$$\langle |\mathcal{M}_\gamma|^2 \rangle = \frac{1}{4} \sum_{\text{spins}} |\mathcal{M}_\gamma|^2$$

$$= \frac{e^4}{36 s^2} \Big\{ \underbrace{\sum_{s,s'} [\bar{u}^s(p_1)\gamma^\mu v^{s'}(p_2)][\bar{v}^{s'}(p_2)\gamma^\nu u^s(p_1)]}_{\ell^{\mu\nu}_{(\mu)}} \times \underbrace{\sum_{r,r'} [\bar{v}^{r'}(p_4)\gamma_\mu u^r(p_3)][\bar{u}^r(p_3)\gamma_\nu v^{r'}(p_4)]}_{\ell_{(e)\mu\nu}} \Big\}$$

$$\Rightarrow \ell^{\mu\nu}_{(\mu)} = \sum_{s,s'=1}^{2} [\bar{u}^s_a(p_1)\gamma^\mu_{ab} v^{s'}_b(p_2)][\bar{v}^{s'}_c(p_2)\gamma^\nu_{cd} u^s_d(p_1)]$$

$$= \Big[\sum_{s=1}^{2} u^s_d(p_1)\bar{u}^s_a(p_1)\Big]\gamma^\mu_{ab}\Big[\sum_{s'=1}^{2} v^{s'}_b(p_2)\bar{v}^{s'}_c(p_2)\Big]\gamma^\nu_{cd}$$

$$= [(\not{p}_1 + m_\mu)\gamma^\mu(\not{p}_2 - m_\mu)\gamma^\nu]_{dd}$$

$$= \mathrm{Tr}\,[(\not{p}_1 + m_\mu)\gamma^\mu(\not{p}_2 - m_\mu)\gamma^\nu]$$

$$= \mathrm{Tr}\,[\not{p}_1\gamma^\mu\not{p}_2\gamma^\nu - m_\mu\not{p}_1\gamma^\mu\gamma^\nu + m_\mu\gamma^\mu\not{p}_2\gamma^\nu - m_\mu^2\gamma^\mu\gamma^\nu]$$

$$= p_{1\alpha}p_{2\beta}\,\mathrm{Tr}[\gamma^\alpha\gamma^\mu\gamma^\beta\gamma^\nu] - m_\mu^2\,\mathrm{Tr}[\gamma^\mu\gamma^\nu]$$

$$= p_{1\alpha}p_{2\beta}[4g^{\alpha\mu}g^{\beta\nu} - 4g^{\alpha\beta}g^{\mu\nu} + 4g^{\alpha\nu}g^{\mu\beta}] - m_\mu^2(4g^{\mu\nu})$$

$$= 4p_1^\mu p_2^\nu - 4(p_1\cdot p_2)g^{\mu\nu} + 4p_1^\nu p_2^\mu - 4m_\mu^2 g^{\mu\nu}$$

Applying the same technique to $\ell_{(e)\mu\nu}$ we get,

$$\ell_{(e)\mu\nu} = 4p_{4\mu}p_{3\nu} - 4(p_4\cdot p_3)g_{\mu\nu} + 4p_{4\nu}p_{3\mu} - 4m_e^2 g_{\mu\nu}$$

Thus,

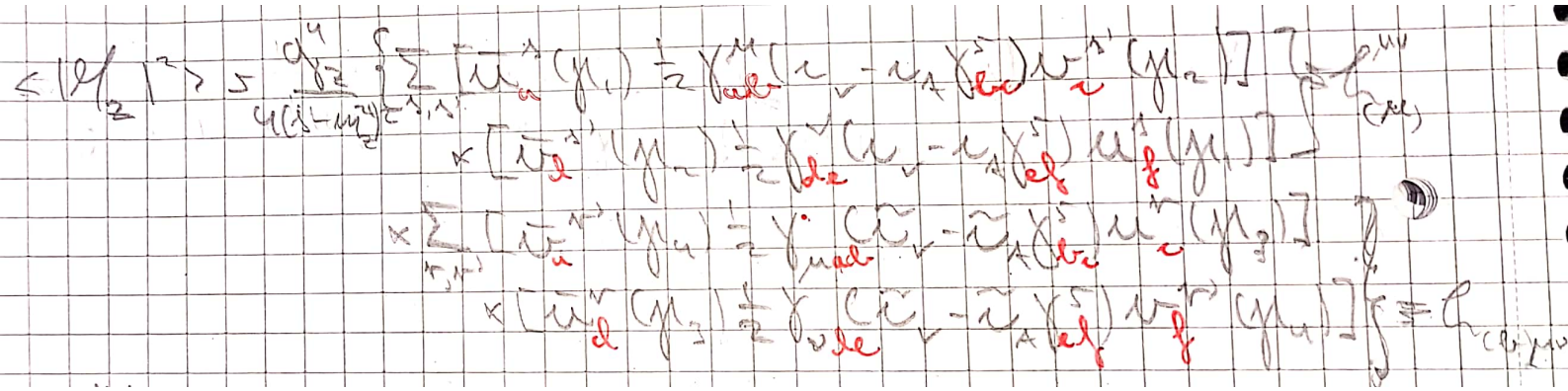
$$\langle |\mathcal{M}_\gamma|^2 \rangle = \frac{e^4}{36 s^2}\,\ell^{\mu\nu}_{(\mu)}\,\ell_{(e)\mu\nu}$$

$$= \frac{16e^4}{36 s^2}\Big\{[p_1^\mu p_2^\nu - (p_1\cdot p_2)g^{\mu\nu} + p_1^\nu p_2^\mu - m_\mu^2 g^{\mu\nu}] \times [p_{3\mu}p_{4\nu} - (p_3\cdot p_4)g_{\mu\nu} + p_{4\mu}p_{3\nu} - m_e^2 g_{\mu\nu}]\Big\}$$

$$= \frac{4e^4}{q^4} \{ (p_1\cdot p_4)(p_2\cdot p_3) - (p_1\cdot p_2)(p_3\cdot p_4) + (p_1\cdot p_3)(p_2\cdot p_4)$$
$$- m_e^2 (p_1\cdot p_2) - (p_1\cdot p_2)(p_3\cdot p_4) + 4(p_1\cdot p_2)(p_3\cdot p_4)$$
$$- (p_1\cdot p_2)(p_4\cdot p_3) + 4m_e^2 (p_1\cdot p_2) + (p_1\cdot p_3)(p_2\cdot p_4)$$
$$- (p_3\cdot p_4)(p_1\cdot p_2) + (p_1\cdot p_4)(p_2\cdot p_3) - m_e^2 (p_1\cdot p_2)$$
$$- m_\mu^2 (p_4\cdot p_3) + 4m_\mu^2 (p_4\cdot p_3) - m_\mu^2 (p_4\cdot p_3) + 4m_e^2 m_\mu^2 \}$$

$$= \frac{4e^4}{q^4} [2(p_1\cdot p_4)(p_2\cdot p_3) + 2(p_1\cdot p_3)(p_2\cdot p_4)$$
$$+ 2m_e^2 (p_1\cdot p_2) + 2m_\mu^2 (p_3\cdot p_4) + 4m_e^2 m_\mu^2]$$

$$= \frac{2e^4}{q^4} [(p_1\cdot p_4)(p_2\cdot p_3) + (p_1\cdot p_3)(p_2\cdot p_4)$$
$$+ m_e^2 (p_1\cdot p_2) + m_\mu^2 (p_3\cdot p_4) + 4m_e^2 m_\mu^2] \quad (*)$$



$$\mathcal{M}^{\mu\nu}_{(1)} = \frac{1}{4}\mathrm{Tr}\big[(\not{k}_1\gamma^\mu(c_V - c_A\gamma^5)(\not{k}_2 + m_\mu)\gamma^\nu(c_V - c_A\gamma^5)$$
$$-\not{k}_1\gamma^\mu(c_V - c_A\gamma^5)m_\mu\gamma^\nu(c_V - c_A\gamma^5)$$
$$+m_\mu\gamma^\mu(c_V - c_A\gamma^5)(\not{k}_2 + m_\mu)\gamma^\nu(c_V - c_A\gamma^5)$$
$$-m_\mu^2\gamma^\mu(c_V - c_A\gamma^5)\gamma^\nu(c_V - c_A\gamma^5)\big]$$

$$= \frac{1}{4}\mathrm{Tr}\big[\not{k}_1\gamma^\mu c_V(\not{k}_2 + m_\mu)c_V\gamma^\nu + \not{k}_1\gamma^\mu c_A\gamma^5(\not{k}_2 + m_\mu)\gamma^\nu c_A\gamma^5 \quad (1)$$
$$-m_\mu\not{k}_1\gamma^\mu c_V\gamma^\nu c_V - m_\mu\not{k}_1\gamma^\mu c_A\gamma^5\gamma^\nu c_A\gamma^5 \quad (2)$$
$$+m_\mu\gamma^\mu c_V(\not{k}_2 + m_\mu)\gamma^\nu c_V + m_\mu\gamma^\mu c_A\gamma^5(\not{k}_2 + m_\mu)\gamma^\nu c_A\gamma^5 \quad (3)$$
$$-m_\mu^2\gamma^\mu c_V\gamma^\nu c_V - m_\mu^2\gamma^\mu c_A\gamma^5\gamma^\nu c_A\gamma^5 \quad (4)$$
$$-\not{k}_1\gamma^\mu c_A\gamma^5(\not{k}_2 + m_\mu)\gamma^\nu c_V - \not{k}_1\gamma^\mu c_V(\not{k}_2 + m_\mu)\gamma^\nu c_A\gamma^5 \quad (5)$$
$$+\not{k}_1\gamma^\mu c_A\gamma^5 m_\mu\gamma^\nu c_V + \not{k}_1\gamma^\mu c_V m_\mu\gamma^\nu c_A\gamma^5 \quad (6)$$
$$-m_\mu\gamma^\mu c_V(\not{k}_2 + m_\mu)\gamma^\nu c_A\gamma^5 - m_\mu\gamma^\mu c_A\gamma^5(\not{k}_2 + m_\mu)\gamma^\nu c_V \quad (7)$$
$$+m_\mu^2\gamma^\mu c_V\gamma^\nu c_A\gamma^5 + m_\mu^2\gamma^\mu c_A\gamma^5\gamma^\nu c_V \quad (8)$$

(1): $(c_V^2 + c_A^2)\big[\gamma^\mu\not{k}_2\gamma^\nu - (k_1\cdot k_2)g^{\mu\nu} + \not{k}_1\gamma^\mu\big]$

(2): 0

(3): 0

(4): $-m_\mu^2(c_V^2 + c_A^2)\,g^{\mu\nu}$

(5): $-\frac{1}{4}\mathrm{Tr}\big[-\not{k}_1\gamma^\mu c_A\gamma^5\not{k}_2\gamma^\nu c_V - \not{k}_1\gamma^\mu c_V\not{k}_2\gamma^\nu c_A\gamma^5\big]$

$$= -k_{1\rho}c_V k_{2\sigma}\gamma_{\lambda\beta}\,\mathrm{Tr}[\gamma^\beta\gamma^\mu\gamma^5\gamma^\sigma\gamma^\nu]$$
$$-c_A c_V k_{1\rho}k_{2\sigma}\gamma_{\lambda\beta}\,\mathrm{Tr}[\gamma^\beta\gamma^\mu\gamma^\sigma\gamma^\nu\gamma^5]$$
$$= -c_A c_V k_{1\rho}k_{2\sigma}\gamma_{\lambda\beta}\,\mathrm{Tr}[\gamma^\beta\gamma^\mu\gamma^\sigma\gamma^\nu\gamma^5]$$
$$-c_A c_V k_{1\rho}k_{2\sigma}\gamma_{\lambda\beta}\,\mathrm{Tr}[\gamma^\beta\gamma^\mu\gamma^\sigma\gamma^\nu\gamma^5]$$
$$= -c_A c_V k_{1\rho}k_{2\sigma}\gamma_{\lambda\beta}(4i\,\varepsilon^{\beta\mu\sigma\nu}) - c_A c_V k_{1\rho}k_{2\sigma}\gamma_{\lambda\beta}(4i\,\varepsilon^{\beta\mu\sigma\nu})$$
$$= -2ic_A c_V k_{1\rho}k_{2\sigma}\varepsilon^{\rho\mu\sigma\nu}$$

(6): $\mathrm{Tr}[\not{k}_1 \gamma^\mu \not{\epsilon}_A \gamma^5 \not{m}_\mu \gamma^\nu \not{\epsilon}_V + \not{k}_1 \gamma^\mu \not{\epsilon}_V \not{m}_\mu \gamma^\nu \not{\epsilon}_A \gamma^5]$

$= i\epsilon_A \epsilon_V m_\mu p_{1\sigma} p_{2\rho} \mathrm{Tr}[\gamma^\sigma \gamma^\mu \gamma^5 \gamma^\nu] +$

$+ \epsilon_A \epsilon_V m_\mu p_{1\sigma} p_{2\rho} \mathrm{Tr}[\gamma^\sigma \gamma^\mu \gamma^\nu \gamma^5]$

$= 0$

(7): 0

(8): 0

$\Rightarrow \mathcal{L}^{\mu\nu}_{(\mu)} = (\epsilon_V^2 + \epsilon_A^2)(p_1^\mu p_2^\nu - (p_1 \cdot p_2) g^{\mu\nu} + p_1^\nu p_2^\mu)$

$-2i\epsilon_V \epsilon_A p_{1\sigma} p_{2\rho} \varepsilon^{\sigma\mu\rho\nu}$

$- m_\mu^2 (\epsilon_V^2 - \epsilon_A^2)_{(\mu)} g^{\mu\nu}$

$$\mathcal{M}_{e\mu\nu} = \frac{1}{4}\mathrm{Tr}\big[\not{p}_4\gamma_\mu(c_V - c_A\gamma^5)\not{p}_3\gamma_\nu(c_V - c_A\gamma^5)\quad (1)$$
$$+\not{p}_4\gamma_\mu(c_V - c_A\gamma^5)m_e\gamma_\nu(c_V - c_A\gamma^5)\quad (2)$$
$$-m_e\gamma_\mu(c_V - c_A\gamma^5)\not{p}_3\gamma_\nu(c_V - c_A\gamma^5)\quad (3)$$
$$-m_e^2\gamma_\mu(c_V - c_A\gamma^5)\gamma_\nu(c_V + c_A\gamma^5)\big]\quad (4)$$

(1): $\mathrm{Tr}\big[\not{p}_4\gamma_\mu c_V\not{p}_3\gamma_\nu c_V - \not{p}_4\gamma_\mu c_V\not{p}_3\gamma_\nu c_A\gamma^5$
$- \not{p}_4\gamma_\mu c_A\gamma^5\not{p}_3\gamma_\nu c_V + \not{p}_4\gamma_\mu c_A\gamma^5\not{p}_3\gamma_\nu c_A\gamma^5$

$+ c_V^2 p_4^\beta p_3^\sigma \mathrm{Tr}[\gamma_\beta\gamma_\mu\gamma_\sigma\gamma_\nu] - c_V c_A p_4^\beta p_3^\sigma \mathrm{Tr}[\gamma_\beta\gamma_\mu\gamma_\sigma\gamma_\nu\gamma^5]$
$- c_A c_V p_4^\beta p_3^\sigma \mathrm{Tr}[\gamma_\beta\gamma_\mu\gamma^5\gamma_\sigma\gamma_\nu] + c_A^2 p_4^\beta p_3^\sigma \mathrm{Tr}[\gamma_\beta\gamma_\mu\gamma^5\gamma_\sigma\gamma_\nu\gamma^5]$

$= c_V^2 p_4^\beta p_3^\sigma (4g_{\beta\mu}g_{\sigma\nu} - 4g_{\beta\sigma}g_{\mu\nu} + 4g_{\beta\nu}g_{\mu\sigma})$
$- c_V c_A p_4^\beta p_3^\sigma (4i\varepsilon_{\beta\mu\sigma\nu})$
$- c_A c_V p_4^\beta p_3^\sigma (4i\varepsilon_{\beta\mu\sigma\nu})$
$+ c_A^2 p_4^\beta p_3^\sigma (4g_{\beta\mu}g_{\sigma\nu} - 4g_{\beta\sigma}g_{\mu\nu} + 4g_{\beta\nu}g_{\mu\sigma})$

$= 4(c_V^2 + c_A^2)(p_{4\mu}p_{3\nu} - (p_4\cdot p_3)g_{\mu\nu} + p_{4\nu}p_{3\mu})$
$- 8i c_V c_A p_4^\beta p_3^\sigma \varepsilon_{\beta\mu\sigma\nu}$

(2): $\mathrm{Tr}\big[\not{p}_4\gamma_\mu m_e\gamma_\nu c_V - \not{p}_4\gamma_\mu m_e\gamma_\nu c_A\gamma^5$
$- \not{p}_4\gamma_\mu c_A\gamma^5 m_e\gamma_\nu c_V + \not{p}_4\gamma_\mu c_A\gamma^5 m_e\gamma_\nu c_A\gamma^5\big]$

$= 0$

(3): $\mathrm{Tr}\big[-m_e\gamma_\mu\not{p}_3\gamma_\nu c_V + m_e\gamma_\mu\not{p}_3\gamma_\nu c_A\gamma^5$
$+ m_e\gamma_\mu c_A\gamma^5\not{p}_3\gamma_\nu c_V - m_e\gamma_\mu c_A\gamma^5\not{p}_3\gamma_\nu c_A\gamma^5\big]$

$= 0$

(4): $\mathrm{Tr}[-m_e^2\gamma_\mu(c_V - c_A\gamma^5)\gamma_\nu(c_V - c_A\gamma^5)]$

$= \mathrm{Tr}[-m_e^2\gamma_\mu c_V\gamma_\nu c_V + m_e^2\gamma_\mu\gamma_\nu c_V c_A\gamma^5$
$+ m_e^2\gamma_\mu c_A\gamma^5\gamma_\nu c_V - m_e^2\gamma_\mu c_A\gamma^5\gamma_\nu c_A\gamma^5]$

$\gamma^5\gamma_\nu = -\gamma_\nu\gamma^5$

$= -m_e^2 c_V^2\,\mathrm{Tr}[\gamma_\mu\gamma_\nu] + m_e^2 c_A^2\,\mathrm{Tr}[\gamma_\mu\gamma_\nu]$
$= -4m_e^2(c_V^2 + c_A^2)\,g_{\mu\nu}$

$\Rightarrow \ell_{(e)\mu\nu} = (c_V^2 + c_A^2)(p_{4\mu}p_{3\nu} - (p_4\cdot p_3)g_{\mu\nu} + p_{4\nu}p_{3\mu})$
$-2ic_Vc_A p_4^\sigma p_3^\rho \varepsilon_{\sigma\mu\rho\nu}$
$- m_e^2(c_V^2 - c_A^2)\,g_{\mu\nu}$

$\langle|\mathcal{M}_2|^2\rangle = \frac{e^4}{q(s-m_2^2)^2}\,\ell^{\mu\nu}_{(\mu)}\,\ell_{(e)\mu\nu}$

$= \frac{e^4}{q(s-m_2^2)^2}\{(c_V^2 + c_A^2)(p_1^\mu p_2^\nu - (p_1\cdot p_2)g^{\mu\nu} + p_1^\nu p_2^\mu)$ (1)
$-2ic_Vc_A\varepsilon^{\sigma\mu\rho\nu}$ (2) $- m_1^2(c_V^2 - c_A^2)g^{\mu\nu}$ (3)
$\times\{(c_V^2 + c_A^2)(p_{4\mu}p_{3\nu} - (p_4\cdot p_3)g_{\mu\nu} + p_{4\mu}p_{3\nu})$ (4)
$-2i\tilde{c}_V\tilde{c}_A p_4^\alpha p_3^\beta\varepsilon_{\alpha\mu\beta\nu} - m_e^2(\tilde{c}_V^2 - \tilde{c}_A^2)g_{\mu\nu}\}$ (5) (6)

(1)·(4): $(c_V^2 + c_A^2)(\tilde{c}_V^2 + \tilde{c}_A^2)[(p_1^\mu p_2^\nu - (p_1\cdot p_2)g^{\mu\nu} + p_1^\nu p_2^\mu)$
$\times(p_{4\mu}p_{3\nu} - (p_4\cdot p_3)g_{\mu\nu} + p_{4\nu}p_{3\mu})]$

$= (c_V^2 + c_A^2)(\tilde{c}_V^2 + \tilde{c}_A^2)[(p_1\cdot p_4)(p_2\cdot p_3) - (p_1\cdot p_2)(p_4\cdot p_3) + (p_1\cdot p_3)(p_2\cdot p_4)$
$-(p_1\cdot p_2)(p_4\cdot p_3) + 4(p_1\cdot p_2)(p_4\cdot p_3) - (p_1\cdot p_4)(p_2\cdot p_3)$
$+(p_1\cdot p_3)(p_2\cdot p_4) - (p_1\cdot p_4)(p_2\cdot p_3) + (p_1\cdot p_2)(p_3\cdot p_4)]$

$= 2(c_V^2 + c_A^2)(\tilde{c}_V^2 + \tilde{c}_A^2)[(p_1\cdot p_4)(p_2\cdot p_3) + (p_1\cdot p_3)(p_2\cdot p_4)]$

(1)·(5): $(c_V^2 + c_A^2)(\tilde{c}_V^2 + \tilde{c}_A^2)(-2i)\tilde{c}_V\tilde{c}_A[p_1^\mu p_2^\nu - (p_1\cdot p_2)g^{\mu\nu} + p_1^\nu p_2^\mu]$
$\times p_4^\alpha p_3^\beta\varepsilon_{\alpha\mu\beta\nu}$

$= (c_V^2 + c_A^2)(\tilde{c}_V^2 + \tilde{c}_A^2)(-2i)\tilde{c}_V\tilde{c}_A[p_1^\mu p_2^\nu p_4^\alpha p_3^\beta\varepsilon_{\alpha\mu\beta\nu}$
$-(p_1\cdot p_2)g^{\mu\nu}p_4^\alpha p_3^\beta\varepsilon_{\alpha\mu\beta\nu} + p_1^\nu p_2^\mu p_4^\alpha p_3^\beta\varepsilon_{\alpha\mu\beta\nu}] = 0$

(1·6): $-(c_V^2+c_A^2)\,m_D^2\,(\tilde{c}_V^2-\tilde{c}_A^2)\,[y_1^\mu y_2^\nu-(y_1\cdot y_2)g^{\mu\nu}+y_1^\nu y_2^\mu]\,g_{\mu\nu}$

$= -m_D^2\,(c_V^2+c_A^2)(\tilde{c}_V^2-\tilde{c}_A^2)\,[(y_1\cdot y_2)-4(y_1\cdot y_2)+(y_1\cdot y_2)]$

$= \underline{2m_D^2\,(c_V^2+c_A^2)(\tilde{c}_V^2-\tilde{c}_A^2)(y_1\cdot y_2)}$

(2·4): $-2i\,c_V c_A\,(\tilde{c}_V^2+\tilde{c}_A^2)\,y_{1\beta}y_{2\sigma}\varepsilon^{\beta\mu\sigma\nu}\,[y_{4\mu}y_{3\nu}-(y_4\cdot y_3)g_{\mu\nu}+y_{4\nu}y_{3\mu}]$

$= -2i\,c_V c_A\,(\tilde{c}_V^2+\tilde{c}_A^2)\,[y_{1\beta}y_{2\sigma}\varepsilon^{\beta\mu\sigma\nu}y_{4\mu}y_{3\nu}$ $-(y_4\cdot y_3)\,y_{1\beta}y_{2\sigma}\varepsilon^{\beta\sigma\mu\nu}+y_{1\beta}y_{2\sigma}y_{4\nu}y_{3\mu}\varepsilon^{\beta\mu\sigma\nu}]$

$= \underline{0}$

(2·5): $-4\,c_V c_A\,\tilde{c}_V\tilde{c}_A\,y_{1\beta}y_{2\sigma}y_4^\alpha y_3^\gamma\,\varepsilon^{\beta\mu\sigma\nu}\varepsilon_{\alpha\mu\gamma\nu}$

$= -4\,c_V c_A\,\tilde{c}_V\tilde{c}_A\,y_{1\beta}y_{2\sigma}y_4^\alpha y_3^\gamma\,\varepsilon^{\mu\nu\sigma\beta}\varepsilon_{\mu\nu\alpha\gamma}$

$= -4\,c_V c_A\,\tilde{c}_V\tilde{c}_A\,y_{1\beta}y_{2\sigma}y_4^\alpha y_3^\gamma\,[+2(\delta_\alpha^\beta\delta_\gamma^\sigma-\delta_\gamma^\beta\delta_\alpha^\sigma)]$

$= \underline{-8\,c_V c_A\,\tilde{c}_V\tilde{c}_A\,[(y_1\cdot y_4)(y_2\cdot y_3)-(y_1\cdot y_3)(y_2\cdot y_4)]}$

(2·6): $+2i\,m_D^2\,c_V c_A\,(\tilde{c}_V^2-\tilde{c}_A^2)\,y_{1\beta}y_{2\sigma}\varepsilon^{\beta\mu\sigma\nu}\,q_\mu q_\nu$

$= \underline{0}$

(3·4): $-m_\mu^2\,(c_V^2-c_A^2)(\tilde{c}_V^2+\tilde{c}_A^2)\,q^\mu q^\nu\,[y_{4\mu}y_{3\nu}-(y_4\cdot y_3)g_{\mu\nu}+y_{4\nu}y_{3\mu}]$

$= -m_\mu^2\,(c_V^2-c_A^2)(\tilde{c}_V^2+\tilde{c}_A^2)\,[(y_4\cdot y_3)-4(y_4\cdot y_3)+(y_4\cdot y_3)]$

$= \underline{2m_\mu^2\,(c_V^2-c_A^2)(\tilde{c}_V^2+\tilde{c}_A^2)(y_4\cdot y_3)}$

(3·5): $2i\,m_\mu^2\,(c_V^2-c_A^2)\,\tilde{c}_V\tilde{c}_A\,q^\mu q^\nu\,y_4^\alpha y_3^\beta\,\varepsilon_{\alpha\mu\beta\nu}=0$

(3·6): $m_\mu^2 m_D^2\,(c_V^2-c_A^2)(\tilde{c}_V^2+\tilde{c}_A^2)\,q^\mu q^\nu\,g_{\mu\nu}$

$= \underline{4m_\mu^2 m_D^2\,(c_V^2-c_A^2)(\tilde{c}_V^2-\tilde{c}_A^2)}$

$\Rightarrow \langle|\mathcal{M}_{fi}|^2\rangle = \frac{e^4}{2(s-m_D^2)^2}\{(c_V^2+c_A^2)(\tilde{c}_V^2+\tilde{c}_A^2)\,[(y_1\cdot y_4)(y_2\cdot y_3)+(y_1\cdot y_3)(y_2\cdot y_4)$

$+m_D^2\,(c_V^2+c_A^2)(\tilde{c}_V^2-\tilde{c}_A^2)(y_1\cdot y_2)$

$+m_\mu^2\,(c_V^2-c_A^2)(\tilde{c}_V^2+\tilde{c}_A^2)(y_3\cdot y_4)$

$-4c_V c_A\,\tilde{c}_V\tilde{c}_A\,[(y_1\cdot y_4)(y_2\cdot y_3)-(y_1\cdot y_3)(y_2\cdot y_4)]$

$+2m_\mu^2 m_D^2\,(c_V^2-c_A^2)(\tilde{c}_V^2-\tilde{c}_A^2)\}$

(**)

(5)

$s = -m_z^2 + a \Xi \mathrm{Re}(s - m_z^2 + i m_z \Gamma_z)$

$\langle | \mathcal{M}_{fi} | \rangle = | \mathcal{M}_\gamma + \mathcal{M}_z |^2 \quad \sum_{\text{spins}}$

$= \frac{e^4}{s^2} \{ [\bar{u}^{s'}(y_2) \gamma^\mu u^s(y_1)][\bar{u}^{r'}(y_3) \gamma_\mu u^{r'}(y_4)] \}^2$

$\times \frac{g_z^2}{s - m_z^2 + a} [\bar{u}^{s'}(y_2) \tfrac{1}{2} \gamma^\mu (v_\nu - a_\nu \gamma^5) u^s(y_1)]$

$\times [\bar{u}^{r'}(y_3) \tfrac{1}{2} \gamma_\mu (\bar{v}_\nu - \bar{a}_\nu \gamma^5) u^{r'}(y_4)]$

$+ \frac{e^2}{s^2} [\bar{u}^s(y_1) \gamma^\mu u^{s'}(y_2)][\bar{u}^{r'}(y_4) \gamma_\mu u^r(y_3)]$

$\times \frac{g_z^2}{s - m_z^2} [\bar{u}^{s'}(y_2) \tfrac{1}{2} \gamma^\nu (v_\nu - a_\nu \gamma^5) u^s(y_1)]$

$\times [\bar{u}^r(y_3) \tfrac{1}{2} \gamma_\nu (\bar{v}_\nu - \bar{a}_\nu \gamma^5) u^{r'}(y_4)]$

$+ \frac{e^2 g_z^2}{12 s (s - m_z^2)} \{ [\bar{u}^s(y_1) \gamma^\mu u^{s'}(y_2)][\bar{u}^{s'}(y_2) \tfrac{1}{2} \gamma^\nu (v_\nu - a_\nu \gamma^5) u^s(y_1)] \}^2 \rho^{\mu\nu}_{(\mu)}$

$\times [\bar{u}^{r'}(y_4) \gamma_\mu u^r(y_3)][\bar{u}^r(y_3) \tfrac{1}{2} \gamma_\nu (\bar{v}_\nu - \bar{a}_\nu \gamma^5) u^{r'}(y_4)] \}^2 L_{(\nu)}$

$\Rightarrow \rho^{\mu\nu}_{(\mu)} = \sum_{s,s'} [\bar{u}^s_a(y_1) \gamma^\mu_{ab} u^{s'}_b(y_2)][\bar{u}^{s'}_c(y_2) \tfrac{1}{2} \gamma^\nu_{cd} (v_\nu - a_\nu \gamma^5_{de}) u^s_e(y_1)]$

$= \sum_{s,s'} [u^s_e(y_1) \bar{u}^s_d(y_1)] \gamma^\mu_{ab} \sum_{s'=1}^{2} [u^{s'}_b(y_2) \bar{u}^{s'}_c(y_2)] \tfrac{1}{2} \gamma^\nu_{cd} (v_\nu - a_\nu \gamma^5_{de})$

$= [(\not{y}_1 + m_\mu) e_{ea} \gamma^\mu_{ab} (\not{y}_2 - m_\mu) e_{bc}] \tfrac{1}{2} \gamma^\nu_{cd} (v_\nu - a_\nu \gamma^5_{de})$

$= \tfrac{1}{2} \mathrm{Tr} [(\not{y}_1 + m_\mu) \gamma^\mu (\not{y}_2 - m_\mu) \gamma^\nu (v_\nu - a_\nu \gamma^5)]$

$= \tfrac{1}{2} \mathrm{Tr} [\not{y}_1 \gamma^\mu \not{y}_2 \gamma^\nu (v_\nu - a_\nu \gamma^5) - m_\mu \not{y}_1 \gamma^\mu \gamma^\nu (v_\nu - a_\nu \gamma^5)$

$+ m_\mu \gamma^\mu \not{y}_2 \gamma^\nu (v_\nu - a_\nu \gamma^5) - m_\mu^2 \gamma^\mu \gamma^\nu (v_\nu - a_\nu \gamma^5)]$

$= \tfrac{1}{2} \{ v_\nu y_{1\beta} y_{2\alpha} \mathrm{Tr} [\gamma^\beta \gamma^\mu \gamma^\alpha \gamma^\nu] - a_\nu y_{1\beta} y_{2\alpha} \mathrm{Tr} [\gamma^\beta \gamma^\mu \gamma^\alpha \gamma^\nu \gamma^5]$

$+ m_\mu v_\nu y_{1\beta} \mathrm{Tr} [\gamma^\beta \gamma^\mu \gamma^\nu] + m_\mu a_\nu y_{1\beta} \mathrm{Tr} [\gamma^\beta \gamma^\mu \gamma^\nu \gamma^5]$

$+ m_\mu v_\nu y_{2\alpha} \mathrm{Tr} [\gamma^\mu \gamma^\alpha \gamma^\nu] - m_\mu a_\nu y_{2\alpha} \mathrm{Tr} [\gamma^\mu \gamma^\alpha \gamma^\nu \gamma^5]$

$+ m_\mu^2 v_\nu \mathrm{Tr} [\gamma^\mu \gamma^\nu] + m_\mu^2 a_\nu \mathrm{Tr} [\gamma^\mu \gamma^\nu \gamma^5] \}$

$= \tfrac{1}{2} \{ v_\nu y_{1\beta} y_{2\alpha} [4 g^{\beta\mu} g^{\alpha\nu} - 4 g^{\beta\alpha} g^{\mu\nu} + 4 g^{\beta\nu} g^{\mu\alpha}]$

$- a_\nu y_{1\beta} y_{2\alpha} (-4 i \varepsilon^{\beta\mu\alpha\nu}) - m_\mu^2 v_\nu (4 g^{\mu\nu}) \}$

$= 2 \{ v_\nu [y_1^\mu y_2^\nu - (y_1 \cdot y_2) g^{\mu\nu} + y_1^\nu y_2^\mu]$

$+ i a_\nu y_{1\beta} y_{2\alpha} \varepsilon^{\beta\mu\alpha\nu} - m_\mu^2 v_\nu g^{\mu\nu} \}$

$$\mathcal{L}_{(e)\mu\nu} = \sum_{r,r'} [\bar{v}^{r'}(y_4)\gamma_\mu u^r(y_3)][\bar{u}^r(y_2)\tfrac{i}{2}\gamma_\nu(\tilde{c}_V - \tilde{c}_A\gamma^5)v^{r'}(y_1)]$$

$$= \sum_{r,r'} \bar{v}^{r'}_a(y_4)\gamma_{\mu ab} u^r_b(y_3)][\bar{u}^r_c(y_2)\tfrac{i}{2}\gamma_{\nu cd}(\tilde{c}_V - \tilde{c}_A\gamma^5)_{de} v^{r'}_e(y_1)]$$

switch and that $\not{y}_3\gamma_\nu\not{y}_4\gamma_\mu$

$$= \sum_{r=1}^{2}(\bar{v}^r_e(y_4)\bar{v}^{r'}_a(y_4)]\gamma_{\mu ab}\sum_{r=1}^{2}[u^r_b(y_3)\bar{u}^r_c(y_2)]\gamma_{\nu cd}\tfrac{i}{2}(\tilde{c}_V - \tilde{c}_A\gamma^5)_{de}$$

$$= \frac{1}{2}\mathrm{Tr}[(\not{y}_4 - m_e)\gamma_\mu(\not{y}_3 + m_e)\gamma_\nu(\tilde{c}_V - \tilde{c}_A\gamma^5)]$$

$$= \frac{1}{2}\mathrm{Tr}[\not{y}_4\gamma_\mu\not{y}_3\gamma_\nu(\tilde{c}_V - \tilde{c}_A\gamma^5) + m_e\not{y}_3\gamma_\mu\gamma_\nu(\tilde{c}_V - \tilde{c}_A\gamma^5) - m_e\not{y}_4\gamma_\mu\gamma_\nu(\tilde{c}_V - \tilde{c}_A\gamma^5) - m_e^2\gamma_\mu\gamma_\nu(\tilde{c}_V - \tilde{c}_A\gamma^5)]$$

for $(-)$ in front of $\mathcal{L}_{e\mu\nu}$...

$$= \frac{1}{2}\{\tilde{c}_V y_4^\alpha y_3^\beta \mathrm{Tr}[\gamma_\alpha\gamma_\mu\gamma_\beta\gamma_\nu] - \tilde{c}_A y_4^\alpha y_3^\beta \mathrm{Tr}[\gamma_\alpha\gamma_\mu\gamma_\beta\gamma_\nu\gamma^5] + m_e^2\tilde{c}_V\mathrm{Tr}[\gamma_\mu\gamma_\nu]\}$$

$$= \frac{1}{2}\{\tilde{c}_V y_4^\alpha y_3^\beta[4g_{\alpha\mu}g_{\beta\nu} - 4g_{\alpha\beta}g_{\mu\nu} + 4g_{\alpha\nu}g_{\beta\mu}] - \tilde{c}_A y_4^\alpha y_3^\beta(-4i\varepsilon_{\alpha\mu\beta\nu}) - m_e^2\tilde{c}_V(4g_{\mu\nu})\}$$

$$= 2\{\tilde{c}_V[y_{4\mu}y_{3\nu} - (y_4\cdot y_3)g_{\mu\nu} + y_{4\nu}y_{3\mu}] + i\tilde{c}_A y_4^\alpha y_3^\beta\varepsilon_{\alpha\mu\beta\nu} - m_e^2\tilde{c}_V g_{\mu\nu}\}$$

$$\Rightarrow \langle \mathcal{H}_\gamma^\dagger \mathcal{H}_Z\rangle = \frac{e^2Q^2}{12\pi^3(s-m_Z^2)}\mathcal{L}^{\mu\nu}_{(\gamma)}\mathcal{L}_{(e)\mu\nu}$$

$$= \frac{e^2Q^2}{12\pi^3(s-m_Z^2)}\cdot 2\{\tilde{c}_V\underbrace{[y_1^\mu y_2^\nu - (y_1\cdot y_2)g^{\mu\nu} + y_1^\nu y_2^\mu]}_{(1)} + i\tilde{c}_A\underbrace{y_{1\rho}y_{2\sigma}\varepsilon^{\rho\sigma\mu\nu}}_{(2)} - m_e^2\underbrace{\tilde{c}_V g^{\mu\nu}}_{(3)}\}\cdot\zeta$$

$$\times\{\tilde{c}_V\underbrace{[y_{4\mu}y_{3\nu} - (y_4\cdot y_3)g_{\mu\nu} + y_{4\nu}y_{3\mu}]}_{(4)} + i\tilde{c}_A\underbrace{y_4^\alpha y_3^\beta\varepsilon_{\alpha\mu\beta\nu}}_{(5)} - m_e^2\underbrace{\tilde{c}_V g_{\mu\nu}}_{(6)}\}$$

(1-4): $$2\tilde{c}_V\tilde{c}_V[(y_1\cdot y_4)(y_2\cdot y_3) - (y_1\cdot y_2)(y_4\cdot y_3) + (y_1\cdot y_3)(y_2\cdot y_4) - (y_1\cdot y_2)(y_4\cdot y_3) + 4(y_1\cdot y_2)(y_4\cdot y_3) - (y_1\cdot y_4)(y_2\cdot y_3) + (y_1\cdot y_3)(y_2\cdot y_4) - (y_1\cdot y_2)(y_4\cdot y_3) + (y_1\cdot y_4)(y_2\cdot y_3)]$$

$$= 2\tilde{c}_V\tilde{c}_V[(y_1\cdot y_4)(y_2\cdot y_3) + (y_1\cdot y_3)(y_2\cdot y_4)]$$

(1.5): $i\nu_1\tilde{\epsilon}_4\left[y_1^\mu y_2^\nu - (y_1\cdot y_2)g^{\mu\nu} + y_1^\nu y_2^\mu\right] y_4^\alpha y_3^\beta \Sigma_{\alpha\mu\beta\nu}$

$= i\nu_1\tilde{\epsilon}_4\left[y_1^\mu y_2^\nu y_4^\alpha y_3^\beta \Sigma_{\alpha\mu\beta\nu} - (y_1\cdot y_2) y_4^\alpha y_3^\beta \Sigma_{\alpha\mu\beta}{}^{\mu} + y_1^\nu y_2^\mu y_4^\alpha y_3^\beta \Sigma_{\alpha\mu\beta\nu}\right]$

$= 0$

(1.6): $-\nu_1\tilde{\epsilon}_1 m_2^2\left[y_1^\mu y_2^\nu - (y_1\cdot y_2)g^{\mu\nu} + y_1^\nu y_2^\mu\right] g_{\mu\nu}$

$= -\nu_1\tilde{\epsilon}_1 m_2^2\left[(y_1\cdot y_2) - 4(y_1\cdot y_2) + (y_1\cdot y_2)\right]$

$= 2\nu_1\tilde{\epsilon}_1 m_2^2 (y_1\cdot y_2)$

(2.4): $i\nu_2\tilde{\epsilon}_2 y_3 y_2 \varepsilon^{\beta\mu\alpha\nu}\left[y_{2\mu}y_{3\nu} - (y_2\cdot y_3)g_{\mu\nu} + y_{3\mu}y_{2\nu}\right]$

$= 0$

(2.5): $-\nu_2\tilde{\epsilon}_2 y_1 y_2 y_4^\alpha y_3^\beta \varepsilon^{\beta\mu\alpha\nu}\Sigma_{\alpha\mu\beta\nu}$

$= -\nu_2\tilde{\epsilon}_2 y_\beta y_2 y_4^\alpha y_3^\beta \varepsilon^{\mu\nu\beta\alpha}\Sigma_{\mu\nu\alpha\beta}$

$= -\nu_2\tilde{\epsilon}_2 y_\beta y_2 y_4^\alpha y_3^\beta\left[+2\left(\delta^\beta_\alpha\delta^\alpha_\beta - \delta^\beta_\beta\delta^\alpha_\alpha\right)\right]$

$= -2\nu_2\tilde{\epsilon}_2\left[(y_1\cdot y_4)(y_2\cdot y_3) - (y_1\cdot y_3)(y_2\cdot y_4)\right]$

(2.6): $-im_2^2\nu_2 y_3 y_2 \varepsilon^{\beta\mu\alpha\nu}\tilde{\epsilon}_2 q_{\mu\nu}$

$= 0$

(3.4): $-m_1^2\nu_2\tilde{\epsilon}_2\left[y_{3\mu}y_{4\nu} - (y_3\cdot y_4)g_{\mu\nu} + y_{4\mu}y_{3\nu}\right]q^{\mu\nu}$

$= -m_1^2\nu_2\tilde{\epsilon}_2\left[(y_3\cdot y_4) - 4(y_3\cdot y_4) + (y_3\cdot y_4)\right]$

$= 2m_1^2\nu_2\tilde{\epsilon}_2(y_3\cdot y_4)$

(3.5): $-im_1^2\nu_2\tilde{\epsilon}_2 q^{\mu\nu} y_4^\alpha y_3^\beta \Sigma_{\alpha\mu\beta\nu}$

$= 0$

(3.6): $m_1^2 m_2^2 q^{\mu\nu} q_{\mu\nu} = 4m_2^2 m_1^2$

$$\langle \mathcal{M}_\gamma^\dagger \mathcal{M}_Z \rangle = \frac{e^2 g_Z^2}{3s(s-m_Z^2)} \times 2 \{ c_V \tilde{c}_V [(p_1 p_4)(p_2 p_3) + (p_1 \cdot p_3)(p_2 \cdot p_4)]$$
$$+ c_V \tilde{c}_V m_e^2 (p_1 \cdot p_2)$$
$$+ c_V \tilde{c}_V m_\mu^2 (p_3 \cdot p_4)$$
$$- c_A \tilde{c}_A [(p_1 \cdot p_4)(p_2 \cdot p_3) - (p_1 \cdot p_3)(p_2 \cdot p_4)]$$
$$+ 2 m_e^2 m_\mu^2 c_V \tilde{c}_V \} \quad (\text{***})$$

$$\mathcal{M}_H = \frac{1}{q^2(s-m_H^2)}\left(m_\mu - \frac{q_{\mu\nu}}{2m_\mu}\right)\left(m_\nu - \frac{q_{\mu\nu}}{2m_\nu}\right) \times [\bar{v}^{r'}(p_2)u^r(p_1)][\bar{u}^r(p_3)v^{r'}(p_4)]$$

$$\Rightarrow \langle|\mathcal{M}_H|^2\rangle = \frac{m_\mu^2 m_\nu^2 q_{\mu\nu}^4}{16(s-m_H^2)^2 m_{\mu\nu}^4} \times \frac{1}{4}\sum_{spins}[\bar{v}^{r'}(p_2)u^r(p_1)]^\dagger[\bar{u}^r(p_3)v^{r'}(p_4)]^\dagger \times [\bar{v}^{r'}(p_2)u^r(p_1)][\bar{u}^r(p_3)v^{r'}(p_4)]$$

$$= \frac{e^4}{4}\sum_{spins}[\bar{u}^r(p_1)v^{r'}(p_2)][\bar{u}^r(p_3)\bar{v}^{r'}(p_4)] \times [\bar{v}^{r'}(p_2)u^r(p_1)][\bar{u}^r(p_3)v^{r'}(p_4)]$$

$$= \frac{e^4}{4}\left\{\sum_{r,r'}[\bar{u}^r(p_1)v^{r'}(p_2)][\bar{v}^{r'}(p_2)u^r(p_1)]\right\}^{\mu\nu}_{\alpha\gamma} \times \left\{\sum_{r,r'}[u^r(p_3)\bar{v}^{r'}(p_4)][\bar{u}^r(p_3)v^{r'}(p_4)]\right\}^{\alpha\gamma}_{\mu\nu}$$

$$L^{\mu\nu}_{(\mu)} = \sum_{r,r'}\bar{u}^r_\mu(p_1)\mathbb{1}_{\mu\alpha}v^{r'}_\alpha(p_2)\bar{v}^{r'}_\beta(p_2)\mathbb{1}_{\beta\delta}u^r_\delta(p_1)$$

$$= \sum_{r,r'}[u^r_\delta(p_1)\bar{u}^r_\alpha(p_1)]\mathbb{1}_{\alpha\beta}\sum[v^{r'}_\beta(p_2)\bar{v}^{r'}_\gamma(p_2)]\mathbb{1}_{\gamma\delta}$$

$$= \mathrm{Tr}[(\not{p}_1 + m_\mu)(\not{p}_2 - m_\mu)]$$

$$= \mathrm{Tr}[\not{p}_1\not{p}_2 - \not{p}_1 m_\mu + \not{p}_2 m_\mu - m_\mu^2]$$

$$= p_{1\alpha}p_{2\nu}\mathrm{Tr}[\gamma^\alpha\gamma^\nu] - m_\mu^2\mathrm{Tr}[\mathbb{1}]$$

$$= \underline{4(p_1\cdot p_2) - 4m_\mu^2}$$

$$L_{(\alpha\gamma)} = \underline{4(p_3\cdot p_4) - 4m_\nu^2}$$

$$\Rightarrow \langle|\mathcal{M}_H|^2\rangle = \frac{e^4}{4}L^{\mu\nu}_{(\mu)}L_{(\alpha\gamma)}$$

$$= 4e^4[(p_1\cdot p_2) - m_\mu^2][(p_3\cdot p_4) - m_\nu^2]$$

$$= 4e^4[(p_1\cdot p_2)(p_3\cdot p_4) - m_\nu^2(p_1\cdot p_2) - m_\mu^2(p_3\cdot p_4) + m_\mu^2 m_\nu^2]$$

$$= \frac{m_\mu^2 m_\nu^2 q_{\mu\nu}^4}{4(s-m_H^2)^2 m_{\mu\nu}^4} \times [(p_1\cdot p_2)(p_3\cdot p_4) - m_\nu^2(p_1\cdot p_2) - m_\mu^2(p_3\cdot p_4) + m_\mu^2 m_\nu^2]$$

(***)