CHAPTER 8 QUARKS AND PARTONS

[=> NOT PERSON BUT V. IMPORTANT!]

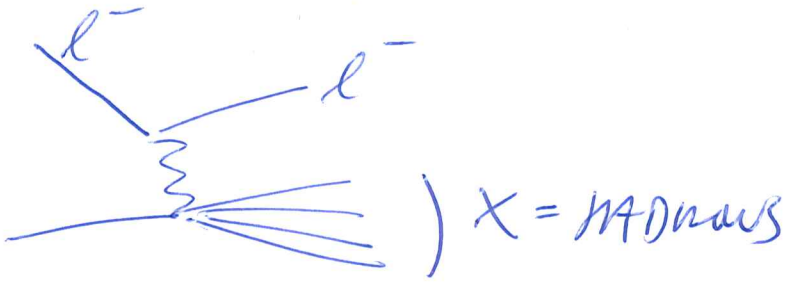
SO FAR FOCUS ON QUARKS INSIDE HADRONS "STATIC QUARKS"

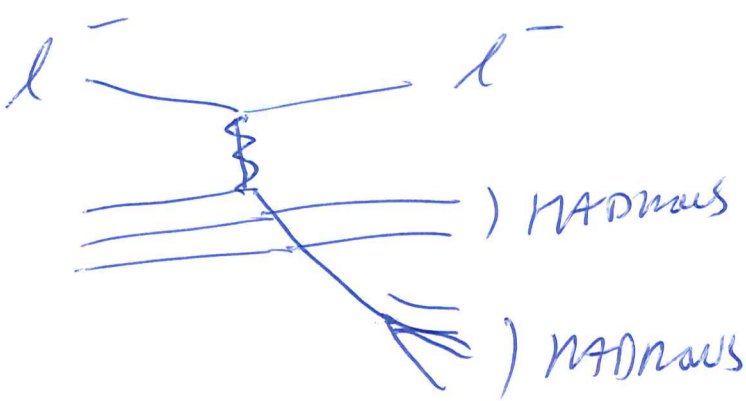
WE HAVE LEARNED ~~A~~ LOT ABOUT QUARKS, GLUONS, QCD IN SCATTERING EXPERIMENTS

$l^- p^+ \to l^- p^+$: ELASTIC SCATTERING

=> PROTON HAS CHARGE AND MAGNETIC MOMENT DISTRIBUTION, DOES NOT BEHAVE AS DIRAC POINT-PARTICLE

INELASTIC SCATTERING $l^- p^+ \to l + X$ AT INCREASED ENERGIES.





FUNCTIONS THAT DESCRIBE
INTERNAL STRUCTURE

DEPEND ON PARTICLES MASSES, E, P

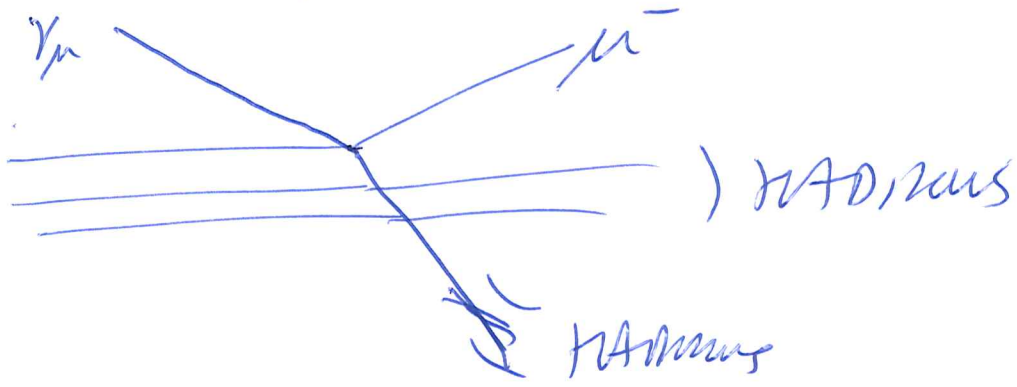
$\Rightarrow \hbar m, \hbar\vec{p}, \hbar E$
LEADS STRUCTURE FUNCTION
INVARIANT

$\Rightarrow$ SCALE INVARIANCE

BUT QCD: GLUONS INTRODUCE
SCALING VIOLATIONS $\rightarrow$ SEEN IN
DATA.

NEUTRINO SCATTERING AS WELL!

$\nu_\mu p^+ \rightarrow \mu^- X^{++}$



$\Rightarrow$ ENERGY-DEPENDENCE CONSISTENT W/
4-FERMION INTERACTION, BUT
ALSO HINTS AT BREAKDOWN AT
$\sqrt{s} \sim M_W$.

AT HIGH Q^2 (MOMENTUM OF PROBE)

PROTON (AND NEUTRON) ARE NOT JUST 3 QUARKS, THERE ARE $q\bar{q}$ PAIRS AND GLUONS TO ACCOUNT FOR.

$\Rightarrow$ 3 MASSES OF VALENCE QUARKS CONTRIBUTE SMALL FRACTION OF MASS

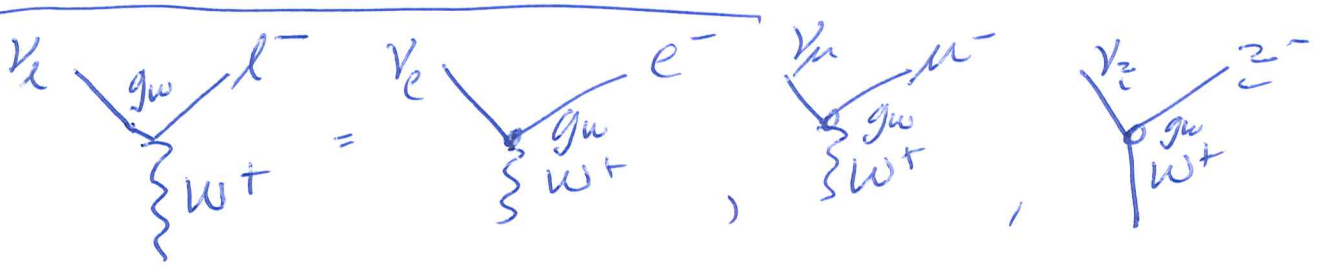
$\Rightarrow \sim 1/2$ PROTON MOMENTUM IS GLUONS.

CHAPTER 9 - WEAK INTERACTIONS OF QUARKS AND LEPTONS. [CHANGED!]

- NEUTRON, $K^{\pm}$, $\pi^{\pm}$, $K^{(-)0}$, CHARM, STRANGE, BOTTOM, TOP CHARGED WEAK DECAYS?

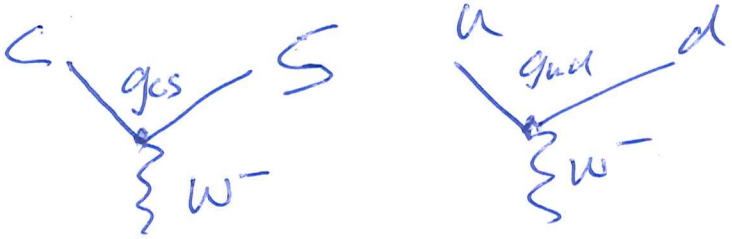
- HOW TO DESCRIBE THEM ALL CONSISTENTLY W/ SIMPLEST POSSIBLE MODEL?!

LEPTON-UNIVERSALITY



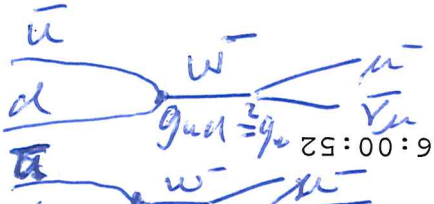
DIFFERENCES DUE TO $m_e \ll m_\mu \ll m_\tau \ll m_W$

LEPTON-QUARK SYMMETRY?



COULD TRY $g_{cs} \tilde{=} g_{ud} \tilde{=} g_W$

~WORKS FOR $\pi^- \to \mu^- \bar{\nu}_\mu$



BUT FAILS FOR $K^- \to \mu^- + \bar{\nu}_\mu$

ABOUT SIMILAR LIFETIMES.

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CABIBBO: WHAT IF WEAK AND STRONG EIGENSTATES NOT THE SAME?!

$$\begin{pmatrix} d' \\ s' \end{pmatrix} = \begin{pmatrix} \cos\theta_c & \sin\theta_c \\ -\sin\theta_c & \cos\theta_c \end{pmatrix} \begin{pmatrix} d \\ s \end{pmatrix}$$

"QUARK MIXING"

→ SIMILAR TO 2-GEN ν-MIXING!

APPLY "LEPTON-QUARK SYMMETRY" TO $\begin{pmatrix} u \\ d' \end{pmatrix}, \begin{pmatrix} c \\ s' \end{pmatrix}$ INSTEAD OF $\begin{pmatrix} u \\ d \end{pmatrix}, \begin{pmatrix} c \\ s \end{pmatrix}$

i.e. $g_{ud} = g_{cs} = g_w \cos\theta_c$

$g_{us} = -g_{cd} = g_w \sin\theta_c$

HISTORICALLY DON'T EXIST W/O THE C-QUARK!

EXPERIMENTALLY $\theta_c \simeq 13°$, $\cos\theta_c \simeq 0.974$, $\sin\theta_c \simeq 0.225$

$$\frac{\Gamma(K^- \to \mu^- \bar{\nu}_\mu)}{\Gamma(\pi^- \to \mu^- \bar{\nu}_\mu)} \propto \frac{g_{us}^2}{g_{ud}^2} = \frac{\sin^2\theta_c}{\cos^2\theta_c} = \tan^2\theta_c \sim 0.05$$

SO SUPPRESSED BY FACTOR ~20, BUT NOT e.g. 100 (g_w)

CHARMED QUARK DECAYS MOST OFTEN TO S.

$$\left|\frac{g_{cs}}{g_{cd}}\right| = \frac{\cos\theta_c}{\sin\theta_c} >> 1$$

"CABIBBO-ALLOWED" $u \to d$
$c \to s$

"CABIBBO-SUPPRESSED" $u \to s$
$c \to d$

W-DECAYS

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LEPTON-QUARK SYMMETRY
+
QUARK MIXING.

$W^+ \to u\bar{d}, c\bar{s}$

$l^+ \nu_l$

C-ALLOWED $W^+ \to u\bar{d}, c\bar{s}$

C-SUPPRESSED $W^+ \to c\bar{d}, u\bar{s}$

3 LEPTON FAMILIES

2 QUARK GENERATIONS × 3 COLORS

$= 3 + 6 = 9$ ~ EQUAL DECAYS.

$B(W^+ \to l^+ \bar{\nu}_l) \sim \frac{1}{9}$

$B(W^+ \to \text{HADRONS}) \sim 1 - \frac{3}{9} \simeq 2/3$

AGREES QUITE WELL W/ EXP

THE THIRD GENERATION

$\begin{pmatrix} e^- \\ \nu_e \end{pmatrix} \begin{pmatrix} \mu^- \\ \nu_\mu \end{pmatrix} \begin{pmatrix} \tau^- \\ \nu_\tau \end{pmatrix}$ τ: 1975) SLAC

$\begin{pmatrix} u \\ d \end{pmatrix} \begin{pmatrix} c \\ s \end{pmatrix} \begin{pmatrix} t \\ b \end{pmatrix}$ b: 1977, t: 1995) FERMILAB

CKM: KEEP LEPTON–QUARK SYMMETRY BY ~~EXTENDED~~ QUARK MIXING

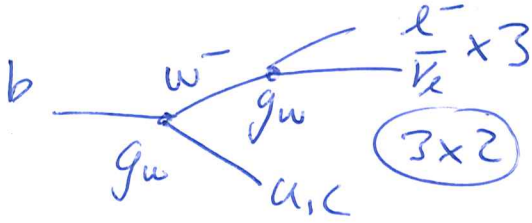
$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

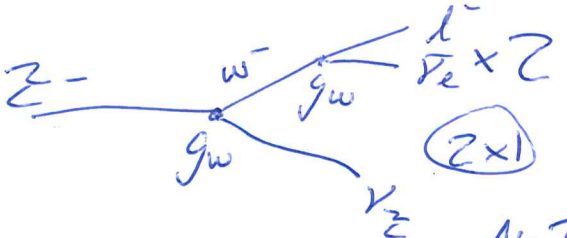
=> t-QUARK SEEN AS NATURAL EXTENSION!

WEAK EIGENSTATES ARE $\begin{pmatrix} u \\ d' \end{pmatrix}, \begin{pmatrix} c \\ s' \end{pmatrix}, \begin{pmatrix} t \\ b' \end{pmatrix}$

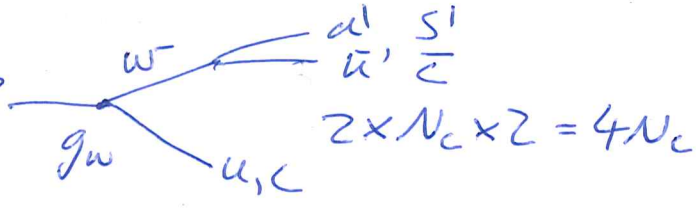
$g_{\alpha\beta} = g_W \cdot V_{\alpha\beta}$, e.g. $g_{cb} = g_W \cdot V_{cb}$

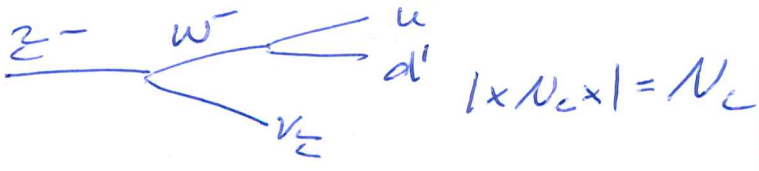
ESTIMATE V_{ub}, V_{cb} BY ~~ASSUMED~~ FIRST $V_{ba} = V_{bc} = 1$





N=3





N=4

$\Gamma_b \approx N \cdot \left(\frac{m_b}{m_\tau}\right)^5 \cdot \Gamma_\tau$, $\tau = \frac{1}{\Gamma}$, $\tau_b \approx 10^{-15}$ s, $\tau_b^{exp} \approx 10^{-12}$ s

SO $V_{ub}, V_{cb} \neq 1$!

IN FACT $|V_{ub}|^2 \sim 10^{-5}$

$|V_{cb}|^2 \sim 10^{-3}$

BUT $\frac{|V_{ub}|^2}{|V_{cb}|^2} \ll 1$

$\rightarrow$ b-LIFETIME "LONG" {COMPARED TO OTHER WEAK PROCESSES}

b-DECAYS MOSTLY TO c

2-QUARK MIXING, OFTEN A GOOD APPROX.

$$\begin{pmatrix} V_{ud} & & \\ & \ddots & \\ & & V_{tb} \end{pmatrix} \equiv \begin{pmatrix} \cos\theta_c & \sin\theta_c & 0 \\ -\sin\theta_c & \cos\theta_c & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

$$\Rightarrow \begin{pmatrix} u \\ d' \end{pmatrix}, \begin{pmatrix} c \\ s' \end{pmatrix}, \begin{pmatrix} t \\ b \end{pmatrix}$$

$\Rightarrow$ CAN UNDERSTAND A LOT ABOUT DECAYS OF TOP-QUARK

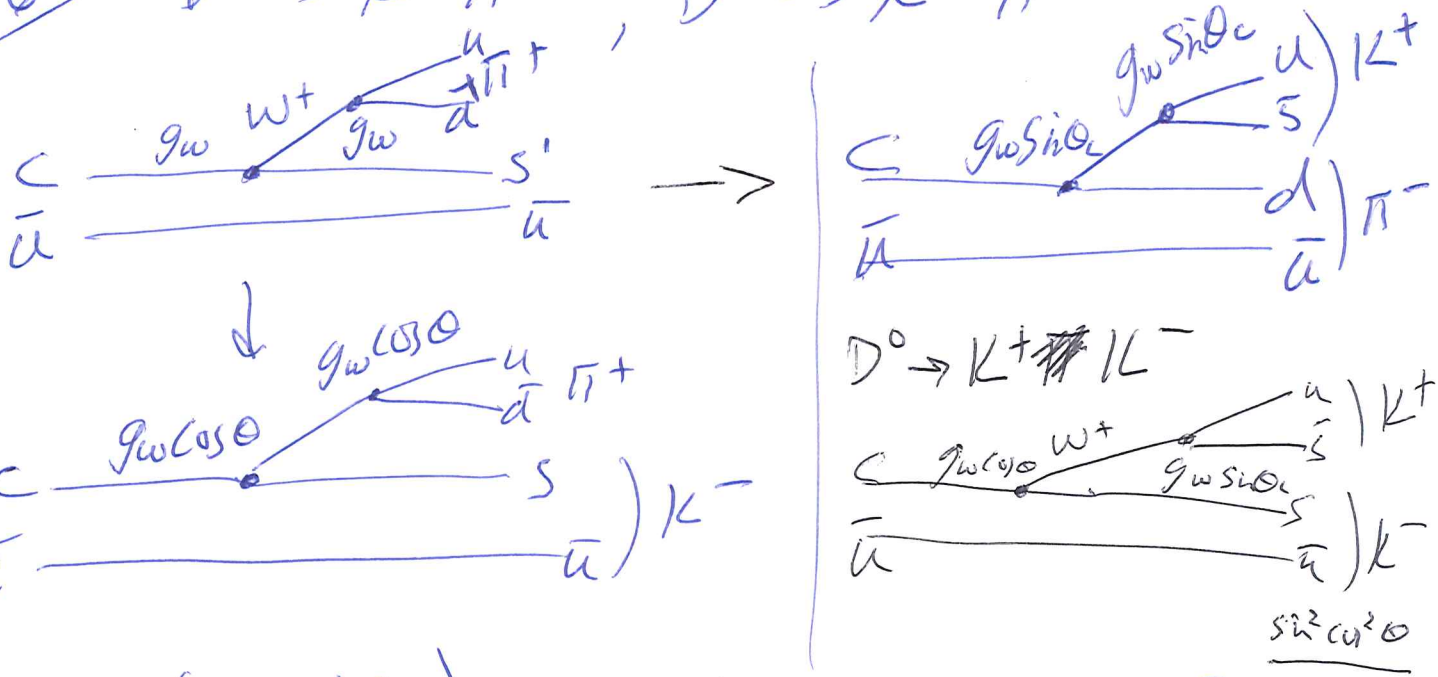
$t \rightarrow b(W^+) \rightarrow c(W^+) \rightarrow s(W^+) \rightarrow u(W^+)$

FAST | V. FAST | VERY SLOW | SLOW | SLOW | SUPER SLOW

$t \rightarrow$ leptons + JETS + missing

$\Gamma \sim \alpha_w m_t \sim 1\,\text{GeV} \Rightarrow \tau_t \sim 4 \cdot 10^{-25}\,\text{s}$ [or $\Gamma = 1.76\,\text{GeV}$]

9.6) $D^0 \to K^-\pi^+$, $D^0 \to K^+\pi^-$



$\frac{\sin^2\theta\cos^2\theta}{\cos^4\theta^2} = \tan^2\theta_c$

$$\frac{B(D^0 \to K^+\pi^-)}{B(D^0 \to K^-\pi^+)} = \tan^4\theta_c = 0.29 \cdot 10^{-2} = 2.7 \cdot 10^{-3}$$

$\theta_c = 13.02°$

EXPT: $K^-\pi^+$ $(3.89 \pm 0.4)\%$

$K^+\pi^-$ $(1.385 \pm 0.027) \cdot 10^{-4}$

$$\frac{B(K^+\pi^-)}{B(K^-\pi^+)} = (3.6 \pm 0.4) \cdot 10^{-3}$$ wow!

PREDICT $\frac{B(D^0 \to K^+K^-)}{B(D^0 \to K^-\pi^+)} = \tan^2\theta_c = 0.054$ WITHIN FACTOR 2

PDG: K^+K^- $(4.0 \pm 0.07) \cdot 10^{-3}$, $R\frac{(K^+K^-)}{(K^-\pi^+)} = 0.10$