SPIN ORBITA NUCLEARE

$$H \propto \vec{L}\cdot\vec{S}\cdot f(\vec{r})$$

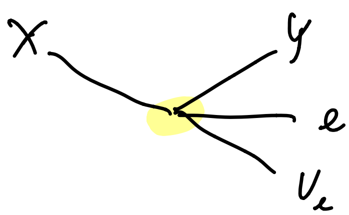
↳ in fisica atomica: $\propto \frac{1}{r^3}$

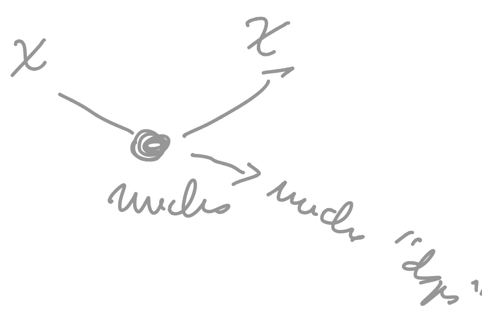
NUMERO DI STATI e ν nel decadimento β

- $dN_e = \frac{d^3p}{\left(\frac{2\pi\hbar}{a}\right)^3} = \frac{d^3p}{(2\pi\hbar)^3}V$
- dN_ν
- x

DECADIMENTO β

$$^{A}_{Z}X \to {}^{A}_{Z\pm1}Y + e^{\mp} + \overset{(-)}{\nu}_e$$





$$\tau \quad \left(= \frac{1}{\lambda}\right)$$

$$d\lambda = G_F^2 \frac{(m_e c^2)^5}{2\pi^3 \hbar} |M_{fi}|^2 F(\pm Z, T_e)\, P_e (m_e c^2 + T_e)\, P_\nu$$

$$\times E_\nu \, dT_e$$

$Q = T_e + E_\nu$

$W = E_e + E_\nu$

$m_\nu \equiv 0$

$$\lambda \propto \int_0^W P_e \cdot E_e (W - E_e)^2 \, dE_e$$

LEGGE DI SARGENT

$$\lambda = \frac{1}{\tau} \propto W^5$$

COME MISURO G_F?

$$\lambda = \frac{G_F^2 (m_e c^2)^5}{2\pi^3 \hbar} |M_{fi}|^2 f(\pm Z, Q)$$

$$\frac{f}{\lambda} = f\tau = \frac{2\pi^3 \hbar}{G_F^2 (m_e c^2)^5 |M_{fi}|^2}$$

$$X \to Y + e^- + \bar{\nu}_e$$

ci eravamo messi nel caso "DECADIM. PERMESSO" $\equiv \vec{L}_{e\nu} = 0$

($\neq$ "DECADIM. PROIBITO" $\equiv L \neq 0$)

$$\vec{J}_X = \vec{J}_Y + \vec{L}_{e\nu} + \vec{S}_{e\nu}$$

devo fare la composizione di momenti angolari di e $(1/2)$, ν $(1/2)$

- $S_{e\nu} = 0$ TRANSIZIONI DI FERMI $\quad \Delta J = 0$
- $S_{e\nu} = 1$ TRANSIZIONI DI GAMOW-TELLER $\quad \Delta J = 1$

$$\left[\frac{1}{\sqrt{2}}\left(e\uparrow \bar{\nu}_e\downarrow - e\downarrow \bar{\nu}_e\uparrow\right)\right]$$

$S_{e\nu}=0$

$$\uparrow n \rightarrow \uparrow p + \uparrow e^- + \bar{\nu}_e \downarrow$$

$$\frac{1}{\sqrt{2}}\left(\uparrow\downarrow + \downarrow\uparrow\right)$$

$S_{e\nu}=1$

$M_S=0$: $\quad \uparrow n \rightarrow \uparrow p + \uparrow e^- + \bar{\nu}_e \downarrow$

$M_S=1$: $\quad \uparrow n \rightarrow \downarrow p + \uparrow e^- + \uparrow \bar{\nu}_e$

$M_S=-1$: $\quad \downarrow n \rightarrow \uparrow p + \downarrow e^- + \downarrow \bar{\nu}_e$

decadimento	transizione ($X \to Y$)	τ (s)	W	p_e^{max}	$f\,\tau$ (MeV^2 fm^6)	$g^2\,\|M_{if}\|^2$
$n \to p\, e^-\, \bar\nu$	$\frac{1}{2}^+ \to \frac{1}{2}^+$	890	1.29	1.18	$1.61\ 10^3$	$4.25\ 10^{-8}$
$^3_1H \to\ ^3_2He\, e^-\, \bar\nu$	$\frac{1}{2}^+ \to \frac{1}{2}^+$	$5.60\ 10^8$	0.53	0.14	$1.63\ 10^3$	$4.20\ 10^{-8}$
PURO FERMI → $^{14}_8O \to\ ^{14}_7N^*\, e^+\, \nu$	$0^+ \to 0^+$	102	2.32	2.26	$4.51\ 10^3$	$1.52\ 10^{-8}$
$^{34}_{17}Cl \to\ ^{34}_{16}S\, e^+\, \nu$	$0^+ \to 0^+$	2.21	4.97	4.94	$4.54\ 10^3$	$1.51\ 10^{-8}$
PURO G.T. → $^6_2He \to\ ^6_3Li\, e^-\, \bar\nu$	$0^+ \to 1^+$	1.15	4.02	3.99	$1.17\ 10^3$	$5.85\ 10^{-8}$
$^{13}_5B \to\ ^{13}_6C\, e^-\, \bar\nu$	$\frac{3}{2}^- \to \frac{1}{2}^-$	$2.51\ 10^{-3}$	13.4	13.4	$1.11\ 10^3$	$6.17\ 10^{-8}$

$$G_F |M_{if}|^2 = G_F \left(|M_{if}^F|^2 + \beta |M_{if}^{GT}|^2 \right)$$

dai dati

$$\beta \simeq 1.24$$

$$G_F \simeq 1.14 \cdot 10^{-5}\ \text{GeV}^{-2}$$

INTERAZIONE DEBOLE

$Q \sim 1$ MeV nel β decay

$q \sim 1$ MeV/c (impulso trasferito)

(EM) $\dfrac{4\pi\alpha}{(qc)^2} \simeq 0.1\ \text{MeV}/c^2$

DEBOLE $G_F \simeq 1.16 \cdot 10^{-5}$ MeV/c^2

→ per impulsi $q \sim 1$ MeV/c,
EM >>> DEBOLE

→ a quali impulsi le due interazioni sono comparabili?

$$\frac{4\pi\alpha}{(qc)^2} \equiv 10^{-11} \text{ MeV}/c^2$$

→ per $q \cong 100$ GeV

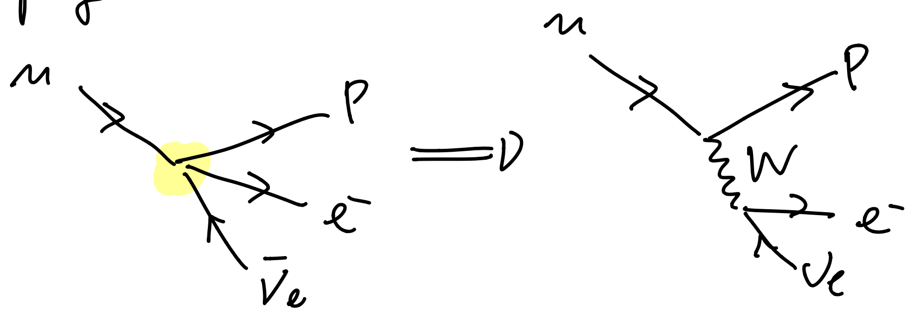
→ la vedo come mediata da un mediatore di $m \sim 100$ GeV

Propagatore EM $\propto \frac{1}{q^2}$

WEAK $\propto \frac{1}{q^2 + M_W^2}$

per basso q: → $\frac{1}{M_W^2}$

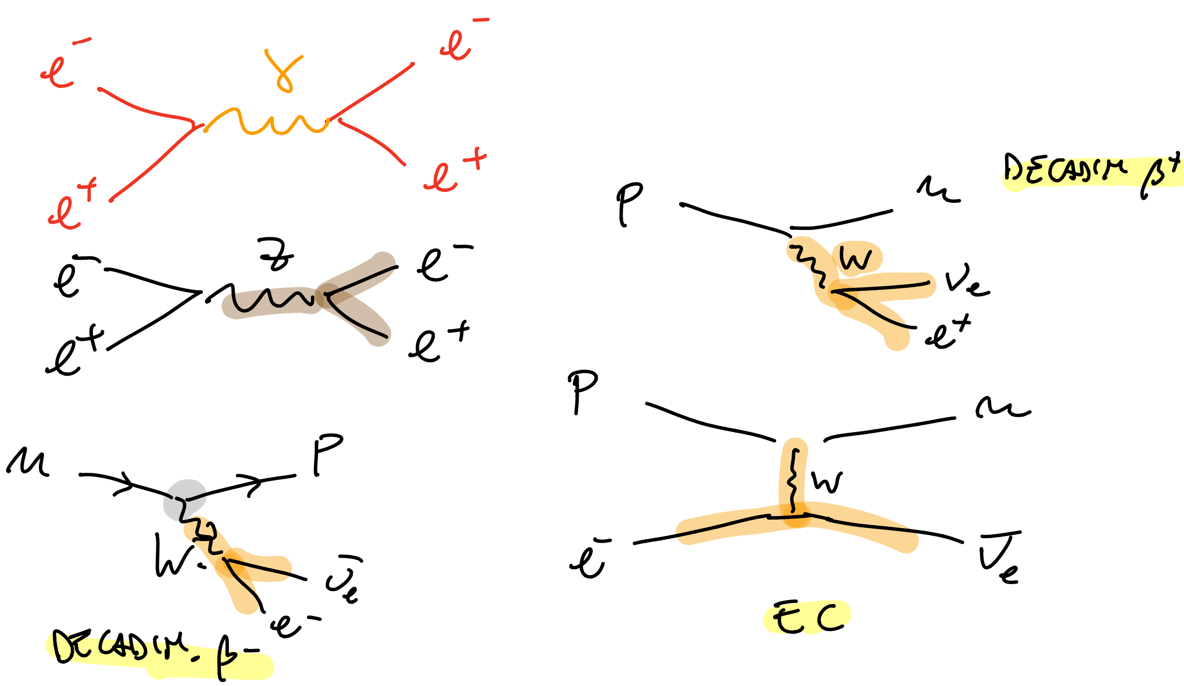
significa:



→ si scopre che ESISTONO questi mediatori

$$W^+ , W^- , Z^0$$

$$m_W \simeq 80 \text{ GeV}$$
$$m_Z \simeq 90 \text{ GeV}$$



SCOPERTA DEL $\bar{\nu}_e$

- FISSIONE produce nuclidi con troppi n
- → avremo decadimenti β^-

⇒ emissione di $\bar{\nu}_e$

Cerchiamo

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

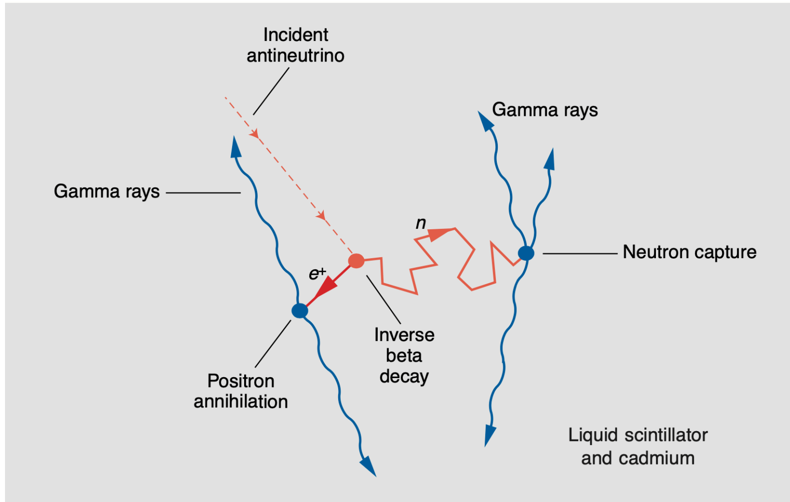
"DECADIMENTO β INVERSO"

$$E_\nu \simeq 1\ \text{MeV}$$

$$\sigma = 10^{-47}\left(\frac{E_\nu}{\text{MeV}}\right)^2 m^2$$

rivelo n mediante

$$n + p \to d + \gamma$$



se ho 0.7 GW, ogni reattore produce 200 MeV di energia → calcolo

$$\phi = 10^{17} m^{-2} s^{-1}$$

e voglio $\frac{dN_\nu}{dt} \simeq 10^{-3}\ Hz$

$$\frac{dN_\nu}{dt} = \phi\, \sigma \cdot N_B \equiv 10^{-3}\ Hz$$

↳ $10^{-47}\ m^2$

↳ $10^{17}\ m^{-2} s^{-1}$

$$N_B = \rho \cdot \frac{N_A}{A_{H_2O}} \cdot V \cdot Z_{H_2O} = 15\ \text{litri}$$

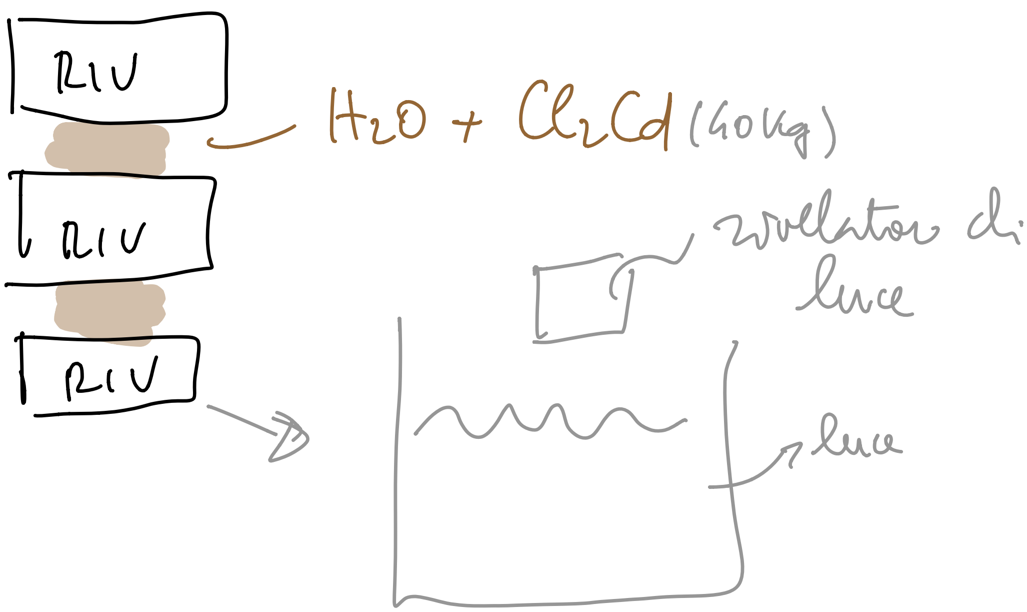
→ scegliamo 200 litri di H_2O

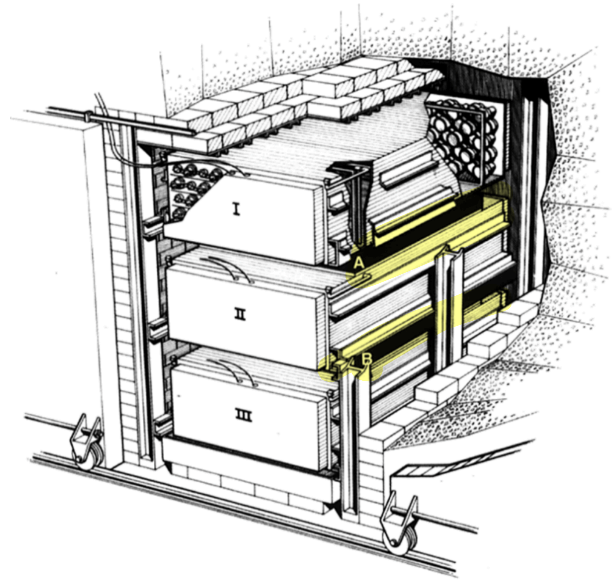
→ ci sciogliamo $CdCl_2$

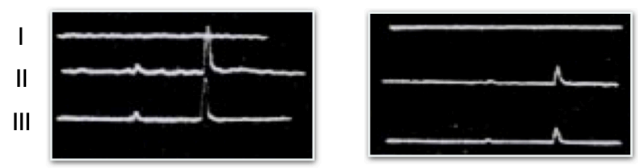
$$n + {}^{108}Cd \to {}^{109}Cd^{*} \to {}^{109}Cd + \gamma$$

(n, γ)

$\tau \simeq 10\,\mu s$







Positron scope　　Neutron scope

~ 3 eventi / l'ora

$$\bar{\nu}_e + p \to e^+ + n \quad (A)$$

$L_e = -1 \quad L_e = 0 \quad L_e = -1 \quad L_e = 0$

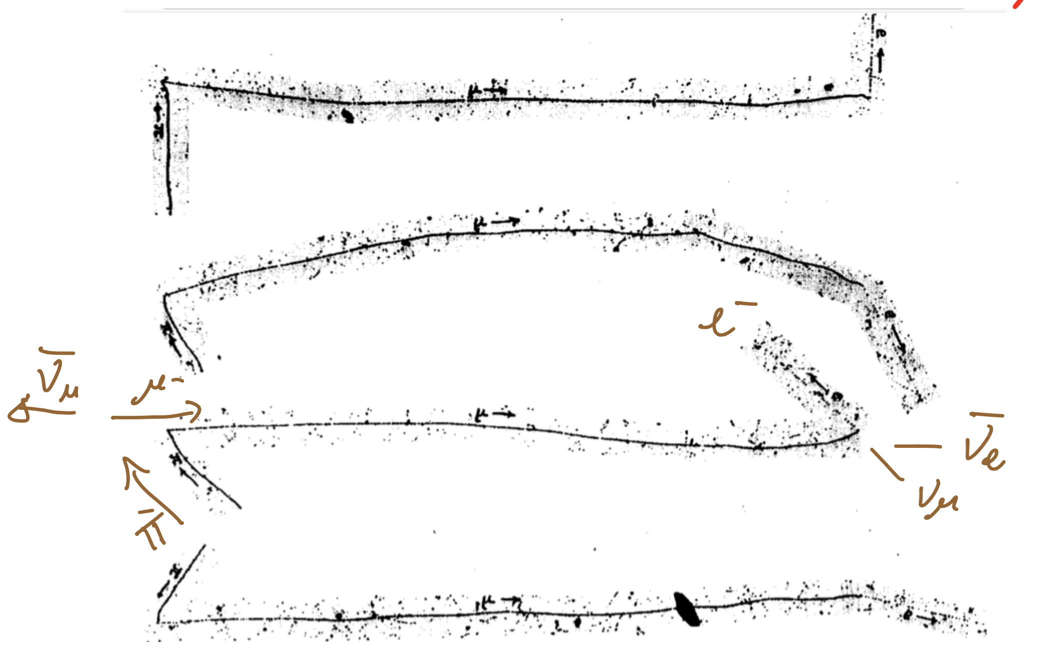
MA NON OSSERVO

$$\bar{\nu}_e + n \to e^- + p \quad (B)$$

$L_e = -1 \quad L_e = 1$

→ Viola la conservazione del NUMERO LEPTONICO ELETTRONICO L_e

NON SOLO! C'E' ANCHE IL μ e ν_μ



$$\begin{pmatrix} e^- \\ \nu_e \end{pmatrix}, \quad \begin{pmatrix} \mu^- \\ \nu_\mu \end{pmatrix}, \quad \begin{pmatrix} \tau^- \\ \nu_\tau \end{pmatrix}$$

SCOPERTA ν_μ

- produco un fascio di PIONI

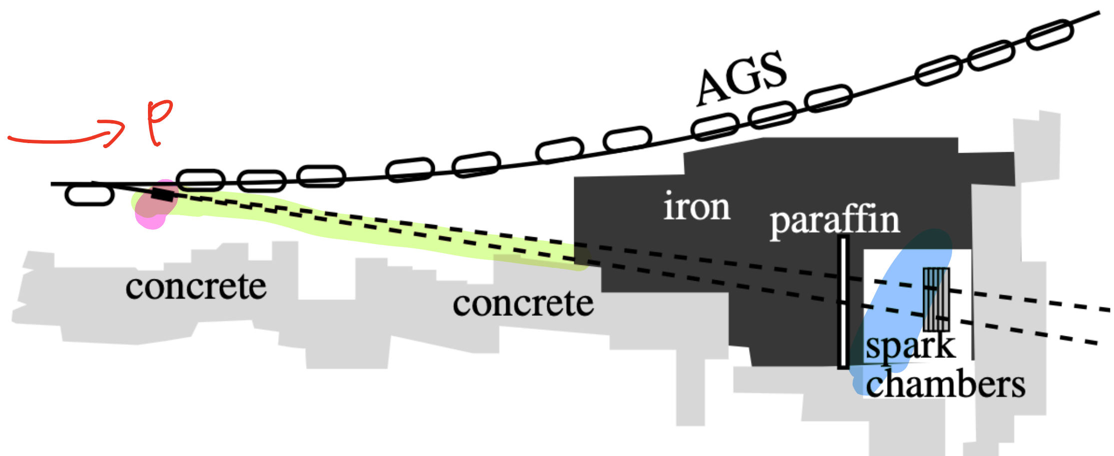
$$\pi^+ \longrightarrow \mu^+ + \nu \qquad \Rightarrow \nu_\mu ? \; \nu_e ?$$

$$\pi^- \to \mu^- + \bar{\nu} \quad]$$

– Cercare

$$\nu + n \to p + \mu^-$$
$$\nu + n \to p + e^-$$
} quale?

$$\bar{\nu} + p \to n + \mu^+$$
$$\bar{\nu} + p \to n + e^+$$
} quale?



1) $p + Be \to$ PIONI

2) PIONI $\to \mu^+ + \nu$

$\mu^- + \bar{\nu}$

3) neutrini interagiscono

→ producono e^- ? $\Longrightarrow \nu_e$

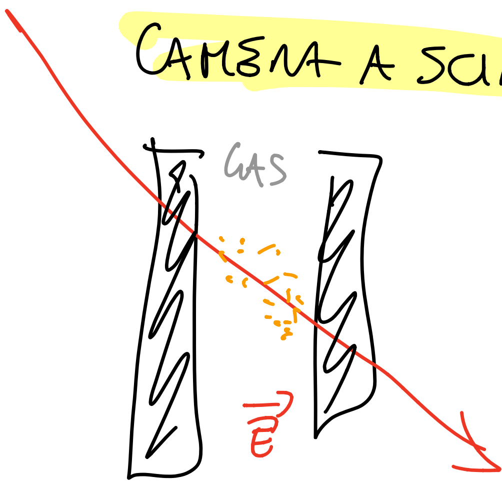
→ producono μ^- ? $\Longrightarrow \nu_\mu$

DISTINGUO usando BREM

CAMERA A SCINTILLA

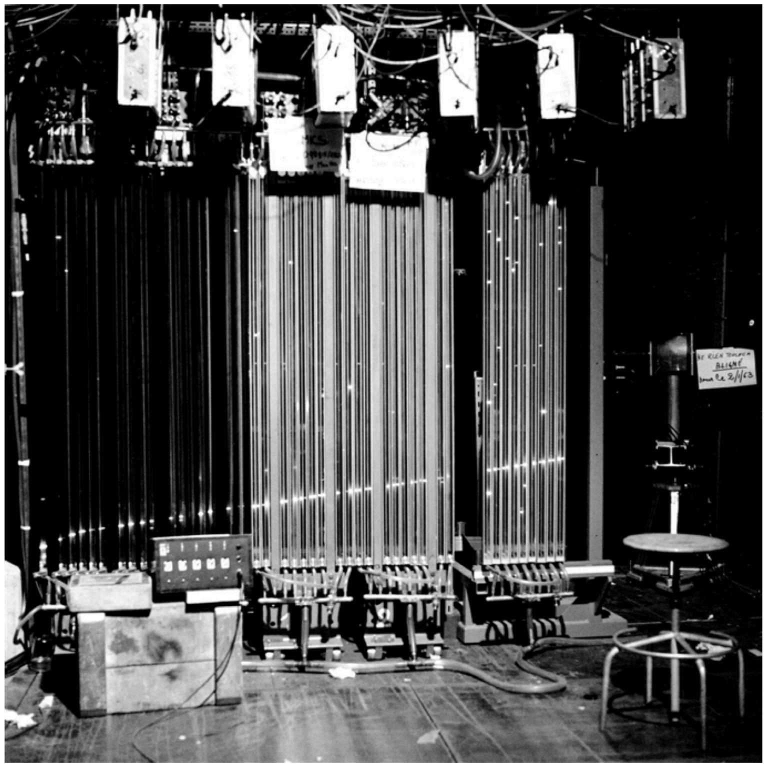
$m_e \sim 511$ keV

$m_\mu \sim 106$ MeV



PIATTI METALLICI DI Al (10 t)

$\vec{E} = 10$ MV/m



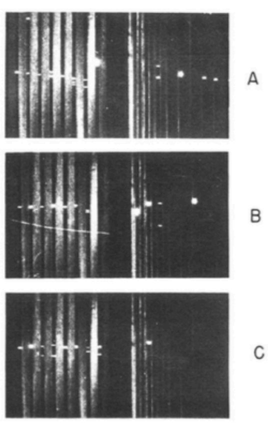


FIG. 8. 400-MeV electrons from the Cosmotron.

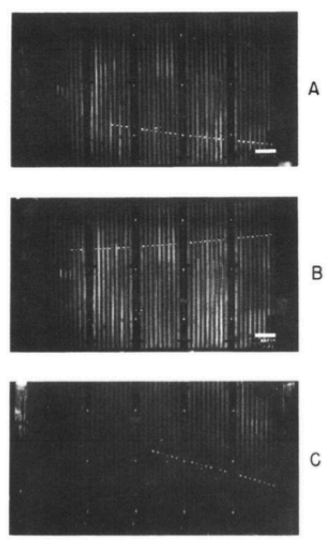


FIG. 5. Single muon events. (A) $p_\mu > 540$ MeV and δ ray indicating direction of motion (neutrino beam incident from left); (B) $p_\mu > 700$ MeV/c; (C) $p_\mu > 440$ with δ ray.

TROVANO SOLO μ`

PERCHE' p non decade?

$$p \rightarrow e^+ + \gamma$$

$B=1$ $\quad B=0 \quad B=0$

$$\tau \geq 10^{34}\, y$$

→ NUMERO BARIONICO (SI CONSERVA SEMPRE)

→ se esiste $\bar{p}$, come lo produco?

$$p + p \rightarrow \bar{p} + p + p + p$$

$B=1 \quad B=1 \quad -1 \quad +1 \quad +1 \quad +1$

- $$E_{SOGLIA} = \frac{(4m_p)^2 - (2m_p^2)}{2m_p} = 7m_p$$

$$\simeq 6.6\, GeV$$

- distinguere $\bar{p}$ da π^-