Dark Matter searches with the ArDM detector

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Abstract. The goal of the ArDM project is to develop and operate a detector to search for
direct evidence of Weakly Interacting Massive Particles (WIMP) as Dark Matter in the
Universe. The technical design of the detector aims at independently measuring the
scintillation light and the ionization charge generated by the recoil of argon nuclei after the
WIMP collision. A Large Electron Multiplier system is used to collect the charge while an
array of photomultipliers detects the light. A 1-ton prototype is currently developed with the
goal of demonstrating the feasibility of such a direct detection experiment with large target
mass. The principle of the experiment and the conceptual design of the detector are described.

1. Introduction
The understanding of the nature of Dark Matter (DM), presumably over 80% of the total mass content
of the universe, is one of the most exciting problems in Particle Physics. Common models of DM
distribution describe it as consisting of a sea of non-baryonic, heavy weakly interacting massive
particles (WIMPs), forming a cold thermal relic gas. The detection of these WIMPs is based on the
capability of measuring the recoils of target nuclei with kinetic energy in the range of 10−100 keV.
Due to the weak coupling and the low imparted energy, WIMP signals are rare and elusive events. The
total interaction rate depends on underlying models whose parameters are numerically poorly known,
even in the context of well defined extensions of the Standard Model like e.g. SUSY, and is therefore
not yet predictable. Noble liquid detectors like argon or xenon provide advantageous features for
direct WIMP detection like high density and low ionization potential, resulting in a high ionization
(charge) and scintillation (light) yields. By computing the relative charge and light yields induced by
different types of interactions, the particles causing events in the detector can be identified.
Additionally, the time dependence of the scintillation light can be used to further discriminate between
WIMP signals and background signals. In addition, background radiation must be reduced to a very
low level by locating the experiment underground and by the use of low radioactive detector materials.
The Argon Dark Matter project (ArDM) [1], initiated in 2004, aims at developing a 1-ton liquid argon
detector with independent ionization and scintillation readout to demonstrate the feasibility of a ton-
scale liquefied noble gas Dark Matter detector.

2. Detection principle and detector design
The conceptual ArDM detector design is illustrated in Fig. 1. The detector is contained in a cylindrical
vessel where the liquid and vapour of the argon are in equilibrium.

\(^1\) On behalf of the ArDM collaboration
The three technical keypoints are the charge readout on the top, the drift field on the central region and the light readout on the bottom. If a particle interaction occurs in the active volume free ionization electrons and scintillation light (λ~128 nm) are produced (see Fig. 2). The former are pulled away from the interaction point and drifted upwards thanks to a strong electric field provided by a Greinacher high-voltage circuit, designed to reach up to 4 kV/cm. The maximal drift length is ~120 cm. When the electrons reach the level of the liquid argon surface, they are extracted into the gaseous argon volume on the top of the detector where the readout of the ionization charge takes place. Two LEM (Large Electron Multiplier) provide the needed electron amplification by means of a high electric field generated in small cylindrically shaped holes (500 µm diameter, 800 µm spacing). This defines the location of the event in space together with the prompt light signal.

On the other hand, scintillation light is readout with an array of 14 photomultiplier tubes (PMT) located at the bottom of the detector, just behind the semi-transparent cathode. The primary VUV scintillation light of argon needs to be shifted to visible light in order to match the PMT sensitivity window. This is achieved by coating the photocathode with a wavelength shifter like Tetra-Phenyl-Butadiene. The vessel wall is also covered with foils of Mylar coated with a thin aluminium layer to reflect the light, increasing the photon detection efficiency.

One of the most important backgrounds comes from the $^{39}$Ar isotope, present in natural argon liquefied from the atmosphere, due to its beta decay of approximately 1 kHz/ton of liquid argon [2]. The alternative possibility of using $^{39}$Ar-depleted argon extracted from underground natural gas is currently also under study. Nevertheless, the combination of charge and light readout should provide a powerful enough background rejection. Since nuclear recoils due to WIMP or neutron interactions have a much higher characteristic light over charge ration than electron and gamma interactions, these types of events are in principle well distinguishable if the light over charge ratio is measured precisely. This effect is clearly seen in Fig. 3 which shows the ArDM detector capabilities on rejecting $^{39}$Ar as a result of a GEANT4 simulation. In addition, the comparison on fast ($\tau_{\text{single}}$~6ns) and slow ($\tau_{\text{triplet}}$~1.7μs) light components can also be used to further discriminate between nuclear recoils and background events. Due to ionization densities, the population of argon excimer states is different for nuclear recoil and electron/gamma events, leading to characteristic contributions to the fast and slow scintillation light components [3].
3. Outlook

The first goal of the ArDM collaboration is to build and test a 1-ton liquid argon prototype to demonstrate the feasibility of the current design. The key points of the operation are (1) the LEM-based charge readout in gaseous argon, (2) the generation of a very high and stable electric field and (3) the efficient readout of the argon scintillation light. A full test programme will be carried out at CERN, where the prototype is currently under construction (Fig. 4). The operation also involves the design, acquisition and run of a cryogenic system and a complex liquid argon purification system. The first milestone to be achieved during the last months of 2007 is a proof of principle and stability studies, as well as optimization of the detector performance regarding γ-ray and β-electron background rejection versus nuclear recoils. In a second phase, the design of a shielding against neutrons from detector components, surrounding facilities and muon-induced neutrons will be addressed. After the successful testing of the prototype, an underground operation is planned in order to minimize background radiation induced by cosmic rays.

With a recoil energy threshold of 30 keV, a WIMP-nucleon cross section of $10^{-42}$ cm$^2$ would yield approximately 100 events/day/ton, accessing the WIMP-nucleon cross section region of $10^{-6}$ pb. By improving the background rejection power and further limiting the background sources, a sensitivity of $10^{-8}$ pb would become reachable. Due to scalable technologies used, an enlargement of the volume is a realistic prospect.

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