Observation of the first ultra-high-energy cosmic neutrino with KM3NeT

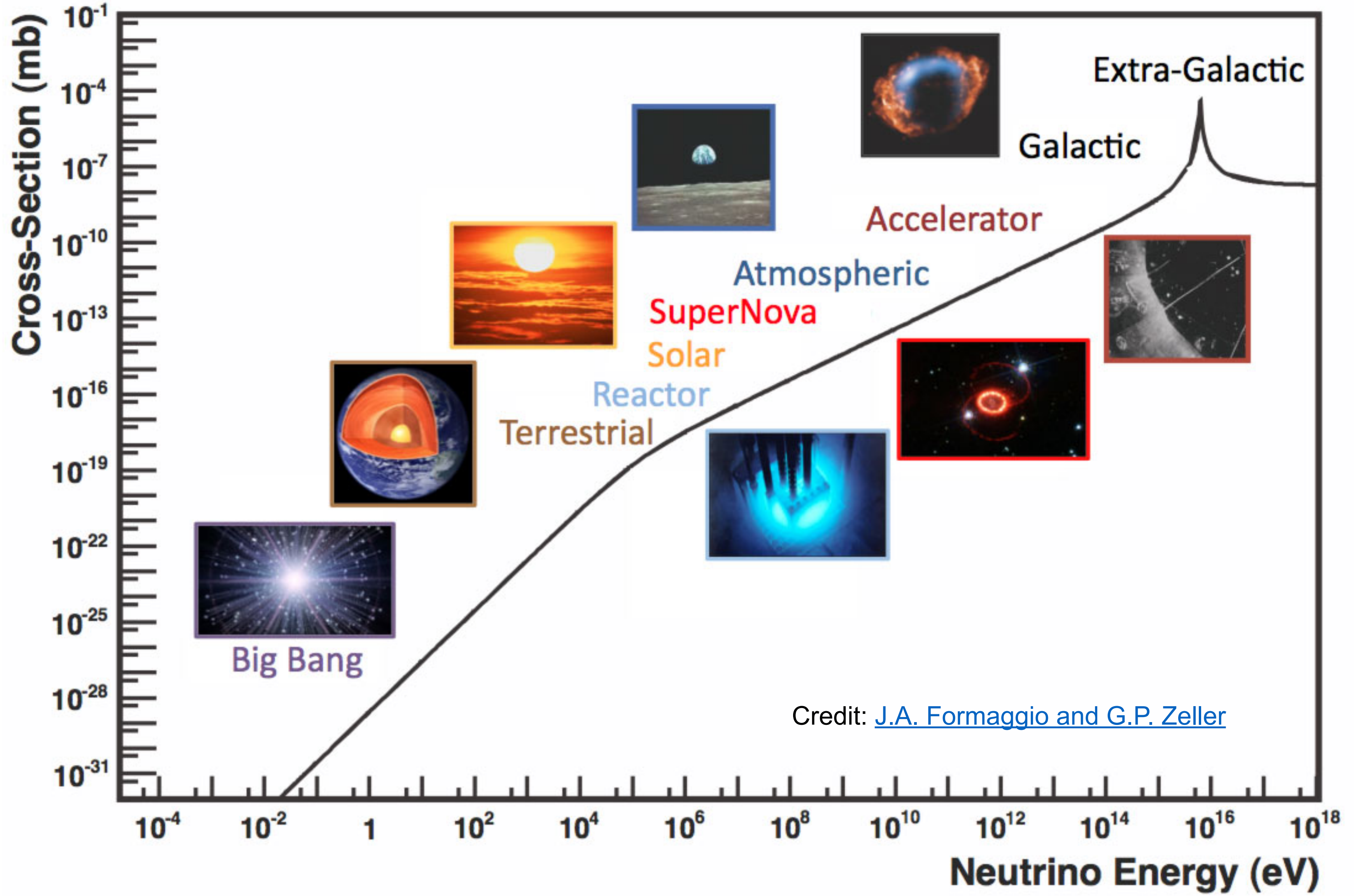
Antonio Marinelli
(Università Federico II, INFN Napoli, INAF OAC)

On behalf of the KM3NeT Collaboration

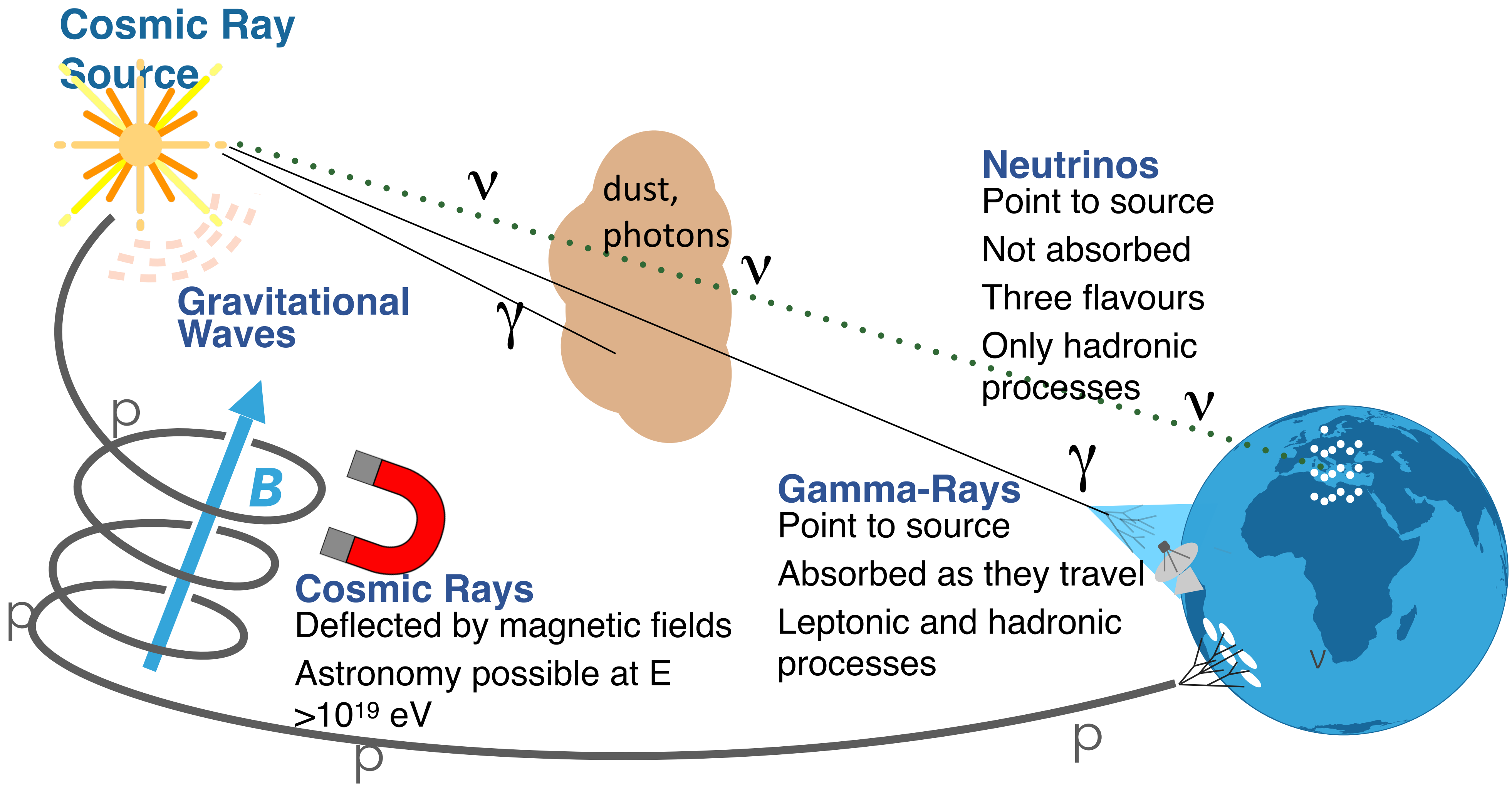
Seminario del Dipartimento di Fisica, UNIGE 20/03/2025

Dipartimento di Fisica
Università degli studi di Genova

Neutrinos at different energy scales



Neutrinos and multi-messenger astronomy



The idea of a under-ice/water neutrino telescope

ON HIGH ENERGY NEUTRINO PHYSICS

M. A. Markov

Joint Institute for Nuclear Research, Dubna, USSR

energy spectrum is reconstructed. We propose setting up apparatus in an underground lake or deep in the ocean in order to separate charged particle directions by Čerenkov radiation. We consider μ mesons produced in the ground layers under the apparatus.

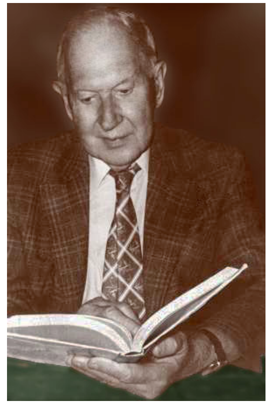
Rare events of a frequency of less than one per month are also detectable in cosmic rays. Experiments with cosmic rays are also of interest for their own sake because they may give information on possible high energy neutrinos of cosmic origin.

Proceeding of 10th ICHEP 1960 Rochester (pag. 578)

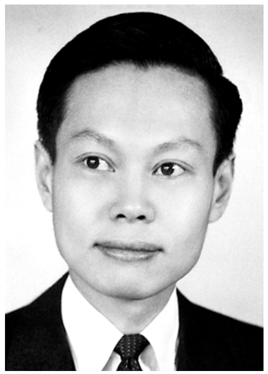
B.Pontecorvo

Бруно Понтекорво

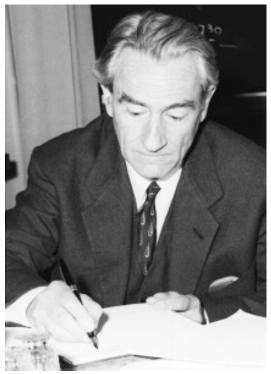
A.Markov



C.N.Yang



G.Bernardini



M.Schwartz

Interesting discussion on that between the 5 physicists

The timeline of Cherenkov neutrino telescopes at VHE

- DUMAND: Deep Underwater Muon and Neutrino Detector - proposed by F. Reynes on 1975 (9 strings and 216 OMs, 4.6 Km deep of bottom level).
- BAIKAL - Bezrukov, Domogatsky, Berezinsky, Zatsepin - 1981 First site exploration and R&D, 1.3 Km depth, Baikal lake, from NT36 (36 OMs) to NT200 (200 OMs)
- NESTOR - Pylos island, Greece - 3.8 Km deep. Survey started in the 90's (12 floors with 14 OMs per floor, 168 in total)
- AMANDA - South Pole - 1996 started (19 strings and 677 OMs)
- ANTARES - R&D started in 1997, off-shore of Toulon, 2.5 Km deep (12 strings, 75 OMs each string)
- NEMO - R&D start in 1998 - first site exploration in 2002, off-shore of Capopassero, 33.5 Km deep, phase 1 (4 floors 16 OMs), phase 2 (8 floors 32 OMs)
- IceCube - construction 2005-2010, South Pole, 86 strings, 5160 OMs
- KM3NeT/ARCA - construction started on Dec 2015, off-shore Capopassero, 2 building blocks with 115 strings per block and 18 Doms each string.

KM3NeT is a Mediterranean research infrastructure hosting two neutrino detectors

- **KM3NeT/ARCA** (**A**stroparticle **R**esearch with **C**osmics in the **A**byss)
  - observation of high energy (GeV ÷ PeV) neutrino sources 👉 a telescope offshore Capo Passero (Sicily-Italy) is in construction at a depth of 3500m

- **KM3NeT/ORCA** (**O**scillation **R**esearch with **C**osmics in the **A**byss)
  - determination of the neutrino mass hierarchy 👉 a detector offshore Toulon (France) able to detect neutrinos of tens of GeV is in construction at a depth of 2500m

1 collaboration 1 technology 👉 2 detectors

Journal of Physics G: Nuclear and Particle Physics

PAPER · OPEN ACCESS

Letter of intent for KM3NeT 2.0

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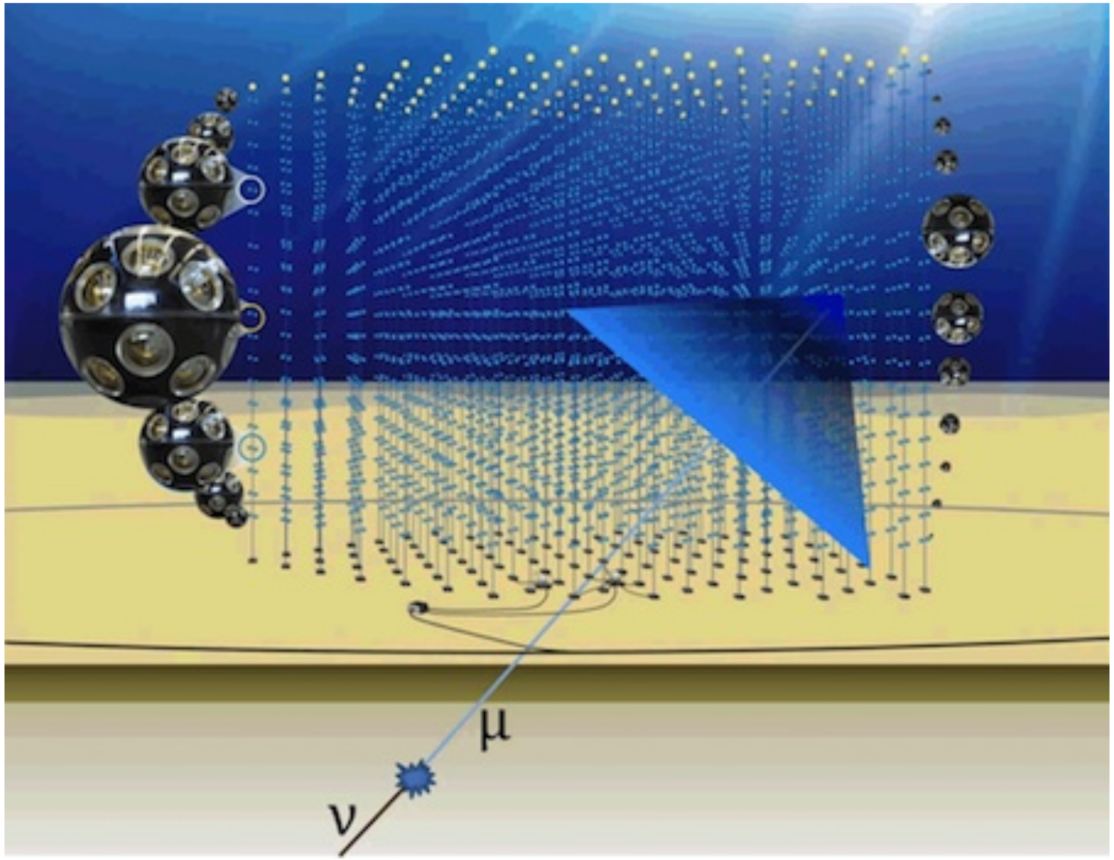
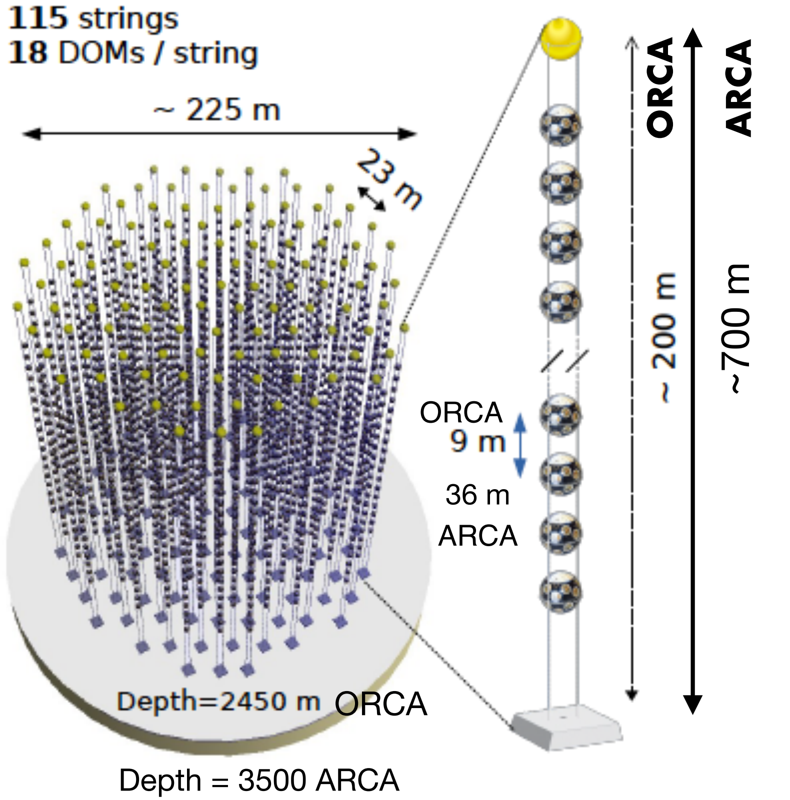
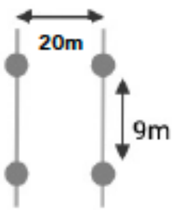
The Telescopes ORCA & ARCA



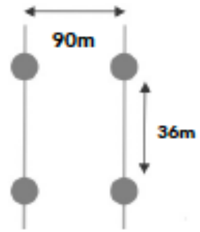


ORCA



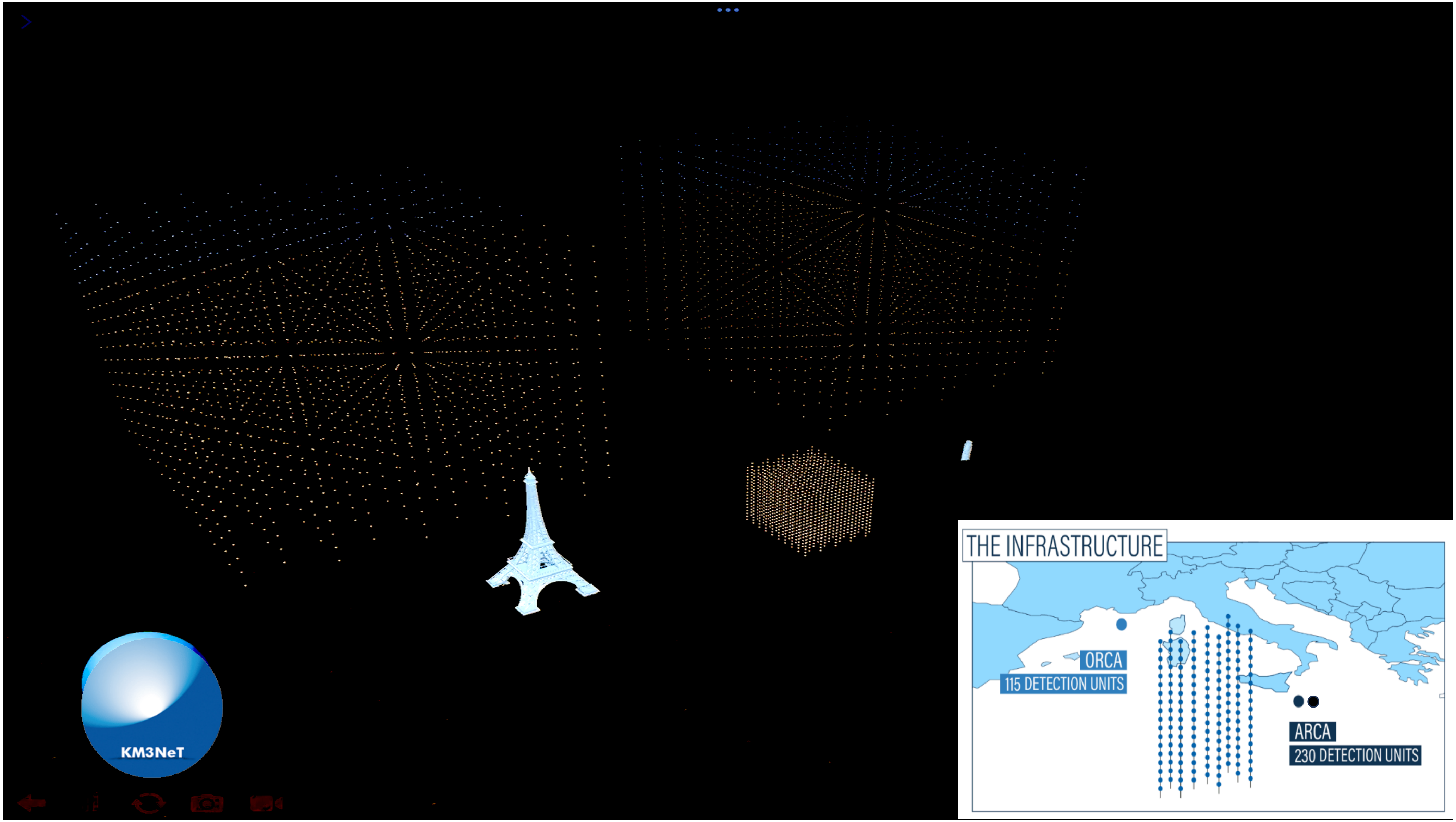
- Depth ~2500 m
- One block of 115 Detection Units
- Distance between Detection Units ~20 m
- Vertical distance between DOMs ~9 m
- **≈8 Mton**

ARCA

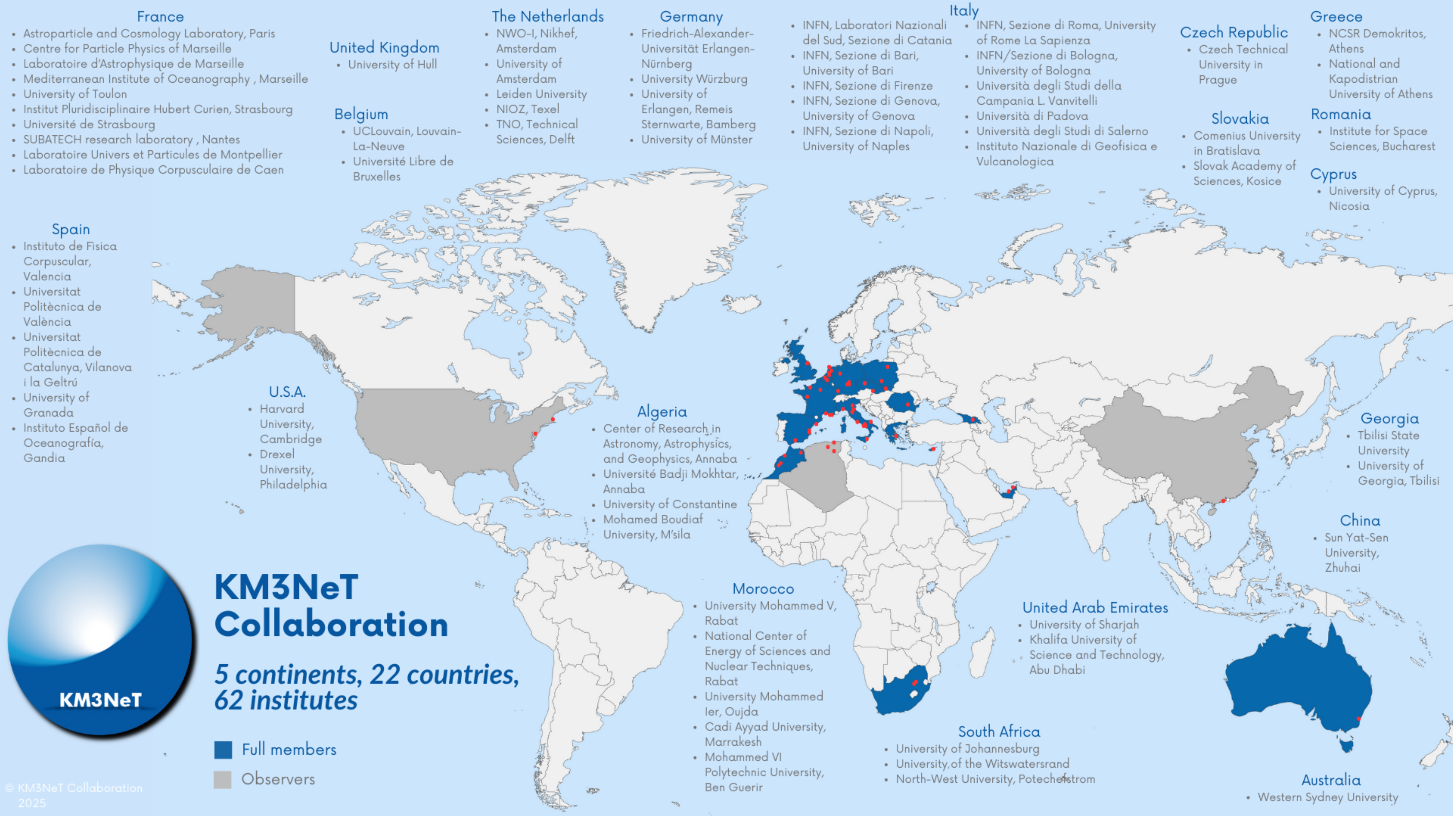


- Depth ~3500 m
- Two blocks of 115 Detection Units each
- Distance between Detection Units ~90 m
- Vertical distance between DOMs ~36 m
- **Volume (0.5 × 2) km3**

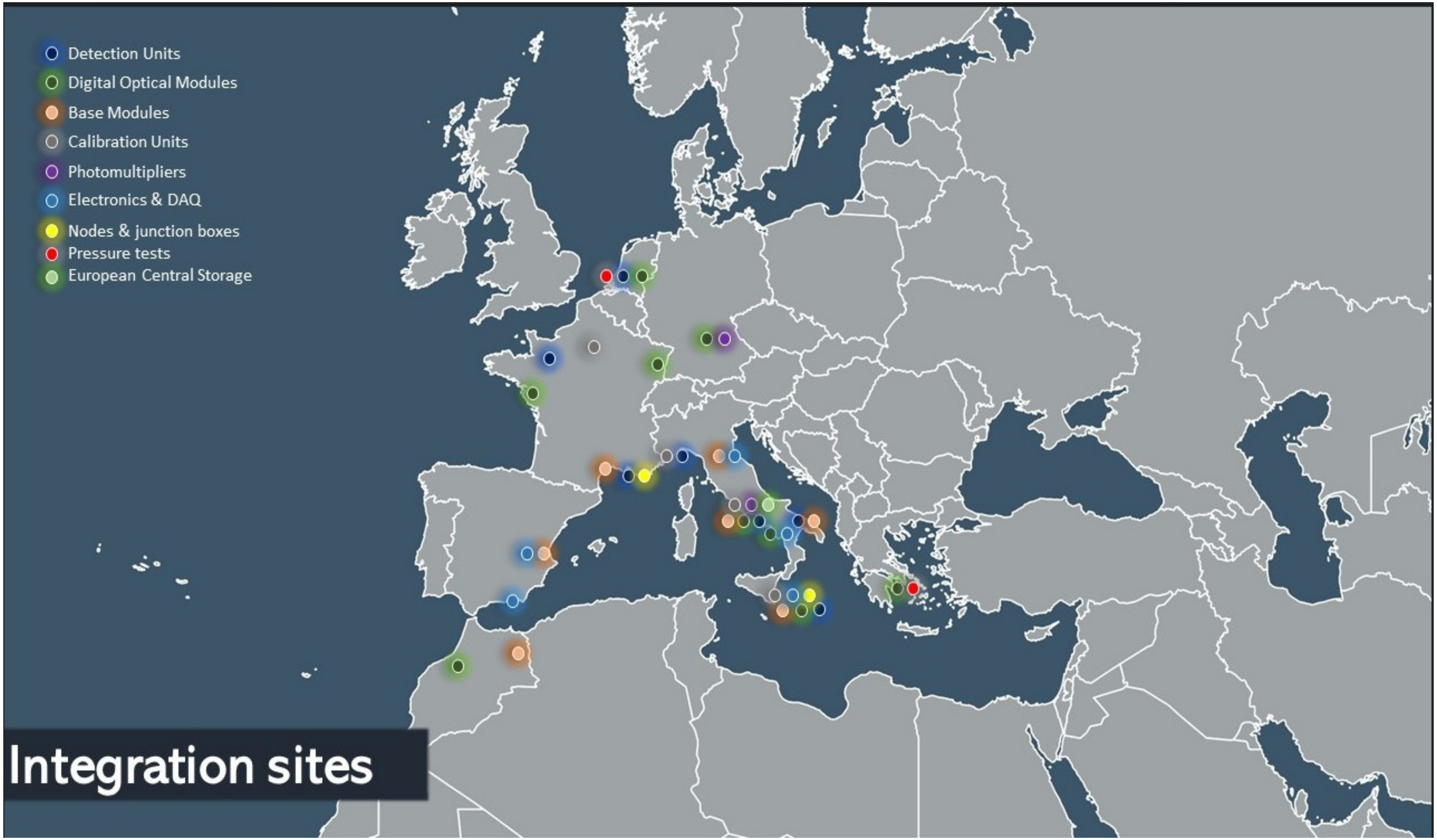
The Telescopes ORCA & ARCA



KM3NeT collaboration has grown from a core of a few European countries. It now comprises 62 institutes from 22 countries

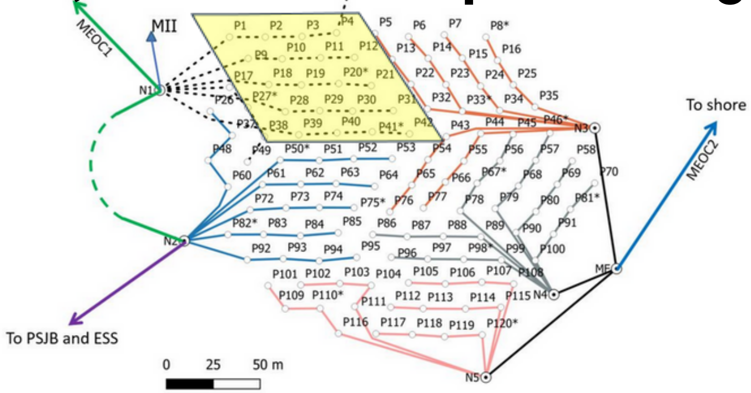


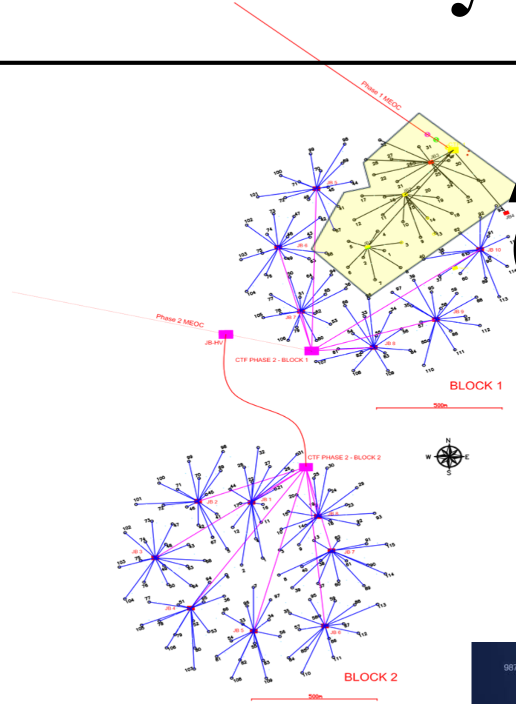
Where KM3NeT takes shape



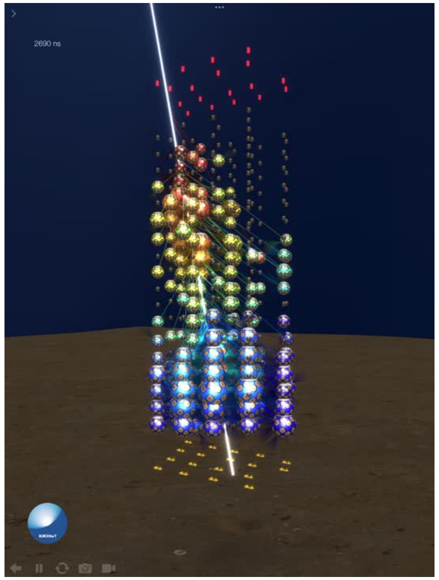
KM3NeT today

ORCA 24 DU installed
(21% of the complete configuration)





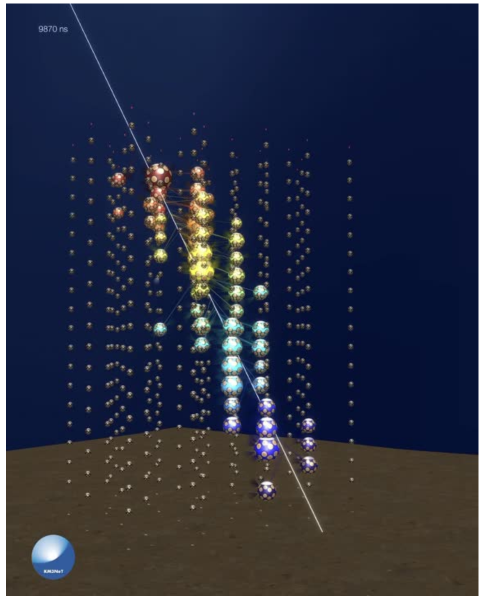
ARCA 33 DU installed
(14% of the complete configuration)



Next sea campaign:

- **ORCA (spring 2025)**
From 4 to 6 DU

- **ARCA (summer 2025)**
25 detection units

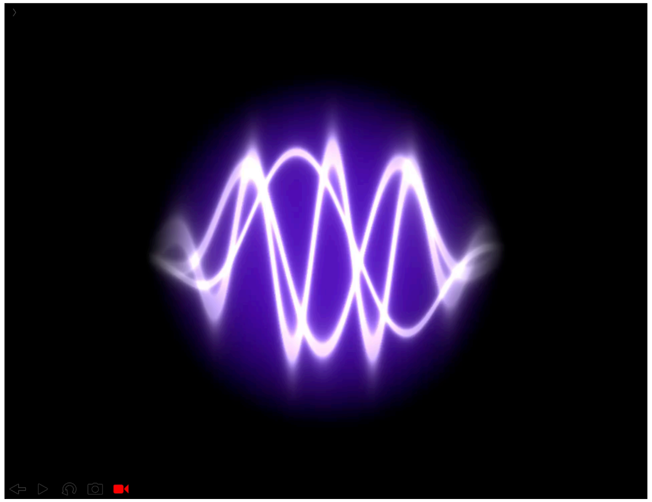


Science of the KM3NeT telescope

Exploration of the neutrino universe

Study the fundamental properties of neutrinos

Exploration of the abyss



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Article

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The KM3NeT Collaboration*✉

The detection of cosmic neutrinos with energies above a teraelectronvolt (TeV) offers a unique exploration into astrophysical phenomena[1–3]. Electrically neutral and interacting only by means of the weak interaction, neutrinos are not deflected by magnetic fields and are rarely absorbed by interstellar matter: their direction indicates that their cosmic origin might be from the farthest reaches of the Universe. High-energy neutrinos can be produced when ultra-relativistic cosmic-ray protons or nuclei interact with other matter or photons, and their observation could be a signature of these processes. Here we report an exceptionally high-energy event observed by KM3NeT, the deep-sea neutrino telescope in the Mediterranean Sea[4], which we associate with a cosmic neutrino detection. We detect a muon with an estimated energy of 120^{+110}_{-60} petaelectronvolts (PeV). In light of its enormous energy and near-horizontal direction, the muon most probably originated from the interaction of a neutrino of even higher energy in the vicinity of the detector. The cosmic neutrino energy spectrum measured up to now[5–7] falls steeply with energy. However, the energy of this event is much larger than that of any neutrino detected so far. This suggests that the neutrino may have originated in a different cosmic accelerator than the lower-energy neutrinos, or this may be the first detection of a cosmogenic neutrino[8], resulting from the interactions of ultra-high-energy cosmic rays with background photons in the Universe.

Cosmic neutrinos may be produced either in the vicinity of the cosmic-ray source or along the cosmic-ray propagation path, leading to the production of secondary unstable particles, which subsequently decay into neutrinos. Cosmic rays interacting in the Earth's atmosphere produce atmospheric neutrinos, which form an experimental background to cosmic neutrinos. To detect cosmic neutrinos, very-large-volume neutrino observatories monitor natural bodies of water or ice for the Cherenkov light induced by the passage of the charged particles that result from neutrino interactions in or near the detector. The KM3NeT research infrastructure comprises two detector arrays of optical sensors deep in the Mediterranean Sea[4]. The ARCA detector is located offshore Portopalo di Capo Passero, Sicily, Italy, at a depth of about 3,450 m and connected by means of an electro-optical cable to the shore station of the INFN, Laboratori Nazionali del Sud (LNS). The geometry of ARCA is optimized for the study of high-energy cosmic neutrinos. The ORCA detector is located at a depth of about 2,450 m, offshore Toulon, France, and is optimized for the study of neutrino oscillations. Both detectors are under construction but already operational. Once completed, they will comprise 345 (230 for ARCA and 115 for ORCA) vertical detection lines, each holding 18 optical modules. Each module hosts 31 3-inch photomultiplier tubes (PMTs) pointing in all directions and ensuring 4π coverage[9]. Both detectors can identify all flavours of neutrino interactions: those producing long-lived muons, denominated 'tracks', and those producing electromagnetic and hadronic cascades at the neutrino interaction vertex, denominated 'showers'.

Of interest in this article are neutrino interactions that produce high-energy muons, which can travel several kilometres in seawater before being absorbed. These muons lose energy as they propagate mainly because of stochastic radiative processes such as bremsstrahlung, pair production and photonuclear reactions. The average energy loss per unit path length is proportional to the muon energy. Electromagnetic cascades arise from these stochastic energy losses; the number of charged particles that produce Cherenkov radiation in the cascades is proportional to the amount of energy lost by the muon in the process. The recorded time of arrival and time-over-threshold of the signals on the PMTs (denoted as 'hits') are used to reconstruct the muon direction and energy.

Although atmospheric neutrinos are more abundant at lower energies (≈TeV), cosmic neutrinos should become dominant at energies above 100 TeV. The neutrino energy is thus a crucial parameter for establishing a cosmic origin. The IceCube Collaboration announced the discovery of PeV cosmic neutrinos in 2013 (ref. 10). The most energetic neutrinos reported so far are a 6.05 ± 0.72 PeV electron antineutrino observed at the energy of the Glashow resonance[11] and a muon neutrino above 10 PeV from the observation of a 4.4-PeV muon[5].

The neutrino event KM3-230213A

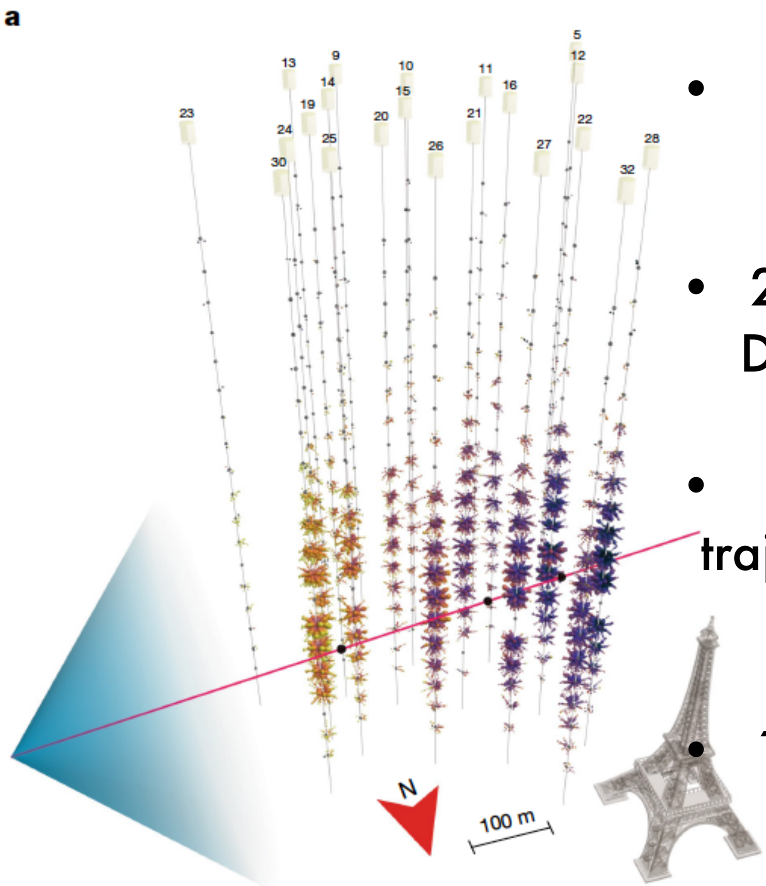
An extremely high-energy muon traversing the ARCA detector was observed on 13 February 2023 at 01:16:47 UTC. This event is referred to here as KM3-230213A. At that time, 21 detection lines were in operation.

*A list of authors and their affiliations appears at the end of the paper. ✉e-mail: km3net-pc@km3net.de

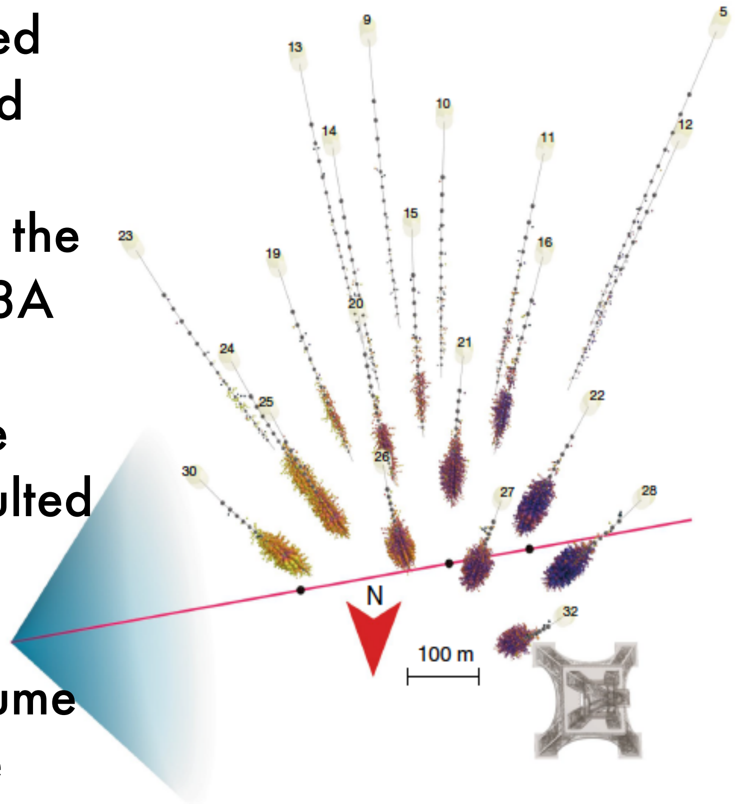
A unique event observed by KM3NeT

The KM3NeT detector was taking data with the configuration of ARCA21 from 23/09/22 up to 11/09/23 moving then to a higher number of detection units

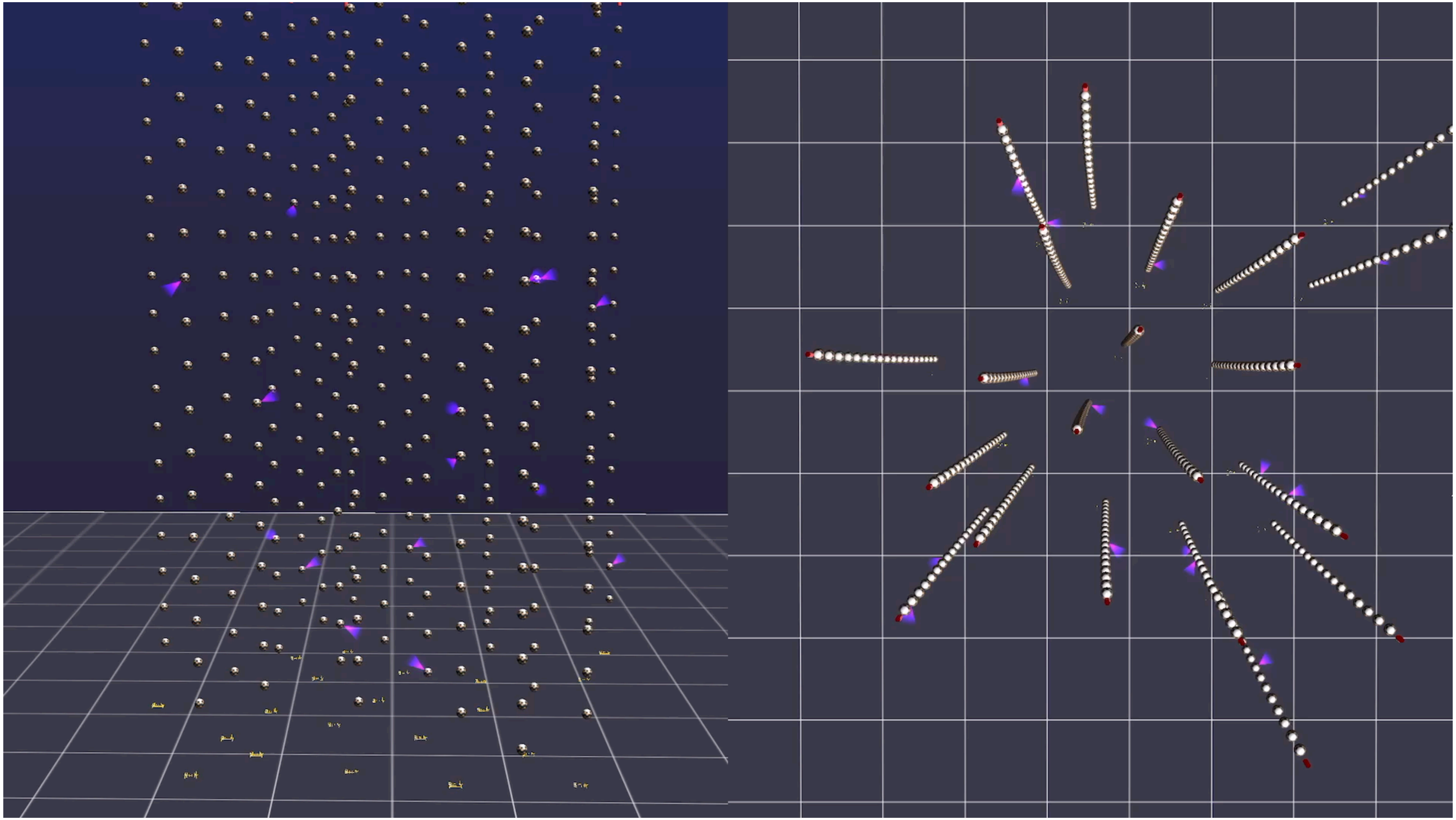
KM3NeT coll.
Nature 638,
376-382 (2025)



- 110 Million of registered events during this period
- 28000 hits produced on the Detector by KM3-230213A
- The PMTs close to the trajectory of the muon resulted to be saturated
- 1/3 of instrumented volume was triggered for the reconstruction of the event



A unique event observed by KM3NeT

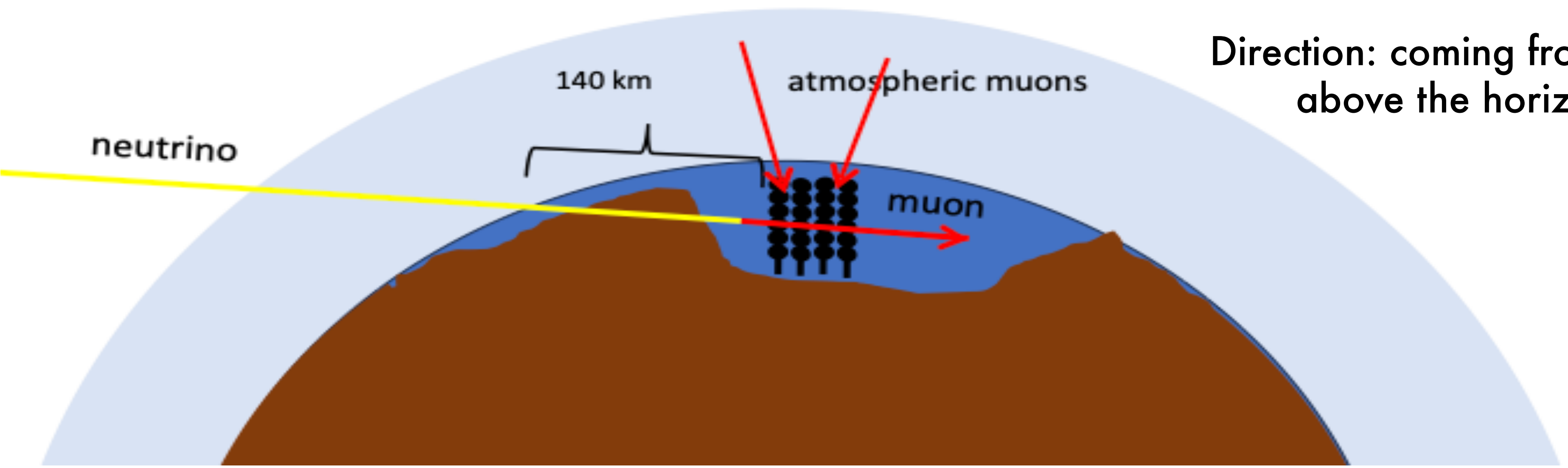


From the reconstructed μ to the ν

The muon energy is obtained From the quantity of light measured $E_\mu = 120^{+110}_{-60}$ PeV

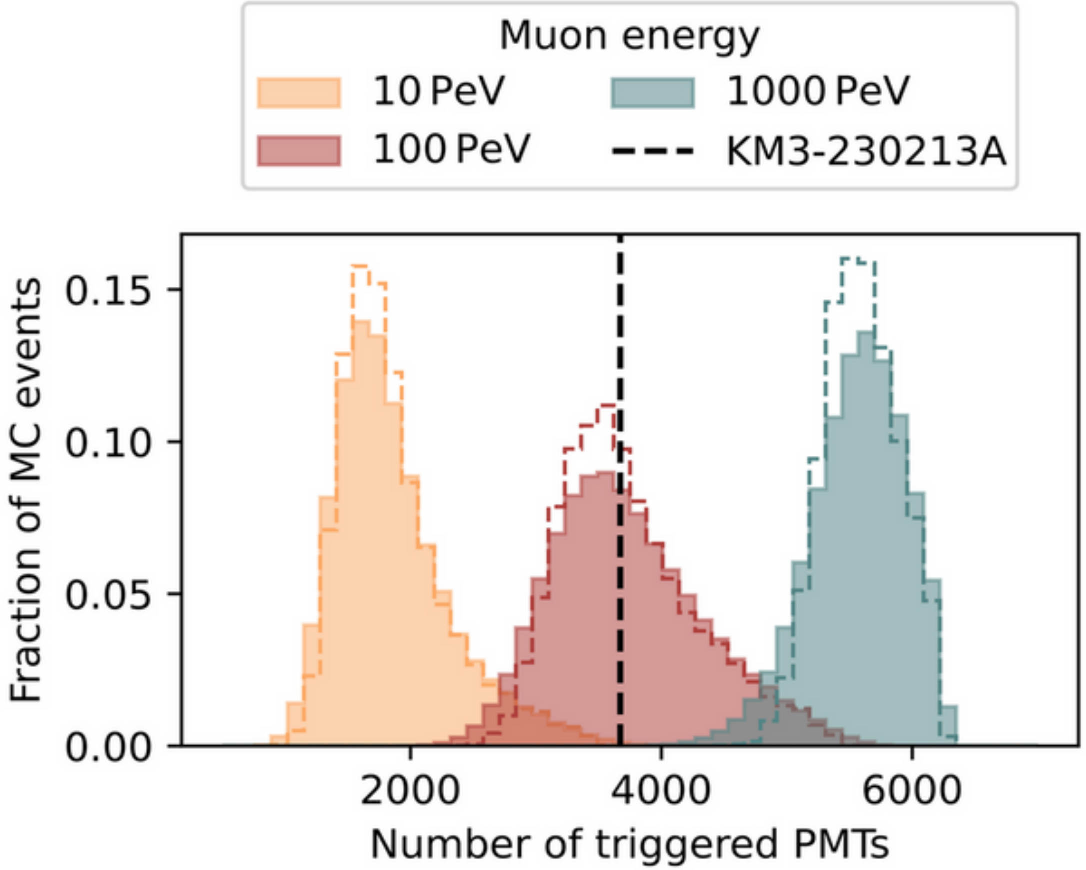
The corresponding neutrino Energy is $E_\nu = 220^{+570}_{-100}$ PeV

A horizontal muon caused by a neutrino



Direction: coming from 0.6°
above the horizon

From the reconstructed μ to the ν

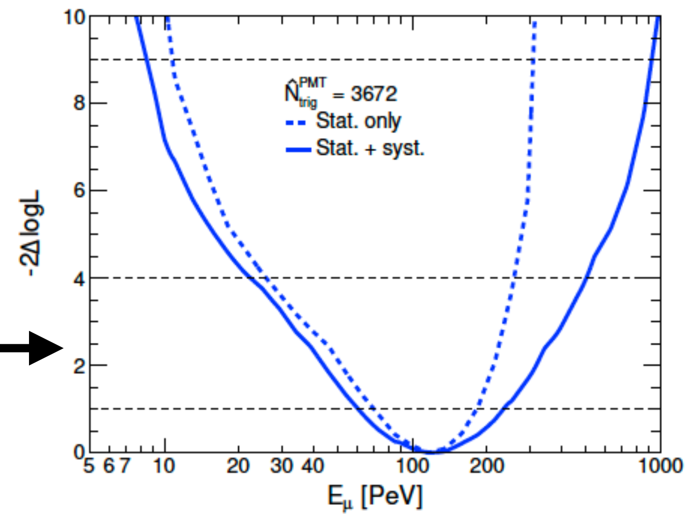


KM3NeT coll. Nature 638, 376-382 (2025)

With the Monte Carlo simulations we can reproduce In details the quantity of light produced by the event.

THE NUMEBER OF TRIGGERED PMTS are 3672
This number can be used to Estimate the energy

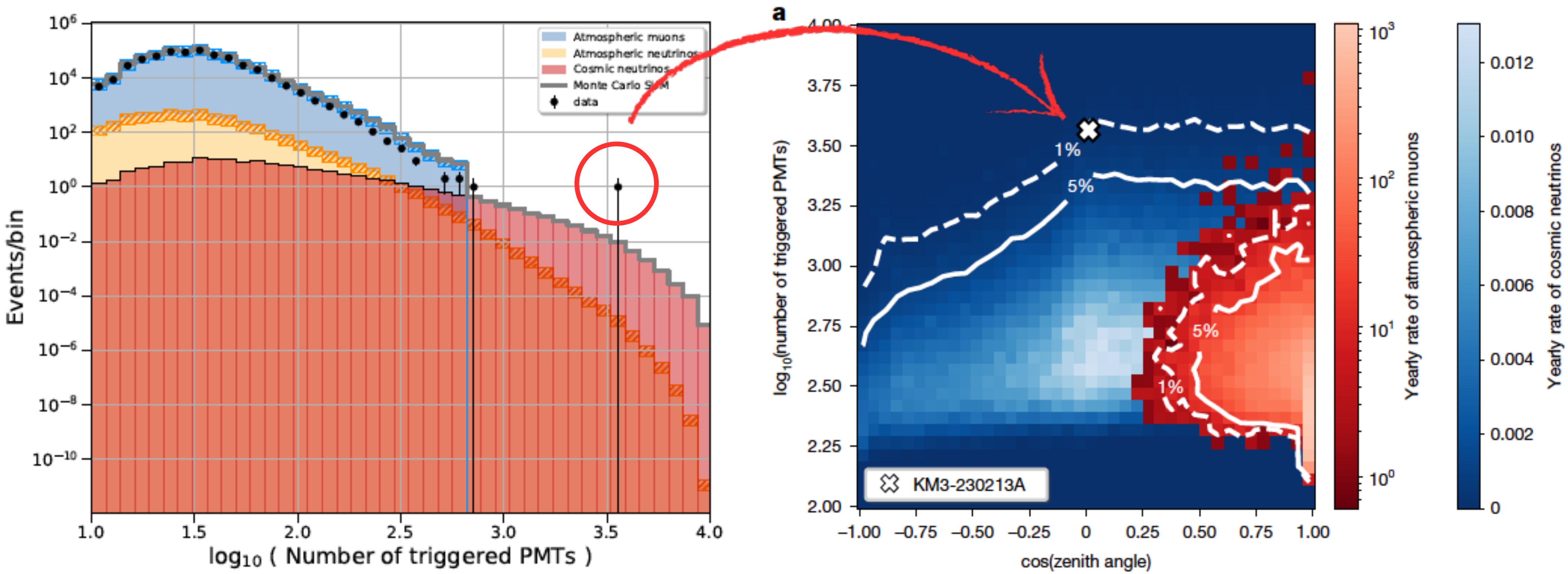
Log-likelihood profile for 3672 PMTs triggered, and the values corresponding to 1,2,3 σ Confidence level according to the Wilks theorem



The peculiar properties of KM3-230213A

Taking into account the quality cuts applied to the data it was clear that cannot be a background event and at the same time we have seen a very rare event.

KM3NeT coll. Nature 638, 376-382 (2025)



The contamination of atmospheric neutrino with the selection made is at the level

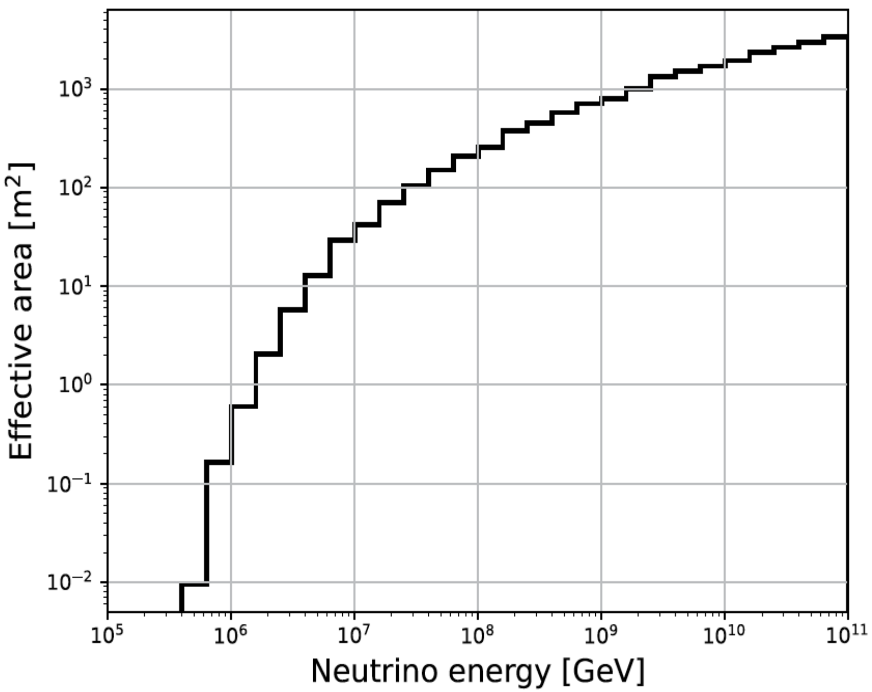
$1 - 5 \times 10^{-5}$ events per year

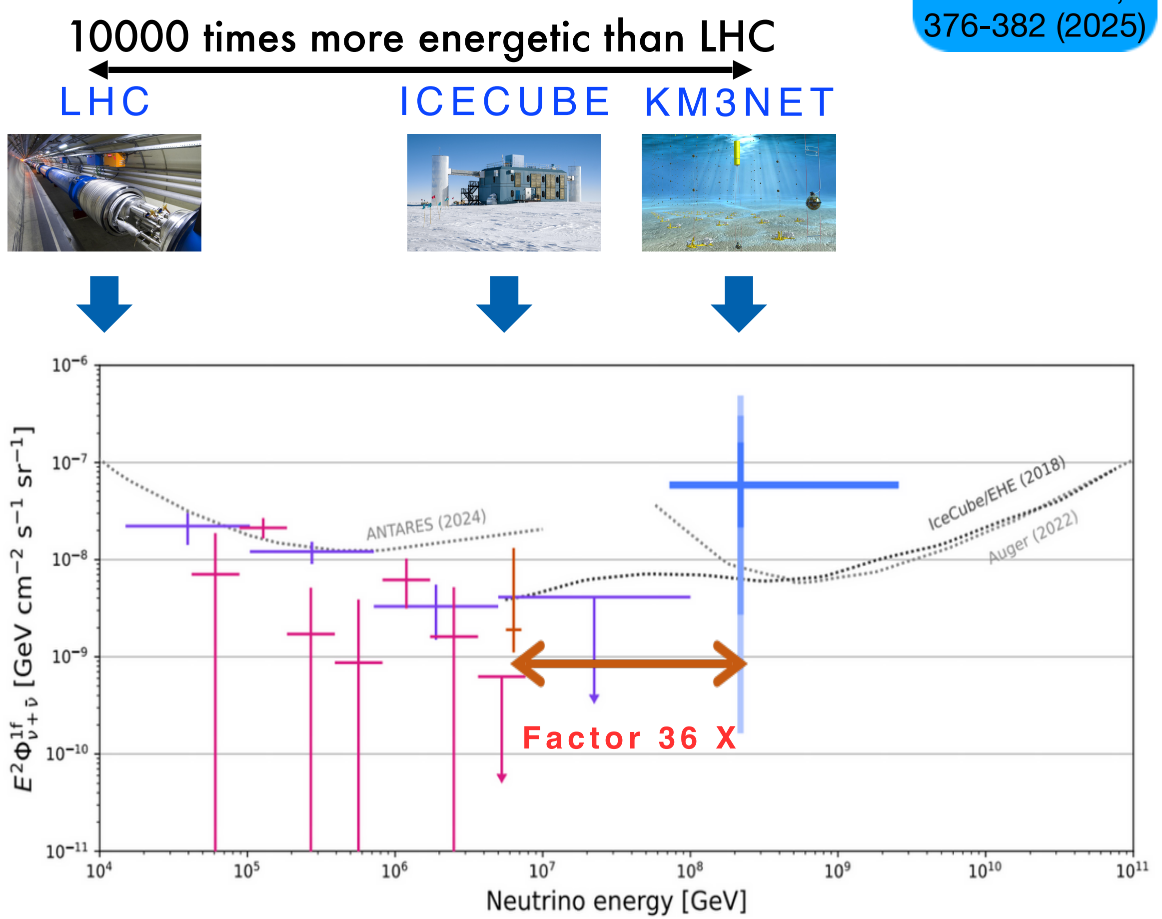
The peculiar properties of KM3-230213A

On the left we reported the Effective Area obtained using the quality cuts used for the Selection of KM3-230213A, on the right the equivalent diffuse flux needed to produce one event with the time of data taking of ARCA19/21

KM3NeT coll. Nature 638, 376-382 (2025)

ARCA21 Effective Area





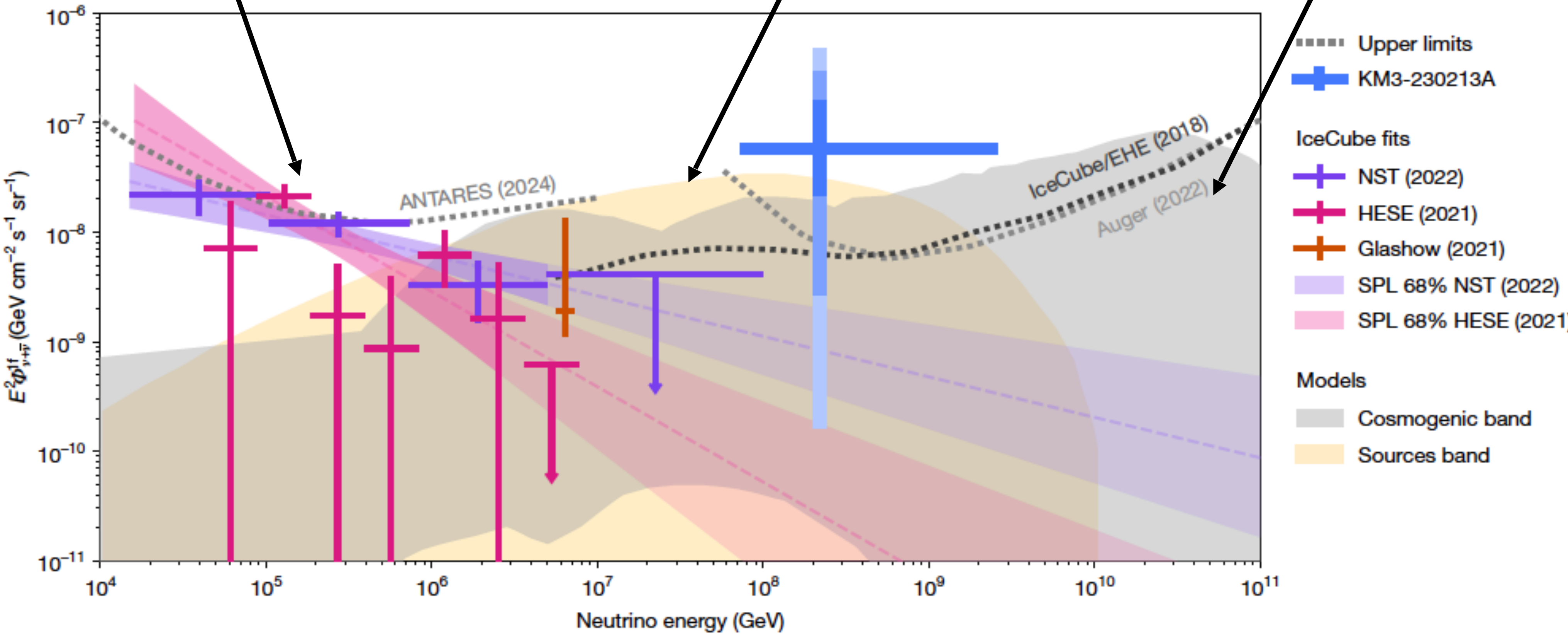
The equivalent flux of KM3-230213A & the cosmic ν

KM3NeT coll. Nature 638, 376-382 (2025)

Neutrinos observed At 10 TeV - 10 PeV da Icecube

Flux of diffuse neutrinos from the Extragalactic sources

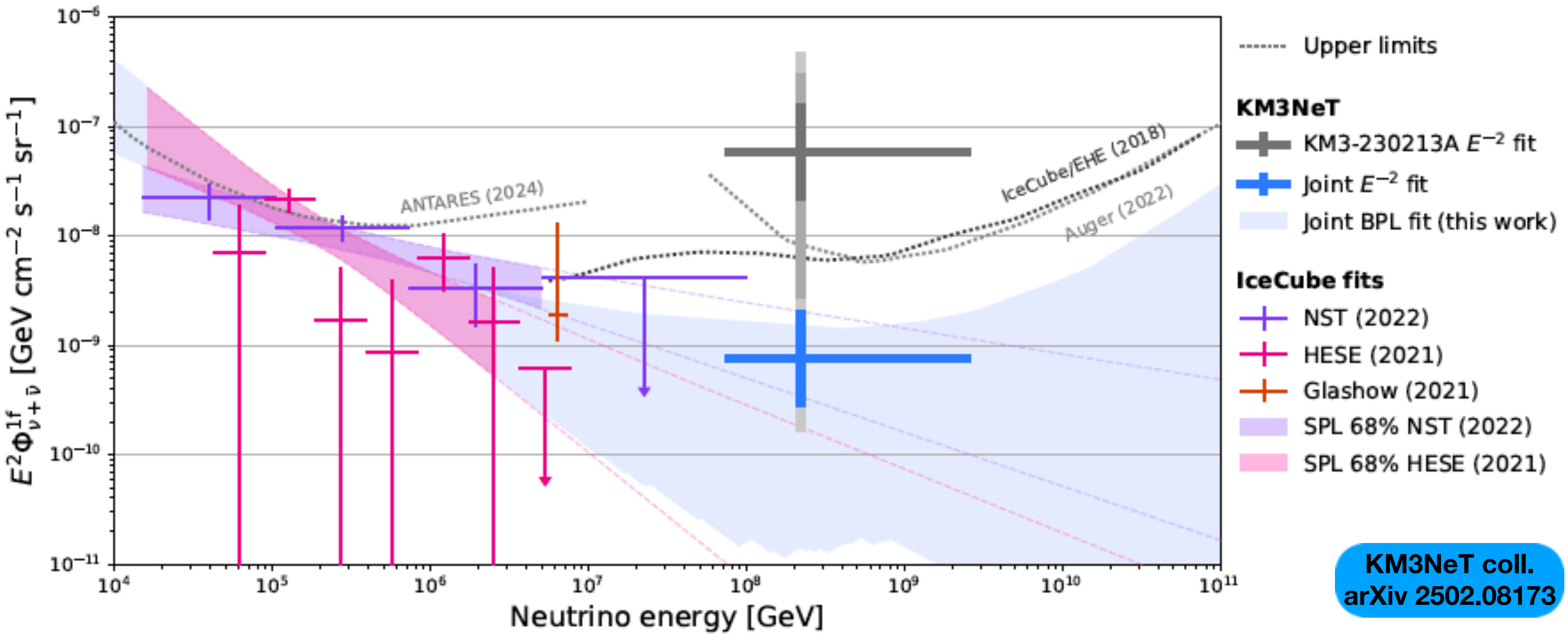
Flux of Cosmogenic Neutrinos



The equivalent flux of KM3-230213A & the cosmic ν

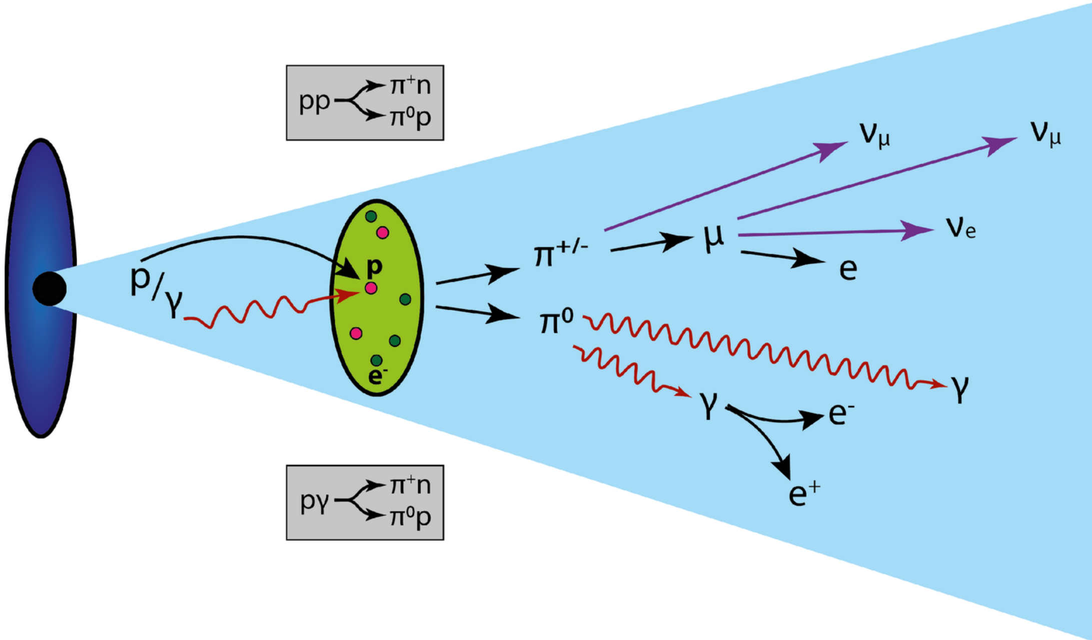
When considering the null observation of IceCube and Pierre Auger telescopes in this energy range
The equivalent flux move from $5.8 \times 10^{-8} GeV cm^{-2} s^{-1} sr^{-1}$ to $7.5 \times 10^{-10} GeV cm^{-2} s^{-1} sr^{-1}$

In this case the measurement of KM3-230213A can be considered a fluctuation of 2.2 - 2.6 σ



KM3NeT coll. arXiv 2502.08173

Production of the cosmic ν



$$p+\gamma \rightarrow \Delta^+ \rightarrow \begin{cases} \pi^+ + n & 1/3 \text{ of all cases} \\ \pi^0 + p & 2/3 \text{ of all cases} \end{cases}$$

$$p+p \rightarrow \begin{cases} \pi^+ + \text{anything} & 1/3 \text{ of all cases} \\ \pi^- + \text{anything} & 1/3 \text{ of all cases} \\ \pi^0 + \text{anything} & 1/3 \text{ of all cases} \end{cases}$$

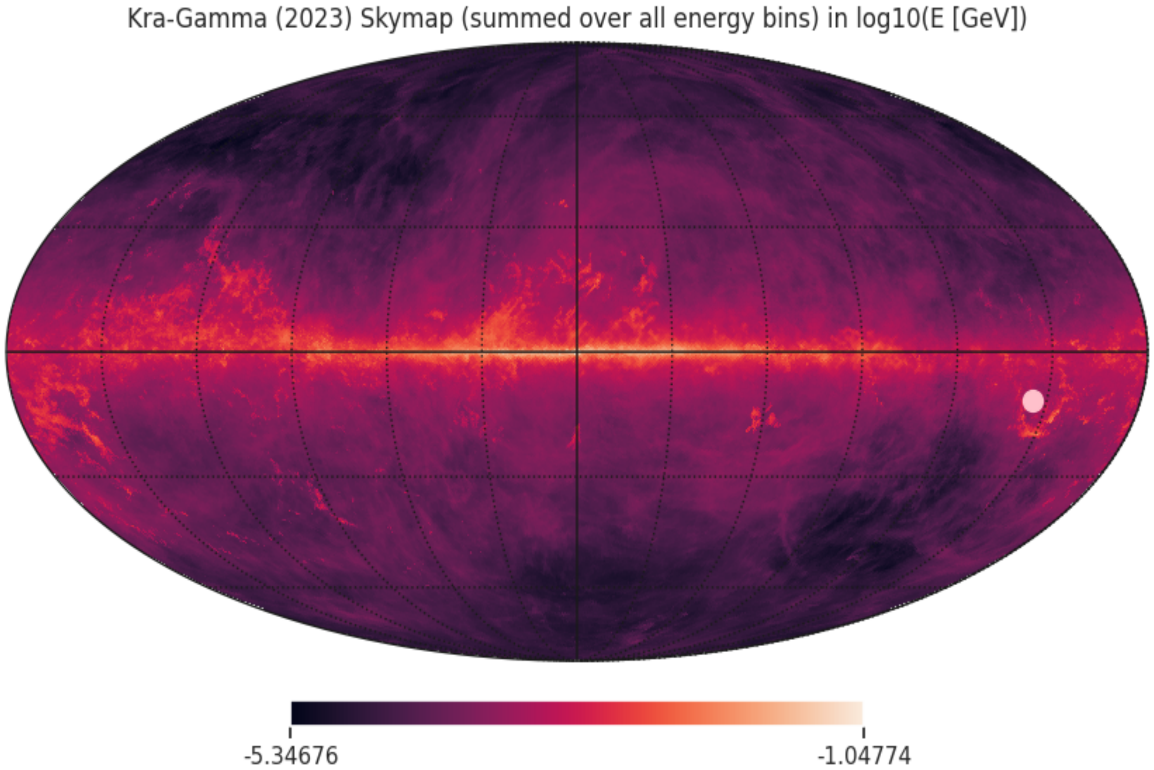
$$\pi^+ \rightarrow \nu_\mu + \mu^+ \rightarrow \nu_\mu + e^+ + \nu_e + \bar{\nu}_\mu$$

When a accelerated Cosmic Ray interact with a nucleon or a photon in a astrophysical environment charged pions are produced and then they decay on $\nu/\bar{\nu}, \mu^{+/-}, e^{+/-}$

Galactic emission hypothesys

The event KM3-230213A it is hardly connected to the Galactic emission

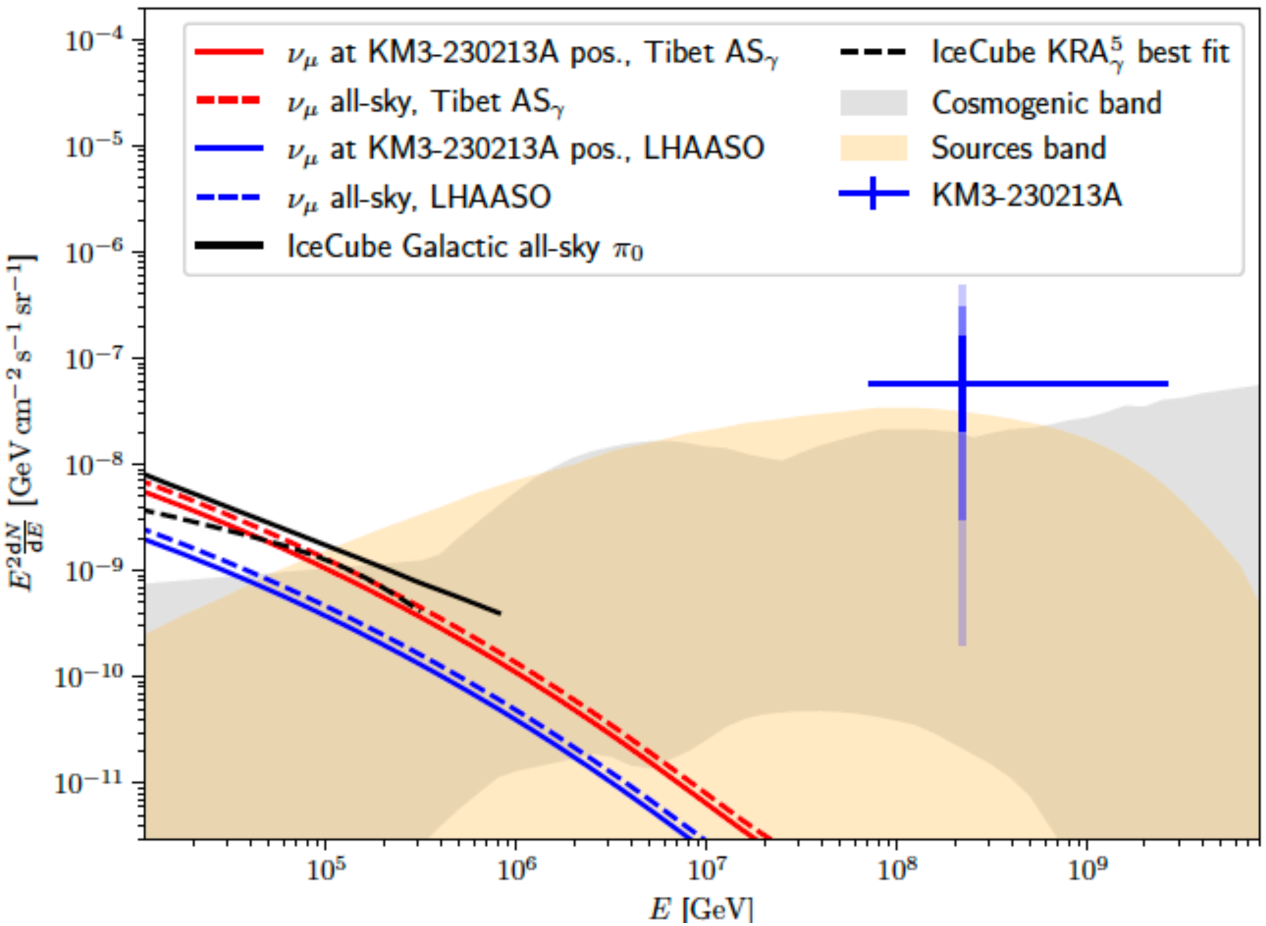
Map from: Gaggero et al. ApJ Letter 2015



- It is difficult to imagine that a Galactic accelerator can reach the EeV energies
- A CR with such energy cannot be contained in the Galaxy
- If a local accelerator would be connected with this event we would probably have seen a strong electromagnetic counterpart.

Galactic emission hypothesys

The event KM3-230213A it is hardly connected to the diffuse Galactic emission



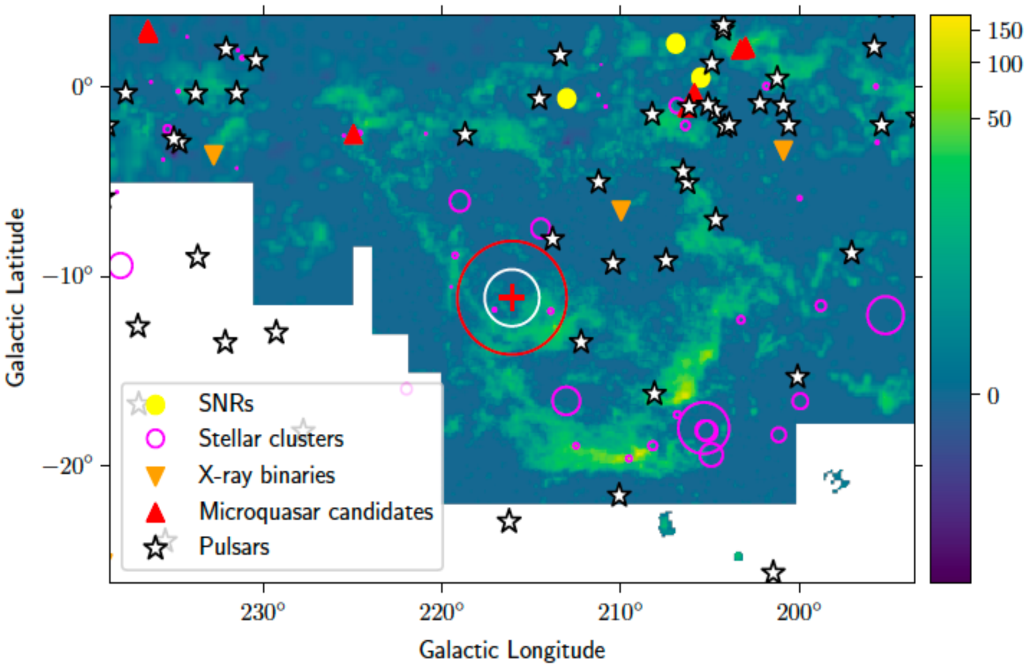
KM3NeT collaboration arXV2502.0837

In this part of the Galaxy, Homogeneous and disohomgeneaous Cosmic-ray Transport scenarios does not different drastically, however the reported equivalent flux of KM3-230213A is hardly conceivable with a Galactic diffuse component.

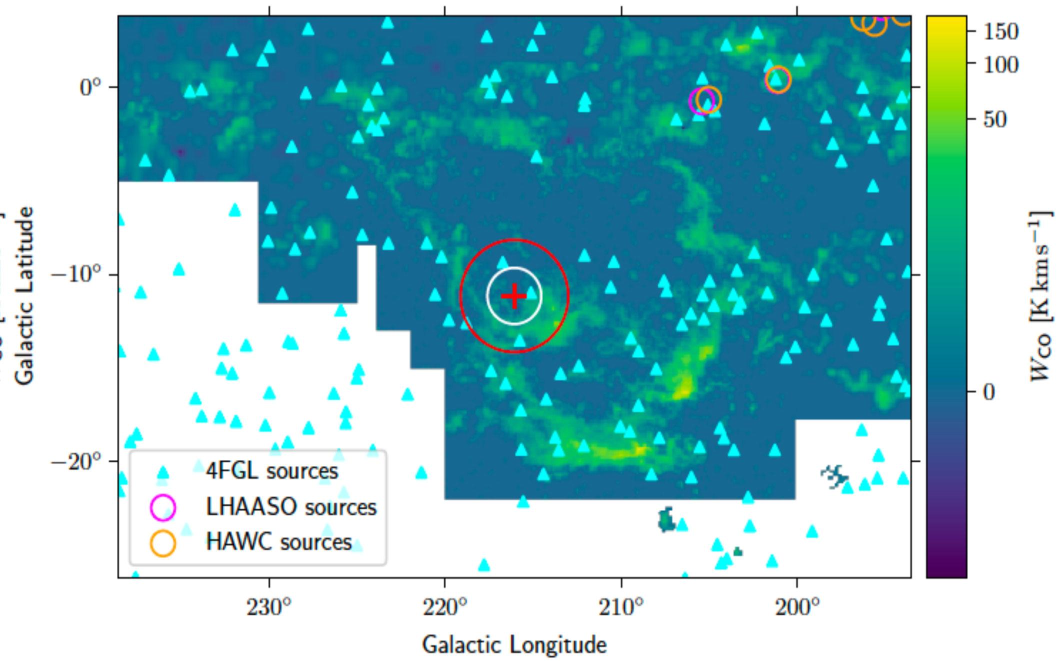
Galactic emission hypothesis

KM3NeT coll.
arXiv 2502.08387

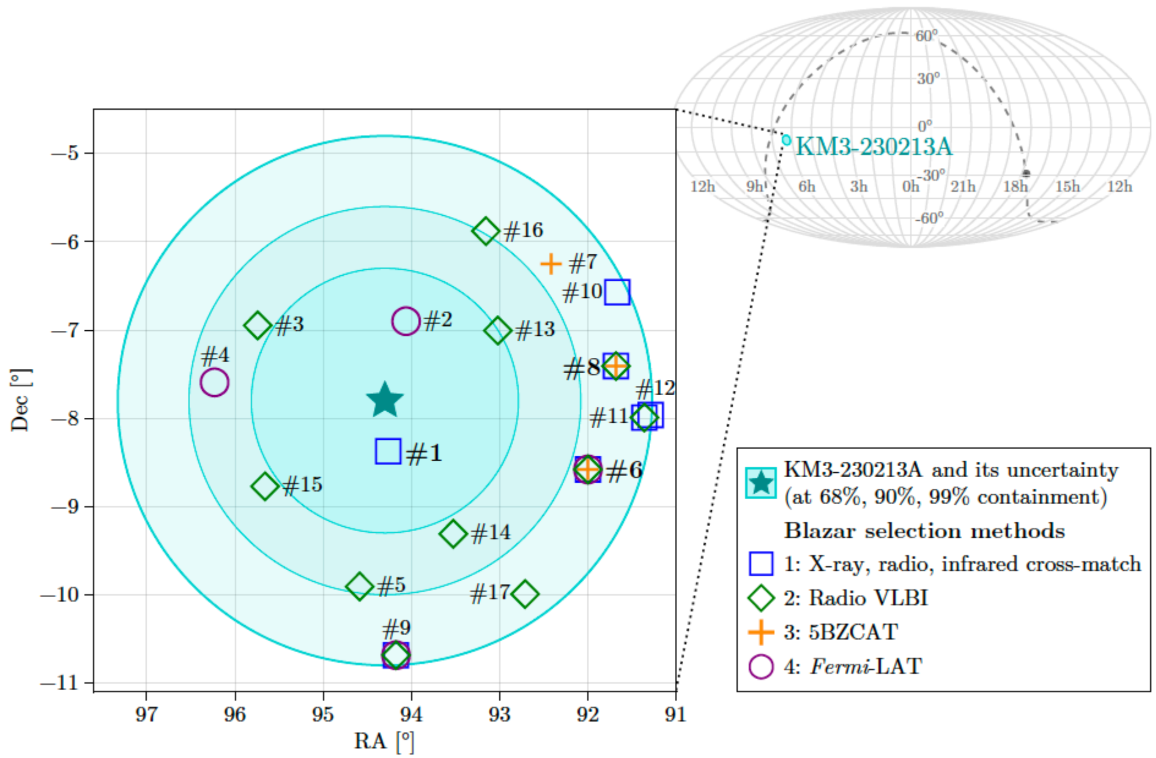
Whitin the 3° error there are no Galactic potential accelerators



And no VHE gamma-ray counterpart have been observed in the mentioned region by HAWC and LHAASO



Extragalactic emission hypothesis



KM3NeT coll.
arXiv 2502.08484

KM3NeT coll.
Nature 638, 376-382 (2025)

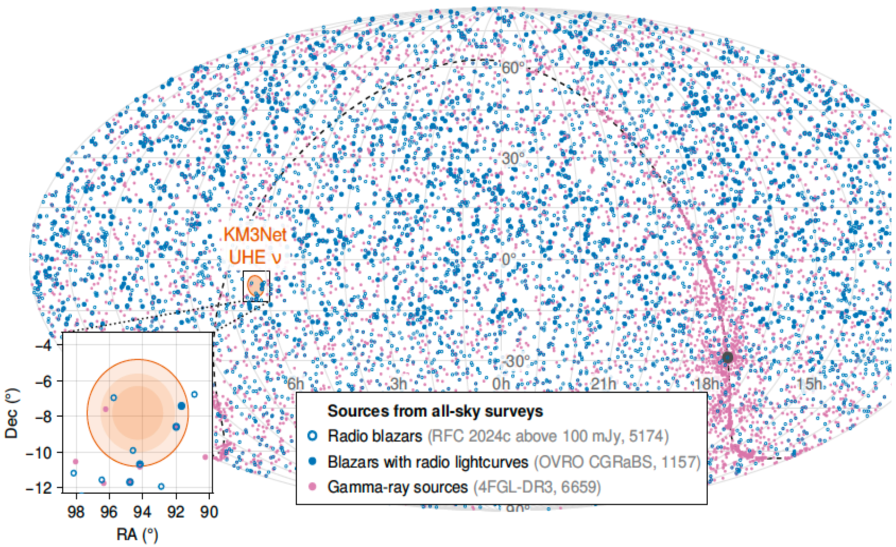
Within the angular incertitude of the teak-like event a search for known extragalactic sources have been performed from radio to gamma-ray.

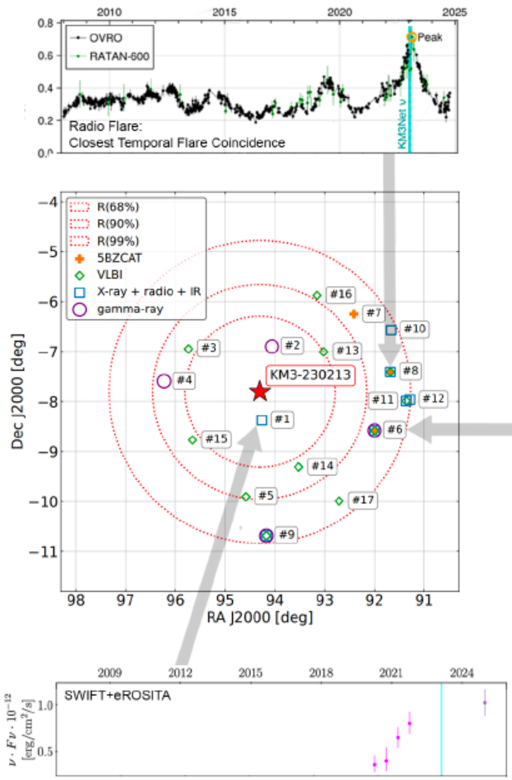
The J2000 coordinates of KM3-230213A are: RA = 94.3°, DEC = 7.8°
With R(50%) =1.2 and R(99%) = 3.0°, 17 Blazars have been identified within the 3° region, with no significant activity associations looking at 4FGL, e-Rosita, VLA, WISE, NRAO

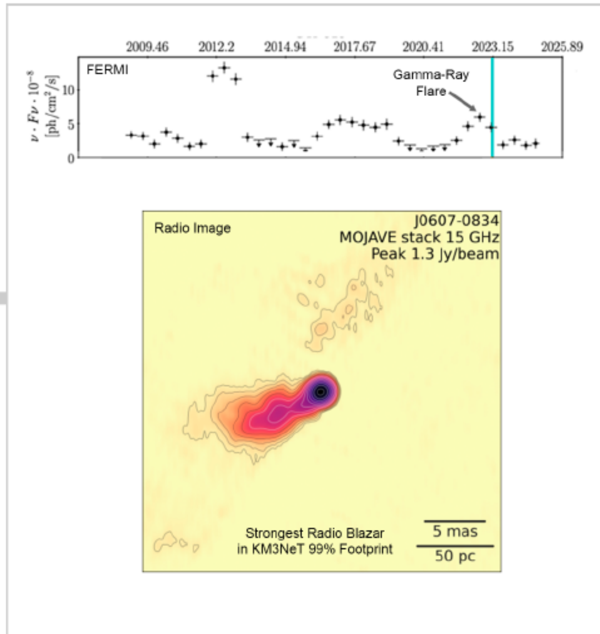
Extragalactic emission hypothesis

Even if no significant correlations have been highlighted it is interesting to pose the attention on three possible coincident flaring activities on radio, X and gamma-ray bands from the reported blazars.

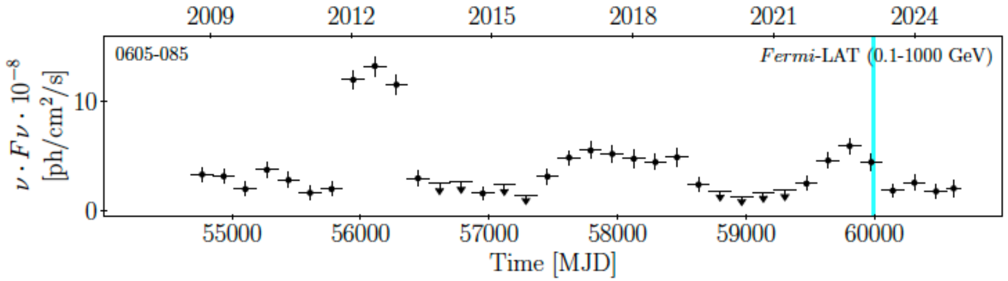
KM3NeT coll. arXiv 2502.08484

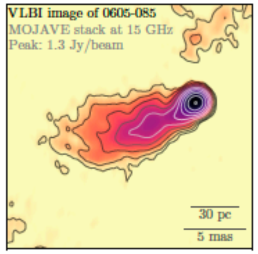






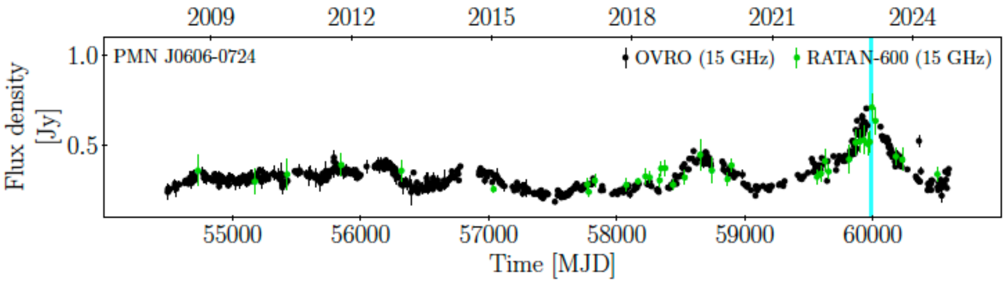
Extragalactic MM in more detail





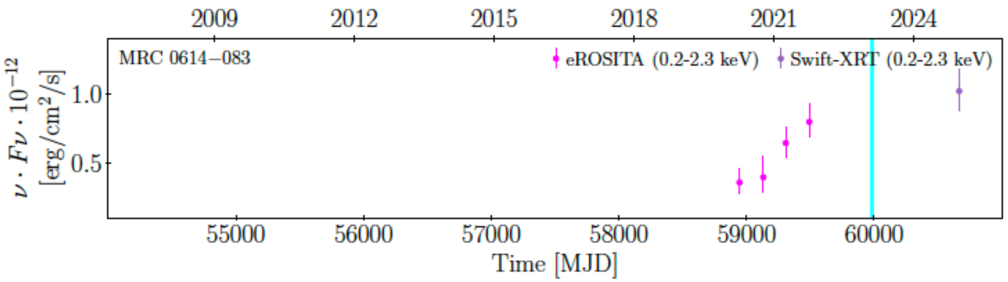
(a) The *Fermi*-LAT light curve and a VLBI image of 0605-085: the brightest radio source in the neutrino localisation region that experiences a gamma-ray flaring activity around the neutrino arrival (Section 5.1).

Year long gamma-ray enhancement activity Coincident with UHE ν



(b) The radio light curve for PMN J0606-0724 that experiences a major flare in close coincidence to the neutrino arrival (Section 5.2).

Radio flare with a time difference of 5 days of UHE ν arrival



(c) The X-ray light curve for MRC 0614-083 that indicates a flaring activity around the neutrino arrival (Section 5.3).

The sparse e-ROSITA sample only extend to $\sim$ 488 days before The UHE ν leaving 3.2 years gap Between it and swift-XRT observations

Summarizing the Extra Galactic Multi Messenger associations

1. Blazar MRC 0614-083 is the closest objects, located 0.6° away from the best fit neutrino position. An indication of the X-ray flare cannot be noted.

2. Blazar 0605-085 is one of the 50 brightest blazars on the sky on parsec scales. A long-term gamma-ray flare peaking before the ν arrival is observed, however not very significant.

3. Blazar PMN J0606-0724 has presented the major radio flare, which peaks at 15 GHz within 5 days from the UHE ν arrival, the pre-trial chance coincidence p-value is estimated to be 0.26.

Checking the source emitting power

Considering a single emitting Blazar to produce the neutrino observed

$$E_\nu \sim 100\,E_{17}\,\mathrm{PeV} \text{ with } 0.72 \lesssim E_{17} \lesssim 26 \qquad E_p \sim 20E_\nu \gtrsim 1.5\,\mathrm{EeV}$$

A single source at $z \approx 1$ (Table 1; luminosity distance $d_L \approx 7\,\mathrm{Gpc}$)

The Luminosity and the Jet Power can be estimated with a rough calculation assuming a beaming factor of $f_{beam} \sim 10^3$ when the emission is concentrated within 4° around the Jet direction.

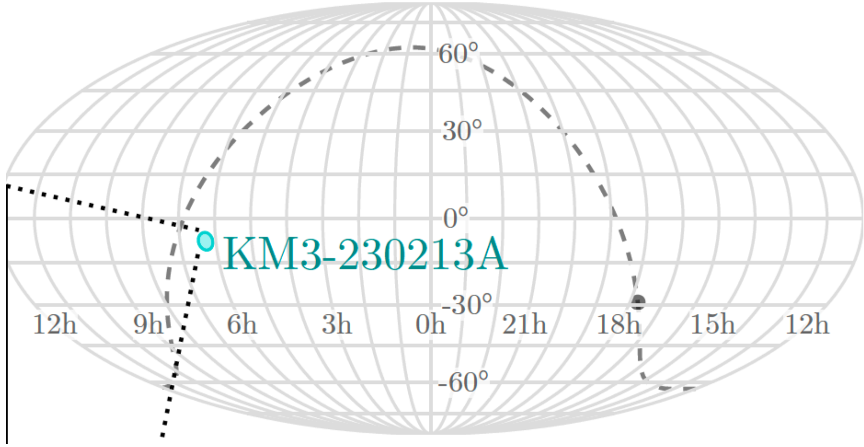
This imply a source luminosity $$L_\nu = \frac{E_\nu \cdot 4\pi d_L^2}{A \cdot T \cdot f_{\mathrm{beam}}} \approx \frac{1.5 \cdot 10^{49}\mathrm{erg\,s^{-1}}}{\frac{T}{yr} \cdot f_{\mathrm{beam}}}.$$

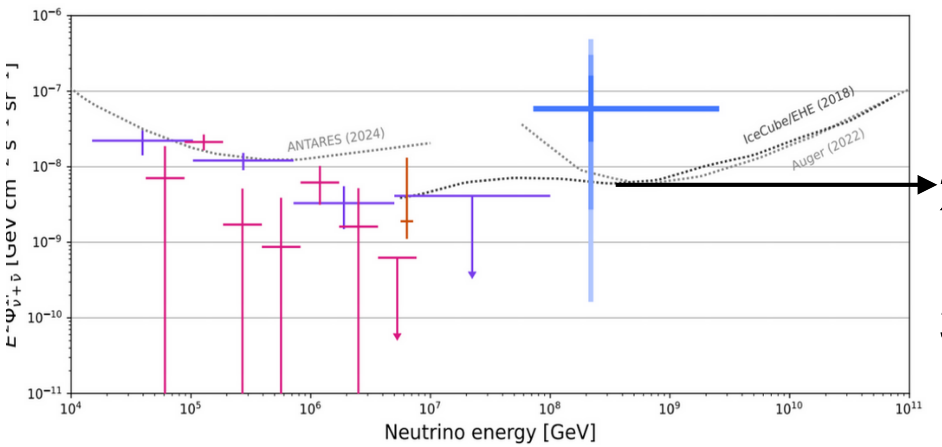
The hadronic power of the jet $$L_p = 20L_\nu \approx \frac{3 \cdot 10^{50}\mathrm{erg\,s^{-1}}}{\frac{T}{\mathrm{yr}} \cdot f_{\mathrm{beam}}}.$$

For a tipical blazar the power of the jet is $10^{45} ergs^{-1}$ which requires hundreds of years to obtain the same flux with the same beaming factor.

Extragalactic transient hypothesis

KM3NeT coll. Nature 638, 376-382 (2025)





When checking the spatial and temporal Coincidence with transient events from GCNs **no** <u>GRB, TDEs or supernova</u> **has been identified** as a possible origin of the UHE neutrino event

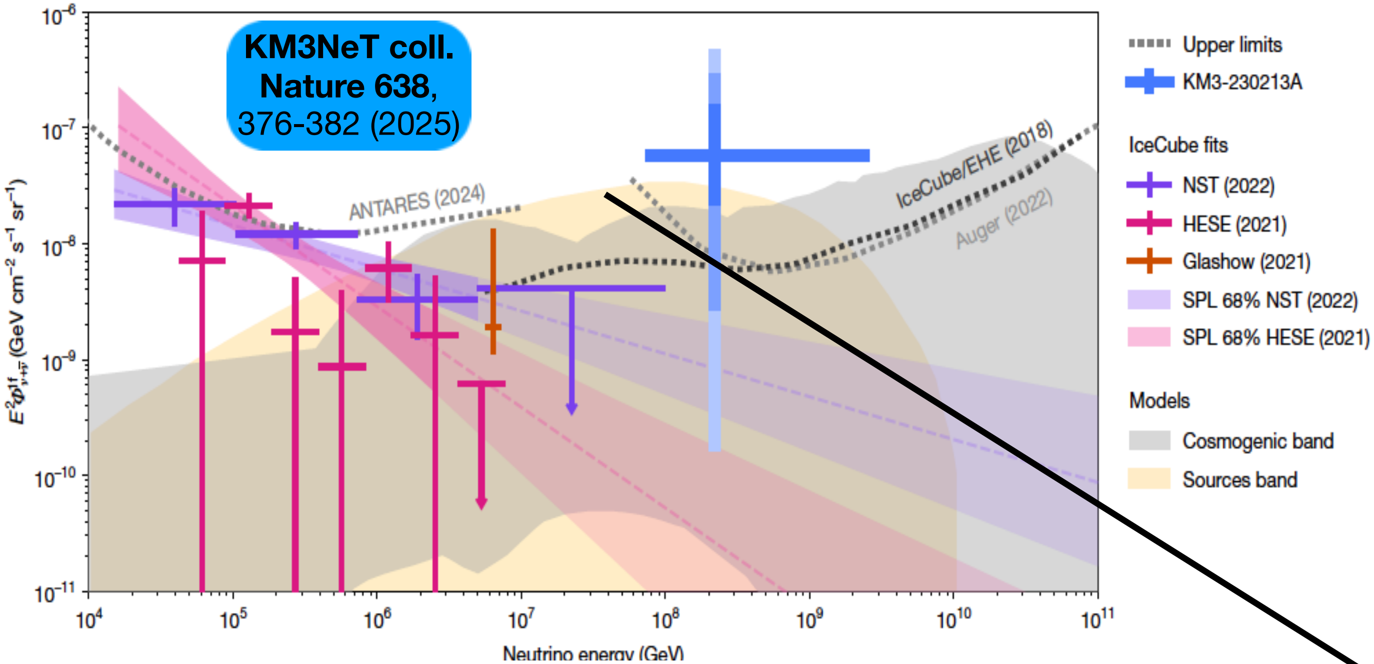
Some considerations about the single transient events:

1) The power of such events can be quite higher respect to a blazar flare.
2) This hypothesis can avoid to deal with the PA and IceCube upper limits for the equivalent flux.
3) They should not be necessarily accompained by an EM counterpart.

A Lorentz Violation case can drastically increase the time window of MM association for GRB cases

A.Camelia et al. arXiv 2502.13093

The diffuse extragalactic hypothesis



The vanilla band represents different classes of extragalactic objects, mostly variable and transients as Blazars, GRBs, TDEs with luminosity between 10^{44} to 10^{54} erg/s

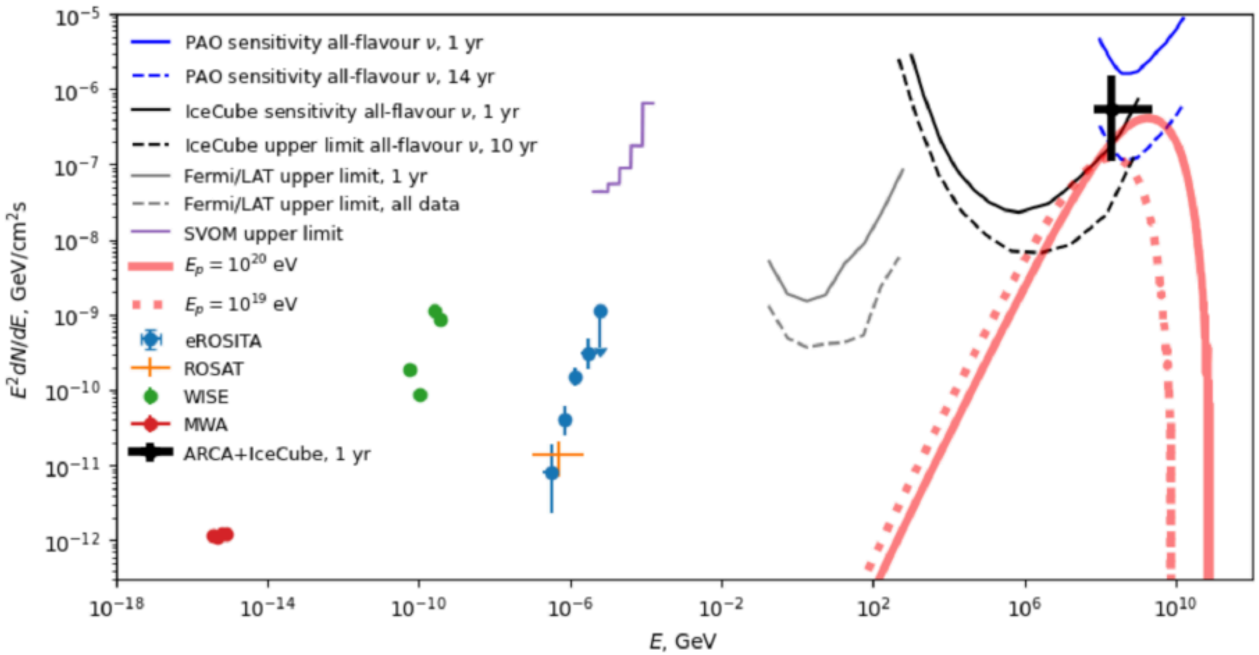
These neutrinos are mostly produced through the photohadronic processes when accelerated cosmic rays interact with thermal or leptonic emitted photons.

Tested flux	Expected events in ARCA19-21 in full energy range	in 72 PeV – 2.6 EeV
Source (transient) diffuse models		
Pulsar (Fang. et al [43])	1.3	0.47
LL-BLLacs (Rodrigues et al. [45])	0.56	0.26
TDE (Winter et al. [39])	0.42	5.5×10^{-2}
LL-GRBs (Boncioli et al. [34])	0.15	2.5×10^{-3}
Sample FSRQ (Rodrigues et al. [46])	1.2×10^{-2}	4.6×10^{-5}
LL-GRB (Tamborra et al. [41])	1.0×10^{-2}	5.9×10^{-4}
Sample LL-BLLac (Rodrigues et al. [46])	5.0×10^{-3}	3.3×10^{-6}
s-GRB (Tamborra et al. [41])	2.8×10^{-6}	6.6×10^{-7}

Event rate expected in ARCA21 for different diffuse flux cases.

The diffuse extragalactic hypothesis

Considering a population of long-lasting emitting sources to produce the neutrino observed



Neronov et al.
arXiv 2502.12986

A year flare duration

Difficult to reconcile this With UHECR observations

$$D_{cosm} \approx 20Gpc$$

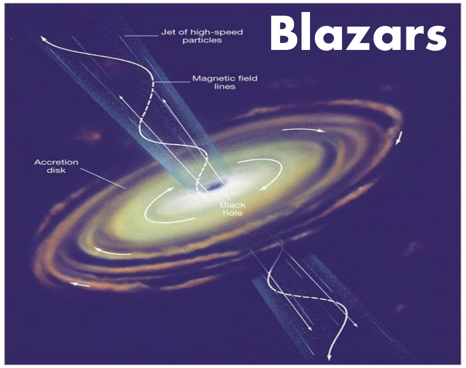
$$\mathcal{R}_{\text{KM3-230213A-like-flares}} \lesssim 0.4 \left[\frac{D}{D_{cosm}}\right] \text{yr}^{-1}$$

$$\rho_s = \frac{\mathcal{R}_{\text{KM3-230213A-like-flares}}}{(4\pi/3)D^3} \lesssim 10^{-5} \left[\frac{D}{D_{cosm}}\right]^{-2} \frac{1}{\text{Gpc}^3\text{yr}} \quad (12)$$

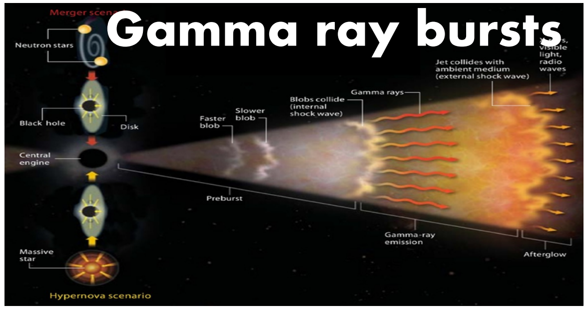
However to explain the UHECR measure by the PA and TA you need $n_{UHECR} \geq 10^4 Gpc^{-3}$

Extragalactic emitter candidates

When we do a population study up to a certain redshift:



- Important constrains by the Fermi-LAT diffuse gamma-ray emission and IceCube observations.
- Function luminosity distribution known.



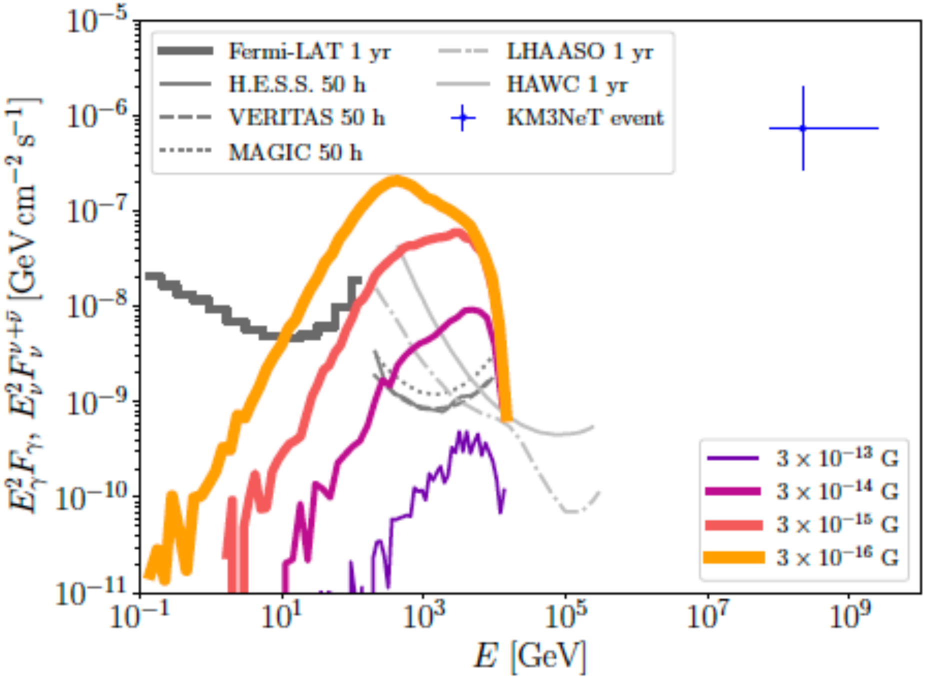
- No constrain from the Fermi-LAT diffuse gamma-ray emission, staking constrain from IceCube observations.
- Function luminosity distribution known (SFR)

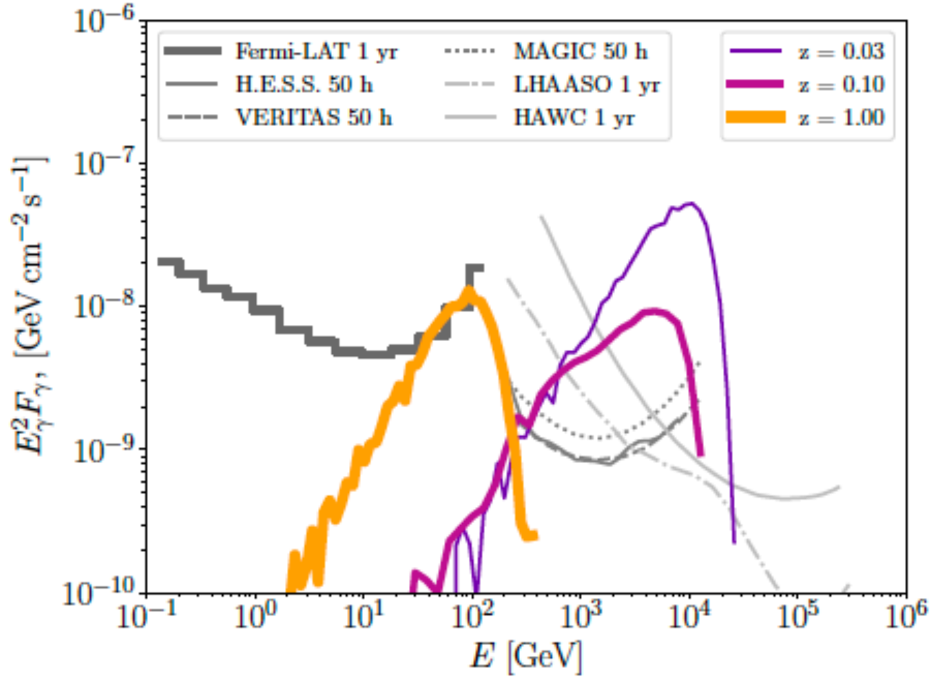
- No constrain from the Fermi-LAT diffuse gamma-ray emission and IceCube observations.
- Function luminosity distribution ?

The single transient source hypothesis

In case of a single emitter lasting 1 y it is possible to constrain the inter galactic magnetic field and the redshift also looking for the equivalent electromagnetic cascade considering a $E_{\pi_0} = 440 PeV$

Halzen et al.
arXiv 2502.09545

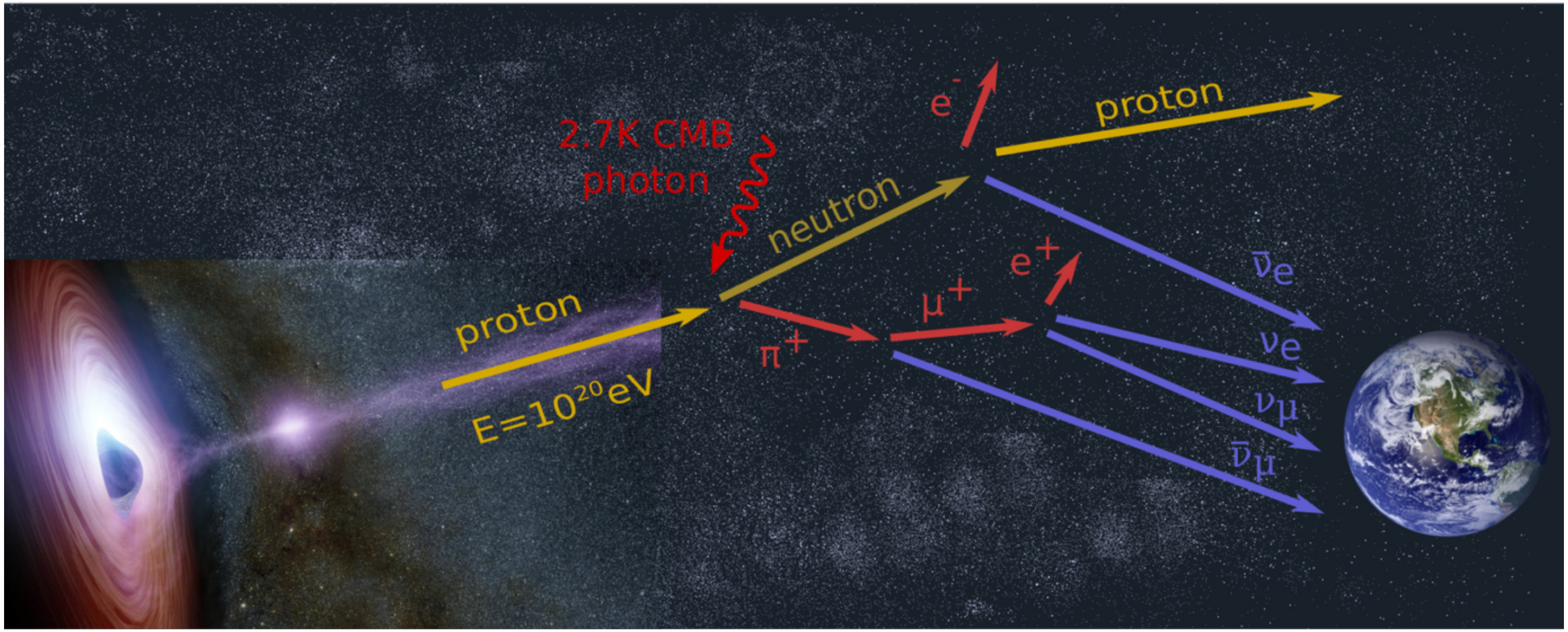


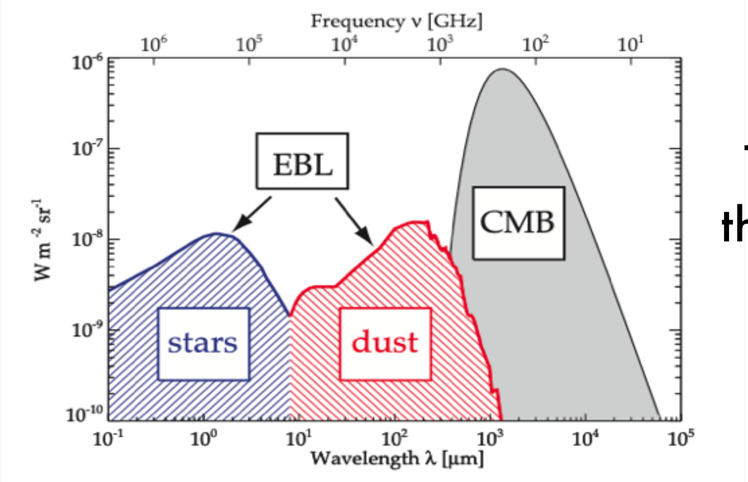


With $E_\nu^2 \Phi = 5.8 \times 10^{-8} GeV cm^{-2} s^{-1} sr^{-1}$

$$E_\gamma^2 \frac{dN}{dE_\gamma}(z) = \frac{4\pi d_L^2}{1+z} \left(4\, E_\nu^2 \frac{dN}{dE_\nu dA}\right)(z=0)\Big|_{E_\gamma = 2(1+z)E_\nu}$$

Possible cosmogenic origin of KM3-230213A



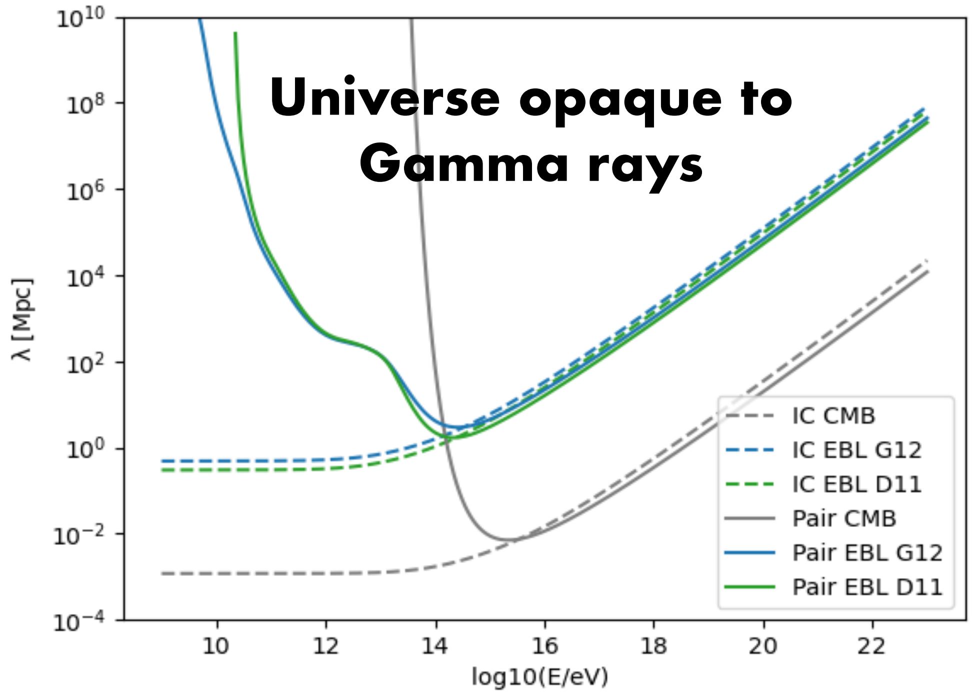


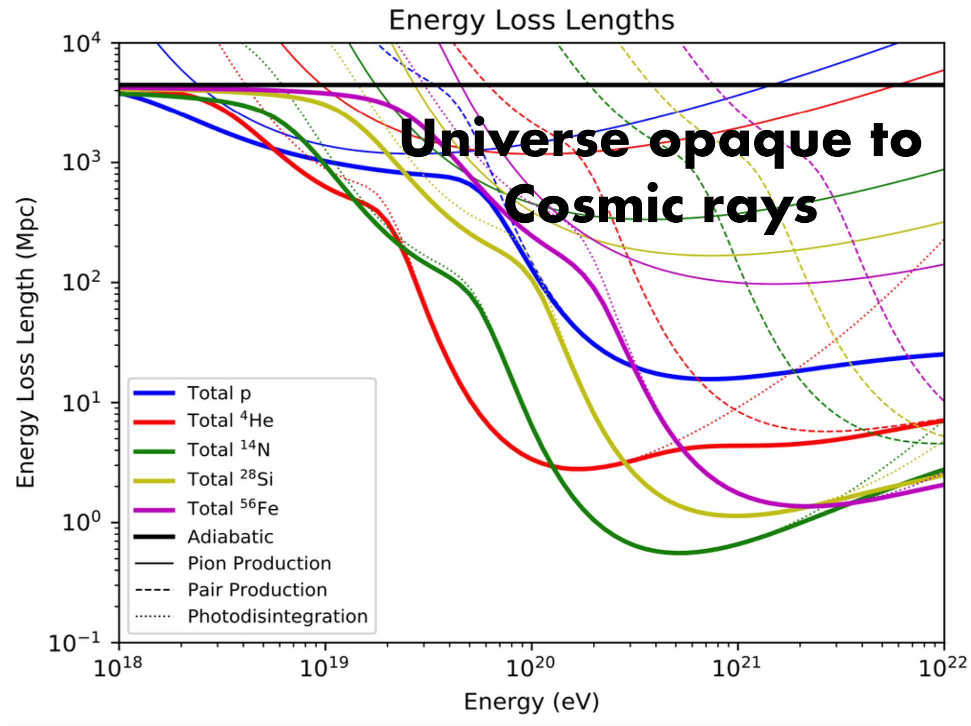
The cosmic rays accelerated on the sources can interact with the background photons (CMB or EBL) during their path to the earth and produce neutrinos called "cosmogenic"

The deep universe observed through the ν

For the observed energy we can make the hypothesis to explore of the Universe never explored before, or in other words the most faraway accelerators observed for such energies

KM3NeT coll.
arXiv 2502.08508





Modeling the extragalactic injectors

Aloisio et al.
JCAP 10 (2015) 006

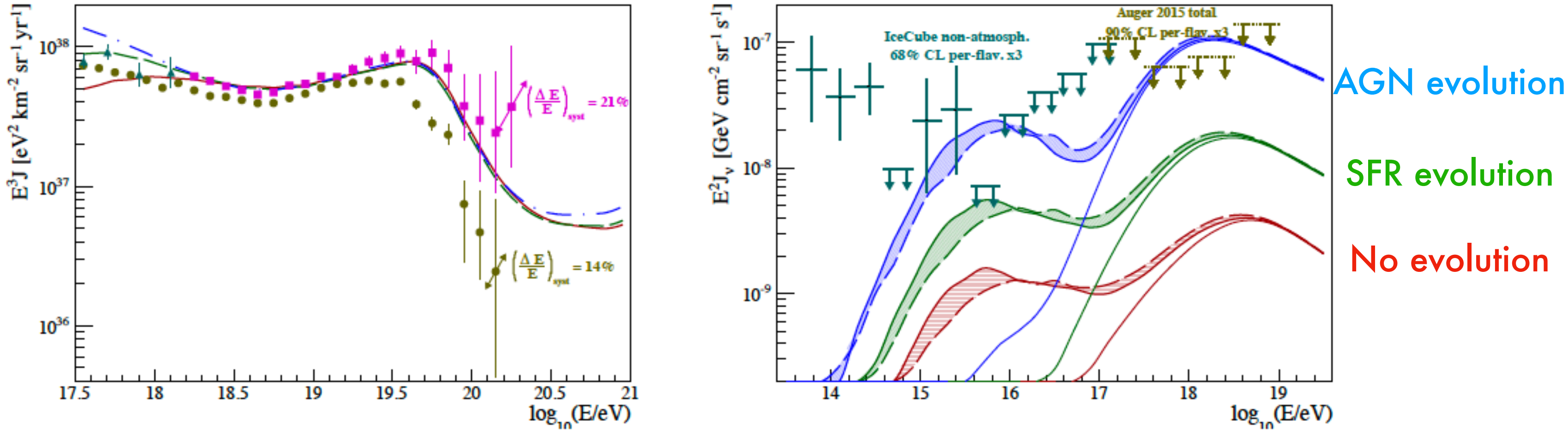


Figure 2. [Left Panel] Fluxes of protons expected at Earth in proton-only scenarios with various models for the cosmological evolution of sources (solid red: no evolution; dashed green: SFR evolution; dot-dashed blue: AGN evolution [38]) normalized to TA data (purple squares); Auger data (olive disks) and KASCADE-Grande data [63] (blue triangles) are also shown for comparison. [Right Panel] Fluxes of neutrinos in the same scenarios (same color code; from bottom to top: no evolution, SFR, and AGN), with colored bands showing the difference between the Stecker (solid) [46, 47] and Kneiske (dashed) [48] EBL models; thin solid lines are neutrino fluxes obtained taking into account only the interaction with CMB photons.

Looking at UHECR composition

Pierre Auger Coll.
JCAP05 (2023) 024

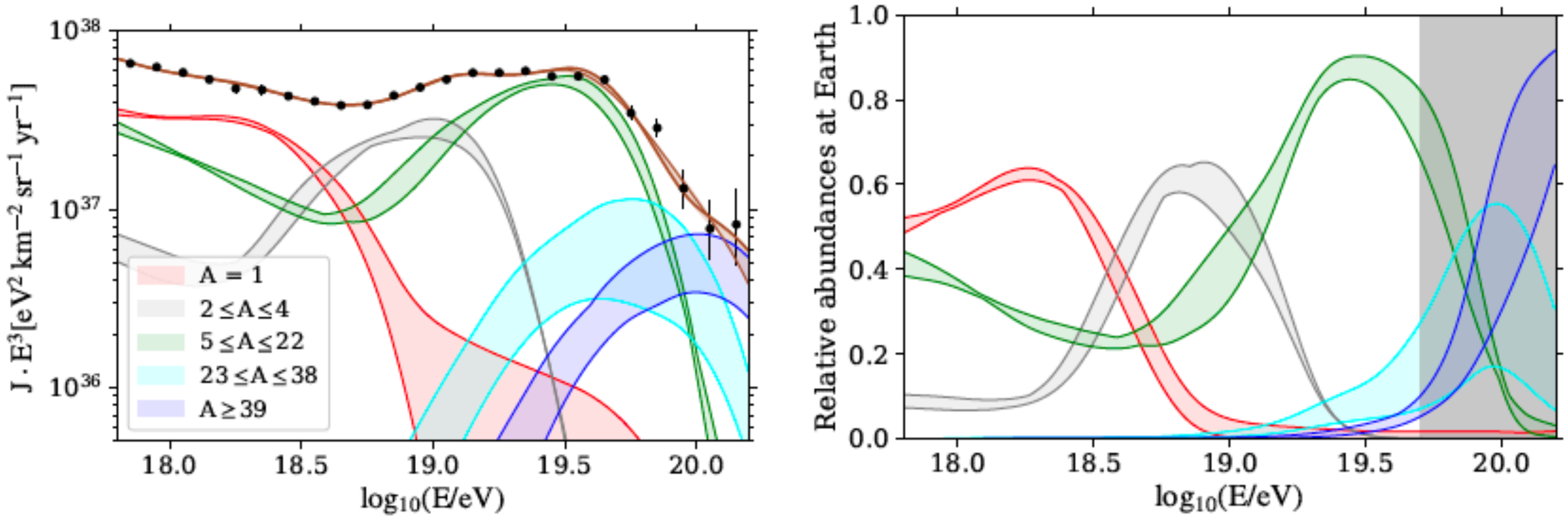


Figure 11. *Left:* the effect of the uncertainties from models on the energy spectrum. *Right:* the effect on the relative abundances at the top of the atmosphere. The bands represent the maximal variations given by the results in Table 3. The shaded grey area indicates the energy region where energy-by-energy estimates of the mass composition are not available (i.e. above the median of the highest energy bin used for X_{max} data) and mass predictions are mainly based on the shape of the all-particle spectrum.

Cosmological model used for the paper

KM3NeT coll.
arXiv 2502.08508

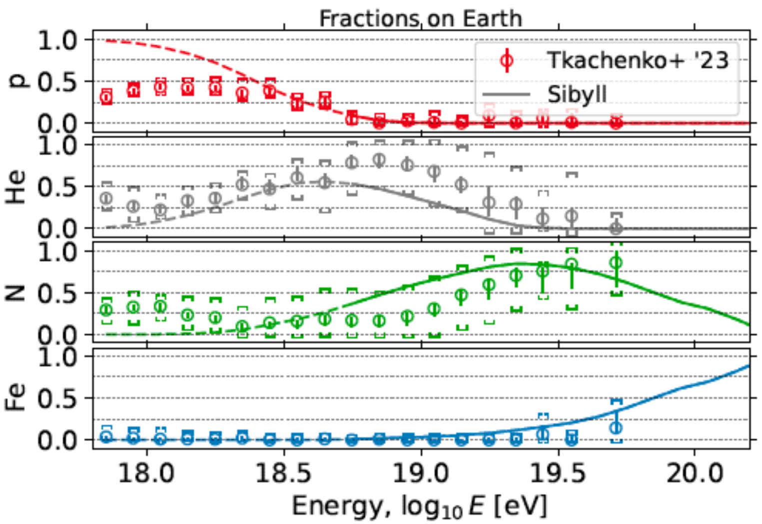
- Cosmological framework to compute neutrino fluxes produced in EG propagation;
- Assume that each source is identical and distributed with a given evolution m

$$\frac{dN}{dE} \propto f_A \left(\frac{E}{10^{18} eV}\right)^{-\gamma} \times f_{cut}(E, Z_A R_{cut}) \times \boxed{(1+z)^m}$$

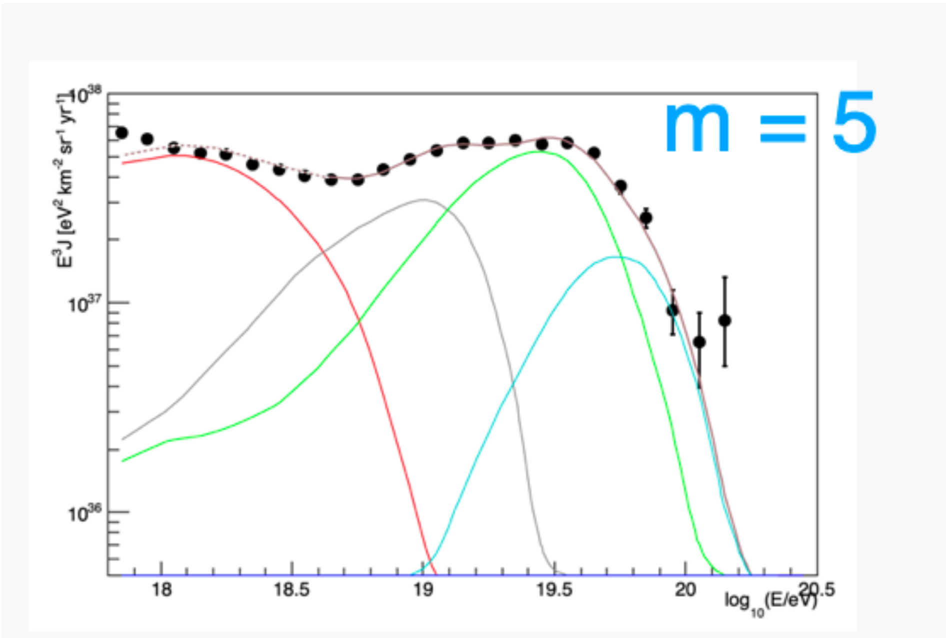
- Fit to UHECR data –> normalization to neutrino flux.
- Important parameters to fix : m and z. All the others are fitted to describe UHECR data.

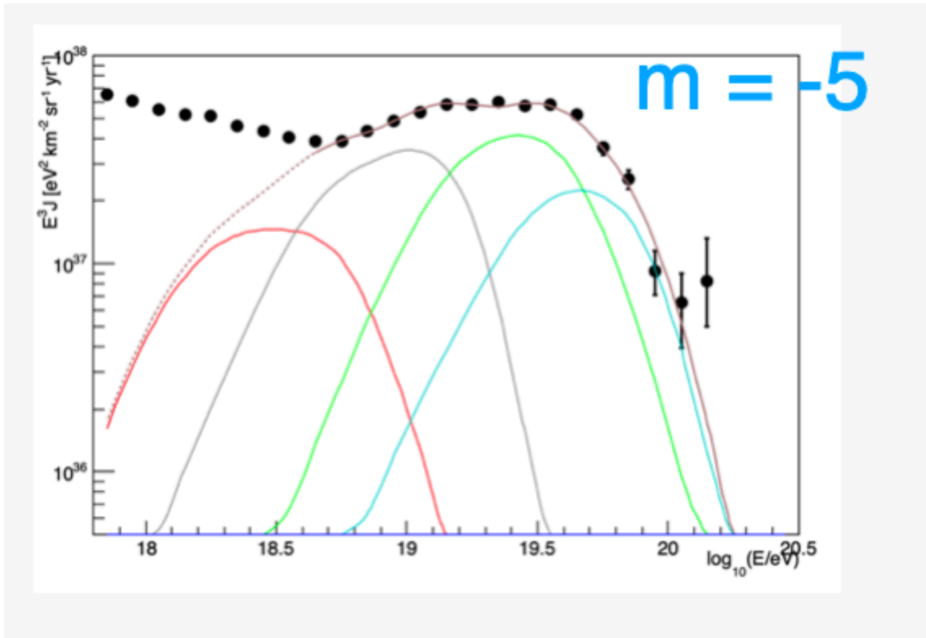
Parameters at the source → Description of UHECR measurements → Expected neutrino flux → Constrain with our exposure

Fitting cosmic-ray data with different evolution parameter m

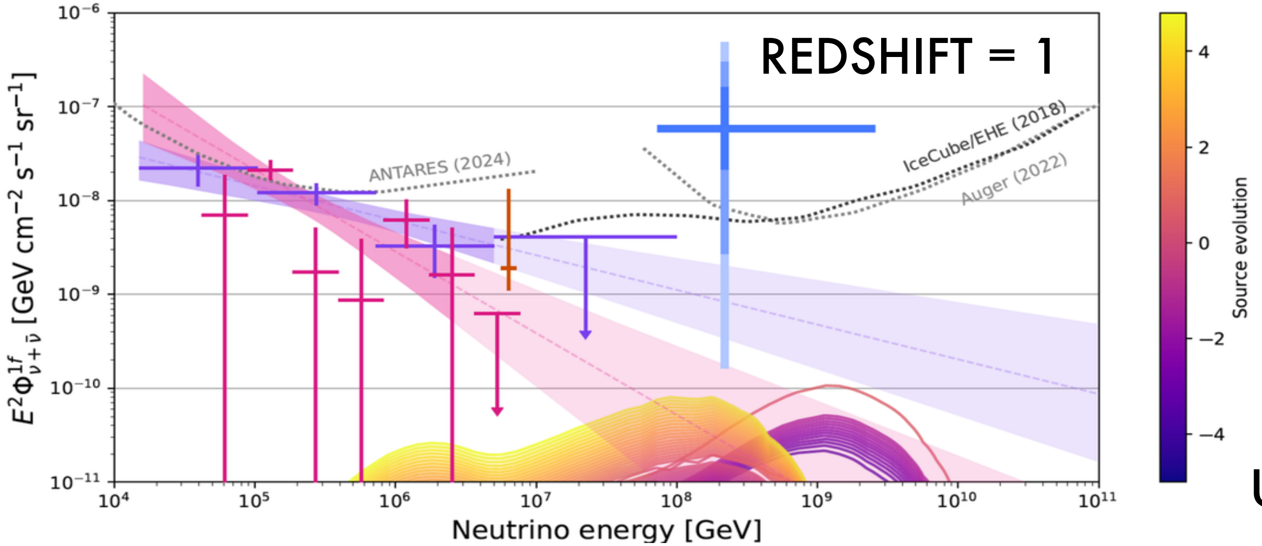


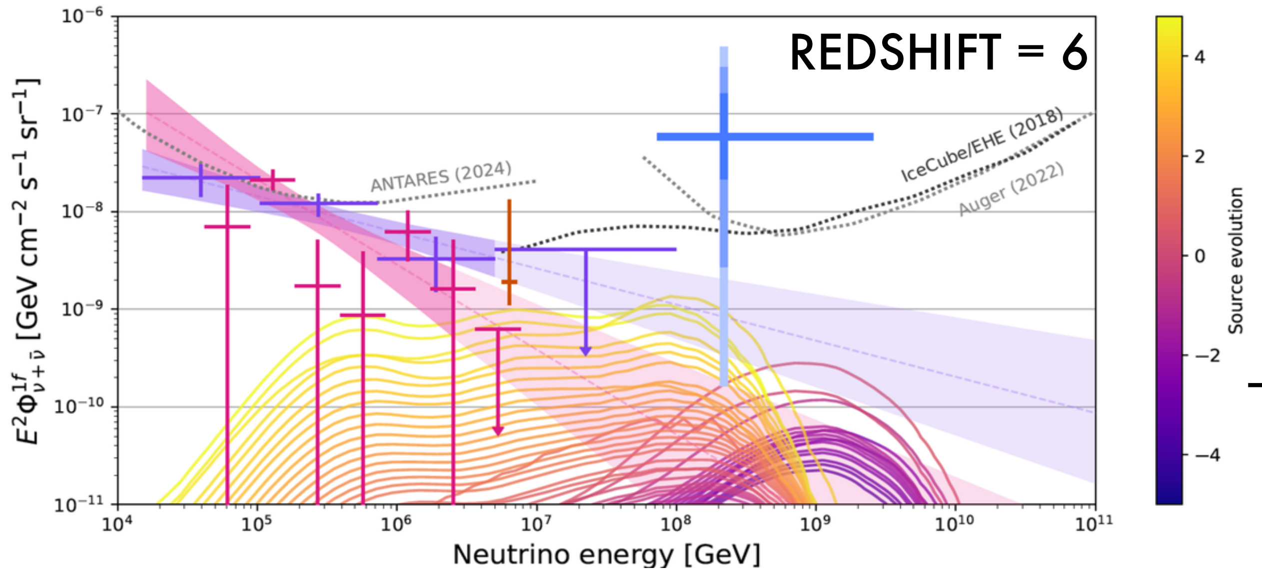
High m~5 →	High luminosity sources
Intermediate m~3 →	Star formation evolution
m~0 →	Stellar mass density
Negative m~-3-5 →	LL BL-Lac. Radio galaxies





Possible cosmogenic origin of KM3-230213A





KM3NeT coll.
arXiv 2502.08508

To be slightly consistent with the equivalent flux of the UHE ν event, we need to integrate The cosmogenic component up to high Redshift

We can be compatible with the most distant Cosmic accelerators ever seen In this range of energy

Possible cosmogenic origin of KM3-230213A

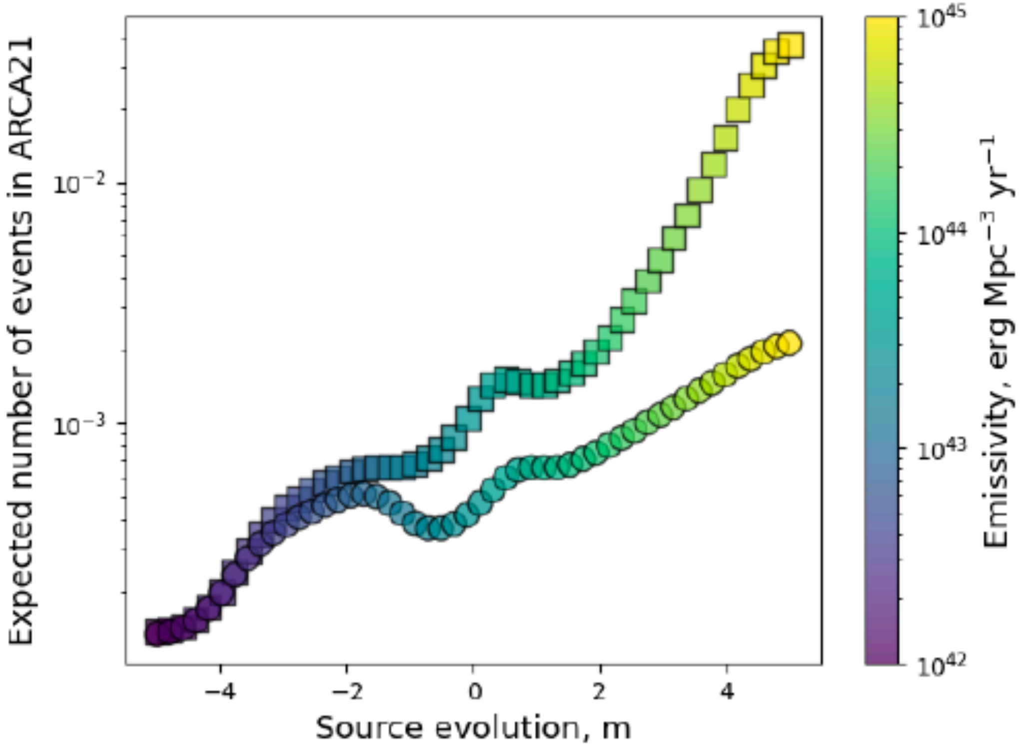
The emission rate density $L(E,z)$ of cosmic rays per coming volume can be described as:

Source Evolution — Injection Term

$$L(E,z) = S(z) \times Q_{CR}(E)$$

The coming sources density can be described by :

$$S(z) \propto (1+z)^m$$



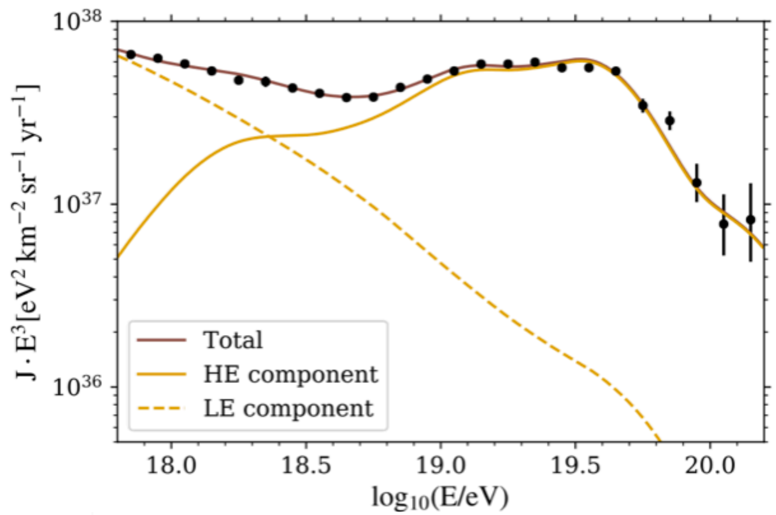
KM3NeT coll. arXiv 2502.08508

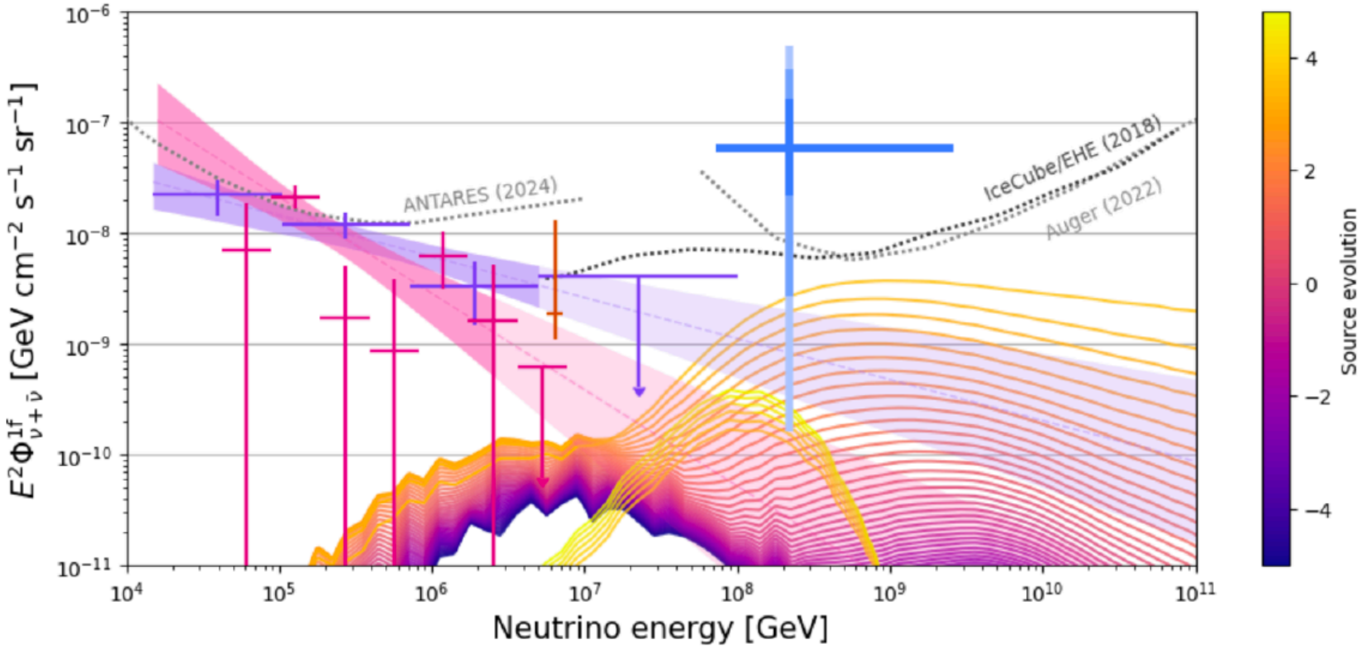
To account for the observed event
We possibly need a excessively
Strong evolution of sources,
More luminous sources.

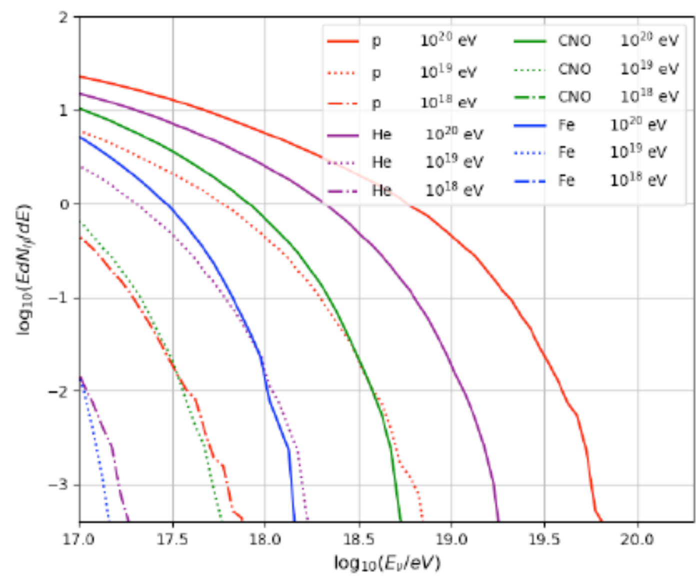
Possible cosmogenic origin of KM3-230213A

Eventually a subdominant component of
Protons up to highest energies observed
By Pierre Auger and Telescope Array
can increase the number of expected
cosmogenic events

KM3NeT coll.
arXiv 2502.08508



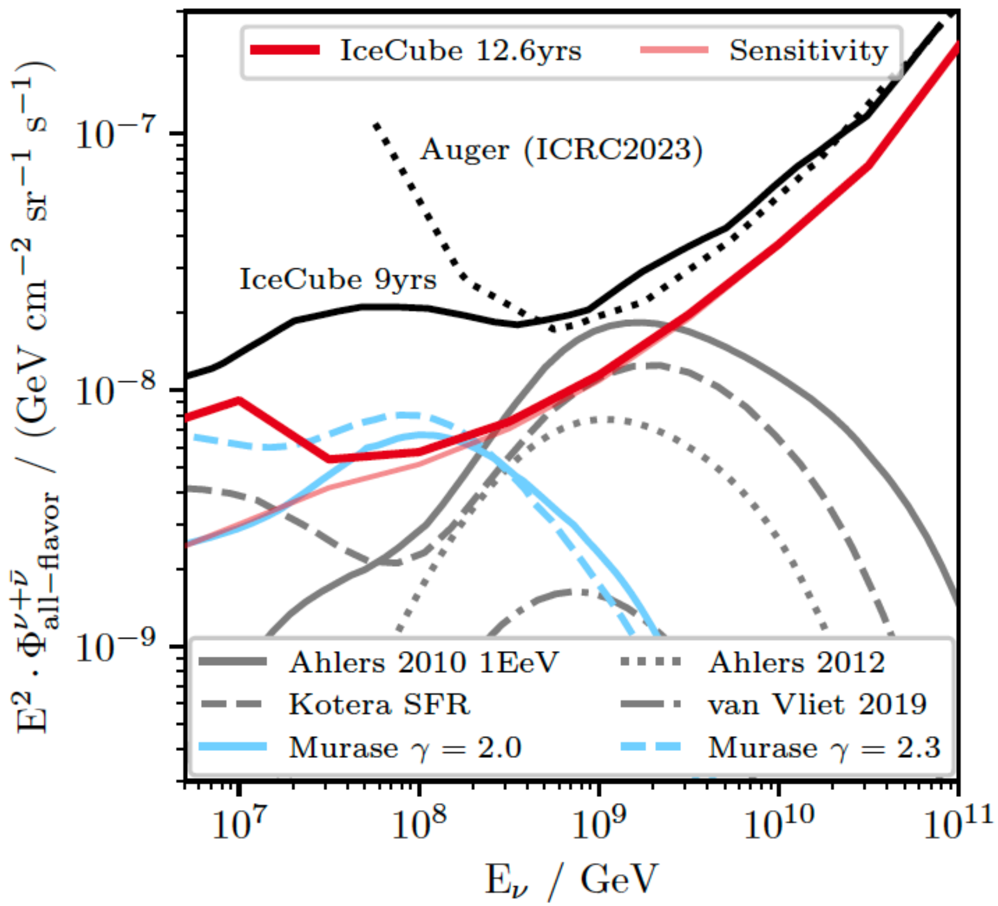


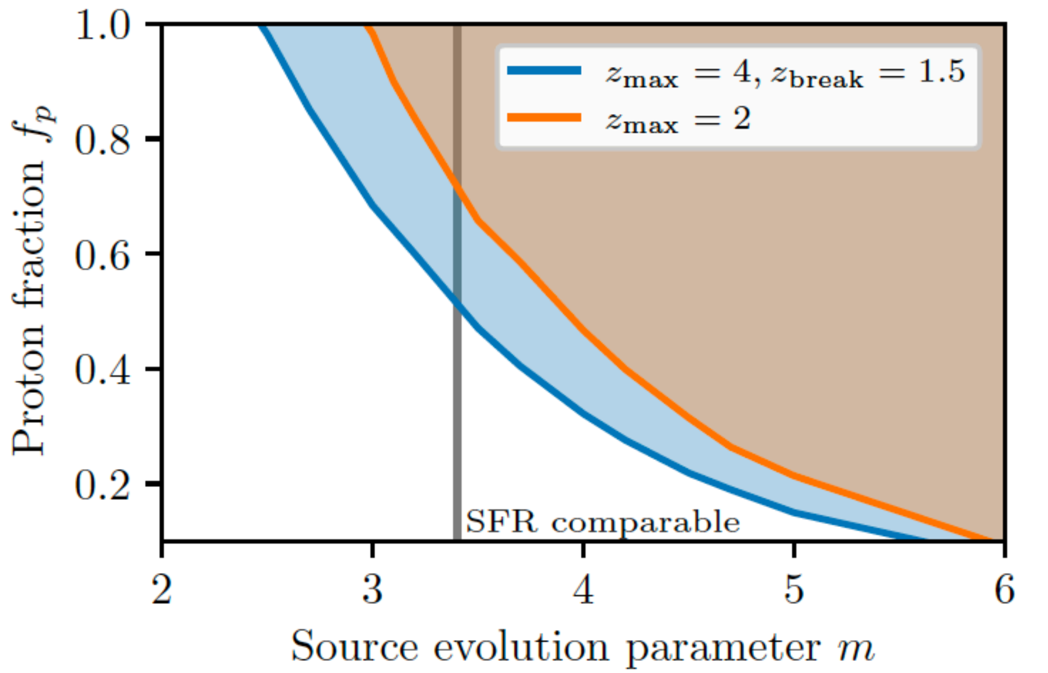


New constrain on proton fraction from IceCube

IceCube presents a new constrain on UHE neutrino flux,
Considering 12.6 years of data taking and a new UL up to 10^{11} GeV

IceCube coll.
arXiv 2502.01963

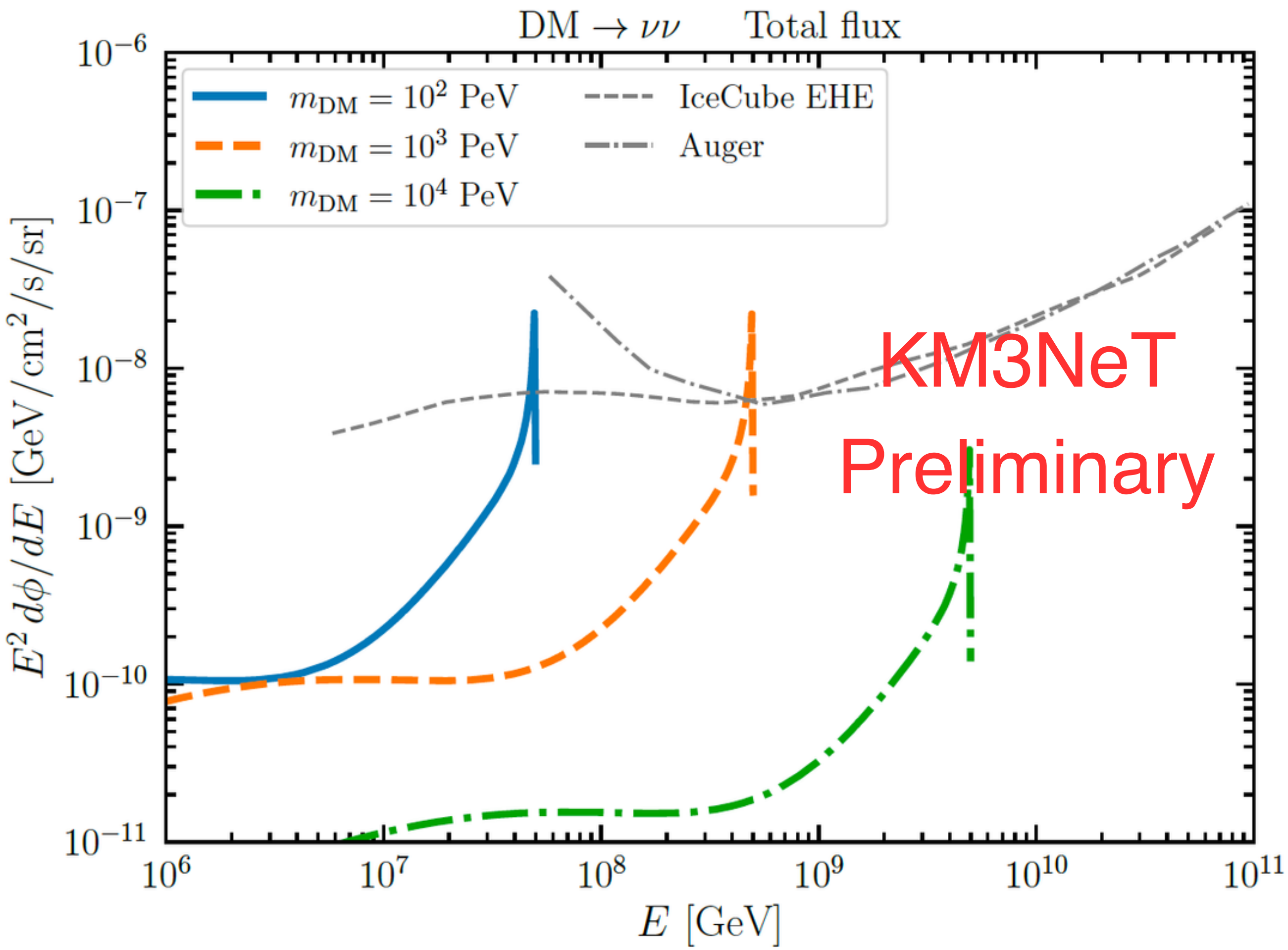




A limit of 70% of proton composition on the total energy range observed by PA is posed for a SFR evolution, not in contrast with our hypnoses of a proton hypothesis in:

KM3NeT coll.
arXiv 2502.08508

Possible origin of KM3-230213A from heavy DM decay



KM3NeT coll. &Chianese, Morisi, Saviano

Under study the hypothesis that The UHE neutrino event would have been originated from the decay of heavy Dark Matter, a side three Examples of different DM candidates.

Many interesting hypotheses are under study for Physics BSM, many related works appear in the literature to explain KM3-230213A

Summary

- KM3NeT observed the most energetic neutrino ever detected, ~36 times more than most energetic one measured by IceCube, ~10000 times the energies at LHC.

- The event KM3-230213A suggests the rising of a new cosmic component in this energy range.

- The UHE measured event did not present at the moment significant correlations with sources known in the electromagnetic band.

- More observations on this energy range are needed to characterize better this new component.

Thank you for the Attention