Interações Eletrofracas: (21) ①

Na QED temos que: as interações são

$$\mathcal{L} = i\bar{\psi} D_\mu \gamma^\mu \psi - m\bar{\psi}\psi$$

$$-ieA_\mu \bar{\psi}\gamma^\mu\psi = -ieJ^\mu_{em}$$

Nas interações Eletrofracas, teremos interações com os seguintes bósons de gauge:

$W_\mu^+, W_\mu^-, W_\mu^3$ (ou $W_\mu^1 W_\mu^2; W_\mu^3$) B_μ!

→ as interações são

$$-ig J^a_\mu W^{a\mu} - ig' J^Y_\mu B^\mu$$

$$-ig\,\overline{\chi}_L\left(\frac{1}{2}\sigma_1 W^{1\mu}+\frac{1}{2}\sigma_2 W^{2\mu}\right)\gamma_\mu\,\chi_L$$

$$=-ig\,j^i_\mu\,W^{i\mu}$$

usando fine $\frac{1}{2}\left(\sigma_1 W^{1\mu}+\sigma_2 W^{2\mu}\right)=\frac{1}{\sqrt{2}}\left(\sigma_+ W^{+\mu}+\sigma_- W^{-\mu}\right)$

$$\Rightarrow\; =-\frac{ig}{\sqrt{2}}\,\overline{\chi}_L\left(\sigma_+ W^{+\mu}+\sigma_- W^{-\mu}\right)\gamma_\mu\,\chi_L$$

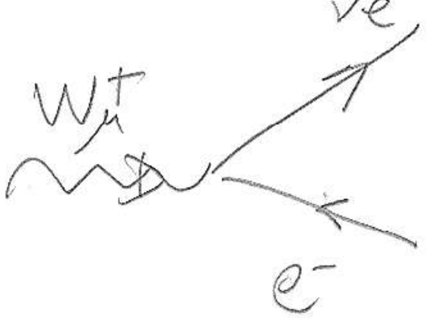
$$=-\frac{ig}{\sqrt{2}}\left(j_\mu W^{+\mu}+j^\dagger_\mu W^{-\mu}\right)$$

$$=-\frac{ig}{\sqrt{2}}\left(\overline{\nu}_{e_L}\gamma_\mu e_L W^{+\mu}+\overline{e}_L\gamma_\mu \nu_{e_L} W^{-\mu}\right)$$

Correntes (Est.) carregadas

$$-ig\left(j^1_\mu W^{1\mu} + j^2_\mu W^{2\mu}\right) = -\frac{ig}{\sqrt{2}}\left(j_\mu W^{+\mu} + j^\dagger_\mu W^{-\mu}\right)$$

eg :



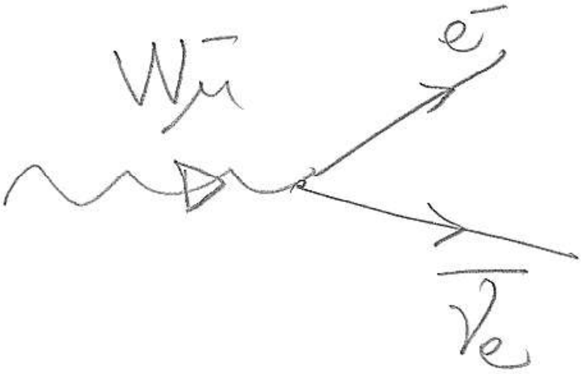
$$-\frac{ig}{\sqrt{2}} W^+_\mu \bar{\nu}_{eL}\gamma^\mu e_L$$

ou

Entanto que

$$-\frac{ig}{\sqrt{2}} W^-_\mu \bar{e}_L\gamma^\mu \nu_{eL}$$

o que também descreve



Correntes Neutras

$$-i g J^3_\mu W^{3\mu} - i g' J^Y_\mu B^\mu$$

Mais
$$\begin{cases} W^3_\mu = Z_\mu \cos\theta + A_\mu \operatorname{sen}\theta \\ B_\mu = A_\mu \cos - Z_\mu \operatorname{sen}\theta \end{cases}$$

$$\Rightarrow = -i\left(g \operatorname{sen}\theta J^3_\mu + g' \cos\theta J^Y_\mu\right) A^\mu$$

$$-i\left(g \cos\theta J^3_\mu - g' \operatorname{sen}\theta J^Y_\mu\right) Z^\mu$$

I) Acopl. do Fóton

5

$$e\, j^{\mu}_{em} = e\left(j^{3}_{\mu} + j^{Y}_{\mu}\right)$$

$$\Rightarrow \boxed{g \operatorname{sen}\theta = g' \cos\theta = e\,!}$$

II) Acoplamento do Z^0!

$$j^{Y}_{\mu} = j^{em}_{\mu} - j^{3}_{\mu}$$

$$\Rightarrow -i\left(g\cos\theta\, j^{3}_{\mu} - g' \operatorname{sen}\theta\left[j^{em}_{\mu} - j^{3}_{\mu}\right]\right) Z^{\mu}$$

$$= -\frac{i g}{\cos\theta}\left(\cos^2\theta\, j^{3}_{\mu} - g' \operatorname{sen}\theta \frac{\cos\theta}{g}\left[j^{em}_{\mu} - j^{3}_{\mu}\right]\right) Z^{\mu}$$

$$= -\frac{i g}{\cos\theta}\left[\cos^2\theta\, j^{3}_{\mu} + \operatorname{sen}^2\theta\, j^{3}_{\mu} - \operatorname{sen}^2\theta\, j^{em}_{\mu}\right] Z^{\mu}$$

$$= -\frac{i g}{\cos\theta}\left[j^{3}_{\mu} - \operatorname{sen}^2\theta\, j^{em}_{\mu}\right] Z^{\mu}$$

$$\Rightarrow J_\mu^{NC} \equiv J_\mu^3 - \sin^2\theta \, J_\mu^{em}$$

$$= -\frac{ig}{\cos\theta} J_\mu^{NC} Z^\mu$$ acopl. do Z!

$$J_\mu^3 = \bar{\chi}_L \gamma_\mu \frac{1}{2}\sigma^3 \chi_L = \frac{1}{2}\bar{\nu}_L \gamma_\mu \nu_L - \frac{1}{2}\bar{e}_L \gamma_\mu e_L$$

$J_\mu^3 = 0$ para RH!

$\Rightarrow$ acopl. do Z_μ^0!

Se LH:

$$-\frac{ig}{\cos\theta}\left(T_f^3 - \sin^2\theta \, Q_f\right)$$

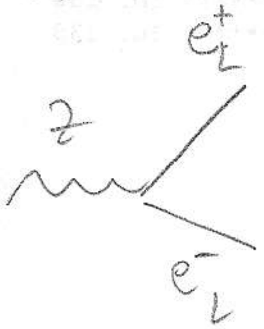
$\Rightarrow$ predições em termos de e e $\sin\theta$ para

$Z \to f\bar{f}$ com $f = e^-, \nu_e, \mu^-, \nu_\mu, u, d, s, \ldots$

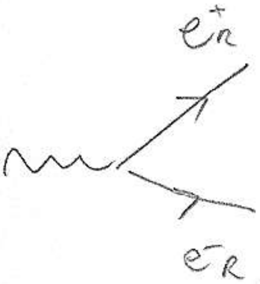
LH e RH!

⇒

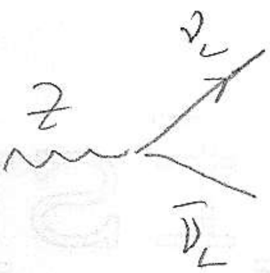
Z com léptons



$$= -\frac{ig}{\cos\theta}\left(-\frac{1}{2}+\sin^2\theta\right) Z_\mu \bar{e}_L \gamma^\mu e_L$$



$$= -\frac{ig}{\cos\theta}\left(\sin^2\theta\right) Z_\mu \bar{e}_R \gamma^\mu e_R$$

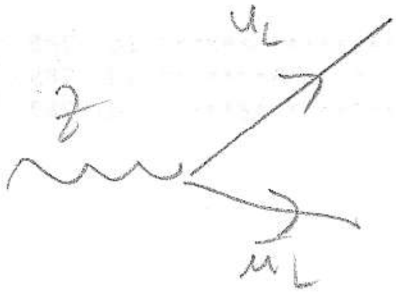


$$= -\frac{ig}{\cos\theta}\frac{1}{2} Z_\mu \bar{\nu}_L \gamma^\mu \nu_L$$

$$= 0 \quad !$$

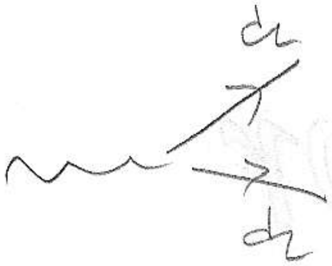
+ 2 gerações

Z com quarks

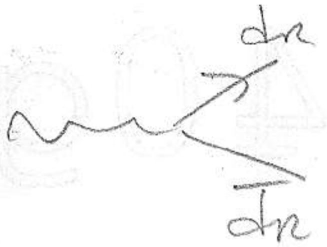


$$= \frac{-ig}{\cos\theta}\left(\frac{1}{2} - \frac{2}{3}\sin^2\theta\right) Z_\mu \bar{u}_L \gamma^\mu u_L$$

$$= \frac{-ig}{\cos\theta}\left(-\frac{2}{3}\sin^2\theta\right)$$



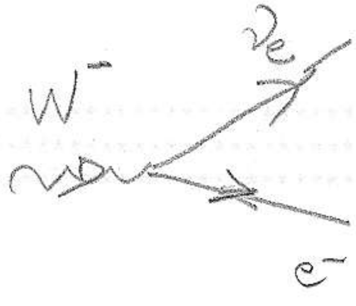
$$= \frac{-ig}{c\theta}\left(-\frac{1}{2} + \frac{1}{3}s^2\theta\right) Z_\mu \bar{d}_L \gamma^\mu d_L$$



$$= \frac{-ig}{\cos\theta}\left(\frac{1}{3}s^2\theta\right) Z_\mu \bar{d}_R \gamma^\mu d_R$$

Léptons:

$W \to e\nu$



$$= \frac{-ig}{\sqrt{2}} W_\mu \bar{e}_L \gamma^\mu \nu_L + h.c.$$

$$-i\mathcal{M} = \frac{-ig}{\sqrt{2}} \epsilon^\mu_\lambda \bar{e}_L \gamma_\mu \nu_L$$

$$d\Gamma = \frac{1}{2M_W} |\overline{\mathcal{M}}|^2 (2\pi)^4 \delta^{(4)}(P_W - P_e - P_{\bar{\nu}_e}) \frac{d^3 P_e}{(2\pi)^3 2E_e} \frac{d^3 P_\nu}{(2\pi)^3 2E_\nu}$$

Para calcular $|\overline{\mathcal{M}}|^2$

1) $$\sum_{\lambda=1,2,3\,!} \epsilon^{*\mu}_\lambda \epsilon^\nu_\lambda = -g^{\mu\nu} + \frac{P_W^\mu P_W^\nu}{M_W^2}$$

2) W tem 3 possíveis helicidades

$$\Rightarrow |\overline{\mathcal{M}}|^2 = \frac{1}{3} |\mathcal{M}|^2$$

$$\overline{|\mathcal{M}|}^2 = \frac{1}{3}\,\frac{g^2}{2}\left(-g^{\mu\nu}+\frac{p^\mu p^\nu}{M_W^2}\right) Tr\left[\not p_e\, \gamma_\mu\, \not p_\nu\, \gamma_\nu \frac{(1-\gamma^5)}{2}\right]$$

3.) $Tr\left[\gamma_\alpha \gamma_\mu \gamma_\beta \gamma_\nu \gamma_5\right] = 4i\,\epsilon_{\alpha\mu\beta\nu}$

$\Rightarrow$ γ^5 contribui 0!

$$\Rightarrow \overline{|\mathcal{M}|}^2 = \frac{g^2}{6}\cdot\frac{1}{2}\cdot 4\left(-g^{\mu\nu}+\frac{p^\mu p^\nu}{M_W^2}\right)\left(p_\mu k_\nu + k_\mu p_\nu - g_{\mu\nu}\, p\cdot k\right)$$

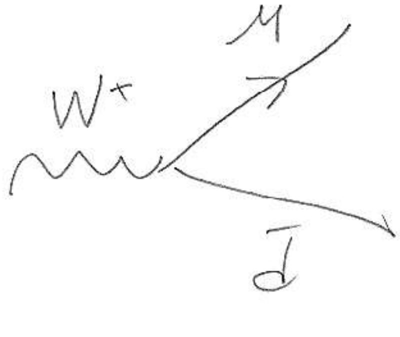
No W-rest frame:

$$\boxed{\overline{|\mathcal{M}|}^2 = \frac{1}{3} g^2 M_W^2}$$

Fazer!

$\rightarrow$ in the $m_e = m_{\nu_e} = 0$ limit

Para

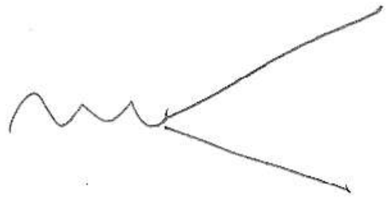


$\Rightarrow$ mesmo * 3 cores!

Z decay :

$Z \to e^+e^-$

$$g_A = \frac{g_R - g_L}{2}$$

 =

$$g_V = \frac{g_R + g_L}{2}$$

$$-i\frac{g}{\cos\theta} Z_\mu \left\{ \underbrace{\left(-\frac{1}{2}+s^2_\theta\right)}_{g_L^e} \bar{e}_L \gamma^\mu e_L + \underbrace{s^2_\theta}_{g_R^e} \bar{e}_R \gamma^\mu e_R \right\}$$

$$-\frac{ig}{\cos\theta} Z^\mu \bar{e} \gamma_\mu \left\{ g_L^e \frac{(1-\gamma^5)}{2} + g_R^e \frac{(1+\gamma^5)}{2} \right\} e$$

$$= -\frac{ig}{\cos\theta} Z^\mu \bar{e} \gamma_\mu \left\{ \underbrace{\frac{(g_L^e + g_R^e)}{2}}_{g_V^e} + \underbrace{\frac{(g_R^e - g_L^e)}{2}}_{g_A^e} \gamma_5 \right\} e$$

$$\Rightarrow \boxed{\Gamma(Z \to e^+e^-) = \frac{1}{6\pi} \frac{g^2}{\cos^2\theta} \frac{\left(g_V^{e\,2} + g_A^{e\,2}\right)}{2} M_Z}$$

$$\Rightarrow \boxed{\text{PAR} \quad \Gamma(Z \to \mu\bar{\mu}) = 3 * \frac{g^2}{12\pi \cos^2\theta} \left(g_V^{\mu\,2} + g_A^{\mu\,2}\right) M_Z}$$

etc !