Latest Results with the KM3NeT Neutrino Telescope

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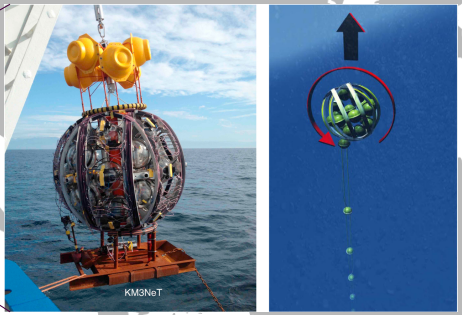
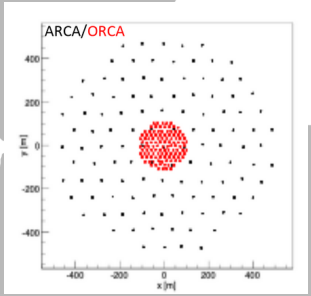
Neutrino detectors in the Mediterranean Sea

KM3NeT/ORCA

ex ANTARES site





KM3NeT/ARCA

ORCA (spacing 23×9 m): very high statistics of atmospheric ν

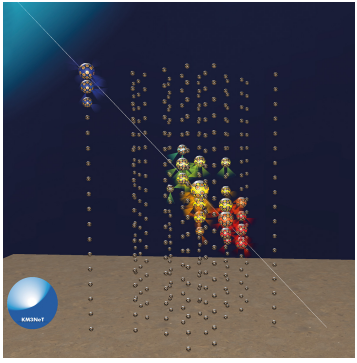
ARCA (spacing 90×36 m): very rare fluxes of extraterrestrial ν

KM3NeT: currently taking data with 21 lines ARCA + 19 lines ORCA

Optical module: 31 3" PMTs
Digital photon counting
Directional information
Wide angle of view

Neutrino astronomy in the making: experimental challenge

Astrophysical ν: atmospheric ν: atmospheric $\mu = 1{:}10^4 : 10^{10}$



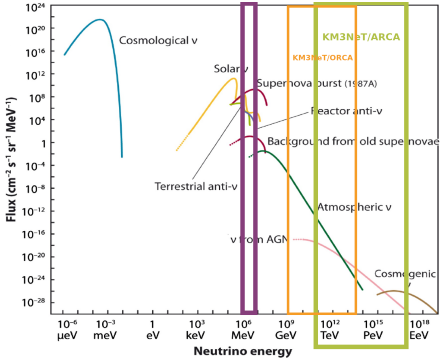
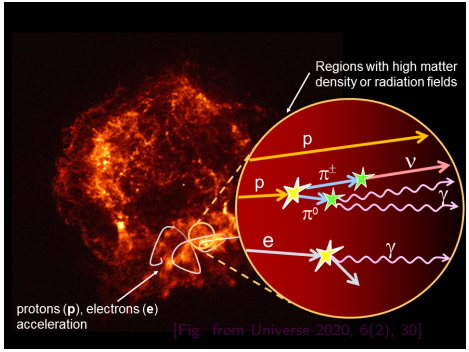


Figure: Left: A muon neutrino candidate recorded with ARCA21 [CERN Courier (2022)]. Right: Fig. adapted from U. Katz and C. Spiering [https://doi.org/10.1016/j.ppnp.2011.12.001]

Physics case 1: extraterrestrial neutrinos

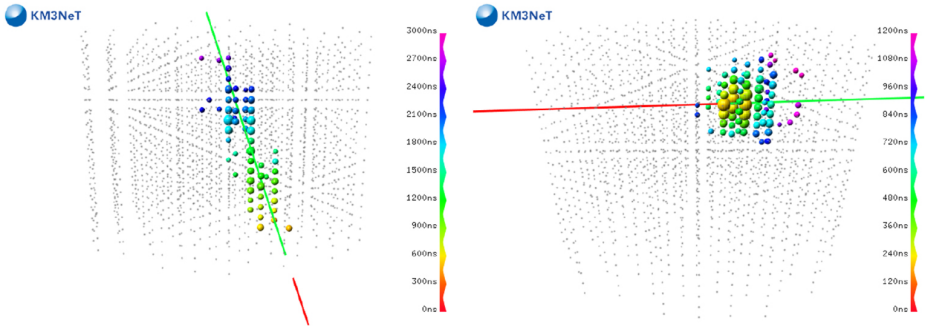
High energy cosmic neutrinos are expected from collisions yielding particles such as $\pi^{\pm}$ and $\mu^{\pm}$, through pp and $p\gamma$ scattering, taking place in different environments, steady or with flares



[Fig. from Universe 2020, 6(2), 30]

- Neutrino astronomy: backtracking sources
  1. As a correlation with underlying catalogue
     1. Jets of active galactic nuclei (AGNs)
     2. Starburst galaxies
     3. Tidal disruption events (TDEs)
     4. Expanding front of supernova remnants
     5. Gamma-ray bursts
  2. As autocorrelation or clusters in space (-time)
- Search for a diffuse excess and measurement of its spectrum. Accelerator properties.
- Search for prompt multimessenger coincidences

Performance: pointing



Tracks: predominantly $\nu_\mu CC$; angular resolution down to 0.1° at 1 PeV

Showers: predominantly ν_e CC or any NC; angular resolution 1° at 1 PeV

Performance: coverage

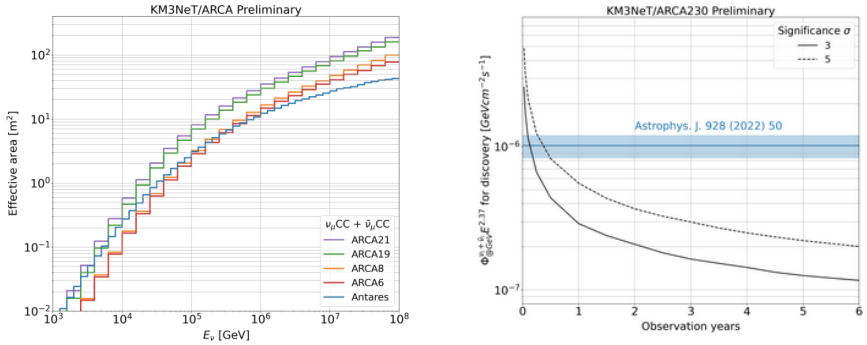
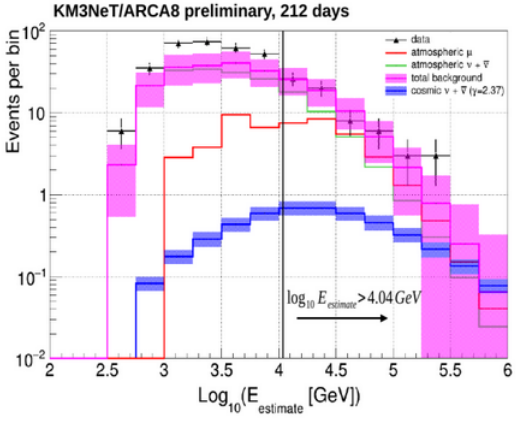
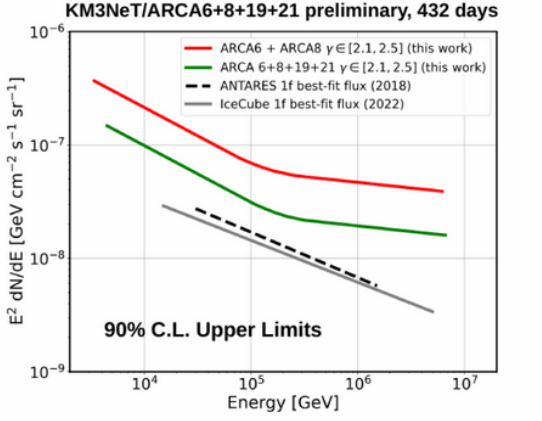


Figure: Left: The current configuration of KM3NeT has reached the effective area of ANTARES. Right: Assuming flux parameters from IceCube, KM3NeT/ARCA will observe same flux in half a year with 5σ significance, using both track and shower events [PoS(ICRC2023)1018]

Measurement of diffuse ν flux

Upper limits to diffuse flux of astrophysical neutrinos assuming IceCube best fit $\gamma = 2.37$ $\Phi_{90} = 3.06 \times 10^{-18}$ GeV^{-1}cm^{-2} s^{-1} sr^{-1} [PoS(ICRC2023)1195].





Search for single sources

Different search modes

1. point-like sources (extra-Galactic)
   - **auto-correlation**: search for clusters of events: space or space-time coincidences
   - correlation with underlying **catalogue of preselected sources** upon astrophysical motivation

   > AGNs catalogued by Fermi, star-forming Galaxies, IceCube HE sample

2. extended sources (Galactic)
   - disk-shaped, fitted or based on extension seen in γ-ray emission
   - assuming **shape of γ-ray emission**, when morphology is resolved

   > Neutrinos and γ rays are strictly connected as they are daughters of $\pi^{\pm}$, π^{0}.

3. follow-up of prompt **multi-messenger** alert

Search for point sources (all-sky)

Assuming ν flux $\propto E^{-2}$, KM3NeT/ARCA will reach comparable level to IceCube for the Northern Hemisphere, and improve by almost a factor 2 for the Southern Hemisphere

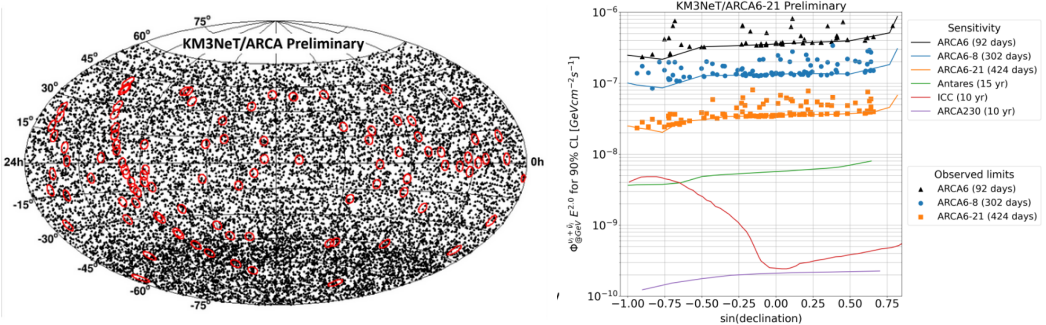
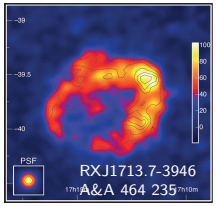


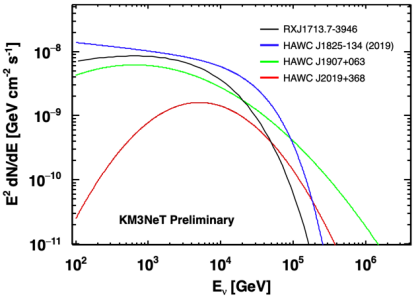
Figure: Upper limits at 90% C.L. reached with KM3NeT/ARCA [PoS(ICRC2023)1018]. Red circles are 2.5° around the candidate source positions.

Sensitivity to strongest Galactic sources

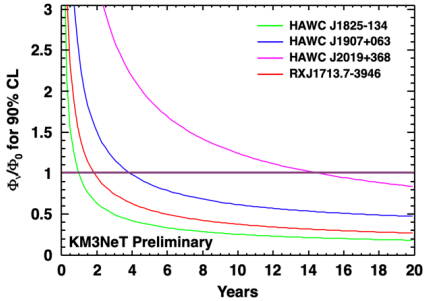
In hypothesis of hadronic emission, computing ν flux from γ-ray flux, several **extended Galactic sources** will be observable in a few years of operation.



Example of γ-ray emission as seen by H.E.S.S.



Expected ν fluxes (assumed 100% hadronic scenario)



Sensitivity at 90% CL as a function of the observation time

Physics case 2: fundamental neutrino properties

From analysis of **atmospheric neutrinos** at very high statistics.

1. Neutrino oscillations
   - Measurement of flavour oscillations through ν rate count and best-fit Δm^2_{23} and $\sin^2\theta_{23}$
   - Matter effects in propagation through the Earth and different interaction cross section $\sigma_\nu/\sigma_{\bar{\nu}}$ $\rightarrow$ differences in neutrino rates for normal and inverted ordering
   - ν_τ appearance $\rightarrow$ see talk by C. Lastoria
2. Physics beyond the Standard Model
   - Non-standard oscillations (NSI) $\rightarrow$ see talk by A. Lazo
   - Neutrino quantum decoherence
   - Neutrino decay
   - Sterile neutrinos
   - Violation of Lorentz Invariance
   - Heavy Neutral Leptons

Neutrino oscillations with ORCA-6 lines

Oscillations are seen with significance $> 6\sigma$ in L/E distributions [PoS(ICRC2023)996] with ORCA-6 data set 433 kton-years (540 days)

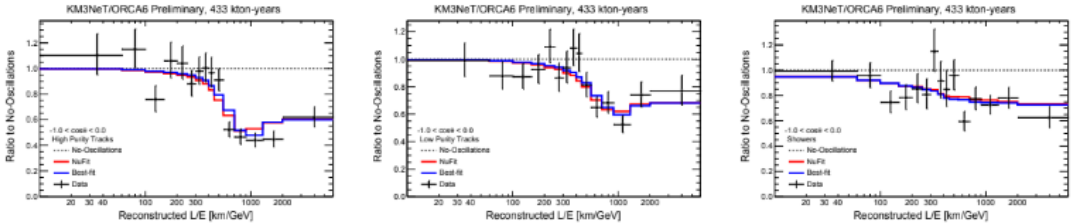
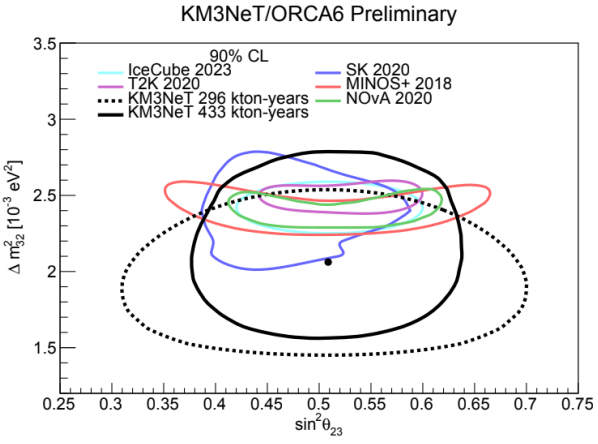
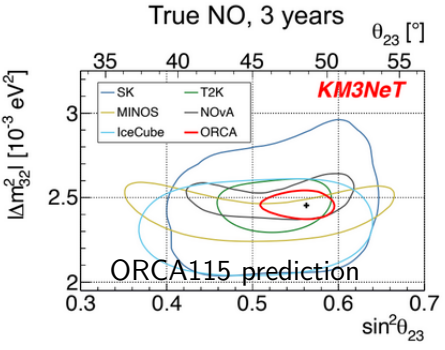


Figure: L/E distributions. Left: high-purity tracks; middle: low purity tracks; right: showers.

Atmospheric oscillation parameters

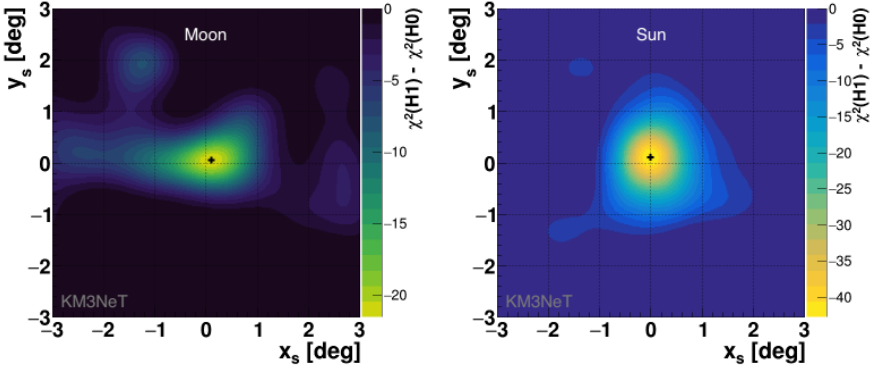
Best fit: $\sin^2\theta_{23} = 0.51^{+0.06}_{-0.07}$ $\Delta m^2_{31} = 2.14^{+0.36}_{-0.25} \cdot 10^{-3}\text{eV}^2$. Normal ordering is preferred.





Measurements with atmpspheric muons

Sun shadow seen with 6.2 σ significance (extension 0.65°), moon shadow seen with 4.2 σ significance (extension 0.49°) [Eur. Phys. J. C 83, 344 (2023)].



Core-collapse supernova ν

Produced in stellar core collapse at the end of stellar evolution like SN1987A. Real-time search for simoultaneous rate raise in DOMs [PoS(ICRC2021)941]

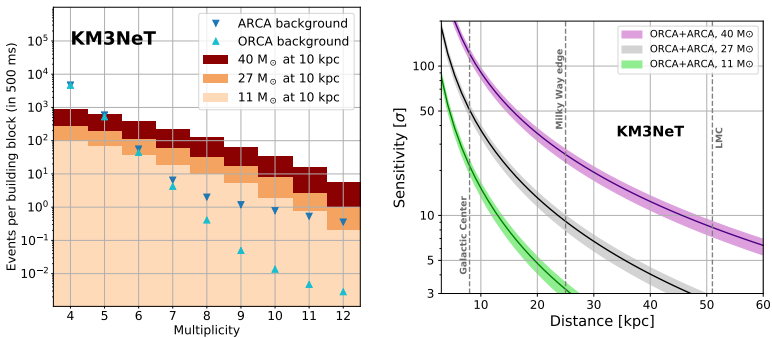


Figure: Left: SN events expected from 3 simulated progenitors at ORCA and ARCA as a function of different multiplicity values compared with BG rates. Right: Sensitivity as a function of distance.

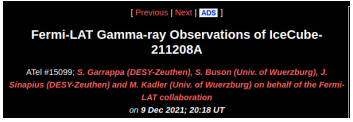
Multi-messenger networking

Flares, transients and other sources with time variability (GRBs, gravitational waves, SN)

Including the case of mixed hadronic/leptonic emission, where flares are caused by hadronic emission on top of quiescent state → Prompt alerting system between experiments, associated with rapid online analysis (and pointing directions for telescopes)

KM3NeT is getting ready to send and receive alerts in multi-messenger network

1. SN pipeline already active for real-time analysis
2. KM3NeT will replace ANTARES in follow up of alerts (ATel, GCN via AMON)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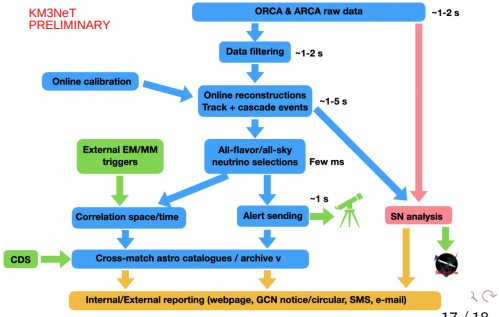
Fermi-LAT Gamma-ray Observations of IceCube-211208A

ATel #15099; *S. Garrappa (DESY-Zeuthen), S. Buson (Univ. of Wuerzburg), J. Sinapius (DESY-Zeuthen) and M. Kadler (Univ. of Wuerzburg) on behalf of the Fermi-LAT collaboration*
on *9 Dec 2021; 20:18 UT*



Summary

KM3NeT/ARCA - current status: 21 lines, topping up ANTARES effective area

1. able to detect the **diffuse flux** observed by IceCube with **5σ** significance in **half a year**
2. sensitivity to **astrophysical sources** in the Southern Hemisphere improves by almost 2 orders of magnitude with respect to IceCube
3. participation in **multi-messenger** prompt alert network

KM3NeT/ORCA - current status: 19 detection line, recording data at $\sim$ 400 kton year

1. Measurement of **neutrino oscillations** and best fit of oscillation parameters
2. Seach for new physics: ν_τ normalization factor, NSI, quantum decoherence, violation of Lorentz invariance, neutrino decay, dark matter through indirect detection