The Twins: A dual-crystal HPGe system at the BHUC

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BLACK HILLS STATE UNIVERSITY

Black Hills Underground Campus

The Black Hills Underground Campus (BHUC):

- Based at the Ross campus in the 4850 level of the Sanford Underground Research Facility (SURF) in South Dakota, US (Figure 1).
- The 4850 level has a rock overburden of 1.5 km, which gives an equivalent of 4.2 km of water shielding from cosmogenic rays
- Within the BHUC is a 55 m^2 class 1,000 cleanroom that houses 7 High Purity Germanium (HPGe) systems :
  - Maeve
  - Merlin
  - Mordred
  - Morgan
  - Ge IV
  - RHYM/RESEN
  - Twins

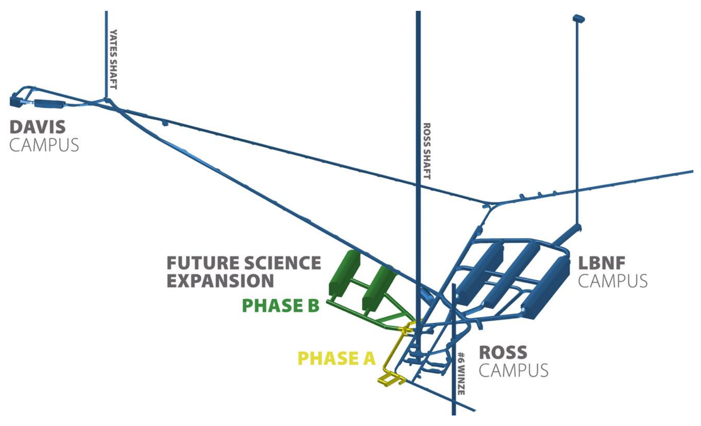

Figure 1: Map of the 4850 level of SURF

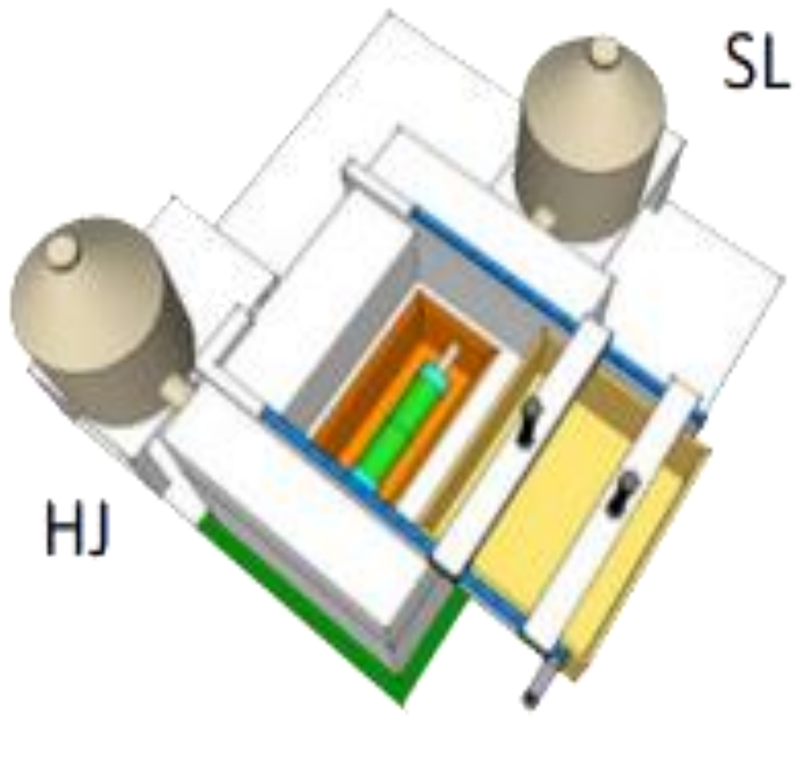

Figure 2: Diagram of the Twins setup

Low background counting:

- HPGe's within the BHUC are used as low background counting instruments
- The BHUC was used heavily during construction of LUX-ZEPLIN (LZ), assaying over 300 components [1]
- Currently open to screening materials from the community as available

Hardware of the Twins:

- The Twins is a dual-crystal configuration in one shield, aiming both crystals towards a sample (Figure 2).
- The additional crystal increases the solid angle and potential total efficiency of the system
- Both HPGe crystals are 2.1 kg ORTEC 100% p-type HPGe detectors [2]
- The "side-looking" crystal is labelled SL, and the "J-junction" crystal is labelled HJ [3]
- The inner chamber of the Twins is a 30 L volume surrounded by 2.5 cm-thick layer of Oxygen-Free High Conductivity (OFHC) Cu, then a 25 cm-thick layer of Pb bricks.
- The SL system can be moved horizontally to accommodate large sample geometries.

Establishing the Twin's Performance

- The performance of the Twins systems can be achieved by carrying out a calibration run using well-characterised Table Mountain Latite (TML)
- For initial characterisation of the system, a petri dish of 99.59 g of TML was oriented parallel with respect to the faces of each detector to have the largest surface area visible to the detectors (Figure 4).
- TML data was collected for two weeks, and background data was collected for one month.
- From the background data, background rates in counts/day/kg for HJ and SL were found (Table 1).
- Using the TML and background data, the expected efficiency for each detector for the 100 to 2700 keV range was determined for isotopes in the ^{238}U, ^{232}Th and ^{40}K decay chains (Figure 3).

Table 1: Background counts per day for both Twin crystals normalised for crystal mass

Crystal	100-2700 keV Count Rate (counts/day/kg)	Peak Background Count Rate (counts/day/kg) Bi-214 (609 keV)	Ti-208 (2614 keV)
SL	1476.89 ± 38.43	8.47 ± 0.57	0.57 ± 0.15
HJ	1106.71 ± 33.27	9.72 ± 0.60	0.82 ± 0.17

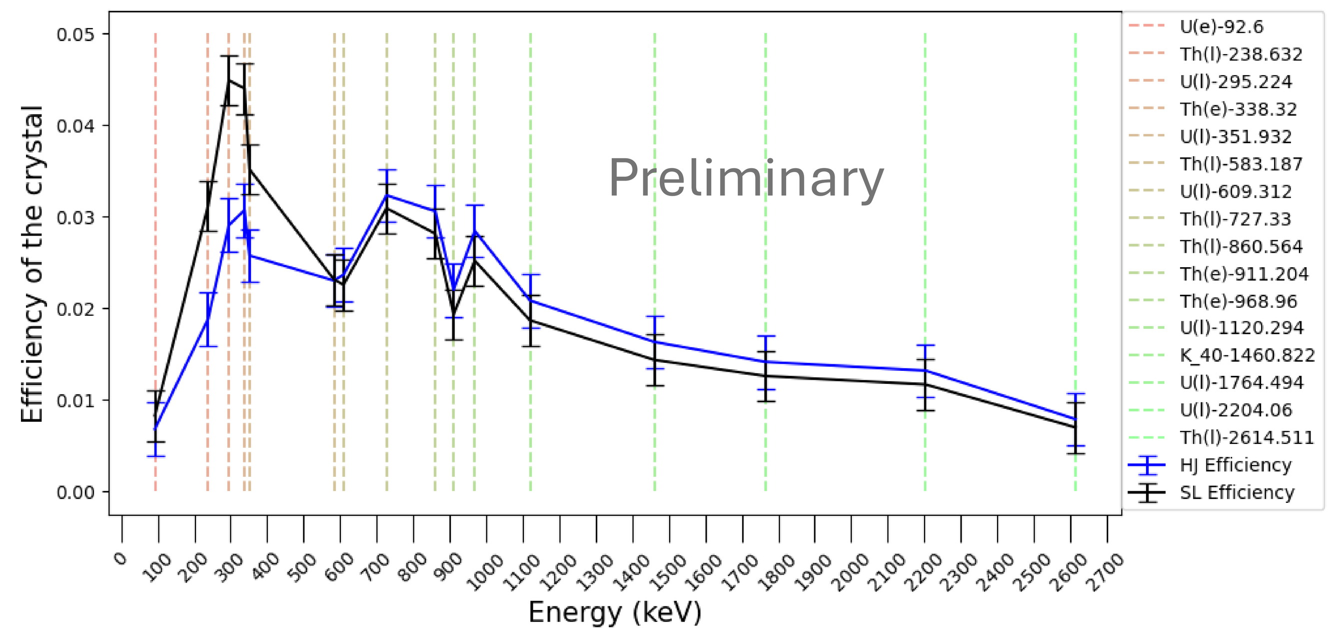

Figure 3: Comparison of the calculated efficiency of HJ and SL crystals of the twins

Simulating the Twin's Behaviour

The Simulations:

- Alongside the physical Twins detectors, a Geant4 simulation [4] of the Twins was developed to determine detector efficiencies for arbitrary sample geometries (figure 5).
- Initial simulations are overestimating the photopeak yields across the full energy range, resulting in larger simulated efficiencies with respect to efficiencies calculated using the TML data (figure 6).
- The largest discrepancy between simulations and data occurs in the lower energy range, but the ratio between simulations and data tend towards ~2 for energies above 500 keV.

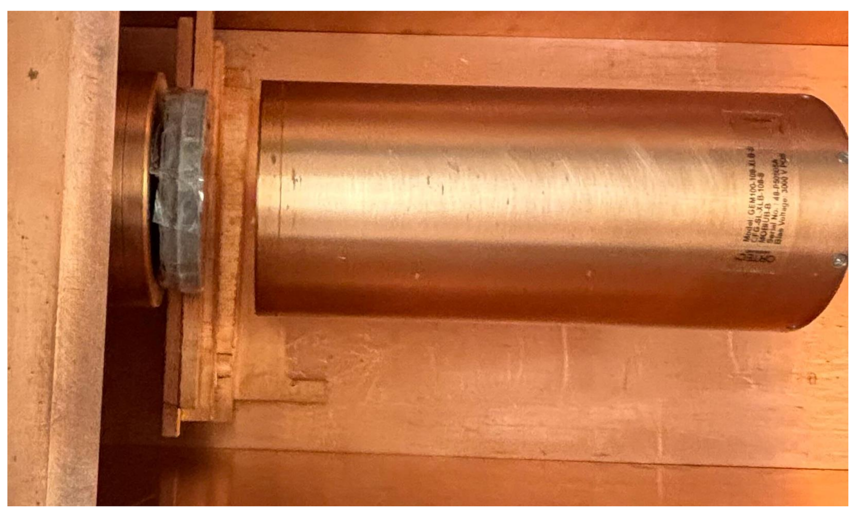

Figure 4: Picture of the opened Twins system with a petri dish of TML between the crystals, with the SL on the right, and the HJ on the left.

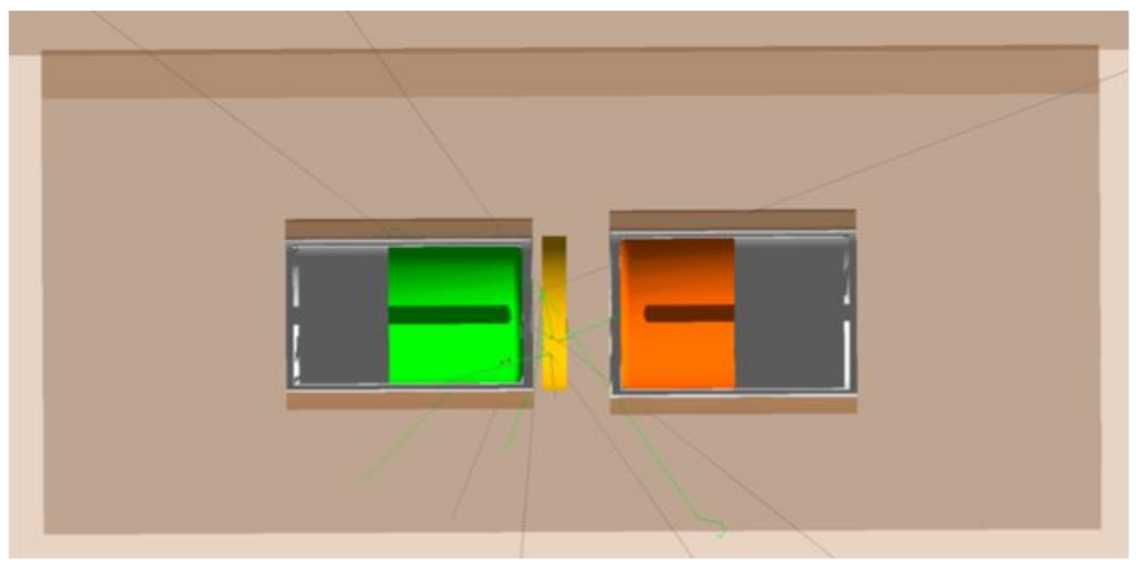

Figure 5: Rendering of detector geometry implemented in the simulation: SL on the right, HJ on the left, petri dish of TML placed between the crystals

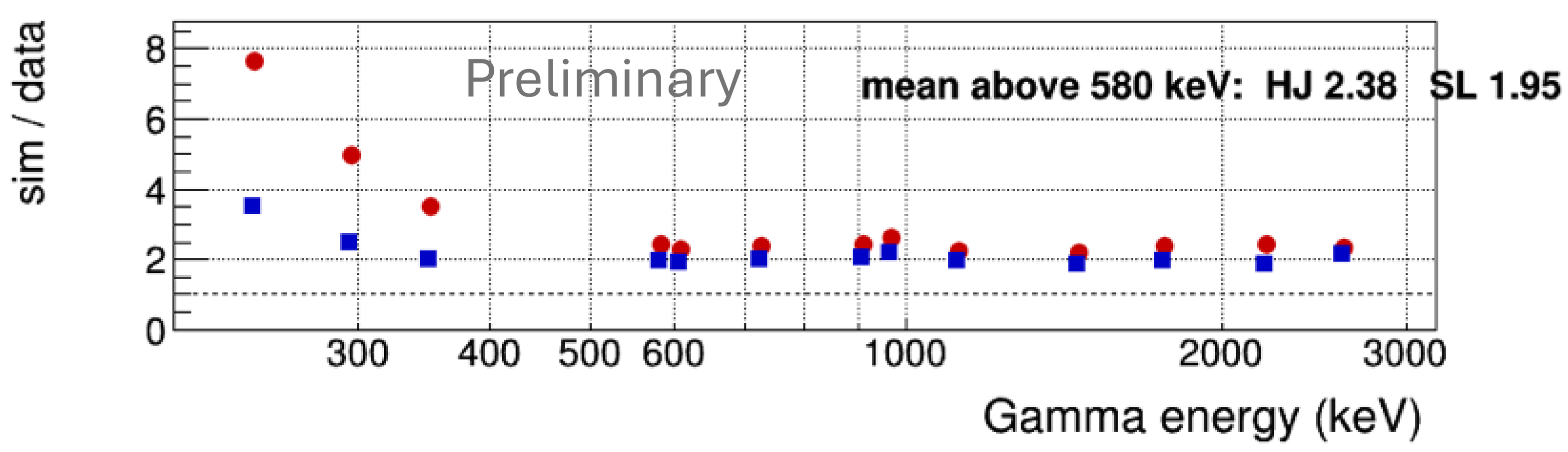

Figure 6: Photopeak detection efficiency ratio derived from simulation of the data-taking configuration shown in Figure 5, and the efficiency measured with reference sample. HJ (red) and SL (blue)

Anti-Coincidence Counting Rejection

Motivation:

- Dual HPGe detectors for single sample radioassay can be used to provide additional background rejection from sources such as Compton scattering
- The chosen configuration of the Twin's detectors optimises the large solid angle coverage of the sample, increasing the probability to detect coincidence gammas from cascades and scatters.
- First signals are identified that occur within a set time window between both detectors, currently chosen as 1μ second
- Events that occur within the time window are matched with their timewise counter part in the opposing detector and their energies summed
- A filter is applied to only consider events with energies that correspond to events from the ^{238}U, ^{232}Th and ^{40}K decay chains, giving distinct populations of events that can be rejected from the Twins data (Figure 7 left plot).
- A Monte Carlo simulation is in development to understand the patterns observed in the data (Figure 7 right plot).

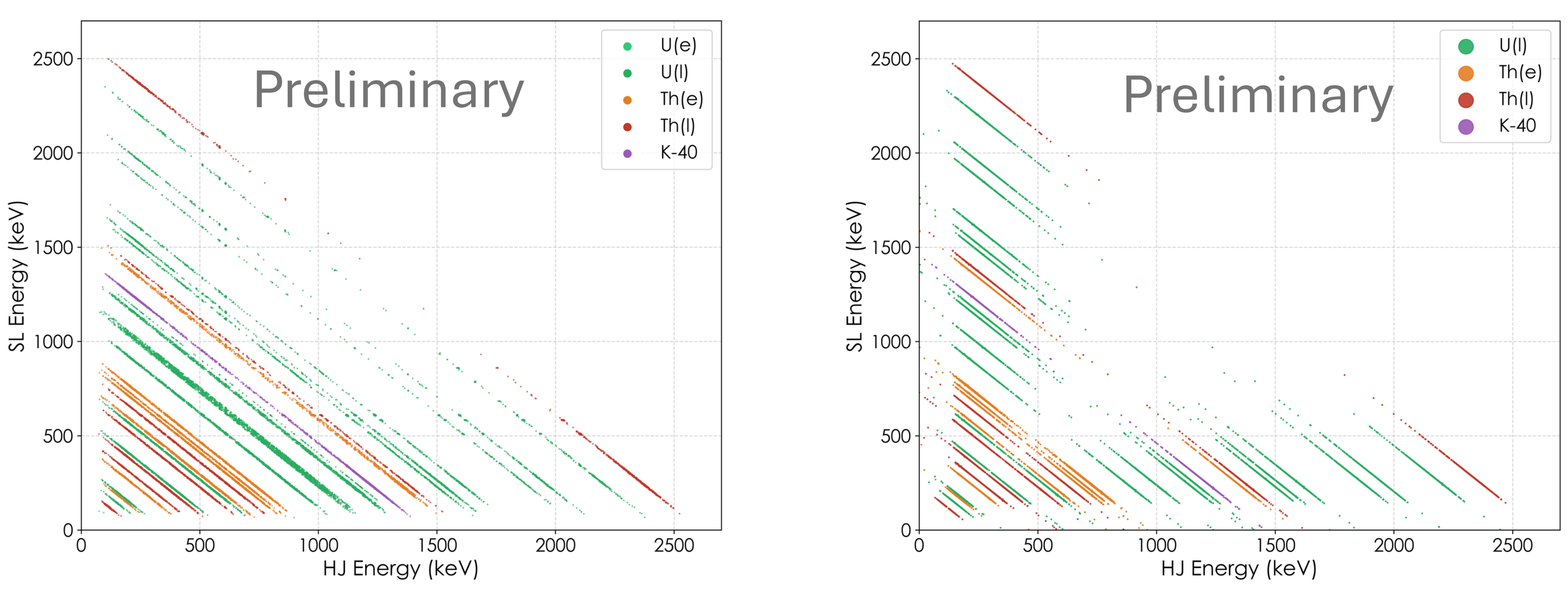

Figure 7: Time matched events from TML data of the Twins that have summed energies that correspond to decays of interest. Left plot corresponds to TML data, right plot correspond to Monte Carlo simulations

Future Work

- Investigate methods to combine the recorded counts from each individual detector into a single measurement
- Improve the Geant4 simulation to account for detector response beyond energy resolution smearing
- Utilise point sources and samples of different geometries to stress test the capabilities of the Twins
- Characterize detection efficiencies and background rates under different event selection conditions, such as coincidence and anti-coincidence selection

References and Acknowledgements

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[2] B. J. Mount et al., Appl. Radiat. Isot. 126, 130 (2017).

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[4] Geant4 - A Simulation Toolkit, S. Agostinelli et al., Nucl. Instrum. Meth. A 506 (2003) 250-303

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