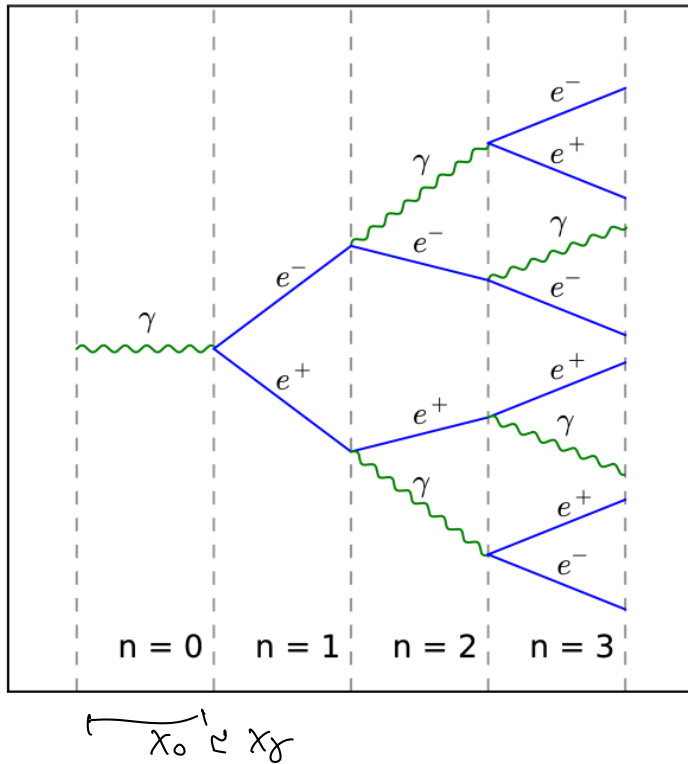


Sciame Elettromagnetici:



$$e^\pm: E_e > E_c = \frac{600 \text{ MeV}}{Z}$$

$$E(x) = E_0 e^{-x/x_0}$$

x_0 : lungh. di radiazione

$$\gamma_0 \geq E = 2mc^2 = 1.022 \text{ MeV}$$

$$E(x) = E_0 e^{-x/x_g}$$

$$\frac{1}{x_g} = \frac{7}{9} \frac{1}{x_0} \sim Z^2 \ln(7^{1/3})$$

x_g : lungh. di attenuazione

$E_{e,\gamma} \gg \text{MeV} \Rightarrow$ Bremsstrahlung + produzione di coppie
 \Rightarrow Sciame EM

processo stocastico di generazione di γ, e^+, e^-

Energia

$$E_0 \xrightarrow{x_0} \left\{ \begin{array}{l} \frac{E_0}{2} \\ \frac{E_0}{2} \end{array} \right. \begin{array}{l} \frac{1}{2} \left(\frac{E_0}{2} \right) \\ \frac{1}{2} \left(\frac{E_0}{2} \right) \end{array} \quad \dots \quad \left. \begin{array}{l} \frac{E_0}{2^n} \\ \frac{E_0}{2^n} \end{array} \right\} \begin{array}{l} \frac{1}{2^n} \left(\frac{E_0}{2^n} \right) \\ \frac{1}{2^n} \left(\frac{E_0}{2^n} \right) \end{array}$$

2^n particelle.

$x = nx_0 \quad E_i = \left(\frac{1}{2}\right)^n E_0$

$\leftarrow \bullet \rightarrow \xRightarrow{\text{Boost}} \rightarrow$

Rif. solide
con particelle

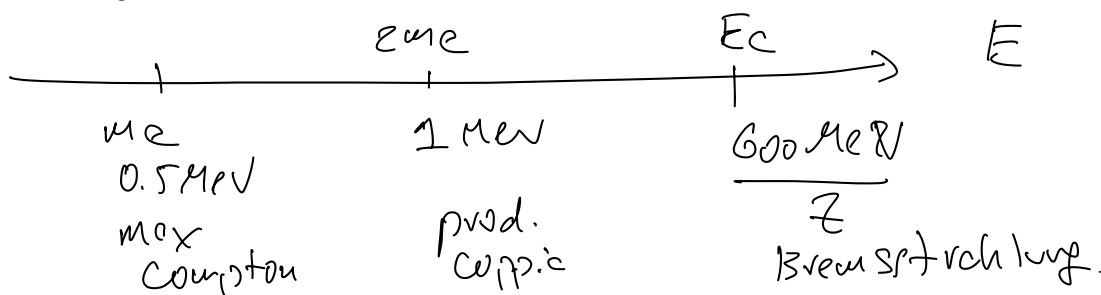
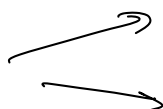
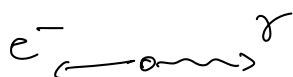
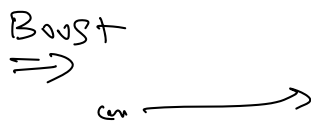
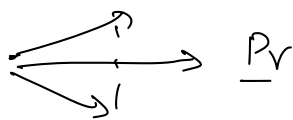
LAB

$$\left. \begin{array}{l} E_{e^\pm} > E_c \\ E_\gamma > 2mc^2 \end{array} \right\} \text{Cond. per sviluppo dello sciame.}$$

$$\gamma \rightarrow$$

$$\underline{P} = (E_\gamma, \underline{p}_\gamma)$$

LAB



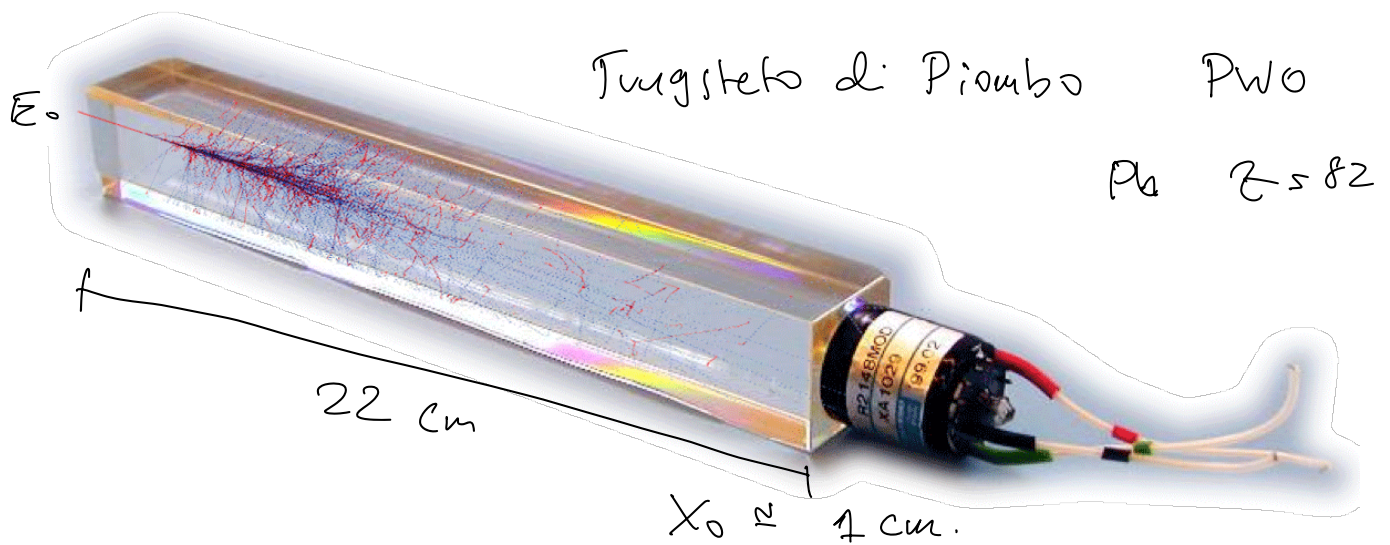
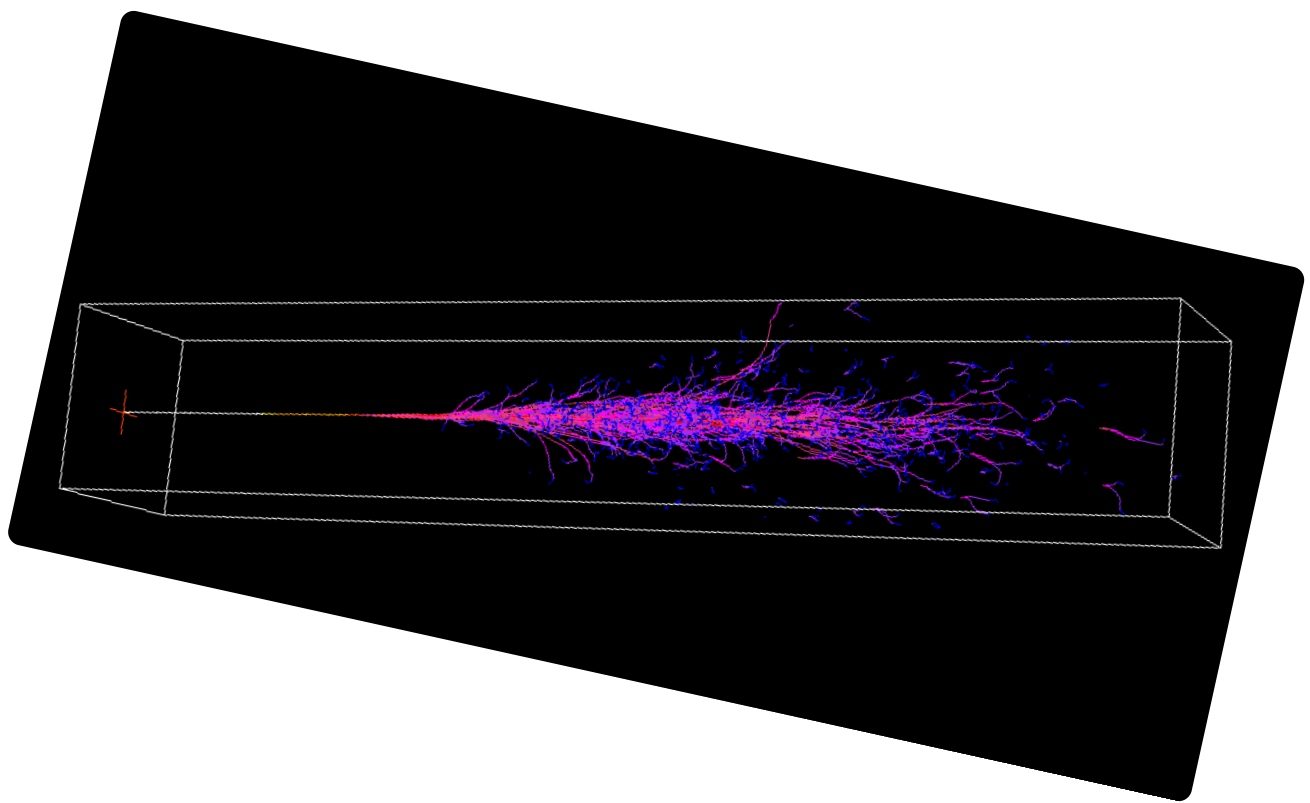
$E_\gamma < 2m_e \Rightarrow$ Compton + photoelectric.
 \Rightarrow non contribuisce allo scintillazione

$E_\gamma < m_e \Rightarrow$ photoelettrico (dominante).

$E_{e^\pm} > E_c :$ Bremsstrahlung

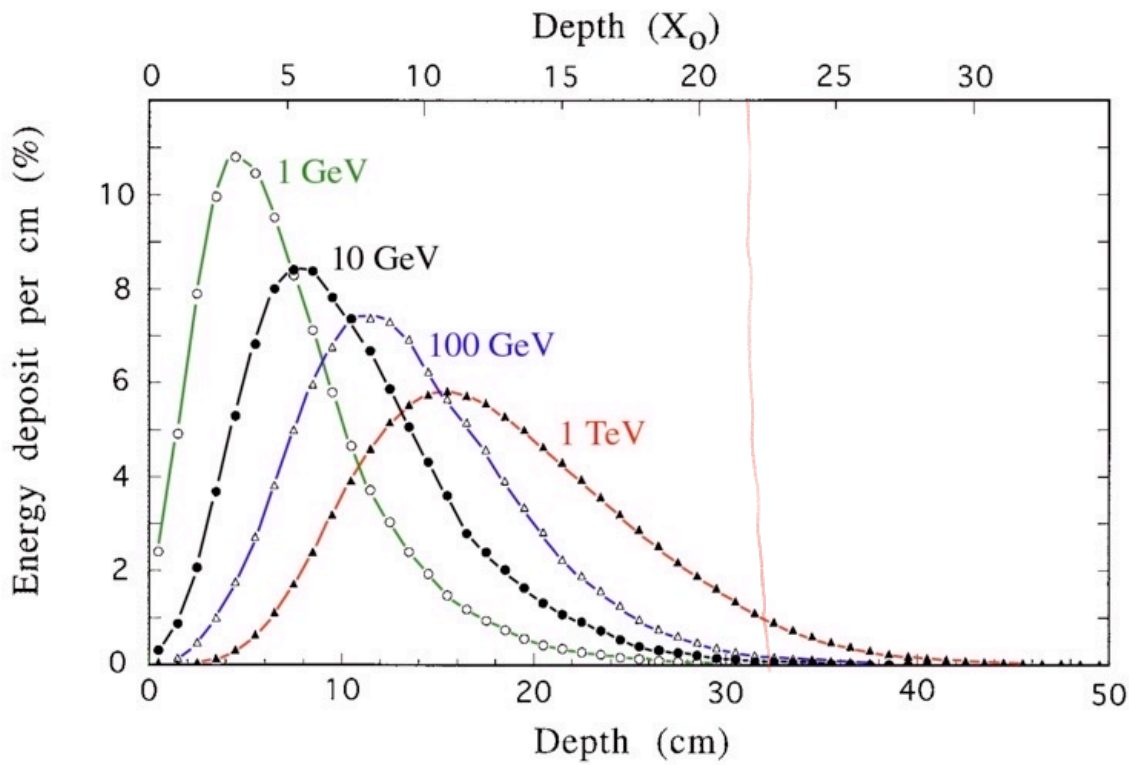
$E_{e^\pm} < E_c :$ ionizzazione (non contribuisce allo scintillazione)

$E_{e^+} < m_e \Rightarrow e^+ + e^- \rightarrow \text{pos. ann.} \rightarrow \gamma + \gamma$



Due parametri fisici regolano lo sviluppo dello sciume

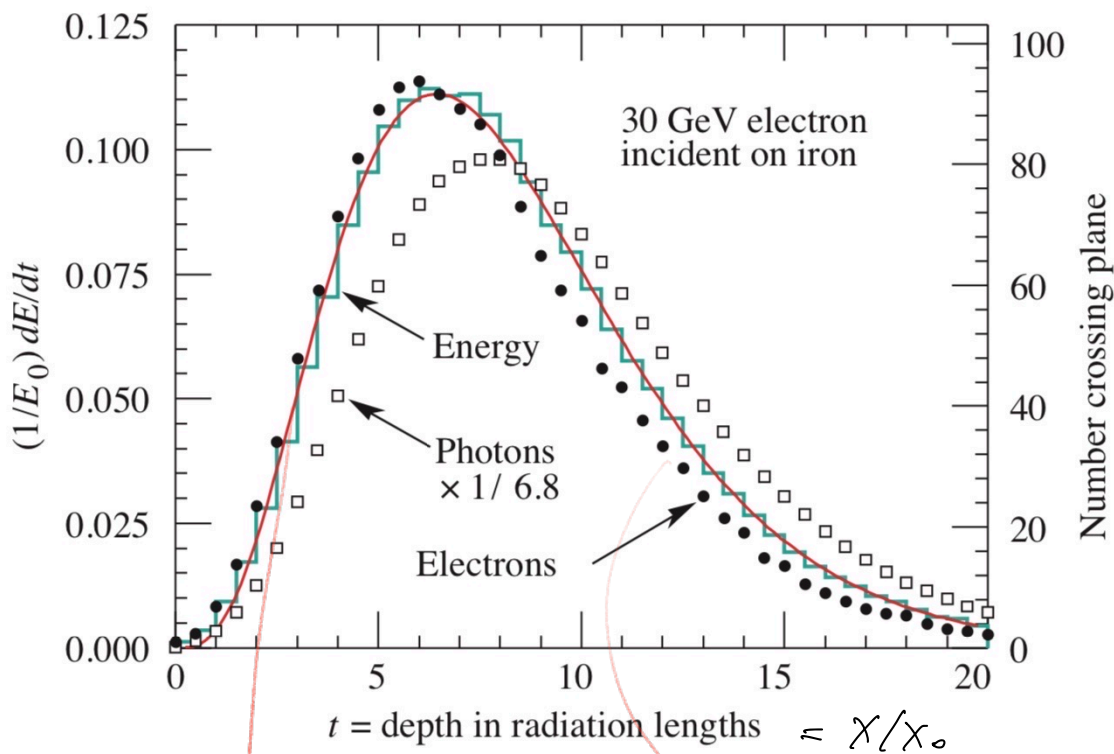
- 1) E_c (soglia di Brems)
- 2) X_0 (soglia per sviluppo dello sciume profilo longit. dello sciume).



e^-
SV CU
(Rene)

$X \rightarrow t = X/X_0$ Spessore in unita di X_0

$$\frac{dE}{dX} \rightarrow \frac{1}{E_0} \frac{dE}{dX} \rightarrow \frac{1}{E_0} \frac{dE}{dX/X_0} = \frac{1}{E_0} \frac{dE}{dt} = \frac{dE/E_0}{dX/X_0}$$



Profilo
longitudinale.

$$F(t) \sim \frac{E_0}{E_c} t^a e^{-bt}$$

Fit ai dati $\Rightarrow a, b$ per e^-, γ

Max profondità dello sciume:

$$t_{max} = \ln\left(\frac{E_0}{E_c}\right) + C$$

diverso per γ e e^\pm

$$\xi \approx 60 \Rightarrow E_c = \frac{600 \text{ MeV}}{60} \approx 10 \text{ MeV}$$

$$E_{me} = 1 \text{ MeV}$$

Sviluppo Trasversale dello sciume

- indipendente da E_0 iniziale

- dipende solo della diffusione multiple coulomb.

Raggio di Moliere ρ_M

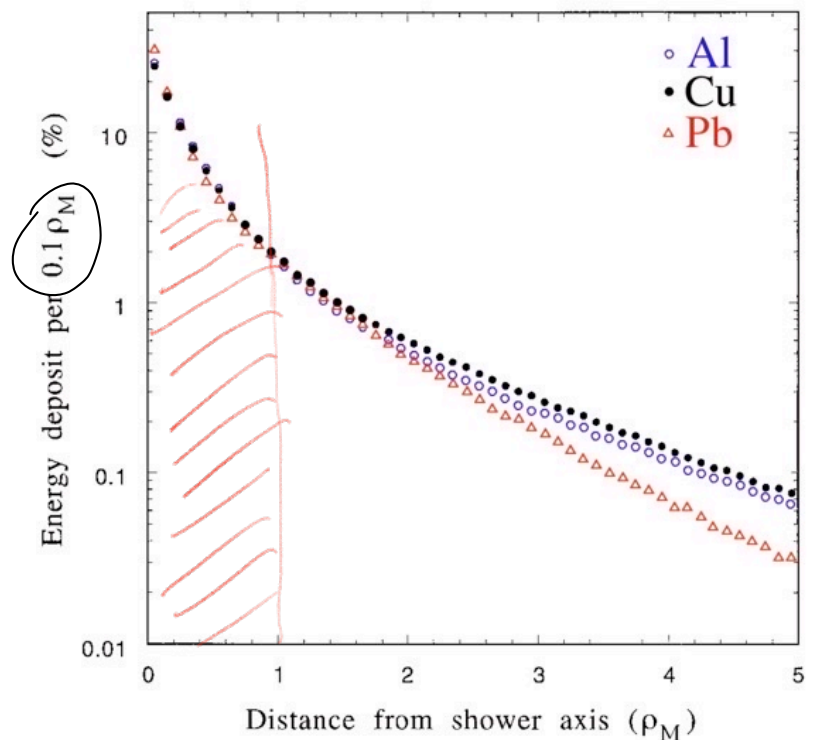
$$\rho_M = \frac{Z^2}{E_c [\text{MeV}]} X_0$$

$$E_c = \frac{600 \text{ MeV}}{Z}$$

Raggio entro il quale

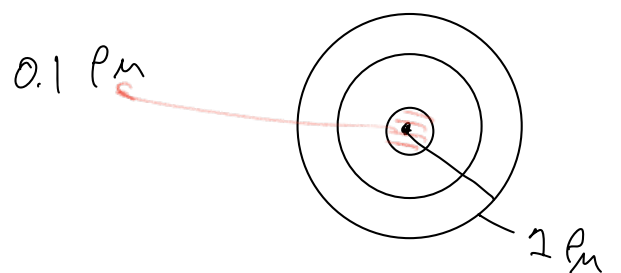
90% energia dello sciume

viene depositata.

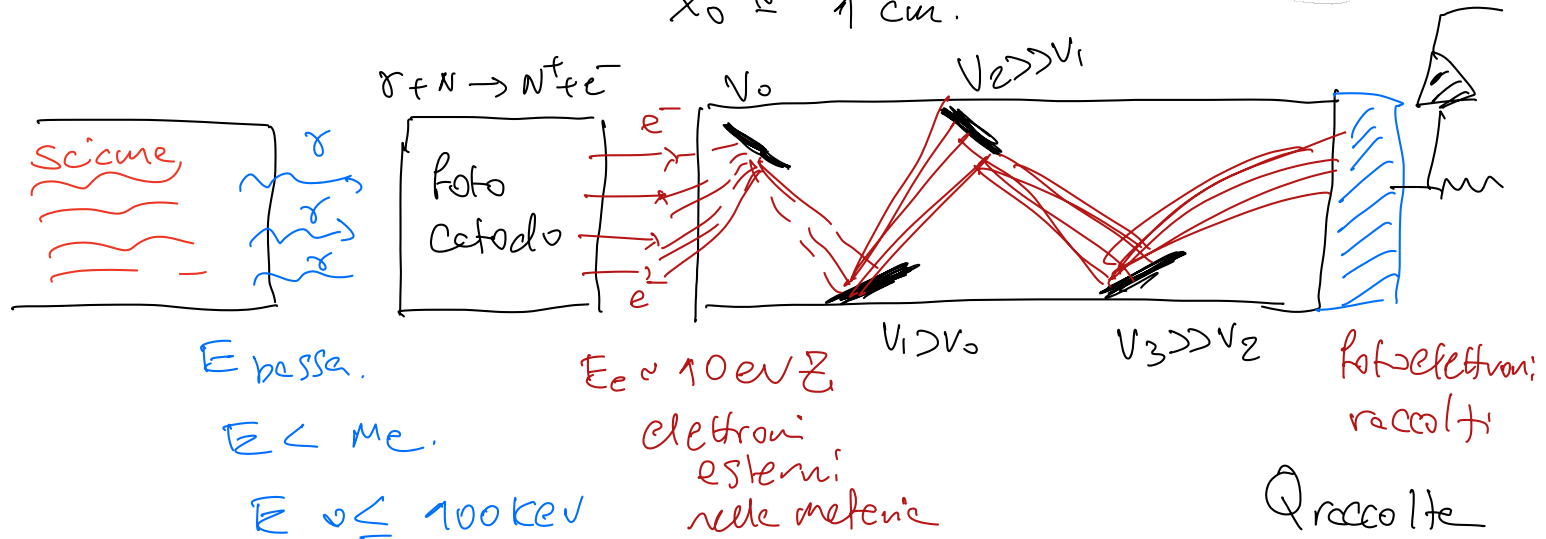
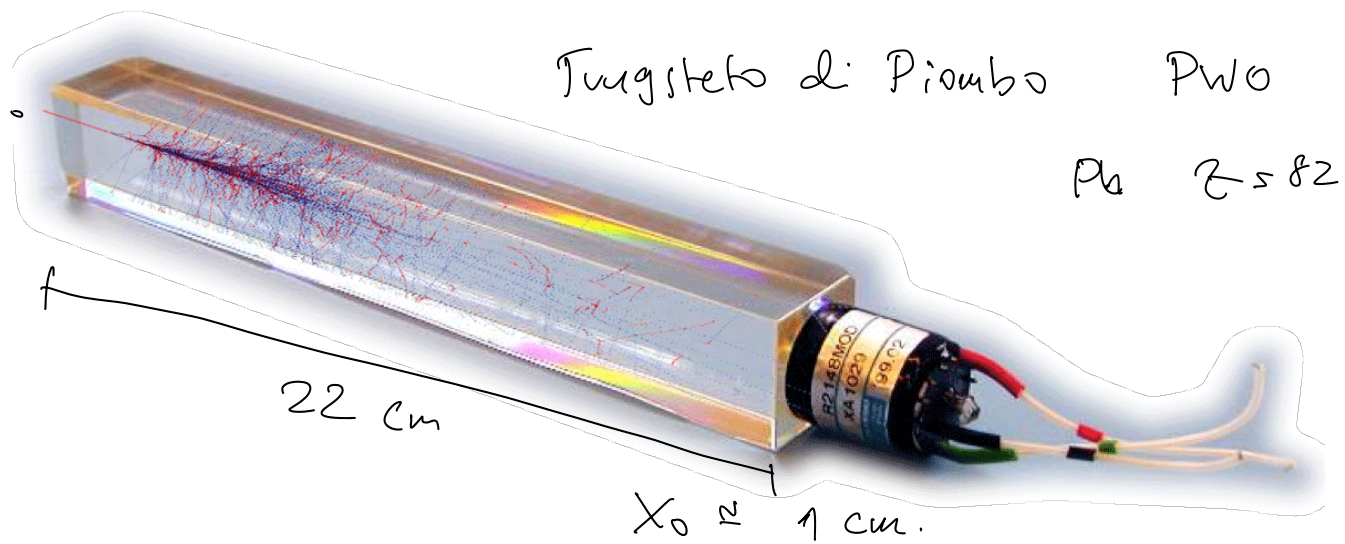


Atomic and nuclear properties of copper (Cu)

Quantity	Value	Units	Value	Units
Atomic number	29			
Atomic mass	63.546(3)	g mole ⁻¹		
Specific gravity	8.960	g cm ⁻³		
Mean excitation energy	322.0	eV		
Minimum ionization	1.403	MeV g ⁻¹ cm ²	12.57	MeV cm ⁻¹
Nuclear collision length	84.2	g cm ⁻²	9.393	cm
Nuclear interaction length	137.3	g cm ⁻²	15.32	cm
Pion collision length	109.3	g cm ⁻²	12.20	cm
Pion interaction length	165.9	g cm ⁻²	18.51	cm
Radiation length	12.86	g cm ⁻²	1.436	cm
Critical energy	19.42	MeV (for e ⁻)	18.79	MeV (for e ⁺)
Molière radius	14.05	g cm ⁻²	1.568	cm
Plasma energy $\hbar\omega_p$	58.27	eV		
Muon critical energy	317.	GeV		
Melting point	1358.	K	1085.	C
Boiling point @ 1 atm	2835.	K	2562.	C



<https://pdg.lbl.gov/2024/AtomicNuclearProperties/>



$Q_{raccolte} \propto Q_{indotte} \propto E_{nucleate} \propto E_0$
dello
scienze

$$Q_{raccolte} = G \cdot Q_{prodotta} \quad G \approx 10^4 - 10^7$$

Interazione nelle metene:

particelle cariche \rightarrow ionizzazione

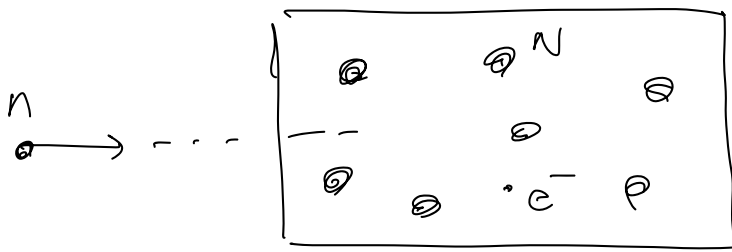
$e^\pm \rightarrow$ radiazione

$\gamma \rightarrow$ Conversione in e^+e^- , Compton, Ph. el.

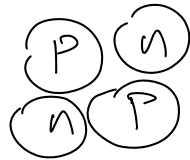
Adroni: nelle materia

$p, \bar{p}, \pi^\pm, K^\pm, \pi^0$

adroni carichi ionizzano.



Interazione forte avviene solo a distanze piccole



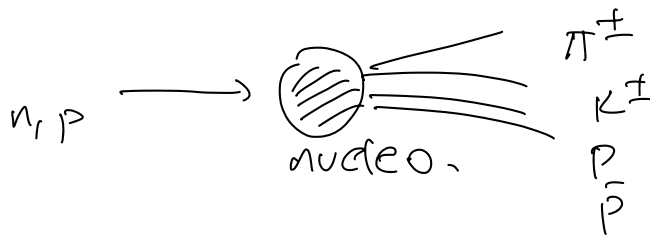
Forza forte si fa sentire per distanze $\propto 1/r$

$n + \text{nucleo} \rightarrow$ interazione nucleone.

elastico.

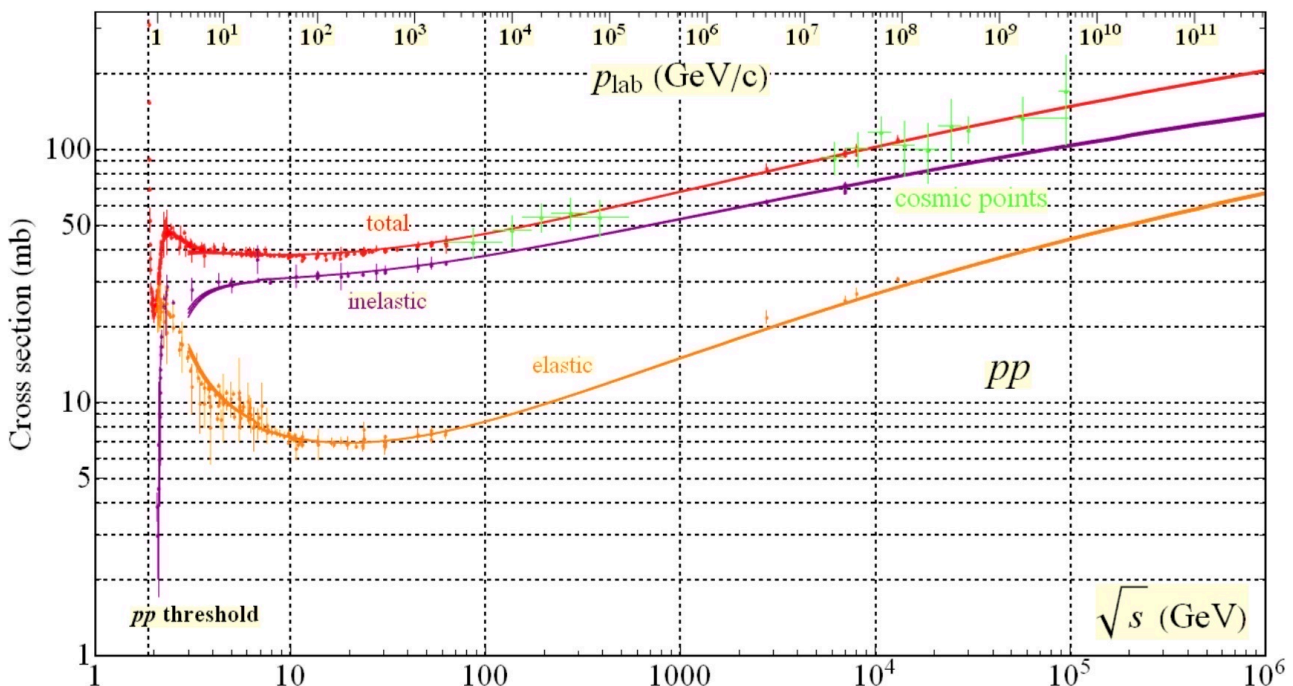
inelastico

$n, p + N \rightarrow n, p + N$



urto anelastico

$p + p \rightarrow X$



$$p+p \rightarrow p+p$$

$$p+p \rightarrow p+p+x$$

processo a soglia.

$$\left. \begin{array}{l} B \quad 1 \quad 1 \quad 1 \quad 1 \quad \emptyset \\ Q \quad 1 \quad 1 \quad 1 \quad 1 \quad \emptyset \end{array} \right\} \pi^0$$

$$p+p \rightarrow p+p+\pi^0$$

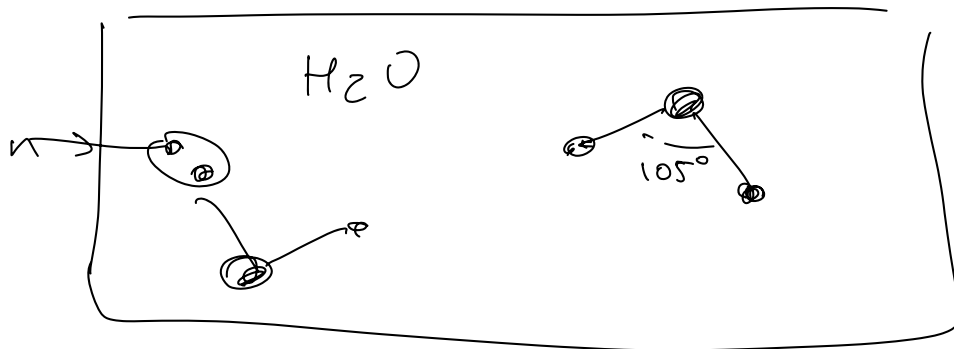
neutrone: $m \sim 1 \text{ GeV} \sim m_p$

Nucleo: $m \sim A \cdot m_p$

$$n+N \rightarrow n+N$$

$$m_N \gg m_n$$

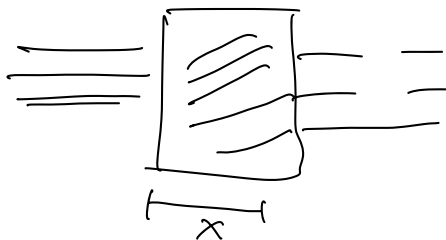
\Rightarrow urto elastico



$$n+p \rightarrow n+p \text{ e perdere energia al neutrone}$$

Adroni nelle materie \Rightarrow generano scorie adronico
Simile al mecc. dello scorie EM.

fascio di adroni di intensità I_0 .



$$I(x) = I_0 e^{-x/\lambda}$$

λ : lunghezza d'interazione.

$$\frac{1}{\lambda} = \sigma_{\text{had}} \cdot n = \sigma_{\text{had}} \cdot \frac{\rho}{A} N_A$$

$$\frac{1}{\rho \lambda} = \sigma_{\text{had}} \cdot \frac{N_A}{A}$$

	Z	A	$\rho [\text{g/cm}^3]$	$X_0 [\text{cm}]$	$\lambda [\text{cm}]$
Fe	26	56	7.9	1.8	16.8
Pb	82	208	11.3	0.6	17.6

lunghezza
radiazione

lunghezza interazione
nucleare

$\lambda \gg X_0 \Rightarrow$ Calorimetro adronico \gg calorimetro EM.
dimensioni: fisiche