$\Gamma(n \to p e^- \bar{\nu}_e)$: prob. di decad. / unità di tempo.

$N(t) = N_0 e^{-\Gamma t}$ $\qquad N(t) \propto |\psi|^2 \sim e^{-\Gamma t}$

$H = H_0 + H_I$

$\psi(\vec{r},t) = \psi(\vec{r})\, e^{-iE_0 t}\, e^{-\frac{\Gamma}{2}t}$

Fourier $\psi(\vec{r}) \longrightarrow \psi(E)$

$$A(E) = \frac{1}{2\pi}\int_{-\infty}^{+\infty} dt\, e^{iEt}\left(e^{-iE_0 t}\, e^{-\frac{\Gamma}{2}t}\right)$$

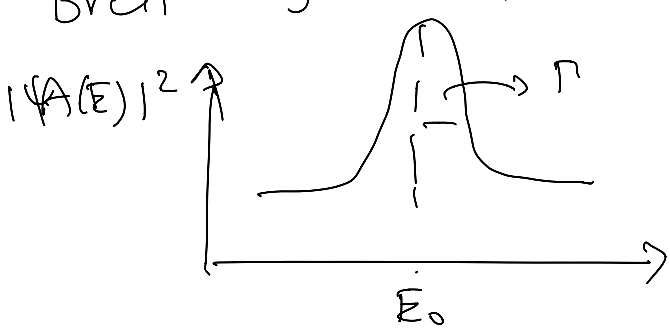
$t \geq 0$ per una particella creata a $t = 0$.
che decade dopo tempo medio
$\langle t \rangle = \tau = \frac{1}{\Gamma}$

$$A(E) = \frac{1}{2\pi}\,\frac{1}{i(E-E_0) - \frac{\Gamma}{2}}$$

$$|A(E)|^2 \propto \frac{1}{(2\pi)^2}\,\frac{1}{(E-E_0)^2 + \left(\frac{\Gamma}{2}\right)^2}$$

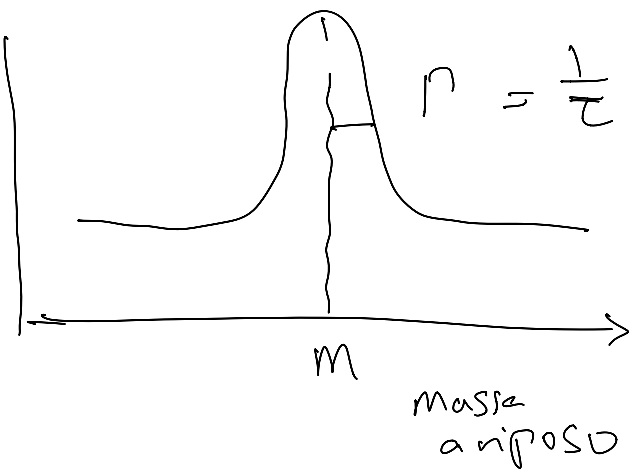
Lorentziana
Cauchy
Breit-Wigner

Risonanze



nel rif solidale con la particella instabile

$|\psi(E)|^2$



$\tau \to$ grande   limite particella stabile $\Rightarrow$ massa ben determinata.

$$\Gamma \cdot \tau = \hbar = 1$$

$\mu \to e^- \bar{\nu}_e \nu_\mu$ $\tau \simeq 10^{-6}$ s.

$\pi^- \to \mu^- \bar{\nu}_\mu$ $\tau \simeq 10^{-8}$ s

$\pi^- = \begin{pmatrix} \bar{u} \\ d \end{pmatrix}$ bosone scalare $S=0$ $m \simeq 140$ MeV

$\rho^- = \begin{pmatrix} \bar{u} \\ d \end{pmatrix}$ $S = 1$

$m_\rho = 770$ MeV $\Gamma = 150$ MeV

$820 \to 920$

se $\Gamma \to 0$ B-W $\to$

nella vita reale   Distrib. sperim $= f(x) \otimes$ Risol.

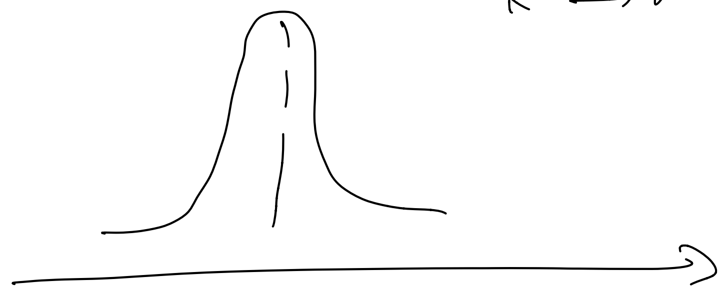
se $\Gamma = 0 \Rightarrow$ Gaussiana dettata dalla risol. sper.

$\Gamma \neq 0$ $\quad\quad$ $B\text{-}W(E \mid M, \Gamma) \otimes G$

$\dfrac{\Gamma}{M}$

$\pi^- \longrightarrow \mu^- \bar{\nu}_\mu$ $\quad\quad$ $\bar{B}^0 \longrightarrow K^- \pi^+$

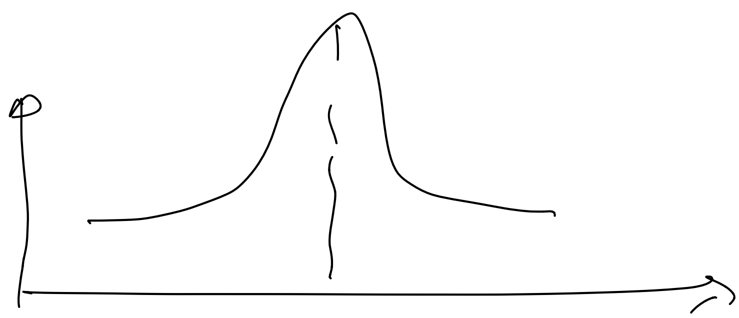
$K^0 \longrightarrow \pi^+ \pi^-$



$m_{inv} = \sqrt{(\underline{P}_{\pi^+} + \underline{P}_{\pi^-})^2}$

$\xrightarrow{\pi^+} \quad \xleftarrow{\pi^-}$ $\quad\quad$ misuro σ

σ



$\sqrt{s}$: en. nel. c.d.m $\pi^+ + \pi^-$

$\pi^+ + \pi^- \longrightarrow X$

$\pi^+ \pi^-$

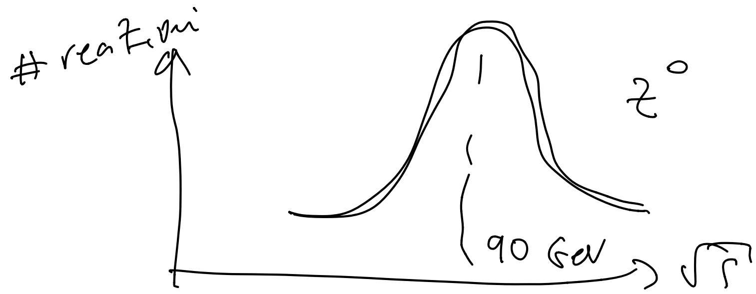
$\pi^+ \pi^- \pi^0$

$\pi^+ \pi^- \pi^+ \pi^-$

$\pi^+ \pi^- \pi^0 \pi^0$

$\pi^+ \pi^- p \bar{p}$

$\sqrt{s}$ aumenta

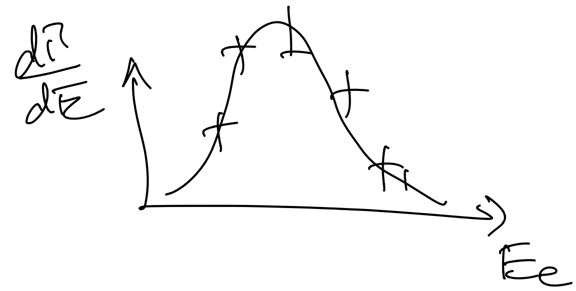


$e^+ + e^- \longrightarrow X$

$n \to p\, e^- \bar{\nu}_e$

Pauli suppone ν_e

Fermi calcola $\frac{d\Gamma}{dE}$



$n \to p\, e^- \bar{\nu}_e$ $\qquad V_I = G_F$

$a + b \to c + d.$

$a + \bar{c} \to \bar{b} + d$

$e^+ + n \to p\, \bar{\nu}_e$

$\bar{\nu}_e + p \to e^+ + n$

$E_s = 1.8\ MeV$

1956 Reines-Cowan.

vicino a un reattore $\qquad P = 1\ GW$

Fissione dell'uranio $\qquad Q = 200\ MeV$

$\langle N_\nu \rangle = 6$

$P = 10^9 \frac{J}{s}$ $\qquad 1\ eV = 1.6 \times 10^{-19}\ \underbrace{C \cdot V}_{J}$

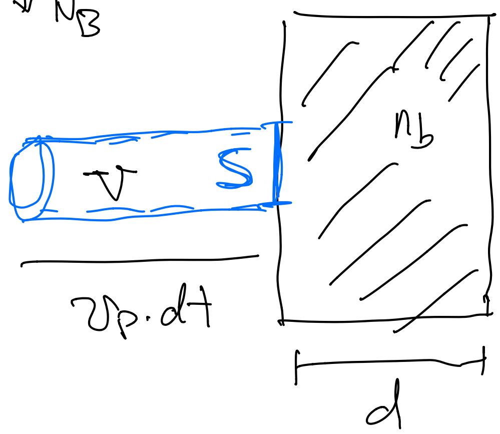
$= \frac{\cancel{10^9}}{1.6 \times 10^{-19}} \frac{eV}{s} =$

$\frac{\#\ \text{reazioni}}{\text{sec}} = \frac{P}{Q} = 3 \times 10^{19}\ Hz$

$$\# \nu_e = 6\times 3\times 10^{19} \simeq 2\times 10^{20}\ \nu/s. \qquad \frac{dN_p}{dt}$$

$$\bar{\nu}_e + p \longrightarrow n + e^+$$

$$\frac{dN_r}{dt} = \sigma \cdot \frac{dN_p}{dt\,S}\, \underbrace{n_b \cdot d\, S}_{N_B}$$



$$\frac{dN_r}{dt} = \sigma \cdot \frac{dN_p}{dt \cdot S}\, N_B \qquad\qquad \frac{dN_p}{dt\,S} = \Phi_p = v_p \cdot n_p$$

$$= v_p \cdot \frac{N_p}{V}$$

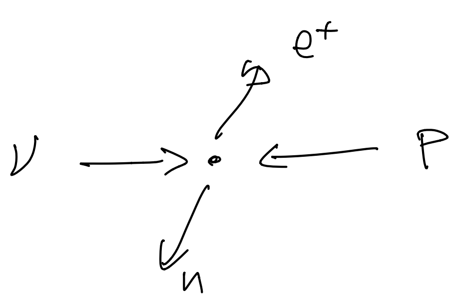
$$= \sigma\, v_p \frac{N_p}{V} N_B$$

$$\underbrace{\frac{1}{N_B}\frac{1}{N_p}\frac{dN_r}{dt}}_{} = \sigma \cdot \frac{v_p}{V}$$

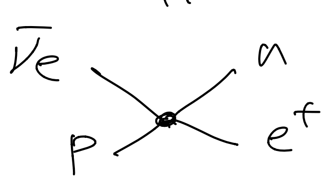
$$\|$$

$$\Gamma(i \to f) = \Gamma(\bar{\nu}_e + p \to n + e^+)$$

$$= 2\pi\, |M_{fi}|^2\, \rho(E)$$



$$M_{fi} = -i \int d^3r\, \varphi_f^* H_I\, \varphi_I$$



$$\mathcal{M}_{fi} = -i \frac{G_F}{V} N \Rightarrow |\mathcal{M}_{fi}|^2 = \frac{G_F^2}{V^2} \underbrace{|N|^2}$$

$$\int \psi_n^* \psi_p \, d^3r$$

$$\rho(E) = \int \delta(E_f - E_i)\, dn$$

$$\vec{P}_e + \vec{P}_n = 0 \qquad |\vec{P}_e| = |\vec{P}_n| = p^*$$

$$dn_e = \frac{1}{8} \frac{V}{(2\pi)^3} 4\pi \, p^{*2} dp^*$$

$$E_f = E_e^* + E_n^* = \sqrt{m_e^2 + p^{*2}} + \sqrt{m_n^2 + p^{*2}}$$

$$\delta(E_f - E_i)\, dp^* = \delta(E_f - E_i) \underbrace{\frac{dp^*}{dE_f}} dE_f$$

$$\frac{dE_f}{dp^*} = \frac{\cancel{2}p^*}{\cancel{2}E_e^*} + \frac{\cancel{2}p^*}{\cancel{2}E_n^*} = \beta_e^* + \beta_n^* = \beta_f^*$$

$$\rho(E) = (--)\, p^{*2} \frac{1}{\beta_f^*}$$

$$\sigma \frac{v_p}{\cancel{V}} = (2\pi) \frac{G_F^2}{\cancel{V^2}} |N|^2 \cancel{V}(--)\, p^{*2} \frac{1}{\beta_f^*}$$

$$\sigma(\bar{\nu}_e + p \to e^+ + n) \propto \frac{1}{8\pi} G_F^2 |N|^2 \frac{1}{\beta_p} \frac{1}{\beta_f^*} p^{*2}$$

$$|N|^2 \simeq 1 \qquad \beta_p = \frac{p_\nu}{E_\nu} = 1 \qquad \beta_f^* \simeq 1$$

$$\sigma \simeq G_F^2 \, p^{*2} \qquad G_F \simeq 10^{-5}\ \text{GeV}^{-2}$$

$$[G_F^2] \simeq E^{-4} = L^4 \qquad [p^{*2}] = E^2 = L^{-2}$$

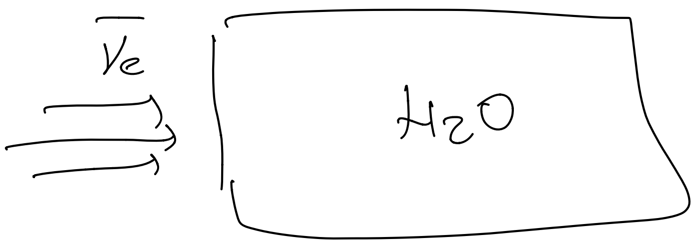
$$[\sigma] \sim [L]^2$$

$$G_F^2 = 1.4 \times 10^{-10}\ \text{GeV}^{-4}$$

$$1 = 200\ \text{MeV} \times \text{fm} = 0.2\ \text{GeV} \times \text{fm}.$$

$$1\ \text{fm} = \frac{1}{0.2}\ \text{GeV}^{-1} = 5\ \text{GeV}^{-1}$$

$$\sigma \simeq 10^{-44}\ \text{cm}^2 \left(\frac{p^*}{\text{MeV}}\right)^2$$



$$\frac{dN_r}{dt} = \sigma \cdot n \cdot dx \, \frac{dN_p}{dt}.$$

$$\frac{\frac{dN_r}{dt}}{\frac{dN_p}{dt}} = dP(\text{int}) = \sigma \cdot n\, dx.$$

$$P(x) = e^{-\underline{\sigma \cdot n} \cdot x}$$

$\frac{1}{\lambda} = \sigma \cdot n$ lungh. media fra interazioni

$$H_2O : n_b = \frac{\rho}{A} N_A Z = \frac{1}{18} \times 6. \times 10^{23} \times Z \ cm^{-3}$$

$$\simeq 3 Z \times 10^{22} \ cm^{-3}$$

$$\frac{1}{\lambda} = \sigma \cdot n. = 10^{-44} \ cm^2 \times 3 \times 10^{22} \ cm^{-3} \left(\frac{P}{MeV}\right)^2$$

$$= 10^{-22} \ cm^{-1}$$

$$\lambda \simeq 10^{22} \ cm.$$

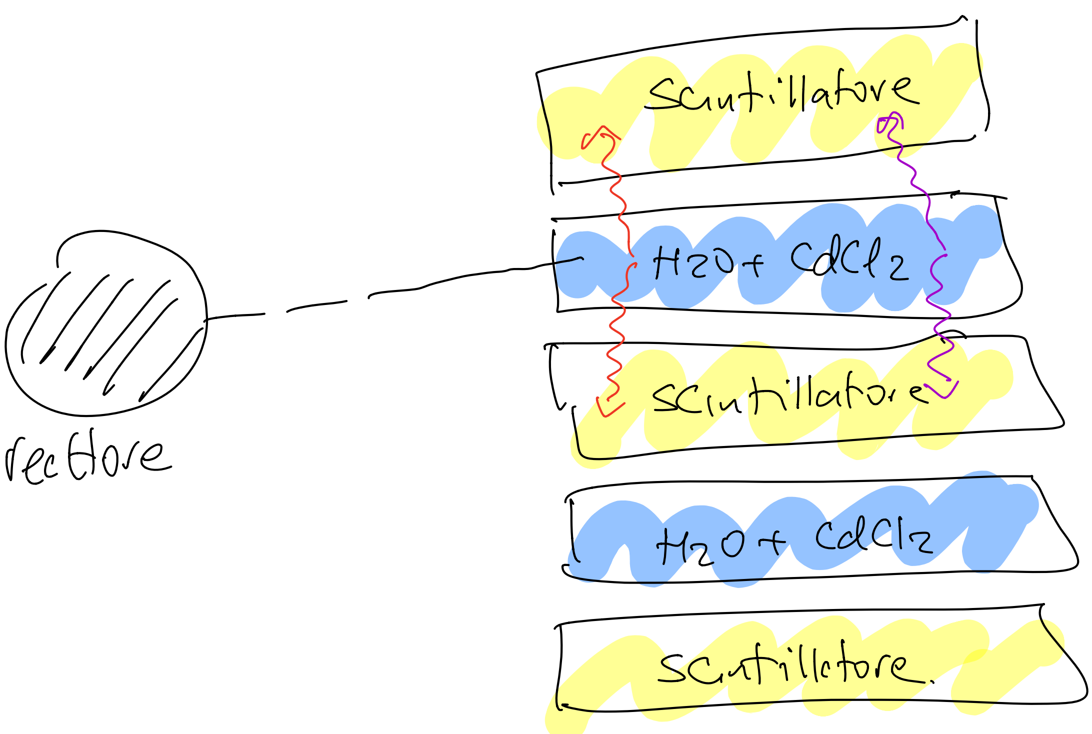
Roma – Milano 10^3 Km $= 10^6$ m

$= 10^8$ cm.

Terra – sole $= 150$ Km $\times 10^6 = 10^8 \times 10^3 \times 10^2$ cm

$= 10^{13}$ cm.

$$\frac{dN_r}{dt} = \sigma \cdot n \frac{dP}{dt} d. = \sigma \cdot N_B \, \Phi_P$$

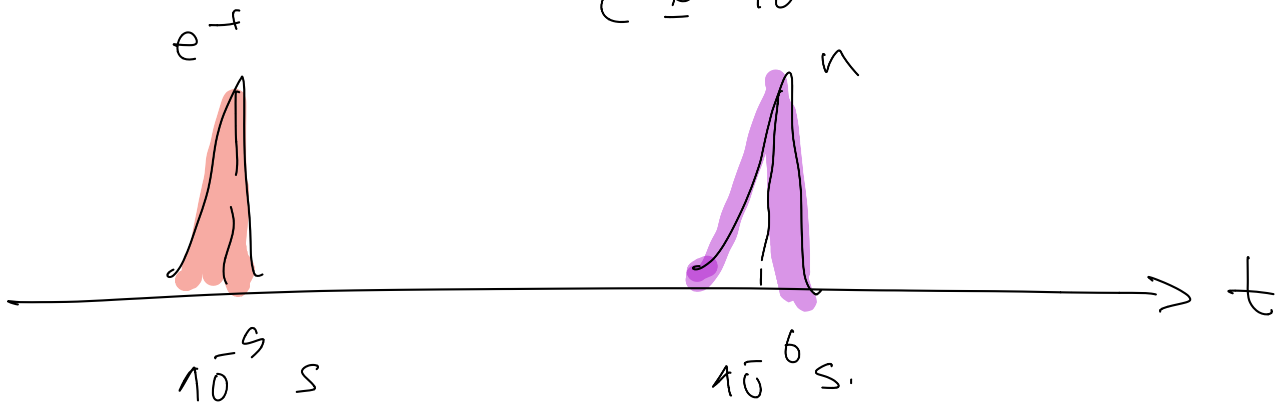


$\nu_e + p \longrightarrow n + e^+$

$e^+ + e^- \longrightarrow 2\gamma \qquad \tau \simeq 10^{-9}\ s.$

$n + Cd \longrightarrow Cd^* \longrightarrow Cd + 2\gamma$

$\tau \simeq 10^{-6}\ s$



$\Delta T \qquad N_{tot} \simeq 567 \qquad$ Reattore acceso.

$N_{tot} = N_S + N_B$

$\Delta T \qquad N_{tot} = 209 \qquad$ reattore spento.

$N_{tot} = N_B$

$$N_S = \frac{N_{tot} - N_B}{\delta N_B} = \frac{567-209}{\sqrt{20}}$$