FIRST RESULTS FROM DARKSIDE-50

D. FRANCO FOR THE DARKSIDE COLLABORATION
APC, Univ. Paris Diderot, CNRS/IN2P3, CEA/Irfu, Obs. de Paris, Sorbonne Paris Cité, 75205 Paris, France

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

DarkSide-50 is dual-phase liquid argon time projection chamber, designed for direct WIMP search. The detector, consisting of 50 kg of liquid argon and shielded by active neutron and muon vetoes, is installed at Gran Sasso underground laboratory. DarkSide-50 is taking data since November 2013, collecting more than 10^7 events with atmospheric argon, naturally contaminated with cosmogenic ^{39}Ar beta decay. This contamination is equivalent to ~20 years of data taking with underground argon, depleted in ^{39}Ar by a factor larger than 150. Thanks to the excellent nuclear-electron recoil discrimination power of liquid argon and to the high efficiencies of the vetoes, no event has been observed in the WIMP region of interest in 47.1 days of data taking. We present the detector design and performance and the results from the atmospheric argon run.

1 Introduction

In the last two decades several observations have provided a wide range of astronomical evidences for the existence of Dark Matter, even if its nature is still a deep mystery. Among the different explanations, the Weakly Interacting Massive Particle (WIMP) represents one of the leading candidates. Several experiments are exploring new avenues to increase the sensitivity to the WIMPs trough their scattering with target nuclei.

Liquid argon (LAr) based detectors offers at the same time the advantage of a scalable target, and the unique add-on key feature of the excellent pulse shape discrimination (PSD) power to disentangle WIMP signal from electron-like background. This in fact relies on the singlet (6 ns) and triplet (~1.5 μs) excimer states, responsible of the emission of the 128 nm scintillation photons. The probability to excite singlet and triplet states depends on the interacting particle stopping power: nuclear recoils, from WIMP or neutron scattering, populate more singlet states than electron recoils, from β/γ radiation. The net effect is a faster scintillation component in the nuclear recoil signals, which represent a clean signature to efficiently discriminate electron recoil events.

In addition, the long-standing issue of the ^{39}Ar contamination in natural argon was recently solved by the DarkSide collaboration. ^{39}Ar is a cosmogenic beta-decay with a Q-value of 565 keV, produced by the interaction of cosmic rays with natural argon. Liquid argon is commonly extracted from the atmosphere, which is naturally exposed to cosmic ray radiation and hence largely contaminated in ^{39}Ar. The DarkSide collaboration identified in the argon extracted from deep underground the solution to this issue. Underground argon (UAr) is in fact naturally shielded against cosmic rays, and hence depleted in ^{39}Ar. Measurements of ^{39}Ar in UAr determined a depletion factor larger than 150 [2].

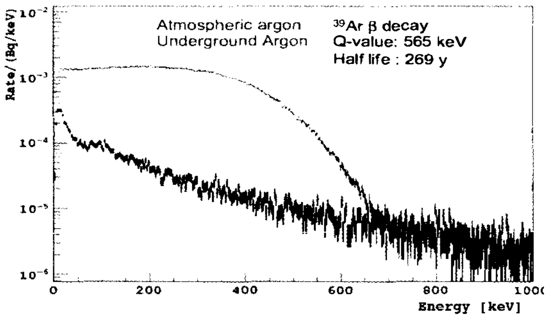

Figure 1 – Comparison between the atmospheric Argon (green) and the underground Argon (blue) spectra, as measured at the KURF underground laboratory .

DarkSide-50 is a direct dark matter search detector based on the double-phase LAr time projection chamber (TPC) technique, with ~50 kg target mass, located in Hall C of LNGS at a depth of 3800 m.w.e.. DarkSide-50 is running since October 2013 with atmospheric argon, and it was recently filled (February 2015) with UAr. We report here the results obtained with the atmospheric argon run.

2 The DarkSide-50 detector

The DarkSide-50 TPC is designed to simultaneous detect the prompt scintillation light pulse (S1) and ionization electrons produced by the WIMP interaction in LAr. Ionization electrons are drifted toward the top of the TPC and extracted in the argon gaseous phase, producing a secondary light pulse (S2) by electroluminescence. Two arrays of 19 3" PMTs, placed at the top and the bottom of the TPC, observe the light pulses. The drift field is 200 V/cm and the maximum drift time, corresponding to the height of the TPC (35.6 cm), is ~375 μs. The low drift field provides a double advantage: a high precision determination of the z-position of the particle interaction, by looking the time delay between S1 and S2, and the enhancement of the electron-ion recombination effect, which contributes to the increasing of the S1 light yield. The extraction field is set to 2.8 kV/cm. A sketch of the TPC is shown in figure 2.

The TPC is placed at the center of the Liquid Scintillator Veto (LSV), designed to shield the TPC against radiogenic and cosmogenic neutrons, gammas and cosmic muons. The anti-

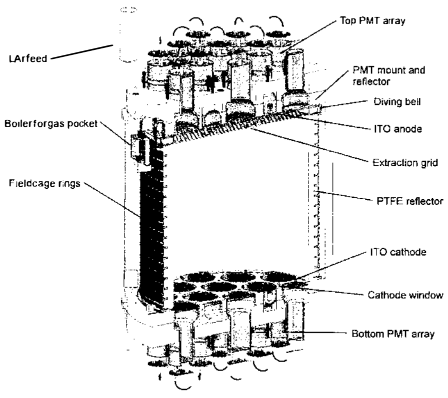

Figure 2 – The DarkSide-50 Liquid Argon Time Projection Chamber.

coincidence between LSV and TPC is particularly effective in rejecting neutrons, originating in the detector materials, interacting in the LAr target, and escaping the TPC. The 30 t of borated scintillator surrounding the TPC allows to detect and reject ~98% of neutrons with a single scattering in LAr, thanks to the neutron-capture reaction $^{10}B(n,\alpha)^{7}Li$. Single scattering neutrons represent the most dangerous source of background, being able to perfectly mimic the WIMP signal. The LSV is a 4.0 m-diameter stainless steel sphere and equipped with an array of 110 Hamamatsu R5912 8" PMTs, with low-radioactivity glass bulbs and high-quantum-efficiency photocathodes.

The LSV is in turn located inside the Water Cherenkov Detector (WCD), serving as shielding and as anti-coincidence for cosmic muons. The WCD is an 11 m-diameter, 10 m-high cylindrical tank filled with high purity water. An array of 80 ETL 9351 8" PMTs, mounted on the side and bottom of the water tank, detects Cherenkov photons produced by muons or other relativistic particles traversing the water.

A scale sketch of the of the entire detector system is shown in figure 3.

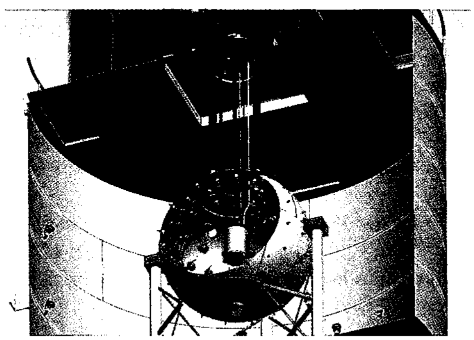

Figure 3 – Scale sketch of the three DarkSide detectors.

3 Analysis of the atmospheric Argon data set

The detector was calibrated with a ^{83m}Kr source, diffused inside LAr with the circulation loop. The ^{83m}Kr decays with τ=2.64 h to the ground state in two sequential electromagnetic transitions of 32.1 keV and 9.4 keV energy. The short intermediate mean life of about 222 ns cannot be resolved in the TPC because of the slow scintillation component. The two decays are then observed as a single deposition of 41.5 keV. The so-measured light yield resulted in 7.9 $\pm$ 0.4 pe/keV in absence of electric field, and $\sim$7.0 pe/keV at 200 V/cm. Figure 4 shows the combined fit of the ^{39}Ar spectrum and of the ^{83m}Kr peak in the field-on configuration.

Thanks to the ^{83m}Kr calibration, the high purity of the LAr target was also established: the electron lifetime was measured to be larger than 5 ms, with respect to the maximum electron drift time of 375 μs (drift velocity $\sim$ 0.93 mm/μs). In addition, the large statistics of ^{39}Ar events and the ^{83m}Kr calibration itself, allowed to accurately constrain the TPC non-uniformity of the light collection efficiency.

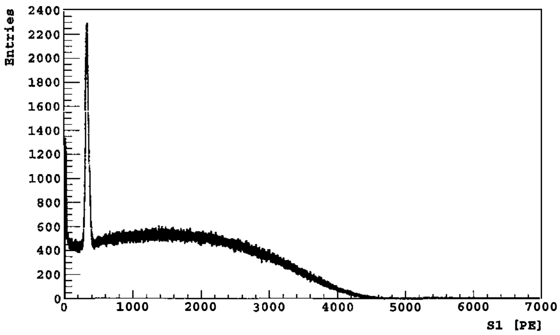

Figure 4 – Combined fit of the ^{83m}Kr peak and of the ^{39}Ar spectrum with DarkSide-50.

The WIMP acceptance band is defined in DarkSide-50 as the portion of the f90–S1 parameter space, containing 90% of the nuclear recoil interactions. The f90 variable is an estimator of the PSD, defined as the fraction of photons detected in the first 90 ns, with respect to the entire acquisition gate ($\sim$7 μs). The WIMP search energy range is defined from 60 to 460 pe, corresponding to 40 to 200 keVnr (8 to 40 keVee).

The WIMP acceptance band was determined by exploiting the results of the SCENE detector, a small scale TPC exposed to a low energy pulsed narrowband neutron beam produced at the Notre Dame Institute for Structure and Nuclear Astrophysics [3]. The limited size of the SCENE detector strongly reduced the probability of multiple scattering neutrons. Measuring the angles of the single scattered neutrons with respect to the source-TPC direction by means of neutron detectors, SCENE was able to select, by kinematical constraints, samples of nuclear recoils at different energies and with different drift fields. The SCENE results were then "scaled" to DarkSide-50 to define the nuclear acceptance band, taking into account the systematics induced by the differences of the two detectors. A direct DarkSide-50 calibrations with neutron (AmBe) and gamma (^{57}Co, ^{133}Ba, ^{137}Cs) sources, deployed in the LSV next to the cryostat, was run afterward the publication of the here presented results. These calibrations indeed confirmed our procedure for translating the Scene results to DarkSide-50.

The atmospheric argon data campaign lasted 47.2 days of live-time, along which $\sim$1.5$\times$10^{7} of ^{39}Ar events falling in the WIMP energy range were acquired. The very high statistical sample of electron recoil events and the stringent requirement of the maximum electron recoil leakage of 0.01 events / 5 pe in the nuclear band, reduced the acceptance of the WIMP interactions, as

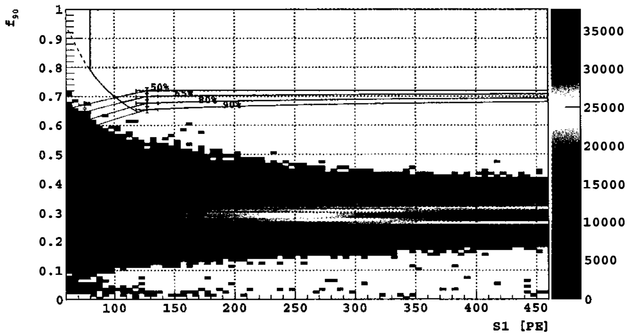

Figure 5 – Distribution of the events in the scatter plot of S1 vs. f90 after all quality and physics cuts. Shaded blue with solid blue outline: Dark Matter search box in the f90 vs. S1 plane. Percentages label the f90 acceptance contours for nuclear recoils drawn connecting points (shown with error bars) determined from the corresponding SCENE measurements.

shown in figure 5. The electron recoil leakage was obtained by fitting the F90 distributions for fixed energies, with the Hinkley model [4], as shown in figure 6.

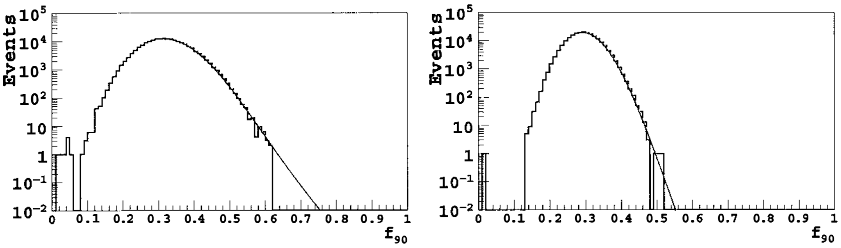

Figure 6 – Fits of f90 experimental distributions using the Hinckley model in the [80-85] (left) and [180-185] (right) pe WIMP search regions.

The nuclear recoil background, as already mentioned, is mostly due to cosmogenic and radiogenic neutrons. The fraction of cosmogenic neutrons, not detected by the double veto and falling in the WIMP search energy region, is negligible. For what concerns the radiogenic component, the dominant source of neutrons are the PMTs, and the subdominants are the cryostat and the fused silica windows, serving as anode and cathode in the TPC. The total expected neutron emission yield was evaluated with the TALYS package[5] in $\sim$100 n/y. Geant4 based simulations evaluated in 5×10^{-4} the fraction of neutrons interacting once in the TPC and escaping the NV without any detectable signal (<30 pe). The large error associated to this fraction (20%) is mostly due to the uncertainty on the liquid scintillator α–quenching factor. The residual neutron background is rejected with $\sim$98% efficiency by the LSV (this comparatively low efficiency of the LSV has since been improved to an anticipated 99.5%. [7]).

A fiducialization of the active volume is applied only in the vertical coordinate (measured by electron drift time) and no radial cut is applied. The fiducial cut vetoes about 3.6 cm of the LAr mass below the extraction grid and above the cathode. This reduced the total active volume to (36.9 ± 0.6) kg.

The last background component expected in DarkSide-50 are the α's emanated from the TPB-coated cylindrical reflector (TPB is the wavelength shifter), with a rate $<10/\mathrm{m}^2$/day. In this case, an additional light contribution is expected from the TPB's own scintillation. No α

event was observed in the analyzed data set and preliminary studies exploiting the reconstructed x-y event position suggest that the radial fiducialization will suppress any surface background that may become evident in longer running.

4 Results and perspectives

The DarkSide-50 detector successfully concluded the atmospheric argon run, collecting a statistics corresponding to an an exposure of 1422 $\pm$ 67 kg days. No event was observed in the WIMP search region. The amount of collected ^{39}Ar events corresponds to a data taking of 215,000 kg days with UAr, assuming an ^{39}Ar depletion factor of 150. Further, the preliminary results from the UAr run suggests an even larger depletion factor (>300[6]), enhancing the final sensitivity of DarkSide-50.

The 0-event observation in the WIMP region in the atmospheric argon run was translated in a 90% WIMP mass-nucleon cross section, shown in figure 7. The limit at 100 GeV WIMP mass is equal to 6.1×10^{-44} cm^2, the most stringent ever obtained with a LAr target.

The excellent PSD power, in association with the preliminary results from the UAr run and the performances of the LSV in rejecting neutrons, are paving the way toward the next DarkSide phase, a dual-phase LAr detector with a fiducial mass of 20 ton, with the ambition to reach a sensitivity of $\sim10^{-47}$ cm^2 at 1 TeV WIMP mass.

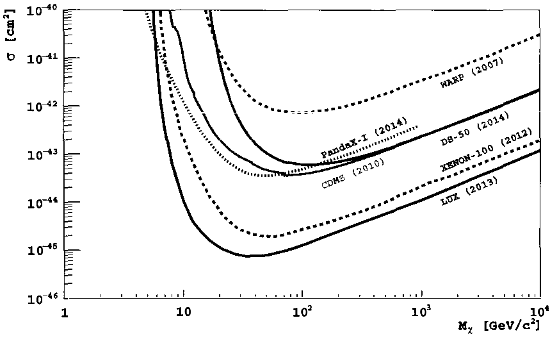

Figure 7 – 90% C.L. exclusion limits in the spin-independent WIMP nucleon cross section - mass parameter space.

Acknowledgments

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