CYCLOTRON INSTITUTE
Texas A&M University

Energy & Efficiency Calibration for HpGe Detector Using Standard Sources

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Classification of radiations

Type	Radiation	Penetrability
charged particles	• heavy (alpha) • light (beta)	range ~10^{-5} m range ~10^{-3} m
uncharged radiation	• EM (gamma, X) • neutrons	$d_{1/2}$ ~0.1 m $d_{1/2}$ ~0.1 m

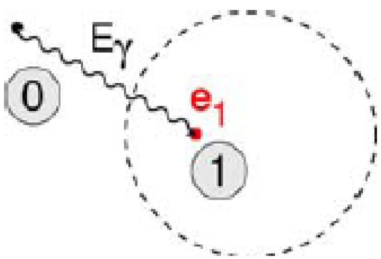
Gamma rays (denoted as γ) are:

electromagnetic radiation of high energy. They are produced by sub-atomic particle interactions, such as electron-positron annihilation, neutral pion decay, radioactive decay, fusion, fission or inverse Compton scattering in astrophysical processes. Gamma rays typically have frequencies above 10^{19} Hz and therefore energies above 100 keV and wavelength less than 10 picometers

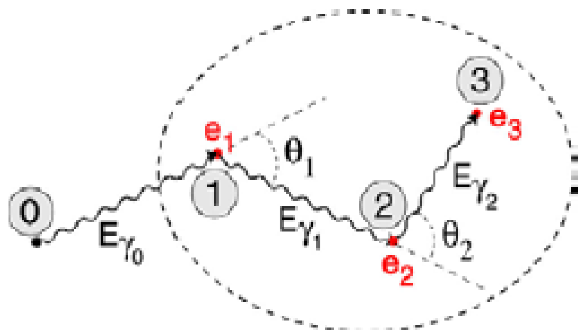
Gamma ray interactions with matter

~ 100 keV | ~1 MeV | ~ 10 MeV | γ-ray energy

Photoelectric



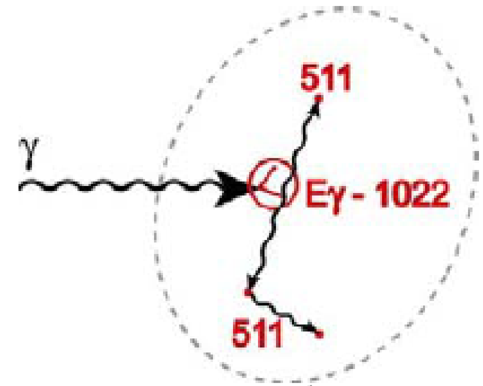
Compton Scattering



Angle/Energy

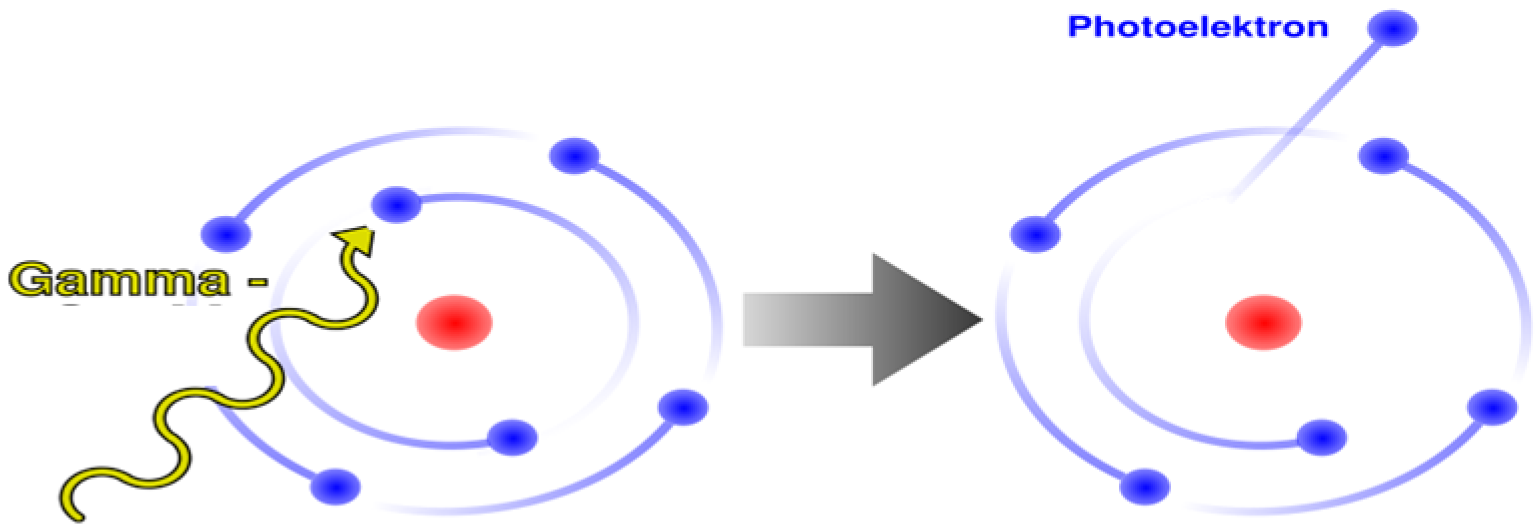
$$E_{\gamma'} = \frac{E_\gamma}{1 + \frac{E_\gamma}{m_0 c^2}(1 - \cos\theta)}$$

Pair Production



$$E_{1st} = E_\gamma - 2\,mc^2$$

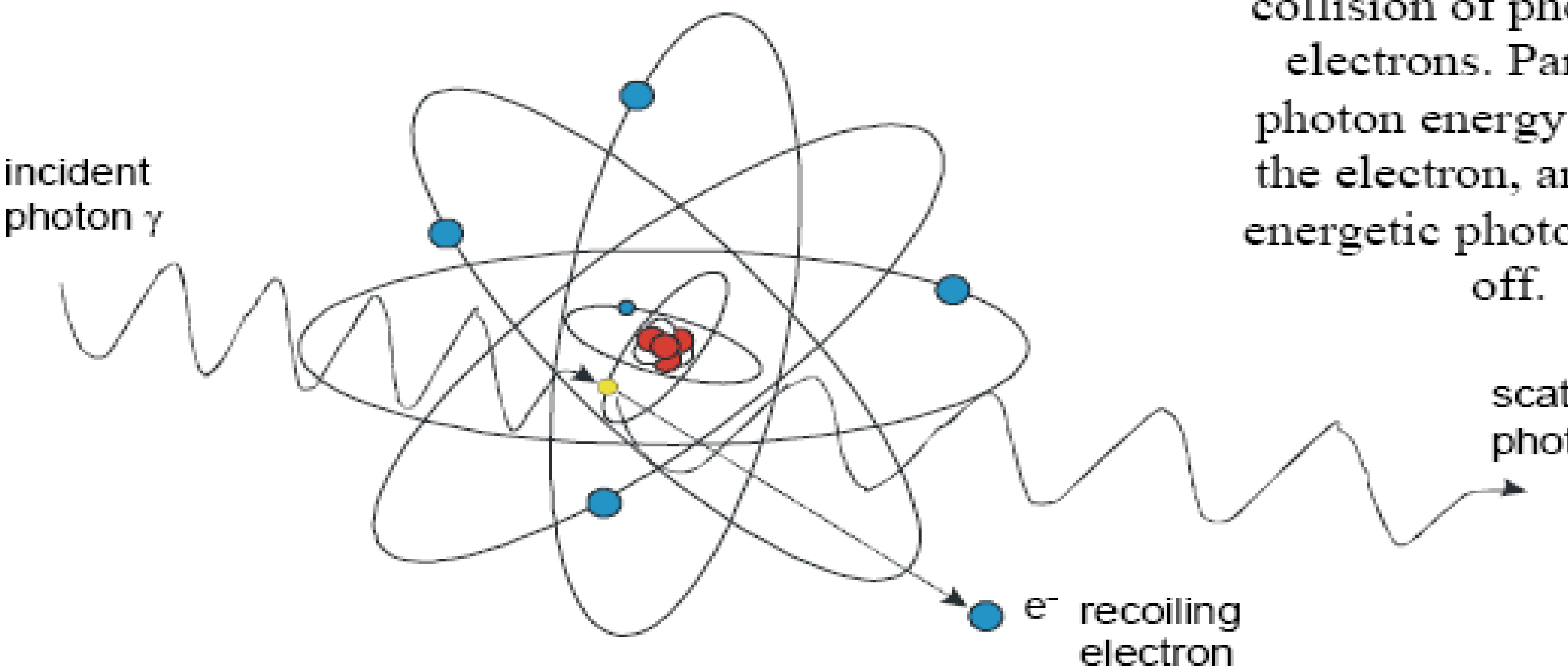
Gamma rays: Photoelectric Effect:



- This describes the case in which a gamma photon interacts with and transfers all of its energy to an orbital electron, ejecting that electron from the atom.
- The kinetic energy of the resulting photoelectron is equal to the energy of the incident gamma photon minus the binding energy of the electron. $E_e = E_\gamma - E_b$
- The photoelectric effect is thought to be the dominant energy transfer mechanism for x-ray and gamma ray photons with energies below 50 keV, but it is much less important at higher energies.

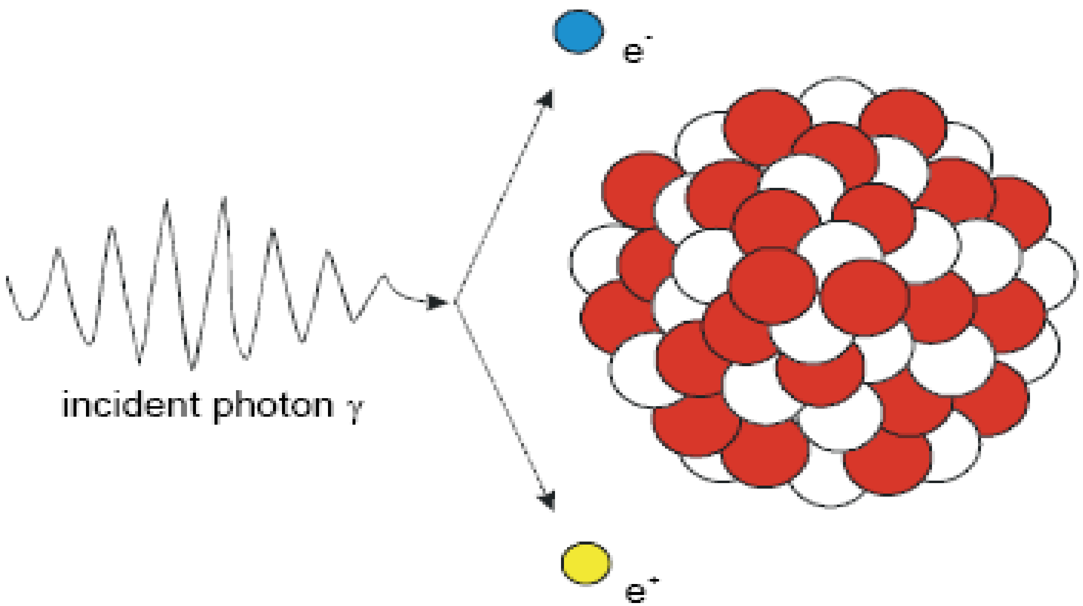
Gamma rays: Compton scattering

The **Compton effect** is equivalent to inelastic collision of photon with electrons. Part of the photon energy is lost to the electron, and a less-energetic photon bounce off.



Note: scattering – not absorption!

Gamma rays: Pair production

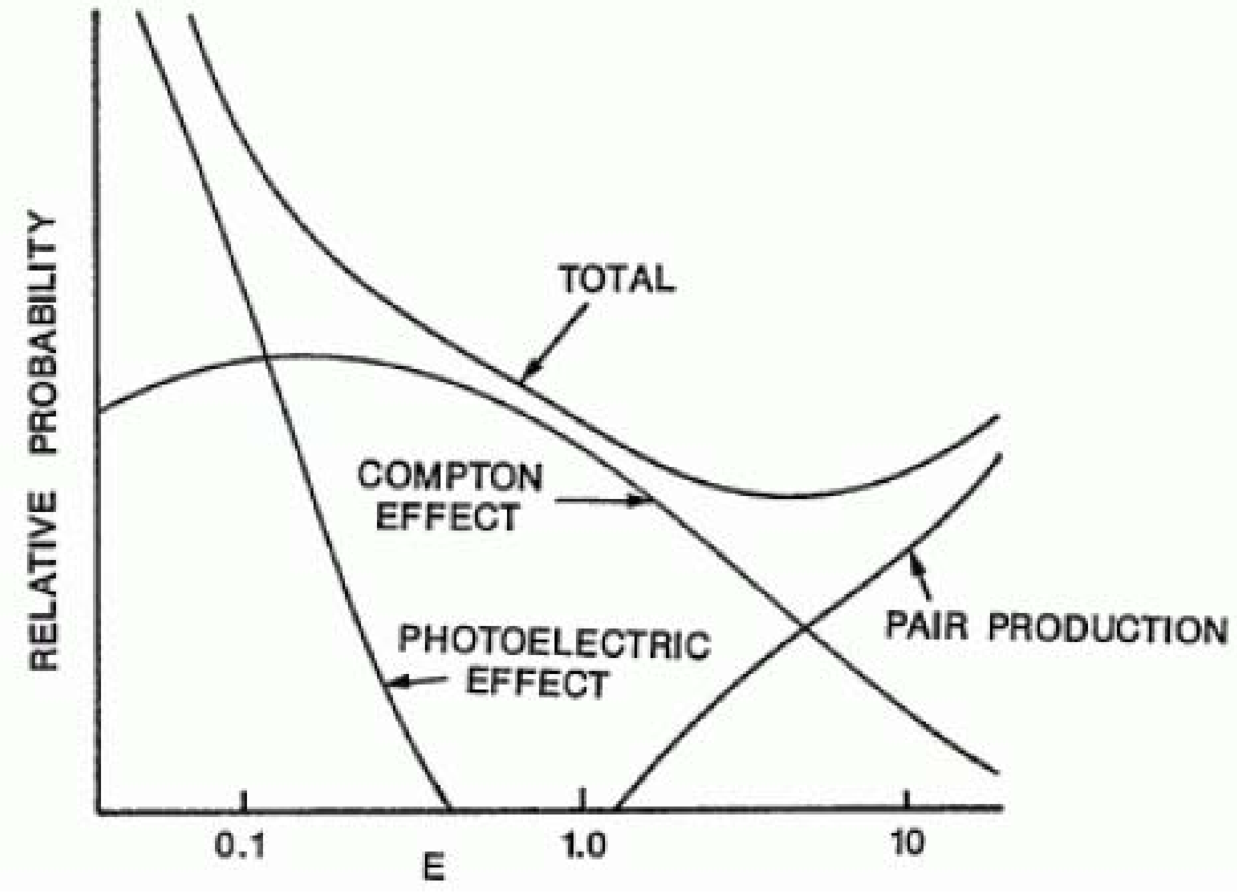


At the vicinity of an atom, a photon with energy greater than 1.02 MeV creates a positron-electron pair, and such a process is called **pair production**. Pair production also occurs in the field of an atomic electron, especially for photons with energy of more than 2.04 MeV. Pair production is not exactly the reverse of annihilation, because the former involves only one phobton, and two photons are emitted in annihilation. Note that the two electrons produced, e- and e+, are not scattered orbital electrons, but are created, *de novo*, in the energy/mass conversion of the disappearing photon.

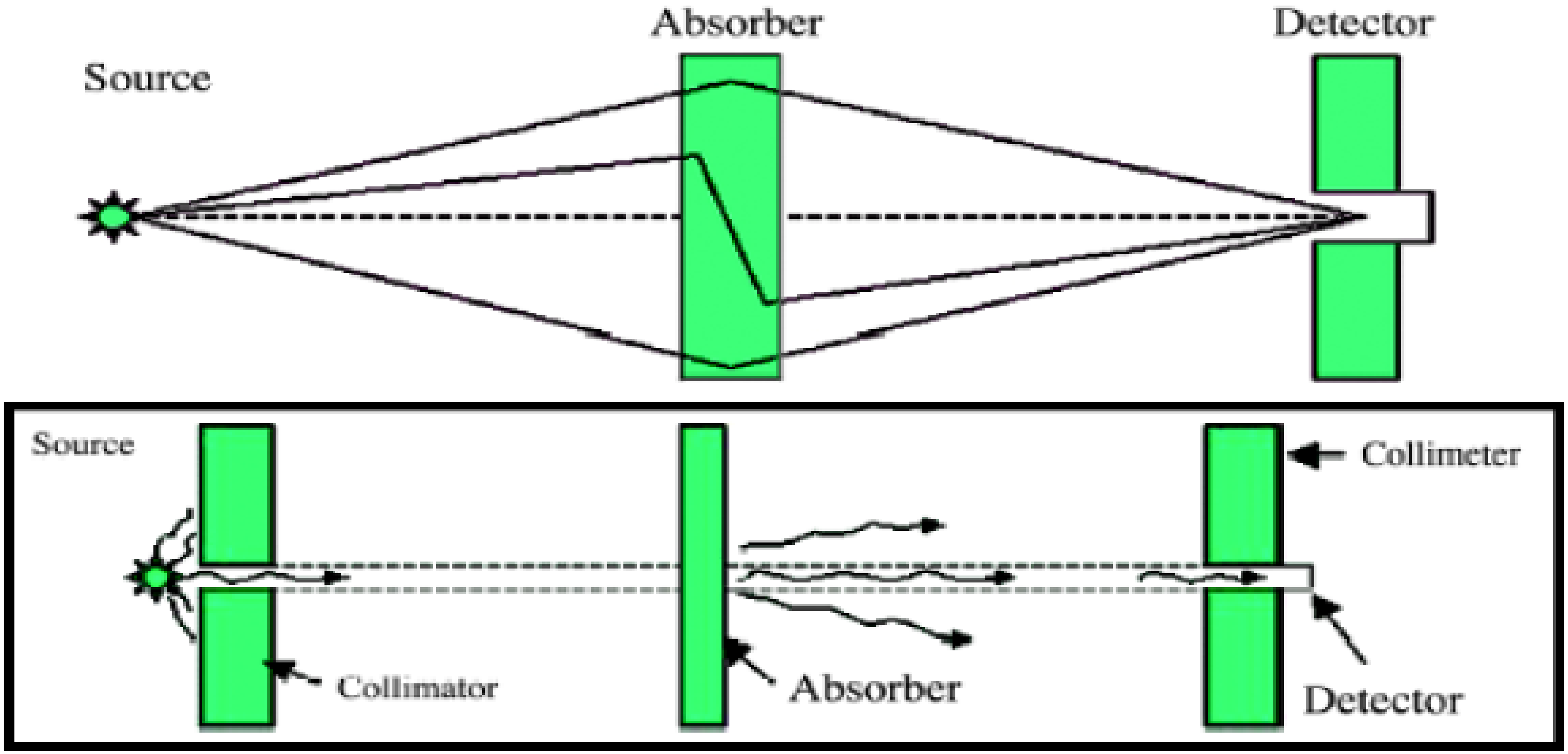
Positron annihilation:

$$e^+ + e^- \rightarrow 2\,\gamma \text{ (511 keV)}$$

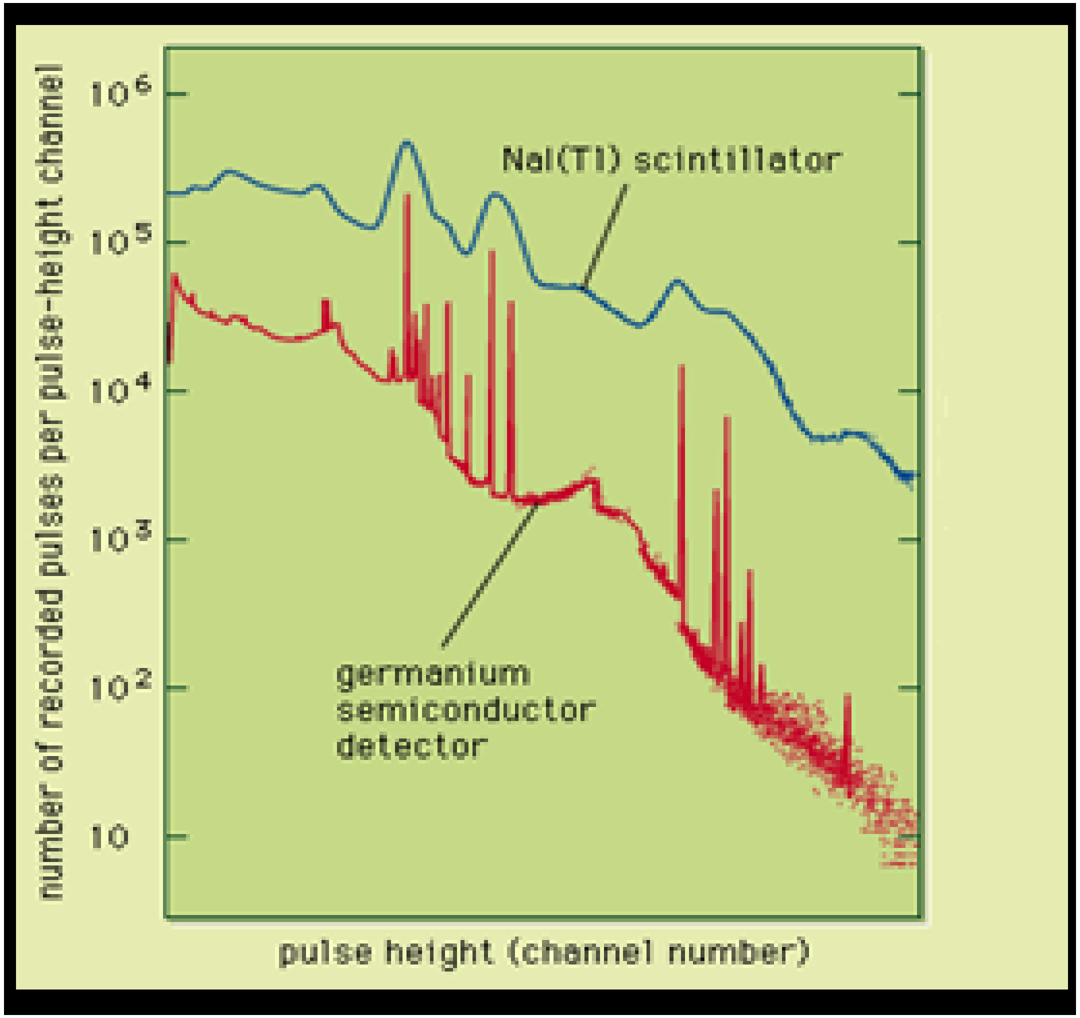
Relative probabilty of each of the three types of gamma interactions with matter as a function of energy.



Attenuation & absorption of gamma radiation



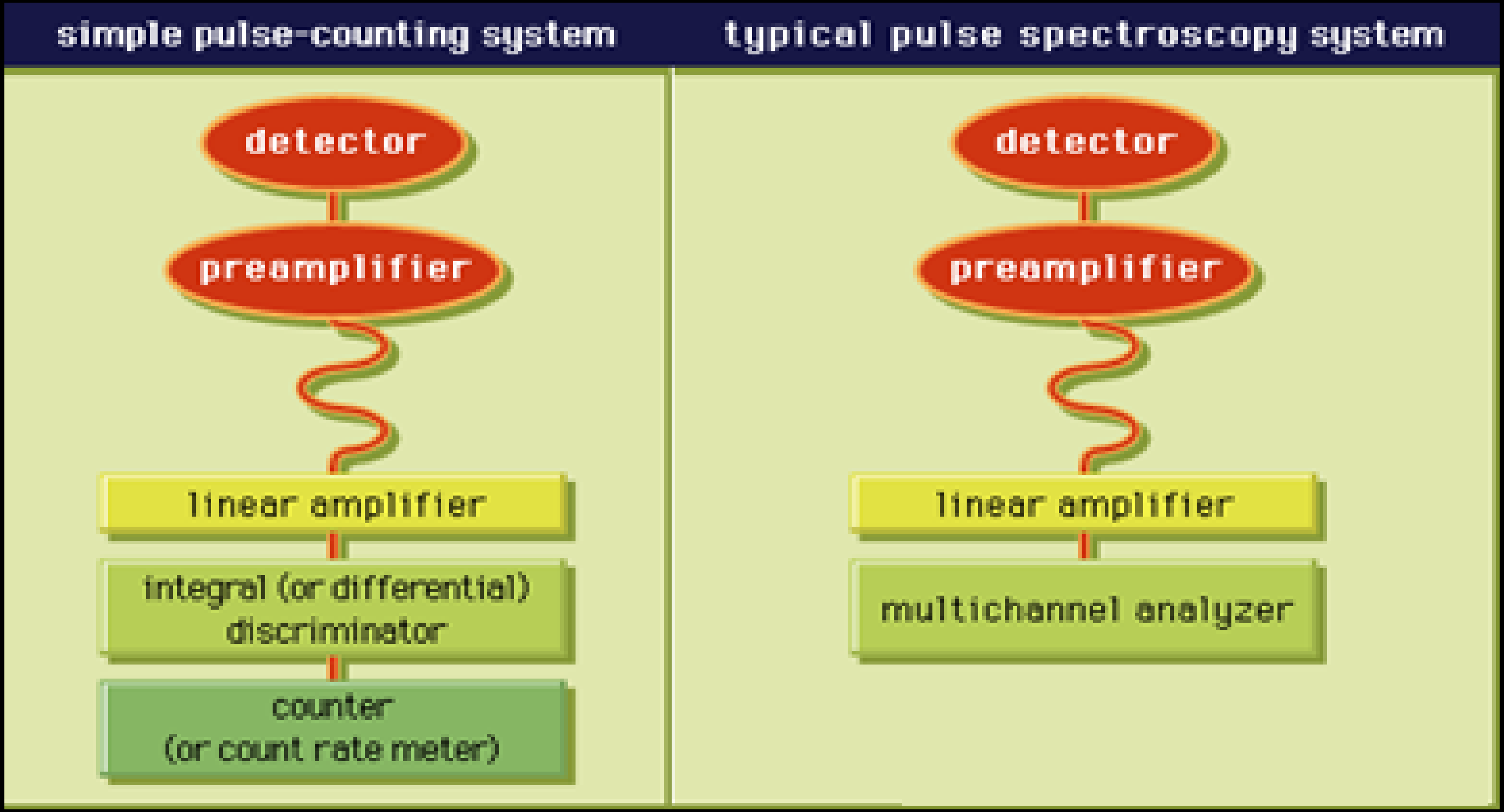
Comparison between the energy resolution for germanium detectors and NaI(TI) Scintailator



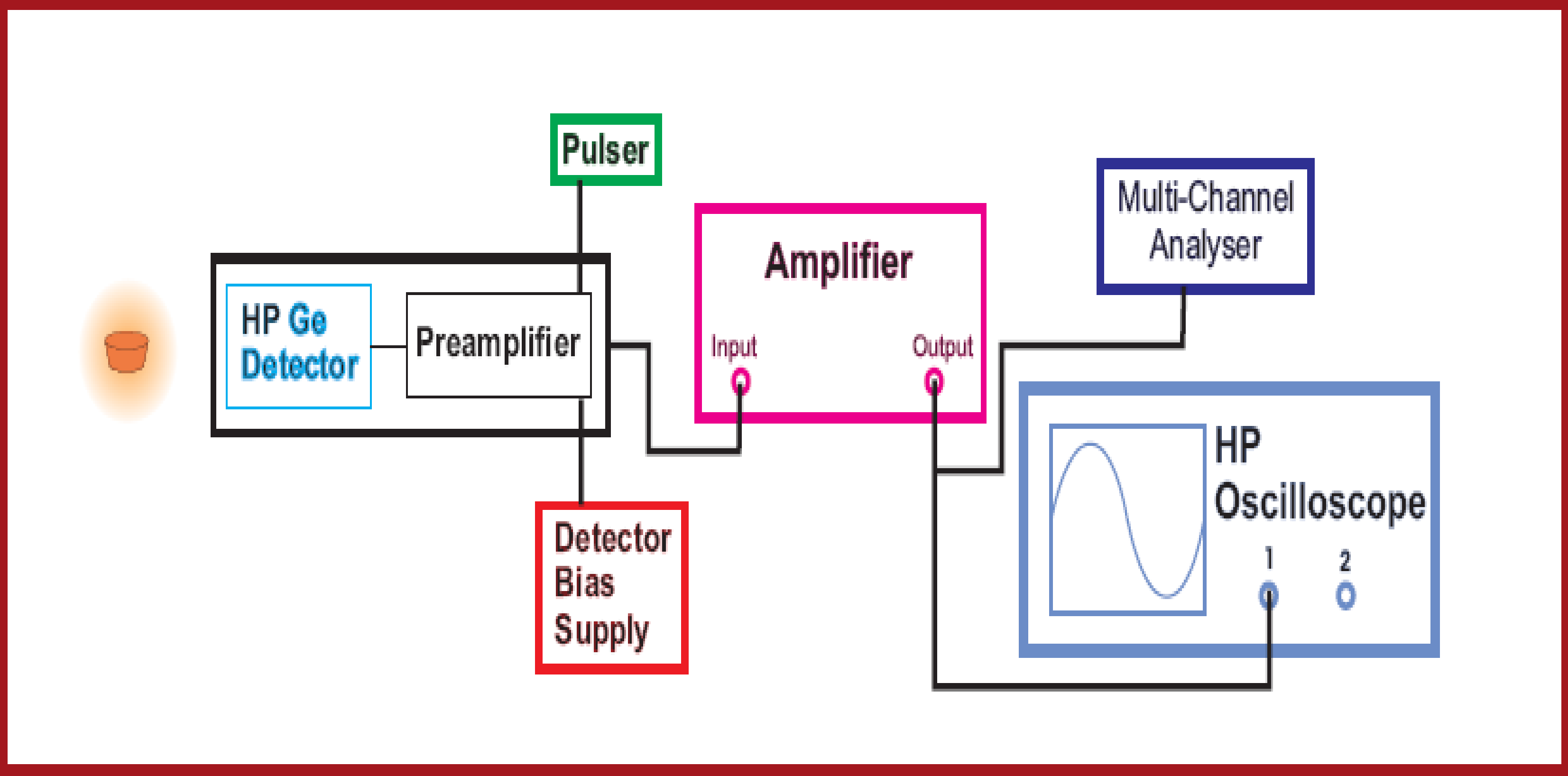
- The top spectrum is from a scintillation detector.
- The bottom is from a germanium semiconductor detector.

The superior energy resolution of the germanium is evident from the much narrower peaks, allowing separation of gamma-ray energies that are unresolved in the scintillator spectrum.

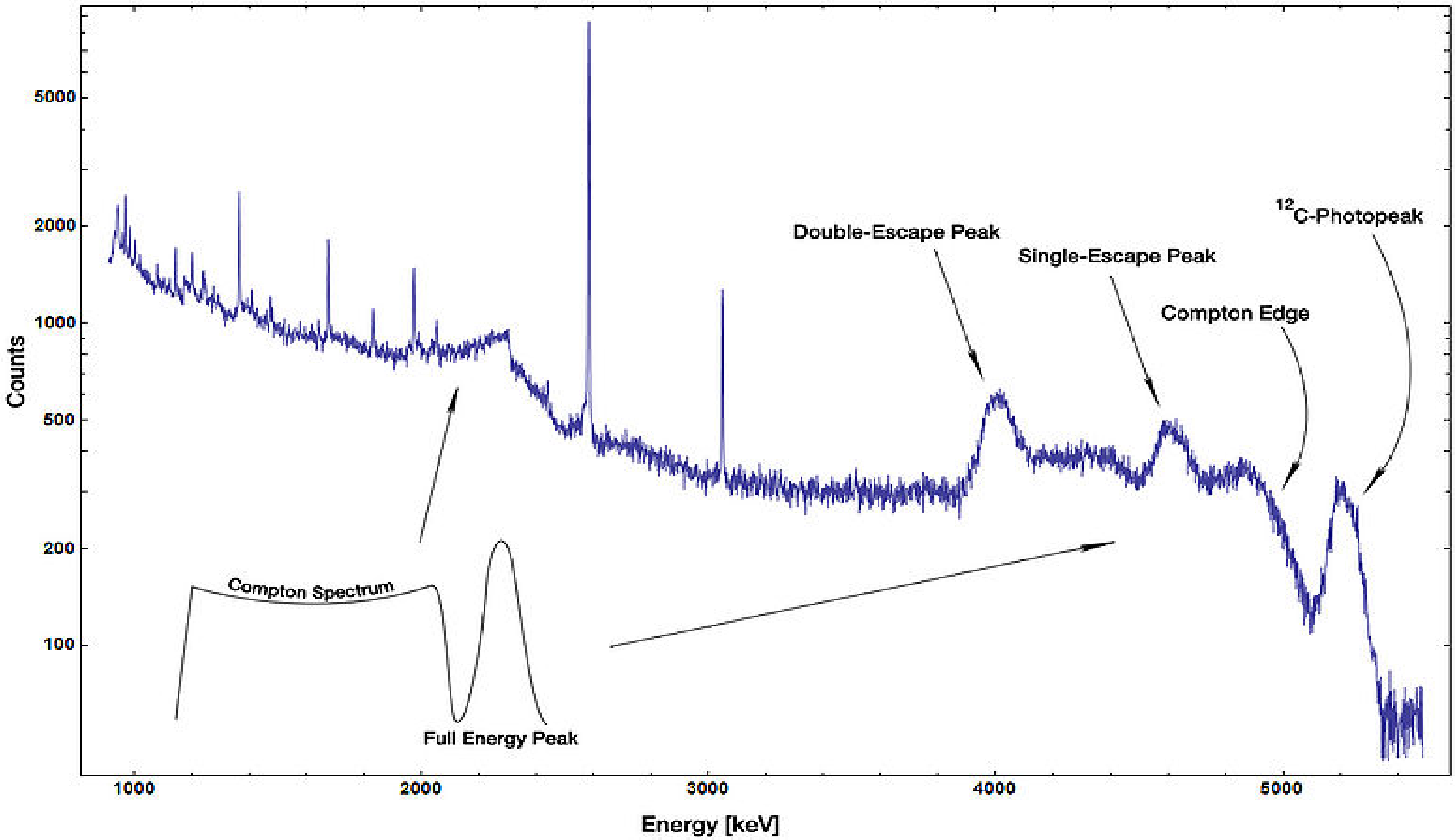
Apparatus for counting system



Electronics block diagram for high resolution germanium detection system



Example for gamma ray spectrum obtained by High purity germanium detector



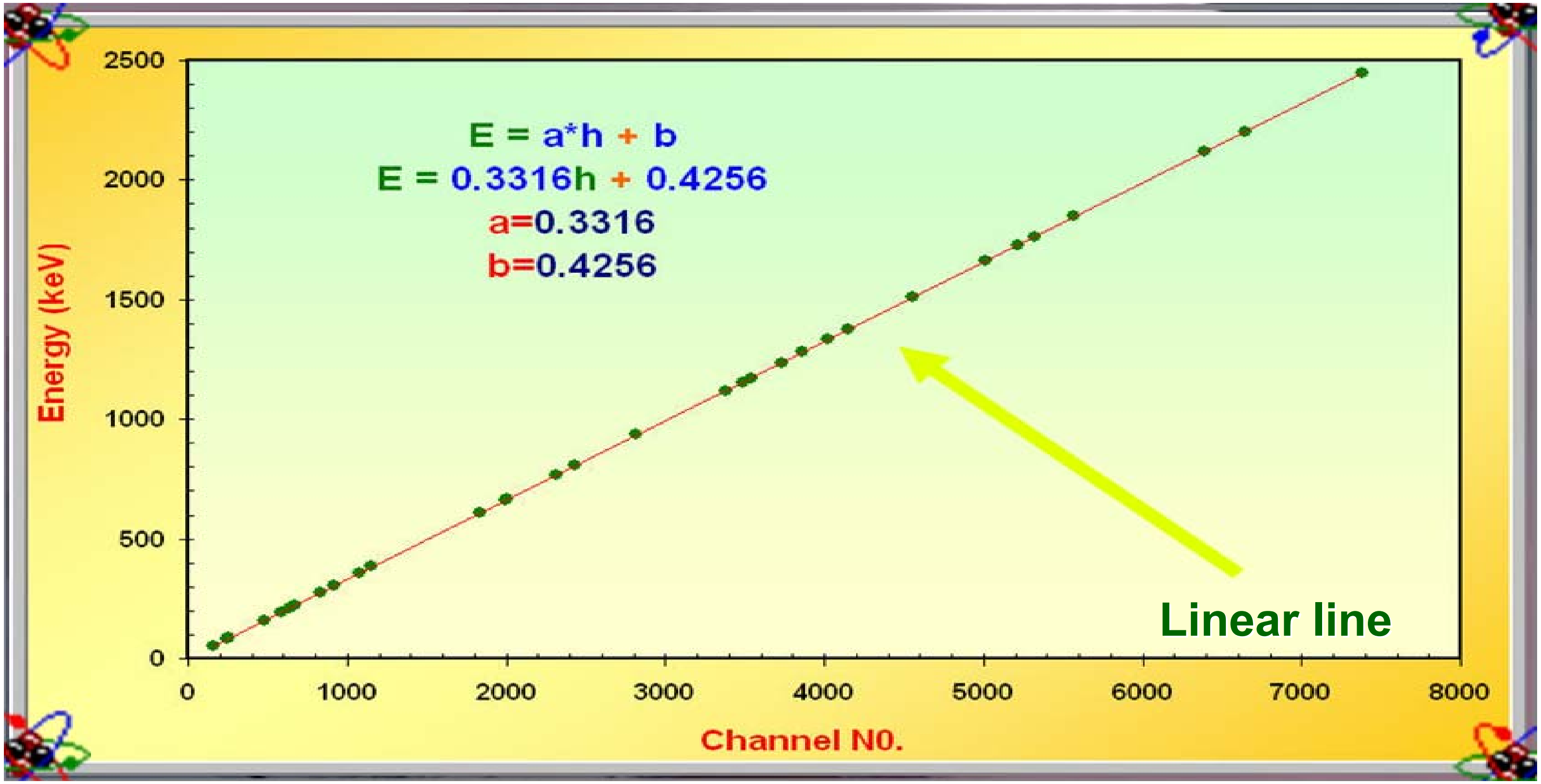
The detector Energy and efficiency calibration can be found by:

Counting a standard source of known activity by the detector. Such as ^{60}Co, ^{137}Cs and ^{152}Eu.

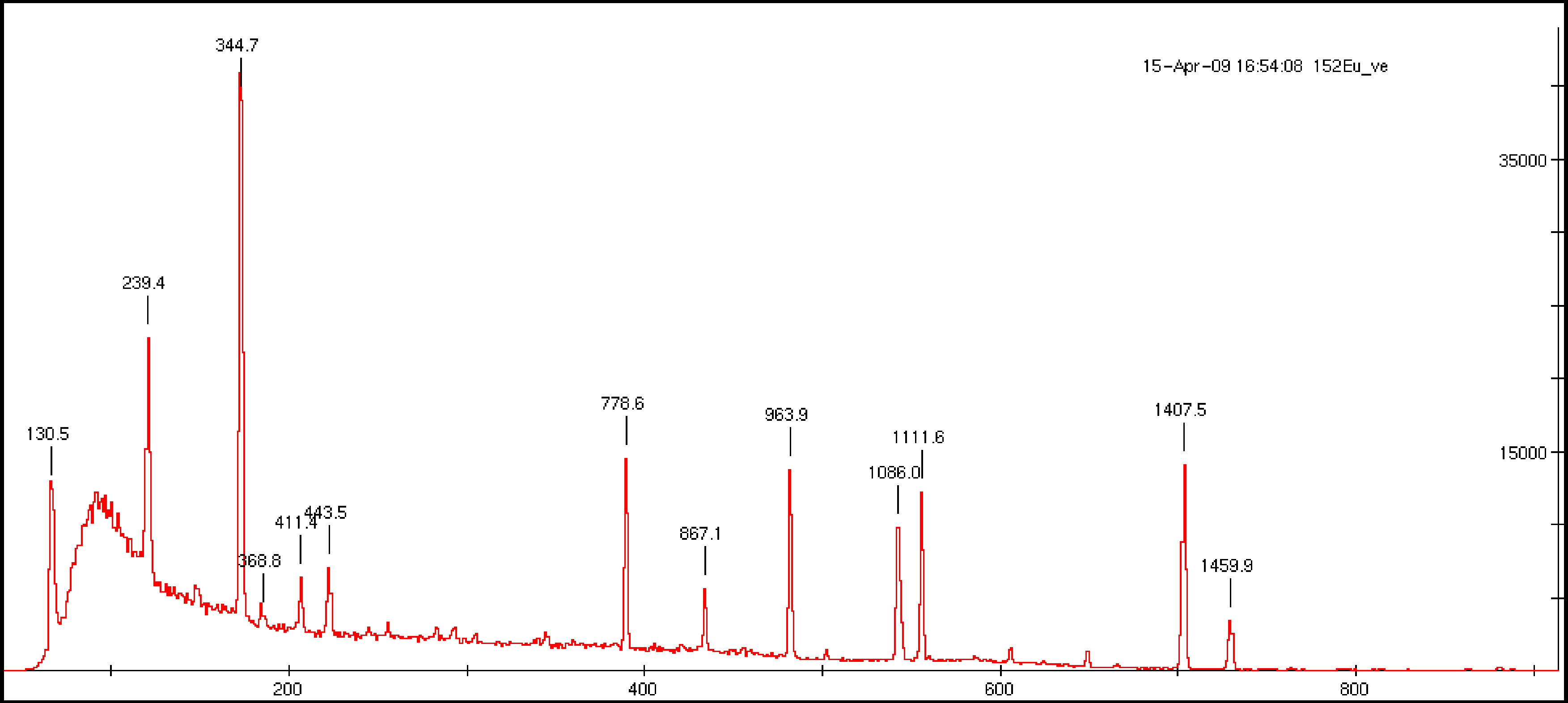
Standard Radioactive isotope	$T_{1/2}$	γ-line energies (keV)	γ-line intensities Iγ%	Channel number
^{60}Co	5.2714 y	1173.228	99.857	
		1332.490	99.983	
^{137}Cs	30.07 y	661.657	85.10	
^{152}Eu	13.542 y	121.7817	28.37	
		244.6975	7.53	
		344.2785	26.57	
		411.1165	2.238	
		444.0	3.125	
		778.9045	12.97	
		867.378	4.214	
		964.10	14.63	
		1112.07	13.54	
		1212.948	1.412	
		1299.14	1.626	
		1408.011	20.85	

HpGe Detector Energy Calibration

Is a relation between gamma ray energies and channel number, which will be used to determine the unknown measured gamma lines.



Example Spectrum: ^{152}Eu



- For low energy peaks (< 1.1 MeV), see mainly photopeaks and Compton.
- Should subtract background (peak-fitting) to calculate “photopeak” efficiency. (Programs gf3, root, etc.)

Figure courtesy: E. Simmons

HpGe Detector Efficiency

The detector efficiency is:

a function of the variables that describe the event, but depending on definition may also include the effects of other events,

e.g. by "dead-time" in the detector or its electronics caused by a previous event. If these variables are not completely specified, i.e. if some or all of them are random variables, then the interesting quantity is the expectation value of the detector efficiency. This expectation value is again often called the

detector efficiency.

HpGe Detector Efficiency

Absolute detector efficiency :

$$\varepsilon_{abs} = \frac{no.of\ pulses\ recorded}{no.of\ radiation\ quanta\ emitted\ by\ the\ source}$$

$$\varepsilon_{abc} = \frac{T_\gamma}{A \times I_\gamma}$$

Intrinsic detector efficiency :

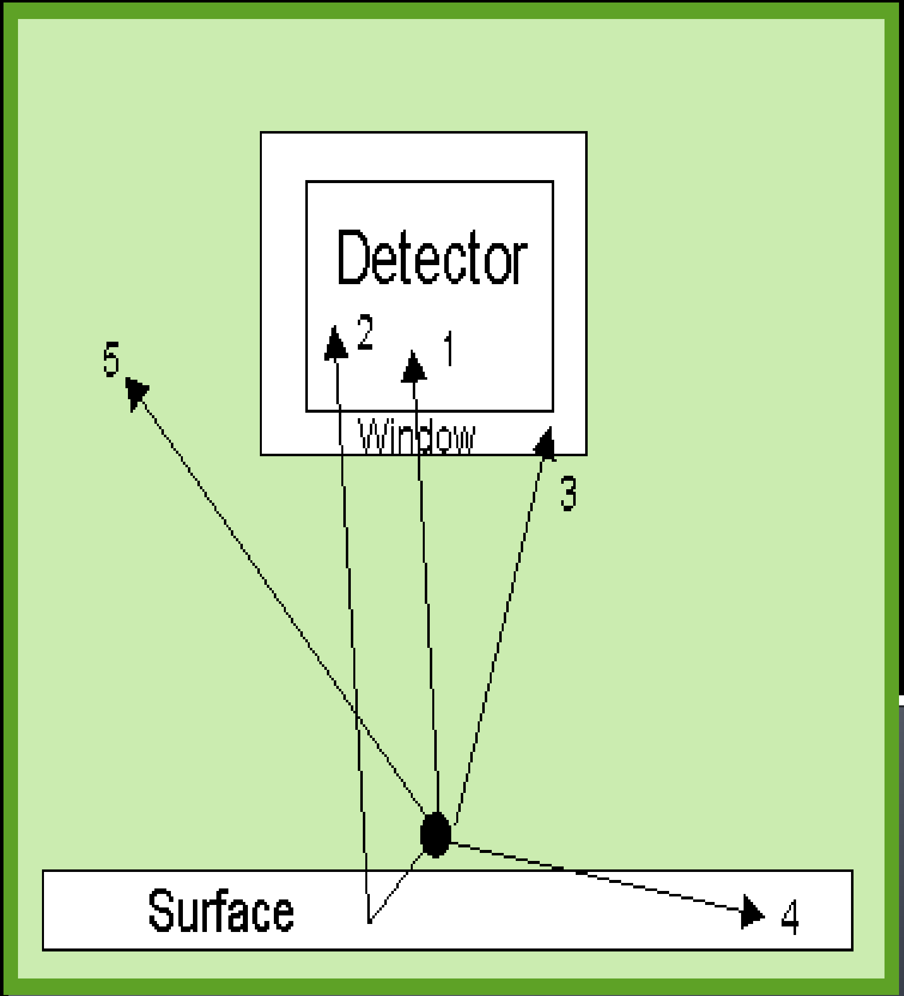
$$\varepsilon_{int} = \frac{no.of\ pulses\ recorded}{no.of\ quanta\ incident\ on\ the\ detector}$$

THE DETECTOR EFFICIENCY DEPENDS UPON:

- the type of detector (GM, NaI Scintillation, Plastic Scintillation, Liquid Scintillation, Semi conductor) and its response to ionizing radiation,
- the detector size and shape (larger areas and volumes are more sensitive),
- the distance from the detector to the radioactive source,
- the radioisotope and type of radiation measured (alpha, beta and gamma radiation and their energies),
- the backscatter of radiation toward the detector (the denser the surface, the more scattering)
- the absorption of radiation before it reaches the detector (by air and by the detector covering).

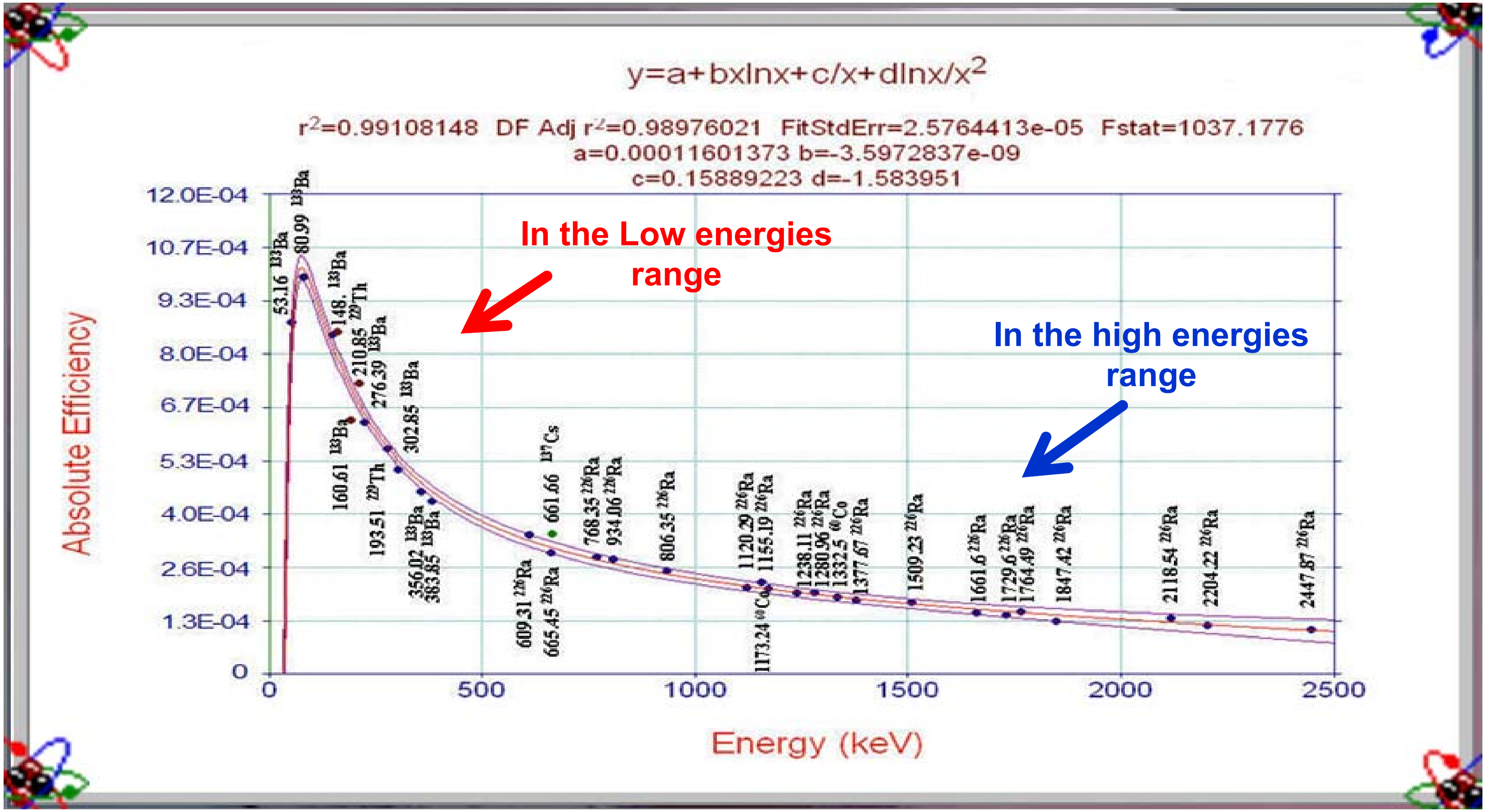
FACTORS AFFECTING DETECTION EFFICIENCY :

1. Some radiation goes directly from the radioactive material into the detector.
2. Some radiation will backscatter off the surface into the detector.
3. Some radiation is absorbed by the detector covering.
4. Most radiation doesn't even get detected.
5. If the detector was closer, this radiation would be detected.



The efficiency curve is:

a relation between absolute efficiencies and the energies.



Correction for the Efficiency

$$A(E_\gamma) = \varepsilon(E_r) \bullet b_\gamma(E_r) \bullet N_0(t) \bullet \Delta t \bullet \left(1 - \frac{\tau_{live}}{\Delta t}\right)$$

$A(E_\gamma) =$ Activity of γ-source at detector

$\varepsilon(E_r) =$ Photopeak efficiency (intins. and geom.)

$b_\gamma(E_r) =$ branching ratio to decay energy level

$N_0(t) =$ strength of gamma source at time of measurement

$\Delta t =$ length of measurement (seconds)

$1 - \frac{\Delta t}{\tau} =$ "live-time" of measurement (data-acq.)

- Use efficiency curve from measurement to calculate "true" activity of gamma decay.
- Use to determine information such as β-decay branching ratios and cross sections.