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The DarkSide-20k neutron veto

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Summary. — DarkSide-20k is a background-free experiment under construction at INFN, Laboratori Nazionali del Gran Sasso. It aims to directly detect Dark Matter particles exploiting WIMP-nucleon scattering in liquid argon. In order to identify neutron interactions, a gadolinium-doped veto was developed, which takes advantage of liquid argon scintillation. Studying the optimal placement of the photodetectors in the veto, the non-uniformity of the light collection was simulated to be 3% at 1σ.

1. – Description

Only five percent of our Universe is known. What is the rest made up of? All matter around us is mainly formed by three particles: protons, neutrons and electrons. In this context, the most surprising discovery of the 20th century was that this ordinary matter constitutes an incredibly small amount of the total mass of the Universe. The rest appears to be made of Dark Energy (70%) and about 25% is a kind of invisible matter, called Dark Matter, so difficult to directly detect that it seems to be playing hide and seek with our experiments [1]. Although several evidences of its presence were found, Dark Matter is still undetected with current instruments. To date, exploiting its experimental evidences and based on several studies made in the last decades, a Dark Matter particle candidate has to satisfy some properties: it has to be stable on cosmological timescales, since nowadays we can observe its effects that would not be present if it had already decayed; it has to be with neither electrical nor colour charge, since it does not interact electromagnetically and via strong nuclear force; it has to be weakly and gravitationally coupled to standard particles. Among all the particles that can have all these features, Weakly Interacting Massive Particles (WIMP) were theorized, which are one of the different Standard Model extensions that can explain Dark Matter.

The purpose of DarkSide-20k is to detect the WIMP-nucleon scattering in liquid argon, thus at cryogenic temperatures (87 K) exploiting ionization and scintillation processes and by the use of photodetectors. DarkSide is a Dark Matter direct detection experiment: based on its predecessor DarkSide-50 experience [2], the aim is to detect

Dark Matter scattering with ordinary matter nuclei; what happens next is the recoil of the nucleus with energy of some tens of keV which is released to atoms and molecules, giving origin to an observable signal. DarkSide has three main active regions: from the inside out, a dual-phase Time Projection Chamber (TPC), where the detector is expected to be sensitive to WIMP-nucleon interaction, a neutron veto and a cryostat.

DarkSide is an extremely ambitious experiment which aims to be background-free for its entire planned exposure of 100 tons × year. Its task is to investigate WIMP-nucleon cross sections up to 10^{-47} cm^2 for a 1 TeV WIMP in a 5 years run. It is therefore necessary to minimise all radioactive backgrounds that can induce false signals, so it needs to distinguish WIMP from β and γ radioactivity (which are rejected directly in the TPC with efficiency higher that 10^9) and from neutron-induced nuclear recoils.

Thus it is essential to identify neutrons interaction, since elastic scattering on Ar nuclei would produce a nuclear recoil that can mimic a WIMP interaction. For this purpose, DarkSide employs an active veto. It is built with gadolinium-doped acrylic, which slows down and captures neutrons with a consequent energy release in the form of a gamma-ray cascade, whose energy totals 8 MeV. In addition, as in the TPC, cryogenic Silicon PhotoMultipliers (SiPM) are used to detect argon scintillation photons generated by the gadolinium gamma photons.

The gadolinium-doped acrylic emits gamma photons isotropically, and to maximise their detection it is placed at the center of a liquid argon volume, dividing it in two distinct and optically isolated regions, the Inner Argon Buffer (IAB) and the Outer Argon Buffer (OAB), as sketched in fig. 1. SiPM will be mounted on both sides of the gadolinium-doped acrylic in order to detect events in both the buffers.

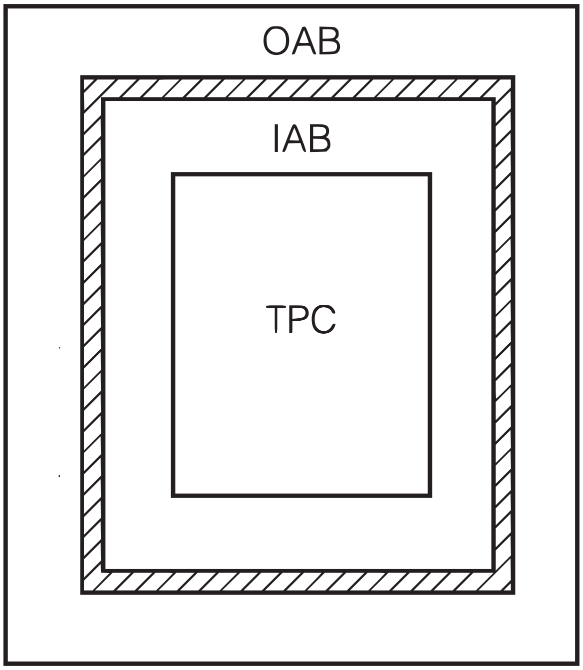

Fig. 1. – DarkSide-20k scheme: please observe the TPC at the center, the liquid argon buffers (IAB and OAB) and the gadolinium-doped acrylic, dashed.

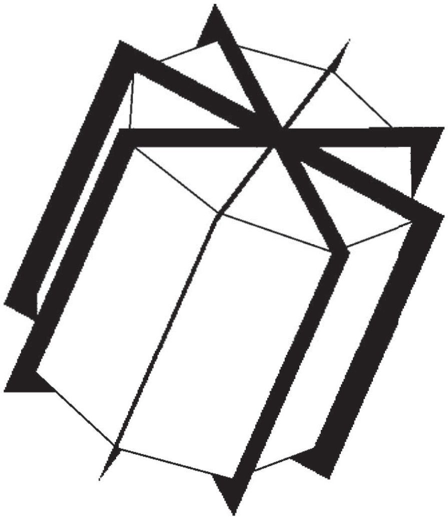

Fig. 2. – Geant4 visualisation mode picture of DarkSide-20k: please observe the eight optically isolated sectors of the veto.

Each one of the two regions is in turn divided in eight optically isolated sectors (see fig. 2) by reflector sheets held up by an acrylic support, to reduce pile-up events on veto SiPM. In fact, the veto is filled with atmospheric argon, which contains the long-lived β-emitter ^{39}Ar with a specific activity of 1 Bq/kg. The high rate in the veto due to ^{39}Ar can cause a significant dead time for the experiment.

Since SiPM are not sensible to argon scintillation wavelength (128 nm), a wavelength-shifter is deposited on all internal surfaces, which changes that wavelength up to 420 nm, at which SiPM photon detection efficiency is of the order of 40%.

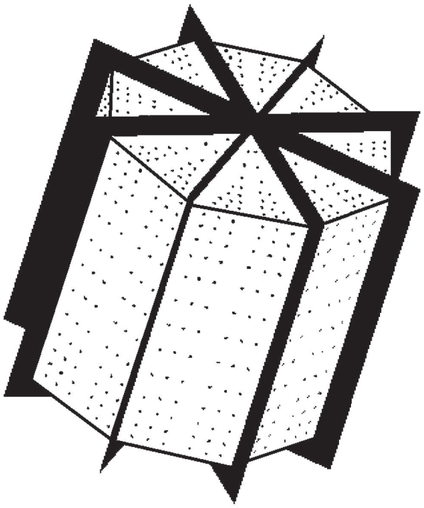

Fig. 3. – Geant4 visualisation mode picture of DarkSide-20k: the dots represent the SiPM on the gadolinium-doped acrylic surface, please observe their accumulation in correspondence of the upper and lower surface edges.

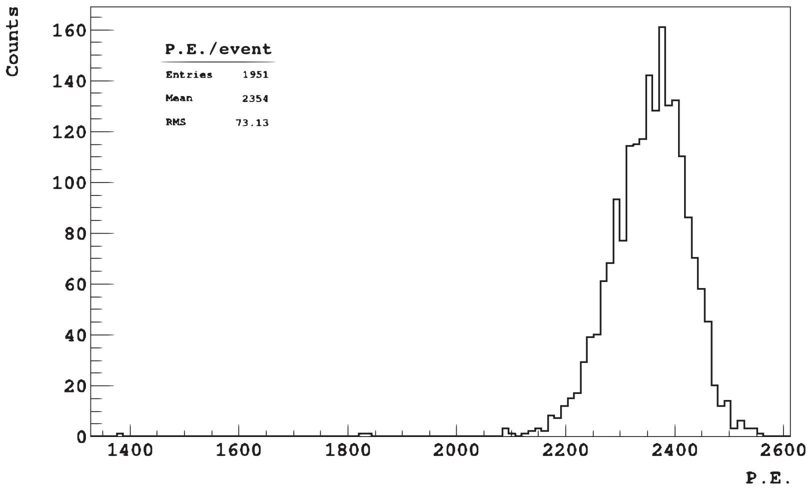

Fig. 4. – DarkSide-20k veto, OAB case: number of photons collected per event. The events correspond to 1 MeV electrons uniformly generated within the OAB.

A veto basic requirement is a uniform light collection in the three spatial directions, since all the parts of the veto argon buffers have to behave the same way in order to identify as accurately as possible neutron events. In addition, a uniform light collection allows for an easier conversion from photons collected to energy deposited in the veto, regardless of the position of the neutron capture. If this need is satisfied, the generation of uniform events in a buffer should result in a uniform light collection in the buffer itself. For this purpose Monte Carlo simulations exploiting Geant4 software were done, in order to determine the best placement for the veto SiPM. A non-uniform distribution for SiPM is chosen for all surfaces, which provides for an accumulation of photosensors in correspondence of the upper and lower surface edges, as one can observe in fig. 3.

In order to generate light in the veto system, 1 MeV electrons, uniformly distributed within the veto argon buffers, were simulated to release their energy in liquid argon, giving rise to excitation and ionization of argon atoms. The studies on SiPM optimal placement made it possible to obtain a light collection non-uniformity of 3.1% at 1σ in the OAB and 3.7% at 1σ in the IAB [1]; fig. 4 shows the result for the OAB case.

REFERENCES

[1] Rossi Matteo, *Full simulation of a LAr-based neutron detector for a Dark Matter experiment*, Master's Thesis, Università degli Studi di Genova (October 2020).

[2] The DarkSide Collaboration (Agnes P. *et al.*), *Phys. Rev. D*, **98** (2018) 102006.