

Searches for cosmic neutrino point source with KM3NeT

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Incontri di Fisica delle Alte Energie (IFAE 2026)

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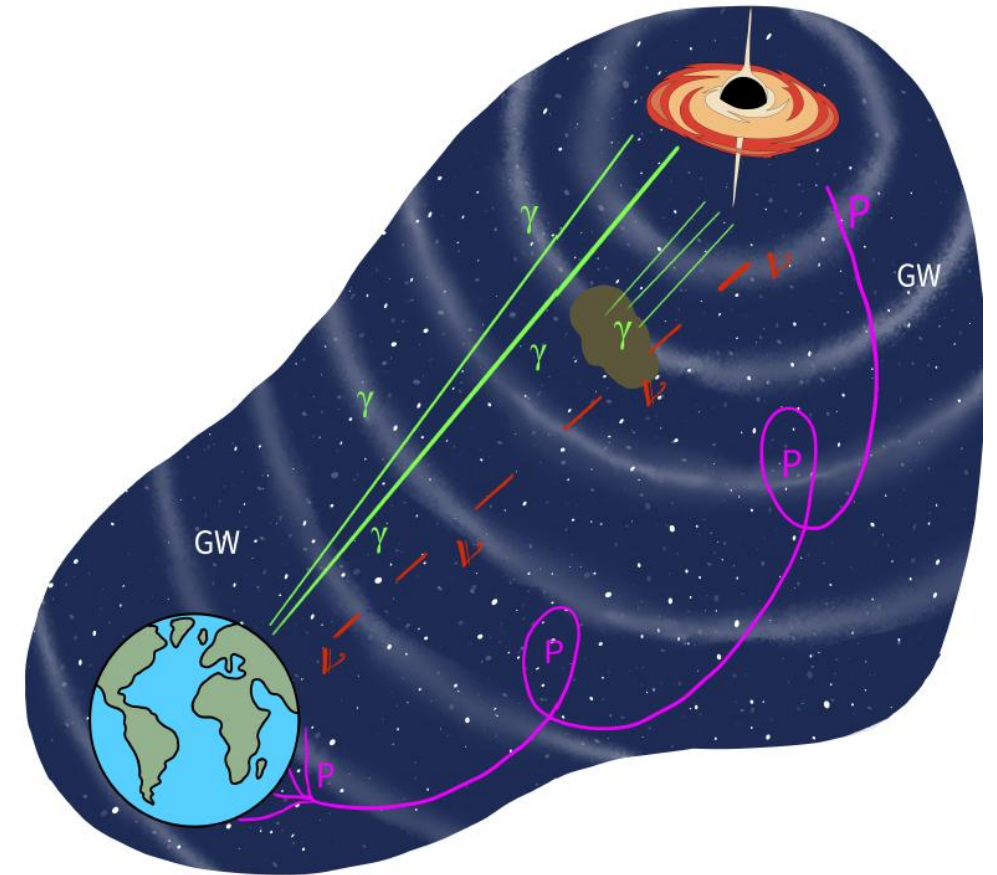
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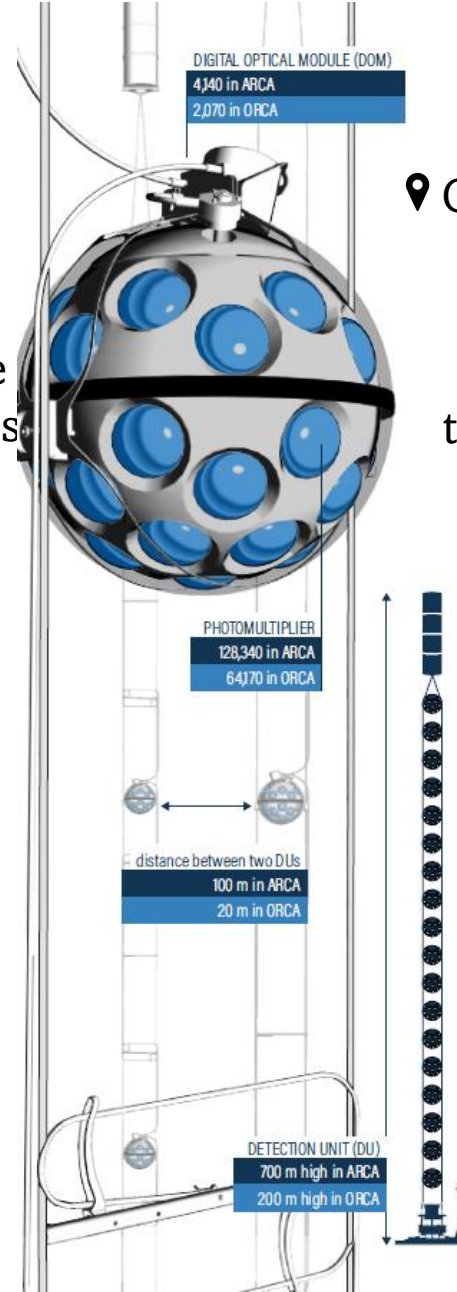
- 1. Context: neutrino astronomy**
- 2. KM3NeT detectors**
- 3. KM3NeT/ARCA: data sample & event selection**
- 4. KM3NeT/ARCA performances**
- 5. Analysis approach**
- 6. Candidate sources**
- 7. Results**

- **Cosmic ray protons** are charged particles deflected by B-fields.
- **Photons** point to their sources but are absorbed and can be produced also in purely leptonic processes.
- **Neutrinos** are almost massless and neutral particles that point to their sources, without being deflected or absorbed. They have no horizon and can escape extreme environments. They are the **signature of hadronic mechanisms** in production and acceleration sites of high energy cosmic rays



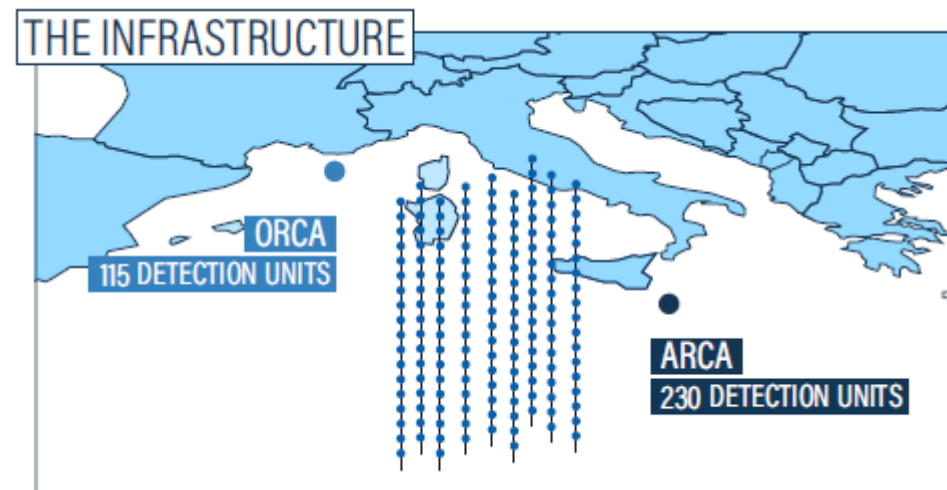
KM3NeT/ARCA

- Off-shore Sicily, Italy at ~ 3.5 km below sea level
- \rightarrow 230 foreseen Detection Units (DUs), each one composed of 18 Digital Optical Module (DOMs)
- \rightarrow Search for high-energy cosmic neutrinos in the **TeV-PeV** energy range from astrophysical sources

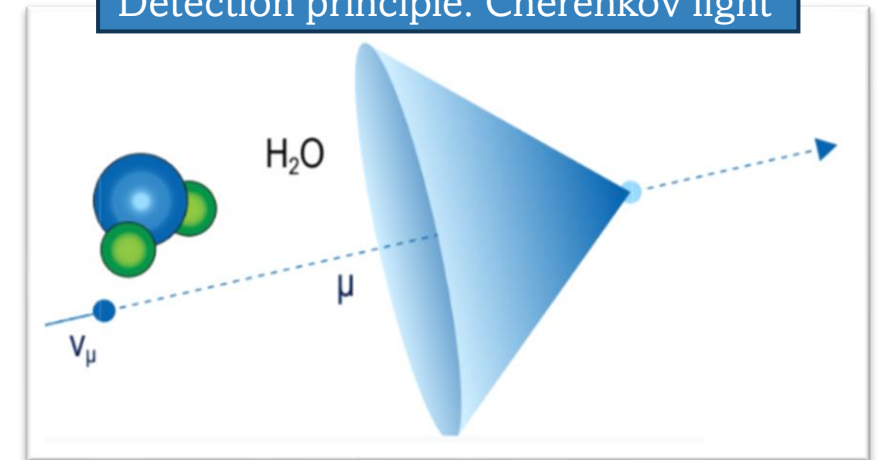


KM3NeT/ORCA

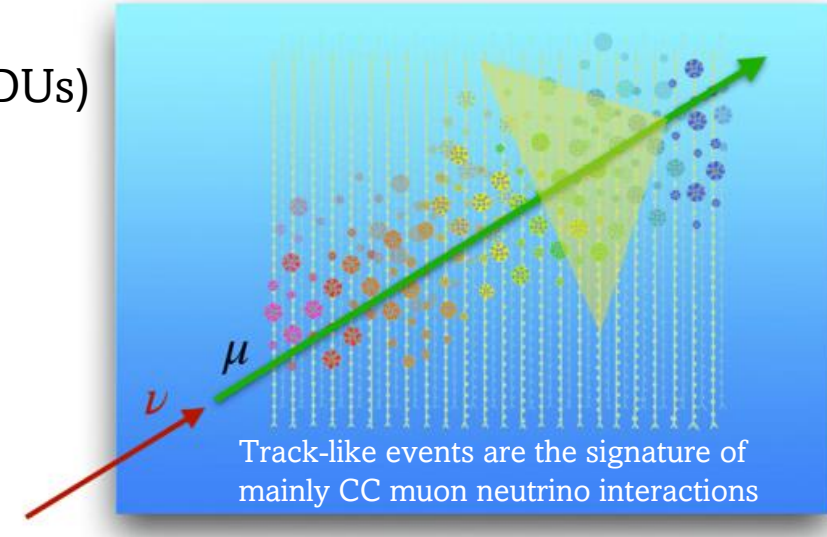
- Off-shore Toulon, France at ~ 2.5 km below sea level
- \rightarrow 115 foreseen Detection Units (DUs), each one composed of 18 Digital Optical Module (DOMs)
- \rightarrow Detection of **GeV-TeV** atmospheric neutrinos to study oscillations and mass ordering, thereby also detecting low-energy astrophysical neutrinos



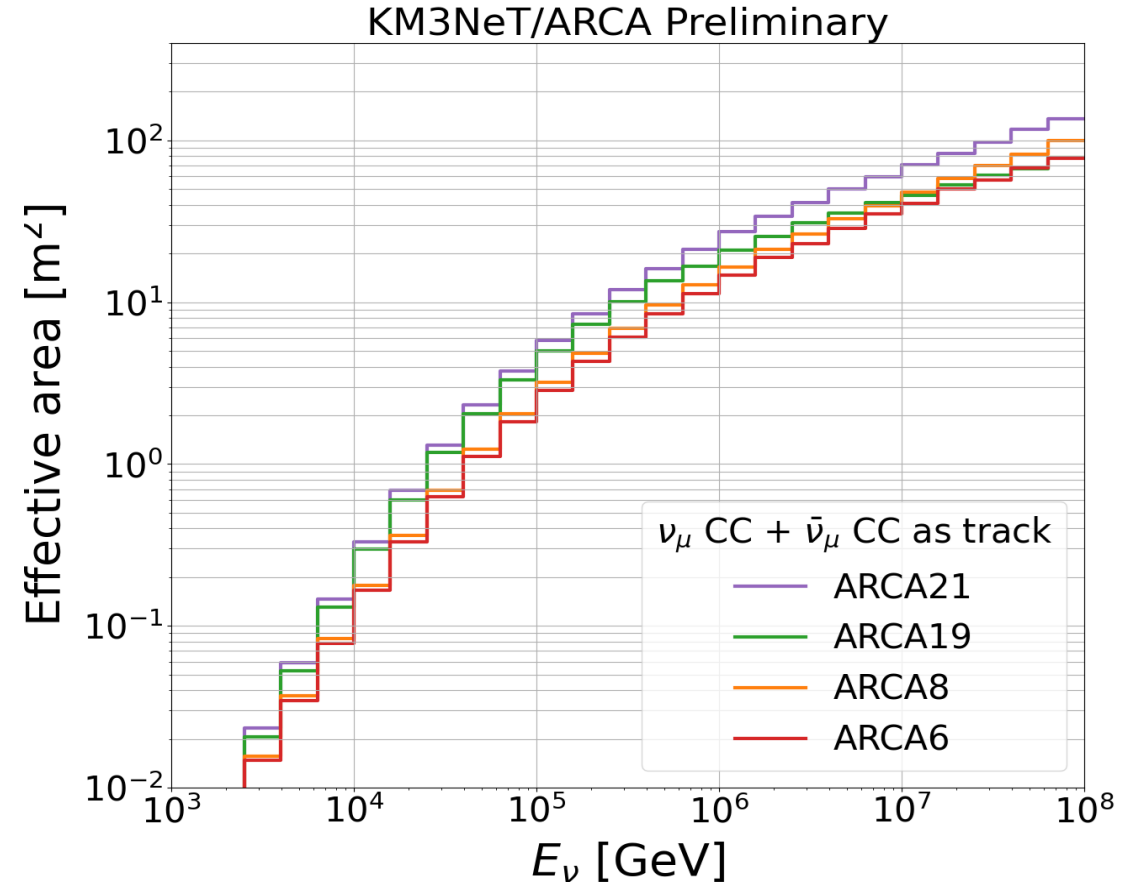
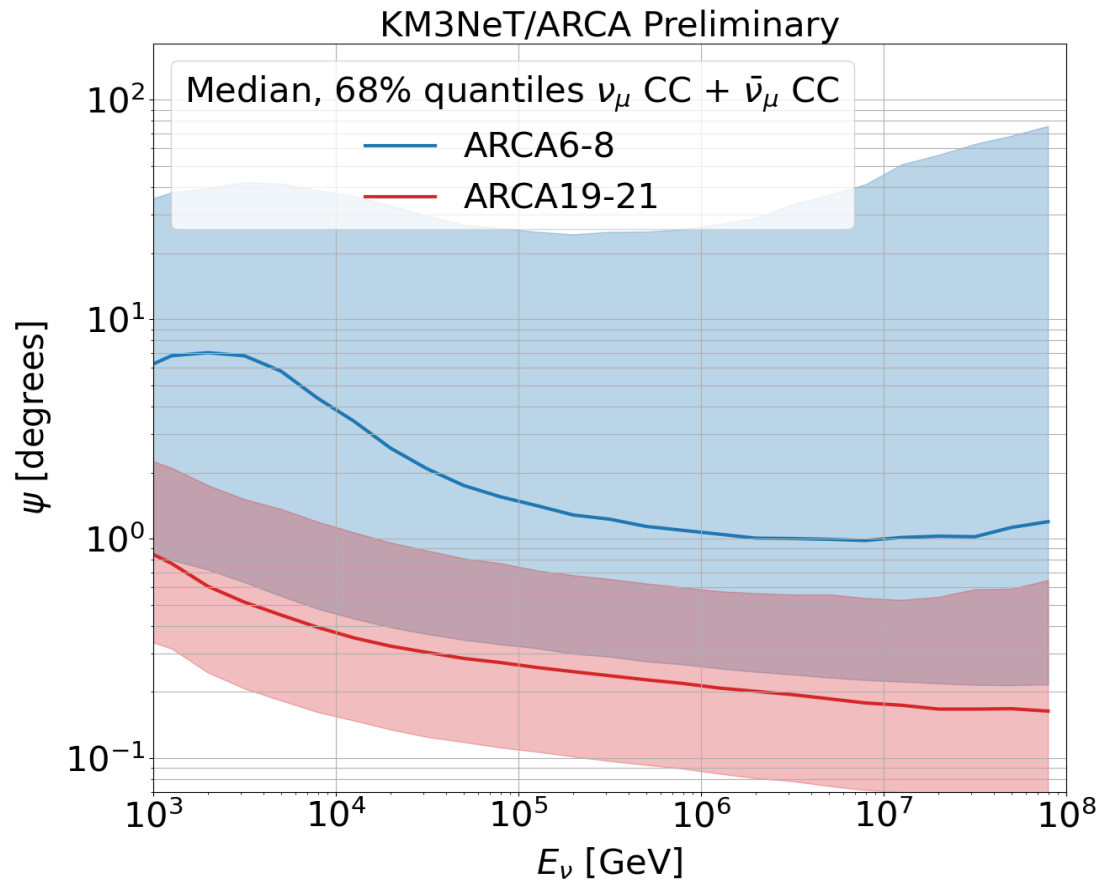
Detection principle: Cherenkov light



- Taking data during construction phase, currently 51 DUs operational
- All data analysed from **KM3NeT/ARCA6** (6 DUs) to **KM3NeT/ARCA21** (21 DUs) for a total livetime of 640 days
- **Upgoing & horizontal track-like events are employed**
- Event selection:
 - Horizontal/up-going tracks
 - Event with high number of hits used in the reconstruction and with good fit quality (based on the likelihood of the reconstruction)
 - Long track length and small error in its reconstructed direction
 - Boosted decision tree
- After selection, ~ 17285 events are employed
- Muon contamination of 15% after selection
- A cosmic neutrino flux of $\Phi_{\nu+\bar{\nu}} = 1.2 \cdot 10^{-4} (E_{\nu} / \text{GeV})^2$ per flavour yields **21.4 cosmic neutrino events** in the full ARCA6-21 sample, of which 12.1 contain a **muon** and are reconstructed with **<1° accuracy**.



The **median angular uncertainty** for ARCA6-8 is $< 2^\circ$ above 100 TeV, this improved significantly to $< 0.3^\circ$ for ARCA19-21, and is expected to improve further down to $< 0.1^\circ$ for the full detector (ARCA230^[*])



* KM3NeT Collaboration: "Astronomy potential of KM3NeT/ARCA." *The European Physical Journal C* 84.9 (2024): 885.

- Binned likelihood search: PDFs of expected signal & background from 2D histogram with values of distance (α) in range $[0^\circ, 5^\circ]$ and $\log_{10}(E_{\text{rec}})$ in $[2, 8]$ GeV

- Likelihood function $\log_{10} L = \sum_{\text{bins}} N_i \log(B_i + \xi S_i) - (B_i + \xi S_i)$
↘ Number of data events in i-bin

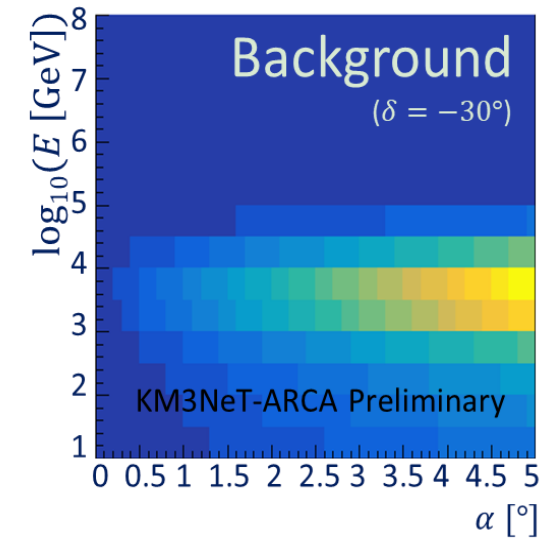
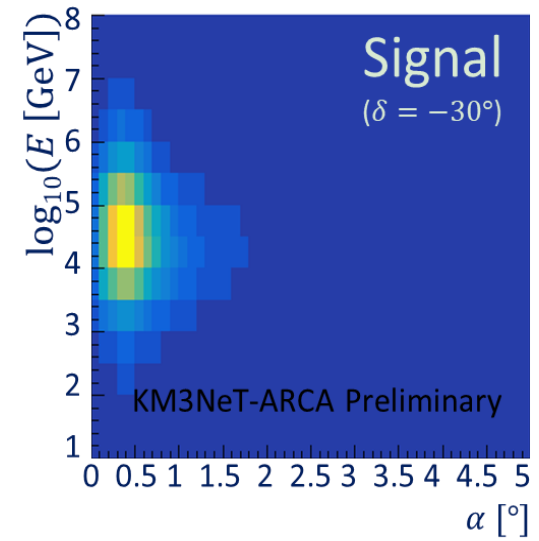
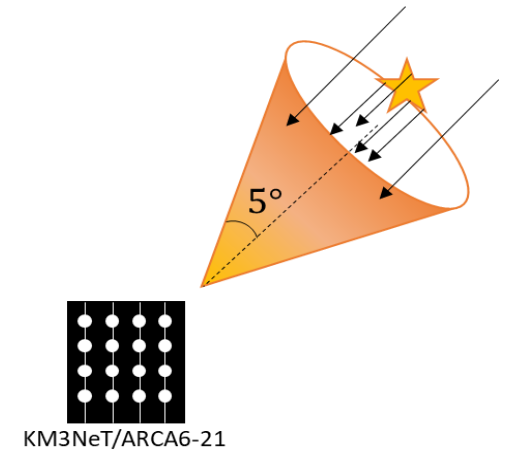
- Signal PDF S_i is extracted from Monte Carlo simulations
- Background PDFs from scrambled data

- Pseudo-experiments varying the free parameter ξ (signal strength)

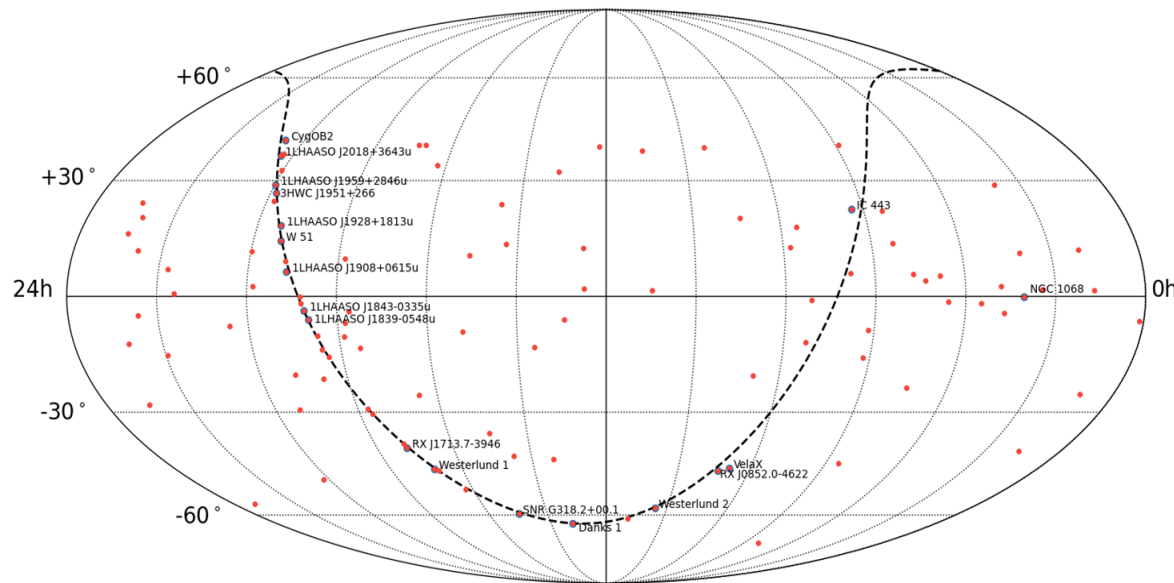
$$\lambda = \text{Log} L(\xi = \hat{\xi}) - \text{Log} L(\xi = 0)$$

$$\Phi_{\nu+\bar{\nu}} \propto E^{-\gamma}$$

| |
|----------------|
| $\gamma = 2.0$ |
| $\gamma = 2.5$ |
| $\gamma = 3.2$ |

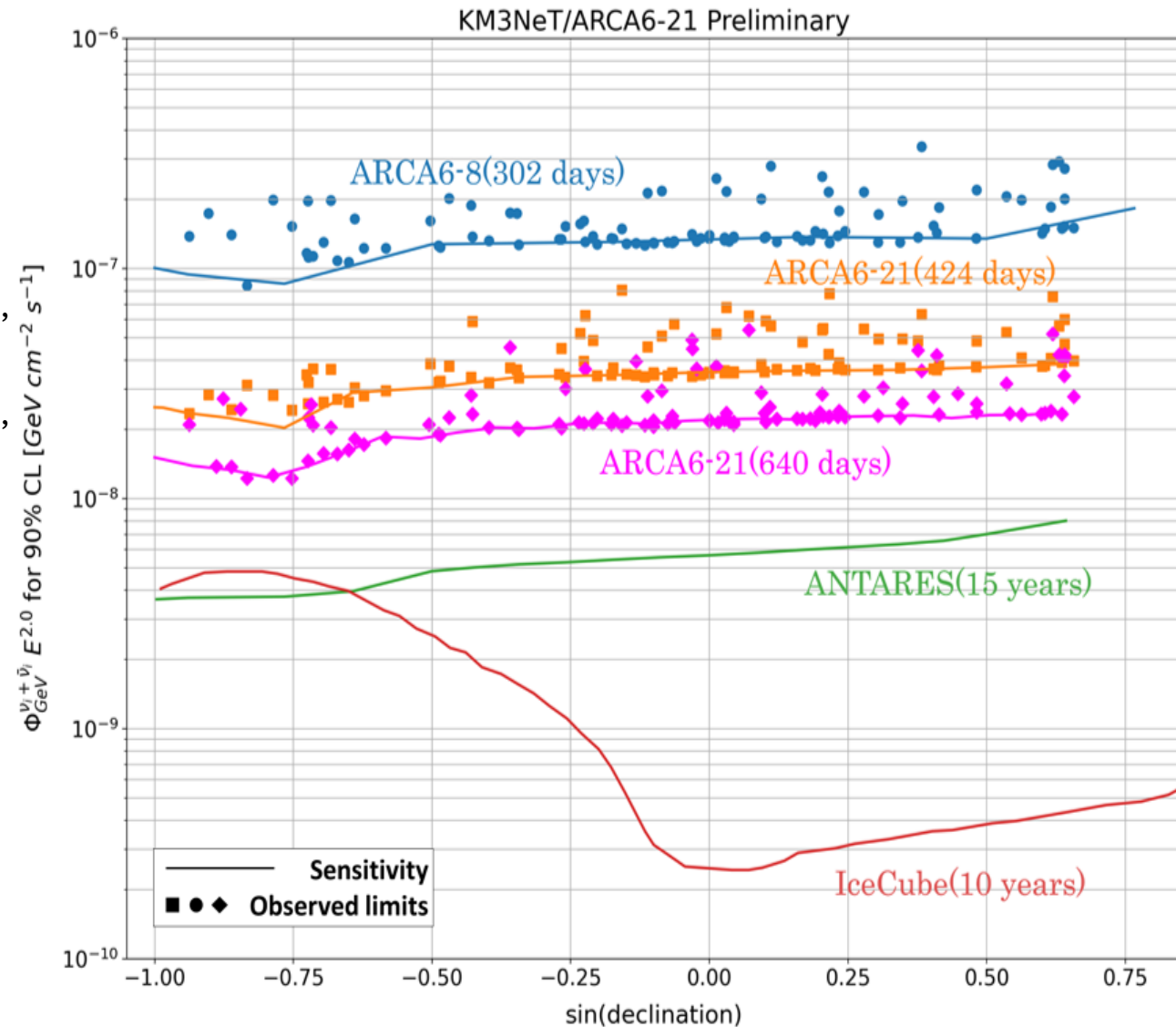


- 106 sources** are selected based on: **GeV – EeV information** from other **neutrino** experiments, **cosmic ray** experiments as well as **optical** measurements in the range $-90^\circ < \delta < 40^\circ$ for which KM3NeT has **>35% visibility** (after cut of upgoing + horizontal). The 19 **extended sources** are tested assuming a Gaussian with spread (σ) equal to their extension $[0.1^\circ - 2.2^\circ]$, and assumed to be circularly-symmetric.

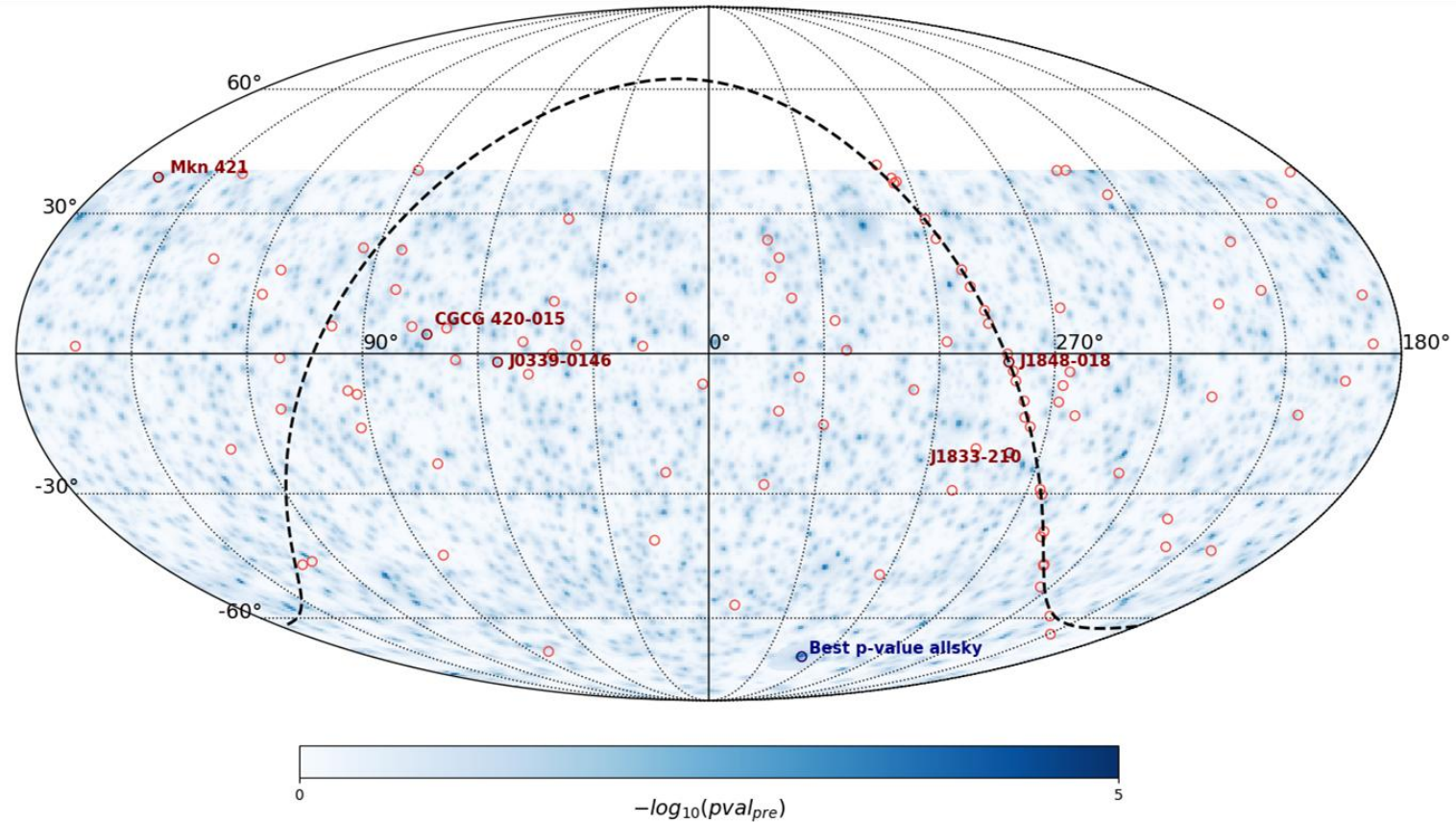


- All-sky scan** in equatorial coordinates of the local p-values (pre-trial): after scanning the full sky divided in $2.6 \cdot 10^6$ bins, the location with the lowest p-value are highlighted

- All candidate sources are **consistent with a background-only hypothesis**.
- The **most signal-like sources** in the candidate list are:
 - for the $E^{-2.0}$ spectrum: Seyfert galaxy **CGCG 420-015** at R.A. 73.35° , $\delta = 4.06^\circ$ with a pre-trial p-value of $6.37 \cdot 10^{-3}$,
 - for the $E^{-2.5}$ spectrum: super-bright blazar **Mkn 421** at R.A. 166.1° , $\delta = 38.2^\circ$ with a pre-trial p-value of $3.84 \cdot 10^{-3}$,
 - for the $E^{-3.2}$ spectrum only **NGC 1068** at R.A. 40.7° , $\delta = 0.0^\circ$ was tested. A pre-trial p-value of **0.33** was found.
- The same sources (though in different order) were in the top 3 for $E^{-2.0}$ and $E^{-2.5}$:
 - CGCG 420-015**, **Mkn 421**, and **J0339-0146**.
- Post-trial p-values are under calculation.

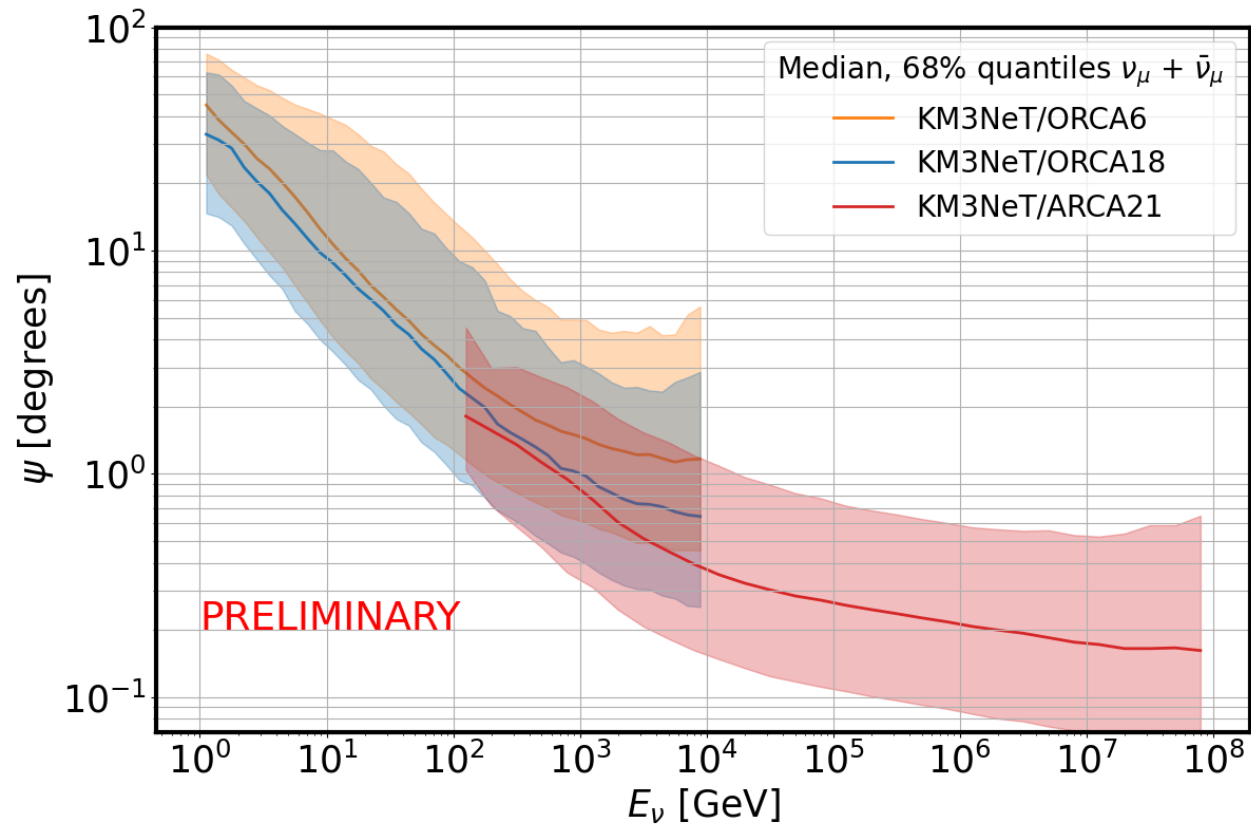


- The lowest p-value (pre-trial: $6.69 \cdot 10^{-5}$) is found at **R.A = 310.4°**, **$\delta = -71.3^\circ$**
- **Candidate sources** are visualized in the sky map by red circles. The five **most significant sources from the candidate search** (dark red) are labelled, as well as the position with the lowest p-value in the all-sky scan.

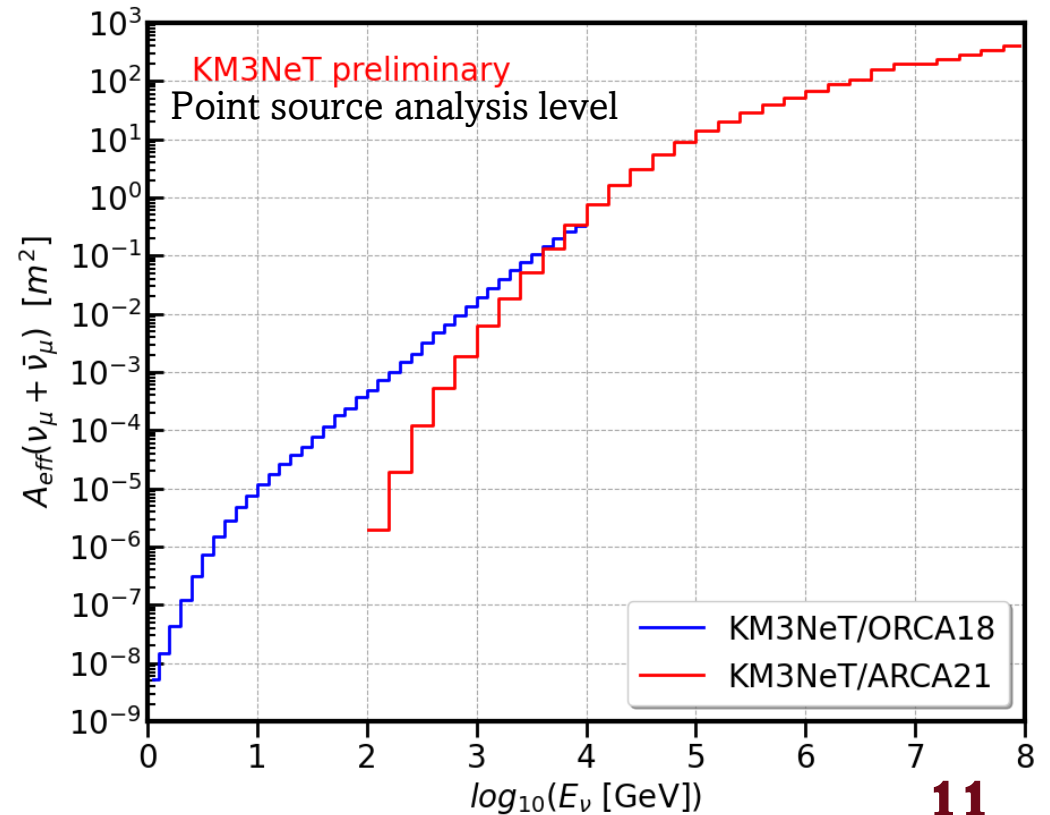


A point source analysis is ongoing also with KM3NeT/ORCA data, targeting lower-energy astrophysical neutrinos and softer spectra.

- The median **angular resolution** improves with the growing detector $\rightarrow < 1^\circ$ at few TeV



- KM3NeT/ORCA complements KM3NeT/ARCA by providing higher **effective area** at low energy



- No excess was found, but upper limits were set on the neutrino flux
- With the rapid growth of KM3NeT/ARCA, and data of September 2023-today still to be included in the analysis, the results are expected to significantly improve in the near future.
- KM3NeT/ORCA data are also being exploited for point source searches at lower energies and testing softer spectra
→ a joint ARCA+ORCA analysis is foreseen, further extending KM3NeT's sensitivity.

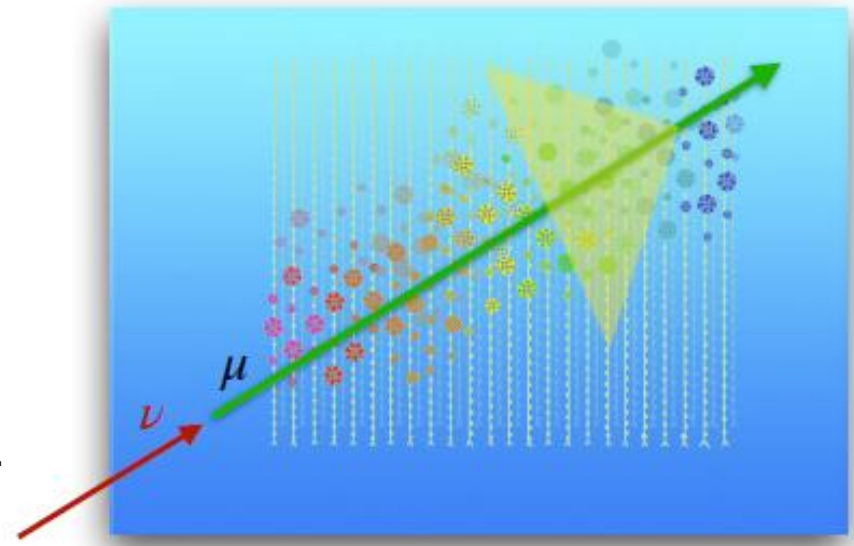
Thanks for your attention!



Backup

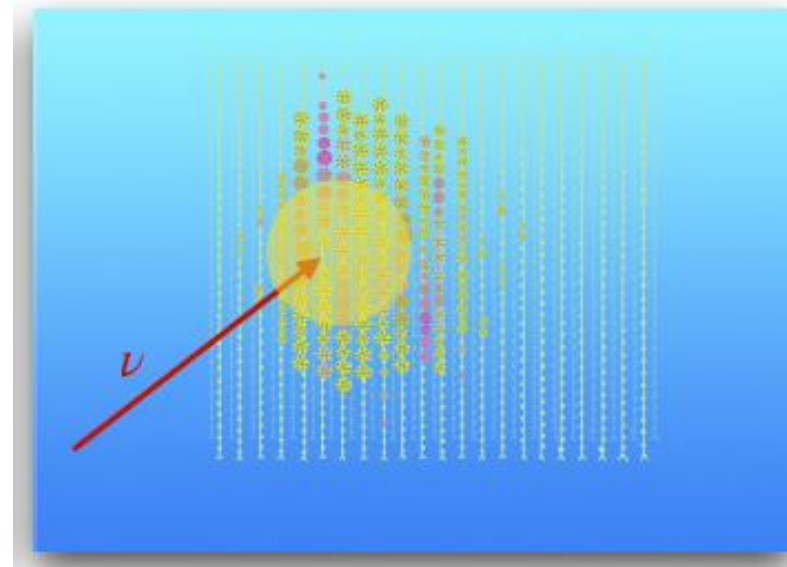
Tracks

- Mainly from charge current (CC) interactions of a ν_μ
- Golden channel for neutrino astronomy
- Clear long track-like signature in the detector (~ 1 TeV muon in water travel > 5 km!)
- Very good angular resolution while energy resolution is poorer

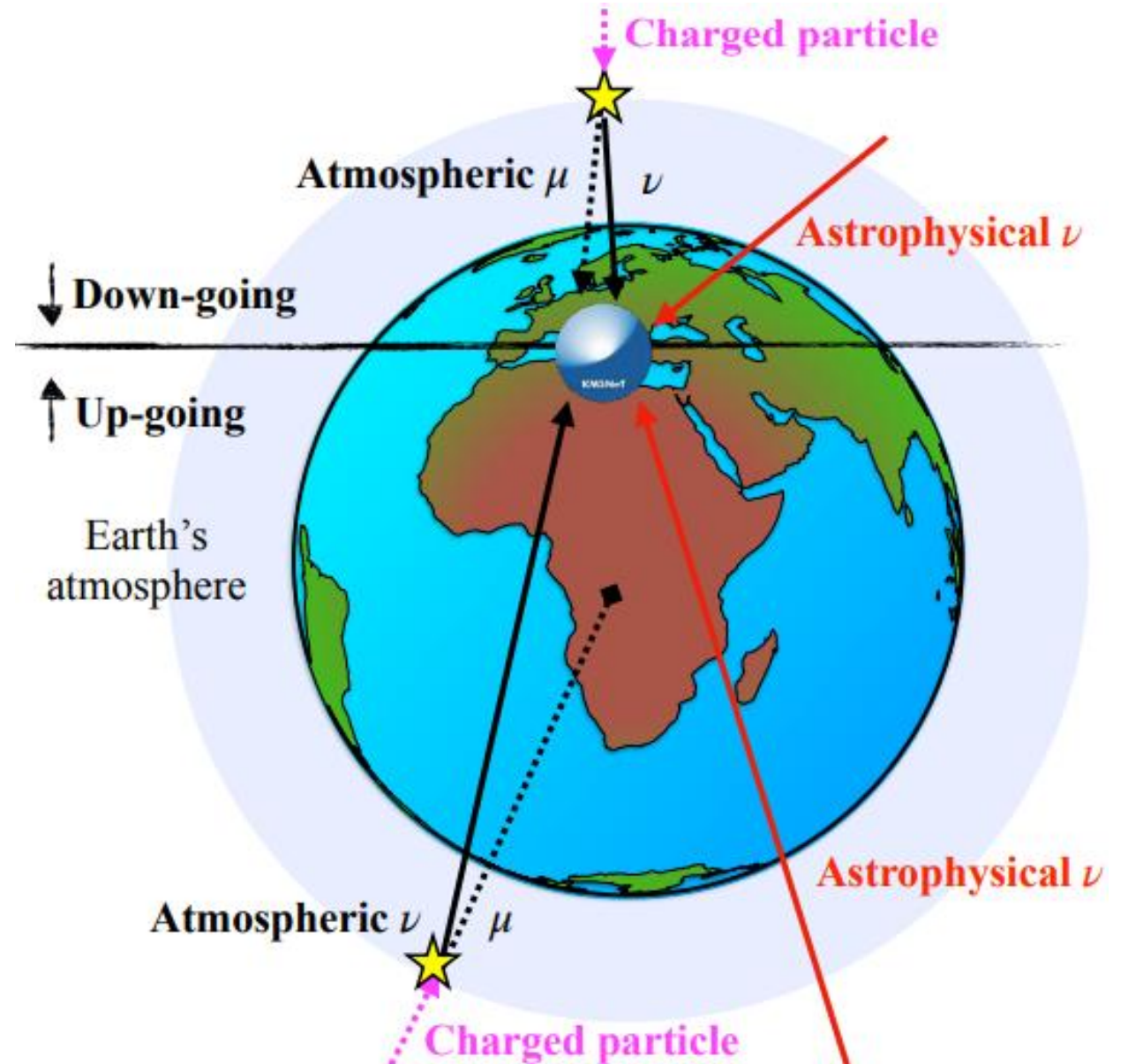


Showers/cascades

- From all flavours neutral current (NC) interactions and CC interactions of ν_e and ν_τ
- Almost symmetrical light emission
- Good energy resolution while poorer angular resolution

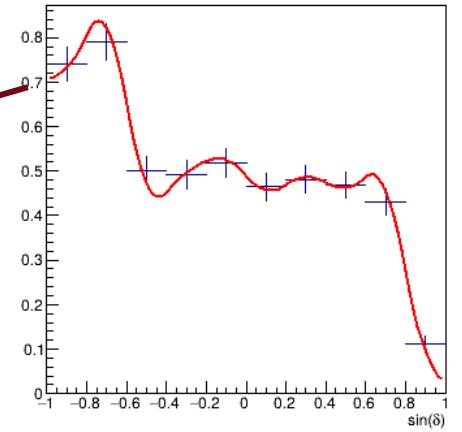
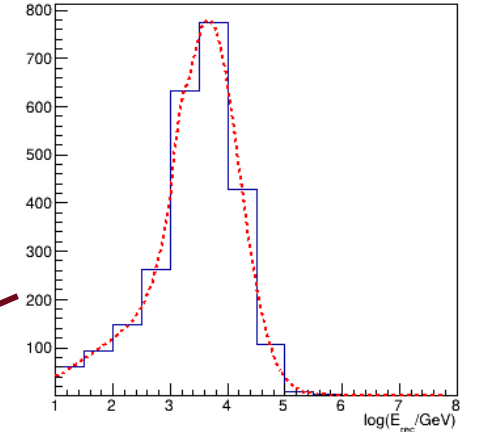
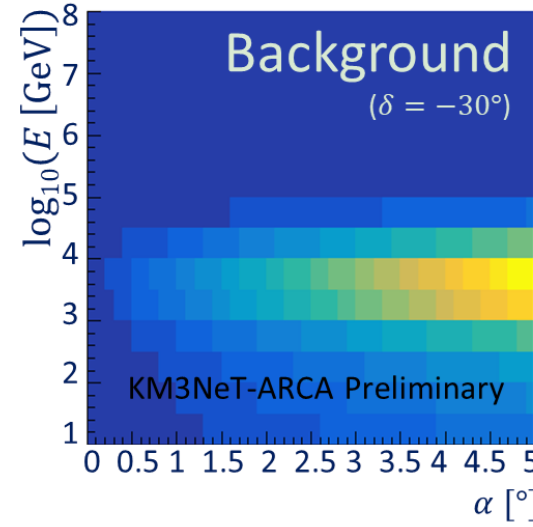
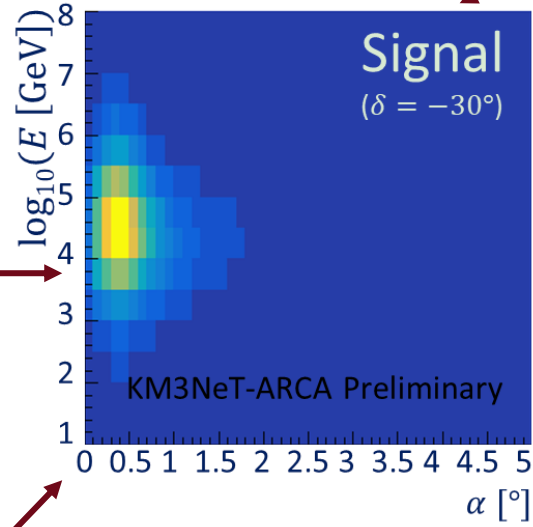
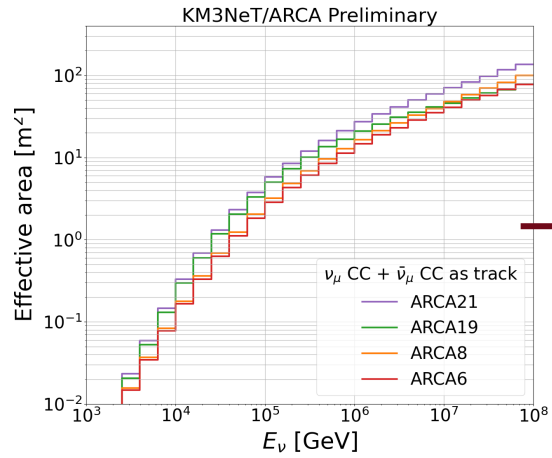


Up-going and down-going sky



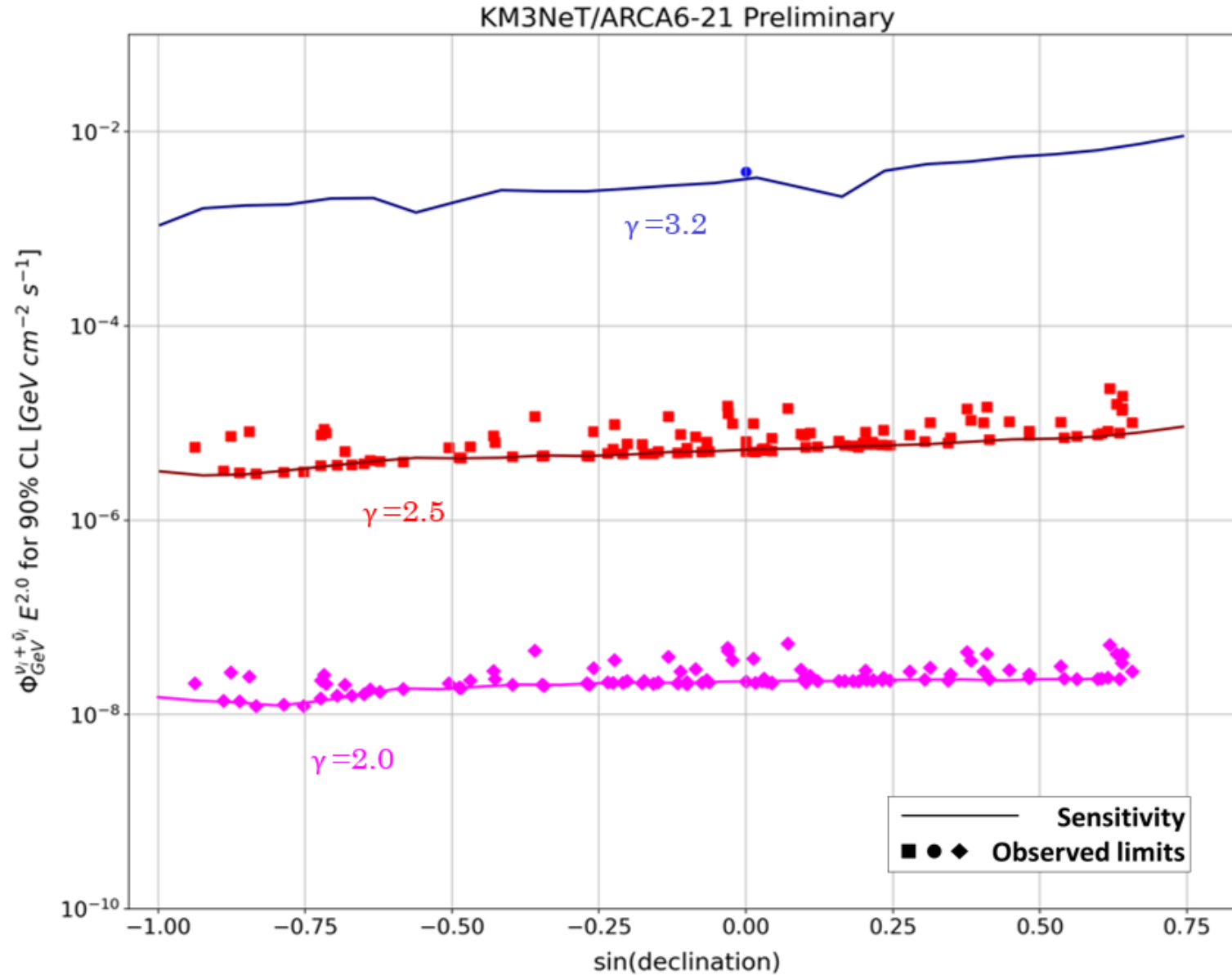
Binned likelihood

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



$$\Phi_{\nu+\bar{\nu}} \propto E^{-\gamma}$$

$\gamma = 2.0$
 $\gamma = 2.5$
 $\gamma = 3.2$





Article

Observation of an ultra-high-energy cosmic neutrino with KM3NeT


<https://doi.org/10.1038/s41586-024-08543-1> The KM3NeT Collaboration[✉]

Received: 19 August 2024

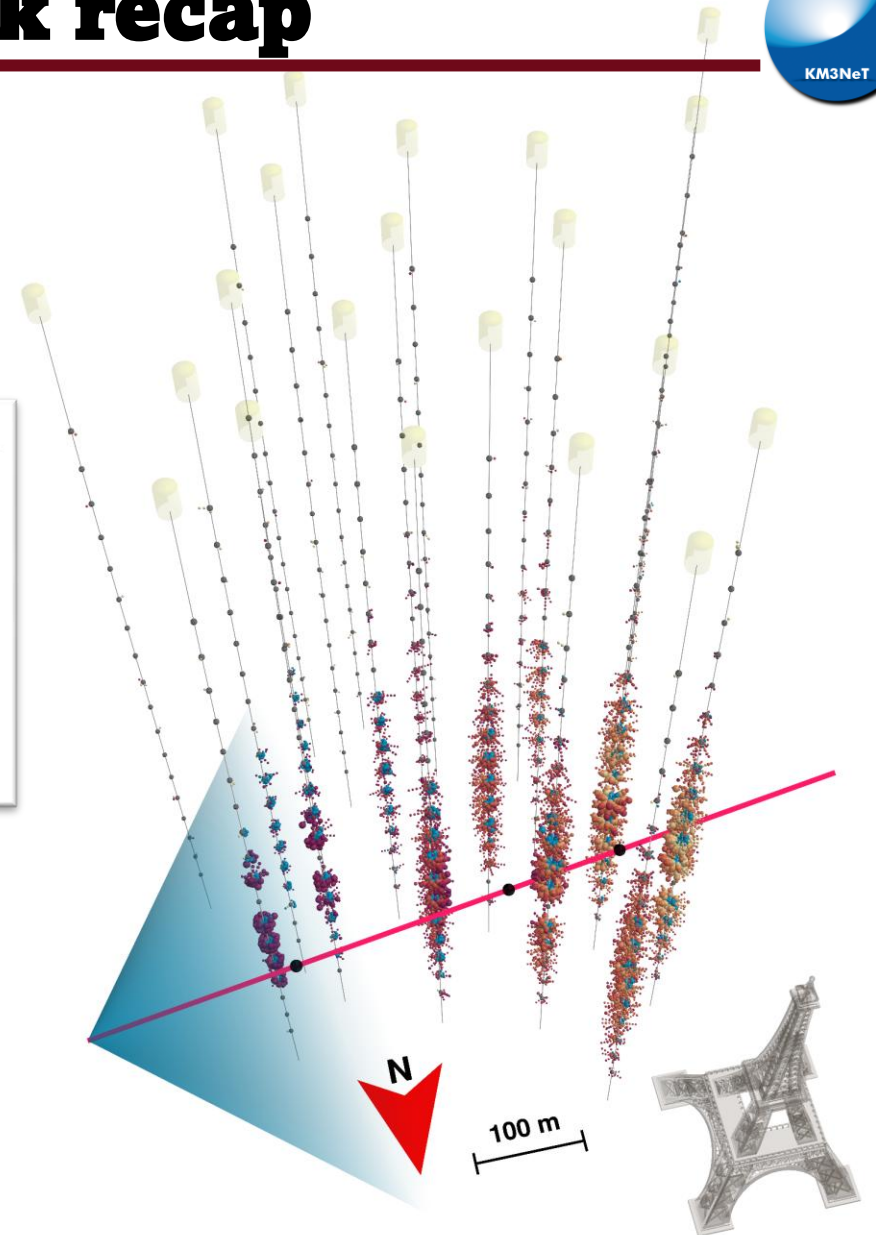
Accepted: 18 December 2024

Published online: 12 February 2025

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The detection of cosmic neutrinos with energies above a teraelectronvolt (1eV) offers a unique exploration into astrophysical phenomena^{1–3}. Electrically neutral and interacting only by means of the weak interaction, neutrinos are not deflected by magnetic fields and are rarely absorbed by interstellar matter: their direction indicates that their cosmic origin might be from the farthest reaches of the Universe.



KM3-230213A: An Ultra-High-Energy Neutrino Event(*)

- Detected by KM3NeT/ARCA on February 13, 2023
- Reconstructed energy = 220^{+570}_{-110} PeV (68% CL)
- Possible origin: from extragalactic to cosmogenic scenarios
- Hypothetical source may also emit **low&high-energy neutrinos**
→ motivates multi-detector follow-up from KM3-230213A direction