Mandelstamove spem.

$p, k \to p', k'$

$s = (p+k)^2 = (p'+k')^2$

$t = (p-p')^2$

$u = (p-k')^2 = (p'-k)^2$

Izospin I, I_3

$I_i = \frac{\sigma_i}{2} \quad [I_i, I_j] = i\varepsilon_{ijk} I_k$

$|p\rangle = |1/2\ 1/2\rangle_I = \begin{pmatrix}1\\0\end{pmatrix} \quad |n\rangle = |1/2\ -1/2\rangle_I = \begin{pmatrix}0\\1\end{pmatrix}$

$I_\pm = I_1 \pm i I_2$

$I^2 |I I_3\rangle = I(I+1) |I I_3\rangle$

$I_3 |I I_3\rangle = I_3 |I I_3\rangle$

$I_\pm |I I_3\rangle = \sqrt{I(I+1) - I_3(I_3 \pm 1)}\, |I I_3\rangle$

$I_+ = \begin{pmatrix}0&1\\0&0\end{pmatrix} \quad I_- = \begin{pmatrix}0&0\\1&0\end{pmatrix}$

Triplet $I=1$: $|11\rangle = |p\rangle|p\rangle$

$|10\rangle = \frac{1}{\sqrt{2}}(|p\rangle|n\rangle + |n\rangle|p\rangle)$

$|1-1\rangle = |n\rangle|n\rangle$

Singlet $I=0$: $|00\rangle = \frac{1}{\sqrt{2}}(|p\rangle|n\rangle - |n\rangle|p\rangle)$

Za vse fermione je $|\psi\rangle$ antisim.

Zamenjava delcev $1 \leftrightarrow 2$

$|\chi\rangle_I \to (-1)^{I+1} |\chi\rangle_2$

$|\chi\rangle_S \to (-1)^{S+1} |\chi\rangle_S$

$|\psi\rangle_r \to (-1)^{l} |\psi\rangle_r$

$|\psi\rangle \to (-1)^{I+S+l} |\psi\rangle$

$1 = S + l$

Magnetni moment

$\hat{\mu}_z = \frac{e\hbar}{2m} g \hat{s}_z \qquad \hat{s}_z |S\, s_z\rangle = s_z |S\, s_z\rangle$

$\hat{\mu}_z^2 = \frac{e_2 \hbar}{m_2} \hat{s}_z$

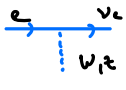
$\mu_z^u = \frac{e_0 \hbar}{3 m_u} \qquad \mu_z^d = \frac{-e_0 \hbar}{6 m_d}$

$\sigma_1 = \sigma_x = \begin{pmatrix}0&1\\1&0\end{pmatrix}$

$\sigma_2 = \sigma_4 = \begin{pmatrix}0&-i\\i&0\end{pmatrix}$

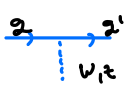
$\sigma_3 = \sigma_z = \begin{pmatrix}1&0\\0&-1\end{pmatrix}$

Šibka interakcija



$-\frac{ig}{\sqrt{2}} \gamma^\mu P_L \qquad P_L = \frac{1-\gamma_5}{2}$

Propagator $\frac{-i\left(g^{\mu\nu} - \frac{q^\mu q^\nu}{m_W}\right)}{q^2 - m_W^2}$



$-\frac{ig}{\sqrt{2}} \gamma^\mu P_L V_{CKM}$

Diracova enačba

$(i\gamma^\mu \partial_\mu - m)\psi = 0$

$\gamma^\mu \partial_\mu = \vec{\gamma}\nabla + \gamma^0 \frac{\partial}{\partial t}$

$(\vec{\alpha}\cdot\vec{p} + \beta m)\psi = i\frac{\partial \psi}{\partial t}$

$\vec{\gamma} = \gamma^0 \vec{\alpha} \qquad \gamma^0 = \beta$

$H = \gamma^0(\vec{\gamma}\cdot\vec{p} + m)$

$\bar{\psi} = \psi^\dagger \gamma^0$

$j^\mu = e\bar{\psi}\gamma^\mu\psi$ gostota el. toka

$\partial_\mu j^\mu = 0$

$\not{p} = \gamma_\mu p^\mu = E\gamma_0 - \vec{\gamma}\cdot\vec{p}$

$\not{p}\not{p} = p\cdot p = p^2$

Rešitve Diracove enačbe

$\psi_{\vec{p}}^s = N e^{-ip\cdot x} u^s(\vec{p})$

Delec $u^s(\vec{p}) = N\begin{pmatrix}\chi^s\\ \frac{\vec{\sigma}\cdot\vec{p}}{E+m}\chi^s\end{pmatrix}$ $\chi^\uparrow = \begin{pmatrix}1\\0\end{pmatrix}\uparrow$ $\chi^\downarrow = \begin{pmatrix}0\\1\end{pmatrix}\downarrow$

Antidelec $v^s(\vec{p}) = N\begin{pmatrix}\frac{\vec{\sigma}\cdot\vec{p}}{E+m}\chi^{-s}\\ \chi^{-s}\end{pmatrix}$ $\chi^{-\uparrow} = \begin{pmatrix}0\\1\end{pmatrix}\uparrow$ $\chi^{-\downarrow} = \begin{pmatrix}1\\0\end{pmatrix}\downarrow$

$N = \sqrt{E+m}$

$\int \varphi\, dV = \int \psi^\dagger \psi\, dV = 2E$

Lastnosti rešitev

$u^{(r)}(\vec{p})^\dagger u^{(s)}(\vec{p}) = \delta^{rs}\, 2E$

$v^{(r)}(\vec{p})^\dagger v^{(r)}(\vec{p}) = \delta^{rs}\, 2E$

$\bar{u}^{(r)}(\vec{p})^\dagger u^{(s)}(\vec{p}) = \delta^{rs}\, 2m$

$\bar{v}^{(r)}(\vec{p})^\dagger v^{(s)}(\vec{p}) = \delta^{rs}\, 2m$

$\sum_s u^{(s)}(\vec{p})\,\bar{u}^{(s)}(\vec{p}) = \not{p} + m$

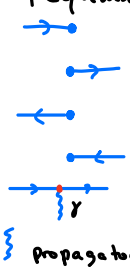
$\sum_s v^{(s)}(\vec{p})\,\bar{v}^{(s)}(\vec{p}) = \not{p} - m$

Sučnost / helicity

$h = \frac{\vec{p}}{|\vec{p}|}\cdot\vec{s} \qquad \vec{s} = \frac{1}{2}\begin{pmatrix}\vec{\sigma}&0\\0&\vec{\sigma}\end{pmatrix}$

last. vred. $\pm\frac{1}{2}$

Feynmanova pravila



$-iM = \bar{u}(k')[-ieQ\gamma^\mu]u(k)\left\{\frac{-ig^{\mu\nu}}{q^2}\right\}\bar{u}(p')[-ieQ\gamma^\nu]u(p)$

$q^2 = 2m_e^2 - 2k\cdot k' = -8m_e T_e \sin^2\frac{\theta}{2}$

$\frac{d\sigma}{d\Omega} = \frac{1}{64\pi^2 s}|M|^2 \quad p_f/p_i$

$-iM = \bar{v}(p)[\ ]u(k)\{\ \}\bar{u}(k')[\ ]v(p')$

Lastnosti γ matrik

$(\gamma^0)^2 = 1 \qquad (\gamma^i)^2 = -1 \qquad i = 1,2,3$

$(\gamma^0)^\dagger = \gamma^0 \qquad (\gamma^i)^\dagger = -\gamma^i$

$(\gamma^\mu)^\dagger = \gamma^0\gamma^\mu\gamma^0$

$\gamma_\mu = g^{\mu\nu}\gamma^\nu$

$\{\gamma^\mu, \gamma^\nu\} = 2g^{\mu\nu}$

$\gamma^\mu\gamma^\nu = -\gamma^\nu\gamma^\mu$ če $\nu \neq \mu$

$\gamma^5 = i\gamma^0\gamma^1\gamma^2\gamma^3 = -\frac{i}{4!}\varepsilon^{\mu\nu\alpha\beta}\gamma_\mu\gamma_\nu\gamma_\alpha\gamma_\beta$

$(\gamma^5)^\dagger = \gamma^5$

$(\gamma^5)^2 = 1$

$\{\gamma^5, \gamma^i\} = 0$

$\gamma^0 = \begin{pmatrix}I&0\\0&I\end{pmatrix}_{4\times4} \qquad \gamma^i = \begin{pmatrix}0&\sigma_i\\-\sigma_i&0\end{pmatrix}$

$\mathrm{Tr}\,\gamma^\mu = 0$

$\mathrm{Tr}\,\gamma^5 = 0$

$\mathrm{Tr}\,\gamma^\mu\gamma^\nu\ldots\gamma^\lambda = 0$ št. γ je liho

$\mathrm{Tr}\,\gamma^5\gamma^\mu\ldots\gamma^\nu = 0$ št. γ je sodo

$\mathrm{Tr}\,\gamma^\mu\gamma^\nu = 4g^{\mu\nu}$

$\mathrm{Tr}\,\gamma^\mu\gamma^\nu\gamma^\alpha\gamma^\beta = 4(g^{\mu\nu}g^{\alpha\beta} - g^{\mu\alpha}g^{\nu\beta} + g^{\mu\beta}g^{\nu\alpha})$

$\mathrm{Tr}\,A+B = \mathrm{Tr}\,A + \mathrm{Tr}\,B$

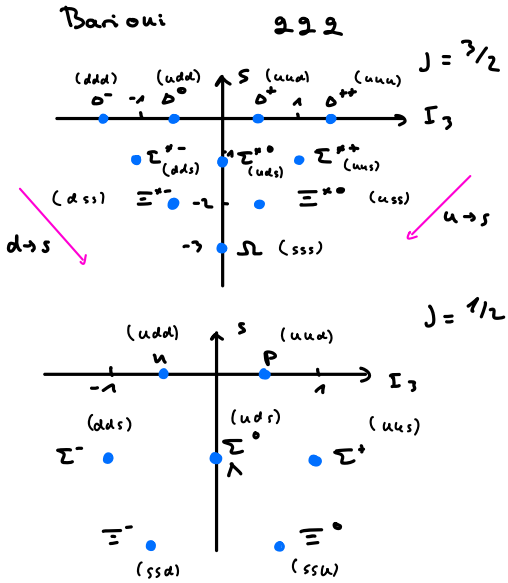
$\mathrm{Tr}\,rA = r\,\mathrm{Tr}\,A$

$\mathrm{Tr}\,ABC = \mathrm{Tr}\,BCA = \mathrm{Tr}\,CAB$

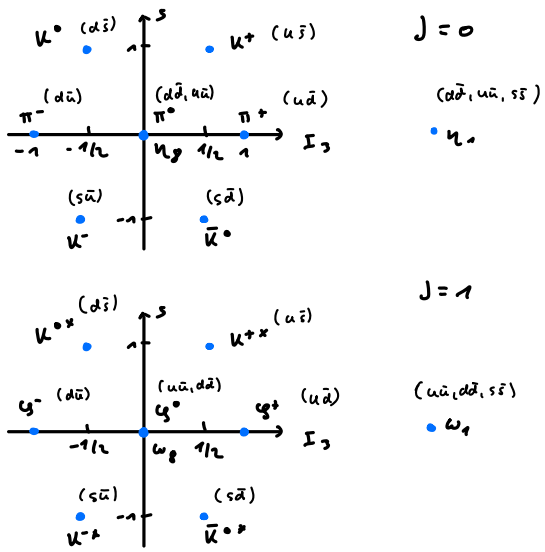
$\mathrm{Tr}((\not{p} - m)\gamma^\mu(\not{k} + m)\gamma^\nu) = 4(-m^2 g^{\mu\nu} + p^\mu k^\nu - (p\cdot k)g^{\mu\nu} + p^\nu k^\mu)$

mass →	≈2.3 MeV/c²	≈1.275 GeV/c²	≈173.07 GeV/c²	0	≈126 GeV/c²
charge →	2/3	2/3	2/3	0	0
spin →	1/2	1/2	1/2	1	0
	u up	c charm	t top	g gluon	H Higgs boson
QUARKS	≈4.8 MeV/c²	≈95 MeV/c²	≈4.18 GeV/c²	0	
	-1/3	-1/3	-1/3	0	
	1/2	1/2	1/2	1	
	d down	s strange	b bottom	γ photon	
	0.511 MeV/c²	105.7 MeV/c²	1.777 GeV/c²	91.2 GeV/c²	
	-1	-1	-1	0	
	1/2	1/2	1/2	1	
	e electron	μ muon	τ tau	Z Z boson	
LEPTONS	<2.2 eV/c²	<0.17 MeV/c²	<15.5 MeV/c²	80.4 GeV/c²	GAUGE BOSONS
	0	0	0	±1	
	1/2	1/2	1/2	1	
	ν_e electron neutrino	ν_μ muon neutrino	ν_τ tau neutrino	W W boson	

Barioni $q\bar{q}q$



Mezoni $q\bar{q}$



antisimetrična

$J = 3/2$ $\quad |\chi\rangle_b = \frac{1}{\sqrt{6}}(RGB - GRB + \dots) = \frac{1}{\sqrt{6}}\varepsilon_{ijk}|ijk\rangle$ $\quad |\chi\rangle_s = |\frac{3}{2}\,\frac{3}{2}\rangle = |\uparrow\uparrow\uparrow\rangle$ $\quad |\frac{3}{2}\,-\frac{3}{2}\rangle = |\downarrow\downarrow\downarrow\rangle$

uuu	$\|\Delta^{++}\rangle = \|uuu\rangle$
uud	$\|\Delta^{+}\rangle = \frac{1}{\sqrt{3}}(uud + udu + duu)$
udd	$\|\Delta^{0}\rangle = \frac{1}{\sqrt{3}}(udd + dud + ddu)$
ddd	$\|\Delta^{-}\rangle = \|ddd\rangle$
uus	$\|\Sigma^{*+}\rangle = \frac{1}{\sqrt{3}}(uus + usu + suu)$
uds	$\|\Sigma^{*0}\rangle = \frac{1}{\sqrt{6}}(uds + dus + dsu + usd + sdu + sud)$

$J = 1$

$u\bar{d}$	$\|\pi^{+}\rangle = u\bar{d}$
$u\bar{u}, d\bar{d}$	$\|\pi^{0}\rangle = \frac{1}{\sqrt{2}}(u\bar{u} - d\bar{d})$
$d\bar{u}$	$\|\pi^{-}\rangle = d\bar{u}$
$u\bar{s}$	$\|K^{+}\rangle = u\bar{s}$
$u\bar{u}, d\bar{d}, s\bar{s}$	$\|\eta_1\rangle = \frac{1}{\sqrt{3}}(u\bar{u} + d\bar{d} + s\bar{s})$
$u\bar{u}, d\bar{d}, s\bar{s}$	$\|\eta_8\rangle = \frac{1}{\sqrt{6}}(u\bar{u} + d\bar{d} - 2s\bar{s})$

$|\chi\rangle_s = |11\rangle = \uparrow\uparrow$

$|10\rangle = \frac{1}{\sqrt{2}}(\uparrow\downarrow + \downarrow\uparrow)$

$|1{-1}\rangle = \downarrow\downarrow$

$|00\rangle = \frac{1}{\sqrt{2}}(\uparrow\downarrow - \downarrow\uparrow)$

$J = 1/2$ $\quad |\chi\rangle_s = 2\uparrow\uparrow\downarrow - \uparrow\downarrow\uparrow - \downarrow\uparrow\uparrow = |\frac{1}{2}\,\frac{1}{2}\rangle$

uud	$\|p\rangle = \frac{1}{\sqrt{18}}(uud + udu + duu)$
udd	$\|n\rangle = \frac{1}{\sqrt{18}}(udd + dud + ddu)$
uus	$\|\Sigma^{+}\rangle = \frac{1}{\sqrt{18}}(uus + usu + suu)$
uds	$\|\Sigma^{0}\rangle = \frac{1}{\sqrt{36}}(dus + uds + dsu + usd + sdu + sud)$
uds	$\|\Lambda^{0}\rangle = \frac{1}{\sqrt{12}}[s(ud - du)\uparrow(\uparrow\downarrow - \downarrow\uparrow) + (usd - dsu)(\uparrow\uparrow\downarrow - \downarrow\uparrow\uparrow) + (ud - du)s(\uparrow\downarrow - \downarrow\uparrow)\uparrow]$

$J_z = 1/2$ $\quad -1/2$

Relativnost

$\beta = \frac{v}{c}$ $\quad \gamma = \frac{1}{\sqrt{1-\beta^2}}$

$p^\mu = (E, \vec{p})$

$E = m + T = \gamma m$

$E^2 = m^2 + p^2$

$p = \gamma\beta m = \beta E$

$T = (\gamma - 1)m$