- 1897 : e^-
- 1900
  1923 γ
- 1911 : nucleo , p
- 1939 : $p \to e^+ + \gamma \Rightarrow B$
- 1947 : $\pi^\pm$ π^0 μ
- 1930 : e^+
- 1954 : $\bar{\nu}_e$ L_e
  $\bar{p}$
- 1962 : ν_μ L_μ

$$\begin{pmatrix} e^- \\ \nu_e \end{pmatrix} \qquad \begin{pmatrix} \mu^- \\ \nu_\mu \end{pmatrix}$$

L_e $\qquad$ L_μ

ADRONI
particelle che int. forte

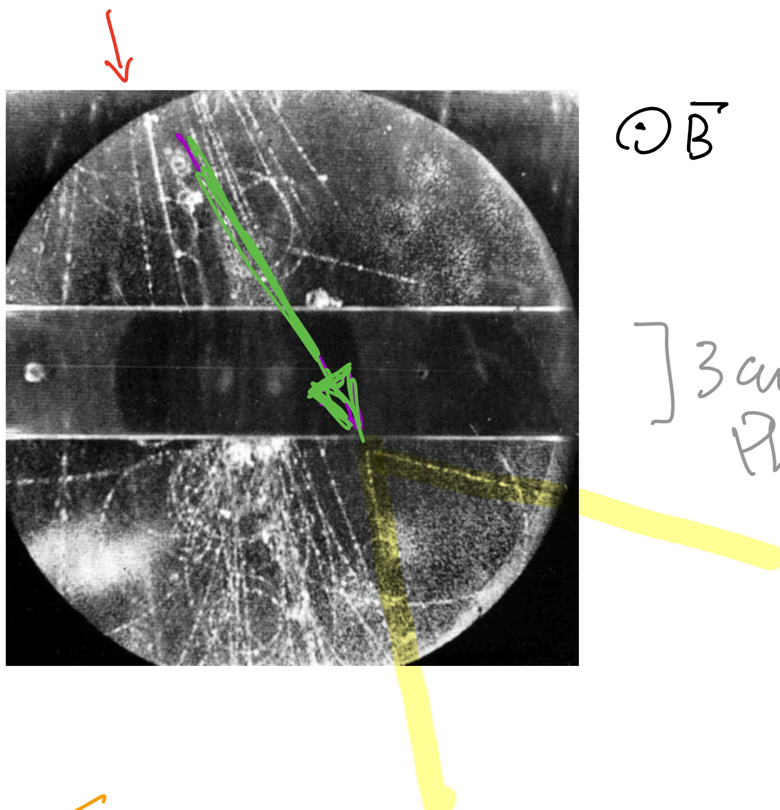
LEPTONI
int. debole

- mesoni π^+, π^-, π^0
- barioni
  p, n

in realtà MESONE $q\bar{q}$

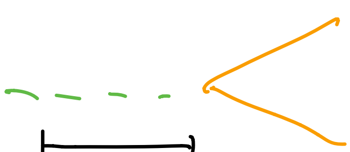
BARIONE qqq

$\boxed{1947}$



$\odot \vec{B}$

3 cm Pb

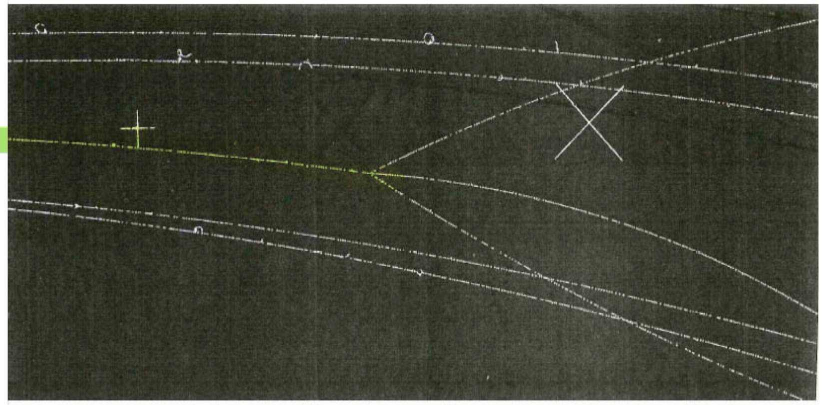


mm

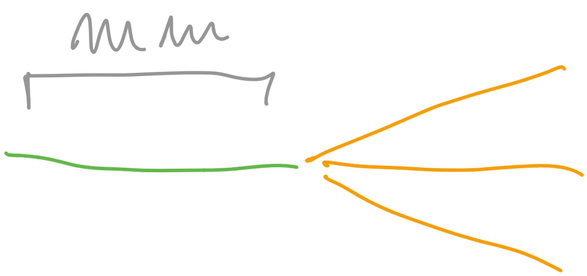
"V_0" $K^0 \to \pi^+ + \pi^-$

$m_{K^0} \sim 490 \ \mathrm{MeV}/c^2$

$\boxed{1949}$



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



$K^+ \to \pi^+ + \pi^+ + \pi^-$

$m_{K^\pm} \simeq 490 \ \mathrm{MeV}$

$\boxed{1950}$

$\Lambda^0 \longrightarrow p + \pi^-$

iperone

$m_\Lambda \simeq 1.1 \ \mathrm{GeV}/c^2$

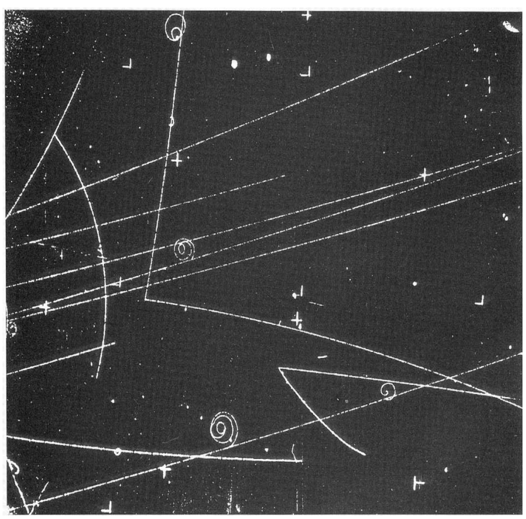
Sono processi in cui una particella STRANA decade con tempi "lunghi" (rispetto all'interazione forte) in adroni

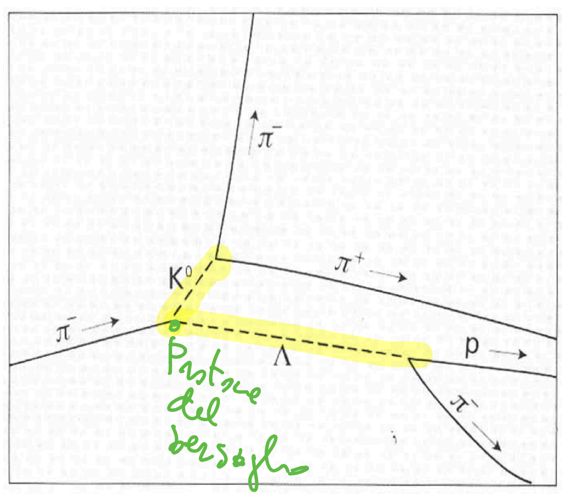
1952

$$\pi^- + p \to K^0 + \Lambda$$

$$\Lambda \to p + \pi^-$$

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





$$\tau_{\text{decadimento}} \sim 10^{-10}\ \text{s}$$

(int. forte sarebbe stato 10^{-24})

particelle strane: è prodotta da int. forte ma decade debole

(PRODUZIONE)

$$\pi^- + p \to K^+ + \Sigma^-$$

$$K^0 + \Sigma^0$$

$$K^0 + \Lambda^0$$

$S=0 \quad S=0 \qquad S=+1 \quad S=-1$

introduco la STRANEZZA S

osservo $\pi^- + p \to \pi^+ + \Sigma^-$? No!

$S_1 = 0$, $S_2 = 0$ $\to S_i = 0$; π^+: $S=0$; Σ^-: $S \neq 0$

l'interaz. forte conserva la stranezza

(DECADIMENTO)

$$\Lambda \to p + \pi^-$$

$$\Sigma^+ \to p + \pi^0$$

$$\Sigma^+ \to n + \pi^+$$

posso avere nel decadimento

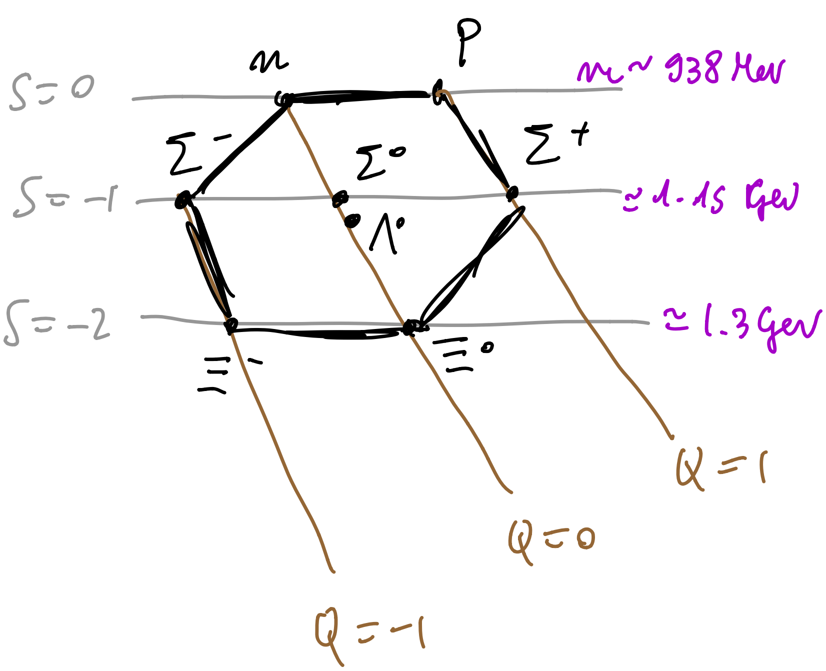
$$\Delta S = \pm 1$$

l'interaz. debole non conserva la stranezza

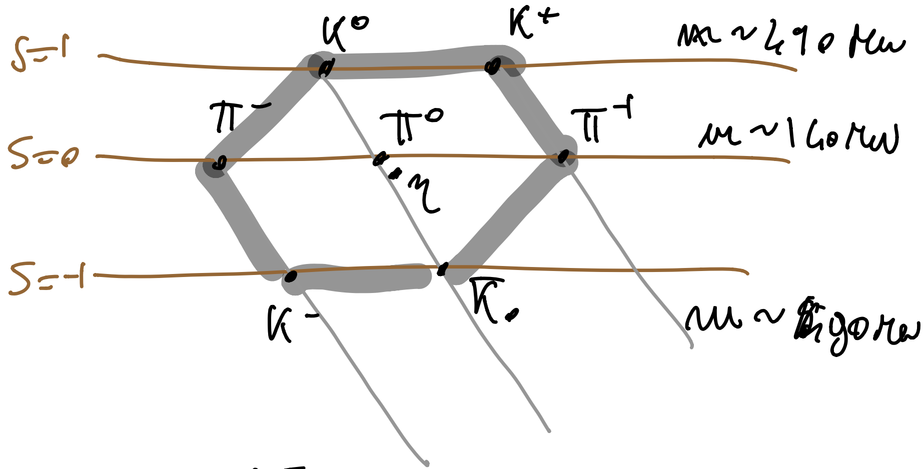
	Q	S	m (MeV)	τ (ps)	$c\tau$ (mm)	Principal decays (BR in %)
Λ	0	−1	1116	263	79	$p\pi^-(64)$, $n\pi^0(36)$
Σ^+	+1	−1	1189	80	24	$p\pi^0(51.6)$, $n\pi^+(48.3)$
Σ^0	0	−1	1193	7.4×10^{-8}	2.2×10^{-8}	$\Lambda\gamma(100)$
Σ^-	−1	−1	1197	148	44.4	$n\pi^-(99.8)$
Ξ^0	0	−2	1315	290	87	$\Lambda\pi^0(99.5)$
Ξ^-	−1	−2	1321	164	49	$\Lambda\pi^-(99.9)$

	Q	S	m (MeV)	τ (ps)	Principal decays (BR in %)
K^+	+1	+1	494	12	$\mu^+\nu_\mu(63)$, $\pi^+\pi^+\pi^-(21)$, $\pi^+\pi^0(5.6)$
K^0	0	+1	(498)	n.a.	
K^-	−1	−1	494	12	$\mu^-\bar{\nu}_\mu$, $\pi^-\pi^-\pi^+$, $\pi^-\pi^0$
$\bar{K}^0$	0	−1	(498)	n.a.	

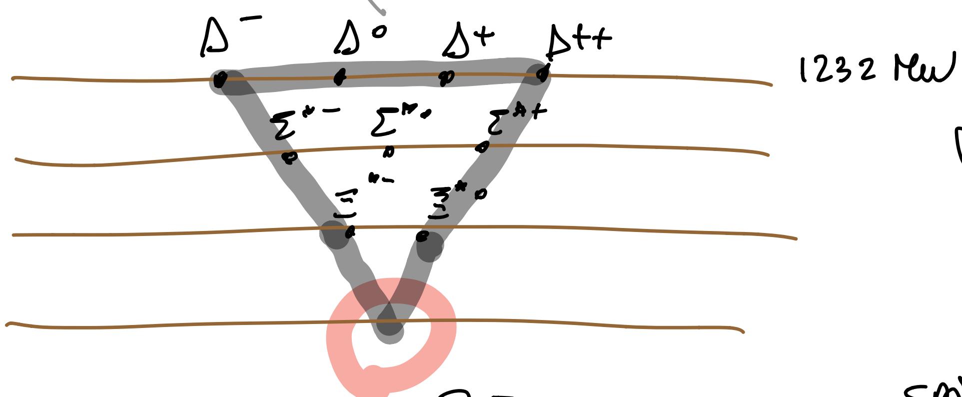
OTTETTO ("EIGHTFOLD WAY")



OTTETTO DEI BARIONI



OTTETTO DEI MESONI



DECUPLETTO DI BARIONI

spin = 3/2

Ω^- (osservata due anni dopo)

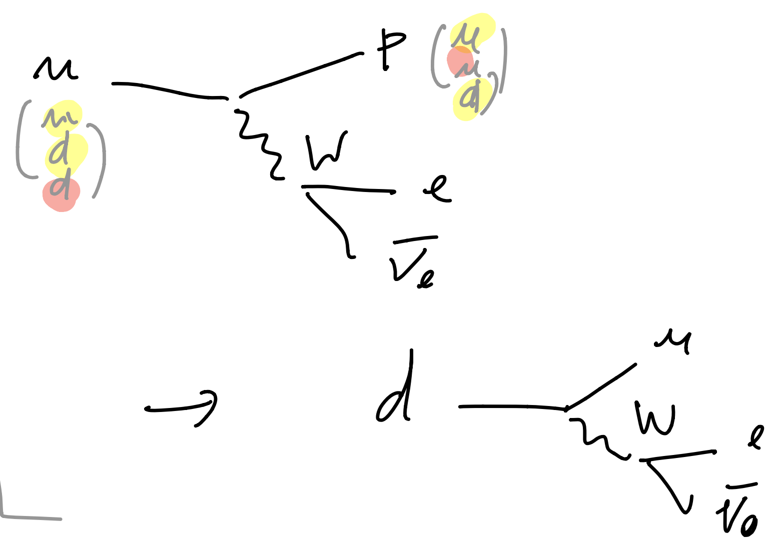
oggi: quark

$$\begin{pmatrix} u \\ d \end{pmatrix} \begin{pmatrix} c \\ s \end{pmatrix} \begin{pmatrix} t \\ b \end{pmatrix} \quad \begin{matrix} Q \\ 2/3 \\ -1/3 \end{matrix}$$

qqq	Q	S	NOME
uuu	2	0	Δ^{++}
uud	+1	0	p

(ETC)

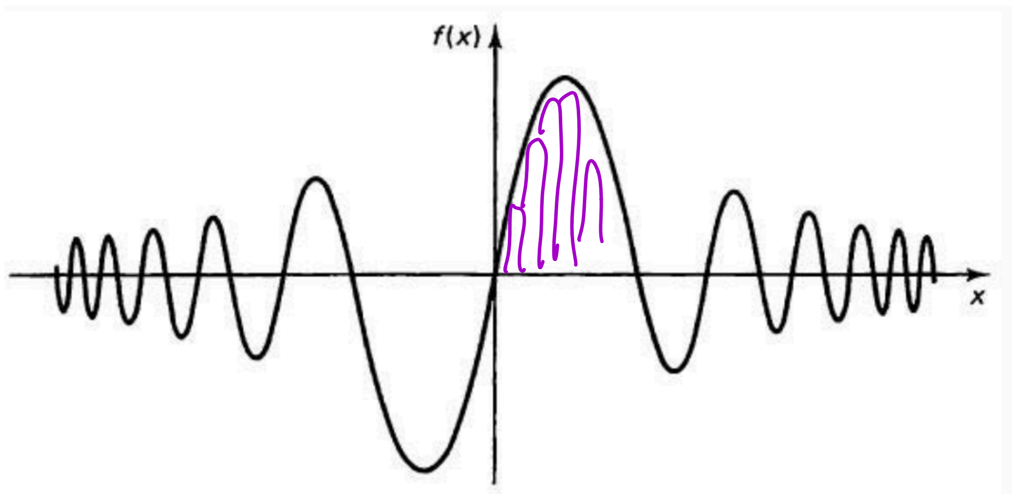
$$n \to e^- + \bar{\nu}_e + p$$



$u: \frac{2}{3}$

$d: -\frac{1}{3}$

SIMMETRIE

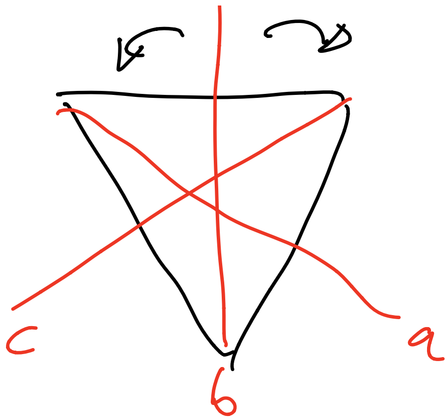


si calcoli $\displaystyle\int_{-2}^{2} f(x)\,dx$

$$= \int_{0}^{2} f(x)\,dx + \int_{-2}^{0} f(x)\,dx = 0$$

$$f(x) = -f(-x)$$

ES



SIMMETRICO SOTTO

- 1
- R_a, R_b, R_c
- $R_{+120°}$
- $R_{-120°}$

sono 6 trasformazioni R_i

- esiste la trasformazione $I \cdot R_i = R_i \cdot I$
- $R_i^{-1} R_i = I$
- $R_i \cdot R_J \in$ alle 6
- $R_i \cdot (R_J \cdot R_K) = (R_i \cdot R_J) R_K$

$\longrightarrow$ formano un GRUPPO

esistono gruppi

$U(n)$ $\quad U^{\dagger} = U^{-1}$

$SU(n)$ $\quad \det = +1$

$O(n)$ $\quad$ reali

$SO(n)$ $\quad$ con $\det = +1$

$$\underbrace{a \cdot b}_{\text{ROTAZ. DEL TRIANGOLO}} = c \implies M(a) \cdot M(b) = M(c)$$

SIMMETRIA

$\rightarrow$ DEGENERAZIONE

evoluz. di un operatore $\tilde{Q}$

$$i\hbar \frac{d\tilde{Q}}{dt} = i\hbar \frac{\partial \tilde{Q}}{\partial t} + [\tilde{Q}, H]$$

$$\left(\frac{d\langle \hat{Q} \rangle}{dt} = \ldots ? \right)$$

se $\hat{Q}$ è indip. del tempo

$$[\hat{Q}, H] = 0$$

trasformazione

$$\psi \to \psi' = U\psi$$

$$\langle \psi' | \psi' \rangle = \langle \psi | U^\dagger U | \psi \rangle$$

$$\equiv \langle \psi | \psi \rangle$$

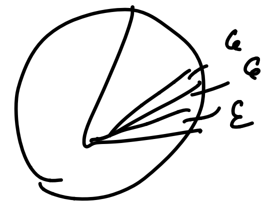
$$\Longrightarrow U^\dagger U = 1$$

operatore unitario

se trasf. continue

$$U(\varepsilon) = 1 + i\varepsilon\sigma$$

$$\varepsilon \in \mathbb{R}$$



$$U^\dagger(\varepsilon)\,U(\varepsilon) \equiv 1$$

$$= (1 - i\varepsilon\sigma^\dagger)(1 + i\varepsilon\sigma)$$

$$= 1 + i\varepsilon(\sigma - \sigma^\dagger) + O(\varepsilon^2)$$

$$\Longrightarrow \sigma = \sigma^\dagger$$

potete fare

$$U(\alpha) = \lim_{N\to\infty} \prod \left(U\left(\frac{\alpha}{N}\right)\right)$$

$$= \lim_{N\to\infty} \left(1 + i\frac{\alpha}{N}\sigma\right)$$

$$= e^{i\alpha\sigma}$$

$\boxed{\text{GENERATORE}}$

(ES) TRASLAZIONE

$(\hbar = 1)$

$$U|\psi(x)\rangle = |\psi(x+\delta x)\rangle$$

$$= |\psi(x)\rangle + \frac{\partial|\psi(x)\rangle}{\partial x}\delta x$$

$$= \left(1 + \delta x \frac{\partial}{\partial x}\right)|\psi(x)\rangle$$

$$= \left(1 + i \cdot (-i) \cdot \delta x \cdot \frac{\partial}{\partial x}\right)|\psi(x)\rangle$$

$$= \left(1 + i \cdot \delta x \cdot \vec{p}\right)|\psi(x)\rangle$$

ISOSPIN

nucleo : $\begin{pmatrix} p \\ n \end{pmatrix}$ $m_p \simeq m_n$

$d = pn$ esiste MA pp, nn

$S \quad 1/2 \qquad$ 2 valori S_z $\pm 1/2$

$\rightarrow 2S+1$ stati

ISOSPIN

$$p \equiv |\underset{I}{1/2}, \underset{I_3}{1/2}>$$

$$n \equiv |1/2, -1/2>$$

Nucleone : $\begin{pmatrix} \alpha \\ \beta \end{pmatrix}$

$$|N> = \alpha|p> + \beta|n>$$

$\alpha, \beta \in \mathbb{C}$

Heisenberg :

le interazioni forti sono invarianti

sotto rotazione nello spazio di isospin

$\rightarrow$ Noether: c'è una grandezza conservata, l'isospin

π : $m \sim 140\ MeV/c^2$

$$\pi = \begin{array}{c} \\ \begin{pmatrix} \pi^+ \\ \pi^0 \\ \pi^- \end{pmatrix} \end{array} \begin{array}{c} I_3 \\ +1 \\ 0 \\ -1 \end{array}$$

$2I+1 = 3$

$\rightarrow I = 1$

Λ : (Λ) $\qquad I = 0$

$$\psi = \psi_{SPAZ} \times \psi_{ISOSPIN} \times \dots$$

$$\Delta : \begin{pmatrix} \Delta^{++} \\ \Delta^{+} \\ \Delta^{0} \\ \Delta^{-} \end{pmatrix} . \quad I = 3/2$$

1232 MeV/c^2

Relazione di Gellmann - Nishijima

$$Q = I_3 + \frac{1}{2}(B + S)$$

$$\underline{p + p} \to \underline{d + \pi^+}$$

$$p + n \to d + \pi^0$$

$$n + n \to d + \pi^-$$

$$\pi^+ + p \to \pi^+ + p$$

$|1\ {+1}\rangle$ $|\tfrac{1}{2}\ \tfrac{1}{2}\rangle$

$$|1\ 1\rangle|\tfrac{1}{2}\ \tfrac{1}{2}\rangle = |\tfrac{3}{2}\ \tfrac{3}{2}\rangle$$

$I^{(1)}\ I_z^{(1)}$

$\cdots$ $|\tfrac{3}{2}\ \tfrac{3}{2}\rangle$

$$\langle f|H|i\rangle = ? \qquad \langle a|H|a\rangle$$