

Study of the veto system for the DarkSide-20k experiment

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One of the major challenges of modern physics is to detect and determine the nature of the Dark Matter component of the Universe. The DarkSide Collaboration is going to construct DarkSide-20k at the Laboratori Nazionali del Gran Sasso, a direct WIMP search detector using a two-phase Liquid Argon Time Projection Chamber with a fiducial mass of 20 t. This is a new-generation dark-matter experiment conceived to detect nuclear recoils produced by dark matter particles scattering off target nuclei with background-free conditions. The aim of the present work is to provide the collaboration of useful information in the decision-making process of the veto design. This review summarises the different simulations carried out, in order to study the efficiency of a possible veto configuration by analyzing important features as the inefficiency, the neutron capture time, the sensitivity of neutron event discrimination, the intrinsic activity of the veto and how they depend on composition and geometry.

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I. INTRODUCTION

There are evidences that the 27 % of the content of the universe is a type of non-luminous matter that we call dark matter (DM) [1, 2]. Understanding the nature of dark matter is one of the most important challenges of current physics.

The concept of dark matter was developed more than 80 years ago to explain anomalous motions of galaxies gravitationally bound in clusters. Observational evidence has continued to accumulate since then, including rotation curves of galaxies and their clusters and discrepancies in the distributions of galaxy cluster mass estimated from luminosity vs gravitational lensing. That this matter is not only dark but also cold and nonbaryonic is strongly implied by simulations of observed large scale structure in the universe, fluctuations in the cosmic mi-

crowave background radiation and big bang nucleosynthesis.

We have to understand this work as a study within DarkSide collaboration, that aims to provide information in order to explore different ways to design a veto system that fulfills its main objective: achieving near zero-background measurements.

This paper is structured in the following way. In the introduction we present the dark matter hypothesis motivations, as well as the main characteristics of one of the candidates of dark matter particles, WIMPs, which in the context of our experiment is the one we aim to detect.

In section II we review the status of direct dark matter searches and the noble liquid detector technologies used to directly detect dark-matter particles.

The final part of section II is devoted to explain in more detail the DarkSide-20k experiment, the expected signal, main background sources, and the geometry configuration.

In sections III, IV and V we present the results of this work. We have three different simulation scenarios, with different geometry models and material composition. We will discuss the main features that affect the veto efficiency, the neutron capture time, (the time it takes to capture a neutron since it is produced), the intrinsic radioactivity of the materials used in the veto configurations and the geometric efficiency, the capacity to capture the neutrons inside the veto.

Sections III and IV are closely related, and are focused to implement a segmented veto geometry that allows to discriminate the signals from the intrinsic activity of the veto. The first one is a preliminary work that we have done to test the suitability of implementing a segmented veto geometry, studying a less complex geometry model approach. Finally, due to the interesting results from the approximate geometry model, we have implemented the full geometry in simulations described in section IV.

In section V, alternative veto configurations are discussed. We have simulated veto geometries that alternate

plastic scintillator layers with liquid argon, changing in each simulation the thickness of the layers and two types of plastic.

We will end up in section VI with some discussion and conclusions.

The simulation of the detector is performed [3] with Geant4, a MonteCarlo software widely used in particle physics, implemented in C++ and developed at CERN. We can encode a complete detector geometry, sensitive volumes, a large number of materials and different physics models that can be used to describe particles behavior at the detector. G4DS is a simulation code, based on Geant4, that has been designed to simulate DarkSide detectors [4].

A. Dark Matter. WIMPs

While the Standard Model of particle physics does not include a viable dark matter candidate, the existence of new particles through different models of physics beyond the Standard Model has been proposed, some of which are good DM candidates.

Two examples of the most popular DM candidates are axions [5] and Weakly Interacting Massive Particles (WIMPs) [6].

Taking into account the fact that massive particles are naturally good candidates for cold dark matter, WIMPs have focused most of the direct search efforts as it happens for DarkSide-20k.

WIMPs can arise from supersymmetry models proposed as extensions of the Standard Model. An example of a supersymmetric candidate is the neutralino, the lighter neutral particle of the Minimal Supersymmetric Standard Model.

Regardless the model, the discovery of WIMPs would give observational evidence for new physics beyond the Standard Model. WIMPs are estimated to have masses between the GeV and the TeV and must be electrically neutral, non-relativistic, non-barionic and interact weakly with ordinary matter.

II. DIRECT DARK MATTER SEARCHES

Dark Matter detection can be approached via three processes, the production of DM particles at particle accelerators, indirect DM detection by searching for signals from annihilation products or Direct DM searches via scattering on target nuclei.

Because the DarkSide-20k experiment is designed for the direct detection of WIMPs, this section will be devoted to the Direct DM Detection in order to provide a framework for understanding the operation of the detector.

According to the Standard Halo Model, the sun is moving through the dark matter halo at $v=225\text{km/s}$ [7]. Because of this motion, WIMPs can interact with ordinary

matter via coherent WIMP-nucleus scattering, causing nuclear recoils, NR. For the mass range from 10 GeV to 10 TeV, the typical energy of nuclear recoils is of the order of 1 to 100 keV for argon targets, so DM direct-detection experiments must be sensitive to this range of energy.

The cross section of coherent WIMP-nucleus scattering is expected to be low, so the events that we want to measure are extremely rare. For this reason and because the signal they produce in our detectors is very weak, this type of experiments represent an experimental challenge. In order to discriminate a rare low-energy signal from natural sources of background, these experiments are located underground, isolating them from cosmic rays to a large extent [8].

Although no signal has been found so far, it is interesting to note that there is an experiment that claims to have a positive signal of annual modulation, that has been claimed to be an observable signature of the existence of Dark Matter.

The annual modulation is an expected variation of DM-nucleon interactions throughout the year, as a consequence of the Earth orbit around the Sun, which is moving in the Galactic frame.

Earth orbits in a plane tilted 60 degrees with respect to the Sun propagation direction with a speed of approximately 30km/s, and for that reason the relative speed between the detector and the dark matter halo changes during the year and the event rate has a cosine dependence with time. The expected maximum for the DM signal is in June and the minimum in December [9].

The DAMA/LIBRA experiment has detected a clear signature of annual modulation in the Laboratori Nazionali del Gran Sasso with a 12.9σ CL, using ultra low background NaI crystal detectors [10, 11].

This modulation is compatible with WIMPs masses between 8 GeV, and 54 GeV and cross sections between 10^{-42} and 10^{-39} cm^2 .

Nevertheless, other experiments where the systematics are more under control have set exclusion limits that are incompatible with the DAMA/LIBRA observations, the most recent one of Xenon1T taking the exclusion limit down to 10^{-46} cm^2 [12].

Hence, although the modulation signal is clear, most of the community rejects the hypothesis that is produced by DM. Three experiments, the Spanish ANAIS, in the Canfranc Underground Laboratory, the Korean COSINE-100, and the Japanese PICO-LON, in the Kamioka Laboratory, are repeating the measurements at different locations where the systematics are expected to be different, and dated results are being awaited.

The nature of DM has not been identified yet. Direct dark matter searches have established the most restricted exclusion limits. To build a competitive detector we need it to be sensitive to a WIMP-nucleon cross sections in the order of 10^{-48} cm^2 .

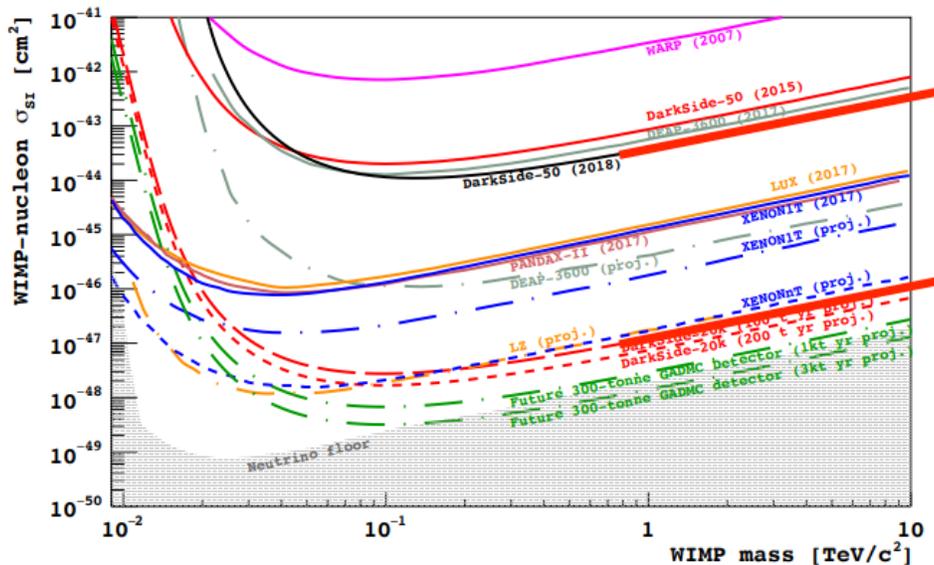


Figure 1: Summary of results from direct dark matter search experiments in the WIMP-nucleon spin-independent cross section vs. WIMP mass [2]

A. Noble Liquid detectors, LAr technology and TPCs

Noble liquid detectors are based on detecting the energy produced by nuclear recoils, when WIMPs collision in the ordinary matter from the detector. Experiments headed in this direction work at cryogenic temperatures to ensure that argon and xenon are in liquid phase.

Liquified noble elements such as argon and xenon offer excellent media for building detectors. They are good scintillators and have a high ionization rate in response to energy deposits. The simultaneous detection of ionization and scintillation signals allows to identify the primary particle interacting in the liquid. These features, together with the relative availability of large masses and its high density, have contributed to make liquid Xe (LXe) and liquid argon (LAr) suitable targets for WIMP searches.

Charged particles deposit energy in the detector, through interactions with the electrons of the argon atoms producing electron recoils (ER), while neutral particles, such as neutrons and WIMPs, interact directly with the argon nucleus producing nuclear recoils (NR). Both interactions produce scintillation light and ionization. These two signatures used at the same time enable us to identify the different recoil processes.

Argon has advantages over xenon: it is cheaper and easier to obtain in large quantities, it has a lower energy threshold for recoils and pulse-shape discrimination techniques can be used. On the other hand, the drawback associated with Ar is the presence of Ar^{39} , which is a beta emitter with a half-life 269 yr and a Q-value of 565 keV [2].

The main part of a noble liquid detector, where the interactions that we detect occur, is the time projection

chamber (TPC).

A time projection chamber (TPC) is a type of particle detector. It consists of a liquid-filled detection volume (LXe or LAr) in an electric field. When a particle interacts inside the detection volume, it will produce primary ionization and scintillation light. A double-phase TPC operates with an additional volume placed above the liquid-filled detection volume, the gas pocket [2].

In the double-phase TPC, the emission of light is produced by two mechanisms, the double-phase detectors allow to detect two signals, one of scintillation, S1, and another of electroluminescence S2, originated by the accelerated ionization electrons in a gas pocket.

Since the photons have an energy of 9.8 eV, insufficient energy to excite the argon atoms and cannot be reabsorbed by them, they are propagated through the detector to the light-collection system, like PMTs or SiPMs, placed on top and bottom.

High voltage is applied between the cathode and a grid just below the gas-liquid interphase to produce a vertical electric field and drift the released electrons to the gas pocket on top. There, a stronger electric field is induced between the grid and the anode, in the gas pocket, to extract the ionization electrons and accelerate them to create a secondary scintillation light, the S2 signal. S2 is then mainly detected at the top light-collection devices.

The detector is sensitive to the event position. The interaction coordinates xy are reconstructed using the light pattern at the light-collection planes. The drift time, the time between the S1 and S2 signals, determines the z-coordinate of the event in the TPC.

The wavelength of the argon S1 and S2 signals is 128 nm. In order to be detected, it must be wavelength-shifted. For this reason, all inner surfaces delimiting the active volume are coated with tetraphenylbutadiene

(TPB), which absorbs the 128 nm scintillation light and reemits photons with a wavelength of 420 nm.

Another advantage of detecting S1 and S2 signals is that studying the S2/S1 ratio allows the discrimination between nuclear and electronic recoils. This discrimination can be carried out in both, Argon and Xenon detectors. For electron recoils a higher charge-to-light ratio (S2/S1) is expected than for neutron recoils [2].

In LAr detectors an additional discrimination method is possible using the time structure of the S1 pulse. This method is known as pulse shape discrimination (PSD) and allows to reject the ER background events from NR.

It is based on the fact that the light produced due to the molecular de-excitation of Ar_2^* , can be produced from a singlet $^1\Sigma_u^+$ or a triplet excited state $^3\Sigma_u^+$ to the ground state $^1\Sigma_g^+$. Due to the transition probability, the first is allowed and the second is suppressed, leading to a higher lifetime, being $\tau = 5ns$ for the first case and for the triplet $\tau = 1.6 \mu s$. Therefore, these are called the fast and slow components, respectively. In the case of Xenon the time difference is too small for this technique to be viable [13]

In a practical way, the discrimination parameter that we use is f_{90} , defined as the fraction of scintillation light S1 collected in the first 90 ns, associated with the fast signal, with respect to the total signal collected. ER events can be chosen at first order by requiring $f_{90} < 0.6$.

Combining these two discrimination methods, the detector keeps only nuclear recoil events susceptible of having a WIMP origin. Given the low probability of dark matter particles to interact, the removal of multiple simultaneous hits in the TPC are used for neutron background suppression.

B. DarkSide-20k experiment

The DarkSide-20k experiment, will be located in the Gran Sasso National Laboratory (LNGS) in Italy at a depth of 3800 m.w.e..

The final goal is to perform a zero-background measurement. The main challenge is, then, minimizing and identifying the background.

The main disadvantage of Ar with respect to Xe are the β decays of ^{39}Ar . DarkSide-50 have addressed this issue extracting argon from underground wells. The isotopic abundance of ^{39}Ar in this argon is depleted by a factor 1400 [4]

Solved this problem, neutron radiation constitutes the most important background because they can induce nuclear recoils in the detector volume. Neutrons can come from fission and from (α, n) reactions where alphas are produced by the ^{238}U and ^{232}Th decay chains. These elements are present in small amounts in all materials. Also cosmogenic neutrons produced in cosmic ray muons showers have to be identified and excluded from the analysis.

The goal that has been set by DarkSide collaboration is to have a background below 0.1 irreducible (unidentified) neutron-like events in the full exposure of 100 t yr exposure. With such background, 5 WIMP-like events in the full exposure would be statistically significant enough to claim a detection with a 5σ confidence level

In order to achieve this neutron background goal, several things must be taken into account. On the first place, selecting materials with low radioactive contamination. Second, shielding the detector with an efficient passive veto. Third, set some constraints in the signal measured in the TPC. Finally, using an external detector surrounding the TPC to reject coincidences. This is what we call the veto system and we have studied in detail.

1. DarkSide-20k geometry

DarkSide-20k TPC (Figure 2a) is an octagonal prism of 150 cm edge and 262 cm height with a total active mass of 23 t. The active LAr volume is separated by a grid from the electron extraction region at the top. The cathode at the bottom and the anode at the top are made with a transparent conductive indium-tin-oxide (ITO) layer, since it is optically transparent, as well as it can be deposited as a thin film. The TPC is covered with a reflecting material and the TPB on its sides, so that the visible photons are redirected to the top and bottom light readout planes. A fiducial volume in the TPC is defined rejecting the events measured at less than 30 cm from walls, top and bottom [2].

The design voltage applied in the TPC is of 200V/cm. Ionization electrons are drifted to the anode [2]. Between the grid and anode, in the gas pocket, we apply an extraction field in the order of 2.8kV/cm, that gives us the S2 signal [2].

The full Ar-TPC is inside a cryostat, and a cryogenic system cools down and purifies the liquid argon. The cryostat walls are 90 cm thick and have a multilayer structure. They consist of an inner corrugated thin membrane of stainless steel surrounded by plywood board and insulating polyurethane foam with a secondary thicker aluminum membrane placed between another layer of plywood board and insulated polyurethane foam.

The goal of the cryostat is to enable for a temperature drop (in the order of 200 K) between its outer and inner surfaces, minimizing heat loss through its walls and, at the same time, guaranteeing the sealing of the detector, avoiding outer contaminants into the argon.

The main goal of this work is studying plausible configurations of the veto system (Figure 2b) that will surround the TPC, in order to minimize the probability of getting neutron induced NR not identified.

At the time of this work, the veto design is still being discussed. To carry out an efficient design we have simulated three different models of veto where we study the geometric efficiency and neutron capture time.

One of the most important features proposed for the

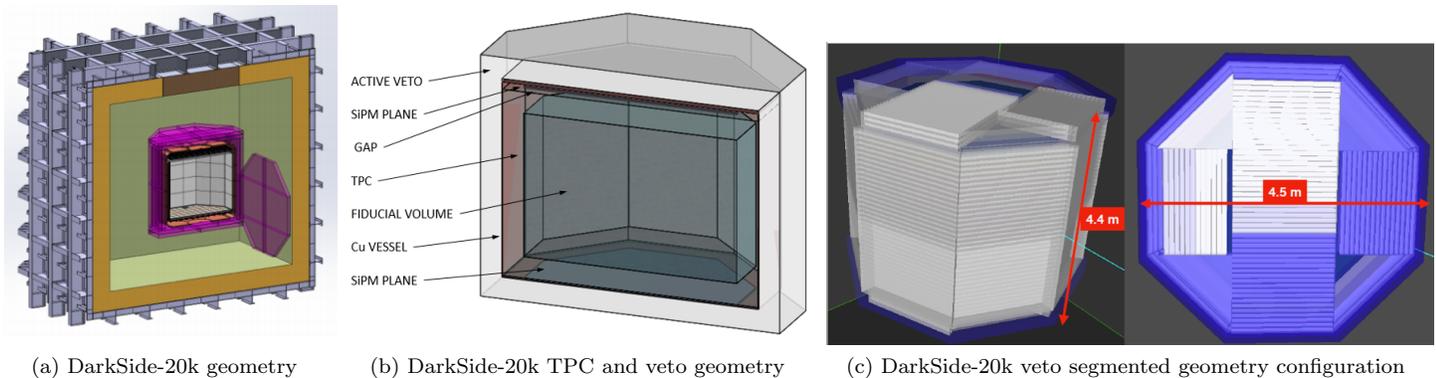


Figure 2: DarkSide-20k geometry

veto design is to divide it into bars to set a signal pattern to distinguish the signals produced by neutron captures and those produced by intrinsic radiation of the veto materials.

If we have a signal that could seem a WIMP-like event (a single nuclear recoil that deposits from 7.5 keV to 50 keV in the TPC) and simultaneous a neutron capture in the veto, we will be able to reject the event, due the low probability of WIMP-nucleus interaction.

The SiPMs are placed at the end of the bars will detect the γ rays produced by the neutron capture, but also the radiative activity of the veto itself, producing potential accidental coincidences.

The three simulations that have been performed. The first one, a preliminary simulation of a segmented veto approach configuration, secondly, we have implemented the fully-segmented geometry and finally, we have performed alternative simulations with a multilayer veto.

III. HOMOGENEOUS-VETO APPROACH

We want to study a segmented veto configuration that consists on a veto divided into approximately 1400 bars of $10 \times 10 \times 200 \text{ cm}^3$ of a plastic scintillator material wrapped with a $50 \mu\text{m}$ film of Gd_2O_3 , as shown in Figure 2c.

Implementing this geometry in Geant4 is a tedious work, and for this reason it is convenient to study its viability beforehand. The way to carry out this preliminary study has been to generate a homogeneous material that presents the same proportion of gadolinium and plastic that would present the original geometry with the bars. Subsequently, in the analysis process, the veto has been divided into volumes equivalent to the bars.

The main goal of studying a veto configuration divided into bars, is to apply a new technique of discrimination of the background radiation, based on the relation of number of bars where energy is deposited.

The simulated neutrons are those produced by (α, n) in some materials of the detector, the α particles coming from the disintegration chains of the radioisotopes

^{238}U and ^{232}Th . Neutrons have been simulated from the veto itself and from the SiPMs, since these materials are among the most critical sources. The overall rate of intrinsic activity due to ^{238}U and ^{232}Th decay chains is 13.5 kHz, in the worst possible scenario. It is necessary to distinguish between neutrons and gammas because this rate is too high.

Neutrons captured in Gd release 3.6 γ -rays in average, emitting a total energy of 8.8 MeV. These large amount of γ -rays, emitted in different directions, tend to leave energy in more bars than self background. This is the pattern that we look for. We simulated both gamma sources and determined the average number of bars in which light signal is detected, for each case.

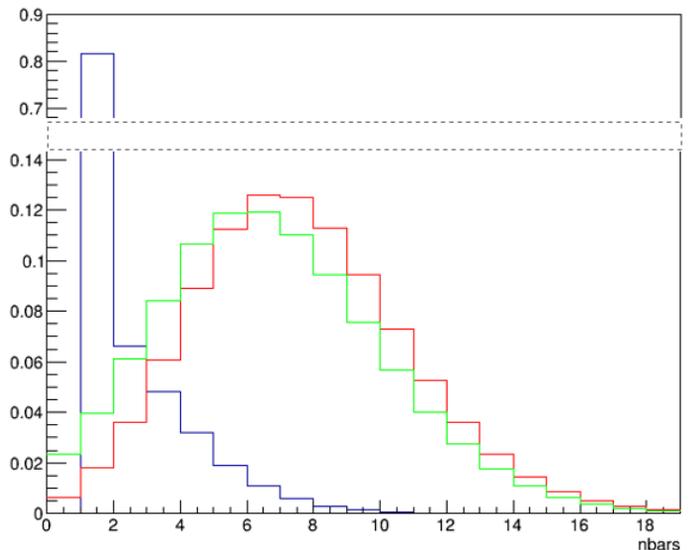


Figure 3: In blue, number of bars hit by gamma intrinsic background, in red the number of bars hit produced by neutrons from the veto simulation and in green the number of bars hit by neutrons from SiPM's

As we can observe in Figure (3), gammas produced

in neutron captures deposit energy in 6 bars in average for neutrons coming from SiPMs (7 for those coming from the veto). In the same figure, we also show the number of bars hit by the intrinsic gamma activity. This latter case shows a very different pattern with less than 12% of the cases touching more than two bars. Hence, two bars has been used as threshold and the inefficiency introduced by this cut, which is the number of neutron captures that leave energy in less than three bars, is of 6% (13%).

The time that the veto coincidence window is open a critical factor. Long windows assure that delayed signals are not ignore, but enhance of random coincidences and dead time due to uncorrelated background events.

The need to discriminate the neutron background radiation, by establishing coincidences between neutrons that interact in the TPC and then that are captured in the veto, determines how long it is necessary to keep the trigger window open.

In Figure 4 we represent the capture time of neutrons produced in the SiPMs. We have fitted two exponentials, one in the prompt region and one in its tail. We can noticed that the 97% of neutron captures are produced before 0.1 ms. The characteristic time associated to the neutron captures for the prompt captures is 10.8 us and and 150.6 us in the tail.

In Figure 5, we see the same the neutron capture time for neutrons simulated from the veto, where the 99% of captures are produced before 0.1 ms and the characteristic times for the prompt captures is 4.7 us and 151.2 us in the tail.

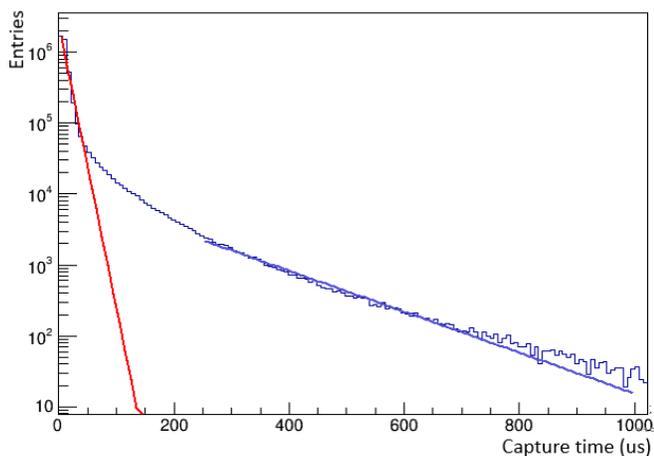


Figure 4: Neutron capture time from neutrons produced at the SiPMs.

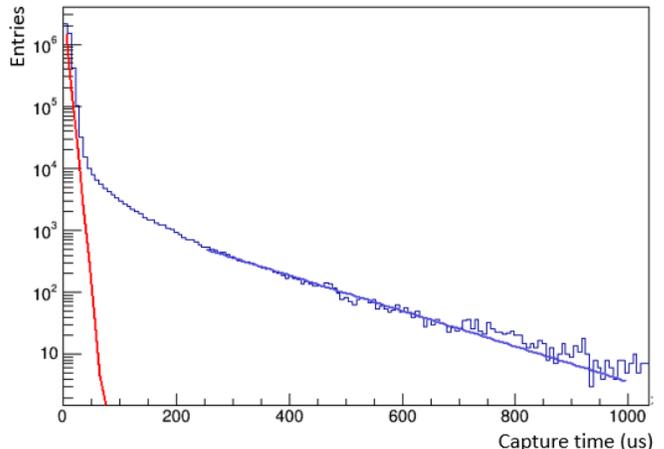


Figure 5: Neutron capture time from neutrons produced at the veto.

The most important feature that can be observed in figures 4 and 5 is that the 99% of the captures are captured before 0.1 ms for the case of neutrons simulated from the veto, and the 97% for those from the SiPMs.

These characteristic time values are not very important themselves, but they show us that the efficiency of the full system the is not impaired by a short veto window. This is a topic under study but acquisition time windows below 0.5 ms are only considered.

In order to test the relation between the inefficiency and proportion of the in the veto, we have carried out two different simulations changing the gadolinium mass fraction ($\frac{m_{Gd}}{m_{veto}}$), from the desing case of 0.006 to 0.003. We have to remember that, in the real geometry, Gd_2O_3 will be a film that wraps the plastic bars from the veto and in this veto-approach we are working with an homogeneous material that emulate the real gadolinium and acrylic proportions.

Table I: Neutron capture inefficiency

Inefficiency of neutron captures in Gd	Gd mass fraction = 0.003	Gd mass fraction = 0.006
Th232 from gdAc	2.2e-5	3,8e-5
Th232 from SiPM's	2,7e-4	2,1e-4
U238 from gdAc	3,4e-5	3,4e-5
U238 from SiPM's	2,4e-4	2,4e-4

According to the table I , practically no difference is appreciated in terms of neutron captures between the two configurations and it is not worth increasing the thickness of gadolinium film.

IV. FULLY IMPLEMENTED

Once we have proved the suitability of the design with the homogeneous veto approach, the detail geometry is coded in G4DS to study the case with more realism.

In the first place, we have studied again the number of bars where the gammas, that are produced in the neutron captures, have deposited energy. The average number of bars continues to be significantly higher than the case of the decay chains. Using the same threshold of number of bars, above 2, the inefficiency is 17% .

From the data analysis we can observe that the 77 % of neutrons are captured before 0.1ms, 98 % before 0.3 ms and 99% before 0.4 ms. Taking into account that the most of captures occurs in the first 0.4 ms, it would be reasonable to consider a time window acquisition of that order since it would not suppose a great loss in efficiency.

For the rest of this section we are going to study the inefficiency with the TPC cuts(produce a single nuclear recoils in a fiducial volume of 30 cm and that they deposit 7.5 keV to 50 keV).

In table II it is shown that 165 events pass all the cuts and not are captured in the veto out of 4 million neutrons. This 0.004% of the total neutrons produced are our irreducible background. We expect to have 4600 neutrons in the full exposure, that means that we will not be able to identify 0.16 neutrons in the veto. Studies in course in order to reduce this factor.

Out of the total production 40% that are not captured in the veto, are captured in the liquid Argon that is before the veto but is not instrumented, identify the materials where these neutrons are captured. Studying the effect of the materials in neutron capture interactions, we can implement some possible alternatives that improve the geometric efficiency of the experiment.

We have to bear in mind that for the 0.004% inefficiency we have not imposed any threshold energy for the veto be sensitive. Therefore the number of captures in the veto that we are able to detect can decrease and therefore increase the number of neutrons that constitute the background radiation and that we do not detect in the veto.

If we impose additional condition to the the threshold energy that we can detect in the veto. This implies 0.011% of inefficiency, 0.52 background neutrons that we could not detect for the full exposure of DarkSide-20k, this neutron background is above our goal, and is under study.

The geometric efficiency, the neutrons that are captured in the veto from the total neutrons produced, is 76.4% without taking into account the TPC cuts.

Table II: Inefficiency of DarkSide-20k segmented veto

	Number of neutrons	Number of neutrons that pass the TPC cuts
Total number of neutrons simulated	4e6	1490 (0.04% of the total number of neutrons)
Neutrons that are not captured in the veto	1e6 (33.6% of the total number of neutrons)	165 (0.004% of the total number of neutrons)

V. ALTERNATIVE VETO SIMULATIONS

We have done six veto simulations in which plastic scintillator and liquid argon are interspersed.

Three types of geometry have been simulated, varying the thickness of the layers. Each of them with two different scintillation plastics, an acrylic and with a borated plastic.

Neutrons are simulated with a homogeneous distribution of energies between 1 MeV and 10MeV from outside the TPC and in z-direction.

The main objective of this simulation is to compare the efficiency of the six simulations to determine if alternating plastic with liquid argon allows to thermalize neutrons better and improves the neutron capture efficiency.

The idea behind behind the simulation is that plastic is good in thermalization but neutron captures in plastic produce low energy gamma rays. Argon instead is not good thermalising neutrons but will emit 6 MeV gammas, better for tagging. For that reason, in this configuration, it is convenient that neutrons thermalize in the acrylic and would be captured in argon.

In the borated case, captures in the plastic will happen more often and this will release more energy. Both cases are compared for studying.

Table III: Geometric efficiency of the different veto configurations

Nº layers	Plastic (cm)	L.Ar (cm)		Captures in plastic	Captures in Liquid Argon	Neutron captures ratio in the veto
12	2,5	2,5	Bored plasitc	78%	3%	81%
12	2,5	2,5	Acrylic	30%	29%	59%
12	1	4	Bored plasitc	59%	5%	64%
12	1	4	Acrylic	8%	33%	41%
6	5	5	Bored plasitc	88%	3%	91%
6	5	5	Acrylic	32%	45%	76%

In the table III , we have summarized the geometric efficiency values obtained for three diferent veto configurations, each of them with acrylic and borated plastic. The veto from the fist simulation is composed by six layers of 2.5 cm thick from plastic and another six layers of 2.5 cm of LAr. We have done this simulation with acylic plastic and borated plastic. In the two following ones, we have changed the plastic thickness, from 2.5 cm to 1 cm, and LAr layers from 2.5 cm to 4 cm. Finally, the last veto geometry that we have simulated has three plastic layers and three LAr layers of 5 cm thick each one.

From table III we can extract that when we use a plastic doped with boron we increase the overall efficiency of captures in the veto. When we use conventional acrylic, neutron captures are distributed between liquid argon and plastic, whereas with the borated plastic most of the captures take place in the plastic. The best geometric configuration is the one that inserts 3 cm layers of borated plastic with 3 layers of 5 cm LAr, but it is required a larger quantity of plastic. The veto efficiency for this configuration is 91%.

From this simulation we can extract qualitative conclusions, but we cannot compare it directly with the previous simulations. This is a very preliminary study and we have simulated neutrons from different sources and different range of energies.

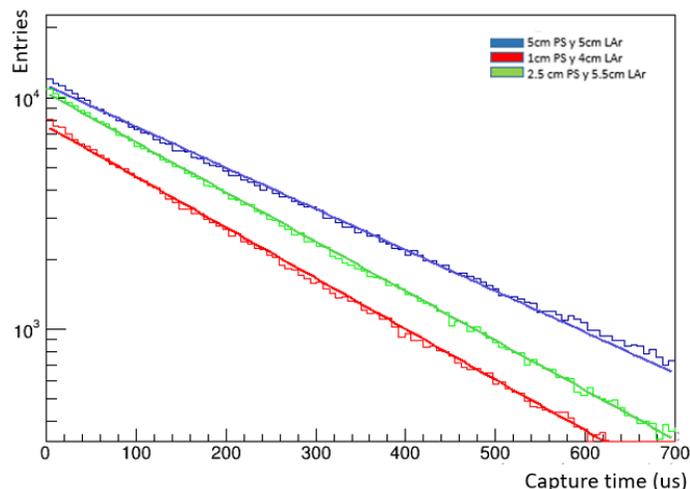


Figure 6: Neutron capture time in acrylic configuration.

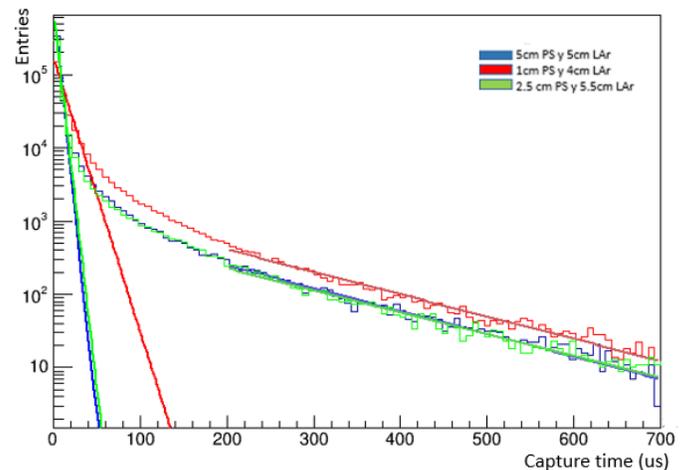


Figure 7: Neutron capture time in borated plastic configuration.

In figures 6 and 7, we can stand out that for the capture time distribution from borated plastic we have fitted two exponentials instead of only one, in the case of using acrylic. The difference may result of the domination of the borated plastic cross section on the argon cross section at high energy.

Table IV: Ratio of neutrons that are captured after 1 ms and before.

Plastic (cm)	L.Ar (cm)	Nº layers	Material	Ratio (t _{cap} >1ms/t _{cap} <1ms)
2,5	2,5	12	Bored Plastic	0,020
2,5	2,5	12	Acrylic	0,035
1	4	12	Bored Plastic	0,047
1	4	12	Acrylic	0,063
5	5	6	Bored Plastic	0,018
5	5	6	Acrylic	0,047

The ratio between the captures that occur before the first ms and those that occur later reveal that the most efficient configuration for the veto corresponds to the geometry with 5 cm thick each layer and borated plastic material IV. But the advantages of boron may not be so decisive if we consider that dissolving boron in plastic compromises the transparency of the material, increasing the attenuation of light, and it is more polluting and expensive.

VI. CONCLUSIONS

In this work we have studied the behavior of three veto configurations, focusing in the efficiency of different possible vetos by analyzing important features as the neutron capture time, the capability of neutron event discrimination, and the intrinsic activity of the veto.

First we prove, with a segmented veto approach, that a segmented veto is desirable since allows us to tagg neutrons efficiently and being able to reject the intrinsic background of the veto.

Then with de fully-segmented veto geometry implemented, we get an overall total inefficiency for neutrons of 0.004%. That corresponds to 0.16 background events

that we will not be able to identify during the full exposure of DarkSide-20k. There is work in progress to take this number down to the goal of 0.1 neutrons in the full exposure.

Alternative veto system has been studied differnt ways of reducing this background. It is a very preliminary study and results at this stage have to be understood as qualitative.

The veto design is still open and studies to improve the veto efficiency are in course, yet.

To conclude, this work belongs to an international collaboration project and has implied a coding and analysis challenge for the student.

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