The Argon Dark Matter Experiment (ArDM)

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The ArDM experiment, a 1 ton liquid argon TPC/Calorimeter, is designed for the detection of dark matter particles which can scatter off the spinless argon nuclei. These events producing a recoiling nucleus will be discerned by their light to charge ratio, as well as the time structure of the scintillation light. The experiment is presently under construction and will be commissioned on surface at CERN. Here we describe the detector concept and give a short review on the main detector components.

1 Introduction

Recent developments in noble liquid detectors give a promising outlook for this scalable technology which is favored by high scintillation and ionization yields. For the first time, a liquid xenon detector [1] is producing limits that are competitive with the currently well established dark matter searches of cryogenic semiconductor detectors [2]. Gross target masses of around 50 kg are currently employed and are pushing the effective exposures for experiments with event by event background recognition into the range of 100 kg·d. Upcoming larger noble liquid experiments [3, 4, 5] will naturally have to fight more and more background events, not only for the feedthrough in the phase space of the data but also in terms of maximal tolerable trigger rates. However, selfshielding should improve performance for larger and larger target sizes, which is one of the strongest motivations to go to large masses. Above all, the number of single scattering neutrons can then be determined (on a statistical base) from the distribution of multiple interacting neutrons of a given background spectrum. Figure 1 shows the frequency distribution of neutron interactions on the example of the ArDM geometry [6].

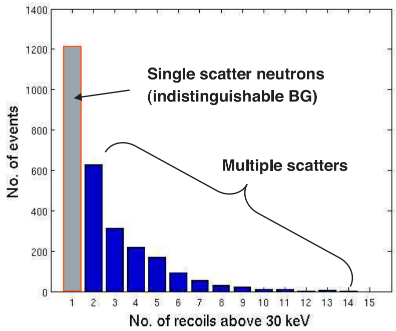

Figure 1: Interaction multiplicity of background neutrons in ArDM (MC).

The best recognition of electron recoils (usually background) should generally be achieved in a two phase configuration of a noble liquid detector allowing for the multiplication and hence the measurement of small ionization charges. In the case of liquid argon, both, the scintillation light to charge ratio and the temporal structure of the light emission itself [7, 8, 9] can be used for electron recoil discrimination. This is due to the ionization-density-dependent population of the two ground states of argon excimers ($^1\Sigma_u^+$ and $^3\Sigma_u^+$) which are responsible for the VUV luminescence of liquid argon. The large ratio of their radiative lifetimes ($\approx 10^2$) allows for a good discrimination between electron and nuclear recoils, even at energies below 20 keV on the electron equivalent scale [10]. A drawback of the argon technology is the short wavelength of the scintillation light (128 nm) and the presence of the ^{39}Ar β-emitter. However, because of form factors, argon is less sensitive to the threshold of the nuclear recoil energy, than is e.g. xenon. For the same reason the recoil energy spectra of argon and xenon are quite different. These liquids are therefore complementary in providing a crosscheck once a WIMP signal has been found.

2 Conceptual design

The main design goal of the ArDM project [5] was the construction of a ton scale liquid argon detector for spectroscopy of nuclear recoils above 30 keV. Three dimensional imaging and event by event interaction type identification will be used to reach a very high background suppression. An estimate of the final sensitivity and its extrapolation to larger LAr projects is one of the main subjects of this R&D program which is a prototype unit for future large LAr detectors. With current MC calculations we expect a sensitivity in the range of 10^{-44} cm^2 for a measurement of the spin independent cross section for weakly interacting dark matter particles.

In liquid argon about 400 VUV photons and a few free elementary charges[1] are typically produced in a WIMP interaction at 30 keV. Background rejection will be achieved by the combination of cuts on the fiducial volume, the event topology (e.g. no multiple scatter), the scintillation light to charge ratio, and the temporal structure of the light emission. This requires a large homogeneous electric field over the full detector volume, a large area position sensitive charge readout (3rd dimension from drift time), a large area light readout with good time resolution, and an efficient liquid argon purification system. The event trigger is generated by the fast light signal. Figure 2 shows a sketch of the two-phase operating mode of the detector. An interaction in the liquid produces VUV radiation (128 nm) by a complicated process of excitation and ionization of argon atoms, which results in the formation and subsequent radiative decay of the argon excimers [8]. This light can not be absorbed by neutral argon atoms and hence propagates to the side walls of the experiment which are coated with the wave shifting material tetraphenylbutadiene (TPB). The VUV light is absorbed and re-emitted with high efficiency at wavelengths around 430 nm, which is a region of high quantum efficiency of standard bialkali photomultipliers (PMTs). By diffusive reflection on the side walls, the light is transported to the bottom of the apparatus where an array of 14 hemispherical 8" PMTs is located. The strong electric field is capable of preventing free electrons in the densely ionized region around a nuclear recoil from recombining and sweeps them to the surface of the liquid. Here there they are extracted into the gaseous phase and multiplied ($\approx 10^4$) in the high field regions ($\approx$30 kV/cm) of a rigid large gas electron multiplier (LEM) which extends over the full detector surface.

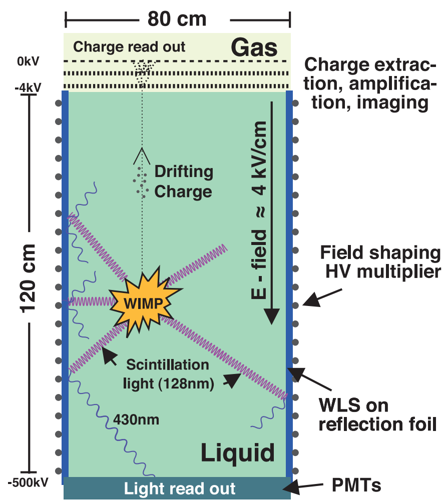

Figure 2: Conceptual design of ArDM.

[1]if the electrical field is above 1 kV/cm

3 Main experimental components and status

Figure 3 left shows the mechanical arrangement of the cryogenic cooling and cleaning system together with the main stainless steel dewar (containing roughly 1800 kg of liquid argon). An inner cylindrical volume of 80 cm diameter and 120 cm height is delimited by round ring electrodes (field shapers). It is instrumented and used as a 850 kg active LAr target in a vertical TPC configuration (Fig. 3 right). The field shaper rings are connected to a HV diode-capacitor charge pump system (Cockroft-Walton circuit) which is fully immersed in the liquid argon. It consists of 210 stages and is designed to reach a voltage of -500 kV at its end creating an approximately 4 kV/cm vertical electric field. This design avoids an electrical HV feedthrough

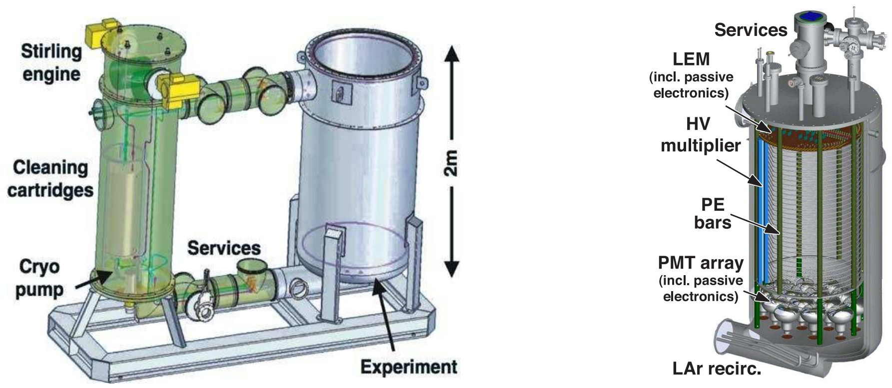

Figure 3: Left: 3D drawing of cryo-system and main dewar, right: view inside the main dewar with arrangement of the detector components hanging from the top flange on polyethylene bars.

into the liquid phase, as well as a (lossy) voltage divider. The system was tested successfully and takes advantage of the high dielectric breakdown voltage of liquid argon.

Another unique feature of the experiment is the realization of charge readout by a two-stage LEM manufactured by standard printed circuit board (PCB) methods. It will be placed 5 mm millimetres above the liquid level in the argon gas. It consists of two 1.6 mm thick 3 mm spaced Vetronite boards with holes of 0.5 mm diameter and a readout anode. A stable overall gain of 10^3 is routinely attained by prototypes. The positional readout is achieved by segmenting the upper LEM surface and the anode plate with 1.5 mm wide x and y-strips respectively. In total there are 1024 readout channels which are AC coupled to charge sensitive preamplifiers located externally on the top flange of the apparatus. Because it is operated in pure argon gas, which cannot quench charge avalanches, the LEM is built with considerable attention to HV discharges.

The readout for the 128 nm scintillation light was designed with the constraint that large VUV sensitive photosensors (e.g. MgF_2 windowed PMTs) are commercially not available. To keep the system simple and scalable, we chose an approach similar to a light diffusion cell with an array of PMTs in the liquid argon at the bottom (Figure 4). To shift the light into the range of high quantum efficiency of the borosilicate windowed bialkali PMTs, we evaporated a thin layer ($\approx$1 mg/cm^2) of tetraphenylbutadiene (TPB) onto the 15, cylindrically arranged, 25 cm wide reflector sheets which are located in the vertical electric field. These sheets, which are made out of the PTFE fabric Tetratex^{TM} (TTX), are clamped to the upper- and lowermost field shaper rings. The Hamamatsu PMTs R5912-02MOD-LRI, sensitive to single photons, are made from particularly radiopure borosilicate glass and feature bialkali photocathodes with Pt-underlay for operation at cryogenic temperatures. This ineluctably reduces their quantum efficiency by roughly one third to a value of approximately 15% [11]. The PMT glass windows are also coated with TPB to convert directly impinging VUV photons. The average number of detected photoelectrons per produced 128 nm photon of the overall detector is currently under investigation. From laboratory measurements we expect a value around 2-5%. The development of this light detection system and particularly the operation of (gaseous) argon test cells with α particle excitation were described in earlier work [12, 13]. A more detailed description of the present experimental state can be found in [14].

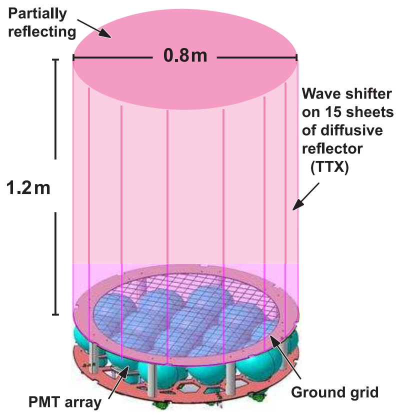

Figure 4: ArDM light diffusion cell.

Outlook

While R&D work for sub detector parts is finalizing, the main mechanical components are set together on surface at CERN, allowing for their commissioning. Following a successful operation at surface and later on at shallow depth (CERN), we consider a deep underground operation.

Acknowledgements

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