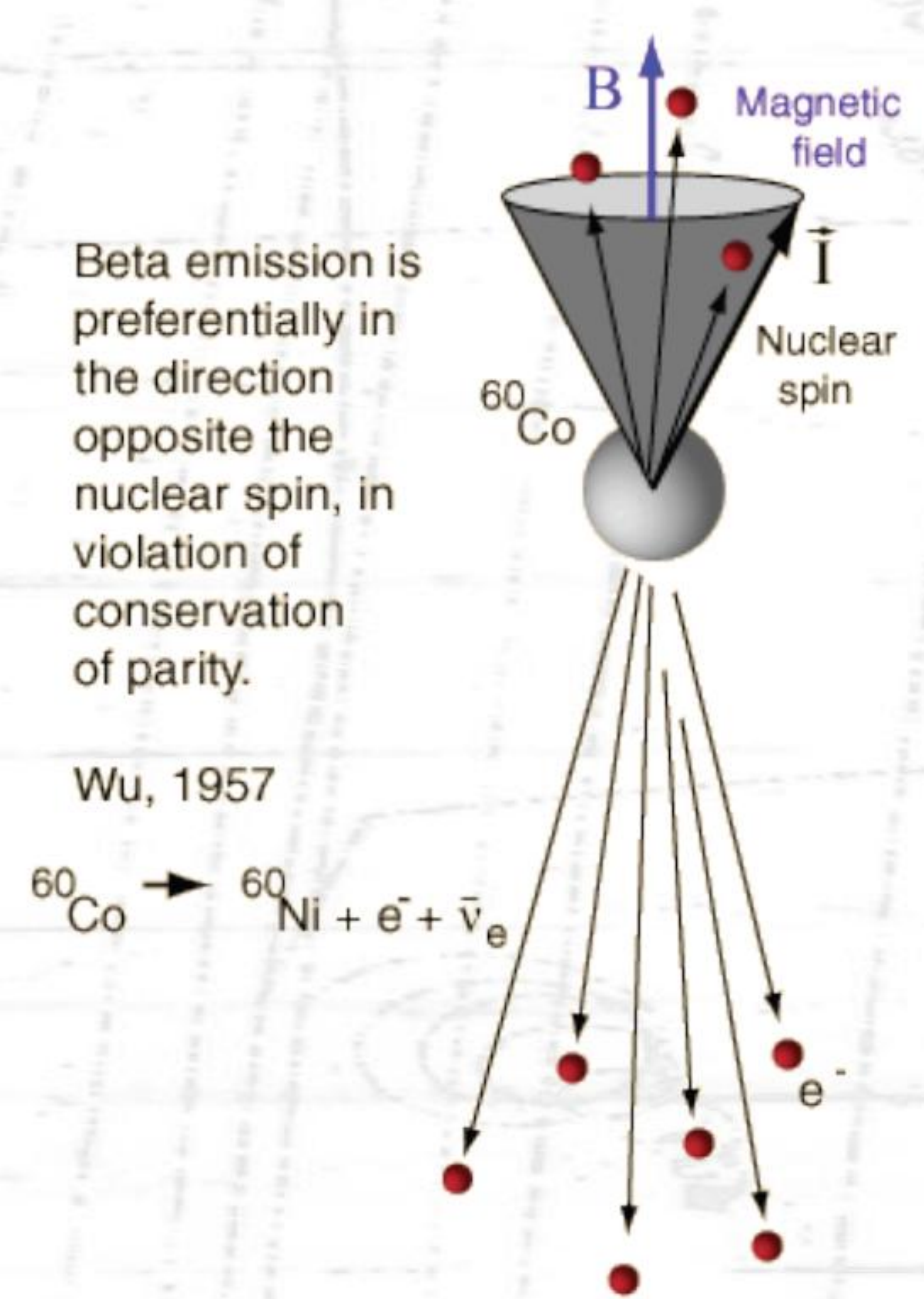
VII. Slabi procesi (II)

RASPAD MIONA – USPOREDBA SA SEMILEPTONSKIM RASPADIMA

- RASPAD MIONA
- BETA RASPADI MEZONA
- RASPAD TAUONA



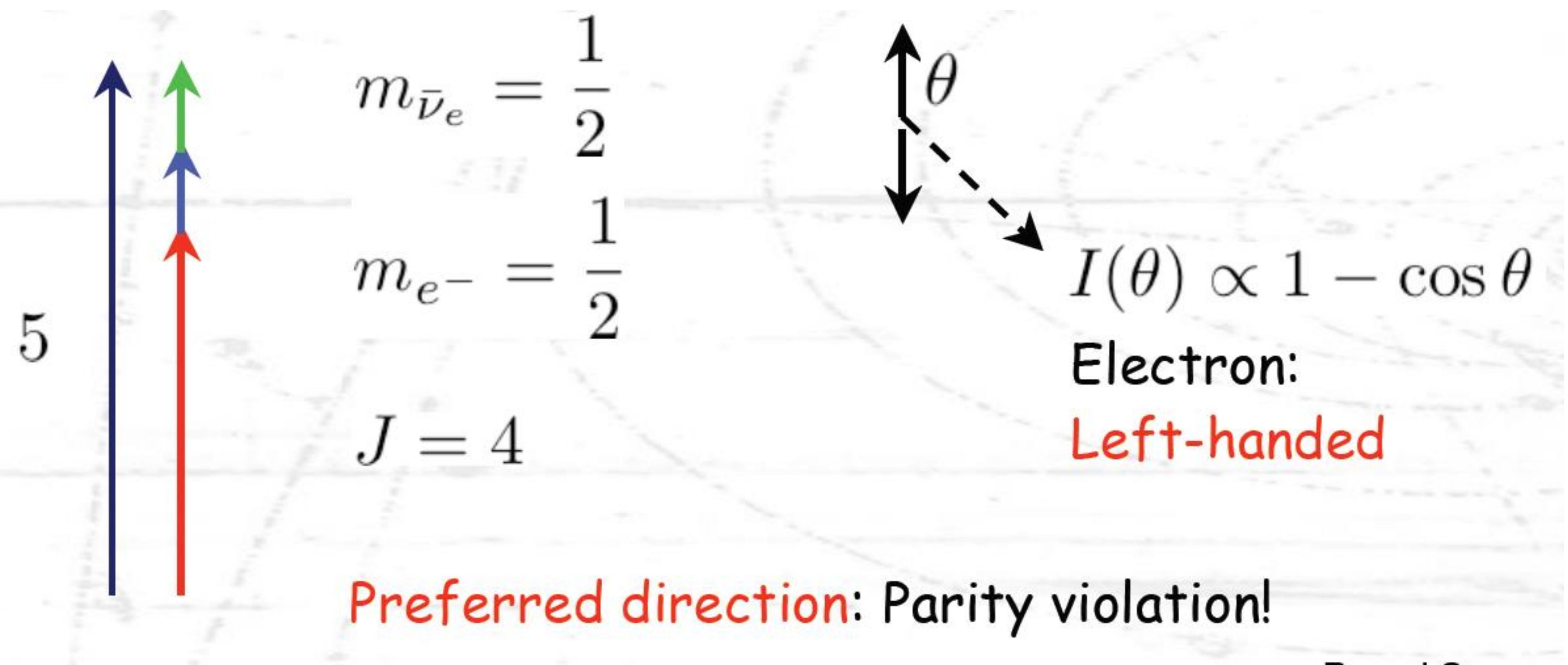
Prvo mjerenje neočuvanja pariteta u slabim raspadima (C.S. Wu, 1957)

arXiv:hep-ph/0605017

"$\cdots$ 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.

$\cdots$ 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? $\cdots$ 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.

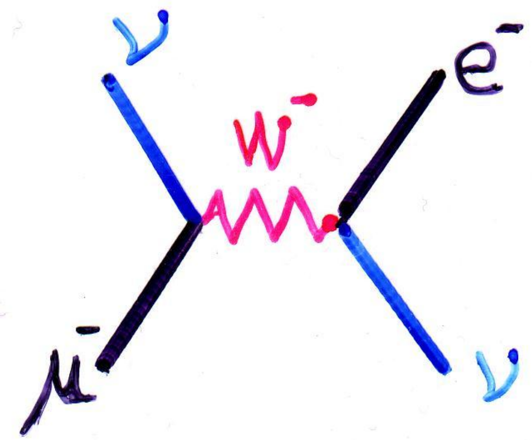
Wu je mjerila smjerove emitiranih elektrona (anti-neutrini su desni)

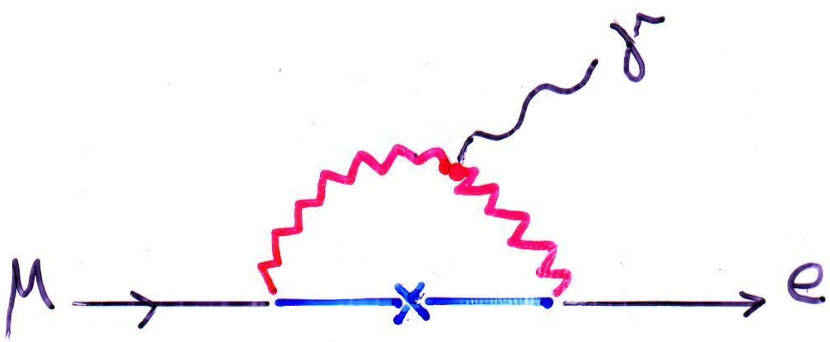


Slabi procesi ostalih elementarnih čestica

- β-raspad miona

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

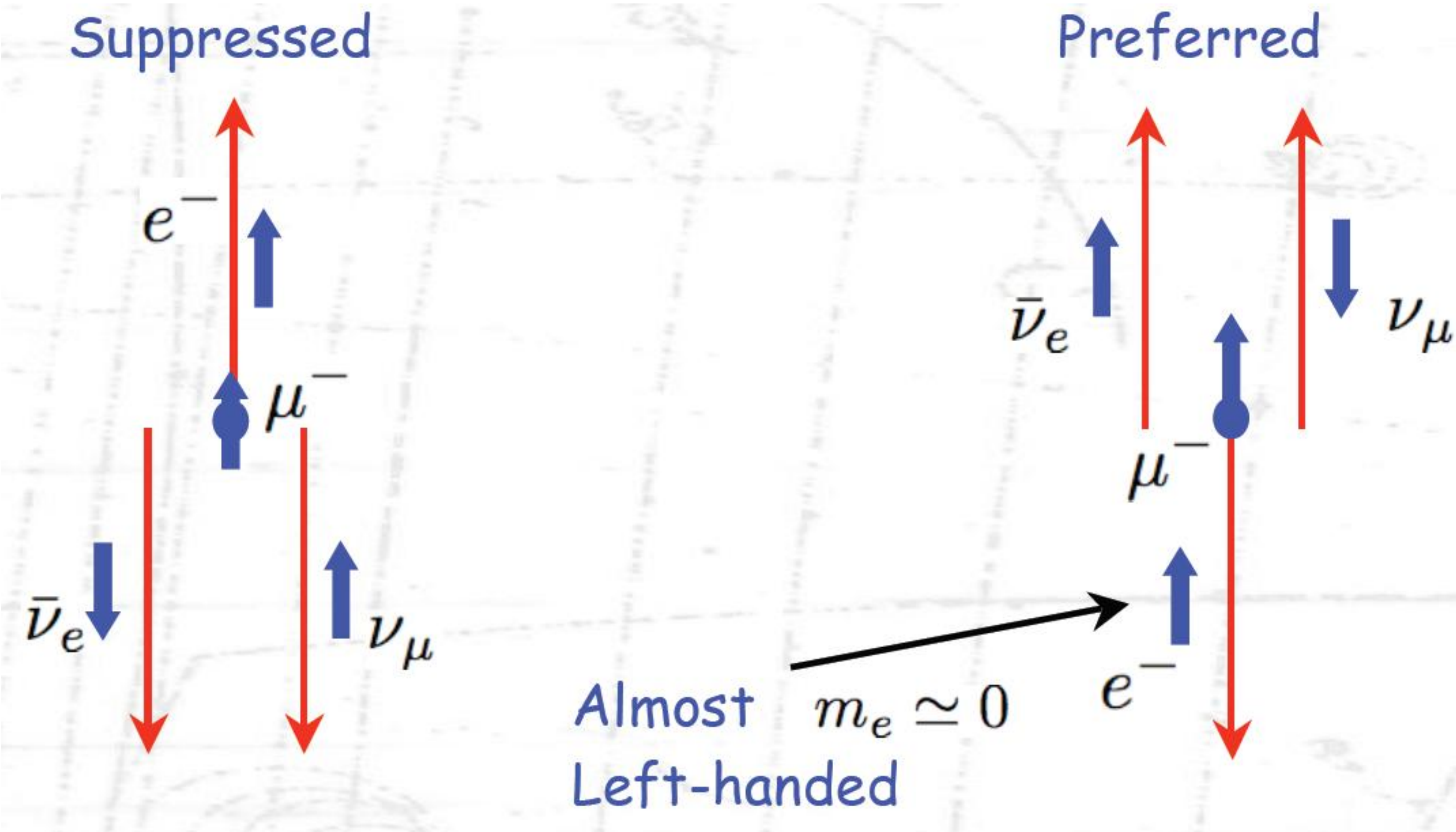




$\nu_\mu \neq \nu_e$ objašnjenje neopažanja!

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

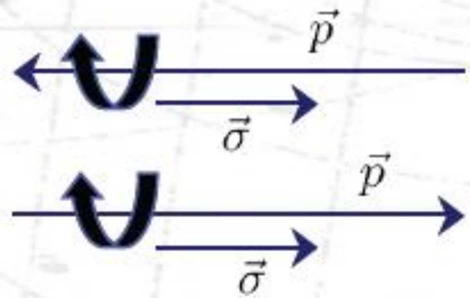
Iz kutne raspodjele elektrona može se odrediti omjer V i A doprinosa



HELICITET i KIRALNOST

Helicity

- Definition: $h = \frac{\vec{\sigma} \cdot \vec{p}}{|\vec{p}|}$
- 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?

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

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

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

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

$$S = \frac{\hbar}{2} \begin{pmatrix} \sigma & 0 \\ 0 & \sigma \end{pmatrix} = \frac{\Sigma\hbar}{2} \qquad \Sigma \equiv \begin{pmatrix} \sigma & 0 \\ 0 & \sigma \end{pmatrix}$$

$$\frac{1}{2}(1 - \gamma^5) u(p) = \begin{cases} 0 & \text{for } h = +1 \;\; R \\ u(p) & \text{for } h = -1 \;\; L \end{cases}$$

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:

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

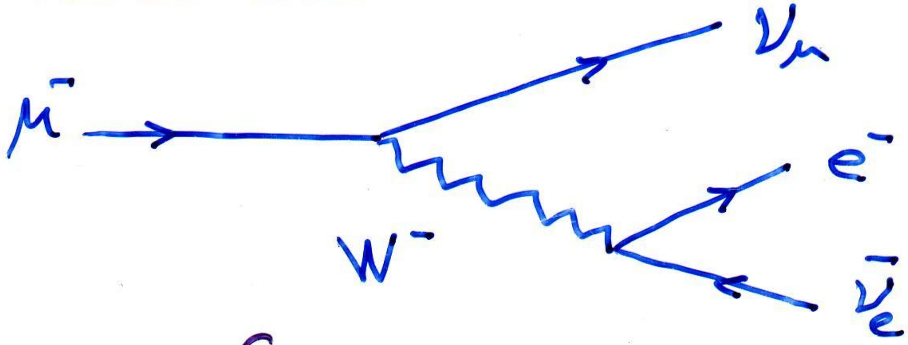
Lagrangian of free Dirac fields in terms of helicity states for neutrinos and electrons (m=0)

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 $\mathrm{S}\bar{p}p\mathrm{S}$ 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

V-A TEORIJA
- MIONSKI RASPAD KAO REFERENTNI SLABI PROCES
- USPOREDBA S RASPADOM SLOBODNOG NEUTRONA

$\mu^- \to e^- \bar{\nu}_e \nu_\mu$ - decay diagram:



$$\tau_\mu \simeq 2.197 \cdot 10^{-6}\,\mathrm{s}$$

$$\Downarrow$$

$$G_\mu = 1.16639(2) \cdot 10^{-5}\,\mathrm{GeV}^{-2} \equiv G_F \simeq (293\,\mathrm{GeV})^{-2}$$

$$\mathcal{H}_{eff} = \frac{G_F}{\sqrt{2}} \left[\bar{\nu}_\mu \gamma^\alpha (1-\gamma_5)\mu\right]\left[\bar{e}\gamma_\alpha(1-\gamma_5)\nu_e\right]$$

Mjereni spektar pozitrona

$$\frac{d\Gamma}{d\varepsilon} = \frac{G_F^2}{96\pi^3} m_\mu^5 \times (3-2\varepsilon)\varepsilon^2$$

$$\varepsilon = \frac{E}{E_{max}} \; ; \; \int_0^1 d\varepsilon \Rightarrow$$

$$\Gamma = \frac{G_F^2 m_\mu^5}{192\pi^3}$$

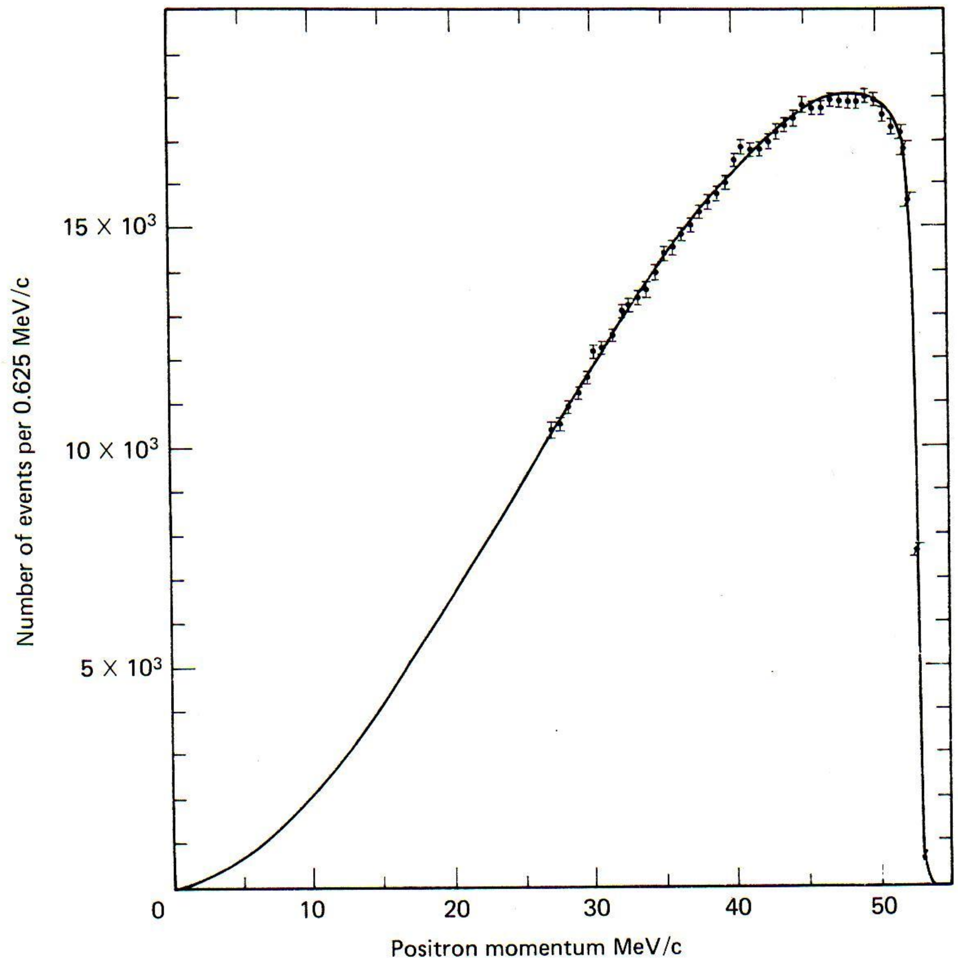


Figure 10.1 Experimental spectrum of positrons in $\mu^+ \to e^+ + \nu_e + \nu_\mu$. The solid line is the theoretically predicted spectrum based on equation (10.35), corrected for electromagnetic effects. (*Source:* M. Bardon et al., *Phys. Rev. Lett.* **14**, 449 (1965).)

Usporedba s izmjenom W-bozona

$$M_{fi} = [\frac{g_W}{\sqrt{2}}\overline{\psi}\frac{1}{2}\gamma^{\mu}(1-\gamma^5)\psi]\frac{g_{\mu\nu}-q_{\mu}q_{\nu}/m_W^2}{q^2-m_W^2}[\frac{g_W}{\sqrt{2}}\overline{\psi}\frac{1}{2}\gamma^{\nu}(1-\gamma^5)\psi]$$

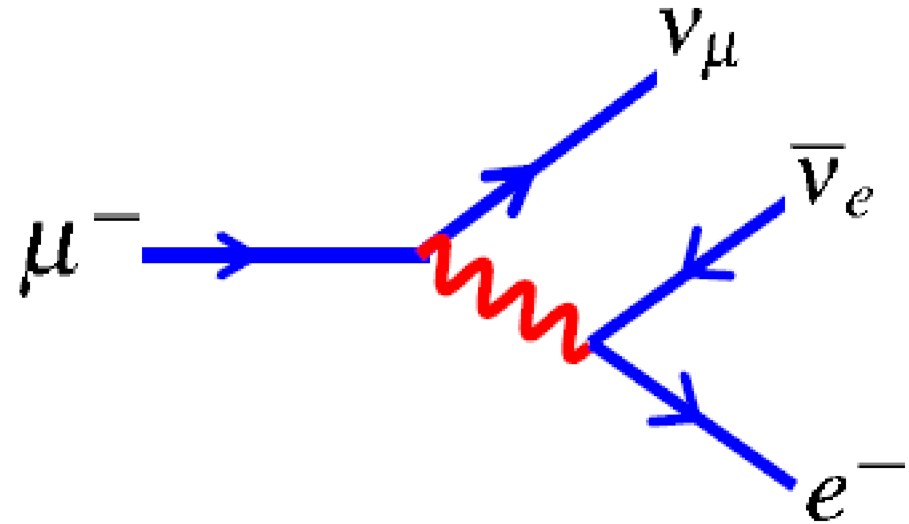
which for $q^2 \ll m_W^2$ becomes:

$$M_{fi} = \frac{g_W^2}{8m_W^2}g_{\mu\nu}[\overline{\psi}\gamma^{\mu}(1-\gamma^5)\psi][\overline{\psi}\frac{1}{2}\gamma^{\nu}(1-\gamma^5)\psi]$$

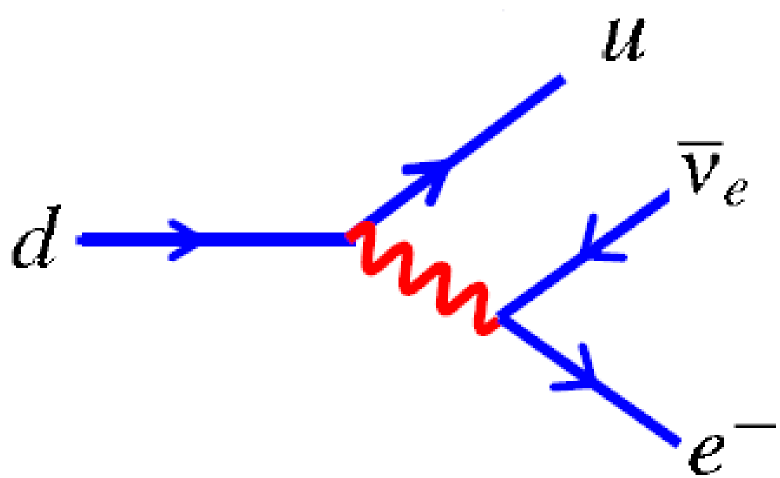
$$\Rightarrow \boxed{\frac{G_F}{\sqrt{2}} = \frac{g_W^2}{8m_W^2}}$$

$$m_W = 80.403 \pm 0.029\,\mathrm{GeV}$$

$$\Rightarrow \quad \alpha_W = \frac{g_W^2}{4\pi} = \frac{8m_W^2 G_F}{4\sqrt{2}\pi} = \frac{1}{30}$$



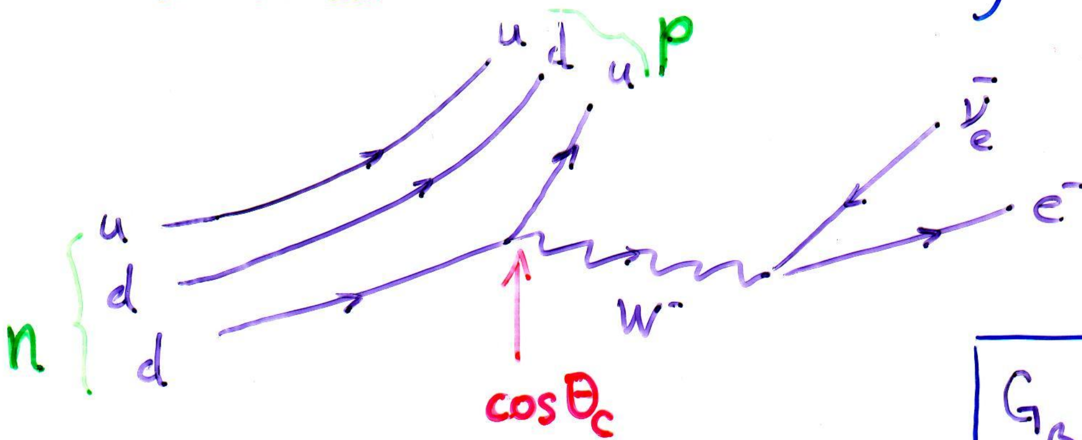
$$G_F^{\mu} = (1.16632 \pm 0.00002) \times 10^{-5}\,\mathrm{GeV}^{-2}$$



$$G_F^{\beta} = (1.136 \pm 0.003) \times 10^{-5}\,\mathrm{GeV}^{-2}$$

Pitanje univerzalnosti slabe sile

Universality of weak interactions ($G_\beta \neq G_\mu$)
achieved at the elementary level



$$\boxed{G_\beta = G_F \cos\theta_c}$$

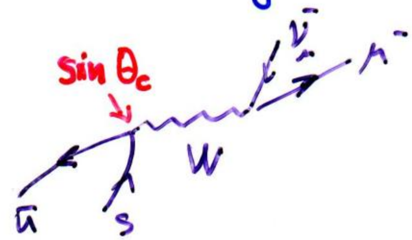
W's couple to the "Cabibbo rotated" state

$$d' = \cos\theta_c \, d + \sin\theta_c \, s$$

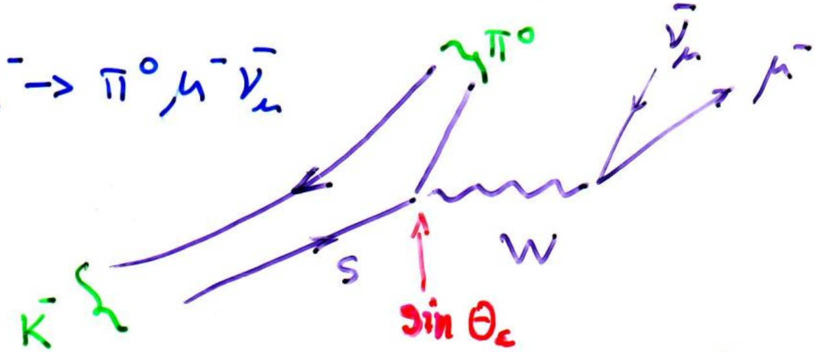
$$d' = \cos\theta_c \, d + \sin\theta_c \, s$$

- explains suppression of the strangeness-changing transitions, e.g.

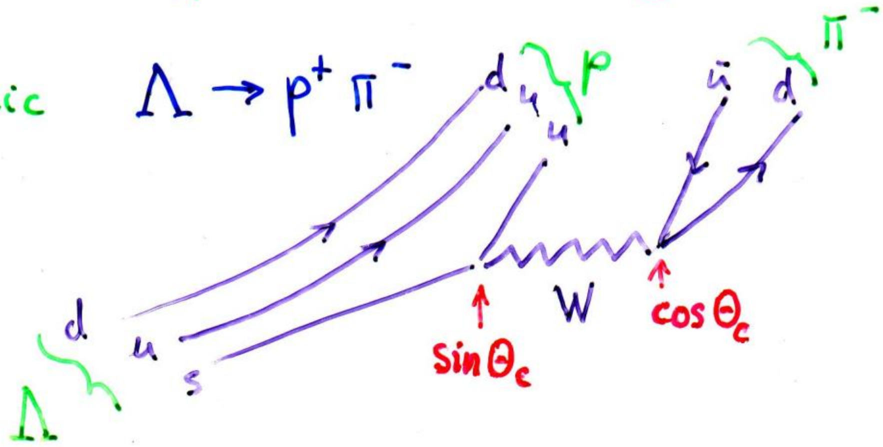
leptonic $K^-(s\bar{u}) \to \mu^- \bar{\nu}_\mu$



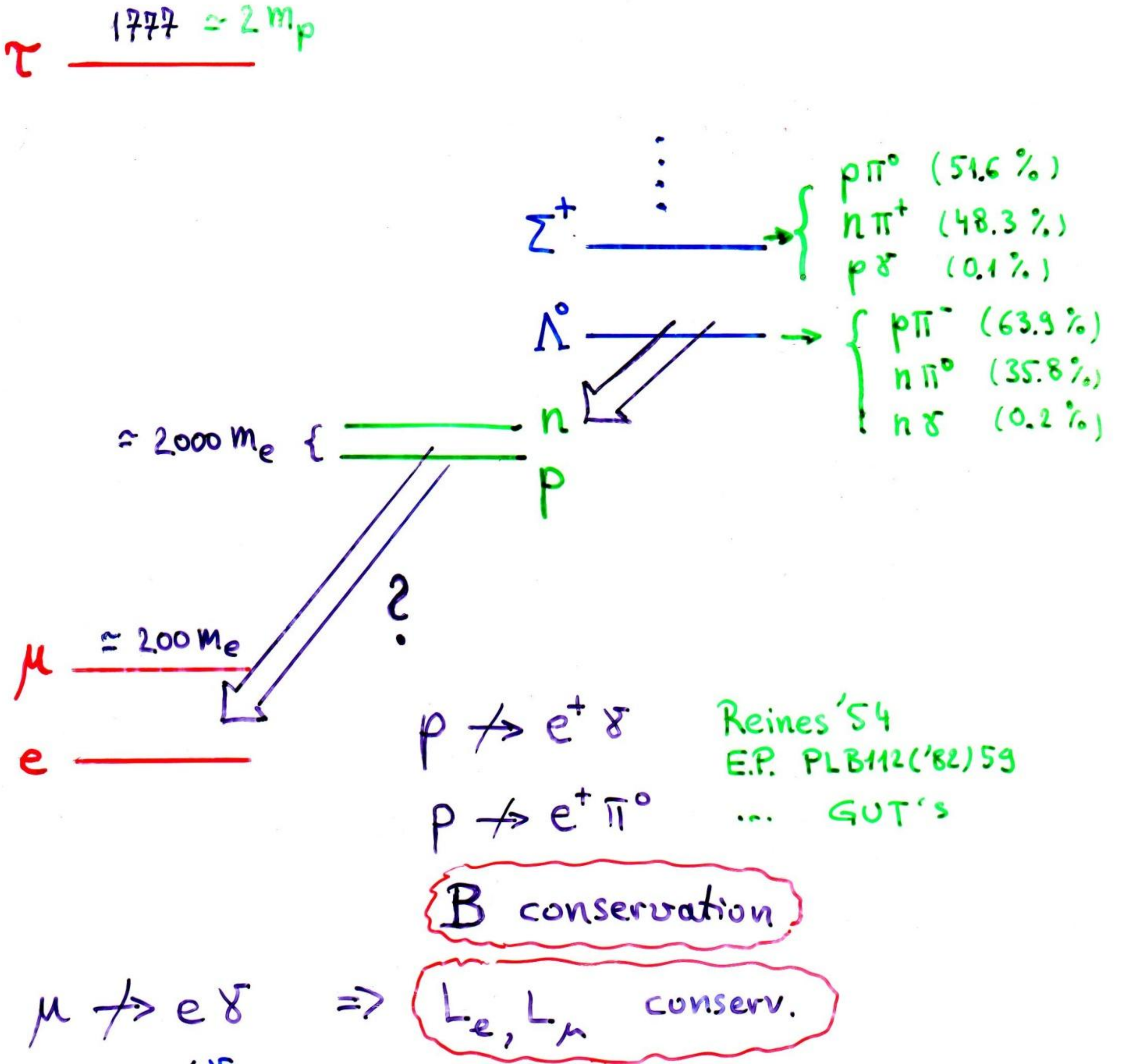
semileptonic $K^- \to \pi^0 \mu^- \bar{\nu}_\mu$



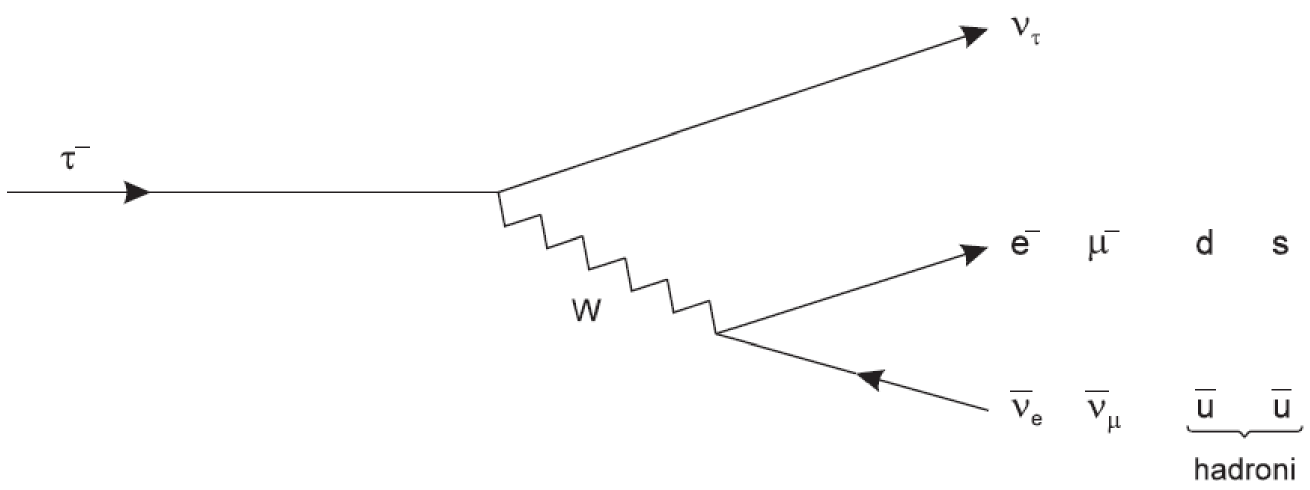
nonleptonic $\Lambda \to p^+ \pi^-$



Koji su raspadi mogući?



Raspad tau-leptona (FEČ 6.3.1)



- **Ukupna širina raspada uklj. semileptonske**

$$
\begin{aligned}
\frac{1}{\tau_\tau} \equiv \Gamma(\tau) &\approx \Gamma(\mu) \left(\frac{m_\tau}{m_\mu}\right)^5 \left\{2 + N_C \left(|V_{ud}|^2 + |V_{us}|^2\right)\right\} \\
&\approx \frac{5}{\tau_\mu} \left(\frac{m_\tau}{m_\mu}\right)^5 ,
\end{aligned}
$$

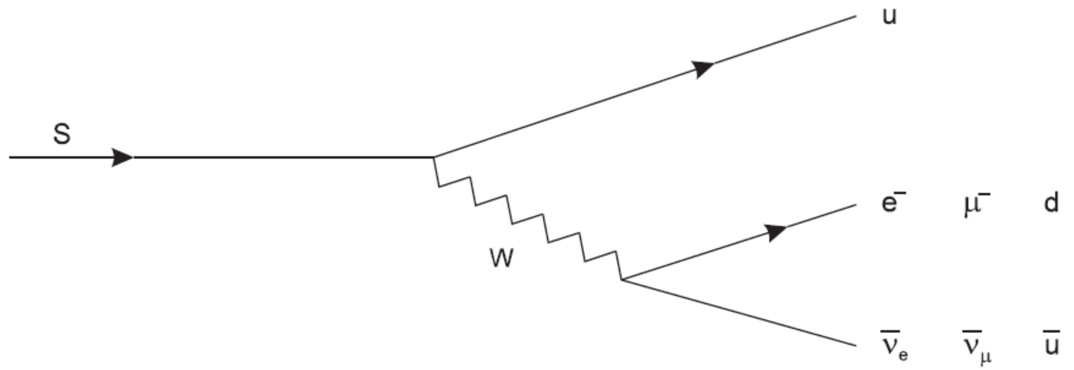
Za same leptonske raspade

$$\mathrm{Br}(\tau^- \to \nu_\tau e^- \bar{\nu}_e) \approx \frac{1}{5} = 20\%$$

- slaganje očekivanja i mjerenja je izvrsno

$$\Gamma(\tau^- \to \nu_\tau e^- \bar{\nu}_e) \approx \frac{1}{\tau_\mu}\left(\frac{m_\tau}{m_\mu}\right)^5 = 6.12 \times 10^{11}\ \mathrm{s}^{-1}$$

$$[\mathrm{eksp}: \qquad (6.10 \pm 0.05) \times 10^{11}\ \mathrm{s}^{-1}]\,.$$



Raspadi s-kvarka, npr. semileptonska širina

$$\Gamma(s \to e^- \bar{\nu}_e X) \approx \frac{1}{\tau_\mu}\left(\frac{m_s}{m_\mu}\right)^5 |V_{us}|^2 \approx 5.4 \times 10^5\ \mathrm{s}^{-1},$$

- znatno odstupa od mjerenja

$$\Gamma(K^- \to \pi^0 e^- \bar{\nu}_e) = (3.90 \pm 0.05) \times 10^6\ \mathrm{s}^{-1},$$
$$\Gamma(\bar{K}^0 \to \pi^+ e^- \bar{\nu}_e) = (7.49 \pm 0.11) \times 10^6\ \mathrm{s}^{-1},$$
$$\Gamma(\Lambda \to p\, e^- \bar{\nu}_e) = (3.16 \pm 0.06) \times 10^6\ \mathrm{s}^{-1}.$$