Test in Liquid Argon of the Light Readout System for the ArDM Experiment.

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***Abstract*—ArDM is a new-generation WIMP detector which will measure simultaneously light and charge from scintillation and ionization of liquid argon. Our goal is to construct, characterize and operate a 1 ton liquid argon (LAr) underground detector. The project relies on the possibility to read out the VUV scintillation light and to extract the electrons produced by ionization from the liquid into the gas phase of the detector, to amplify and read out with Large Electron Multipliers detectors. The light has to be converted with wavelength shifters such as TetraPhenyl Butadiene in order to be detected by photomultipliers with bialkali photocathodes. I'll describe the light readout system R&D and report about the tests and the calibration of the prototype with liquid argon in the full size detector.**

***Index Terms*—IEEEtran, Dark Matter, NSS09, ArDM, liquid argon, photomultiplier.**

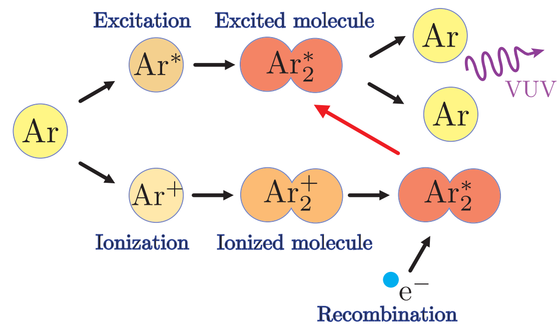

Fig. 1: Scintillation of argon.

I. Introduction

NOBLE liquids such as argon or xenon are today two of the best options for large-size Dark Matter (DM) experiment such as WIMPs[1] searches because they serve as target and detecting media at the same time. WIMPs, with particular regard to the lightest neutralino, are in fact the most popular DM candidates within the Minimal Supersymmetric Standard Model (MSSM). Most of the DM models predict that WIMPs interact almost only gravitationally and maybe weakly with matter thus forming cold relic halos around massive astronomical objects. For this reason DM is very difficult to detect directly nevertheless its evidence has been observed using astronomical observation [1].

II. Detection of Dark Matter with liquid argon

The detectors should have big target masses and excellent noise rejection capabilities because of the small cross section between DM and ordinary matter. Noble liquids have a relatively low ionization energy and a good cross section for nuclear recoil processes, moreover they can act as active target because they have good scintillation properties and a long electron lifetime. Argon, because of its availability and low cost, is an excellent candidate and is very competitive for large detectors. The expected DM signal from a WIMP-argon head on collision is a single $10-100$ keV recoiling nucleus. The passage of ionizing particles in argon produces ionization and excitation of the argon atoms. Ionized and excited atoms form the excited molecular states Ar_2^+ and Ar_2^*. Ar_2^+ eventually recombines with an electron, producing Ar_2^* in the molecular excited state which decays radiatively as shown in Fig.1.

[1]Weak Interacting Massive Particles.

The lowest allowed radiative decays from the molecular excited states are the transitions from the singlet and the triplet states ($^1\Sigma_u^+$ and $^3\Sigma_u^+$) to the dissociative ground state ($^1\Sigma_g^+$) which consists of two independent atoms; the emission spectrum for those transitions has a narrow peak at (128 ± 10)nm in the Vacuum Ultra Violet (VUV) band [2], but they have two different decay times, τ_1 and τ_2, which do not depend on the type or on the energy of the incident particle; in liquid argon (LAr) $\tau_1 \simeq 5$ ns and $\tau_2 \simeq 1.6$ μs. Only impurities such as water, N_2 and CO_2 can eventually reabsorb VUV light and capture the electrons. As was measured in gas and liquid [3], [4] the electron lifetime and the decay time of triplet state strongly depend on the on the purity of argon.

The ratio between the population of the two states depend on the ionization density properties of the projectile as can be seen from Fig.2. About 70% of the scintillation light produced by electrons and $\gamma-$rays is concentrated in the slow component (Fig.2a). On the contrary for heavy projectiles like neutrons, $\alpha-$particles and eventually WIMPs the slow component represent only 30% of the total light (Fig.2b).

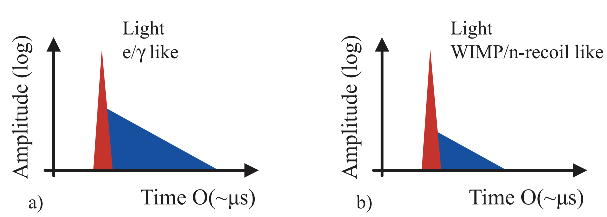

Fig. 2: Temporal distribution of the scintillation light for different particle interaction topologies.

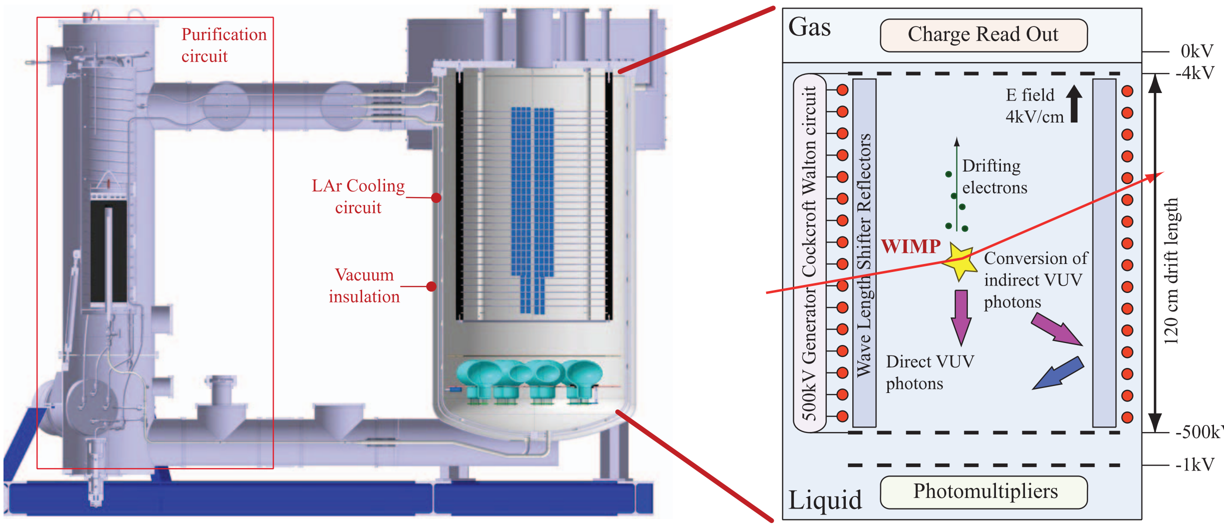

Fig. 3: Conceptual layout of the ArDM experiment.

III. The ArDM experiment

The conceptual layout of the ArDM experiment [5] is illustrated in Fig.3. Ionizing particles traveling through an active mass of 850 kg generate scintillation and ion pairs; a 500 kV Cockcroft Walton generator chain provides the electric field which drift the electrons towards the gas phase on the top of the detector. The electrons are then extracted from the liquid to the gas phase (E_{extr} $\sim$3 kV/cm) and accelerated towards the double stage Large Electron Multiplier detector [6] which provide multiplication and position reconstruction.

Detection of light is performed by an array of 14×8" cryogenic photomultipliers (PMTs) located below the cathode. Most of the VUV scintillation light hits the side walls of the detector, therefore installed wavelength shifter (WLS) coated diffusive reflectors which shift the light from 128 nm to 420 nm (λ_{peak} for bialkali photocathode) and diffuse the blue light in the detector. A WLS coating of the PMT surface is also foreseen to detect the direct light which is $\sim$10% of the total light. We plan to achieve an average light collection efficiency of 2%.

Argon purity is obtained by recirculating the LAr through an active copper filter and is monitored using two independent purity monitoring systems which measure the electron drift length and the decay time of slow component (τ_2).

Common background sources for this type of detectors are neutrons, electrons and γs. The U- and Th-chains contaminating the detector components produce neutron and γ background, P isotopes (present in steel) have β activities. Muons interacting with argon produce the unstable long living ^{39}Ar isotope; LAr obtained from the liquefaction of air contains this isotope in a non negligible fraction of 1 Bq/kg [7] which then makes ^{39}Ar one of the main source of background for ArDM. $\gamma-$ray and electron background can be rejected using the combination of charge and light information as shown in Fig.4.

With a combined light/charge analysis we should reach an energy threshold of approximately 30 keV.

IV. Test of the light readout system in liquid argon

The light readout system was tested for the first time in liquid argon in May 2009; at this time the system included the complete wavelength shifting side reflector, the complete DAQ but only 8 of the 14 PMTs.

Normal PMTs cannot be used at liquid argon temperature. The standard bialkali photocathode are insulant at cryogenic temperatures and the emitted electron are not restored. Special PMTs with Pt underlay on the photocathode have been selected: 5 Hamamatsu R5912-02mod, 2 Hamamatsu R5912-01mod and an ETL9357 have been installed and tested. Both types were subject of R&D studies [8], [9]. Each PMT was mounted on a 3 mm thick cryogenic PCB base which provides voltage supply, signal extraction and mechanical support.

The side reflector is made of 15 Tetratex®[2] foils (120×25 cm^2) on which an optimal thickness of WLS (TetraPhenyl Butadiene)[10] was evaporated using a custom-made evaporator. The PMT windows were also coated with WLS in different configurations. The signal was acquired using fast sampling ADC boards (10 bits, 1 GS/s) with a large memory buffer.

In August 2009 the PMT modules were replaced with 14 new Hamamatsu R5912-02mod PMTs with low background

[2] ePTFE membrane, Donaldson Company, Inc.

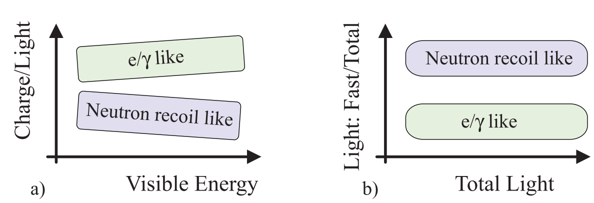

Fig. 4: Ratio between charge and light (**a**) and between prompt and total light (**b**) for different particle interaction topologies as a function of the measured energy.

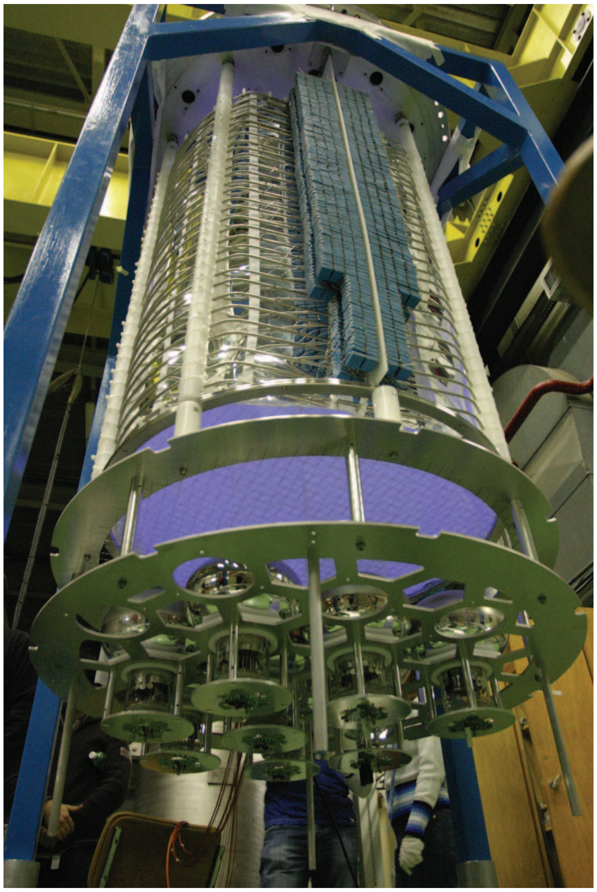

Fig. 5: The light readout installed in the ArDM experiment and illuminated with an UV light (254 nm).

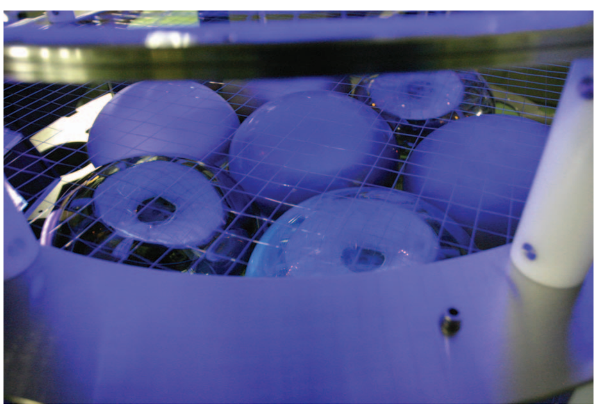

Fig. 6: The photomultipliers illuminated with an UV light (254 nm).

glass. An additional light reflector around the PMT array was also installed.

The setup was evacuated down to 10^{-8} mbar and liquid argon was circulated in the cooling circuit for more than two days, then the detector was filled with liquid argon. The gain curve of the PMTs was measured and the stability of the gain was monitored. The PMTs were operated at a constant gain of about $2.5 \cdot 10^7$.

A total of $\sim$ 100 M events were collected with different configurations. The energy calibration of the detector was

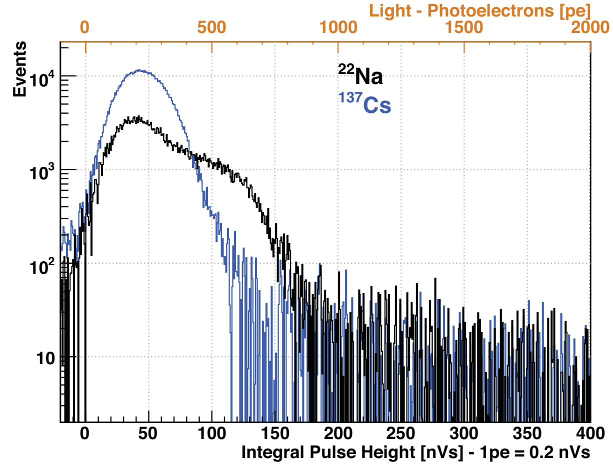

Fig. 7: Light spectrum measured for ^{137}Cs and ^{22}Na sources. Natural background has been subtracted.

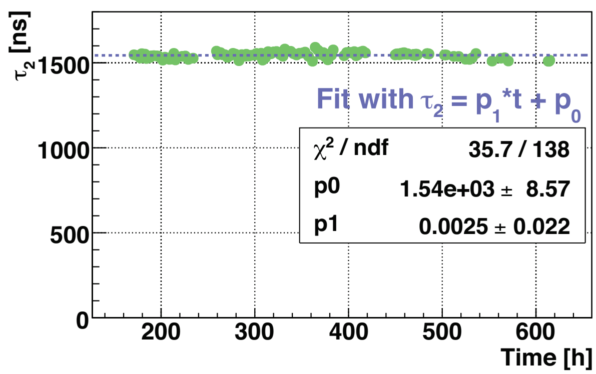

Fig. 8: Evolution of the decay time of the slow component (τ_2) over more than 600 hours.

performed with $\gamma-$ray (^{137}Cs, ^{22}Na) and neutron (Am-Be) sources installed on the side of the detector at different positions. Background spectrum was measured as well. For the ^{22}Na source data were also collected using an external NaI crystal to tag different configurations of the 1274 keV photon and the second 511 keV photon from the positron annihilation.

As an example of this analysis the light distribution of ^{137}Cs (E_γ = 661 keV) and ^{22}Na (E_γ^{Na} = 511 keV and 1274 keV) are shown is Fig.7. Data were acquired triggering on the detected scintillation light requiring at least 2 PMTs with a signal bigger than 20 pe; natural background has been subtracted. Light yield is not uniform in the detector and the full absorption peaks are smeared out. We estimate a preliminary light-yield of $\sim$ 0.5 pe/keVee with 7 PMTs. Comparison with MonteCarlo is ongoing.

The purity of argon was constantly monitored over 600 hours through the measurement of the decay time of the slow component (τ_2). The evolution of τ_2 as a function of time can be seen in Fig.8 and is compatible with a straight line model. The absolute value of the measured decaying constant is compatible with the best measurements found in literature.

V. Conclusions

I reported about the progresses done in the development of the light readout system for the ArDM experiment. The full reflector and 8 cryogenic PMTs have been installed and tested successfully in its preliminary version. In October 2009 the PMTs have been upgraded and a prototype of the charge readout has been installed at CERN where soon will be tested in liquid argon.

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