PROCEEDINGS OF SCIENCE

DarkSide

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The DarkSide project at Laboratori Nazionali del Gran Sasso (LNGS) is a dark matter direct search experiment based on the detection of rare nuclear recoils possibly induced by hypothetical dark matter particles, which are supposed to be neutral, massive (> 10 GeV) and weakly interacting (WIMP).
DarkSide aims to perform background-free WIMP searches using a series of dual-phase liquid argon time projection chambers filled with ultra-pure liquid argon. The detector currently operating at LNGS is DarkSide-50, a detector which holds 46 kg of active liquid argon and is now filled with argon extracted from underground and taking data in its final configuration.
Combining the underground argon data with the preceding search made with atmospheric argon, a 90% C.L. upper limit on the WIMP-nucleon spin-independent cross section of 2.0×10^{-44} cm^2 is set.
The next phase of the experiment foresees the construction of a new detector with an active mass of ~ 20 and equipped with silicon photomultipliers, called DarkSide-20k.

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1. Why liquid Argon

The choice of using argon as active target has many advantages for dark matter experiments: it has a high scintillation yield, it can be easily purified of radioactive impurities, and it is possible to scale to large masses with relative ease. Liquid argon also has excellent ionization and scintillation properties, in fact, a particle can produce more than 10^4 photons per MeV of deposited energy.
An interaction in the LAr generates primary scintillation light (called S1) both by excitation and recombination after ionization. The scintillation photons are emitted from two nearly degenerate excimer states, a long-lived triplet state and a short-lived singlet state. The fraction of these two states is significantly different between nuclear recoils (from WIMP or neutron scattering) and electron recoils, hence the time profile of the scintillation light is different. Nuclear recoils have more of the fast scintillation component than electron recoils, providing a very powerful pulse shape discrimination (PSD) between electron backgrounds and nuclear-recoil signals. The PSD parameter used in the WIMP searches is called f90, which is the fraction of S1 light in the first 90 ns of the scintillation pulse [1].

The high performances of the background rejection are strongly limited if atmospheric argon is used as active medium, because it contains ^{39}Ar, an isotope made by cosmic ray activity. ^{39}Ar decays by beta emission (Q = 565 keV and τ = 388 years) with an activity of $\sim$ 1 Bq/kg. The presence of ^{39}Ar does not only increase the background rate, but acting as an impurity, it limits the sensitivity of the experiment because favors electron recombination. To solve this problem the DarkSide collaboration made a multi-year effort to extract argon from underground sources: underground argon from the Doe Canyon plant, in Colorado, contains a factor of $\sim 10^3$ less ^{39}Ar with respect to atmospheric argon (AAr). The detector has been filled with underground argon (UAr) between March and April 2015 and measurements confirm that the ^{39}Ar activity of UAr is a factor $(1.4 \pm 0.2) \times 10^3$ lower than in AAr, corresponding to (0.73 ± 0.11) mBq/kg.

2. DarkSide-50

The DarkSide-50 detector system consists of three nested detectors. The innermost is a cylindrical dual-phase time projection chamber (TPC), with an active UAr mass of 46.4(7) kg observed by 38 PMTs, described in detail in [2]. The 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 neutron detector is a liquid scintillator veto (LSV), consisting of a 4.0 m diameter stainless steel sphere instrumented with 110 PMTs and filled with boron-loaded liquid scintillator. The scintillator is a solution of pseudocumene, with 5% by volume trimethylborate [4]. The LSV is located in the middle of a 1 kilo-ton water Cherenkov muon veto, 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.
An interaction inside the TPC causes excitation and ionization of the argon atoms. The electrons escaping recombination drift to the surface of the liquid argon due to the electric field present along the vertical axis of the TPC. At the interface between liquid and gas a stronger field extracts the

electrons, so that they induce further light emission (called S2) via proportional scintillation. The presence of two signals, S1 and S2, allows the interaction vertex to be localized in 3D, and the time profile of the scintillation signal S1 allows rejection of backgrounds from β or γ events by using pulse-shape discrimination techniques.
A first run of DarkSide-50 with a (1422 ± 67) kg-day exposure of AAr produced a null result for the dark matter search and zero backgrounds from ^{39}Ar decays. All except two of the events falling within the WIMP search region were rejected using the pulse shape discrimination. The two remaining events in the WIMP region of interest had a signal in coincidence with the active veto and were therefore discarded. The analysis of the first WIMP search in DarkSide-50 using UAr, reported in [3], shows that UAr is depleted in ^{39}Ar by a factor of $(1.4 \pm 0.2) \times 10^3$ relative to AAr. Dark matter limits from the present exposure are determined from our WIMP search region using the standard isothermal galactic WIMP halo parameters. Given the background-free result, a 90 % C.L. exclusion curve corresponding to the observation of 2.3 events for spin-independent interactions can be obtained. Combining it with the null result of the previous AAr exposure, we get a 90 % C.L. upper limit on the WIMP-nucleon spin-independent cross section of 2.0×10^{44} cm^2 for a WIMP mass of 100 GeV/c^2.

3. The future: DarkSide-20k

The combined results with AAr and UAr would allow DarkSide-50 to be free from ^{39}Ar background for several tens of years: the expectation is that this result could also be obtained from a much larger exposure with a multi-tonne detector. In the near future the DarkSide program will construct a 20 ton time projection chamber called DarkSide-20k [5]. The scintillation signal in argon will be detected by silicon photomultipliers. The procurement of low radioactivity underground argon necessary to fill the DarkSide-20k detector is a critical technical challenge for the experiment and it will be addressed within the framework of two parallel projects: Urania and Aria. The Urania project will provide a plant capable of extracting 100 kg/d of UAr from the same wells that yielded the UAr for DarkSide-50. The Aria project will consist of a cryogenic distillation plant, installed in the Seruci mine in Sardinia, capable of reducing the residual 39Ar in the UAr by exploiting the small difference in vapor pressure between ^{39}Ar and ^{40}Ar.

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