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Current status of the dark matter experiment DarkSide-50

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Summary. — DarkSide-50 is a dark matter direct search experiment at LNGS, searching for rare nuclear recoils possibly induced by WIMPs. It has two nested vetoes and a dual phase liquid argon TPC as dark matter detector. Key features of this experiment are the use of underground argon as radio-pure target and of muon and neutron active vetoes to suppress the background. The first data-taking campaign was running from November 2013 to April 2015 with an atmospheric argon target and a reduced efficiency neutron veto due to internal contamination. However, an upper limit on the WIMP-nucleon cross section of $6.1 \times 10^{-44}\,\mathrm{cm}^2$ at 90% CL was obtained for a WIMP mass of $100\,\mathrm{GeV}/c^2$ and an exposure of $(1422 \pm 67)\,\mathrm{kg{\cdot}d}$. At present DarkSide-50 started a 3 years run, intended to be background-free because the neutron veto was successfully recovered and underground argon replaced the atmospheric one. Additionally calibration campaigns for both the TPC and the neutron veto were completed. Thanks to the good performance of the background rejection, the results obtained so far suggest the scalability of DarkSide-50 to a ton-scale detector, which will play a key role into the dark matter search scenario.

1. – Existence of dark matter

The history of dark matter begins in 1930 when the first data implying non-luminous matter was collected by the dutch astronomer Oort. Since then, numerous observations at both galactic and extragalactic scales [1] confirmed the presence of a non luminous matter that holds galaxies together, enhances the effects of gravitational lensing and causes phenomenon such as the Bullet Cluster. Since 1930, a lot of effort has been put into the dark matter field, and some upper limits and estimations have been evaluated, but our knowledge of dark matter still has not changed very much since the first observations [2]. What we do know now is that there is a huge part of the Universe that we cannot see or study until the dark matter mystery is solved. As a matter of fact the most precise measurement of the CMB, combined with the results from large-scale structure observations, indicates that dark matter and dark energy contribute, respectively, to 26.8% and 68.3% of the mass/energy density of the Universe leaving only 4.9% to the ordinary matter [3]. One of the possible solutions is to postulate the existence of weakly interactive massive particles (WIMPs), which permeate the Universe.

2. – The DarkSide project

The DarkSide (DS) project is designed for direct detection of dark matter particles, using a dual phase liquid argon time projection chamber (LAr-TPC). DS is deployed at Gran Sasso National Laboratory (LNGS) in Abruzzo, Italy. If WIMPs exist they are expected to collide with nuclei and produce recoil nuclei with kinetic energies in the range 0–200 keV. Therefore, in order to see such a rare and low energy event, it is crucial for this experiment to be background free in the region of interest for WIMP search. The current phase and the first WIMP-sensitive detector of the DS family is DarkSide-50 (DS-50). Its underground location gives to DS-50 a great advantage: thanks to 3500 m water equivalent of rock, separating the experiment from the external surface, the detector is well shielded from cosmic rays. Moreover, two active vetos shield the main detector from the residual cosmogenic and external radiogenic background. The LAr-TPC is surrounded by a liquid scintillator veto (NV) doped with boron [4]. The NV tags neutrons that could produce in the TPC a nuclear recoil which can mimic the WIMP-nucleus interaction. Both the detectors are inserted in an ultra-pure water Cherenkov detector, the former CTF of Borexino [5], which serves as an active veto for cosmogenic muons and a passive shielding for external neutrons and gammas.

2˙1. *TPC*. – The core of DS-50 is a dual phase LAr-TPC made of low-radioactivity components and with high light and ionization collection efficiency. The active medium for WIMP detection is LAr, a noble liquid particularly suitable as target material for dark matter experiments because of its scintillation properties and because the low temperature of its liquid phase limits the diffusion of radioactive impurities, such as Rn. A particle interaction in the target volume produces both scintillation and ionisation. The scintillation is promptly detected by the PMTs while the electrons which survive the recombination are drifted by an electric field to the gas phase where they produces a delayed fluorescence. These two signals allow useful strategies to reject background using ionization to scintillation ratio and 3D position reconstruction. To further suppress the background, in LAr it is possible to use pulse shape discrimination (PSD), a powerful rejection method that take advantage of the time dependence of scintillation light [6]. With the PSD it is possible to distinguish electron recoils (due to β and γ) from nuclear recoils (caused by heavy ionizing particles such as α, n and possibly WIMPs).

3. – History of DarkSide

The DS adventure started in 2010 with the first prototype of a three-stage program, called DarkSide-10. It was a small version of the present experiment but it had the crucial role of proving the feasibility of the DS program and to measure fundamental parameters of the detector such as important figures of merit for background rejection. DS-50 was commissioned in October 2013 and has been operating since then. For the first year of operation, it was filled with atmospheric argon (AAr). During the AAr run, tests and calibrations were performed for a more complete knowledge of the detector and the possibility to run a background free experiment. After DS-50, the next phase will be DarkSide-multiton, a LAr-TPC with few tons of fiducial mass which will be competitive with other similar projects, already at the ton scale.

3˙1. ^{14}C. – As soon as the veto of DS-50 was turned on, an unexpected high rate in the NV was observed. The batch of TMB used to dope the scintillator was contaminated with an unexpectedly high content of ^{14}C. This contamination limited the NV performance, but nevertheless it was adequate to suppress the very low rate of neutron-induced events. To fully restore the design performance of NV, in August 2014 the old TMB was removed and replaced with a clean batch of TMB.

3˙2. *Calibration campaigns*. – The TPC energy calibration was performed using ^{83m}Kr gamma peak and by fitting the end-point of the ^{39}Ar spectrum, naturally present in the atmospheric argon. The ^{83m}Kr was added to the LAr during dedicated calibration campaigns. The light yield obtained during calibrations with the electric field on is about 7 PE/keV. From October 2014 to January 2015 a long calibration campaign was performed using both gamma and neutron sources deployed in the neutron veto through an insertion system. The goal of this campaign was performing an energy calibration of

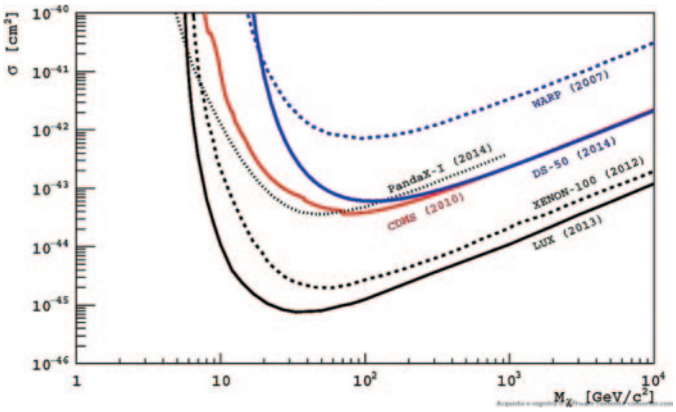

Fig. 1. – Exclusion plot obtain with DarkSide-50 data from the first 50 days of AAr.

the neutron veto, confirming the rejection and identification power for neutrons of the veto scintillator and validating the nuclear recoil acceptance region of the TPC.

3·3. *Underground argon filling.* – To really accomplish a background free experiment during April 2015, ∼160 kg of ultra pure argon (UAr) extracted from underground sources were delivered to LNGS as the dark matter research target for the DS experiment. The UAr has a low content of ^{39}Ar, a cosmogenic isotope of argon which undergoes beta decay with an activity of aproximately of 1 Bq/kg, in atmospheric argon. Since the filling of the TPC with UAr DS-50 began the real dark matter search run that will give results in both the dark matter field and on argon technology for low-energy experiments.

4. – First results and conclusions

The first year of data taking with AAr accumulated about 1.5×10^7 events, dominated by the beta decay of the ^{39}Ar. The region of interest showed no events and therefore we can say to be background free in that region. This result gives an upper limit (fig. 1) on the WIMP cross section *vs.* WIMP mass [7]. The upper limit on the WIMP-nucleon cross section obtained is of $6.1\times10^{-44}\,\text{cm}^2$ at 90% CL for a WIMP mass of $100\,\text{GeV/c}^2$ from an exposure of $(1422\pm67)\,\text{kg}\cdot\text{d}$.

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