Photon-matter interactions

Photon

-- It presents dual behavior (particle-wave)
-- Interacts though the electromagnetic force (parity and total angular and linear momenta are conserved)
-- It does not have rest mass

Photon-matter interactions

Main interaction processes

-- Photoelectric effects
-- Coherent or Rayleigh scattering
-- Incoherent or Compton scattering
-- Pair production

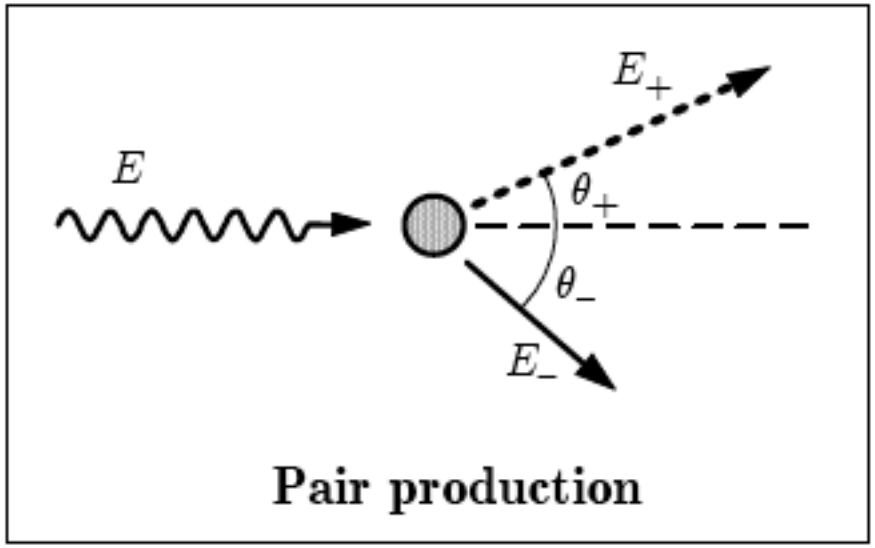
Photon-matter interactions

Pair production if the nucleus field

-- The presence of the nucleus allows for linear momentum conservation
-- It occurs if $E_{ph}>2m_ec^2=1.022$ MeV.
-- It is relatively frequent at high very energies (>50 MeV)
-- An electron-positron pair is produced. The photon does not survive after the interaction

Photon-matter interactions

Pair production at the nucleus field. Simple diagram.



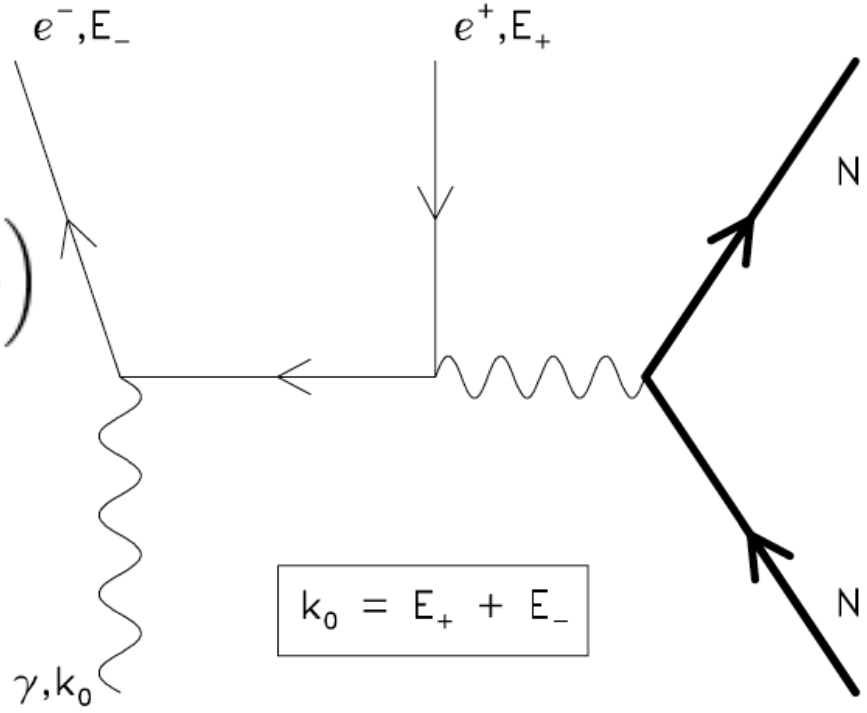
Photon-matter interactions

Pair production at the nucleus field. Feynman diagram and asymptotic cross section

$$\lim_{\alpha\to\infty}\sigma_{\mathrm{PP}}(\alpha) = \sigma_0^{\mathrm{PP}} Z^2 \left(\ln(2\alpha) - \frac{109}{42}\right)$$

$$\alpha = E_\gamma / m_e c^2$$

$$\sigma_0^{\mathrm{PP}} = 1.80 \times 10^{-27}\ \mathrm{cm}^2/\mathrm{nucleus}$$



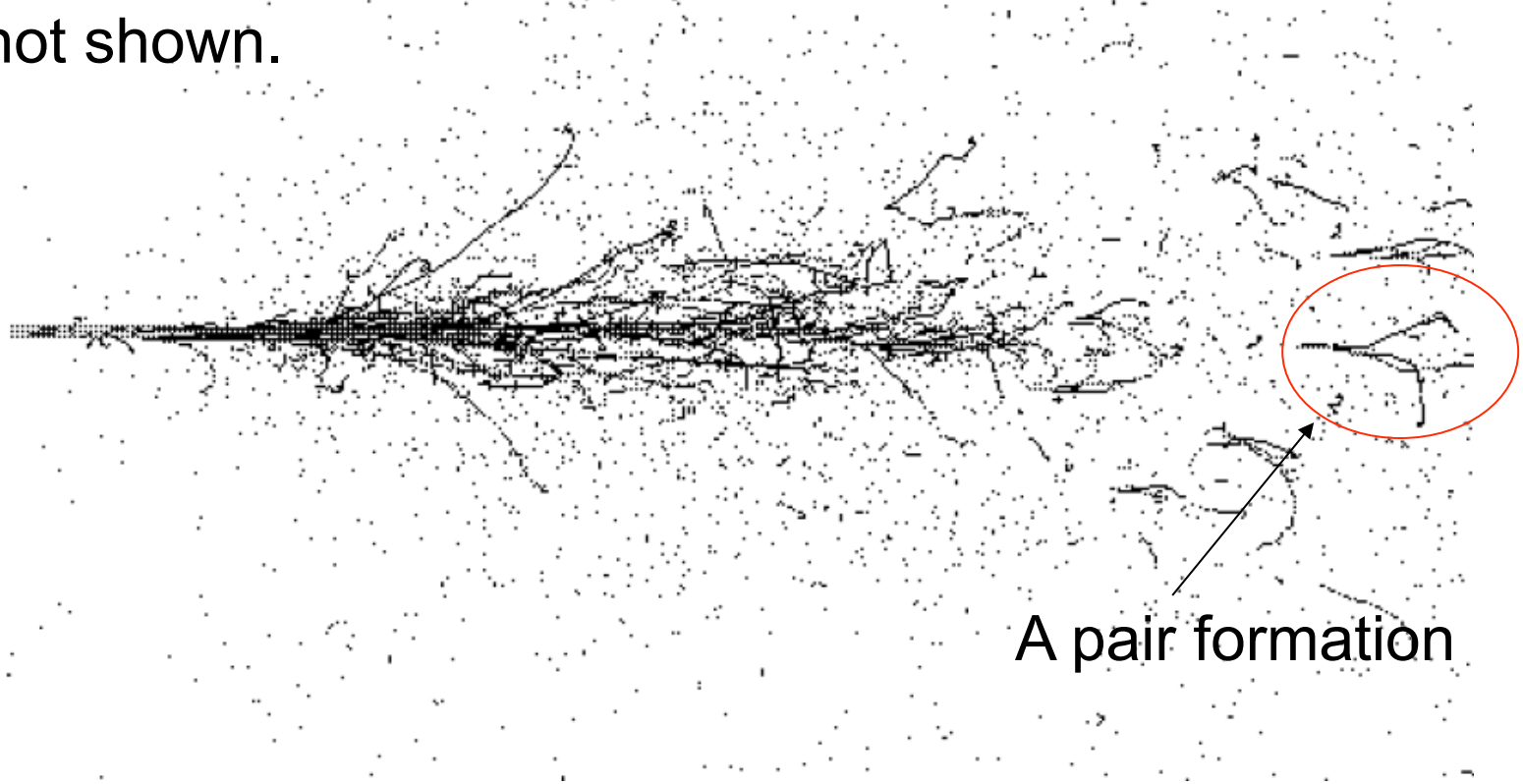
Photon-matter interactions

Pair production in a atomic electron field (triplet production)

-- The atomic electron allows for the linear momentum conservation.
-- Two electrons, one of them is the atomic electron and one positron are emitted.
-- The photon does not survive after the interaction
-- It is 1/Z less probable than the analog nuclear process

Photon-matter interactions

Particle shower generated by five 1 GeV electrons. Electron and positron tracks are represented by lines. Photon tracks are not shown.



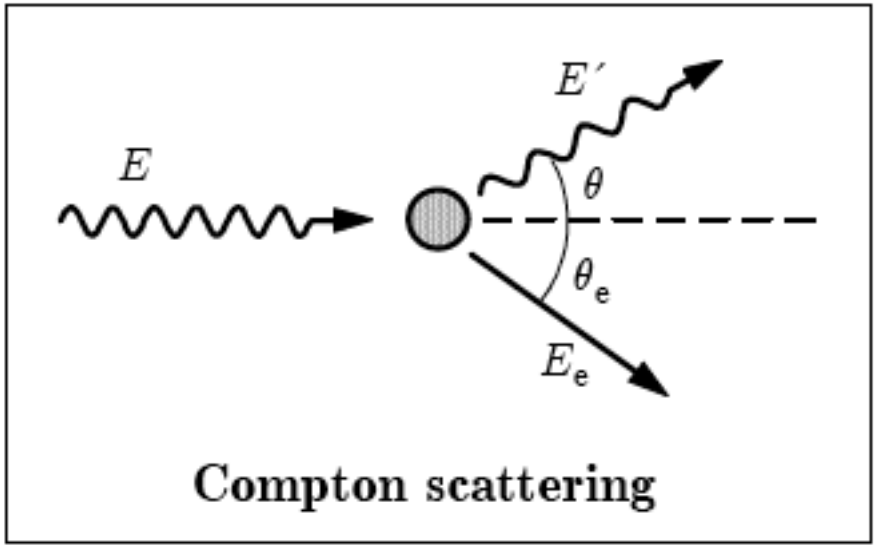
Photon-matter interactions

Incoherent or Compton interaction

- A photon interacts with a free electron at rest (Klein-Nishina model). A fraction of the photon energy is transferred to the electron.
- In nature, electrons are bound to atoms. If the energy transfer is high enough, the electron is removed from the atom and the latter is ionized
- The photon is emitted with an energy lower than its initial energy (incoherence)

Photon-matter interactions

Incoherent or Compton interaction with a free electron at rest (Klein-Nishina model)



Photon-matter interactions

Incoherent or Compton interaction with a free electron at rest (Klein-Nishina model)

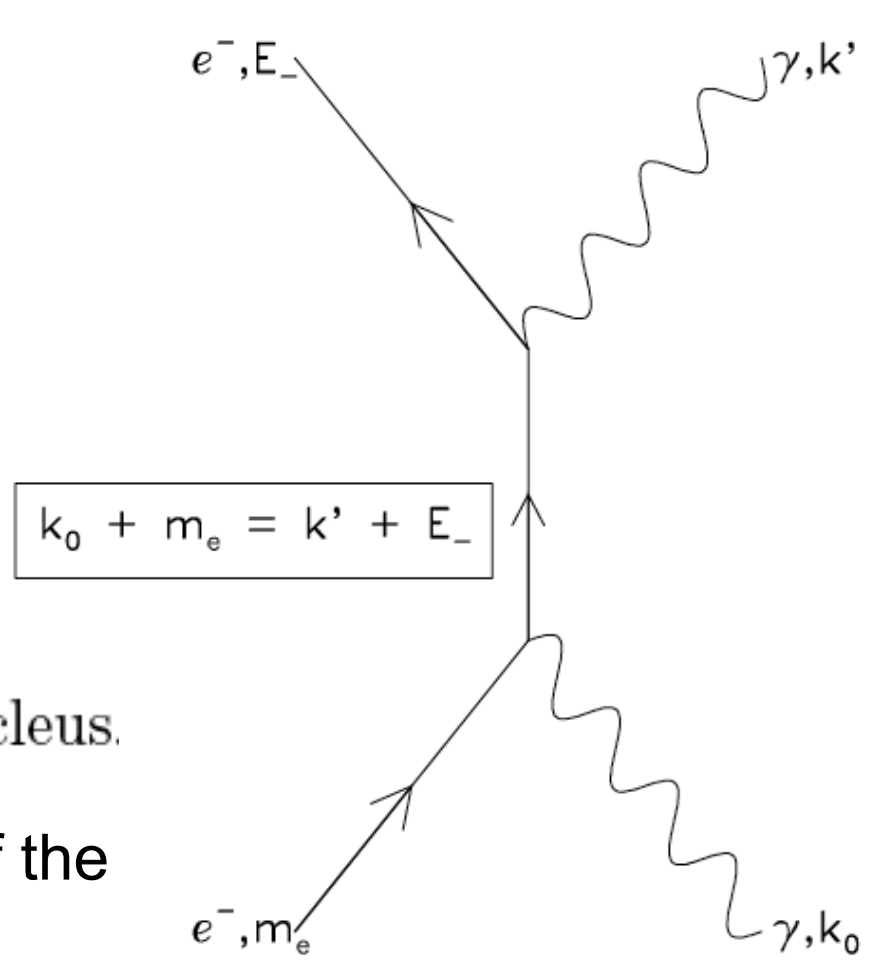
.

$$\lim_{\alpha\to\infty} \sigma_{\text{inc}}(\alpha) = \sigma_0^{\text{inc}} \frac{Z}{\alpha}$$

$$\lim_{\alpha\to 0} \sigma_{\text{inc}}(\alpha) = 2\sigma_0^{\text{inc}} Z$$

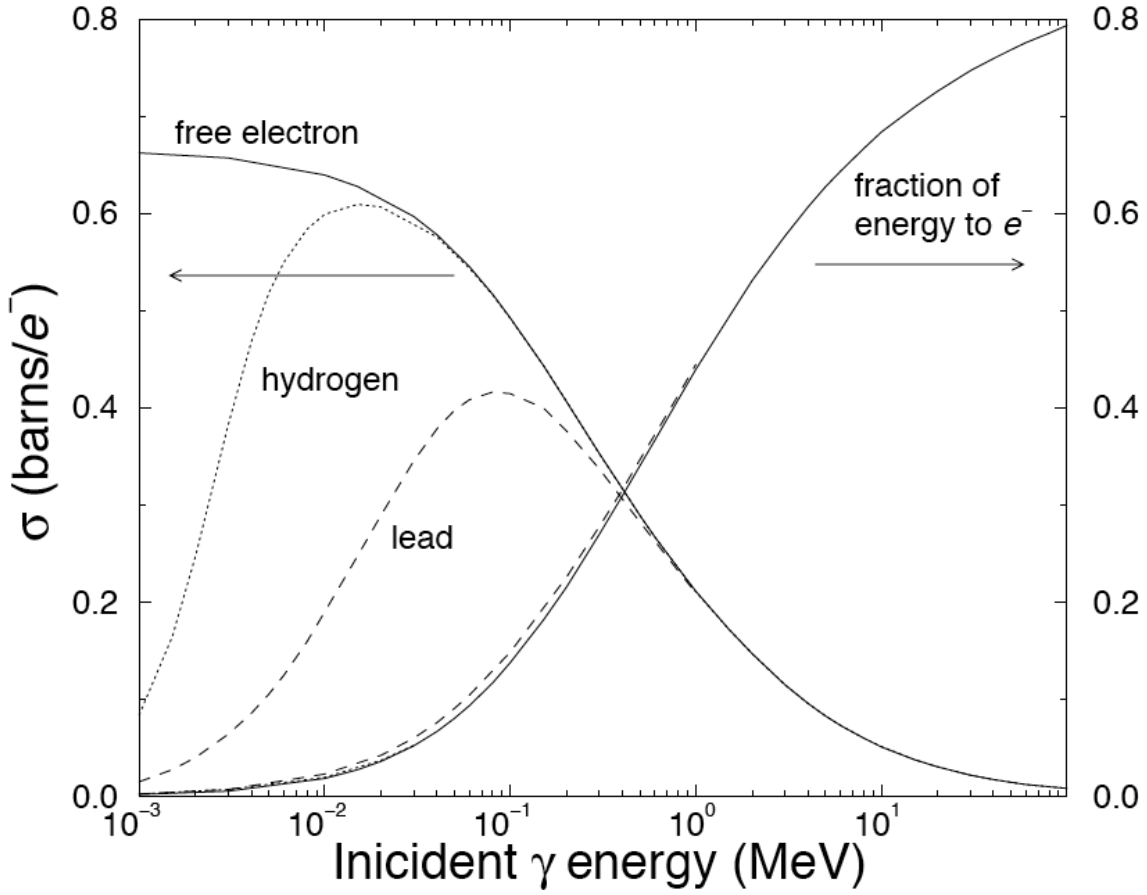
$$\sigma_0^{\text{inc}} = 3.33 \times 10^{-25} \text{ cm}^2/\text{nucleus}$$

μ/ρ is almost independent of the target material



Photon-matter interactions

Incoherent or Compton interaction with bound electrons atômico.



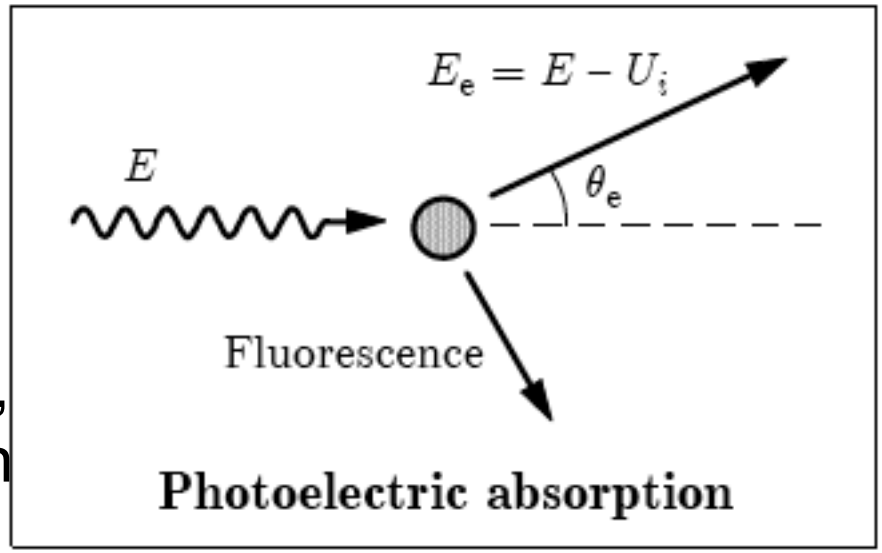
Photon-matter interactions

Photo-electric effect

- The photon is completely absorbed by the atom
- An electron is emitted
- The target atom is left ionized

-Unlike the Compton process,

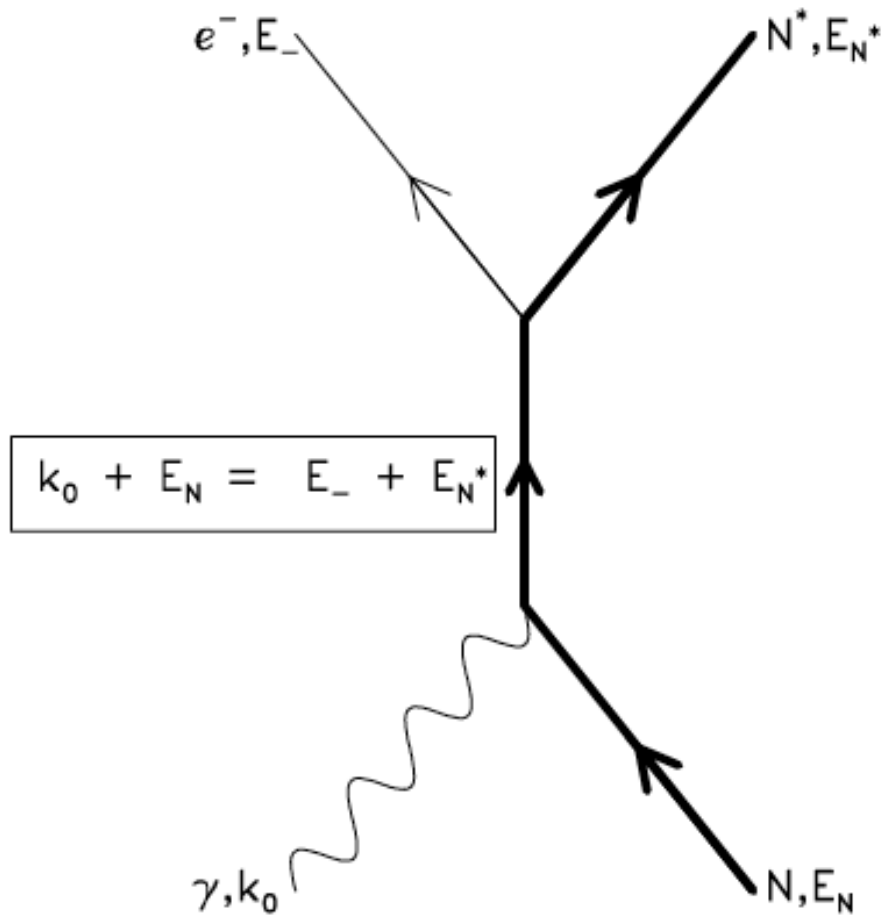
-The photo-electric interaction is more likely in inner atomic shells.



Photon-matter interactions

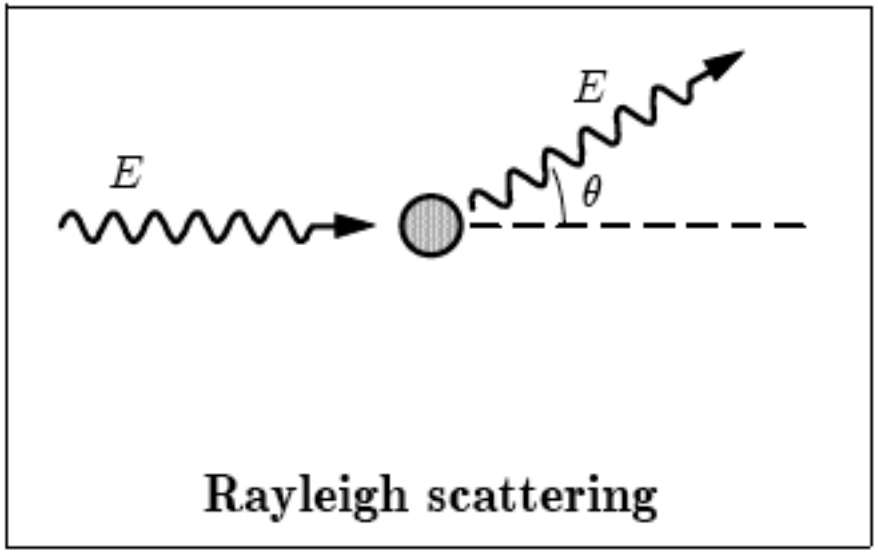
Photo-electric effect
Feynman diagram and
cross section

$$\sigma_{\mathrm{ph}}(E_\gamma) \propto \frac{Z^4}{E_\gamma^3}$$



Photon-matter interactions

Coherent or Rayleigh scattering



Photon-matter interactions

Coherent or Rayleigh scattering

$$\sigma_{\mathrm{coh}}(E_\gamma, \Theta) = \frac{r_e^2}{2}(1 + \cos^2\Theta)[F(q, Z)]^2$$

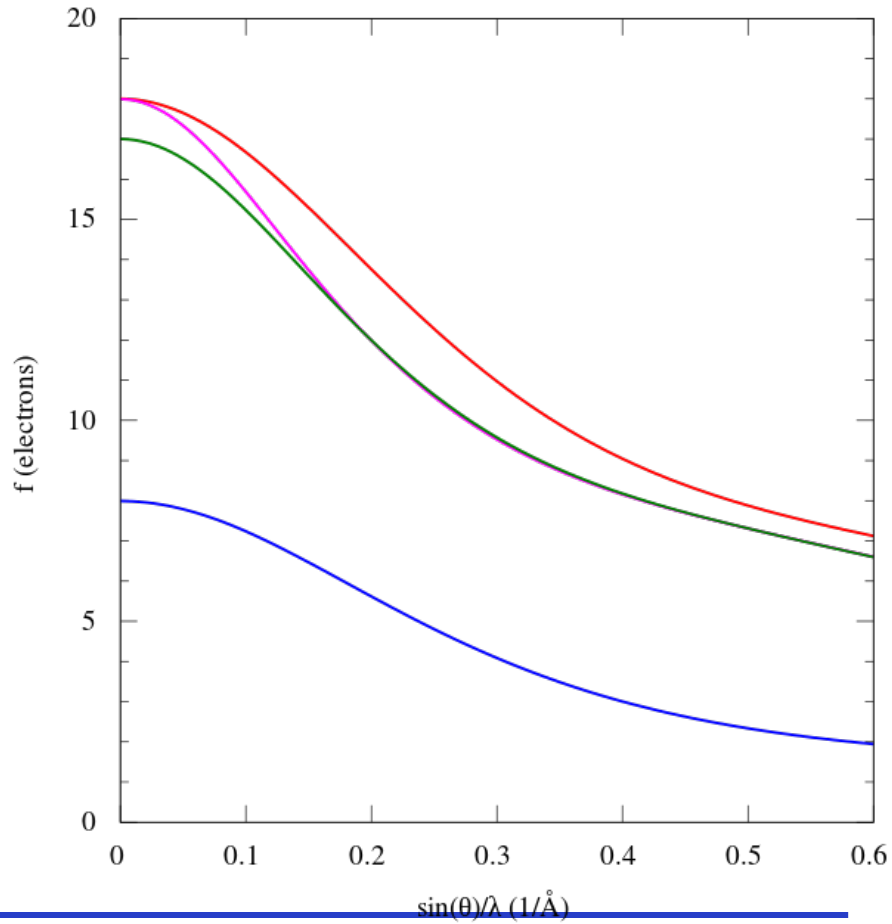
$$q = (E_\gamma/hc)\sin(\Theta/2)$$

F(q,Z) is the elastic atomic form factor. It is just the Fourier transform of the electron density around the atom

Photon-matter interactions

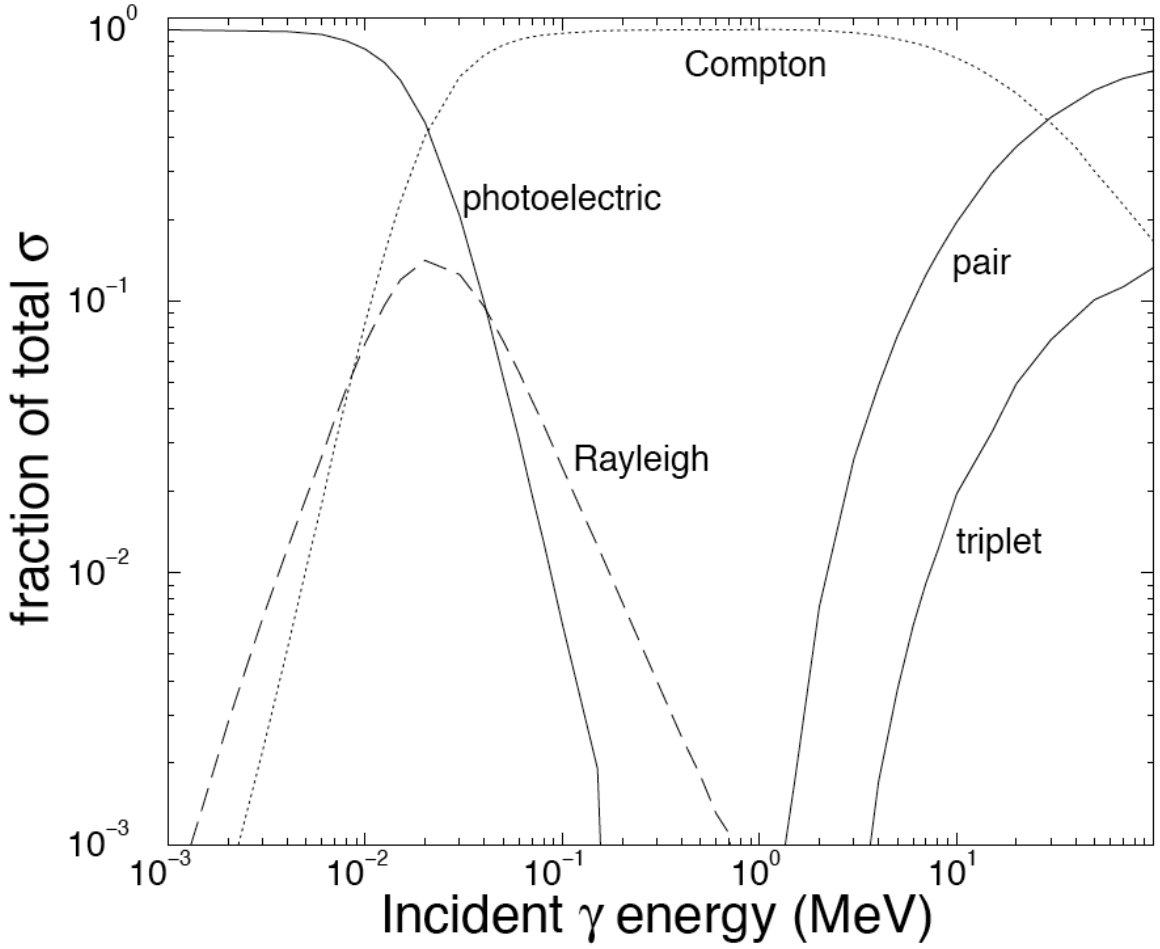
Coherent or Rayleigh scattering

F(q,Z) is the elastic atomic form factor. It is just the Fourier transform of the electron density around the atom



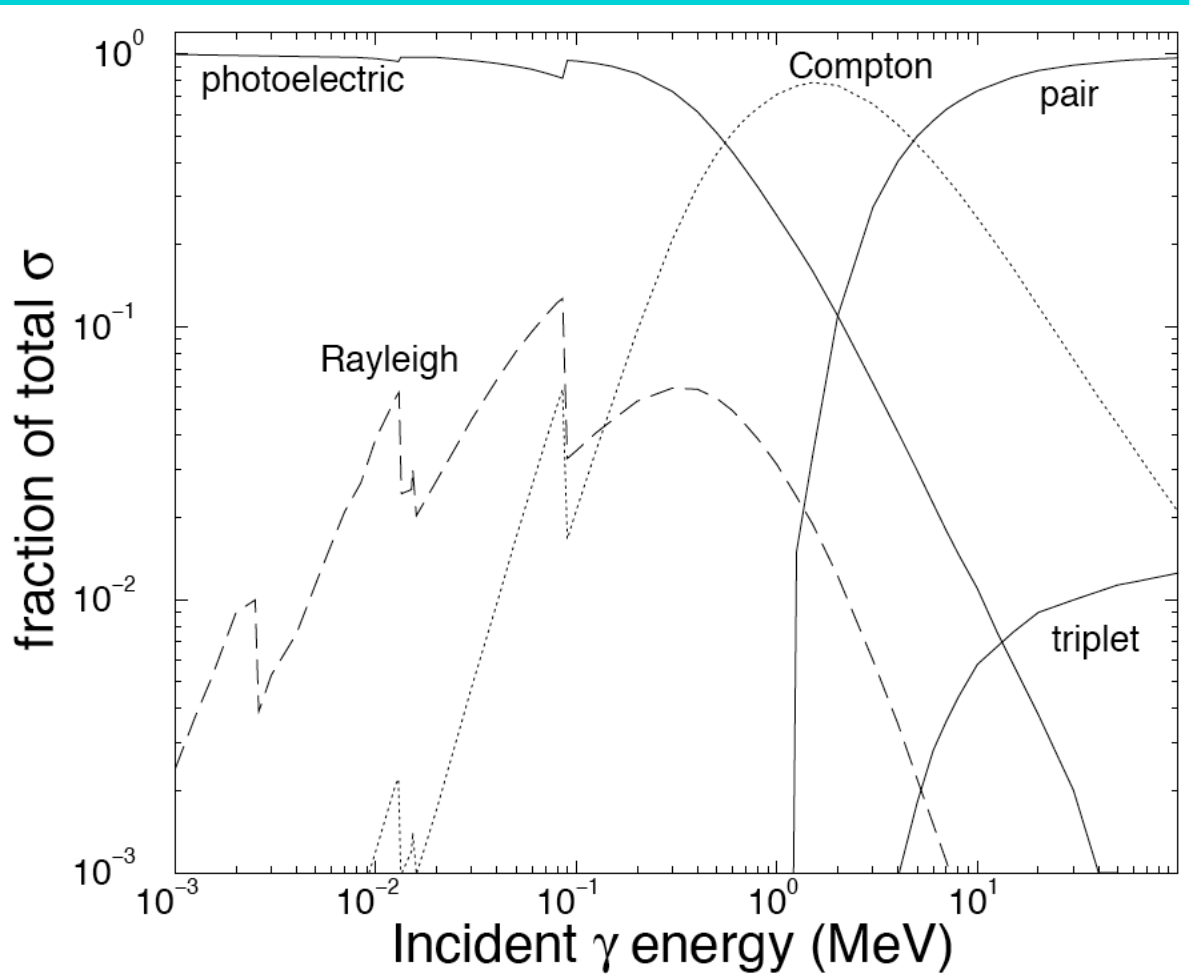
Photon-matter interactions

Cross sections in Carbon



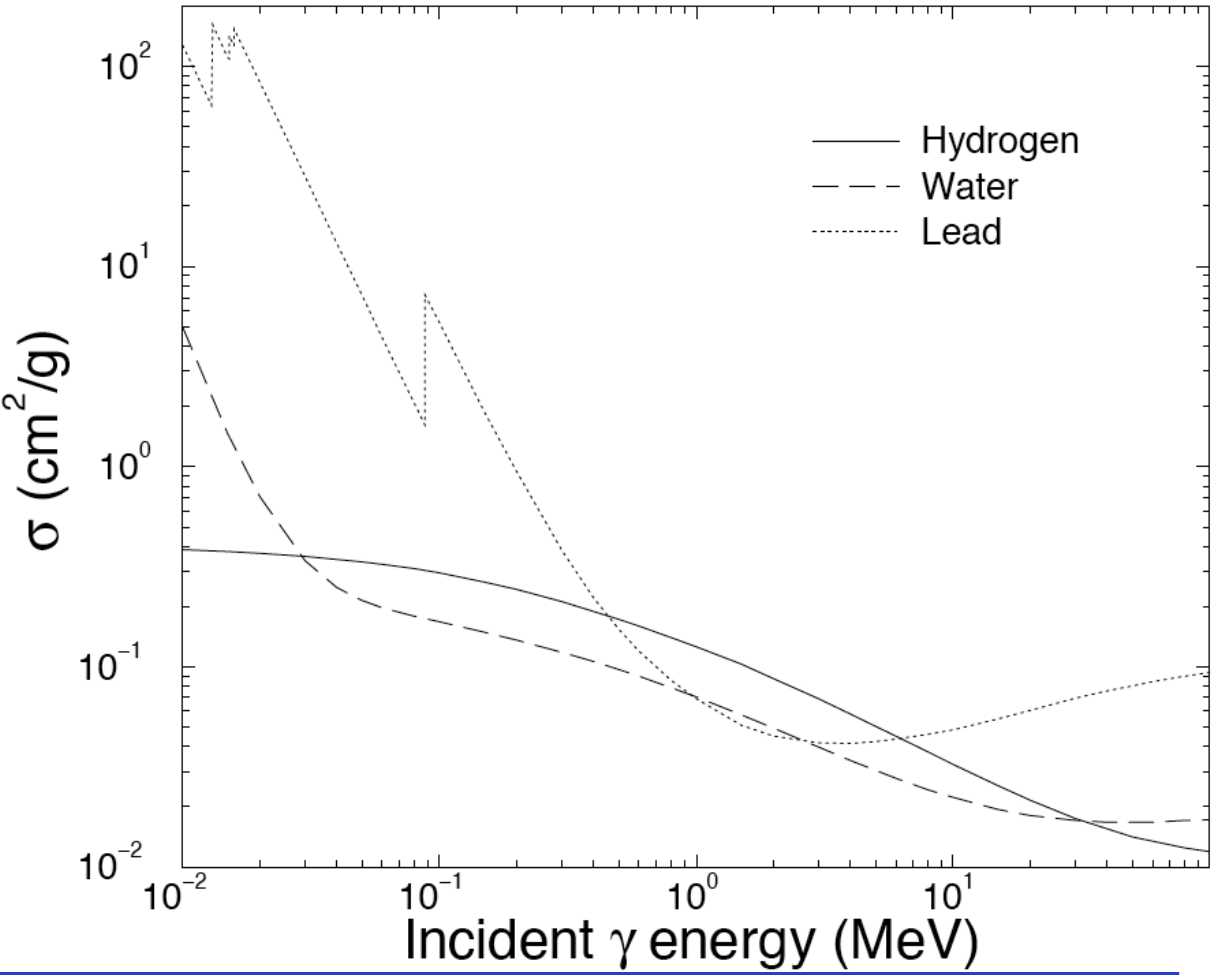
Photon-matter interactions

Cross sections in Lead



Photon-matter interactions

Cross sections for hydrogen, water and lead.



Photon-matter interactions