SM Charged Flavor Violation with dim 6 operators

Saereh Najjari

University of Warsaw

This research is supported by the ITN programme PITN-GA-2009-237920.

MEG experiment:

Search for $\mu^+ \rightarrow e^+ \gamma$ with sensitivity to BR ~ 10^{-13}

BR($\mu \rightarrow e \gamma$) < 10^{-12} (90% C.L.)

J. Adam et al. [MEG Collaboration]. Nucl. Phys. B 834 (2010) [arXiv:0908.2594 [hep-ex]].

$$\mathcal{L}_{\rm SM} \;=\; \mathcal{L}_{\rm SM}^{(4)} + \frac{1}{\Lambda}\sum_k C_k^{(5)} Q_k^{(5)} + \frac{1}{\Lambda^2}\sum_k C_k^{(6)} Q_k^{(6)} + \mathcal{O}(\frac{1}{\Lambda^3})$$

The only operator 5 operator is:

$$\epsilon_{ij}\bar{l}_R^{ci}\varphi^j \epsilon_{kl} l_L^k \varphi^l + H.c.$$

Majorana mass to neutrino

For $m_\nu \leq 5$ ev $\longrightarrow$ $\Lambda \sim 10^{13}$ Gev

LFV dim 6 operators

$llll$		$llX\varphi$		$ll\varphi^2 D$	
Q_{ll}	$(\bar{l}_p \gamma_\mu l_r)(\bar{l}_s \gamma^\mu l_t)$	Q_{eW}	$(\bar{l}_p \sigma^{\mu\nu} e_r)\tau^I \varphi W^I_{\mu\nu}$	$Q^{(1)}_{\varphi l}$	$(\varphi^\dagger i \overleftrightarrow{D}_\mu \varphi)(\bar{l}_p \gamma^\mu l_r)$
Q_{ee}	$(\bar{e}_p \gamma_\mu e_r)(\bar{e}_s \gamma^\mu e_t)$	Q_{eB}	$(\bar{l}_p \sigma^{\mu\nu} e_r)\varphi B_{\mu\nu}$	$Q^{(3)}_{\varphi l}$	$(\varphi^\dagger i \overleftrightarrow{D}^I_\mu \varphi)(\bar{l}_p \tau^I \gamma^\mu l_r)$
Q_{le}	$(\bar{l}_p \gamma_\mu l_r)(\bar{e}_s \gamma^\mu e_t)$			$Q_{\varphi e}$	$(\varphi^\dagger i \overleftrightarrow{D}_\mu \varphi)(\bar{e}_p \gamma^\mu e_r)$

$llqq$					
$Q^{(1)}_{lq}$	$(\bar{l}_p \gamma_\mu l_r)(\bar{q}_s \gamma^\mu q_t)$	Q_{ld}	$(\bar{l}_p \gamma_\mu l_r)(\bar{d}_s \gamma^\mu d_t)$	Q_{lu}	$(\bar{l}_p \gamma_\mu l_r)(\bar{u}_s \gamma^\mu u_t)$
$Q^{(3)}_{lq}$	$(\bar{l}_p \gamma_\mu \tau^I l_r)(\bar{q}_s \gamma^\mu \tau^I q_t)$	Q_{ed}	$(\bar{e}_p \gamma_\mu e_r)(\bar{d}_s \gamma^\mu d_t)$	Q_{eu}	$(\bar{e}_p \gamma_\mu e_r)(\bar{u}_s \gamma^\mu u_t)$
Q_{eq}	$(\bar{e}_s \gamma^\mu e_t)(\bar{q}_p \gamma_\mu q_r)$	Q_{ledq}	$(\bar{l}^j_p e_r)(\bar{d}_s q^j_t)$	$Q^{(1)}_{lequ}$	$(\bar{l}^j_p e_r)\varepsilon_{jk}(\bar{q}^k_s u_t)$
				$Q^{(3)}_{lequ}$	$(\bar{l}^j_p \sigma_{\mu\nu} e_r)\varepsilon_{jk}(\bar{q}^k_s \sigma^{\mu\nu} u_t)$

B. Grzadkowski, M. Iskrzynski, M. Misiak and J. Rosiek, JHEP **1010**, 085 (2010) [arXiv:1008.4884 [hep-ph]].

Operators which contribut to muon decay

$$(\varphi^\dagger i \overleftrightarrow{D}_\mu \varphi)(\bar{l}_p \gamma^\mu l_r)$$

$$(\varphi^\dagger i \overleftrightarrow{D}^I_\mu \varphi)(\bar{l}_p \tau^I \gamma^\mu l_r)$$

$$(\varphi^\dagger i \overleftrightarrow{D}_\mu \varphi)(\bar{e}_p \gamma^\mu e_r)$$

$$\varphi^\dagger i \overleftrightarrow{D}_\mu \varphi = i\varphi^\dagger (D_\mu \varphi) - i(D_\mu \varphi)^\dagger \varphi$$

$$\varphi^\dagger i \overleftrightarrow{D}^I_\mu \varphi = i\varphi^\dagger \tau^k (D_\mu \varphi) - i(D_\mu \varphi)^\dagger \tau^k \varphi$$

$$l_I = \begin{pmatrix} \nu_I \\ P_L e_I \end{pmatrix}, \quad \varphi = \begin{pmatrix} G^+ \\ \frac{1}{\sqrt{2}}(H^0 + v - iG^0) \end{pmatrix}, \quad e_I = P_R e_I$$

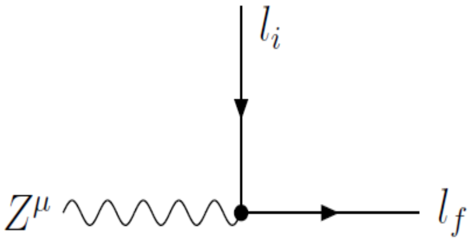
Operators which contribut to muon decay

$$(\bar{l}_p \gamma_\mu l_r)(\bar{l}_s \gamma^\mu l_t)$$

$$(\bar{l}_p \gamma_\mu l_r)(\bar{e}_s \gamma^\mu e_t)$$

$$(\bar{e}_p \gamma_\mu e_r)(\bar{e}_s \gamma^\mu e_t)$$

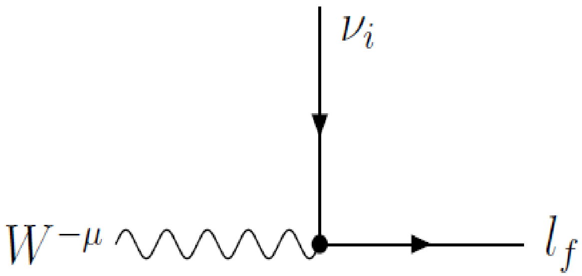
Vertices:



$$i\gamma^\mu \left[\Gamma^{ZL}_{fi} P_L + \Gamma^{ZR}_{fi} P_R\right]$$

$$\Gamma^{ZL}_{fi} = \frac{e}{2 s_W c_W}\left(\frac{v^2}{M^2}\left(C^{(1)fi}_{\phi l} + C^{(3)fi}_{\phi l}\right) + \left(1 - 2 s_W^2\right)\delta_{fi}\right)$$

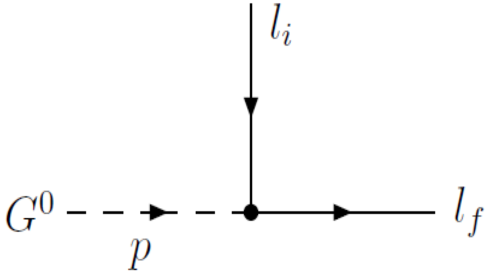
$$\Gamma^{ZR}_{fi} = \frac{e}{2 s_W c_W}\left(\frac{v^2}{M^2} C^{fi}_{\phi e} - 2 s_W^2 \delta_{fi}\right)$$



$$i\Gamma^{WL}_{fi}\gamma^\mu P_L$$

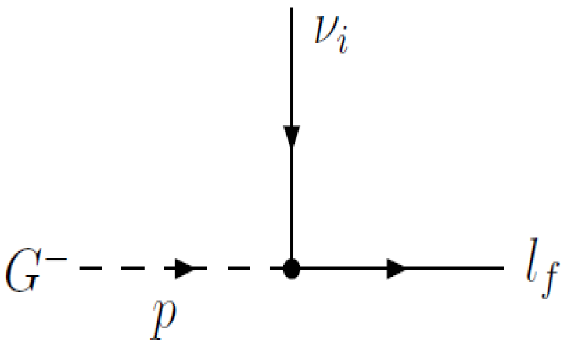
$$\Gamma^{WL}_{fi} = -\frac{e}{\sqrt{2} s_W}\left(\frac{v^2}{M^2} C^{(3)fj}_{\phi l} + \delta_{fj}\right) V^{PMNS}_{ji}$$

Vertices:



$$i\left(\left(\not p\,\Gamma^{G^0L}_{fi} + \frac{i}{v}\delta_{fi} m_{\ell_i}\right)P_L + \left(\not p\,\Gamma^{G^0R}_{fi} - \frac{i}{v}\delta_{fi} m_{\ell_i}\right)P_R\right)$$

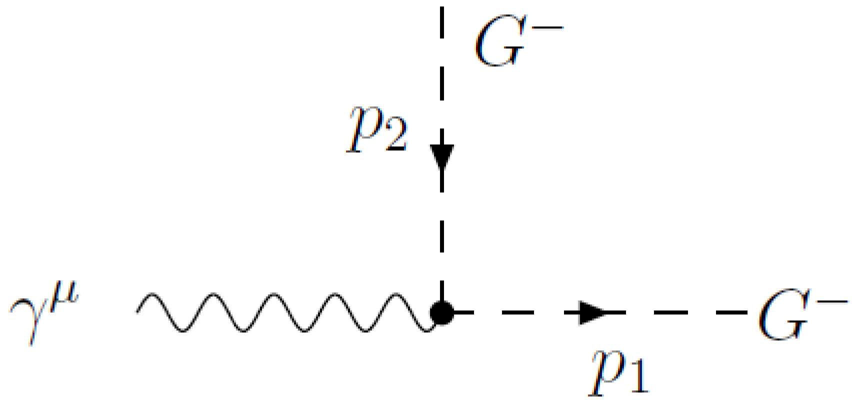
$$\Gamma^{G^0L}_{fi} = \frac{iv}{M^2}\left(C^{(1)fi}_{\phi l} + C^{(3)fi}_{\phi l}\right)$$
$$\Gamma^{G^0R}_{fi} = \frac{iv}{M^2}C^{fi}_{\phi e}$$



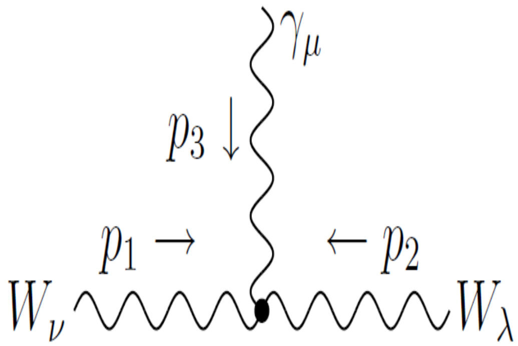
$$i\left(\Gamma^{G^-L}_{fi}\not p - \frac{\sqrt{2}}{v}\delta_{fj} m_{\ell_f}\right) V^{PMNS}_{ji} P_L$$

$$\Gamma^{G^-L}_{fi} = -\frac{\sqrt{2}}{v}\frac{v^2}{M^2}C^{(3)fj}_{\phi l}$$

Vertices:

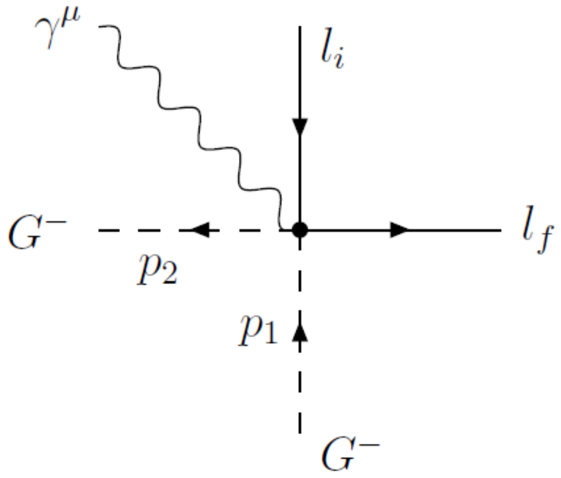


$$ie\,(p_1^\mu + p_2^\mu)$$



$$ie[g^{\nu\lambda}(p_1 - p_2)^\mu + g^{\lambda\mu}(p_2 - p_3)^\nu + g^{\mu\nu}(p_3 - p_1)^\lambda]$$

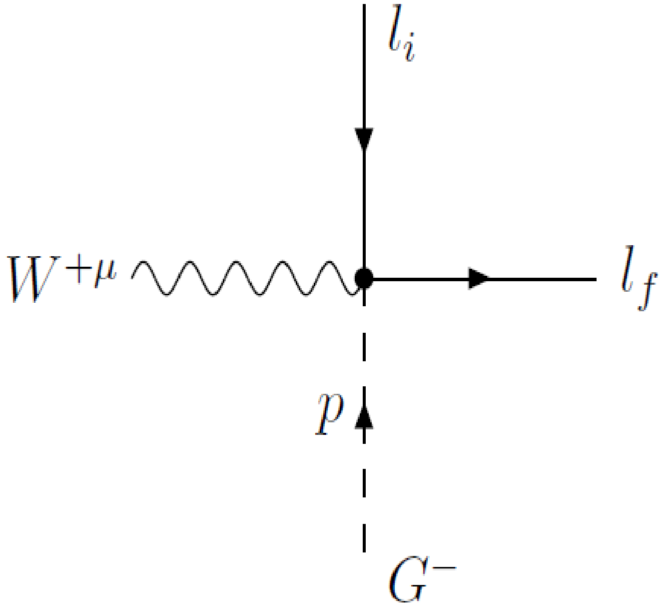
Vertices:



$$i\gamma^\mu\left(\Gamma_{fi}^{GG\gamma L}P_L+\Gamma_{fi}^{GG\gamma R}P_R\right)$$

$$\Gamma_{fi}^{GG\gamma L}=-\frac{2e}{M^2}\left(C_{\phi l}^{(1)fi}-C_{\phi l}^{(3)fi}\right)$$
$$\Gamma_{fi}^{GG\gamma R}=-\frac{2e}{M^2}C_{\phi e}^{fi}$$

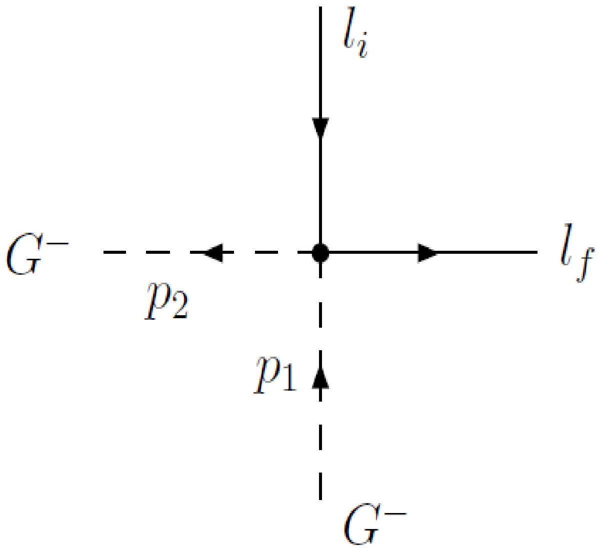
Vertices:



$$i\gamma^\mu\left[\Gamma^{GWL}_{fi}P_L+\Gamma^{GWR}_{fi}P_R\right]$$

$$\Gamma^{GWL}_{fi} = -\frac{ev}{M^2 s_W} C^{(1)fi}_{\phi l}$$

$$\Gamma^{GWR}_{fi} = -\frac{ev}{M^2 s_W} C^{fi}_{\phi e}$$

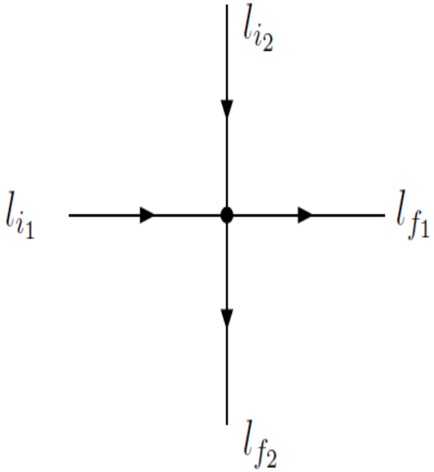


$$i\left(\not p_1+\not p_2\right)\left[\Gamma^{GGL}_{fi}P_L+\Gamma^{GGR}_{fi}P_R\right]$$

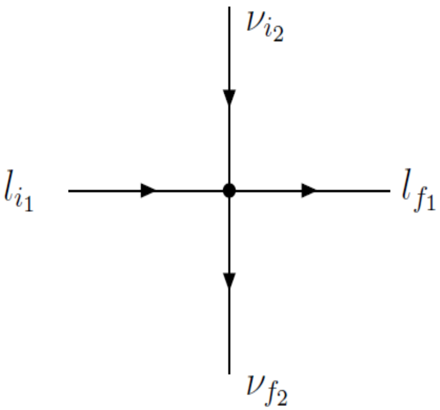
$$\Gamma^{GGL}_{fi} = -\frac{e}{M^2}\left(C^{(1)fi}_{\phi l}-C^{(3)fi}_{\phi l}\right)$$

$$\Gamma^{GGR}_{fi} = -\frac{e}{M^2}C^{fi}_{\phi e}$$

4- fermion vertices:

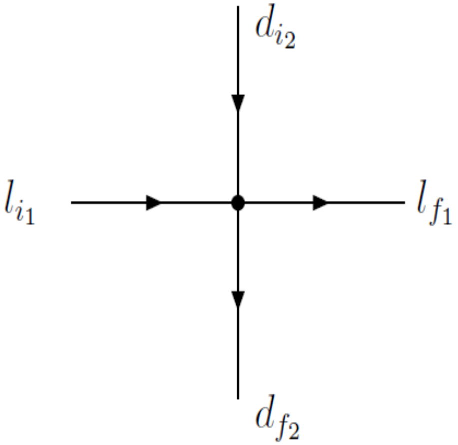


$$\frac{i}{4}\Big[C_{ll}^{f_1i_1f_2i_2}(\gamma^\mu P_L)_{i_1f_1}(\gamma_\mu P_L)_{f_2i_2} + C_{le}^{f_1i_1f_2i_2}(\gamma^\mu P_L)_{f_1i_1}(\gamma_\mu P_R)_{f_2i_2} \\ + C_{ee}^{f_1i_1f_2i_2}(\gamma^\mu P_R)_{f_1i_1}(\gamma_\mu P_R)_{f_2i_2}\Big]$$

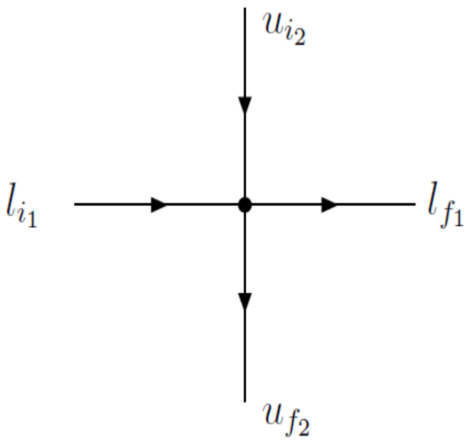


$$i\Big[C_{ll}^{f_1i_1f_2i_2}(\gamma^\mu P_L)_{i_1f_1}(\gamma_\mu P_L)_{f_2i_2} + 2\mathrm{Re}(C_{le}^{f_1i_1f_2i_2})(\gamma^\mu P_L)_{f_1i_1}(\gamma_\mu P_R)_{f_2i_2}\Big]$$

4- fermion vertices:

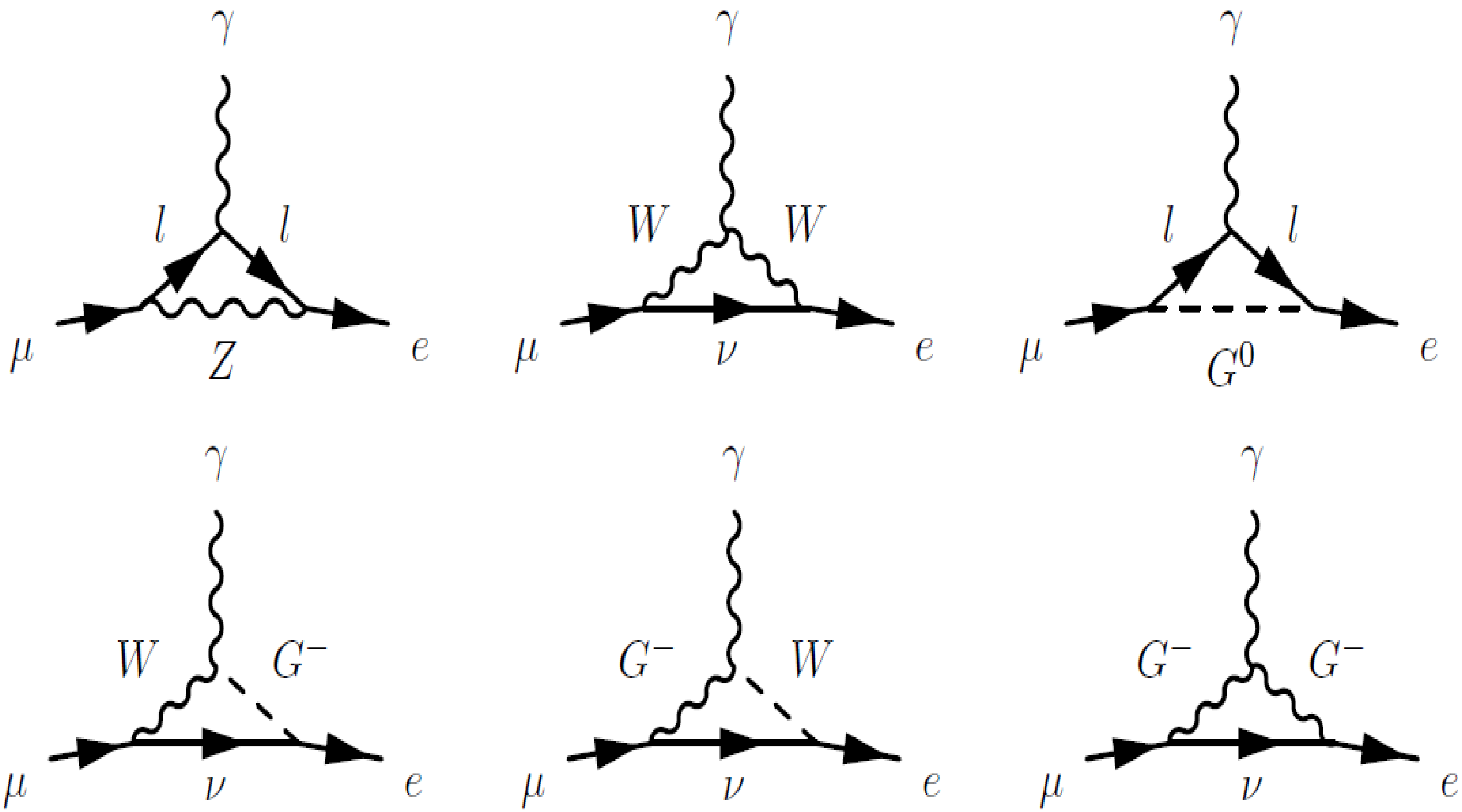


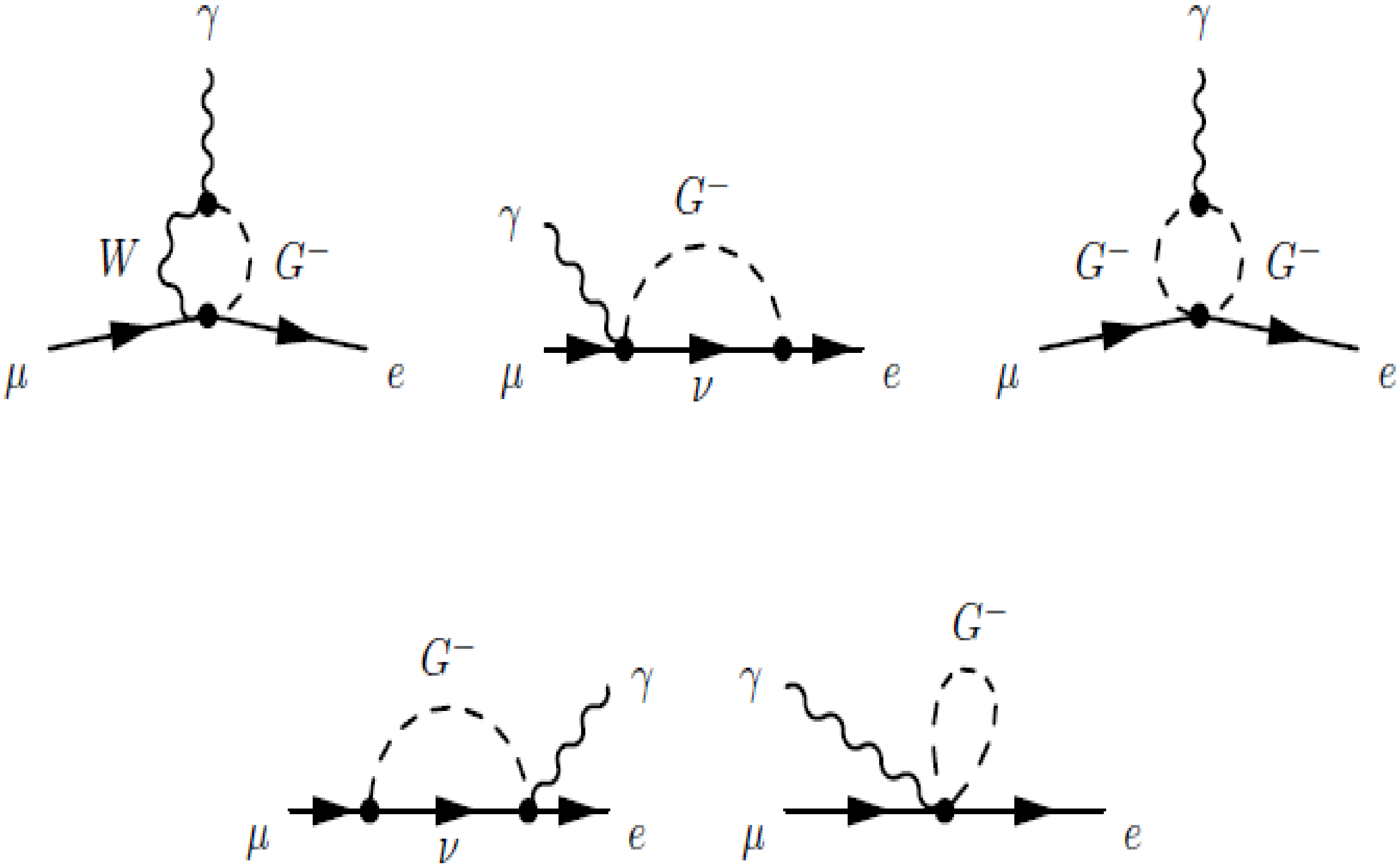
$$
\begin{aligned}
&i\Big[(C_{lq}^{(1)f_1i_1f_2i_2} + C_{lq}^{(3)f_1i_1f_2i_2})(\gamma^\mu P_L)_{i_1f_1}(\gamma_\mu P_L)_{f_2i_2} \\
&+C_{ld}^{f_1i_1f_2i_2}(\gamma^\mu P_L)_{f_1i_1}(\gamma_\mu P_R)_{f_2i_2} + C_{eq}^{f_1i_1f_2i_2}(\gamma^\mu P_R)_{f_1i_1}(\gamma_\mu P_L)_{f_2i_2} \\
&+C_{ed}^{f_1i_1f_2i_2}(\gamma^\mu P_R)_{f_1i_1}(\gamma_\mu P_R)_{f_2i_2} + C_{leqd}^{f_1i_1f_2i_2}(P_R)_{f_1i_1}(P_L)_{f_2i_2}\Big]
\end{aligned}
$$

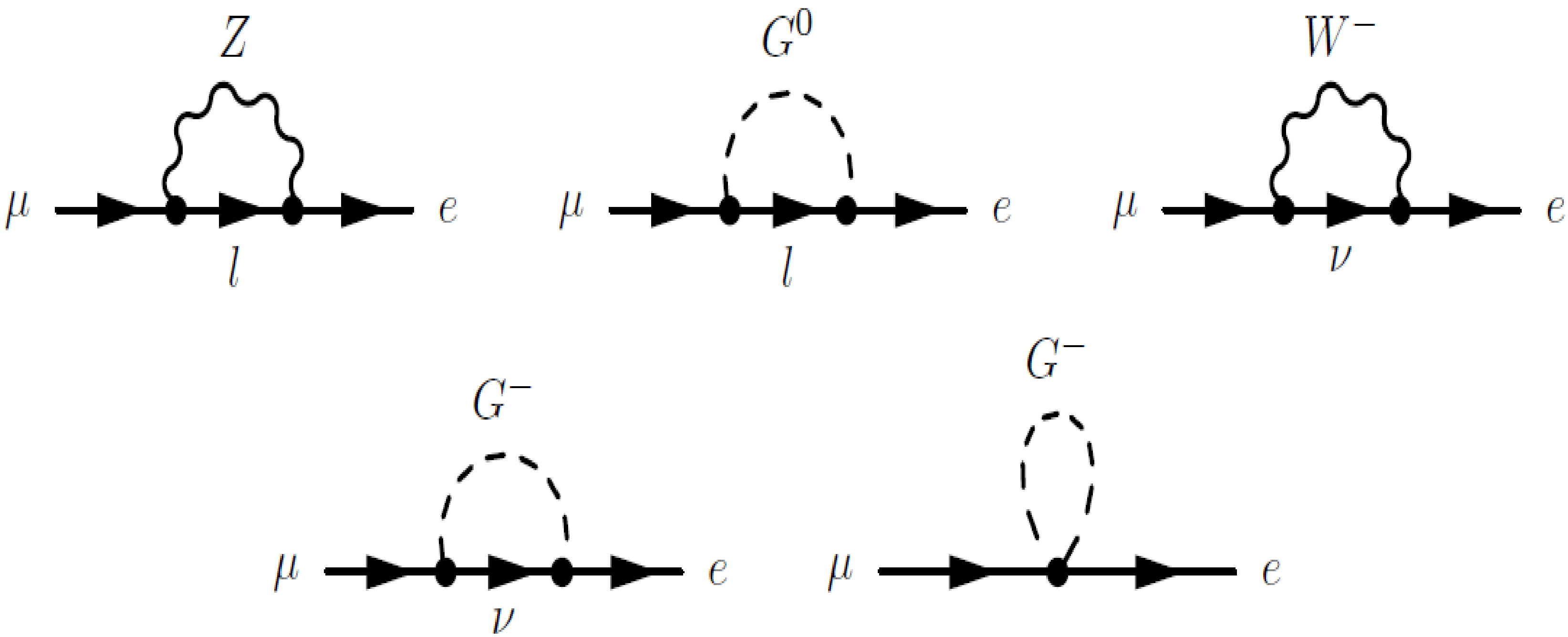


$$
\begin{aligned}
&i\Big[(C_{lq}^{(1)f_1i_1f_2i_2} - C_{lq}^{(3)f_1i_1f_2i_2})(\gamma^\mu P_L)_{i_1f_1}(\gamma_\mu P_L)_{f_2i_2} \\
&+C_{lu}^{f_1i_1f_2i_2}(\gamma^\mu P_L)_{f_1i_1}(\gamma_\mu P_R)_{f_2i_2} + C_{eq}^{f_1i_1f_2i_2}(\gamma^\mu P_R)_{f_1i_1}(\gamma_\mu P_L)_{f_2i_2} \\
&+C_{eu}^{f_1i_1f_2i_2}(\gamma^\mu P_R)_{f_1i_1}(\gamma_\mu P_R)_{f_2i_2} - C_{lequ}^{(1)f_1i_1f_2i_2}(P_R)_{f_1i_1}(P_R)_{f_2i_2} \\
&- C_{lequ}^{(3)f_1i_1f_2i_2}(\sigma^{\mu\nu} P_R)_{f_1i_1}(\sigma_{\mu\nu} P_R)_{f_2i_2}\Big]
\end{aligned}
$$

$\mu^+ \rightarrow e^+\gamma$




γ
W
G⁻
μ
e
ν


Z
μ
e
l
G⁰
μ
e
l
W⁻
μ
e
ν
G⁻
μ
e
ν
G⁻
μ
e

$\mu^+ \to e^+\gamma$

The most general form of the on-shell amplitude is given by

$$M = \epsilon^\lambda \bar{u}_e(p-q)[[iq^\nu \sigma_{\lambda\nu}(A + B\gamma_5)]u_\mu(p)$$

A straiht forward calculation of the decay rate yields

$$\Gamma(\mu \to e\gamma) = \frac{m_\mu^3}{8\pi}(|A|^2 + |B|^2)$$

T. -P. Cheng and L. -F. Li, Phys. Rev. D **16**, 1425 (1977)

Work in progress ....

Conclusion:

- The flavor physics is very important not just because of the confirmation of the SM but also to search for some new physics beyond the SM where we can undrestand the originn of flavors more deeply.

- Non-trivial calculation with higher order operators