Andres Ruberg, Summer Student Work Report From June 29 to End of Work Term, 2004

<u>$^{12}C(\quad,\quad)^{16}O$ Reaction (revisited after many weeks)</u>
<u>Part 1: Scaling the bins to line up data</u>

Runs at the 10.356 MeV resonance (1.07 Mev/u beam intensity) were located, and selected out of those runs were 8217, 8218 and 8219 as the runs to analyze. (For a complete list of runs taken at this resonance please consult pgs. 109 and 110 of my lab notebook). The motivation for this analysis was to strengthen the case for the GEANT simulation of the BGO array and to provide a method for calculating BGO efficiencies in the future. A comparison between the simulations of this experiment to the data that agreed to within error would lend much to the confidence of GEANT's predictive power when it comes to the efficiency of our BGO array.

The proposed method to calculate the efficiency from the data was to integrate under the full photopeaks and first and second escape peaks at 3.439 MeV and 6.917 MeV and then compare these integrations to the actual number of reactions that were thought to have occurred. This integration was going to be done after the peaks were Monte Carlo fitted using a technique outlined in Dario's thesis. Basically this involves the convolution of a GEANT spectra (where ratios of photopeak events and escape peak events are established) with a Gaussian and then scaling the simulation counts in order to have the function well represent the data in question. This fit was going to prove difficult however, unless good statistics could be obtained.

To obtain these statistics one could not just blindly add up spectra due to the "drifting" of voltage gains on the BGO detectors. This resulted in the spectra peaks being un-aligned with each other as can be seen on the following page. In the graph the y-axis represents the 30 different BGO spectra displayed on top of each other, and the x-axis represents different energies. It is fairly apparent from this plot that the energy peaks do not line up, so multiplicative factors (gain corrections) had to be found for each detector to have the peaks align. Of note here, is that the points on this plot represent only the gamma rays from coincidence measurements, and that these spectra were not available separately. This created the problem of analyzing each spectra separately in order to find its gain correction, so a macro was written to "chop up" this plot and the code is provided at the end of this document.

cγ0 Energy x cγ0 Detector
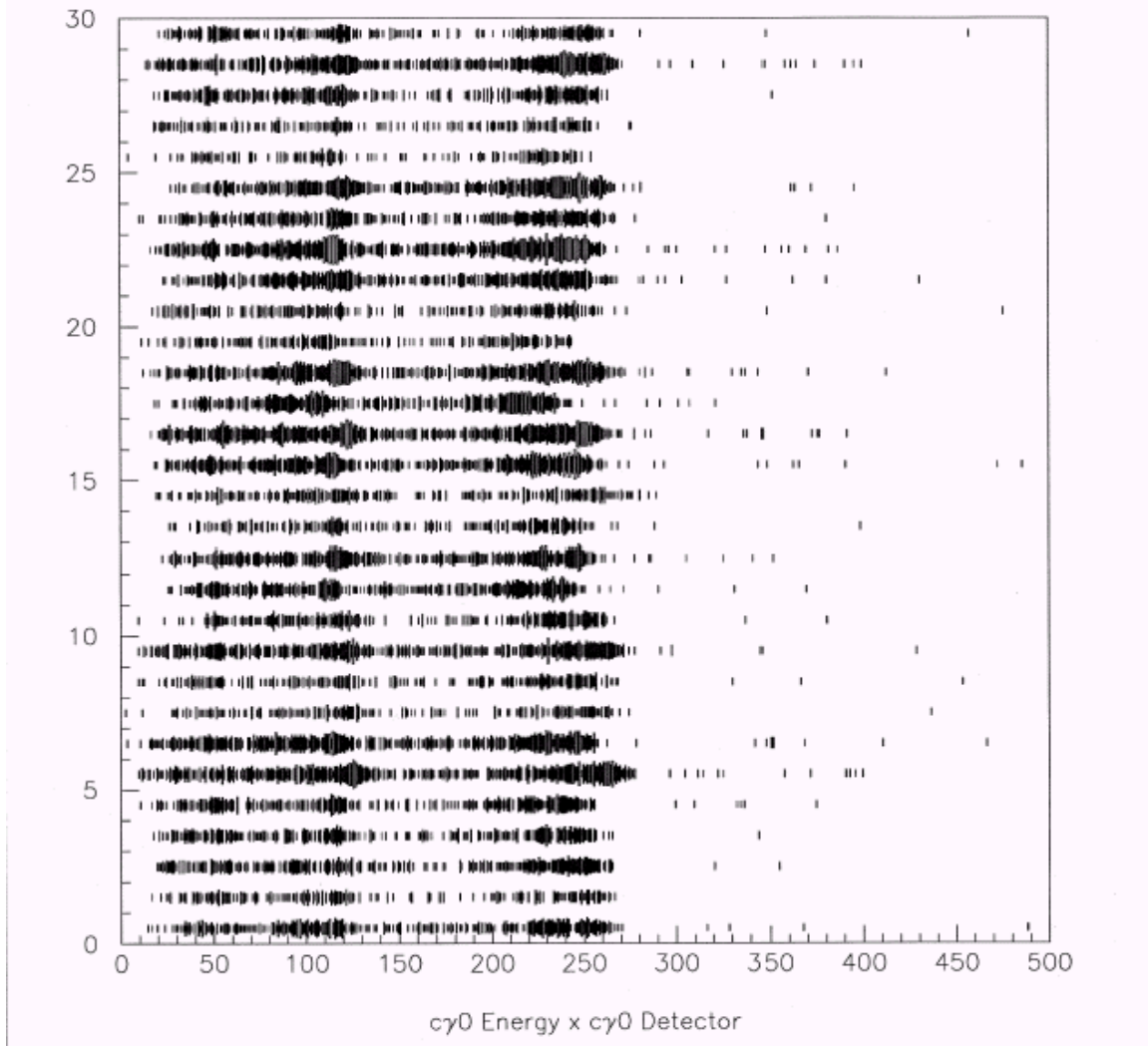
Below is outlined the process used to align the energy peaks.
(Process is in lab notebook on pgs. 111 – 119)

1. Re-ran runs 8217, 8218 and 8219 in order to achieve best statistics possible. ".rz" files are located on ISDAQ04 in the folder "/data1/dragon/andres0". Also in this folder is the aforementioned PAW++ macro and other folders, which contain various incarnations of the data being analyzed.
2. One run was looked at in detail, and the centroids for the energy peaks in question were calculated. Then each set of peaks was used as a possible "reference set" to which the centroids for all other peaks would be scaled. The centroids which yielded the smallest standard deviation in the final scaled peaks was chosen as the reference set for all three runs and all runs were scaled to this reference set.
3. This created the trouble of having non-integer bin numbers, so these were all rounded to the nearest integer and in data sets where a bin number was now

       repeated, a line was used in Mathematica to combine these points (Mathematica code on pg. 117 of lab notebook). Then all data sets were cut off to contain only 250 points to make things consistent and easy to add together.

4. The three scaled runs were added together to produce a spectra with significant enough statistics to do a decent fit.

The Mathematica notebooks and the larger combined data set "colrun8217.dat" can be found on ISDAQ04 in the folder:
/data1/dragon/andres0

Below is a ROOT-produced set of graphs, which show the effect of adjusting the data for voltage-gain drifting. This seems to have improved the resolution of the data a great deal and ideally one would be able to automate the process outlined above.
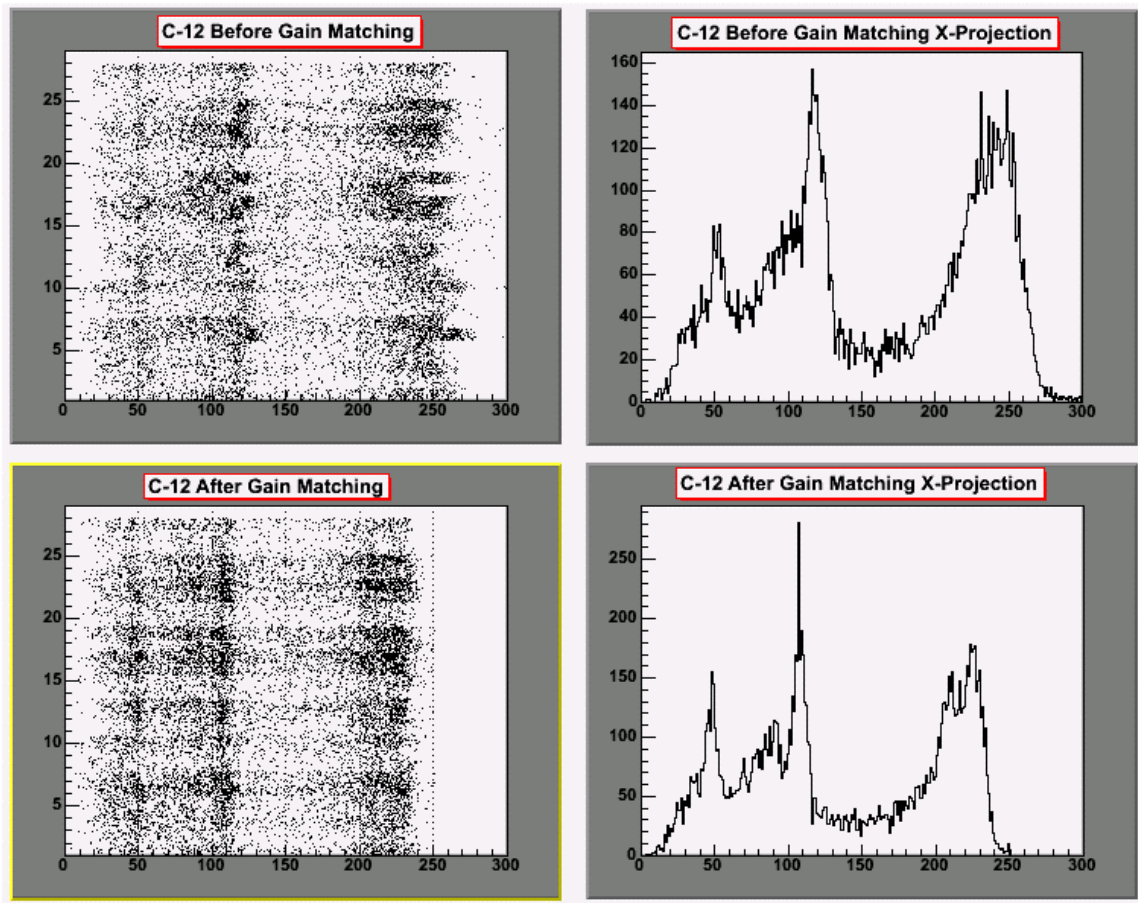
Carbon Work Report Continued on page 9

Doing BGO Efficiency Measurements with ^{88}Y and ^{137}Cs within the BGO Target Box
(procedure and data on pgs. 122 – 142 of lab notebook)

We wanted to take some source measurements with the samples within the target area
however had no convenient means of accurately placing the source at the center of the
target, where reactions are most often thought to occur. Hence a plastic rod was found
and modified for this purpose. Below is a picture of the rod and one will note that this
device could be slid through the target and have the 6mm end placed in the 6mm aperture
of the gas target box, with the larger end sitting in the 8mm aperture.

Source Measurement Rod
(for placement within target)

8 mm ⬌   ⬌ 6 mm

Slit for source placement
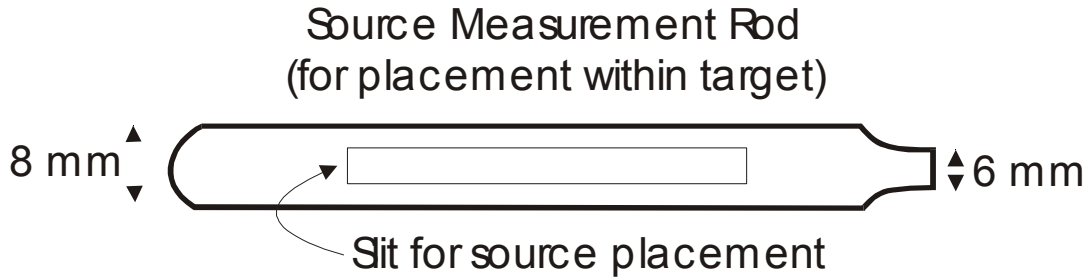
The run corresponding to the ^{88}Y measurement (1.836 and 0.898 MeV) is 13021
The run corresponding to the ^{137}Cs measurement (0.662 MeV) is 13022

The run information can be found on ISDAQ04 in the directory:
/data1/from_data/data/dragon/datad/

Fitting this data was a first step in analyzing the carbon data as a similar technique could
be applied in both cases and this provided a valuable experience with the GEANT
simulation and fitting software.

To simulate the gamma emitters inside the array I used the GEANT version located on
IBM00 in the folder:
/export/home/gamdet/gbox_v5_trials/gbox_mod/v12/
Note: ^{88}Y data located in subfolder "/1836data/" and ^{137}Cs data located in subfolder
"/662data/"

Before running a new simulation I had to modify the ".ffcards" which specify the
simulated run parameters. I had to change the following variables:

RUNG # (where the # represents the name of the simulation)
TRIG # (where the # is the number of events you want triggered)
KINE a b c d e f g h i j k (where h was the only parameter I needed to change and
represented the energy of the gamma ray in question)
EGAM (where one indicated if there were more than one energy of gamma ray being
emitted, but as it turned out GEANT did not handle cascades the way we needed it to so
this variable was left alone))

So for example when I ran the simulation with a point source emitting 662 keV gamma rays these lines of code looked as follows (where a line of code preceded by a C means it is commented out)

```
RUNG  6620  0
TRIG 1000000
KINE  1  0.0  0.0  0.0  0.0  0.0  0.0  0.662  0.0  0.0  0.0
C EGAM  3.44  1.0
```

In the case of Yttrium, since we needed to simulate two gammas, we just simulated both separately taking the branching ratios into account by just scaling the number of triggers in the lower energy simulation. Then I added the spectra together before exporting them as ".dat" files. The PAW++ macro (addexporty88.kumac) used to do this can be found at the end of this report.

In order to integrate the number of photopeak events it was necessary to fit the data. The fitting technique outlined many times in the past, involves the convolution of the GEANT spectra with a gaussian and then using the parameters describing that gaussian as the fit parameters. The reason one starts with the GEANT spectra is because GEANT does a good job of predicting the relative peak height ratios of different gammas. The fit parameter, which scales the peak height, is the one of interest, because that is what you use to scale the GEANT-simulated peaks in order to find the number of events in your measurement. This is also outlined in Dario's thesis.

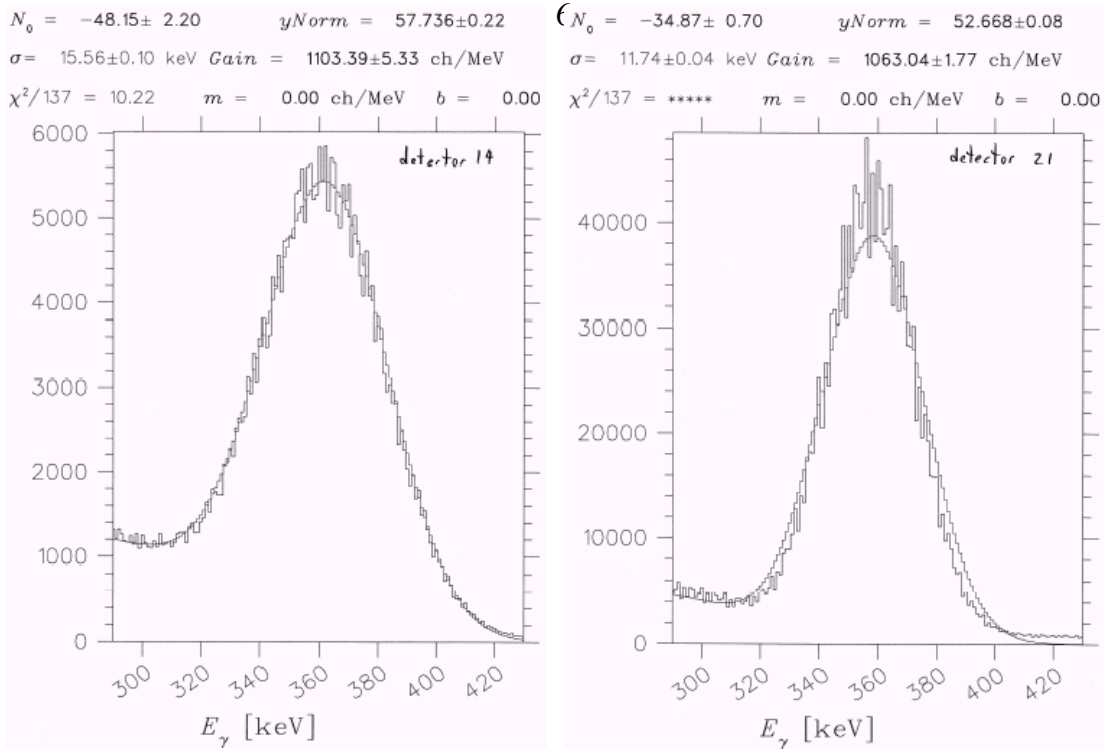The program that performs this fit can be found on IBM00 in the folder: /home/aruberg/dansfit/

So one gives the program a file to which it will fit the data, an initial set of fitting parameters and the GEANT spectra it is to convolve. From the runs done with the sources, we extracted each detector's spectra from the ".hbook" into a ".dat" file.   This was also done with the ".hbook" created from the GEANT simulation so we had a simulation file and measurement file for each detector. A PAW++ macro (convertdata.kumac) was again used to do this and can be found in the same folder as the fitting program.

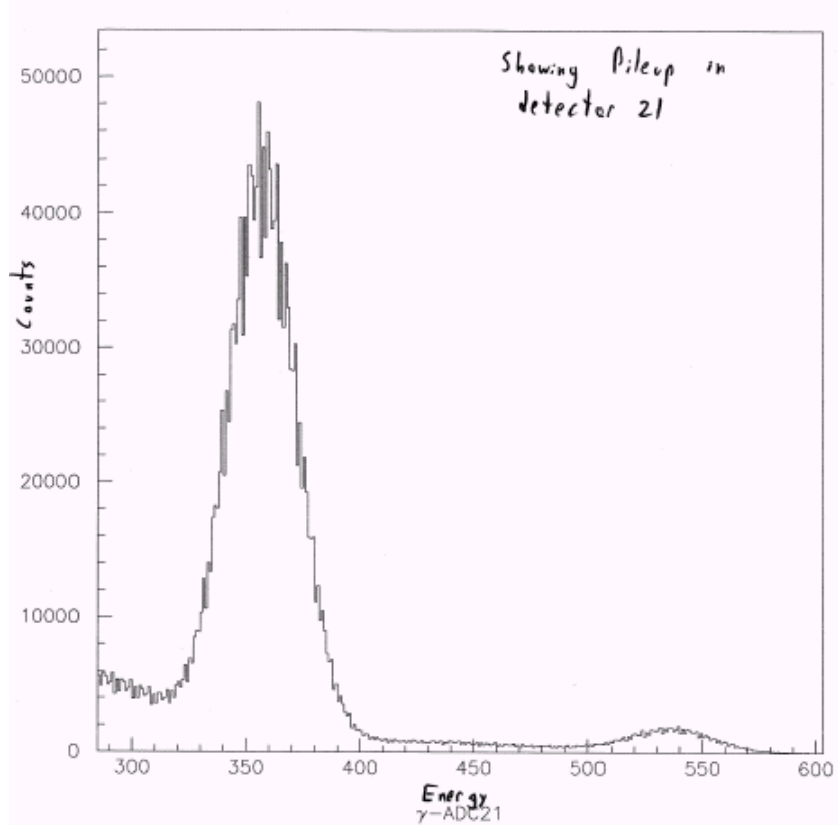Below is a summary of the files used (all found in the "/dansfit" folder)

Source	Measured data	Fit Parameters	GEANT Simulation
^{88}Y	1302110$$.dat	1302110$$-Fit.dat	ghex_geant18363##.dat
^{137}Cs	13022210$$.dat	13022210$$-Fit.dat	ghex_geant66203##.dat

Where ## corresponds to the detector number of interest and $$ is (## + 1) as the PAW++ spectra have it such that the spectra number is always one higher than the actual detector number of interest.
After this it was just a matter of picking good initial conditions for the fits and writing down the resultant scaling factors. Below are 2 sample fits for ^{88}Y:

$N_0 = -48.15 \pm 2.20$ $yNorm = 57.736 \pm 0.22$ $N_0 = -34.87 \pm 0.70$ $yNorm = 52.668 \pm 0.08$

$\sigma = 15.56 \pm 0.10$ keV $Gain = 1103.39 \pm 5.33$ ch/MeV $\sigma = 11.74 \pm 0.04$ keV $Gain = 1063.04 \pm 1.77$ ch/MeV

$\chi^2/137 = 10.22$ $m = 0.00$ ch/MeV $b = 0.00$ $\chi^2/137 = *****$ $m = 0.00$ ch/MeV $b = 0.00$

It should be noted that added to the scaled GEANT counts for [88]Y were any events in the measurement past the photopeak as these were pileup events not simulated in GEANT. Below it is illustrated that this pileup contributed a significant number of counts:

The large peak here is the 1836 keV photo peak and everything from bin 450 to 600 was added to the total counts as pileup.

All calculations and relevant data used in calculating the detector efficiencies can be found on the tables on pg. 132 and 139 of my lab notebook and in the excel workbooks located on my computer in:
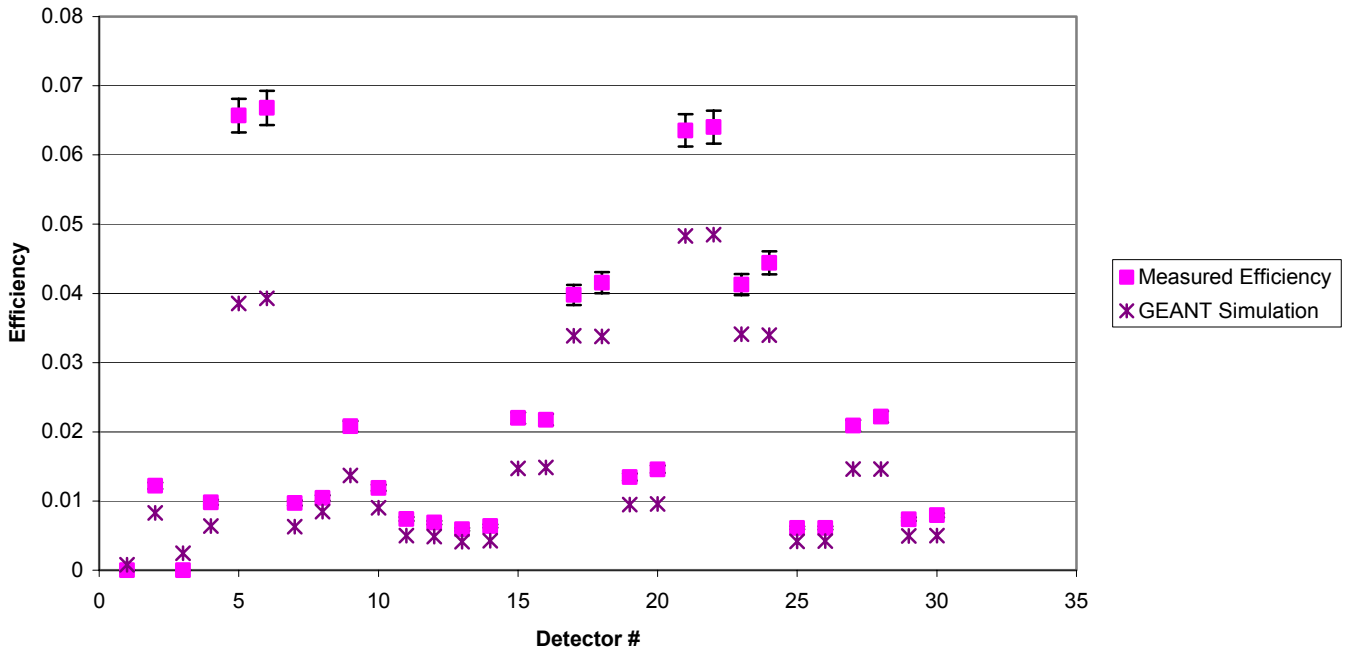C:\My Documents\Andres\gammaanalysis\1836data, and
C:\My Documents\Andres\gammaanalysis\662data

To find source activity calculations please consult the spreadsheet named "efficiency calibration.xls" found on my computer in the folder:
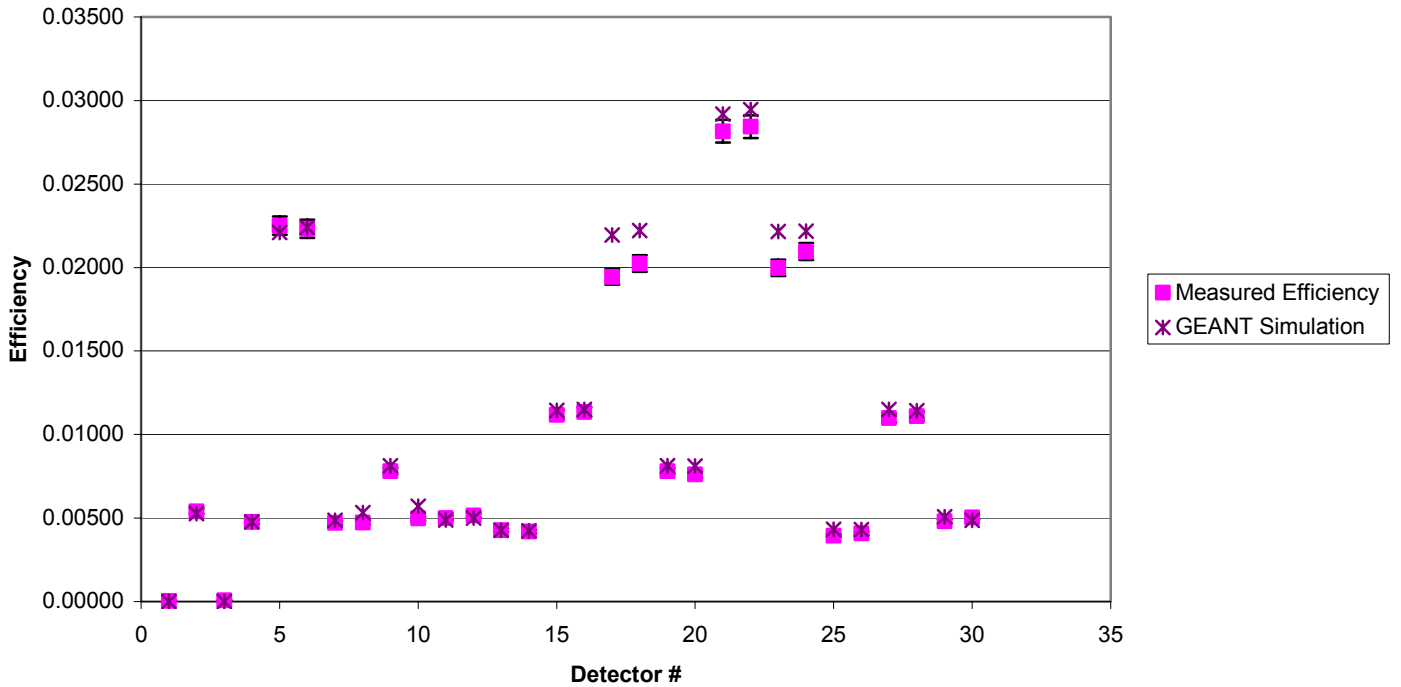C:\My Documents\Andres\gammaanalysis\germanium detector

Worth mentioning is that detectors 1 and 3 were not properly simulated by GEANT as they had been pulled back for an earlier run and hence were not really comparable in this experiment. For the [88]Y run these efficiencies were just set to zero for simplicity. Below are the graphs, which show detector-by-detector the efficiency of the BGO array comparing simulated to measured efficiency for both the Cesium (662 keV) and the Yttrium (1836 keV).

Comparison of measured to GEANT simulated BGO efficiencies at 662 keV

Comparison of measured to GEANT simulated BGO efficiencies at 1836 keV (Y-88)

Total Efficiencies at 662 keV from within target chamber
Measured: $(67.1 \pm 2.5)\%$
Simulated: 48.0 %

Total Efficiencies at 1836 keV from within target chamber
Measured: $(31.1 \pm 0.8)\%$
Simulated: 32.5 %

For the Cesium as we saw earlier this summer, the measured efficiency is far higher than the predicted GEANT efficiency. Possible reasons for this were previously outlined in my May report on pages 2 and 3. The Yttrium data seems to correspond well with the predicted efficiency and this is encouraging, as this is an energy range with previously little data.

^{12}C(,)^{16}O Reaction
Part 2: Simulation and Efficiency Calculation
(Process and data available on pgs. 143 – 152 of lab notebook)

Again, GEANT simulations were carried out, as outlined earlier and the simulation data
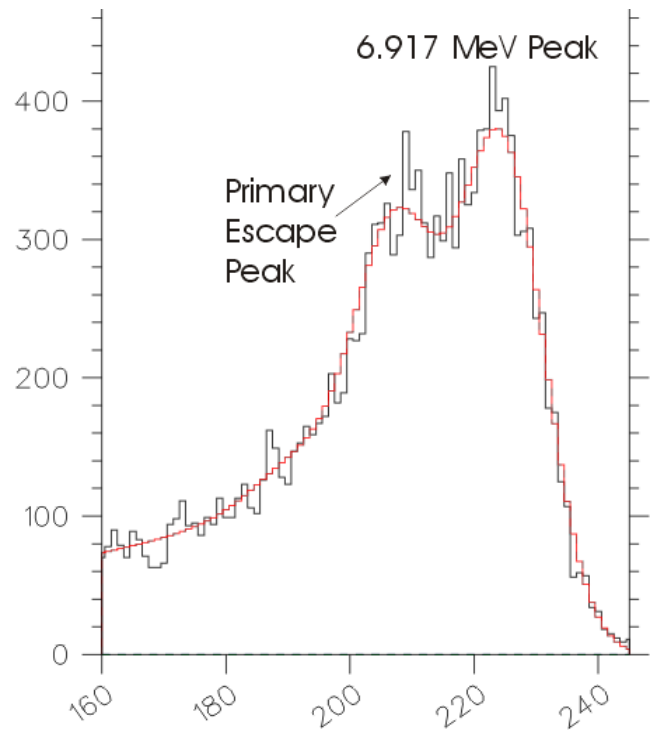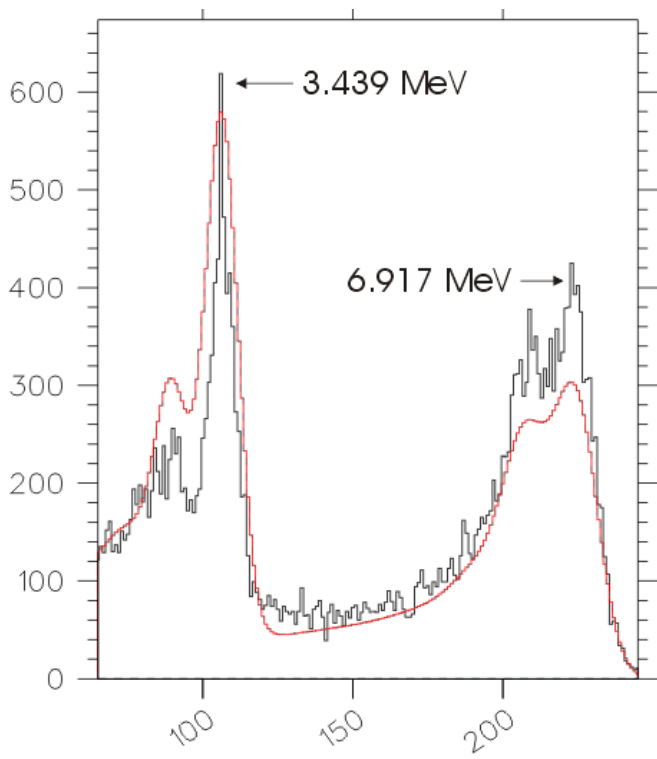can be found on IBM00 in the folder:
/export/home/dragon/gamdet/gbox_v5_trials/gbox_mod/v12/c12ag

Also, the problem GEANT was having simulating cascades was not fixed at this point so
we had to add together two spectra (3.439 MeV and 6.917 MeV) to simulate the pair of
gammas produced in the reaction (100 % branching ratios made this rather easy).

The same fitting technique employed for the Yttrium source was used here, although
where with the Yttrium the gaussian width was not allowed to vary with energy, here the
width of the gaussian varied according to the formula below:

$$\sigma^2 = \sigma_N^2 + E \cdot \sigma_S^2 \qquad (1)$$

However, in the end both peaks had to be separately fitted due to the photopeak ratios not
being predicted accurately. See below for a sample of a full spectra fit and the fit for a
single photopeak and it's first escape peak:

The files used in the fits are all on IBM00 and below is where one can find them:
Measured data: /home/aruberg/dansfit/c12ag1070.dat
Simulated data: /home/aruberg/dansfit/c12ag200.dat
Fit parameters table: /home/aruberg/dansfit/c12ag1070-Fit.dat

These fits again allowed us to extract the necessary scaling factors, which gave way to the calculation of the number of gammas observed. However, to extrapolate the efficiency one needed to know both the number of particles that passed through the target chamber and also the yield (Y) of the reaction at the 1.07 MeV/u resonance. The formula for the yield is:

$$Y = \frac{\omega_\gamma \lambda^2}{2} \frac{M+m}{M} \left(\frac{dE}{dx}\right)^{-1} \quad (2)$$

The calculation and source of all these parameters is available on page 148 of my lab notebook.

$$Y = (5.19 \pm .62) \times 10^{-12}$$

To find the number of particles that passed through the chamber is was necessary to obtain the average beam current. This was done with a few FC4 readings and from a view of the elastic monitor data.

$$ABC = (145 \pm 15)\,enA$$

So now one had all the information required to obtain the number of events one would expect.

$$ExpectedEvents = \frac{ABC}{q_{incidentbeam}} t_{runtime} Y \quad (3)$$

Then one had to scale the number of observed events to take into account the deadtime of the system and the charge state distribution. The charge state distribution for a 3+ incoming and 5+ outgoing beam had not been entirely looked at, but the ratio between the two most prevalent states had been measured (those being 6+ and 5+). Based on other measurements I assumed that 90% of the distribution lay within these 2 states:

$$\%5+ = (48.9 \pm 5.0)\%$$

So then the total events supposedly caught by the BGO array was:

$$DetectedEvents = \frac{IntegratedEvents}{5+_{fraction}} \times \frac{gammas_{presented}}{gammas_{acquired}} \quad (4)$$

This was all one needed to calculated the BGO array efficiency.

Efficiency of array at 3.439 MeV:
Measured: $(25.1 \pm 4.7)\%$
Simulated: 48.7 %

Efficiency of array at 6.917 MeV:
Measured: $(26.9 \pm 5.0)\%$
Simulated: 38.2 %

Clearly these results are not within acceptable limits of each other. Suggestions were given as to why this might be the case, none of which there was time to rigorously investigate.

1. A calculation might have been carried out in error, resulting in a factor of two loss. This was thoroughly checked, but not yet by a second party.
2. The fitting technique needs some revision:
    a. There was too much weighting given by the chi-squared to unimportant areas of the curve.
    b. The energy dependence of the gaussian width needs further examination and adjustment.

The conclusion here is that a technique has been developed that successfully takes into account the voltage gain drifting of the BGOs. Also, a process has been laid out by which one can calculate the efficiency of the array in a beam experiment. However, in the future the fitting program might need adjustment and perhaps more care taken in the calculations of the various parameters that go into finding the yield, average beam current etc.

Documents Referred to within report:

PAW++ Macro for splitting up the coincidence gamma ray spectra:

```
lunid=10
  read hisname
    histo/file 0 /data1/dragon/andres0/his0[hisname].rz 0 -X
    Cdir //LUN[lunid]
    /HISTOGRAM/COPY '1000' '2000'
    Cdir //PAWC
a=0
b=1
 repeat
   if [b] .NE. 31 then
    /HISTOGRAM/CREATE/BANX '2000' [a] [b]
    Hi/Proj 2000
    Hi/Plot 2000.banX.[b]
    Cdir //PAWC
```

```
   h/copy 2000.banx.[b] 300[b]
   vec/create vecname(500) R
   histogram/get_vect/contents 300[b] vecname
   vec/write vecname /data1/dragon/andres0/run[hisname]/gd[b].dat
 a=[a]+1
 b=[b]+1
 endif
 until [b] .EQ. 31
    lunid=lunid+10
*  endif
*until [hisname] .EQ. 29
```

PAW++ Macro for adding together two spectra and then exporting the spectra of interest:

```
lunida=1
 read hisname
   histo/file 0 /export/home/aruberg/dansfit/[hisname].hbook 0 -X
lunidb=2
 read hisnameb
   histo/file 0 /export/home/aruberg/dansfit/[hisnameb].hbook 0 -X
   hist/delete 0
   Cdir //LUN[lunida]
   hrin 0
   Cdir //LUN[lunidb]
   hrin 0 ! 99999
   Cdir //PAWC
   vec/create vecname(1000) R
   histogram/get_vect/contents 301 vecname
   vec/write vecname /export/home/aruberg/dansfit/[hisname]301.dat F10.0
   do i=302,330
     vec/create vecname(1000) R
     histogram/get_vect/contents [i] vecname
     vec/write vecname /export/home/aruberg/dansfit/[hisname][i].dat F10.0
   enddo
```