

PhD annual report - first year

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Summary of research activity

I carry out my research as part of the KM3NeT experiment. The KM3NeT telescope, currently under construction in the deep Mediterranean Sea, is an advanced facility designed to detect neutrinos. It consists of two detectors: KM3NeT/ARCA, dedicated to the study of TeV-PeV cosmic neutrinos, and KM3NeT/ORCA, primarily focused on the intrinsic properties of neutrinos. Overall, the KM3NeT telescope is sensitive to neutrinos across a range from a few MeV to tens of PeV. The detection principle consists of using a network of hundreds of thousands of photo-multiplier tubes to capture Čerenkov light produced by high-energy neutrinos interacting with seawater. While ongoing construction, both detectors are already taking data with about 15% of the planned detection units.

KM3NeT Real-Time Analysis: alert-sending system

KM3NeT plays an active role in real-time multi-messenger astronomy. The KM3NeT Real-Time Analysis (RTA) framework quickly reconstructs KM3NeT/ARCA and KM3NeT/ORCA events, receives alerts from other multi-messenger observatories, selects the relevant ones and performs follow-up analyses, searching for neutrino events in spatial and temporal coincidences with cosmic phenomena indicated by external alerts.

During my first year of PhD, my primary focus has been on the KM3NeT RTA program, particularly on developing the KM3NeT alert-sending system. The aim of the alert-sending system is to promptly select well-reconstructed events and to notify the multi-messenger community, allowing other observatories to perform follow-up analyses on KM3NeT neutrino alerts and draw statistical conclusions. The event selection process minimizes contamination from atmospheric background and favours events with better angular resolution. I have defined a strategy for calculating the event-by-event directional uncertainty to be associated with KM3NeT alerts and tested it for KM3NeT/ARCA28 detector, that is actually taking data. Currently, I am involved in developing the architecture for the alert-sending system for KM3NeT/ARCA and establishing the event selection criteria for various types of neutrino alerts that the system will support. My main focus is on refining the criteria for Very-High-Energy (VHE) neutrino alerts.

Additionally, as a member of the KM3NeT RTA group, I have participated in 4 multi-messenger shifts, including one as shift leader, as well as 2 standard shifts. The multi-messenger shifts were crucial in helping me understand the process and requirements for sending KM3NeT alerts automatically.

KM3NeT VHE event follow-up analysis

In June, during the “Neutrino 2024” conference held in Milan, the KM3NeT Collaboration announced the detection of a significant event by the KM3NeT/ARCA21 detector. This event triggered 3672 PMTs, i.e. 35% of the active sensors in KM3NeT/ARCA21. It was reconstructed as a track-like event, indicating a high-energy muon passing through the detector, with three large showers observed along its path, attributed to stochastic energy losses from the muon. Simulations show that atmospheric muons with 10 PeV of energy would rarely produce this much light, suggesting that the neutrino responsible for generating the muon likely had multiple tens of PeV energy. The event’s incoming direction was nearly horizontal, consistent with the behaviour expected for VHE neutrinos, since the Earth becomes opaque to neutrinos at PeV energies.

Regarding this event, I have contributed by conducting several analyses to look for additional neutrinos in the KM3NeT/ORCA and KM3NeT/ARCA datasets to better understand the nature of this event. This work has now been completed and details of the event and its analysis will be published soon.

Alternative design for KM3NeT/ARCA 2nd building block

In its final configuration, KM3NeT/ARCA will consist of 230 detection units (DUs) organised into two building blocks of 115 DUs each. The DUs are flexible strings anchored to the seabed, each carrying 18 Digital Optical Modules (DOMs) with 31 PMTs for Čerenkov light detection. Currently, 28 strings from the first block are deployed and operational. In

this configuration, the DUs are spaced 90 m apart with the DOMs placed at intervals of 36 m. This arrangement is optimised to increase the detector's response to neutrinos in the TeV-PeV energy range.

I am currently investigating an alternative design for the second block of KM3NeT/ARCA, with larger spacing between DUs and DOMs, as a more sparse arrangement could improve the detector's sensitivity to neutrinos with energies above 100 GeV. This work is particularly relevant following the recent detection of the VHE neutrino event, which highlights the need for enhanced sensitivity in this energy range.

Attended courses

- Advanced Statistics for Data Analysis (F. Badaracco, F. Di Bello, F. Parodi) - exam not given yet
- Introduction to High-Energy Astrophysics (F. Tavecchio) - exam not given yet
- Metodi di Machine Learning per la Fisica (F. Di Bello, A. Coccaro, R. Torre) - 2 slots from LM-17 - exam not given yet
- International School of Nonequilibrium Phenomena - 6th Course: Astroparticle Physics, Dark Matter and High Energy Physics, Erice (IT), 1-7/08/2024

Publications

- [1] KM3NeT collaboration, *Embedded software of the KM3NeT central logic board*, *Comput. Phys. Commun.* **296** (2024) 109036 [[2308.01032](#)].
- [2] CTA CONSORTIUM, KM3NeT collaboration, *Prospects for combined analyses of hadronic emission from γ -ray sources in the Milky Way with CTA and KM3NeT*, *Eur. Phys. J. C* **84** (2024) 112 [[2309.03007](#)].
- [3] KM3NeT collaboration, *Searches for neutrino counterparts of gravitational waves from the LIGO/Virgo third observing run with KM3NeT*, *JCAP* **04** (2024) 026 [[2311.03804](#)].
- [4] KM3NeT collaboration, *The Power Board of the KM3NeT Digital Optical Module: design, upgrade, and production*, *Electronics* **13** (2024) 2044 [[2311.14872](#)].
- [5] KM3NeT collaboration, *Differential Sensitivity of the KM3NeT/ARCA detector to a diffuse neutrino flux and to point-like source emission: Exploring the case of the Starburst Galaxies*, *Astropart. Phys.* **162** (2024) 102990 [[2402.09088](#)].
- [6] KM3NeT collaboration, *Search for neutrino emission from GRB 221009A using the KM3NeT ARCA and ORCA detectors*, *JCAP* **08** (2024) 006 [[2404.05354](#)].
- [7] KM3NeT collaboration, *Atmospheric muons measured with the KM3NeT detectors in comparison with updated numeric predictions*, *Eur. Phys. J. C* **84** (2024) 696 [[2403.11946](#)].

Conferences

- Talk at "International School of Nonequilibrium Phenomena - 6th Course: Astroparticle Physics, Dark Matter and High Energy Physics", *The KM3NeT neutrino telescope and its Real-Time Analysis framework*, Erice, 1-7/08/2024.
- Talk at "KM3NeT Astronomy face-to-face Meeting", *Compute direction containment circles for KM3NeT neutrino alerts*, Granada, Spain, 16-19/04/2024.
- Talk at "KM3NeT Astronomy face-to-face Meeting", *Event selection and direction error for KM3NeT/ARCA neutrino alerts*, Kalamata, Greece, 10-13/09/2024.

Other activities

- I have attended the "KM3NeT Boot Camp 2023" (KM3NeT's early-career scientist training program)
- Teaching assistant for
 - "Fisica generale - modulo A" class at the Mechanical Engineering bachelor course.
 - "Fisica generale - modulo B" class at the Mechanical Engineering bachelor course.