Weak interactions

eg $\quad \beta$ decay $\quad d \to u e^- \bar{\nu}_e$

$\quad\mu^+$ " $\quad \mu^+ \to \bar{\nu}_\mu e^+ \nu_e$

$\quad\pi^+$ " $\quad u\bar{d} \to \mu^+ \nu_\mu$

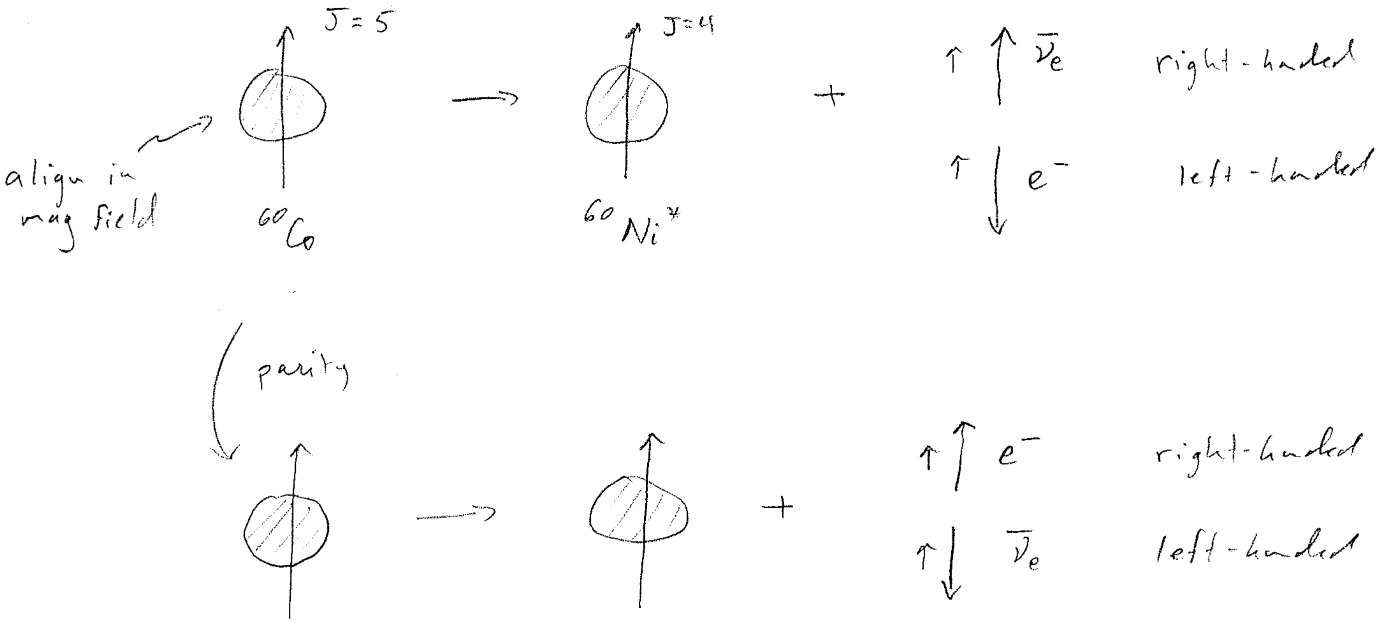
etc.

Features:

1. Doublet structure: $\quad u \leftrightarrow d \quad$ (smaller $u \leftrightarrow s$)
   $\nu_e \leftrightarrow e$
   $\nu_\mu \leftrightarrow \mu$
   } see above

2. Parity violating

   e.g. $^{60}Co \to {}^{60}Ni^* + e^- + \bar{\nu}_e$. Wu et al, 1957:



... much smaller probability

likewise - many other effects.

$\rightsquigarrow$ coupling to LH particles
RH anti "

3. Vectorial - e.g. see above, carries spin 1

4. Universal strength.

Summarized by <u>Effective interaction</u> (Fermi)

$$\mathcal{L}_W^{eff} = \frac{4G_F}{\sqrt{2}} J_\mu^+ J^{-\mu}$$

$$J_\mu^- = \sum_{i=1}^{3} \left(\bar{\nu}_i \gamma_\mu P_L e_i + \bar{u}_i \gamma_\mu P_L d_i' \right)$$

w/ $P_L = \frac{1-\gamma_5}{2}$,

w/ $d_i' = V_{ij} d_j$, $V^\dagger V = 1$ (to discuss)

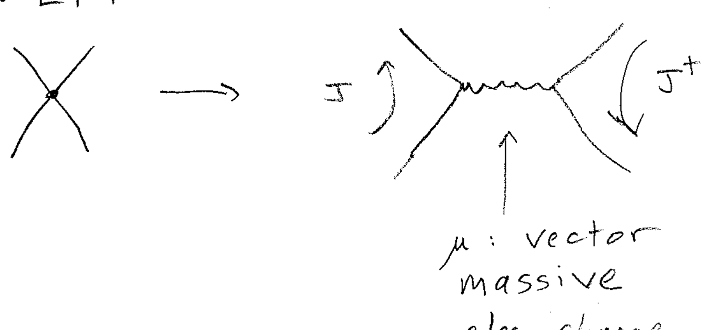
$$J_\mu^+ = (J_\mu^-)^\dagger$$

But: $[J] = 3 \Rightarrow [G_F] = -2$ irrelevant

$$G_F \simeq \frac{10^{-5}}{M_p^2}$$

$\therefore$ <u>strong</u>, ~~predictivity~~ at ~ 100 GeV.

$\Rightarrow$ New EFT:



$$\mathcal{L}_W^{int} = \frac{g_2}{\sqrt{2}} \left(J^{+\mu} W_\mu^- + J^{-\mu} W_\mu^+ \right)$$

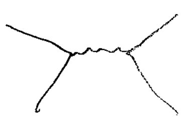
Kinetic ? Reps: $M_W \neq 0 \Rightarrow 3$ states ; W^μ : 4 components.

Let $W_{\mu\nu}^\pm = \partial_\mu W_\nu^\pm - \partial_\nu W_\mu^\pm$

$$\mathcal{L}^{Proca} = -\frac{1}{2} W_{\mu\nu}^+ W^{-\mu\nu} - M_W^2 W_\mu^+ W^{-\mu}$$

EOM $\rightsquigarrow$ (ex) $\partial^\mu W_\mu^\pm = 0$ - eliminates 1 comp. ✓

$$\Delta^{\mu\nu} = -i \frac{\eta^{\mu\nu} - \frac{k^\mu k^\nu}{M_W^2}}{k^2 + M_W^2 - i\epsilon}$$ (ex) (HW: more general ...)



$$\underset{k \ll M_W}{\simeq} \frac{g_2^2 J^{\mu +} J_\mu^-}{2 M_W^2} \Rightarrow G_F = \frac{g_2^2}{4\sqrt{2} M_W^2}$$

now observed. $M_W = 80.4$ GeV (E.F.T. strikes again)

<u>Not complete</u>

Renormalizability: $k \to \infty$ $\Delta^{\mu\nu} \sim - \frac{k^\mu k^\nu}{k^2 M_W^2} \sim$ const

$\Rightarrow$ ~~predictivity~~

2.13

More direct: consider $\nu\bar{\nu} \to W^+W^-$

$$i\mathcal{M} = -\frac{g_2^2}{2} \quad \bar{v}(p')\,\not{\epsilon}'\,P_L\,\frac{-i}{\not{p}-\not{k}-m_e}\,\not{\epsilon}\,P_L\,u(p)$$

let $k^\mu = (E,0,0,k)$

Long polar. $$\epsilon_L^\mu = \frac{(k,0,0,E)}{M_W} \xrightarrow[k\to\infty]{} \frac{k^\mu}{M_W} + \mathcal{O}\left(\frac{M_W}{E}\right)$$

$\sim \parallel k$

W_L's: $k \to \infty$

$u, v \sim \sqrt{E}$ (norm or spin sums)

$$\mathcal{M} \sim \frac{g_2^2}{M_W^2} E^2 \sin\theta \qquad \text{(ex)}$$

$J=1$ from chirality

violates <u>partial</u> <u>wave</u> <u>unitarity</u>

(cf. basic QM: $f_\ell \lesssim$ const.)

$\Rightarrow$ new physics

Clue: universal strength $\rightsquigarrow$ gauge symmetry ?

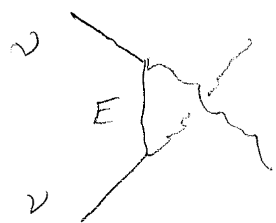
If so, charges : νe :

$$Q^- = \int d^3x \; \nu^\dagger P_L e$$

$$Q_{em} = -\int d^3x \; e^\dagger e$$

$$[Q^+, Q^-] \neq Q_{em} .$$

1. New fermions, eg $\begin{pmatrix} E^+ \\ \nu \\ e^- \end{pmatrix} = 3$ of $SU(2)$ Georgi-Glashow



unitarizes

(difficulties w/ quarks, ...)

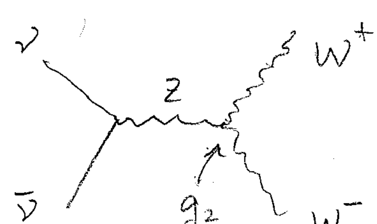
2. New charge/ gauge bosons

$$[Q^+, Q^-] = 2Q^3 = \int d^3x \left[\nu^\dagger P_L \nu - e^\dagger P_L e \right]$$ neutral

i.e, $\begin{pmatrix} \nu \\ e \end{pmatrix} = 2$ of $SU(2)$

new boson, vertex

YM-like couplings $\Rightarrow$



unitarizes! (ex)