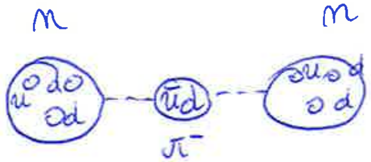
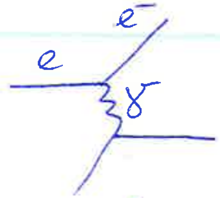


IZMENJAVA PIONA
– ANALOGIJA Z
VAN DER VAALSOVIMI SILAMI



PO ANALOGIJI : SIPANJE ELEKTRONA NA JEDRO

$$f = \int u(r)\, e^{i\vec{q}\cdot\vec{r}}\, d^3r$$

$$f = \int \frac{g}{r} e^{-\frac{r}{R}} \underbrace{d^3r}_{4\pi r^2 dr} \cdot e^{i\vec{q}\vec{r}} = g4\pi \int r^2 dr\, e^{-\frac{r}{R}} e^{i\vec{q}\cdot\vec{r}} \frac{1}{r}$$

$$w = \frac{r}{R} - i\vec{q}\cdot\vec{r} = r\left(\frac{1}{R} - iq\right)$$
$$dw = dr\left(\frac{1}{R} - iq\right)$$

$$= g4\pi \int e^{-w} \frac{w}{\left(\frac{1}{R} - iq\right)^2} dw =$$

$$= \frac{g4\pi}{\left(\frac{1}{R} - iq\right)^2} \underbrace{\int_0^\infty e^{-w} w\, dw}_{= \text{konstanta (neodvisna od } q)}$$

$$\sigma \propto |f|^2 \propto \frac{g^2}{\left(\left|\frac{1}{R} - iq\right|^2\right)^2} \frac{g^2}{\left(\frac{1}{R^2} + q^2\right)^2} = \frac{g^2}{\left(\frac{m^2c^2}{\hbar^2} + q^2\right)^2} = \frac{g^2}{\left(m^2c^4 + \hbar^2 q^2 c^2\right)^2} (\hbar c)^4$$

$$\Rightarrow \sigma \propto \frac{g^2}{\left(m^2c^4 + \hbar^2 q^2 c^2\right)^2}$$

ČE $m = 0$, $g = \frac{e^2}{4\pi\varepsilon_0}$

$$\sigma \propto \left[\frac{me}{8\pi\varepsilon_0 p^2}\right] \frac{1}{\sin^4\frac{\theta}{2}} |F(q)|^2$$

16.3.

POSLEDICA PRI ŠIBKI INTERAKCIJI

W , $m_W c^2 = 83\ \text{GeV}$ PRI NERELATIVISTIČNIH ENERGIJAH

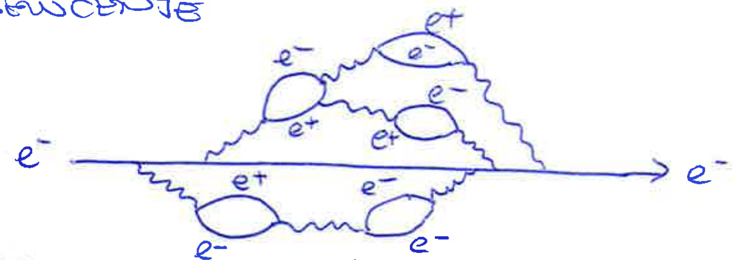
$$\sigma_W \propto \frac{g^2}{\left(m_W^2 c^4 + \hbar^2 q^2 c^2\right)^2} \xrightarrow[m_W c^2 \gg \hbar q c]{} \frac{g^2}{\left(m_W^2 c^4\right)^2}$$

→ ŠIBKA INTERAKCIJA JE ŠIBKA

SENČENJE NABOJA IN POLARIZACIJA VAKUUMA

DIELEKTRIK: ČE SE PRIBLIŽAMO, BOMO VIDELI „GOLI" NABOJ → VEČJA VREDNOST
DALJE OD e^- — SENČENJE

OSNOVNI DELEC (e^-) V VAKUUMU

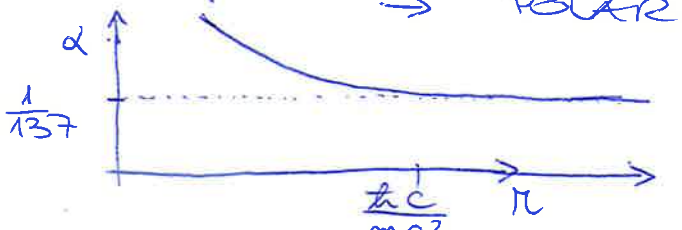


$\Delta E \, \Delta t \gtrsim \frac{\hbar}{2}$

OKOLI ELEKTRONA OBLAK FOTONOV IN PAROV e^+e^-. OBLAK SEGA DO $R \sim c\Delta t \sim c\frac{\hbar}{2\Delta E} \sim \frac{\hbar c}{2 m_e c^2} \sim \frac{200 \text{ MeV fm}}{2.05 \text{ MeV}} \sim 200 \text{ fm}$

DOSEG OBLAKA $\sim 10^3$ fm

$\alpha = \frac{e^2}{4\pi\varepsilon_0 \hbar c}$



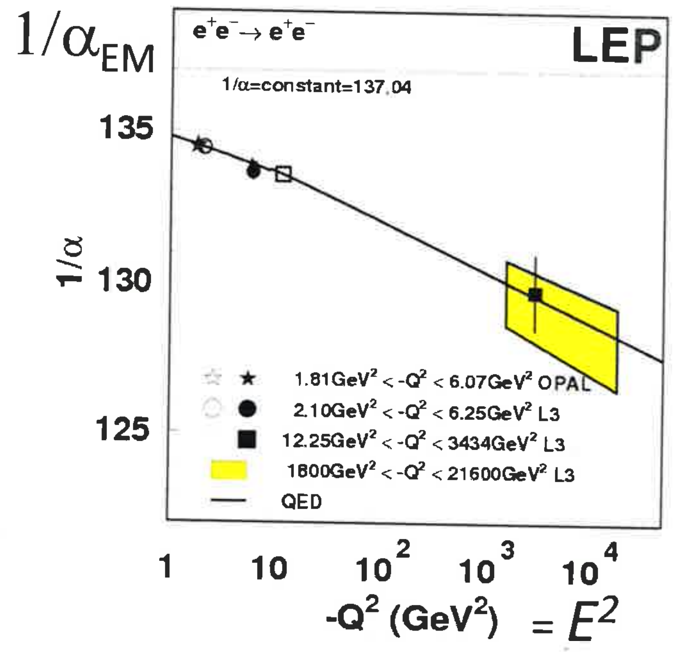
→ POLARIZACIJA VAKUUMA

$\alpha(r)$

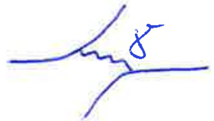
$\Delta p \, \Delta x \geq \frac{\hbar}{2}$

$E \, r \sim \hbar \Rightarrow r \sim \frac{\hbar}{E}$

$\longleftarrow E$



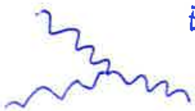
EKSPERIMENTALNA POTRDITEV $e^+e^- \to e^+e^-$



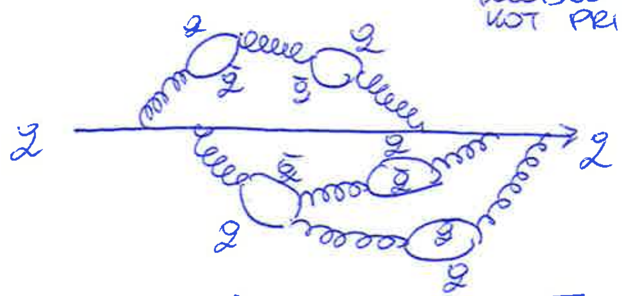
ODVISNOST α_W IN α_S OD ENERGIJE

DRUGAČNA!

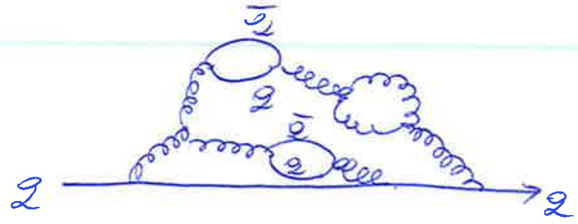
EM.: NI MOŽNO!



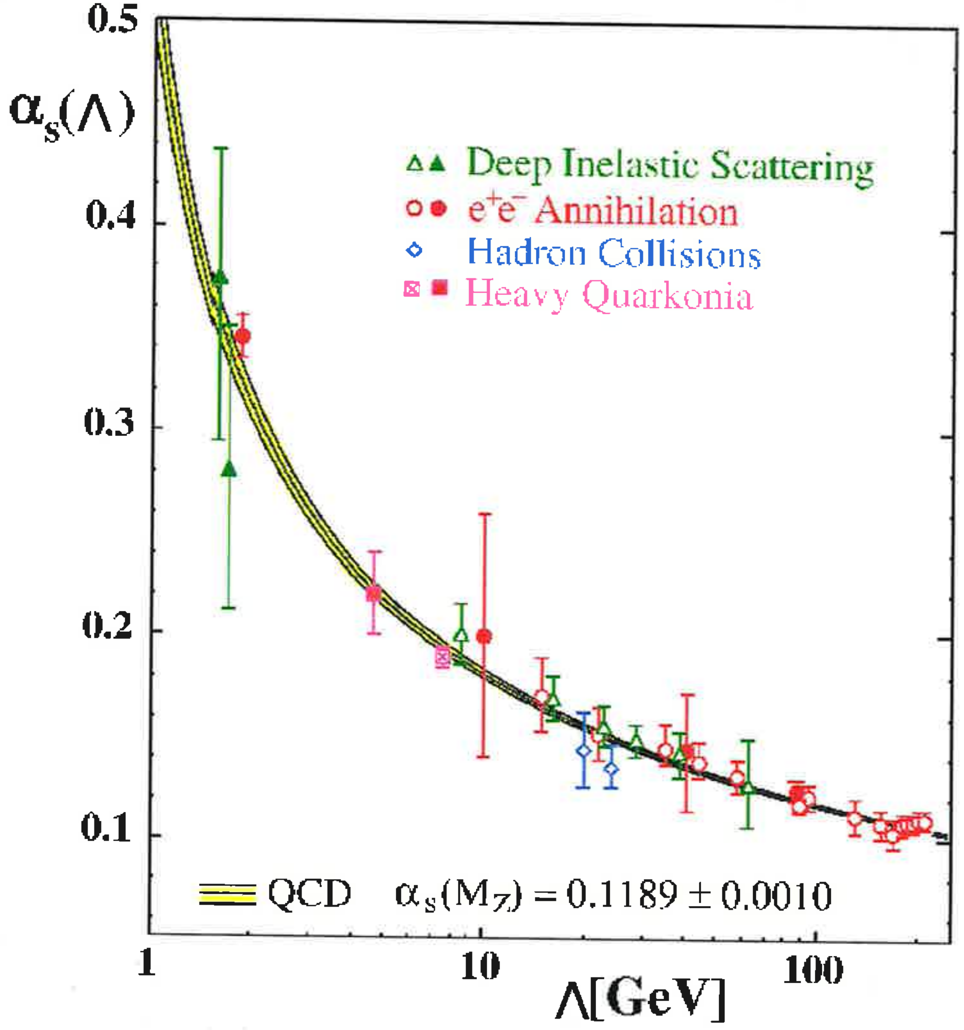
MOČNA INTERAKCIJA: MOŽNO!
ŠIBKA — " — — " —



PODOBNO KOT PRI E.M.

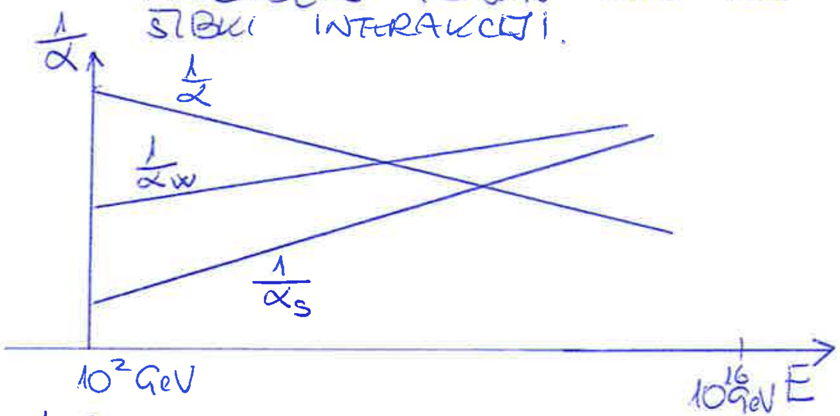


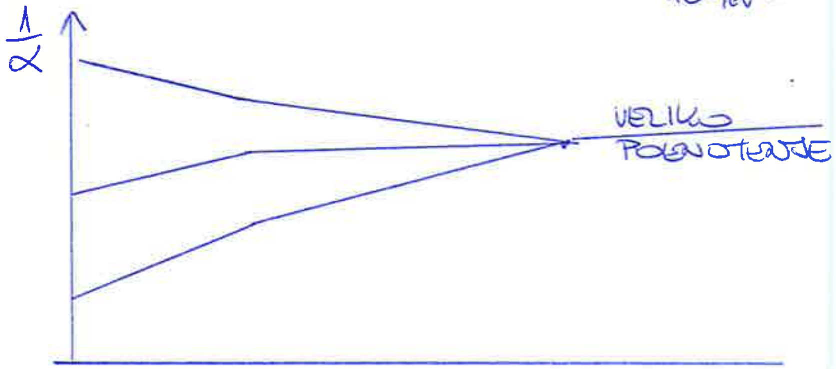
-ANTISENČENJE → BLIŽJE KOT GREMO, MANJŠA BO α_s, ŠIBKEJŠA SKLOPITEV



DRAMATIČNA ODVISNOST OD r OZIROMA E.

PODOBEN POJAV TUDI PRI ŠIBKI INTERAKCIJI.





↑ PRELOM V STRMINI ZARADI DODATNIH MASIVNIH DELCEV

RECIMO: SUPERSIMETRIČNI PARTNERJI DELCEM

SPIN $\frac{1}{2} \to 0$ ELEKTRON → SELEKTRON

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SIMETRIJE IN OHRANITVENI ZAKONI

OPAZLJIVKE, KI SE OHRANJAJO

POLJUBNO STANJE $|\psi(t)\rangle$, ob $t=0$: $|\psi(t=0)\rangle$

$$i\hbar \frac{\partial}{\partial t}|\psi(t)\rangle = \hat{H}\,|\psi(t)\rangle$$

$$|\psi(t)\rangle = e^{-\frac{i\hat{H}t}{\hbar}}\,|\psi(0)\rangle$$

$$|\psi(t)\rangle = \hat{U}(t)\,|\psi(0)\rangle \qquad \hat{U}(t) = e^{-\frac{i\hat{H}t}{\hbar}}$$

$\hat{U}(t)$ = UNITAREN $\quad \hat{U}^+\hat{U} = I = \hat{U}\hat{U}^+$

$\frac{df}{dt} = c\,f \Rightarrow f = Ae^{ct}$

ČE JE $\psi(t)$ LASTNA F. $\hat{H}$

$$\hat{H}|\psi(t)\rangle = E|\psi(t)\rangle$$

$$|\psi(t)\rangle = e^{-\frac{i\hat{H}t}{\hbar}}|\psi(0)\rangle = \left(1-\frac{i\hat{H}t}{\hbar}+\dots\right)|\psi(0)\rangle = \left(1-\frac{iEt}{\hbar}+\dots\right)|\psi(0)\rangle = \exp\left(-\frac{iEt}{\hbar}\right)|\psi(0)\rangle$$

OPAZLJIVKA, KI SE OHRANJA X

$$\langle\psi(t)|\hat{X}|\psi(t)\rangle = \langle\psi(0)|\hat{U}^+\hat{X}\,\hat{U}|\psi(0)\rangle =$$

$$= \langle\psi(0)|\hat{X}|\psi(0)\rangle = X_0 \equiv \langle\psi(0)|X_0|\psi(0)\rangle$$

$$\Rightarrow \hat{U}^+ X\hat{U} = X_0 \Rightarrow \underbrace{\hat{U}\hat{U}^+}_{I} X \underbrace{\hat{U}\hat{U}^+}_{I} = \hat{U}X_0\hat{U}^+ \Rightarrow X = \hat{U}X_0\hat{U}^+$$

$\hat{H}^+ = \hat{H}$

$$0 = \frac{\partial X}{\partial t} = \frac{\partial\hat{U}}{\partial t}X_0\hat{U}^+ + \hat{U}X_0\frac{\partial\hat{U}^+}{\partial t} = -\frac{i\hat{H}}{\hbar}\hat{U}X_0\hat{U}^+ + \hat{U}X_0\left(+\frac{i\hat{H}}{\hbar}\right)\hat{U}^+$$

U^+U

---

v 2. členu: $\hat{U}\hat{H}\hat{U}^+ = e^{-\frac{i\hat{H}t}{\hbar}}\hat{H}e^{+\frac{i\hat{H}t}{\hbar}} =$

$$= \left(1-\frac{i\hat{H}t}{\hbar}+\dots\right)\hat{H}\left(1+\frac{i\hat{H}t}{\hbar}\dots\right) = \hat{H}\hat{U}\hat{U}^+ = \hat{H}$$

$$0 = \frac{\partial X}{\partial t} = -\frac{i}{\hbar}\Big(H\underbrace{\hat{U}X_0\hat{U}^+}_{X} - \underbrace{\hat{U}X_0U^+}_{X}H\Big) = -\frac{i}{\hbar}[H,X]$$

OPERATOR ZA OPAZLJIVKO, KI SE OHRANJA, KOMUTIRA Z H

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

VSAK OHRANITVENI ZAKON JE POVEZAN Z NEKO SIMETRIJO SISTEMA

PRIMER: 3. KOMPONENTA VRTILNE KOLIČINE. ČE SE J_z OHRANJA $\Rightarrow [\hat{H},\hat{J}_z]=0$

$\hat{J}_z$ JE POVEZAN Z OPERATORJEM ZASUKA PROSTORA OKOLI OSI Z

OPERATOR ZA ROTACIJO OKOLI OSI Z $e^{\frac{i\hat{J}_z\varphi}{\hbar}}$

DN. POKAŽI, DA JE $e^{\frac{i\hat{J}_z\varphi}{\hbar}}\psi(x,y,z)$ V ZAROTIRANEM SISTEMU OKOLI Z.

ZA MAJHNE φ $\left(1+\frac{i\hat{J}_z\varphi}{\hbar}\right)\psi(x,y,z)$

OHRANITVENI ZAKONI

OHRANITEV BARIONSKEGA ŠTEVILA B

B BARIONSKO ŠTEVILO ZA BARIONE 1, ZA ANTI BARIONE −1
ZA VSE OSTALE = 0 $\underset{qqq}{\downarrow}$ $\overline{qqq}$

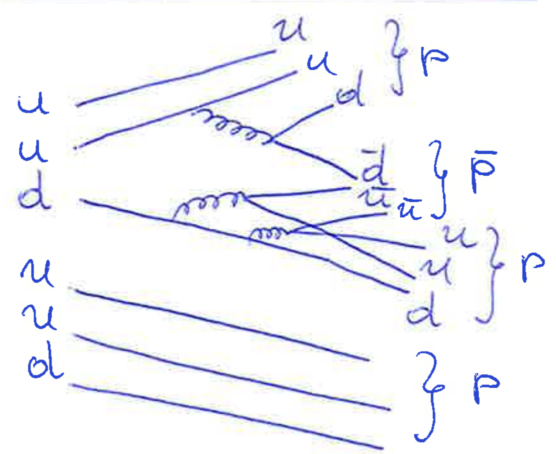
p uud B=1, n udd B=1, Λ uds. B=1, $\bar{u}\bar{u}\bar{d}=\bar{p}$ B=−1,
π^+ $u\bar{d}$ B=0

OHRANITEV B $\quad pp \longrightarrow ppp\bar{p}$ $\quad pp \not\rightarrow p\bar{p}\pi^+\pi^+$
B $1+1=\underline{\underline{2}} \longrightarrow 1+1+1-1=\underline{\underline{2}}$ $\quad$ B= $1+1=\underline{\underline{2}}$ $\quad 1-1+0+0=\underline{\underline{0}}$

OHRANITEV B NA NIVOJU KVARKOV

KVARKI $B=+\frac{1}{3}$

ANTIKVARKI $B=-\frac{1}{3}$



OHRANITEV LEPTONSKEGA ŠTEVILA

LEPTONI : $L = +1$ ANTILEPTONI : $L = -1$ HADRONI $L = 0$

$$e^+e^- \to \tau^+\tau^- \quad \checkmark$$
$$L \quad -1+1 \qquad -1+1$$

$$pp \not\to e^+e^+ \quad \times$$
$$L \quad 0+0 \not\to -1+1$$

$$\nu_\mu\, n \to p\, \mu^-$$
$$L \quad +1+0 \to 0+1 \quad \checkmark$$
$$B \quad 0+1 \to 1+0 \quad \checkmark$$
$$L_\mu \quad +1+0 \to 0+1 \quad \checkmark$$

$$\nu_\mu\, n \not\to p\, e^-$$
$$+1+0 \to 0+1 \quad \checkmark$$
$$0+1 \to 1+0 \quad \checkmark$$
$$L_\mu \quad 1+0 \to 0+0 \quad \times$$
$$L_e \quad 0+0 \to 0+1 \quad \times$$

$$\mu^- \not\to e^- \gamma$$
$$L_\mu \quad +1 \to 0 \quad \times$$
$$L_e \quad 0 \to +1 \quad \times$$

PRI LEPTONIH SE OHRANJA TUDI OKUS LEPTONOV

$$L_e = L_e' \qquad L_\mu = L_\mu' \qquad L_\tau = L_\tau'$$

DN $\tau^- \to \mu^- + \ldots\ldots ?$ ALI JE MOGOČEN $\pi^+ \to \mu^+ \nu_\mu$?

SIMETRIJA VALOVNIH FUNKCIJ

VALOVNA FUNKCIJA DVEH DELCEV (IDENTIČNIH DELCEV) $\psi(1,2)$

$$|\psi(1,2)|^2 = |\psi(2,1)|^2 \qquad \psi(2,1) = \pm\psi(1,2)$$

VALOV. F. POSAMEZNEGA DELCA $\phi(1)$, $\phi(2)$, DVE MOŽNI STANJI a, b

$$\psi_S = \frac{1}{\sqrt{2}}\left[\phi_a(1)\,\phi_b(2) + \phi_b(1)\,\phi_a(2)\right] \quad \text{SIMETRIČNA VAL. F.}$$

$$\psi_A = \frac{1}{\sqrt{2}}\left[\phi_a(1)\,\phi_b(2) - \phi_b(2)\,\phi_a(2)\right]$$

ČE $a = b$ $\psi(1,2) = 0$