The ArDM - a ton - scale liquid argon experiment for direct Dark Matter Detection

Polina Otyugova, on behalf of ArDM collaboration
Physik-Institut der Universität Zürich, Winterthurerstrasse 190, CH-8057 Zürich, Switzerland

DOI: http://dx.doi.org/10.3204/DESY-PROC-2009-05/otyugova_polina

The ArDM is a ton-scale double phase detector for the direct search of the Weakly Interacting Massive Particle (WIMPs) as Dark Matter candidates. The detector is based on a liquid Argon (LAr) target. The present goal is to assemble, fully characterize the detector on the surface and then operate it at an underground facility. The scintillation light and ionization charge produced by recoiling nuclei in WIMP-Ar collision can be measured independently. The discrimination of the WIMP induced nuclear recoils from the electron/gamma background is done using the pulse discrimination technique and the ratio between the produced light and charge. The experiment and the last results from the detector commissioning are presented.

1 Direct Dark Matter Detection Principle Based on Liquid Argon Technology

Understanding the nature of Dark Matter is one of the most exciting problems of particle physics. One of the main evidences for Dark Matter comes from the observations of clusters of galaxies. Weak lensing observations of 1E0657-558, a system of two merged galaxy clusters, enabled a direct detection of Dark Matter [1].

A reasonable hypothesis is that Dark Matter is composed of a new kind of matter, made of so-called Weakly Interacting Massive Particles (WIMPs). The most favored candidate for these particles is the lightest supersymmetric (SUSY) particle, the neutralino. The idea of a direct detection of the Dark Matter with noble liquids is based on the detection of a nuclear recoil induced by the interaction of a WIMP with the nuclei of the target. The nuclear recoil results in the emission of scintillation light and the ionization charge which can be detected in the detector medium. The typical recoil energies are of the order of 10-100 keV.

The scintillation of LAr occurs through the radiative decays of excited molecular states Ar_2^*. The radiatively excited molecules are created in 2 spin states: $^1\Sigma_u^+$ (singlet state) and $^3\Sigma_u^+$ (triplet state). The luminescence light is in the vacuum ultra violet (VUV) region with a wavelength of 128 nm. The two spin states have different decay times: $\tau_1 \simeq 5$ ns for the singlet state and $\tau_2 \simeq 1.6$ μs for the triplet state. The significant difference in the decay time allows a possibility to do an efficient pulse shape analysis. In addition LAr is characterized by a low ionization potential and a long electron lifetime. The decay time of the triplet state and the electron lifetime strongly depend on the purity of the liquid or gas as demonstrated in [2].

The combination of pulse shape discrimination with the analysis of the ratio of the scintillation to ionization yields leads to the efficient background rejection. These features and the low cost of argon makes LAr an extremely promising target material for direct Dark Matter detection.

2 The ArDM Experiment

The design of the ArDM detector [3] is based on the possibility to measure both signals of scintillation and ionization independently. The layout of the detector with its components are shown in the Fig.1. The high voltage for the drift field is supplied from the Greinacher [4]

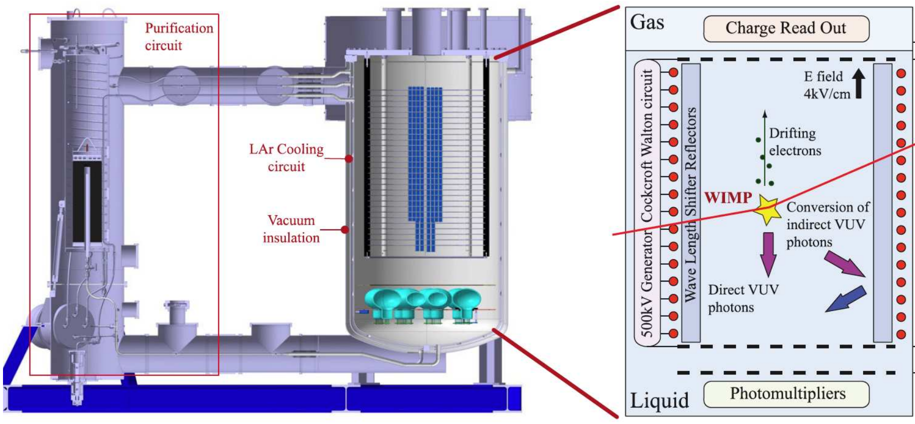

Figure 1: Conceptual layout of the ArDM experiment.

(Cockroft-Walton) chain which consists of 210 stages. The high electric drift field of about 4 kV/cm ensures the drift of ionization charges towards the gas phase. The maximum drift distance does not exceed 120 cm. The field shaping rings are covered on the inner side with reflectors in order shift the light in to the visible range and to increase the light collection efficiency. Fourteen PMTs are located below the HV cathode. The charge readout system is located in the top of the detector. The charge is extracted from the liquid phase into the gas by the high electric field between the extraction grid and the first electrode of the charge readout system. The extraction grid is immersed in the LAr and placed 1 mm below the liquid surface. The fiducial mass of the detector is estimated to be about 850 kg.

The LAr recirculation and purification system based on a CuO filled cartridge, provides the necessary purity of the LAr for long drift paths upto 120 cm. The monitoring of the LAr purity is independently done using the electron drift path and the decay time of slow component of the light signal (τ_2) see [2].

3 First Test of the ArDM Detector in Liquid Argon

For the first time the ArDM detector was filled with 1 ton of LAr and tested in May 2009. The test was performed with a partial light readout assembly (8 PMTs instead of 14), zero drift electric field and no charge readout system installed. The side reflectors and the light readout

DAQ were complete. The light readout assembly contained 7 Hamamatsu R5912. The side reflectors and the windows of the PMTs were coated with tetraphenil Butadien (TPB) WLS.

The side reflector was made of 15 Tetratex® foils[1] (120×25 cm^2). The foils were coated with an optimal thickness of WLS [5] using the evaporation technique. A custom made evaporator was used for the TPB deposition.

The setup was filled with LAr so that the side reflectors were fully immersed. The detector was kept full for about 3 weeks and various measurements using different radioactive sources were performed. The purity of LAr (τ_2) was constantly monitored within 600 hours and the constant value of $\tau_2 \simeq 1.5$ μs was measured in agreement with expectations [2]. This indicates a good purity of the used LAr taking into account that no purification system was involved during the test. To study the detector response on γ radiation we used ^{137}Cs ($E_\gamma = 661$ keV) and ^{22}Na ($E_\gamma = 511$ keV and 1274 keV) sources and Am-Be source for neutron studies. The γ energy spectra are shown in Fig.2. The spectrum for ^{137}Cs was obtained with the detector self-trigger. For the spectra for ^{22}Na the trigger was set up to the detector in coincidence with an external NaI scintillator. From these spectra a preliminary estimation of the lower limit for

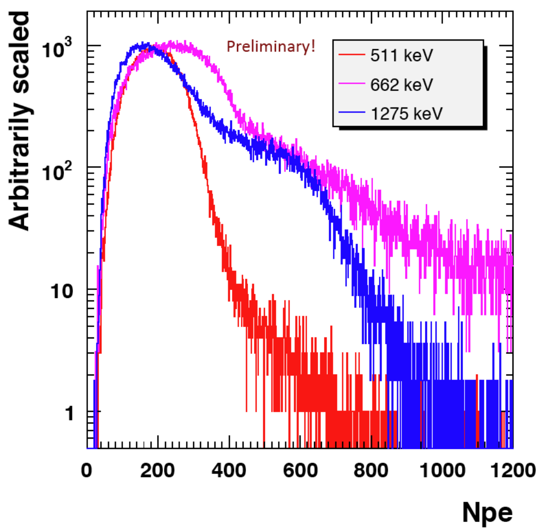

Figure 2: The energy spectra for ^{137}Cs and ^{22}Na

light yield is ~ 0.5 photoelectrons/keV for electrons (pe/keVee) with the 7 PMTs assembly.

Another important measurement was performed using ^{22}Na triggering on the external scintillator crystal. The triggering was done by requiring from the NaI crystal an energy given by the sum of 511 keV and 1275 keV γ energies. This then allowed the detection of the second 511 keV γ in argon. The spectrum is shown in Fig.3. Taking into account the light yield of 0.5 pe/keVee events with the energy deposit ~ 50 keV can be observed with a 1- ton detector.

A large data sample was taken in to study the detector responce to fast neutrons from Am-Be source. The analysis of these data is in progress but a preliminary evidence for neutron-induced nuclear recoils was obtained.

[1] ePTFE membrane, Donaldson Company, Inc.

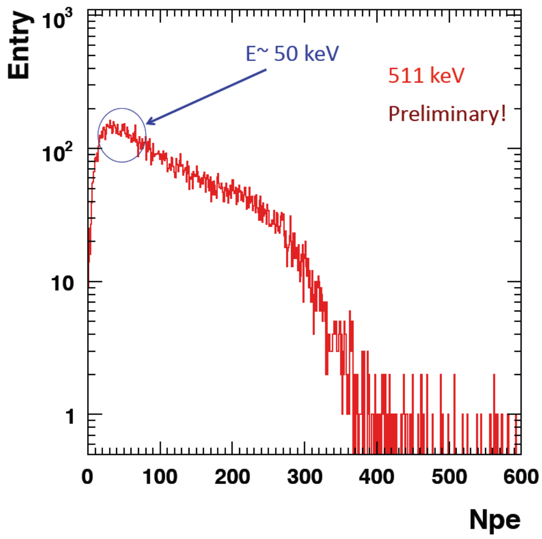

Figure 3: Energy spectra for ^{22}Na 511 keV γs in photoelecrons obtained with the external trigger. Events with the energy of ~ 50 keV can be observed.

4 Conclusions

The ArDM detector was recently tested fully filled with liquid argon. Various studies of the detector response on neutrons and electromagnetic radiation were performed. The tests proved a good constant purity of LAr during ~ 600 hours of operation. The preliminary calibration showed the lower limit on the light yield ~ 0.5 phe/keVee. It was also demonstrated that the events with an energy deposit of ~ 50 keV can be observed with the 1-ton detector. Evidence for neutron- induced nuclear recoils was also obtained.

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