Veto Design

Veto and Monte Carlo and Science working groups

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1 Conceptual design

The design of the Darkside veto is based on the concepts reported into the Report to the XLX LNGS Scientific Committee[1]. The veto detector is composed by three volumes as shown in figure 1 :

- an inner volume of active liquid atmospheric Argon (Inner Argon Buffer, IAB) surrounding the TPC;
- a passive shell of acrylic (PMMA) loaded with Gadolinium with octagonal shape (GdA) mounted around the TPC. The IAB is in between the TPC and GdA. The acrylic shell loaded with Gd surrounds the TPC in all the directions (lateral, top and bottom).
- an outer active volume of atmospheric Argon (Outer Argon Buffer, OAB)

IAB, GdA and OAB define a volume that should be optically insulated from the rest of the Argon external to OAB. A copper cage (Faraday cage) provides this optical insulation and, at the same time, it realizes the necessary electric shields.

The required thickness of both the IAB and OAB is 40 cm, with no performance penalty for a thickness increase. The required thickness of GdA is 10 cm. The mass fraction of Gd in the acrylic should be between 1% and 2% [2].

The TPC and GdA are shaped as polyedron with octagonal cross section. The apothem of the inner face of GdA octagon is 225 cm; the internal height of the GdA is 400 cm. Assuming a density of 1.18 g/cm^3 the mass of the acrylic loaded with Gadolinium is 11.7 tons.

Neutrons are moderated by collisions (mostly with Hydrogen) in the acrylic. The presence of Gd ensures the emission of multiple high energy γ-rays after the neutron capture. With Gd concentration between 1 and 2% by weight, capture of neutrons in Gd happens with about 54% probability and in Hydrogen with 24%. The remaining neutrons are caught in Argon with 16% probability and copper (8%). Note that the GdA acts as moderator and neutron capture agent and then there are not requests about its transparency to the scintillation light. γ-rays following the n capture interact in the IAB and OAB producing scintillation light that is detected by light sensors mounted on the two sides of

GdA and facing IAB and OAB. The required GdA thickness and Gd loading fraction, as well as the minimum required IAB and OAB thickness [3], result in a γ-rays detection efficiency of XX.

As shown in figures 1 and 2, IAB and OAB are divided into vertical sectors using thin acrylic panels. The sectorization has the purpouse of reducing the pile-up event rate due to the decay of ^{39}Ar and to obtain a sufficiently high photoelectron yield. Each side of the IAB and OAB volumes will be divided into 5 vertical sectors (the precise number of section is going to be optimized shortly). The thin walls of the sectors as well as the walls of the GdA and the external wall of the TPC and of the Faraday cage will be lined with a light reflector covered by the wavelength shifter TPB. The presence of the reflectors enhances the light collection and consequently the veto energy resolution, crucial to reject ^{39}Ar signals.

The vertical sectors are realized with acrylic sheet (as reference 4 mm thick) not loaded with Gd.

Sectors are not liquid tight and the proper Argon should flow should be ensured both during filling and re-circulation. Details are under study and possible ideas include the mounting of proper tubes and collectors on the top and bottom of each sectors.

The various sectors are thus in good approximation optically insulated.

A dedicated mechanical structure, realized with Stainless Steel, must be designed to hold the GdA, the panels, the light sensors and to handle the routing of cables and/or optical fibers.

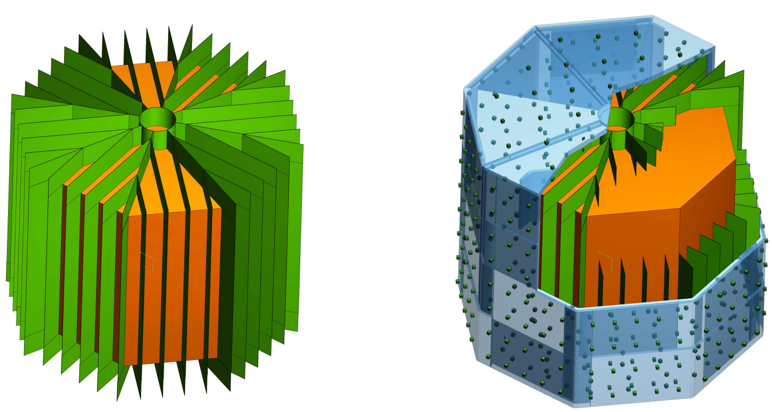

Figure 1: Views of the veto detector: in orange the external walls of the TPC, in green the acrylic panels of the IAB and in light blues the the GdA with the SiPm tile. The left plot only shows the TPC and the IAB, while the right plot also shows the GdA. The number of designed SiPm is only for pictorial view.

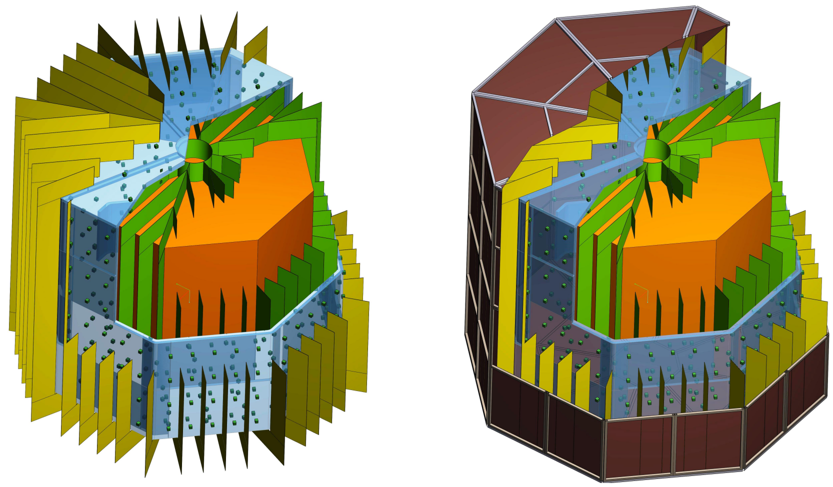

Figure 2: Views of the veto detector: in orange the external walls of the TPC, in green the acrylic panels of the IAB, in light blues the the GdA with the SiPm tile and in yellow the panels of the OAB. The left plot only shows the TPC, the IAB, the GdA and the OAB while the right plot also shows the Faraday cage. The number of SiPm is only for pictorial view.

2 Energy threshold and photoelectron yield

The combined signal of the IAB and OAB will be used to tag and reject neutron captures. A detection energy threshold of 800 KeV should be set for each of the two detectors in order to minimize dead time losses due to β-decay from ^{39}Ar in the veto filled with AAr. A lower energy threshold, 100 KeV, is set for events triggering a coincidence of the IAB and OAB detectors.

Preliminary optical simulation indicates that the photoelectron yield can reach 1 phe/KeV assuming a 10 m as light absorption length in Argon and 0.98 specular reflection efficiency of the TPB. The corresponding energy resolution is 10% at 300 keV. Thanks to the good energy resolution, the probability for a ^{39}Ar to be reconstructed as an event of energy greater than 700 keV is lower than $2 \cdot 10^{-9}$. Moreover the rate of ^{39}Ar pile-up events exceeding 800 keV in a single sector is 0.07 Hz [4]

3 Light sensors and readout

The wavelength shifted Argon scintillation light is detected using the same SiPm developed for the LAr TPC and arranged in tiles with the same size as the ones of the TPC. We will use 3000 tiles mounted on both side of the vertical wall and on the top and bottom of the GdA acrylic. Their position is still under optimisation.

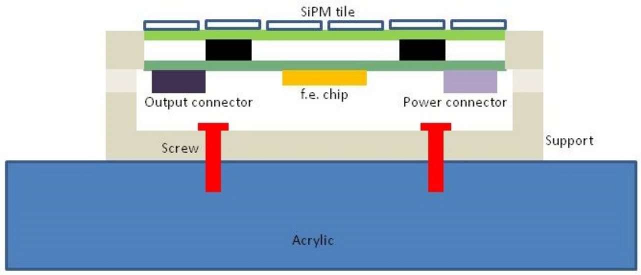

Figure 3: VPDM assembly scketch.

The baseline option for the front end readout is the use of the integrated cryogenic electronics, that is currently an R&D of the PE working group of DS20K [5]. This chip allows the same functionalities of the TPC front end circuit while exploiting more compactness and lower power dissipation.

The electronic board hosting the front–end chip will be connected to the SiPM tile on its back side parallel to it. In this board we also implement the electro–optical conversion of the analog output signal. The use of optical fibers and a signal transmission like the one of the TPC is the most promising solution and we consider it as the baseline option. It has to be assumed that there will be some mechanical support structure (still to be defined) that holds this assembly, permits the mounting in the correct place on the acrylic and performs the cable routing. This assembly (tile + front–end + support) will be called Veto Photo Detector Module (VPDM). In figure 3 a preliminary conceptual sketch is represented.

Each VPDM (≈ 3000 in total) will be screwed individually to the acrylic in the designated places. We foresee to use 4 threaded small holes (tentatively 1 cm deep M4) to permit the correct positioning over the sensitive area.

An additional module is needed to distribute power and bias voltage to the VPDMs. We foresee to have in the cryogenic environment a dedicated version of the Steering Module already developed for the TPC detector. This module (called Veto Steering Module, or VSM) has the following functionalities:

- It receives the power (low voltages) for the electronics and bias (high voltage) for the SiPMs.
- It receives dedicated control signals (tentatively 2 wires). These signals will be active only during the system configuration.
- It routes the power and bias voltage to a set of VPDMs permitting to switch them on and off individually by means of the control signals.

We will manage 15–30 VPDMs with one VSM. The SiPM tiles will be selected/binned to have minimum breakdown voltage dispersion so only one bias voltage will be needed to power all the SiPM managed by a VSM.

The VSM will be screwed to the acrylic by means of 4 threaded small holes in the same way of the VPDM.

Routing of the cables has to be studied. Some additional holes will be needed on the acrylic to hold ducts and cable holders.

4 Calibration and service interfaces

We assume that most of the TPC and calibration services require holes on the top of the GdA acrylic. Possible service holes on the bottom may be needed to drain the Ar.

Changes of the light attenuation length in each sector could be monitored by sending in each sector external light through optical fibers placed in convenient positions. Details are under investigations.

5 Veto material radio-purity requests

The main goal of the Veto is to tag and reject neutrons mainly (but not only) originated from (α,n) reactions, where the α particle comes from a decay of some radioactive contaminant of the construction materials. The rejection of neutrons is obtained by a combination of cuts applied to the TPC and Veto signals occurring in coincidence within a time window of 2 msec. The TPC cuts are designed to tag events with multiple neutron interactions in the undergroung Argon. The veto cuts remove events where neutron-induced signals either in the IAB or in the OAB or in both are detected within 2 ms after LAr TPC trigger. The design goal is to get less than 0.1 undetected neutrons in 100 t $\cdot$ year exposure. The radio-purity limits of the veto materials are fixed by requiring that, after the analysis cuts, the contribution of the Veto to the final untagged neutron background must not exceed the one originated by the TPC materials. Monte Carlo studies show that the fraction of neutrons generated by radioactive contaminants of the Veto itself and not tagged by the combined cuts (inefficiency) is $2.3 \cdot 10^{-6}$.

In the actual design the only materials present in the Veto are the acrylic loaded with Gd, the pure acrylic of the panels, the SiPm with their cryogenic readout and related cables or fibers, the reflector foils covered by TPB, the stainless steel mechanical support structure (to be designed) and the external copper Faraday cage. Table 1 summarizes the information about the veto induced neutron background. The number of calculated neutrons assume secular equilibrium in the ^{238}U and ^{232}Th decay chains.

As it results from table 1, the number of wimp-like events induced by the veto building materials and the veto light sensors with their readout is expected to be $4.8 \cdot 10^{-3}$ n bg/(100 t year). The veto induced background is thus negligible with respect to other background sources [8] as the total number of expected untagged neutrons events originated by all the materials, TPC and Veto, is 0.11 n/(100 t year). With these number in minds there is still a safety factor of

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Material	Mass	^{238}U	^{232}Th	n/(100 t y)	n back/100 t y
	Kg	mBq/Kg	mBq/Kq		
Acrylic shell	11700	$1.2 \cdot 10^{-2}$	$4.1 \cdot 10^{-3}$	38	$8.6 \cdot 10^{-5}$
Acrylic panels	1116	$1.2 \cdot 10^{-2}$	$4.1 \cdot 10^{-3}$	4	$9.2 \cdot 10^{-6}$
$Gd_2(SO_4)_3$	459	7	0.2	185^a	$4.3 \cdot 10^{-4}$
$Gd_2(SO_4)_3$	459	7	0.2	577^b	$1.3 \cdot 10^{-3}$
Veto SiPm	3000 tiles			806	$1.9 \cdot 10^{-3}$
Reflector	100	1.6	0.9	56	$1.3 \cdot 10^{-4}$
Stainless Steel	1170	2.4	0.8	396	$9.1 \cdot 10^{-4}$
Total				2062	$4.8 \cdot 10^{-3}$

Table 1: Neutron background induced by the veto material. We assume a combined cut inefficiency of $2.3 \cdot 10^{-6}$. Data adapted from [8]. The mass fraction of Gd in the acrylic is 2% corresponding to 4% of Gd sulfide. a) refers to neutrons generated by αn reaction in the Gd sulfide and b) in the acrylic with the α coming from the contaminants of the Gd sulfide. The mass of the support structure is evaluated as 10% of the mass of the acrylic. 1 ppt $\simeq$ 1.2 10^{-2} mBq/Kg for ^{238}U and 1 ppt = 4.1 10^{-3} for ^{232}Th.

about 10, that is we can tolerate a factor 10 more neutrons generated by the Veto materials and still satisfy the DS20K design goal.

5.1 Surface contamination

Surface contamination due to plate-out of Radon progeny on the surfaces should not be neglected. Radon is present in the outdoor air with a concentration of few to 10 Bq/m^3 and inside buildings and in underground laboratories the concentration is typically higher (up to 120-150 Bq/m^3). ^{210}Pb atoms accumulate on every surface of materials exposed to air and then, they decay to ^{210}Bi that thus produce ^{210}Po. This is the potentially dangerous isotope because the α originated in its decay could produce neutrons.

We estimate the number of ^{210}Pb adsorbed on a acrylic surface using the data measured in [12] for polyethylene exposed to the SNOLAB air. The typical rate of ^{210}Pb deposition on a surface is $R_{Pb} \simeq$ 200-250 10^4 atoms/(m^2 day). The number of adsorbed ^{210}Pb atoms increases linearly with the time T_{air} during which the sample stays exposed to air and with its surface.

The number N_α of α produced by the decay of ^{210}Po (generated by ^{210}Pb) during the data taking time of DS20K, T_{DS} = 5 years, is estimated as $N_\alpha = S_{tot} R_{Pb} T_{air} \frac{T_{DS}}{\tau_{Pb}}$ where S_{tot} is the total surface of the acrylic. Half of the time the α goes into the acrylic eventually making a neutron. Referring to the actual design, the surface of the GdA is 406.4 m^2, the one of the panels of the IAB is 204 m^2 and that of the panels of the OAB is 269 m^2. This is giving S_{tot}= 879.4 m^2. Using the yield of (αn) from [8] of 1.2 10^{-7} n/α we get about 30 $\cdot T_{air}[d]$

neutrons.

Similarly we can estimate [13] the amount of deposited ^{210}Pb knowing the Rn concentration in air and assuming that all the atoms of ^{210}Pb produced within an effective height (plate out height) above the sample are adsorbed. Using a plate out height of the order of 1 m and a radon activity of few tens Bq/m^3 we get results consistent with the previous ones.

These estimations are approximated because the deposition rate can vary according to the status of the surface and of the environmental conditions: the message is that we may expect few tens of neutrons for every day during which the entire surface of the veto acrylic stays exposed to air. Care must be taken to limit the exposition to air during the transportation, handling and mounting of the acrylic.

6 Comments and backup solution

This design promises to achieve the full compliance with the criterion of allowing no instrumental background interference to the nuclear recoil signal. Also, it is mostly based on elements which require no R&D and therefore can be built out of materials already available. However a critical element is the availability of clean panels of GdA. Despite the technical feasibility of loading Gd in acrylic was successfully demonstrated in small samples [10], having a massive production of panels of GdA satisfying the radio-purity levels of table 1 requires a dedicated industrial facility. A meeting will be held in China at the end of February with the Donchamp Acrylic Co. company (the same that produces the acrylic for the JUNO experiment) to clarify the feasibility of the Gd loading while preserving the radiopurity of the compound. This is the company producing acrylic with the radio-purity specifications of table 1.

In case of negative answer, the backup solution under study consists in replacing the uniformly GdA with a sandwich of clean PMMA panels (1 cm in thickness) coupled to foils with 100 μm of Gd Oxide, for a total acrylic-Gd sandwich of about 10 cm. Preliminary simulations suggest that this option does not affect significantly the veto performances. Safety requirements demand for a proper sealing of Gd acrylic sandwich. Sealing with technologies available from MITEC company has been investigated [11]. They can cover materials with a thin (few μm) of plastic ensuring the tightness. This solution is in principle possible but in practice it is extremely difficult because the company can only seal pieces of very small size (size of a A4 foil) of material and then we will need to build the Veto holding too many small pieces.

The solution under considerations requires to machine the 1 cm thick acrylic plates with a thin groove extending over all the surface of the panel, on both sides, leaving a border along the four edges. This groove provides a site to allocate the Gd foil. Two panels should then glued together around the border under nitrogen flux. This in principle ensures the Gd sealing.

Finally, it has to be noted that the design concept is scalable and lends well to serve as the base for the future Argo detector.

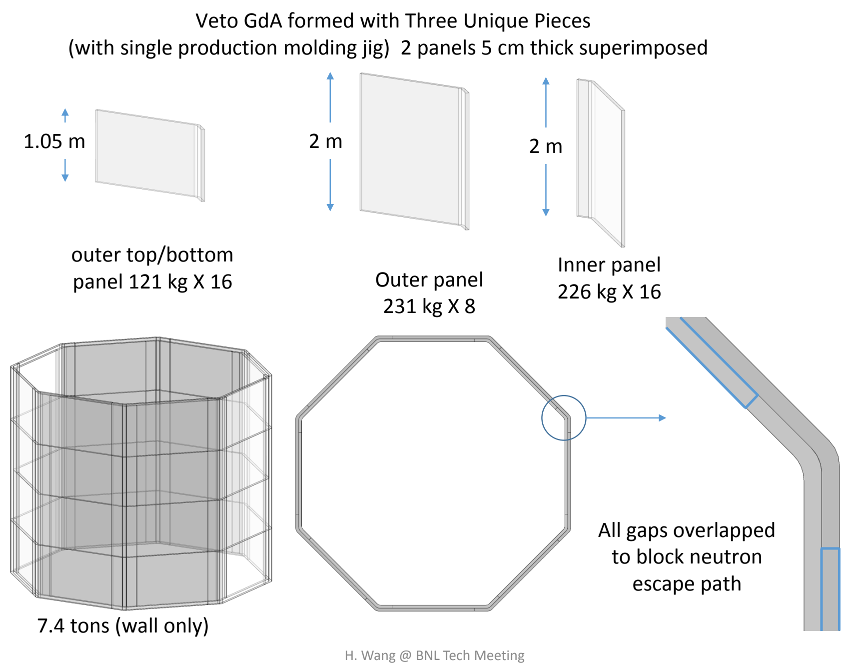

Figure 4: Preliminary design of the panels of acrylic loaded with Gd. These drawings should be considered as a starting point for a discussion. Detailed drawings will be provided later.

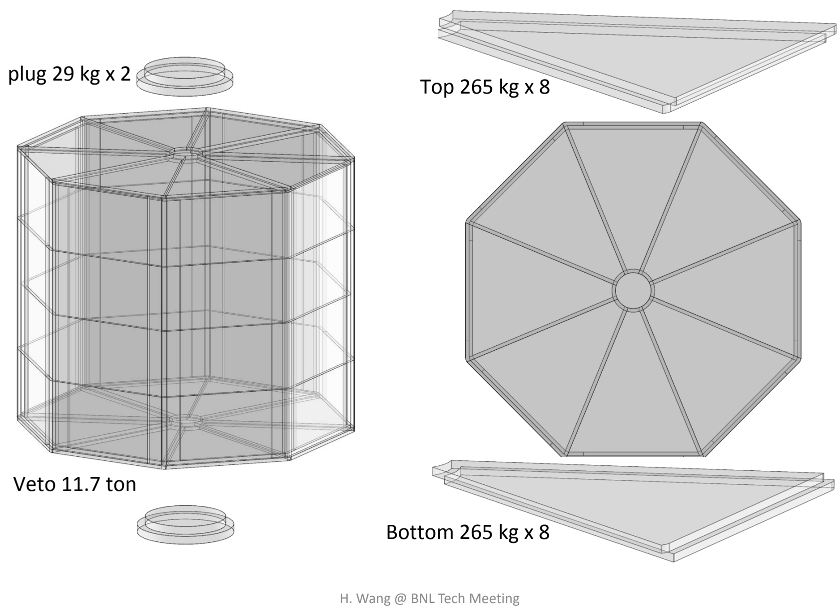

Figure 5: Preliminary design of the panels of acrylic loaded with Gd. These drwaings should be considered as a starting point for a discussion. Detailed drawings will be provided later.

7 Veto Acrylic specifications

- DS20K needs acrylic loaded with gadolinium for the construction of the Veto. Gd must be loaded uniformly in the acrylic with a concentration of at least 1% in weight and not more than 2%. The preferred Gd compound to be used is $Gd_2(SO_4)_3$ whose radio-purity has been measured to be 0.6 ppb in ^{238}U (and smaller ^{232}Th). Others compounds can be considered. Small scale tests have been performed by DS20K using also $GdCl_3$ and $Gd(NO)_3$ [10].
- The Gd loaded acrylic does not need to be transparent to light.
- The choice of the company delivering the Gd compound should be done in collaboration with DS20K. DS20K will perform radiopurity tests on samples to identify the producer and then it will repeat the tests on samples of the final batch.
- DS20K has special requirements about the radiopurity of the acrylic loaded with Gd. With 1 ppt in ^{238}U and ^{232}Th as bulk contamination of the acrylic, the contribution of the acrylic itself to the overall neutron yield negligible with respect to the one expected from Gd-impurities. These values are consistent with the ones measured by the Juno group [9] for samples of acrylic produced by Donchamp. 10 ppt in ^{238}U and ^{232}Th is still acceptable as the contribution of the acrylic and the Gd are comparable.
- Mixing of Gd and acrylic should happen without introducing significant additional radioactive contaminants other than the ones contained in the PMMA and the Gd compound. The final contamination of the acrylic mixed with Gd should not exceed 20 ppt of ^{238}U and 20 ppt of ^{232}Th.
- Samples of acrylic produced using the same procedure of the entire DS20K production should be made available for radiopurity measurements that will be performed by DS20K.
- DS20K also needs panels of pure acrylic (without Gd loading) for the construction of the sectors of the veto. The bulk contamination in ^{238}U and ^{232}Th should be less than 10 ppt. Their thickness will probably be 4 mm, their size and number will be specified.
- DS20K will furnish to Donchamp the mechanical drawings of the acrylic panels (with and without Gd laoding) including holes necessary for their installation and for the mounting of the light sensors. Examples of dimensions (useful for discussion, final drawings will be provided) are in figure 4 and 5.
- Donchamp should document the entire procedure adopted to produce the pure acrylic and the Gd loaded acrylic starting from the procurement,

transportation and handling of the raw materials. This is necessary to predict the possible sources of radioactive contamination.

- Exposure of all the panels and of the raw materials used to cast the acrylic to normal air which contains Radon must be avoided or reduced at minimum. The casting of the pure acrylic and the production of the acrylic mixed with Gd must be performed in a clean room with air filtering to reduce the Radon contamination below XX.

  After fabrication in the Radon controlled environment the acrylic panels (with or without Gd) must be sealed and shipped using two layers of a foil with low Rn permeability (say which material). The first layer will be removed by DS20K people directly before entering a clean room, the second layer is removed inside the clean room.

References

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