Maximizing the KURF Materials Screening Sensitivity with Cosmic Ray Veto

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INTRODUCTION & MOTIVATION

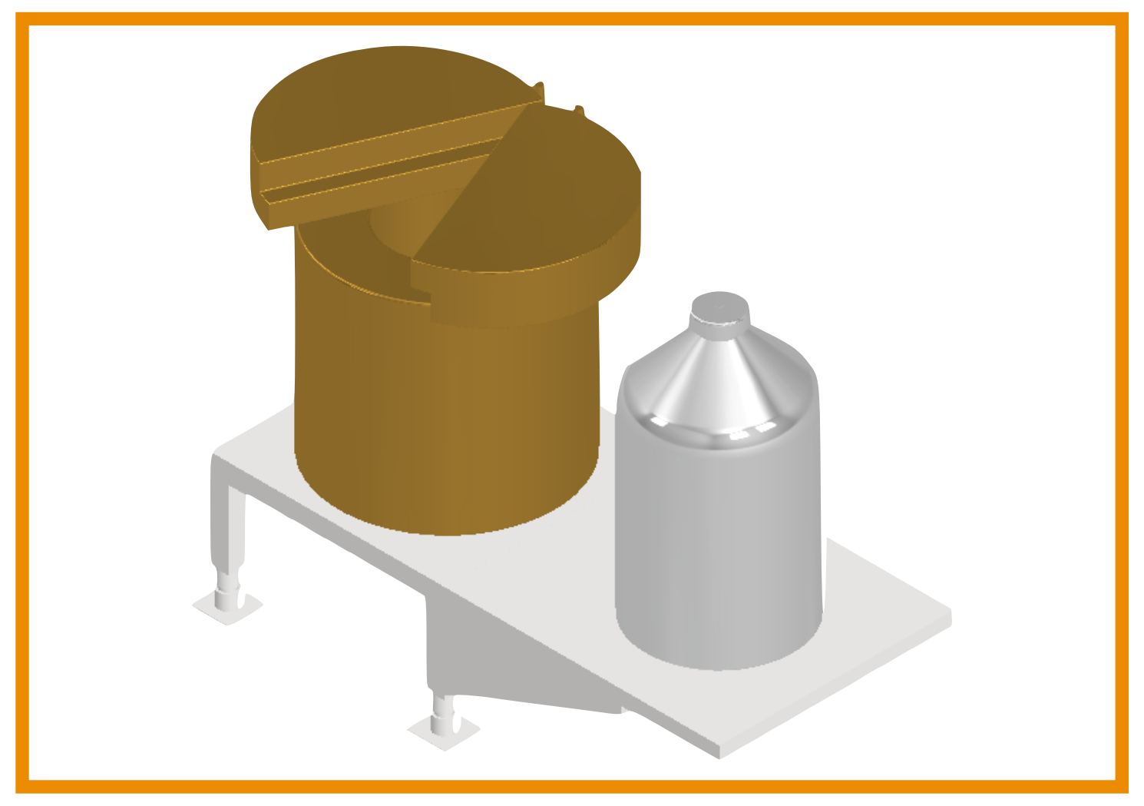
Above: Entrance to KURF, ground floor.

Gamma-ray spectroscopy is used to identify events occurring on a subatomic level, such as radioactive decay, fusion, or fission. The Kimballton Underground Research Facility (KURF) in the upper levels of an active limestone mine is the site of one of Virginia Tech's high-purity germanium (HPGe) detectors.

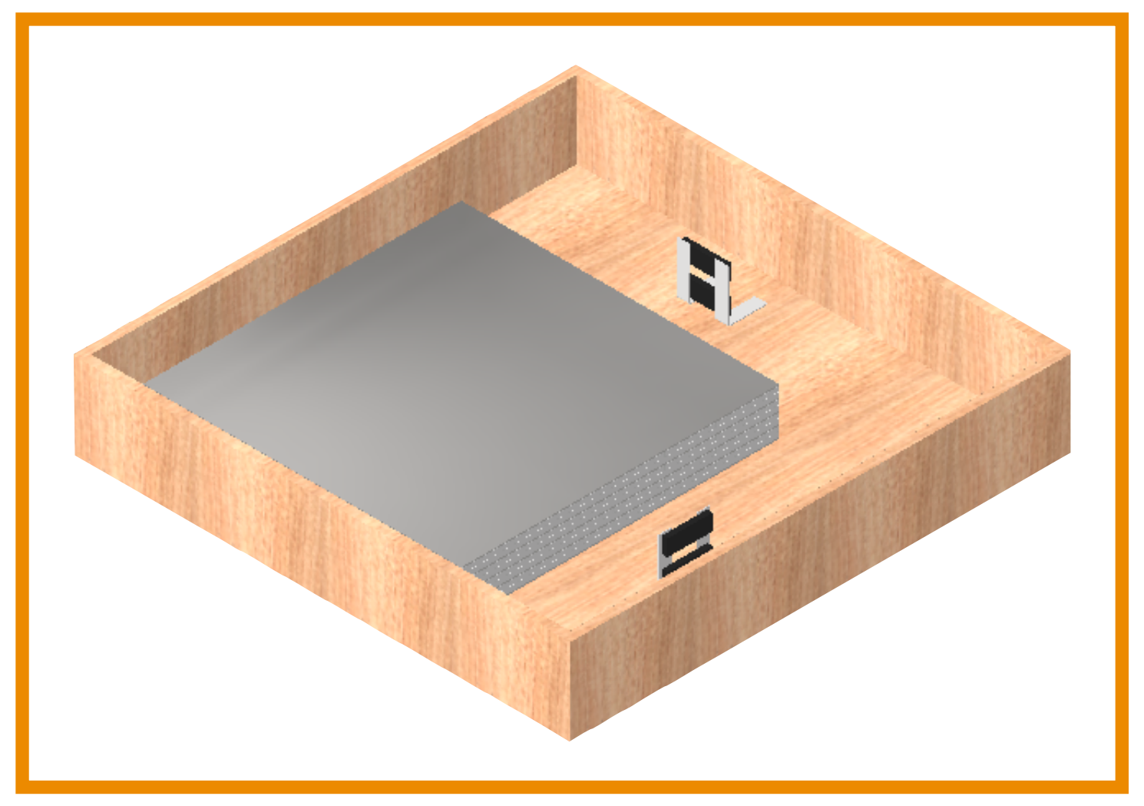
The HPGe detector is the highest-resolution radiation detector. However, it is susceptible to various sources of interference, including from high-energy cosmic ray muons traveling to Earth from the sun. Due to the depth of the limestone at KURF (300 ft), muon flux is decreased by a factor of over 200, but still provides a large background. To increase the purity further, our team worked to integrate a muon detector with the HPGe detector to veto muon events from the HPGe spectra as they occur.

BACKGROUND

COSMIC RAYS are high-energy particles which arrive in Earth's atmosphere from various sources in space such as the Sun, active galactic nuclei, and supernovae. They produce showers of secondary particles when they strike the Earth's atmosphere, including pions, which quickly decay into pairs of muons and neutrinos. These muons have half-lives of 2 μs and travel at near-light speeds through the Earth. The muon flux at the surface is about 170 Hz/m^2, while at KURF the flux is 0.6 Hz/m^2.



Right: the **HPGE DETECTOR** and housing. Photoemissions from the radiative material engage the photoelectric effect in the HPGe crystal's depleted region, the emitted photoelectrons having charge proportionate to the energy of the incoming photon. These charges are then registered by a preamplifier and counted using the MAESTRO PC software, where they are composed into spectra. The detector is housed in a case composed of lead, tin, and copper and kept in thermal contact with a liquid nitrogen dewar, which cools the detector to operable levels.



Left: **MUON DETECTOR** and housing. The muon detector is composed of 96 bars of scintillating polystyrene laid in eight layers, each threaded through with optical fibers. Particles traveling through the detector scintillate in the bars, and these scintillations pass through the optical fibers and are amplified in one of the four photomultiplier tubes (PMTs) fixed beside the detector. They are then transmitted to the crate modules which make up the readout system. The muon detector is housed above the HPGe detector in a light-proof wooden box.

METHODS

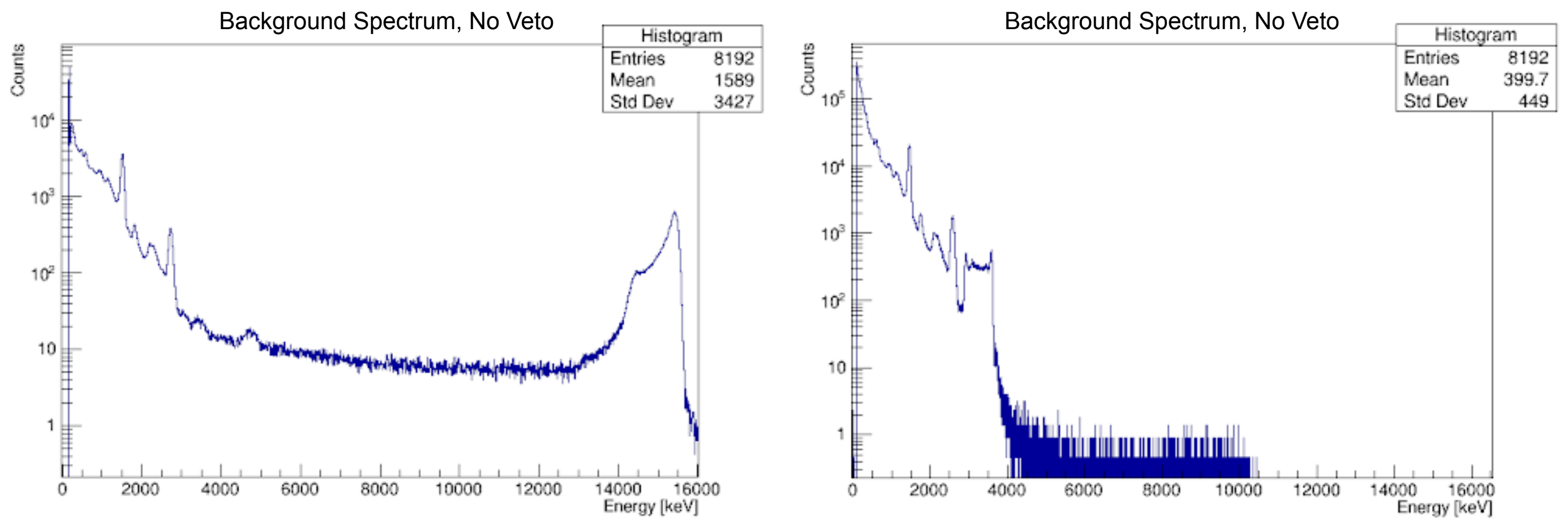
Before installation at KURF, the muon detector was updated to perform more efficiently. This involved several adjustments to the physical detector, including:

- ***Repackaging the detector*** in a more maneuverable unit and building mobile stand;
- ***Shortening optical fibers,*** decreasing attenuation distance;
- ***Light-proofing*** by sealing detector with caulking and tape;
- ***Adjusting logic*** to create redundancy and reduce loss;
- ***Raising photoemission threshold*** to maximize efficiency and minimize processing time while avoiding phase space cut.

Ultimately, we increased efficiency from less than 40% to 80.2%, leaving an expected muon flux rate through the muon detector of 0.12 Hz/m^2, or 0.56 muons per second through the detector. Installation occurred over four days at the KURF mine, where we confirmed performance by measuring incident rate of radiation when a source was placed at predetermined places over the surface of the detector; we observed identical incoming channel rates between KURF and Virginia Tech, confirming that measurements were being taken accurately.

RESULTS

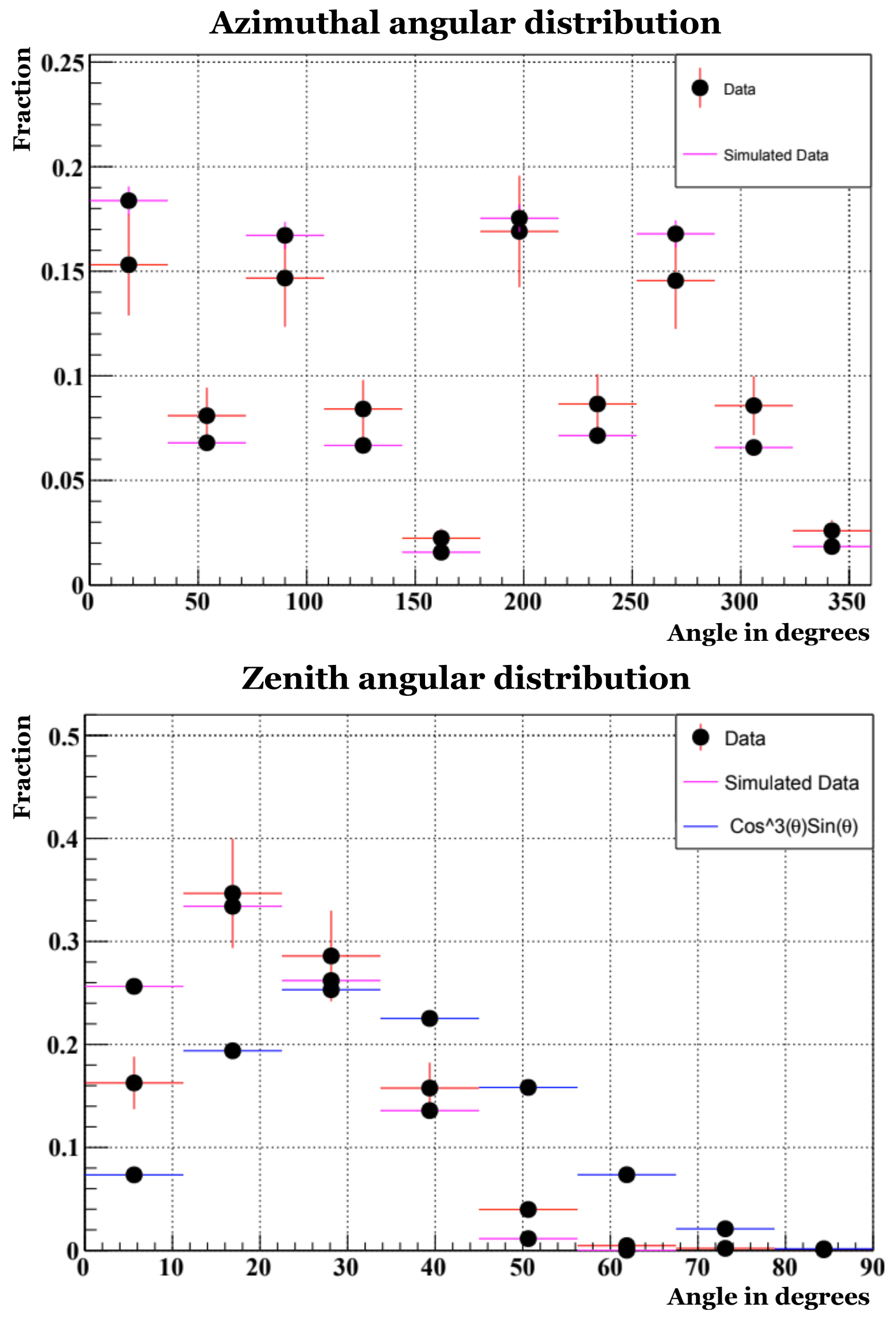
Spectra taken using an NaI(Tl) scintillator show number of counts versus energy of counts, resulting in background spectra which showed unidentified energy deposited between 14 and 16 MeV. This peak was hypothesized to be caused by muons. Our group set the NaI(Tl) scintillator in anti-coincidence with the muon detector for 18 hours and vetoed 30 μs of data for each muon interaction in the detector. Our prediction was that this unidentified peak would not be present in the anti-coincidence data.



Background spectra taken with NaI(Tl) scintillator. Left shows background without veto; right shows background with veto applied.

We observe in the final spectrum that contributions above 4 MeV have been reduced to less than 1 count per day or completely erased, confirming our assumption that the highest-energy depositions were caused by muons. The intermediate energies between 4 MeV and the highest-energy contributions were inferred to be the Compton continuum of the muon decay.

However, higher-energy contributions than the Tl-208 line at 2615 keV still remain in the data and the peak between 2.6 and 4 MeV persists in both coincidence and anti-coincidence runs, while energies in the muon range are not present. This may be because the NaI(Tl) detector was placed above the muon detector: muons crossing the detector would be vetoed successfully, but would not pass through the detector to be measured. We are also investigating substances within the detector housing which may be causing the mid-energy scintillations.



Fraction of captured muons which pass through angles relative to the horizontal. The above graph shows the azimuthal angle; the below graph shows the zenith angle.

The data at right is taken from a series of background tests performed at Virginia Tech. Placement of measured muons corresponds well with simulated data. Azimuthal angular measurements are well within error bounds in each case. Zenith angle of the incoming muons skews toward smaller angles as predicted, but not to the extent that had been predicted, which may be explained by the building shadow.

CONCLUSION

Our group was able to successfully modify the muon detector to be remotely operable and to run continuously with the HPGe detector. Our detector integration removed over 99% of muon background with over 80% efficiency, resulting in spectra containing the expected decay peaks but for which the muon interference had been removed. In future, we will investigate further the disparity in energy of data caught during the muon veto and continue monitoring the veto performance with the HPGe. Afterward, we will be able to use the integrated detectors in combination to analyze radiation spectra.

REFERENCES & ACKNOWLEDGEMENTS

This research was sponsored by NSF Grant Number 1757087. Thank you to Andy Jackson, Kevin Marquez Diaz, and the O'Donnell research team at Virginia Tech for your support.

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