Token: 880 588

$e^+ + e^- \to e^+ + e^-$

$\frac{dN_r}{dt} = \sigma \frac{dN_b}{dt}$ u.b.d.

$\sigma \to \propto |M_{fi}|^2 \rho(E)$

$M = M_0 + \alpha M_1 + \alpha^2 M_2$

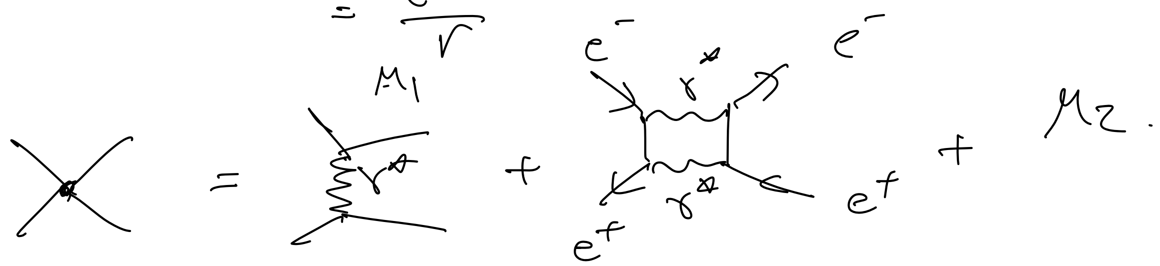
$H = H_0 + H_I$

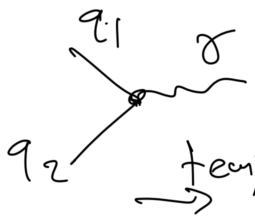
$(1+\varepsilon)^n \simeq 1 + n\varepsilon$

$H_I = qV = \frac{Ze e}{4\pi\varepsilon_0} \frac{1}{r}$

$Ze \qquad e$

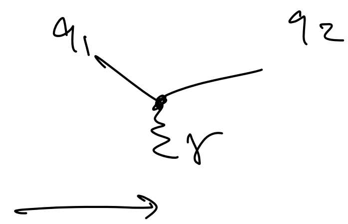
$= \frac{Z\alpha}{r}$





vertice EM.

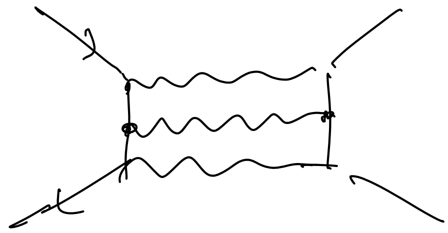
$q_1 + q_2 = 0 \Rightarrow q_1 = -q_2$



$q_1 = q_2$.

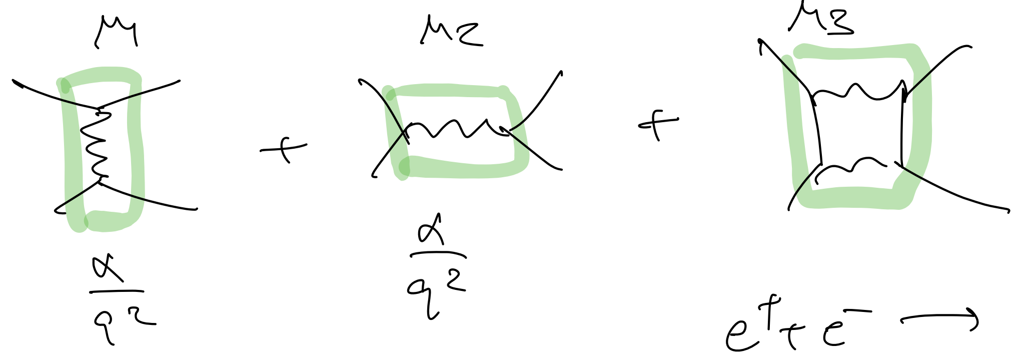
$M_1 \propto \frac{\alpha}{q^2}$

$M_2 \propto \frac{\alpha}{q^2}\frac{\alpha}{q^2}$



$\frac{\alpha^3}{q^6}$

$M = M_1 + M_2 + M_3 + \cdots$



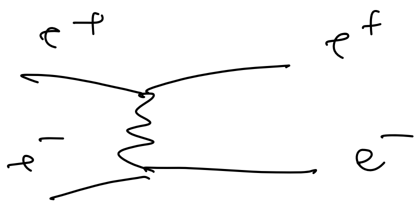
$e^+ + e^- \longrightarrow e^+ + e^-$

$$M_{tot} = M_1 + M_2 + M_3$$

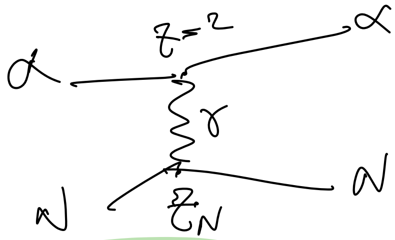
$$\sigma \propto |M_{tot}|^2 = (M_1 + M_2 + M_3)(M_1 + M_2 + M_3)^\dagger$$
$$= |M_1|^2 + |M_2|^2 + |M_3|^2 + M_1^\dagger M_2 + M_2^\dagger M_1 + \ldots$$

N eventi $\simeq \sigma$

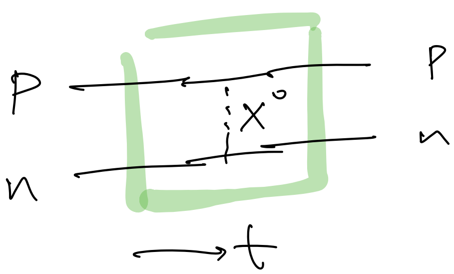
$\alpha + N \rightarrow \alpha + N.$

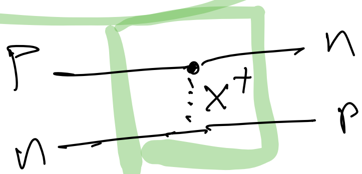


$\alpha + N \rightarrow$



$p + p \longrightarrow p + p$ $\quad$ $p + n \longrightarrow p + n.$ $\quad$ $p + p \rightarrow p\bar{p}pp$





Conservazione carica e num quantici in ciascun vertice

Int. forte a raggio finito $R_0 \simeq 1$ fm

$$V_{coul.} = \frac{e}{4\pi} \frac{1}{r}$$

$\bullet\, e$

$$\nabla^2 V = -\rho(r) \qquad \rho(r) = e\,\delta(r)$$

Eq di Poisson $\nabla^2 V = -\rho(\vec{r})$

$$V(\vec{r}) = \int_{\text{vol.}} d^3 r' \, \frac{\rho(\vec{r}')}{|\vec{r}-\vec{r}'|}$$

$$\vec{\nabla}\cdot\vec{E} = \rho \qquad \vec{\nabla}\times\vec{E} = -\frac{\partial \vec{B}}{\partial t}$$

$$\vec{\nabla}\cdot\vec{B} = 0 \qquad \vec{\nabla}\times\vec{B} = \vec{J} + \frac{\partial \vec{E}}{\partial t}$$

unità rat.
$c = 1 \Rightarrow \varepsilon_0 = \mu_0 = 1$

$\Rightarrow$ ~~Eq.~~ dell'onda

$$\underbrace{\left(\frac{\partial^2}{\partial t^2} - \nabla^2\right)}_{\Box^2} (\vec{E}, \vec{B}) = 0 \qquad \nabla^2(\text{campo}) = \cancel{0}.$$

Gauge. Lorentz

$$\vec{\nabla}\cdot\vec{A} + \frac{\partial V}{\partial t} = 0.$$

$$\vec{E} = -\vec{\nabla} V - \frac{\partial \vec{A}}{\partial t}$$

$$\vec{B} = \vec{\nabla}\times\vec{A}$$

$$\begin{cases} \left(\frac{\partial^2}{\partial t^2} - \nabla^2\right) V = \rho \\ \left(\frac{\partial^2}{\partial t^2} - \nabla^2\right) \vec{A} = \vec{J} \end{cases}$$

$$\Box^2(\text{potenziale}) = \text{sorgente}$$

nel caso stazionario $\frac{\partial}{\partial t} = 0 \Rightarrow \nabla^2 V = \rho$

$$\Rightarrow -\nabla^2 V = \rho.$$

$$\Rightarrow \nabla^2 V = -\rho$$

Yukawa 1935

principio di equivalenza $\quad E \to i\frac{\partial}{\partial t} \quad \vec{P} \to -i\vec{\nabla}$

$$\Box^2 = \frac{\partial^2}{\partial t^2} - \nabla^2 = E^2 - p^2$$

$$(E^2 - p^2)(--) = 0 \Rightarrow E = p$$

fotone $m = 0$.

per particelle $m \neq 0 \quad E^2 = p^2 + m^2$

secondo Yukawa $\quad (E^2 - p^2 - m^2)\psi = 0 \quad$ funzione d'onda

$$\left(-\frac{\partial^2}{\partial t^2} + \nabla^2 - m^2\right)\psi = 0$$

$$(\Box^2 + m^2)\psi = 0$$ Klein-Gordon
funzione d'onda portatore.

sol. staz. $\frac{\partial}{\partial t} = 0 \Rightarrow (\nabla^2 - m^2)\psi = 0$.

per similitudine con Coulomb.

$$(\nabla^2 - m^2)\phi = -\rho(r)$$

↳ potenziale nucleare.

potenziale

$\phi(r)$ $\quad g$

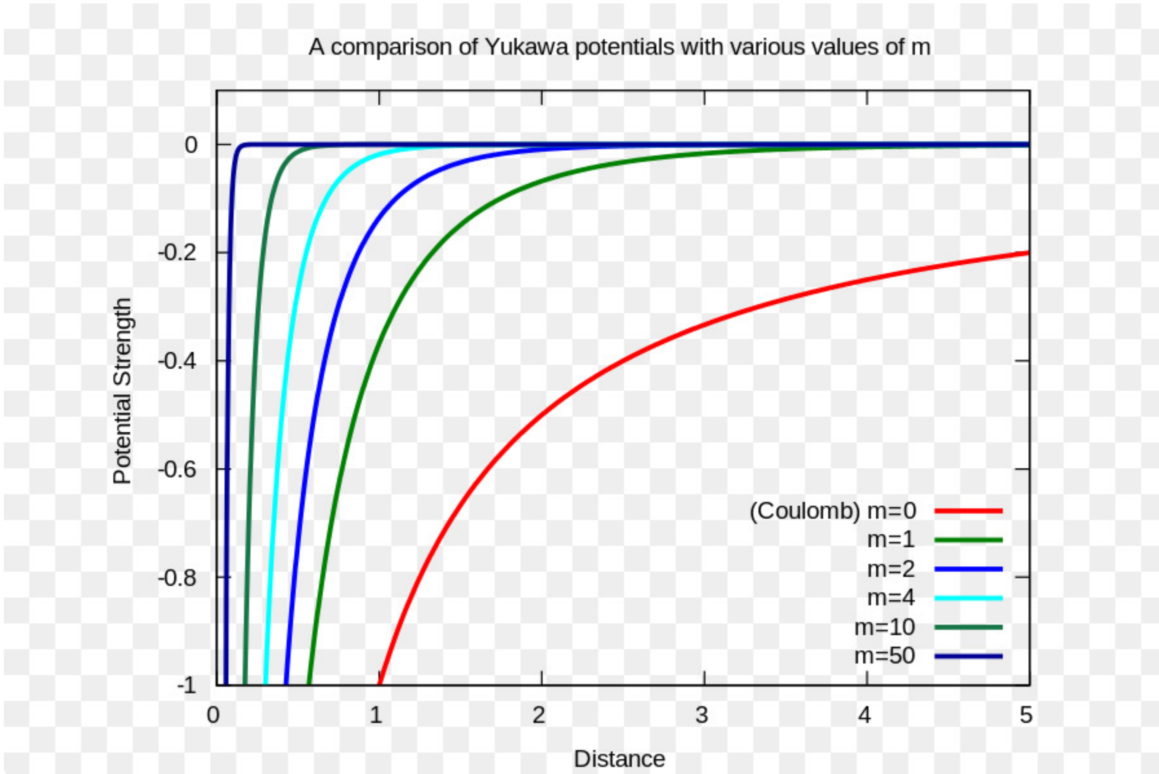
$$\rho(r) = -\frac{g}{4\pi}\delta(r)$$

g : carica forte

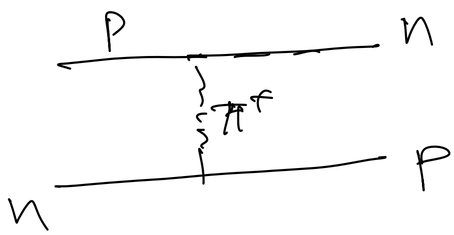
$g > 0$

forza nucleare sempre attrattiva.

$$\phi(r) = \frac{g}{4\pi}\frac{e^{-mr}}{r}$$



$m = ?$ $\quad \Delta E \cdot \Delta t \simeq \hbar \Rightarrow m \simeq 100-200$ MeV



$$\phi(r) = -\frac{g}{4\pi}\frac{e^{-mr}}{r}$$

portatore di forze $m \neq 0$ potenziale $\propto \frac{e^{-mr}}{r}$

Teoria debole di Fermi $H_I \simeq G$ $\quad [G] = E^{-2}$.

Yukawa: $H_I = g\phi(r) = -\frac{g^2}{4\pi}\frac{e^{-mr}}{r}$ $\quad g$ adim.