PROCEEDINGS OF SCIENCE

The WArP Dark Matter Search

Giuliana Fiorillo[1]

Università degli Studi di Napoli Federico II and INFN, Sezione di Napoli

Complesso Universitario di Monte S. Angelo, Via Cinthia, 80122 Napoli, Italy

E-mail: `Giuliana.Fiorillo@na.infn.it`

WArP is a graded programme to search for Wimp dark matter with liquid argon. The WArP 100l detector is being assembled and should start data taking in the next few months. We expect to increase the sensitivity of about a factor 100 with respect to the 2.3 liters protoype, which has been operational since 2005, allowing for an intense R&D programme that has given us insight to crucial LAr properties. The current status of the experiment and the main results obtained with the prototype are reviewed.

Identification of dark matter 2008
Stockholm, Sweden
August 18-22, 2008

[1] Speaker on behalf the WARP Collaboration
INFN and University of L'Aquila (Italy) R.Acciarri, M.Antonello, N.Canci, F.Cavanna, F.Di Pompeo
Laboratori Nazionali del Gran Sasso, INFN (Italy) L. Grandi, O.Palamara, L.Pandola, C.Rubbia*, E.Segreto
Institute of Nuclear Physics PAN, Krakow (Poland) A.M.Szelc
INFN and Federico II University of Napoli (Italy) F.Carbonara, A.G.Cocco, G.Fiorillo, G.Mangano
INFN and University of Padova (Italy) B.Baibussinov, S.Centro, M.B.Ceolin, G.Meng, F.Pietropaolo, S.Ventura
INFN and University of Pavia (Italy) P.Benetti, E.Calligarich, M.Cambiaghi, C.Montanari, A.Rappoldi, G.L.Raselli, M.Roncadelli, M.Rossella, C.Vignoli
Princeton University (USA) J.Appel, F.Calaprice, C.Galbiati, D.Krohn, B.Loer

PoS(idm2008)016

1.The WArP Programme

The WArP experiment aims at the direct search of WIMPs in the galactic halo through the detection of elastic scatterings on the target nuclei of liquid argon (LAr) with a 100 l (140 kg) LAr fiducial volume and a detection threshold of about 20 keV_{ion}. A unique feature of this experiment is that the active volume is fully contained in a 8 ton, 4π LAr active anticoincidence vetoing incident neutrons, with a recoil threshold as low as 30 keV.

In order to demonstrate the technology, a small 2.3 l (3.2 kg) prototype (without active shielding) has been installed already in 2005 in the INFN National Laboratory of Gran Sasso (LNGS) to perfect the technology and to demonstrate the rejection capability of the electromagnetic backgrounds. Since summer 2007, the upgraded 2.3 l chamber has been operated with improved radiopurity (low activity materials) and shielding.

1.1Detection technique

In order to be sensitive to the expected tiny energy depositions and to be able to discriminate nuclear recoils generated by WIMPs scattering from the dominant electromagnetic background, the standard Time Projection Chamber technique has been modified, foreseeing a gaseous region above the sensitive LAr volume where luminous multiplication can occur. An interaction in the medium produces scintillation light and ionization charge: an electric field can then be used to drift a fraction of ionization electrons towards the liquid-gaseous interface, where they are extracted and accelerated in order to induce electroluminescence light. Photomultipliers placed in the gas phase detect both the prompt scintillation light (S1) and the delayed secondary light (S2) associated with ionization. The ratio between the two intensities can be used to discriminate the nature of the ionizing particle; a second very powerful identification technique is provided by prompt scintillation signal shape analysis, which is possible in argon due to its peculiar wide separation in rise times between fast (≈ 5 ns) and slow (≈ 1.2 μs) components of the emitted UV light.

The results obtained with the 3.2 kg prototype show that minimum ionising particles are characterized by an high S2/S1 ratio (~100) and a slow S1 signal ($F=I_{fas}t/(I_{slow}+I_{fast})\approx 0.3$). On the contrary, α particles and nuclear recoils (R-like events) exhibit a low (<30) S2/S1 ratio and a fast S1 (F≈0.75).

2.Summary of main results of the 3.2 kg prototype

The 3.2 kg prototype was run in Gran Sasso Laboratories for a total live-time of 52.8 days (i.e. 96.5 kg • day). The total number of triggered events was 2.8 x 10^7 above a threshold of 3.5 keV_{rec}. The analysis of this large data sample led to the selection of only 5 events showing a single recoil above 40 keV_{rec} and 0 events with the same features above 55 keV. This result allowed the WArP Collaboration to publish the first limit on DM obtained with an argon detector [1].

The sensitivity reached by the 3.2 kg detector was $0.05 evt / (kg.day)$. Such or even better sensitivities require a good control of the detector and a perfect understanding of the backgrounds. In liquid argon, and in most DM searches, the background can be divided into γ-like and recoil-like. The first type comes from particles interacting with the electron cloud rather than the nucleus of the target atoms like the WIMPs. As already mentioned, the liquid argon bi-phasic technique provides two extremely powerful methods of rejecting these events using the difference in the S1/S2 ratio and in the S1 pulse shape of recoil-like and electron-like events. Used together the two methods can provide a discriminating power of up to 10^{-9} , which is more than that needed to operate the 140 kg detector, in spite of the intrinsic background present in argon due to the cosmogenic isotope ^{39}Ar. This isotope is a β-emitter with a half-life of 269 y, and an end-point energy of 565 keV and could prove to be a problem with larger argon detectors due to the sheer number of background events. The contamination of this radioactive isotope in natural argon has been measured with the 3.2 kg detector to be 1 Bq/kg [2].

3.Status of the 140 kg detector

The 140 kg active target detector is under construction at LNGS. It will possibly allow to reach a sensitivity in the WIMP nucleon cross section as low as 10^{-45} cm^2, covering the most critical part of SUSY parameter space.

The main features of the detector are schematically shown in figure 1: a complete neutron shield consisting of 70 cm thick polyethylene and a 4π active neutron veto (8 tons liquid argon viewed by 303 cryogenic photomultipliers); a very large cryostat containing the 140 kg inner detector but designed to allocate a possible 1400 kg detector; the inner bi-phasic detector where 37 PMT provide the capability of XY event localization through the S1 pulse height centroid and of Z coordinate reconstruction by the measurement of the time delay between S1 and S2 signals, thus allowing for the definition of a fiducial volume for surface background rejection.

The assembly of the deector started in July 2007 in the installation area in Gran Sasso Laboratory Hall B. All the pre-assembly operations where completed at the beginning of year 2008, including the test in liquid nitrogen of all the 340 PMTs, the mechanical components pre-assembly, the vacuum evaporation of the wavelength-shifter on reflective layers and their installation on copper supports forming the detector structure both for the inner and the veto detectors. A de-humidified, clean room for the final assembly has been operational underground since the spring 2008. The final assembly of the internal volume was completed in July 2008 while we expect to complete that of the outer part of the detector, including the cabling by mid November. Positioning of the full detector inside the cryostat will follow and the commissioning will start with vacuum pumping operation. At the same time all the ancillary systems for cryogenics and purification as well as the passive shields (Polyethylene and Lead shield) will be installed.

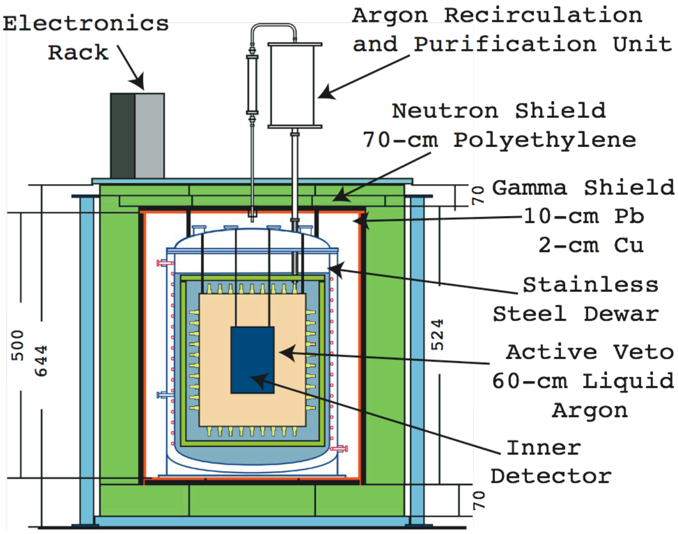

Figure 1: Schematic view of the 140 kg WARP detector.

4.Auxiliary measurements and developments

4.1Light yield studies

The presence of contaminants at a residual level in commercial argon can affect the scintillation light emission in LAr, reducing the light yield and the background rejection capability. Dedicated studies on the effect induced by O_2 and N_2 were performed with a dedicated 0.7 l chamber [3,4]. By flushing controlled amounts of contaminant into the LAr chamber a loss of light was observed as shown in figure 2. The effect can be explained by scintillationless transfer of energy to N_2 and dimolecules, which can influence the total light yield as well as the decay time of the slow component. The O_2 contamination in particular is very harmful, producing light quenching at a rate of 0.54 $ppm^{-1}ms^{-1}$ (fig. 2). It can however be reduced by filtering as done in the WARP experiment.

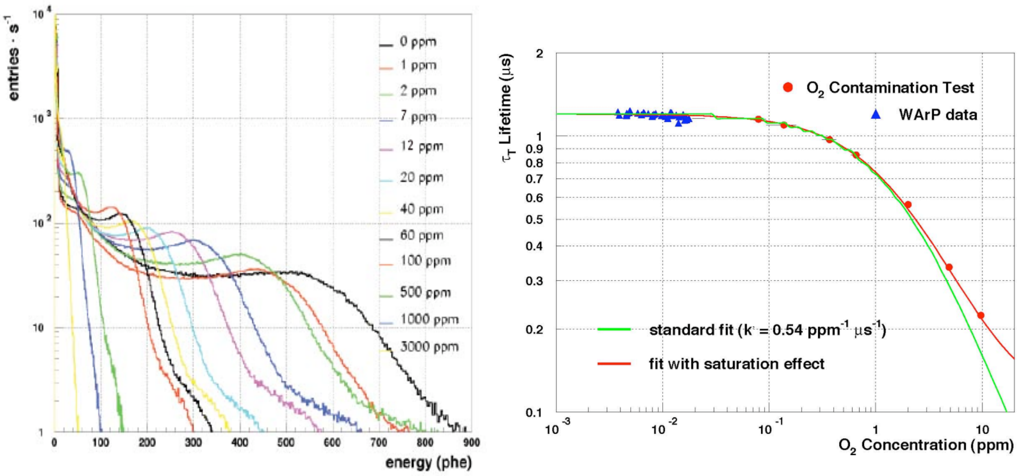

Figure 2: Compton spectra measured at different N2 concentrations (left) and long decay constant variation with O2 concentration (right) [3,4].

4.2 Low activity Argon

The presence of cosmogenic ^{39}Ar is commonly considered as a major source of background in the WIMP search with LAr technology, especially at a large mass scale (tons). The ^{39}Ar is a β-emitter with specific activity in natural Ar of about 1 Bq/kg and β-energy end-point at 565 keV. The discrimination criteria with double-phase argon detectors exhibit very effective rejection power of γ/β background from Ar-recoil signals, however ^{39}Ar β-event can be mis-identified as nuclear recoil due to statistic fluctuations of the signal shapes and of the identification parameters used to discriminate the nature of the ionizing particle.

Another approach is to use argon depleted in the radioactive isotope. ^{39}Ar-depleted argon is commercially available via centrifugation or thermal diffusion, though this method is expensive at the ton scale. A different approach was proposed by the WArP Princeton group, who demonstrated that argon contained in underground wells shows a strongly suppressed ^{39}Ar contamination [5]. According to the preliminary tests being performed by our collaboration the depletion factor should be 40 relative to atmospheric argon. The WArP collaboration is developing with industry the infrastructure for massive collection and underground storage of depleted argon.

4.3 Upgrade of the 140 kg detector

An upgrade of the 100 liters detector for the run with low activity argon is being designed. Two main modifications can be foreseen with respect to the present configuration: (1) a completely separated volume for the inner detector with independent filling, purification and recovery systems for the low activity argon; (2) an increased light collection efficiency (≈ x2) by the addition of photomultipliers on the bottom of the inner detector. Depending on the results obtained with the current set-up the collaboration may decide to step-up to a modified configuration or to a larger scale.

References

[1] WARP Collaboration (P. Benetti et al.), *Astropart. Phys.* **28** (2008) 495-507 [astro-ph/0701286]

[2] WARP Collaboration (P. Benetti et al.), *Nucl. Instrum. Meth.* **A 574** (2007) 83-88 [astro-ph/0603131]

[3] WARP Collaboration (R. Acciarri et al.), *ArXiv:0804.1217*.

[4] WARP Collaboration (R. Acciarri et al.), *ArXiv:0804.1222*.

[5] WARP Collaboration *Nucl. Instrum. Meth.* **A 587** (2008) 46-51