# Energy-loss of Alpha Particles in Matter

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# Aims

- Find stopping power of each material
- Compare results for validity
- Find ionisation energies of materials

# The Bethe - Bloch equation

- Stopping power can be theoretically calculated using the Bethe-Bloch equation:

$$-\frac{dE}{dx} = 4\pi z^2 \left[\frac{e^2}{4\pi\varepsilon_0}\right]^2 \frac{NZ}{mv^2}\left(\ln\left[\frac{2mv^2}{I}\right] - \ln\left[1 - \left(\frac{v}{c}\right)^2\right] - \frac{C_K}{Z}\right)$$

- Which can be simplified to:

$$-\frac{dE}{dx} = 3.801\frac{NZ}{E}(\ln E + 6.307 - \ln I) * 10^{-19} eVm^{-1}$$

# How do alpha particles lose energy?

- Elastic collisions
- Alpha particle loses energy
- Electron excited or liberated

# Differential Range

- Calculate differential range from stopping power

$$\Delta R = -\int_{E_1}^{E_2} \frac{dE}{\left({}^{dE}/_{dx}\right)}$$

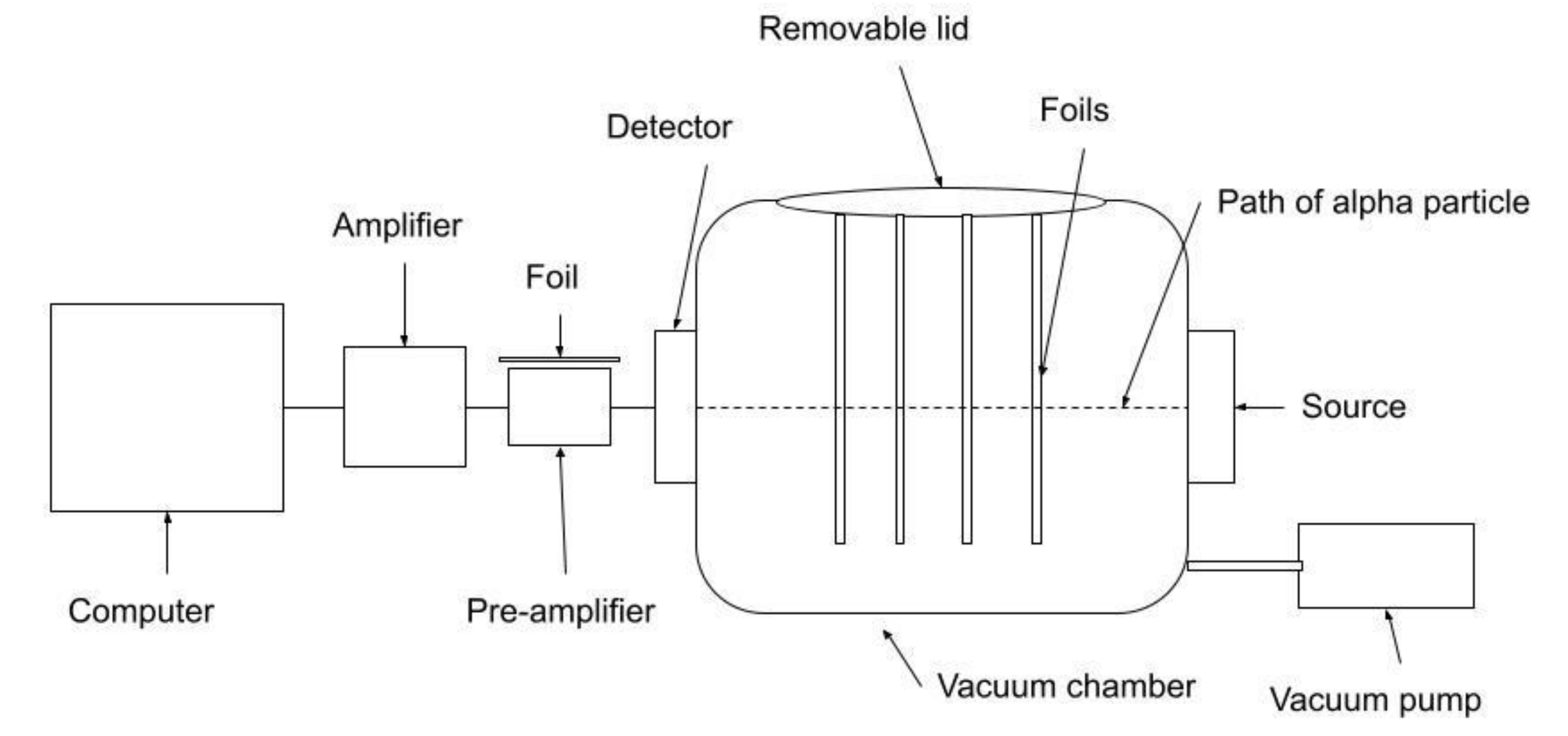
- dE/dx calculated both theoretically and experimentally

# Finding the Ionisation energy

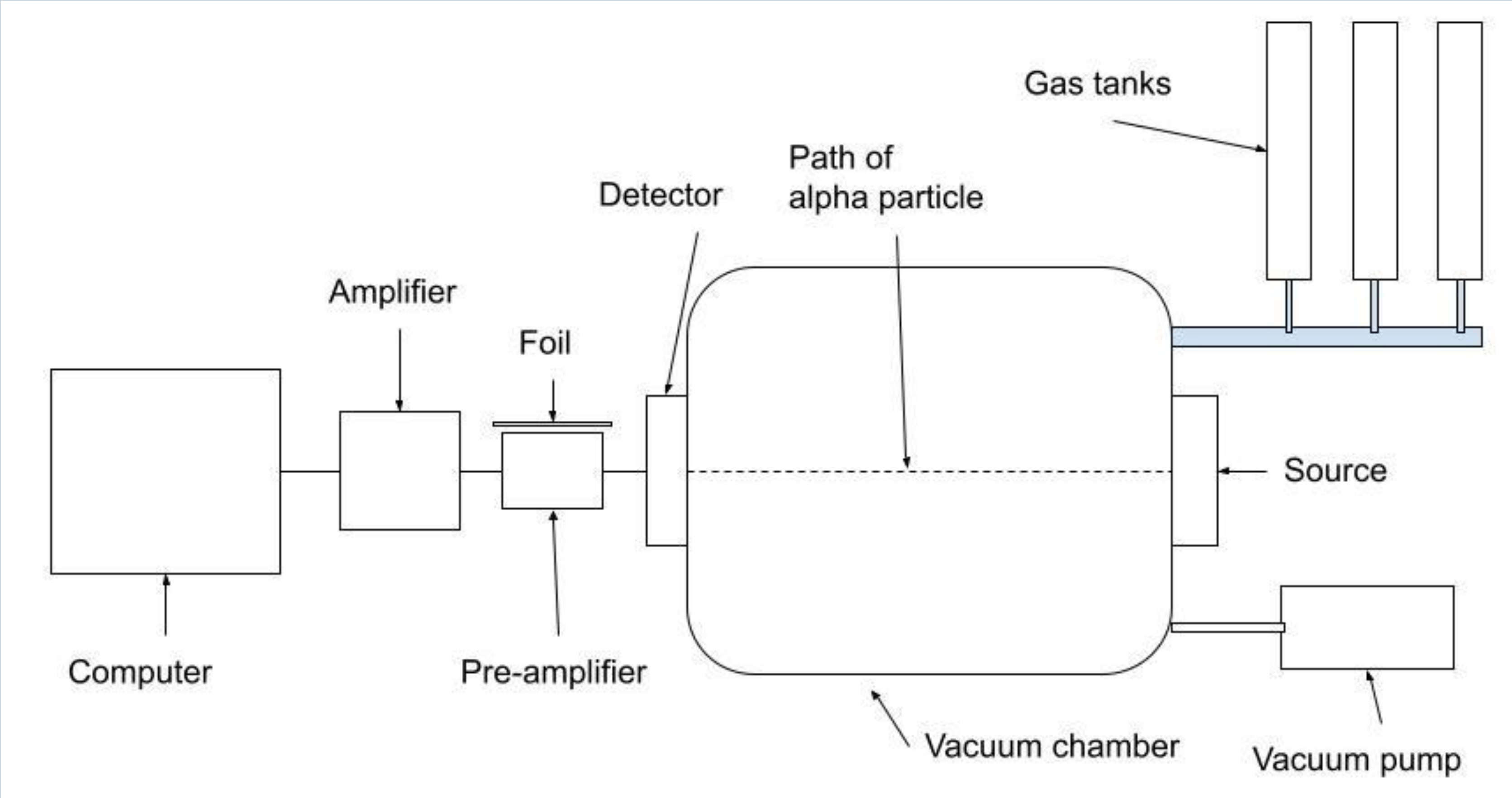
- For each value of I, the reduced chi squared between the theoretical and the experimental values of the differential range was calculated
- The best value of the ionisation energy is the one with the minimum reduced chi squared, as this shows the best agreement between theoretical and experimental results

# Experiment and results

# Experimental set-up - foils



# Experimental set-up - gases



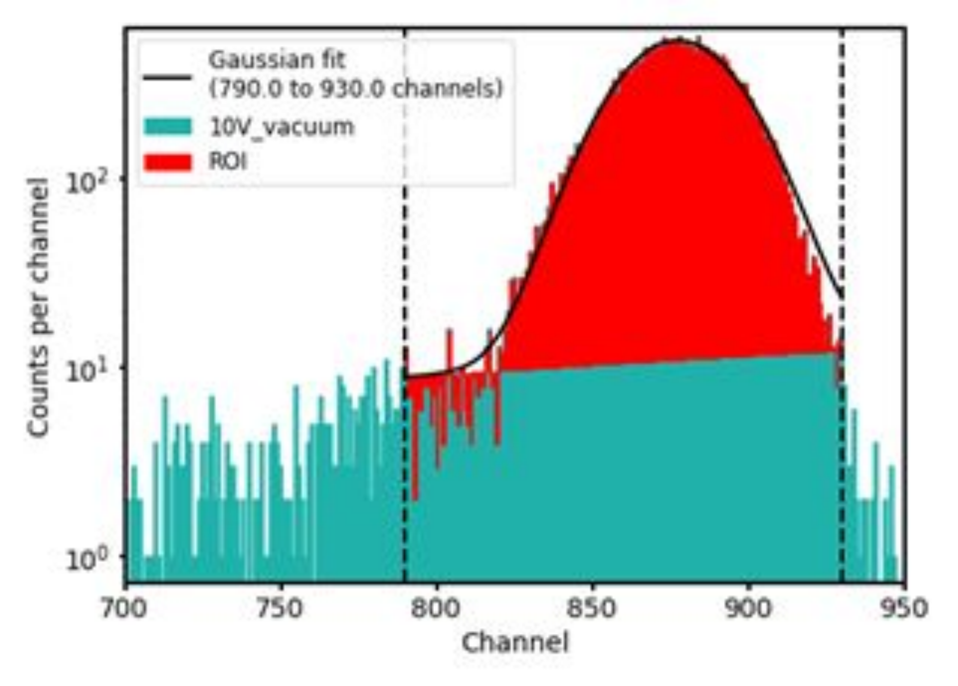
# How does the Si detector work?

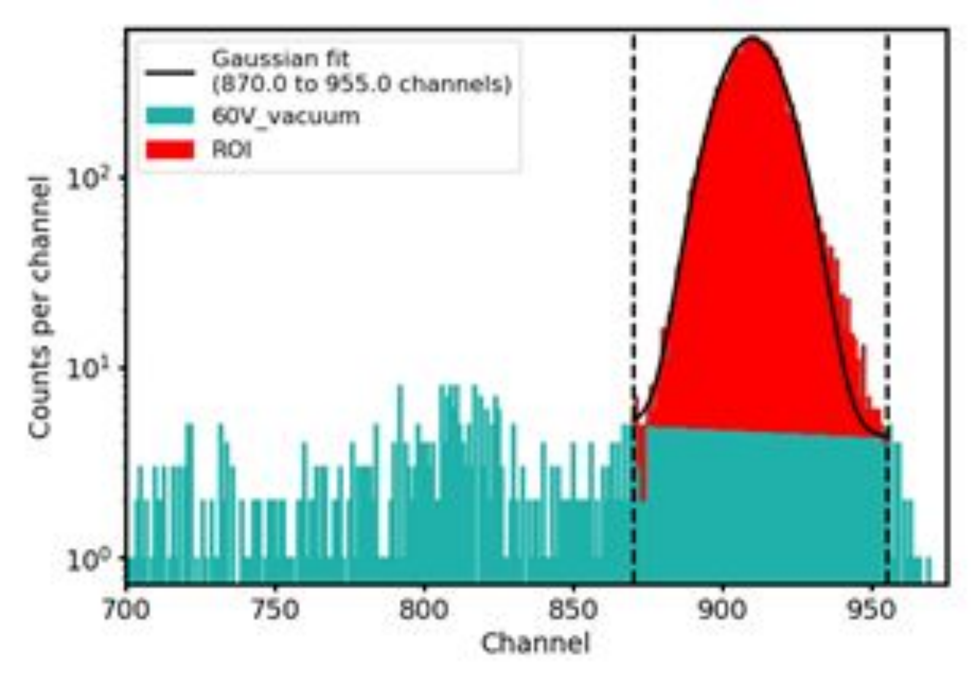
- Alpha particles incident on depletion region
- Ionizes electrons in region
- Electrons-holes pair is created
- Electrons flow to the p-type material
- Hole flow to the n-type
- Total electrons collected at electrode produces a pulse
- Pulse amplitude proportional to the incident alpha particle
- Once signal is picked up, its sent to preamplifier, the amplifier, the multichannel analyzer then computer

# Bias Voltage

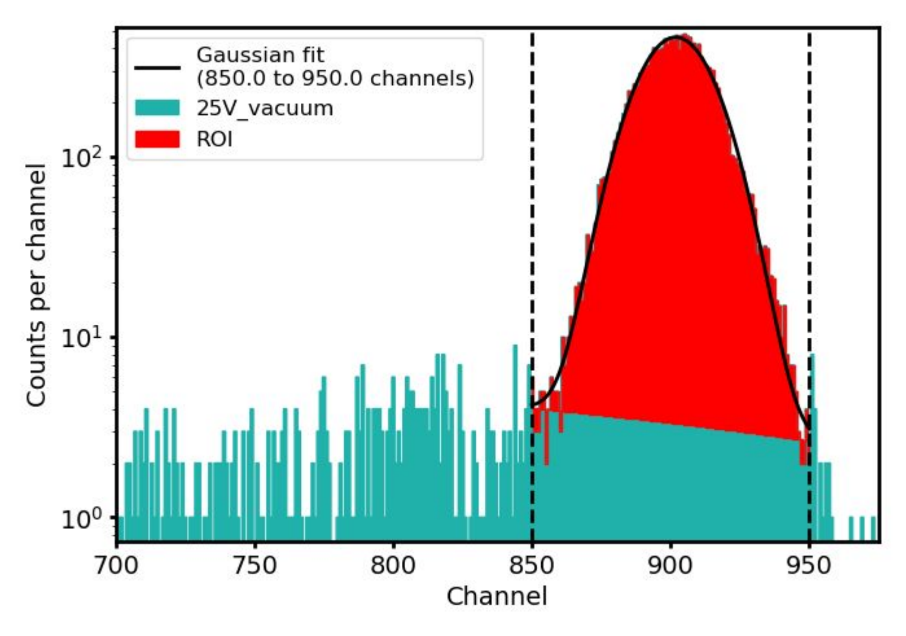
- Bias voltage applied to detector
- Increases efficiency of detector
- Increases region of sensitivity

# Choosing Bias Voltage



# Reasoning

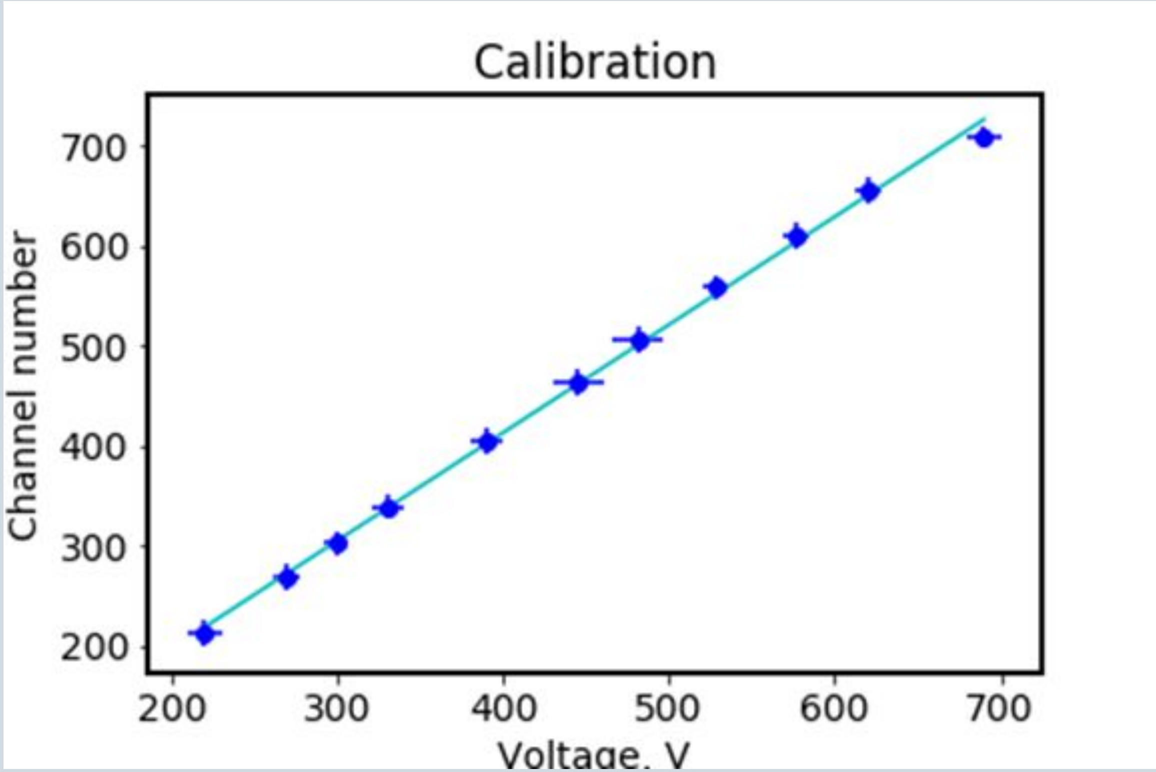



| Voltage(V) | Centroid(Channel) | FWHM(Channel width) |
|---|---|---|
| 2 | 642.953 | 147.955 |
| 3 | 676.269 | 135.193 |
| 4 | 734.484 | 102.502 |
| 5 | 797.938 | 82.793 |
| 6 | 824.99 | 68.622 |
| 8 | 861.807 | 53.363 |
| 10 | 877.397 | 44.606 |
| 15 | 892.045 | 36.419 |
| 20 | 898.223 | 32.927 |
| 25 | 901.781 | 30.519 |
| 30 | 904.152 | 29.638 |
| 35 | 905.796 | 27.827 |
| 40 | 907.224 | 26.377 |
| 45 | 907.978 | 25.656 |
| 50 | 908.79 | 24.599 |
| 60 | 909.902 | 23.946 |

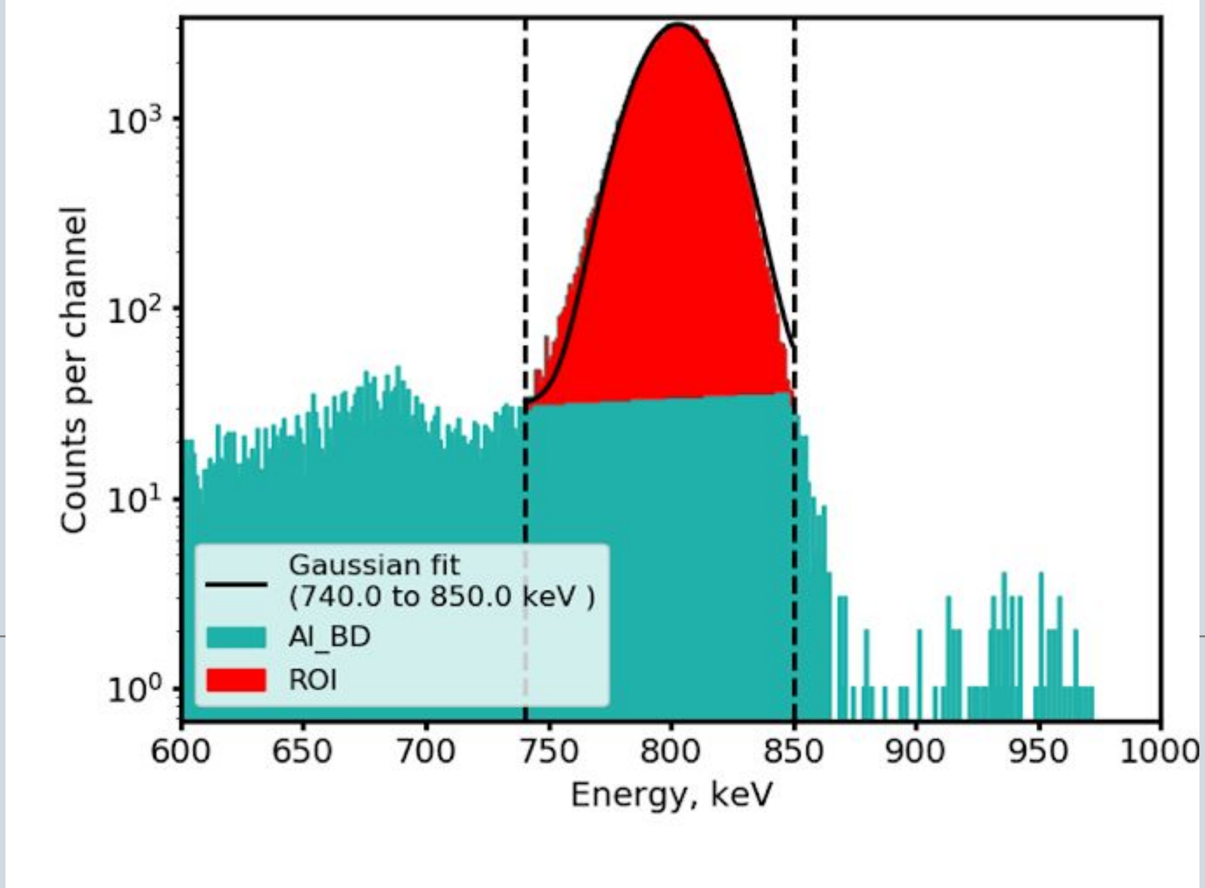
# Calibration

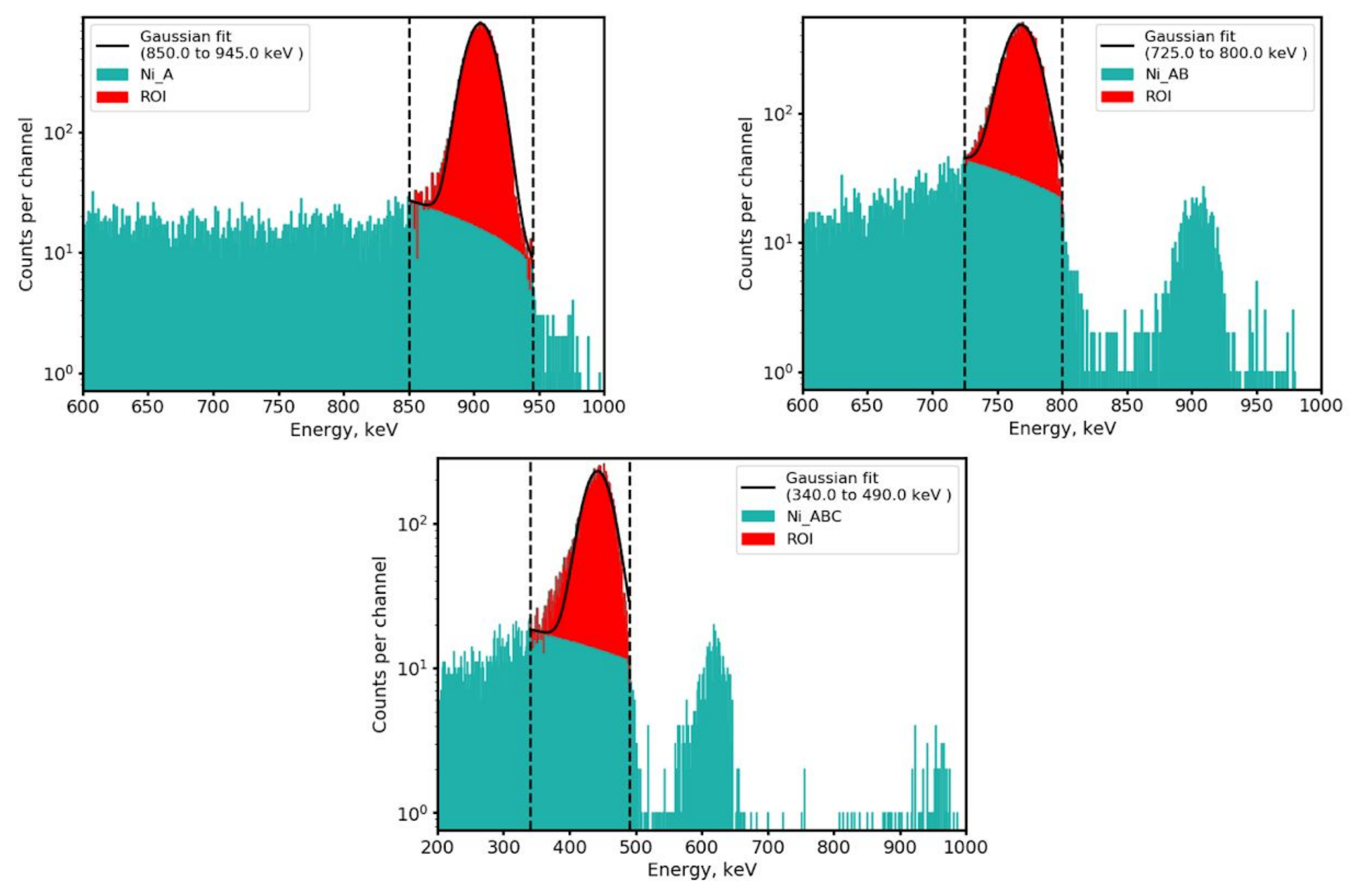
- Calibration required for all data
- Oscilloscope used to simulate peaks at lower energies
- Voltage-Channel Number relationship used to ascertain gain and offset

# Calibration



# Foils


Counts per channel
$10^3$
$10^2$
$10^1$
$10^0$
Gaussian fit
(740.0 to 850.0 keV )
Al_BD
ROI
600
650
700
750
800
850
900
950
1000
Energy, keV



Gaussian fit
(850.0 to 945.0 keV )
Ni_A
ROI
Counts per channel
Energy, keV
Gaussian fit
(725.0 to 800.0 keV )
Ni_AB
ROI
Counts per channel
Energy, keV
Gaussian fit
(340.0 to 490.0 keV )
Ni_ABC
ROI
Counts per channel
Energy, keV

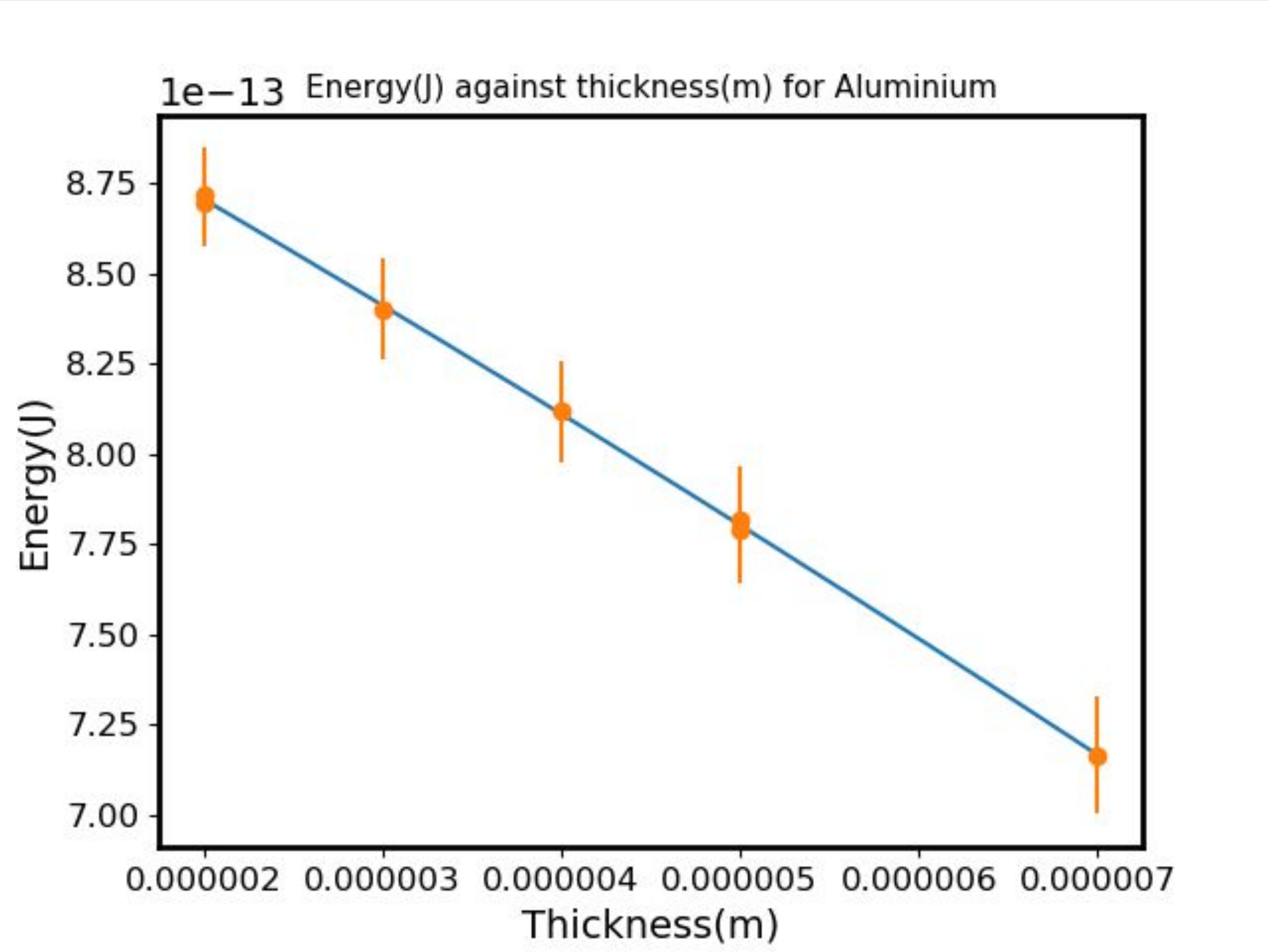
# Equation:

E=Ax^2 + Bx + C

A=3.51e-4

B=-2.77e-8

C=9.27e^-13



# Equation:

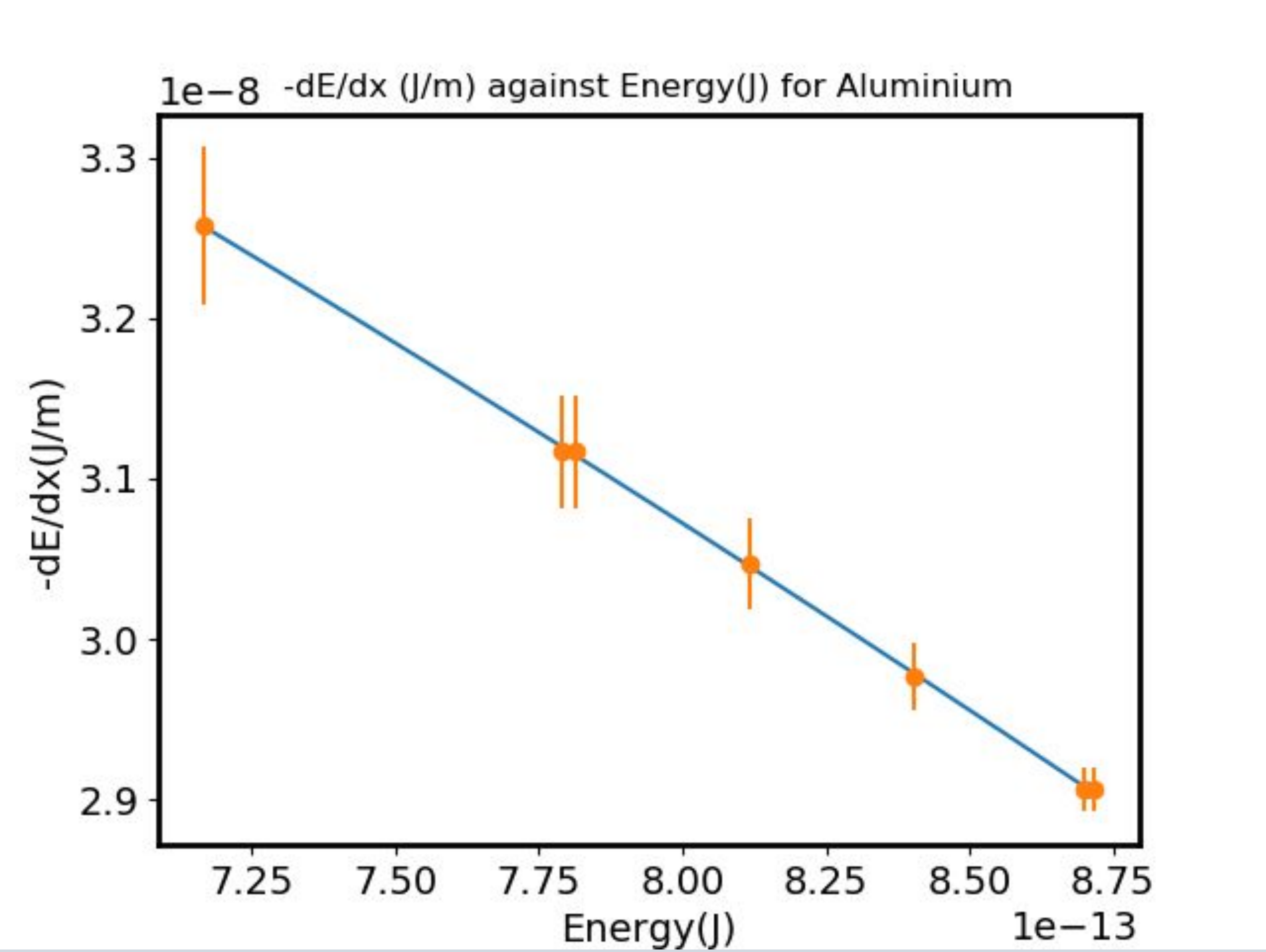
-dE/dx=(AE^2 + BE + C)

A= -8.301e+15

B= -9593

C= 4.371e-08

Uncertainty in -dE/dx = 2*A*(uncertainty in thickness)

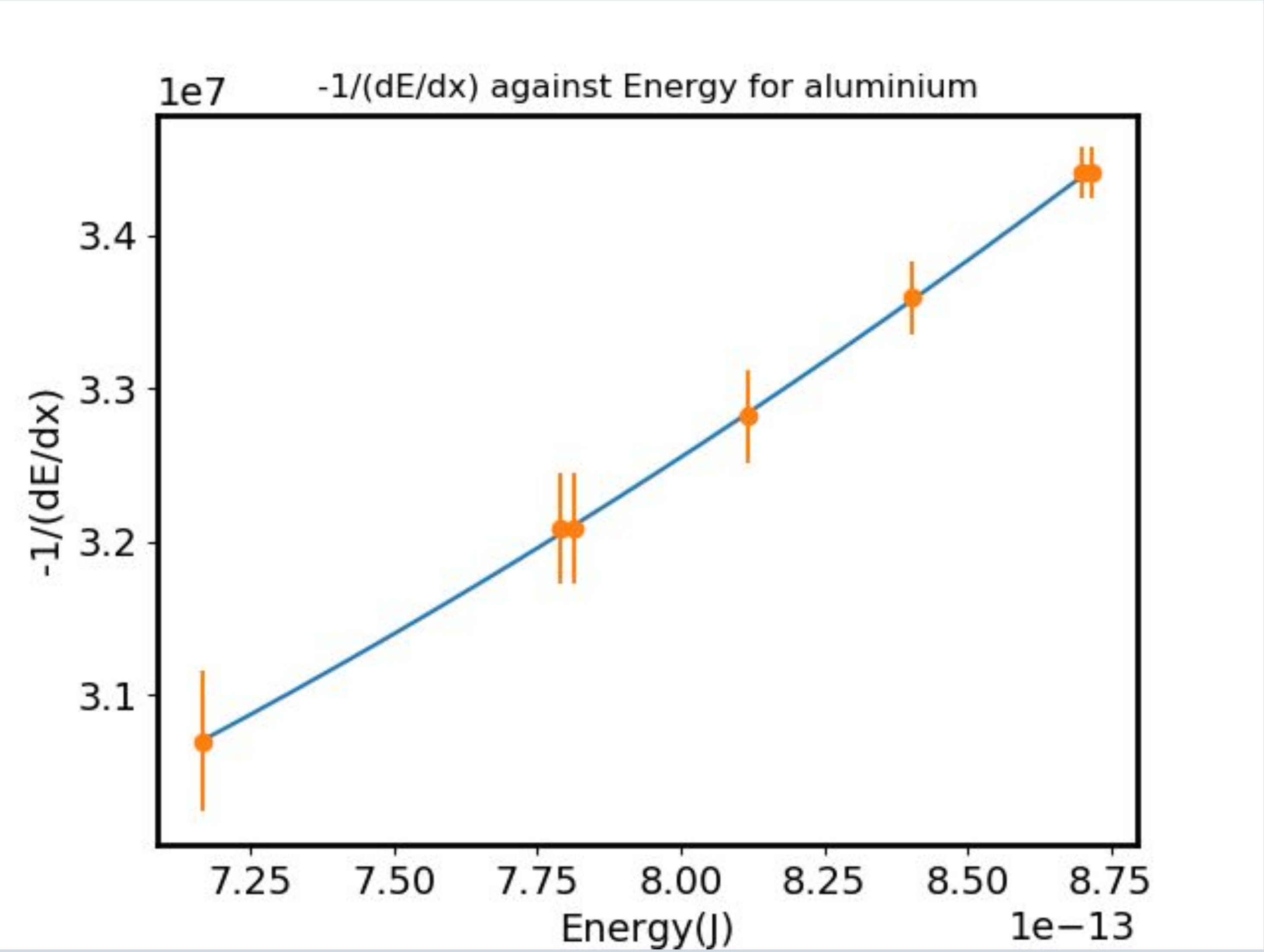


# Integral prediction:

(7.75-8.5)*10^-13 integral

Did ½ * base * height + the rectangle underneath

Differential Range comes to 2.42 micrometers



Simpson rule is that

Integral = (1/3)*(h)*(f_1 + 4f_2 + f_3)

Where h is (f_1 - f_3)/2 and f_(1,2,3) where 1 is the final energy, 2 is the middle energy and 3 is the final energy

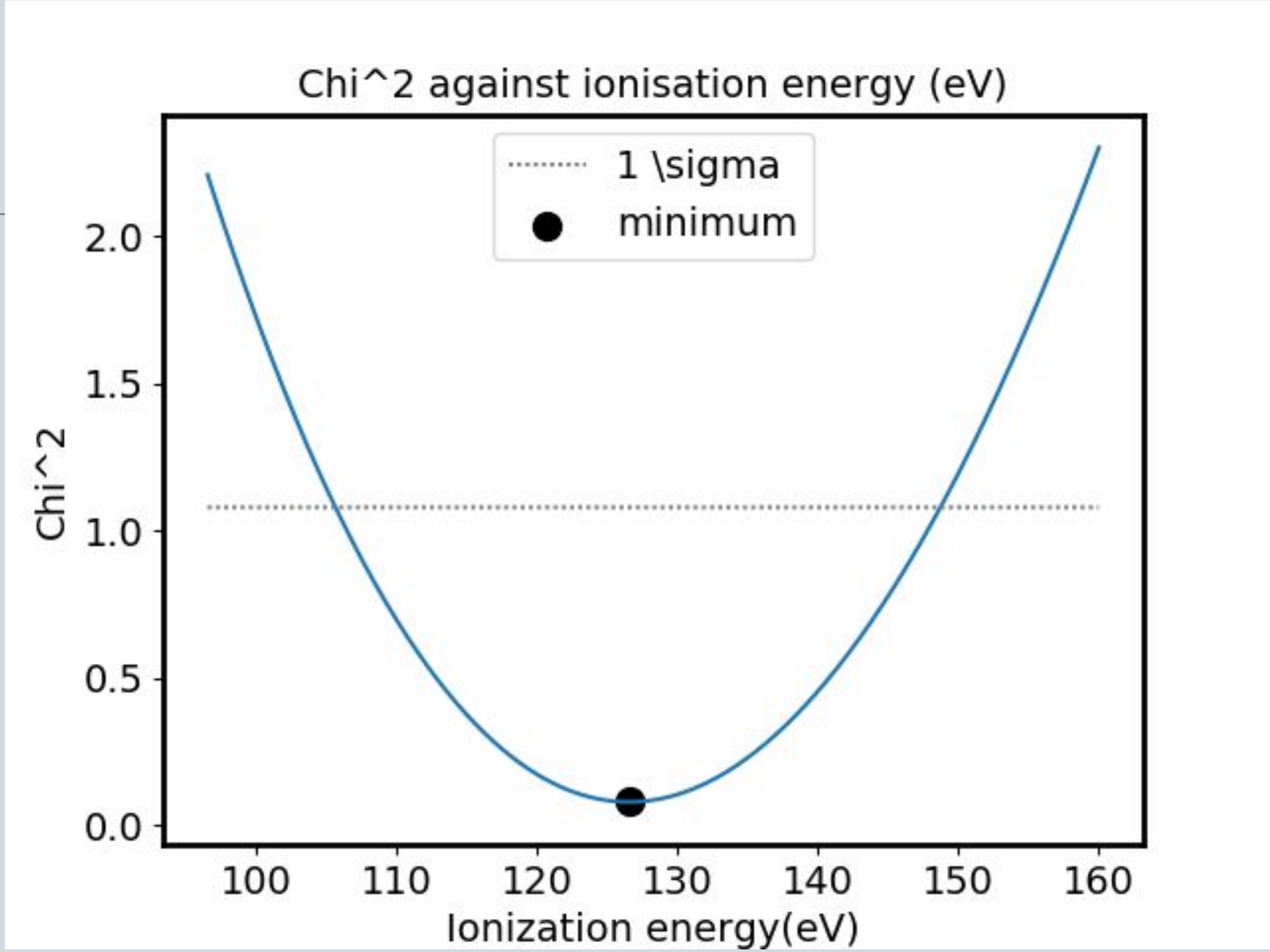
Uncertainty in the integral is given by the following formula

$$\Delta R\hat{}2 = \left(\frac{f_1+4f_2+f_3}{3}\right)^2 (uncertainty\ in\ h)^2 + \left(\frac{h}{3}\right)^2 (\Delta f_1)^2 + \left(\frac{4h}{3}\right)^2 (\Delta f_2)^2 + \left(\frac{h}{3}\right)^2 (\Delta f_3)^2$$

Where uncertainty in f_1, f_2 and f_3 is given by

$$\Delta f = (\Delta E)^2 \left(\frac{(2 * A * \Delta E + B)}{(Ax^2 + Bx + C)^2}\right)^2$$

Where E is the uncertainty in the energy recorded, A, B and C are the coefficients of the quadratic equation.


Chi^2 against ionisation energy (eV)
1 \sigma
minimum
2.0
1.5
1.0
0.5
0.0
Chi^2
100
110
120
130
140
150
160
Ionization energy(eV)

# Gases

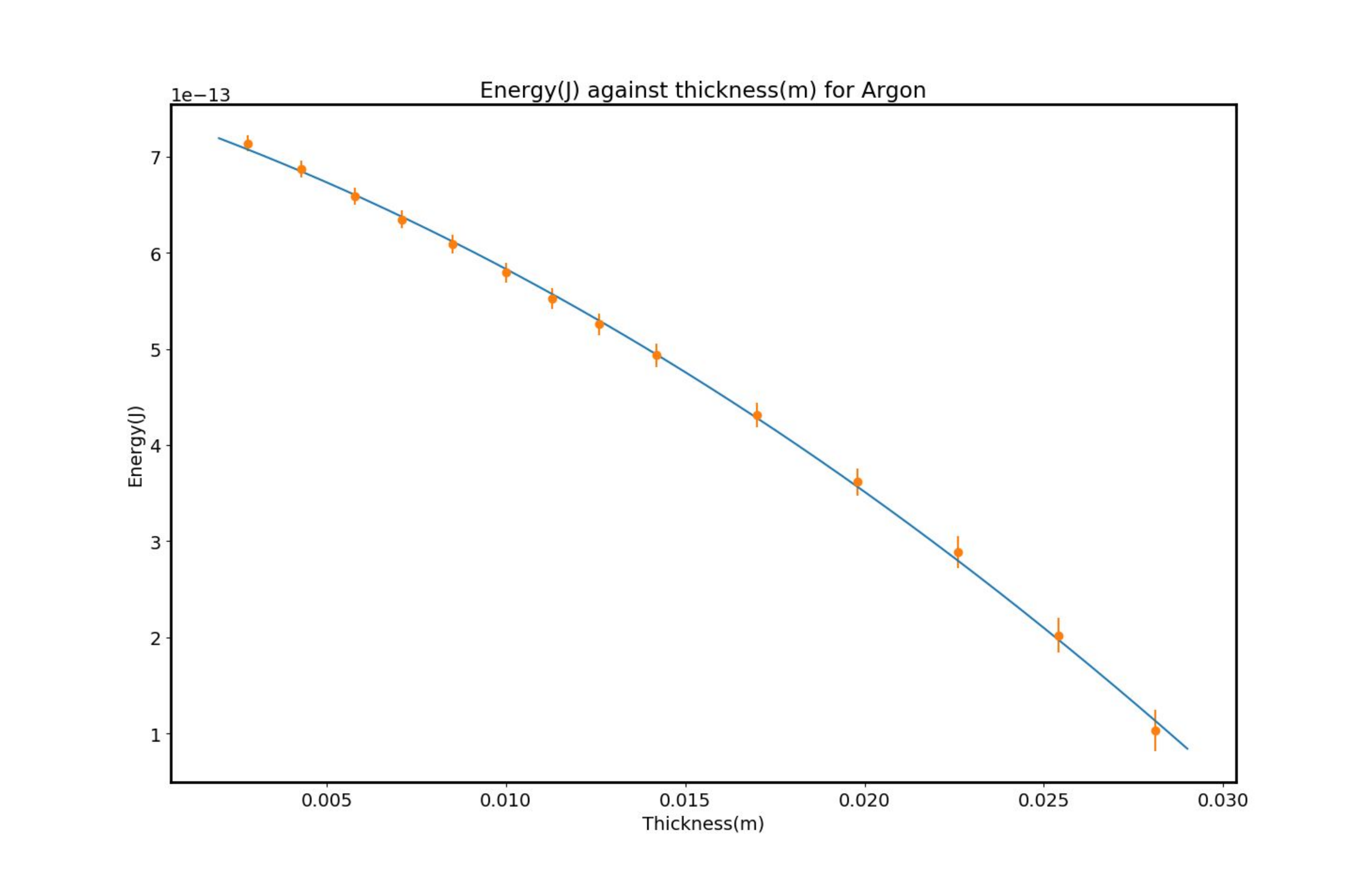
Source: 230 Thorium

# Calculating thickness

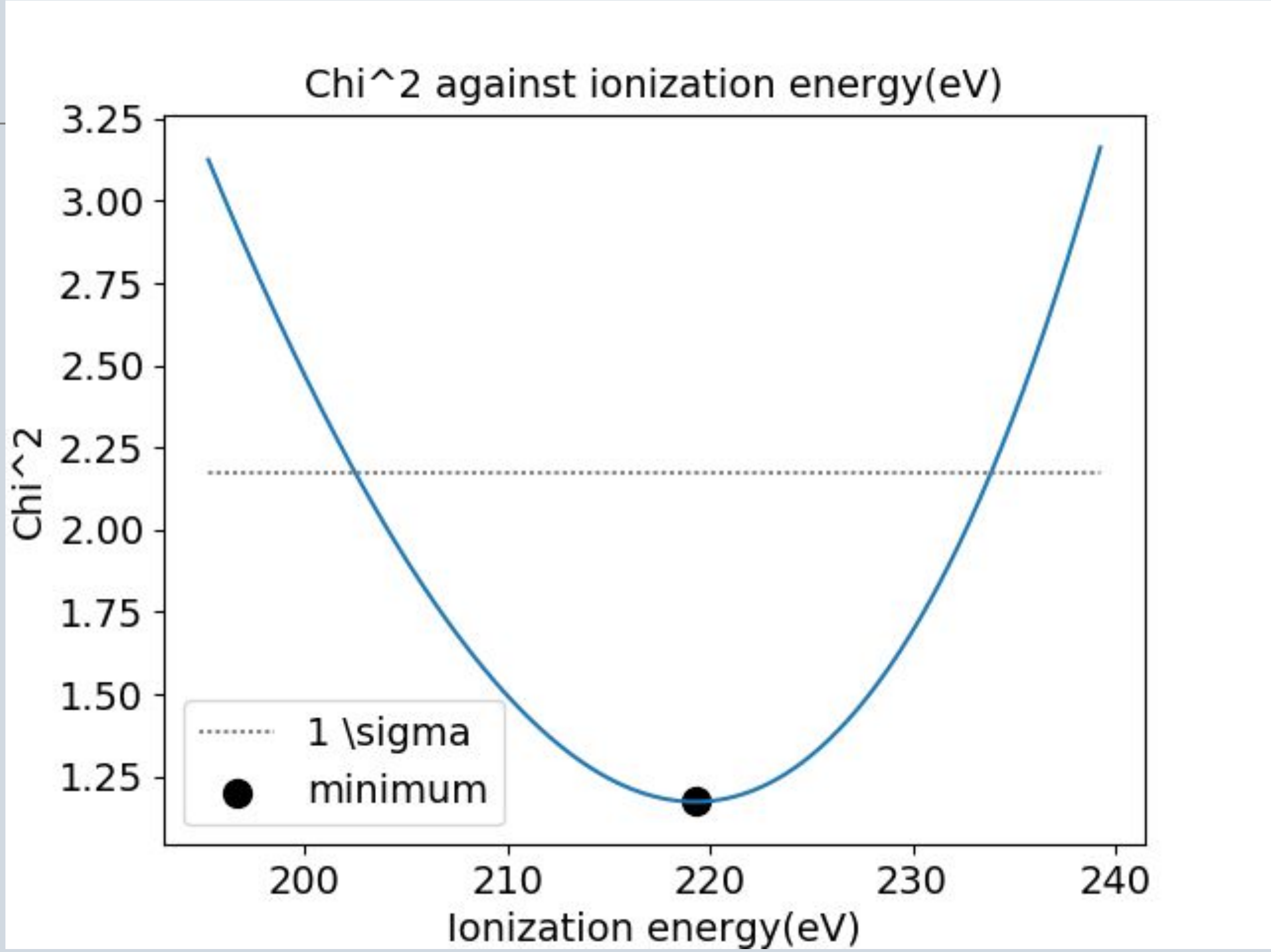
$$x_1 = x_2 \frac{P_2}{P_1}$$

$$\Delta f = \sqrt{\left(\frac{P_2}{P_1}\,\Delta x_2\right)^2 + \left(\frac{x_2}{P_1}\,\Delta P_2\right)^2} = \frac{1}{P_1}\sqrt{(P_2\,\Delta x_2)^2 + (x_2 \Delta P_2)^2}$$

# Argon

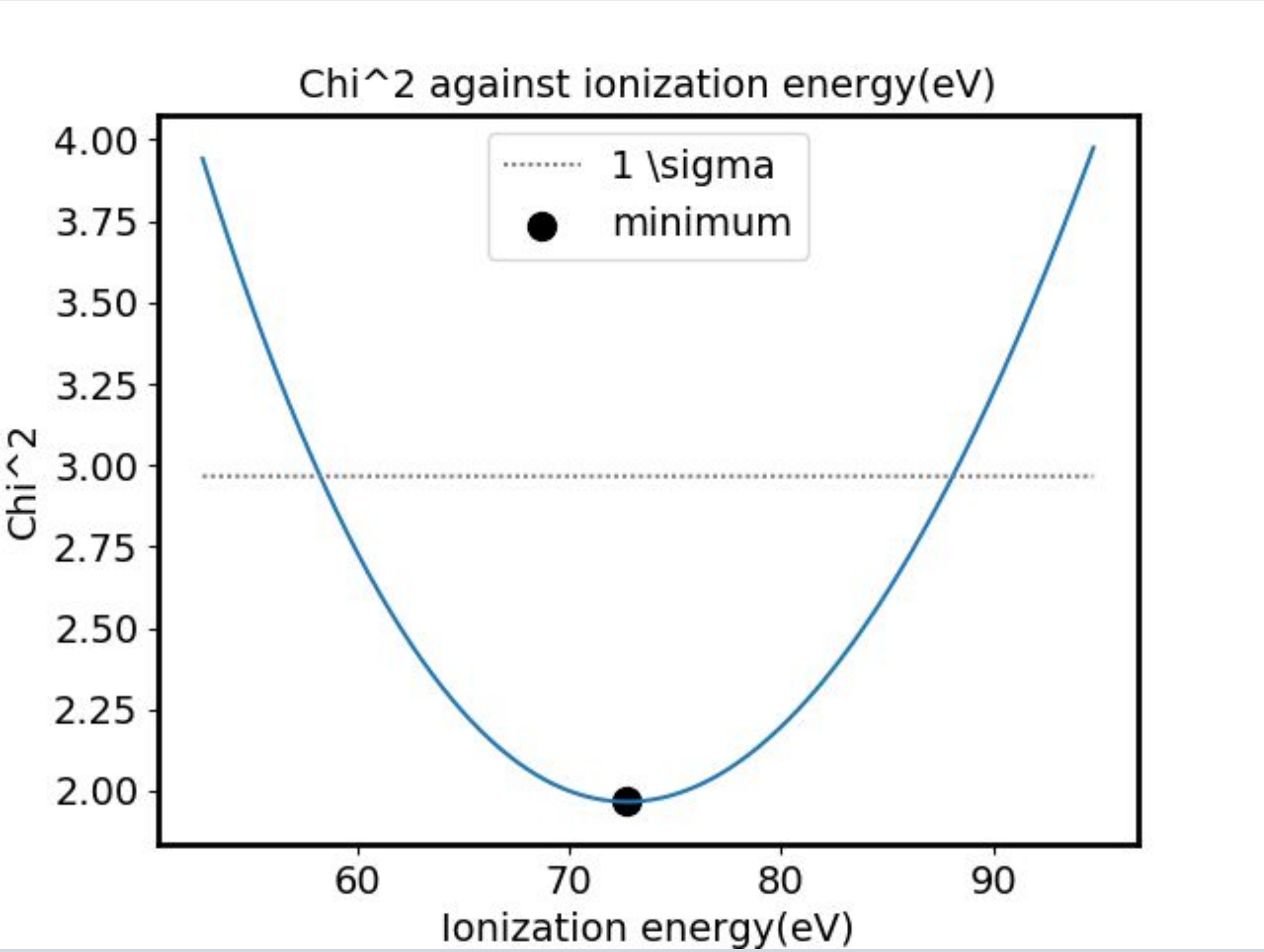

Energy(J) against thickness(m) for Argon
1e−13
Energy(J)
7
6
5
4
3
2
1
0.005
0.010
0.015
0.020
0.025
0.030
Thickness(m)

# Argon

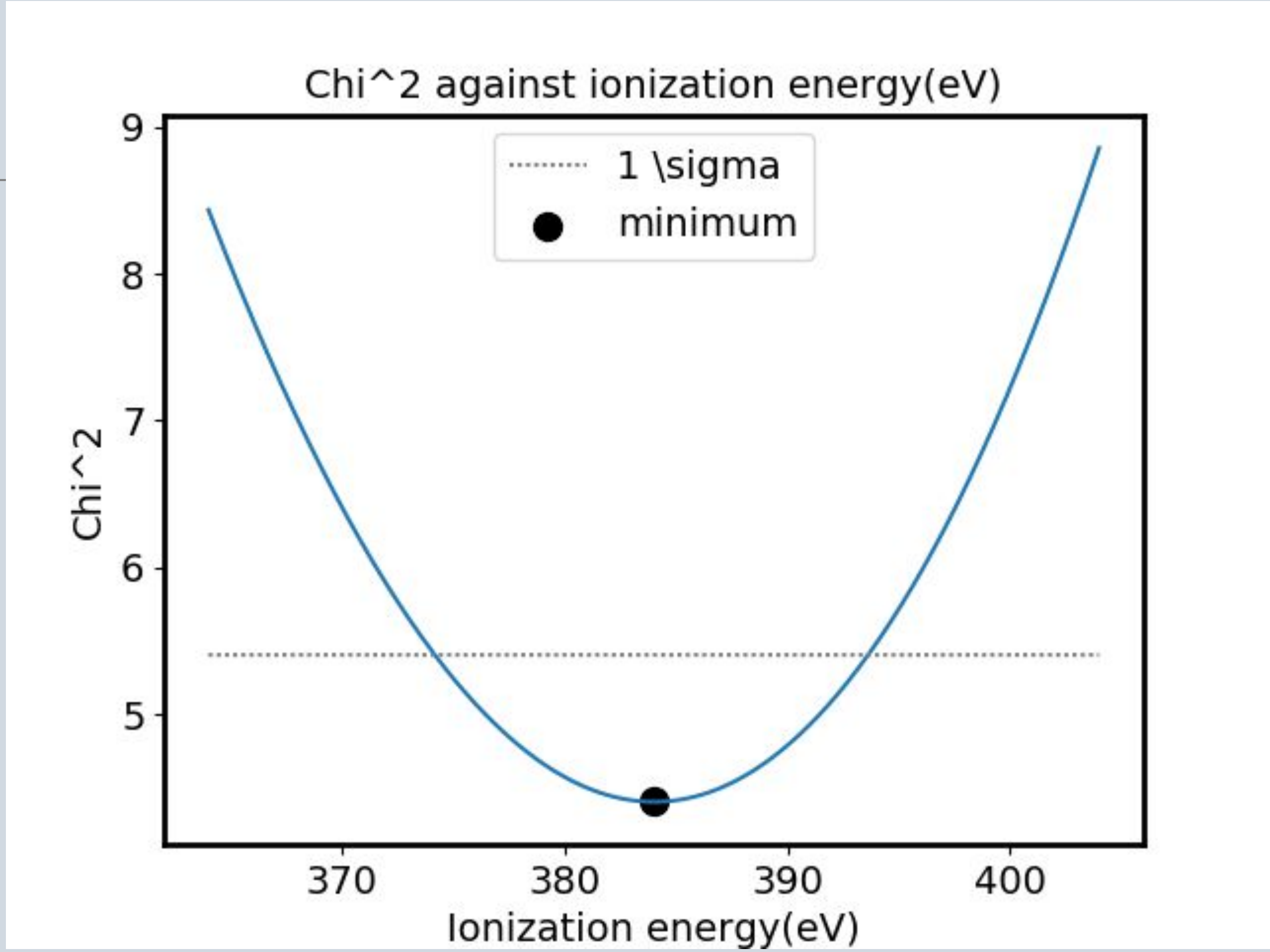


Chi^2 against ionization energy(eV)
3.25
3.00
2.75
2.50
2.25
2.00
1.75
1.50
1.25
Chi^2
1 \sigma
minimum
200
210
220
230
240
Ionization energy(eV)

# Helium


Chi^2 against ionization energy(eV)
1 \sigma
minimum
4.00
3.75
3.50
3.25
3.00
2.75
2.50
2.25
2.00
Chi^2
60
70
80
90
Ionization energy(eV)

# Nitrogen



Chi^2 against ionization energy(eV)
1 \sigma
minimum
Chi^2
9
8
7
6
5
370
380
390
400
Ionization energy(eV)

| Element | Average ionization energy(e | Calculated ionization energy(eV) | Reduced chi squared |
|---|---|---|---|
| Al | 166 ± 2 | 126.53 ± 20.90 | 0.02 |
| Ni | 311 ± 10 | 384.02 ± 9.85 | 0.44 |
| He | 41.8 ± 0.8 | 72.73 ± 15.37 | 0.33 |
| Ar | 188 ± 10 | 219.27 ± 16.76 | 0.1 |
| N2 | 82.0 ± 2 | 104.92 ± 1.62 | 5.18 |

# Sources of error

- Holes in foil:
- Not all particles required to pass through foil
- Higher energy peak counts than expect for not just one but 2 or more foils
- Way to reduce is overlap foils with half thickness at rotated 90 degrees to ensure most holes covered

- Overestimating of uncertainty:
- FWHM used to determine uncertainty in energy
- Looking at chi squared values, appear to be very low
- Maybe due to contribution from background and taking FWHM at too low a point

- Uncertainty in creating a vacuum:
- When making the vacuum there would be error in taking making one
- Not possible to produce an exact vacuum
- Air can always leak into the experiment
- Leads to uncertainty in the pressure being measured

# Conclusion

- Results are consistent with literature values
- Low reduced chi-squared values
- Ionization energy increases with proton number

# Improvements

- Quantify and account for gas leakage
- Increase run times
- Improve background subtraction method
- Use more accurate alternative to Simpson’s Rule