Counting Facilities at the Black Hills Underground Campus

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Abstract. The Black Hills Underground Campus (BHUC) houses a low background counting facility on the 4850' level of the Sanford Underground Research Facility (SURF) with ∼4300 m w.e. of rock overburden. Currently there are five ultra-low-background, high-purity germanium detectors operating inside of a class-1,000 cleanroom at the Davis Campus, with a sixth anticipated to be installed within a year. A robust nitrogen purge system and on-site personnel assistance allow these detectors to run continuously to support groups that need low background counting of materials.

INTRODUCTION

Rare event searches, such as the LUX-ZEPLIN (LZ) dark matter search or the Majorana Demonstrator (MJD) neutrinoless double beta decay experiment, are located deep underground to reduce the backgrounds caused by cosmic-ray muons [1, 2]. The remaining backgrounds that dominate deep underground are emitted by the detector's material. As a result it is necessary to ensure that the components and materials that go into the construction of these experiments are measured so that their contributions to the radioactive backgrounds are understood.

The Black Hills Underground Campus (BHUC) has been performing low background screening at the Sanford Underground Research Facility (SURF) since 2016. Several High Purity Germanium (HPGe) counters have been operating at two facilities, referred to as the Davis Campus and the Ross Campus, located 4850' underground at SURF [3]. The BHUC at the Ross Campus contained 55 m^2 of class-1,000 cleanroom space dedicated to low background counting, in addition to an automatic liquid-nitrogen-fill system and boiloff-nitrogen purge for the detectors. This cleanroom is located in close proximity to the site of the Long-Baseline Neutrino Facility (LBNF), where 800,000 tons of rock are being excavated to make room to house the Deep Underground Neutrino Experiment (DUNE) [4]. As a result, this facility has been mothballed for the duration of the excavation, with the cleanroom sealed up and the cavern it is housed in walled off to protect and isolate it from the ongoing blasting operations, with operations expected to resume in FY2024. While the Ross Campus location is unavailable, the detectors were relocated across the level to a cleanroom at the Davis Campus, where the MJD and LZ experiments operate. Plans are currently being developed to relocate the detectors back to the original BHUC located at the Ross Campus while minimizing downtime as the equipment and shielding is moved.

COUNTING AT THE BHUC

The first samples were processed by the BHUC in 2016 while operating at the Ross Campus, with 32 samples counted in that inaugural year. The BHUC averaged about 73 samples a year from 2017-2019, primarily supporting the construction of the LZ detector at SURF [2]. Notable samples counted as part of this effort include the 3" PMTs used in the xenon TPC, shown in figure 1, as well as titanium samples used to select the material used in the construction of the TPC cryostats. As part of this campaign samples were cross calibrated with detectors at the BHUC as well as with detectors located at the Boulby Underground Germanium Suite (BUGS), Lawrence Berkeley National Laboratory (LBNL), and the University of Alabama.

Calibrations of the detectors at the BHUC are performed using a supply of Table Mountain Latite, or TML. This crushed rock has been well characterized for its concentration of U/Th/K, and can be used to fill various geometries that are commonly used for samples. Once a dataset has been taken with the TML geometry, any new samples using the same geometry can have their U/Th/K contents quickly analyzed by comparing the ratio of peaks to the TML data, which produces good results with any systematic effects from the detector canceling out [5]. This method also eliminates any issues that may arise with incomplete or inaccurate simulations, although it is limited to sample geometries that can be mimicked by a volume of TML, while also providing good energy calibration at a wide range of commonly measured peaks.

FIGURE 1. Left: Four PMTs for the LUX-ZEPLIN experiment installed in a frame for counting. Right: The PMTs installed in one of the low background counters at the BHUC

THE MOVE TO THE NEWBHUC

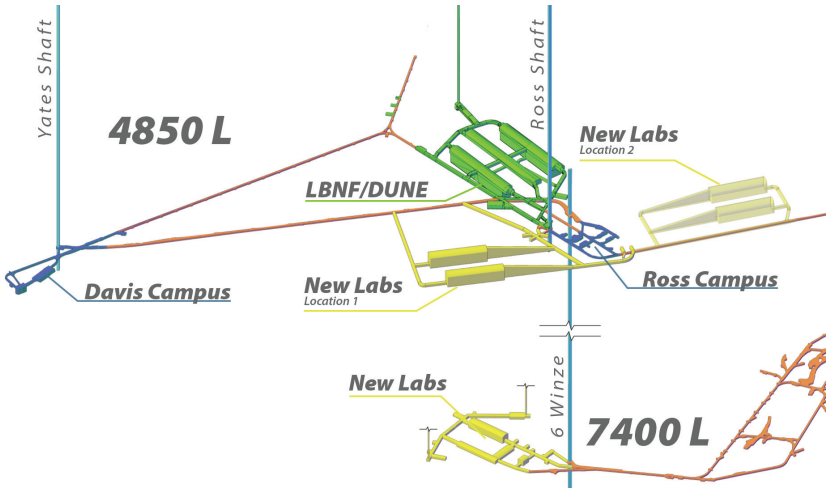

FIGURE 2. The underground layout of SURF. BHUC counters are currently located on the 4850L at the Davis Campus, and were moved from the Ross Campus in 2020, with both locations shown in blue. Also shown are the caverns being excavated for LBNF/DUNE in green, and potential future cavern locations in yellow.

In the meantime, the newBHUC facility was commissioned to allow continued low background counting at SURF during the LBNF excavation. Figure 2 shows the 4850' level at SURF, and the relative locations of the Ross and Davis Campuses. The newBHUC facility is located in the Machine Shop at the Davis Campus that was used to produce parts for the Majorana Demonstrator experiment. Approximately 41 m^2 of space was freed up to make room for detectors, with nearly 3000 lead bricks moved by rail in the process, with support from SURF personnel aiding the move. The Maeve, Morgan, Mordred, Ge-IV, and Twins detectors were also transported, with the SOLO detector being relocated to a surface facility at Black Hills State University. Removed from the SOLO lead stack was an inner layer of 19th century low activity "German" Pb bricks. These bricks were then incorporated into a new shield design for the Morgan detector. In addition to the lead shields, all detectors at the BHUC feature an inner copper layer forming a box around the crystal, which is then purged with boiloff nitrogen to shield from ambient radon. The detectors that were moved to

the newBHUC were also upgraded with Ortec Möbius recycling cooling systems, which only require additional liquid nitrogen fills approximately once every two years [6]. This upgrade eliminated the need for a new liquid-nitrogen distribution system at the temporary location. Figure 3 shows the layout of this facility shortly after the majority of the detectors finished commissioning. A scale and 180-l dewar of liquid nitrogen is present in this picture. This setup was used initially to provide liquid for the initial cooldowns of the detectors, as well as providing boiloff nitrogen gas for radon purges for the detectors. This setup was not ideal, as the dewars are staged and filled in dirty areas of the lab, resulting in the need for extra cleaning as well as bagging before they can be brought into the cleanroom. In 2021 additional scales were installed in the drift outside the clean space, with tubing run into the cleanroom. This setup both allowed for a second 180-l dewar without causing an increased oxygen deficiency hazard, while also eliminating the need to regularly clean dewars for cleanroom use.

CURRENT AND FUTURE BHUC USE

Background data-taking and calibrations resumed in early 2021 after the detectors returned with their upgraded coolers and were installed in the relocated shields, with the first samples for counting following shortly on the Morgan detector, and with Maeve and Mordred following in the coming months. The two dual-crystal detectors (the "Twins" and RHYM+RESN) underwent final commissioning and initial background data in the early part of 2022 and are expected to start counting samples in a production mode shortly. Cross-calibration samples have also started to be counted, in order to compare against other low background counting facilities from around the world. Table I details the counters that are currently being operated or installed at the newBHUC facility.

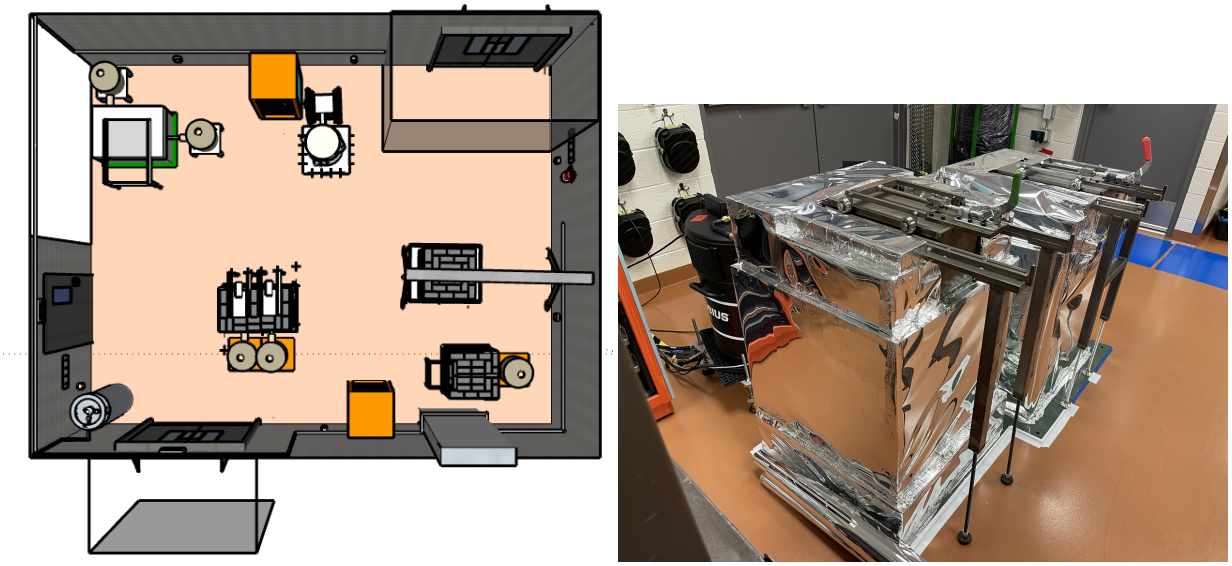

FIGURE 3. Left: An overhead view of the newBHUC layout. Clockwise from top left are the Twins, RHYME & RESN, Ge-IV, Mordred, Morgan, and Maeve. Right: Maeve and Morgan located in the newBHUC.

SUMMARY

The BHUC has successfully relocated during the excavation of the caverns that will house DUNE. It continues to provide reliable and readily-available low background counting with ∼4300 m w.e. of rock overburden and quick turnaround times. There are currently three detectors taking production data, two additional dual-crystal detectors operating, and a fifth detector should be installed shortly. Plans to return to the original cleanroom with room for the addition of new detectors in the 2024 fiscal year are being developed.

TABLE I. Low-background counter sensitivities for a sample of order ∼1 kg and counting for approximately two weeks; see also [2]. "Davis" and "Ross" indicate the respective 4850L campus of installation. Cooling systems for most detectors were upgraded in 2020 to reduce liquid nitrogen use and associated oxygen deficiency hazards. Table from [4].

Detector (Group)	**Ge Crystal**	**[U] mBq/kg**	**[Th] mBq/kg**	**Install Date**	**Status/ Comment**
Maeve (LBNL)	2.2 kg, p-type (ε=85%)	0.1 (10 ppt)	0.1 (25 ppt)	Davis: Nov 2020 Ross: Nov 2015 Davis: May 2014	Production assays. Relocated from Oroville, old Pb inner shield.
Morgan (LBNL)	2.1 kg, p-type (ε=85%)	0.2 (20 ppt)	0.2 (50 ppt)	Davis: Nov 2020 Ross: Nov 2015 Davis: May 2015	Production assays.
Mordred (USD/CUBED, LBNL)	1.3 kg, n-type (ε=60%)	0.7 (60 ppt)	0.7 (175 ppt)	Davis: Nov 2020 Ross: Jul 2016 Davis: Apr 2013	Production assays. Shield access upgrade.
Dual HPGe "Twins" (LBNL, BHSU, UCSB)	2×2.1 kg, p-type (ε=2×120%)	∼0.01 (∼1 ppt)	∼0.01 (∼1 ppt)	Davis: Sep 2020 Ross: Mar 2018, Jul 2017 (initial)	Operating. Flexible shield configuration.
Ge-IV (Alabama, Kentucky)	2.0 kg, p-type (ε=111%)	0.04 (3 ppt)	0.03 (8 ppt)	Davis: Fall 2022, Nov 2020 (initial) Ross: Jul 2018, Oct 2017 (initial)	Installation underway. Vertical design w/ gantry and hoist.
Dual HPGe "RHYM+RESN" (LLNL)	2×1.1 kg, p-type (ε=2×65%)	<0.1 (<10 ppt)	<0.1 (<25 ppt)	Davis: Feb 2022, Sep 2020 (initial)	Operating. BEGe low-E ^{210}Pb (<2 mBq/kg).

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