

Bremsstrahlung

$$P \propto \frac{E^4}{m^4}$$

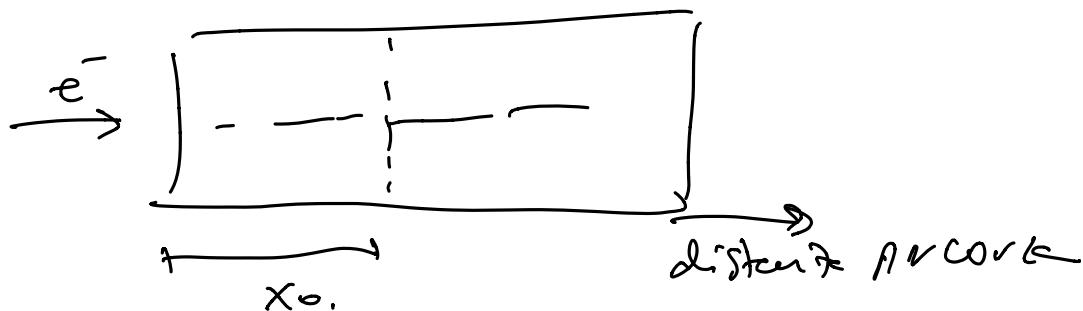
dannante per me
fratamente N usare
fusori E non abbastanza
grande

$$-\frac{dE}{dx} \approx \frac{E}{x_0}$$

Lunghezza di radiazione x_0
prop. del materiale

$$\frac{1}{x_0} = 4\pi e^2 \alpha \frac{N_A}{A} \rho Z^2 \ln(183 Z^{-1/3})$$

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



$E(x_0) \approx \frac{E_0}{e} \approx 30\%$ del veloce iniziale.

in 1 lunghezza x_0 ha perso $\approx 63\%$ di energia

$$x_0' \approx 170 \frac{A}{Z^2} g/cm^2$$

$$x_0' = \rho x_0$$

$$-\frac{dE}{dx} \Big|_{\text{Brems}} \propto \frac{E}{x_0} \quad \text{per E piccoli} \quad \text{perde} \\ \text{piccole}$$

Cose si contratti con $-\frac{dE}{dx}|_{\text{ion}}$

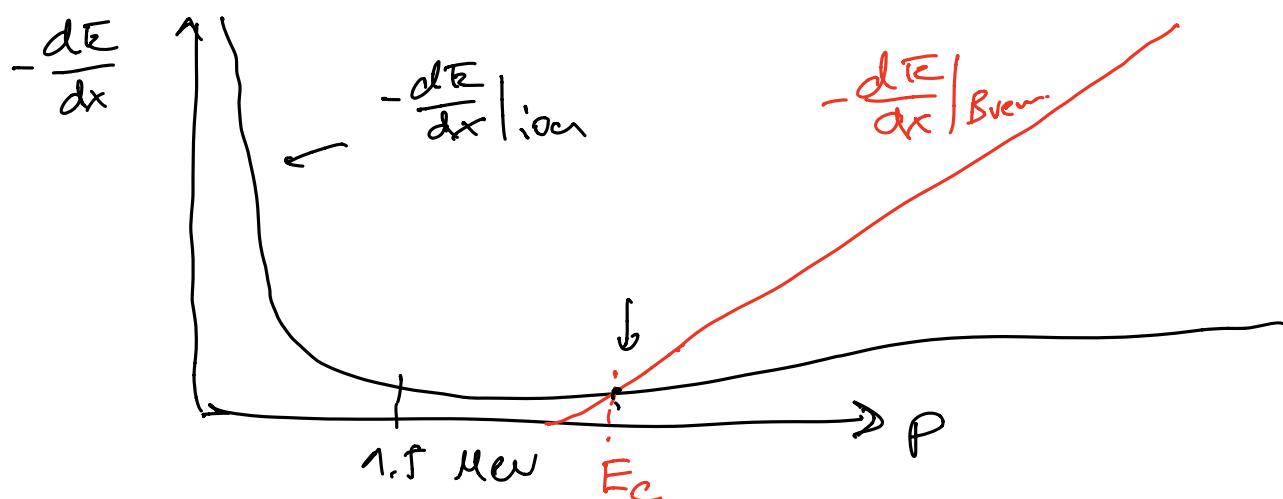
$$\text{per e}^{+/-} \quad -\frac{dE}{dx}\Big|_{\text{tot}} = \left(-\frac{dE}{dx}\Big|_{\text{ion}}\right) + \left(-\frac{dE}{dx}\Big|_{\text{Brems}}\right)$$

$$\frac{-\frac{dE}{dx}\Big|_{\text{Brems}}}{-\frac{dE}{dx}\Big|_{\text{ion}}} \approx \frac{K_e Z}{1200 \text{ MeV}} \quad K_e = E_e - m_e \quad E_e \gg m_e \quad K_e \ll E_e$$

S: definisce energia critica E_C del mezzo.

$$\frac{-\frac{dE}{dx}\Big|_{\text{Brems}}}{-\frac{dE}{dx}\Big|_{\text{ion}}} \approx 1 = \frac{E_C Z}{1200 \text{ MeV}} \quad \text{ma } S \ll \text{proiettile}$$

$$m_e \approx 0.5 \text{ MeV} \Rightarrow E_C = \frac{600 \text{ MeV}}{12Z}$$

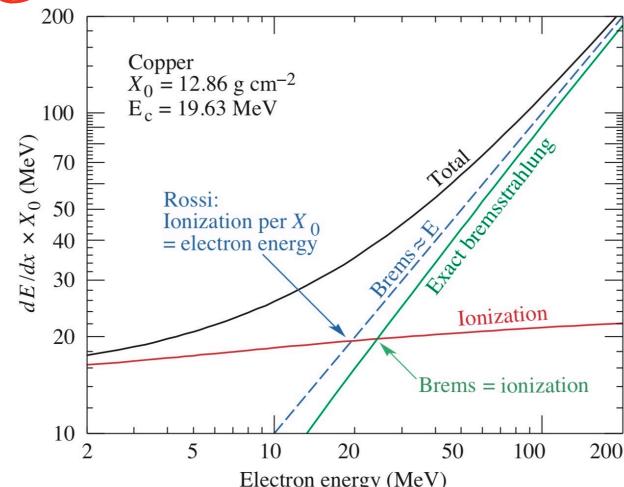


Rame (Cu)

$$Z = 29 \rightarrow E_C \approx \frac{600}{29} \text{ MeV} \approx 20 \text{ MeV}$$

Piombo Z = 82

$$E_C \approx 7 \text{ MeV}$$



$$-\frac{dE}{dx}|_{\text{ion}} = -\left.\frac{dE}{dx}\right|_{\text{Brem.}} \approx \frac{E_C}{X_0} \quad E_C = \frac{600 \text{ MeV}}{Z}$$

$$\frac{E_C}{X_0} \approx (3.5 \text{ MeV}) \frac{Z}{A}$$

$$X_0 = 170 \frac{A}{Z^2} \text{ g/cm}^2$$

$$\approx 1.7 \text{ MeV/cm}^{-2}\text{g}$$

Stime del numero diioni d'azione.

entro 30% hanno stime per tutti i materiali:

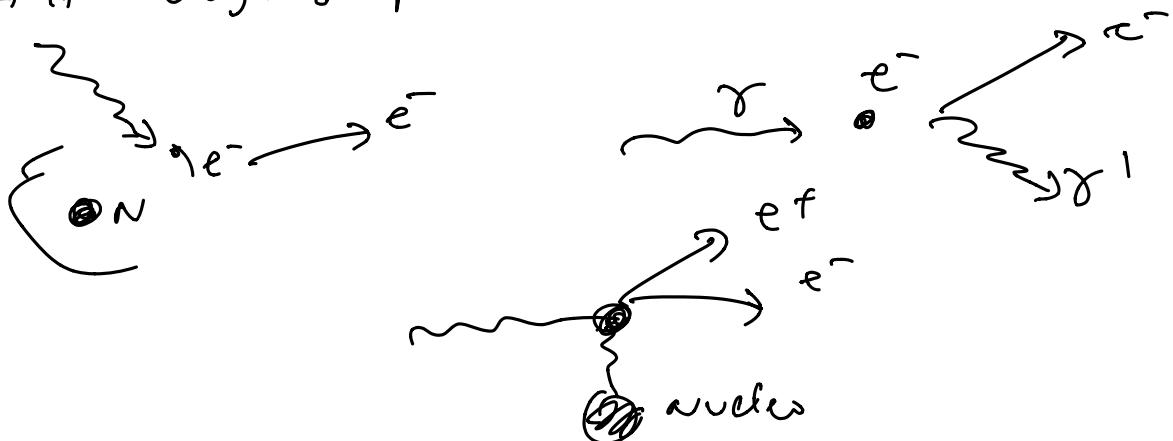
Fotoni nelle materie

3 processi importanti a secondi dell'energia Er fotone

Bassa energia: effetto fotoelettrico $\gamma + A \rightarrow e^- + A'$

mezz' energia: effetto Compton $\gamma + e^- \rightarrow \gamma' + e^-$

A lte energie: produzione di coppie $\gamma + N \rightarrow e^+ e^-$



- presente del nucleo fondamentale
- $\sigma = \sigma(E_\gamma, Z)$
- elettroni liberi o legati a secondi di Er

$$\sigma_{\text{tot}}^\gamma = \sigma_{\text{phot.}} + \sigma_{\text{Comp}} + \sigma_{e^+ e^-}$$

Fotoelettrico

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

$$S_{\text{fin}} = m_e^2 \neq S_{\text{ini}} = m_e^2 + \underbrace{2m_e E_\gamma}_{> 0} ?$$

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

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

impulso orbital del
nucleo.

$$m_A \gg m_e \quad \Delta E_A \approx E_A = \Delta E_\gamma$$

$\Rightarrow E_\gamma$ trasferisce un e^-

Efecto quantistico.

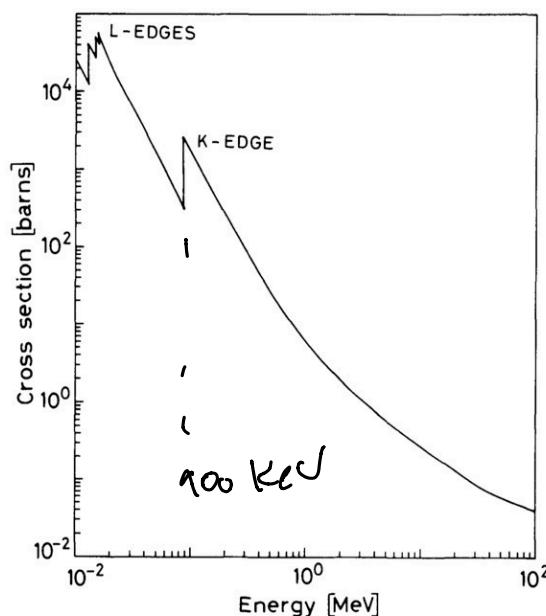
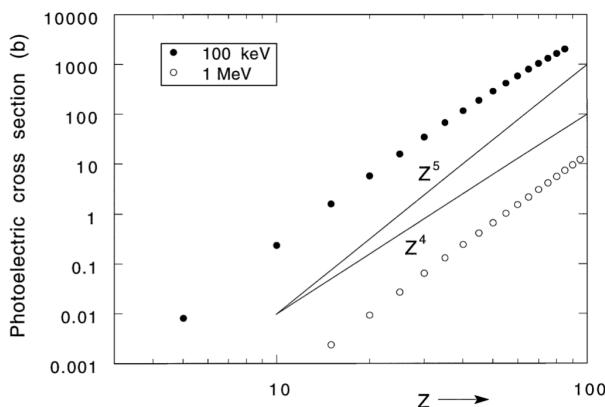
$$E_e = E_\gamma - I_B$$

↳ energia ionizante

$$E_\gamma = I_B + K_e$$

Efecto dominante per $E_\gamma < m_e$ $E_\gamma \sim 10^2 \text{ keV}$

$$\sigma_{\text{f.e.}} \propto \begin{cases} \frac{Z^5}{E_\gamma^3} & E_\gamma < m_e \\ \frac{Z^5}{E_\gamma} & E_\gamma > m_e \end{cases}$$



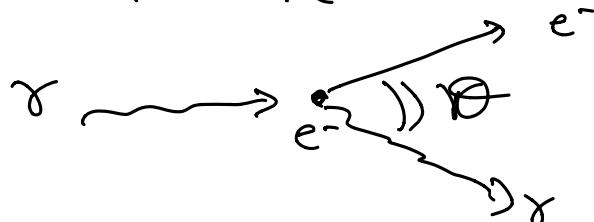
Effetto Compton



$E_r \gg I_B \approx 10^7 \text{ eV}$ per elettroni esterni

$$I_B \approx 10^2 \text{ keV}$$

Compton si uote per $E_r \sim 100 \text{ keV} \rightarrow$ Oltre allo stesso tempo $T_{\text{f.e.}}$ scende



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

energy photons
dopo Compton.



$$E_{\gamma'} = \frac{E_\gamma}{1 + \frac{2E_\gamma}{mc}}$$

$$E_r \approx mc \Rightarrow E_{\gamma'} = \frac{mc}{1 + \frac{2mc}{mc}} \approx \frac{mc}{3} \approx \frac{E_\gamma}{3}$$

γ ha perso 66% dell'energia

DT max dell' e^-

$$T_{\text{Coup}} \propto \frac{\epsilon_1}{E_\gamma} \quad \text{diminuisce per } E_\gamma \rightarrow mc$$

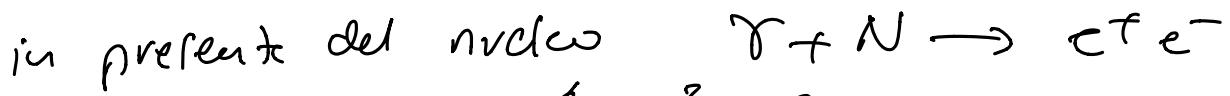
Produzione di Coppie



$$\sqrt{s_n} = mc = \gamma$$

$$S_{\text{fin}} = mc^2 + mc^2 + 2(E_{e^+} E_{e^-} - \vec{P}_{e^+} \cdot \vec{P}_{e^-}) > 0$$

impossibile.



$$S_{in} = m_f^2 + m_A^2 + 2E_\gamma m_A$$

$\underbrace{\quad\quad\quad}_{\text{conservazione dell'impulso}}$

effetto a soglia.

E_γ minima?

$$K\gamma \equiv E_\gamma = m_e + m_e = 1.022 \text{ MeV}$$

Dovunque

Fotoelettrico:

$$10 \text{ eV} \rightarrow \sim 100 \text{ keV}$$

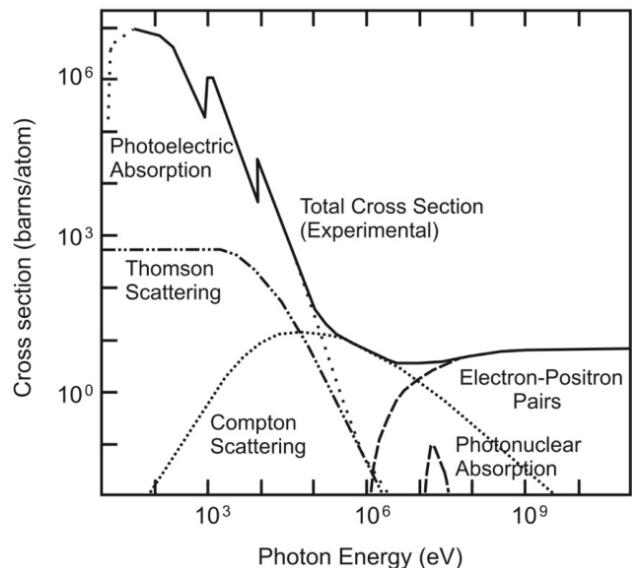
Compton:

$$100 \text{ keV} \rightarrow 10 \text{ MeV}$$

$$m_e c^2 \approx E_\gamma \approx m_e c^2$$

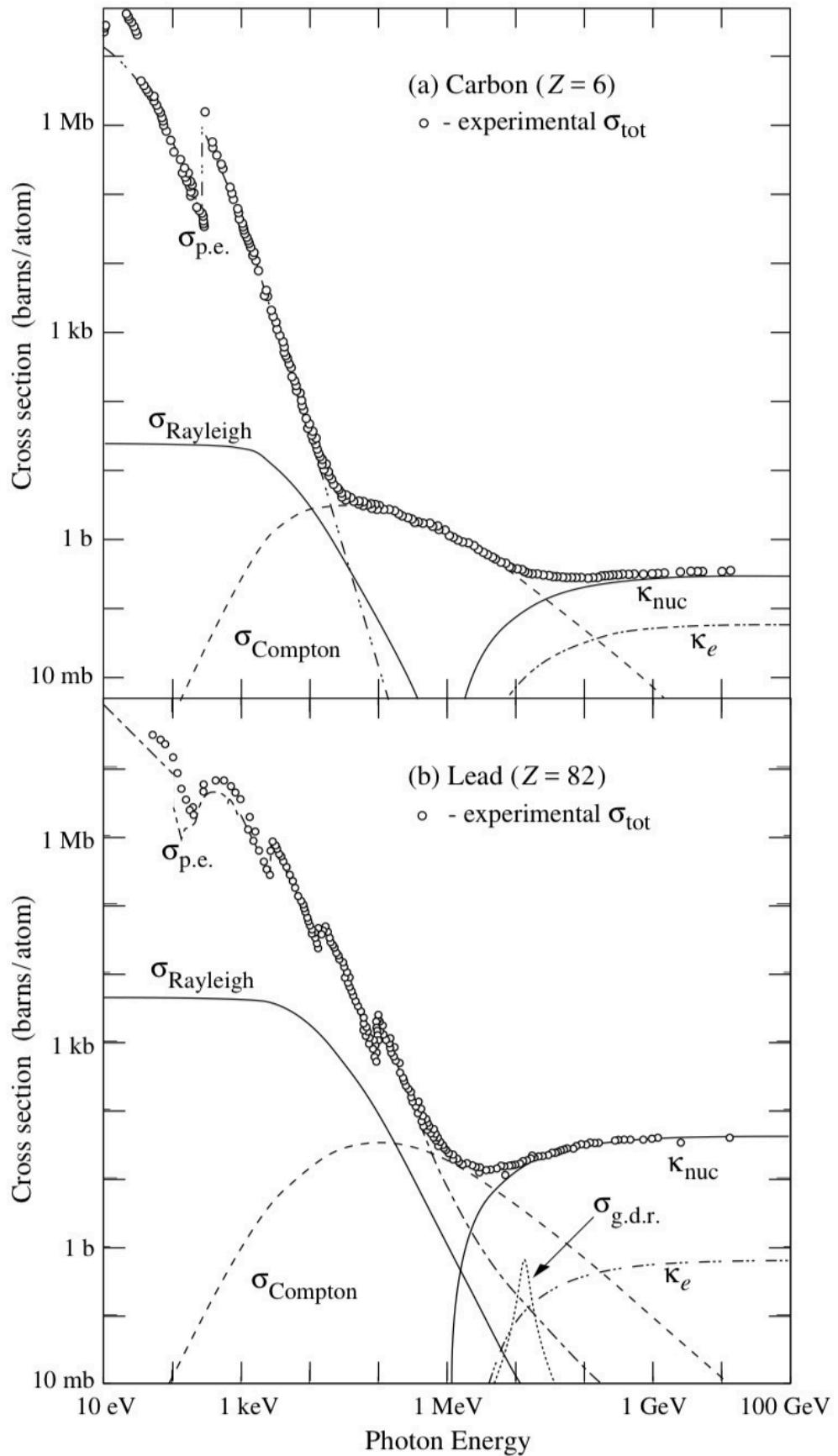
Produzione di coppie

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



$E_\gamma > 10 \text{ MeV}$ rete chiusa.

$E_\gamma > 100 \text{ MeV}$ di fatto solo $\gamma \rightarrow e^+ e^-$



Lunghezza di attenuazione per i fotoni

Perco
di potoni →

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

μ : coeff. di assorbito.

$$\begin{aligned}\mu &= \mu_{e^+e^-} + \mu_{camp} + \mu_{f.e.} = \sigma \cdot n \\ &= (\epsilon_i \sigma_i) \cdot n\end{aligned}$$

Per $E_r > 100 \text{ MeV}$ $\tau \approx \text{cost}$

$$\frac{1}{\lambda_r} = \mu = \sigma \cdot n \quad \lambda_r: \text{lunghezza di attenuazione}$$

$$\frac{1}{\lambda_r} \approx \frac{7}{9} \frac{1}{\lambda_0} \quad \lambda_0: \text{lunghezza di rad. del urto.}$$

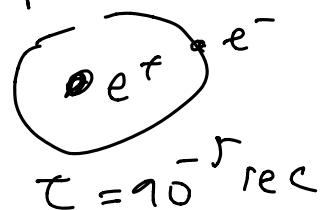
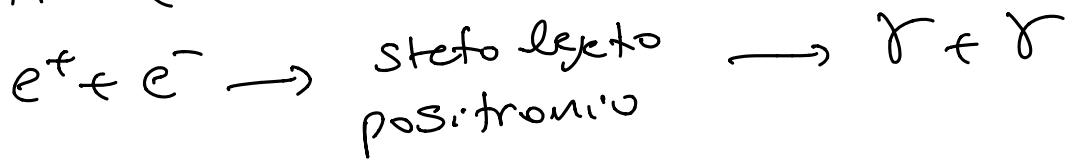
$$\sigma_{e^+e^-} = \frac{1}{\lambda_r} \frac{1}{n} = \frac{7}{9} \frac{1}{\lambda_0} \frac{1}{P} \frac{A}{N_A}$$

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

A (te energie)

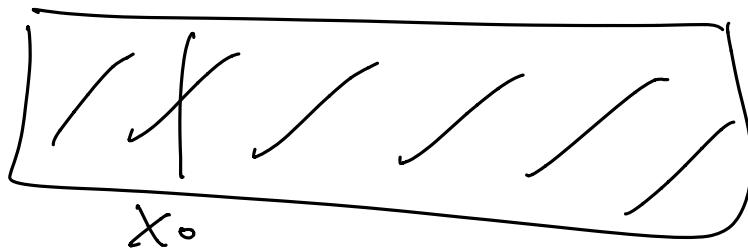
Positroni

e^- positivo: (tutti uscite con $q \in ee$)



Sciame elettromagnetici nel mezzo

e^\pm alte energie: Bremsstrahlung. $e^{\pm} \rightarrow e^{\mp} + \gamma$.



Dopo x_0 $E_{e^\pm} \approx 37\% E_0$.

$$E_\gamma \approx 60\% E_0$$

γ alte energie: $\gamma \rightarrow e^+ e^-$

$$x_\gamma \approx \frac{g}{f} x_0$$

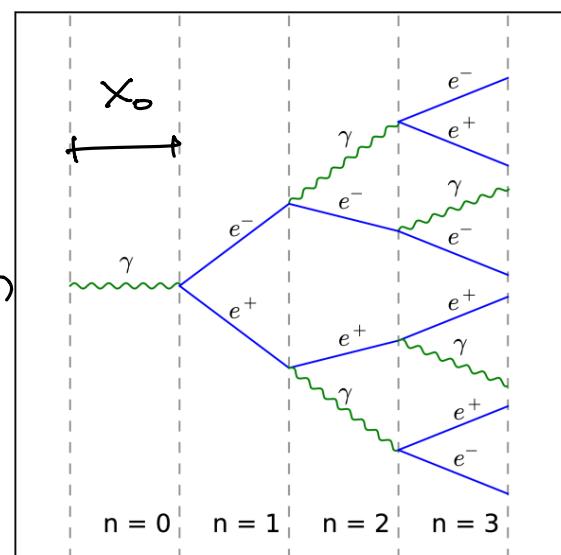
e^\pm, e^+, e^-

si ricomincia. Formano a cerchi, sfaccettato.

$$E > E_C$$

Funghi

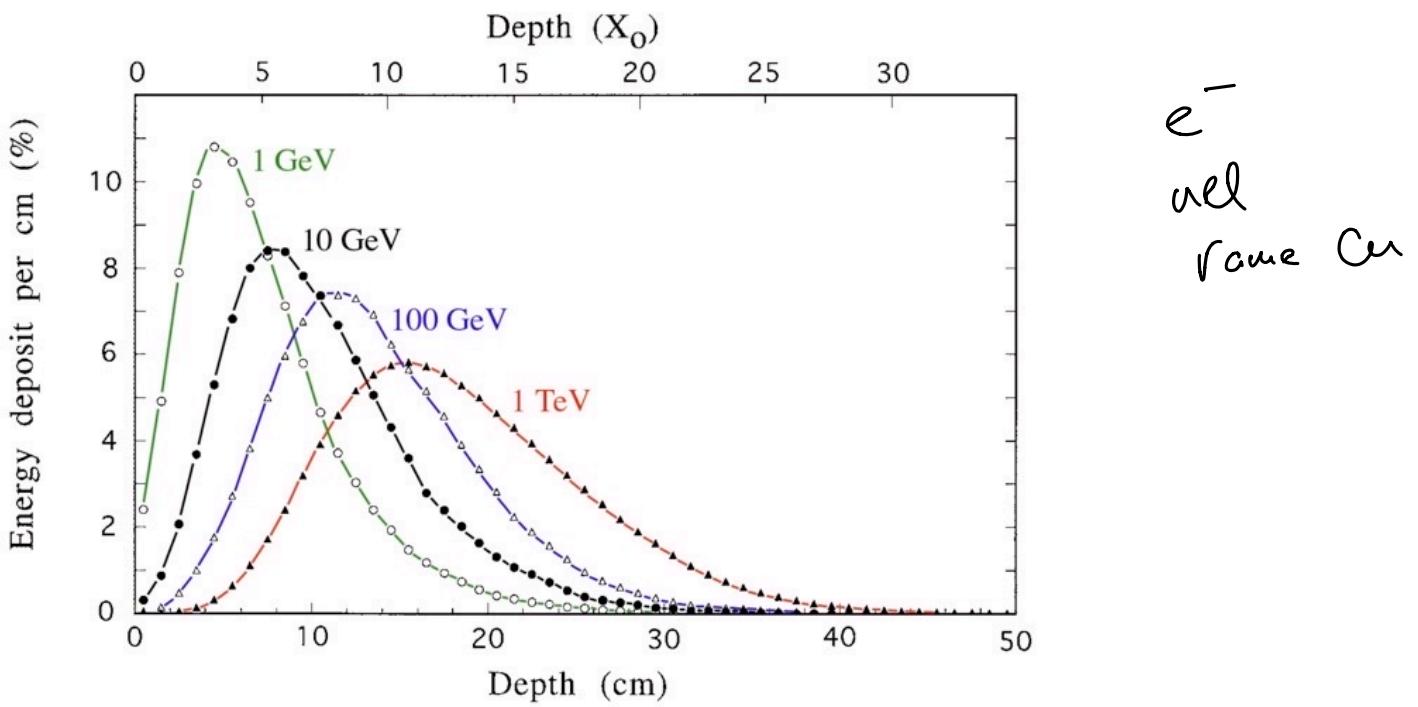
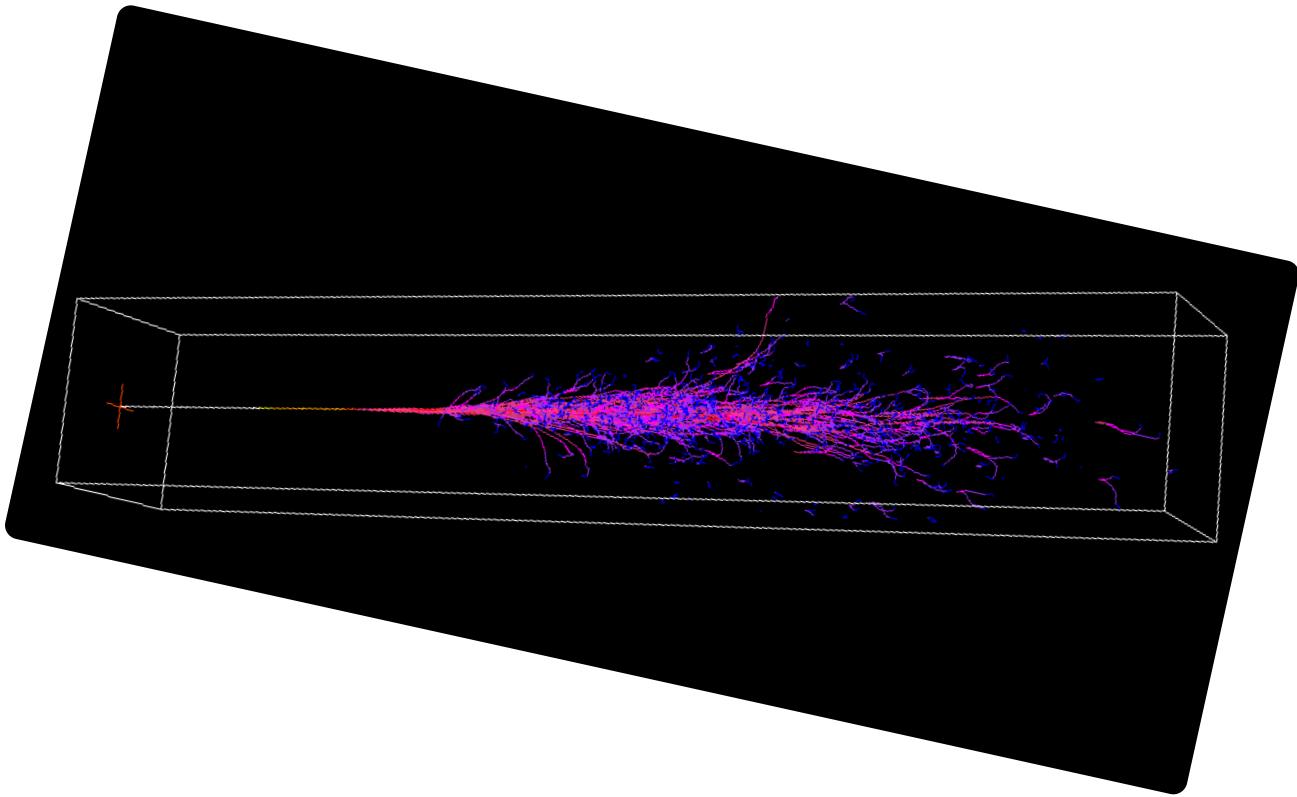
$$E_i > E_C$$



particelle

$$E_i$$

$$\begin{aligned} & 2 & e & e^3 \dots e^n \\ & \frac{E_0}{2} & \frac{E_0}{2^2} & \frac{E_0}{2^3} - \frac{E_0}{e^2} \end{aligned}$$



Sviluppo dello scieno, determinato da.

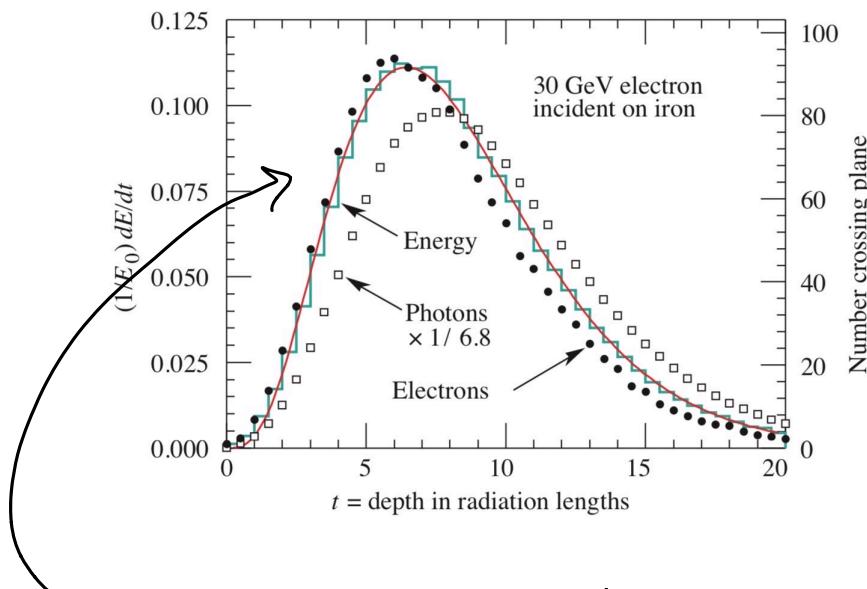
X_0 : ogni evento si raddoppie # partecile
si dimentica E_i

E_C : quando non c'è Bremsstrahlung.

Studiamo in funzione di:

$$\text{Espressione } t = \frac{x}{x_0}$$

$$-\frac{1}{E_0} \frac{dE}{dx}$$



profilo
longitudinale
dello scintillatore

$$t = \frac{x}{x_0}$$

$$F(t) \propto \frac{E_0}{E_C} t^a e^{-b t}$$

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

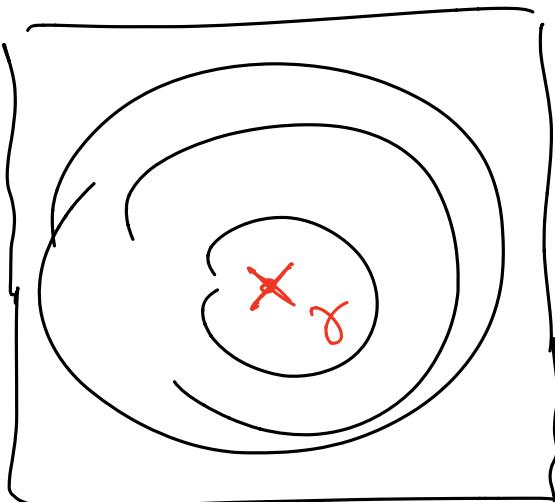


massimo sviluppo scintilla

{ correzione
per r.v.s. $e^{+/-}$



sviluppo laterale.
dalla c
diffusione
Coulombica
multiplo.



no perdite di energie ma solo dev. angolare.

per un materiale. Raggio Moliere = $\frac{Z_1}{E_C (\text{MeV})} X_0$

Raggio del cilindro nel piano trasverso che contiene 90% di E_0 delle particelle incidenti

Interazione di adroni:

p, π^\pm, K^\pm, n

se $q \neq 0 \Rightarrow$ ion: Heav.

Potente interazione forte nel metallo.

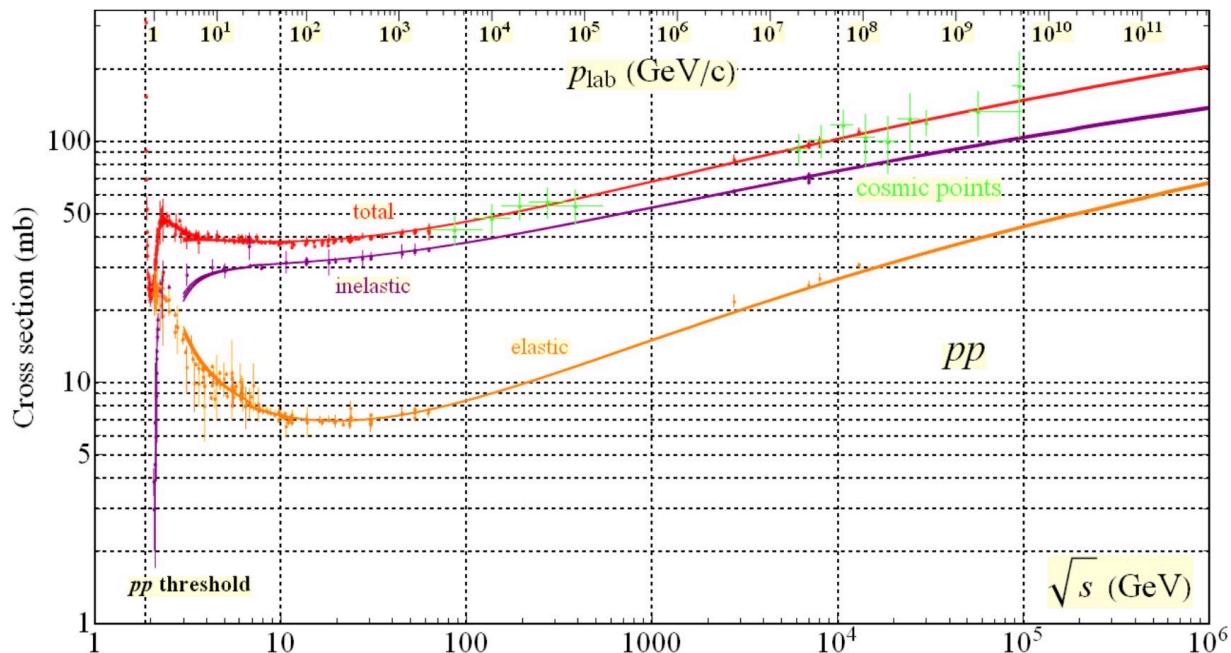
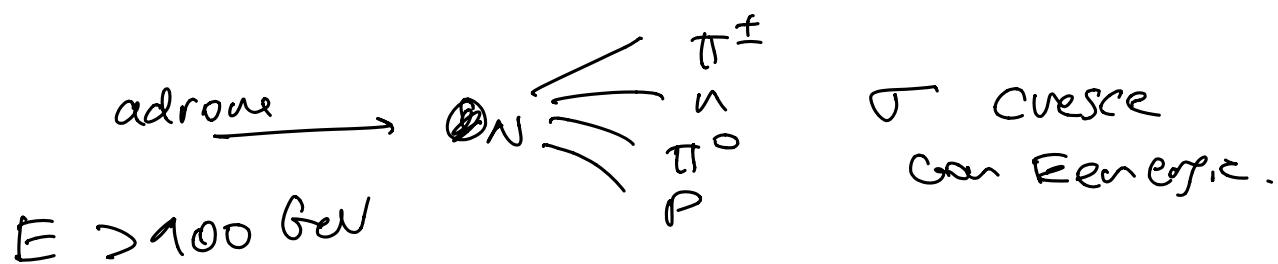
ballo energie: $E \sim 2-5 \text{ GeV}$ carri elettrici
no perdite di energia.

intermedio: $S \rightarrow 100 \text{ GeV}$ si ha interazione
con energia totale $\sim 100 \text{ MeV}$

$$\sigma_{\text{nucleo}} \approx \pi R_N^2 \approx \pi (1 \text{ fm})^2 \approx 30 \text{ mb}$$

principale \rightarrow N $R_N \approx 1 \text{ fm. } A^{1/3}$

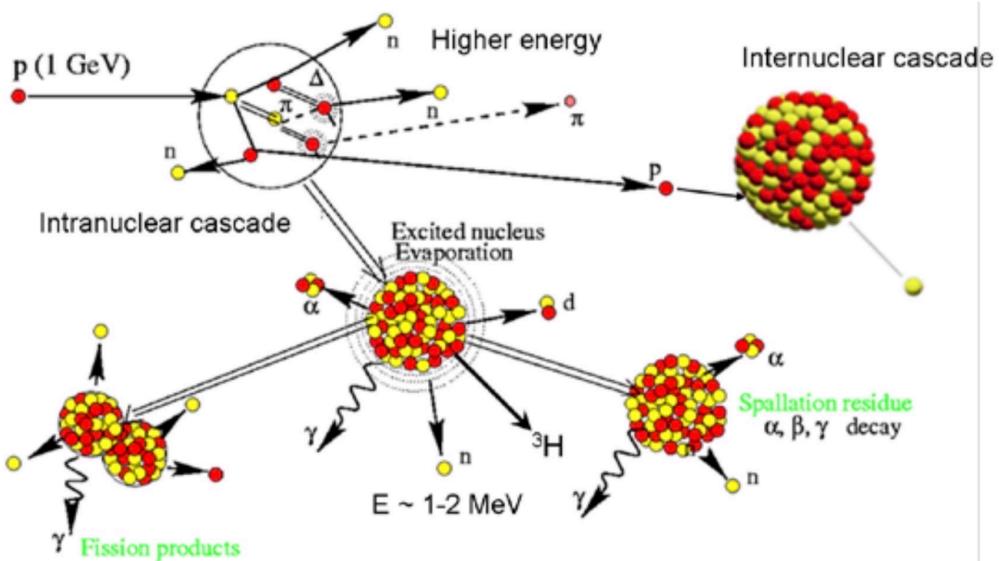
intermedie $\sigma_{\text{nucleo}} \approx \sigma_0 A^{2/3}$
 sezione d'urto inelastica.



σ si vede nucleone.
 ρ/ν A nucleon $\sigma \approx \sigma_0 A^{2/3}$



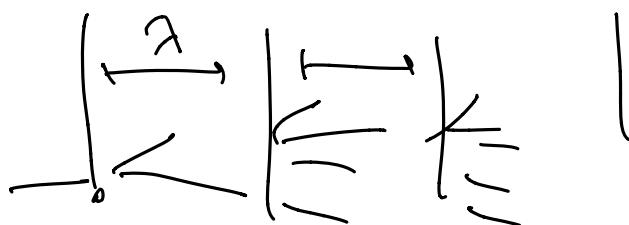
Sarà al CERN EM, si ha una SCATRE.



Fase di adroni: $I(x) = I_0 e^{-x/\lambda}$

$$\frac{1}{A} = \sigma_{\text{nucleo}} \cdot n \cdot = \sigma \cdot \rho \frac{N_A}{A}$$

λ : lunghezza di interazione nucleare.
Cavano liberi medi fra une interazione
inelastiche.



$$\sigma_{\text{tot}}^{\text{nucleo}} \approx 1 \text{ b.}$$

$$\sigma_{\text{nucleo}} < \sigma_{\text{EM}} \Rightarrow \lambda > x_0$$

	A	$\rho \text{ g/cm}^3$	$x_0 \text{ (cm)}$	$\lambda \text{ (cm)}$
Fe	56	7.9	1.8	16.8
Pb	207	11.3	0.6	17.6

Rivelatori per contenere sciami adronici devono essere
piuttosto spessi.