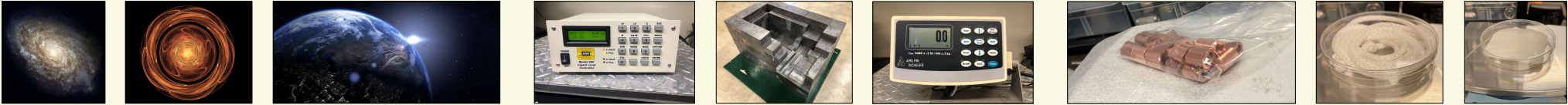
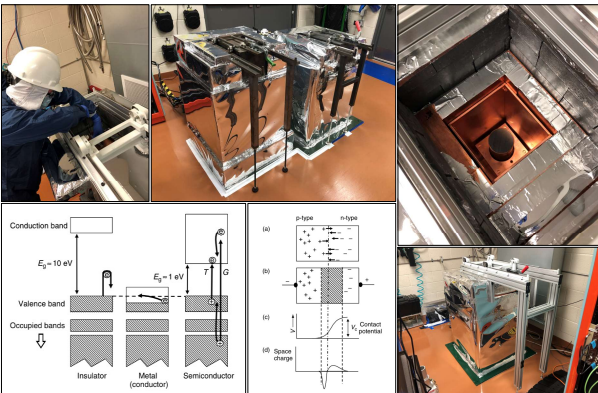


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## Introduction

There is a world-wide search for dark matter, a substance which makes up over 80% of the mass in the universe. A front-runner candidate for a dark matter particle is called the WIMP (Weakly Interacting Massive Particle) due to its rare interaction with baryonic matter. One experiment designed to detect a WIMP is LUX-ZEPLIN (LZ) located at the Sanford Underground Research Facility (SURF) in Lead, SD. WIMPs interact only via nuclear recoil events, so measures within LZ are taken to eliminate outside sources of radiation that might replicate such events within a detector.



**Figure 1.** Top (left-to-right): Student replaces copper lid over Ge detector, Mordred. HPGe detectors Maev and Morgan. Ge crystal and lead shielding inside Mordred. Bottom (left-to-right): Schematics of the electric band structures in insulators, metals and semiconductors. Semiconductor before (a) and after (b) carrier redistribution. Variation in potential (c) and space charge (d) across the junction. The exterior of Mordred.

We aid in LZ's search for dark matter by maintaining five High-Purity Germanium (HPGe) detectors (fig. 1) on the 4850 ft level of SURF, which assay potential LZ building materials for radioactive isotope concentrations. Data acquisition of a sample requires two weeks of low-background counting, then spectral analysis is performed.

A sixth detector, SOLO, has been assembled on the BHSU campus and will begin low-background counting in the summer of 2022. SOLO is a 30% relative efficiency p-type HPGe detector, previously located in the Soudan Underground Laboratory until its relocation to SURF, then to BHSU for LZ sample analysis.

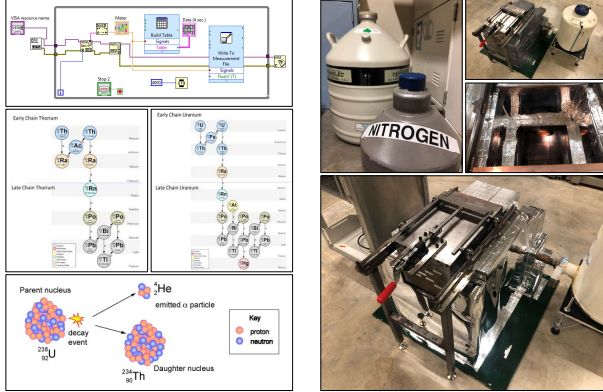
### Why use germanium as a detector medium?<sup>1</sup>

- Semiconductor with relatively small band gap.
- Easy to purify compared to silicon.
- Large charge carrier mobility.
  - Can measure higher energy gamma-rays.

## Materials and Methods

Germanium crystals are very sensitive radiation detectors, so various shielding methods are in place to eliminate background signals from the environment. Lead bricks are stacked around SOLO to absorb outside radiation, while liquid nitrogen boil-off purges radon within the detector housing.<sup>2</sup> Additionally, a layer of mylar is laid and sealed on top of the lead brick stack to create a vacuum chamber. SOLO's operation will utilize a liquid level controller and weight scale to aid in dispensing liquid nitrogen at the appropriate times.

The LabVIEW program (top of fig. 2) will interpret data from the scale and controller, then send a voltage to the solenoid valves when it is time to fill the detector chamber. Various hardware connectivity issues have provided challenges with instrument communication. Instrument driver solutions are being explored, including NI Modbus Library, NI VISA Serial, and NI VISA USB-Raw.



**Figure 2.** Top: LabVIEW program which sends scale data to a file. Middle: Decay chains of thorium (left) and uranium (right). Bottom: Alpha decay of a U-238 nucleus.

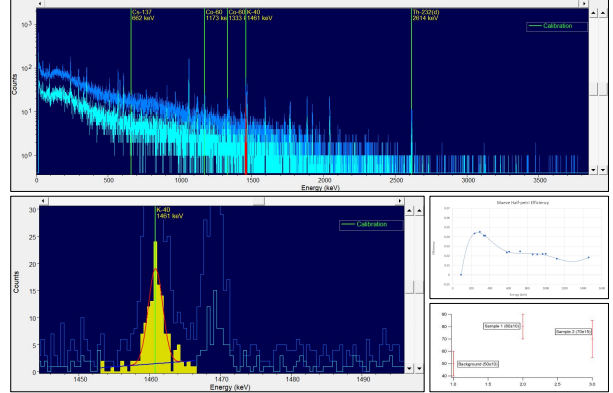
Once SOLO is fully constructed and ready for operation, samples will be loaded into the chamber for assay. When determining isotope concentrations within a sample for use in a dark matter search, it is ideal to detect relatively low concentrations of radioactive material, ensuring that the building materials will not interfere with a WIMP signal. However, many materials are contaminated with uranium (U) and thorium (Th) isotopes, which undergo a series of various alpha and beta decays according to the middle illustrations in fig. 2. Each decay emits a gamma ray with a unique energy. Detecting these unique energies allows us to pinpoint what isotope is present within a sample, while the amount of the isotope present is determined by how many gamma rays of a characteristic energy are detected.<sup>1</sup> We refer to the number of gamma rays detected as *counts*.

## Analysis

After two weeks of low-background counting per sample, the data is analyzed via background-subtracting software—in this case, we are using PeakEasy. Equation 1 below is used to determine the concentrations of uranium and thorium within a sample, where  $N_{peak}$  is defined as the total peak area for a given isotope,  $\epsilon_{peak}$  is the efficiency of the detector given a sample geometry,  $M_{sample}$  is the mass of the sample,  $P_i$  is the emission probability of an isotope, and  $LT$  is the live time of the sample run in minutes.

$$C = \frac{N_{peak}}{\epsilon_{peak} M_{sample} P_i LT} \quad (1)$$

As displayed at the top of fig. 4 below, a sample of neutron putty was counted in Morgan for two weeks, then the data was entered into PeakEasy. This data shows how many gamma rays were detected between 0 and 4000 keV during the two-week period. The area of each peak is then used to find U, Th, and K concentrations.



**Figure 4.** Top: Neutron putty (light blue) and detector background spectrum (dark blue). Bottom Left: Finding a peak's area using PeakEasy. Middle Right: Efficiency curve for sample with half-petri geometry in Maev. Bottom Right: Example of determining peak significance.

### Our long-term goals include:

- Completing LabVIEW automation for SOLO.
- Automating data-analysis procedures.

The outlined procedures will allow us (and collaborating scientists) to increase the sensitivity of our dark matter detectors and potentially discover a dark matter particle for the very first time.