The DarkSide program at LNGS

S. Davini, M. Bossa, A. Mandarano, C. Savarese
Gran Sasso Science Institute, L'Aquila AQ 67100, Italy

A. Razeto, G. Bonfini, A. Candela, M. Carlini, P. Cavalcante, M. De Deo, M. D'Incecco, F. Gabriele, A. M. Goretti, A. Ianni, M. Orsini, N. Rossi, D. Sablone, R. Tartaglia
Laboratori Nazionali del Gran Sasso, Assergi AQ 67010, Italy

M. Pallavicini, G. Testera, B. Bottino, M. Cariello, L. Marini, P. Musico, L. Pagani
Istituto Nazionale di Fisica Nucleare, Sezione di Genova, Genova 16146, Italy

S. M. Mari, F. Budano, S. Bussino, M. De Vincenzi, I. James
Istituto Nazionale di Fisica Nucleare, Sezione di Roma Tre, Roma 00146, Italy

G. Fiorillo, S. Catalanotti, A. G. Cocco, G. Covone, F. Granato, B. Rossi, P. Trinchese, S. Walker
Istituto Nazionale di Fisica Nucleare, Sezione di Napoli, Napoli 80126, Italy

A. Devoto, M. Cadeddu, M. Cadoni, M. Lissia
Istituto Nazionale di Fisica Nucleare, Sezione di Cagliari, Cagliari 09042, Italy

G. Ranucci, A. Brigatti, D. D'Angelo, P. Lombardi, S. Parmeggiano, P. Saggese
Istituto Nazionale di Fisica Nucleare, Sezione di Milano, Milano 20133, Italy

D. Franco, P. Agnes, A. Tonazzo
APC, Université Paris Diderot, CNRS/IN2P3, CEA/Irfu, Obs. de Paris, Sorbonne Paris Cité, Paris 75205, France

S. De Cecco, C. Giganti
LPNHE Paris, Université Pierre et Marie Curie, Université Paris Diderot, CNRS/IN2P3, Paris 75252, France

C. Galbiati, P. D. Meyers, I. F. M. Albuquerque, J. Brodsky, H. Cao, F. Calaprice, G. Koh, X. Li, H. Qian, W. Sands, E. Shields, C. Stanford, M. Wada, S. Westerdale, X. Xiang, J. Xu, C. Zhu
Department of Physics, Princeton University, Princeton, NJ 08544, USA

S. Pordes, K. Biery, G. Forster, K. Herner, Y. Guardincerri, C. L. Kendziora, J. Yoo
Fermi National Accelerator Laboratory, Batavia, IL 60510, USA

H. Wang, A. Fan, Y. Suvorov
Department of Physics and Astronomy, University of California, Los Angeles, CA 90095, USA

A. Pocar, A. Monte, K. Randle
Amherst Center for Fundamental Interactions and Dept. of Physics, University of Massachusetts, Amherst, MA 01003, USA

J. Maricic, E. Edkins, B. R. Hackett, R. Milincic, B. Reinhold
Department of Physics and Astronomy, University of Hawai'i, Honolulu, HI 96822, USA

E. V. Hungerford, A. L. Renshaw, N. Canci, A. Empl, G. Korga, P. N. Singh
Department of Physics, University of Houston, Houston, TX 77204, USA

C. J. Martoff, J. Napolitano, T. Miletic, A. W. Watson
Department of Physics, Temple University, Philadelphia, PA 19122, USA

E. Pantic, T. Johnson
Department of Physics, University of California, Davis, CA 95616, USA

A. Chepurnov, M. Gromov
Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow 119991, Russia

O. Smirnov, K. Fomenko, D. Korablev, A. Sotnikov, A. Wishneva
Joint Institute for Nuclear Research, Dubna 141980, Russia

M. M. Wojcik, K. Pelczar, G. Zuzel
Smoluchowski Institute of Physics, Jagiellonian University, Krakow 30348, Poland

(The DarkSide Collaboration)

The DarkSide program at Laboratori Nazionali del Gran Sasso aims to perform background-free WIMP searches using double phase liquid argon time projection chambers, with the ultimate goal of covering all parameters down to the so-called neutrino floor. One of the distinct features of the program is the use of underground argon with has a reduced content of the radioactive ^{39}Ar compared to atmospheric argon. The DarkSide Collaboration is currently operating the DarkSide-50 experiment, the first such WIMP detector using underground argon, resulting in the best WIMP limits obtained with argon. The results obtained with DarkSide-50 and the plans for the next steps of the DarkSide program, the 20 t fiducial mass DarkSide-20k detector and the 200 t fiducial Argo, are reviewed in this proceedings.

1 Introduction

The existence of dark matter, postulated since 1930, is today widely accepted among particle physicists and cosmologists. Among a wide range of theories and dark matter candidates, one hypothesis is that dark matter could be constituted of weakly interacting massive particles (WIMP) with masses in the GeV/c^2 or TeV/c^2 range. There are many WIMP candidates from different theoretical models, but all sharing these common features: WIMPs are electrically neutral and stable over cosmological times, they interact through gravitational force and eventually with other unknown interactions of weak intensity (elastic scattering cross sections below the 10^{-44} cm^2 ballpark). According to these properties, WIMPs could interact with the nuclei of detectors releasing kinetic energies of few tens of keV. Very low interaction rates are expected, based on existing detection limits. Ultra-low background detectors with target masses of 0.1 – 10 tons may be required to discover WIMPs.

The DarkSide project at Laboratori Nazionali del Gran Sasso (LNGS) aims to perform background-free WIMP searches using double phase liquid argon time projection chambers (LAr TPCs). One of the advantages of argon is the powerful pulse-shape discrimination (PSD) between electron recoils (such as β and γ decays) and nuclear recoils (such as an elastic scattering interaction between a WIMP and a nucleus). One of the distinctive features of the program is the use of underground argon (UAr), which has a lower content of the radioactive ^{39}Ar compared to atmospheric argon (AAr).

2 DarkSide-50

The DarkSide-50 experiment is running at LNGS since November 2013. The DarkSide-50 detector system is described in Ref. [1] and in several proceedings of the collaboration. The apparatus consists of three nested detectors. Innermost is the cylindrical LAr TPC, with an active UAr mass of 46.4(7) kg observed by 38 3" PMTs. The design of the DarkSide-50 TPC is based upon the successful prototype DarkSide-10 [2]. The LAr TPC is mounted and operated at the center of a liquid scintillator veto (LSV), described in Ref. [4], consisting of a 4.0 m diameter stainless steel sphere instrumented with 110 PMTs and filled with boron-loaded liquid scintillator. The scintillator is a solution of pseudocumene (PC), with 5% by volume trimethylborate (TMB). Surrounding the LSV is a 1 kilo-ton water Cerenkov veto (WCV) instrumented with 80 PMTs to veto the residual cosmic-ray muons present at the LNGS depth. Signals from the LSV and WCV are used to reject events in the LAr TPC caused by cosmogenic neutrons or by neutrons and γ-rays from radioactive contamination in the detector components.

An interaction in the LAr target generates primary scintillation light (S1 pulse) and ionization electrons. The electrons escaping recombination drift in the TPC electric field to the surface of the LAr, where a stronger electric field extracts them into the gaseous region, where they induce further light emission (S2 pulse) via proportional scintillation. The S1 and S2 signals together allow the interaction vertex to be localized in 3D. The time profile of the scintillation signal S1 allows rejection of backgrounds from γ-ray- and β-decay-induced events by using PSD. The PSD parameter used in the WIMP searches is f_{90}, the fraction of S1 light in the first 90 ns of the scintillation pulse.

The DarkSide-50 detectors have been calibrated during 2014, 2015, and 2016, using a series of γ and neutron radioactive sources placed inside the LSV next to the TPC. Data taken with ^{57}Co, ^{133}Ba, and ^{137}Cs γ-ray sources were used to validate Monte Carlo (MC) simulations. Data taken with AmBe and AmC neutron sources were used to validate the transfer of the nuclear recoil response from SCENE [5] to DarkSide-50, as described in Ref. [3], and also to study the response of the LSV to neutron captures and neutron recoils.

The DarkSide-50 collaboration published two null WIMP search results in 2015 [1] and 2016 [3]. A first run of DarkSide-50, with data taken during 2014 with a 1422(67) kg-day exposure of AAr, produced a null result for the WIMP search with zero backgrounds from ^{39}Ar decays [1]. A total of 15 million events in the LAr TPC, mostly originating from ^{39}Ar, were collected. All but two of the events falling within the WIMP region of interest were rejected using the PSD. The two remaining events in the WIMP search region had a signal in coincidence with the LSV and were therefore discarded.

After the AAr run, the TPC was drained and filled with low radioactivity UAr in April 2015. The low radioactivity UAr was extracted from the Doe Canyon (Colorado, USA) CO_2 wells. A total of 155 kg of low radioactivity UAr has been obtained. The ^{39}Ar activity of the UAr corresponds to a depletion by a factor of $1.4(2) \times 10^3$ relative to AAr [3].

The first WIMP search in DarkSide-50 using UAr has been reported in Ref. [3], where it is shown that the combination of the electron recoil background rejection observed in the AAr run, and the reduction of ^{39}Ar from the use of UAr would allow DarkSide-50 to be free from ^{39}Ar background for several tens of years. A non-blind physics analysis was performed. The TPC and veto physics cuts applied, as well as their efficiency and acceptance, are described in Refs. [3 4]. The distribution of events in the f_{90} vs. S1 plane, after all quality and physics cuts, is shown in the left panel of Fig. 1. No events are present within the WIMP search region, shown in Fig. 1, which is defined as a region in the f_{90} vs. S1 plane with known high acceptance for nuclear recoils and low leakage of single-scatter ER events between 20–460 PE (13–201 keV_{nr}).

Dark matter limits from the present exposure are determined from the WIMP search region using the standard isothermal galactic WIMP halo parameters. When combined with the null result of the previous AAr exposure in DarkSide-50, a 90% CL upper limit on the WIMP-nucleon spin-independent cross section of $2.0 \times 10^{-44}\,cm^2$ ($8.6 \times 10^{-44}\,cm^2$, $8.0 \times 10^{-43}\,cm^2$) for a WIMP mass of $100\,GeV/c^2$ ($1\,TeV/c^2$, $10\,TeV/c^2$) is obtained. Fig. 2 compares these limits to those obtained by other experiments. A detailed description of the procedure can be found in Ref. [3].

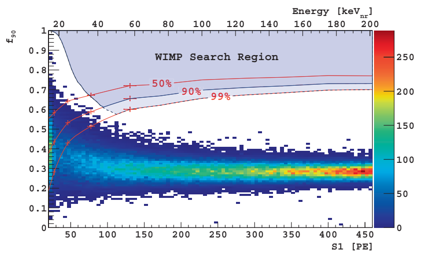

Figure 1 – Distribution of events in the f_{90} vs S1 plane which survive all physics cuts. Shaded blue with solid blue outline: WIMP search region.

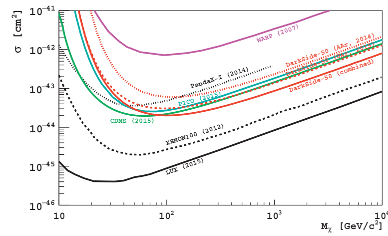

Figure 2 – Spin-independent WIMP-nucleon cross section 90% C.L. exclusion plot for DarkSide-50, compared to other experiments.

3 The future steps of the DarkSide program

The combination of the AAr and UAr results in DarkSide-50 leads to the expectation that a background-free result can also be obtained from a much larger exposure with a multi-tonne detector. On this basis, an enlarged DarkSide Collaboration has proposed the construction of DarkSide-20k, a direct WIMP search using a LAr TPC with a fiducial mass of 20 t of depleted argon (DAr). DAr is UAr which has been further depleted in ^{39}Ar by means of isotopic separation. DarkSide-20k is designed to achieve a background-free exposure of 100 t yr accumulated during a run of 5 years, giving a sensitivity to WIMP-nucleon interaction cross sections of $1 \times 10^{-47}\,\mathrm{cm}^2 (1 \times 10^{-46}\,\mathrm{cm}^2)$ for WIMPs of 1 TeV/c^2 (10 TeV/c^2) mass.

In the longer term, the aim of the DarkSide collaboration is to develop a path towards a WIMP detector to be built and operated at LNGS with a 200 t DAr fiducial mass. For now, this ultimate experiment is called Argo. Argo is planned to accumulate an exposure of 1000 t yr, free of backgrounds other than those induced by coherent scattering of neutrinos, and thus be sensitive to WIMP cross sections below the neutrino floor.

Procurement of the necessary quantity of low radioactivity UAr for DarkSide-20k is the critical technical challenge for the experiment, and will be addressed within the framework of the Urania and Aria projects. The Urania project will provide a plant capable of extracting 100 kg/d of UAr from the same wells that yielded the UAr for DarkSide-50. The Aria project will provide a cryogenic distillation plant capable of reducing the residual ^{39}Ar in the UAr by a factor of 10 per pass, at a rate of 150 kg/d, by exploiting the small difference in vapor pressure between ^{39}Ar and ^{40}Ar. The Urania and Aria projects will ultimately supply the DAr for the DarkSide-20k experiment.

4 Conclusions and Outlook

The DarkSide collaboration reported the first WIMP search using low radioactivity UAr [3], resulting in the best WIMP limits obtained with argon. The combination of PSD in argon and low radioactivity UAr lead to the expectation that a background-free result can also be obtained with a multi-tonne detector. The DarkSide collaboration has proposed the construction of the 20 t fiducial mass DarkSide-20k detector.

References

1. P. Agnes *et al*, *Phys. Lett.* B **743**, 456-466 (2015)
2. T. Alexander *et al*, ASTROPARTICLE PHYSICS **49**, 44-51 (2013)
3. P. Agnes *et al*, *Phys. Rev.* D **93**, 081101 (2016)
4. P. Agnes *et al*, JINST **11**, P03016 (2016)
5. H. Cao *et al*, *Phys. Rev.* D **91**, 092007 (2015)