) system
- to the on-sky coordinate system (spherical coordinates eR, eTheta, ePhi)
- to a ground coordinate system where the y-axis is oriented to magnetic North (instead of geographic North)

and vice versa.

`__init__`(*zenith, azimuth, magnetic_field_vector=None, site=None*)

Initialization with signal/air-shower direction and magnetic field configuration.

All parameters should be specified according to the default coordinate system of the radiotools package (the Auger coordinate system).

**Parameters:**

- **zenith** (*float*) – zenith angle of the incoming signal/air-shower direction (0 deg is pointing to the zenith)
- **azimuth** (*float*) – azimuth angle of the incoming signal/air-shower direction (0 deg is North, 90 deg is South)
- **(optional)** (*site*) – the magnetic field vector in the cartesian ground coordinate system, if no magnetic field vector is specified, the default value for the site specified in the 'site' function argument is used.

## helper

`helper.gps_to_datetime`(*gps*)

conversion between GPS seconds and a python datetime object (taking into account leap seconds)

`helper.datetime_to_gps`(*date*)

`helper.GPS_to_UTC`(*gps*)

`helper.UTC_to_GPS`(*utc*)

`helper.datetime_to_UTC`(*dt*)

`helper.spherical_to_cartesian`(*zenith, azimuth*)

`helper.cartesian_to_spherical`(*x, y, z*)

`helper.get_angle`(*v1, v2*)

`helper.get_normalized_angle`(*angle, degree=False*)

`helper.get_declination`(*magnetic_field_vector*)

`helper.get_magnetic_field_vector`(*site=None*)

get the geomagnetic field vector in Gauss. x points to geographic East and y towards geographic North

`helper.get_angle_to_magnetic_field_vector`(*zenith, azimuth*)

returns the angle between shower axis and magnetic field

`helper.get_magneticfield_azimuth`(*magnetic_field_declination*)

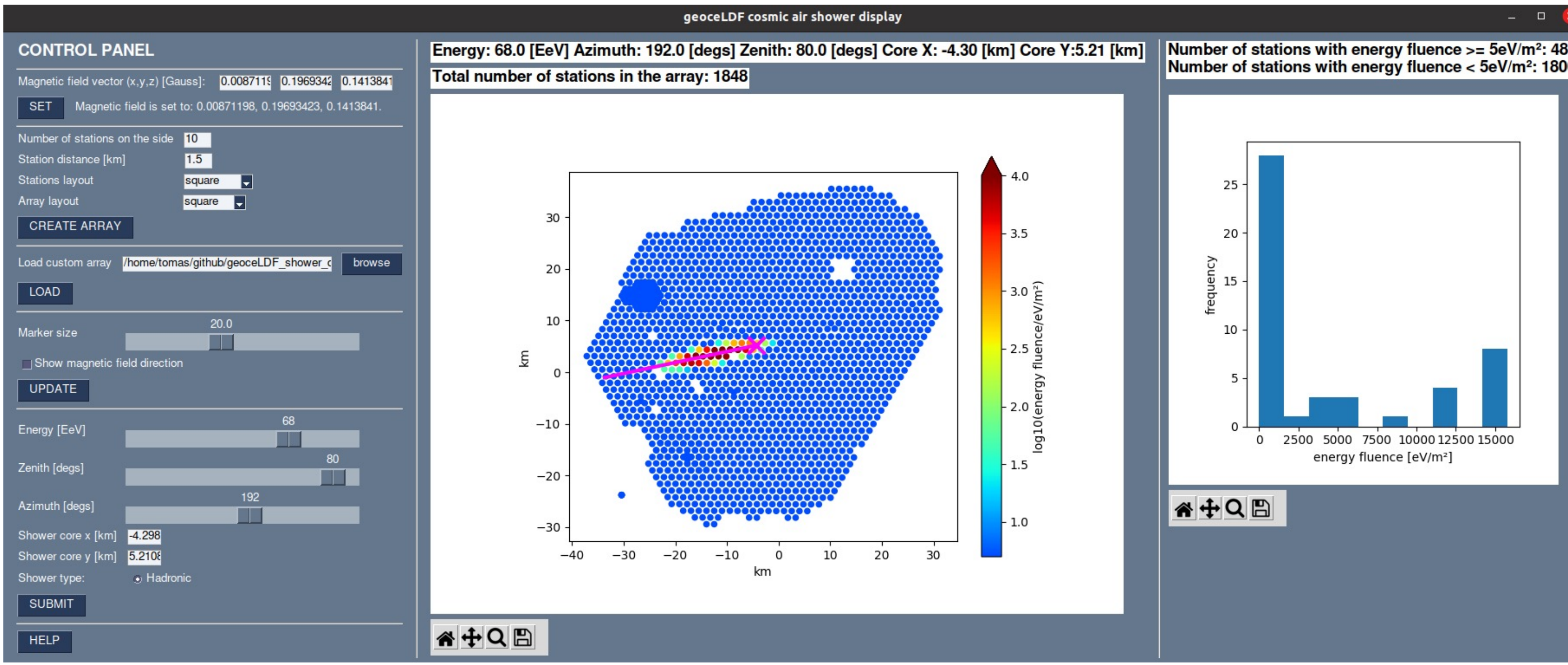
`helper.get_magneticfield_zenith`(*magnetic_field_inclination*)

`helper.get_lorentzforce_vector`(*zenith, azimuth, magnetic_field_vector=None*)

# Some toys for you … 😊

GUI and Python 3:

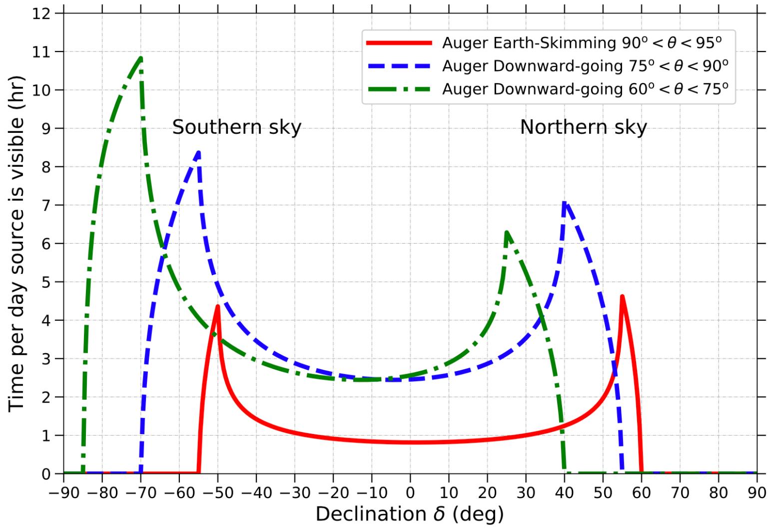
https://github.com/F-Tomas/EAS_array_visualizer (Tomas Fodran, RU Nijmegen)

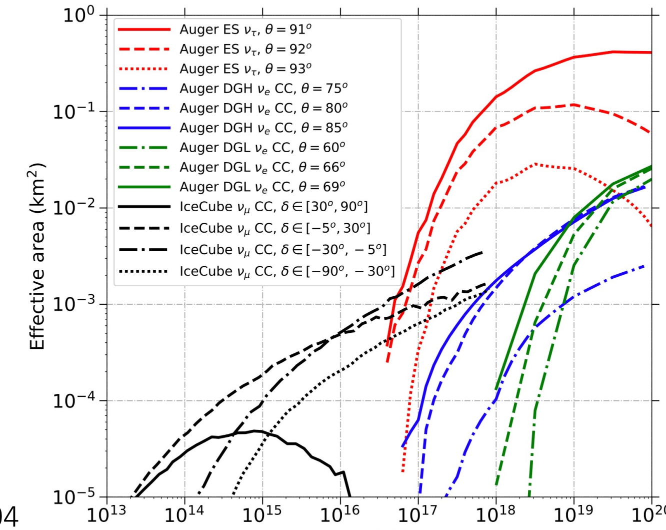



Have fun!

# Extras …

# Extras: Searches so far (point-like sources)

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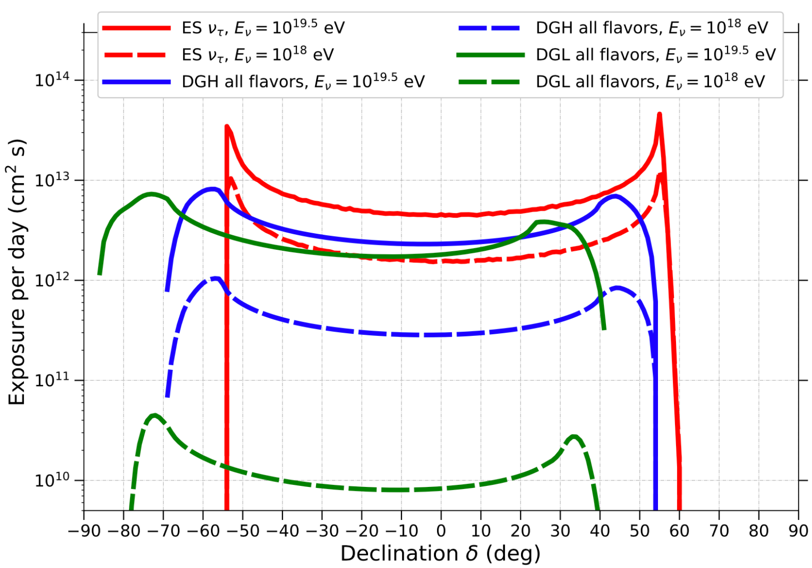


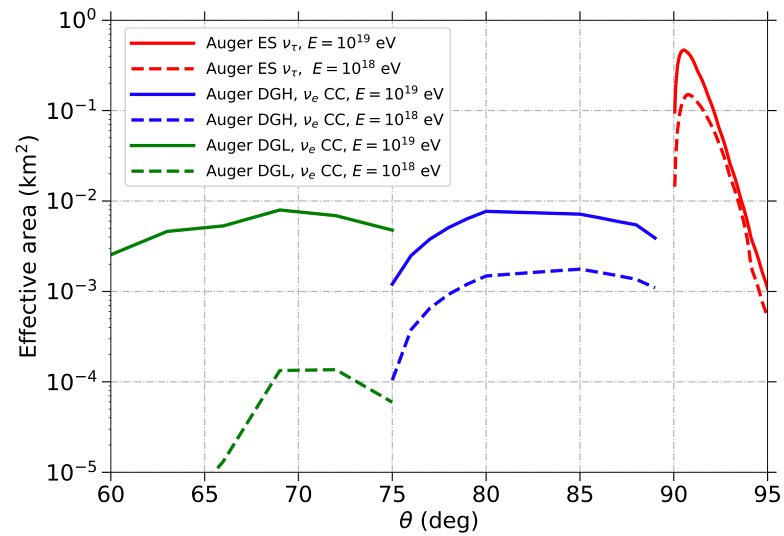

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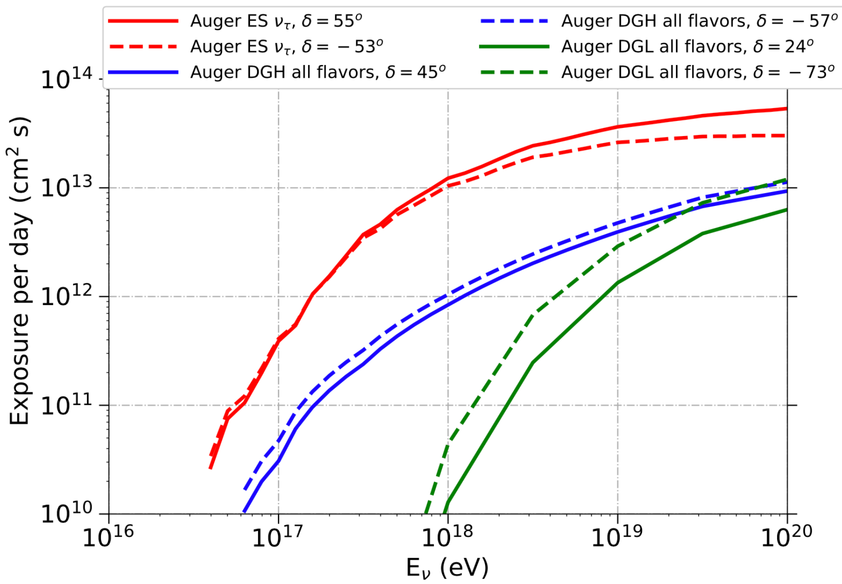


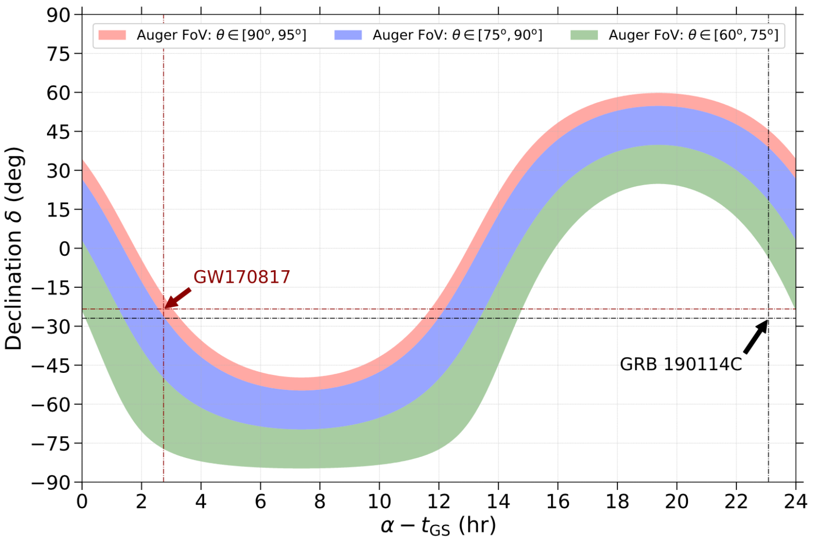


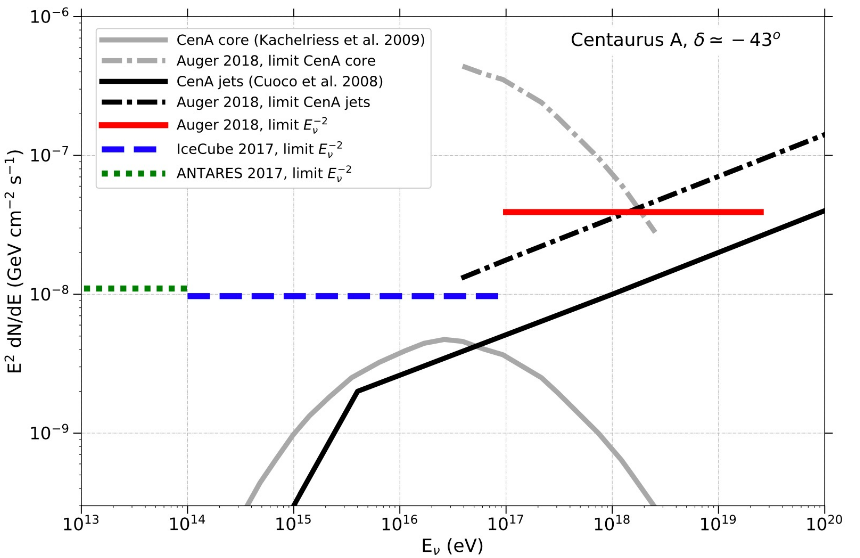


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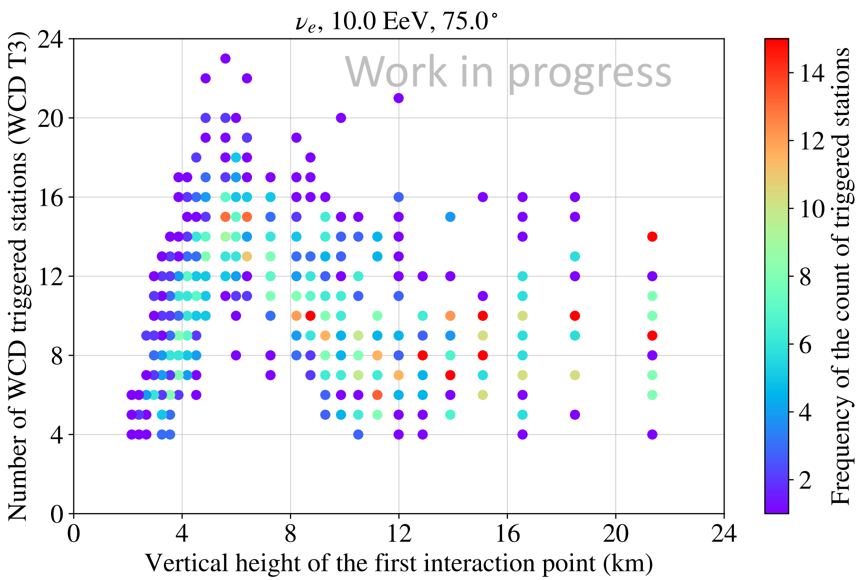
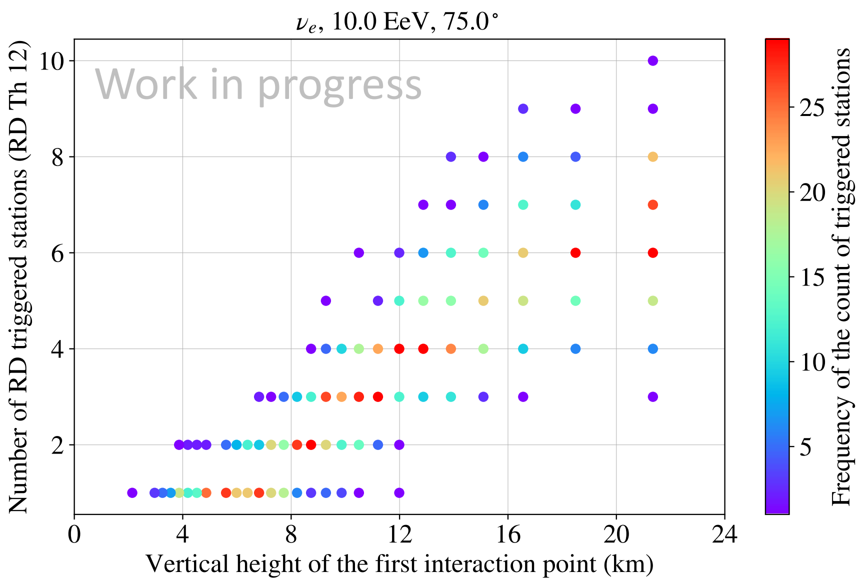
# Extras: Preliminary study with test simulations




Less stations have RD signal per shower but it occurs frequently