Interaction of radiation with matter

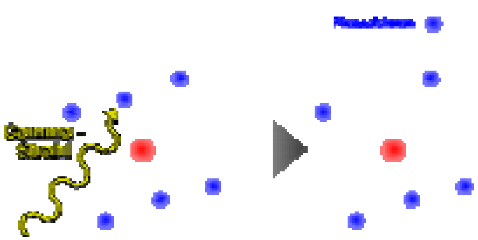
2- Interaction of photons with matter

- **Photoelectric effect**
- **Compton Scattering**
- **Pair production**
- **Photon absorption cross-section**

Interacção dos fotões com a matéria

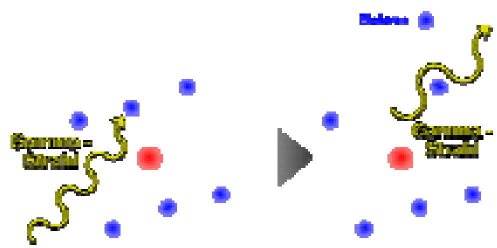
Os fotões interagem com a matéria, produzindo partículas carregadas, através dos seguintes processos: **Efeito fotoeléctrico, Dispersão de Compton, Produção de pares, Interacção fotonuclear.**

Efeito fotoeléctrico



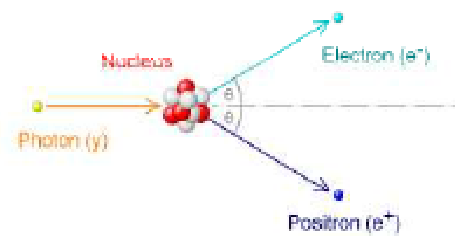
Fotão é absorvido por um átomo ejectando um electrão.

Dispersão de Compton



Fotão choca com um electrão quase livre do átomo, ejectando-o.

Produção de pares



Fotão converte-se num par electrão-positrão;

Interacção fotonuclear: **Fotão é absorvido por um núcleo atómico, dissociando-o.**

Photoelectric Effect

$$\gamma + atom \rightarrow e + atom$$

Photon is absorbed by an atom, ejecting an electron with energy T,

$$T = E_\gamma - E_b$$

E_γ - photon energy
E_b - electron binding energy

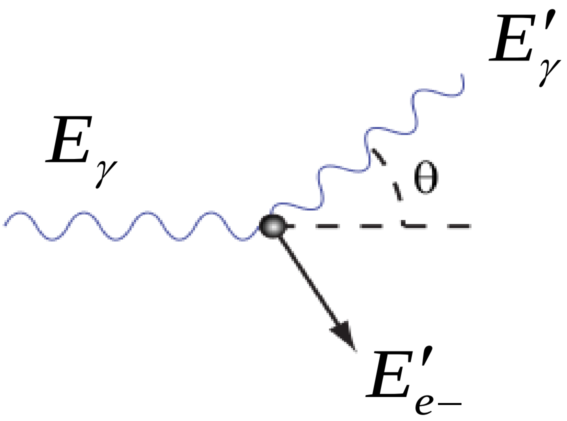
Cross-section :

$$\sigma_{ph} \sim Z^5 \left(\frac{m_e c^2}{E_\gamma} \right)^3$$

Compton scattering

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

Photon scatters off an atomic electron with small binding energy (essentially free)



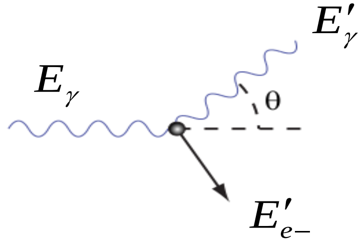
Energy momentum conservation:

$$E_\gamma + m_e c^2 = E'_\gamma + E'_e$$
$$p_\gamma = p'_\gamma \cos\theta + p'_e \cos\phi$$
$$0 = p'_\gamma \sin\theta - p'_e \sin\phi$$

$$E'_\gamma = \frac{E_\gamma}{1 + \frac{E_\gamma}{m_e c^2}(1 - \cos\theta)}$$

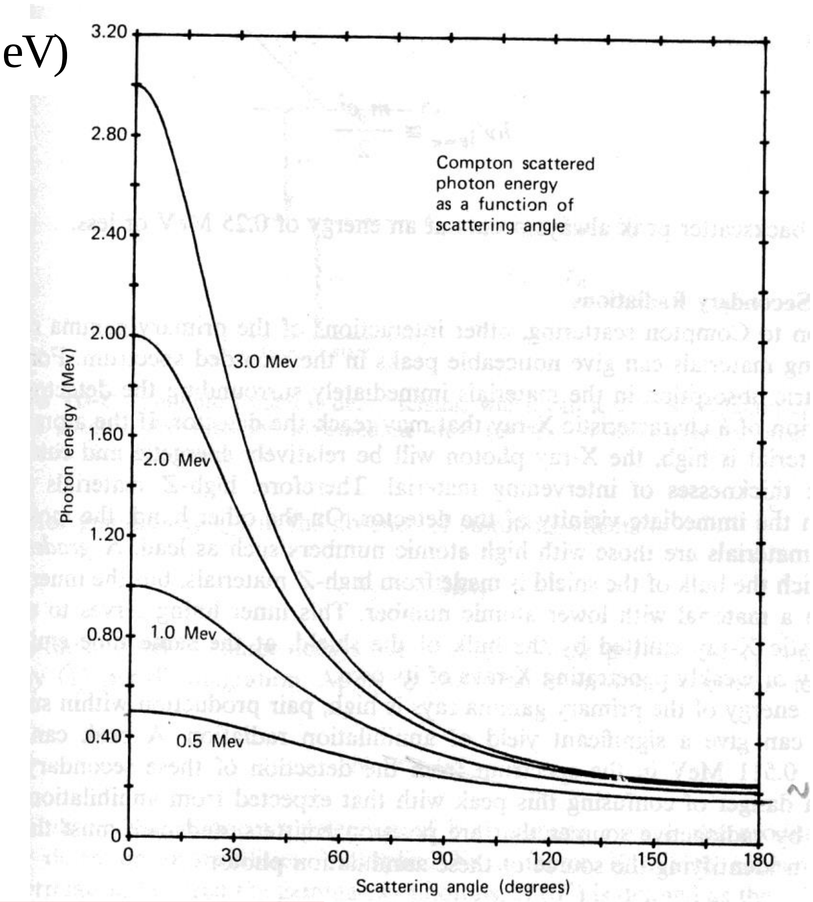
$$T'_e \equiv E'_e - m_e c^2 = E_\gamma - E'_\gamma$$

Compton scattering



$$E'_\gamma = \frac{E_\gamma}{1 + \frac{E_\gamma}{m_e c^2}(1-\cos\theta)}$$

E'_γ(MeV)



Limit cases:

$\theta \cong 0:$

$$E'_\gamma \equiv E'_{\gamma,máx} \cong E_\gamma$$

$$T'_e \equiv T'_{e,\min} \cong 0$$

$\theta = \pi:$

$$E'_\gamma \equiv E'_{\gamma,\min} = \frac{E_\gamma}{1 + 2\frac{E_\gamma}{m_e c^2}}$$

$$T'_e \equiv T'_{e,máx} \qquad (\equiv \text{"Compton edge"})$$

If $E_\gamma >> m_e c^2$:

$$E'_\gamma(\theta = \pi) \cong \frac{m_e c^2}{2} = 0.256 \text{ MeV}$$

$$T'_{e,\max} = E_\gamma - 0.256 \text{ MeV}$$

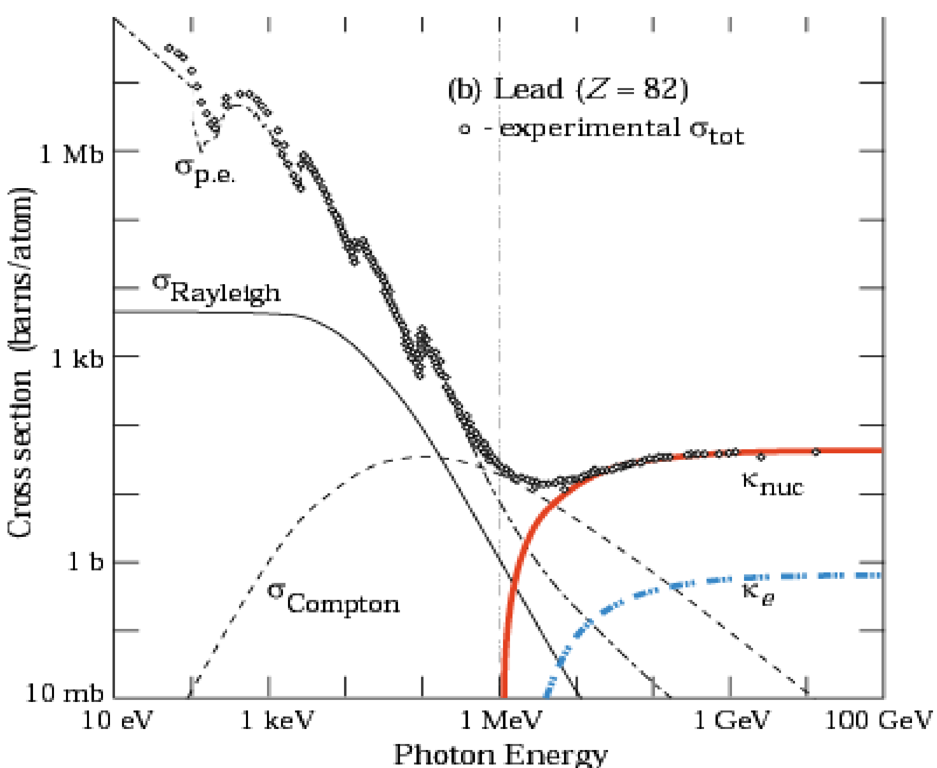
Pair production

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

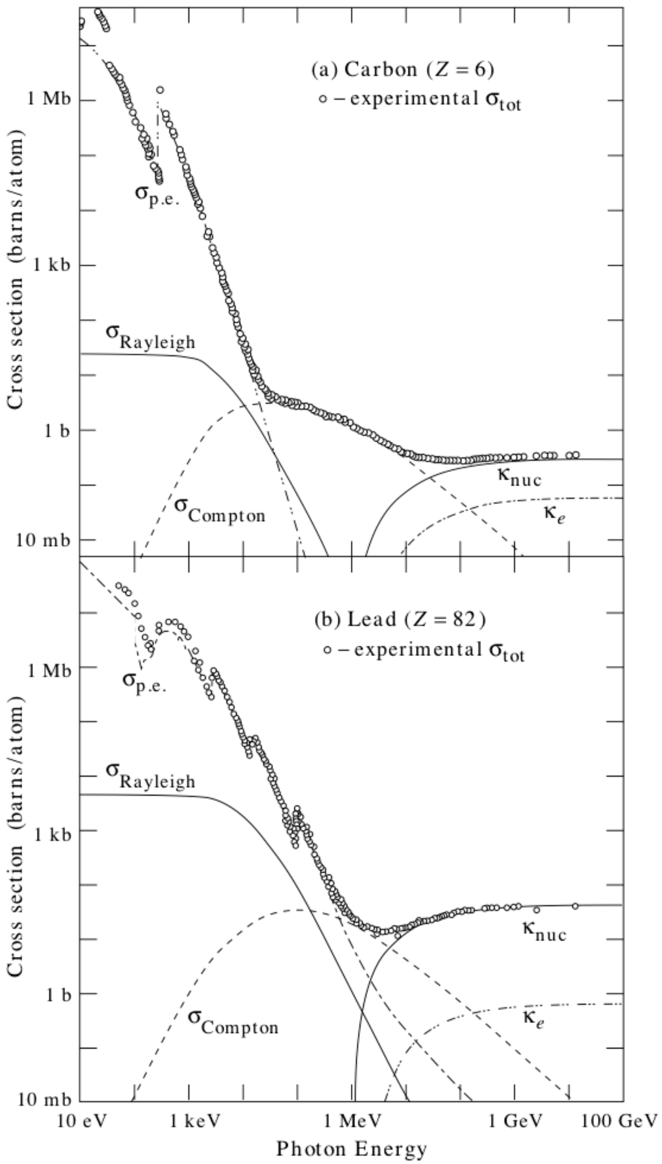
Creation of an electron/positron pair in the field of an atom.

Threshold energy : $E_\gamma \geq 2m_e c^2 \quad (=1.022 \quad MeV)$

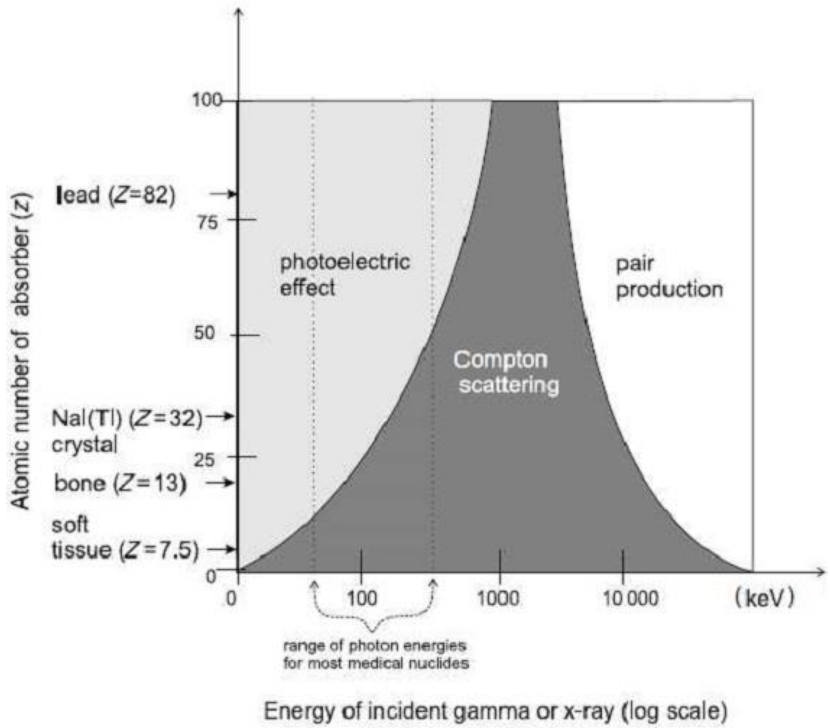
Cross-section : $\sigma_{pair} \sim 4\ \alpha\ Z^2\ r_e^2 \left[\frac{7}{9} \ln\left(\frac{183}{Z^{1/3}}\right)\right] \sim \frac{7}{9}\ \frac{A}{N_A}\ \frac{1}{X_0}$



Photon interactions



$\sigma_{p.e.}$	photo electric effect
$\sigma_{Rayleigh}$	Coherent scattering (Rayleigh scattering —atom neither ionized nor excited)
$\sigma_{Compton}$	Incoherent scattering (Compton scattering off an electron)
κ_{nuc}	Pair production, nuclear field
κ_e	Pair production, electron field



Photon absorption in matter

Total cross-section for interacting with an atom:

$$\sigma_\gamma^{tot} = \sigma_{pe} + Z\,\sigma_C + \sigma_{pair}$$

Interaction probability per unit length of traversed matter (linear attenuation coefficient) :

$$\mu \equiv p_\gamma = \frac{N_A}{}\frac{\rho}{A}\,\sigma_\gamma^{tot}$$

Photon beam attenuation:

$$I_\gamma(x) = I_0\, e^{-\mu\, x}$$

Mass attenuation coefficient:

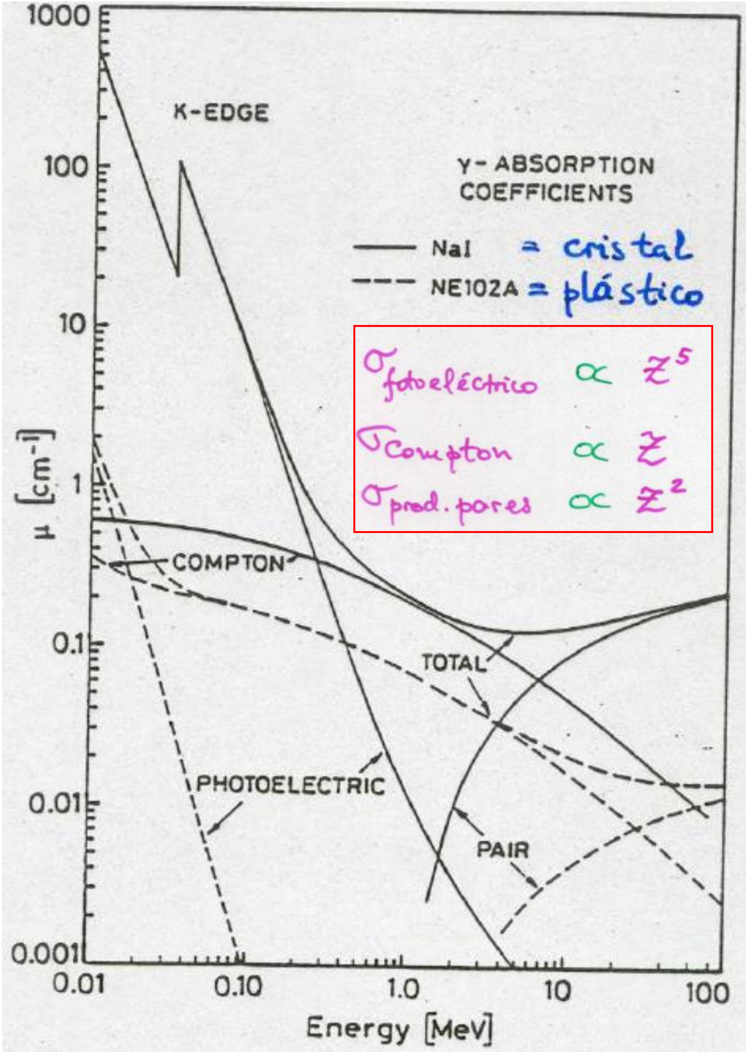
$$\frac{\mu}{\rho} = \frac{N_A}{A}\,\sigma_\gamma^{tot}$$

Absorption length:

$$\lambda_{abs} = \frac{1}{p}$$

$$\lambda_{abs} = \frac{A}{N_A\ \rho\ \sigma_\gamma}\quad \text{[cm]}$$

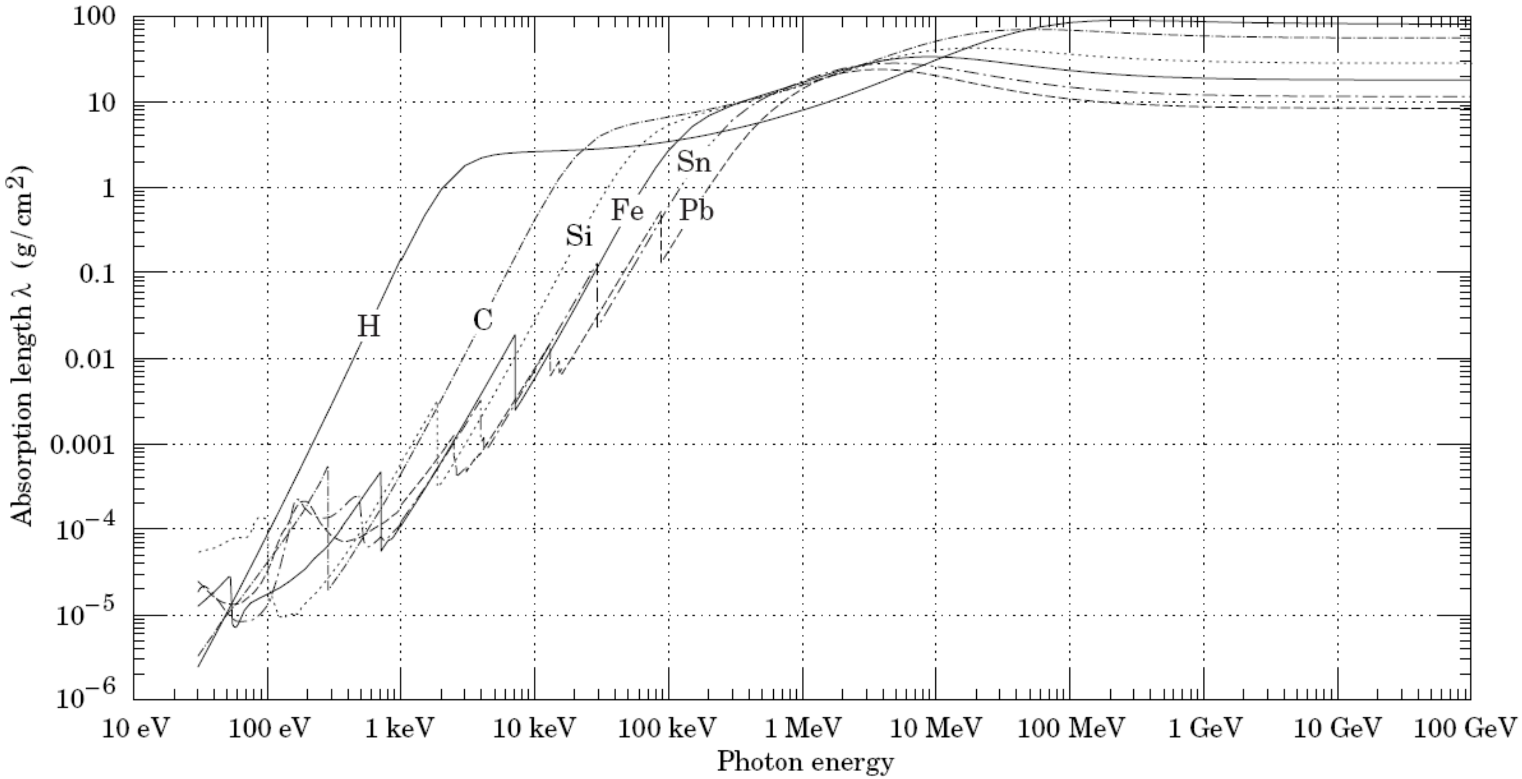
$$\lambda_{abs}\ \rho = \frac{A}{N_A\ \sigma_\gamma}\quad \text{[gr.cm}^{-2}\text{]}$$



Photon absorption in matter (cont.)

- Example:

Compute the ammount of Pb shielding (ρ =11.34 g·cm^{-3}) required to absorb 99% of the photons emmited by a ^{137}Cs source ($E\gamma$ = 0.662 MeV).



Photon absorption in matter (cont.)

- Example:

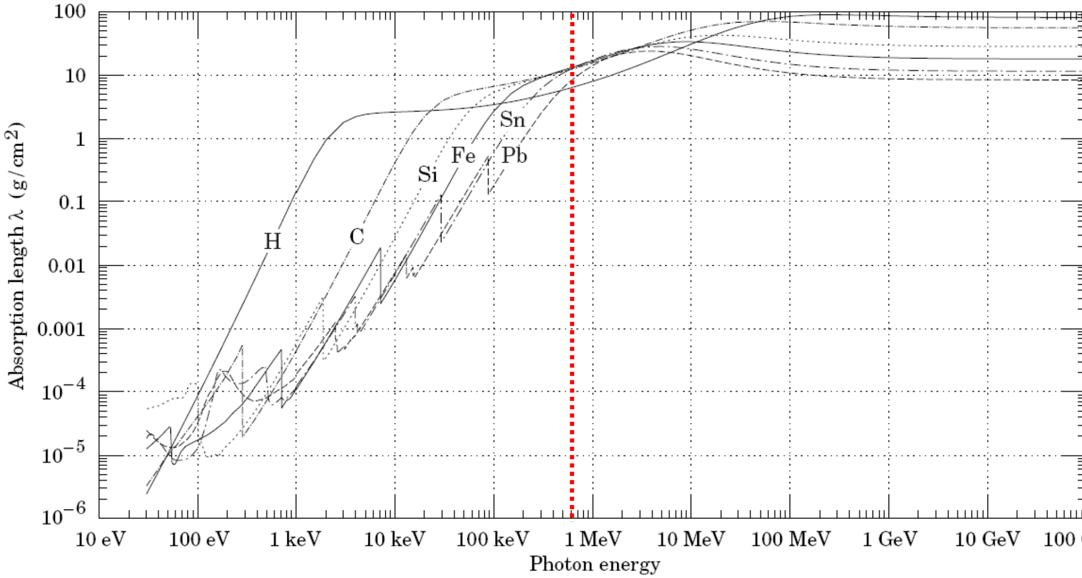
Compute the ammount of Pb shielding (ρ =11.34 g·cm^{-3}) required to absorb 99% of the photons emmited by a ^{137}Cs source ($E\gamma$ = 0.662 MeV).

$$\frac{I}{I_0} = e^{-\frac{x}{\lambda_{abs}}} \Leftrightarrow x = -\lambda_{abs} \ln \frac{I}{I_0} \Leftrightarrow$$

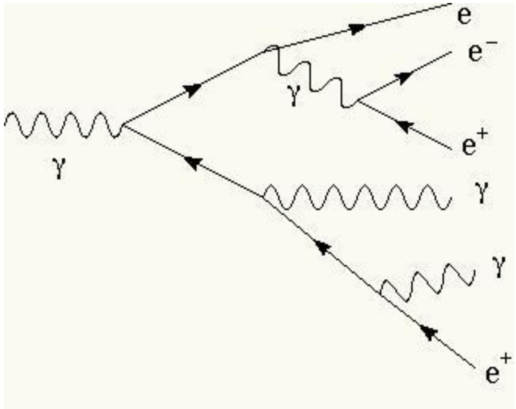
$$\Leftrightarrow x = -\lambda_{abs} \ln(0.01) = 4.6 \times \lambda_{abs};$$

$$\left(\lambda_{abs} = \frac{10\ gcm^{-2}}{\rho_{Pb}} \approx 1\ cm \right)$$

$$x \approx 4.6\ cm$$



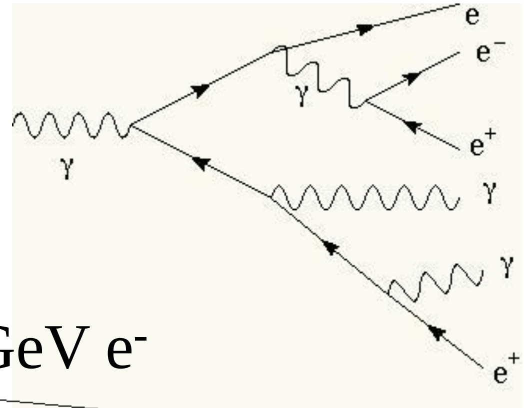
Electromagnetic showers



Particle multiplication

continues while $E_{part} > E_{critical}$

Electromagnetic showers

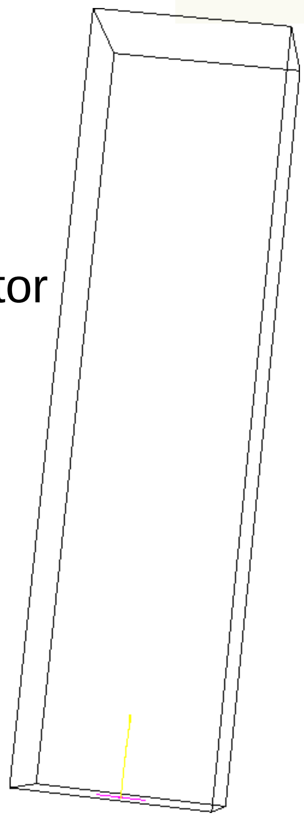


Particle multiplication

continues while

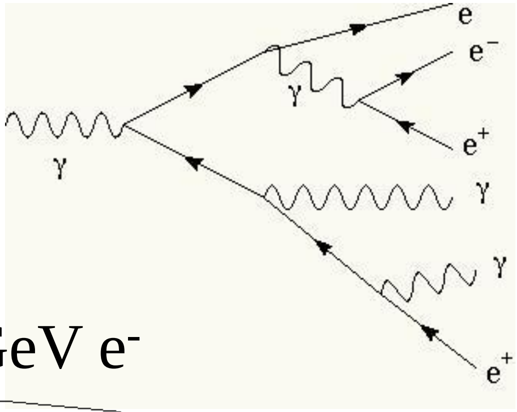
$E_{part} > E_c$, $E_\gamma > 2\ m_e c^2$

2 GeV e^-



37 x 10 x 10 cm^3
Lead Glass scintillator

Electromagnetic showers

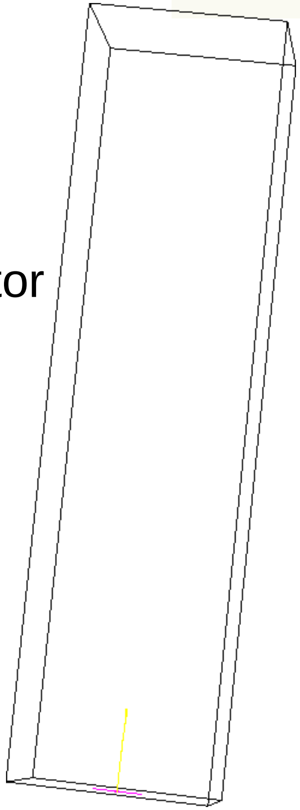


Particle multiplication

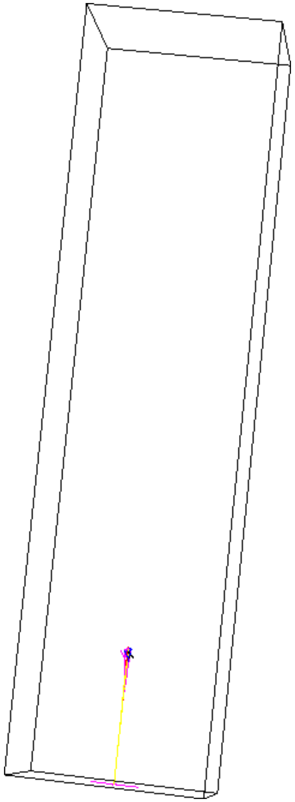
continues while

$E_{part} > E_c$, $E_\gamma > 2\ m_e c^2$

2 GeV e$^-$



80 GeV e$^-$



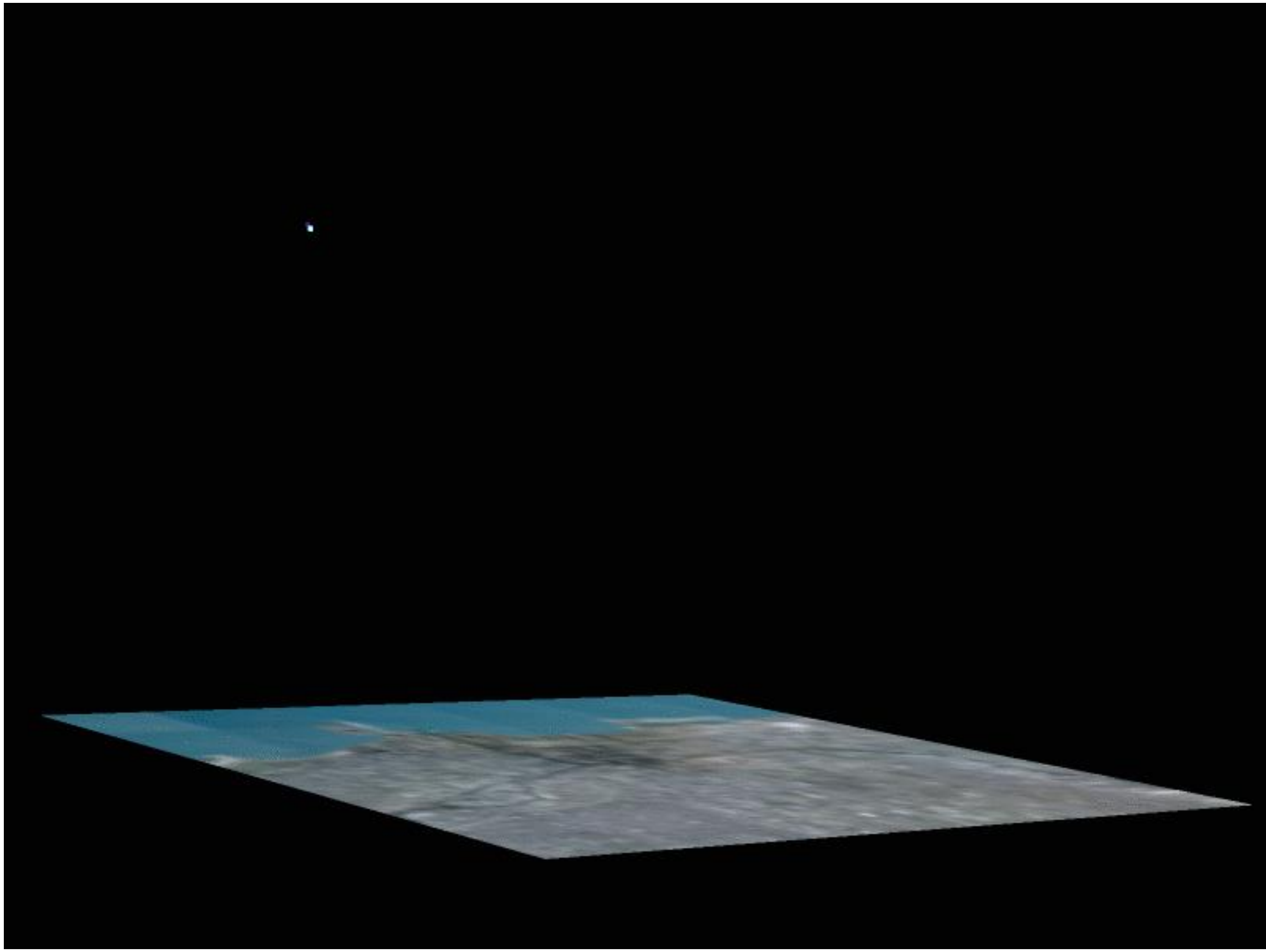
37 x 10 x 10 cm^3
Lead Glass scintillator

Extensive air showers

1 EeV (10^9 GeV) proton shower. Pictures\proton_1EeV.mov

Extensive air showers

200GeV gamma ray shower, starting 5km high.



Slides preparados por

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baseados em:

Sérgio Ramos, Slides da cadeira de Física da Radiação, http://www.lip.pt/~sramos/ist/frad_biom06.html

Fernando Barão, Slides do Laboratório de Raios Cósmicos, http://labrc.ist.utl.pt/MyContents/Lab.RaiosCosmicos/LabRC.main.html

W. Riegler, O. Ullaland, G.Cowan, CERN Summer students programme lectures http://indico.cern.ch/categoryDisplay.py?categId=345 (2006-2008)

E na seguinte bibliografia:

•G.F. Knoll, “Radiation detection and measurement”
•W.R. Leo, “Techniques for nuclear and particle physics experiments”
•G. Cowan, “Statistical data analysis”
•L. Lyons, “Statistics for nuclear and particle physicists”
•Particle Data Group, http://pdg.lbl.gov/