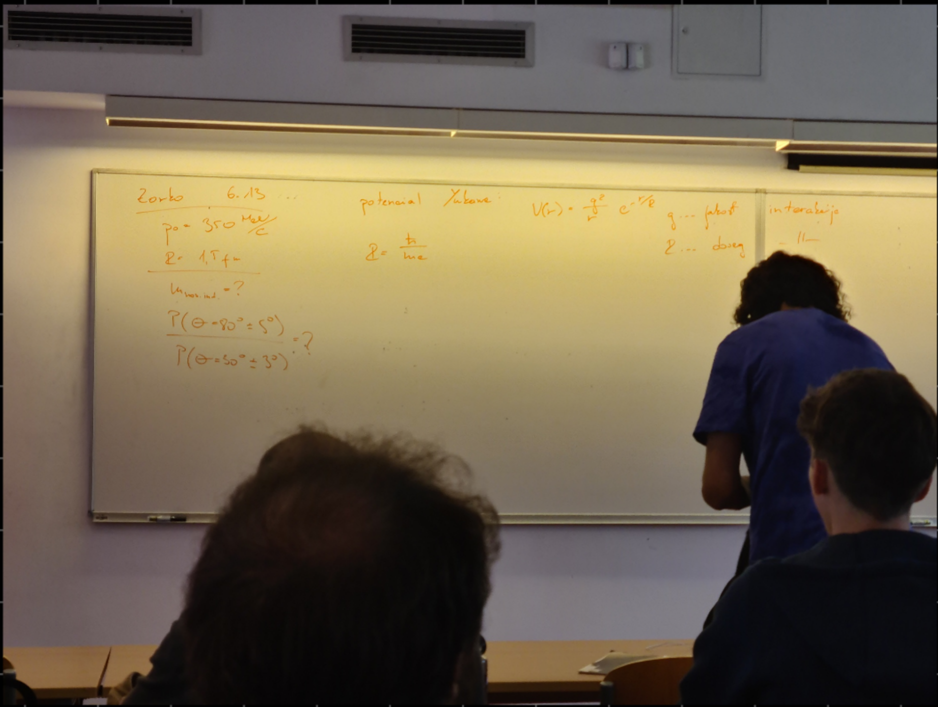

Elastično sipanje e^-

Interakcija se obravnava kot hipno.
Drugače je interakcija retardirana / zaostala.

EM interakcija, ki jo prenaša foton, bo doseg interakcije $R = \infty$
(enačba $R = \frac{\hbar}{m_\gamma}$)

Masa delca $m_x c^2 = \frac{\hbar c}{R} = 130$ MeV (mirovna en. π, nosilci močne int. na ravni hadronov, gluoni pa so pri kvarki)

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sipalni presek $\frac{d\sigma}{d\Omega} \propto |\mathcal{M}|^2$

final state

initial state

matrični el. začetne interakcije $\mathcal{M} = \langle f | U_{if} | i \rangle$

operator, ki pripelje do prehoda $|i\rangle \rightarrow |f\rangle$

Označimo tudi $|i\rangle = \psi_i$
$|f\rangle = \psi_f$

hamiltonka

$H = H_0 + H_0 + U_{00}$

interakcija

V našem primeru je potencial Yukawe U_{if}

$$\langle f | U_{if} | i \rangle = \mathcal{M} = \int \psi_f^*(\vec r)\, V(\vec r)\, \psi_i(\vec r)\, d^3\vec r$$

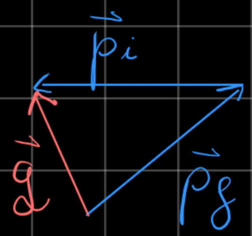
Ker nevtron miruje, vzamemo ravni val

$$|i\rangle \propto e^{-i\vec k_i \vec r} = e^{-i\frac{\vec p_i \vec r}{\hbar}}$$

$$|f\rangle \propto e^{-i\frac{\vec p_f \vec r}{\hbar}}$$

$\rightarrow$ potencial

$$\mathcal{M} \propto \int d^3\vec r\, \frac{g^2}{r} e^{-\frac{r}{R}}\, e^{i\frac{(\vec p_f - \vec p_i)\vec r}{\hbar}}$$

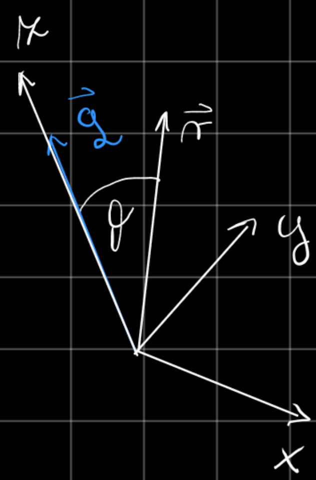


Vpeljemo $\vec p_f - \vec p_i = \vec q$ (sprememba GK)

Kartezične v sferične

$\rightarrow \cos\vartheta$

$$\mathcal{M} = \int_0^{2\pi} d\varphi \int_{-1}^{1} dc_\vartheta \int_0^\infty r^2\, dr\, \frac{g^2}{r} e^{-\frac{r}{R}}$$



Usmerimo koord. sistem, da je $\vec q \parallel \vec z$

$$\vec q \cdot \vec r = |\vec q| \cdot |\vec r| \cos\vartheta$$

$$\mathcal{M} = 2\pi \int_0^\infty dr\, g^2 r\, e^{-\frac{r}{R}} \underbrace{\int_{-1}^{1} dc_\vartheta\, e^{\frac{iqrc_\vartheta}{\hbar}}}$$

$$\frac{\hbar}{iqrc_\vartheta} e^{\frac{iqrc_\vartheta}{\hbar}} \Big|_{-1}^{1}$$

$$= \frac{\hbar}{iqrc_\vartheta}\left(e^{+\frac{iqr}{\hbar}} - e^{-\frac{iqr}{\hbar}}\right) = \frac{\hbar}{iqrc_\vartheta}\, 2i \sin\left(\frac{iqr}{\hbar}\right)$$

Zapišemo sorazmernost in konstante zavržemo

$$\mathcal{M} \propto \int_0^\infty e^{-\frac{r}{R}} \frac{\hbar}{q} \sin\left(\frac{qr}{\hbar}\right) dr$$ // per partes ali to, kar naredimo

$$\propto \int_0^\infty e^{-\frac{r}{R}} \left(e^{\frac{iqr}{\hbar}} - e^{-\frac{iqr}{\hbar}}\right) dr$$

$$= \frac{\hbar}{q} \int_0^\infty \left[e^{\left(\frac{iq}{\hbar} - \frac{1}{R}\right)r} - e^{\left(\frac{iq}{\hbar} + \frac{1}{R}\right)r} \right] dr$$

$$= \frac{\hbar}{q} \left[\frac{1}{\frac{iq}{\hbar} - \frac{1}{R}} e^{\left(\frac{iq}{\hbar} - \frac{1}{R}\right)r} + \frac{1}{\frac{iq}{\hbar} + \frac{1}{R}} e^{-\left(\frac{iq}{\hbar} + \frac{1}{R}\right)} \right]\Bigg|_0^\infty$$

$$\mathcal{I}(\infty) \to \emptyset \left(\lim_{x\to\infty} e^{-x}\right)$$

$$\mathcal{M} \propto \frac{\hbar}{q} (-1) \left[\frac{1}{\frac{iq}{\hbar} - \frac{1}{R}} + \frac{1}{\frac{iq}{\hbar} + \frac{1}{R}} \right] =$$

$$= -\cancel{\frac{\hbar}{q}} \left[\frac{\cancel{\frac{iq}{\hbar}} + \cancel{\frac{1}{R}} + \cancel{\frac{iq}{\hbar}} - \cancel{\frac{1}{R}}}{\left(\frac{iq}{\hbar} - \frac{1}{R}\right)\left(\frac{iq}{\hbar} + \frac{1}{R}\right)} \right] = -\frac{2i}{\frac{q^2}{\hbar^2} - \frac{1}{R^2}} \propto \frac{\hbar^2}{q^2 + \frac{\hbar^2}{R^2}}$$

Upoštevamo $R = \frac{\hbar c}{mc^2}$

$$\boxed{= \frac{(\hbar c)^2}{q^2c^2 + (mc^2)^2}}$$

Matrični element je sorazmeren s tem.

$$\frac{d\sigma}{d\Omega} \propto |\mathcal{M}|^2 \propto \frac{1}{\left[q^2c^2 + (mc^2)^2\right]^2}$$

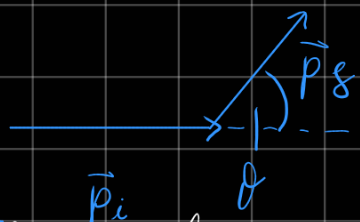
$d\Omega = d\varphi \, d c_\vartheta = 2\pi \, c_\vartheta \, d\vartheta$

$$q = |\vec{q}| = |\vec{p}_f - \vec{p}_i|$$

$$\Rightarrow \quad q^2 = \left(\vec{p}_f - \vec{p}_i\right)^2 = p_f^2 + p_i^2 - 2\vec{p}_i\vec{p}_f$$

Upoštevamo $|\vec{p}_f| = |\vec{p}_i| = p_0$ (elastični trk)

$$q^2 = 2p_0^2 - 2p_0^2 \cos\vartheta$$



Ta ϑ != od ϑ pri sipalnem preseku

$$\cos\left(2\frac{\vartheta}{2}\right) = \cos^2\frac{\vartheta}{2} - \sin^2\frac{\vartheta}{2}$$

$$q^2 = 2p_0^2\left(1 - \cos\vartheta\right)$$

$$1 = \cos^2\frac{\vartheta}{2} + \sin^2\frac{\vartheta}{2}$$

$$= 4p_0^2 \sin^2\frac{\vartheta}{2}$$

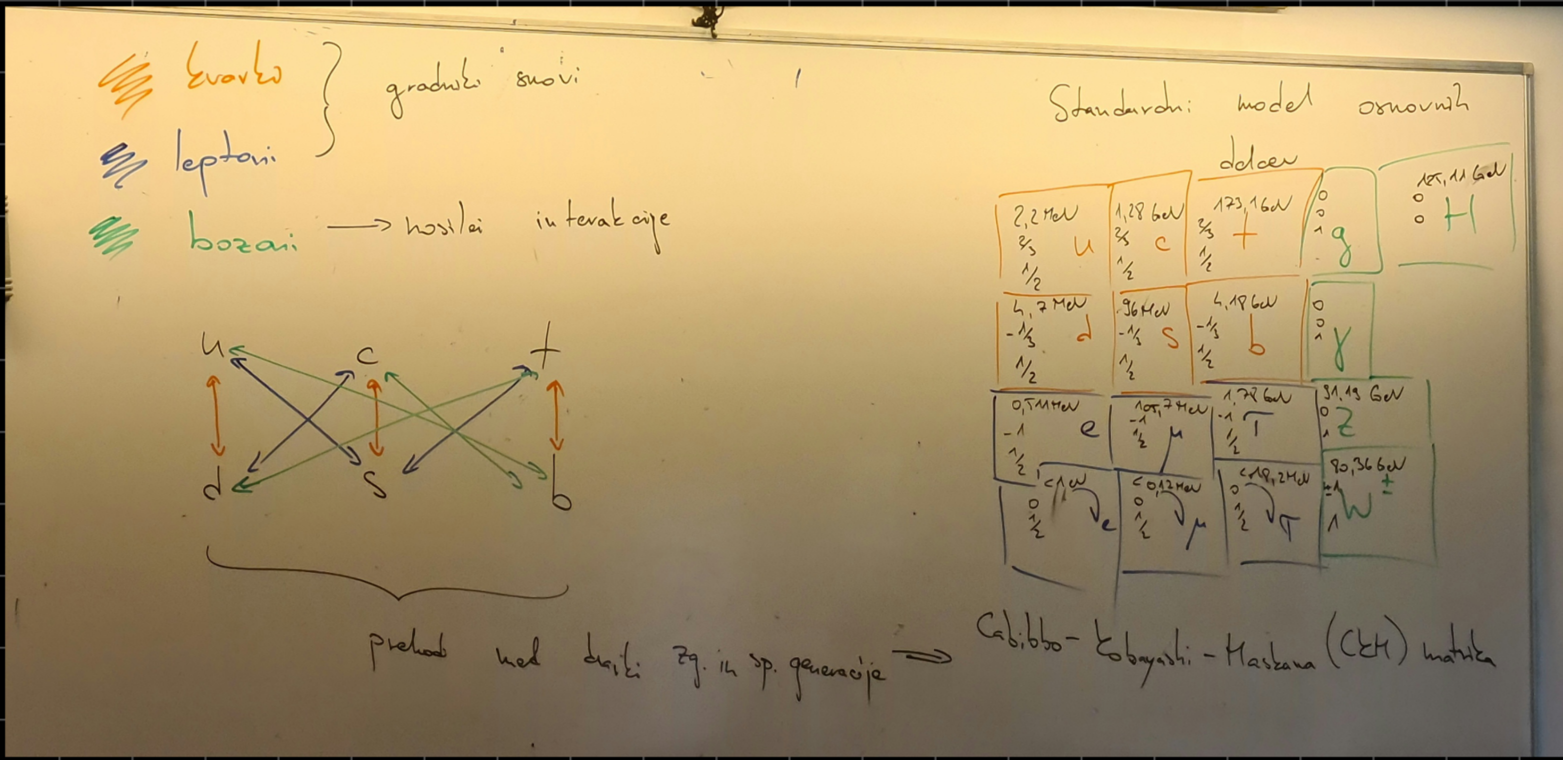
$$\Rightarrow \frac{d\sigma}{d\Omega} \propto \frac{1}{\left[4p_0^2c^2\sin^2\frac{\vartheta}{2} + (mc^2)^2\right]^2}$$

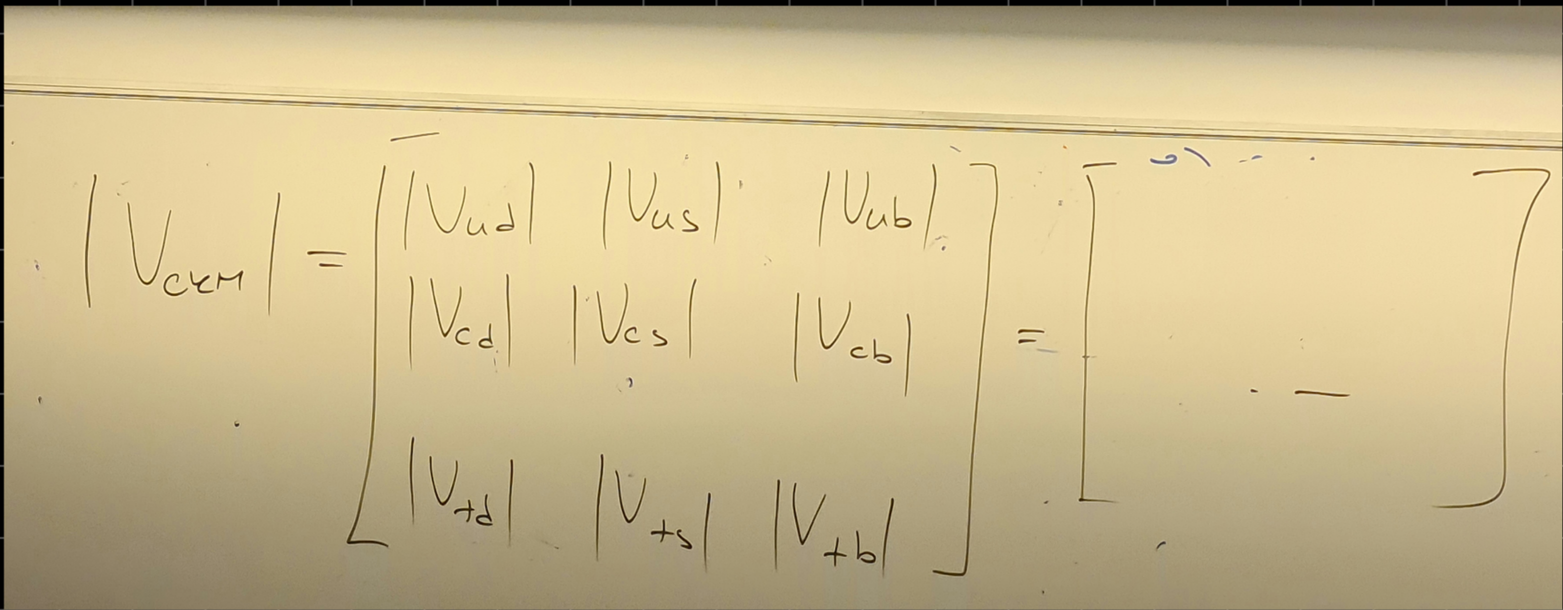
$$P(\vartheta \pm \Delta\vartheta) = \int_{\Omega(\vartheta_0 - \Delta\vartheta)}^{\Omega(\vartheta_0 + \Delta\vartheta)} \frac{d\sigma}{d\Omega}\, d\Omega \propto \int \frac{d\sigma}{d\vartheta}\, \underbrace{d(\cos\vartheta)}_{\sin\vartheta\, d\vartheta}$$

Upoštevamo, da so $\Delta\vartheta$ majhne, kar pomeni, da integral zapišemo z diferencialom (aproksimacija)

$$P(\vartheta \pm \Delta\vartheta) = \left[\frac{d\sigma}{d\vartheta}\sin\vartheta\right]\Bigg|_{\vartheta_0} \Delta\vartheta \cdot 2 \quad \text{za } \Delta\vartheta \ll \vartheta_0$$

$$\frac{P(\vartheta = 80^\circ \pm 5^\circ)}{P(\vartheta = 30^\circ \pm 3^\circ)} = 0{,}17$$





Ohranitveni zakoni

1) Ohranitev polne energije

2) Ohranitev GK in VK

3) Ohranitev barionskega števila

$$B = \frac{1}{3}\left(\underset{\#\text{ kvarkov}}{n_q} - \underset{\#\text{ anti-kvarkov}}{n_{\bar{q}}}\right)$$

4) Ohranitev leptonskega števila

$$L = N_\ell - N_{\bar{\ell}}$$

5) Ohranitev el. naboja

Približni ohranitveni zakon

okus čudnih kvarkov je čudnost

1) Ohranitev okusa (vsak kvark ima svoj okus / tip)
(krši ga šibka)

Zorko 6.7

a) $p e^- \longrightarrow n \bar{\nu}_e$

$p(uud)$, $n(udd)$

naboj leve strani $e_L = \emptyset$,
desne $e_D = \emptyset$
5) velja, je možno

Ohranitev 3) $B_L = 1$ (p), $B_D = 1$ (n), $B_L = B_D$ ✓

Ohranitev 4) $L_L = 1$, $L_D = -1$ $\Longrightarrow L_L \neq L_D$ krši 4), ni mogoč

b) $K^+ \longrightarrow \mu^+ \bar{\nu}_\mu$

u in anti s

$K^+(u\bar{s})$

5) $e_L = e_D$ ✓
3) $B_L = \emptyset = B_D$
4) $L_L = \emptyset$, $L_D = \emptyset$ ✓

1) $m_{K^+} > m_\mu + m_{\bar{\nu}_\mu}$ ✓

Ohranitveni zakoni obstajajo.

Spremenijo se okusi (levo: 1 kvark, desno: leptoni), šibka interakcija je krivec za spremembo.