



Gamma-ray Spectrometry

Basic Concepts I – Interactions of gamma-ray with matter

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Obligatory slide

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Alpha-particle



Beta-particle



Gamma-rays



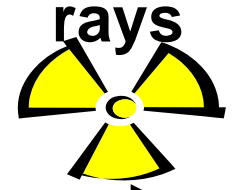
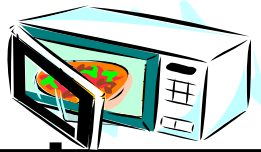
Radiowaves

Microwaves

Light

X-rays

Gamma-rays



micro-
eV

meV

eV
(electron-Volt)

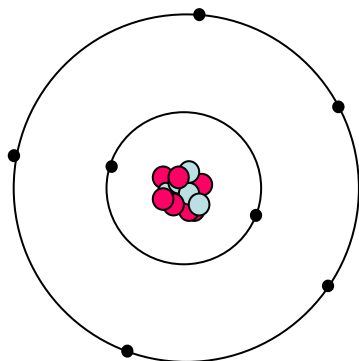
keV

MeV

Photon Energy

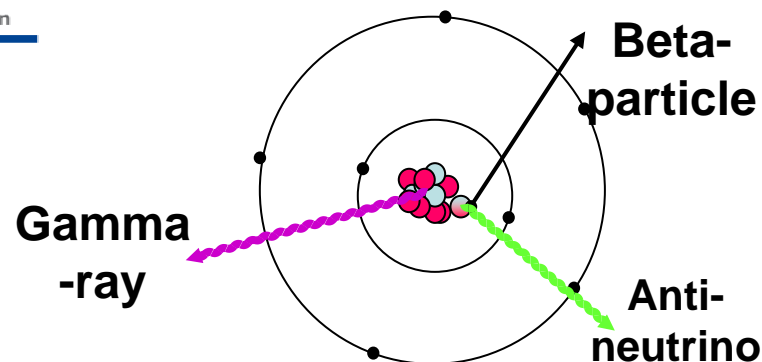
Radioactivity

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A stable atom

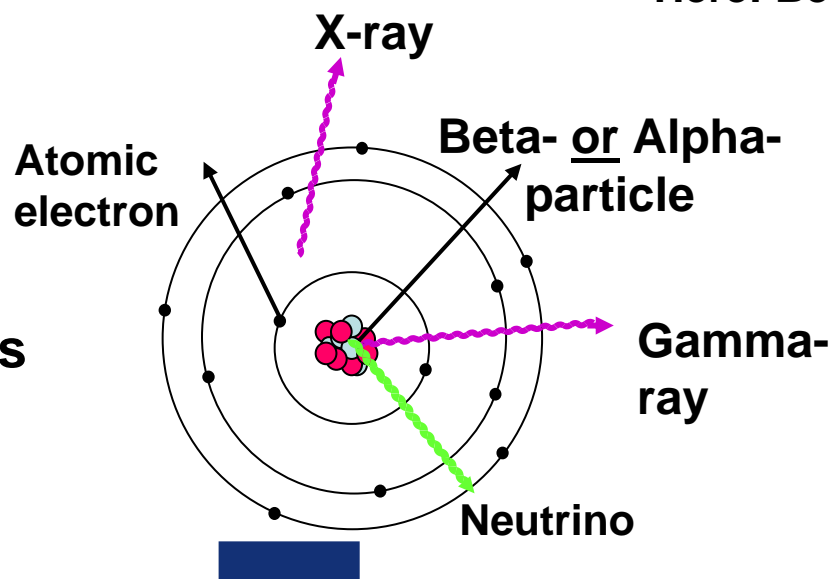
The electrons circulate
around the nucleus in
certain shells



An unstable atom = a radionuclide

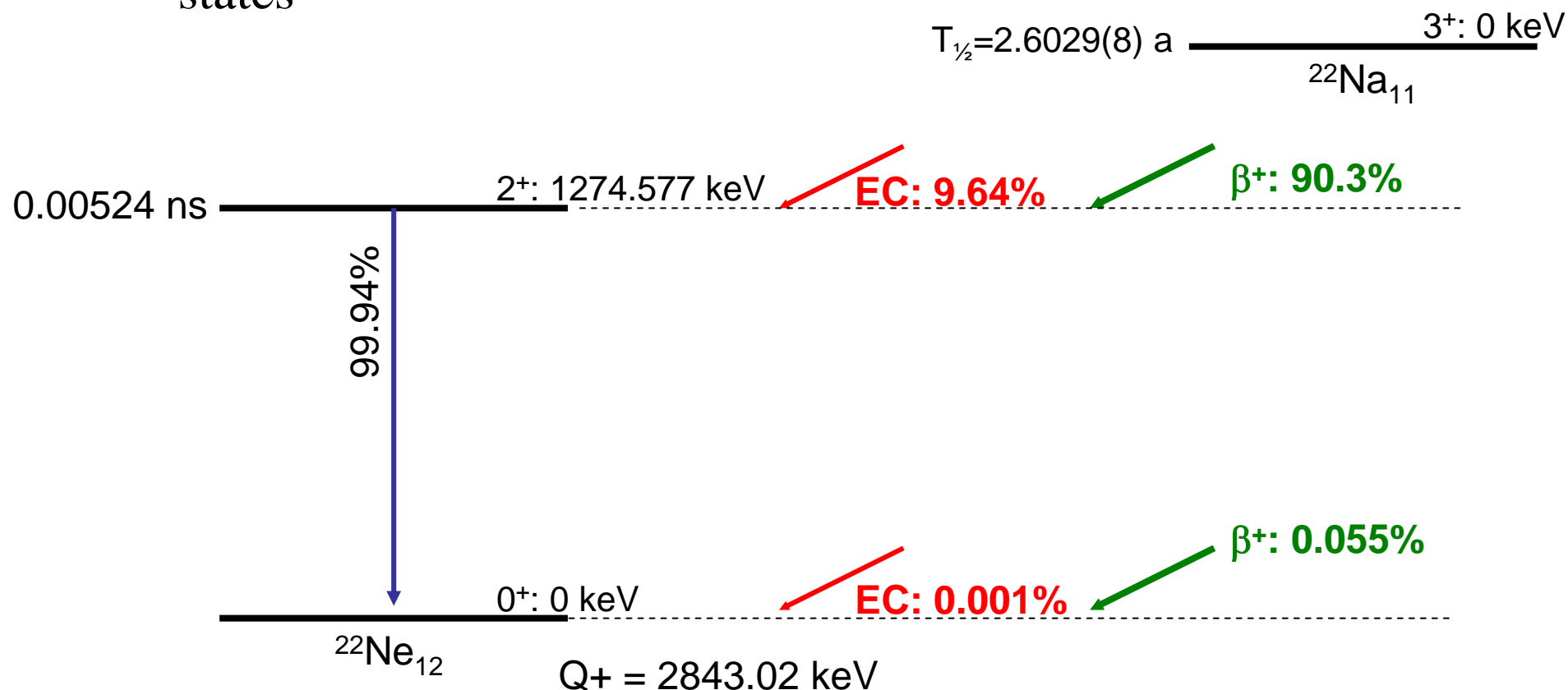
Here: Beta-decay

When a radionuclide decays
many different types of
radiation can be emitted





- Emitted in the de-excitation of nuclear states populated in either alpha or beta decay.
- Their energies are defined by the energies of the nuclear states





Gamma Rays

- Typically 0.1-10 MeV

$$E_i = E_f + E_\gamma + T_R$$

Recoil kinetic energy of
the nucleus

$$0 = p_R + p_\gamma$$

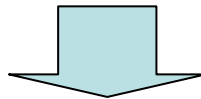
Conservation of momentum:

$$E_\gamma = Mc^2 \left[-1 \pm \left(1 + 2 \frac{\Delta E}{Mc^2} \right)^{1/2} \right]$$

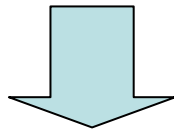


Gamma Rays

Since: ΔE are typically of the order of MeV, while the rest energies Mc^2 are order of $A \times 10^3$ MeV, A is mass number.



$$\Delta E \ll Mc^2$$



$$E_{\gamma} \cong \Delta E - \frac{(\Delta E)^2}{2Mc^2} \quad \Rightarrow \quad E_{\gamma} \cong \Delta E$$



Gamma Rays

Selection rules for gamma-ray transitions

Type	Symbol	Angular momentum change, l	Parity change
Electric dipole	$E1$	1	yes
Magnetic dipole	$M1$	1	no
Electric quadrupole	$E2$	2	no
Magnetic quadrupole	$M2$	2	yes
Electric octupole	$E3$	3	yes
Magnetic octupole	$M3$	3	no
Electric 16-pole	$E4$	4	no
Magnetic 16-pole	$M4$	4	yes



Gamma Rays

Selection rules for gamma-ray transitions

Useful for a lot of calculations. E.g. conversion coefficients:

See e.g. <http://www.nndc.bnl.gov/>



Gamma Rays

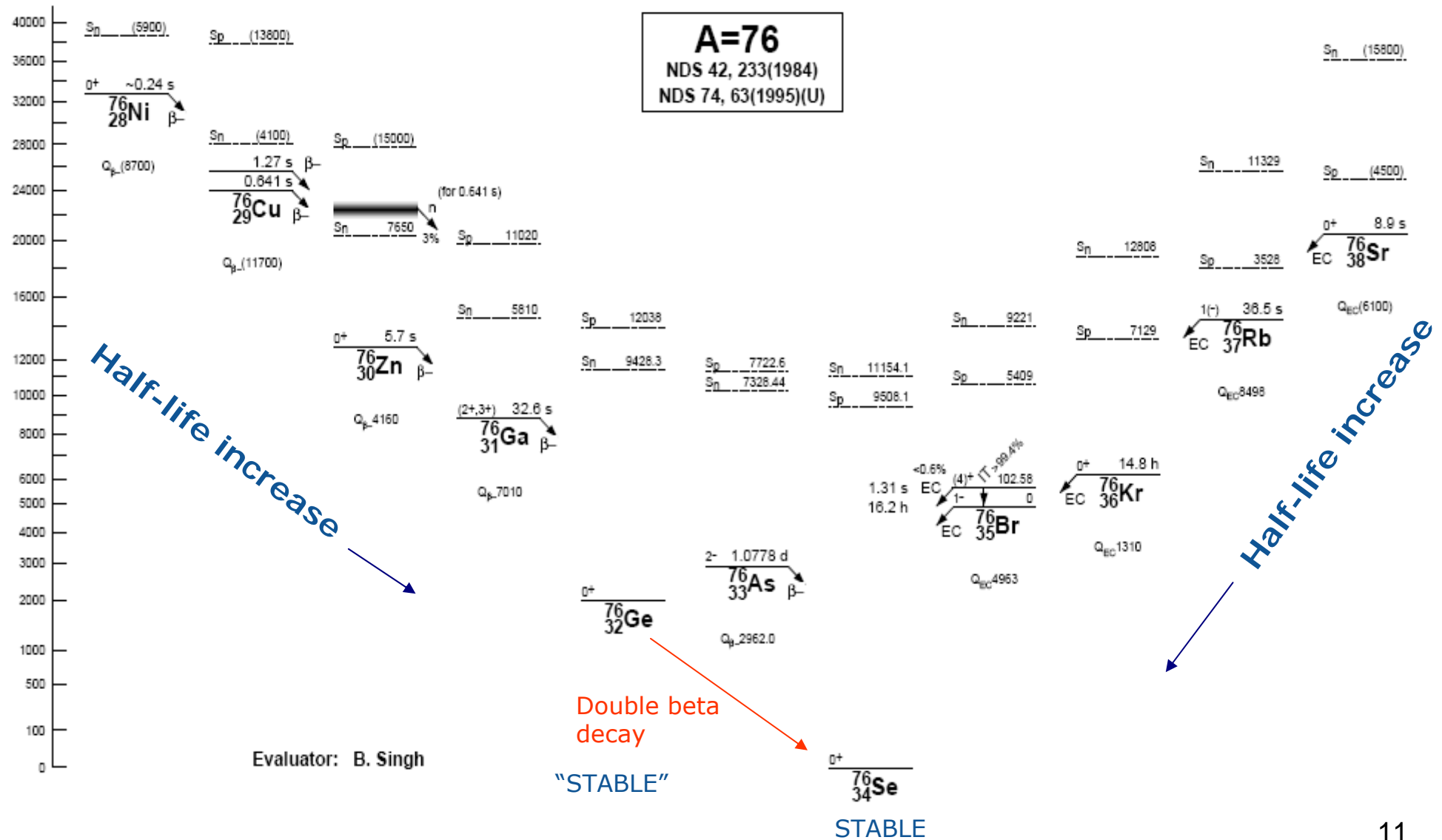
Depending on the initial and final state each gamma-ray has a description:

E1, M1, E2, M2, E3, M3 etc.

E.g. a 2^+ to 0^+ transition: No parity change, Angular momentum changes by 2 \Rightarrow E2 transition

Gamma Rays

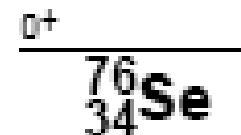
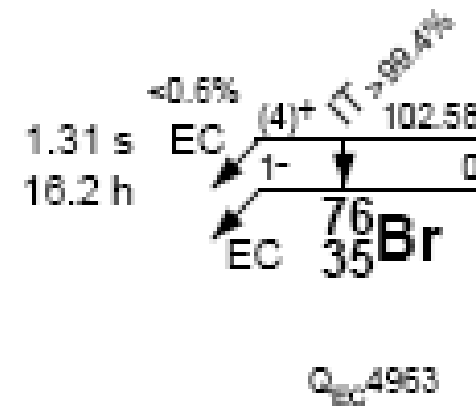
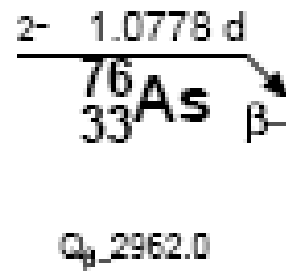
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Internal transition

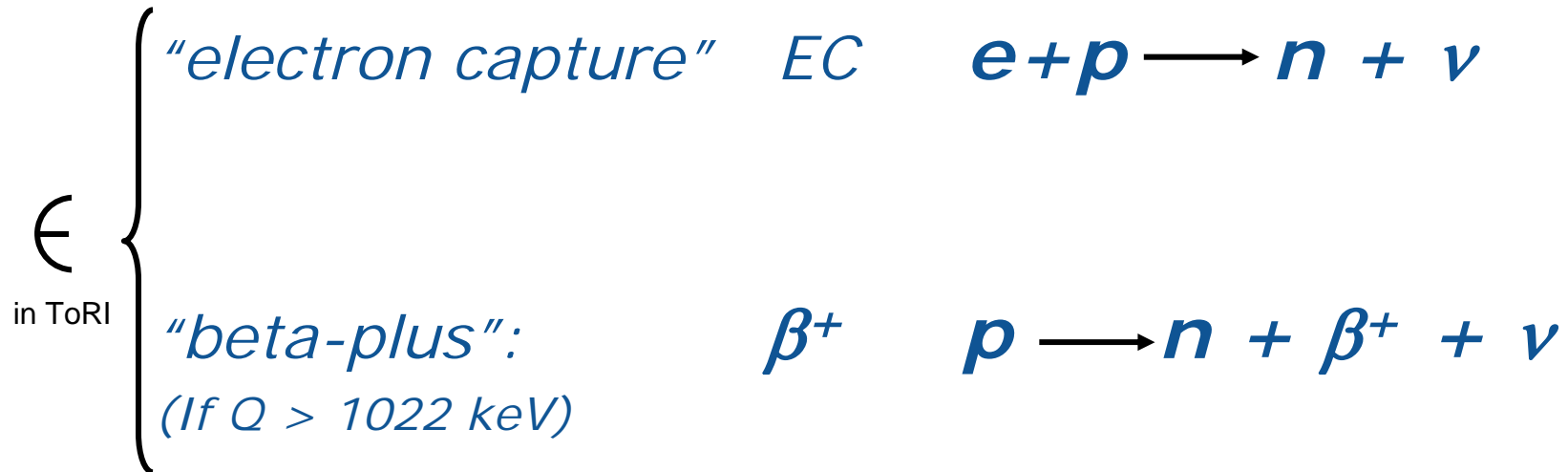
Isomeric state





Beta decay

"beta-minus":

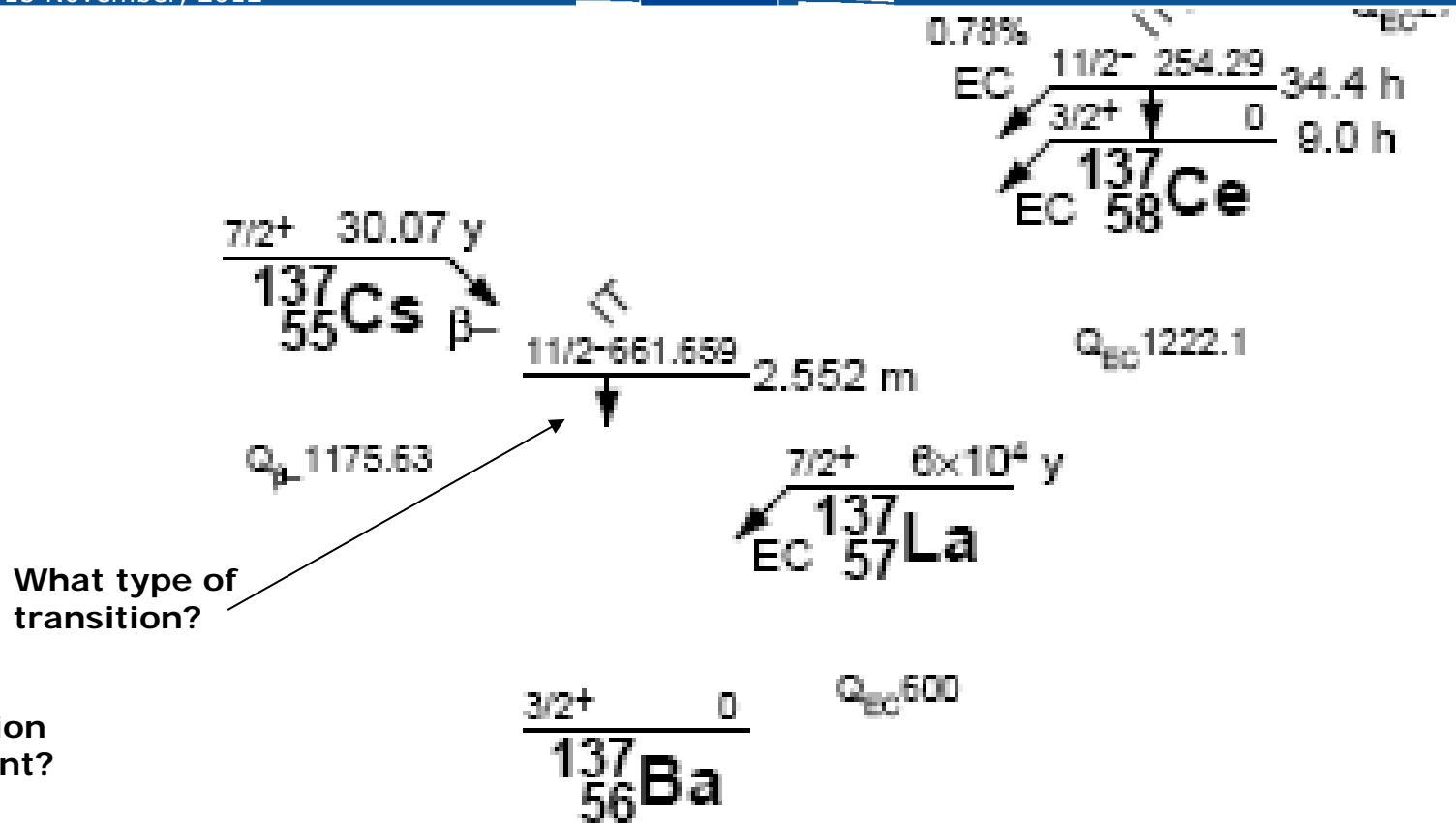




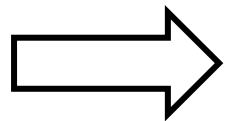
Beta decay



Some radionuclides can decay with several different beta decays



<http://ie.lbl.gov/toi/nuclide.asp?iZA=560437>



One cannot measure ^{137}Cs using (normal) $4\pi\beta\gamma$ coincidence technique



Interactions of Gamma Rays with Matter

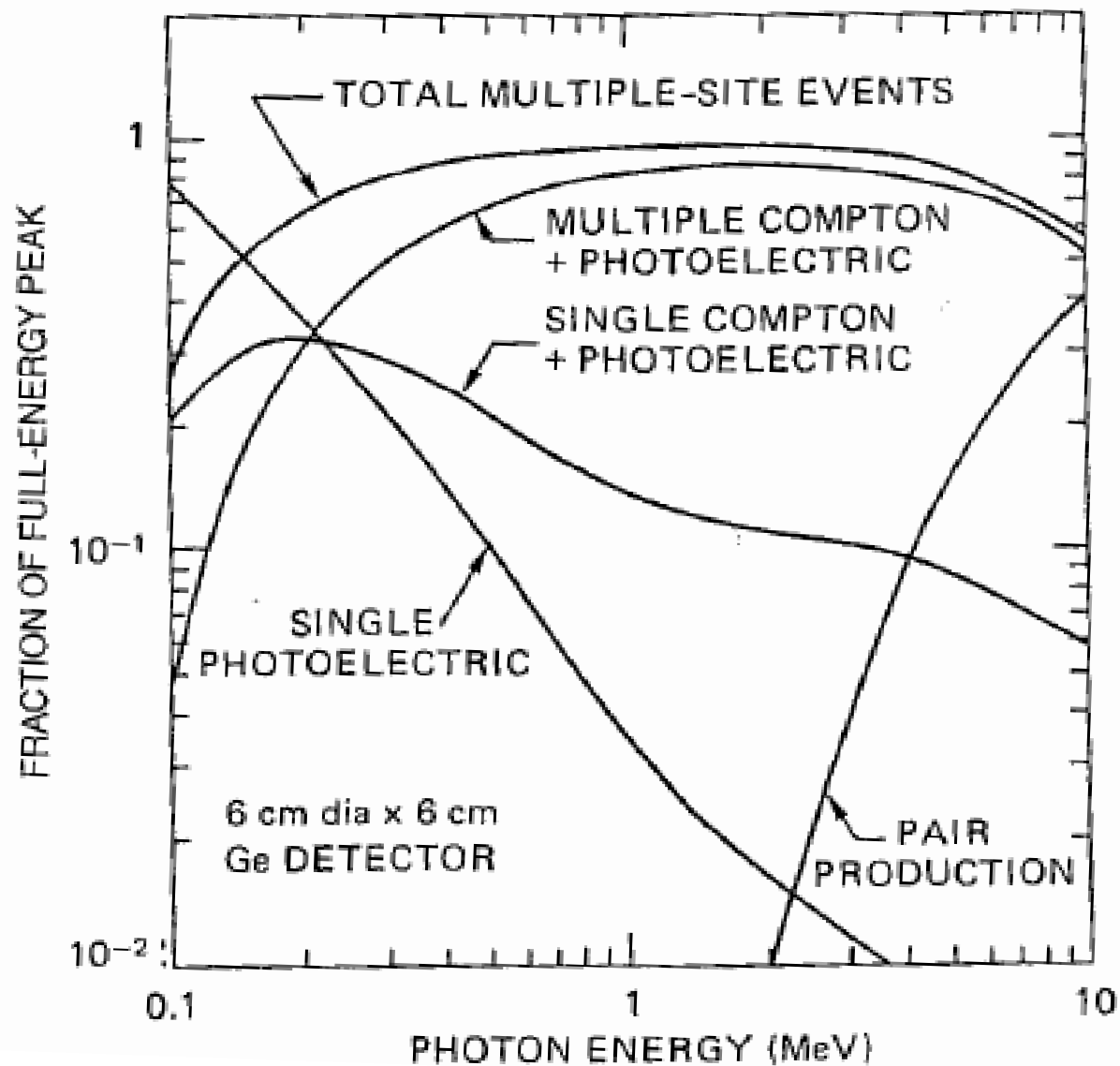
- The interactions of gamma rays with matter all produce high energy electrons which cause measurable ionisation in the material through which they pass.



Interactions of Gamma Rays with Matter

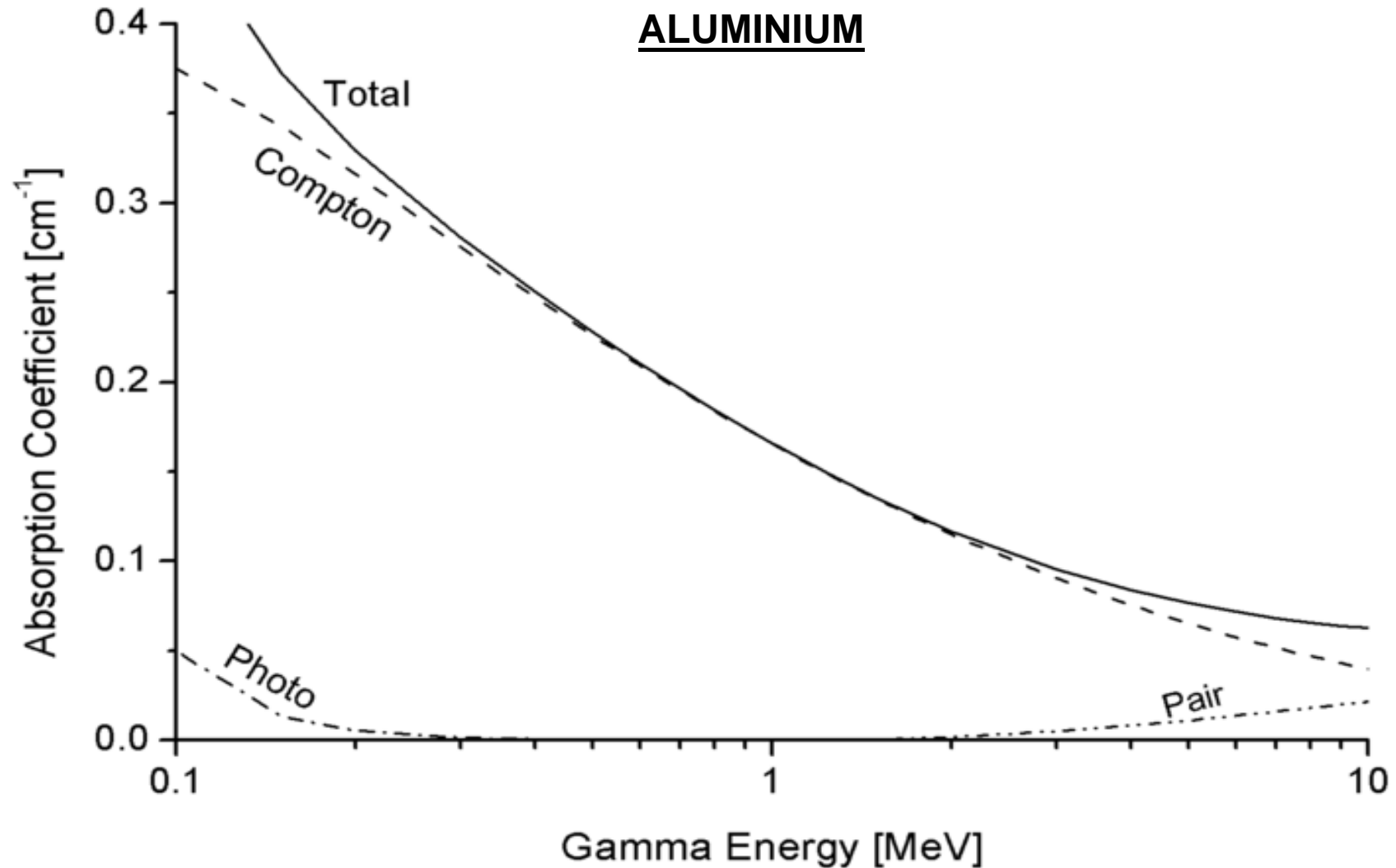
- Photoelectric effect
- Compton effect
- Pair production

Interactions of Gamma Rays with Matter

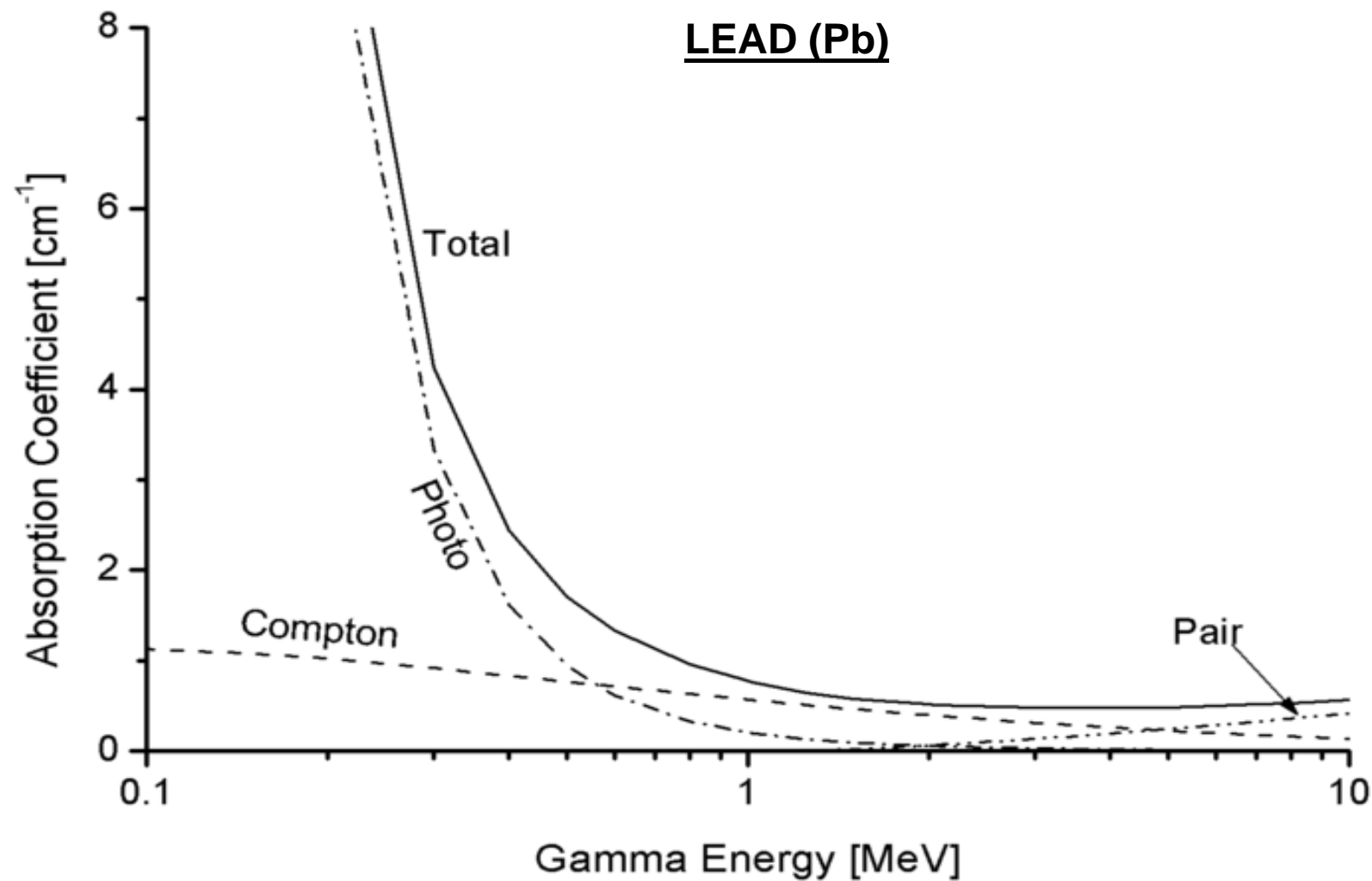


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"Radiation
Detection and
Measurements"

Interactions of Gamma Rays with Matter



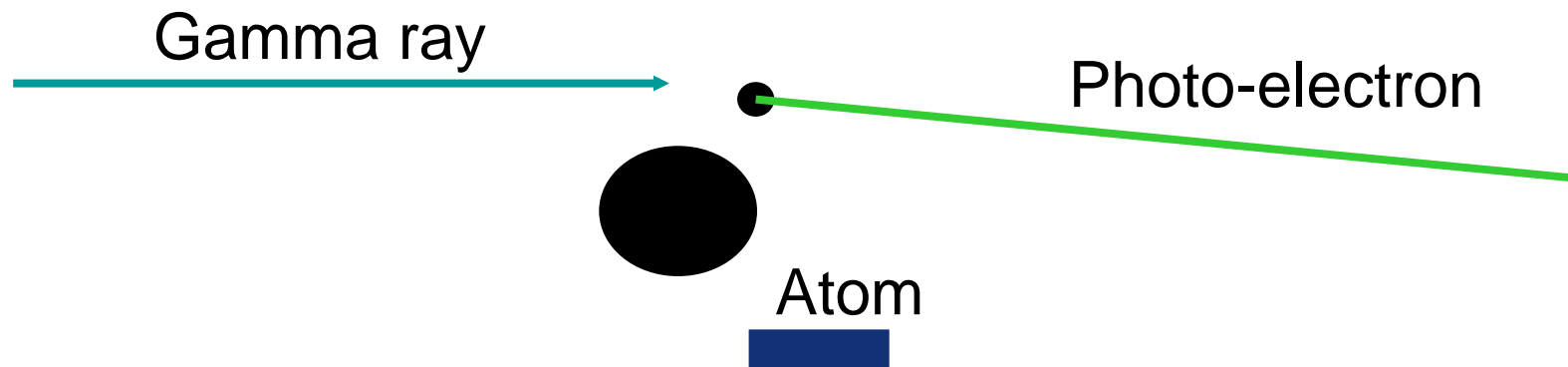
Interactions of Gamma Rays with Matter





Interactions of Gamma Rays with Matter

- ♦ **Photoelectric Effect**
- ♦ The gamma-ray gives up all its energy to a bound electron;
- ♦ energy and momentum cannot be simultaneously conserved in such a reaction with a free electron.





Photoelectric Effect

- ♦ Conservation of energy:

$$E_e = E_\gamma - E_b$$

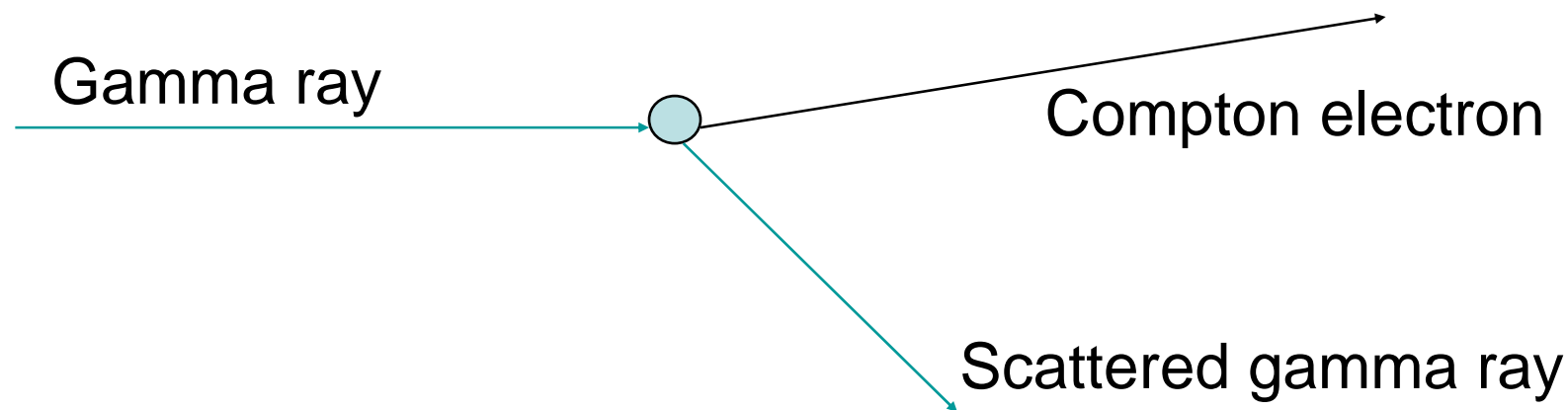
where E_b is the electron binding energy.

- ♦ The photoelectric effect is most important at low gamma ray energies and for high atomic number materials.



Interactions of gamma rays with matter

- **Compton Scattering** is an interaction between a gamma ray and an electron where the gamma ray gives up part of its energy to the electron.
- This interaction may occur with free electrons.





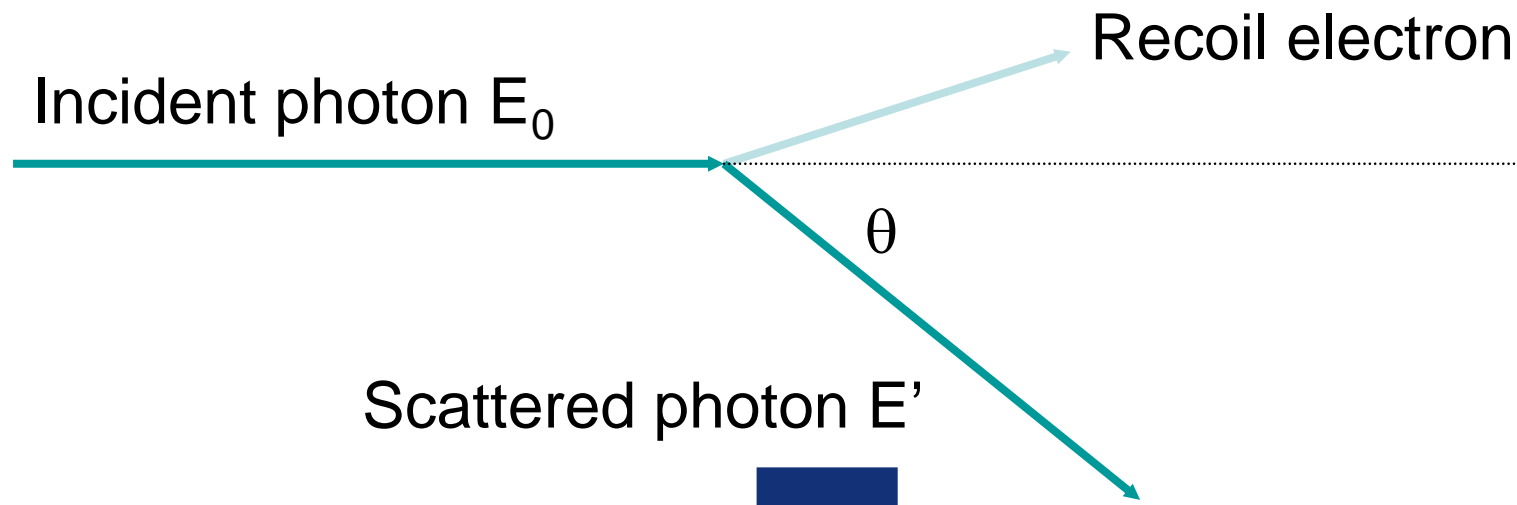
Compton Scattering

- In this reaction, the outgoing electron can have an energy between zero (gamma ray continues with the same energy and direction) and a maximum value when the gamma ray is scattered through 180° .
- Compton scattering dominates for intermediate gamma ray energies (100 keV – 10 MeV) and for low to medium atomic number materials.



Compton Scattering

$$E' = \frac{E_0}{1 + \frac{E_0}{m_0 c^2} (1 - \cos \theta)}$$

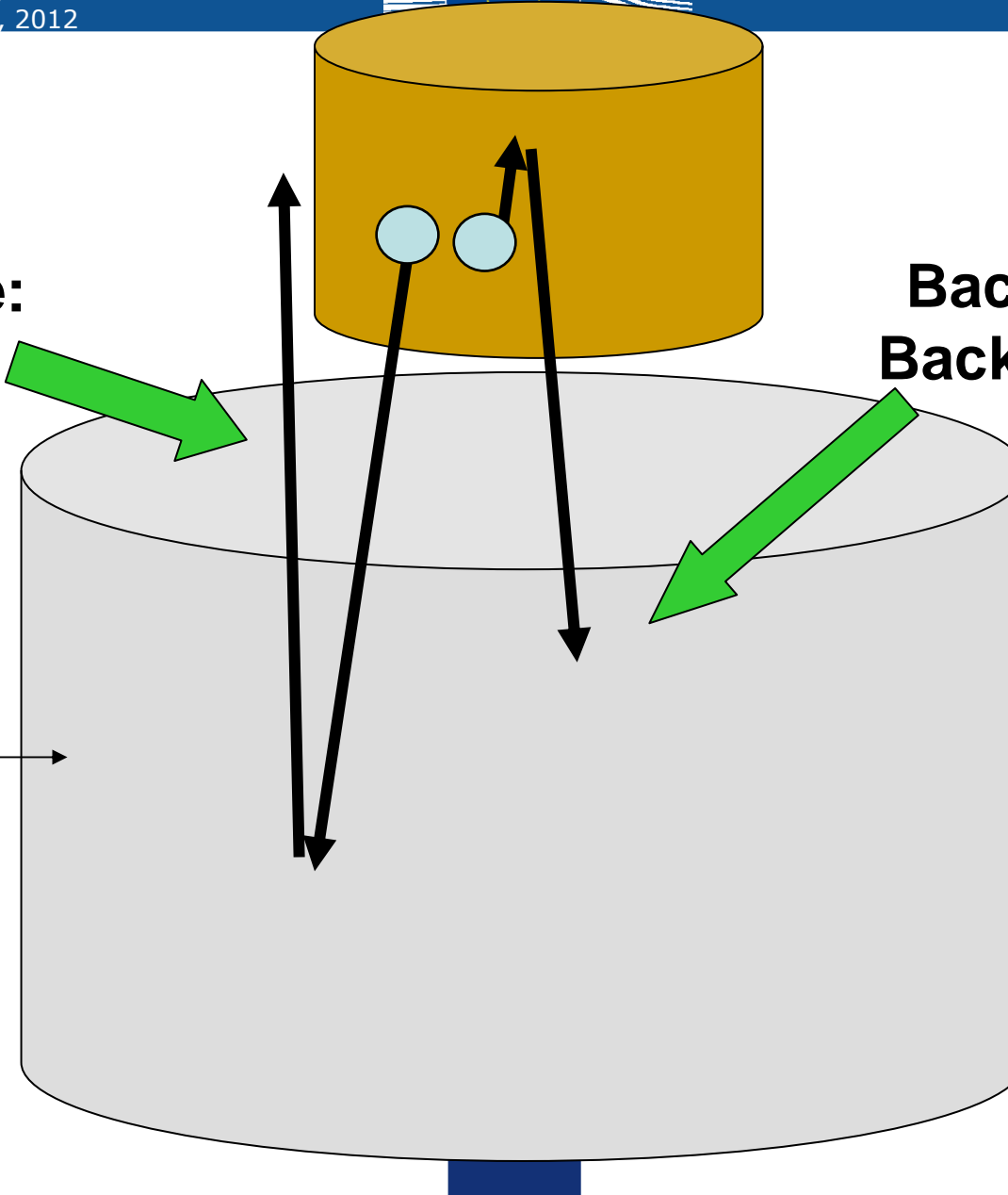




**Compton edge:
Backscatter
inside crystal**

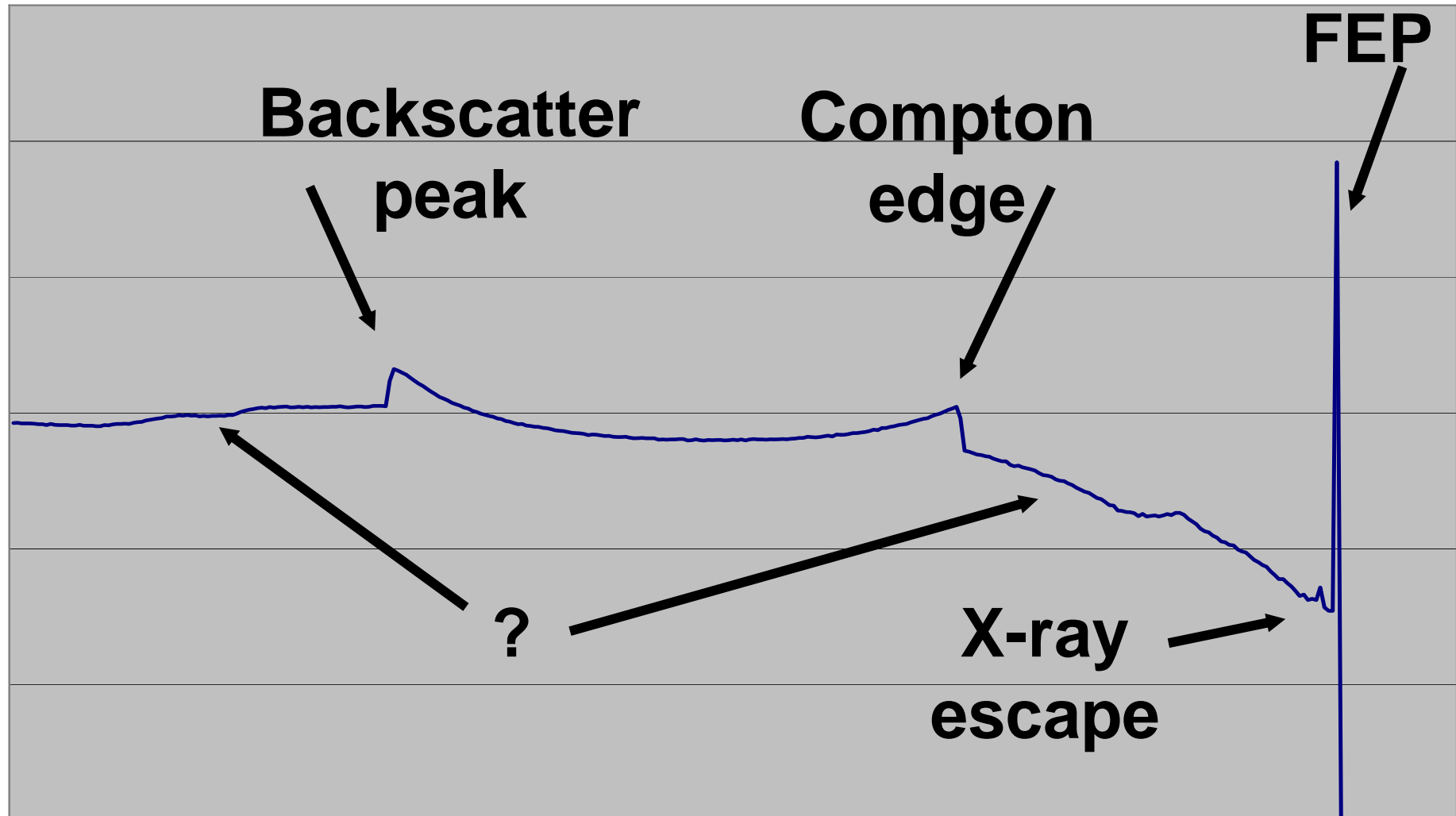
**Backscatter peak:
Backscatter outside
crystal**

Detector →



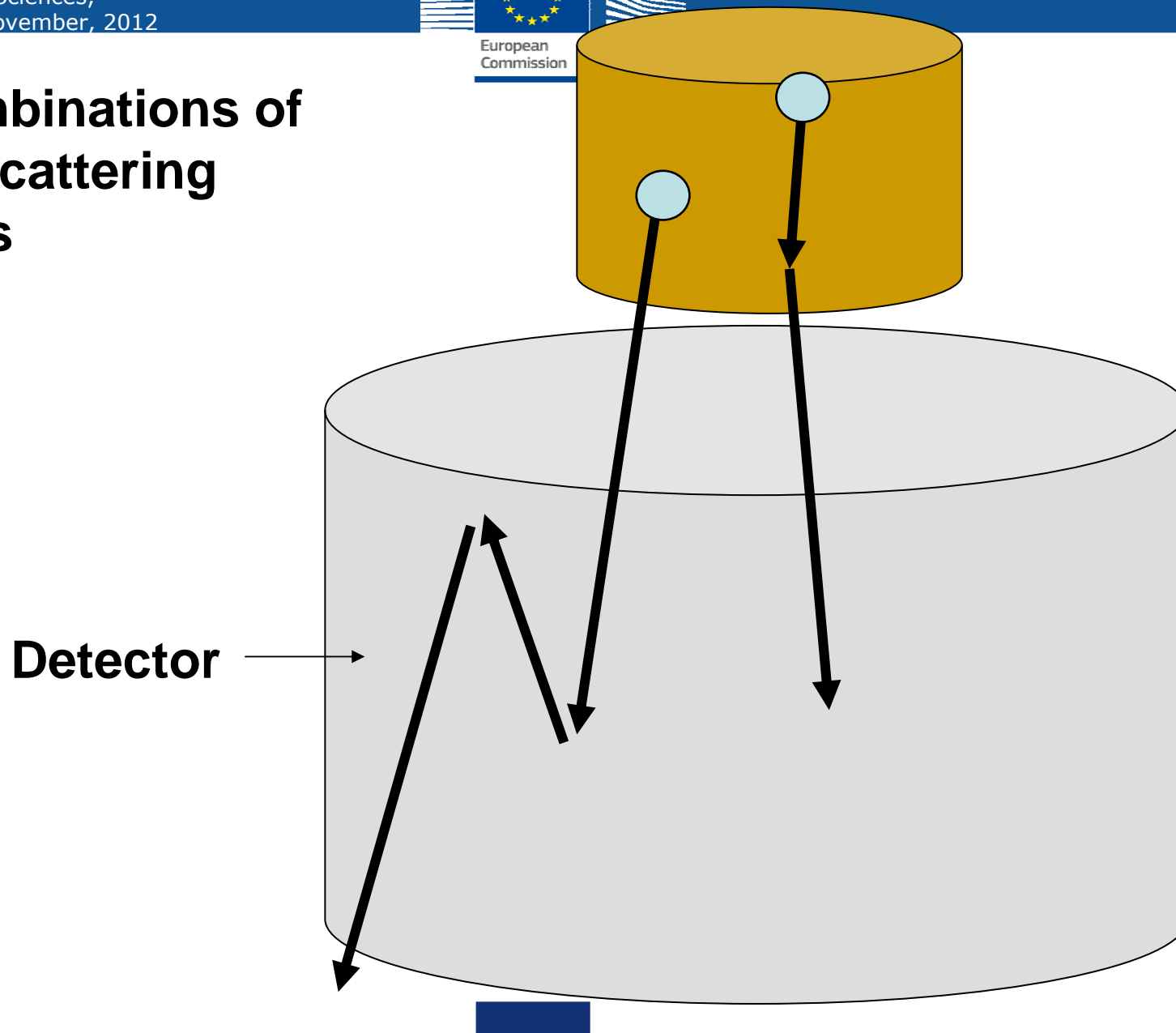


HPGe-response function





Many combinations of multiple scattering processes

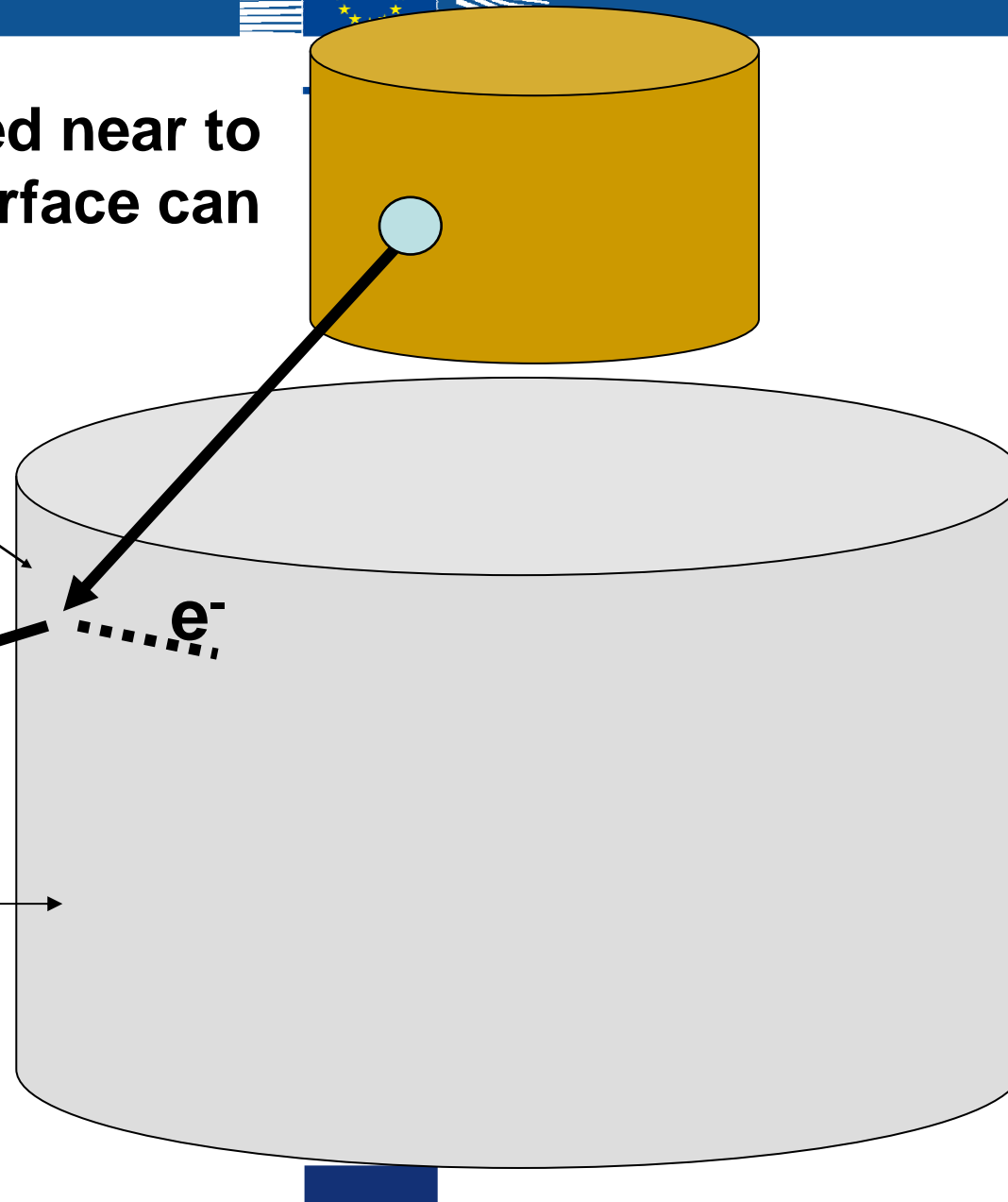




**An X-ray created near to
the detector surface can
easily escape**

Photoeffect

**X-ray
Detector**

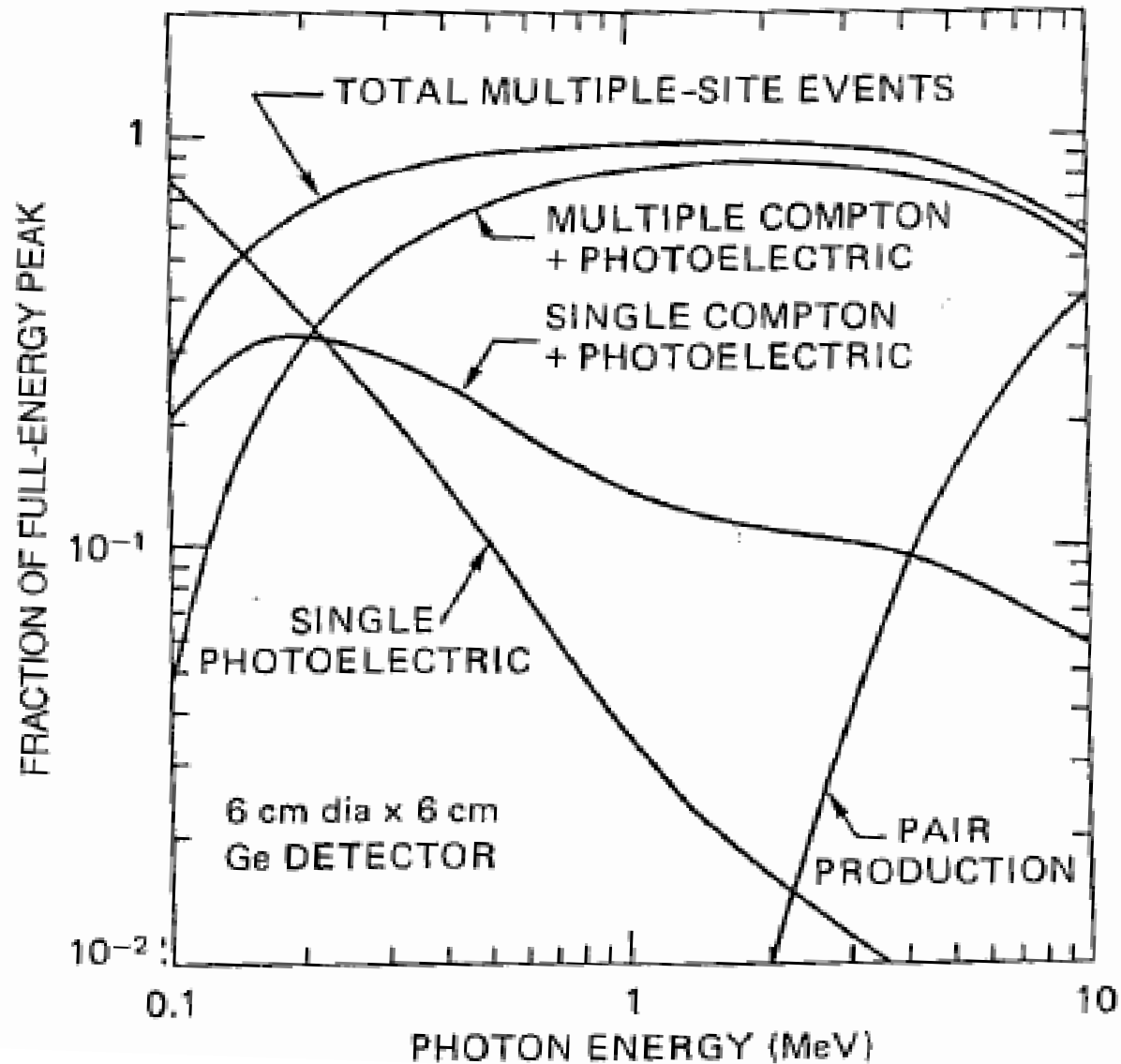




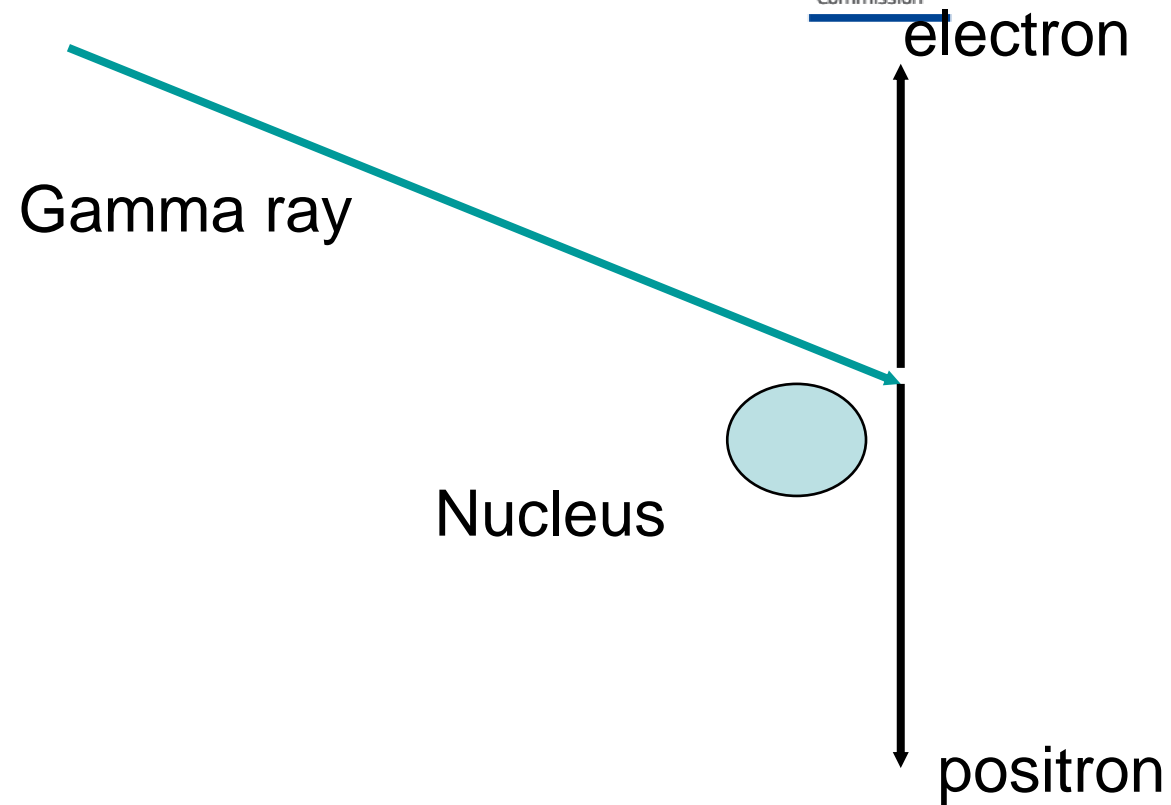
Pair Production

- In this reaction the gamma ray interacts with the Coulomb field of a nucleus to produce an electron-positron pair.
- The gamma ray energy must be greater than the the energy corresponding to the rest mass of two electrons, i.e. $2 \times 511 \text{ keV} = 1022 \text{ keV}$.
- Pair production becomes the most important interaction for gamma rays above a few MeV.

Interactions of Gamma Rays with Matter



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Pair Production

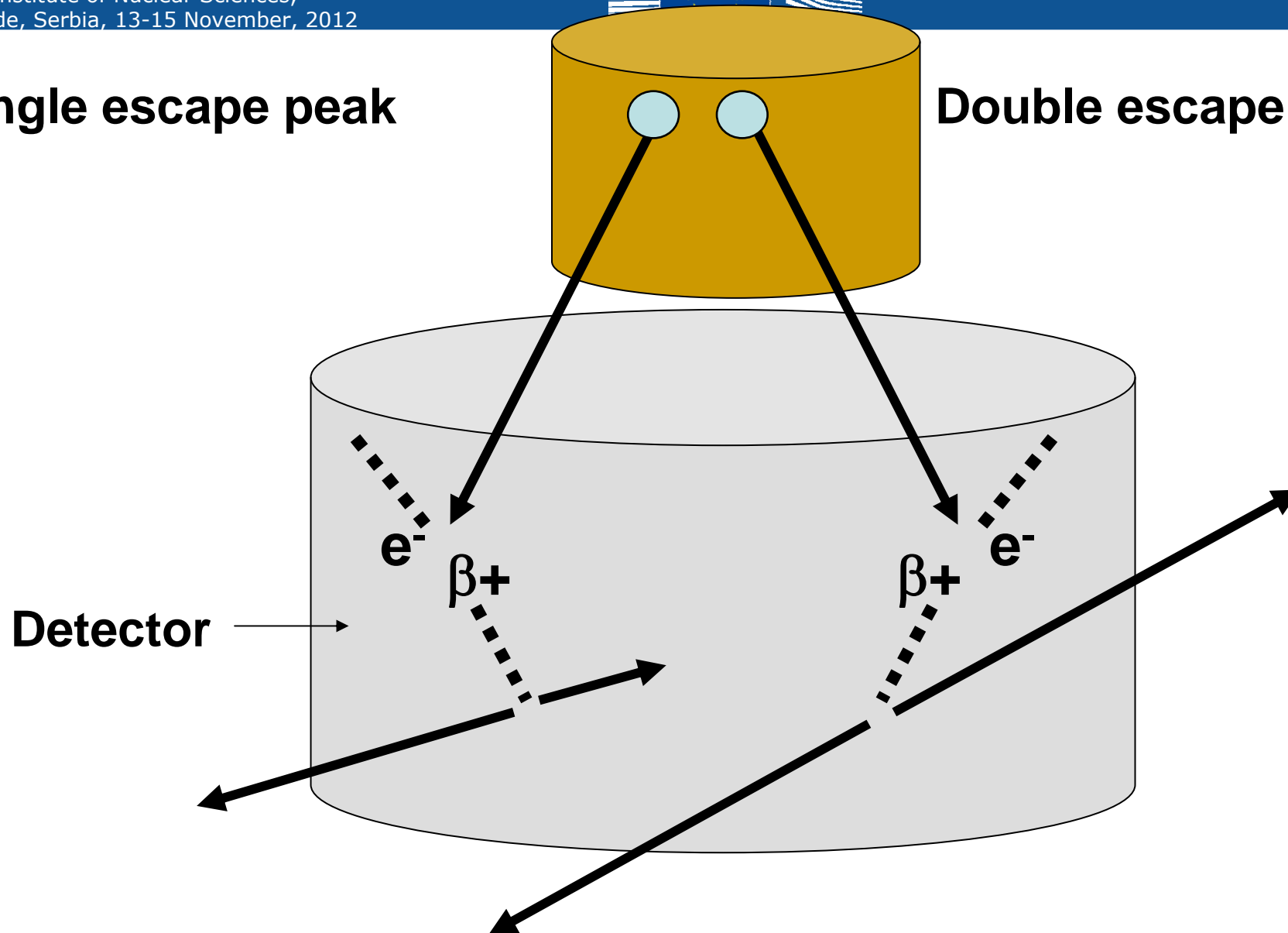
For $E > 1022 \text{ keV}$

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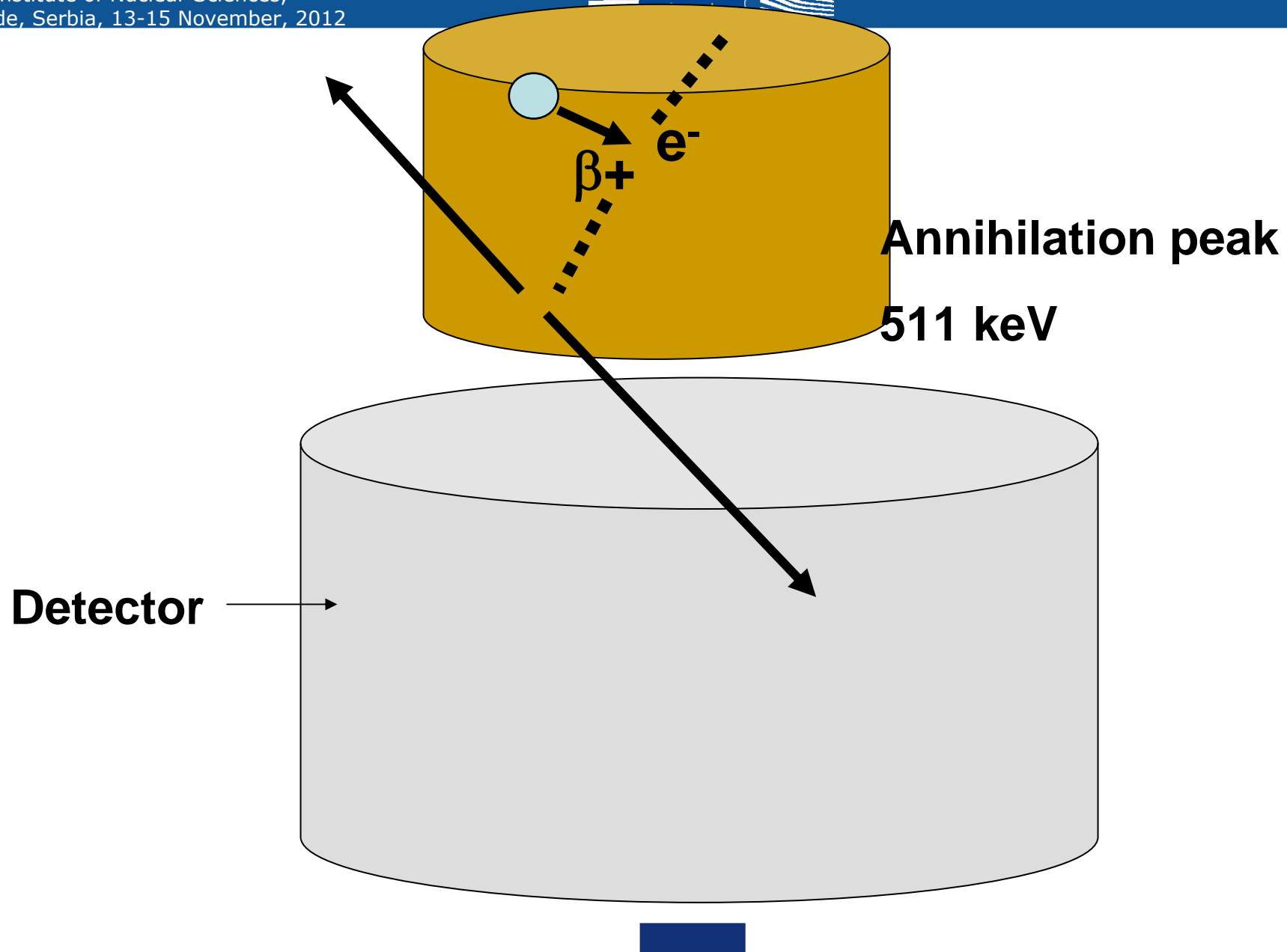
Single escape peak

Double escape peak



For $E > 1022 \text{ keV}$

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Spectrum from a gamma ray detector

- What you really measure in a gamma ray spectrometer is the energies of the electrons produced by the gamma ray interactions described above.
- **Photopeak**: produced by the total absorption of the gamma ray energy in the detector.
Better word: Full energy peak or FEP



Spectrum from a gamma ray detector

- **Compton continuum**: at energies lower than the FEP we see a continuum resulting from mainly Compton interactions where only part of the gamma ray energy has been deposited in the detector.

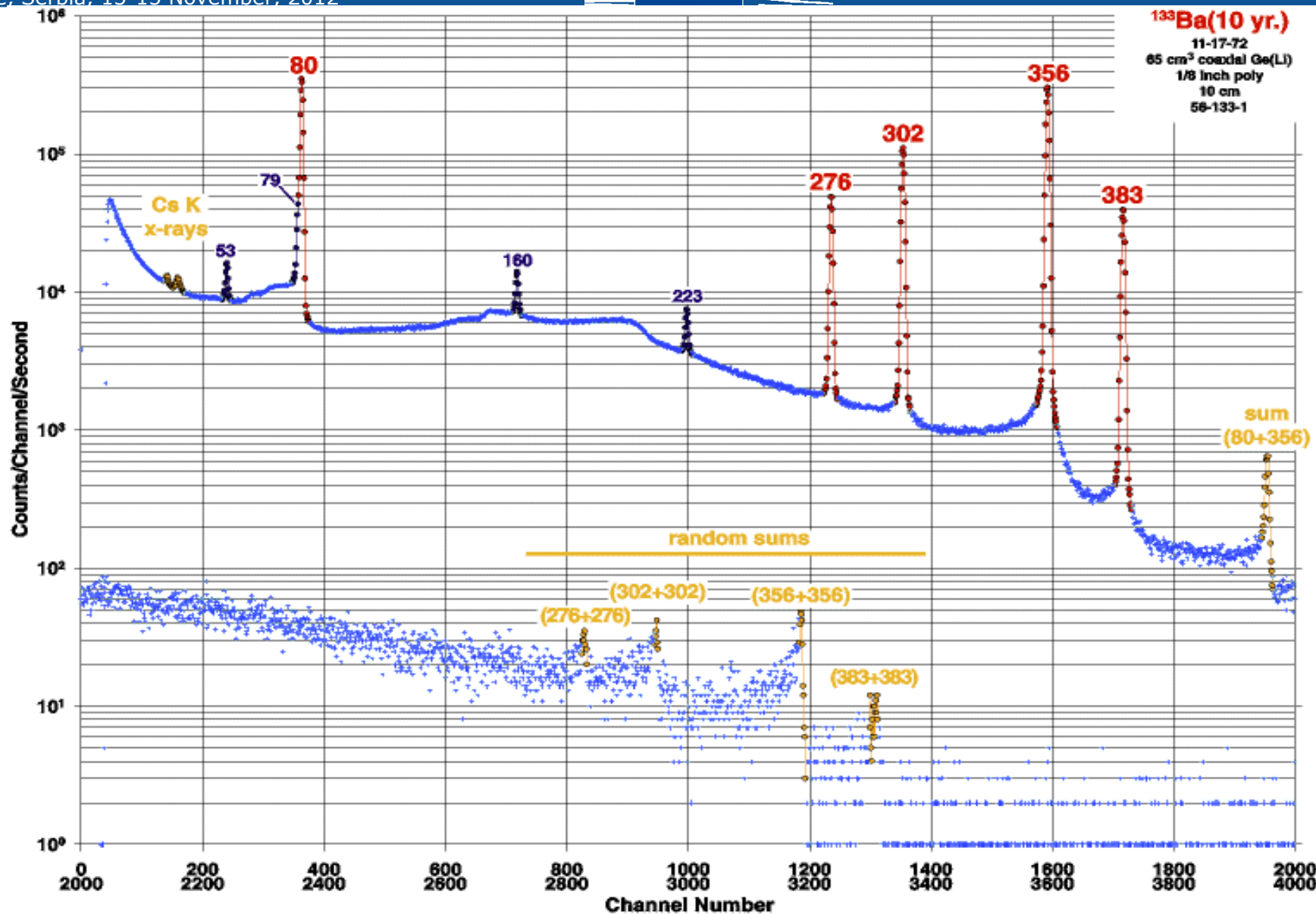


Spectrum from a gamma ray detector

- **Pair production**: when this occurs the positron will annihilate with another electron in the detector to produce two 511 keV photons.
- What you see in the spectrum depends on whether these two photons are absorbed in the detector or escape from it.
- If one photon escapes, you will find a peak at exactly 511 keV below the main photopeak, known as a single escape peak.

Germanium Spectrum of Barium-133

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Examples of gamma-ray spectra – today easy to find on the web.

http://www.inl.gov/gammaray/catalogs/ge/catalog_ge.shtml

Idaho National Laboratory - Gamma-ray Spectrometry Center - Online Catalogs - Windows Internet Explorer

File Edit View Favorites Tools Help

http://www.inl.gov/gammaray/catalogs/ge/catalog_ge.shtml

Idaho National Laboratory - Gamma-ray Spectrometry...

(Note: "_2" or "_N" right after mass number indicates the second data or the new measurement taken with a HPGe detector, respectively)

Group

Period

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1A	2A	3B	4B	5B	6B	7B	8	8	8	1B	2B	3A	4A	5A	6A	7A	8A
1 H	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
3 Li	7											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
11 Na	12 Mg	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
19 K	20 Ca	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
37 Rb	38 Sr	57 La*	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
55 Cs	56 Ba	89 Ac**	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110	111	112		114		116		118
87 Fr	88 Ra																
Lanthanide Series*		58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu		
Actinide Series**		90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr		

The INL's Gamma-ray Spectrum Catalogue is an attempt to compile spectra from various detector types and present these spectra with decay schemes and data tables based on the latest ENSDF data. It includes recently acquired Ge spectra and decay data as well as available spectra acquired for the original NaI(Tl) and Ge(Li) Catalogues. All information is documented by the spectra acquisition date and the ENSDF download date.

Progeny peaks are colored red or blue as are the parent radioactinide peaks. The radionuclide symbols of the progeny peaks are placed in parenthesis by the labeled peak and colored brown. The decay schemes and Y-ray energy and emission probability tables associated with the parent and progeny are given for each member of the decay chain.

Spectral content and shape is dependent on the "source age" when progeny grow-in is occurring at the time of spectral acquisition. "Source age" is defined as the calculated time since the parent activity could be considered free of any progeny or the actual (measured) time since the parent was chemically separated from all of its progeny. Whenever a meaningful "source age" can be measured or calculated, it is given in the legend. Spectra with different source ages and taken on different types and sizes of detectors are to be included in the Gamma-ray Spectrum Catalogue.

The spectral data from the original NaI(Tl) and Ge(Li) Catalogues have been incorporated for different uses and to allow comparisons of detector type, size, and source age.

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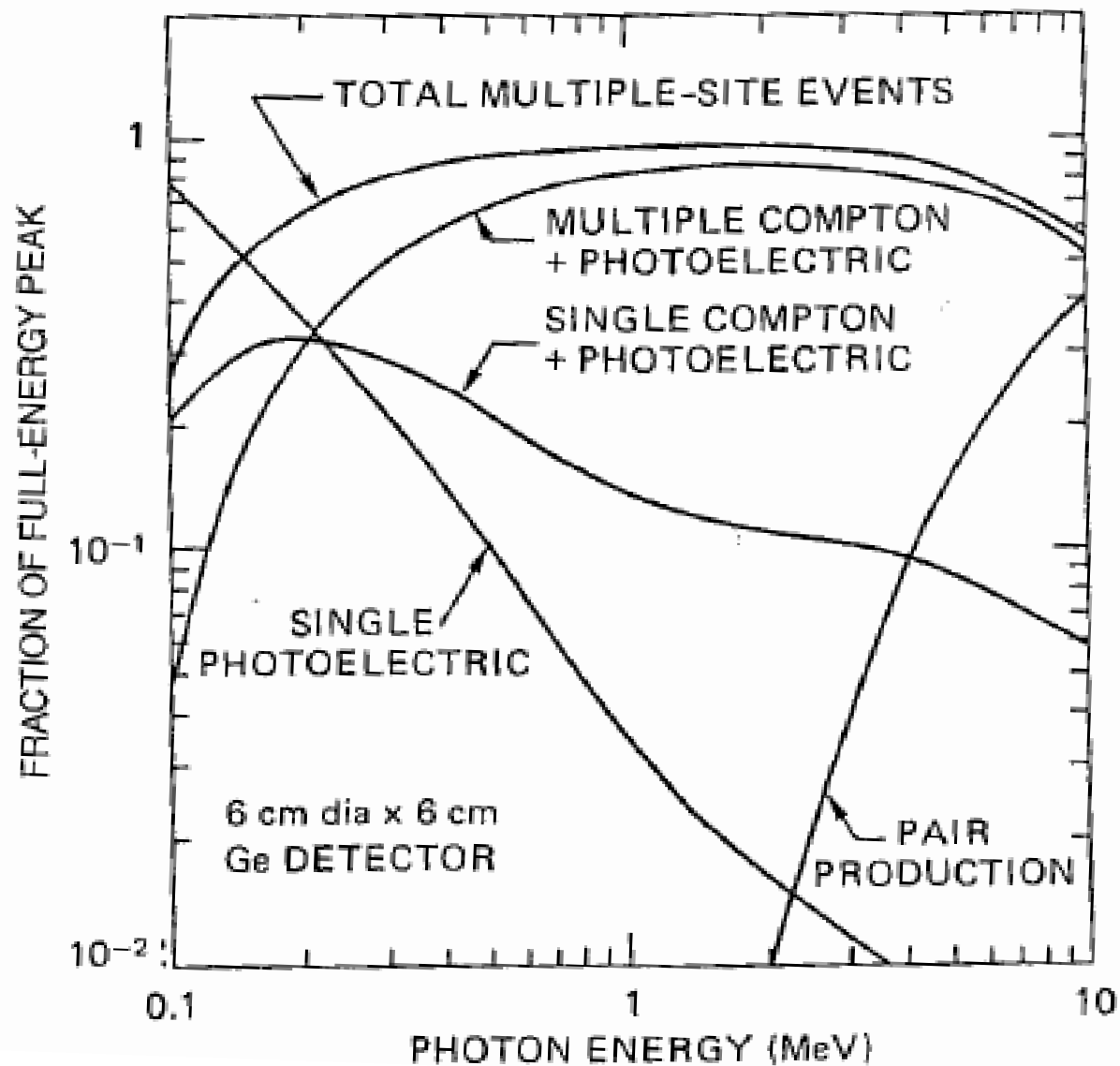
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