6 Weak neutral currents

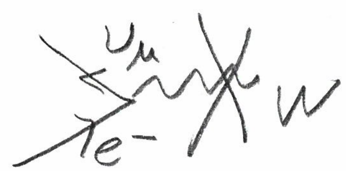
So far we have discussed weak interactions in which there is a change of electric charge ± 1 between the fermions in the vertex. ≡ weak charge current.

In 1973 some processes including ν's were observed

$\nu_\mu e^- \to \nu_\mu e^-$

$\nu_\mu \underset{p, or\, n}{\underset{|||}{N}} \to \nu_\mu N$

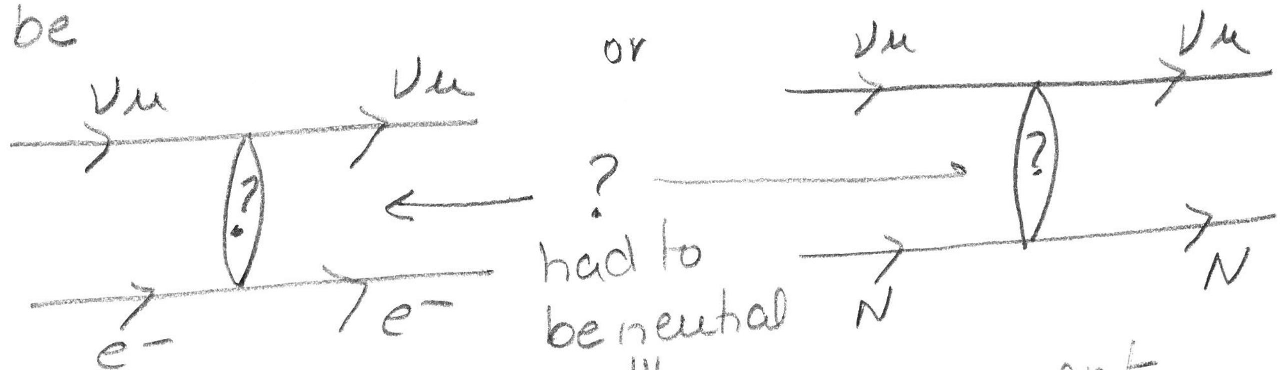
Since ν's do not have electric charge nor colour these processes had to be due to weak int. But weak interactions of leptons do not change flavour (in limit $m_\nu \to 0$) so



Furthermore in $\nu_\mu N \to \nu_\mu N$ there is no charge lepton

So the amplitudes for these processes had to be

be



had to be neutral $\equiv$ weak neutral current

the observed cross sections and many other similar would explain with pure neutral current amplitudes

same G_F as μ dec

constant $\simeq 1$

e^- or $q \equiv f$

$$\mathcal{M}(\nu_\mu f \to \nu_\mu f) = -\frac{8G_F}{\sqrt{2}}\rho\left[\bar{u}_{\nu_\mu}\gamma^\alpha\frac{(1-\gamma_5)}{2}u_{\nu_\mu}\right] \times \left[\bar{u}_f\gamma_\alpha\left(C_L^f\frac{(1-\gamma_5)}{2}+C_R^f\frac{(1+\gamma_5)}{2}\right)u_f\right]$$

with

f	C_L^f	C_R^f	charge Q_f
ν	$1/2$	0	0
e	-0.27	0.23	-1
u	0.35	-0.15	$2/3$
d	-0.43	0.07	$-1/3$

$$\Rightarrow \quad C_R^f = -Q_f X$$
$$C_L^{\nu,u} = \frac{1}{2} - Q_f X$$
$$C_R^{e,d} = -\frac{1}{2} - Q_f X$$

with $X \simeq 0.22 - 0.23$

These amplitudes can be understood in terms of an effective interaction with

- interaction is mediated by a neutral vector $\equiv Z^\mu$
- Z has a mass M_Z

So the effective Lagrangian

$$\mathcal{L}^{NC} = -\sum_{f=u,d,\nu,e} \underbrace{g_Z}_{\text{coupling constant}} \bar{\Psi}_f \gamma^\alpha \Big(C_L^f \underbrace{P_L}_{\frac{1-\gamma_5}{2}} + C_R^f \underbrace{P_R}_{\frac{1+\gamma_5}{2}}\Big) \Psi_f Z_\alpha$$

. So the FR for this interact

$$-ig_Z \gamma^\alpha \left[C_L^f \frac{(1-\gamma_5)}{2} + C_R^f \frac{(1+\gamma_5)}{2}\right]$$

since $M_Z \neq 0$
$\lambda = \pm 1, 0$

- Z^μ external lines

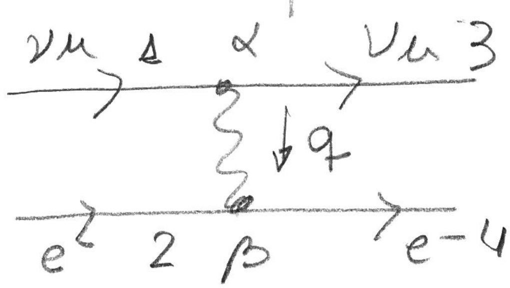
Z incoming $\quad \epsilon^\alpha_\lambda(q)$

Z outgoing $\quad \epsilon^{\alpha *}_\lambda(q)$

- Z propagator

$$-i \frac{g_{\alpha\beta} - \frac{q_\alpha q_\beta}{M_Z^2}}{q^2 - M_Z^2}$$

For example



$$\mathcal{M} = g_Z^2 \left[\bar{u}^{3}_{\nu_\mu} \gamma^\alpha C_L^\nu \frac{(1-\gamma_5)}{2} u^{1}_{\nu_\mu} \right] \frac{g_{\alpha\beta} - \frac{q_\alpha q_\beta}{M_Z^2}}{q^2 - M_Z^2} \left[\bar{u}^{4}_e \gamma^\beta \left(C_L^e \frac{(1-\gamma_5)}{2} + C_R^e \frac{(1+\gamma_5)}{2} \right) u^{2}_e \right]$$

$$\xrightarrow{q^2 \ll M_Z^2} -\frac{g_Z^2}{M_Z^2} \left[\gamma^\alpha \quad \right] \left[\gamma_\alpha \quad \right]$$

$$\Rightarrow \frac{8 G_F}{\sqrt{2}} \rho = \frac{g_Z^2}{M_Z^2}$$ and in CC $\frac{G_F}{\sqrt{2}} = \frac{g_W^2}{8 M_W^2}$

$$\Rightarrow \frac{g_W^2}{M_W^2} \rho = \frac{g_Z^2}{M_Z^2}$$ and since $\rho \simeq 1$

$$\frac{M_W^2}{M_Z^2} \sim \frac{g_W^2}{g_Z^2}$$ $\Rightarrow$ the masses and couplings of the weak CC and NC come in the same ratio (?)

We have written $\mathcal{L}^{NC}$ for the 1s generation

For 3 generations we can make 3 copies.

this opens up the issue of generation mixing

Let us write $\mathcal{L}^{NC}$ in the prime basis in which

the couplings are generation diagonal

$$\mathcal{L}^{NC}_{quarks} = -g_Z \sum_{i=1}^{3} \underset{\swarrow \text{generation } i}{\bar{u}_i} \gamma^\alpha [C_L^u P_L + C_R^u P_R] u_i$$

$$+ \bar{d}'_i \gamma^\alpha [C_L^d P_L + C_R^d P_R] d'_i$$

notice that $C^{u,d}_{L,R}$ are the same for the 3 generation

we can write this as

$$\mathcal{L}^{NC}_{dquarks} = -g_Z (\bar{d}', \bar{s}', \bar{b}') \gamma^\alpha \left[C_L^d \begin{pmatrix} 1 & & \\ & 1 & \\ & & 1 \end{pmatrix} + C_R^d \begin{pmatrix} 1 & & \\ & 1 & \\ & & 1 \end{pmatrix} \right] \begin{pmatrix} d' \\ s' \\ b' \end{pmatrix}$$

and rotating to mass basis

$$= -g_Z (d, s, b) \underbrace{U^\dagger \gamma^\alpha [C_L^d I_{3\times3} + C_R^d I_{3\times3}] U}_{\gamma^\alpha [C_L^d \underbrace{U^\dagger U}_{I_{3\times3}} + C_R^d \underbrace{U^\dagger U}_{I_{3\times3}}]} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

$$\begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

$\Rightarrow$ no generation mixing

So there is no generation mixing in NC weak interaction ≡ GIM mechanism
in Glashow, Iliopoulos and Maiami

Notice that for this to happen we need to consider full generations (1 up and one down quark per generation).

But when NC were discovered we only have observed 3 quarks (u, d, s). So the observation of no flavour changing NC would not be easily explained.
GIM realised that they could explain it if they postulated the existence of a 4th quark with $Q = Q_u = +\frac{2}{3}$.

In 1974 the J/ψ ≡ meson made of these 4th "charm" quark and antiquark $c\bar{c}$ was discovered!