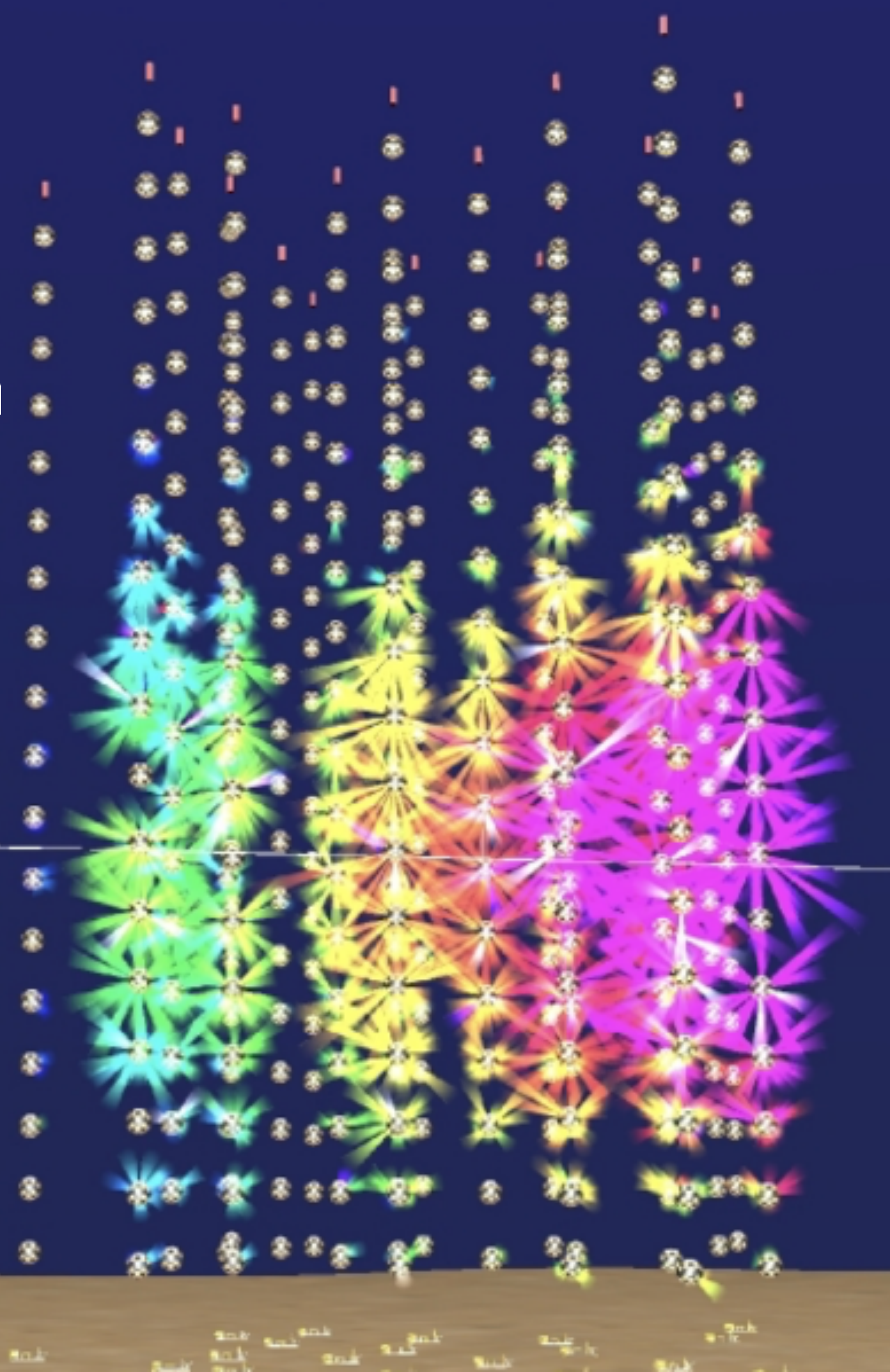
# First observation of an Ultra-High Energy neutrino with KM3NeT

**Silvia Celli**
**on behalf of the**
**KM3NeT Collaboration**
silvia.celli@roma1.infn.it

Sapienza Università di Roma, Italy
INFN - Sezione di Roma, Italy

# Outline of the talk

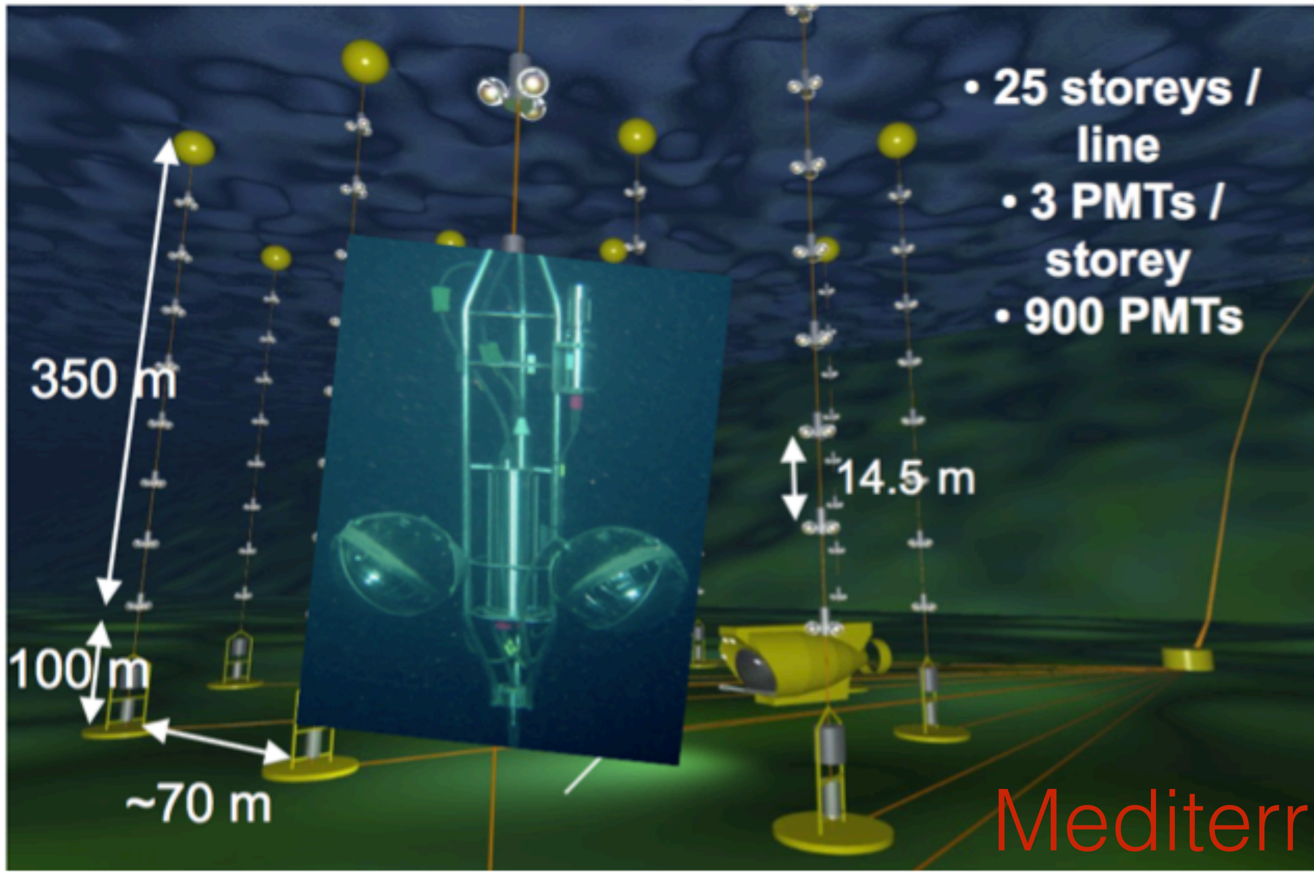
- The KM3NeT infrastructure
- KM3NeT/ARCA observation of KM3-230213A
- Possible origin
- Conclusions

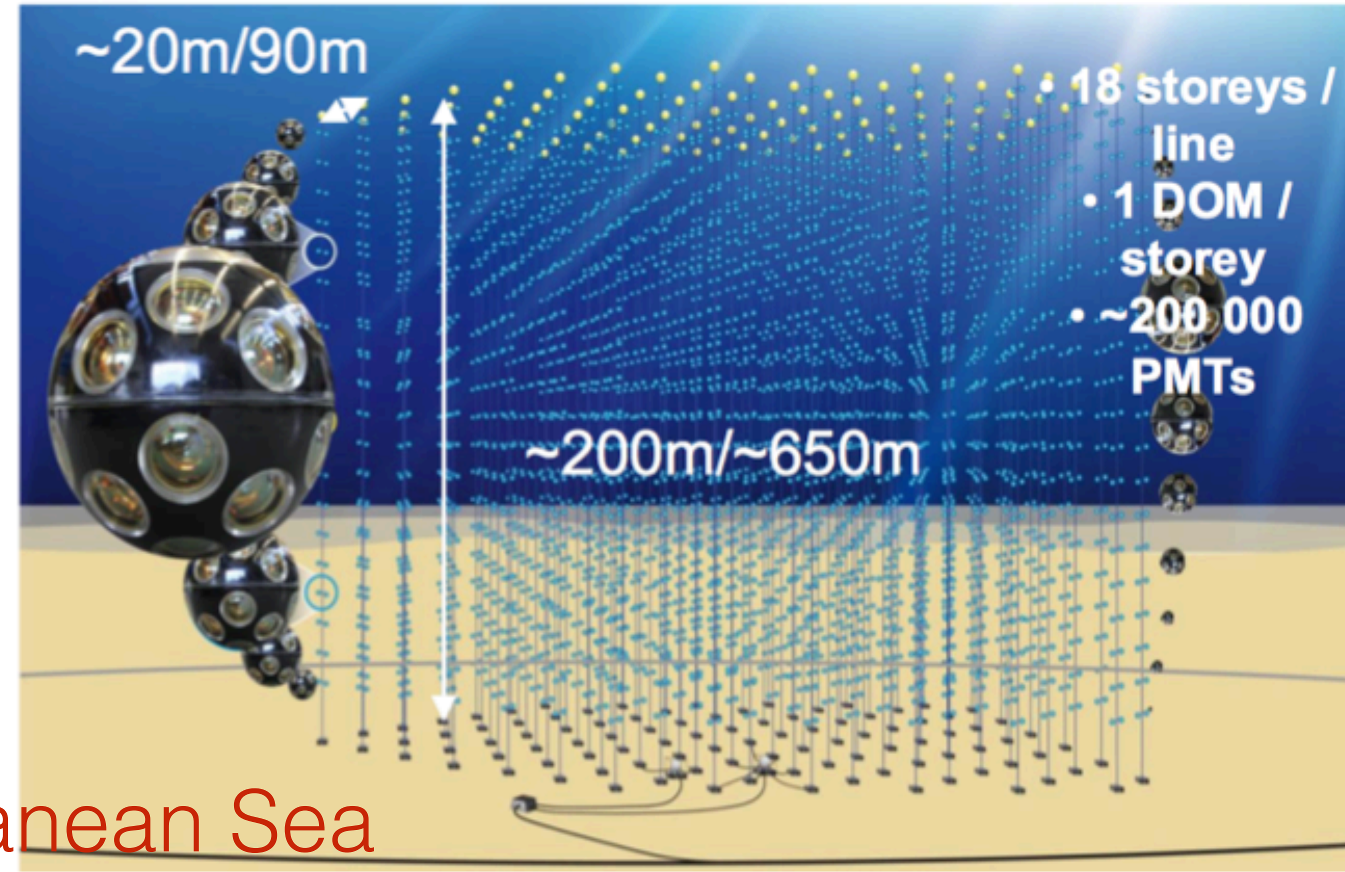


# Neutrino telescopes around the world

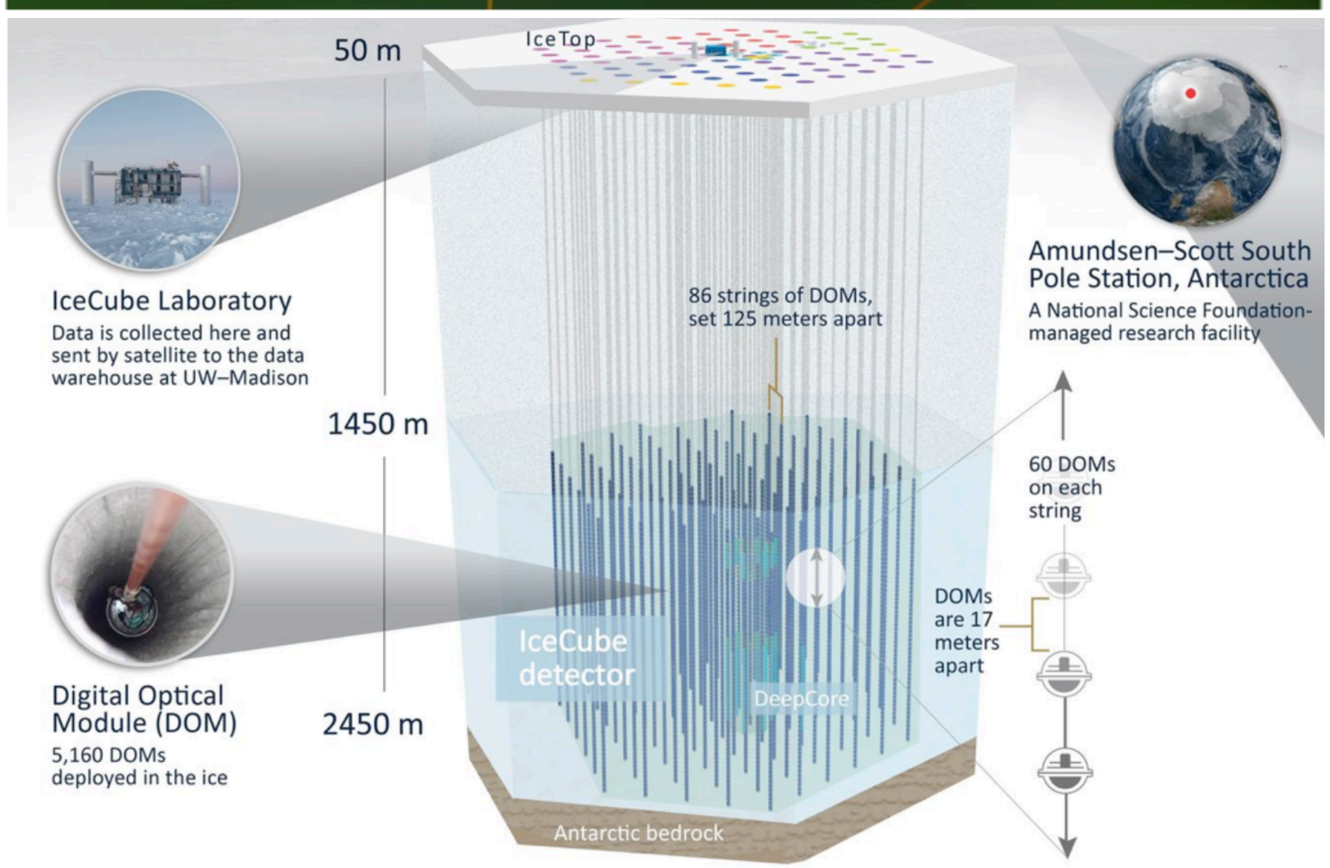
ANTARES Complete since 2008

KM3NeT Under Construction

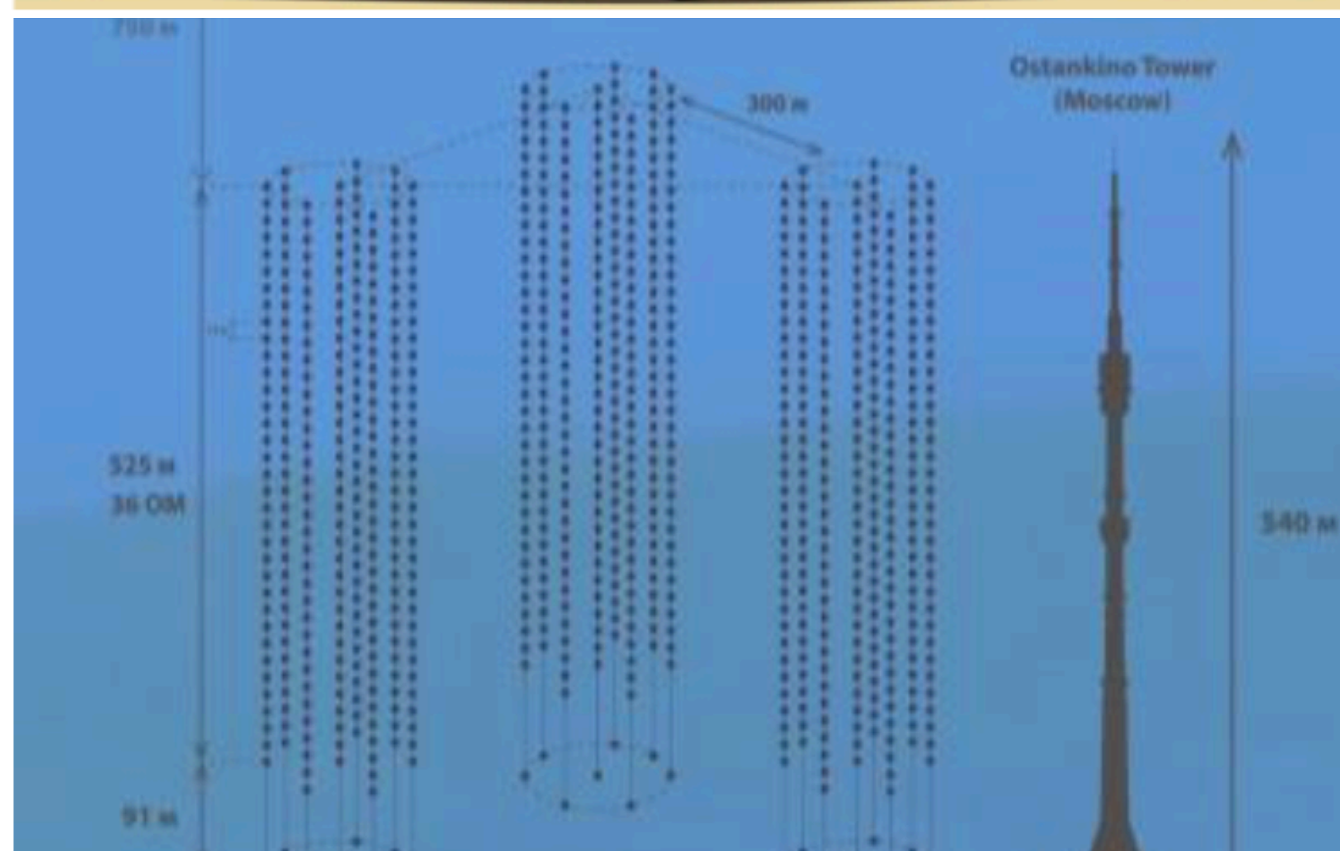



Mediterranean Sea




IceCube @ South Pole



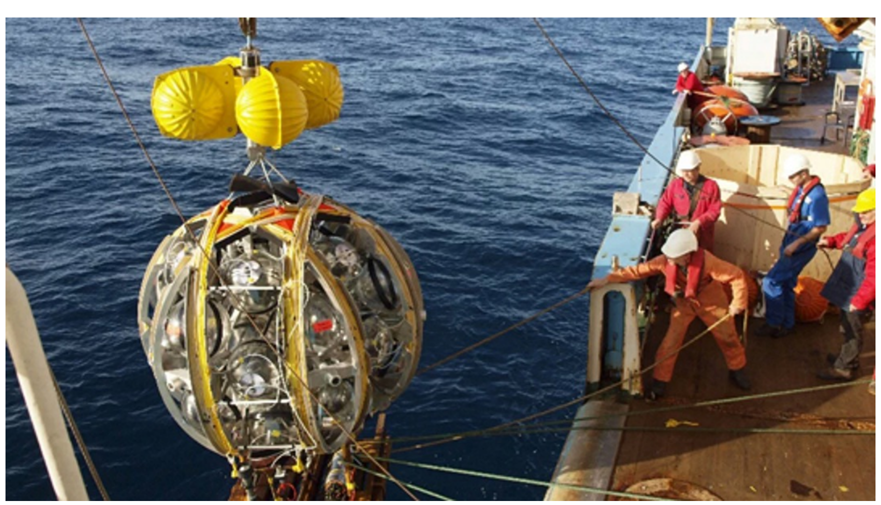

GVD @ Baikal Lake

# KM3NeT at a glance

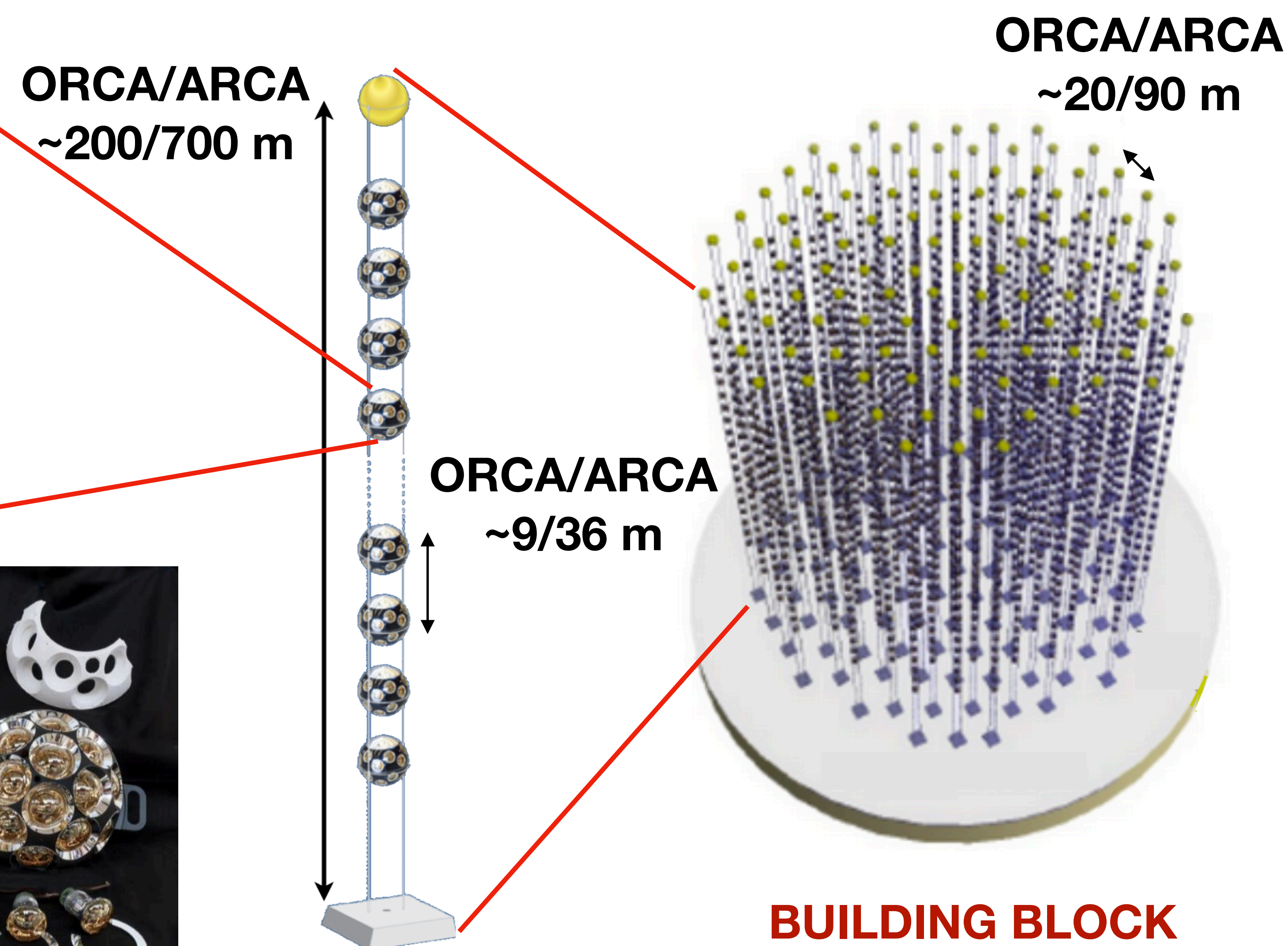
<u>Main detector elements:</u>
- Digital Optical Modules (DOMs)
- Detection Units (DUs)
- Seafloor network: Junction Boxes (JBs) and electro-optical cables

<u>DOM:</u>
**17” glass sphere containing:**
**31x3” PMTs**
**LED and Piezo**
**Front end electronics**

- Uniform coverage
- Directional information
- Digital photon counting
- All data to shore



**DOM**




**DU**
**18 DOMs+1base module/DU**

**BUILDING BLOCK**
**115 DUs/building block**

**Launcher of Optical Modules**

# KM3NeT: a top view

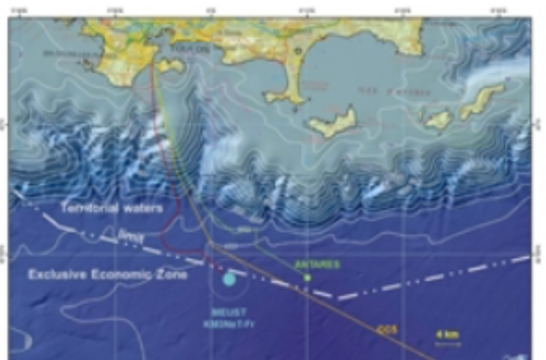
## ARCA (1 GTon)

Astroparticle Research
with Cosmics in the Abyss

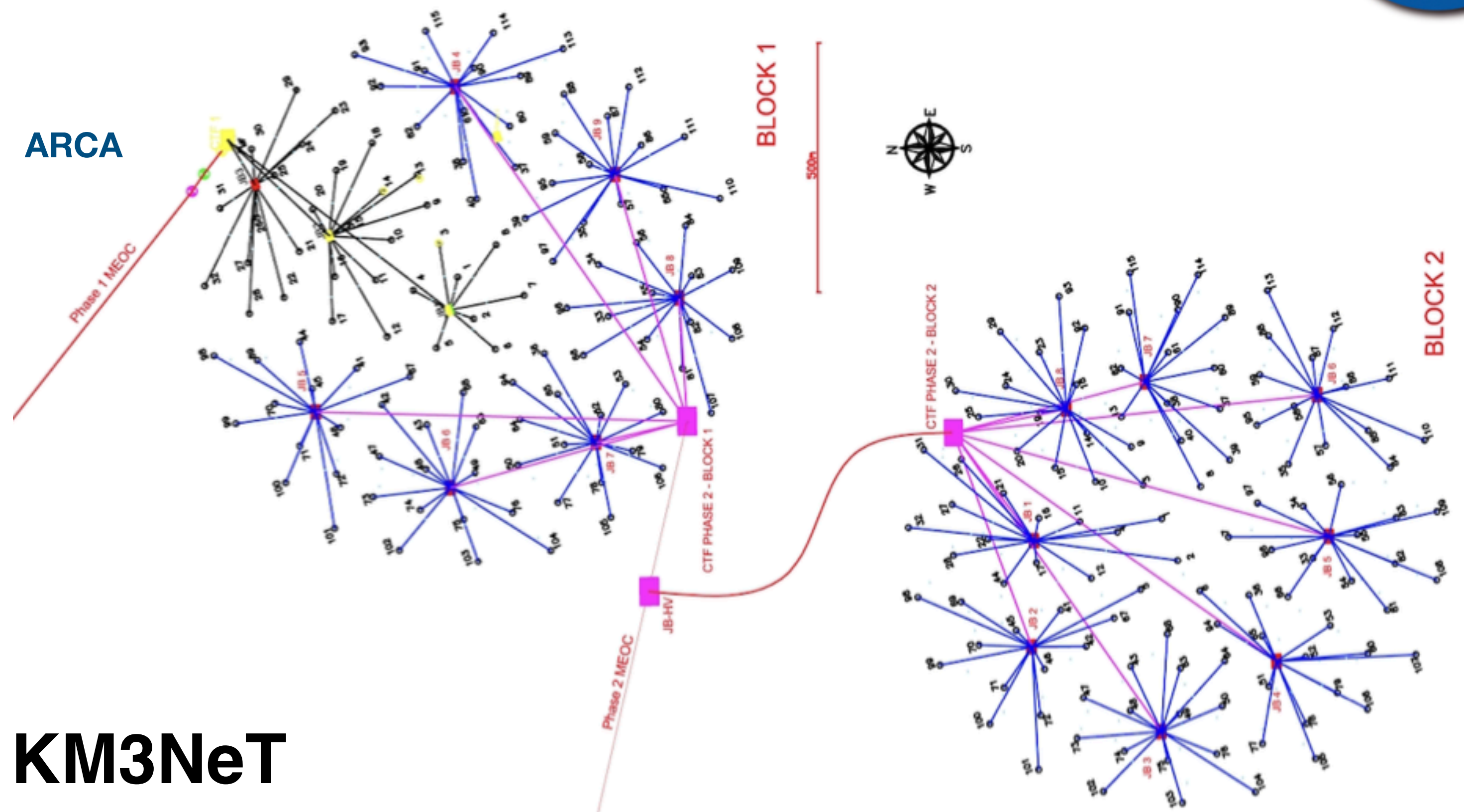

**3500 m depth,**
offshore Sicily

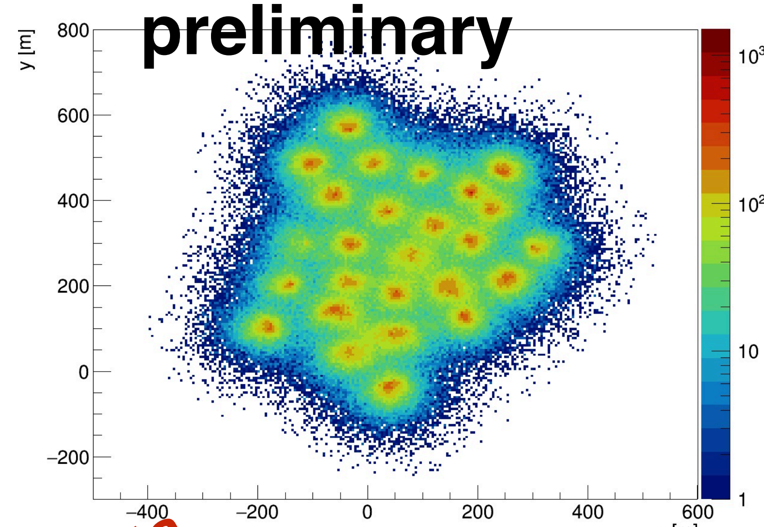
## ORCA (6 MTon)

Oscillation Research
with Cosmics in the Abyss



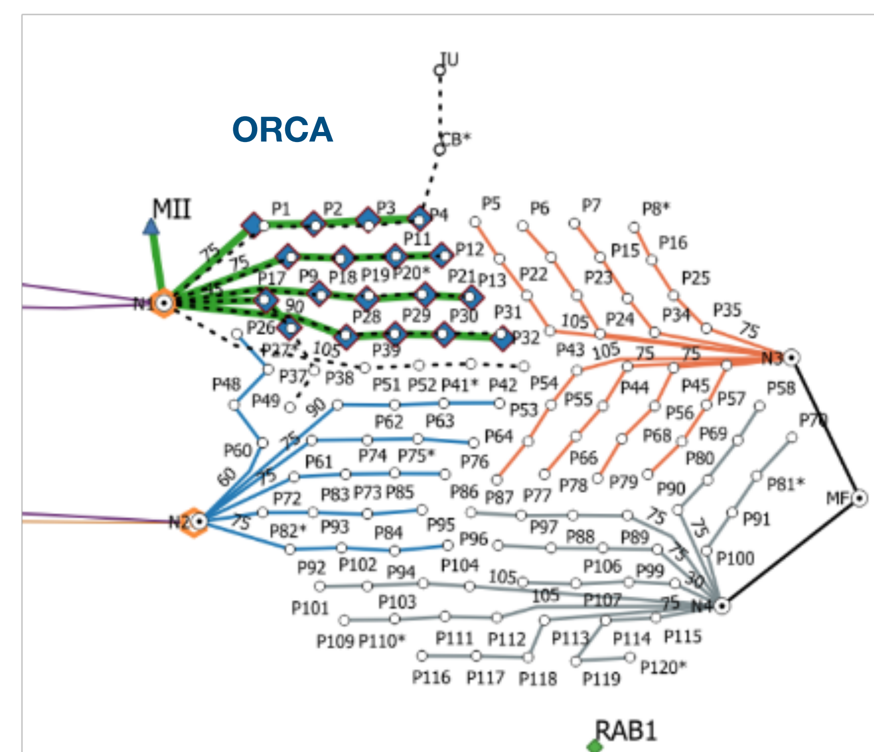

**2500 m depth,**
offshore Toulon



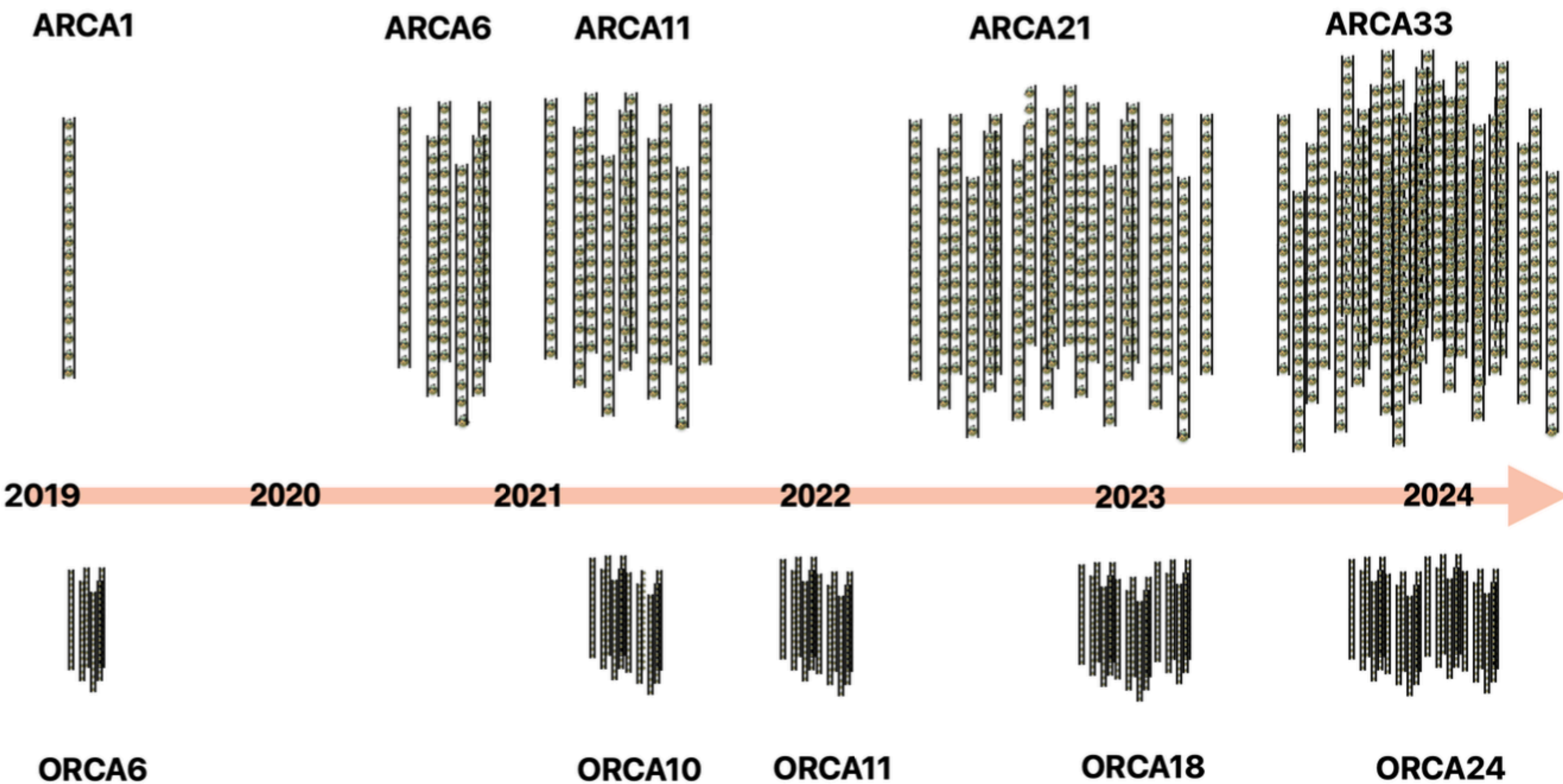




real data
from ARCA28

KM3NeT Coll., JPGNPP 43 (2016)



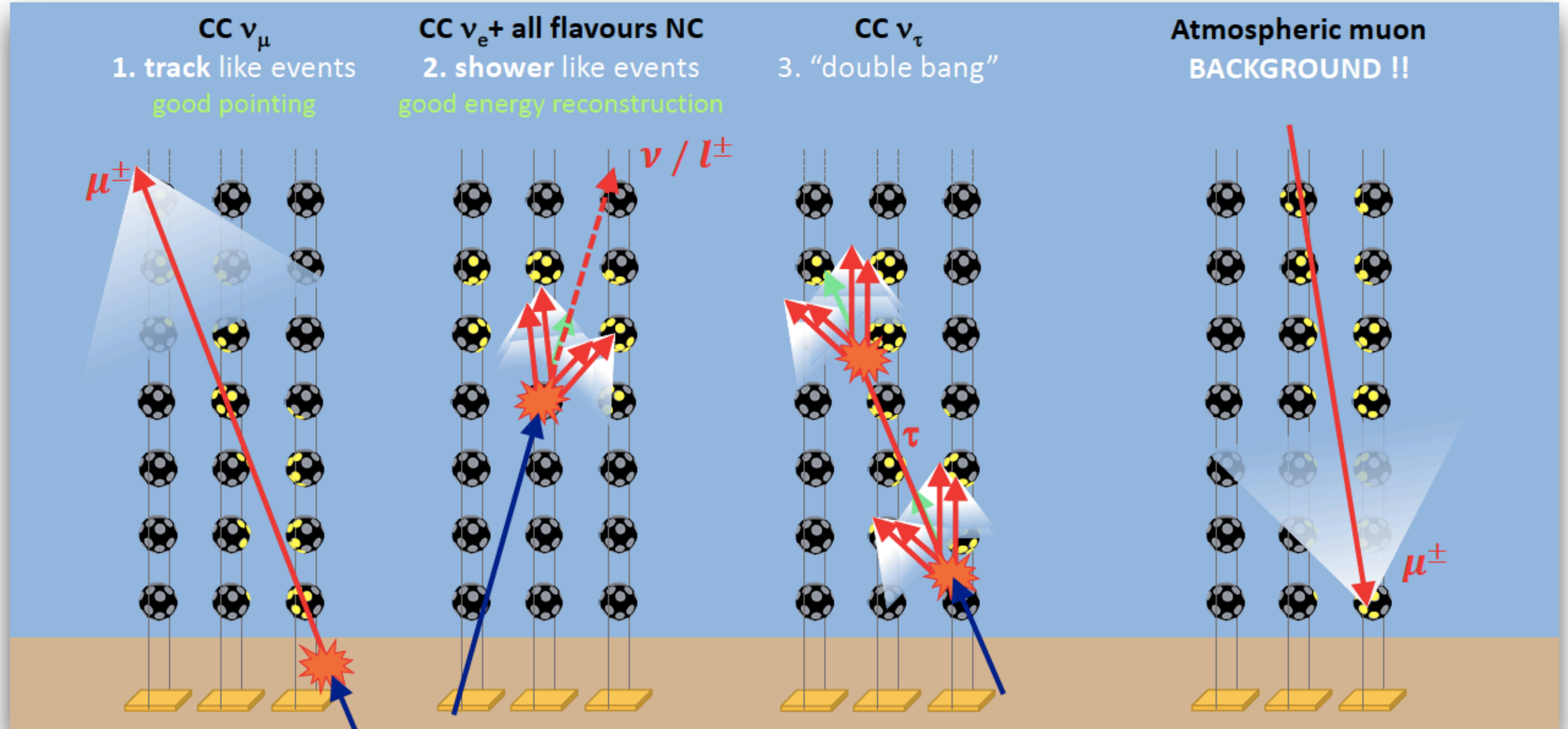
# Current status of the KM3NeT detectors




Further **sea campaigns** planned in next months

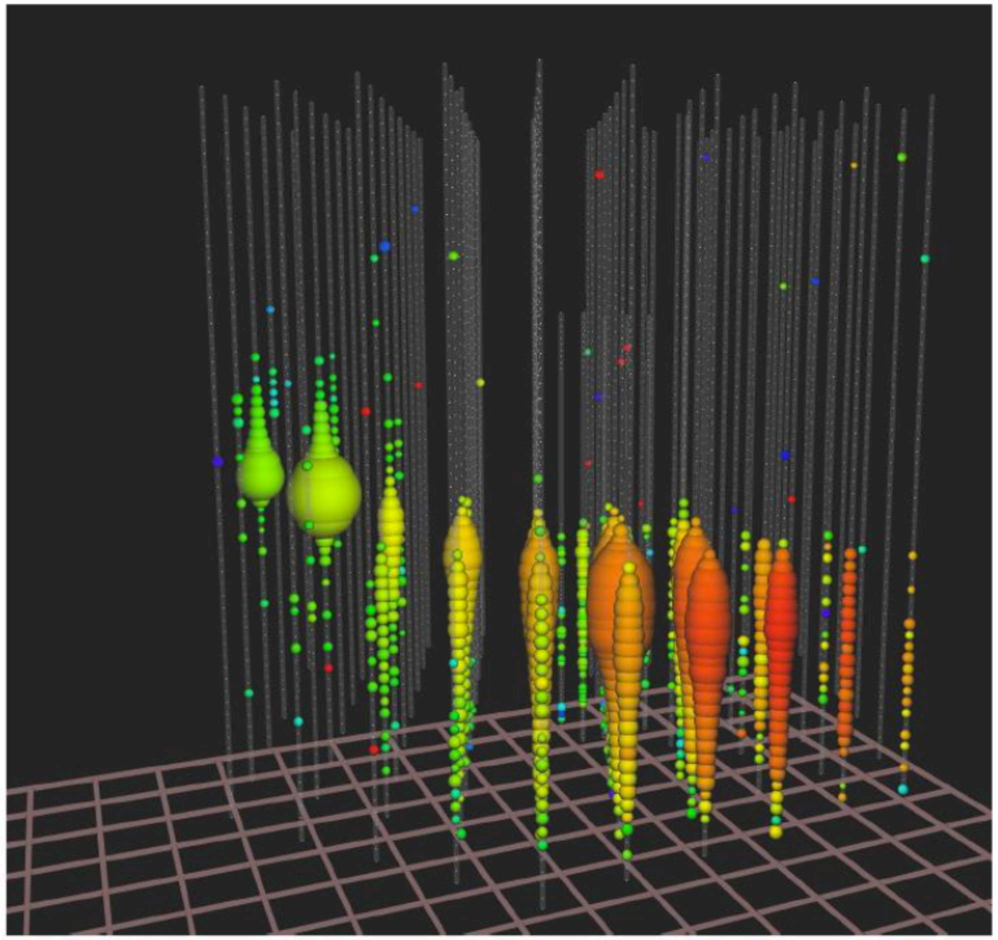
# Neutrino detection principle & event topologies

- Track like events ⟶ golden astronomical channel
- Shower like events ⟶ calorimetric ⟶ diffuse analyses



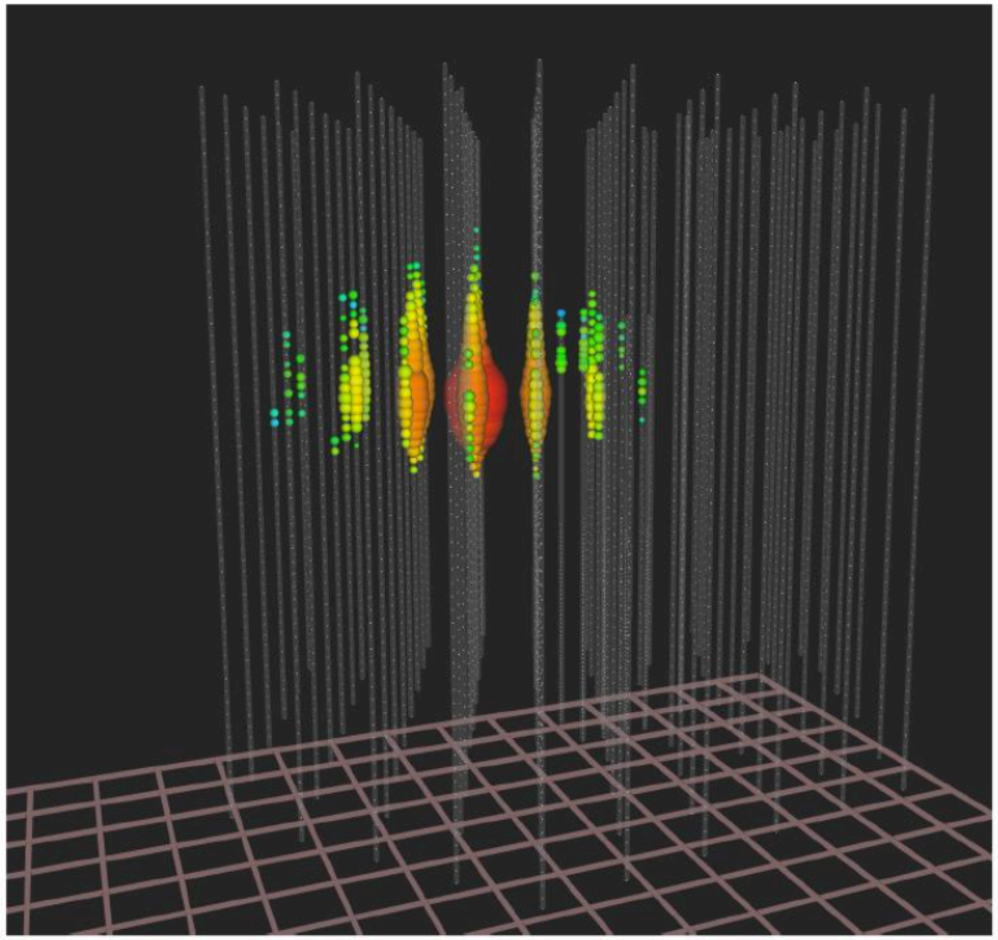
# Neutrino event topology

Muon tracks



Astronomy: angular resolution

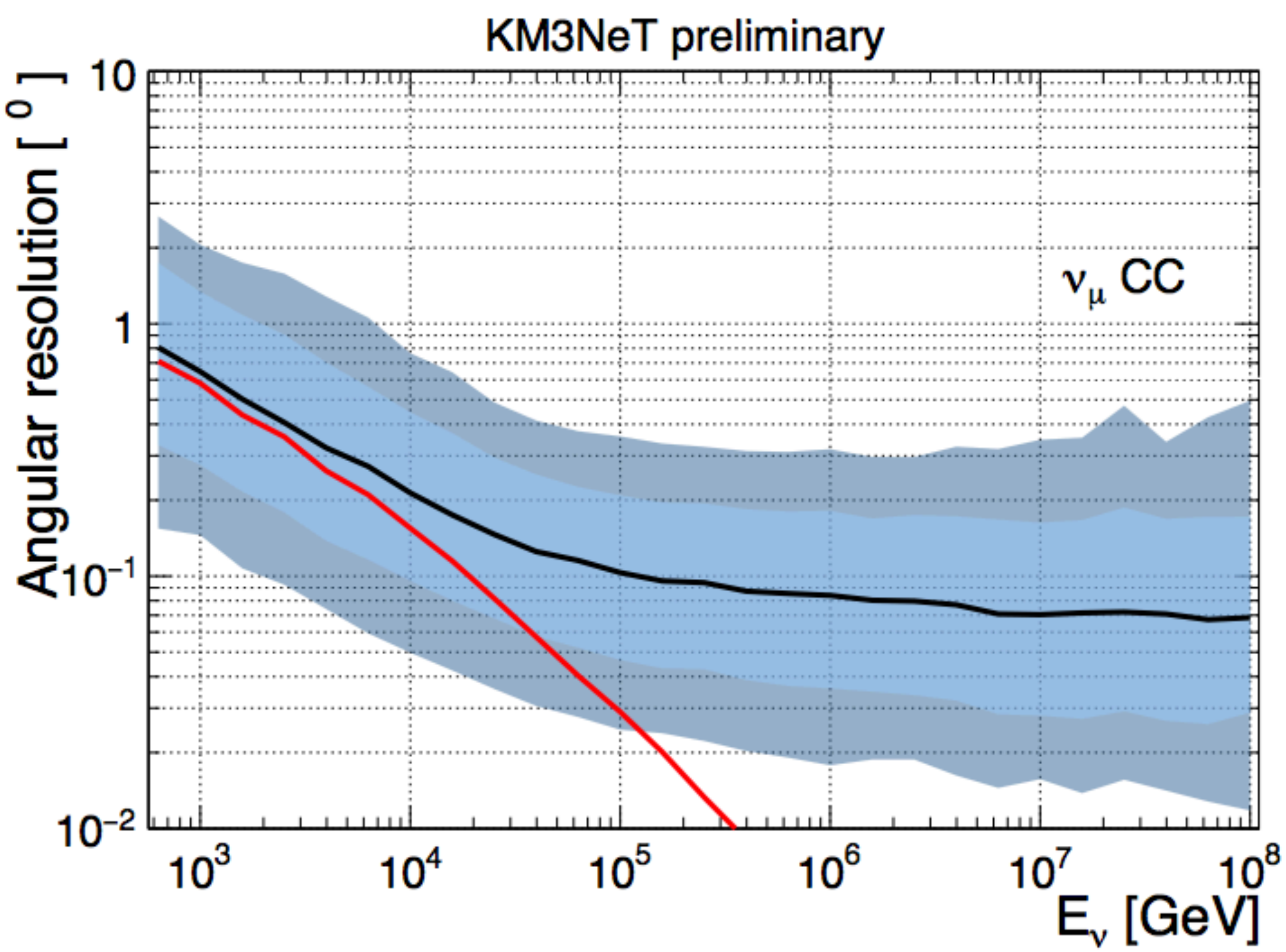
Isolated neutrinos interacting in the detector

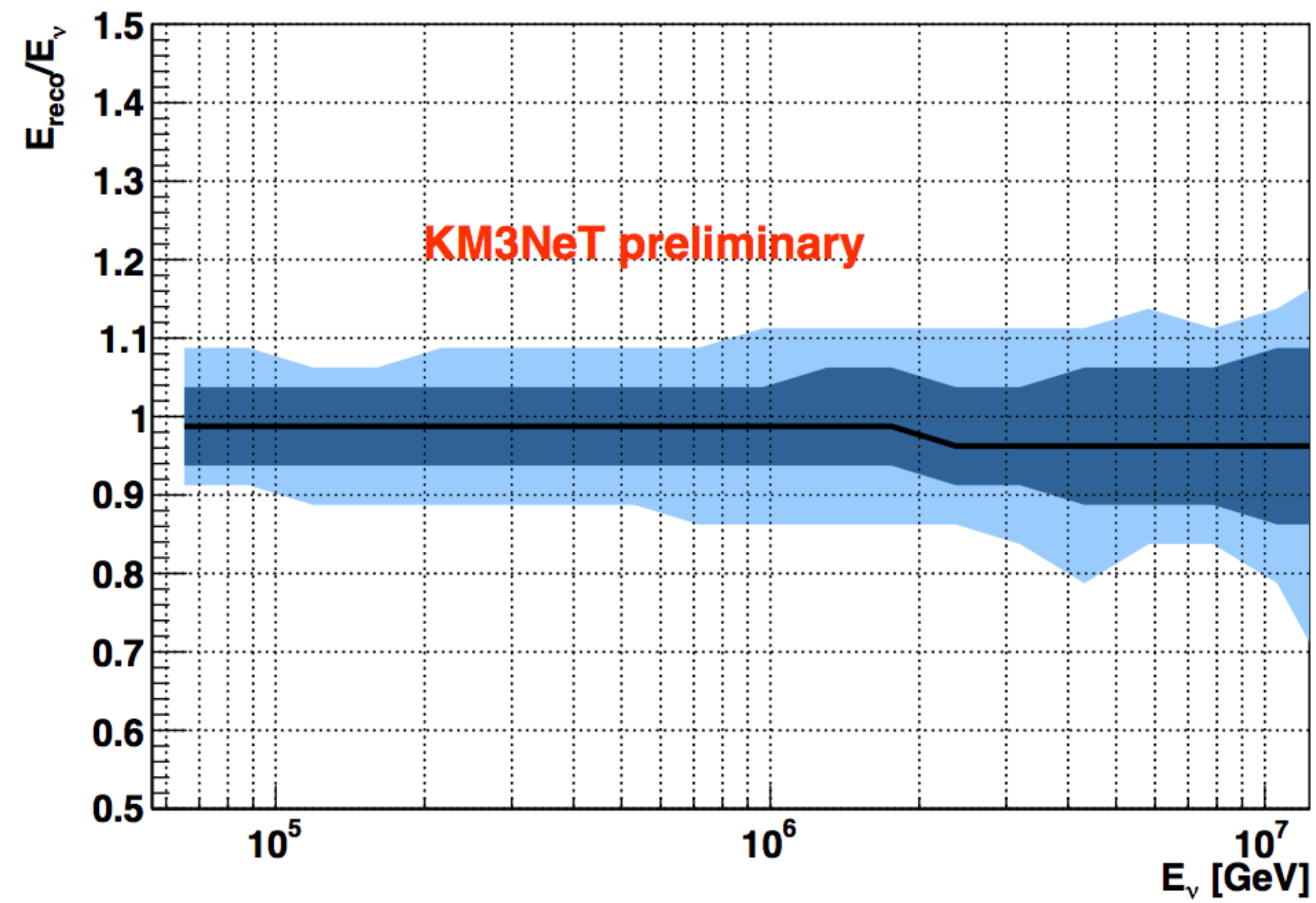


Calorimetry + all flavors

# Neutrino event topology

| Muon tracks | Isolated neutrinos interacting in the detector |
|---|---|



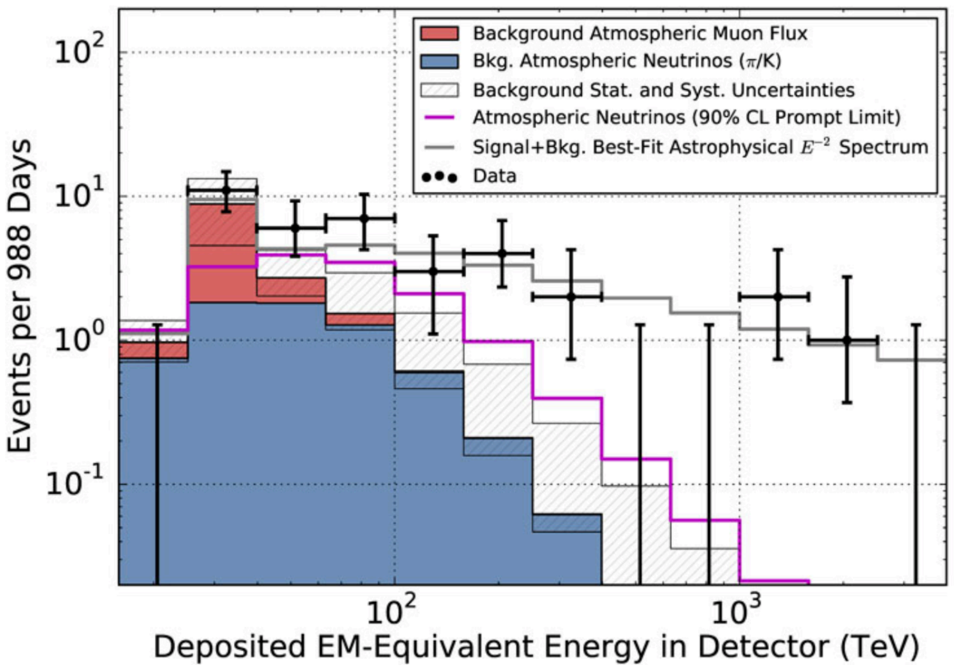




| Astronomy: angular resolution | Calorimetry + all flavors |
|---|---|

Adrian-Martinez et al. [KM3NeT Coll.], J. Phys. G: Nucl. Part. Phys. 43 (2016)

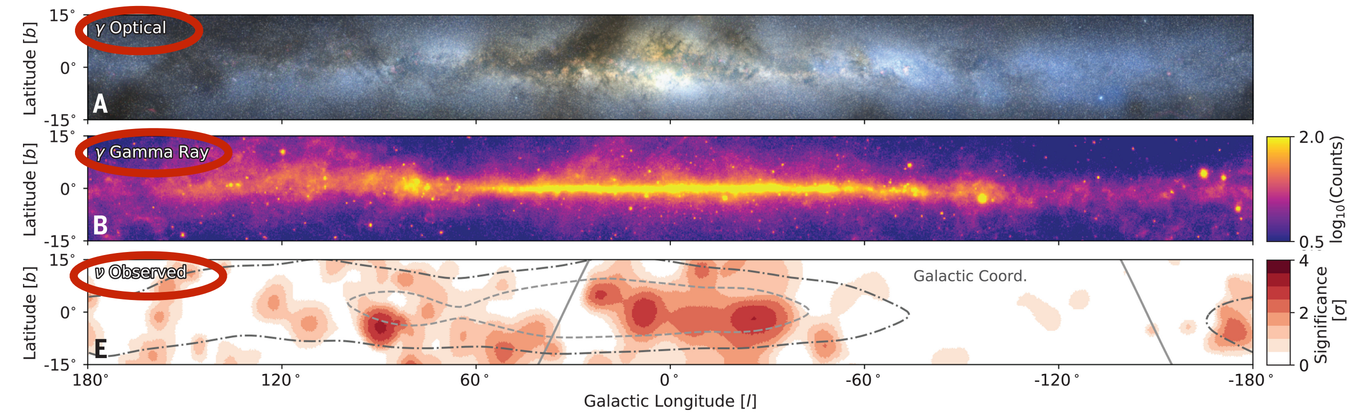
# The cosmic neutrino sky before Feb 2023

## 1. THE ALL-SKY DIFFUSE



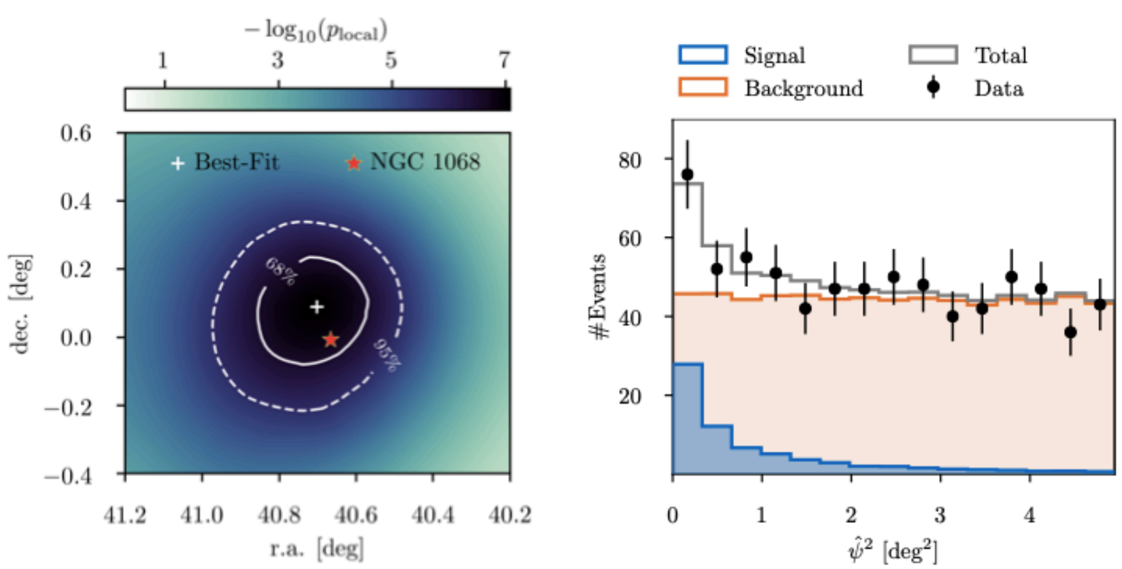

Aartsen et al. [IceCube], PRL 113 (2014)

## 2. THE MILKY WAY IN MULTI-MESSENGERS

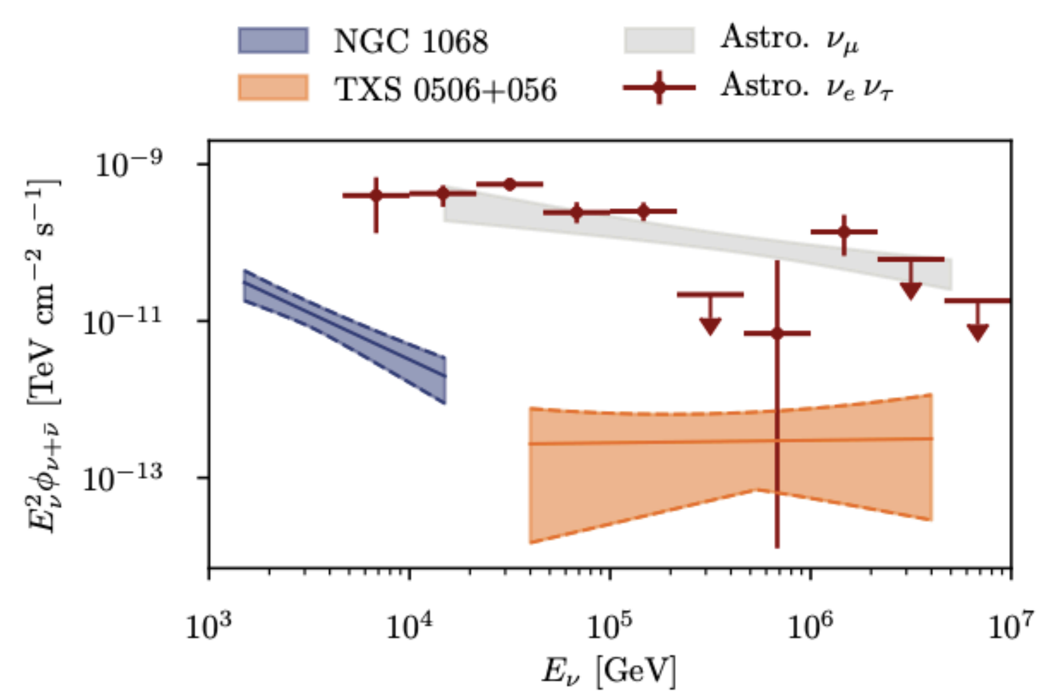



Abbasi et al. [IceCube], Science 380 (2023) 6652

## 3. NEUTRINO STEADY SOURCES



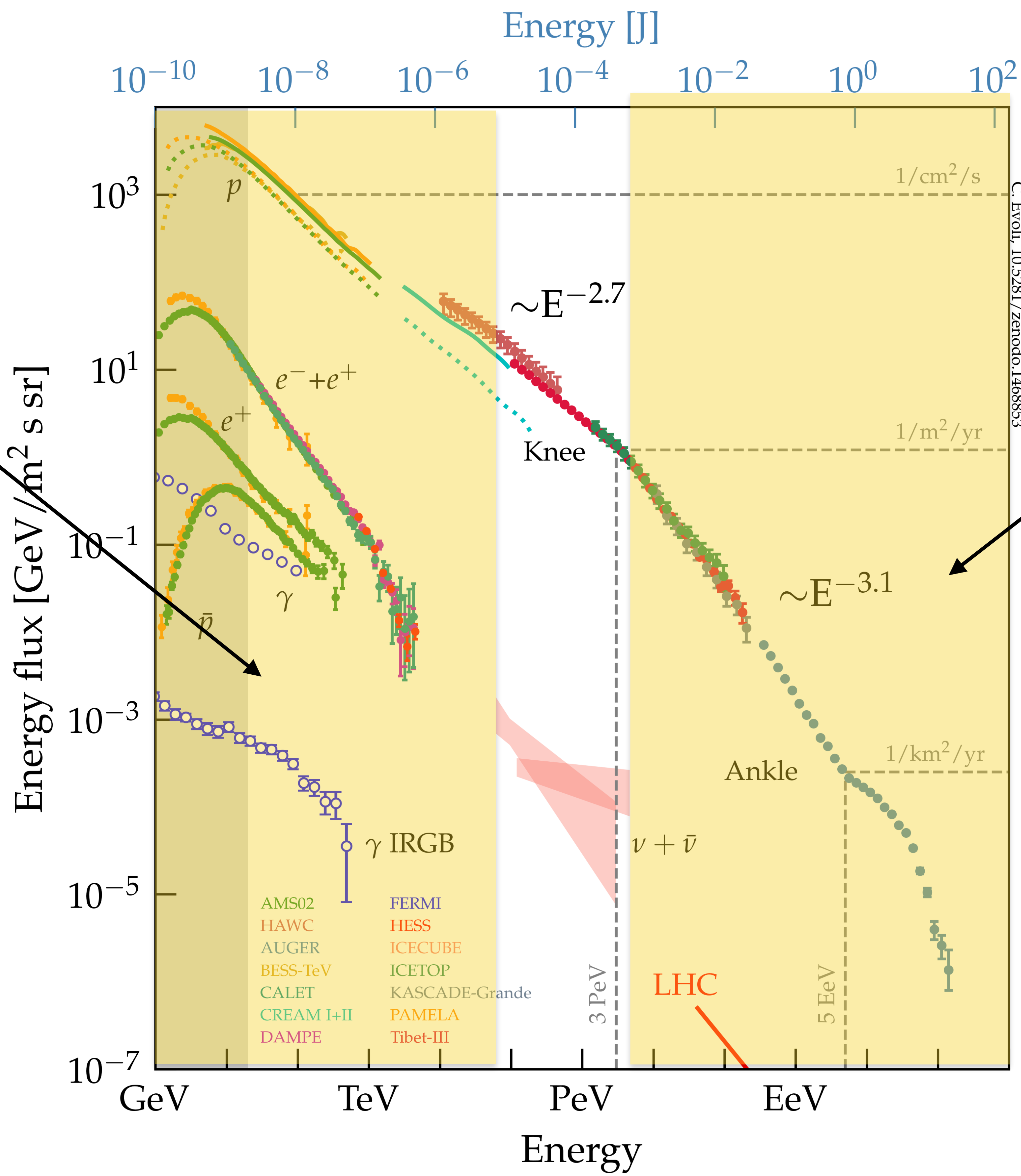

## 4. NEUTRINO TRANSIENT SOURCES




Abbasi et al. [IceCube], Science 378 (2023) 6619

# The neutrino landscape before Feb 2023

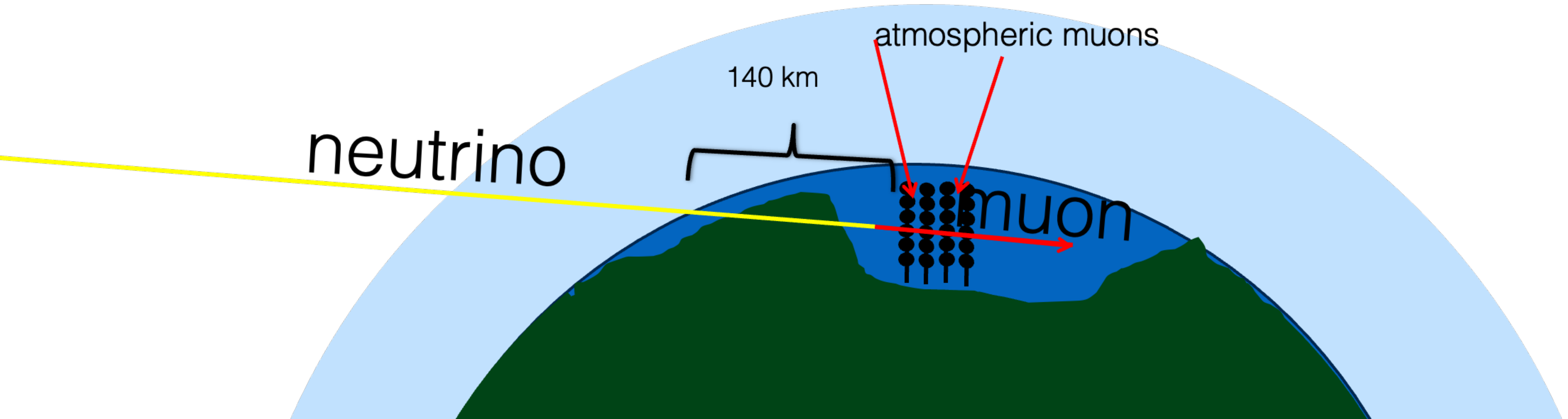
dominated by atmospheric background



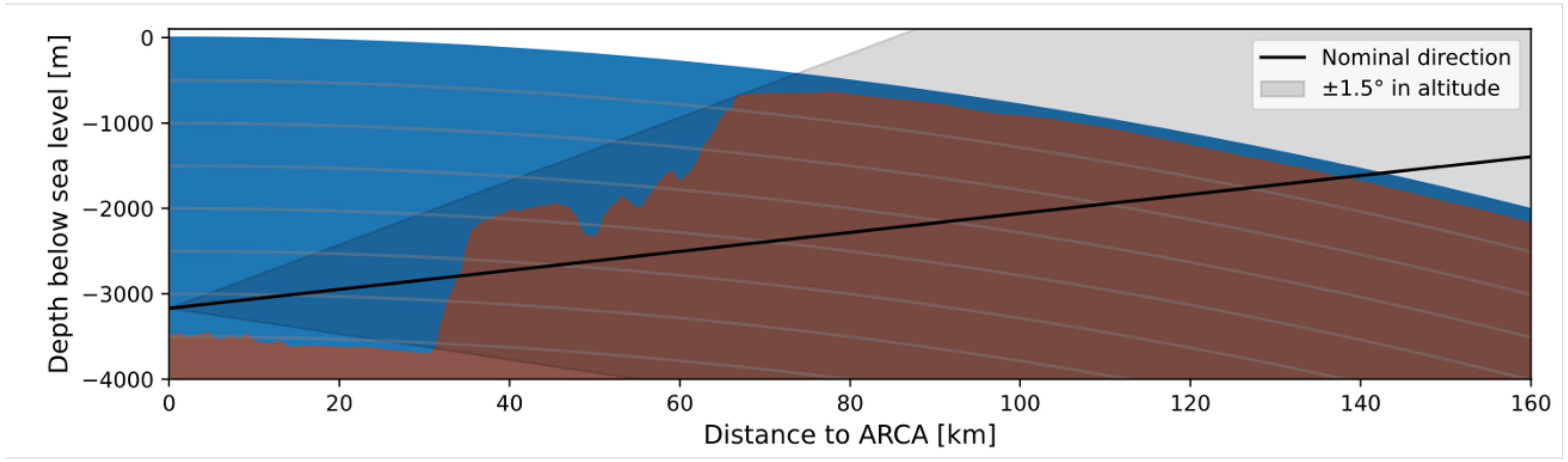

“terra incognita” (F. Halzen)

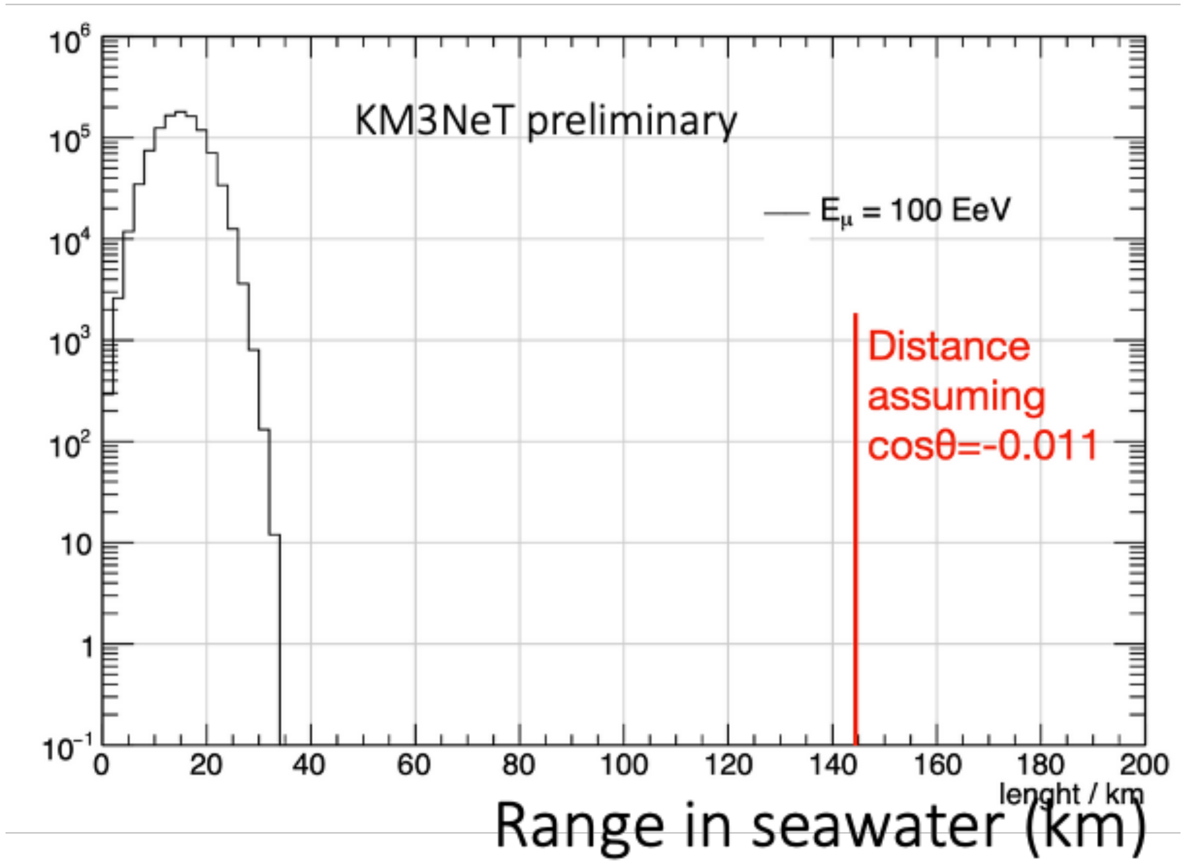
# KM3-230213A: features

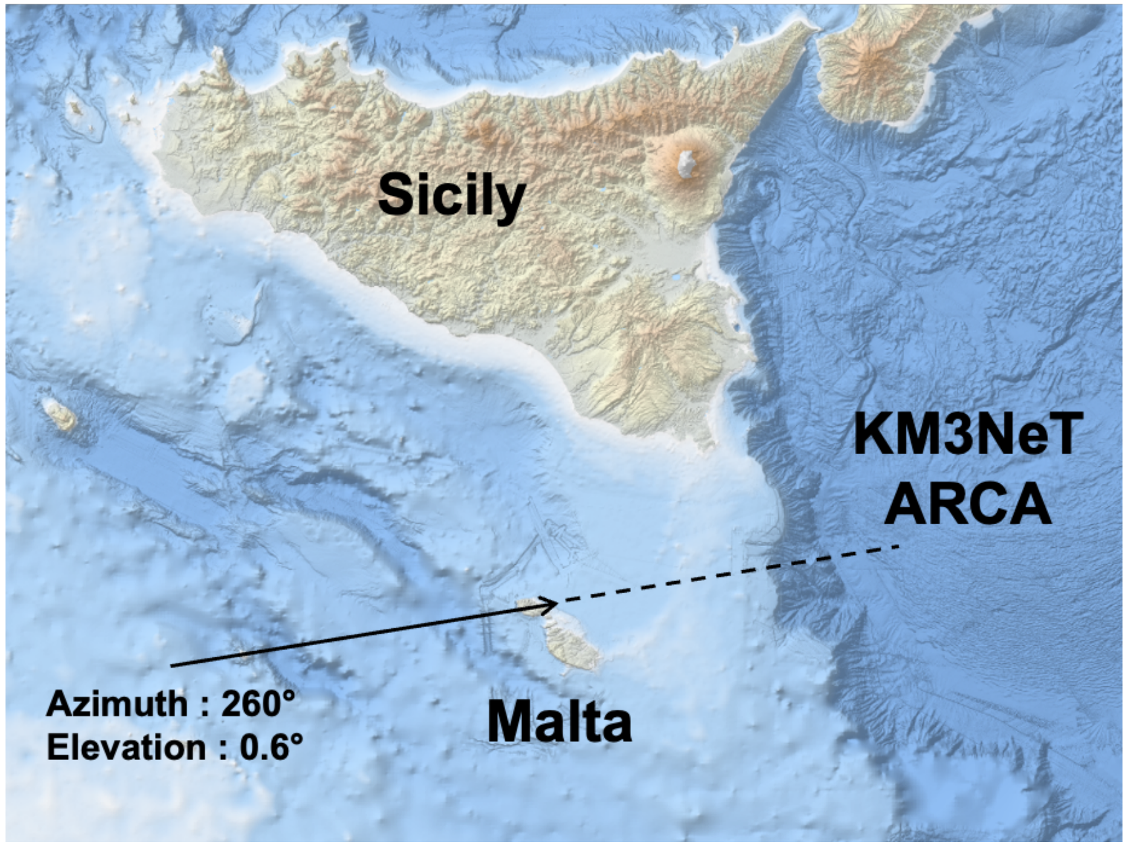
- Trigger time: Feb 13th 2023, 01:16:47 UTC
- **ARCA21** configuration (21 DUs, ~0.2 $km^3$), **335 days** of livetime
- Bright track selection (length > 250 m, $N^{trigPMT}$ > 1500, logL > 500)
- KM3-230213A: **nearly horizontal** event (0.6° above horizon), **RA=94.3°, DEC=-7.8°** (l=216.1°, b=-11.1°)
- Containment radii: **R(68%)=1.5°**, R(90%)=2.2°, R(99%)=3.0°




# Not an atmospheric muon



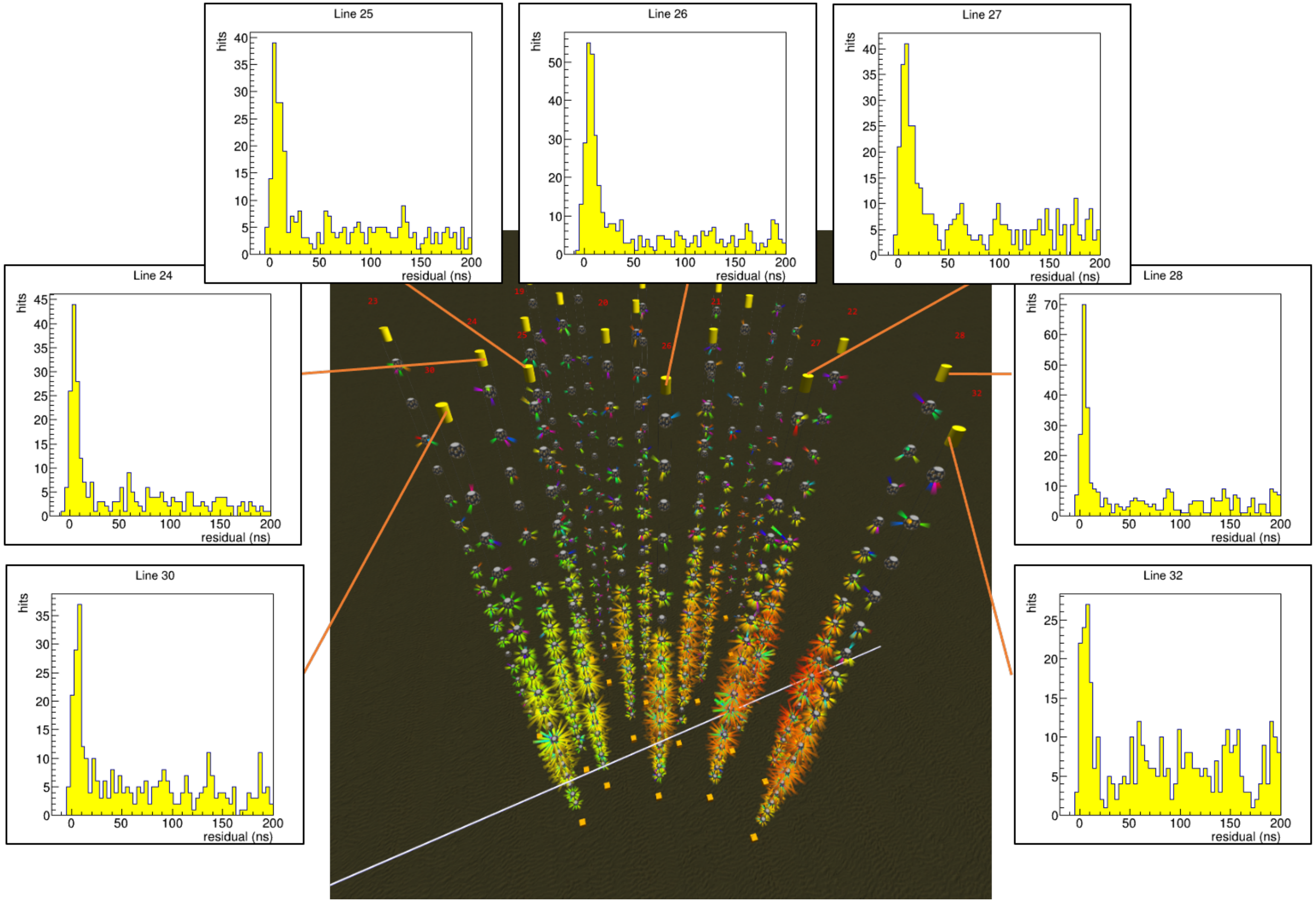




Passes through continental shelf/Malta

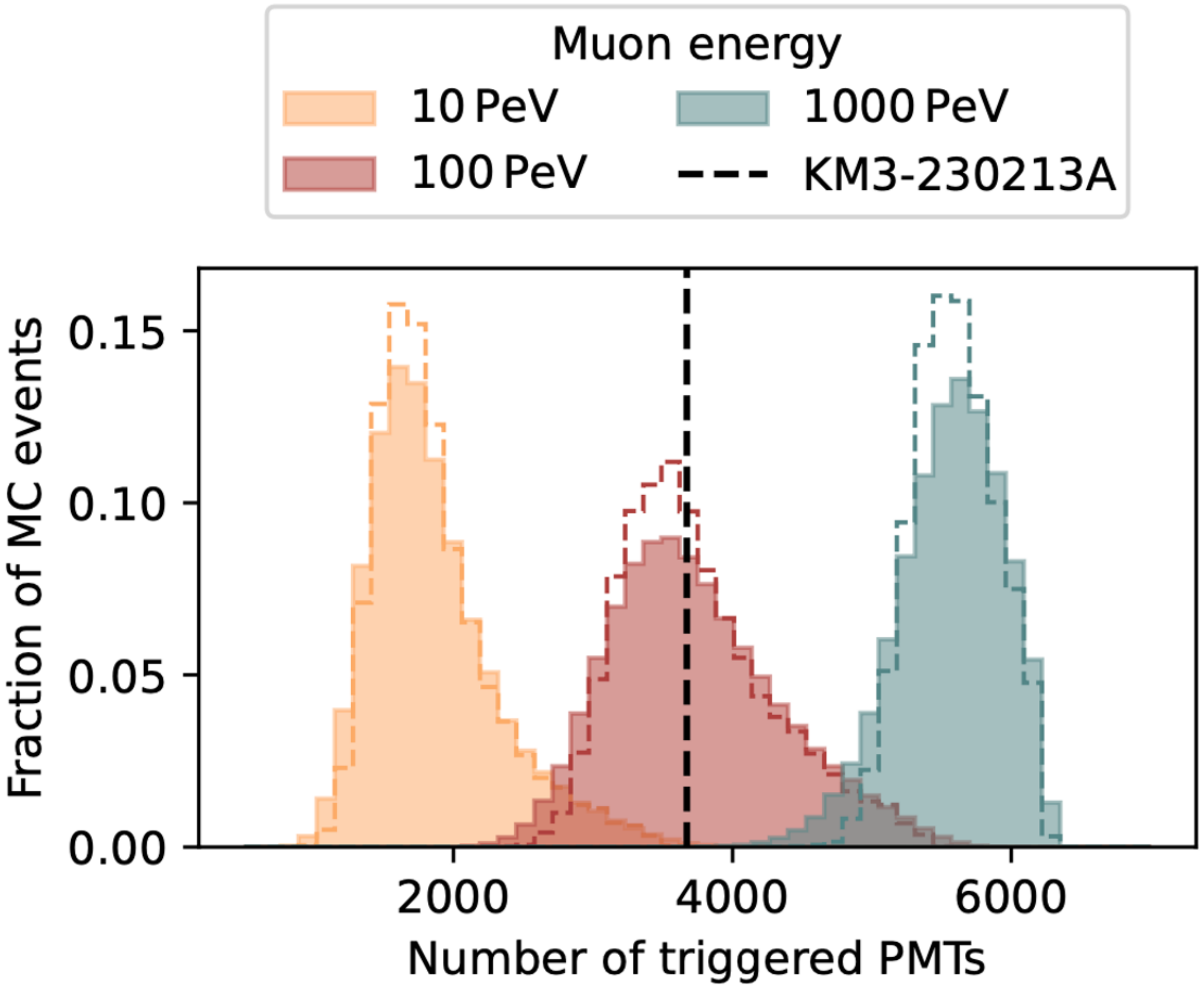
Actual amount of crossed matter is even larger…

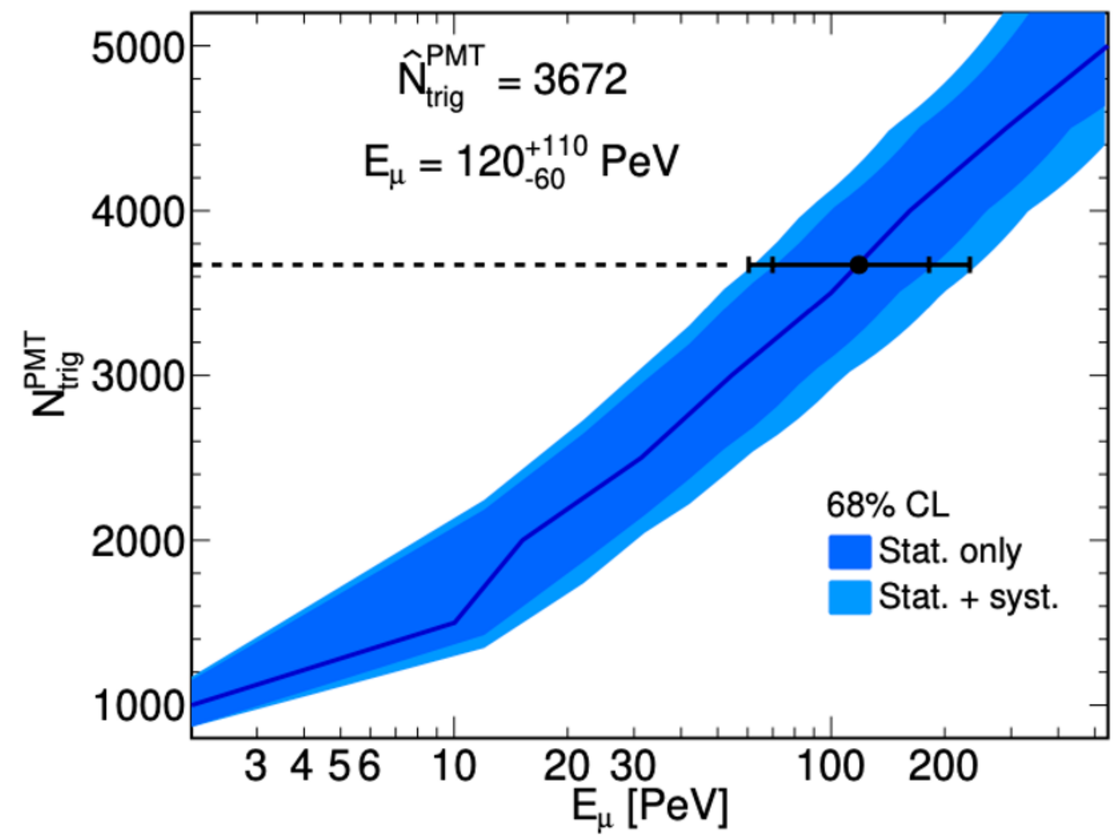
# A very well reconstructed muon track




Time residual distributions on different DUs

# KM3-230213A: energy



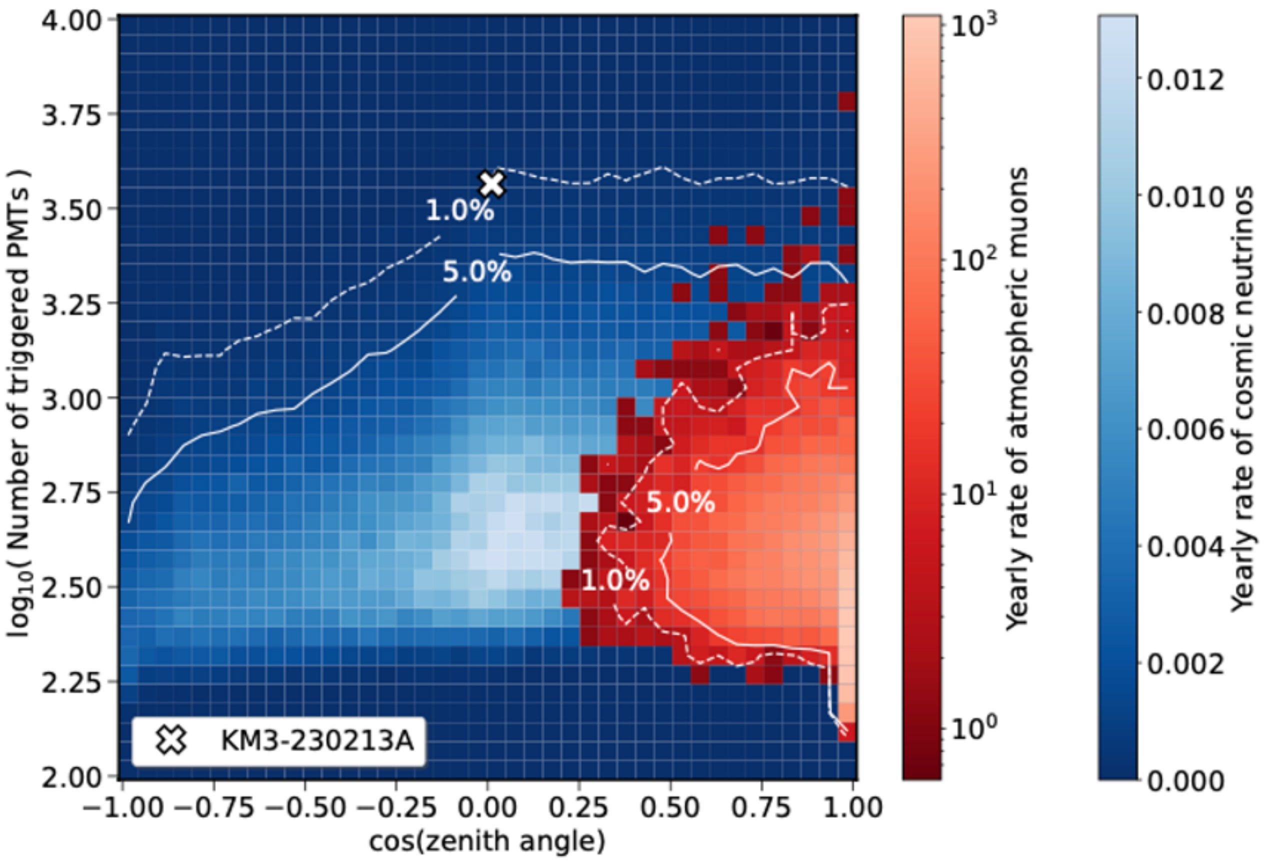



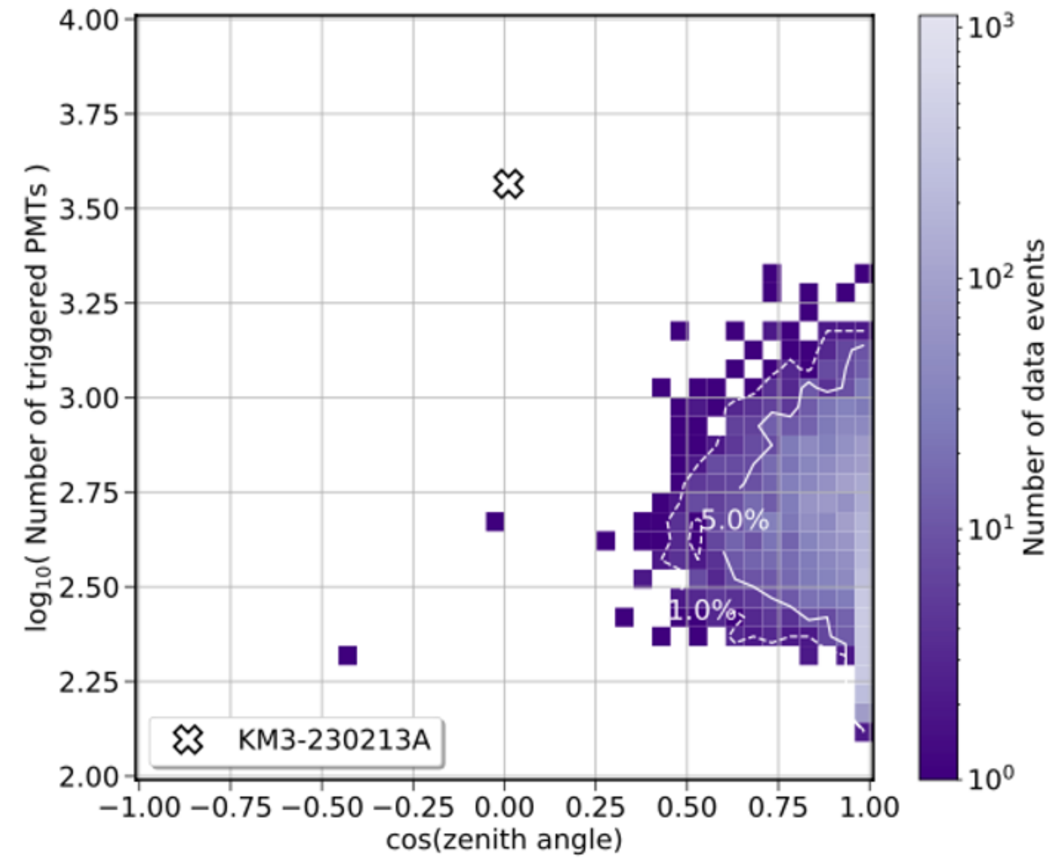

KM3NeT Coll., Nature 638 (2025) 8050

**~35% of the detector was recording light**

- Energy is measured from the amount of light: $E_\mu = 120^{+110}_{-60}$ PeV
- The parent neutrino energy is estimated to be ($E^{-2}$ source flux): $E_\nu = 220^{+570}_{-100}$ PeV

# KM3-230213A

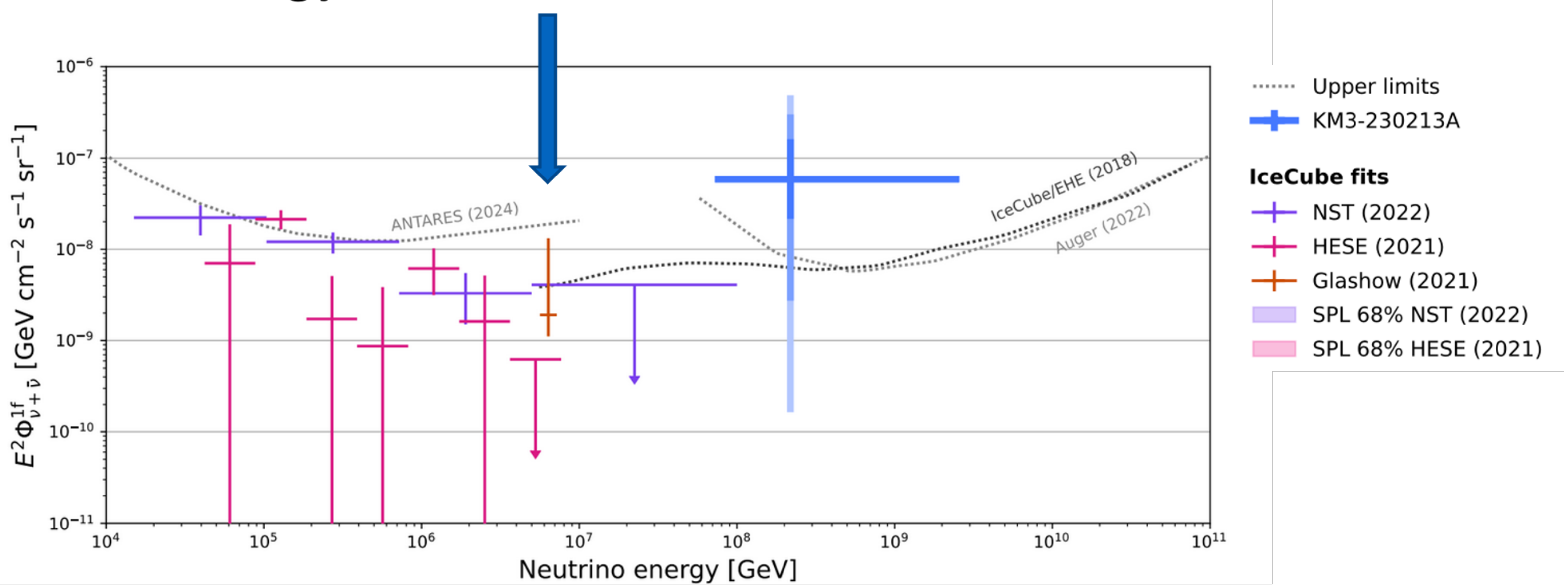



- Assuming reconstructed energy and direction
  - Expected atmospheric muon contamination @ 100 (10) PeV:
    << $10^{-10}$ ($10^{-9}$) event/year within 2σ of reconstructed direction
    << $10^{-4}$ event/year within 5σ of reconstructed direction
  - Expected rate of atmospheric neutrinos >100 PeV:
    << (1-5) x $10^{-5}$ event/year

# The most energetic neutrino ever probed

Previous highest energy neutrino



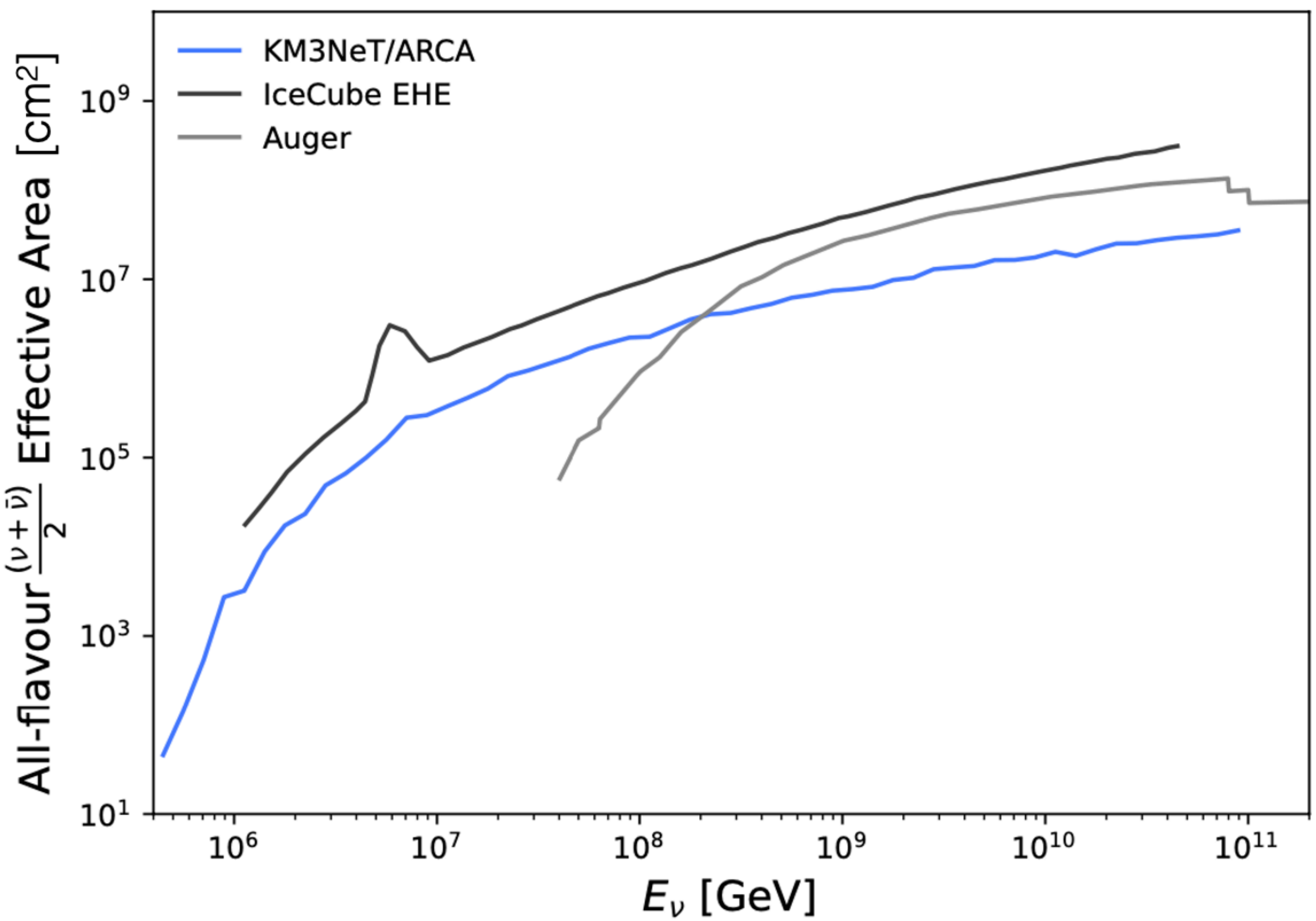

KM3-230213A

$$E^2\phi_\nu = 5.8 \times 10^{-8}\,\mathrm{GeV cm^{-2} s^{-1} sr^{-1}}$$

KM3NeT Coll., Nature 638 (2025) 8050

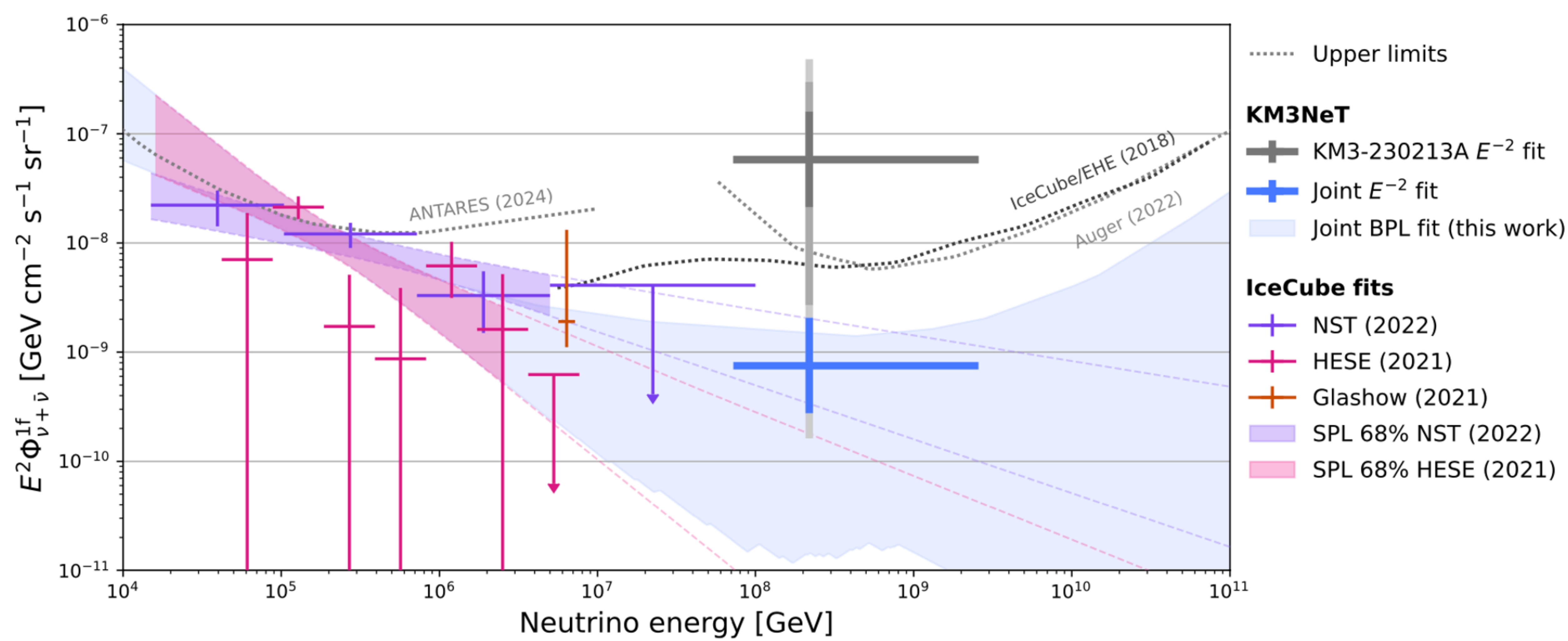
# Comparison with existing limits

- Non-observations by IceCube & Auger place **stringent constraints** on the neutrino flux associated with KM3-230213A **if this were associated with a steady source**




KM3NeT Coll., arXiv:2502.08173

# The neutrino flux from a steady source



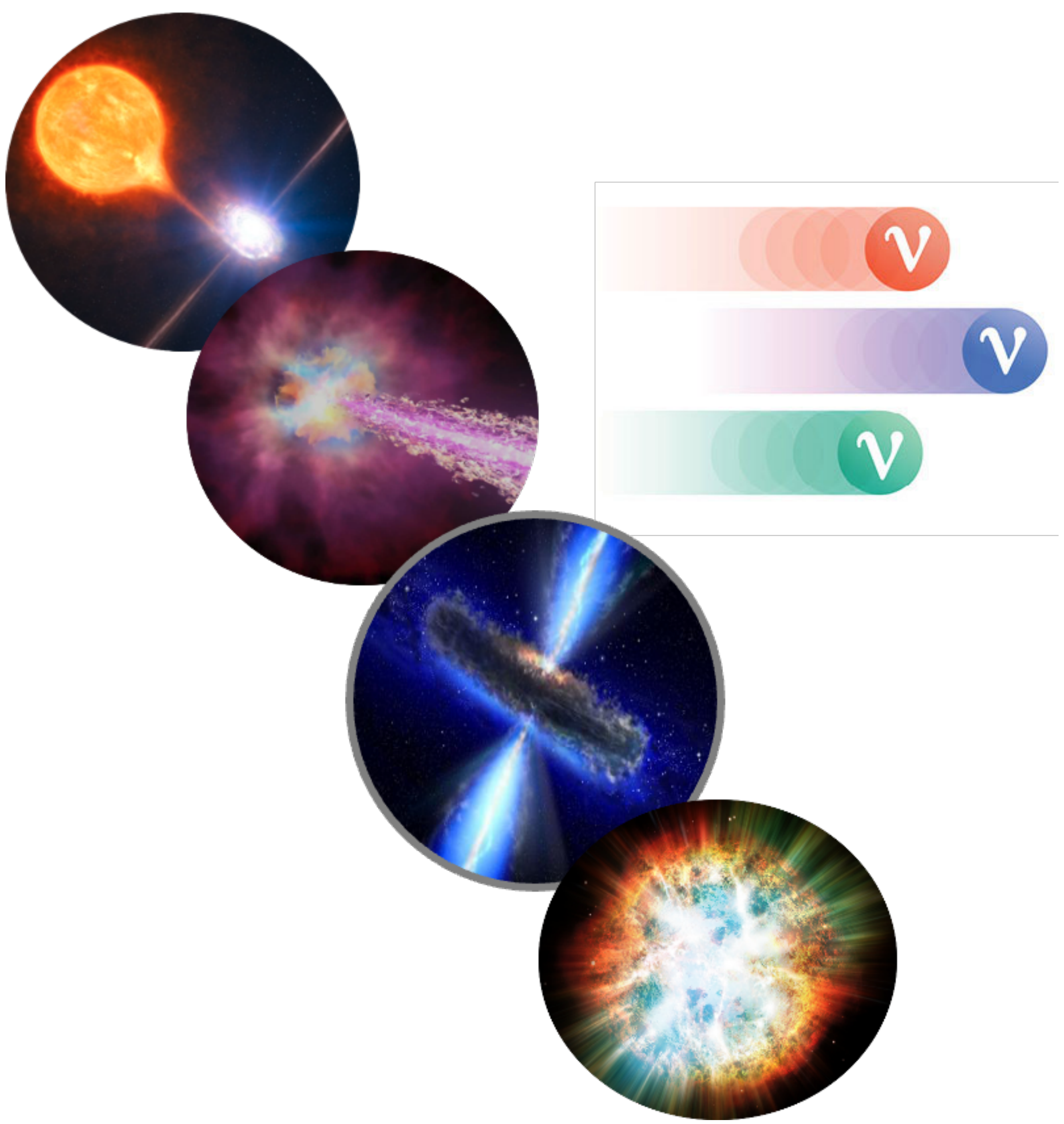

Accounting for IceCube & Auger non-observations we could estimate

$$E^2\phi_\nu = 5.7 \times 10^{-10}\,\mathrm{GeV cm^{-2} s^{-1} sr^{-1}}$$

KM3NeT Coll., arXiv:2502.08173

# Cosmic or cosmogenic?

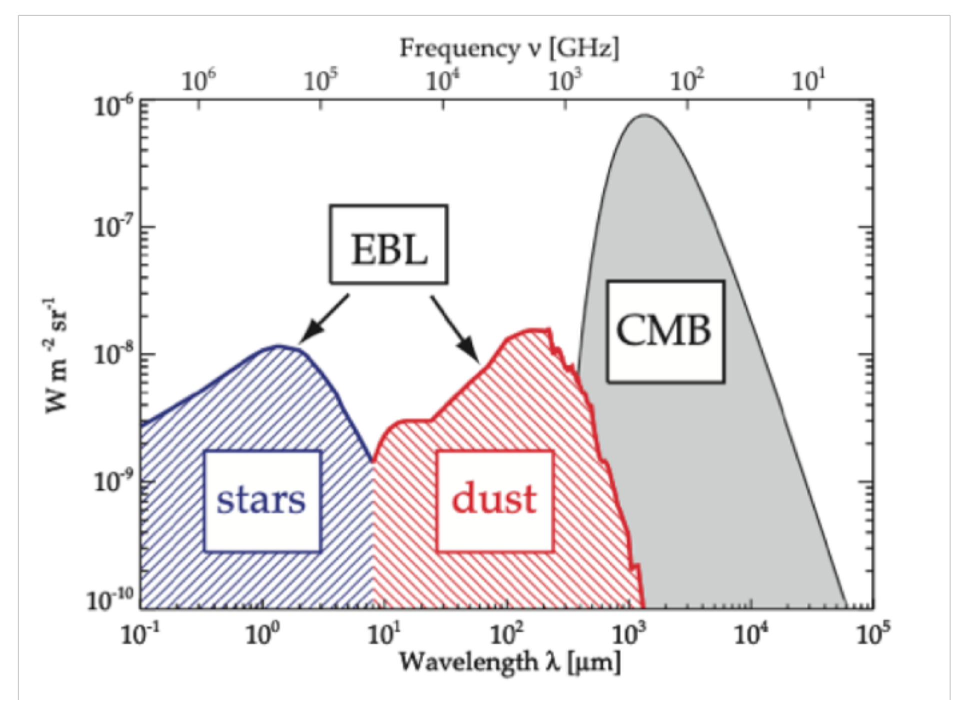
**COSMIC** = in situ production at an extreme astrophysical accelerator




**COSMOGENIC** = resulting from UHECR interaction with background radiation fields permeating the Universe

$$p + \gamma \longrightarrow p + \pi^0, n + \pi^+$$

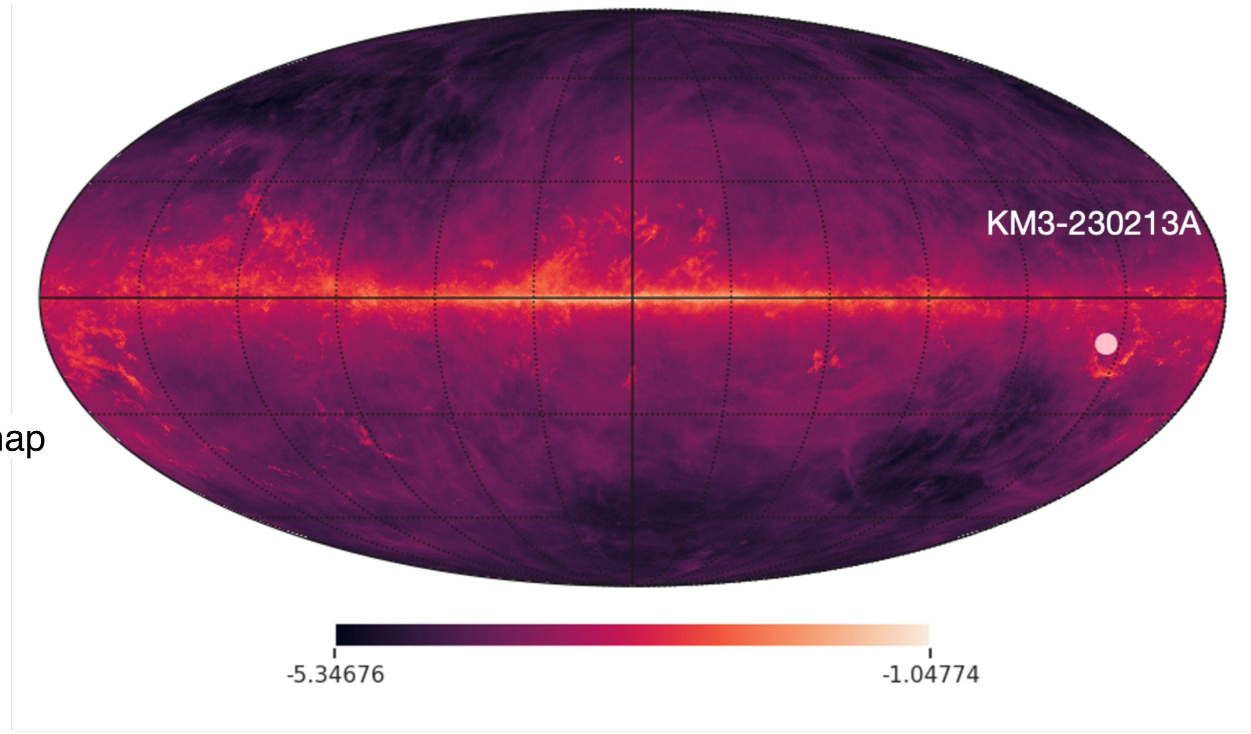
$$(A, Z) + \gamma \longrightarrow (A-1, Z) + N$$



# Testing the cosmic origin

- Out of the Galactic Plane, in the Orion molecular cloud region

Diffuse neutrino sky map
from KRA-γ model




- Neutrino counterparts searched for in ANTARES, KM3NeT/ORCA & IceCube datasets

| Dataset | | | | Radius |
|---|---|---|---|---|
| Detector | Covered Period dd/mm/yyyy | Livetime [days] | Type of Data | [deg] |
| ARCA6-21[a] | 12/05/2021 - 11/09/2023 | 640 | offline[b] | 3 |
| ORCA6-18 | 11/02/2020 - 31/08/2023 | 1005 | offline | 4 |
| ORCA18-23 | 01/09/2023 - 29/07/2024 | 126 | online[c] | 4 |
| ANTARES | 29/01/2007 - 31/12/2017 | 3125 | public[d] | 3 |
| IceCube | 06/04/2008 - 08/07/2018 | 3577 | public [93] | 3 |

Upper limit on potential point-like source flux set to:

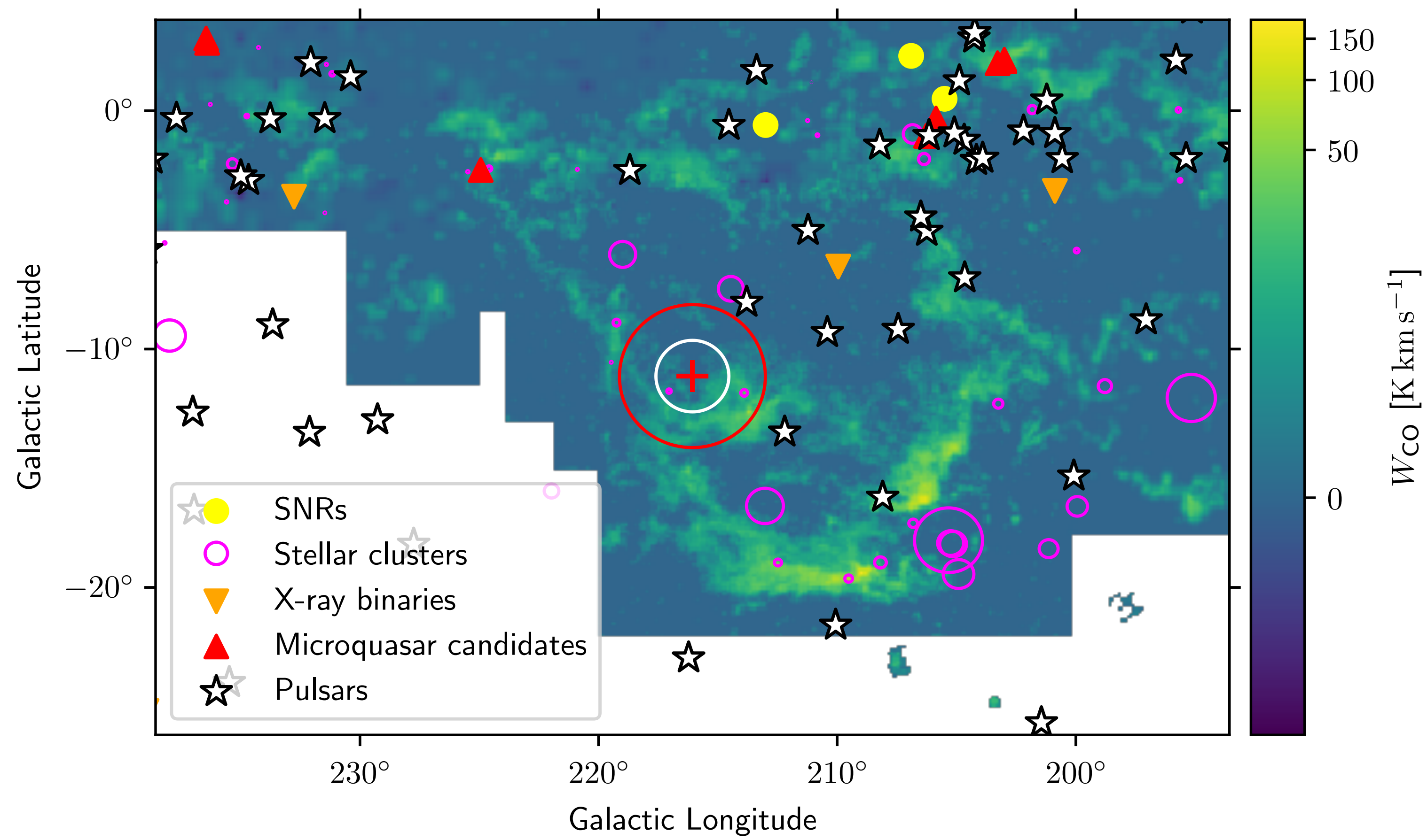
$$(E^2\phi_\nu)^{90\%CL} \leq 1.2 \times 10^{-9}\,\mathrm{GeV cm^{-2} s^{-1}}$$

KM3NeT Coll., Nature 638 (2025) 8050

# Hardly of Galactic nature

Potential nearby accelerators searched among:

- SNRs (GreenCat)
- Young star clusters (Gaia DR2)
- X-ray binaries and microquasars (eRosita)
- Pulsars and PWNe (ATNF)
- Gamma-ray catalogs (4FGL, 3HWC, 1LHAASO)




KM3NeT Coll., arXiv:2502.08387

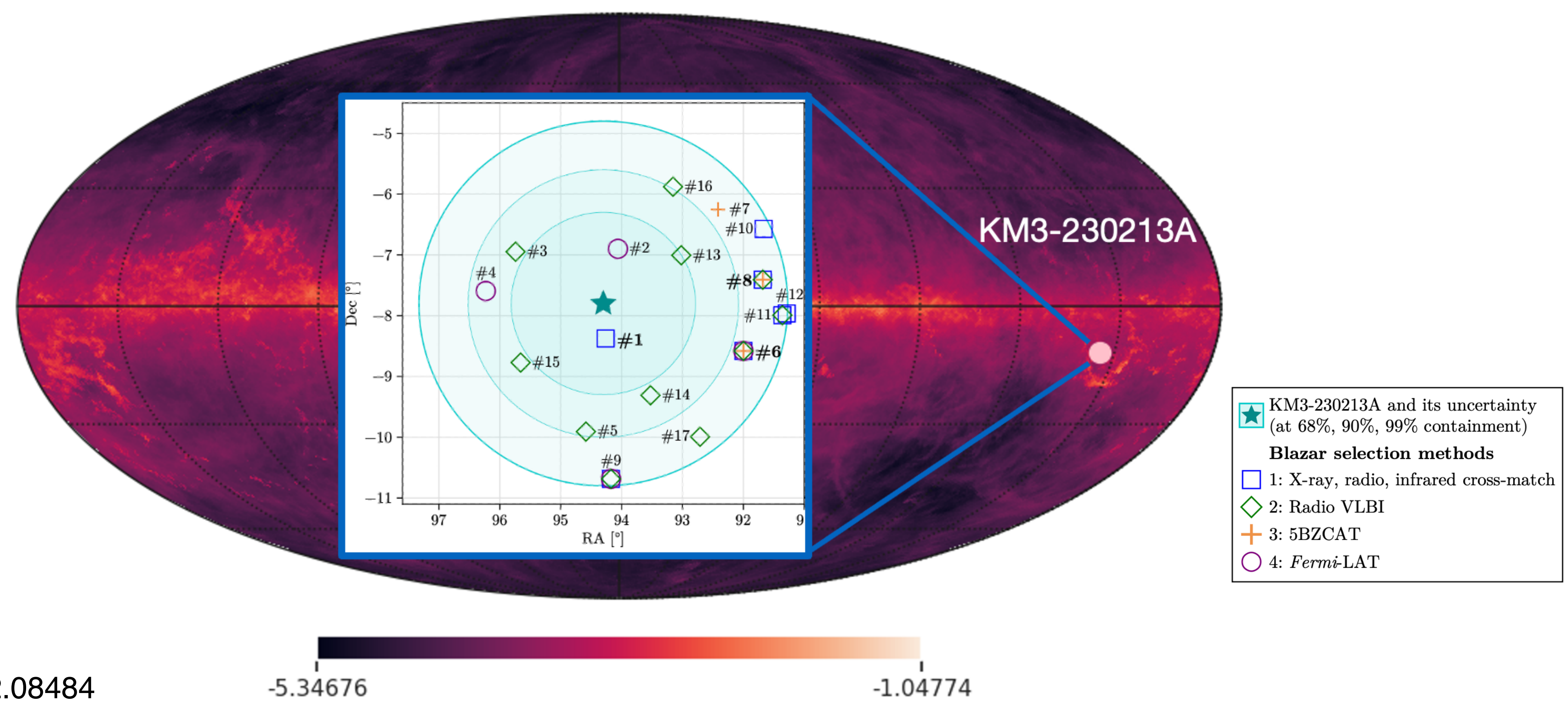
No plausible counterparts found

# Testing the extra-galactic origin

Electromagnetic counterparts searched in a 3° cone around the event direction

- Fermi 4FGL sources
- TeVCat and 3HWC data
- Optical transients (ZTF)
- GCN, TNS and AT transients
- Blazars (radio VLBI/ALMA, infrared WISE/, optical ATLAS/CRTS/ZTF/ Gaia, X rays SWIFT/Chandra/ROSAT/SVOM, gamma rays Fermi)

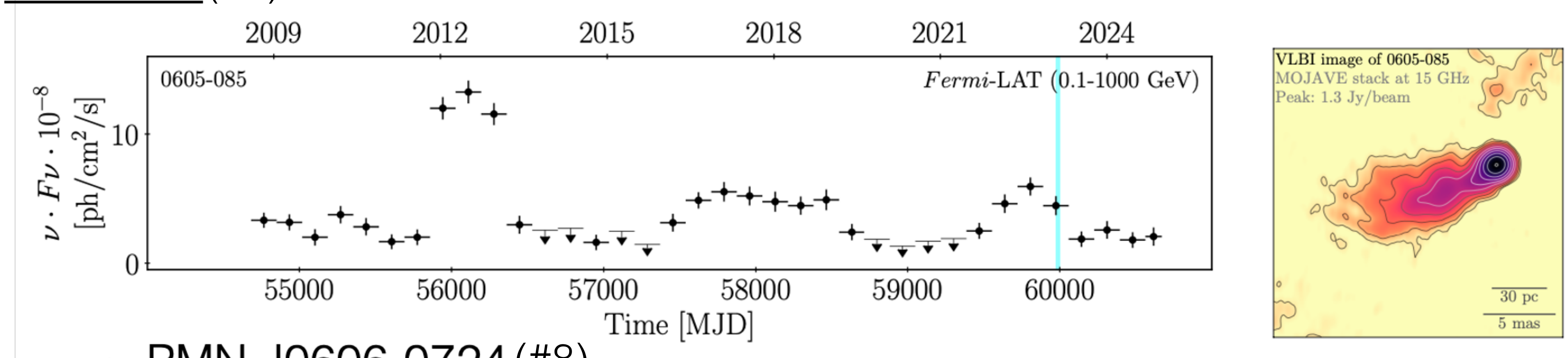
17 (2) blazars found in the 3σ (1σ) uncertainty region of 3° (1.5°) radius



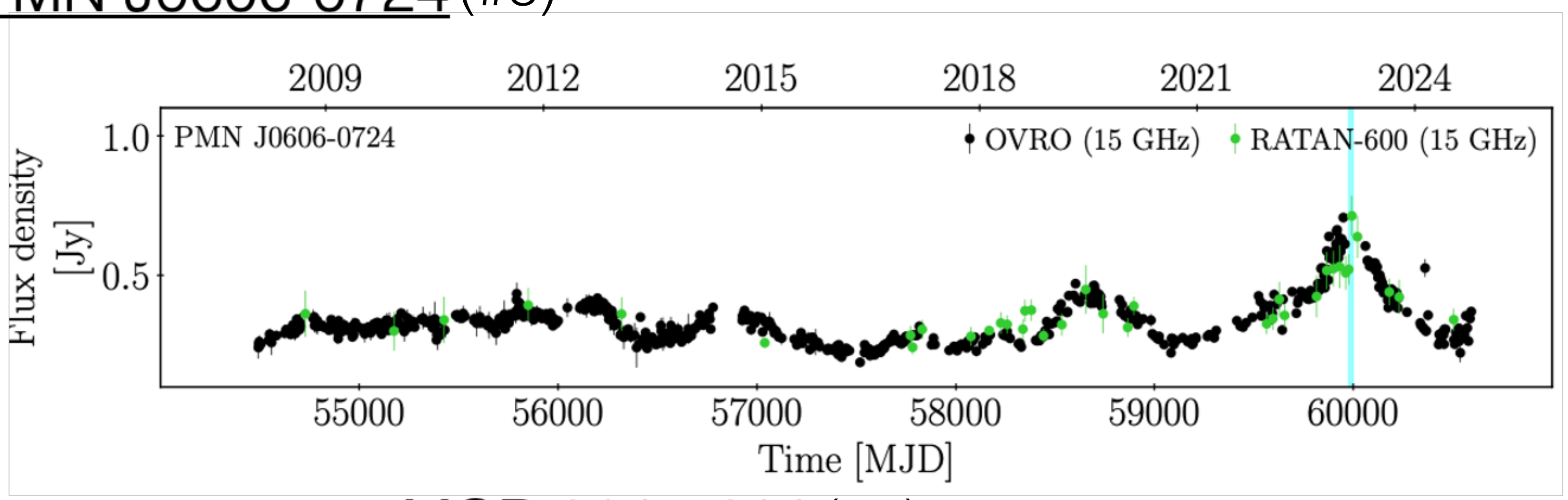

KM3NeT Coll., arXiv:2502.08484

# Possible flaring blazar counterparts

- 0605-085 (#6)

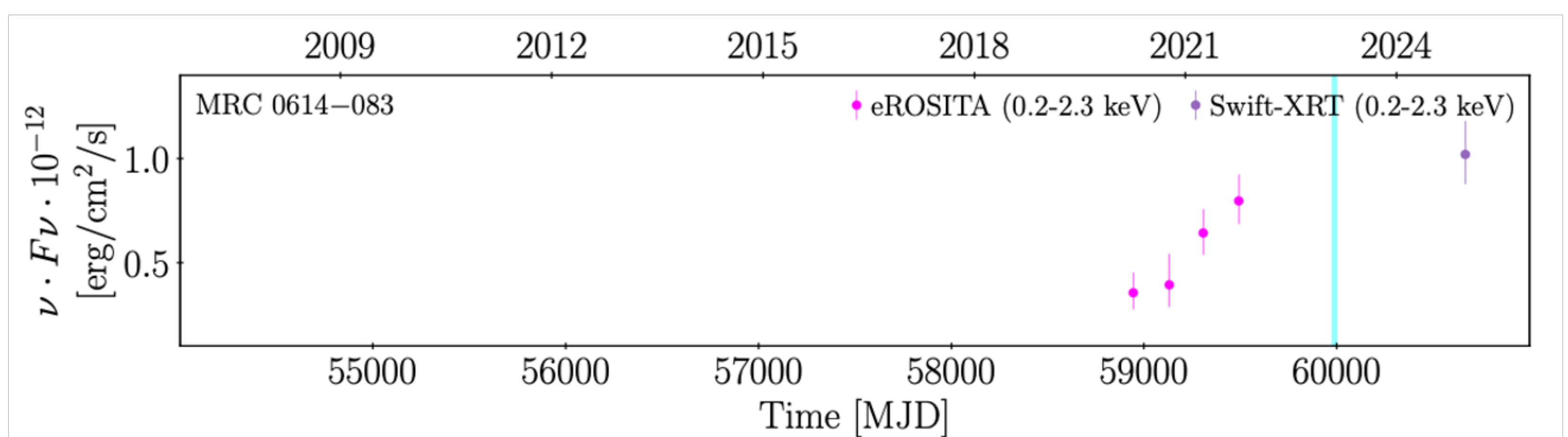



- PMN J0606-0724 (#8)




pre-trial p-value
p = 0.26%

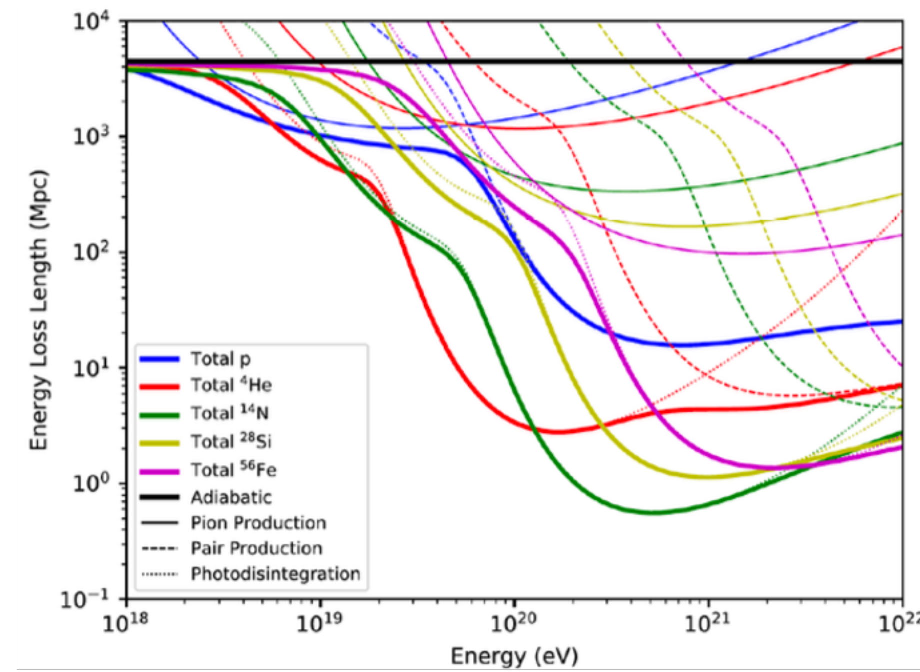
- MCR 0614-083 (#1)




No conclusive evidence

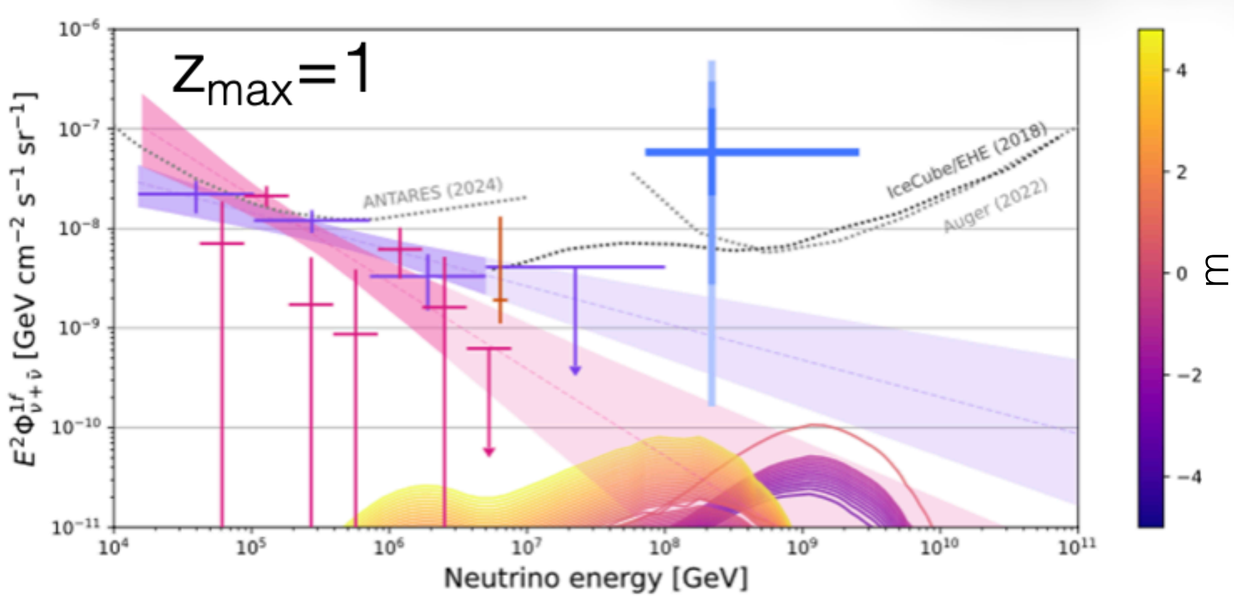
# Testing the cosmogenic origin

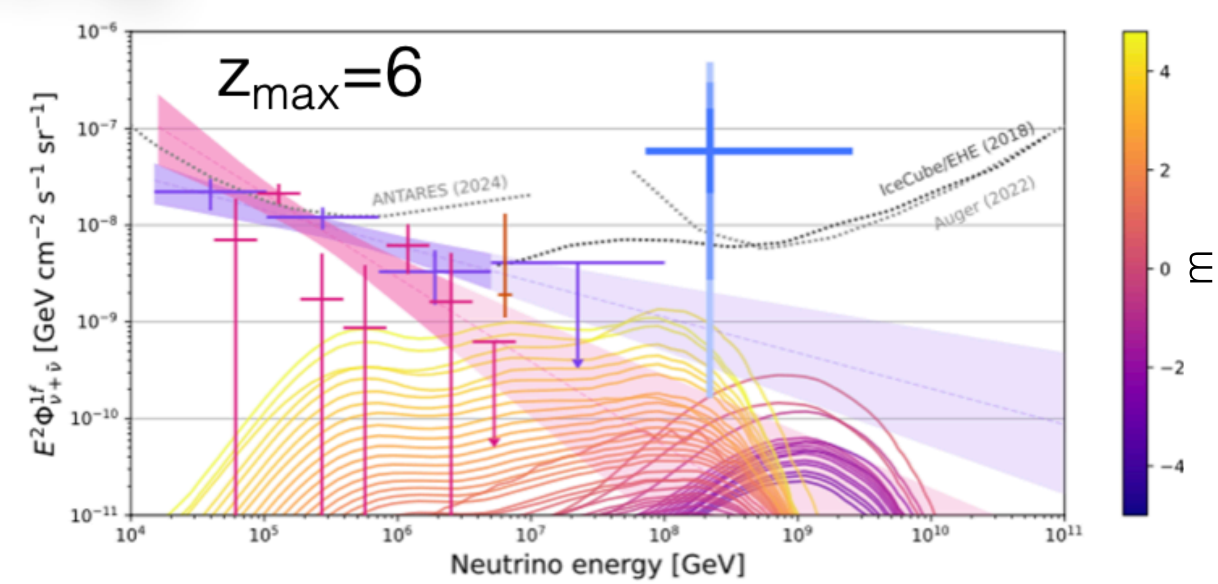
UHECR interaction length depends on their energy distribution and mass composition




On Earth fluxes also vary with cosmological source evolution:

$$S(z) = (1+z)^m$$

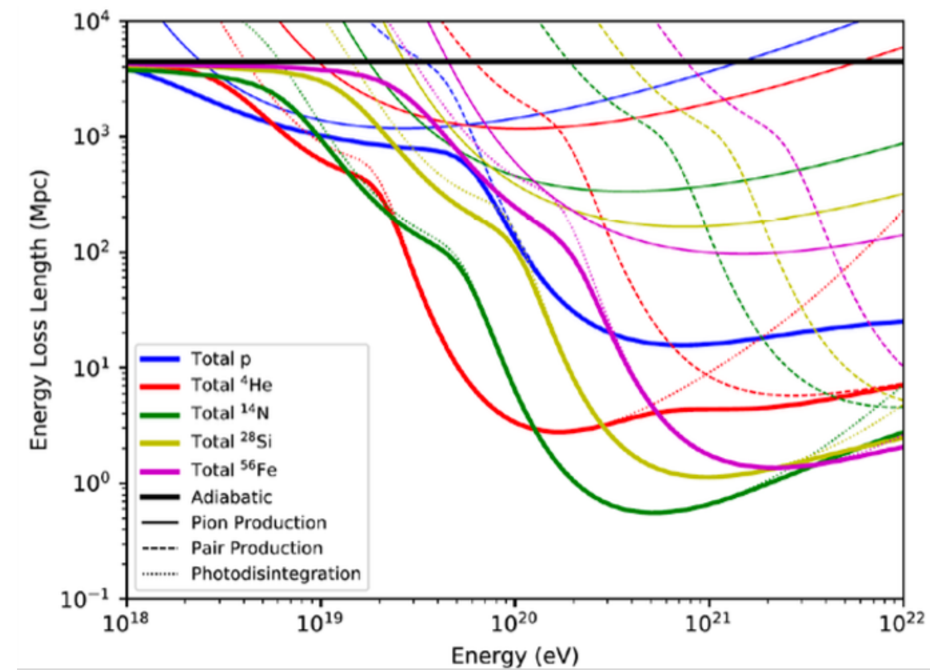



KM3NeT Coll., arXiv:2502.08508

# Testing the cosmogenic origin

UHECR interaction length depends on their energy distribution and mass composition

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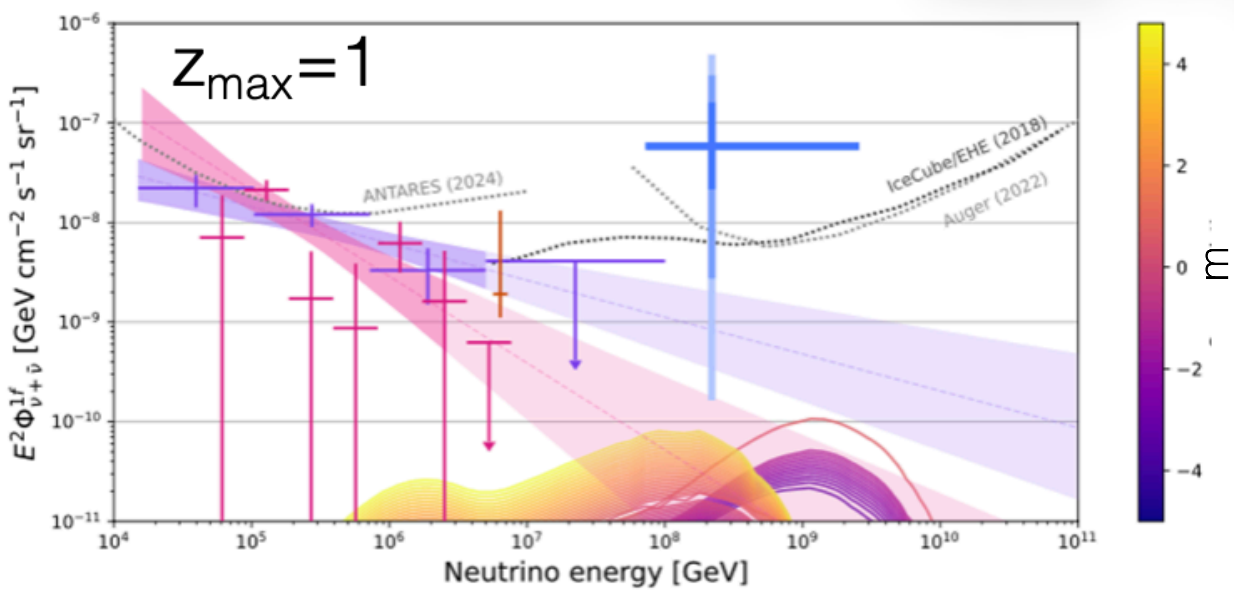
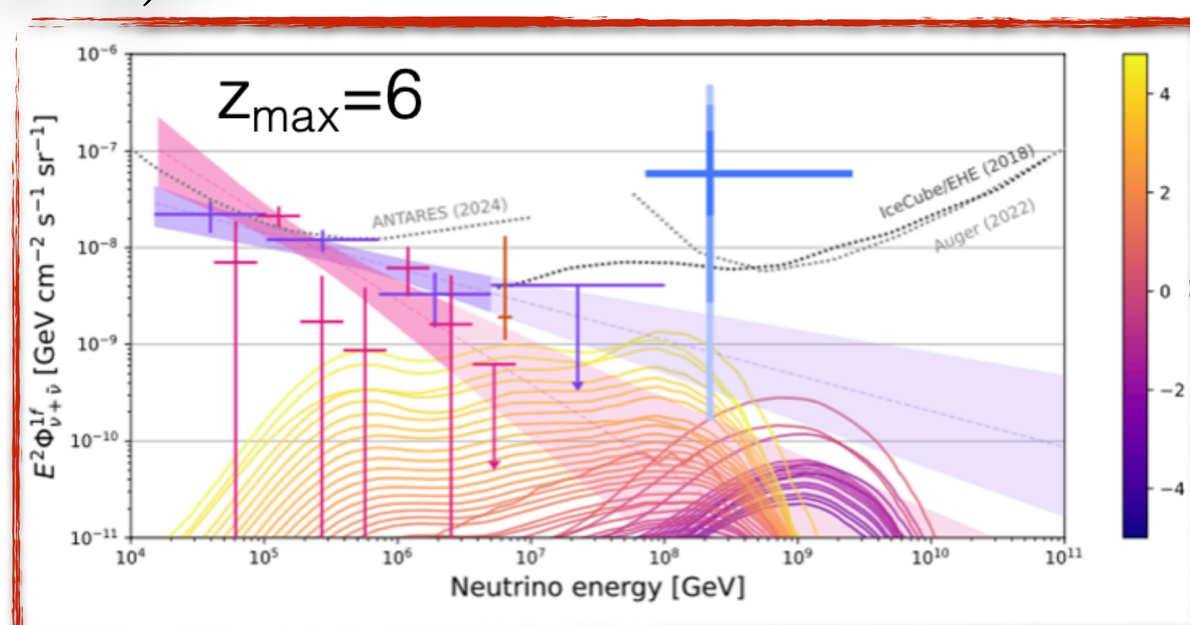



KM3NeT Coll., arXiv:2502.08508

# A milestone in neutrino astronomy

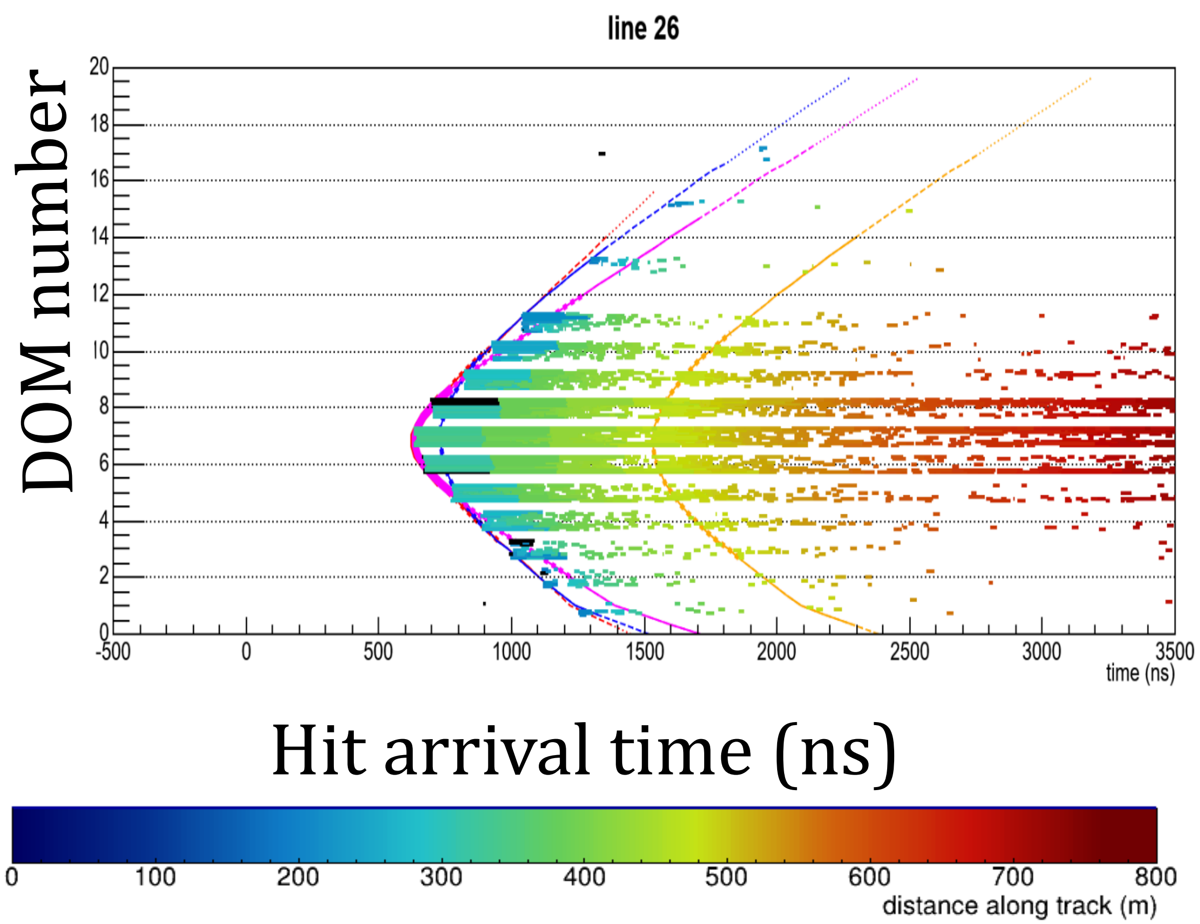
- **KM3-230213A** is by far the most energetic neutrino measured so far
- It is the **first UHE neutrino detected**, opening the explorations of physics in a new energy region
- Several plausible scenarios might explain its nature
- More observations to come will clarify the origin of UHE neutrinos
- KM3NeT is taking data and growing rapidly

**STAY TUNED FOR UPDATES!**

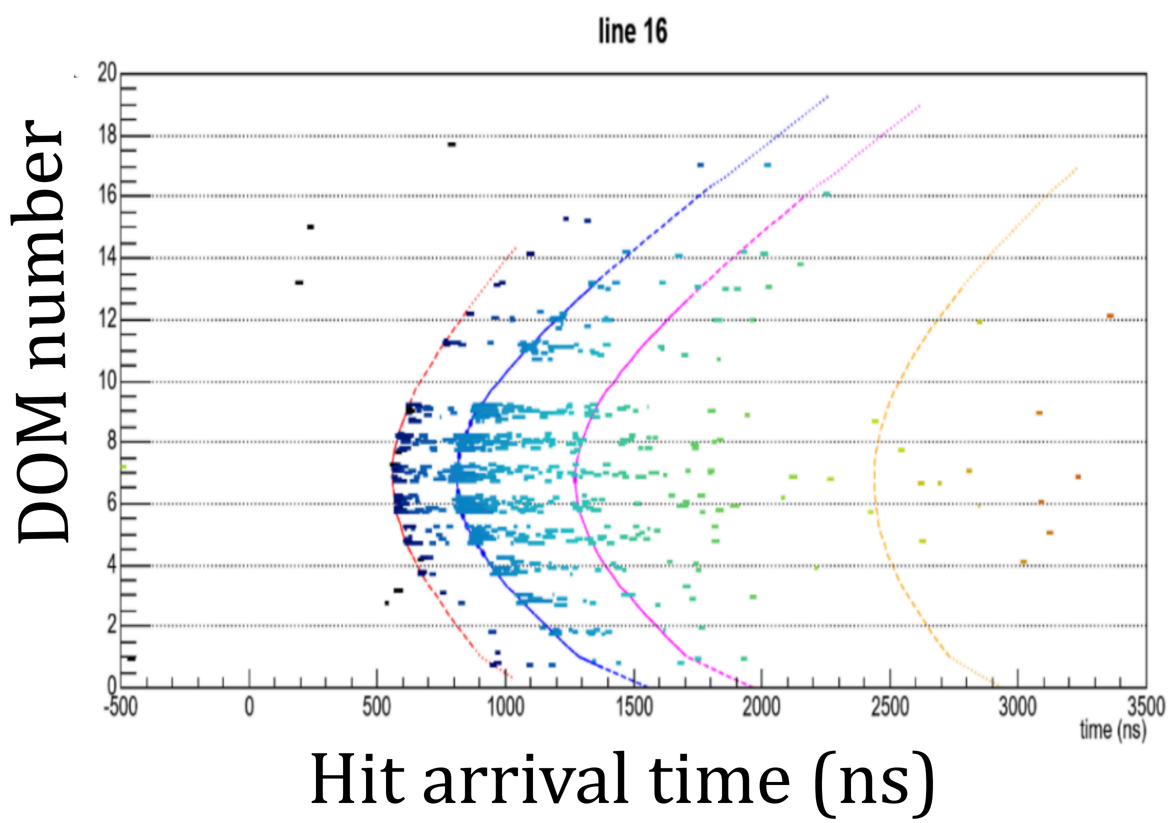

Thanks for your kind attention!

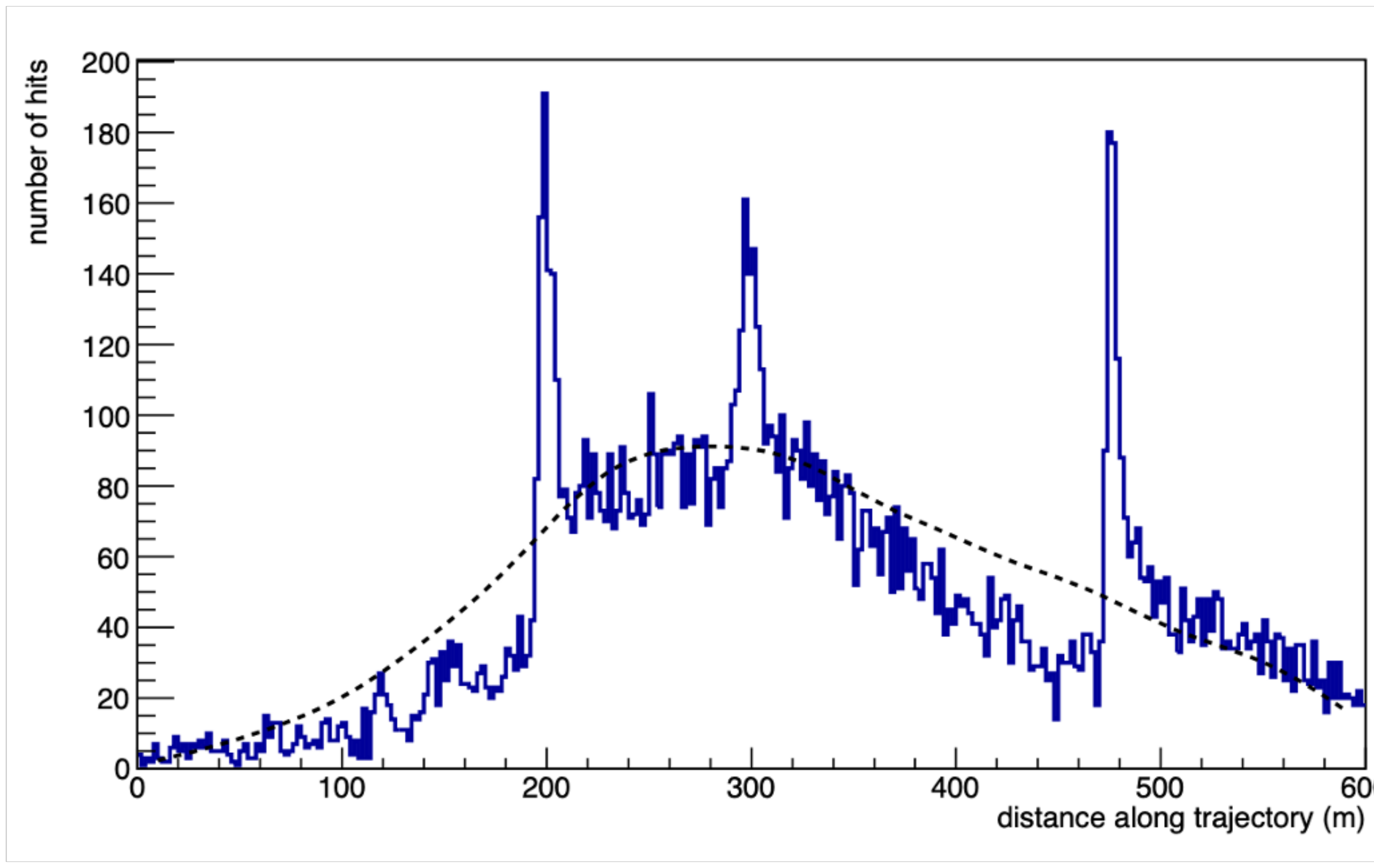
# KM3-230213A

# KM3-230213A: direction

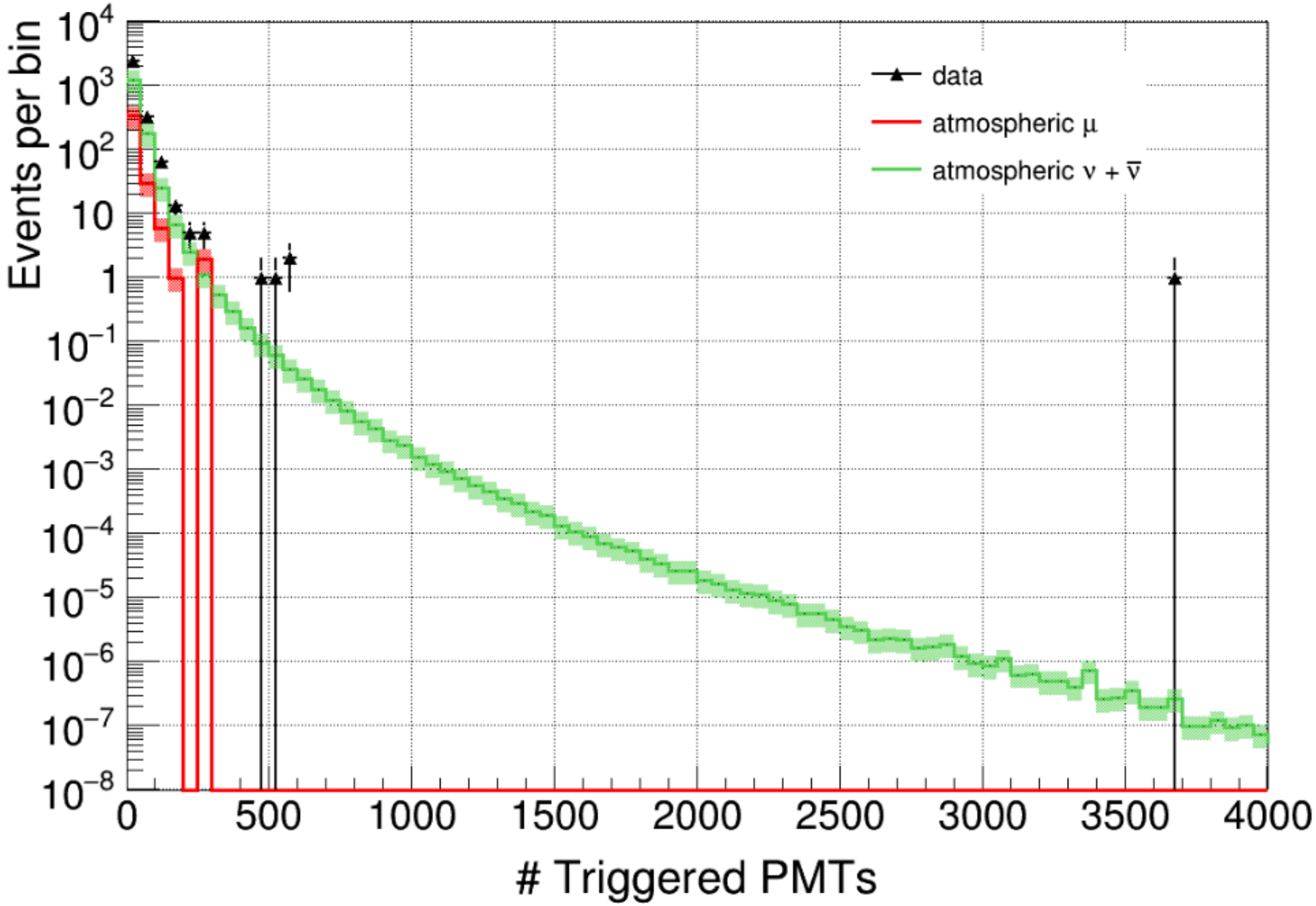



- Hit times fully consistent with **Cherenkov photons**
- From reconstruction algorithms, a muon track and three showers detected, as expected in muon stochastic energy losses
- The collinearity of showers supports the **single muon** hypothesis

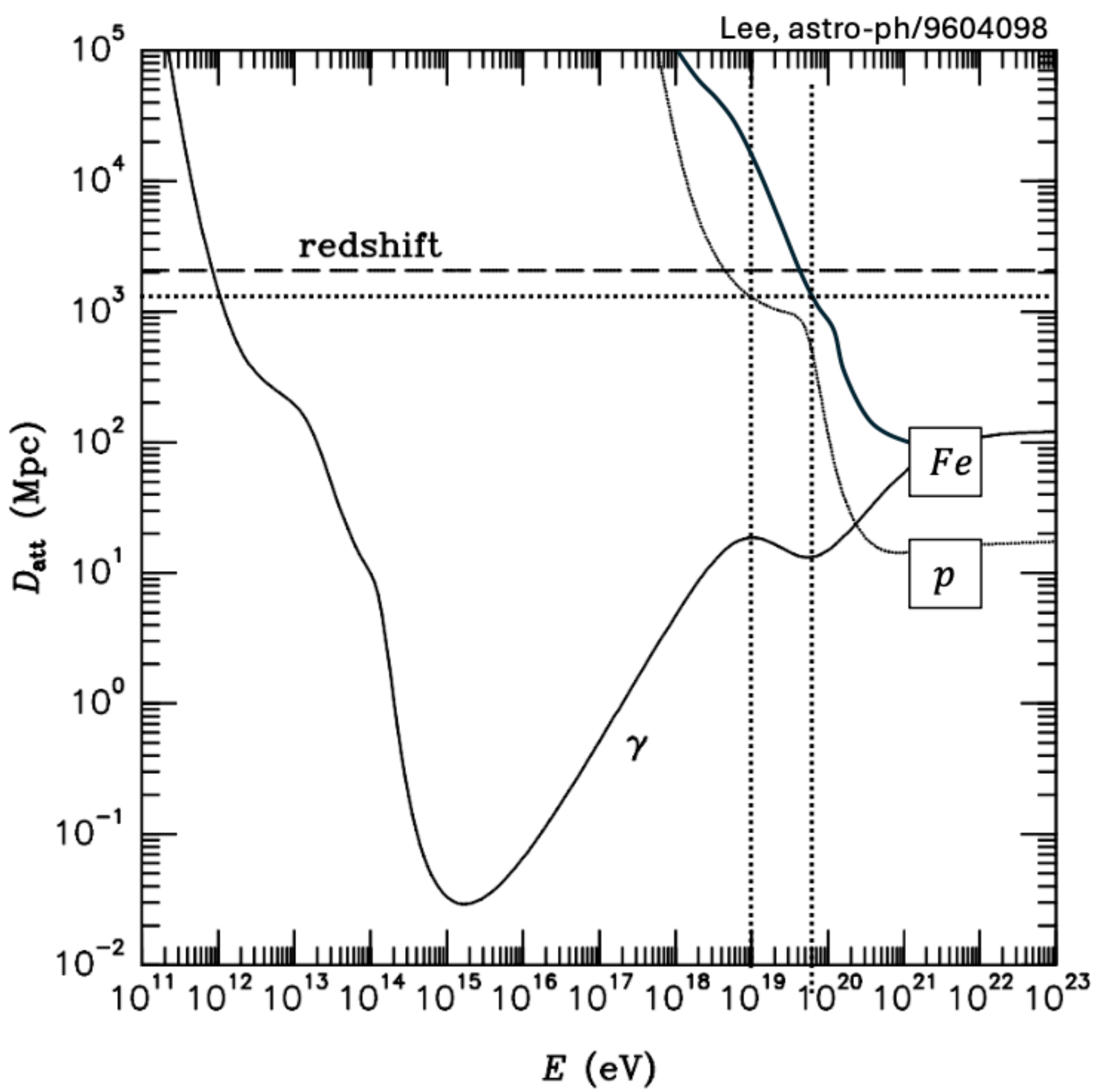


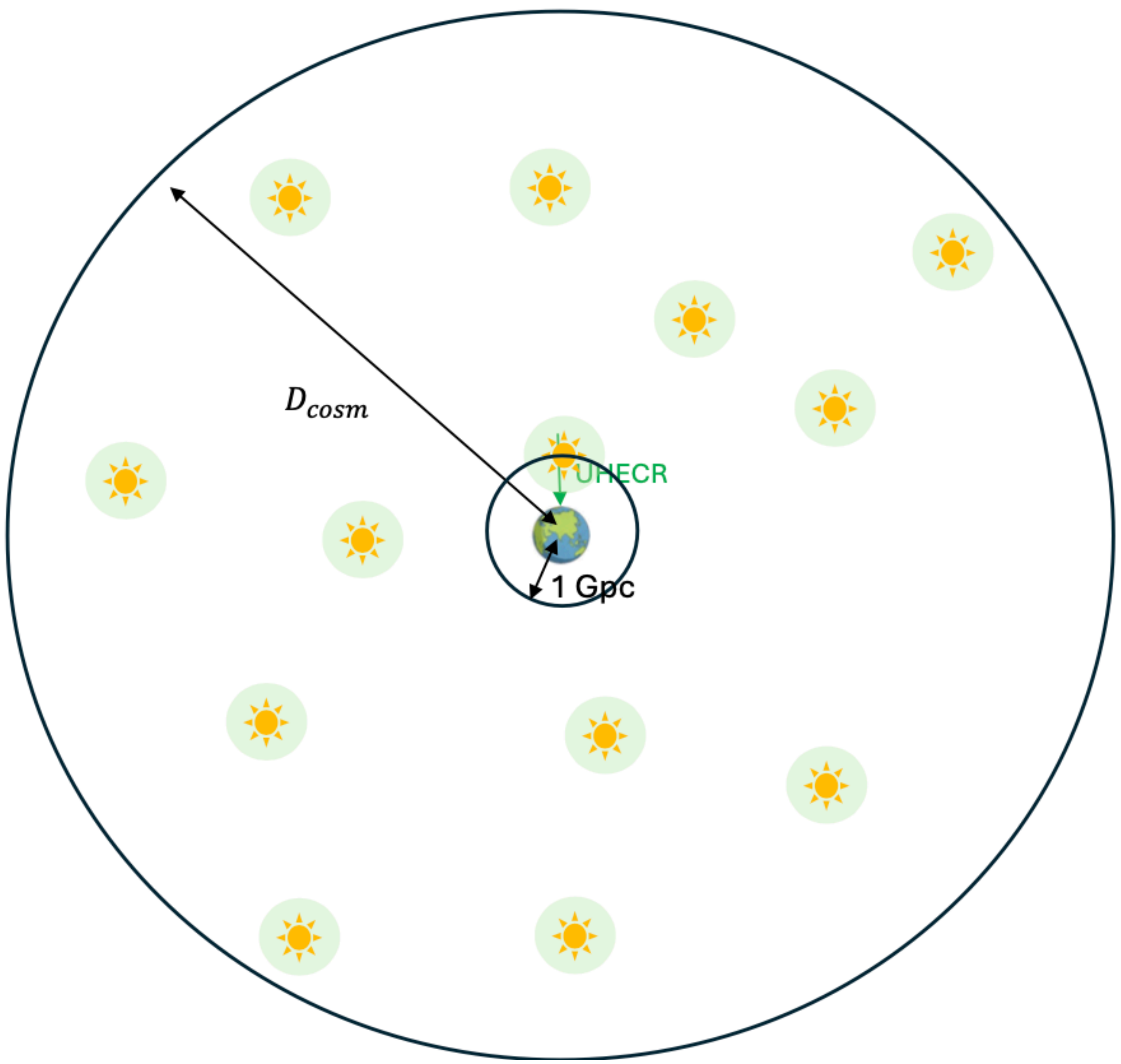



# Background distribution



# A nearby transient source?

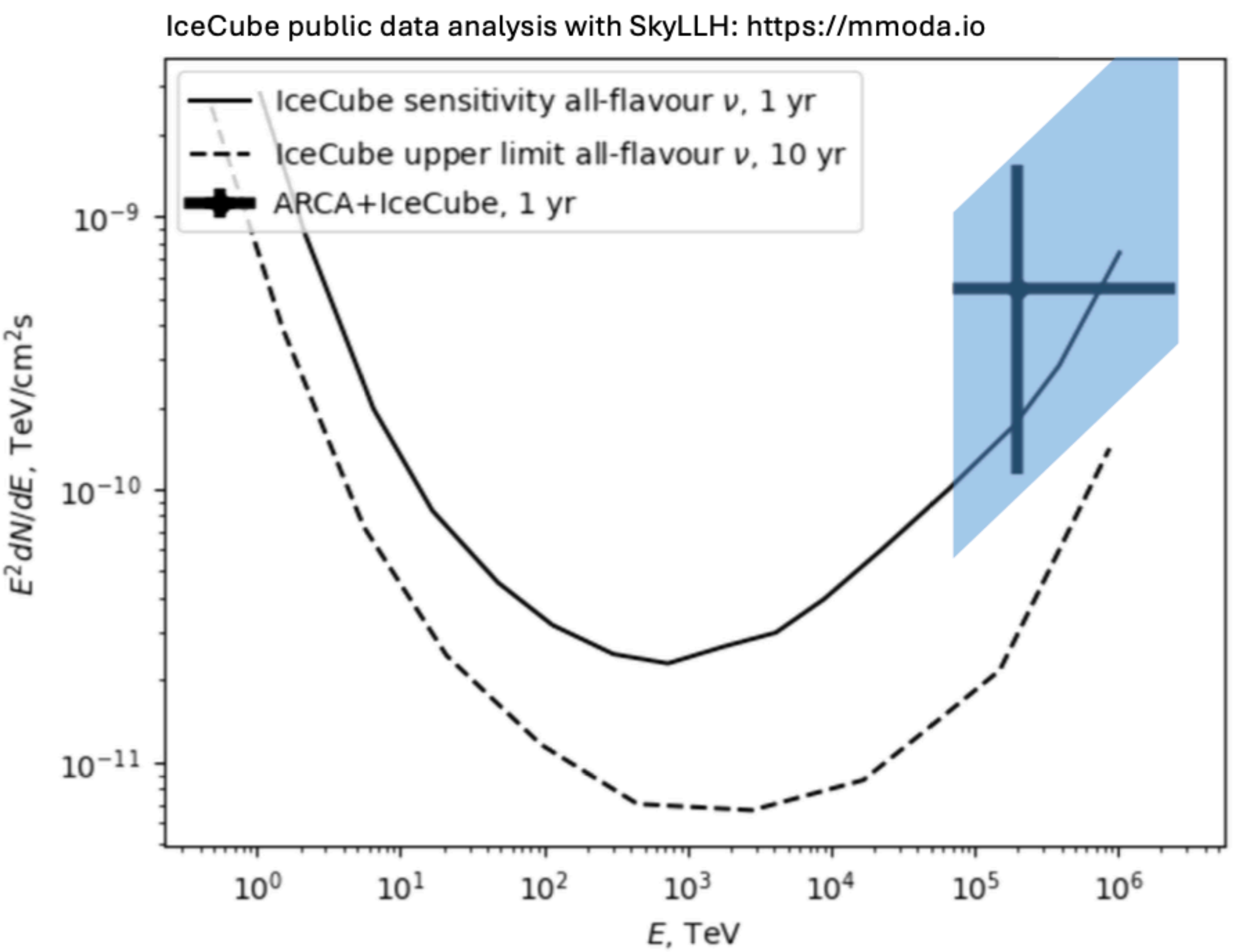


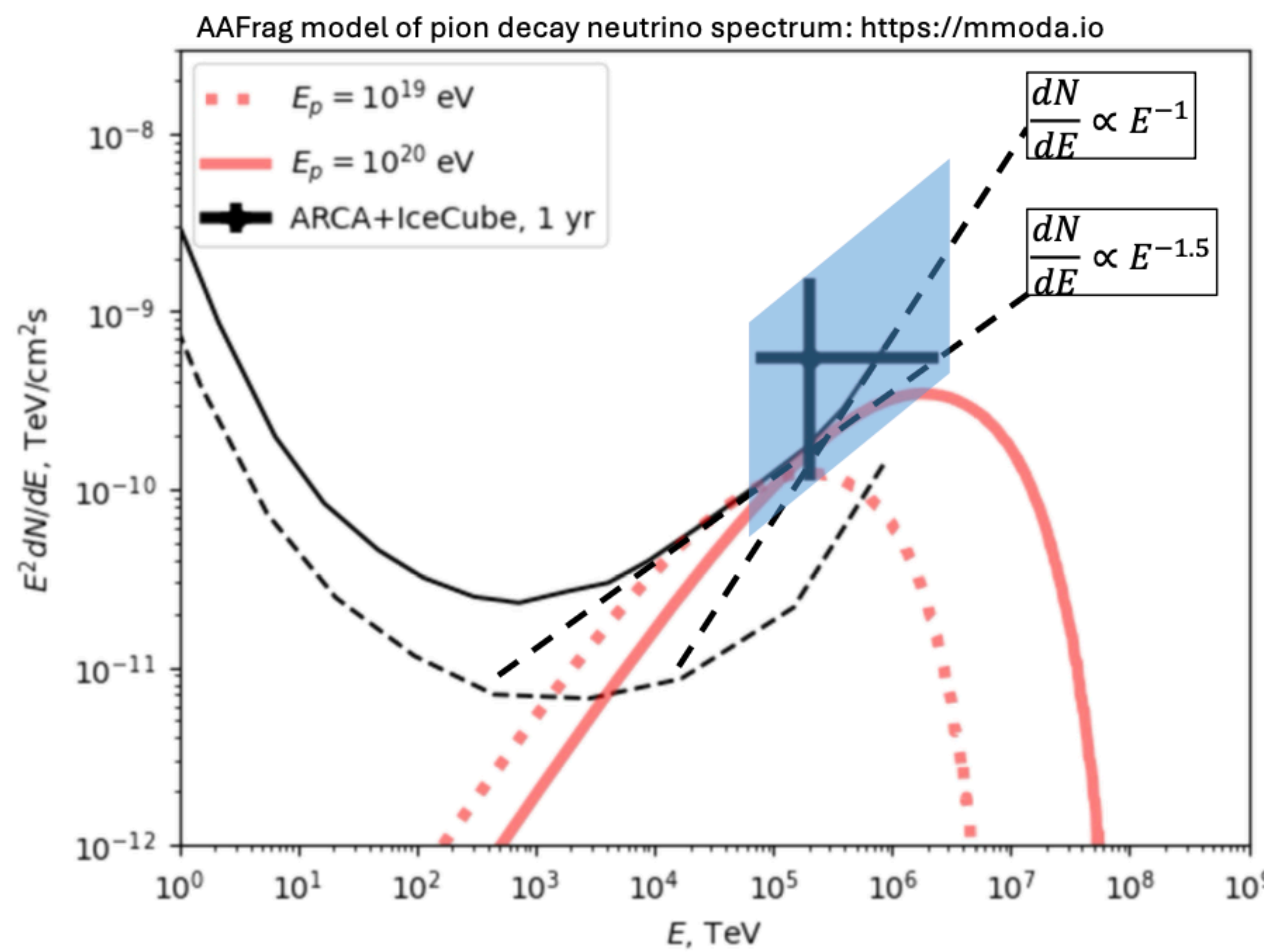




Neronov et al., arXiv:2502.12986

# A nearby transient source?

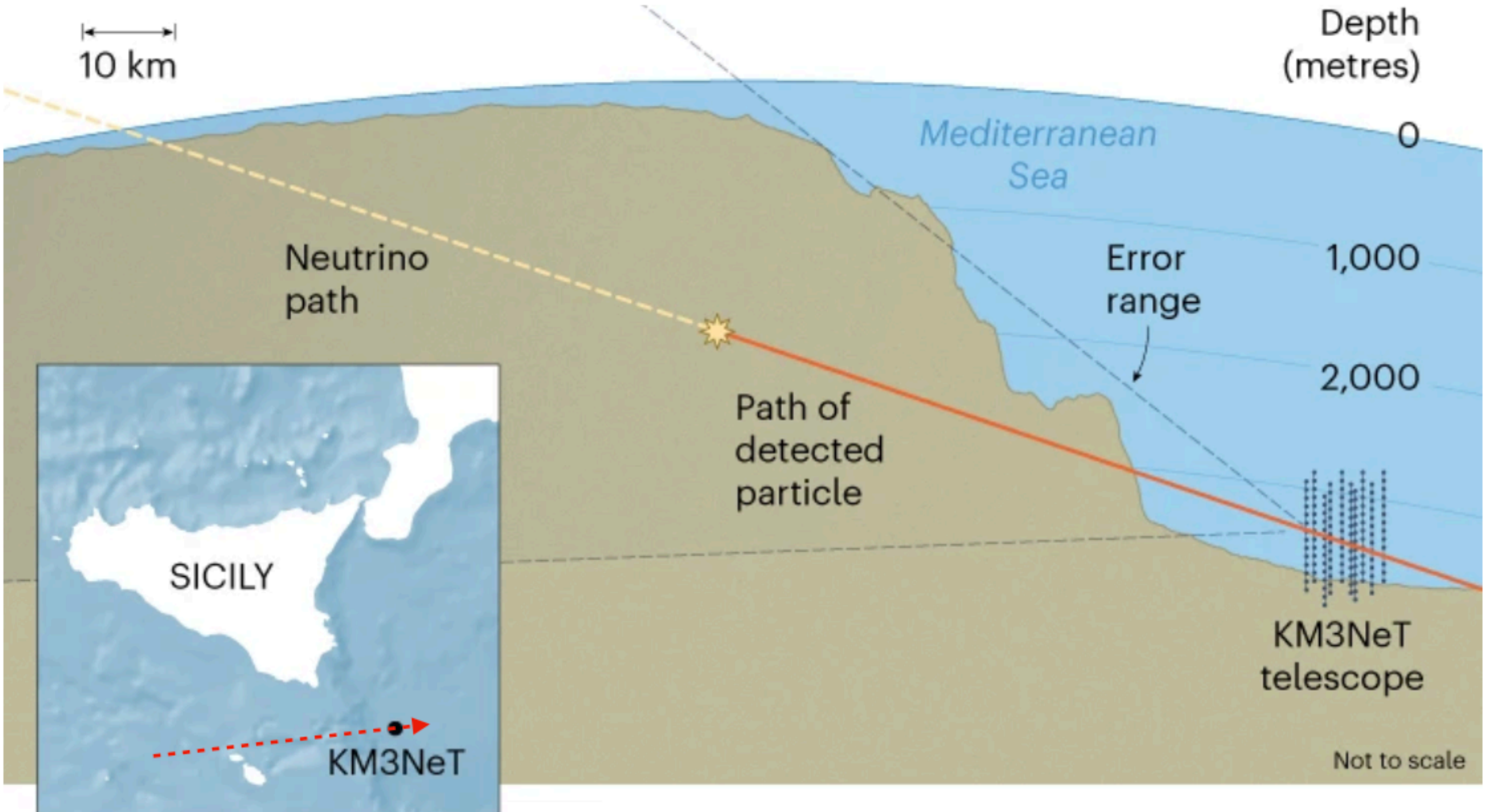
- Flare with duration T<2 yr compatible with IC non observation
- Particle injection spectrum must be harder than $E^{-2}$ (either from monochromatic protons or as a result of pγ interactions)
- Source rate not extreme



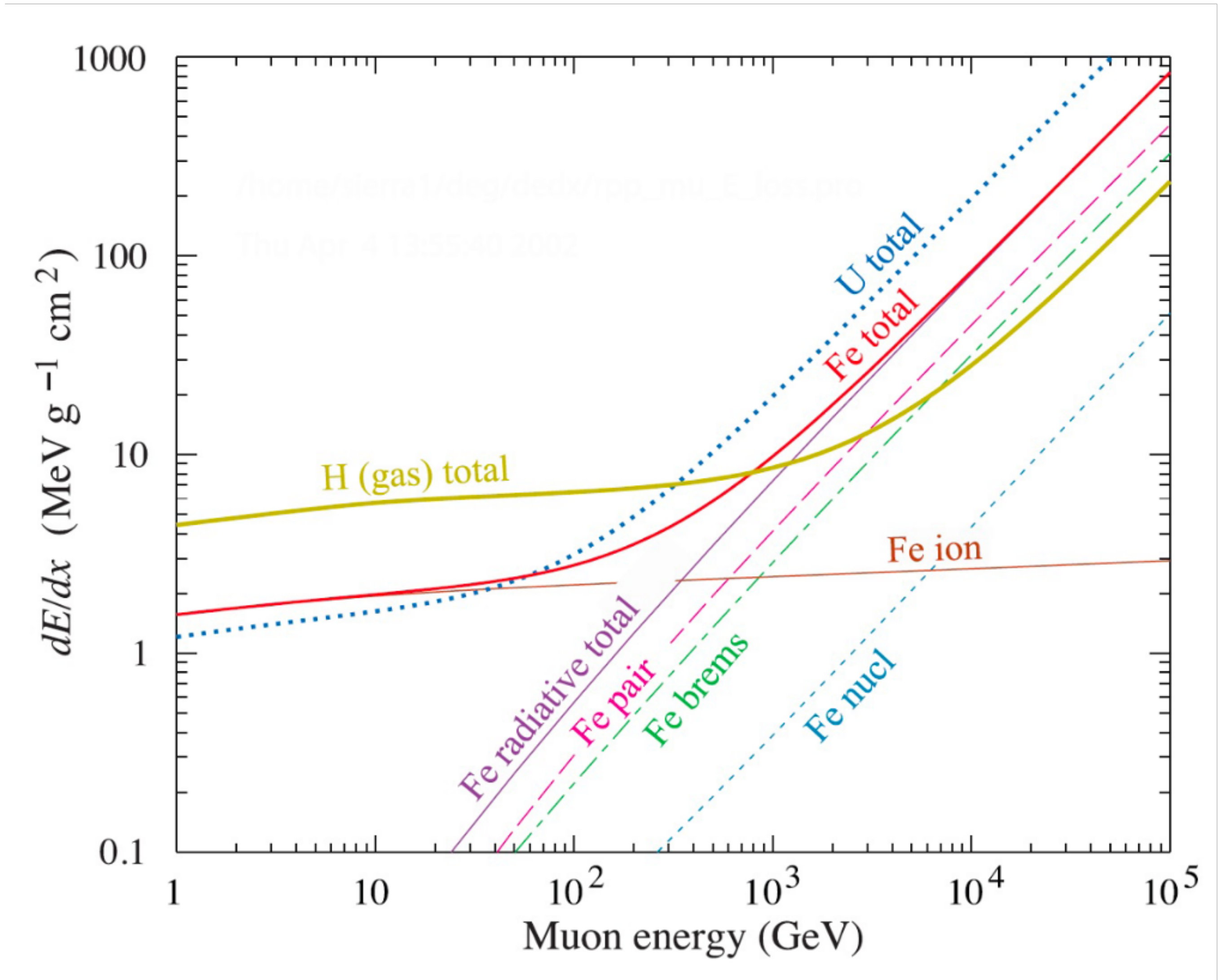



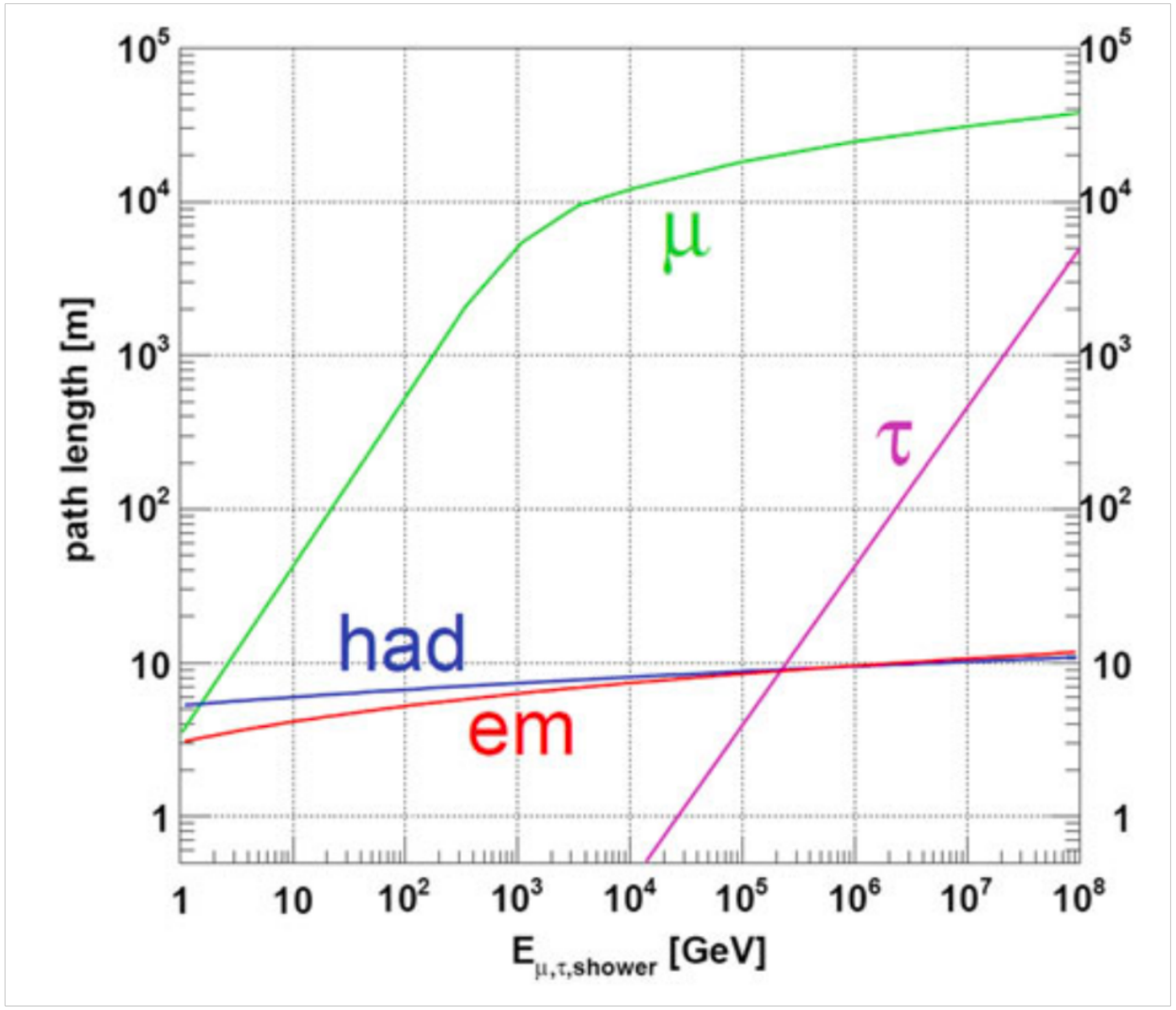

Neronov et al., arXiv:2502.12986

# The large shielding from Malta's shelf



# Muon energy losses




$$\boxed{\frac{\mathrm{d}E_\mu}{\mathrm{d}X} = -\alpha - \beta E_\mu}$$

$$\alpha \simeq 2\,\mathrm{MeV\,g^{-1}\,cm^2}$$

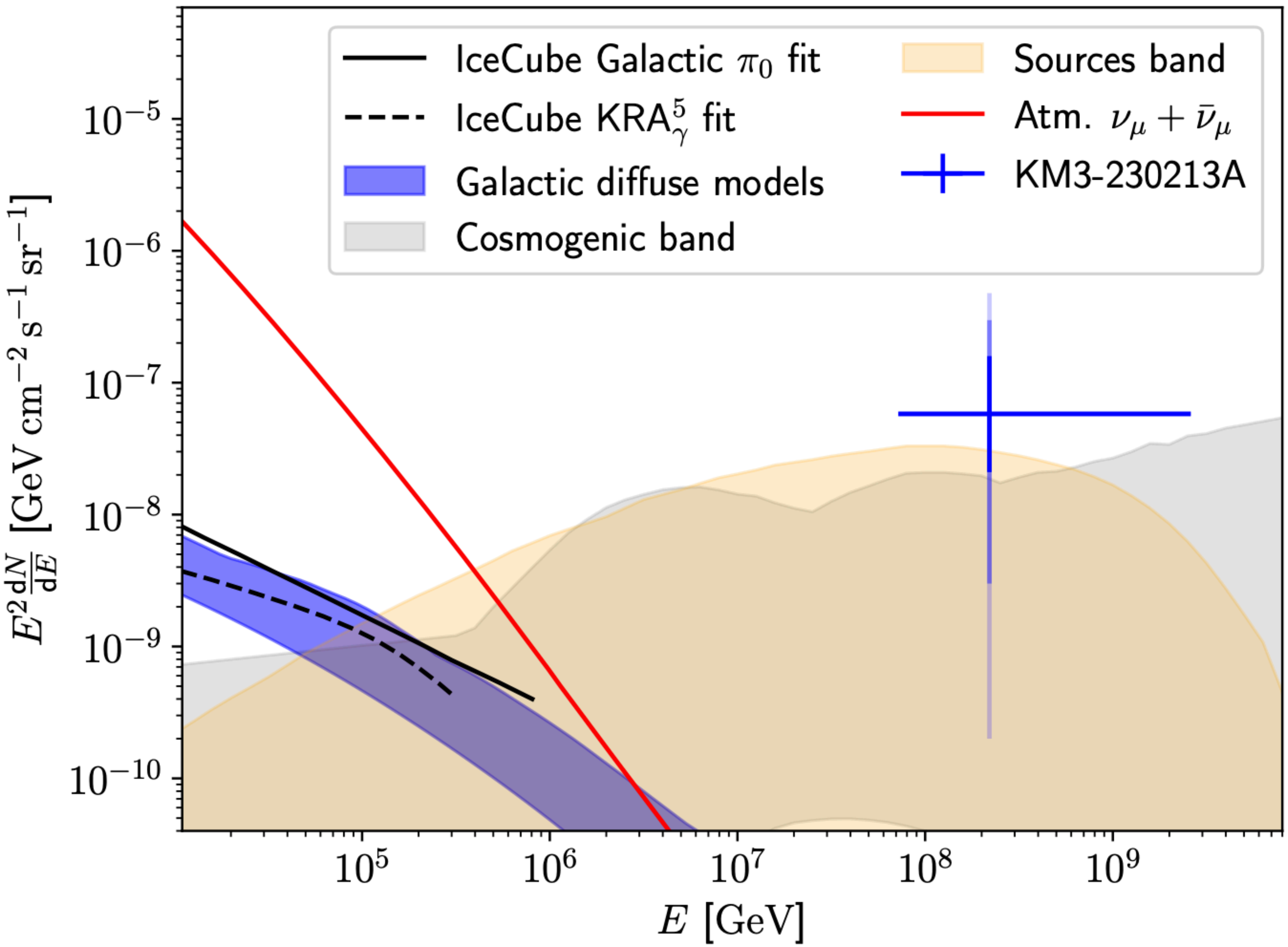
$$\beta = \beta_{\rm br} + \beta_{\rm pair} + \beta_{\rm ph} \longrightarrow \beta \simeq 4\times 10^{-6}\ \mathrm{g^{-1}\,cm^2}$$

$$\langle E_\mu(X)\rangle = (E_\mu^0 + \epsilon_\mu)e^{-\beta X} - \epsilon_\mu$$

$$\epsilon_\mu = \alpha/\beta \simeq 500\ \mathrm{GeV}$$

$$\boxed{R(E_\mu^0) = \frac{1}{\beta}\ln\left(1+\frac{E_\mu^0}{\epsilon_\mu}\right)}$$

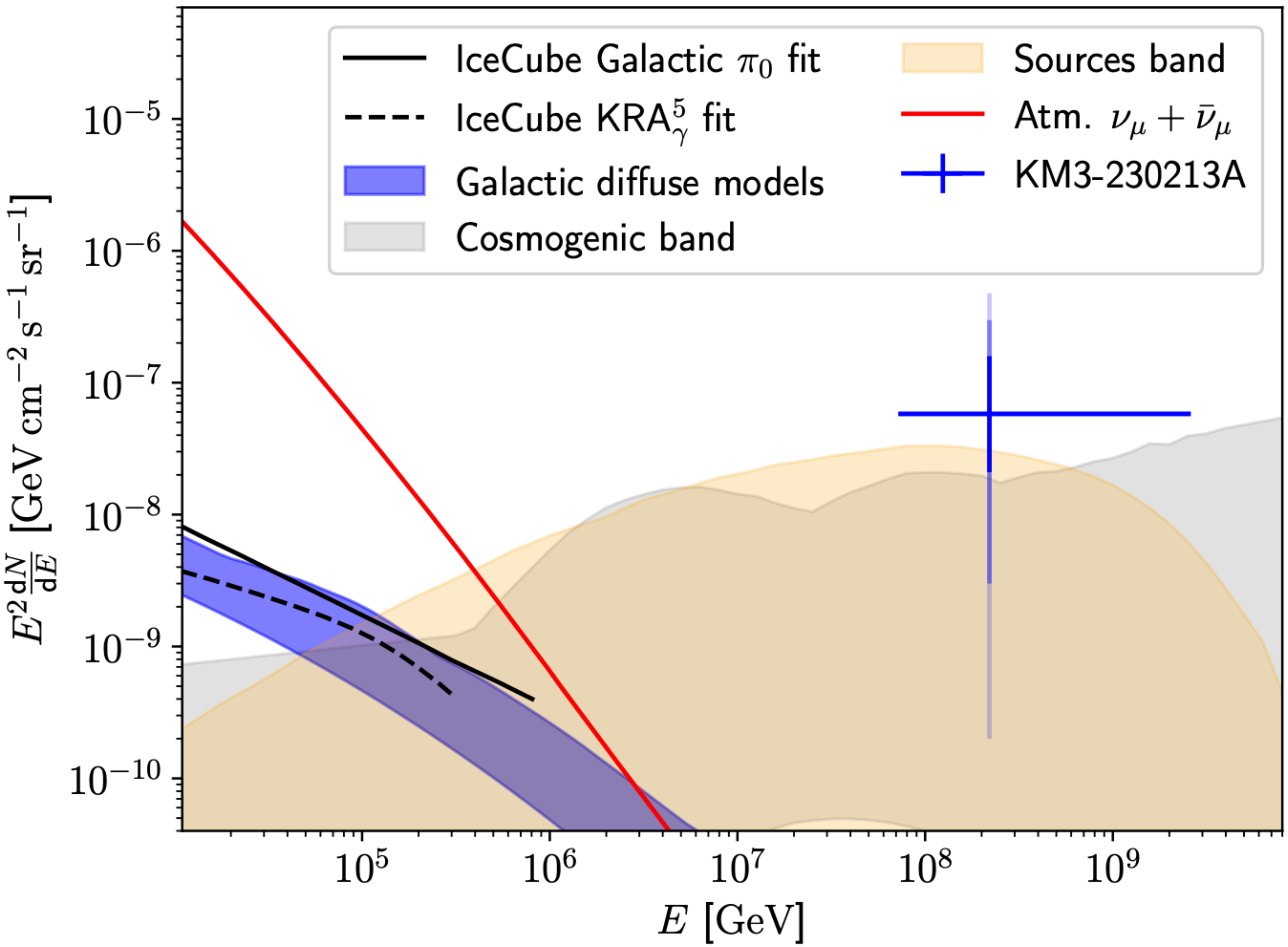
# Hardly of Galactic nature




Unlikely related to Galactic diffuse neutrino emission… even with the dense target of MonR2

KM3NeT Coll., arXiv:2502.08387

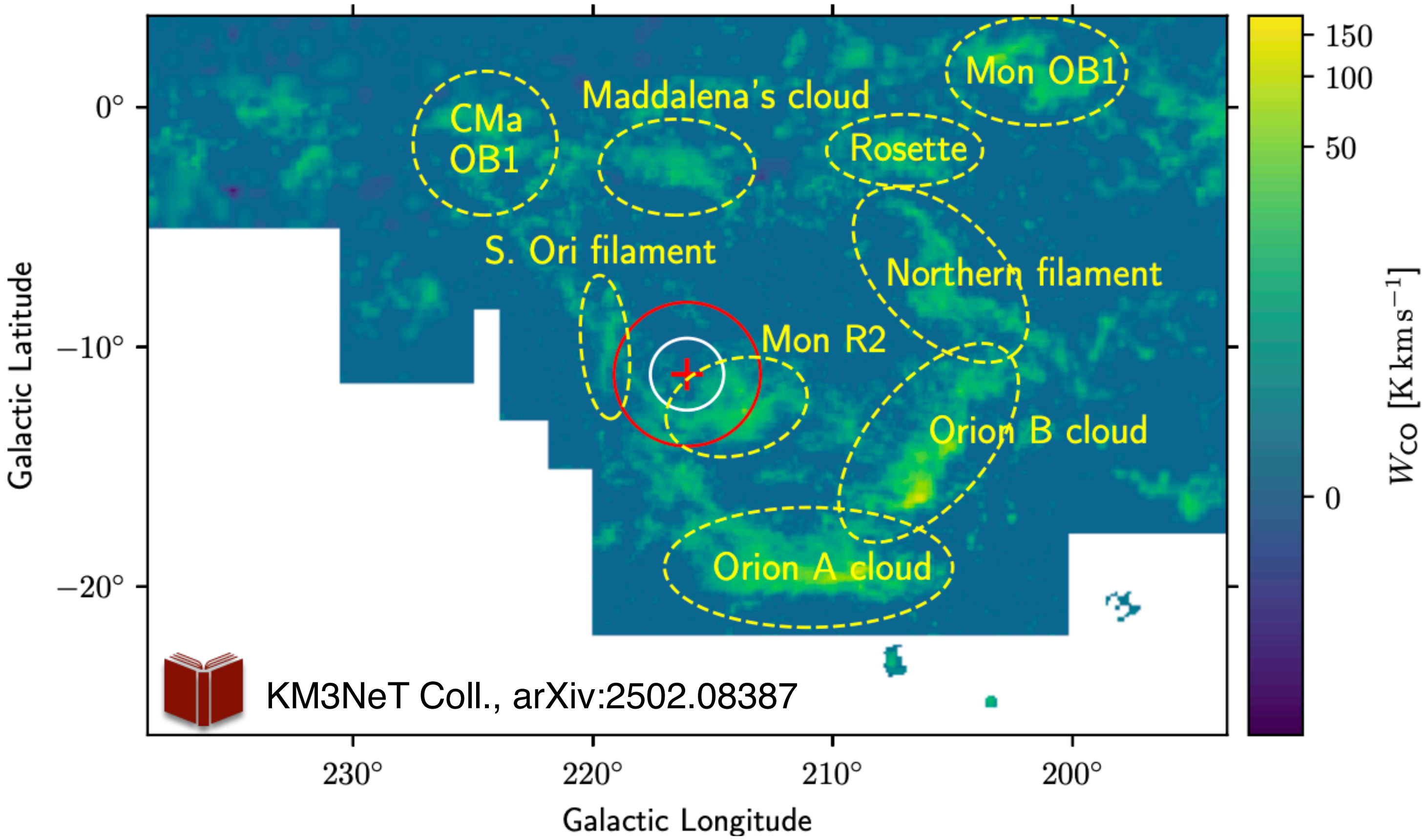
# Hardly of Galactic nature

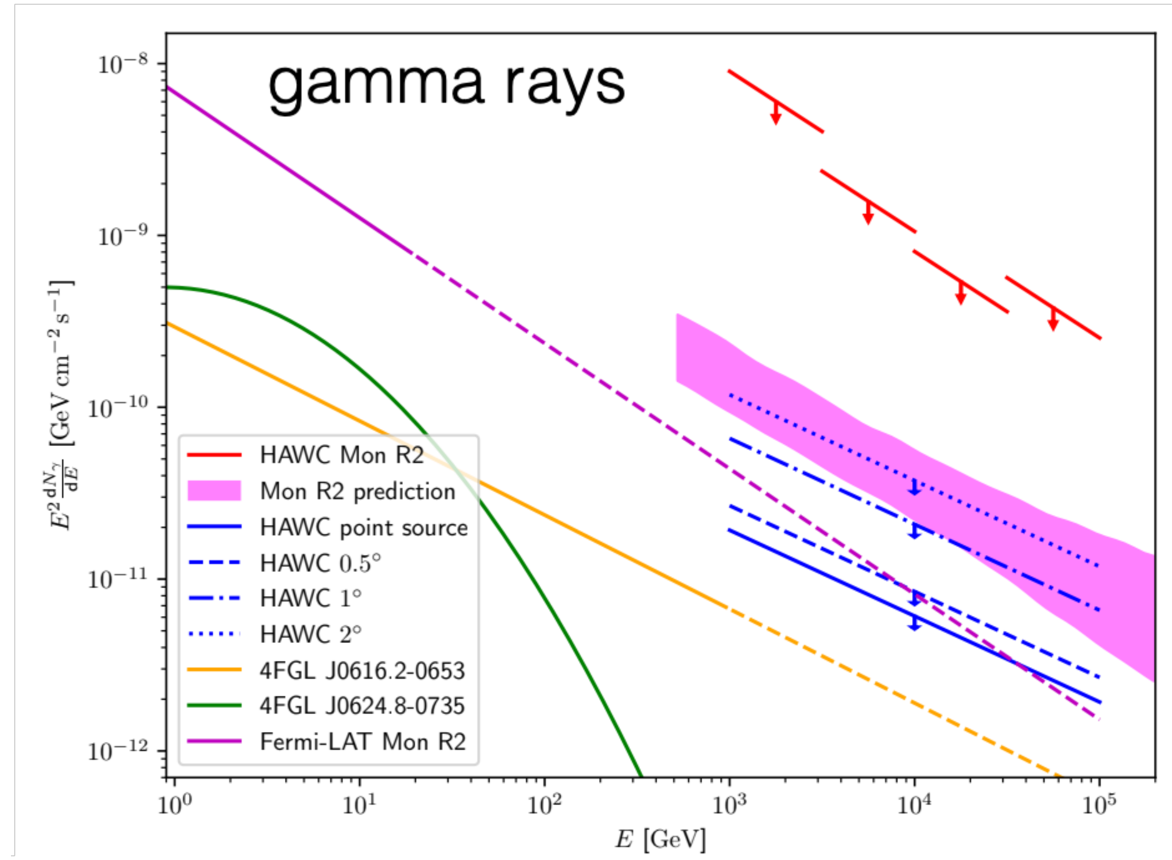


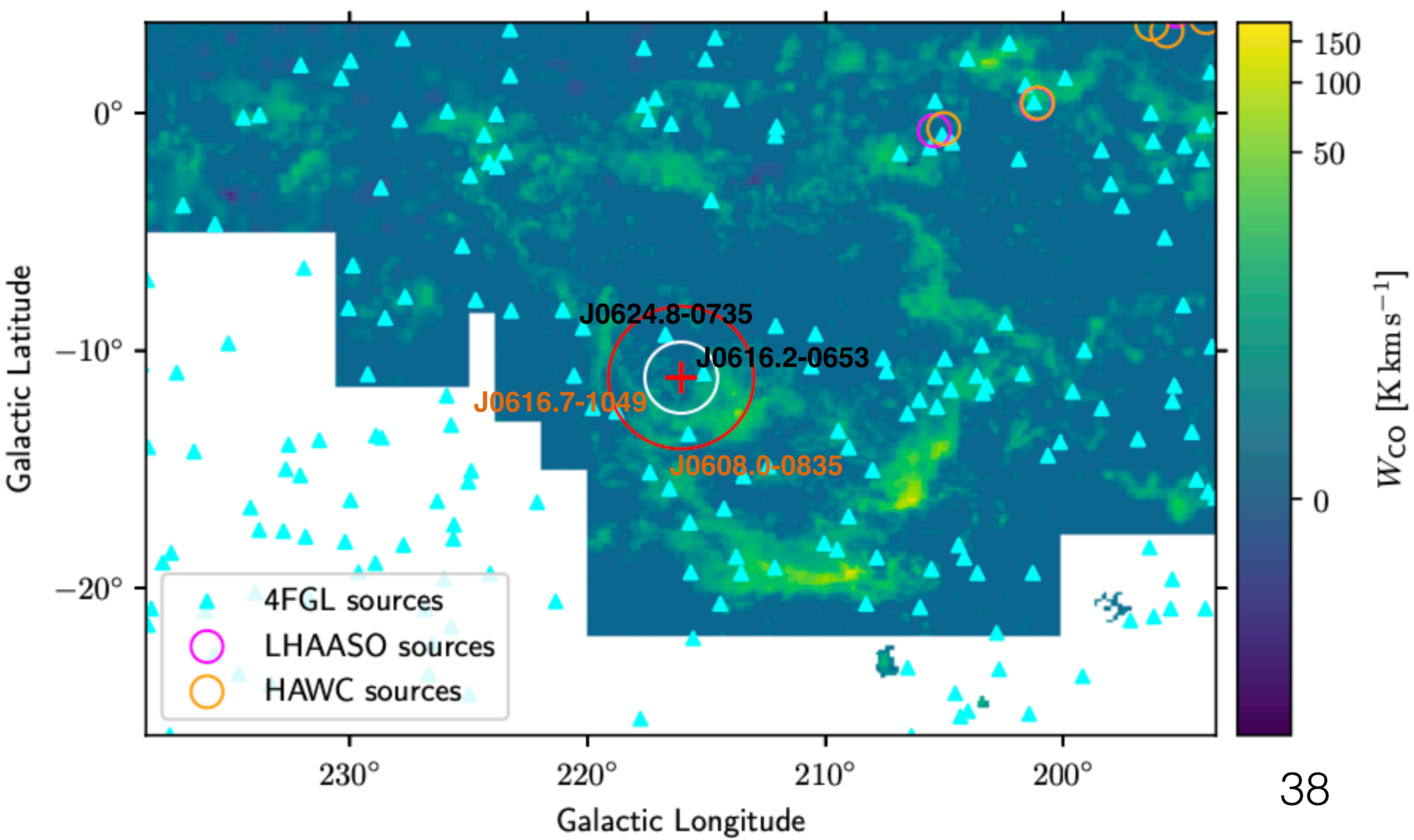

Unlikely related to Galactic diffuse neutrino emission… even with the dense target of MonR2

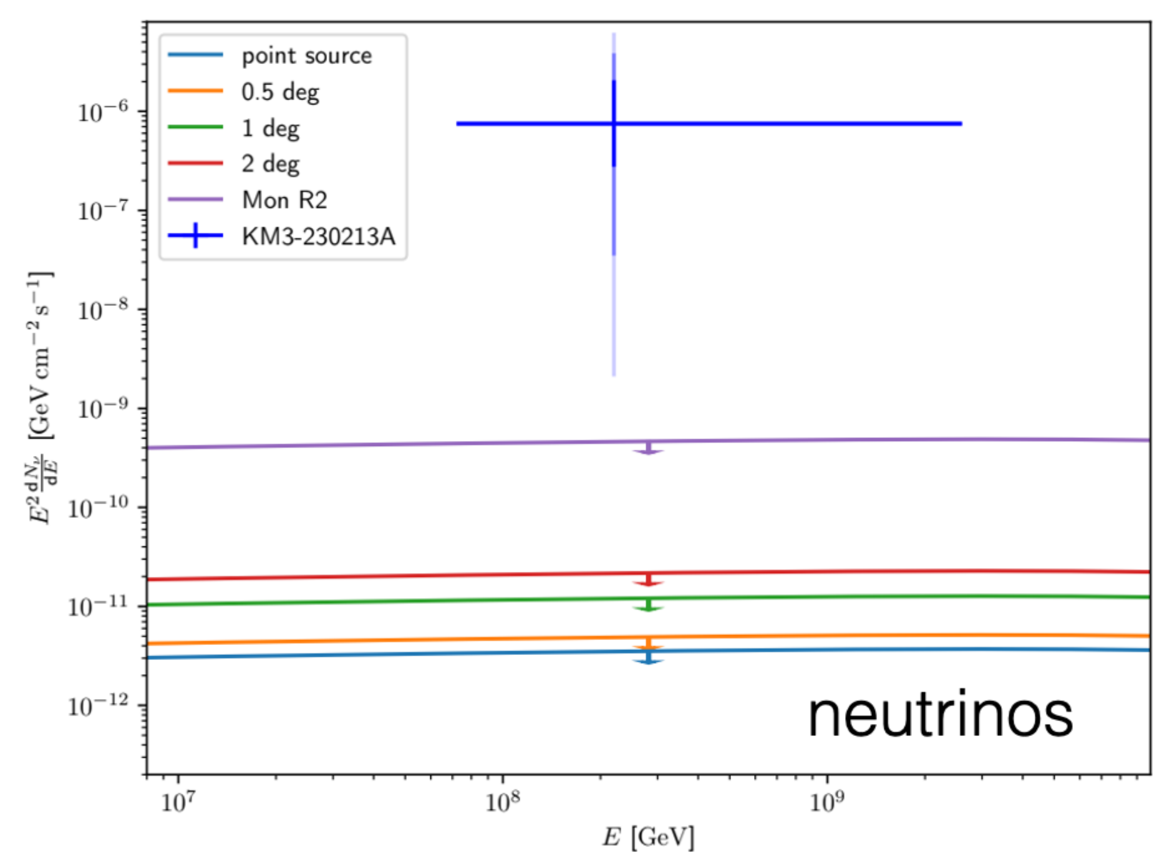
KM3NeT Coll., arXiv:2502.08387

# Hardly of Galactic nature



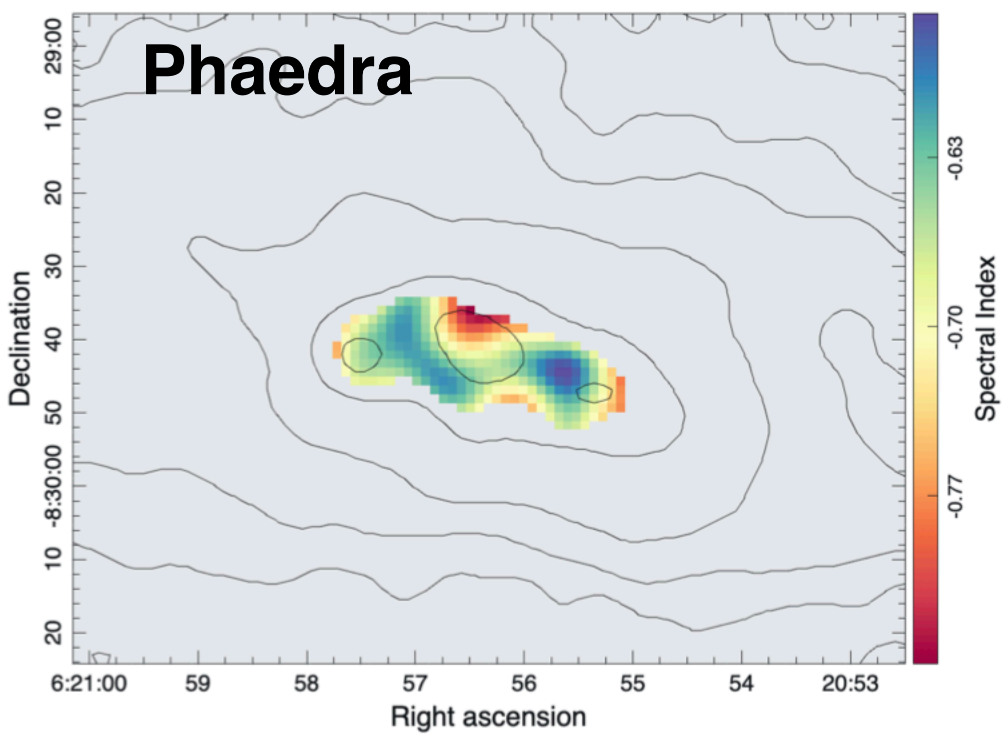



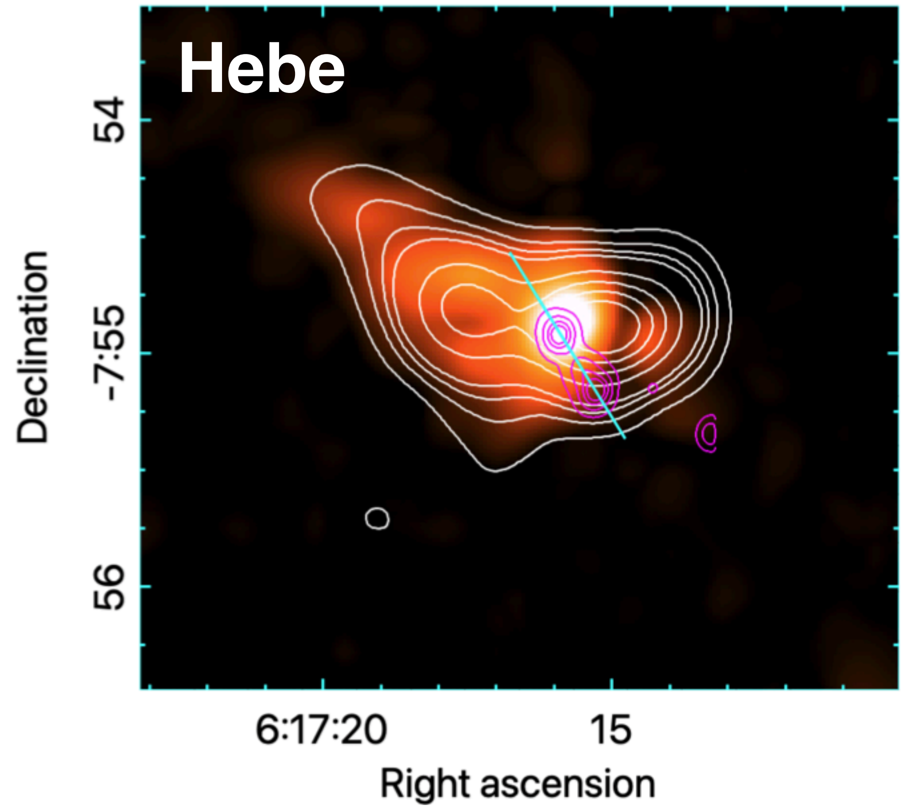



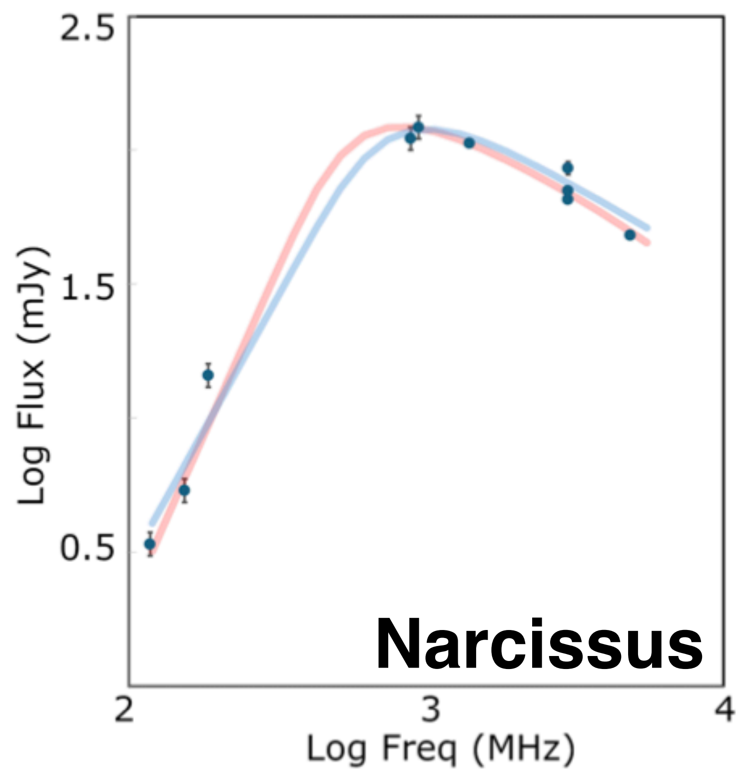
# KM3-230213A and non-blazar searches

- 3 non-blazar AGN identified in the KM3-230213A 68% search region via ASKAP/VLASS data
  - UGCA (aka Phaedra)
  - WISEA J061715.89−075455.4 (aka Hebe)
  - EMU J062248−072246 (aka Narcissus)

Filipovic et al., arXiv:2503.09108

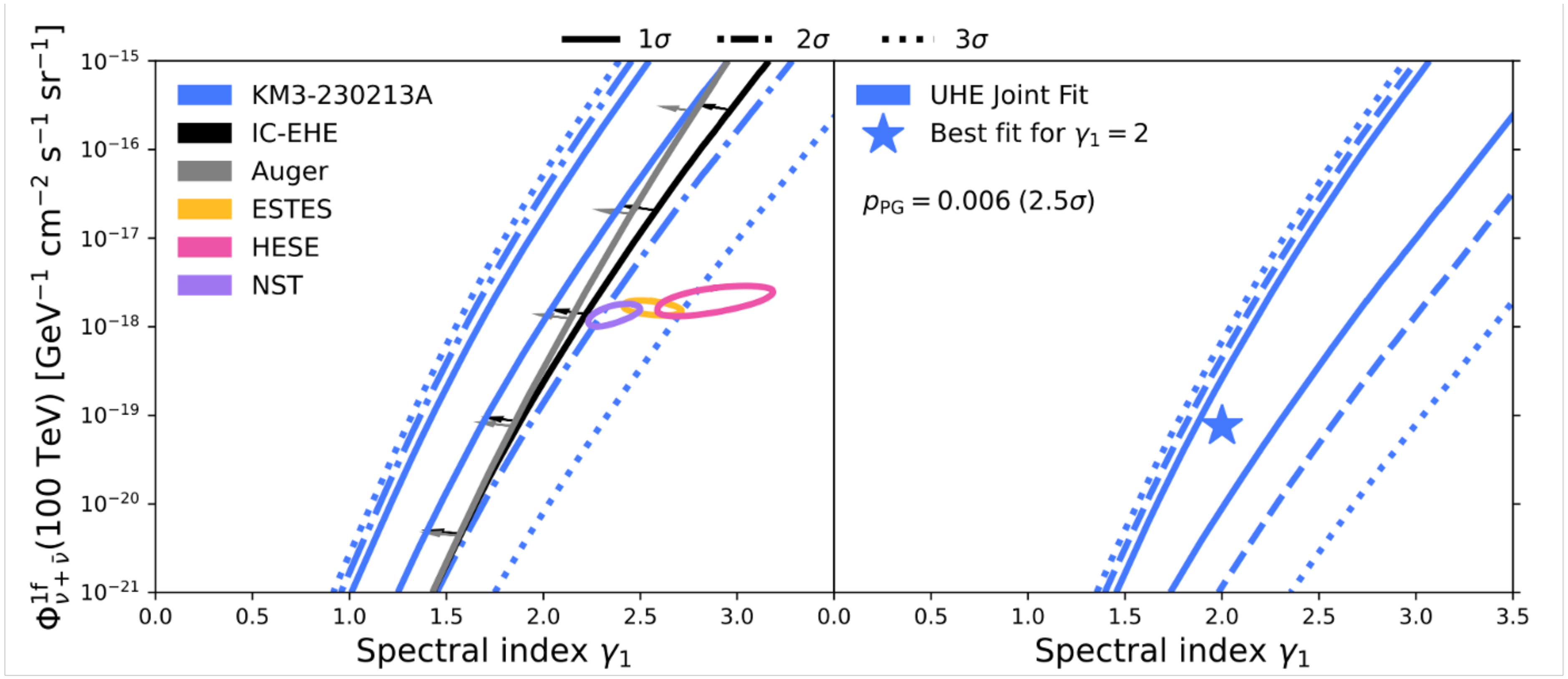


# Is there tension with IC/Auger non observations?

We tested a generic single power-law flux in UHE band




Bayesian approach    Frequentist approach

→ 2.5σ tension

KM3NeT Coll., arXiv:2502.08173

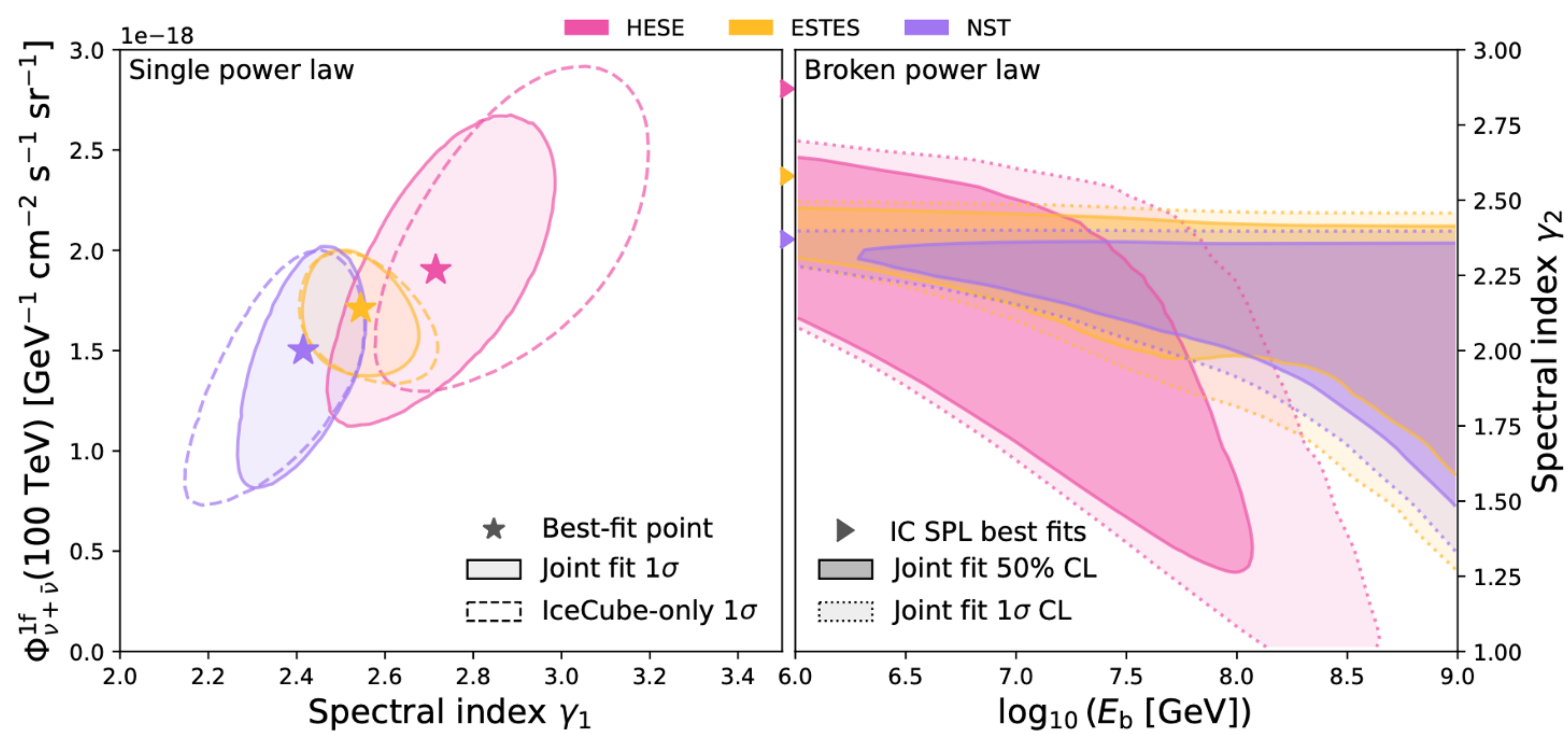
# Is there evidence of a new component?

- Both single (SPL) and broken power law (BPL) flux hypotheses tested across the entire astrophysical neutrino spectrum

- Three IceCube measurements below 10 TeV: HESE, ESTES, and NST

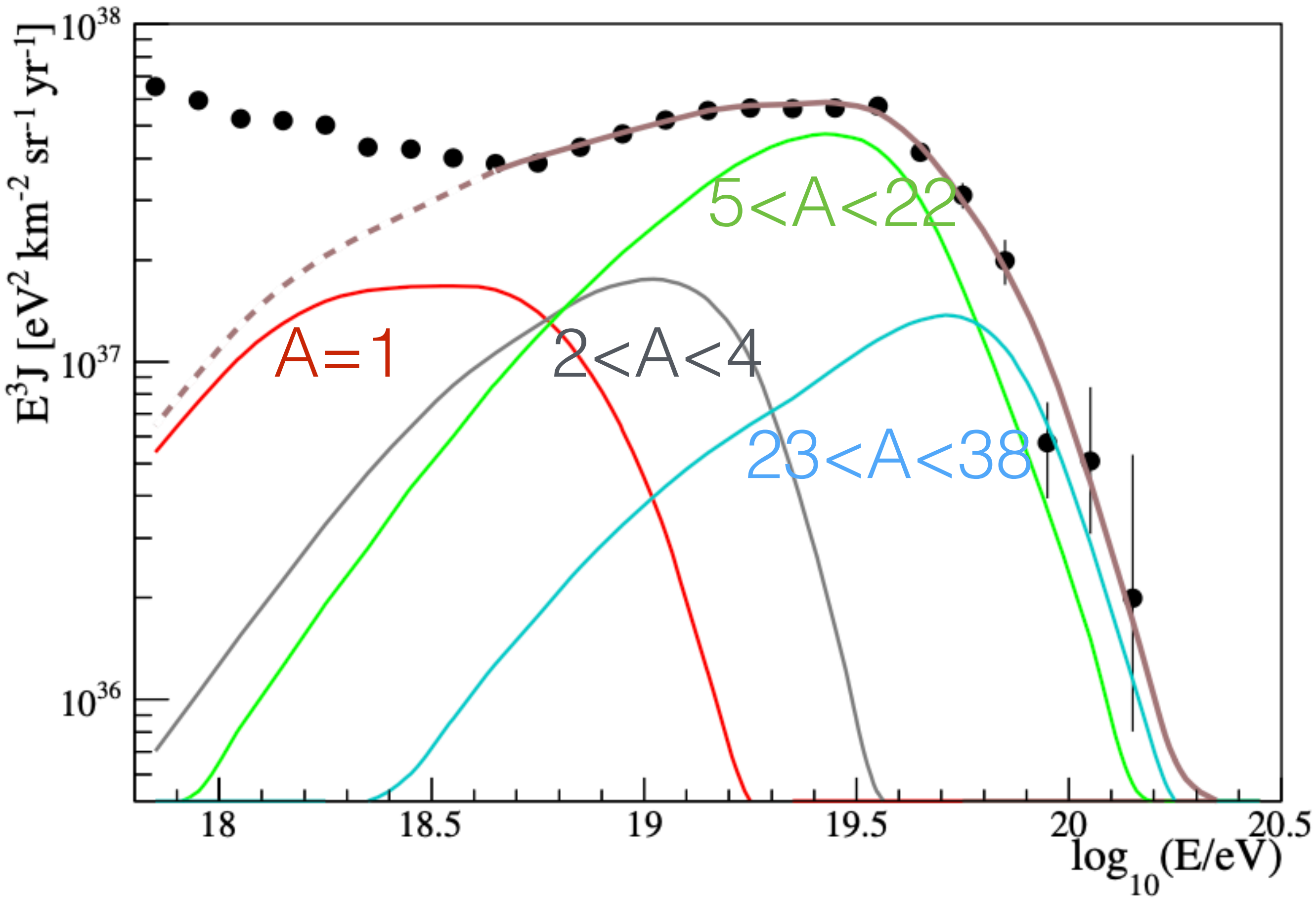
| UHE Sample(s) | KM3-230213A | | | Global | | |
|---|---|---|---|---|---|---|
| HE Sample | HESE | ESTES | NST | HESE | ESTES | NST |
| Bayes factor $\mathcal{B}$ | 27.0 | 8.7 | 3.9 | 1.2 | 0.6 | 0.3 |
| LR p-value (%) | 0.4 | 1.7 | 5.9 | 33 | 86 | 100 |

- No preference for BPL over SPL in the global fit




KM3NeT Coll., arXiv:2502.08173

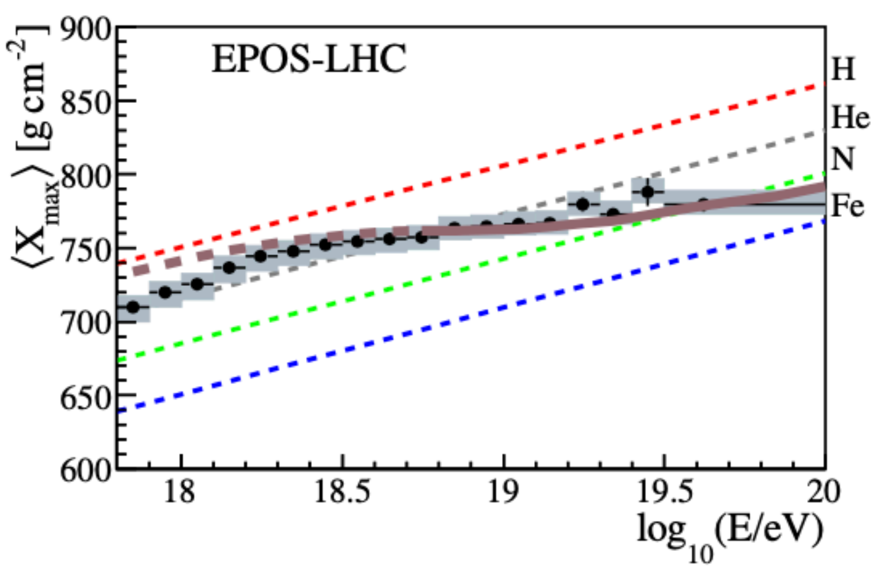
# UHECRs by Auger

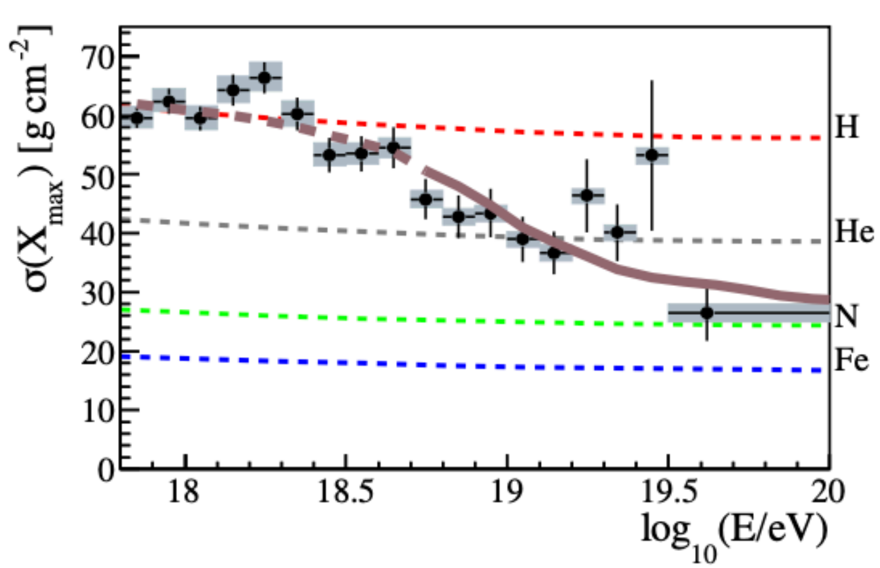



| reference model | best fit | average | shortest 68% int. |
|---|---|---|---|
| $\gamma$ | 1.22 | 1.27 | $1.20 \div 1.38$ |
| $\log_{10}(R_{\rm cut}/{\rm V})$ | 18.72 | 18.73 | $18.69 \div 18.77$ |
| $f_{\rm H}(\%)$ | 6.4 | 15.1 | $0.0 \div 18.9$ |
| $f_{\rm He}(\%)$ | 46.7 | 31.6 | $18.9 \div 47.8$ |
| $f_{\rm N}(\%)$ | 37.5 | 42.1 | $30.7 \div 51.7$ |
| $f_{\rm Si}(\%)$ | 9.4 | 11.2 | $5.4 \div 14.6$ |
| $\Delta X_{\rm max}/\sigma_{\rm syst}$ | $-0.63$ | $-0.69$ | $-0.90 \div -0.48$ |
| $\Delta E/\sigma_{\rm syst}$ | $+0.00$ | $+0.12$ | $-0.57 \div +0.54$ |

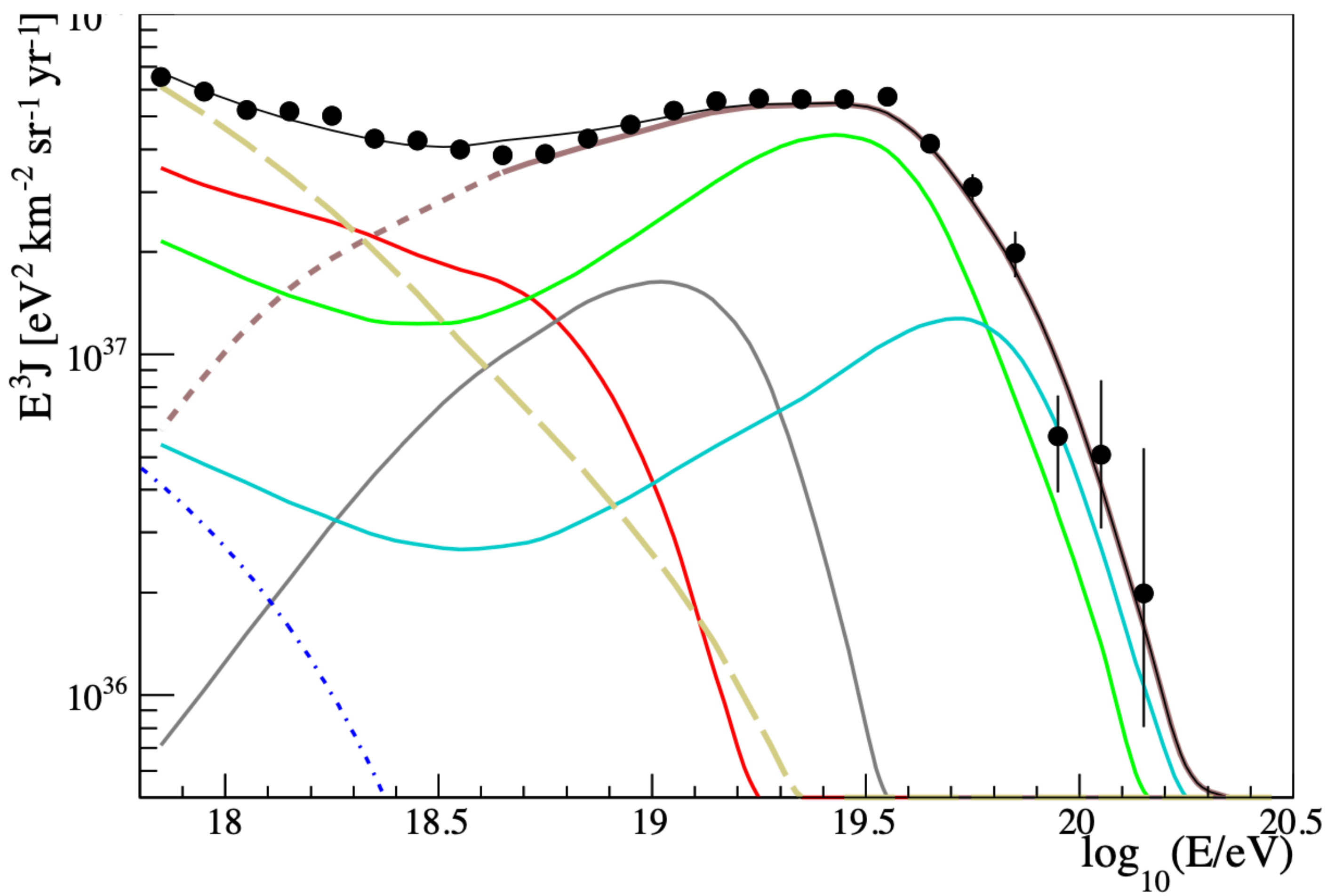
Auger Coll., JCAP 04 (2017) 038

- fit above the ankle



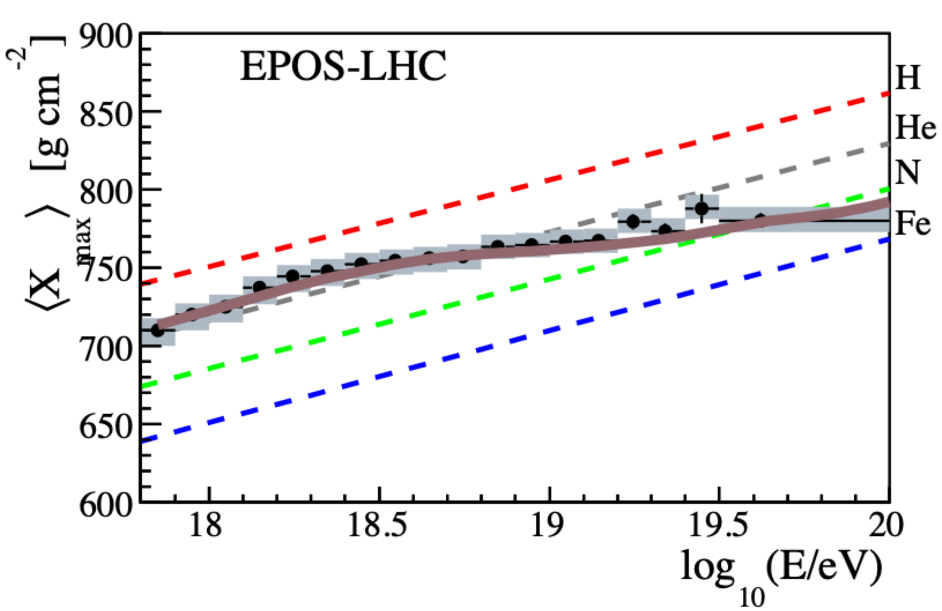



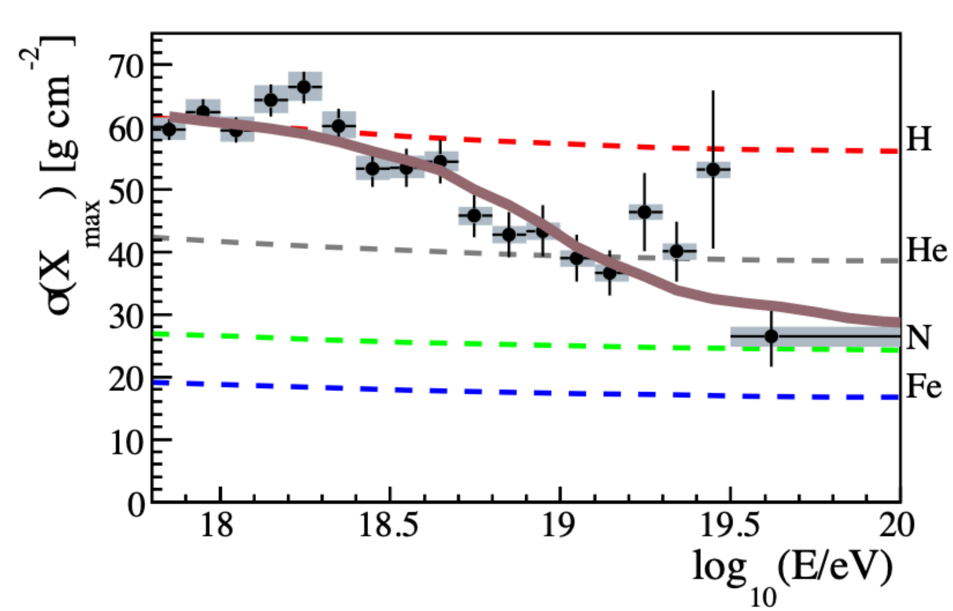
# UHECRs by Auger and the sub-ankle component



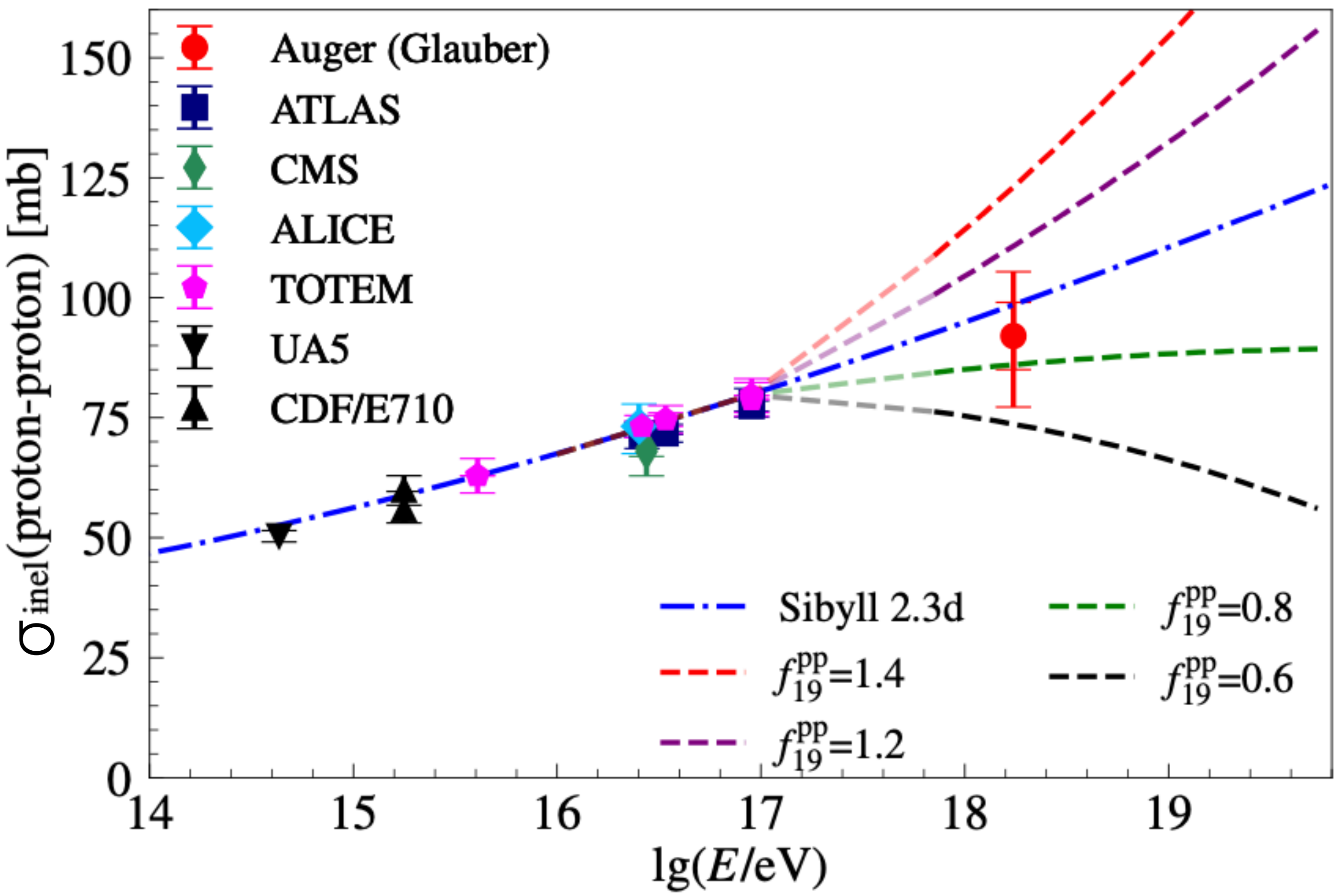

- spectral index γ = 3.6
- rigidity cutoff $\log_{10}(R_{cut}/V)$ = 18.4
- a mix of ~56% H, 35% N and 9% Si

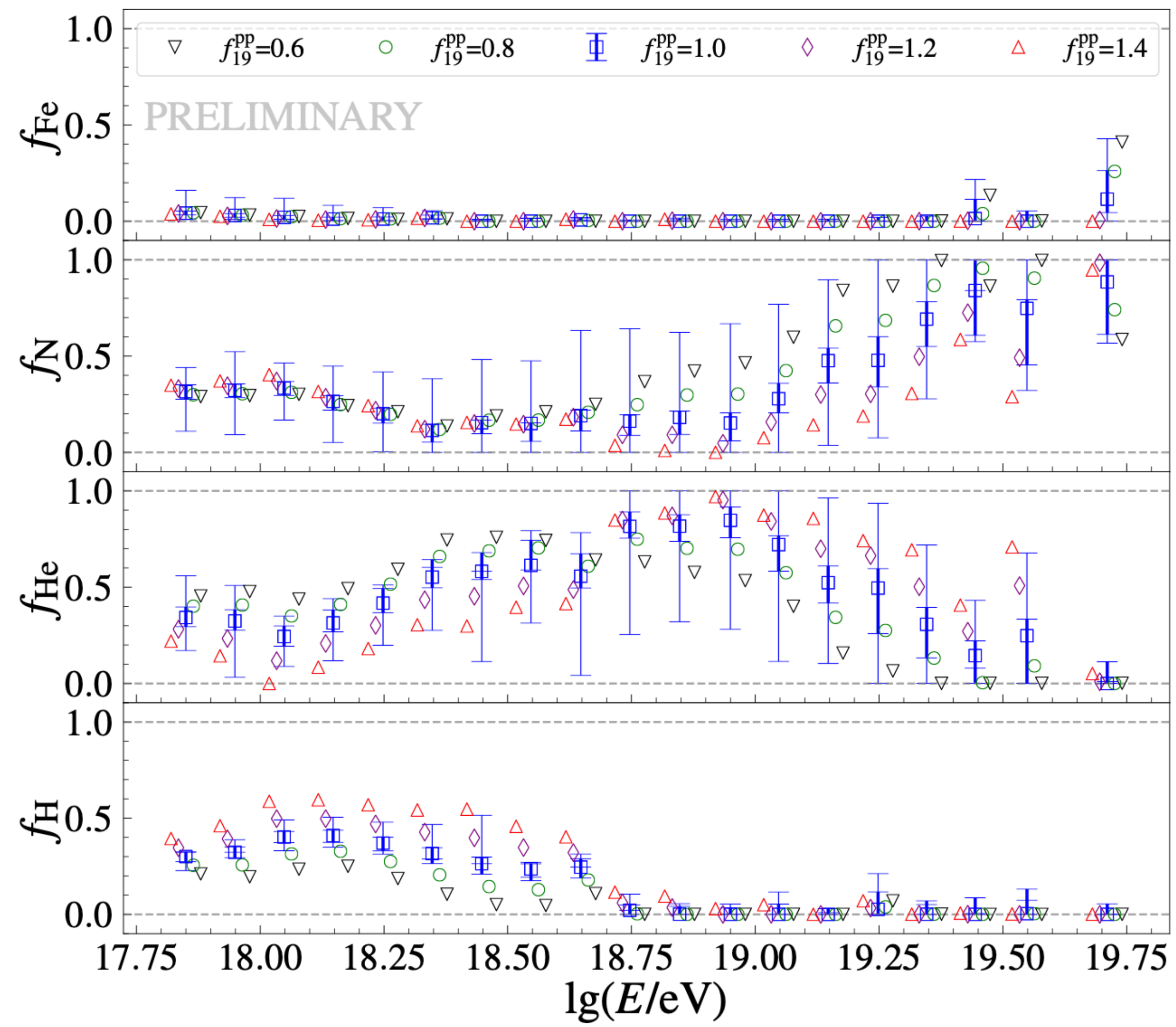
Auger Coll., JCAP 04 (2017) 038



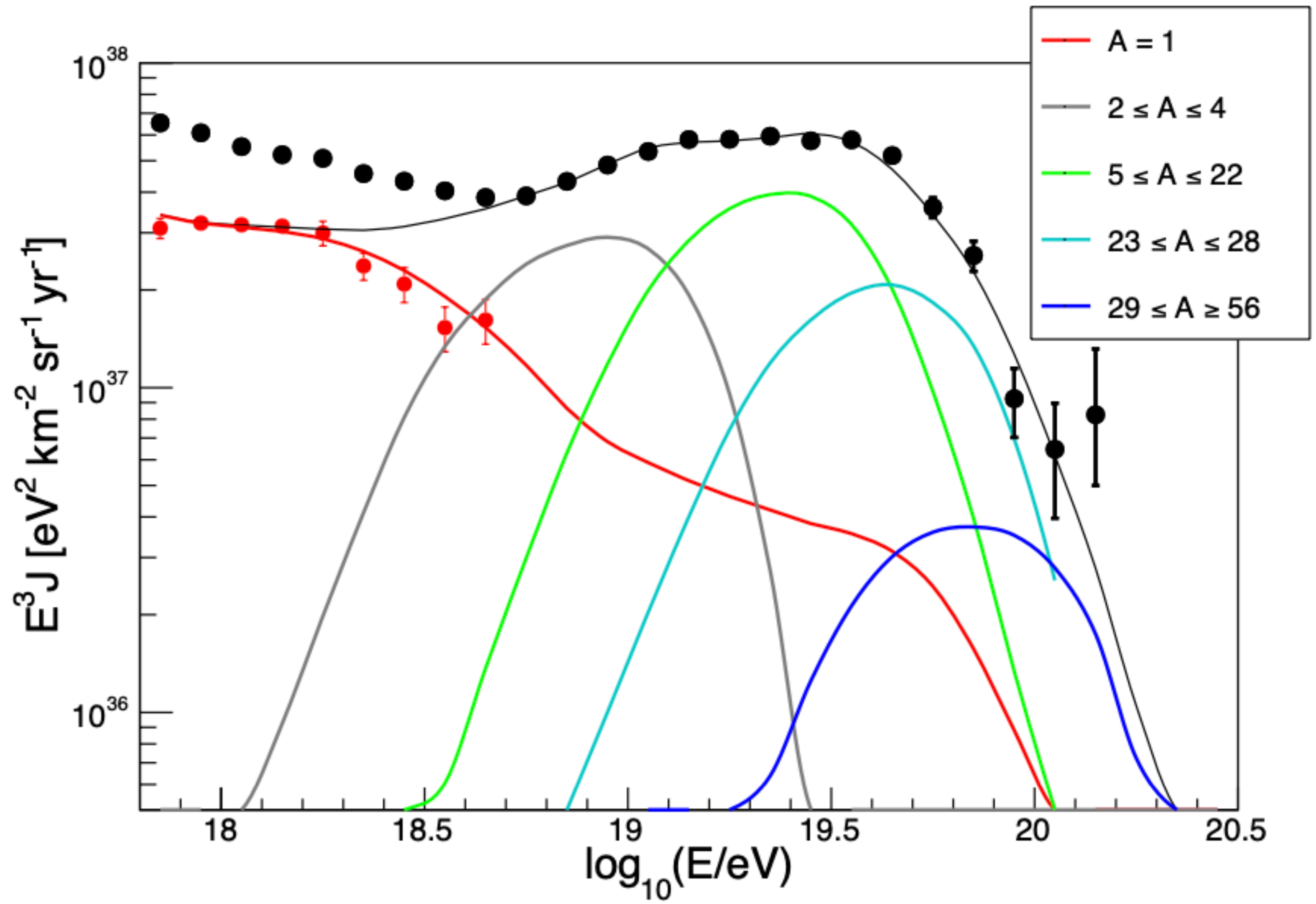
# UHECRs by Auger: hadronic cross section

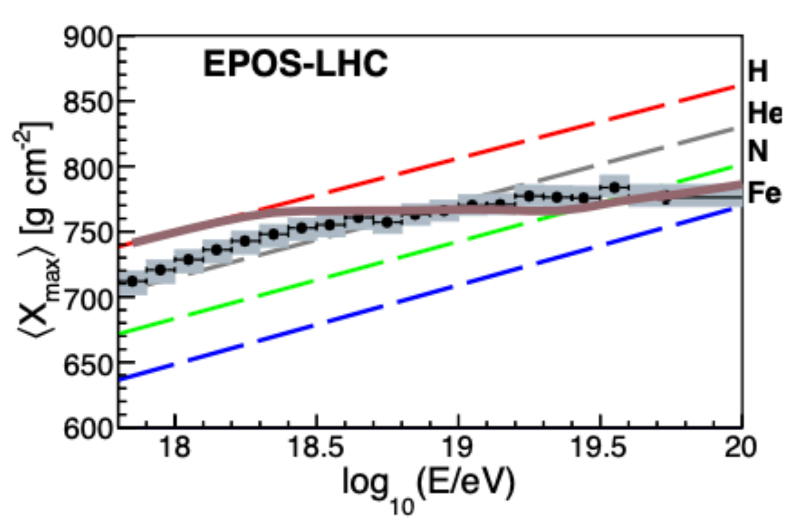


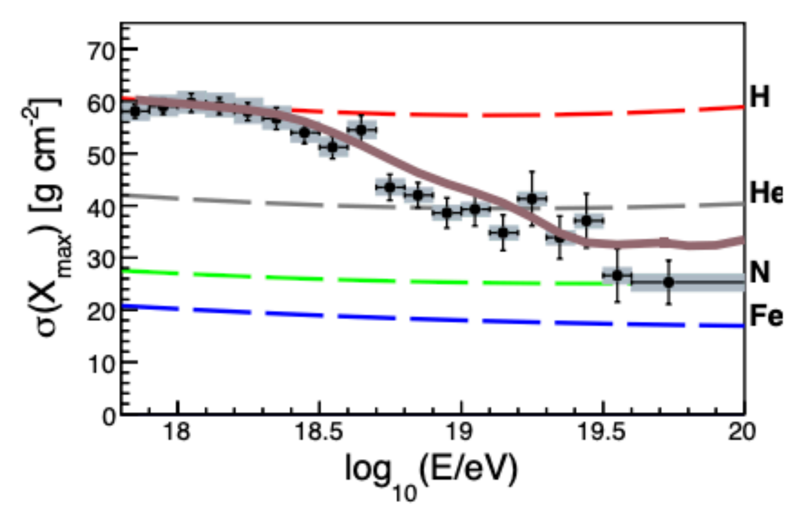




Auger Coll., PoS 438 (2023)

# UHECR fit by KM3NeT



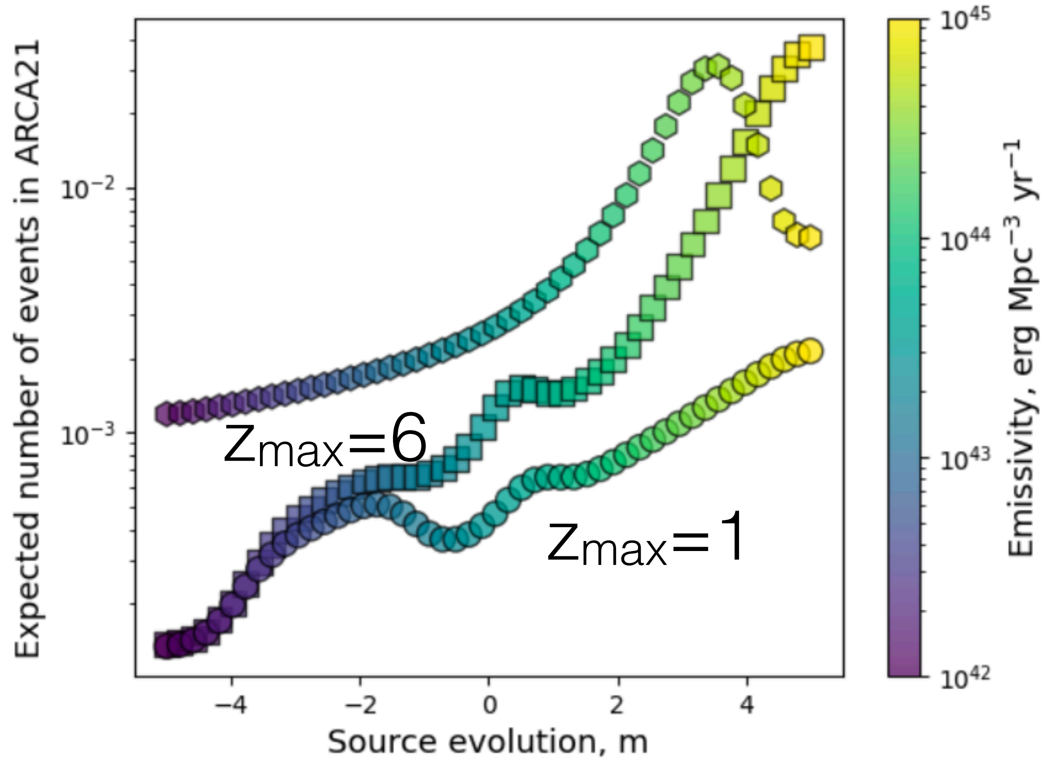



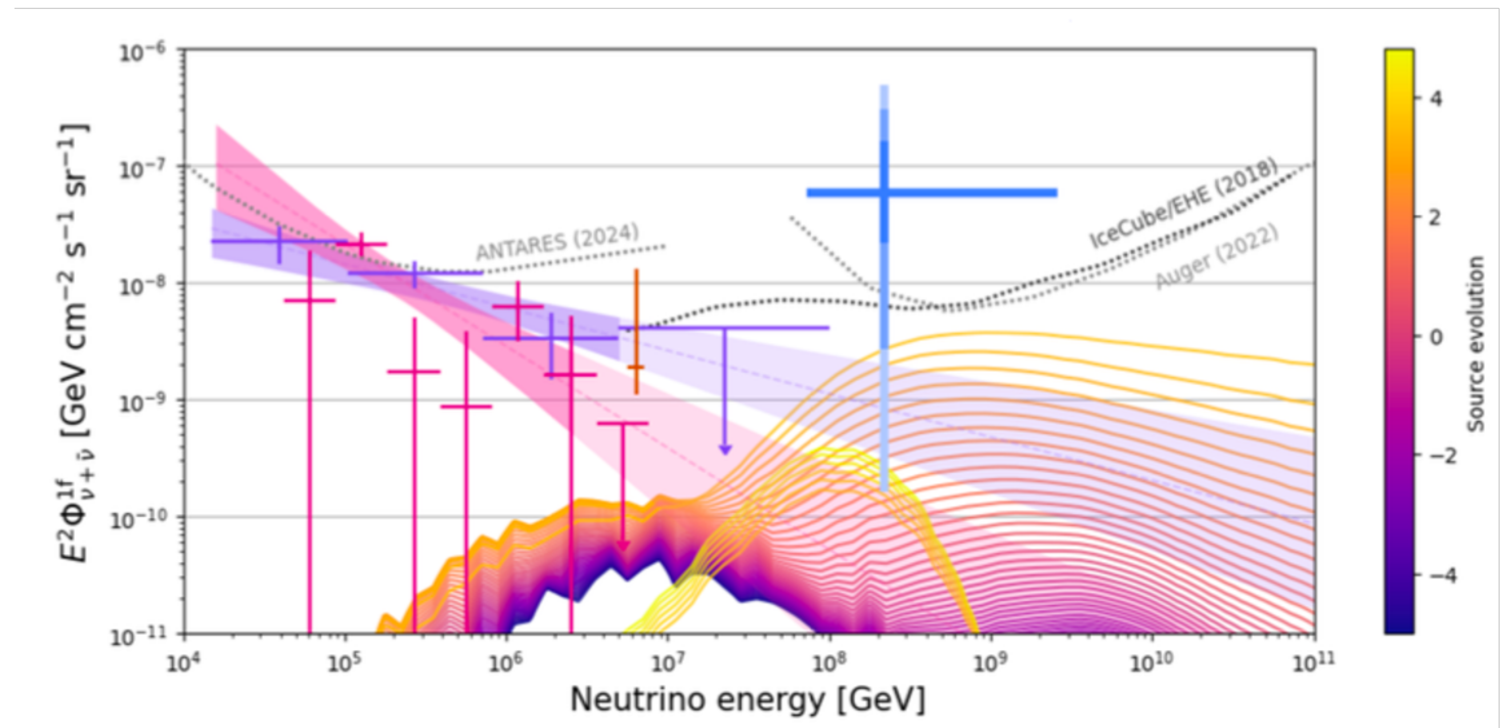

KM3NeT Coll., arXiv:2502.08508

# Testing the cosmogenic origin

Event rate in ARCA21
(335 days livetime)



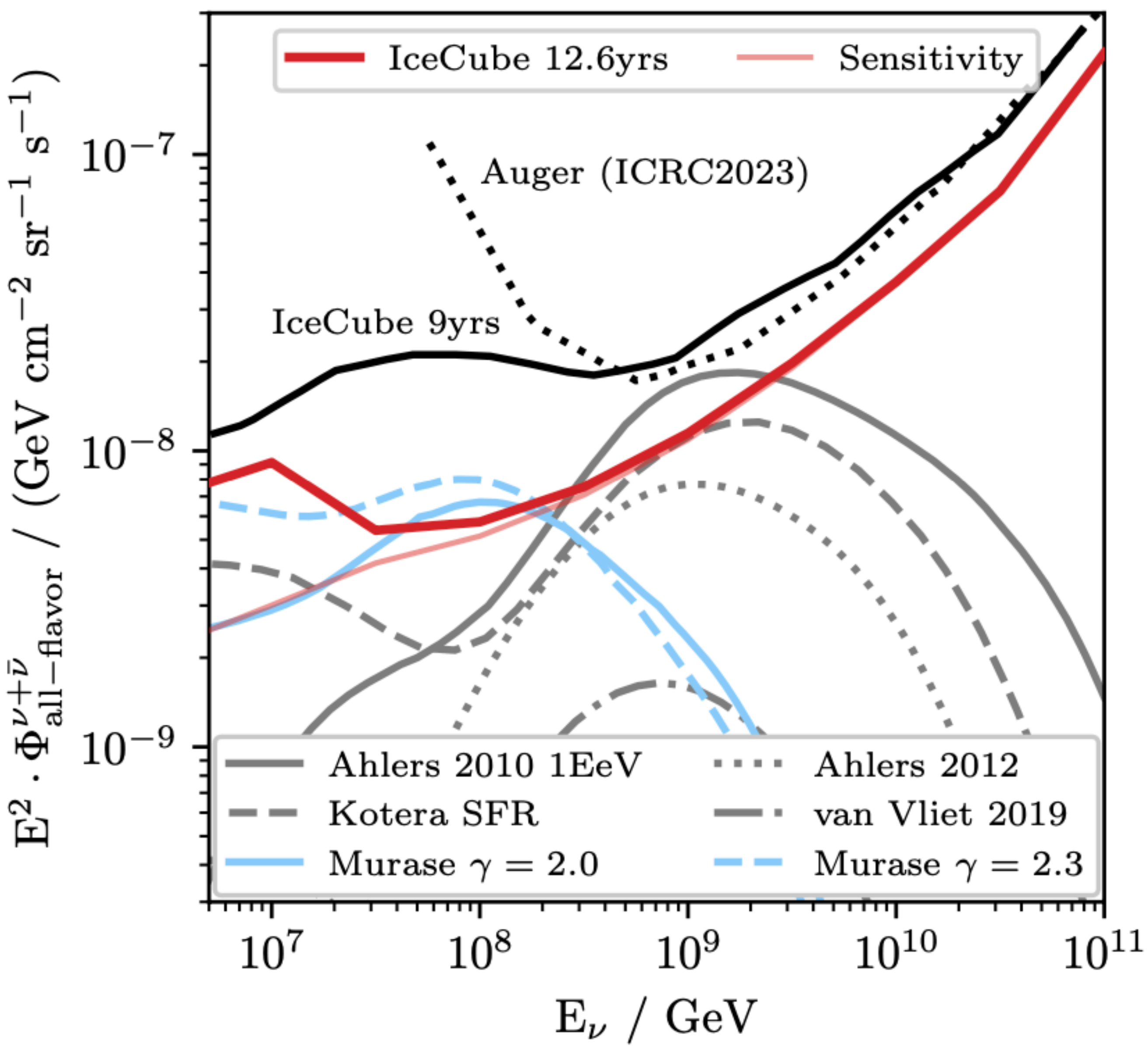

Maximal proton content allowed
by UHECR mass composition

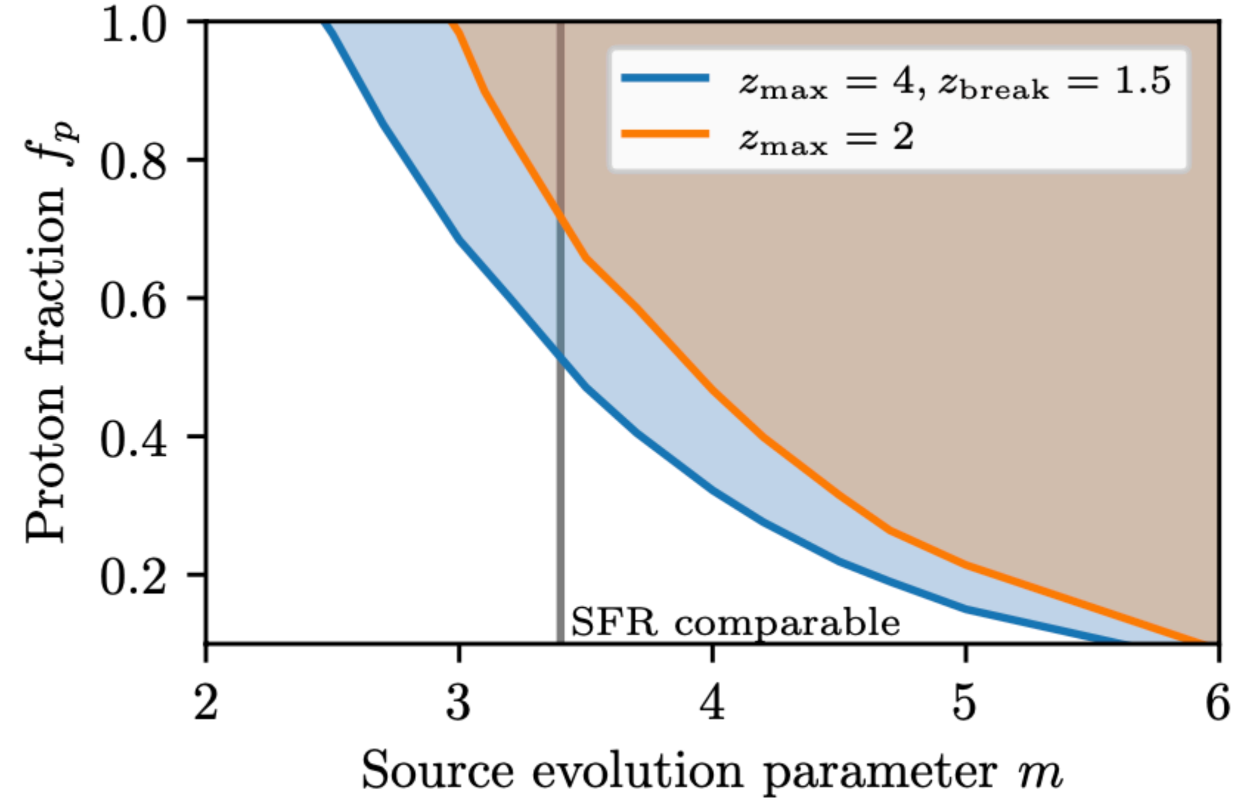



Dominant contribution expected from sources in the deep Universe: increased source number & effects due to photo-disintegration interaction

KM3NeT Coll., arXiv:2502.08508

# IC latest results on cosmogenic neutrinos

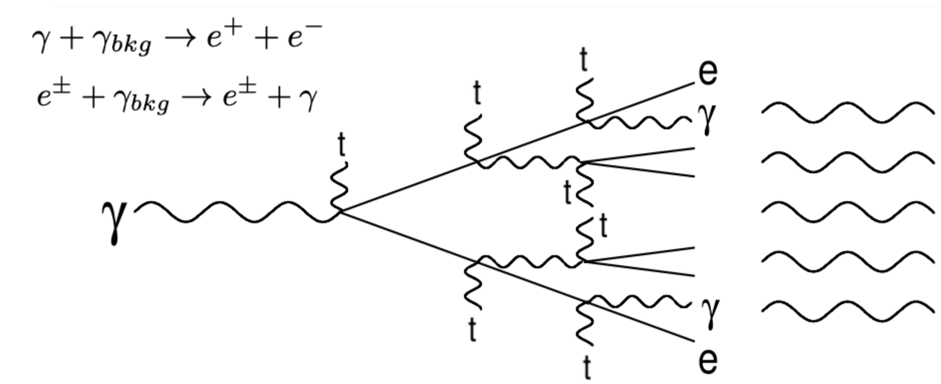


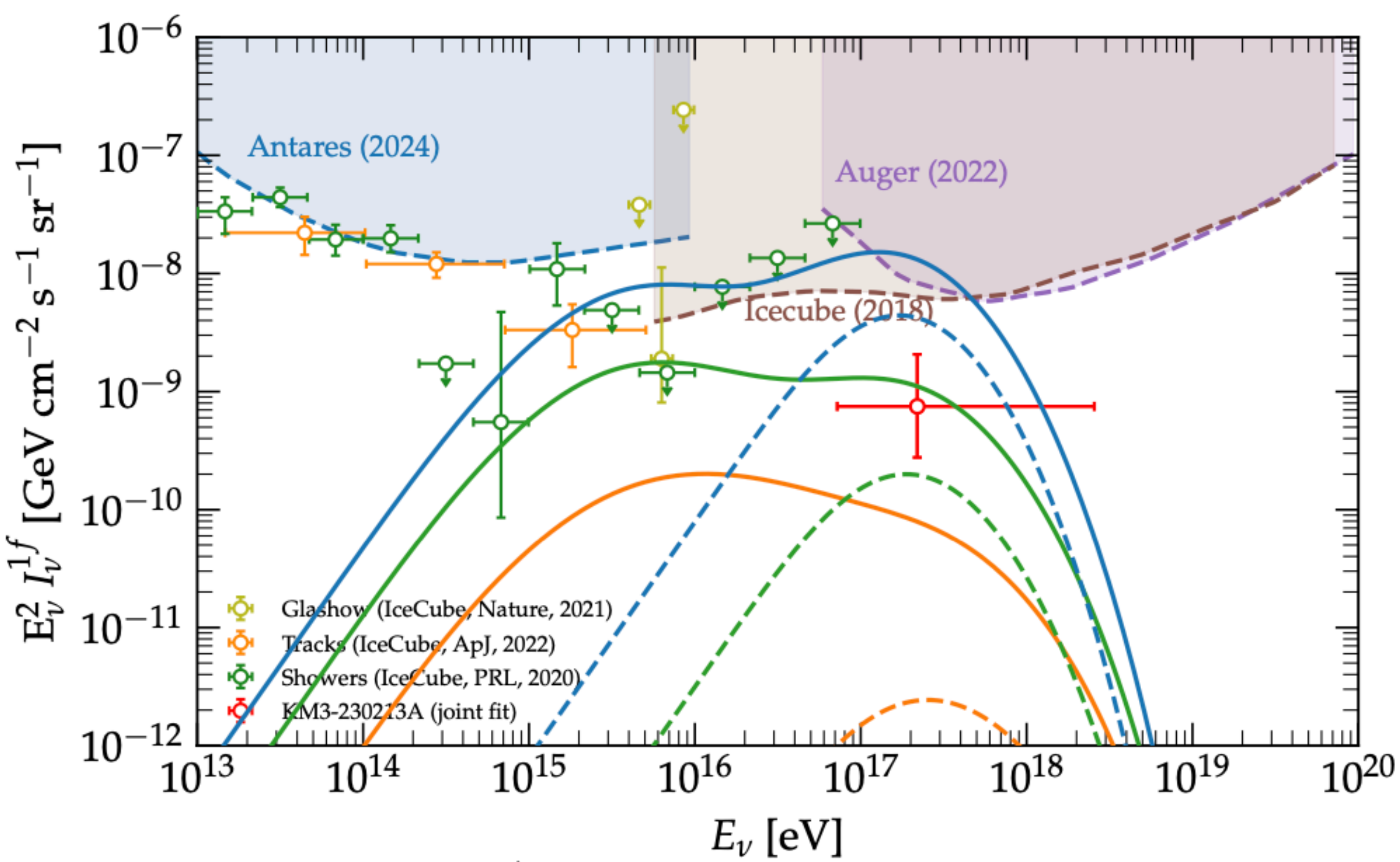



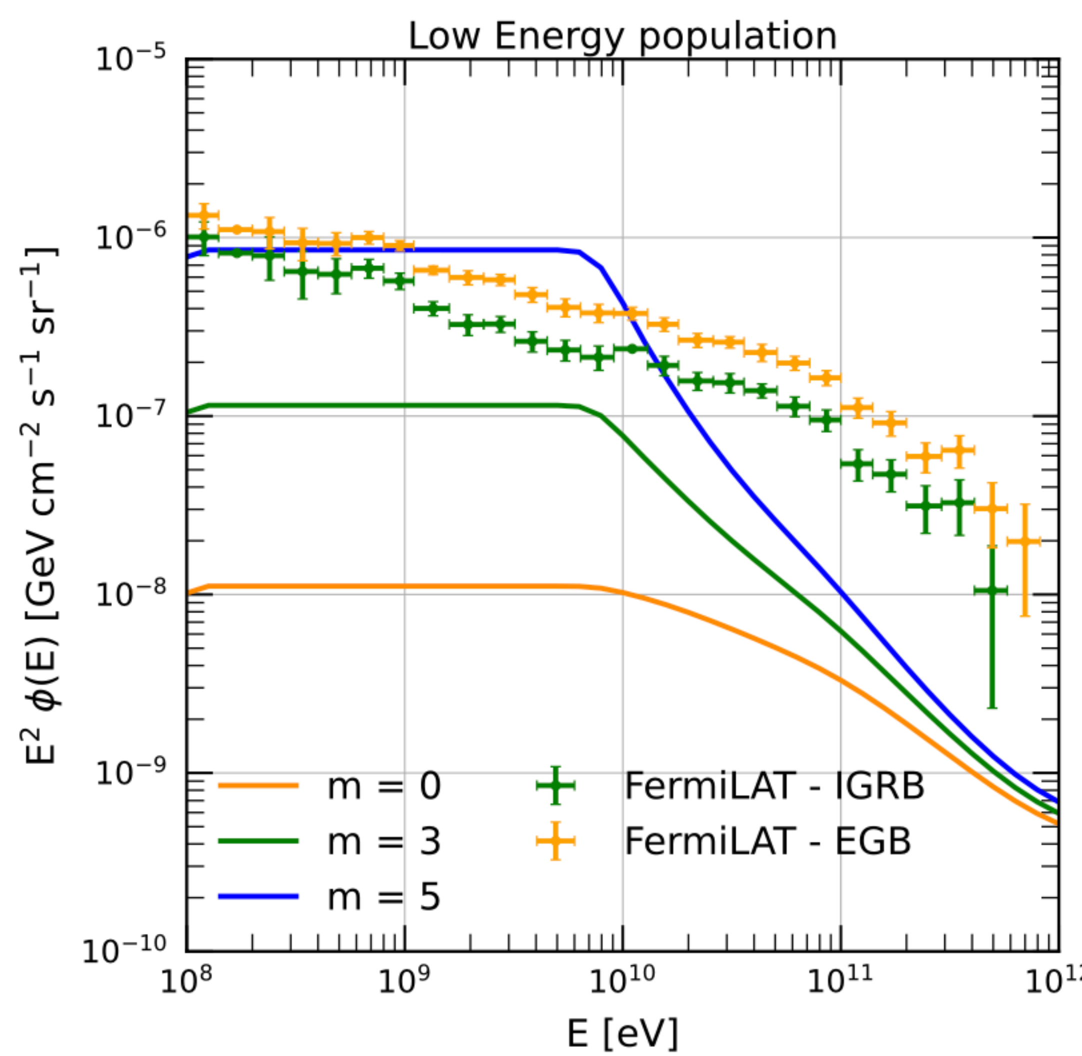

IceCube Coll., arXiv:2502.01963

# Diffuse gamma-ray constraints to cosmogenic neutrinos

The diffuse extragalactic gamma-ray flux is a very powerful observable to constrain the fraction of protons in the UHECR spectrum, therefore the expected cosmogenic neutrinos.



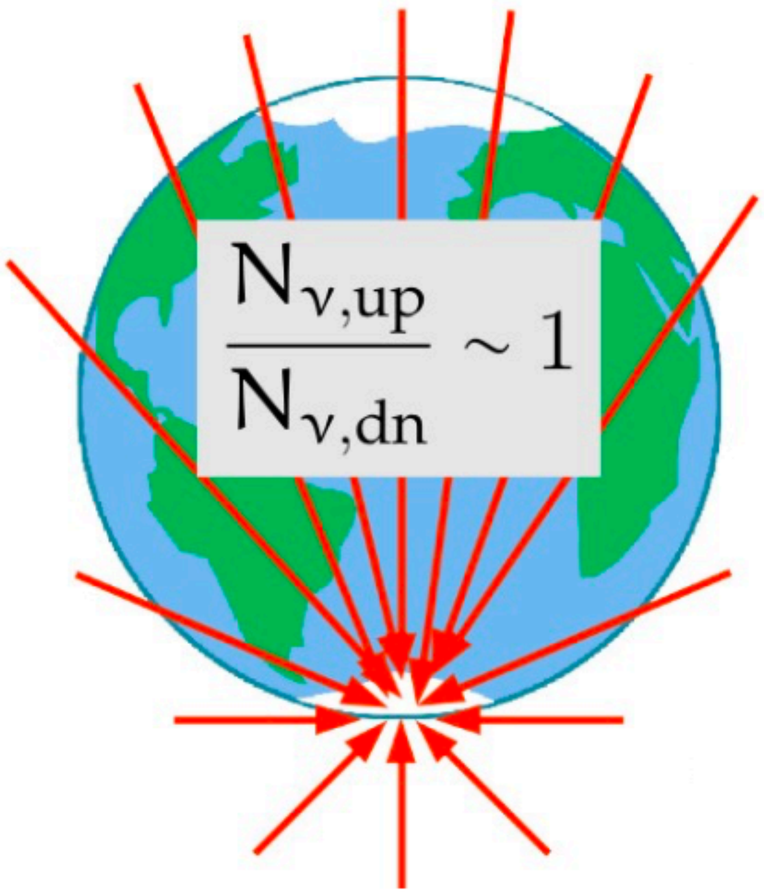



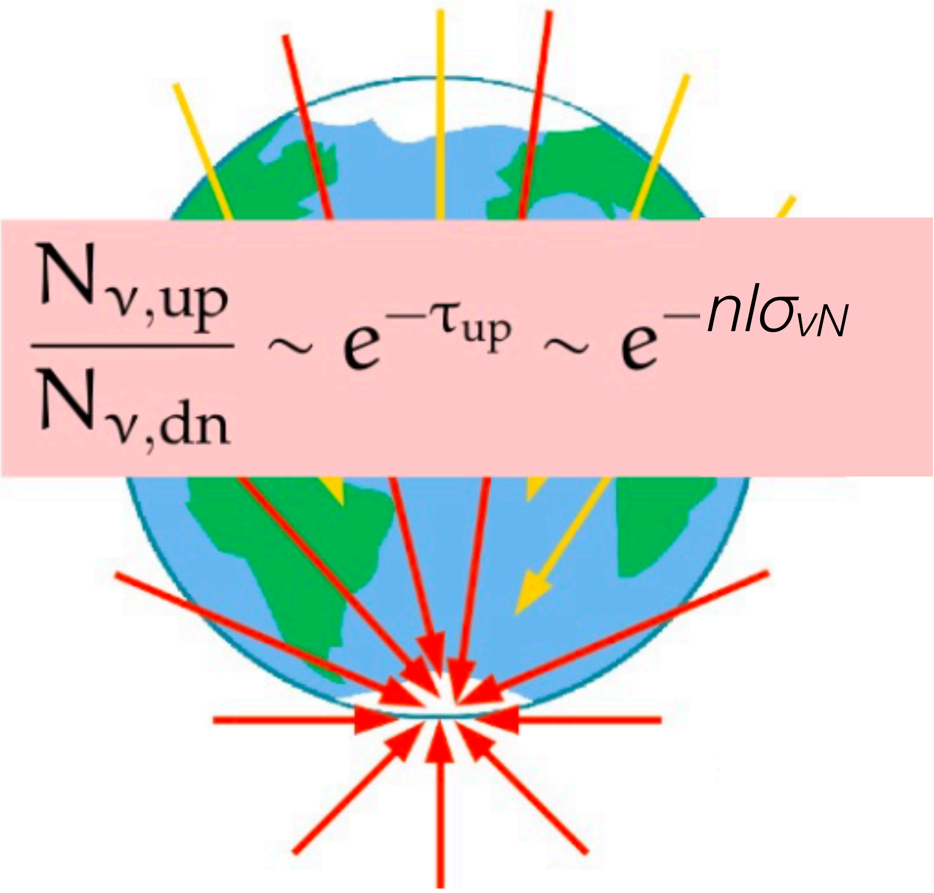

Cermenati, Ambrosone, Boccioli, Evoli, Aloisio (in prep.)

# Measuring the HE vN cross section

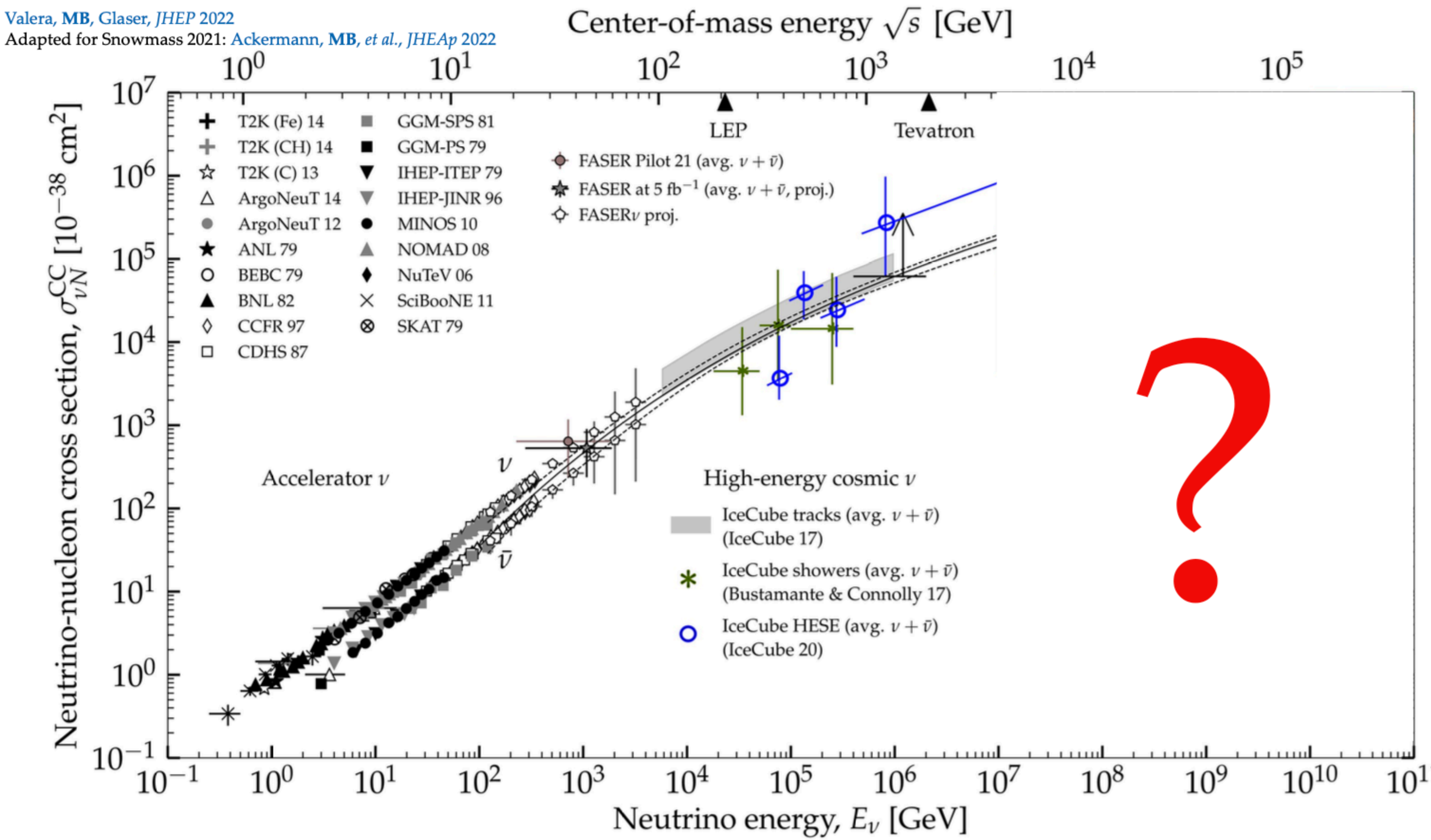
Below ~ 10 TeV: Earth is transparent



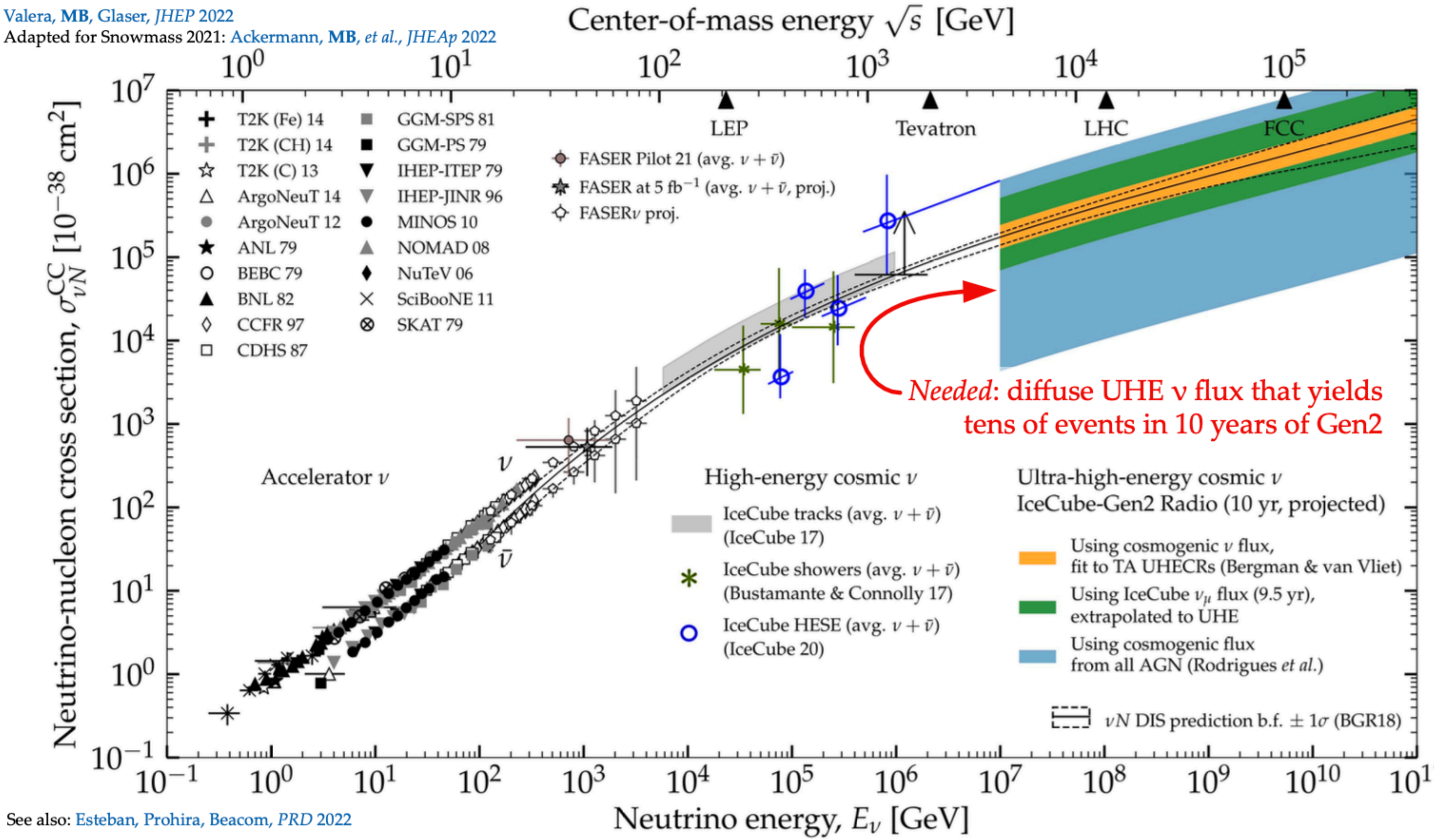

Above ~ 10 TeV: Earth is opaque



# Measuring the HE vN cross section



# Measuring the HE νN cross section



# World-leading constraints on LIV

- A superluminal neutrino would quickly loose energy via

$$\nu \to \nu + e^+ + e^-$$

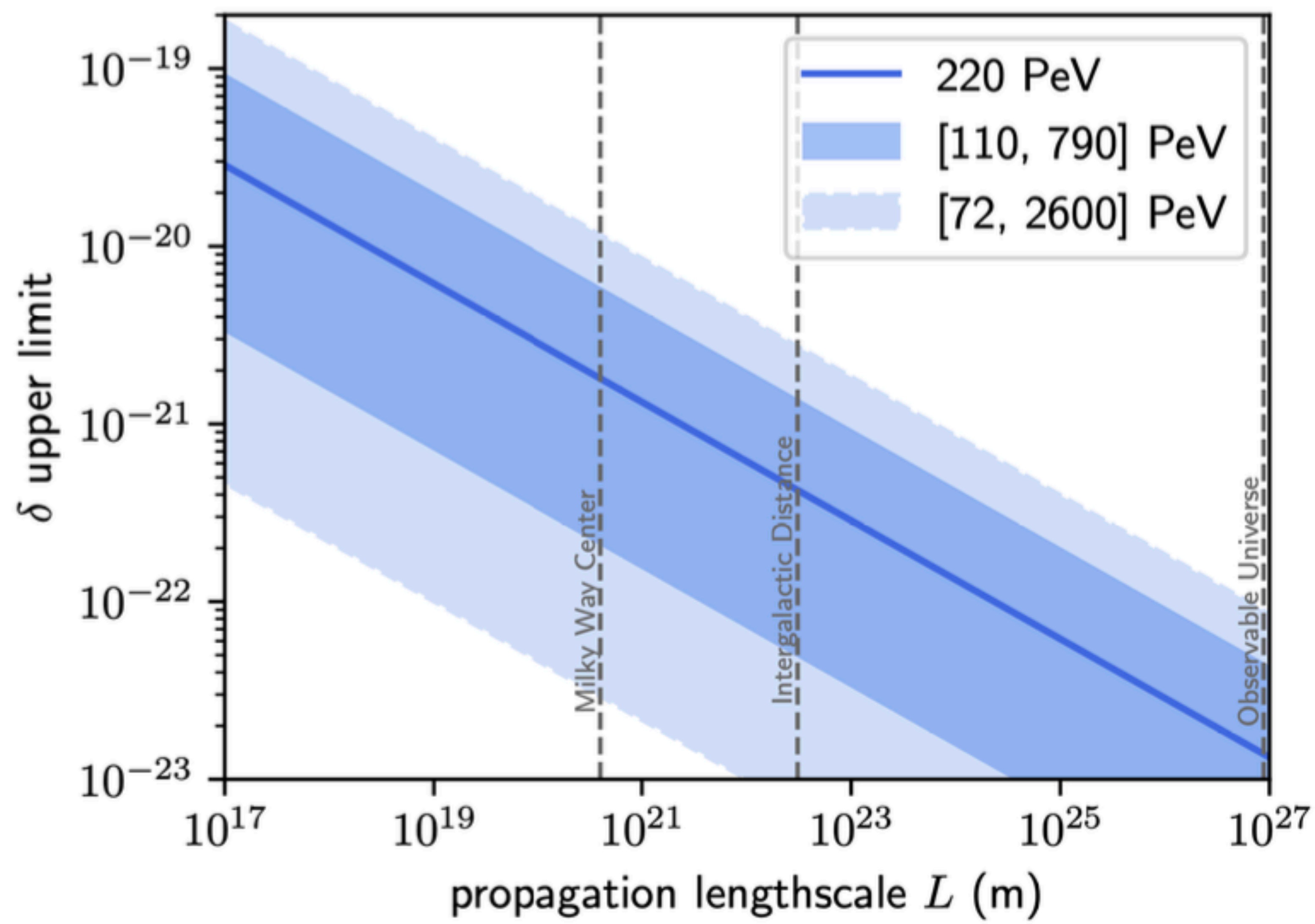
- Decay width given by

$$\Gamma \propto E^5 \delta^3$$

with $\delta = c_\nu^2 - 1$

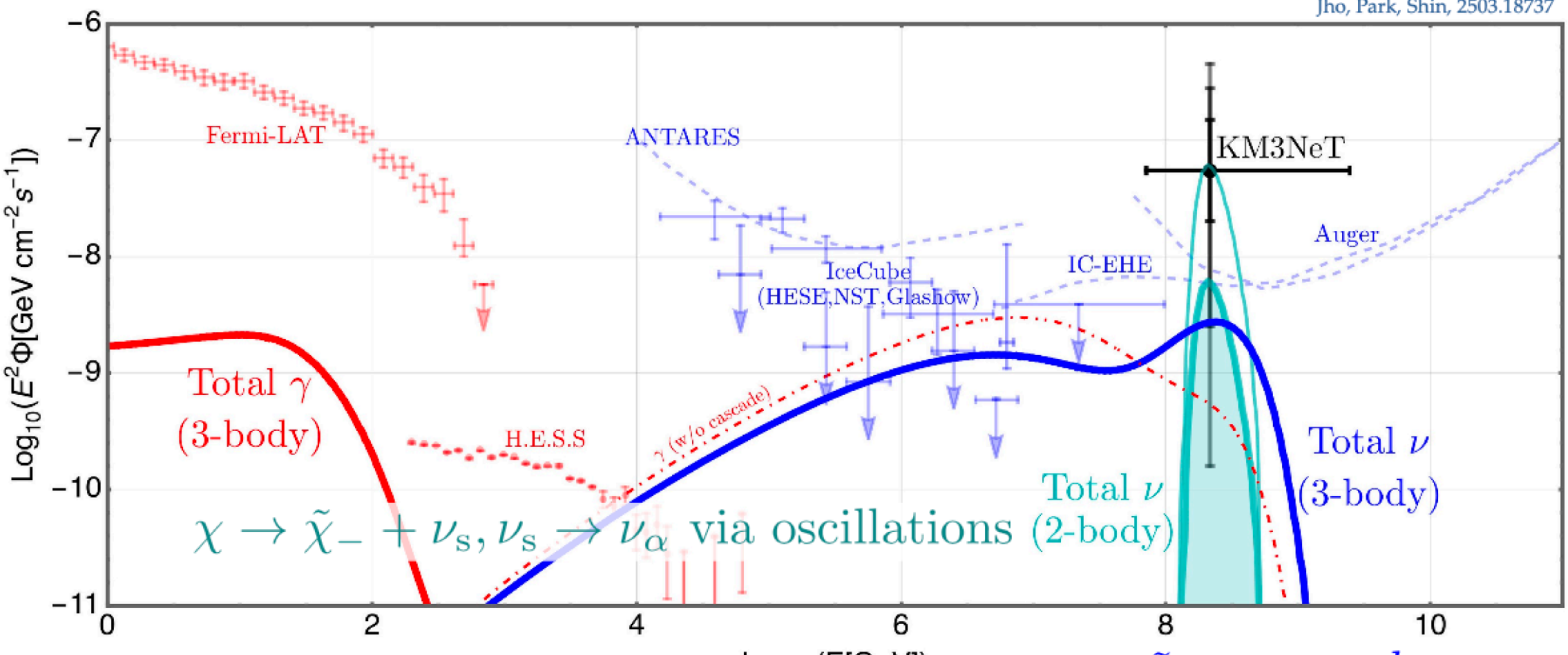
- Thus KM3-230213A energy place the stringent existing constraint

| Method | Limit |
|---|---|
| IceCube atmospheric | $6.2 \times 10^{-11}$ |
| IceCube NGC 1068 | $1.5 \times 10^{-15}$ |
| IceCube TXS 0506+056 | $2.4 \times 10^{-18}$ |
| Stecker et al. (Ref. [20]) | $5.2 \times 10^{-21}$ |
| KM3-230213A (conservative) | $1.8 \times 10^{-21}$ |
| KM3-230213A (likely) | $4.2 \times 10^{-22}$ |



# BSM origin of KM3-230213A? Decay of heavy dark matter

Multi-component DM: heavy ($\chi$, unstable) & lighter ($\tilde{\chi}_-$, stable)




$\Delta m_\chi \equiv m_\chi - m_{\tilde{\chi}_-} \sim E_\nu \ll m_\chi$

$\chi \to \tilde{\chi}_- + \nu_\alpha + h$

(Higgs decays into $\gamma$)

Slide credit: M. Bustamante

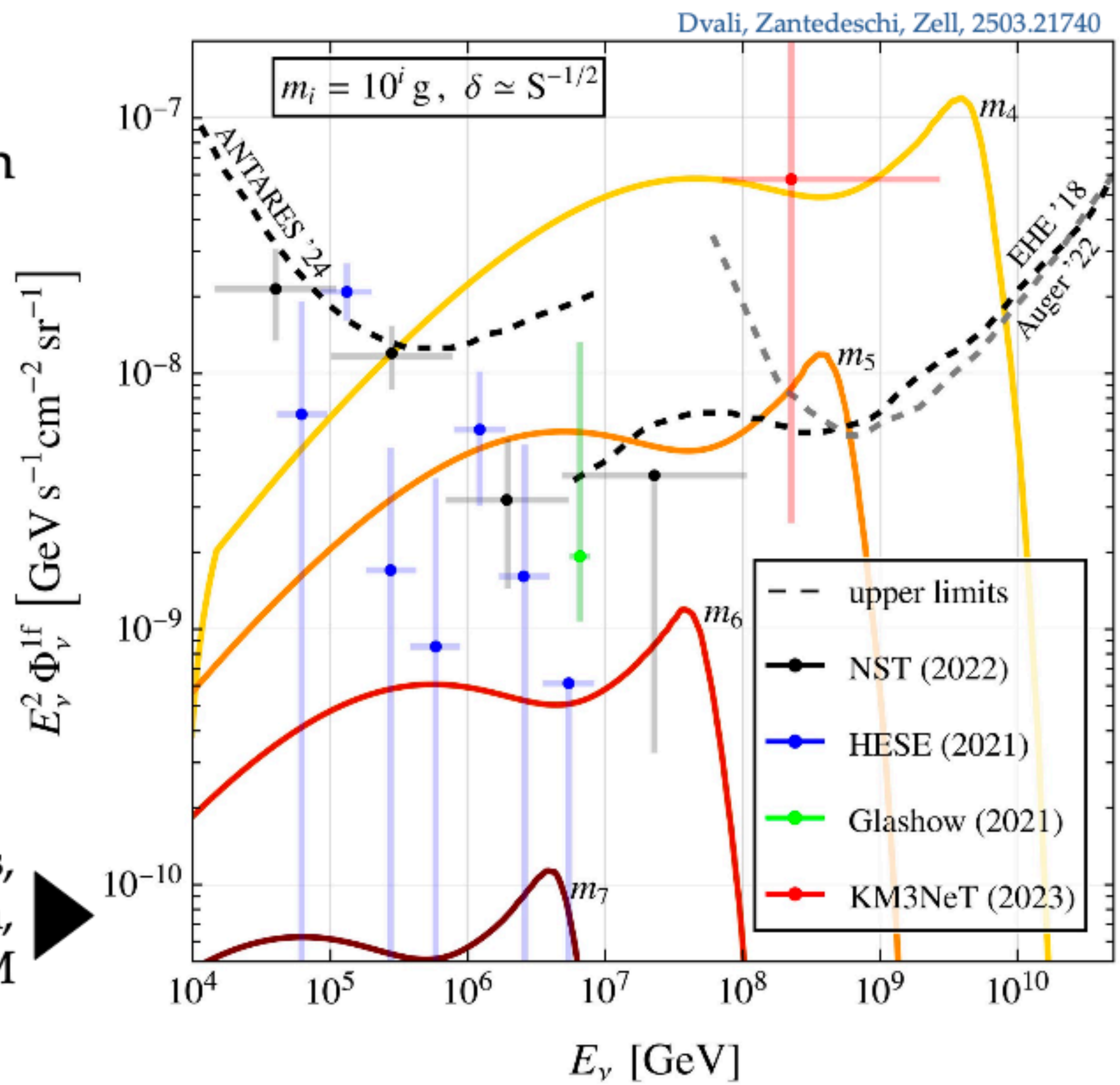
# BSM origin of KM3-230213A? Primordial black holes

Primordial black holes (PBHs) evaporate through Hawking radiation

"Memory burden" effect: quantum back-reaction lengthens the life of the black hole

Most of the contribution is from intermediate-mass PBHs, transitioning to memory burden

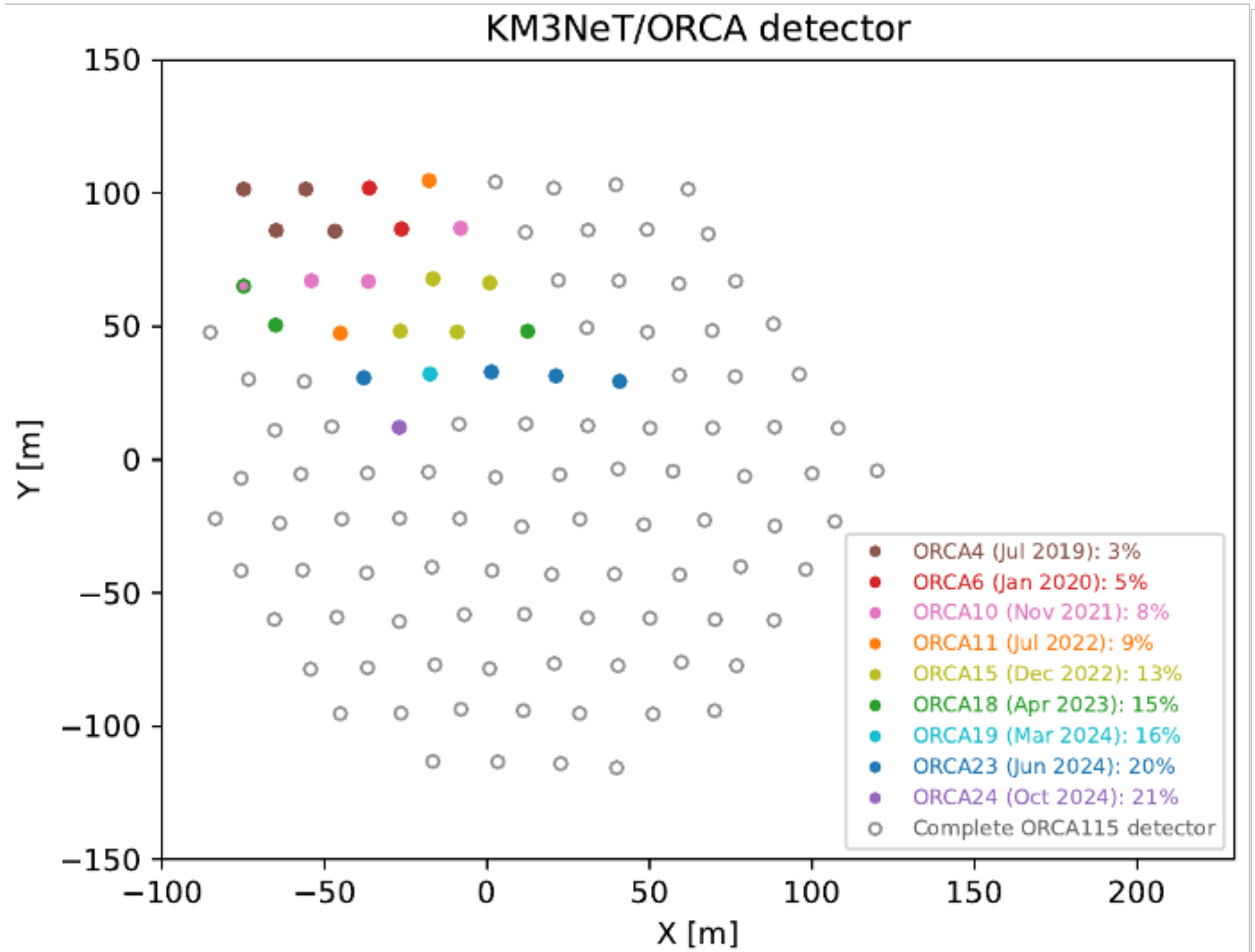
Galactic + extragalactic contributions, monochromatic mass spectrum, PBHs make up all of DM

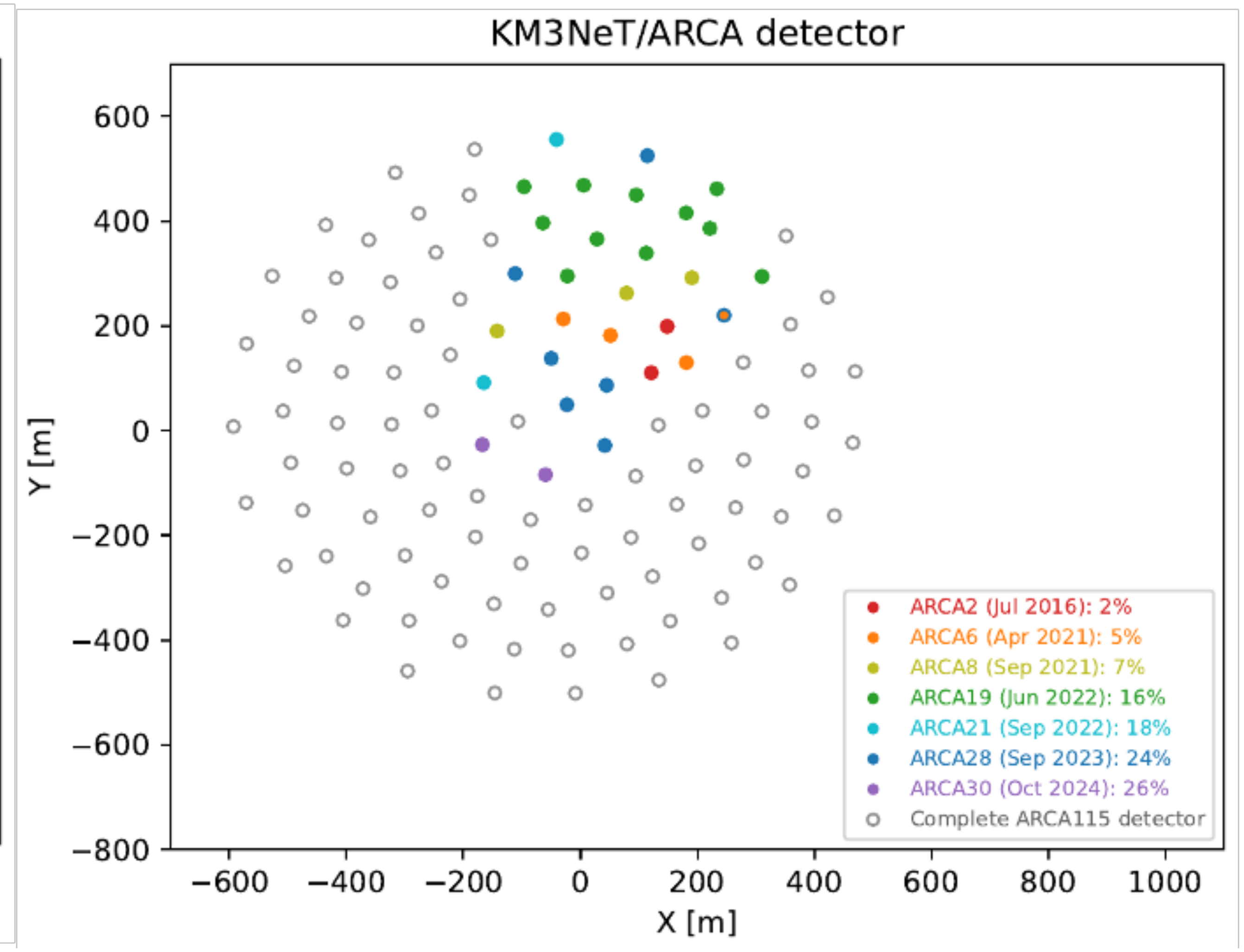



Slide credit: M. Bustamante

# KM3NeT

# A growing detector




Further sea campaigns planned in the next months

# Absorption and scattering: water vs ice

| | acqua marina (Mar Mediterraneo) $\lambda = 473(375)\,nm$ | acqua (Lago di Baikal) $\lambda = 480\,nm$ | ghiaccio (Polo Sud) $\lambda = 400\,nm$ |
|---|---|---|---|
| $\lambda_a$ | $60 \pm 10(26 \pm 3)\,m$ | $20 - 24\,m$ | $110\,m$ |
| $\lambda_s^{\text{eff}}$ | $270 \pm 30(120 \pm 10)\,m$ | $200 - 400\,m$ | $20\,m$ |

**Tabella 3.2.** Parametri della propagazione della luce in acqua e ghiaccio.

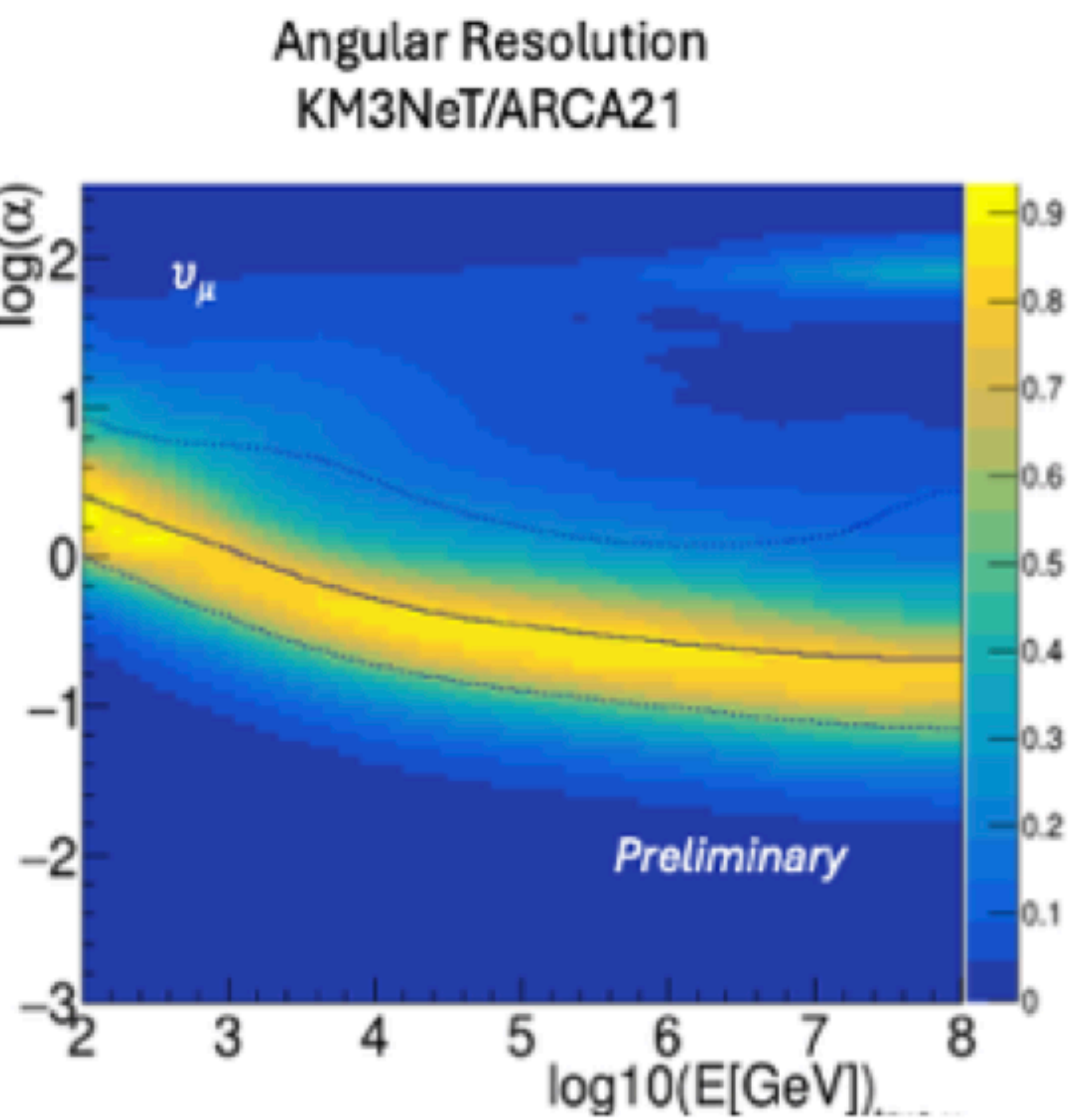
$$^{40}\mathrm{K} \rightarrow {}^{40}\mathrm{Ca} + e^- + \bar{\nu}_e$$

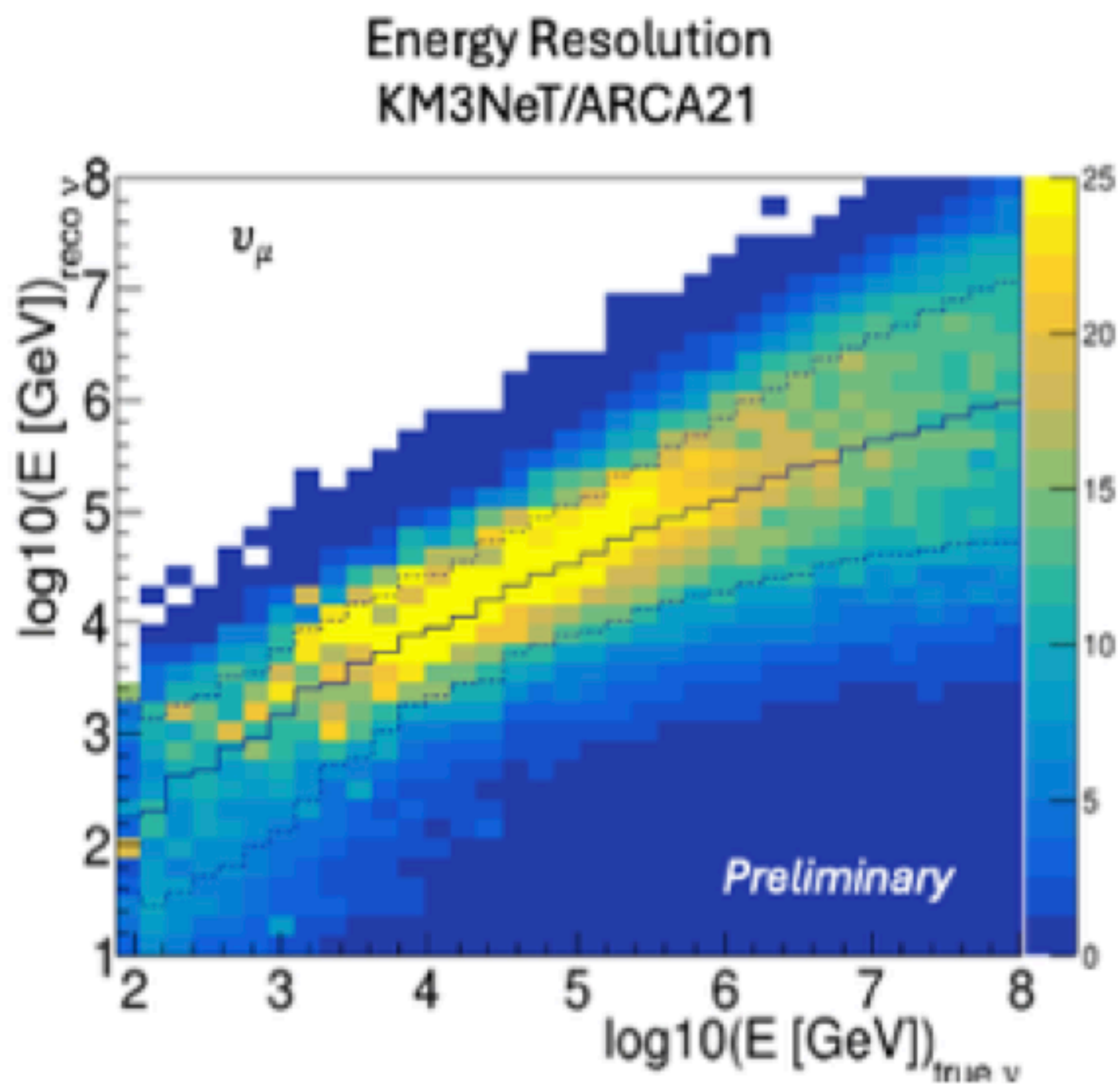
e

$$^{40}\mathrm{K} + e^- \rightarrow {}^{40}\mathrm{Ar} + \nu_e + \gamma.$$

Gli elettroni prodotti nel primo processo, spesso, hanno energia sufficientemente elevata da indurre l'effetto Cherenkov, mentre nel processo di cattura dell'elettrone, il fotone nello stato finale viene prodotto con un'energia ($E_\gamma = 1.46\,MeV$) che può facilmente portare alla produzione di elettroni con energie sopra la soglia di emissione di luce Cherenkov.

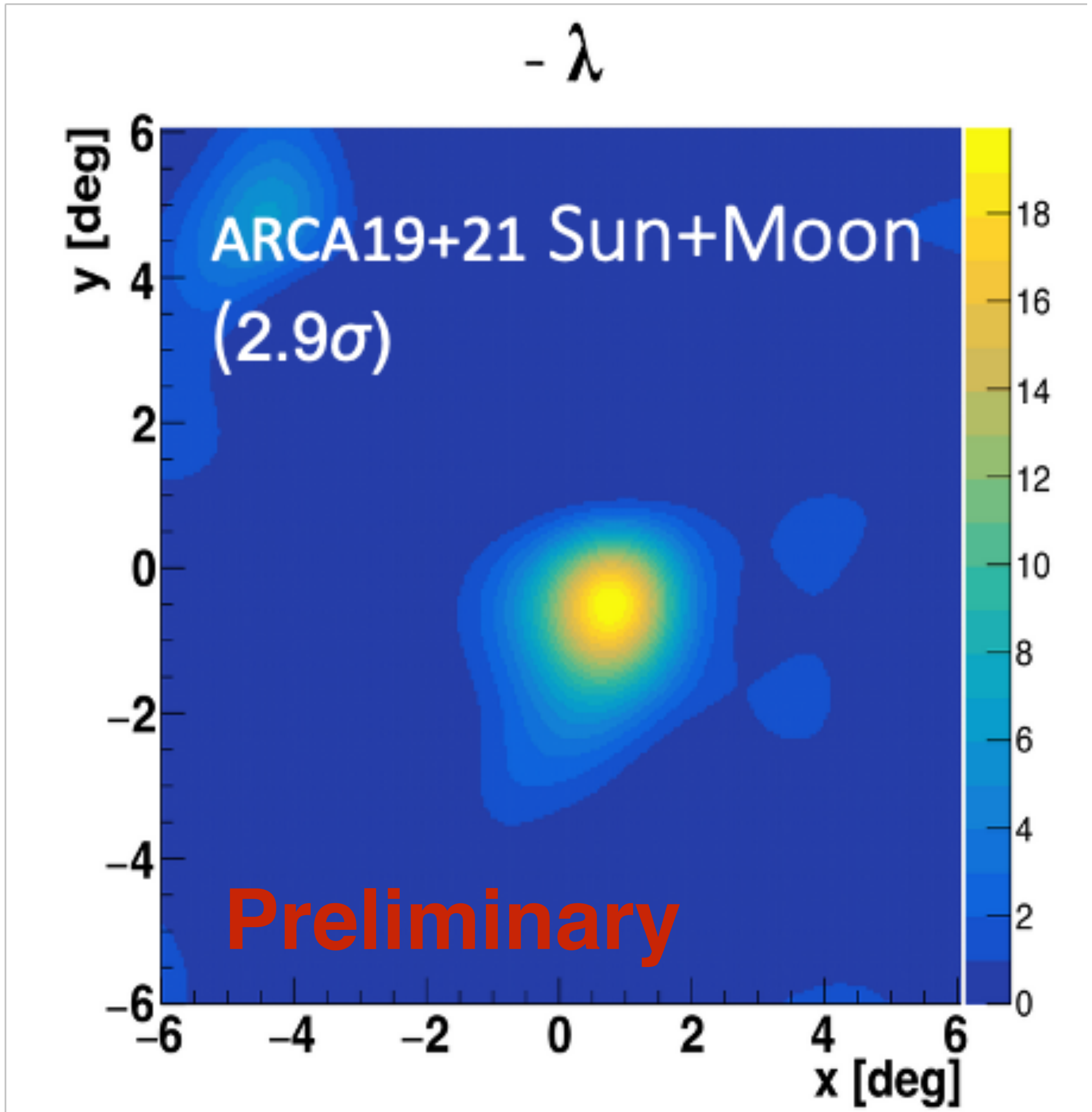
# ARCA21 performance

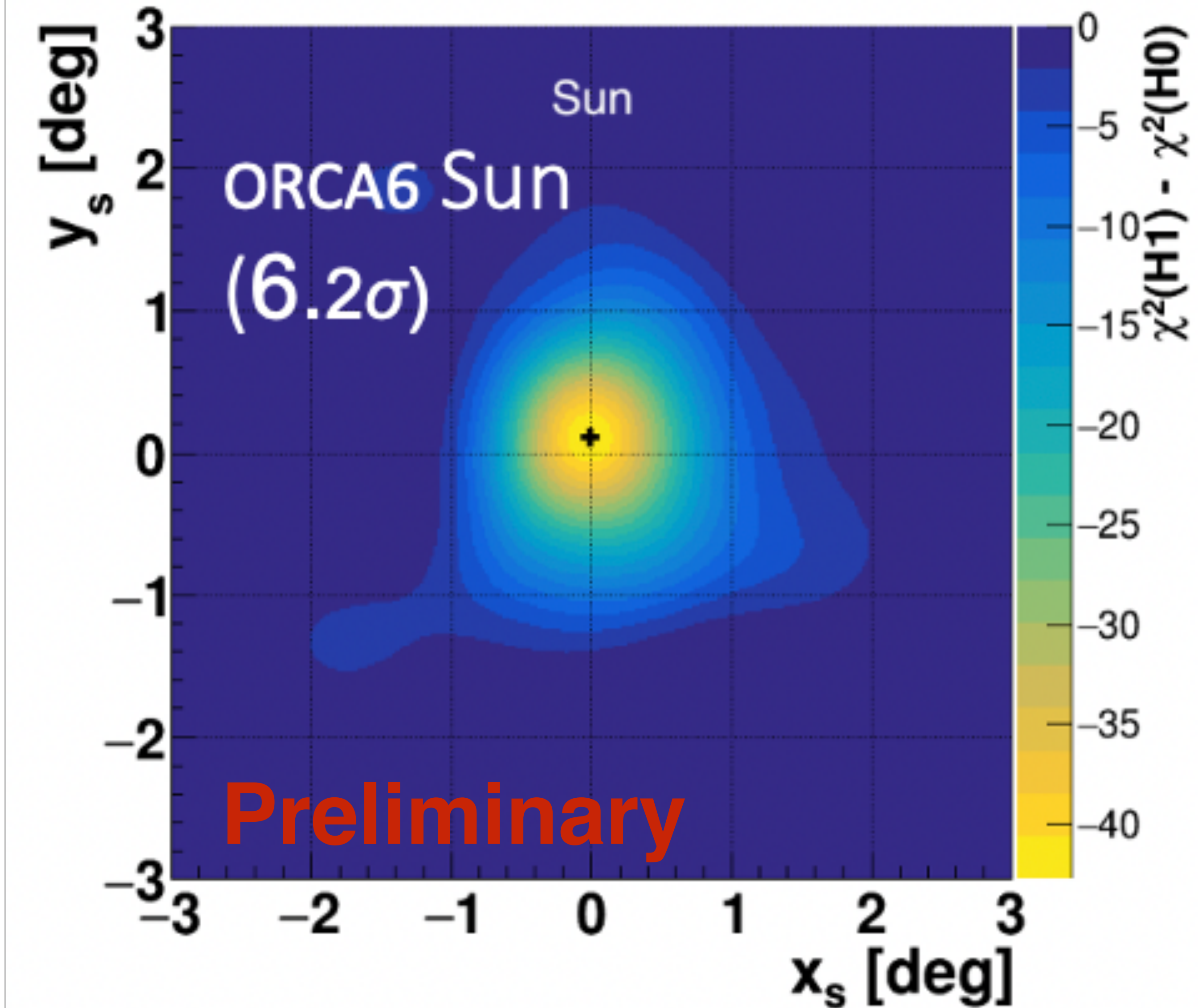


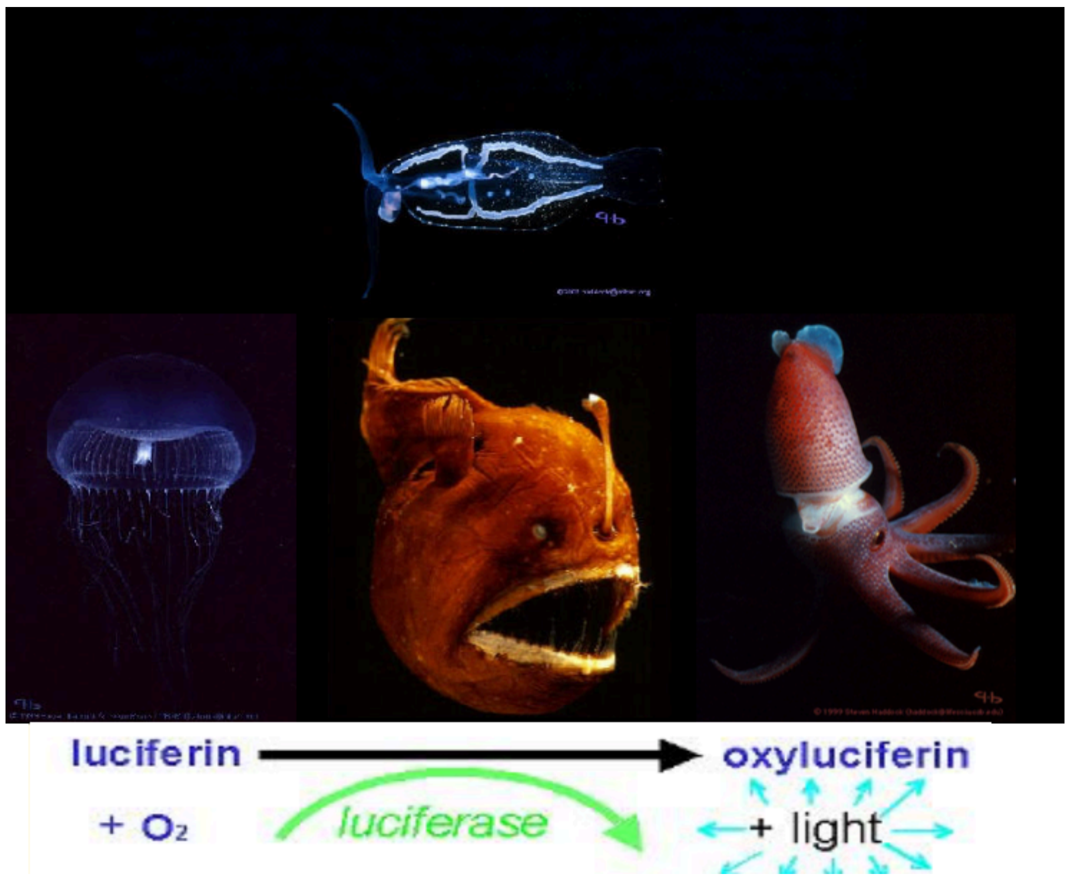

Zavatarelli et al., RICAP2024, doi:10.1051/epjconf/202531906010

# Pointing capabilities

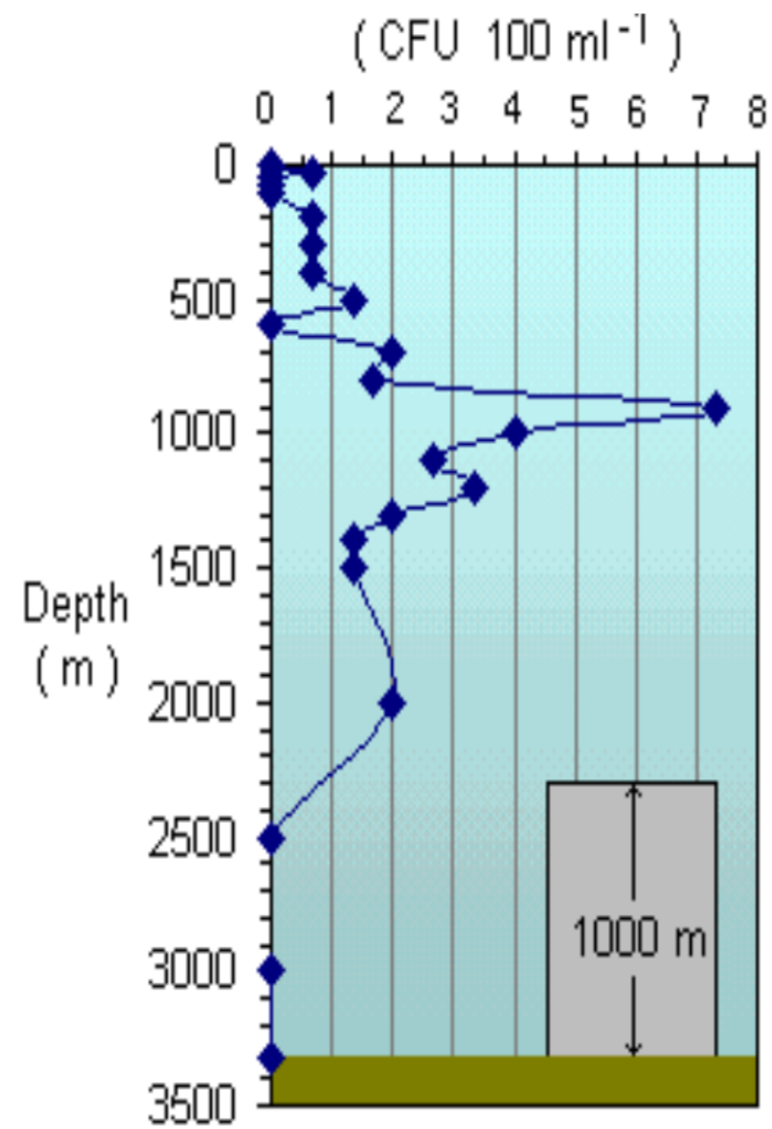


# Natural water background: bioluminescence

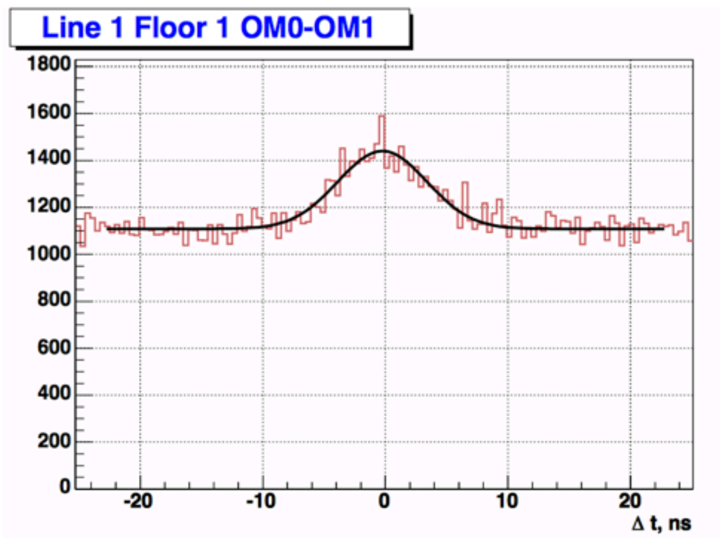


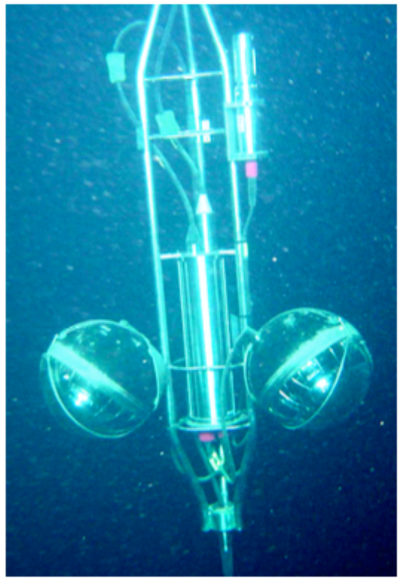

**No luminescent bacteria have been observed in Capo Passero below 2500 m**

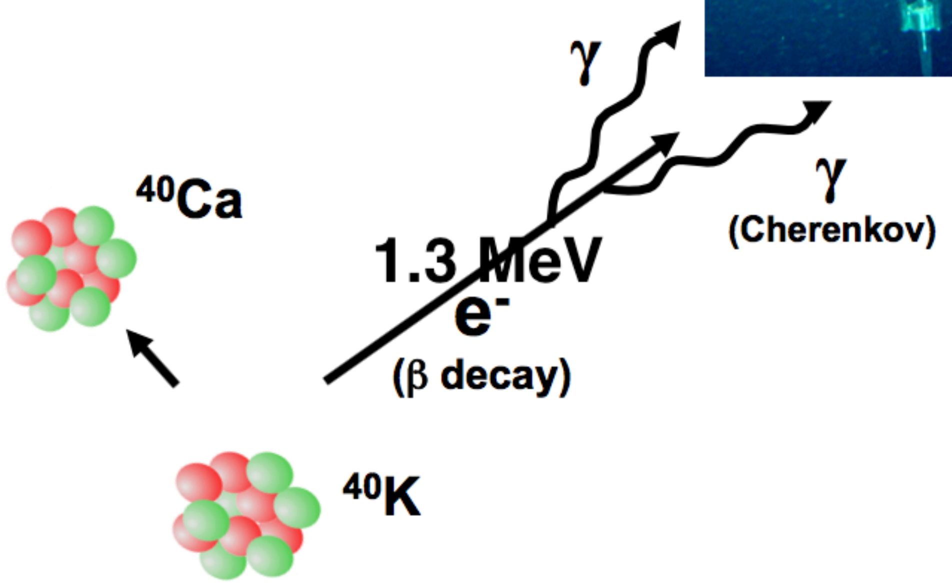



- Limited in deep sea location
- Uncorrelated hits
- Real time monitoring
- Correlation with water current

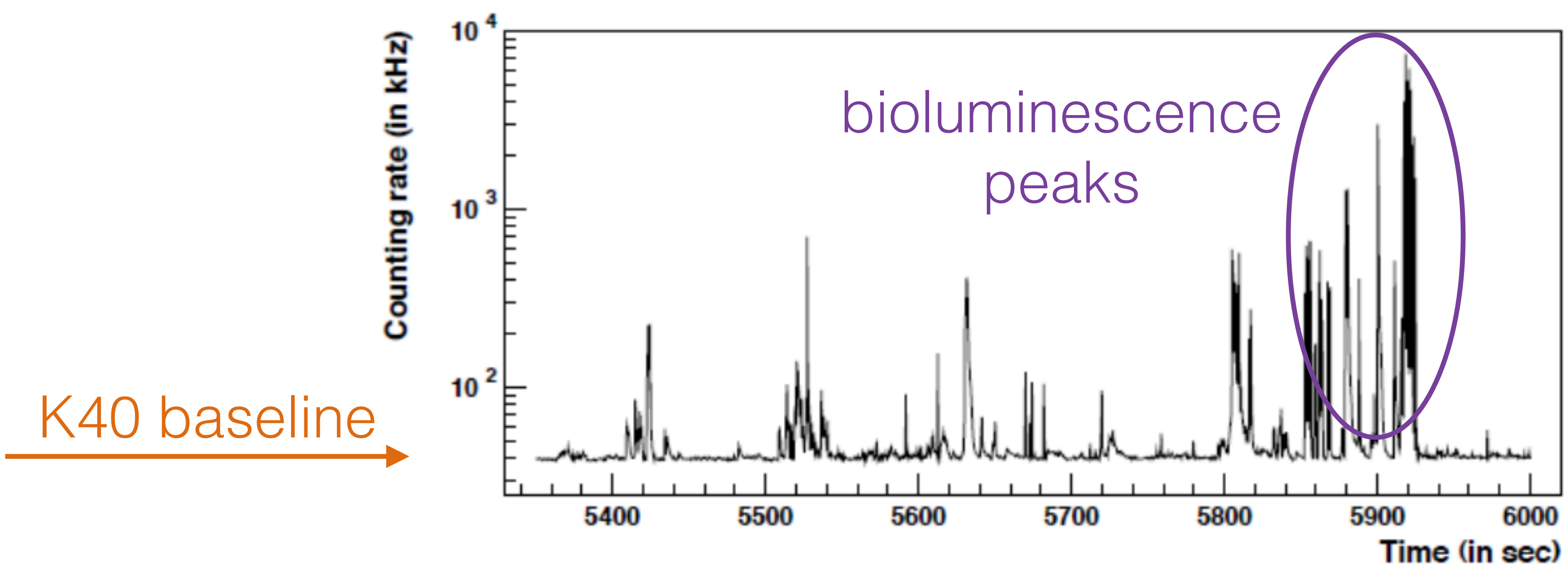
# Natural water background: K40 decay





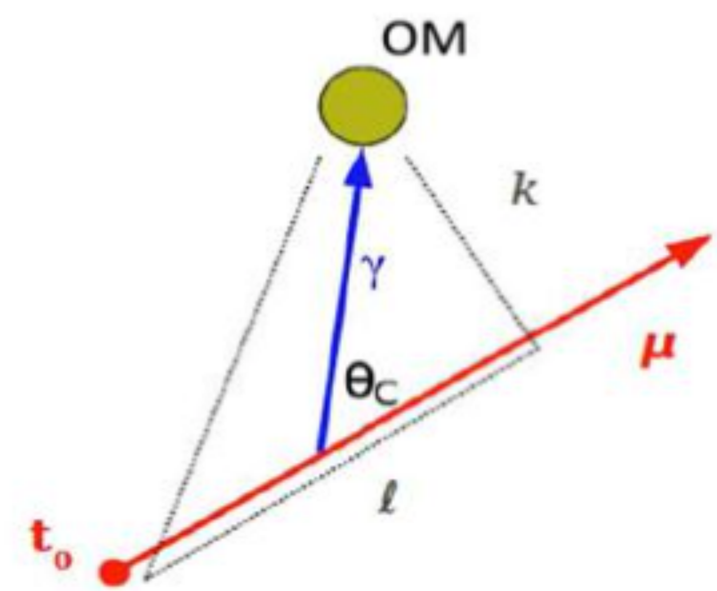

- Uncorrelated hits (usually on single PMT)
- Trigger filtering L1: requires coincidences within 10 ns in the same DOM
- Trigger filter L2: uses the known orientation of PMTs
- Physics event filter

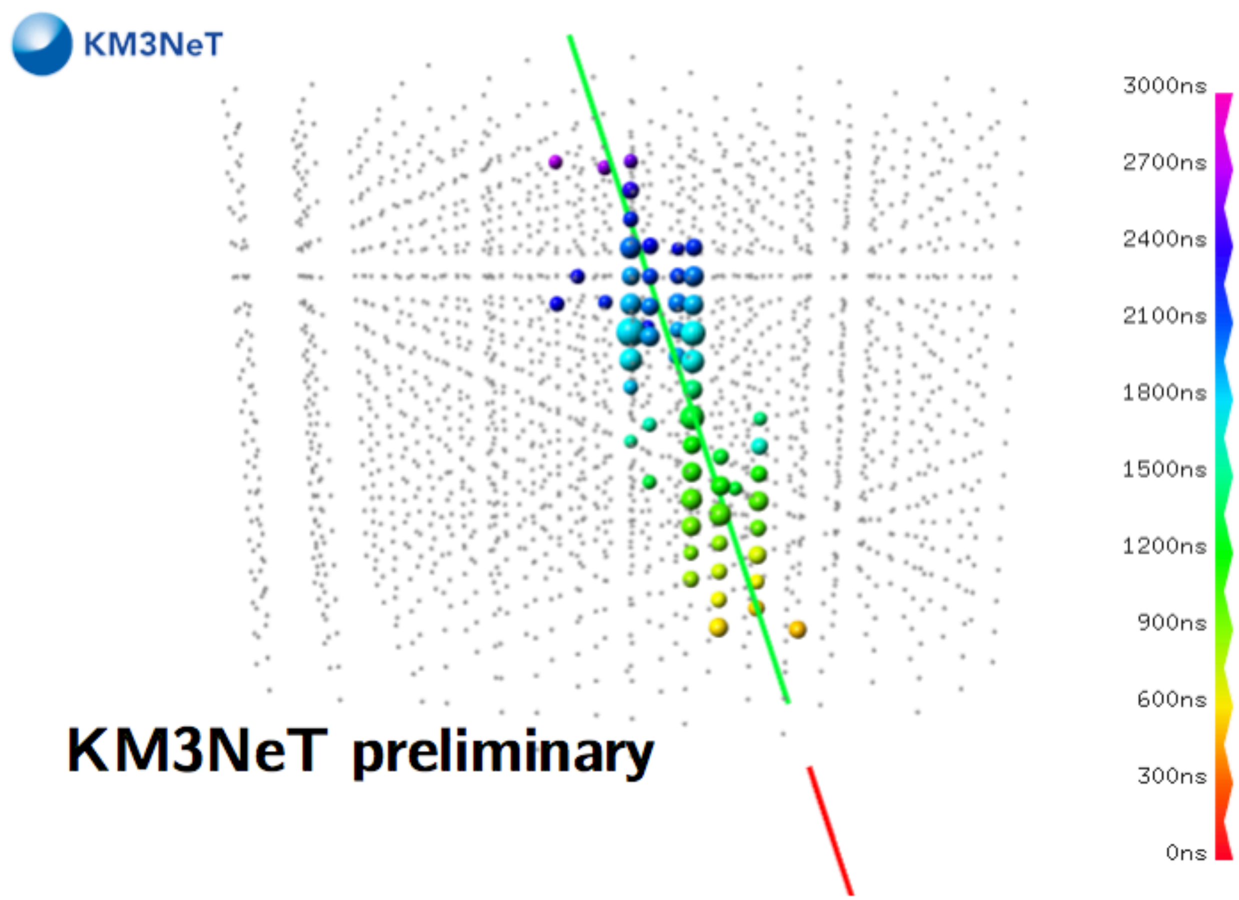



Count rate on single PMT

# Event reconstruction

Full sky search with directional filter:
**Time + Position** information
on individual PMTs
for track reconstructions



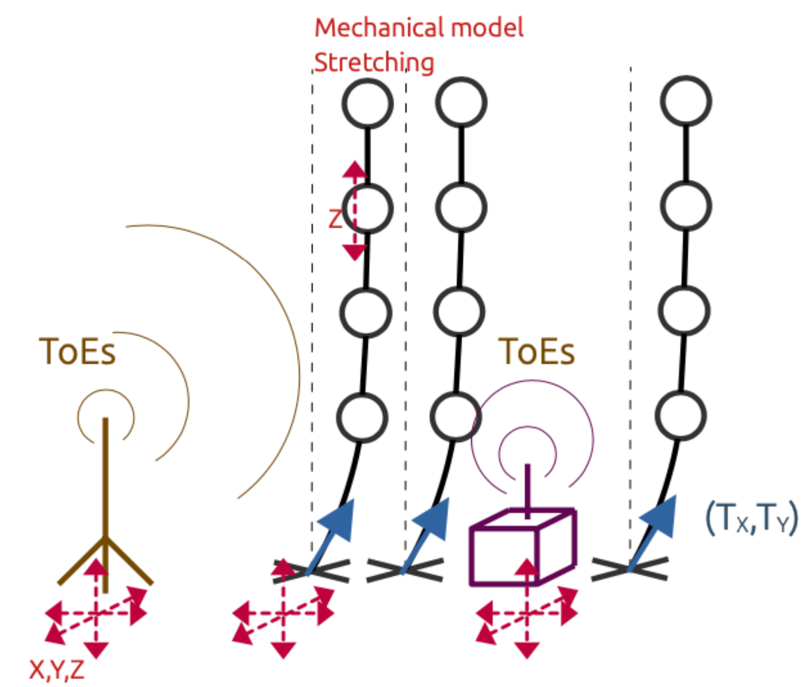

$$t_i^{th} = t_0 + \frac{1}{c}(l - \frac{k}{\tan\theta_c}) + \frac{1}{v_g}(\frac{k}{\sin\theta_c})$$

Minimization of the time residuals
between measured hits
and expected hits, based on
fitted muon track direction
(+ maximum distance
travelled by light)

# Geometry calibrations

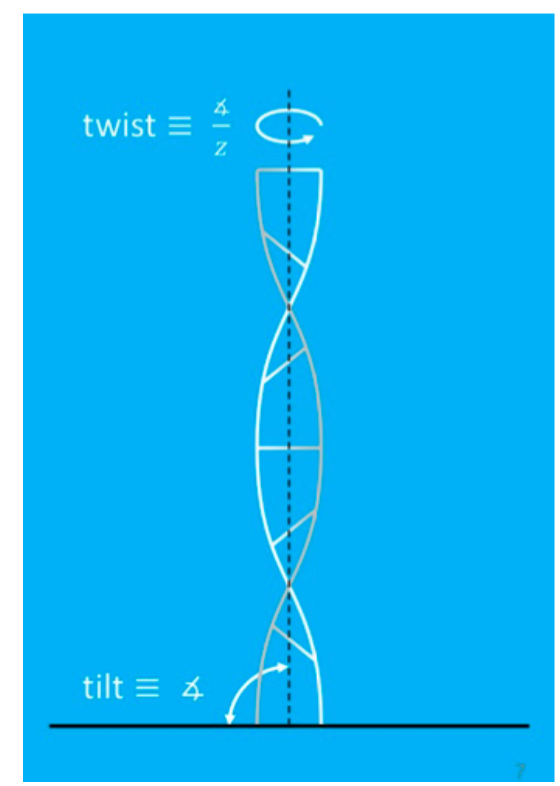
## position → acoustic data

- emitters: beacons anchored to the seabed closely the detector
- receivers: hydrophones located at DU bases & piezo sensors glued in DOMs
- triangulation of acoustic signals to derive DOM positions, constrained by mechanical model of DUs




## orientation → compass data

- attitude and heading reference system (AHRS), aka compass
- it is a set of accelerometers and magnetometers mounted on the electronics boards of each DOM

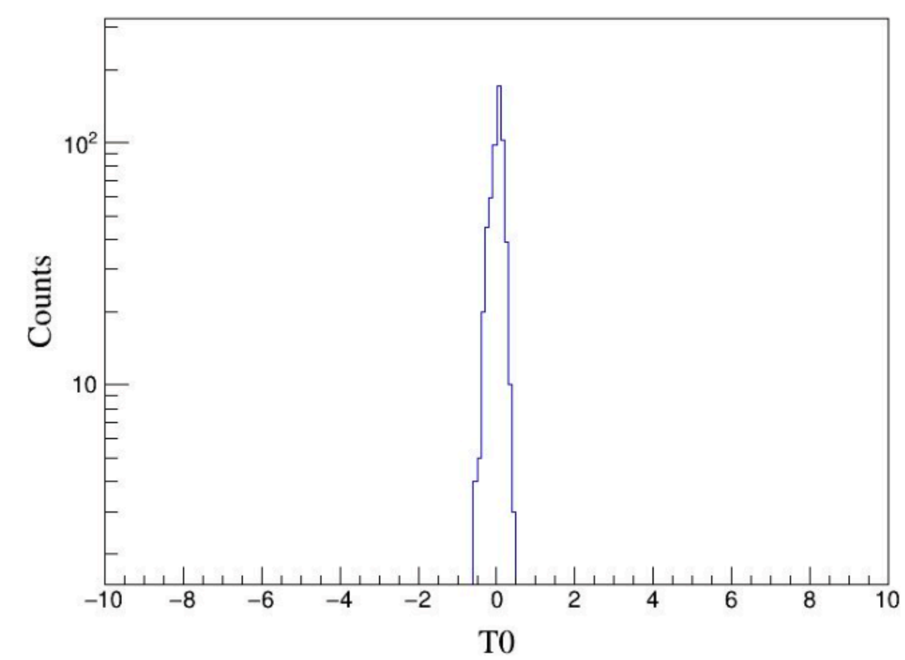



**Dynamic position and orientation systems updating every 10 minutes, with expected accuracies of < 10 cm and a few degrees**

# Time calibrations

## → optical data

- Intra DOM calibration (PMT t0 set)




**K40 fit to extract relative time shift between PMTs**

**T0 shift correction due to HV tuning (1-2 ns)**

**Requires a set of runs leading to the max # of active PMTs**

- Inter DOM calibration (DOM t0 set)

**So far only performed in dark room before deployment**

**For the future, nanobeacon runs might be used for in-sea interDOM calibrations**

- Inter DU calibration (DU t0 set)

**Atmospheric muons used as the maximum likelihood in reconstruction algorithms is achieved for a detector as close as possible to reality**

+ **master clock system** (onshore), providing common reference to all offshore electronics, via a network of optical fibers (WR)

# PMT efficiency calibrations

## → optical data

- Coincidence signals on adjacent PMTs is dominated by K40 decay

$$
\begin{aligned}
{}^{40}\mathrm{K} &\rightarrow {}^{40}\mathrm{Ca} + e^- + \bar{\nu}_e && (89.3\%) \\
{}^{40}\mathrm{K} + e^- &\rightarrow {}^{40}\mathrm{Ar}^* + \nu_e && (10.7\%) \\
&\hookrightarrow {}^{40}\mathrm{Ar} + \gamma &&
\end{aligned}
$$

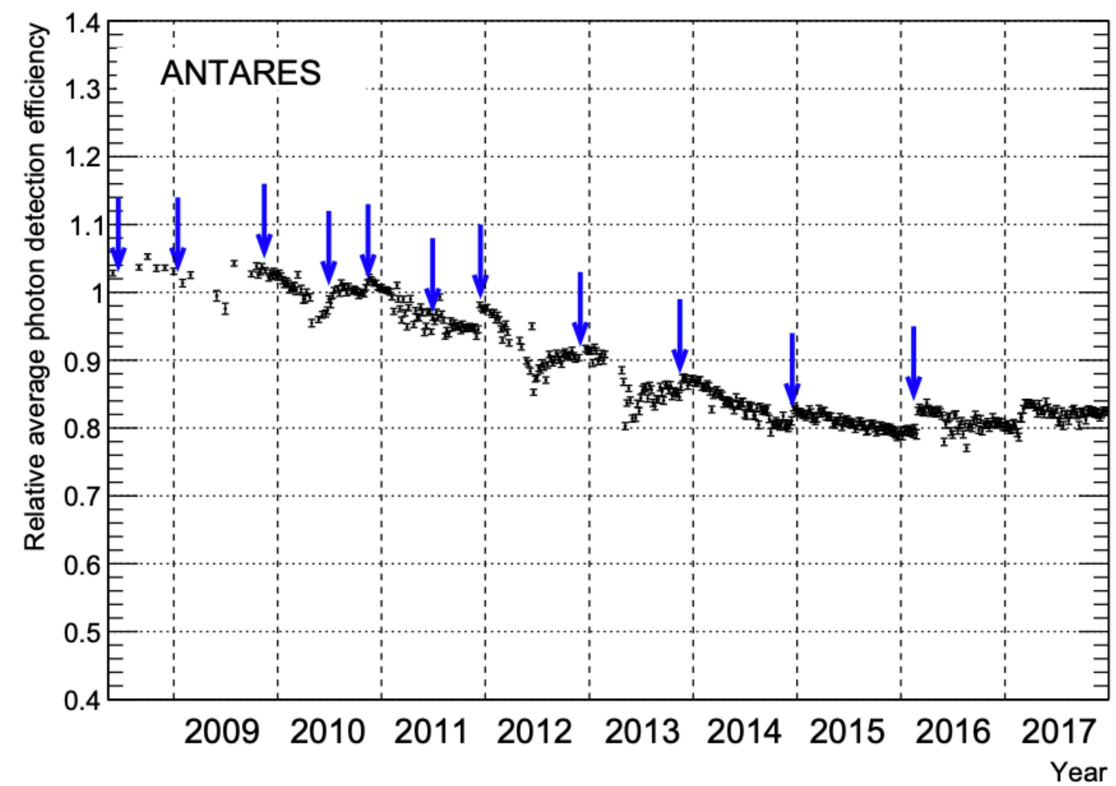
- Distribution of coincident hits is fitted:

$$f(t) = p + a \cdot \exp\left(-\frac{(t-t_0)^2}{2\sigma^2}\right)$$

$$R = \frac{a \cdot \sigma \cdot \sqrt{2\pi}}{\Delta\tau} \longrightarrow \epsilon_i = \sqrt{\frac{1}{R_c^*} \frac{R_{ij} \cdot R_{ki}}{R_{jk}}}$$

- Measurements:
  Gain, Gain spread, Efficiency

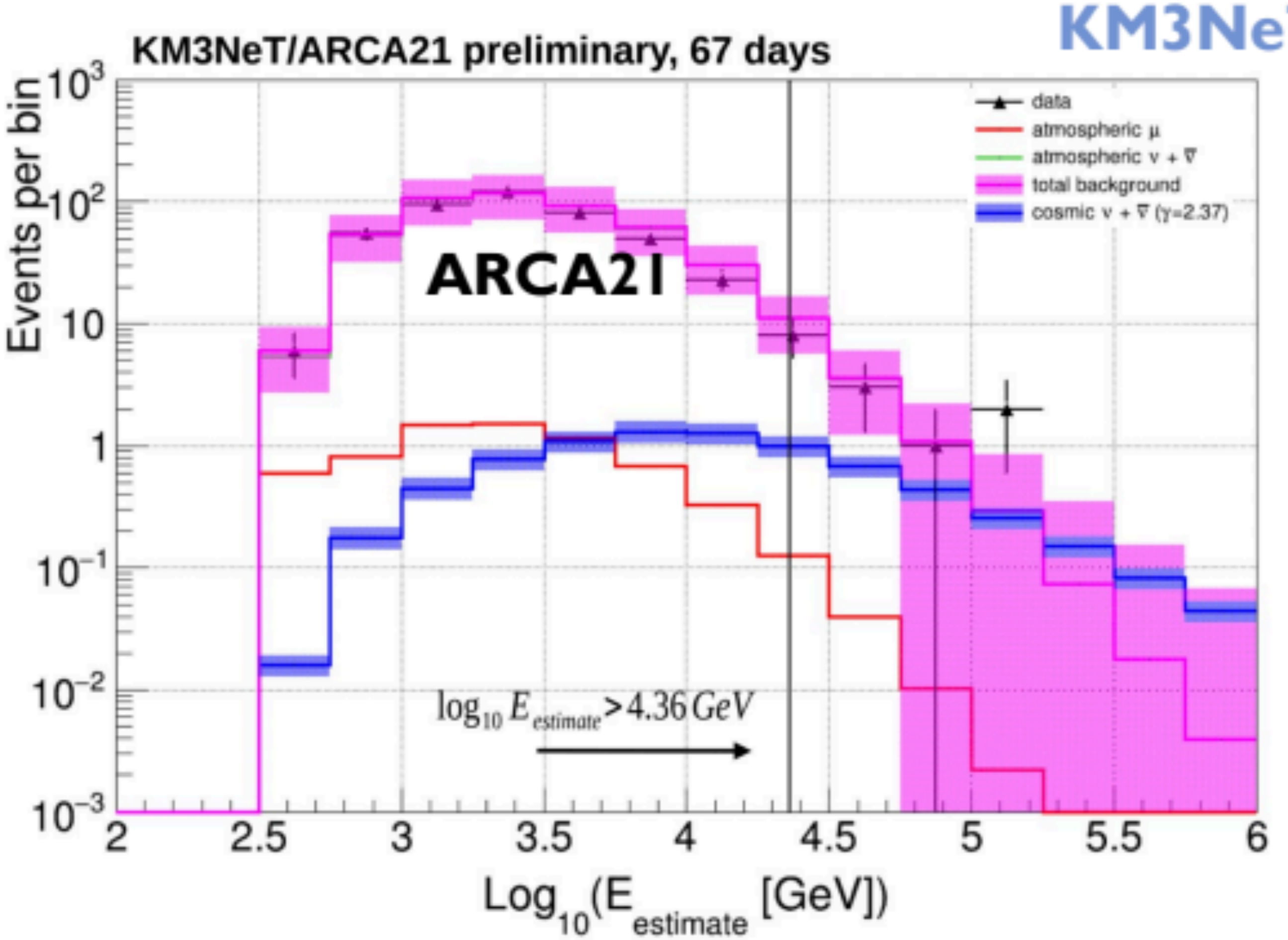
- Channels with bad response are masked (sedimentation, biofouling and exchange of deep sea water might affect efficiencies)



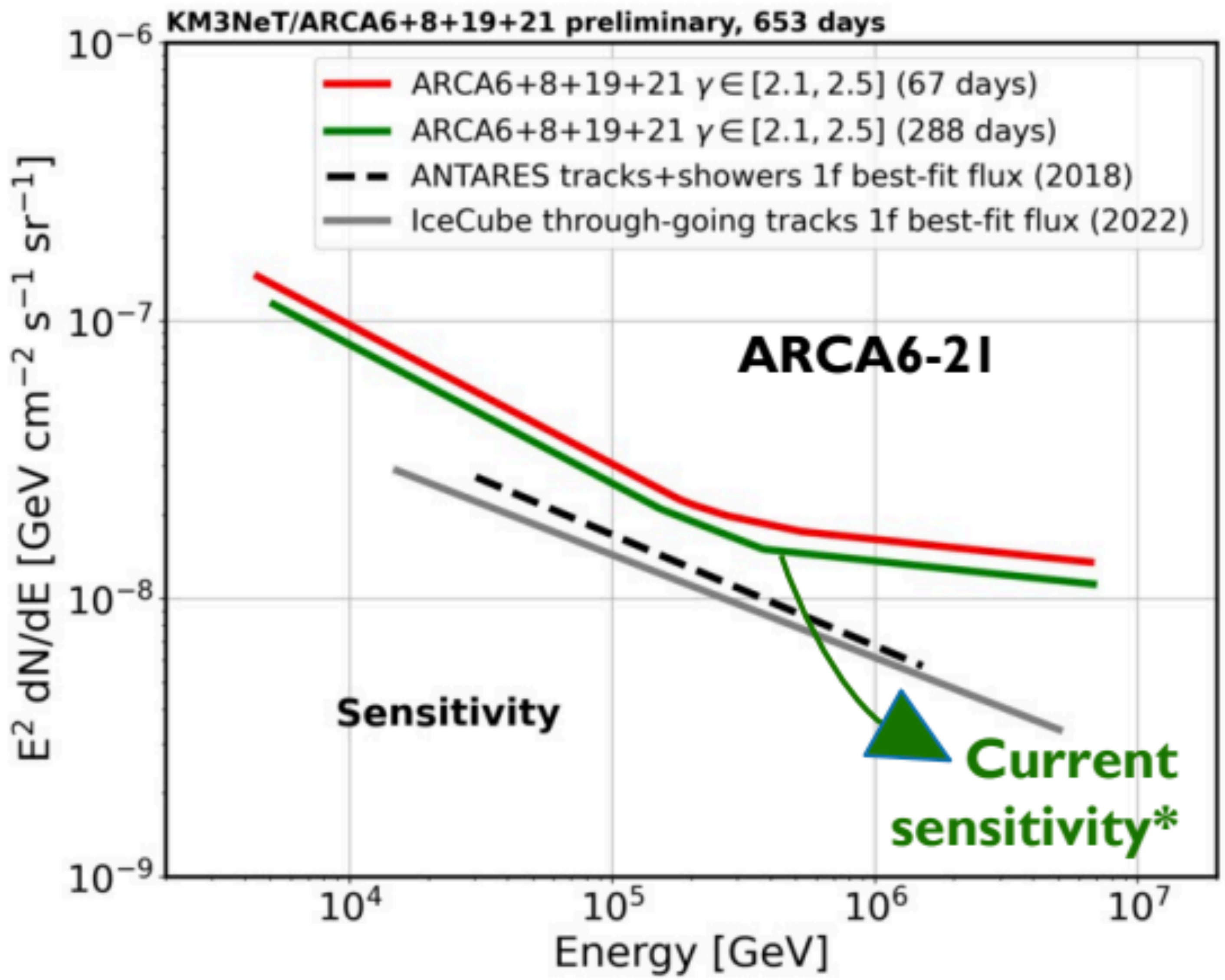

A. Albert et al. [ANTARES Coll.], EPJC 78 (2018) 699

# KM3NeT ongoing analyses & prospects

# ARCA diffuse flux analysis




**KM3NeT/ARCA is rapidly evolving approaching ANTARES and IceCube fitted fluxes**




Tsourapis et al., ICRC2023, doi:10.22323/1.444.1195

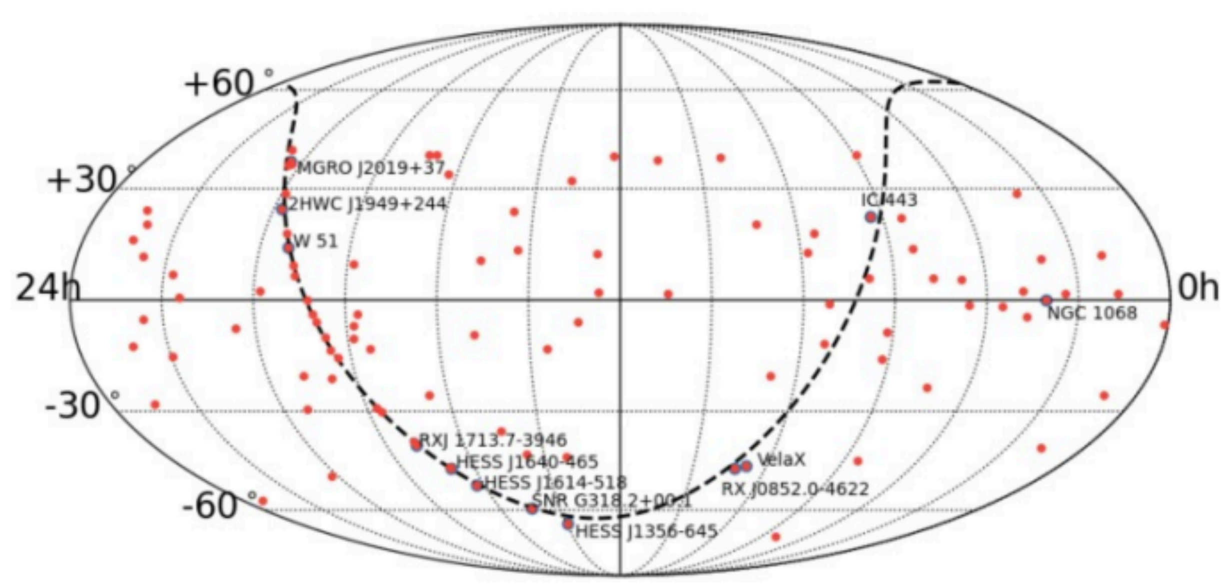
Fusco et al., Neutrino 2024, doi:10.5281/zenodo.13899660

*More than one year of ARCA28/33 data not included yet

# ARCA point source search

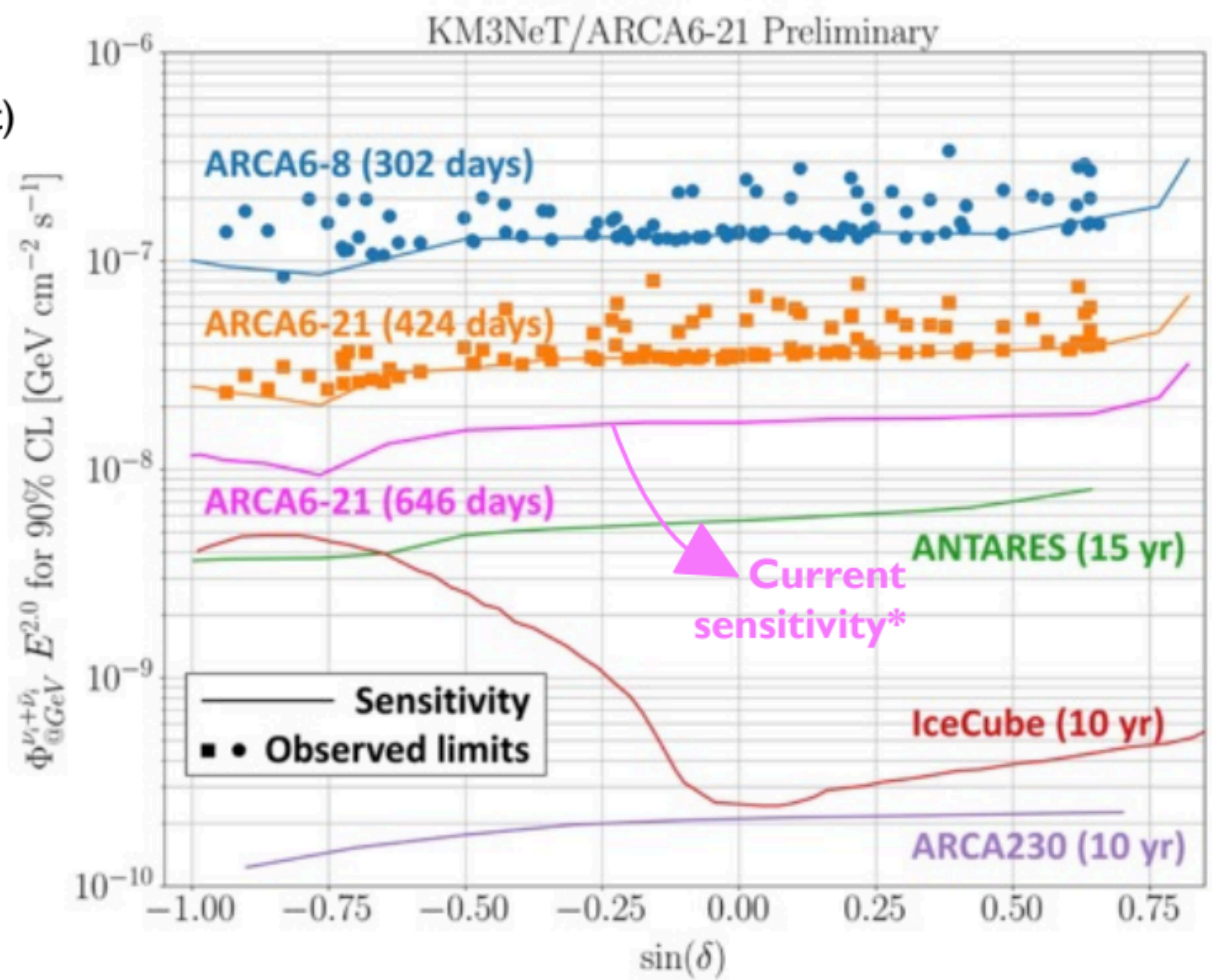
**~100 sources analysed, selected based on:**

- Interesting sources in earlier IceCube & ANTARES searches / alerts
- Bright gamma-ray emitters
- Galactic gamma-ray sources with hints of hadronic component (TeVCat)
- Extragalactic AGN with highest maximal flux observed in radio (VLBI)




**Most significant source:**
BL Lac **Mkn 421** (assuming $E^{-2.5}$ spectrum), post trial p-value **56%**

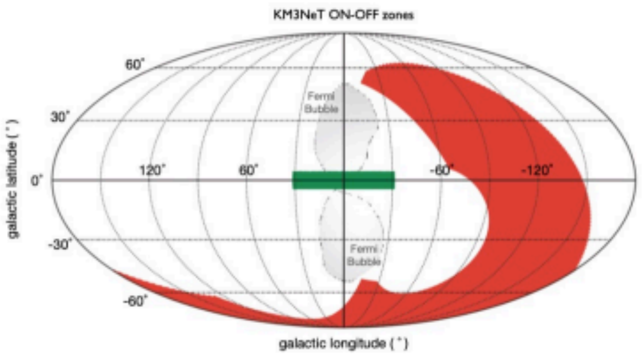
KM3NeT/ARCA is rapidly evolving approaching ANTARES and IceCube sensitivities




*More than one year of ARCA28/33 data non included yet

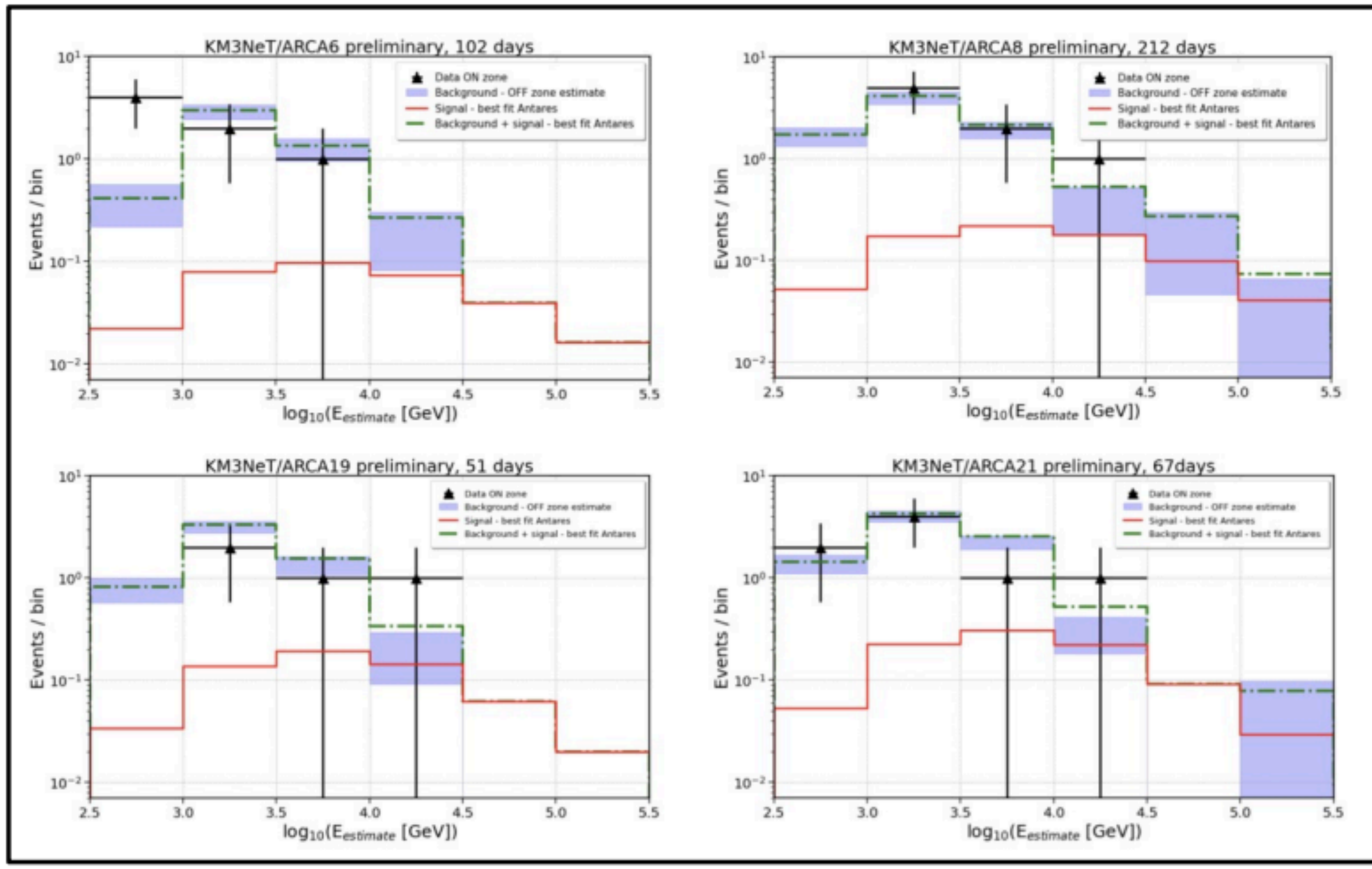
Muller et al., ICRC2023, doi:10.22323/1.444.1018

# ARCA Galactic Ridge analysis

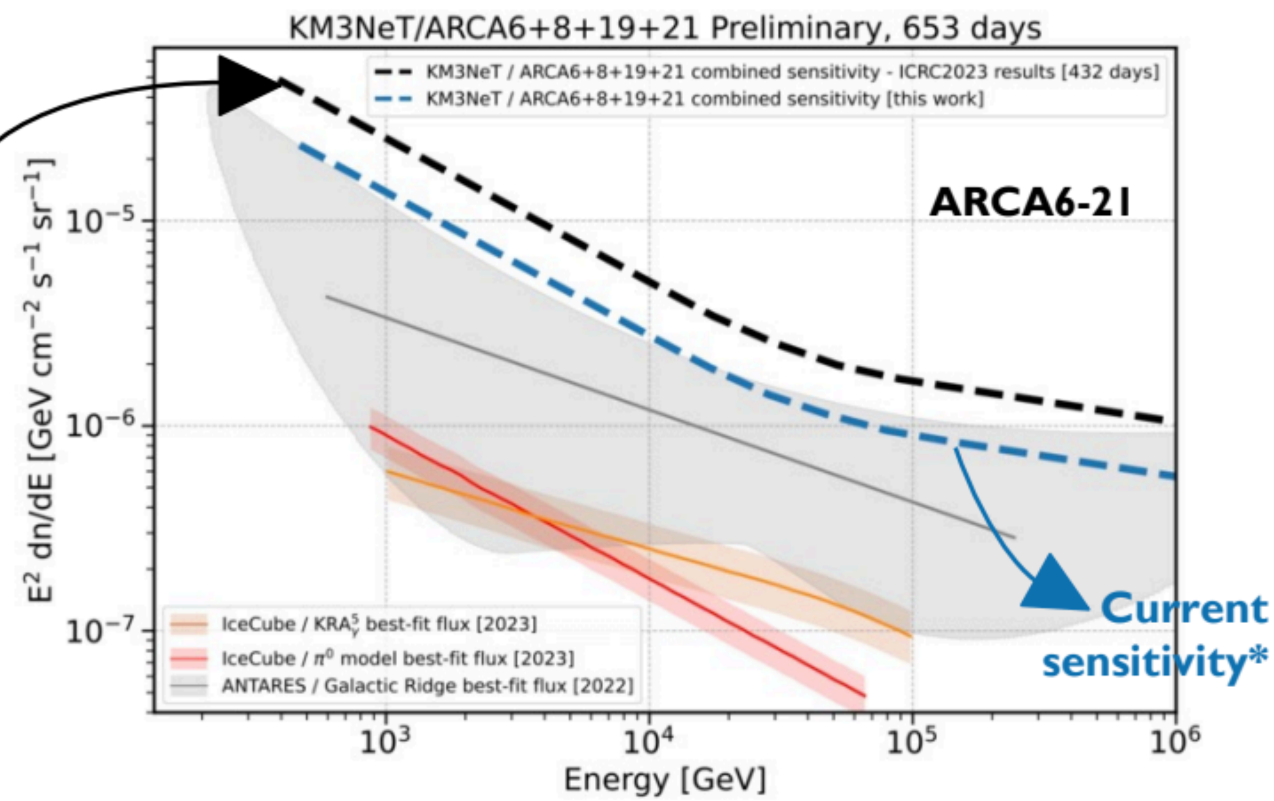



|longitude| < 30°
|latitude| < 2°

**ARCA6-21**




**KM3NeT/ARCA is rapidly evolving approaching ANTARES and IceCube fitted fluxes**



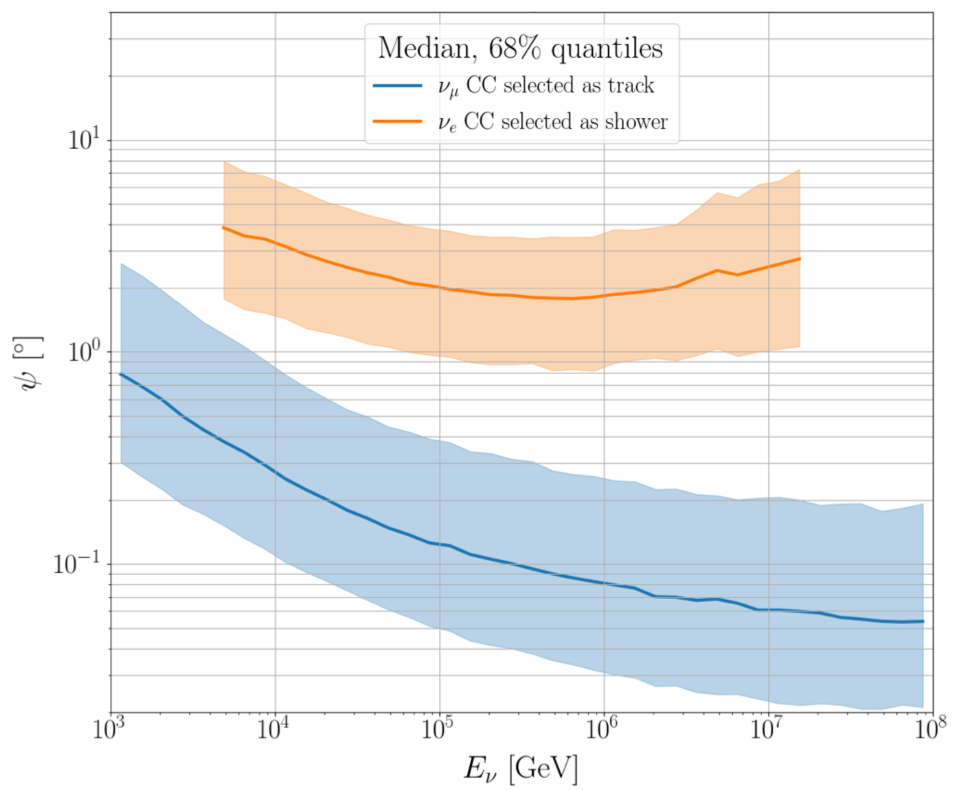

***More than one year of ARCA28/33 data not included yet**

Filippini et al., ICRC2023, doi:10.22323/1.444.1190

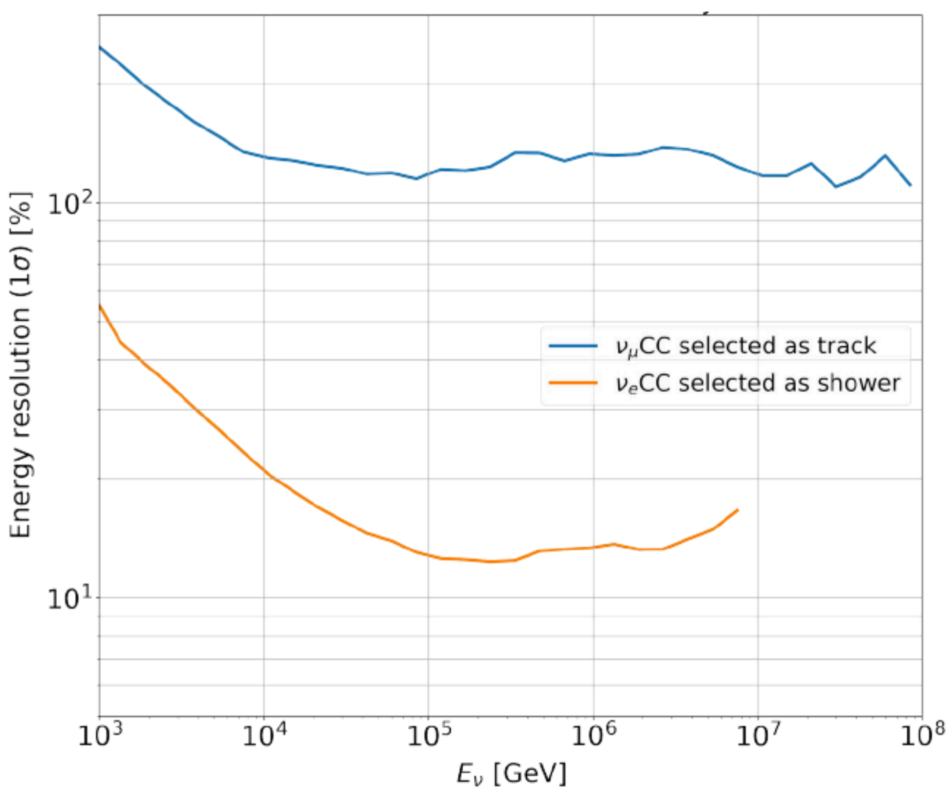
Fusco et al., Neutrino 2024, doi:10.5281/zenodo.13899660

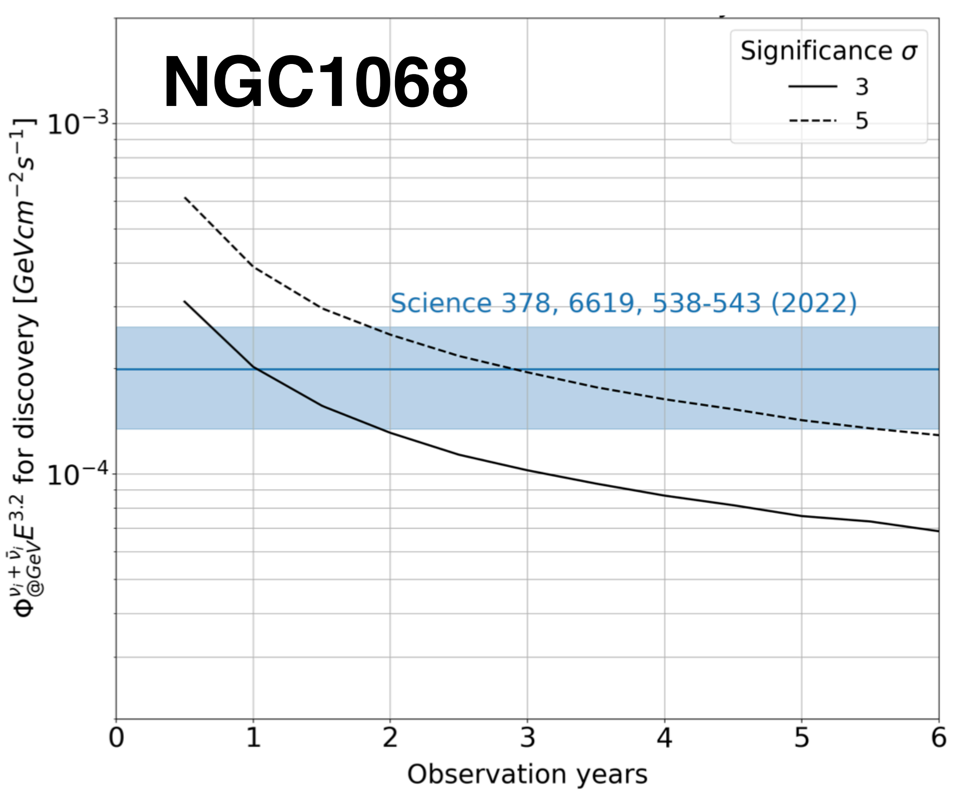
# The KM3NeT/ARCA astronomical potential

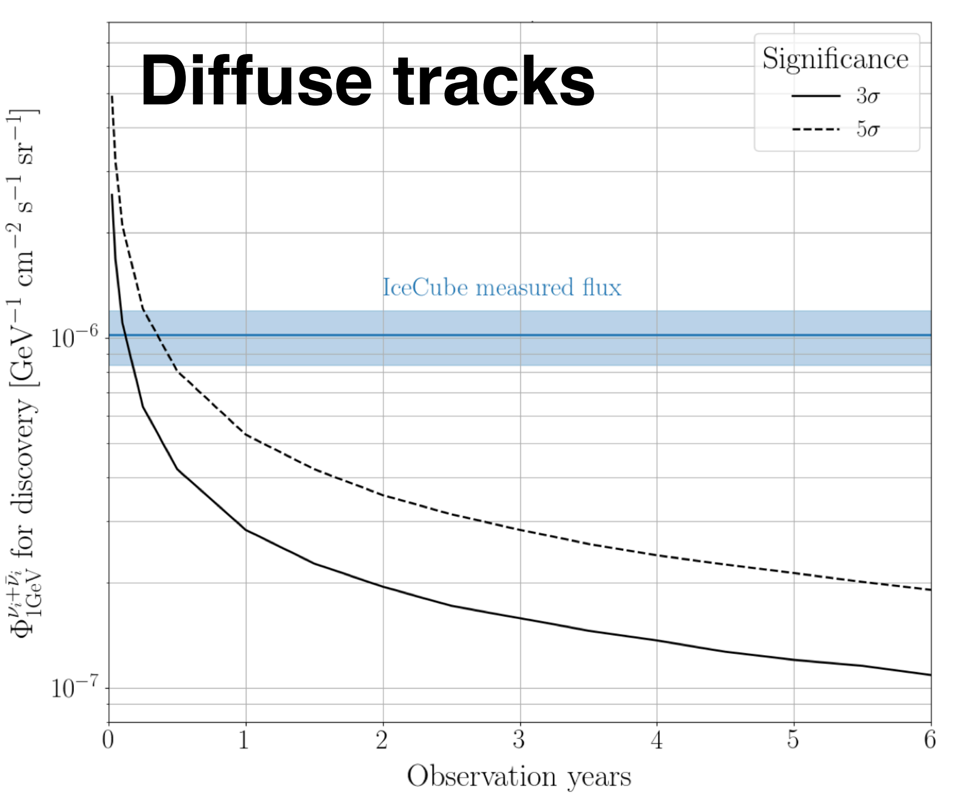
## Angular resolution




## ARCA energy resolution



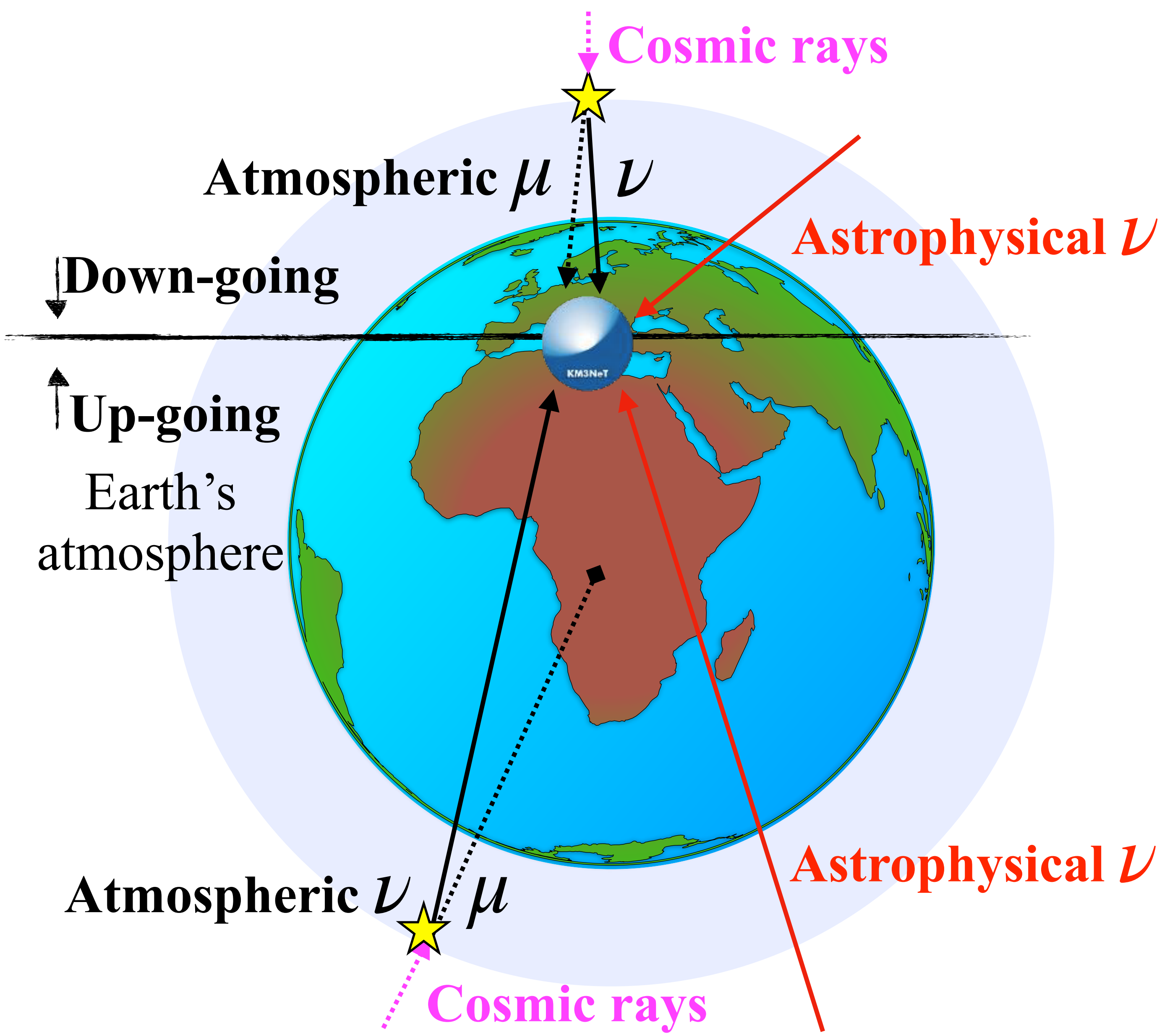




S. Aiello et al. [KM3NeT Coll.] arXiv:2402.08363

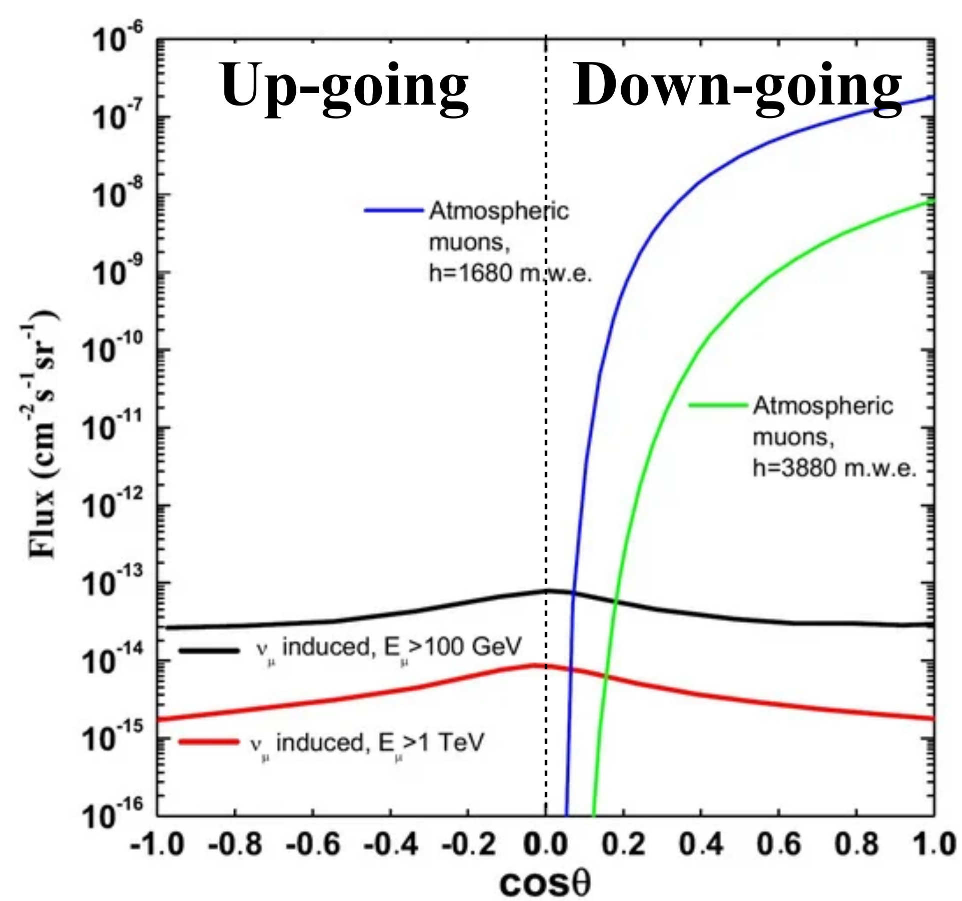
R. Muller et al. [KM3NeT Coll.], PoS (ICRC2023) 1018

# Neutrino astronomy

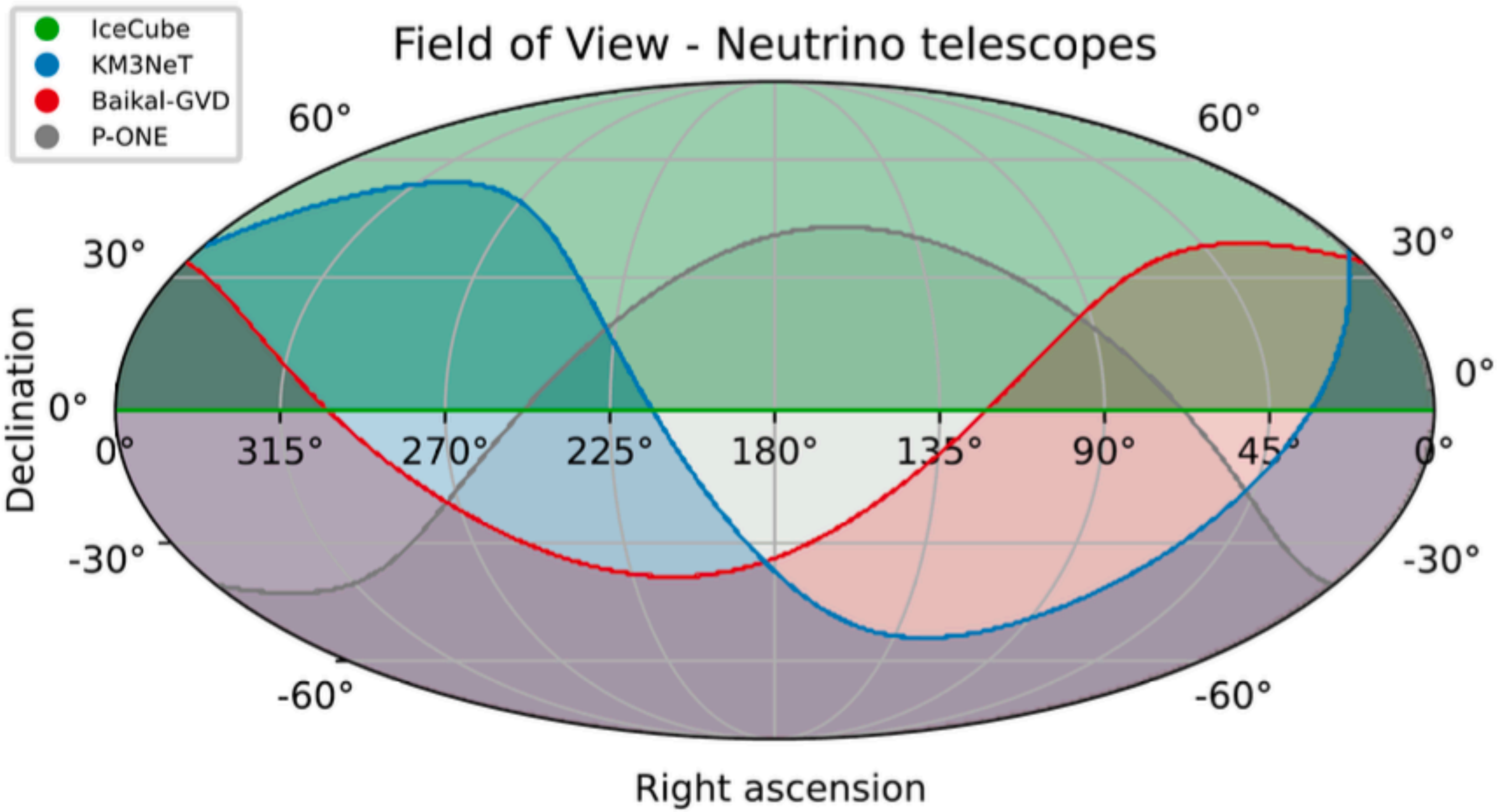
# 1. Search for cosmic neutrinos with the upgoing track-like sample




Earth is used as shield against all particles, except neutrinos that can traverse the Earth

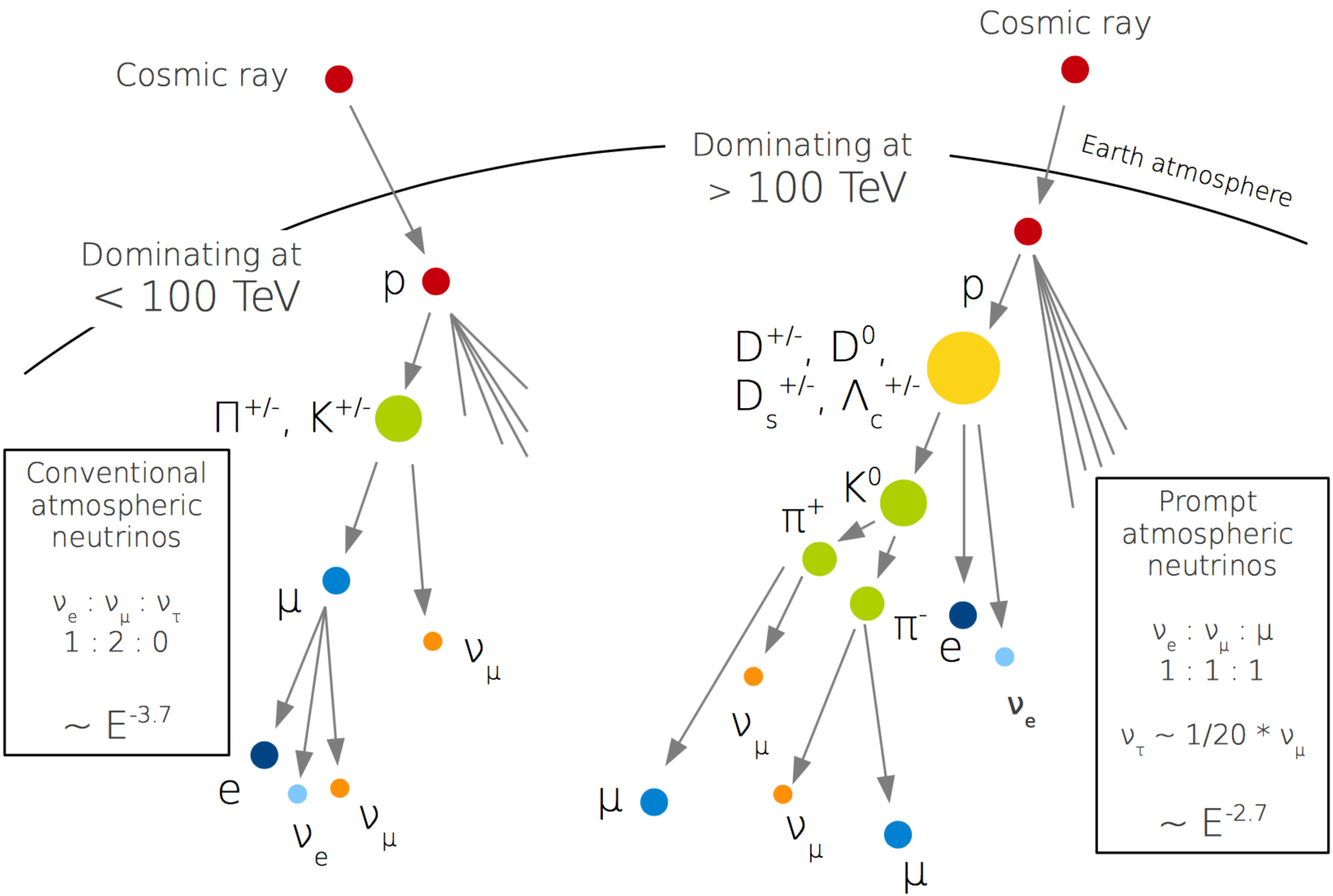


# Upgoing event selection




Palacios et al., PoS (IHEP 2024)

# Neutrino background

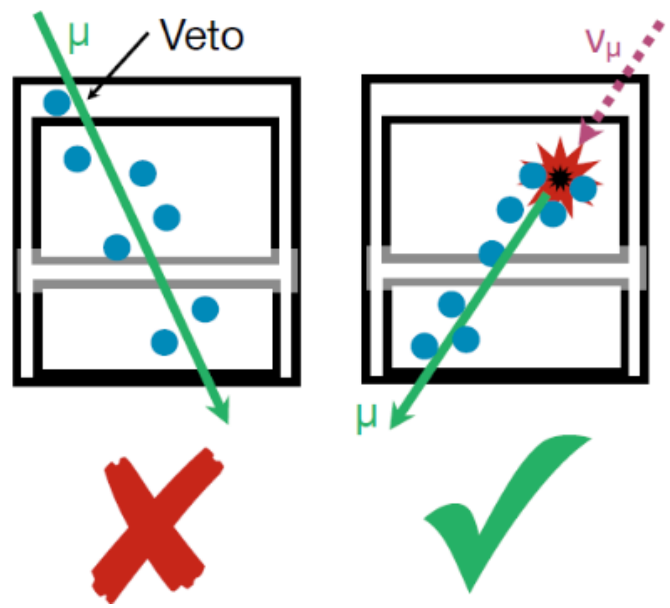


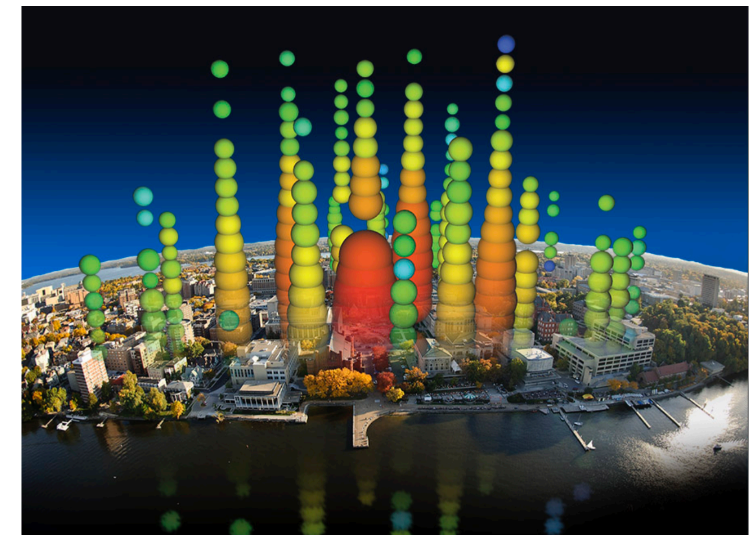

$$\epsilon_\pi = 115\,\mathrm{GeV}$$
$$\epsilon_K = 850\,\mathrm{GeV}$$

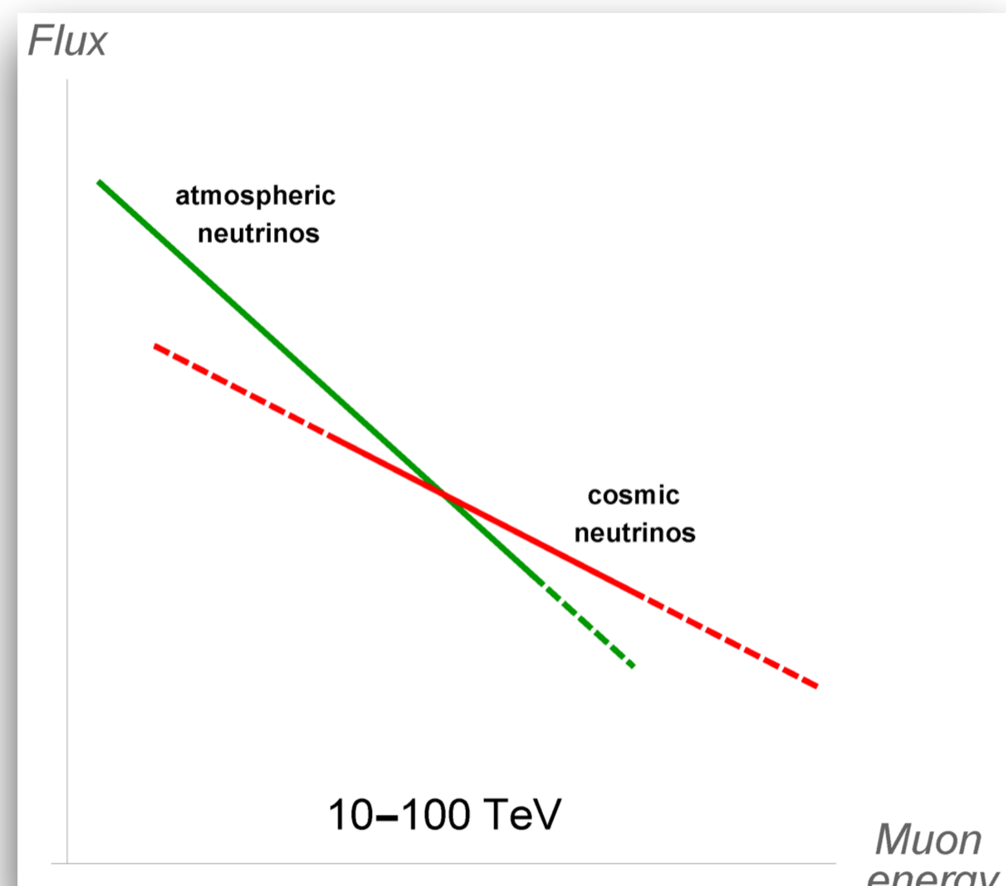
# 2. Search for cosmic neutrinos with the high-energy starting sample

"Vetoing the muon produced by the same parent meson decaying in the atmosphere"

$$\pi \longrightarrow \mu^{atmo} + \nu_\mu^{atmo}$$



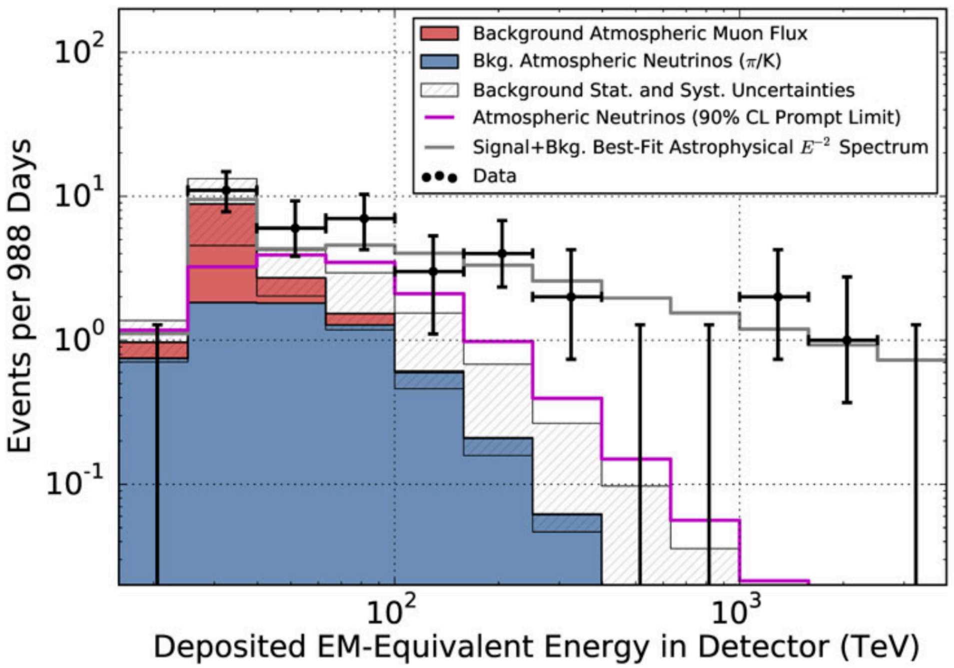



Schonert, Gaisser, Resconi & Schult, Phys. Rev. D79 (2009) 4

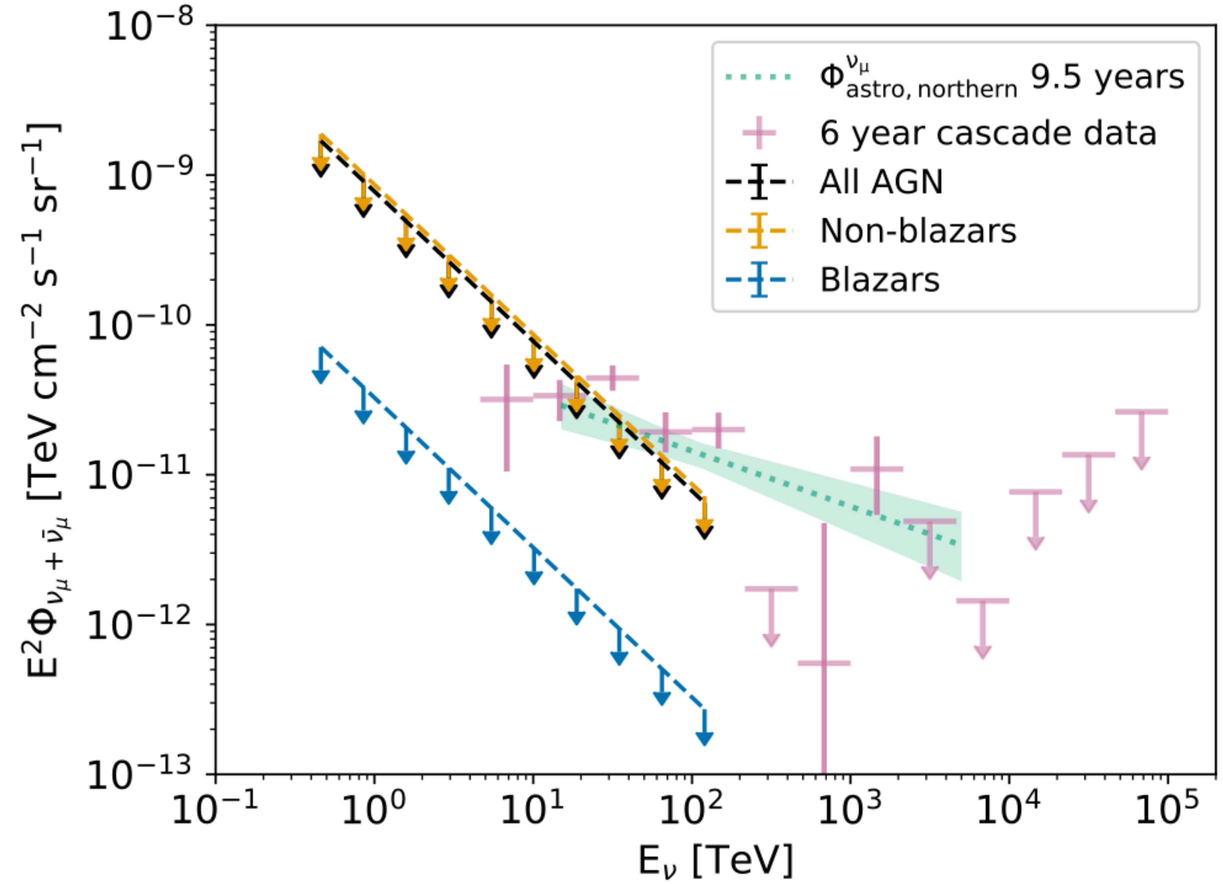
- Detects penetrating muons
- Reduced effective volume (400 MTon)
- Sensitive to all flavors
- Sensitive to the entire sky

$\boxed{E_\nu > 60\ \mathrm{TeV}}$ in IceCube

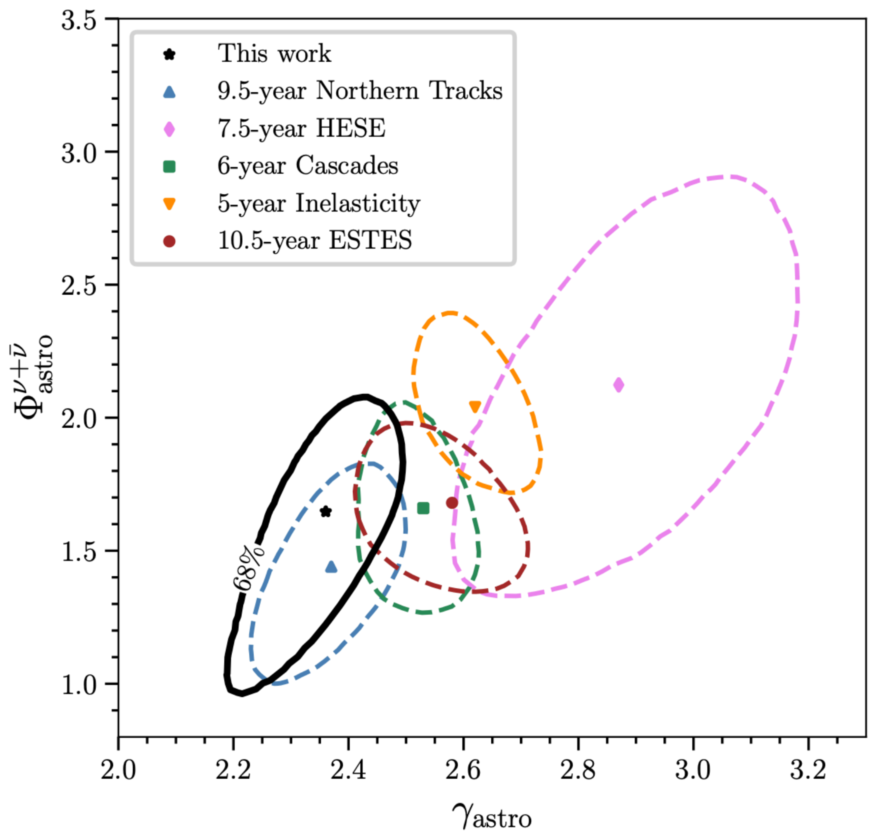
# 1. The all-sky diffuse neutrino flux



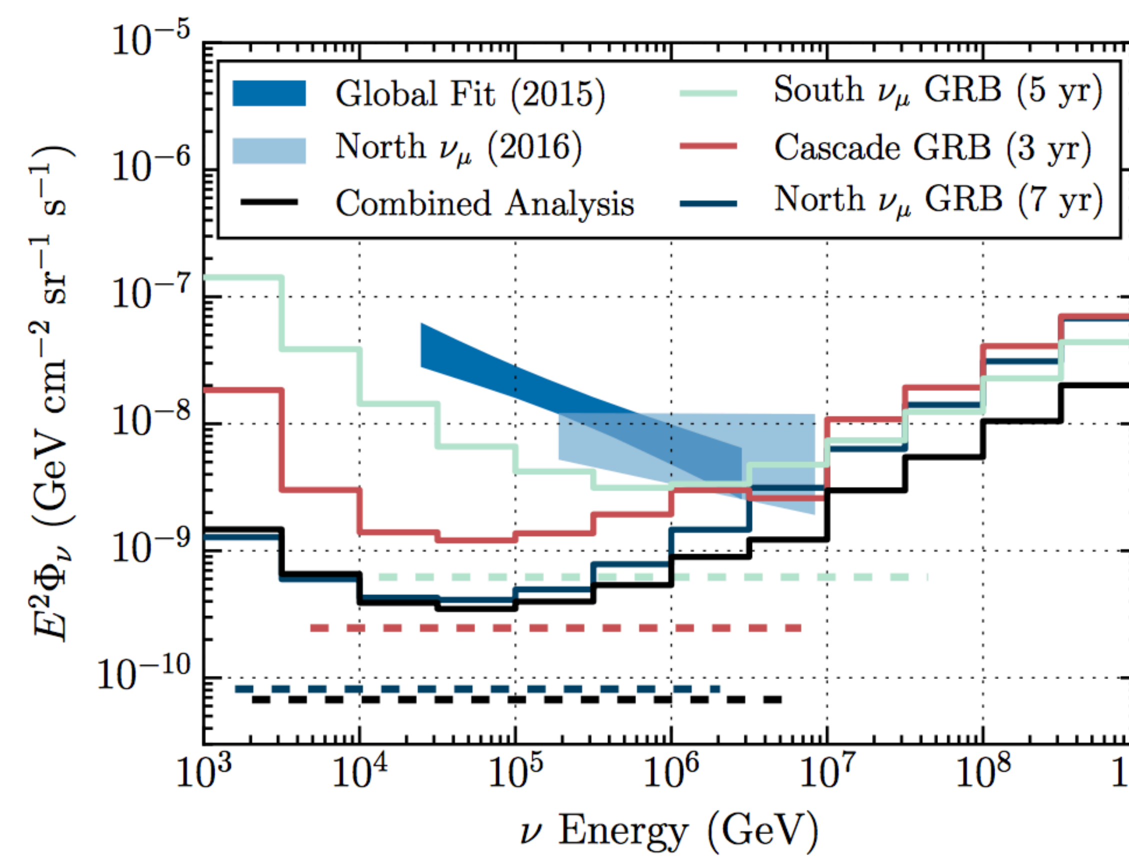

Aartsen et al. [IceCube], PRL 113 (2014)




IceCube Coll., arXiv:2406.06684

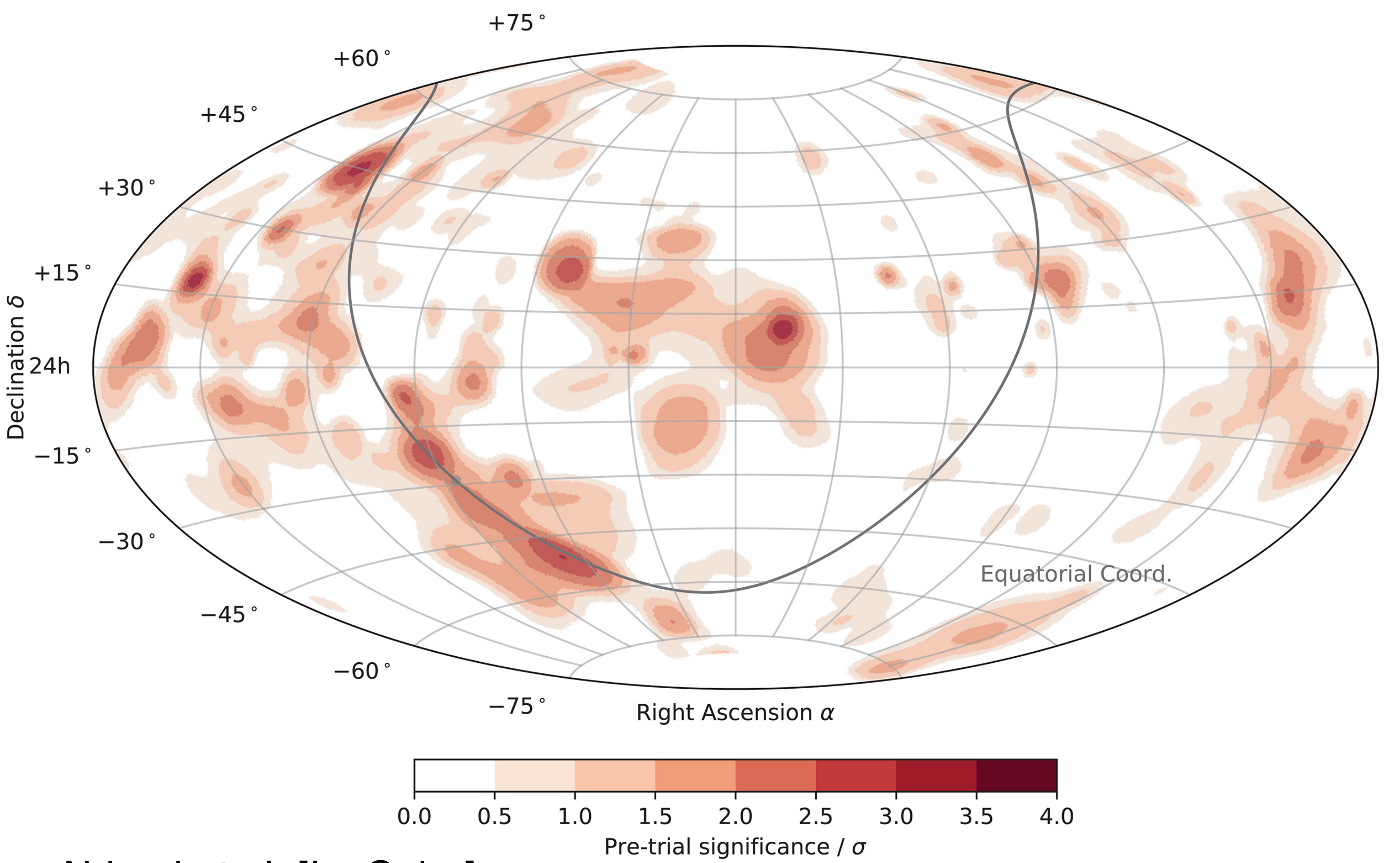


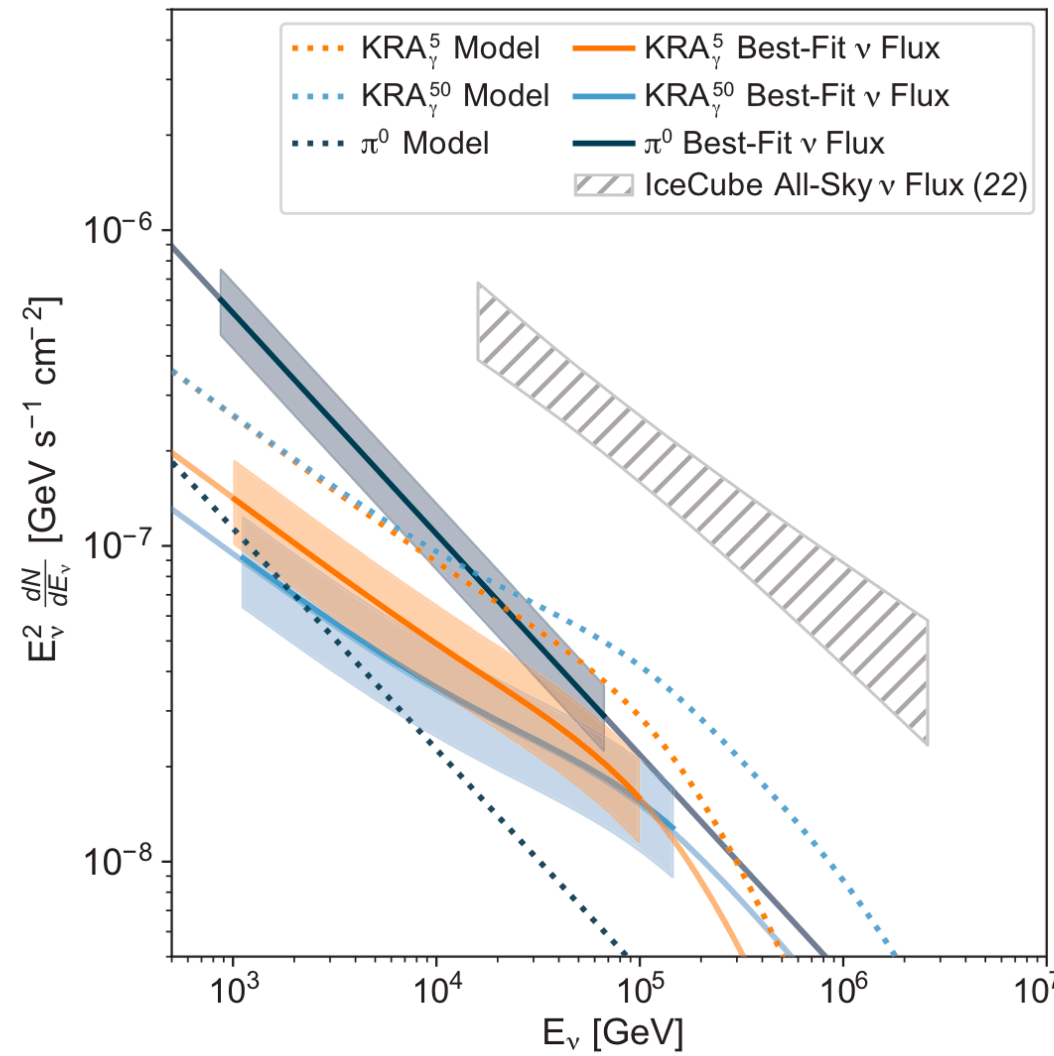

IceCube Coll., arXiv: 2502.19776



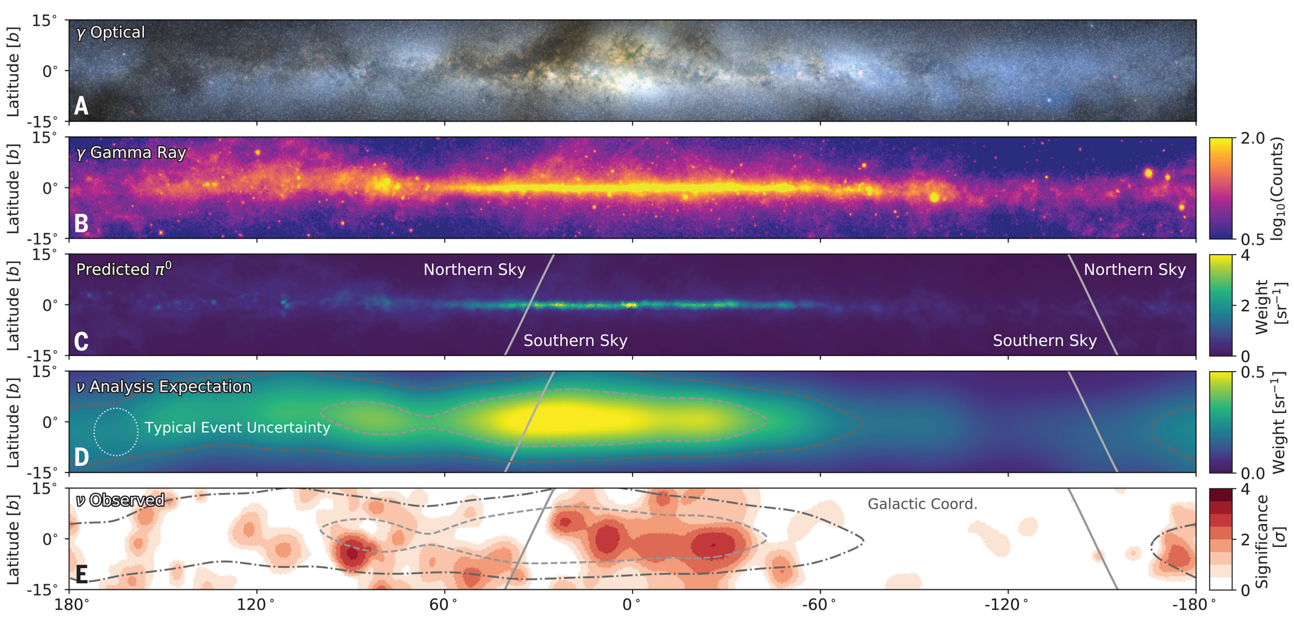

A. Artsen et al. [IceCube Coll.], ApJ 843 (2017) 2

# 2. Neutrinos from the Galactic Plane




Abbasi et al. [IceCube], Science 380 (2023) 6652

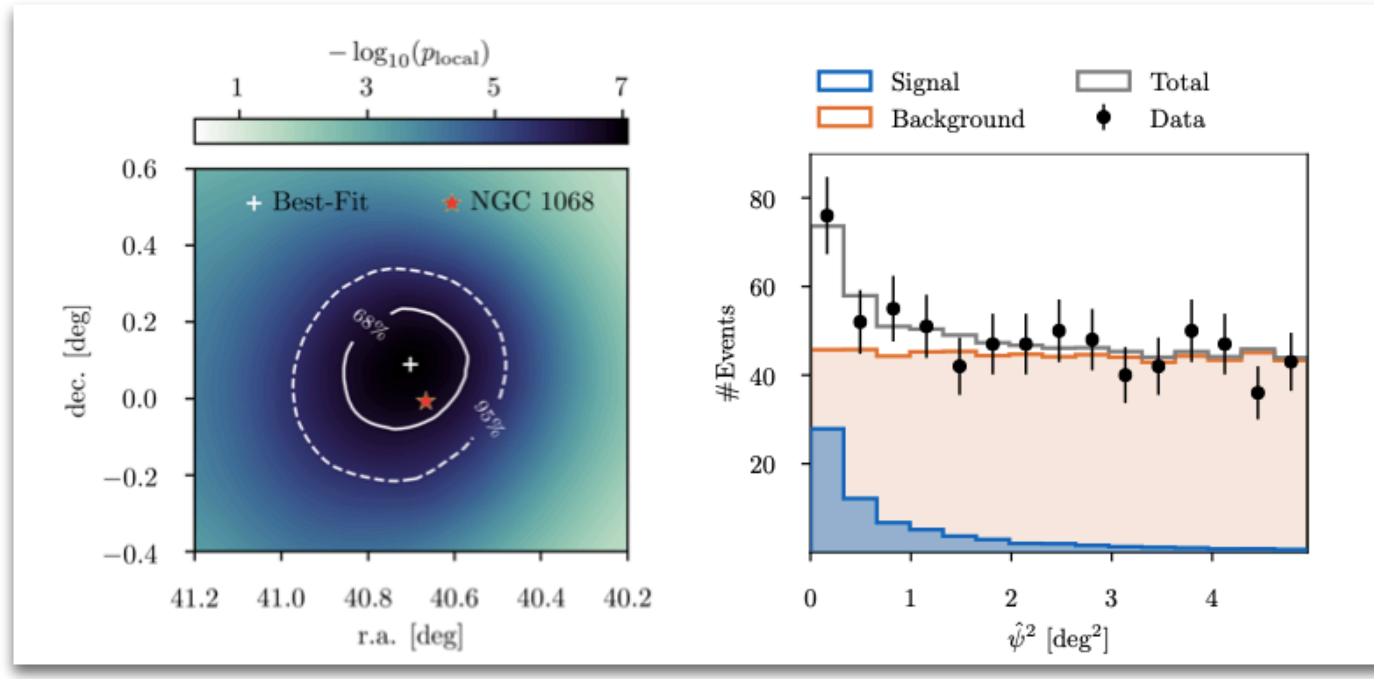


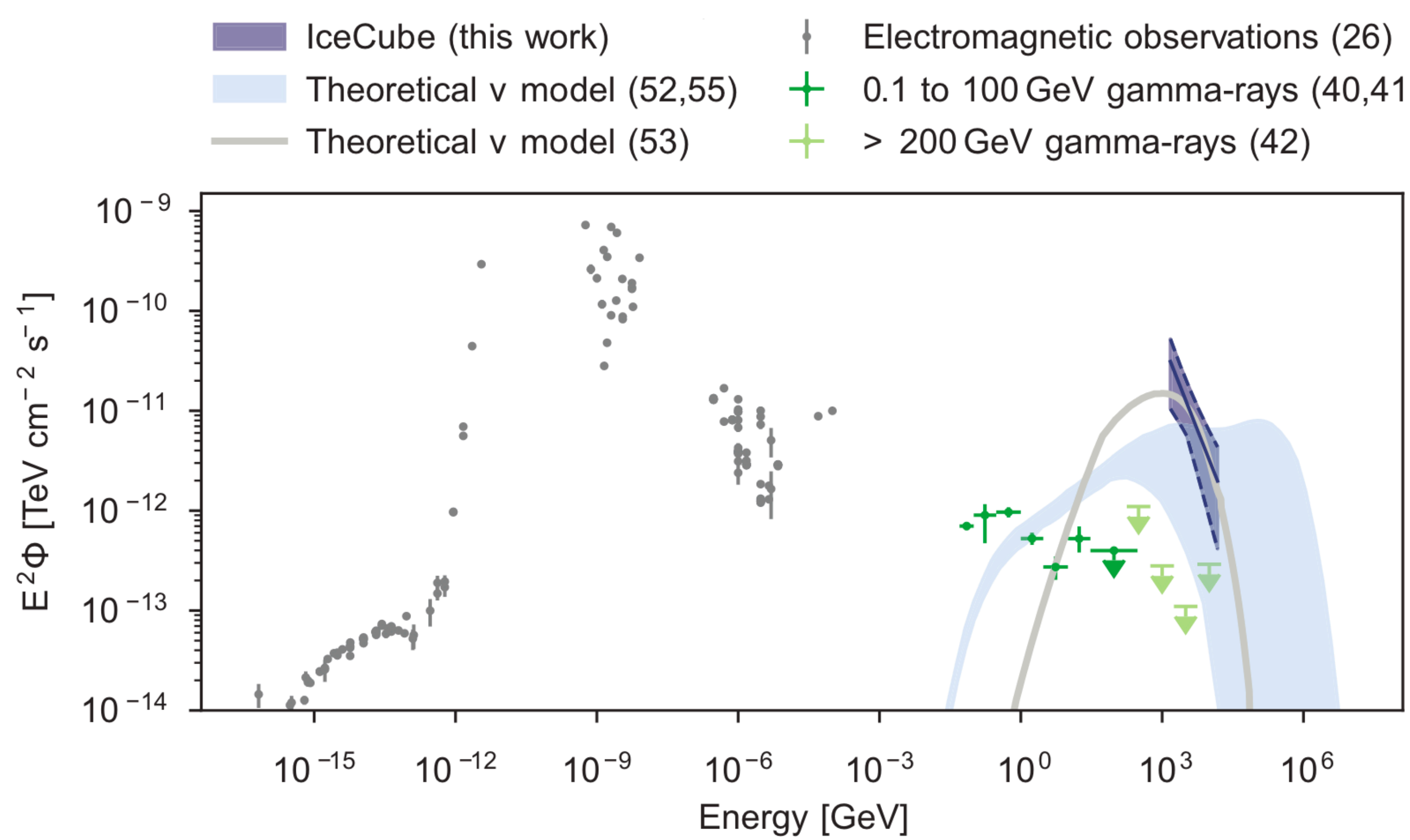

- **Template-based data fit** assuming different models reproducing the GeV gamma-ray Galactic diffuse emission:
  - $\pi^0$ - extrapolation of Fermi-LAT spectrum ($E^{-2.7}$) to VHE;
  - $KRA_\gamma$ - CR propagation with (harder) spatial dependent diffusion;
- Signal excess @ **4.5σ**.
- Galactic flux contribution to total diffuse between **6% and 13%** @ 30 TeV.

# 3. IceCube all-sky scan & catalog-based analysis: an excess from NGC1068

- 10yr time-integrated IceCube data show a 2.9σ hot-spot from the direction of the Seyfert-II galaxy NGC1068, a disk-obscured AGN (no TeV gamma rays detected so far);

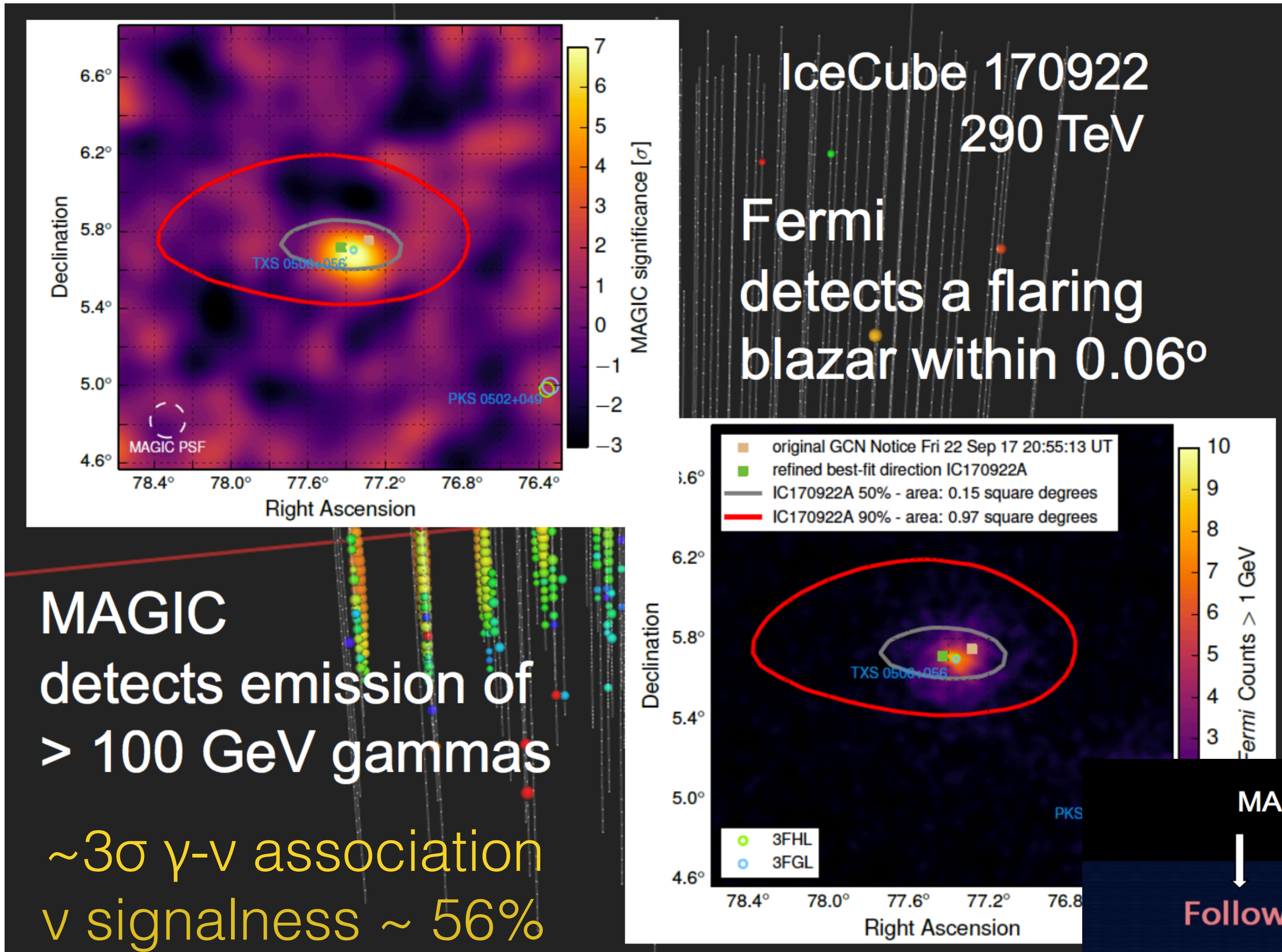
- In catalog-based search, the signal excess amounts to **4.2σ**.




Abbasi et al. [IceCube], Science 378 (2023) 6619

# 4. TXS 0506+056: a flaring blazar

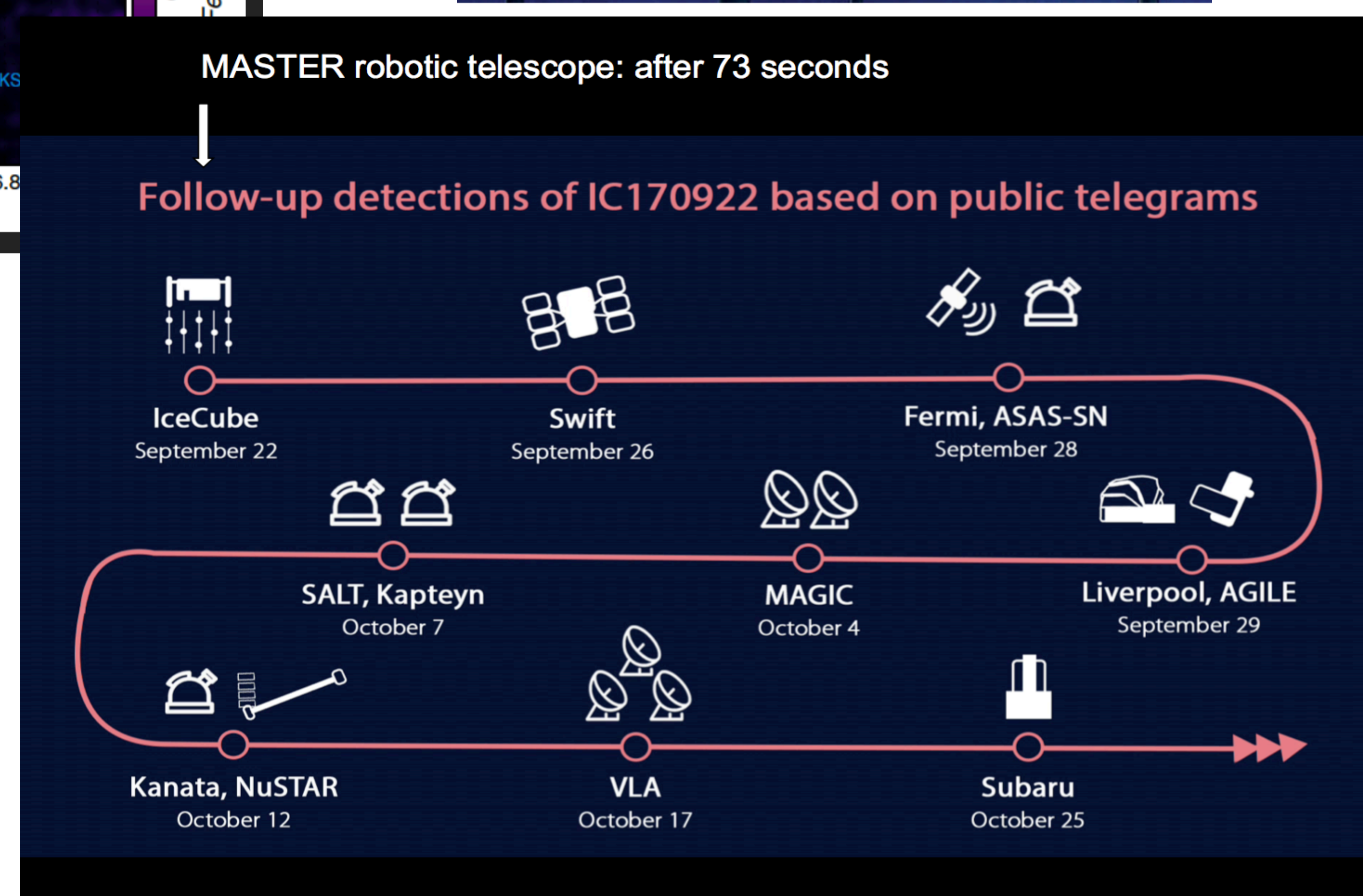




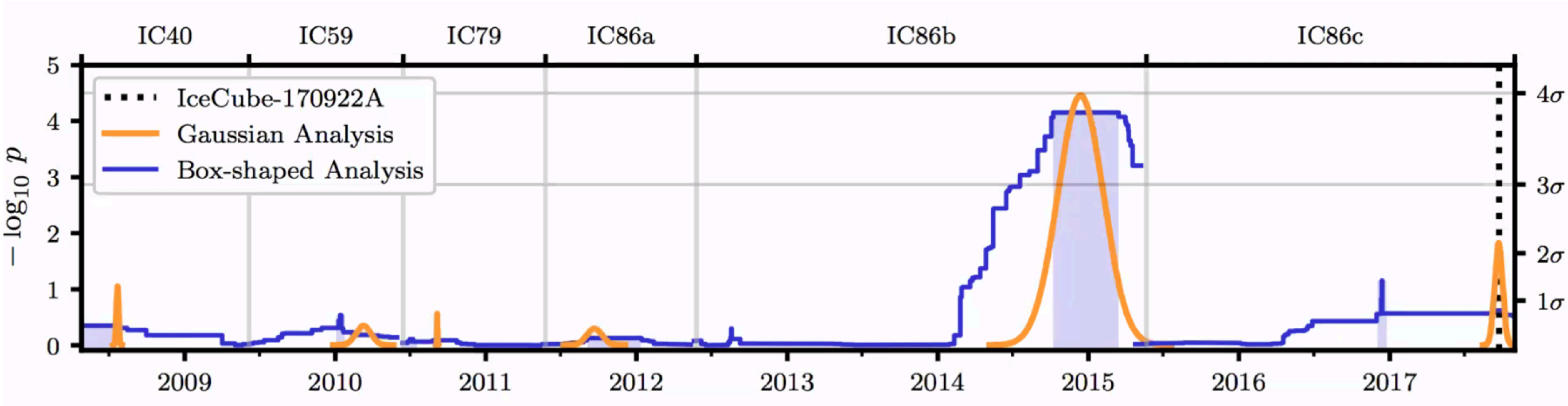
IceCube Coll. et al., Science 361 (2018) eaat1378

A follow up campaign was performed starting from GCN, allowing the identification of the source redshift **z=0.33**

GCN 21916



# 4. TXS 0506+056: a 3σ excess in archival search




- **13±5** events in 110 days
- coincidence probability (**post-trial**): p-value ~2x10$^{-4}$ (~**3.5σ**)
- energy range (68%): **32 TeV - 3.6 PeV**
- $L_\nu > 10^{37}$ erg/s