PHY3004W Laboratory
Neutron activation of ^{27}Al
(also known as Half-Life)

Dr Tanya Hutton

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May 2025

Data upload

Submit a **single .zip file** using your ID as the file name, e.g. XYZABC001.zip containing:

- gamma ray calibration spectra,
- time-dependent spectra for activated Al
- a README.txt file containing a description of the .zip contents and experimental conditions.

Neutron activated Al
Measurements made by T Hutton, 27 May 2021
Experimental station 1
Gamma ray calibration measurements for:
    137Cs (.tsv, .spu)
    60Co (.tsv, .spu)
    22Na (.tsv, .spu)
    Notes: source-detector distance = 5.0 cm, live time = 300s, red box 8

Al activation:
    Aluminium cylinder 2, lowest position in water bath, irradiation time = 15 mins, time to measurement start = 90s.
    Multiple runs set up for 180 x 10s real time with no wait, .tsv output.
    File prefix = Al2_Run1

```
'''
Python script to read .tsv files from USX multi-run,
and extract spectrum data
T. Hutton, tanya.hutton@uct.ac.za
Dept Physics, University of Cape Town
April 2018
Updated March 2023
'''


import numpy as np
from matplotlib import pyplot as plt

# What file prefix did you choose on USX multi-run?(string)
filePrefix = 'TH\\ActivatedAl_run1'

# How many runs? (integer)
nRuns = 400

# what are your lower and upper limits for integration in channels? (integers)
lowerLimit = 0
upperLimit = 2048

# Initialise time array, will contain the integrated
# number of counts between lowerLimit and upperLimit
# for each run
timeArray = np.zeros(nRuns)

# Placeholder
headerLen = 1000
```

Locate in same directory as .tsv spectra then change:

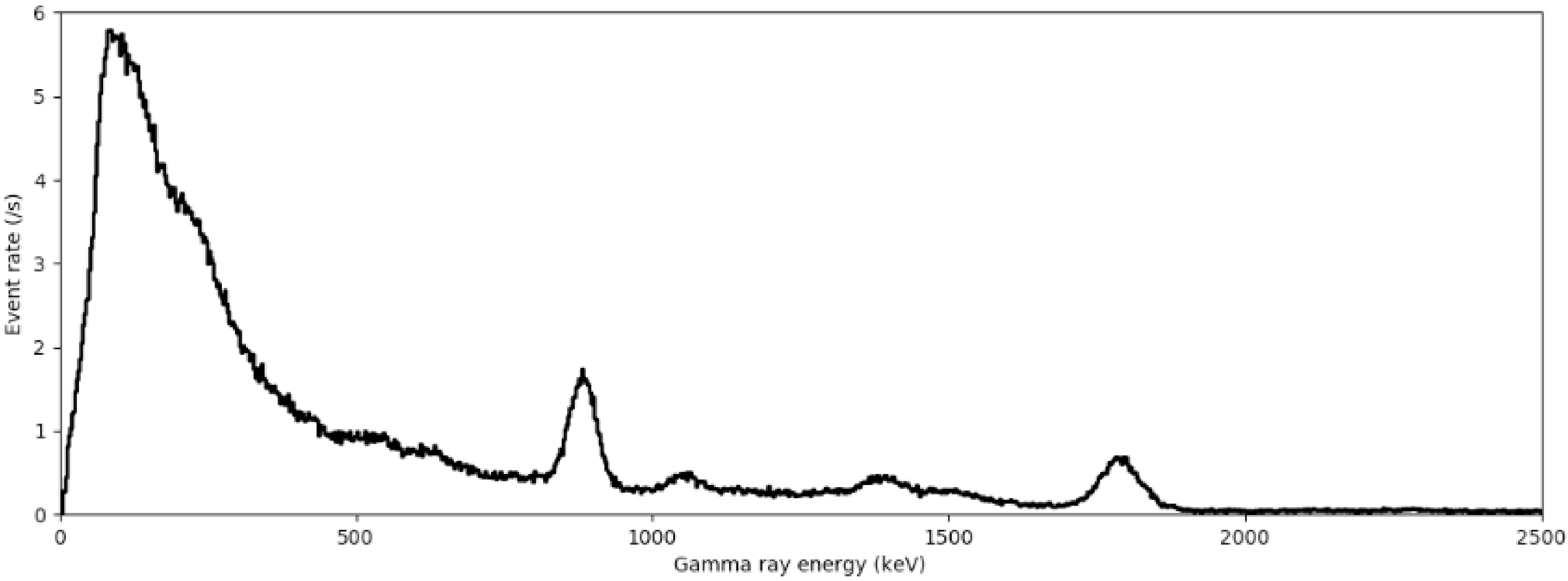
- filePrefix - whatever you chose in USX
- nRuns – number of multiple run spectra
- lowerLimit/upperLimit – channel range to sum over

```
Loop through each run file
r i in range(1, nRuns+1):

  open file
  fileName = filePrefix + str(i) + '.tsv'
  fileObject = open(fileName, 'r')

  loop through file line-by-line
  for l, line in enumerate(fileObject):

      if "Conversion Gain" in line:
          # Extract parameters from header and initialise arrays
          nChannels = int(line.split(':')[1])
          if nChannels < upperLimit: upperLimit = nChannels
          if i == 1: sumArray = np.zeros(nChannels)
          countArray = np.zeros(nChannels)

      if "Channel Data" in line: headerLen = l+2

      if l >= headerLen:
#             split line and convert number of counts per channel to float
#             populate countArray channel-by-channel
          part = line.split()
          if (len(part)) > 2: countArray[l - headerLen] = float(part[2])
          else: countArray[l - headerLen] = float(part[1])

#   close run file to release memory
  fileObject.close()

#   sum counts between lowerLimit and upperLimit
#   populate timeArray run-by-run
  timeArray[i-1] = sum(countArray[lowerLimit:upperLimit])

#   add run spectrum to sumArray
  sumArray += countArray

  print('fileName: %s\t integrated counts = %.0f' % (fileName, timeArray[i-1]))
```

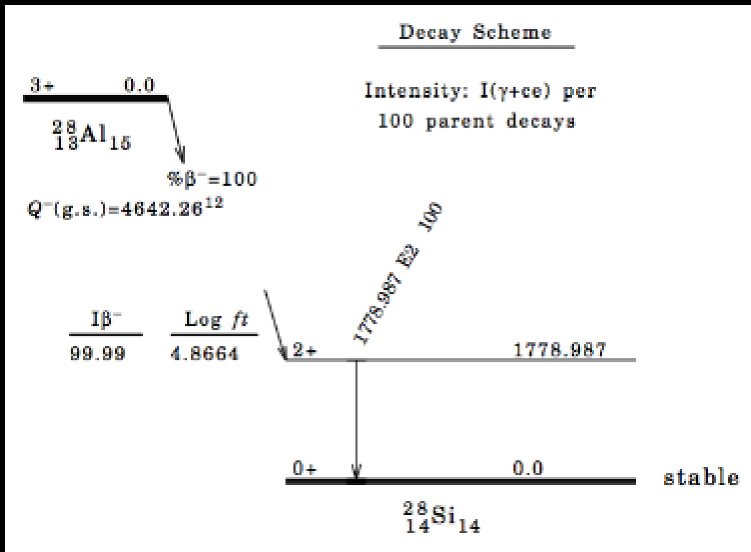
Parsed data in:

- countArray – gamma ray spectrum per file
- timeArray – summed counts in range per countArray
- sumArray – cumulative gamma ray spectrum over nRuns

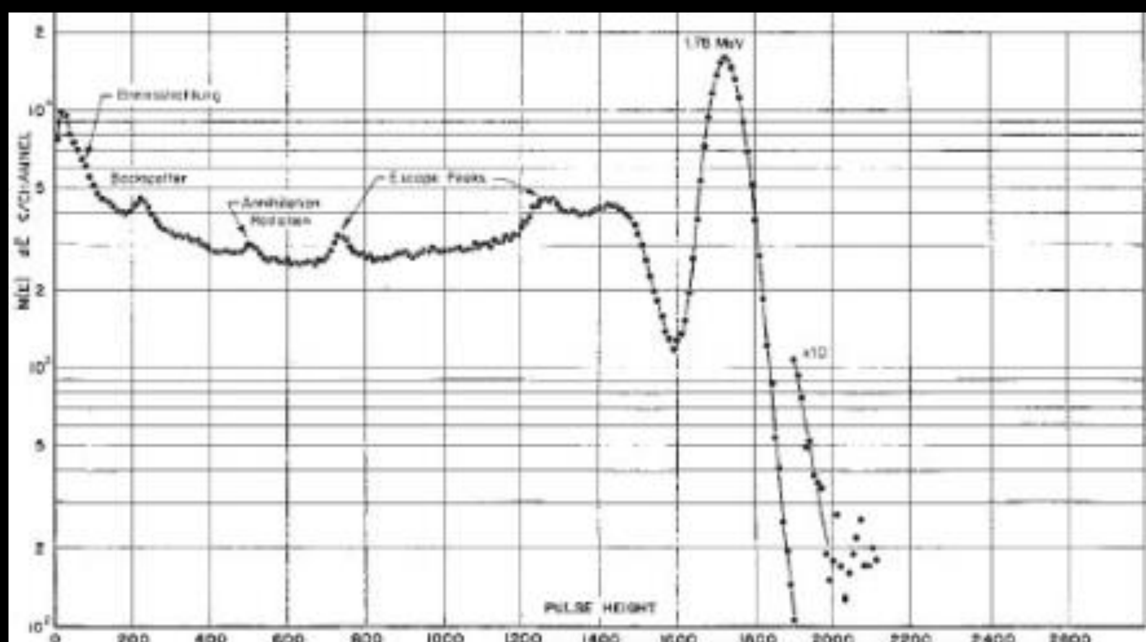
Analysis of gamma ray spectra



$$^{28}\mathrm{Al} \to {}^{28}\mathrm{Si} + \beta^- + \gamma + \bar{\nu}_e$$



Feature	Expected energy (keV)
Photopeak	1779
Compton continuum	< 1556
Back scatter	223
Escape peaks	1288, 757
Annihilation radiation	511
Bremsstrahlung	< 200



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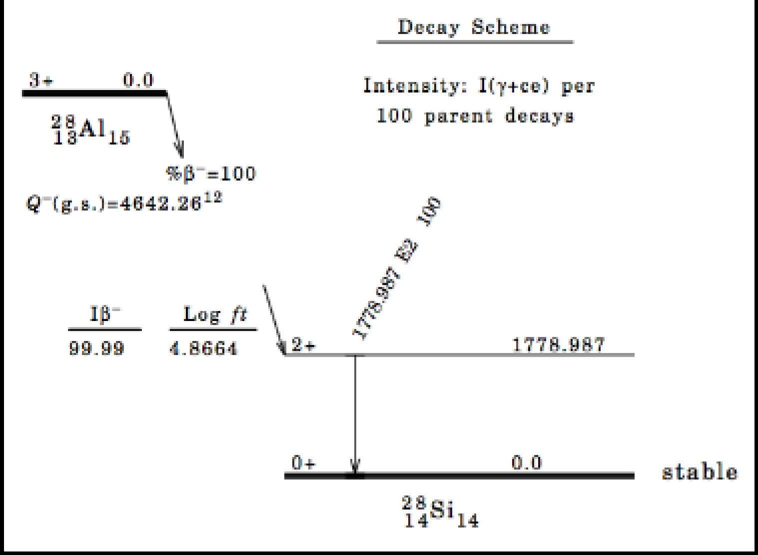

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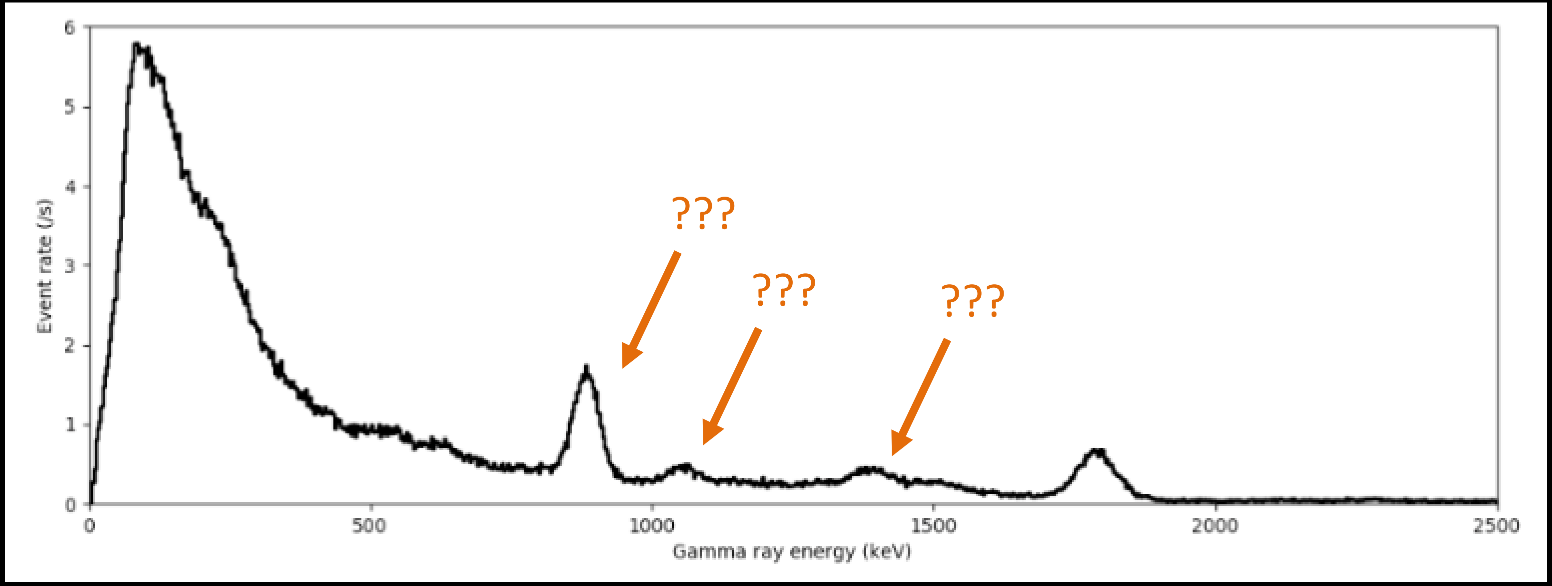


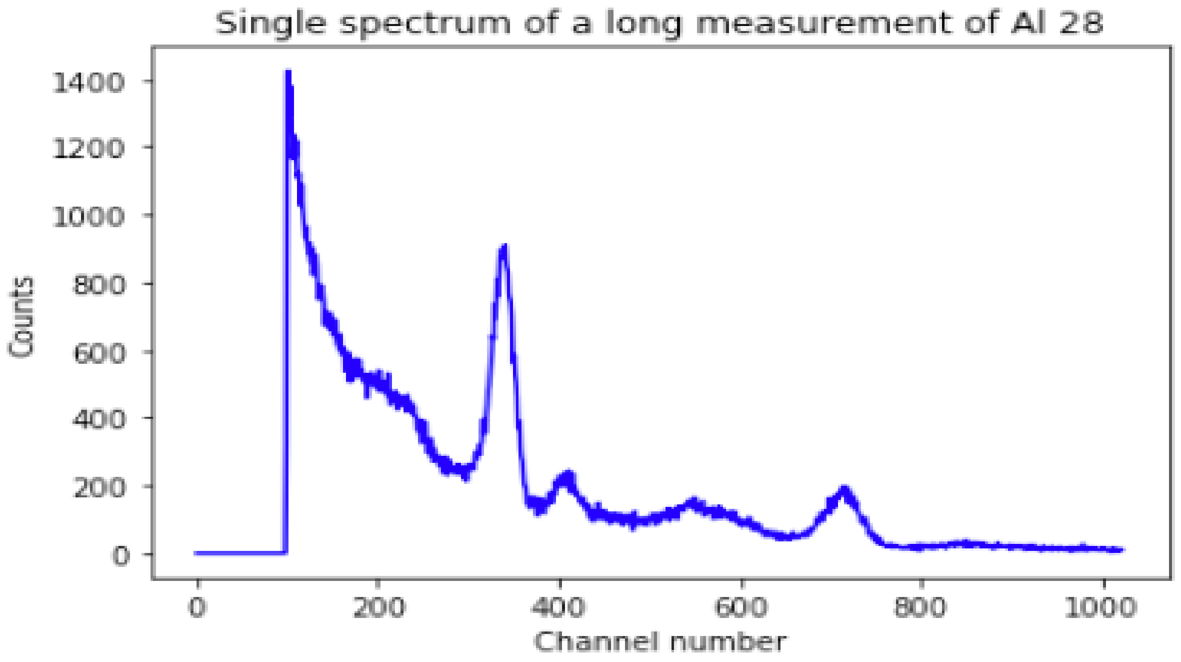


Figure 1: This spectrum was taken using the cylinder from the middle of the water bath

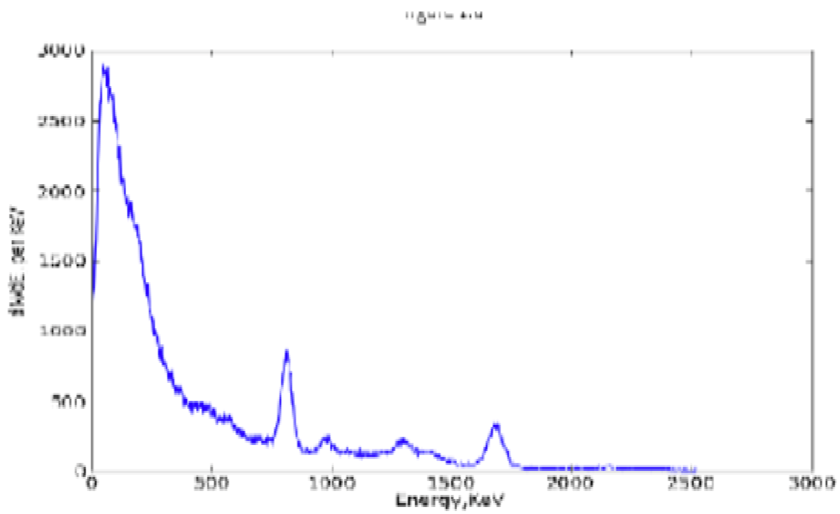


Figure 6: shows the full spectrum of Aluminium-28 for count rate as a function of energy with channel centroid of 1850

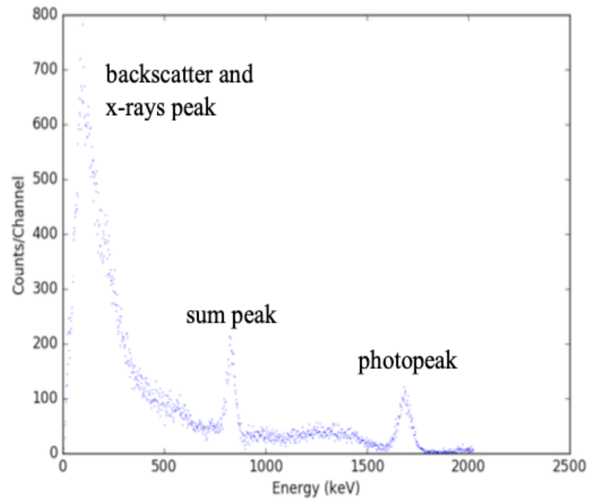


Figure 2. Calibrated pulse height spectrum for ^{28}Al, displaying the frequency of signals at different energies, with the background noise removed. The photopeak corresponding to the emission of the characteristic gamma-ray at (1778.987 ± 0.015) keV was identified.

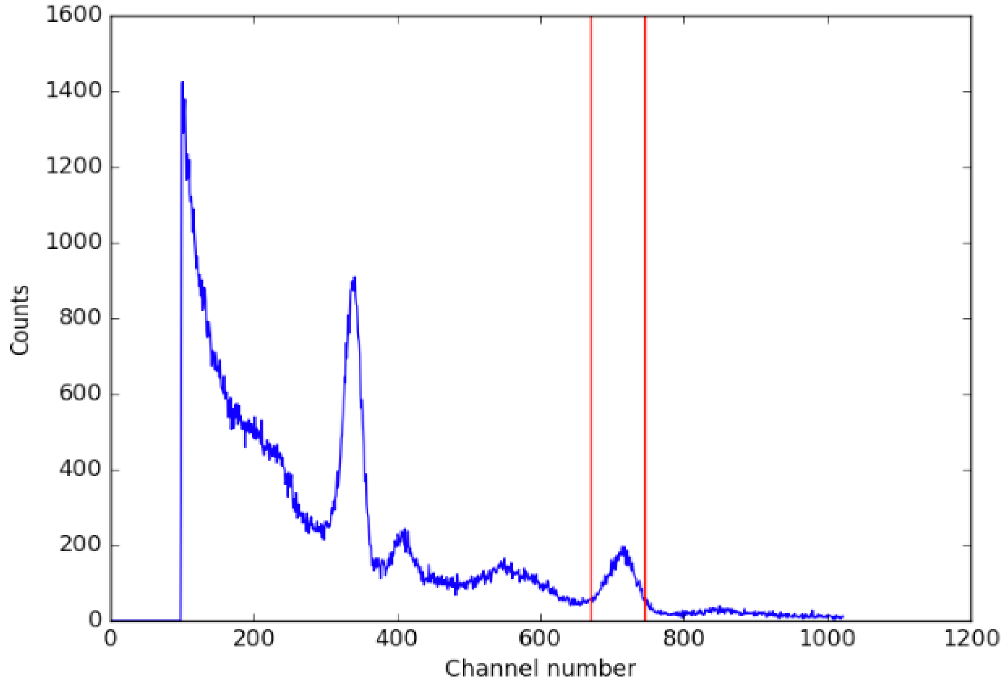


Figure 2: Spectrum for 28Al obtained by summing many measurements

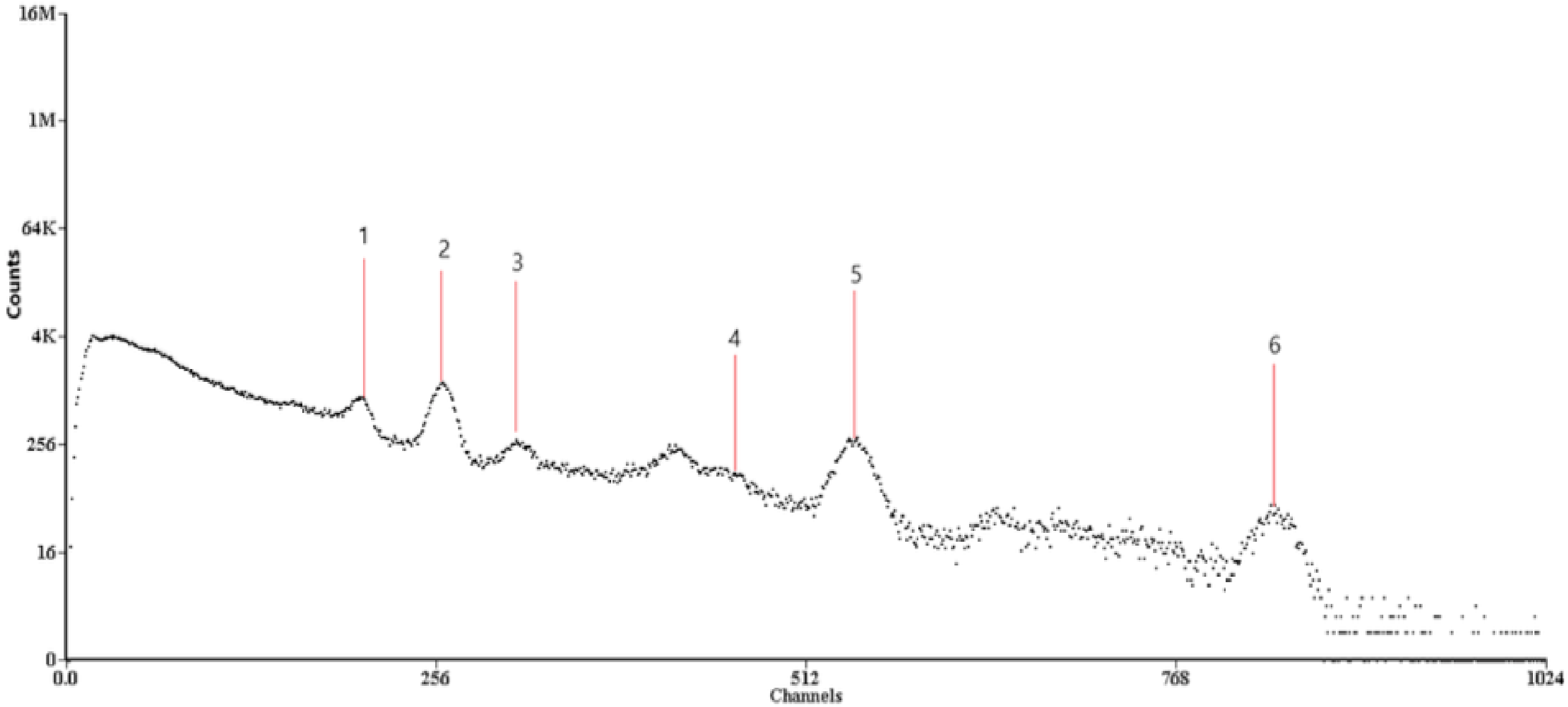


Figure 4: Labeled gamma ray spectrum of a neutron activated 27-Al sample source on a 1025 MCA. The spectrum contains the spectra of both 27-Mg and 28-Al.

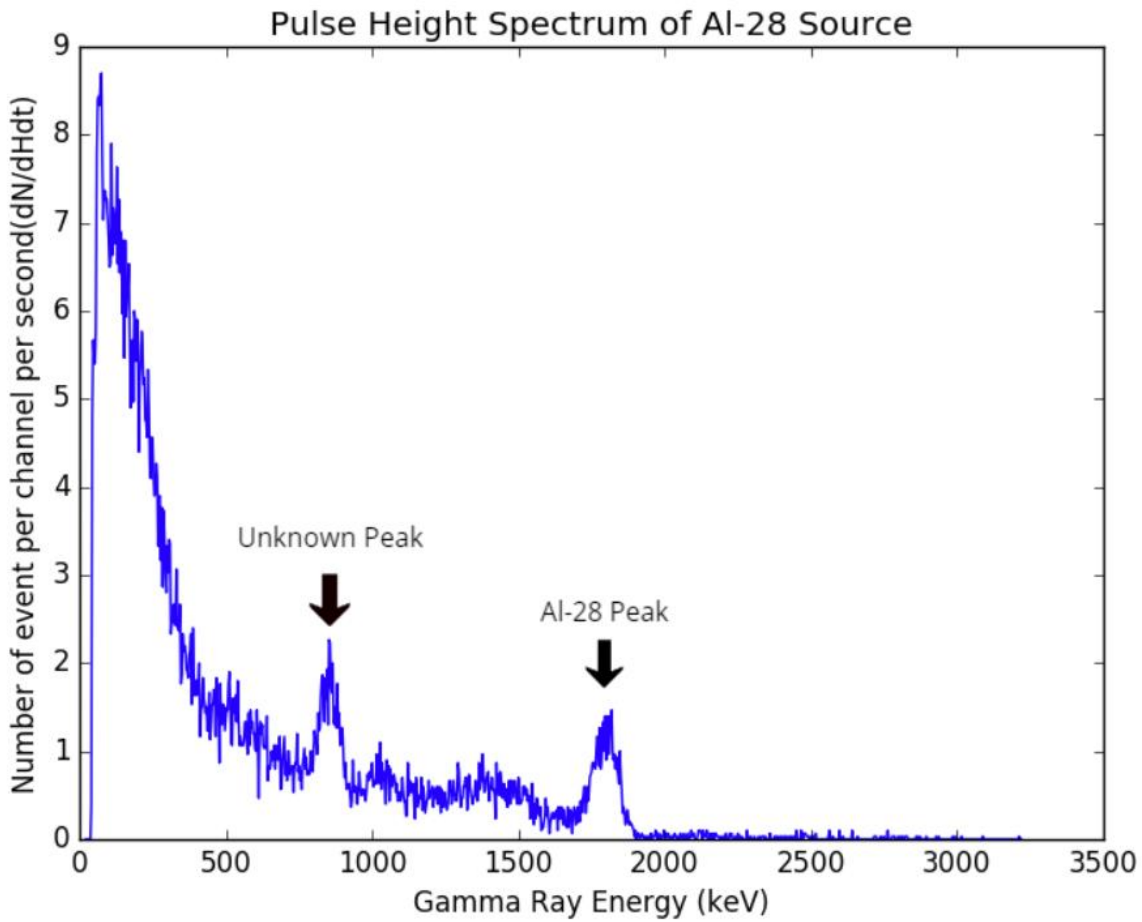
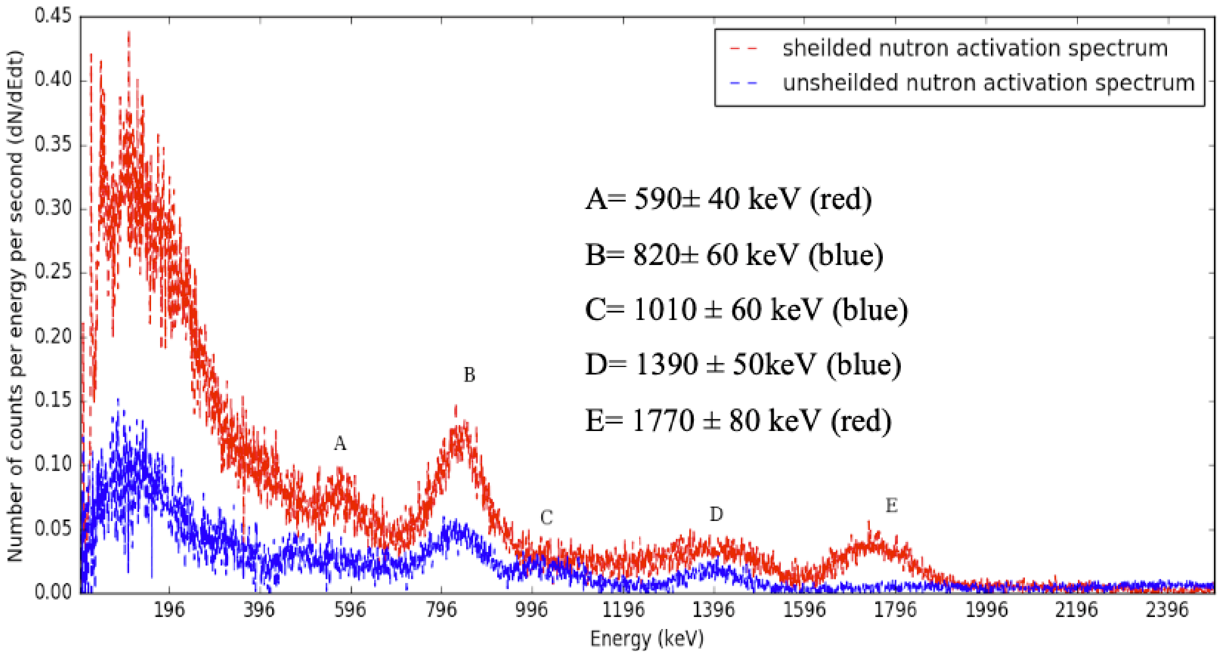


Figure 2: An example of the spectrum of the neutron bombarded Al-27 cylinder. A peak is present at around the energy emitted by an Al-28 source (around 1778 keV), but another peak is present at around 800 keV which is more active.



Graph 3: Gamma ray spectrums of the neutron activated aluminium cylinder, with (red) and without (blue) shielding (water bath). It can be noted that the shielded data has much more counts, which can be attributed to the continual reflection of the neutrons in the water bath, hence more neutrons available for Collison. Peaks A-E have been indicated on the graph and their energy values have been read off the graph with an associated uncertainty. Background data has been accounted for, and counts are represented per second as the two cylinders had different run and activation times.

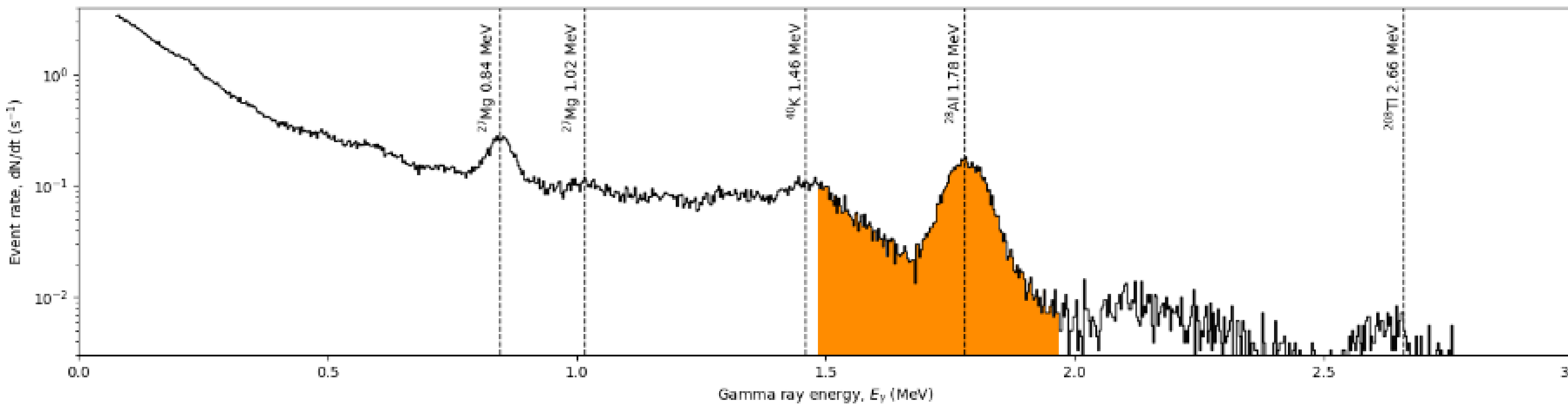
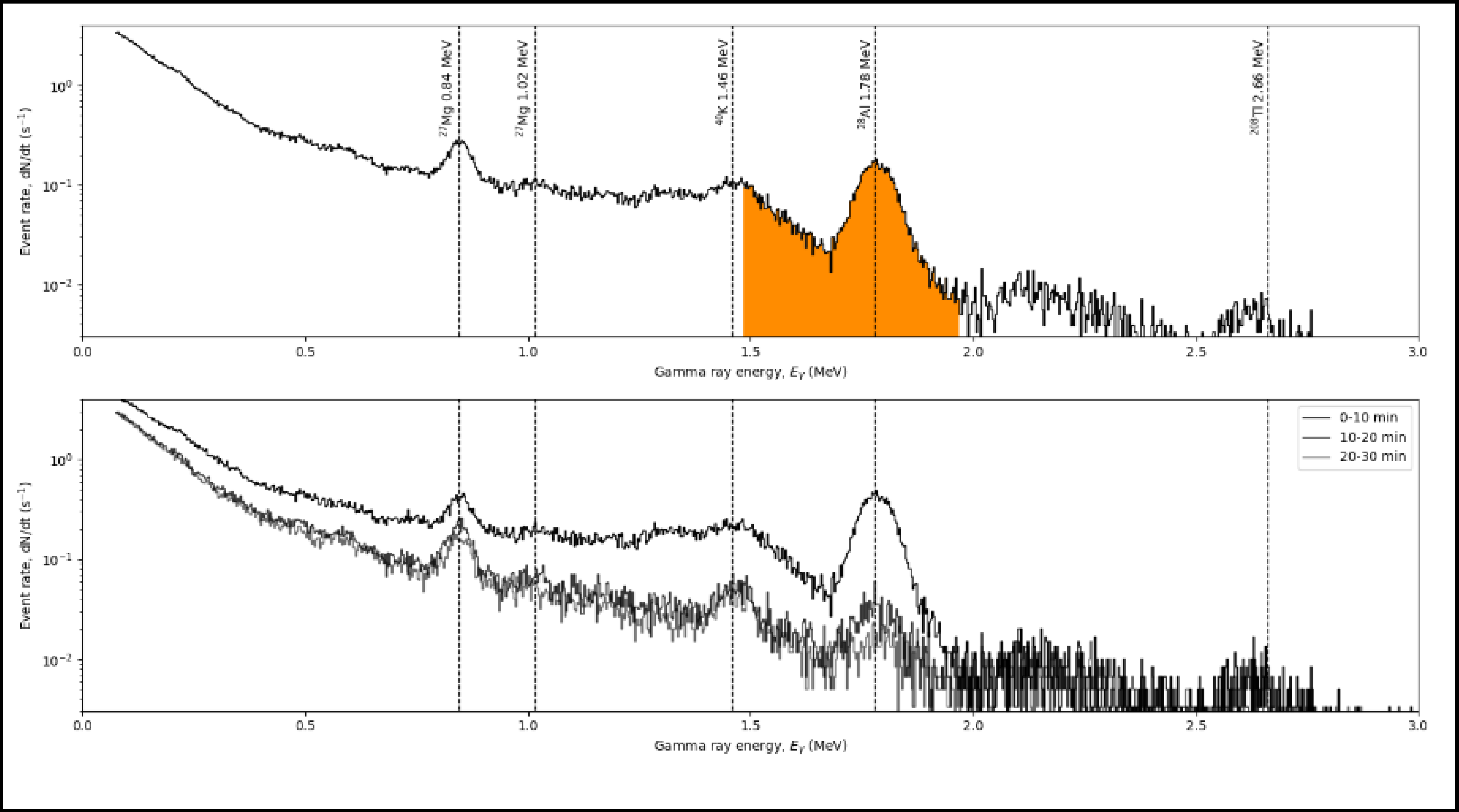
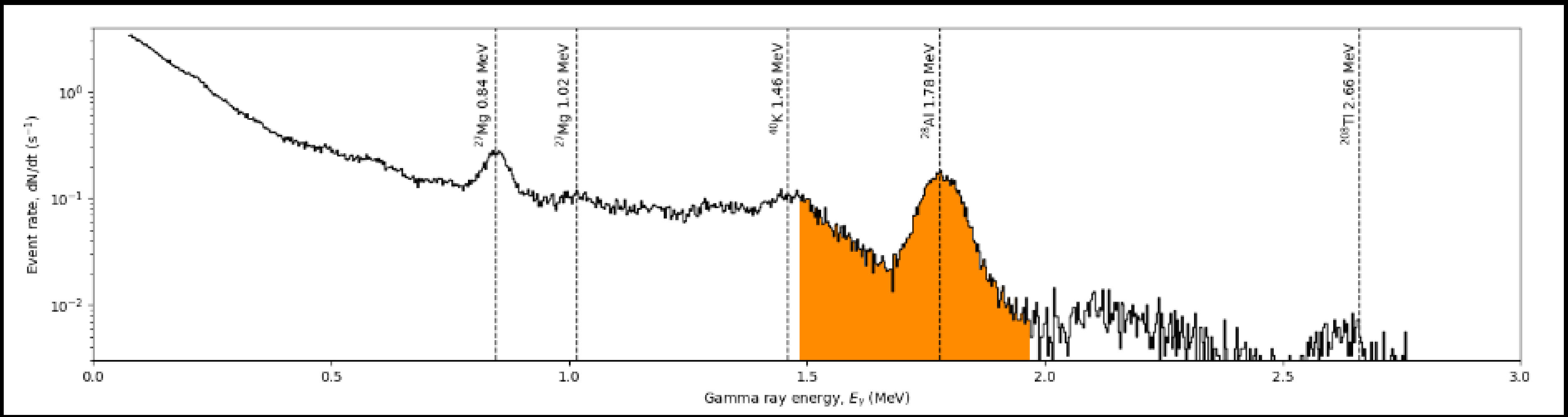


Fig. 1: Gamma ray spectrum averaged over 30 minutes measured with a 2” NaI detector for the aluminium cylinder after 15 minutes irradiation and 1 minute wait time. Key features are indicated with the dashed lines for the activation products ^{27}Mg, and ^{28}Al, and natural background contributions from ^{40}K and ^{208}Tl. The region shaded in orange shows the energy range used to produce the decay curve of ^{28}Al.



^{27}Mg 0.84 MeV
^{27}Mg 1.02 MeV
^{40}K 1.46 MeV
^{28}Al 1.78 MeV
^{208}Tl 2.66 MeV
Event rate, dN/dt (s^{-1})
Gamma ray energy, E_γ (MeV)
0-10 min
10-20 min
20-30 min



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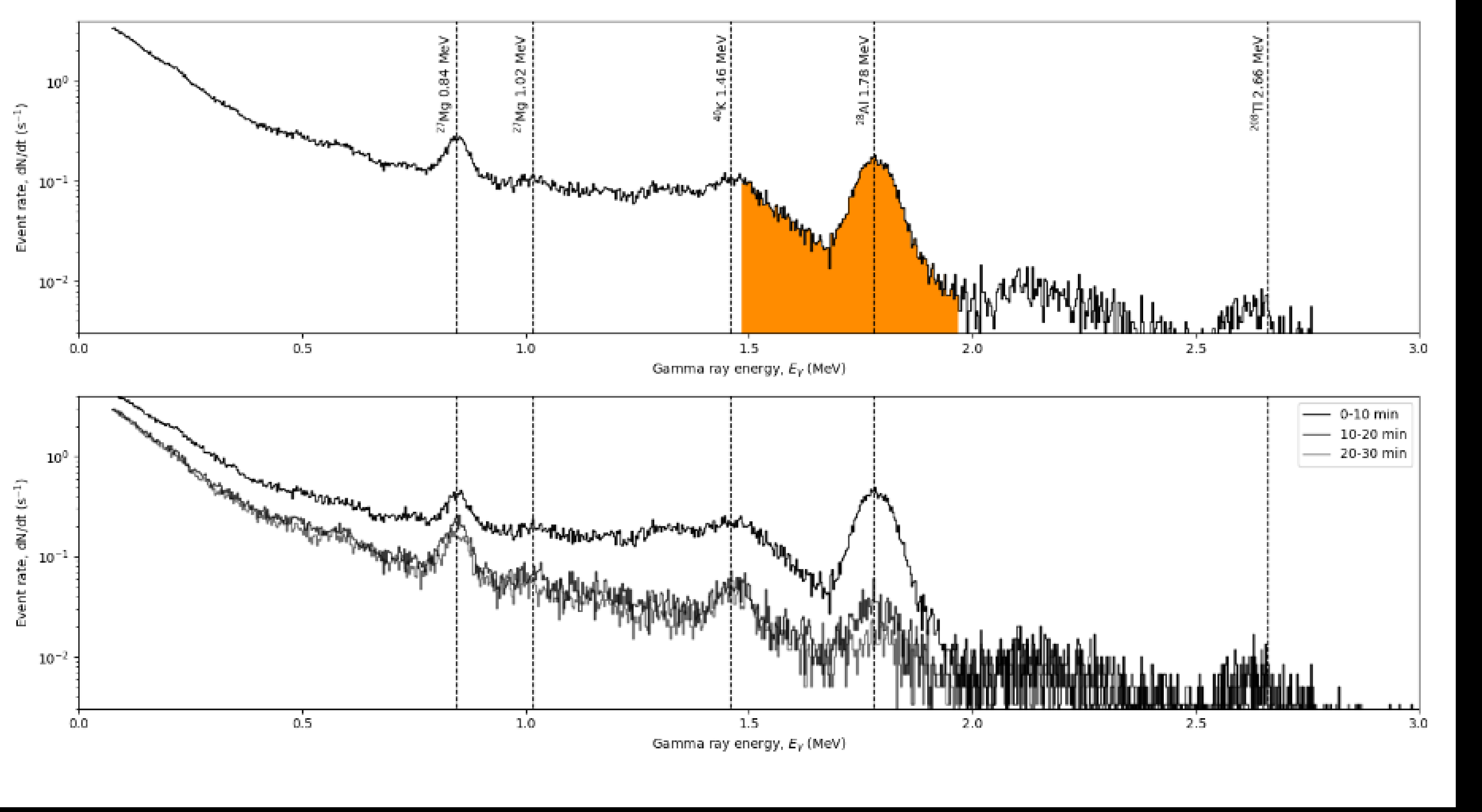

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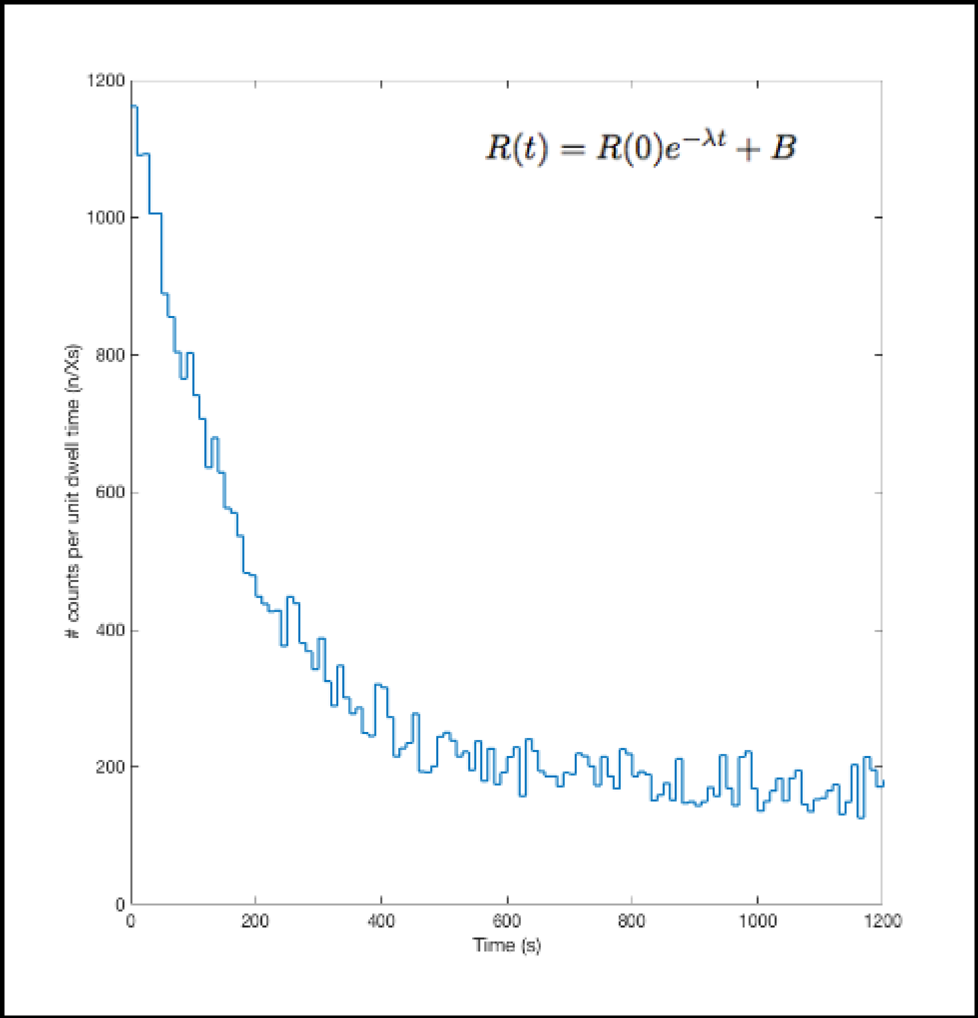
Exponential fitting



- Data collected from time-dependent spectra

- Think about:
  - How much data to use
  - Uncertainties on each channel
  - Uncertainty propagation
  - Improving statistics (if needed)
  - Background contributions

Experimental Methods for Science and Engineering Students

An Introduction to the Analysis and Presentation of Data

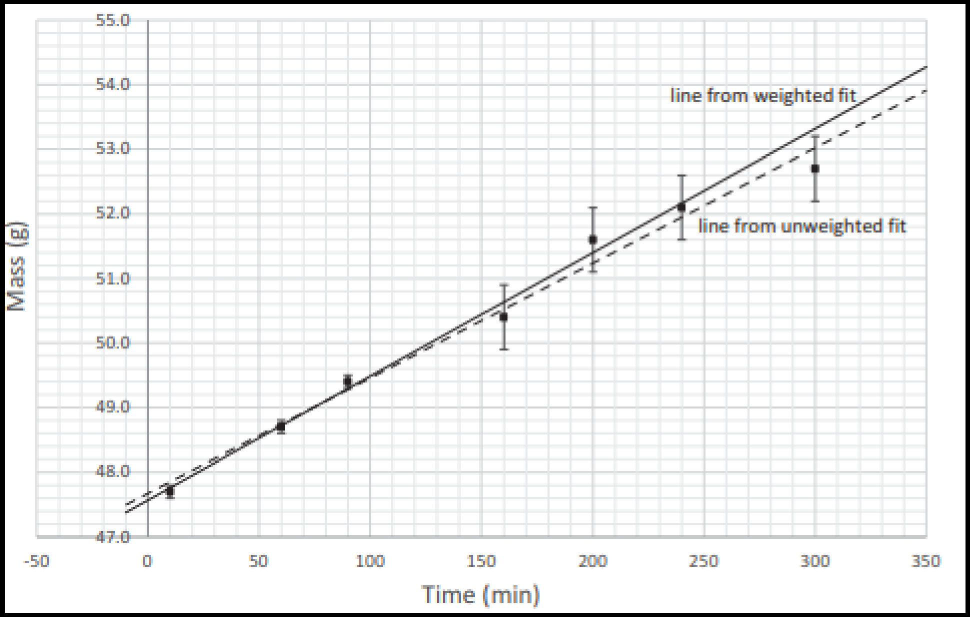
SECOND EDITION

Les Kirkup

University of Technology, Sydney

6.3 Weighting the Fit

To account for situations in which the uncertainties in the *y* values vary from point to point, we use *weighted* least squares when fitting a line to data.[8] The sum of squares is weighted such that, when fitting takes place, the calculated line lies closest to those points with least uncertainty, in effect favouring those points. Situations in which a weighted fit is required are quite common and include those where:



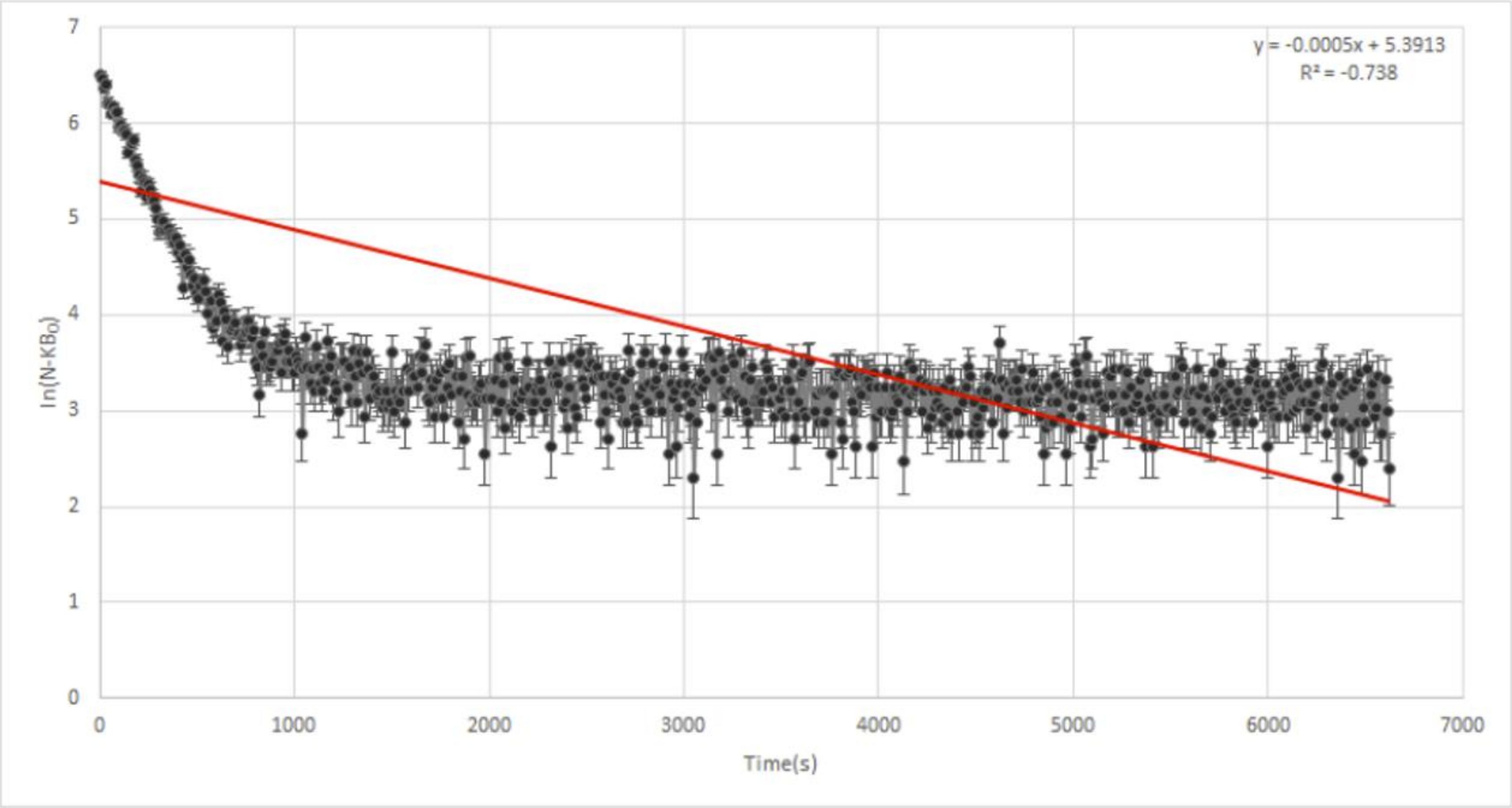
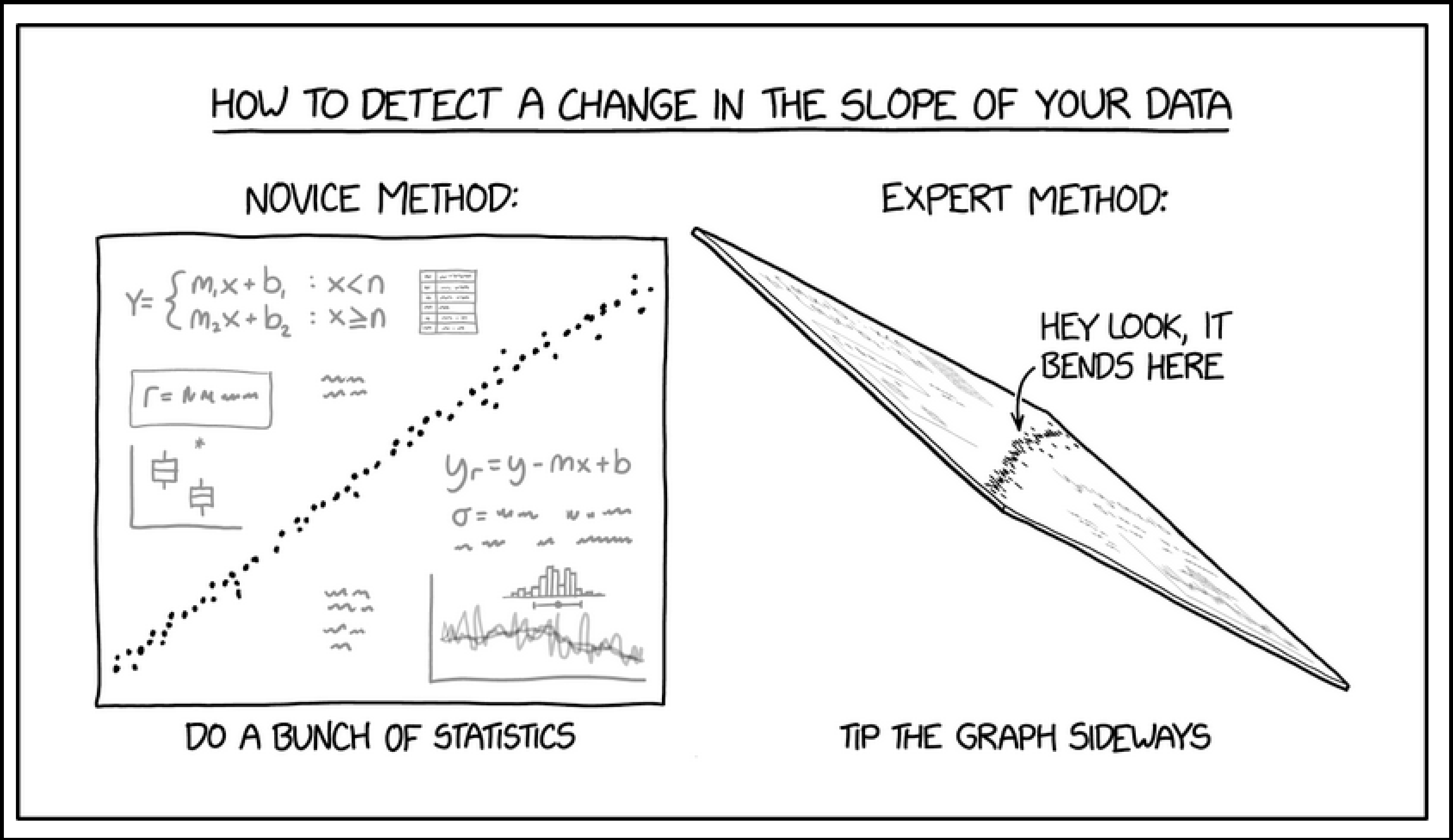


Fig. 1: The plot shows the linearized number of counts minus the KB_0 per 10 seconds dwell time vs the recording time. The background constant per dwell time is $B_0 \pm \sqrt{B_0} = 3.1 \pm 1.8s^{-1}$. The data was linearly weighted and thus fitted with equation $y = -0.0005x + 5.3913$, where the decay constant $\lambda = -m$ gives the half life of $t_{1/2} = 23.104 \pm 0.006min$. The fitted line does not agree with the data at large counts, hence it is a good fit as $R^2 = -0.738$ (almost perfect negative linear correlation).



Munroe, R., *xkcd: Change in slope*, `https://xkcd.com/2701/` [accessed 01 March 2024]

Chi-square test and the method of least-squares

DATA REDUCTION AND ERROR ANALYSIS FOR THE PHYSICAL SCIENCES

THIRD EDITION

Philip R. Bevington

Late Associate Professor of Physics
Case Western Reserve University

D. Keith Robinson

Emeritus Professor of Physics
Case Western Reserve University

Minimise the variance of the fit $y(x_i)$:

$$s^2 = \frac{1}{\nu} \sum w_i \big(y_i - y(x_i)\big)^2,$$

where

$$w_i = \frac{1/\sigma_i^2}{(1/N)\sum\left(1/\sigma_i^2\right)}$$

Chi-square statistic:

$$\chi^2 = \sum \frac{1}{\sigma_i^2}\big(y_i - y(x_i)\big)^2$$

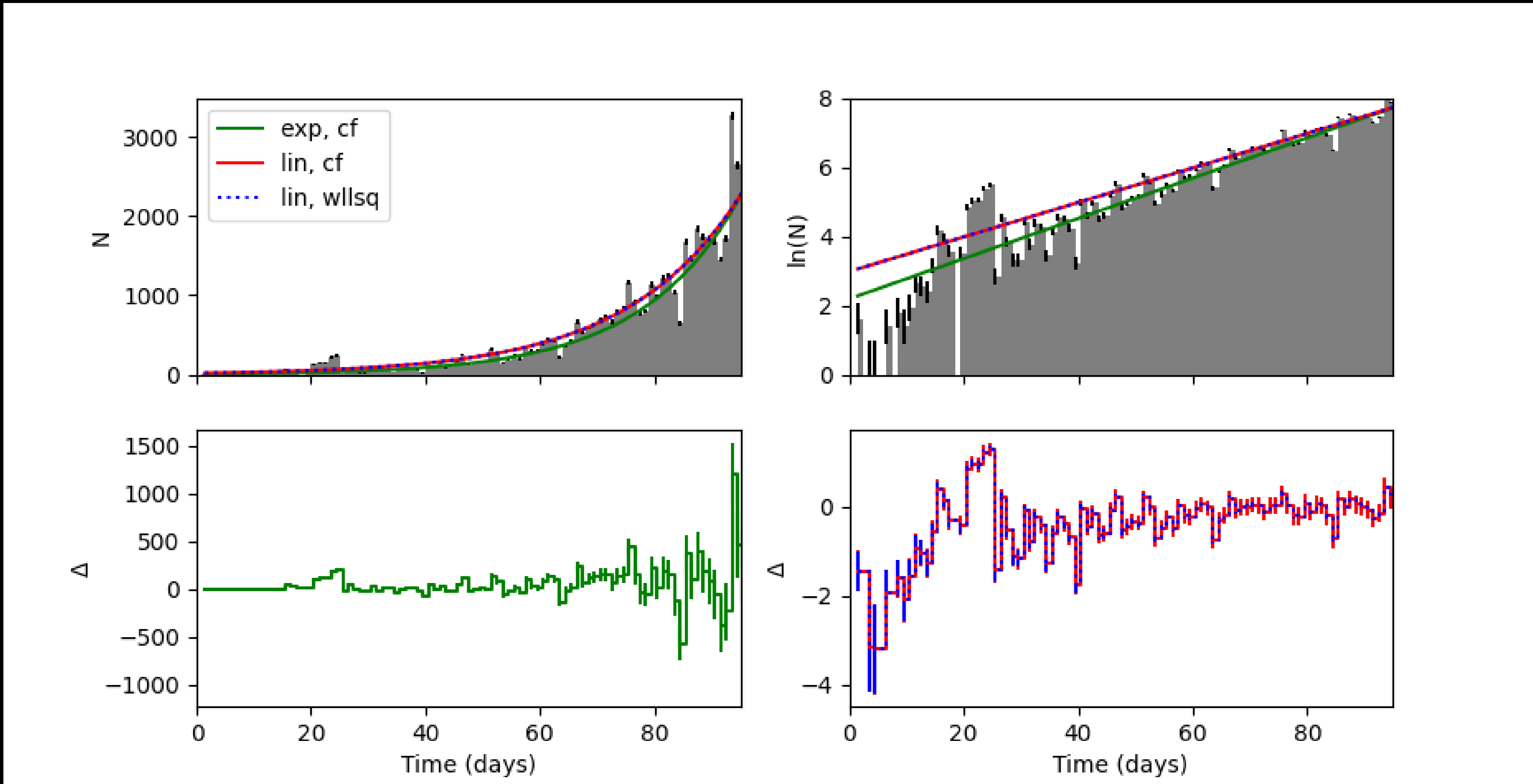
$$\chi_\nu^2 = \frac{\chi^2}{\nu} = \frac{s^2}{\langle \sigma_i^2 \rangle}$$

Weighted average of individual variances

The parent variance of the data, $\langle \sigma_i^2 \rangle$, is a characteristic of the dispersion of the data about the parent distribution and is not descriptive of the fit.

The estimated variance of the fit, s^2, is characteristic of the spread of the data and the accuracy of the fit.

If $s^2 \approx \langle \sigma_i^2 \rangle$ then $\chi_\nu^2 \approx 1$.



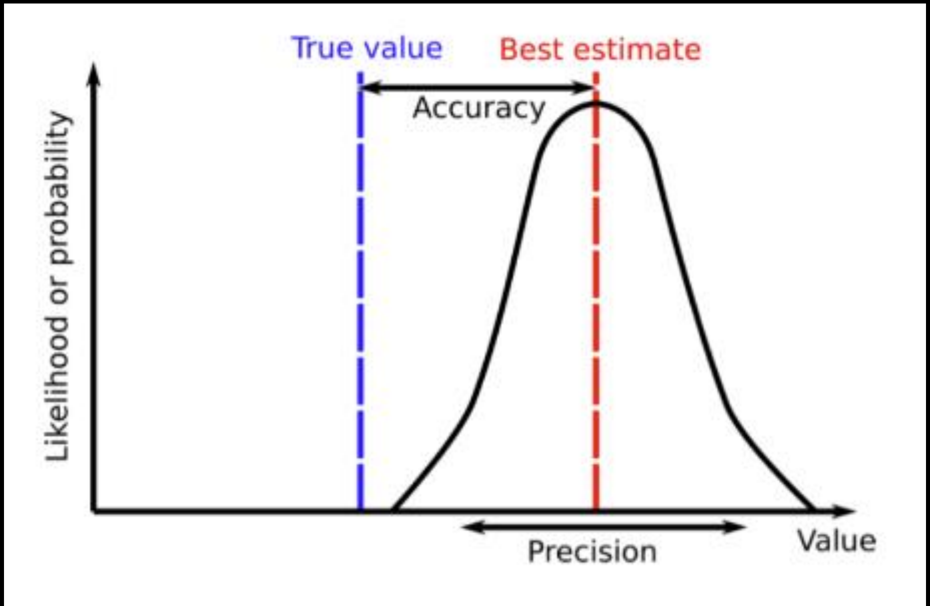
Exponential, curve_fit
λ = 0.0582 ± 0.0017 day^{-1}
X^2_{DOF} = 40.4

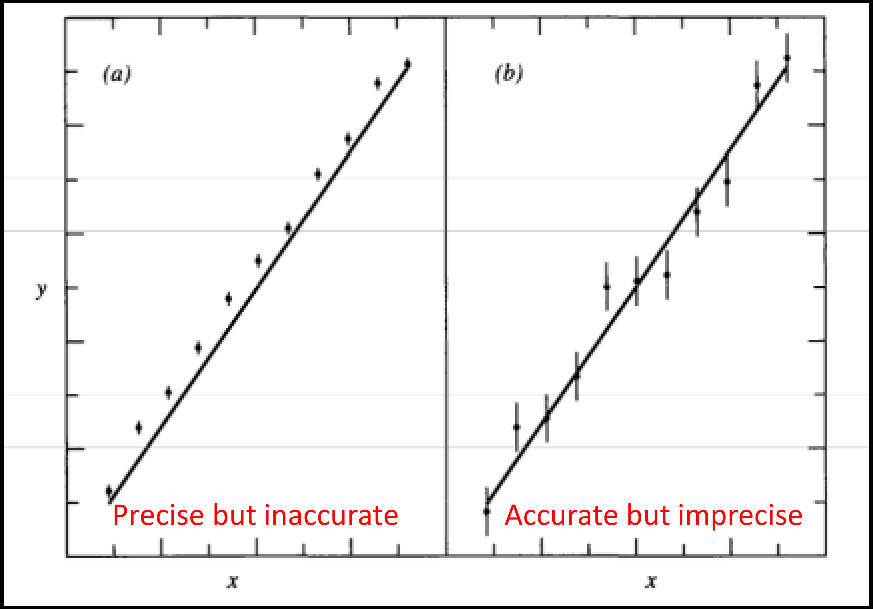
Linearised, curve_fit
λ = 0.0499 ± 0.0016 day^{-1}
X^2_{DOF} = 41.5

Linearised, wllsq
λ = 0.04990 ± 0.00025 day^{-1}
X^2_{DOF} = 41.5

Accuracy vs precision

Measure to find an estimate of the true value of a quantity





Accuracy: a measure of how close the result is to the true value

Precision: how well the result has been determined, without reference to the true value