Search for dark matter with multi-tonne liquid argon detectors

Mystery of dark matter. We know that most of the matter in our universe is dark matter, which accounts for 23% of the mass-energy density of the observable universe (while ordinary matter accounts for only 4.6% and the remainder is attributed to dark energy). However, the exact nature of dark matter (and dark energy) is still unknown and its origin is at present one of the most important questions in physics. A currently favored hypothesis is that dark matter is composed of WIMPs, Weakly Interacting Massive Particles, which have so far remained undetected. A direct detection of a dark matter particle would be a clear sign of new physics beyond the Standard Model of particle physics, would greatly contribute to our understanding of the Universe, fundamental laws of physics and will guide the scientific community towards a more complete theory.

Direct searches for dark matter. The search for WIMP interactions with ordinary matter is carried out with large detectors located in underground laboratories (such as SNOLAB in Canada or Gran Sasso in Italy), in order to suppress the background from cosmic rays. The currently most promising detection technology is based on the use of a large instrumented mass of liquid argon or xenon as the target in the detector. WIMPs can be detected as they may induce scintillation (emission of light) and ionization (release of electric charge) when passing through e.g. liquid argon.

Given the advantages of liquid argon, the four major experiments joined in a global collaboration to continue operation of the DEAP-3600 detector with 3.3 tons of liquid argon at SNOLAB, Canada, and build the DarkSide-20k detector at Laboratori Nazionali del Gran Sasso, Italy, by 2026. The final goal is then to build ARGO, a 400 ton Global Argon Dark Matter Collaboration detector (GADMC), which will reach the ultimate sensitivity for heavy WIMPs, but will require crucial R&D to achieve such sensitivity.

Background events caused by natural sources of radioactivity are the main challenge in dark matter detectors, as they can mimic the expected signal from WIMPs. Backgrounds are mitigated with a variety of hardware and analysis methods, among the latter primarily with pulse shape discrimination, which critically depends on the number of detected photons.

Using larger than ever before liquid argon mass is necessary for achieving the desired sensitivity, and maximizing potential for a groundbreaking discovery. The efficient collection and detection of scintillation light, also directly affects the sensitivity to signal from WIMPs, in addition to improving the background rejection capabilities.

Therefore more efficient collection/detection of argon light after scaling-up to very large target masses is the key challenge for the next generation dark matter detectors. Scale-up of the existing light collection and detection solutions to these very large scales is a non-trivial task and a significant technological bottleneck, and the main focus of the R&D program proposed here.

Project goals. This proposal aims to make key contributions to the GADMC experimental program, through: (i) analysis of data and new physics results from DEAP-3600, currently the most sensitive running liquid argon-based detector operating at SNOLAB in Canada with the goal of improving its sensitivity by an order of magnitude, (ii) construction and commissioning of the next generation DarkSide-20k detector, particularly in the context of light collection system and pulse shape discrimination, and (iii) establish a unique facility for representative characterization of optical materials in cryogenic conditions for dark matter and neutrino detectors.

For the last item, the system will be equipped with a pulsed nanosecond source of vacuum ultraviolet (VUV) light close to the wavelength of liquid argon scintillation, and will allow for measurements close to liquid argon temperature. It will be used for quality control of materials for the DarkSide-20k detector, as well as in future research on scalable technologies for converting VUV to visible light.