# PhD annual report

**PhD student**: Andrey Romanov. First year student of Physics and Nanoscience program.
**Tutors**: Vladimir Kulikovskiy, Matteo Sanguineti.

**Summary of research activity.**

I perform my research within the KM3NeT Collaboration. The KM3NeT detector is an underwater neutrino telescope currently taking data while being still under construction in the Mediterranean Sea. Atmospheric muons produced in the interactions of cosmic rays in the atmosphere represent a main background for the underwater neutrino telescopes. Hence, a correct estimation of such background is essential in order to be able to detect cosmic neutrinos. The KM3NeT detectors - ORCA, moored at 2450 m depth and ARCA moored at 3500 m depth are capable to precisely reconstruct muon directions and measure muon energy left in the detector volume. The muon composition at such depths is a unique probe for the cosmic ray models.

Evaluation of atmospheric muons properties at the detector site can be done using a full Monte Carlo (MC) simulation software. However, a main disadvantage of such simulations is a large CPU time. On the other hand, there is a fast event generator of atmospheric muons which is called MU-PAGE (MUon GEnerator from PArametric formulas). MUPAGE is based on parametric formulas describing the flux of muon bundles at different water depths and zenith angles, the lateral spread and the energy spectrum of muons. In practice, MUPAGE does not actually simulate particles and their propagation and interactions, but it provides a table containing the kinematics of atmospheric muon bundles for a certain depths and zenith angle. Using this approach, it works much faster than any full MC simulation programs. Parametric formulas used in the MUPAGE were obtained using the HEMAS (Hadronic, Electromagnetic and Muonic components in Air Showers) code which provides the full MC simulation. However, there is a discrepancy between the MUPAGE results and the real data as it was measured by the ANTARES and the KM3NeT neutrino telescopes. Therefore, we decided to find a new parametrisation of the MUPAGE using a more recent MC full simulation program which is CORSIKA (COsmic Ray SImulations for KAscade).

During my first year of PhD, I was developing a framework to tune the MUPAGE parametrisation on the CORSIKA simulation. In particular, I used atmospheric muons at the sea-level obtained from the CORSIKA that I subsequently propagated under water to large cylinders with a radius of 10 km and a height of 1 m located at a certain water depth. The propagation of muons through water was performed using the gSeaGen code, that in

turn uses MUSIC or PROPOSAL propagators. Then, I fitted the muon distributions at different depths with the MUPAGE formulas obtaining the new parametrisation. It was done for the CORSIKA version 7.7400, using SIBYLL-2.3d to describe the high-energy hadronic interactions. But I found that this version contains a bug related to a vertical muons simulation. The CORSIKA developers were informed about it and the new correct version is ready. For the moment, I am working with the latest CORSIKA version 7.7410. The next step will be to compare the results from the new MUPAGE parametrisation with the real data measured by the KM3NeT telescope.

**List of attended courses and exams given**:

- Electronics and data acquisition.
- Gravitational Waves.
- Introduction to High-Energy Astrophysics.
- Summer School, ISAPP 2021 Valencia "Neutrino Physics, Astrophysics and Cosmology".

**List of publications**:

- "Observation of the cosmic ray shadow of the Sun with the ANTARES neutrino telescope", A, Albert *et al.*, Phys. Rev. D **102**, 122007 (2020). (topic of the Master Thesis, publication finalized during the PhD)
- "The KM3NeT potential for the next core-collapse supernova observation with neutrinos", S. Aiello *et al.*, Eur. Phys. J. C **81**, 445 (2021).

**List of conference presentations**:

- 37th International Cosmic Ray Conference, ICRC 2021, Berlin (Online Conference), 12-23 July 2021. "Observation of the cosmic ray shadow of the Sun with the ANTARES neutrino telescope" (poster)
- VLVnT 2021 - Very Large Volume Neutrino Telescope Worksop, Valencia (Online Conference), 18-21 May 2021. "Observation of the cosmic ray shadow of the Sun with the ANTARES neutrino telescope" (talk)
- Two ANTARES and KM3NeT Online Collaboration Meetings, 7-18 June 2021 and 8-19 February 2021. "CORSIKA and MUPAGE comparison at different depths at generation level".