Vol. 37 (2006) *ACTA PHYSICA POLONICA B* No 7

# THE SEARCH OF DARK MATTER WITH ArDM DETECTOR* **

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*(Received May 8, 2006)*

The ArDM project aims at developing and operating a 1 ton-scale liquid argon detector for direct detection of Weakly Interacting Massive Particle (WIMP) as Dark Matter in the Universe. In the first part of this paper the main features of the detector are presented. The second part includes a discussion on expected experimental background.

PACS numbers: 13.75.–n, 28.20.Cz, 95.35.+d

## 1. Introduction

There are many evidences that ordinary baryonic matter compose only ∼4% of the matter in the Universe. The rest is dominated by Dark Energy (∼73%) and Dark Matter (∼23%). The latter one presumably comprises of a new type of elementary particles. Understanding of its nature is a key issue in the contemporary particle physics. One of the promising candidate is the Weakly Interacting Massive Particle (WIMP), introduced in some SUSY models. There are worldwide efforts aimed to detect these particles. It seems to be clear that future Dark Matter experiments will need very high sensitivity detectors (big target mass and high background discrimination powers) to explore effectively the region of WIMP parameters and achieve sufficient counting rate.

* Presented at the Cracow Epiphany Conference on Neutrinos and Dark Matter, Cracow, Poland, 5–8 January 2006.

** Supported partially by the Polish State Committee for Scientific Research, SPUB 621/E-78/P-03/DZ214/2003-05.

## 2. ArDM detector

In 2004, interested groups started a new initiative for direct detection of Dark Matter — Argon Dark Matter experiment, ArDM[1]. The goal of this project is to design, assemble and operate a dual-phase ≈1 ton argon underground detector, to demonstrate the feasibility of a noble gas ton-scale experiment in terms of efficient performance and sufficient background discrimination capabilities.

The experimental technique is based on detecting tiny recoils of argon nuclei induced by the collisions of Dark Matter particles with the detector target. Deposited energy leads to the production of scintillation light and ionization charge in the medium. Typical kinetic energy of recoils is in the range of 10–100 keV. The signal is therefore quite elusive and requires very good background rejection. In addition, due to the very small WIMP-nucleus interaction cross section, a very rare event is expected.

The conceptual layout of the detector is shown in Fig. 1. More detailed information can be found in [1]. One of the key features is to independently

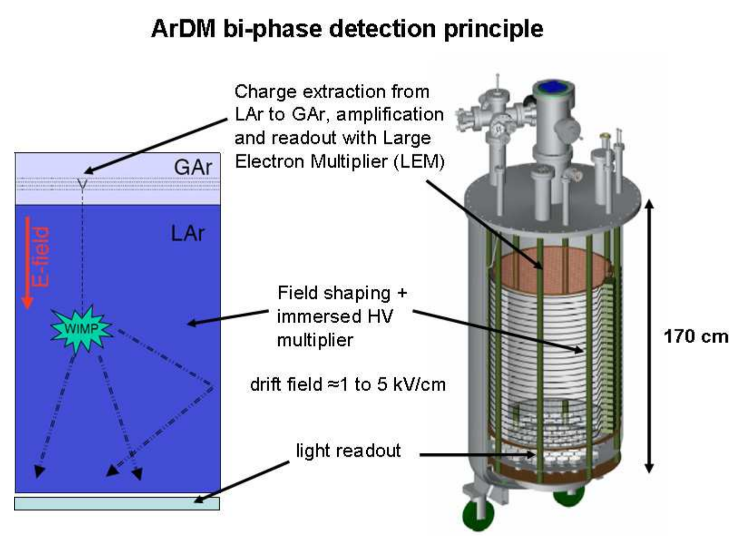


Fig. 1. Illustration of ArDM experiment and WIMP detection principle.

detect the primary (scintillation) and secondary (charge) signals. The light produced in the scintillation and recombination of free electrons will be detected by a light readout system located on the bottom of the detector behind the transparent HV cathode. To increase the light collection effi-

[1] See: `http://neutrino.ethz.ch/ArDM`. ETH Zürich, CIEMAT, Granada University, Sheffield University, Soltan Institute Warszawa, Zürich University.

ciency, primary VUV scintillation light of argon (128 nm) will be reflected by specially conceived high reflectivity mirrors placed around the field shaping electrodes.

Ionizing charges will be drifted towards the top of the detector, extracted to the gas phase and amplified there by the Large Electron Multiplier (LEM) system. By segmenting the LEMs it is possible to obtain a 2 dimensional image of an event. The time correlation between scintillation and charge could provide the information on the third coordinate, thus allowing a full spatial event reconstruction.

The ratio of the primary to the secondary signal allows to distinguish effectively between heavy recoils and other backgrounds. The time dependence of scintillation light can be used further to provide additional possibility of background discrimination.

The immediate plan of ArDM group is to setup and operate a 1 ton prototype at CERN. R&D efforts are under way to acquire and construct all crucial parts of the detector: LEM based charge amplification and readout, light detection system, cryogenics, drift volume, LAr purification and HV system. Assuming the successful operation of the prototype, the group is considering a deep underground operation at the Canfranc Underground Laboratory.

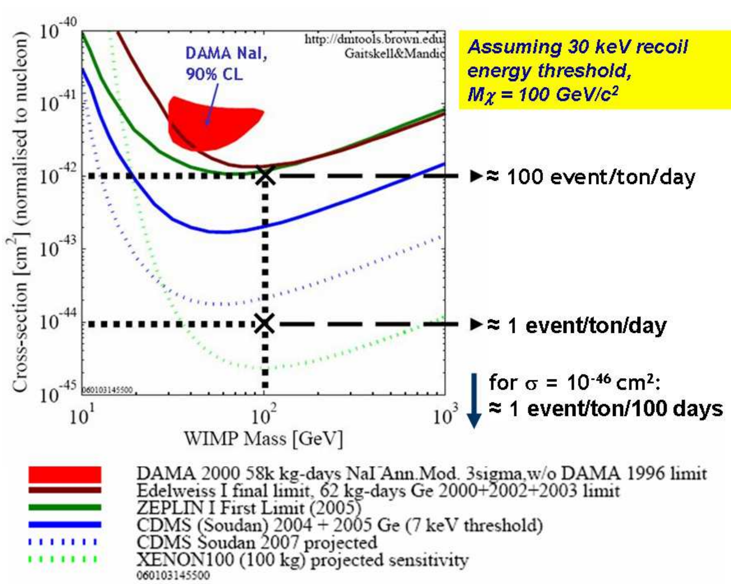


Fig. 2. Cross-section normalized to nucleon *versus* WIMP mass. The expected ArDM event rates for a true recoil energy threshold of 30 keV and certain cross-section values are indicated with crosses.

The sensitivity expectation of the ArDM 1 ton prototype is shown in Fig. 2. Expected event rate for a true recoil energy threshold 30 keV, WIMP mass of 100 GeV and WIMP-nucleon cross-section of $\sim 10^{-42}$ cm$^2$ ($10^{-6}$ pb) is 100 events per day per ton. Providing that sufficiently low gamma and neutron background levels can be reached, this sensitivity would increase to $\sim 10^{-8}$ pb. For the year of operation it would results in $\sim 10^{-10}$ pb.

## 3. Experimental background

The background particles, consisting mainly of electrons, photons, neutrons, helium nuclei, muons and neutrinos could produce nuclear and electron recoils inside the detector. The dominant electron/gamma background leads to the production of electron recoils and could be rejected by the ratio of the scintillation to the ionization yields, which is much lower in that case than for a nuclear recoils expected also for a WIMP interactions. However, high discrimination power ($> 10^9$) is needed in the experiment using LAr due to the presence of $^{39}$Ar beta-emitter in natural argon liquefied from the atmosphere. $^{39}$Ar isotope decays with a half life of 269 years and a value $Q = 565$ keV. Its activity in LAr has been measured [2] and is expected to induce a background rate of $\approx 1$ kHz in a 1 ton detector. The alternative way to suppress it, is to obtain $^{39}$Ar-depleted targets by extracting argon from well gases rather than from the atmosphere [1].

Providing that electron/gamma background rejection is sufficiently high, this type of background does not limit the detector sensitivity. The nuclear recoils induced by muons can be usually tagged by active veto, and events associated with neutrinos are reported to be negligible [3]. Alpha particle interactions usually can be rejected as they deposit a few MeV energy in the target and their keV interactions occur only near the vessel walls, thus could be eliminated by a good fiducial volume definition. Multiple elastic scattering of neutrons is also a clear indication for the background events, as WIMPs, due to the weak coupling, do not undergo multiple interaction in the detector. Only the single elastic scattering of a low energy neutrons would be indistinguishable from expected WIMP scattering. That provides a solid argument for a careful neutron background studies.

There are two possible sources of neutrons in deep underground locations: either they are produced in cosmic-ray muon interactions, or by natural radioactivity. The first ones are induced by the high energy through-passing muons in the rock and elements surrounding the detector. Neutrons from local radioactivity are cased by U/Th traces in the rock and detector components. They are produced in spontaneous fission of $^{238}$U or via $(\alpha,\mathrm{n})$ reactions initiated by $\alpha$'s from decays of radioactive isotopes in U/Th chains.

Following the approach presented in [4] we can consider three classes of neutron sources:

(1) neutrons from radioactivity in surrounding rock,

(2) neutrons from radioactivity in detector components,

(3) muon-induced neutrons.

Energy spectra, flux, place of the origin and methods of their suppression are different in each case. The overall flux of neutrons from the surrounding rock is expected to be the most dominant ($\phi_{\rm rock} = 3.8 \times 10^{-6}{\rm cm}^{-2}{\rm s}^{-1}$ at the Canfranc site [5]) but it can be effectively reduced by the hydrocarbon shielding. The flux of neutrons from detector components depends strongly on the choice and radiopurity of the detector materials. This type of background is considered to be the most difficult to reject as it cannot be suppressed by any shielding and it is also not possible to estimate its flux and energy spectrum with high accuracy. Contamination of U/Th cannot be measured for all detector components, it shows a variation between the samples of the same kind, and converting it to the resulting neutron flux is not an easy task and requires often some simplifying assumptions. In the ArDM experiment the glass parts of PMTs, glass fibres in Vetronite plates and capacitors are recognized as the major internal source of neutrons.

The mean energy of neutrons associated with the radioactivity is typically in the order of 1–2 MeV, depending on the composition of the material. The energy spectrum of muon-induced neutrons is hard, extending to GeV scale. This results in the following consequences: muon-induced neutrons can reach the detector from large distances, they produce higher energy recoils and can easily penetrate through the shielding. The flux of muon-induced neutrons $\phi_{\mu-{\rm ind}}$ is usually of a three orders of magnitude lower than $\phi_{\rm rock}$ for various underground locations ($\phi_{\mu-{\rm ind}} = 1.7 \times 10^{-9}{\rm cm}^{-2}{\rm s}^{-1}$ at the Canfranc site [5]). Very often events induced by these neutrons can be tagged using the active veto system and information about the time correlation with the passing muon.

Investigations on neutron background sources and simulations on their propagation and interactions inside the detector are being performed within the ArDM group. Their purpose is to evaluate the expected number of events with a single neutron scattering in the detector what will help to specify requirements for veto system, shielding and purity of the detector materials.

The author's Diploma thesis [7] concerned the neutron background studies for liquid argon Dark Matter detector. First stage of presented work consists of a set of tests and verifications of the low energy neutron physics applied in the developed simulation program. Neutron interactions in LAr

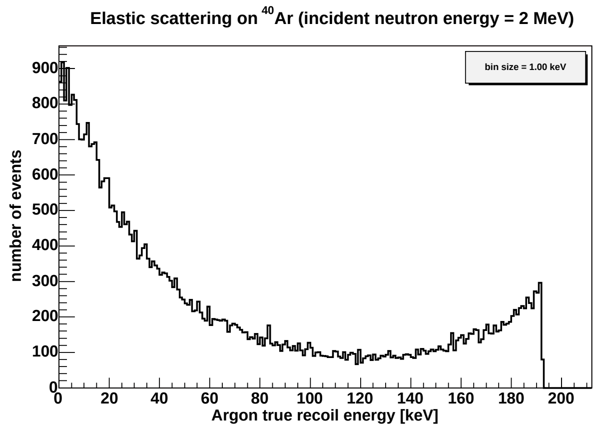


Fig. 3. Simulated $^{40}$Ar recoil spectra. Elastic scattering of 2 MeV neutrons in liquid argon.

were simulated using the Geant4 toolkit [6]. Mainly the neutron elastic scattering and neutron capture processes were investigated as they contribute the most in the low energy range. The example of a true recoil energy spectrum of argon nuclei obtained for the 2 MeV incident neutrons is shown in Fig. 3. Thereafter, some preliminary results on the rock neutrons were discussed. Assuming the flux $\phi_{\rm rock}$ reported for the Canfranc site at the walls of the fiducial volume, one can expect $\sim 10000$ incoming neutrons per day. Simulations showed that more than a half of them would interact inside the detector and half of the interacting ones would scatter more then once. Some of the multiple scattering events however could not be recognized due to limited spatial resolution of the detector, what will slightly increase the number of seen single recoil (WIMP-like) events. After assuming 2 cm detector resolution, we are left with several thousands WIMP-like events per day. To reach acceptable level of high sensitivity required for a successful WIMP detection, one should further reduce the number of a WIMP-like events by $10^4$–$10^6$ orders of magnitude by using an external neutron shielding. Similar simulations were also performed for neutrons from the detector components, showing that roughly 70% of the interacting ones can be recognized in the experiment as multiple scattering events. These studies are presently continued in the collaboration.

## 4. Outlook

The plan of the ArDM group is to develop and operate a dual-phase argon detector for direct detection of WIMPs with independent ionization and scintillation readout. With a 1 ton prototype the validity of this design should be shown. The first goal would be to understand and control the detector performance and a proof of principle test on electron background ($^{39}$Ar) rejection *vs.* nuclear recoils.

The help of all ArDM colleagues from ETH Zürich, CIEMAT, Granada University, Sheffield University, Sołtan Institute and Zürich University, is greatly appreciated.

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