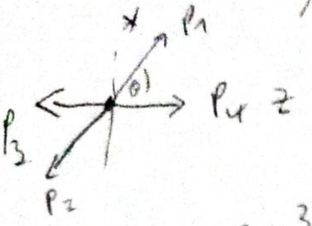
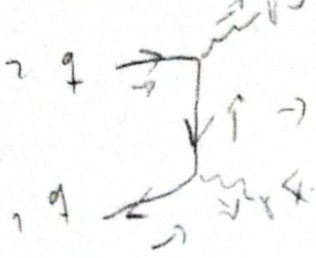
20 | 22.3 | $s = \sin\theta$ cos analog
$s' = \sin\frac{\theta}{2}$

$$M = \frac{(Qg)^2}{4p^2} \bar{V}(1)\left[\left(\frac{1}{s'^2}\left(p(4)\,\epsilon^*(4)\,\epsilon^*(3) + 2(p_1 \epsilon^*(4))\,\epsilon(3)\right)\right.\right.$$
$$\left.\left. + \left(\frac{1}{c'^2}\left(p(3) - p(4)\right)\epsilon^*(3)\,\epsilon^*(4) + 2(p_1 \epsilon^*(3))\,\epsilon(4)\right)\right]$$



$\epsilon_\uparrow^* = \frac{1}{\sqrt{2}}\begin{pmatrix}-1\\ \cdot \\ 0\end{pmatrix}$ $\epsilon_\downarrow^* = \frac{1}{\sqrt{2}}\begin{pmatrix}1\\ \cdot \\ 0\end{pmatrix}$
$\epsilon_\uparrow^* \epsilon_\downarrow^* = -1$ $\epsilon_\uparrow^* \times \epsilon_\downarrow^* = \begin{pmatrix}0\\0\\ \cdot\end{pmatrix}$



$$M_1 = \frac{(Qg)^2}{(p_1-p_4)^2}\,\bar{V}(1)\,\epsilon(4)\,(p_1 - p_4)\,\epsilon(3)\,U(2)$$
$(p_1-p_4)^2 = 4p^2 s'^2$

$$M_2 = \frac{(Qg)^2}{(p_1-p_3)^2}\,\bar{V}(1)\,\epsilon(3)\,(p_1 - p_3)\,\epsilon(4)\,U(2)$$
$(p_1-p_3)^2 = 4p^2 c'^2$, $-p_3 = +p_4$

↳ ↯ Falsch

$U_\uparrow(2) = \sqrt{p}\begin{pmatrix}s'\\c'\\s'\\c'\end{pmatrix}$ $U_\downarrow(2) = \sqrt{p}\begin{pmatrix}-c'\\s'\\+c'\\-s'\end{pmatrix}$
ϕ $\{_{180°\text{ rot}}$

$\bar{V}(1)_\uparrow = \sqrt{p}\,(s' \; -c' \; s' \; -c')$
$\bar{V}(1)_\downarrow = \sqrt{p}\,(c' \; s' \; -c' \; -s')$

$\bar{V}$	U	$\epsilon(3)$	$\epsilon(4)$
↑	↑	↑	↓
↑	↑	↓	↑
↓	↓	↑	↓
↓	↓	↓	↑

$\Gamma_1 = p_1 \epsilon(4)\,\epsilon(3) - p_1\,\epsilon(4)\,\epsilon(3) + p_4\,\epsilon(4)\,\epsilon(3)$
$\Gamma_2 = p_1 \epsilon(3)\,\epsilon(4) - p_1\,\epsilon(3)\,\epsilon(4) + p_3\,\epsilon(3)\,\epsilon(4)$
$= -p_4\,\epsilon(3)\,\epsilon(4)$

$\bar{V}(1)\,p_1 = 0$

$$\Rightarrow M_1 = \frac{(Qg)^2}{-4p^2 s'^2}\,\bar{V}(1)\left((p_1 \cdot \epsilon(4))\,\epsilon(3) + p(4)\,\epsilon(4)\,\epsilon(3)\right)U(2)$$

$$M_2 = \frac{(Qg)^2}{-4p^2 c'^2}\,\bar{V}(1)\left((p_1 \epsilon(3))\,\epsilon(4) - p(4)\,\epsilon(3)\,\epsilon(4)\right)U(2)$$
$+ \epsilon(3)$! ← F!
$\epsilon_\uparrow^* \epsilon_\uparrow^* = 0$

$\epsilon_\downarrow^* = \sqrt{2}\begin{pmatrix} & & & -1\\ & & 0 & \\ & 1 & & \\ 0 & & & \end{pmatrix}$

$\epsilon_\uparrow^* = \sqrt{2}\begin{pmatrix} & & & 0\\ & & 1 & \\ & 0 & & \\ -1 & & & \end{pmatrix}$

$\bar{V}\,\epsilon^*\,U$: $\uparrow\uparrow\uparrow = \sqrt{2}p\,(s' \; -c' \; s' \; -c')\begin{pmatrix}0\\s'\\0\\-s'\end{pmatrix}$
$= p\sqrt{2}\,(-c's' + c's') = 0$

✓ $p_1 \epsilon_\uparrow^* = \frac{ps}{\sqrt{2}}$ $p_1 \epsilon_\downarrow^* = \frac{-ps}{\sqrt{2}}$

$\uparrow\downarrow\uparrow = \sqrt{2}p\,(s' \; -c' \; s' \; -c')\begin{pmatrix}-c'\\0\\c'\\0\end{pmatrix} = 0$

$\uparrow\uparrow\downarrow = \sqrt{2}p\,(s' \; -c' \; s' \; -c')\begin{pmatrix}0\\c'\\0\\c'\end{pmatrix}$
$= \sqrt{2}p\,(-c'^2 - c'^2) = -2\sqrt{2}p\,c'^2$

~~$\frac{\uparrow\downarrow\downarrow}{\sqrt{2}p} = (s' \; -c' \; s' \; -c')\,(\ldots) = 2sc'$~~

$\frac{\downarrow\uparrow\downarrow}{\ldots} = (c' \; s' \; -c' \; -s')\begin{pmatrix}0\\c'\\0\\c'\end{pmatrix}$
$= 0$

$\frac{\downarrow\uparrow\uparrow}{\sqrt{2}p} = (c' \; s' \; -c' \; -s')\begin{pmatrix}0\\s'\\0\\-s'\end{pmatrix} = 2s'^2$

27 | 22.3

$\downarrow\downarrow\uparrow = (c' s' -c' -s') \begin{pmatrix} -c \\ 0 \\ c \\ 0 \end{pmatrix} = -2c'^2$ $\uparrow\downarrow\downarrow = (s' -c' s' -c') \begin{pmatrix} s' \\ 0 \\ s' \\ 0 \end{pmatrix} = 2s'^2$

$\downarrow\downarrow\downarrow = (c' s' -c' -s') \begin{pmatrix} s' \\ 0 \\ s' \\ 0 \end{pmatrix} = 0$

(V) $\neq 0 \to \uparrow\uparrow\downarrow = -2c'^2$ $\uparrow\downarrow\downarrow = 2s'^2$ $\downarrow\uparrow\uparrow = 2s'^2$ $\downarrow\downarrow\uparrow = -2c'^2$

↳ Trick: Symetrie in Erg! + $\theta \to \theta + 180$ → umdrehen der Erg !! :)

$P_4 \mathcal{E}^*(a) \mathcal{E}^*(b)$: $\mathcal{E}^*_\uparrow \mathcal{E}^*_\uparrow = \mathcal{E}^*_\downarrow \mathcal{E}^*_\downarrow = 0$! $\frac{\mathcal{E}^*_\uparrow \mathcal{E}^*_\downarrow}{2} = \begin{pmatrix} 0&0&0&0 \\ 0&1&0&0 \\ 0&0&0&0 \\ 0&0&0&1 \end{pmatrix}$

(V) $\frac{\mathcal{E}^*_\downarrow \mathcal{E}^*_\uparrow}{2} = \begin{pmatrix} 1&0&0&0 \\ 0&0&0&0 \\ 0&0&1&0 \\ 0&0&0&0 \end{pmatrix}$ $\mathcal{E}_\uparrow \mathcal{E}_\downarrow + \mathcal{E}_\downarrow \mathcal{E}_\uparrow = -2 \cdot -1 = 2\mathbb{1}$ ✓

(V) $P_4 = p \begin{pmatrix} \mathbb{1} & \begin{smallmatrix} -1&0 \\ 0&1 \end{smallmatrix} \\ \begin{smallmatrix} 1&0 \\ 0&-1 \end{smallmatrix} & -\mathbb{1} \end{pmatrix}$ $P_4 \uparrow\downarrow = \begin{pmatrix} 0&0&0&0 \\ 0&1&0&1 \\ 0&0&0&0 \\ 0&-1&0&-1 \end{pmatrix}$ $P_4 \downarrow\uparrow = \begin{pmatrix} 1&0&-1&0 \\ 0&0&0&0 \\ 1&0&-1&0 \\ 0&0&0&0 \end{pmatrix}$

$\bar{v} P_4 \mathcal{E}^* \mathcal{E}^* v$: $\frac{\uparrow\downarrow\uparrow}{2\sqrt{pp}} = \begin{pmatrix} 0 \\ 2c' \\ 0 \\ -2c' \end{pmatrix}$ $\uparrow\downarrow\downarrow = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \end{pmatrix}$ $\downarrow\uparrow\uparrow = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \end{pmatrix}$ $\downarrow\uparrow\downarrow = \begin{pmatrix} -2c' \\ 0 \\ -2c' \\ 0 \end{pmatrix}$

$\frac{\uparrow\uparrow\downarrow\uparrow}{2p^2} = (s' -c' s' -c') \begin{pmatrix} 0 \\ 2c' \\ 0 \\ -2c' \end{pmatrix} = 0$ $\frac{\uparrow\uparrow\downarrow\downarrow}{2p^2} = 0$ $\uparrow\downarrow\uparrow\uparrow = 0$ $\uparrow\downarrow\uparrow\downarrow = (s' -c' s' -c') (\ldots) = -4c's' = -2s$

$\downarrow\uparrow\downarrow\uparrow = (c' s' -c' -s') \begin{pmatrix} 0 \\ 2c \\ 0 \\ -2c' \end{pmatrix} = 4s'c' = 2s$ $\downarrow\uparrow\downarrow\downarrow = 0$ $\downarrow\downarrow\uparrow\uparrow = 0$

(V)

$\downarrow\downarrow\uparrow\downarrow = (c' s' -c' -s') \begin{pmatrix} -2c' \\ 0 \\ -2c' \\ 0 \end{pmatrix} = 0$ $\neq 0$: $\uparrow\downarrow\uparrow\downarrow = -4p^2 s$ $\downarrow\uparrow\downarrow\uparrow = 4p^2 s$

Ok unter 180° drehen ✓

22.122.3

$4p^2 \frac{\mathcal{M}}{(e s)^2}$:

$(p_1 \cdot \varepsilon) \bar{v}_4 \not{\varepsilon}_3 \not{\varepsilon}_2 u + \frac{1}{v} p_{(4)} \not{\varepsilon} \not{\varepsilon} v \quad) + \frac{1}{c'^2} (p_{(1)} \cdot \varepsilon \, \bar{v} \not{\varepsilon} \not{\varepsilon} u - \bar{v}_4 \not{\varepsilon} \not{\varepsilon} v$

$\uparrow\uparrow\uparrow\uparrow$ (1 3 4 2) $= \frac{1}{s'^2} (\uparrow \cdot \uparrow\uparrow\uparrow + \uparrow\uparrow\uparrow\uparrow \quad) + \frac{1}{c'^2} (\uparrow \cdot \uparrow\uparrow\uparrow - \uparrow\uparrow\uparrow$

$0 \quad \frac{1}{c'^2} \; 0 \quad 0$

$= \frac{1}{s^2} (0$

$= 0$

$\uparrow\uparrow\uparrow\downarrow$ (1 2 3 4) $= \frac{1}{s'^2} (\downarrow \; \uparrow\uparrow\uparrow + \uparrow\downarrow\uparrow\uparrow) + \frac{1}{c'^2} (\uparrow \cdot \uparrow\downarrow\uparrow - \uparrow\uparrow\downarrow\uparrow)$

$= 0$

$\uparrow\uparrow\downarrow\uparrow$ (1 2 3 4) $= \frac{1}{s'^2} (\uparrow \cdot \uparrow\downarrow\uparrow + \uparrow\uparrow\downarrow\uparrow) + \frac{1}{c'^2} (\downarrow \cdot \uparrow\uparrow\uparrow - \uparrow\downarrow\uparrow\uparrow)$

$0 \quad 0 \quad 0 \quad 0$

$= 0$

$\uparrow\uparrow\downarrow\downarrow$ (1 2 3 4) $= \frac{1}{s'^2} (\downarrow \cdot \uparrow\downarrow\uparrow + \uparrow\downarrow\downarrow\uparrow) + \frac{1}{c'^2} (\downarrow \cdot \uparrow\downarrow\uparrow - \uparrow\downarrow\downarrow\uparrow)$

$= 0$

$\uparrow\downarrow\uparrow\uparrow$ (1 2 3 4) $= \frac{1}{s'^2} (\uparrow \cdot \uparrow\uparrow\downarrow + \uparrow\uparrow\uparrow\downarrow) + \frac{1}{c'^2} (\uparrow \cdot \uparrow\uparrow\downarrow - \uparrow\uparrow\uparrow\downarrow)$

$= \frac{1}{s'^2} \cdot (-\frac{p^2 s}{\sqrt{2}} \sqrt{2} \, 2c'^2) + \frac{1}{c'^2} \cdot (-p^2 s \, 2c'^2) = -2 s c'^2 p^2 \left(\frac{1}{s'^2} + \frac{1}{c'^2} \right) = -\frac{8 c'^2}{s} p^2$

$= -2p^2 s \left(\frac{c'^2}{s'^2} + 1 \right) = -4p'^2 \left(\frac{c'}{s'} \right) = -4p^2 \cot'^2$

$-p^2 2s \left(\frac{c'^2}{s'^2} + 1 \right) = -p^2 2 s \frac{1}{s'^2 c'^2} = \frac{4}{s^2}$

$\uparrow\downarrow\uparrow\downarrow$ (1 2 3 4) $= \frac{1}{s'^2} (\downarrow \cdot \uparrow\uparrow\downarrow + \uparrow\downarrow\uparrow\downarrow) + \frac{1}{c'^2} (\uparrow \cdot \uparrow\downarrow\downarrow - \uparrow\uparrow\downarrow\downarrow)$

$= \frac{1}{s'^2} (+ \frac{p^2 s}{\sqrt{2}} \sqrt{2} \, 2c'^2 - 4p^2 s) + \frac{1}{c'^2} (\frac{p^2 s}{\sqrt{2}} \sqrt{2} \, 2s'^2)$ im Weg?

$= -\frac{4p^2 s}{s'^2} + 2p^2 s \left(\frac{c'^2}{s'^2} + \frac{s'^2}{c'^2} \right) = 2p^2 s \left((\cot'^2 + \tan'^2) - 2 \frac{1}{s'^2} \right)$

$= \tan'^2 - \cot'^2 - 2$

Lugly

$\uparrow\downarrow\downarrow\uparrow$ (1 2 3 4) $= \frac{1}{s'^2} (\uparrow \cdot \uparrow\downarrow\downarrow + \uparrow\uparrow\downarrow\downarrow) + \frac{1}{c'^2} (\downarrow \cdot \uparrow\uparrow\downarrow - \uparrow\downarrow\uparrow\downarrow)$

$= \frac{1}{s'^2} (\frac{p^2 s}{\sqrt{2}} \sqrt{2} \, 2s'^2 + 0) + \frac{1}{c'^2} (+ p^2 s \, 2c'^2 + 4p^2 s)$

$= 4p^2 s + \frac{4p^2 s}{c'^2} = 4p^2 s \left(1 + \frac{1}{c'^2} \right) = 4p^2 s (2 + \tan'^2) = 4p^2 s + \frac{2 s'^2}{c'^2} = 4p^2 (s + 2\tan'^2)$

$1 + 1 + \tan'^2 = 2 + \tan'^2$

23 | 22.3

$|\uparrow\downarrow\downarrow\downarrow\rangle_{1234} = \frac{1}{s'^2}\left(\downarrow\uparrow\downarrow\downarrow + \uparrow\downarrow\downarrow\downarrow\right) + \frac{1}{c'^2}\left(\downarrow\uparrow\downarrow\downarrow - \uparrow\downarrow\downarrow\downarrow\right)$

$= \frac{1}{s'^2}\left(-\frac{p^2 S}{\sqrt{2}}\sqrt{2}\, 2 s'^2 + 0\right) + \frac{1}{c'^2}\left(-p^2 S\, 2 s'^2 \right. = -4p^2 \frac{s'c'}{c'^2} = \underline{\underline{-4p^2 \tan'}}$

$= -2p^2 S \left(1 + \tan'^2\right) = -2p^2 \frac{S}{c'^2}$

$|\downarrow\uparrow\uparrow\uparrow\rangle_{1234} = \frac{1}{s'^2}\left(\uparrow\downarrow\uparrow\uparrow + \downarrow\uparrow\uparrow\uparrow\right) + \frac{1}{c'^2}\left(\uparrow\downarrow\uparrow\uparrow - \downarrow\uparrow\uparrow\uparrow\right)$

$= \frac{1}{s'^2}\left(\frac{p^2 S}{\sqrt{2}}\sqrt{2}\, 2 s'^2\right) + \frac{1}{c'^2} p^2 S\, 2 s'^2 = 2p^2 S\left(1 + \tan'^2\right)$

$|\downarrow\uparrow\uparrow\downarrow\rangle_{1234} = \frac{1}{s'^2}\left(\downarrow\downarrow\uparrow\uparrow + \downarrow\downarrow\uparrow\uparrow\right) + \frac{1}{c'^2}\left(\uparrow\downarrow\downarrow\uparrow - \downarrow\uparrow\downarrow\uparrow\right)$

$= \frac{1}{s'^2}\left(-p^2 S\, 2 s'^2\right) + \frac{1}{c'^2}\left(-p^2 S\, 2 c'^2 - 4p^2 S\right)$

$=$ ~~$-2p^2 S + -4p^2 S = -$~~ $-4p^2 S\left(1 + \frac{1}{c'^2}\right)$

$|\downarrow\uparrow\downarrow\uparrow\rangle_{1234} = \frac{1}{s'^2}\left(\uparrow\downarrow\downarrow\uparrow + \downarrow\uparrow\downarrow\uparrow\right) + \frac{1}{c'^2}\left(\downarrow\downarrow\uparrow\uparrow - \downarrow\downarrow\uparrow\uparrow\right)$

$= \frac{1}{s'^2}\left(-p^2 S\, 2c'^2 + 4p^2 S\right) + \frac{1}{c'^2}\left(-p^2 S\, 2 s'^2\right)$

$= -2p^2 S\left(\frac{c'^2}{s'^2} + \frac{s'^2}{c'^2}\right) \ldots \frac{2}{s'^2}\right)$

$\downarrow\downarrow\uparrow\uparrow = 0 \quad \downarrow\downarrow\uparrow\downarrow = 0 \quad \downarrow\downarrow\downarrow\uparrow = 0 \quad \downarrow\downarrow\downarrow\downarrow = 0$

$|\downarrow\uparrow\downarrow\downarrow\rangle = +2p^2 S\left(\frac{c'^2}{s'^2} + 1\right)$

24 | 23.3

$s^{12}\bar{\Gamma}_1 = \gamma^0 (p_1 \varepsilon(4))^* \not\varepsilon(3)^\dagger + \not\varepsilon(3)^\dagger \not\varepsilon(4)^\dagger \not p(4)^\dagger) \gamma^0$

$= p_1 \varepsilon(4^a) \not\varepsilon(3^b) + \not\varepsilon(3)^b \not\varepsilon(4)^a \not p(4)^a$ (conj*)

$a_1 = 4 \quad b_1 = 3$

$a_2 = 3 \quad b_2 = 4$

$s^{12}\bar{\Gamma}_2 = p_1 \varepsilon(3) \not\varepsilon(4) \; \not\varepsilon(4) \not\varepsilon(3) \not p(4)$

$\not p(1) = -\not p(1)$

$|M|^2 = \left(\frac{e g}{4p^2}\right)^2 \mathrm{tr}(\Gamma \not p(1) \bar{\Gamma} \not p(1)) + \ldots$

$\Gamma_1 \not p \bar{\Gamma}_1 \not p + \Gamma_1 \not p \bar{\Gamma}_2 \not p + \Gamma_2 \not p \bar{\Gamma}_1 \not p$

$(\Gamma_1 + \Gamma_2) \not p (\bar{\Gamma}_1 + \bar{\Gamma}_2) \not p = \Gamma_1 \not p \bar{\Gamma}_1 \not p + \Gamma_1 \not p \bar{\Gamma}_2 \not p + \Gamma_2 \not p \bar{\Gamma}_2 \not p$

$p(\gamma^0 - \gamma^3)$

~~$\Gamma_i \not p \not p \Gamma_j \not p$~~

$\neq$

$\not p_1 \bar{\Gamma}_j = \not p_1 (p_1 \varepsilon(a_j) \not\varepsilon(b_j) + \not\varepsilon(b_j) \not\varepsilon(a_j) \not p(4))$

$= p_1 \varepsilon(a) \, (\varepsilon(b) p_1 - \not\varepsilon(b) \not p_1) + \varepsilon(b) p_1 - \not\varepsilon(b) \not p_1) \not\varepsilon(a) \not p(4)$

$= \varepsilon(b) p_1 \not\varepsilon(a) \not p(4)$

$- \not\varepsilon(b) (\varepsilon(a) p_1 - \not\varepsilon(a) \not p_1) \not p(4)$

$= \varepsilon(b) p_1 \not\varepsilon(a) \not p(4)$

$- \not\varepsilon(b) \varepsilon(a) p_1 \not p(4)$

$+ \not\varepsilon(b) \not\varepsilon(a) \not p_1 \not p_4$

$= \varepsilon(b) p_1 \not\varepsilon(a) \not p(4)$

$- \not\varepsilon(b) \varepsilon(a) p_1 \not p(4)$

$+ \not\varepsilon(b) \not\varepsilon(a) \, p_1 \cdot p_4$

$- \not\varepsilon(b) \not\varepsilon(a) \not p_4 \not p_1$

$=$ ~~$p_1 \cdot \varepsilon(a) (p_1 \varepsilon(b))$~~

wird weg

$(p_1 \cdot \varepsilon(a))(p_1 \varepsilon(b)) - (p_1 \varepsilon(a)) \not\varepsilon(b) \not p_1 + p_1 \cdot \varepsilon(b) \not\varepsilon(a) \not p(4) - (p_1 \varepsilon(a)) \not\varepsilon(b) \not p(4)$

$+ p_1 p_4 \not\varepsilon(b) \not\varepsilon(a) - \not\varepsilon(b) \not\varepsilon(a) \not p_4 \not p_1$

$\cdot \not p_1 = 0$

$\not p_1 \not p_1 = p_1^2 = 0$

25 | 24.3

Nutze $\sum \varepsilon_{ij}^{(s)\mu} \varepsilon_j^{*(s)\nu} = \delta_{ij} - p_i p_j = \begin{pmatrix} 0 & & & \\ & 1 & & \\ & & 1 & \\ & & & 0 \end{pmatrix}$

hin z

$\Rightarrow \sum_\lambda \varepsilon_\lambda^\mu \varepsilon_\lambda^{*\nu} = -g^{\mu\nu}$!! $= \delta_{\mu\nu}$

(Eichinvar!)

↳ von Seite 20 → Mandelst + cos trick

$\sum_{\lambda_1\lambda_2 s_1 s_2} \sum \frac{|M|^2}{4} = 4\left(\frac{e\, q}{4\pi\, 2p}\right)^4 \frac{1}{4} \frac{1}{?} \operatorname{tr}\left(\left(\frac{\Gamma_1}{s^2} + \frac{\Gamma_2}{t^2}\right) \not{p}_2 \left(\frac{\Gamma_1}{s^2} + \frac{\Gamma_2}{t^2}\right) \not{p}_1\right)$

$\lambda_1\lambda_2 \quad = E_{cp}$ I

I: $\sum_{\lambda_1\lambda_2} \operatorname{tr}(\Gamma_i \not{p}_2 \bar{\Gamma}_j \not{p}_1) = \sum_{\lambda_1\lambda_2} \operatorname{tr}\left([p_1\cdot\varepsilon^*(a_i)\, \not{\varepsilon}^*(b_i)\, \not{p}_2 + \not{p}(a_i)\, \not{\varepsilon}^*(a_i)\, \not{\varepsilon}^*(b_i)\, \not{p}_2]\right.$
$\left.\cdot [p_1\varepsilon(a_j)\, \not{\varepsilon}(b_j)\, \not{p}_1 + \not{\varepsilon}(b_j)\, \not{\varepsilon}(a_j)\, \not{p}(a_j)\, \not{p}_1]\right)$

$= \sum_{\lambda_1\lambda_2} \operatorname{tr}(p_1\varepsilon^*(a_i)\, \not{\varepsilon}^*(b_i)\, \not{p}_2 (p_1\varepsilon(a_i)\, \not{\varepsilon}(b_j)\, \not{p}_1$
$+ p_1\varepsilon^*(a_i)\, \not{\varepsilon}^*(b_i)\, \not{p}_2\, \not{\varepsilon}(b_j)\, \not{\varepsilon}(a_j)\, \not{p}(a_j)\, \not{p}_1$
$+ \not{p}(a_i)\, \not{\varepsilon}^*(a_i)\, \not{\varepsilon}^*(b_i)\, \not{p}_2\, \not{\varepsilon}(p_1\varepsilon(a_j))\, \not{\varepsilon}(b_j)\, \not{p}_1$
$+ \not{p}(a_i)\, \not{\varepsilon}^*(a_i)\, \not{\varepsilon}(b_i)\, \not{p}_2\, \not{\varepsilon}(b_j)\, \not{\varepsilon}(a_j)\, \not{p}(a_j)\, \not{p}_1)$

↳ $i=j$: $= \operatorname{tr}(\not{p}_1 \not{p}_2 \not{p}_1 \not{p}_1) + \operatorname{tr}(\not{p}_1 \gamma_\nu \not{p}_2 \gamma^\nu \not{p}(a_j) \not{p}_1)$ (↓0 da $p^2=0$)
$+ \operatorname{tr}(\not{p}(a_i) \not{p}_1 \gamma_\nu \not{p}_2 \gamma^\nu \not{p}_1) + \operatorname{tr}(\not{p}(a_i) \gamma_\nu \gamma_\mu \not{p}_2 \gamma^\mu \gamma^\nu \not{p}(a_j) \not{p}_1)$

$\gamma_\mu \not{a} \gamma^\mu = -2\not{a}$ $\quad = -2 \operatorname{tr}(\not{p}_1 \not{p}_2 \not{p}(a_j) \not{p}_1) - 2 \operatorname{tr}(\not{p}(a) \not{p}_1 \not{p}_1 \not{p}_1)$
$= 0$

$+ 4 \operatorname{tr}(\not{p}(a) \not{p}_1 \not{p}(a) \not{p}_1) = 4 \operatorname{tr}(\not{p}(a) \not{p}_1 \not{p}(a) \not{p}_1)$!!
$= 8\left((p(a) p_1)^2 - p(a)^2\, p_1^2 + (p(a) p_1)^2\right)$
$= 8\left(2 (p(a) p_1)^2 - p(a)^2 p_1^2\right) = 16\, (p(a) p_1)^2)$
$= 0 \quad\quad$ ↳ $p^2 (1 \pm \cos\theta)^2$

$i \neq j$:

$i \neq j$: $= \operatorname{tr}(\not{p}_1 \not{p}_1 \not{p}_1 \not{p}_1) + \operatorname{tr}(\not{p}_1 \gamma_\nu \not{p}_1 \gamma^\mu \not{p}(a_j) \not{p}_1)$
$+ \operatorname{tr}(\not{p}(a_i) \gamma_\mu \not{p}_1 \not{p}_1 \gamma^\mu \not{p}_1) + \operatorname{tr}(\not{p}(a_i) \gamma_\mu \gamma_\nu \not{p}_1 \gamma^\mu \gamma^\nu \not{p}(a_j) \not{p}_1)$

$\gamma_\mu \gamma^\mu = 4\,\mathbb{1} \quad\quad 2g^{\mu\nu} - \gamma^\nu \gamma^\mu$

$= 8 \operatorname{tr}(\not{p}(a_i) \not{p}_1 \not{p}(a_j) \not{p}_1) - 4 \operatorname{tr}(\not{p}(a_i) \not{p}_1 \not{p}(a_j) \not{p}_1)$!!
$= 4 \operatorname{tr}($ "

2.4.3 | 26

$(P_1 \cdot a)(P(ai)) P_1 P(aj))$

$= 8 \left((P(ai) P_1)(P(aj) P_1) - (P(ai) P(aj))(P_1^2) + (P_1 a)(P(ai)) P_1 P(aj) \right)$

$= 16 \left(P(ai) P_1 \cdot P(aj) P_1 \right) = 16 p^4 \left\{ (1-\cos(\theta))(1+\cos(\theta)) \right\}$ $4 s'^2 c'^2$

$(1+2) p(\cdot 1 + 2) p = 1p1p + 1p2p + 2p1p + 2p2p$

$= 16 p^4 \left(\frac{(p(4)P_1)^2}{s'^4} + \frac{2p^4(1+\dots)(1-\dots)}{s'^2 c'^2} + \frac{(p(3)P_1)^2}{c'^4} \right)$

$= 16 p^4 \left(\frac{(1-\cos\theta)^2}{s'^4} + \frac{8 s'^2 c'^2}{s'^2 c'^2} + \frac{(1+\cos\theta)^2}{c'^4} \right)$

~~$= 16 p^4 ($~~

falsch da $p_1 = -p_2$ ☹

$i = j$: $= tr(\gamma^\mu P_1^2 \gamma_\nu P_2 \gamma^\nu P_1) + tr(\gamma_\nu P_2 \gamma^\nu P_1 P(aj) P_1)$

$+ tr(P(ai) P_1 \gamma_\nu P_2 \gamma^\nu P_1) + tr(P(ai) \gamma_\mu \gamma_\nu P_2 \gamma^\nu \gamma^\mu P(aj) P_1)$

$= -2\, tr(P_2 P_1 P(aj) P_1) - 2\, tr(P(ai) P_1 P_2 P_1)$

$P(2P(aj)P_1 - P_1 P(aj))$

$= tr(P_2 P_1 P_1 P(aj)) + P(aj) P_1\, tr(P_2 P_1)$

$+ 4\, tr(P(ai) P_2 P(aj) P_1)$

$= -16 (P(aj)P_1)(P_2 \cdot P_1) - 16 (P(aj)P_1)\, 2p^2 + 4 \left((P(a)P_2)(P(a)P_1) - 0 + (P(a)P_1)(P(a)P_2) \right)$

$= -32 (2p^2 (P(a)P_1)) + 8 ((P(a)P_2)(P(a)P_1))$

27 $i \neq j$ ~~= tr(~~

24.3

$a_1 = 4 \quad b_1 = 3$

$\Gamma_1 = \not\epsilon^*(4)(\not p_1 - \not p_4)\not\epsilon^*(3) \quad \Gamma_2 = \not\epsilon(3)^*(\not p_1 - \not p_3)\not\epsilon^*(4)$

$\bar\Gamma_1 = \not\epsilon(3)(\not p_1 - \not p_4)\not\epsilon(4) \quad \bar\Gamma_2 = \dots$

$i = j$

$\sum_{\lambda_1, \lambda_2} tr(\Gamma_i \not p_2 \bar\Gamma_j \not p_1) = tr(\gamma_\mu(\not p_1 - \not p(a_i))\gamma_\nu \not p_2 \gamma^\nu (\not p_1 - \not p(a_j))\gamma^\mu \not p_1)$

$\not\epsilon^*(a_i)(\not p_1 - \not p(a_i))\not\epsilon^*(b_i)\not p_2 \not\epsilon(b_j)(\not p_1 - \not p(a_j))\not\epsilon(a_j)\not p_1$

$\gamma_\nu \not a \gamma^\nu = -2\not a$

$= -2\, tr(\gamma_\mu(\not p_1 - \not p(a_i))\not p_2(\not p_1 - \not p(a_j))\gamma^\mu \not p_1)$

$\gamma_\nu \not a \not b \not c \gamma^\nu = -2\not c \not b \not a$

$= 4\, tr((\not p_1 - \not p(a))\not p_2(\not p_1 - \not p(a))\not p_1)$

$= 4[\underbrace{tr(\not p_1 \not p_2 \not p_1 \not p_1)}_{=0} - \underbrace{tr(\not p_1 \not p_2 \not p(a)\not p_1)}_{=0} - \underbrace{tr(\not p(a)\not p_2 \not p_1 \not p_1)}_{=0} + tr(\not p(a)\not p_2 \not p(a)\not p_1)]$

$= 16[(p(a)p_2)(p(a)p_1) - 0 + (p(a)p_1)(p(a)p_2)] = 32[(p(a)p_2)(p(a)p_1)]$

$i \neq j$

$= tr(\gamma_\mu(\not p_1 - \not p(a_i))\gamma_\nu \not p_2 \gamma^\mu(\not p_1 - \not p(a_j))\gamma^\nu \not p_1)$

$= \gamma_\nu p(2)_\sigma \gamma^\sigma \gamma^\mu$

$= \gamma_\nu p(2)_\sigma (2g^{\mu\sigma} - \gamma^\mu \gamma^\sigma)$

$= 2\gamma_\nu p(2)^\mu - \gamma_\nu \gamma^\mu p(2)_\sigma \gamma^\sigma$

$= 2\gamma_\nu p(2)^\mu - g_{\nu\delta}\gamma^\delta \gamma^\mu \gamma^\sigma p(2)_\sigma$

$2g^{\delta\mu} - \gamma^\mu \gamma^\delta$

$= 2\gamma_\nu p(2)^\mu - 2 g_{\nu\delta} g^{\delta\mu}\gamma^\sigma p(2)_\sigma + \gamma^\mu \gamma_\nu \gamma^\sigma p^{(2)}_\sigma$

δ_ν^μ

28 | 26.3 | Neuberechnung $\quad \gamma^\nu \gamma^\mu = 2g^{\mu\nu} - \gamma^\mu\gamma^\nu$

$$\sum_{\lambda_1 \lambda_1}^{i \neq j} tr \dots = tr(\gamma_\mu (\not p_1 - \not p(a_i)) \gamma_\nu \not p_2 \gamma^\mu (\not p_1 - \not p(a_j)) \gamma^\nu \not p_1)$$

$\gamma_\nu \not p \gamma^\mu$

$$\hookrightarrow = \gamma^\nu \gamma^\sigma \gamma^\mu = \gamma^\nu (2g^{\sigma\mu} - \gamma^\mu \gamma^\sigma)$$

$$= 2\gamma^\nu g^{\sigma\mu} - \gamma^\nu \gamma^\mu \gamma^\sigma$$

$$= 2\gamma^\nu g^{\sigma\mu} - 2 g^{\nu\mu} \gamma^\sigma + \gamma^\mu \gamma^\nu \gamma^\sigma$$

↖ Schon hier muss der Fehler sein

$$= 2tr(\not p_2 (\not p_1 - \not p(a_i)) \gamma^\nu (\not p_1 - \not p(a_j)) \gamma_\nu \not p_1)$$

$$- 2tr(\gamma^\nu (\not p_1 - \not p(a_i)) \not p_2 (\not p_1 - \not p(a_j)) \gamma_\nu \not p_1)$$

$$+ tr(\gamma_\mu (\not p_1 - \not p(a_i)) \gamma^\mu \gamma^\nu \not p_2 (\not p_1 - \not p(a_j)) \gamma_\nu \not p_1)$$

$$= +4 tr(\not p_2 (\not p_1 - \not p(a_i)) \not p(a_j) \not p_1)$$

~~$-4 tr($~~

$$+ 4 tr((\not p_1 - \not p(a_j)) \not p_2 (\not p_1 - \not p(a_i)) \not p_1)$$

$$- 8 tr((\not p_1 - \not p(a_i)) \not p_2 (\not p_1 - \not p(a_j)) \not p_1)$$

$$= 8 (p_1 p_2) tr((\not p_1 - \not p(a_i)) \not p(a_j)) + 4 tr(\not p_2 \not p_1 \not p(a_i) \not p(a_j))$$

$$8(p_1 p(a_i)) tr(\not p_2 \not p(a_j))$$

$$- 4 tr(\not p_2 \not p(a_i) \not p_1 \not p(a_j))$$

$$+ 4 tr(\not p(a_j) \not p_2 \not p(a_i) \not p_1)$$

$$- 8 tr(\not p(a_i) \not p_2 \not p(a_j) \not p_1)$$

$$= 4 \cdot 8 (p_1 p_2)(p_1 - p(a_i)) p(a_j) + 8 \cdot 4 (p_1 p(a_i))(p_2 p(a_j))$$

$$- (p(a_i) p(a_j))(p_1 p_2) + (p(a_i) p_1)(p_2 p(a_j))$$

$$- 8 \cdot 4 ((p(a_i) p_2)(p(a_j) p_1)$$

$$= 32 [(p_1 p_2)(p_1 p(a_j)) - (p_1 p_2)(p(a_i) p(a_j)) + (p_1 p(a_i))(p_2 p(a_j))$$

$$- (p_1 p(a_j))(p_2 p(a_i)) + (p_1 p_2)(p(a_i) p(a_j)) - (p_2 p(a_i))(p_1 p(a_j))]$$

$$+ 2 (p_1 p(a_i))(p_2 p(a_j))$$

$$= 32 [(p_1 p_2)(p_1 p(a_i)) - 2 (p(a_i) p(a_j))]$$

$$- (p_1 p(a_j))(p_2 p(a_i))]$$

$$= 32 p^4 [2 (\hat p_1 \hat p(a_i)) - 4) + 2 (\hat p_1 \hat p(a_i))(\hat p_2 \hat p(a_j)) - (\hat p_1 \hat p(a_j))(\hat p_2 \hat p(a_i))]$$

29. 26.3

$\gamma_\mu \, \alpha_{\delta} \, \gamma^{\sigma} \gamma^{\nu} p_{2\delta} \, \gamma^{\delta} \gamma^{\mu}$

$\downarrow = -2\alpha_{\sigma} \, \gamma^{\delta} \gamma^{\nu} \gamma^{\sigma} p_{2\delta}$

$\Rightarrow -2\,tr(\not{p}_2 \gamma^{\nu} (\not{p}_1 - \not{p}(a_i)) (\not{p}_1 - \not{p}(a_j)) \gamma_\nu \not{p}_1$

$= 4\, tr(\not{p}_2 (\not{p}_1 - \not{p}(a_i)) (\not{p}_1 - \not{p}(a_j)) \not{p}_1)$

$= 4\, tr\, \not{p}_2 (\not{p}_1 - \not{p}(a_i)) \not{p}(a_j) \not{p}_1)$

$= -4 \cdot 4((p_1 p_2)[(p_1 - p(a_i)) p(a_j)] + (p_1 p(a_i))(p_2 p(a_j))$

$+ (p_1 p(a_j))(p_2 p_1) - (p_1 p(a_j))(p_2 p(a_i)))$

$= -16[(p_1 p_2)((p_1 p(a_j)) - p(a_i) p(a_j) + p_1 p(a_j)))$

$+ (p_1 p(a_i))(p_2 p(a_j)) - (p_1 p(a_j))(p_2 p(a_i)))$

All ~~$\Rightarrow \Sigma\; 2\, 2(1 \pm \cos c) - \;\; 2$~~ $(1+c)^2$

~~$+ (1 \mp c)(1 \pm c)$~~

$12 + 21 \quad 4 \quad (1-c)^2$

$= 2(2(1+c) - 2) + (1-c)(1-c) - (1+c)(1+c)$

$+ 2(2(1-c) - 2) + (1+c)(1+c) - (1-c)(1-c)$

$= 0$:)

29 | 26.3 | NB

30

$12 = \frac{32p^4}{s'^2c'^2}[2(1-c-4) + 2(1-c)(1-c) - (1+c)(1+c)]$

$21 = \frac{32p^4}{s'^2c'^2}[2(1+c-4) + 2(1+c)(1+c) - (1-c)(1-c))$

$12+21 = \frac{32p^4}{s'^2c'^2}[-12 + (1-c)^2 + (1+c)^2]$

Bolbels B

$= 32[(p_1p_2)((p_1 P(a_2'))$ $- (p_1 P(a_2'))(p_2 P(a_1'))]$

$2-1-c$
$1-c$

$12 = \frac{32p^4}{\dots}[2(1+c) - (1+c)(1+c)] = \frac{32p^4}{\dots}[(1+c)(1-c)$
$1-c^2$

$21 = \frac{32p^4}{\dots}(2(1-c) - (1-c)(1-c))$

$= \frac{32p^4}{\dots}(1-c)(2-1+c) = \frac{32p^4}{\dots}(1+c)(1-c)$

$= 32p^4 \frac{4}{s^2}s^2$ → Sollte 0 geben

$\hookrightarrow T_0$ ✓

$12+21 = p^4 8 \cdot 32$

$11+22 = 32p^4 \, s^2\left(\frac{1}{s'^4} + \frac{1}{c'^4} - \frac{2}{s'^2c'^2} + \frac{2}{s'^2c'^2}\right)$

$\frac{s'^4+c'^4}{s'^4c'^4} = \frac{2^4(s'^4+c'^4)}{s^4}$

$= 32p^4 \, 4$

$s'^2c'^2(\dots) = 4 \cdot 32p^4\left(\frac{c'^2}{s'^2} + \frac{s'^2}{c'^2}\right) - 2$

$= 32p^4s^2\left(\left[\frac{1}{s'^2} + \frac{1}{c'^2}\right]^2 - \frac{2}{s'^2c'^2}\right) = 4 \cdot 32p^4\left(\frac{c'^4}{s'^2}\right.$

$= 32p^4s^2\left(\frac{16}{s^4} - 8\right.$

$(s'^2 + c'^2)$

$= 8 \cdot 32p^4\left(\frac{4}{s^2} - 1\right)$ $= \frac{8 \cdot 32 p^4}{s^2}$

$= 8 \cdot 32p^4\left(\frac{2-s^2}{s^2}\right) = 8 \cdot 32p^4\left(\frac{1+c^2}{s^2}\right)$

3.1 $= \sum |M|^2 = \frac{1}{4} \frac{8\, 32\, p^4}{2^4 p^4} \left(\frac{1+c^2}{s^2}\right) (Qg)^4$

$= 4(Qg)^4 \left(\frac{1+c^2}{2s^2}\right) = 4(Qg)^4 \left(\frac{1}{2}\cosh \cdot (1+\tanh^2 \eta)\right)$

$= \frac{d\sigma}{d\Omega} = \frac{1}{64} \frac{1}{(8\pi)^2 E_{sp}^2} (\alpha Q^2 4\pi)^2 (\dots)$

$= \frac{1}{E_{sp}^2 2} (\dots) \left(\frac{\alpha Q^2}{2}\right)^2 = \frac{1}{2}\left(\frac{\alpha Q^2}{E_{sp}}\right)^2 \left(\frac{1+c^2}{s^2}\right)$

$= \frac{1}{3} \frac{\alpha^2 Q^4}{2F^2} \left(\frac{c^2+1}{s^2}\right) \to$ falsch $\frac{1}{2} \to \frac{1}{3} \to$ calc. ideal Rhol

$\left(\frac{2 - s^2}{s^2} = \frac{2}{s^2} - 1 = 2\cosh^2 \eta - 1 \right)$

$\hookrightarrow \sigma = 2\pi F \int_{\theta_1}^{\theta_2} d\theta \sin\theta \left(\frac{2-s^2}{s^2}\right)$

$= 2\pi F \int_{x_2}^{x_1} dx \frac{x^2+1}{1-x^2}$

$\left(= \frac{x^2+1}{(1+x)(1-x)} \right)$

$x^2 + 1 = -x^2 + 1 \,/\, 2$

$= 2\pi \int_{x_2}^{x_1} dx \; -1 + \frac{2}{1-x^2}$

$= 2\pi F \left[-(x_1 - x_2) + 2(\operatorname{atanh}(x_2) - \operatorname{atanh}(x_1)) \right]$

$= 2\pi F \left[\cos(\theta_2) - \cos\theta_1 + 2(\operatorname{atanh}(\cos\theta_1) - \operatorname{atanh}(\cos\theta_2)) \right]$

$= 2\pi F \left[\tanh \eta_2 - \tanh(\eta_1) + 2(\eta_1 - \eta_2) \right]$ ✓