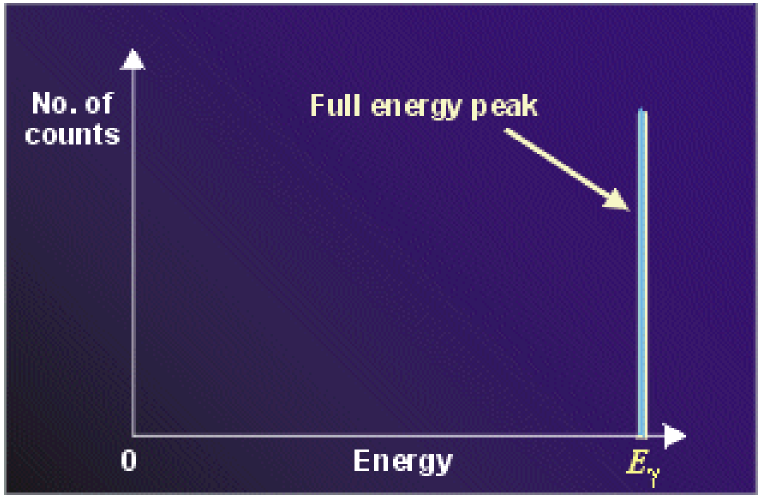
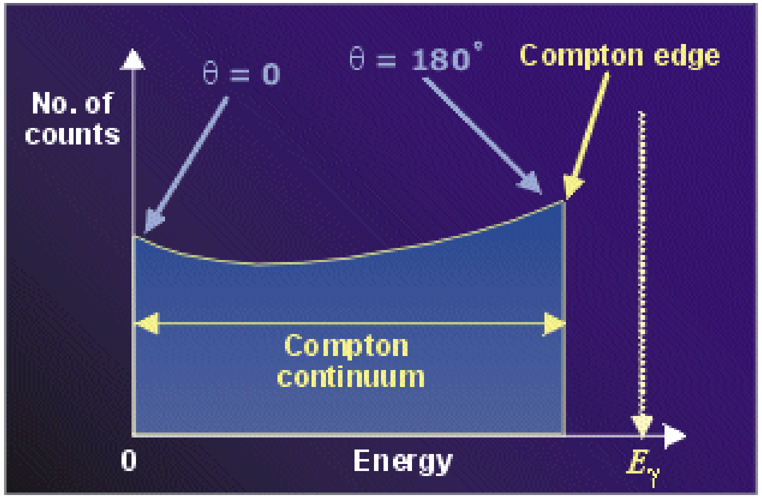
Lecture 14: Radiation detectors III

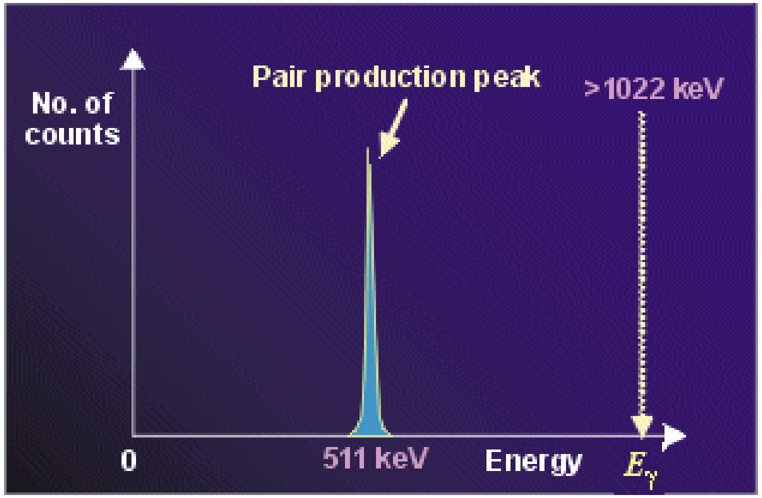
- Germanium detectors
  - Interactions in surroundings
  - Graded shielding
  - Linear Attenuation Coefficients
  - Build-up factor
- Spectrum Analysis

How do γ-rays Interact with Matter?

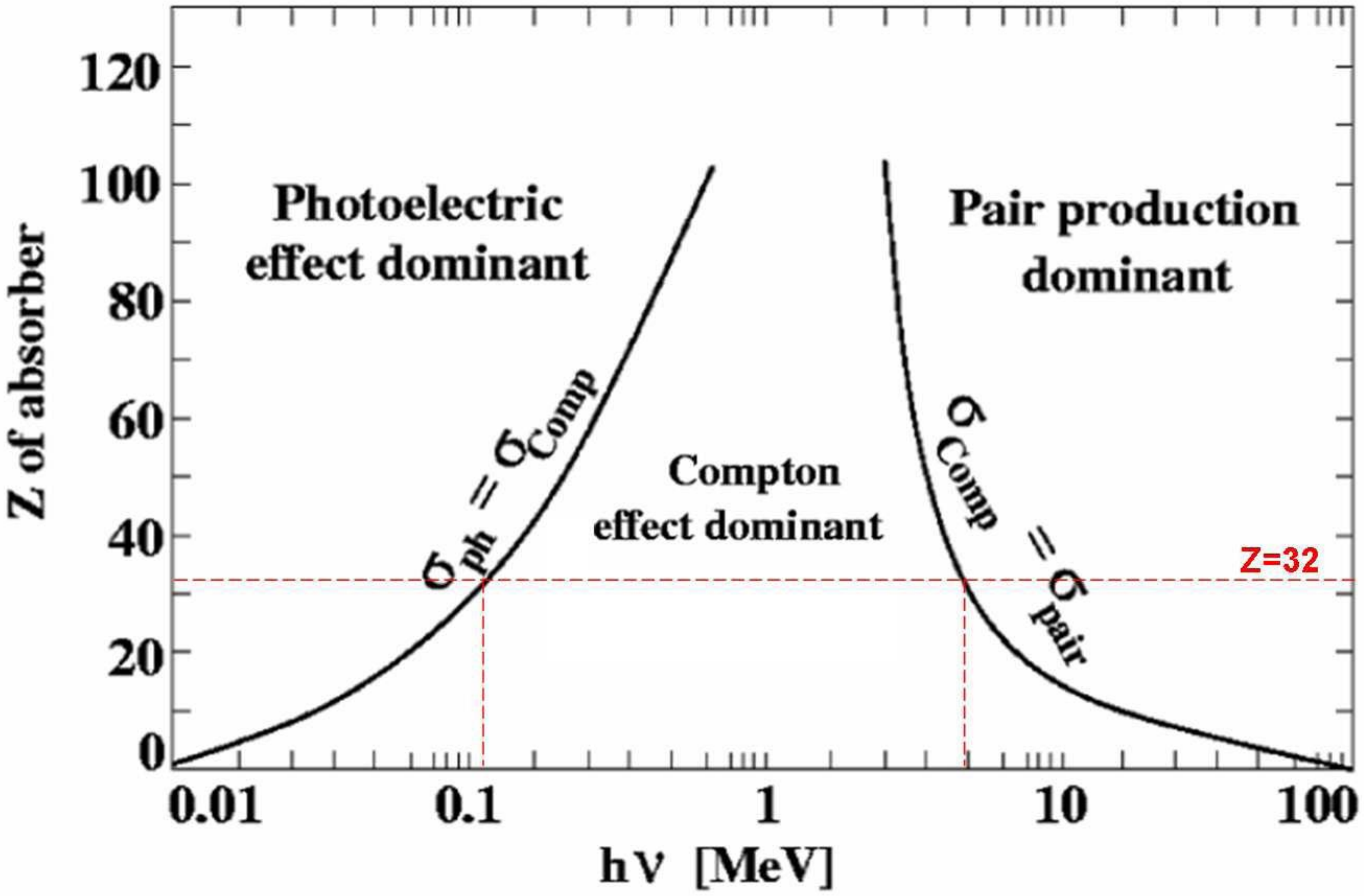
- Gamma-ray photons can interact with matter through 3 primary processes:
  - Photo-electric absorption.
  - Compton Scattering
  - Pair Production.
- An electron with a finite energy will be left in the semiconductor material.



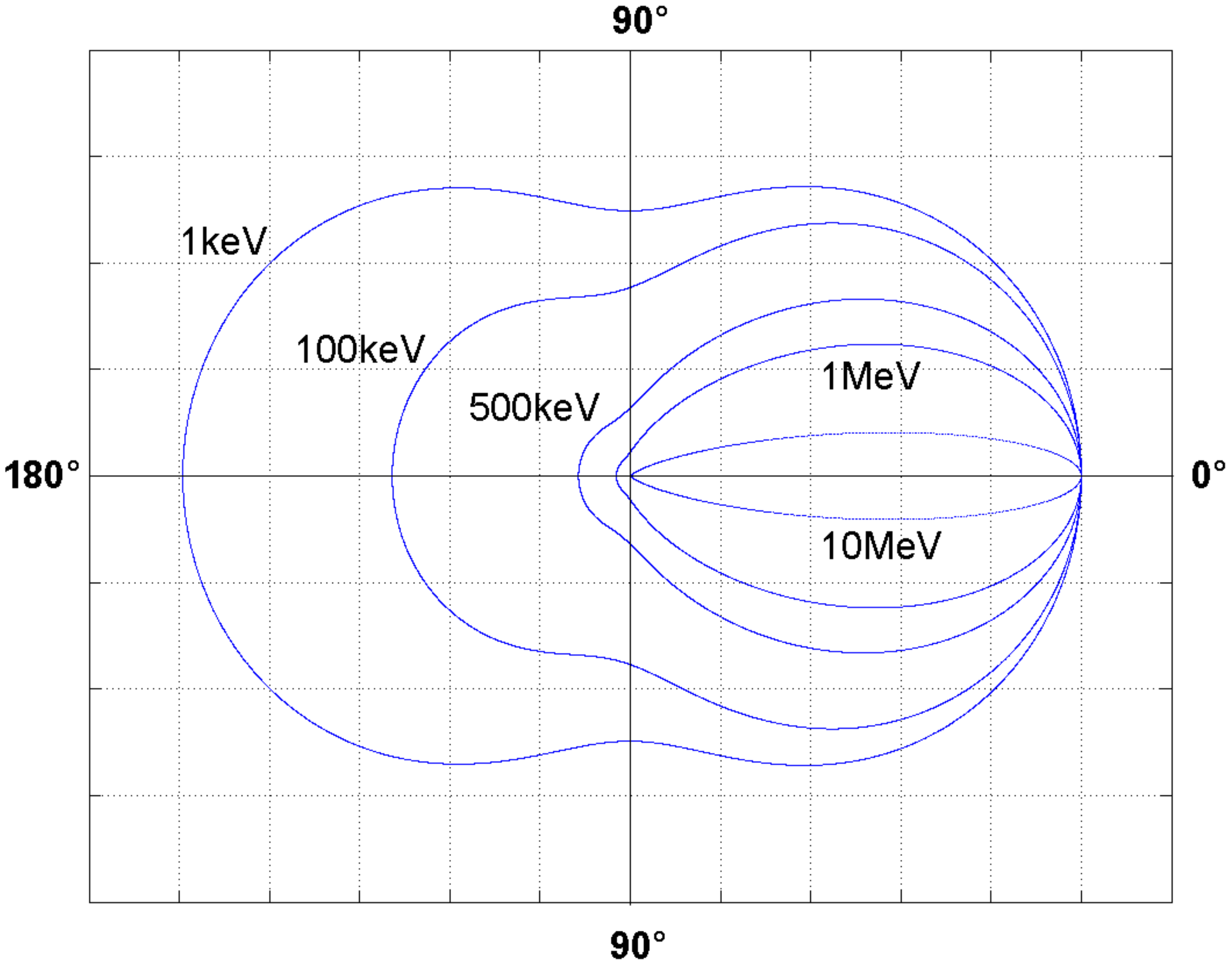




Compton Scattering



Klein-Nishina equation



$$\frac{d\sigma}{d\Omega} = Zr_0^2\left(\frac{1}{1+\alpha\left(1-cos\theta\right)}\right)^2\left(\frac{1+cos^2\theta}{2}\right)\left(1+\frac{\alpha^2\left(1-cos\theta\right)^2}{\left(1+cos^2\theta\right)\left[1+\alpha\left(1-cos\theta\right)\right]}\right)$$

where $\alpha \equiv h\nu/m_0c^2$ and r_0 is the classical electron radius.

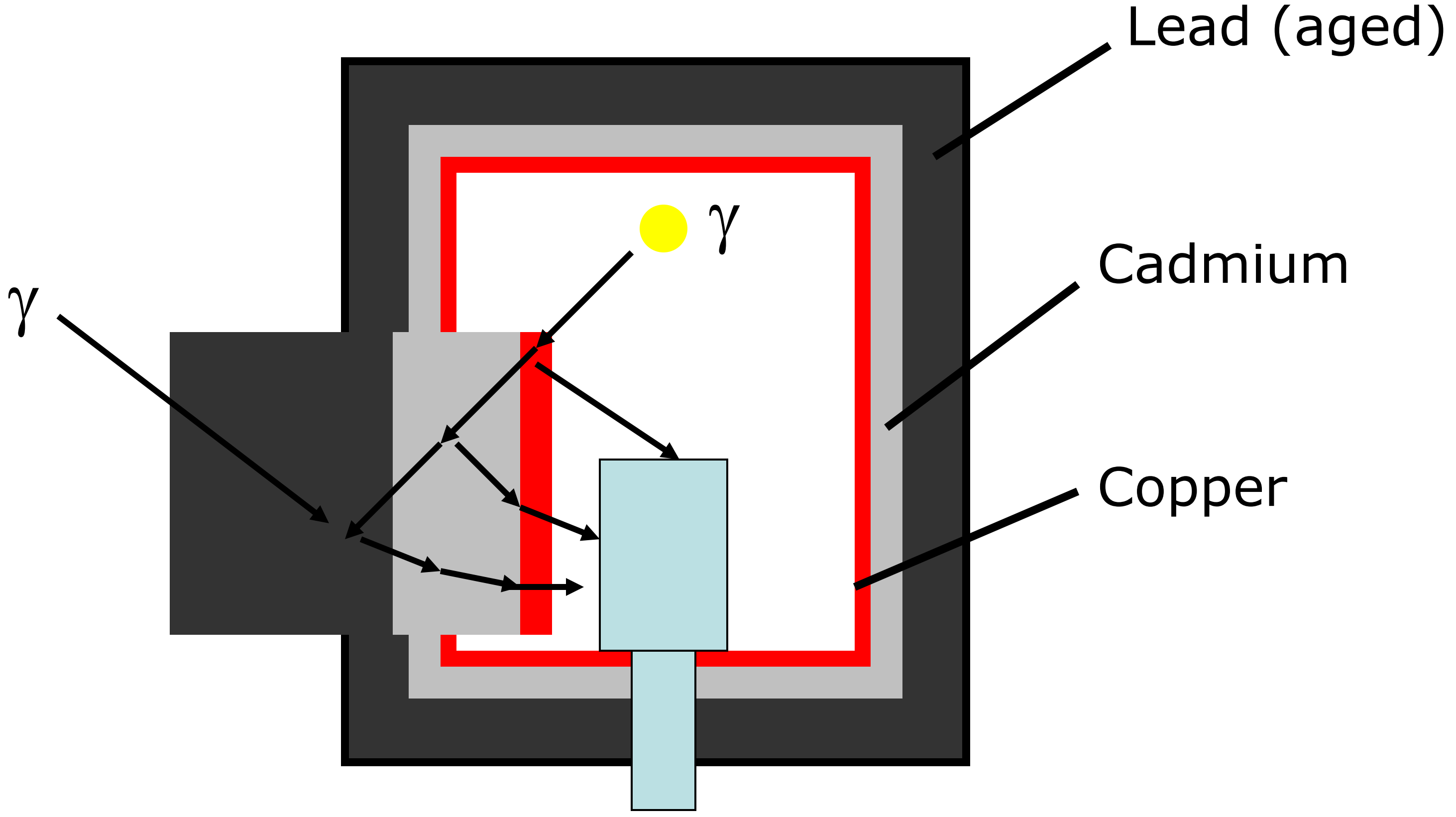
Interactions with surroundings

- Gamma-ray photons from the source will undergo interactions with the surroundings of the detector, i.e. the:
  - the shielding
  - the cryostat
  - the detector cap
  - the source mount etc
- These unavoidable interactions can influence the shape of the spectrum recorded by the detector.
- Interactions in shielding

The graded shield

- For the common shielding material lead.
- X-ray peaks at energies between 70-85 keV.
- These X-rays introduce unwanted background particularly for low energy gamma-ray measurements.
- The solution is to use a graded shield:
  - The inner surface of the lead shield (~10 cm thick).
  - A thin layer of cadmium (~3 mm)
  - A thin layer of copper (~0.7 mm)
  - Example!

Typical low level counting system



Backscattering

- Close inspection of a gamma-ray spectrum may reveal a wide peak with energy <250keV which does not correspond to a known photon from the source.
- Such a feature, termed a *Backscatter* peak, is due to gamma-rays which first interact by Compton scattering with the shielding.
- Backscattered gamma-rays are those scattered through a large angle (> 120°) by the shielding.
- Example!

Shielding and Pair Production

- Pair production in the surrounding material of the detector gives rise to the 'annihilation peak' at 511 keV in the energy spectrum.
- This is due to the escape of one of the 511 keV gamma-rays to the detector.
- The mechanism is similar to the double and single escape peaks in the detector but only one of the 511 keV photons can ever reach the detector because they are emitted in opposite directions.
- The annihilation peak in a spectrum only arises if the source emits at an energy greater than 1022 keV.

Attenuation Coefficients

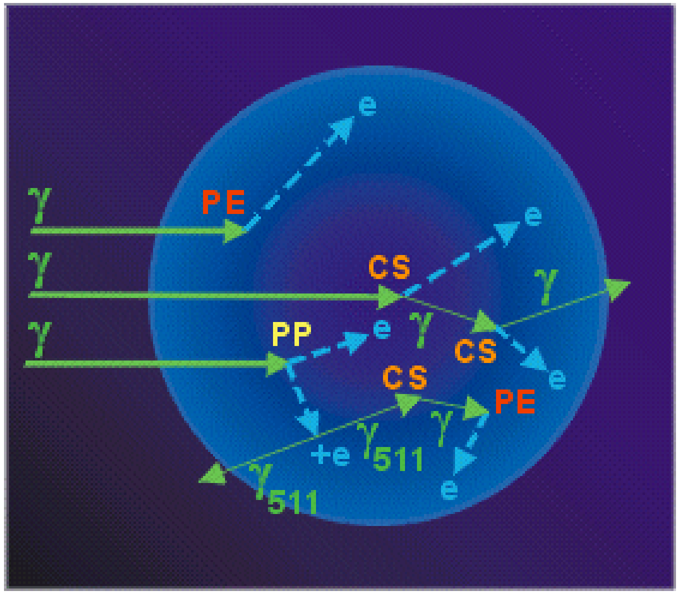
- When a collimated beam of monoenergetic gamma-ray photons passes through a material, the interaction processes remove gamma-rays by absorption or by scattering the gamma-rays away from the detector direction.
- The linear attenuation coefficient :
  - describes the probability of absorption occurring per unit length within the absorber material;
  - it is also sometimes related to the density of the absorber material and called the mass attenuation coefficient.
  - Linear attenuation coefficients for certain gamma energies and absorber materials are found from linear attenuation graphs.

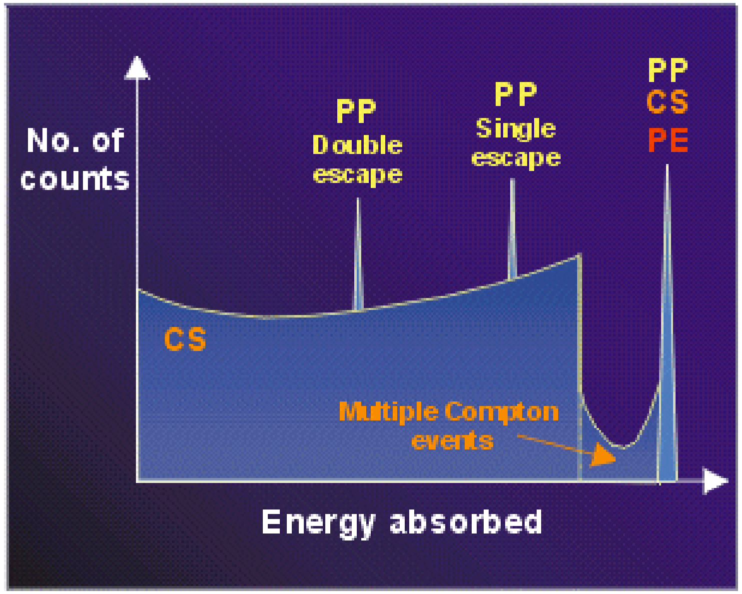
The build up factor

- If we insert an absorber between the source and the detector, some of the transmitted gamma-rays still travel directly from the source to the detector.
- As well as these, some gamma-rays which would not otherwise reach the detector may be Compton scattered in the absorber, such that they then reach the detector.
- This can increase the signal at the detector.
- This phenomenon is referred to as **build-up**.
- Example!

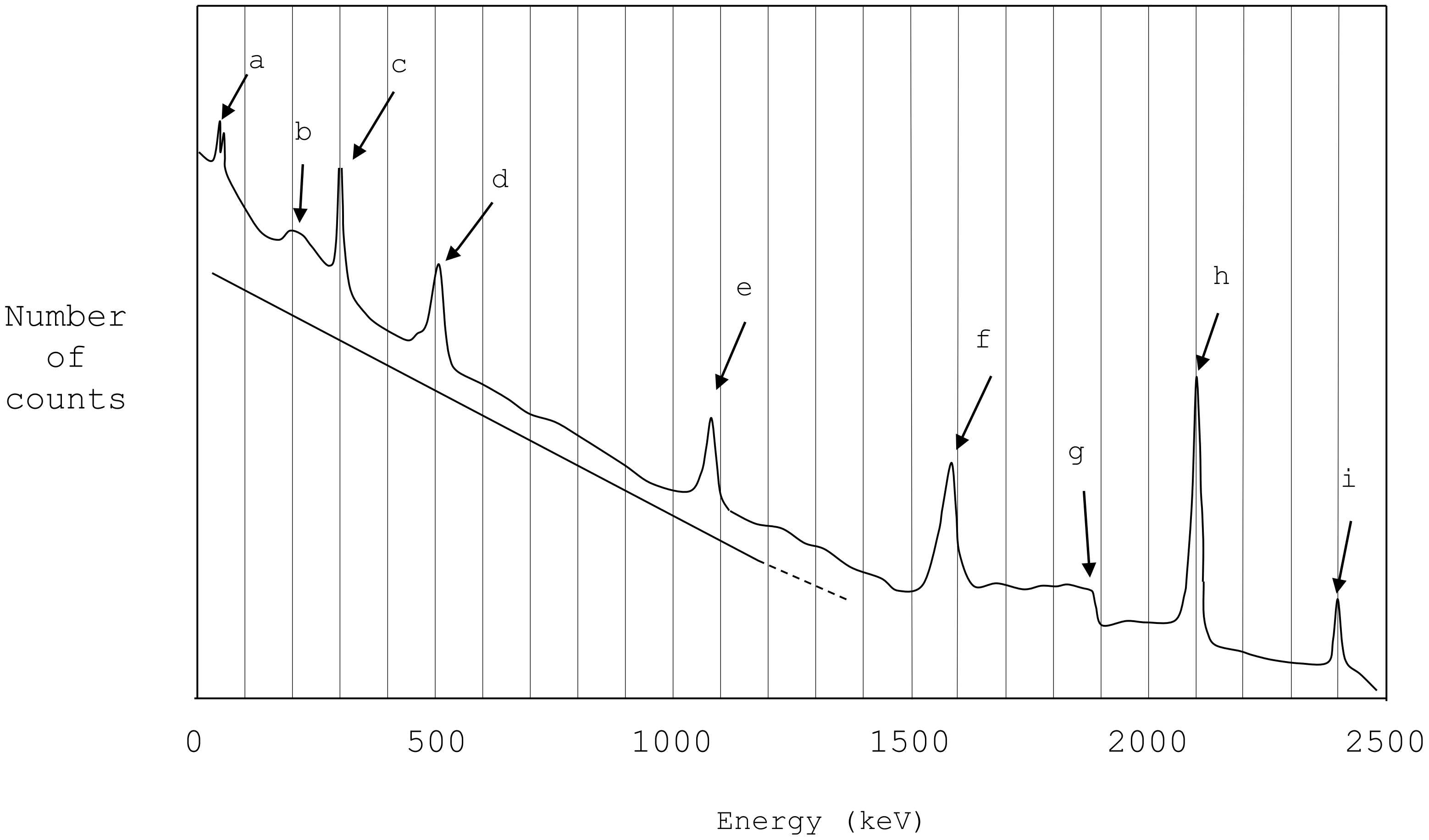
Interactions in a real detector

- Within a **real detector** the interaction outcome is not as simple to predict as the small or large detector case. Compton scattering may be followed by other Compton scatterings before the gamma-ray photon escapes from the detector. Also, pair production may be followed by the loss of only one annihilation gamma-ray, resulting in a single escape peak as well as a double escape peak.



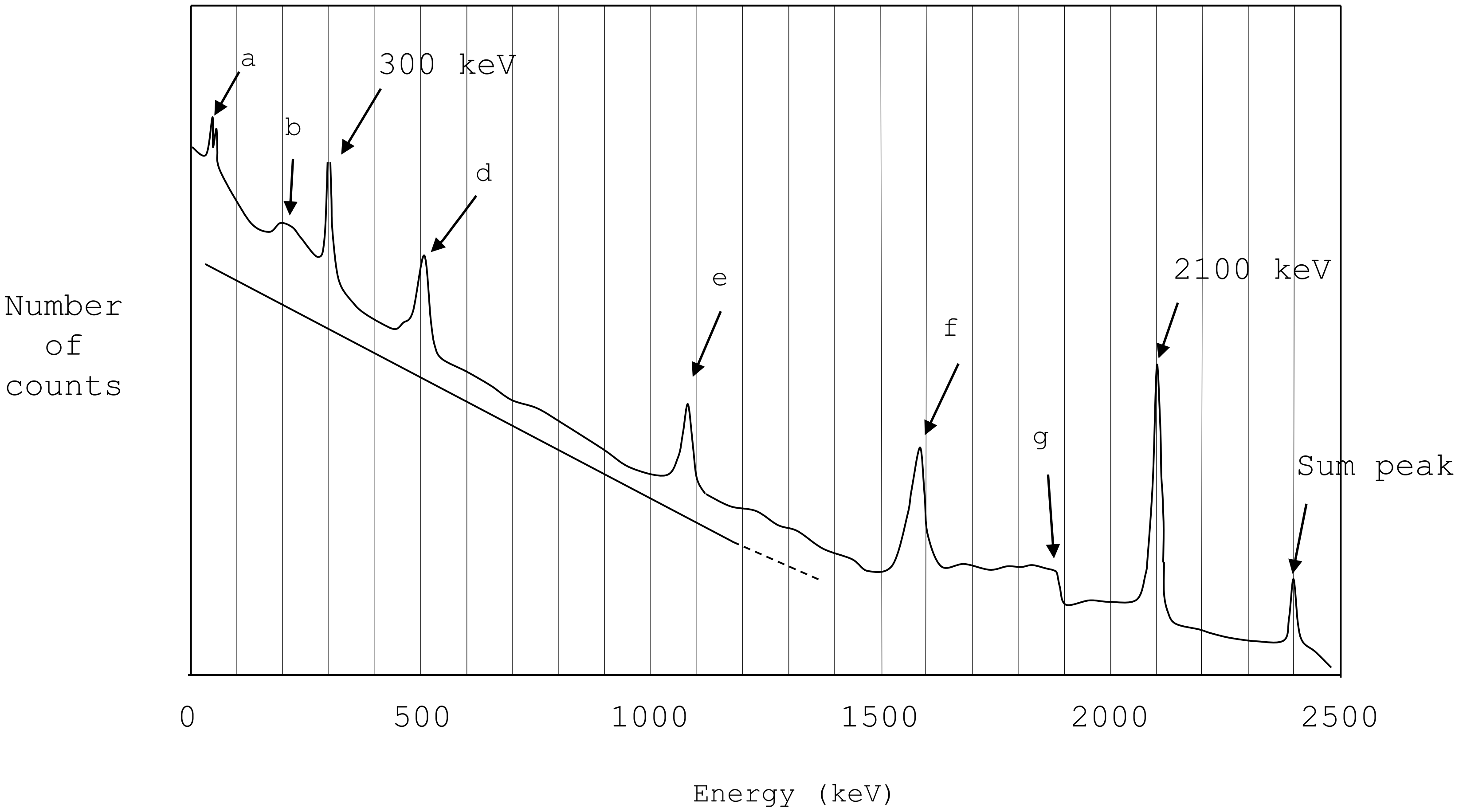


Schematic Gamma Spectrum



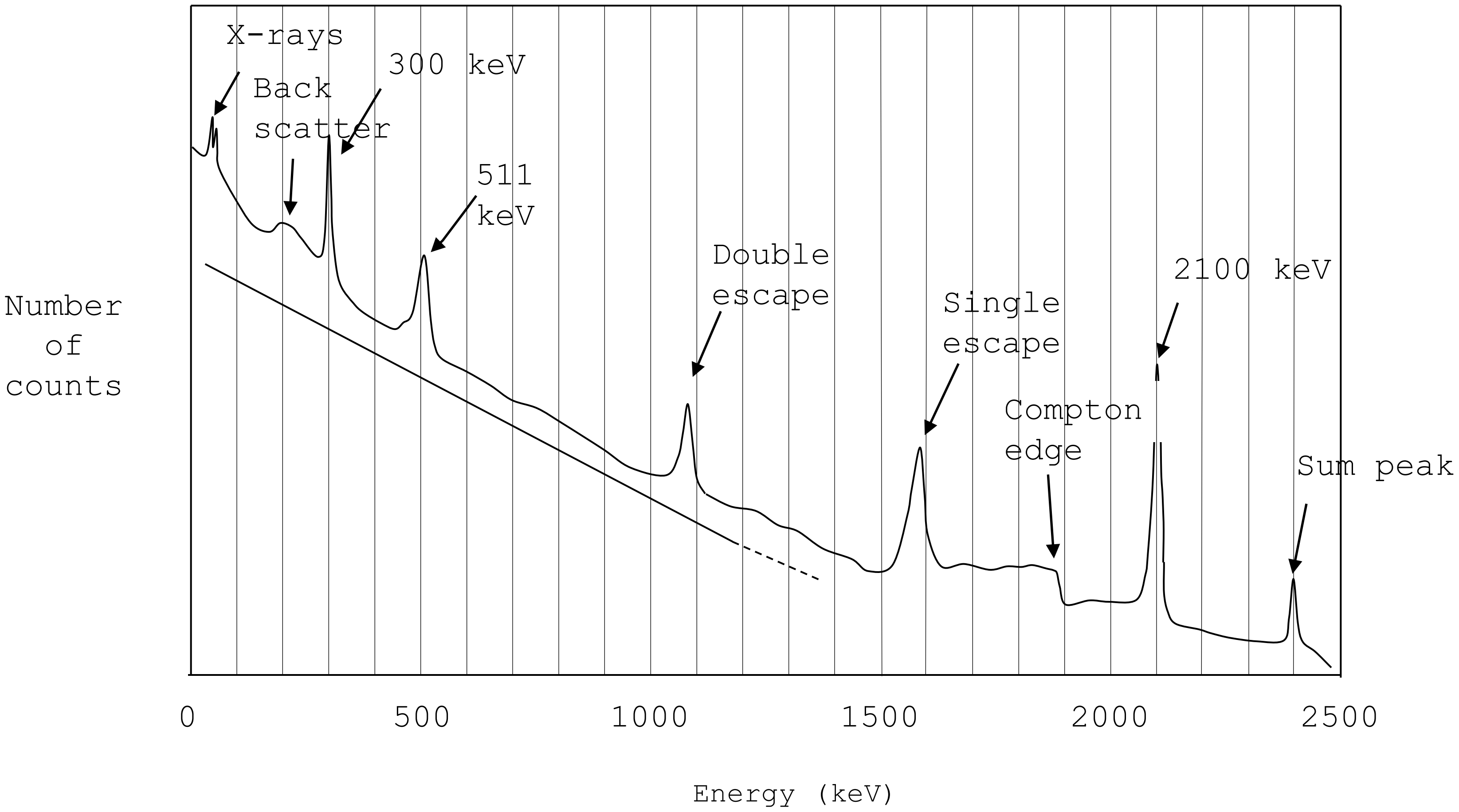
- A radionuclide is known to decay by high-energy positron emission and to emit two gamma rays. One of these is at 300 keV. When a low activity source of this nuclide is counted close to a germanium detector the following spectrum is seen.
- How might we understand the features in this spectrum?

Schematic Gamma Spectrum



- First label the known and identify the other photopeak
- Look at the top - this could be 2100 keV or 2500 keV
- 2100 + 300 = 2500. So 2100keV is the photopeak and 2500 is the sum peak when the nucleus decays an both gammas are simultaneously detected.

Schematic Gamma Spectrum



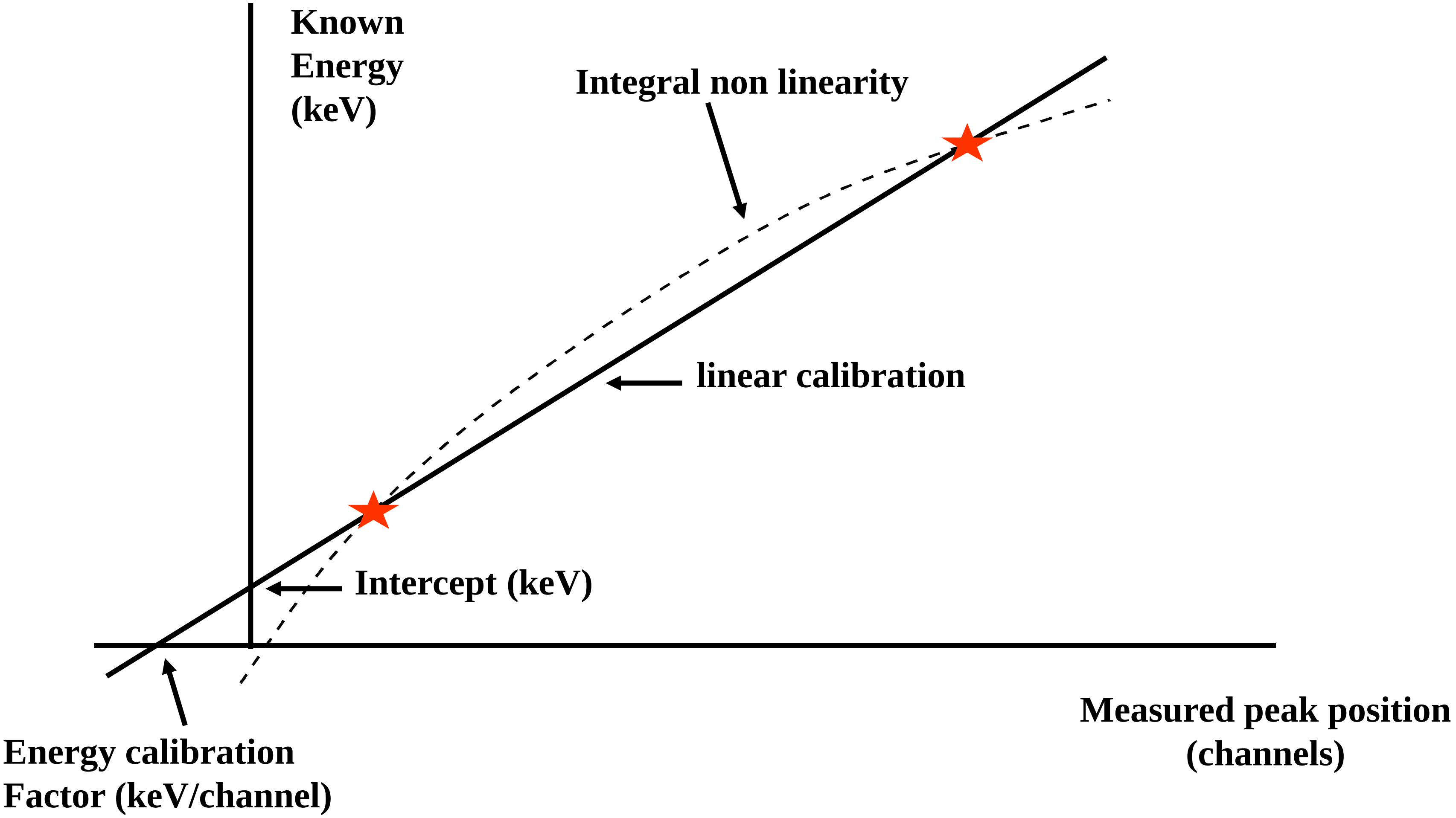
- We would expect both single and double escape peaks.
- The Compton continuum from the 2100 keV photopeak should also be seen there we will see the Compton edge.
- X-rays, 511 keV and a backscatter peak should also be seen.

Standard Analysis procedures

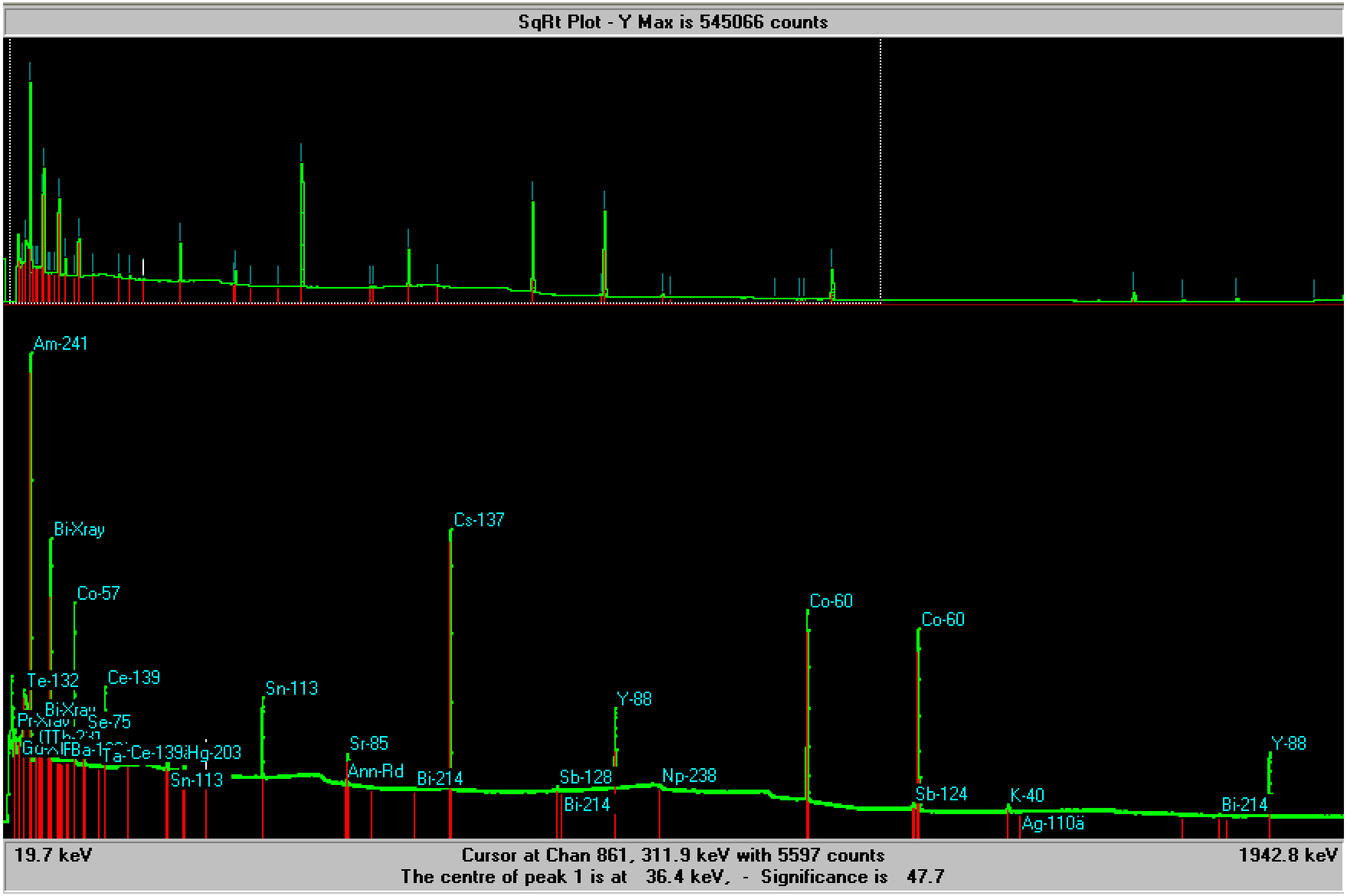
- If you want to analyse real spectra you need to perform:
  - Energy calibration
  - Peak Shape Calibration
  - Efficiency Calibration
- You can then convert peak areas to true intensities
- In a gamma-ray spectrum a peak consists of a number of counts in several adjacent channels.
  - Simplest peak area is just the summation of the channel contents within the peak.
  - Gross Count or Gross area.

Energy Calibration

- Energy calibration is achieved by collecting a spectrum of a known radioisotope and recording the channel number of the peaks of known gamma-ray energy.



Real Calibration Spectra: Energy



SqRt Plot - Y Max is 545066 counts

19.7 keV

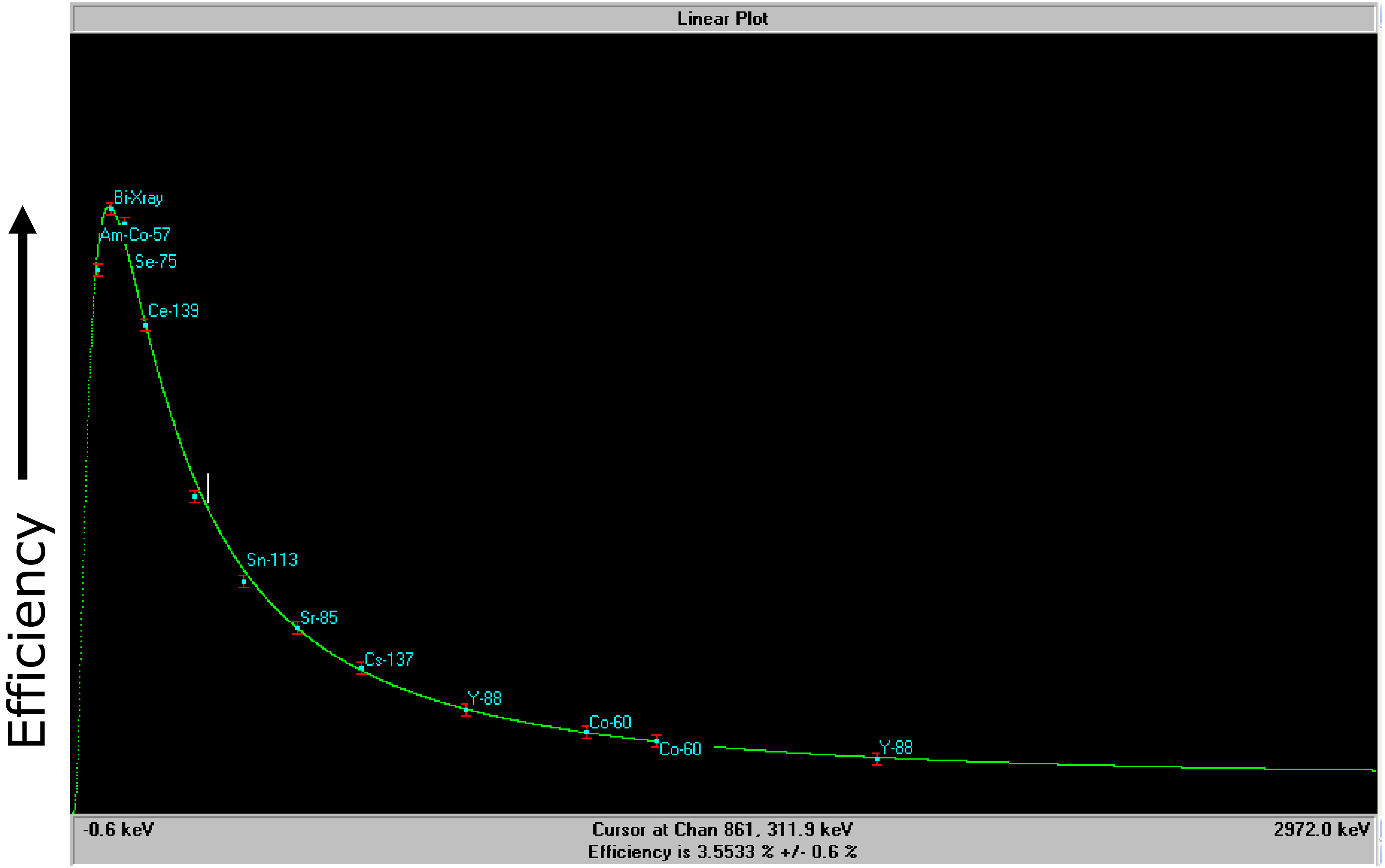
Cursor at Chan 861, 311.9 keV with 5597 counts

The centre of peak 1 is at 36.4 keV, - Significance is 47.7

1942.8 keV

- This is a typical mixed source calibration spectrum

Real Calibration Spectra: Efficiency



-0.6 keV

Cursor at Chan 861, 311.9 keV
Efficiency is 3.5533 % +/- 0.6 %

2972.0 keV

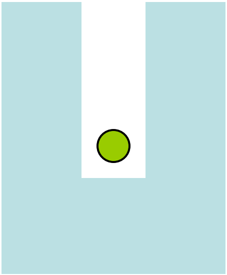
- The efficiency curve from an n-type detector

Counting geometries

- For low level counting it is important to maximise detector efficiency:
  - For large quantities of sample utilise a **Marinelli** beaker.

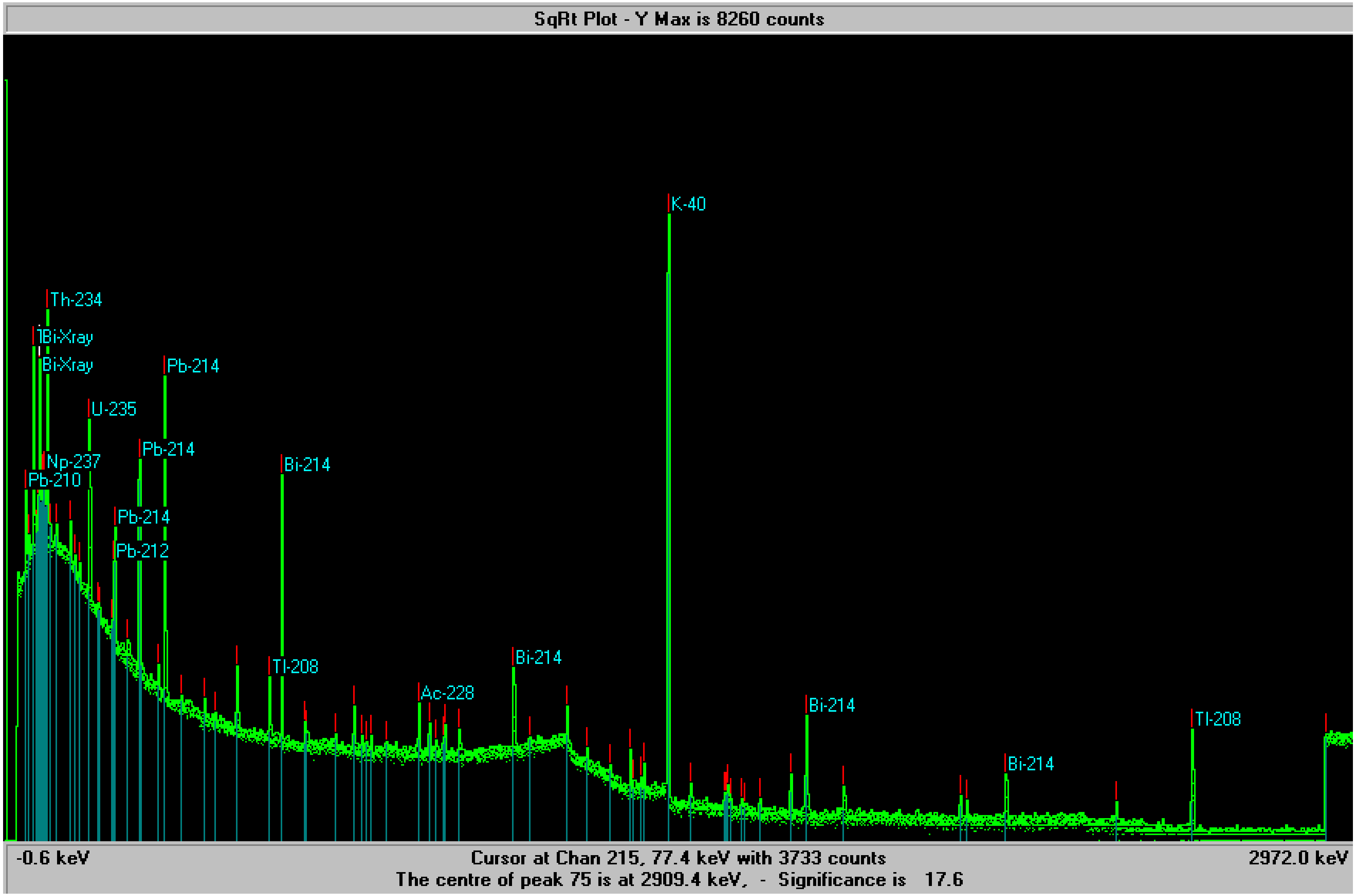
Marinelli geometry

  - For small samples place in known geometry on top of detector – or utilise a **well** detector.



Well geometry

Real Unknown Spectra: Sample



SqRt Plot - Y Max is 8260 counts

-0.6 keV

Cursor at Chan 215, 77.4 keV with 3733 counts

2972.0 keV

The centre of peak 75 is at 2909.4 keV, - Significance is 17.6

- Unknown marinelli sample

Analysing a real unknown spectrum

- In general analysis of a spectrum may take the following form:
    - Search for peaks.
    - Measure the width of peaks.
- If the width is consistent with the energy perform a peak area calculation.
- If peak is too wide, deconvolute the peaks.
- Identify peaks in particular isotopes.
- Use the efficiency calibration to determine the intensities of the peaks and estimate the isotope activities.

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