4. Neutral currents (CERN, 1973)

Gargamelle Bubble Chamber

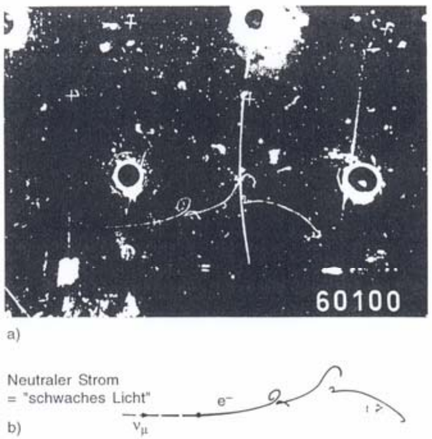
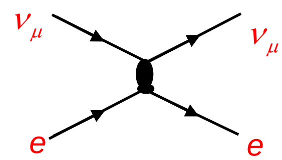


Abb. 9. Dieses erste Ereignis mit einem neutralen schwachen Strom wurde in Aachen entdeckt. Ein Neutrino dringt von links in die Blasenkammer ein (auf dem Bild nicht sichtbar) und wird elastisch an einem Elektron gestreut. Das Elektron ist als rechte Spurkaskade (Bremsstrahlung) zu erkennen. Dieses Bild ist in die Geschichte des CERN eingegangen

One out of three $\nu e \rightarrow \nu e$ events

$$\nu_\mu + e^- \rightarrow \nu_\mu + e^-$$



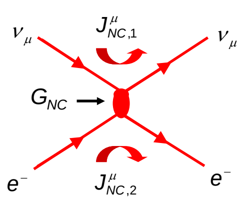
Neutral current νN events appear with a significant rate:

$$R_\nu = \frac{\sigma_{NC}(\nu N \rightarrow \nu X)}{\sigma_{CC}(\nu N \rightarrow \mu X)} = 0.307 \pm 0.008$$

i.e. approx.1/3 of the νN interactions are neutral current interactions.

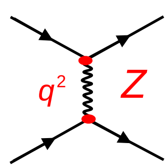
Structure of Neutral currents

Ansatz: four-fermion interaction



$$M = \frac{8G_{NC}}{\sqrt{2}} \cdot J_{NC,1,\mu} \cdot J^\mu_{NC,2}$$

as $q^2 \rightarrow 0$ approximation of:



Experimental determination of the structure of the weak neutral currents:

$$J^\mu_{NC} = \bar{u}\,\gamma^\mu \frac{1}{2}(g_V - g_A\gamma^5)u$$

➡ Neutral weak interaction couples to left- and right-handed fermion current contributions differently:

$$g_L = \frac{1}{2}(g_V + g_A) \qquad g_R = \frac{1}{2}(g_V - g_A)$$

$$J^\mu_{NC} = \bar{u}\gamma^\mu(g_R \frac{1+\gamma^5}{2} + g_L \frac{1-\gamma^5}{2})u$$

4.1 Vector and axial-vector couplings

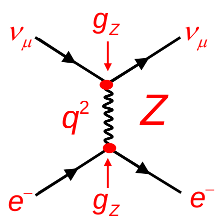
Standard Model prediction for g_V and g_A:

	g_V	g_A
ν	$1/2$	$1/2$
ℓ^-	$-1/2 + 2\sin^2\theta_W$	$-1/2$
$u-quark$	$+1/2 - 4/3\sin^2\theta_W$	$1/2$
$d-quark$	$-1/2 + 2/3\sin^2\theta_W$	$-1/2$

with $\sin^2\theta_W = 1 - \frac{M_W^2}{M_Z^2} \approx 0.223$

In case of the left-handed neutrinos: $J_\nu^\mu = \bar{u}_\nu \gamma^\mu \frac{1}{2} \cdot \frac{1}{2} \underbrace{(1-\gamma^5)}_{\text{pure V-A structure}} u_\nu$

4.2 Effective coupling G_{NC}



As 4-fermion interaction is the $q^2 \to 0$ approximation of a massive boson exchange:

$$J_e^\mu = \bar{u}\,\gamma^\mu \frac{1}{2}(g_V - g_A\gamma^5)u$$

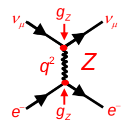
$$M = J_{e,\mu} \cdot g_Z \cdot \frac{g_{\mu\nu} - q_\mu q_\nu / M_Z^2}{q^2 - M_Z^2} \cdot g_Z \cdot J_\nu^\nu$$

$$M = \frac{8G_{NC}}{\sqrt{2}} \cdot J_{e,\mu} \cdot J_\nu^\mu$$

Comparison of the coupling constants in the $q^2 \to 0$ limit:

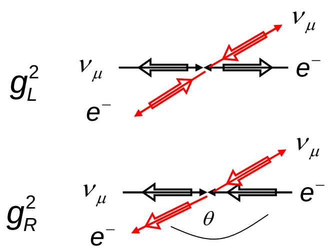
$$\frac{G_{NC}}{\sqrt{2}} = \frac{g_Z^2}{8M_Z^2} = \frac{g_W^2}{8M_W^2} \cdot \underbrace{\frac{g_Z^2 M_W^2}{g_W^2 M_Z^2}}_{\rho = 1 \text{ in the SM}} = \frac{g_W^2}{8M_W^2} \cdot \rho = \frac{G_F}{\sqrt{2}}$$

4.3 Neutrino-electron scattering (NC)



Using the matrix element above one finds:

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



$$\frac{d\sigma}{dy} = \frac{G_F^2 s}{\pi}\left[\underbrace{\left(\frac{g_V^e + g_A^e}{2}\right)^2}_{g_L^2} + \underbrace{\left(\frac{g_V^e - g_A^e}{2}\right)^2}_{g_R^2}(1-y)^2\right]$$

$$\sigma(\nu_\mu e^-) = 2mE_\nu \frac{G_F^2}{\pi}\left[\left(\frac{g_V^e + g_A^e}{2}\right)^2 + \frac{1}{3}\left(\frac{g_V^e - g_A^e}{2}\right)^2\right]$$

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

$$\frac{d\sigma}{dy} = \frac{G_F^2 s}{\pi}\left[\underbrace{\left(\frac{g_V^e - g_A^e}{2}\right)^2}_{g_R^2} + \underbrace{\left(\frac{g_V^e + g_A^e}{2}\right)^2}_{g_L^2}(1-y)^2\right]$$

$$\sigma(\bar{\nu}_\mu e^-) = 2mE_\nu \frac{G_F^2}{\pi}\left[\left(\frac{g_V^e - g_A^e}{2}\right)^2 + \frac{1}{3}\left(\frac{g_V^e + g_A^e}{2}\right)^2\right]$$

Determination of the vector/axial-vector couplings

$$\sigma(\nu_\mu e^-) = 2mE_\nu \frac{G_F^2}{3\pi}\left[g_V^{e^2} + g_V^e g_A^e + g_A^{e^2}\right]$$

$$\sigma(\bar{\nu}_\mu e^-) = 2mE_\nu \frac{G_F^2}{3\pi}\left[g_V^{e^2} - g_V^e g_A^e + g_A^{e^2}\right]$$

$$\frac{\sigma(\nu_\mu e)}{E_\nu} = [1{,}9 \pm 0{,}4\,(\text{stat.}) \pm 0{,}4\,(\text{syst.})]\cdot 10^{-42}\,\frac{\text{cm}^2}{\text{GeV}},$$

$$\frac{\sigma(\bar{\nu}_\mu e)}{E_{\bar{\nu}}} = [1{,}5 \pm 0{,}3\,(\text{stat.}) \pm 0{,}4\,(\text{syst.})]\cdot 10^{-42}\,\frac{\text{cm}^2}{\text{GeV}}.$$