Università degli Studi della Campania *Luigi Vanvitelli*

Astroparticle School

KM3NeT arca&orca

EXTREME BLAZAR:
KM3NeT/ARCA Offline follow-up of X-ray flares of Extreme Blazar sources

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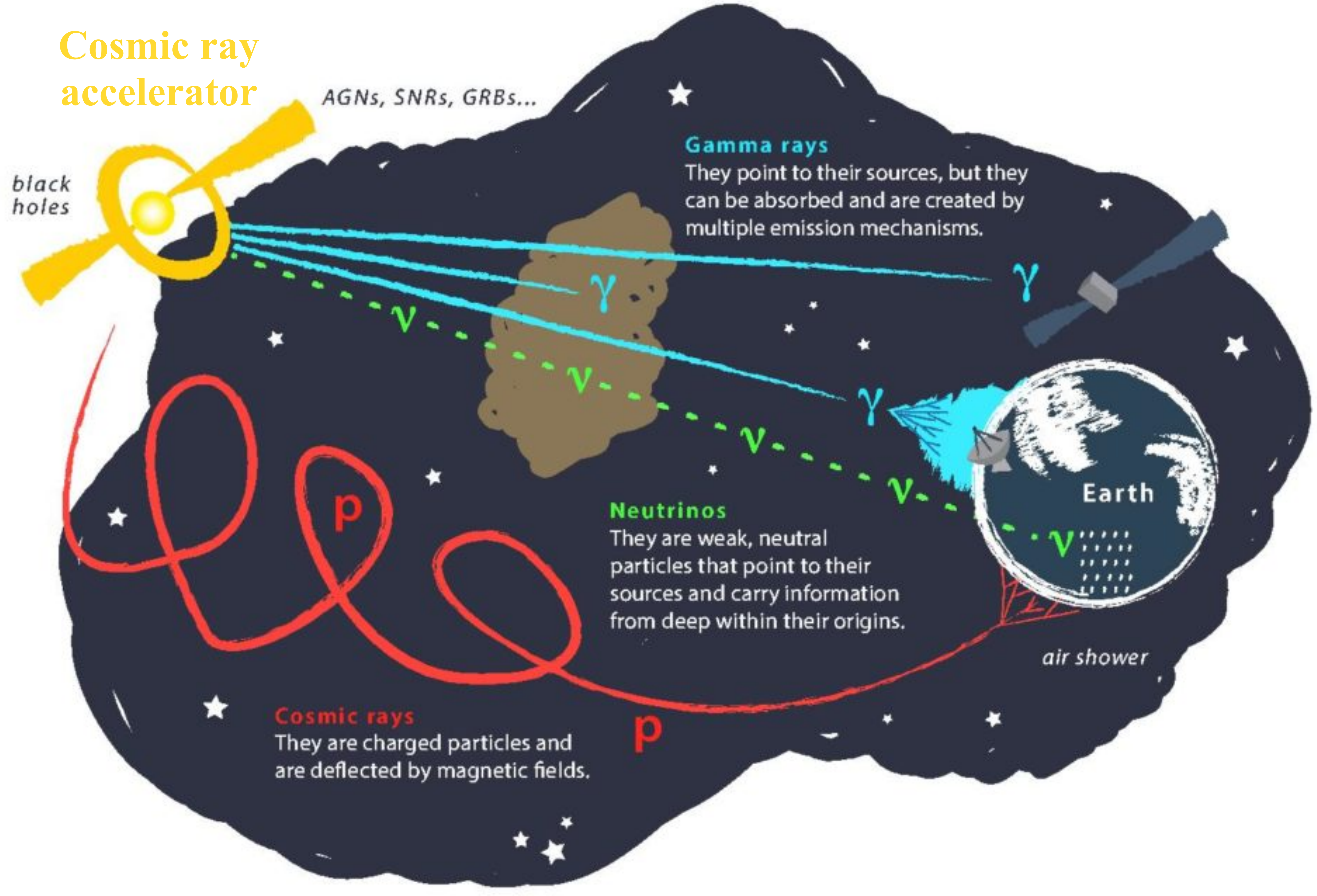
Neutrino astronomy



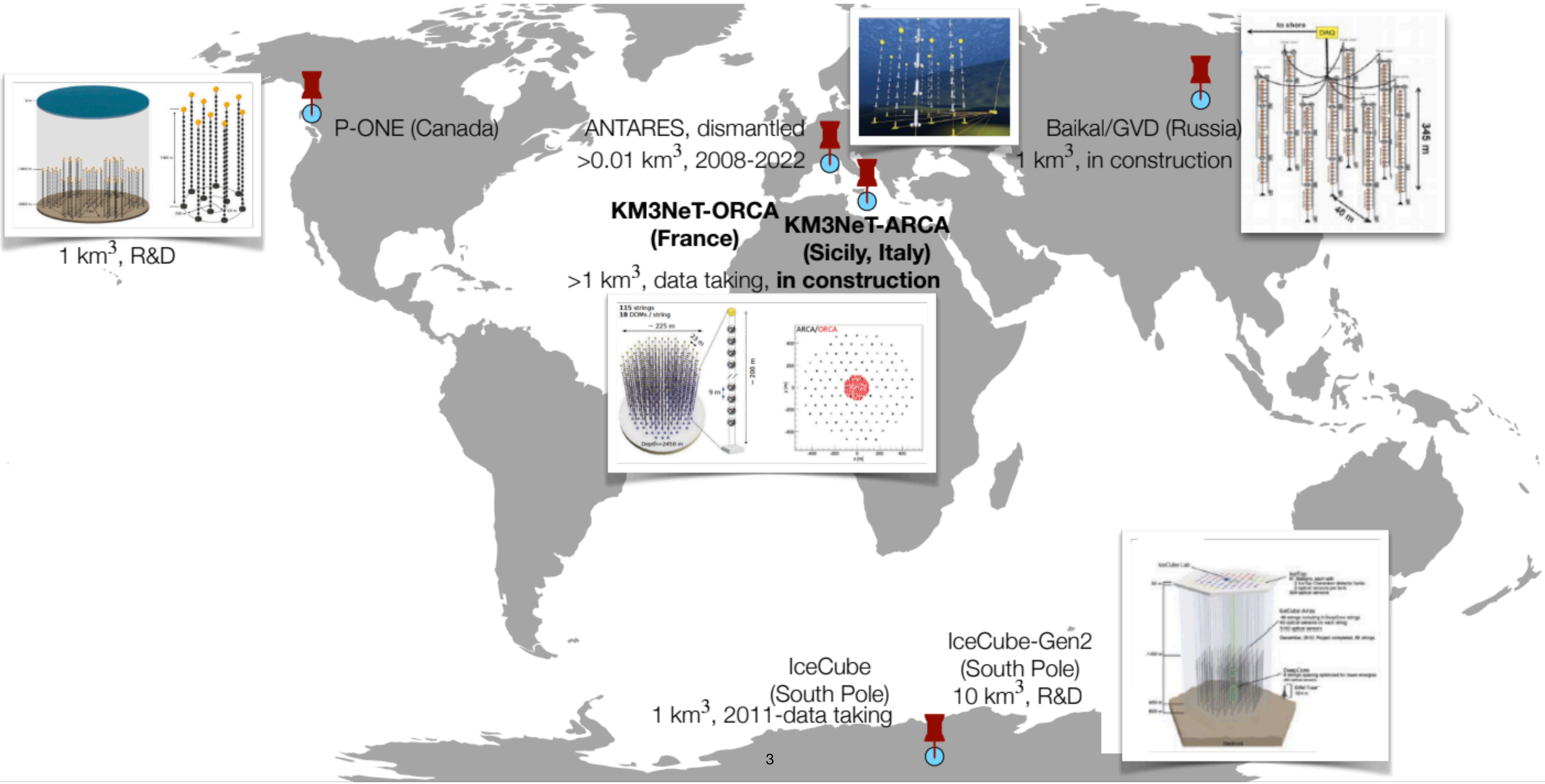
Neutrinos are <u>ideal messengers</u> in the search for distant astrophysical objects

Thanks to its unique properties, neutrino:

- ✳interacts only weakly with matter, so it can bridge large distances without absorption (e.g. Extragalactic Background Light, unlike gamma-rays);
- ✳is not deflected by magnetic fields because it is electrically neutral, unlike cosmic rays;

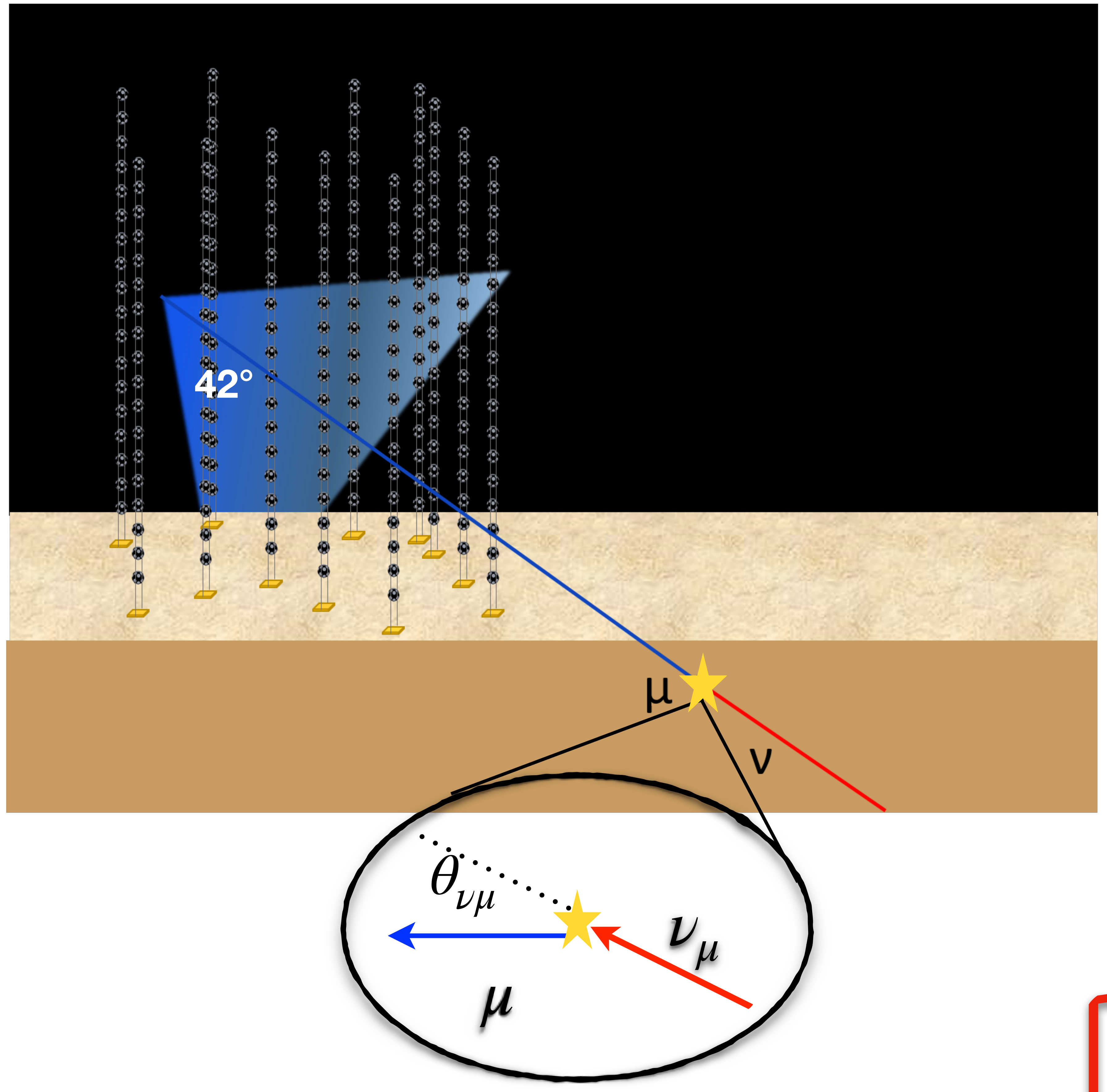
Neutrinos produced by astrophysical objects can provide fundamental proofs about emission mechanisms at work

Neutrino telescopes: World map



Neutrino telescopes: detection principle

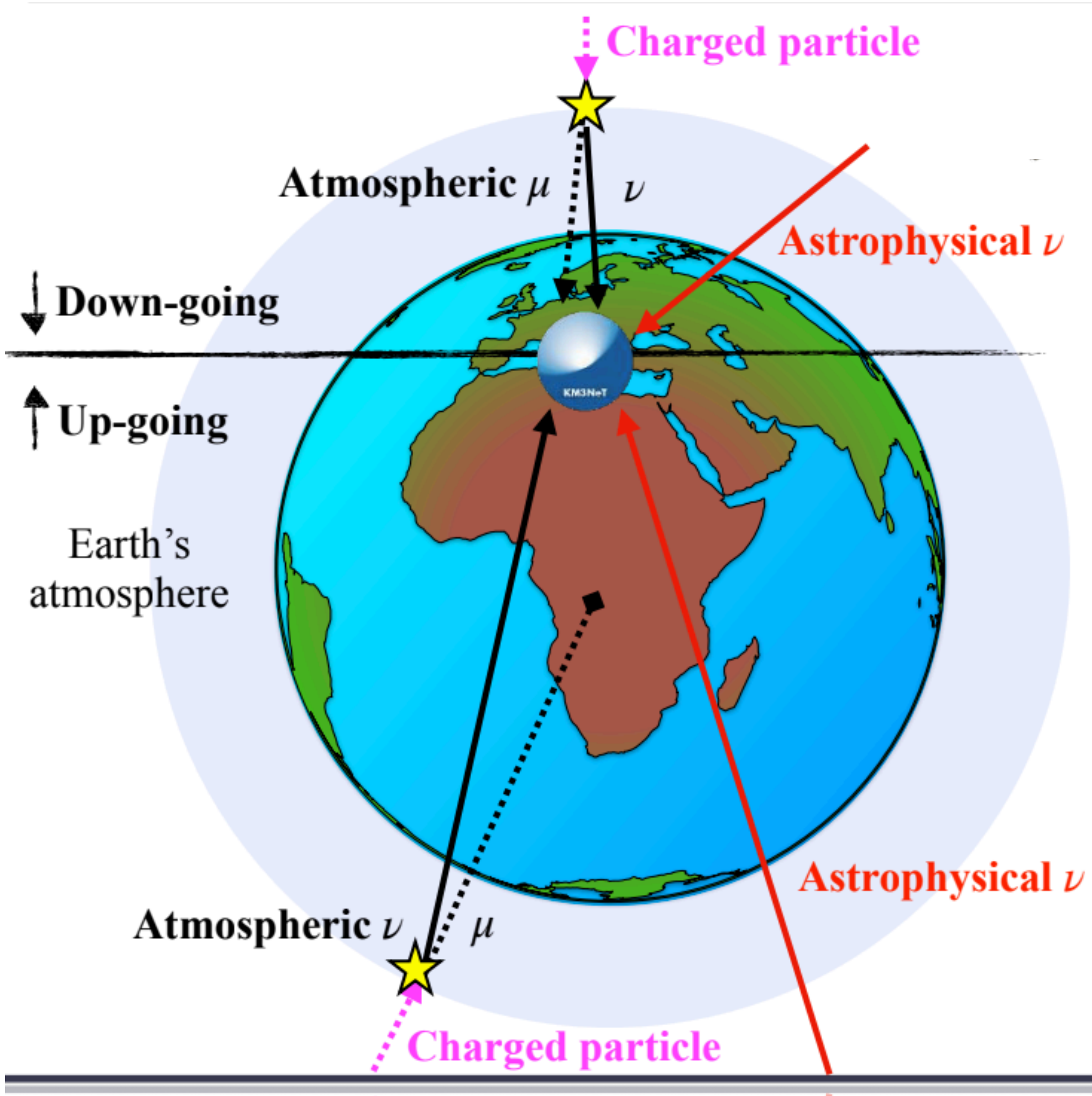
High-Energy Neutrino Astrophysics, John G. Learned, Karl Mannheim; Annual Review of Nuclear and Particle Science, Vol 50: 679-749



$$\nu_\mu + N \rightarrow \mu + X$$

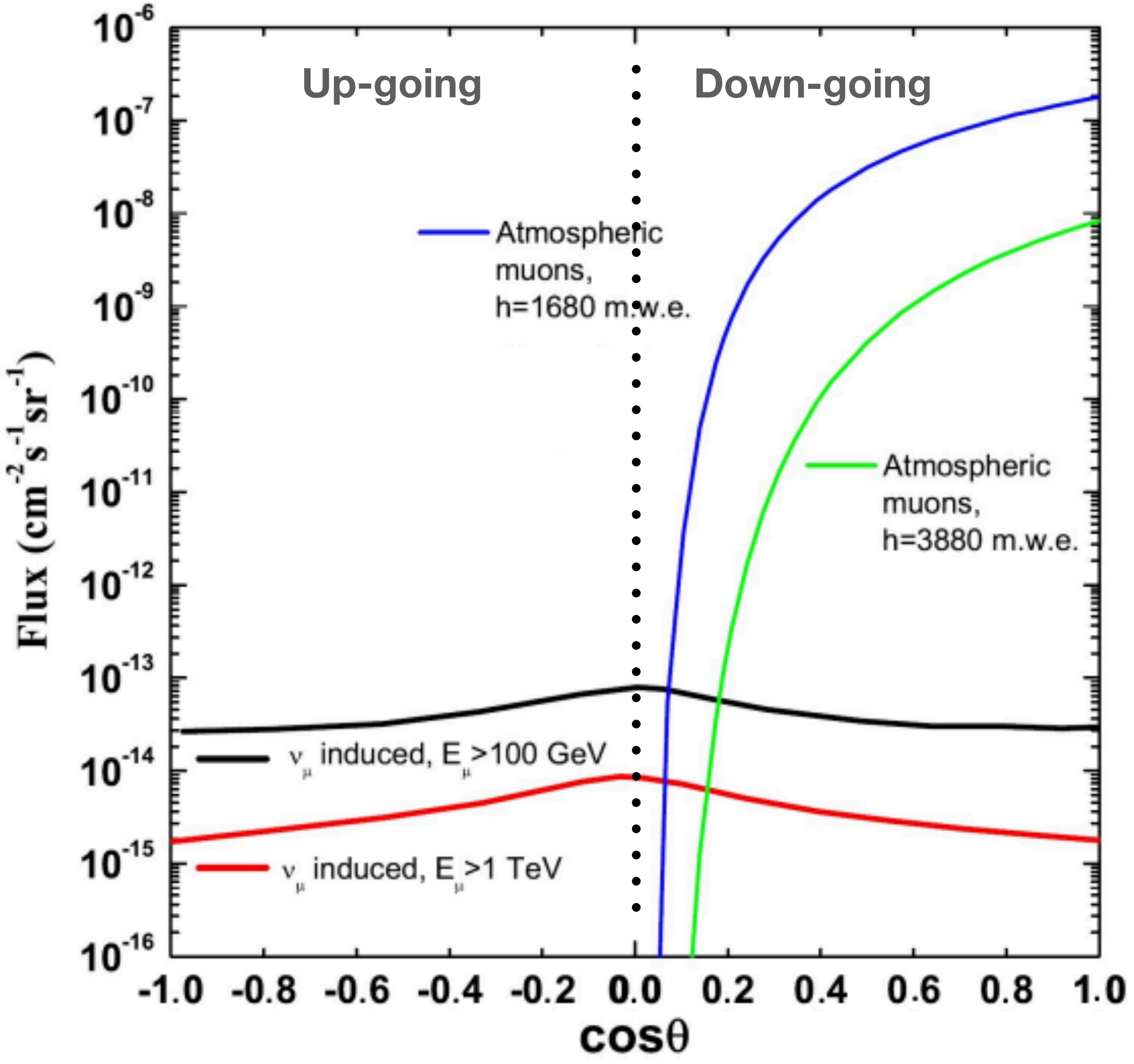
✦charged current interactions ν_μ produce long muon path inside the detector (**track-like events**)

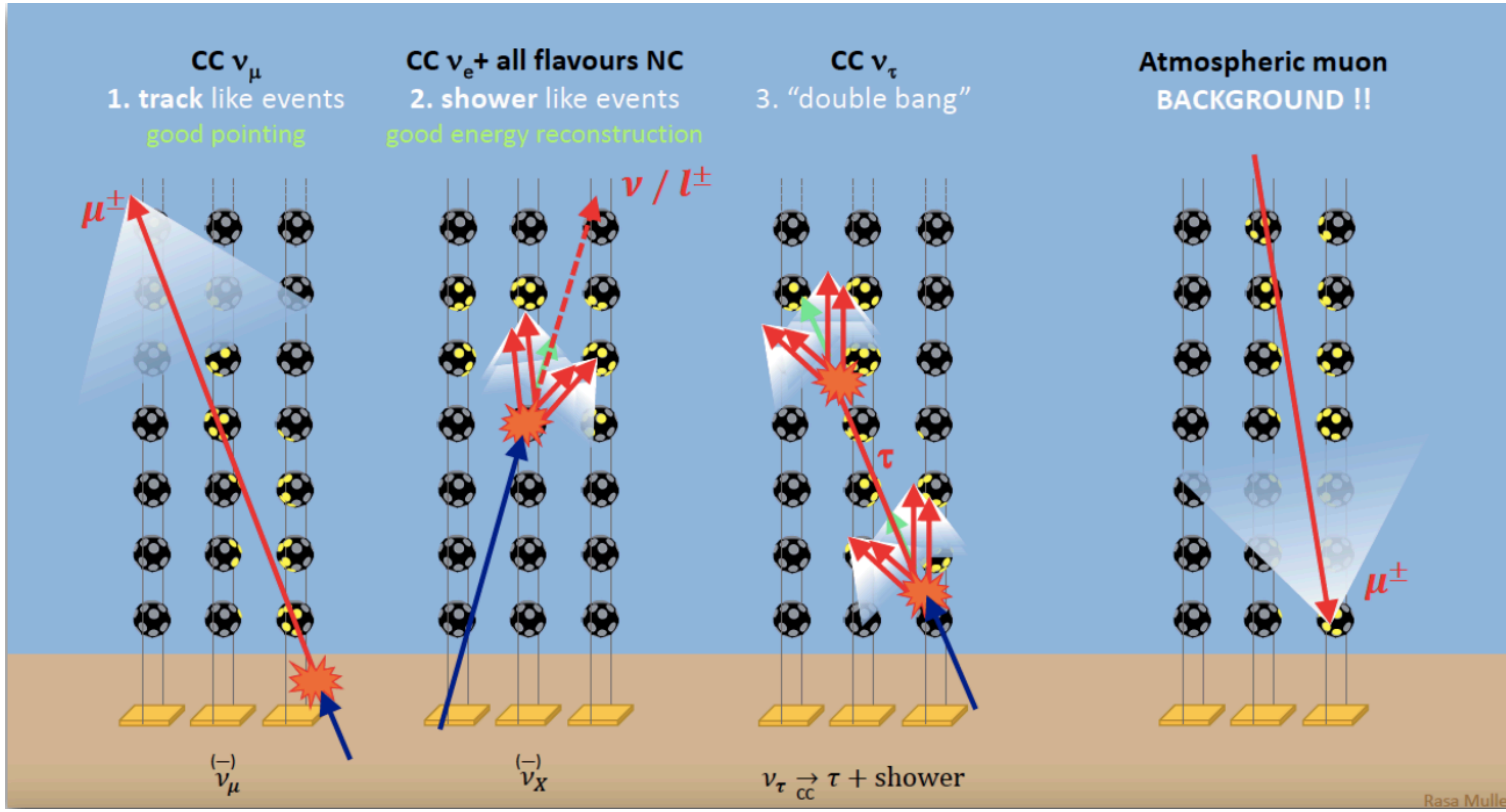
$$\theta_{\nu\mu} \simeq \frac{0.7^\circ}{[E_\nu(TeV)]^{0.7}}$$



Atmospheric background and event topologies

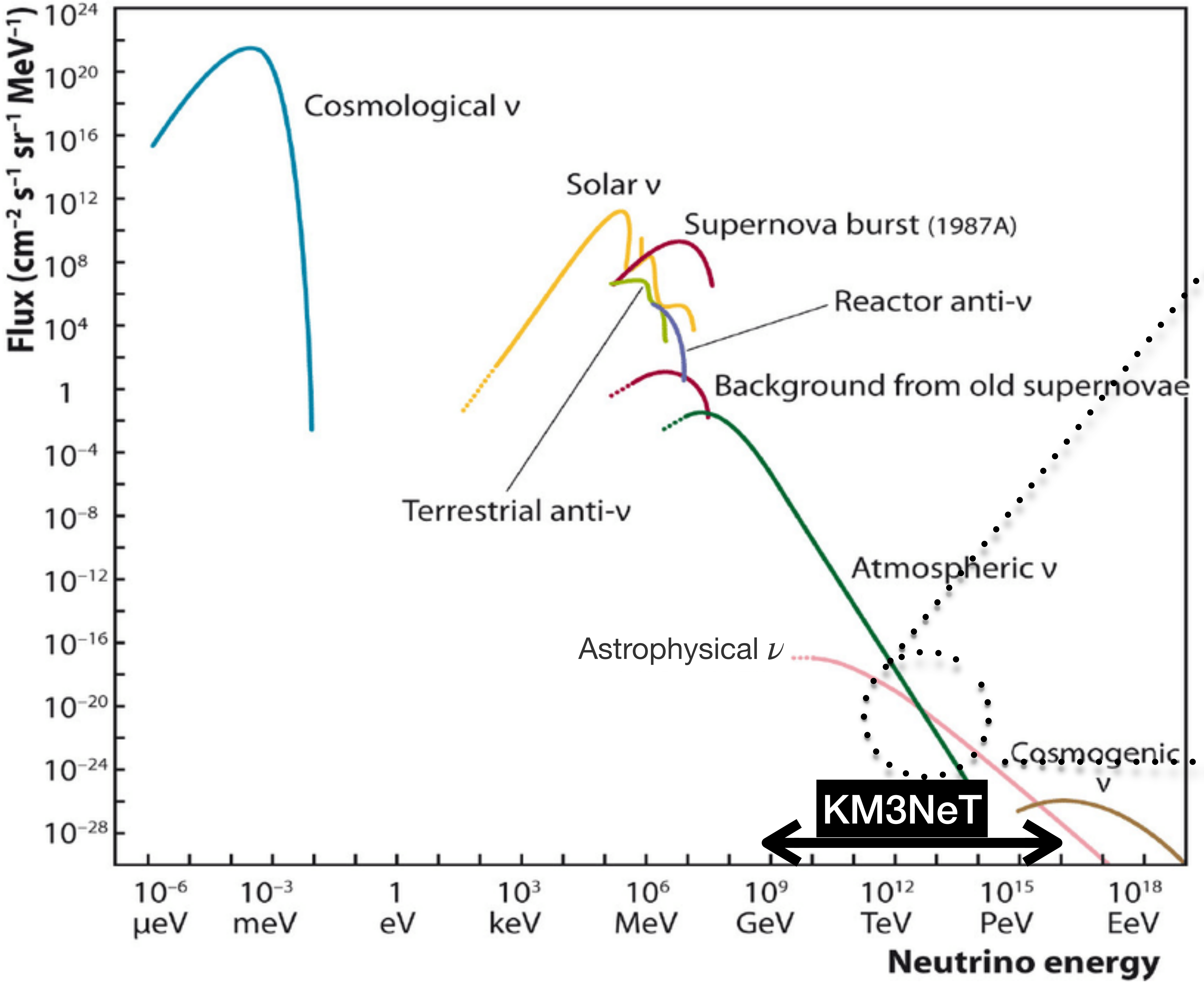
The **Earth** is used as screening against all particles

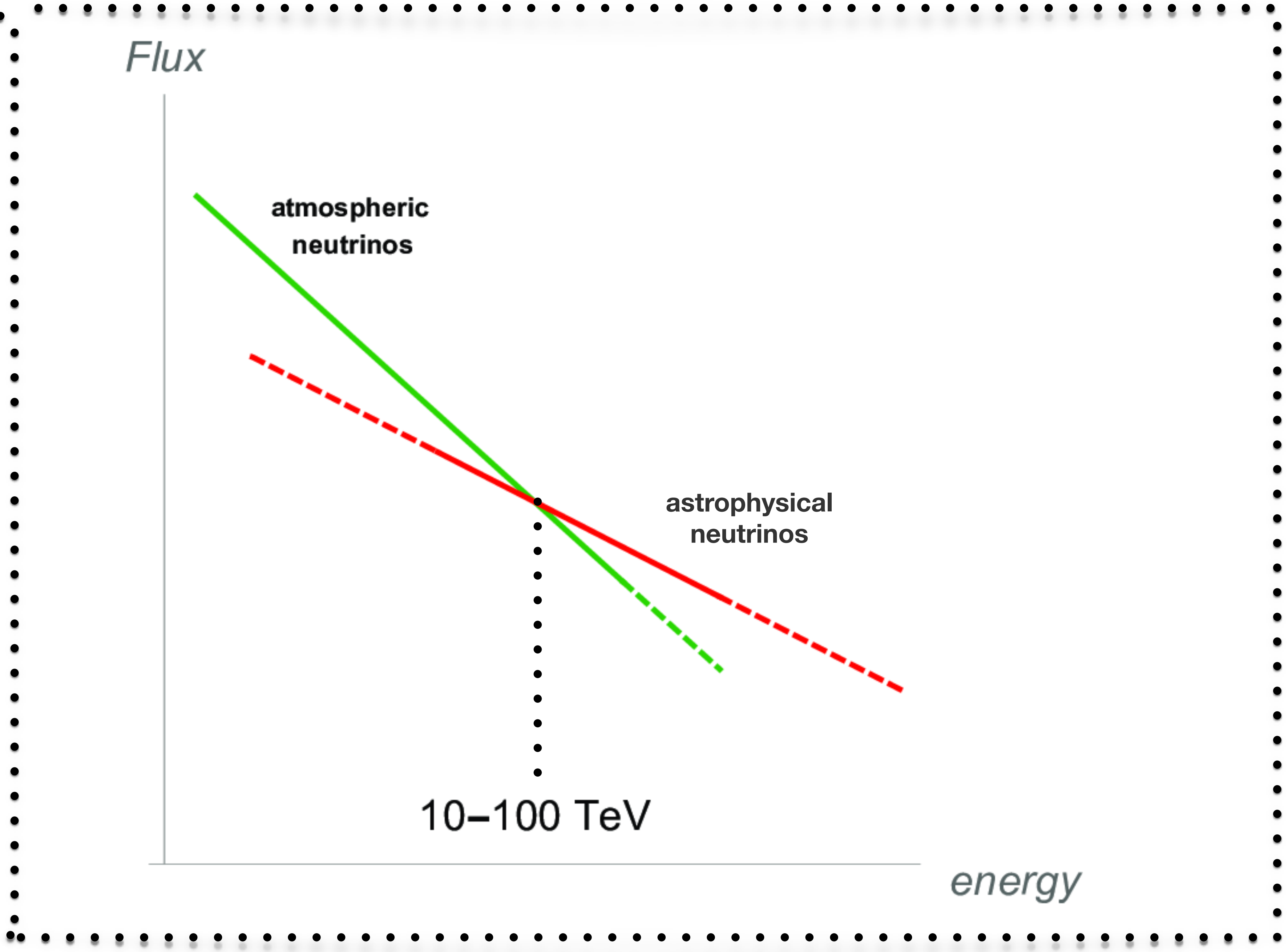




Neutrino spectrum

High-energy neutrino telescopes with astrophysical purposes optimized for E > TeV





KM3NeT Neutrino telescope

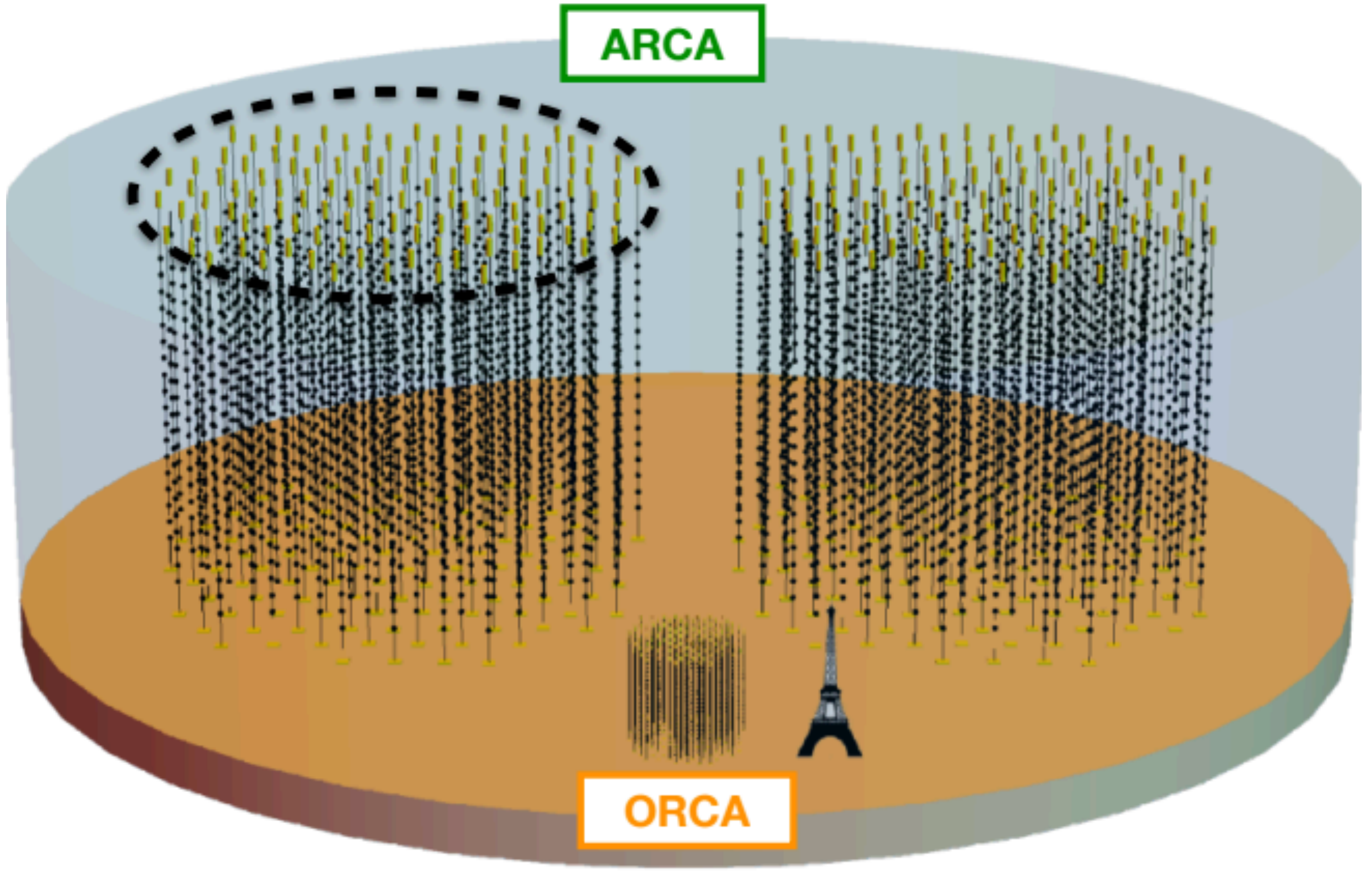
The KM3NeT research infrastructure includes two underwater Cherenkov telescopes in two different abyssal sites of the Mediterranean Sea.

ARCA (Astroparticle Research with Cosmics in the Abyss)
ORCA (Oscillation Research with Cosmics in the Abyss)

The **ARCA telescope**, a future cubic kilometer volume detector focuses on studying the high-energy astrophysical neutrinos in the TeV-PeV range.

The **ORCA telescope**, with a denser instrumented detector volume is optimized to explore the atmospheric neutrino oscillations in the GeV energy range.

3D array of optical sensors



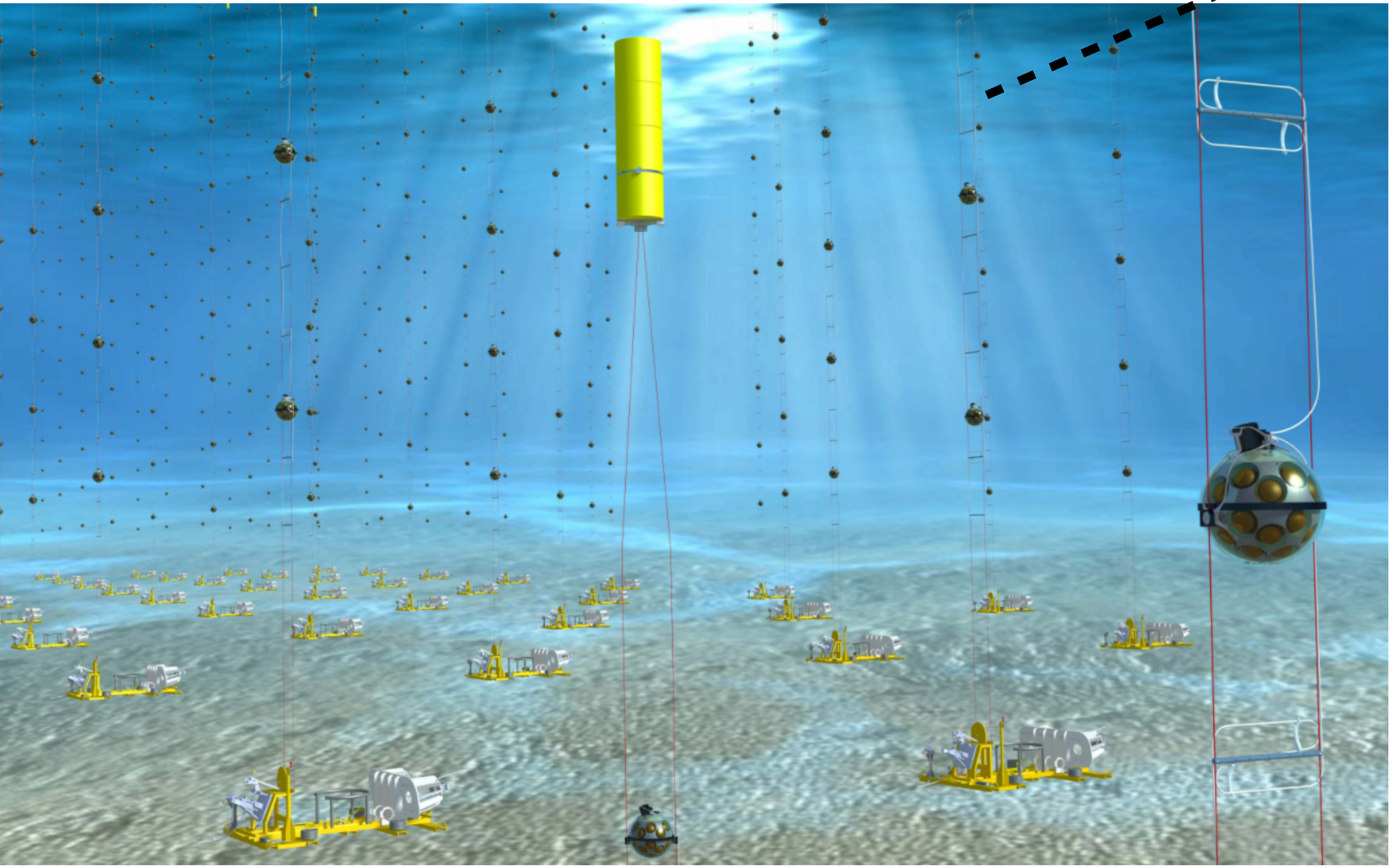
1 Building Block = 115 Detection Units

The detection technology is the same for both telescopes, the scientific goals are distinct thanks to the difference in the geometrical layout.

Track-like event: angular resolution down to 0.1° at 100 TeV

Neutrino spectrum

https://www.km3net.org/



1 DU = 18 DOMs

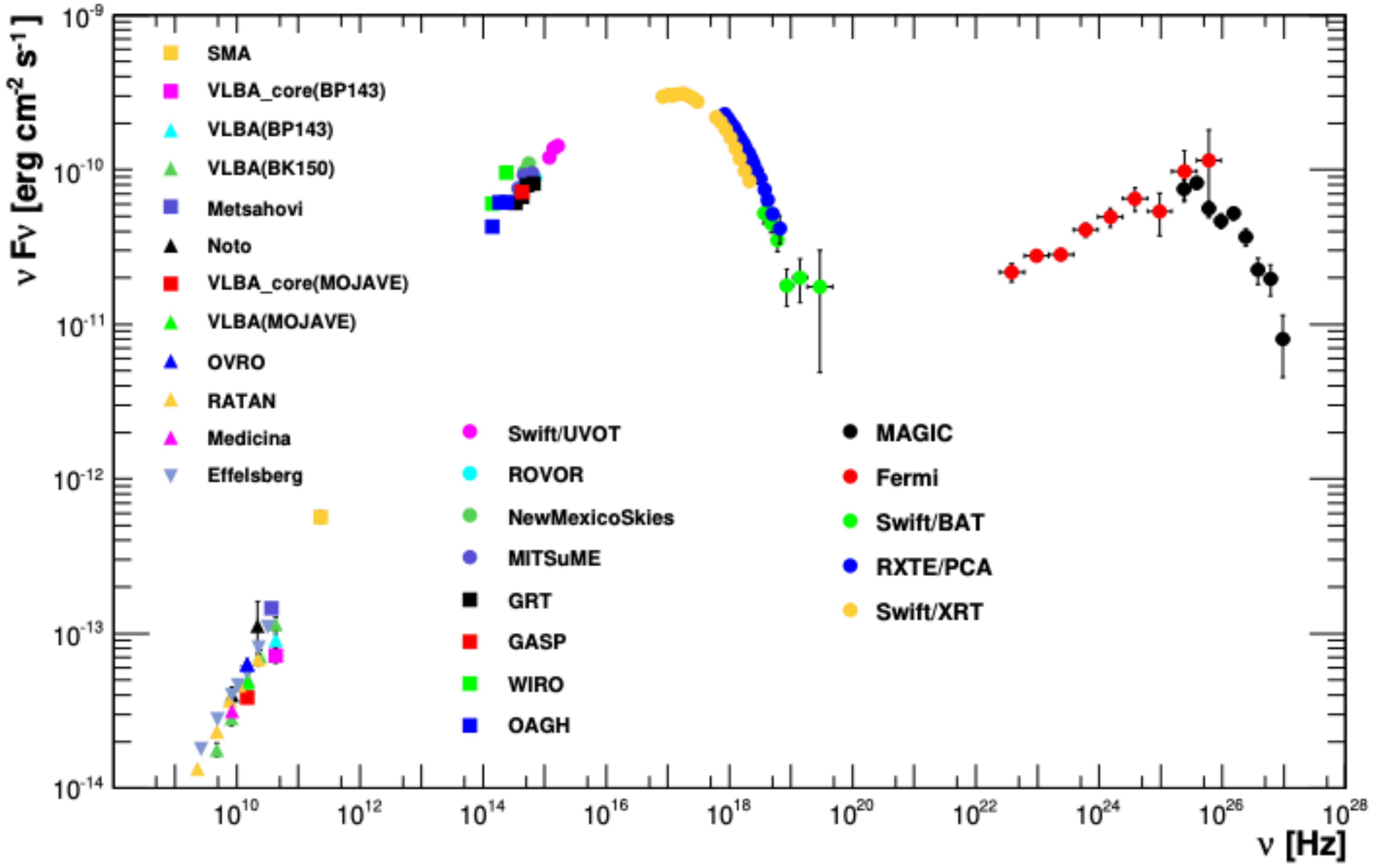
1 DOM = 31 PMTs

17'' glass sphere containing:

- 31x 3" PMTs
- LED and piezo sensor
- A compass and tilt meter

Astrophysical neutrino sources: BLAZAR

Mrk 421



arXiv:1106.1348

Two main groups of objects:
- the flat spectrum radio quasars (**FSRQs)**
- the **BL Lac**

I hump:
It is the result of **synchrotron radiation** from relativistic electrons in the jet.

II hump:
It is originated from **inverse Compton (IC)** scattering of photons. These photons can be originated from the same population of electrons responsible for the synchrotron radiation (Synchrotron Self–Compton).

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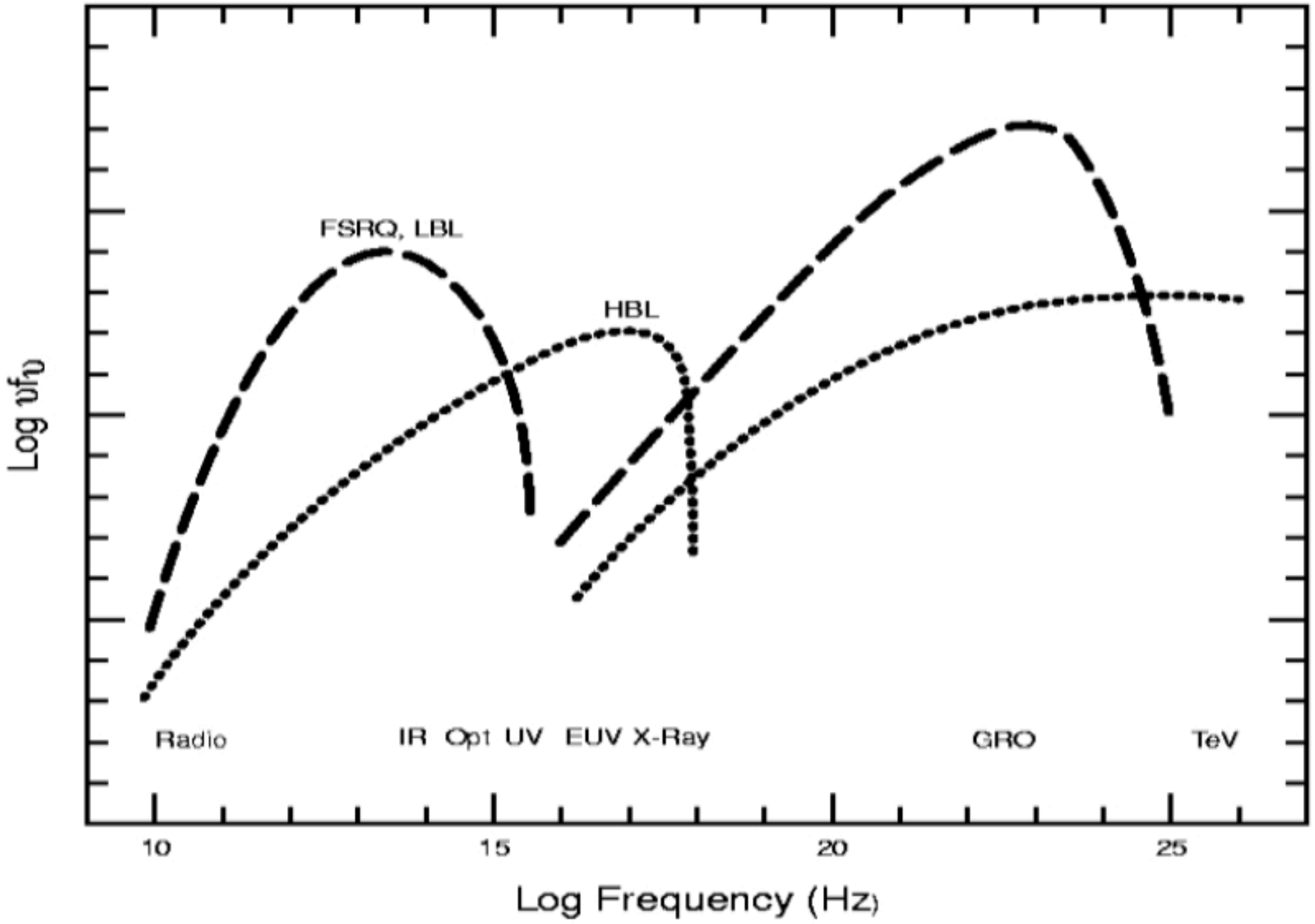
Extreme Blazars : definition

BL Lac

are subdivided in several subclasses classified through their synchrotron radiation frequency peak ν_{peak}^{sync}.

- Low synchrotron peaked BL lac (LSPs) with $\nu_{peak}^{sync} < 10^{14}$ Hz,
- Intermediate synchrotron peaked BL lac (ISPs) with 10^{14} Hz < $\nu_{peak}^{sync} < 10^{15}$ Hz,
- High synchrotron peaked BL lac (HSPs) with 10^{15} Hz < $\nu_{peak}^{sync} < 10^{17}$ Hz,
- **Extremely-high synchrotron peaked BL lac** (EHSPs) with $\nu_{peak}^{sync} > 10^{17}$ Hz.



Lepto-hadronic model

According to lepto-hadronic scenarios high energy neutrinos and photons are produced by the interaction of relativistic protons in the jets with non thermal photons encountered during their path. In particular, for ours analysis we consider as target photons the ones synchrotron emitted by co-accelerated electrons.

The **photopion production (** $p\pi$ **):**

$$p + \gamma \rightarrow \pi^0 + p$$

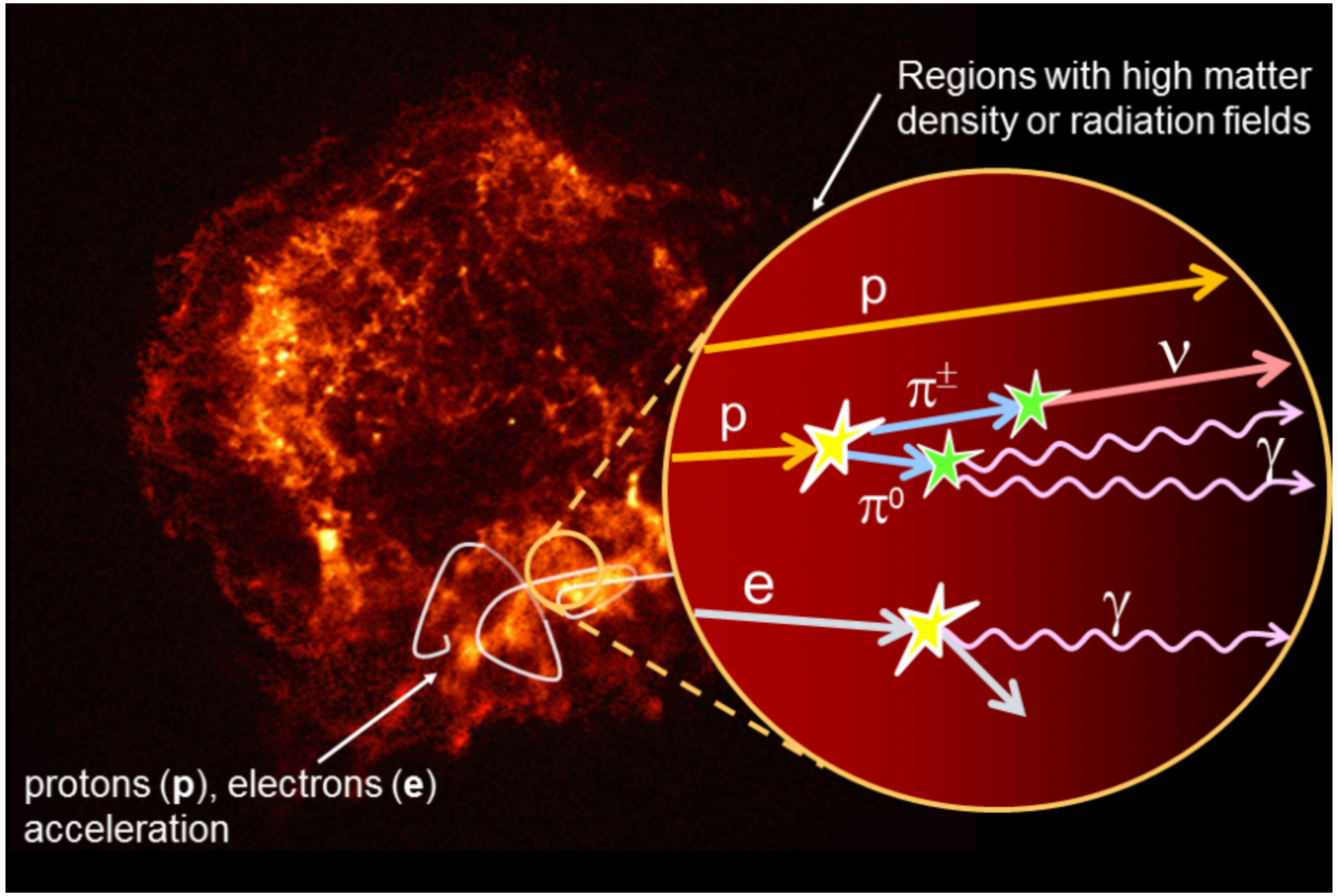
$$\pi^0 \rightarrow \gamma + \gamma$$

or

$$p + \gamma \rightarrow \pi^\pm + n(\Delta^{++})$$

$$\pi^\pm \rightarrow \mu^\pm + \nu_\mu(\bar{\nu}_\mu)$$

$$\mu^\pm \rightarrow e^\pm + \bar{\nu}_\mu(\nu_\mu) + \nu_e(\bar{\nu}_e)$$



Why Extreme Blazars?

arXiv:1411.1908

The low-energy bump of the SED is explained in terms of primary electron synchrotron radiation. Its peak frequency ν_s is then written as:

$$\nu_s = \delta(1+z)^{-1}h^{-1}(B/B_{cr})m_e c^2\gamma_e^2$$

the proton threshold energy for $p\pi$ interactions is given by:

$$\gamma_{p,p\pi} \simeq 3.5 \cdot 10^6\delta(1+z)^{-1}\nu_s^{-1}$$

So, the neutrino energy can be written as :

$$\epsilon_\nu \simeq 0.2\ PeV\ \delta^2(1+z)^{-2}\nu_s^{-1}$$

Inversely proportional to the energy of the synchrotron photon target

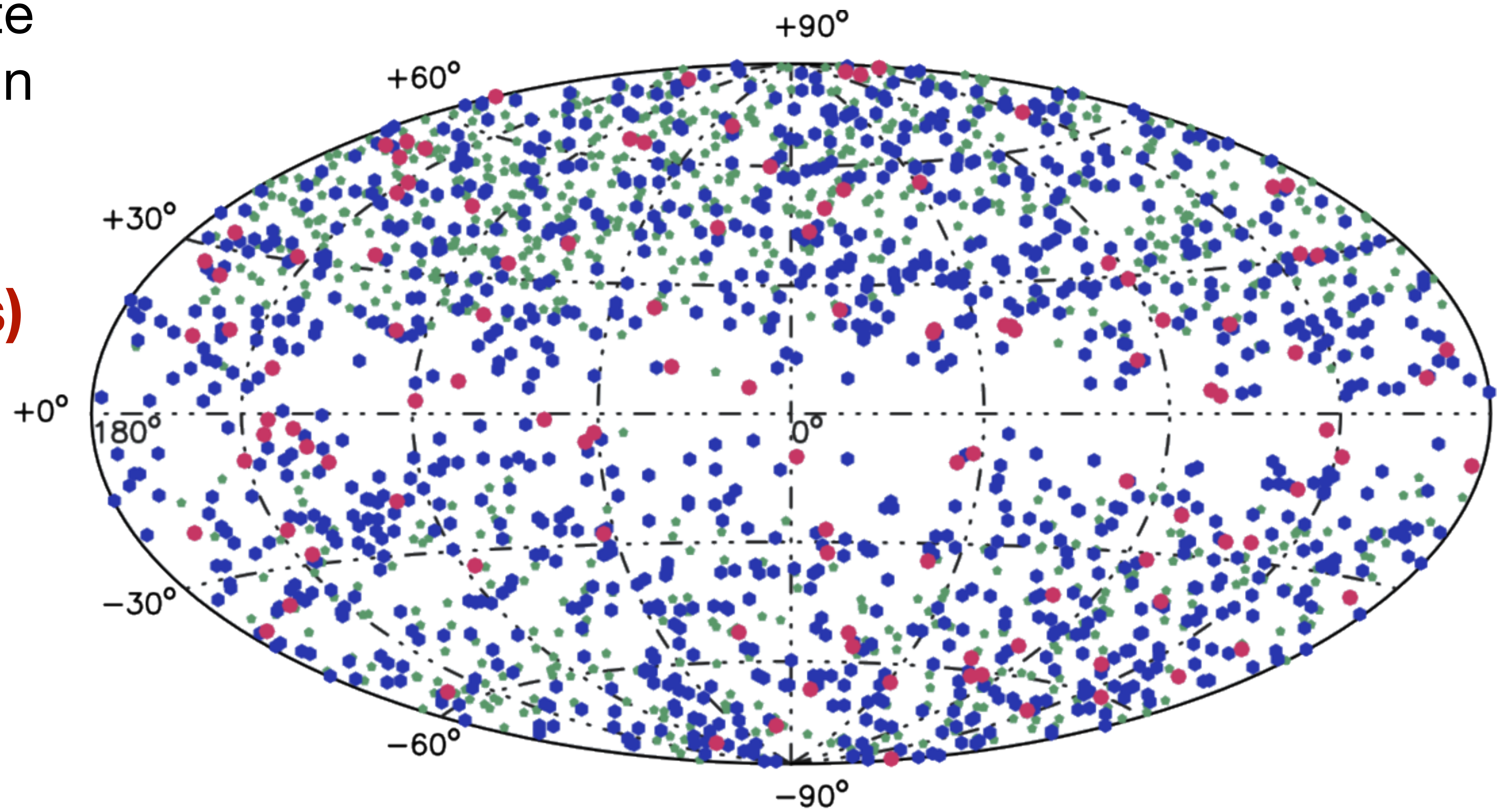
If we consider the synchrotron peak at an average energy of $10^{16}\ Hz$ then the neutrino produced flux is expected to peak at tens of PeVs, while for a peak of the synchrotron emission at $\nu_s > 10^{17}\ Hz$ we can expect neutrino emission in the range of **hundred of TeVs .**

The 3HSP catalogue

Up to now the number of known EHBLs is very limited, and only recent observations have started to populate this class. They are characterized by a peak emission in hard X-rays > 10 keV

Extreme blazars are rare (~ 1/100 of all BL Lacs)

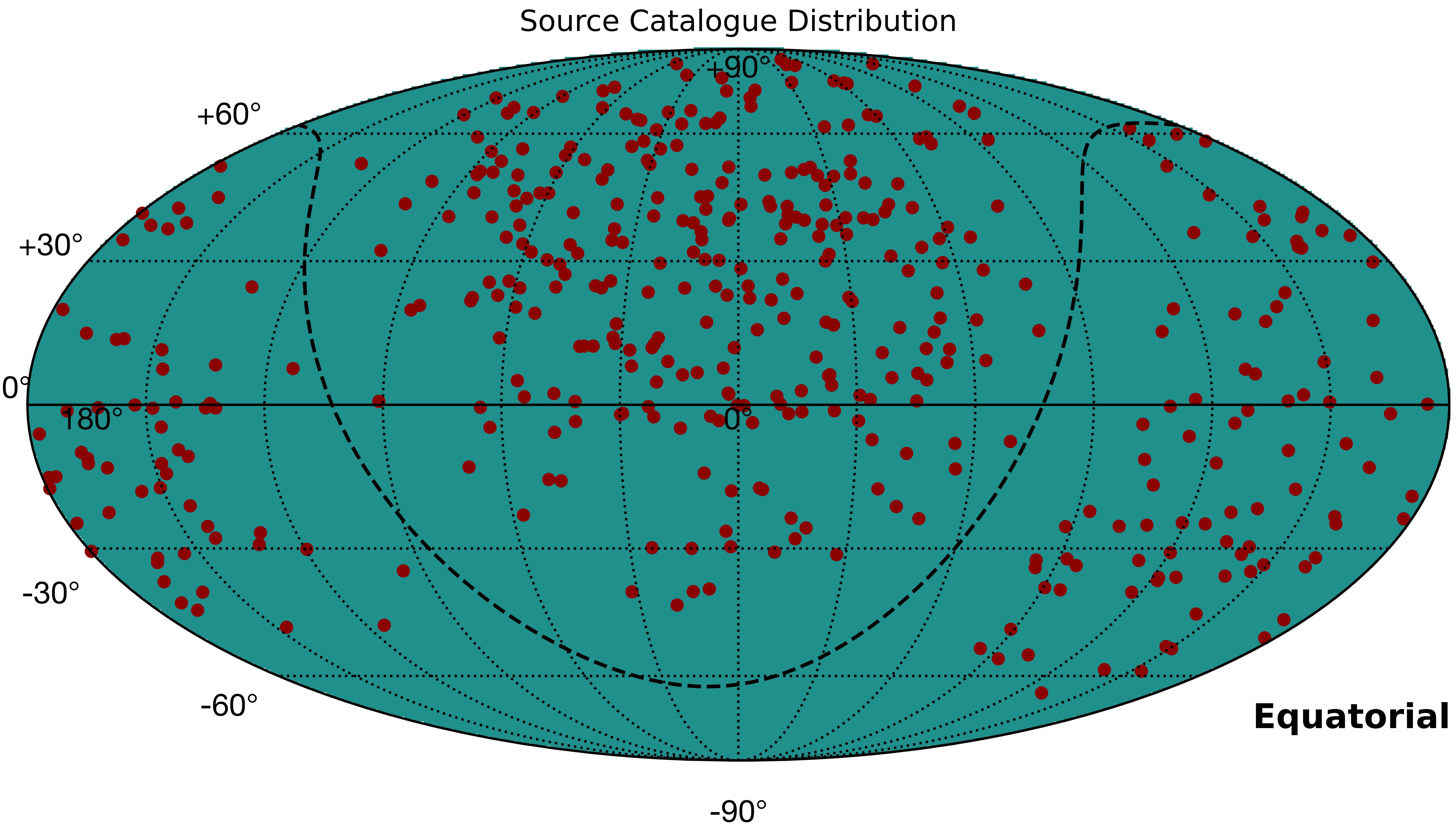
The catalog used to search for EHBLs is:
The 3HSP catalogue of Extreme & High Synchrotron Peaked Blazars.
The 3HSP is the largest compilation of high-synchrotron peaked blazars, it is an update of the 2WHSP (Chang et al. 2017) and 1WHSP catalogues (Arsioli et al. 2015). arXiv:1909.08279



Hammer–Aitoff Equal–Area Projection in Galactic coordinates

Extreme Blazers from 3HSP catalogue

3HSP extreme blazars ($\nu_s \geq 10^{17}\ Hz$) are ~ 384!



Flaring activity periods are considered to be ideal for increasing the predicted neutrino signal:

- the increased electromagnetic flux during flares implies that the density of photons used as targets for photomeson interactions is enhanced.
- the contribution from the atmospheric background remains undisturbed, so it could be much smaller than the signal.

Searching for the flare catalog

For selecting EHBL flares, I reproduce the light curves of interesting sources using the data collected by both **Swift-BAT** Hard X-ray Transient Monitor and **MAXI** (Monitor of All-sky X-ray Image).

Specifically, **MAXI** is more sensitive in the hard-X band thanks to one of its two X-ray detectors: the Gas Slit Camera (**GSC; 2-30 keV**)

https://heasarc.gsfc.nasa.gov/docs/maxi/
https://swift.gsfc.nasa.gov/results/transients/index.html

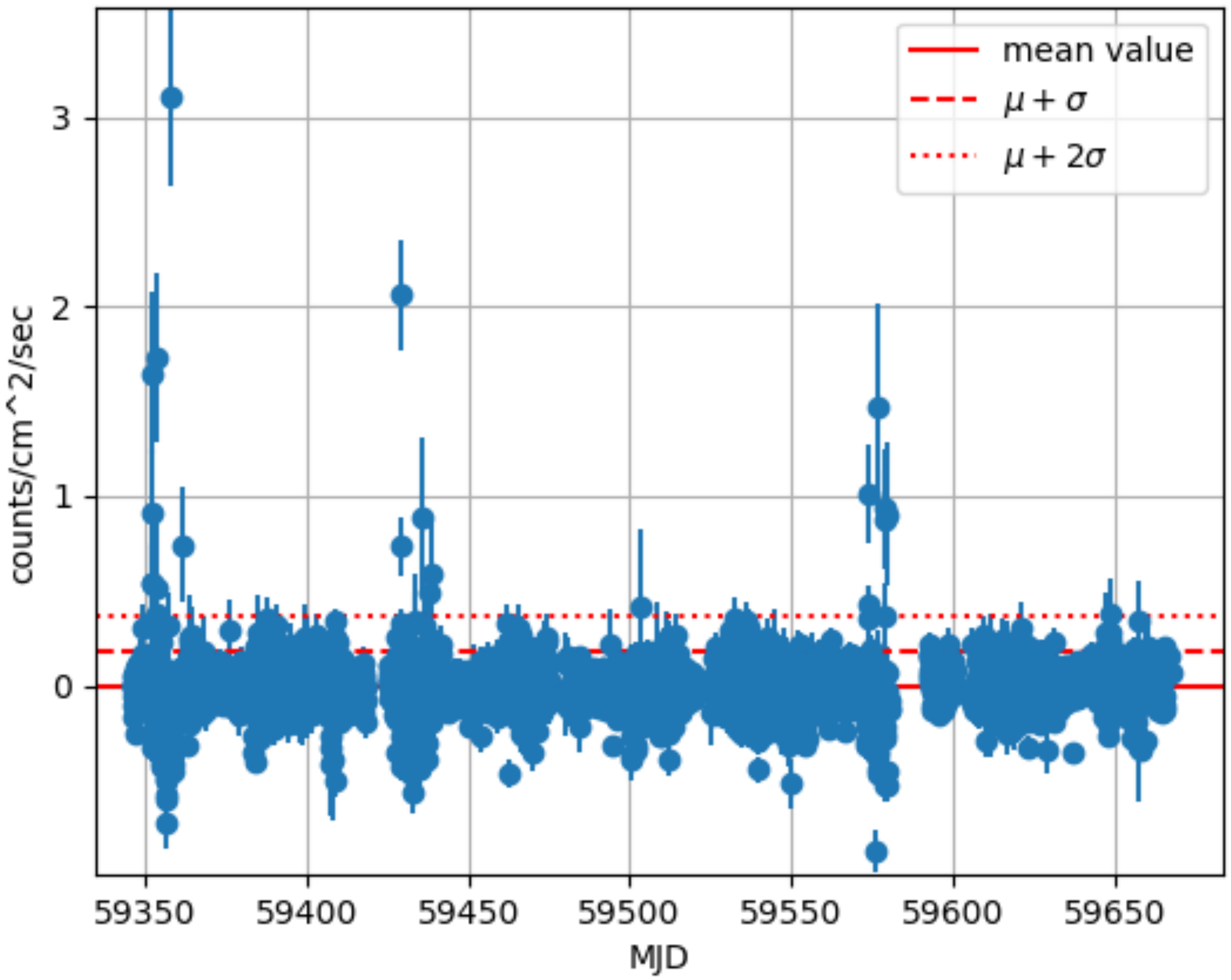
HEAsoft is the software used to download and analyze MAXI data.

Many HEASoft tasks require access to the **CALDB**: the HEASARC's calibration database (CALDB) system stores datasets associated with the calibration of high energy astronomical instrumentation.

mxdownload_wget searches and retrieves the archived MAXI data for a given sky position and time interval

mxproduct runs the MAXI ftools and general ftools to generate MAXI images, light curves, spectra, and response files.

Light curve



3HSPJ123511.2-140323

R.A. = 188.79662

DEC. = -14.05650

$\nu_s = 10^{17}\ Hz$

The period taken into account is **data taking for ARCA6 and ARCA8,** from 12/05/2021 to 30/03/2022

SUMMARY

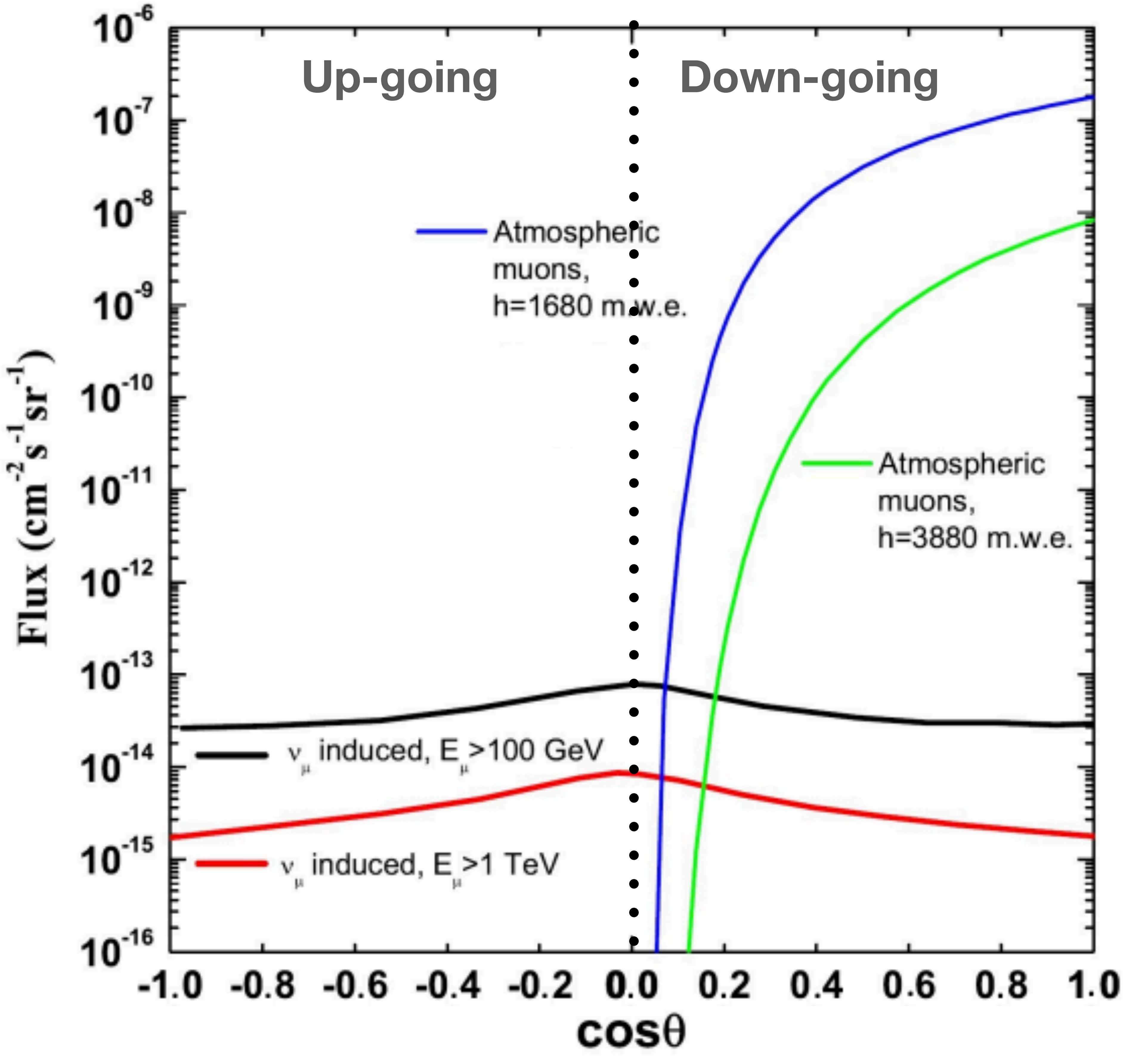
- The next generation neutrino telescope KM3NeT (ORCA + ARCA) is under construction in the Mediterranean Sea;
- KM3NeT/ARCA (in Sicily, Italy) is designed for the detection of high-energy neutrinos (from ~100 GeV to PeV) , thus is optimized for neutrino astronomy & multimessenger studies;
- First string is operating since more than 6 years and ARCA is taking data with 28 strings since last month;
- In the coming years ARCA will achieve the predicted volume of $1\ km^3$;
- To maximize the possibility of discovering neutrinos with energies of hundreds of TeV, a range in which ARCA is most sensitive for track-like events, in my project I will study Extremely-high synchrotron peaked BL lacs;
- The goal of my project will be obtain neutrino upper limits during the most luminous X-ray flares of selected EHBLs for ARCA/KM3NeT

THANKS FOR YOUR ATTENTION

BACK UP

Atmospheric background and event topologies

Neutrino telescopes use the **Earth** as screening against all particles, only neutrinos can traverse the Earth



Atmospheric muon flux is shown at two different depths (1680 and 3880 m water equivalent) and it is compared to the flux of muons due to atmospheric muon neutrinos considering two different muon energy thresholds.

https://www.researchgate.net/publication/344662920_Monte_Carlo_simulations_for_the_ANTARES_underwater_neutrino_telescope

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Its peak frequency ν_s is then written as:

$$\nu_s = \delta(1+z)^{-1}h^{-1}(B/B_{cr})m_e c^2\gamma_e^2$$

If the synchrotron photon target has energy:

$$\epsilon_s = h\nu_s(1+z)/\delta$$

the proton threshold energy for $p\pi$ interactions is given by:

$$\gamma_{p,p\pi} \simeq 3.5 \cdot 10^6 \delta(1+z)^{-1}\nu_s^{-1}$$

So, the neutrino energy is written as:

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Neutrinos carry only 5% of the initial parent proton's energy, while the gamma rays produced in the decay of the neutral π^0, carry 10% of the initial energy.

$$\epsilon_\nu \sim \frac{\epsilon_\gamma}{2} \sim \frac{\epsilon_\pi}{5} \sim \frac{\epsilon_p}{20}$$