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DarkSide-20k: Direct Dark Matter search(*)

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Summary. — DarkSide-20k, currently under construction at INFN, Laboratori Nazionali del Gran Sasso, is a direct detection Dark Matter experiment; it aims to directly detect WIMP Dark Matter particles scattering with liquid Argon nuclei in a 20 t fiducial volume dual-phase Time Projection Chamber (TPC), exploiting the subsequent scintillation signal and specific cryogenic photodetectors to detect it. The experiment is expected to obtain a sensitivity to WIMP-nucleon cross section of 7.4×10^{-48} cm^2 for the 90% C.L. exclusion considering 1 TeV/c^2 mass WIMPs over a 200 t yr exposure, while maintaining an instrumental background level in the WIMP search region lower than 0.1 events for the whole exposure. To achieve that result, an innovative Gadolinium-doped veto system mechanically integrated with the TPC itself is exploited, useful to identify neutron interactions in the detector.

1. – Description

The 20th century yielded a groundbreaking revelation: ordinary matter, comprised of protons, neutrons, and electrons, constitutes an exceedingly minuscule fraction of the total energy density of the Universe. The vast majority appears to be attributed to Dark Energy (about 70%), while roughly 25% is attributed to an enigmatic substance known as Dark Matter. Although various indicators of its existence have surfaced, the fundamental nature of this matter remains unknown. To account for the current prevalence of Dark Matter, any candidate particle must meet specific criteria: it has to be stable on cosmological timescales, as we currently witness its effects, which would not persist if it had already undergone decay. Moreover, it should exhibit interactions with ordinary particles involving gravity and interactions limited to scales not greater than the electroweak one, while remaining non-reactive to both electromagnetic and strong interactions. Weakly Interacting Massive Particles (WIMPs) represent one class of particles that meet these requisites and are considered among the possible extensions to the Standard Model that could unravel the enigma of Dark Matter.

The DarkSide-20k [1] experiment aims to be background-free for its entire planned exposure of 200 ton years; this means that the detector is designed to operate while maintaining the background coming from construction materials and environment in

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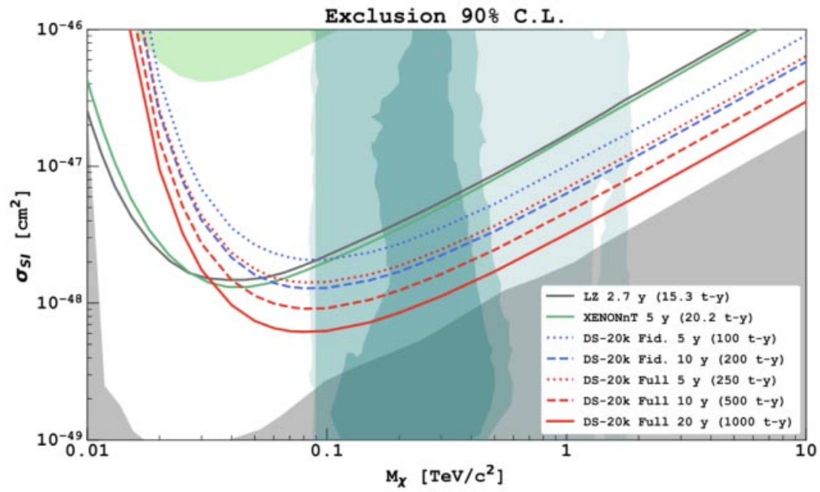

Fig. 1. – The sensitivity of DarkSide-20k to spin independent WIMP-nucleon cross-section as a function of the WIMP mass, for different lengths of runs compared to the nominal sensitivity of currently funded experiments LZ (2.7 yr run, 15.3 t yr exposure) and XENONnT (5 yr run, 20.2 t yr exposure). The region excluded by XENON1T is shown in shaded green, the neutrino fog for Argon in shaded gray, and the turquoise filled contours represent the 1σ, 2σ, and 3σ favored regions from the pMSSM11 model constrained by astrophysical measurements and the $\sim$36 fbarn LHC data at 13 TeV [1].

the WIMP search region less than 0.1 events for the total exposure [1]. It aspires to investigate WIMP-nucleon cross-sections down to 7.4×10^{-48} cm^2 for the 90% C.L. for WIMPs with a mass of 1 TeV/c^2 over a period of 10 years. The experiment projected sensitivity is shown in fig. 1. As shown in fig. 2, the whole detector is composed of three main volumes: from the inside out, a 20 t fiducial volume dual-phase (liquid and gaseous Argon) Time Projection Chamber (TPC), where the detector is expected to be sensitive to WIMP-nucleon interactions, a neutron veto and a cryostat. Both the TPC and the neutron veto, integrated in a single mechanical structure, present octagonal prisms shapes: the TPC height and inscribed radius are respectively 350 cm and 175 cm, while the neutron veto thickness is 90 cm both radially and vertically [2].

The purpose of the TPC is to directly detect WIMP scattering on liquid Argon nuclei, looking at nuclei recoil energies in the range [30,200] keV and measuring both ionisation and scintillation produced by WIMP interactions; in fact, as a result of the scattering event, a nucleus recoils with an energy of a few tens of keV, which is released to atoms and molecules, generating an observable signal after wavelength-shifting obtained with a TetraPhenyl-Butadiene (TPB) coating of all TPC surfaces in contact with the active Argon volume; this allows to convert liquid Argon scintillation light to a wavelength detectable by cryogenic silicon photomultipliers (SiPMs) with $\sim$40% efficiency, arranged in 528 20×20 cm^2 PhotoDetection Units (PDUs) will view the Argon volume through the top and bottom TPC windows. The high sensitivity desired for DarkSide-20k, for its entire planned exposure of 200 tons per year, makes it necessary to minimize all radioactive backgrounds that can induce false signals in the TPC; this means to distinguish the interaction of a WIMP from both β and γ radioactivity (directly rejected in the TPC with an efficiency greater than 10^7 [3]), and from nuclear recoils induced by neutrons.

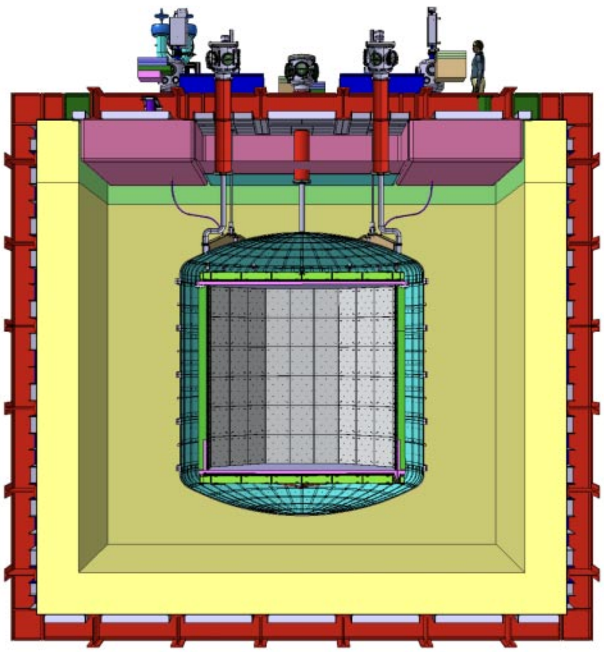

Fig. 2. – Front view cut of the DarkSide-20k detector, enclosed in its cryostat. The TPC, coloured in grey, is formed by the green Gadolinium-doped acrylic walls; the veto buffer, filled with underground liquid Argon as well as the TPC, is enclosed inside a stainless steel vessel, represented in light blue, to divide it from the atmospheric liquid Argon that fills the cryostat volume. SiPMs are mounted both on the inner top/bottom surfaces of the TPC (facing the active TPC volume) and on the outer top/bottom/side surfaces to face the veto buffer [1].

The neutron veto, as well as the TPC, is filled with underground Argon, depleted by a factor of 10^3 [4] of the isotope ^{39}Ar with respect to the atmospheric Argon which, with a β decay activity of 1 Bq/kg, would emit a 500 keV electron every second per kg, causing Argon scintillation and thereby dominating the experiment dead time making the light sensors blind. The veto purpose is to identify neutron interactions in the detector, as the elastic scattering of a neutron on an Argon nucleus produces a nuclear recoil that can mimic the interaction of a WIMP. To achieve this, DarkSide-20k employs a veto system consisting of 15 cm-thick panels of Gadolinium-doped PolyMethyl-MethAcrylate (PMMA) by 0.5%-1% in mass. As shown in fig. 2, these walls are both an integral part of the TPC and of the neutron veto detector, which are united in a single mechanical structure. The Gd-doped PMMA efficiently slows down and captures neutrons, resulting in an energy release of 8 MeV in the form of a cascade of gamma-rays; as in the TPC, the use of 120 PDUs, distributed over the surface of the Gd-doped PMMA facing the veto Argon volume, allows for the detection of Argon scintillation light produced by Gadolinium gamma-rays. Both the thickness and the Gadolinium concentration of the veto panels are set to achieve a neutron capture inefficiency lower than 10^{-6} [1]. Since SiPMs are not sensitive to the Argon scintillation light (128 nm), PolyEthylene Naphthalate (PEN) wavelength-shifter foils are applied to all interior surfaces of the veto, changing this wavelength to 420 nm, where the SiPMs photon detection efficiency is about 40%.

2. – Conclusions

The construction phase of DarkSide-20k will conclude in 2026, marking the beginning of a 10 years data-taking campaign during which the investigation of WIMP-nucleon cross-sections down to 10^{-47} cm^2 for 1 TeV/c^2 mass WIMPs will be pursued, with the goal of directly detecting WIMP-nucleus elastic scattering exploiting a liquid Argon dual-phase Time Projection Chamber. The scattering event, searched in the region of recoil energy [30-200] keV, is expected to generate photons, that can be collected using cryogenic silicon photomultipliers. The use of an active veto, made of PMMA loaded with Gadolinium, allows the detection of particles that may mimic a WIMP interaction signal. In addition, the background reduction achievable by an optimal choice of materials and the use of Argon depleted of the ^{39}Ar isotope allows the DarkSide-20k experiment to achieve such extreme performance.

REFERENCES

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