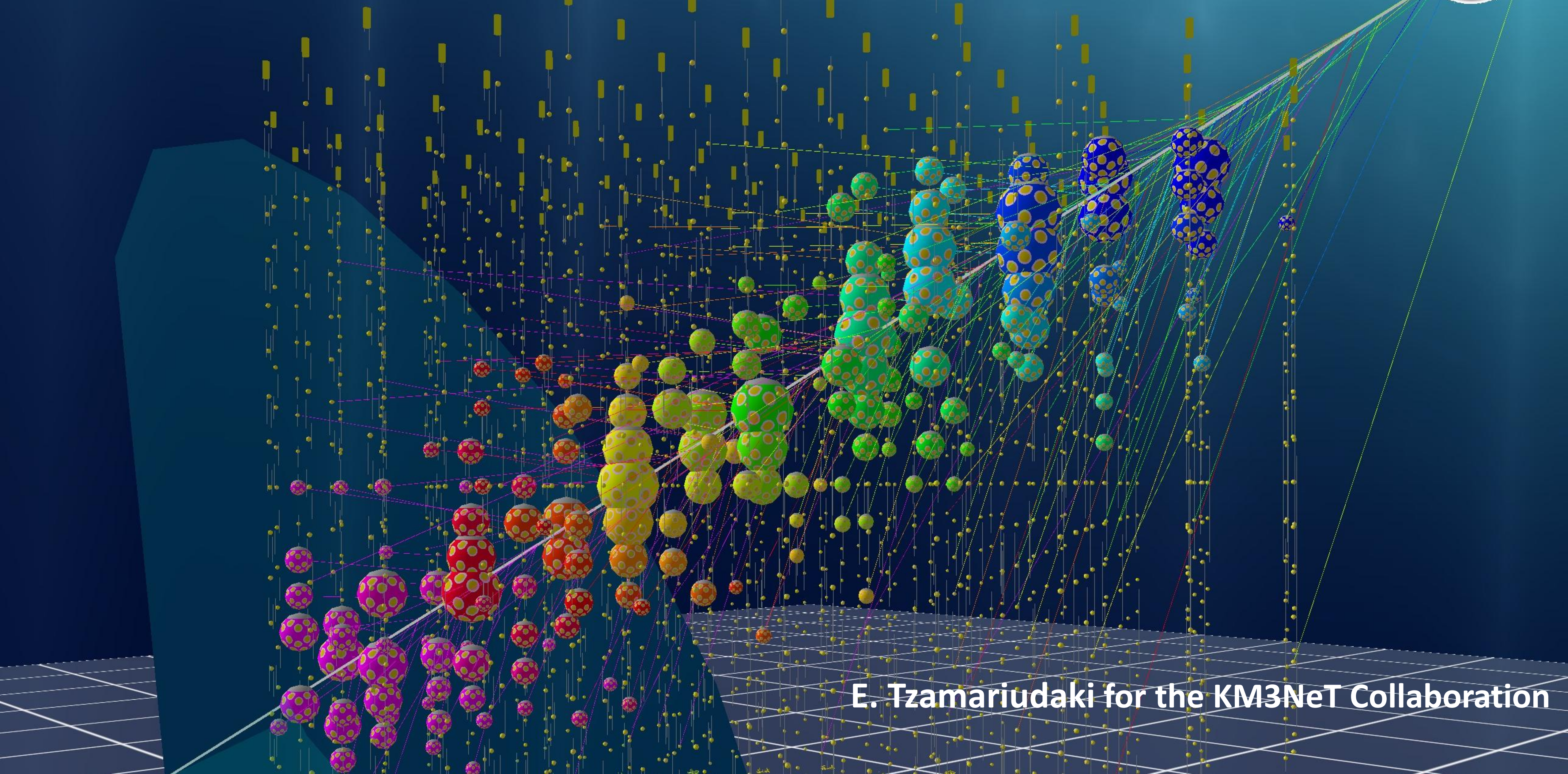
Astrophysics with the KM3NeT neutrino telescopes



E. Tzamariudaki for the KM3NeT Collaboration

KM3NeT Science Objectives: Astroparticle

Astrophysical neutrino sources are cosmic ray accelerators

Astrophysical beam dumps:
High-energy cosmic rays interact with gas or radiation

$$
\begin{aligned}
p + p/\gamma \rightarrow X + \pi^0 &\rightarrow \gamma\gamma \\
\rightarrow X + \pi^\pm &\rightarrow \mu^\pm + \overset{(-)}{\nu}_\mu \\
\mu^\pm &\rightarrow e^\pm + \overset{(-)}{\nu}_e + \overset{(-)}{\nu}_\mu
\end{aligned}
$$

Neutrino production processes:

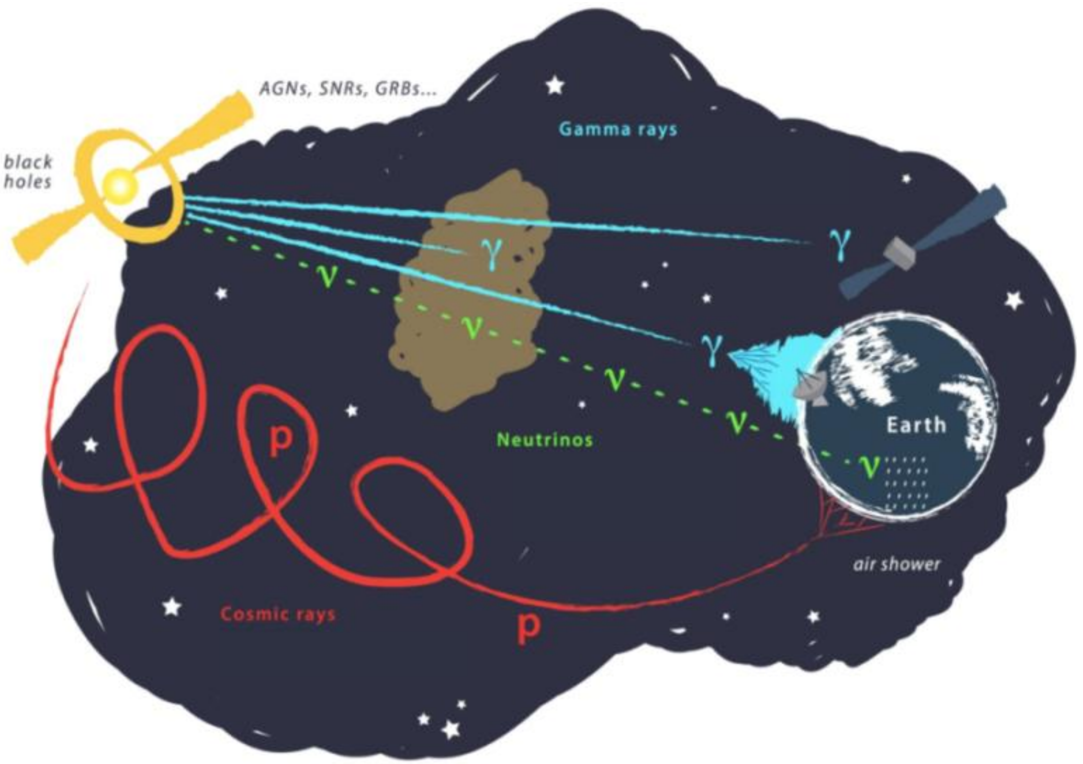
- Hadro-nuclear interactions (*p + p*)
- Photo-hadronic interactions (*p + γ*)

ν and γ produced in interactions of HE nucleons with matter or radiation

but γ not exclusively produced in hadronic processes - high-energy electrons collide with low-energy ambient photons (inverse Compton scattering)

neutrinos:
"smoking gun" signature for hadronic acceleration

KM3NeT Science Objectives: Astroparticle



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&\qquad\qquad \mu^\pm \rightarrow e^\pm + \overset{(-)}{\nu}_e + \overset{(-)}{\nu}_\mu
\end{aligned}
$$

Cosmic ray acceleration yields ν and γ with similar abundance and energy

Explore the High Energy Universe

Current knowledge about the Universe comes mostly from photons and cosmic rays

neutrinos: unique messengers

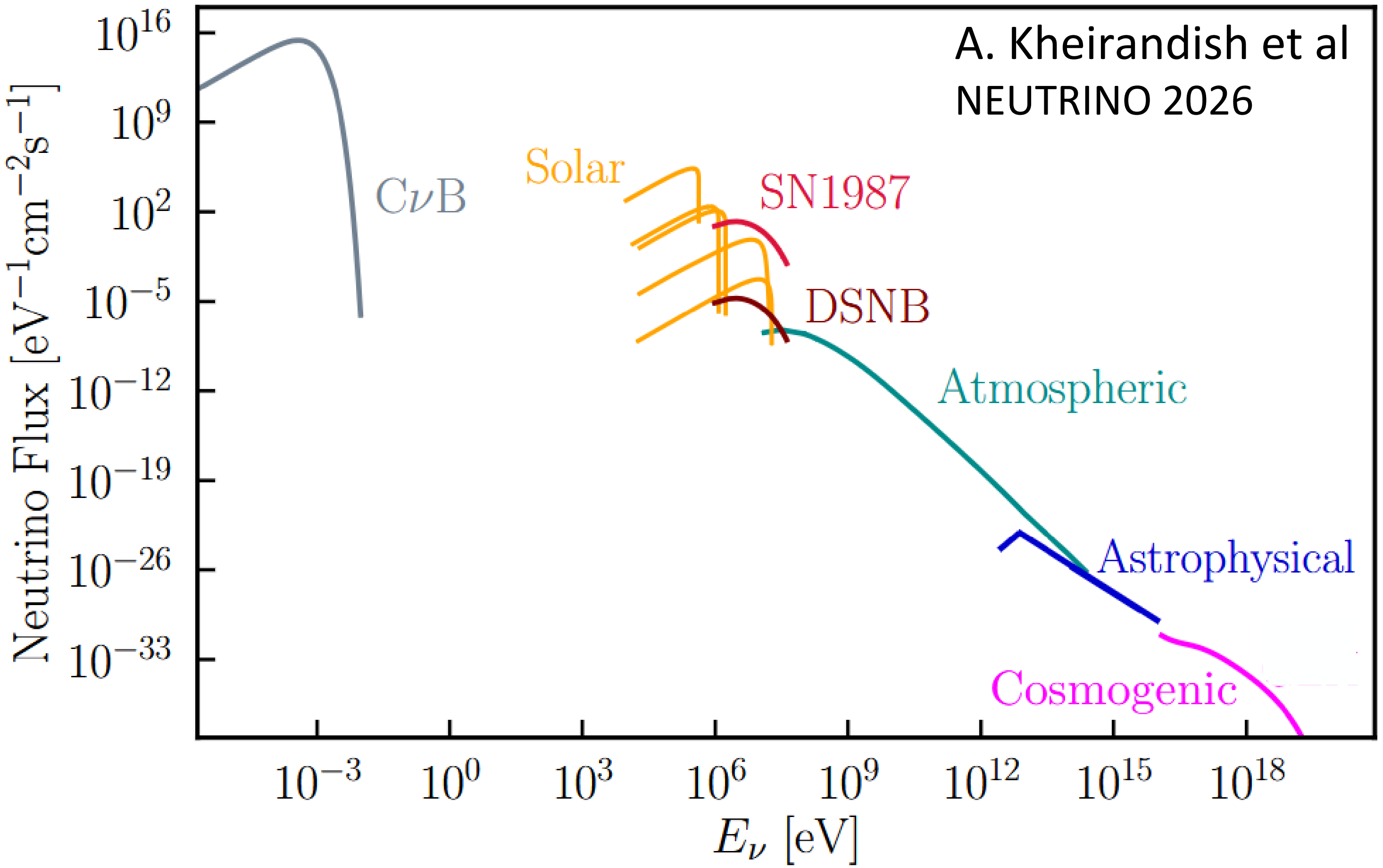
- no interactions with ambient matter or radiation
- no deflection by magnetic fields
- information on the internal processes of the astrophysical sources inaccessible through photons or cosmic rays

neutrinos: probe of fundamental processes

- origin of UHE cosmic rays
- production mechanism of HE gamma-rays (hadronic / leptonic)

KM3NeT/ARCA for Neutrino Astronomy

Neutrino flux



➢ Supernova neutrinos:
99% of the gravitational binding energy of a collapsing star is released in the form of neutrinos

➢ Atmospheric:
Cosmic ray interactions in the atmosphere produce charged mesons whose decays produce neutrinos

➢ Astrophysical:
High energy cosmic ray interactions with gas / radiation

➢ Cosmogenic:
Ultra high energy cosmic ray interactions with the cosmic microwave background

Science Objectives: from MeV to PeV neutrinos

Supernova explosions

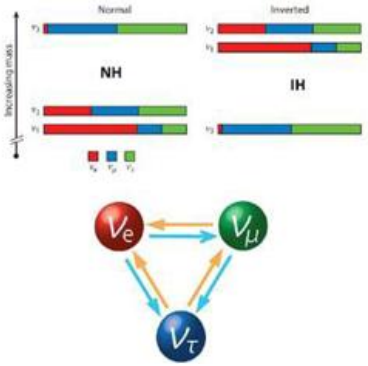
Neutrino oscillations
Neutrino mass hierarchy

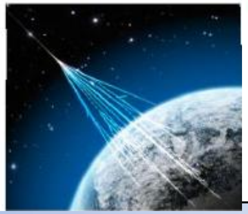
Dark matter
Exotic searches

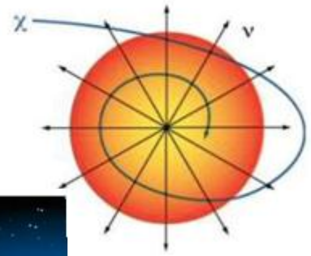
Cosmic neutrinos
Multi-messenger astronomy

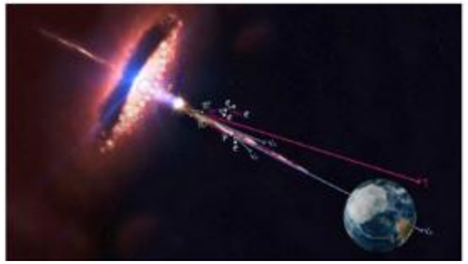
Cosmic rays studies

MeV — **GeV** — **TeV** — **PeV**







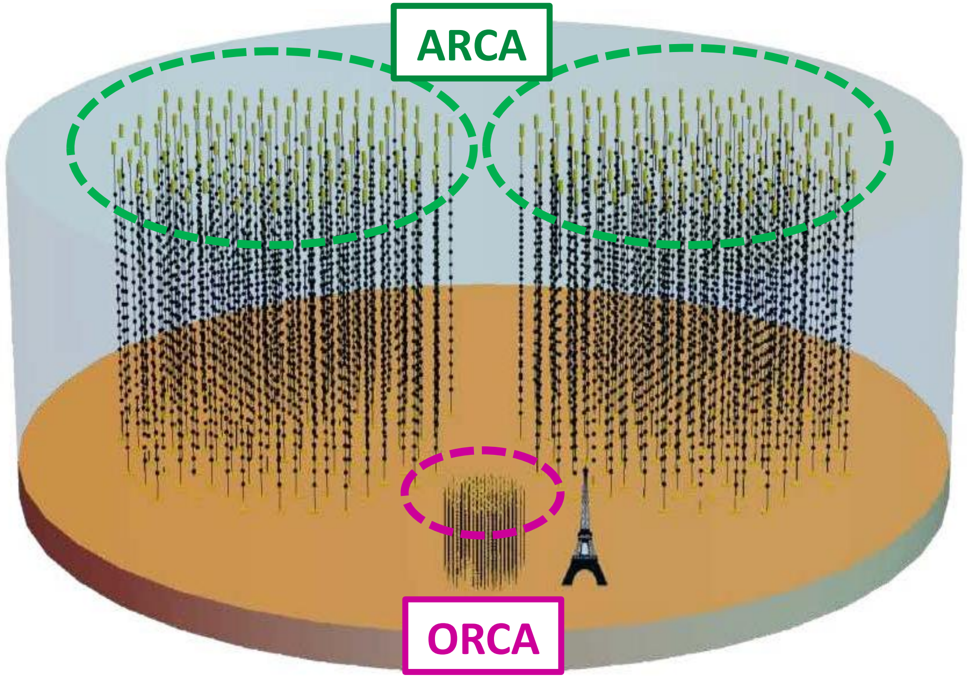


KM3NeT/ORCA ⟷ **KM3NeT/ARCA**

Direction and energy resolution are of primary importance

+ oceanology, biology, seismology

Science Objectives: from MeV to PeV neutrinos

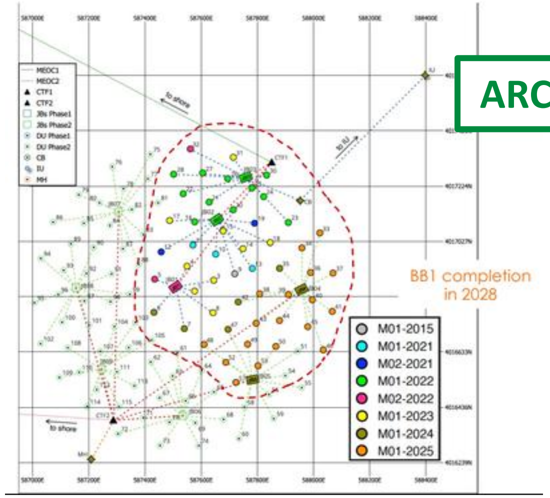


- ARCA: 51 DUs
- ORCA taking data with 42 DUs (since early July)

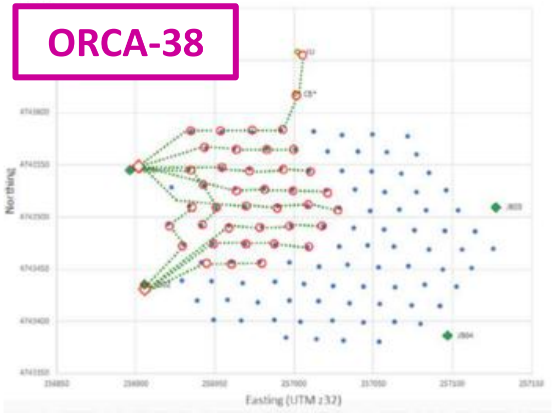
Analyses/results:

- ARCA6-21 dataset
- ORCA6-18 dataset

ARCA-51



ORCA-38



ARCA	Optimised to identify and study astrophysical neutrino sources (TeV – PeV)
ORCA	Optimised to study neutrino properties through oscillation studies (GeV)

Both can be used for neutrino astronomy from few MeV to hundreds of PeV

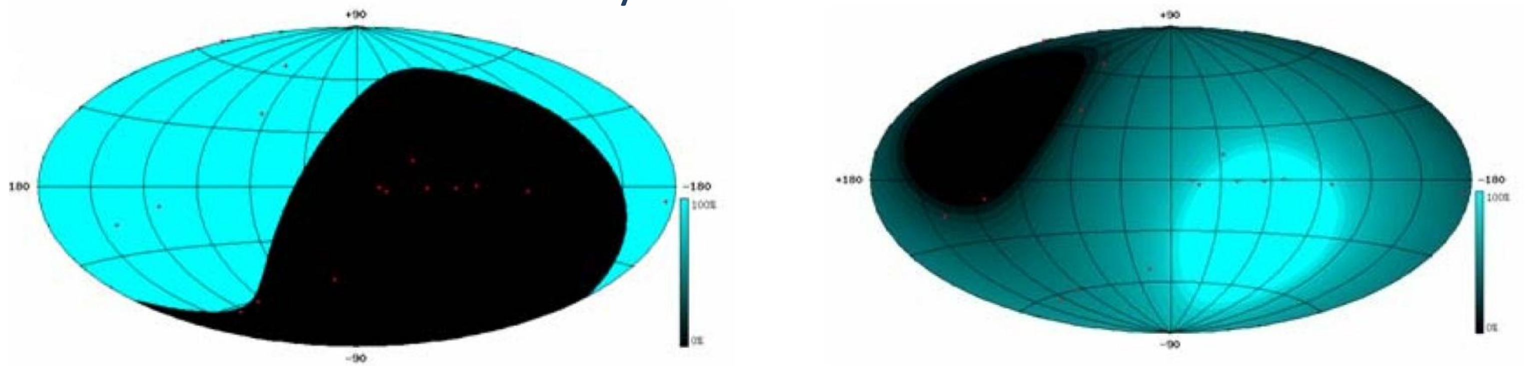
The KM3NeT neutrino telescope in the Mediterranean

- High visibility of the Galactic region ➔ ~ 70 % for the Galactic Centre
- Optical properties of water ➔ Mapping the **Southern sky** with unprecedented angular resolution

KM3NeT-ARCA

- tracks @ 10 TeV : ~**0.1°**
- cascades @ 10TeV : **< 2°**

The sky in Galactic coordinates



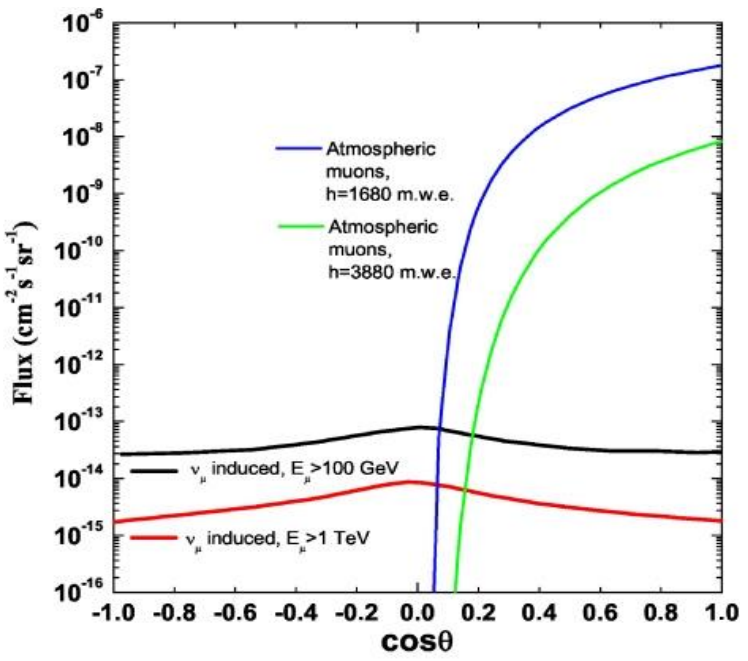
From the South Pole　　From the Mediterranean Sea

Visibility for up-going neutrinos

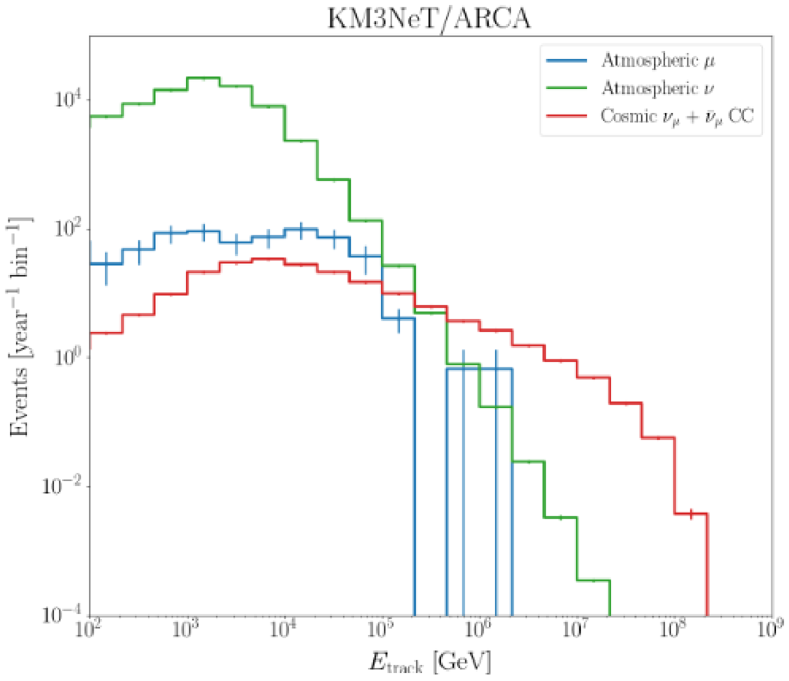
Neutrino telescopes: background sources

- **<u>noise:</u> background from ^{40}K decays (constant natural source for PMT calibration) and background from bioluminescence (life forms in the deep sea emitting light)**

- **cosmic ray interactions in the atmosphere produce $\pi^{\pm}$ and $K^{\pm}$ whose decays produce neutrinos and muons**



http://doi.org/10.1016/j.physrep.2025.04.001



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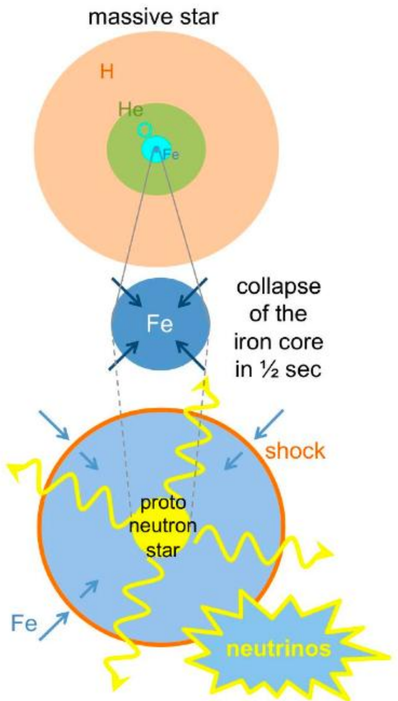
Neutrinos from core-collapse supernovae

➢ Supernova neutrinos:



Unique Supernova neutrino detection

SN1987A in the Large Magellanic Cloud

Neutrinos arrived 2 h earlier than photons

confirmation of the basic theoretical picture of the death of a star

- 99% of the gravitational binding energy of a collapsing star is released in the form of neutrinos
- neutrinos in the 10 – 20 MeV energy range
- neutrinos emitted on a timescale of ~10 s from the onset of the collapse, when the star envelope is opaque to the electromagnetic radiation

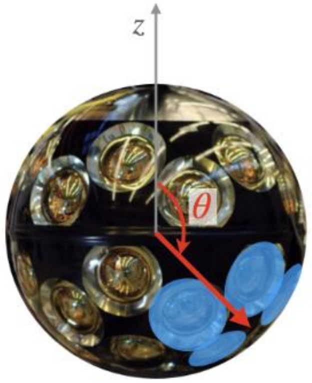
- Expected rate of CCSNe in the Galaxy ~ 1.6 ± 0.5 per century
- KM3NeT detection of the neutrino burst to generate an alert for optical observatories.

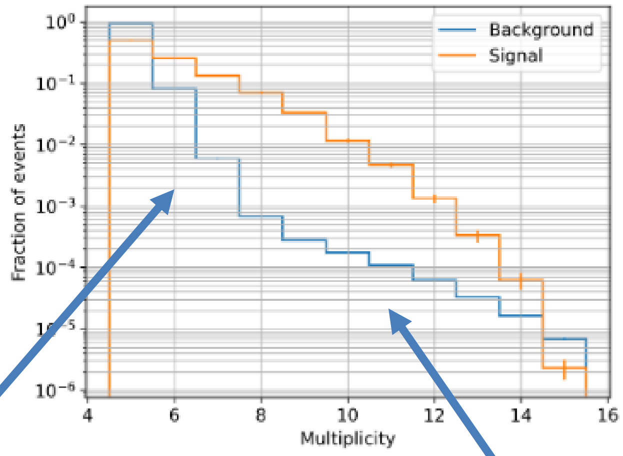
Information from different telescopes to identify a CCSN, locate it and alert telescopes for prompt electromagnetic follow-up

Neutrinos from core-collapse supernovae

- neutrinos in the 10 – 20 MeV energy range -> far below KM3NeT sensitivity
- explore multi-pmt DOM
- supernova burst can be detected by observing an increase of multiple PMT hits within a single DOM in a narrow time window (~ 10 ns)

✓ at least 4 hits in a single DOM within 15 ns from PMTs whose axes lie within 90°
✓ veto applied on the number of triggered DOMs to suppress atmospheric muon background





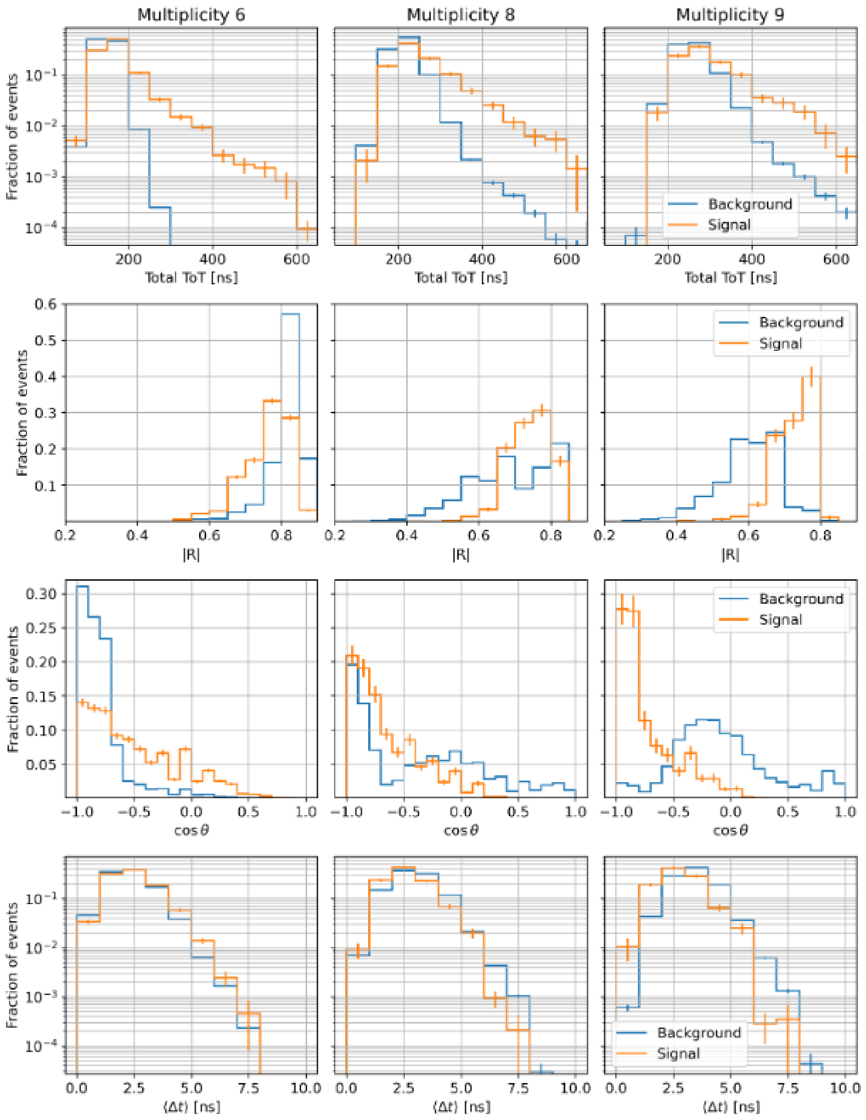
^{40}K decays

atmospheric muons

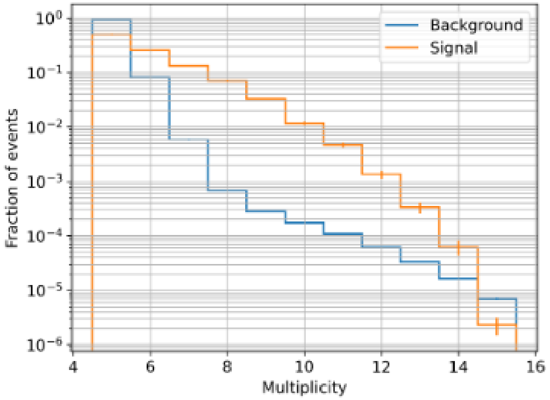
Five observables to describe the spatial distribution of hit PMTs in the DOM to separate signal from background by ^{40}K decays and atmospheric muons.

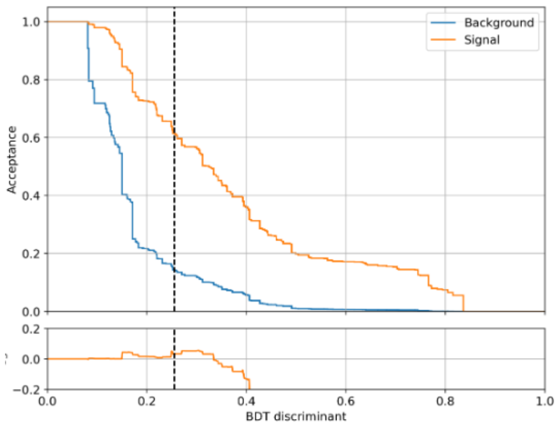
Neutrinos from core-collapse supernovae

to separate signal from background by ^{40}K decays and atmospheric muons
- multiplicity & total ToT (related to the signal intensity)
- hit concentration/cluster R (related to the spatial distribution)
- position (cosθ) of the hit cluster on the DOM
- average hit timing (Δt) (related to the temporal spread of the signal)



https://arxiv.org/abs/2511.18565





Use BDTs for separating CCSN signatures from background

Neutrinos from core-collapse supernovae

- neutrinos in the 10 – 20 MeV energy range -> far below KM3NeT sensitivity
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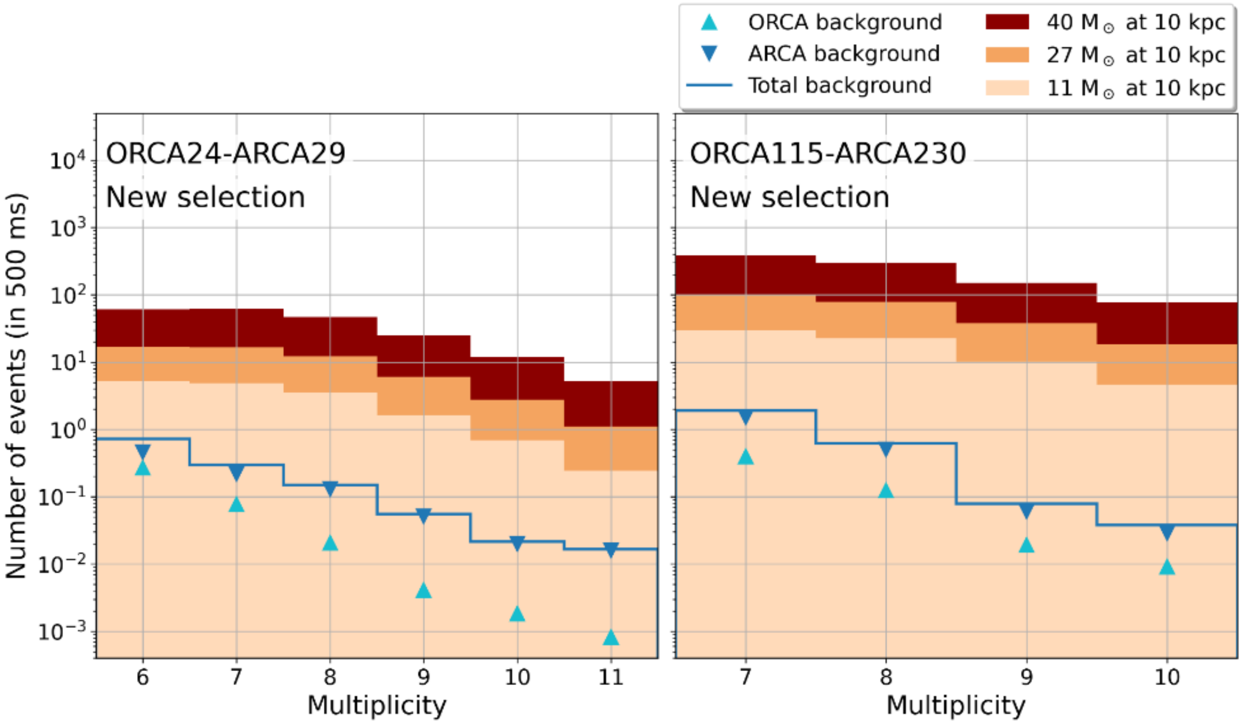
- supernova burst can be detected by observing an increase of multiple PMT hits within a single DOM in a narrow time window (~ 10 ns)

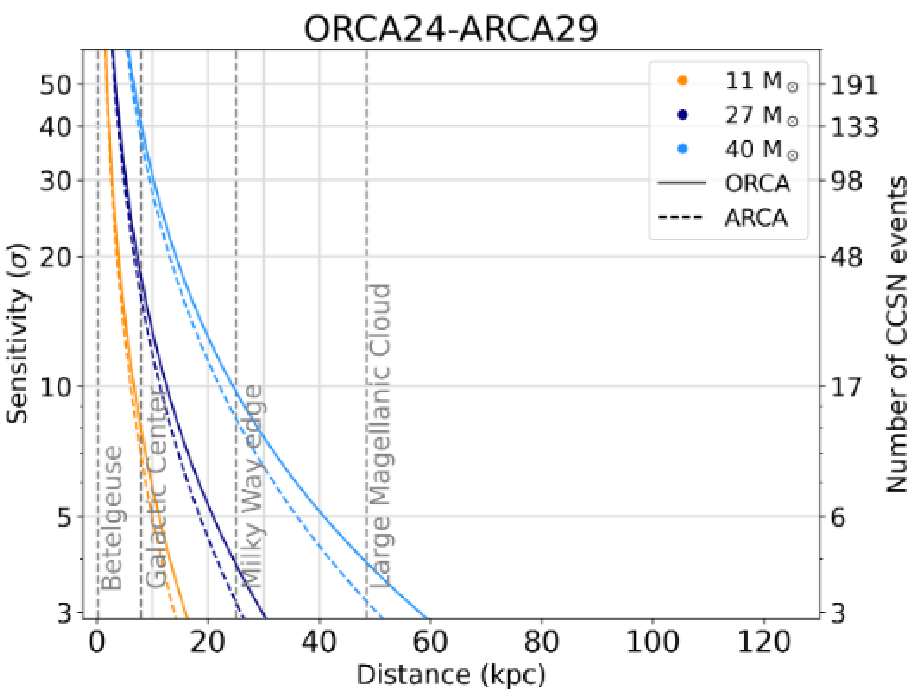


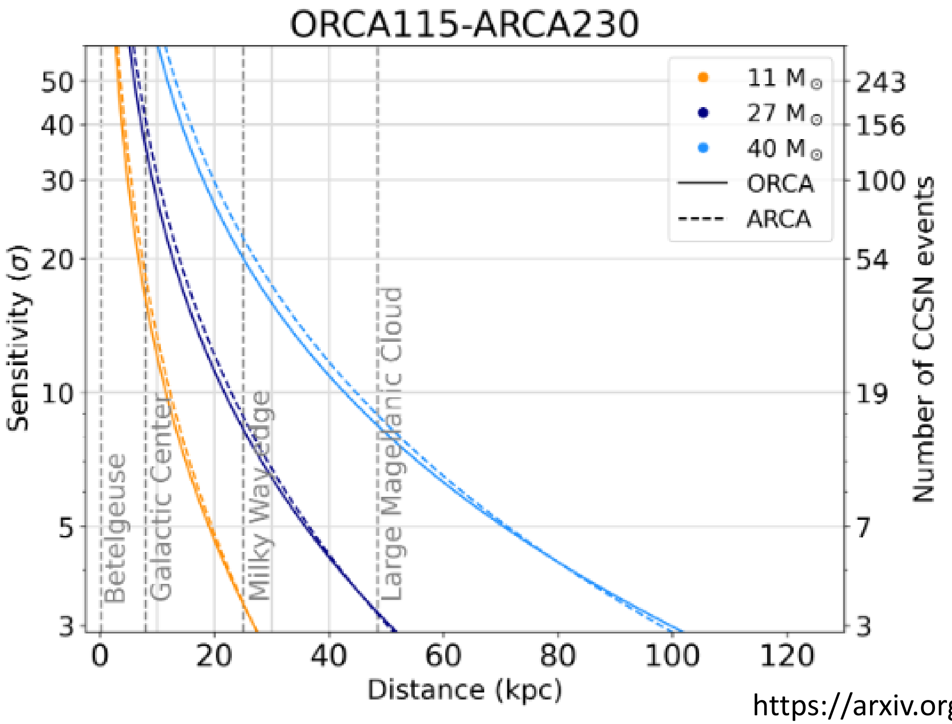
https://arxiv.org/abs/2511.18565

- Use single DOM variables to search for supernova neutrino bursts
- Machine learning techniques (Boosted Decision Trees) for event selection
- Identify CCSN neutrinos without relying on information from other experiments

Neutrinos from core-collapse supernovae

Sensitivity as a function of the CCSN distance to Earth





https://arxiv.org/abs/2511.18565

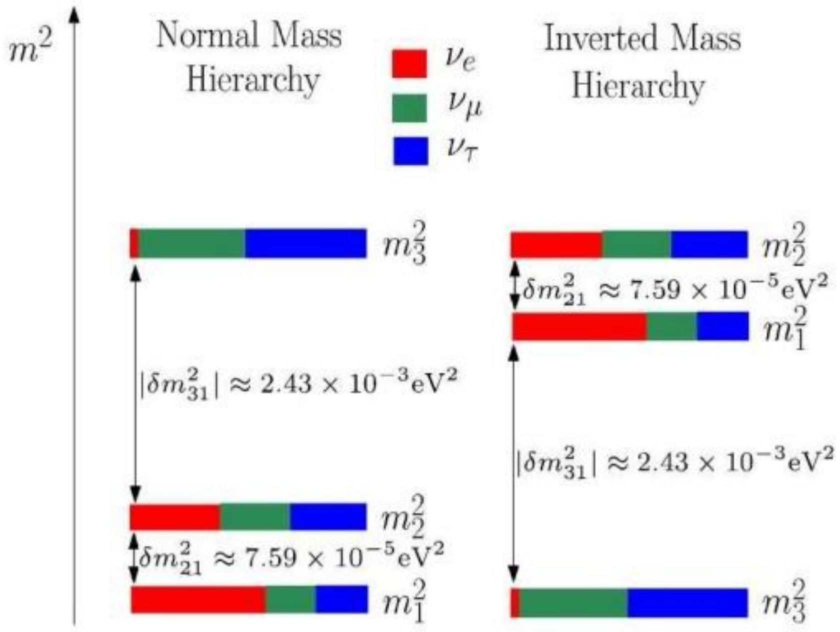
- KM3NeT will achieve full Galactic sensitivity
- KM3NeT can play an important role in the detection and localization of the next Galactic supernova

neutrino oscillations

- Mixing between neutrino flavour and mass eigenstates – PMNS matrix

$$\begin{bmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{bmatrix} = \begin{bmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{bmatrix} \begin{bmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{bmatrix}$$

- Neutrinos are produced as flavour eigenstates and propagate as a superposition of the three mass eigenstates
- as they propagate, the wavefunction of each mass state evolves with a different frequency
- Change of superposition mixture of mass eigenstates as the neutrino travels large distances



$$P_{\alpha \to \beta} = \sin^2(2\theta)\sin^2\left(1.27\frac{\Delta m^2 L}{E}\right)$$

can happen only if neutrinos have mass

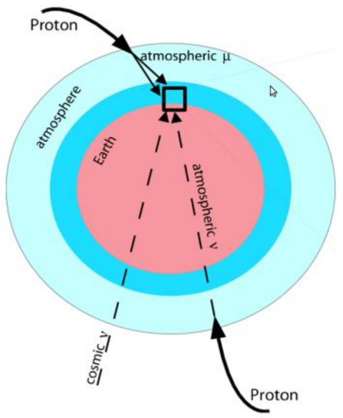
➡ Standard Model is not the complete theory of the fundamental components of the Universe

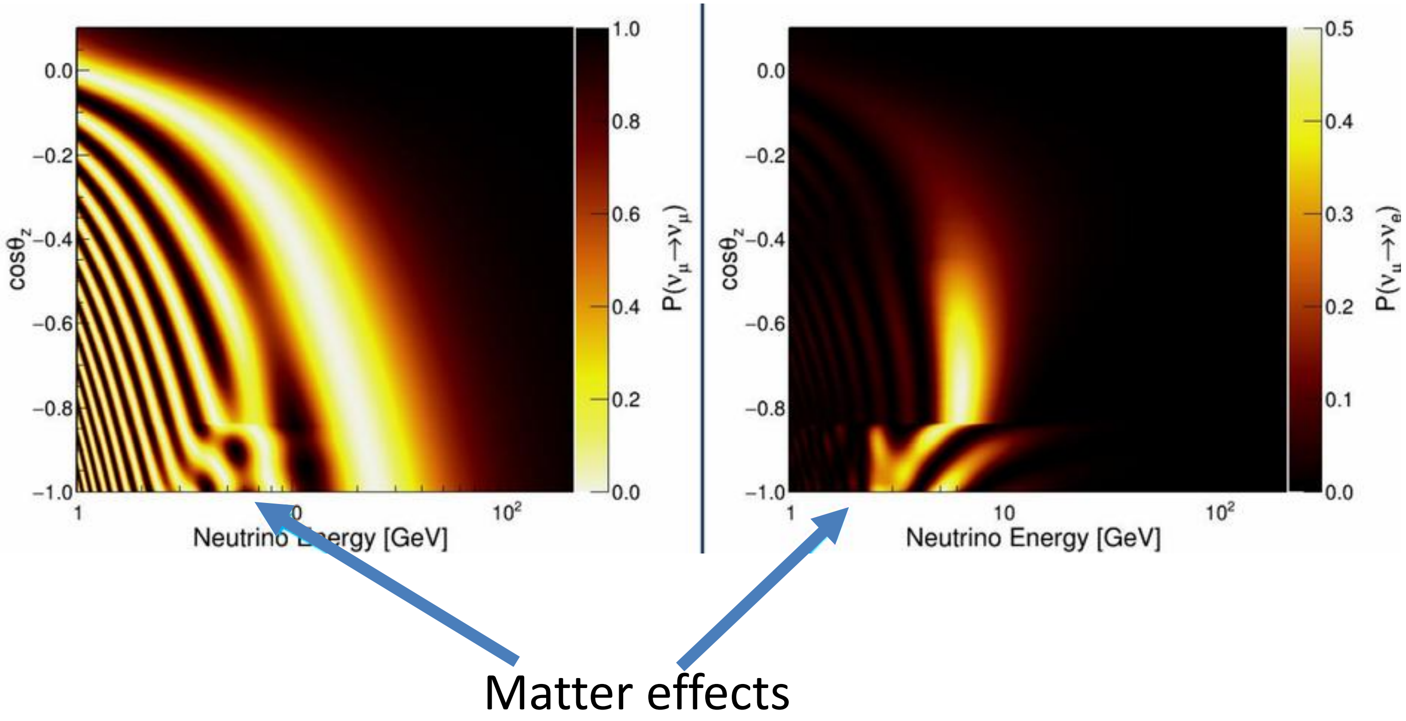
KM3NeT/ORCA

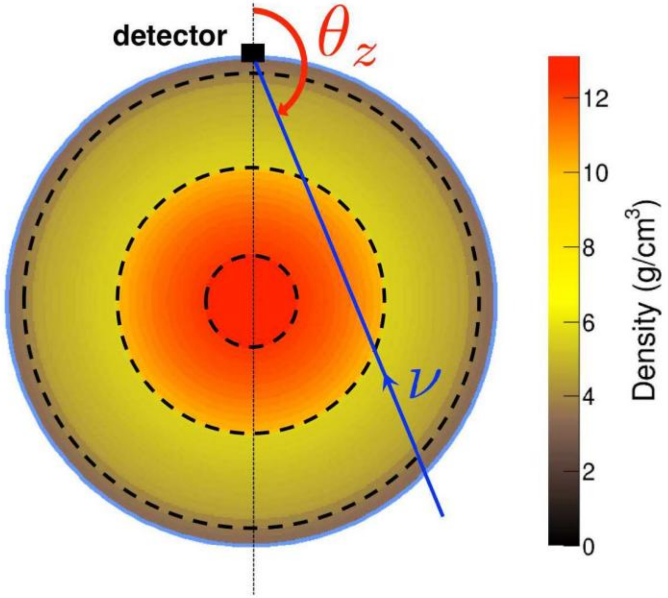
Neutrino properties through atmospheric neutrino oscillation studies
- neutrino mass ordering
- measure oscillation parameters
- New physics (sterile neutrinos, NSI & other)

Science Objectives: Study atmospheric neutrino oscillations

- Large flux of atmospheric neutrinos
- Study atmospheric neutrino oscillations (few GeV energy regime)
- Oscillation pattern distorted by Earth matter effects leading to an enhancement of the $\nu_\mu/\overline{\nu}_\mu \leftrightarrow \nu_e/\overline{\nu}_e$ transition. Largest effects for ~7 GeV neutrinos passing through the Earth mantle. Allows for determination of mass ordering because of different behaviour of neutrinos/antineutrinos







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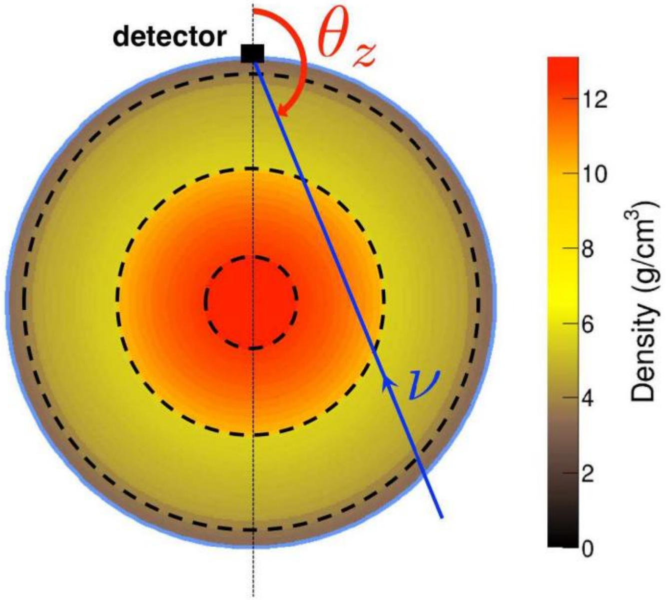
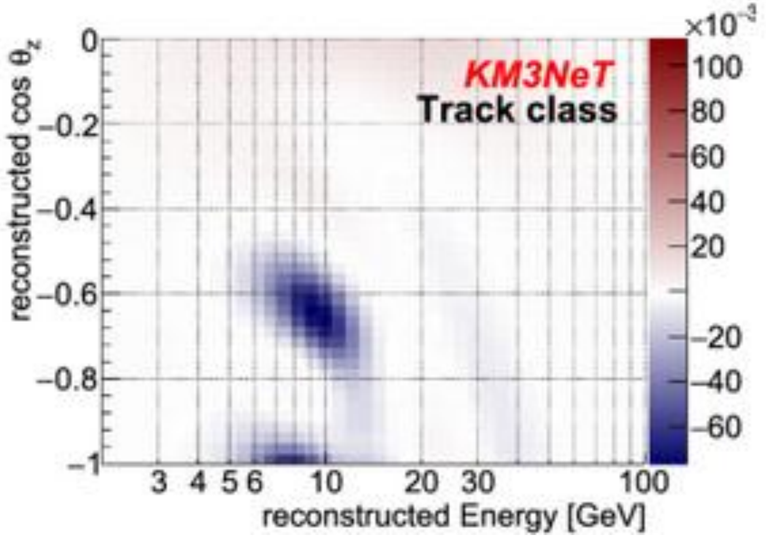
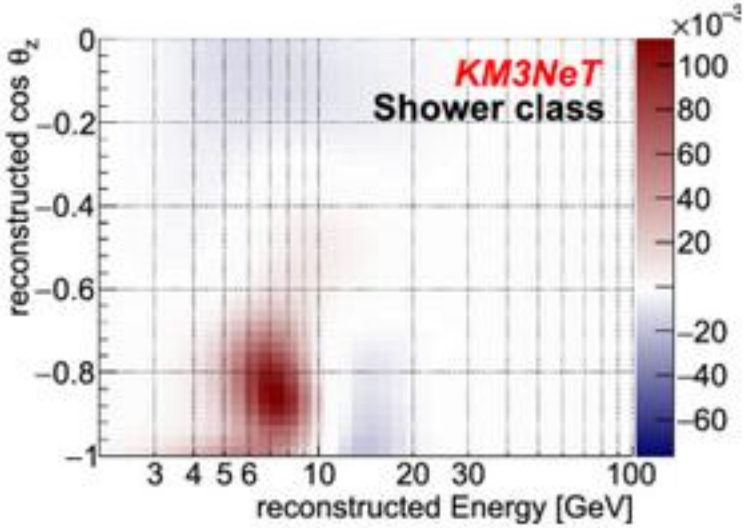
- KM3NeT: no event-by-event $\nu/\overline{\nu}$ separation, but event rates affected by differences in flux/kinematics/cross-section





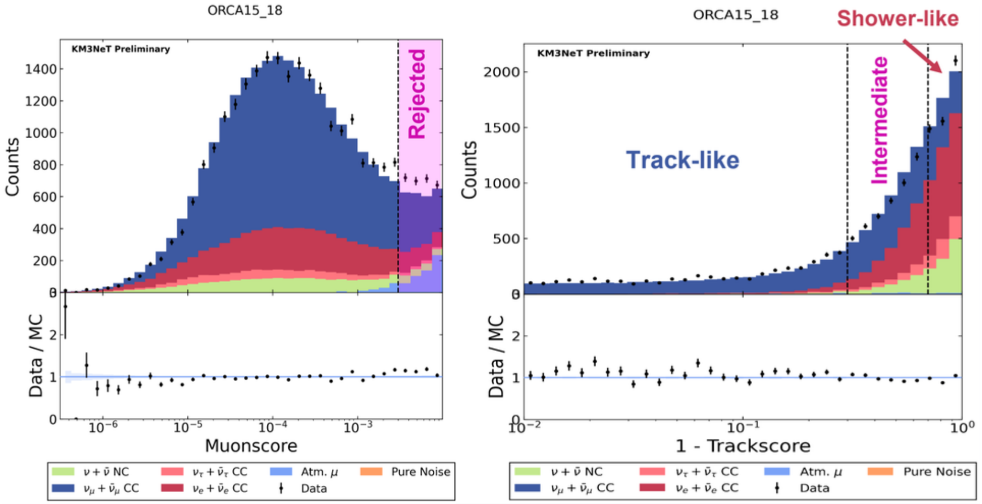


Impact specific regions in θ(L) and E

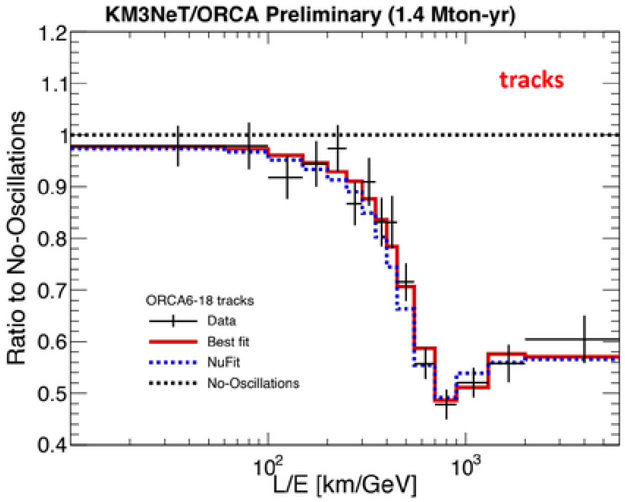
Neutrino oscillations with KM3NeT/ORCA6-18

2 BDTs:

- Rejecting atmospheric muons
- Distinguish event topology



ORCA6-18: Clear oscillation pattern



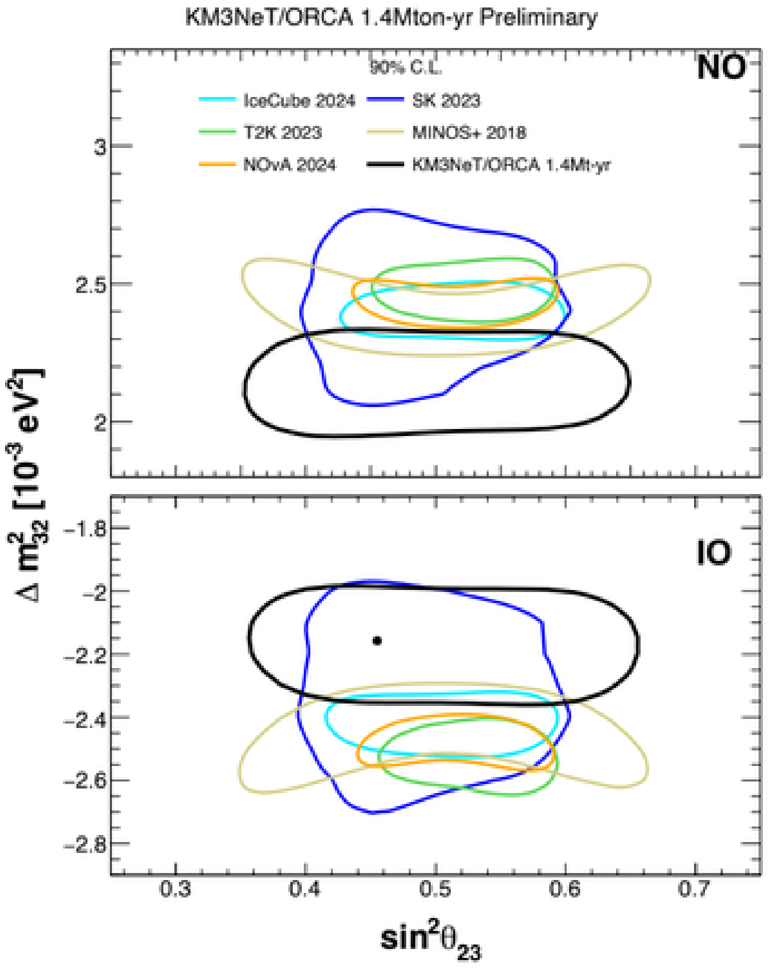
best-fit values:

$$\Delta m^2_{31} = \begin{cases} -2.08^{+0.08}_{-0.09} \times 10^{-3}\mathrm{eV}^2, & \mathrm{IO} \\ [2.12,\ 2.28] \times 10^{-3}\mathrm{eV}^2, & \mathrm{NO} \end{cases}$$

$$\sin^2\theta_{23} = 0.45^{+0.16}_{-0.05}$$

$$2\log(\mathcal{L}_{NO}/\mathcal{L}_{IO}) = -0.18$$

Slight preference for Inverted Ordering



Neutrino oscillations with KM3NeT/ORCA6-18

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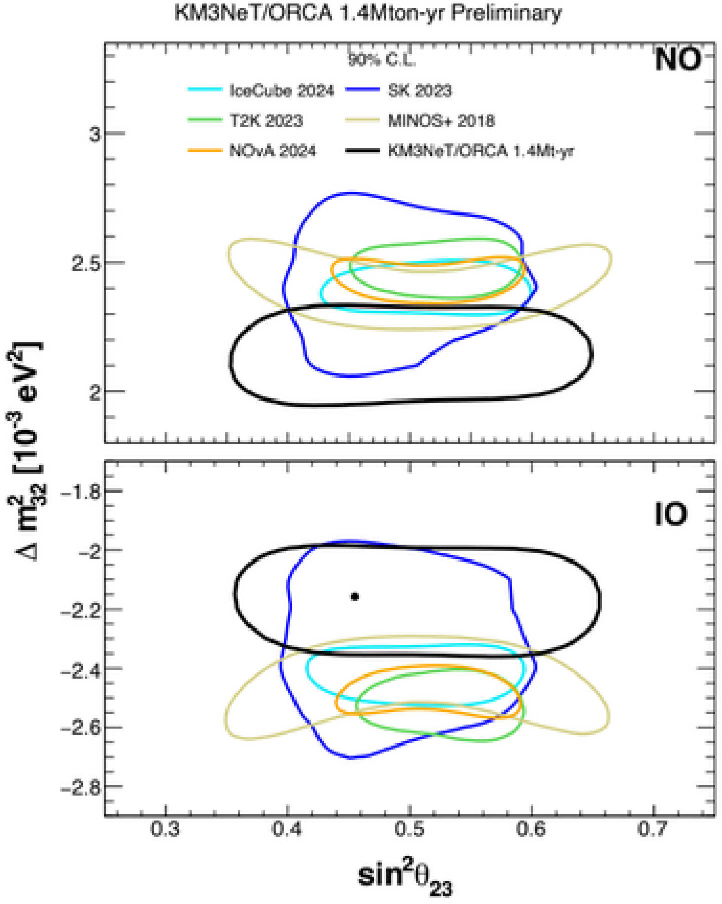
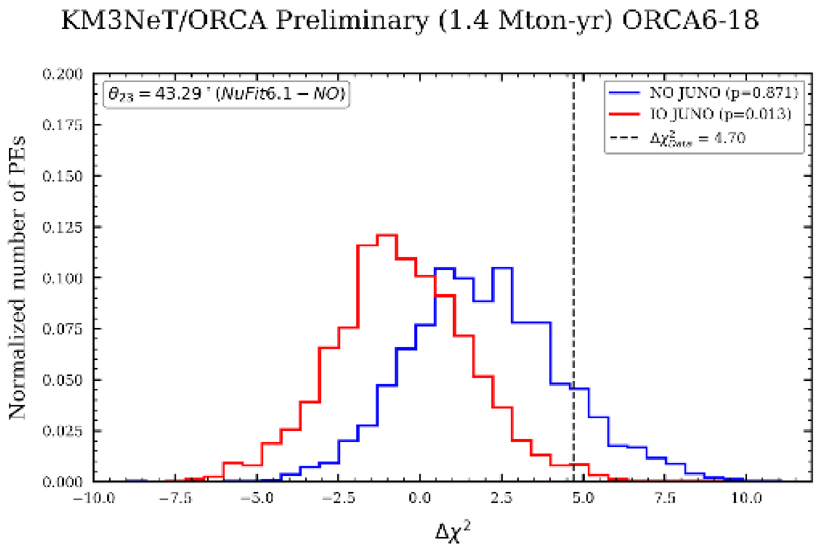


Adding DayaBay + JUNO constraint

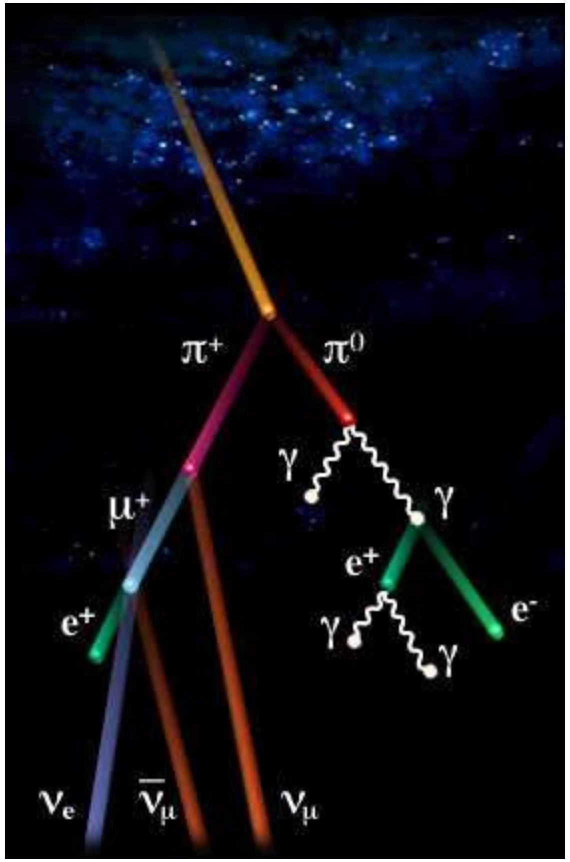
- Tight constraint from JUNO & DayaBay on the absolute value of the atmospheric mass splitting Δm^2_{31}
- Can be used as external constrain



IO rejected with 2.5 σ

Cosmic Ray studies

➢ <u>Atmospheric muons and neutrinos:</u>
Products of hadronic interactions of (charged) cosmic rays in the upper atmosphere of the Earth



- Background for neutrino astronomy
- Calibration
- Cosmic ray physics
    - composition of cosmic rays
    - composition of air showers
    - muon deficit puzzle: simulations of cosmic-ray-induced air showers, which include state-of-the-art hadronic interaction models, underestimate the number of muons detected on Earth

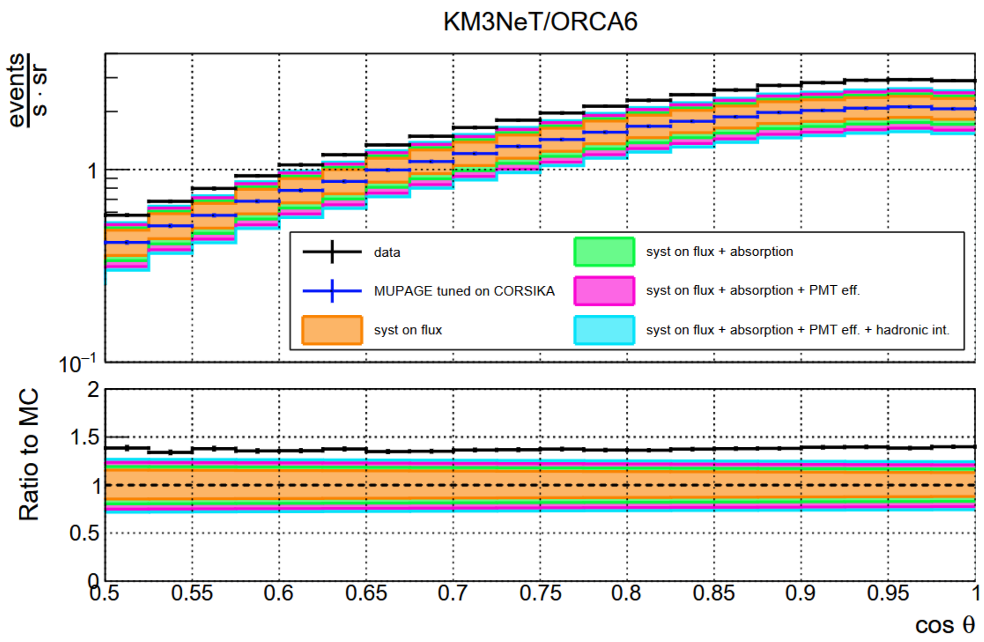
Cosmic Ray studies

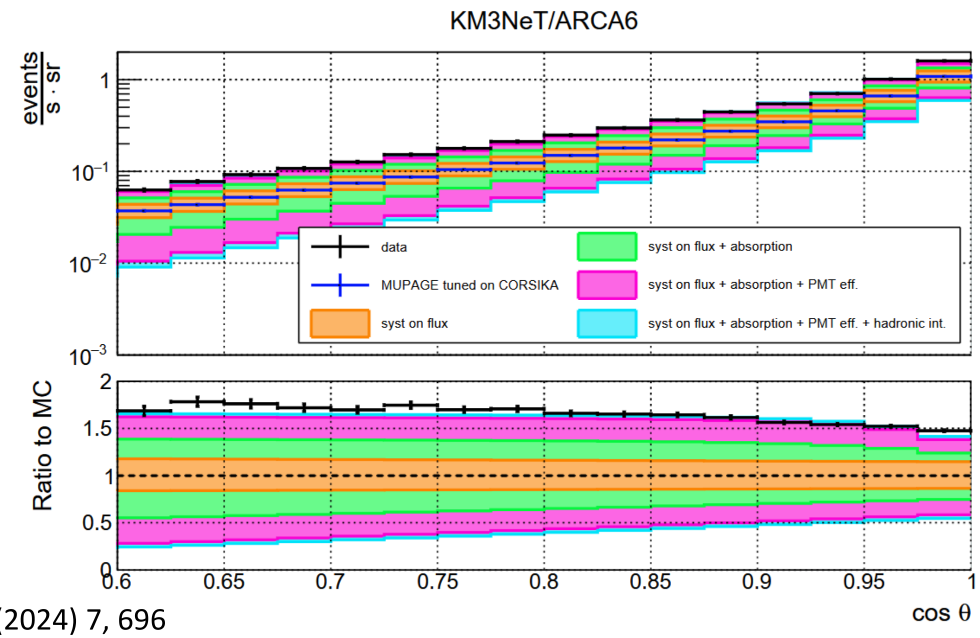
DEMOKRITOS

KM3NeT

➢ Atmospheric muons

Atmospheric muon event rate: different zenith angles correspond to different slant depths travelled (different path lengths in the atmosphere imply different energy thresholds)





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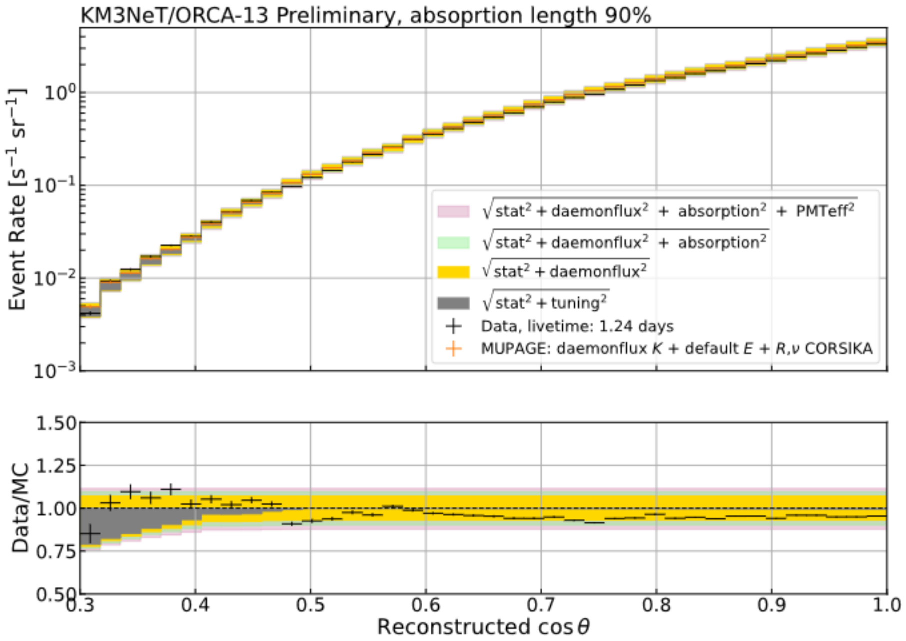
❖ Atmospheric muon bundles weighted to detailed cosmic ray air shower simulation (CORSIKA) with GSF to describe the primary cosmic ray flux and mass composition + Sibyll 2.3d for the high-energy HIMs

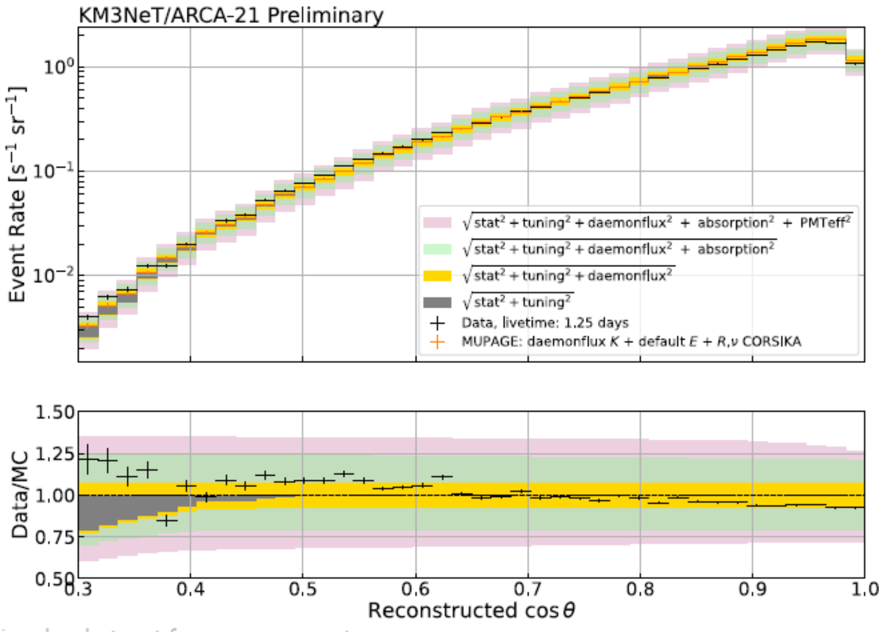
❖ 40–50% excess of data

➢ Atmospheric muons

Atmospheric muon event rate: different zenith angles correspond to different slant depths travelled (different energy thresholds for muons at sea level).

B. Ó Fearraigh et.al. PoS ICRC2025
V. Ellajosyula et al. TeVPa 2025

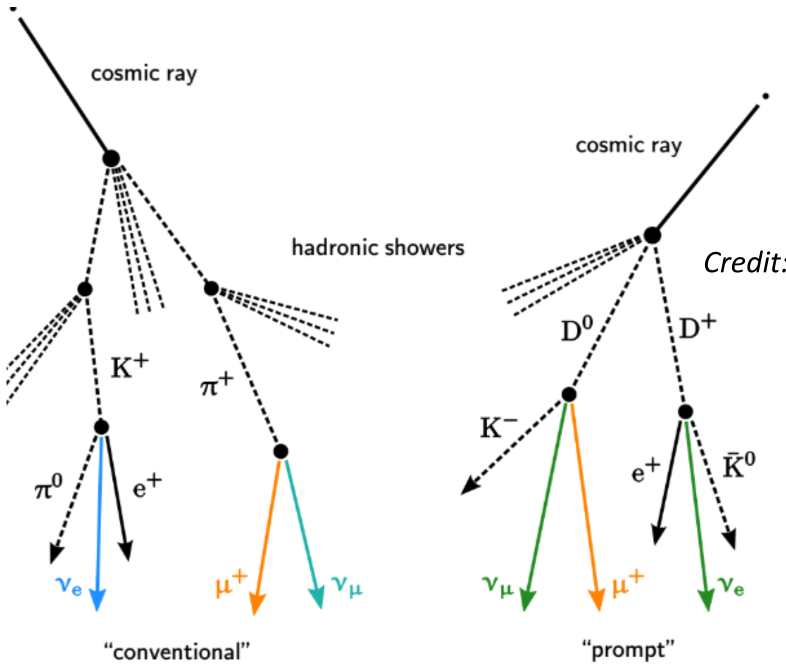




- Flux parametrization in atmospheric muon bundle generator tuned to Daemonflux weighted CORSIKA
- Daemonflux: GSF for primary cosmic ray flux and mass composition + data driven model (DDM) as HIMs
- Better agreement with the data

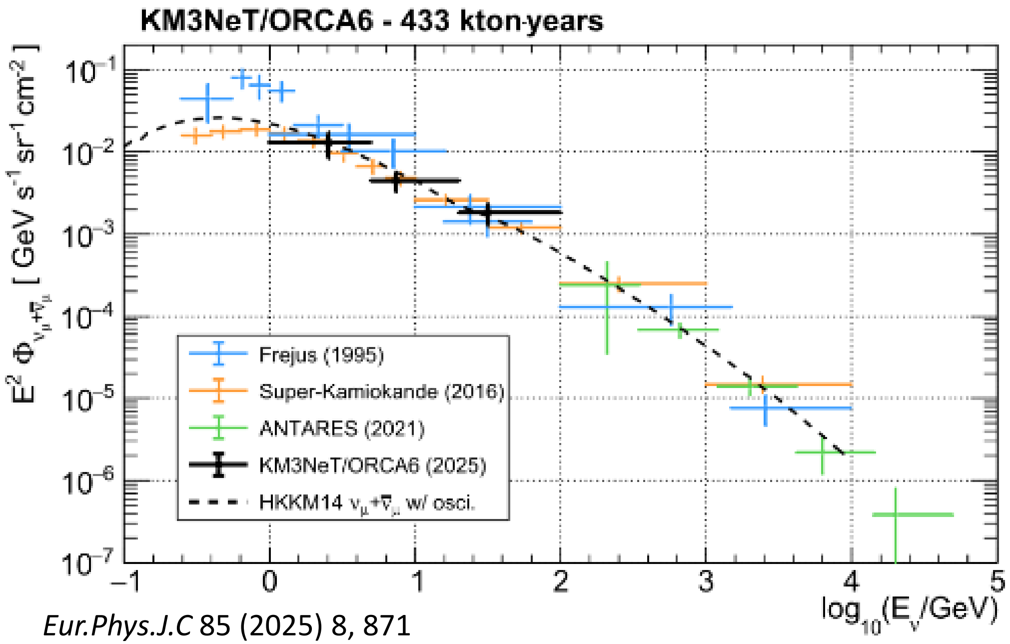
Cosmic Ray studies

➢ Atmospheric neutrinos



Credit: A. Franckowiak

Measurement of the atmospheric muon neutrino flux with ORCA6



Eur.Phys.J.C 85 (2025) 8, 871

Measurement of the atmospheric neutrino flux

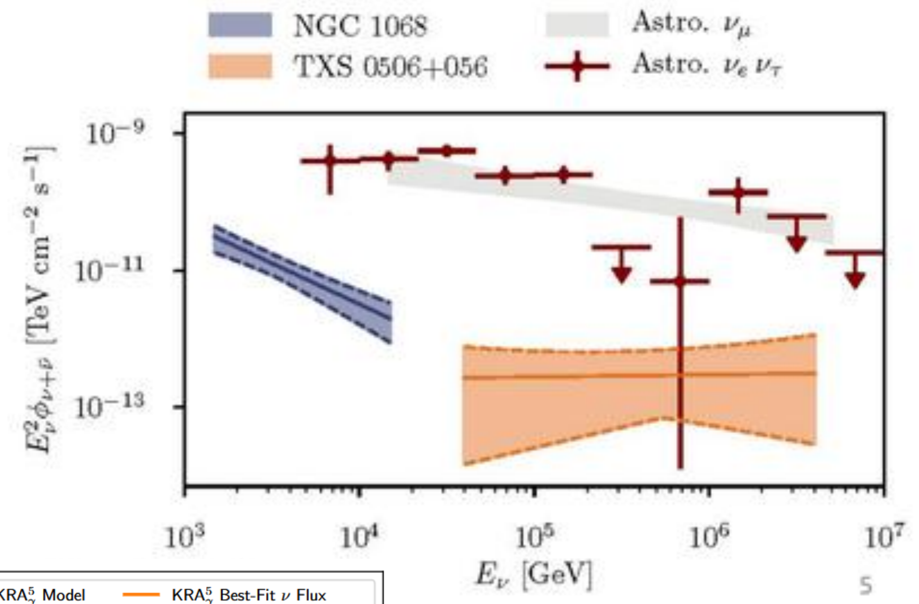
- Conventional (kaons & pions) – mainly muon neutrinos → results for ORCA / work in progress for ARCA
- Prompt (charm) – becomes important at high E_ν - produced by the decay of short-lived charm mesons - direct probes of the energy and composition of UHE cosmic rays → challenging: calculations of charm production need PDFs at very low Bjorken-x & need high statistics at HE

Astrophysical neutrinos

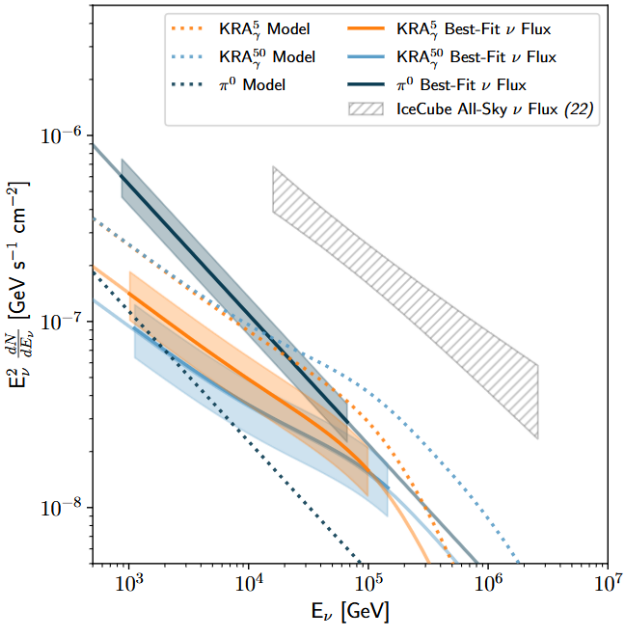
- Neutrinos from source candidates
  - check EM source catalog
  - look for hotspots in the neutrino sky
- Neutrinos from the Galactic plane
- Diffuse flux → summed neutrino emission from unresolved cosmological sources

Astrophysical neutrinos

- In their respective energy ranges the sources NGC 1068 and TXS 0506+056 contribute no more than 1% to the overall diffuse flux of astrophysical neutrinos.



- Galactic neutrinos contribute ~6-13% to the diffuse astrophysical flux (at 30 TeV)



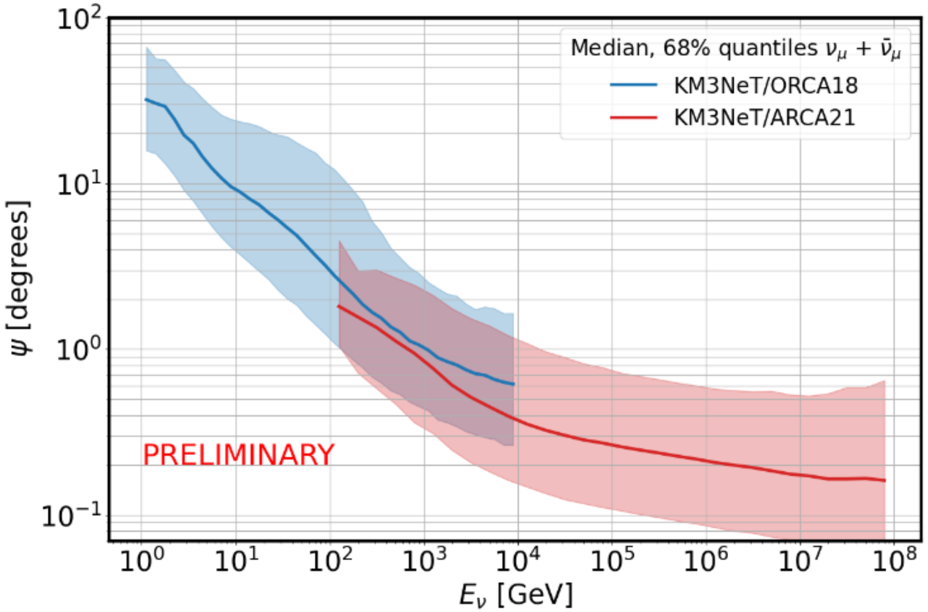
Astrophysical neutrinos: point sources

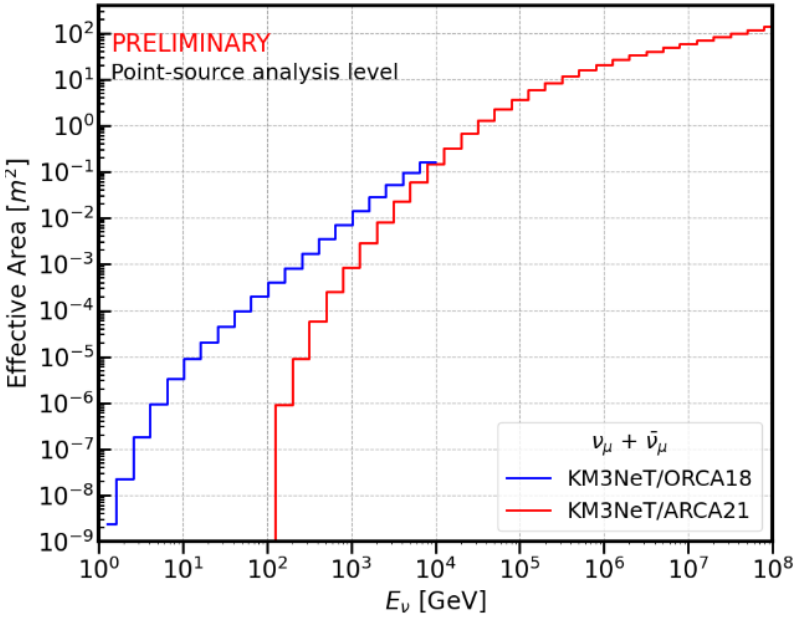
- Select upgoing and horizontal events (zenith > 80°) to suppress the atmospheric muon background
- Reconstructed tracks: apply cuts to ensure reliable reconstruction ⟶ mostly ν_μ CC events
- Machine learning techniques (Boosted Decision Trees) for the final event selection

Point sources search selection:
accurate direction reconstruction is vital

ORCA:
enhances the effective area at low energies

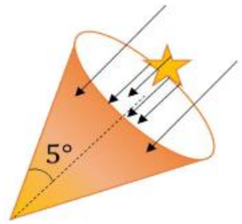
angular resolution





Astrophysical neutrinos: point sources

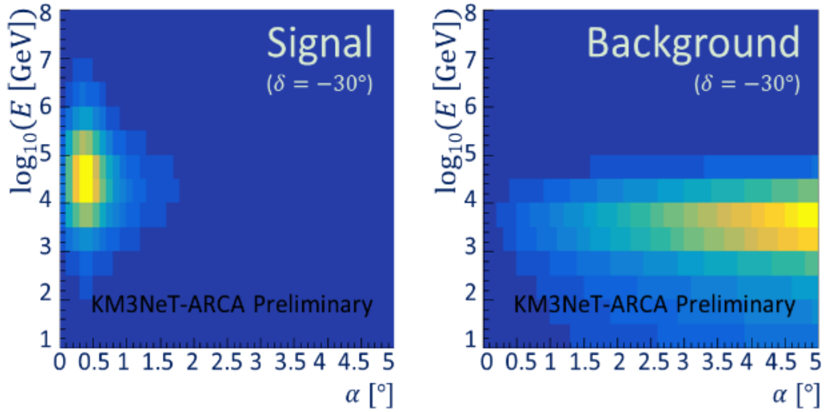
Angular search region: a cone centered at the source position with extension α



Binned log-likelihood search: PDFs of expected signal and background from 2D histograms of $\log_{10} E_{reco}$ vs semi-aperture angular region around each source α in [0°, 5°]

Likelihood function: $\log_{10} L = \sum_{bins} [N_i \log(B_i + \xi S_i) - (B_i + \xi S_i)]$

- N_i : number of data events in bin i
- S_i : signal PDF extracted from MC
- B_i : background PDF from scrambled data
- ξ : signal strength



Pseudo-experiments varying ξ: $\lambda = \log_{10} L\ (\xi = \hat{\xi}) - \log_{10} L\ (\xi = 0)$

106 sources tested for different spectral index hypotheses: $\Phi_\nu \propto E^{-\gamma}$ for γ = 2.0, 2.5 and 3.2 (for NGC 1068 only)

Sources in the range $-90° < \delta < 40°$ where the KM3NeT visibility for upgoing and horizontal events is >35%

Binned likelihood formalism

Testing two hypotheses:

the null hypothesis $H_0 = H_{background}$ and the alternative hypothesis $H_1 = H_{signal + background}$

signal strength

$$\log \mathcal{L}(\xi) = \sum_{i \in \text{bins}} [N_i \log(\overbrace{B_i + \xi S_i}^{\text{Expected number of events}}) - B_i - \xi S_i]$$

Number of observed events

expected background

Expected signal

Test statistic (*TS*) $\lambda = \log \mathcal{L}(\xi = \hat{\xi}) - \log \mathcal{L}(\xi = 0)$

$\hat{\xi}$ value of ξ that maximizes the likelihood for a given dataset and signal/background model

background only hypothesis

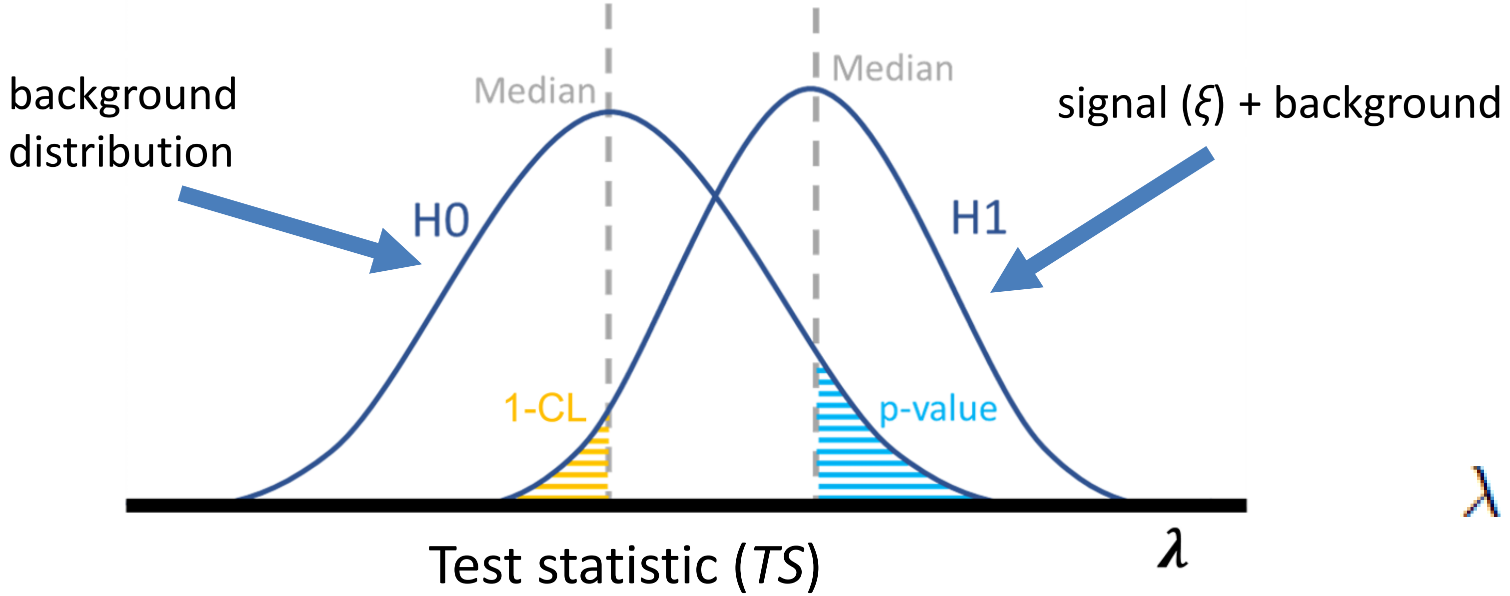
Sensitivity and Discovery potential

Testing two hypotheses:

the null hypothesis $H_0 = H_{background}$ and the alternative hypothesis $H_1 = H_{\text{signal + background}}$

Pseudo-experiments (PEs)

randomly draw N_i events in each bin from a Poisson distribution with mean B_i and $B_i + \xi_{true} S_i$

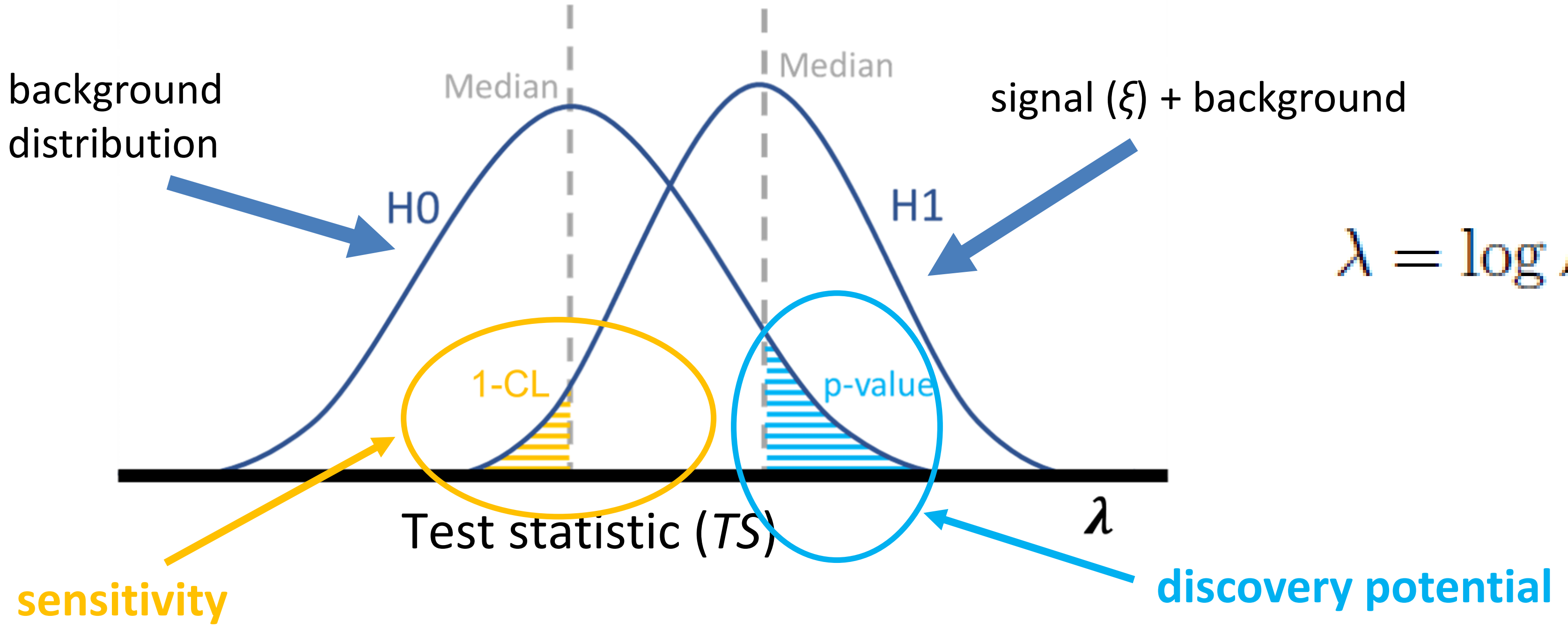


$$\lambda = \log \mathcal{L}(\xi = \hat{\xi}) - \log \mathcal{L}(\xi = 0)$$

Sensitivity and Discovery potential

Testing two hypotheses:

the null hypothesis $H_0 = H_{background}$ and the alternative hypothesis $H_1 = H_{signal + background}$



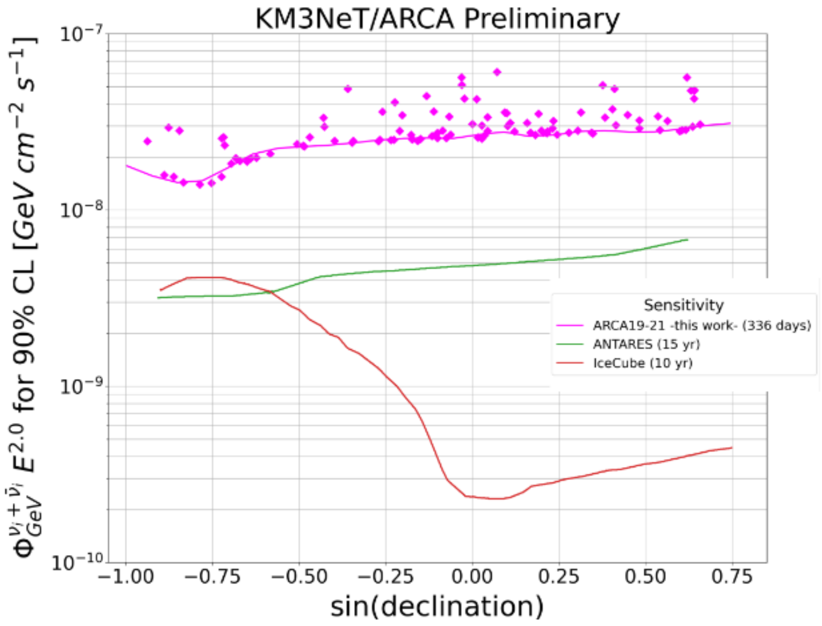
$$\lambda = \log \mathcal{L}(\xi = \hat{\xi}) - \log \mathcal{L}(\xi = 0)$$

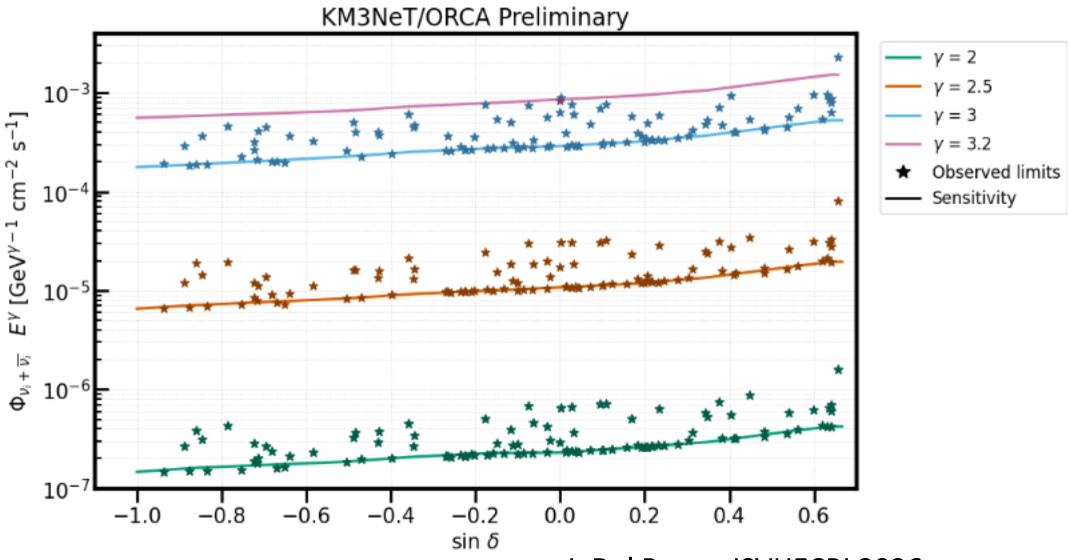
signal strength (neutrino flux) for which TS higher than the median for background-only in 90% of the cases

P-value: integrating background-only TS from the median of a signal TS until infinity.
flux normalisation for which a 3σ or 5σ discovery could be claimed in 50% of the PEs

Astrophysical neutrinos: point sources

- For all candidate sources data are consistent with the background-only hypothesis
- KM3NeT/ARCA: top 3 candidates consistent for E^{-2} , $E^{-2.5}$ spectra (CGCG 420-015, Mkn 421, J0339-0146)
- KM3NeT/ORCA: top candidates shift with spectral index - for $E^{-2.5}$, E^{-3} spectra top candidate is the unknown source LHAASO J1848-0001u

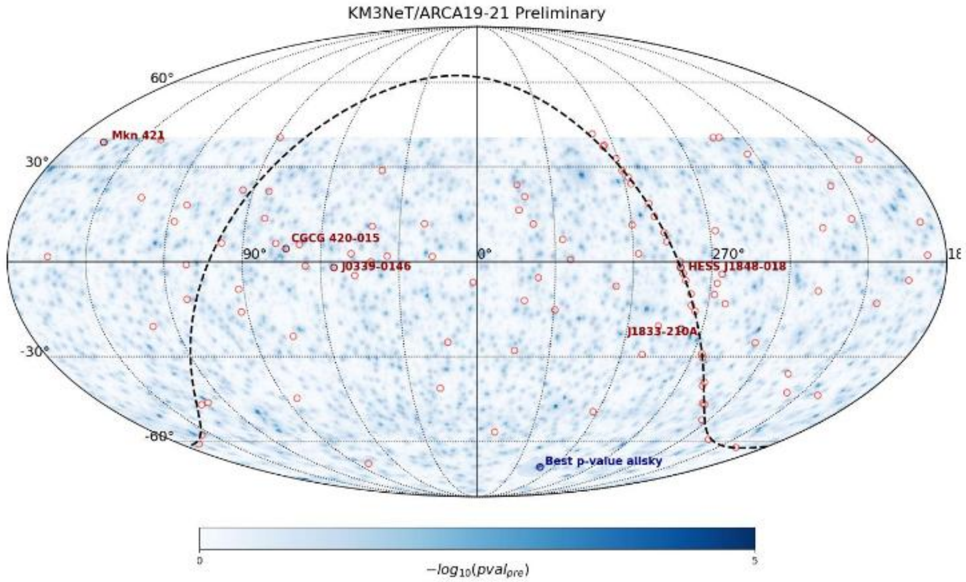


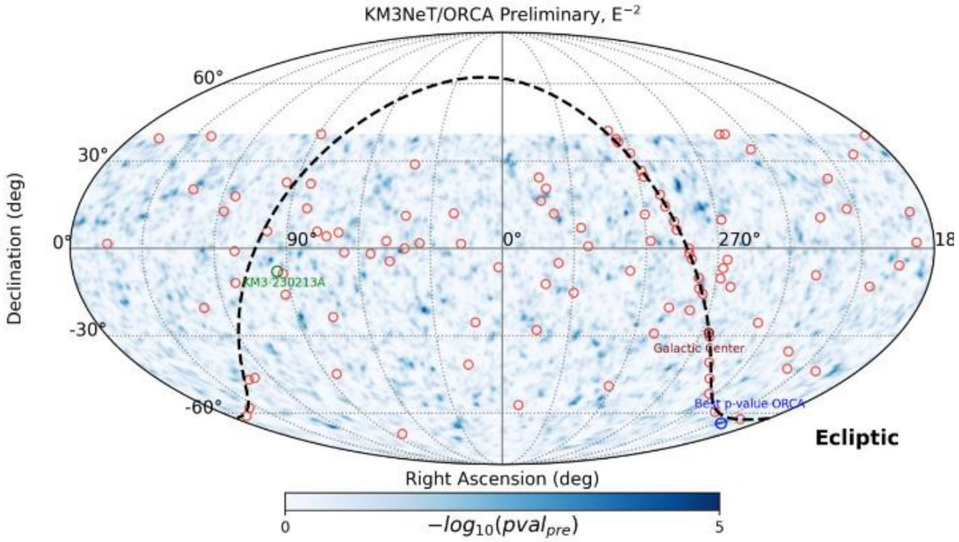


I. Del Rosso, ISVHECRI 2026

Astrophysical neutrinos: point sources – all sky scan

- Search for an excess over uniform background: 2.6 million bins; $\delta < 40°$
- Binned log-likelihood search – 2D histograms in reconstructed energy and direction
- Data-driven background
- Sky map: candidate sources indicated by red circles - hotspots do not coincide with any of our pre-selected candidate sources





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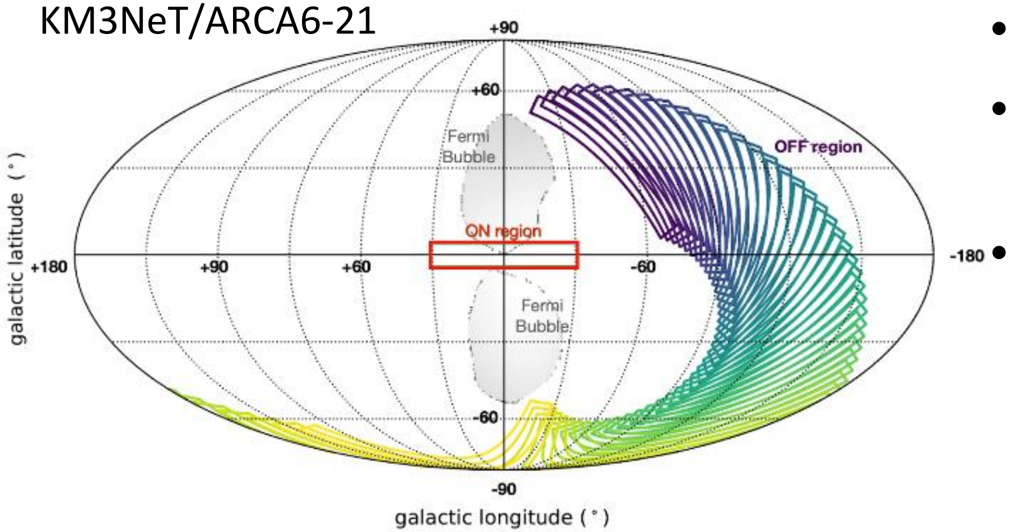
Diffuse flux of neutrinos from the Galactic Ridge

Galactic plane: most prominent source in the sky
Galactic Ridge: inner region of the Galactic plane defined by $|l| < 30°$ and $|b| < 2°$
(l: Galactic longitude; b: Galactic latitude)

- ANTARES found an excess of events incompatible with the background-only hypothesis at 96% C.L.
- IceCube reported the first observation of high energy neutrino emission from the Galactic plane at 4.5σ

KM3NeT/ARCA6-21



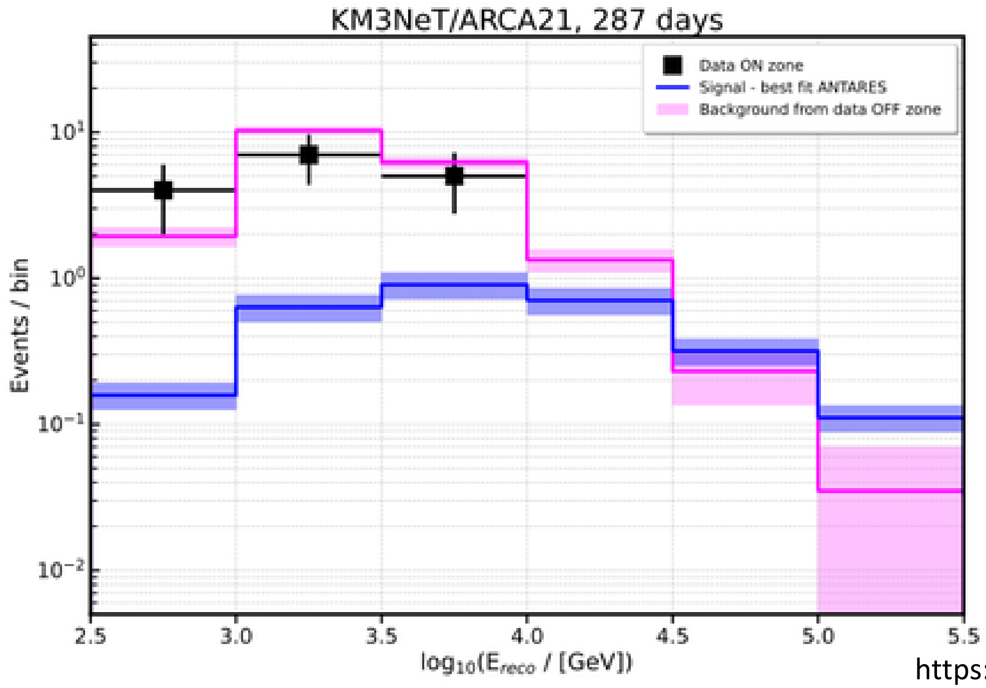
- Select upgoing tracks to reduce atmospheric muon background
- Loose selection and then BDT to further suppress mis-reconstructed atmospheric muons
- Model independent approach & data-driven background: event counts & energy distributions in pre-defined signal (ON) region & in signal-depleted (OFF) control region

OFF regions correspond to the ON region in sky coverage but shifted in right ascension

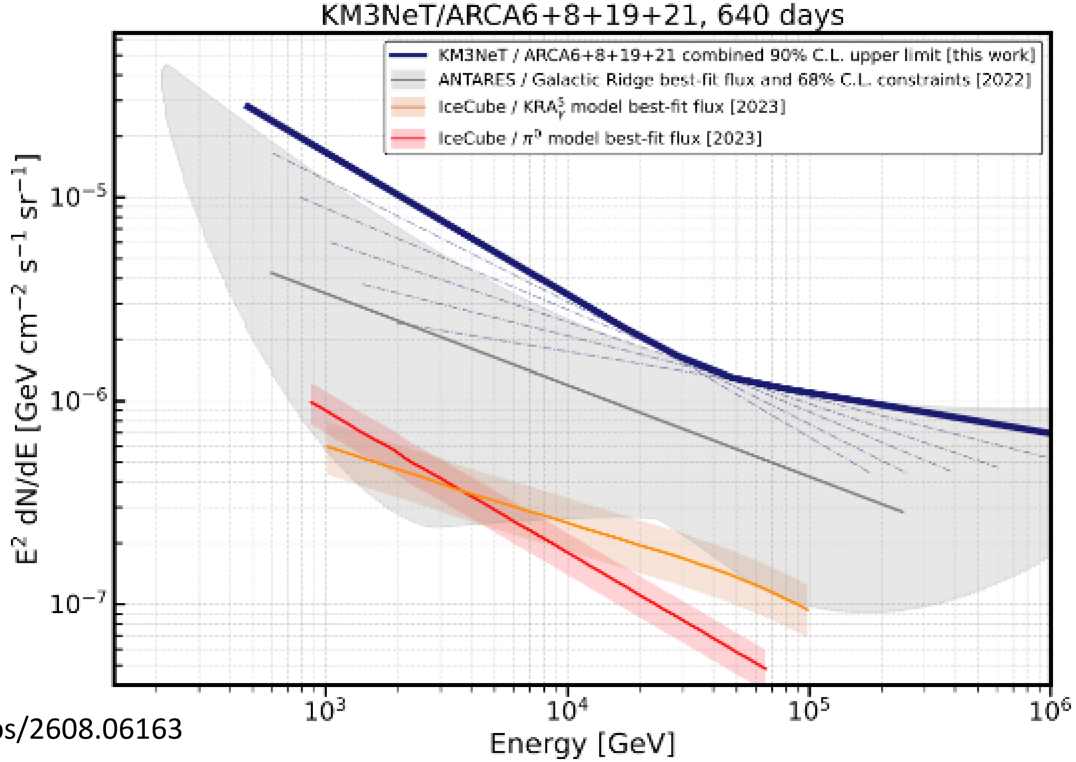
https://arxiv.org/abs/2608.06163

Diffuse flux of neutrinos from the Galactic Ridge

- Search for an excess at high energies in the ON region – no excess found so far ⟶ limits
- 90% C.L upper limits (U.L.) derived for spectral indices ν ∈ [2.2. 2.7]



https://arxiv.org/abs/2608.06163

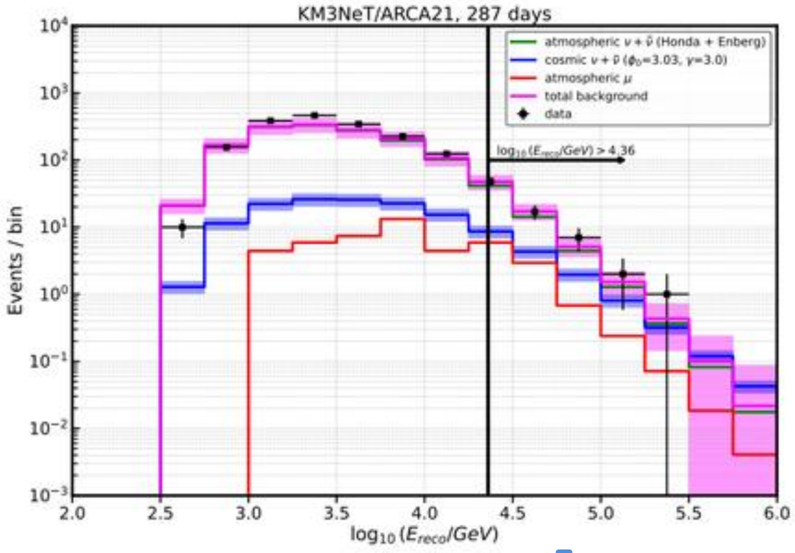


U.L. expresses the maximum value of the signal flux compatible with the number of observed events assuming no real signal is observed.

All sky diffuse astrophysical neutrino flux

All sky: cannot exploit source position to search for an excess of neutrinos in a specific direction – need a neutrino sample of high purity

- Select upgoing tracks (zenith > 90°) to reduce atmospheric muon background – ARCA 6-8-19-21 dataset used
- Loose selection and then BDT to further suppress mis-reconstructed atmospheric muons
- Selection and BDT inputs based on the reconstruction output
- Background estimation from MC simulation



https://arxiv.org/abs/2608.06163

Use the Model Rejection Factor (MRF) technique to find the optimal cut on the energy estimate

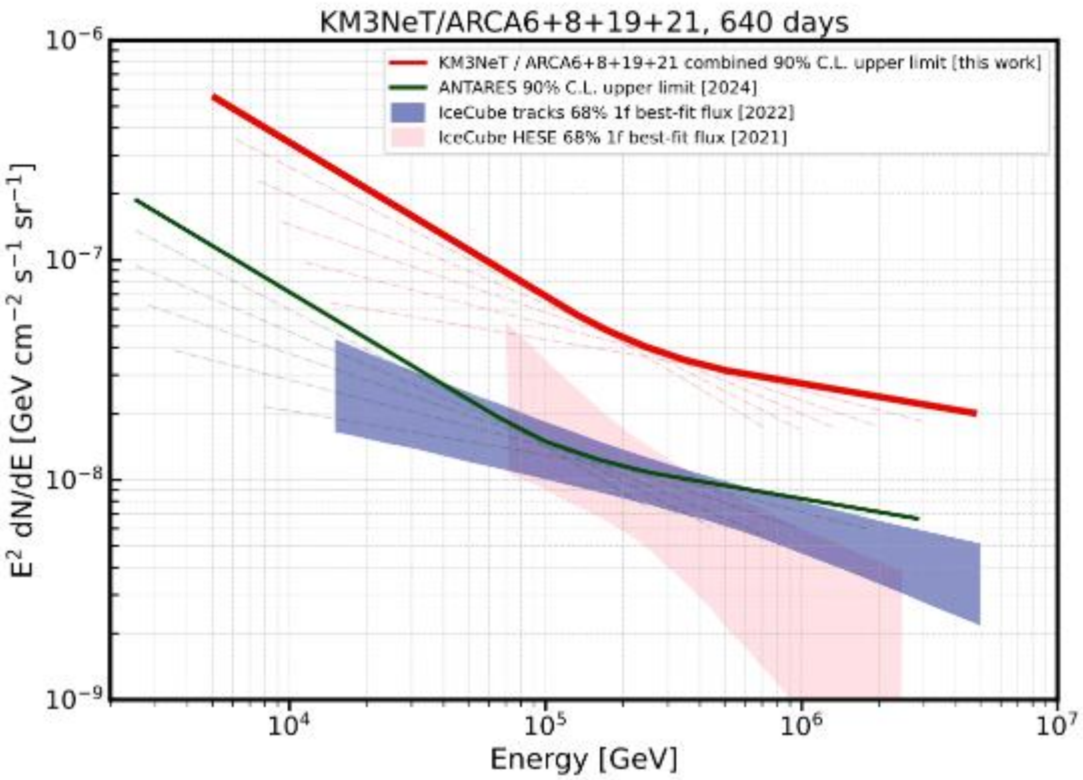
Talk by C. Karagiannis

Contribution of astrophysical neutrinos enhanced at high energies

All sky diffuse astrophysical neutrino flux

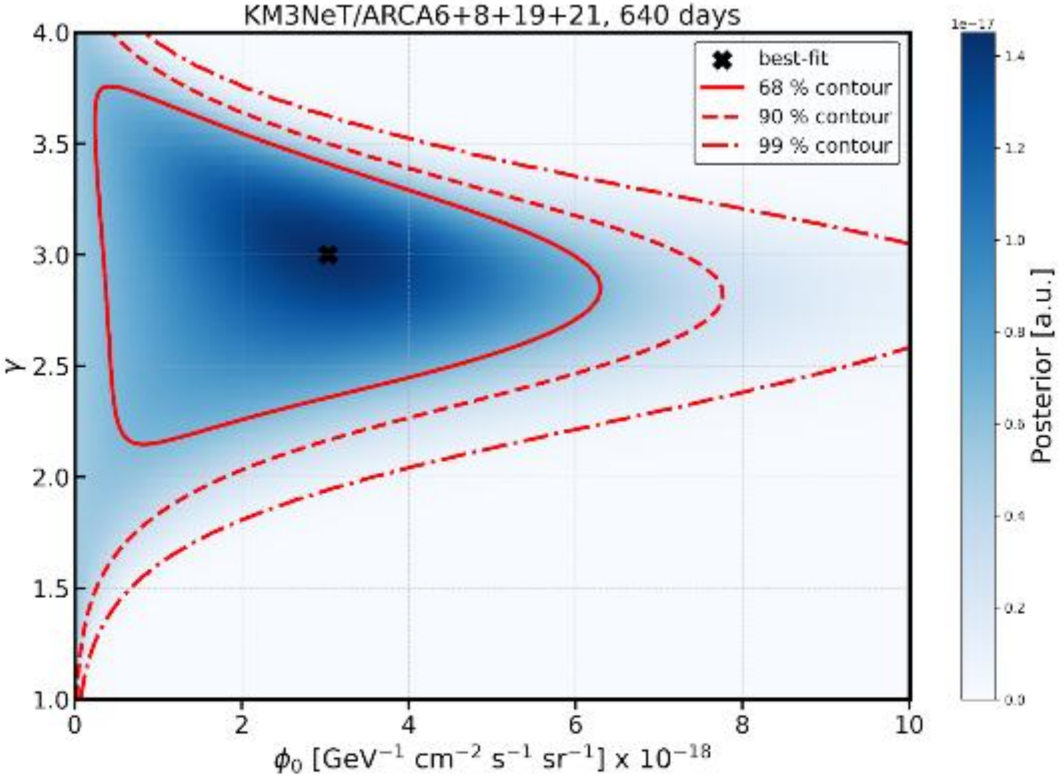
KM3NeT/ARCA6-21 detector sensitivity

- Assume single-power-law spectrum for the cosmic flux
- 90% upper limits for selected spectral indices



https://arxiv.org/abs/2608.06163

Astrophysical flux parameters estimation with KM3NeT/ARCA6-21 data (Bayesian framework)



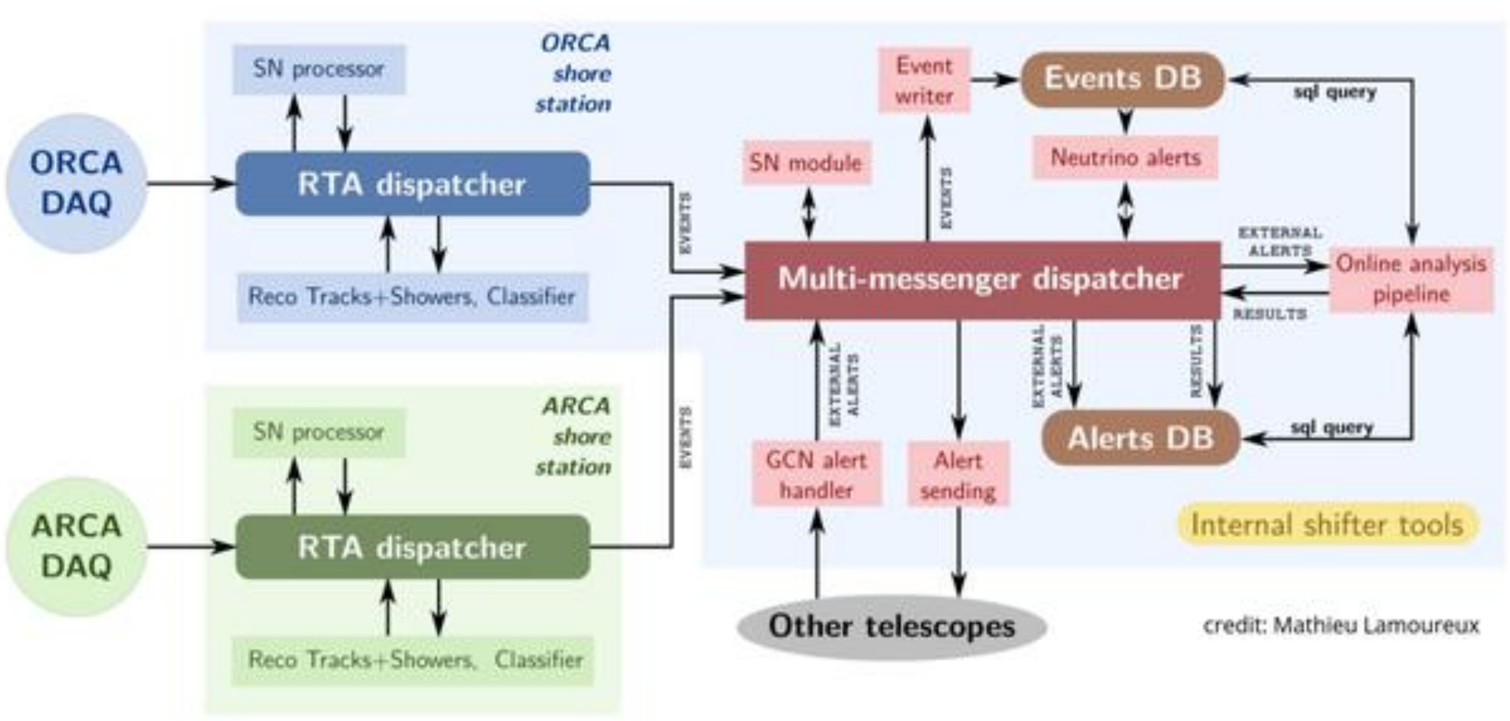
$\phi_0 = 3.0^{+2.1}_{-2.0} \times 10^{-18}\ \mathrm{GeV^{-1}\ cm^{-2}\ s^{-1}\ sr^{-1}}$ $\qquad \gamma = 3.00^{+0.30}_{-0.35}$

Real-time analysis system

Multi-messenger astronomy – simultaneous observation of different cosmic messengers

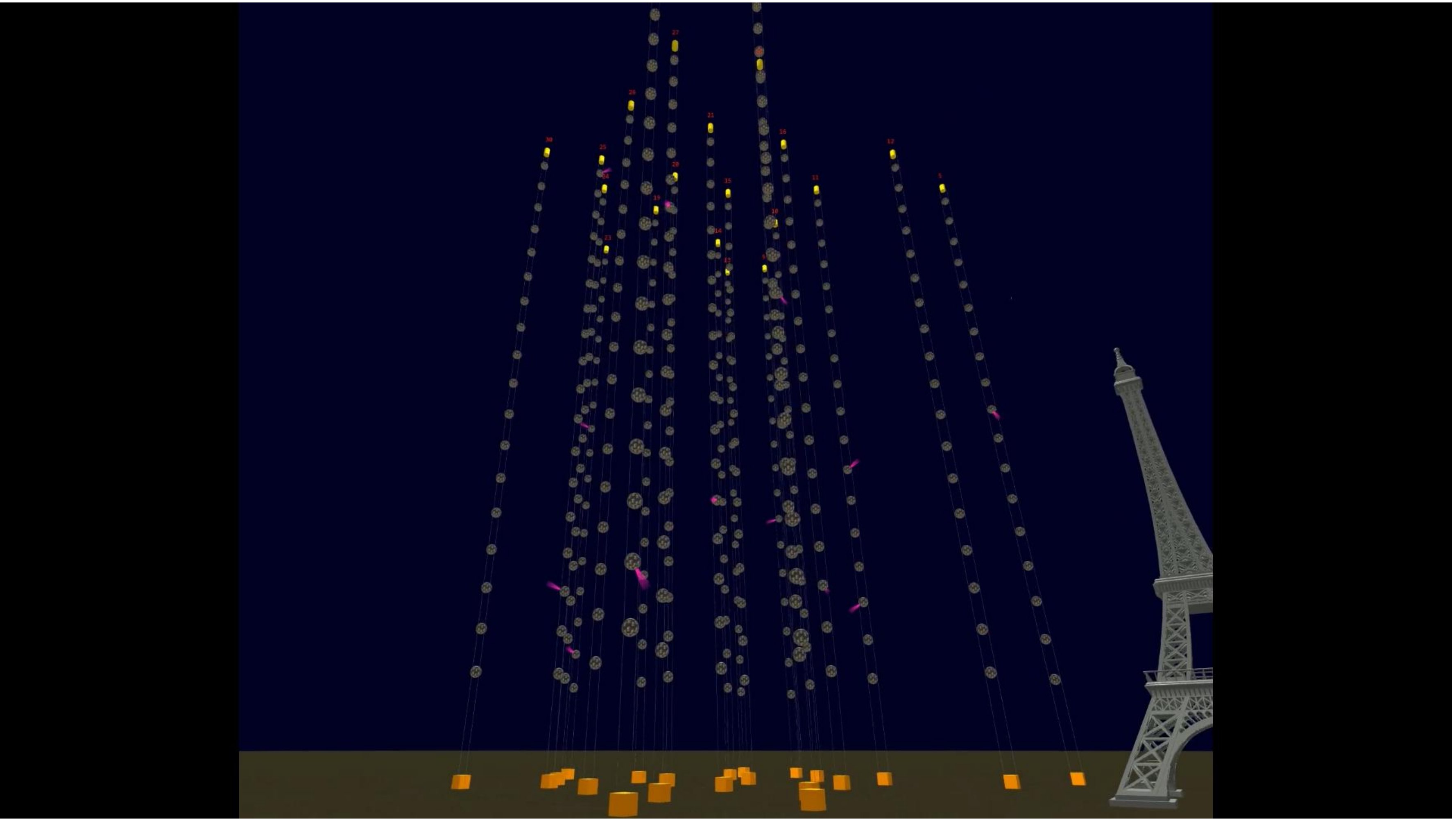
Real-Time Analysis (RTA) system:

- detection of SN neutrinos (MeV)
- Selection of GeV-PeV neutrinos - reconstruction and classification
  - Follow-up of external alerts
  - Neutrino alert sending



KM3NeT alert sending system currently under commissioning

KM3NeT/ARCA: observation of an ultra-high energy neutrino



3672 triggered PMTs!
~35% of ARCA21 illuminated

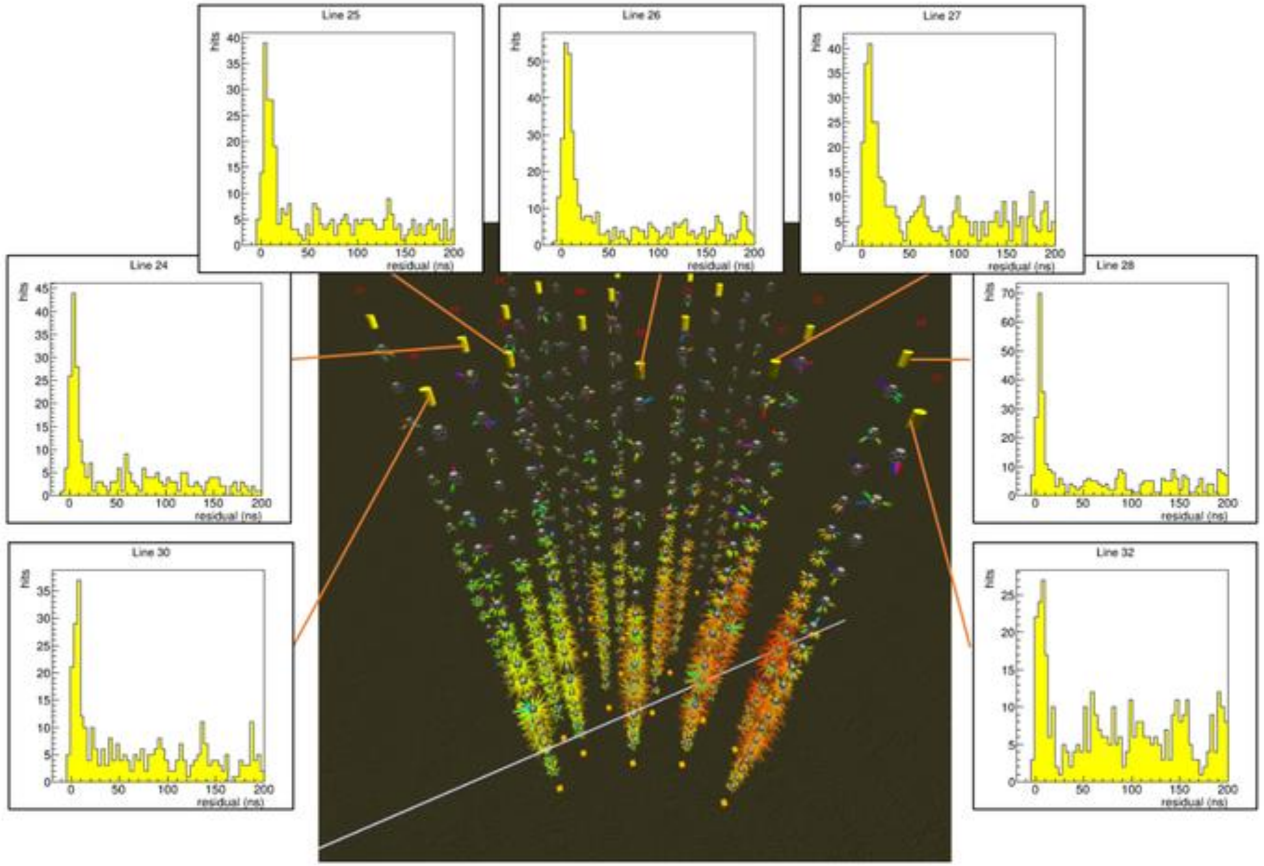
- colour-coded based on detection time relative to the first triggered hit.
- length of each cone corresponds to the number of photons detected by the respective PMT.

KM3-230213A: ~30 times higher energy compared to the highest energy neutrino from IceCube

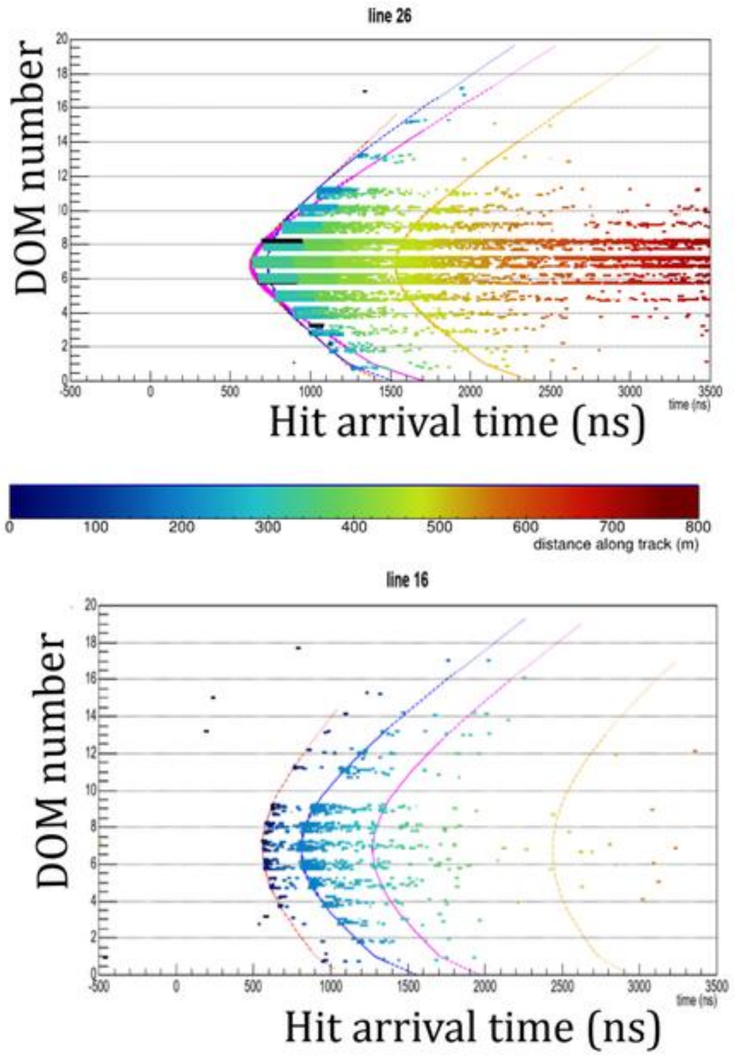
KM3-230213A

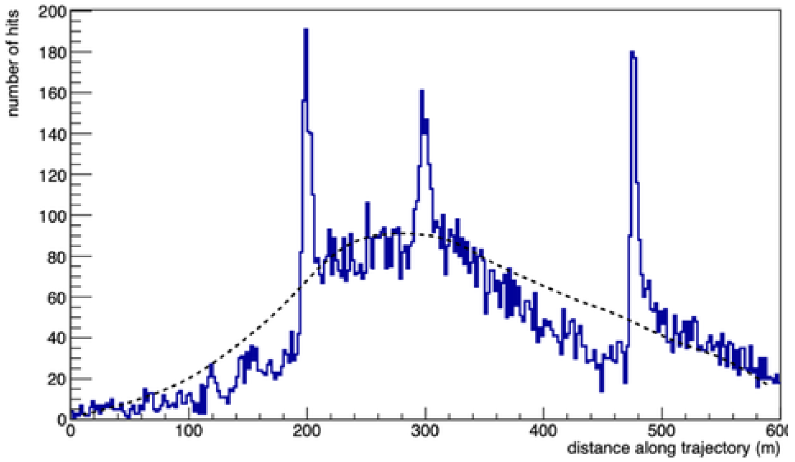
- well reconstructed track: “bright” track selection (length > 250 m, NtrigPMT > 1500, logL > 500)
- time residuals consistent with Cherenkov light emission

Difference between time of arrival of the detected photons and the expected time from Cherenkov radiation by a relativistic muon



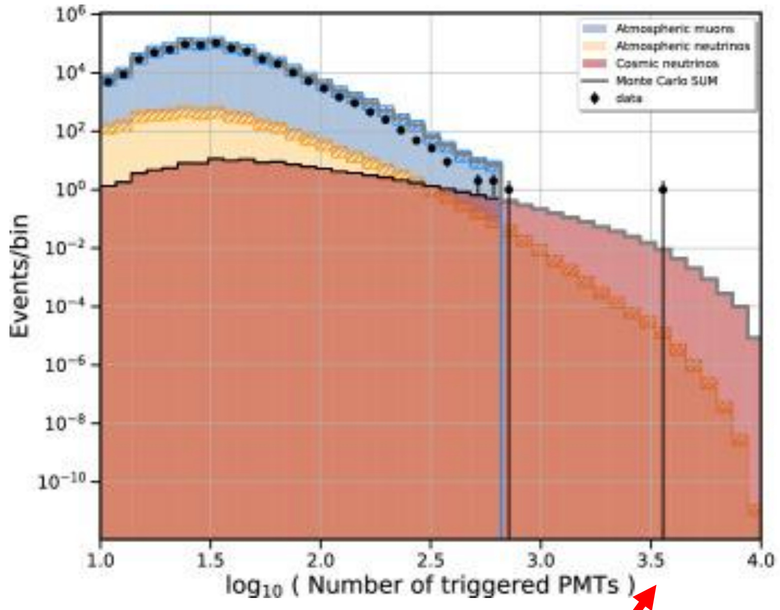
KM3-230213A





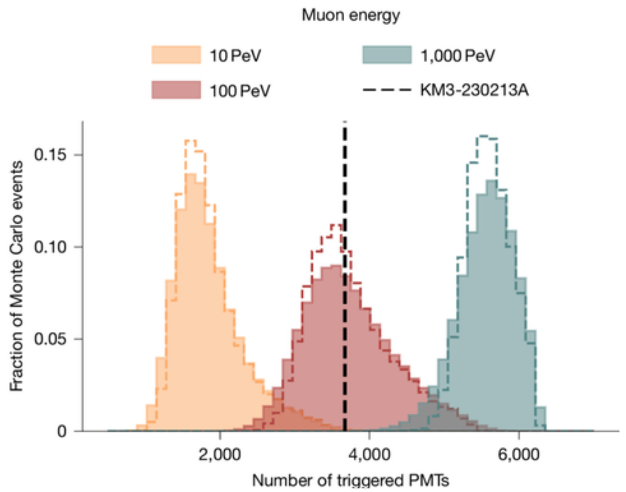
- Hit times fully consistent with Cherenkov photons
- Well reconstructed muon track
- Three showers detected – light profile as expected from stochastic losses from very high energy muons

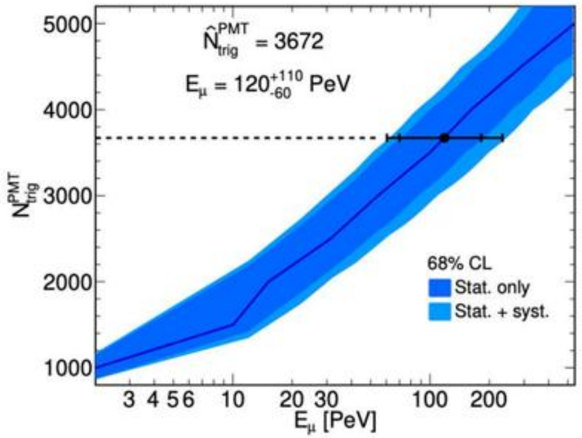
- 0.6° above the horizon – not included in the diffuse flux sample
- celestial coordinates: (RA, dec) = (94.3°, −7.8°)
- reconstructed track: "bright" track selection (length > 250 m, NtrigPMT > 1500, logL > 500)



KM3-230213A

Nature 638 (2025) 8050



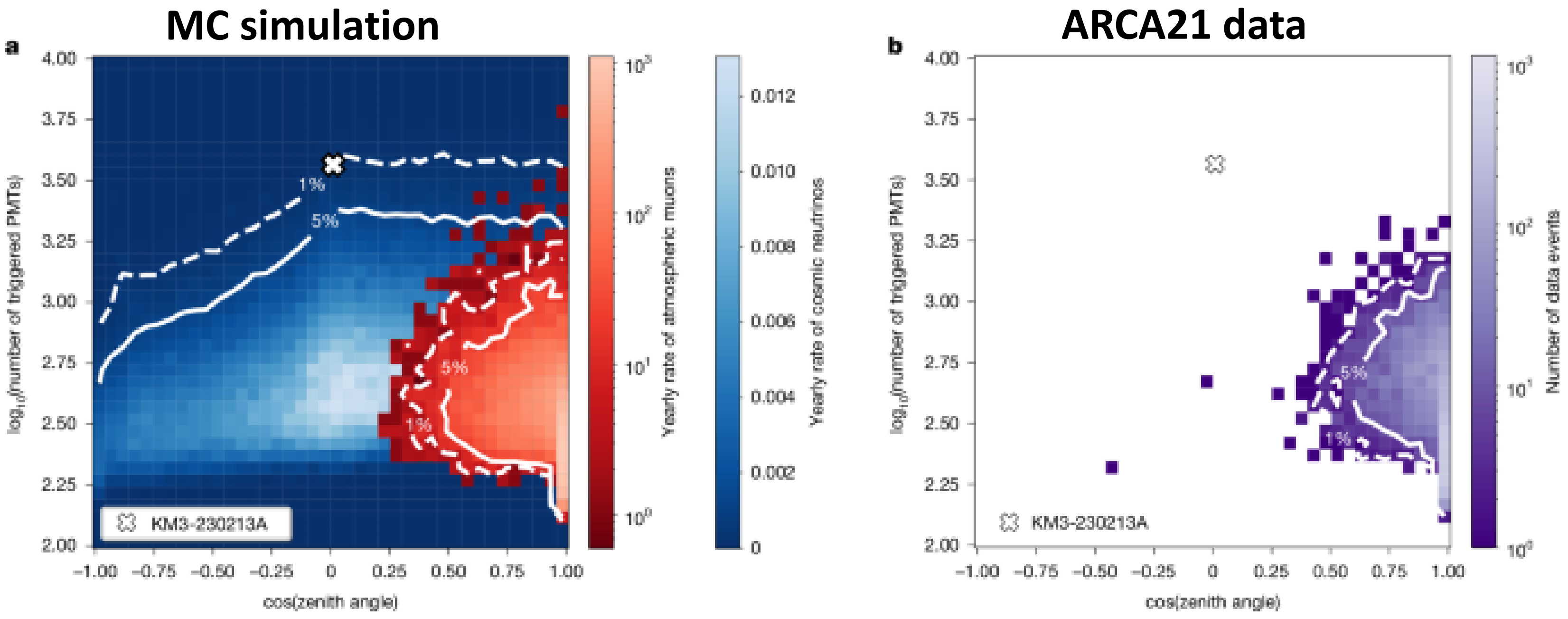


High-quality reconstructed horizontal muon with energy: $E_\mu = 120^{+110}_{-60}$ PeV

Simulated muons traversing the detector in the same location and direction

corresponding neutrino energy: $E_\nu = 220^{+570}_{-100}$ PeV (E^{-2} spectrum)

KM3NeT/ARCA21: observation of an ultra-high energy neutrino



Nature 638 (2025) 8050

High-quality reconstructed horizontal muon with energy: $E_\mu = 120^{+110}_{-60}\ \mathrm{PeV}$

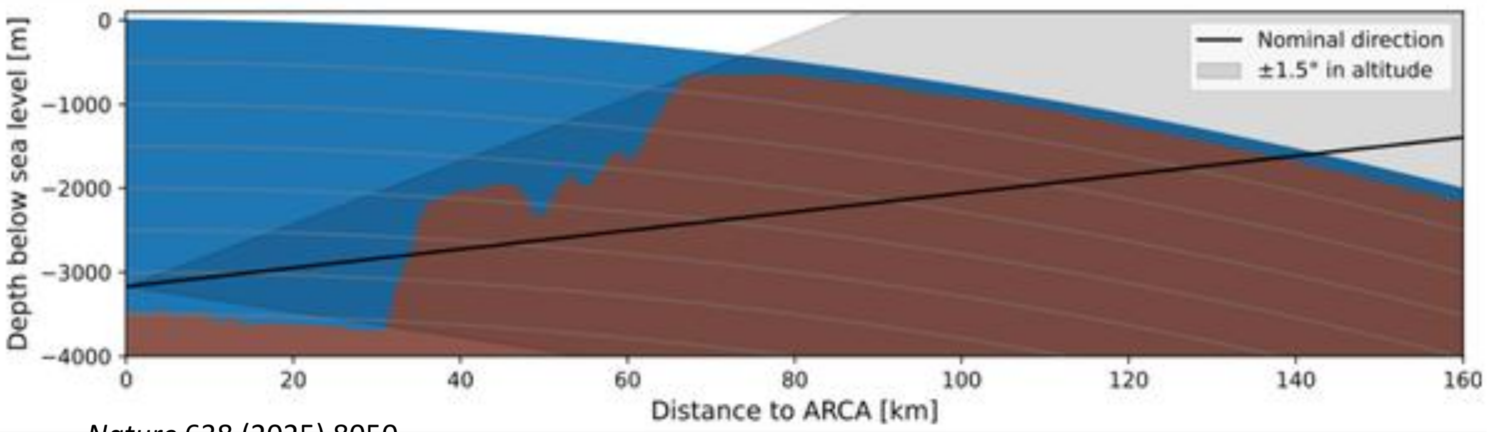
corresponding neutrino energy: $E_\nu = 220^{+570}_{-100}\ \mathrm{PeV}$ (E^{-2} spectrum)

Assuming reconstructed direction and energy:

- Expected atmospheric muon contribution @ 100 PeV: << 10^{-10} event/year (2σ of reconstructed direction)
- Atmospheric neutrinos with energy >100 PeV: << (1-5) x 10^{-5} event/year

KM3-230213A

- 0.6° above the horizon – could it be an atmospheric muon?

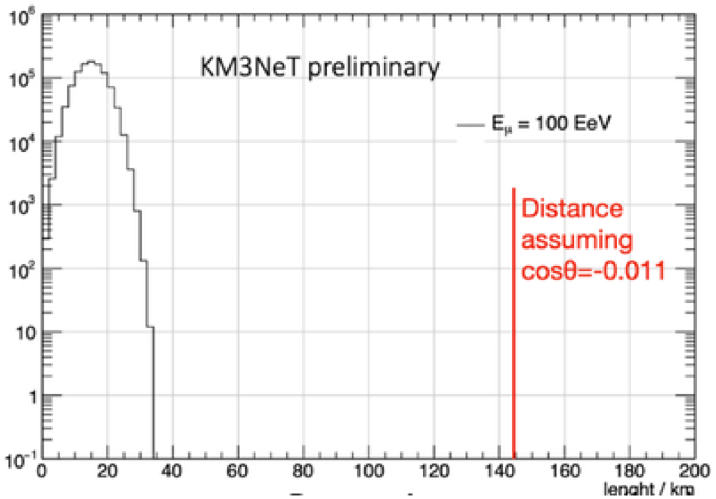


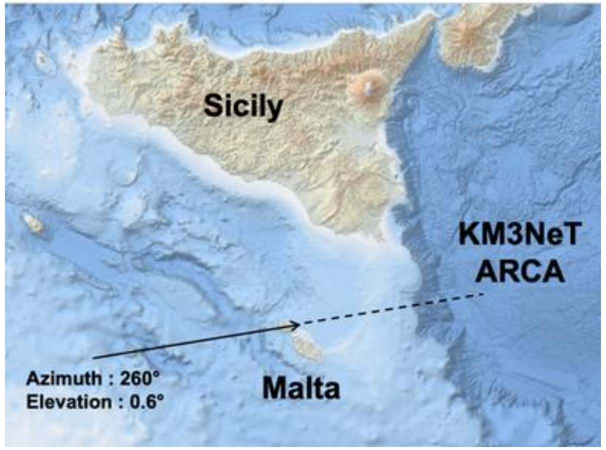
Nature 638 (2025) 8050

- Maximal range of EeV energy muons in water ~60km (if E_μ > 10 PeV effective range ~30km)
- Bathymetric data showing the path travelled by a muon along the reconstructed direction – total amount of traversed matter ~300km

<< 10^{-10} / year at this direction / energy

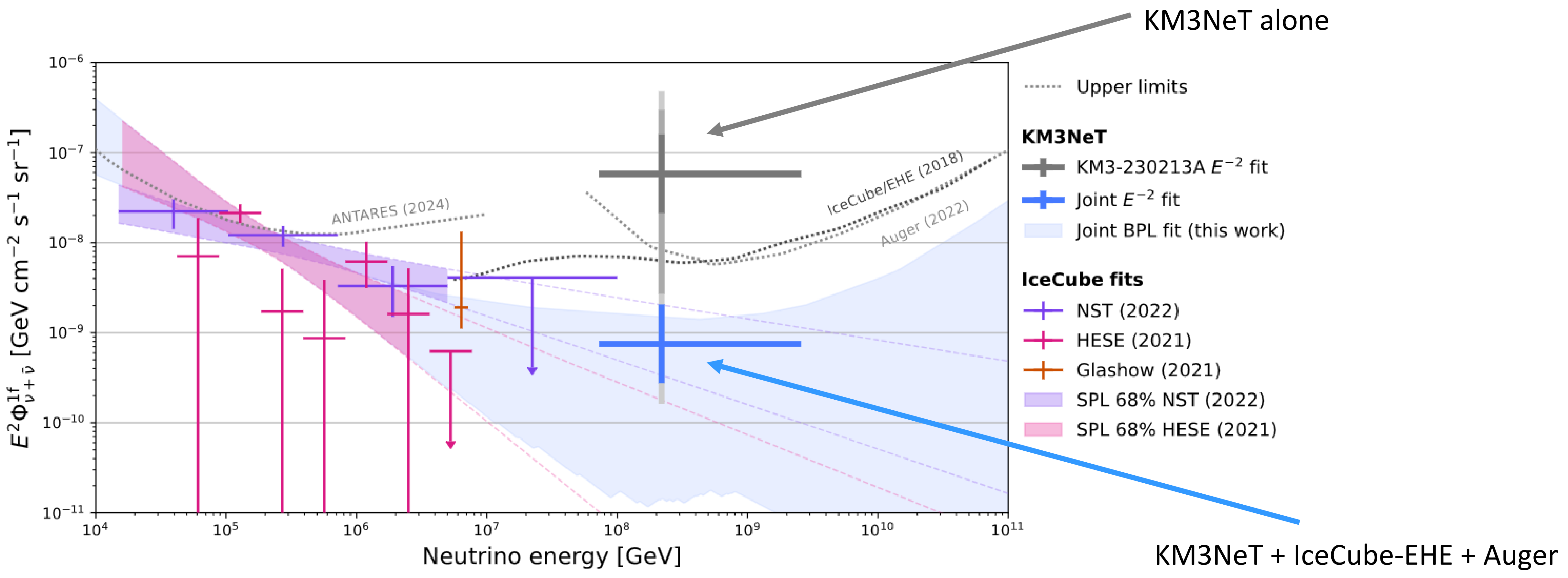
<< 10^{-5} / year assuming 5σ directional error





Not an atmospheric muon

KM3-230213A: highest energy neutrino detected



Phys.Rev.X 15 (2025)

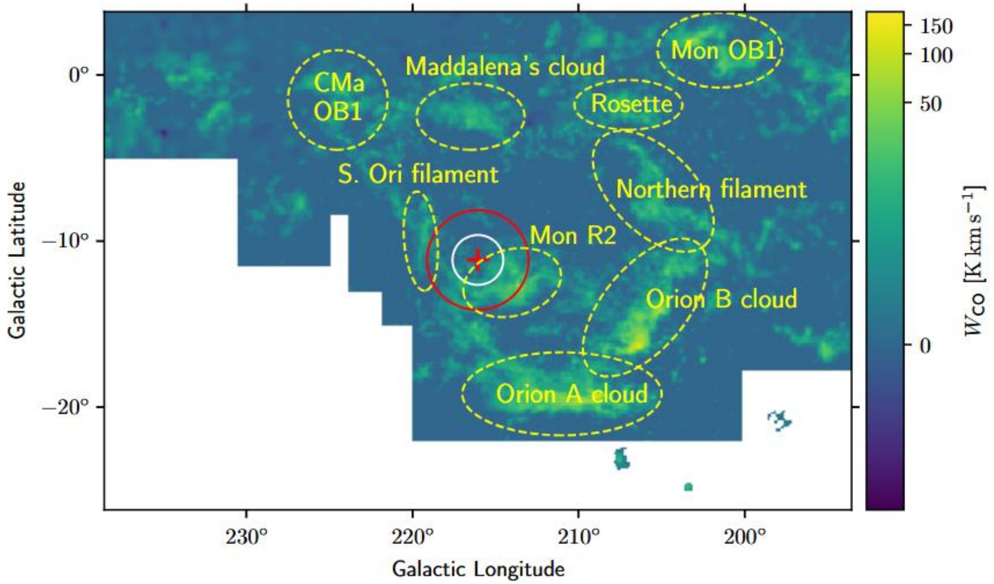
Probability of observing one event in KM3NeT and zero in both IC-EHE and Auger assuming the flux resulting from the joint fit is about 0.5%

KM3-230213A origin: galactic / extra-galactic / cosmogenic

KM3-230213A of galactic origin?

KM3-230313A far away from the Galactic Centre, and ~11° offset from the Galactic Plane
search for potential gas targets within the vicinity of the event

Velocity-integrated CO brightness temperature tracing molecular gas



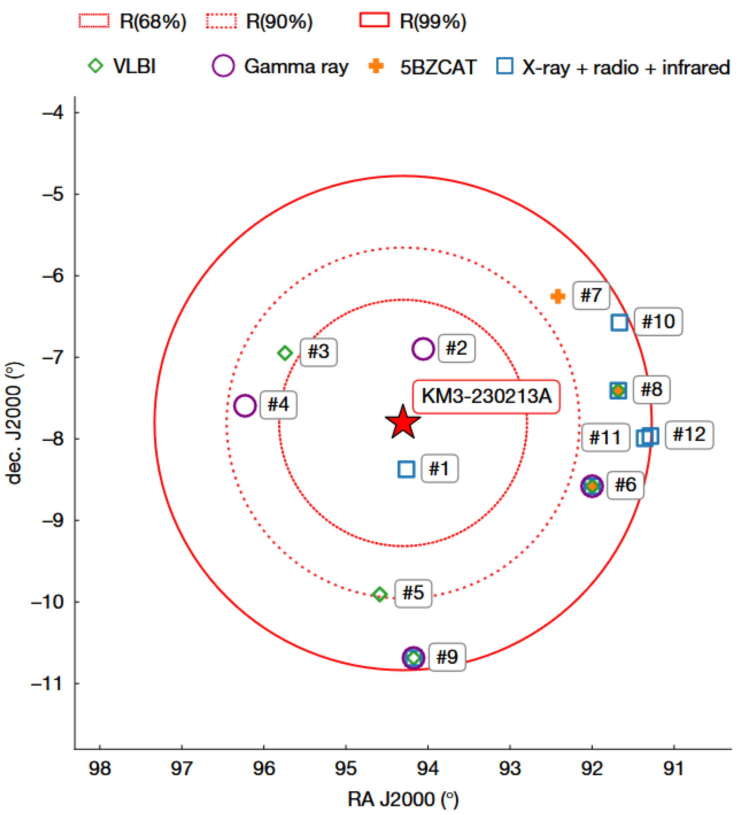
Astrophys.J. 1003 (2026)

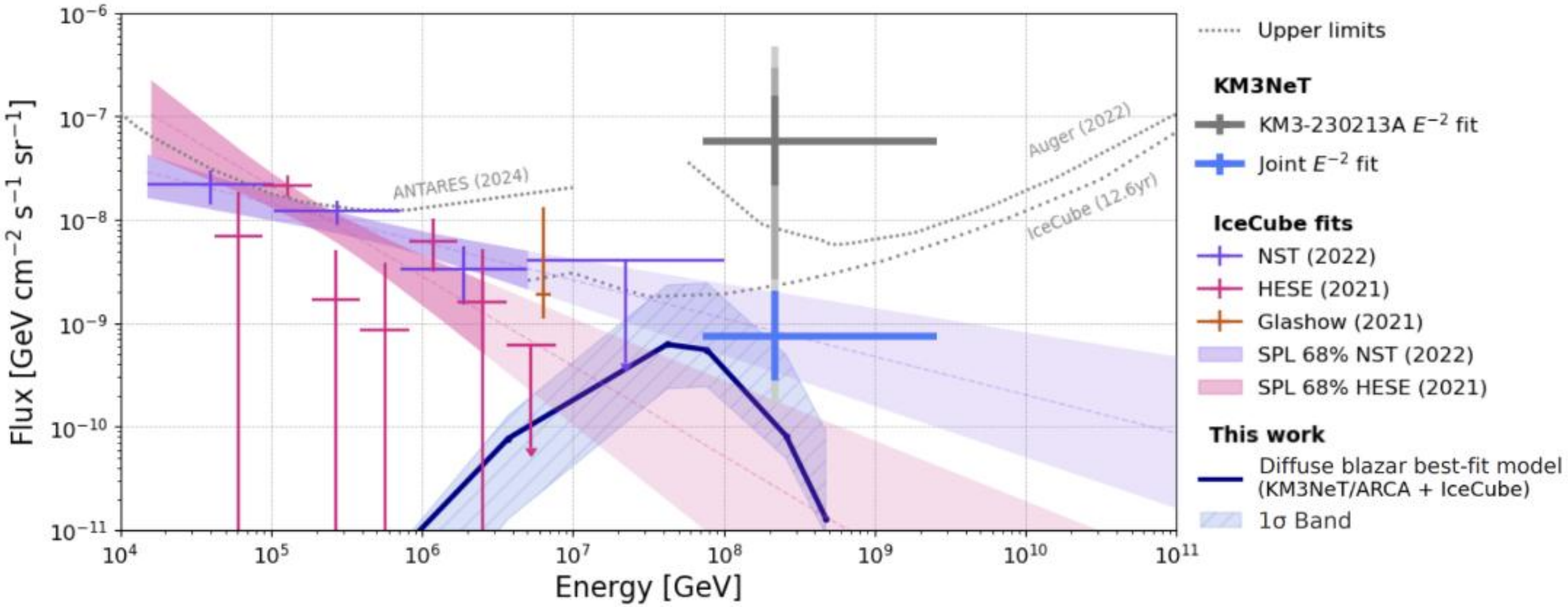
- low fluxes of the Galactic diffuse emission at UHE
- difficult to accelerate particles to such high energies in Galactic systems
- lack of a nearby potential Galactic particle accelerator (LHAASO & HAWC: no VHE γ-ray counterpart detected)

Not likely of galactic origin

KM3-230213A origin: galactic / extra-galactic / cosmogenic

KM3-230213A of blazar origin?





JCAP 03 (2026) 033

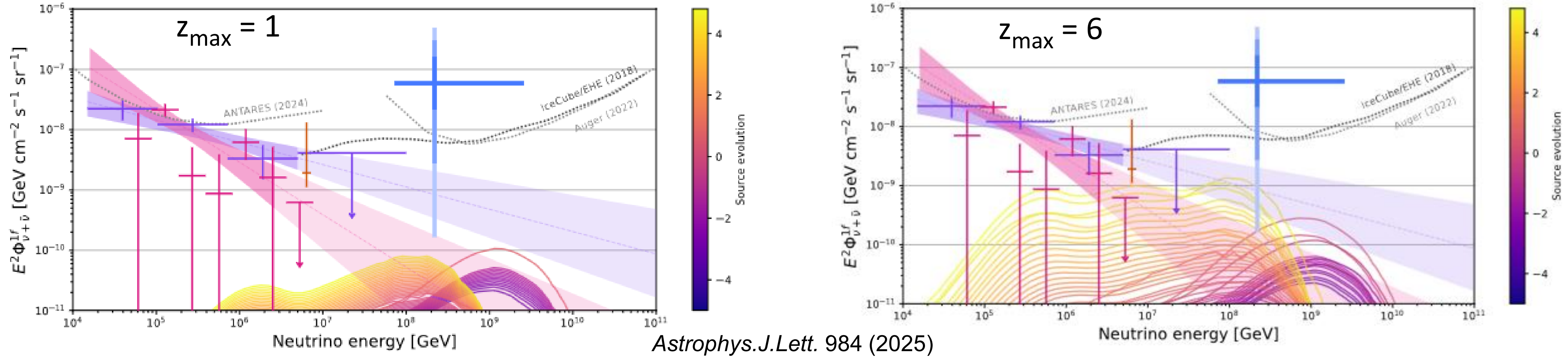
A population of blazars may contribute significantly to the UHE neutrino emission leading to KM3-230213A

KM3-230213A origin: galactic / extra-galactic / cosmogenic

KM3-230213A of cosmogenic origin?

$$p + \gamma_{2.7K} \rightarrow \Delta^+ \rightarrow n + \pi^+$$
$$\hookrightarrow \mu\nu_\mu$$
$$\hookrightarrow e\nu_e\nu_\mu$$

Cosmogenic neutrinos: Cosmic rays can interact with background photons (Cosmic Microwave Background or Extragalactic Background Light) on their path to the Earth



Astrophys.J.Lett. 984 (2025)

in tension with the standard cosmogenic neutrino predictions based on the observations by Auger and TA

Strong positive cosmological source evolution allowing for a non-negligible fraction of protons in the UHECR flux

redshift evolution of the UHECR luminosity density $S(z) \propto (1+z)^m$

Cosmogenic flux will depend on source evolution m, z_{max}, fraction of protons in the UHECR flux

Summary

KM3NeT instrumented volume increasing (currently ARCA51 & ORCA42)

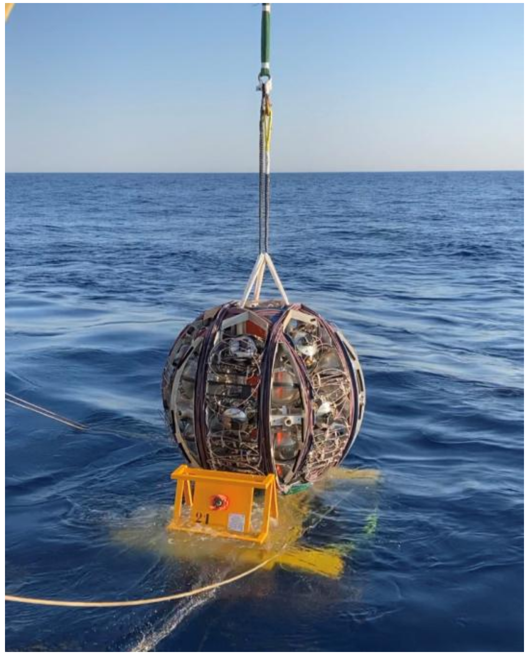
- CCSN neutrinos
- Atmospheric neutrino oscillations
- Cosmic ray studies
- Astrophysical flux
- Real-time multi-messenger program
- Dark matter studies, BSM physics (not covered here)

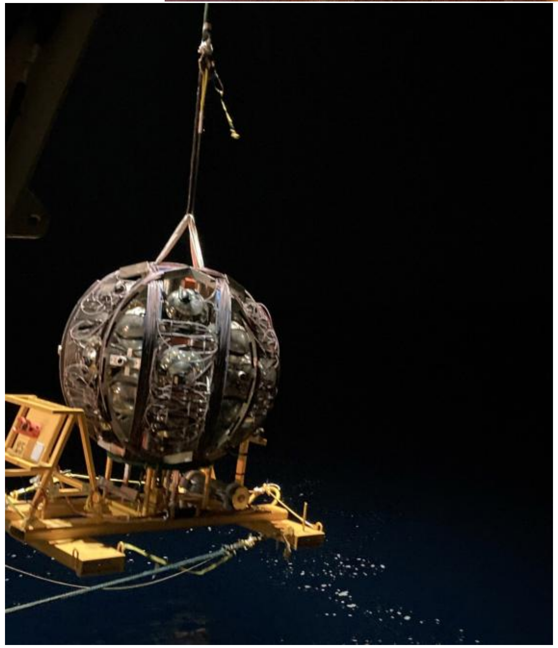
- ❑ Point source and diffuse flux results using up to ARCA21 & ORCA18 data
- ❑ Analyses being updated for more recent detector configurations
- ❑ Observation of the UHE event KM3NeT-230213A: a milestone in the search for the origin of UHE neutrinos – more UHE events are required to identify their sources

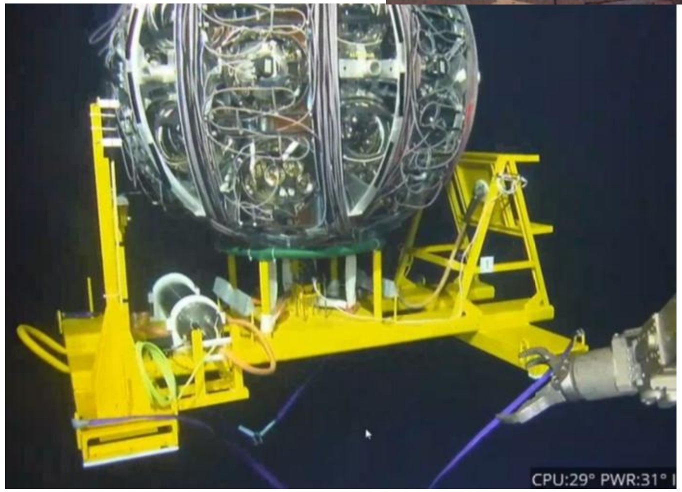
DEMOKRITOS

KM3NeT

Thank you for your attention!



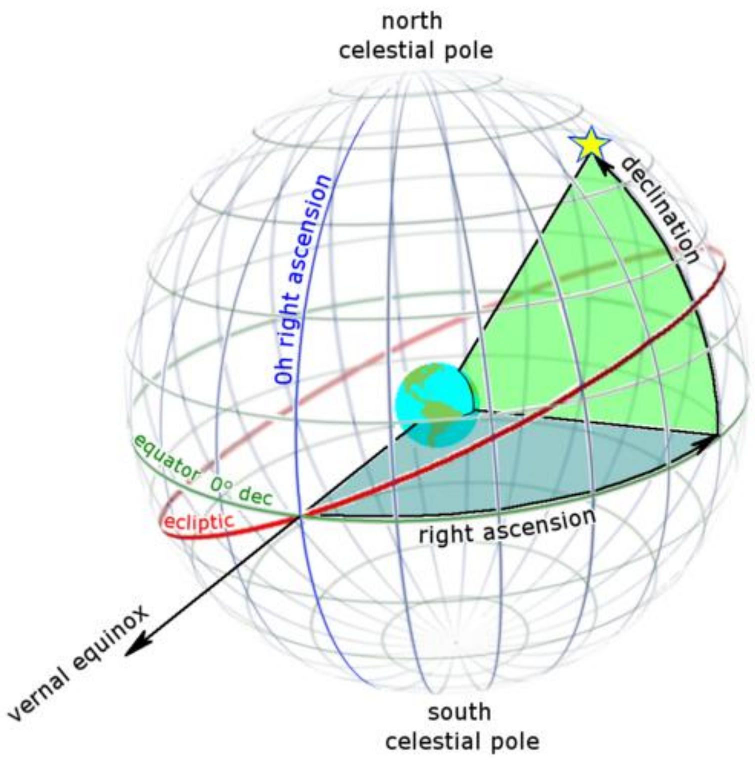




For more follow us at:
https://www.km3net.org

Backup

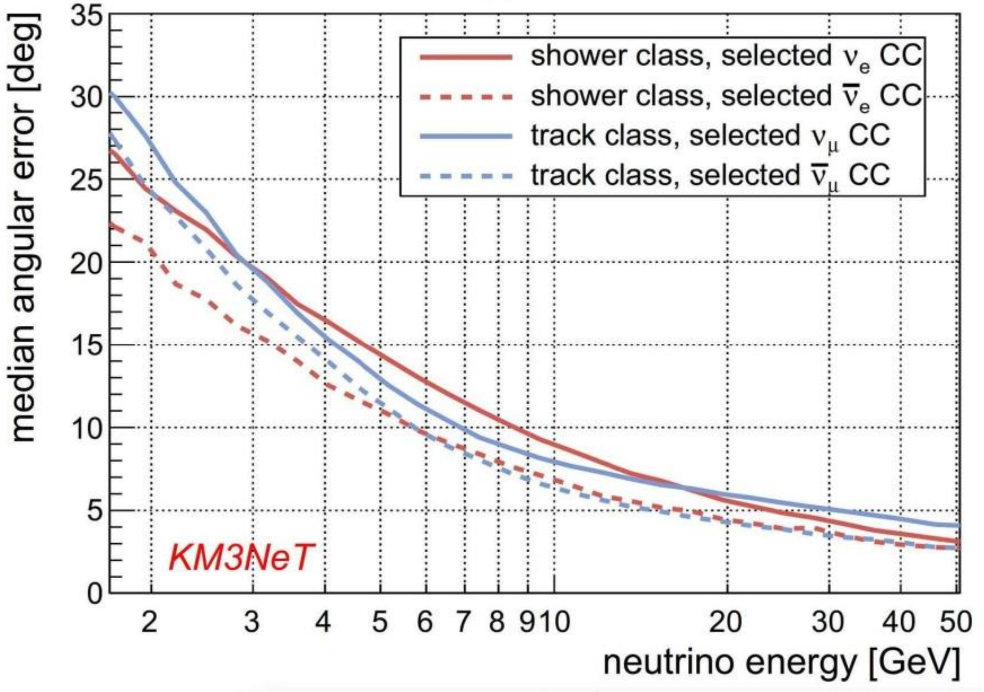
Astronomical coordinates



Earth's orbital plane

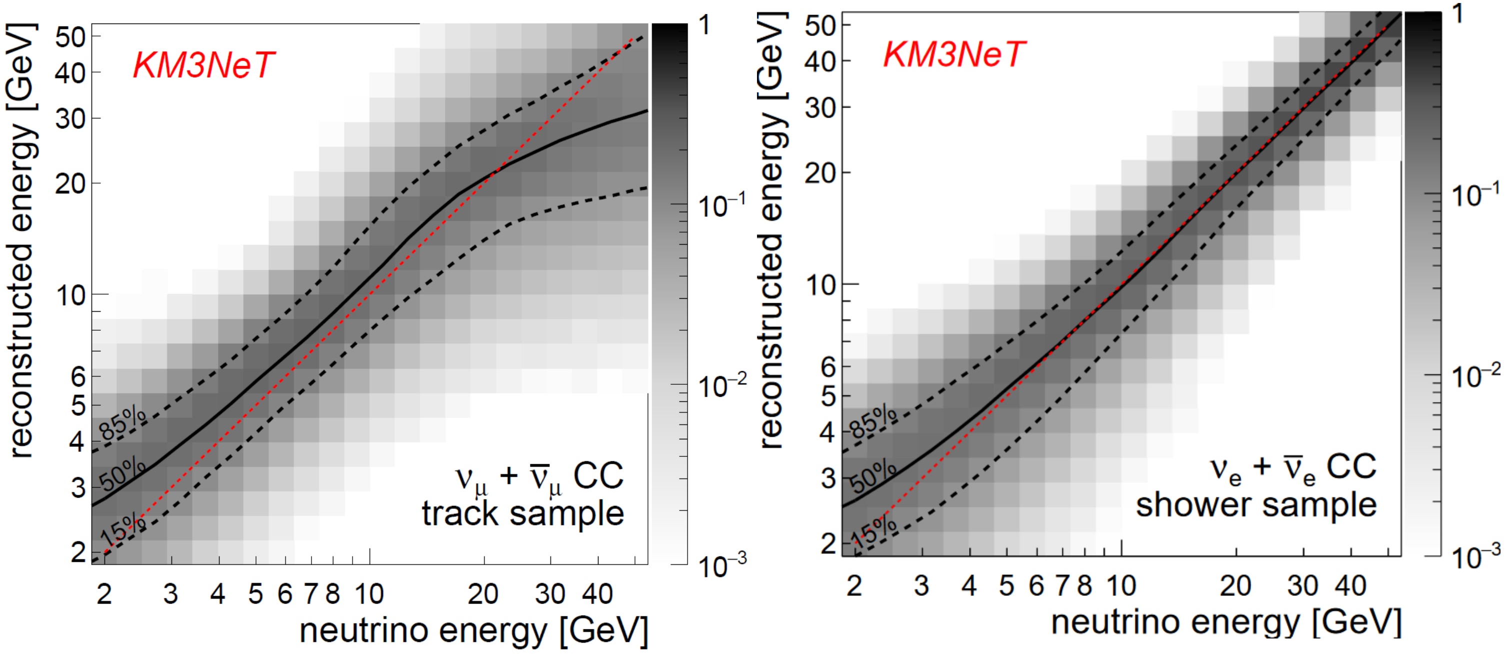
KM3NeT/ORCA performance

Angular resolution



Pointing accuracy dominated by neutrino kinematics

Energy resolution



- Direction resolution better than 15° at relevant energies
- Energy resolution: ~ 25%

Binned likelihood formalism

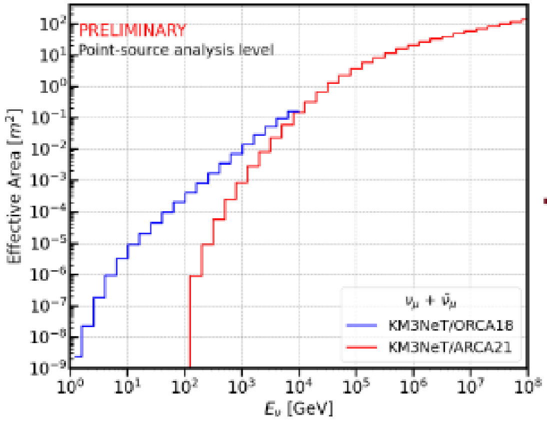
to identify source candidates datasets are represented by 2D distributions:

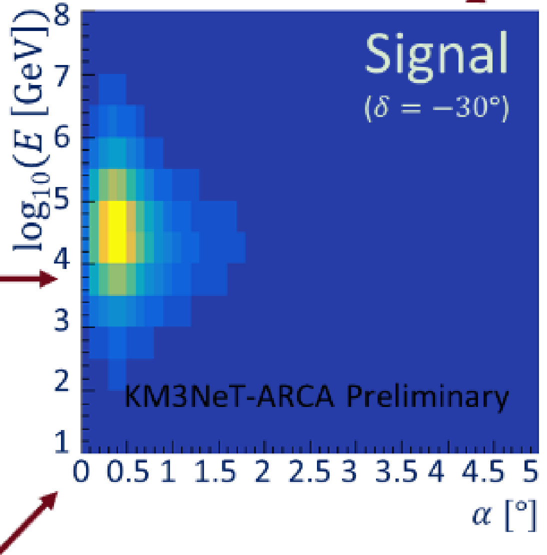
- distance of a reconstructed direction to the candidate source location
- reconstructed energy: different spectral indices for signal and atmospheric backgrounds

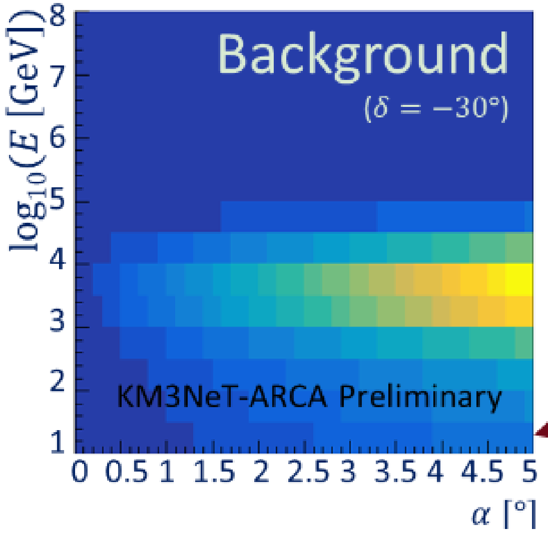
scrambling the data in right ascension

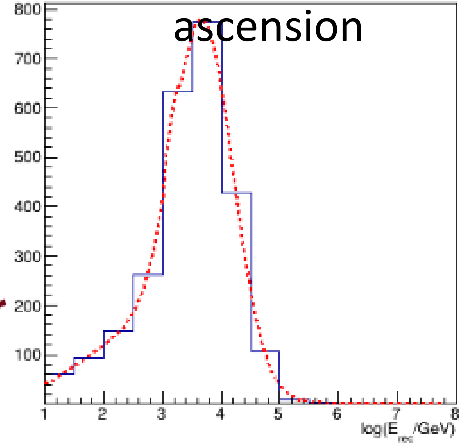
$$\text{Log}\, L(\xi) = \sum_{i \in bins} N_i \,\text{Log}(B_i + \xi S_i) - B_i - \xi S_i$$

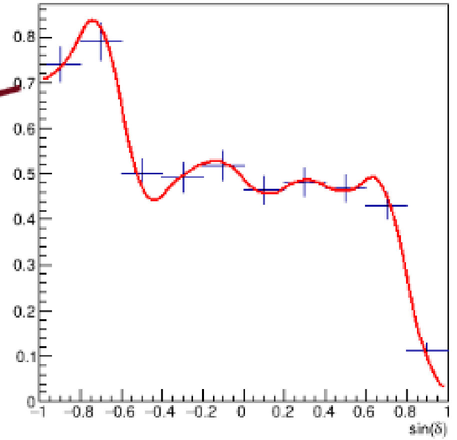
A_{eff}











$$N_{\text{bkg}} = n \times F(\delta) \times F(\log_{10}(E))$$

$$\Phi_{\nu+\bar{\nu}} \propto E^{-\gamma} \qquad \gamma = 2.0 \quad \gamma = 2.5 \quad \gamma = 3.2$$

I. Del Rosso (ISVHECRI 2026)