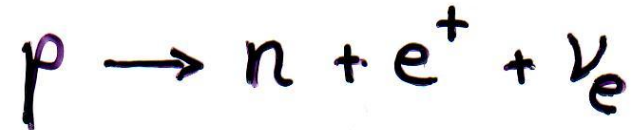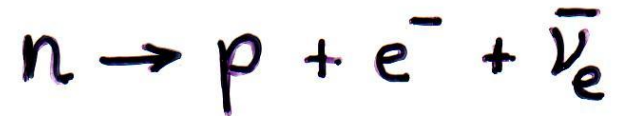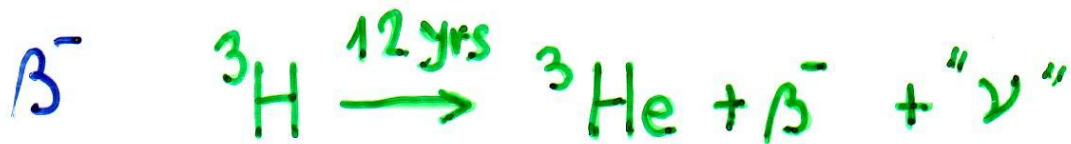# VI. Slabi procesi (I)

OD PRIRODNE RADIOAKTIVNOSTI DO V-A TEORIJE SLABE SILE

- **UVOD U SLABA MEĐUDJELOVANJA**
- **FERMIJEVA STRUJA x STRUJA TEORIJA**
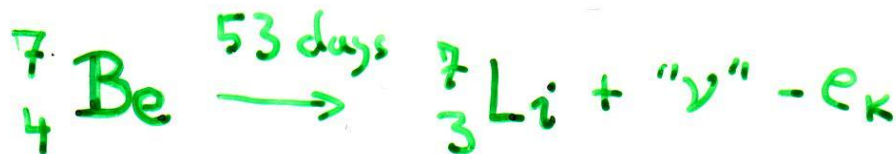- **NARUŠENJE PARITETA i V-A TEORIJA**

KRATKA POVIJEST

- Becquerelove zrake (1896.)
- α i β omponenta radioaktivnosti, Rutherford 1898.
- Mjerenje naboja β-komponente, Cuiriejevi 1900.
- Postuliranje neutrina (Pauli, 1930.)
- Fermijeva teorija, 1934.

INAČICE BETA-PROCESA

β^-

$$^3H \xrightarrow{12 \text{ yrs}} {}^3He + \beta^- + "\nu"$$

$$(2n)(1p) \rightarrow (1n)(2p) \qquad\qquad n \rightarrow p + e^- + \bar{\nu}_e$$

β^+

$$^{11}_{6}C \xrightarrow{20'} {}^{11}_{5}B + \beta^+ + "\nu"$$

$$(6p)(5n) \rightarrow (5p)(6n) \qquad\qquad p \rightarrow n + e^+ + \nu_e$$

K-capture

$$^7_4Be \xrightarrow{53 \text{ days}} {}^7_3Li + "\nu" - e_K$$

$$p \rightarrow n \qquad\qquad e^- + p \rightarrow n + \nu_e$$

- **Nemogućnost hvatanja neutrina (Bethe & Peierls, 1934.)**
- **Atmosferske "probe", reaktorski v i Pontecorvov proces (1946.)**

$$\nu + {}^{37}Cl \longrightarrow {}^{37}Ar + e^-$$

– **Alvarez s reaktorskim (1949)**

-**četvrt stoljeća Davisova radiokemijskog pokusa (ekstrahirano 2000 atoma Ar); Raymond Davis i M. Koshiba podijelili Nobelovu nagradu iz fizike za 2002. za detekciju neutrina**

Još u 50-tim nije jasno da $\nu \neq \bar{\nu}$

inverse-β , Bethe & Peierls

impossible tusk

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

done by Reines & Cowan

the 1st neutrino observation

reactor $\bar{\nu}_e$ flux 10^{12}-10^{13} $\bar{\nu}$/cm^2.sec (1953 – 1956)

½ of the Nobel award for physics

1995

*) the free neutron decay ($\tau_n \simeq 925$ sec)

first observation in a reactor expt's (1948)

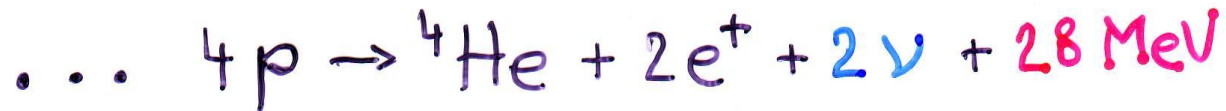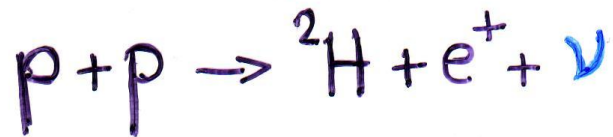$$\mathcal{H}_{eff} = \frac{G_\beta}{\sqrt{2}} J^{weak} \cdot J^{weak} \quad ; \quad \boxed{G_\beta = 1.136 \cdot 10^{-5} \; GeV^{-2}}$$

NOVA SILA, ODGOVORNA ZA PRETVORBU ELEMENATA

- **Izvor Sunčeve energije – pretvorba vodika u helij**

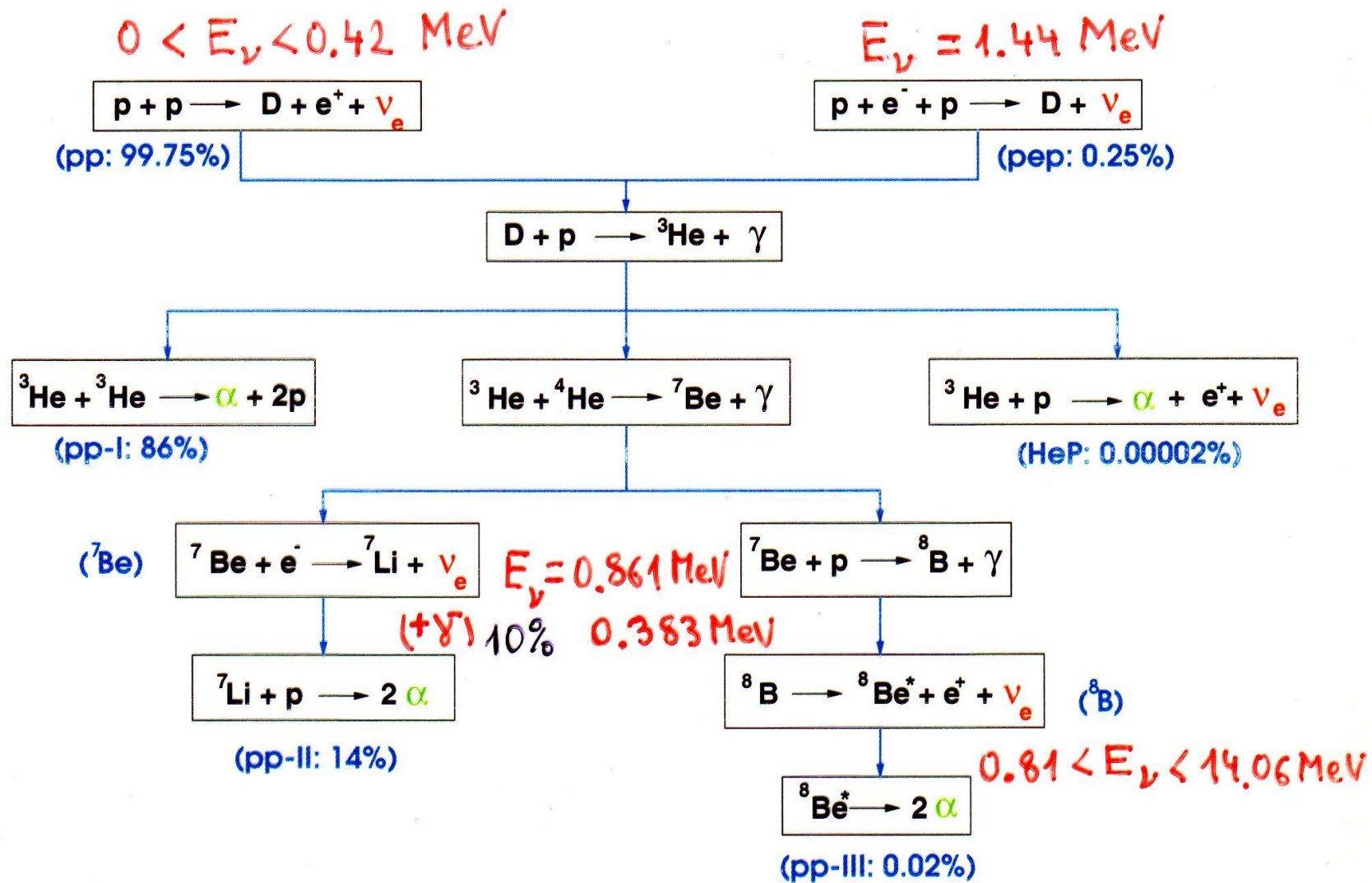- **Iza toga stoje procesi pretvorbe jedne elementarne čestice u drugu**
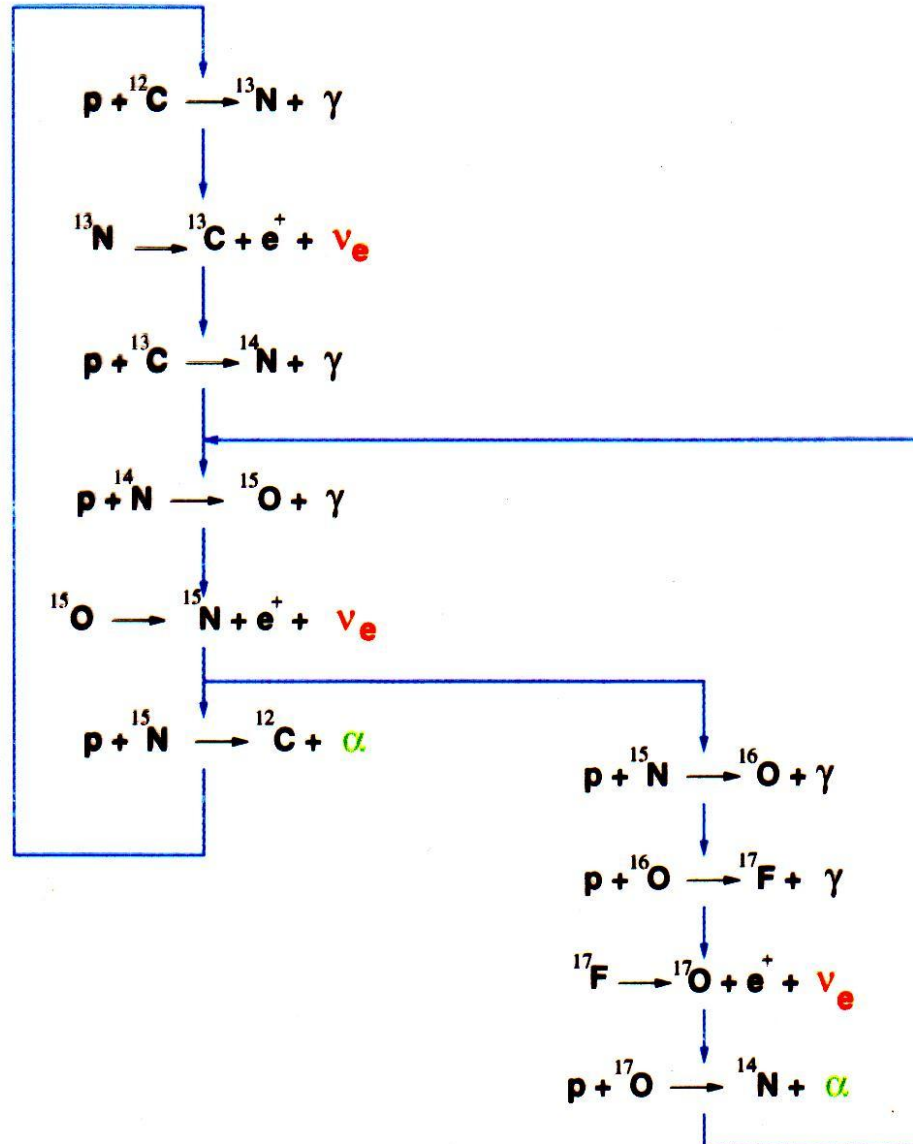
◊ "Alkemija" u Suncu

PPI lanac $\quad p + p \rightarrow {}^2H + e^+ + \nu$

$\ldots \quad 4p \rightarrow {}^4He + 2e^+ + 2\nu + 28\,MeV$

$6 \cdot 10^{14}\,J$ fuzijom $1kg$ vodika

Sunčev pp lanac

$$0 < E_\nu < 0.42 \text{ MeV}$$

$$E_\nu = 1.44 \text{ MeV}$$

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

$$p + e^- + p \longrightarrow D + \nu_e$$

(pp: 99.75%)

(pep: 0.25%)

$$D + p \longrightarrow {}^3He + \gamma$$

$${}^3He + {}^3He \longrightarrow \alpha + 2p$$

$${}^3He + {}^4He \longrightarrow {}^7Be + \gamma$$

$${}^3He + p \longrightarrow \alpha + e^+ + \nu_e$$

(pp-I: 86%)

(HeP: 0.00002%)

$$({}^7Be) \quad {}^7Be + e^- \longrightarrow {}^7Li + \nu_e$$

$$E_\nu = 0.861 \text{ MeV}$$

$${}^7Be + p \longrightarrow {}^8B + \gamma$$

(+γ) 10%   0.383 MeV

$${}^7Li + p \longrightarrow 2\alpha$$

$${}^8B \longrightarrow {}^8Be^* + e^+ + \nu_e \quad ({}^8B)$$

(pp-II: 14%)

$$0.81 < E_\nu < 14.06 \text{ MeV}$$

$${}^8Be^* \longrightarrow 2\alpha$$

(pp-III: 0.02%)

Sunčev CNO lanac

$$p + {}^{12}C \longrightarrow {}^{13}N + \gamma$$

$${}^{13}N \longrightarrow {}^{13}C + e^+ + \nu_e$$

$$p + {}^{13}C \longrightarrow {}^{14}N + \gamma$$

$$p + {}^{14}N \longrightarrow {}^{15}O + \gamma$$

$${}^{15}O \longrightarrow {}^{15}N + e^+ + \nu_e$$

$$p + {}^{15}N \longrightarrow {}^{12}C + \alpha$$

$$p + {}^{15}N \longrightarrow {}^{16}O + \gamma$$

$$p + {}^{16}O \longrightarrow {}^{17}F + \gamma$$

$${}^{17}F \longrightarrow {}^{17}O + e^+ + \nu_e$$

$$p + {}^{17}O \longrightarrow {}^{14}N + \alpha$$

Tokovi Sunčevih neutrina pp lanca u ovisnosti o energiji neutrina
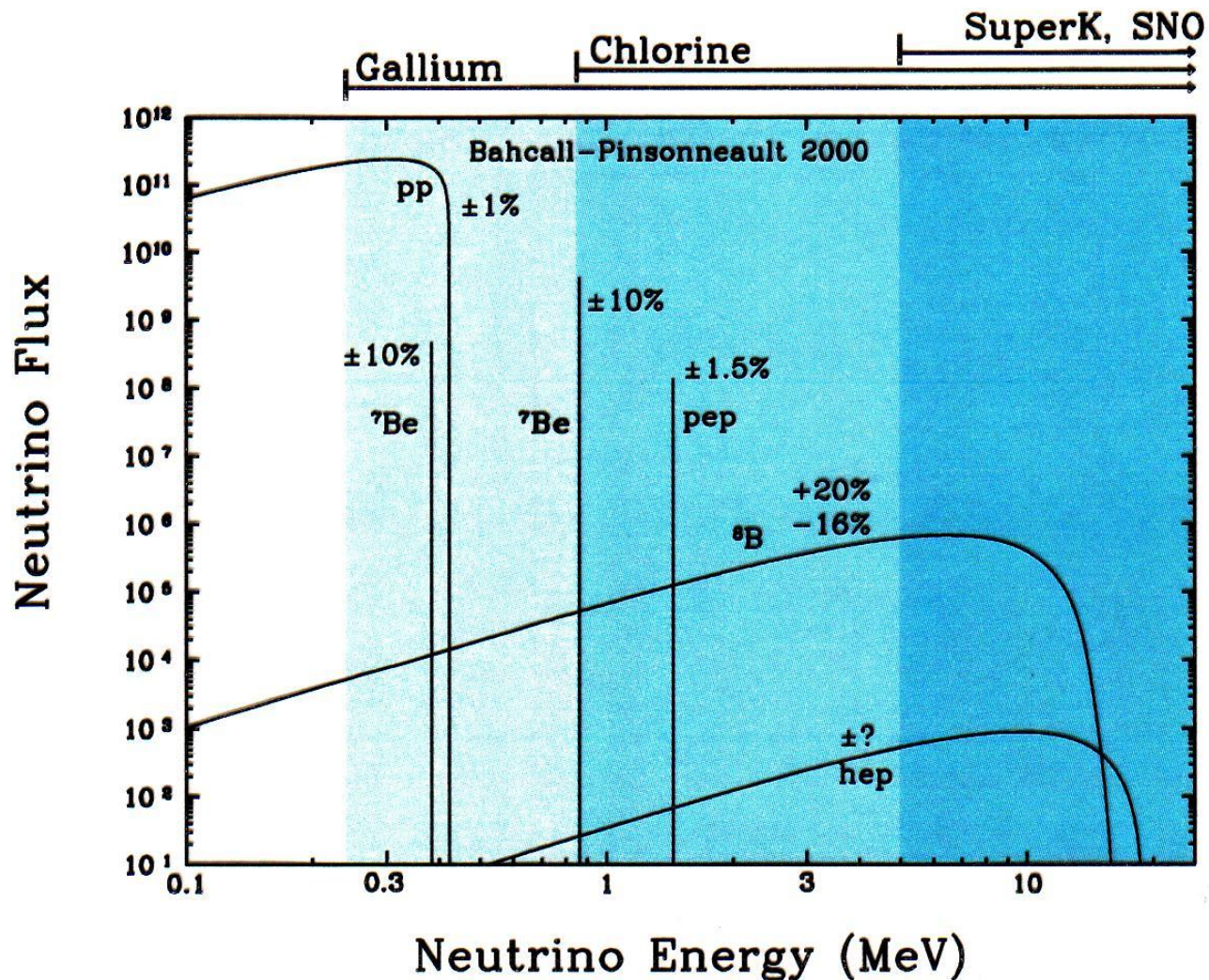
Točke produkcije neutrina pp lanca
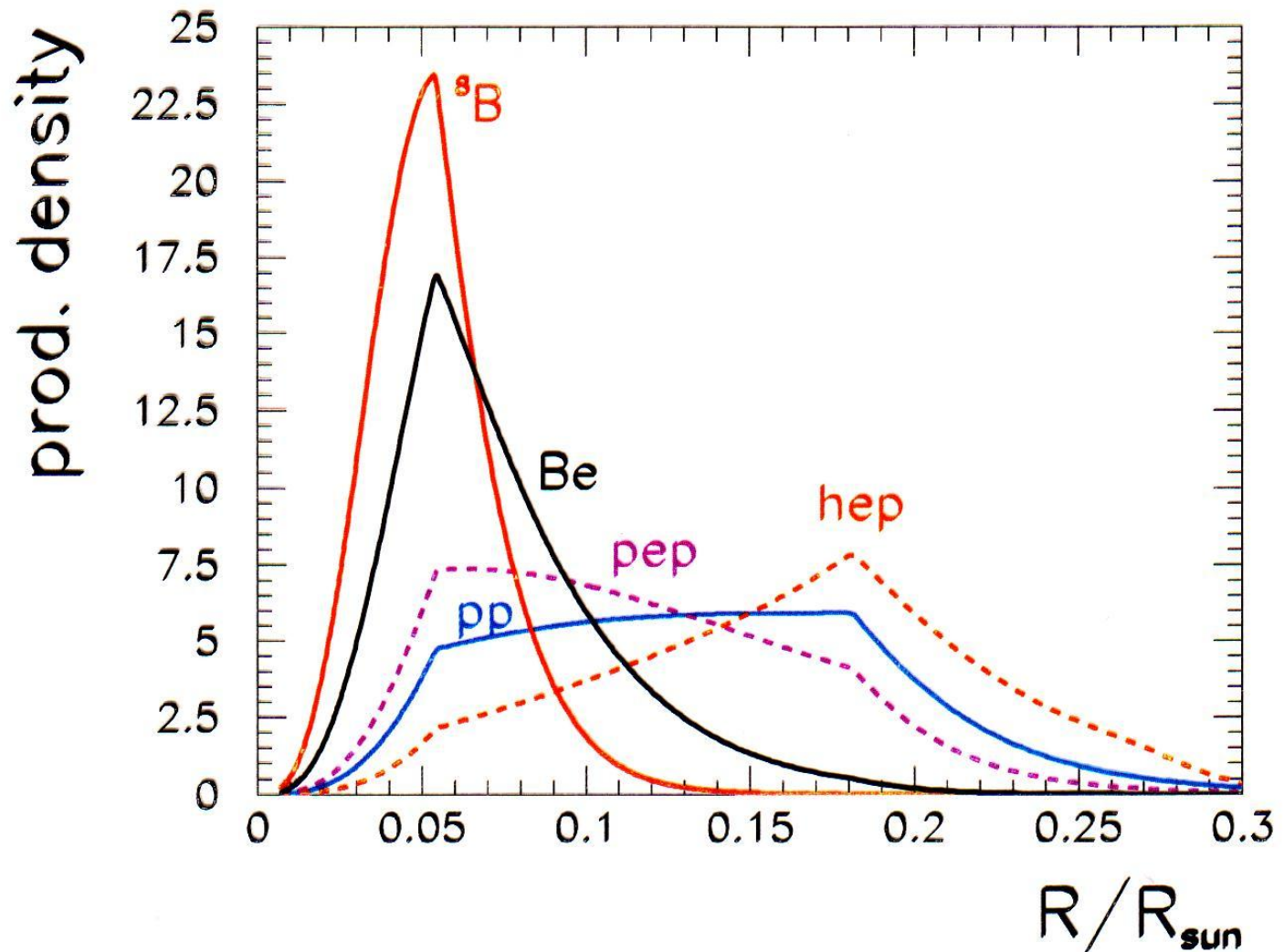
Izborna pravila Fermijeve "struja x struja" teorije

$$^{14}O \rightarrow {}^{14}N^* + e^+ + \nu_e$$

$$p\uparrow \rightarrow n\uparrow + e^+\uparrow + \nu_e\downarrow$$

$$p\uparrow \rightarrow n\downarrow$$
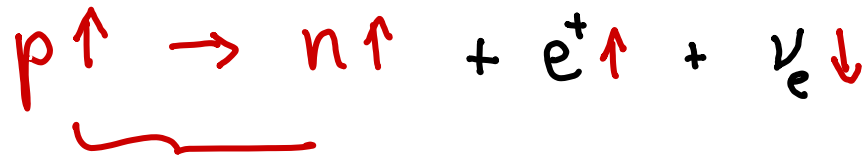
F-prij. $\Delta J = 0$

____ usp. G-T $\Delta J = 1$

Spinski multiplicitet $M_F^2 = 1$

$\Delta J = 1$

$$M_{GT}^2 = 3$$

Iz mjerenog života $\tau \simeq 3100\,s$

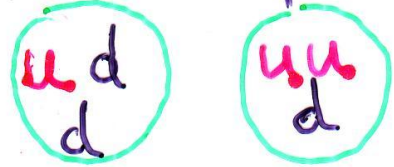$\Rightarrow \Gamma = 1.16 \cdot 10^{-5}\ GeV^{-2}$

Od STRUJAxSTRUJA do IVB

◊ Prirodna ($\beta^{\pm}$) radioaktivnost

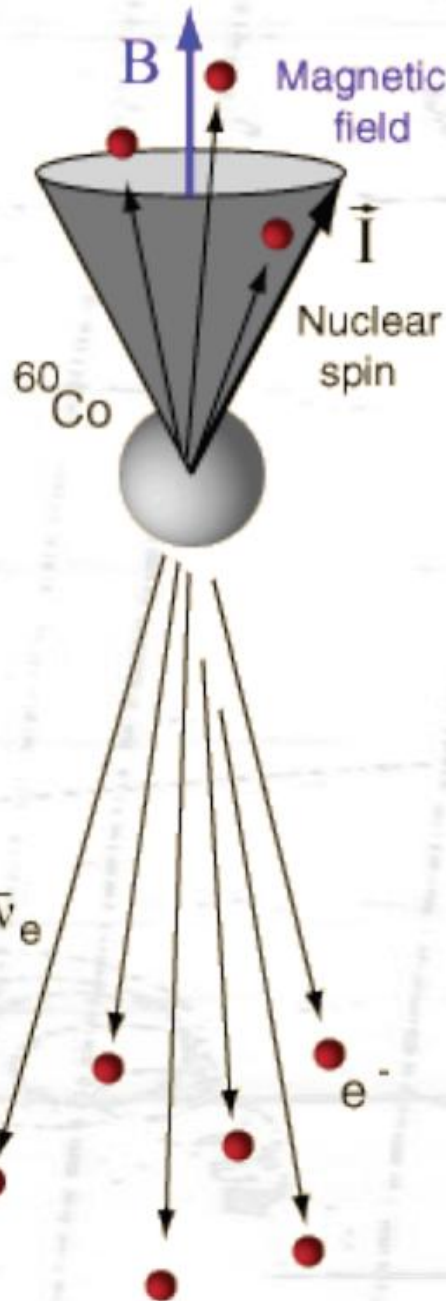reducirana na $n \rightarrow p + e^- + \nu$

G_F
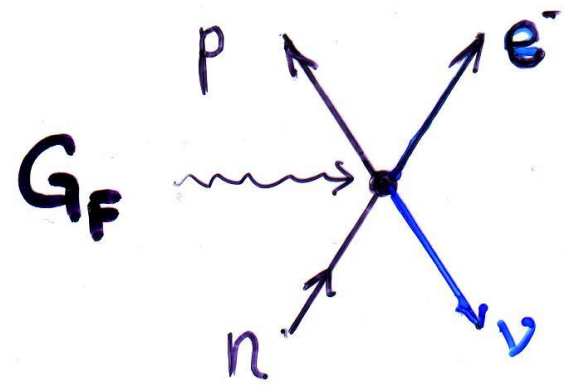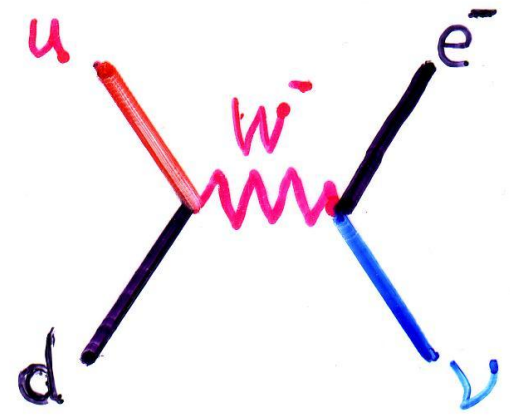
JAKA
SILA
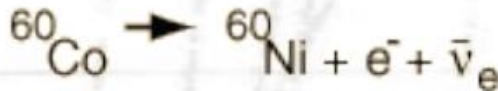
QCD

$SU(3)_c$

Beta emission is preferentially in the direction opposite the nuclear spin, in violation of conservation of parity.

Wu, 1957

$^{60}Co \rightarrow {}^{60}Ni + e^- + \bar{\nu}_e$

B — Magnetic field

^{60}Co

$\vec{I}$ — Nuclear spin

e^-

Prvo mjerenje neočuvanja pariteta u slabim raspadima (C.S. Wu, 1957)

arXiv:hep-ph/0605017

"··· One day in the early Spring of 1956, Professor T. D. Lee came up to my little office on the thirteenth floor of Pupin Physical Laboratories. He explained to me, first, the τ-θ puzzle. If the answer to the τ-θ puzzle is violation of parity–he went on–then the violation should also be observed in the space distribution of the beta-decay of polarized nuclei: one must measure the pseudo-scalar quantity $< \sigma \cdot \mathbf{p} >$ where $\mathbf{p}$ is the electron momentum and σ the spin of the nucleus.

··· Following Professor Lee's visit, I began to think things through. This was a golden opportunity for a beta-decay physicist to perform a crucial test, and how could I let it pass? ··· That Spring, my husband, Chia-Liu Yuan, and I had planned to attend a conference in Geneva and then proceed to the Far East. Both of us had left China in 1936, exactly twenty years earlier. Our passages were booked on the Queen Elizabeth before I suddenly realized that I had to do the experiment immediately, before the rest of the Physics Community recognized the importance of this experiment and did it first. So I asked Chia-Liu to let me stay and go without me.
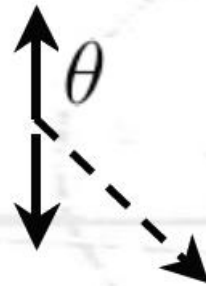
Wu je mjerila smjerove emitiranih elektrona (anti-neutrini su desni)
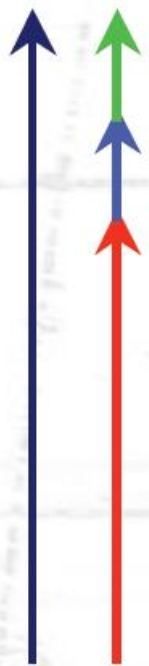
$$m_{\bar{\nu}_e} = \frac{1}{2}$$

$$m_{e^-} = \frac{1}{2}$$
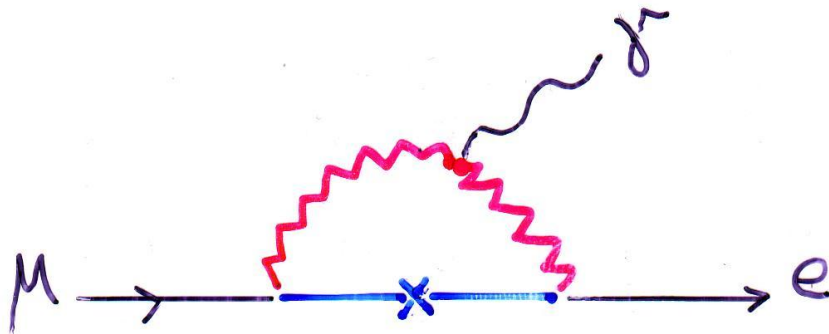
$$J = 4$$

$$I(\theta) \propto 1 - \cos\theta$$

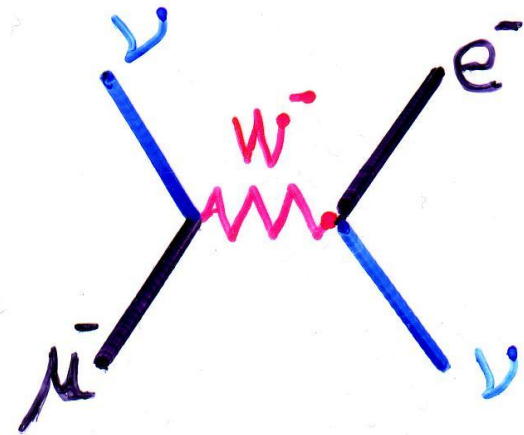Electron:
Left-handed

Preferred direction: Parity violation!

5

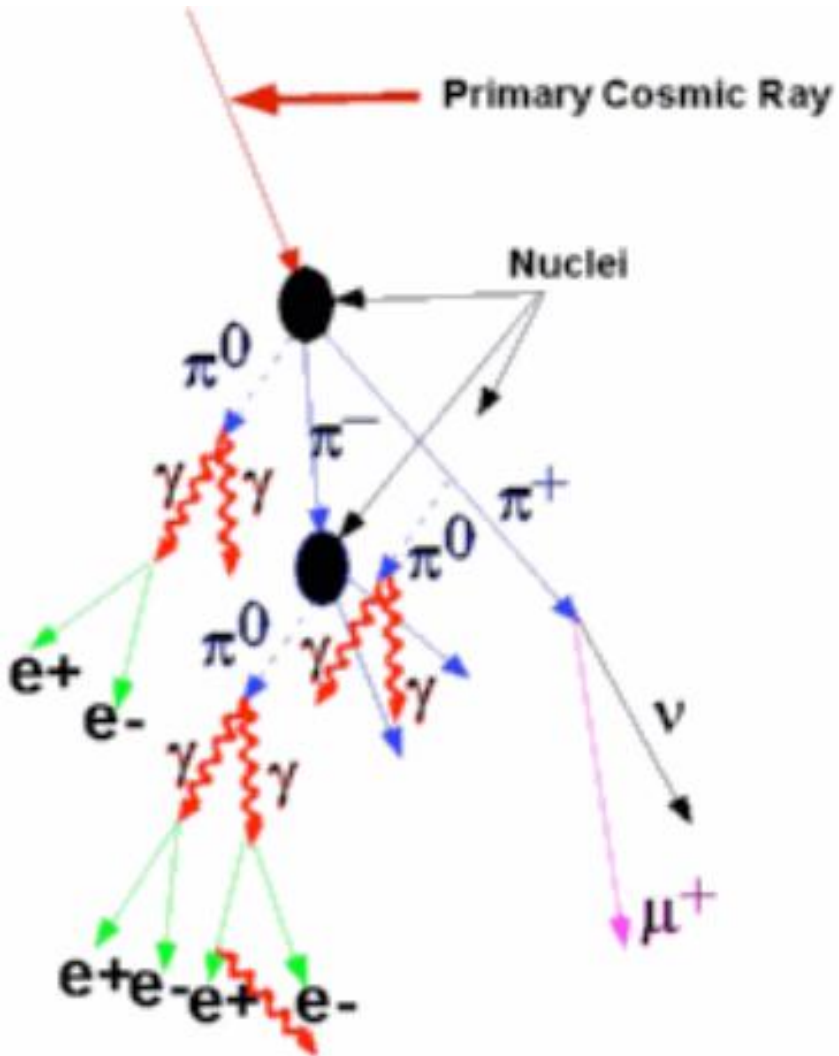# Slabi procesi ostalih elementarnih čestica

◊ B-raspad miona

$$\mu^- \rightarrow e^- + \nu + \nu$$

$$\nu_\mu \neq \nu_e \quad \text{objašnjenje neopažanja!}$$

Potvrda STR u raspadu miona

Primary Cosmic Ray

Nuclei

π^0

π^-

π^0 π^+

γ γ

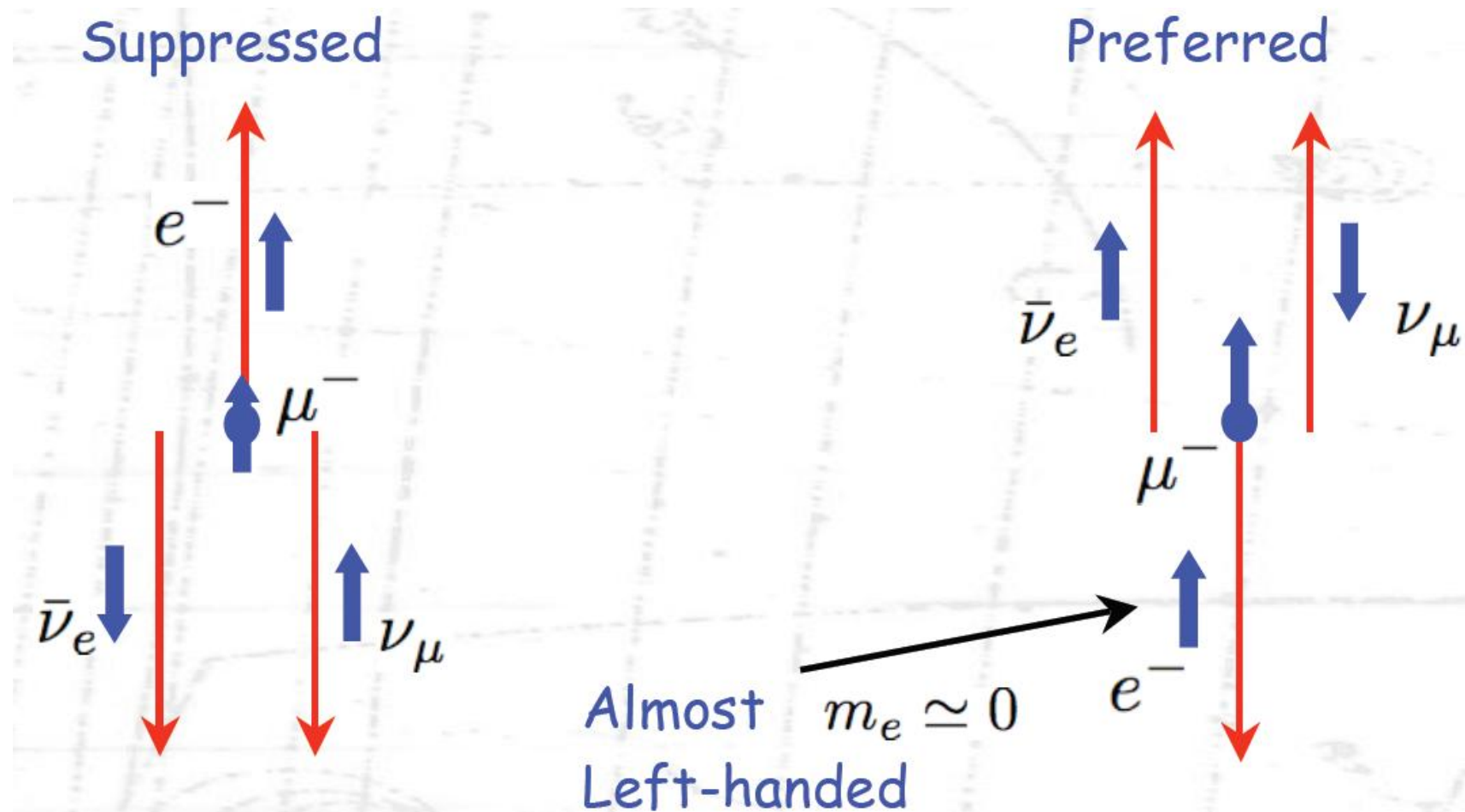π^0 γ

γ

e+

e-

γ γ

ν

μ^+

e+ e- e+ e-

- Usp. uz Einstein 1905-2005

L. Lederman, "How we violated parity", p.256 , God particle;

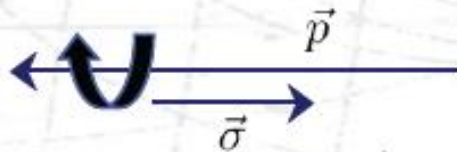**Iz kutne raspodjele elektrona može se odrediti omjer V i A doprinosa**

HELICITET i KIRALNOST

Helicity

- **Definition:** $h = \dfrac{\vec{\sigma} \cdot \vec{p}}{|\vec{p}|}$

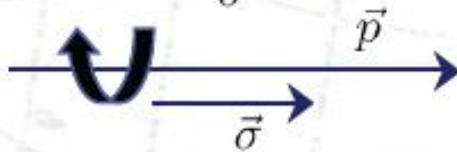- **Helicity**   **+1:**   Right-handed particle

- **Helicity**   **-1:**   Left-handed particle

- Recall: All neutrinos are left-handed and all anti-neutrinos are right-handed!

- How can we pick out the left and right-handed components of a Dirac spinor?

$$m = 0 (E \gg mc^2)$$

$$\gamma^5 u(p) = (\hat{p} \cdot \Sigma) u(p)$$

$$\gamma^5 \equiv i\gamma^0 \gamma^1 \gamma^2 \gamma^3 = \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}$$

Helicity (h=+1 or h=-1)

$$S = \frac{\hbar}{2} \begin{pmatrix} \sigma & 0 \\ 0 & \sigma \end{pmatrix} = \frac{\Sigma \hbar}{2} \qquad \Sigma \equiv \begin{pmatrix} \sigma & 0 \\ 0 & \sigma \end{pmatrix} \qquad \frac{1}{2}(1 - \gamma^5) u(p) = \begin{cases} 0 & \text{for } h = +1 \ \ R \\ u(p) & \text{for } h = -1 \ \ L \end{cases}$$

LAGRANGIAN ZA SPECIFIČNA STANJA HELICITETA

With projection of left-handed states:

$$u_L(p) = \frac{(1 - \gamma^5)}{2} u(p)$$

Helicity -1

Lagrangian separated into left-handed and right-handed coupling:

$$\mathcal{L} = (\bar{\nu}_{e_L}, \bar{e}_L)(i\gamma^\mu \partial_\mu)\begin{pmatrix} \nu_{e_L} \\ e_L \end{pmatrix} + \bar{e}_R i\gamma^\mu \partial_\mu e_R$$

Lagrangian of free Dirac fields in terms of helicity states for neutrinos and electrons (m=0)

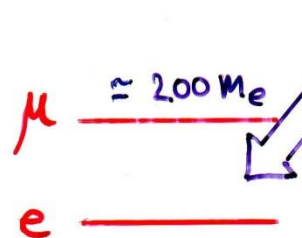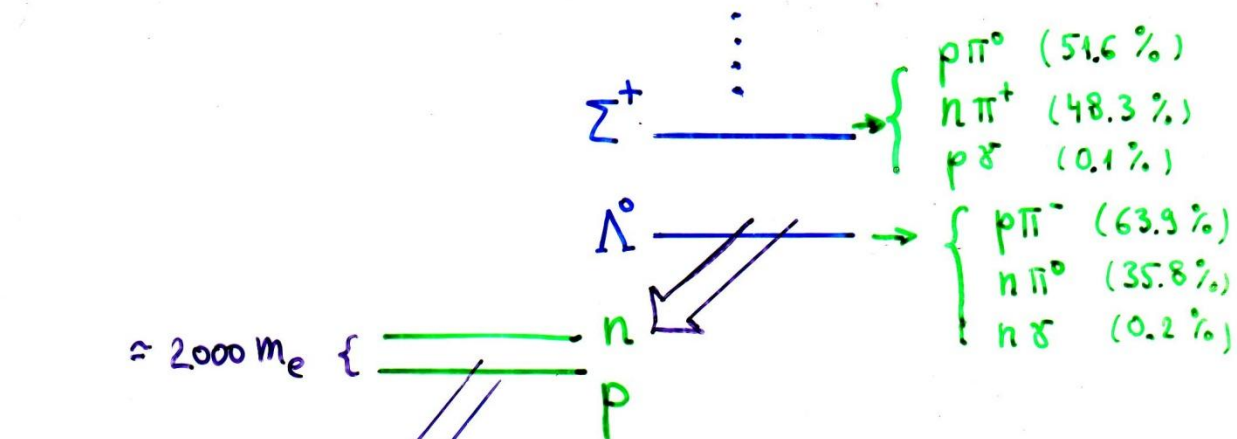Nobel prizes in physics since 1957 related to the Standard Model

Year	Recipient(s)	Subject
1957	T. D. Lee and C. N. Yang	Parity violation
1960	D. A. Glaser	Bubble chamber
1965	R. P. Feynman, J. S. Schwinger, and S. I. Tomonaga	Quantum electrodynamics
1968	L. W. Alvarez	Discovery of resonances
1969	M. Gell-Mann	Particle classification
1976	B. Richter and S. C. C. Ting	J/ψ discovery
1979	S. L. Glashow, A. Salam, and S. Weinberg	Electroweak unification
1980	J. W. Cronin and V. L. Fitch	CP violation
1982	K. G. Wilson	Critical phenomena
1984	C. Rubbia and S. Van Der Meer	W and Z discovery via $S\bar{p}pS$ collider
1988	L. M. Lederman, M. Schwartz, and J. Steinberger	Discovery that $\nu_\mu \neq \nu_e$
1990	J. I. Friedman, H. W. Kendall, and R. E. Taylor	Deep inelastic electron scattering
1992	G. Charpak	Particle detectors
1995	M. L. Perl	τ lepton
	F. Reines	Neutrino detection
1999	G. 't Hooft and M. J. G. Veltman	Electroweak interactions
2002	R. Davis M. Koshiba	Cosmic neutrino detection

Koji su raspadi mogući?

$\tau \underline{\quad 1777 \simeq 2\,m_p \quad}$

$\Sigma^+ \longrightarrow$
$\begin{cases} p\,\pi^0 & (51.6\,\%) \\ n\,\pi^+ & (48.3\,\%) \\ p\,\gamma & (0.1\,\%) \end{cases}$

$\Lambda^0 \longrightarrow$
$\begin{cases} p\,\pi^- & (63.9\,\%) \\ n\,\pi^0 & (35.8\,\%) \\ n\,\gamma & (0.2\,\%) \end{cases}$

$\simeq 2000\,m_e \begin{cases} \\ \end{cases}$ n p

$\simeq 200\,m_e$ μ

?

e

$p \not\to e^+ \gamma$ Reines '54
E.P. PLB112('82)59

$p \not\to e^+ \pi^0$ ...   GUT's

$\boxed{B \text{ conservation}}$

$\mu \not\to e\gamma \;\Rightarrow\; \boxed{L_e, L_\mu \text{ conserv.}}$