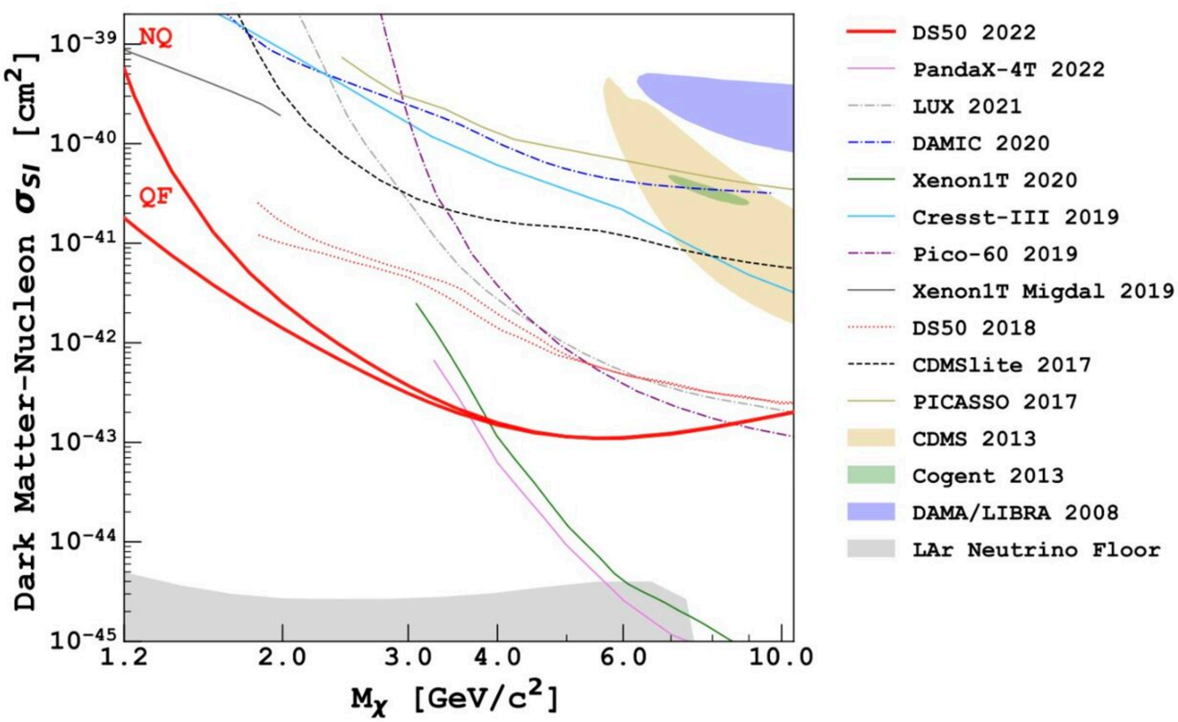
The DarkSide experiment extends its search to dark matter–nucleon interactions

April 20 2023, by Ingrid Fadelli



The plot shows the DarkSide-50 90% C.L. exclusion limit for the spin-independent WIMP-nucleon cross sections, compared to the existing limits. The labels QF (quenching fluctuations) and NQ (non quenching fluctuations) are associated to models for describing the energy response to WIMP interactions. Specifically, the NQ model is the most conservative one in terms of sensitivity to WIMP interactions. Therefore, even assuming the NQ model, our result excludes a new region in the parameter space of dark matter interactions. Credit: DarkSide Collaboration.

The DarkSide experiment is an ambitious research effort aimed at detecting dark matter particle interactions in liquid argon using a dual-phase physics detector located at the underground Gran Sasso National Laboratory. These interactions could be observed by minimizing background signals, and this could be possible thanks to the remarkable discrimination power of the scintillation pulse of liquefied argon in the DarkSide-50 detector, which can separate nuclear recoil events associated with these interactions from more than 100 million electronic recoil events linked to radioactive background.

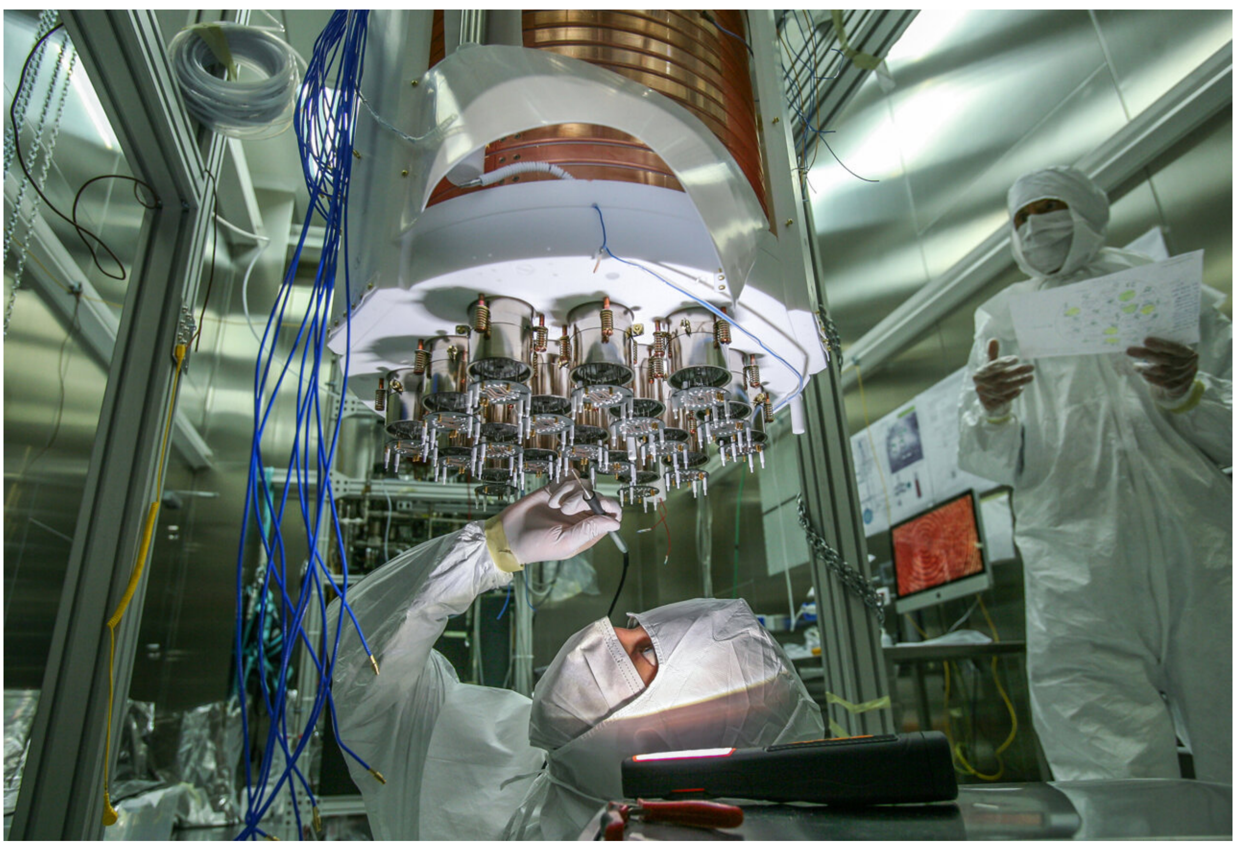
The large team of researchers involved in the DarkSide experiment has recently been using the detector to search for lighter dark matter particles. The results of a new search for dark matter–nucleon interactions, published in *Physical Review Letters*, allowed them to set new constraints for sub-GeV/c^2 dark matter.

"The DarkSide-50 experiment was designed as a test for the use of argon from underground sources, naturally depleted in the radioactive ^{39}Ar, for very large scale dark matter searches," Cristiano Galbiati a Researcher at Princeton University and the Gran Sasso Science Institute, told Phys.org. "It is remarkable to see how a group of young researchers within the collaboration was able to exploit the apparatus to extract the best limit for dark matter searches that were not part of the original scope of the experiment. If anything, the ingenuity and resolve of this group should be credited for this important result."

Theoretical predictions suggest that dark matter interactions are extremely rare, several orders of magnitude less frequent than interactions caused by the radioactivity of materials in the detectors and in the surrounding environment. To reliably search for dark matter interactions, therefore, researchers must be able to suppress these confounding environmental signals, known as radioactive background.

The DarkSide experiment specifically searches for dark matter interactions using a noble target, specifically argon liquefied at cryogenic temperatures, at nearly 200 Celsius degrees below zero. Noble liquids are ideal targets when searching for rare physical events, as they respond to particle interactions by both emitting light, through a process known as scintillation, and liberating charges via ionization.

"Dual-phase time projection chambers are detectors able to measure both the scintillation light and the ionization charges," Paolo Agnes, a researcher at Gran Sasso Science Institute, told Phys.org. "The bulk of the target mass is in the liquid state. A thin layer of gas is sitting on top of the liquid. The detector is equipped with light detectors, typically sensitive to single photons. By measuring the scintillation light produced in the liquid we can reconstruct the interaction energy."



Credit: Yury Suvorov, DarkSide Collaboration.

By means of an electric field, the ionization electrons inside the DarkSide detector drift towards the surface of the liquid argon. This creates a stronger electric field on the surface of the liquid, enabling the extraction and subsequent acceleration of these ionization electrons in a gas. These accelerated electrons generate a second light burst, which generally consists of hundreds of photons for each extracted electron.

"By combining the scintillation and ionization signals, event vertex reconstruction is possible with precision better than 1 cm, allowing for very efficient suppression of some backgrounds, particularly the one coming from the detector surfaces," Agnes explained. "A prerogative of liquid argon with respect to other liquids is the very powerful rejection of backgrounds induced by beta and gamma radioactivity, which can be suppressed by nine orders of magnitude by using the shape of the prompt scintillation signal. To further reduce the target intrinsic radioactivity, DarkSide-50 uses a specialized batch of argon, extracted from a CO_2 well in Colorado, 1,000 times less radioactive than the argon, commercially available, extracted from the atmosphere."

The DarksSide-50 detector was operated for five consecutive years at the underground National Laboratory of Gran Sasso in Italy. The data collected during this time was then analyzed by researchers who are part of the DarkSide collaboration to search for dark matter interactions.

In 2018, the collaboration published the findings of the first background-free search for dark matter in their dual-phase liquid argon detector. By specifically focusing on argon scintillation, they can search for interactions of WIMPs inducing recoils with energy higher than 40 keV, corresponding to WIMP masses larger than 20 GeV/c^2.

Recently, the detector's potential was increased further, allowing the team to search for far lighter dark matter particles by only leveraging argon ionization. While the ionization channel is not as great as the scintillation channel for distinguishing meaningful signals from radioactive background, it lowers the threshold for the analysis of collected data down to the sub-keV range.

"A great effort was devoted to accurately characterize the ionization response to both electronic (background-like) and nuclear (signal-like) recoils, poorly known in such a low energy range," Davide Franco, a researcher at Laboratoire Astroparticule et Cosmologies CNRS / Paris 7, told Phys.org. "The work done in this direction in 2021 allowed the detector to be calibrated to a few tens of eV], a key element for the recent results. In addition, this work extends the potential of the next generation 50-ton LAr detector (DarkSide-20k) to the detection of core-collapse supernova neutrinos via coherent elastic scattering off nuclei."

Credit: Yury Suvorov, DarkSide Collaboration.

In one of their previous studies, published in *Physical Review D* in March 2023, DarkSide researchers accurately modeled all background components in excellent agreement with the expected rates from previous detector material screening efforts. Collectively, these works improved their overall understanding of the detector, offering precious insight that is informing the creation of the DarkSide-20k, an even more advanced detector with a target 1,000 times greater than that of DarkSide-50.

One key novelty of the team's recent search for dark matter-nucleon interactions is that it was the first to specifically search for nuclear recoils accompanied by the emission of an electronic component (i.e., the Migdal effect) in liquid argon. While the team did not detect meaningful interactions, they were thus able to set new limits on weakly interactive massive particles (WIMPs), bringing them down to a mass of 40 MeV/c^2.

"This result broke the generally recognized paradigm of direct dark matter searches, for which the sub-GeV/c2 range is dominated in sensitivity by solid-state technology," Franco explained. "At the same time, it demonstrated the potential of a few tens of kilograms of liquid argon in such a range, compared with ton-scale liquid xenon detectors. It should not be forgotten among the achievements, those related to the search for interactions of 'leptophilic' dark matter particles, i.e., with electron final states."

The recent work by the DarkSide collaboration represents an important milestone in the ongoing quest to detect WIMPs, as it was the first direct search for sterile neutrinos interpreted as possible dark matter candidates. Currently, the Global Argon Dark Matter Collaboration is building DarkSide-20K, which will be the most advanced detector to date, set to contain a total target mass of 50 tons of liquid argon.

"We have designed a detector that, for a 100 t yr exposure, should see