PROCEEDINGS OF SCIENCE

Dark Matter Searches with DarkSide-20k: Solar Neutrinos and Ar-39 backgrounds

M. Atzori Corona[a,b,*] on behalf of the DarkSide-20k Collaboration

[a] *Dipartimento di Fisica, Università degli Studi di Cagliari, Complesso Universitario di Monserrato - S.P. per Sestu Km 0.700, 09042 Monserrato (Cagliari), Italy*

[b] *Istituto Nazionale di Fisica Nucleare (INFN), Sezione di Cagliari, Complesso Universitario di Monserrato - S.P. per Sestu Km 0.700, 09042 Monserrato (Cagliari), Italy*

E-mail: mattia.atzori.corona@ca.infn.it

Arguably, one of the most important problems in fundamental physics today concerns the nature of dark matter (DM). The experimental quest for non-gravitational signatures of dark matter has ramped up over the past decades. This contribution will focus on the search for Weakly Interacting Massive Particles (WIMPs) with the DarkSide-20k experiment, the next generation of liquid argon (LAr) dual-phase time projection chamber (TPC), presently in construction at INFN Laboratori Nazionali del Gran Sasso in Italy. The detector is specifically designed for the direct detection of WIMPs with masses exceeding 10 GeV/c^2. Moreover, as demonstrated with the previous DarkSide-50 detector, the experiment has a significant potential for discovering lighter dark-matter particles ($m_\chi \sim 1 - 10$ GeV/c^2). The search for low-mass dark matter particles with LAr presents many experimental challenges, such as the loss of background discrimination power, the presence of few-electron events and thus the need to have control over the various background components. Among them, the signals due to solar neutrino interactions and the beta decay of argon-39, an unstable argon isotope, are relevant and must be well characterized. In this contribution, I will discuss the latest calculations of the expected coherent elastic neutrino-nucleus scattering (CEνNS) and neutrino-electron (νES) event rates for the DarkSide-20k searches as well as the importance of reducing the argon-39 content. Finally, perspectives for the measurement of core-collapse supernovae signals in the DarkSide-20k detector will be given.

12th Neutrino Oscillation Workshop (NOW2024)
2-8, September 2024
Otranto, Lecce, Italy

*Speaker

PoS(NOW2024)074

1. DarkSide-20k and the Argon Chain

The DarkSide TPC consists of an active volume filled with LAr, which is immersed in a uniform electric field to drift ionization electrons towards a gaseous region on top of the detector, where charges are accelerated to stimulate light production by electroluminescence, so-called S2 signal, of interest for low-mass WIMP searches. Building upon the experience gained with the DarkSide-50 experiment [1], the Collaboration is now developing the DarkSide-20k [2] detector schematized in the left panel of Fig. 1, consisting of 47.9 tons of underground argon (UAr) as a target material. The use of UAr allows for a substantial reduction in the ^{39}Ar contamination: this unstable isotope has an activity of (0.964 ± 0.024) Bq kg^{-1} in atmospheric argon (AAr) [3], an endpoint of 565 keV, a half-life of 269 years, and limits the discovery potential of the experiment. For this reason, the DarkSide-20k Collaboration plans to extract UAr from CO_2 wells in Cortez, CO (US), through the Urania plant and to distil it in Sardinia at the ARIA plant [4], which is responsible for argon purification and chemical distillation. The ^{39}Ar concentration will be measured by DArT [5], in Canfranc (Spain). The DarkSide-50 Collaboration demonstrated that underground argon contains ^{39}Ar at concentrations approximately 1400 times lower than those found in AAr [6].

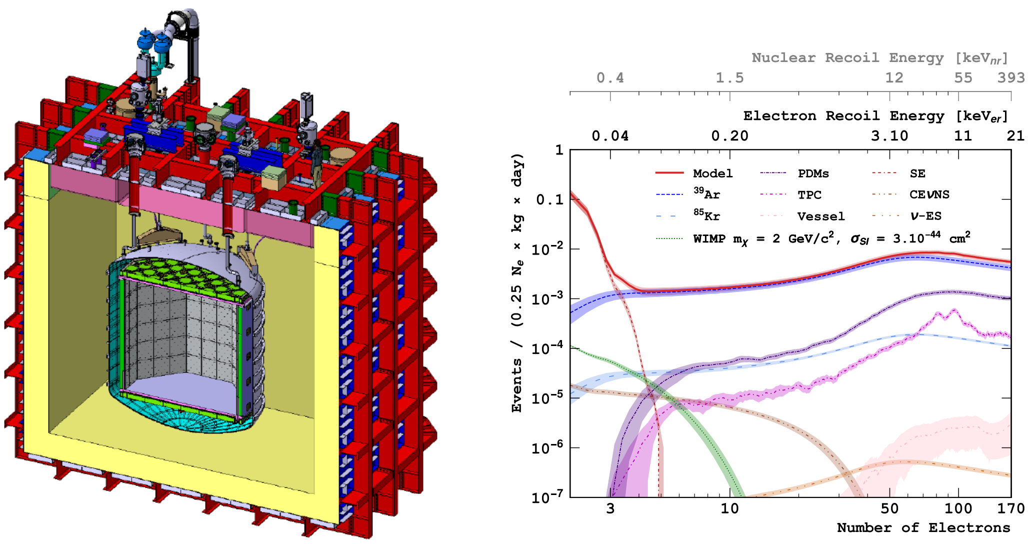

Figure 1: Left panel: cross-section of the DarkSide-20k detector showing the inner detector with the acrylic walls in green and the electrodes in pink. The stainless steel vessel is in grey and the Proto DUNE-like cryostat is in yellow and red. Right panel: pre-fit background spectra expected in the low-mass analysis of DarkSide-20k as a function of the number of photoelectrons N_e. Neutrino signals from CEνNS and νES are depicted by the brown and orange dot-dashed lines, respectively. Figures from Ref. [7].

2. DarkSide-20k Sensitivity to Low-Mass WIMPs and Supernova Neutrinos

The right panel of Fig. 1 shows a summary of the expected backgrounds in the DarkSide-20k low-mass search [7], as a function of the number of photoelectrons N_e. It is evident that the intrinsic background in LAr is dominated by the β-decay of the ^{39}Ar isotope present in the active volume of UAr for $N_e > 4$, while for lower energies one has to deal with the so-called single-electron background [8], whose origin is still unknown. The figure also shows the irreducible neutrino backgrounds from coherent elastic neutrino nucleus scattering (CEνNS) and the elastic neutrino scattering off atomic electrons (νES). The CEνNS process describes the interaction of a neutrino with the whole nucleus and is characterized by an enhanced interaction cross section due to the coherent response of the nucleons. Such backgrounds cannot be removed, and hence a detailed theoretical characterization is pivotal. Therefore, a detailed description of both CEνNS and νES which encompasses radiative corrections [9] as well as an accurate description of both the nuclear and atomic structure of argon [10], respectively, is included in the calculation. The DarkSide-20k

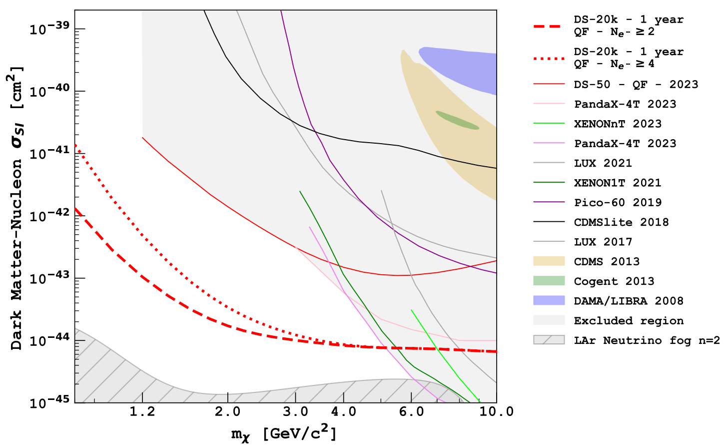

Figure 2: Expected DarkSide-20k 90% CL exclusion limits for spin-independent WIMP interaction (dotted: fit from $N_e = 4$, dashed: fit from $N_e = 2$). One year of data-taking is assumed, corresponding to a total exposure of 17.4 ton · yearThe results are compared to the limits from other experiments, with currently excluded parameter space shaded in light grey and the neutrino fog in LAr with index $n = 2$ [12] is also shown. Figure from Ref. [7].

90% CL upper limit on the spin-independent WIMP-nucleon cross section is reported in Fig. 2 [7]. The results on the sensitivity are compared with the published 90% CL limits from DarkSide-50 [11] and from other experiments. An improvement in sensitivity by up to a factor 40 over DarkSide-50 is achieved within one year of data taking, even when a conservative fit is performed restricting the range between $4 < N_e < 170$. As the sensitivity scales with the square root of the exposure, within 10 years of data taking, the sensitivity will improve by a factor 3 compared to one year, whatever the WIMP mass. Moreover, the neutrino fog in LAr with index $n = 2$ [12] could be reached for WIMP masses around 5 GeV/c^2. In addition, thanks to the low-energy threshold of $\sim$ 0.5 keV$_{\text{nr}}$ achievable by exploiting the ionization channel, the DarkSide-20k detector is suitable for detecting core-collapse supernovae neutrinos through CEνNS, as $\sim$ 50% of the events are expected to occur below 5 keV$_{\text{nr}}$. This process is almost flavor-blind as it gains a small flavor dependence only through radiative corrections [9], enabling one to estimate the total energy carried by supernova neutrinos. Specifically, the total neutrino energy is reconstructed at 3σ by DarkSide-20k with an accuracy of about 21% summing the contributions from both accretion and cooling phases, while simultaneously measuring the mean energy with an accuracy of 13% when considering a 27-$M_\odot$ supernova explosion at 10 kpc from Earth [13]. To conclude, the DarkSide-20k discovery potential entirely covers distances up to the edge of the Milky Way [13].

PoS(NOW2024)074

References

[1] DarkSide Collaboration, "*DarkSide-50 532-day Dark Matter Search with Low-Radioactivity Argon*," *Phys. Rev. D*, 98, 102006 (2018)

[2] DarkSide-20k Collaboration, "*DarkSide-20k: A 20 tonne two-phase LAr TPC for direct dark matter detection at LNGS*," *Eur. Phys. J. Plus*, 133, 131 (2018)

[3] DEAP Collaboration, "*Precision measurement of the specific activity of ^{39}Ar in atmospheric argon with the DEAP-3600 detector*," *Eur. Phys. J. C*, 83, 642 (2023)

[4] DarkSide-20k Collaboration, "*Separating ^{39}Ar from ^{40}Ar by cryogenic distillation with Aria for dark-matter searches*," *Eur. Phys. J. C*, 81, 359 (2021)

[5] DarkSide-20k Collaboration, "*Design and Construction of a New Detector to Measure Ultra-Low Radioactive-Isotope Contamination of Argon*," *JINST*, 15, 02024 (2020)

[6] DarkSide Collaboration, "*Results From the First Use of Low Radioactivity Argon in a Dark Matter Search*," *Phys. Rev. D* 93, 081101 (2016), Addendum: *Phys. Rev. D*, 95, 069901

[7] DarkSide-20k Collaboration, "*DarkSide-20k sensitivity to light dark matter particles*," arXiv:2407.05813, Accepted by Communications Physics (2024)

[8] DarkSide-50 Collaboration, "*A study of events with photoelectric emission in the DarkSide-50 liquid argon Time Projection Chamber*," *Astropart. Phys.*, 140, 102704 (2022)

[9] Atzori Corona, M. and Cadeddu, M. and Cargioli, N. and Dordei, F. and Giunti, C., "*Momentum dependent flavor radiative corrections to the coherent elastic neutrino-nucleus scattering for the neutrino charge-radius determination*," *JHEP*, 05, 271 (2024)

[10] Atzori Corona, M. and Cadeddu, M. and Cargioli, N. and Dordei, F. and Giunti, C. and Li, Y. F. and Ternes, C. A. and Zhang, Y. Y., "*Impact of the Dresden-II and COHERENT neutrino scattering data on neutrino electromagnetic properties and electroweak physics*," *JHEP*, 09, 164 (2022)

[11] DarkSide-50 Collaboration, "*Search for low-mass dark matter WIMPs with 12 ton-day exposure of DarkSide-50*," *Phys. Rev. D*, 107, 063001 (2023)

[12] O'Hare, Ciaran A. J., "*New Definition of the Neutrino Floor for Direct Dark Matter Searches*," *Phys. Rev. Lett.*, 127, 251802 (2021)

[13] DarkSide-20k Collaboration, "*Sensitivity of future liquid argon dark matter search experiments to core-collapse supernova neutrinos*," *JCAP*, 03, 043 (2021)