Preparation for a Precision Measurement of the $^{3}\text{He}(\alpha,\gamma)^{7}\text{Be}$ cross section

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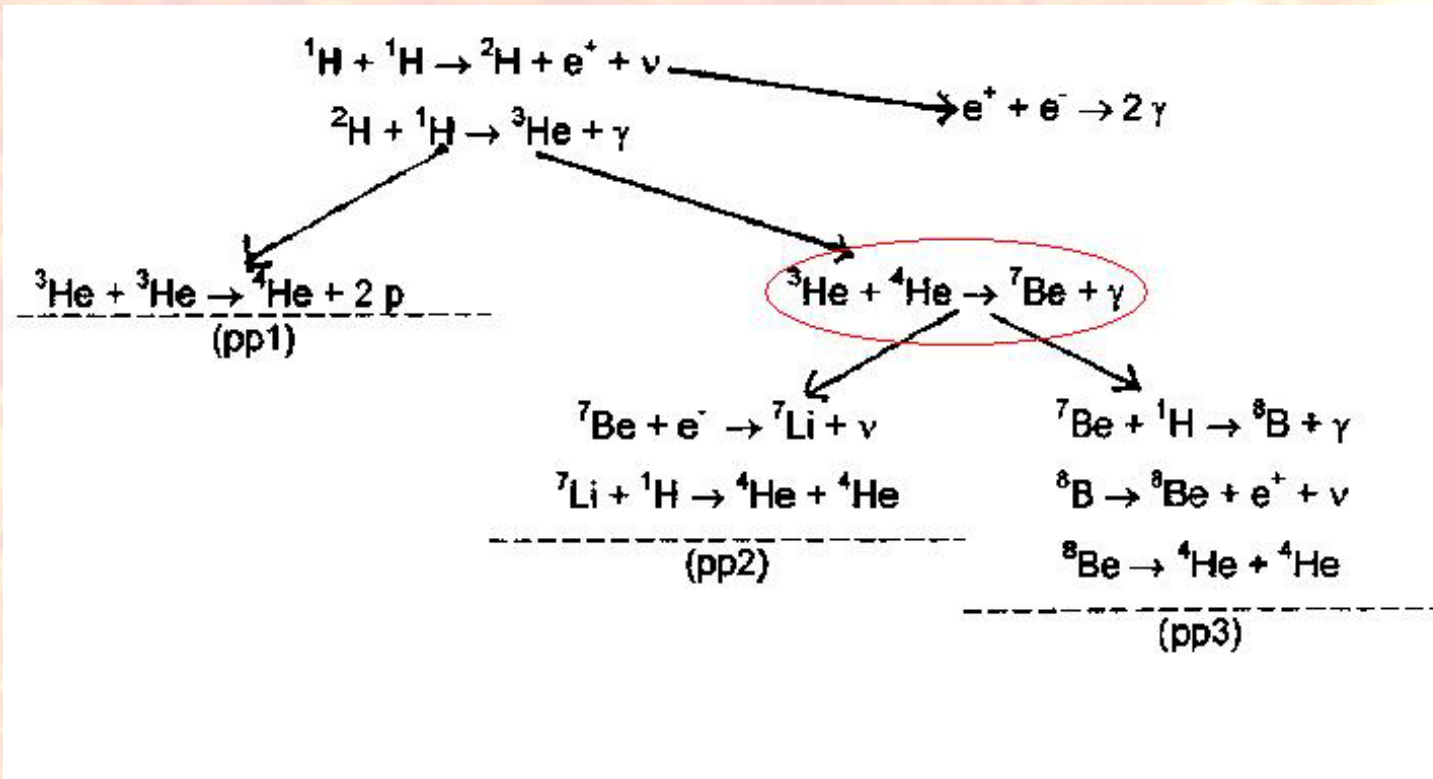
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The Solar Neutrino Problem

- Neutrino observations do not agree with the predictions from the Standard Solar Model (SSM)

- Every experiment had found 1/3 to 1/2 the number of electron neutrinos as predicted

- This was shown to be due to neutrino oscillations by SNO; these oscillations require the neutrinos to have mass, so to learn more about this we need to learn more about the reactions which produce the neutrinos.

The proton-proton chain

$$^1H + {}^1H \rightarrow {}^2H + e^+ + \nu$$
$$^2H + {}^1H \rightarrow {}^3He + \gamma$$
$$e^+ + e^- \rightarrow 2\gamma$$
$$^3He + {}^3He \rightarrow {}^4He + 2p \quad (pp1)$$
$$^3He + {}^4He \rightarrow {}^7Be + \gamma$$
$$^7Be + e^- \rightarrow {}^7Li + \nu$$
$$^7Li + {}^1H \rightarrow {}^4He + {}^4He \quad (pp2)$$
$$^7Be + {}^1H \rightarrow {}^8B + \gamma$$
$$^8B \rightarrow {}^8Be + e^+ + \nu$$
$$^8Be \rightarrow {}^4He + {}^4He \quad (pp3)$$

The $^3He(\alpha,\gamma)^7Be$ reaction is the branching point of the pp2 and pp3 branches, which makes it especially important. Many of the neutrinos detected are produced by the $^7Be(p,\gamma)^8B$ reaction.

The Experiment

- In order to know more about the $^3\text{He}(\alpha, \gamma)^7\text{Be}$ reaction, we need a more precise value for the cross section.

- There are two methods of determining the cross section.

- Right now, there is a difference of about 10% between the values obtained using the two methods, suggesting a systematic error.

- There must be a more precise value to be able to try to verify the SSM.

- By understanding where the differences come from and by measuring the cross section in both ways we hope to be able to obtain a more precise value.

Two methods of detecting ^{7}Be
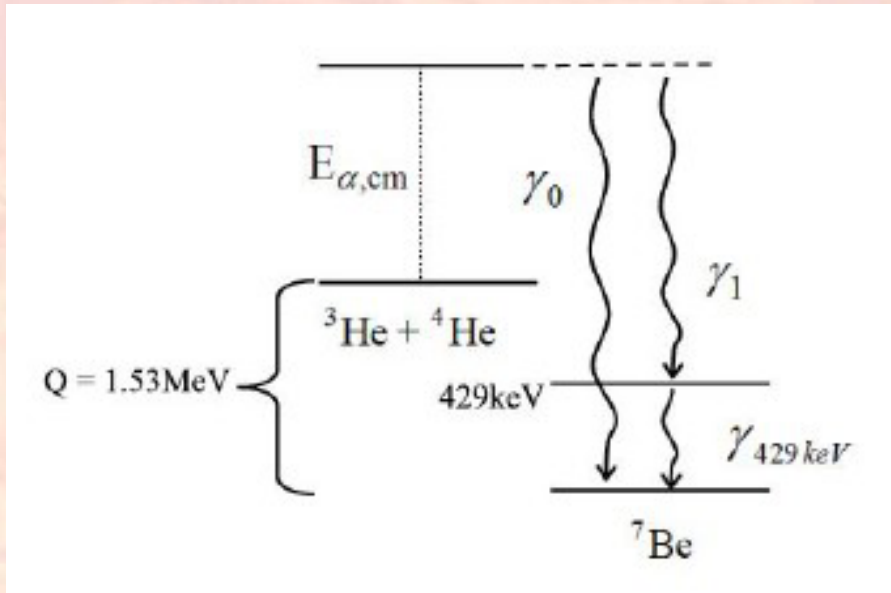
Detect the prompt γ-rays emitted when the ^{7}Be is produced

Detect the γ-ray emitted when the ^{7}Be decays
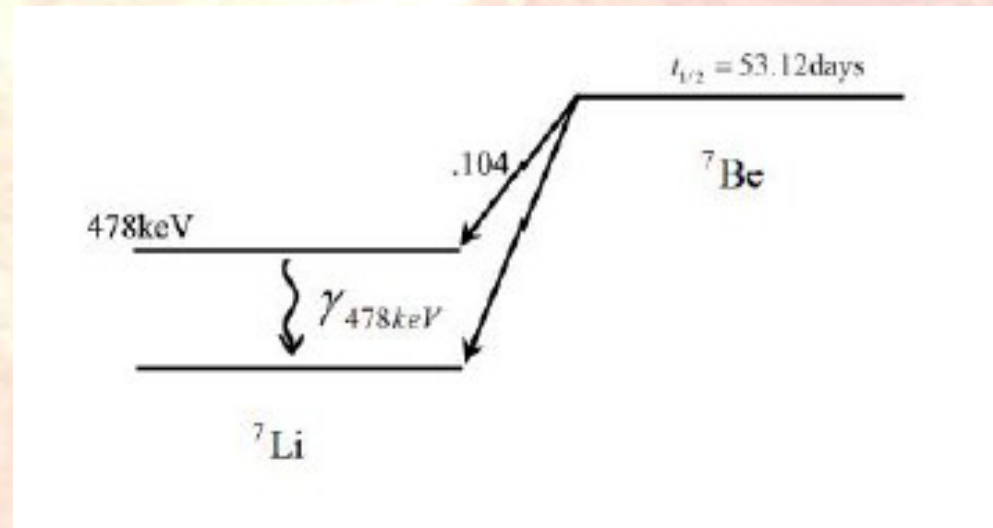
Where is the difference?

- There are two main possible sources for the differences:
    - That ^{7}Be can be formed without emitting the prompt γ-rays.
    - That ^{7}Be can be formed by a process other than $^{3}\text{He}(\alpha,\gamma)^{7}\text{Be}$.

- It has been shown that the first possibility is negligible [6].

Experiment Set-up
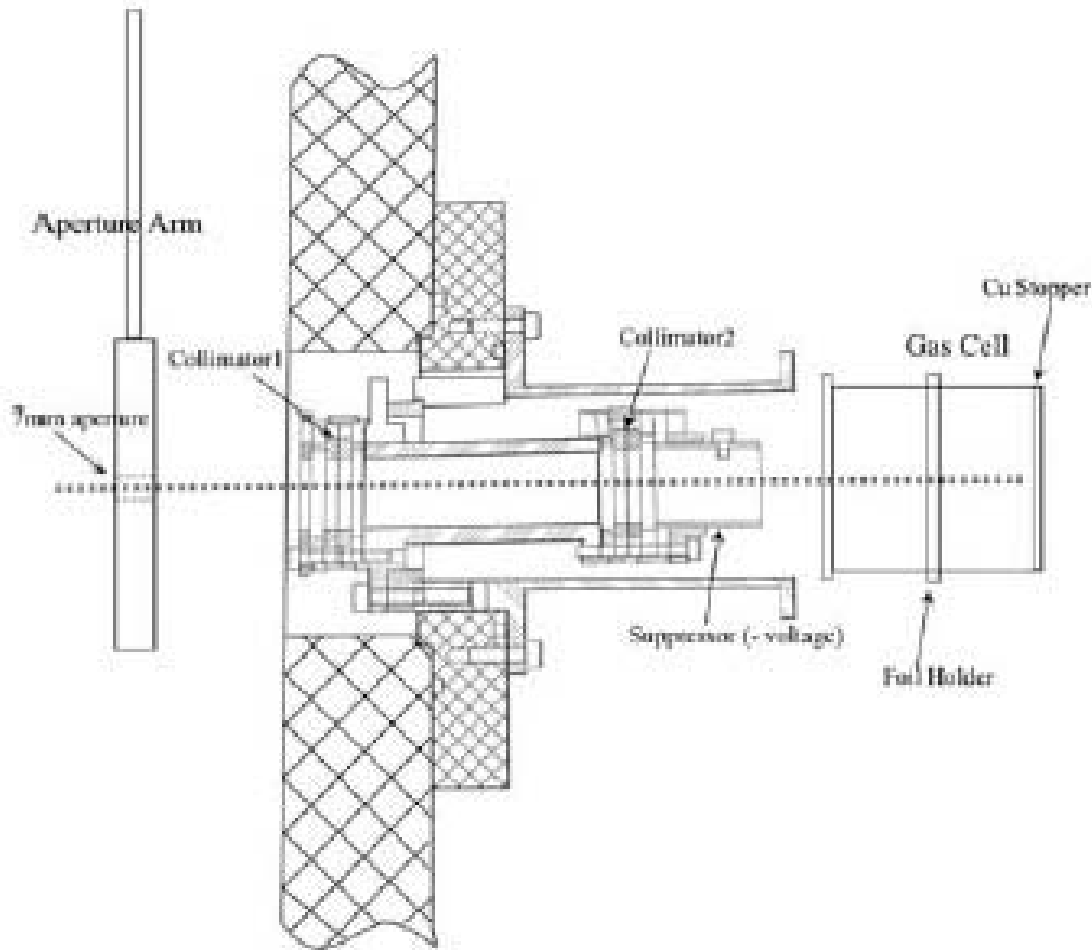
In the summer of 2004 a test run of the experiment was done.

The set-up for the precision run will be essentially the same as for the test run.

Detector Efficiency Measurement

- One of the main sources of error in the test run was the uncertainty of the detector efficiency (~24%).

- The detector efficiency was estimated based on similar detectors, but never measured for our specific detectors.

The efficiency of the detector is energy-dependent.

By calculating the efficiency of the detector using three gamma sources (five gamma rays), we can fit a curve and then extrapolate the efficiency at the desired energy.
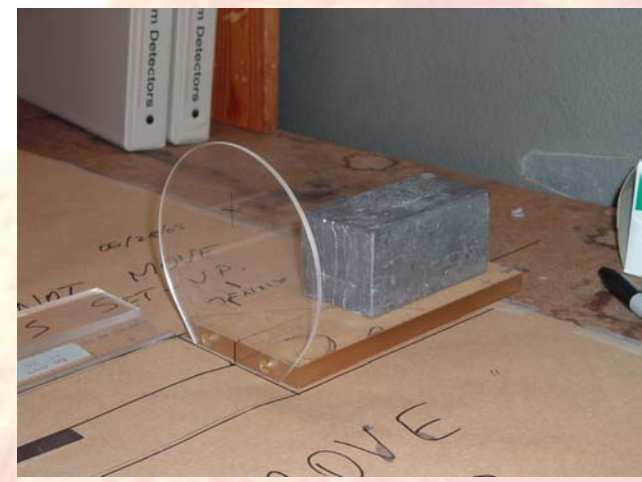
Detector Efficiency Measurement

By finding the efficiency of one detector (Canberra 2) we can find the efficiency of the other detector (Canberra 1) using the relative efficiencies provided by the manufacturer.
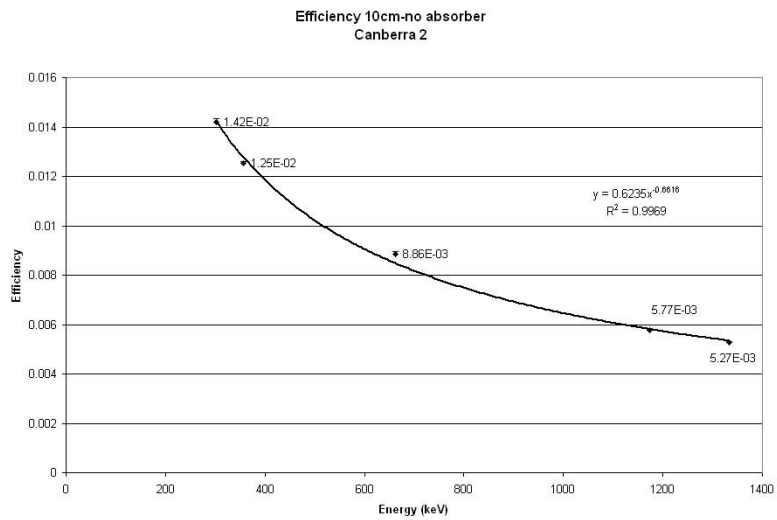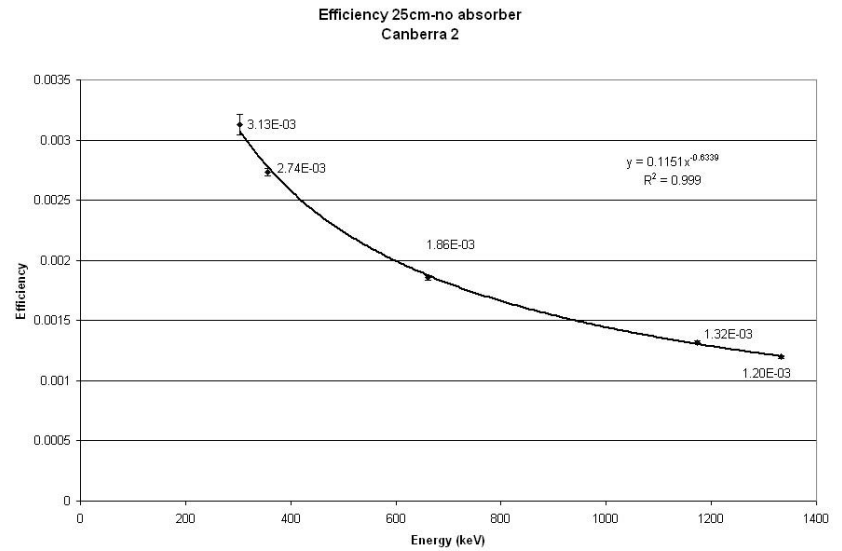

Canberra 2

Canberra 1

The efficiency curve for the source at 25 cm away from the detector

Efficiency 25cm-no absorber
Canberra 2

$y = 0.1151x^{-0.6339}$
$R^2 = 0.999$

The efficiency curve for the source at 10 cm away from the detector

Efficiency 10cm-no absorber
Canberra 2

$y = 0.6235x^{-0.6616}$
$R^2 = 0.9969$

Contamination Testing

- There is a difference between the two methods of measuring the cross section.

- We already said the first possibility is negligible, but what about the second?

- ^{7}Be can be formed by another process; in fact, there are two such processes that require only a small amount of beam and test material contaminant:

$$^{6}Li + d \rightarrow {}^{7}Be + n$$

$$^{10}B + p \rightarrow {}^{7}Be + \alpha$$
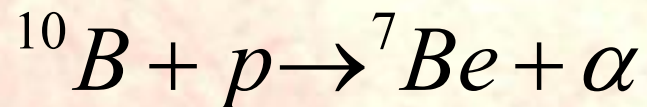
Contamination Testing

- The beam will always have contaminants of protons and deuterons.

- This means that if our Cu targets contain any ^{6}Li or ^{10}B we may produce ^{7}Be.

- We must take this into account when measuring the amount of ^{7}Be produced by ^{3}He$(\alpha, \gamma)^7$Be .
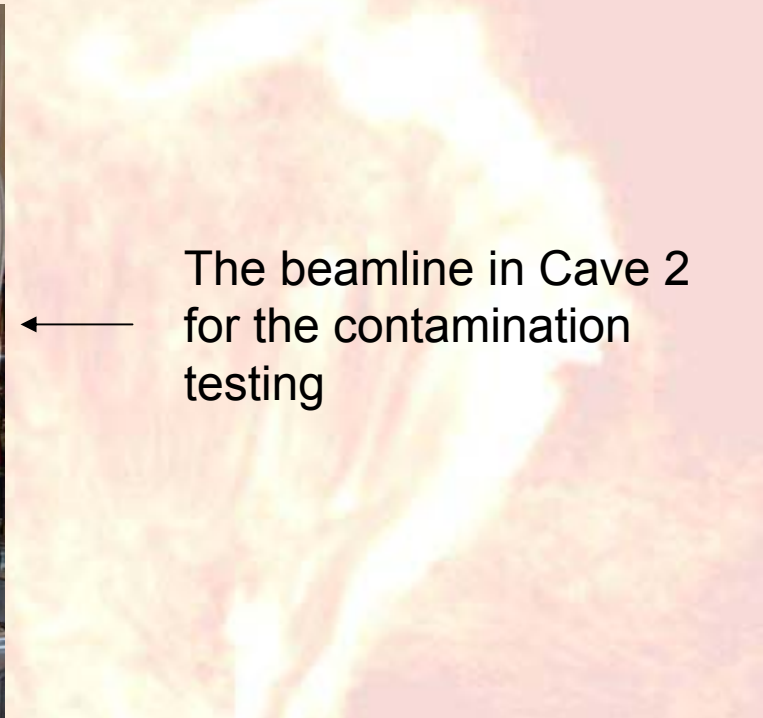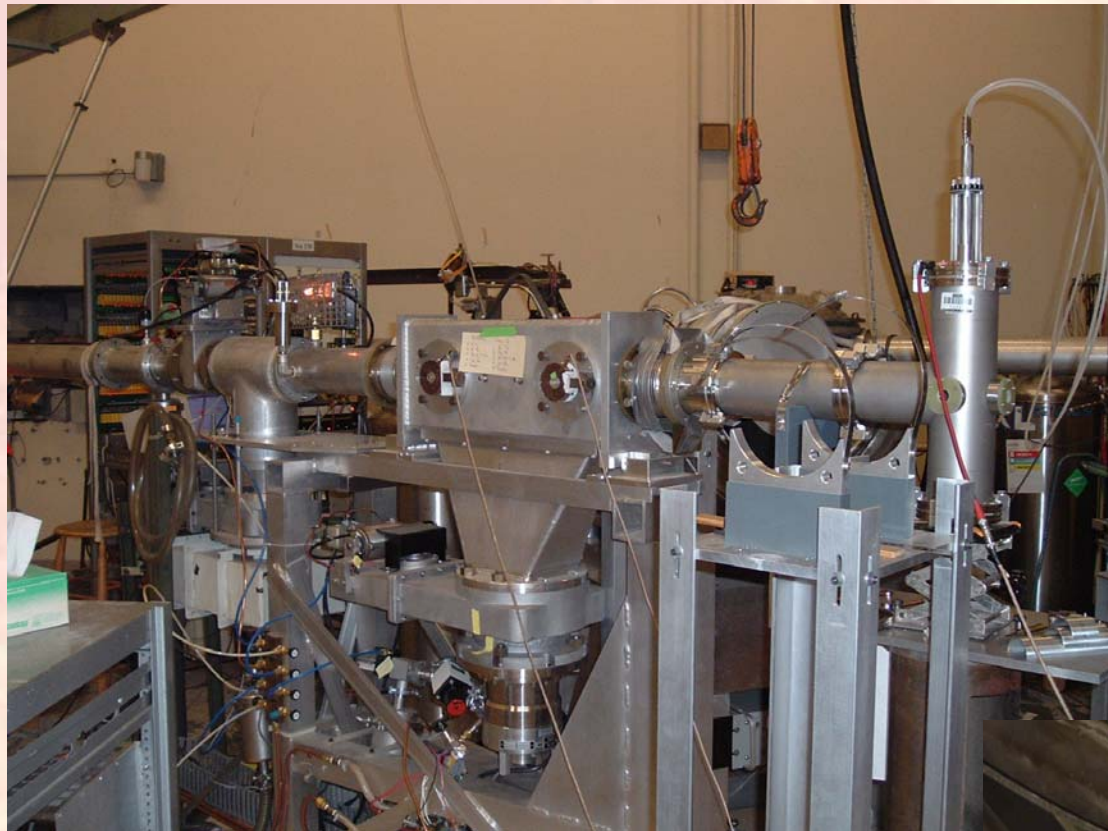
The beamline in Cave 2 for the contamination testing

The target ladder after being irradiated

Contamination Testing

- In June we tested Cu and Ta, one each with protons and deuterons.

- We found that the background was four times higher than without the sample.

- We also found new peaks in the spectrum; later we found that these peaks were from products of the test material reacting with the beam as a result of running at a higher energy.

Contamination Testing

The two peaks were formed as a result of running at a higher energy.

The 478 keV peak should be in the area of channels 1049-1199 (approximately the area of the yellow circle)
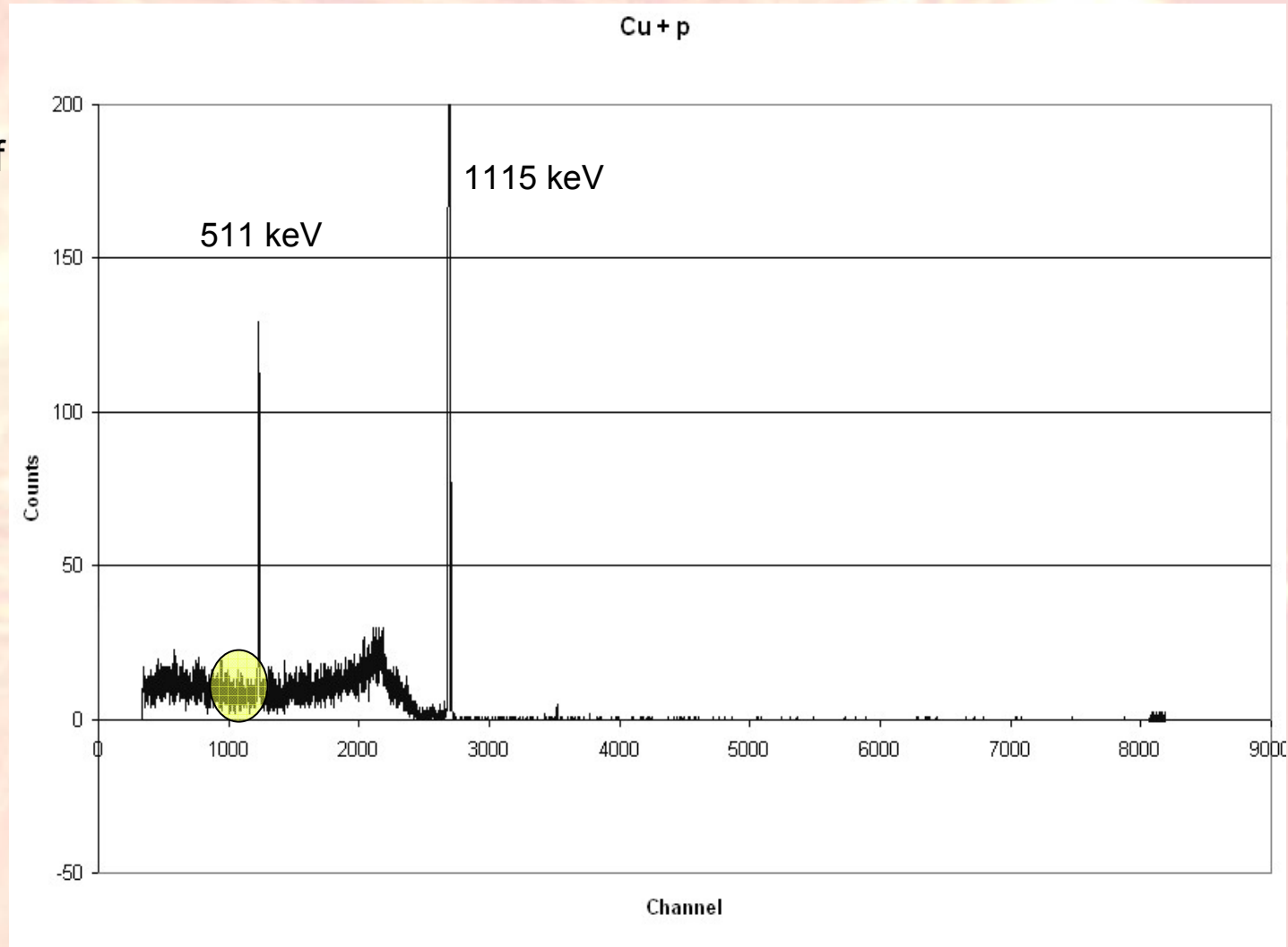
Contamination Testing: Round 2

- We decided to do a second run, this time with two Cu targets and one Ni target.

- We ran the beam as a terminal ion source again to get a lower energy

- This time we did not get extra peaks in the spectra.

- We succeeded in calculating the number of ^7Be atoms produced per proton or deuteron.

Contamination Testing: Round 2
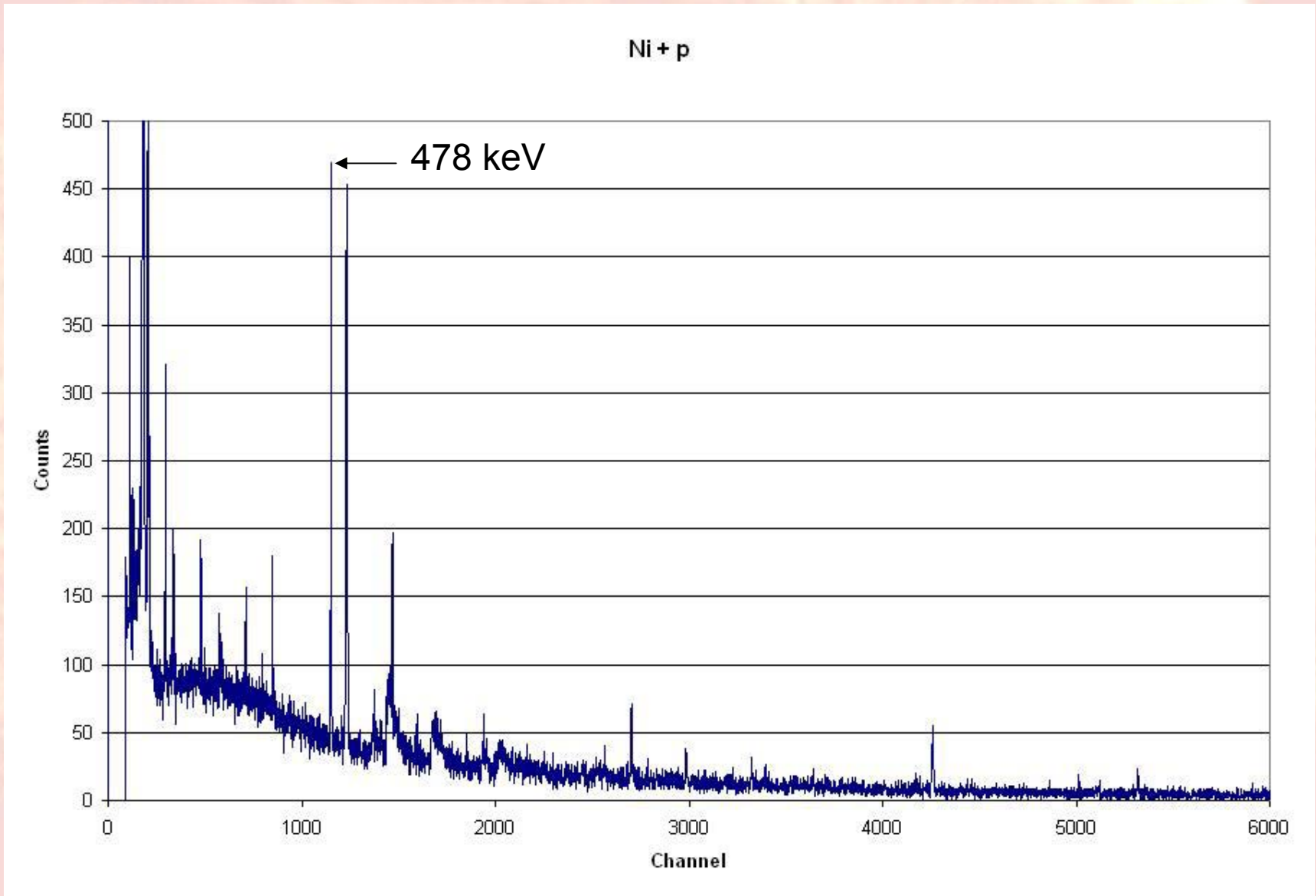
The summer in review:

This summer I participated in two main parts of the $^3\text{He}(\alpha,\gamma)^7\text{Be}$ cross section project:

-Measurement and calculation of the detector efficiencies

-Measurement and calculation of the target material contamination

Still to come…

- Precision run of the experiment, with prompt gamma-ray detection as well as offline counting of ^{7}Be decay

- Another efficiency measurement, with more data points to get a better curve

- Calculation of cross section and S-factor

Special Thanks to…

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References

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