Radiation measurements

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Sensor or detector is a device that detects the physical properties of objects and gives an electronic signal

Input: electromagnetic radiation

Output: electronic signal that is converted to human-readable display

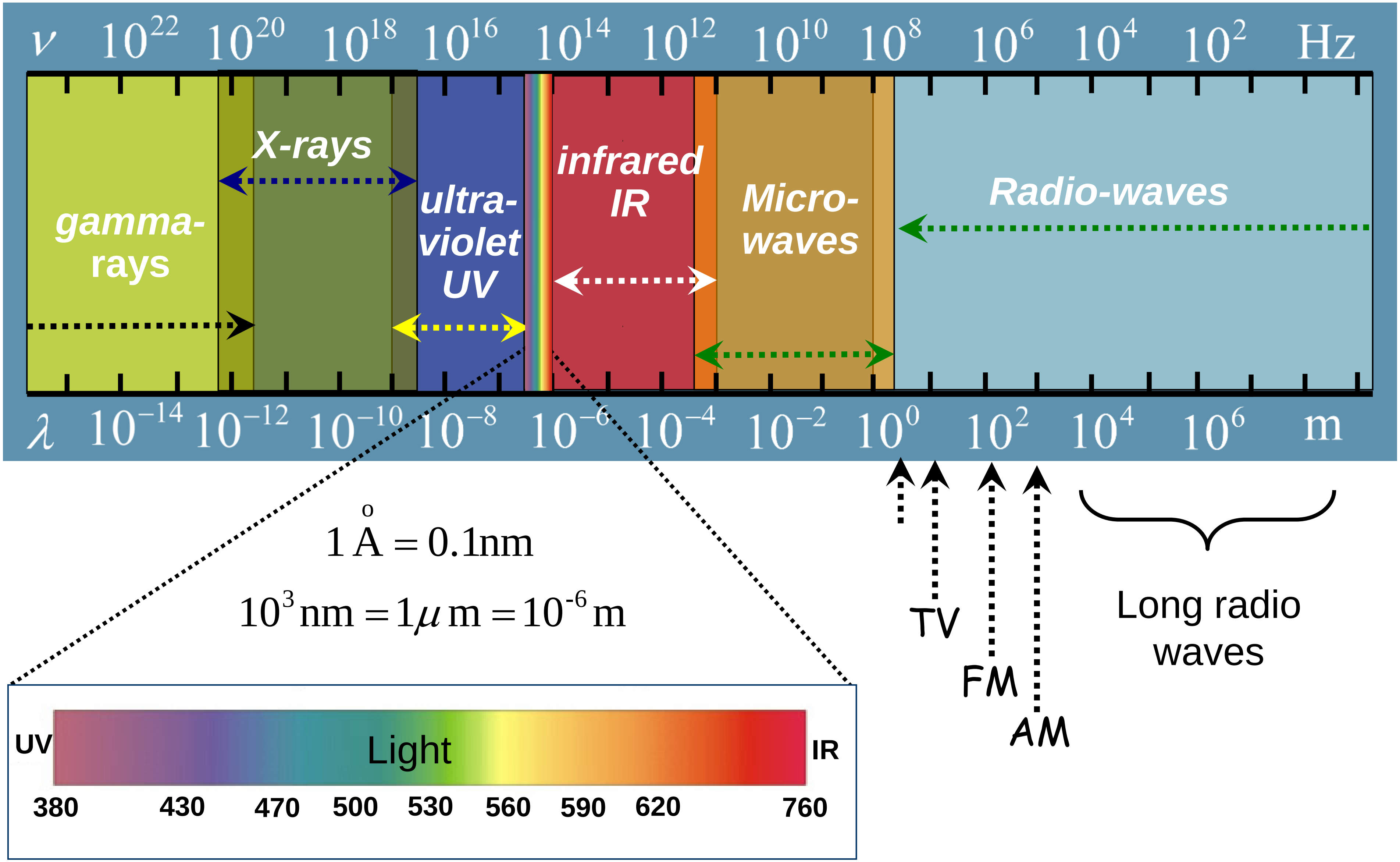
Physical effects which are frequently used for detection:

- ionization rate
- properties of the atomic excitation
- electronic conductivity in crystals
- light production, etc.

Nuclear radiations: charged particles, EM radiation (gamma-, X-ray), beta-particles, alpha-particles, ions

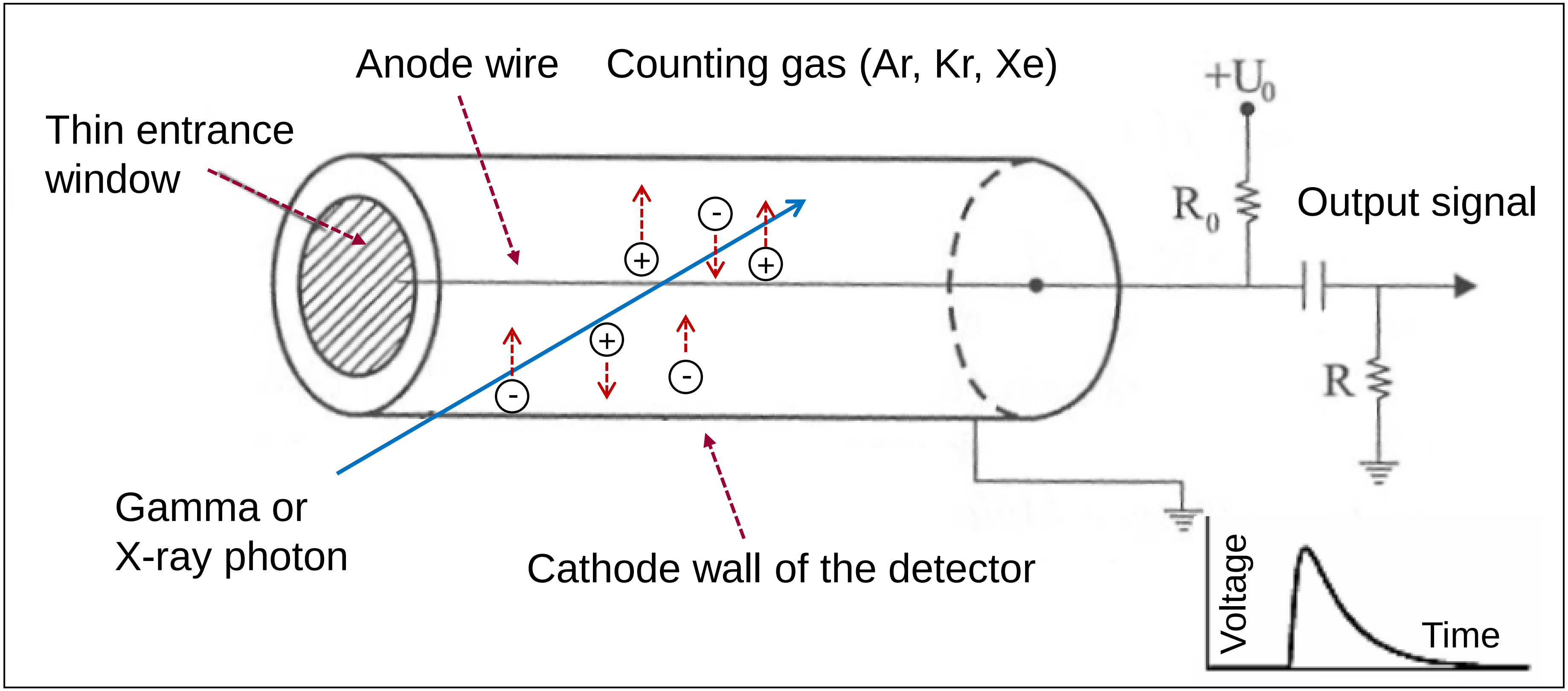
Detection of nuclear radiations by interactions between photons/particles and matter ⇨ producing electrons and/or light

Spectral distribution of electromagnetic (EM) radiation

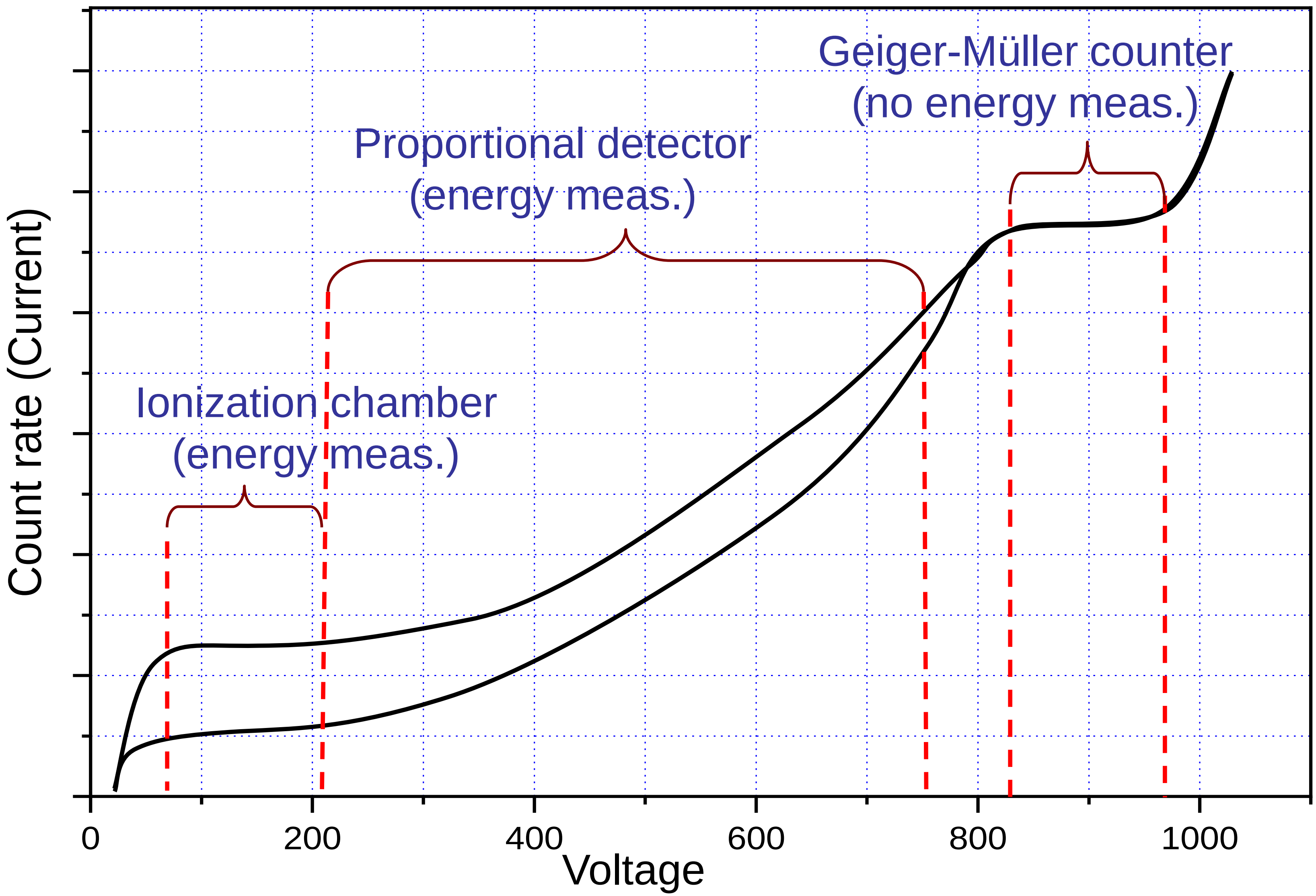


Gas-filled detectors

- Ionization and excitation of gas atoms/molecules along the particle trajectory ⇨ positive ions and free electrons
- External electric field ⇨ (-) charged move to anode and (+) to cathode ⇨ production of electronic signal ⇨ $U_{anode}(t)$ ⇨ electric pulse



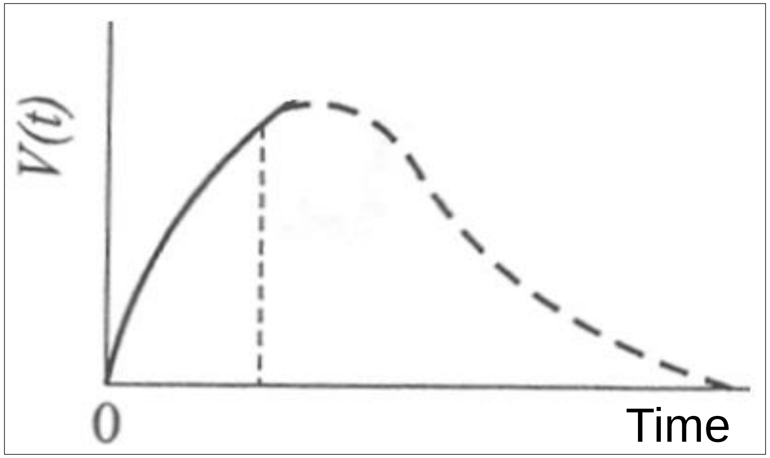
Characteristic properties of the electronic signal (output) in gas-filled detectors (constant ionization effect)



Gas-filled detectors

- First electronic sensor measuring ionization radiation
- Development: first half of the 20th. century
- Simple structure and electronics ⇨ low cost
- Suitable to measure α (He), β (electron or positron), γ and X radiations

- Energy measurements ⇨ integral of the output electric signal

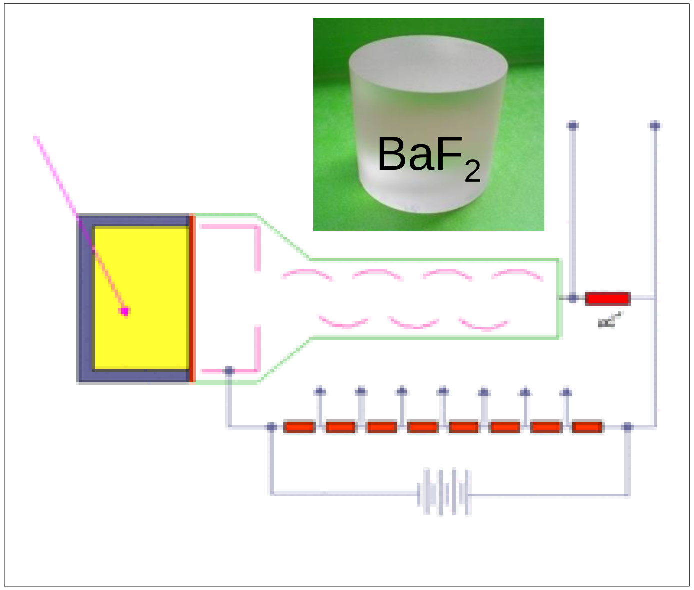


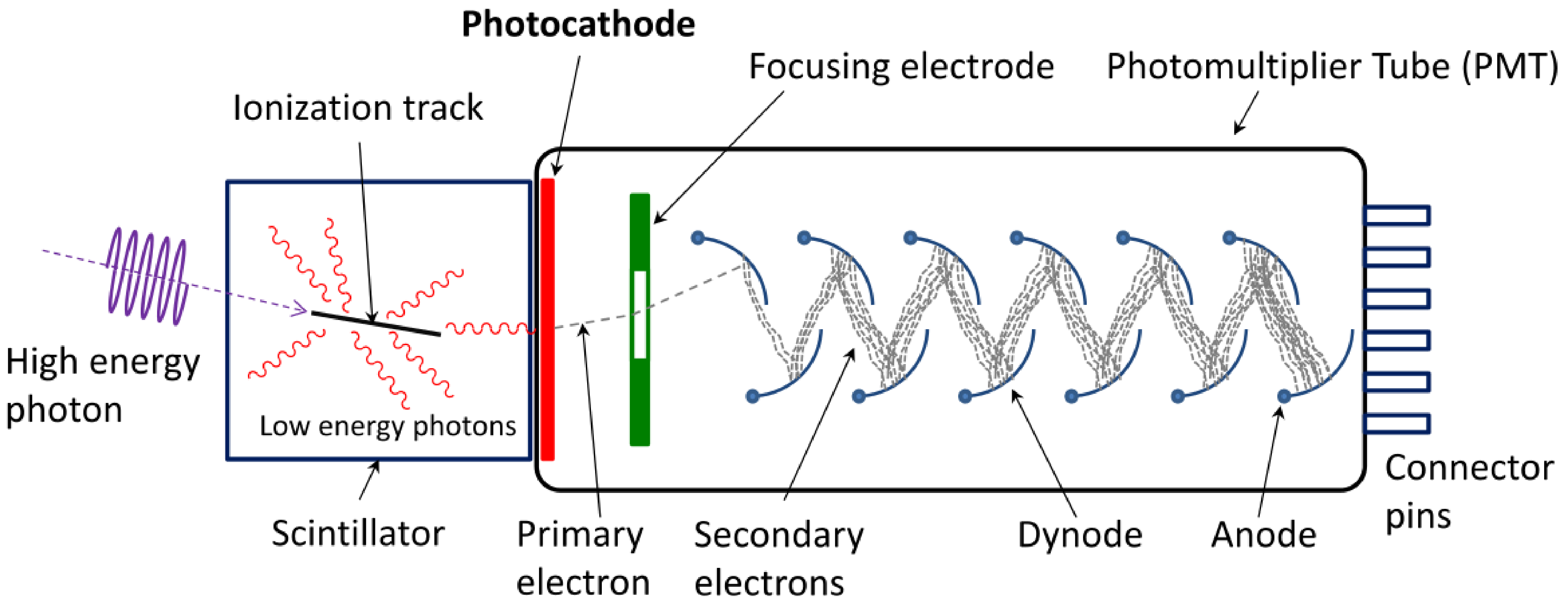
Dose measuring gas-filled detectors

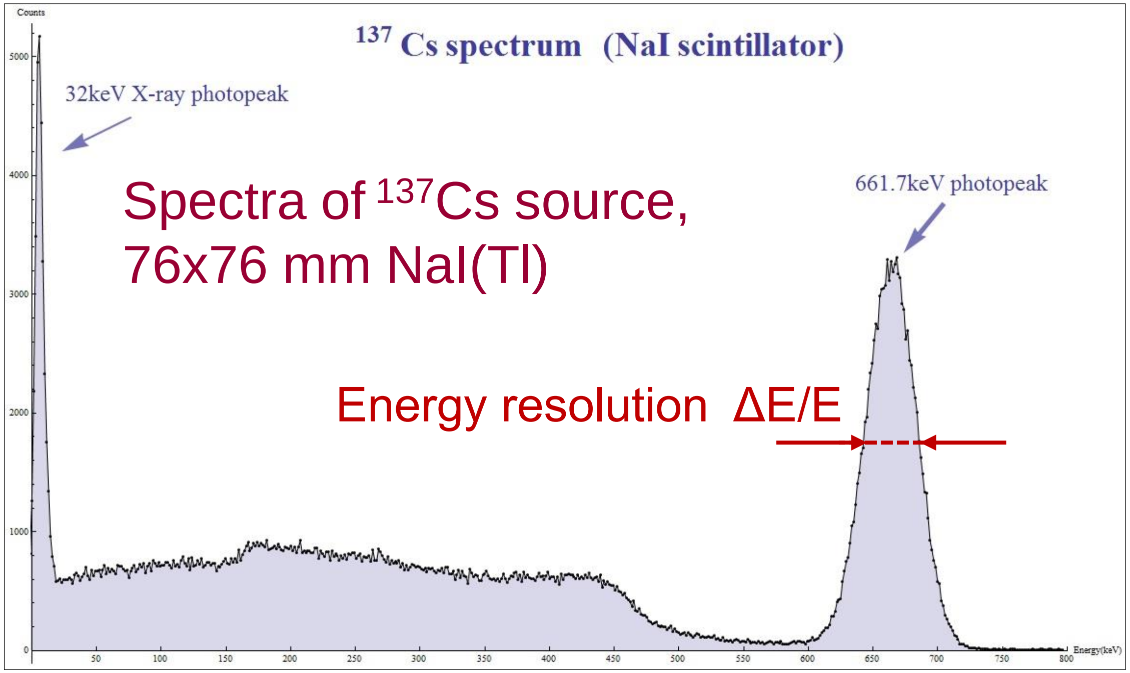
- W = average energy loss per ion pair formed in gas
- S = energy loss of the radiation in the material to that gas
- P = number of ion pairs per unit mass formed in the gas
- D = absorbed dose ⇨ D = WSP

Scintillation detectors

- ZnS + ionization radiation (charged particles, EM) ⇨ light emission
- 1940s ⇨ luminosity is proportional to the absorbed energy
- What material is suitable as a scintillator?
- Inorganic, organic materials, liquid and gas.

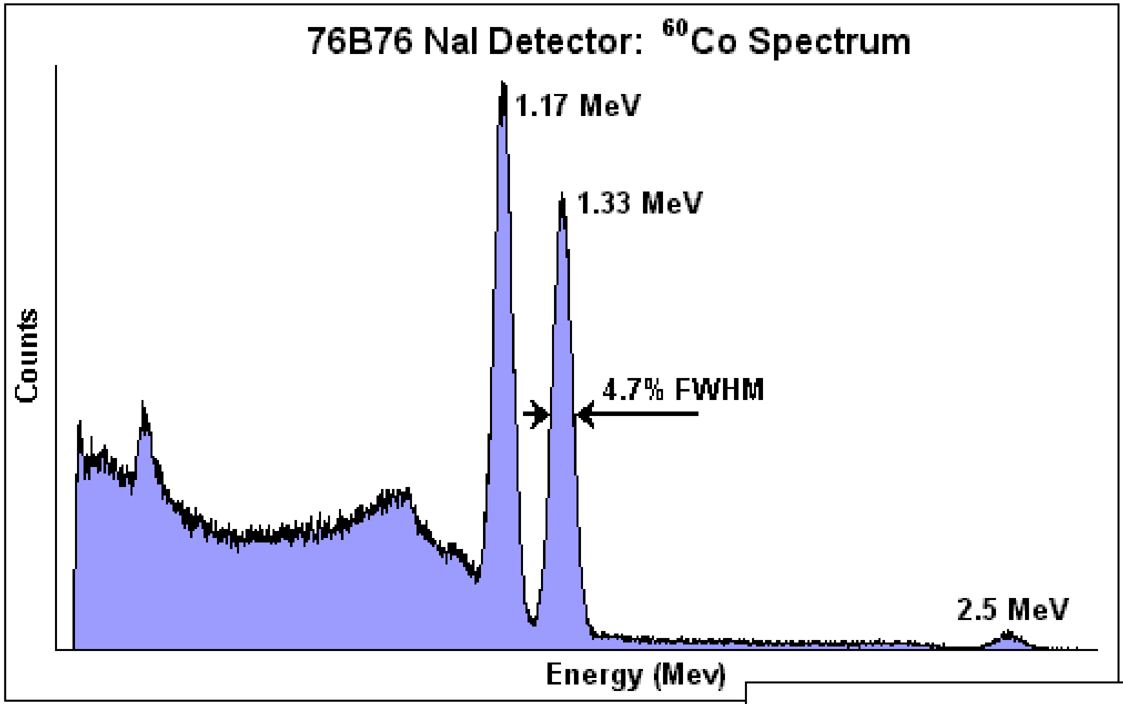






Physical properties of inorganic scintillator materials

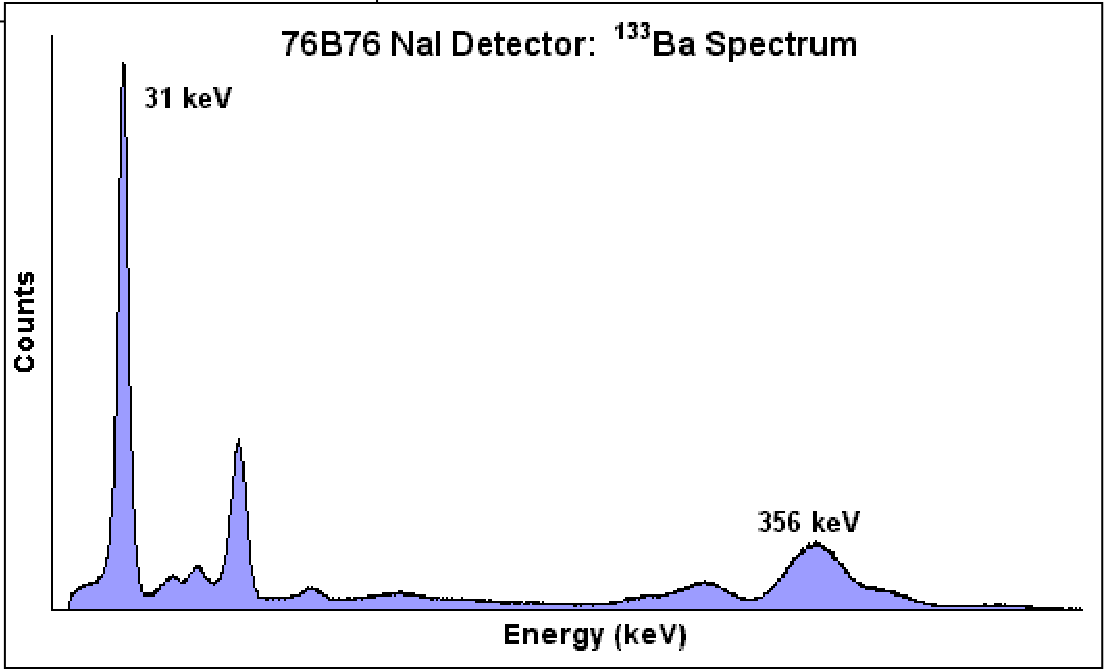
Material	NaI(Tl)	CsI(Tl)	$Bi_4Ge_3O_{12}$
Density (g/cm^3)	3.67	4.51	7.13
Time constant (ns)	230	1000	300
Luminesence wavelength (nm)	420	565	480
Relative light intensity	100	45	7-10
Refractive index	1.85	1.78	2.15



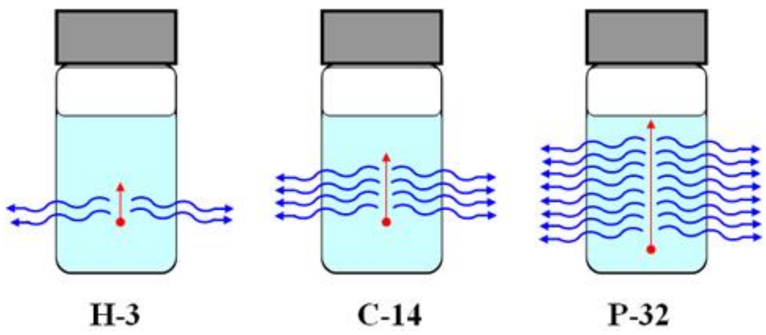
Gamma spectra

measured by

scintillation detectors



Liquid Scintillation Spectroscopy (LSC)



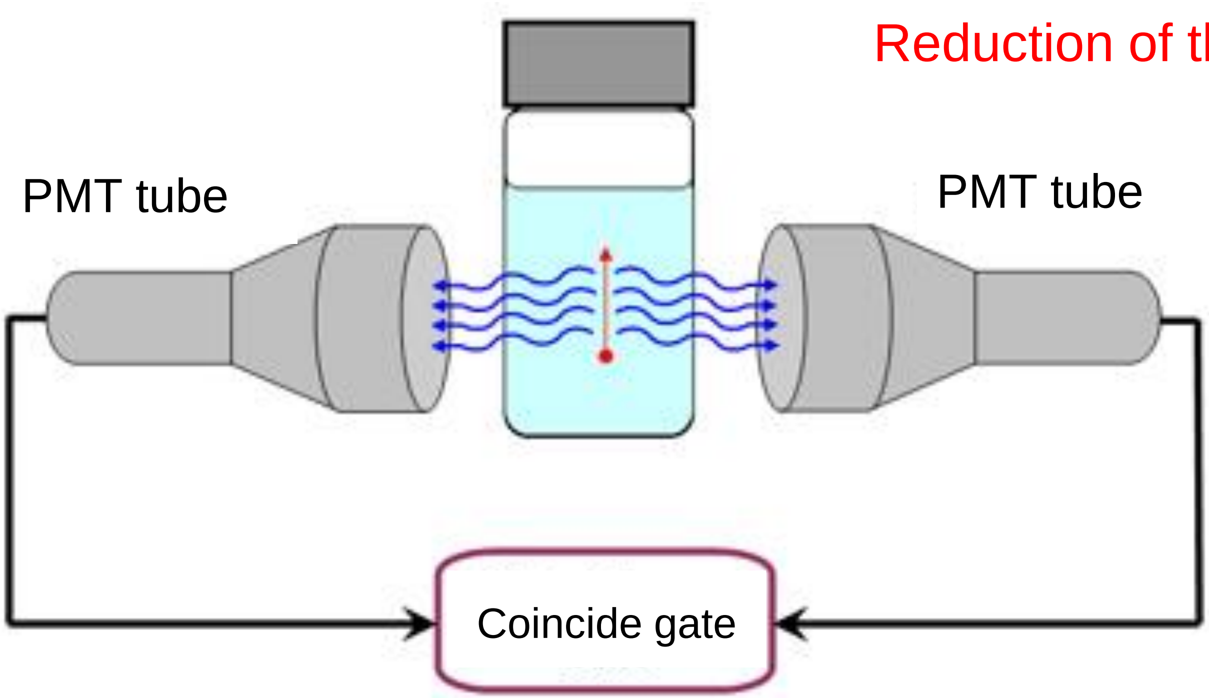
^{3}H E_{max}=18.6 keV ⇨ ≈ 30 photons

^{14}C E_{max}=156 keV ⇨ ≈ 250 photons

^{32}P E_{max}=1,71MeV ⇨ ≈ 3300 photons

Low fluorescence yield ⇨ ≈ 1% of the β energy is converted into light.

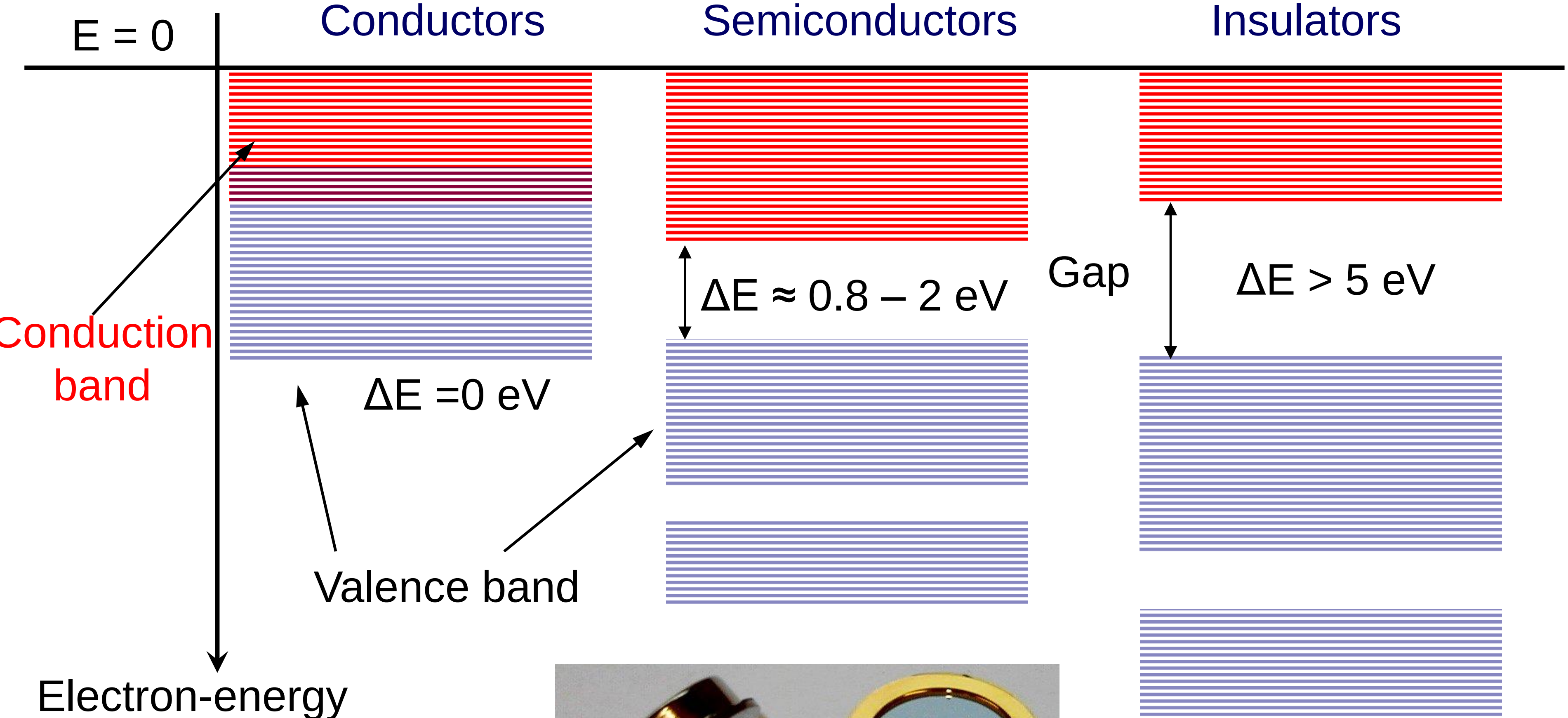
Reduction of the noise is necessary!



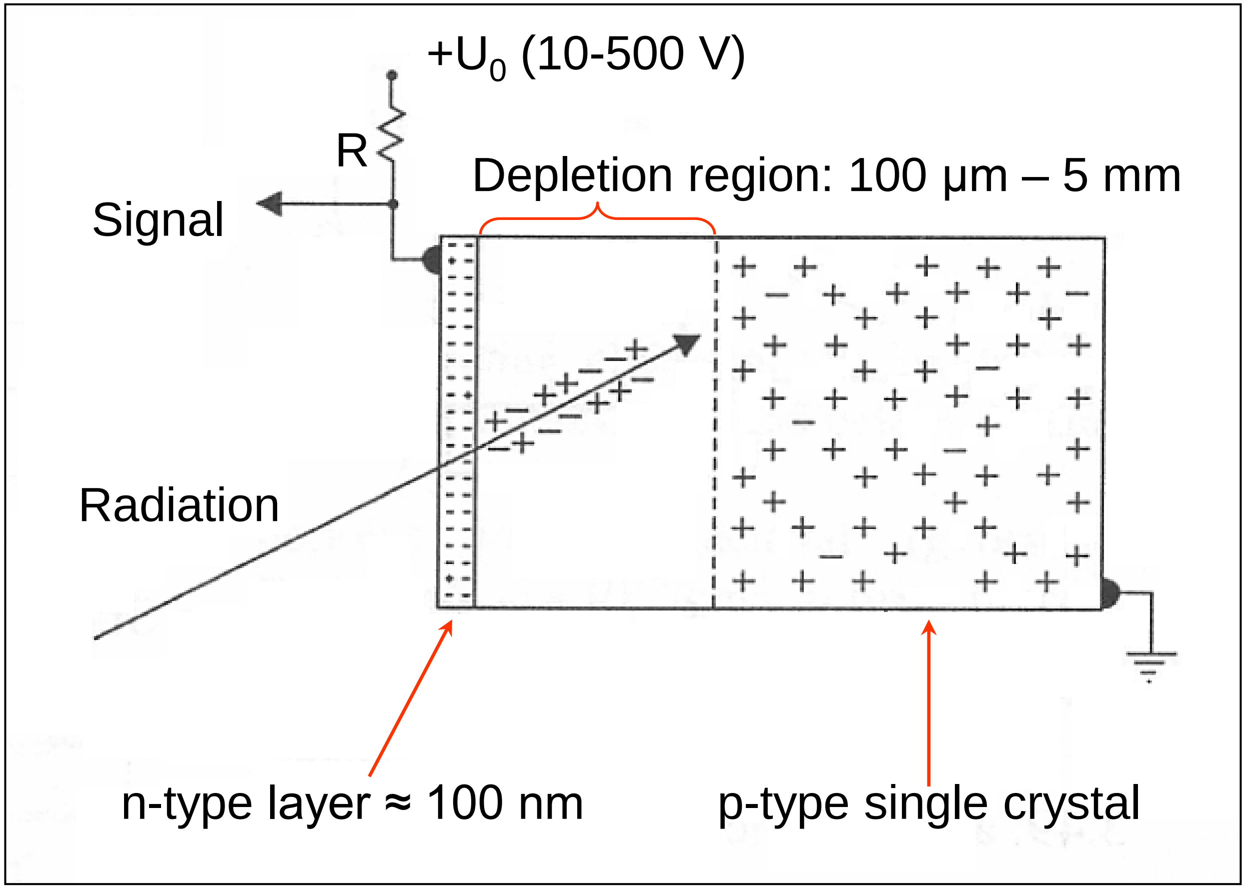
Toluene, xylene,…

Semiconductor detectors

Band structure of solid materials



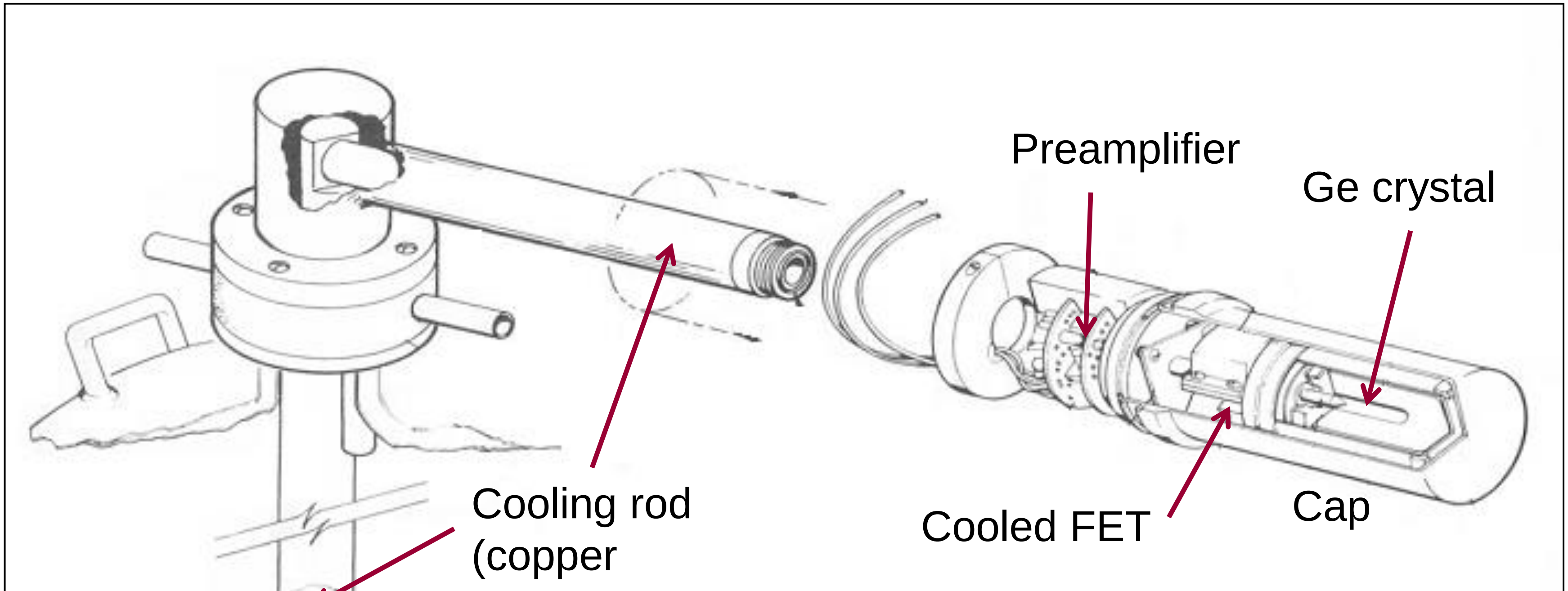
General structure of semiconductor detectors

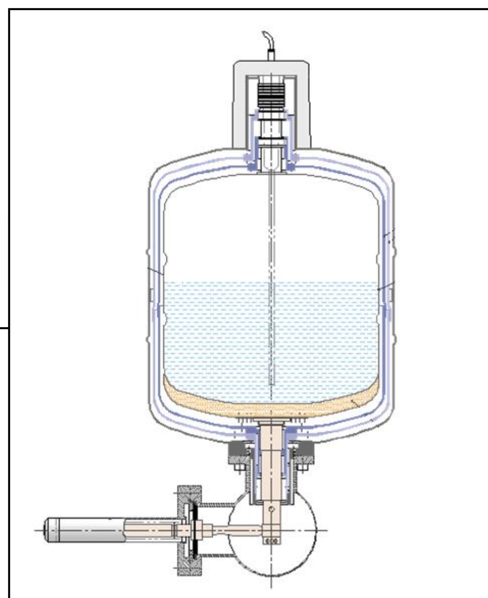


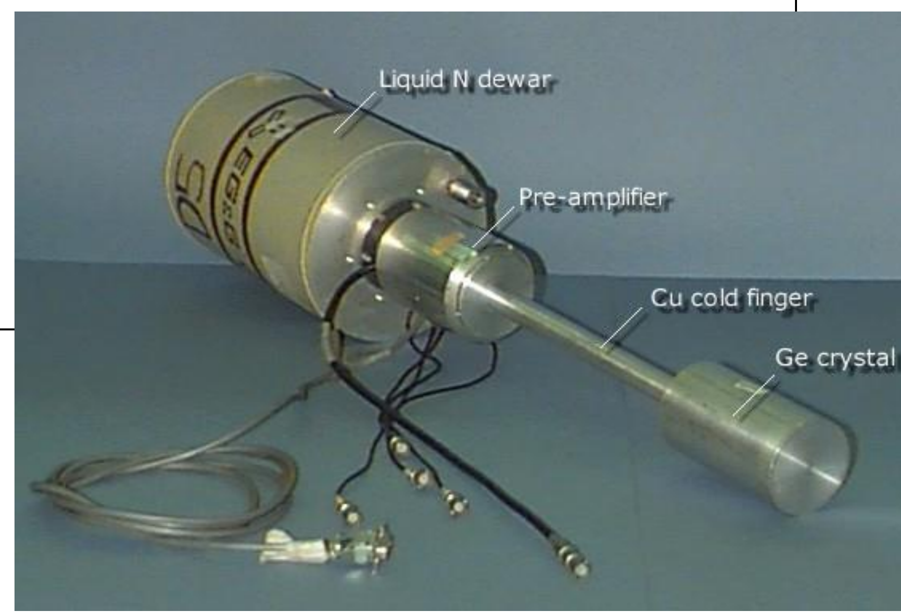
- Electrode: Au layer
- Ion implantation
- p-n junction
- High volume space charge region
- Sensitive volume: 0.2 – 50 mm

- Cooling is necessary to decrease the thermal noise
- T = 92 K liquid nitrogen temperature
- Peltier-type cooling system
- Charge collection time: $10^{-7} – 10^{-8}$ s

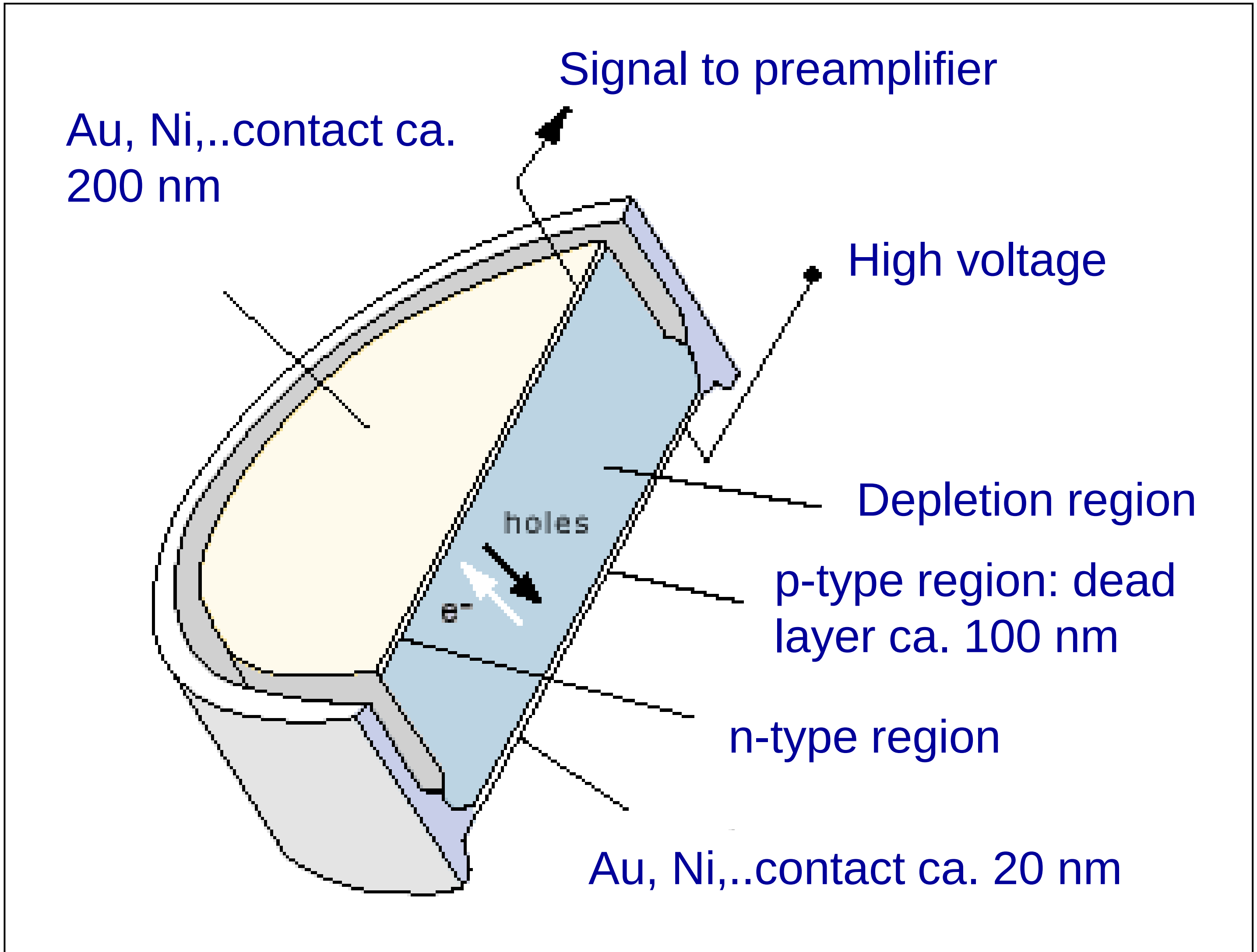
Structure of HPGe detector cooled with LN_2

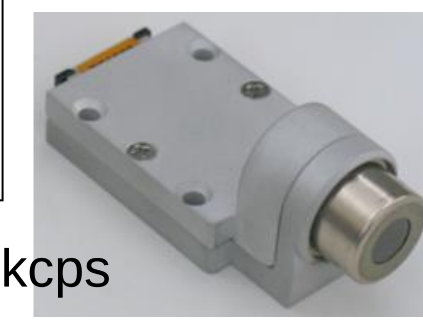






Si(Li) and Silicon Drift detectors for X-ray measurement

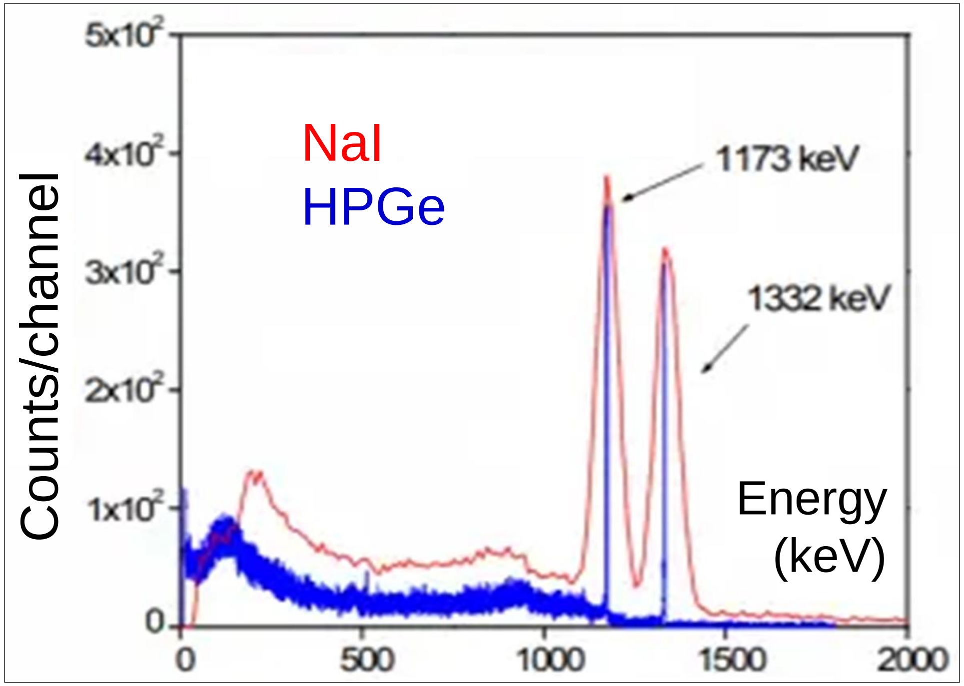


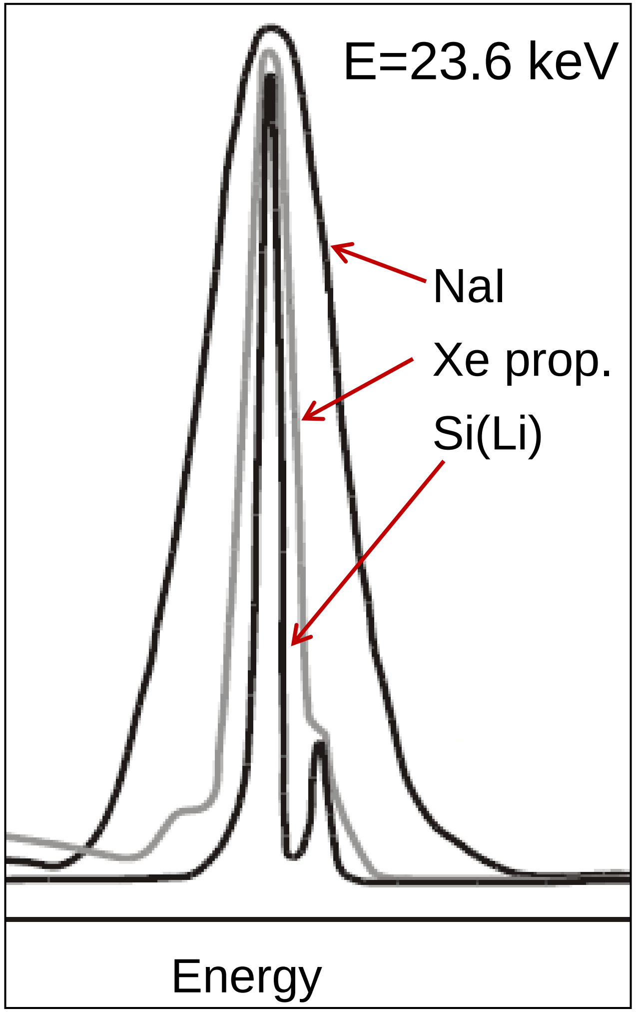


Si(Li) $\Delta E \approx 125$ eV, E = 6.4 keV, Max. count rate ≈ 20 – 50 kcps

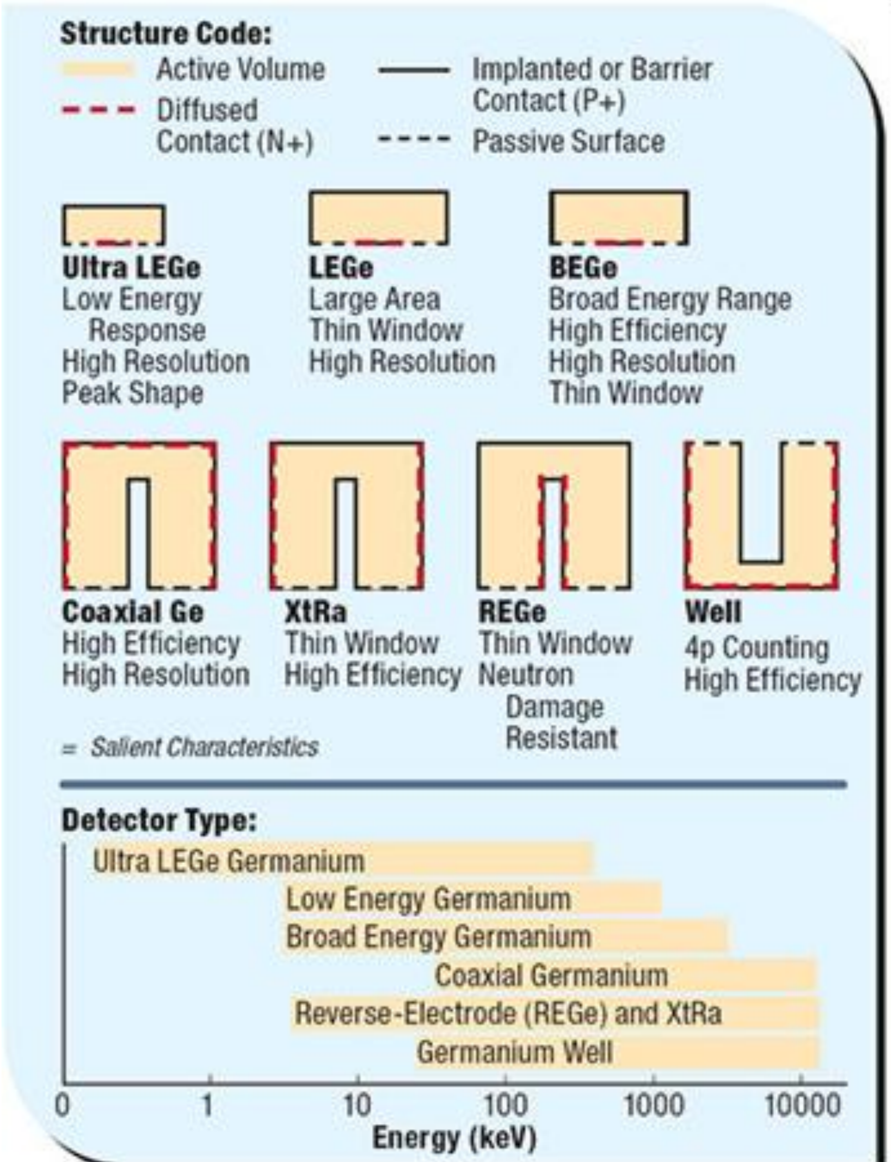
General properties of semiconductor detectors

- Solid material ⇨ higher density ⇨ higher excitation probability
- Higher density compared to the gases ⇨ higher detection efficiency
- Operation in atmospheric and vacuum condition
- First applications: 1960, Si, Ge, CdTe, HgI_2,….
- Short response time: ≈ ns!!!
- Energy resolutions

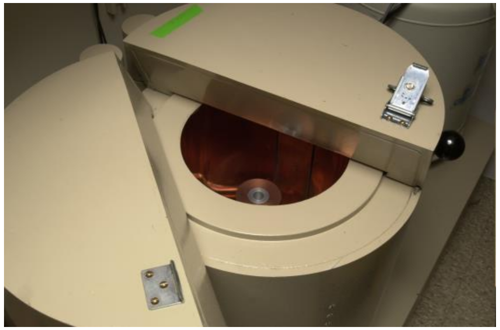


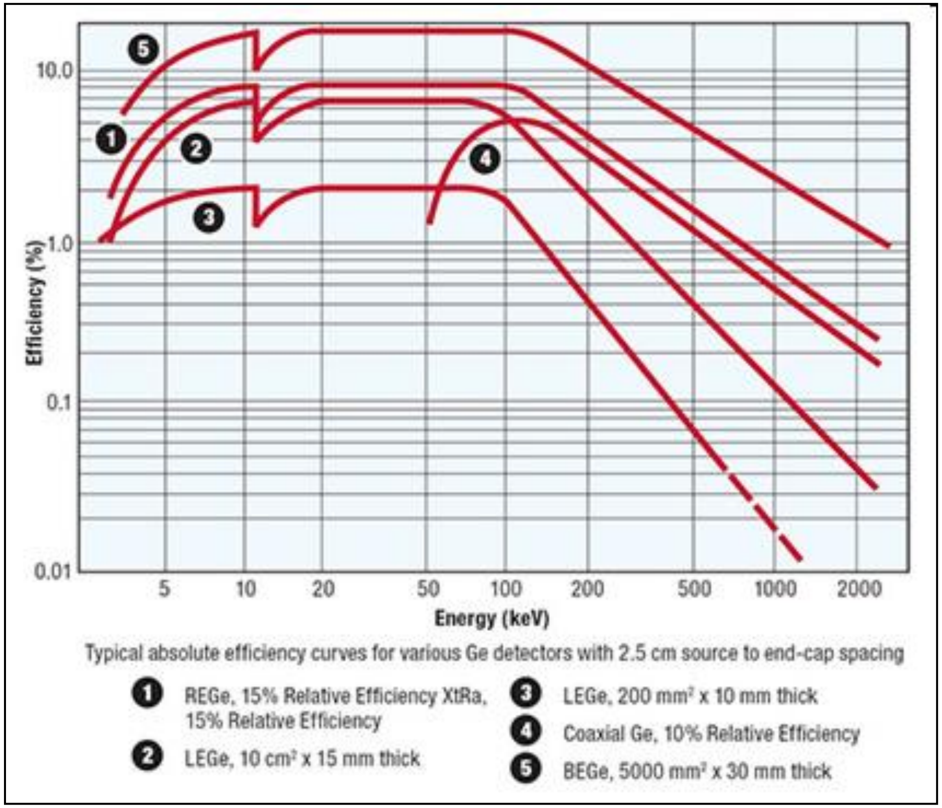


Usual geometry of HPGe detectors



- Coaxial Ge
- Well
- Planar
- REGe

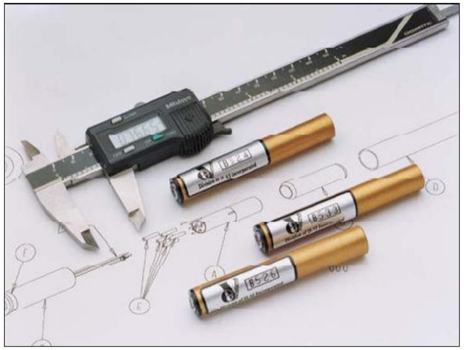


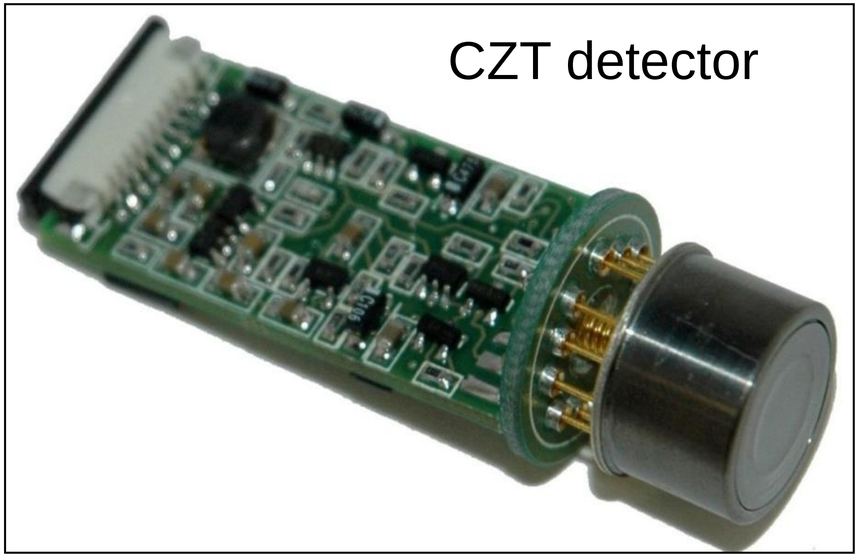


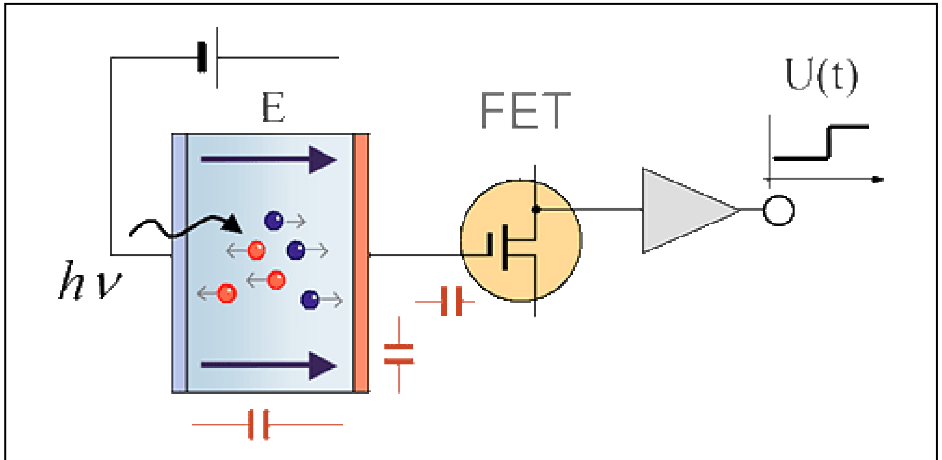
Typical absolute efficiency curves for various Ge detectors with 2.5 cm source to end-cap spacing

Si PIN and CZT (CdZnTe) detectors

- 10^2 - 10^4 times lower mass and volume than HPGe
- Low efficiency on high energy
- Operate at T= - 40-50 °C, room temperature (!)
- Extreme conditioning: space, Mars, underground deep
- High count rate without loss of resolution
- Cheap manufacturing
- Integral design on a single chip



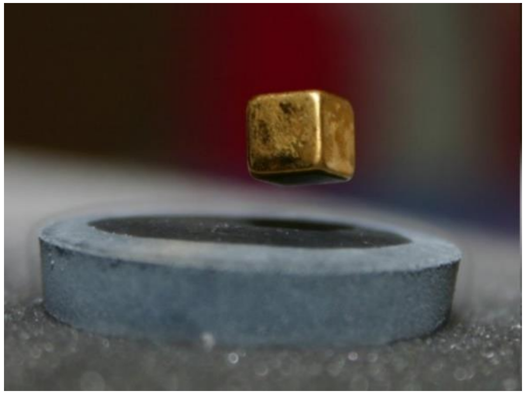


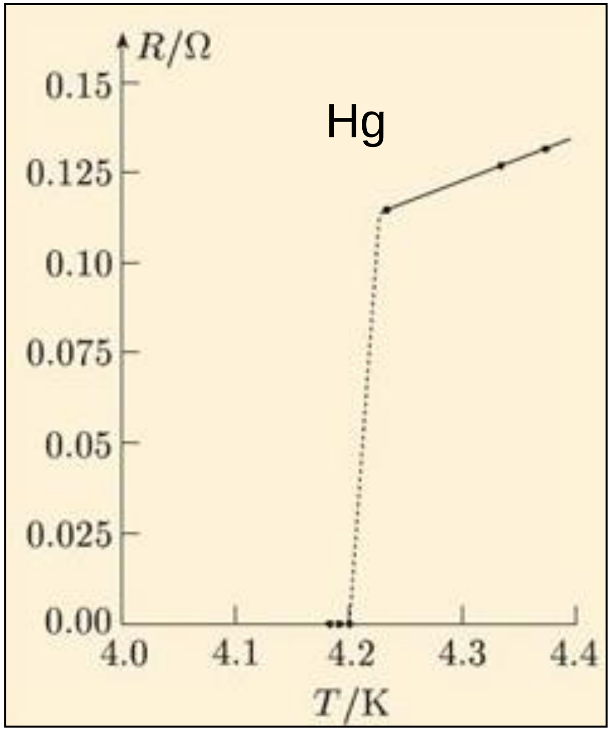


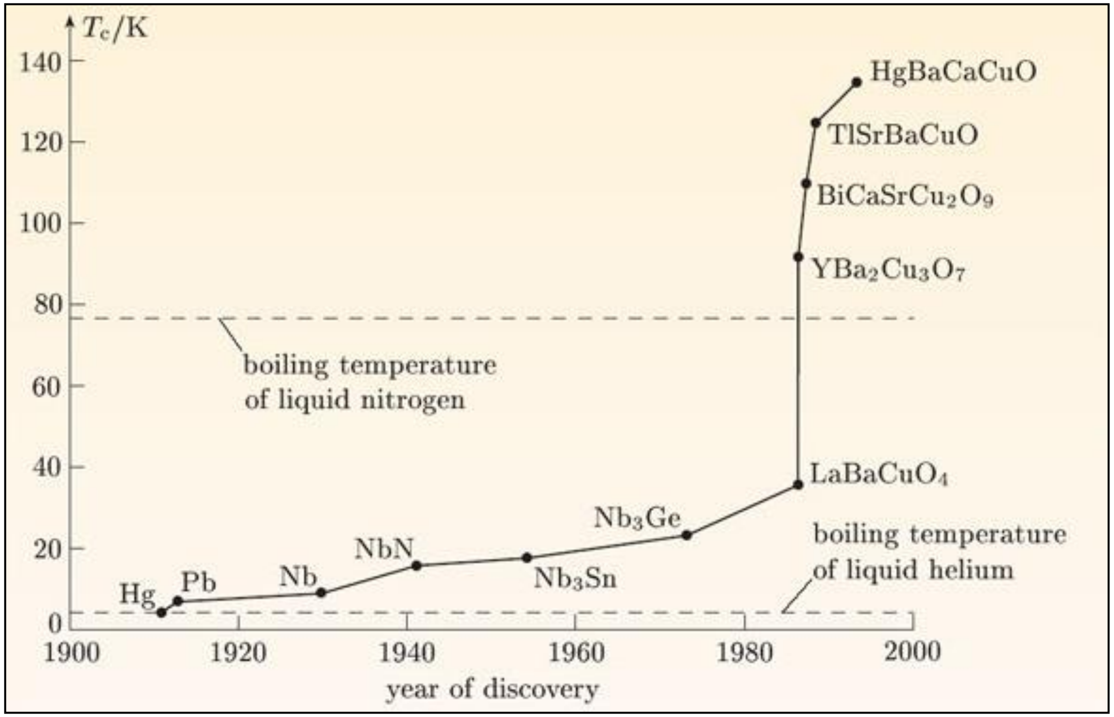
$$n_e = h\frac{\nu}{\varepsilon}$$

Superconducting detectors

- Temperature dependence of electrical resistivity
- Meissner-effect
- Critical magnetic filed







Conductor	Crit. Temp. (K)
Zn	0.79
Ga	1.1
Al	1.14
Sn	3.69
Hg	4.17
V	4.29
Pb	7.26

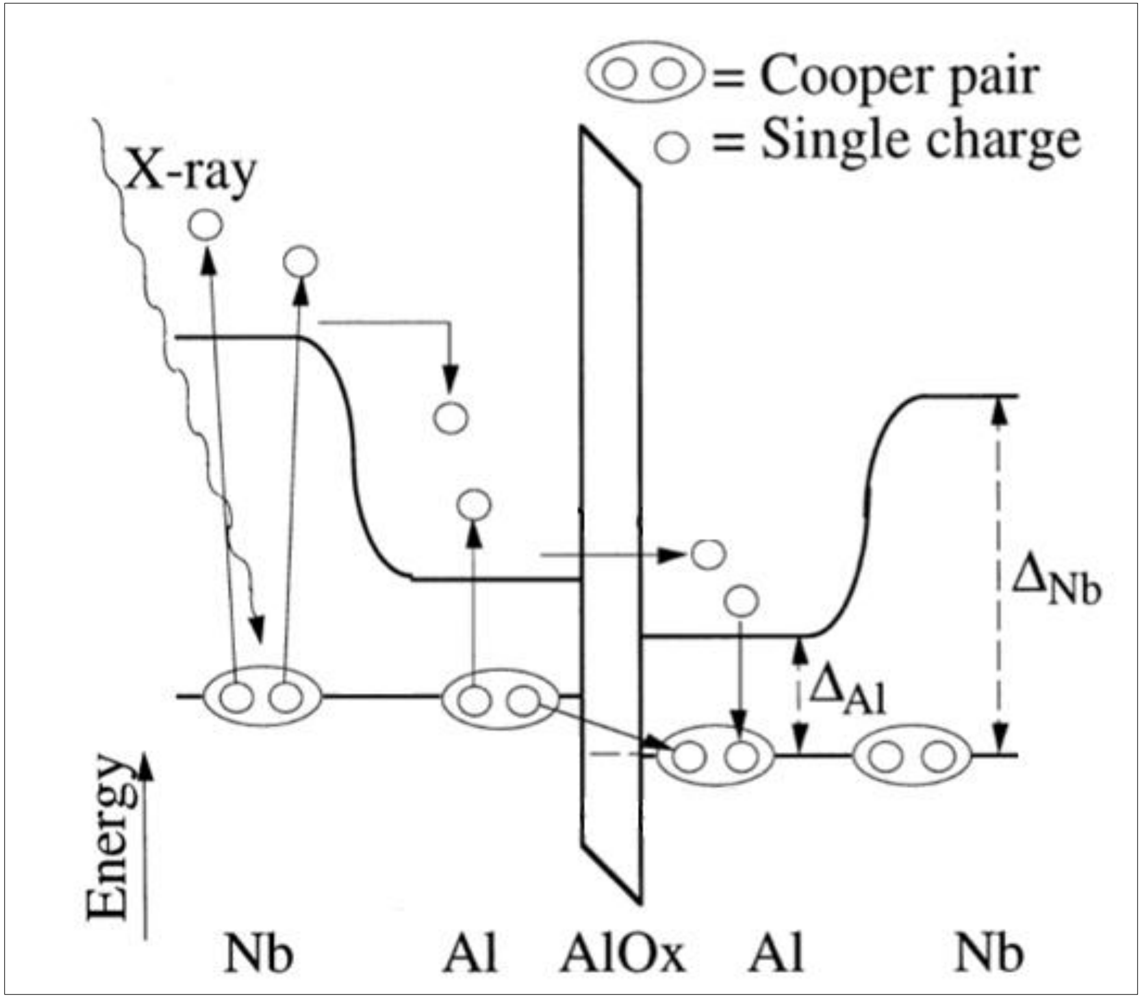
Superconductor detectors

- Superconductive Tunnel Junction = STJ
- Cooper-pairs
- $E_{binding} \approx$ 1-2 meV
- FWHM ≈ 5-15 eV

  E= 100 eV < E < 10 keV
- Count rate: < 100-200 cps
- Cooling: He, N_2
- Surface ≈ 140x140μm²

$$\frac{\Delta E}{E} \sim \frac{1}{\sqrt{N}} \qquad E_{Cooper} = 1.76kT_c$$

$$\Rightarrow \qquad E_{Cooper} \approx 10^{-3} - 10^{-5}\, eV$$



G. Angloher, *Nuclear Instruments and Methods in Physics Research A*,512, 401,2003