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Title:	Searching for Double Beta Decay of Nd-146
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Searching for Double Beta Decay of Nd-146

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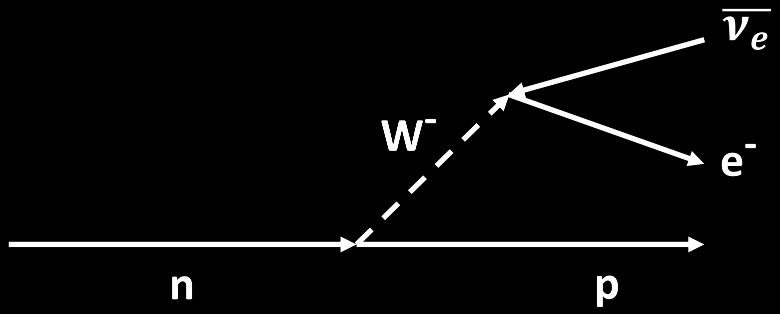
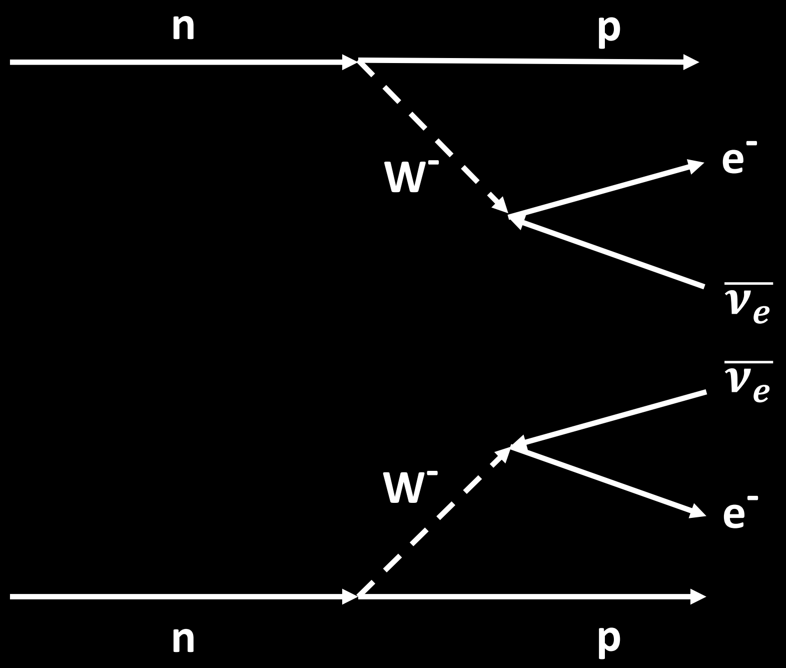
Beta Decay vs. Double Beta Decay

Beta Decay



$$^{A}_{Z}X \rightarrow {}^{A}_{Z+1}Y + e^{-} + \overline{\boldsymbol{\nu_e}}$$

2$\boldsymbol{\nu\beta\beta}$ Decay



$$^{A}_{Z}X' \rightarrow {}^{A}_{Z+2}Y' + 2e^{-} + 2\overline{\boldsymbol{\nu_e}}$$

(shown as beta minus decay, similar decay modes exist)

Information on **ββ** Decay

- 13 isotopes have been observed undergoing either double beta decay (**ββ** decay) or double electron capture (**εε** capture).

- Their experimentally determined half-lives tend to be around 10^{21} years.

- 42 isotopes with A ≤ 260 are theoretically capable of **ββ** decay.

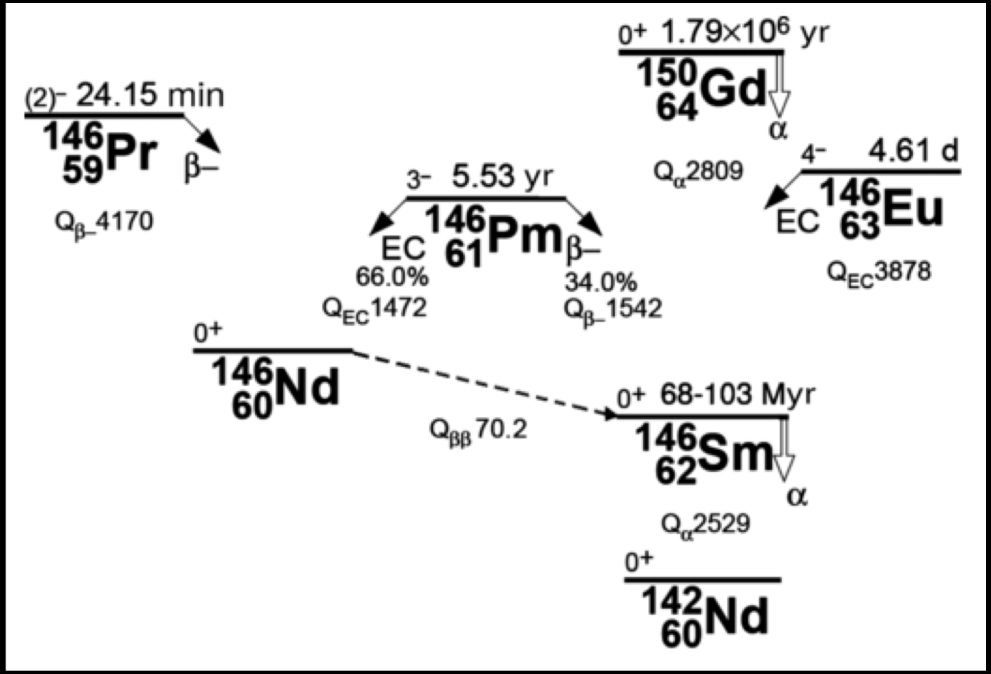
- 46 isotopes with A ≤ 260 are theoretically capable of **εε** capture.

Neodymium 146 ββ Decay

- Nd-146 is one of the 42 isotopes that is theoretically capable of ββ decay.

- Binding energy must increase for nuclear decays to occur.

- The relative binding energy of these 146 isobars is such that Pm < Nd < Sm.



Detecting Nd-146 $\beta\beta$ Decay

- Nd-146 is a naturally occurring, stable isotope (supposedly).

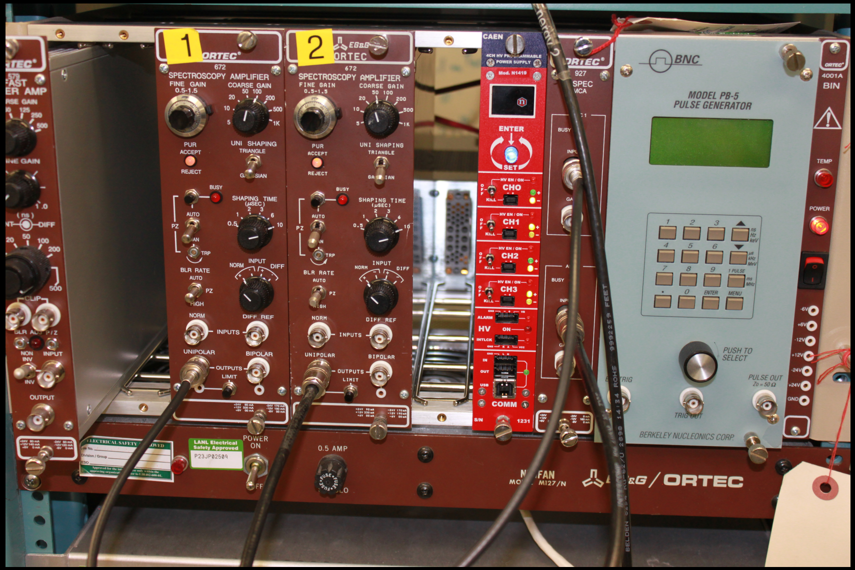
- Sm-146 undergoes alpha decay with a half-life around 6.8×10^{7} years.

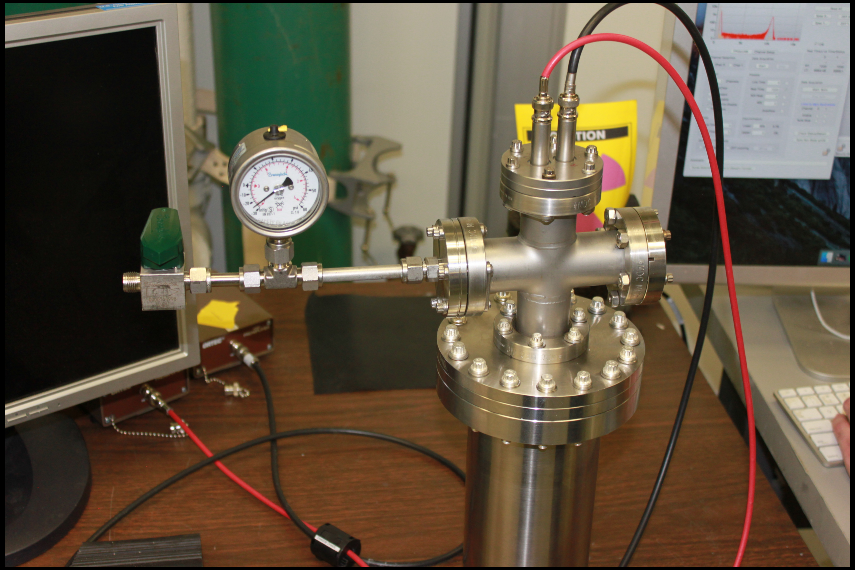
$$^{A}_{Z}X'' \rightarrow \, ^{A-4}_{Z-2}Y'' + \, ^{4}_{2}\boldsymbol{\alpha}$$

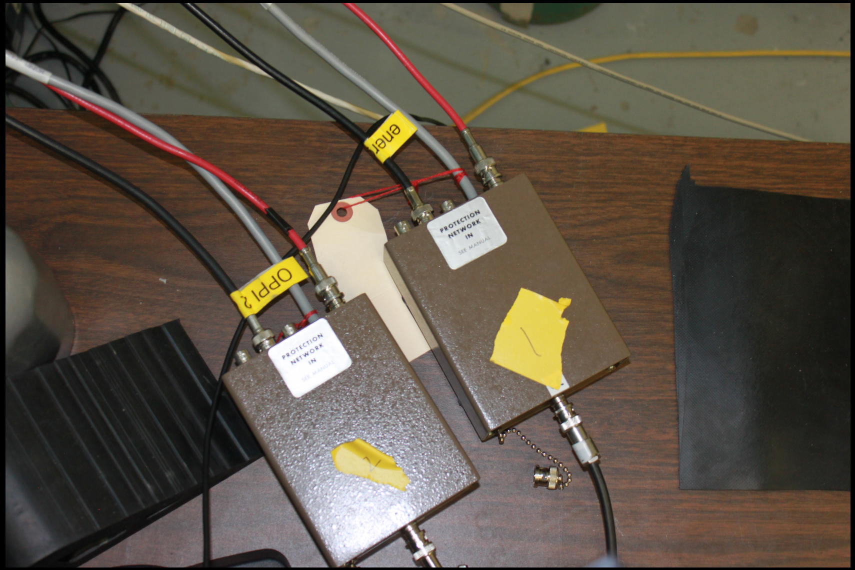
- Relative to the age of the universe Sm-146's half-life is short enough that if there is no natural production method then only trace amounts could remain.

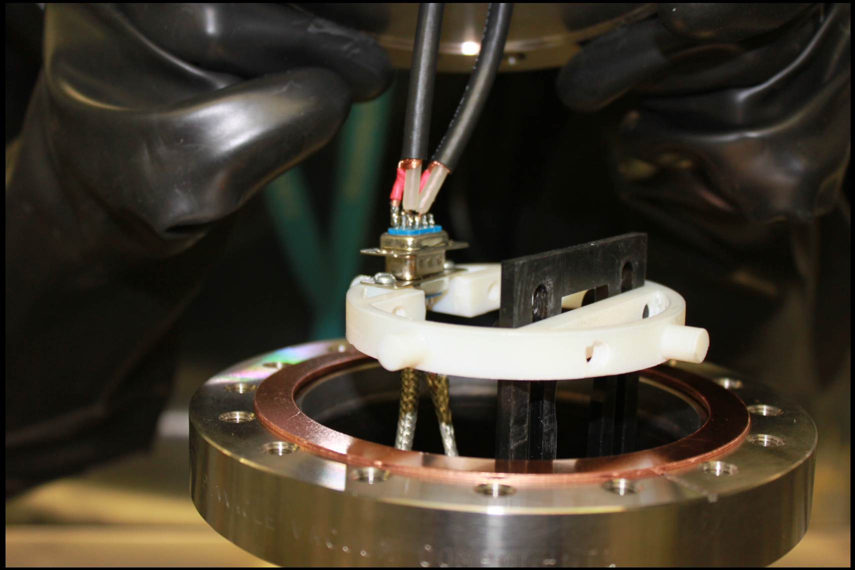
- Therefore, if we can show that there is a measurable presence of Sm-146 in a natural source then there must be a production method, such as Nd-146 $\beta\beta$ Decay.

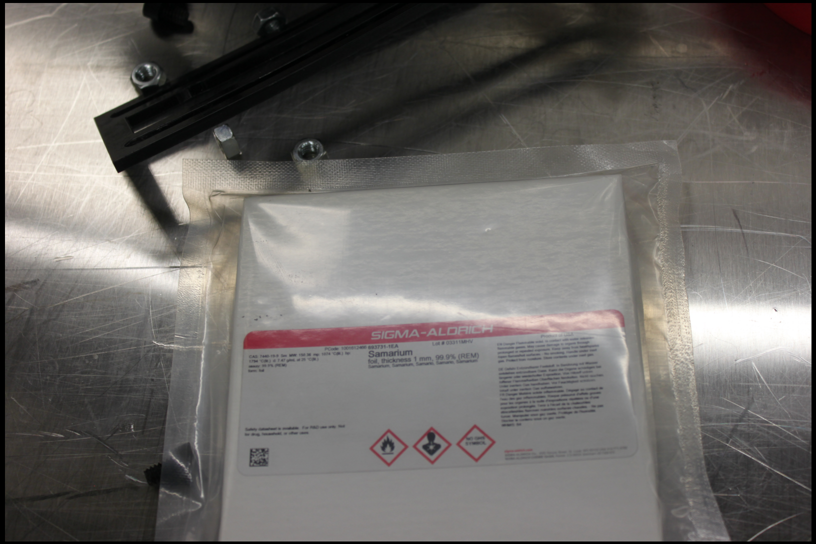
Setup and Design

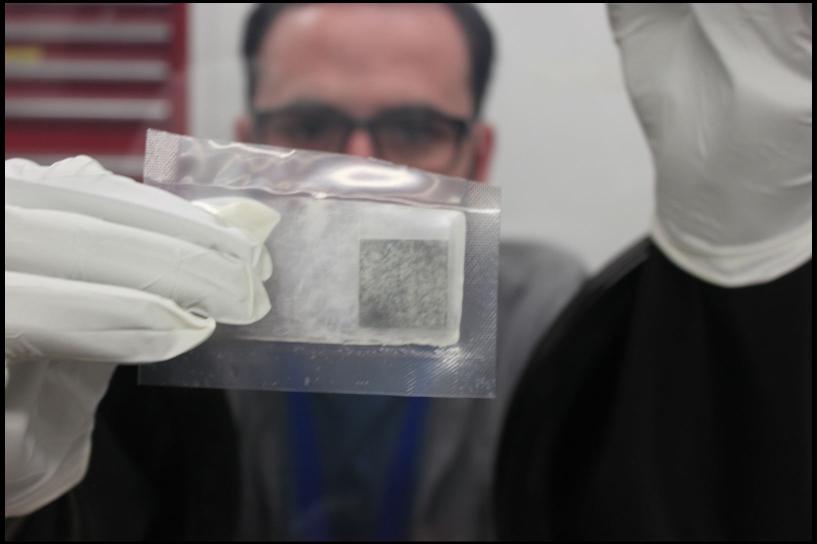


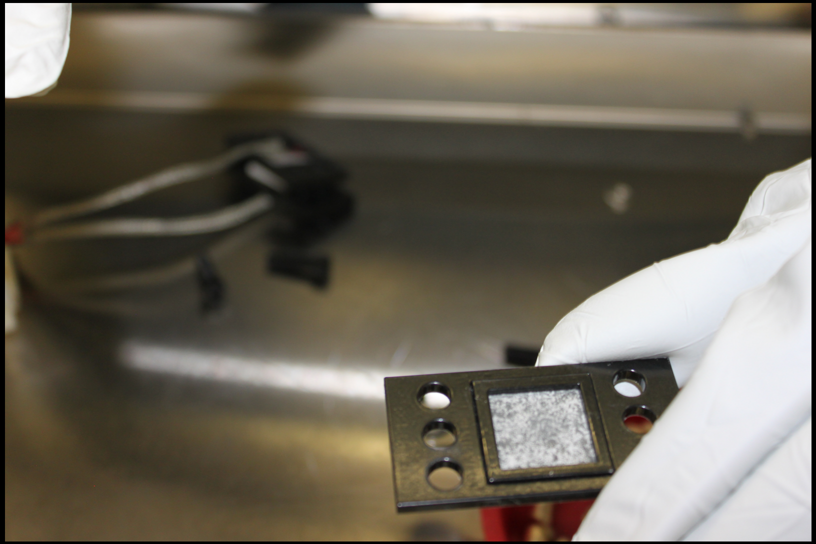


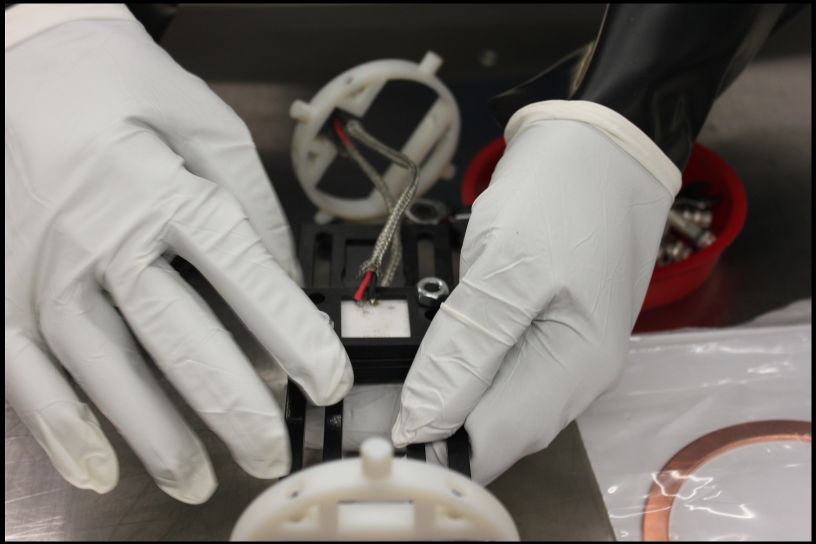


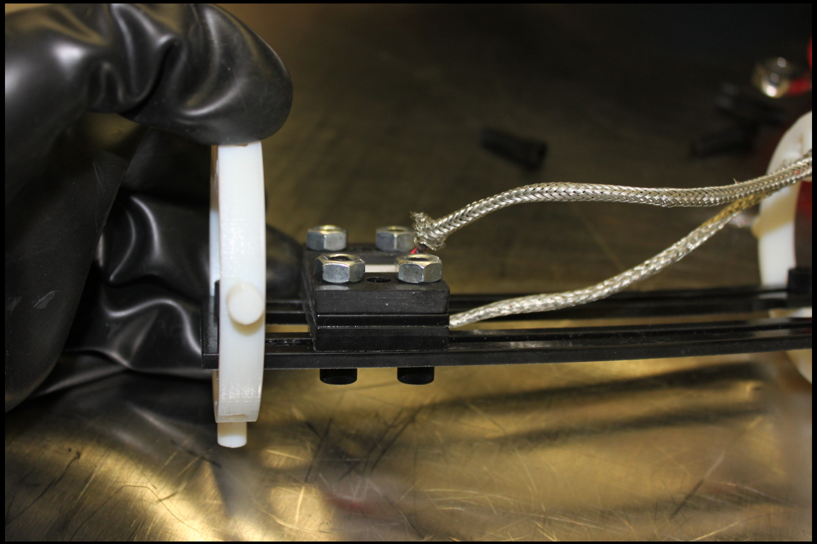


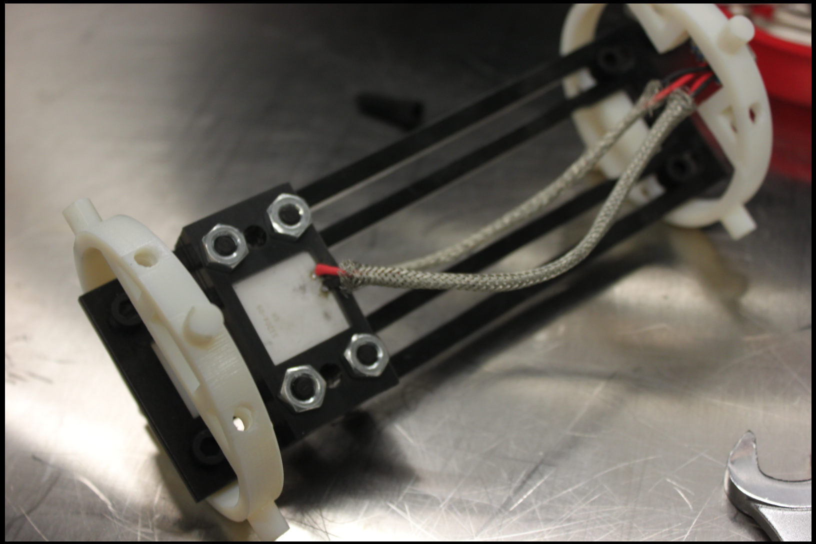

SIGMA-ALDRICH
Lot # 03311MHV
PCode: 1001612466 693731-1EA
Samarium
foil, thickness 1 mm, 99.9% (REM)





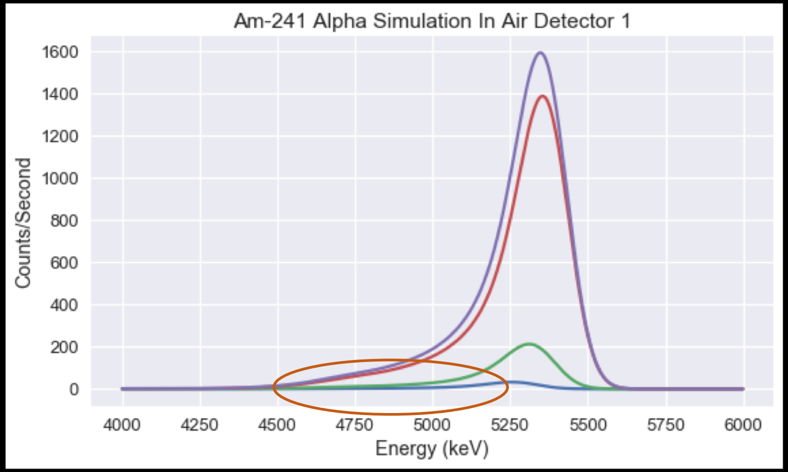


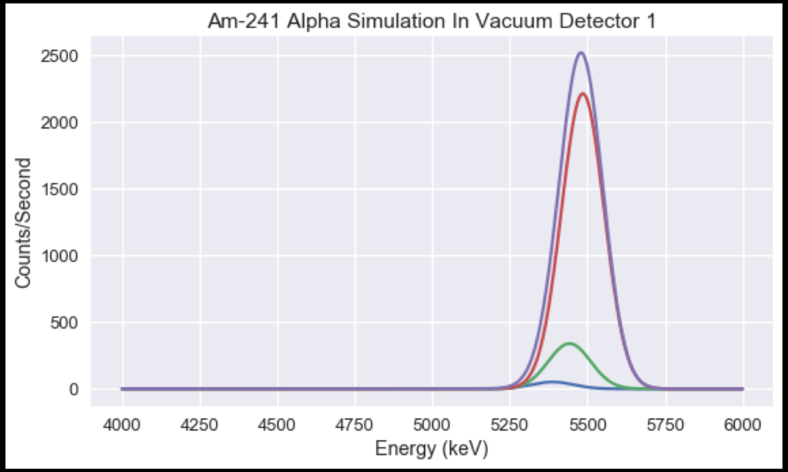




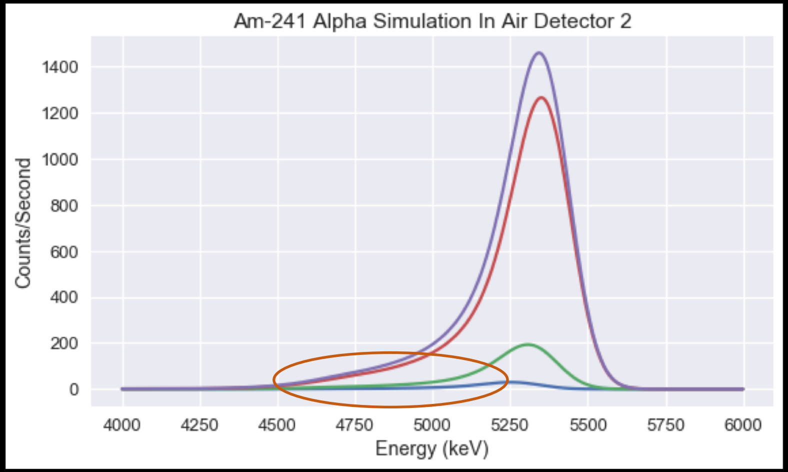
Simulations of Am-241 Alpha Spectrum

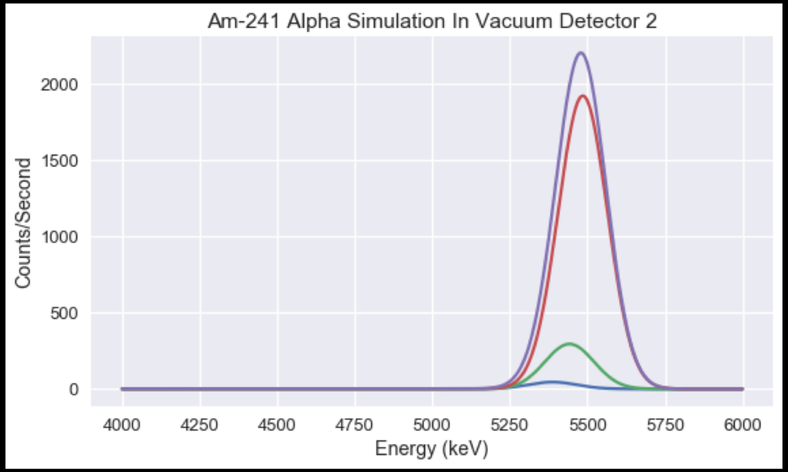
- We want to eliminate the tails (circled in orange) to the best of our ability.
- The effect is caused by energy loss before the particles can reach the detector.
- The easiest way to eliminate this effect is to place the detectors in a vacuum.





Blue – 5388keV, Green – 5443keV, Red – 5486keV, Purple – 5474keV



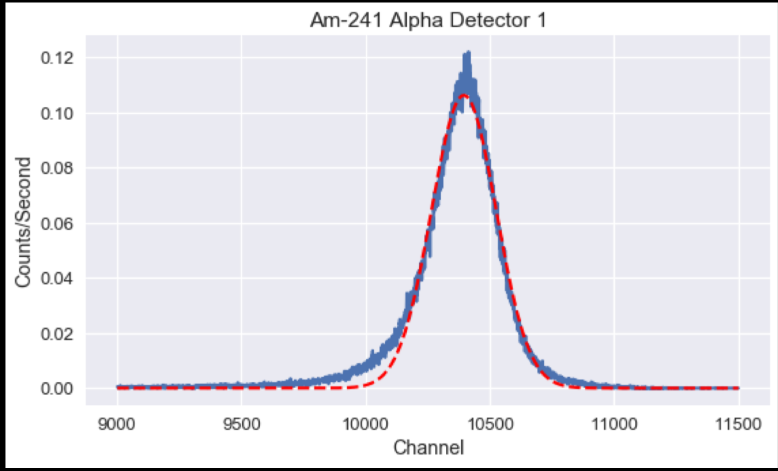


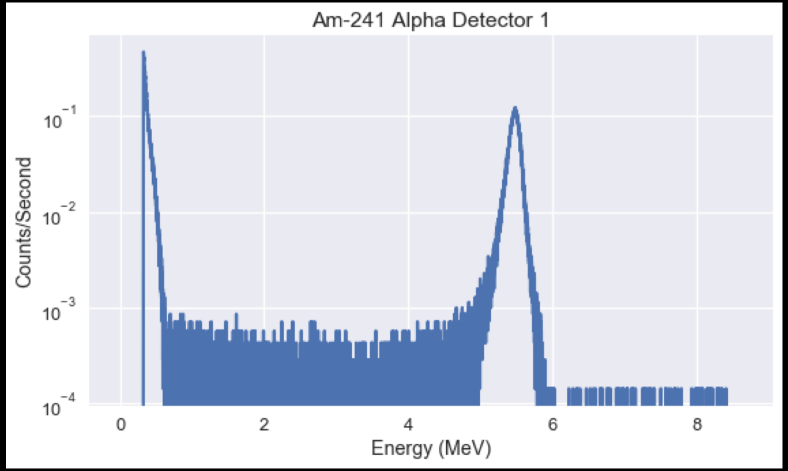
Am-241 Calibration Runs

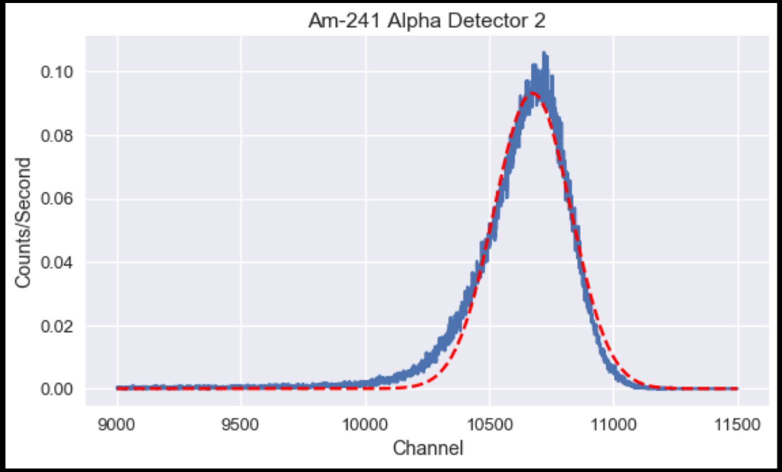
- Fitting a Gaussian to the peak allows us to find the center of it as well as the width.

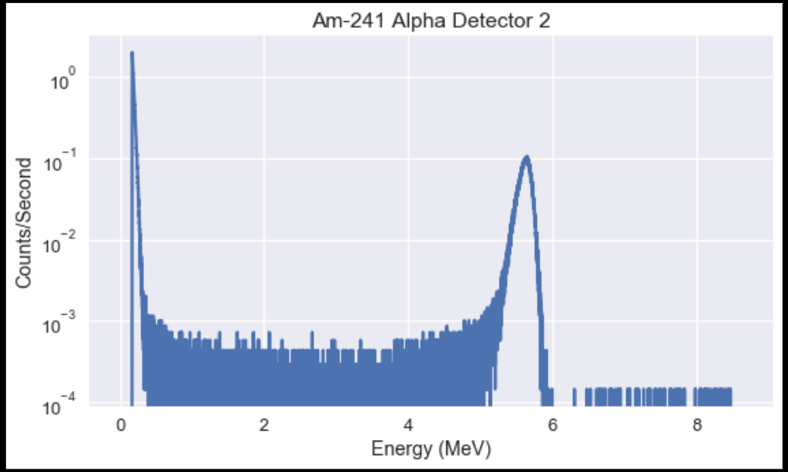
- Knowing the center allows us to convert the channels to energy because the peak energy is known.

- The width of the peak allows us to calculate the resolution of the detector for a given energy.

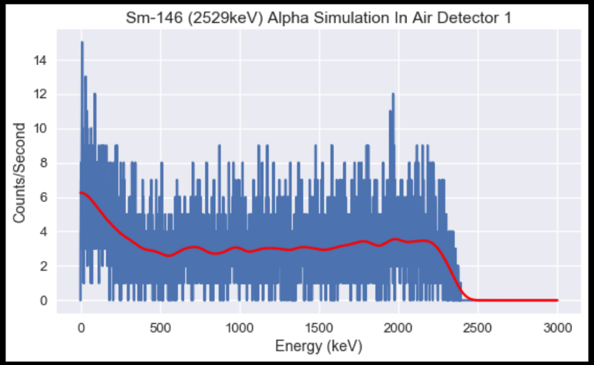


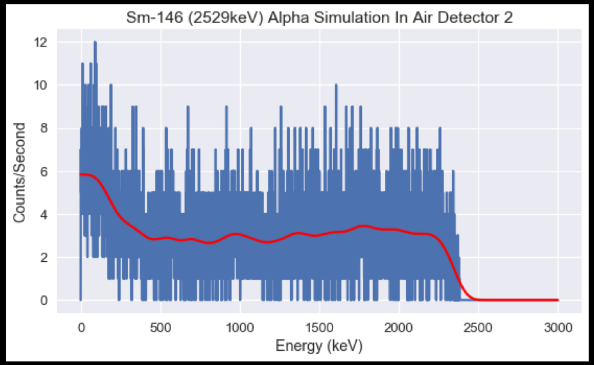


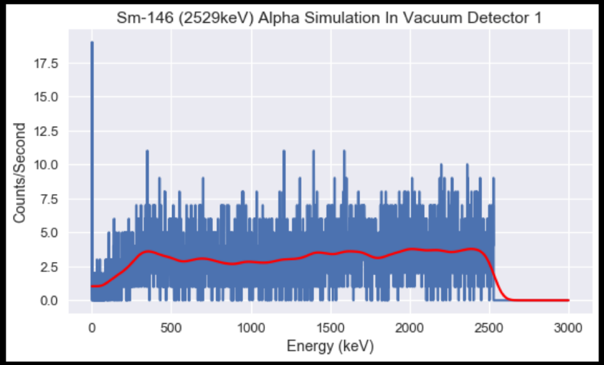


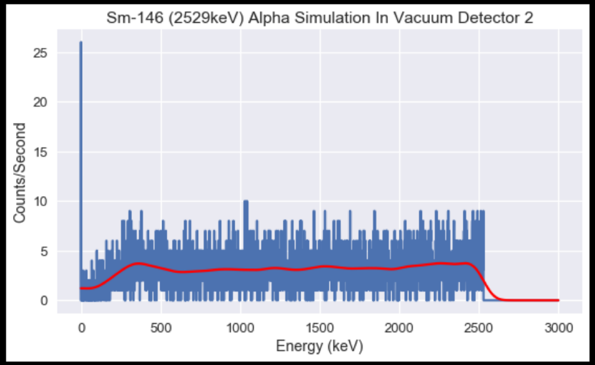


Simulation of Sm Foil Data







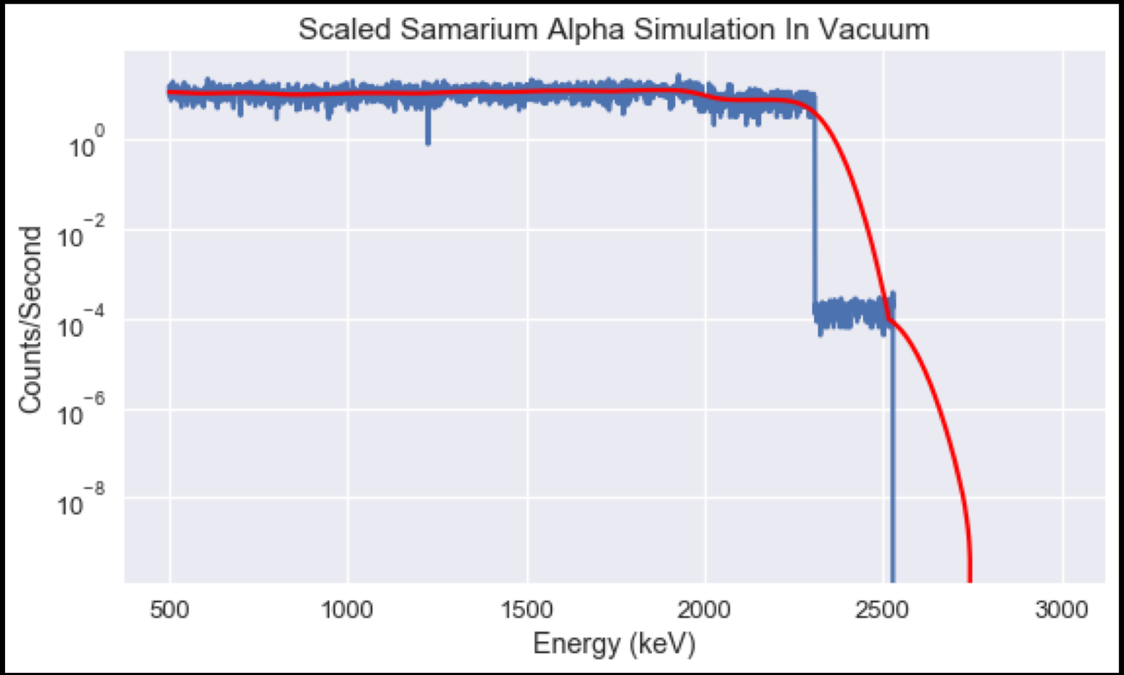


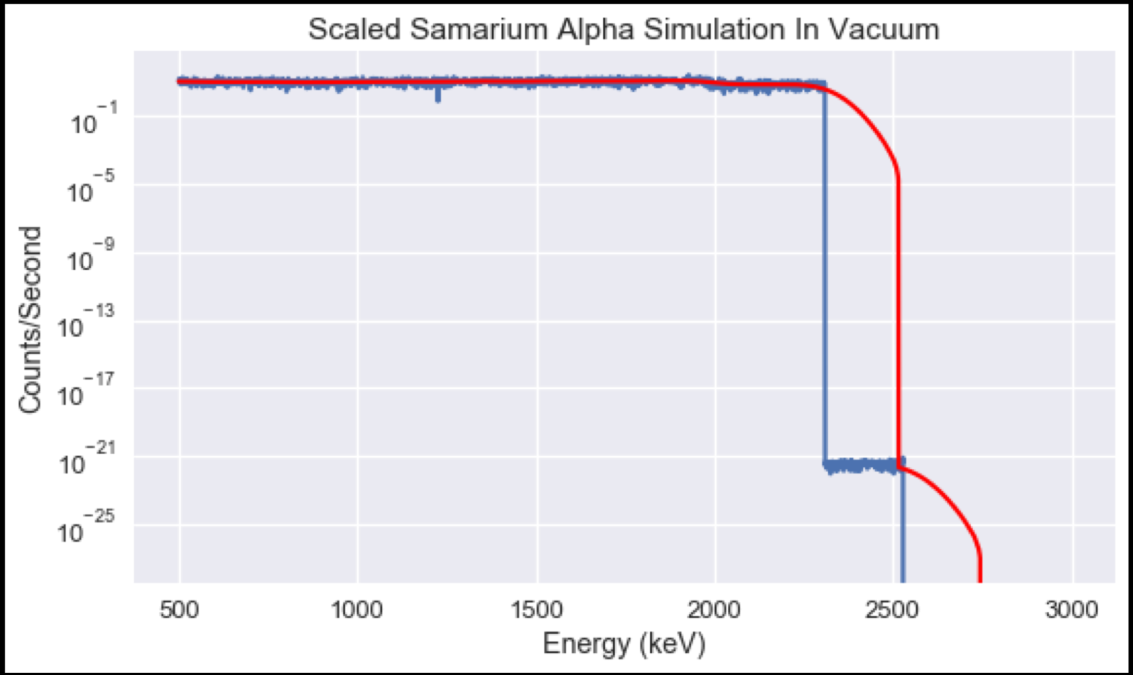
- This is a simulation of the Sm-146 alpha spectrum that is, in theory, emitted from the foil.

- There are two other isotopes that we expect to see decay which are Sm-147 and Sm-148, with energies 2310keV and 1985keV respectively.

- We expect to see a step function, which is essentially true, but below 400keV there is some deviation.

Sum of the Data from Sm Foil Simulations





Calculating the **ββ** Decay Half-life from the Data

Activity is a measure of the rate of decay of an isotope.

$$A_{Isotope} = \boldsymbol{\lambda}_{Decay\ Mode} * N_{Isotope}$$

Decay rate is the inverse of the mean lifetime of a particle.

$$\boldsymbol{\lambda}_{Decay\ Mode} = \frac{\ln(2)}{t_{1/2}}$$

Isotopic abundance is the percentage of a natural source that is a specific isotope.

$$\%_{Isotope} = \frac{N_{Isotope}}{N_{Element}} * 100\%$$

$$A_{Nd146} = A_{Sm146}$$

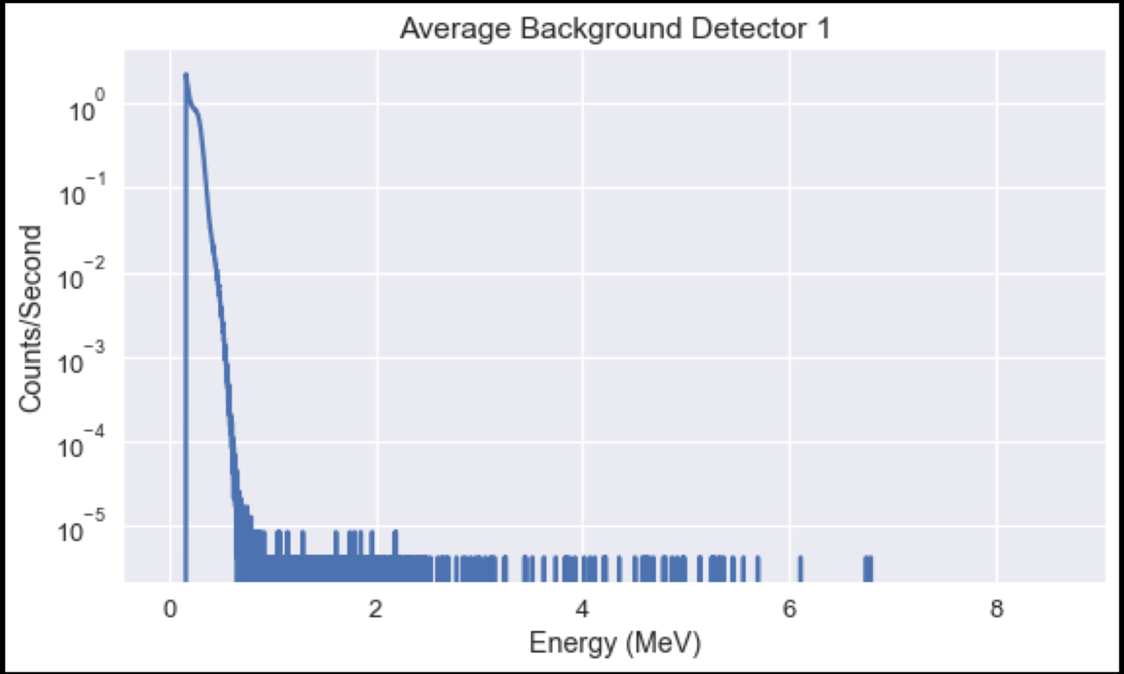
$$\boldsymbol{\lambda}_{\beta\beta} * N_{Nd146} = A_{Sm146}$$

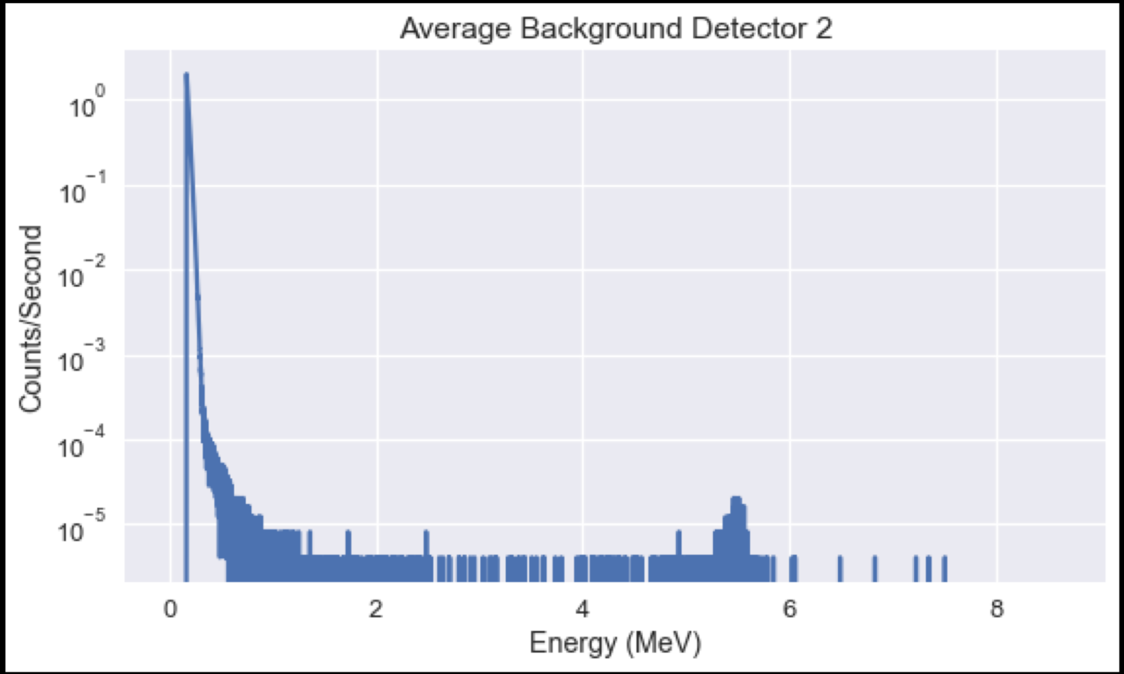
$$\boldsymbol{\lambda}_{\beta\beta} = \frac{A_{Sm146}}{N_{Nd146}} = \frac{A_{Sm146}}{\frac{N_{NdNat}}{N_{SmNat}} * \%_{Nd146} * N_{Sm}}$$

$$N_{sm} = \frac{A_{Sm147}}{\boldsymbol{\lambda}_{Sm147} * \%_{Sm147}}$$

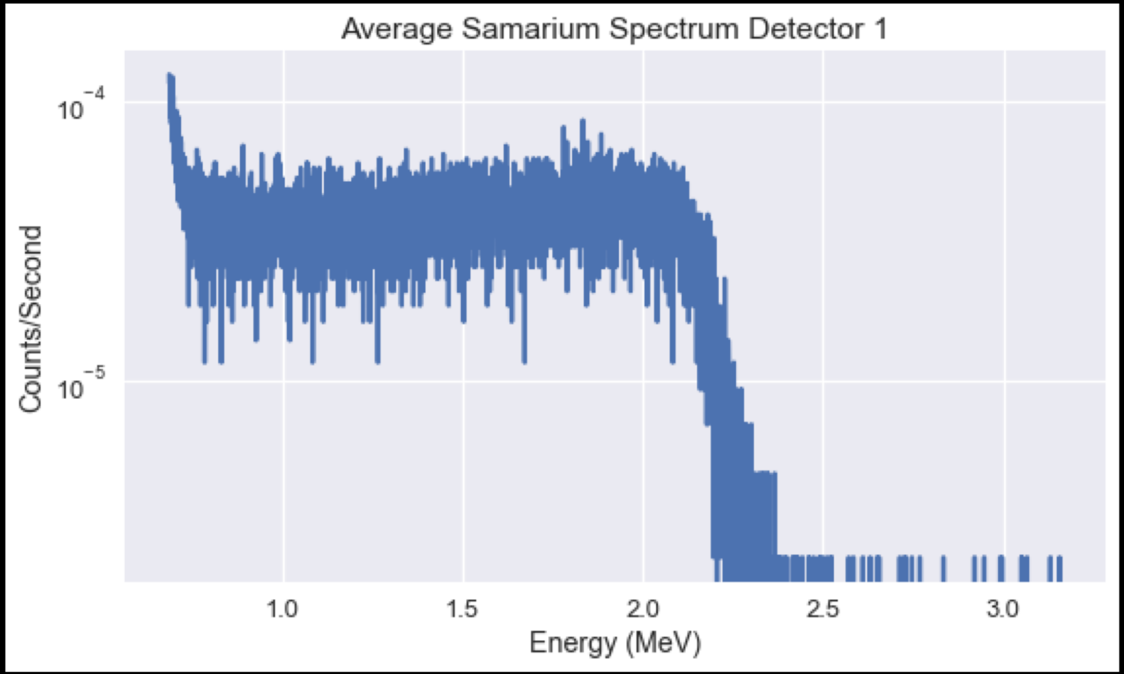
$$\boldsymbol{\lambda}_{\beta\beta} = \frac{A_{Sm146}\boldsymbol{\lambda}_{Sm147}}{A_{Sm147}} * \frac{\%_{Sm147}}{\%_{Nd146}} * \frac{N_{SmNat}}{N_{NdNat}}$$

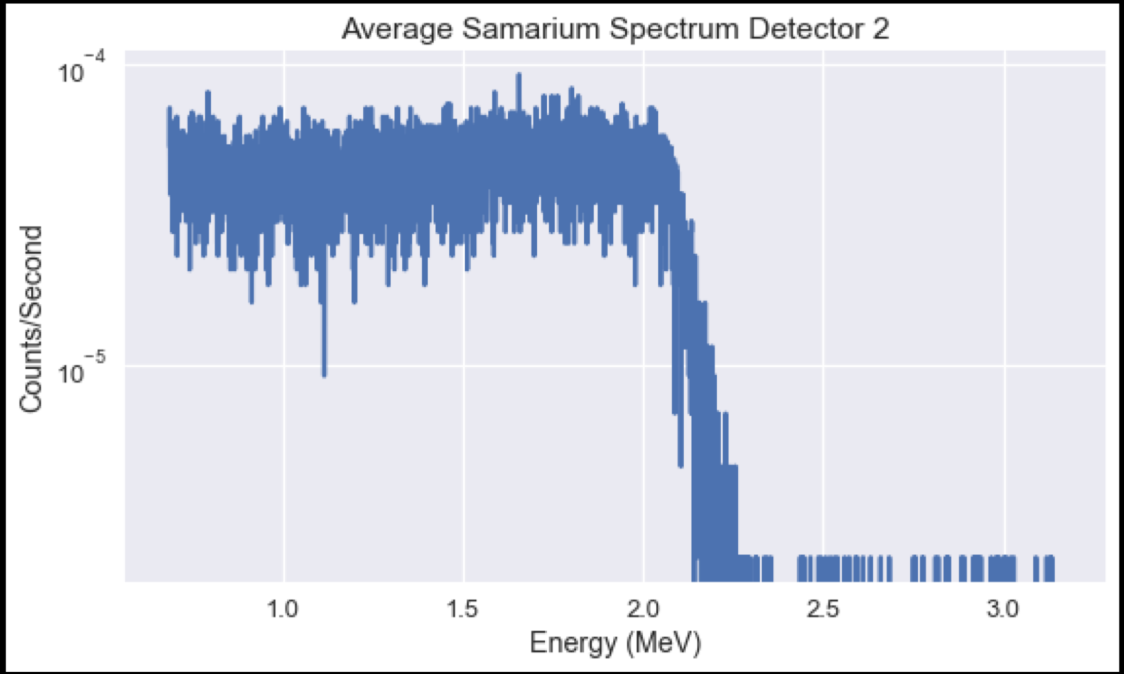
Background Data with Aluminum Foil



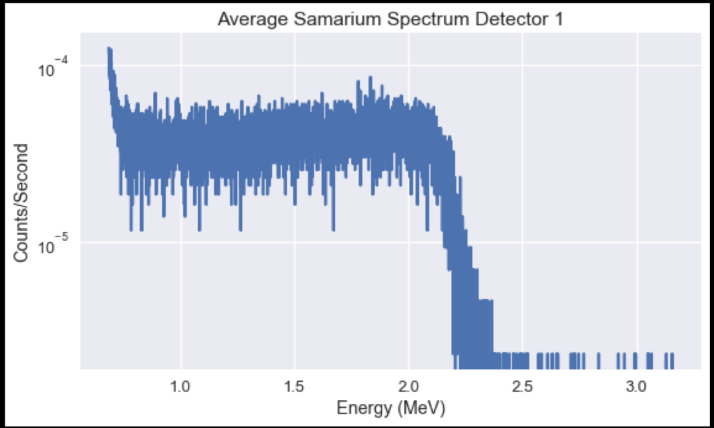


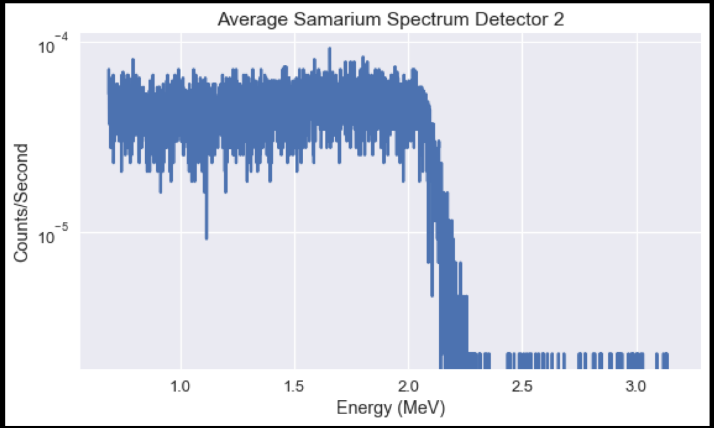
Samarium Foil Data

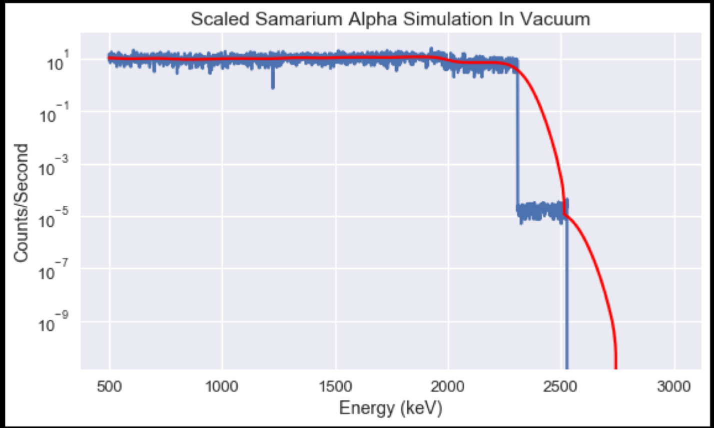




Comparison of Samarium Data and Samarium Simulations







- This simulation is to show the stark difference in appearance between actual data and what our simulations show.

- The limit used for the simulation is the same (tentative) limit that is set by the data to the left of it (with our current analysis method).

- To reiterate, some of the causes of this are from the difference in vacuum and background.

Methods to Improve Results

- Improving the vacuum of our system, during data taking our vacuum was around 5×10^{-2}torr and we can now get a few orders of magnitude better.

- Perform a background run without the aluminum foil to lower background.

- Improve cabling to reduce noise and improve data quality. There are known ground issues on at least one of the cables that we are using.

- Replace at least one detector (the one from UNM).

- Increase number of detectors and amount of samarium.

- Operate in a lower background environment.