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Status of the ArDM experiment

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The Argon Dark Matter (ArDM) experiment is a search for direct evidence of Weakly Interacting Massive Particle (WIMP) as Dark Matter candidate, with a ton-scale double phase liquid argon Time Projection Chamber (TPC). The scattering of the WIMP induces the recoil of an argon nucleus, that excites and ionizes the surrounding argon atoms. The detector design allows to detect independently the ionization and the scintillation signals. The background rejection is based on the time distribution of the scintillation photons and on the ratio of the ionization charge to the scintillation light. The detector is presently under construction and commissioning on surface at CERN. Cryogenic operation, light detection, high voltage system and a preliminary charge readout were recently tested. This article describes the experimental apparatus and presents some preliminary results from the most recent run.

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1. Introduction

Astronomical observations suggest the presence of a non-luminous and non-baryonic mass excess in the Universe. The so called Weakly Interacting Massive Particle (WIMP) is a leading candidate to describe the excess [1]. WIMPs interact only weakly and gravitationally, therefore are expected to scatter elastically on ordinary matter producing nuclear recoils with energies up to few tens of keV [2].

Assuming a WIMP mass of 100 GeV/c^2 and the WIMP-nucleon cross section of 10^{-8} pb, the expected rate of nuclear recoil events above 30 keV in 1 ton liquid argon is about 1 event/day.

The aim of the Argon Dark Matter (ArDM) experiment [3] is to design, construct and operate a ton-scale double phase liquid argon Time Projection Chamber (TPC) and to prove the possibility of direct search of WIMP Dark Matter with a ton-scale liquid argon detector, addressing the needed background rejection power and the required energy threshold.

The ArDM detector is presently installed on surface at CERN for construction and commissioning. A successful first test of cryogenic and basic elements of the light readout was performed in Spring 2009, when the detector was operated in single phase mode with a partial light readout system and without drift field [4]. In Summer 2010 a second test run was performed. The hardware improvements and some preliminary results of the most recent run are presented in this paper.

2. Detector

The conceptual scheme of the detector is shown in figure 1. A particle interacting with the liquid argon bulk produces 128 nm photons and quasi-free electrons. The light is detected with Photomultiplier Tubes (PMTs) installed in the liquid argon and the charge is drifted to the liquid-vapor interface, extracted into the gas and amplified with the charge readout system.

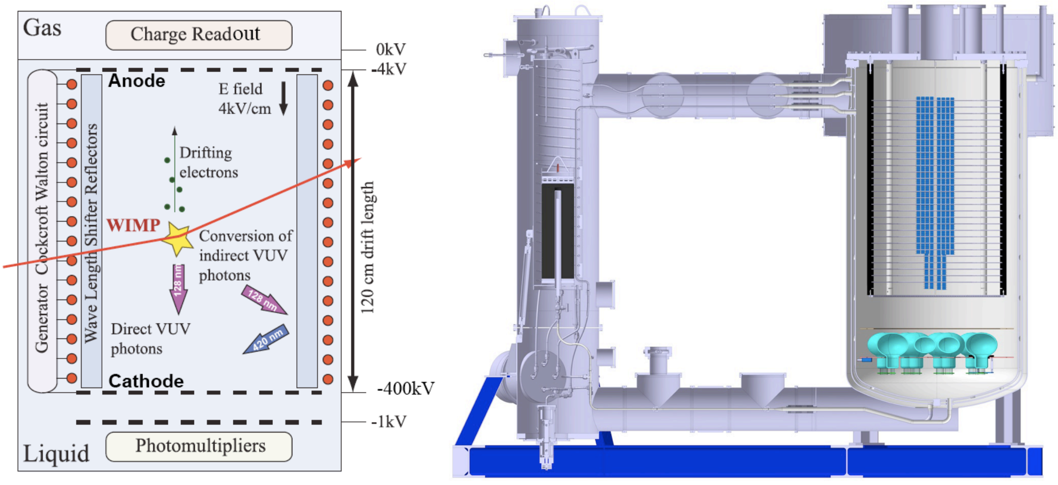

Figure 1: Conceptual layout (left) and CAD drawing (right) of the ArDM detector.

The detector volume is kept cold and in stable thermodynamic conditions by an open bath of liquid argon, automatically refilled when the liquid level crosses a defined threshold. The vessel consists of two main parts. A first cylinder that contains the liquid argon pump and the reduced copper oxide cartridge for the purification of the liquid argon and a second cylinder that hosts the active volume and the instrumentation (see figure 1).

The active volume (80 cm diameter and 120 cm height) is surrounded by field shaping rings. The argon atoms, ionized or excited by the interaction of charged particles, eventually form excited argon dimers that radiate 128 nm photons when they fall on the ground state. To increase the light collection efficiency the field shaping rings are covered with reflector foils (Tetratex) coated with TetraPhenyl Butadiene (TPB), that acts as wavelength shifter for the VUV scintillation photons. The active volume is delimited at the bottom by the cathode and at the top by the liquid argon level, set in between two extraction grids. Their role is to create an electric field of the order of 3 kV/cm at the liquid-vapor interface in order to efficiently extract the drifting electrons into the gas phase.

The high voltage to produce the drift field is provided by a 210-stages Greinacher (Cockcroft-Walton) voltage multiplier installed inside the vessel. The advantage of using this kind of circuit is that the high voltage feedthrough has to sustain only about 2 kV AC, while at the cathode the voltage is of the order of 400 kV. Each of the 30 field shaping rings is connected to one Greinacher stage, chosen in order to produce a uniform electric field in the drift region. The high voltage to the grids is supplied independently.

A temporary charge readout, consisting of an anode segmented into 32 pads, is installed above the extraction grids. In figure 2 (right) the grids and the anode are shown. The readout "sandwich" is mounted on a movable system that allows to modify the height and the planarity of the grids in order to adjust them to the liquid argon level (monitored with three capacitive level meters). The final solution for the charge readout will be a Large Electron Multiplier (LEM) [5, 6, 7, 8], presently under development.

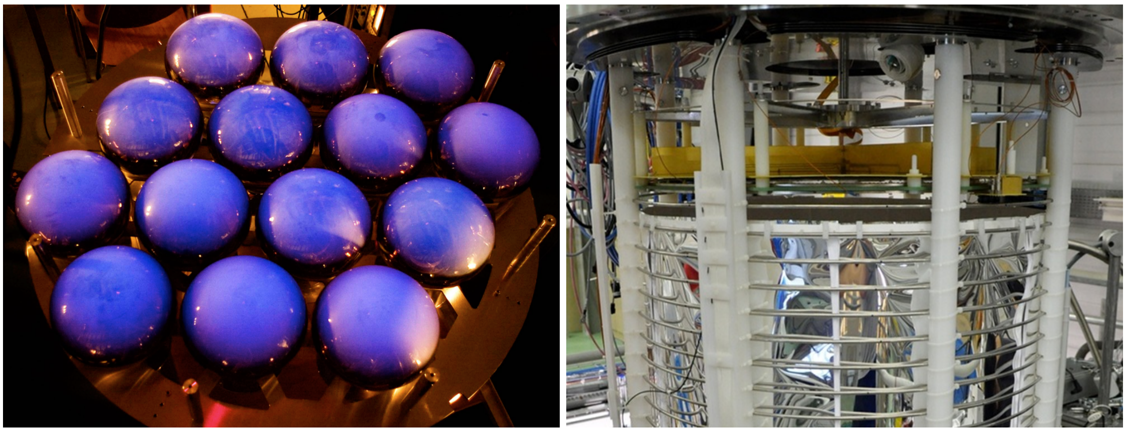

Figure 2: The left image shows a picture of the 14 PMTs illuminated with a UV lamp. The blue layer on top of each photocathode is the evaporated TPB. The right image displays the temporary charge readout and the extraction grids mounted on the movable system and hanging from the top flange (see text).

The 14 PMTs (8” Hamamatsu R5912-02MOD with bialkali photocathodes and Pt-underlay) are installed 13 cm below the transparent cathode grid, behind a ground shielding mesh. They are coated with a layer of evaporated TPB that wave-shifts also the direct incident photons [9] (see the left picture in figure 2). The gain of each PMT is set in order to have the signal amplitude of a single photoelectron of about 15 mV, well above the electronic noise (0.5 mV RMS). The internal trigger is defined by a threshold on the amplitude of the analog sum of the 14 signals.

The PMT signals are digitized with two CAEN V1720 8 channel 12 bit 250 MS/s digitizer, while the temporary anode signals are pre-amplified and digitized with the CAEN SY2791 32 channel 12 bit 2.5 MHz TPC readout system. The data acquisition synchronizes the two modules and merges the "light events" with the "charge events".

In addition the pressure and temperature monitors, the controllers of the vacuum pumps, the slow control and the security processes are managed by a Programmable Logic Controller (PLC). This is a key issue to safely operate a cryogenic detector underground.

3. Summer 2010 surface run

The aim of this section is to describe the different data taking conditions and the achievements of the Summer 2010 test run. Analysis of the collected data is ongoing.

The Greinacher circuit was operated in stable condition up to 70 kV at the cathode in order to obtain about 500 V/cm drift field. The light and charge events were successfully merged and the charge extraction to the vapor phase was confirmed triggering on cosmic muons crossing the detector vertically and checking the signals from the temporary charge readout or the proportional scintillation (S2) light produced in the gas phase between the extraction grids.

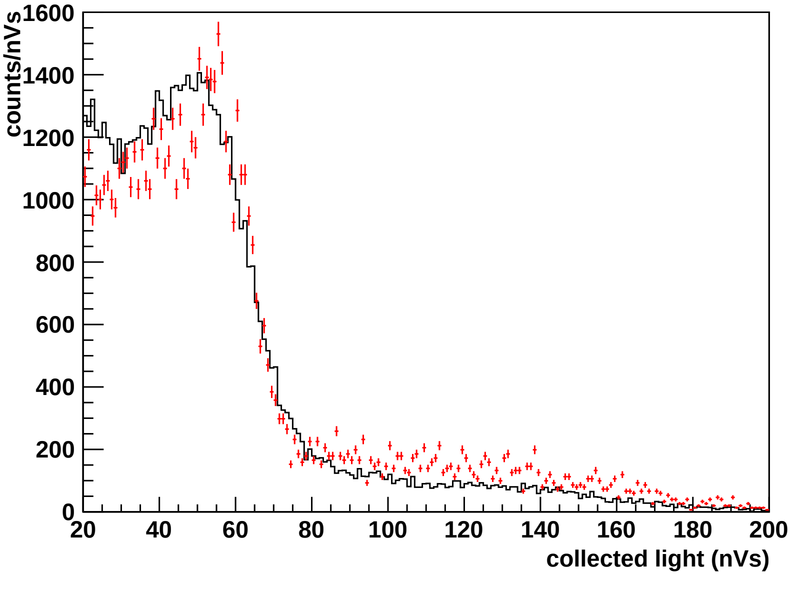

Figure 3: Collected light distribution irradiating the detector with ^{22}Na source (external trigger). The Monte Carlo simulation (dots) is overlapped to the experimental data (solid line).

The detector was irradiated with neutrons from an AmBe source. The trigger was either from the analog sum of the 14 PMT signals (internal trigger) or from the 4.4 MeV γ, emitted from the de-excitation of $^{12}C^{*}$ produced during the ^{9}Be(n,α)^{12}C* nuclear reaction (external trigger). The latter was implemented with an external NaI crystal.

In addition, a ^{22}Na source was used, triggering externally with the NaI crystal on one of the two 511 keV photons from the annihilation of the positronium. The ^{22}Na source was positioned outside the detector vessel 30 cm above the cathode. A similar measure was performed during the previous run, for details see [4].

In figure 3 we show a preliminary distribution of the scintillation light recorded by the PMTs with no drift field. The peak around 50-60 nVs is the full absorption of the 511 keV photon. At lower energy the Compton edge is not evident because of the multiple Compton scattering in the fiducial volume. The events up to 200 nVs are due to the Compton scattering of the 1275 keV γ radiated in coincidence with the positron from the ^{22}Na source. In spite of the premature status of the analysis and the low Monte Carlo statistics, it is confirmed that the MC simulation provides a good description of the data.

The data analysis of the runs with the γ source, the neutron source and cosmic muons as well as the improvement of the Monte Carlo simulation are ongoing.

4. Conclusions and outlooks

The development of the ArDM detector was confirmed with a test run on surface during Summer 2010. The detector was successfully operated in cryogenic conditions, the Greinacher voltage multiplier provided stable high voltage to the cathode up to 70 kV. Drifting electrons, released by cosmic muon crossing the detector, were extracted to the gas phase and recorded with a temporary charge readout. The detector was irradiated with γ rays and neutrons from sources and the 14 8” PMTs were working in liquid argon for more than one week. In addition all the slow control processes were managed by a PLC.

Further improvements on the developing of the ArDM experiment are (1) the installation of cryocoolers in order to re-condensate the liquid argon boil-off (needed for the underground operation), (2) the successful operation of the liquid argon purification and achievement of ppb level purity and (3) the design and the construction of a passive neutron shielding. All the issues are in preparation.

The ArDM experiment was approved for operation in the underground Canfranc Laboratory (LSC) and we expect to start the installation in the first half of 2011.

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