Spectrum Viewer and Calibration

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1 Introduction

This software is intended for use to calibrate, view, and analyze spectrum collected from various nuclear instrumentation. The document serves as the primary usage document. This software was developed using Python 3.8 and PyQt5 using packages such as Matplotlib and NumPy. The software has been developed into an executable file such that it can be run as any other program, this is done using PyInstaller. All code is considered open source.

This software is very much in beta phase testing, as such bugs and glitches are to be expeceted. You should report such bugs to the developer or care holder of the software upon discovery of such issues.

2 Install and Initial Opening of Software

This software is provided in a zip folder named Spectrum_Viewer.zip, this folder contains all required libraries and packages for the software to run on a Windows configured machine. Before operation the software first must be unzipped, the built in method doing this in Windows10 should suffice. In the unzipped folder there will be 2 items, a folder named "Spectrum_Viewer" and a shortcut 'Spectrum". The file contains all necessary files to launch the application, this files should not be moved. The shortcut is a shortcut to launch the application, this can be drag and dropped for ease of use. There is a known bug when attempting to start the software from various biulds of Windows. If you experience these issues, you will either be forced to run the software from source or install serval packages and build the software against the specific build.

The interface will open a window containing three main areas, shown below in Figure 1. The left most window will be populated when spectrum are loaded. The right most window will be populated when spectrum are added to the graph. The center section features a full featured graphing utility. This graphing tool bar features the capabiltiy to zoom, pan, save, as well as other varius graphing features.

3 Discussion of Graph Setup

The graph is initiated to be a energy calibrated, count rate spectrum. The count rate by default is shown in logarithmic scale to reveal small magnitude peaks. The energy by default ranges from 0 to 14MeV, the should encompass to vast majority of all possible energies normally seen, this can be adjusted, but more about that in a later section.

4 File Menu

This menu is primarily used for the loading and saving of calibrated spectrum. The methods are listed below as well as there functions:

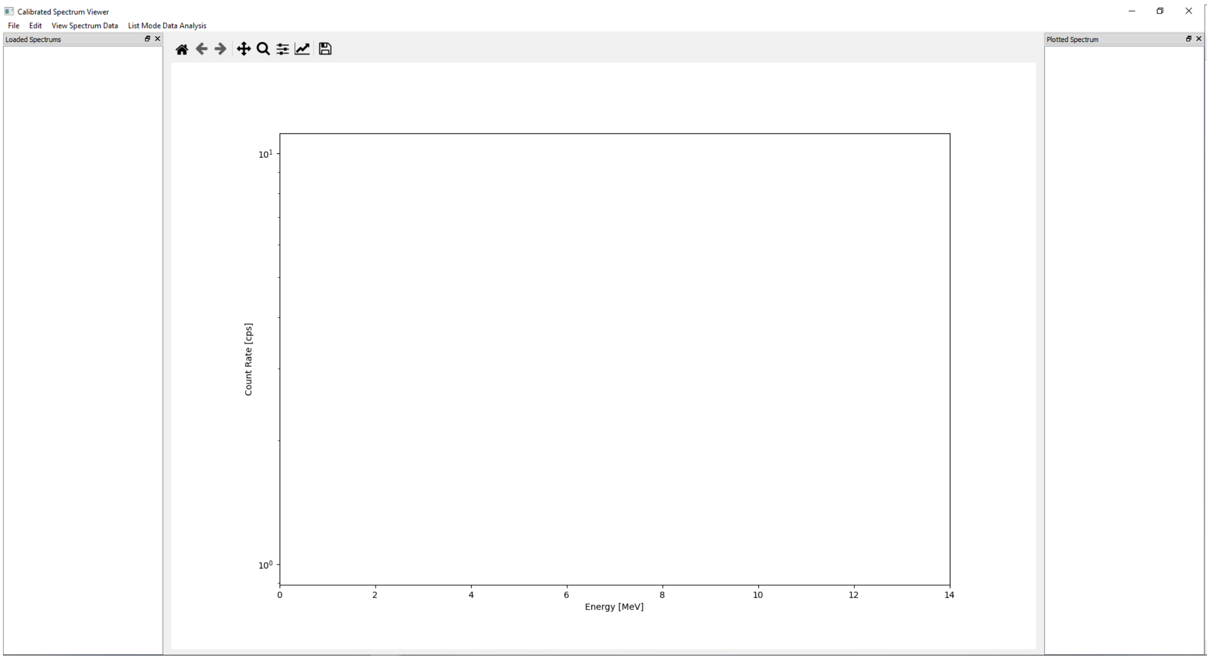

Figure 1: User interface upon initial startup.

4.1 Load New Spectrum

This will open a pop up, this is seen below in Figure 2.
It expects as input:

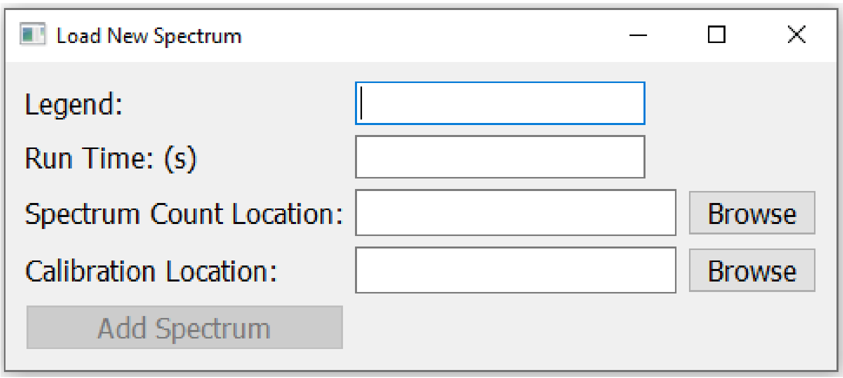

Figure 2: GUI to load new spectrum and calibration.

4.1.1 Legend

The name associated with the calibrated spectrum that will appear in the legend generated during graphing.

4.1.2 Run Time(s)

The total run time of the spectrum accumulation. If left blank, it will default to 1.

4.1.3 Spectrum Count Location

The absolute path to the file containing the spectrum counts on a per channel basis. Will accept plan text(.txt), comma seperated(.csv), and IAEA(.spe). If an IAEA file is loaded, the real-time in the file will be used as the run time, this can not be overridden.

4.1.4 Calibration Location

Absolute path to the calibration file generated using the calibrate spectrum feature (discussed in more detail later). This file will be a single column of energy values whose length corresponds to the total number of channels the spectrum was accumulated using.

4.2 Save Spectrum Image

This will save a high quality image, 600dpi, to the file name and location entered in the standard windows file explorer that will be brought up upon selection.

4.3 Save Spe File

Saves the loaded spectrum out to a .spe file format, including the accumulation time. If a non-linear calibration is incorporated, it will fit a linear equation to the data. This is done to ensure an approximate calibration is saved.

5 Edit Menu

The only option is Calibrate Spectrum. This will launch a new window, seen in Figure 3. The main widget features two indepenedent graphs. The upper represents the raw, uncalibrated spectrum and is plotted on a channel basis. The lower graph shows a linearly calibrated spectrum, this initializes to a 3MeV maximum, with a single peak added it adjusts to a 0 intercept with a single point slope, two or more calibration points results in a linear least squares regression fit being shown. The dotted black line that appears is used to track the cursor to help in the identification of peak centroids. Double-right clicking with initiate a input dialog that will take the energy of the peak in MeV. This will be added to the widget on the left-hand side. Double-left clicking will remove the peak-channel pair. There is no limit to the numer of peaks that can be selected, but a minimum of two are required. This window has one drop down in the menu bar:

5.1 Load New Spectrum

This will load the per channel counts in the spectrum. This will accept plain text, comma-seperated, and IAEA file types. It expects a single column of data for the plain text and comma-seperated variants.

5.2 Rebin Data

This will take the loaded data and compress it into a limited number of bins. The predetermined values for this are factors of 2. Use of this will enable saving of the rebinned data, this must be used to save the compressed data in order to save plot the spectrum in the main window.

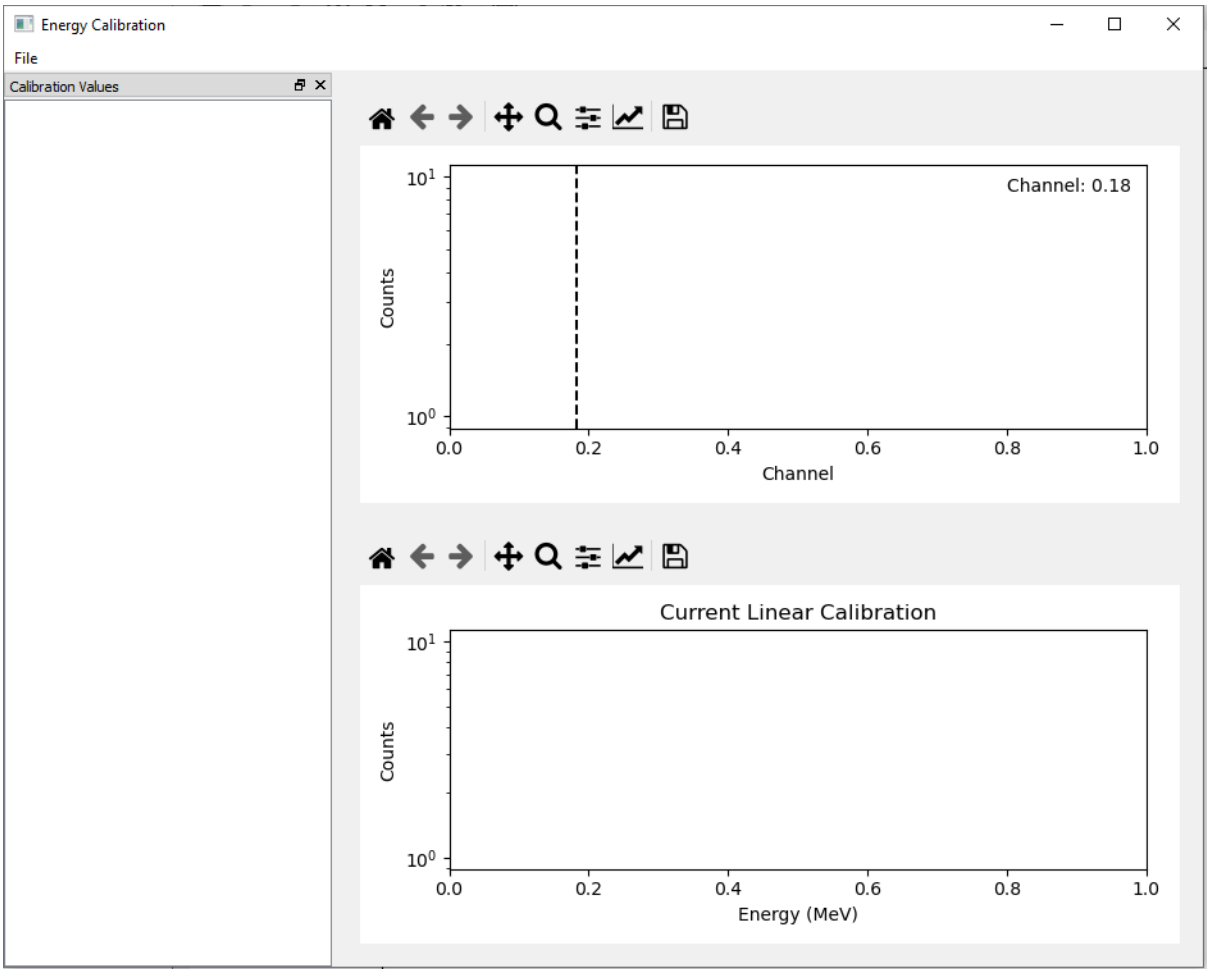

Figure 3: Calibration interface.

5.3 Calibrate

This loads a drop down menu with the following options:

5.3.1 Linear

Performs a linear least squares regression, ultimately resulting in the calibration being in the form of:

$$y = mx + b \tag{1}$$

5.3.2 Deviation Pairs

Conducts a linear least squares fit, the determines the devaition from this at the known points to create and scale each data point. This can be used to generate a non-linear calibration.

5.3.3 External Calibration

Used if a known slope and intercept are to be input. It will fit the calibration to equation 1.

5.3.4 Segmented Linear

Fits a line between each successive point of the inputs.

5.4 Save Calibration

Will save a single column of that relate the channel to calibrated energy as a plain text file(.txt) to the specified location.

6 View Spectrum Data

This drop down has options that come directly from the data loaded into the main interface.

6.1 View Energies

This takes a set of energies, in MeV, separated by commas to draw vertical lines on the graph. These lines will be drawn as a dotted red line.

6.2 Change Zoom Location

Changes the minimum and maximum energies shown on the graph. Much like a zoom feature.

6.3 Calibration Energies

Takes a set of values, separated by commas to draw vertical lines representing calibration energies. These will appear as solid black lines.

6.4 Count Rates

Will display the count rate of all loaded spectrum in counts per second. If a time of 1 second has been entered for the accumulation time, the value displayed will be the total number of counts in the total spectrum.

6.5 ROI Uncertainties

This will compute the gross count rate, net count rate, and the associate uncertainties for each in a specified region of interest. The gross count uncertainties are found using $\sigma = \sqrt{N}$, where σ is the standard deviation and N is the number of counts in the region of interest. The net uncertainty is found using equation 2, where σ_F and σ_B are foreground and background standard deviations respectively.

$$\sigma_{net} = \sqrt{\sigma_F^2 + \sigma_B^2} \tag{2}$$

6.6 Energy Resolution

Once a spectrum has been plotted and is located in the Plotted Spectrum section, the option to view the energy resolution will be enabled. This option uses a peak finding algorithm to analyze and determine the peaks. The energy resoution is calculated as the full width half maximum of the identified peak divided by the peak centroid location. This is calculated and displayed for each peak found in the spectrum. The energy resolution is displayed next to a vertical line as a percentage.

7 List Mode Data Analysis

For data collected using a digitizer, or similiar equipment, this menu features numerous options to analyze and save various data. This has the expectation of time dependent data being collected, i.e. a source is being pulsed using a logic pulse. With detector and sync pulse data both being captured and recoreded as raw data.

7.1 View Time Decay

This is used to generate a plot of multiple region of interest pulse arrival times relative to the sync pulse. This must be run after having used the list mode data set of tools. The first pop up will request the number of data sets to be plotted. After selection of this, the windows file explorer will be generated. It will expect a file that is two columns, the first being time stamps, the second being a number of counts accumulated during the time step. This will be repeated for the total number of files selected. Several additional windows will appear that request additional information regarding the frequency, duty cylce, and location of region dividers. All of which are optional. The data will be processed and plotted in the window upon clicking the “Process” button. A high quality image, 600dpi, can be saved with the selection of the “Save Image” button.

7.2 Analyze List Mode Data

This is the primary interface for loading and manipulating time dependent data. As such an entire section is dedicated to this later in this document.

7.3 Detection Probability

7.3.1 Theory

This is used to determine the time required to reach 99% detection probability. Poisson and Gaussian Statistics are implemented in their respsective regimes, less than 30 counts for Poisson and any number of counts greater than 30 for Gaussian. For Poisson statistics, the distribution is only dependent on the mean, μ, in this case the mean is taken as the number of counts, this is seen in equation 3. Gaussian statistic distribution is dependent on a mean, μ, and variance, the mean is again taken to be the number of counts and the standard deviation to be $\sigma = \sqrt{N}$, the distribution function is seen in equation 4.

$$P = \frac{\mu^k exp\left(-\mu\right)}{k!} \tag{3}$$

$$P = \frac{1}{2\pi\sigma^2} exp\left(\frac{(\mu - k)^2}{2\sigma^2}\right) \quad (4)$$

An example of a foreground and background distribution plotted together are seen in Figure 4. The background distribution is used in conjunction with a maximum false alarm rate, one alarm per eight hours is the default, to find a threshold to be used to determine the detection probability.

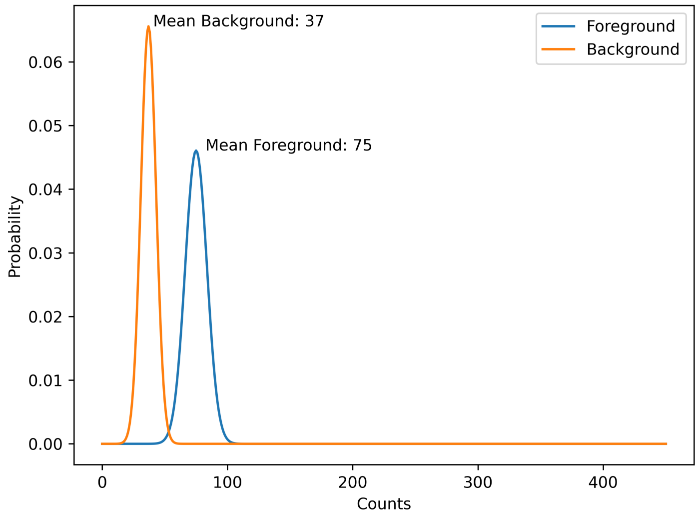

Figure 4: Probability distribution functions for a foreground and background plotted together.

The probability distribution functions are then numerically integrated using trapezoidal rule. The integration of this must sum to exactly one. The foreground and background cumulative density functions, along with the threshold is seen in Figure 5.
Using the cummulative density function and the threshold, the detection probability is

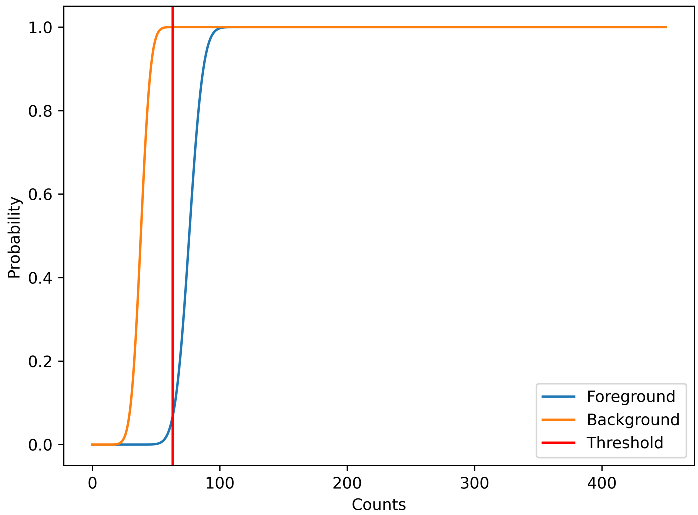

Figure 5: Cummulative density function with detection threshold indicated.

found as $1 - f_{cdf}$ where f_{cdf} is the foreground cummulative density function evaluated at the threshold index. For the given examples the detection probability is 93%.

7.3.2 Implementation

Two files are required for this to work, a background and a foreground, these are selected in this order. The files are generated using the "Save ROI" method in the "List Mode Reader" interface. The files take a two column form with a time of arrival and energy as the two columns. A window will appear to set the first time step to begin integrating. This is due to statistical fluctuations at extremely low count fields. A total of 181 time steps are taken over the entire length of the accumulated time.

It should be noted that this portion may take a significant portion of time to run due to have to generate, and integrate 362 discrete functions.

Upon completeion of the analysis, the software will automatically bring up a windows file explorer to save the data points out, to be used for generation of a video. This will then generate a plot of the probability of detection versus time, the software will indicate the point at which the detection probability rises above 99% for the first time. Care should be taken by the user to ensure the start point has not removed prudent data, but is high enough to remove any erroneous data points.

7.4 Save Probability Video

This generates a video from the probability data saved using the detection probability function. It expects as input a two column file with time in the first column and a detection probability in the second. It saves as an mp4 file type.

7.5 View Detection Probability

When the detection probability algorithm is used, it generated a data file containing the number of pulses, along with time stamp and detection probability. This interface allows for the user to analyze this data and plot multiple files on top of each other. This interface features a slider that can be used to change the detection probability, this will update the legend to show the new time needed to determine a detection.

8 List Mode Viewer

This window is launched from within the main spectrum viewer application. Upon launching there are four individual graphs, seen in Figure 6. This is used to split the list mode data acquired using the sync pulse and detector data. This will split that data relative to a sync pulse with an offset, with the data before the divider being referenced herein as region 1 and data after the divider as region 2.

The top left graph will display the arrival of the pulse relative to the sync pulse. Top right will display the total spectrum as well as split data (region 1 & 2). Bottom left will display only the region 2 spectrum, and the bottom right will display region 1 data.

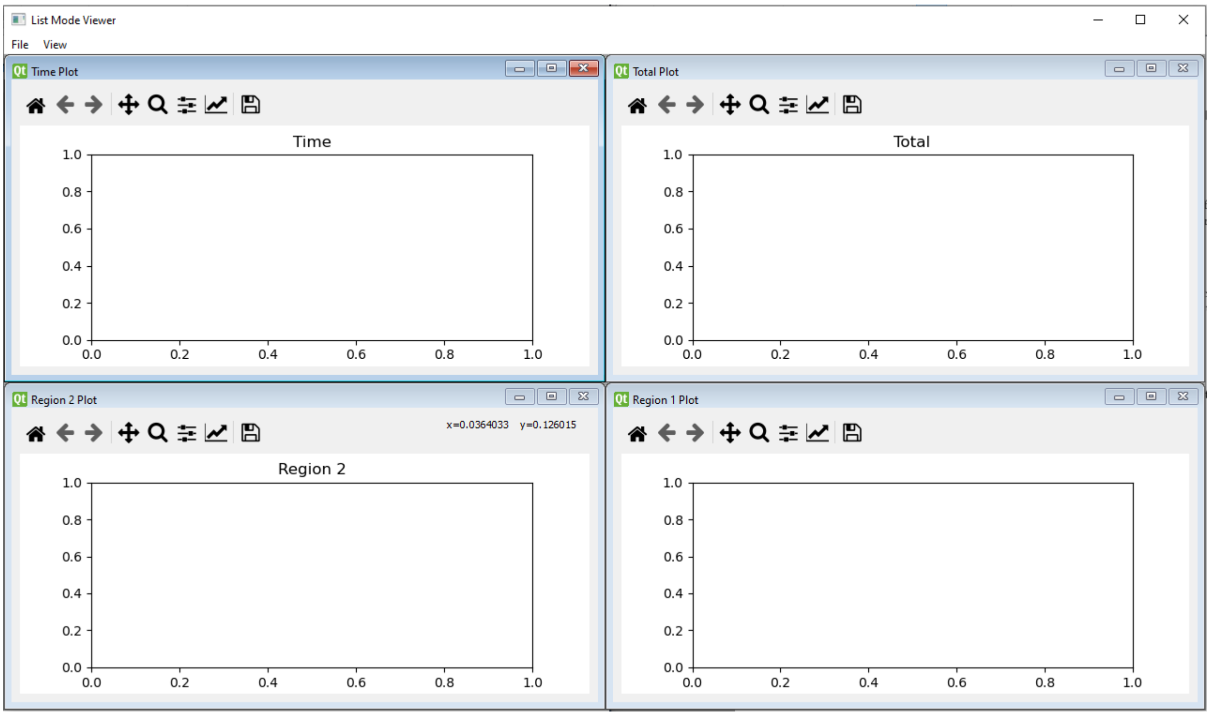

Figure 6: Initial launching of list mode viewer

8.1 File Menu

8.1.1 Load New Data

This launches the interface seen in Figure 7. The sync pulse and detector pulse are comma seperated files, corresponding to there respective files. It is expected that the comma seperated file will be in the form of having time, in nanoseconds, in the first column and a channel number being the second column. Once the files are loaded, the browse buttons with change to green. The final option is to add a calibration file, having been generated using the "Calibrate Spectrum" functionality. This is required to generate detection probability data.

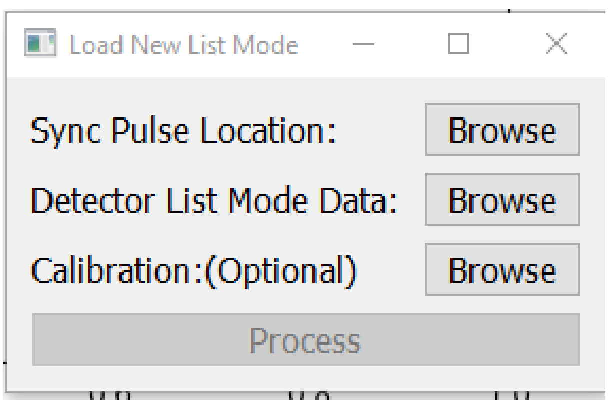

Figure 7: List mode viewer data loader

Once the appropriate files have been selected, the sync pulse and detector list mode data buttons will change to green. Additionally the process button will become enabled.

Clicking the process button will initiate the process of reading the data in. The software will split the data into two regions by comparing the sync pulse arrival and the arrival of the lsit mode data. **This process can take several minutes dependent on file size and host computer.** The software will automatically calculate the frequency of the pulse arrival, but the software cannot determine the duty cylce of the pulse, as such, once the data has been imported and loaded, a new control panel be loaded, as seen in Figure 8.

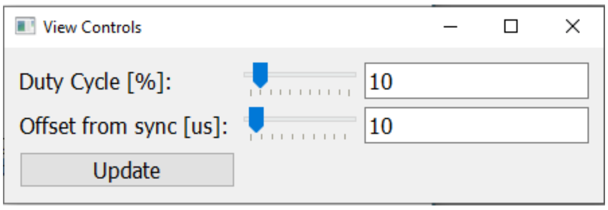

Figure 8: Control panel for adjusting duty cycle and offset times.

This panel can be used to adjust the duty cycle, in percentage, and offset, in μs. The offset is the divider for region one and region two, while this is typically a positive integer, it is possible to adjust the slider bar negative. Both of these default to 10. It should be noted that adjustments must be made using the sldier bar for both values. Once a change has been made, the update button must be pressed, **again, this may take upwards of several minutes to process**.

As has been noted multiple times, this process is extremely memory intensive and time consuming. Use of a machine with limited memory is not advised, it is suggest that a minimum of 32GB of memory be installed in the machine. You can go online and download more memory if necessary.

8.1.2 Save Spectrum

This initiates a spectrum saving sequence. First is unsures the values in the controls window represent the data shown on the screen, this may take several minutes to validate. A pop up will appear to select the data to be saved, Region 1, Region 2, or Time Decay. Region 1 and Region2 will save a plain text file(.txt) having a single column of counts related to the channel. Time Decay will save either a plain text file (.txt) or comma-seperated file(.csv) having two columns, the first being time, in microseconds, the second being the number of counts accrued during that integration.

8.1.3 Save ROI

This initiates a raw data saving sequence. This will take the data from region 2 in a specified region of interest and save only these pulses to a seperate file, this is designed to be used for detection probability tools. The first windows explorer that will appear will ask for the location in which to save the comma seperated file. This file will have the energy, in MeV, followed by the time, in seconds for the two columns. If no calibration file was selected during loading of data, an additional file explorer will be displayed to select the desired calibration file. There will be two final pop-up windows to enter the region of interest. The data will be processed with no additional indications of success.

8.2 View Menu

The first two options in the view menu will shows the time adjustment tool and show all plots, respectively. The two remaining options investigate the consistency of sync pulse arrival and the arrival times of the region of interest pulses relative to the sync pulse.

8.2.1 Pulse Deviation

This uses the sync pulse file to generate a arrival profile for the sync pulse. The file is parsed and the time delta between pulse arrival times is tabulated. The mean and standard deviation are calculated from this tabulation. A histogram is generated using the full featured plotting windows used for all other plots. The mean and standard deviation are displayed on the plot.

8.2.2 ROI Arrival Times

The breakdown of when region of interest pulses arrive relative to the sync pulse is found. Using the two region dividers, three discrete regions can be defined in which the software will tabulate the number of pulses that occured through the entire accumulation. This generates a plot using the fully featured plotter and displays the breakdown of the three regions contribution to the total signal.

A save feature is incorporated so as to save the raw data generated from this. It will create a text file that has the percentage breakdown as the first line, followed by a two column format, time in microseconds, followed by associated counts.

9 Future Work

As was stated in the introduction, this software is in beta testing, as such new features are continually being added and old features becoming more robust. New features that are currently being added include the ability to edit information inserted into the primary spectrum viewer and loading of different file formats into the spectrum viewer.