

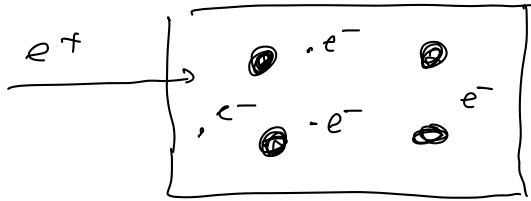
particelle cariche nella materia: (leptoni, adroni)

- int. EM \Rightarrow ionizzazione

$$e^{\pm}: E > E_C = \frac{600 \text{ MeV}}{Z_{\text{mat}}}$$

irraggiamento (Bremsstrahlung)

positrone e^+ :
- ion. Z_{te}
- irragg. e



$$E_{e^+} \approx m_e \quad K_{e^+} \approx \emptyset$$

(e^+e^-) positronio Stato legato instabile

$$Q \quad \begin{array}{c} \text{positronio} \rightarrow \gamma \\ +1 \quad -1 \end{array} \quad \emptyset$$

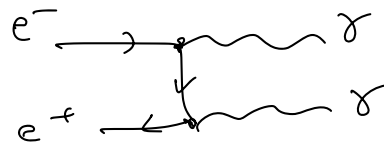


NO non si
conserva \vec{p}

$$S_{fin} = \underline{p}_\gamma^2 = \emptyset$$

$$S_{in} = (\underline{p}_{e^+} + \underline{p}_{e^-})^2 = \underbrace{m_e^2 + m_e^2}_{\text{positronio}} + 2 \underline{p}_{e^+} \cdot \underline{p}_{e^-}$$

$$\text{positronio} \rightarrow \gamma \gamma$$



nel riferimento solide con positronio:

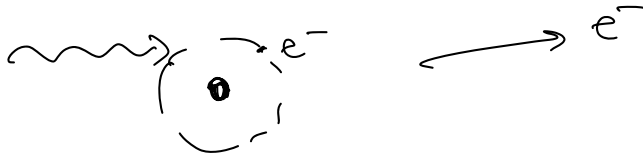
$$\begin{array}{c} \bullet \rightarrow \gamma \\ (e^+e^-) \rightarrow \gamma \\ \phi = \vec{p}_{in} \neq \vec{p}_f = \vec{p}_\gamma \end{array}$$

$$\begin{array}{c} \gamma \leftarrow \bullet \rightarrow \gamma \\ \vec{p}_{in} = \phi \\ \vec{p}_f = \vec{p}_{\gamma 1} + \vec{p}_{\gamma 2} = \phi \end{array}$$

$$M_{\text{Pos.}} \approx 2m_e \Rightarrow E_\gamma \approx m_e = \frac{1}{2} (m \text{ positronio})$$

Interazioni del fotone nella materia

1) Effetto fotoelettrico $\gamma + A \rightarrow A^+ + e^-$



2) Effetto Compton $\gamma + e^- \rightarrow \gamma' + e^-$



elettroni esterni $I_B \approx 10 \text{ eV}$ Z

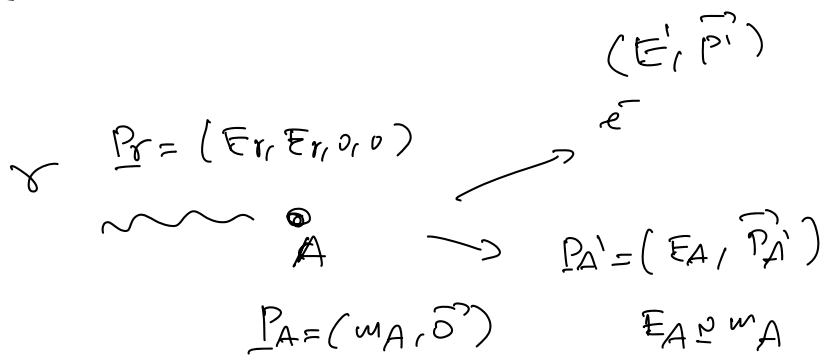
elettroni interni $I_B \approx 100 \text{ eV} \rightarrow \text{keV}$

fotoelettrico dominante a basse energie

Compton dominante per energie $\sim 100 \text{ keV}$

Effetto fotoelettrico

$$\gamma + A \rightarrow A^+ + e^-$$



$$m_A \gg m_e \Rightarrow E_A \approx m_A$$

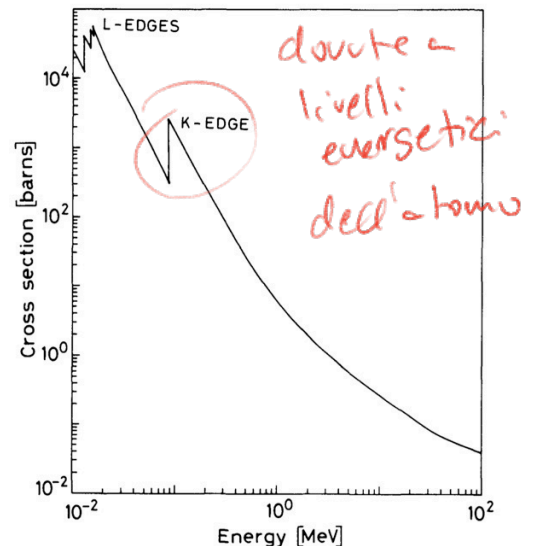
$$S_{fin} = P_{fin}^2 = (\underline{P}_A + \underline{p}_e)^2 = m_A^2 + m_e^2 + 2 \underline{P}_A \cdot \underline{p}_e$$

$$= m_A^2 + m_e^2 + 2(E_e E_A - \vec{p}_e \cdot \vec{P}_A)$$

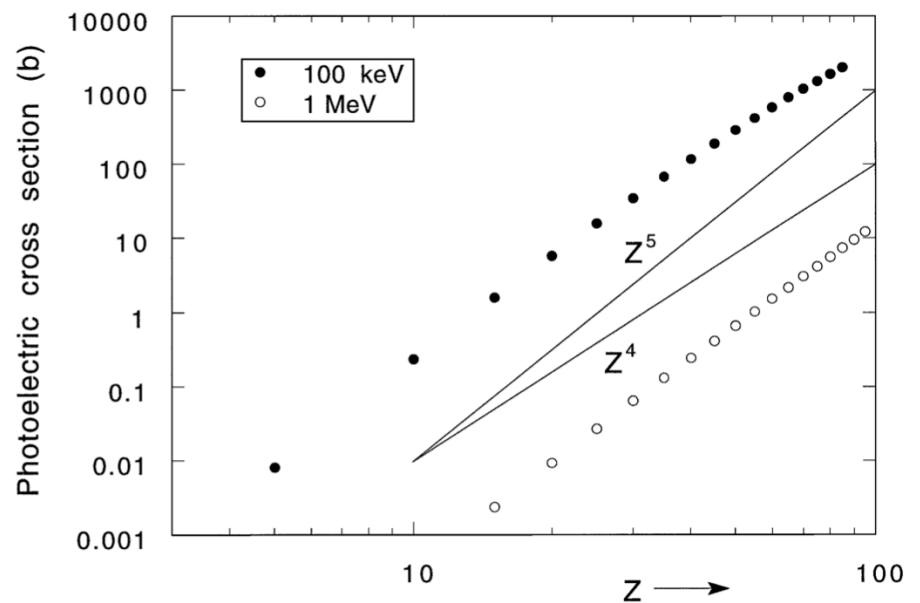
presenti
curve all'inizio.

impulso trasferito ad A

$$\sigma_{photoelec} = \begin{cases} \frac{Z^5}{E_\gamma^3} & E_\gamma < m_e \\ \frac{Z^5}{E_\gamma} & E_\gamma > m_e \end{cases}$$



fotoelettrico
dominante
per $E_\gamma < m_e$

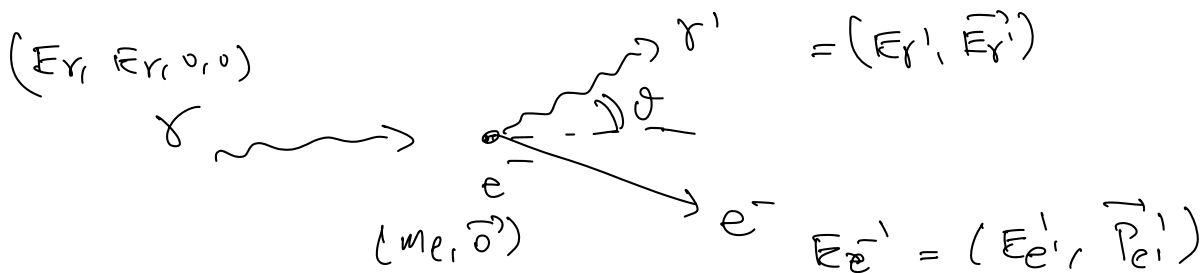


Effetto Compton

urto elastico

$$\gamma + e^- \rightarrow \gamma' + e^-$$

e^- libero: $E_\gamma \sim 10^2 \text{ keV}$ (eu. e^- più intern.)



$$S_{in} = (\underline{p}_\gamma + \underline{p}_e)^2 = \underline{p}_\gamma^2 + \underline{p}_e^2 + 2 \underline{p}_\gamma \cdot \underline{p}_e = 0 + m_e^2 + 2m_e E_\gamma$$

$$S_{fin} = (\underline{p}_{\gamma'} + \underline{p}_{e'})^2 = 0 + m_e^2 + 2 \underline{p}_{\gamma'} \cdot \underline{p}_{e'}$$

Cons. del 4-impulso $\underline{p}_e + \underline{p}_\gamma = \underline{p}_{e'} + \underline{p}_{\gamma'} \Rightarrow \underline{p}_{e'} = \underline{p}_e + \underline{p}_\gamma - \underline{p}_{\gamma'}$

$$S_{fin} = S_{in} \Rightarrow$$

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

Caso limite

$$\gamma \rightarrow e^- \quad \gamma' \rightarrow e^-$$

$$\theta = \pi \quad E_{\gamma'} = \frac{E_\gamma}{1 + \frac{E_\gamma}{m_e} (2)}$$

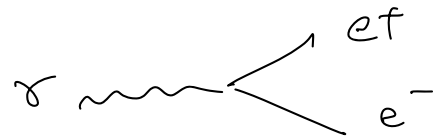
$$E_\gamma \geq m_e \Rightarrow E_\gamma' = \frac{E_\gamma}{1+2} = \frac{1}{3} E_\gamma.$$

e^- prodotto di ionizzazione $E_{e^-} \geq 200 \text{ keV}$

γ : Compton o photoelec.

produzione di coppia

$$\gamma (\text{+ materia}) \rightarrow e^+ e^-$$



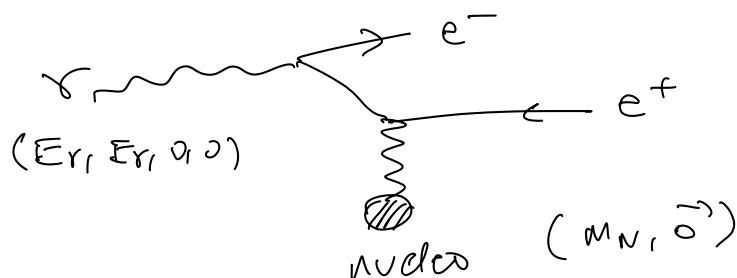
Solo nella materia.

Nel vuoto:

$$S_{in} = \underline{P}_\gamma^2 = 0$$

$$S_{fin} = (\underline{P}_{e^+} + \underline{P}_{e^-})^2 = \underbrace{m_e^2 + m_e^2}_{\neq 0} + 2 \underline{P}_{e^+} \cdot \underline{P}_{e^-}$$

$$\Rightarrow S_{fin} \neq 0 \Rightarrow \text{impossibile}$$



$$\gamma + N \rightarrow e^+ + e^- + N$$

$$S_{in} = (\underline{P}_\gamma + \underline{P}_N)^2 = \underline{P}_\gamma^2 + \underline{P}_N^2 + 2 \underline{P}_\gamma \cdot \underline{P}_N = m_N^2 + 2 m_N E_\gamma$$

$$S_{fin} = (\underline{P}_N + \underline{P}_{e^+} + \underline{P}_{e^-})^2 = \underline{P}_N^2 + (\underline{P}_{e^+} + \underline{P}_{e^-})^2 + 2 \underline{P}_N \cdot (\underline{P}_{e^+} + \underline{P}_{e^-})$$

Soglia del processo:

o soglia $\vec{P}_{e^+} = \vec{P}_{e^-} = \vec{0}$ nessun impulso.

$$\underline{P}_{e^-} = (m_e, \vec{0}) \quad \underline{P}_{e^+} = (m_e, \vec{0})$$

$$S_{fin} = m_N^2 + 2 m_e^2 + 2 m_e m_e + 2 m_N (m_e + m_e)$$

$$S_{fin} = \cancel{m_N^2} + 4m_e^2 + 4m_e m_N$$

$$S_{in} = \cancel{m_N^2} + 2m_N E_\gamma$$

$$S_{fin} = S_{in} \Rightarrow 2m_N E_\gamma = 4m_e m_N + 4m_e^2$$

$$E_\gamma = 2m_e + \frac{m_e}{m_N} (2m_e)$$

$$m_N \gg m_e$$

Nucleo: A nucleoni (protoni) neutroni)

$$m_p \approx m_n \approx 1 \text{ GeV}$$

$$m_e = 0.5 \text{ MeV}$$

$$\frac{m_e}{A m_p} \ll 1.$$

produzione di coppia per $E_\gamma \geq 2m_e = 1.022 \text{ MeV}$
processo a soglia

photoelectric

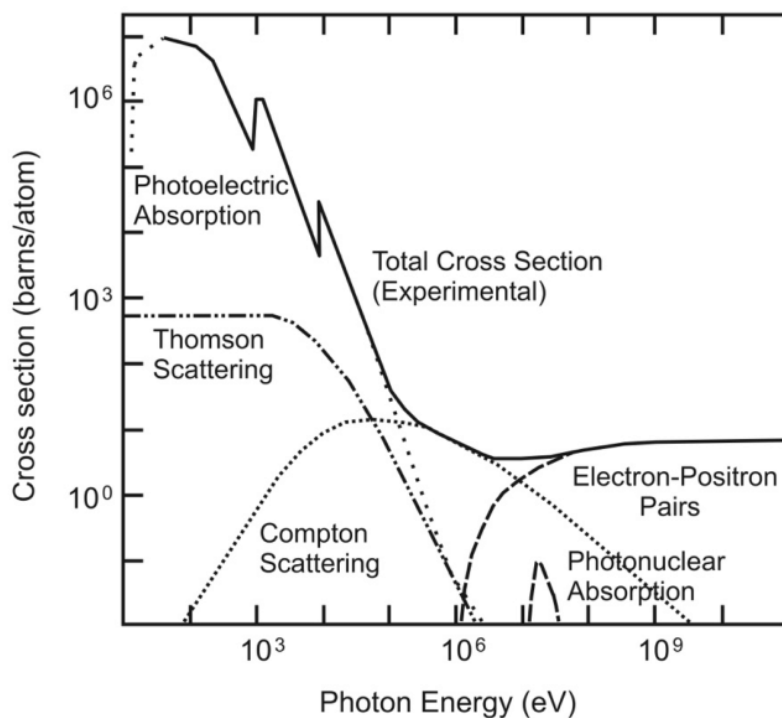
$$E_\gamma < 100 \text{ keV}$$

Compton:

$$\text{Max } \odot \quad E_\gamma \approx m_e = 500 \text{ keV}$$

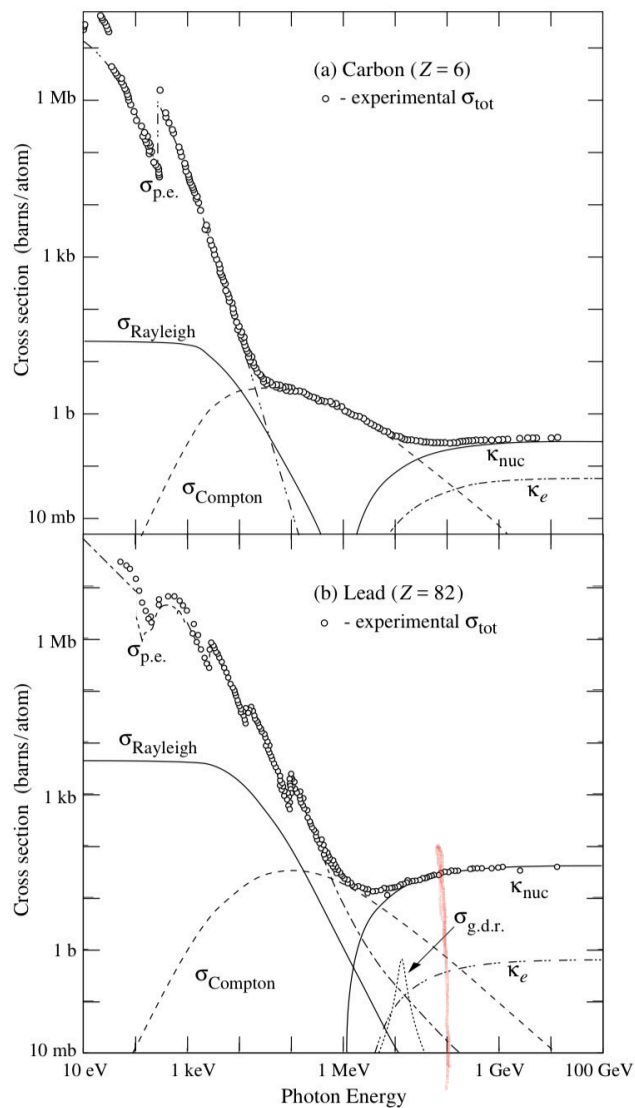
produzione di coppia
a soglia

$$E_\gamma \geq 1.022 \text{ MeV}$$



$$E_\gamma \approx 1 \text{ GeV} \Rightarrow$$

$$e^\pm \approx 500 \text{ MeV} \Rightarrow \text{irraggiamento}$$



Lunghezze di attenuazione per fotoni:



$$I(x) = I_0 e^{-\mu x} = I_0 e^{-\sigma \cdot n \cdot x} = I_0 e^{-x/\lambda_\gamma}$$

$$n = \frac{\rho}{A} N_A \quad \text{densità di nuclei}$$

$$\lambda_\gamma = \frac{1}{\sigma \cdot n} \quad \text{lunghezza di attenuazione}$$

σ : Sezione d'urto totale del fotone

Fotoni con $E_\gamma > 100 \text{ MeV}$ $\sigma \approx \text{costante} = \sigma_{\gamma \rightarrow e^+e^-}$

$$\lambda_\gamma = \frac{1}{\sigma_{e^+e^-} \cdot n} \Rightarrow \sigma_{e^+e^-} = \frac{1}{\lambda_\gamma} \cdot \frac{1}{n}$$

sperimentalmente si osserva $\frac{1}{\chi_r} \approx \frac{7}{9} \frac{1}{\chi_0}$

χ_0 : lunghezza di radiazione

$$\sigma_{\gamma \rightarrow e^+e^-} = \frac{1}{\chi_r} \frac{1}{n} = \frac{7}{9} \frac{1}{\chi_0} \frac{1}{n} = \frac{7}{9} \frac{1}{\chi_0} \frac{1}{\rho} \frac{A}{N_A}$$

$$\approx Z^2 \ln(183 Z^{-1/3})$$

Sciam: elettromagnetici

$$E_\gamma \gg 2mc^2$$

