Celebration of Undergraduate Research, 2024

Simulating HPGe Detector Signals for Machine Learning Applications

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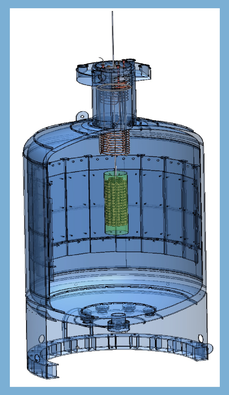
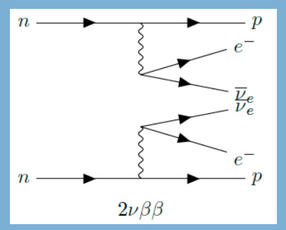
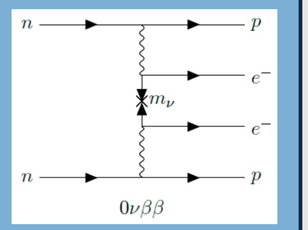
Large Enriched Germanium Experiment for Neutrinoless ββ Decay (LEGEND)

- Are neutrinos their own antiparticle?
- Determined by examining 0νββ through Ge-76 decay
- First phase is LEGEND-200, which uses 200 Kg of Ge-76 which ββ decays to Se-76
- Next phase to be implemented is LEGEND-1000



LEGEND-200 Detector

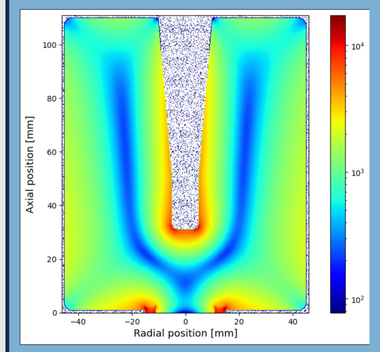




The benefits of finding neutrinoless ββ Decay:
- Proving that neutrinos are a Majorana particle
- In violation of lepton number conversation
- Provides more background about where neutrino masses come from
- Potentially explains why there is more matter than antimatter in the universe

Germanium Detector Design

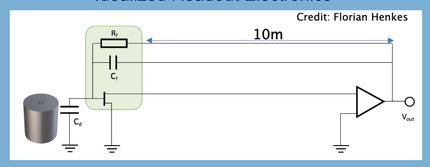
LEGEND-200 Detector Geometries



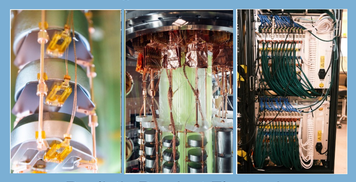
The detector is 111 mm in length with a radius of 46 mm with an Li-thickness of 1.

- Decays occur inside the detector
- Emitted particles drift through the electric fields creating a charge signal.
- A cross-section above shows the intensity of the electric fields

Idealized Readout Electronics



- Data retrieved from the detector is altered by the electronics in between the detector and the digitization of results.
- It causes issues in accurately simulating detector results
- This impact is dependent upon capacitors, op-amps, and wires
- Modeling electronic response is imperative to better simulating the real HPGe data.

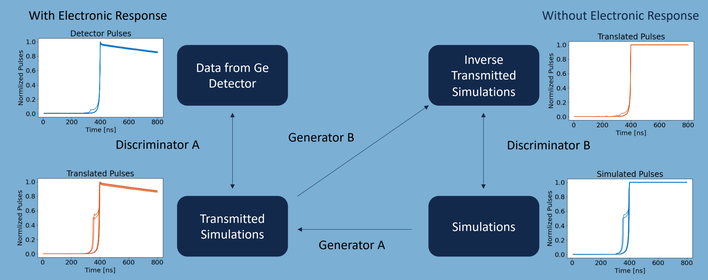


Realistic Readout Electronics

Credit: Michael Willers

Machine Learning Implementation and Validation

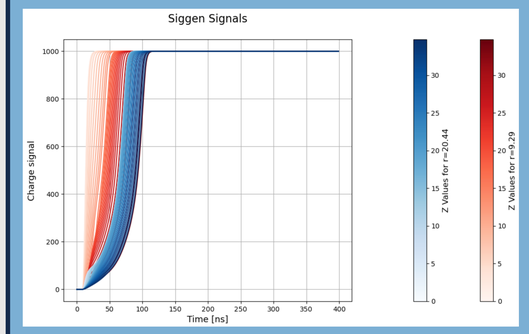
The goal is to implement simulated data and data modeled with electronic response and noise into a Cycle-Gan Model to better understand how the ML algorithm trains and generates the waveforms.



This approach uses predetermined noise and electronic simulations so there can be direct validation with the ML algorithm.

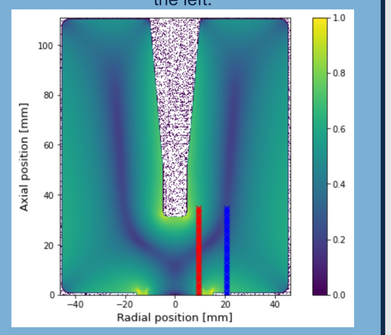
Simulated Waveforms

- Waveforms are generated using siggen simulations
- Simulations only model single sight events
- Library created by taking points every 0.5mm of the radius and the axial position at constant ϕ
- Below shows charge signal for varying axial positions at two different radii



Signal is induced as charges drift through the detector's fields.

The graph below shows positions corresponding to the signals produced on the left.



Acknowledgements

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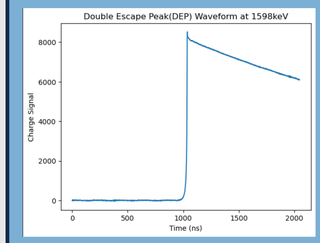
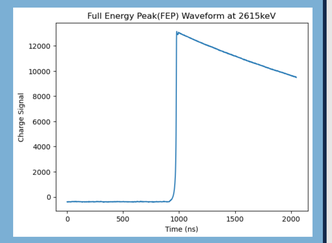
Modeling Electronic Response and Noise

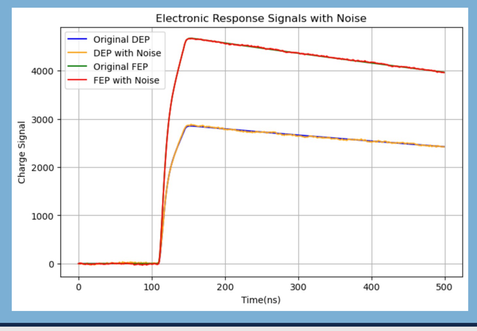
Data taken from the HPGe Detector





Creating a Library with known Noise and Background

- Scaled simulated data to match amplitudes of current data for FEP and DEP signals
- Applied a single pole transfer function to model electronic response using a pole of 3370 ns
- Added pink noise by calculating the standard deviation in amplitude of the original function and scaling the noise to that value.



Conclusion

- Have two fully simulated data sets consisting of completely simulated data and a model with added electronic background and noise
- With the next steps to run these through the ML algorithm to better understand pulse shape rejection and better simulations of pulse shapes in general.

Future Directions

- Increasing the validity of our simulations by creating data sets that account for diffusion and charge cloud size will provide more information for future analysis
- Train the data for a full range of ϕ values to create a 3D model instead of just one angle in the detector.