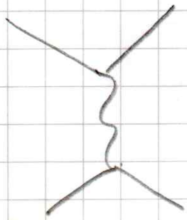
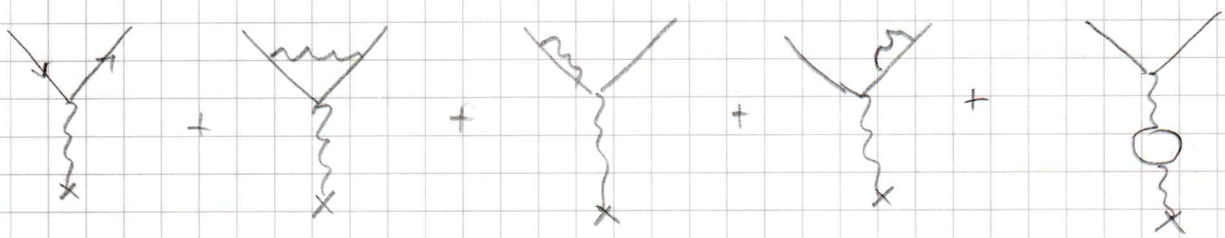
RADIJATIVNE KOREKCIJE

• TREE-level diagrams



• DOPRINOSI VIŠEG REDA = RADIJATIVNE KOREKCIJE (loops, bremsstrahlung)



$\sim e$ + $\sim e^3$ + $\sim e^3$ + $\sim e^3$ + $\sim e^3$

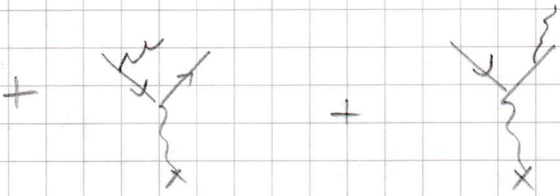
VERT. KOR. (daje anom. mag. mom.)

KOREKCIJE EXT. el. LINIJE

POLARIZACIJA VAKUUMA

$k \to \infty$ UV divergencija.

$k \to 0$ (IR div.)



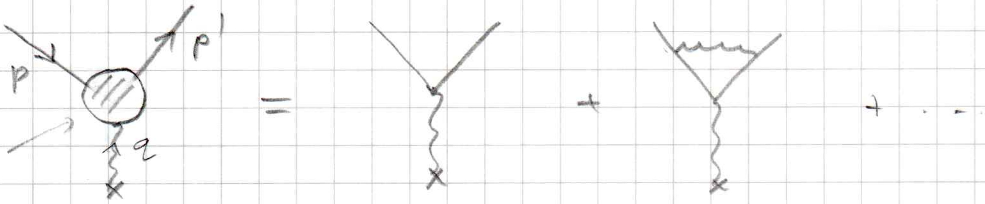
emitiraju se niskoener. fotoni koji ne mogu biti detektirani

PONIŠTAVAJU SE SA IR div

ELEKTRONSKA VERT. F-JA

1) Lorenc. sim.
2) gauge sim QED
3) Ward ident.

$\boxed{\text{Nael. elektrona je } e}$



$-ie\Gamma^\mu$
(amputirana vert. fja)

$$S = -ie \langle \Psi_f | \gamma^\mu A_\mu(x) | \Psi_i \rangle = -ie \int d^4x\, \bar{\Psi}_f \not{A}(x)\, \Psi_i(x)$$

$$= -ie \frac{m}{V\sqrt{E_i E_f}} \int d^4x\, \bar{u}(p')\gamma^\mu u(p)\, e^{i(p'-p)x} A_\mu(x)$$

$$= \frac{m}{V\sqrt{E_i E_f}} \underbrace{-ie\, \bar{u}(p')\gamma^\mu u(p)\, \tilde{A}_\mu(p'-p)}_{=\, i(2\pi)\, M\, \delta(E-E')} \quad (\text{leading order})$$

iF $A^\mu = A^\mu(\vec{x})$

- usled kvantnih korekcija

$$\underline{2\pi i M\, \delta(E'-E) = -ie\, \bar{u}(p')\, \Gamma^\mu(p,p')\, u(p)\, \tilde{A}_\mu(p'-p)}$$

$$\Gamma^\mu = A\gamma^\mu + B(p+p')^\mu + C(p'-p)^\mu + \cancel{\gamma^5}$$

A, B, C su fje od m^2, q^2.

- Ward: $q_\mu \Gamma^\mu = 0 \Rightarrow \underbrace{A\not{q}}_{=0\ (\text{EoM})} + Cq^2 = 0 \Rightarrow \boxed{C=0}$

+ Gordonov id. $\Rightarrow$

$$\boxed{\Gamma^\mu = F_1(q^2)\gamma^\mu + \frac{i\sigma^{\mu\nu}q_\nu}{2m} F_2(q^2)}$$

$F_{1,2} \rightarrow$ form factors

leading order: $F_1(q^2) = 1, \quad F_2(q^2) = 0$

(I) Kulonov potencijal $A^\mu = (\Phi(\vec{x}), 0)$

nerel. e^- + prostorno sporo promenlj. polje $\Rightarrow \tilde{\Phi}(\vec{q})$ lokalizovano oko $q \rightarrow 0$

$$(2\pi)\, iM\, \delta(E'-E) = -ie\, \bar{u}(p')\, \Gamma^{(0)}(p',p)\, u(p)\, (2\pi)\, \delta(E'-E)\, \tilde{\Phi}(\vec{q})$$

$$\Rightarrow \underline{i\mathcal{M} = -ie\,\bar{u}(p')\,\Gamma^0(p',p)\,u(p)\,\tilde{\Phi}(\vec{q})}$$

$$\Gamma^0(p' \approx p) \rightarrow F_1(0)\gamma^0 \Rightarrow$$

$$i\mathcal{M} = -ie\,\bar{u}(p')\gamma^0 u(p)\,F_1(0)\,\tilde{\phi}(\vec{q})$$

$$\bar{u}\gamma^0 u = \sqrt{\frac{E+m}{2m}}\sqrt{\frac{E'+m}{2m}}\left(\varphi'^{+} \quad \varphi'^{+}\frac{\vec{\sigma}\vec{p}'}{E'+m}\right)\begin{pmatrix}\varphi \\ \frac{\vec{\sigma}\vec{p}}{E+m}\varphi\end{pmatrix} \underset{\text{NR limit}}{\approx} \varphi'^{+}\varphi$$

$$\Rightarrow \boxed{i\mathcal{M} = -ieF_1(0)\,\tilde{\phi}(\vec{q})\,\varphi'^{+}\varphi} \quad (*)$$

Born. appr. $\quad S = -2\pi i\,\delta(E_\alpha - E_\beta)\langle\Psi_\beta|V|\Psi_\alpha\rangle$

$\Rightarrow$ (*) je Born-aproksimacija za raspršenje ner. e^- na potencijalu
$$\underline{V = eF_1(0)\Phi(\vec{x})}$$

$$F_1(0) = 1$$

II

$$A^\mu = (0, \vec{A}(\vec{x}))$$

$$i\mathcal{M}2\pi\delta(E'-E) = -ie\,\bar{u}(p')\,\Gamma^i(p',p)\,u(p)\,\tilde{A}_i(\vec{q})\,2\pi\delta(E'-E)$$

$$\Rightarrow i\mathcal{M} = -ie\,\bar{u}(p')\Gamma^i(p',p)\,u(p)\,\tilde{A}_i(\vec{q})$$

$$= +ie\,\bar{u}(p')\left[\gamma^i F_1 + \frac{i\sigma^{i\nu}q_\nu}{2m}F_2\right]u(p)\,\tilde{A}^i(\vec{q})$$

$$\bar{u}'\gamma^i u = \frac{\sqrt{(E+m)(E'+m)}}{2m}\left(+\varphi'^{+} \quad -\varphi'^{+}\frac{\vec{\sigma}\vec{p}'}{E'+m}\right)\begin{pmatrix}0 & \sigma^i \\ -\sigma^i & 0\end{pmatrix}\begin{pmatrix}\varphi \\ \frac{\vec{\sigma}\vec{p}}{E+m}\varphi\end{pmatrix}$$

$$= \frac{\sqrt{(E+m)(E'+m)}}{2m}\left(+\varphi'^{+}\frac{\vec{\sigma}\vec{p}'}{E'+m}\sigma^i\varphi + \varphi'^{+}\sigma^i\frac{\vec{\sigma}\vec{p}}{E+m}\varphi\right)$$

$$\underset{E',E\sim m}{\approx} \frac{1}{2m}\varphi'^{+}\left(\sigma^i\vec{\sigma}\vec{p} + \vec{\sigma}\vec{p}'\sigma^i\right)\varphi$$

$$\underset{\sigma^i\sigma^j = \delta^{ij} + i\varepsilon^{ijk}\sigma^k}{=} \frac{1}{2m}\varphi'^{+}\Big[(p+p')^i + \underbrace{i\varepsilon^{ijk}\sigma^k(p^j - p'^j)}_{\text{bitan dio}}\Big]\varphi$$

(ranije)

Диракова теорија:

$$i\frac{\partial\Psi}{\partial t} = \left(\vec{\alpha}\cdot(-i\nabla - e\vec{A}) + \beta m + eA^0\right)\Psi$$

$$\Psi = \begin{pmatrix}\varphi\\ \chi\end{pmatrix} e^{-imt}$$

$$\Rightarrow \quad i\frac{\partial\varphi}{\partial t} = \Big[\frac{(\vec{p}-e\vec{A})^2}{2m} \underbrace{- \frac{e}{2m}\vec{\sigma}\cdot\vec{B}}_{-\vec{\mu}\cdot\vec{B}} + eA^0\Big]\varphi$$

$$\Rightarrow \vec{\mu} = \frac{e}{mc}\frac{\hbar\vec{\sigma}}{2} = \underset{g}{2}\underset{\mu_B}{\left(\frac{e}{2mc}\right)}\vec{S}$$

$$\bar{u}(p')\frac{i}{2m}\sigma^{i\nu}q_\nu u(p) \xrightarrow[E\approx m]{} \varphi^{+\prime}\frac{i}{2m}\sigma^{ij}q_j\varphi$$

$$= \varepsilon^{ijk}\varphi^{+\prime}\frac{i}{2m}\sigma^k q_j\varphi$$

$$\bar{u}'\left(\gamma^i F_1 + \frac{i\sigma^{i\nu}}{2m}q_\nu F_2\right)u \xrightarrow[\substack{\vec{q}\to 0\\ E\sim m}]{} \varphi'^{+}\Big[-\frac{i}{2m}\varepsilon^{ijk}q^j\sigma^k F_1 + \frac{i}{2m}\varepsilon^{ijk}\sigma^k q^j F_2\Big]\varphi$$

$$= -\frac{i}{2m}\varepsilon^{ijk}\varphi'^{+}q^j\sigma^k\varphi\,\left[F_1(0)+F_2(0)\right]$$

$$i\mathcal{M} = -ie\,\bar{u}'\,\Gamma^i(p,p')u(p)\tilde{A}_i(\vec{q})$$

$$= ie\left(-\frac{i}{2m}\right)\varepsilon^{ijk}\varphi'^{+}q^j\sigma^k\varphi\,(F_1(0)+F_2(0))\tilde{A}^i(\vec{q})$$

$$\vec{B} = \mathrm{rot}\,\vec{A} = \mathrm{rot}\int\frac{d^3k}{(2\pi)^3}\tilde{A}(k)e^{i\vec{k}\vec{x}} \Rightarrow$$

$$\tilde{B}^i = -i\varepsilon^{ijk}q^j\tilde{A}^k(\vec{q})$$

$$i\mathcal{M} = \frac{ie}{2m}\left(F_1(0)+F_2(0)\right)\varphi'^{+}\sigma^k\varphi\,\tilde{B}^k(\vec{q})$$

$$= \frac{ie}{2m}\left(F_1(0)+F_2(0)\right)\varphi'^{+}\vec{\sigma}\vec{B}\varphi$$

Interpretiramo kao raspršenje e^- na potencijalu $-\vec{\mu}\vec{B}$ u Bornovoj aproksimaciji

$$V = -\underbrace{\frac{e}{m}\left(F_1(0)+F_2(0)\right)}_{\vec{\mu}}\frac{\vec{\sigma}\vec{B}}{2}$$

$$\vec{\mu} = \frac{e}{m}\left(F_1(0)+F_2(0)\right)\frac{\vec{\sigma}}{2} = g\left(\frac{e}{2m}\right)\vec{S}$$

$$\Rightarrow g = 2\left(F_1(0)+F_2(0)\right) = 2 + \underbrace{2F_2(0)}_{\sim\alpha}$$

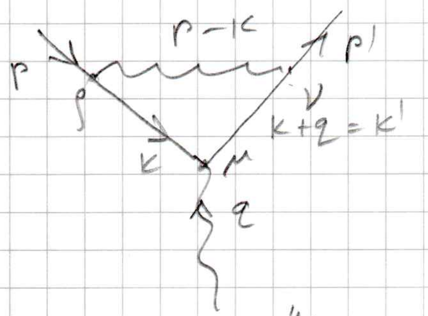
Landé-ov g-factor

Diracov term

(loop-korekcije)

(anomalni mag. mom.)

VERTEKSNA KOREKCIJA - RAČUN



$$\Gamma^\mu = \gamma^\mu + \delta\Gamma^\mu$$

$$\bar{u}'\delta\Gamma^\mu u = \int\frac{d^4k}{(2\pi)^4}\frac{-ig^{\nu\rho}}{(p-k)^2+i\varepsilon}(-ie\gamma^\nu)\frac{i}{\not{k}'-m+i\varepsilon}\gamma^\mu\frac{i}{\not{k}-m+i\varepsilon}(-ie\gamma^\rho)u(p)$$

izvučeno $-ie$ $u(p)$

$$= 2ie^2\underset{\bar{u}'}{\wedge}\int\frac{d^4k}{(2\pi)^4}\frac{\not{k}\gamma^\mu\not{k}' + m^2\gamma^\mu - 2m(k+k')^\mu}{\left((k-p)^2+i\varepsilon\right)\left(k'^2-m^2+i\varepsilon\right)\left(k^2-m^2+i\varepsilon\right)}$$

Feynman-ova PARAMETRIZACIJA

$$\frac{1}{AB} = \int_0^1 dx\frac{1}{\left(xA+(1-x)B\right)^2} = \int_0^1 dx\int_0^1 dy\,\delta(x+y-1)\frac{1}{(xA+yB)^2}$$

$$\frac{1}{A_1\cdots A_n} = \int_0^1 dx_1\ldots dx_n\,\delta(x_1+\cdots+x_n-1)\frac{(n-1)!}{(x_1A_1+\cdots x_nA_n)^n}$$

$$\frac{1}{((k-p)^2+i\varepsilon)(k'^2-m^2+i\varepsilon)(k^2-m^2+i\varepsilon)} = \int_0^1 dx\,dy\,dz\;\delta(x+y+z-1)\;\frac{2}{D^3}$$

$$D = x(k^2-m^2) + y(k'^2-m^2) + z(k-p)^2 + i\varepsilon(x+y+z)$$
$$= (x+y+z)k^2 + 2k(qy - zp) + yq^2 + zp^2 - (x+y)m^2 + i\varepsilon$$
$$= (k+yq-zp)^2 - (q^2y^2 + z^2p^2 - yq^2 - zp^2 - 2yzpq + (x+y)m^2) + i\varepsilon$$
$$= \ell^2 - \Delta + i\varepsilon$$
$$\ell = k + yq - zp$$

$$p' = p + q \Rightarrow q^2 = -2pq$$

$$\Delta = q^2y^2 - yq^2 - 2yzpq + m^2(1-z)^2$$
$$= -xy\,q^2 + (1-z)^2 m^2$$

$q^2 < 0$ jer je $q^2 = 2m^2 - 2pp' \underset{\uparrow}{=} 2m(m - E') < 0$

u sist. gdje je $p^\mu = (m, 0)$

$\Rightarrow \Delta > 0$ (kao efekt. masa)

$$\int \frac{d^4\ell}{(2\pi)^4}\frac{\ell^\mu}{D^3} = 0$$

$$\int \frac{d^4\ell}{(2\pi)^4}\frac{\ell^\mu\ell^\nu}{D^3} = \int \frac{d^4\ell}{(2\pi)^4}\frac{\frac{1}{4}g^{\mu\nu}\ell^2}{D^3}$$

$$N = \bar u(p')\left[\not k\,\gamma^\mu \not k' + m^2\gamma^\mu - 2m(k+k')^\mu\right]u(p)$$
$$= \bar u(p')\Big[(\not\ell - y\not q + z\not p)\gamma^\mu(\not\ell - y\not q + z\not p + \not q) + m^2\gamma^\mu$$
$$- 2m(2\ell - 2yq + 2zp + q)^\mu\Big]u(p)$$
$$\longrightarrow \bar u(p')\Big[-\frac{1}{2}\ell^2\gamma^\mu + (-y\not q + z\not p)\gamma^\mu((1-y)\not q + z\underbrace{\not p}_{\to m})$$
$$+ m^2\gamma^\mu - 2m(2zp^\mu + (1-2y)q^\mu)\Big]u(p)$$

$$= \bar{u}(p')\Big[-\frac{1}{2}l^2\gamma^\mu - (1-y)y\,\not{q}\gamma^\mu\not{q} - yz\,\not{q}\gamma^\mu\not{p} + z(1-y)\,\not{p}\gamma^\mu\not{q}$$
$$+ z^2\,\not{p}\gamma^\mu\not{p} + m^2\gamma^\mu - 2m\left(2zp^\mu + (1-2y)q^\mu\right)\Big]\,u(p)$$

Γ • $\bar{u}'\not{q}\gamma^\mu\not{q}u = 2q^\mu\bar{u}(p')\not{q}u(p) - \bar{u}'\gamma^\mu u\,q^2 = -q^2\bar{u}'\gamma^\mu u$

• $\not{q}\gamma^\mu\not{p} \to (\not{p}'-\not{p})\gamma^\mu\not{p} = m^2\gamma^\mu - m\not{p}\gamma^\mu$
$$= m^2\gamma^\mu - 2p^\mu m + m^2\gamma^\mu$$

• $\not{p}\gamma^\mu\not{q} = \underbrace{2p^\mu\not{q}}_{\to 0} - \gamma^\mu\not{p}\not{q} = -2p\cdot q\,\gamma^\mu + \gamma^\mu(\not{p}'-\not{p})m$
$$= -2p\cdot q\,\gamma^\mu + 2m\,p'^\mu - 2m^2\gamma^\mu$$

• $\not{p}\gamma^\mu\not{p} = 2m\,p^\mu - m^2\gamma^\mu$

$$N \to \bar{u}'\Big\{-\frac{1}{2}l^2\gamma^\mu + (1-y)y\,q^2\gamma^\mu - yz\,m^2\gamma^\mu + 2yzm\,p^\mu - m^2yz\,\gamma^\mu$$
$$+ z(1-y)\left(-2p\cdot q\,\gamma^\mu + 2m\,p'^\mu - 2m^2\gamma^\mu\right) + m^2\gamma^\mu + z^2\left(2m\,p^\mu - m^2\gamma^\mu\right)$$
$$- 2m\left(2zp^\mu + (1-2y)\,q^\mu\right)\Big\}\,u(p)$$

• $-2pq = -2p(p'-p) = -2pp' + 2m^2 = q^2$

$$N \to \bar{u}'\Big\{-\frac{1}{2}l^2\gamma^\mu + (1-y)(1-x)\,q^2\gamma^\mu + m^2\gamma^\mu\left(-2\cancel{y}z + 1 - 2z(1-\cancel{y}) - z^2\right)$$
$$+ 2m\left(yz\,p^\mu + p'^\mu z(1-y) + z^2p^\mu - (1-2y)\,q^\mu - 2z\,p^\mu\right)\Big\}\,u(p)$$

$$= \bar{u}(p')\Big\{-\frac{1}{2}l^2\gamma^\mu + (1-y)(1-x)\,q^2\gamma^\mu + m^2\gamma^\mu\left(1 - 2z - z^2\right)$$
$$+ \underset{\substack{\uparrow \\ 2m\gamma^\mu - i\sigma^{\mu\nu}q_\nu}}{(p+p')^\mu}\,mz(z-1) + \underbrace{m\,q^\mu(z-2)(x-y)}_{=0 \text{ zbog } x\leftrightarrow y}\Big\}\,u(p)$$

(Gordon-ov id.)

$$= \bar{u}(p')\Big\{\gamma^\mu\Big(-\frac{l^2}{2} + (1-x)(1-y)\,q^2 + (1-4z+z^2)\,m^2\Big) - iz(z-1)\,m\,\sigma^{\mu\nu}q_\nu\Big\}\,u(p)$$

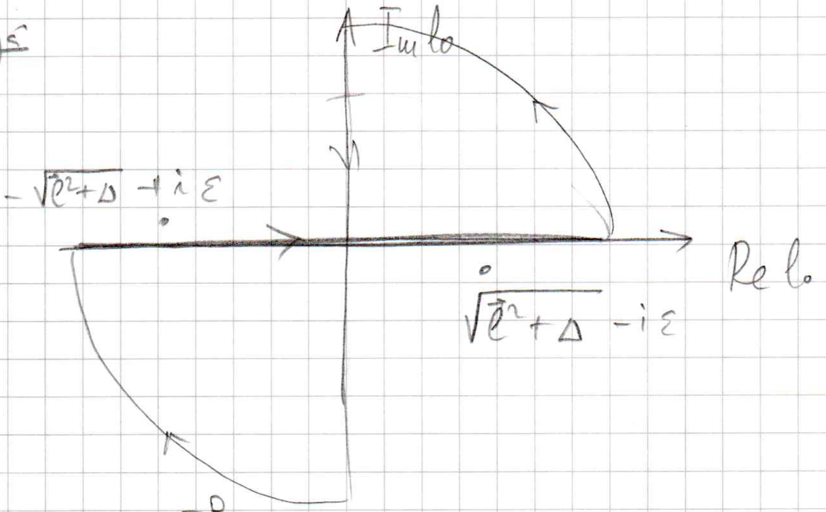
$$\Rightarrow \bar{u}'\,\delta\Gamma^\mu u = 2ie^2 \int \frac{d^4 l}{(2\pi)^4} \int_0^1 dx\,dy\,\delta(x+y+z-1)\,\frac{2}{(l^2-\Delta+i\varepsilon)^3} \times$$

$$\times\, \bar{u}' \Big\{ \Big(-\frac{l^2}{2} + (1-x)(1-y)q^2 + (1-4z+z^2)m^2 \Big)\gamma^\mu + \frac{i\sigma^{\mu\nu}q_\nu}{2m}\, 2m^2 z(1-z) \Big\} u(p)$$

$$\Delta = -xyq^2 + (1-z)^2 m^2 > 0$$

$\boxed{\text{UV}}$ $\quad \displaystyle\int \frac{l^3\,dl}{(l^2)^3}\,\big(\underset{\substack{\uparrow \\ \text{log div.}}}{l^2},\ \underset{\substack{\uparrow \\ \text{konač}}}{1}\big)$

<u>Wick rotacija</u>



$$\int_{-R}^{R} dl_0\, f(l_0) + \int_{R}^{-R} i\,dl_0^E\, f(i l_0^E) = 0$$

$$\Rightarrow \int_{-\infty}^{\infty} dl_0\, f(l_0) = i \int_{-\infty}^{\infty} dl_0^E\, f(i l_0^E)$$

$$l^0 = i\,l^{0E} \equiv i\,\bar{l}^0$$
$$\vec{l} = \vec{l}_E \equiv \bar{\vec{l}}_E$$

$$I = \int \frac{d^4 l}{(2\pi)^4} \frac{1}{(l^2-\Delta)^m} = \frac{i}{(-1)^m} \frac{1}{(2\pi)^4} \int d^4 l_E \frac{1}{(l_E^2+\Delta)^m}$$

$$= \frac{i(-1)^m}{(2\pi)^4} \int d^4\Omega_4 \int_0^\infty dl_E \frac{l_E^3}{(l_E^2+\Delta)^m}$$

F n-dim. sferne koord. $r, \phi, \theta_1, \ldots \theta_{n-2}$

$$x_1 = r \sin\theta_{n-2} \sin\theta_{n-3} \cdots \sin\theta_1 \sin\phi$$

$$x_2 = r \sin\theta_{n-2} \sin\theta_{n-3} \cdots \sin\theta_1 \cos\phi$$

$$x_3 = r \sin\theta_{n-2} \sin\theta_{n-3} \cdots \sin\theta_2 \cos\theta_1$$

$$\vdots$$

$$x_n = r \cos\theta_{n-2}$$

$$dV = r^{n-1} dr\, d\phi \sin\theta_1 d\theta_1 \cdots \sin^{n-2}\theta_{n-2} d\theta_{n-2}$$

$$\int d\Omega_n = \ldots \frac{2\pi^{n/2}}{\Gamma\left(\frac{n}{2}\right)}$$

$$\int d\Omega_4 = 2\pi^2$$

$$I = \frac{i(-1)^m}{4\pi^2} \frac{1}{(m-1)(m-2)} \frac{1}{\Delta^{m-2}}$$

$$\int \frac{d^4 l}{(2\pi)^4} \frac{l^2}{(l^2-\Delta)^m} = \frac{2}{(m-1)(m-2)(m-3)} \frac{1}{\Delta^{m-3}} \quad (m > 3)$$

Pauli-Vilarsova Regularizacija: "pravimo integral konvergentnim"

$$\frac{1}{(k-p)^2+i\varepsilon} \longrightarrow \frac{1}{(k-p)^2+i\varepsilon} - \frac{1}{(k-p)^2-\Lambda^2+i\varepsilon}$$

velika masa
fiktivna restica
fizikalne velicine ne smeju da zavise od Λ

$$\Delta \to \Delta_\Lambda = -xyq^2 + (1-z)^2 m^2 + z\Lambda^2$$

$$\int \frac{d^4 l}{(2\pi)^4} \left[\frac{l^2}{(l^2-\Delta)^3} - \frac{l^2}{(l^2-\Delta_\Lambda)^3} \right] = \frac{i}{(4\pi)^2} \int_0^\infty dl_E^2 \left(\frac{l_E^4}{(l_E^2+\Delta)^3} - \frac{l_E^4}{(l_E^2+\Delta_\Lambda)^3} \right)$$

$$= \frac{i}{(4\pi)^2} \ln \frac{\Delta_\Lambda}{\Delta} \qquad \Delta_\Lambda \to z\Lambda^2$$

$$\int \frac{x^2 dx}{(x+\Delta)^3} = -\frac{x^2}{2(x+\Delta)^2} + \frac{\Delta}{x+\Delta} + \ln(x+\Delta)$$

(10)

$$\bar{u}'\,\delta\Gamma^\mu u = 4ie^2\int_0^\Lambda dx\,dy\,dz\;\delta(x+y+z-1)\;\bar{u}(p')\Big[-\frac{1}{2}\gamma^\mu\frac{i}{(4\pi)^2}\ln\frac{\Delta_\Lambda}{\Delta}$$

$$+\Big((1-x)(1-y)q^2+(1-4z+z^2)m^2\Big)\gamma^\mu\frac{-i}{(4\pi)^2}\frac{1}{2\Delta}$$

$$+\frac{1}{2m}\sigma^{\mu\nu}q_\nu\,2m^2 z(1-z)\frac{-i}{(4\pi)^2}\frac{1}{2\Delta}\Big]u(p)$$

$$+\ldots\frac{1}{\Delta_\Lambda}\;=0\;|\;\text{if }\Lambda\to\infty$$

$F_1(0)$ je divergentan; Ja hoću ($\mu\nu$)

$$-ie\bar{u}'\,\Gamma^\mu(q^2)\,u\Big|_{\substack{p^2=p'^2=m^2\\ q^2=0}} = -ie\gamma^\mu$$

PRAVIM SUBTRAKCIJU $\quad\delta F_1(q^2)\longrightarrow\delta F_1(q^2)-\delta F_1(0)$

first order correct of F_1 $\qquad x=1-y-z$

OVAKO uklanjam divergenciju

$F_1(q^2)$ je IR divergentan ! $\qquad y<1-z \qquad 0<x=1-y-z<1$

For ex.: F $q^2=0$

$$\int_0^1 dx\,dy\,dz\;\delta(x+y+z-1)\frac{(1-4z+z^2)m^2}{(1-z)^2m^2} \rightsquigarrow \int dx\,dy\;\theta(1-y-z)$$

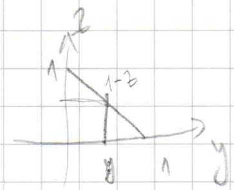
$$=\int_0^1 dz\int_0^{1-z}dy\;\frac{-2+(1-z)(3-z)}{(1-z)^2} = \underbrace{\int_0^1 dz\;\frac{-2}{1-z}}_{\text{divergentno}}+\ldots$$

→ zato dodajemo fotonu malu masu μ^2

$$\boxed{\delta F_1(q^2)=\frac{\alpha}{2\pi}\int_0^1 dx\,dy\,dz\;\delta(x+y+z-1)\Big[\ln\frac{(1-z)^2m^2+\cancel{\mu^2 z}}{m^2(1-z)^2-q^2xy+\cancel{\mu^2 z}} + \frac{m^2(1-4z+z^2)+(1-x)(1-y)q^2}{m^2(1-z)^2-xyq^2+\mu^2 z} - \frac{m^2(1-4z+z^2)}{m^2(1-z)^2+\mu^2 z}\Big]+\mathcal{O}(\alpha^2)}$$

$$\boxed{F_2(q^2) = \frac{4ie^2}{(4\pi)^2}\,\frac{-i}{2}\int_0^1 dx\,dy\,dz\,\delta(x+y+z-1)\,\frac{2m^2 z(1-z)}{-xyq^2+(1-z)^2m^2} + O(\alpha^2)}$$

$F_2(q^2)$ je konačno:



$$F_2(0) = \frac{\alpha}{2\pi}\int_0^1 dx\,dy\,dz\,\delta(x+y+z-1)\,\frac{2z}{1-z}$$

$$= \frac{\alpha}{\pi}\int_0^1 dy\int_0^1 dz\,\frac{z}{1-z}\,\theta(1-y-z)$$

$$= \frac{\alpha}{\pi}\int_0^1 dz\int_0^{1-z} dy\,\frac{z}{1-z}$$

$$= \frac{\alpha}{2\pi}$$

$x = 1-y-z$

$0 < 1-y-z < 1$

$y < 1-z$

$$\boxed{g = 2 + \frac{\alpha}{\pi} + O(\alpha^2)}$$

anomalni m.m

$a = \frac{g-2}{2} = \frac{\alpha}{2\pi} = 0{,}0011614$ Schwinger 1948

exp: $0{,}00115965218073$ (2008) Gabrielse

Ovo je konačna one-loop korekcija!

$$-ie\bar u(p')\left(F_1(q^2)\gamma^\mu + \frac{i}{2m}\sigma^{\mu\nu}q_\nu F_2(q^2)\right)u(p)$$

$$= -ie\,\bar u(p')\left[F_1(0)\gamma^\mu + \frac{i}{m}\frac{\sigma^{\mu\nu}}{2}q_\nu F_2(0) + \dots\right)u(p)$$

Ovaj VERTEKS sledi iz član

$$e F_1(0)\bar\Psi\not{A}\Psi + \underbrace{\frac{e}{2m}F_2(0)F_{\mu\nu}\bar\Psi\frac{\sigma^{\mu\nu}}{2}\Psi + \dots}_{\text{interakcija } e^- \text{ sa } \gamma \text{ koja nije minimalni kapling}}$$