Measurement of the Neutrino Mass Hierarchy with the ORCA Detector

After the successful measurement of the mixing angle θ_{13} [1,2], the determination of the neutrino mass hierarchy (MH) has become a priority for future neutrino experiments. It has been proposed to perform such a measurement with atmospheric neutrinos [3]. The highest sensitivity to the MH is obtained for neutrinos of 5-10 GeV which traverse the Earth at zenith angles of 30˚-60˚. ANTARES, a neutrino telescope in the Mediterranean Sea, designed to search for high-energetic astronomical neutrino signals, has recently demonstrated its ability to reliably measure neutrinos with energies as low as 20 GeV [4], a range where neutrino oscillations start to play a dominant role. KM3NeT [5] will be the next generation neutrino telescope in the Mediterranean Sea with an effective volume of several cubic kilometers. Funds for "phase 1" of the project, corresponding to about 20% of the total envisaged budget, are meanwhile available. A dedicated feasibility study "Oscillation Research with Cosmics in the Abyss" (ORCA), to evaluate the potential of a mass hierarchy measurement with "phase 1" of KM3NeT is currently underway.

ORCA might consist of about 50 detector lines, each equipped with 20 optical modules. Each optical module hosts 31 3'' phototubes, as described in the KM3NeT TDR [5]. Optical modules with many small phototubes have an enhanced photon counting capability and provide better directional information than larger tubes. This can be exploited in reconstruction algorithms and for background rejection. The readout will be largely simplified compared to ANTARES. For each detected pulse only a timestamp and the "time over threshold" will be recorded. Online filter algorithms will be applied in an on-shore computing farm, as successfully done for ANTARES.

The distance of adjacent detector lines on the sea bed will be approximately 20m, a value determined by deployment safety. The vertical distance between modules on a detector line is expected to be between 5m and 10m, the precise value being subject to optimization. This leads to an instrumented water mass of 2-4 Mtons. Preliminary studies have shown that sea water, which is a low-scatter medium allows the reliable reconstruction of muons from ν_μ and (anti-ν_μ) interactions in the energy range of 5-15 GeV. Both the zenith angle of the muons as well as their range can be well measured for tracks which are confined in the instrumented volume. The typical optical noise in sea water does not deteriorate the performance. Current studies focus on the neutrino energy measurement, flavor tagging (distinction of tracks and cascades) and atmospheric muon background rejection.

Determining the MH of neutrinos is not the only physics topic of ORCA. If the envisaged performance specifications can be reached, ORCA will also improve by a substantial factor the precision of the atmospheric oscillation parameters Δm^2_{32} and $\sin^2 2\theta_{23}$. Dark matter annihilation signals from the center of our Galaxy and from the Sun can be searched for as well in the energy range of a few GeV.

If it can be demonstrated that the envisaged physics goals can be reached, the construction of the detector, as described above, could be started within the presently available budget. A new, simplified deployment scheme has been proposed [5] which would allow for deploying several detector lines during one sea operation, thus significantly shortening the installation time in comparison to existing under-water detectors. A decision whether to opt for ORCA as the "phase 1" of the KM3NeT project is aimed for late 2013.

References

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