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The DarkSide veto: muon and neutron detectors

L. Pagani(9), P. Agnes(1), T. Alexander(34), A. Alton(2), K. Arisaka(33), H. O. Back(27), B. Baldin(8), K. Biery(8), G. Bonfini(18), M. Bossa(10), A. Brigatti(20), J. Brodsky(27), F. Budano(28), L. Cadonati(34), F. Calaprice(27), N. Canci(33), A. Candela(18), H. Cao(27), M. Cariello(9), P. Cavalcante(18), A. Chavarria(5), A. Chepurnov(21), A. G. Cocco(22), D. D'Angelo(20), M. D'Incecco(18), S. Davini(12), M. De Deo(18), A. Derbin(24), A. Devoto(4), F. Di Eusanio(27), G. Di Pietro(20), E. Edkins(11), A. Empl(12), A. Fan(33), G. Fiorillo(22), K. Fomenko(7), G. Forster(34), D. Franco(1), F. Gabriele(18), C. Galbiati(27), A. Goretti(27), L. Grandi(5), M. Gromov(21), M. Y. Guan(13), Y. Guardincerri(8), B. Hackett(11), K. Herner(8), P. Humble(23), E. V. Hungerford(12), Al. Ianni(18), An. Ianni(27), C. Jollet(30), K. Keeter(6), C. Kendziora(8), S. Kidner(35)(†), V. Kobychev(15), G. Koh(27), D. Korablev(7), G. Korga(12), A. Kurlej(34), P. X. Li(13), P. Lombardi(20), C. Love(31), L. Ludhova(20), S. Luitz(29), Y. Q. Ma(13), I. Machulin(16)(19), A. Mandarano(28), S. Mari(28), J. Maricic(11), L. Marini(28), C. J. Martoff(31), A. Meregaglia(30), E. Meroni(20), P. D. Meyers(27), R. Milincic(11), D. Montanari(8), M. Montuschi(18), M. E. Monzani(29), P. Mosteiro(27), B. Mount(6), V. Muratova(24), P. Musico(9), A. Nelson(27), S. Odrowski(18), M. Okounkova(27), M. Orsini(18), F. Ortica(25), M. Pallavicini(9), E. Pantic(33)(32), L. Papp(35), S. Parmeggiano(20), R. Parsells(27), K. Pelczar(14), N. Pelliccia(25), S. Perasso(1), A. Pocar(34), S. Pordes(8), D. Pugachev(16), H. Qian(27), K. Randle(34), G. Ranucci(20), A. Razeto(18), B. Reinhold(11), A. Renshaw(33), A. Romani(25), B. Rossi(27)(22), N. Rossi(18), S. D. Rountree(35), D. Sablone(12), P. Saggese(18), R. Saldanha(5), W. Sands(27), S. Sangiorgio(17), E. Segreto(18), D. Semenov(24), E. Shields(27), M. Skorokhvatov(16)(19), O. Smirnov(7), A. Sotnikov(7), C. Stanford(27), Y. Suvorov(33), R. Tartaglia(18), J. Tatarowicz(31), G. Testera(9), A. Tonazzo(1), E. Unzhakov(24), R. B. Vogelaar(35), M. Wada(27), S. Walker(22), H. Wang(33), Y. Wang(13), A. Watson(31), S. Westerdale(27), M. Wojcik(14), A. Wright(27), X. Xiang(27), J. Xu(27), C. G. Yang(13), J. Yoo(8), S. Zavatarelli(9), A. Zec(34), C. Zhu(27) and G. Zuzel(14)

(The DarkSide Collaboration)

(1) *APC, Université Paris Diderot, Sorbonne Paris Cité, Paris 75205, France*
(2) *Physics and Astronomy Department, Augustana College, Sioux Falls, SD 57197, USA*

(†) Deceased

([3]) *Brookhaven National Laboratory, Upton, NY 11973, USA*

([4]) *Physics Department, Università degli Studi and INFN, Cagliari 09042, Italy*

([5]) *Kavli Institute, Enrico Fermi Institute and Dept. of Physics, University of Chicago, Chicago, IL 60637, USA*

([6]) *School of Natural Sciences, Black Hills State University, Spearfish, SD 57799, USA*

([7]) *Joint Institute for Nuclear Research, Dubna 141980, Russia*

([8]) *Fermi National Accelerator Laboratory, Batavia, IL 60510, USA*

([9]) *Physics Department, Università degli Studi and INFN, Genova 16146, Italy*

([10]) *Gran Sasso Science Institute, L'Aquila 67100, Italy*

([11]) *Department of Physics and Astronomy, University of Hawai'i, Honolulu, HI 96822, USA*

([12]) *Department of Physics, University of Houston, Houston, TX 77204, USA*

([13]) *Institute of High Energy Physics, Beijing 100049, China*

([14]) *Smoluchowski Institute of Physics, Jagiellonian University, Krakow 30059, Poland*

([15]) *Institute for Nuclear Research, National Academy of Sciences of Ukraine, Kiev 03680, Ukraine*

([16]) *National Research Centre Kurchatov Institute, Moscow 123182, Russia*

([17]) *Lawrence Livermore National Laboratory, 7000 East Avenue, Livermore, CA 94550, USA*

([18]) *Laboratori Nazionali del Gran Sasso, Assergi (AQ) 67010, Italy*

([19]) *National Research Nuclear University Moscow Engineering Physics Institute, 115409 Moscow, Russia*

([20]) *Physics Department, Università degli Studi and INFN, Milano 20133, Italy*

([21]) *Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow 119991, Russia*

([22]) *Physics Department, Università degli Studi Federico II and INFN, Napoli 80126, Italy*

([23]) *Pacific Northwest National Laboratory, Richland, WA 99352, USA*

([24]) *Saint Petersburg Nuclear Physics Institute, Gatchina 188350, Russia*

([25]) *Chemistry, Biology and Biotechnology Department, Università degli Studi and INFN, Perugia 06123, Italy*

([26]) *Chemical Engineering Department, Princeton University, Princeton, NJ 08544, USA*

([27]) *Physics Department, Princeton University, Princeton, NJ 08544, USA*

([28]) *Physics Department, Università degli Studi Roma Tre and INFN, Roma 00146, Italy*

([29]) *SLAC National Accelerator Laboratory, Menlo Park, CA 94025, USA*

([30]) *IPHC, Université de Strasbourg, CNRS/IN2P3, Strasbourg 67037, France*

([31]) *Physics Department, Temple University, Philadelphia, PA 19122, USA*

([32]) *Physics Department, University of California, Davis, CA 95616, USA*

([33]) *Physics and Astronomy Department, University of California, Los Angeles, CA 90095, USA*

([34]) *Physics Department, University of Massachusetts, Amherst, MA 01003, USA*

([35]) *Physics Department, Virginia Tech, Blacksburg, VA 24061, USA*

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Summary. — The existence of dark matter is known because of its gravitational effects, and although its nature remains undisclosed, there is a growing indication that the galactic halo could be permeated by weakly interactive massive particles (WIMPs) with mass of the order of 100 GeV. Direct observation of WIMP-nuclear collisions in a laboratory detector plays a key role in dark matter searches. However, it also poses significant challenges, as the expected signals are low in energy and very rare. DarkSide is a project for direct observation of WIMPs in a liquid argon time-projection chamber specifically designed to overtake the difficulties of these challenges. A limiting background for all dark matter detectors is the production in their active volumes of nuclear recoils from the elastic scattering of radiogenic and cosmogenic neutrons. To rule out this background, DarkSide-50 is surrounded by a water tank serving as a Cherenkov detector for muons, and a boron-doped liquid scintillator acting as an active, high-efficiency neutron detector.

PACS 95.35.+d – Dark matter (stellar, interstellar, galactic, and cosmological).
PACS 29.40.Gx – Tracking and position-sensitive detectors.
PACS 95.55.Vj – Neutrino, muon, pion, and other elementary particle detectors; cosmic ray detectors.

1. – Dark matter in the universe

The existence of dark matter is known from a wide range of observational evidence, ranging from studies of the internal motions of galaxies [1], to the large scale inhomogeneities in the cosmic microwave background radiation [2]. Although its nature remains undisclosed, there is a growing indication that the galactic halo could be permeated by weakly interactive massive particles (WIMPs), neutral particles with mass of the order of 100 GeV. Direct observation of WIMP-nuclei collisions in a laboratory detector plays a key role in dark matter searches. However, it poses significant challenges, as the expected signals are low in energy (< 100 keV) and very rare (a few interactions per year per ton of target) [3]. To detect these WIMPs, large (0.1–10 tons target mass) discovery (located deep underground and with ultra low-background) detectors are mandatory.

2. – The DarkSide project

DarkSide is a project for direct observation of WIMPs in a two-phase liquid argon time-projection chamber (LAr TPC) in the Gran Sasso National Laboratory (LNGS) in Italy. The first physics detector in the program is DarkSide-50 (DS-50), with a 50 kg active mass of low-radioactivity underground argon.

A limiting background for all dark matter detectors is the production in their active volumes of nuclear recoils from the elastic scattering of radiogenic and cosmogenic neutrons. To rule out this background, the DS-50 apparatus consists of three nested detectors. From the outside inwards, the three detectors are: the water Cherenkov detector or muon detector; the organic liquid scintillator veto or neutron detector; and the LAr TPC, which is the dark matter detector. Events due to neutrons from cosmogenic sources and from radioactive contamination in the detector parts, which also produce nuclear recoils, are efficiently suppressed by the combined action of the neutron and muon vetoes. The water plus-liquid scintillator design was motivated in part by the success of this shielding concept in achieving very low backgrounds in Borexino [4-6].

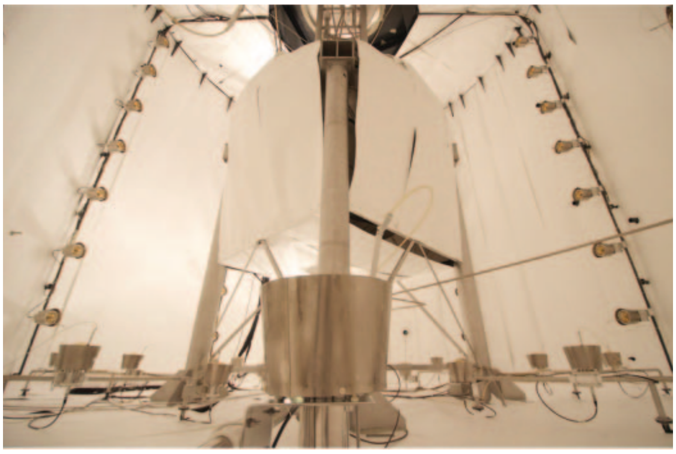

Fig. 1. – Internal view of the CTF muon detector before the filling with high-purity water.

3. – Muon detector

The muon detector (fig. 1) serves as shielding and as anti-coincidence for cosmic muons [7, 8]. It is an 11 m-diameter, 10 m-high cylindrical tank filled with 1000 tons of high purity water. The tank was originally part of the Borexino counting test facility. The inside surface of the tank is covered with a laminated Tyvek-polyethylene-Tyvek reflector [9]. The tank is equipped with 80 ETL 9351 8″ photomultiplier tubes (PMTs), with 27% quantum efficiency (QE) at 420 nm. PMTs are mounted on the side and bottom of the water tank to detect Cherenkov photons produced by muons or other relativistic particles traversing the water.

4. – Neutron detector

The neutron detector (fig. 2) serves as shielding and as anti-coincidence for radiogenic and cosmogenic neutrons, γ-rays, and cosmic muons. It is a 4.0 m-diameter stainless steel sphere filled with 30 tons of borated liquid scintillator. The scintillator is a mixture of

Fig. 2. – Internal view of the neutron detector from its top port.

pseudocumene (PC) and trimethylborate (TMB), with the wavelength shifter diphenyloxazole (PPO) at a concentration of 1.5 g/L. The sphere is internally covered with an high-efficiency Lumirror reflector [10] and it is equipped with 110 Hamamatsu R5912 8″ PMTs, with low-radioactivity glass bulbs and high-quantum-efficiency photocathodes (37% QE at 408 nm). PMTs are mounted on the inside surface of the sphere to detect scintillation photons.

The neutron-capture reaction ^{10}B(n,α)^{7}Li makes the borated scintillator a very effective veto of neutron background [11]. The TMB contains ^{nat}B which has a 20% natural abundance of ^{10}B with its very large (3840 b) thermal neutron capture cross section. The thermal neutron capture time in the borated scintillator is just 2.2 μs, compared to 250 μs for pure PC [4]. The ^{10}B neutron capture proceeds to the ^{7}Li ground state with branching ratio 6.4%, producing a 1775 keV α particle, and to a ^{7}Li excited state with branching ratio 93.6% producing a 1471 keV α particle and a γ-ray of 478 keV. Because of quenching, the scintillation light output of the capture to ^{7}Li(g.s.) is in the β/γ-equivalent range 50 keV to 60 keV [12,13]. The measured neutron detector photoelectron (PE) yield is of the order of 0.5 PE/keV, making this quenched energy readily detectable.

5. – Current status

After the successful filling of both the detectors, DS-50 is taking data since October 2013. During the first period of data taking ended in June 2014 [14], the liquid scintillator veto performance was limited due to the unintentional use of TMB neutron-capture agent containing modern carbon, with its elevated content of ^{14}C compared to petroleum-derived material. The ^{14}C containing material has since been removed and a source of low-activity TMB reintroduced.

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