Introduction to Nuclear and Particle Physics

Lesson 4

interactions of photons in matter

In search of structure

Particle physics experiments

history and today

experimental methods

This semester

- lots of new “vocabulary”
- many things to accept

Tipps:

Script is nicely structured

Griffiths, Historische Einführung

The Particle Zoo

Quarks

Leptons

Bosons

Mesons

Baryons

Quantum field theory (QFT)

Feynman rules

gauge theory

Standard Model

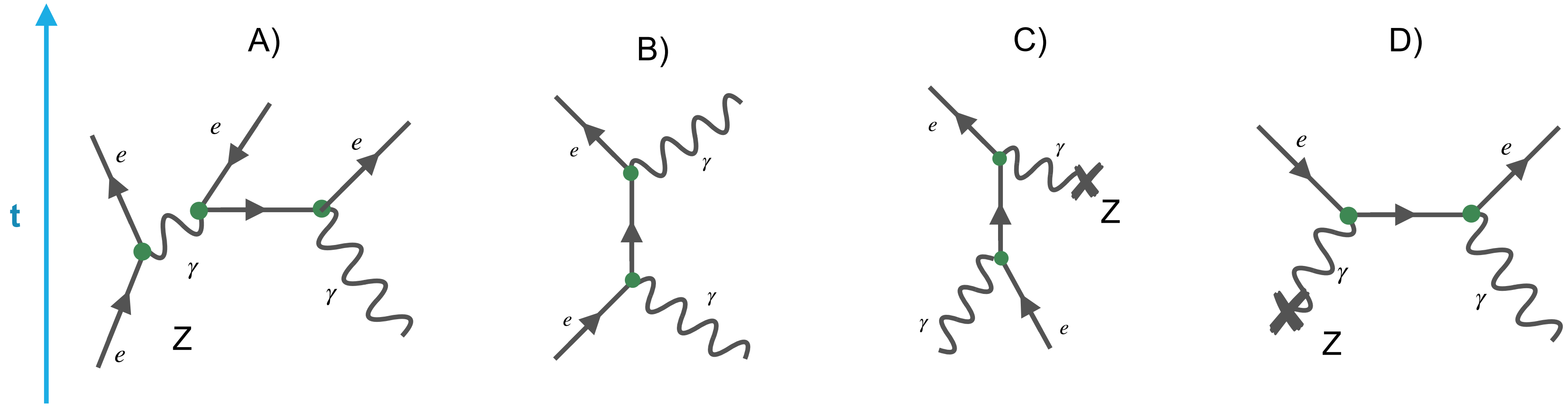
Nuclear Physics and Radioactivity

nuclear models

experiments

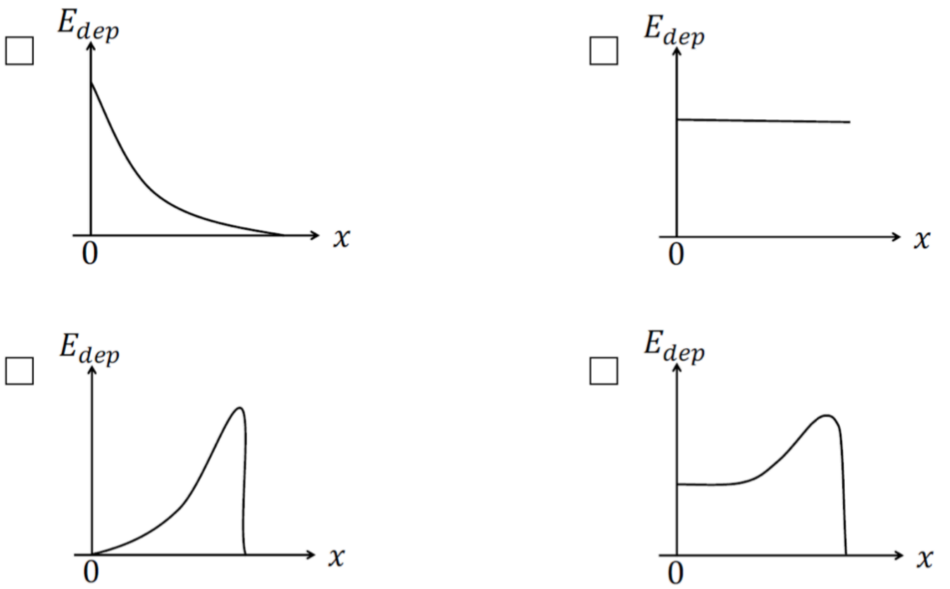
Warmup question 1

A photon with an energy of $E_\gamma = 100\ \mathrm{keV}$ interacts with matter.
Which of the following processes has the highest probability to happen?



Warmup question 2

Photons traveling in +x-direction are entering a material at x = 0. Which graph does best represent the distribution of the energy deposited in the material?



The plan for today

today:

Photons

Particles in matter

next week:

Charged particles, Bethe-Bloch

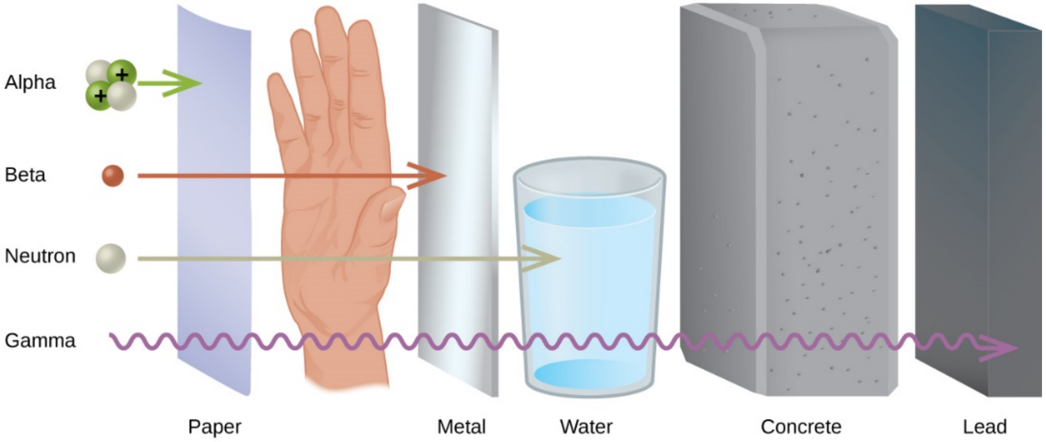
2 steps back:

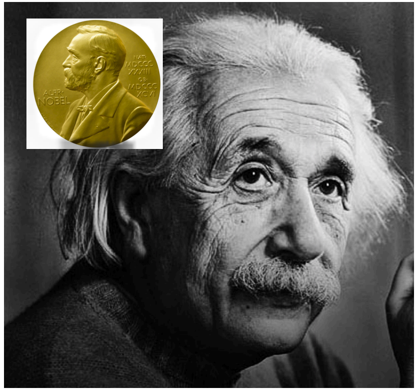
- **only QED**
- **very experimental**

Interaction of particles with matter

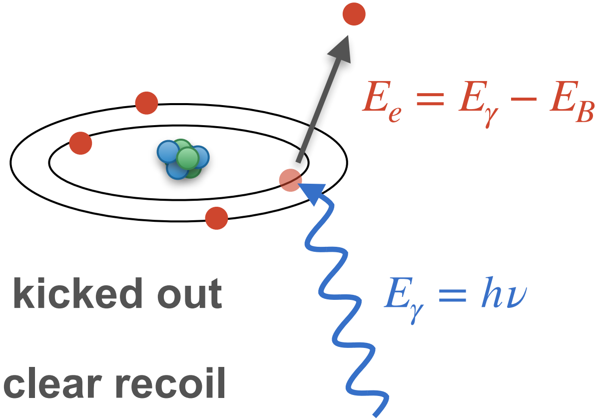
Charged particles

Gamma radiation

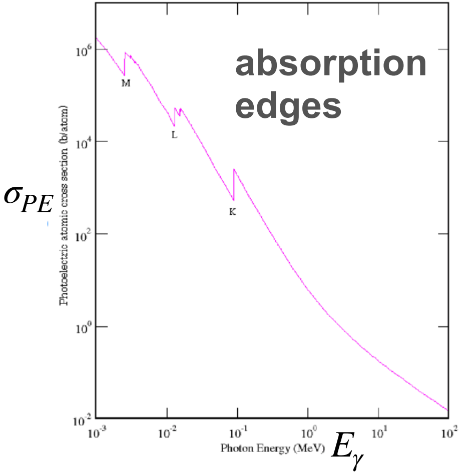




Photoelectric effect



- Photon absorbed, orbital electron kicked out
- Energy passed to electron and nuclear recoil

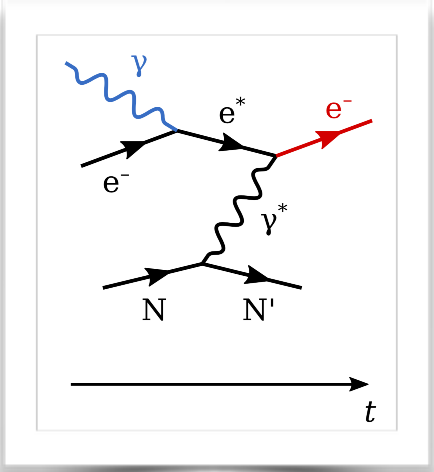


[Tantôt, Laurent. (2007). Modelling ionisation chamber response to nonstandard beam configurations.]

Dependencies (rough approximation)

$$\mu_{PE} \sim \frac{Z^n}{E_\gamma^{3.5}} \qquad 3 < n < 5$$

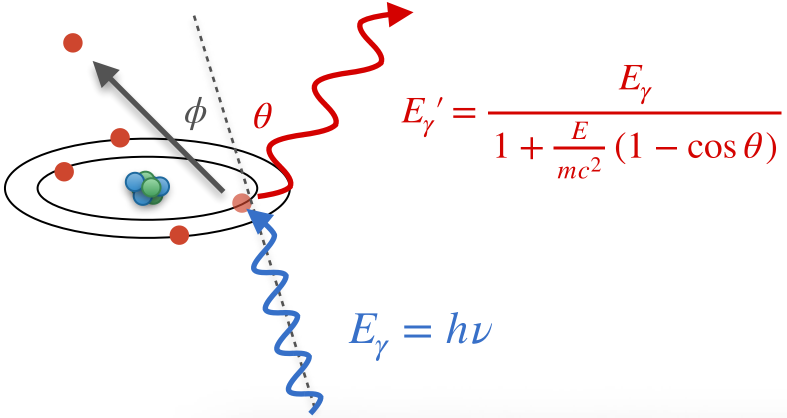
-> dominant at low energy

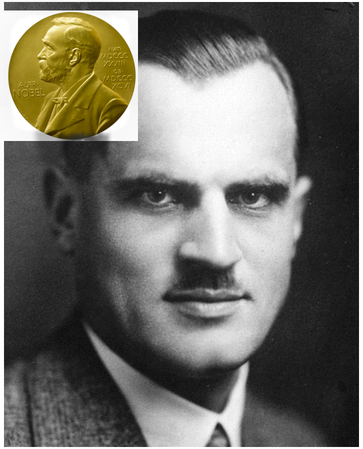


ENGAGING PHYSICS TUTORING EPT

Compton Scattering

- orbital electron kicked out
- Photon scattered with lower energy

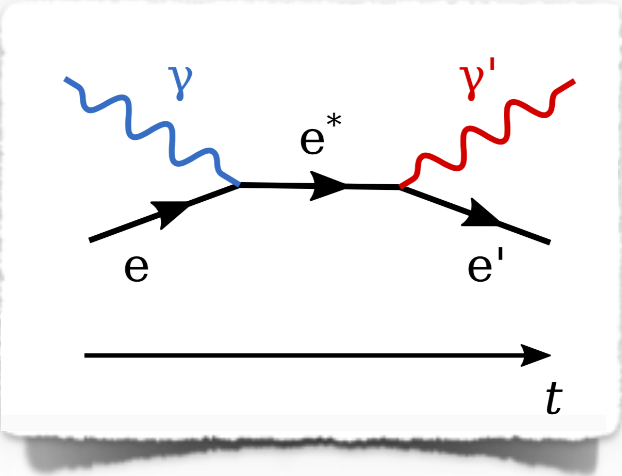




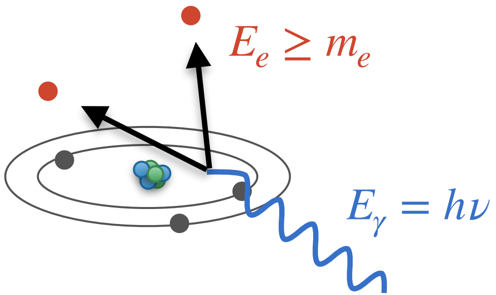
Dependencies (approximation)

$$\mu_{PE} \sim \frac{Z}{E}$$

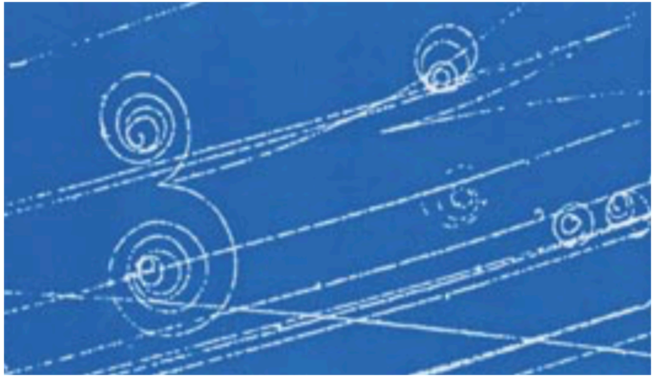
-> dominant at
intermediate energies



Pair production



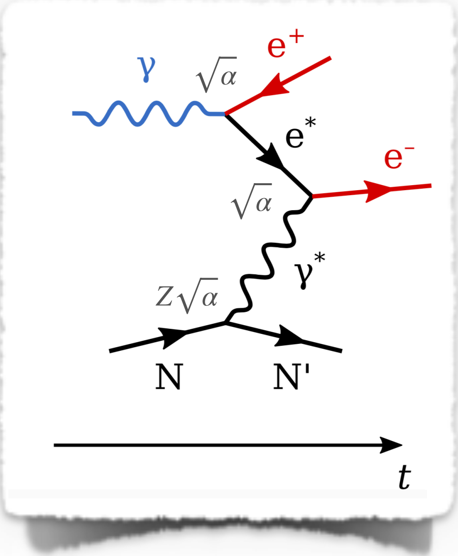
- e⁺- e⁻ pair created in field of nucleus (or electron)
- **Minimum energy:** $E_\gamma \geq 2m_e$



Dependencies (approximately)

$$\mu_{PC} \sim Z^2 E_\gamma$$

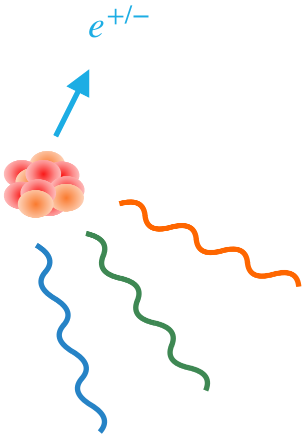
-> dominant at high energies (> few MeV)

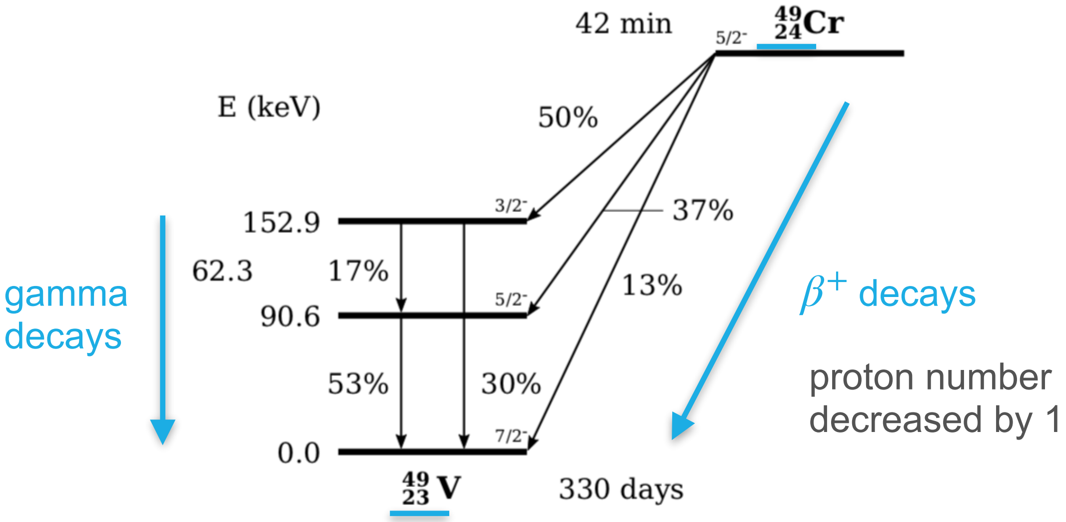


[https://cerncourier.com/a/the-legacy-of-the-bubble-chamber]

Group work about gamma spectroscopy - introduction

β decays accompanied by γ decays



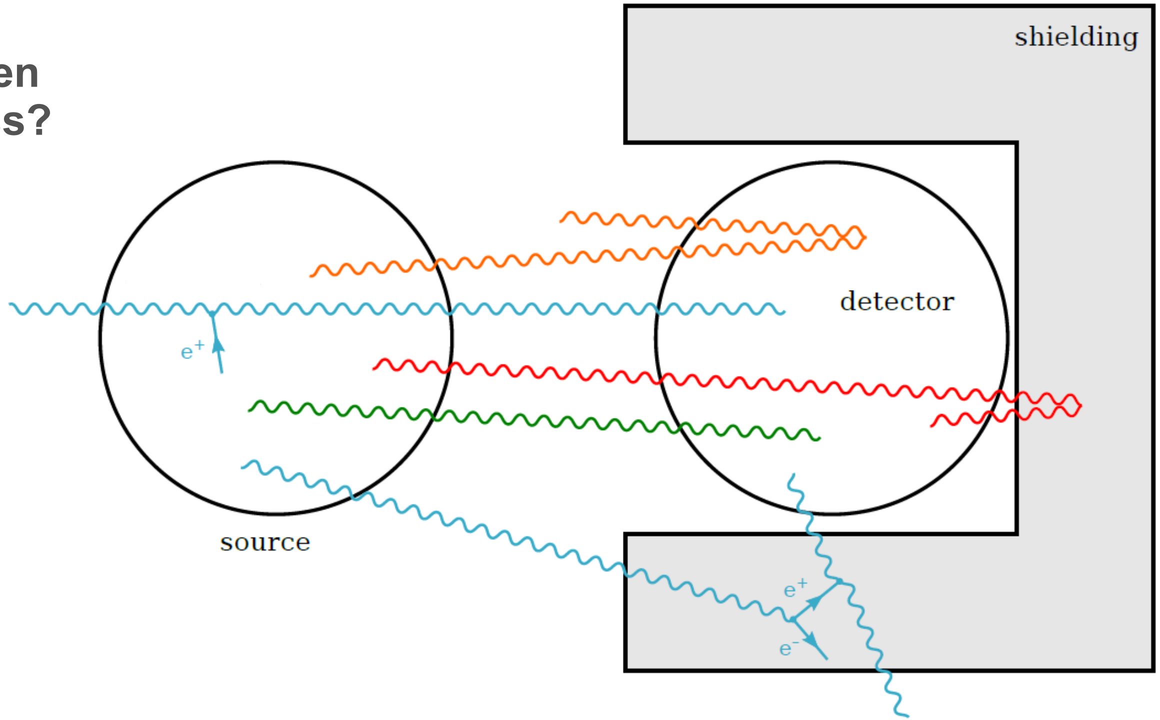


Group work about gamma spectroscopy - introduction

Which processes can happen during the detection process?

- Compton scattering
- Backscattering
- Photoelectric absorption
- Annihilation
- Pair production

… and more!



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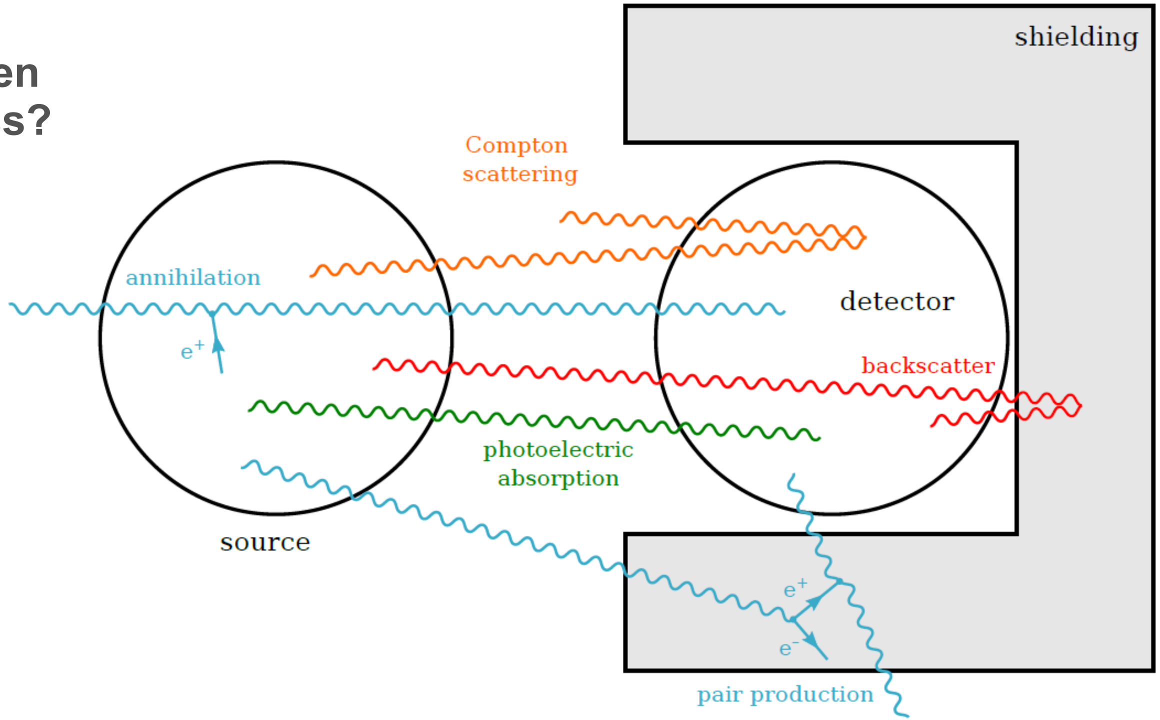
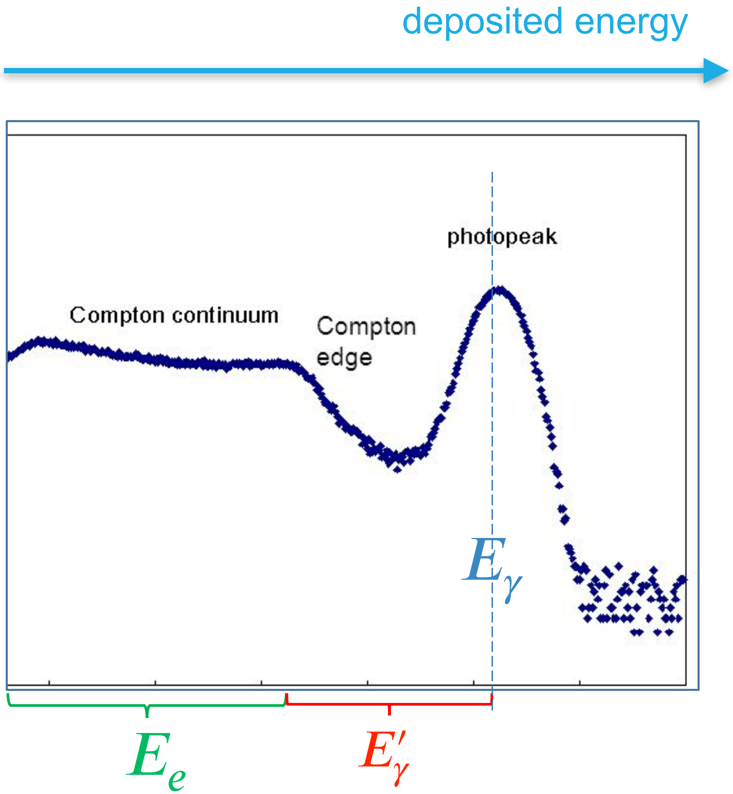
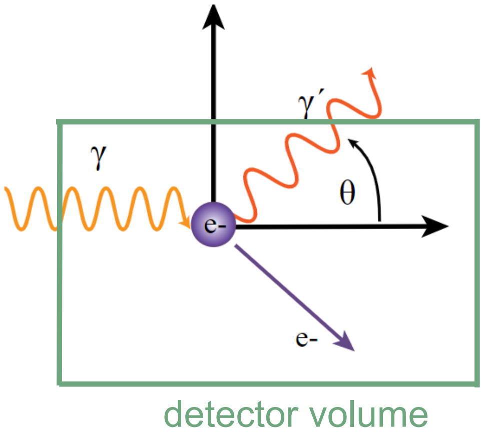


Recap: The Compton spectrum





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

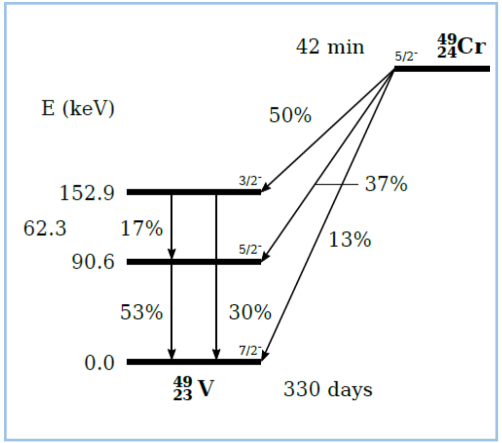
Gamma has minimal energy for $\theta \to 180^o$: $E_\gamma{}' = \dfrac{E_\gamma}{1 + \frac{E_\gamma}{mc^2} \cdot 2}$

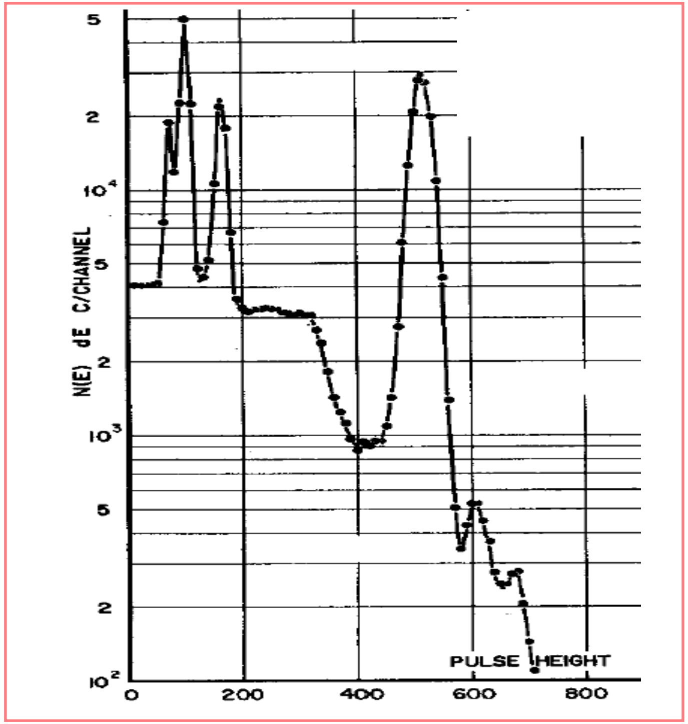
$\Rightarrow$ backscatter energy for $E_\gamma \approx m_e c^2$: $E_\gamma{}' \approx 200\ \mathrm{keV}$

Group activity

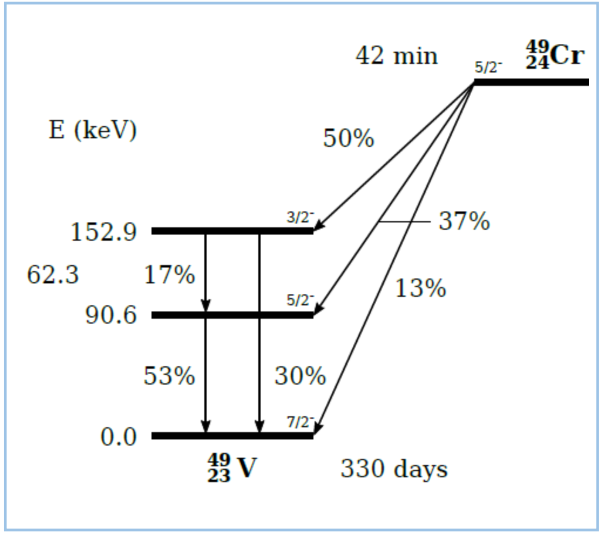
The plot on the right shows a gamma spectrum measured with a ^{49}Cr source (decay scheme below).

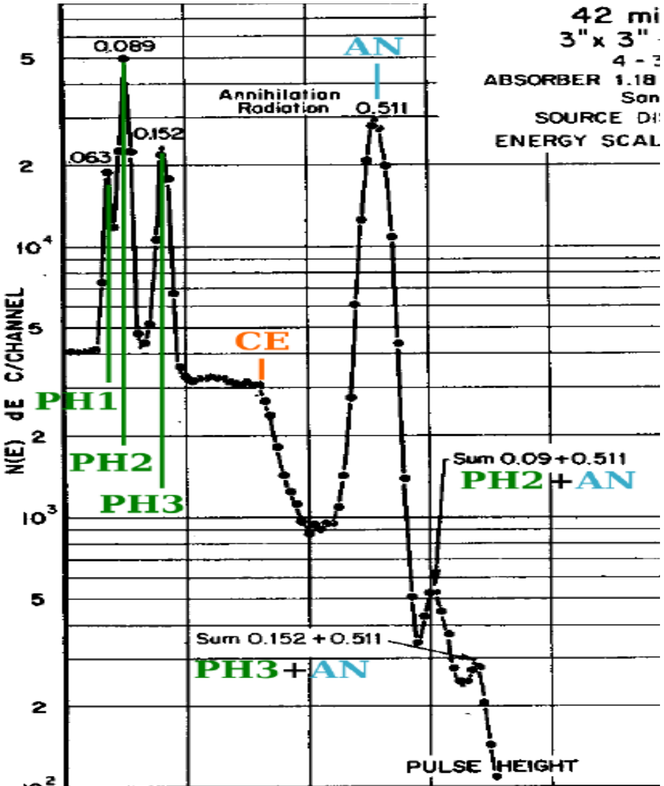
Can you explain the origin of the peaks and edges in the energy spectrum?





Group activity - solution



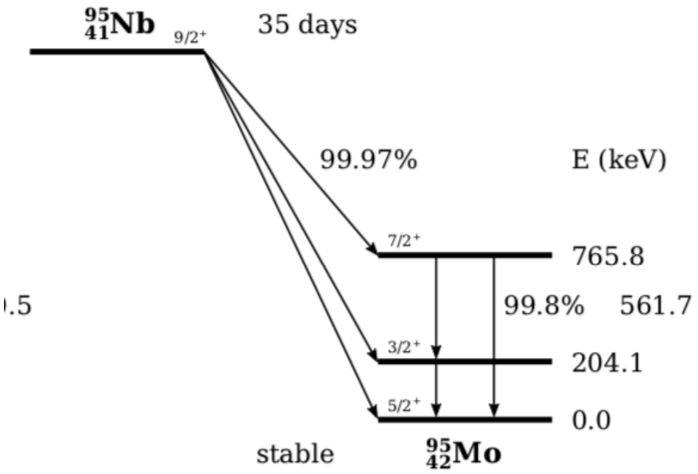


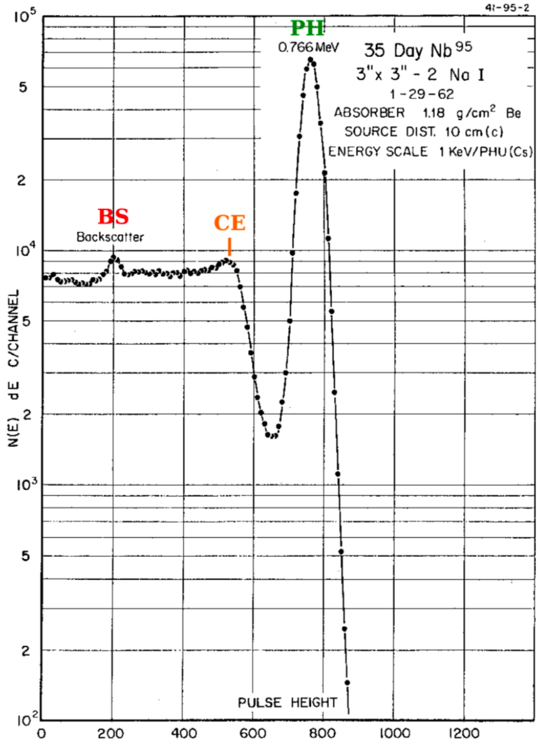
PH: Photoelectric absorption

CE: Compton edge

AN: Annihilation peak (e^+ annihilates in source)

One more spectrum





Detector spectra - question

We want to measure the energy spectrum of γ radiation with a large Germanium detector.

Which statements are correct?

A) The backscatter peak is a direct consequence of Compton scattering in the surrounding material.

B) Every photo-peak will be accompanied by a Compton edge.

C) We will not absorb the full energy of any photon in the detector.

D) The more material we place around the detector, the more clear will be our spectrum.

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Summary: Interaction of gamma radiation in matter

Most photons are absorbed when they interact in material.

"attenuation coefficient"

$\mu = \rho\sigma$

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

No continuous energy loss.

$\Rightarrow$ **Intensity goes down exponentially with depth.**

$$\mu = \mu_{\mathrm{PE}} + \mu_{\mathrm{CS}} + \mu_{\mathrm{PC}}$$

Photo effect

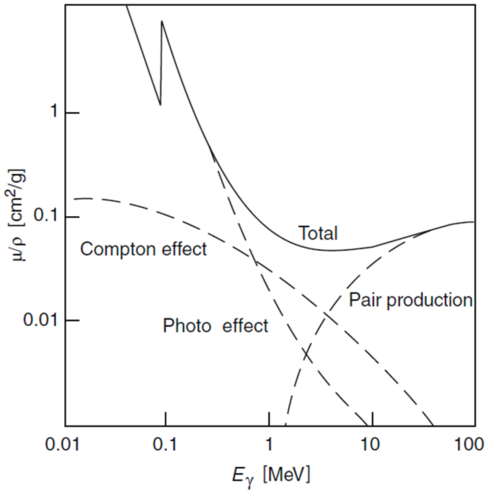
$$\mu_{\mathrm{PE}} \sim \frac{\mathrm{Z^n}}{\mathrm{E}_\gamma^{3.5}}$$

Compton scattering

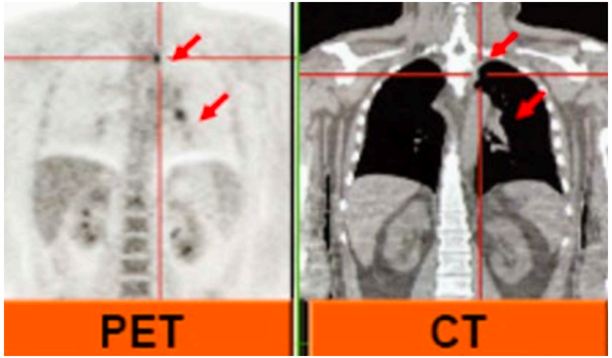
$$\mu_{\mathrm{PE}} \sim \frac{\mathrm{Z}}{\mathrm{E}}$$

Pair production

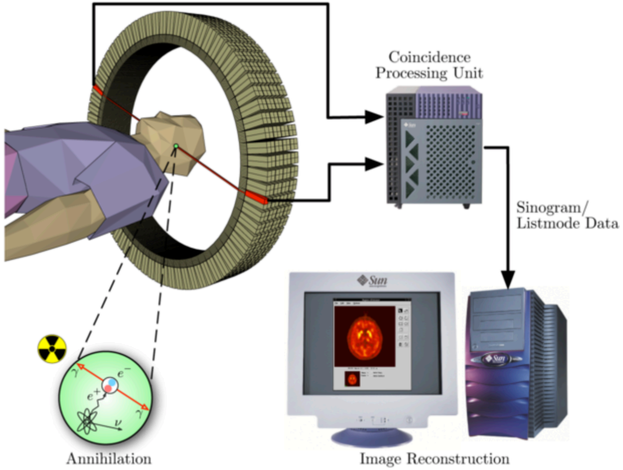
$$\mu_{\mathrm{PC}} \sim \mathrm{Z^2 E_\gamma}$$



Pair Annihilation: The PET scan



How does positron emission tomography work?

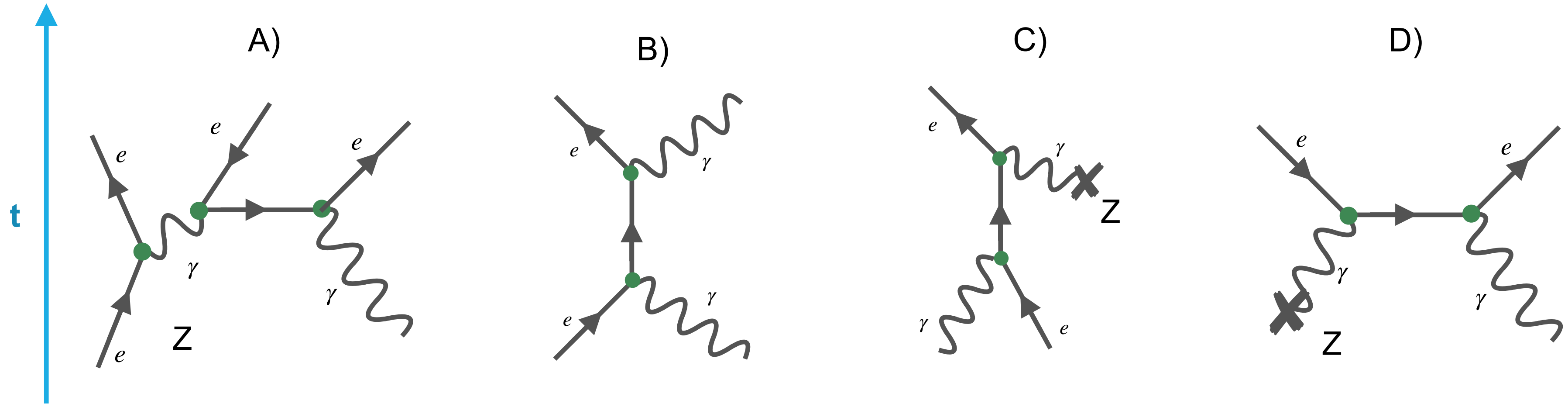


[http://large.stanford.edu/courses/2015/ph241/krishnamurthi1/images/f2big.png]

[https://en.wikipedia.org/wiki/Positron_emission_tomography#/media/File:ECAT-Exact-HR--PET-Scanner.jpg]

Warmup question 1

A photon with an energy of $E_\gamma = 100 \text{ keV}$ interacts with matter.
Which of the following processes has the highest probability to happen?



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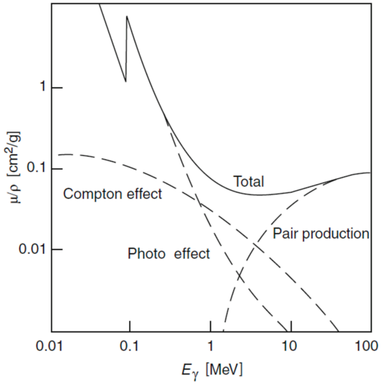
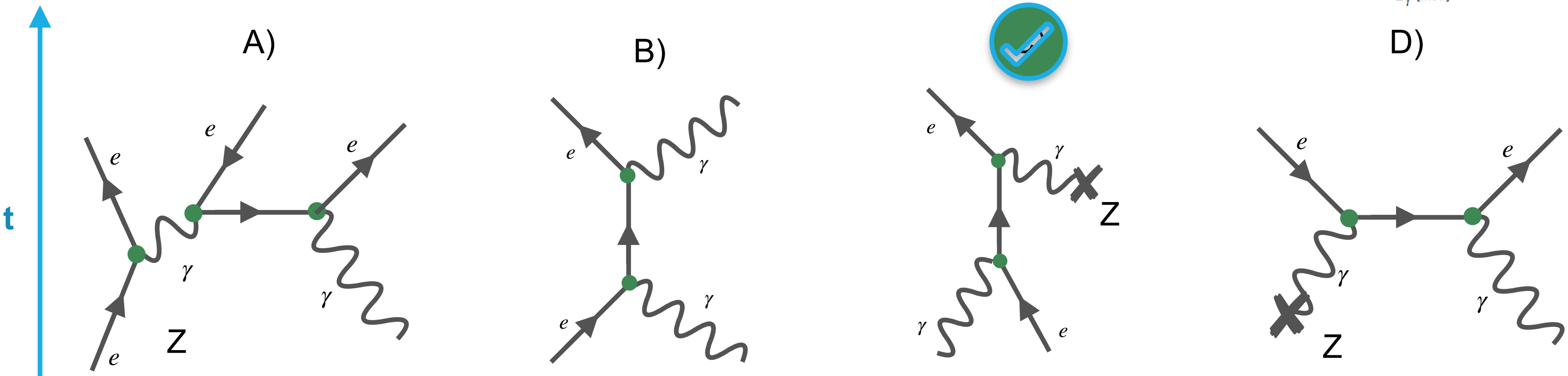




Pair production in electronic field

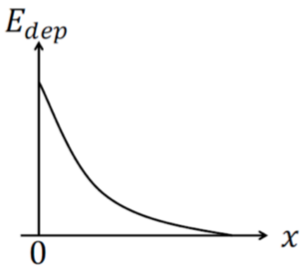
Compton scattering

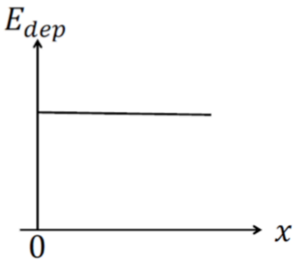
Photo effect

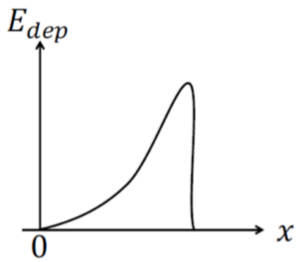
Pair production in nuclear field

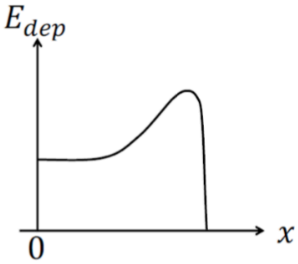
Warmup question 2

Photons traveling in +x-direction are entering a material at x = 0. Which graph does best represent the distribution of the energy deposited in the material?

☐ 

☐ 

☐ 

☐ 

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