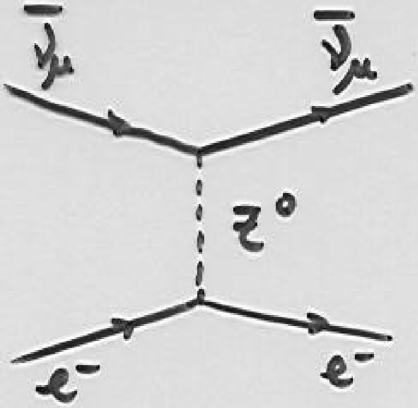
Observação de correntes neutras (CERN 1973):

$\bar{\nu}_\mu e^- \to \bar{\nu}_\mu e^-$



e
$$\begin{cases} \nu_\mu N \to \nu_\mu X \\ \bar{\nu}_\mu N \to \bar{\nu}_\mu X \end{cases}$$

Amplitude do processo $\nu q \to \nu q$:

$$\mathcal{M} = \frac{G_N}{\sqrt{2}} \left[\bar{u}_\nu \gamma^\mu (1-\gamma^5) u_\nu\right] \left[\bar{u}_q \gamma_\mu (c_V^q - c_A^q \gamma^5) u_q\right]$$

$q = u, d, \dots$

ou
$$\boxed{\mathcal{M} = \frac{4G}{\sqrt{2}}\, 2\rho\, J_\mu^{NC} J^{NC,\mu}}$$

com $\rho = \frac{G_N}{G}$, força relativa de interacção neutra e carregada

$$J_\mu^{NC}(\nu) = \frac{1}{2}\left(\bar{u}_\nu \gamma_\mu \frac{1}{2}(1-\gamma^5) u_\nu\right)$$

$$J_\mu^{NC}(q) = \left(\bar{u}_q \gamma_\mu \frac{1}{2}(c_V^q - c_A^q \gamma^5) u_q\right)$$

ρ, c_V^q, c_A^q parametros a determinar experimentalmente

$g_L^q = \frac{1}{2}(c_V^q + c_A^q) \simeq 0{,}3 \qquad g_R^q = \frac{1}{2}(c_V^q - c_A^q) \simeq 0{,}02$

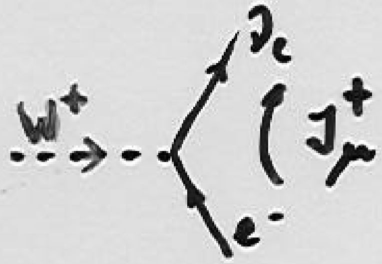
Interacção electrofraca

Isospin fraco e hipercarga:

Como combinar as correntes carregadas (J_μ e $J_\mu^\dagger$) e a corrente neutra J_μ^{NC} num grupo de simetria?

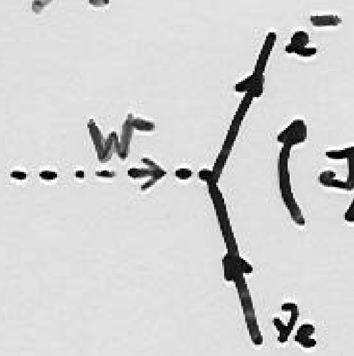
$$J_\mu \equiv J_\mu^+ = \bar{u}_\nu \gamma_\mu \frac{1}{2}(1-\gamma^5) u_e \equiv \bar{\nu} \gamma_\mu \frac{1}{2}(1-\gamma^5) e$$

$$= \bar{\nu}_L \gamma_\mu e_L$$



$$J_\mu^\dagger = J_\mu^- = \bar{u}_e \gamma_\mu \frac{1}{2}(1-\gamma^5) u_\nu =$$

$$= \bar{e}_L \gamma_\mu \nu_L$$



Introduzindo o grupo SU(2) de isospin fraco:

$$\chi_L = \begin{pmatrix} \nu \\ e^- \end{pmatrix}_L \longrightarrow \text{dobleto de } \underline{\text{isospin fraco}}$$

$$\begin{cases} J_\mu^+ = \bar{\chi}_L \gamma_\mu \tau_+ \chi_L & \tau_+ = \begin{pmatrix} 0 & 1 \\ 0 & 0 \end{pmatrix} \\ J_\mu^- = \bar{\chi}_L \gamma_\mu \tau_- \chi_L & \tau_- = \begin{pmatrix} 0 & 0 \\ 1 & 0 \end{pmatrix} \end{cases}$$

$\tau_\pm = \frac{1}{2}(\tau_1 \pm i\tau_2)$; τ_i: matrizes de Pauli (geradores do grupo SU(2)

→ Completando o tripleto de correntes fracas (grupo $SU(2)_L$) :

$$J_\mu^3 = \bar{\chi}_L \gamma_\mu \frac{1}{2} \tau_3 \chi_L$$

$$= \frac{1}{2} \bar{\nu}_L \gamma_\mu \nu_L - \frac{1}{2} \bar{e}_L \gamma_\mu e_L$$

J_μ^3 tem estrutura V-A pura (componentes esquerdas); não se identifica portanto com J_μ^{NC}.

→ Introduz-se a corrente electromagnética :

$$j_\mu^{em} = -\bar{e}\gamma_\mu e = -\bar{e}_R \gamma_\mu e_R - \bar{e}_L \gamma_\mu e_L$$

$$j_\mu = e j_\mu^{em} = e \bar{\Psi} \gamma_\mu Q \psi \qquad Q=-1 \text{ electrão}$$

Q operador de carga eléctrica : gerador do grupo de simetria $U(1)_{em}$.

Considera-se a corrente de hipercarga :

$$j_\mu^Y = \bar{\Psi} \gamma_\mu Y \psi \qquad Y: \text{operador de hipercarga gerador do grupo } U(1)_Y$$

tal que : $\boxed{j_\mu^{em} = J_\mu^3 + \frac{1}{2} j_\mu^Y}$ $\qquad Q = T^3 + \frac{Y}{2}$

e de forma que o grupo de simetria a considerar é :

$$SU(2)_L \times U(1)_Y$$

$$j_\mu^Y = -2(\bar{e}_R \gamma_\mu e_R) - (\bar{\chi}_L \gamma_\mu \chi_L) \qquad \text{corrente neutra}$$

Interacção electrofraca

A interacção electrofraca é de forma "corrente - bosão": $-i\, j_\mu A^\mu$

no modelo "standard":

3 bosões W^i_μ acoplados às correntes J^i_μ : constante g

1 bosão B_μ acoplado à corrente j^Y_μ : constante $g'/2$

$$\boxed{-ig\,(J^i)^\mu W^i_\mu - i\,\frac{g'}{2}\,(j^Y)^\mu B_\mu}$$

→ Bosões $W^\pm$ (correntes carregadas):

$$W^\pm_\mu = \frac{1}{\sqrt{2}}\left(W^1_\mu \mp i W^2_\mu\right)$$

→ o fotão e o bosão neutro Z^0 são combinações lineares de B_μ e W^3_μ:

$$A_\mu = B_\mu \cos\theta_W + W^3_\mu \operatorname{sen}\theta_W$$

$$Z_\mu = -B_\mu \operatorname{sen}\theta_W + W^3_\mu \cos\theta_W$$

θ_W angulo de Weinberg

Interacção electrofraca básica :

$$-ig\,(J^i)^\mu W^i_\mu \;-i\,\frac{g'}{2}\,(j^Y)^\mu B_\mu$$

$$\begin{array}{cc} \downarrow & \downarrow \\ SU(2) & U(1) \\ g & g' \end{array}$$

Os campos físicos A_μ e Z_μ são combinações lineares de B_μ e W^3_μ (parâmetro θ_W)

Resulta:

$$\begin{cases} j^{em}_\mu = J^3_\mu + \frac{1}{2}\, j^Y_\mu \\ J^{NC}_\mu = J^3_\mu - \operatorname{sen}^2\theta_W\, j^{em}_\mu \end{cases}$$

implicando:

$$g \operatorname{sen}\theta_W = g'\cos\theta_W = e$$

e o acoplamento das correntes neutras (NC):

$$-i\,\frac{g}{\cos\theta_W}\, J^{NC}_\mu Z^\mu$$

Interacção efectiva (pequenos q^2):

C. C	N. C.
• $\mathcal{M}^{cc} = \frac{4G}{\sqrt{2}} J^\mu J_\mu^\dagger$	$\mathcal{M}^{NC} = \frac{4G}{\sqrt{2}} 2\rho J_\mu^{NC} J^{NC\mu}$
• $\mathcal{M}^{cc} = \left(\frac{g}{\sqrt{2}} J_\mu\right)\left(\frac{1}{M_W^2}\right)\left(\frac{g}{\sqrt{2}} J^{\mu\dagger}\right)$	$\mathcal{M}^{cc} \simeq \left(\frac{g}{\cos\theta_W} J_\mu^{NC}\right)\left(\frac{1}{M_Z^2}\right)\left(\frac{g}{\cos\theta_W} J^{NC\mu}\right)$
$\Downarrow$	$\Downarrow$
$\frac{G}{\sqrt{2}} = \frac{g^2}{8M_W^2}$	$\rho\frac{G}{\sqrt{2}} = \frac{g^2}{8M_Z^2\cos^2\theta_W}$

pelo que:

$$\boxed{\rho = \frac{M_W^2}{M_Z^2\cos^2\theta_W}}$$

A interacção electrofraca por corrente neutra será da forma:

$$-ig\, J^3_\mu (W^3)^\mu - i\,\frac{g'}{2}\, j^Y_\mu B^\mu =$$

$$= -i\,\underbrace{\left(g \operatorname{sen}\theta_W J^3_\mu + g' \cos\theta_W \frac{j^Y_\mu}{2}\right)}_{①} A^\mu$$

$$-i\,\underbrace{\left(g \cos\theta_W J^3_\mu - g' \operatorname{sen}\theta_W \frac{j^Y_\mu}{2}\right)}_{②} Z^\mu$$

① corrente electromagnética: $e\, j^{em}_\mu \equiv e\left(J^3_\mu + \frac{1}{2} j^Y_\mu\right)$

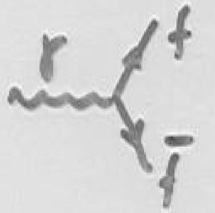
$$\longrightarrow \quad \boxed{g \operatorname{sen}\theta_W = g' \cos\theta_W = e}$$

② corrente fraca neutra:

$$-i\,\frac{g}{\cos\theta_W}\,\underbrace{\left(J^3_\mu - \operatorname{sen}^2\theta_W\, j^{em}_\mu\right)}_{J^{NC}_\mu} Z^\mu$$

FACTORES DE VERTICE :

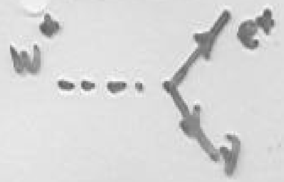
QED



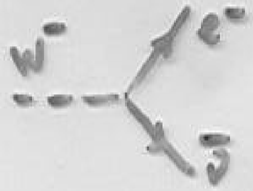
$$-ie(j^{em})^\mu A_\mu = -ie(\bar{\psi}\gamma^\mu Q_f \psi)A_\mu$$

$$\boxed{-ieQ_f\gamma^\mu}$$

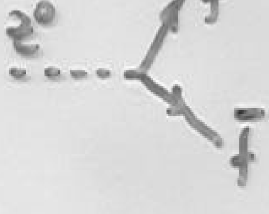
C.C.



$$\boxed{-i\frac{g}{\sqrt{2}}\gamma^\mu\frac{1}{2}(1-\gamma^5)}$$



N.C



$$-i\frac{g}{\cos\theta_W}\left(J^3_\mu - \mathrm{sen}^2\theta_W\, j^{em}_\mu\right)Z^\mu$$

$$= -i\frac{g}{\cos\theta_W}\,\bar{\psi}_f\gamma_\mu\left[\frac{1}{2}(1-\gamma^5)T^3 - \mathrm{sen}^2\theta_W\, Q\right]\psi_f Z^\mu$$

N.C. (cont.) — CORRENTE NEUTRA

O factor de vértice é dado por:

$$-i\,\frac{g}{\cos\theta_W}\,\gamma^\mu\,\frac{1}{2}\left(c_V^f - c_A^f\gamma^5\right)$$

pelo que:

$$\begin{cases} c_V^f = T_f^3 - 2\,\mathrm{sen}^2\theta_W\, Q_f \\ c_A^f = T_f^3 \end{cases}$$

exp: $\mathrm{sen}^2\theta_W = 0.234$

f	Q_f	c_A^f	c_V^f
$\nu_e, \nu_\mu \ldots$	0	$1/2$	$1/2$
$e^-, \mu^-, \ldots$	-1	$-1/2$	$-1/2 + 2\,\mathrm{sen}^2\theta_W \simeq -0.03$
$u, c, \ldots$	$2/3$	$1/2$	$1/2 - \frac{4}{3}\,\mathrm{sen}^2\theta_W \simeq 0.19$
$s, d, \ldots$	$-1/3$	$-1/2$	$-1/2 + 2/3\,\mathrm{sen}^2\theta_W \simeq -0.34$