Ultra-Low Background Counting For LUX-ZEPLIN (LZ) Dark Matter Detector

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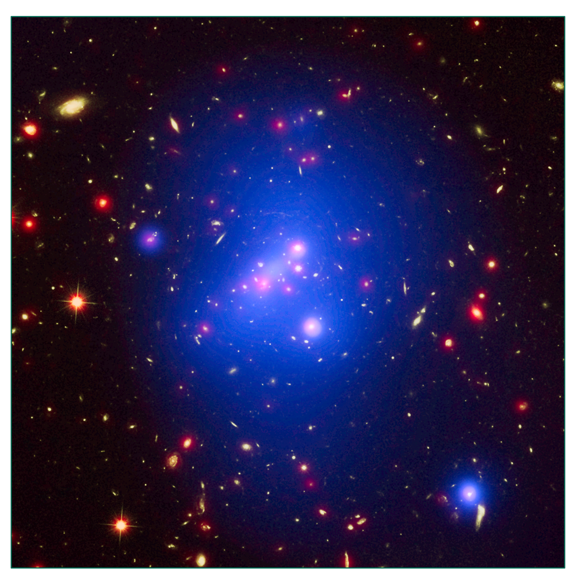
Dark Matter & Ultra-Low Background Counting

Dark matter makes up approximately 27% of the universe [1]. The reason we can only "see" regular matter is because dark matter does not interact electromagnetically with photons, making it transparent to light. Hence, it remains invisible to telescopes and other traditional means of particle detection. Instead, we infer the existence of dark matter through its gravitational effects on visible matter and its influence on the large-scale structure of the universe. The LUX-ZEPLIN (LZ) experiment at the Sanford Underground Research Facility (SURF) uses a highly sensitive detector designed to capture rare interactions between dark matter particles and ordinary matter. Specifically, the Xenon in the detector will give off a particular wavelength of light if the desired dark matter particle hits those nuclei in the detector. In addition to the challenge of locating such rare particles, the LZ detector detects interactions so thoroughly that it can detect the extra earthly radiation surrounding it as well [2]. Low background counting at the BHUC ensures the integrity of this dark matter detector by mitigating interference from other forms of radiation. Peaks of Uranium, Thorium, and Potassium are recorded so that they are not mistaken for the sought-after dark matter particles known as WIMPs (Weakly Interacting Massive Particles).



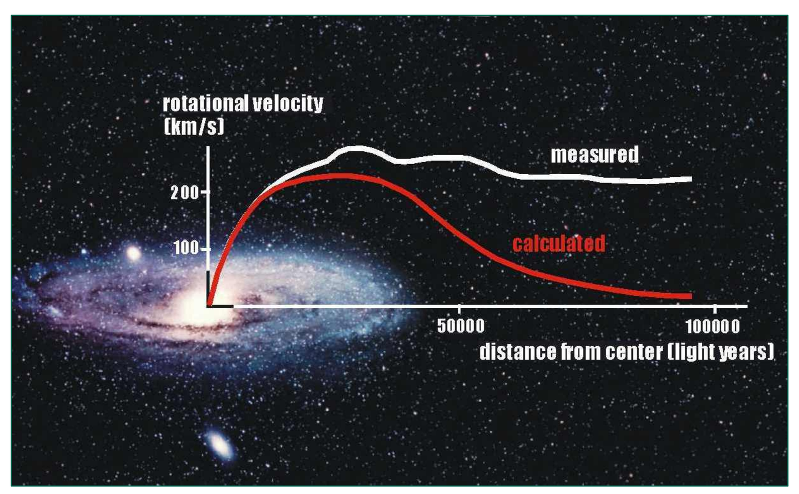


Figure 1 (left) - Bullet Cluster galaxy with separation of visible matter and gravitational lensing [4]
Figure 2 (right) - Rotation curve of dwarf spiral galaxy M33 [5]

High-Purity Germanium Detectors

MORDRED
- One of six high purity germanium detectors at BHUC
- Housed in class 2000 cleanroom at the 4850' level of SURF
- Ran for two weeks with sample from LZ

PARTS [3]
- <u>Crystal</u> - high purity germanium for sensitive gamma ray detection
- <u>Cryostat</u> - Maintains cryogenic temperature to reduce noise
- <u>Amplifier</u> - strengthens electrical signals for analysis
- <u>Multichannel Analyzer (MCA)</u> - categorizes and records signal energies
- <u>Lead shielding</u> - minimizes background radiation interference

SAMPLE
- Small metal cylinder
- Has expected peaks for U, Th, K
- Also examined for levels of ^{54}Mn and ^{60}Co

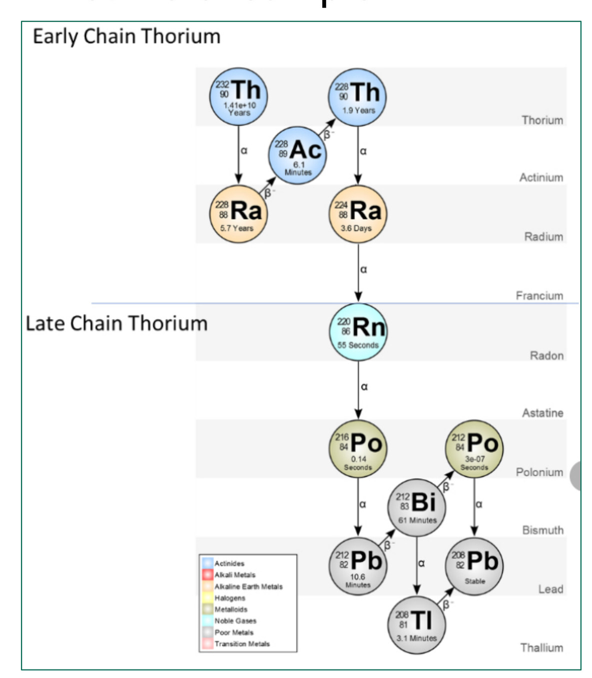
Figure 3 (left) - Photo of LZ sample assayed in Mordred
Figure 4 (right) - Photo of Mordred detector at BHUC

Gamma Ray Spectroscopy

Radioactive decay follows a chain of transformations from parent isotopes to daughter isotopes, with each step emitting characteristic gamma rays with specific energies. This technique allows identification of radioactive isotopes in a sample and determination of their concentrations by analyzing gamma ray energies and intensities using the below equation [3], where:

N_{peak} - Background-adjusted net peak area
Σ_{peak} - Full energy peak efficiency
M_{sample} - Mass of sample in grams
P_{γ} - Emission probability
LT - Livetime of sample in min

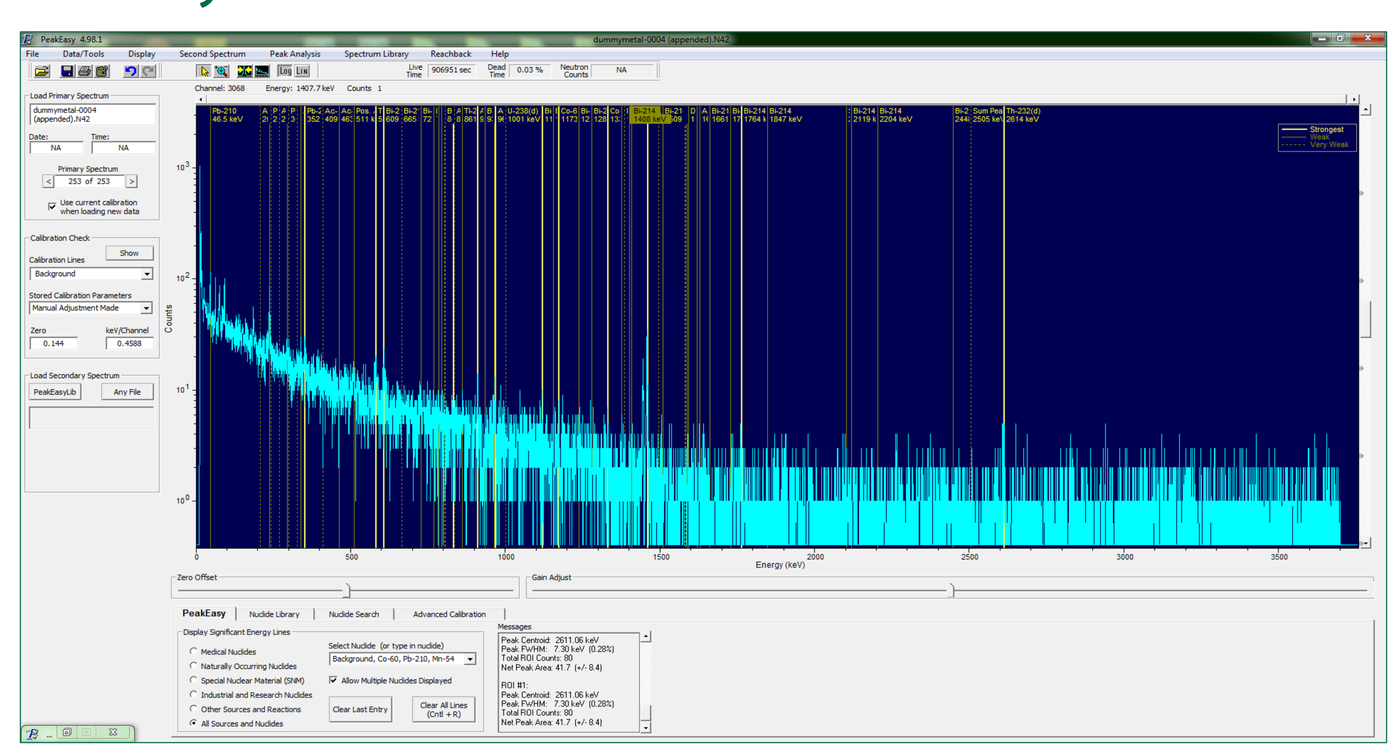
$$C = \frac{N_{peak}}{\varepsilon_{peak} M_{sample} P_{\gamma} LT}$$

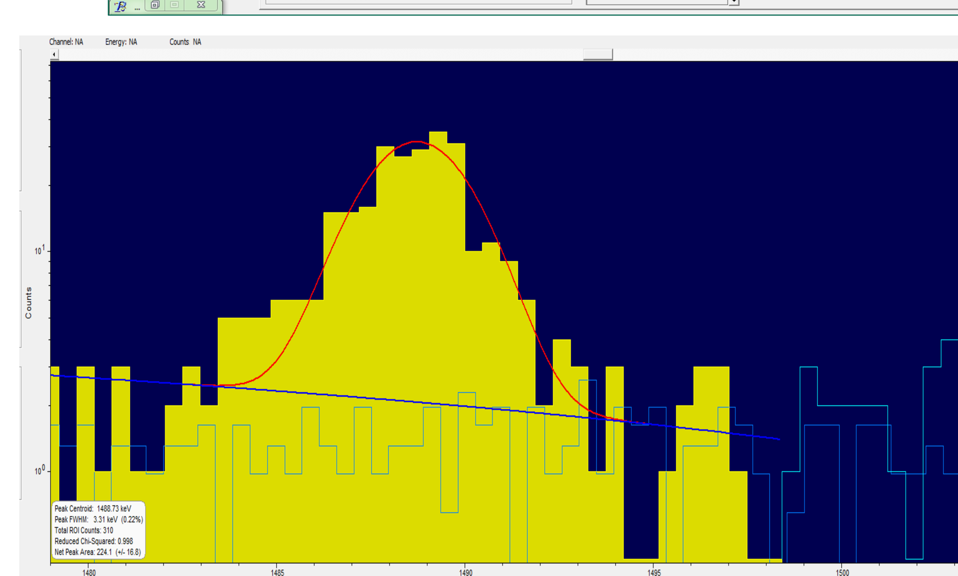


Radioactive elements like uranium, thorium, and potassium are naturally occurring on Earth, and are detected by high-purity germanium detectors. Each intermediate beta-decay step in the decay chain emits characteristic gamma rays with specific energies. During this decay process, thorium undergoes a decay chain that eventually results in a stable lead isotope. Similarly, uranium and potassium have their own unique decay chains that form other stable isotopes. [3]

Figure 5 - Thorium decay chain, [3]

Data Analysis





Chain	Value (ppb)
U (early)	<11.3 ± 0.000
U (late)	1.91 ± 2.00
Th (early)	43.47 ± 10.50
Th (late)	43.11 ± 8.03
K-40	69.57 ± 6.41

Figure 6 (top) – PeakEasy graph of Mordred sample (light blue) with expected natural radioactivity peaks (yellow), overlayed with background counts from Mordred with an empty sample chamber (dark blue)
Figure 7 (left) - Zoomed-in peak of K-40 on counts for Mordred sample (light blue trace) with fitted curve (red trace) and background spectra (dark blue trace)
Figure 8 (right) - chart of found areas under peaks in a weighted average for each decay chain, with error

SOLO

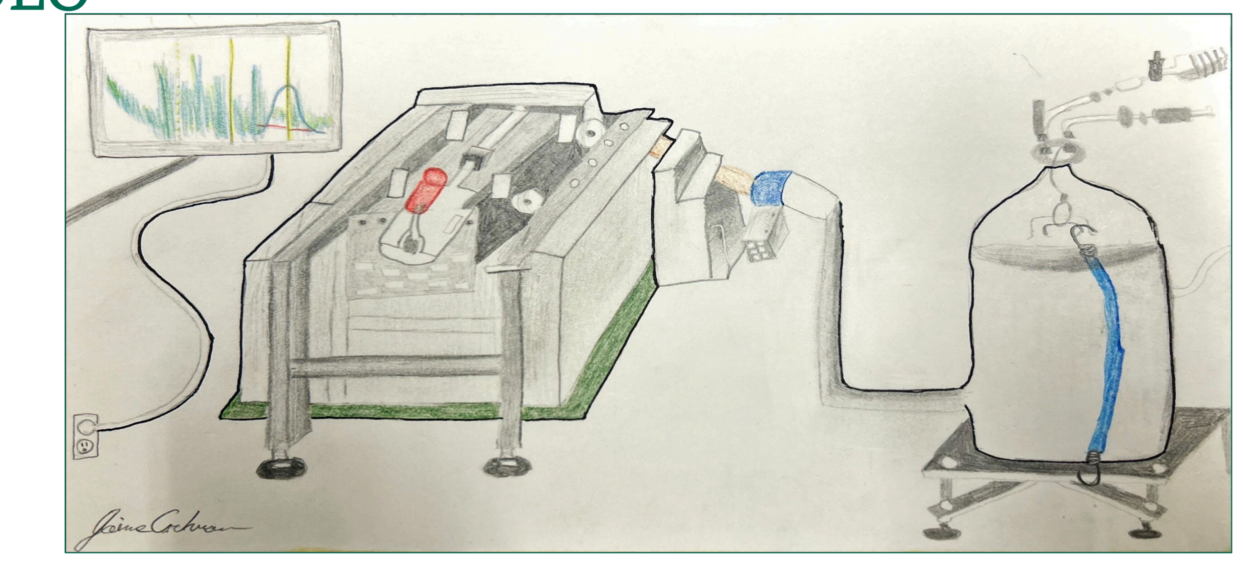
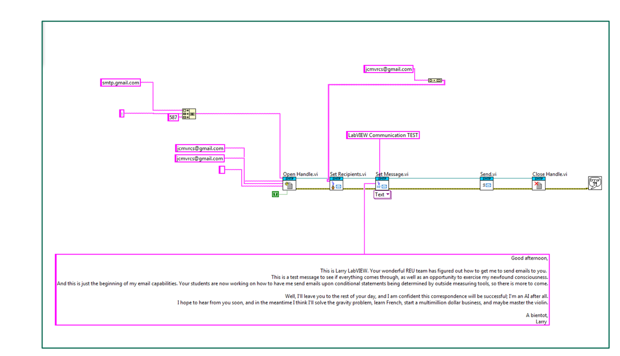


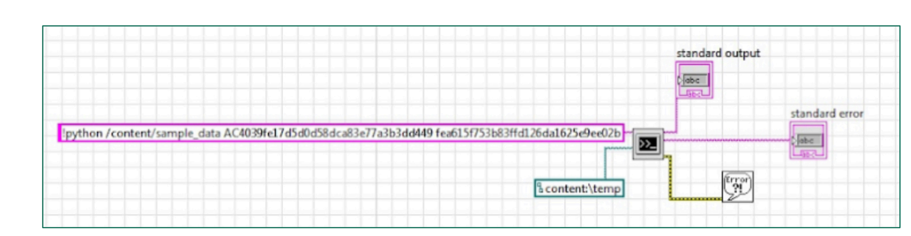
Figure 9 - Drawing of SOLO detector at Black Hills State University

- Above-ground radioactivity detector
- Lower sensitivity and less cosmic shielding than underground detectors
- Uses a high-purity germanium crystal to screen samples for radioactivity to determine if their levels are low enough to be assayed by underground detectors

Programming Progress & Goals

- <u>Goal</u> - Integrating LabVIEW and Python languages to automate the cryogen levels of SOLO
  - Will allow samples to remain cool and accurate readings to be taken for their radioactivity peaks
- <u>Drafting Process</u> - Monitoring & Reporting Cryogenic Levels





Figures 10 (top) & 11 (bottom) - Block diagrams of LabVIEW programming drafts (10=emailing draft, 11=texting draft)

- LabVIEW can connect with instruments that monitor SOLO's cryogen levels
- Python script links as an input in LabVIEW, and can contact phone numbers by text when levels are low
- <u>Current Progress</u> - Successful MANUAL Python communication with smart phones, initiated by LabVIEW
- <u>Next Steps</u> - Connect LabVIEW's instrument drivers to a Python-LabVIEW communication script that can give AUTOMATIC text alerts to relevant phone numbers

References

[1] Nath, Dipak. "The Darkness of Dark Matter and Dark Energy." *International Journal of Engineering and Applied Sciences*, vol. 5, no. 6, Jun. 2018.
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Acknowledgements

I would like to thank SURF for the opportunity to work underground at the BHUC, and my research colleague Steven Flores. This work was funded partially by NSF award 2150517.