

Interactions of Radiation With Matter

Milan Matos

Nuclear Science and Instrumentation Laboratory



Types of Interactions

Electro-magnetic

- charged – betas, alphas, protons, ions
- not charged – photons (gammas)



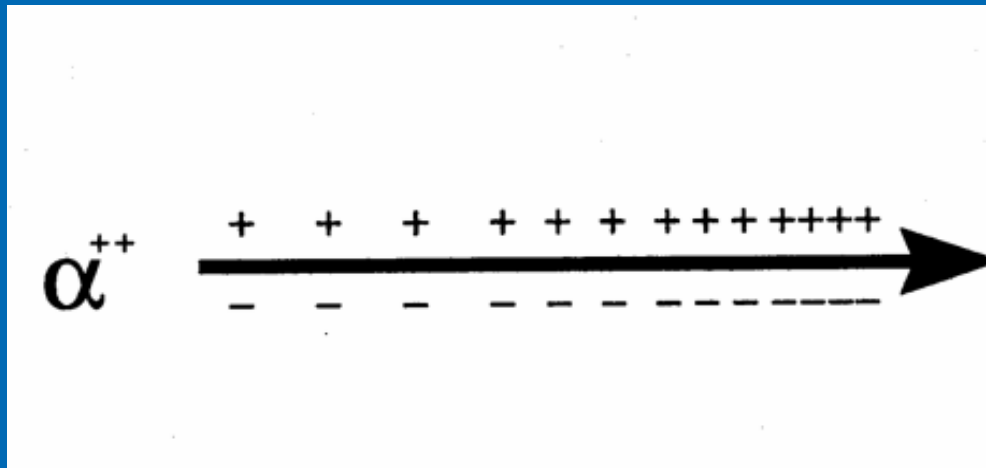
Non-electro-magnetic – neutrons

Energy Loss of Heavy Charged Particles

Alphas, protons, ions

Multiple collisions:

- Inelastic collisions with electrons
- Elastic scattering from nuclei
- Etc.



Energy Loss of Heavy Charged Particles

The stopping power is proportional to Z^2 , it increases rapidly at low energies

sr-treatment: nuclear stopping power in silicon

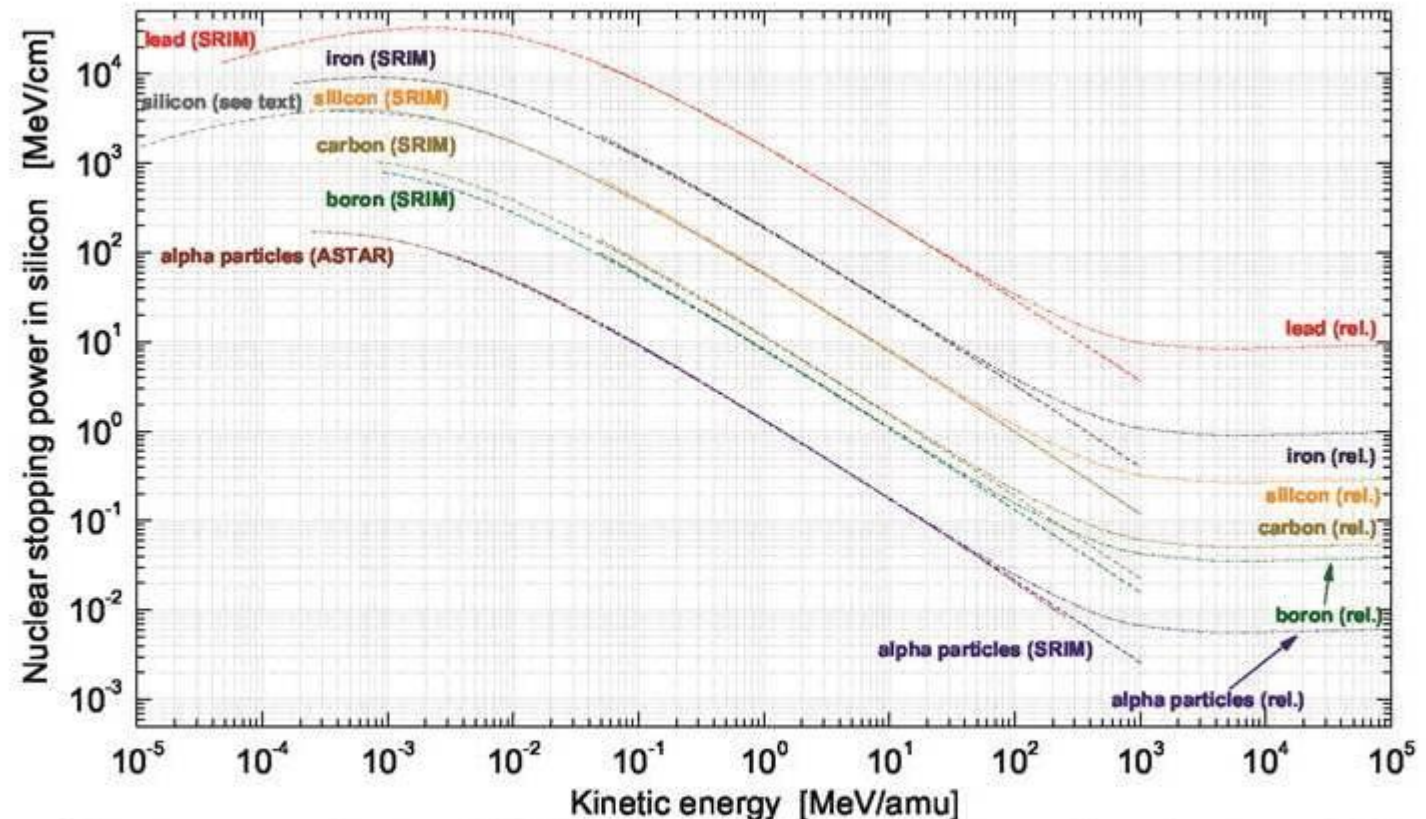
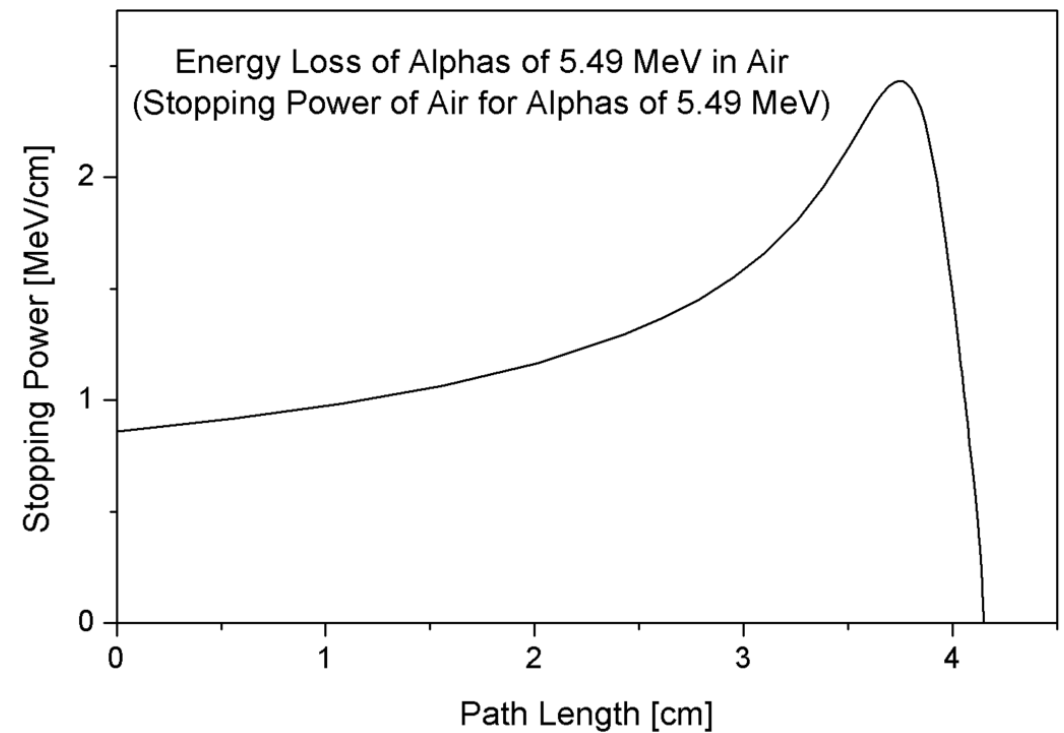
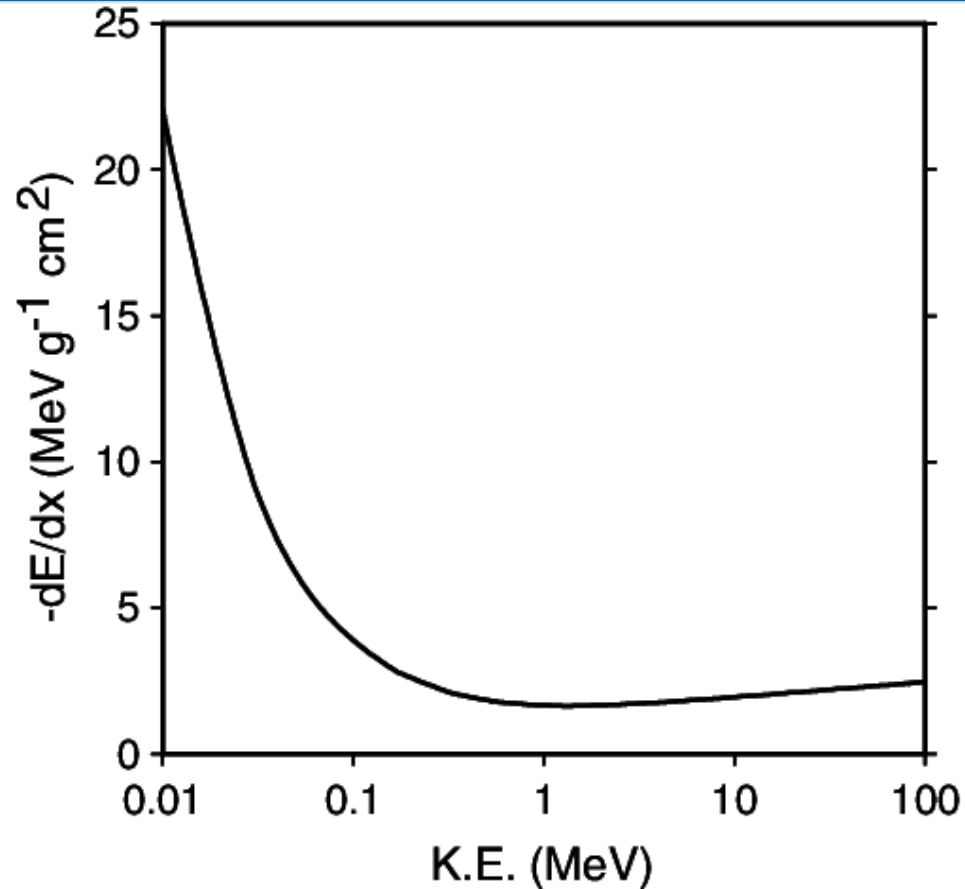
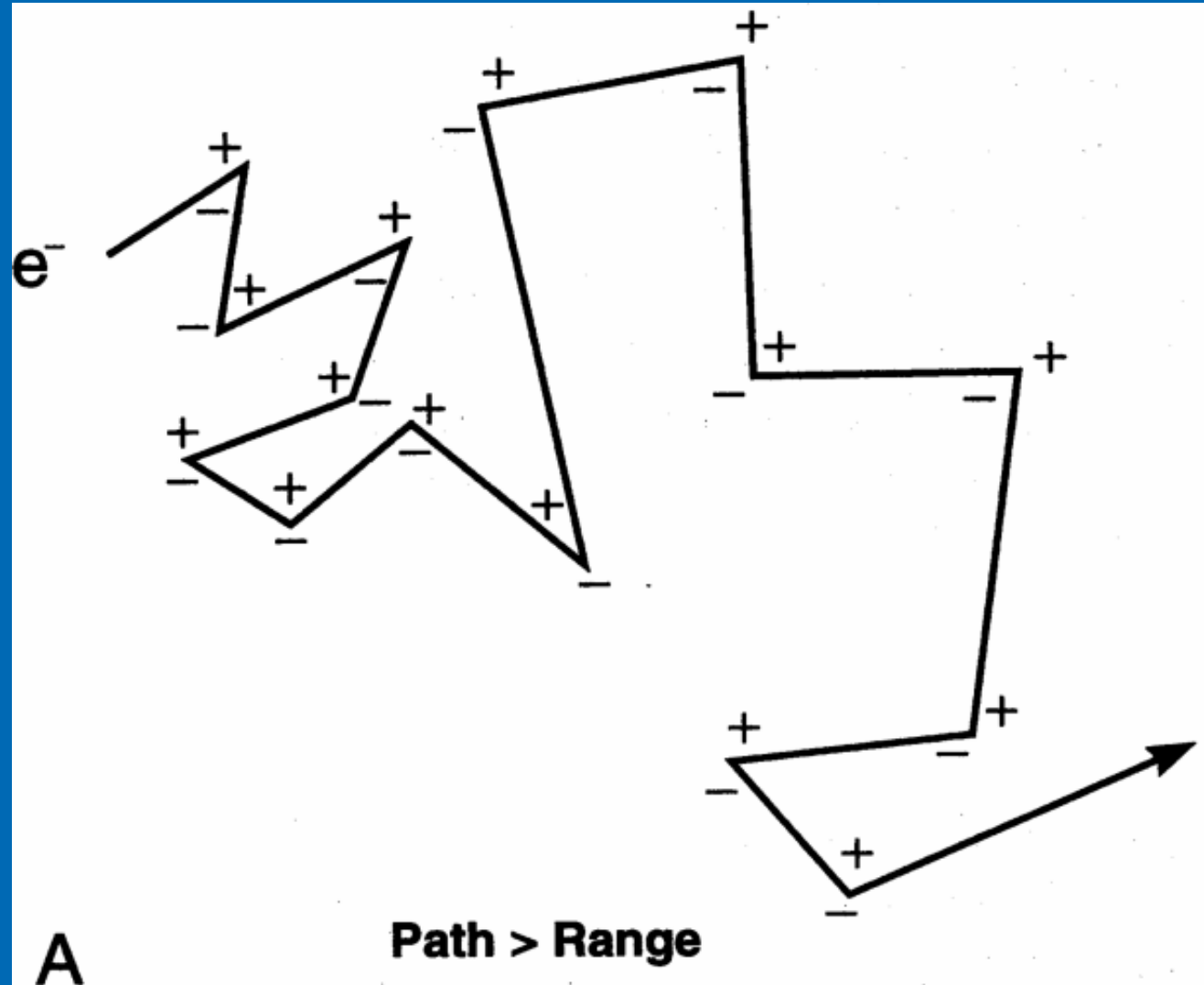


Fig. 2.23 Nuclear stopping powers (in units of MeV/cm) in a silicon medium for α -particles, boron-, carbon-, silicon-, iron- and lead-ions as function of the kinetic energy of incoming ions in units of MeV/amu. The data for α -particles (ASTAR) are from [Berger, Coursey, Zucker and Chang (2010)]; those indicated as "silicon (see text)" are calculated using Eq. (2.79) for incoming ^{28}Si ions; the data for ^{208}Pb ("lead"), ^{56}Fe ("iron"), ^{28}Si ("silicon"), ^{12}C ("carbon"), ^{11}B ("boron") ions and α -particles - indicated as "SRIM" - are those available in [Ziegler, J.F. and M.D. and Biersack (2008)]. The data for ^{208}Pb ("lead"), ^{56}Fe ("iron"), ^{28}Si ("silicon"), ^{12}C ("carbon"), ^{11}B ("boron") ions and α -particles - indicated

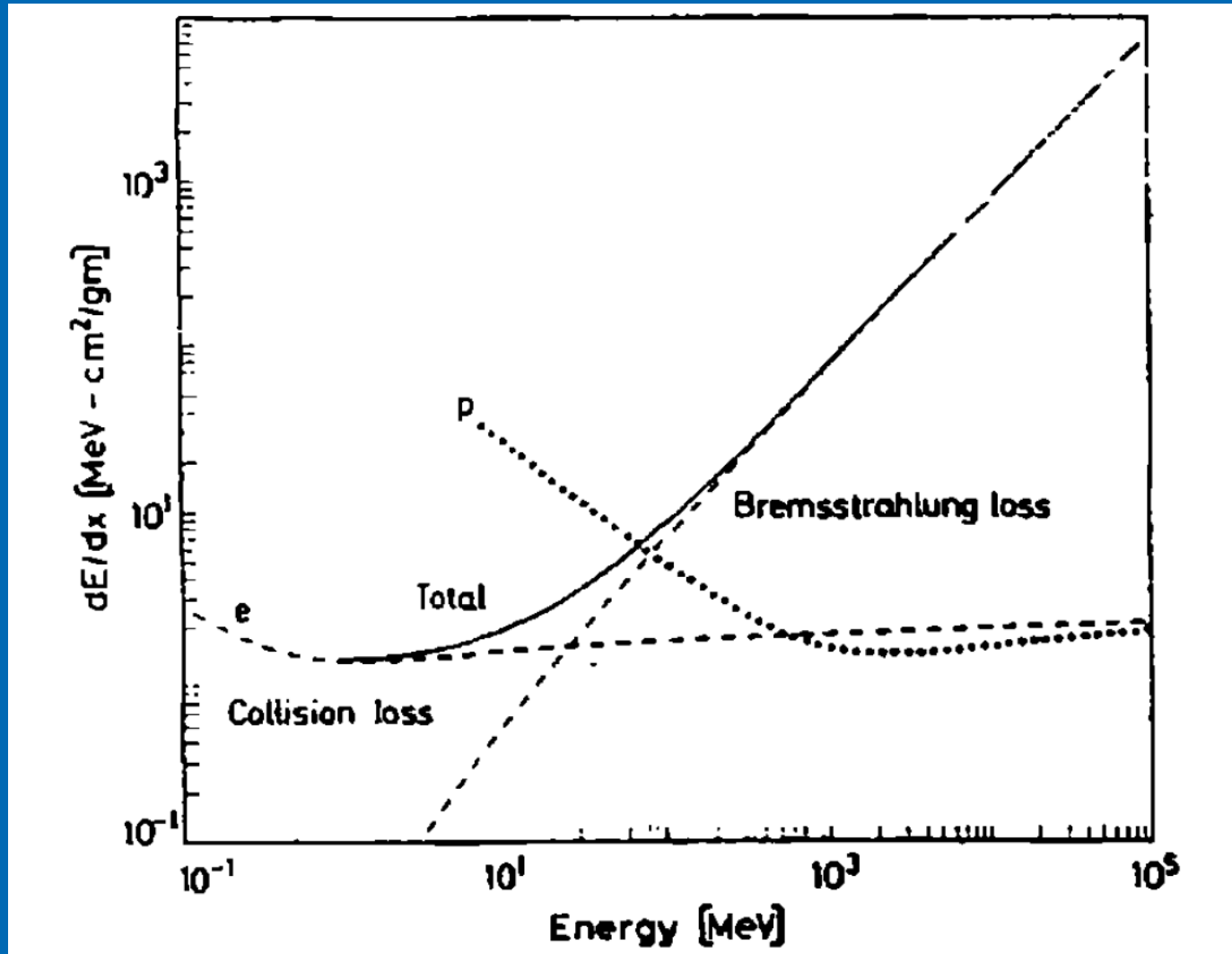
Energy Loss of Heavy Charged Particles



Energy Loss of Electrons And Positrons

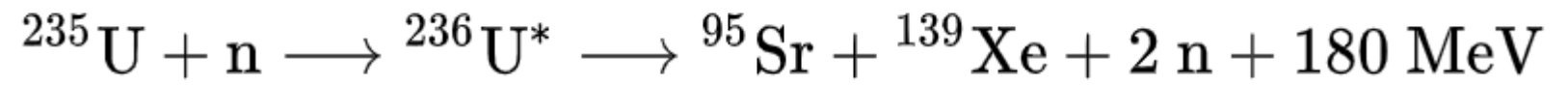


Energy Loss of Electrons And Positrons



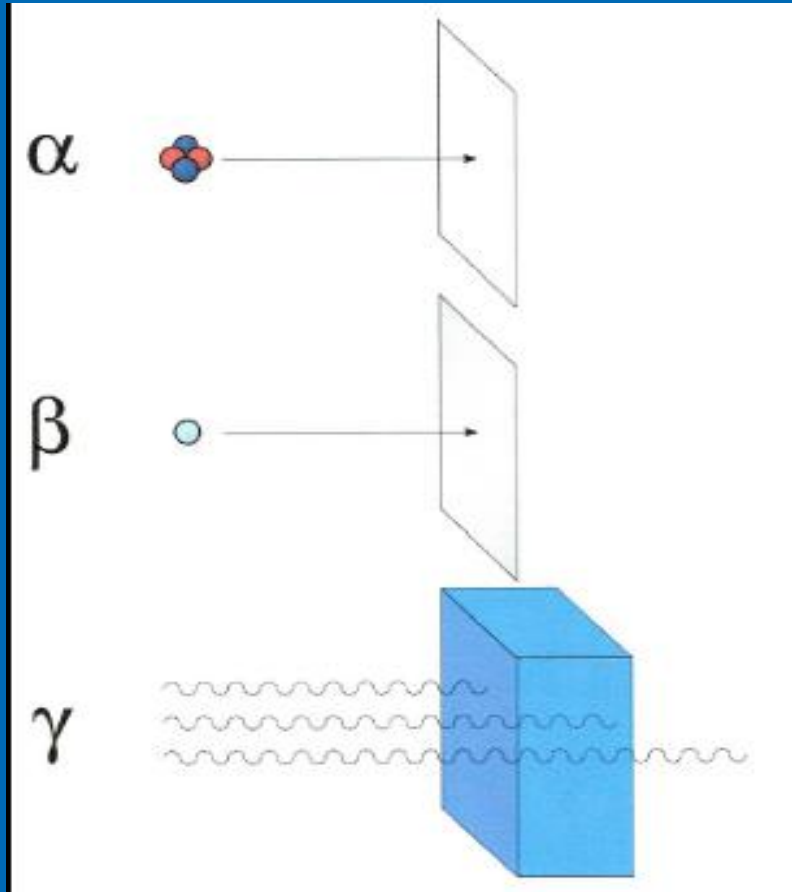
The Interaction of Neutrons

- no electric charge – no Coulomb interaction
- strong (nuclear) interaction:
 - elastic scattering from nuclei
 - inelastic scattering from nuclei $A(n,n')A^*$
 - fission



- nuclear reactions – used for detection:
 $^3\text{He} + \text{n} \rightarrow ^3\text{H} + \text{p}$

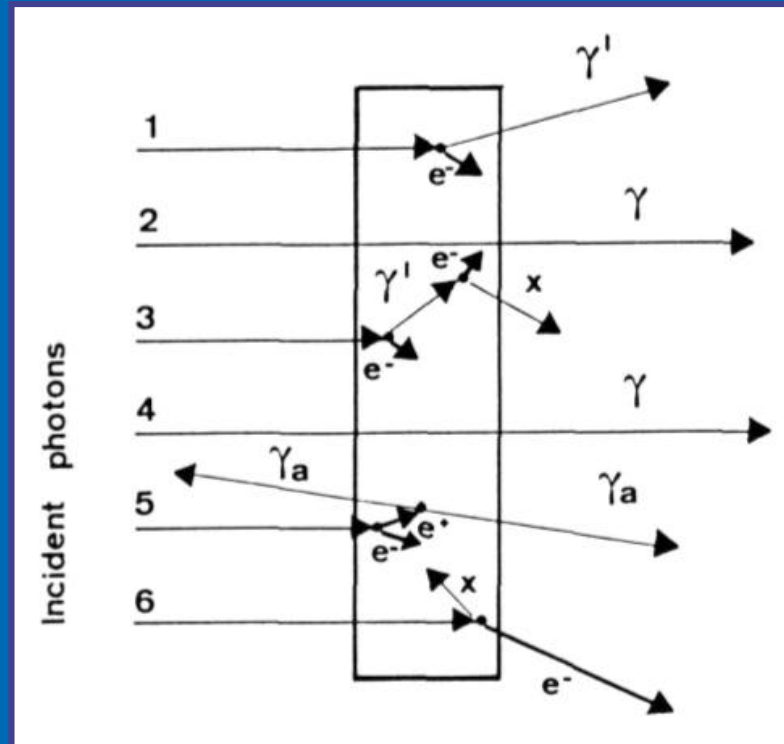
Three Common Types of Radioactive Emissions - Penetrability



- **Alpha particles** may be completely stopped by a sheet of paper
- **Beta particles** by aluminum shielding
- **Gamma rays**, however, can only be reduced by much more substantial obstacles, such as a very thick piece of lead.

Gamma Interactions

The total attenuation coefficient effects the intensity loss of the photons in an absorber of thickness t as discussed before.

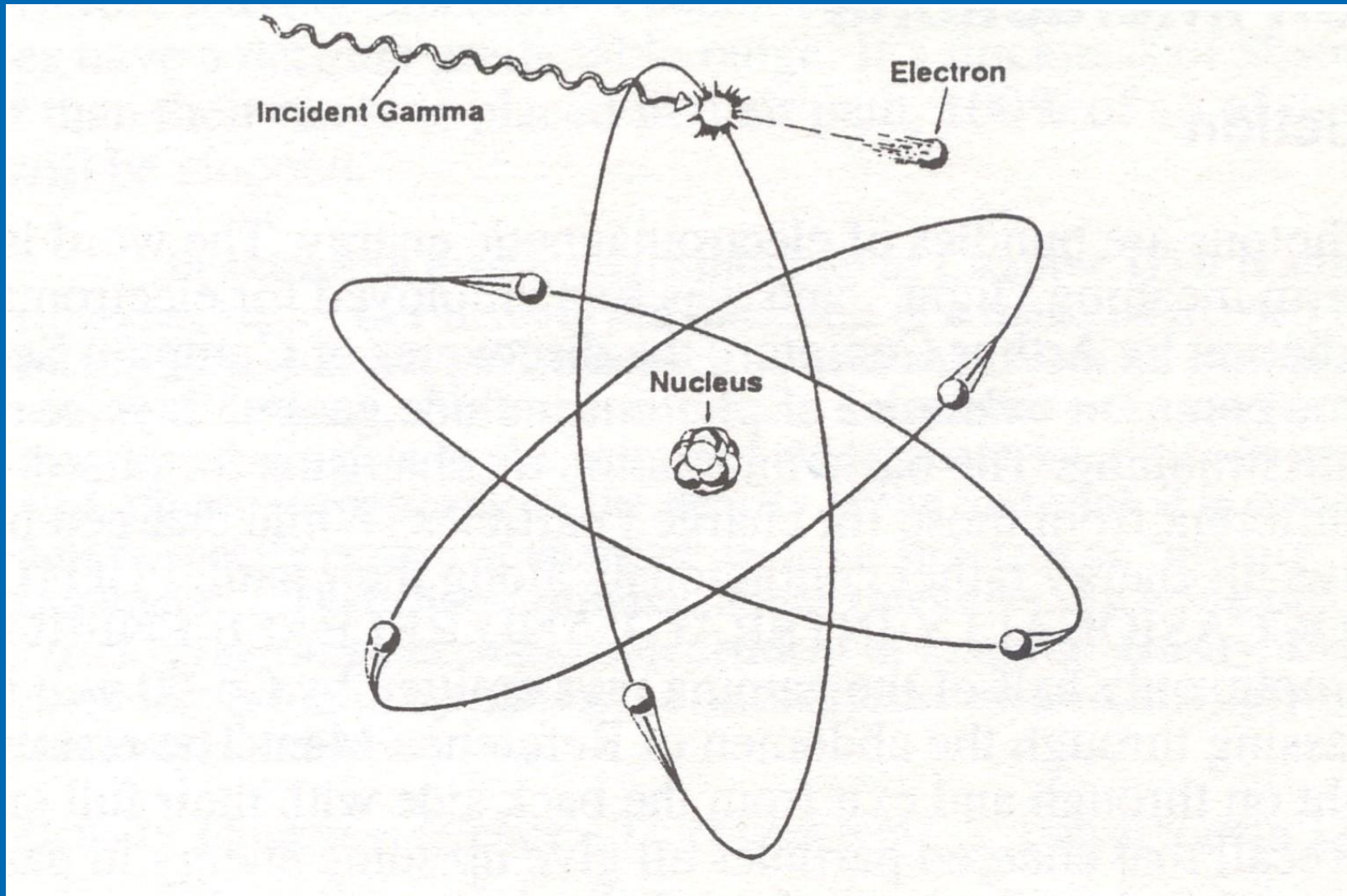


$$I(t) = I_0 \cdot e^{-\mu \cdot t}$$

Gamma Interactions

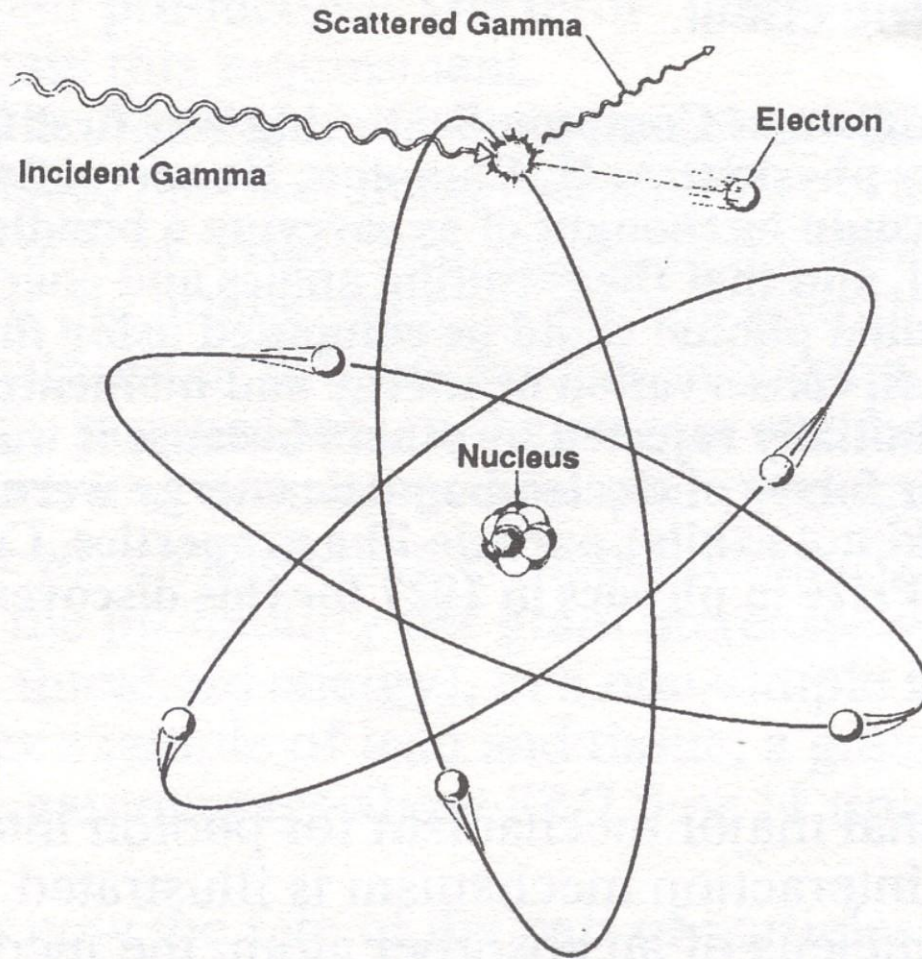
- Photoelectric Absorption
- Compton Scattering
- Pair Production

Photoelectric Absorption



- Electron deposits the energy
- Energy is used to free electrons
- Charge can be collected
- Charge ~ gamma energy

Compton Scattering



- Electron deposits the energy
- Energy is used to free electrons
- Charge can be collected
- Charge $\sim$ deposited energy

< gamma energy

depends on the angle

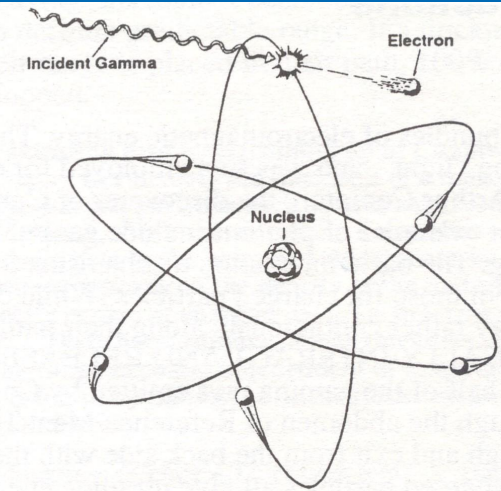
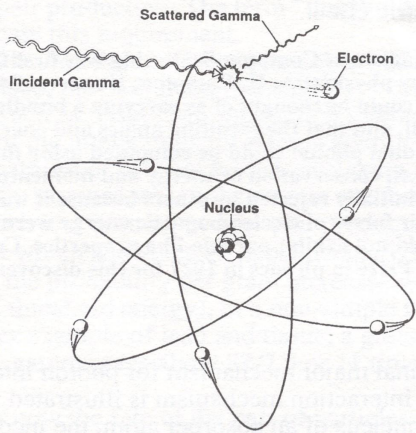
Idealized Gamma-Ray Spectrum

Counts
per
Energy
Interval

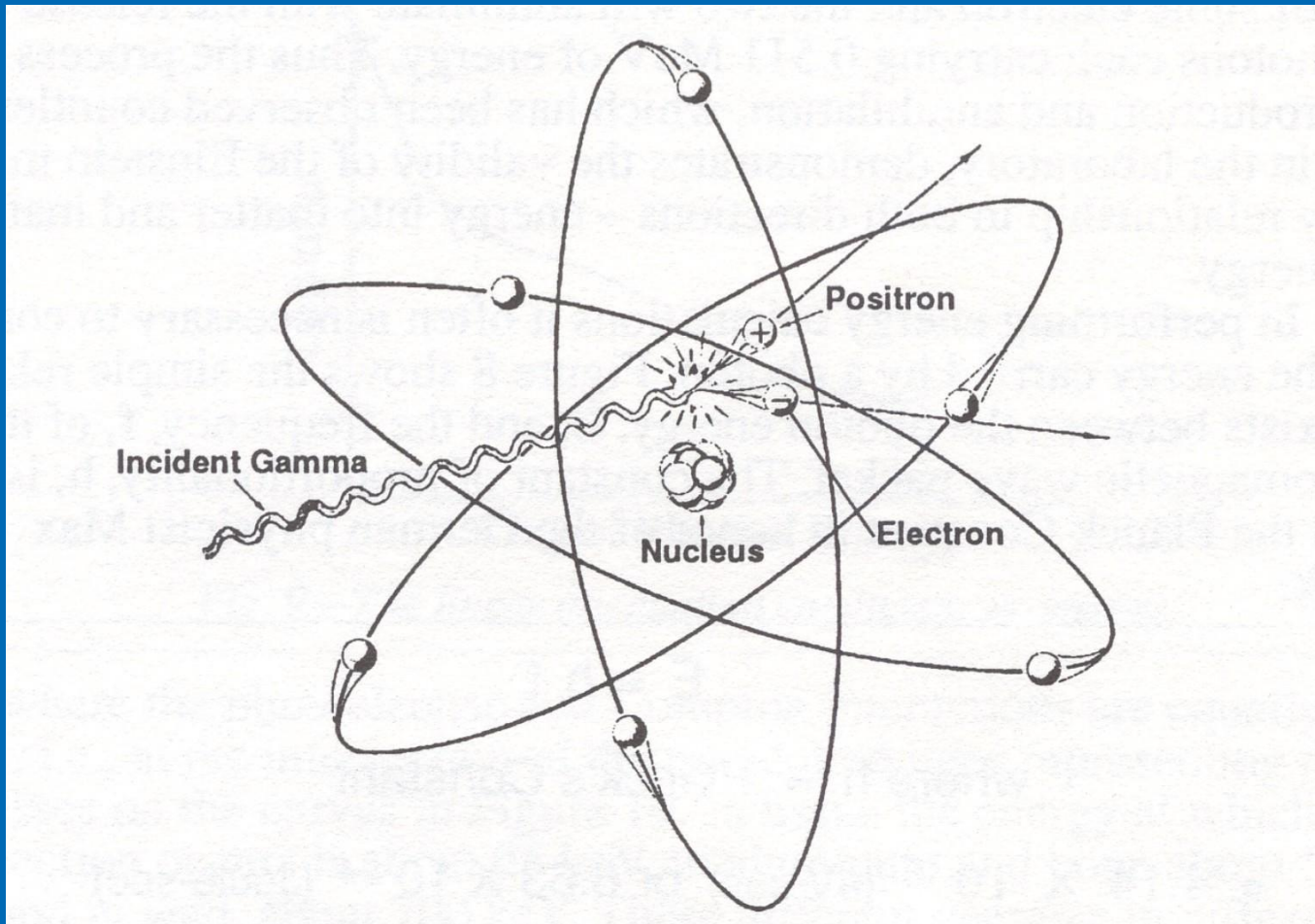
theoretical

Actual

Energy



Pair Production

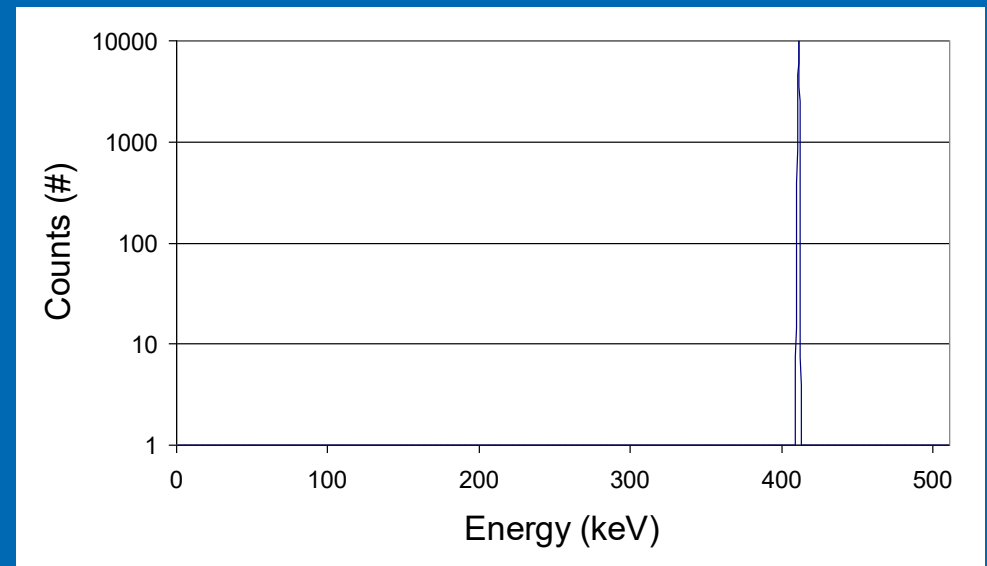
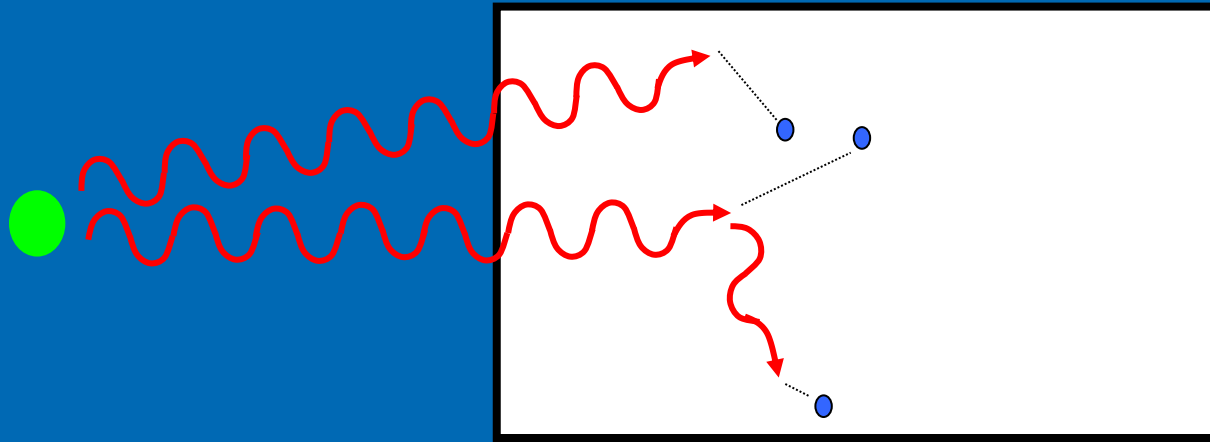


- Electron deposits the energy
- Positron quickly finds an electron
- They annihilate and produce 2 gammas

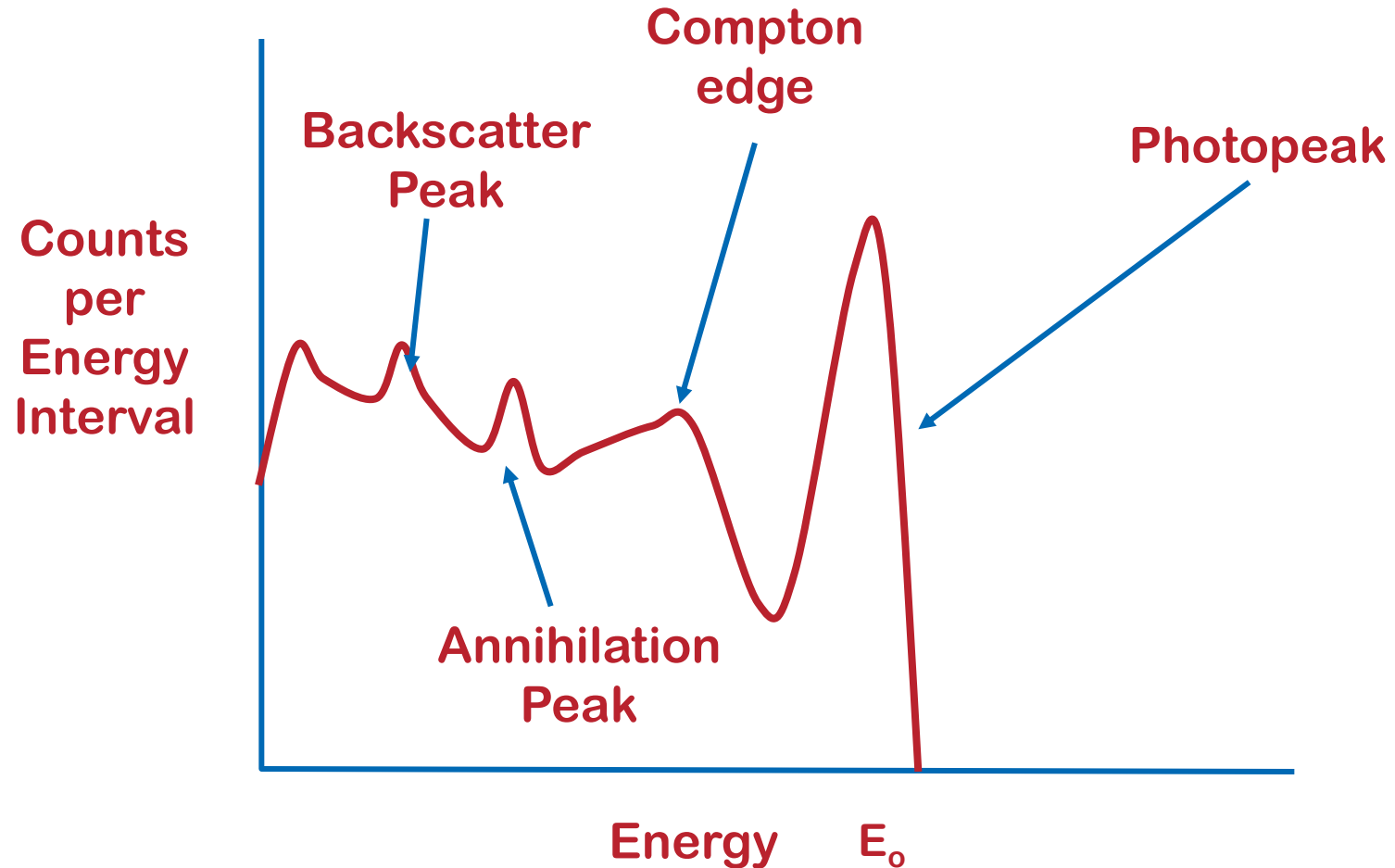


- The gammas can
 - ✓ be absorbed (full energy)
 - ✓ escape (511/1022 keV less deposited)
 - ✓ scatter (some energy less deposited)

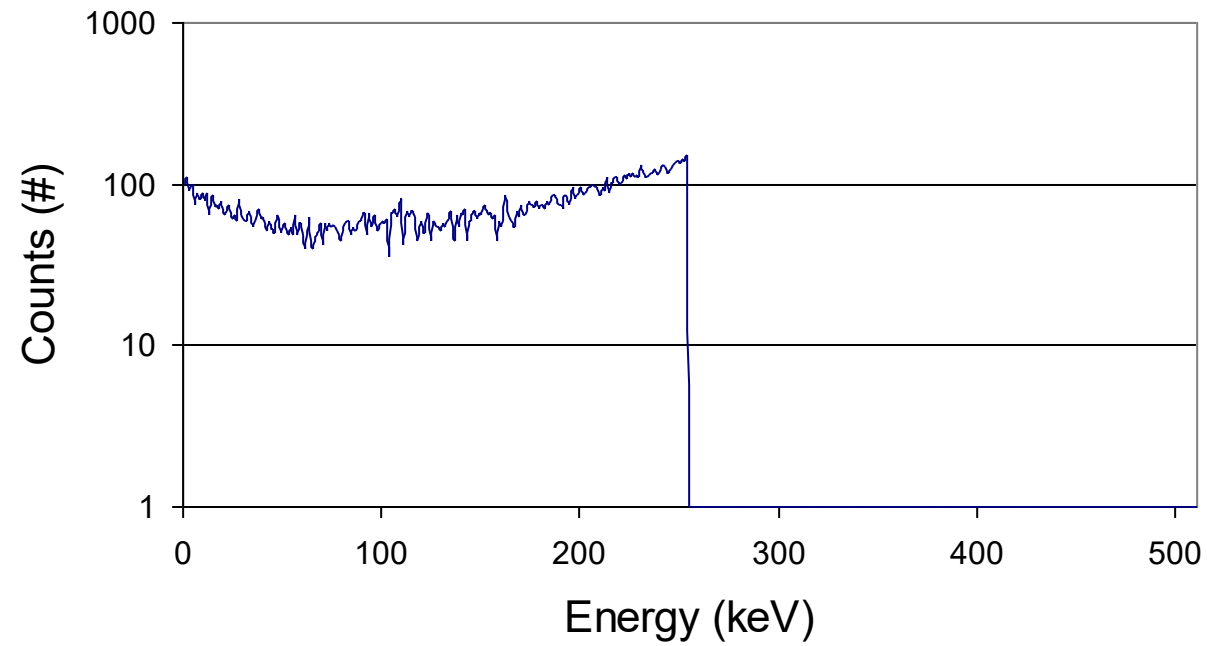
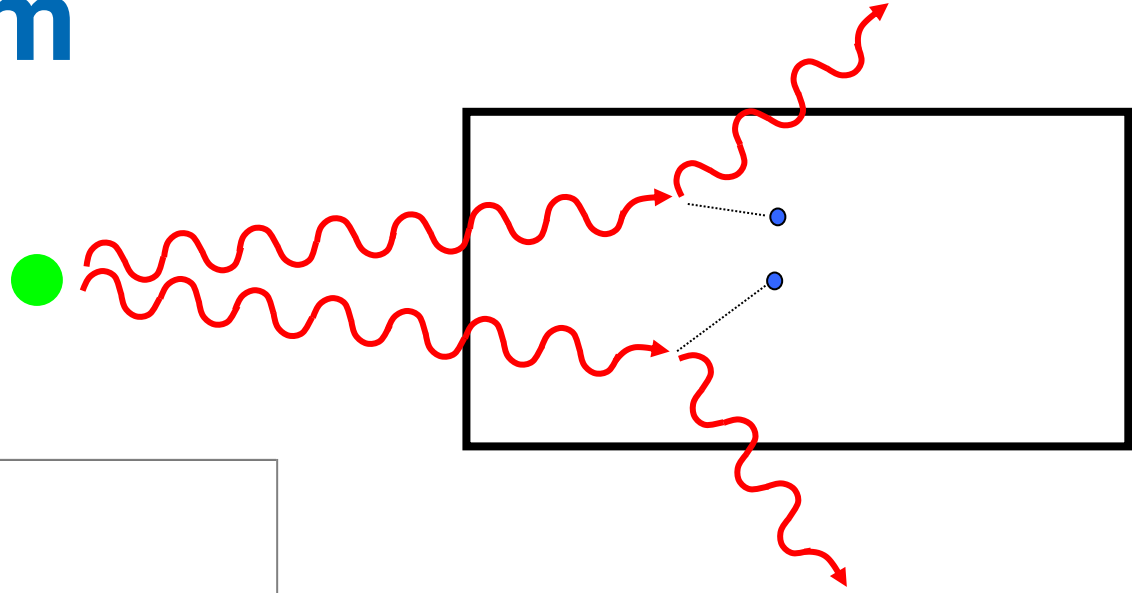
Photopeak - Total Absorption Peak



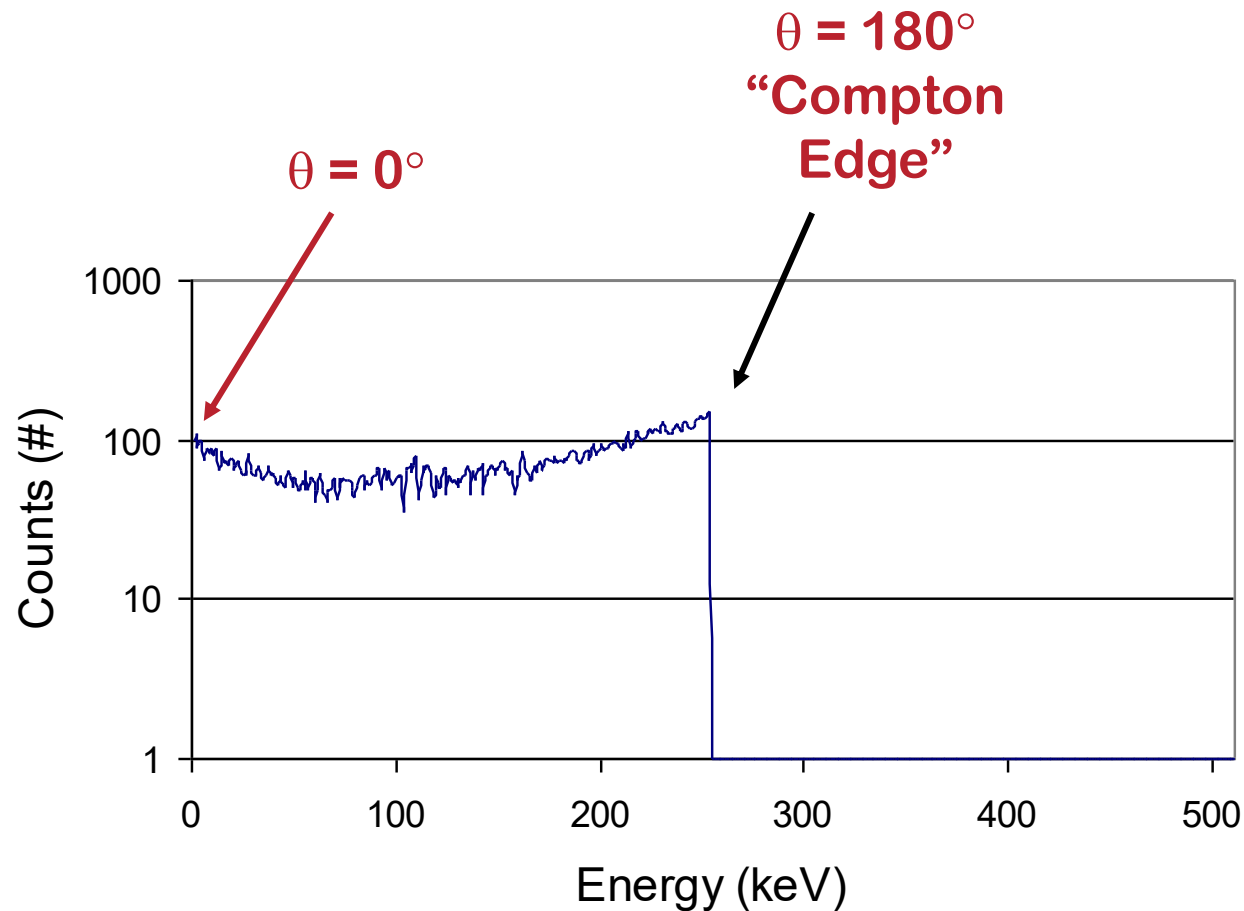
Components of Spectrum



Compton Continuum



Compton Basics



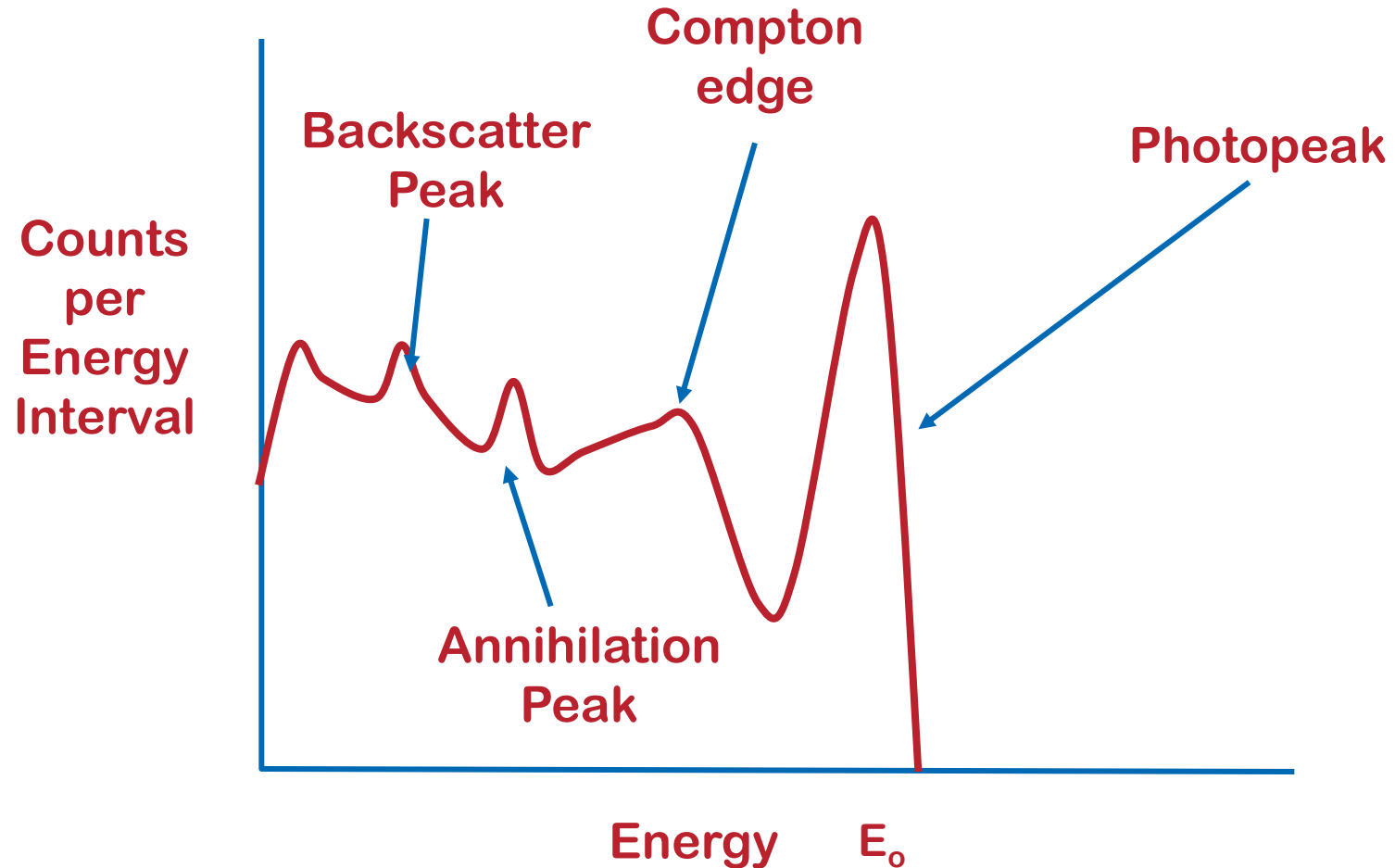
$$E_e = E_\gamma - \left[\frac{E_\gamma}{1 + \frac{E_\gamma}{511 \text{ keV}} (1 - \cos \theta)} \right]$$

$$E_{e_{\max}} = 411 \text{ keV} - \left[\frac{411 \text{ keV}}{1 + \frac{411 \text{ keV}}{511 \text{ keV}} (1 - \cos 180^\circ)} \right]$$

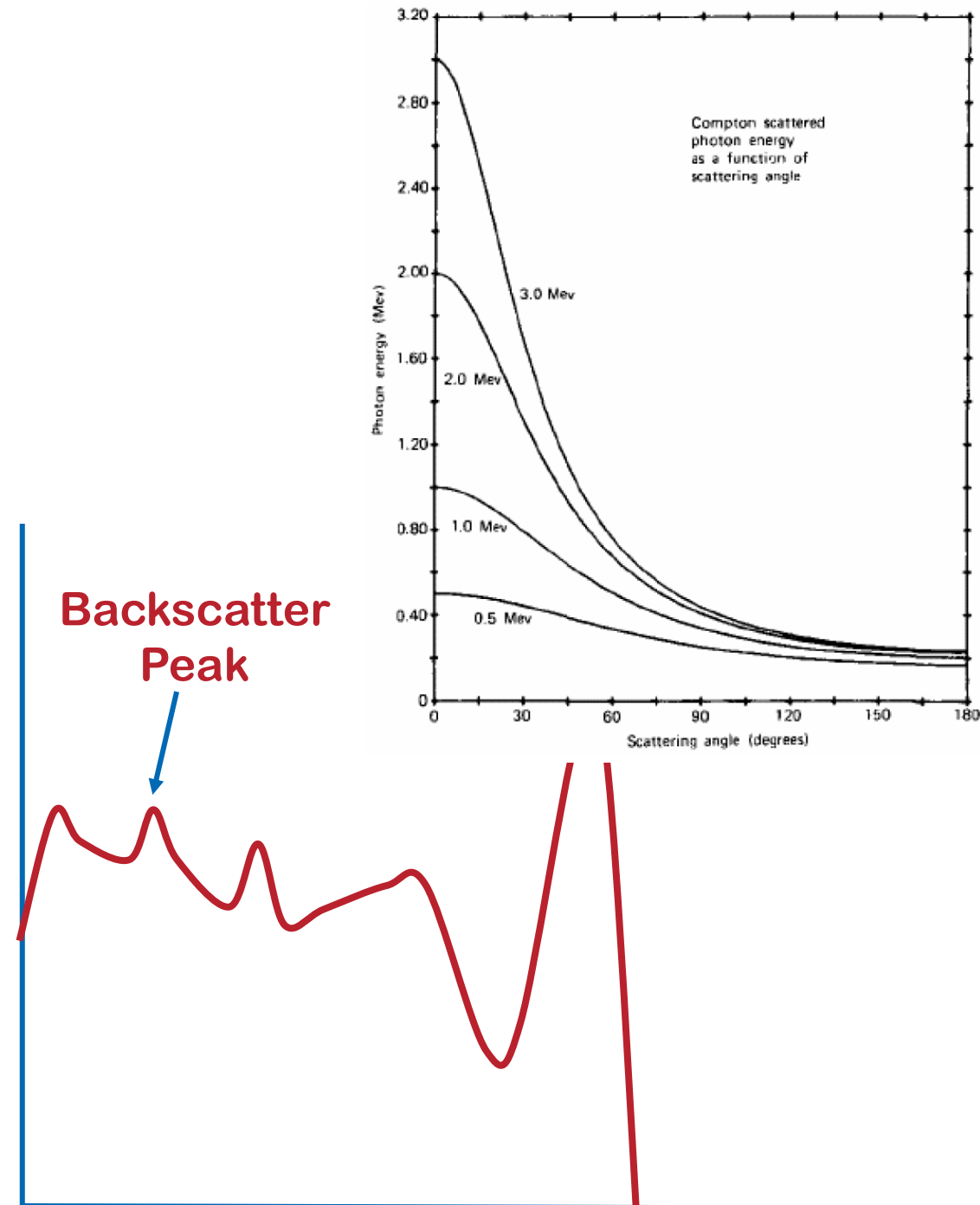
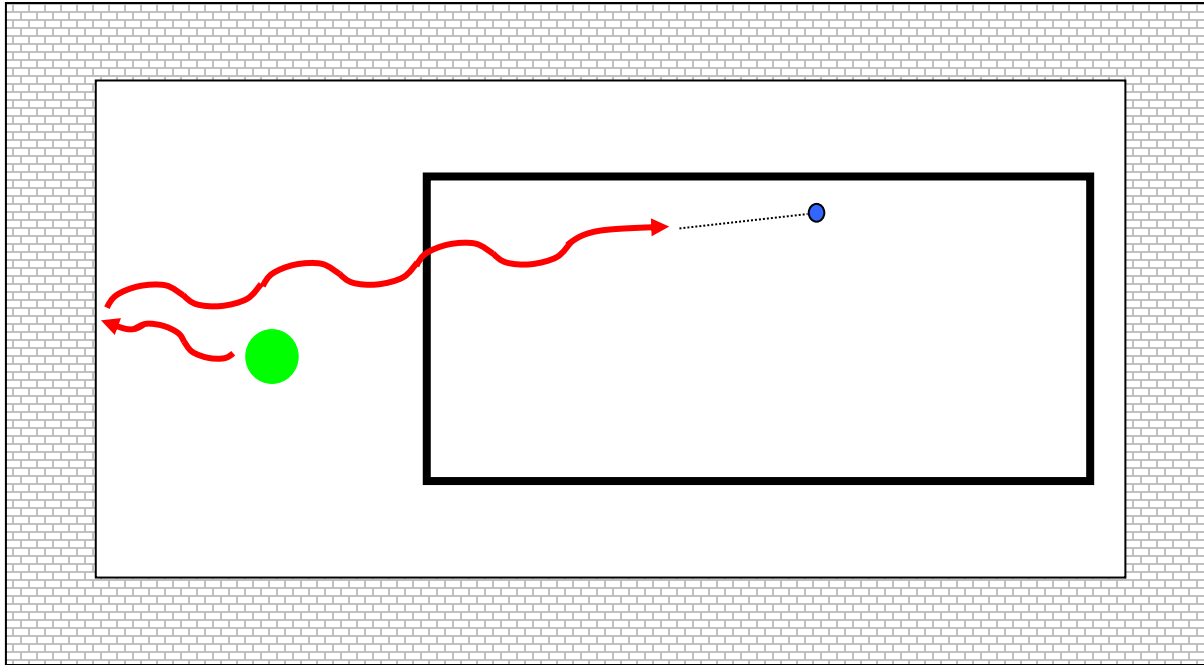
$$E_e = 254 \text{ keV at } \theta = 180^\circ$$

$$E_{e_{\min}} = 0 \text{ at } \theta = 0^\circ$$

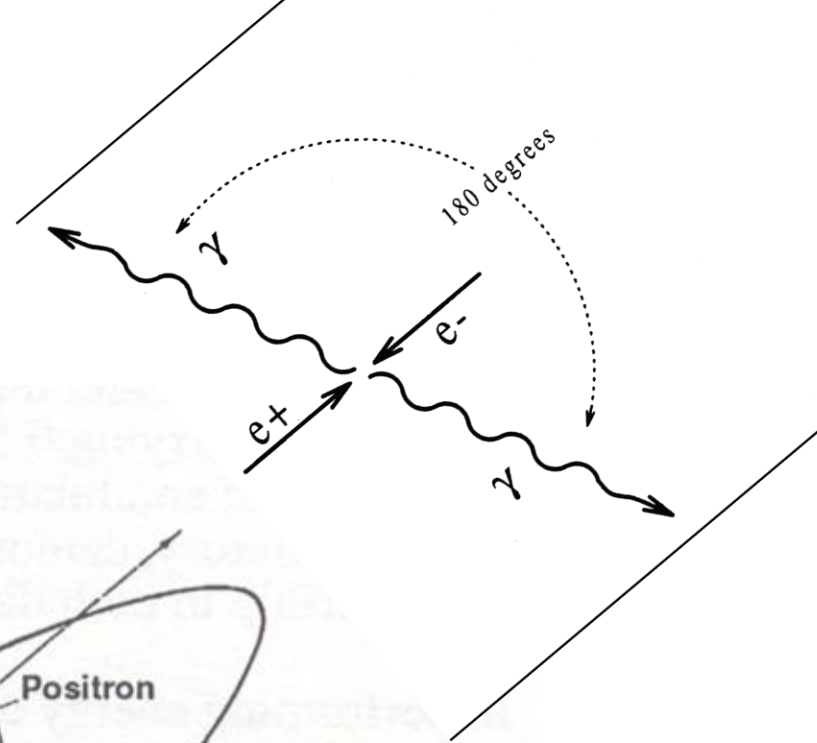
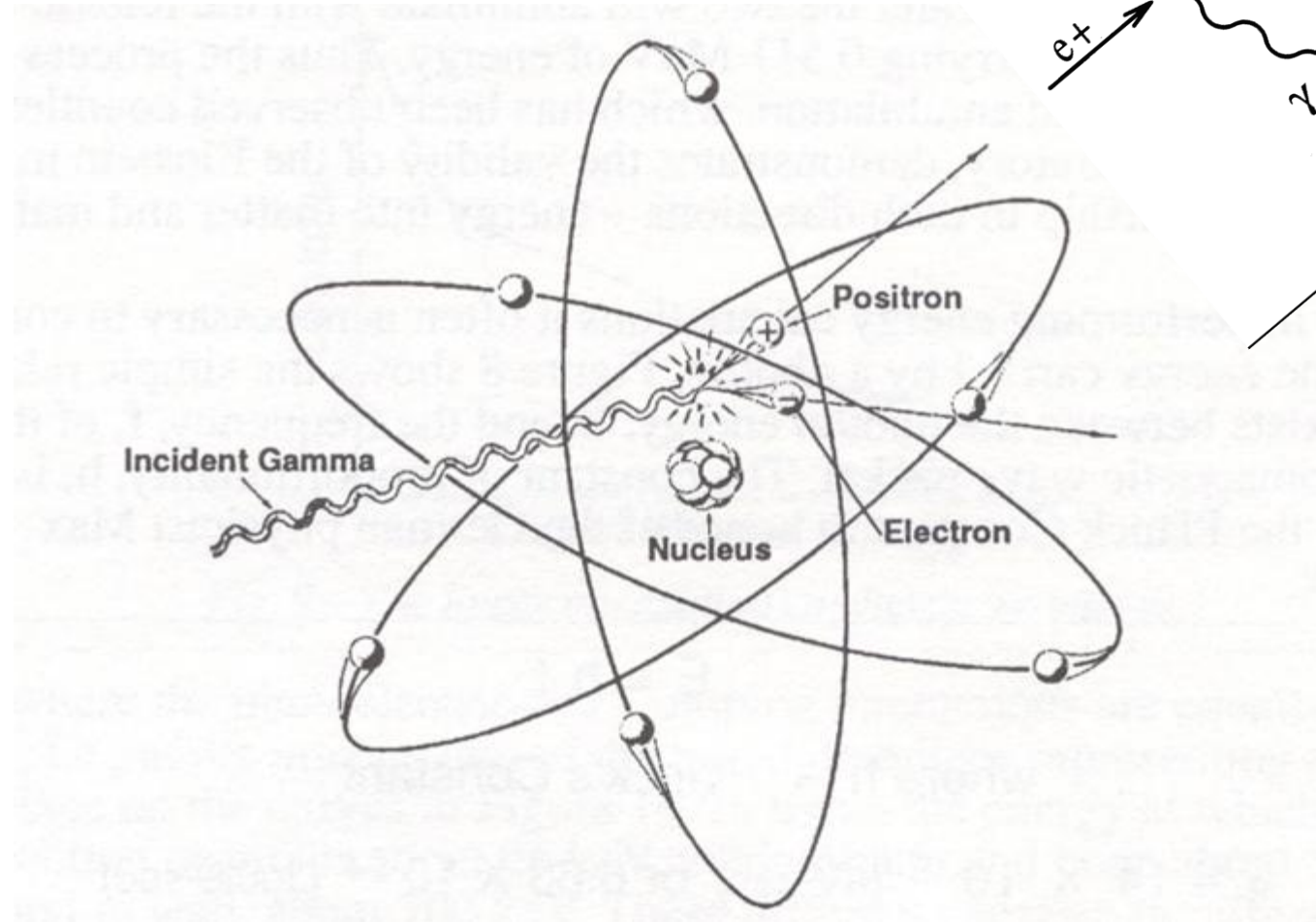
Components of Spectrum



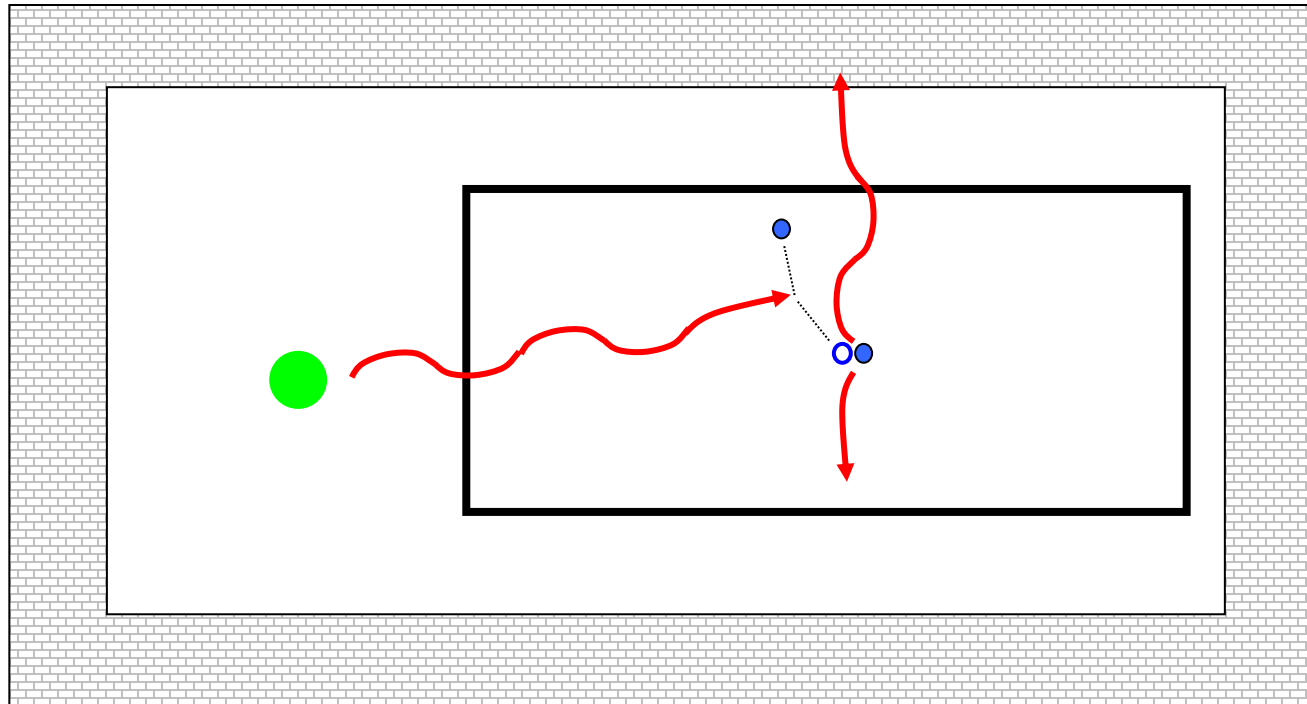
- Here we are looking at the scattered photon off the surrounding lead. The peak appears always at the same energy (~ 200 keV) from a photon scattered back at $\sim 180^\circ$.



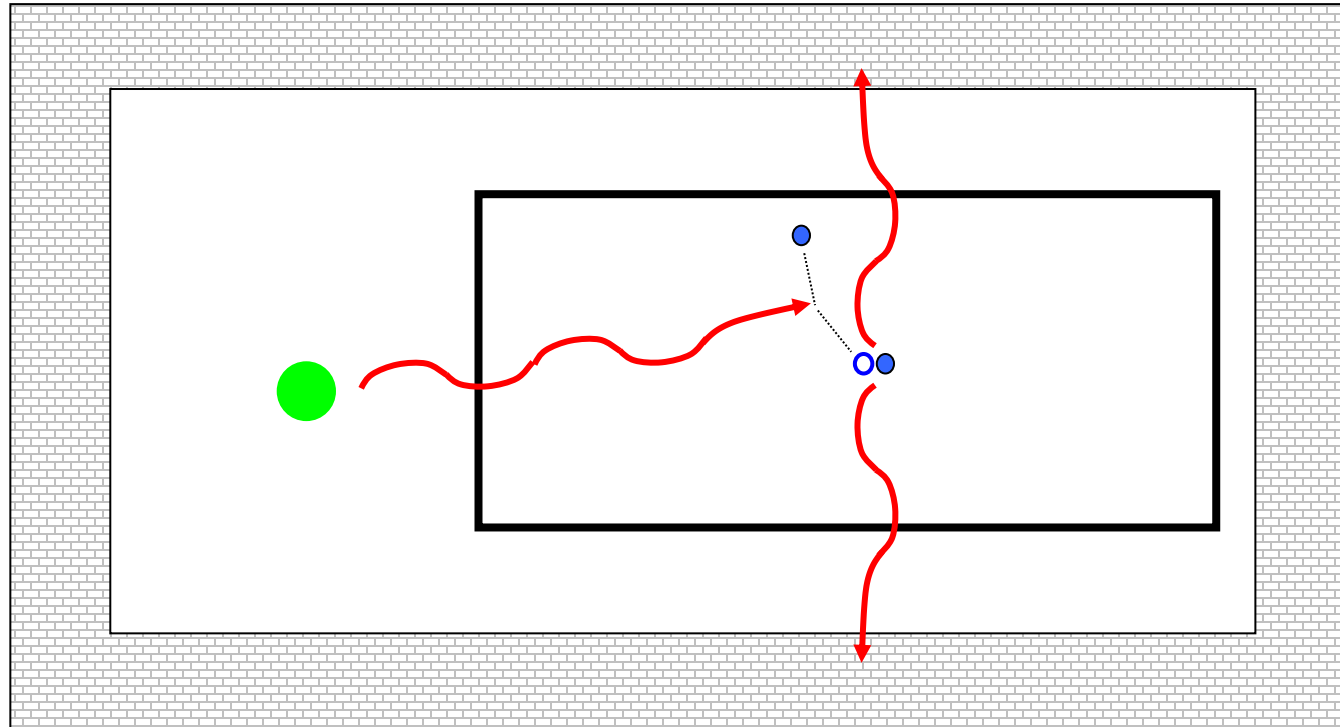
Pair Production



- Because the detector volume is finite, there is a possibility that one of the annihilation photons created from pair production events in the detector can escape.
- When this happens, a peak can be observed at an energy equal to the TAP - 511 keV.

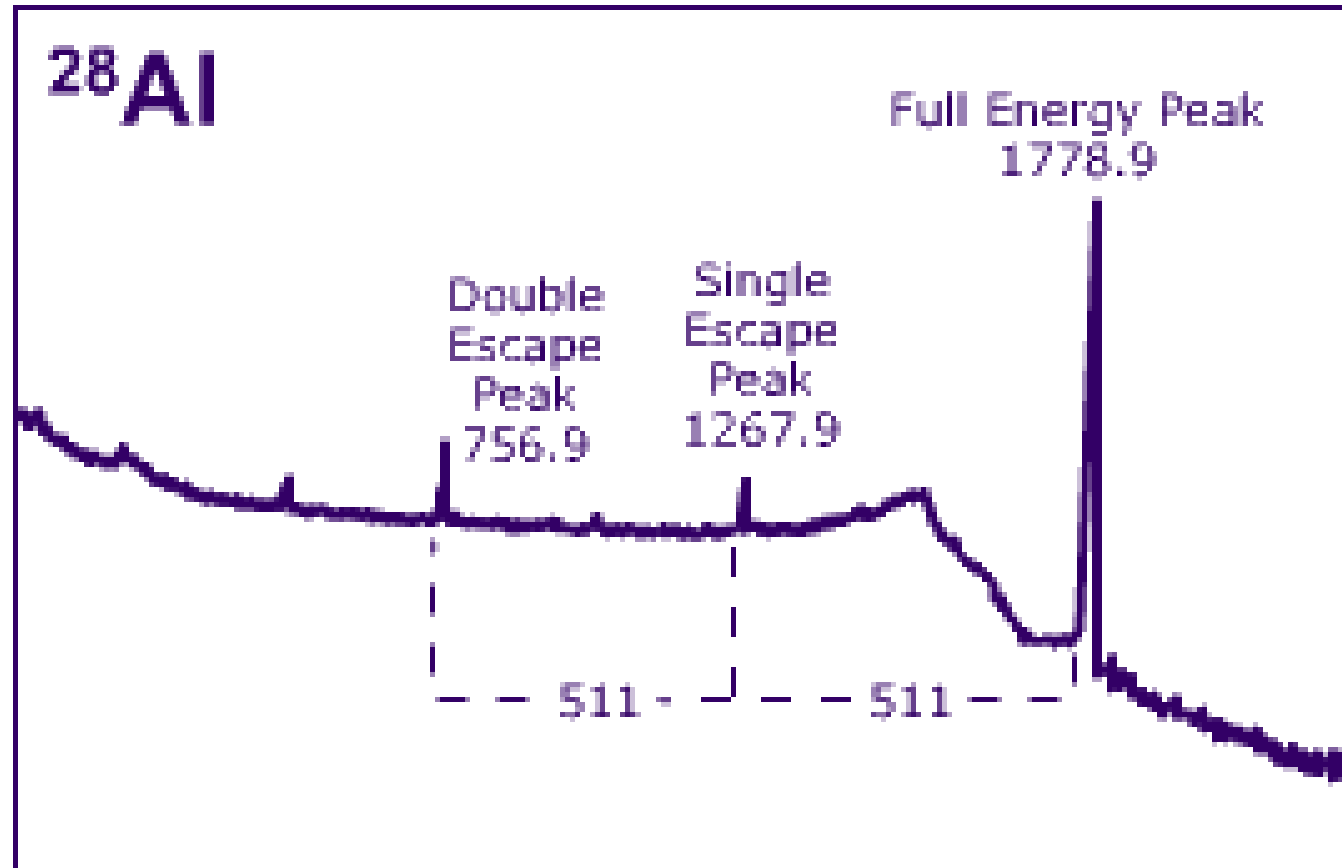


- If both annihilation photons exit the detector, then a peak can be observed at TAP – 1022 keV.



Escape Peaks

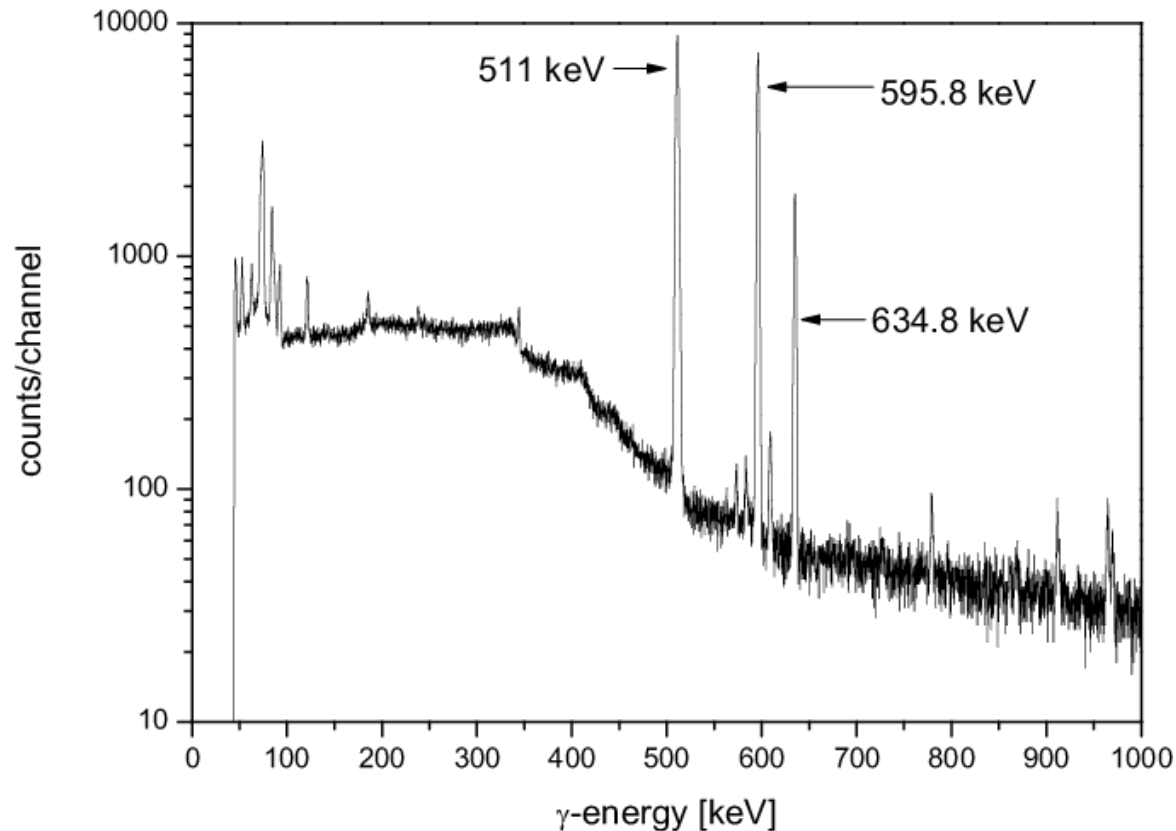
Counts per channel (log scale)



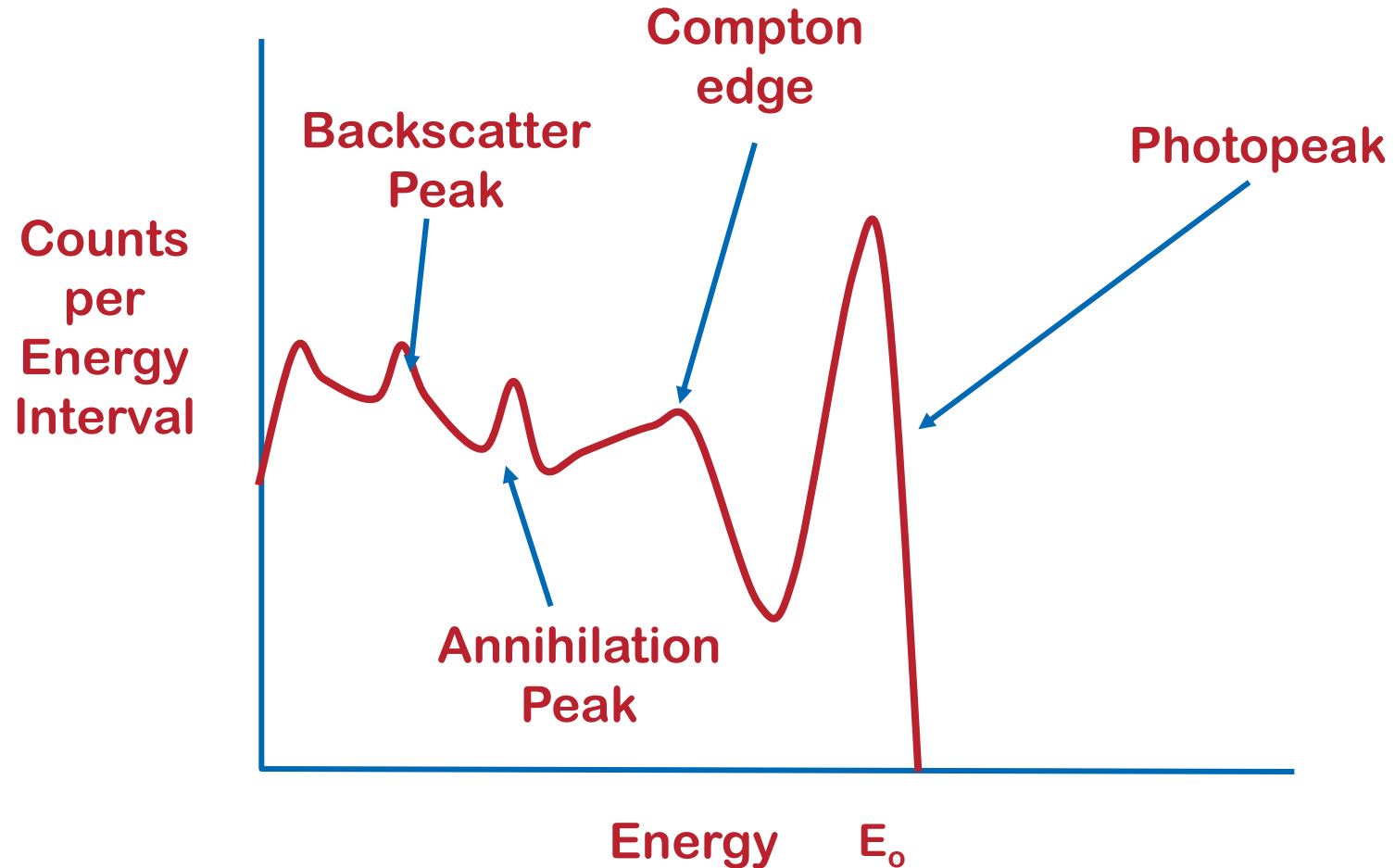
Channel number (Energy)

Annihilation Peak

- pair production event occurs in the surrounding shielding material
- one of the two annihilation photons will deposit energy into the detector
- an *annihilation peak* can be observed at 511 keV.



Components of Spectrum





IAEA

