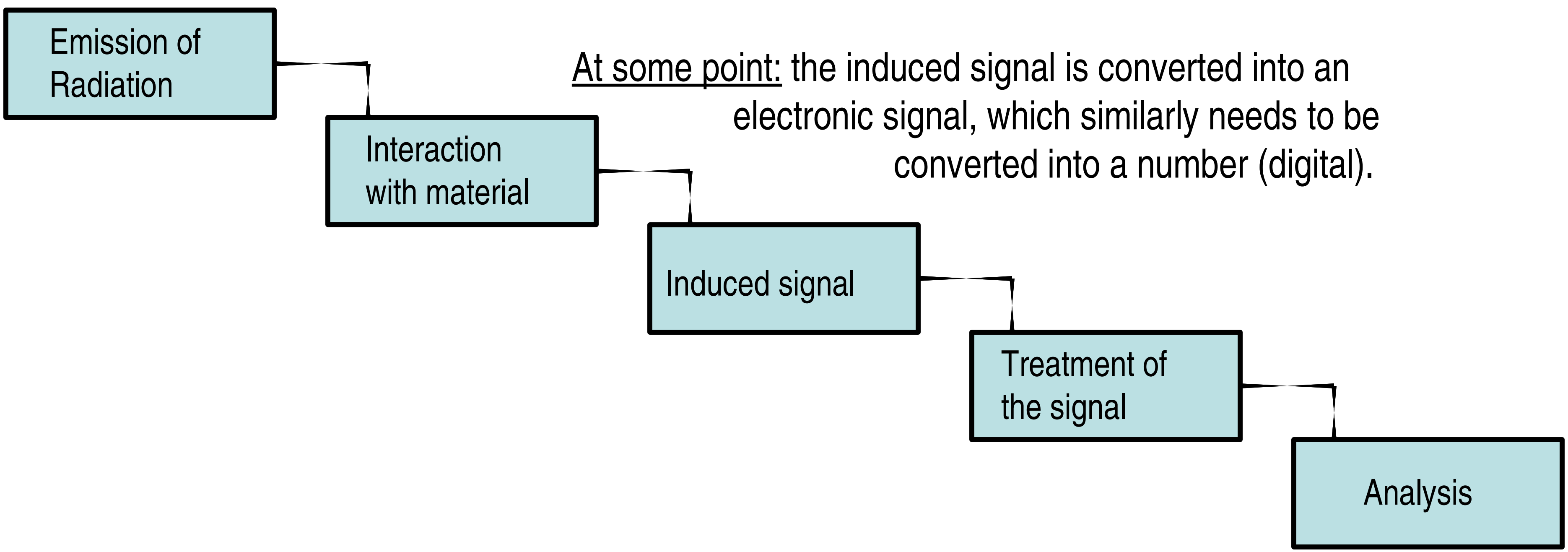
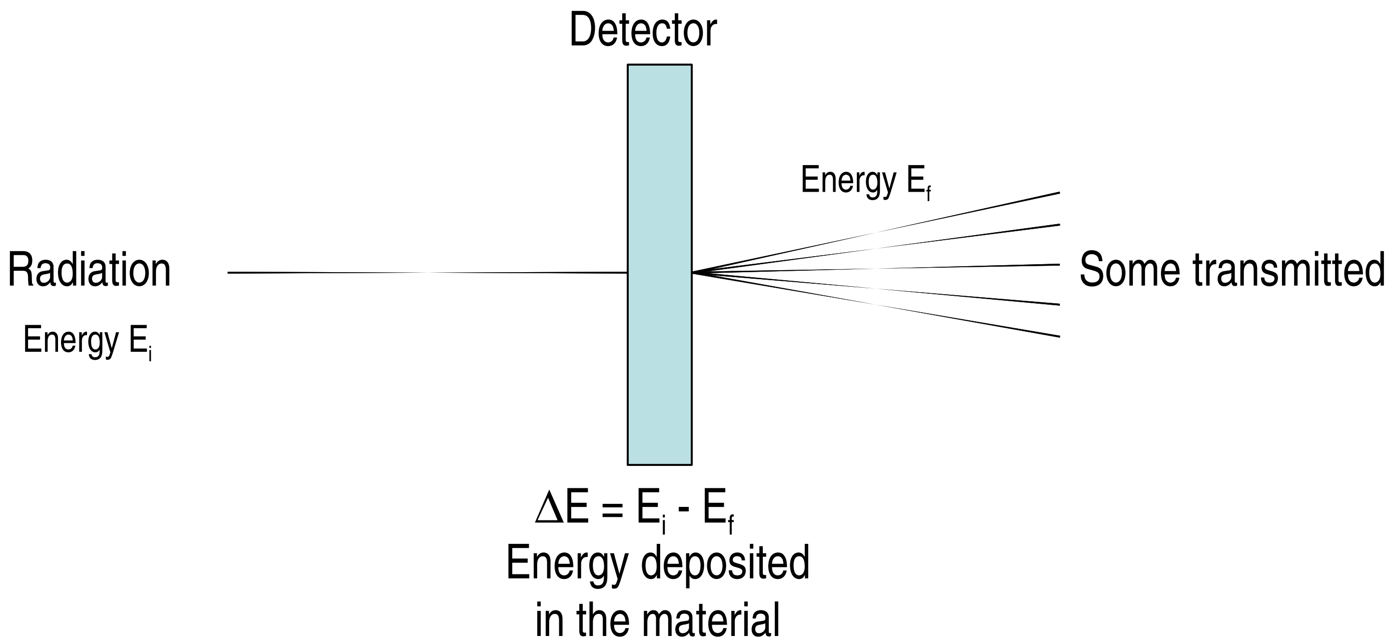
Radiation Detection and Measurement

Radiation detection implies that the radiation interacts (e.g. leaves at least part of its energy) in the material.
A specific material is chosen, because of its intrinsic properties (e.g. how sensitive it is to the type of radiation one want to measure), but it also depends on what information we need to extract from the measurement.



<u>At some point:</u> the induced signal is converted into an electronic signal, which similarly needs to be converted into a number (digital).

Basic principle of Interaction



Interaction depends on the type of radiation and properties of the material (including its thickness)

Interactions

<u>Charged Particles</u> (α- and β-radiations, but also all ions for example):

A charged particle loses energy in the material by kicking out (ionizing) some electrons from the atoms of the material (Coulomb force).

→ Collect the electrons: generate an electronic signal !

<u>Neutrons:</u>

Neutrons are not charged, they don't interact with the electrons !
Interaction happens only at the nucleus level… much less likely.

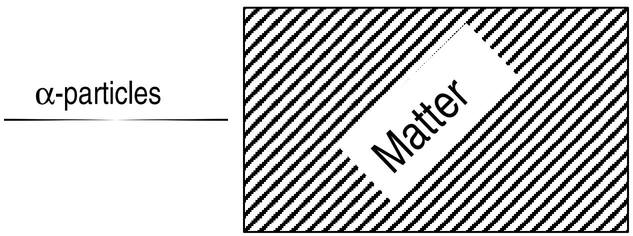
→ Induce recoil of the nucleus/ion, then see "Charged Particles"

<u>γ's (electromagnetic radiation):</u>

γ's are high-energy photons. Do not carry charge.
Interactions with the electrons present in the material, but not through the Coulomb force.

→ Collect the electrons, electronic signal

Charged Particles



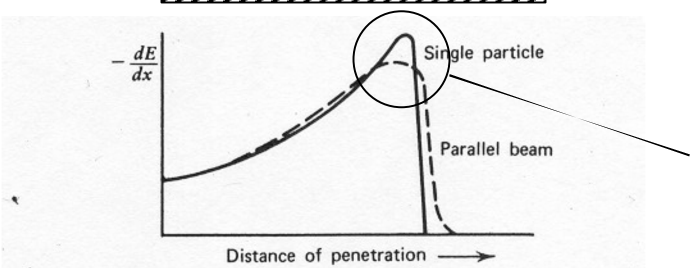


Figure 2-2 The specific energy loss along an alpha track.

Linear stopping power:

$$S = -\frac{dE}{dx}(E)$$

Differential energy loss for this particle type within a specific material type, divided by the corresponding differential path length as a function of the energy.

The energy loss is deposited in the material with the highest deposit near the end of the range (Bragg peak)

A charged particle has a certain range in the material. S increases as the velocity of the particle decreases.

<u>One application:</u> cancer radiotherapy (ion beam, implanted radiosource…)

Example of Stopping Power

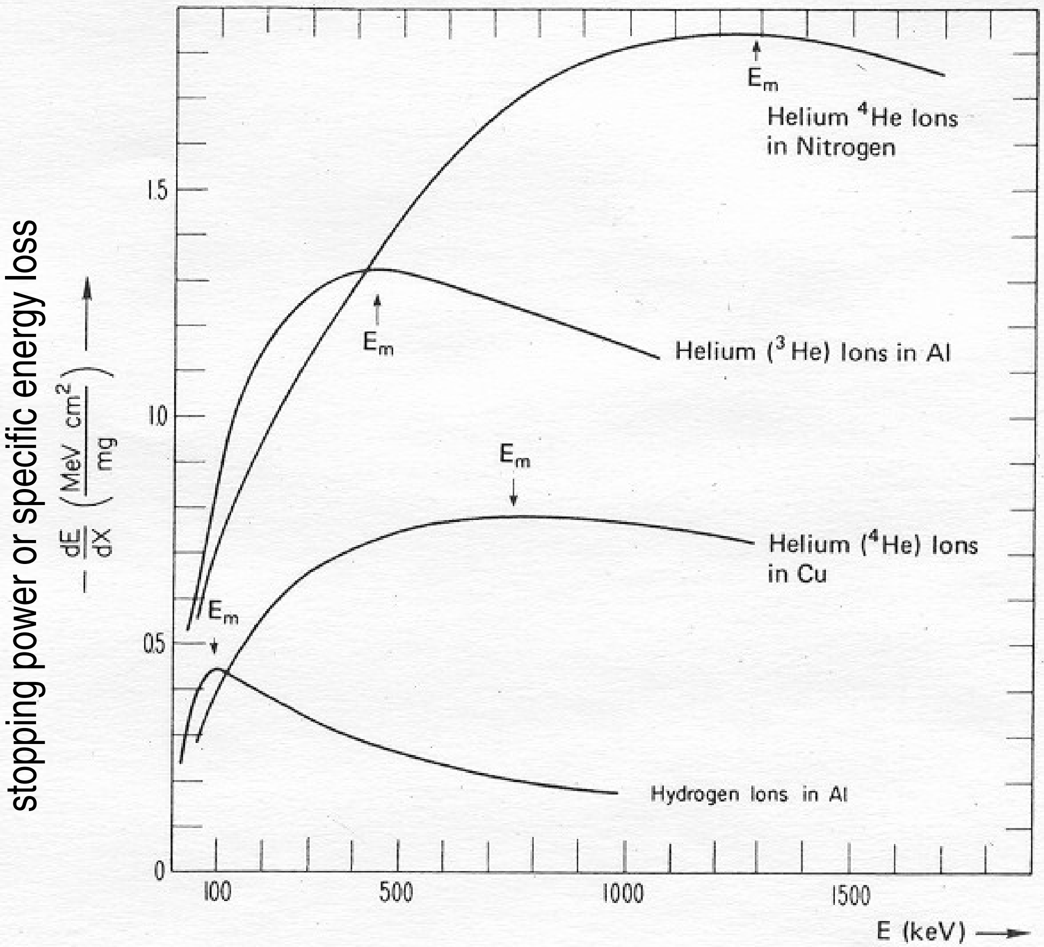


Figure 2-3 Specific energy loss as a function of energy for hydrogen and helium ions. E_m indicates the energy at which dE/dx is maximized. (From Wilken and Fritz.[2])

dx [mg/cm^2] already includes the density of the material

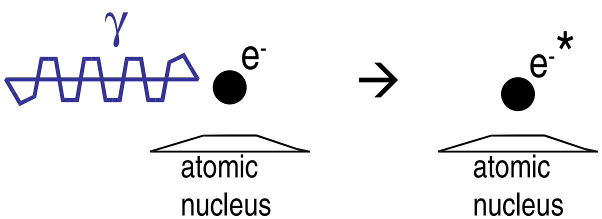
→Can be transformed into a number [atoms/cm^2]

Helium ions looses more energy than Hydrogen ions in a given material

Shorter range → Thinner detector

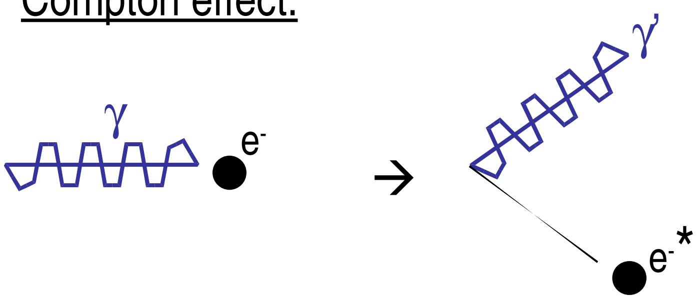
Interaction of γ-radiation with matter

<u>Photoelectric effect:</u>



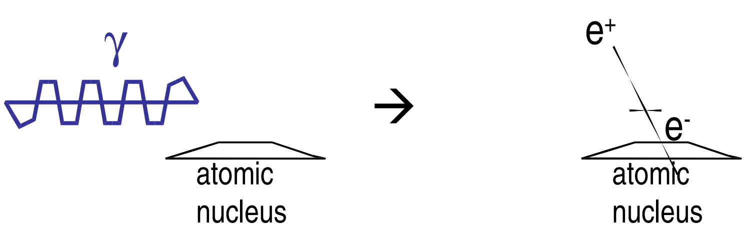
Atomic electron absorbs the energy and momentum of the γ photon (simultaneous energy and momentum conservation possible due to participation of atomic nucleus)

<u>Compton effect:</u>



γ-photon is scattered off a free (or quasi-free) electron in the material. Energy and momentum are conserved in the scattering process.

<u>Pair production effect:</u>



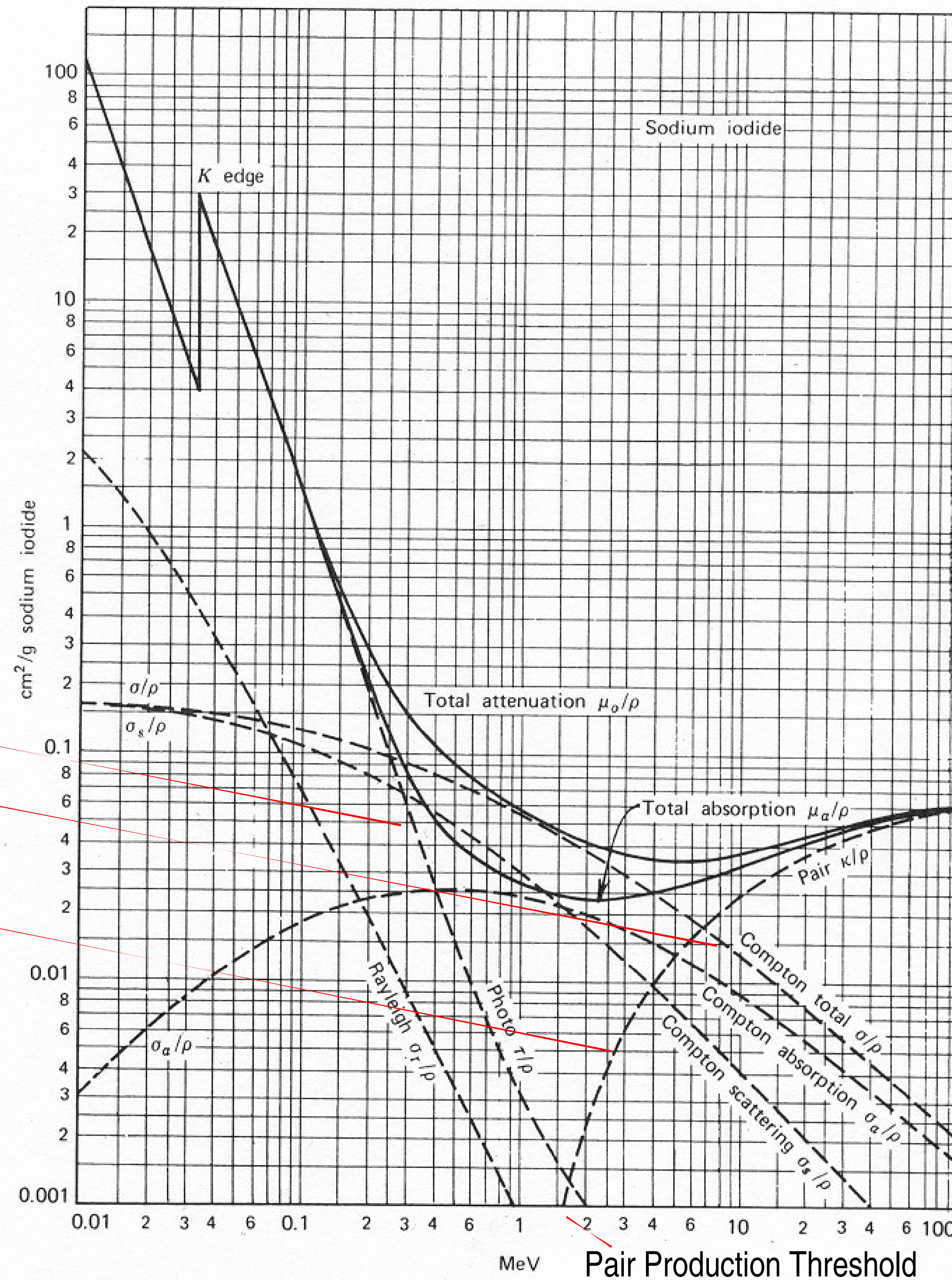
Production of a matter / antimatter pair by the γ-photon in the Coulomb field of the atomic nucleus. Threshold: incident γ-energy has to be larger than the rest mass of particles produced.

Energy dependence of the various γ-ray interactions

Photoelectric effect

Compton effect

Pair production (notice threshold @ 2 x 0.511MeV)



Interaction (energy transfer) mechanisms in detectors (I)

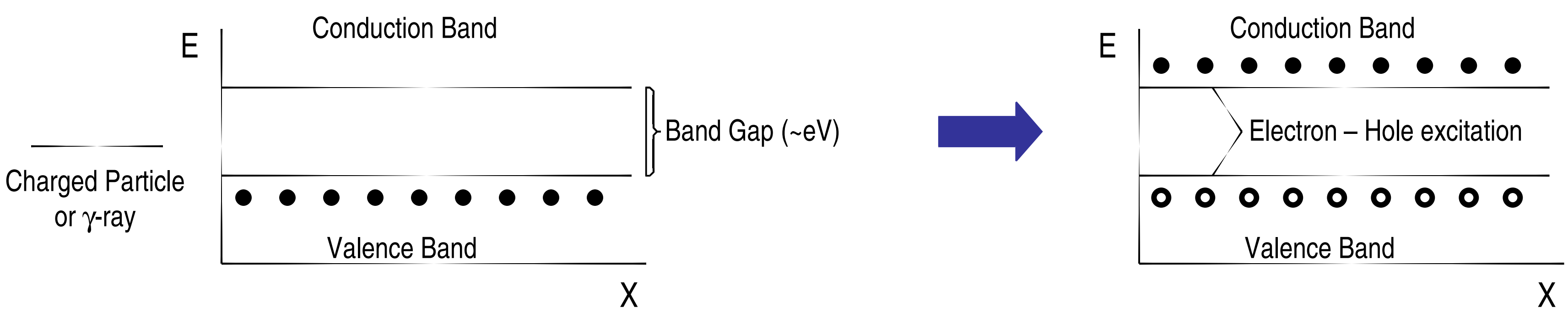
What detector ? Which response ? What signal ?

As seen previously, (all or part of) the radiation energy (e.g. kinetic energy) is transferred at some point to the electrons in the material (excitation or ionization).

<u>1. Semi-Conductors</u>

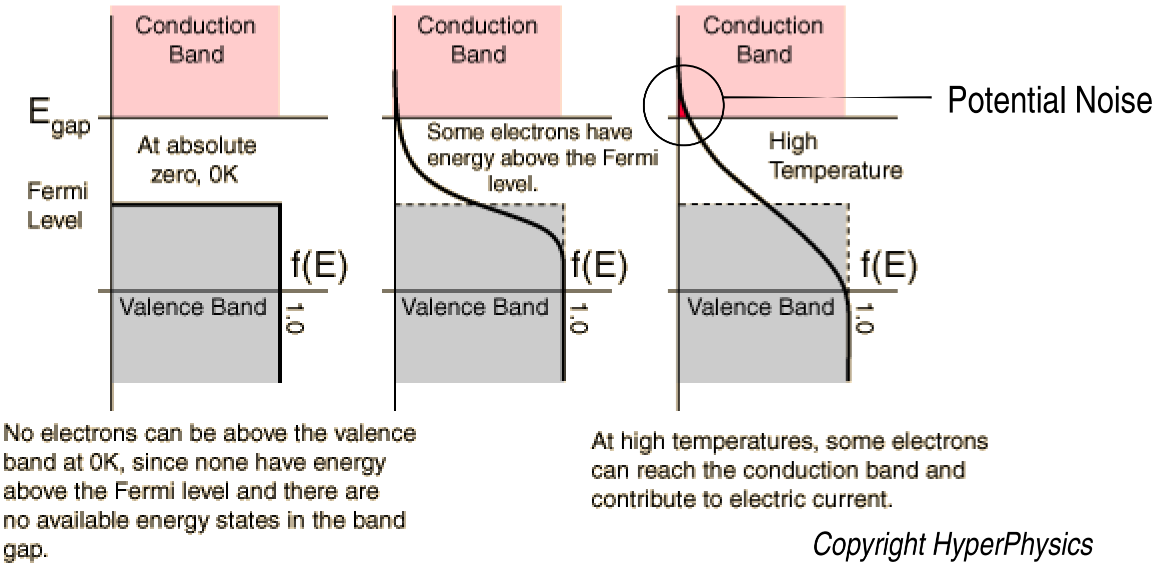
Silicon detectors are commonly used to detect charged particles, whereas Germanium detectors can be used to detect γ-rays.

→ Based on a similar principle



→ By applying a voltage, the charges can be collected (electronic pulse)

Silicon (Si) VS Germanium (Ge)



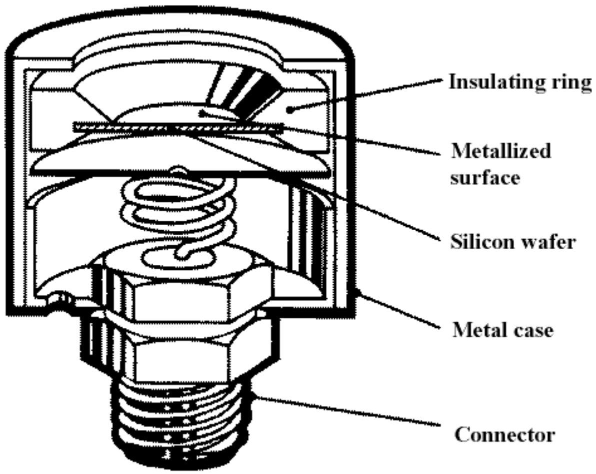
Silicon and Germanium are the most commonly used semi-conductors in Nuclear Physics. In practice, it is very difficult to make “thick” (>1mm) Si detectors, whereas there are ways to make thick Germanium detectors (tens of cm).

+ Charged particles generate plenty of electron-hole pairs, loses full energy in a relatively short distance.
  → Silicon detectors OK.
+ γ-rays interact with electrons, low probability of interaction, more material required
  → Silicon detectors NO, Germanium OK.

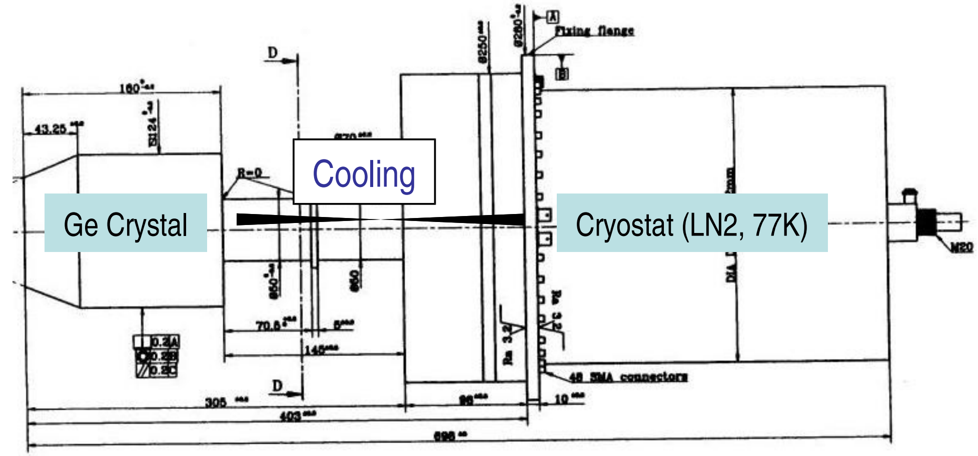
also, because there are less electron-hole pairs created, the “signal” is weak
  → Requires much careful treatment.
  - Cooled at Liquid Nitrogen (LN2) temperature (77 K) to reduce noise.

SemiConductor Detectors

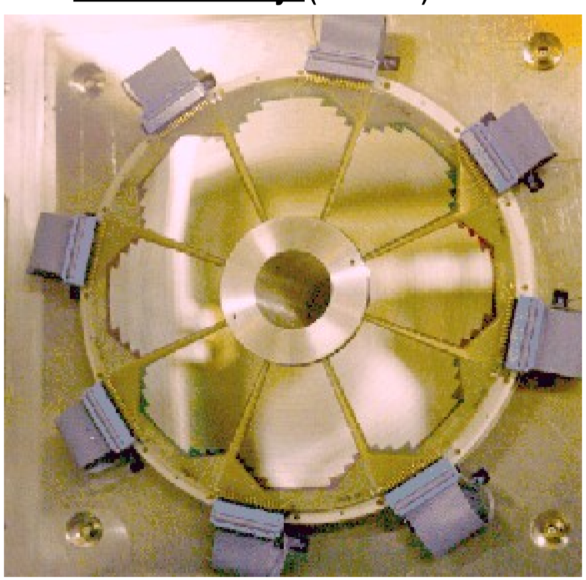
Silicon Junction



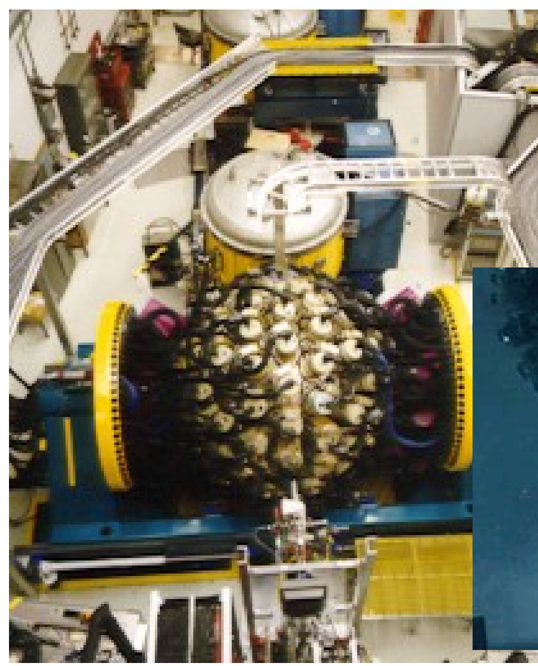
Germanium Detector

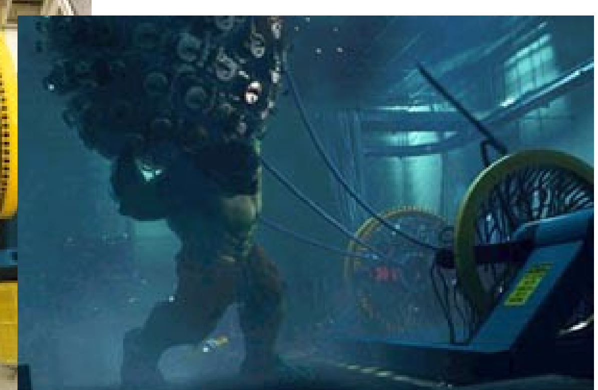


Silicon Array (LEDA)



Germanium Array (GammaSphere)



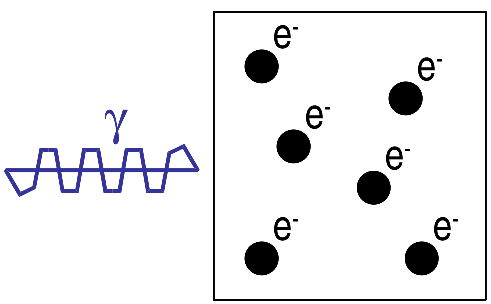


Interaction (energy transfer) mechanisms in detectors (II)

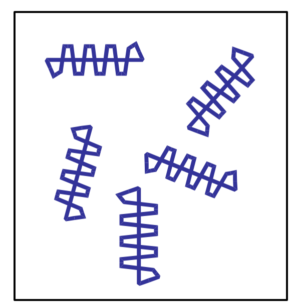
2. Scintillators (ex: NaI detector)

Photon emissions result from excited or ionized electrons returning to their initial orbit (or when other electrons are filling their positions).

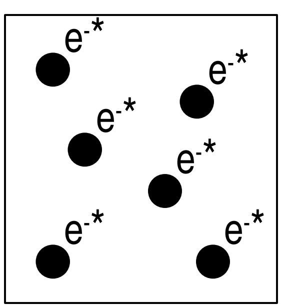
→ emission of secondary electromagnetic radiation (but with lower energy): scintillation



1. γ-radiation hits scintillator and interacts with electrons



3. De-excitation leads to production of many low energy photons (ultraviolet → Visible light)

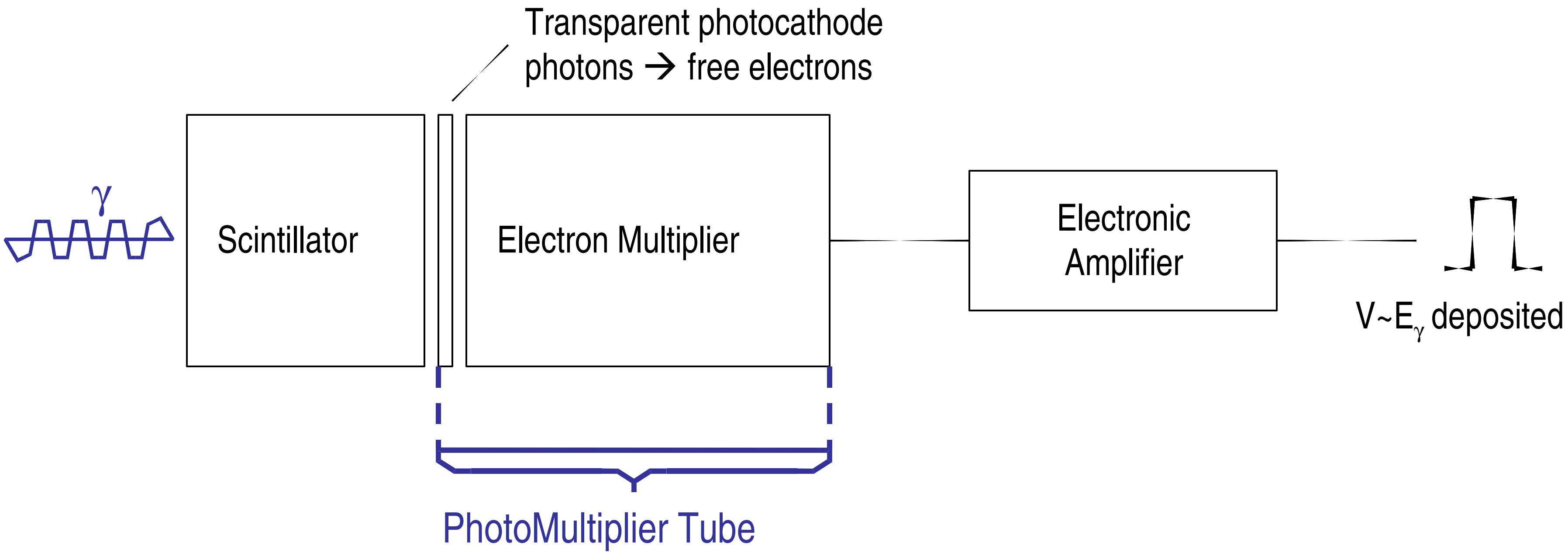


2. γ-energy absorbed and distributed on many excited electrons/atoms

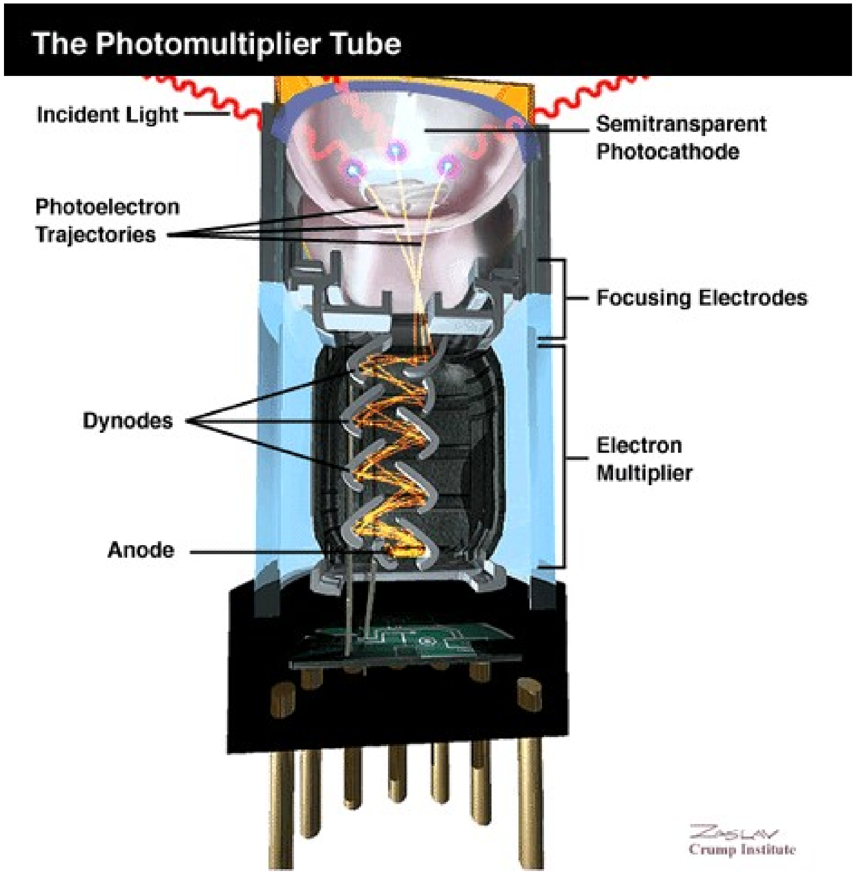
Collection of the photons

We have now many low energy photons in scintillator emitted in all directions.
We need to:

→ Collect them
→ Amplify the signal
→ "Digitalize"



Photo(multiplier)tubes



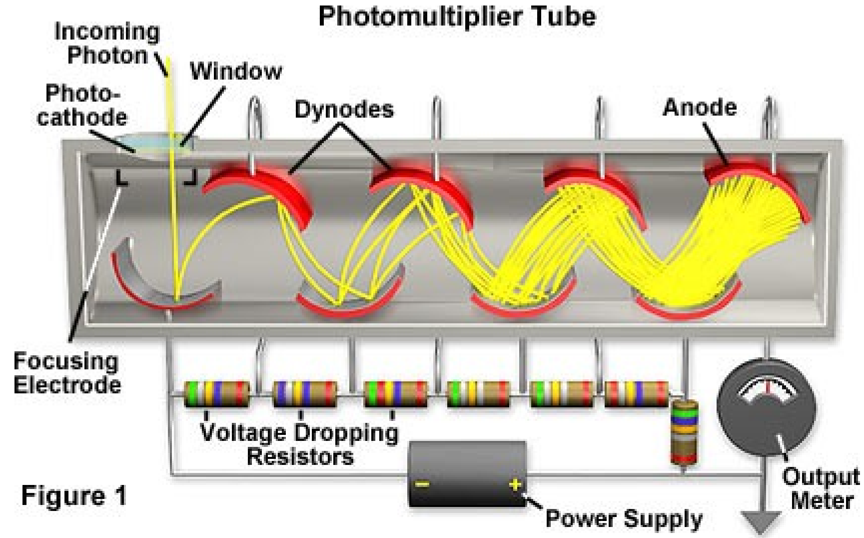


Figure 1

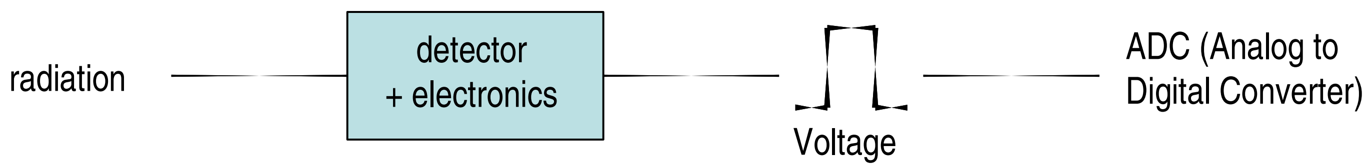
Other detectors…

There are other types of detectors (but the basic principle of interaction remains the same: ionization or excitation).

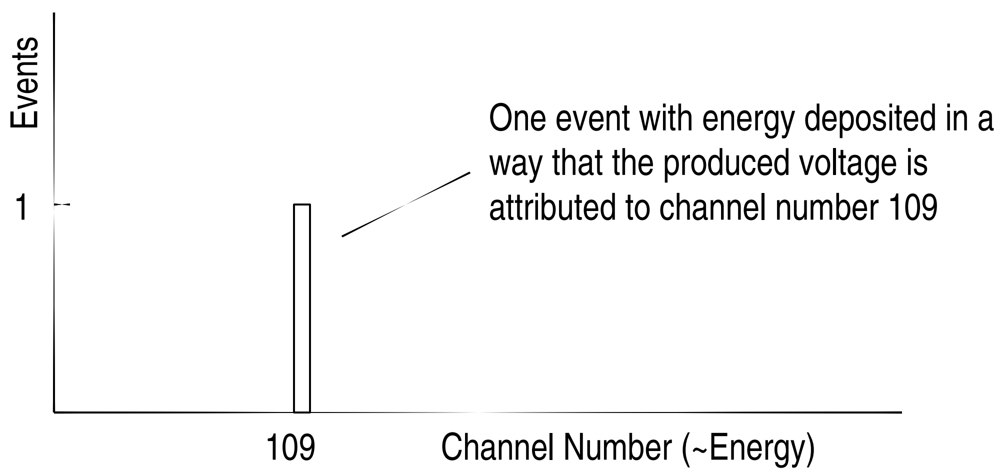
- Ionization chamber, Proportional counters…
- Solid-state detectors (other than Silicon and Germanium)
- Neutron detectors
- Cerenkov detectors
- Bolometers…

Electronics

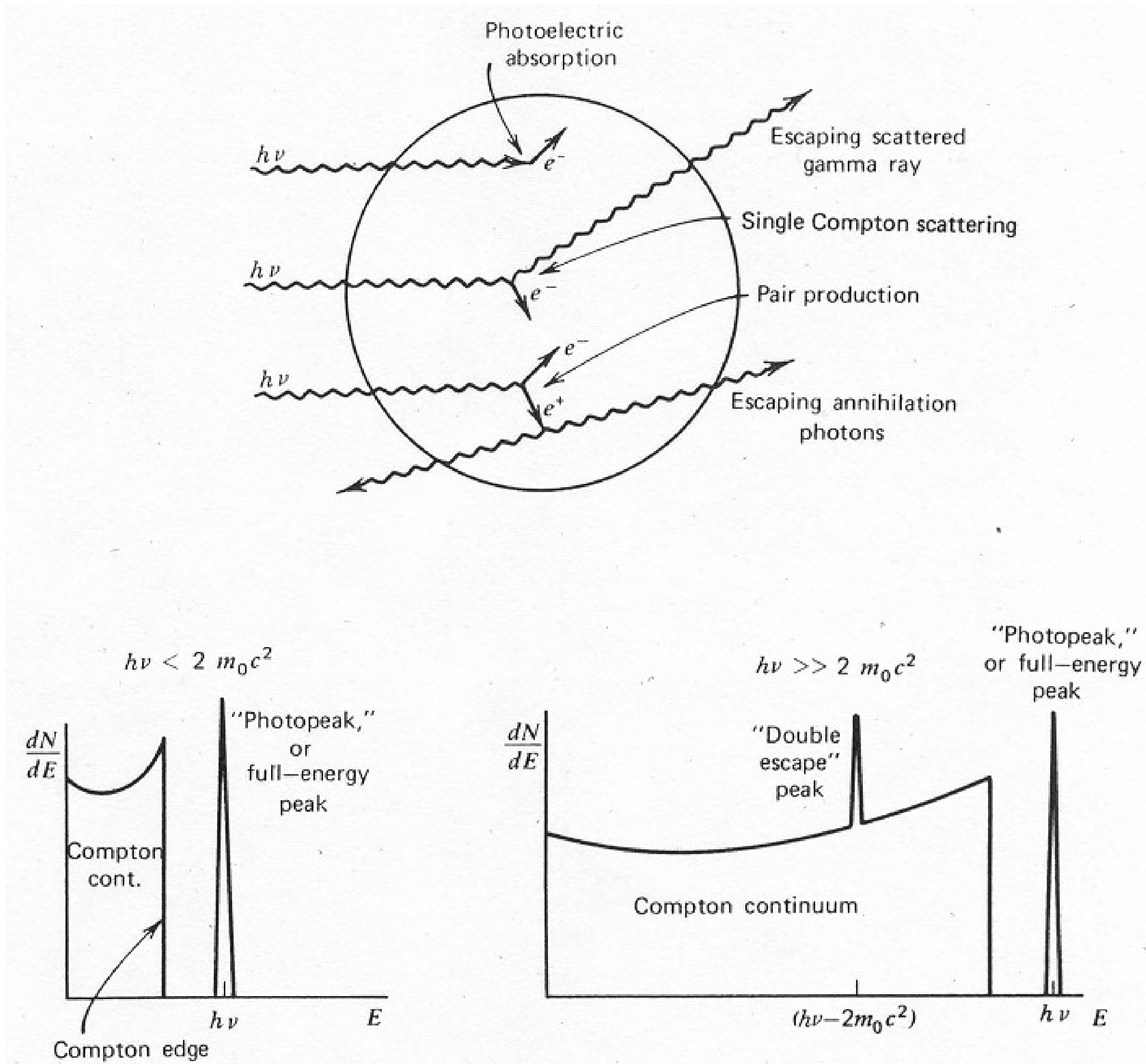
Once we have an electronic signal (proportional to the energy deposited in the detector), we need to convert it into a “useful” signal.



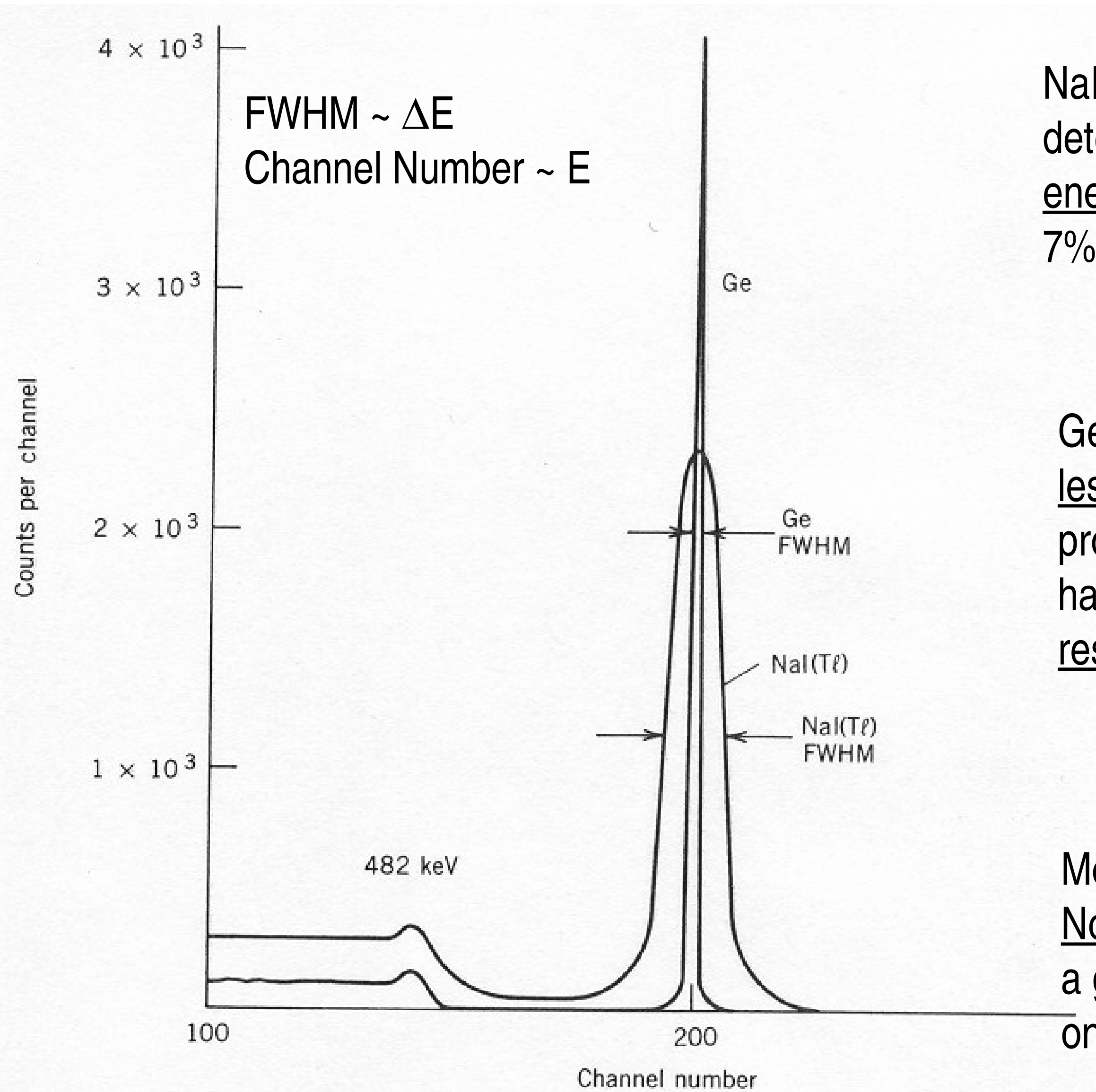
In the ADC, the voltage is converted into a (channel) number that can be read by a MCA (Multi-Channel Analyzer) → Spectrum



Example: Gamma Spectra



NaI VS Germanium detector (I)



NaI detectors are <u>fairly efficient</u> in detecting γ-rays, however their <u>energy resolution</u> is only around 7%:

$$\frac{\Delta E}{E} \sim 7\%$$

Germanium detectors are usually <u>less efficient</u> than NaI's (lower probability of interaction), but they have a <u>much better energy resolution</u>:

$$\frac{\Delta E}{E} \sim 0.5\%$$

Most of the time:
<u>No detector is ideal !</u> Choice of a given detector usually depends on the application

NaI VS Germanium detector (II)

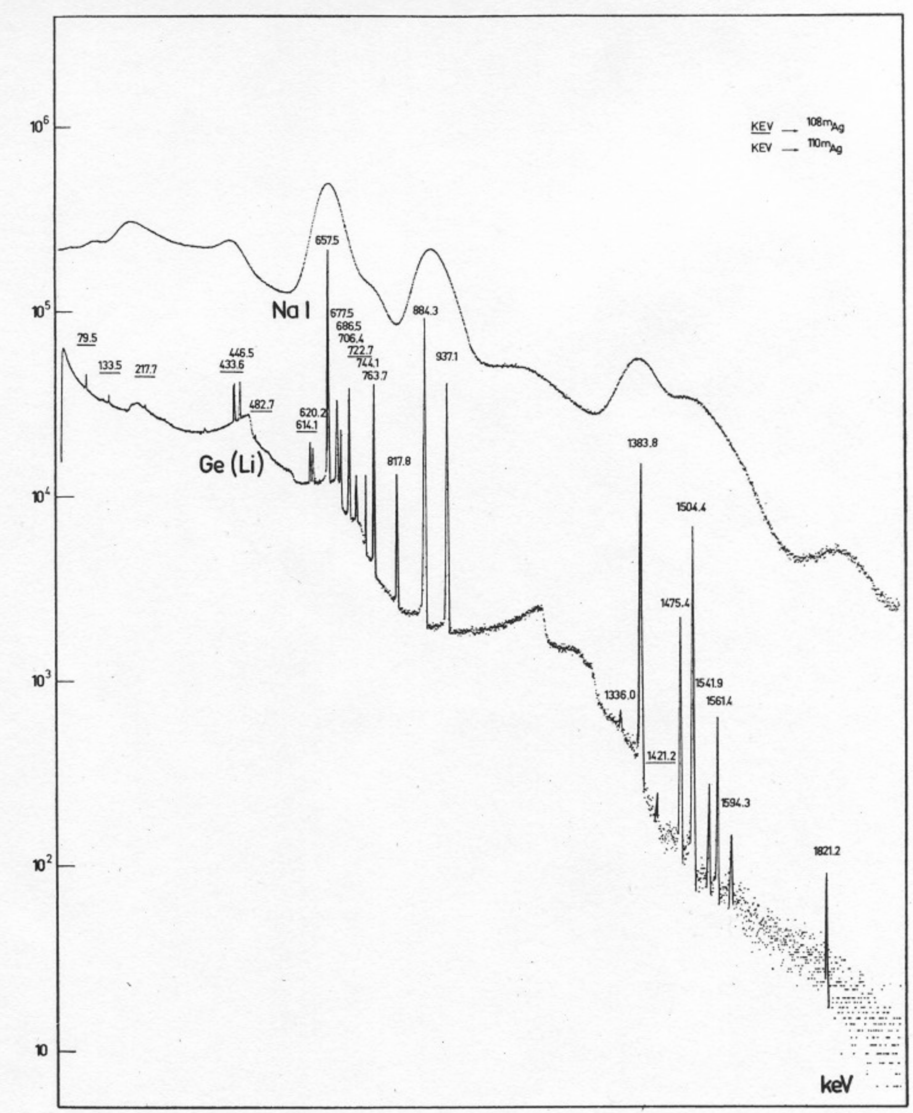


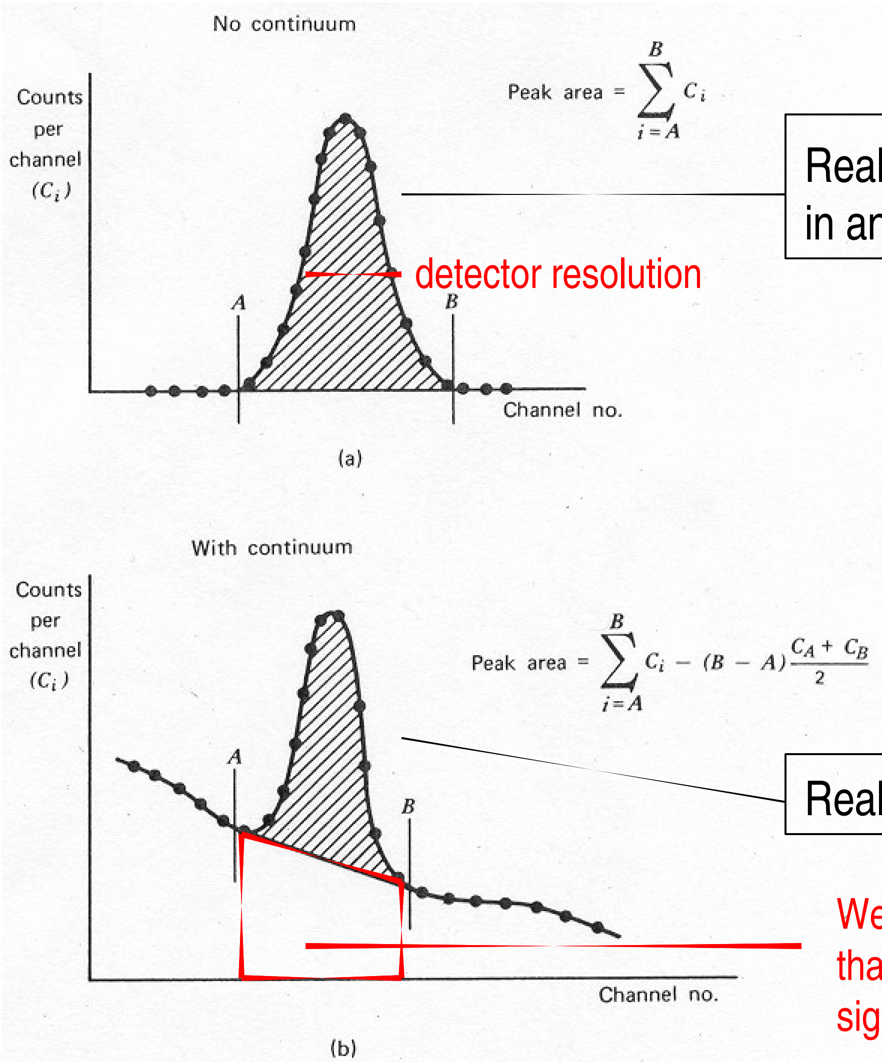
Figure 12-6 Comparative pulse height spectra recorded using a sodium iodide scintillator and a Ge(Li) detector. The source was gamma radiation from the decay of ^{108m}Ag and ^{110m}Ag. Energies of peaks are labeled in keV. (From Philippot.[9])

Background

The real world is not background free…

Main sources:

- cosmic radiations
- natural radioactivity



Real detector (Photopeak for example) in an ideal world

Real detector in the real world

We have to subtract the background that is not induced by our photopeak signal…