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DarkSide: Latest results and future perspectives

B. BOTTINO(1)(2), P. AGNES(20), I. F. M. ALBUQUERQUE(49), T. ALEXANDER(38), A. K. ALTON(6), D. M. ASNER(38), M. P. AVE(49), H. O. BACK(38), G. BATIGNANI(36)(37), K. BIERY(18), V. BOCCI(42), G. BONFINI(4), W. BONIVENTO(12), S. BUSSINO(40)(41), M. CADEDDU(11)(12), M. CADONI(11)(12), F. CALAPRICE(39), A. CAMINATA(2), N. CANCI(4)(20), A. CANDELA(4), M. CARAVATI(11)(12), M. M. CARDENAS(15), M. CARIELLO(2), M. CARLINI(4), M. CARPINELLI(16)(44), S. CATALANOTTI(30)(31), V. CATAUDELLA(30)(31), P. CAVALCANTE(4)(50), S. CAVUOTI(30)(31), A. CHEPURNOV(29), C. CICALÒ(12), L. CIFARELLI(9)(10), A. G. COCCO(30), G. COVONE(30)(31), D. D'ANGELO(27)(28), M. D'INCECCO(4), D. D'URSO(16)(44), S. DAVINI(2), A. DE CANDIA(30)(31), S. DE CECCO(42)(43), M. DE DEO(4), G. DE FILIPPIS(30)(31), G. DE ROSA(30)(31), M. DE VINCENZI(40)(41), A. V. DERBIN(33), A. DEVOTO(11)(12), F. DI EUSANIO(39), G. DI PIETRO(4)(27), C. DIONISI(42)(43), E. EDKINS(19), A. EMPL(20), A. FAN(47), G. FIORILLO(30)(31), K. FOMENKO(22), D. FRANCO(3), F. GABRIELE(4), C. GALBIATI(5)(39), P. GARCIA ABIA(15), C. GHIANO(4), S. GIAGU(42)(43), C. GIGANTI(25), G. K. GIOVANETTI(39), O. GORCHAKOV(22), A. M. GORETTI(4), F. GRANATO(45), M. GROMOV(29), M. GUAN(21), Y. GUARDINCERRI(18), M. GULINO(16)(17), B. R. HACKETT(19), K. HERNER(18), B. HOSSEINI(12), D. HUGHES(39), P. HUMBLE(38), E. V. HUNGERFORD(20), AN. IANNI(4)(39), V. IPPOLITO(42), I. JAMES(40)(41), T. N. JOHNSON(46), K. KEETER(8), C. L. KENDZIORA(18), I. KOCHANEK(39), G. KOH(39), D. KORABLEV(22), G. KORGA(4)(20), A. KUBANKIN(7), M. KUSS(36), M. LA COMMARA(30)(31), M. LAI(11)(12), X. LI(39), M. LISSIA(12), G. LONGO(30)(31), A. A. MACHADO(14), I. N. MACHULIN(24)(26), A. MANDARANO(4)(5), L. MAPELLI(39), S. M. MARI(40)(41), J. MARICIC(19), C. J. MARTOFF(45), A. MESSINA(42)(43), P. D. MEYERS(39), R. MILINCIC(19), A. MONTE(48), M. MORROCCHI(36), B. J. MOUNT(8), V. N. MURATOVA(33), P. MUSICO(2), R. NANIA(9), A. NAVRER AGASSON(25), A. O. NOZDRINA(24)(26), A. OLEINIK(7), M. ORSINI(4), F. ORTICA(34)(35), L. PAGANI(46), M. PALLAVICINI(1)(2), L. PANDOLA(16), E. PANTIC(46), E. PAOLONI(36)(37), K. PELCZAR(4), N. PELLICCIA(34)(35), V. PESUDO(15), A. POCAR(48), S. PORDES(18), S. S. POUDEL(20), D. A. PUGACHEV(24), H. QIAN(39), F. RAGUSA(27)(28), M. RAZETI(12), A. RAZETO(4), A. L. RENSHAW(20), M. RESCIGNO(42), Q. RIFFARD(3), A. ROMANI(34)(35), B. ROSSI(30), N. ROSSI(42), D. SABLONE(4)(39), O. SAMOYLOV(22), W. SANDS(39), S. SANFILIPPO(40)(41), R. SANTORELLI(15), C. SAVARESE(4)(5), E. SCAPPARONE(9), B. SCHLITZER(46), E. SEGRETO(14), D. A. SEMENOV(33), A. SHCHAGIN(7), A. SHESHUKOV(22), M. SIMEONE(30)(32), P. N. SINGH(20), M. D. SKOROKHVATOV(24)(26), O. SMIRNOV(22), A. SOTNIKOV(22), C. STANFORD(39), S. STRACKA(36), Y. SUVOROV(24)(30)(31), R. TARTAGLIA(4), G. TESTERA(2), A. TONAZZO(3), P. TRINCHESE(30)(31), E. V. UNZHAKOV(33), M. VERDUCCI(42)(43), A. VISHNEVA(22), B. VOGELAAR(50), M. WADA(39), T. J. WALDROP(6),

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H. Wang([47]), Y. Wang([47]), A. W. Watson([45]), S. Westerdale([13]),
M. M. Wojcik([23]), X. Xiang([39]), X. Xiao([47]), C. Yang([21]),
Z. Ye([20]), C. Zhu([39]) and G. Zuzel([23])
The DarkSide Collaboration

([1]) *Physics Department, Università degli Studi di Genova - Genova 16146, Italy*
([2]) *INFN, Sezione di Genova - Genova 16146, Italy*
([3]) *APC, Université Paris Diderot, CNRS/IN2P3, CEA/Irfu, Obs de Paris, USPC - Paris 75205, France*
([4]) *INFN, Laboratori Nazionali del Gran Sasso - Assergi (AQ) 67100, Italy*
([5]) *Gran Sasso Science Institute - L'Aquila 67100, Italy*
([6]) *Physics Department, Augustana University - Sioux Falls, SD 57197, USA*
([7]) *Radiation Physics Laboratory, Belgorod National Research University Belgorod 308007, Russia*
([8]) *School of Natural Sciences, Black Hills State University - Spearfish, SD 57799, USA*
([9]) *INFN, Sezione di Bologna - Bologna 40126, Italy*
([10]) *Physics Department, Università degli Studi di Bologna - Bologna 40126, Italy*
([11]) *Physics Department, Università degli Studi di Cagliari - Cagliari 09042, Italy*
([12]) *INFN, Sezione di Cagliari - Cagliari 09042, Italy*
([13]) *Department of Physics, Carleton University - Ottawa, ON K1S 5B6, Canada*
([14]) *Physics Institute, Universidade Estadual de Campinas - Campinas 13083, Brazil*
([15]) *CIEMAT, Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas - Madrid 28040, Spain*
([16]) *INFN Laboratori Nazionali del Sud - Catania 95123, Italy*
([17]) *Engineering and Architecture Faculty, Università di Enna Kore - Enna 94100, Italy*
([18]) *Fermi National Accelerator Laboratory, Batavia, IL 60510, USA*
([19]) *Department of Physics and Astronomy, University of Hawai'i - Honolulu, HI 96822, USA*
([20]) *Department of Physics, University of Houston - Houston, TX 77204, USA*
([21]) *Institute of High Energy Physics - Beijing 100049, China*
([22]) *Joint Institute for Nuclear Research - Dubna 141980, Russia*
([23]) *M. Smoluchowski Institute of Physics, Jagiellonian University - 30-348 Krakow, Poland*
([24]) *National Research Centre Kurchatov Institute - Moscow 123182, Russia*
([25]) *LPNHE, CNRS/IN2P3, Sorbonne Université, Université Paris Diderot Paris 75252, France*
([26]) *National Research Nuclear University MEPhI - Moscow 115409, Russia*
([27]) *INFN, Sezione di Milano - Milano 20133, Italy*
([28]) *Physics Department, Università degli Studi di Milano - Milano 20133, Italy*
([29]) *Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University - Moscow 119991, Russia*
([30]) *INFN, Sezione di Napoli - Napoli 80126, Italy*
([31]) *Physics Department, Università degli Studi "Federico II" di Napoli - Napoli 80126, Italy*
([32]) *Chemical, Materials, and Industrial Production Engineering Department, Università degli Studi "Federico II" di Napoli - Napoli 80126, Italy*
([33]) *Saint Petersburg Nuclear Physics Institute - Gatchina 188350, Russia*
([34]) *Chemistry, Biology and Biotechnology Department, Università degli Studi di Perugia Perugia 06123, Italy*
([35]) *INFN, Sezione di Perugia - Perugia 06123, Italy*
([36]) *INFN, Sezione di Pisa - Pisa 56127, Italy*
([37]) *Physics Department, Università degli Studi di Pisa - Pisa 56127, Italy*
([38]) *Pacific Northwest National Laboratory - Richland, WA 99352, USA*
([39]) *Physics Department, Princeton University - Princeton, NJ 08544, USA*
([40]) *INFN, Sezione di Roma Tre - Roma 00146, Italy*
([41]) *Mathematics and Physics Department, Università degli Studi Roma Tre Roma 00146, Italy*
([42]) *INFN, Sezione di Roma - Roma 00185, Italy*

([43]) *Physics Department, Sapienza Università di Roma - Roma 00185, Italy*
([44]) *Chemistry and Pharmacy Department, Università degli Studi di Sassari Sassari 07100, Italy*
([45]) *Physics Department, Temple University - Philadelphia, PA 19122, USA*
([46]) *Department of Physics, University of California - Davis, CA 95616, USA*
([47]) *Physics and Astronomy Department, University of California - Los Angeles, CA 90095, USA*
([48]) *Amherst Center for Fundamental Interactions and Physics Department, University of Massachusetts - Amherst, MA 01003, USA*
([49]) *Instituto de Física, Universidade de São Paulo - São Paulo 05508-090, Brazil*
([50]) *Virginia Tech - Blacksburg, VA 24061, USA*

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Summary. — DarkSide is direct-detection dark-matter experimental project based on radiopure argon. The main goal of the DarkSide program is the detection of rare nuclear elastic collisions with hypothetical dark-matter particles. The present detector, *DarkSide-50*, placed at Laboratori Nazionali del Gran Sasso (LNGS), is a dual-phase time projection chamber (TPC) filled with ultra-pure liquid argon, extracted from underground sources. Surrounding the TPC to suppress the background there are neutron and muon active vetoes. One of argon key features is the capability to distinguish between electron and nuclear recoils, exploiting the different shapes of the signals. DarkSide-50 new results, obtained using a live-days exposure of 532.4 days, are presented. This analysis sets a 90% C.L. upper limit on the dark matter-nucleon spin-independent cross-section of 1.1×10^{-44} cm^2 for a WIMP mass of 100 GeV/c^2. The next phase of the project, *DarkSide-20k*, will be a new detector with a fiducial mass of ~ 20 tons, equipped with cryogenic silicon photomultipliers (SiPM).

1. – The DarkSide project: why argon?

At present in the search of WIMP particles with masses larger than a few GeV/c^2 dual-phase liquid-argon time projection chambers (TPC) are one of the most outstanding technologies. More generally noble elements are an excellent choice as a medium to build dark-matter detectors, because they have good scintillation and ionization properties and they do not react chemically. They allow to scale to large-mass detectors, being also homogeneous and easy to purify. In particular, liquid argon (LAr) can provide an extraordinary discrimination power ($> 10^8$) provided by the time profile of the scintillation signal, which allows to identify nuclear recoils, rejecting electron ones [1]. In DarkSide the parameter used to discriminate between the two categories of events is the fraction of light collected in the first 90 ns, called f_{90}. However, atmospheric argon contains the cosmogenic ^{39}Ar isotope, which was considered an irreducible background. DarkSide solved this issue using argon extracted from deep underground sources (UAr) where the ^{39}Ar content is 3 orders of magnitude less than in atmospheric argon [2]. *DarkSide-50* is filled with underground argon and can operate in a basically background-free regime, looking for interactions between argon nulcei and WIMPs, with masses of a few tens of GeV/c^2. Considering less strict background requirements, *DarkSide-50* has also the potentialities to investigate lower energies and hence lower WIMP mass ranges, from few tens of MeV/c^2 to the GeV/c^2 scale [3].

2. – Today: DarkSide-50

The detector currently operating at LNGS is *DarkSide-50*, which is based on a dual phase liquid-argon time projection chamber. The working principle is that an argon nuclear recoil can excite other nuclei and produce ionization electrons. The signal generated in liquid, which is called S1, consists of 128 nm scintillation photons, due to excitation and recombined ionization. The remaining electrons, that avoid recombination, are drifted to the liquid surface and extracted with a strong electric field. In the gas phase there is a further light emission via proportional scintillation, this signal is called S2.

2·1. *The detector*. – The whole experiment is based on three nested detectors: the double-phase TPC is surrounded by two veto detectors that are used to reject events in the TPC caused by cosmogenic (muon-induced) neutrons or by neutrons and γ-rays from radioactive contamination in the detector components. The TPC has an active UAr mass of (46.4 ± 0.7) kg that is seen by two arrays of 19 PMTs at the top and the bottom. The drift field is of 200 V/cm and allows to infer the z-position of the primary event from the time difference between S1 and S2, while the transverse (xy) position is determined from the distribution of the S2 pulses over the top PMT array [4].

The Liquid Scintillator Veto (LSV), is a 4.0 m diameter stainless-steel sphere filled with 30 metric tonnes of boron-loaded liquid scintillator equipped with an array of 110 PMTs, mounted on the inside surface of the sphere to detect scintillation photons. The aim of the neutron veto is to tag neutrons which can mimic the WIMP-nucleus interaction and reject those events requiring the anti-coincidence between LSV and TPC. The presence of TMB in the liquid-scintillator mixture favours neutron capture on ^{10}B producing α-particles of energy 1.47 MeV, corresponding to a signal of about 30 PE which can be easily detected.

The LSV is located in the middle of a water Cherenkov muon veto (WCV), a 11 m diameter, 10 m high cylindrical tank filled with high-purity water, used for rejecting the coincidences in the TPC induced by the residual flux of cosmogenic muons and also used as passive shielding for external neutrons and gammas.

2·2. *Latest results*. – Results from the analysis here reported correspond to data collected in 532.4 live-days, from August 2, 2015 to October 4, 2017. During this period the detector was filled of underground argon and was running in its final configuration. The analysis was performed in blind mode. The basic idea was to open subsequently sections of the blinded data outside of the WIMP search region, in the (S1, f_{90}) parameter space in order to fix all the analysis criteria and to improve the background predictions before unblinding the region of interest.

There are three main categories of background events: surface events, neutrons (cosmogenic and radiogenic), and electron recoils. The first are discarded using the fiducialization of the active volume, neutrons are efficiently rejected with the LSV, and electron recoils are mostly removed with the pulse shape discrimination. The LSV, whose efficiency is estimated to be 0.9964 ± 0.0004, identified 4 neutron candidates and after this cut the dominant component is due to ERs (0.08 ± 0.04). The acceptance after all cuts is

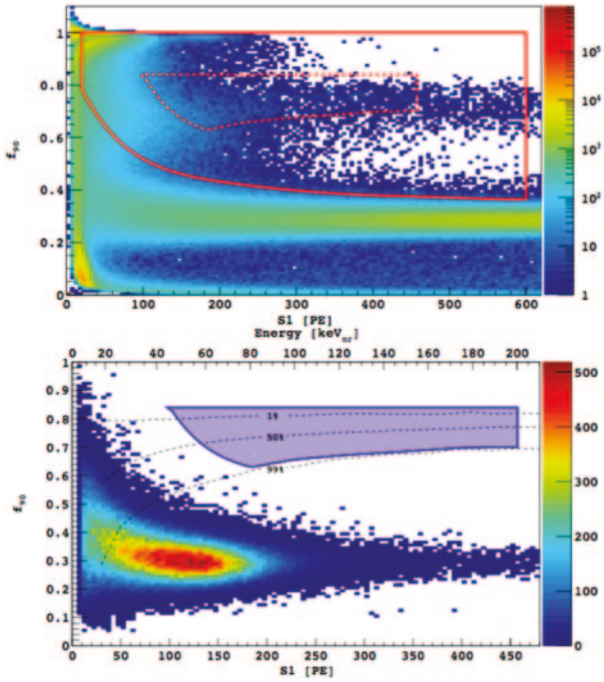

Fig. 1. – Top: blinding box (red) applied to data taken in the previous data set (see [3]). The dashed line is the DM search region. Bottom: observed events in the f_{90}-*vs.*-S1 plane surviving all cuts in the energy region of interest, after the data unblinding. The solid blue outline indicates the DM search region.

60.9% and the fiducial mass corresponds to 36.9 ± 0.6 kg. The number of events expected using the entire statistics and after all the background rejection is 0.09 ± 0.04. After the data unblinding, no events were observed in the region of interest for the WIMP search (fig. 1). The result found is consistent with up to 2.3 WIMP-nucleon scatters expected

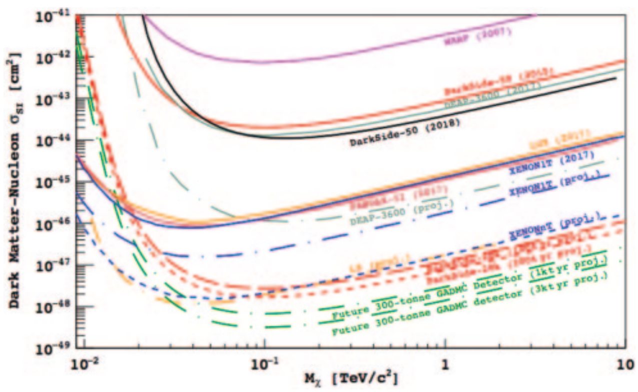

Fig. 2. – Spin-independent DM-nucleon cross-section 90% C.L. exclusion limits.

at 90% C.L. which sets an upper limit on the spin-independent scattering cross-section corresponding to 1.14×10^{-44} (3.79×10^{-44}, 1.10×10^{-44}) for a WIMP mass of $100\,\text{GeV}/c^2$ ($1\,\text{TeV}/c^2$, 126 GeV/c^2) [5]. This limit is obtained assuming a standard isothermal WIMP halo model, with $v_{escape} = 544\,\text{km/s}$, $v_0 = 220\,\text{km/s}$, $v_{Earth} = 232\,\text{km/s}$, and $\text{DM} = 0.3\,\text{GeV}/c^2\text{cm}^3$.

3. – Tomorrow: DarkSide-20k

The DarkSide main detector will be *DarkSide-20k* that is going to be a large-scale time projection chamber with a fiducial mass of ∼20 tons, able to collect a 100 t yr exposure. The scintillation signal in argon will be detected by cryogenic silicon photomultipliers (SiPM). The quantity of purified argon necessary to fill the detector will be extracted in Colorado, as it was done for *DarkSide-50*, using an upgraded extraction plant. Then the UAr will be purified using the distillation column installed in the Seruci mine, in Sardinia [6]. Namely, DarkSide-20k will be able to exclude a WIMP-nucleon cross-section down to $2.8\times10^{-48}\,\text{cm}^2$ for a WIMP mass or $100\,\text{GeV}/c^2$ (fig. 2).

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