THE CURRENT STATUS OF THE WARP EXPERIMENT*

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The WARP detector is a new idea in Dark Matter detection using liquid noble gases, specifically argon. We believe that argon is the medium best suited to detect nuclear recoils coming from interactions with the so called WIMPs (Weakly Interacting Massive Particles). The detection technique, using two different discrimination methods, is capable of an identification power as high as one event in 10^8. During the second half of the year 2006 the next, 100 liter, detector will be constructed with an active veto shield to further suppress the background, while currently a 2.3 liter prototype, installed in the Gran Sasso Laboratory (Italy), has been taking data since May 2004. The small version of the detector is able to not only provide insight on the operation of a two-phase liquid argon chamber but is also able to provide physics results competitive with the current leading edge experiments.

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1. Introduction

The search for Dark Matter is currently one of the fastest developing fields in Astroparticle physics. The result of this search, especially that of the direct detection experiments may solve the riddle of the proportions of a quarter of the mass-energy of the Universe. These direct detection experiments are very challenging since the goal is to be able to observe processes as rare as 0.01 evt/kg/day. For this reason, a large detector mass is highly preferable, while an excellent background suppression method is a must.

Liquid argon is a detection medium that aims to fulfill these needs. Its relatively low price and powerful discrimination technique make it a natural choice for experiments requiring precision. WARP (Wimp Argon Programme) is a novel experiment using the double phase technique in argon. First, the detection method and the detector will be described. The description of the discrimination method used in the experiment will follow. Finally, the physics results from the 2.3 liter prototype currently taking data in the Laboratori Nazionali del Gran Sasso (Italy) will also be presented.

2. The WARP detector

The WARP detector, as has been described elsewhere [1], is a two-phase argon detector. The liquid phase serves as the target medium, while the gas phase is used to measure the ionization left by the incident particle, using the method of proportional multiplication.

The WARP detector is shown in Fig. 1. A WIMP interacting in the lower part of the chamber, via elastic scattering, transfers some of its kinetic energy to one of the argon atoms. This energy is of the order of 40–120 keV and can be expressed mainly as scintillation and ionization. The scintillation, occurring just after the interaction (S1) is registered by the photomultiplier tubes placed on top of the inner chamber. The electrons coming from the ionization are then drifted in the electric field shaped by stainless steel racetracks and then extracted to the gas phase by the extraction field. In the gas phase, the electrons are accelerated to such a level that they emit secondary light (S2), which is also measured by the PMTs. Using the information gained from the drift time, as well as the information in the X–Y plane gained from fitting a centroid to the distribution of light on the array of phototubes one will be able to have a 3D positioning system in the detector.

An important feature of the 100l detector will be the active veto surrounding the detector. The external liquid argon active shielding should, combined with external polyethylene shielding, almost completely suppress the neutron background, which is the most dangerous in the search for WIMPs as it mimics almost exactly the signature of a Dark Matter Particle.

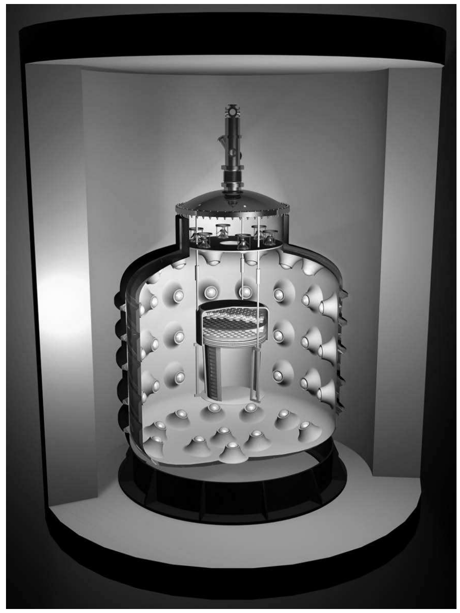
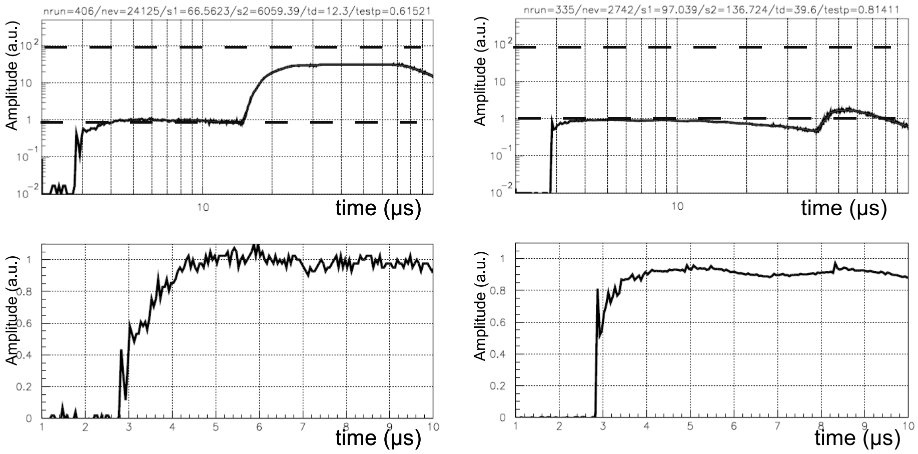


Fig. 1. View of the 100 liter WARP detector. One should note the external passive lead shielding, the outer active LAr veto surrounded by phototubes and the inner detector. The phototube array can be found at the top of the inner chamber, while the cathode is at the bottom.

The difference being that in a volume as large as the combined sensitive volume (0.14 tons) and the veto (8 tons) the probability of a double neutron scattering is very large. This is not the case for WIMPs, which should have a scattering cross-section at least 18 orders of magnitude smaller.

3. The discrimination method

The main drawback of using Liquid Argon is the presence of the cosmogenically created radioactive ^{39}Ar. This isotope is a β-emitter with a half-life of 269 y, and an end-point energy of 565 keV. Its abundance in natural argon, as measured by the WARP collaboration [2] is $0.87 \pm 0.02(\mathrm{stat}) \pm 0.08(\mathrm{syst})$ Bq/kg. A method of separation of the electron- or gamma-like signals from those of WIMP or neutron-like (called recoil-like or r-like) is of utmost importance. To achieve competitive limits with the 100l detector a separation of the order of 1 in 10^7 must be achieved. It will be shown that this is indeed possible using the pulse shape discrimination and so-called S2/S1 methods. See also Fig. 2.



(a) (b)

Fig. 2. Illustration of the WARP discrimination method. (a) an e-like signature generated by an electron or γ interaction. (b) a recoil-like, neutron or WIMP interaction. The top panels show the difference in the amplitude of S2 *versus* S1 signals (note the logscale), the bottom panels show the difference in the primary pulse (S1) rise time. Further description in the text.

3.1. S2/S1 method

When a particle interacts in liquid argon the recoil energy is converted into scintillation and ionization. Columnar recombination causes the ratio of this conversion to be quite different for r-like and e-like type events. This effect can be translated into the secondary to primary pulse ratio which, in the case of the WARP detector is above 100 for electron-like events and between 0.1 and 30 for r-like events above 30 keV energy. This can be seen in Fig. 2 on the top panel.

3.2. Primary pulse shape discrimination

This method is based on the scintillating properties of Liquid Argon. The light from excited argon atoms is emitted through the so-called excimer process. The excimer molecules in liquid argon can be either a singlet or a triplet. The two types are characterized by drastically different decay times (7 ns and 1.5 μs respectively). It is also important to note that the ratio of the singlet is about 70% for r-like events and 30% for e-like events [4]. This means that WIMP like signals will exhibit a much faster rise time than those of electrons. This can be observed in Fig. 2 on the bottom panels.

The combination of the two discrimination methods can give a β background discrimination power in excess of one in 10^8, therefore sufficient for the operation of the 100 liter detector. To increase the sensitivity the possibility of using isotopically depleted argon is also being investigated. This could raise the sensitivity of the WARP detector even further.

4. Results from the 2.3 liter prototype

The 2.3 liter prototype, currently operational at the Laboratori Nazionali del Gran Sasso, meant as a testing ground for the 100 liter detector has been able to provide physics results of its own. The fiducial volume is cut out from the 2.3 liter volume by applying cuts on the drift time (the time between the primary and secondary pulses), to eliminate events from the cathode and too close to the surface of the liquid volume. This results in a sensitive mass of about 2.6 kg (1.87 l). The results described here were obtained in a run where the chamber was equipped with three phototubes. The chamber was surrounded by 10 cm of external lead shielding and, since November 2005, by a 60 cm polyethylene shield to cut off environmental neutrons.

4.1. The measurement of the ^{39}Ar and the radioactive background

In an experiment whose goal is a high precision measurement at low energies the understanding of the background is essential. For this reason, the natural background in the detector prototype has been thoroughly studied.

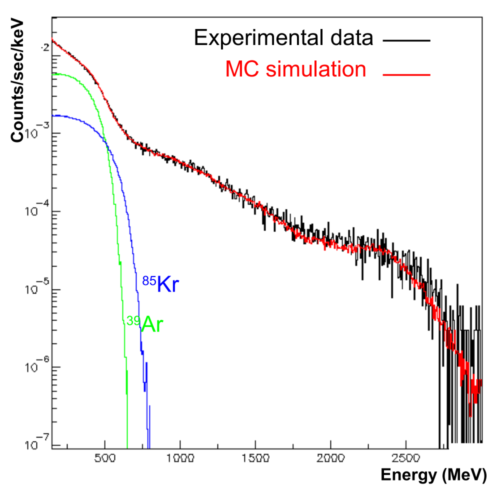


Fig. 3. The natural background spectrum measured in the WARP prototype. The two histograms presenting the data and the Monte-Carlo simulation are in such good agreement that they are almost indistinguishable in the picture. Also shown, are the ^{39}Ar and ^{85}Kr components of the simulation.

The spectrum was then fitted with a Monte Carlo simulation of the background created using the Geant4 software package [5]. Fig. 3 presents the measured background spectrum as well as the fitted Monte Carlo generated spectrum. It can clearly be seen the agreement is very good.

Large contributions to the background come from the ^{232}Th and ^{238}U chains as well as ^{60}Co and ^{40}K. But, as expected, the largest contribution comes from the ^{39}Ar isotope. Also, quite a large component from ^{85}Kr has been observed. The data has made it possible to measure the abundance of both of these isotopes in natural argon with the best accuracy since Loosli [3]. The measured abundance is 0.87 ± 0.02(stat) $\pm\, 0.08$(syst) Bq/kg and is accordance with Loosli's measurement. These results have been also reported elsewhere [2].

4.2. The radon events

Radon is a type of background that is always found in atmospheric argon. Fortunately, the relatively short half-life of radon (3.8 d) and its daughters means that after about one month, this background becomes negligible. Actually, the radon contamination can act in a manner that can be seen as beneficial for the experiment considering that it can be used for calibration purposes.

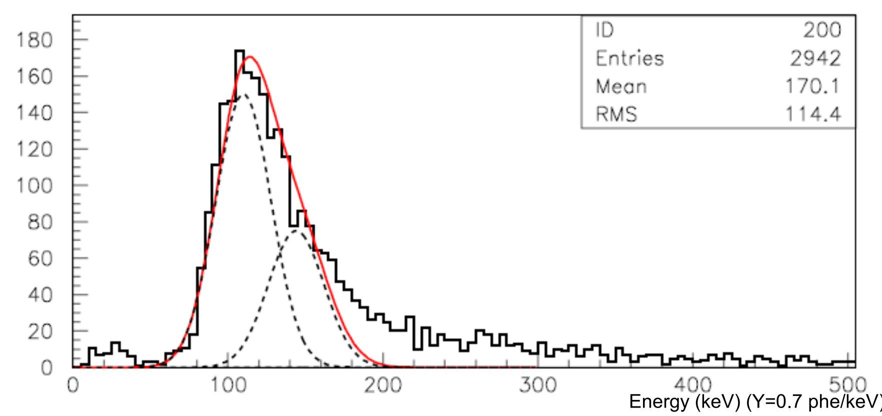


Fig. 4. The calibration using cathode events. The histogram represents the energy spectrum of cathode events taken after the refill of the chamber. The line is the convoluted fit of two Gaussians centered at 144 and 110 keV. The resulting measured light yield is 0.7 photoelectrons/keV for recoil like events which translates into a quenching factor of 0.8.

A decaying radon atom leaves behind an ionized daughter atom that drifts in the electric field present in the chamber towards the cathode, where it sticks to the surface. For this reason, most of the radon daughter events are observed in the cathode region of the detector. For the purposes of the calibration the most important are two isotopes of polonium: ^{218}Po and ^{214}Po. Both are α emitters and so in about one half of the cases the alpha particle is emitted into the cathode and the ionized lead atom is propelled into the liquid argon volume. These atoms cause recoil like events with an energy of 110 or 144 keV respectively. It is therefore possible to calibrate the detector by fitting two Gaussians to the energy spectrum of the cathode events. The result of this fit can be found in Fig. 4. The fit made it possible to determine that the value of the quenching factor (the ratio of the light yield from recoil like events to that from electron like events) is of the order of 0.8.

4.3. Environmental neutrons

The interactions of environmental neutrons have also been studied before installing the polyethylene shield on the prototype. The energy spectrum of r-like events in the fiducial volume has bee compared to a Monte Carlo simulation based on the measurements of the environmetal neutron background in the Gran Sasso Laboratory [6]. The results of this comparison can be seen in figure 5. Note that the Monte Carlo was not scaled to fit the data, and the only parameter changed was the endpoint of the spectrum. From this

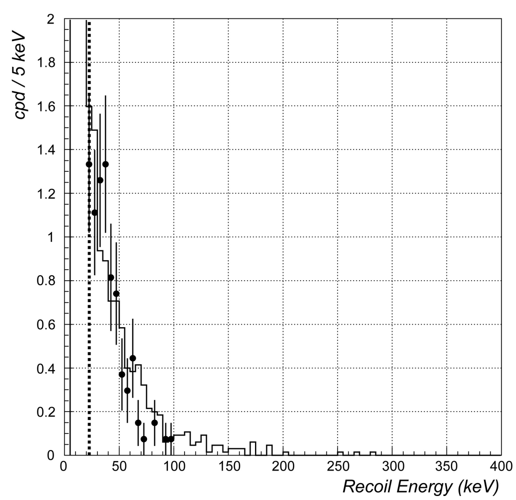


Fig. 5. The environmental neutron spectrum measured with the 2.3 liter prototype without the polyethylene shielding. The points are the data, while the histogram is the result of a Monte-Carlo simulation.

analysis it was also possible to determine the light yield for recoil like events and therefore the quenching factor which is equal to 0.8 and is compatible with the value induced from radon recoils. One should also note, that these results are in good agreement with the measurement of the quenching factor done by the CLEAN collaboration [7].

5. Conclusions

The WARP experiment is a novel experiment set to discover the Weakly Interacting Massive Particles that are expected to be the main constituent of the galactic Dark Matter halo. The 100 liter detector is set to be built by the end of the year 2006. Currently, a prototype 2.3 liter chamber is taking data and is already able to provide physics results of its own, specifically the measurement of the abundance of the radioactive ^{39}Ar isotope in natural argon as well as the measurement of the quenching factor.

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