# Experiment 30a: Interaction of *γ*-rays with matter

## In-lab preliminary analysis

### 0.66 MeV Full Energy Peak

```
(* We import the Cs-137 spectrum. *)
```

In[•]:=
```
<< CurveFit`
```

In[•]:=
```
With[ {name = SystemDialogInput["FileOpen",
     {DataFileName, {"spectrum files" -> {"*.tsv"}, "all files" -> {"*"}}}]},
 If[ name =!= $Canceled,
  LoadFile[name, SkipLines → {"Data:", "Counts"}]]
]
```

```
(* We assign Posson uncertainties to the spectrum,
taking the observed count for each bin as our
 maximum likelihood estimator of the expected count *)
```

In[•]:=
```
MakePoisson[Xerrors -> True]
```

```
(* We select the 0.66 MeV peak *)
```

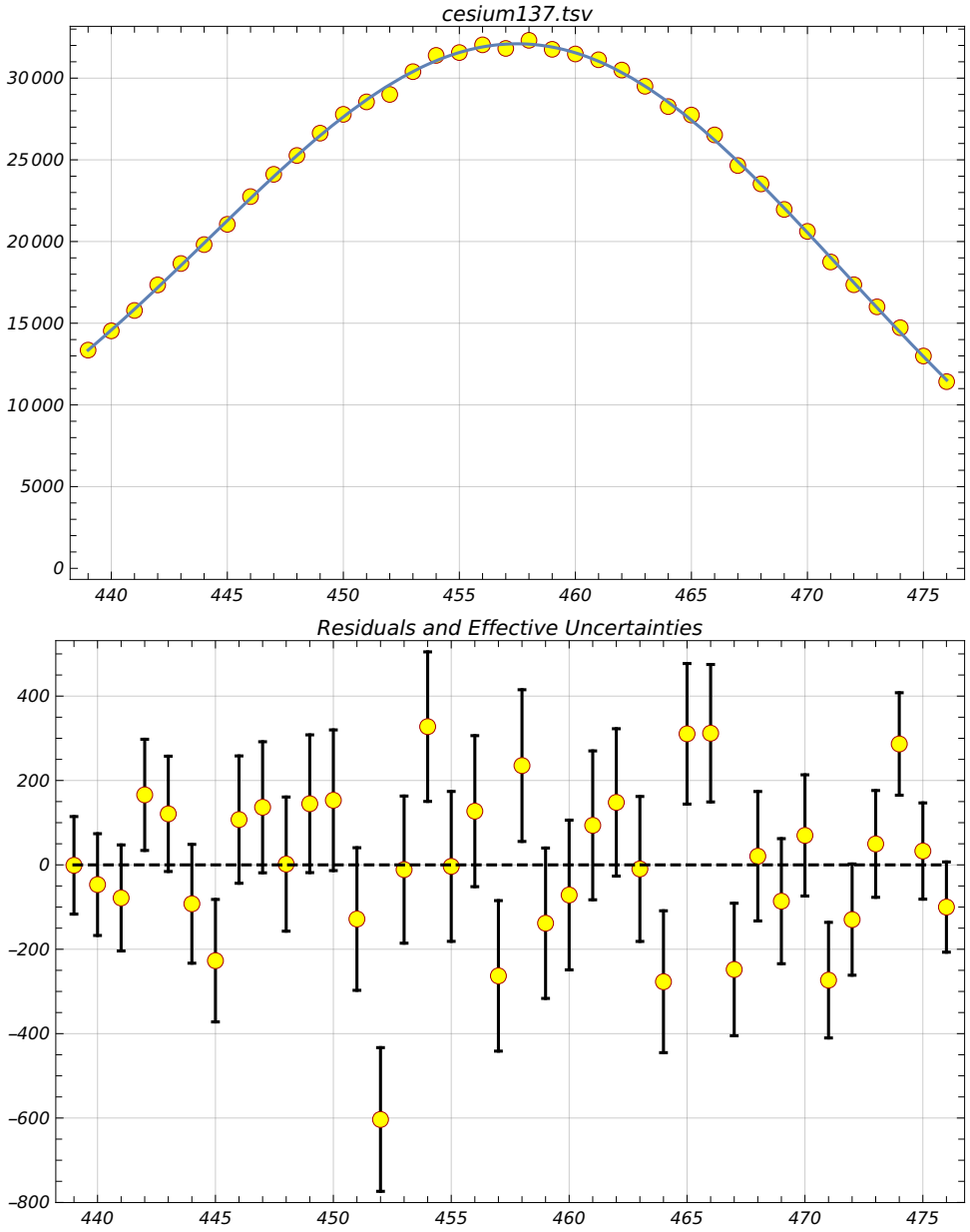
In[•]:=
```
With[{x = SetXRange[ LinearDataPlot[], Log -> False,
     Label -> "Set the X values for the range you wish to keep." ]},
 Print[x];

 XRangeKeep[Sequence @@ x]
]
```

```
(* We now attempt a Gaussian+Linear fit of the 0.66 MeV peak *)
```

In[•]:=
```
GaussianLFit[]
```

In[•]:=
```
LinearDifferencePlot[]
```

Out[•]=




$y(x) =$

$y_{max}\ \exp\left(\frac{-(x-\mu)^2}{2\,sigma^2}\right) +$

$c + d\ (x - \mu)$

| | | | |
|---|---|---|---|
| $c =$ | $d =$ | | |
| −854.481 | −81.196 | | |
| $\sigma_c =$ | $\sigma_d =$ | | |
| 692.989 | 7.92824 | | |
| $y_{max} =$ | $\mu =$ | $sigma =$ | |
| 32936.4 | 457.95 | 13.7094 | |
| $\sigma_{y_{max}} =$ | $\sigma_\mu =$ | $\sigma_{sigma} =$ | $\chi^2/(n-5) =$ |
| 665.693 | 0.0799749 | 0.21572 | 1.69678 |

A reasonably good Gaussian+Linear fit is obtained $\left(\tilde{\chi}^2 = 1.69\right)$, indicating that the distribution limiting

the energy resolution described by Poisson statistics approximates a Gaussian as described in the lab manual.

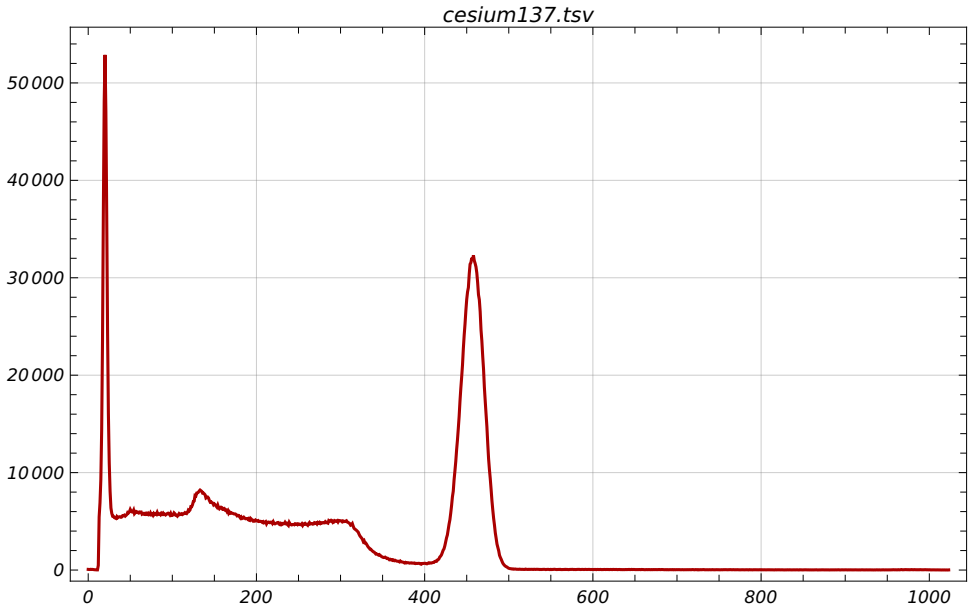
## Rate-related Gain Shift

```
(* We control for rate-related gain shift by observing the spectra for Cs-
 137 with the source near and far from the photomultiplier. First,
we show the spectrum when the source is far from the photomultiplier. *)
```

In[•]:=
```
With[ {name = SystemDialogInput["FileOpen",
    {DataFileName, {"spectrum files" -> {"*.tsv"}, "all files" -> {"*"}}}]},
 If[ name =!= $Canceled,
  LoadFile[name, SkipLines → {"Data:", "Counts"}]]
]
```

In[•]:=
```
LinearDataPlot[]
```

Out[•]=

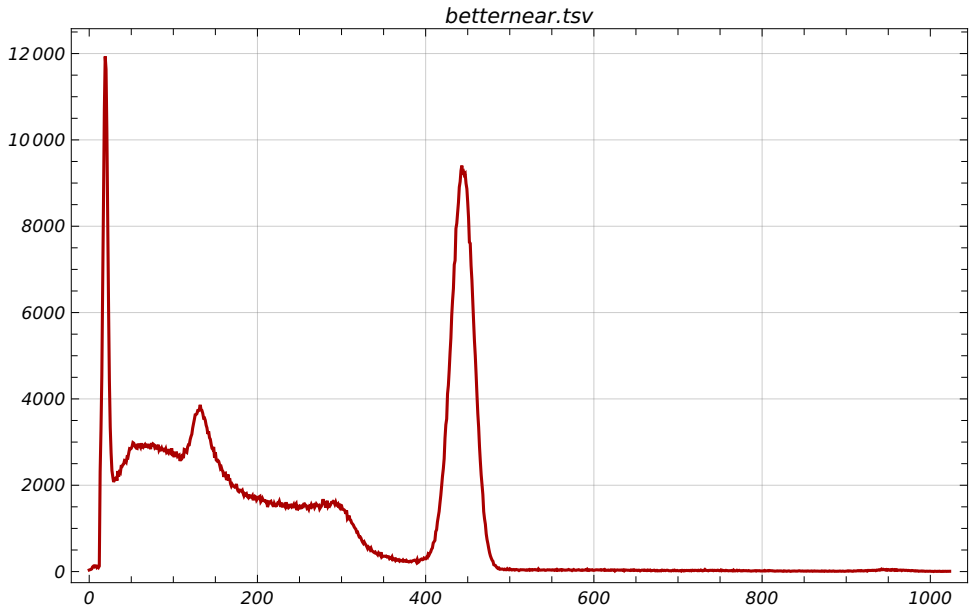



```
(* We now show the spectrum when the source is near the photomultiplier. *)
```

In[•]:=
```
With[ {name = SystemDialogInput["FileOpen",
    {DataFileName, {"spectrum files" -> {"*.tsv"}, "all files" -> {"*"}}}]},
 If[ name =!= $Canceled,
  LoadFile[name, SkipLines → {"Data:", "Counts"}]]
]
```

In[•]:=
```
LinearDataPlot[]
```

Out[•]=



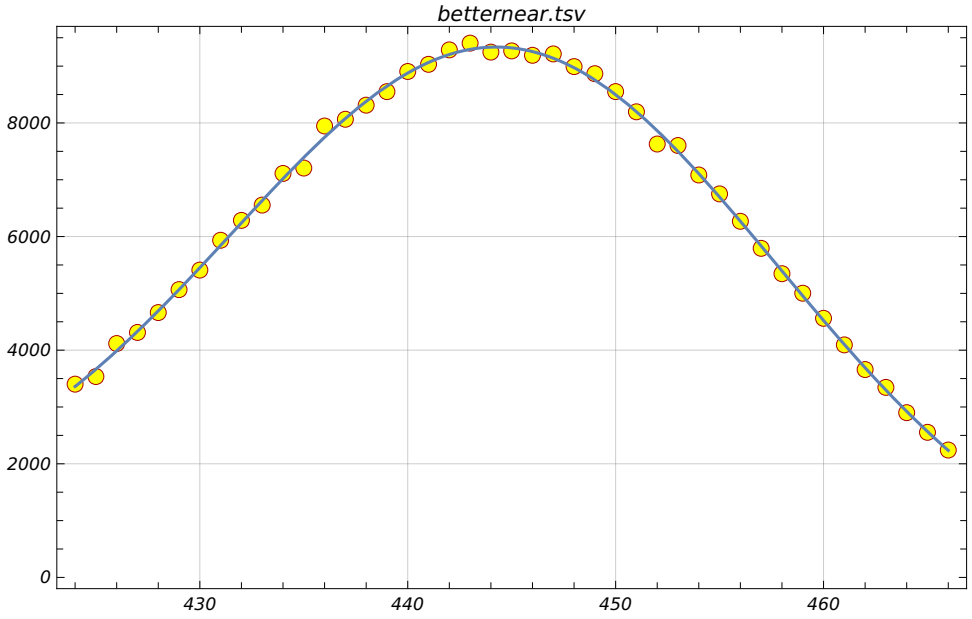

```
(* We obtain the position of the 0.66 MeV peak as before by fitting
  the 0.66 MeV peak against a Gaussian+Linear and fiding the μ. *)
```

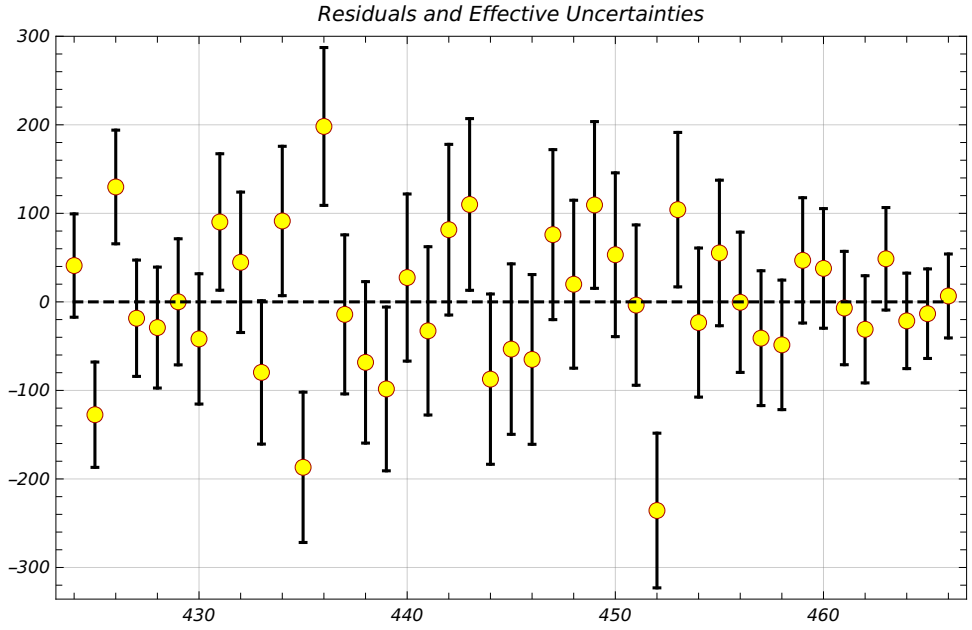
In[•]:=
```
MakePoisson[Xerrors -> True]
```

In[•]:=
```
With[{x = SetXRange[ LinearDataPlot[], Log -> False,
    Label -> "Set the X values for the range you wish to keep." ]},
 Print[x];

 XRangeKeep[Sequence @@ x]
]
```

In[•]:=
```
GaussianLFit[]
```

In[•]:= **LinearDifferencePlot[]**




Out[•]=

$$y(x) = y_{max}\ \exp\left(\frac{-(x-\mu)^2}{2\,sigma^2}\right) + c + d\ (x-\mu)$$

| | | | |
|---|---|---|---|
| c= | d= | | |
| 297.559 | −22.0464 | | |
| $\sigma_c$= | $\sigma_d$= | | |
| 159.204 | 2.39246 | | |
| $y_{max}$= | $\mu$= | sigma= | |
| 9033.77 | 444.674 | 13.1145 | |
| $\sigma_{y_{max}}$= | $\sigma_\mu$= | $\sigma_{sigma}$= | $\chi^2/(n-5)$= |
| 163.995 | 0.0999985 | 0.211323 | 1.1366 |

We observe a shift in the position of the peak of about 13 channels, or less than 3%. We therefore have negligible rate-related gain shift in our spectra and do not have to particularly carefully control for rate

in taking the following spectra. We may have to account, however, for the systematic error introduced by the shift (and the drift described in the next section) in the data analysis.

## Long-term stability of gain

We similarly verify the long-term stability of the system's gain by comparing Co-60 spectra taken at an interval of each other and observing any drift in the position of the peaks. We accurately find the positions of the peaks using the same procedure as above (fit Gaussian+Linear to full-energy a full energy peak, and the mean $\mu$ will give a maximum likelihood estimator of the position of the peak).

```
(* We find the position of one of the Co-60 peaks for the first spectrum. *)
```

In[•]:=
```
With[ {name = SystemDialogInput["FileOpen",
    {DataFileName, {"spectrum files" -> {"*.tsv"}, "all files" -> {"*"}}}]},
 If[ name =!= $Canceled,
  LoadFile[name, SkipLines → {"Data:", "Counts"}]]
]
```

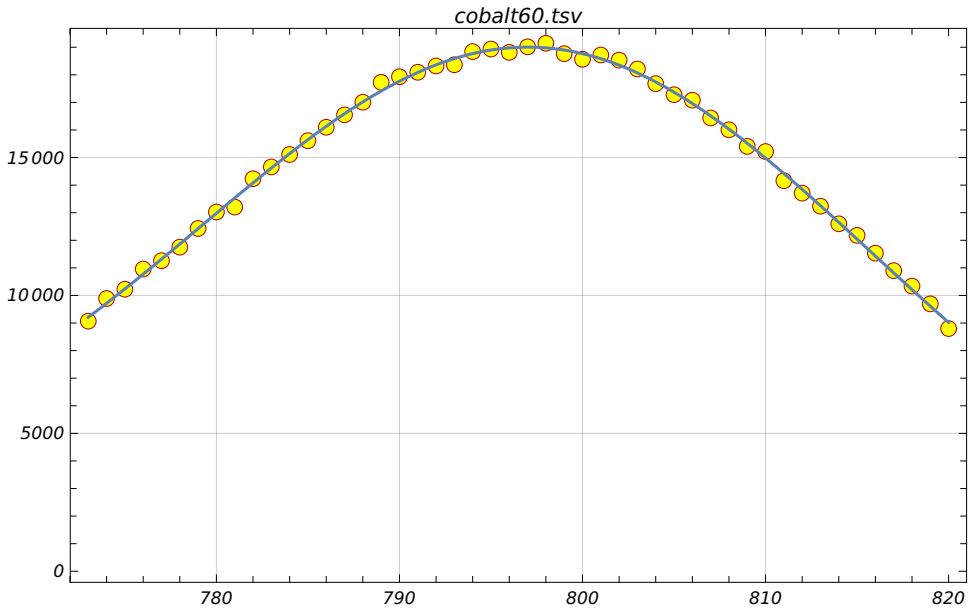
In[•]:=
```
MakePoisson[Xerrors -> True]
```

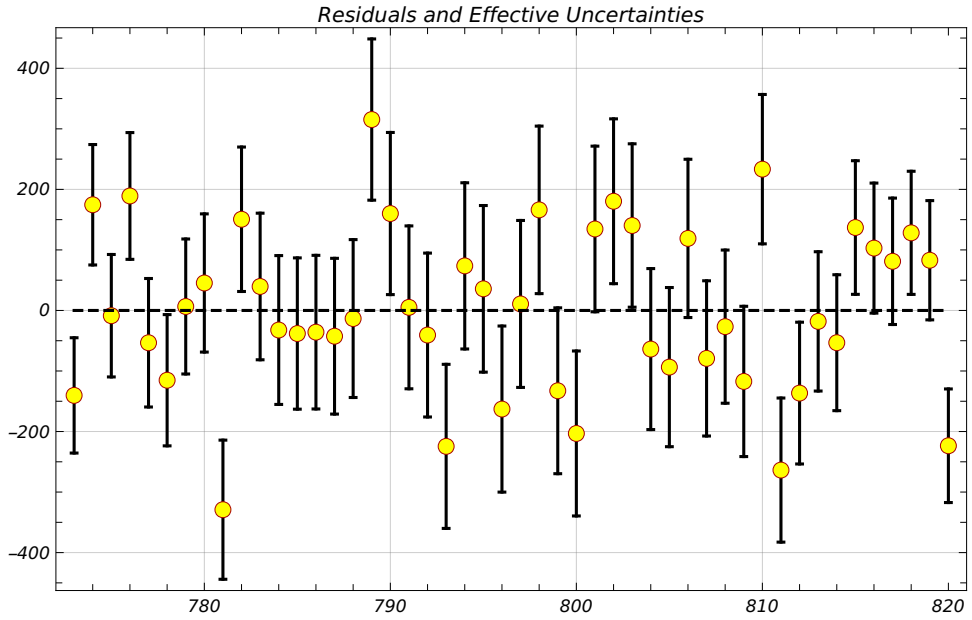
Change the plot from LinearDataPlot[ ] to something else like LogDataPlot[ ] if you wish. If the plot has a log X-axis (like LogLogDataPlot[ ]), then the Log option to SetXRange[ ] must be changed to Log → True

In[•]:=
```
With[{x = SetXRange[ LinearDataPlot[], Log -> False,
    Label -> "Set the X values for the range you wish to keep." ]},
 Print[x];

 XRangeKeep[Sequence @@ x]
]
```

In[•]:=
```
GaussianLFit[]
```

In[•]:=
```
LinearDifferencePlot[]
```




Out[•]=

$$y(x) = y_{max}\ \exp\left(\frac{-(x-\mu)^2}{2\ sigma^2}\right) + c + d\ (x-\mu)$$

| | | | |
|---|---|---|---|
| c= | d= | | |
| 1406.1 | −27.4483 | | |
| $\sigma_c$= | $\sigma_d$= | | |
| 583.759 | 5.38559 | | |
| $y_{max}$= | $\mu$= | sigma= | |
| 17591. | 797.52 | 18.2437 | |
| $\sigma_{y_{max}}$= | $\sigma_\mu$= | $\sigma_{sigma}$= | $\chi^2/(n-5)$= |
| 624.25 | 0.166652 | 0.384855 | 1.49795 |

```
(* We now do the same for the second Co-60 spectrum. *)
```

```
In[•]:= With[ {name = SystemDialogInput["FileOpen",
            {DataFileName, {"spectrum files" -> {"*.tsv"}, "all files" -> {"*"}}}]},
         If[ name =!= $Canceled,
          LoadFile[name, SkipLines → {"Data:", "Counts"}]]
        ]
```

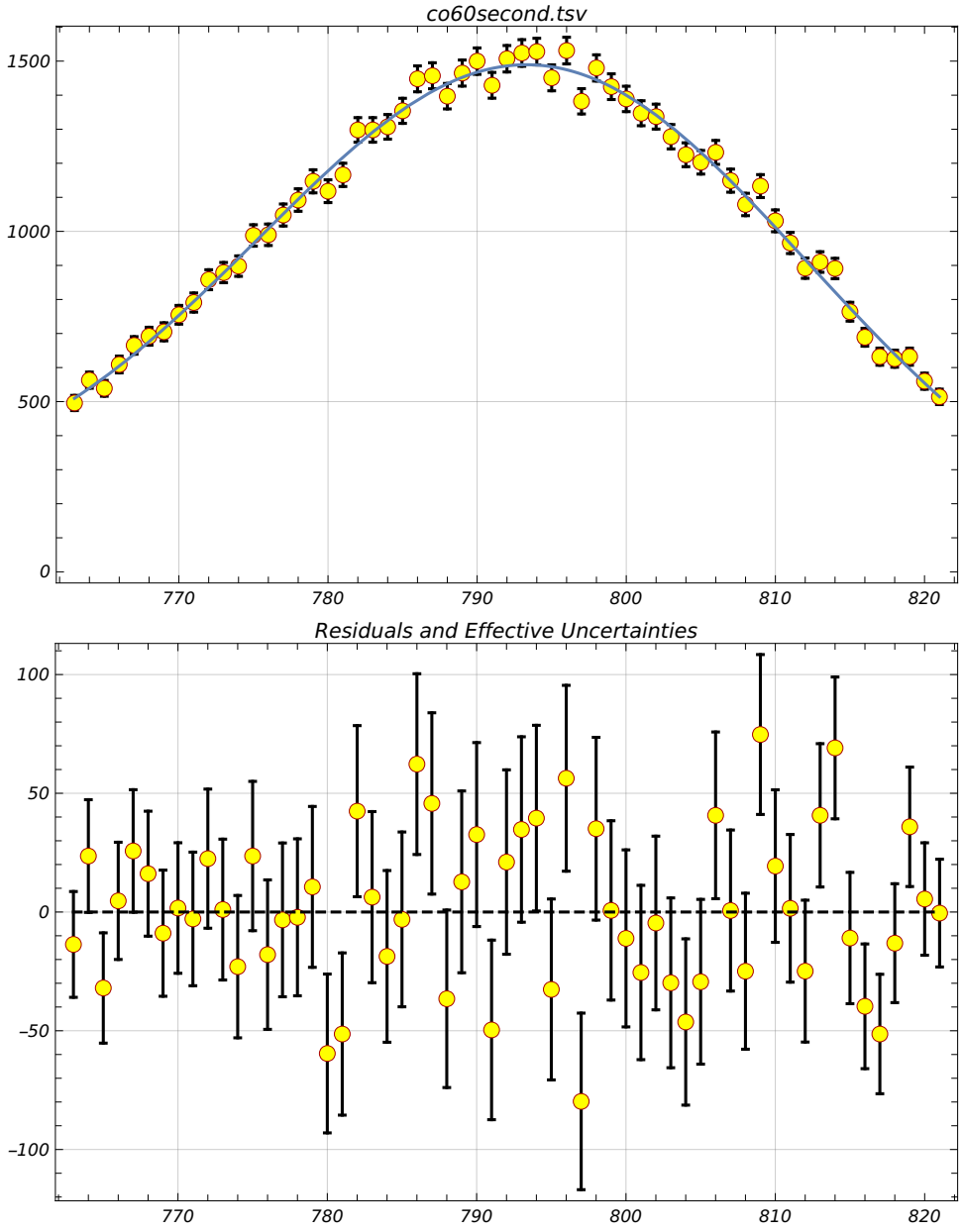
```
In[•]:= MakePoisson[Xerrors -> True]
```

Change the plot from LinearDataPlot[ ] to something else like LogDataPlot[ ] if you wish. If the plot has a log X-axis (like LogLogDataPlot[ ]), then the Log option to SetXRange[ ] must be changed to Log → True

```
In[•]:= With[{x = SetXRange[ LinearDataPlot[], Log -> False,
            Label -> "Set the X values for the range you wish to keep." ]},
         Print[x];

         XRangeKeep[Sequence @@ x]
        ]
```

```
In[•]:= GaussianLFit[]
```

In[•]:= **LinearDifferencePlot[]**




Out[•]=

$$y(x) = y_{max}\ \exp\left(\frac{-(x-\mu)^2}{2\,sigma^2}\right) + c + d\ (x-\mu)$$

| | | | |
|---|---|---|---|
| $c =$ | $d =$ | | |
| 107.41 | −2.04662 | | |
| $\sigma_c =$ | $\sigma_d =$ | | |
| 62.5355 | 0.721534 | | |
| $y_{max} =$ | $\mu =$ | sigma = | |
| 1381.52 | 793.809 | 18.3831 | |
| $\sigma_{y_{max}} =$ | $\sigma_\mu =$ | $\sigma_{sigma} =$ | $\chi^2/(n-5) =$ |
| 67.5434 | 0.318507 | 0.801073 | 1.10908 |

We observe a shift in the peak position of about 4 channels or 0.5%, such that negligible drift occurs. Therefore, the system has long-term stable gain and very little error is introduced by time-variation in

gain. Again, we may have to consider the error introduced by drift in our following analysis, but it is unlikely to play a significant role.

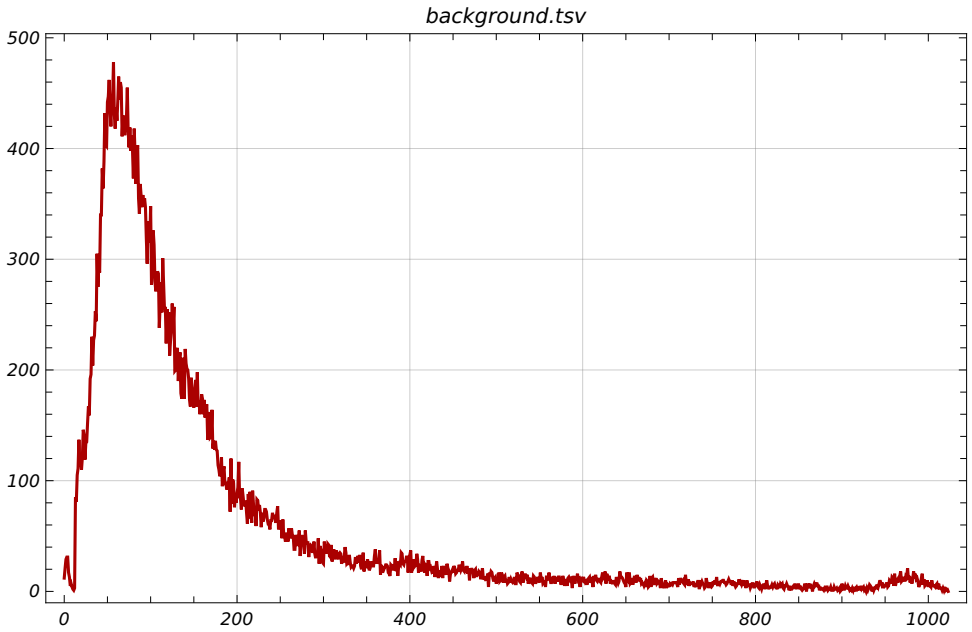
## Background spectrum

A spectrum of the background noise is taken over several minutes, to be used as a baseline.

In[ ]:=
```
With[ {name = SystemDialogInput["FileOpen",
    {DataFileName, {"spectrum files" -> {"*.tsv"}, "all files" -> {"*"}}}]},
 If[ name =!= $Canceled,
  LoadFile[name, SkipLines → {"Data:", "Counts"}]]
]
```

In[ ]:=
```
LinearDataPlot[]
```

Out[ ]=




We observe that the count is small enough that the background will not contribute to observable features of the spectra.

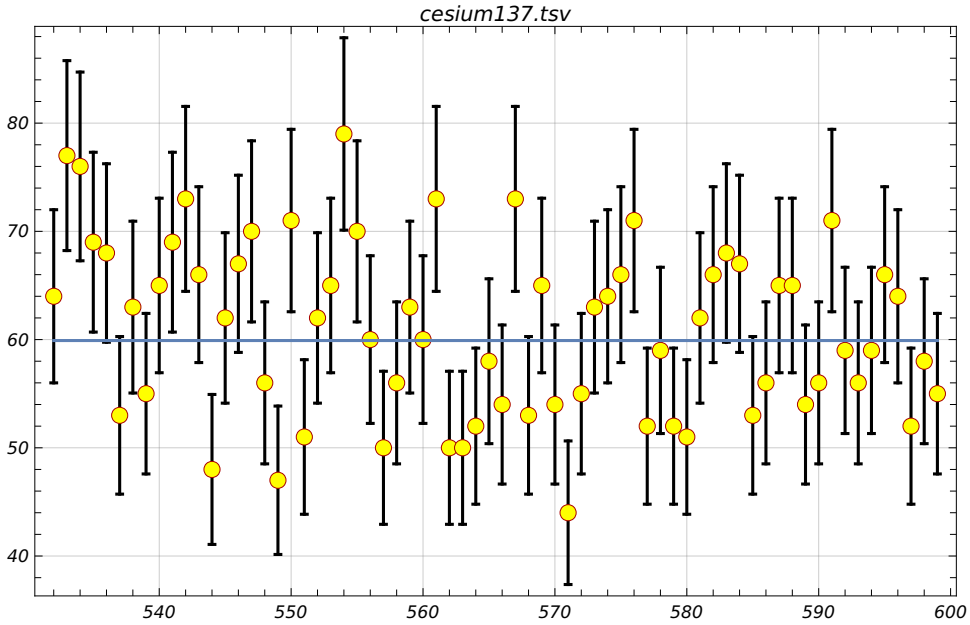
By a rough calibration using the peaks above, we observed a peak with increased counts at ~0.1 MeV. This may correspond to the NaI K-edge as described in the photoelectric absorption section of the lab manual.

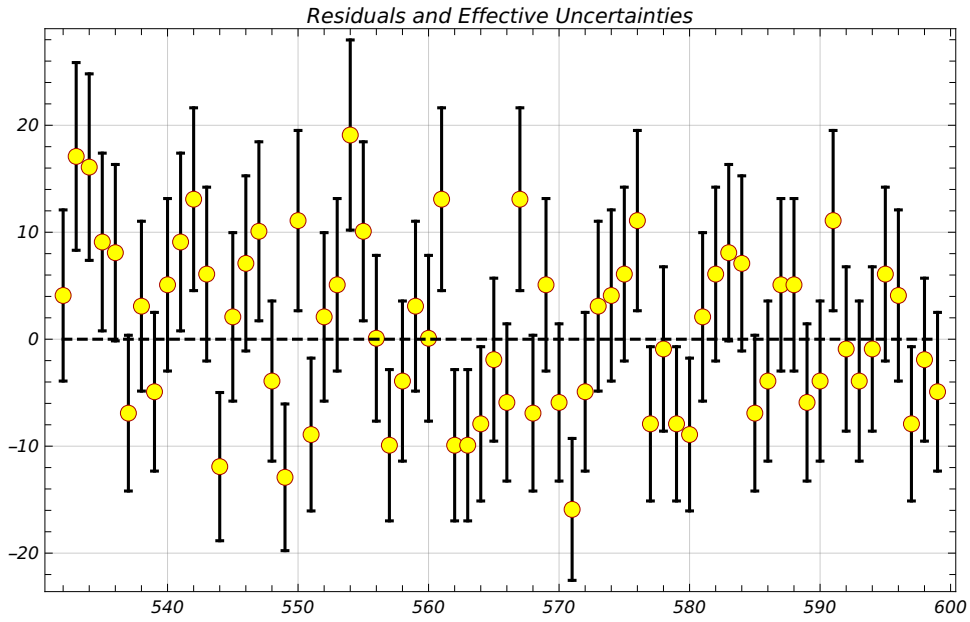
# Data Analysis

```
(* We consider a small, flat portion of the C-
 137 spectrum and fit to a constant to observe the channel-to-channel scatter. *)
```

```
In[•]:= With[ {name = SystemDialogInput["FileOpen",
          {DataFileName, {"spectrum files" -> {"*.tsv"}, "all files" -> {"*"}}}]},
       If[ name =!= $Canceled,
        LoadFile[name, SkipLines → {"Data:", "Counts"}]]
      ]

In[•]:= MakePoisson[Xerrors -> True]

In[•]:= With[{x = SetXRange[ LinearDataPlot[], Log -> False,
          Label -> "Set the X values for the range you wish to keep." ]},
       Print[x];

       XRangeKeep[Sequence @@ x]
      ]


In[•]:= ConstantFit[]
```

In[•]:=
```
LinearDifferencePlot[]
```



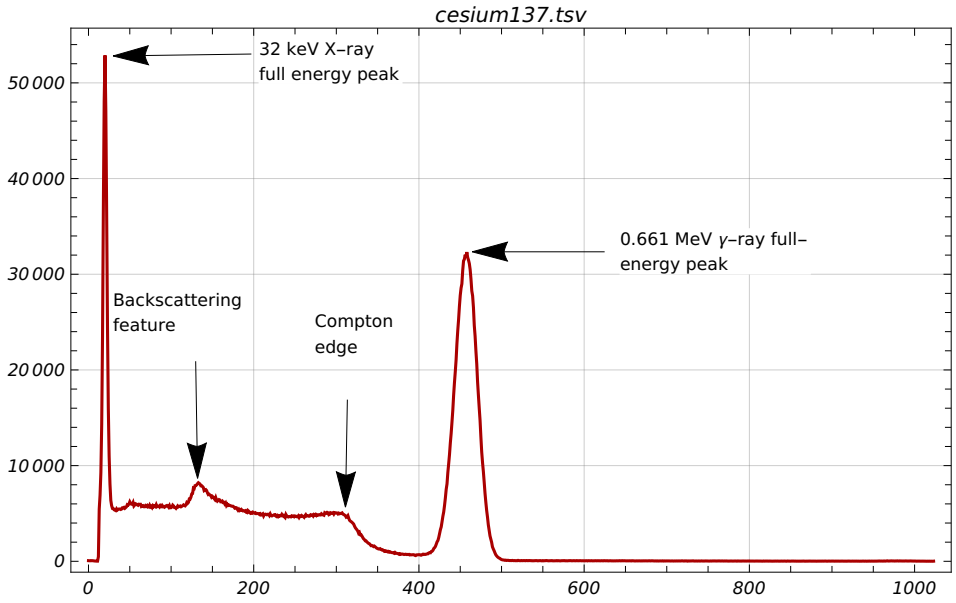

Out[•]=
```
y(x) = a
a=
59.9112
σa=                χ²/(n-1)=
0.938641           1.07515
```

As expected, the linear background very closely fits a constant, with a reduced $\tilde{\chi}^2$very close to 1. The residual plot also allows us to observe that the channel-to-channel scatter should not be significant over high-count features and will not pose an issue when interpreting the spectra of short half-life isotopes, despite being significant with respect to the background count (we will observe a noise feature due to the K-edge of NaI for longer half-life isotopes such as Na-22).

## Cs-137 spectrum

```
In[•]:= With[ {name = SystemDialogInput["FileOpen",
            {DataFileName, {"spectrum files" -> {"*.tsv"}, "all files" -> {"*"}}}]},
         If[ name =!= $Canceled,
          LoadFile[name, SkipLines → {"Data:", "Counts"}]]
        ]
```

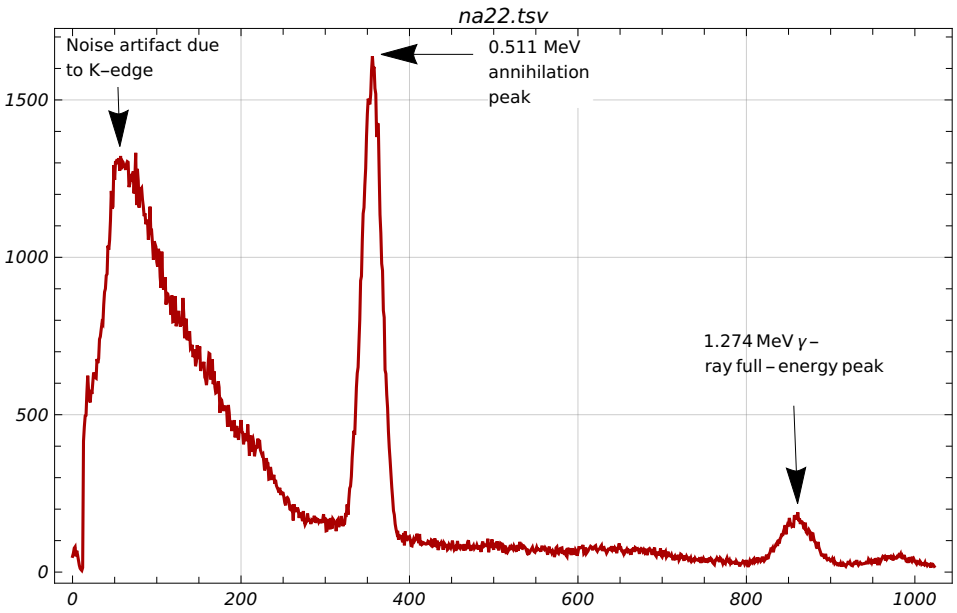
```
In[•]:= LinearDataPlot[]
```




## Na-22 spectrum

```
In[•]:= With[ {name = SystemDialogInput["FileOpen",
            {DataFileName, {"spectrum files" -> {"*.tsv"}, "all files" -> {"*"}}}]},
         If[ name =!= $Canceled,
          LoadFile[name, SkipLines → {"Data:", "Counts"}]]
        ]
```

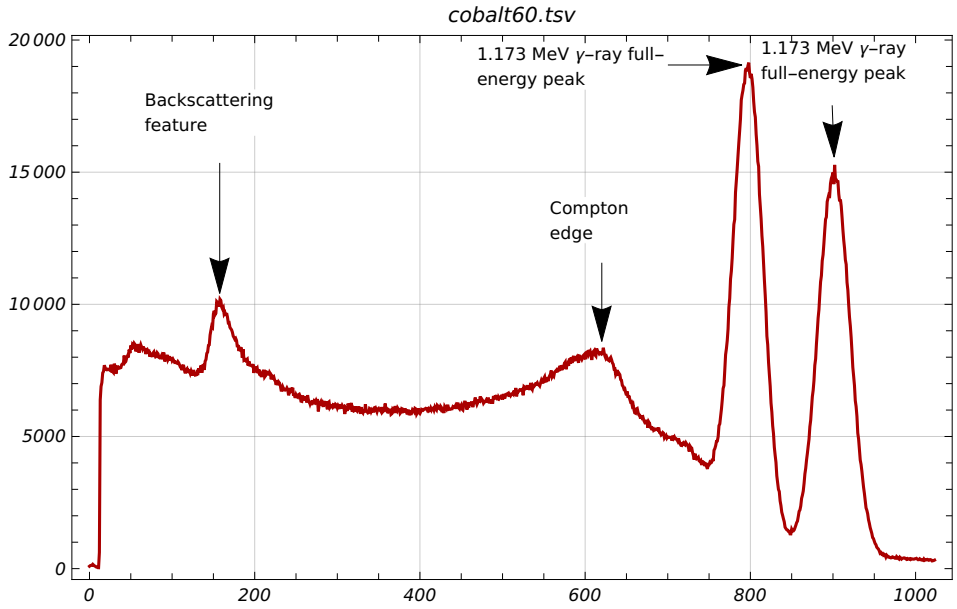
```
In[•]:= LinearDataPlot[]
```




## Co-60 spectrum

```
In[•]:= With[ {name = SystemDialogInput["FileOpen",
     {DataFileName, {"spectrum files" -> {"*.tsv"}, "all files" -> {"*"}}}]},
  If[ name =!= $Canceled,
   LoadFile[name, SkipLines → {"Data:", "Counts"}]]
 ]
```

```
In[•]:= LinearDataPlot[]
```

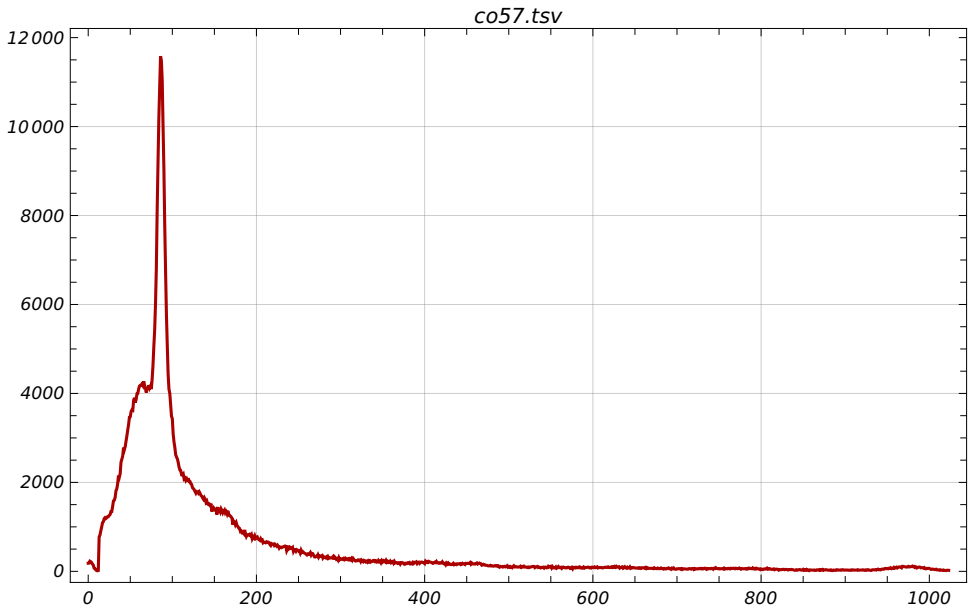


## Co-57 spectrum

In[•]:=
```
With[ {name = SystemDialogInput["FileOpen",
     {DataFileName, {"spectrum files" -> {"*.tsv"}, "all files" -> {"*"}}}]},
 If[ name =!= $Canceled,
  LoadFile[name, SkipLines → {"Data:", "Counts"}]]
]
```

In[•]:=
```
LinearDataPlot[]
```

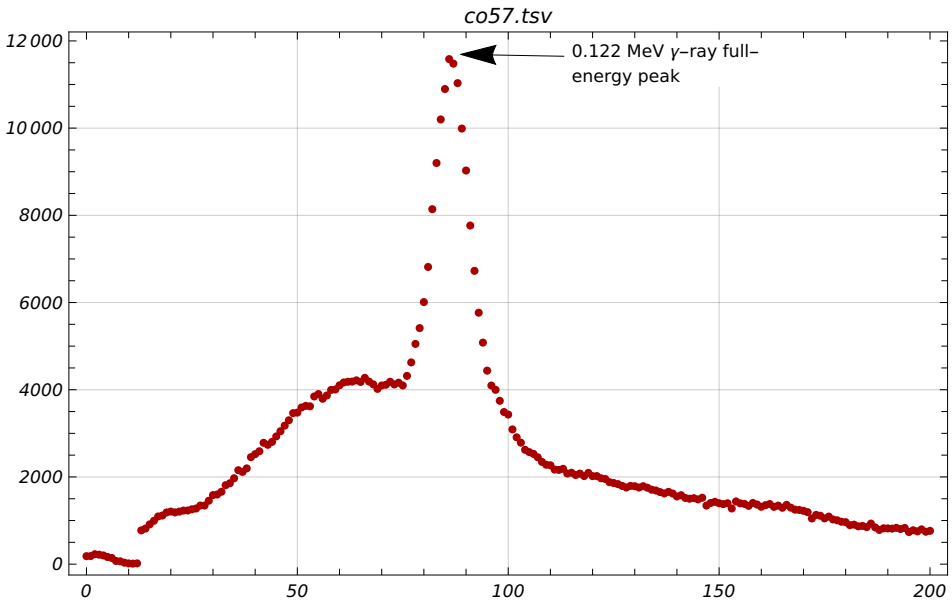
Out[•]=




```
(* We select the leftmost section of the
 spectrum to better discern any interesting features. *)
```

In[•]:=
```
With[{x = SetXRange[ LinearDataPlot[], Log -> False,
     Label -> "Set the X values for the range you wish to keep." ]},
 Print[x];

 XRangeKeep[Sequence @@ x]
]
```

In[•]:=
```
LinearDataPlot[]
```



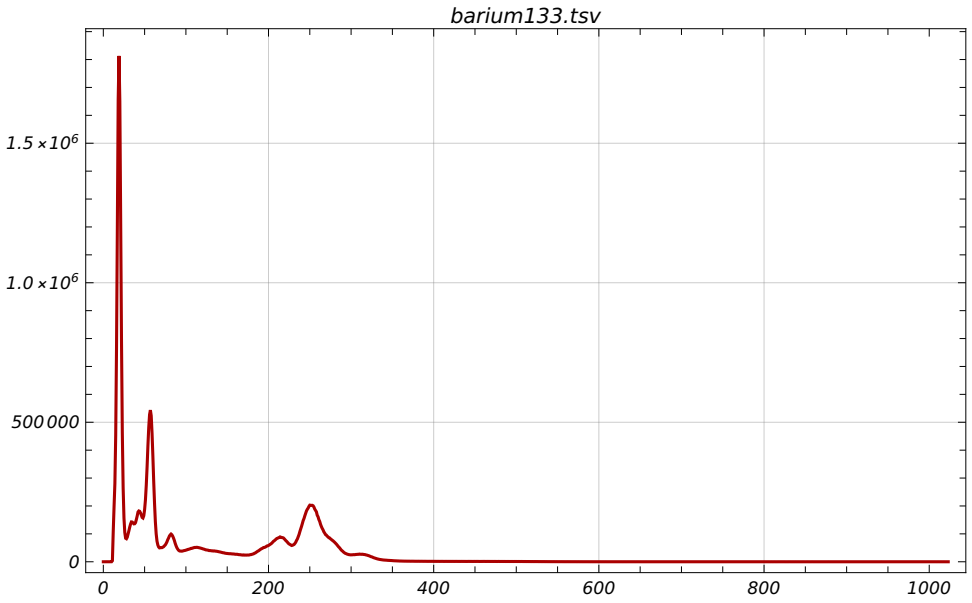

The 0.136 $\gamma$-ray full energy peak has a low count (as expected) and cannot be clearly discerned, and therefore will be left out of the calibration set. The 0.0144 MeV $\gamma$-ray full energy peak is too close to the LLD to be reliably discerned, and will also be left out of the calibration set.

## Ba-133 spectrum

In[128]:=
```
With[ {name = SystemDialogInput["FileOpen",
    {DataFileName, {"spectrum files" -> {"*.tsv"}, "all files" -> {"*"}}}]},
 If[ name =!= $Canceled,
  LoadFile[name, SkipLines → {"Data:", "Counts"}]]
]
```

In[129]:=
```
LinearDataPlot[]
```

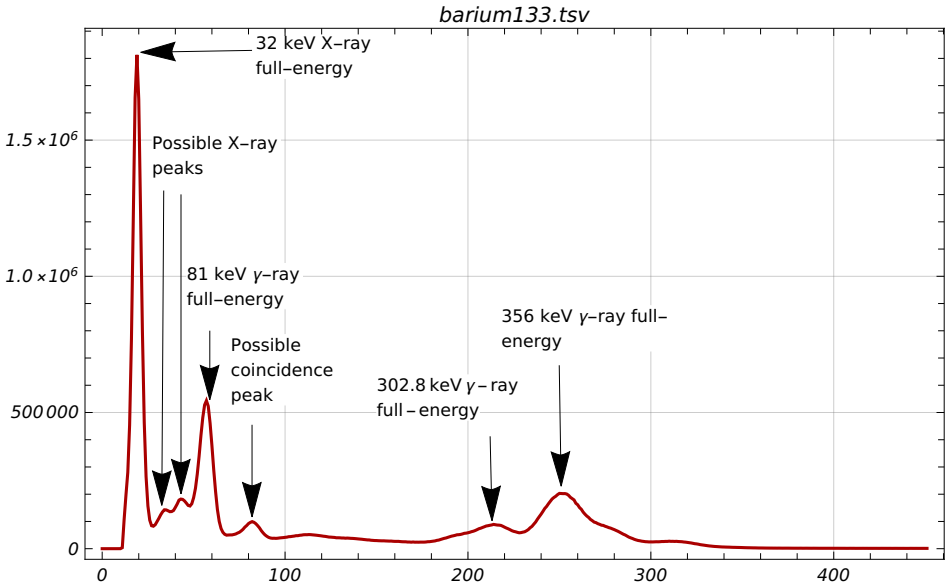
Out[129]=




```
(* We again select the leftmost section of the
 spectrum to better discern any interesting features. *)
```

In[130]:=
```
With[{x = SetXRange[ LinearDataPlot[], Log -> False,
    Label -> "Set the X values for the range you wish to keep."]},
 Print[x];

 XRangeKeep[Sequence @@ x]
]
```

In[131]:=
```
LinearDataPlot[]
```



Other features we would expect to see from the decay cycle of Ba-133 are not clearly discernible and therefore not labelled inMinimizing Chi^2 the above figure. We only consider the full-energy peaks for the calibration set, because those are reliably located on the spectrum above. We may have to exclude the 302.8 keV peak if we find that it is too close to the larger 356 keV peak and that they have superposed significantly near the 302.8 keV peak, skewing the Gaussian+Linear fit.

# Constructing calibration dataset

In[145]:=
```
(* Define loop to prompt for selection of peak from data in file,
then returns fit and prompt for appending
 {energy, mean, sigmean} to calibration dataset calData *)

SetDirectory[NotebookDirectory[]];
fileList = {"na22.tsv", "barium133.tsv", "cesium137.tsv", "co57.tsv", "co60.tsv"};
calData = {{"Energy (MeV)", "mean", "sigmean"}};
ClearAll[energy]

For[
 i = 1,
 i ≤ Length[fileList],
 (
  Block[
   {Print},
   LoadFile[fileList[[i]], SkipLines → {"Data:", "Counts"}];
   MakePoisson[Xerrors -> True];
   With[{x = SetXRange[ LinearDataPlot[], Log -> False,
       Label -> "Set the X values for the range you wish to keep." ]},
 Print[x];

 XRangeKeep[Sequence @@ x]
]
  ];
  GaussianLFit[];
  DialogInput[
   Grid[
    {
     {"Energy (MeV):", InputField[Dynamic[energy], Number]},
     {
      CancelButton[DialogReturn[]],
      DefaultButton[
       DialogReturn[(AppendTo[calData, {energy, mean, sigmean}];)]],
      Button["Next", DialogReturn[(AppendTo[calData, {energy, mean, sigmean}];
         i++;)]]
     }
    },
    Spacings → {1, Automatic}, Alignment → Left]
  ];
 )
]
```