۲۰۱۰/۱۱/۰۳
۰۳:۲۲ ب.ظ

$$P^2 \psi_{p_1\sigma_1 n_1;\, p_2\sigma_2 n_2;\dots} = \eta^2_{n_1}\, \eta^2_{n_2} \cdots \psi_{p_1\sigma_1 n_1;\, p_2\sigma_2 n_2}$$

$$I_P^2\, P^2 = 1$$

تقارن داخلی تازه ؟!   اگر بخشی از تقارن پیوسته‌ی سیستم باشد.

$$e^{i(\alpha B + \beta L + \gamma Q)}$$

$$P' \equiv P I_P \qquad P'^2 = 1$$

سؤال ۵)

$$\Delta \to e^{i\beta} \Delta \qquad \text{تحت } U(1)$$

$$\Delta \to e^{i\vec{\alpha}\cdot\vec{T}} \Delta \qquad \text{تحت } SU(2)$$

$$\left[\frac{\tau^i}{2}, \frac{\tau^j}{2}\right] = i\,\varepsilon^{ijk} \frac{\tau^k}{2}$$

$$T^1 = -i\begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 1 \\ 0 & -1 & 0 \end{bmatrix} \qquad T^2 = -i\begin{bmatrix} 0 & 0 & -1 \\ 0 & 0 & 0 \\ 1 & 0 & 0 \end{bmatrix}$$

$$T^3 = -i\begin{bmatrix} 0 & 1 & 0 \\ -1 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix}$$

$$[T^1, T^2] = i\, T^3 \qquad \text{امتحان}$$

$$D_\mu = \partial_\mu - i g \vec{A}_\mu \cdot \vec{T} - i g' \frac{Y}{2} B_\mu$$

$$\begin{cases} A^3_\mu = \cos\theta_w\, Z_\mu + \sin\theta_w\, A_\mu \\ B_\mu = -\sin\theta_w\, Z_\mu + \cos\theta_w\, A_\mu \end{cases}$$

$$i\bar{\Delta}\, \cancel{D}_\mu\, \Delta = \text{جملۀ جنبشی} + \cdots + A_\mu \bar{\Delta} \gamma^\mu \begin{bmatrix} g'\frac{Y}{2}\cos\theta_w & -ig\sin\theta_w & 0 \\ ig\sin\theta_w & g'\frac{Y}{2}\cos\theta_w & 0 \\ & & \dots \end{bmatrix} \Delta$$

$$0 \qquad 0 \qquad g\frac{Y}{2}\cos\theta_w$$

$$g' \cos\theta_w = g \sin\theta_w = e$$

$$\Delta \rightarrow \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{i}{\sqrt{2}} & 0 \\ \frac{i}{\sqrt{2}} & \frac{1}{\sqrt{2}} & 0 \\ 0 & 0 & 1 \end{bmatrix} \Delta \longrightarrow$$

بار $\Delta^3 = \frac{Y}{2}$

بار $\frac{\Delta^1 + i\Delta^2}{\sqrt{2}} = 1 + \frac{Y}{2}$

بار $\frac{i\Delta^1 + \Delta^2}{\sqrt{2}} = -1 + \frac{Y}{2}$

$$\Delta' = \begin{bmatrix} \Delta^3 & \frac{\Delta^1 - i\Delta^2}{\sqrt{2}}\sqrt{2} \\ \frac{\Delta^1 + i\Delta^2}{\sqrt{2}} \alpha \sqrt{2} & -\Delta^3 \end{bmatrix}$$

$$A = B = \Delta^3_{\ J} \qquad n_1 = 1 = -n_2 \qquad n_3 = \sqrt{2} \qquad n_4 = \sqrt{2}$$

بار $C \longrightarrow \frac{Y}{2} - 1$

بار $D \longrightarrow \frac{Y}{2} + 1$

$$\Delta^i \longrightarrow \left(e^{iT^k \alpha^k} \Delta\right)^i = \left(1 + i T^k \alpha^k\right)_{ij} \Delta^j$$

$$= \Delta^i + \varepsilon^{kij} \Delta^j \alpha^k =$$

$$\Delta^i \tau^i \longrightarrow \Delta^i \tau^i + \underbrace{\underbrace{\varepsilon^{kij} \tau^i}_{-\varepsilon^{kji}\tau^i}}_{i\left[\frac{\tau^k}{2}, \tau^j\right]} \Delta^j \alpha^k$$

$$i\left[\frac{\tau^k}{2}, \tau^j\right] \Delta^j \alpha^k$$

$$\Delta^i \tau^i \longrightarrow \Delta^i \tau^i + i\left[\frac{\vec{\tau} \cdot \vec{\alpha}}{2}, \Delta\right]$$

* جرم‌های مولفه‌های مختلف Δ را به دست آورید. برای این کار باید جمله جنبشی را با نرمالیزاسیون صحیح بنویسید. ضریب جمله برهمکنش با ϕ را به صورت زیر در نظر بگیرید.

$$\mathcal{L}_{int} = -\frac{\lambda}{\Lambda} \phi^\dagger \Delta_i' \Delta_j' \phi \, \varepsilon_{ij}$$

Quantum chromodynamics

SU(3) color symmetry

Yukawa ← 1930

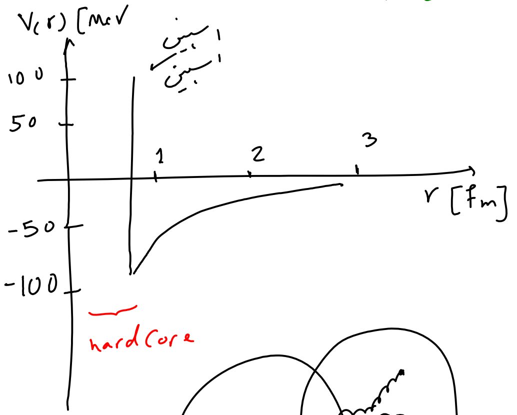
↓ idea of strong interaction

π - exchange

Particles & Nuclei فصل ۱۶

Povh . Rith . Scholz . Zetsche

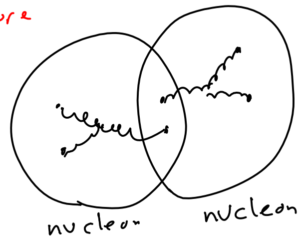
$\boxed{\text{ج ق}}$ ۲ تا ذره نوکلئون



پروتون ← پروتون

interaction

$E <$ few $\times 100$ MeV



→ شبیه نیروی کووالانسی در H_2

chromomagnetism نیروی دافعه :

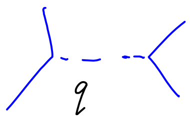
سنگین‌تر → $350\ \frac{MeV}{c^2}$ $u^{\uparrow}u^{\uparrow}d^{\uparrow}$ Δ^{+}

Yukawa → تبادل پایون

$\frac{e^{-mr}}{r}$

پیش بینی جرم π : مزرا با π عوضی گرفتند.

$\Delta E \ll 100$ MeV



$q \ll 100$ MeV

تبادل گلئون چه جرمی؟!

Dynamics of the SM ص ۹

J. Donoghue, Golowich & B. Holstein

در حد تقارن ایزواسپین

$$\mathcal{L} = \bar{\psi}\,(i\not\partial - m)\,\psi + \frac{1}{2}\left[\partial_\mu \pi \cdot \partial^\mu \pi - m_\pi^2\, \pi\cdot\pi\right]$$
$$+ ig\,\bar{\psi}\,\tau\cdot\pi\,\gamma_5\,\psi \quad - \frac{\lambda}{4}\,(\pi\cdot\pi)^2$$

$$\psi = \begin{pmatrix} p \\ n \end{pmatrix} \qquad \pi = \{\pi^i\}$$

$$m = \begin{bmatrix} m & \\ & m \end{bmatrix}$$

نکات

نکته‌ی اول : λ و g در اینجا λ و g قبلی نیستند.

نکته‌ی دوم : γ_5 اینجا چه می‌کند؟

نکته‌ی سوم :

$$\psi \xrightarrow{\text{SU(2) of isospin}} U\psi$$

$$\vec{\tau}\cdot\vec{\pi} \longrightarrow U\,\vec{\tau}\cdot\vec{\pi}\,U^\dagger$$

$$\tau\cdot\pi = \begin{bmatrix} \pi^0 & \pi^+\sqrt{2} \\ \sqrt{2}\pi^- & -\pi^0 \end{bmatrix} \qquad \pi^+ = \left(\frac{\pi^1 - i\pi^2}{\sqrt{2}}\right)$$
$$\pi^- = \frac{\pi^1 + i\pi^2}{\sqrt{2}}$$

$$\bar{\psi}\,\vec{\pi}\cdot\vec{\tau}\,\gamma_5\psi = \pi^0\left(\bar{p}\gamma_5 p - \bar{n}\gamma_5 n\right)$$
$$+ \sqrt{2}\,\pi^+\,\bar{p}\gamma_5 n + \sqrt{2}\,\pi^-\,\bar{n}\gamma_5 p$$

Quantum Chromodynamics

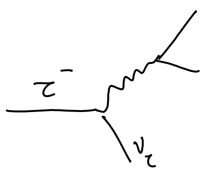
$$g_s\,\frac{\lambda^i}{2} \qquad\qquad \lambda^i \leftarrow \text{Gell-Mann}$$

$$SU(3)\times SU(2)\times U(1) \longrightarrow SU(3)\times U(1)_{em}$$

شاهد برای رنگ

$\Delta^{++}(1232)$

$$R = \frac{\sigma(e^+e^- \to \text{hadrons})}{}$$

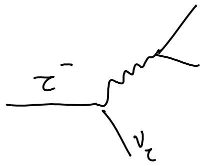


e^-, $\bar{\nu}_e$ | μ^-, $\bar{\nu}_\mu$ | d, $\bar{u}$ | s, $\bar{u}$

$$B = Br(\tau^- \to e^-\bar{\nu}_e\,\nu_\tau)$$

$\Delta^{++}(1232)$

$$R = \frac{\sigma(e^+e^- \to \text{hadrons})}{\sigma(e^+e^- \to \mu^+\mu^-)}$$

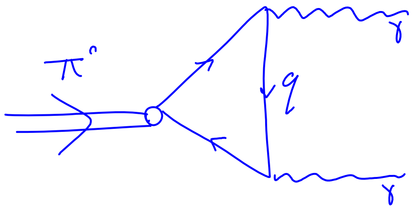


e^- $\bar\nu_e$, | μ^- $\bar\nu_\mu$ | d $\bar u$, | s $\bar u$

$B = Br(\tau^- \to e^- \bar\nu_e \nu_\tau)$

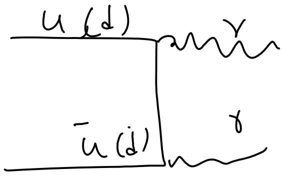
$B = \frac{1}{3}$ ← ب زک

$B = \frac{1}{5}$



$$\Gamma(\pi^0 \to \gamma\gamma) = N_c^2 (e_u^2 - e_d^2)^2 \left(\frac{\alpha}{\pi}\right)^2 \frac{m_\pi^3}{32\pi f_\pi}$$

$$f_\pi \simeq 130 \text{ MeV}$$



??? $\pi \cancel{A_{\mu\nu}} F^{\mu\nu}$ $\pi^0 \varepsilon_{\mu\nu\alpha\beta} F^{\mu\nu} F^{\alpha\beta}$

$$\langle 0 | \bar u \gamma^\mu u \; \bar u \gamma^\nu u | \pi^0 \rangle A_\mu A_\nu = 0$$

$$\langle 0 | \bar u \gamma^\mu \gamma^5 u | \pi^0 \rangle \neq 0$$

لاگرانژی مؤثر $\quad \pi^0 \varepsilon_{\mu\nu\alpha\beta} F^{\mu\nu} F^{\alpha\beta}$

QCD Lagrangian and strength of color forces

$$\mathcal{L} = \bar q (i\not{D} - m) q - \frac{1}{4} F^i_{\mu\nu} F^{i\mu\nu}$$

$$q = \begin{pmatrix} q^R \\ q^G \\ q^B \end{pmatrix} \qquad D_\mu = \partial_\mu - i g_s \frac{\lambda^i A^i_\mu}{2}$$

$$F^i_{\mu\nu} = \partial_\mu A^i_\nu - \partial_\nu A^i_\mu + g_s f_{ijk} A^j_\mu A^k_\nu$$

$$\mathcal{L}_{int} = g_s \, \bar{q} \gamma_\mu \frac{\lambda^i}{2} q \, A^{i\mu} =$$

$$\frac{g_s}{\sqrt{2}} \Big\{ \Big(\bar{q}^R \gamma^\mu q^G G^1_\mu + \bar{q}^G \gamma^\mu q^R G^2_\mu$$

$$+ \frac{1}{\sqrt{2}} \left(\bar{q}^R \gamma^\mu q^R - \bar{q}^G \gamma^\mu q^G \right) G^3_\mu$$

$$+ \bar{q}^R \gamma^\mu q^B G^4_\mu + \bar{q}^B \gamma^\mu q^R G^5_\mu +$$

$$\bar{q}^G \gamma^\mu q^B G^6_\mu + \bar{q}^B \gamma^\mu q^G G^7_\mu +$$

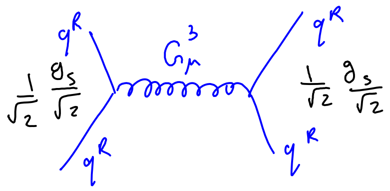
$$\frac{1}{\sqrt{6}} \left(\bar{q}^R \gamma^\mu q^R + \bar{q}^G \gamma^\mu q^G - 2 \bar{q}^B \gamma^\mu q^B \right) G^8_\mu \Big\}$$

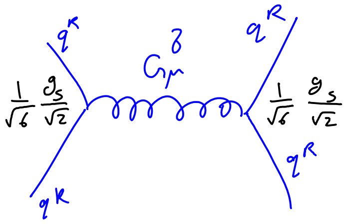
$$G^1_\mu = \frac{A^1_\mu - i A^2_\mu}{\sqrt{2}} \qquad G^2_\mu = \frac{A^1_\mu + i A^2_\mu}{\sqrt{2}} \qquad G^3_\mu = A^3_\mu$$

$$G^4_\mu = \frac{A^4_\mu - i A^5_\mu}{\sqrt{2}} \qquad G^5_\mu = \frac{\left(A^4_\mu + i A^5_\mu\right)}{\sqrt{2}}$$

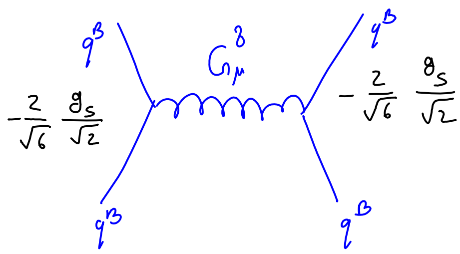
$$G^6_\mu = \frac{A^6_\mu - i A^7_\mu}{\sqrt{2}} \qquad G^7_\mu = \frac{A^6_\mu + i A^7_\mu}{\sqrt{2}} \qquad G^8_\mu = A^8_\mu$$

$$\frac{1}{\sqrt{3}} \left(\bar{R}R + \bar{G}G + \bar{B}B \right)$$



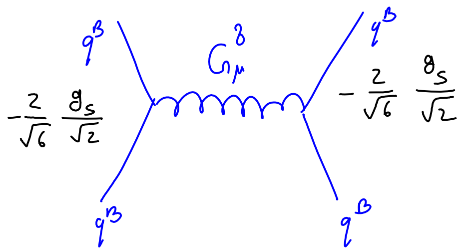


$$\left(\frac{1}{\sqrt{2}} \frac{g_s}{\sqrt{2}} \right)^2 + \left(\frac{1}{\sqrt{6}} \frac{g_s}{\sqrt{2}} \right)^2 = \frac{2}{3} \left(\frac{g_s}{\sqrt{2}} \right)^2$$

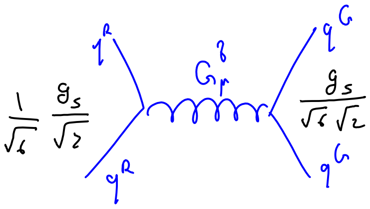


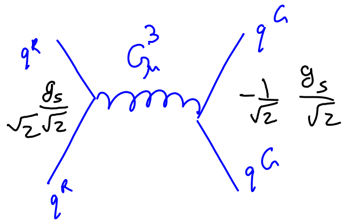
$$\left(-\frac{2}{\sqrt{6}} \frac{g_s}{\sqrt{2}} \right)^2 = \frac{2}{3} \left(\frac{g_s}{\sqrt{2}} \right)^2$$

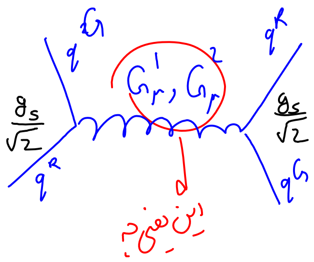
$$\left(\frac{1}{\sqrt{2}}\,\frac{g_s}{\sqrt{2}}\right)^2 + \left(\frac{1}{\sqrt{6}}\,\frac{g_s}{\sqrt{2}}\right)^2 = \frac{2}{3}\left(\frac{g_s}{\sqrt{2}}\right)^2$$



$$\left(-\frac{2}{\sqrt{6}}\,\frac{g_s}{\sqrt{2}}\right)^2 = \frac{2}{3}\left(\frac{g_s}{\sqrt{2}}\right)^2$$







$$\begin{cases} G^1_\mu = \dfrac{A^1_\mu - iA^2_\mu}{\sqrt{2}} \\[2ex] G^2_\mu = \dfrac{A^1_\mu + iA^2_\mu}{\sqrt{2}} \end{cases}$$

$$\mathcal{L}_{int} = \frac{g_s}{\sqrt{2}}\left\{ \bar{q}^R \gamma^\mu q^G G^1_\mu + \bar{q}^G \gamma^\mu q^R G^2_\mu + \dots \right\}$$

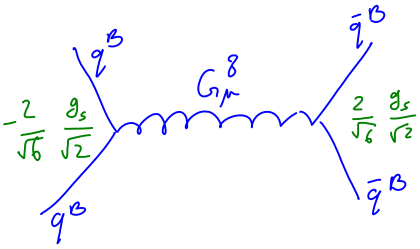
$$\left(\frac{1}{\sqrt{6}}\,\frac{g_s}{\sqrt{2}}\right)^2 + \left(\frac{1}{\sqrt{2}}\,\frac{g_s}{\sqrt{2}}\right)\left(-\frac{1}{\sqrt{2}}\,\frac{g_s}{\sqrt{2}}\right) + \left(\frac{g_s}{\sqrt{2}}\right)^2 = \frac{2}{3}\left(\frac{g_s}{\sqrt{2}}\right)^2$$

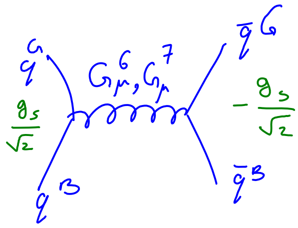
چرا این ضریب ۲ نداره؟

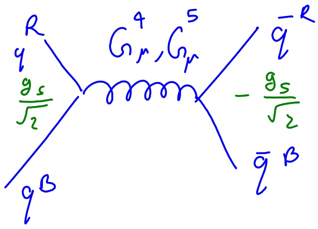
$$\langle G^1_\mu\, G^2_\mu \rangle = ? \qquad \langle G^1_\mu\, G^4_\mu \rangle = ?$$

Color singlet

$$\frac{1}{\sqrt{3}}\left(\bar{R}R + \bar{G}G + \bar{B}B\right)$$







$$\left(\frac{2}{\sqrt{6}}\frac{g_s}{\sqrt{2}}\right)\cdot\left(-\frac{2}{\sqrt{6}}\frac{g_s}{\sqrt{2}}\right) + \left(\frac{g_s}{\sqrt{2}}\right)\cdot\left(\frac{-g_s}{\sqrt{2}}\right) + \frac{g_s}{\sqrt{2}}\cdot\left(-\frac{g_s}{\sqrt{2}}\right) = -\frac{4}{3}\left(\frac{g_s}{\sqrt{2}}\right)^2$$

$$\langle q_i \ldots | \bar{\psi}_i \gamma^\mu \psi_j | q_j \ldots \rangle$$

$$\langle \bar{q}_j \; | \underbrace{\bar{\psi}_i \gamma^\mu \psi_j}_{-1} | \bar{q}_i \ldots \rangle$$

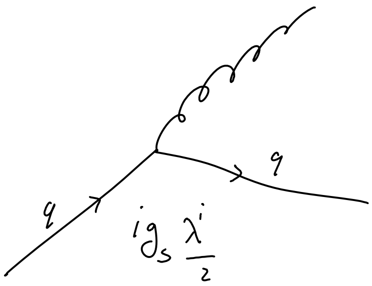
عجب !!

۱) جمع دامنه‌ی حالت‌های نهایی متفاوت؟

۲) s-channel چی شد؟

$$\left\langle \frac{\bar{B}B + \bar{G}G + \bar{R}R}{\sqrt{2}} \right| g_s \bar{q} \gamma_\mu \frac{\lambda^i}{2} q A_\mu^i \left| \frac{\bar{B}B + \bar{G}G + \bar{R}R}{\sqrt{3}} \right\rangle$$ در واقع

$$3 \times \left(\frac{1}{\sqrt{3}}\right)^2 = 1$$



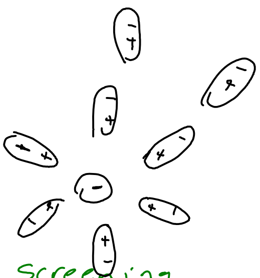
$$M = g_s \; \bar{u}^b \gamma^\mu \left(\frac{\lambda^i}{2}\right)_{ba} u^a \; A^i_\mu$$

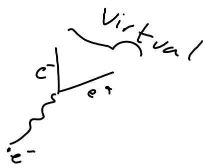
$$\lambda^1 = \begin{bmatrix} 0 & 1 & 0 \\ 1 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix} \qquad \sum_{i,j} \mathrm{Tr}\left[\frac{\lambda^i}{2}\frac{\lambda^j}{2}\right] = \sum_{i,j=1}^{8} \frac{\delta^{ij}}{2} = 4$$

جمع روی
رنگ نهایی

$$\frac{g_s^2}{3} \mathrm{Tr}\left[\frac{\lambda^i}{2}\frac{\lambda^i}{2}\right) = \frac{4}{3} g_s^2$$

Running Coupling Constant

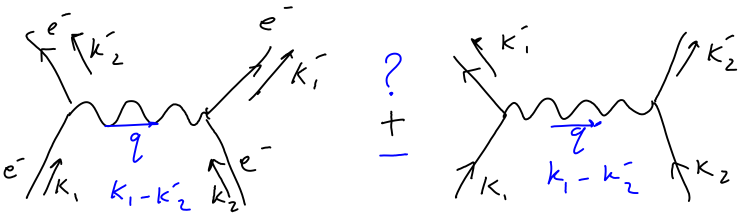


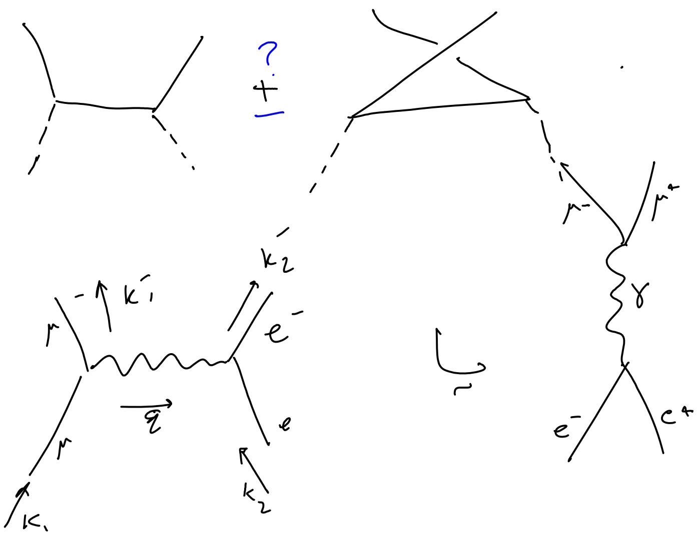


Charge screening
Vacuum polarization

$$\alpha = \frac{e^2}{4\pi} \qquad \alpha(Q^2)$$

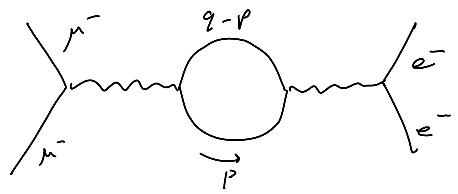
$$e^-(k_1)\, e^-(k_2) \to e^-(k_1') + e^-(k_2'$$





$$q = k_1 - k_1'$$

$$-iM = \Big[ie\, \underset{[\mu]}{\bar{u}}(k_1')\gamma^\mu \underset{[\mu]}{u}(k_1)\Big] \frac{-i\, g_{\mu\nu}}{q^2} \Big[ie\, \underset{[e]}{\bar{u}}(k_2')\gamma^\nu \underset{[e]}{u}(k_2)\Big]$$

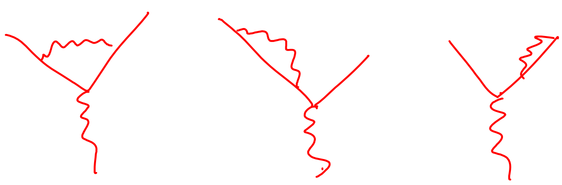


$$-iM = (-1)\Big[ie\, \underset{[\mu]}{\bar{u}}(k_1')\gamma^\mu \underset{[\mu]}{u}(k_1)\Big] \frac{-i\, g_{\mu\rho}}{q^2}$$

$$\frac{1}{(2\pi)^4}\int d^4p\, \mathrm{Tr}\Big[(ie\gamma^\rho)\, \frac{i(\not{p}+m)}{p^2-m^2}\, (ie\gamma^\lambda)$$

$$\frac{i(\not{q}-\not{p}+m)}{(p-q)^2-m^2}\Big] \times \frac{-i g_{\lambda\nu}}{q^2}\Big[ie\, \underset{[e]}{\bar{u}}(k_2')\gamma^\nu \underset{[e]}{u}(k_2)\Big]$$

از کجا آمد؟ -1



Cancel $\longrightarrow$ all orders of perturbation

Ward-Takahashi   اتحاد

$$\frac{-ig_{\mu\nu}}{q^2} \longrightarrow \frac{-ig_{\mu\nu}}{q^2} + \frac{-ig_{\mu\rho}}{q^2} I^{\rho\lambda} \frac{-ig_{\lambda\nu}}{q^2}$$

$$= \frac{-ig_{\mu\nu}}{q^2} + \frac{-i}{q^2} I_{\mu\nu} \frac{-i}{q^2}$$

$$I_{\mu\nu} = \frac{-1}{(2\pi)^4} \int d^4p \, \mathrm{Tr}\left[(-ie\gamma_\mu) \frac{i(\cancel{p}+m)}{p^2-m^2} (ie\gamma_\nu) \frac{i(\cancel{q}-\cancel{p}+m)}{(q-p)^2-m^2}\right]$$

$$I_{\mu\nu} = -ig_{\mu\nu} q^2 I(q^2) + \underbrace{\cdots}_{q_\mu q_\nu}$$

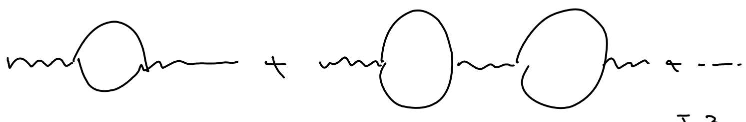
$$q_\mu \bar{u}(k_1') \gamma^\mu u(k_1) = 0$$

$$I(q^2) = \frac{\alpha}{3\pi} \int_{m^2}^{+\infty} \frac{dp^2}{p^2} - \frac{2\alpha}{\pi} \int_0^1 dx \, x(1-x) \log\left(1 - \frac{q^2(1-x)}{m^2}\right)$$

$$\frac{-ig_{\mu\nu}}{q^2} \longrightarrow \frac{-ig_{\mu\nu}}{q^2} (1 - I(q^2))$$

$$I(q^2) = \frac{\alpha}{3\pi} \log\frac{\Lambda^2}{m^2} - \frac{\alpha}{3\pi} \log\left(\frac{-q^2}{m^2}\right) = \frac{\alpha}{3\pi} \log\frac{\Lambda^2}{-q^2}$$

$$(-q^2) \gg m^2$$



$$-I \qquad I^2 \qquad -I^3$$

$$\Rightarrow 1 - I + I^2 - I^3 + \cdots = \frac{1}{I+1}$$

$$-i\mathcal{M} = \left[ie\bar{u}(k_1')\gamma^\mu u(k_1)\right] \frac{-ig_{\mu\nu}}{q^2} \frac{1}{1 + \frac{\alpha}{3\pi}\log\frac{\Lambda^2}{-q^2}} \left[ie\bar{u}(k_2')\gamma_\mu u(k_2)\right]$$

برهنه

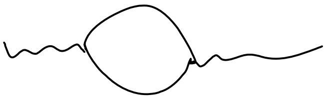
$$\alpha_{eff} = \frac{\alpha}{1 + \frac{\alpha}{3\pi}\log\frac{\Lambda^2}{-q^2}} = \frac{1}{137} \qquad q^2$$

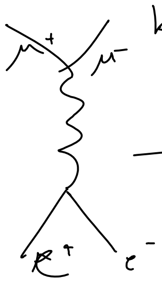
کم

$$\alpha(Q^2) = \frac{\alpha(\mu^2)}{1 - \frac{\alpha(\mu^2)}{3\pi}\log\frac{Q^2}{\mu^2}}$$

μ^2 ↳ renormalization scale

وجه تسمیه

 ← Vacuum polarization

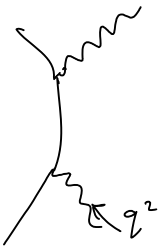


bare mass

$\rightarrow \frac{1}{137} \rightarrow \frac{1}{128}$

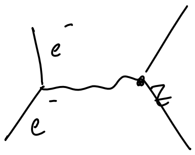
رفتار با Q

Landau pole



پراکندگی کامپتون

فقط برای فوتون مجازی



$-q^2 \ll m^2$

$$\log\left(1 - q^2 x(1-x)\right) \simeq -q^2 \frac{x(1-x)}{m^2}$$

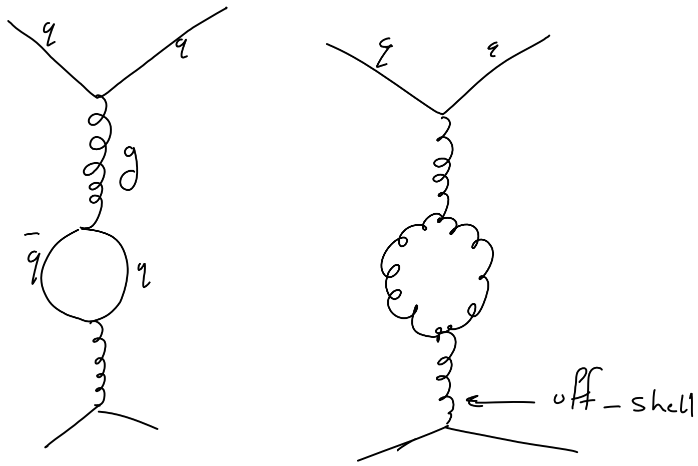
$$I(q^2) = \frac{\alpha}{3\pi} \log\frac{\Lambda^2}{m^2} + \frac{\alpha}{15\pi}\frac{q^2}{m^2}$$

$$-iM = \left[ie\,\bar{u}(k_1')\gamma^\mu u(k_1)\right]\frac{-ig_{\mu\nu}}{q^2}\left[1 - \frac{\alpha}{3\pi}\log\frac{\Lambda^2}{m^2} - \frac{\alpha}{15\pi}\frac{q^2}{m^2}\right](-ij^\nu)$$

$$j^\nu = (\rho = Ze, \vec{j} = 0)$$

$$-iM = \left[ie_R\,\bar{u}(k_1')\gamma_0 u(k_1)\right]\frac{-i}{q^2}(-iZe_R)$$

$$e_R = e\left[1 - \frac{\alpha}{3\pi}\log\frac{\Lambda^2}{m^2}\right]^{\frac{1}{2}}$$



$$\alpha_s(Q^2) = \frac{\alpha_s(\mu^2)}{1 + \frac{33-2n_f}{12\pi}\alpha_s(\mu^2)\log\frac{Q^2}{\mu^2}}$$

Anti-screening

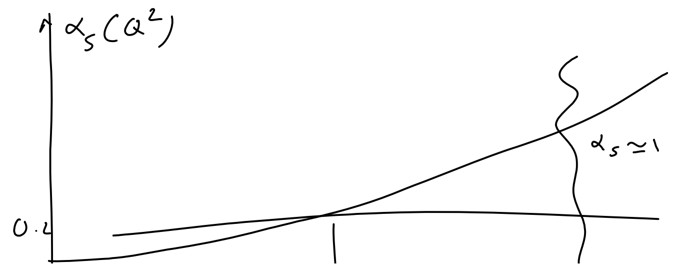
β function $= \mu^2 \frac{d\alpha}{d\mu^2}$

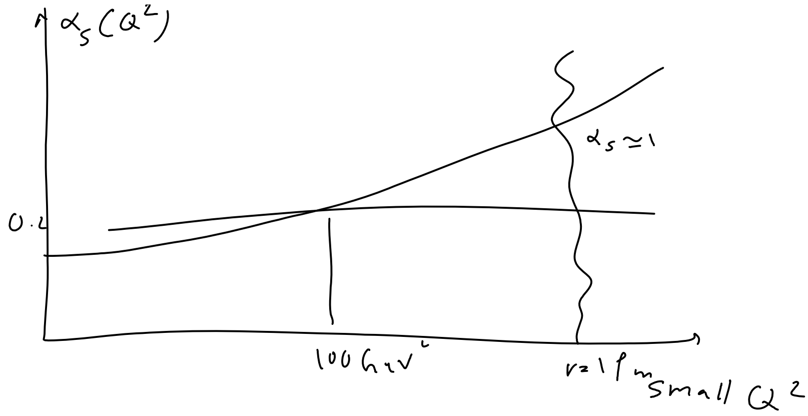
$$\Lambda_{QCD} = \mu^2 \, e^{\frac{-12\pi}{(33-2n_f)\alpha_s(\mu^2)}}$$

$$\alpha_s(Q^2) = \frac{12\pi}{(33-2n_f)\log\frac{Q^2}{\Lambda^2_{QCD}}} \longrightarrow$$

u d s c b $\leftarrow$ $\boxed{Q^2 \simeq 100\ \text{GeV}^2 \quad \alpha_s \simeq 0.2 \quad \Lambda_{QCD} = 200\ \text{MeV}}$

asymptotic freedom $\xleftrightarrow{\Lambda_{QCD}}$ Confinement




$\alpha_s(Q^2)$
$\alpha_s \simeq 1$
0.2
100 GeV^2
$r \approx 1$ fm
small Q^2