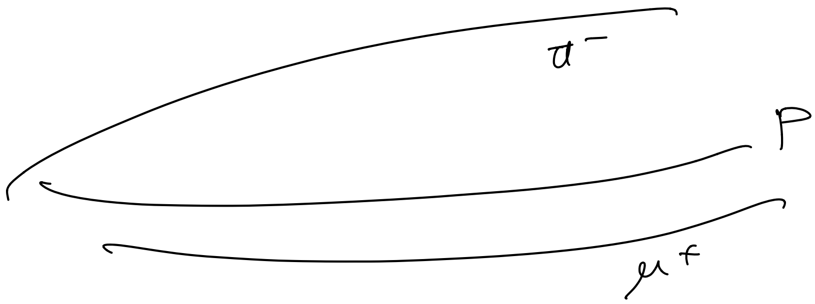
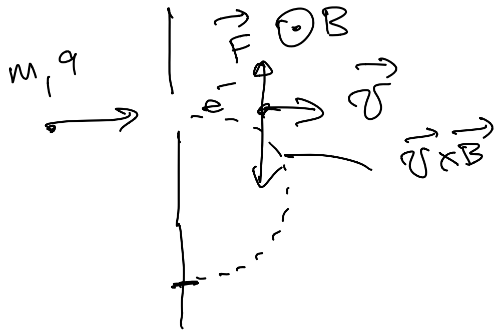
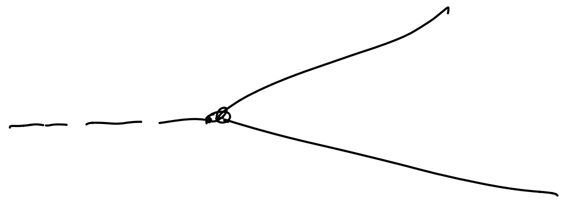
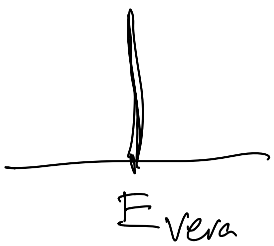






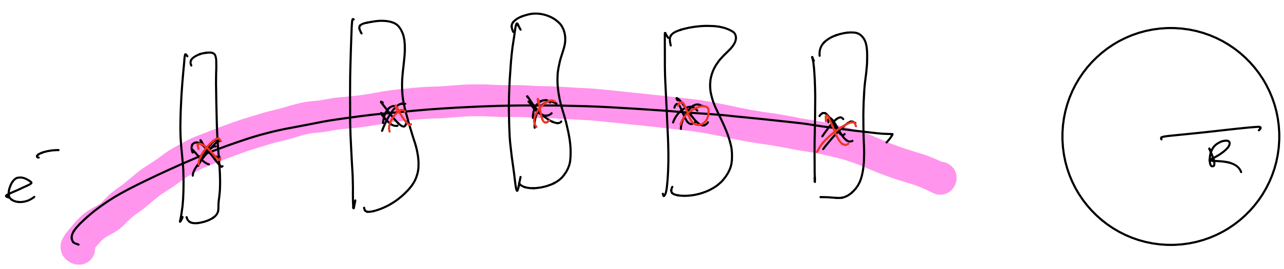
Rivelatore: misurare E, $\vec{p}$, q

trovare uno stimatore statistico della quantità fisica

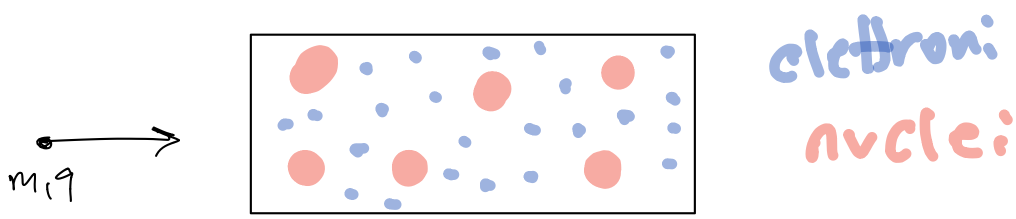


$\langle \mu \rangle = E_{vera}$

$\frac{\sigma}{\mu}$ più piccola possibile.



Interazione tra particelle con la materia.



Natura di interazione: EM, forte, debole

forte → solo quando particelle molto vicine

debole → trascurabile quasi sempre

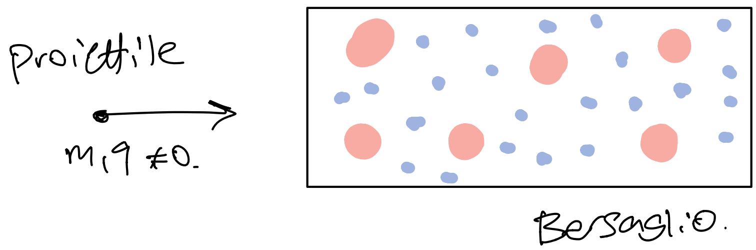
Solo adroni: barioni, mesoni

roba fatta di quark.

Interazione EM: $q = 0$

$q \neq 0$

Interazione di particelle cariche nella materia. $q \neq 0$.



materiale

$$F \propto \frac{q\, Ze}{r}$$

urto tra particelle cariche con
$\left\{ \begin{array}{l} 1/\ \text{nuclei} \\ 2/\ \text{elettroni} \end{array} \right.$

lezione del 31/3

esercitazione del 8/4

$$\underline{P}_p^i = \begin{pmatrix} E_p^i \\ \vec{p}_p^{\,i} \end{pmatrix} \qquad \underline{P}_X^i = \begin{pmatrix} m_X \\ 0 \end{pmatrix}$$

Tipicamente non conosciamo $\underline{P}_X^f = \begin{pmatrix} E_X^f \\ \vec{p}_X^{\,f} \end{pmatrix}$

Conosciamo e misuriamo $\underline{P}_p^f = \begin{pmatrix} E_p^f \\ \vec{p}_p^{\,f} \end{pmatrix}$ $\qquad p_p^i = |\vec{p}_p^{\,i}|$

$$E_p^f = \frac{E_p^i m_X + m_p^2}{m_X + E_p^i - P_p^i \frac{P_p^f}{E_p^f} \cos\theta}$$

Diffusione Compton: $\gamma + e^- \longrightarrow \gamma + e^-$

$m_p = 0$ γ

$m_X = m_e$

$E_\gamma = |\vec{P}_\gamma|$

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

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

elettrone contro nucleo

$m_X = m_N \simeq A\, m_p$ m_p: massa protone $\simeq 1\,\mathrm{GeV}$

$m_e = 0.5\,\mathrm{MeV}$

$$E_{e^-}^f = \frac{E_e \cdot m_N + m_e^2}{M_N + E_e - P_e \frac{P_e'}{E_e'} \cos\theta}$$

$E_e \gg m_e \simeq \mathrm{MeV}$

$m_e^2 \ll m_N \cdot E_e$.

$E_e' = \sqrt{P_e'^2 + m_e^2} \simeq P_e'$

$\frac{P_e'}{E_e'} \simeq 1$

$$E_e^f = \frac{E_e}{1 + \frac{E_e}{m_N}(1 - \cos\theta)}$$

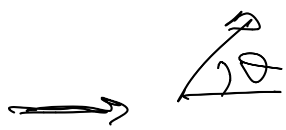
$$\frac{E_e}{m_N} \simeq \frac{1}{A}\frac{m_e}{m_p} \simeq \frac{1}{A}\frac{0.5\times 10^{-3}\,\mathrm{GeV}}{1\,\mathrm{GeV}} \simeq \frac{10^{-3}}{A}$$

H_2O $A = 18$. $\quad \frac{E_e}{m_N} \simeq 10^{-4}$

$$E_e^f \simeq E_e^{in}$$

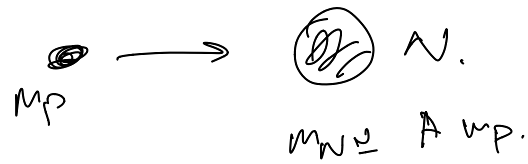
urto contro nucleo: a la Rutherford.
solo diffusione elastica

$p_p^f \simeq p_p^i$



$$E = \sqrt{p^2 + m^2}$$

caso limite: protone contro nucleo.

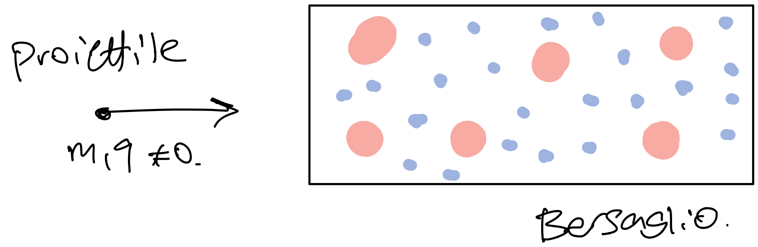


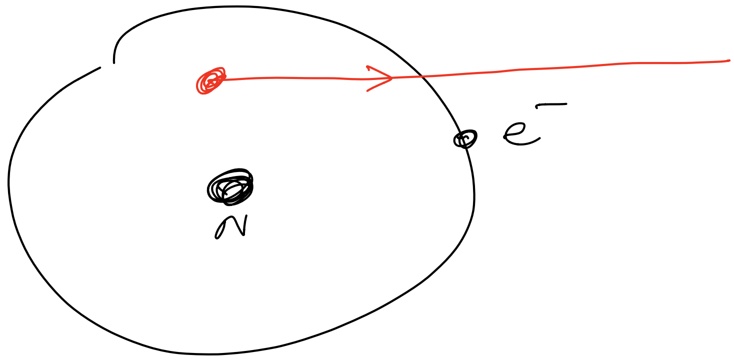
$$E_p^f = \frac{E_p^i m_x + m_p^2}{m_x + E_p^i - p_p^i \frac{p_p^f}{E_p^f}\cos\theta}$$

$m_x \simeq A\, m_p$.

In generale: urto contro nuclei non causa perdite di energia nei proiettili

$\Rightarrow$ Energia persa dal proiettile grande nell'urto contro elettroni nel mezzo.





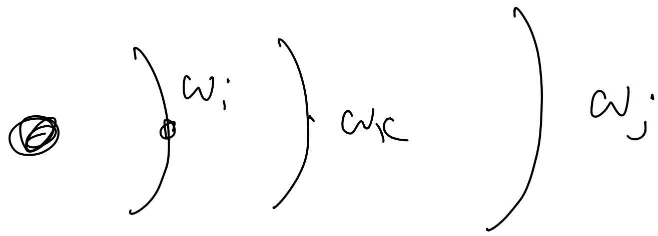
$\Delta E_{proiettile} \simeq 1$ MeV.

urto contro elettroni $\Rightarrow$ ionizzazione del mezzo.

$\Delta E_{proiettile} >> \bar{I}$ energia media di ionizzazione.

$\bar{I} = \hbar \langle \omega \rangle$

$= \hbar \sqrt[N]{\prod_j \omega_j}$

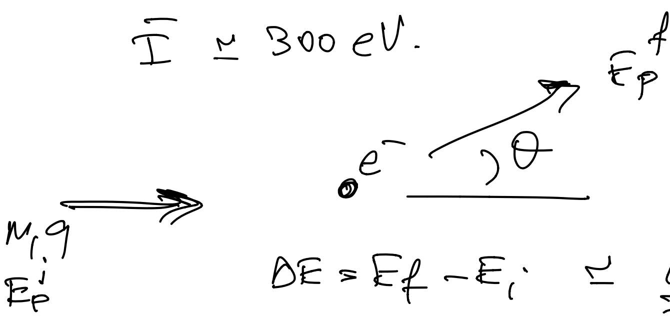


$\bar{I} \simeq 10\, Z$ eV $\quad Z$ num. protoni del mezzo.

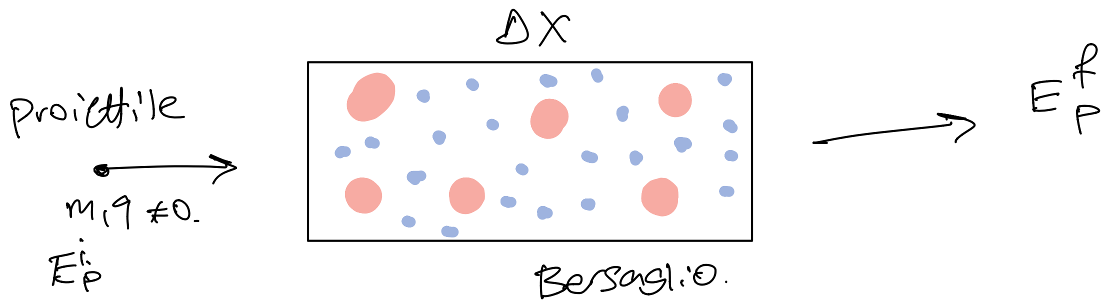
$^{A}_{Z}N$

Ferro $A \simeq 60. \rightarrow Z \simeq \frac{A}{2} = 30.$

$\bar{I} \simeq 300$ eV.



$\Delta E = E_f - E_i \simeq \underline{\underline{\text{MeV}}}.$



$$\Delta E = E_p^i - E_p^f > 0$$

processo stocastico.

$$\Delta E = f(I, \rho, Z, \Delta X, E_p)$$

densità di elettroni

$$n_e = Z \rho \frac{N_A}{A}$$

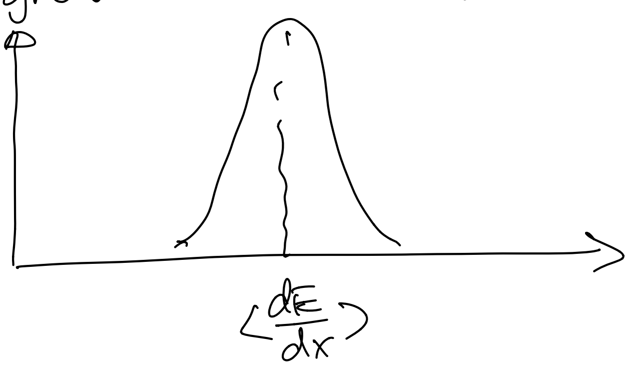
$$\frac{\rho}{A} N_A = n_{nuclei}$$

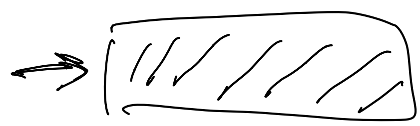
$$\rho = \frac{dm}{dV} = \frac{m}{V}$$

$$\frac{dE}{dX} = \frac{\Delta E}{\Delta X}$$

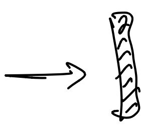
energia persa dal proiettile per unità di spessore.

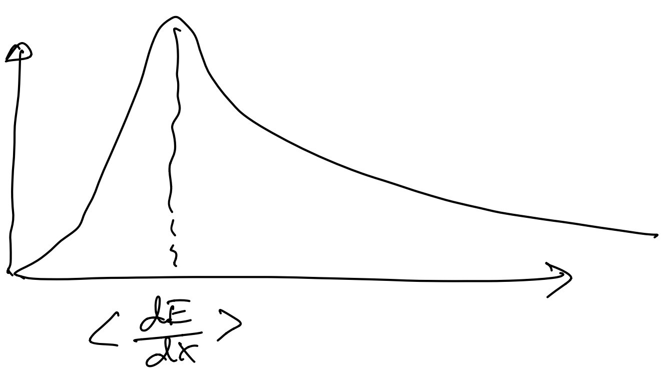
spessore grande $\Rightarrow$ Nurti grande $\Rightarrow$ Teorema del limite centrale

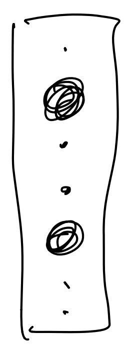




Spessore sottile.

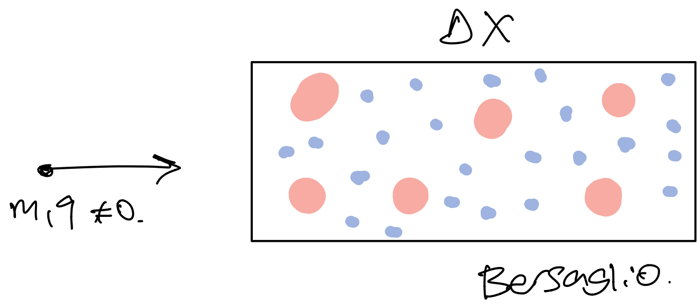






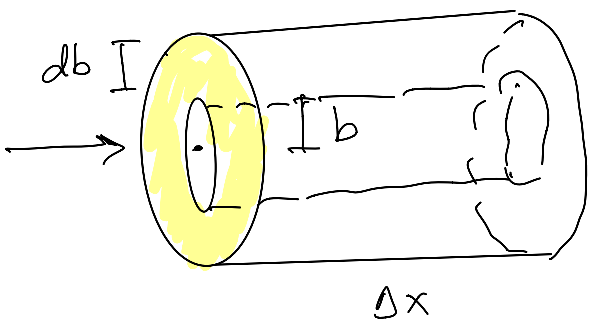
Calcolo $\langle \frac{dE}{dx} \rangle$ medio.

$$\Delta E_{\text{nel mezzo}} = \langle \frac{dE}{dx} \rangle \cdot \Delta X$$



en. persa dal proiettile

$$\Delta E = -\overline{\Delta E} \cdot N_{urti}$$



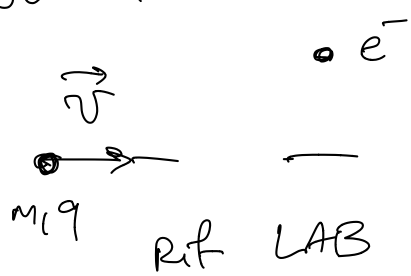
$2\pi b \cdot db \cdot \Delta X \cdot \underset{\text{densità elettroni}}{n_e} = N_{urti}$ in media.

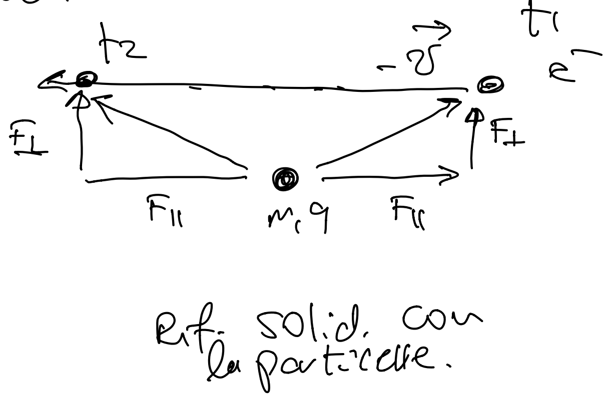
$$\Delta E = -\underbrace{\overline{\Delta E}}_{} \cdot 2\pi\, b\, db\, dx\, n_e$$

↳ energia scambiata nel singolo urto contro un. elettrone

Conto classico Bohr 1914.

conto quantistico. Bethe-Bloch 1930
con QED

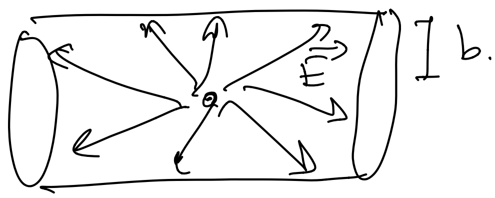




$$\Delta\vec{p} = \int_{-\infty}^{+\infty} \vec{F}\cdot dt = \int_{-\infty}^{+\infty} \vec{F}\,\frac{dx}{v} = \frac{1}{v}\int_{-\infty}^{+\infty} F_\perp\, dt + \frac{1}{v}\int_{-\infty}^{+\infty} F_\parallel\, dt$$

$$\int_{-\infty}^{+\infty} F_\parallel\, dt = 0 \quad \text{per ovvia Simmetria.}$$

$$\Delta\vec{p} = \frac{1}{v}\int_{-\infty}^{+\infty} F_\perp\, dx = \frac{e}{v}\int_{-\infty}^{+\infty} E_\perp\, dx \qquad \Delta p_\perp$$



$$\Phi(\vec{E}) = \int_{Scp.} \vec{E}\cdot d\vec{S} = \int_{Cilin} E_\perp \cdot dS = \frac{Q}{\varepsilon_0} = \frac{Z_p\cdot e}{\varepsilon_0}$$

$$\parallel \quad 2\pi b \int_{-\infty}^{+\infty} E_\perp \cdot dx$$

$$\Rightarrow \int_{-\infty}^{+\infty} E_\perp \cdot dx = \frac{1}{2\pi b}\,\frac{Z_p\cdot e}{\varepsilon_0}$$

$$\Delta p = \frac{e}{v}\,\frac{Z_p\cdot e}{\varepsilon_0}\,\frac{1}{2\pi b} = \frac{Z_p e^2}{2\pi\varepsilon_0}\,\frac{1}{v}\,\frac{1}{b}$$

$$v = \beta\cdot c$$

$$= \frac{Z_p\cdot e^2}{2\pi\varepsilon_0}\,\frac{1}{\beta c}\,\frac{1}{b}$$

$$E = \frac{p^2}{2m}.$$

$$T \equiv \Delta E_p = \frac{\Delta p^2}{2m} = \left(\frac{Z_p\cdot e^2}{2\pi\varepsilon_0}\right)^2 \frac{1}{\beta^2 c^2}\,\frac{1}{b^2}\,\frac{1}{2m}.$$

$$= \left(\frac{Z_p e^2}{4\pi\varepsilon_0}\right)^2 \frac{2}{m\beta^2 c^2}\,\frac{1}{b^2}$$

$$\Delta E_p \propto \frac{1}{\beta^2}\,\frac{1}{b^2}$$