Neutrino Astronomy with KM3NeT/ARCA

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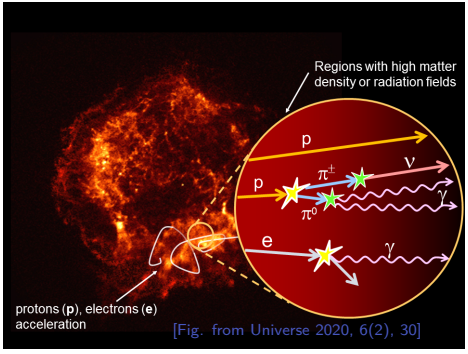
High-energy cosmic neutrinos

Neutrinos are expected from cosmic collisions yielding particles such as $\pi^{\pm}$ and $\mu^{\pm}$.

Two major mechanisms for high-energy neutrino production: pp and $p\gamma$ scattering.



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

This can take place in different environments

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

Neutrino astronomy

High-energy astrophysics is multi-wavelength and multi-messenger. It includes:

- Observation of source = emission (γ rays, ν) caused by projectile (hadron? lepton?) on target (depends on source environment)
- Direct observation of projectile (cosmic rays): anisotropy

Extragalactic sources with high density of γ (AGN jets)

$p + \gamma \to \Delta^+ \to \pi^0 + p$ or $\pi^+ + n$ Inverse Compton $e + \gamma$

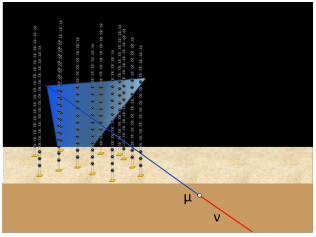
Galactic sources with mixed environment with molecular gas (clouds), starlight, IR light

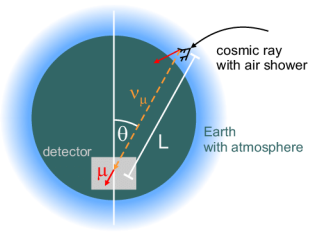
$p + N \to X + \text{many}(\pi^\pm, \pi^0)$ Inverse Compton $e + \gamma$, Bremsstrahlung $e + p$

Neutrinos are fingerprint of hadronic processes.

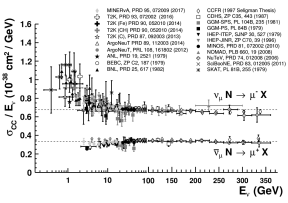
Neutrino astronomy in the making: Cherenkov detectors

Look through the Earth for lepton tracks from $\nu \to l$ conversion. $\sigma_{\nu \to l} \sim 10^{-38}$ cm^2 at 1 GeV!





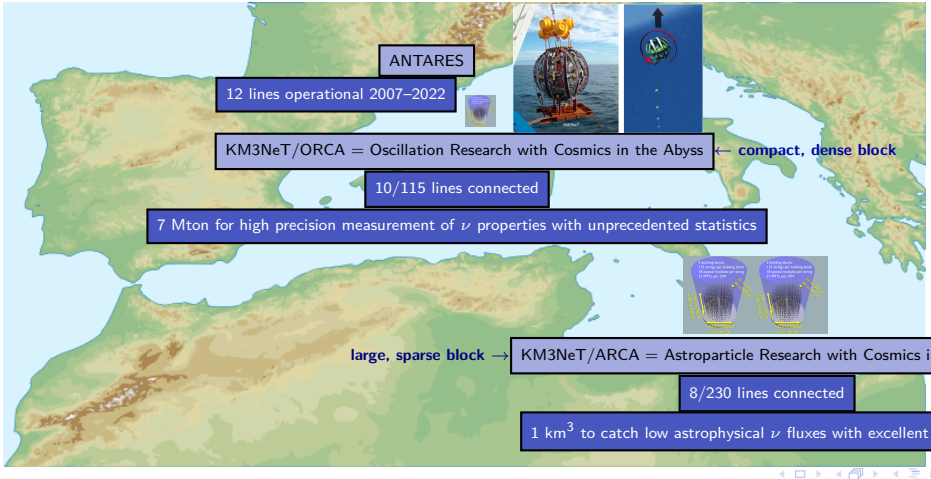
[pdg.lbl.gov/2019]



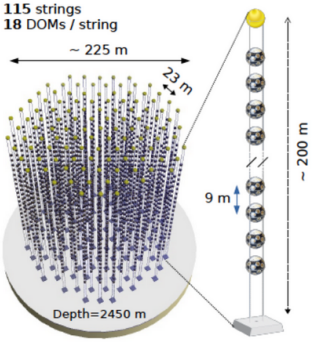
- Work at very faint signal rates instrumenting large reservoirs of transparent medium
- Need excellent angular resolution for directional reconstruction (connected with efficiency, geometry and scattering length of light in medium)
- Need algorithms for energy reconstruction (relying on Monte Carlo simulations)

KM3NeT

Infrastructure of different detectors, remotely operated, almost 100% duty cycle, one unique data set (broad physics program), with transfer of knowledge from ANTARES

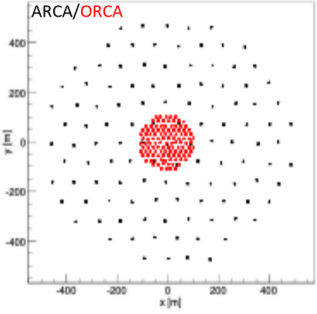


Zoom on the layout of the KM3NeT building block



ORCA and ARCA
same design

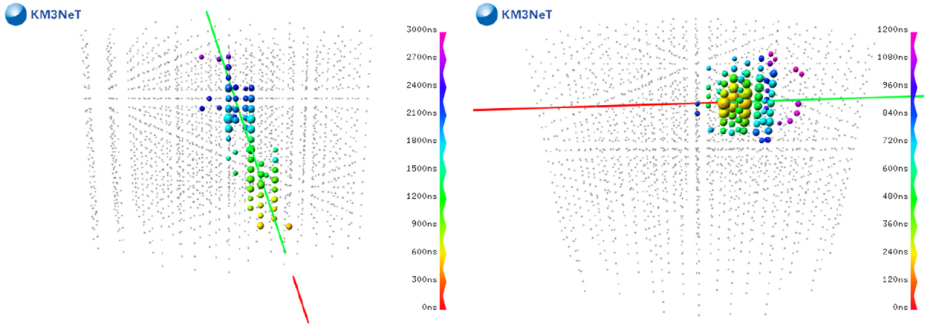
same digital optical
module (DOM)
holds 31 photomultipliers



ARCA: 90 m inter-string
ARCA: 36 m inter-DOM
ORCA: 23 m inter-string
ORCA: 9 m inter-DOM

Experimental challenge

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



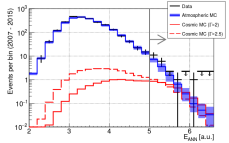
Tracks: predominantly $\nu_\mu CC$; angular resolution down to 0.1° at 1 PeV

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

Typical search modes

Diffuse search

Excess at high energies without directional information

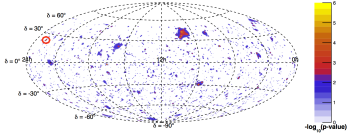


Multimessenger search

Space-time coincidence upon alert from other experiments

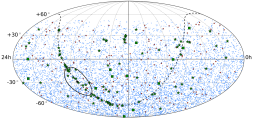
Point source search (auto-correlation)

Space (-time) clusters of events



Point source search (catalogue)

Space coincidence with preselected sources



Performance: KM3NeT/ARCA6 (lines deployed and connected)

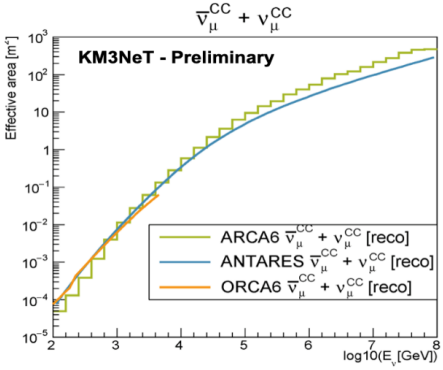


Figure: Effective areas. The current configuration of KM3NeT/ARCA has already topped ANTARES.

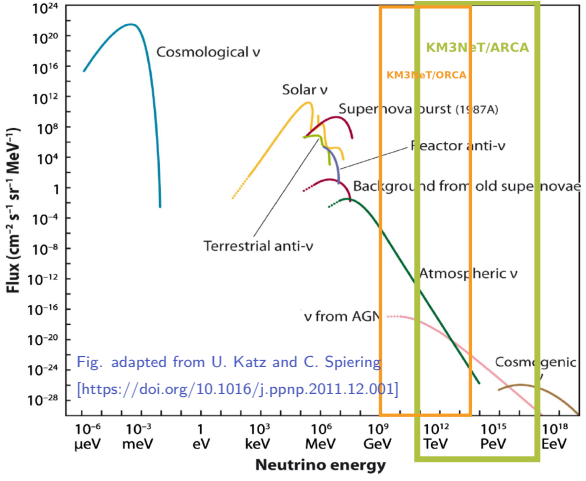
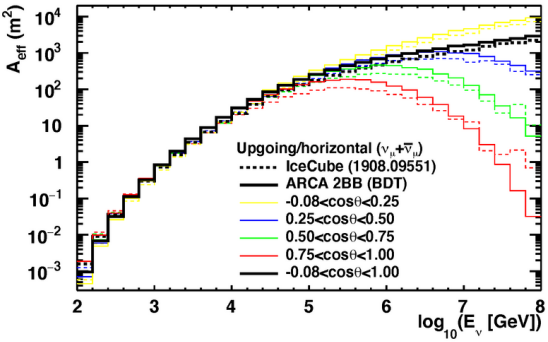


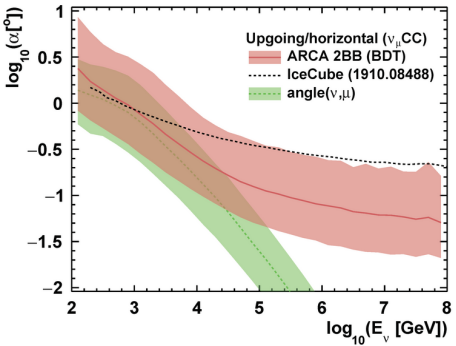
Fig. adapted from U. Katz and C. Spiering [https://doi.org/10.1016/j.ppnp.2011.12.001]

Performance: KM3NeT/ARCA full detector



Effective area $\nu_\mu + \bar{\nu}_\mu$
of complete KM3NeT/ARCA

[PoS(ICRC2021)1077]

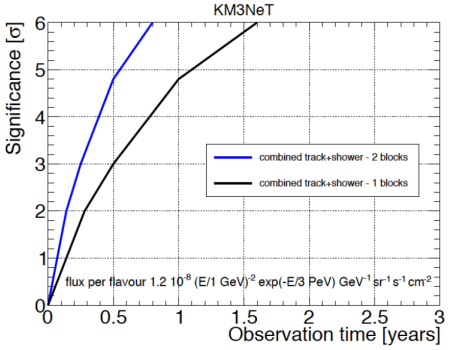


Angular resolution
for ν_μ CC events

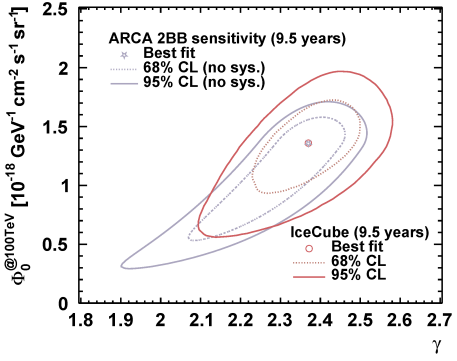
[PoS(ICRC2021)1077]

Measurement of diffuse ν flux

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(ICRC2021)1077].



Time evolution of significance



Confidence regions of flux parameters

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

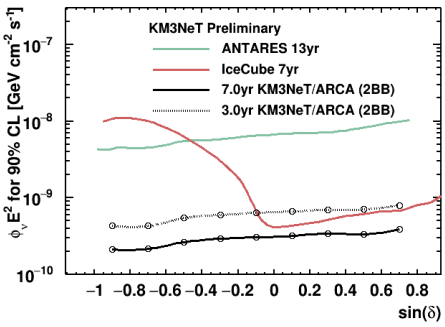
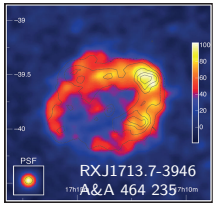


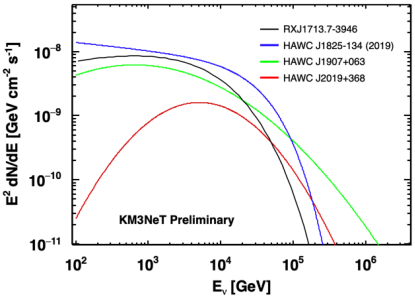
Figure: Sensitivity at 90% C.L. reached with 3 and 7 years of ARCA [PoS(ICRC2021)1077]

Sensitivity to strongest Galactic sources

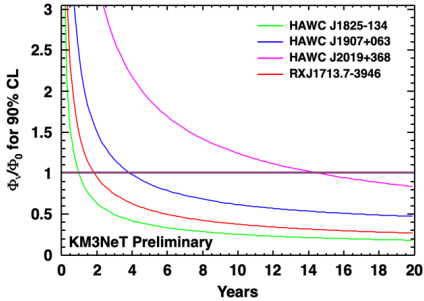
In hypothesis of hadronic emission, computing ν flux from γ-ray flux, several **extended Galactic sources** will be observable in a few years of operation.



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

Core-collapse supernova ν

Produced in stellar core collapse at the end of stellar evolution (like SN1987A). Real-time search based on coincident rate raise in single DOMs (multiplicity 7-11 in 500 ms time window) $\rightarrow$ performed by both ORCA and ARCA [PoS(ICRC2021)941]

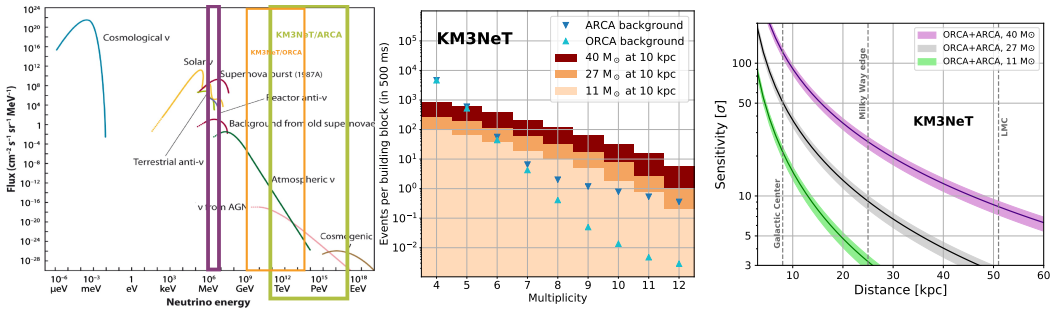


Figure: Middle: SN events expected from 3 simulated progenitors at ORCA and ARCA as a function of different multiplicity values compared with BG rates. Right: Sensitivity as a function of distance.

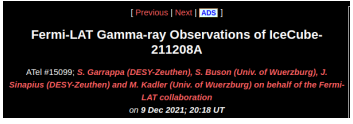
Multi-messenger networking

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)

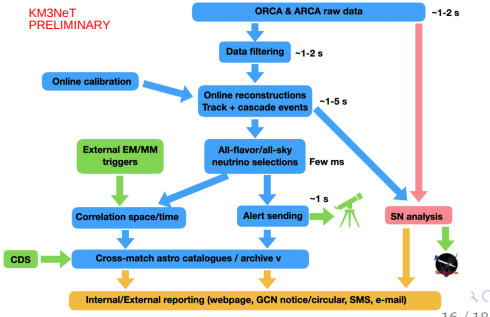
KM3NeT is getting ready to send and receive alerts in multi-messenger network

1. SN pipeline already active for real-time analysis
2. KM3NeT will replace ANTARES in follow up of alerts (ATel, GCN via AMON)


[Previous | Next | ADS]

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 is designed to catch **cosmic neutrinos** in the $10^2 - 10^8$ GeV energy range.

Current status: 8 detection lines are recording data.

Performance of the final km^3 array with 230 lines:

1. pointing accuracy down to **0.1°** at **1 PeV**
2. able to detect the **diffuse flux** observed by IceCube with **5σ** significance in **half a year**
3. sensitivity to **astrophysical sources** in the Southern Hemisphere improves by almost 2 orders of magnitude with respect to IceCube
4. participation in **multi-messenger** prompt alert network