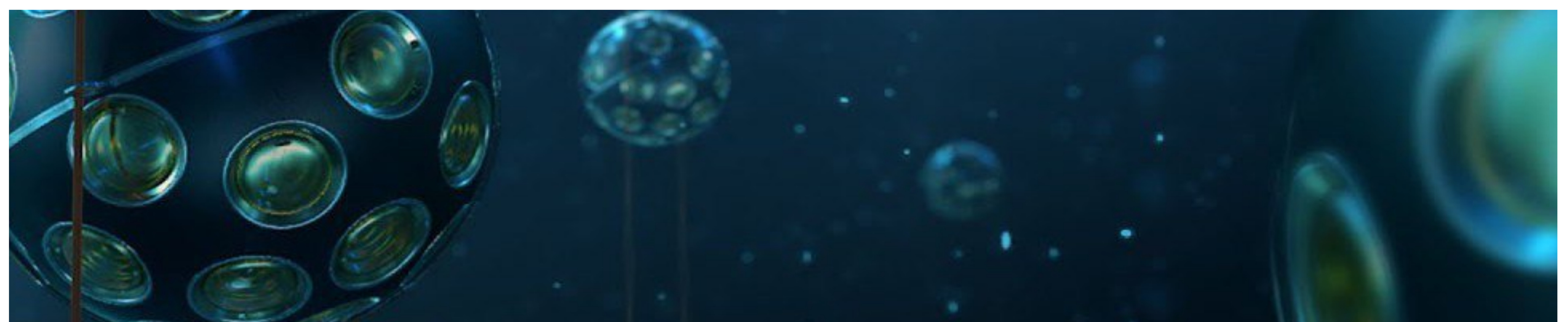




The KM3NeT neutrino detectors: status, results and future perspectives

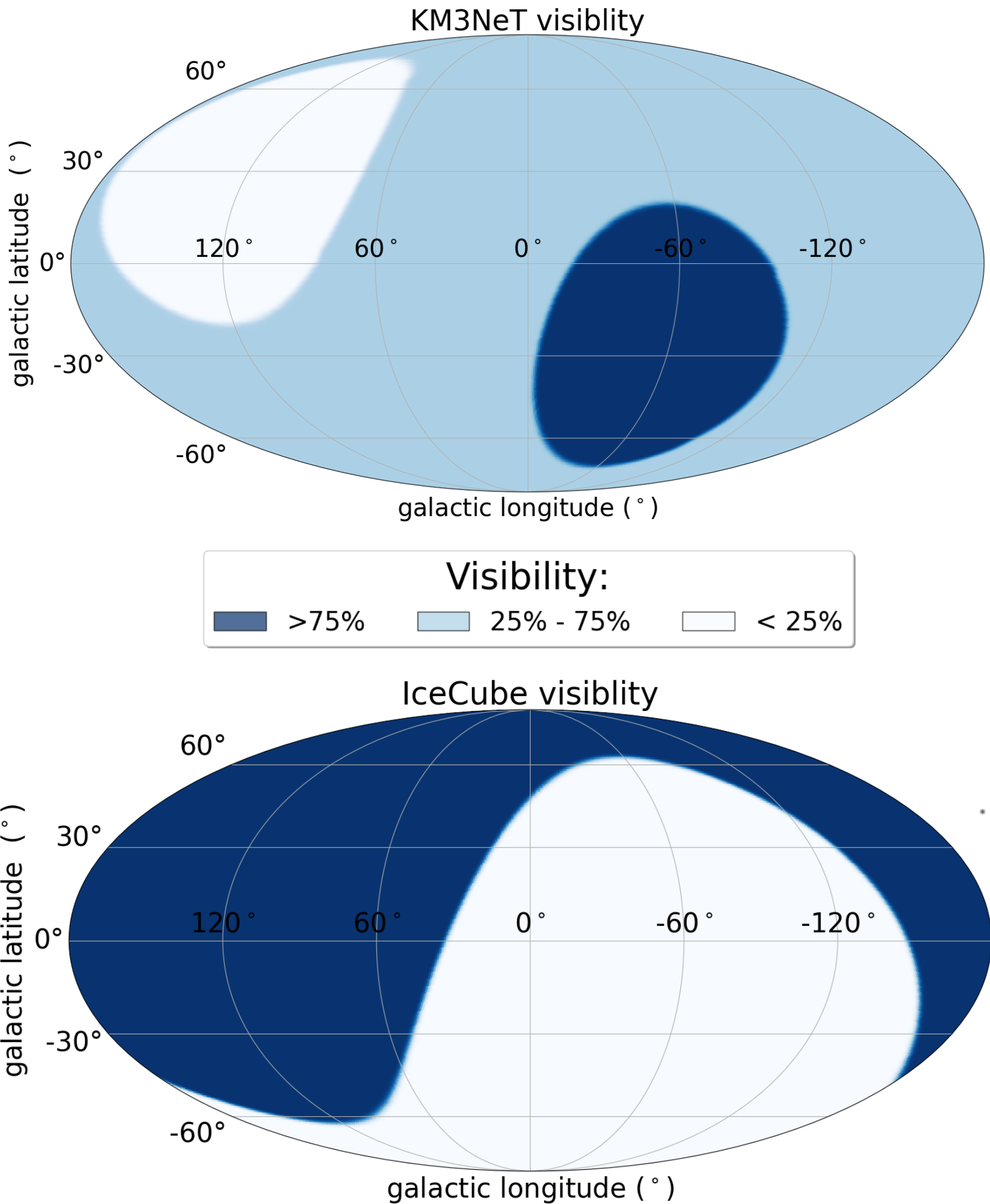
PPC conference, 31/08 - 04/09 Sydney

Francesco Filippini
on behalf of the KM3NeT Collaboration

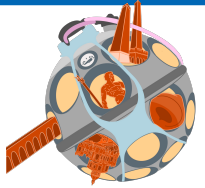
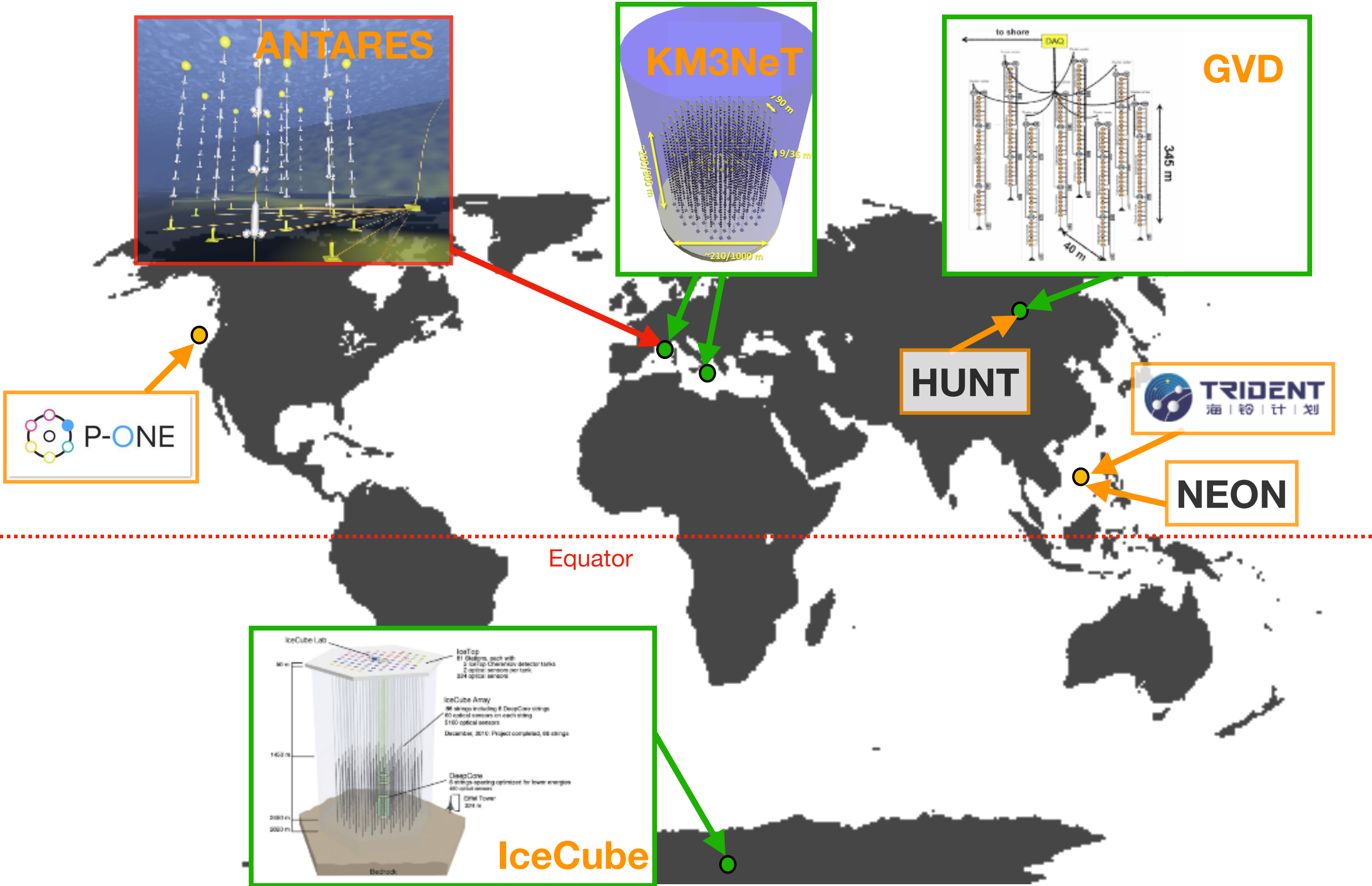
francesco.filippini@bo.infn.it



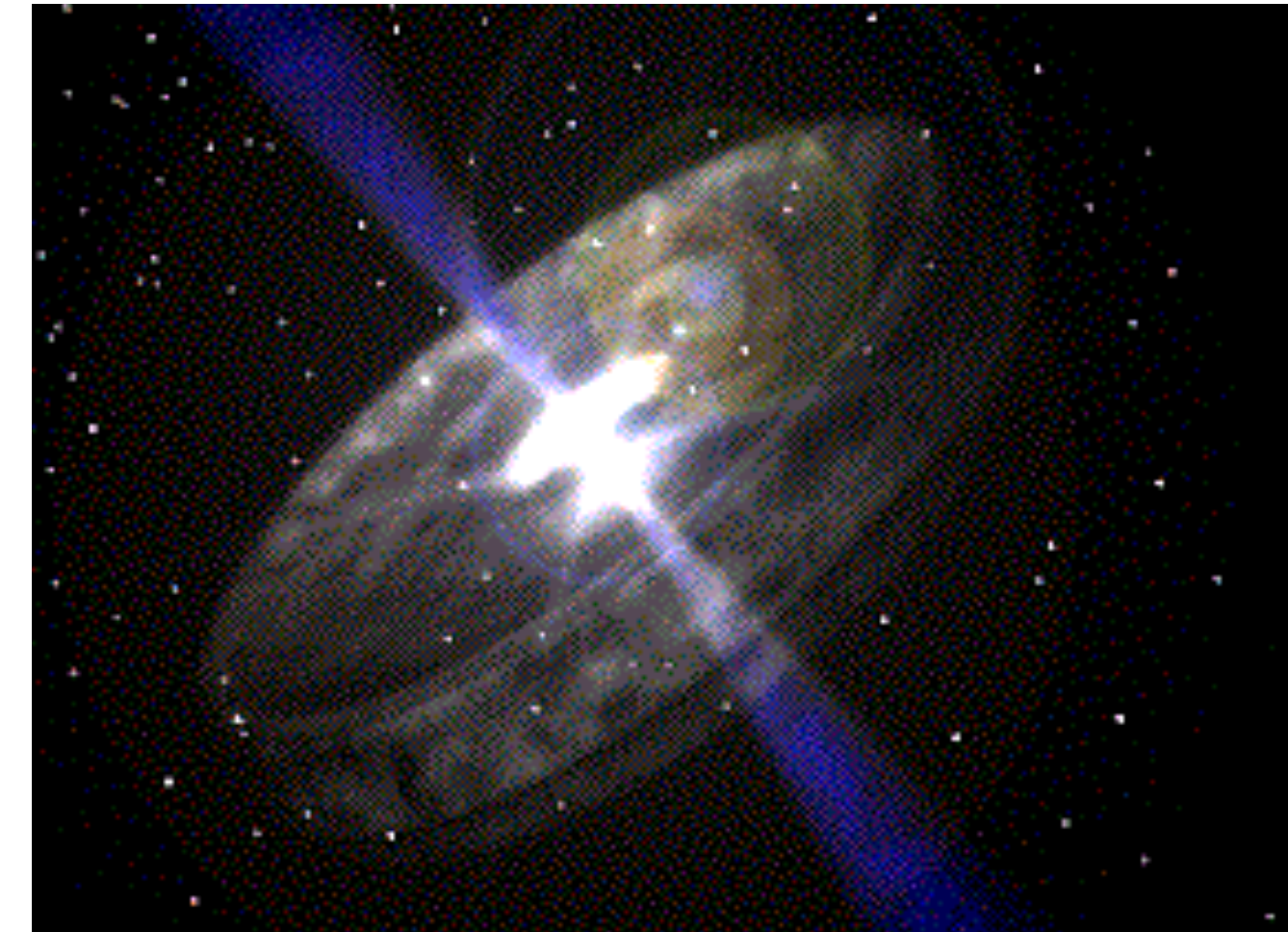
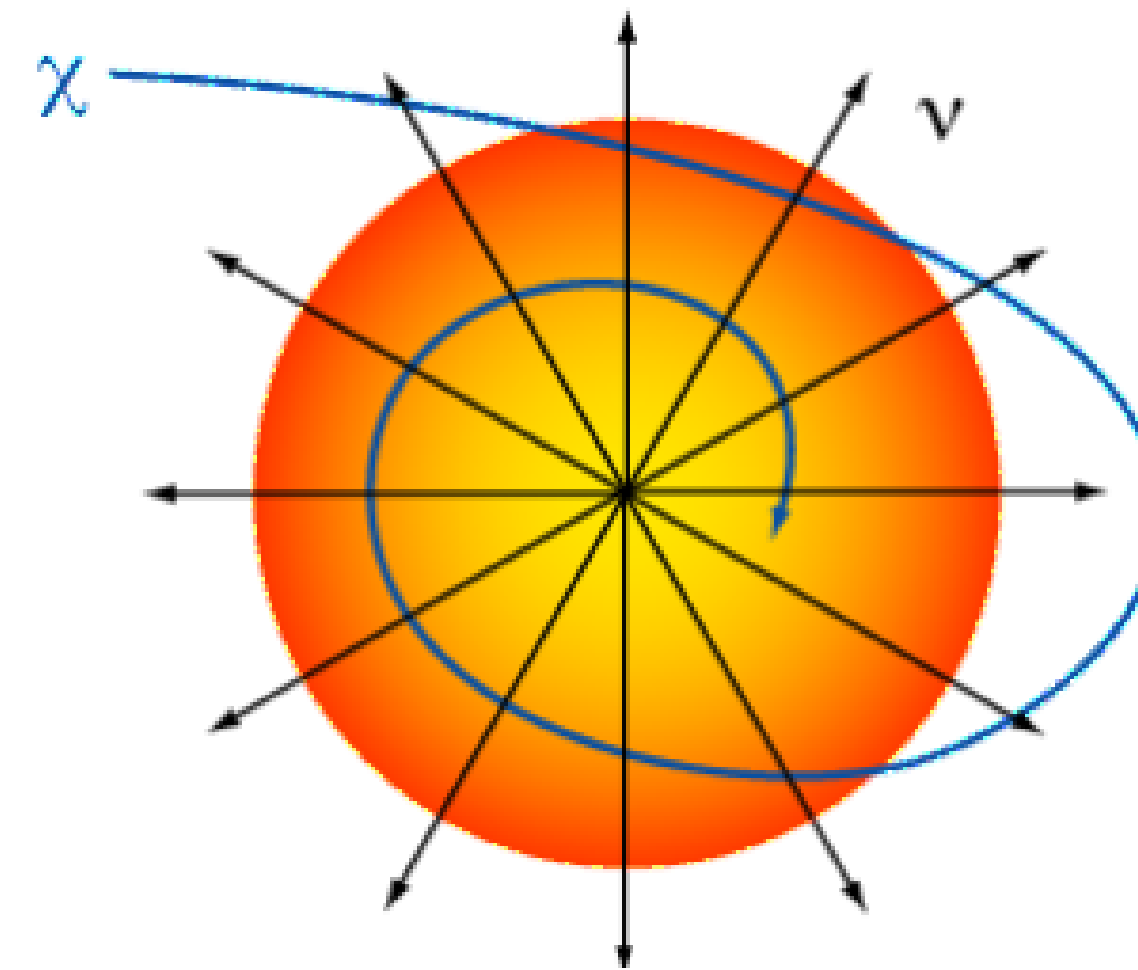
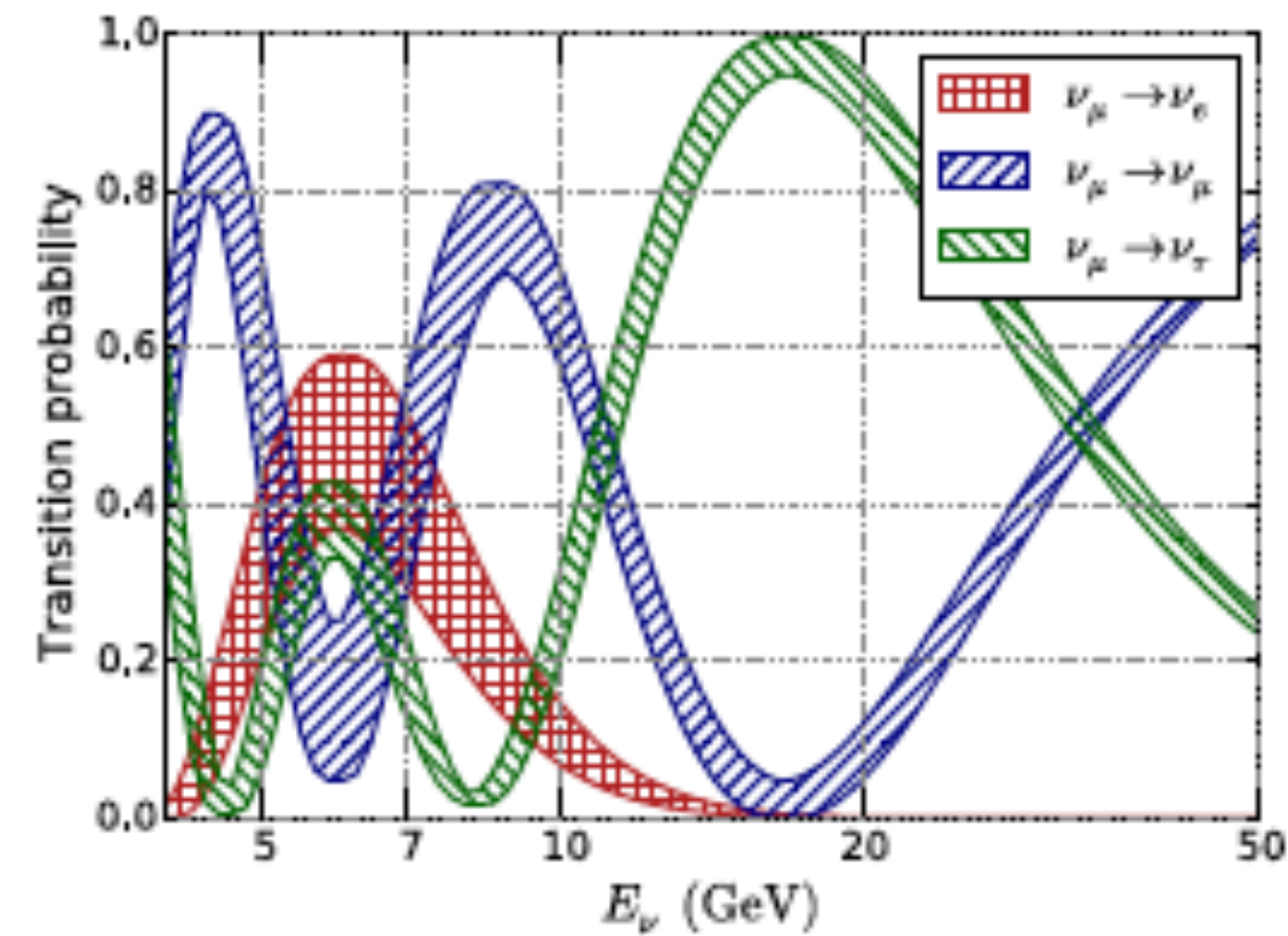
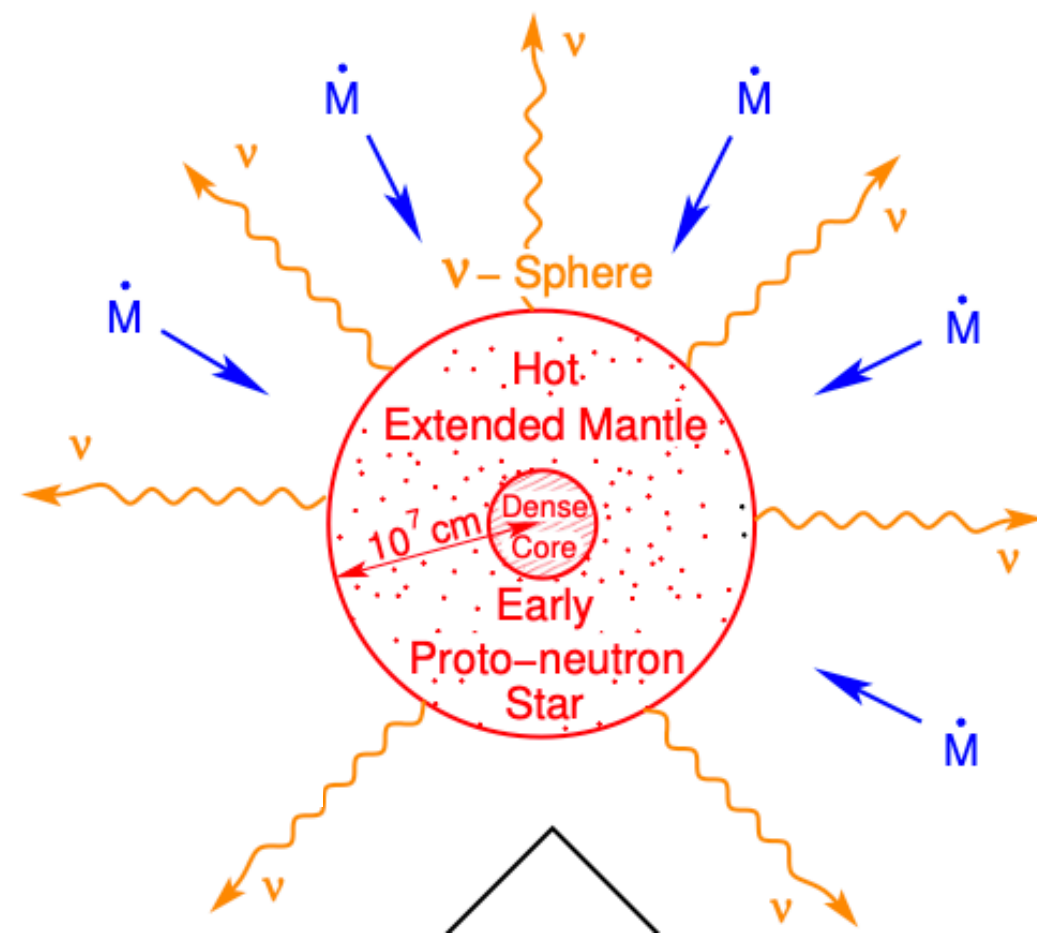
Neutrino telescopes



Visibility over a sidereal day for up-going events.



Neutrino astronomy: astrophysics cases



Super Novae explosion
MeV

Neutrino oscillation
GeV

Dark Matter
GeV-TeV

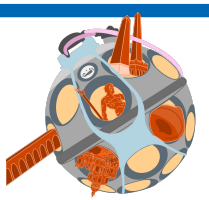
HE neutrinos, CRs
Multi-messenger program
TeV-PeV

ORCA

ARCA

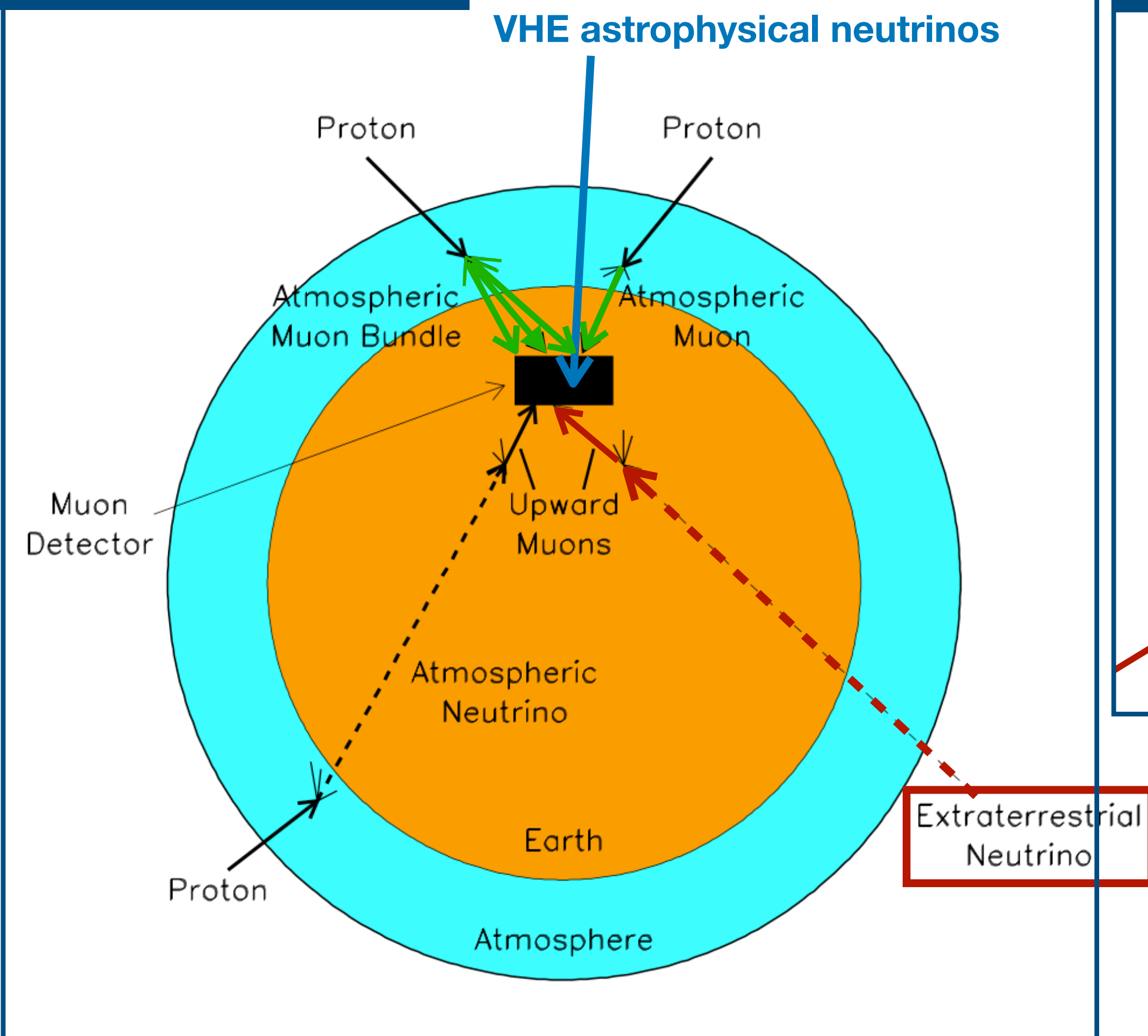
ARCA

To learn more about DM searches, don't miss Rebecca's talk tomorrow at 15:15 in G01!



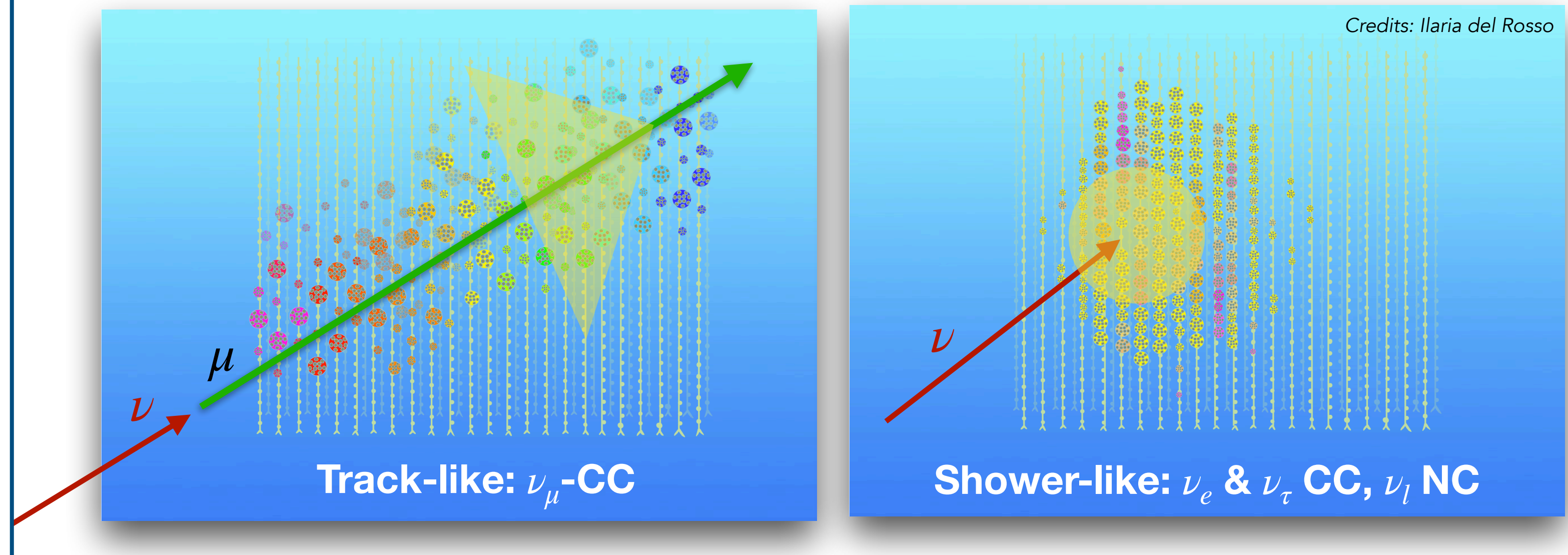
Detection principle and event topology

Detection principle



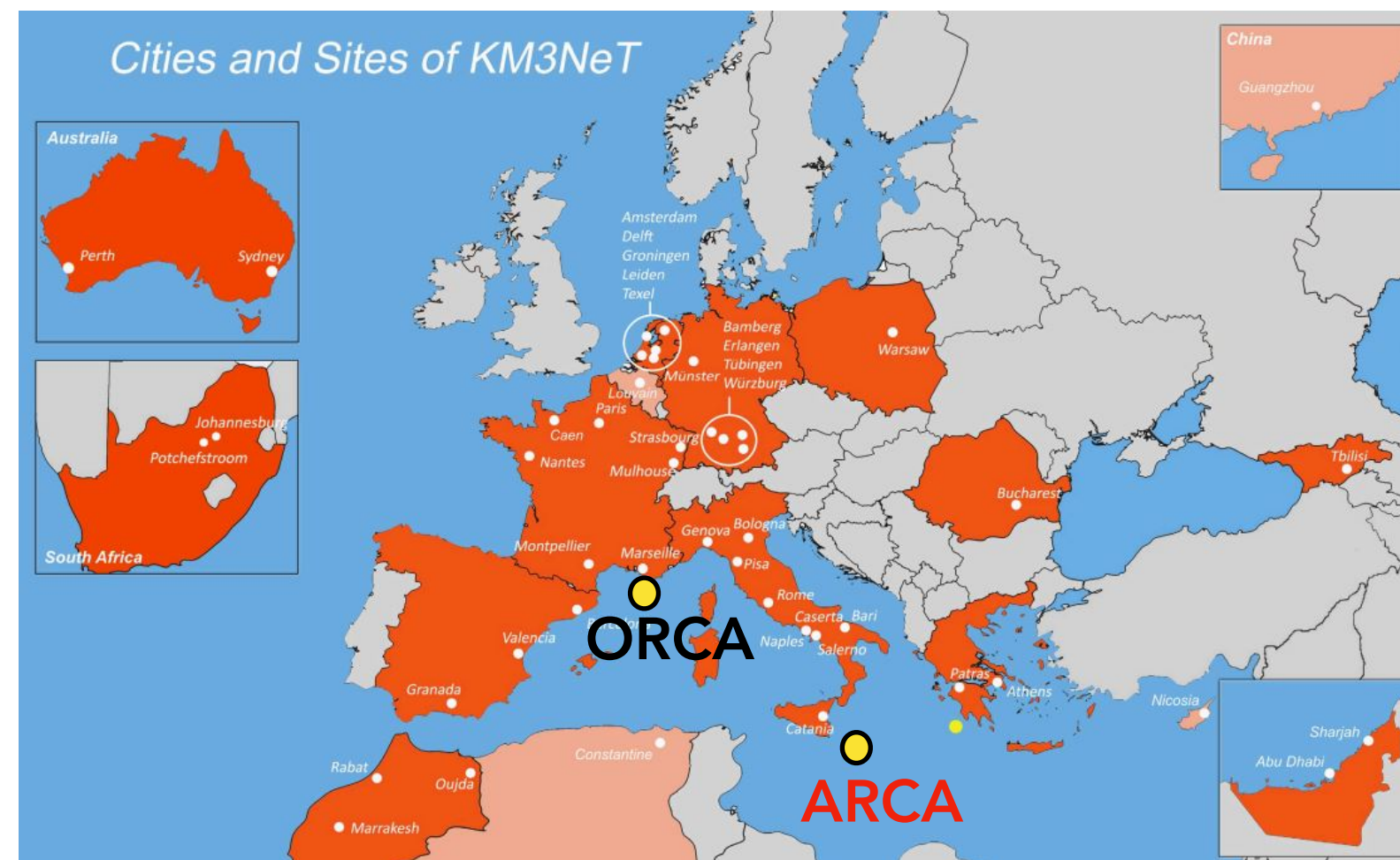
- Atmospheric muon flux $\sim 10^6$ bigger than neutrino flux.
- Earth becoming opaque for $E_\nu > 200 \text{ TeV}$.

Event topology



- ν_μ -CC: outgoing muon. Precise direction determination ($< 1^\circ$): **track-like events**.
- ν_e -CC, ν_l -NC: electromagnetic and hadronic showers. Precise energy determination. Poorer direction determination: **shower-like events**.
- ν_τ -CC: outgoing τ that decay. If both showers contained in the detector: **double-bang** topology.

KM3NeT

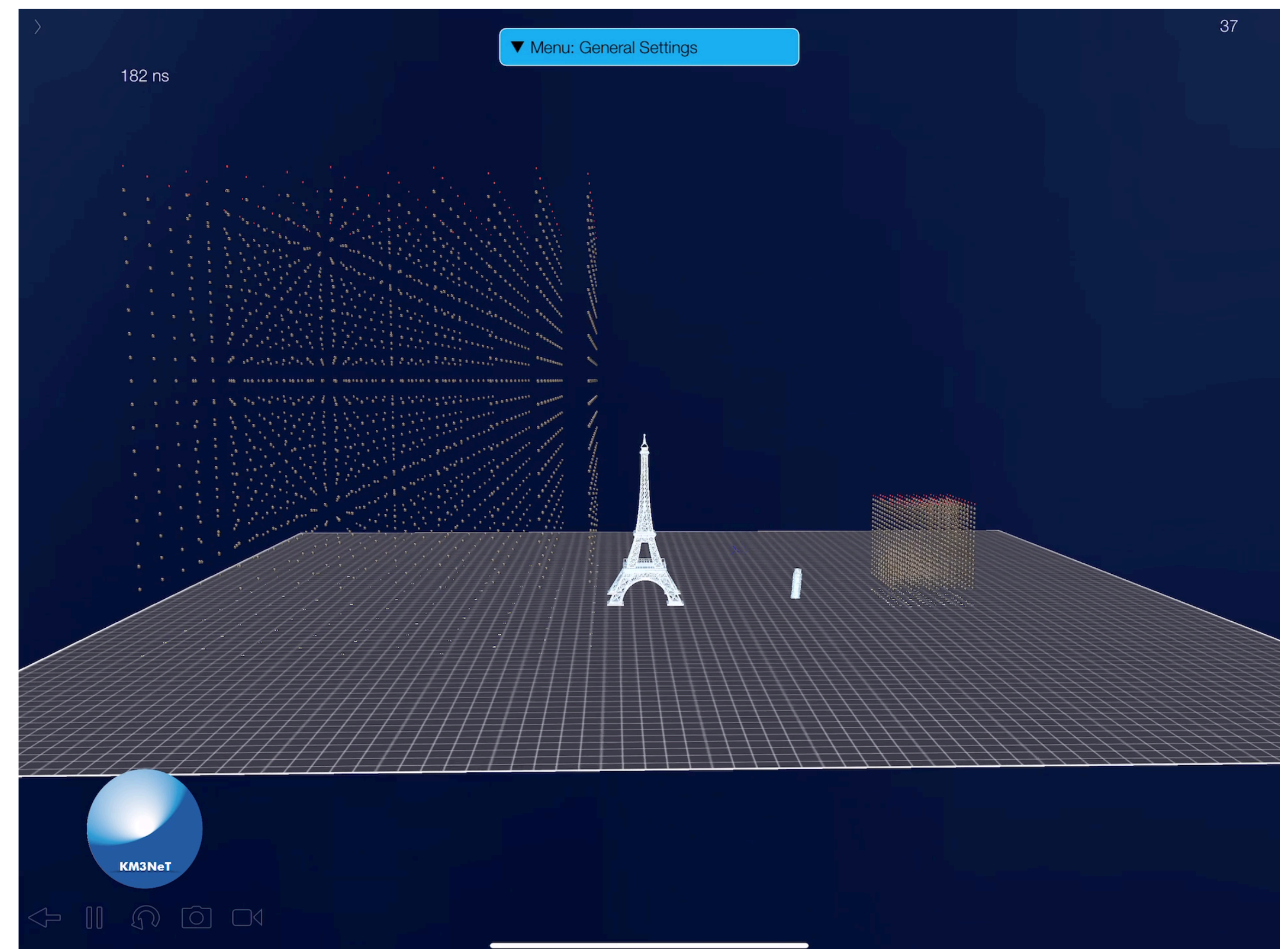
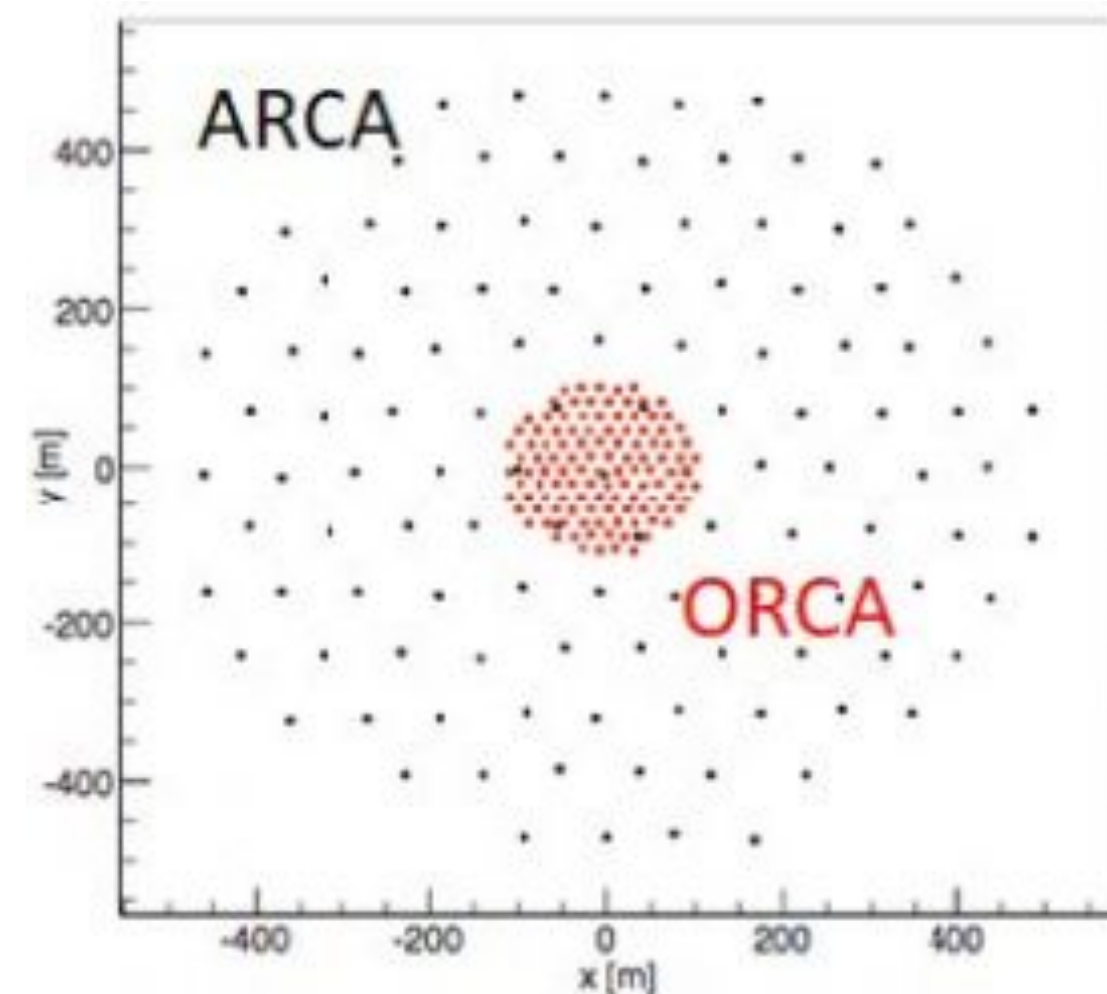


Two detectors, same technology, different layout and physics objectives.

- KM3NeT/ORCA: *O*scillation *R*esearch with *C*osmics in the *A*byss.
- KM3NeT/ARCA: *A*stroparticle *R*esearch with *C*osmics in the *A*byss.



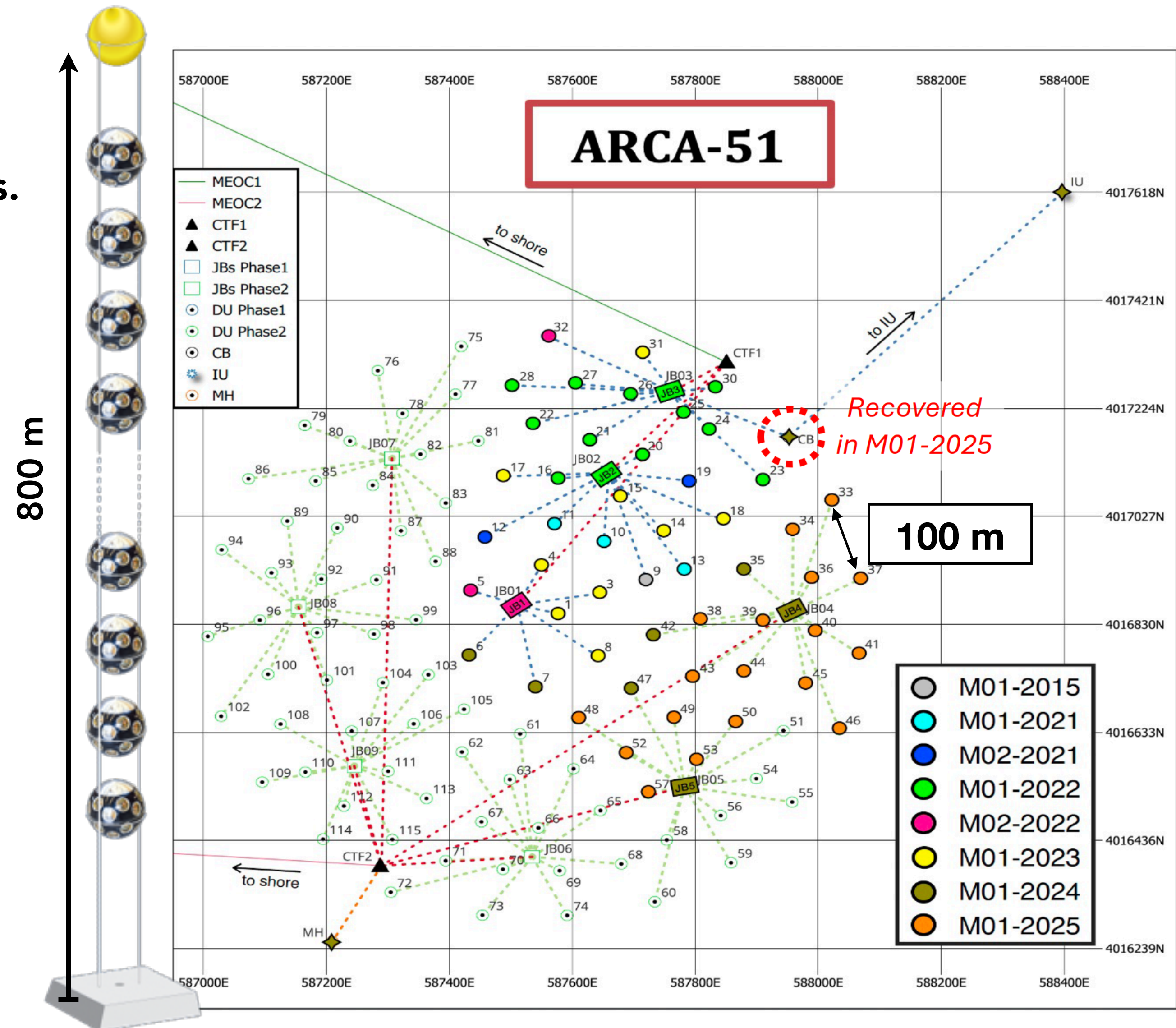
Digital Optical Module (DOM):
31 x 3' PMTs
+ sensors for calibration porpoises



KM3NeT/ARCA current status

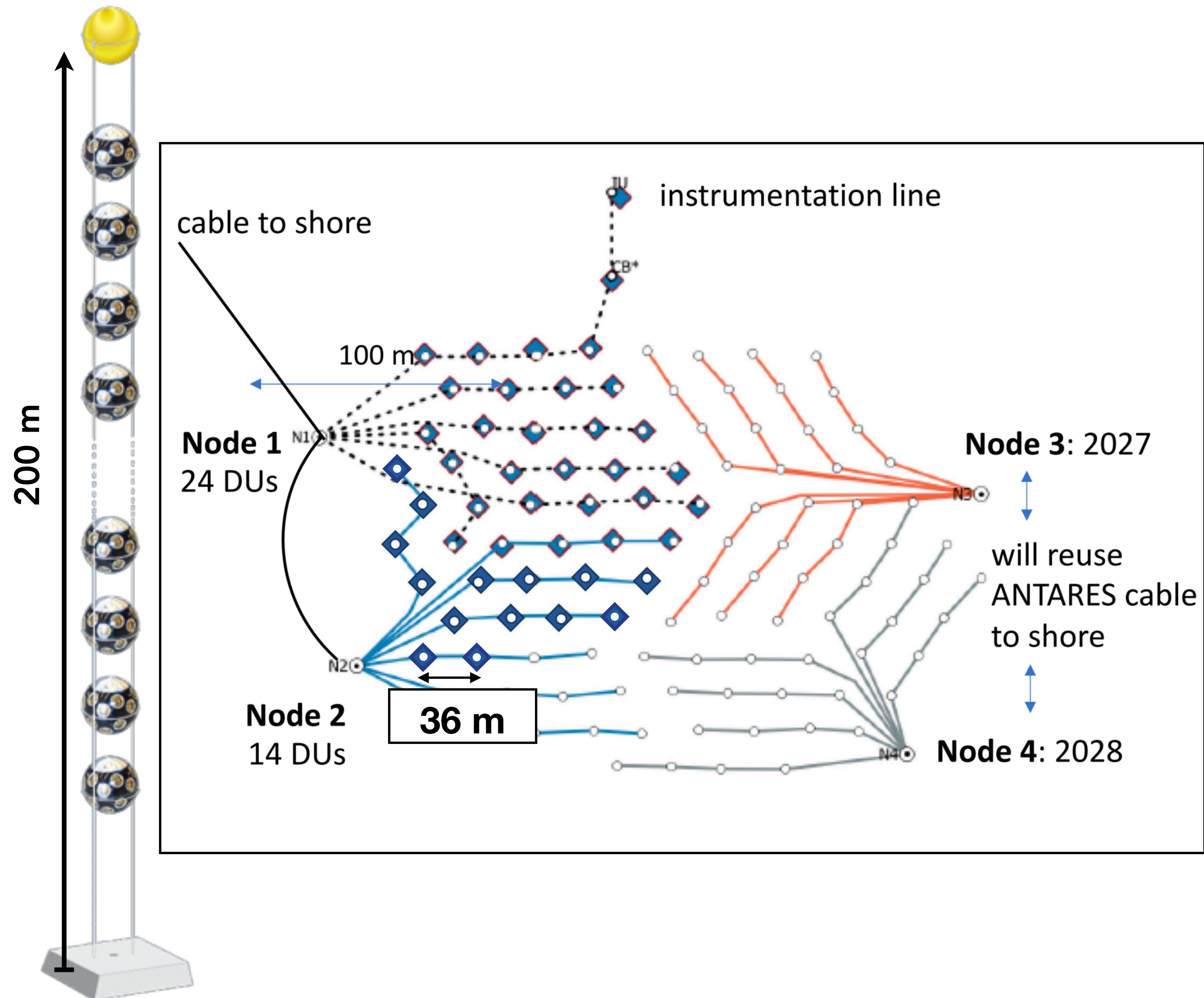
- **Sparse 3D array of DOMs targeting TeV-PeV neutrinos.**
- 100 km off-shore Capo Passero, Sicily.
- 3.5 km depth.
- Currently installed **51 Detection Units (DUs)**.
- **Final goal: 198 DUs** instrumenting 1 Gton (1 km^3), over two building blocks.

A new sea campaign to deploy more DUs is currently underway.

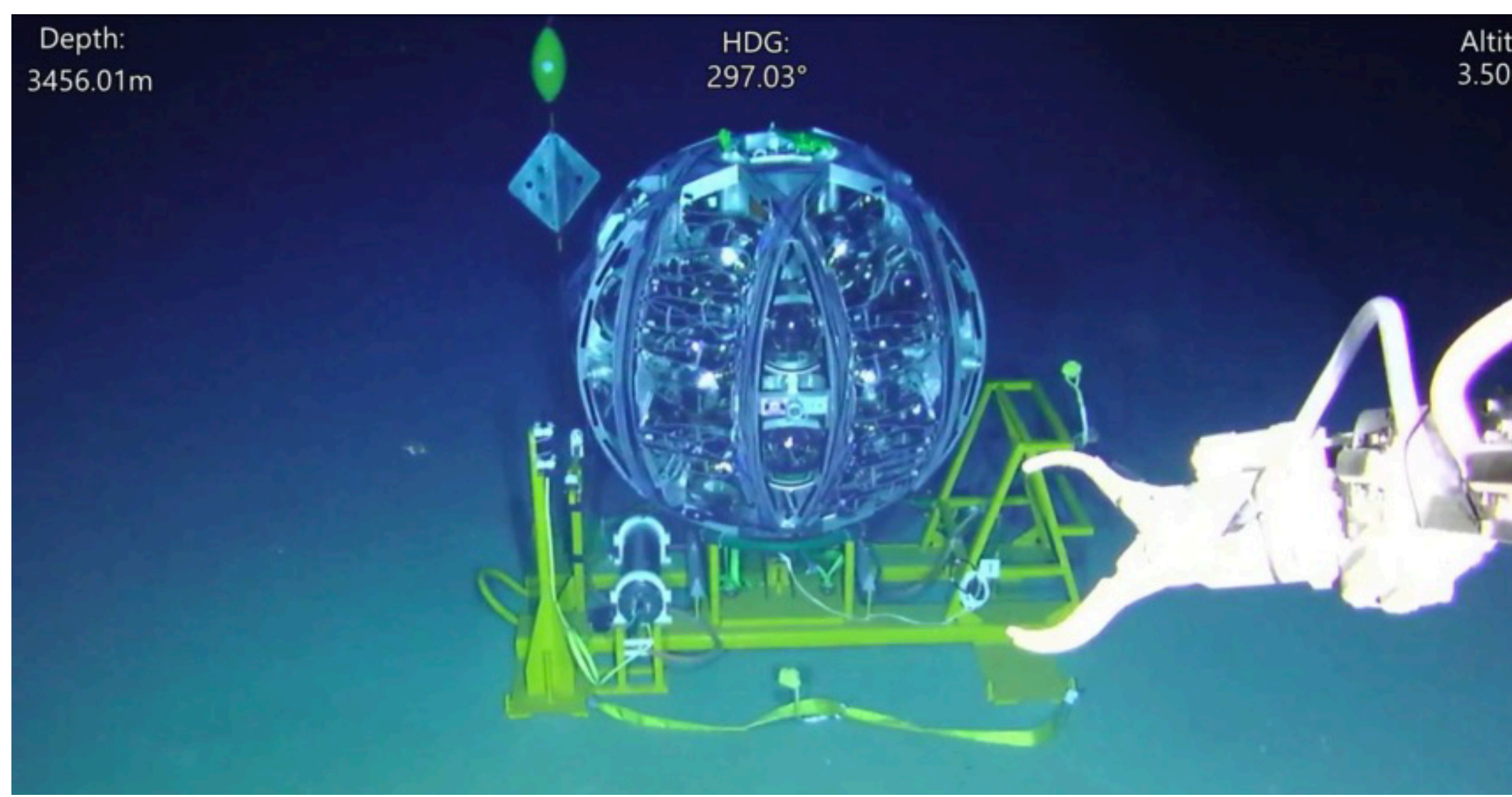
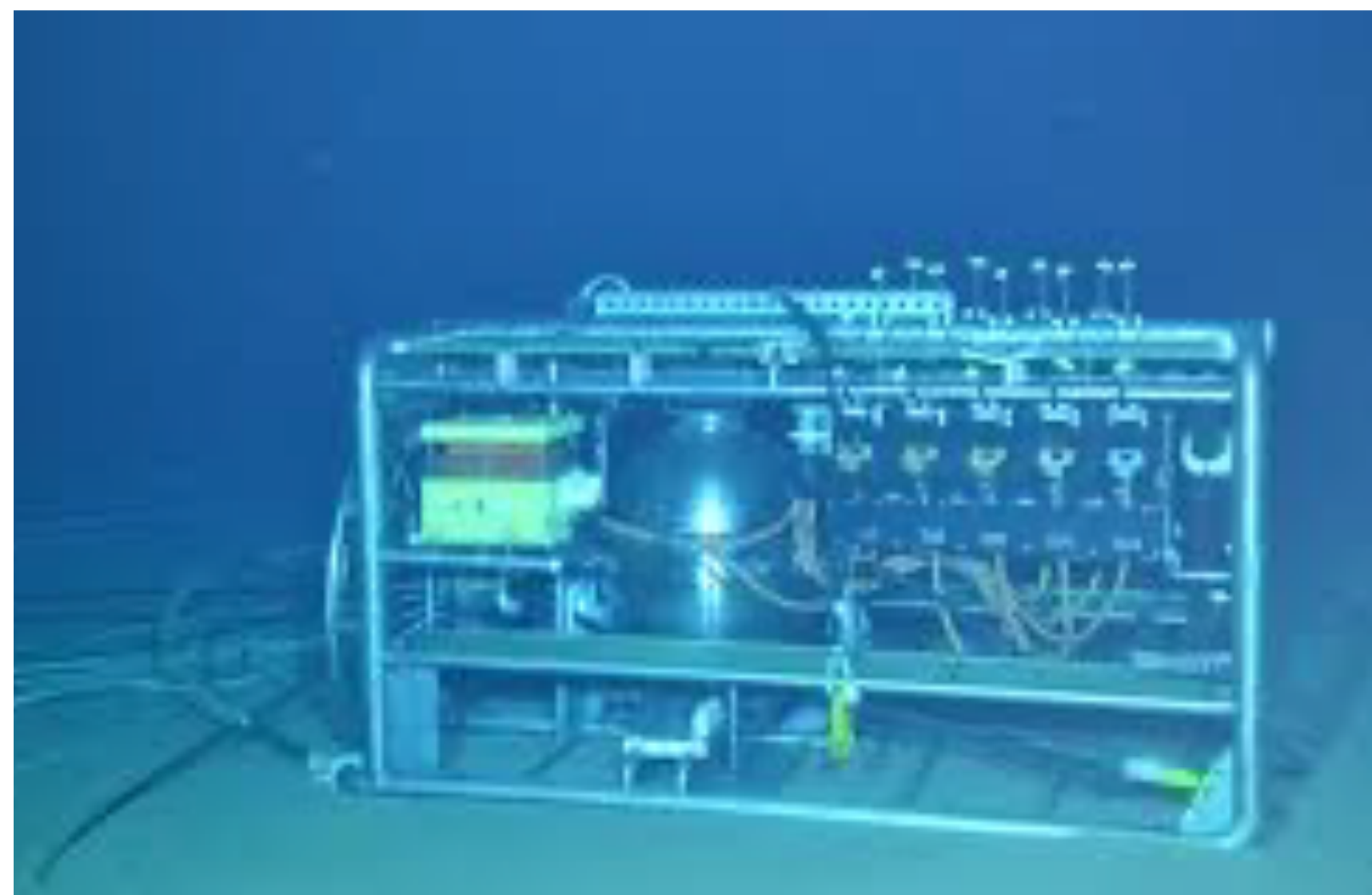
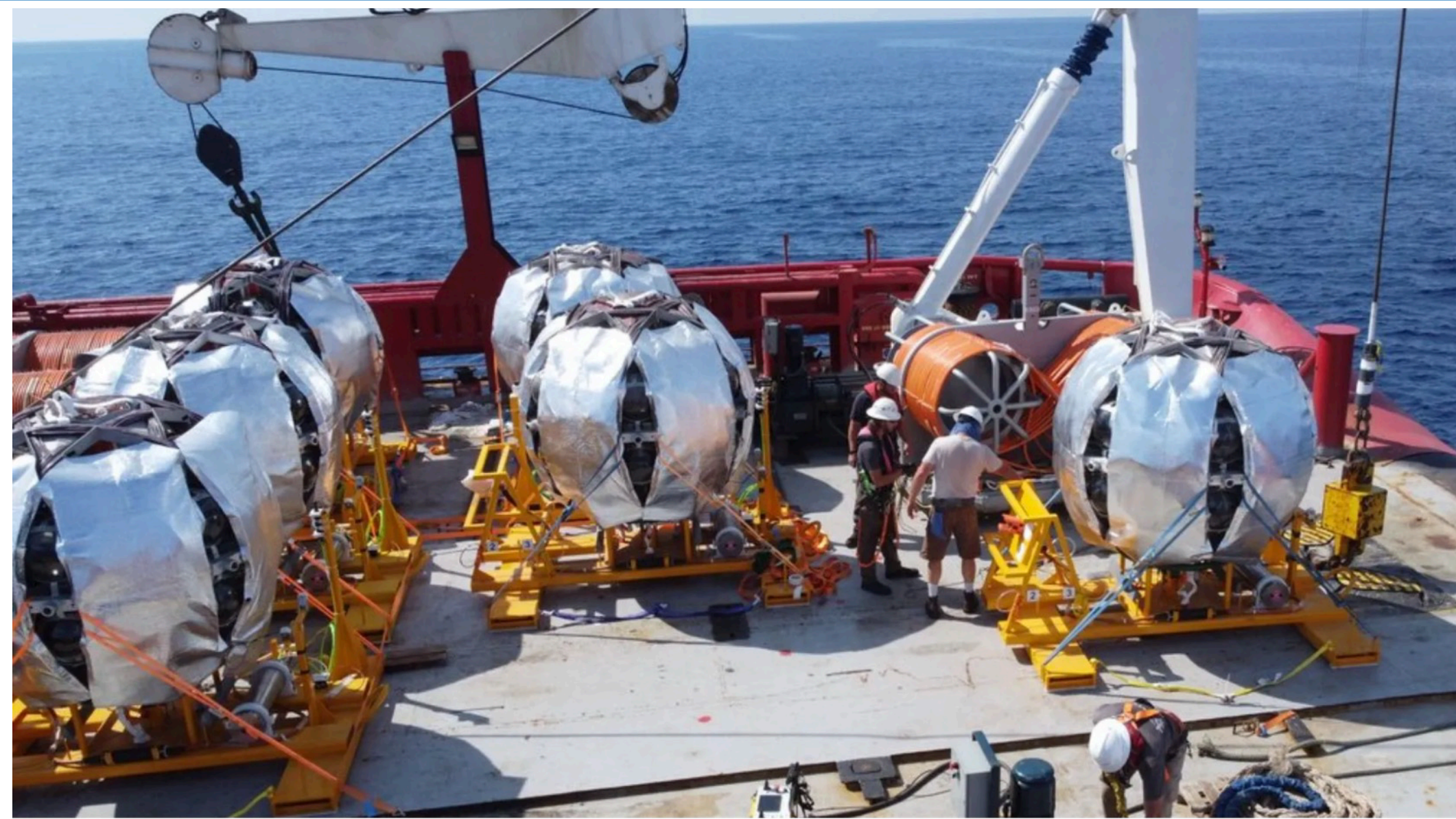


KM3NeT/ORCA current status

- **Dense 3D array of DOMs targeting few GeV - TeV atmospheric neutrinos.**
- 40 km off-shore Toulon, France.
- 2.5 km depth.
- Currently installed **42 DUs**.
- **Final goal: 108 DUs** reaching $\sim 6.5\text{t}$ fiducial mass.



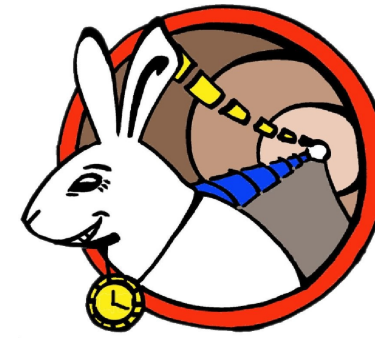
Deployment of detection units



More details @
[JINST 15 \(2020\) P11027](#)

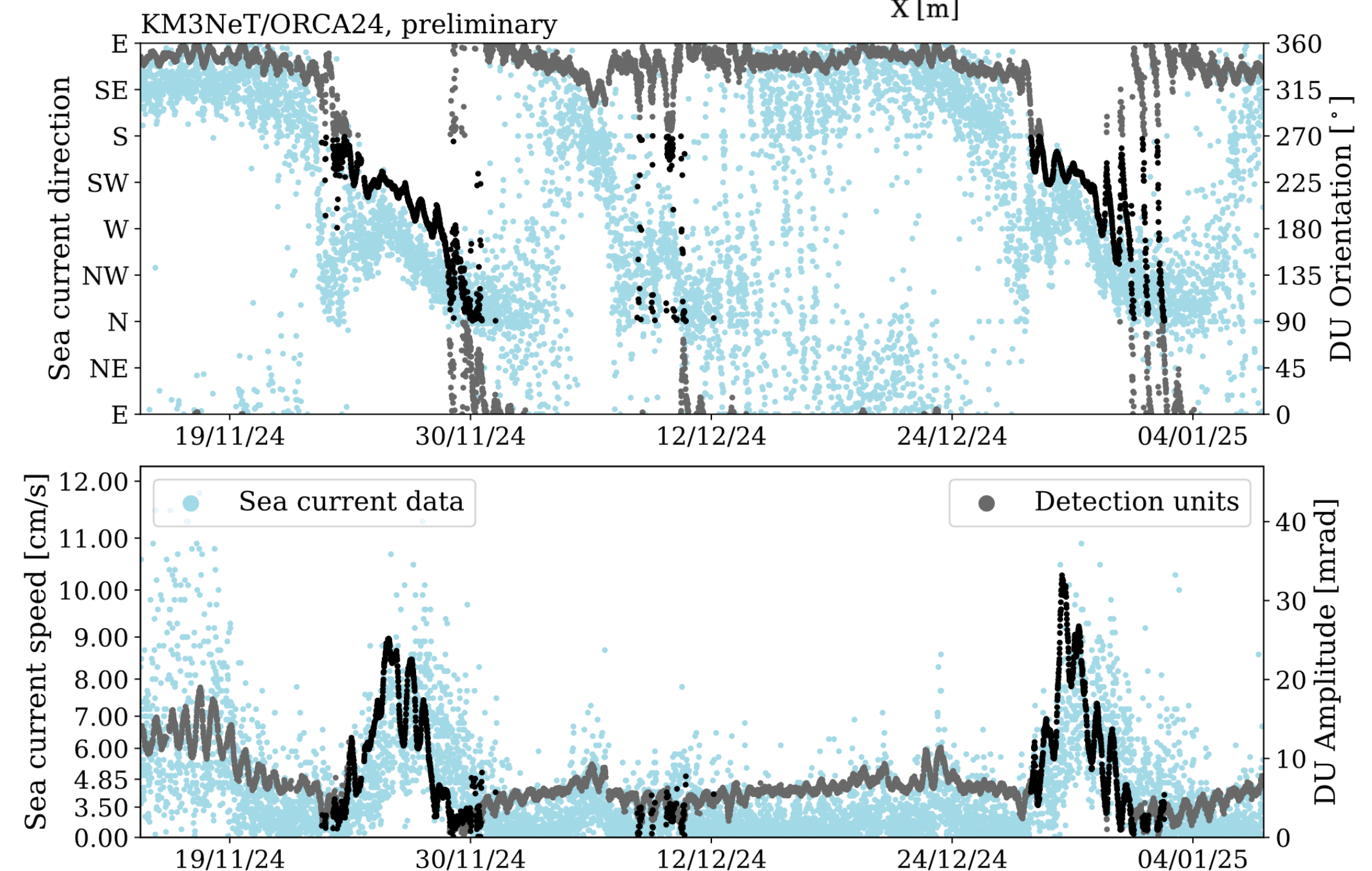
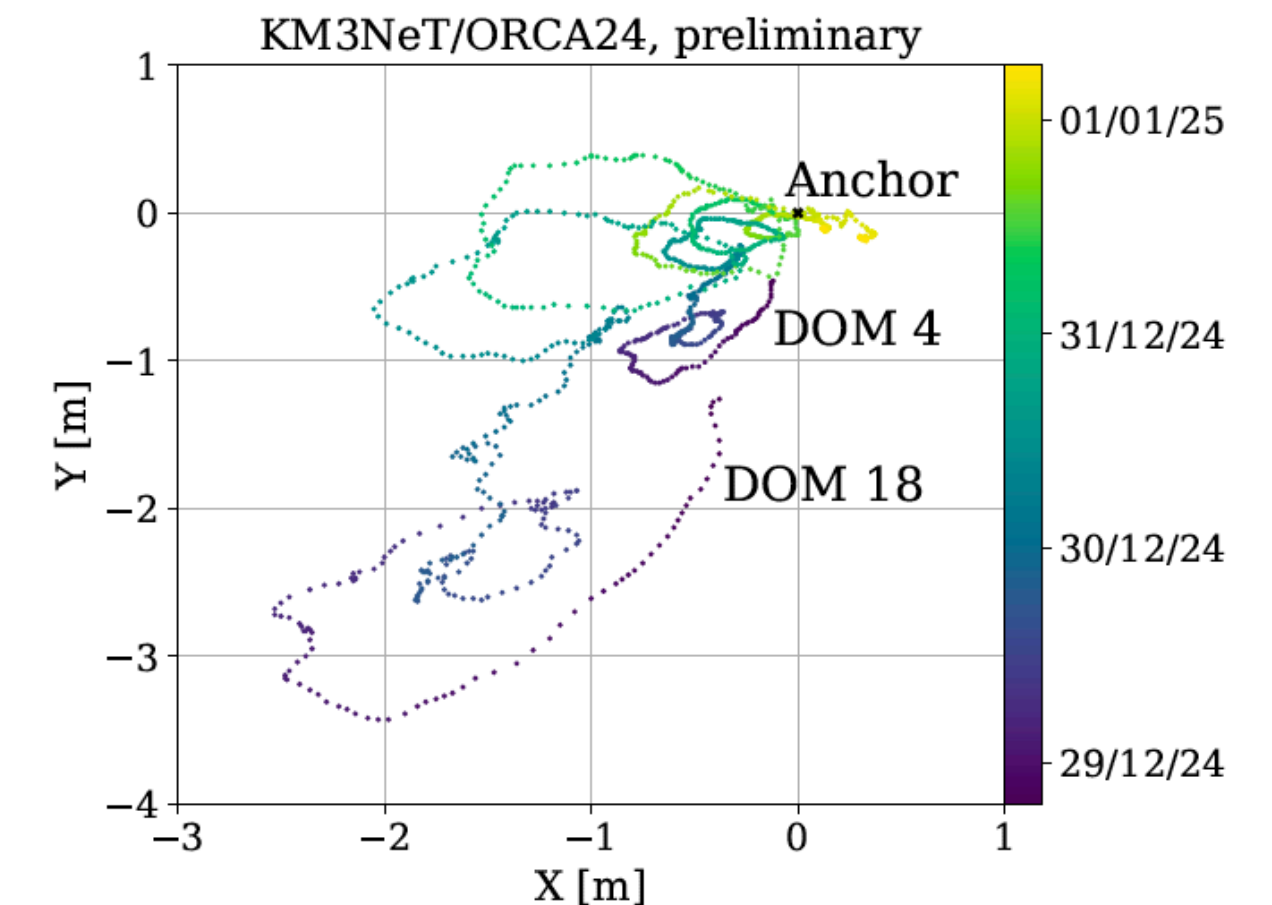
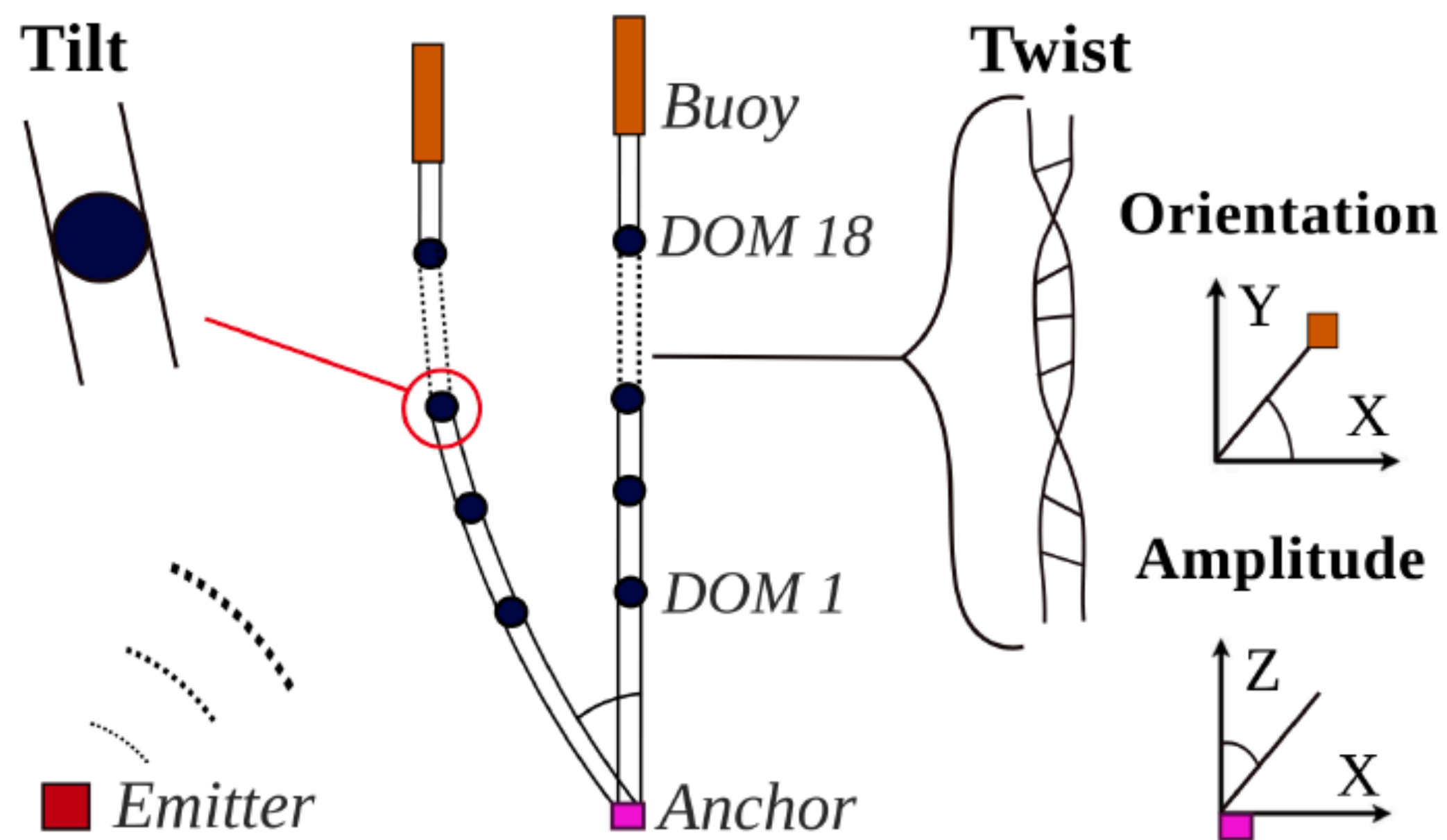
Calibration in KM3NeT

- **White rabbit protocol** to reach ns time-synchronization among DOMs and base module [pos\(ICRC2025\)1137](#).

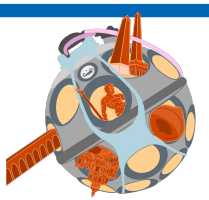


[white-rabbit](#)

- DUs move with variable sea current → System of **acoustic emitters** + receivers, **compasses** to know DOMs position and orientation with 20 cm accuracy [pos\(ICRC25\)1095](#).

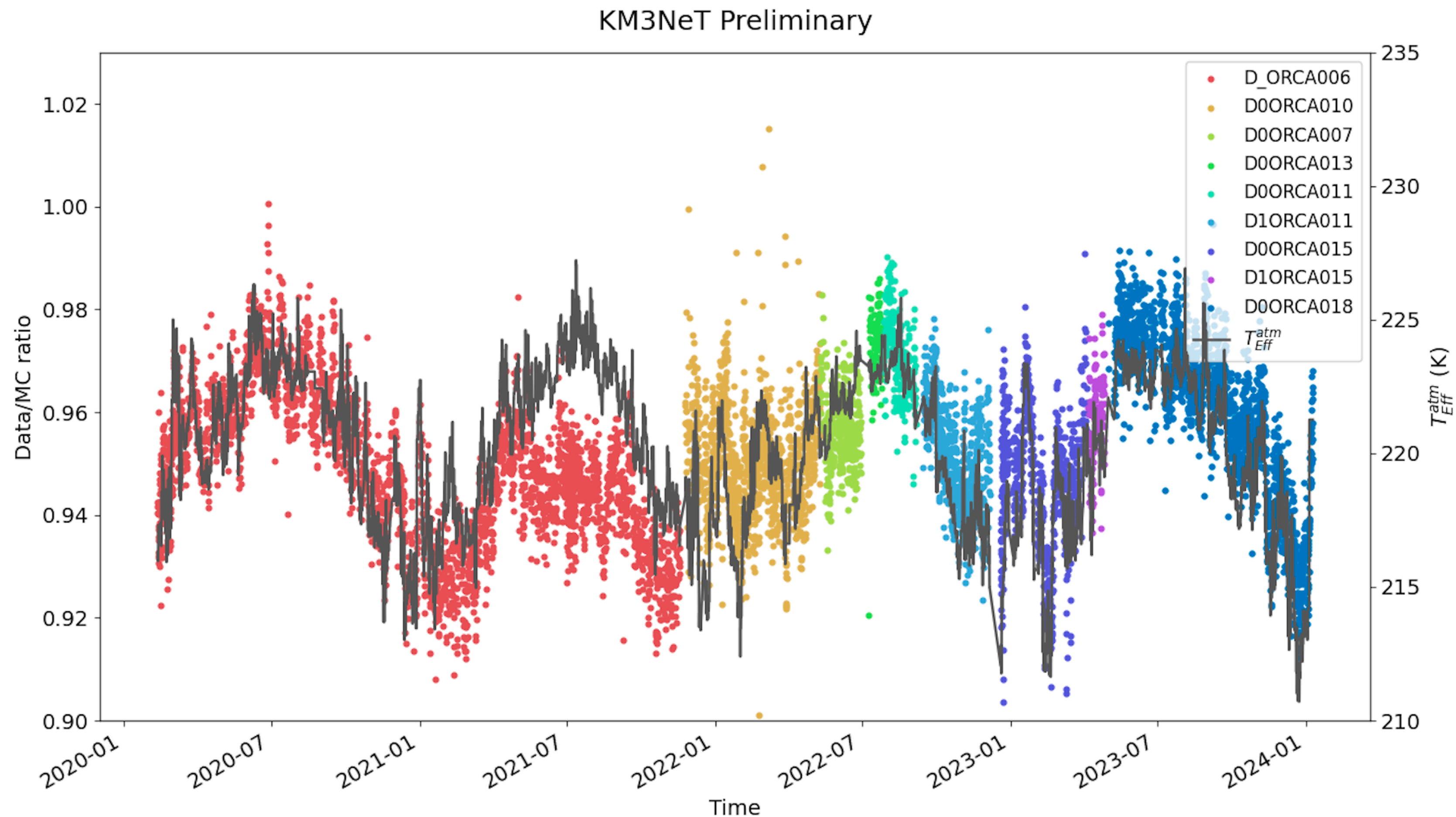


ATMOSPHERIC MUONS



DATA/MC: seasonal modulation

Clear evidence of **seasonal modulation in the atmospheric muon rate** due to temperature variation.
Stable data/Monte Carlo ratio over different detector geometries over 4 years.



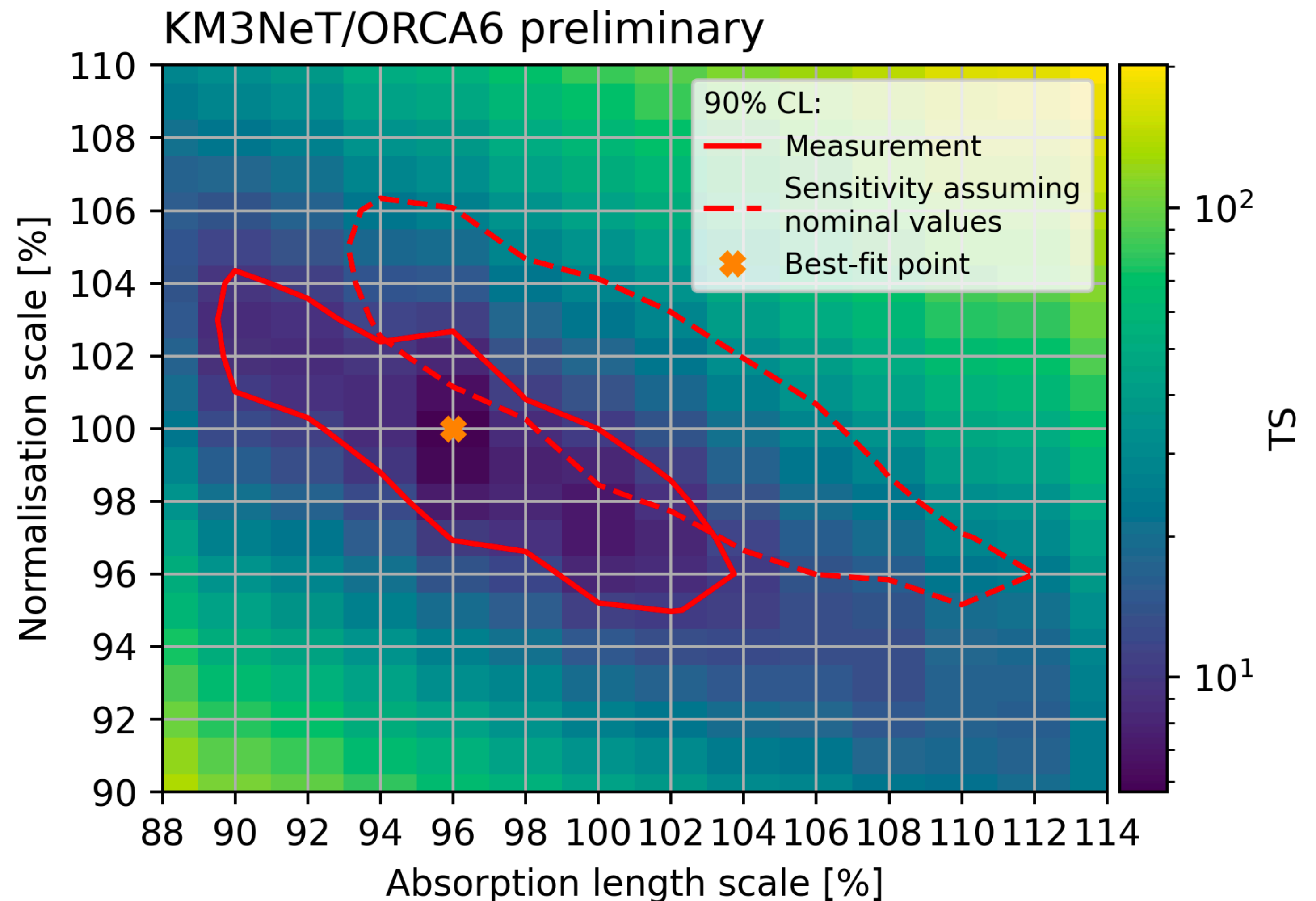
Stopping muons

Stopping muons: minimum ionizing particle.

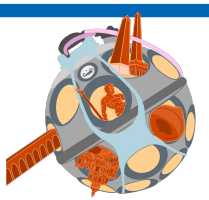
Very clear light emission profile

→ in-situ measurement of water properties.

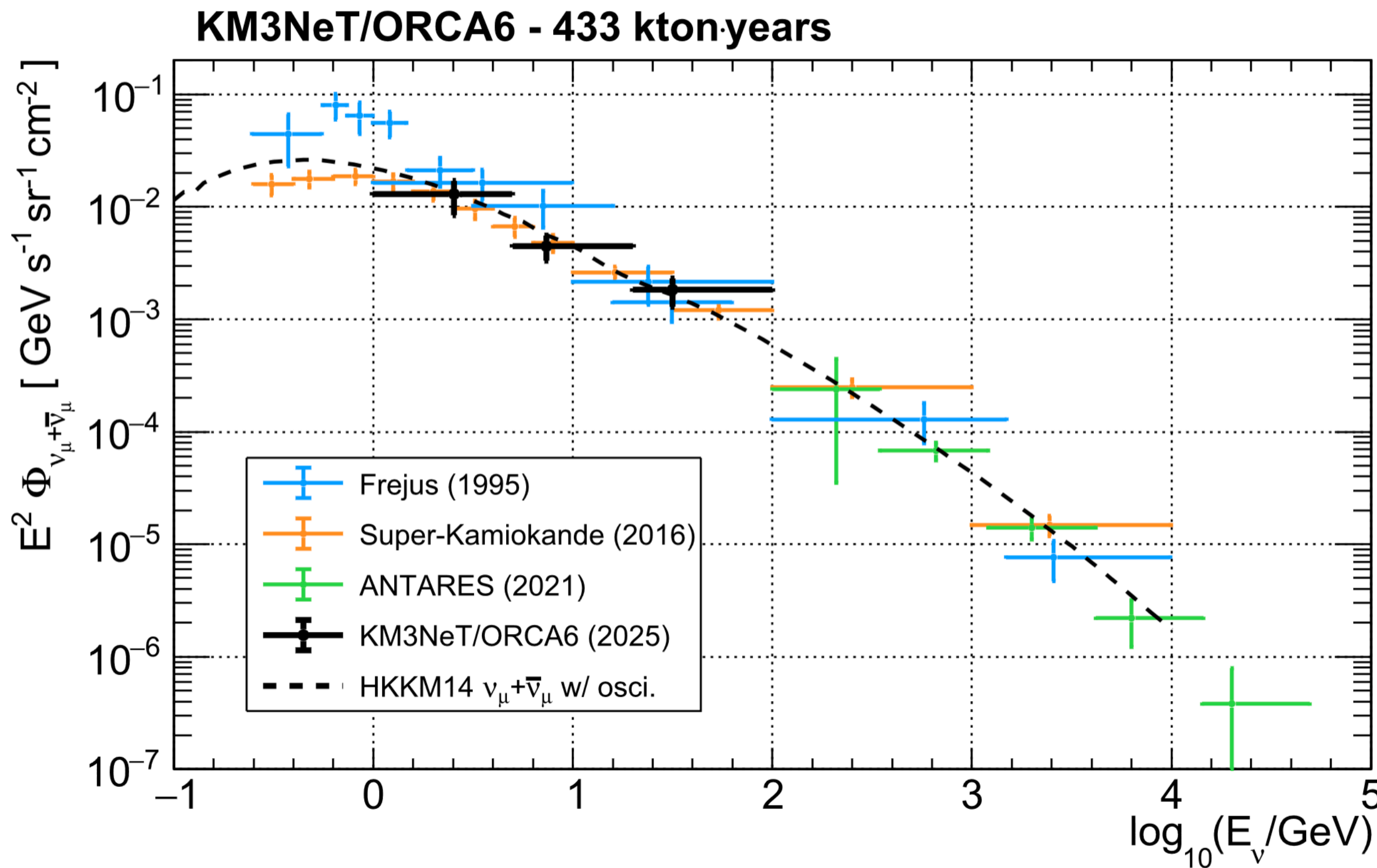
[pos\(ICRC25\)1158](#)



ATMOSPHERIC NEUTRINOS



Atmospheric neutrino flux measurement

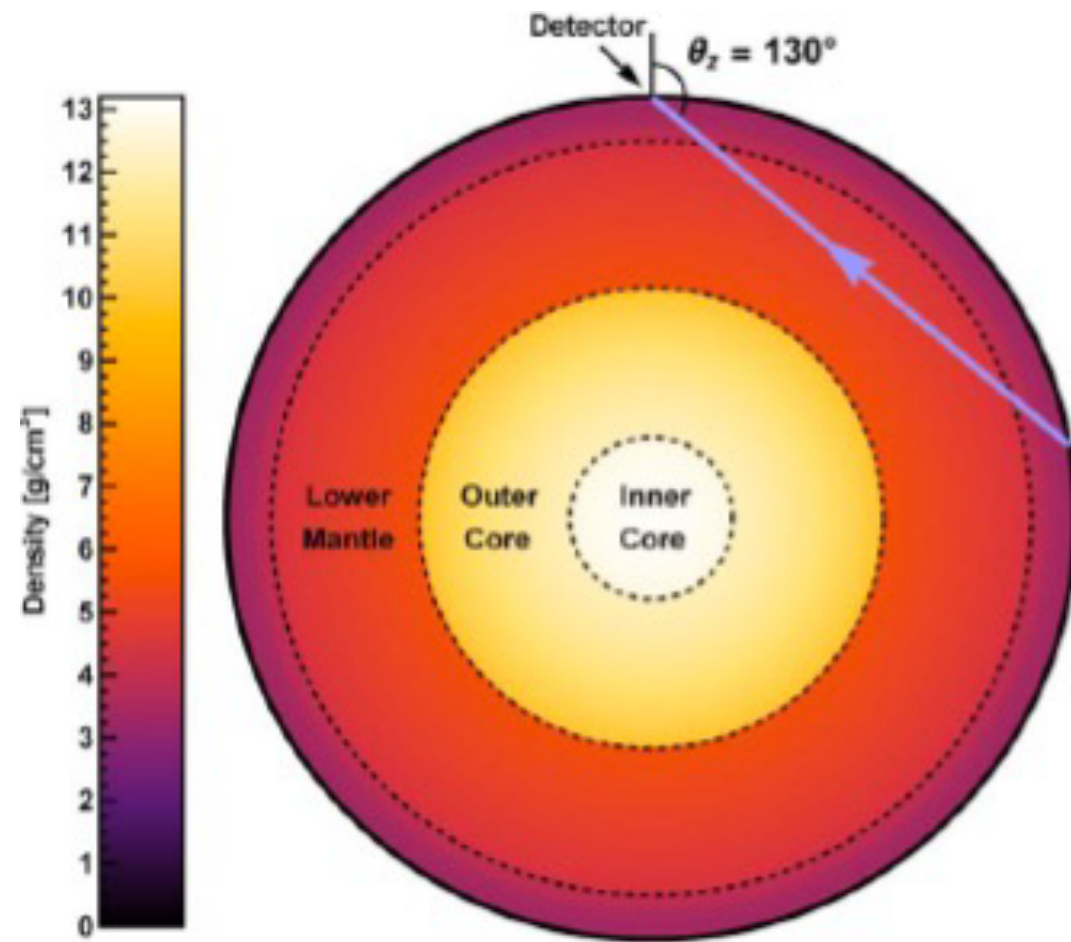


Measurement of the **atmospheric ν_μ flux** with 6 DUs of KM3NeT/ORCA:

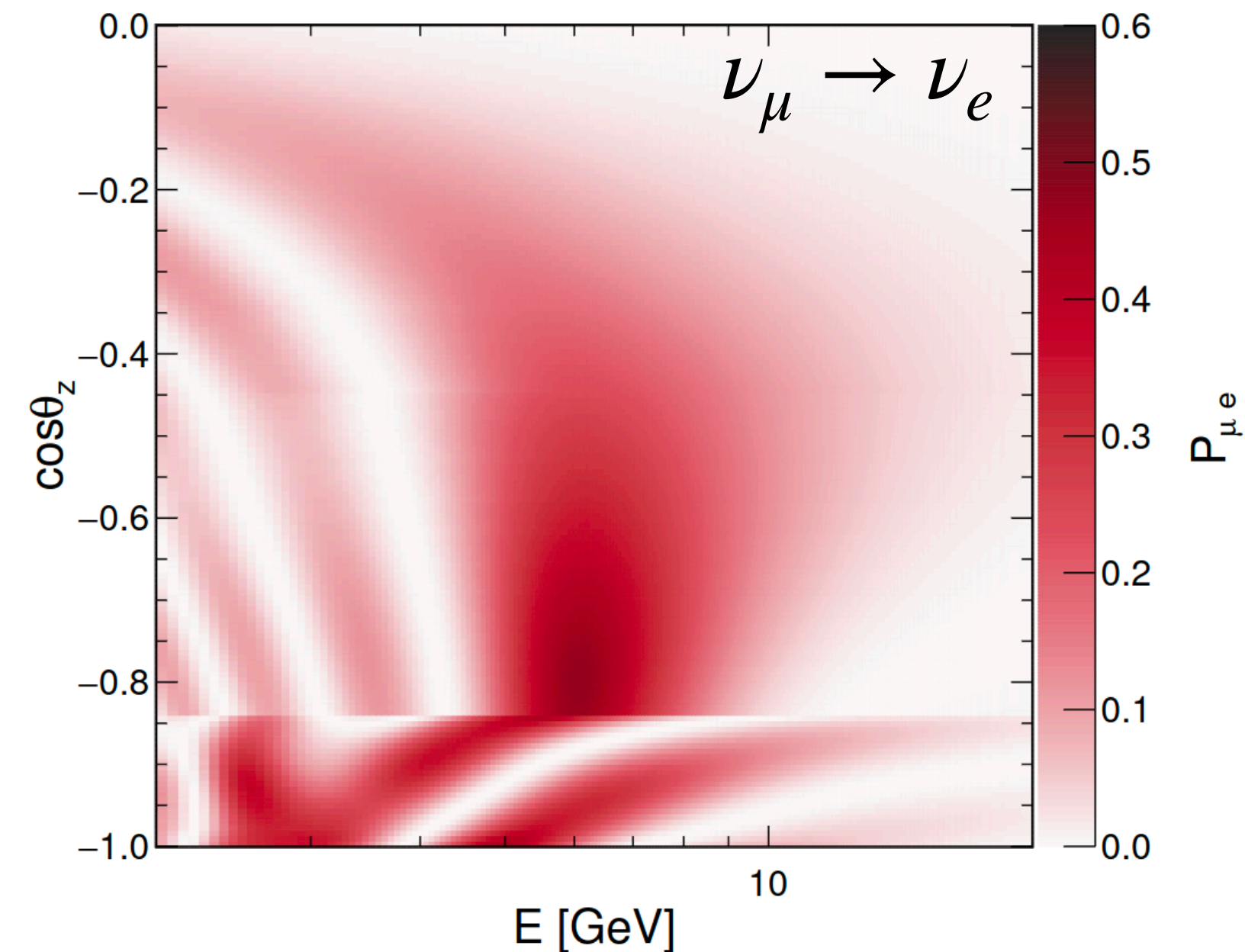
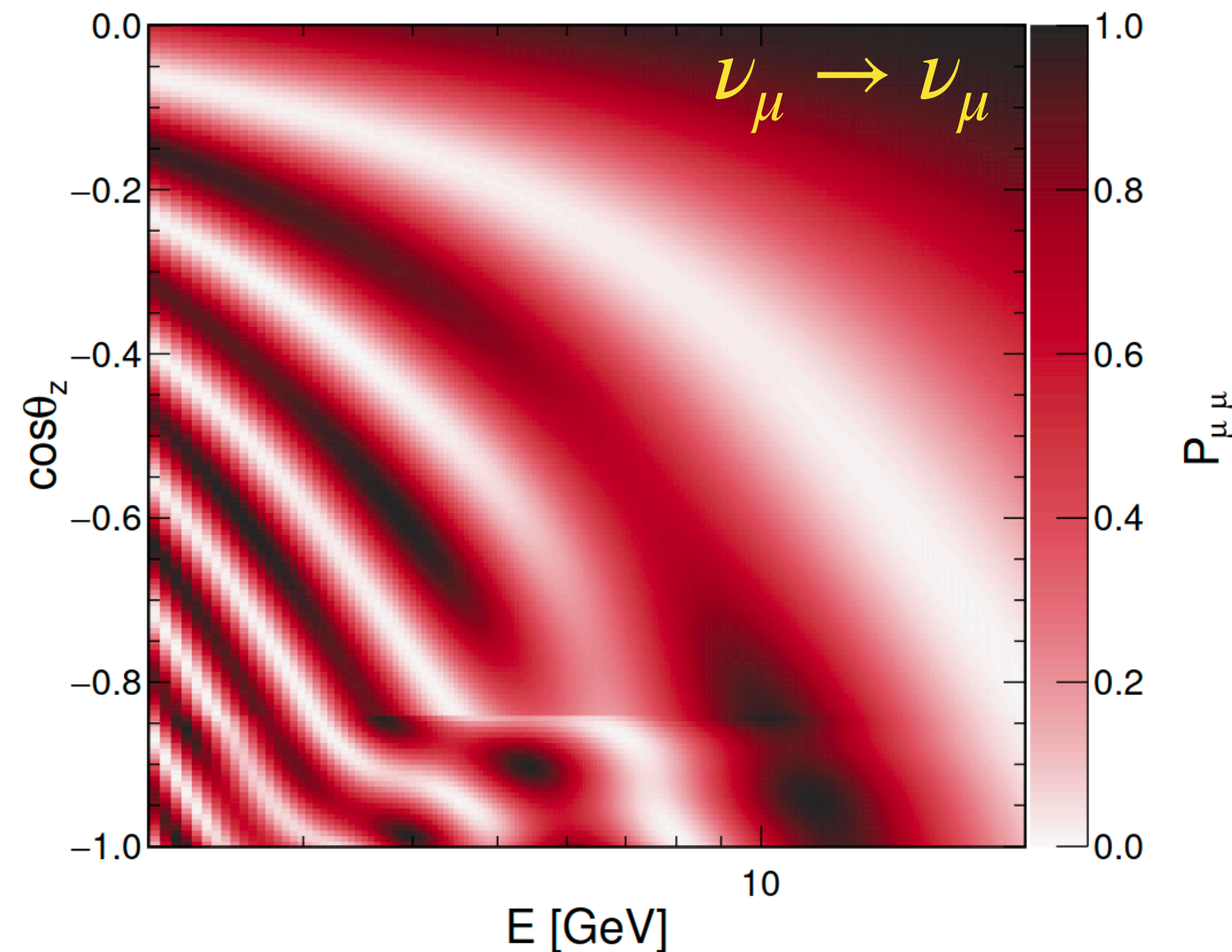
- Results consistent with Honda (HKKM14), and with other experiments. Error bar still sizable.
- Same measurement on-going with KM3NeT/ARCA (up to hundred TeV).

[Eur. Phys. J. C 85 \(2025\) 871](#)

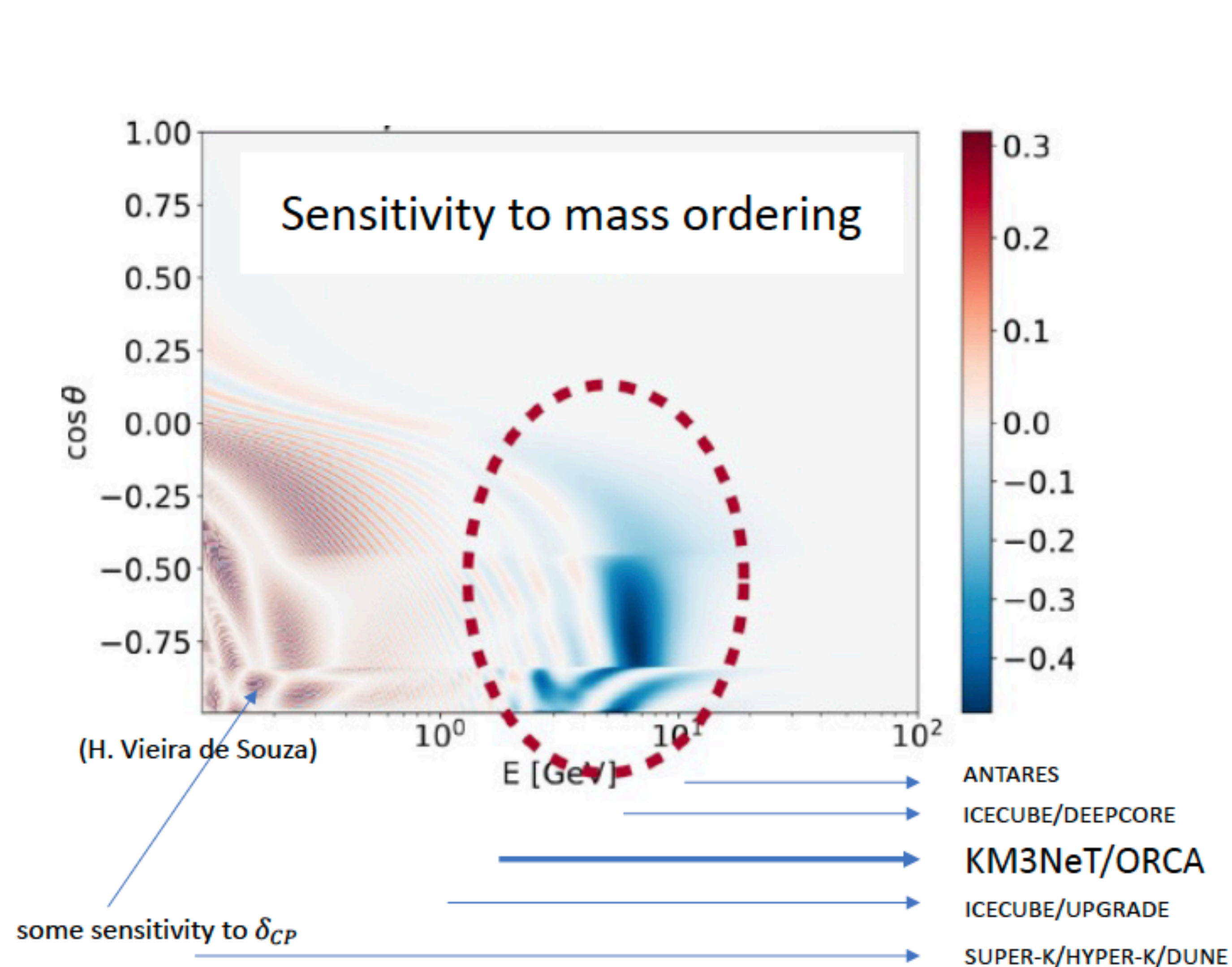
Neutrino oscillation



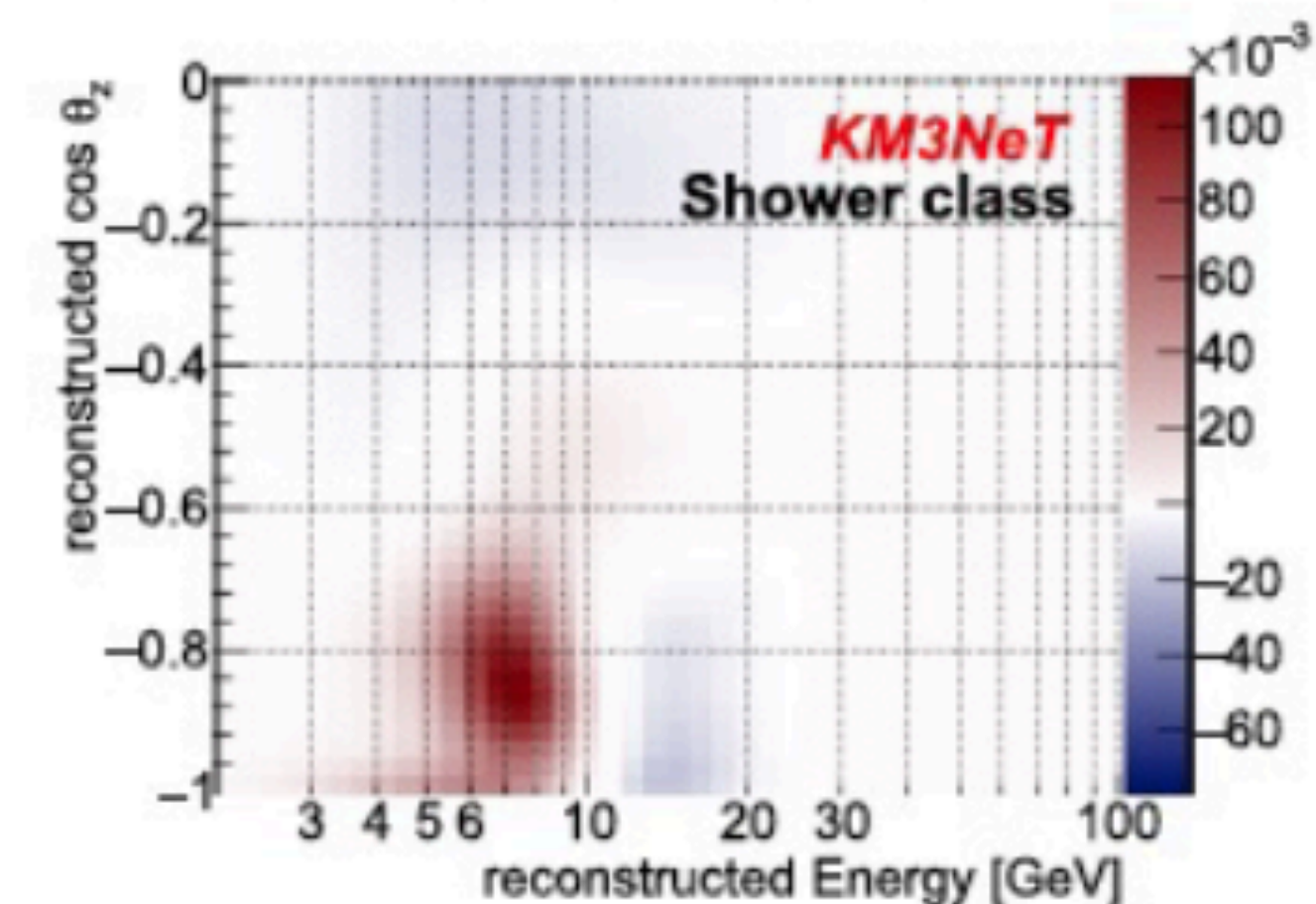
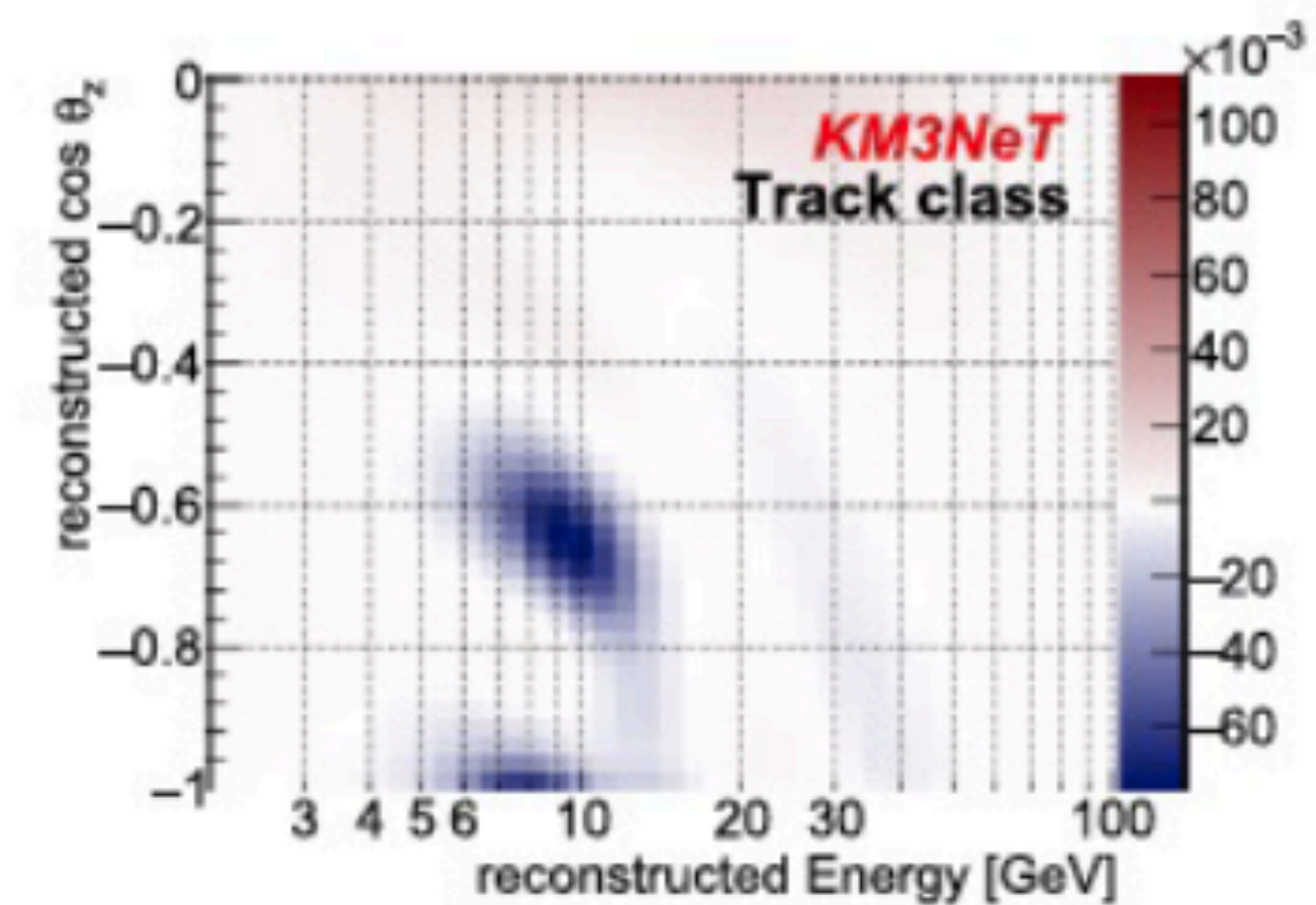
- **Long baselines: 10 - 12700 km**, fully correlated with $\cos(\theta)$.
- **Atmospheric neutrinos** in KM3NeT/ORCA energy span: **1-1000 GeV**.
- **Matter effect:** opportunity to measure the Neutrino Mass Ordering (NMO).



KM3NeT/ORCA relevant neutrino energy range



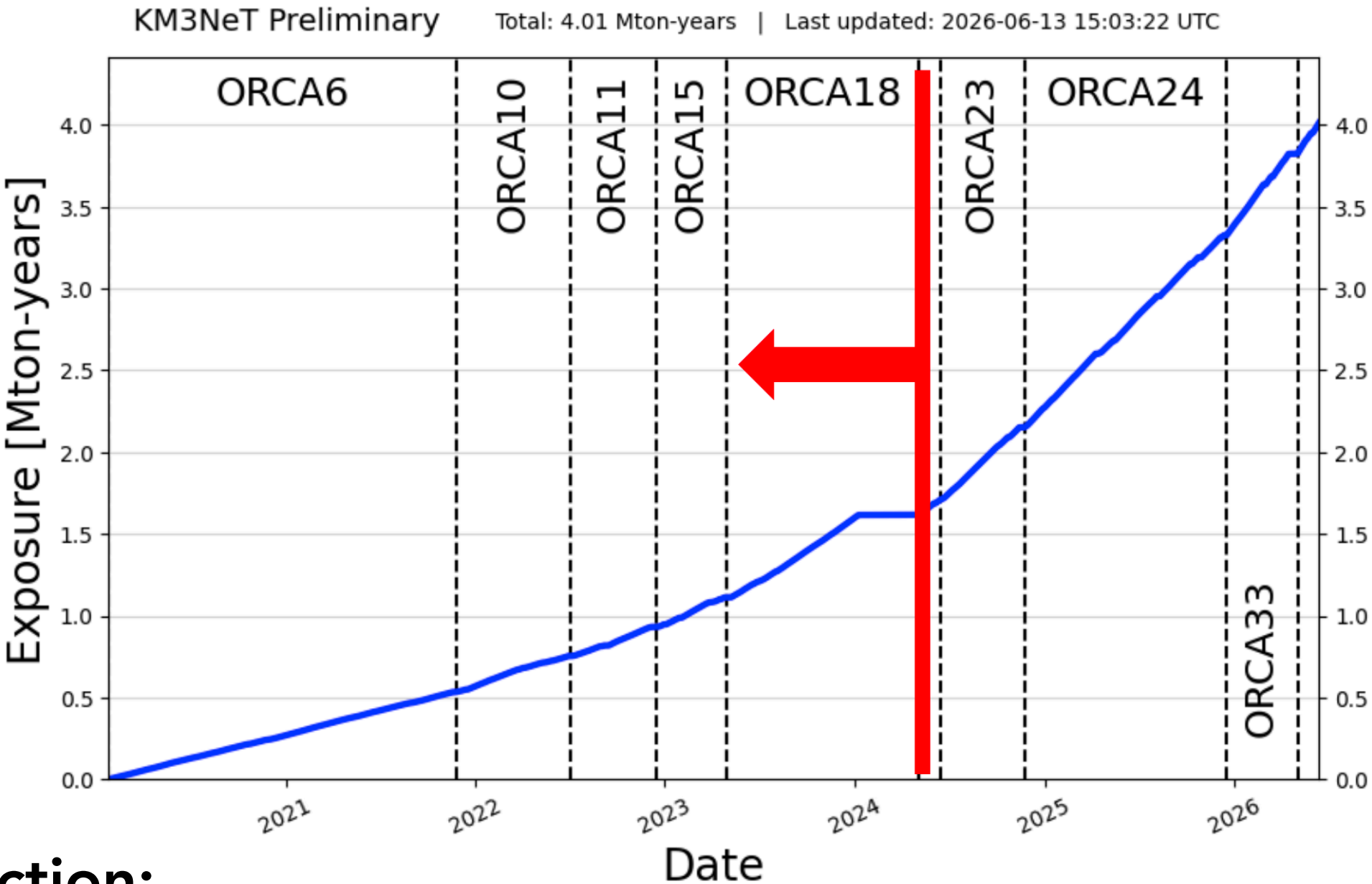
where do NO-IO differ?



Oscillation dataset

ORCA 6-18 (~4 years data)

- ORCA6-7 and ORCA11-18: **exposure 1.4 Mton-years**.
- Neutrino oscillations in **3-generation framework**.
- **Tau neutrino production**.

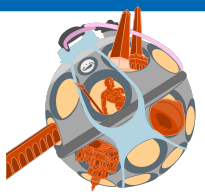
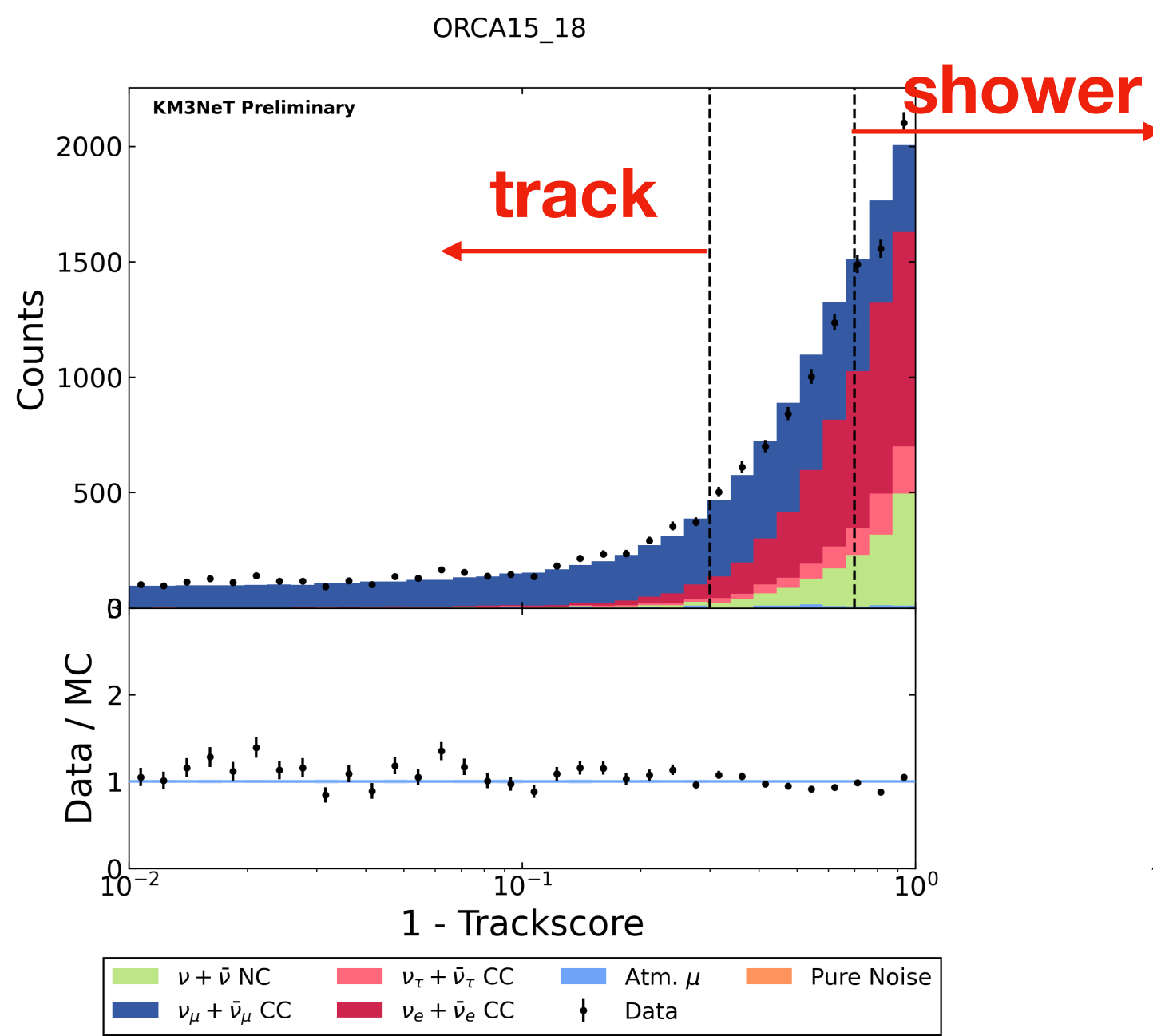
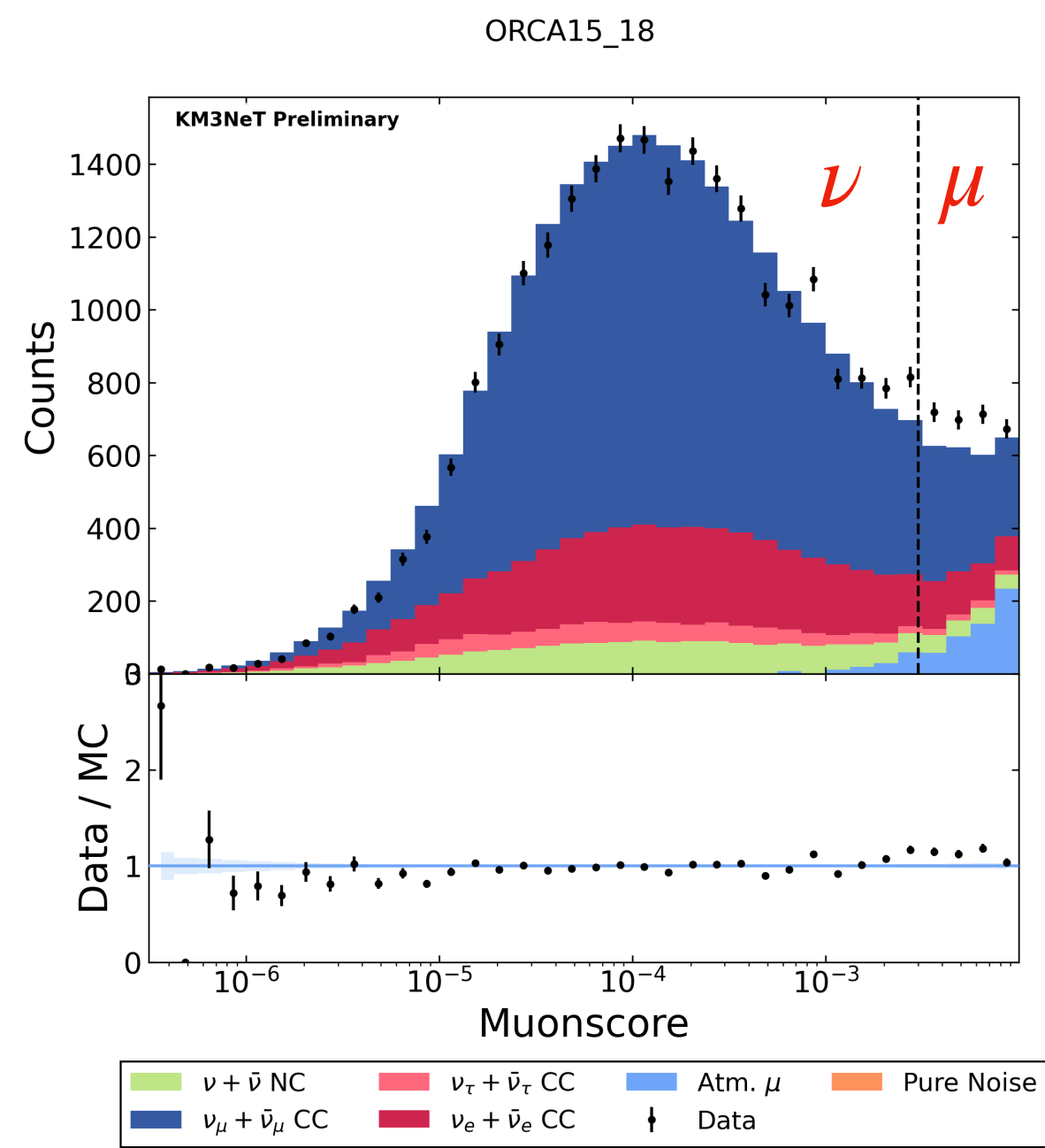


Selection:

- basic quality criteria.
- up-going events.
- atmospheric muon rejection (muonscore BDT).
- 3 class classification: **track** / **shower** / **intermediate** (BDT).

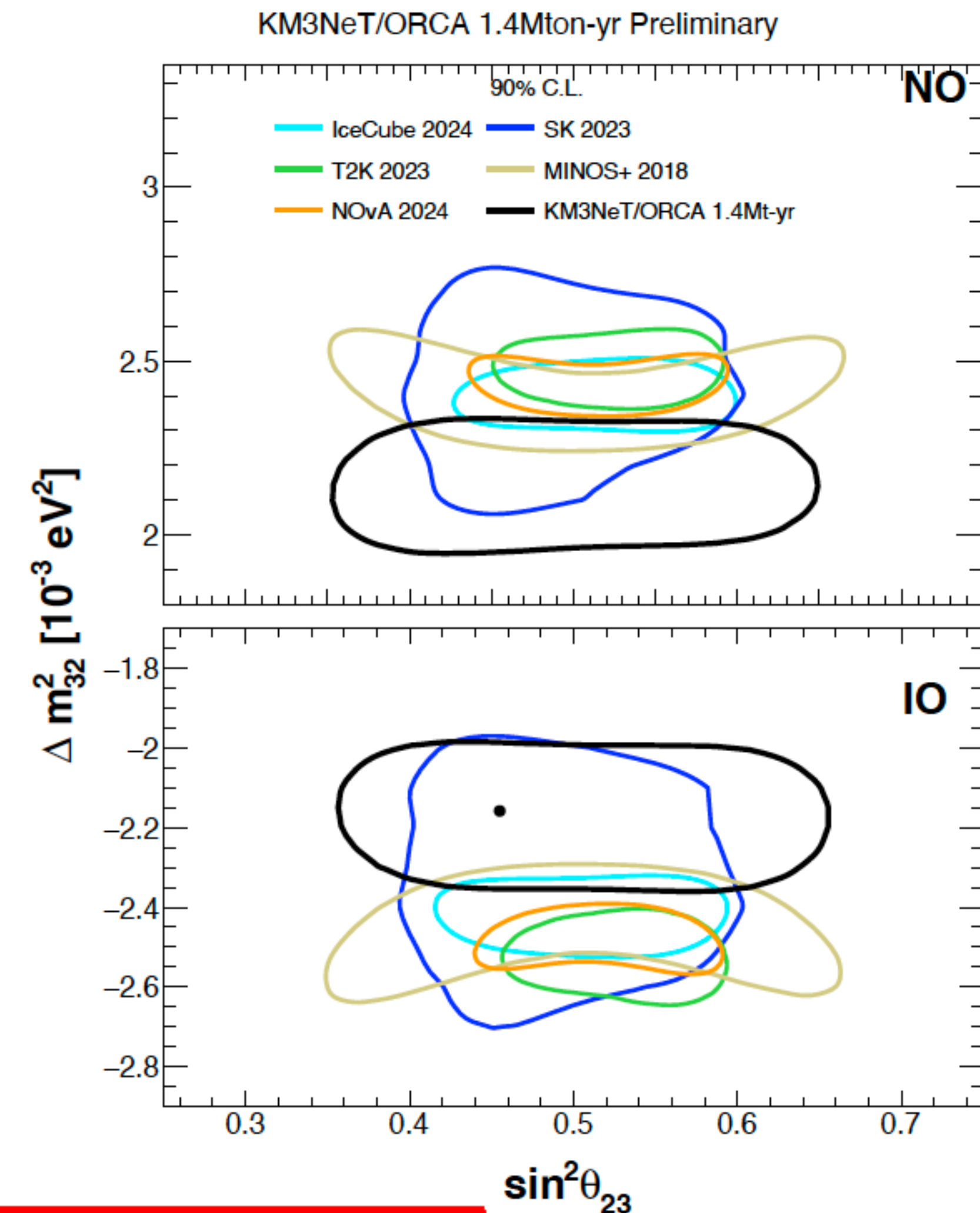
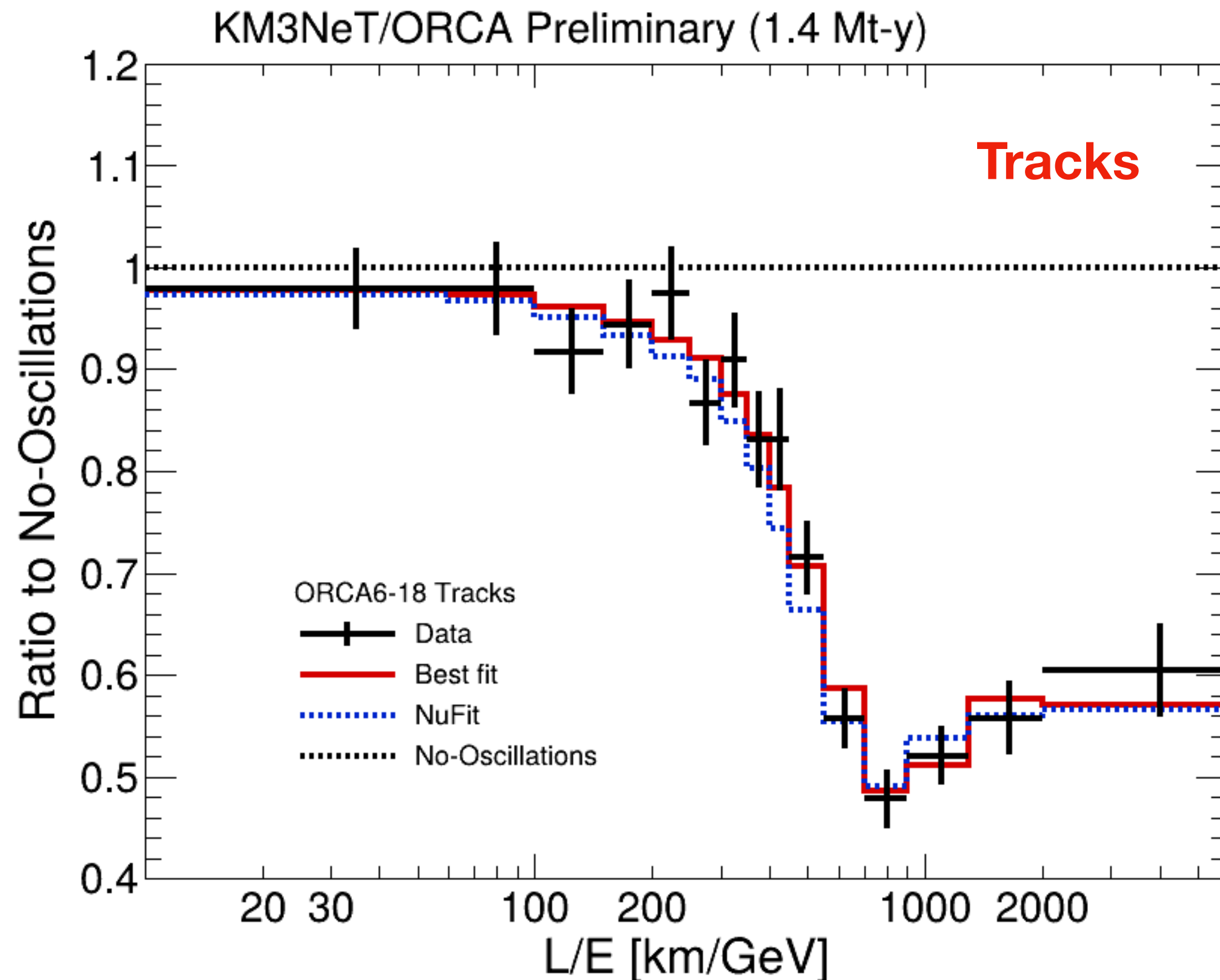
Approximately 17.6k events (%-level μ contamination).

Previous ORCA6 results available: [JHEP 10 \(2024\) 206](#)



Neutrino oscillation results

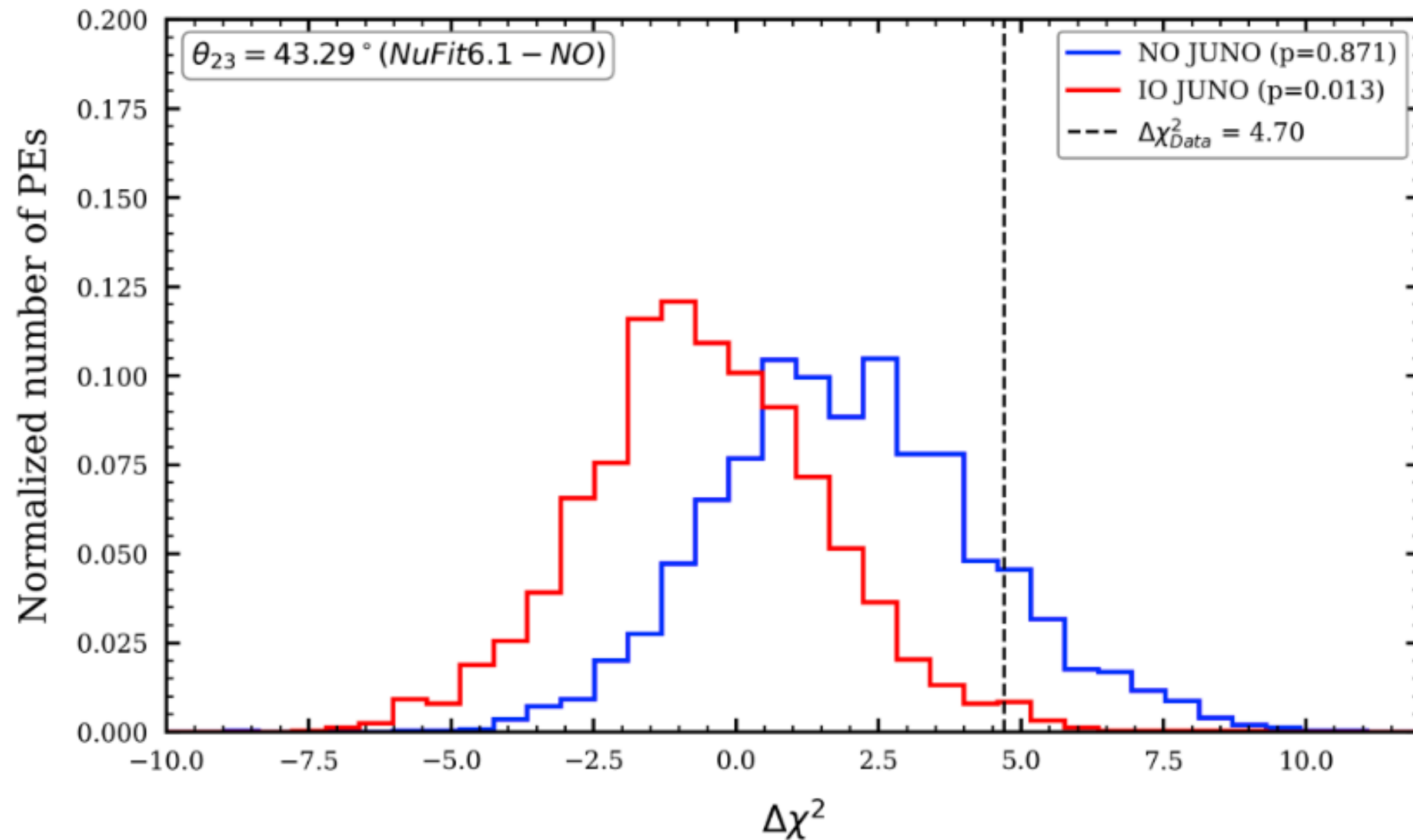
- Neutrino oscillation become visibile in L/E.
- Slightly preference for IO ($\Delta\chi^2 = 0.18$).



$$\sin^2\theta_{23} = 0.45^{+0.16}_{-0.05}, \Delta m_{31}^2 = (-2.08^{+0.08}_{-0.09}) \cdot 10^{-3} \text{ eV}^2$$

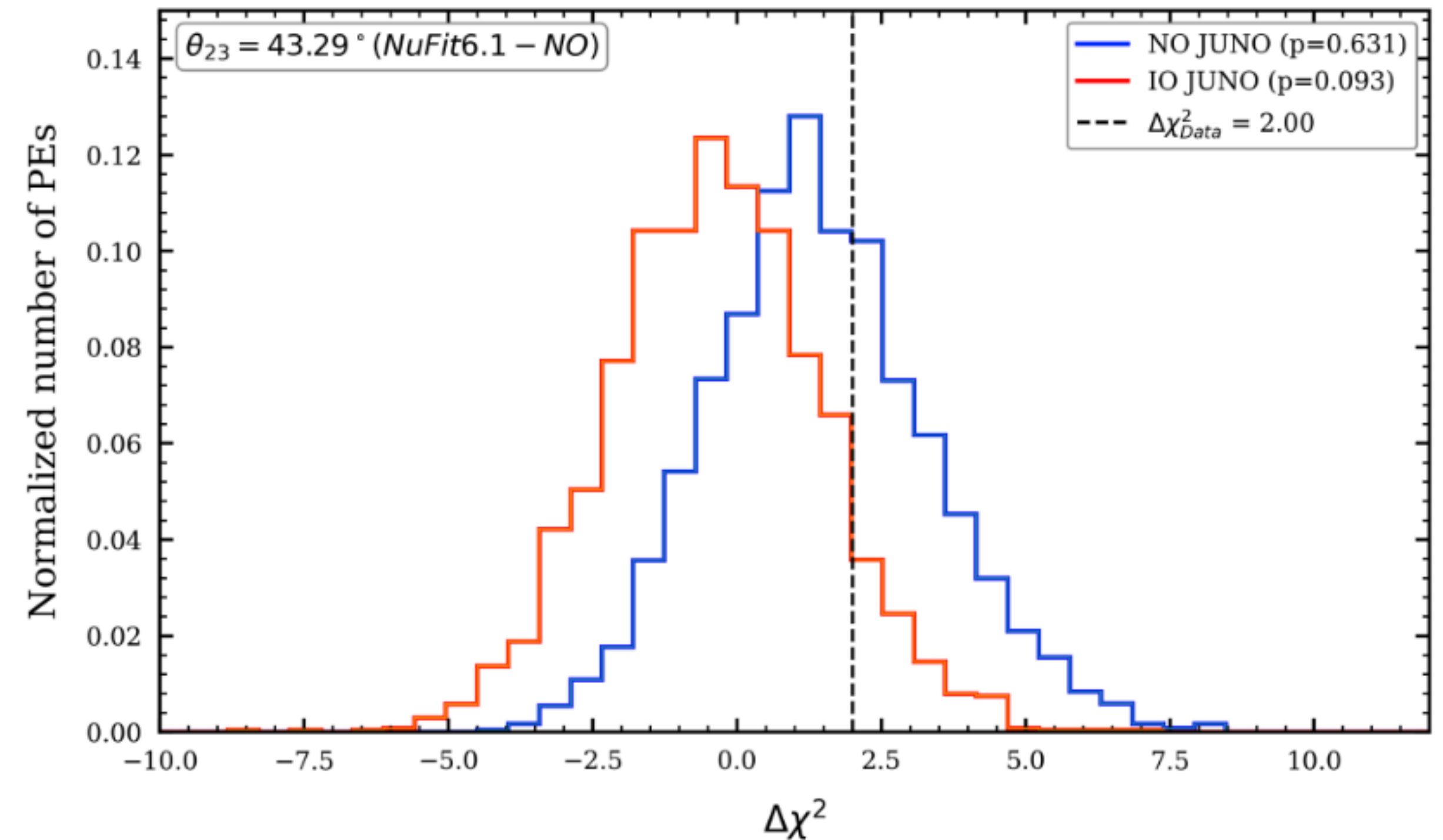
NMO with JUNO + DayaBay constraints

KM3NeT/ORCA Preliminary (1.4 Mton-yr) ORCA6-18



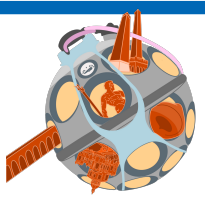
Reject IO with $p=1.3\% \rightarrow \sim 2.5\sigma$
 $\Delta\chi^2_{Data} = 4.7$

KM3NeT/ORCA Preliminary (0.84 Mton-yr) ORCA11-18



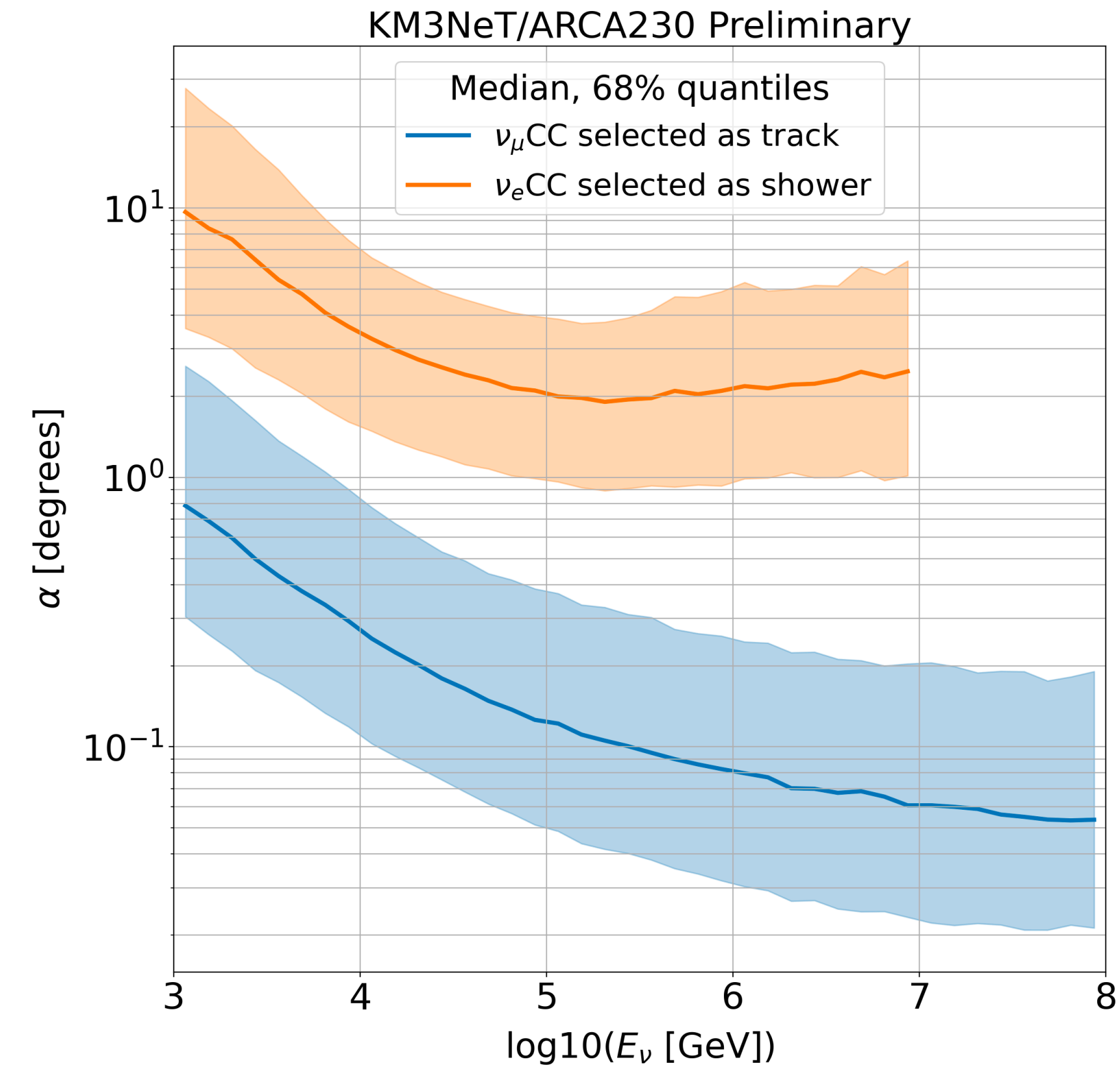
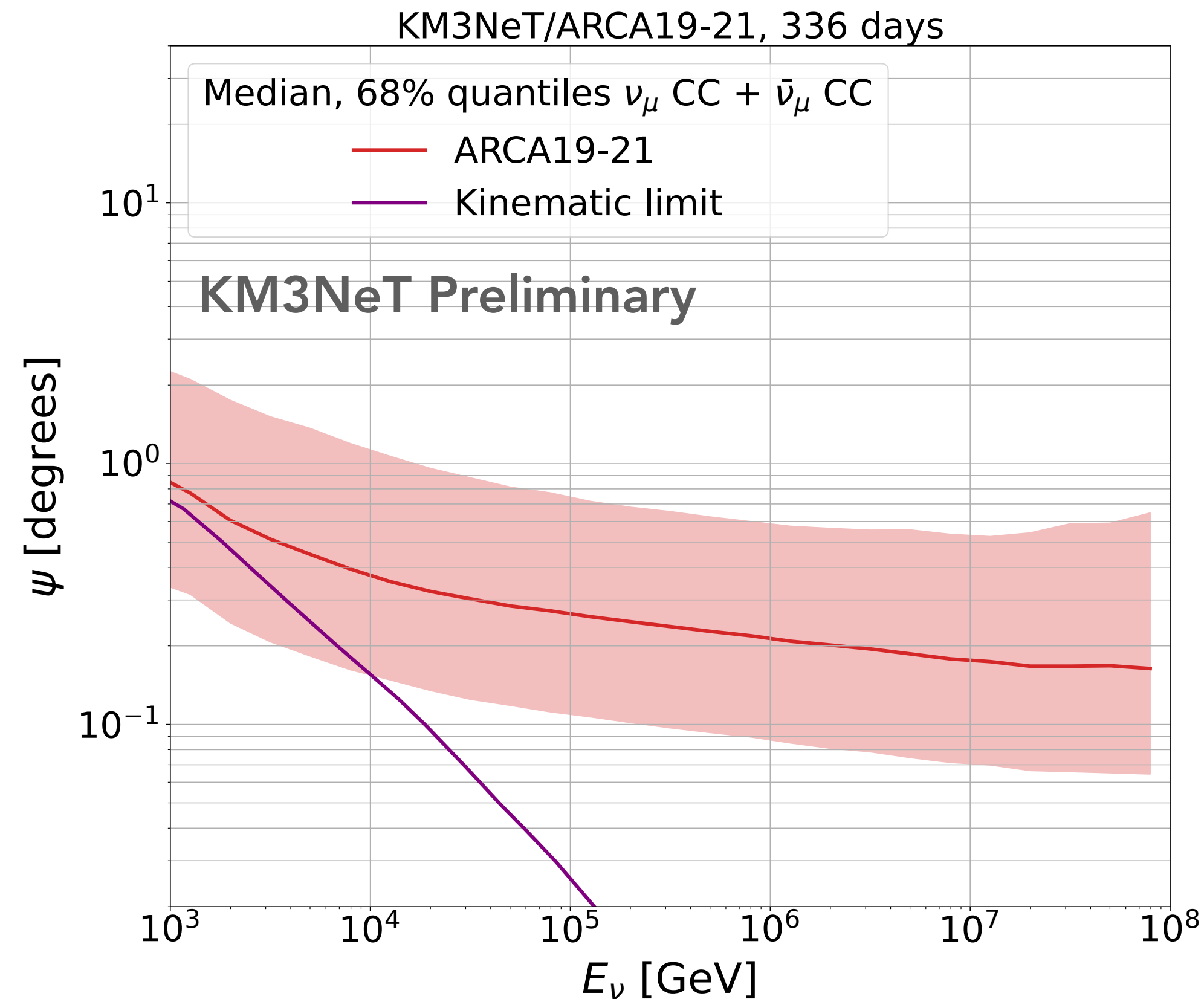
Reject IO with $p=9.3\% \rightarrow \sim 1.68\sigma$
 $\Delta\chi^2_{Data} = 2.0$

COSMIC NEUTRINOS



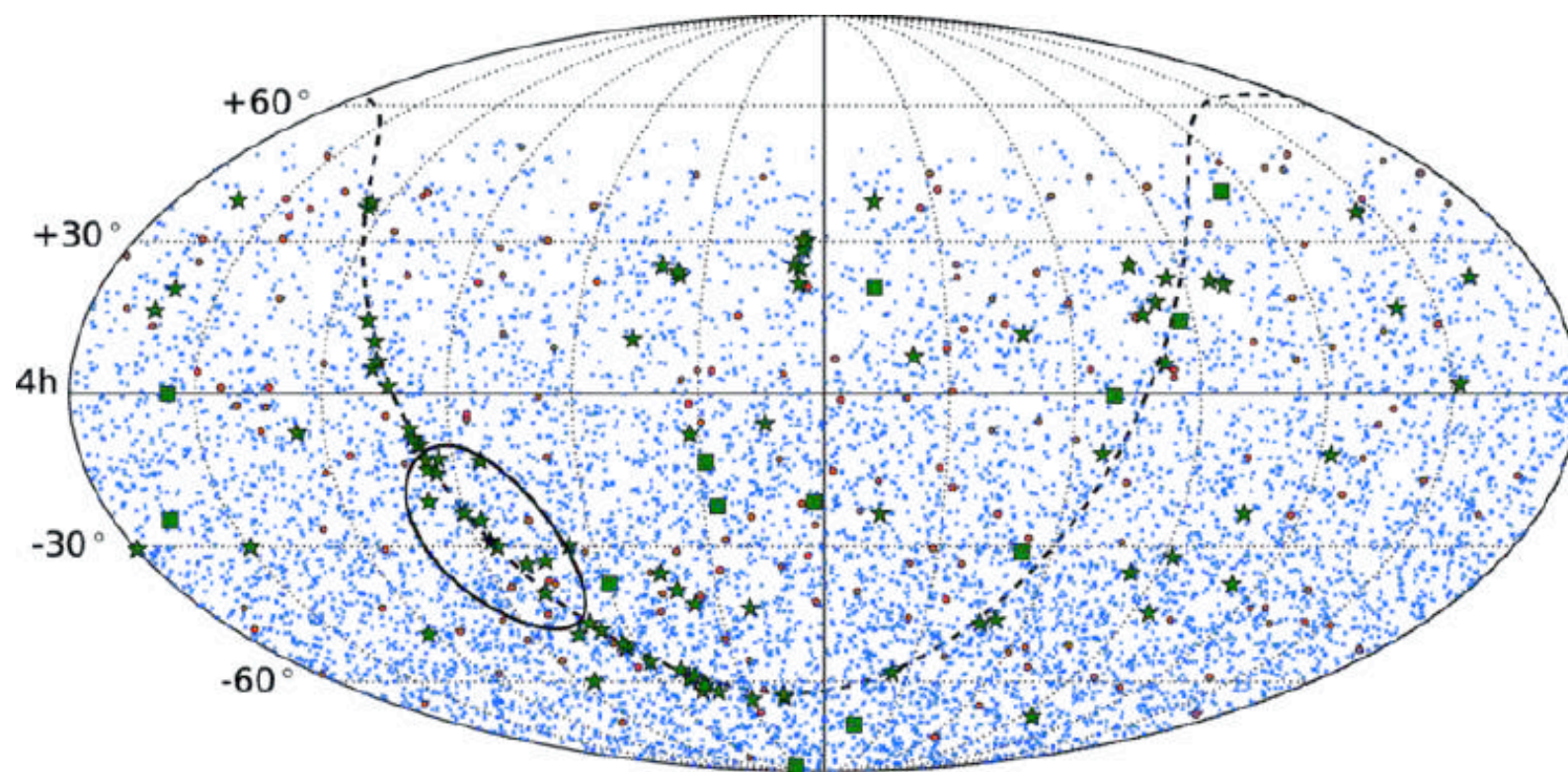
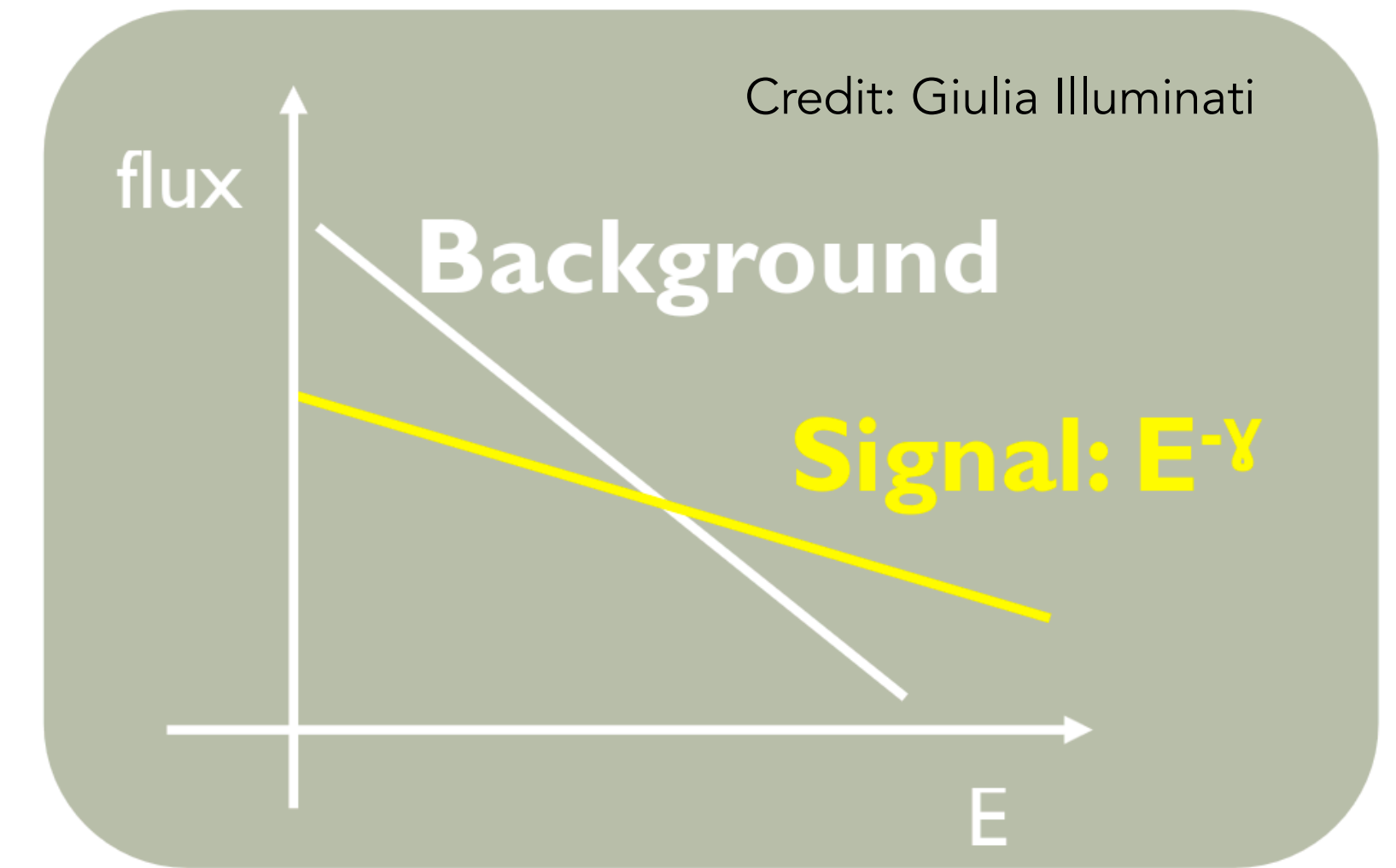
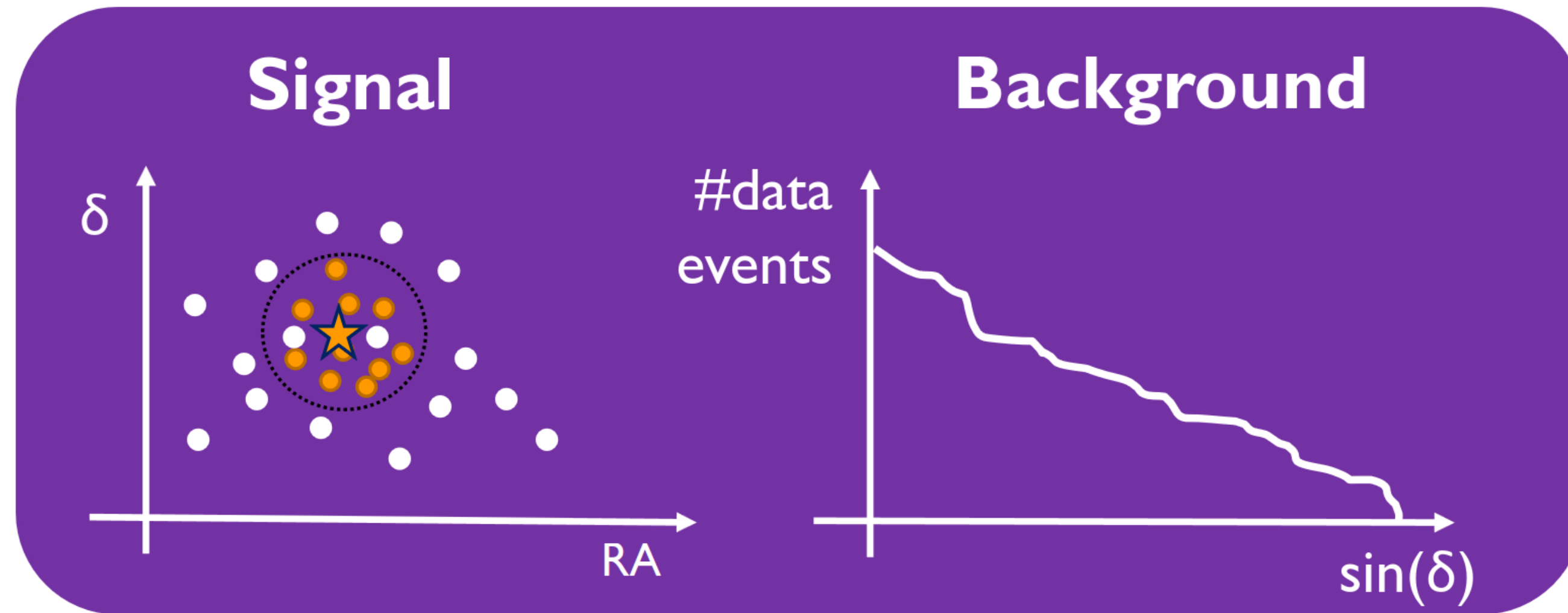
KM3NeT/ARCA angular resolutions

- Expected **angular resolution** (ARCA230): **0.1° (2°)** at 100 TeV in ARCA **for tracks (showers)**.
- Expected **energy resolution** (ARCA230): < 0.3 in $\log_{10} E$, (10–20% in E) at 100 TeV in ARCA for tracks (showers).



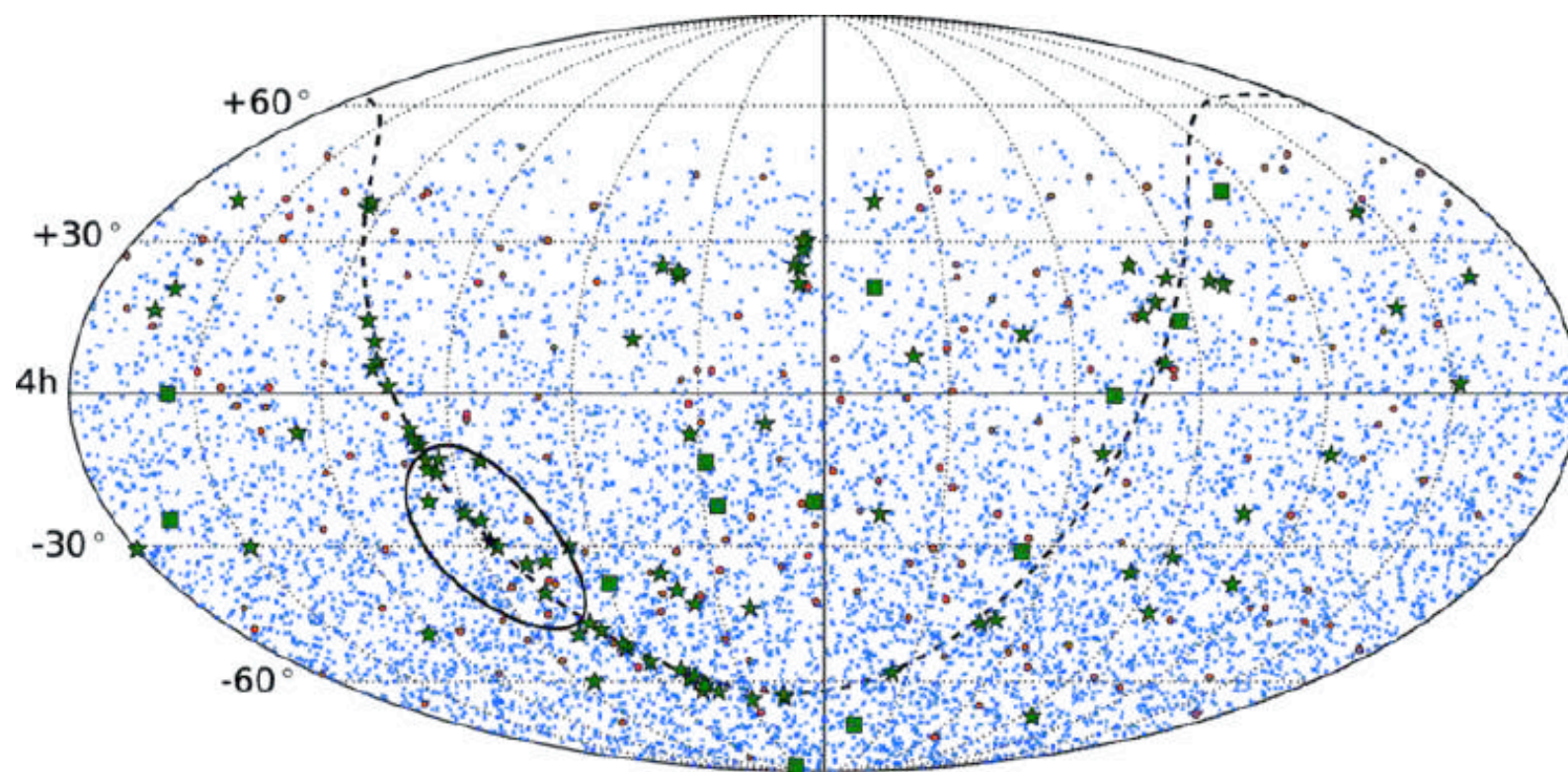
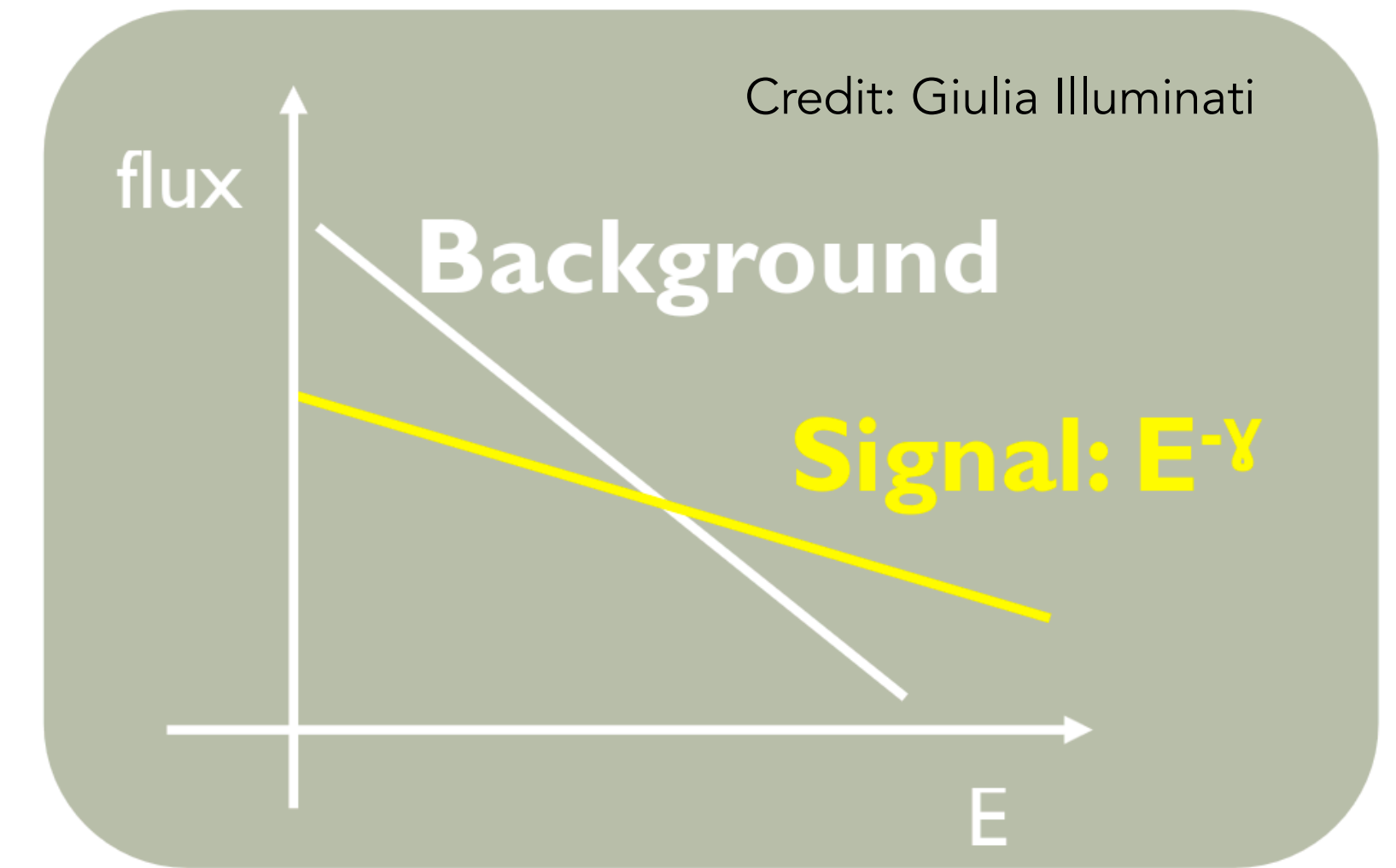
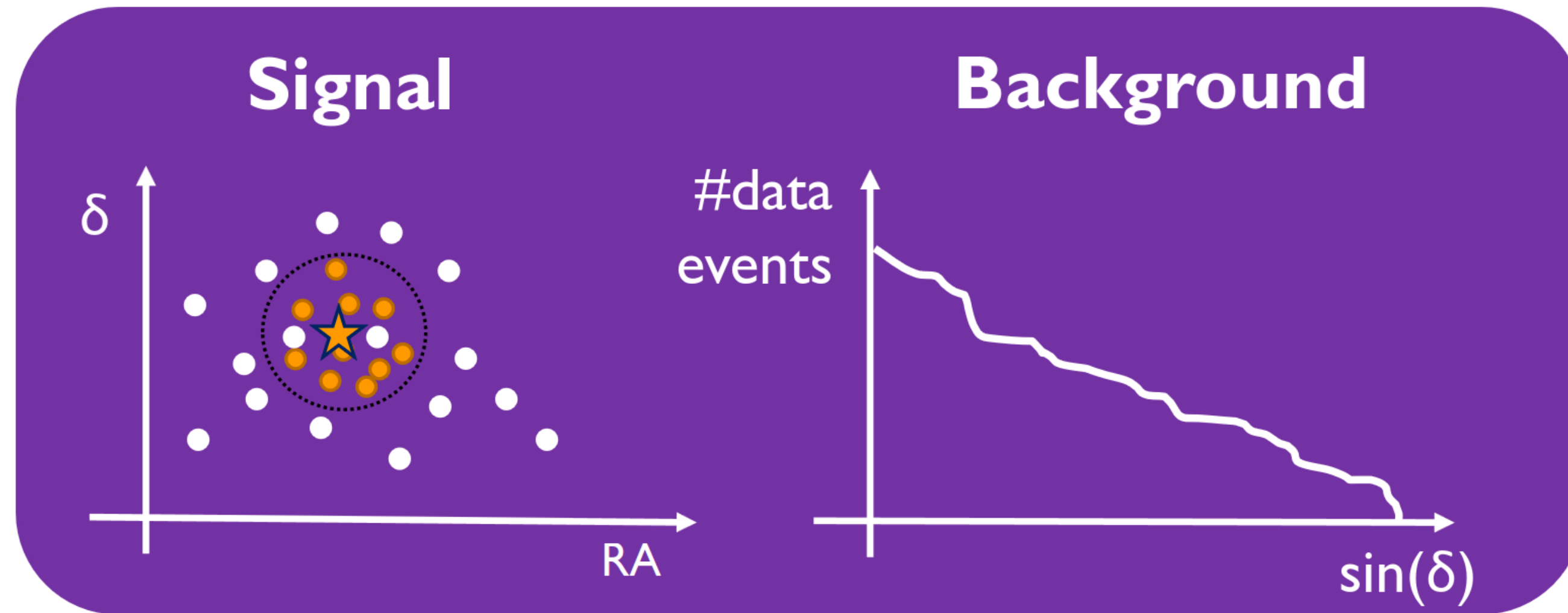
[EPJC 84 \(2024\) 885](#)

Cosmic neutrino searches

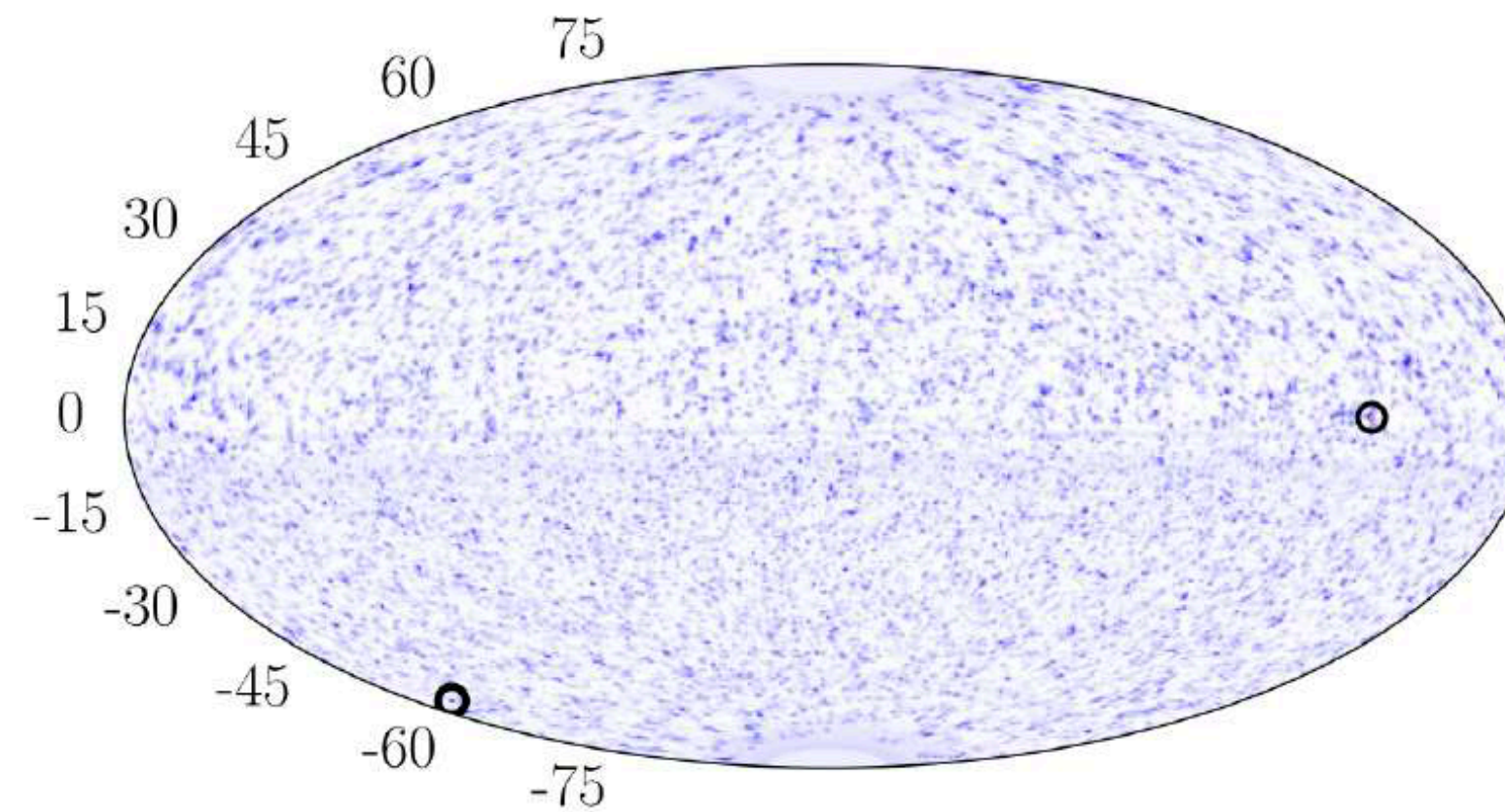


Catalogue searches

Cosmic neutrino searches

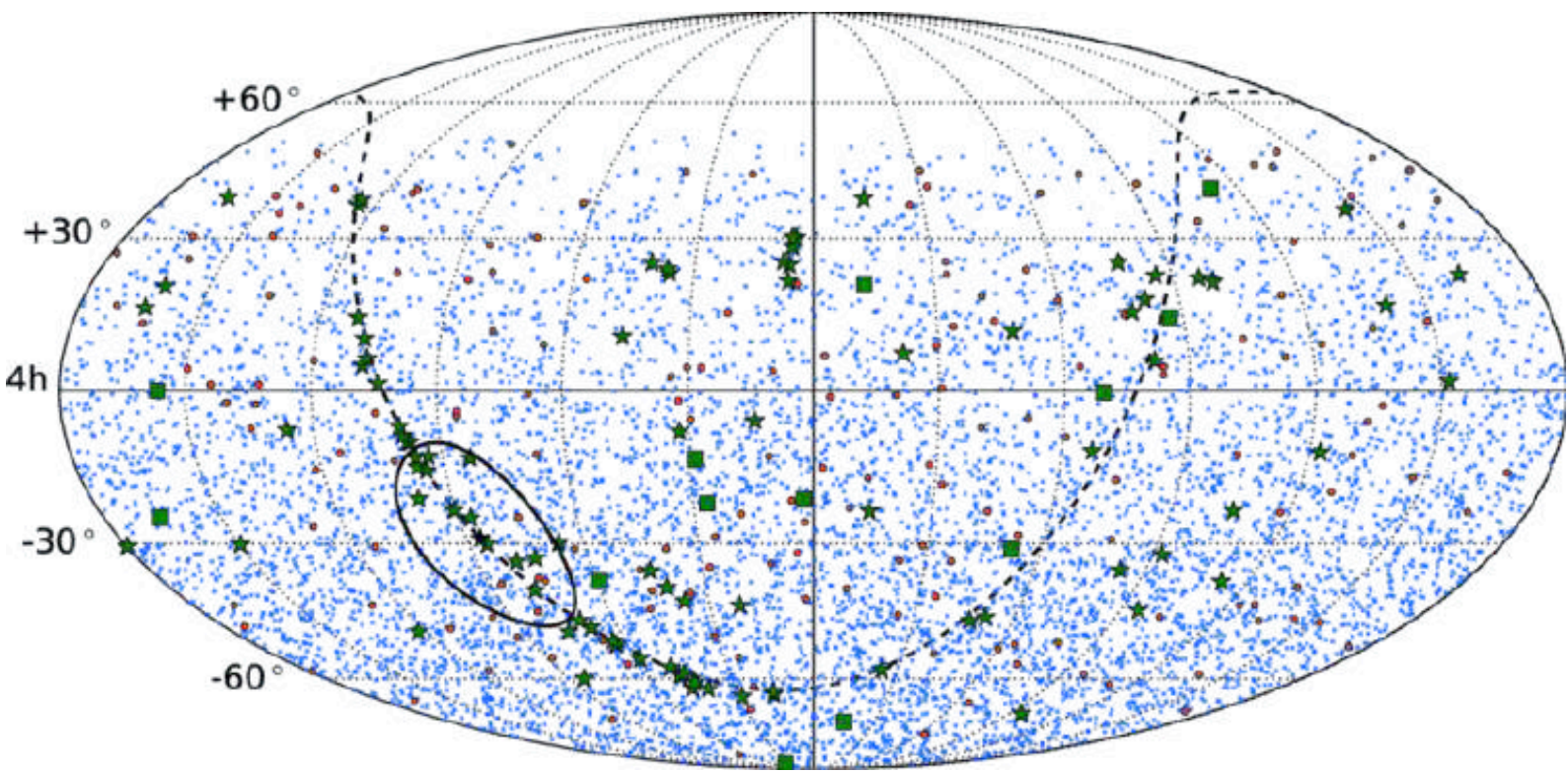
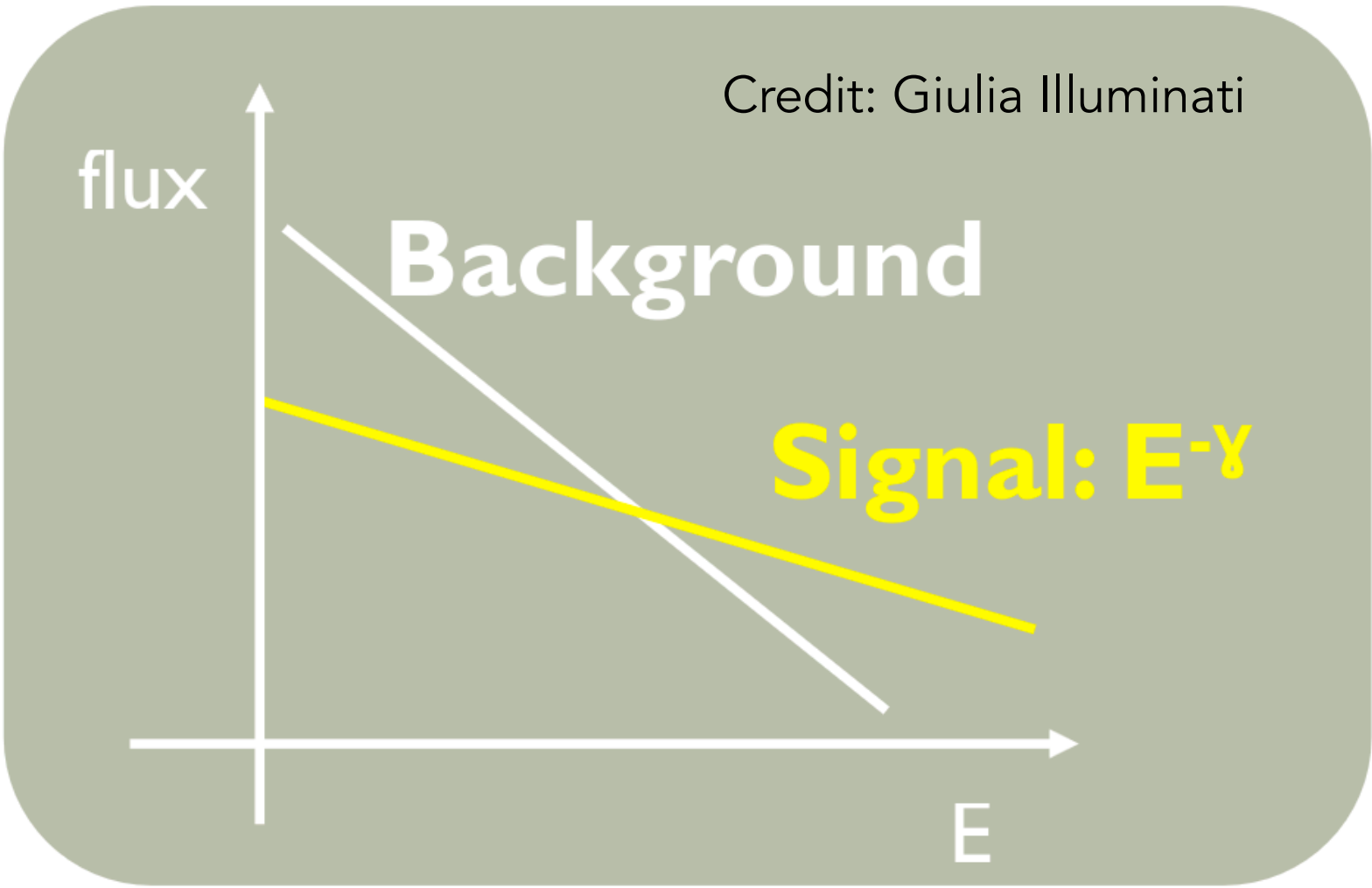


Catalogue searches

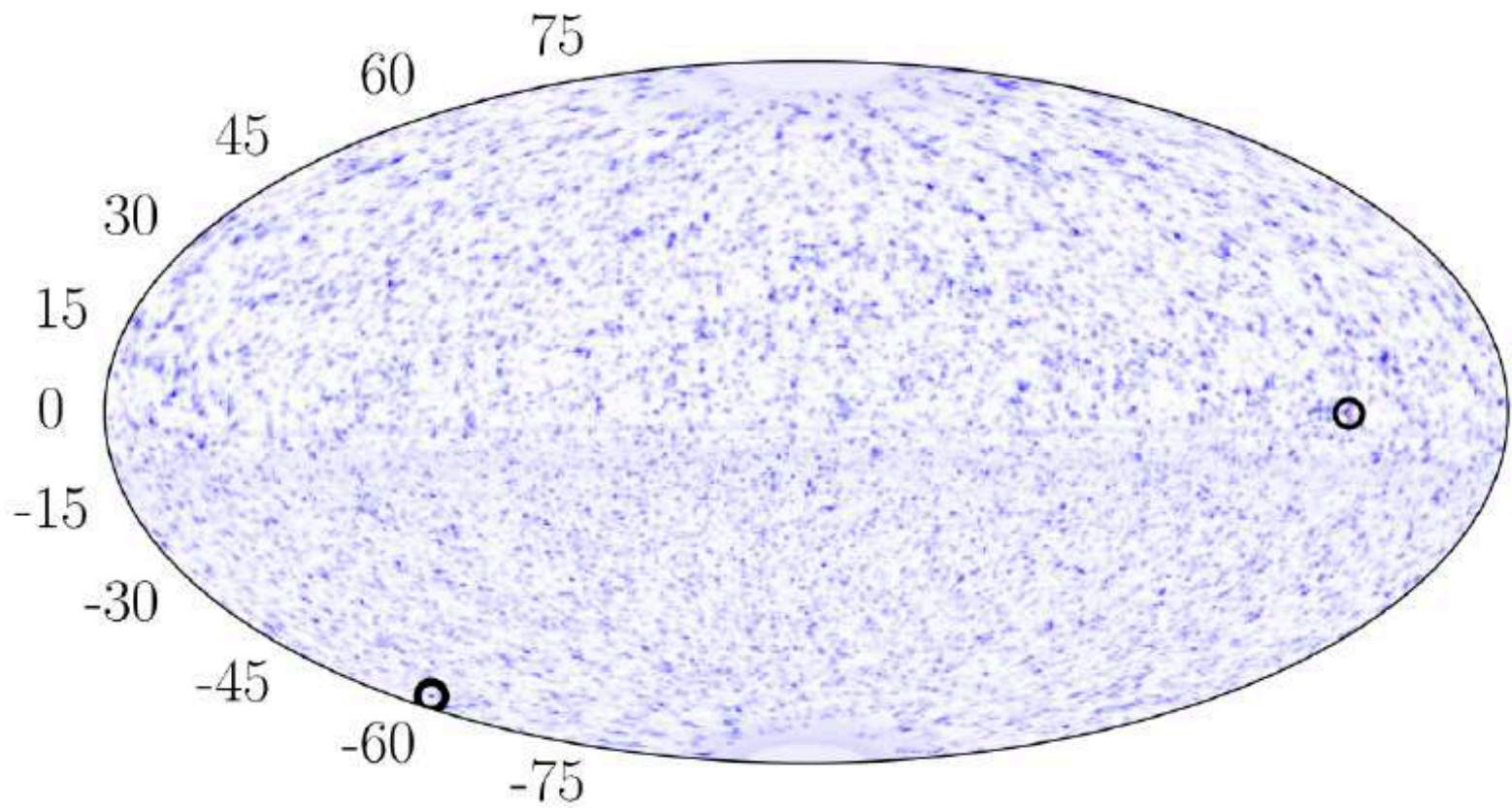


Point source search
(auto-correlation)

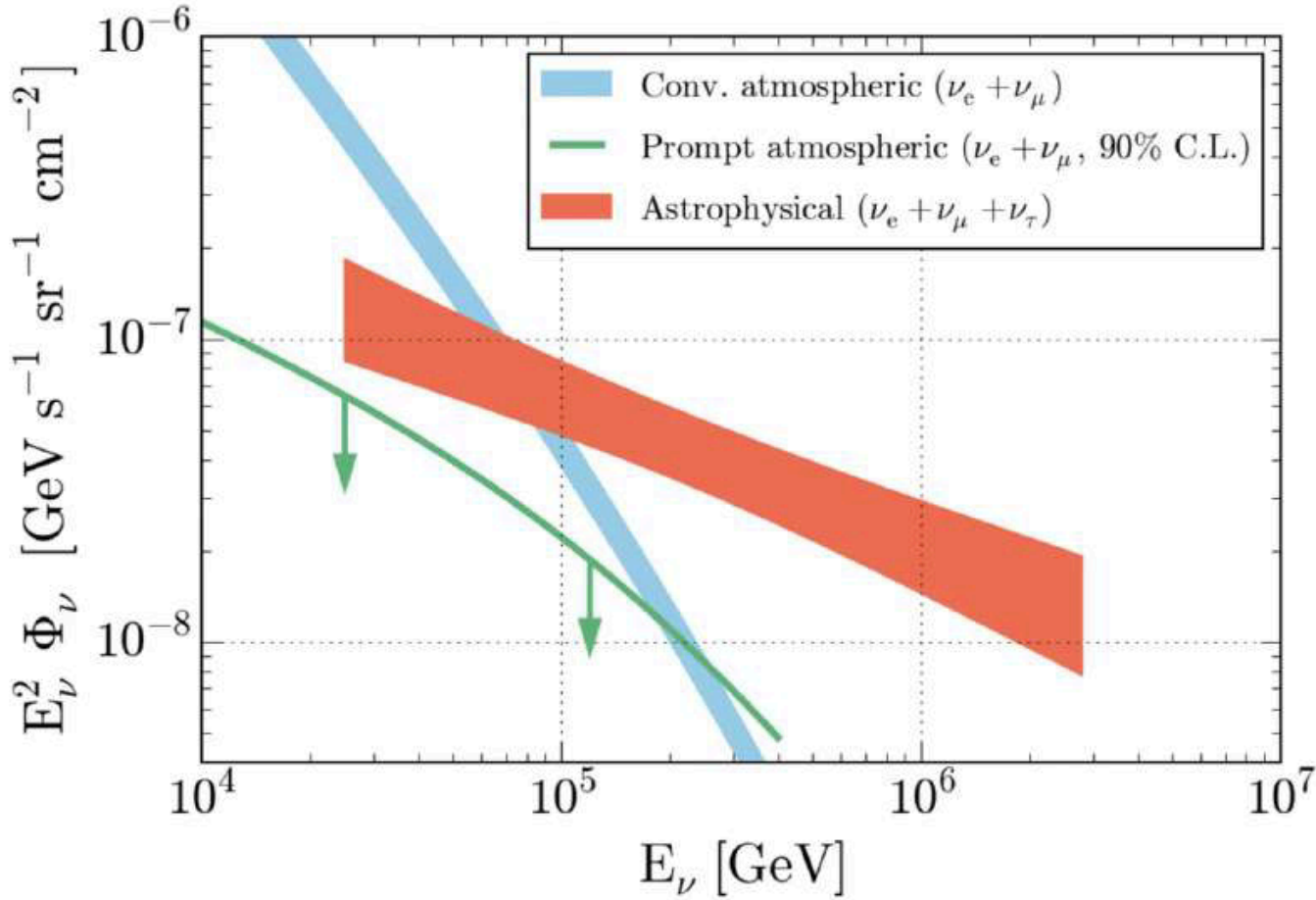
Cosmic neutrino searches



Catalogue searches

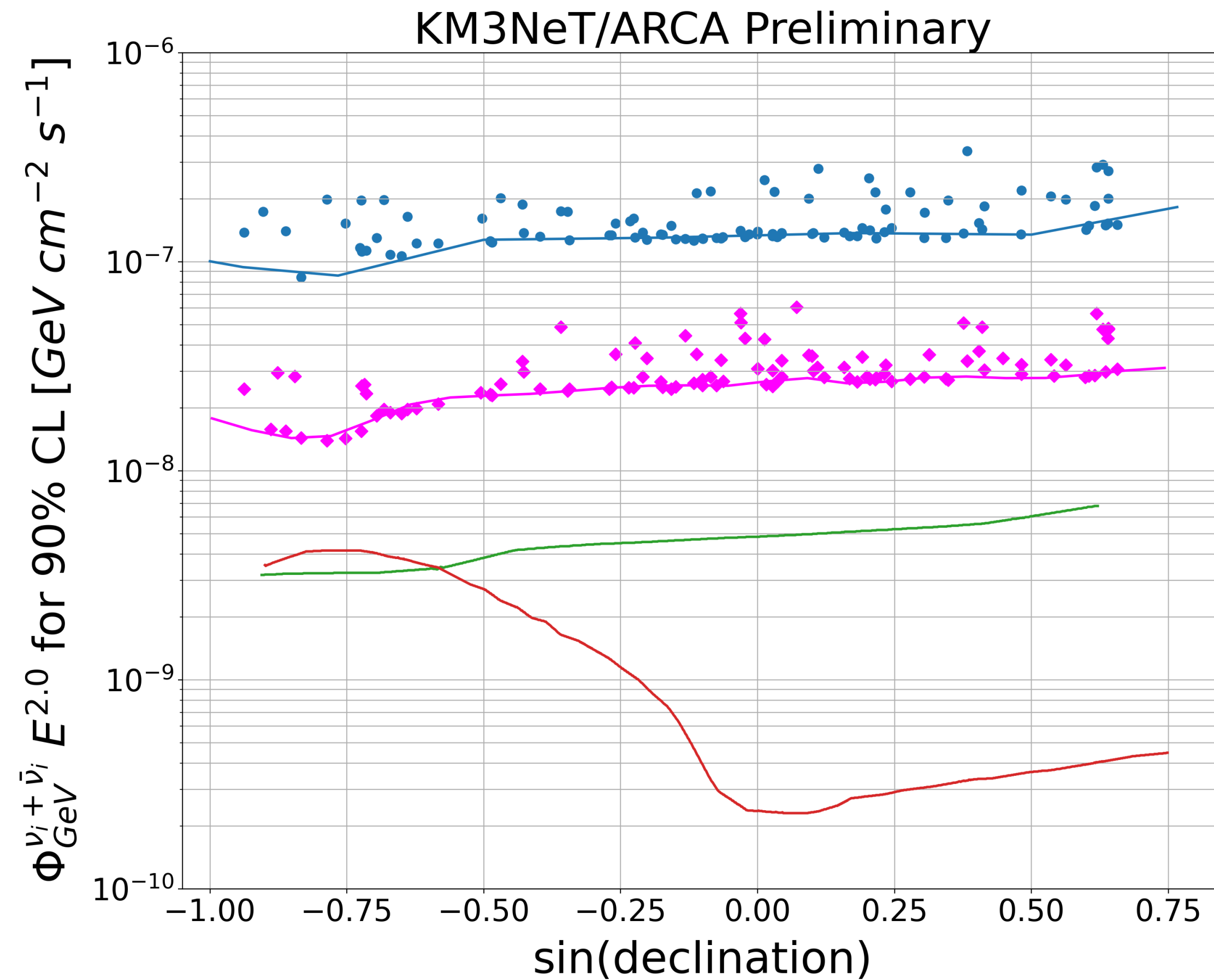


Point source search
(auto-correlation)



Diffuse search

Point source: catalogue search



Comparison of the sensitivities and upper limits for an E^{-2} neutrino flux for KM3NeT/ARCA6-21 as a function of declination.

Sensitivity

- ARCA6-8 (302 days)
- ARCA19-21 -this work- (336 days)
- ANTARES (15 yr)
- IceCube (10 yr)

Observed limits

- ARCA6-8 (302 days)
- ARCA19-21 -this work- (336 days)

Catalog-based search: 106 sources tested with different signal spectral hypotheses: E^{-2} , $E^{-2.5}$ & $E^{-3.2}$.

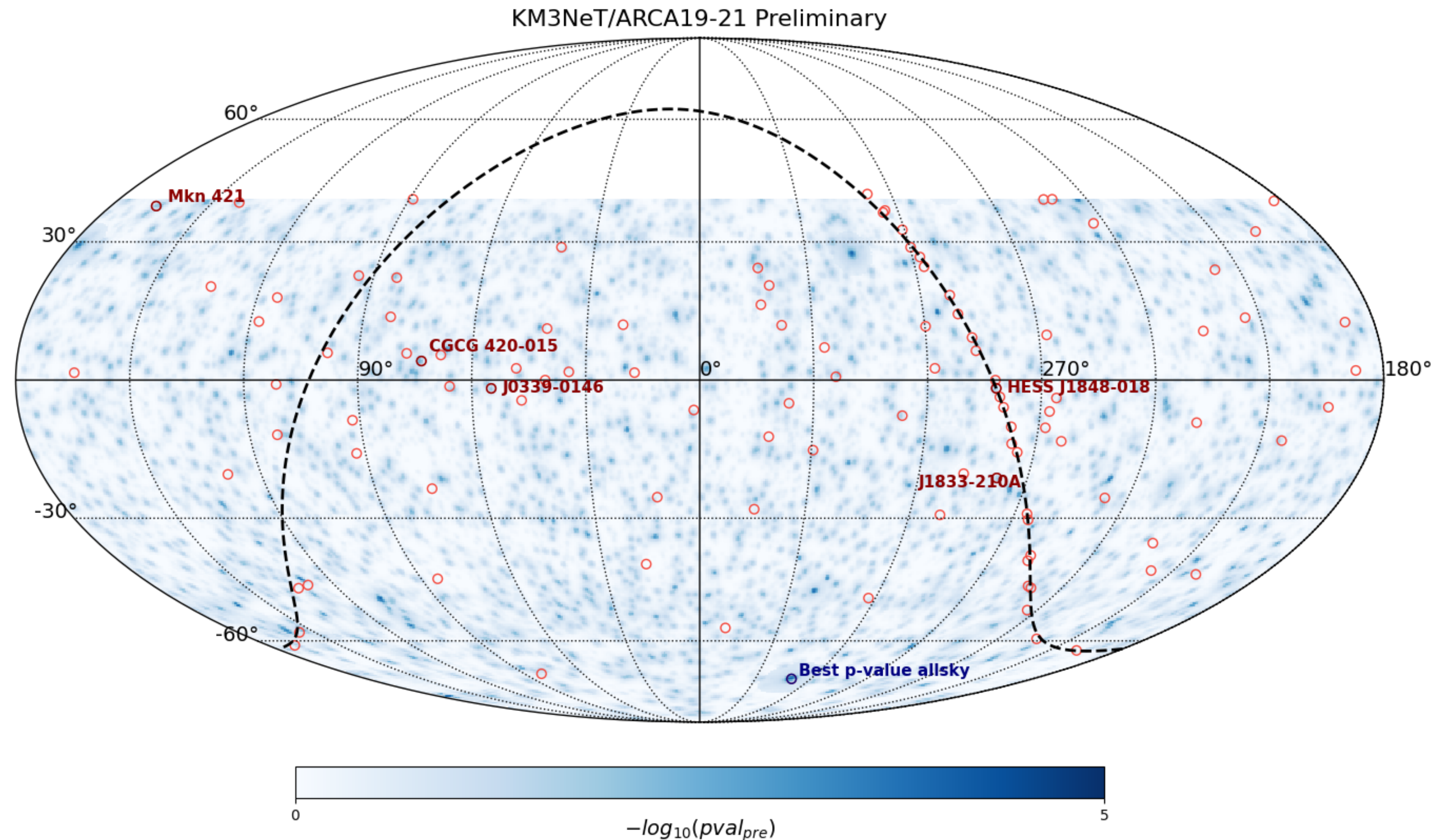
Lowest p-value (pre-trial $5.0 \times 10^{-3.0}$) at **CGCG 420-015** for E^{-2} spectrum.

Point source: all-sky scan

All-sky scan: searches for excess on top of uniform bkg, 2.6 million bins with $\delta < 40^\circ$, signal spectral hypothesis: E^{-2} .

Lowest p-value (pre-trial 4.1×10^{-5}) at RA=310.8°, $\delta = -71.3^\circ$.

Candidate sources are visualized in the sky map by red circles.



Galactic neutrino searches

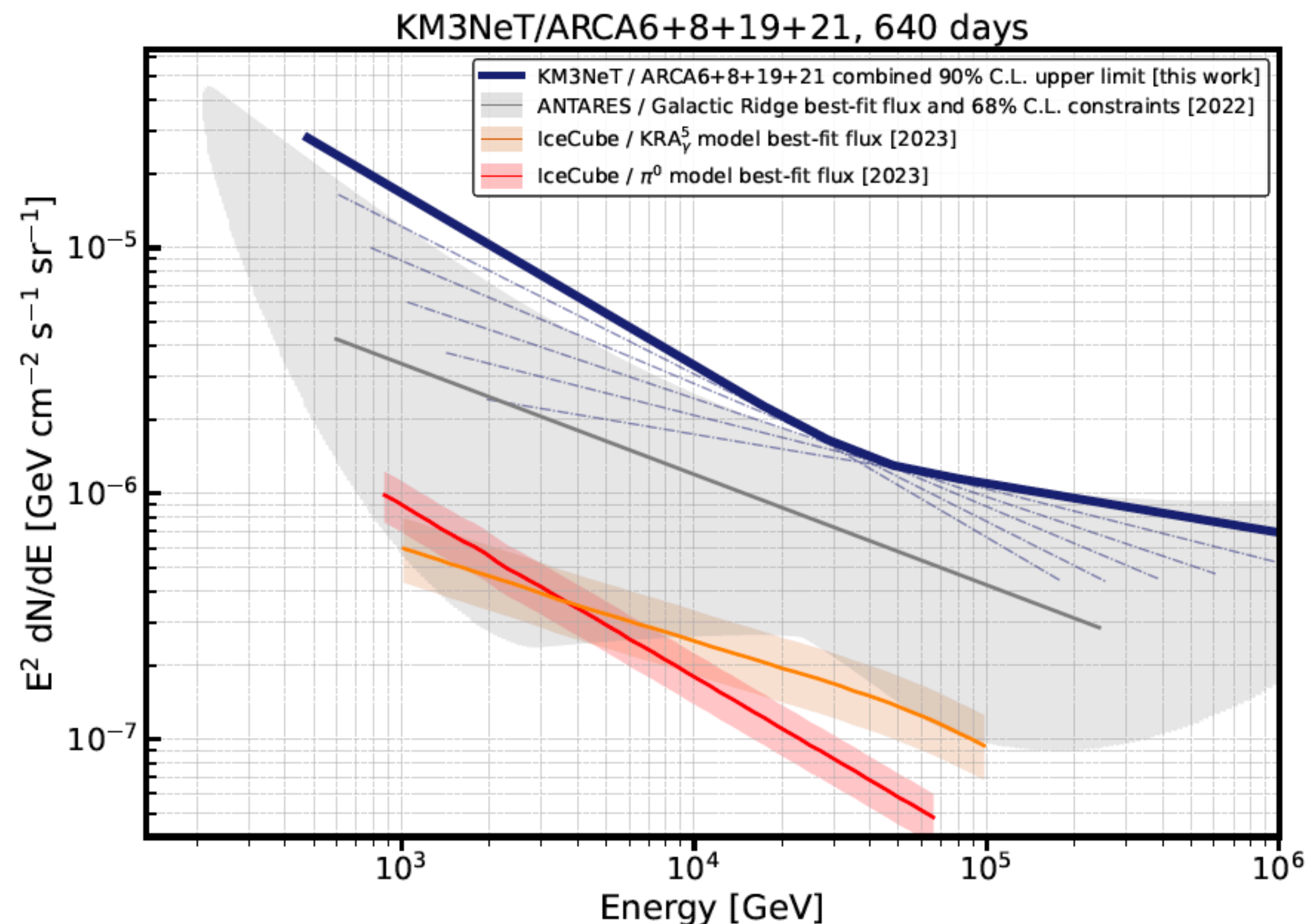
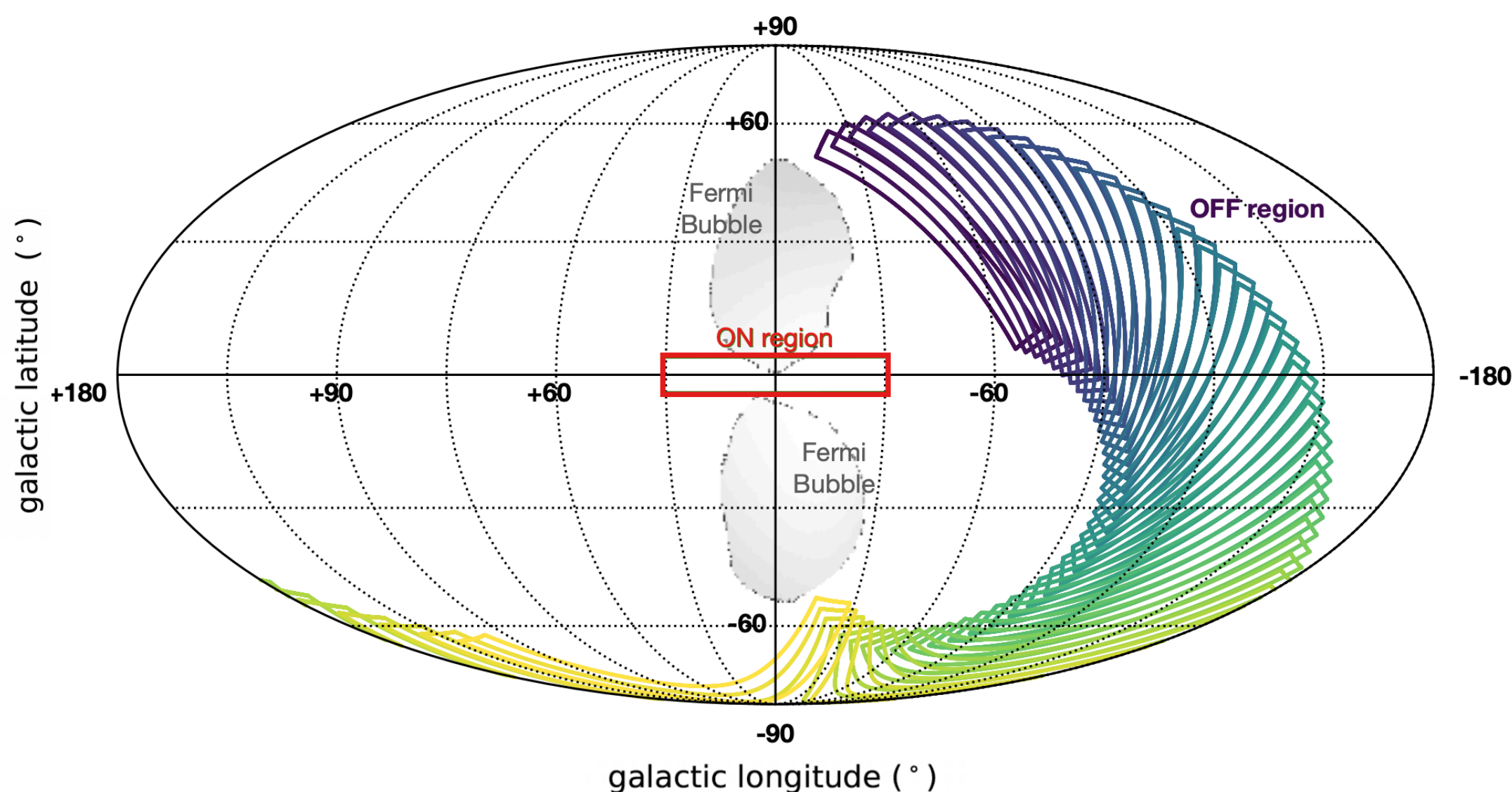
[arXiv:2608.06163](https://arxiv.org/abs/2608.06163)

ON-OFF technique

- Signal: coming from Galactic Ridge region, defined as

$|b| < 2^\circ$, $|l| < 30^\circ$, derived from Monte Carlo simulations, under single power-law assumption: $\Phi_\nu(E) = \frac{dN_\nu}{dE_\nu} = \Phi_0 \times \left(\frac{E_\nu}{E_0}\right)^{-\Gamma_\nu}$.

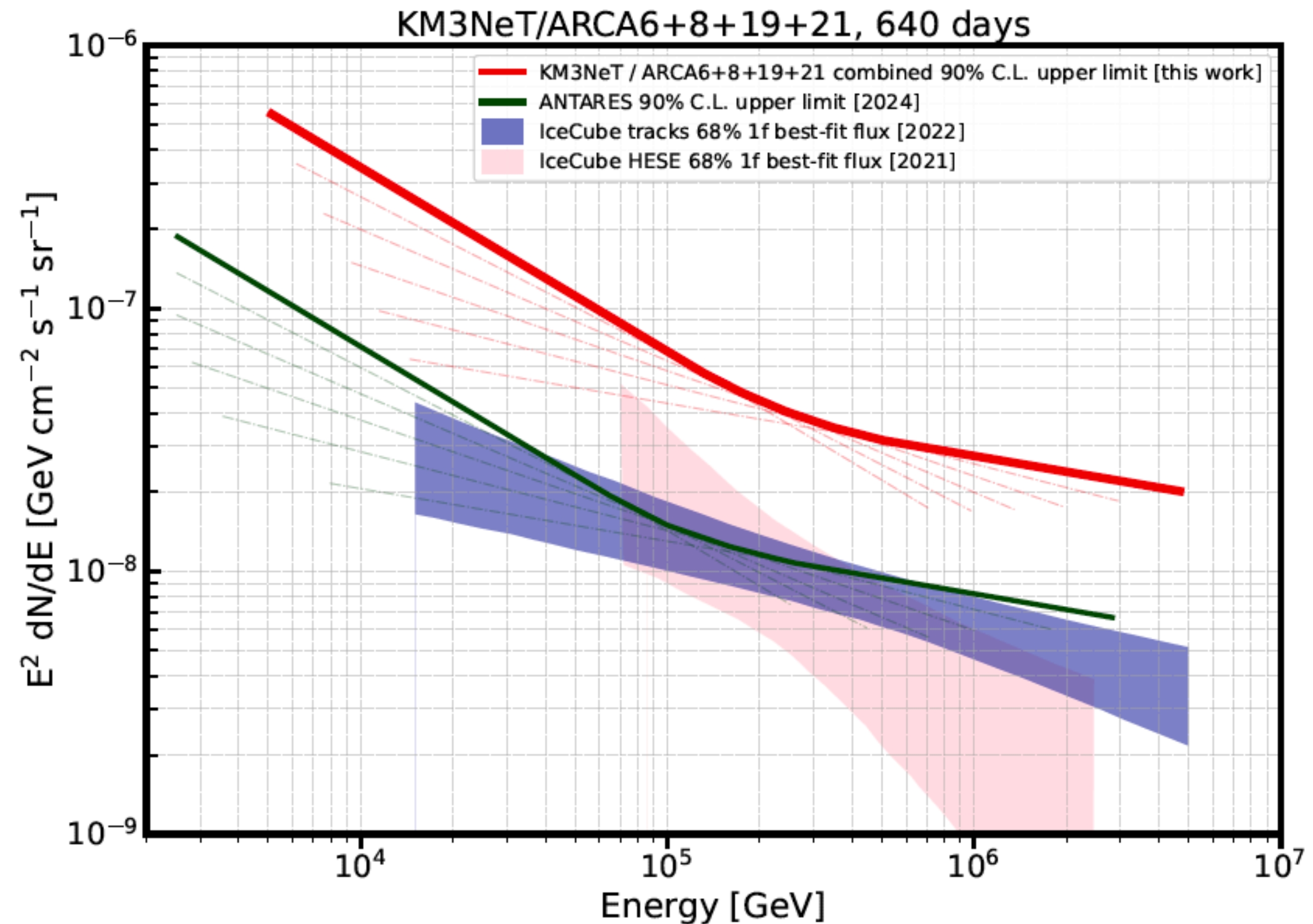
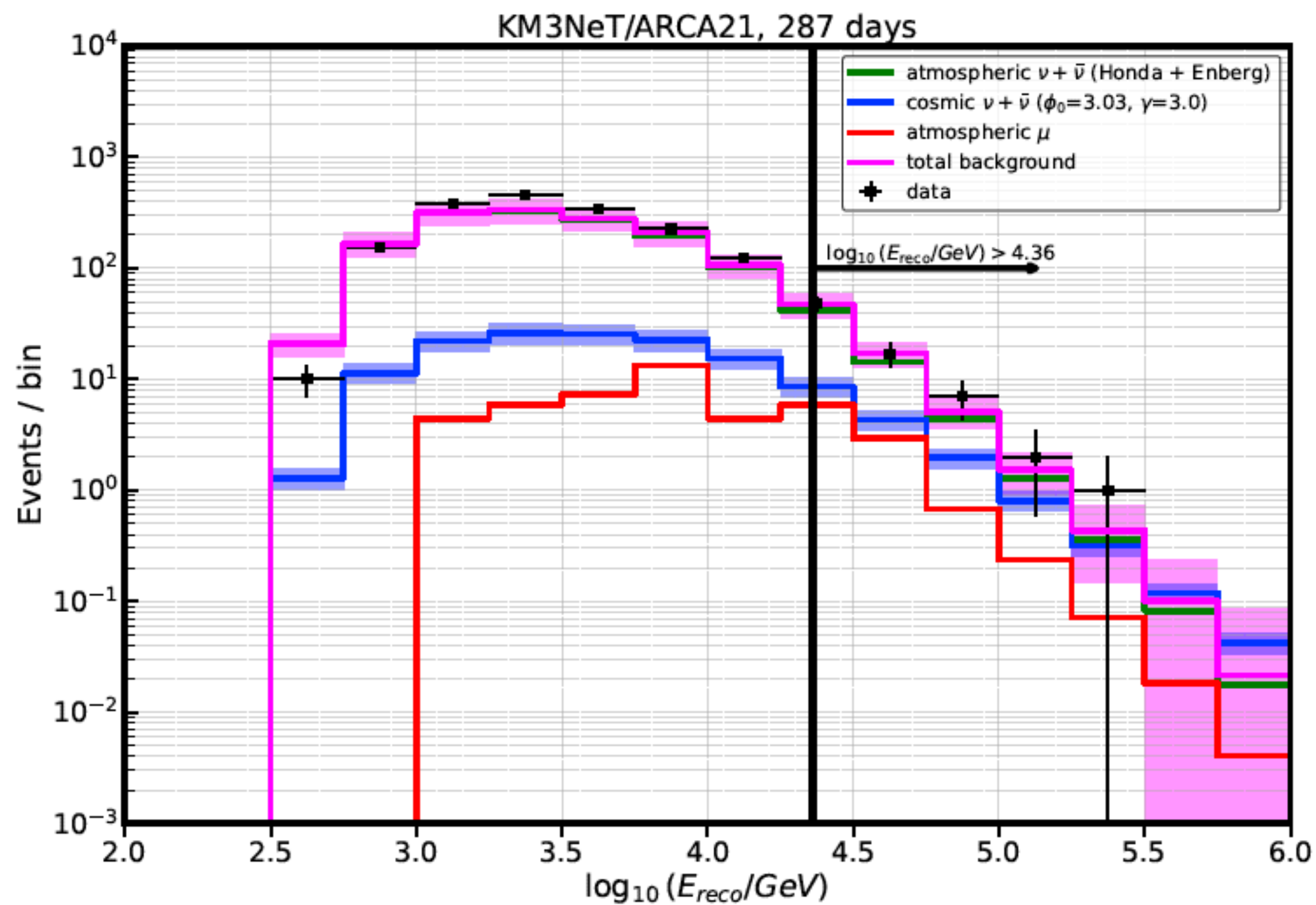
- OFF region: same sky coverage of the ON region and shifted in right ascension, avoiding also the region of the Fermi Bubbles $\rightarrow$ data-driven background estimate.



Diffuse all-sky search

- Up-going track-like events + BDT to further suppress mis-reconstructed atmospheric muons → **97% neutrino purity** in ARCA19-21 dataset.
- **Background from MC** including systematic uncertainties.

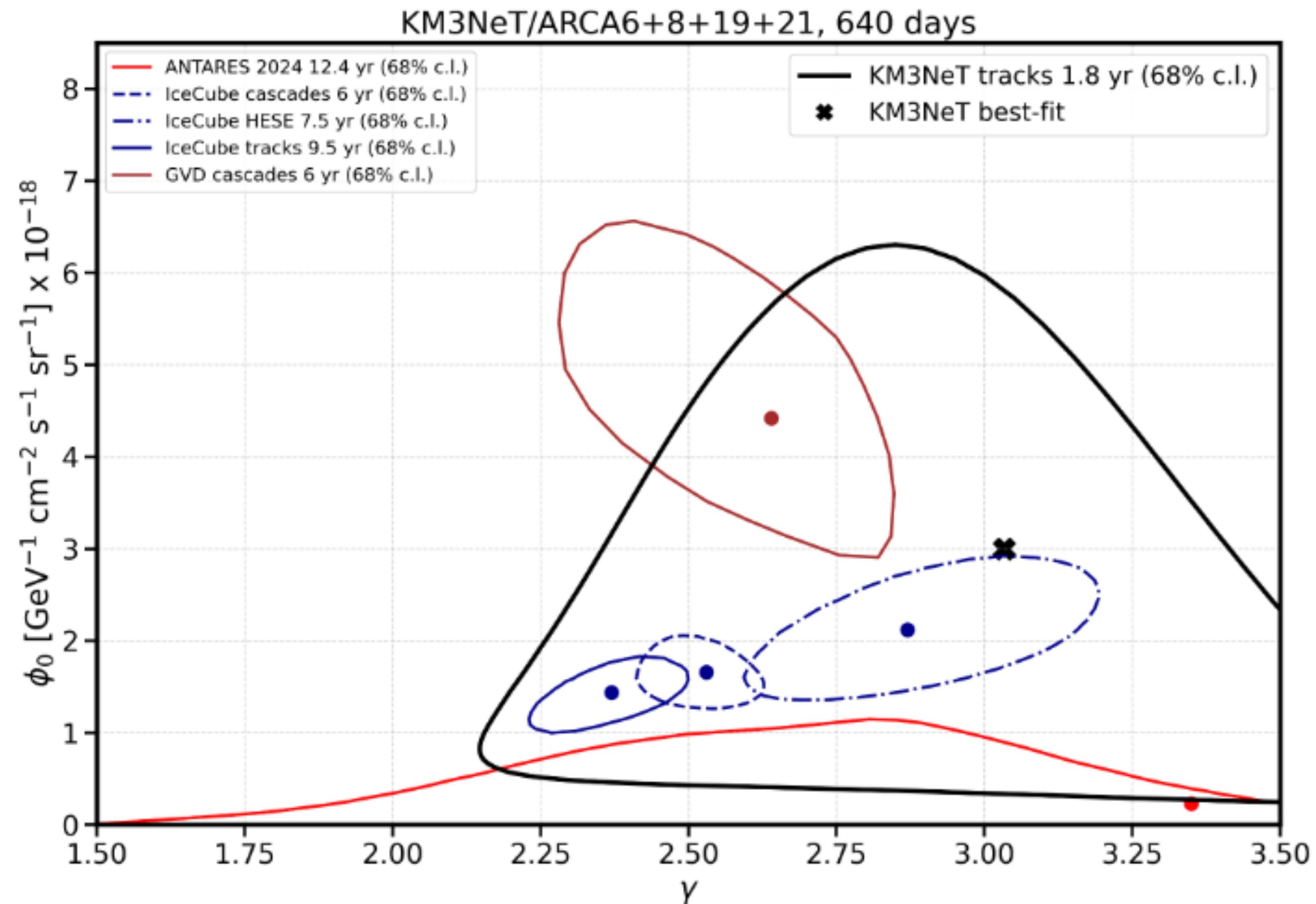
[arXiv:2608.06163](https://arxiv.org/abs/2608.06163)



Diffuse all-sky landscape

KM3NeT best-fit at 68% C.L.:

$$\Phi_0 = 3.0^{+2.1}_{-2.0} \times 10^{-18} \text{ GeV}^{-1} \text{ cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1} \text{ (at 100 TeV)} - \gamma = 3.00^{+0.30}_{-0.35}$$

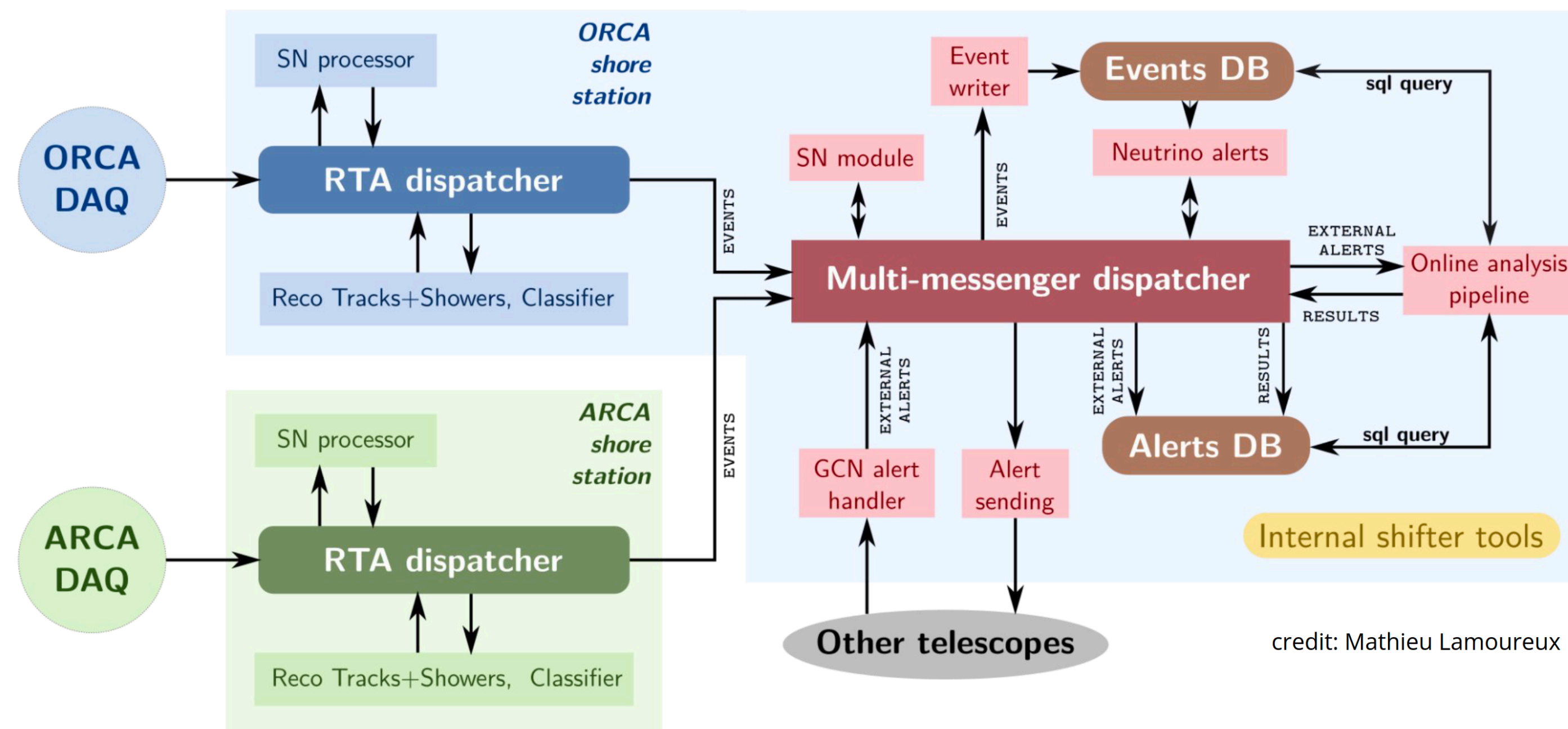
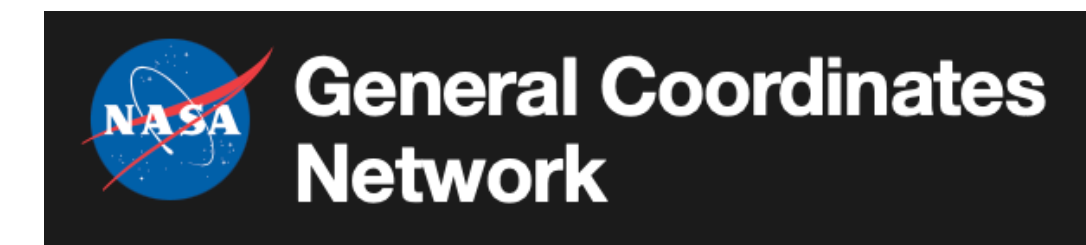


KM3NeT real-time system

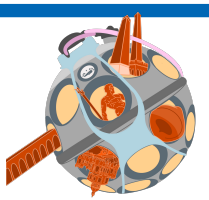
Searching for **correlation between neutrinos and MM signals** (EM, GW). Crucial to be able to identify cosmic neutrinos in real-time to allow fast follow-up for counterpart identification.

The **Real-Time Analysis (RTA)** program includes:

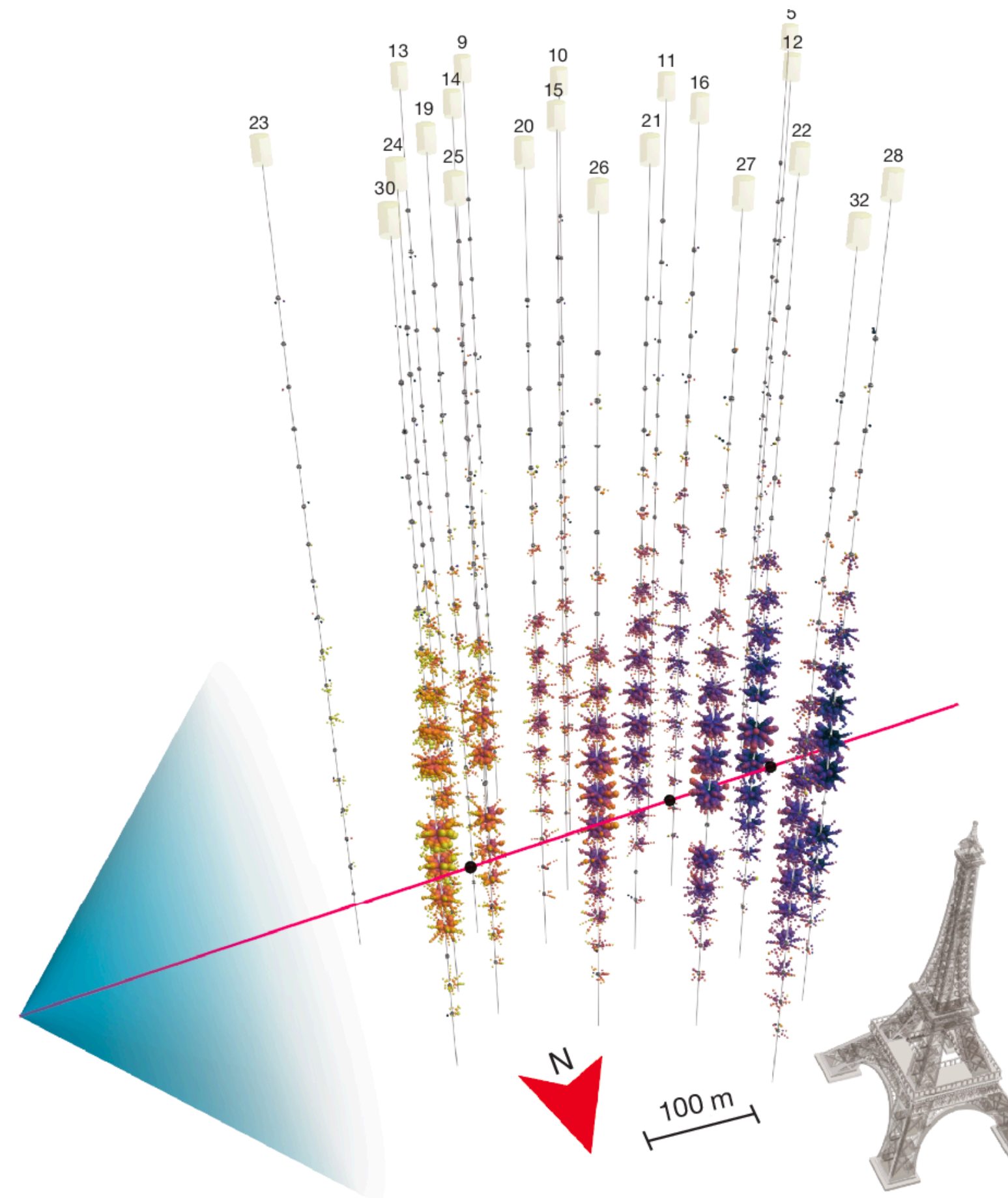
- Continuous Supernovae monitoring (**MeV**) → SNEWS.
- Follow-up of external triggers with KM3NeT data (**>GeV**) → GCN.
- Neutrino **alert sending** (>GeV, HE, multiplets, ...).



credit: Mathieu Lamoureux



KM3-230213A

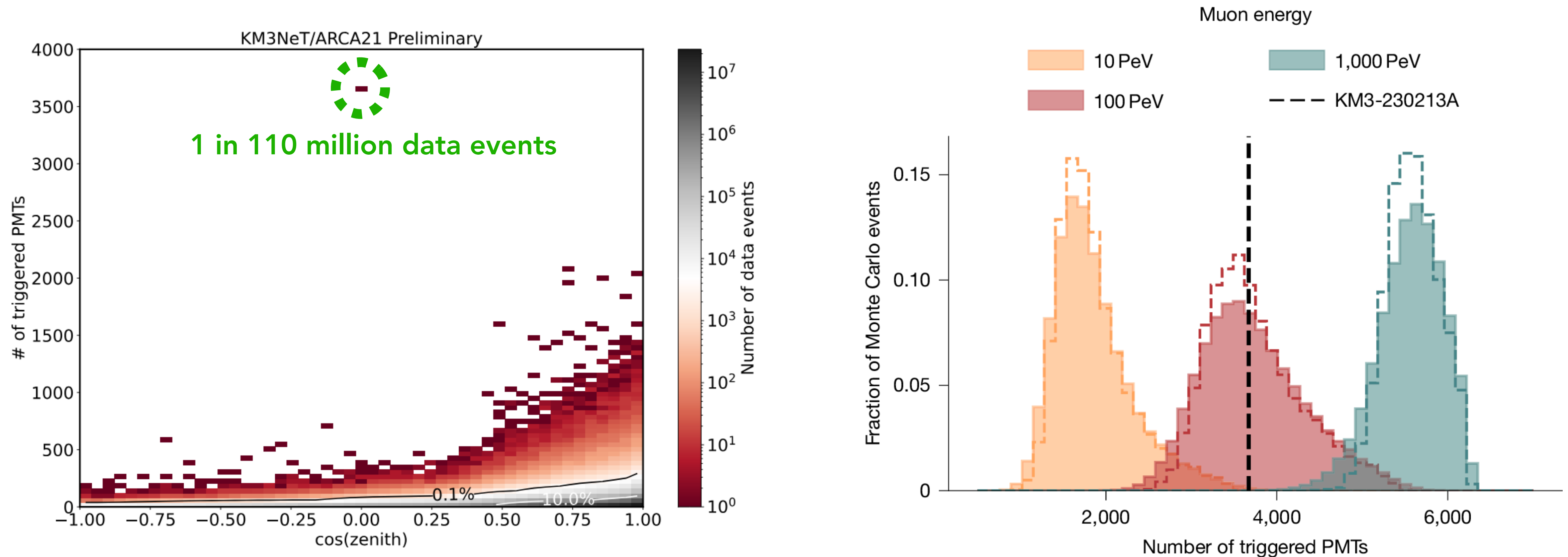


Public data set @ [zenodo-4860165](https://zenodo.org/record/4860165)



A very energetic event

- **Horizontal event** (1° above horizon) as expected since earth opaque to neutrinos at PeV scale.
- **3672 PMTs (35%)** were **triggered** in the ARCA21 detector.
- Energy estimate assuming a passing-through muon: $E_\mu = 120_{-60}^{+110}$ PeV.



Arrival direction

Equatorial coordinates of KM3-230213A:

RA = 94.3° , dec = -7.9°

Direction uncertainty:

R(68%) = 1.5°

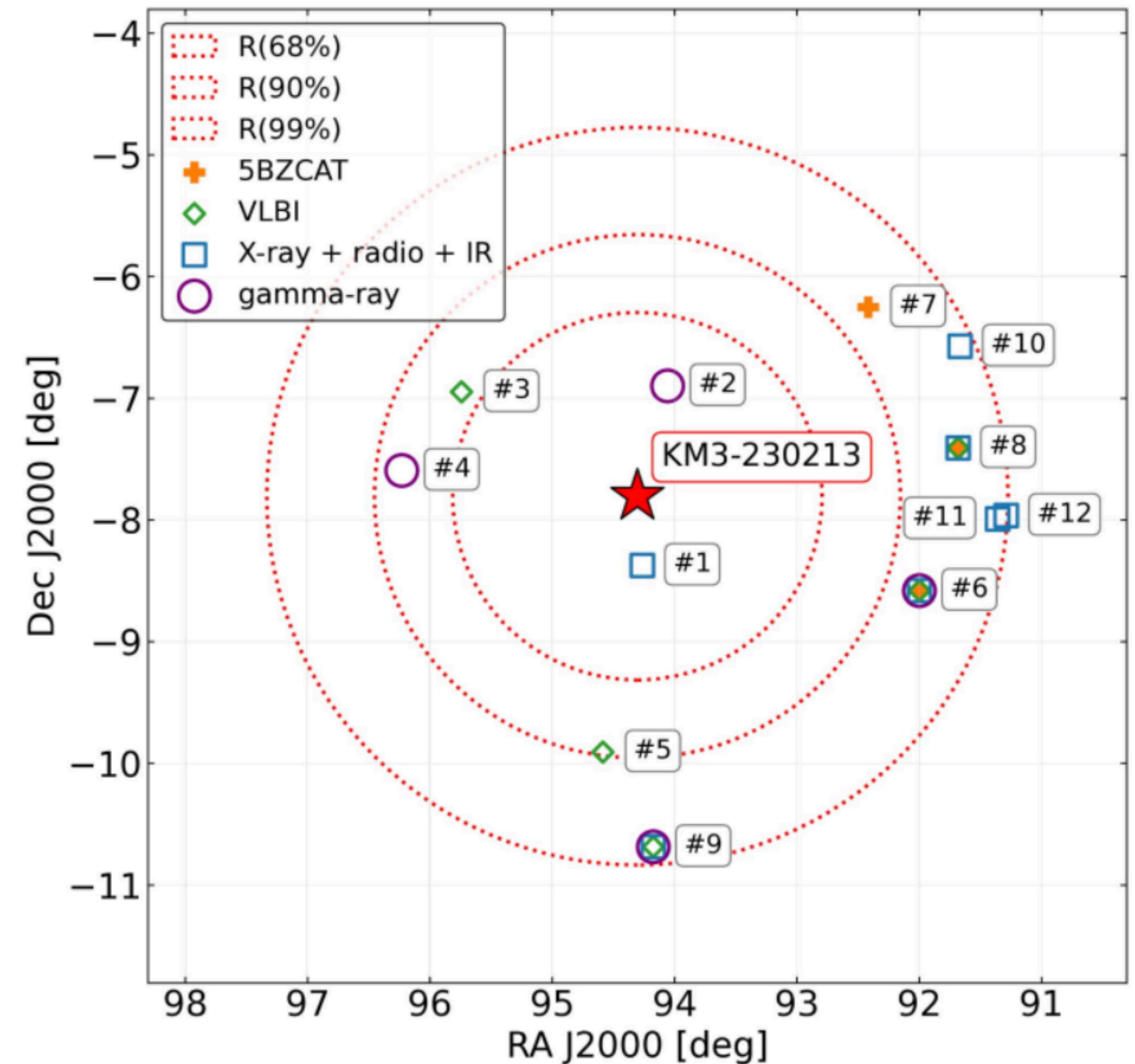
R(99%) = 3.0°

Dominant **systematic** effect due to **absolute orientation** of the detector. **0.12° intrinsic** angular uncertainty.

Improvements planned with the **next sea-operation**: a new dedicated positioning system will be deployed.

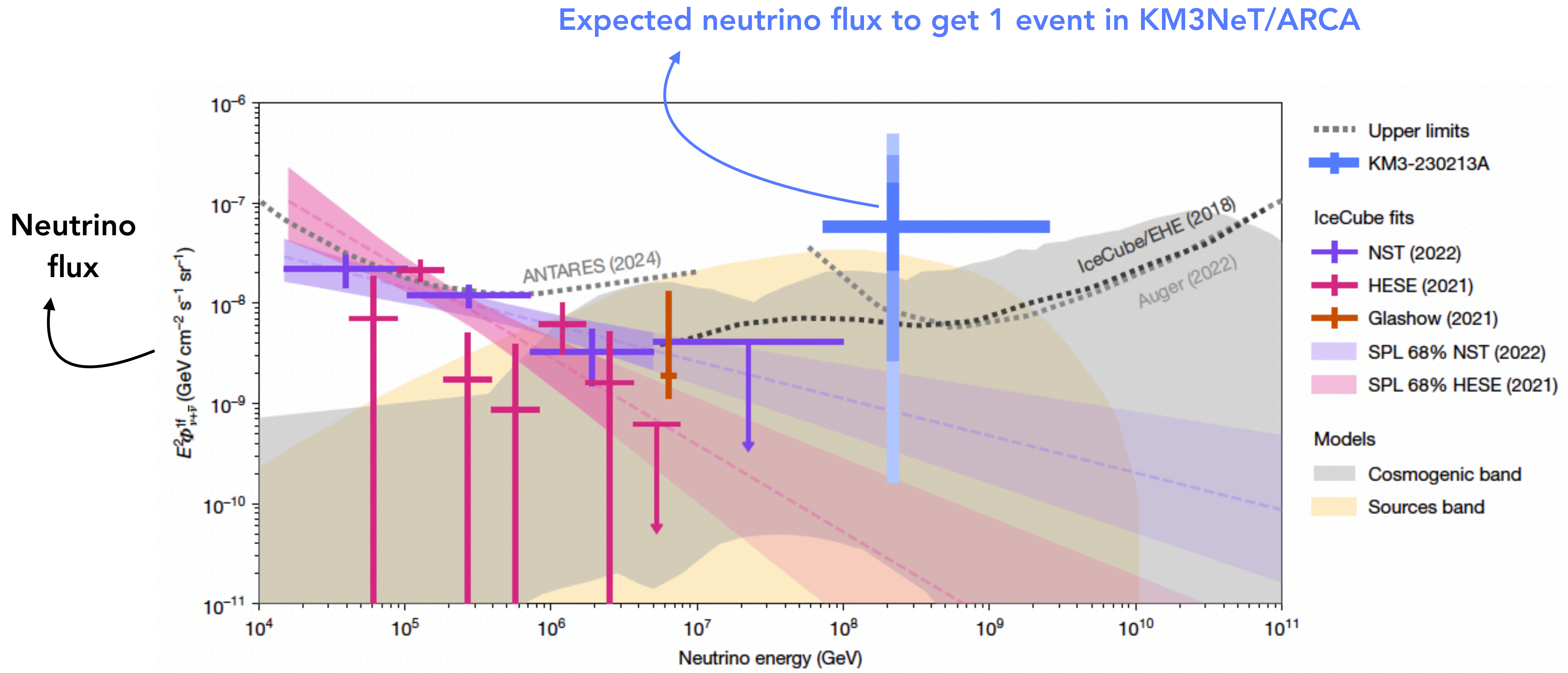
Studied **possible association** with known radio, X-ray and gamma-ray sources.

Found 17 blazar candidates, two of them inside the R(68%).



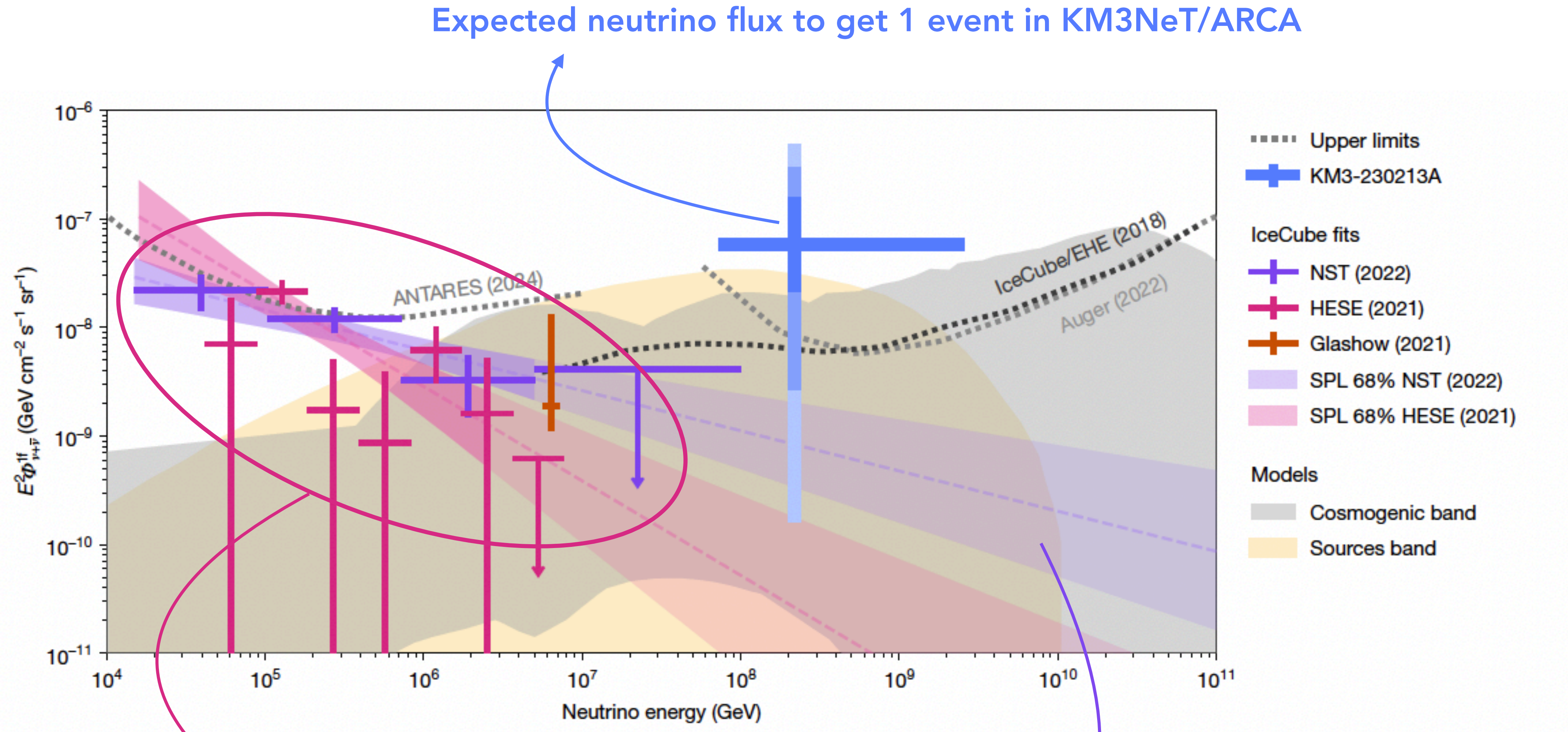
KM3NeT. *Nature* **638**, 376–382 (2025)

The neutrino landscape: KM3NeT



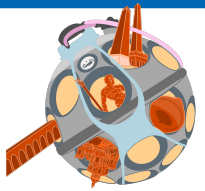
Assuming KM3NeT exposure $\rightarrow \hat{\phi} = 5.85 \times 10^{-8} \text{ GeV}^{-1} \text{cm}^{-2} \text{s}^{-1} \text{sr}^{-1}$ for an E^{-2} spectrum.

The neutrino landscape: KM3NeT

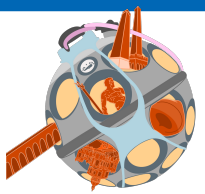
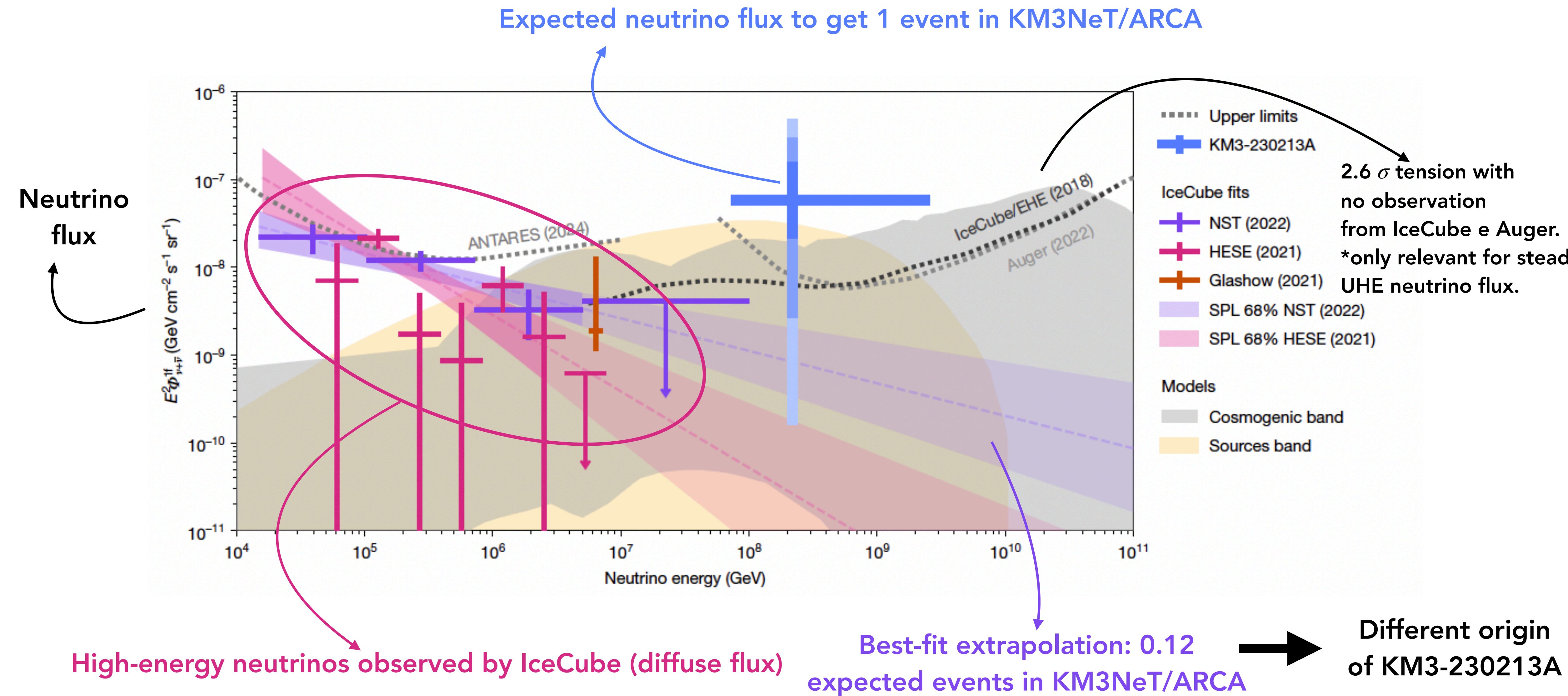


High-energy neutrinos observed by IceCube (diffuse flux)

Best-fit extrapolation: 0.12
expected events in KM3NeT/ARCA



The neutrino landscape: KM3NeT

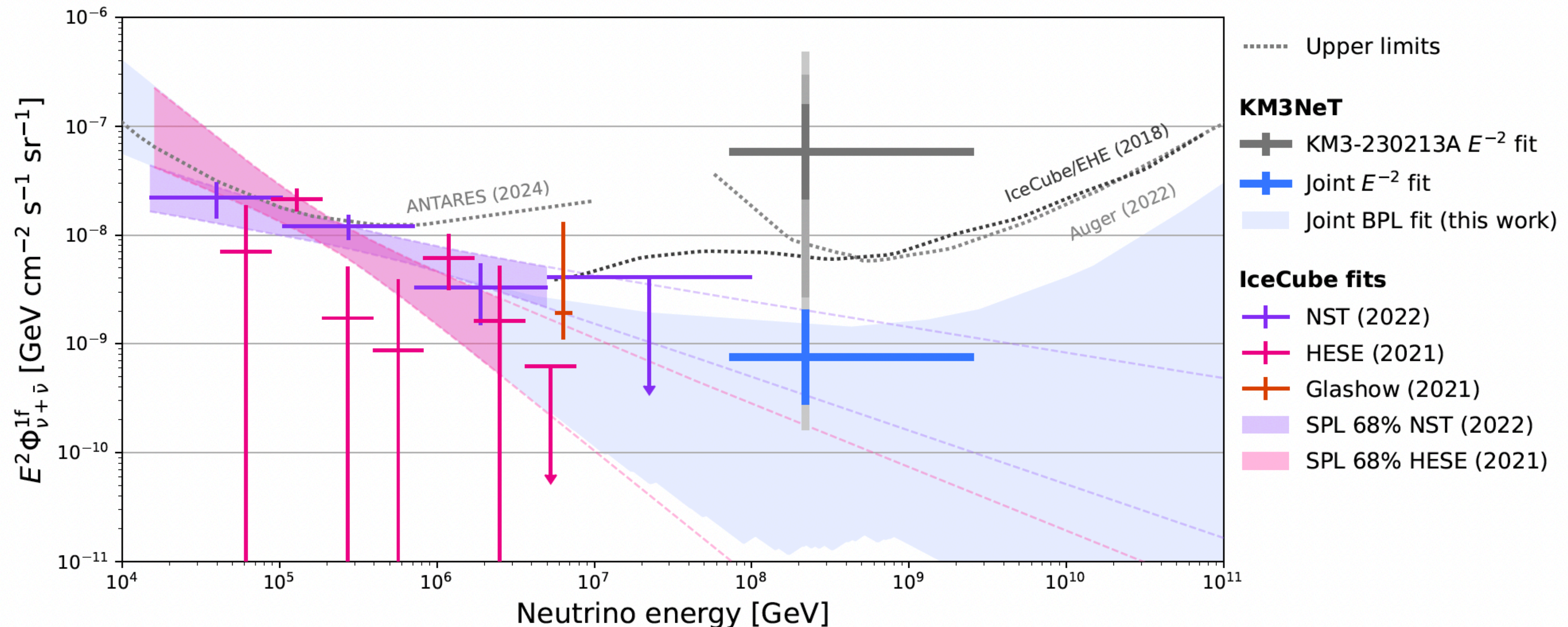


The global neutrino landscape

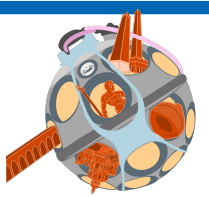
Combined fit for the observation of **1 event in KM3NeT, 0 in Auger and 0 in IceCube**.

Combined poisson likelihood fitting flux normalization (assuming an E^{-2} spectrum).

Auger and IceCube exposure extrapolated from public data.

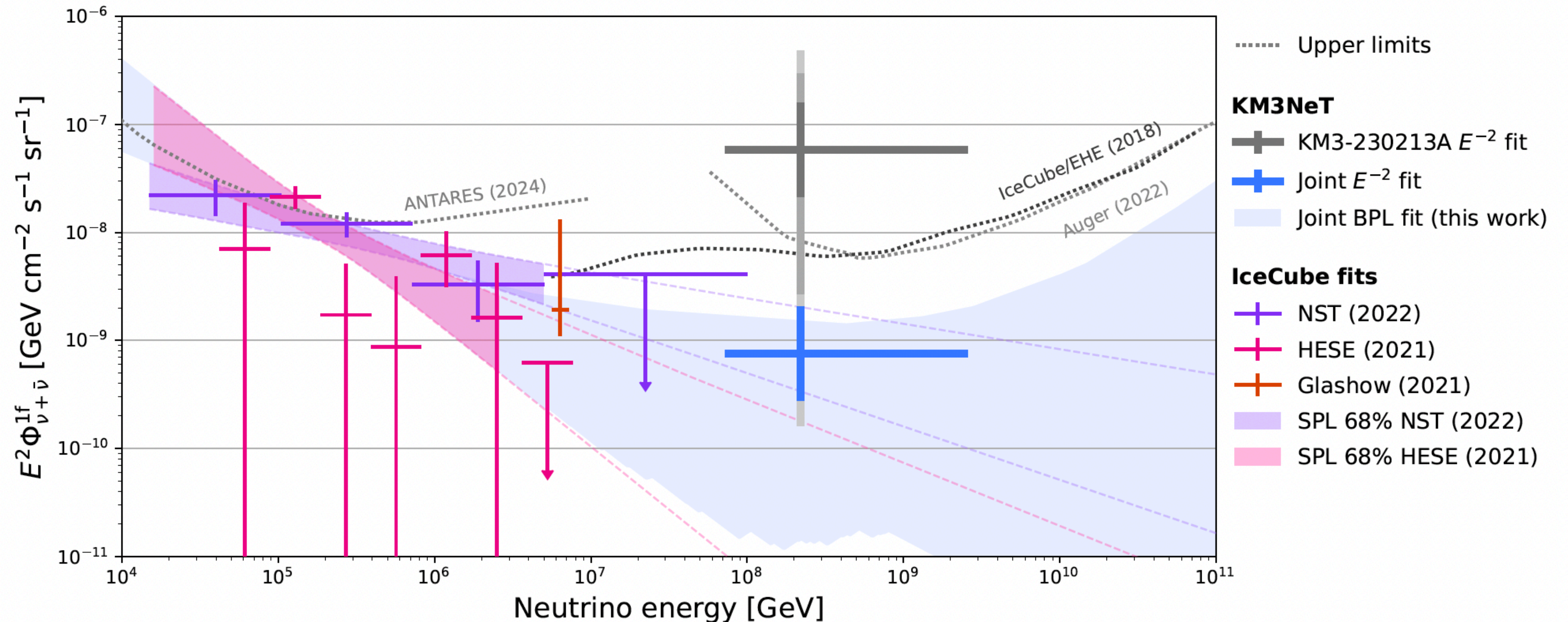


Companion paper by KM3NeT Coll. [Phys. Rev.X 15 \(2025\) 031016](https://arxiv.org/abs/2503.1016).



The global neutrino landscape

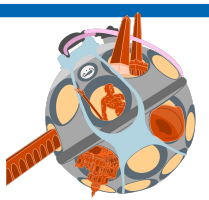
Companion paper by KM3NeT Coll. [Phys. Rev.X 15 \(2025\) 031016](https://arxiv.org/abs/2503.1016).



$\hat{\phi} = 7.5 \times 10^{-10} \text{ GeV}^{-1} \text{ cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1}$ for an E^{-2} spectrum

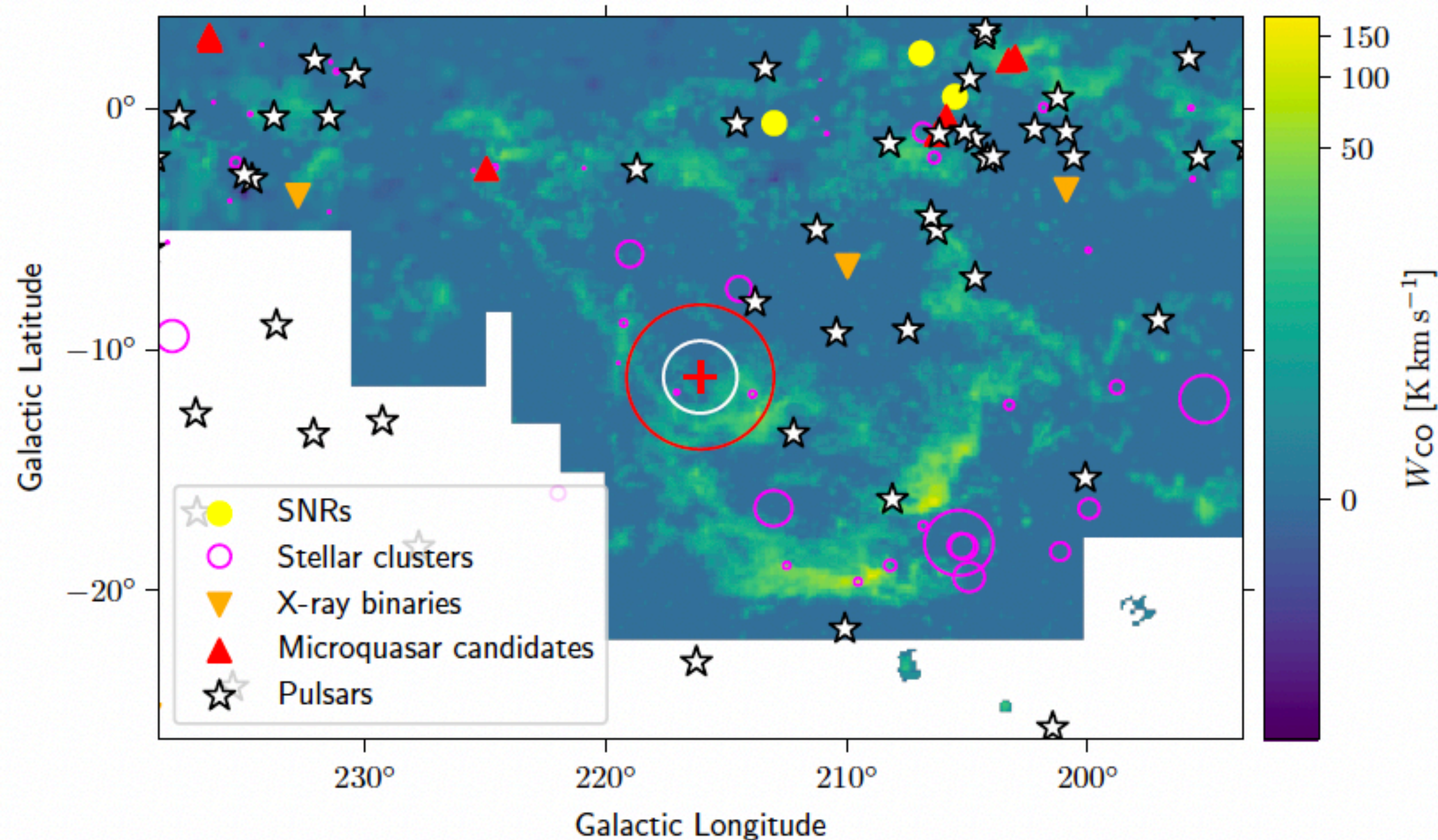
→ **0.59** and **0.40** events would be expected in Ice-Cube and Auger, while **0.013** in KM3NeT/ARCA.

Upward fluctuation at 2.2σ .



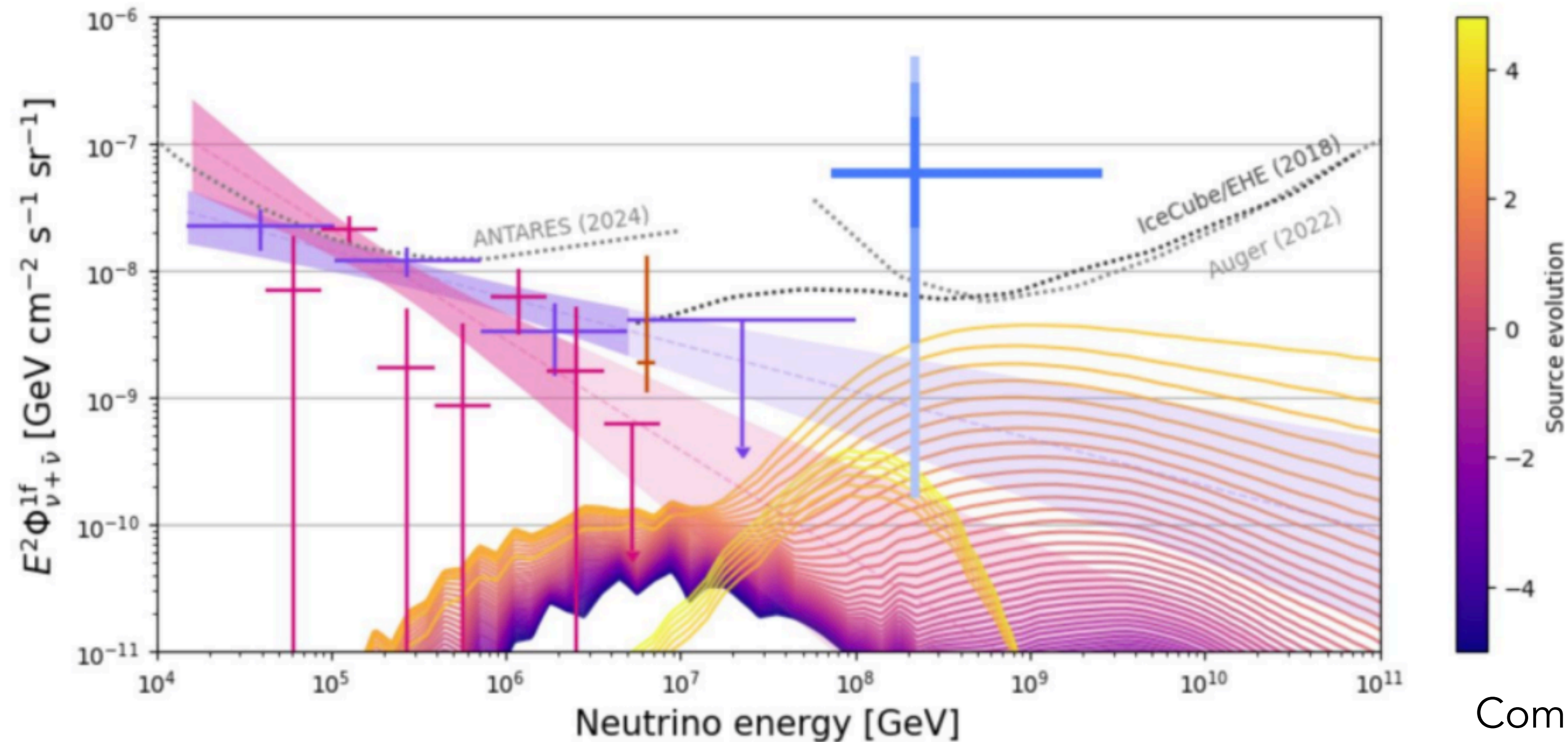
Galactic origin ?

- The center of our Galaxy can emit neutrinos.
Spatial and time correlation did not highlight potential candidates.
- Big challenge for a potential Galactic origin of KM3-230213A: **extreme energy** → **Galactic CR sources failed to reach such high energies.**
- Transition region between the “knee” and the “ankle”.
This is also reflected by the interpretation of the knee in the CR spectrum.



Companion paper by KM3NeT Coll.: [ApJ 1003 \(2026\) 157](#).

Cosmogenic origin ?



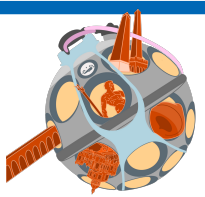
Companion paper by
KM3NeT Coll.: [ApJL 984 \(2025\) L41](#).

- **In tension with the standard cosmogenic neutrino predictions** based on the observations of ultra-high-energy cosmic rays above the ankle (hence from the local Universe, $z \lesssim 1$).
- Observations can be reconciled by **extending** the integration of the cosmogenic neutrino flux up to a redshift of $z \approx 6$ and assuming a **subdominant fraction of protons** in the ultra-high-energy cosmic-ray flux.

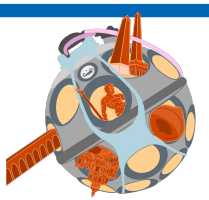
Conclusions and outlook

- KM3NeT has been taking **high quality data** during construction phase.
- The KM3NeT detectors explore the physics of multiple layers thanks to the **multi-PMT DOM design**.
- **ORCA** measures oscillations of atmospheric neutrinos, and is sensitive to the Neutrino Mass Ordering, as well as physics beyond the Standard Model.
- Searches for **astrophysical sources** are under way.
- An **unprecedented event** was observed in rich detail.
- The KM3NeT detectors are steadily growing.

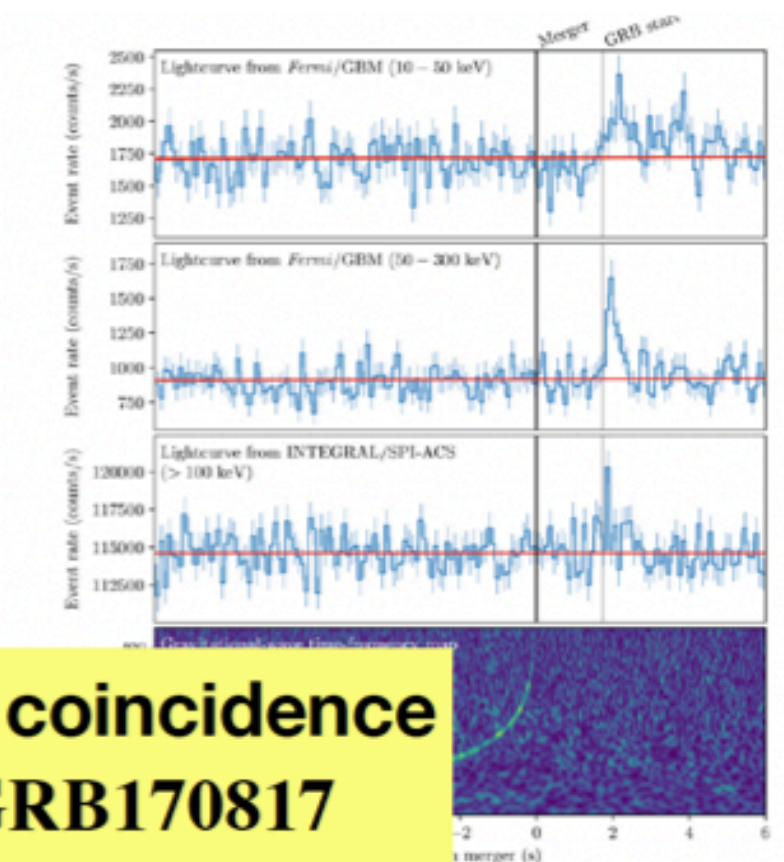
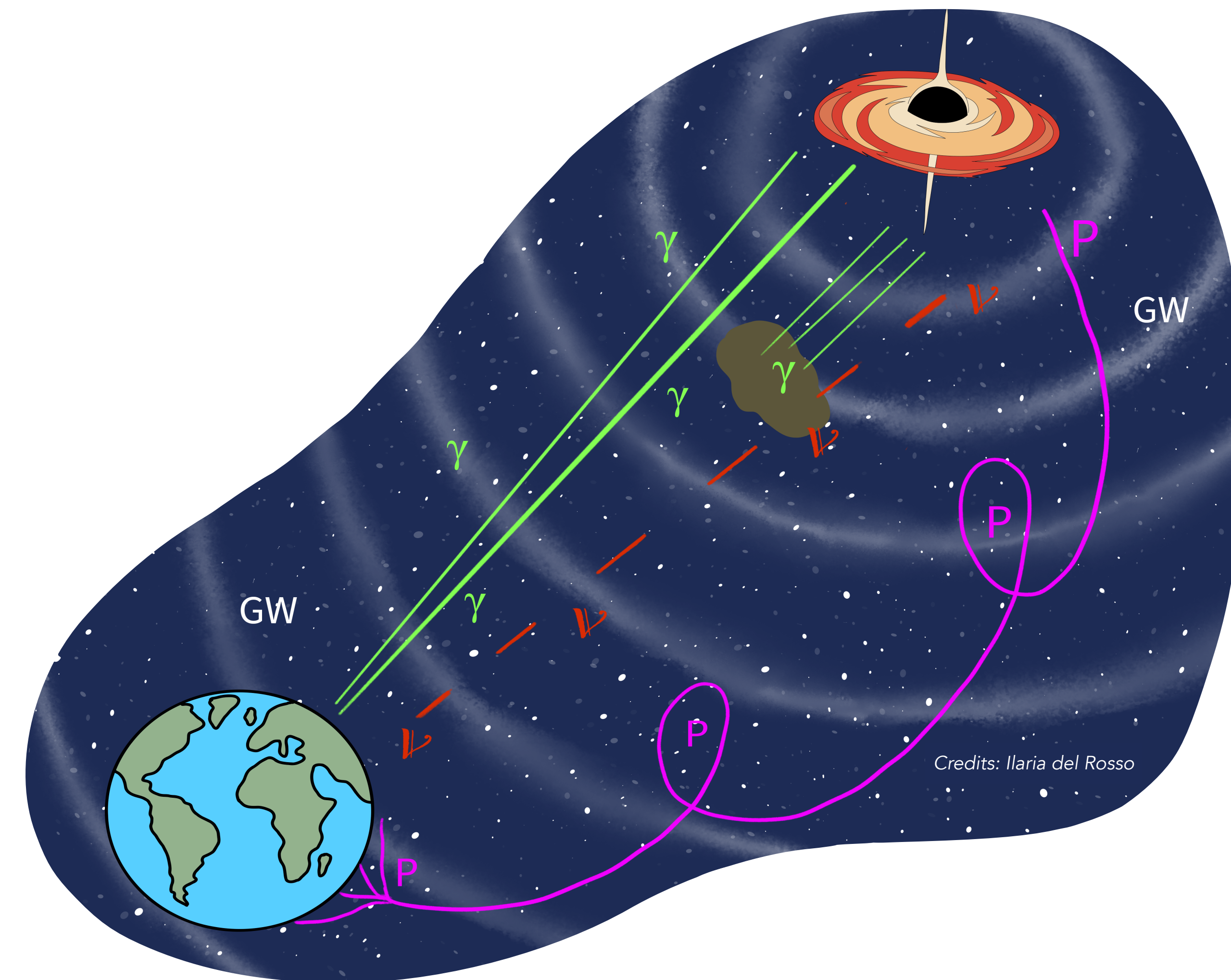
Stay tuned and thanks for your attention!



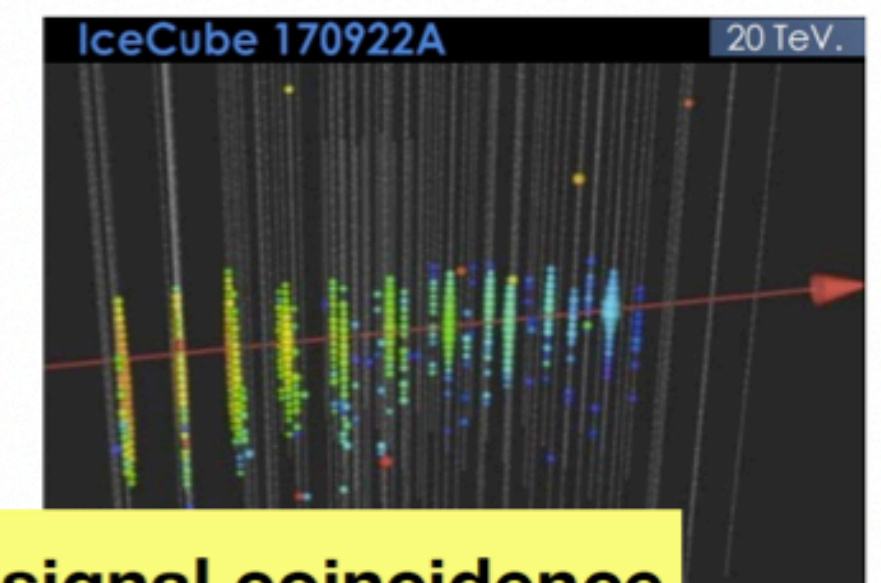
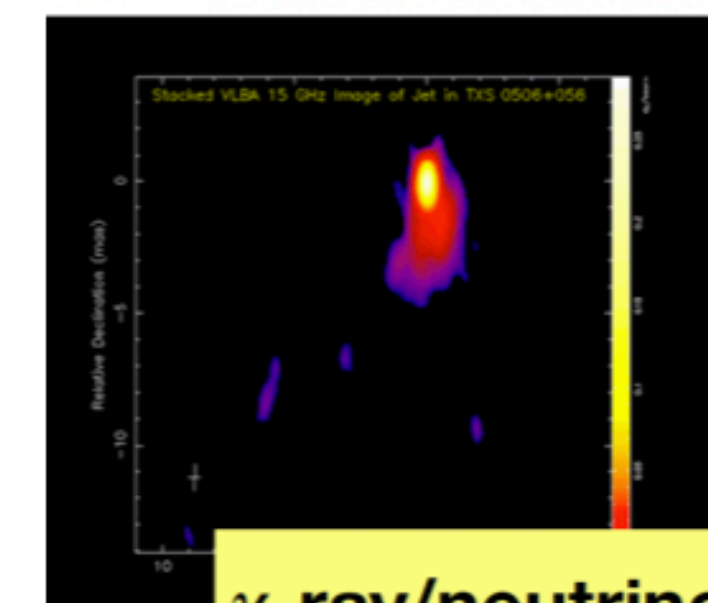
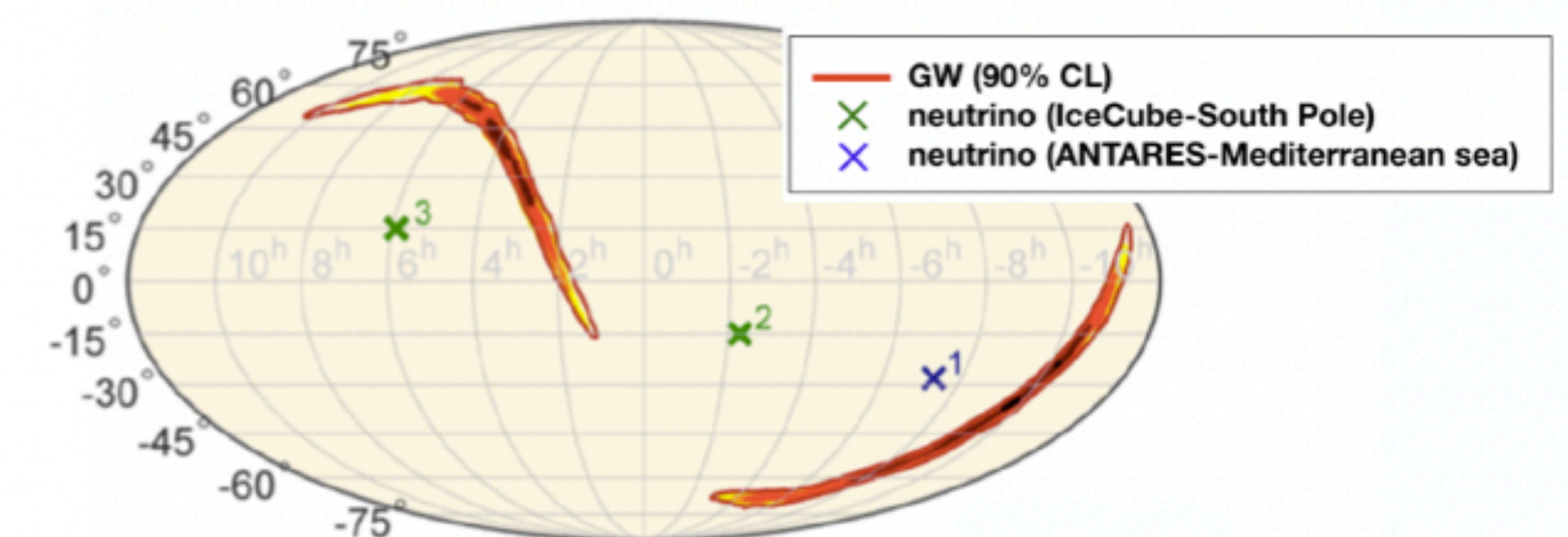
BACKUP SLIDES



Multi-messenger astronomy

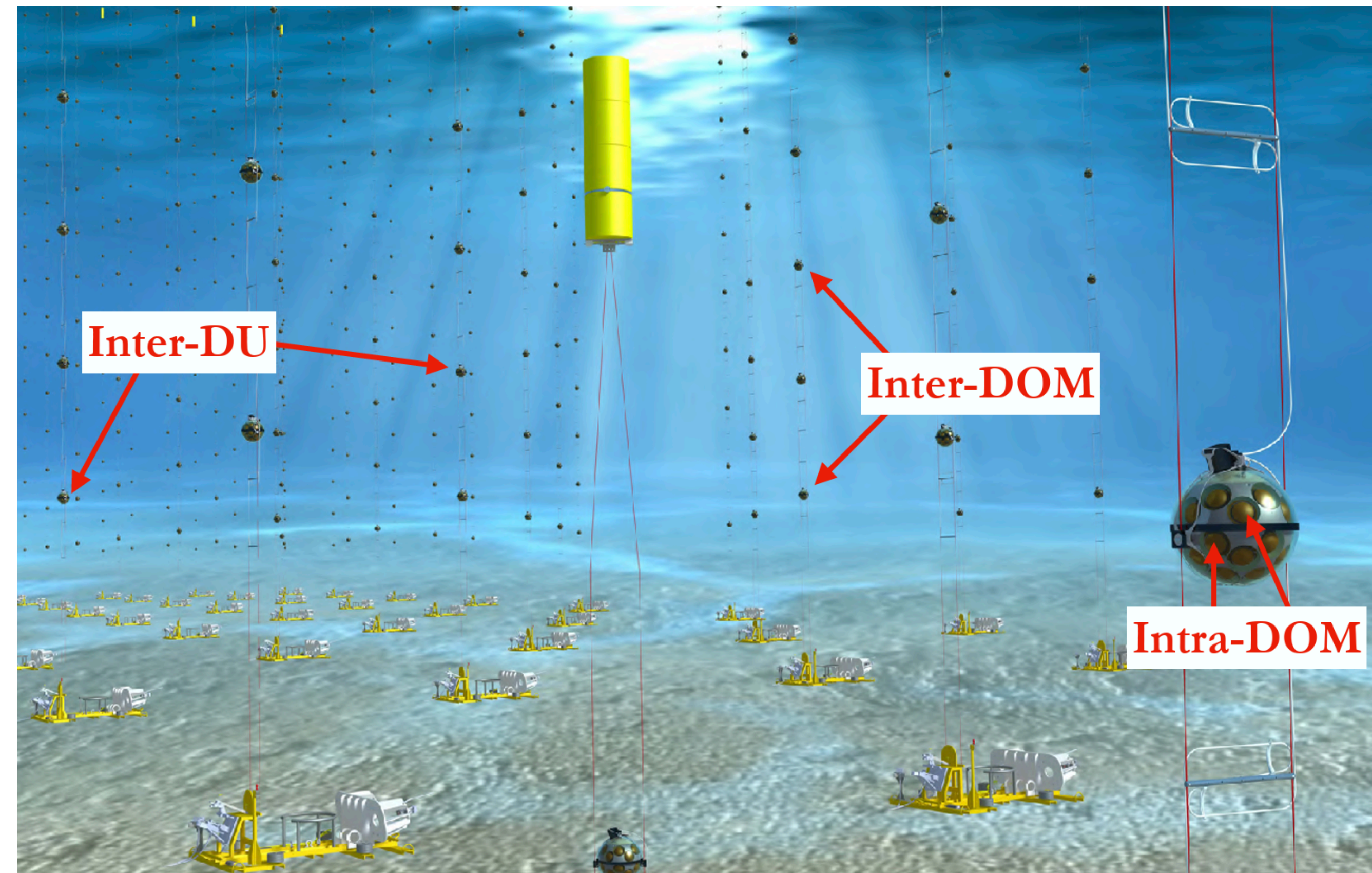


GW/GRB signal coincidence
GW170817 / GRB170817



γ -ray/neutrino signal coincidence
IC170922 / TXS 0506+056

Calibration in KM3NeT



- **Intra-DOM:**

Coincident hits on neighbor PMTs due to ^{40}K decay [pos\(ICRC25\)1081](#).

- **Inter-DOM:**

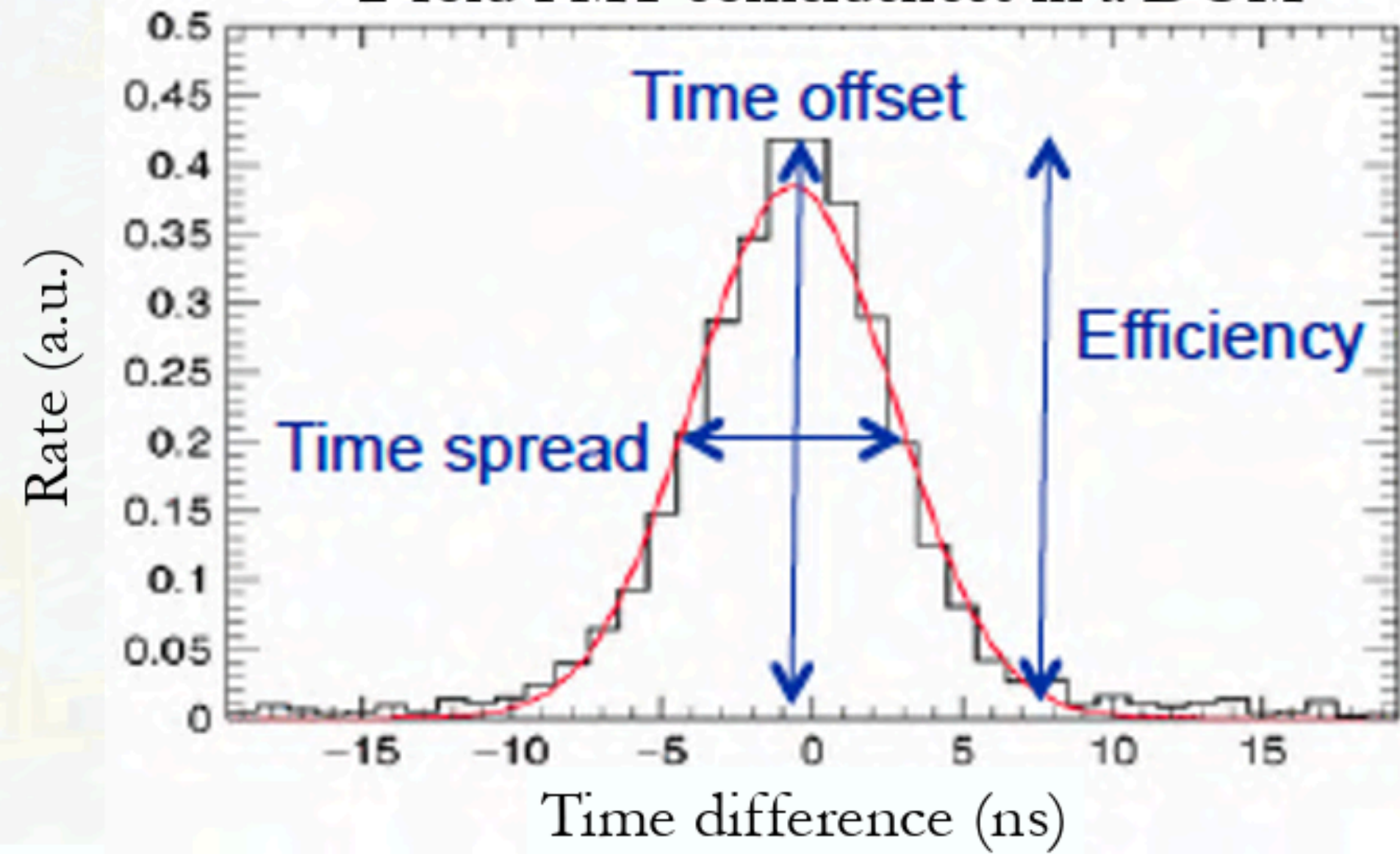
1. Laser source in DarkRoom illuminating simultaneously a reference PMT in all DOMs of a DU.
2. Relative calibration/check in situ:
 - (i) Nano-beacons [pos\(ICRC25\)1062](#).
 - (ii) Atmospheric muons [pos\(ICRC23\)218](#).

- **Inter-DU:**

1. Round-Trip Time measurement between the master clock (on shore) and each DU base (slave).
2. Relative calibration/check in situ:
 - (i) Laser beacons.
 - (ii) Atmospheric muons.

K40 calibration

2-fold PMT coincidences in a DOM



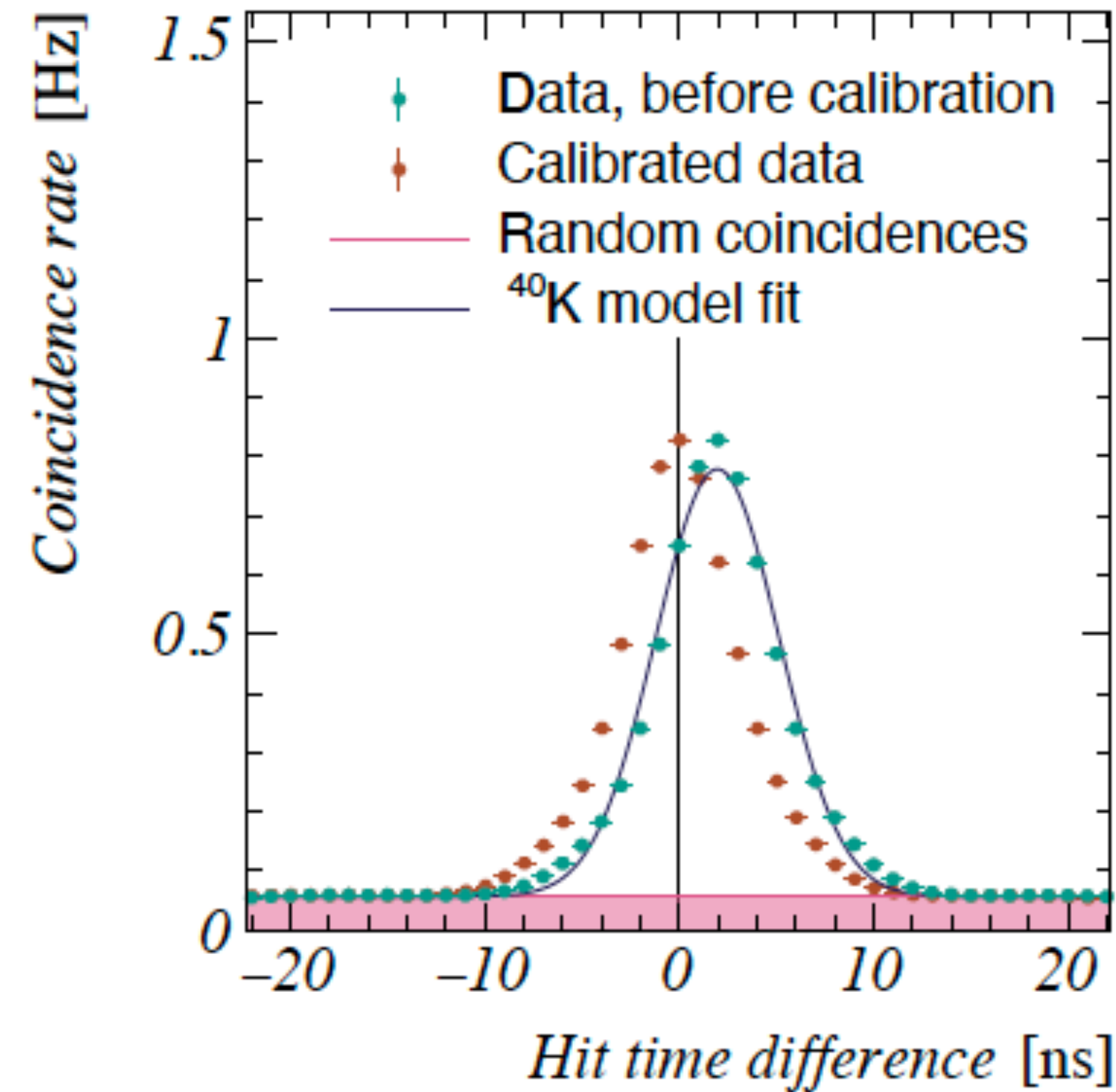
- K40 β^- decay:



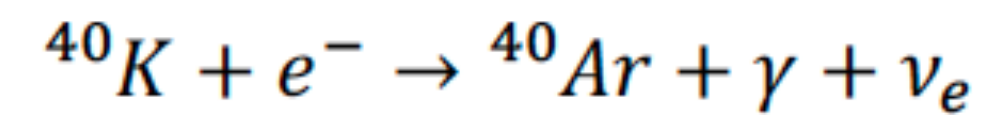
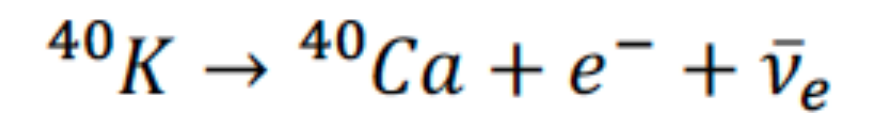
$$E_{e^-} < 1.3 \text{ MeV}$$

Cherenkov threshold in water:

$$E_{e^-} > 0.8 \text{ MeV}$$



^{40}K decays in sea water:

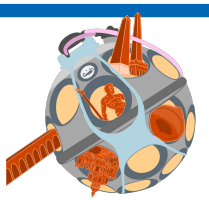


Correlated signals in ≥ 2 PMTs:

- Intra-DOM PMT timing
- PMT efficiency

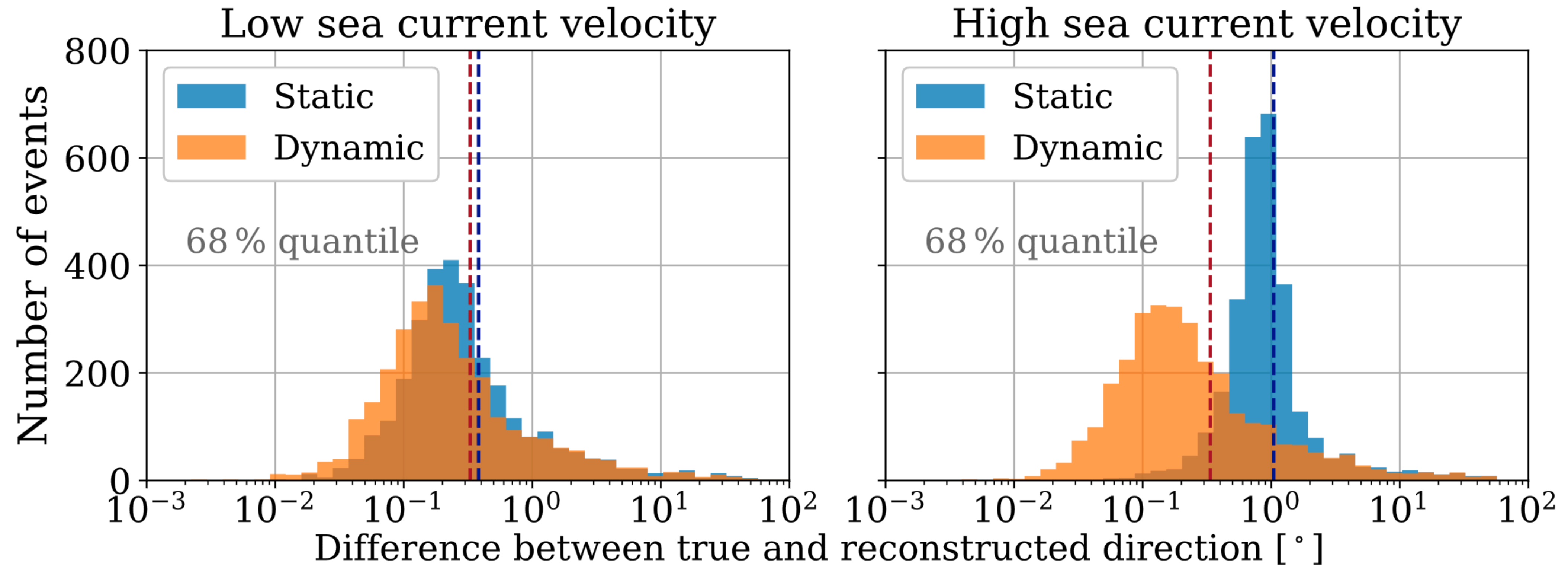
Inter-DOM and Inter-DU timing: Laser calibration before deployment + in-situ atmospheric muons

DOM orientation: Compasses inside DOMs + in-situ atmospheric muons

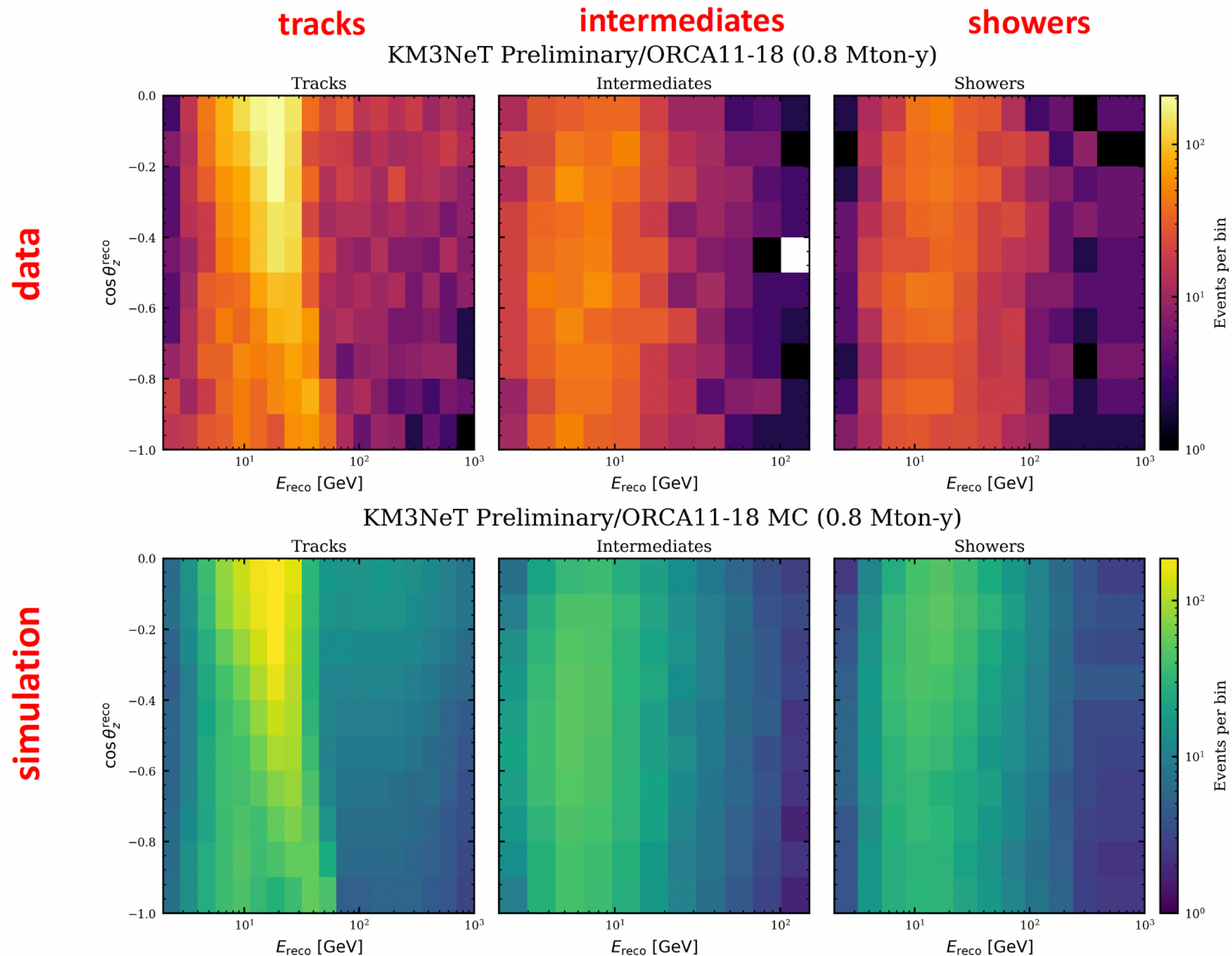


Calibration in KM3NeT

KM3NeT/ARCA30, preliminary



Oscillations fit



Oscillations fit is performed on these 2D distributions of $\cos \theta$ versus E

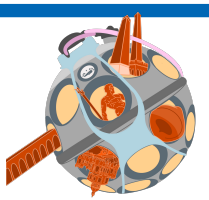
We split the data set in ORCA6-7 and ORCA11-18, with different response functions.

Systematics:

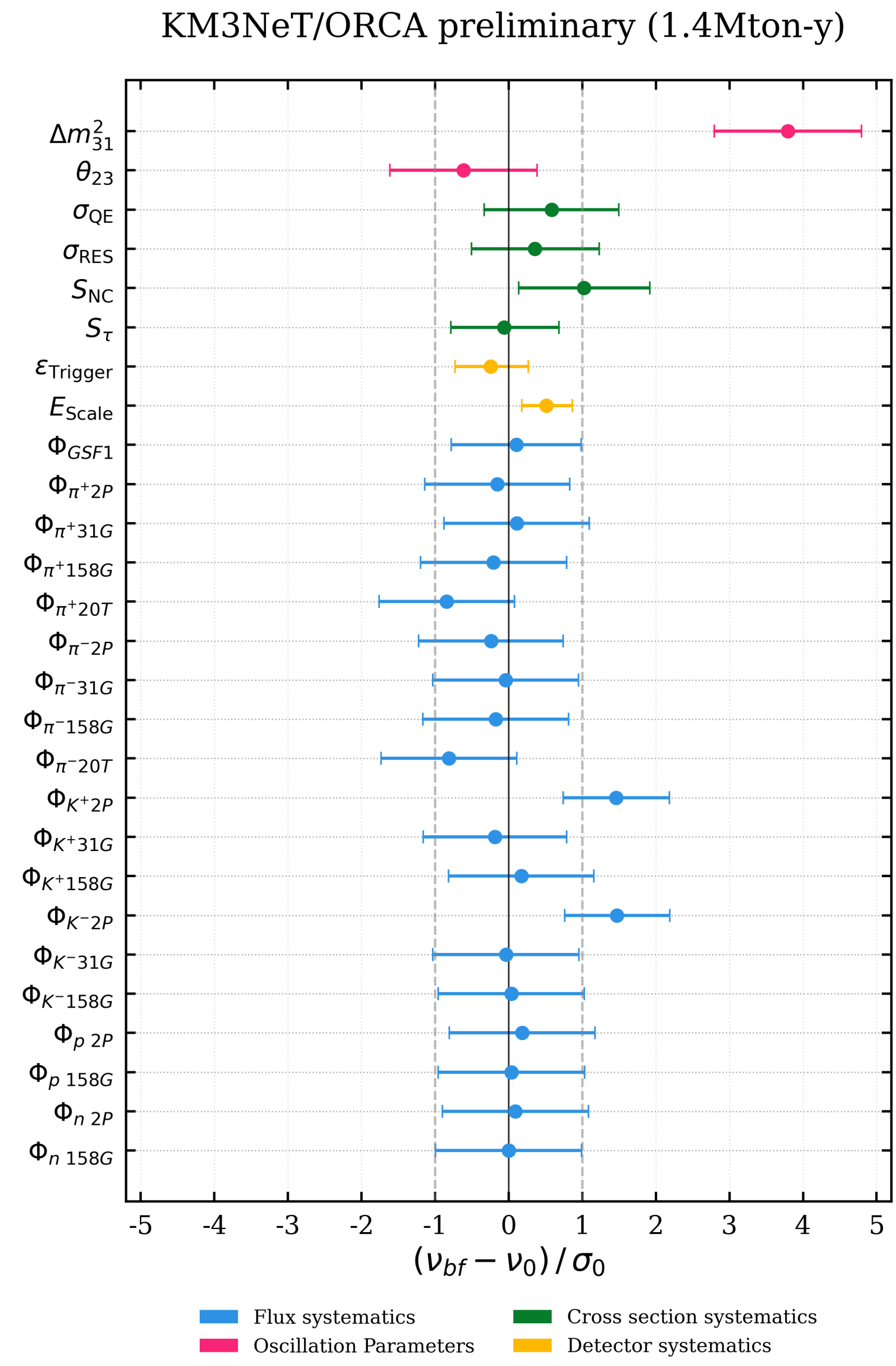
- Flux: HybridFlux parameter variation (also implemented for Honda flux)
- Cross sections: rescale QE, RES, NC, τ
- Detector: trigger efficiency, energy scale (including PMT QE and water properties)

The fit prefers the Honda flux over the HybridFlux by $\Delta\chi^2 = 3.6$

Results are quoted with the Honda flux.

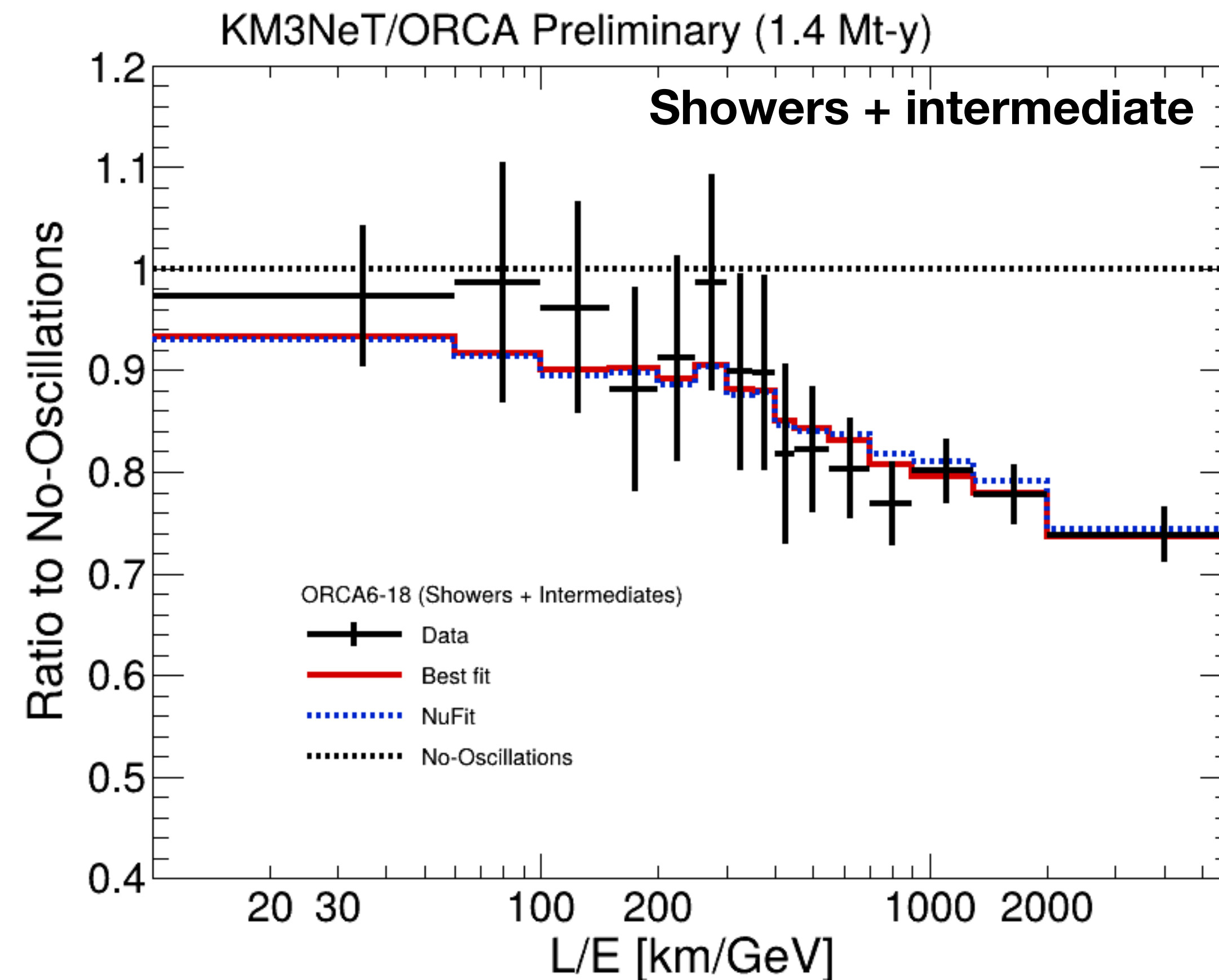


Oscillation systematics



Parameter	Pre-fit		Post-fit	
	Central value	σ_{prior}	Best-fit	1σ uncertainty
<i>Oscillation parameters</i>				
Δm_{31}^2 [10^{-3} eV^2]	2.51	—	-2.08	$+0.08$ -0.09
$\sin^2 \theta_{23}$	0.47	—	0.45	$+0.16$ -0.05
<i>Flux systematics</i>				
Φ_{GSF1}	0.0	± 1.0	0.1	± 0.9
$\Phi_{K_{158G}^-}$	0.0	± 1.0	0.0	± 1.0
$\Phi_{K_{2P}^-}$	0.0	± 1.0	1.5	± 0.7
$\Phi_{K_{31G}^-}$	0.0	± 1.0	0.0	± 1.0
$\Phi_{K_{158G}^+}$	0.0	± 1.0	0.17	± 1.0
$\Phi_{K_{2P}^+}$	0.0	± 1.0	1.5	± 0.7
$\Phi_{K_{31G}^+}$	0.0	± 1.0	-0.19	± 1.0
$\Phi_{\pi_{158G}^-}$	0.0	± 1.0	-0.18	± 1.0
$\Phi_{\pi_{20T}^-}$	0.0	± 1.0	-0.81	± 0.9
$\Phi_{\pi_{2P}^-}$	0.0	± 1.0	-0.24	± 1.0
$\Phi_{\pi_{31G}^-}$	0.0	± 1.0	0.0	± 1.0
$\Phi_{\pi_{158G}^+}$	0.0	± 1.0	-0.21	± 1.0
$\Phi_{\pi_{20T}^+}$	0.0	± 1.0	-0.8	± 0.9
$\Phi_{\pi_{2P}^+}$	0.0	± 1.0	-0.15	± 1.0
$\Phi_{\pi_{31G}^+}$	0.0	± 1.0	0.1	± 1.0
$\Phi_{n_{158G}}$	0.0	± 1.0	0.0	± 1.0
$\Phi_{n_{2P}}$	0.0	± 1.0	0.11	± 1.0
$\Phi_{p_{158G}}$	0.0	± 1.0	0.0	± 1.0
$\Phi_{p_{2P}}$	0.0	± 1.0	0.18	± 1.0
<i>Cross-section systematics</i>				
S_{NC}	1.0	± 0.2	1.2	± 0.18
S_{τ}	1.0	± 0.2	1.0	± 0.15
σ_{QE}	0.0	± 1.0	0.6	± 0.9
σ_{RES}	0.0	± 1.0	0.4	± 0.9
<i>Detector systematics</i>				
E_{scale}	-0.1	± 0.1	-0.05	± 0.03
$\epsilon_{\text{trigger}}$	-1.0	± 1.0	-1.2	± 0.5

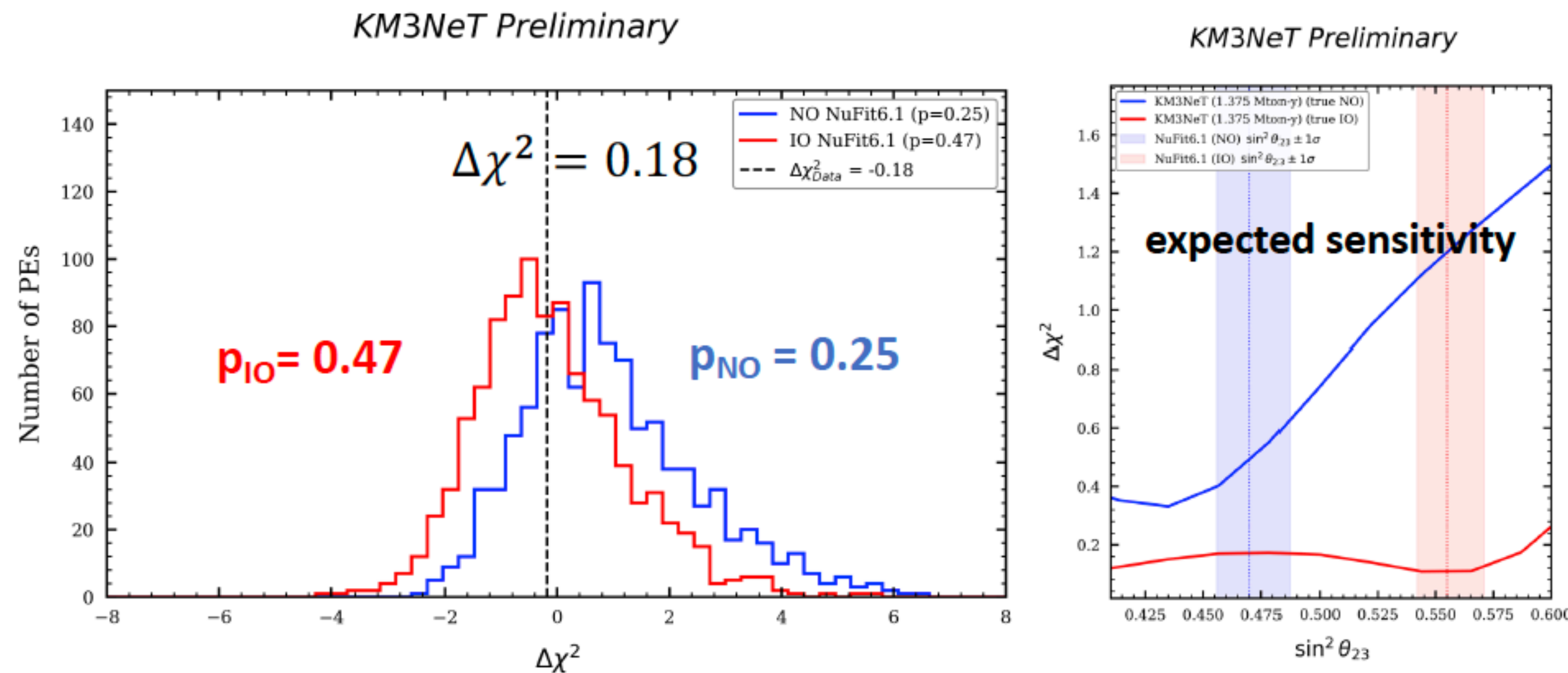
Shower + intermediate oscillation results



NMO present and future sensitivity

Neutrino Mass Ordering

We strive towards a single-experiment determination of the NMO



However, with external input from reactor expts. (Daya Bay and JUNO, **very very preliminary**):

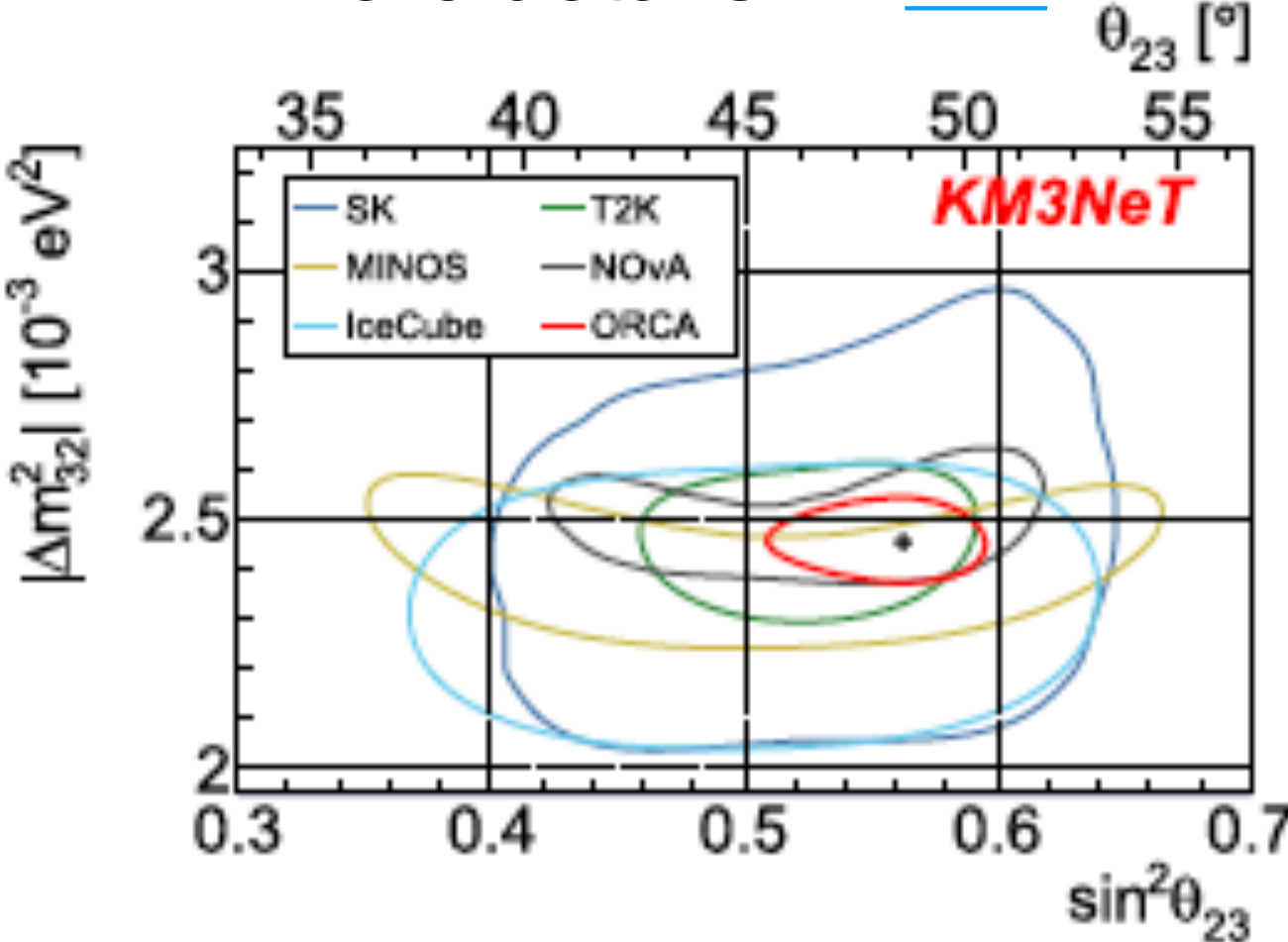
$$\chi^2_{\text{IO}} - \chi^2_{\text{NO}} \approx 4.0$$

(preference for NO)

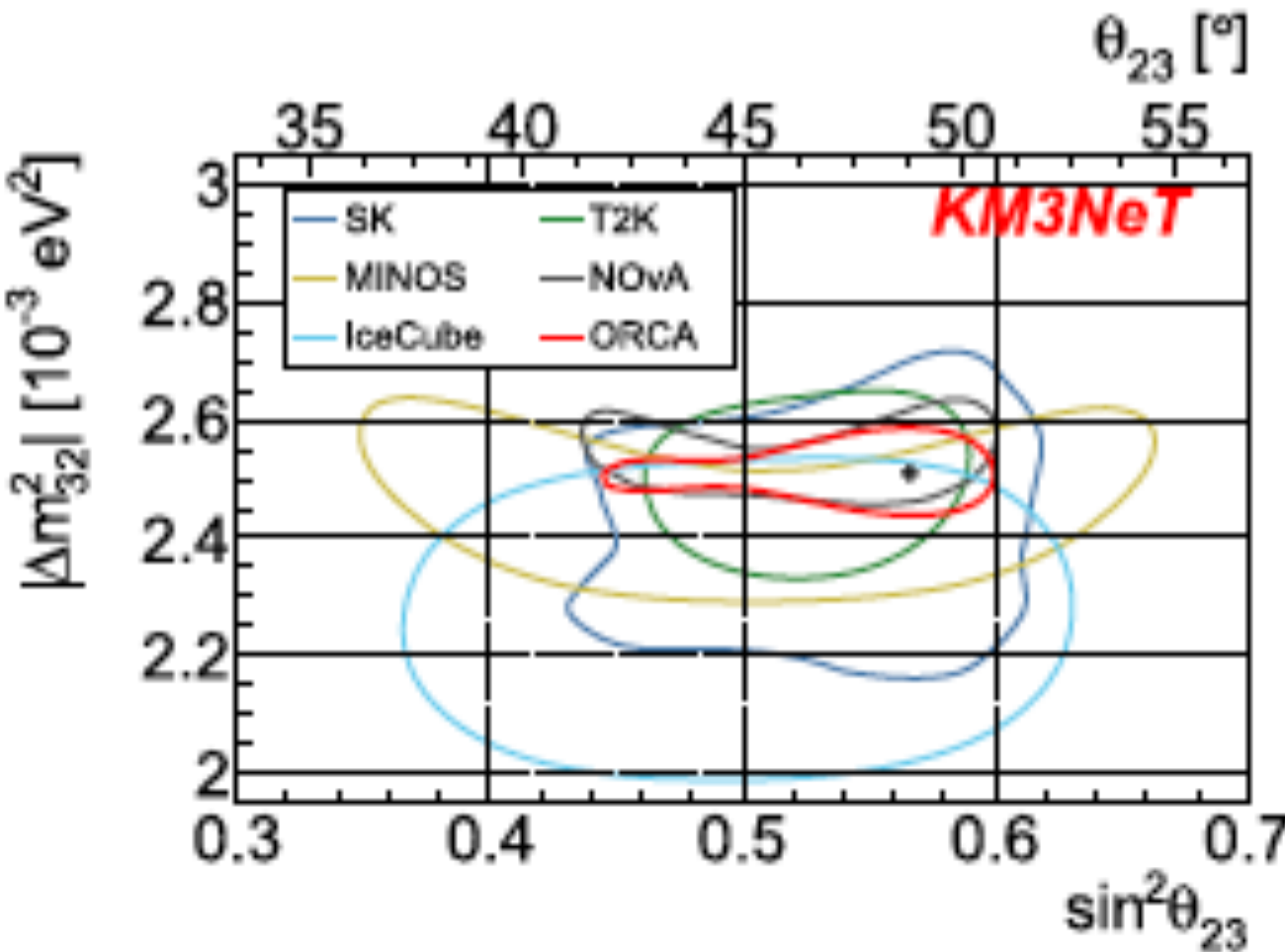
Slight preference for the IO, not statistically significant (as expected)

NMO in the future

More details in: [link](#)

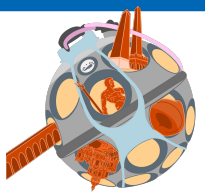
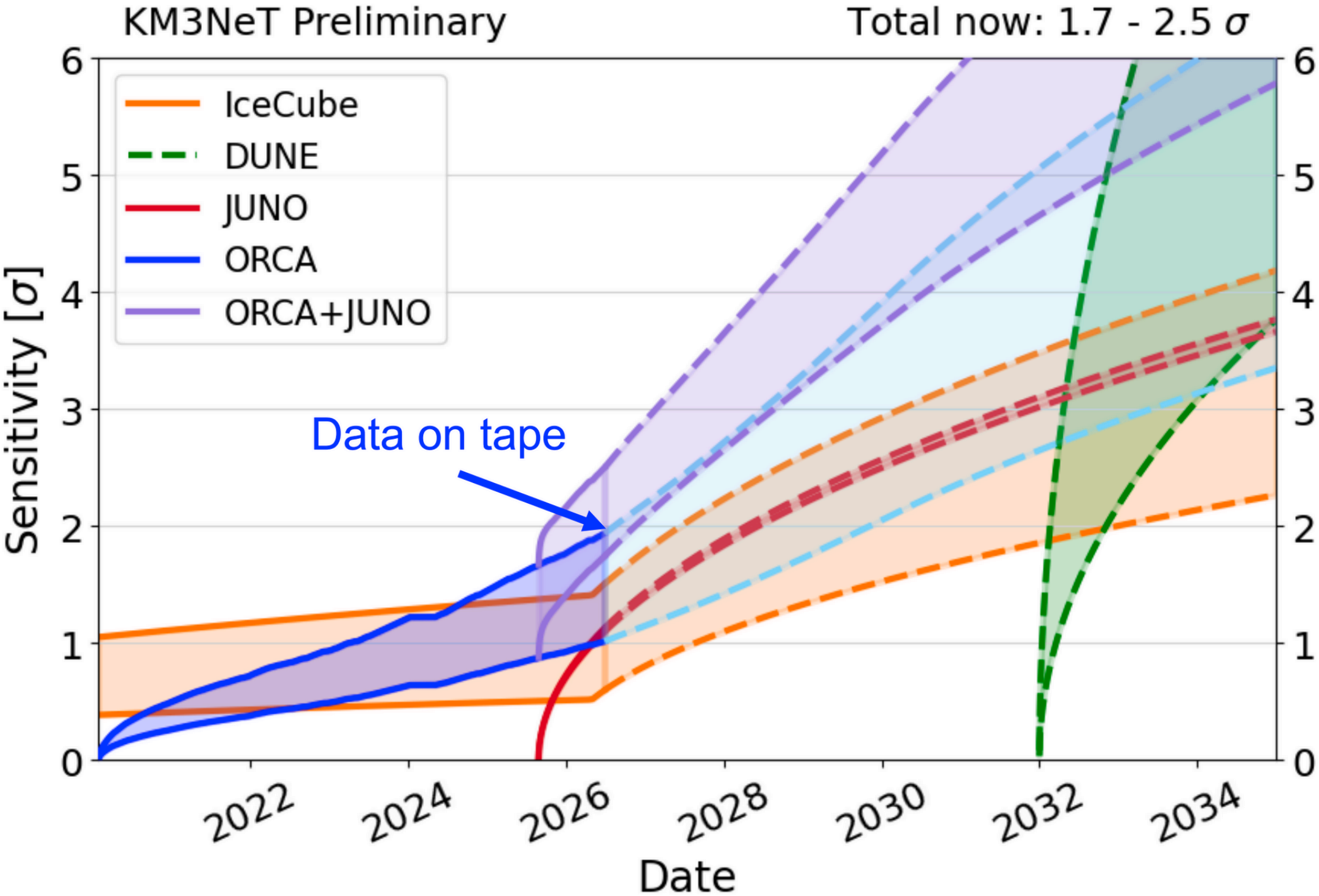


Exposure 20 Mton-years

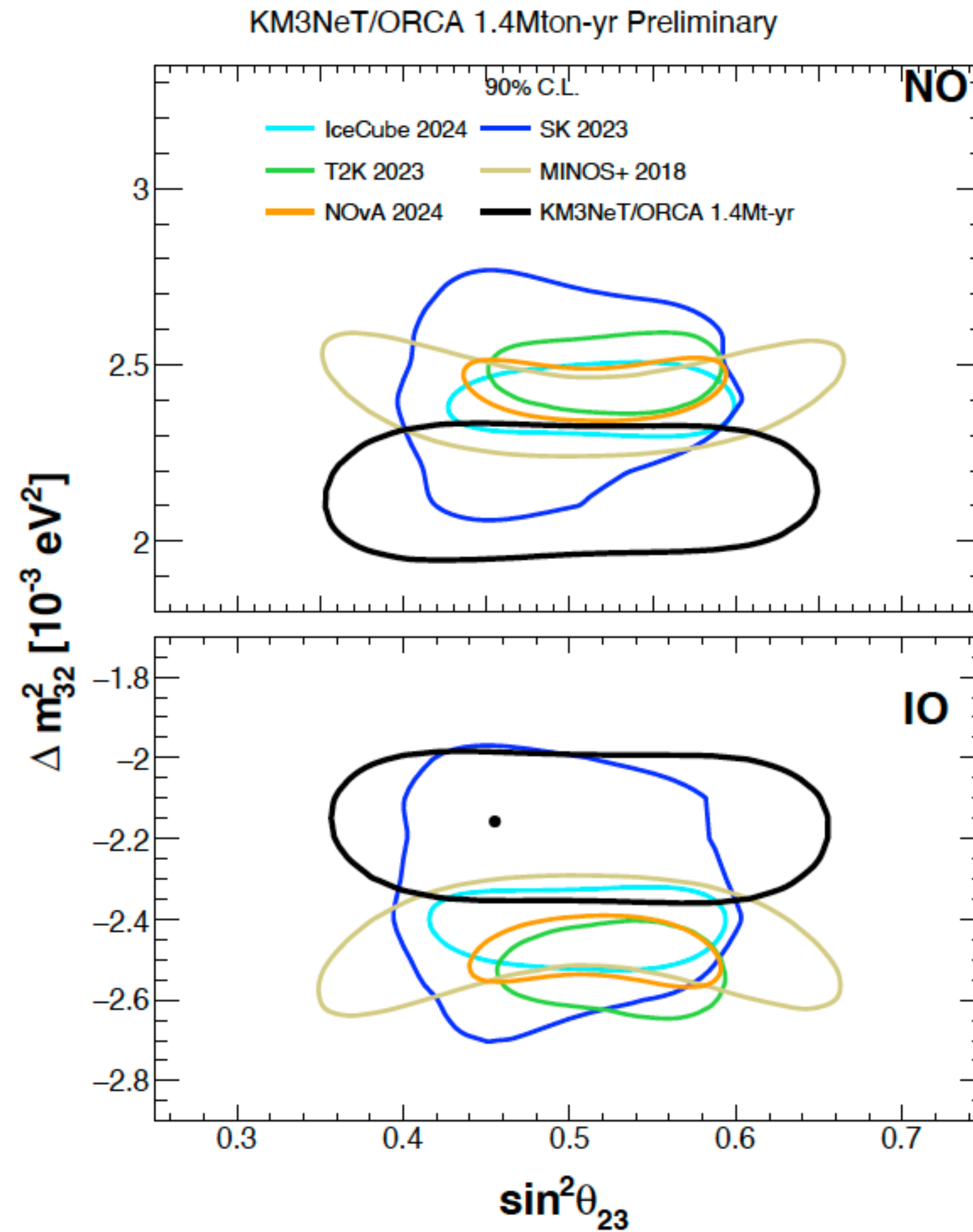


(b)

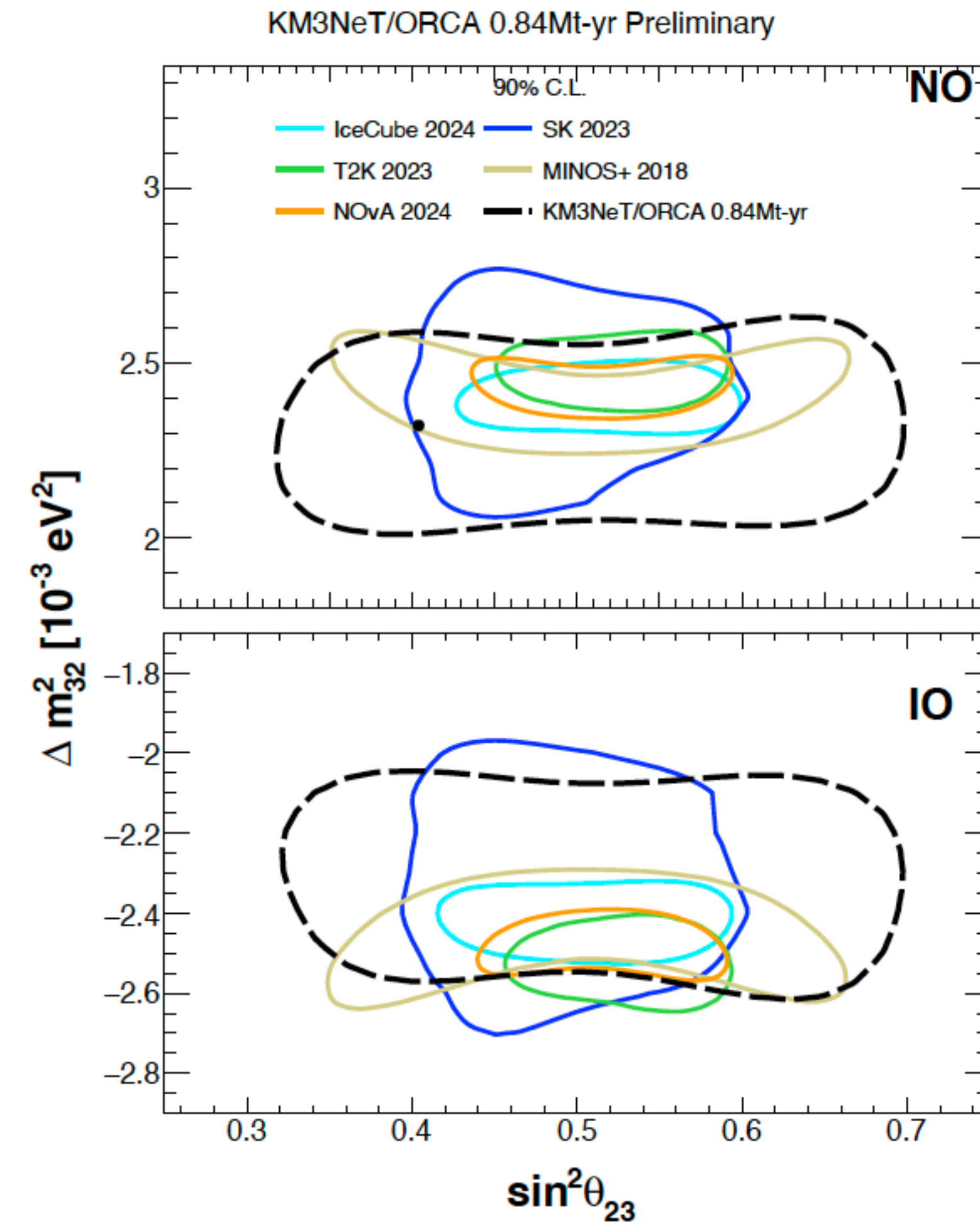
Sensitivity to mass ordering with realistic detector growth: [link](#)



NMO results: more



Full sample



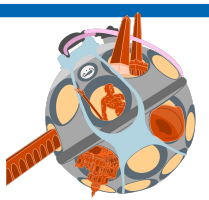
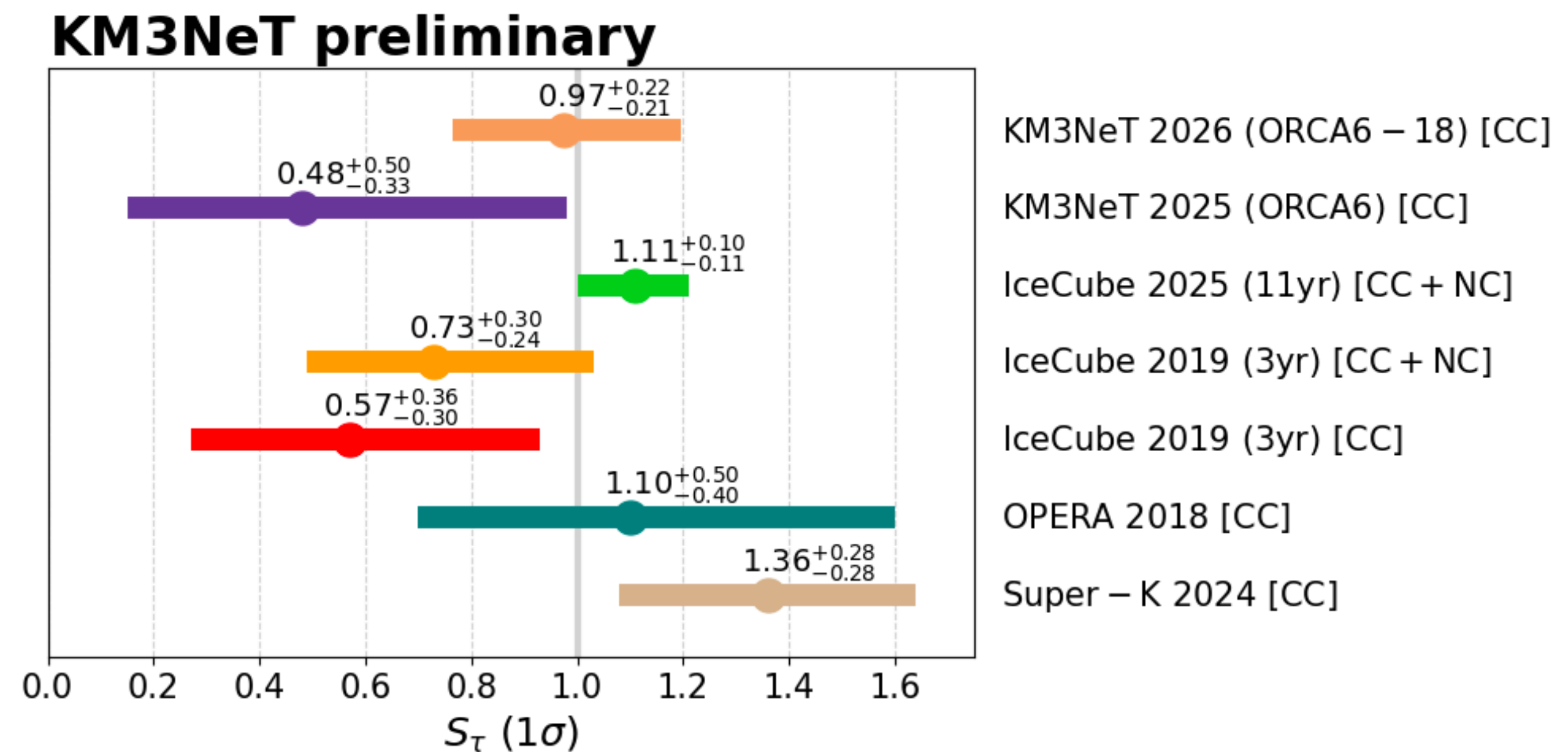
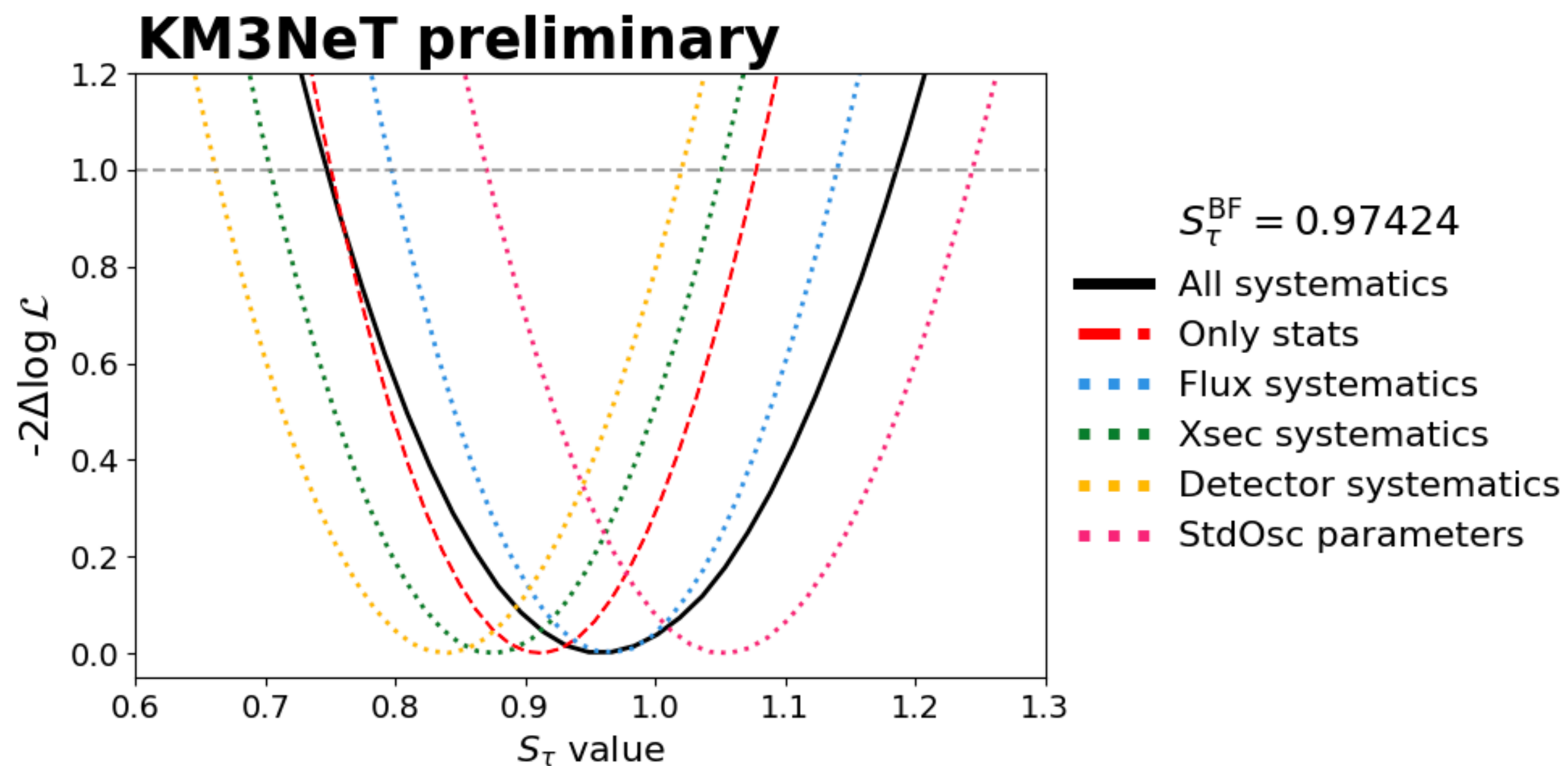
ORCA11 to ORCA18

Tau appearance

- Tau neutrinos mostly originate **from oscillations of muon neutrinos**.
- Tau neutrino **normalization** S_τ **free** in the fit.
- Best visible **in the shower sample**.

$$\text{Result: } S_\tau = 0.97^{+0.21}_{-0.23}$$

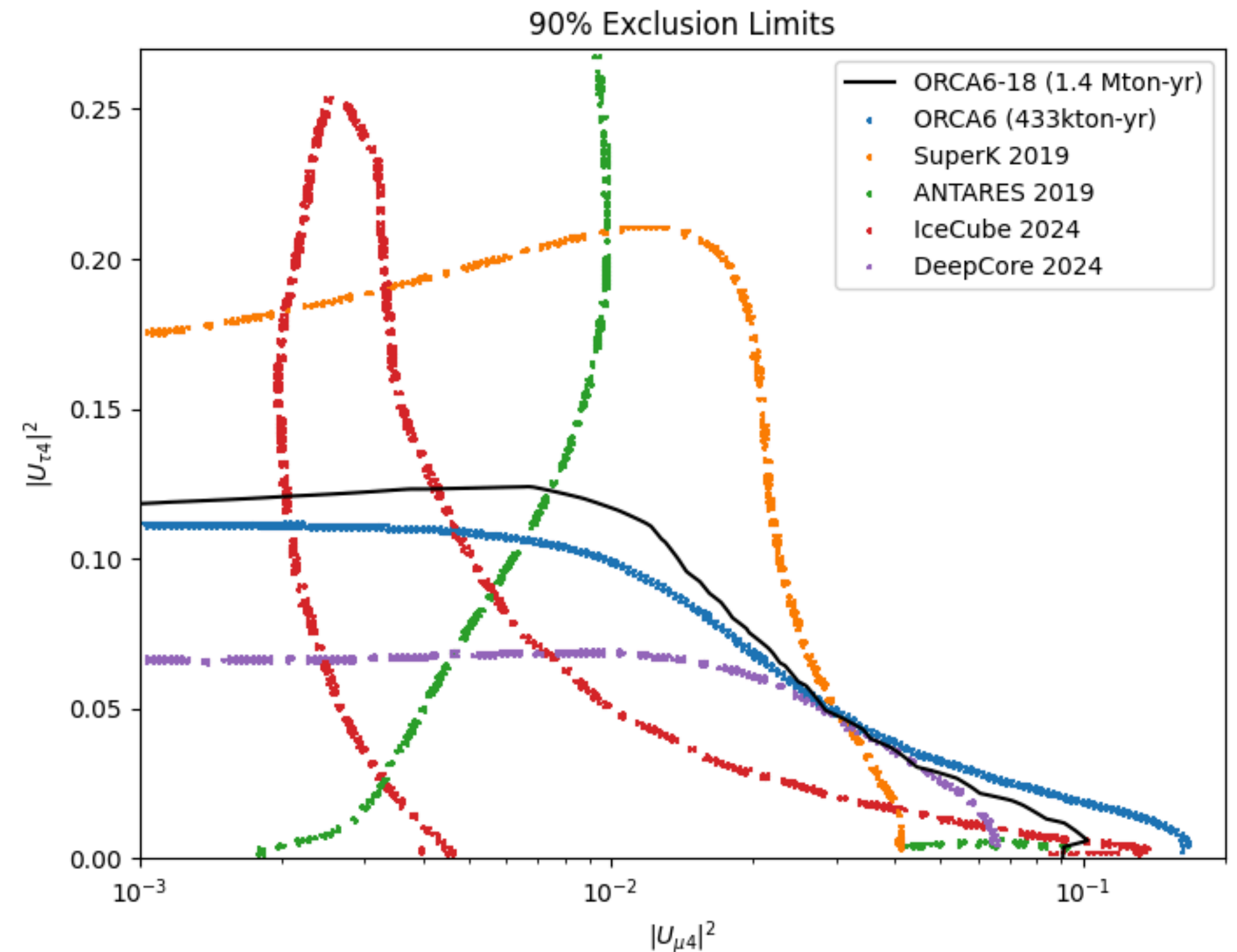
$$N_\tau = 680 \pm 150$$



Sterile neutrinos with KM3NeT/ORCA

Sterile neutrinos

GeV-range atmospheric neutrinos have the right E/L to also show sensitivity to modifications of oscillations arising from a 3+1 neutrino model, with $\Delta m \approx 1 \text{ eV}^2$.
ORCA sensitivity is fairly constant between 0.2 and 10 eV^2 .



LIV with KM3NeT/ORCA

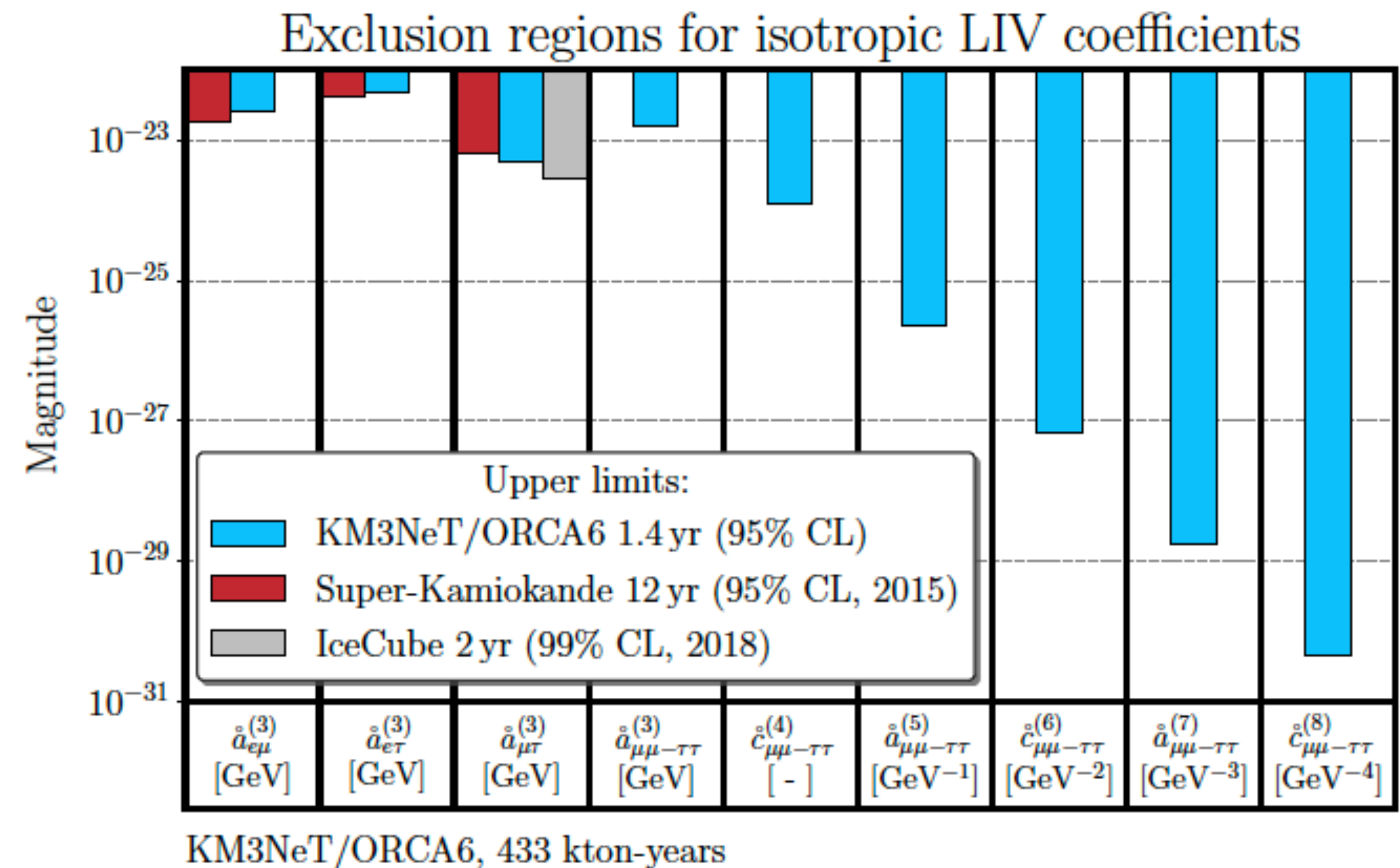
Lorentz invariance violation

Atmospheric neutrino constraints on Lorentz Invariance Violation with the first six detection units of KM3NeT/ORCA → [arXiv:2603.04264](https://arxiv.org/abs/2603.04264)

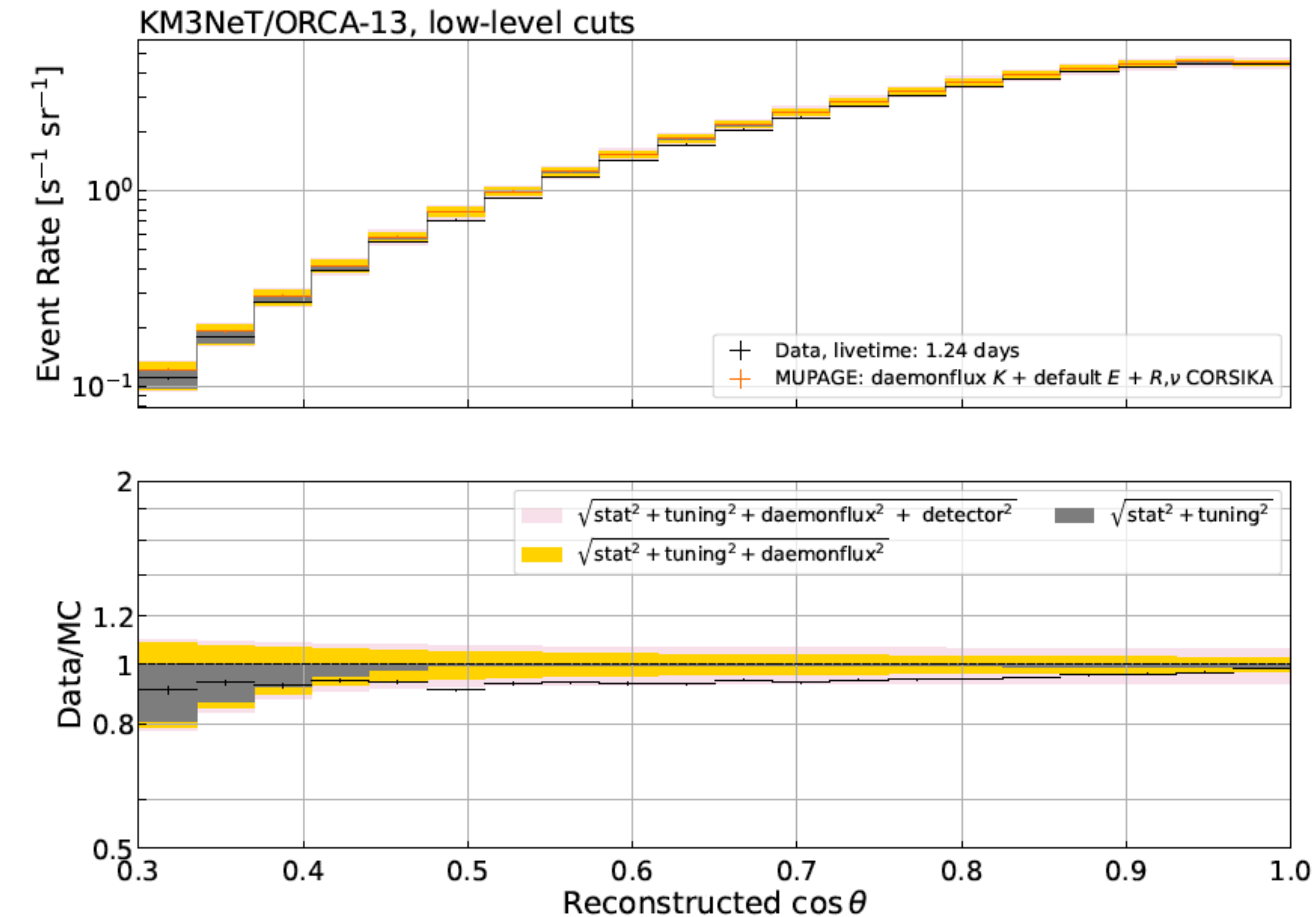
Within Standard Model Extension framework (EFT),
investigated isotropic LIV.
Limits are set on a number of coefficients corresponding
to operators of dimensions $d = 3-8$.

Published earlier:

- [Limits on Non-Standard interactions](#);
- [Limits on Quantum decoherence](#);
- [Limits on Invisible Neutrino decay](#).



Tuning simulation

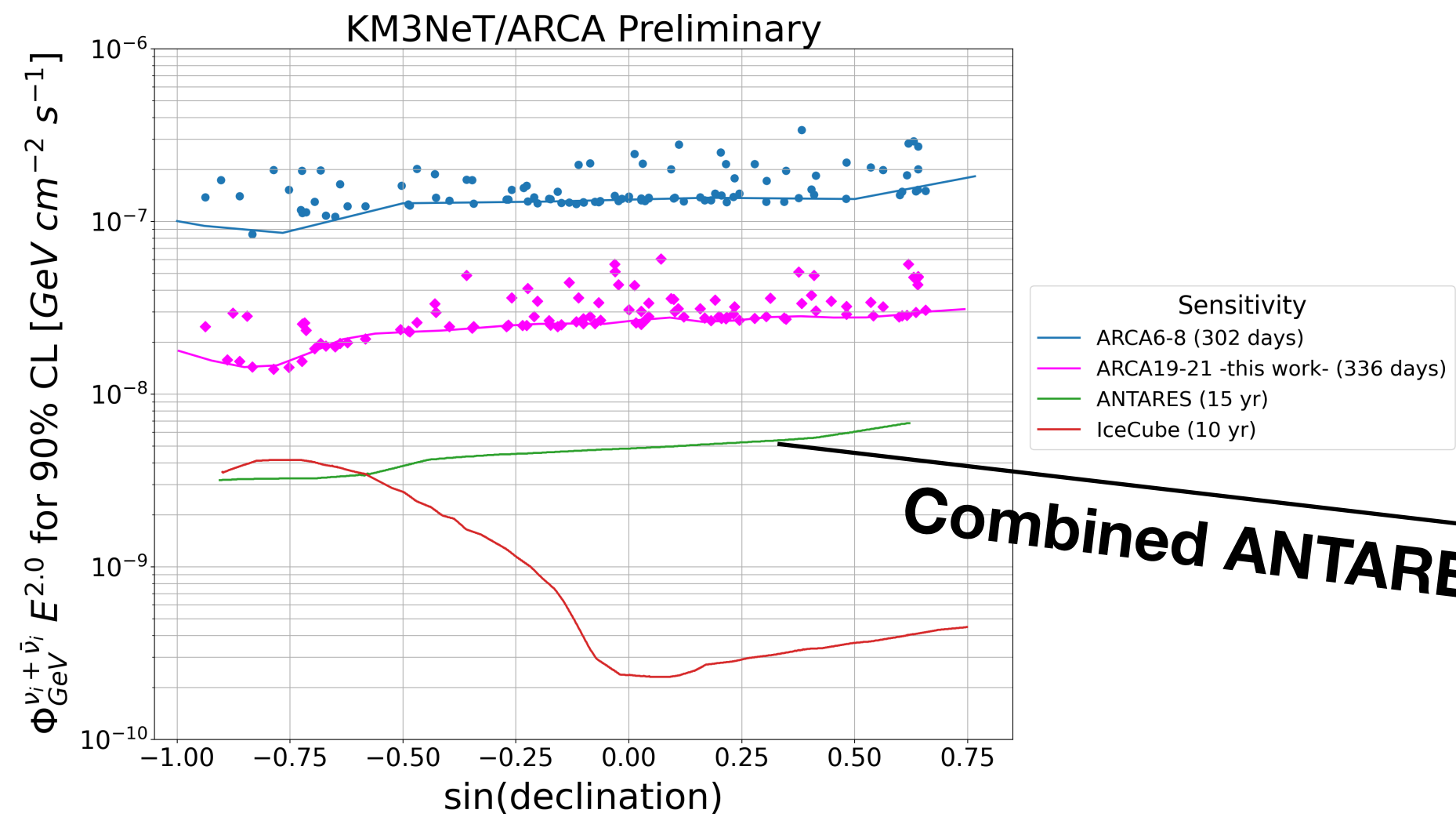


Update and validate **parametric muon generator MUPAGE** to account for:

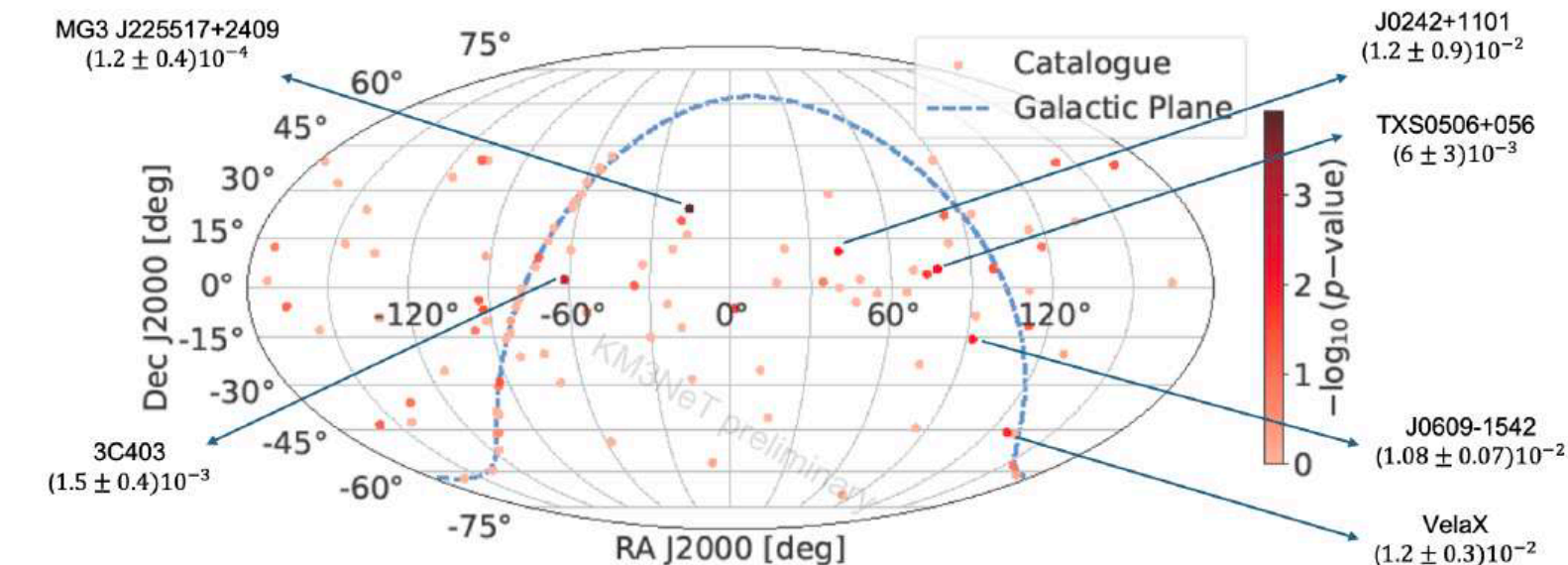
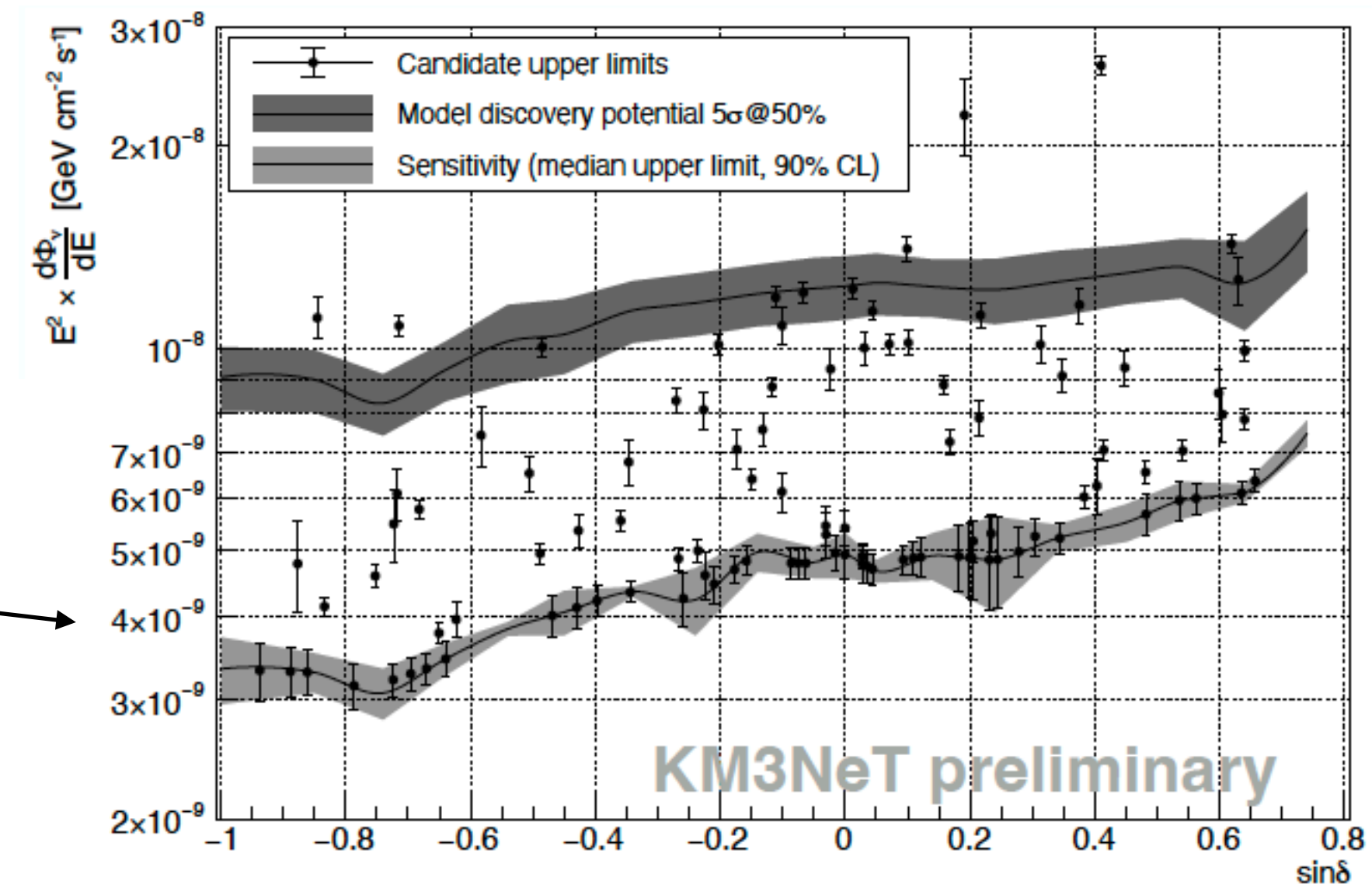
- Up-to-date **CR flux input**.
- **Data-driven tuned** hadronic interaction model (daemonflux + CORSIKA).

[EPJ C 84 \(2024\) 696](#)

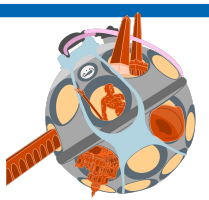
Combined ANTARES/ARCA catalogue search



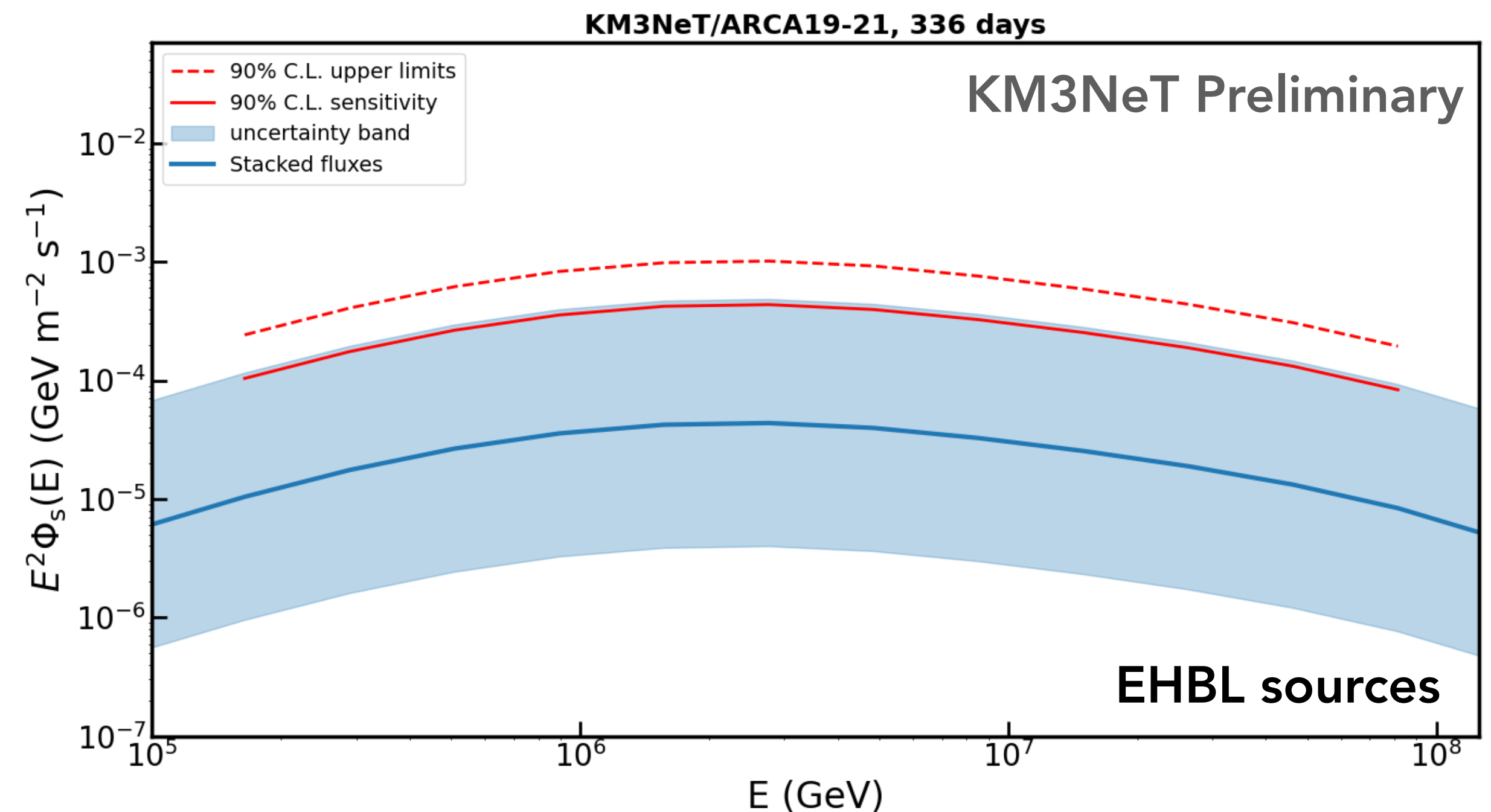
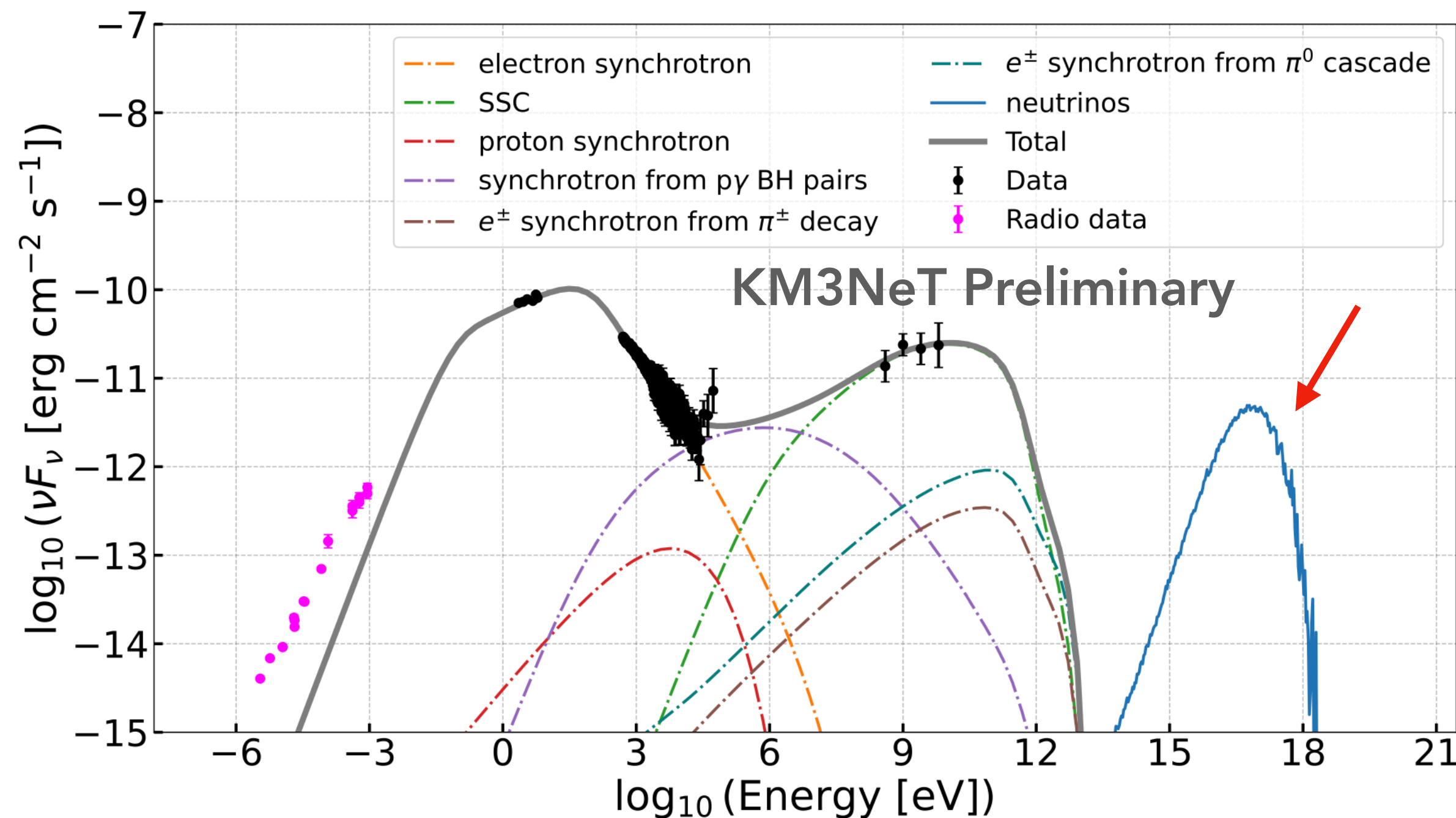
Combined ANTARES + ARCA



- **Common analysis framework** applied to catalog search of 106 sources.
- **20% sensitivity & discovery flux improvement** wrt ANTARES-only ([Eur. Phys. J. C. 8 \(2026\) 86](#)).
- Most significant source is **MG3 J225517+2409**, a blazar from Fermi 3LAC catalog.



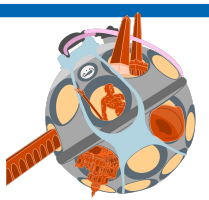
Stacking analysis

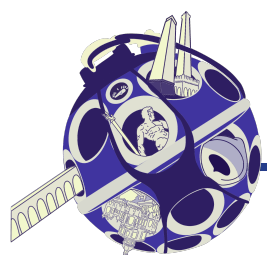


3 candidate source populations:

- ultra luminous IR galaxies (**ULIRGs**).
- high-synchrotron peaked blazars (**HBLs**), selected from 3HSP catalog with known redshift ([pos\(ICRC25\)1006](#)).
- extreme synchrotron peaked blazars (**EHLs**), counterpart in Fermi 4FGL ([pos\(ICRC25\)1125](#)).

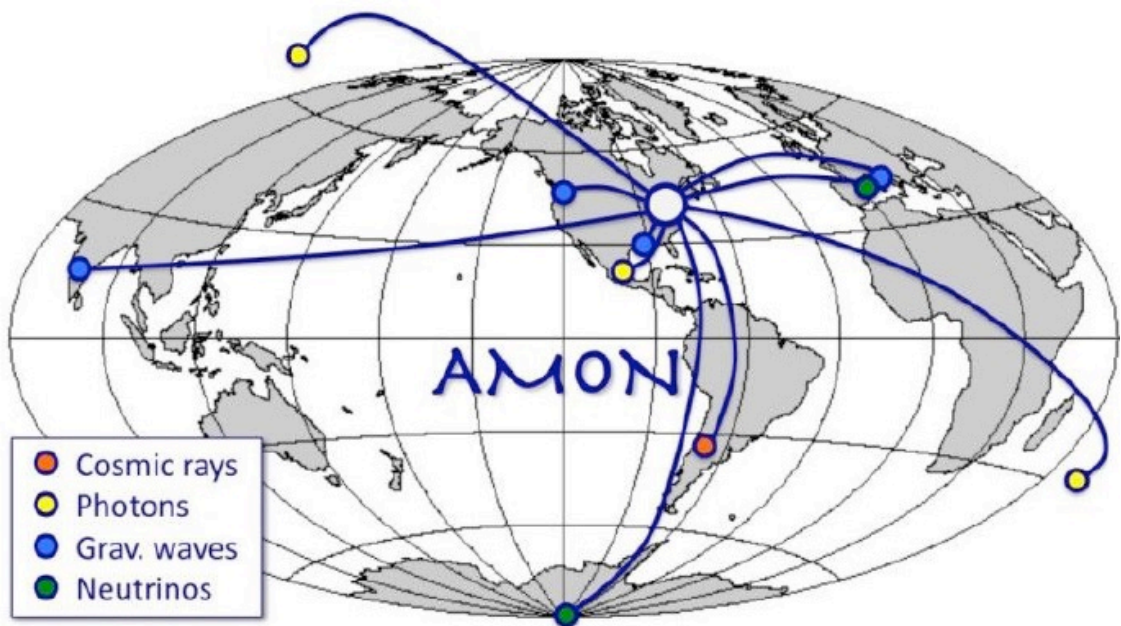
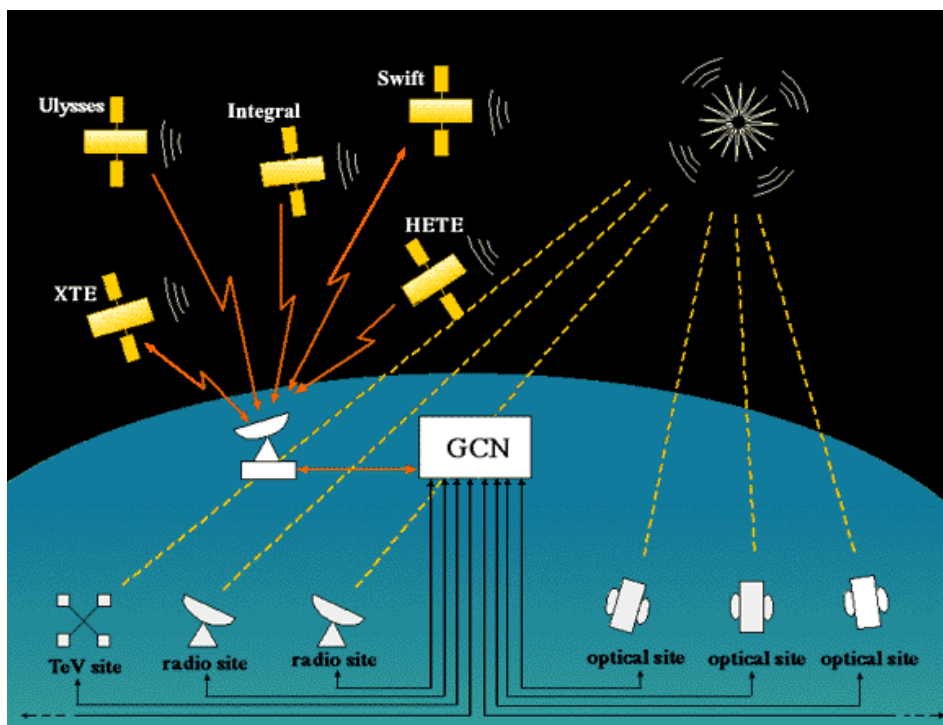
Both blazar sample consider neutrino spectra from **lepto-hadronic modeling** (LeHa-Paris for HBLs & LeHaMoC for EHLs)





Online follow-up strategies for KM3NeT

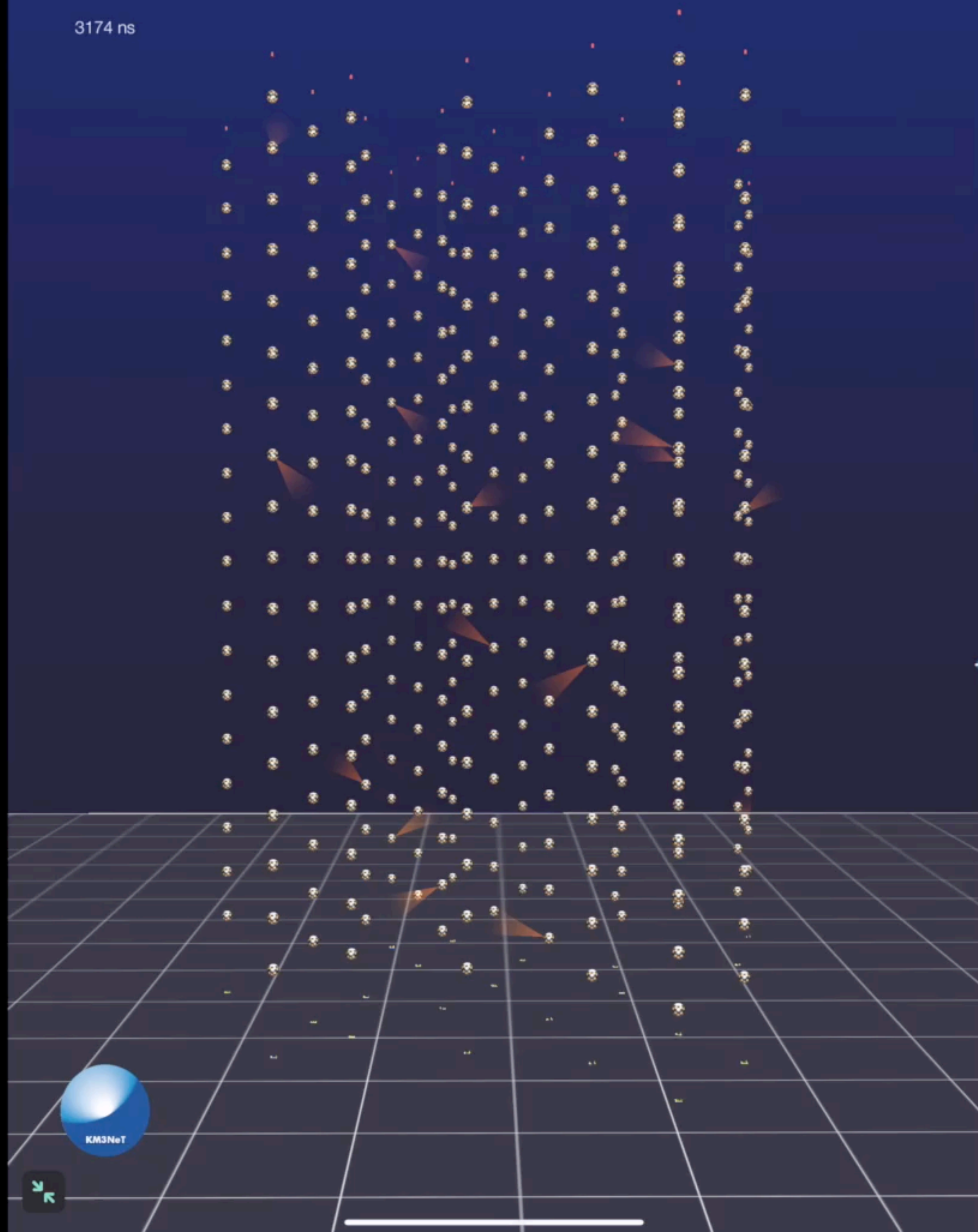
- IC170922A event and subsequent follow-up (see first slide) showed the potentiality of combined rapid observations;
- Detector constantly exchanging informations through circulars on interesting events;
- Specific “brokers” can be subscribed to receive alert stream (GCN, AMON, SNEWS and many others);



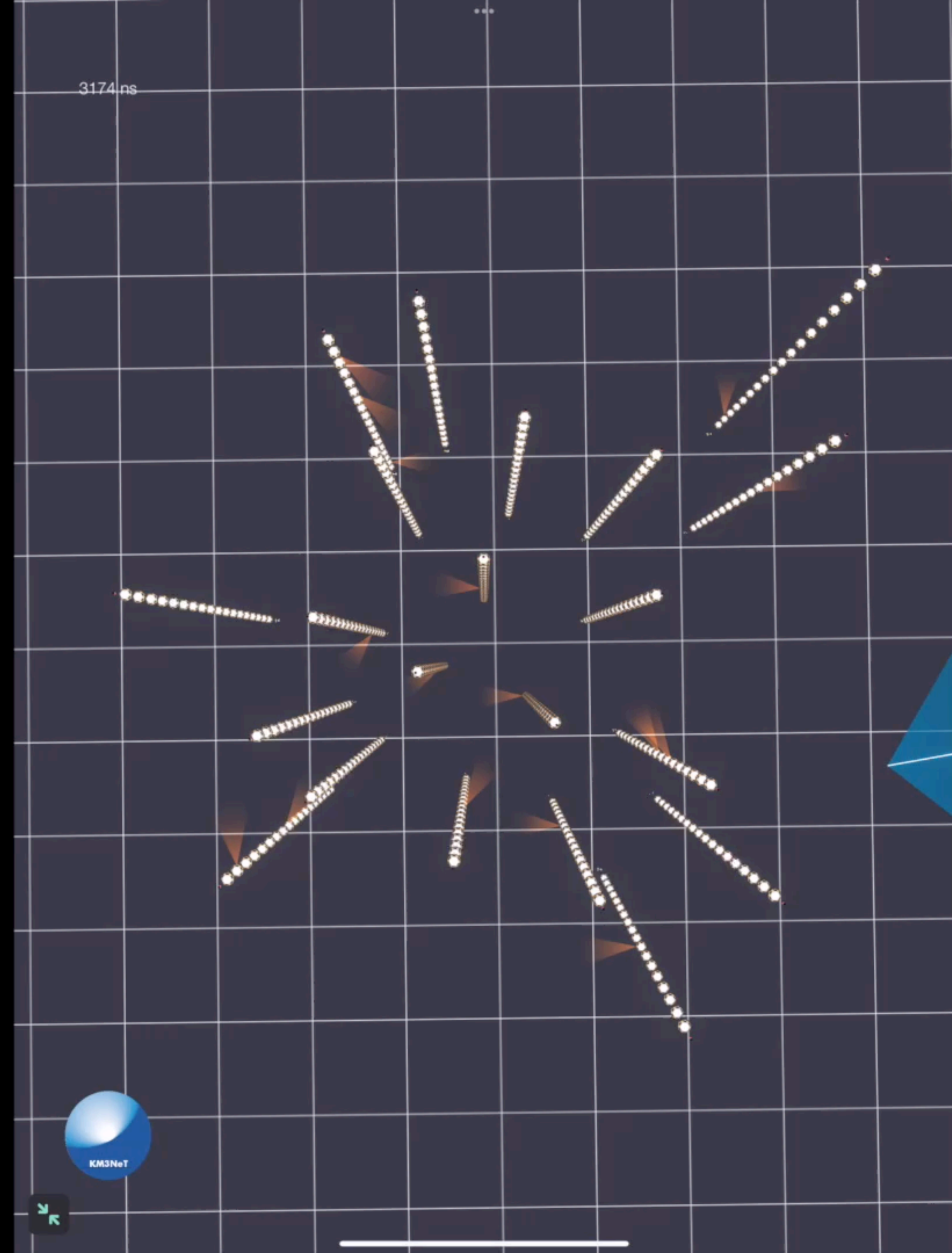
Worldwide effort of the astroparticle community. Many detectors involved in different areas:

 GW interferometers	 Neutrino telescopes	 γ-ray telescopes and ground based detectors	 ...and many others.
---	---	--	--

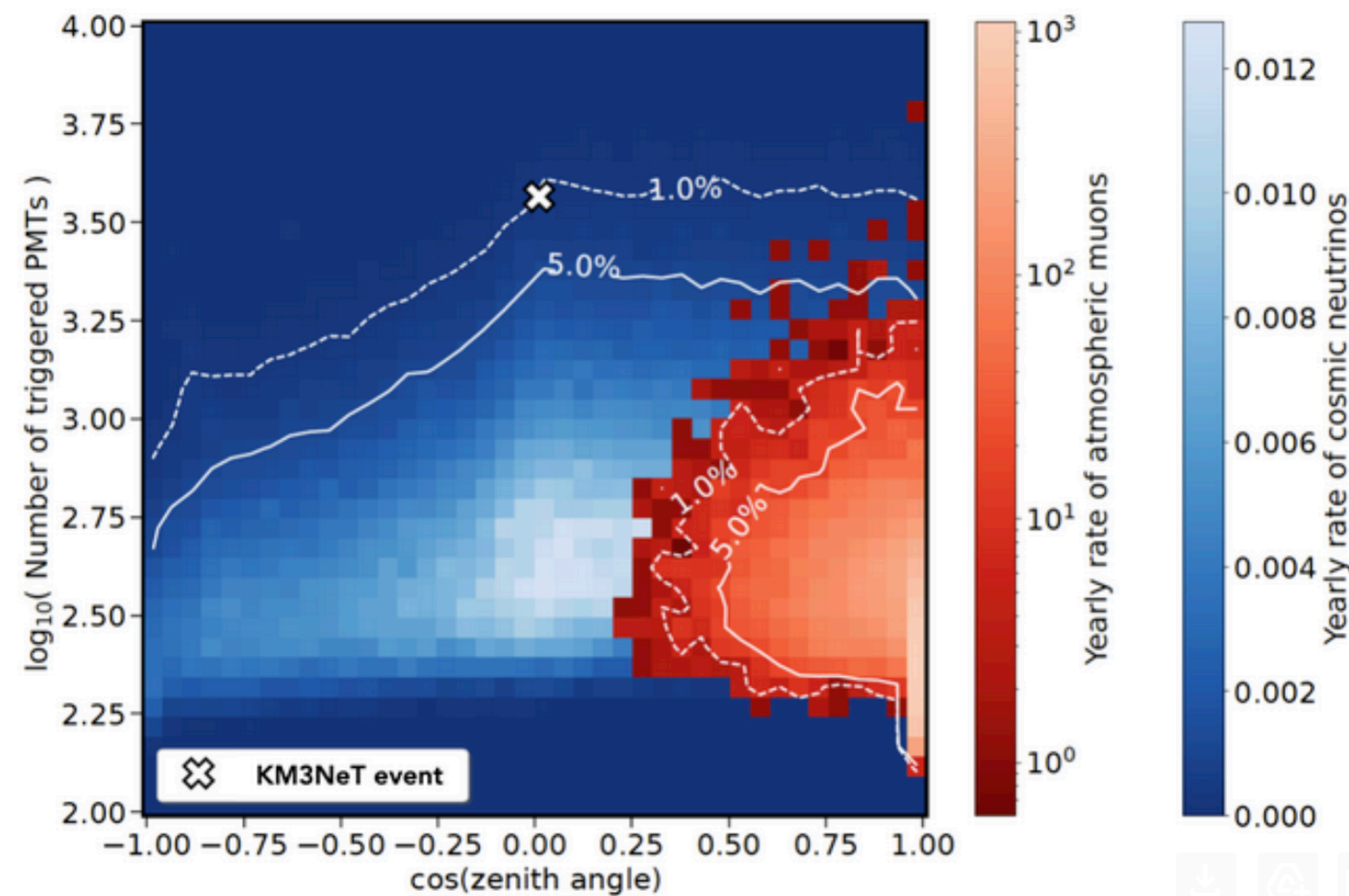
3174 ns



3174 ns



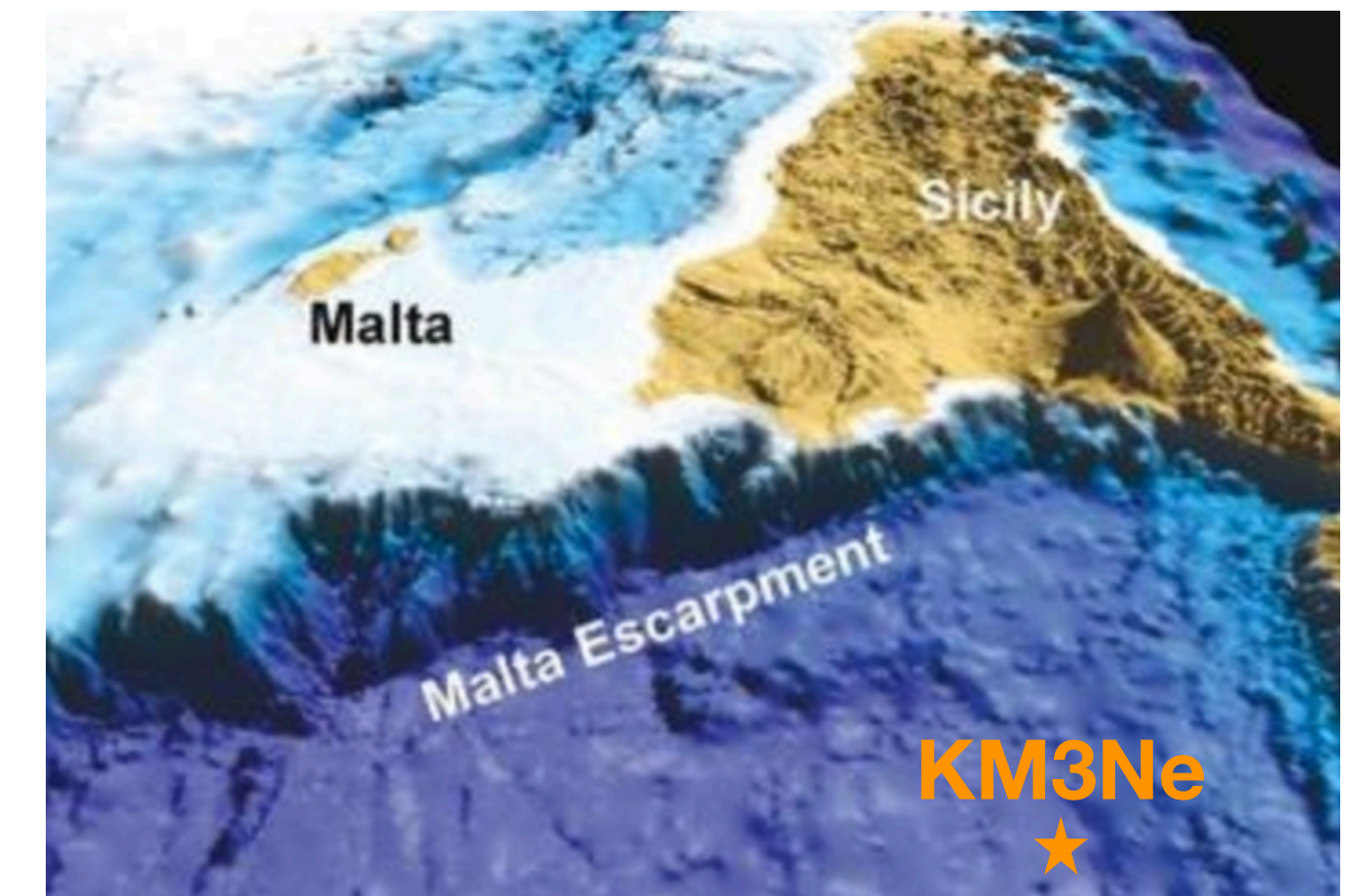
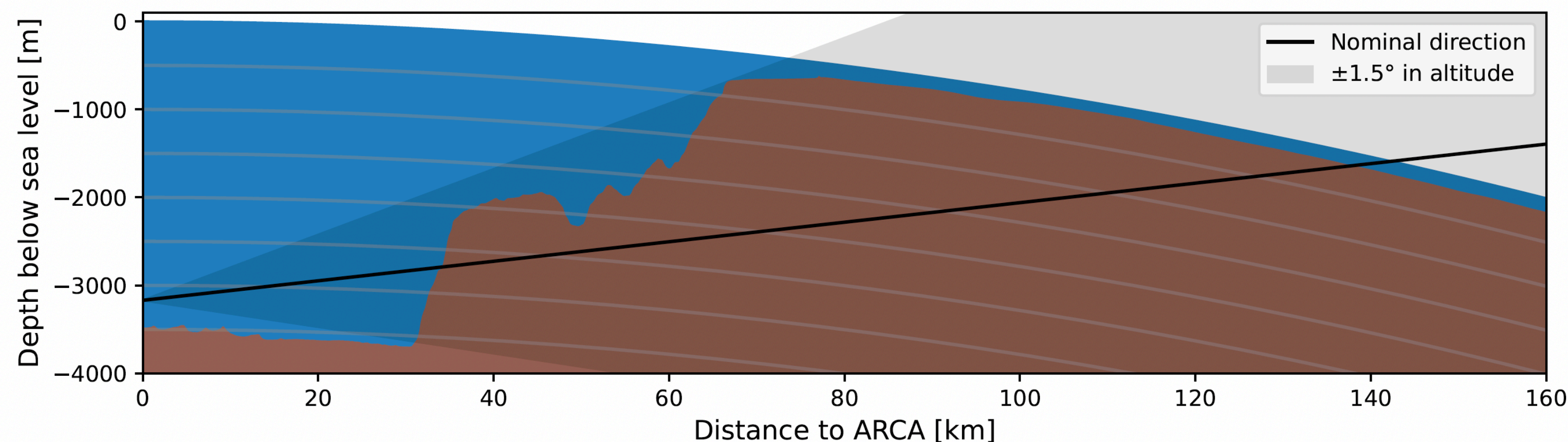
Background estimate



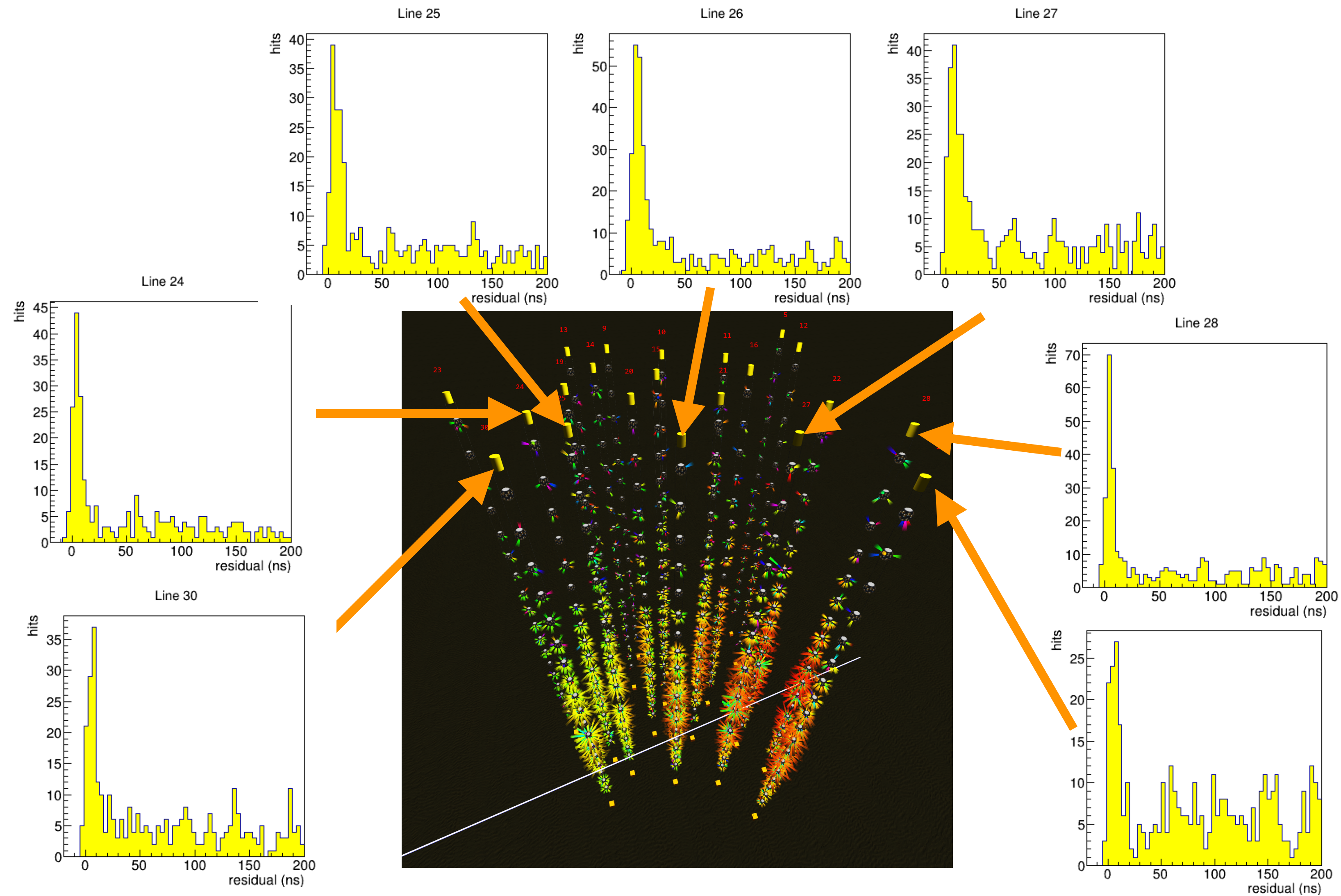
Event direction pointing back to Malta Escarpment.

Total amount of matter = 140 km:

- contribution from atmospheric muons is therefore negligible:
 $\ll 10^{-10}$ event/year within 2σ of reconstructed direction.
 $\ll 10^{-4}$ event/year within 5σ of reconstructed direction.
- contribution from prompt atmospheric neutrinos is also tiny:
 $\ll (1-5) \times 10^{-5}$ event/year.

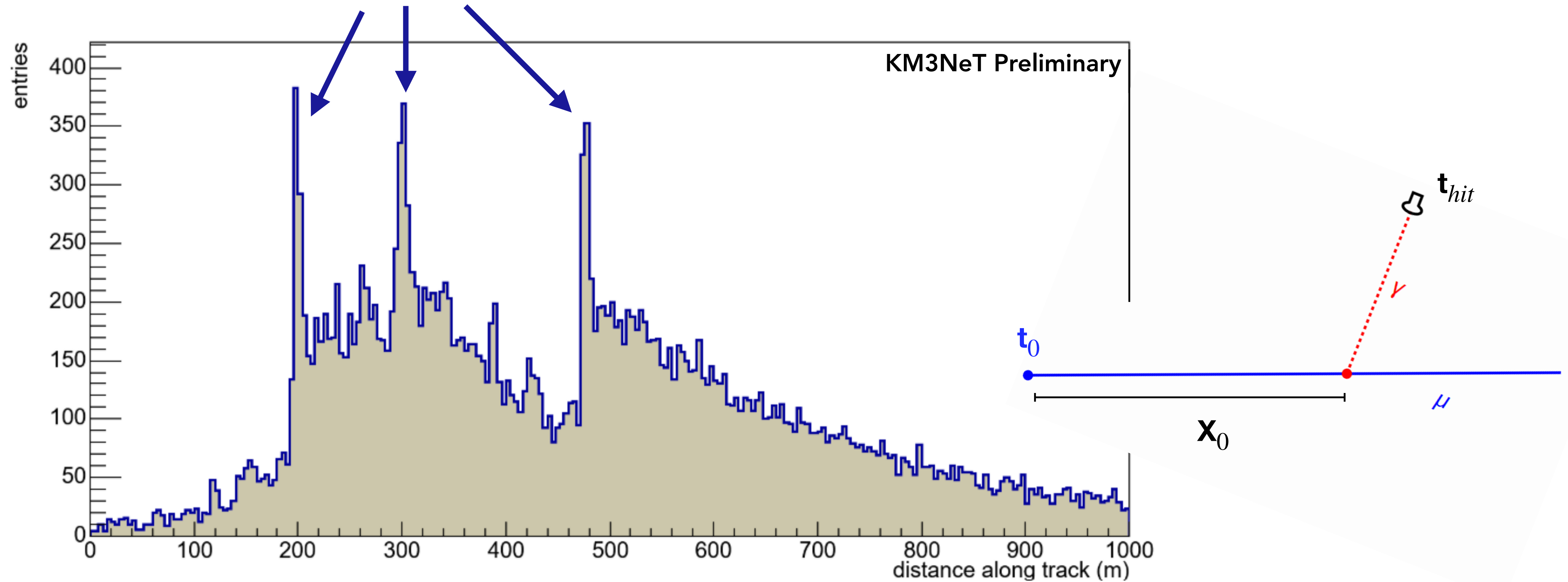


Reconstruction: time residuals



Stochastic losses

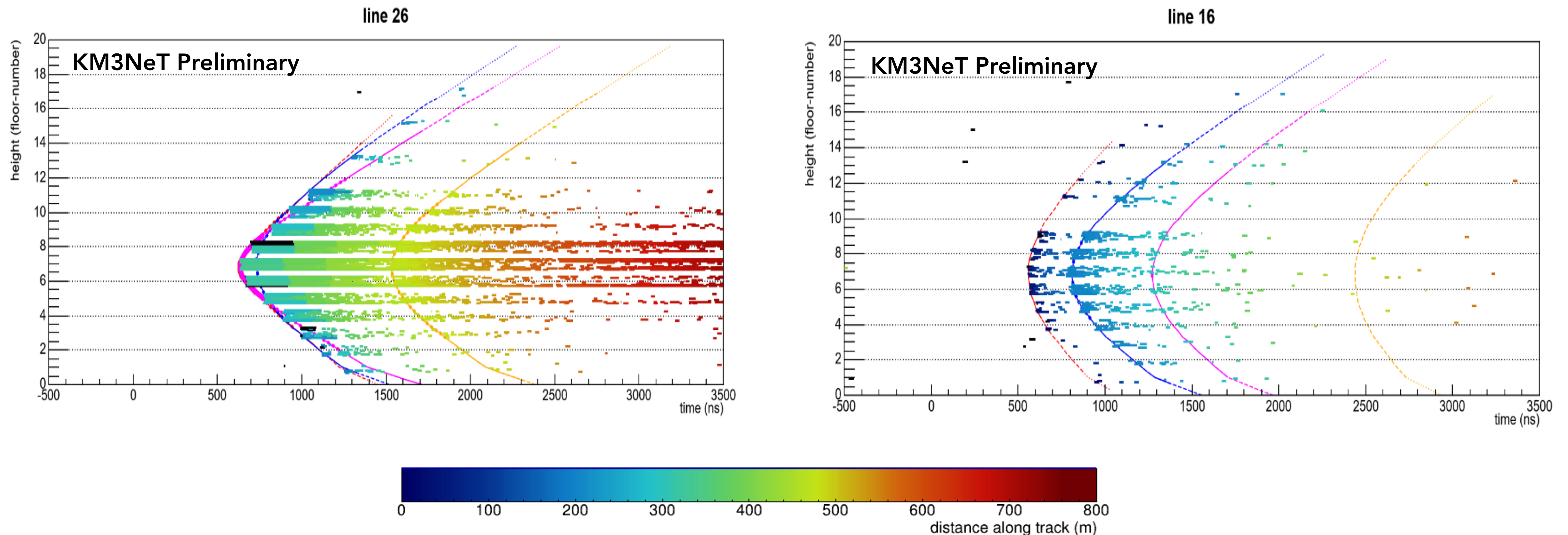
- Light profile consistent with **at least 3 large energy depositions** along the muon track;
- Characteristic of stochastic losses from very high energy muons.



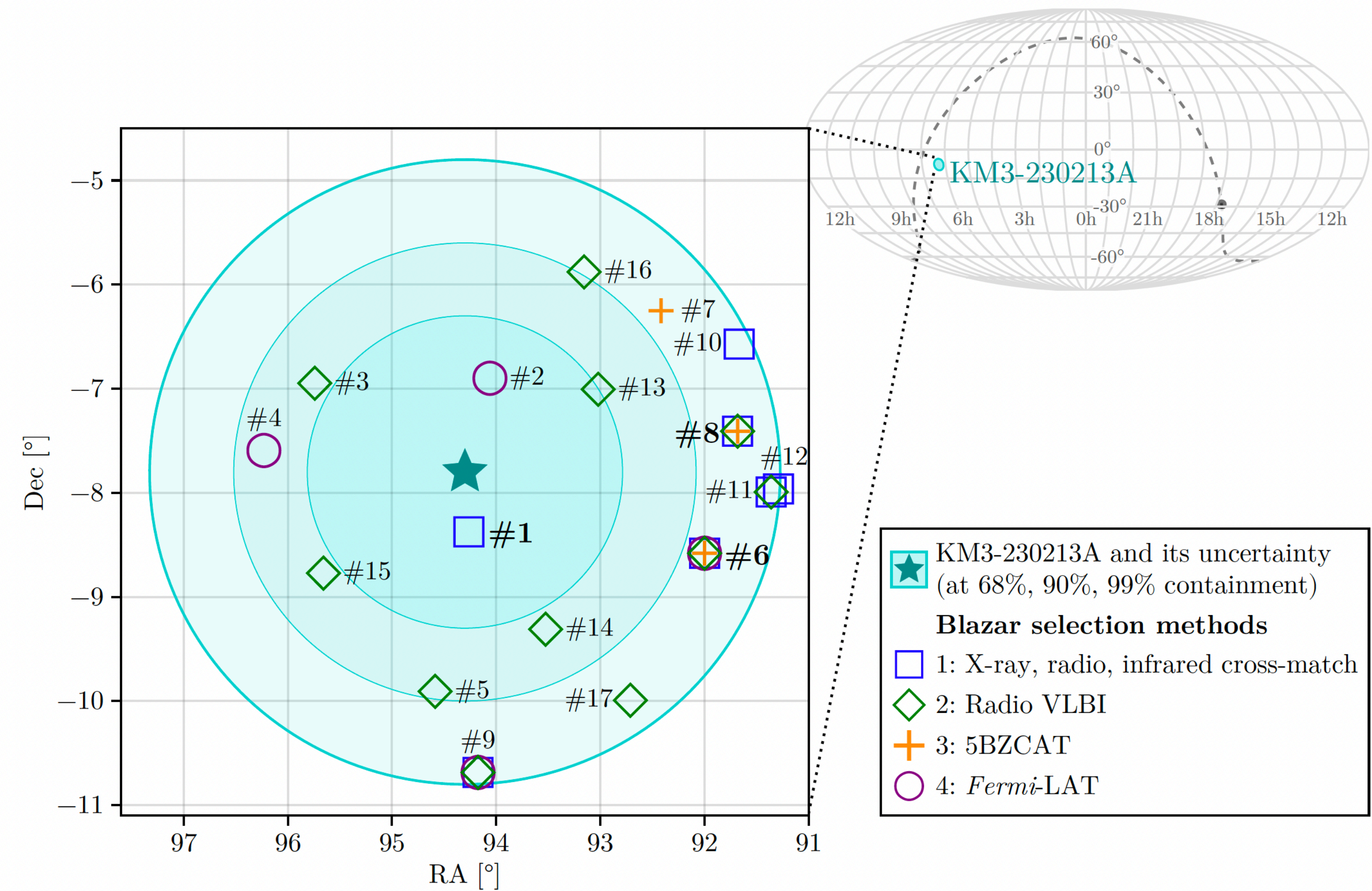
Position of light emission along track consistent with hit time assuming direct light

Height vs time hit distribution

- Light profile consistent with at least 3 large energy depositions along the muon track;
- Characteristic of stochastic losses from very high energy muons;
- Space-time distribution of light consistent with shower hypothesis associated with these energy depositions;
- Low scattering is key to observing this richness of detail.



Source association



Definition of a blazar catalogue:

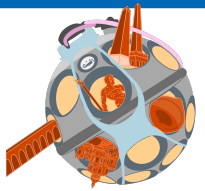
Method 1: this strategy relies on the distinctive X-ray, radio and infrared properties of blazars.

Method 2: radio blazars are selected on the basis of their parsec-scale flux measured by VLBI;

Method 3: the 5th Roma BZ Catalog (5BZCAT), a compilation of 3561 blazars, has been previously used to investigate the possible neutrino-blazar connection;

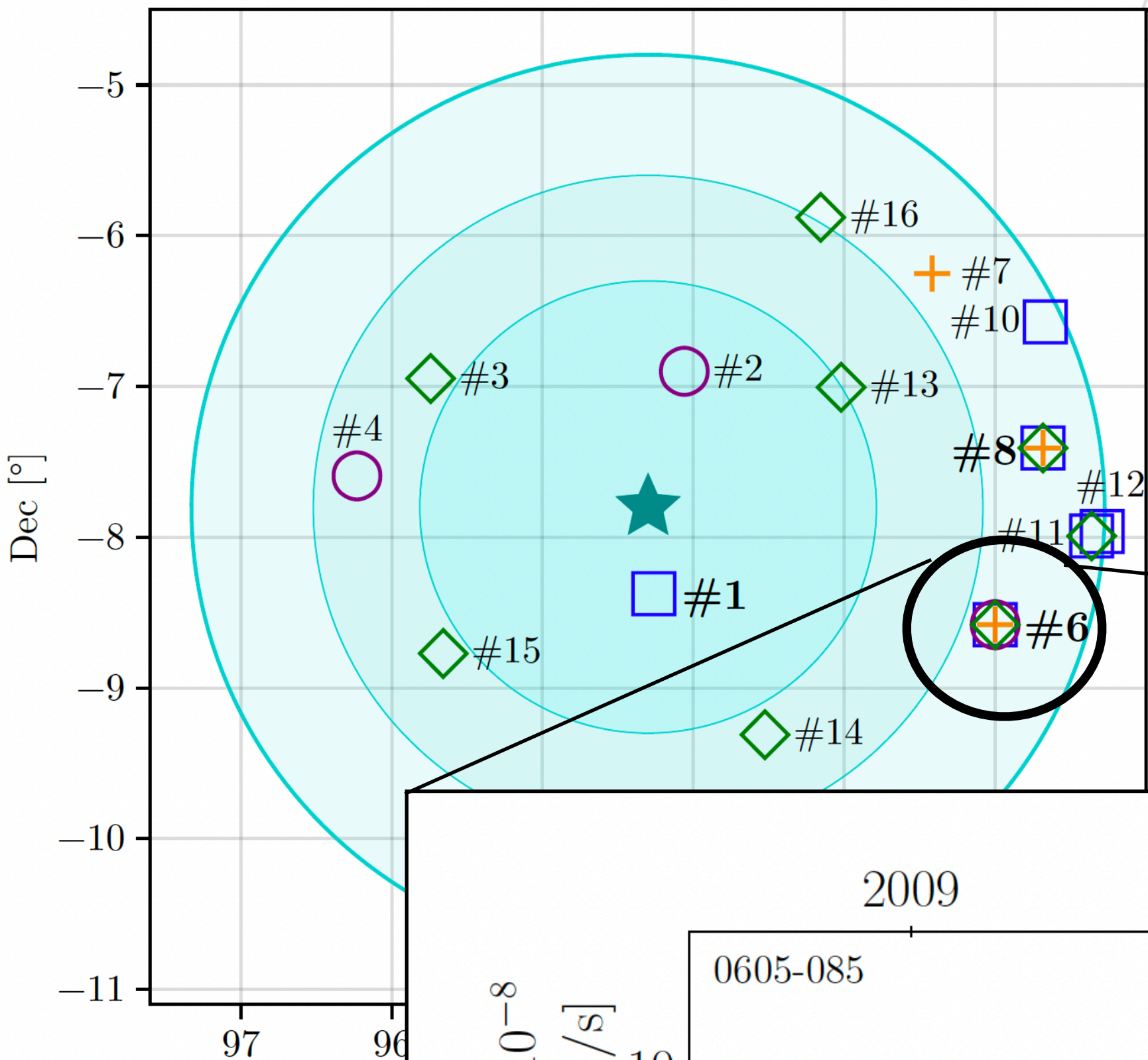
Method 4: The Fermi-LAT fourth source catalog provides the most recent census of γ -ray sources in the 50MeV–1TeV energy range.

Companion paper by KM3NeT Coll.: [arXiv:2502.08484](https://arxiv.org/abs/2502.08484)

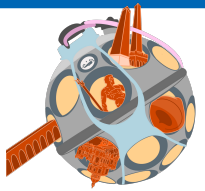
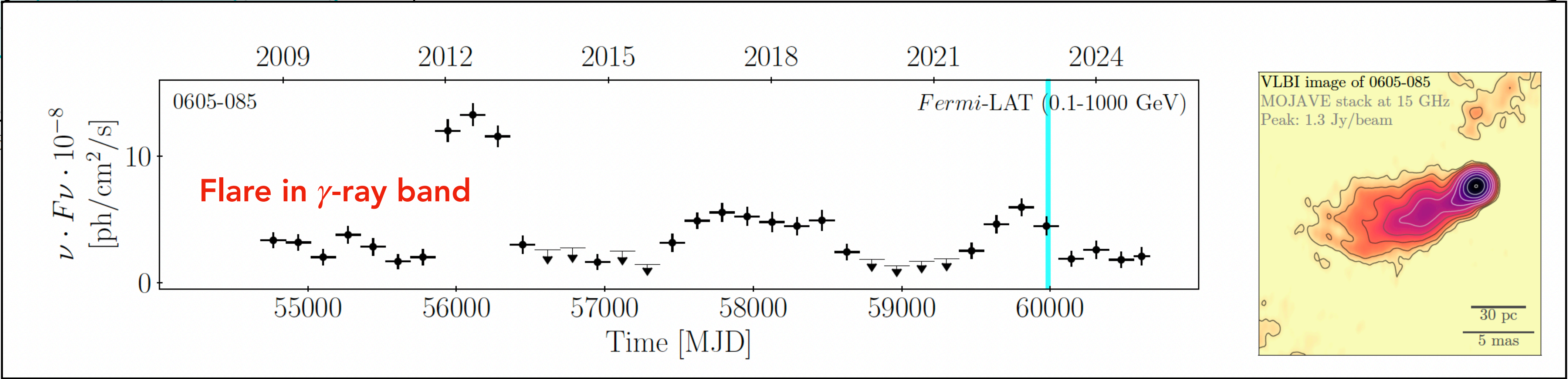


Source association

Companion paper by KM3NeT Coll.: [arXiv:2502.08484](https://arxiv.org/abs/2502.08484)

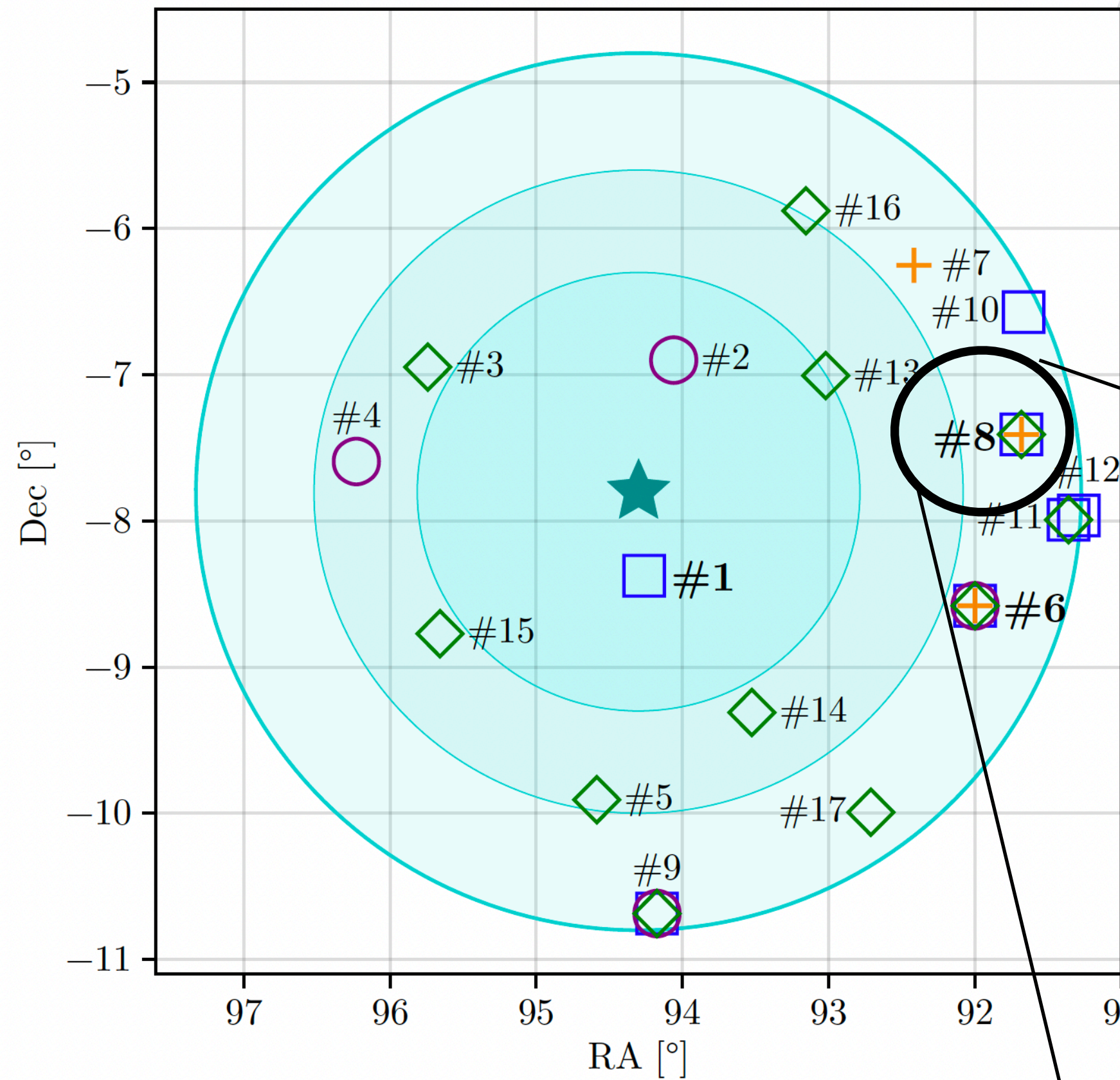


#6 0605-085: brightest source among the selected one in radio and experiencing a flare in gamma.
Among the fifty brightest radio objects in the whole sky in terms of the VLBI flux density.

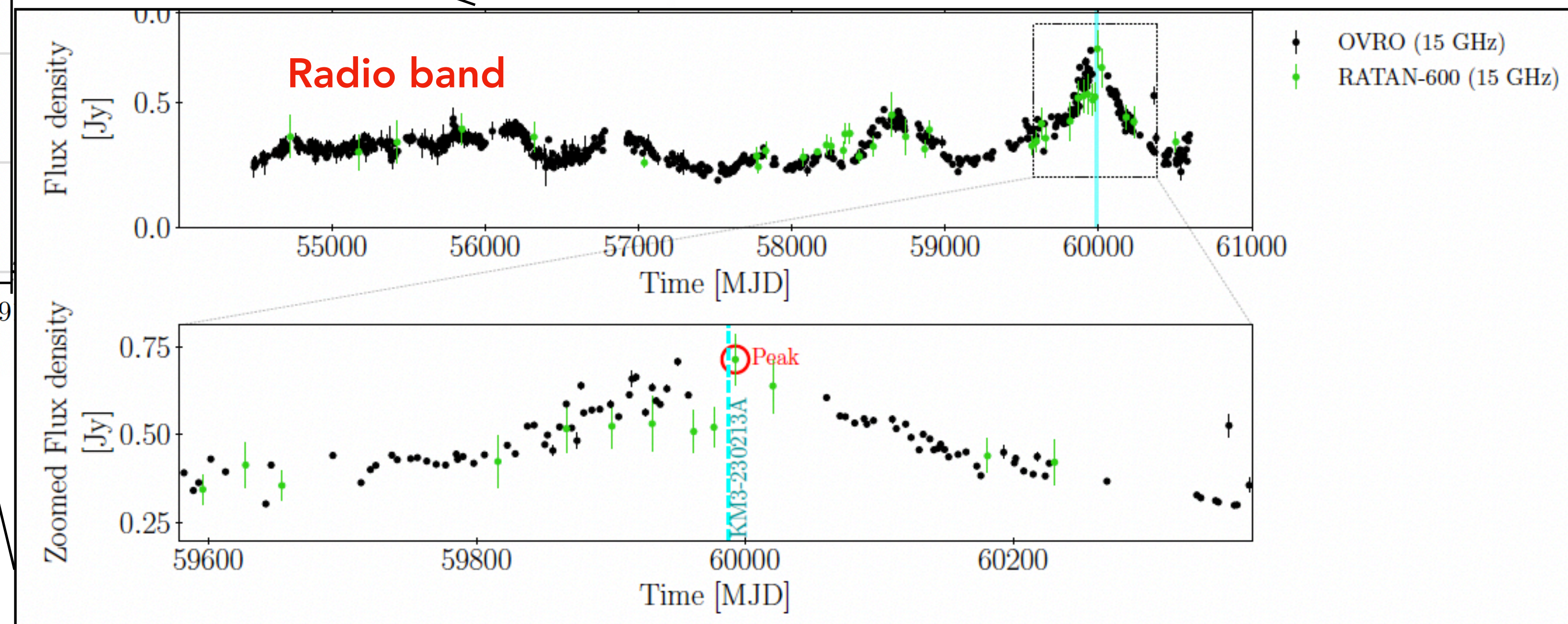


Source association

Companion paper by KM3NeT Coll.: [arXiv:2502.08484](https://arxiv.org/abs/2502.08484)

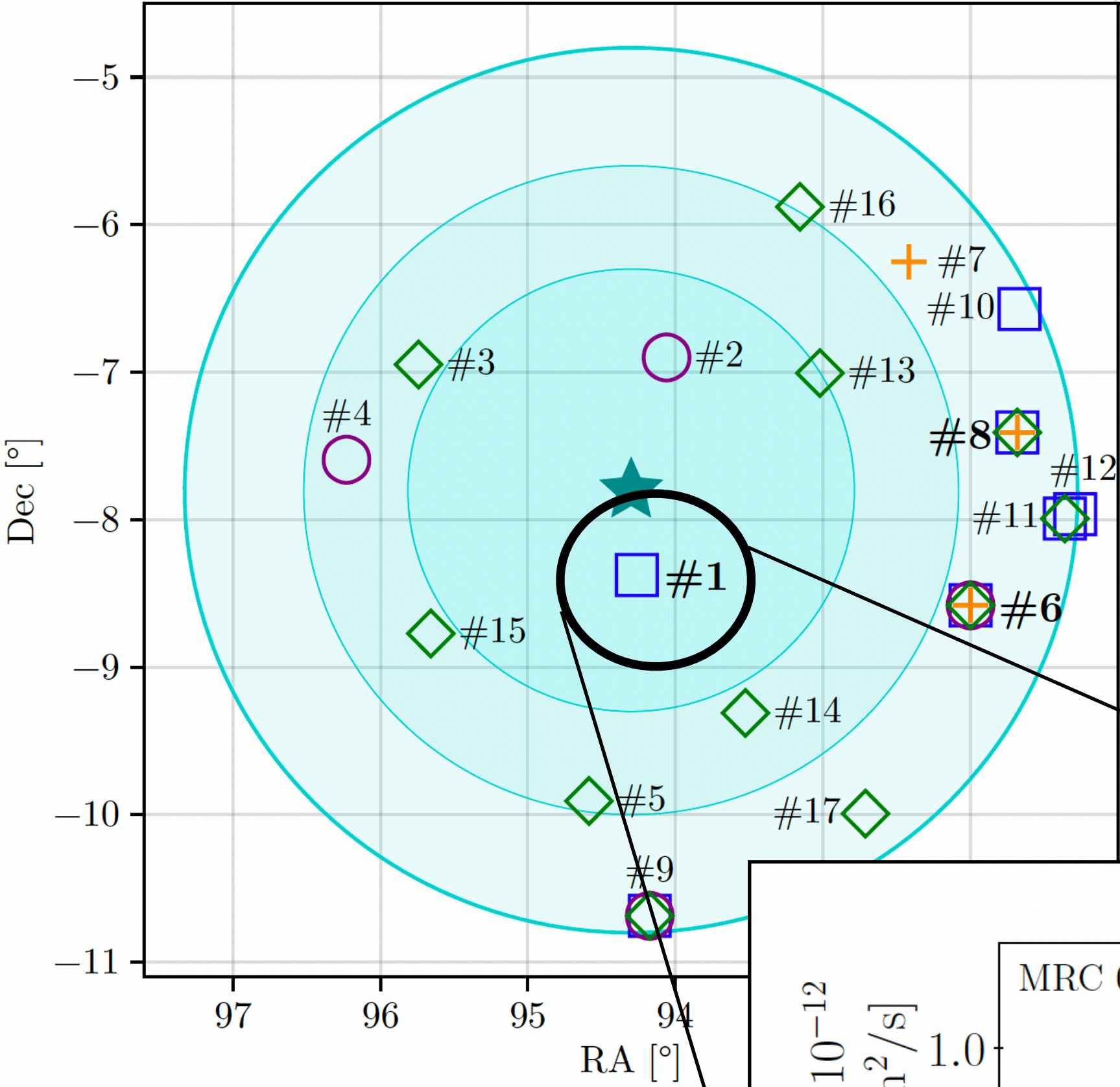


#8 PMNJ0606-0724: large radio flare very close in time to the KM3-230213A event, with a time difference of five days. Time emission coincidence with a pre-trial p-value of $p = 0.26\%$.

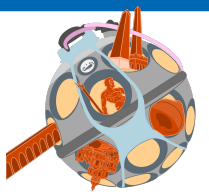
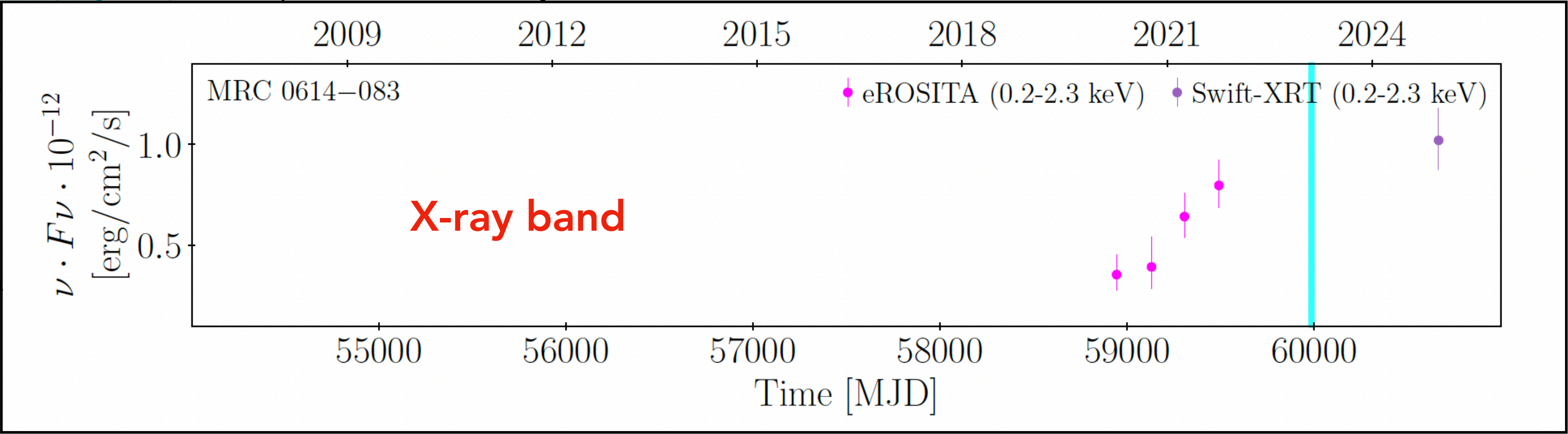


Source association

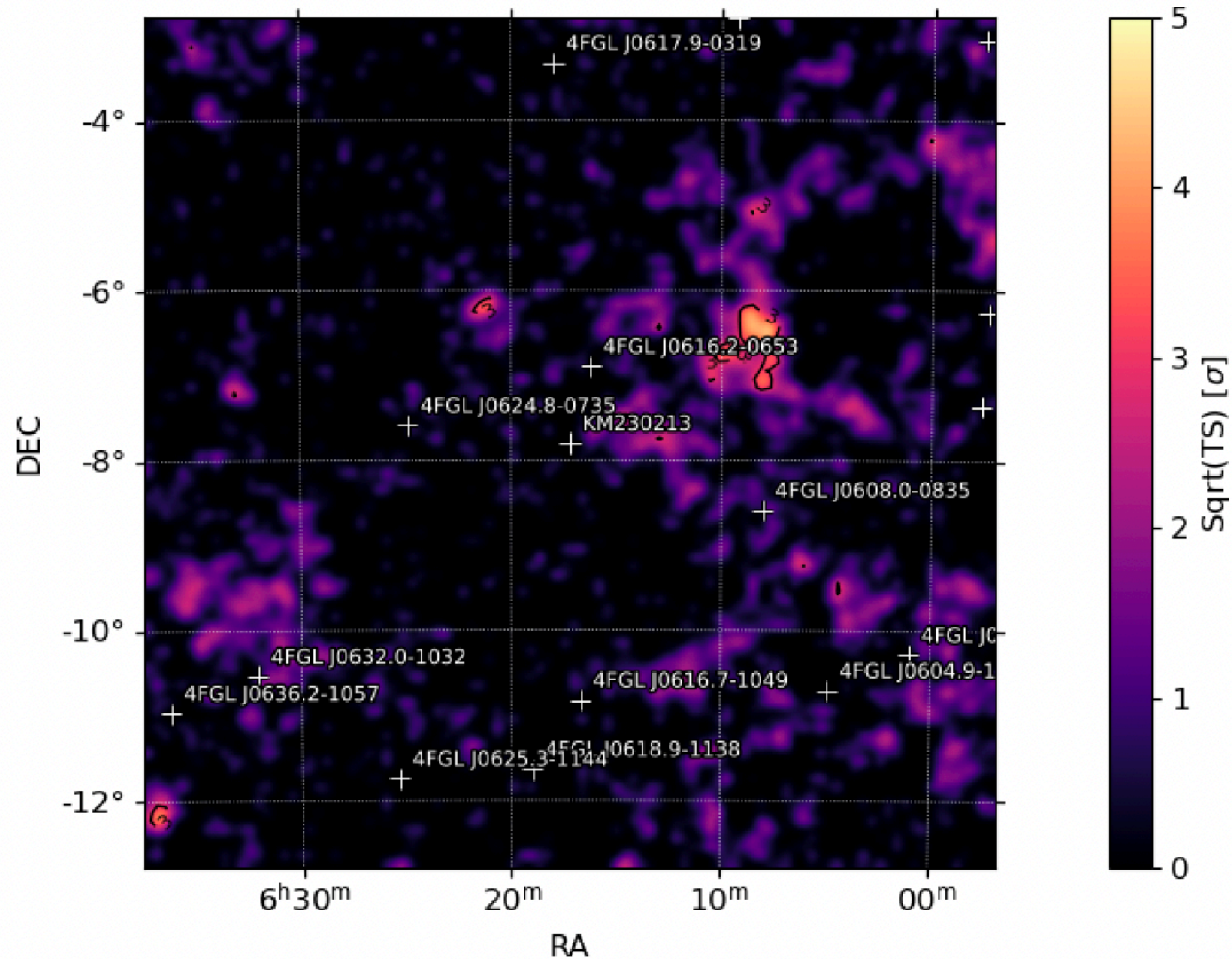
Companion paper by KM3NeT Coll.: [arXiv:2502.08484](https://arxiv.org/abs/2502.08484)



#1 MRC0614-083: the closest to the best fit neutrino localization, displays X-ray activity.
Recent Swift follow-up indicates that the high X-ray state of the object persists: intriguing possibility that KM3-230213A occurs while the object is undergoing an X-ray enhancement.
eROSITA sample only extends to ~ 488 days before KM3-230213A, ~ 3.2 year gap between it and the Swift-XRT observation.



Source association



Fermi-LAT analysis of the region with
16 years of observation

Steady point-like neutrino sources

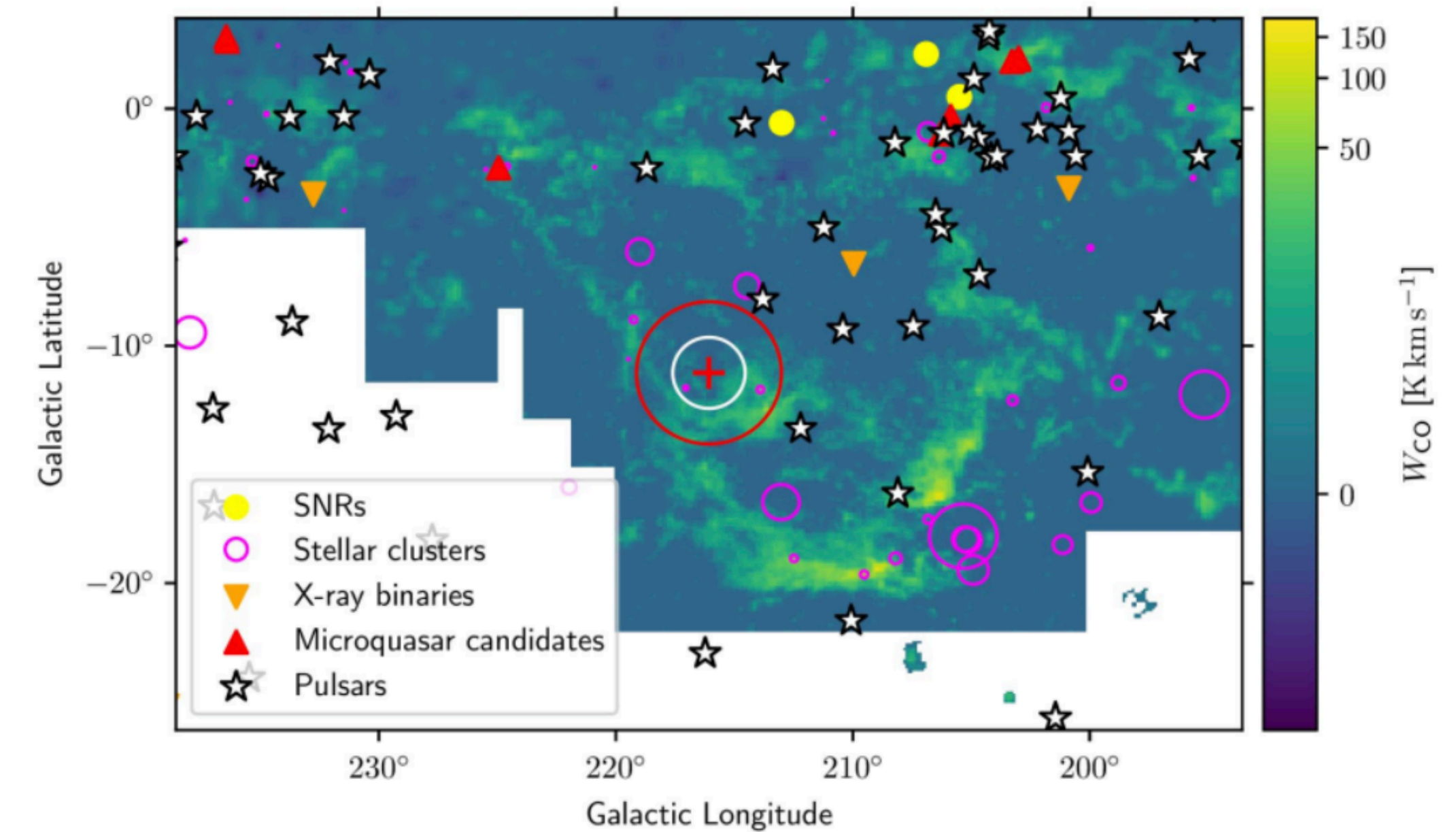
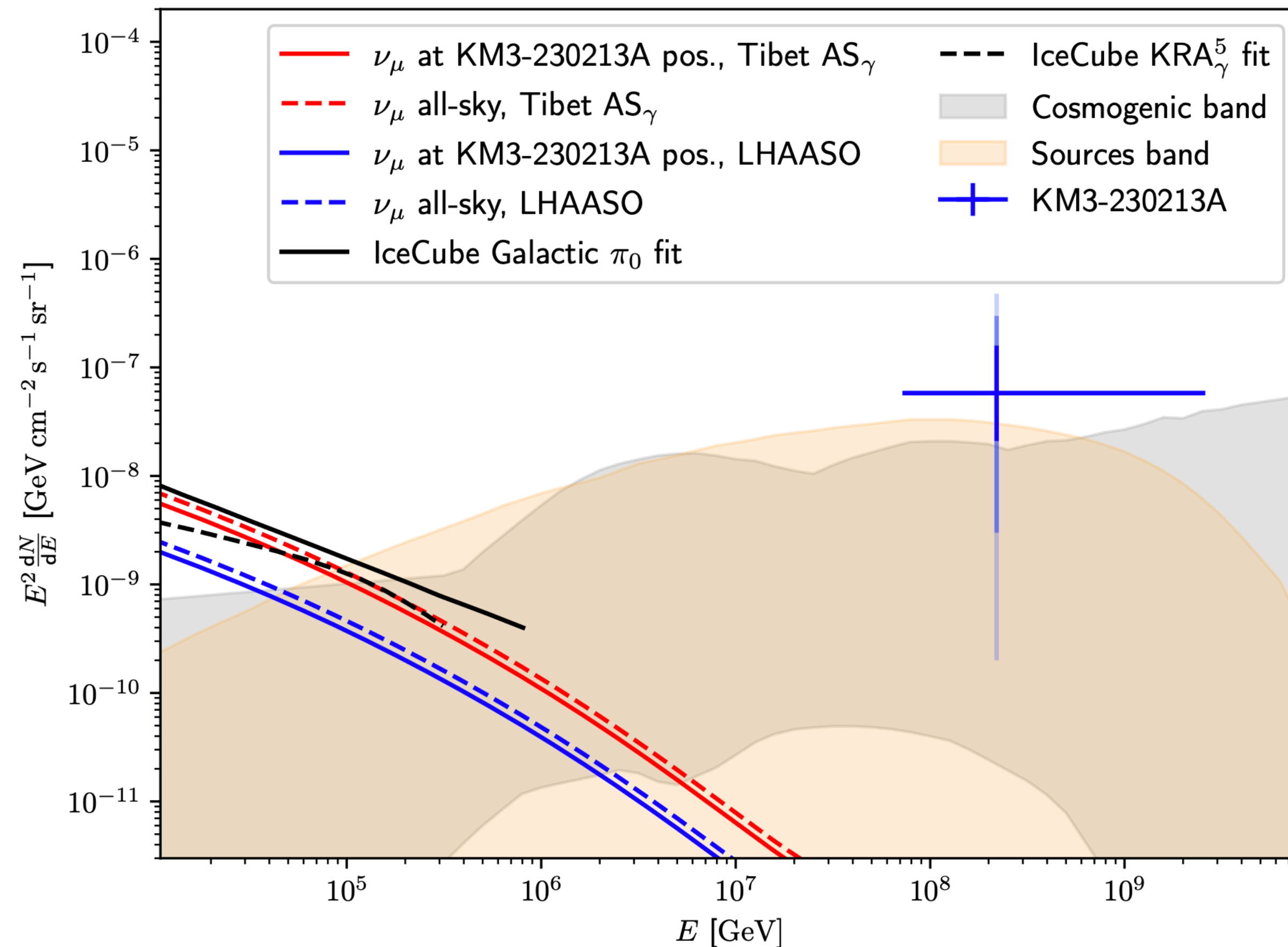
Dataset				Method	
Detector	Covered Period dd/mm/yyyy	Livetime [days]	Type of Data	Analysis Approach	Radius [deg]
ARCA6-21 ^a	12/05/2021 - 11/09/2023	640	offline ^b	binned likelihood [90]	3
ORCA6-18	11/02/2020 - 31/08/2023	1005	offline	ON/OFF [91]	4
ORCA18-23	01/09/2023 - 29/07/2024	126	online ^c	ON/OFF [91]	4
ANTARES	29/01/2007 - 31/12/2017	3125	public ^d	unbinned likelihood ^e	3
IceCube	06/04/2008 - 08/07/2018	3577	public [93]	unbinned likelihood ^f	3

Dataset	n_{sig}	$-\log_{10}(p\text{-value})$	Flux Upper Limit [GeV ⁻¹ cm ⁻² s ⁻¹]	(RA, Dec) [deg, deg]	Distance [deg]	P -value
ARCA6-21	0.4	0.044	1.8×10^{-8}	(94.3, -7.8)	0.0	-
	1.3	1.308	1.9×10^{-8}	(96.7, -6.8)	2.6	0.44
ORCA6-18	0	-	2.1×10^{-7}	-	-	-
ORCA18-23	0	-	2.3×10^{-6}	-	-	-
ORCA-combined	-	-	2.0×10^{-7}	-	-	-
ANTARES	0	-	1.1×10^{-8}	(94.3, -7.8)	0.0	-
	1.9	1.936	1.7×10^{-8}	(94.4, -5.3)	2.5	0.53
IceCube	1.4	0.327	1.2×10^{-9}	(94.3, -7.8)	0.0	-
	15.1	3.782	6.3×10^{-9}	(93.9, -10.1)	2.4	0.07

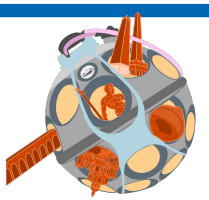
- ANTARES, KM3NeT and public IceCube data analyzed.
- Most strident limits coming from IceCube (up to 2018).
- **No significant signal in the ROI after trial correction.**

Galactic origin ?

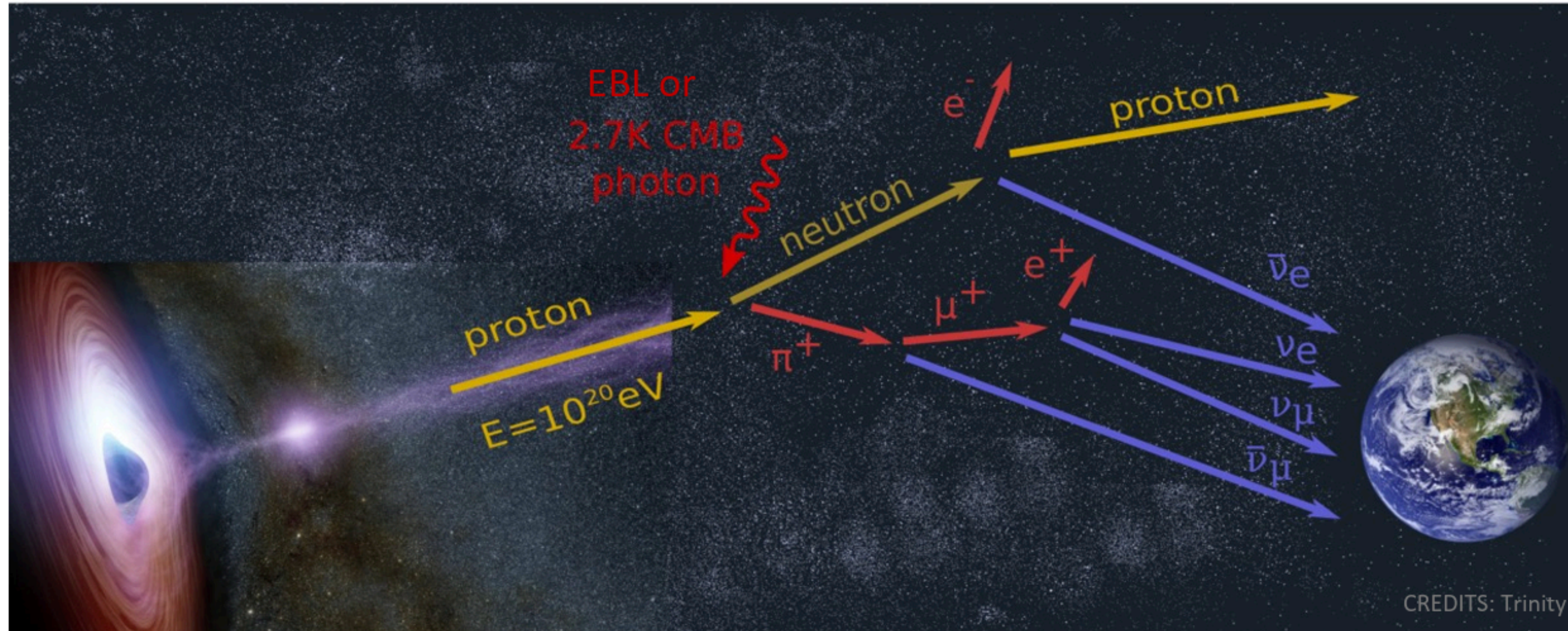
A search for potential γ -ray counterparts revealed two unidentified Fermi-LAT sources, but no detection by HAWC and LHAASO.



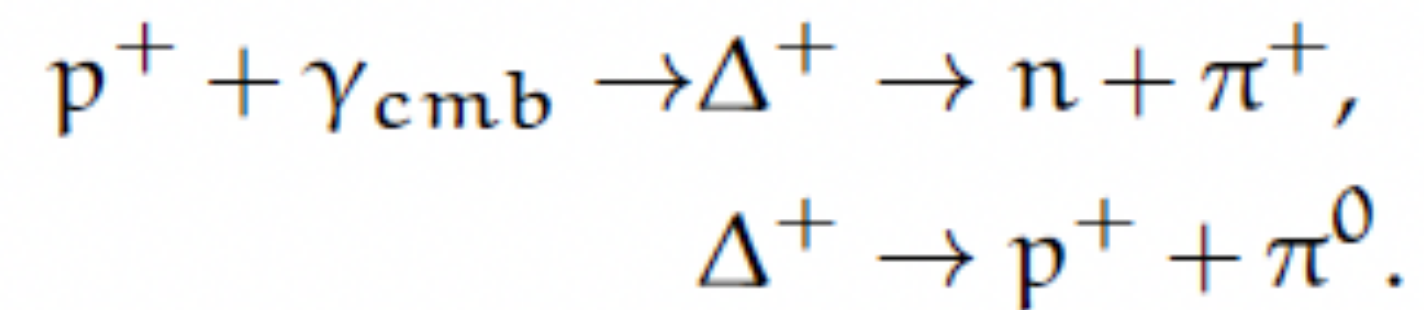
Companion paper by KM3NeT Coll.: [arXiv:2502.08387v2](https://arxiv.org/abs/2502.08387v2)



Cosmogenic origin ?



GZK cut-off: CRs protons attenuate above a threshold $E_{GZK} \sim 5 \times 10^{19} \text{ eV}$. Nuclei attenuated at energy $A \times E_{GZK}$.



Companion paper by KM3NeT Coll.: [arXiv:2502.08508](https://arxiv.org/abs/2502.08508)

Other origins ?

- **Flaring source:** theoretical neutrino 1-year flaring emission from MRC0614-083: [Phys. Rev. D. 8 \(2026\) 113](#);

Many paper on DM candidates and stringent constraints on Lorentz invariance violation.

- Triplet right-handed neutrino: [arXiv.org:2504.01447](#)
- Lorentz invariance violation: [arXiv:2502.13093v3](#), [arXiv:2502.18256v1](#)
- Evaporating primordial black holes: [arXiv:2502.19245v1](#)

and many more: [arXiv:2502.21299](#), [arXiv:2503.00097](#), [arXiv:2503.04464](#), [arXiv:2503.07776](#) ...

To know more see tomorrow's talk of Rebecca at 15:15, G01:

The usual suspect: has a heavy dark matter particle decayed to KM3-230213A?

Sara Rebecca Gozzini

G01, Ainsworth

15:15 - 15:40