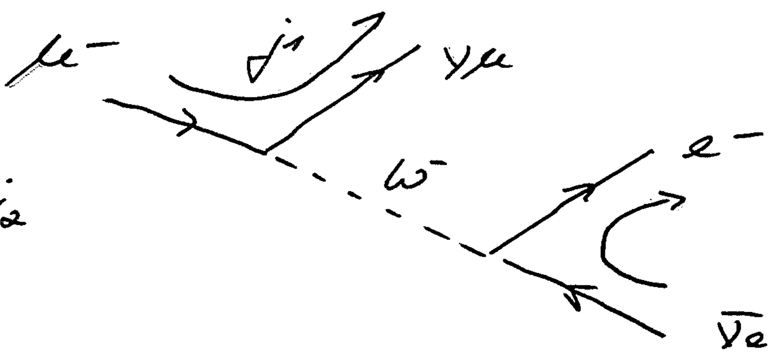
V-A structure of charged current IA

How do we know about the structure of the CC IA? So far we just learned that it violates parity, thus have a look at all possible IA terms.

In order to have LI representations of matrix elements, vertex currents are restricted to the so-called bilinear covariants.

Type	Form	Components	Boson-Spin
Scalar	$\bar\Psi\Psi$	1	0
Vector	$\bar\Psi\gamma^\mu\Psi$	4	1
Tensor	$\bar\Psi(\gamma^\mu\gamma^\nu-\gamma^\nu\gamma^\mu)\Psi$	4×4 (6 independent components)	2
Axialvector	$\bar\Psi\gamma^\mu\gamma^5\Psi$	4	1
Pseudoscalar	$\bar\Psi\gamma^5\Psi$	1	0

Study the behaviour of matrix element under parity transformation. E.g. muon decay



$\mathcal{M} \sim j^1 j^2$

Most general form of exchange of $S=1$ boson:

$$j^1 = \bar u_\nu (g_V\gamma^\mu + g_A\gamma^\mu\gamma^5) u_\mu$$

$$j^2 = \bar u_e (g_V\gamma^\mu + g_A\gamma^\mu\gamma^5) v_\nu$$

Parity transformation on spinors

$$u \xrightarrow{P} \gamma^0 u$$

$$\bar{u} \longrightarrow (\overline{\gamma^0 u}) = u^\dagger \gamma^{0\dagger} \gamma^0 = u^\dagger \gamma^0 \gamma^0 = \bar{u}\gamma^0$$

Parity of matrix element for pure vector current ($g_A = 0$)

$$j_1 = \bar{u}\gamma^\mu u \xrightarrow{P} \bar{u}\gamma^0\gamma^\mu\gamma^0 u$$

$$= \begin{cases} -\bar{u}\gamma^\mu\gamma^0\gamma^0 u = -\bar{u}\gamma^\mu u & \text{for } \mu \neq 0 \\ \bar{u}\gamma^\mu u & \text{for } \mu = 0 \end{cases}$$

$$M \sim j_1 j_2 \longrightarrow j_1 j_2$$ ⇒ parity is conserved (as it is the case for QED)

Parity of matrix element for axial vector current ($g_V = 0$)

$$j_1 = \bar{u}\gamma^\mu\gamma^5 u \xrightarrow{P} \bar{u}\gamma^0\gamma^\mu\gamma^5\gamma^0 u = \begin{cases} -\bar{u}\gamma^\mu\gamma^5 u & \text{for } \mu = 0 \\ \bar{u}\gamma^\mu\gamma^5 u & \text{for } \mu \neq 0 \end{cases}$$

$$M \sim j_1 j_2 \longrightarrow j_1 j_2$$ ⇒ parity is conserved

⇒ Parity is violated if $g_A \neq 0$ <u>and</u> $g_A \neq 0$

g_A, g_V must be determined from data.

Strength of parity violation:

$$j_1 = \bar{u}(g_V\gamma^\mu + g_A\gamma^\mu\gamma^5)u = g_V j_1^V + g_A j_1^A$$

$$j_2 = g_V j_2^V + g_A j_2^A$$

$$M \sim j_1 j_2 = g_V^2 j_1^V j_2^V + g_A^2 j_1^A j_2^A + g_A g_V (j_1^V j_2^A + j_1^A j_2^V)$$

$\xrightarrow{P}$

$$g_V^2 j_1^V j_2^V + g_A^2 j_1^A j_2^A - g_V g_A (j_1^V j_2^A + j_1^A j_2^V)$$

relative strength of parity violation $\dfrac{g_A g_V}{g_V^2 + g_A^2}$

maximal parity violation occurs if $|g_A| = |g_V|$ thus for pure V−A and V+A IA.

We know from experiment $g_V = 1$ $g_A = -1$

$$j = \bar{\Psi} \gamma^\mu (1-\gamma^5) \Psi \sim \bar{\Psi}_L \gamma^\mu \Psi_L + \underbrace{\bar{\Psi}_R \gamma^\mu \Psi_L}_{=0 \text{ (see previous lectures)}}$$

⇒ CC IA couples only left-handed particles with left-handed particles.
It is maximal parity violating.

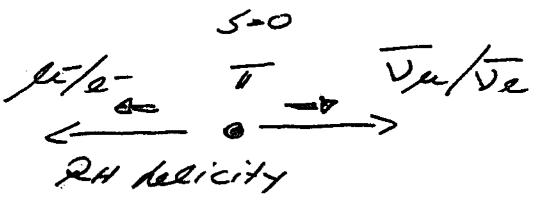
(In the following we will discuss μ decays in the framework of Fermi theory [$q^2 < m_\mu^2 \ll m_W^2$])

Experimental Probes of V−A

1) μ - Decays

(see slides)

2) Pion decays



in CMS of π

phase space factor favours electron decay
[$m(\pi) \sim 140$ MeV, $m(\mu) \sim 105$ MeV, $m(e) \sim 511$ keV]

However weak IA couples only to LH chirality states.

component of RH helicity state

$$\text{Pol}_{\text{of RH helicity state}} = \frac{f_{RH} - f_{LH}}{f_{RH} + f_{LH}} = \frac{v}{c}$$

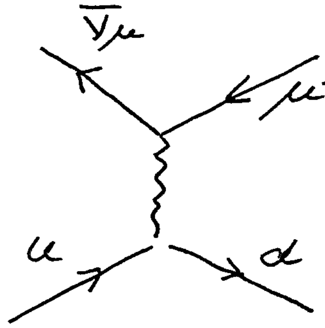
(without computation here)

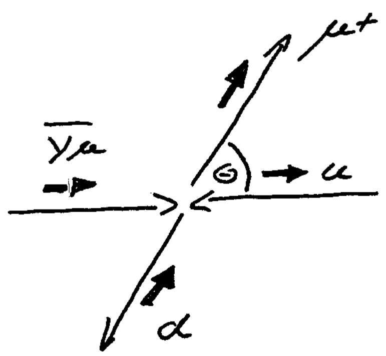
f_{RH} : fraction of RH chirality particles in RH helicity beam

f_{LH} : fraction of LH chirality particles in LH helicity beam

See slides

3) (Anti) Neutrino Quark Scattering



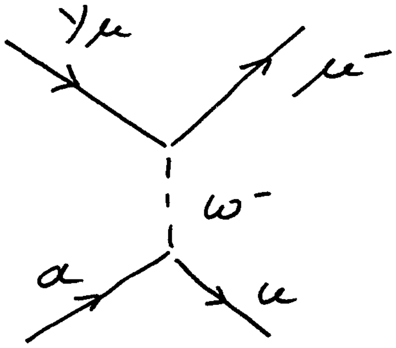


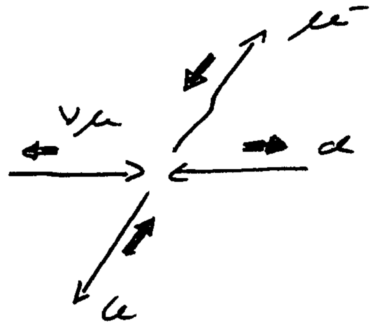
$S = 1$

$$\frac{d\sigma_{\bar{\nu}q}}{d\Omega^*} = \frac{G_F^2}{16\pi}(1+\cos\Theta^*)^2 s$$

"*" in CMS

in Fermi Theory depend on s, already illustrates that theory is not valid at large s divergent cross-section





$S = 0$

↑

no angular dependence of cross-section

$$\frac{d\sigma_{\nu q}}{d\Omega^*} = \frac{G_F^2}{4\pi^2}\, s$$

(remainder of the lecture on the slides)