PROCEEDINGS OF SCIENCE

The COSINUS Underground Cryogenic Facility

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Cryogenic Observatory for SIgnatures seen in Next-generation Underground Searches (COSINUS) will use cryogenic sodium iodide (NaI) calorimeters to search for dark matter. Recently, the construction of an underground facility at Laboratori Nazionali del Gran Sasso (LNGS) for COSINUS has been completed. The features of the COSINUS facility allow for a low background environment for rare event searches. This facility will house a dry dilution refrigerator, which will sit in a drywell inside a water tank. The water tank will be instrumented with photomultiplier tubes and serve as an active muon veto as well as a passive shield.

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1. Introduction

The Cryogenic Observatory for SIgnatures seen in Next-generation Underground Searches (COSINUS) experiment is a direct-detection dark matter experiment using cryogenic sodium iodide (NaI) as an absorber material [1]. The NaI will be mounted inside a dry dilution refrigerator held at $O(10\,\mathrm{mK})$. Both the thermal and light signals from particle interactions in the NaI are measured with a transition edge sensor (TES). With both the thermal and light signals, nuclear recoils on the NaI can be distinguished and measured. The dual-channel operation of NaI detectors has been demonstrated in an underground cryostat [2]. The scintillation light produced by the NaI is absorbed by a silicon beaker around the crystal. The temperature change from the beaker absorbing the light is read out with a TES.

Since NaI is hygroscopic, soft, and has a low melting point, the usual method of depositing a TES directly onto the crystal is challenging. A TES deposited on a sapphire wafer and linked to the absorber with gold wire, which is referred to as a "remoTES," [3] is used to measure the thermal signal of particle interactions [4]. The COSINUS initial run will have eight modules with a 2.1 cm by 2.1 cm by 2.1 cm cube of NaI each glued to a silicon lid, for a total of 272 g.

2. Shielding

COSINUS requires a low background to distinguish any potential rare events which could be contributed to dark matter signals [5]. To achieve this, a specialized facility has been built at Laboratori Nazionali del Gran Sasso (LNGS) under the Gran Sasso mountains. A drawing of the facility is seen in figure 1. The most dangerous backgrounds are neutrons or other particles that could mimic a dark matter nuclear recoil signal, which can come from muons. The rock of the overhead mountain provides muon shielding of 3600 meter water equivalent [6].

To further reduce backgrounds, extra shielding is installed at the facility. Inside the drywell (described below) is 8 cm of copper shielding surrounding the detectors. Surrounding the drywell is a 7 m tall by 7 m diameter cylindrical water tank made out of stainless steel. The water tank is outlined in red on the right side of figure 1. It will be filled with purified water and instrumented with 28 photomultiplier tubes (PMTs) on the wall and on the floor. These PMTs will collect Cherenkov light from muons and let the water tank serve as an active muon veto. Layers of Tyvek on the sides and bottom of the inside of the tank will serve as a reflector for the active muon veto and to delineate the uninstrumented dead layer of water. Without the active veto, the simulated cosmogenic neutron rate is $3.5 \pm 0.7\ \frac{\text{counts}}{\text{kg}\times\text{year}}$ [8]. This rate is reduced to under a count per year with the active veto. An upcoming publication will detail the simulation work done to optimize the number and location of the PMTs, the size of the dead layer, and the triggering conditions of the PMTs [7].

Magnetic fields are a further concern for the facility. Magnetic fields transverse to the direction of the bias current shift the operation point of TESs and make them less sensitive. To compensate for magnetic fields such as the ambient field from the Earth, active magnetic compensation coils will be placed around the detectors around the drywell. The optimal location and number of coils is under investigation.

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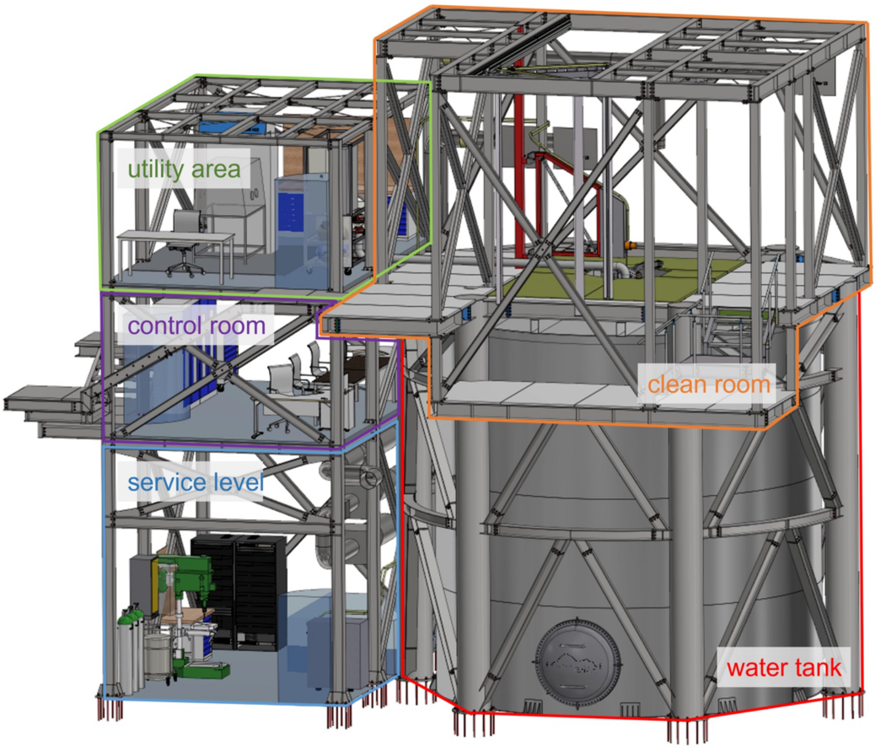


Figure 1: A CAD drawing of the experimental facility. The refrigerator will be inside the water tank that is outlined in red. The region above the water tank outlined in orange is the ISO 6 level clean room. This is where the cryostat will be moved to when the detectors are installed into the cryostat.

3. Facility Features

TESs are very sensitive to vibrations. To prevent any outside vibrations from propagating into the instrumented volume, two separate frames support the setup. The yellow frame, as seen in figure 2, is inside the outer blue frame, but the two frames do not touch. Sensitive cryogenic equipment is fixed to the inner yellow frame. An additional decoupling system will be built into the cryostat, which is described below.

The drywell is a stainless steel cylinder that comes down from the top of the water tank. A picture of the drywell from inside the water tank is shown in figure 3a. The cryostat with the detectors will be lowered into the drywell so that the detectors will be surrounded by the water inside the water tank without getting the outside of the cryostat wet. This is shown in figure 3b, where the yellow frame can also be seen.

The lifting system is custom made to move the cryostat in and out of the drywell. It consists of a triangular truss with three threaded spindle rods in each corner. A lifting frame is suspended on the threaded spindle rods. On the top, a chain and gear system turns all three rods, which raises or lowers the frame. The truss is suspended on rails and can be pushed across the entire clean room. This means that the cryostat can be taken out of the drywell and to a maintenance bay at the side of the clean room. A mini-drywell is planned in the maintenance bay of the cryostat so that it can be placed at a convenient height for mounting detectors. The lifting system and an outside view of the

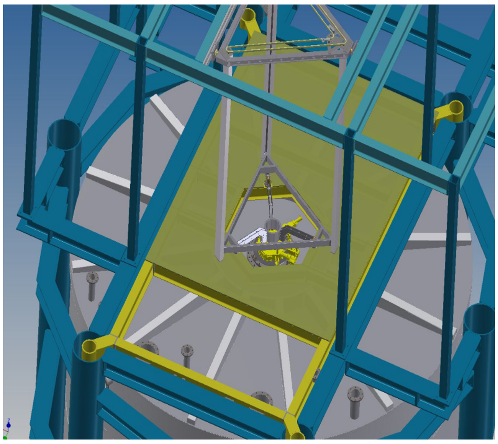
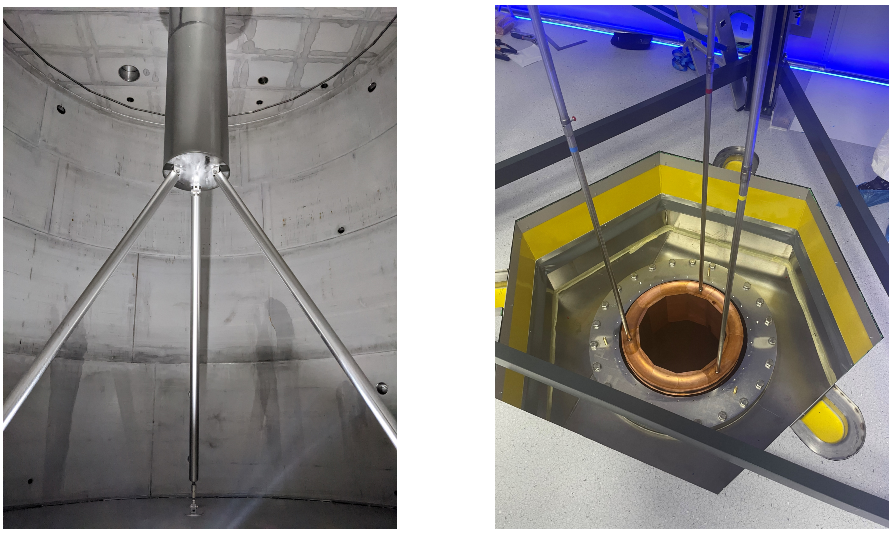


Figure 2: A rendering of the two frames of the experiment as seen from above. The two frames (in blue and yellow) are decoupled, while the water tank is shown in grey.



(a) **(b)**

Figure 3: The drywell from the water tank **a** and from the clean room **b**. The lifting system is seen in **b** being used to install the copper shielding.

clean room can be seen in figure 4a and figure 4b respectively.

The cryostat is a dry dilution refrigerator from Cryoconcept using their "ultra-quiet technology [9]." The total length of the cryostat is 3.5 m. Inside the cryostat, there is 30 cm of copper shielding above the first detector box. Initially, one copper box with eight modules will be installed at the bottom of the cryostat, but plans and space are there for two additional boxes to be installed after first round of data taking. Initial data taking will occupy 16 of the planned 48 superconducting quantum interference devices (SQUIDs), with two SQUIDs used for each module. The detector boxes will hang off of the cryostat from a decoupling system, which is planned to be three modules consisting each of a spring, a damping module, and a Kevlar wire.

The support building is seen on the left side of figure 1, where the utility area, outlined in green,

(a) **(b)**

Figure 4: The lifting system in the maintenance bay inside the clean room **a** and the clean room as seen from outside **b**. The lifting frame is the metal piece in the middle of the painted truss seen in **a**. The lifting system can be seen in the background in **b**. Inside the windows the maintenance bay can be seen.

can be seen on the top. Glove boxes and work tables for final assembly and repairing of detector modules will be in this room. The gas handling system and the vacuum pumps for the cryostat will be on this floor. Vacuum tubing and gas injection lines will run from the utility area to the cryostat in the clean room through holes in the wall. To reduce the transmission of vibrations through the pumping line, sand in a box will surround the pipes.

Below the utility room is the control room. It will have computers for data acquisition and storage. Office space for people on shift will be at this level. The slow control computers will be there so that the status of the experiment can easily be checked on. These slow controls will include parameters such as the cryostat's temperature, the status of any pumps and compressors, and current status of data taking.

The bottom floor is the service room. There is where deliveries for the experiment will be received and replacement parts for the lifting system will be stored. The compressor needed for the pulse tube of the cryostat as well as the clean room ventilation system will be located here. Some basic machining tools will be located here.

4. Conclusion

As of August 2023, the civil construction of COSINUS facility has been completed. The clean room ventilation is functional, the facility has electricity, and the lifting system is installed. The PMTs for the active muon veto have been delivered and will be tested in the coming months. The delivery, installation, and commissioning of the dry dilution refrigerator is planned for December 2023. The inauguration of COSINUS is planned for April 2024 and first data taking will commence after.

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