Published by IOP Publishing for Sissa Medialab

Received: *November 19, 2015*
Accepted: *January 1, 2016*
Published: *February 16, 2016*

Light Detection in Noble Elements (LIDINE2015)
August 28–30, 2015
Albany, NY, U.S.A.

The DarkSide project

P. Agnes,[a] L. Agostino,[b] I.F.M. Albuquerque,[c,d] T. Alexander,[e,f] A.K. Alton,[g] K. Arisaka,[h] H.O. Back,[c,i] B. Baldin,[f] K. Biery,[f] G. Bonfini,[j] M. Bossa,[k,j] B. Bottino,[l,m] A. Brigatti,[n] J. Brodsky,[c] F. Budano,[o,p] S. Bussino,[o,p] M. Cadeddu,[q,r] L. Cadonati,[e] M. Cadoni,[q,r] F. Calaprice,[c] N. Canci,[s,j,1] A. Candela,[j] H. Cao,[c] M. Cariello,[m] M. Carlini,[j] S. Catalanotti,[t,u] P. Cavalcante,[v,j] A. Chepurnov,[w] A.G. Cocco,[u] G. Covone,[t,u] L. Crippa,[x,n] D. D'Angelo,[x,n] M. D'Incecco,[j] S. Davini,[k,j] S. De Cecco,[b] M. De Deo,[j] M. De Vincenzi,[o,p] A. Derbin,[y] A. Devoto,[q,r] F. Di Eusanio,[c] G. Di Pietro,[j,n] E. Edkins,[z] A. Empl,[s] A. Fan,[h] G. Fiorillo,[t,u] K. Fomenko,[aa] G. Forster,[e,f] D. Franco,[a] F. Gabriele,[j] C. Galbiati,[c,j] C. Giganti,[b] A.M. Goretti,[j] F. Granato,[t,ab] L. Grandi,[ac] M. Gromov,[w] M. Guan,[ad] Y. Guardincerri,[f] B.R. Hackett,[z] K. Herner,[f] E.V. Hungerford,[s] Al. Ianni,[ae,j] An. Ianni,[c,j] I. James,[o,p] C. Jollet,[af] K. Keeter,[ag] C.L. Kendziora,[f] V. Kobychev,[ah] G. Koh,[c] D. Korablev,[aa] G. Korga,[s,t] A. Kubankin,[ai] X. Li,[c] M. Lissia,[r] P. Lombardi,[n] S. Luitz,[aj] Y. Ma,[ad] I.N. Machulin,[ak,al] A. Mandarano,[k,j] S.M. Mari,[o,p] J. Maricic,[z] L. Marini,[l,m] C.J. Martoff,[ab] A. Meregaglia,[af] P.D. Meyers,[c] T. Miletic,[ab] R. Milincic,[z] D. Montanari,[f] A. Monte,[e] M. Montuschi,[j] M. Monzani,[aj] P. Mosteiro,[c] B.J. Mount,[ag] V.N. Muratova,[y] P. Musico,[m] J. Napolitano,[ab] A. Nelson,[c] S. Odrowski,[j] M. Orsini,[j] F. Ortica,[am,an] L. Pagani,[l,m] M. Pallavicini,[l,m] E. Pantic,[d] S. Parmeggiano,[n] K. Pelczar,[ap] N. Pelliccia,[am,an] S. Perasso,[a] A. Pocar,[e,c] S. Pordes,[f] D.A. Pugachev,[ak,al] H. Qian,[c] K. Randle,[e] G. Ranucci,[n] A. Razeto,[j,c] B. Reinhold,[z] A.L. Renshaw,[h,s] A. Romani,[am,an] B. Rossi,[u,c] N. Rossi,[j] D. Rountree,[v] D. Sablone,[j] P. Saggese,[n] R. Saldanha,[ac] W. Sands,[c] S. Sangiorgio,[aq] C. Savarese,[k,j] E. Segreto,[ar] D.A. Semenov,[y] E. Shields,[c] P.N. Singh,[s] M.D. Skorokhvatov,[ak,al] O. Smirnov,[aa] A. Sotnikov,[aa] C. Stanford,[c] Y. Suvorov,[h,j,ak] R. Tartaglia,[j] J. Tatarowicz,[ab] G. Testera,[m] A. Tonazzo,[a] P. Trinchese,[t] E.V. Unzhakov,[y] A. Vishneva,[ab] B. Vogelaar,[v] M. Wada,[c] S. Walker,[t,u] H. Wang,[h] Y. Wang,[ad,h,as] A.W. Watson,[ab] S. Westerdale,[c] J. Wilhelmi,[ab] M.M. Wojcik,[ap] X. Xiang,[c] J. Xu,[c] C. Yang,[ad] J. Yoo,[f] S. Zavatarelli,[m] A. Zec,[e] W. Zhong,[ad] C. Zhu[c] and G. Zuzel[ap]

[a]*APC, Université Paris Diderot, CNRS/IN2P3, CEA/Irfu, Obs. de Paris, Sorbonne Paris Citée, Paris 75205, France*

[b]*LPNHE Paris, Université Pierre et Marie Curie, Université Paris Diderot, CNRS/IN2P3, Paris 75252, France*

[c]*Department of Physics, Princeton University, Princeton, NJ 08544, U.S.A.*

[1]Corresponding author

2016 JINST 11 C02051

doi:10.1088/1748-0221/11/02/C02051

[d] Instituto de Física, Universidade de São Paulo, São Paulo 05508-090, Brazil
[e] Amherst Center for Fundamental Interactions and Dept. of Physics, University of Massachusetts, Amherst, MA 01003, U.S.A.
[f] Fermi National Accelerator Laboratory, Batavia, IL 60510, U.S.A.
[g] Department of Physics, Augustana University, Sioux Falls, SD 57197, U.S.A.
[h] Department of Physics and Astronomy, University of California, Los Angeles, CA 90095, U.S.A.
[i] Pacific Northwest National Laboratory, Richland, WA 99354, U.S.A.
[j] Laboratori Nazionali del Gran Sasso, Assergi AQ 67010, Italy
[k] Gran Sasso Science Institute, L'Aquila AQ 67100, Italy
[l] Department of Physics, Università degli Studi, Genova 16146, Italy
[m] Istituto Nazionale di Fisica Nucleare, Sezione di Genova, Genova 16146, Italy
[n] Istituto Nazionale di Fisica Nucleare, Sezione di Milano, Milano 20133, Italy
[o] Istituto Nazionale di Fisica Nucleare, Sezione di Roma Tre, Roma 00146, Italy
[p] Department of Physics and Mathematics, Università degli Studi Roma Tre, Roma 00146, Italy
[q] Department of Physics, Università degli Studi, Cagliari 09042, Italy
[r] Istituto Nazionale di Fisica Nucleare, Sezione di Cagliari, Cagliari 09042, Italy
[s] Department of Physics, University of Houston, Houston, TX 77204, U.S.A.
[t] Department of Physics, Università degli Studi Federico II, Napoli 80126, Italy
[u] Istituto Nazionale di Fisica Nucleare, Sezione di Napoli, Napoli 80126, Italy
[v] Department of Physics, Virginia Tech, Blacksburg, VA 24061, U.S.A.
[w] Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow 119991, Russia
[x] Department of Physics, Università degli Studi, Milano 20133, Italy
[y] St. Petersburg Nuclear Physics Institute NRC Kurchatov Institute, Gatchina 188350, Russia
[z] Department of Physics and Astronomy, University of Hawai'i, Honolulu, HI 96822, U.S.A.
[aa] Joint Institute for Nuclear Research, Dubna 141980, Russia
[ab] Department of Physics, Temple University, Philadelphia, PA 19122, U.S.A.
[ac] Kavli Institute, Enrico Fermi Institute, and Dept. of Physics, University of Chicago, Chicago, IL 60637, U.S.A.
[ad] Institute of High Energy Physics, Beijing 100049, China
[ae] Laboratorio Subterráneo de Canfranc, Canfranc Estación 22880, Spain
[af] IPHC, Université de Strasbourg, CNRS/IN2P3, Strasbourg 67037, France
[ag] School of Natural Sciences, Black Hills State University, Spearfish, SD 57799, U.S.A.
[ah] Institute for Nuclear Research, National Academy of Sciences of Ukraine, Kiev 03680, Ukraine
[ai] Radiation Physics Laboratory, Belgorod National Research University, Belgorod 308007, Russia
[aj] SLAC National Accelerator Laboratory, Menlo Park, CA 94025, U.S.A.
[ak] National Research Centre Kurchatov Institute, Moscow 123182, Russia
[al] National Research Nuclear University MEPhI, Moscow 115409, Russia
[am] Department of Chemistry, Biology and Biotechnology, Università degli Studi, Perugia 06123, Italy
[an] Istituto Nazionale di Fisica Nucleare, Sezione di Perugia, Perugia 06123, Italy
[ao] Department of Physics, University of California, Davis, CA 95616, U.S.A.
[ap] Smoluchowski Institute of Physics, Jagiellonian University, Krakow 30348, Poland
[aq] Lawrence Livermore National Laboratory, Livermore, CA 94550, U.S.A.
[ar] Institute of Physics Gleb Wataghin, Universidade Estadual de Campinas, São Paulo 13083-859, Brazil
[as] School of Physics, University of Chinese Academy of Sciences, Beijing 100049, China

E-mail: nicola.canci@lngs.infn.it

2016 JINST 11 C02051

Abstract: DarkSide is a graded experimental project based on radiopure argon, and is now, and will be, used in direct dark matter searches. The present DarkSide-50 detector, operating at the Gran Sasso National Laboratory, is a dual-phase, 50 kg, liquid argon time-projection-chamber surrounded by an active liquid scintillator veto. It is designed to be background free in 3 years of operation. DS-50 performances, when filled with atmospheric argon, are reported. However DS-50 filled with underground argon, shows impressive reduction of the ^{39}Ar isotope. The application of this powerful technology in a future generation of the DarkSide program is discussed.

Keywords: Time projection Chambers (TPC); Noble liquid detectors (scintillation, ionization, double-phase); Large detector systems for particle and astroparticle physics; Dark Matter detectors (WIMPs, axions, etc.)

2016 JINST 11 C02051

Contents

2016 JINST 11 C02051

1 Introduction

Astronomical and cosmological evidences have unambiguously indicated that only a little fraction of the matter of the Universe is composed of ordinary baryonic matter, showing the existence of an unknown nature form of matter, the so-called dark matter. Proofs of the possible presence of dark matter have been found coming from several and independent investigations in different fields of research. Theoretical predictions suggest that this unknown matter could be made of a generic class of particles called Weakly Interacting Massive Particles (WIMPs), relics of the Big Bang, still existing today. Moreover, the supersymmetric extension of the Standard Model provides a possible WIMP candidate in the lightest supersymmetric particle, that should be stable, enough massive and weakly interacting to explain the dark matter content of the universe. Hence, a great effort is now being devoted to find some evidence of these new particles. Direct dark matter search experiments look for an excess of signals in an underground, low background environment; very different detectors have been built for this purpose, having in common the capability to measure small energy depositions ($1 \div 100\,\mathrm{keV}$). In the context of direct detection techniques, the use of liquified noble gases (neon, argon and xenon) as sensitive medium is one of the most promising way to perform this search. Argon in particular, due to its high scintillation photon yield, powerful background rejection through efficient event discrimination methods, ease of purification and high abundance at reasonable cost, represents an ideal medium to detect WIMPs. In this framework the DarkSide (DS) project based on depleted argon plays a leading role in the direct dark matter search scenario.

2 The DarkSide program

The DarkSide program has been designed with the aim of direct dark matter detection via WIMP-nucleus scattering in liquid argon (LAr) at Gran Sasso National Laboratory, using a dual-phase LAr Time Projection Chamber (TPC), with scalable, zero-background technology [1, 2].

The two-phase (liquid-gas) technology is based on the simultaneous detection of both signals produced by ionization events in liquid argon: free electron charge and scintillation light. In fact, particles interacting in LAr create free electrons and excited Ar molecular states which produce scintillation radiation through de-excitation processes. The two processes are complementary and their relative weight depends on the strength of the electric field applied to the active LAr volume [3, 4]. The main feature of the LAr technology in the direct dark matter search is the capability to efficiently separate nuclear recoil (NR) events, as expected from WIMP interactions, from electron recoil (ER) events. The scintillation light decay time constants coming from the de-excitation of Ar dimers are deeply different respectively for the singlet ($\sim$ 6 ns) and the triplet ($\sim$ 1500 ns) states and the ratio of singlet to triplet states differs for nuclear and electron recoils. The time evolution of the scintillation light provides discrimination between these two kinds of events and the ratio of ionization to scintillation gives further discrimination between nuclear and electron recoils [5–8].

In general, the largest challenge in searching for dark matter is the suppression of the rate of background events to below the very low WIMP interaction rates (a few events per ton$\times$year) to which current dark matter experiments are sensitive. In the case of the LAr technology, the main drawback is the presence of the radioactive isotope of ^{39}Ar in natural atmospheric argon (AAr) with an intrinsic activity of $\sim$ 1 Bq/kg [9]. The cosmogenically produced isotope is a β-emitter with a half-life of 269 years, the end-point of the β spectrum at 565 keV and a mean energy at 220 keV. This shows that the low energy electrons will have an energy in the range interesting from the point of view of a WIMP search and can become a problem for larger detectors. Therefore the reduction of ^{39}Ar content represents a key requirement for large scale dark matter LAr detector; to this purpose a particular effort has been dedicated in procuring argon from underground reservoirs. Underground argon (UAr), protected from cosmic ray activation, is significantly reduced in ^{39}Ar content at least of two orders of magnitude respect to the AAr [10, 11].

The DarkSide project foresees a multi-stage approach: after the operation of a 10 kg detector [12], the DarkSide-50 (DS-50) detector is now operating underground in the Hall C of LNGS. After a first step with the detector initially filled with the AAr [13], the DS-50 filled with argon derived from underground sources (with a 46 kg fiducial mass TPC) is currently running with the goal to conduct a background-free dark matter search reaching a projected sensitivity of 10^{-45} cm^2 for a 100 GeV WIMP mass [14].

The next step of the project is to proceed with a multi-ton detector and a sensitivity improvement of two orders of magnitude. To this purpose, the very low intrinsic background levels, the discrimination of electron recoils and the active suppression of neutron background represent the key features attempted by the DS project for having a background-free exposure large UAr mass detector.

2016 JINST 11 C02051

3 The DarkSide-50 detector

The DarkSide-50 experiment is composed by three nested detectors (see figure 1 [Left]): innermost is the LAr TPC, acting as dark matter detector containing the liquid argon target, housed by the organic Liquid Scintillator Veto (LSV), serving as shielding and as anti-coincidence for radiogenic and cosmogenic neutrons, γ-rays and cosmic muons and the most externally Water Cherenkov Detector (WCD), acting as a shield and as anti-coincidence for cosmic muons [15, 16].

The TPC is made by a high reflectivity PTFE square cylinder (36 cm diameter by 36 cm height) with 46 kg active volume, viewed by 38 (19 at bottom and 19 on the top) Hamamatsu HQE R11065 3″ PMTs. The top of the active volume is defined by a stainless steel grid, allowing for setting the drift and extraction fields independently. The gas pocket above the active volume is 1cm thick. Two fused silica windows coated with transparent conductor, ITO, forming the anode and cathode surfaces, are respectively placed at the top and at the bottom of the PTFE chamber. Field shaping copper rings outside the TPC ensure a uniform electric field inside the LAr active volume. All inner surfaces are coated with the wavelength shifter tetraphenyl-butadiene (TPB) shifting the VUV 128 nm LAr scintillation light to visible 420 nm light detected by the PMTs (see figure 1 [Right]). A detailed description of the DarkSide-50 detector can be found in [13].

Ionizing particles interacting in the sensitive LAr volume of the detector deposit energy inducing both a prompt scintillation and ionization. The scintillation light represents the primary pulse signal S1. The ionization electrons are drifted upwards by an electric field (200 V/cm) to the liquid surface where they are extracted into a gas pocket by a higher electric field (2.8 kV/cm). The acceleration of the electrons across the gas pocket produces a secondary electroluminescence scintillation signal S2, proportional to the number of ionization electrons. The S1 and S2 pulses enable 3D position reconstruction of the primary interaction site: the time between S1 and S2 gives the vertical position, and the hit pattern of the S2 light on the photosensors gives the transverse position. The 3D position reconstruction allows for rejection of surface backgrounds.

The Liquid Scintillator Veto surrounding the TPC is a 4 m diameter stainless steel sphere filled with a mixture of pseudocumene and trimethyl-borate (TMB). The content of ^{10}B in the scintillator provides a large neutron capture cross section. The LSV is instrumented with 110 Hamamatsu R5912 8″ PMTs; it acts as an active veto to tag neutrons in the TPC and for allowing for measurement of the neutron background directly in situ. A Water Cherenkov Detector, made by an 11 m diameter by 10 m height water tank surrounds the LSV; it is equipped with 80 ETL 9351 8″ PMTs and forms an active muon veto to tag cosmogenic induced neutrons. Both the LSV and the WCD provide passive neutron and gamma shielding for the TPC.

4 DS-50 performances

Measurements of DS-50 performances and evaluation of the light yields (LY) with the TPC filled with the AAr for the inner detector and LSV have been performed [13]. The TPC trigger rate was dominated by ^{39}Ar β-decays, giving a value of 50 Hz. The evaluation of the TPC light yield at null field and at 200 V/cm has been performed by using data from a ^{83m}Kr source. As reported in the figure 2 [Left] the resulting spectrum is a convolution of ^{39}Ar and ^{83m}Kr sources; it has been fit to obtain the measurement of the light yield of the detector at the 41.5 keV reference line of ^{83m}Kr.

2016 JINST 11 C02051

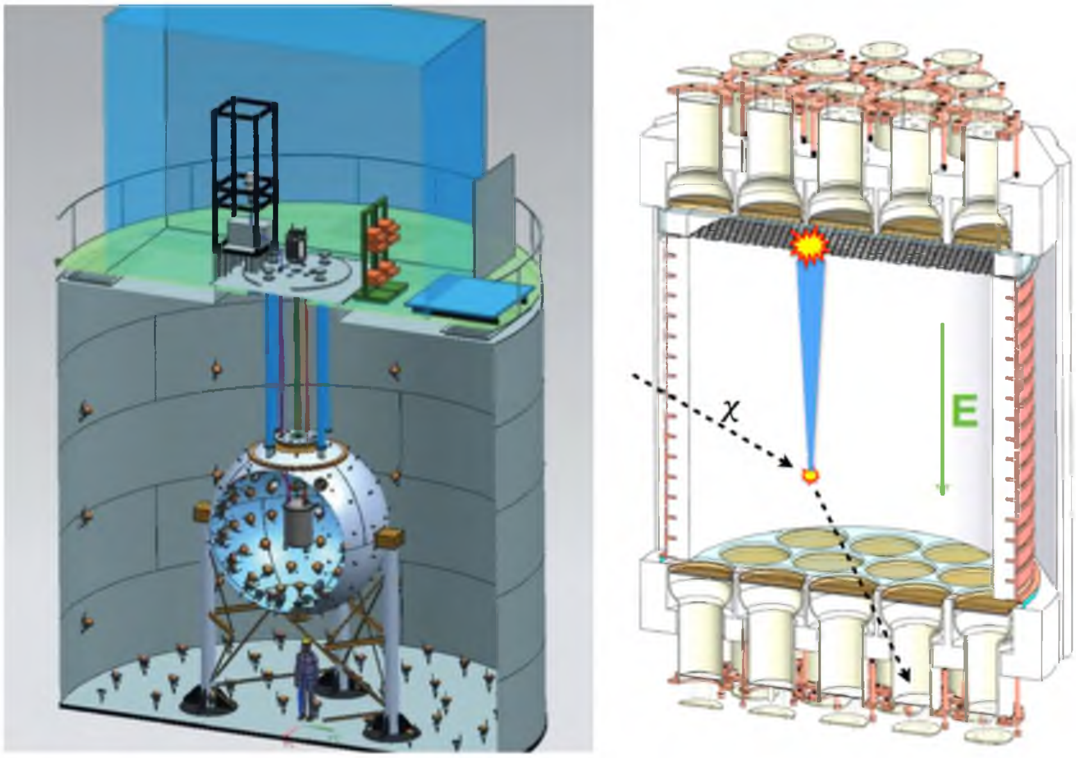

Figure 1. Artistic view of the DS-50 detector with the three nested detectors: TPC in the center of the LSV surrounded by the WCD [Left]; picture of the TPC with the PTFE chamber and the 3″ R11065 PMTs [Right].

The fit of the overall spectrum, accounting for both the ^{39}Ar and ^{83m}Kr contributions, returns a light yield, expressed in photoelectron (PE) per unit energy, of (7.9 ± 0.4) PE/keV at zero drift field, while a value of (7.0 ± 0.3) PE/keV has been measured with the drift field settled at 200 V/cm.

Furthermore, a very low levels of electronegative impurities in liquid argon have been measured, achieving an electron drift lifetime $\tau_e > 5$ ms for the majority of the AAr campaign.

The light yield of the LSV was measured through the ^{14}C content in the TMB[1] and the ^{60}Co coming from the TPC cryostat stainless steel. By combining the fit results of the two spectra a LSV light yield of (0.54 ± 0.04) PE/keV was obtained.

Pulse shape discrimination (PSD) has been performed by using the f90 parameter as the fraction of S1 light collected in the first 90 ns compared to the total S1 light, collected in a 7 μs window. The nuclear recoil (NR) f90 response was extrapolated from the SCENE experiment, which exposed a small LAr TPC to a pulsed low energy neutron beam [17]. The NR energy scale was also transferred from SCENE to DS-50 by referencing the null field LY measured with a ^{83m}Kr source in each experiment.

A calibration campaign, following the first dark matter search, was started with the aim to perform an energy calibration for both TPC and LSV. To this purpose, the calibration hardware was installed in the DS-50 detector, allowing for the placement of several gamma and neutron sources in the LSV next to the TPC cryostat. Data taken with AmBe sources has been used to validate the nu-

[1]The performance of the LSV was reduced due to unexpectedly high ^{14}C content in the TMB, which was found to contain modern carbon; the TMB has since been replaced with a cleaner petrolium-based sample.

2016 JINST 11 C02051

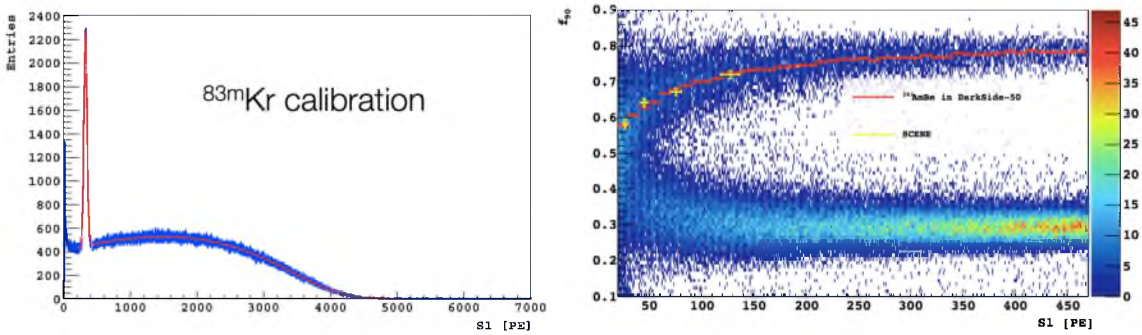

Figure 2. Primary scintillation spectrum from a zero-field run of the DS-50 TPC obtained while the recirculating argon was spiked with ^{83m}Kr (blue), with the superimposed fit to the ^{83m}Kr + ^{39}Ar spectrum (red) [Left]. Comparison of NR f90 medians from AmBe data in DS-50 (red) and extrapolated values from SCENE to DS-50 (yellow). The scatter plot shows the AmBe data in DarkSide-50 [Right].

clear recoil f90 response extrapolated from SCENE to DS-50 as shown in figure 2 [Right], while data taken with ^{57}Co, ^{133}Ba and ^{137}Cs sources provided validation for DarkSide's MC simulation code.

5 First physics result with atmospheric argon

A first dark matter search has been performed with data collected with atmospheric argon target with an AAr exposure of 47.1 live days (1422 kg×day fiducial) of data acquired between October 2013 and May 2014. Planning a run time of at least 3 years, the ^{39}Ar background from 47.1 live days of AAr corresponds to that expected in 38.7 years of UAr DS-50 run at the upper limit ^{39}Ar activity. A set of data quality cuts, both for the LAr TPC and the vetoes, to isolate single scatter recoils and to exclude backgrounds and misconstructed events have been applied; in particular events from pile-up of ^{39}Ar decays or multiple scatter γ's, events with coincident Cherenkov light and events with coincident signal in the LSV or the WCD have been rejected. A fiducial mass of (36.9 ± 0.6) kg was considered. It was defined by requiring the drift time to be between 40 μs and 334.5 μs, while no radial cuts were applied. The accurate description of all cuts, their order of application, their effect on livetime, acceptance and fiducial volume, and their systematics and statistical uncertainties can be found in [13].

The WIMP search region was defined in the range of 80 ÷ 460 PE of S1, corresponding to recoils in the energy range 38 ÷ 206 keV$_{\mathbf{nr}}$. The WIMP region of interest in the f90 vs S1 plane was defined by intersecting the 90% nuclear recoil acceptance curve derived from SCENE with a curve corresponding to fixed ^{39}Ar leakage per S1 bin. The ER leakage was estimated using a statistical model for f90 [18]. The total leakage of ^{39}Ar events into the WIMP box was < 0.1 events for the (1422 ± 67) kg×d exposure. No events in the WIMP search region resulted in the final dark matter search as reported in figure 3. This led to the placement of the 90% CL exclusion curve shown in figure 4, with a minimum cross section of 6.1×10^{-44} cm^2 for a 100 GeV/c^2 WIMP mass.[2]

[2]At the time of their publication, these results represented the most stringent WIMP dark matter search limit using a liquid argon target.

2016 JINST 11 C02051

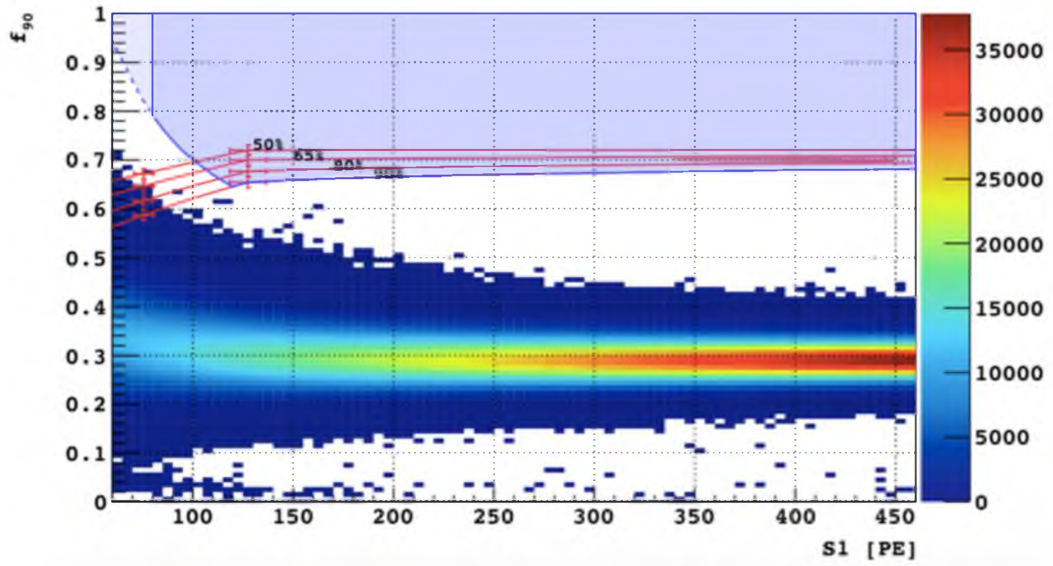

Figure 3. Distribution of events in the f90 vs S1 plane which survive all cuts. Shaded blue with solid blue outline: WIMP search region. Percentages label the f90 acceptance contours for NRs, drawn by connecting points at which the acceptance was determined from the corresponding SCENE measurements.

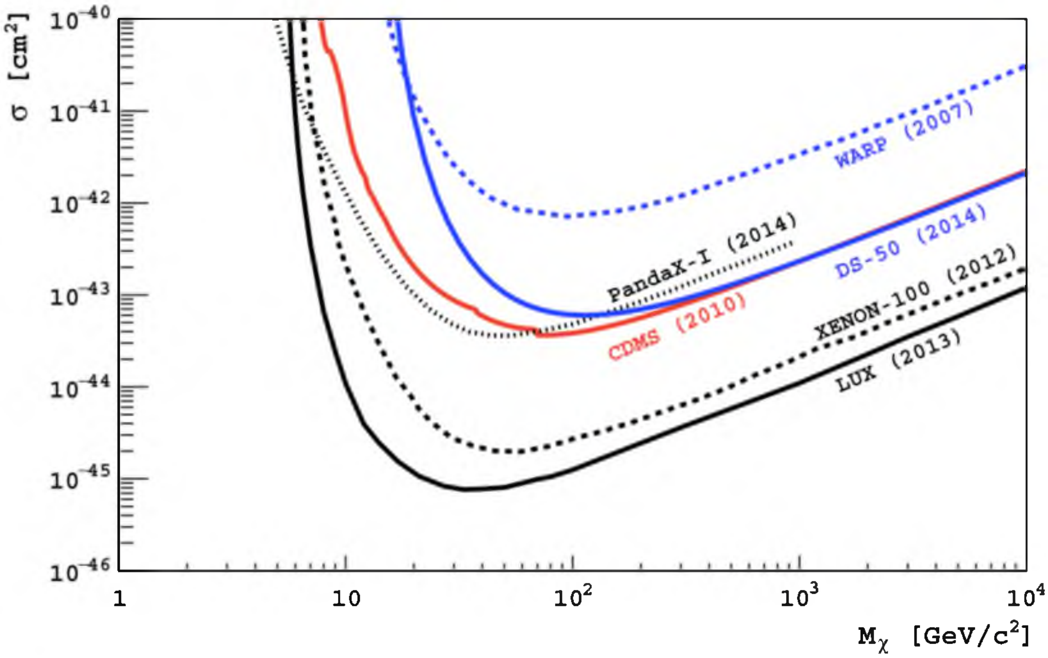

Figure 4. Spin-independent WIMP-nucleon cross section 90% C.L. exclusion plot for the DarkSide-50 atmospheric argon campaign compared to previous results from other experiments.

6 Underground argon first results

After demonstrating the first results with the atmospheric argon, the DS-50 TPC was emptied of AAr in March 2015 and the TPC was filled with the UAr on April 1, 2015. Data taken with the

2016 JINST 11 C02051

underground argon showed a trigger rate of ∼ 1.5 Hz, significantly reduced if compared with the AAr trigger rate of ∼ 50 Hz. After a minimal set of cuts for single scatter events selection have been applied a good agreement between the rate of events beyond the ^{39}Ar endpoint for the AAr and UAr spectra have been observed, as reported in figure 5, indicating an unchanged light yield after TPC chamber was filled with the UAr. Further calibration with the ^{83m}Kr source confirmed the good light yield stability. To initially estimate the reduction factor of the ^{39}Ar activity in the UAr, the S1spectra in a 4 kg core of the TPC, where the rate of the external γ's was significantly attenuated, have been considered and, after the application of LSV anti-coincidence cuts (even if with small effects), have been compared with the AAr spectrum, resulting into a depletion factor of at least 300.

A detailed description of the first results of the DarkSide-50 obtained using a target of low-radioactivity argon has been reported in [14].

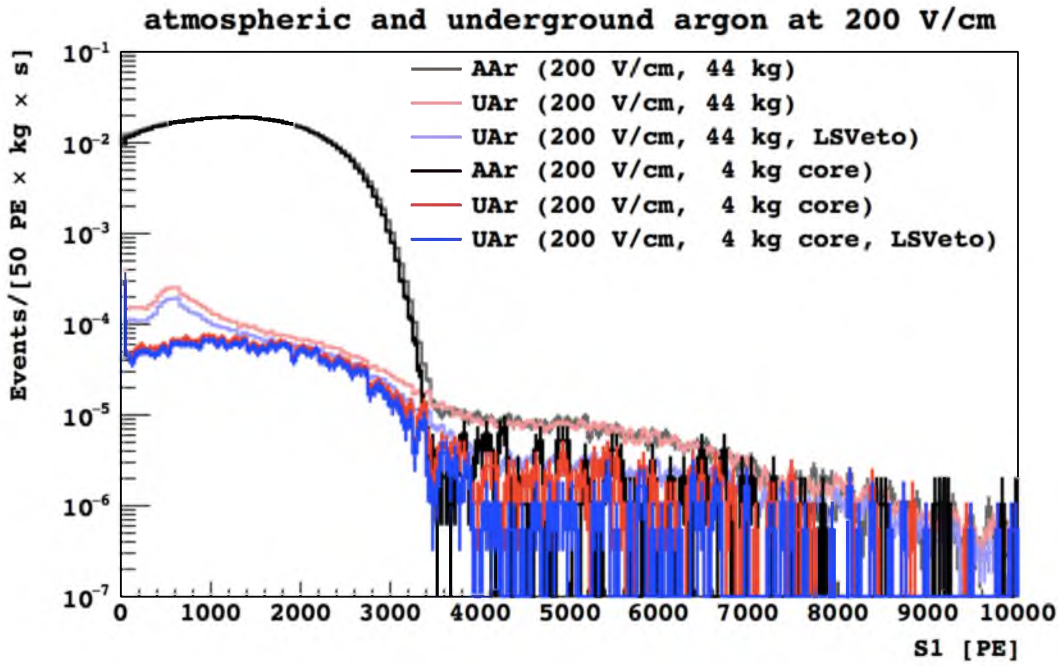

Figure 5. Comparison of S1 spectra from AAr and UAr taken at 200 V/cm drift field. Comparisons made with application of veto anti-coincidence cuts and between the full active volume and the core of the TPC.

7 Conclusions

The DarkSide-50 experiment is stably operating underground at LNGS since October 2013. The first dark matter search campaign of DarkSide-50, with the TPC filled with the atmospheric argon, set the most stringent limit on the WIMP-nucleon cross section for a liquid argon target.

The DarkSide-50 detector, with the TPC filled with UAr, is currently operating and accumulating exposure in a stable, low-background configuration, planning for an extended, 3 years, dark matter search. A first data analysis indicated a depletion factor of ^{39}Ar activity in the UAr showing

2016 JINST 11 C02051

a reduction of the ^{39}Ar concentration at least 300 times lower than in AAr, also confirmed by recent results.

The good performances for dark matter search, especially thanks to the high rejection power, showed by the liquid argon technology and the feasibility of the dark matter detection based on LAr demonstrated by DarkSide-50 (filled with AAr and UAr), lead to the next stage of the DarkSide program, based on the DarkSide-20k, a multi-ton detector with 20 t fiducial volume. In fact, LAr detectors can be scaled to multi-ton and are the most powerful background-free technique devices for the ultimate experiment in dark matter search. DS-20k will be instrumented by using silicon photomultipliers (SiPMs) providing an increased LY and reduced radiogenic neutron background, compared to conventional PMTs. DarkSide-20k aims for a 100 t×yr background-free exposure to give a projected sensitivity of 9×10^{-48} cm^2 for a WIMP mass of 1 TeV/c^2.

References

[1] P. Benetti et al., *First results from a Dark Matter search with liquid Argon at 87 K in the Gran Sasso Underground Laboratory*, Astropart. Phys. **28** (2008) 495 [astro-ph/0701286].

[2] DarkSide collaboration, T. Alexander et al., *DarkSide search for dark matter*, 2013 *JINST* **8** C11021.

[3] T. Doke, *Fundamental properties of liquid Argon, Krypton and Xenon as Radiation detector media*, *Portugal Phys.* **12** (1981) 9.

[4] S. Kubota, A. Nakamoto, T. Takahashi, T. Hamada, E. Shibamura, M. Miyajima et al., *Recombination luminescence in liquid argon and in liquid xenon*, Phys. Rev. **B 17** (1978) 2762;
S. Kubota et al., *Dynamical behaviour of free electrons in the recombination process in liquid Ar, Kr and Xe*, *Phys. Rev. B* **20** (1979) 3486.

[5] E. Morikawa et al., *Argon, Krypton an Xenon excimer luminescence: from dilute gas to the condensed phase*, *J. Chem. Phys.* **91** (1989) 1469.

[6] T. Heindl, T. Dandl, M. Hofmann, R. Krucken, L. Oberauer, W. Potzel et al., *The scintillation of liquid argon*, Europhys. Lett. **91** (2010) 62002 [arXiv:1511.07718].

[7] A. Hitachi, T. Takahashi, N. Funayama, K. Masuda, J. Kikuchi and T. Doke, *Effect of ionization density on the time dependence of luminescence from liquid argon and xenon*, Phys. Rev. **B 27** (1983) 5279 .

[8] M.J. Carvalho et al., *Luminescence decay in condensed Argon under high energy excitation*, *J. Lumin.* **18-19** (1979) 487.

[9] WARP collaboration, P. Benetti et al., *Measurement of the specific activity of ar-39 in natural argon*, Nucl. Instrum. Meth. **A 574** (2007) 83 [astro-ph/0603131].

[10] D. Acosta-Kane et al., *Discovery of underground argon with low level of radioactive 39Ar and possible applications to WIMP dark matter detectors*, Nucl. Instrum. Meth. **A 587** (2008) 46 [arXiv:0712.0381].

[11] NEMO collaboration, S. Aiello et al., *Measurement of the atmospheric muon depth intensity relation with the NEMO Phase-2 tower*, Astropart. Phys. **66** (2015) 1 [arXiv:1412.0849]

[12] DarkSide collaboration, T. Alexander et al., *Light yield in DarkSide-10: A prototype two-phase argon TPC for dark matter searches*, Astropart. Phys. **49** (2013) 44 [arXiv:1204.6218].

[13] DarkSide collaboration, P. Agnes et al., *First Results from the DarkSide-50 Dark Matter Experiment at Laboratori Nazionali del Gran Sasso*, Phys. Lett. **B 743** (2015) 456 [arXiv:1410.0653].

[14] DarkSide collaboration, P. Agnes et al., *Low Radioactivity Argon Dark Matter Search Results from the DarkSide-50 Experiment*, arXiv:1510.00702.

[15] Borexino collaboration, G. Alimonti et al., *Ultra-low background measurements in a large volume underground detector*, *Astropart. Phys.* **8** (1998) 141.

[16] G. Alimonti et al., *A large scale low-background liquid scintillation detector: The counting test facility at Gran Sasso*, *Nucl. Instrum. Meth.* **A 406** (1998) 411.

[17] SCENE collaboration, H. Cao et al., *Measurement of Scintillation and Ionization Yield and Scintillation Pulse Shape from Nuclear Recoils in Liquid Argon*, *Phys. Rev.* **D 91** (2015) 092007 [arXiv:1406.4825].

[18] G. Ruprecht, C. Vockenhuber, L. Buchmann, R. Woods, C. Ruiz, S. Lapi et al., *Precise measurement of the beta decay and electron capture of Na-22, Au-198 and Au-196 in low-temperature metal hosts and reexamination of lifetime modifications*, *Phys. Rev.* **C 77** (2008) 065502 [*Erratum ibid.* **C 78** (2008) 039901].

2016 JINST 11 C02051