SLIMER Update

Mary Kidd, Steve Elliott, Keith Rielage, Gwendolyn Buchanan

June 9, 2017

Contents

Part I

Eqipment Information

1 Objectives

Table 1: Objectives

Objective	N. A.	Light Collection (%)	ϕ
4X	0.13	0.42	—
10X	0.30	2.3	—
20X	0.50	6.7	—
40X	0.75	16.9	—
10XS	0.50	—	4.0
20XS	0.75	—	4.0

2 Sources

Table 2: Source list

Source	Activity$_0$	t_0	$t_{1/2}$	Activity$_t$
^{241}Am α	4.375 nCi	01 Sept 2007	432.2 y	4.313 nCi
^{241}Am γ	10.51 μCi	12 Jan 1970	423.2 y	9.75 μCi
^{14}C β (strong)	0.9853 μCi	15 Nov 2012	5730 y	0.9849 μCi
^{14}C β (weak)	45.18 nCi	01 Sept 2011	5730 y	45.15 nCi
^{133}Ba γ	9.907 μCi	01 Oct 2003	10.51 y	4.263 μCi
^{137}Cs (window)	10 μCi	01 Oct 2003	30.07 y	2.4 μCi
^{90}Sr	31.35 μCi	20 July 1981	28.78 y	13.47 μCi
^{22}Na	9.030 μCi	01 Oct 2003	2.6019 y	0.299 μCi

Part II
Data

3 ^{241}Am α

^{241}Am alphas have energies of 5442.80 keV (13.1%) and 5485.56 keV (84.8%).

3.1 Example Event

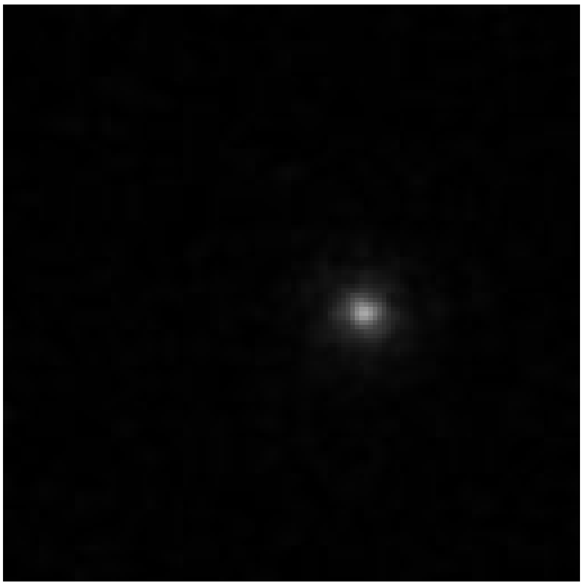


Figure 1: ^{241}Am alpha event with 10XS objective and 4x4 binning.

3.2 Peak Height Data

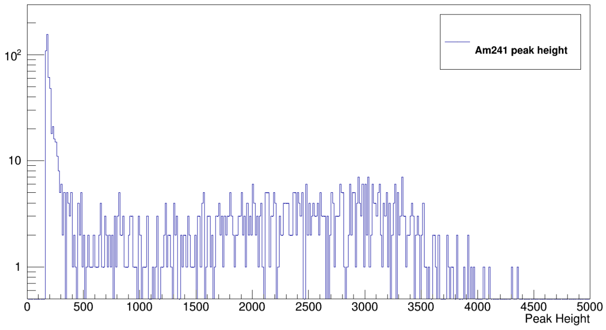


Figure 2: ^{241}Am alpha peak heights, Run 081. Includes gammas.

4 ^{241}Am γ

^{241}Am gammas have energies of 13.9 keV (37%) and 59.5409 keV (35.9%).

4.1 Example Event

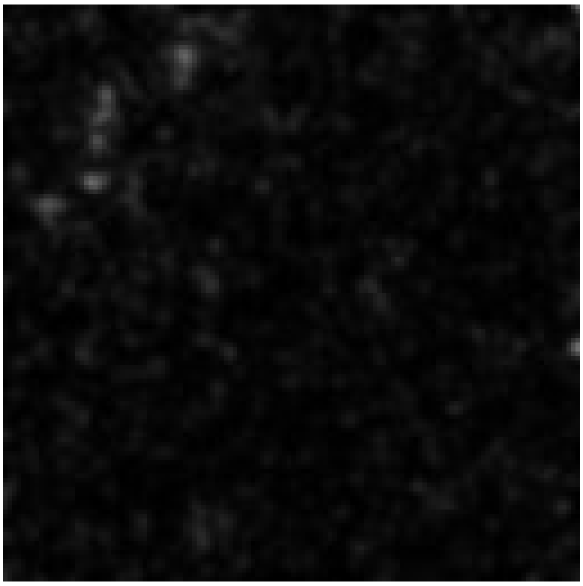


Figure 3: ^{241}Am gamma event with 10XS objective and 4x4 binning. Gamma events are present in the alpha ^{241}Am source, but are adjusted into the background because of the brightness of the alpha events.

4.2 Peak Height Data

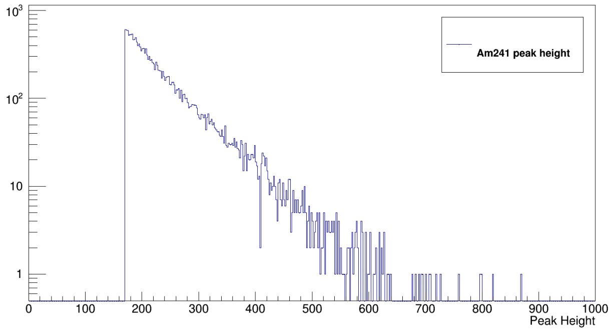


Figure 4: ^{241}Am gamma peak heights, from Run 034. No alpha events.

5 ^{14}C β (strong)

^{14}C betas have an energy spectrum with a mean of 49.47 keV and an endpoint of 156.475 keV.

5.1 Example Event

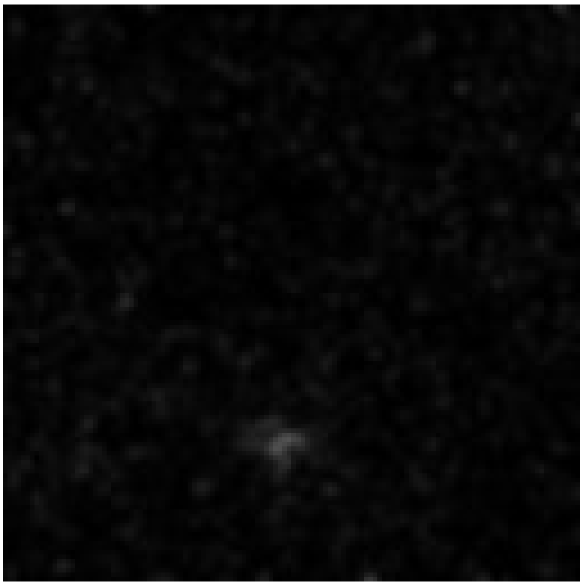


Figure 5: Beta event in the strong ^{14}C source with 10XS objective and 4x4 binning.

5.2 Peak Height Data

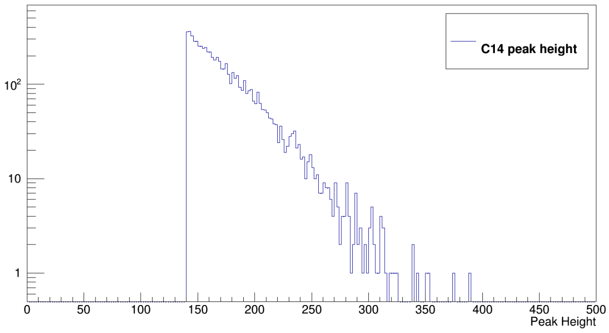


Figure 6: ^{14}C peak heights taken from Run 067, using the strong ^{14}C source.

6 ^{14}C β (weak)

^{14}C betas have an energy spectrum with a mean of 49.47 keV and an endpoint of 156.475 keV.

6.1 Example Event

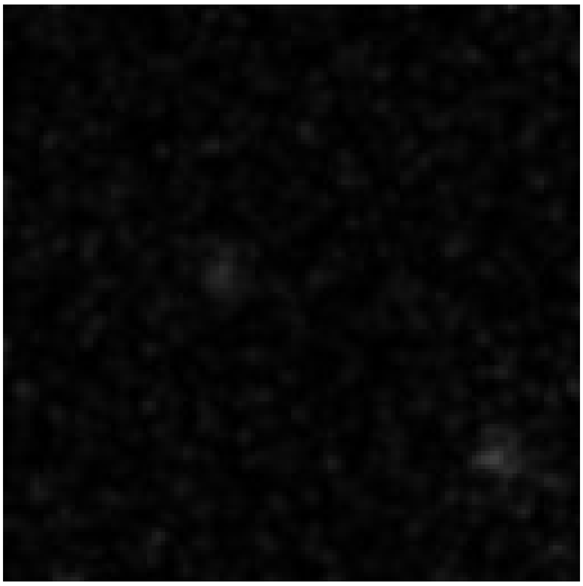


Figure 7: Beta event in the weak ^{14}C source with 10XS objective and 4x4 binning.

6.2 Peak Height Data

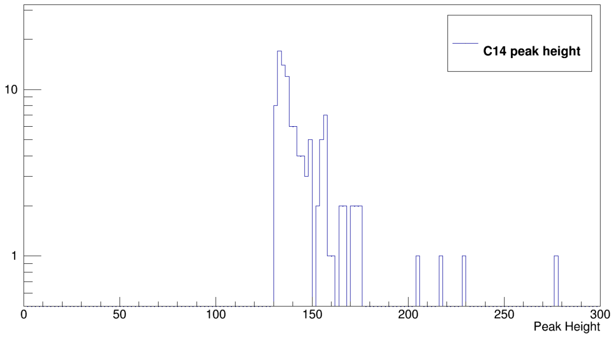


Figure 8: Peak heights from Run 049 with the weak ^{14}C source.

7 ^{133}Ba γ

^{133}Ba gammas have energies of 4.47 keV (16.4%), 31.817 keV (15.1%), 32.194 keV (27.6%), and 275.925 keV (17.69%).

7.1 Example Event

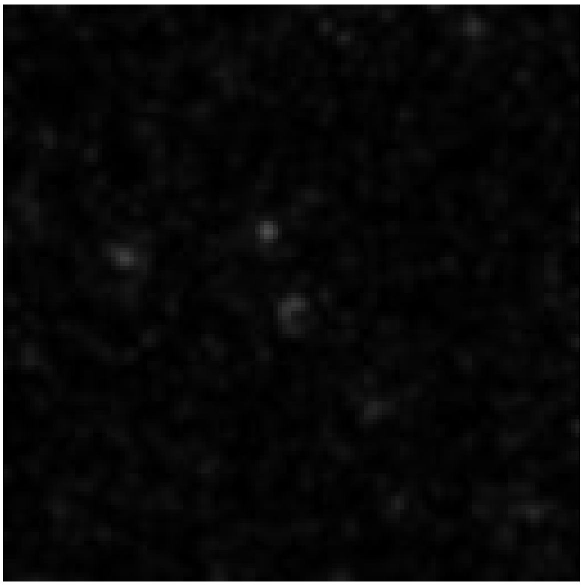


Figure 9: Ba gamma event with 10XS objective and 4x4 binning.

7.2 Peak Height Data

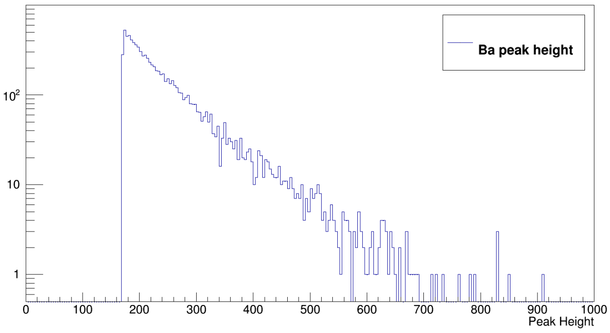


Figure 10: ^{133}Ba peak heights from Run 032.

8 ^{137}Cs (window)

^{137}Cs betas have an energy of 174.32 keV (94.70%) with an endpoint of 513.97 keV. ^{137}Cs gammas have an energy of 661.657 keV (85.10%).

8.1 Example Event

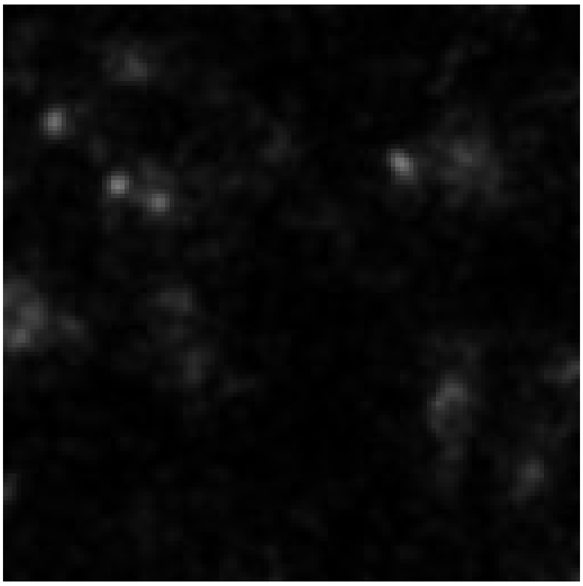


Figure 11: Gamma and beta events with 10XS objective and 4x4 binning.

8.2 Peak Height Data

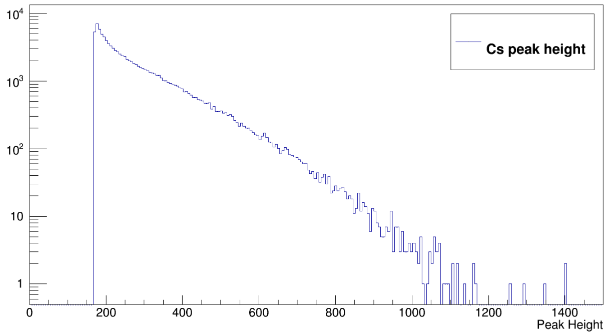


Figure 12: Peak heights of ^{137}Cs from Run 036.

9 ^{90}Sr

^{90}Sr betas have an energy spectrum with a mean of 195.8 keV and an endpoint of 546.0 keV.

9.1 Example Event

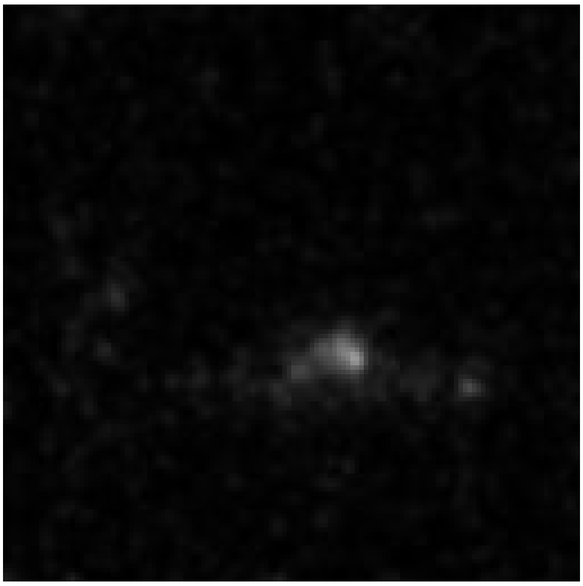


Figure 13: Sr beta event with 10XS objective and 4x4 binning.

9.2 Peak Height Data

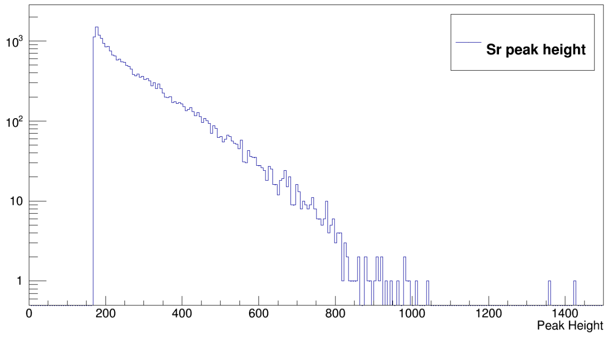


Figure 14: Peak heights of ^{90}Sr from Run 021.

Part III
Simulation

10 Structure and Running

10.1 Structure

The DetectorConstruction file generates the physical objects associated with the simulation: the CsI cylinders, the objective lens, and so on. RunAction oversees the whole run, while EventAction and SteppingAction handle events and steps, respectively. A run consists of events, which consist of steps. TrackingAction tracks particles. PhysicsList gets the necessary physics processes. PrimaryGeneratorAction creates the particle source.

The exec.mac macro sets up the geometry of the detector, while run.mac actually creates particles. Particle location, energy, and type, along with number of runs, are changed in run.mac. CMakeLists.txt is used for making the executable and should not be changed. The executable, exec.cc, should also not be changed.

10.2 Running

Required software:

- Geant4 9.6, patch 04
- CMake 2.8.12 or higher
- ROOT 5.34/14

The primary directory is called *code*, and contains directories labeled *include*, *misc*, and *src* along with files CMakeLists.txt, exec.cc, exec.mac, run.mac, and README.md.

10.2.1 Compiling and running on Ubuntu 12.04

- Create a directory *code_build* parallel to *code*.
- In a terminal, navigate to the *code_build* directory.
- From *code_build*, run `# cmake -DGeant4_DIR=/path/to/geant4.9.6.p04/lib[64]/Geant4-9.6.0/ ../code/` .
- Run `# make && make install` .
- Run `# ./exec exec.mac` to set up the geometry.
- Run `# ./exec run.mac` to run the events and generate the .root file.

10.2.2 Compiling and running on Mac OS X

- Create a directory *code_build* parallel to *code*.
- In a terminal, navigate to the *code_build* directory.
- From *code_build*, run `# cmake -DGeant4_DIR=/path/to/geant4.9.6.p04/build ../code/` .
- Run `# make && make install` .
- Run `# ./exec exec.mac` to set up the geometry.
- Run `# ./exec run.mac` to run the events and generate the .root file.

11 Simulated Spectra

11.1 Simulated ^{14}C

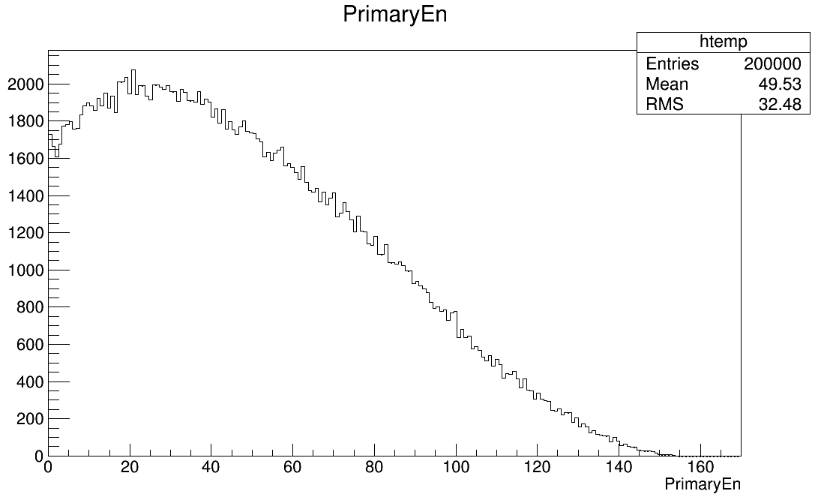


Figure 15: ^{14}C simulated spectrum.

11.2 Simulated ^{137}Cs

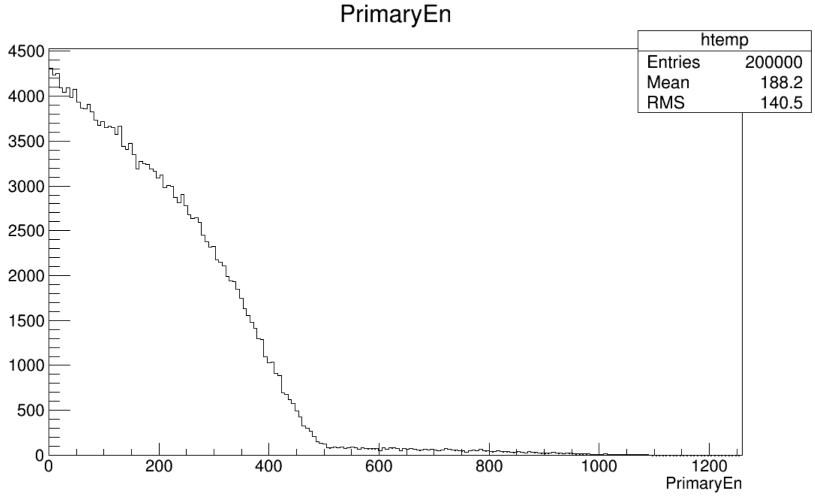


Figure 16: ^{137}Cs simulated spectrum.

11.3 Simulated ^{90}Sr with ^{90}Y

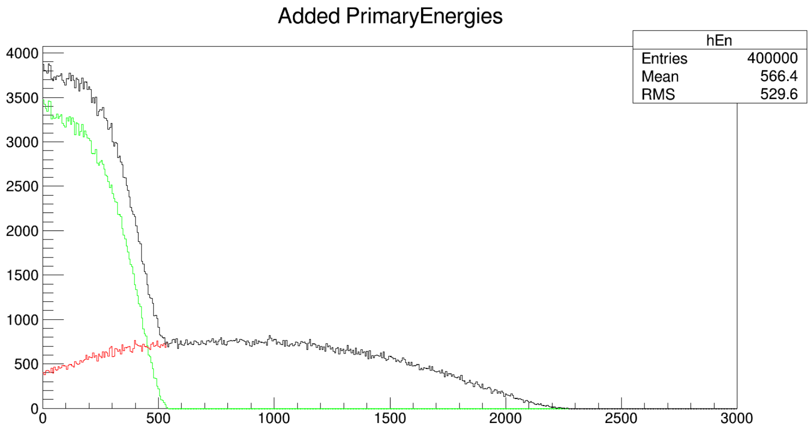


Figure 17: ^{90}Sr and Y simulated spectrum.

Part IV
Simulation/Data Comparison

The real data is calibrated to the simulation data in order to give the simulation data units. The peak height data from ImageJ can be compared to the energy absorbed data from the simulation.

12 Calibration Procedure

For each value in the Max histogram (which contains the peak height data), a calibrated value is produced using the formula maxcal = $b*$max$+a$. The parameters a and b come from a graph of eAbs vs. gray value (see Figure 18), where eAbs is the energy absorbed data from the simulation and gray value is the peak height data from ImageJ. The values used here come from C, Cs, and Sr.

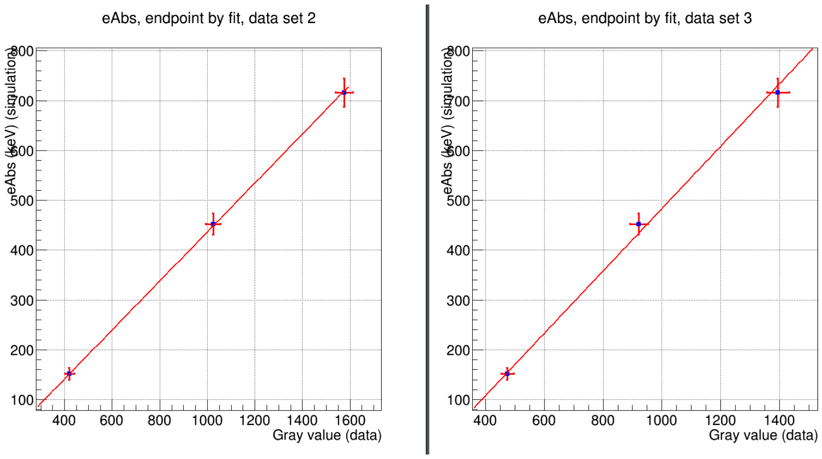


Figure 18: Left: $f(x) = 0.49x - 55$. Right: $f(x) = 0.63x - 141.83$.

13 Issues with Calibration

The first main issue with calibration is that different sets of C, Cs, and Sr data do not produce the same line. The two sets of data in Figure 18 were taken under conditions as identical as possible, within minutes of each other, but produce very different parameters.

The second issue with calibration is that the same values for a and b do not produce the same results for two isotopes. Both sets of data in Figure 19 were calibrated using the second set of parameters from Figure 18.

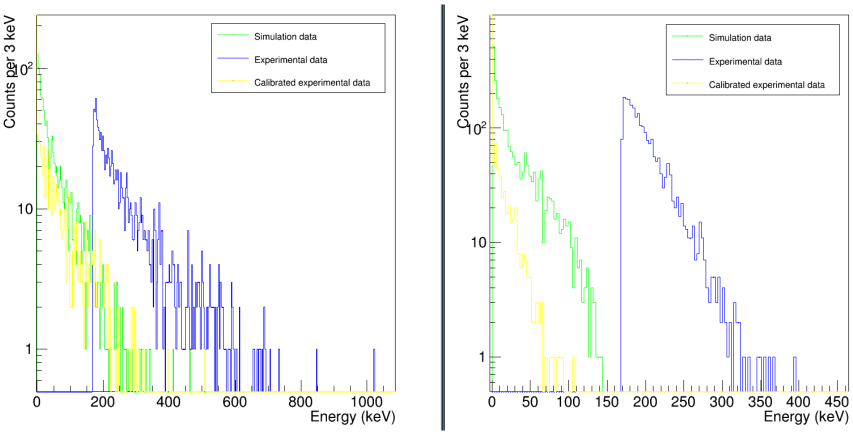


Figure 19: Left: ^{137}Cs, $\chi^2/\mathrm{ndf} = 1.39$. Right: ^{14}C, $\chi^2/\mathrm{ndf} = 3.30$.

Part V
Minimum Detectable Activity

To get an idea of the minimum activity detectable in 10,000 images, runs were taken with several activity levels of ^{14}C and ^{241}Am. This was achieved by masking the available ^{14}C and ^{241}Am sources with two different sizes of colimators: 250 μm and 1 mm. The lower-activity of the two available ^{14}C sources was not masked, because of its already low activity.

The EventFinder macro, which sorts images into those with events and those without, usually picks up about 250 images as having events even though they do not. Therefore, the y-intercept of these graphs is around 250.

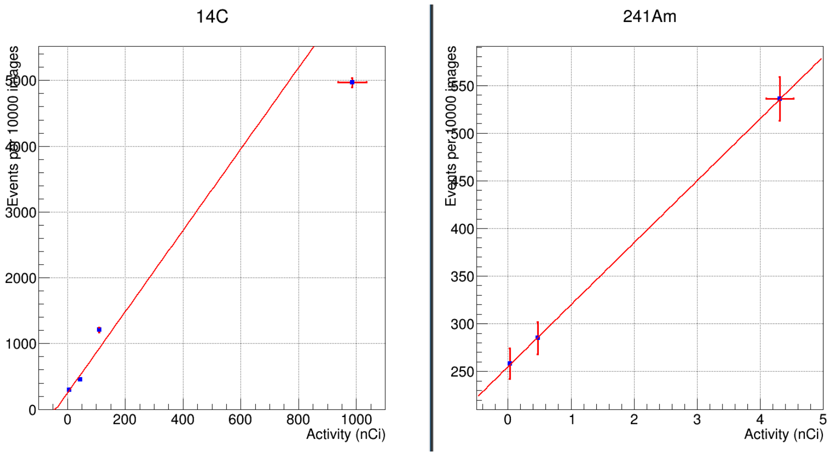


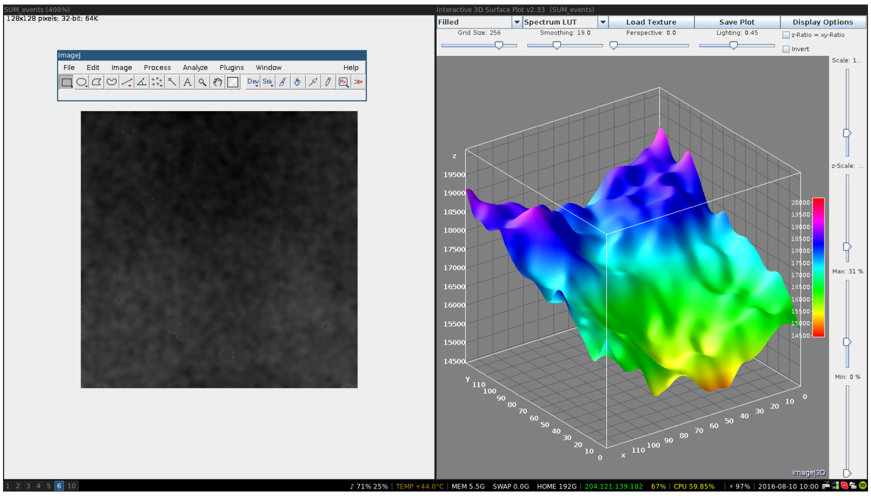
Figure 20: Graph of number of events vs. activity.

Part VI

Position Resolution

14 Data Analysis

Runs were taken using a 1 mm colimator. However, because 1 mm is almost as large as the field of view with the 10XS objective, the colimator was positioned so that only half of it was in the field of view.



SUM_events (400%)

128x128 pixels; 32-bit; 64K

Interactive 3D Surface Plot v2.33 (SUM_events)

Filled

Spectrum LUT

Grid Size: 256

Smoothing: 19.0

Perspective: 0.0

Lighting: 0.45

□ z-Ratio = xy-Ratio

□ Invert

Scale: 1...

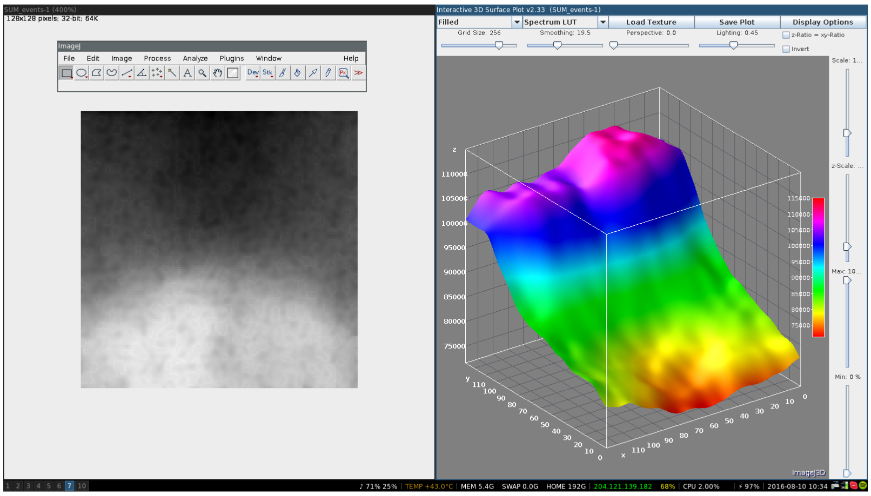
z-Scale: ...

Max: 31 %

Min: 0 %

♪ 71% 25% | TEMP +44.0°C | MEM 5.5G SWAP 0.0G HOME 192G | 204.121.139.182 67% | CPU 59.85% | ⚡ 97% | 2016-08-10 10:00

Figure 21: ^{14}C run and 3D plot. Notice that although (0,0) in the image is at the upper left corner, (0,0) in the 3D plot is at the lower right corner.



SUM_events-1 (400%)

128x128 pixels; 32-bit; 64K

Interactive 3D Surface Plot v2.33 (SUM_events-1)

Filled

Spectrum LUT

Grid Size: 256

Smoothing: 19.5

Perspective: 0.0

Lighting: 0.45

□ z-Ratio = xy-Ratio

□ Invert

Scale: 1...

z-Scale: ...

Max: 10...

Min: 0 %

♪ 71% 25% | TEMP +43.0°C | MEM 5.4G SWAP 0.0G HOME 192G | 204.121.139.182 68% | CPU 2.00% | ⚡ 97% | 2016-08-10 10:34

Figure 22: ^{90}Sr run and 3D plot. Again, (0,0) in the image is at the upper left corner, and (0,0) in the 3D plot is at the lower right corner.

15 Determining Resolution

Ideally, looking at a sideview of the plots would give a clear estimate of the horizontal distance, in pixels, from the top (unmasked area) to the bottom (masked area).

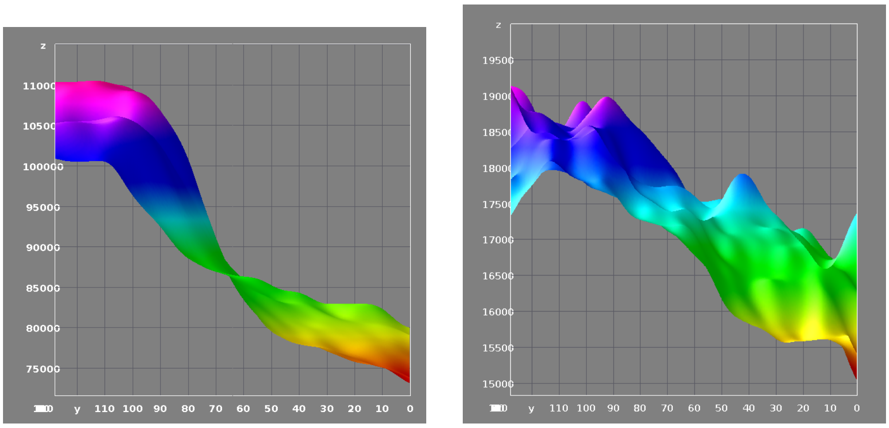


Figure 23: Left: ^{90}Sr. Right: ^{14}C.

A reasonable estimate might be 50 pixels for ^{90}Sr and 80 pixels for ^{14}C. The image is 128x128 pixels, corresponding to 0.707x0.707 mm. Thus, the position resolution for ^{90}Sr is around 0.28 mm, and for ^{14}C is around 0.44 mm.

Part VII

List of Macros

16 ImageJ Macros

16.1 getAverage

getAverage gets the average of all the images in the run. It can be run with up to 25000 images at once.

16.2 subtractAverage

subtractAverage subtracts the average generated with getAverage from every image. It can be run with up to 3000 images at once.

16.3 gaussianBlur

guassianBlur runs ImageJ's Gaussian Blur function on every image. It can be run with up to 5000 images at once.

16.4 getResults2

getResults2 generates a text file with statistics about the images based on a given threshold. It can be run with up to 2000 images at once. However, if a run is longer than 2000 images, the window with results needs to be left open until all images have been analyzed, when it will save automatically.

16.5 eventFinder

eventFinder finds whether or not an image contains an event, and sorts each image into a folder accordingly. It can be run with up to 5000 images at once.

17 Root Macros

17.1 plotResultsAgain.C

plotResultsAgain.C uses plotResultsAgain.h. It is an updated version of plotResults.C, and is used to analyze the Results file generated by the getResults2 ImageJ macro.

17.2 addTwoHists.C

addTwoHists is used on two .root files generated by the simulation. Currently, its only use is to generate the full spectrum for ^{90}Sr and ^{90}Y decay.

17.3 simcompare_with_ij2root.C

simcompare_with_ij2root.C is a combination and update of two older macros: ij2root.C and sim-compare.C. It converts the Results file generated by getResults2 from a .txt file to a .root file, and then compares it to the .root file generated by the simulation. The result needs to be calibrated (see Part IV, Simulation/Data Comparison).