# First Year PhD Report

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## Research activities

I am currently conducting my PhD research within the KM3NeT collaboration [1]. The experiment consists of two deep-sea neutrino telescopes designed to detect neutrinos through the Cherenkov light emitted by charged particles produced in neutrino interactions in seawater. Although both detectors are still under construction, they are already operational and taking data. The instrumented volume is expanding progressively as new Detection Units (DUs) are deployed and connected. KM3NeT/ORCA primarily investigates the fundamental properties of neutrinos in the energy range from hundreds of MeV to tens of TeV, while KM3NeT/ARCA focuses on high energy and cosmic neutrinos, covering an energy range from TeV to tens of PeV.

### Calibration

As part of the integration of new components into the telescopes, I contributed to the calibration activities, which are essential to ensure the optimal performance of each deployed Detection Unit. A DU consists of several equally spaced Digital Optical Modules (DOMs), which are pressure-resistant glass spheres housing photomultiplier tubes (PMTs) and acquisition electronics.
During the first year of my PhD, I performed different calibration steps. First, a power test was carried out to verify the consumption of the various components. The high-voltage settings of the PMTs were then calibrated through HV scans and HV tuning in a dark room, with the analysis of the Time over Threshold (ToT) allowing optimisation of the PMT operating parameters. Subsequently, tests were carried out with nanobeacons, small calibrated LED light sources, and lasers, which are essential for time calibration and synchronisation between DOMs. Acoustic tests were also performed using hydrophones to verify the system's response to sound inputs. All calibration runs and related results were uploaded to the official databases and documented in the ELOGs to ensure traceability and consistency of the process. These activities validated the correct functioning of the DUs and their integration into the detection facility.

### Validation of J-factor calculations

As part of the KM3NeT dark matter group, I contributed to validating the astrophysical factors that determine the expected neutrino flux from dark matter self-annihilation or decay. One crucial ingredient is the J-factor, which quantifies the distribution of dark matter along a given line of sight.
To this end, I reproduced the J-factor calculations performed using the public Clumpy code [2] and implementing an independent Python integration of the smooth halo component. I tested different halo profiles (Einasto, Burkert and NFW), fixing the scale radius and density parameters to the values used by Clumpy for consistency. The results obtained with my code were in good agreement with those obtained with Clumpy for the Einasto and Burkert profiles. For the NFW case, however, I identified small discrepancies, which I traced back to differences in the integration conventions and to the peak feature of NFW profile in the center of DM halo.
This validation work helped to ensure the robustness of the J-factor inputs used in KM3NeT dark matter searches providing confidence in the reliability of the astrophysical assumptions done.

### Template analysis for extended sources

I have started studying and working on a framework to analyze extended astrophysical sources using templates. The aim is to exploit KM3NeT sensitivity to diffuse emission more efficiently. The idea is to model the expected signal using spatial templates that represent the source's emission morphology combined with the detector response and background estimation. This approach enables a more accurate likelihood analysis by incorporating spatial and spectral information that will allow to better characterize potential signals. This method will facilitate comparison of emission models in order to distinguish between hadronic and leptonic origins. The ultimate goal is to estimate KM3NeT sensitivity to selected extended sources, I will work on the Fermi Bubble region, and to search for a possible neutrino flux associated with them.

## Referencies


[1] S Adrián-Martínez et al. "Letter of intent for KM3NeT 2.0". In: *Journal of Physics G: Nuclear and Particle Physics* 43.8 (June 2016), p. 084001. ISSN: 1361-6471. DOI: 10.1088/0954-3899/43/8/084001. URL: http://dx.doi.org/10.1088/0954-3899/43/8/084001.

[2] Moritz Hütten, Céline Combet, and David Maurin. "CLUMPY v3: $\gamma$-ray and $\nu$ signals from dark matter at all scales". In: *Computer Physics Communications* 235 (Feb. 2019), pp. 336–345. ISSN: 0010-4655. DOI: 10.1016/j.cpc.2018.10.001. URL: http://dx.doi.org/10.1016/j.cpc.2018.10.001.


## Attended courses

- Advanced Statistics for Data Analysis
- Astrophysical Experimental Methods
- The Double Trouble of the Missing Matter in the Universe
- Neutrino Physics: Theory and Experiments

## Other activities

- I attended the "KM3NeT Boot Camp 2024" wich took place in Erlangen (KM3NeT's early-career scientist training program)
- I participated to the Collaboration Meeting of June 2025 in Caen
- I had an educational trip to Teide and La Palma astronomical observatories.

## Pubblications


[3] KM3NeT collaboration. "gSeaGen code by KM3NeT: An efficient tool to propagate muons simulated with CORSIKA". In: *Comput. Phys. Commun.* 314 (2025), p. 109660. DOI: 10.1016/j.cpc.2025.109660. arXiv: 2410.24115 [hep-ex].

[4] KM3NeT collaboration. "First searches for dark matter with the KM3NeT neutrino telescopes". In: *JCAP* 03 (2025), p. 058. DOI: 10.1088/1475-7516/2025/03/058. arXiv: 2411.10092 [astro-ph.HE].

[5] KM3NeT collaboration. "Search for non-standard neutrino interactions with the first six detection units of KM3NeT/ORCA". In: *JCAP* 02 (2025), p. 073. DOI: 10.1088/1475-7516/2025/02/073. arXiv: 2411.19078 [hep-ex].

[6] KM3NeT collaboration. "Probing invisible neutrino decay with the first six detection units of KM3NeT/ORCA". In: *JHEP* 04 (2025), p. 105. DOI: 10.1007/JHEP04(2025)105. arXiv: 2501.11336 [hep-ex].

[7] KM3NeT collaboration. "Study of tau neutrinos and non-unitary neutrino mixing with the first six detection units of KM3NeT/ORCA". In: *JHEP* 07 (2025), p. 213. DOI: 10.1007/JHEP07(2025)213. arXiv: 2502.01443 [hep-ex].

[8] KM3NeT collaboration. "Observation of an ultra-high-energy cosmic neutrino with KM3NeT". In: *Nature* 638.8050 (2025). [Erratum: Nature 640, E3 (2025)], pp. 376–382. DOI: 10.1038/s41586-024-08543-1.

[9] KM3NeT collaboration. "Ultrahigh-Energy Event KM3-230213A within the Global Neutrino Landscape". In: *Phys. Rev. X* 15.3 (2025), p. 031016. DOI: 10.1103/yypk-zmb8. arXiv: 2502.08173 [astro-ph.HE].

[10] KM3NeT collaboration. "On the Potential Galactic Origin of the Ultra-High-Energy Event KM3-230213A". In: (Feb. 2025). arXiv: 2502.08387 [astro-ph.HE].

[11] KM3NeT collaboration. "Characterising Candidate Blazar Counterparts of the Ultra-High-Energy Event KM3-230213A". In: (Feb. 2025). arXiv: 2502.08484 [astro-ph.HE].

[12] KM3NeT collaboration. "On the Potential Cosmogenic Origin of the Ultra-high-energy Event KM3-230213A". In: *Astrophys. J. Lett.* 984.2 (2025), p. L41. DOI: 10.3847/2041-8213/adcc29. arXiv: 2502.08508 [astro-ph.HE].

[13] KM3NeT collaboration. "KM3NeT Constraint on Lorentz-Violating Superluminal Neutrino Velocity". In: (Feb. 2025). arXiv: 2502.12070 [astro-ph.HE].

[14] KM3NeT collaboration. "Evaluation of the upgraded 3-inch Hamamatsu photomultiplier for the KM3NeT Neutrino Telescope". In: (Apr. 2025). arXiv: 2504.02989 [hep-ex].

[15] KM3NeT collaboration. "Measurement of the atmospheric $\nu_\mu$ flux with six detection units of KM3NeT/ORCA". In: *Eur. Phys. J. C* 85.8 (2025), p. 871. DOI: 10.1140/epjc/s10052-025-14513-2. arXiv: 2504.09119 [hep-ex].

[16] KM3NeT collaboration. "The Online Data Filter for the KM3NeT Neutrino Telescopes". In: (June 2025). arXiv: 2506.05881 [astro-ph.IM].