DUNE’s Potential to Search for Neutrinoless Double Beta Decay

Elise Chavez

Supervisors: Joseph Zennamo and Fernanda Psihas

GEM Final Presentation

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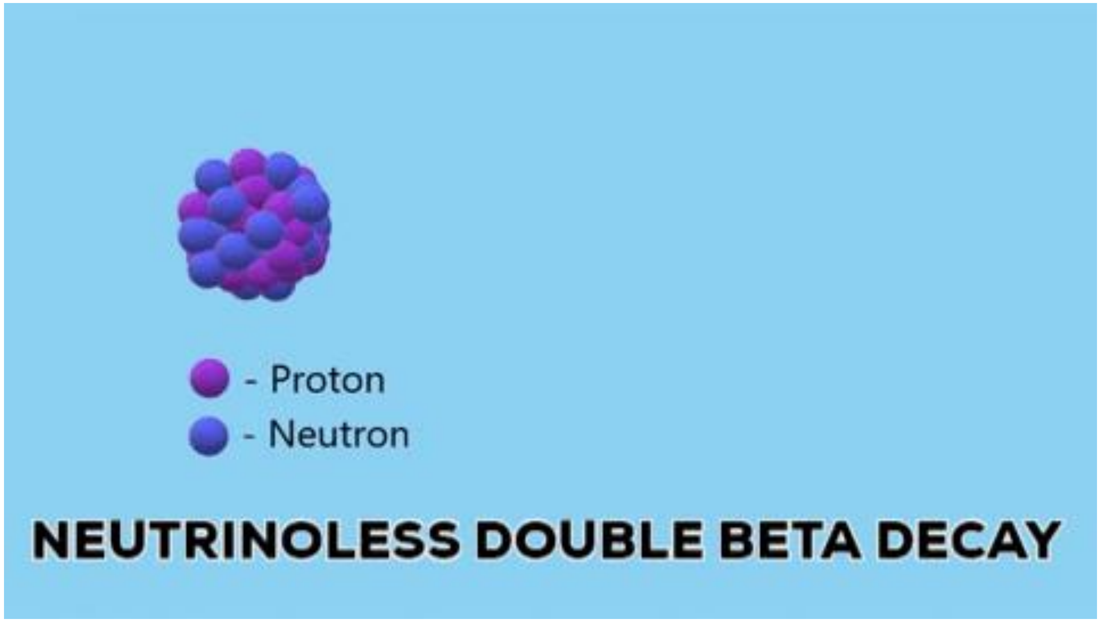
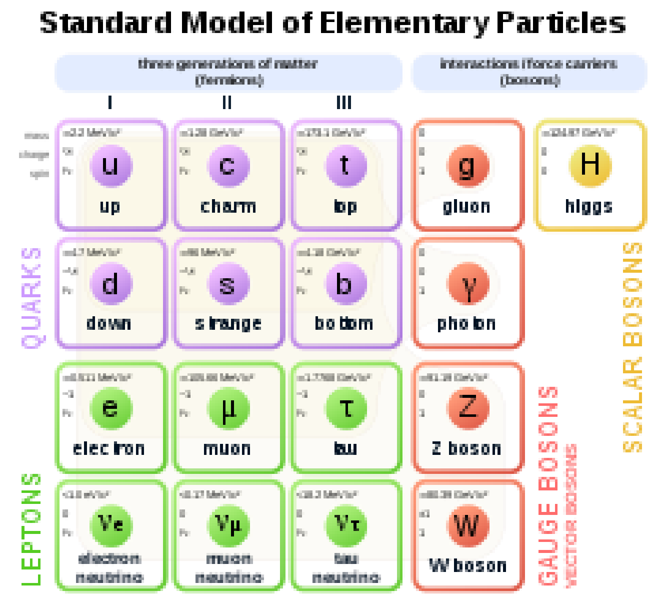
Neutrinoless Double Beta Decay

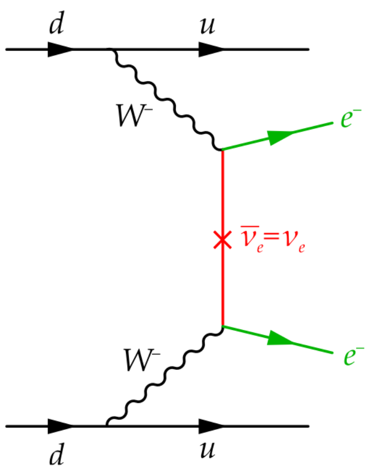
- Occurs when a nucleus has two neutrons decay into two protons but only emits two electrons
  – Xe(136, 54) → Ba(136 , 56) + $2e^-$ + 2.459 MeV (136-atomic number, 54/56-proton number, 2.459-energy released)
  – Monoenergetic signal at 2.459 MeV, two electrons



Neutrinoless Double Beta Decay

- Forbidden by the standard Model
  - Violates lepton number
- For this to occur, the neutrino must be a majorana particle
  - Means the neutrino is the same as its anti-particle
- One of the pieces to the matter/anti-matter asymmetry puzzle





Difficult Search → Try Using DUNE

- Physicists have been searching for $0\nu\beta\beta$ since about the 1960s
  - Led to the $0\nu\beta\beta$ half-life $T_{1/2}^{0\nu}$ limit being improved by several orders of magnitude (for Xenon it is ~10^{27} years, or ~10^16 ages of the universe)
- **Ultra-rare decay**, so we need a big detector
  - DUNE is a really big detector → dope liquid Ar with 2% Xe-136
    - For comparison, EXO200 is only 2kg of Xe
- Need specific isotopes
  - Nuclear physics dictates that only certain nuclei can decay through $0\nu\beta\beta$ decay
  - For TPCs, Xenon is typically used

Isotope	Natural abundance (%)	$Q_{\beta\beta}$ (MeV)
^{48}Ca	0.187	4.263
^{76}Ge	7.8	2.039
^{82}Se	8.7	2.998
^{96}Zr	2.8	3.348
^{100}Mo	9.8	3.035
^{116}Cd	7.5	2.813
^{130}Te	34.08	2.527
^{136}Xe	8.9	2.459
^{150}Nd	5.6	3.371

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- Ultra-rare decay, so we need a big detector
  - Moves us from 2kg to 100s of tons % Xe
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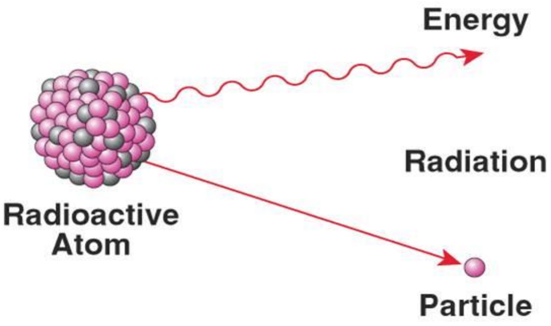
Enhances detector performance and won't destroy it

Strategy and Goals for this Project

- Model the backgrounds for $0\nu\beta\beta$ within the LArTPC to determine the feasibility of a search
- Determine whether the signal can be separated from this background
  - What can we expect to see in this type of search using DUNE
  - $0\nu\beta\beta \rightarrow$ 2 energetic e^- vs. background $\rightarrow$ 1 energetic e^-



- Sources we are looking at
  - Polonium
  - Krypton
  - Argon
  - Radiation From Anode
  - Radiation From Cathode
  - Radon
  - Neutrons From Radioactive Decays in the Surrounding Rock
- Does not include spallation or solar neutrino backgrounds

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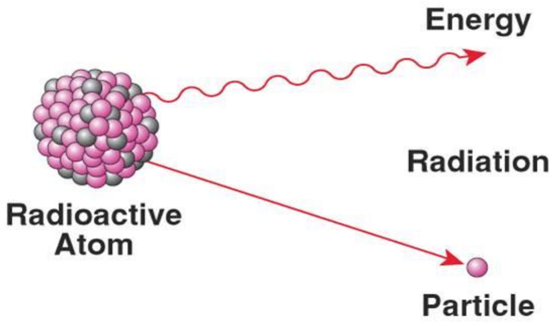

- Sources we are looking at
  - Polonium
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  - Radon
  - Neutrons
- Does not include spallation or solar neutrino backgrounds

Step 1: Using DUNE's Framework

- First, I had to become familiar with DUNE's framework
  - art
  - LArSoft
- This was important to ensure that the ideas we are implementing are applicable to DUNE
  - Used a DUNE simulation file to scope out potential backgrounds, radiopurity from the TDR (technical design report)
  - Analyzer modules, fhicls, making trees

What is art?


```
Total products (present, not present): 181 (181, 0).

Begin processing the 10th record. run: 20000061 subRun: 0 event: 10 at 18-Jun-2020 22:55:08 CDT
PRINCIPAL TYPE: Event
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NiGen....... | poGen.......... | ....................... | std::vector<simb::MCTruth>......................................... | ....1
NiGen....... | cpaGen......... | ....................... | std::vector<simb::MCTruth>......................................... | ....1
NiGen....... | ar42Gen........ | ....................... | std::vector<simb::MCTruth>......................................... | ....1
NiGen....... | krGen.......... | ....................... | std::vector<simb::MCTruth>......................................... | ....1
NiGen....... | neutronGen..... | ....................... | std::vector<simb::MCTruth>......................................... | ....1
NiGen....... | apaGen......... | ....................... | std::vector<simb::MCTruth>......................................... | ....1
NiGen....... | rns............ | ....................... | std::vector<art::RNGsnapshot>...................................... | ....9
NiGen....... | TriggerResults. | ....................... | art::TriggerResults................................................ | ....-
NiGen....... | arGen.......... | ....................... | std::vector<simb::MCTruth>......................................... | ....1
NiGen....... | rnGen.......... | ....................... | std::vector<simb::MCTruth>......................................... | ....1
SupernovaG4. | rns............ | ....................... | std::vector<art::RNGsnapshot>...................................... | ....2
SupernovaG4. | largeant....... | ....................... | std::vector<simb::MCParticle>...................................... | 11699
SupernovaG4. | largeant....... | ....................... | std::vector<sim::AuxDetSimChannel>................................. | ....0
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Detsim...... | daq............ | ....................... | std::vector<raw::RawDigit>......................................... | .6299
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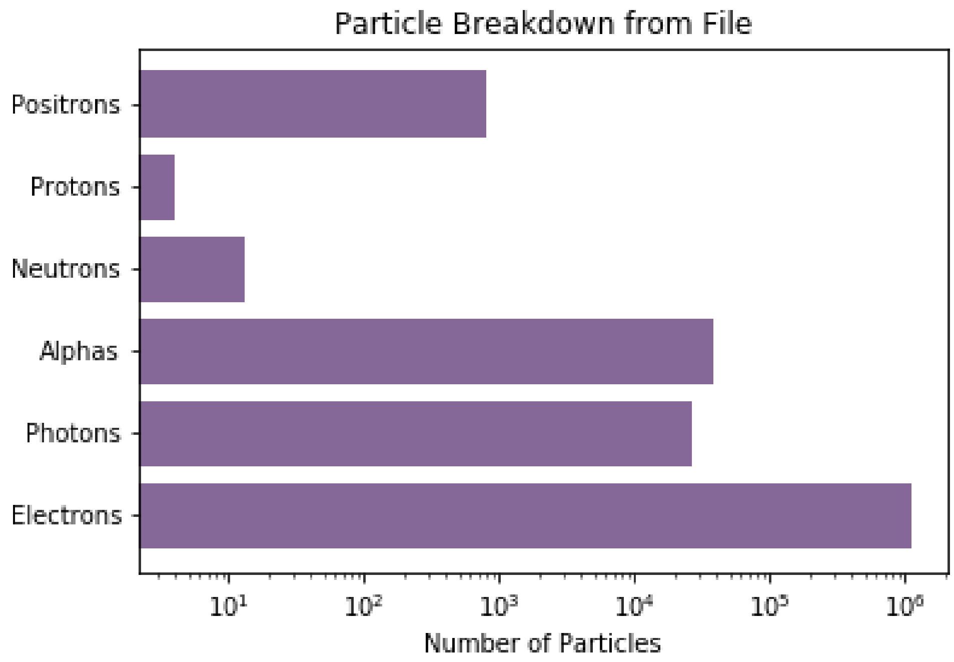
Fermilab

Looking at Background for Feasibility

- Take data from a simulation of radioactive decays to determine where signal is mimicked by the decay products from common radioactive decays in the detector
- As of now, one simulation file is being analyzed to determine what the final products look like from these decays
  - Momenta
  - End Energy
  - Vertex
  - PDG codes
- This file is what is known as a source file, where there is a source that decays
- Exposure: 6.63e-10, for a 10 year time-frame

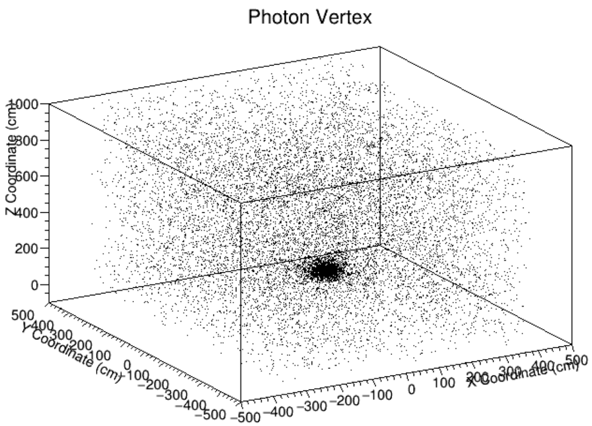
Some Info from the Simulation File

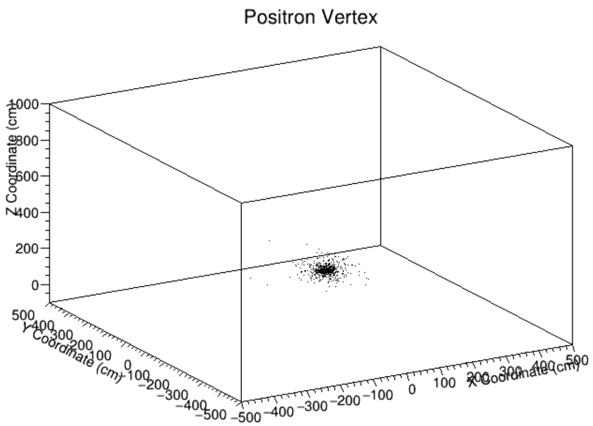
- These plots and data contain a Nickel 59 source
  - Also the other source previously mentioned
    - Argon, Krypton, Radon, Cathode, Anode, Polonium

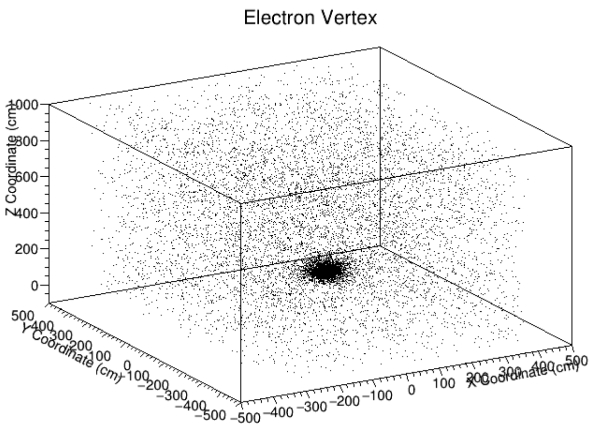


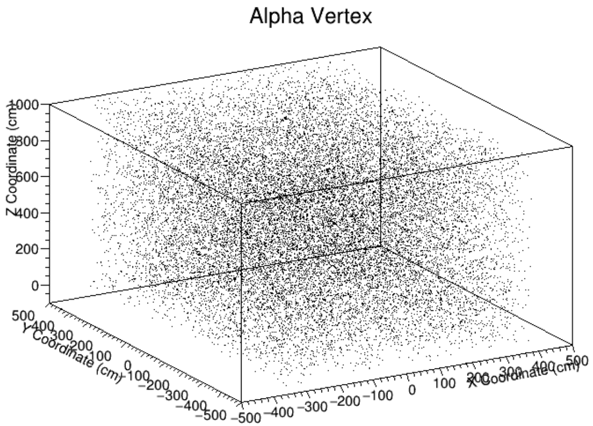
Results

- Source vs. Isotropic



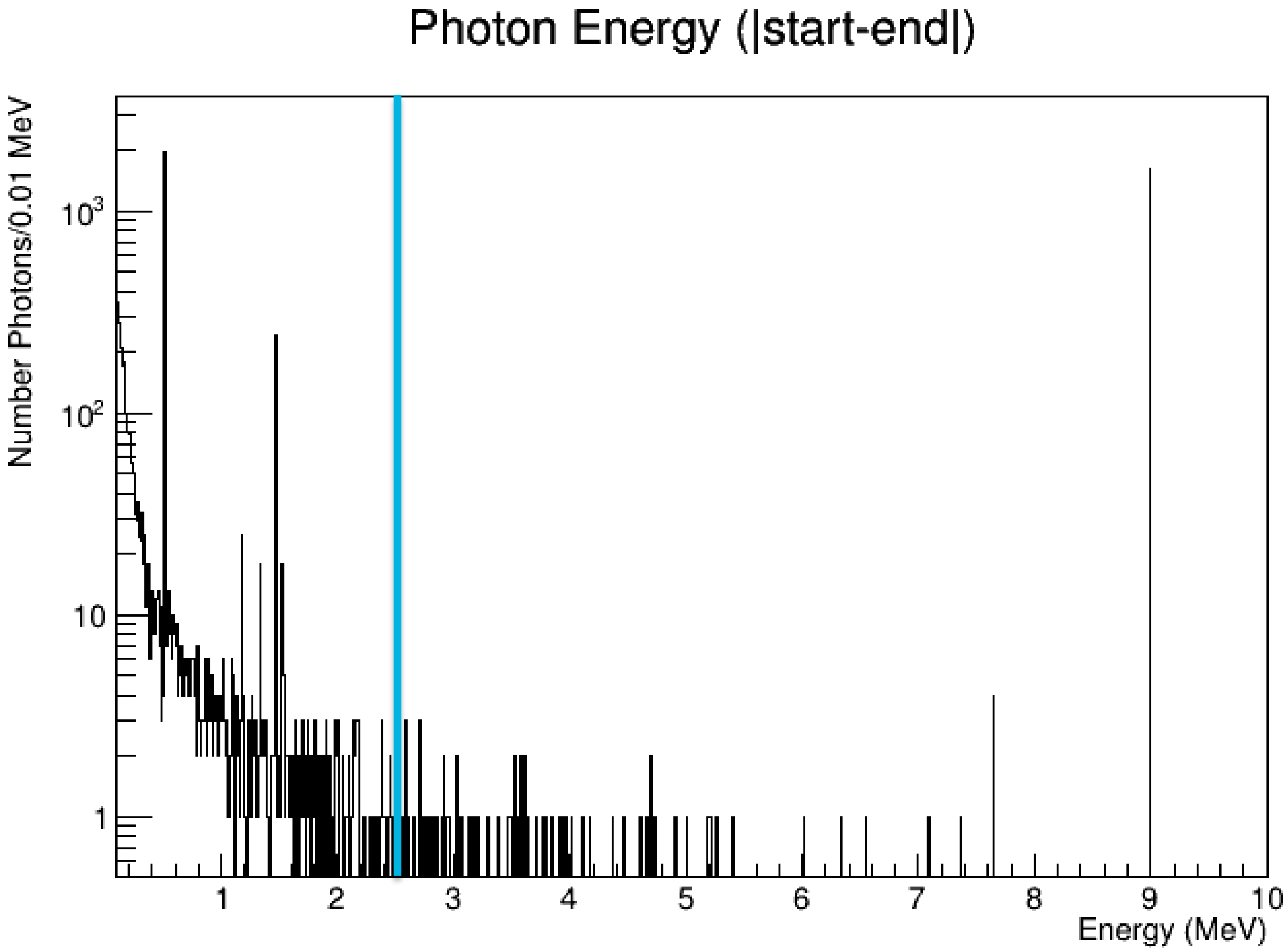






Results

- Energy deposited



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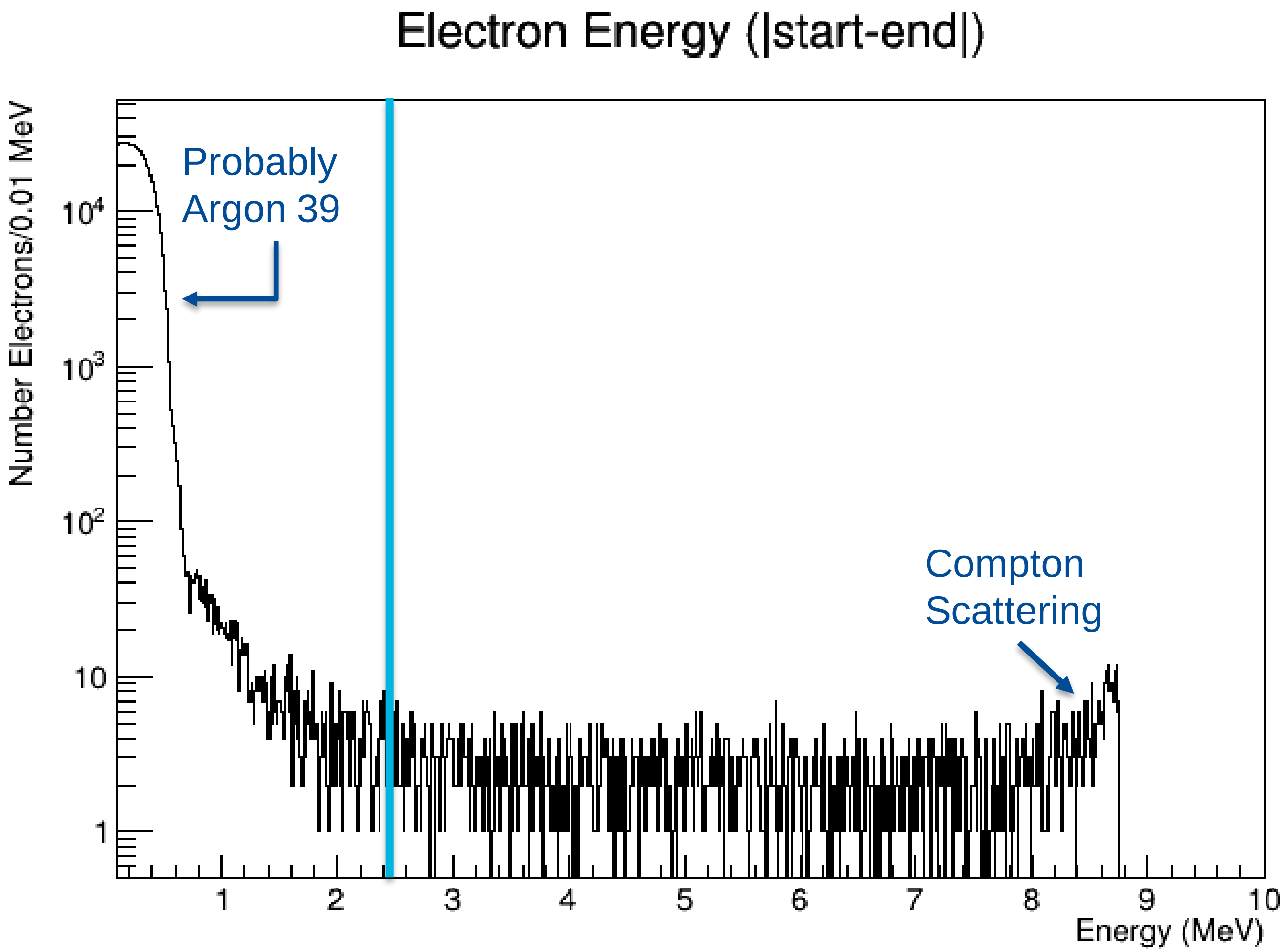

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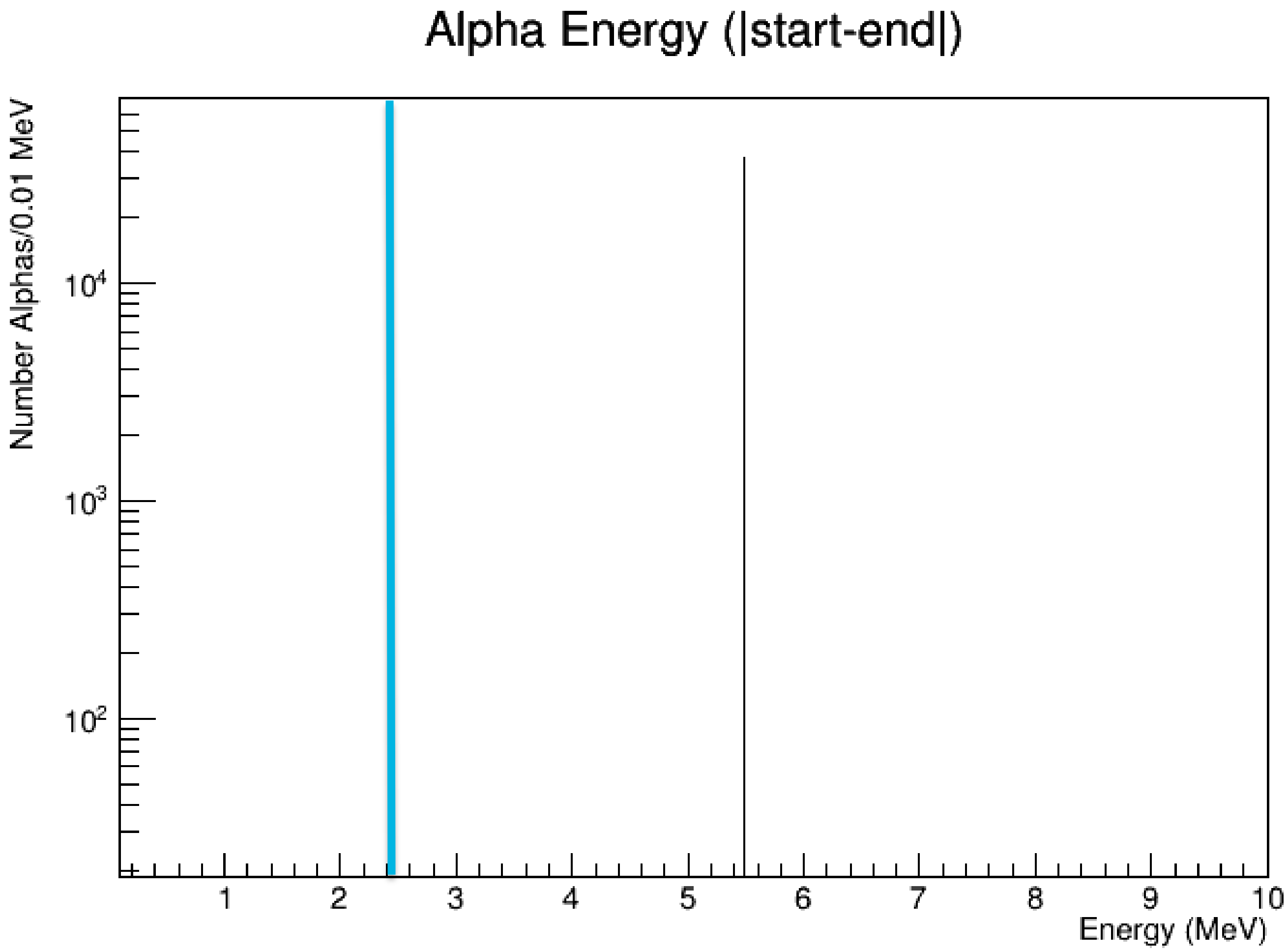

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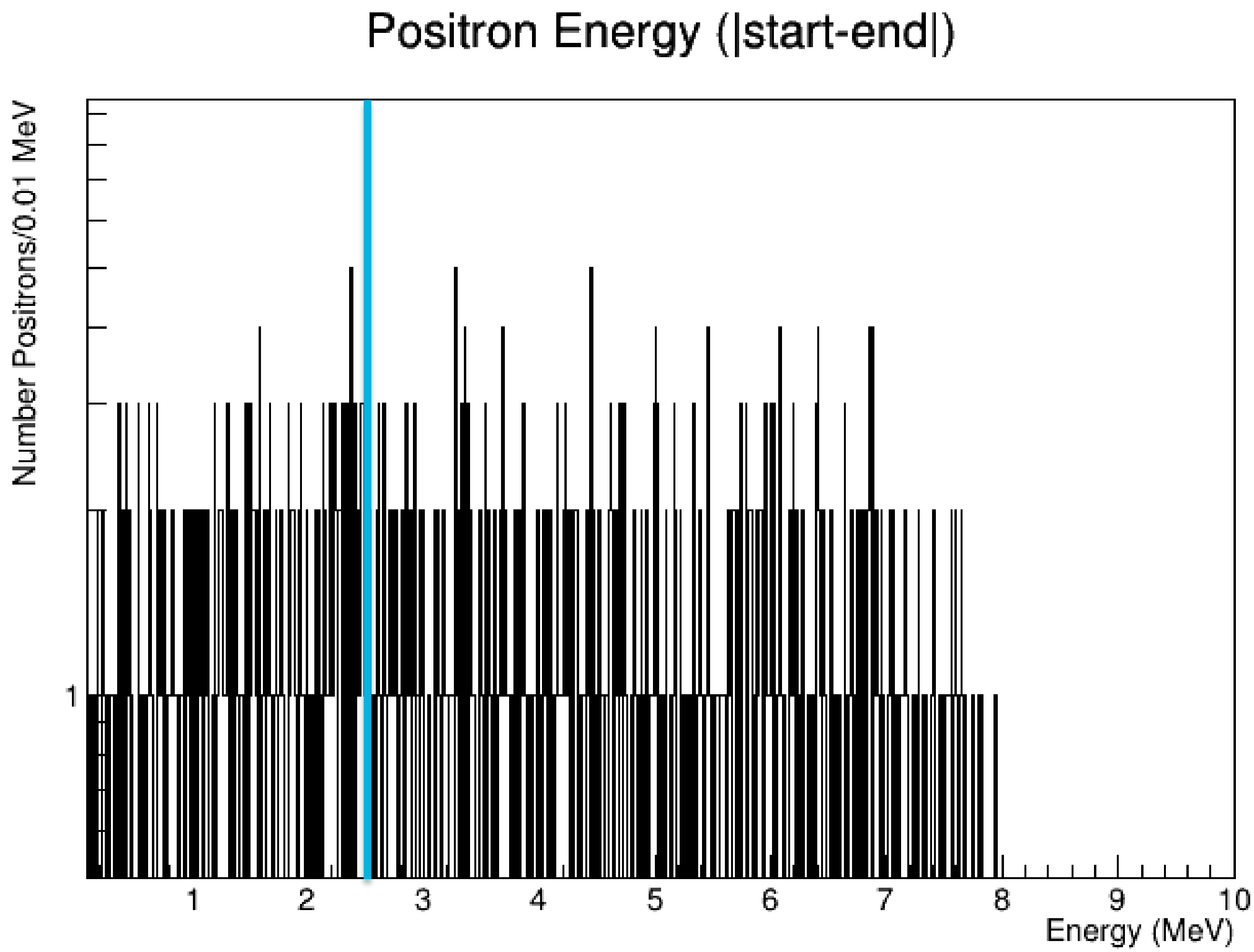

Conclusions

- What do I see?
  - A LOT of electrons that could mask a signal (two energetic electrons)
    - But they are not near 2.5 MeV
  - A decent amount of alphas and photons
  - Not a lot of positrons
    - Means not a lot of electrons can be paired as an electron-positron pair
- Future Steps
  - Look at the motherage, determine the abundances of the parents and their ability to disguise signal
  - Mitigation of background techniques

Thank you!

Joseph Zennamo
Fernanda Psihas
Grace Reesman
Raul Campos
Alex Martinez
Jayson Eddy
Sandra Charles
Judy Nunez
GEM

Thank you!