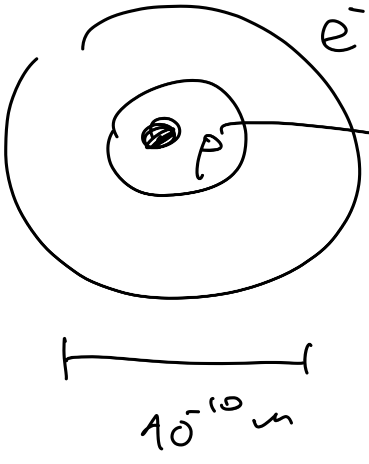
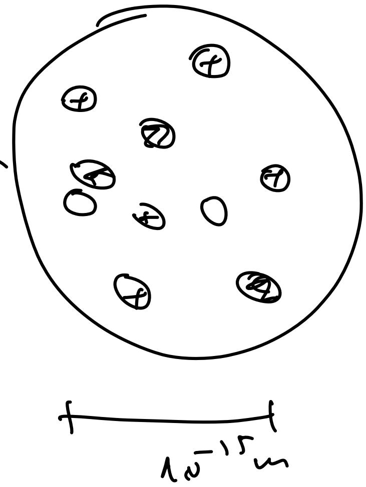




A: numero atomico

Z: numero protoni

A-Z: neutroni

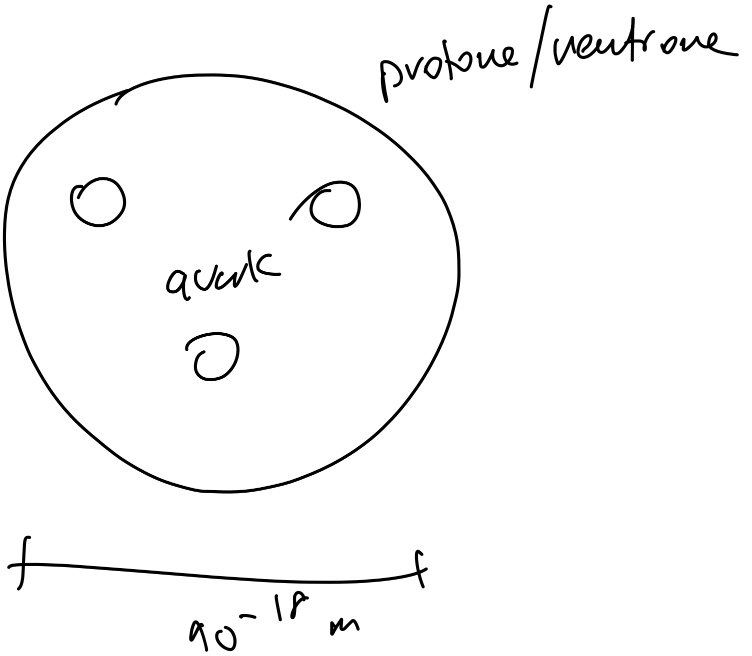
1 fm ordine grandezza raggio protone

nuclei atomici = $R_N = R_0 A^{1/3}$

$R_0 \simeq 1$ fm

- Elettromagnetismo: forza Coulomb
- interazione forte: forza nucleare
- interazione debole

particelle elementari: nessun grado di l.b. interno



Relatività Ristretta

$\underline{x} = (t, \vec{x})$

$\underline{x}_1 \cdot \underline{x}_2 = t_1 t_2 - \vec{x}_1 \cdot \vec{x}_2$

$|\underline{x}|, \quad |\vec{x}|$

$$g^{\mu\nu} = \begin{pmatrix} 1 & & & \\ & -1 & & \\ & & -1 & \\ & & & -1 \end{pmatrix}$$

Galileo

$x = x'$

$y = y'$

$z = z' + vt$

$$\begin{cases} t = \gamma\left(t' + \frac{v}{c^2} z'\right) \\ x = x' \\ y = y' \\ z = \gamma(z + vt') \end{cases}$$

$\beta = \frac{v}{c}$ $\quad \gamma = \frac{1}{\sqrt{1-\beta^2}}$

$$\begin{cases} ct = \gamma\left(ct' + \frac{v}{c} z'\right) \\ x = x' \\ y = y' \\ z = \gamma\left(z + \frac{v}{c} ct'\right) \end{cases}$$

$$\begin{pmatrix} ct \\ x \\ y \\ z \end{pmatrix} = \begin{pmatrix} \gamma & 0 & 0 & \beta\gamma \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ \beta\gamma & 0 & 0 & \gamma \end{pmatrix} \begin{pmatrix} ct' \\ x' \\ y' \\ z' \end{pmatrix}$$

$\underline{X} = (ct, \vec{x})$

$\beta \simeq 1$ $\qquad \beta = 0.981$ $\qquad \beta = 0.999987$

$x = (1+\varepsilon)^n \simeq 1 + n \cdot \varepsilon$

$\gamma = (1-\beta^2)^{-1/2} \simeq 1 + \frac{1}{2}\beta^2$ molto spesso.

Sistema non relativistico

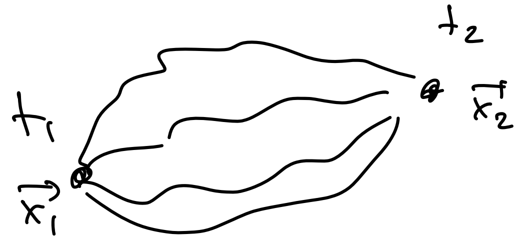
particelle elementare di massa m:

$\vec{p} = m\vec{v}$

$E = \frac{1}{2} m v^2 = \frac{p^2}{2m}$

particella relativistica di massa m:

$$\frac{d}{dt}\frac{\partial L}{\partial \dot q} = \frac{\partial L}{\partial q} \qquad q = \vec{x} \qquad \dot q = \vec{v}$$



$$S = \int_{t_1}^{t_2} L(q,\dot q, t)\, dt$$

$$S = \int_{\tau_1}^{\tau_2} A\, d\tau$$

A: costante

τ: tempo nel riferimento solidale con la particella.

$$\underline{x} = (c\tau, \vec{0})$$

costruzione per avere S invariante in tutti riferimenti inerziali

$$S = \int A\, d\tau = \int_{t_1}^{t_2} L(\vec{x},\vec{v},t)\, dt$$

γ: fattore della particella in moto

$$t = \gamma\tau \Rightarrow dt = \gamma\, d\tau$$

$$= \int_{t_1}^{t_2} \frac{A}{\gamma}\, dt = \int_{t_1}^{t_2} L(\vec{x},\vec{v},t)\, dt$$

caratteristiche della lagrangiana:
- invariante per traslazioni spaziali: $\Rightarrow L(\vec{v}, t)$
- invariante per trasl. temporale: $\Rightarrow L(\vec{v})$
- invariante per rotazioni spaziali $\Rightarrow L(|\vec{v}|)$

$$L = L(v^2) \xrightarrow[v \to 0]{\lim} \frac{1}{2} m v^2.$$

$$\frac{A}{\gamma} \longrightarrow \frac{1}{2} m v^2$$

$$\frac{1}{\gamma} = \sqrt{1-\beta^2} \qquad = \qquad A\sqrt{1-\beta^2} = \frac{1}{2} m v^2$$

$$A\left(1-\frac{1}{2}\frac{v^2}{c^2}\right) = \frac{1}{2}mv^2 \qquad v \to 0.$$

$$\frac{v}{c} \to 0$$

$$A - A\frac{1}{2}\frac{v^2}{c^2} = \frac{1}{2}mv^2$$

costante che posso ignorare (ininfluente sulle eq. del moto)

$$-\frac{A}{\cancel{2}}\frac{\cancel{v^2}}{c^2} = \frac{1}{\cancel{2}}m\cancel{v^2} \Rightarrow A = -mc^2$$

$$v^2 = \Sigma_i v_i^2$$

$$\dot{x}_i = v_i$$

$$L = -mc^2\sqrt{1-v^2/c^2}$$

$$\vec{P}_i = \frac{\partial L}{\partial \dot{x}_i} = \cancel{-}m\cancel{c^2}\frac{1}{\cancel{2}\sqrt{1-v^2/c^2}}\left(\cancel{-}\frac{\cancel{2}v_i}{\cancel{c^2}}\right)$$

$$= \frac{mv_i}{\sqrt{1-v^2/c^2}} = \gamma m\vec{v}$$

$$E = \Sigma P_i v_i - L = \gamma mv^2 - \left(-mc^2\sqrt{1-v^2/c^2}\right)$$

$$= \gamma mv^2 + \frac{mc^2}{\gamma} = \gamma mc^2\left(\frac{v^2}{c^2} + \frac{1}{\gamma^2}\right)$$

$$= \gamma mc^2\left(\cancel{\frac{v^2}{c^2}} + 1 - \cancel{\frac{v^2}{c^2}}\right) = \gamma mc^2$$

$$E = \gamma mc^2$$

$$\underline{P} = \left(\frac{E}{c}, \vec{p}\right) \qquad \underline{P} = \left(E, c\vec{p}\right)$$

$$|\underline{P}|^2 = E^2 - c^2p^2$$

$$= \gamma^2m^2c^4 - c^2\gamma^2m^2v^2$$

$$= \gamma^2 m^2 (c^4 - c^2 v^2) = \gamma^2 m^2 c^4 \left(1 - \frac{v^2}{c^2}\right)$$

$$= \cancel{\gamma^2} m^2 c^4 \frac{1}{\cancel{\gamma^2}} = m^2 c^4$$

$$E = \gamma m c^2 \qquad \vec{p} = \gamma m \vec{v} \qquad |P|^2 = m^2 c^4$$

$$\gamma = \frac{E}{mc^2} \qquad \vec{p} = \gamma m c \frac{\vec{v}}{c} = \gamma m c \vec{\beta}$$

$$\beta = \frac{c|\vec{P}|}{E} \qquad \beta\gamma = \frac{|\vec{P}|}{mc}$$

Unità Naturali

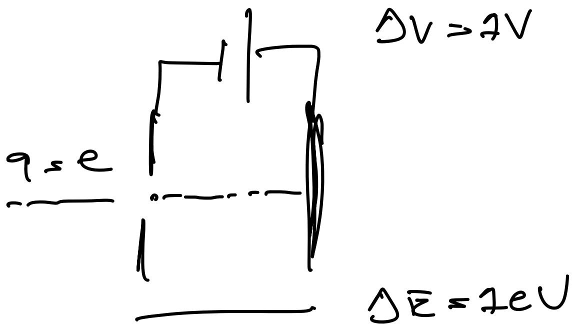
$\hbar = c = 1$ adimensionali

$$[c] = \frac{[L]}{[T]} \qquad [L] = [T]$$

$$[T] = [E]^{-1}$$

$$E = h\nu$$

$$[E] = [L]^{-1} = [T]^{-1}$$



$c = 3 \times 10^8$ m/s

$\hbar = 1.055 \times 10^{-34}$ J·s

$\hbar c = 197$ MeV × fm

$$\Delta E = qV = 1\,eV = 1.6 \times 10^{-19}\,C \times 1\,V$$

$$= 1.6 \times 10^{-19}\,J$$

$\hbar c \simeq 200$ MeV × fm. $\qquad 1\,fm \simeq \frac{1}{200}\,MeV^{-1}$

$\underline{x} = (t, \vec{x})$ $\gamma = \frac{E}{m}$ $\beta = \frac{|\vec{p}|}{E}$ $\beta\gamma = \frac{|\vec{p}|}{m}$

$\underline{P} = (E, \vec{p})$

$|\underline{P}|^2 = m^2$: massa a riposo delle particelle

Nel rif solidale con le particelle:

$\vec{p} = 0$

$$\boxed{E^2 = p^2 + m^2} = m^2 \Rightarrow E = m.$$

$$\underline{P} = (m, \vec{0})$$

$$E^2 = m^2 + p^2 = m^2\left(1 + \frac{p^2}{m^2}\right) \quad p/m \ll 1$$

$p/m \to 0$

$$E = \sqrt{p^2 + m^2} = m\sqrt{1 + \frac{p^2}{m^2}} \simeq m\left(1 + \frac{1}{2}\frac{p^2}{m^2}\right)$$

$$= m + \frac{p^2}{2m}$$

en. cinetica particelle non relativistica

massa a riposo

Definizione energia cinetica

$E = m + K$

↳ en. cinetica relativistica

$K = E - m = \gamma m - m = (\gamma - 1)m.$

Particelle di massa nulla

$E^2 = p^2 + m^2$

$m = 0 \Rightarrow E = P$

$\underline{P} = (E, \vec{p})$ $|\vec{p}| = E$