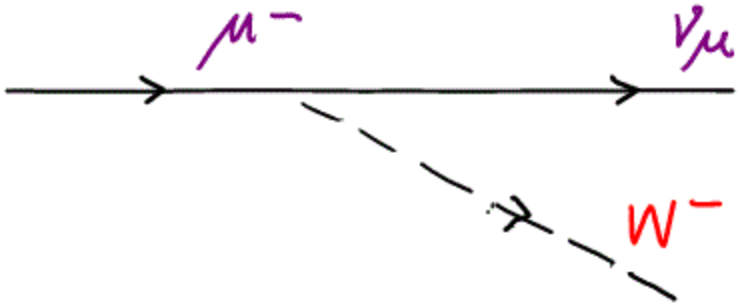
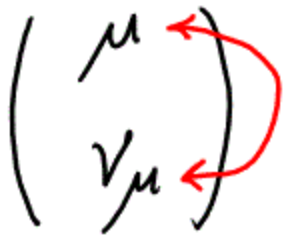
FLAVOUR MIXING BY WEAK FORCE

WEAK FORCE DOES NOT CONSERVE QUARK FLAVOUR

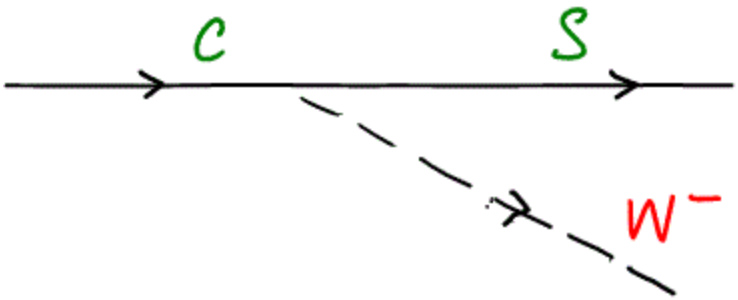
JUST FLIPS LEPTONS WITHIN DOUBLETS





$W^\pm$ FLIPS WITHIN DOUBLET

CHANGES FLAVOUR OF QUARKS



$W^\pm$

THINK ABOUT FIRST 2 GENERATIONS

$$\begin{pmatrix} u \\ d \end{pmatrix} \quad \begin{pmatrix} c \\ s \end{pmatrix}$$

→ STATES OF DEFINITE
- MASS
- COLOUR
- FLAVOUR

→ EIGENSTATES OF MASS

$$M|u\rangle = m_u|u\rangle$$

→ EIGENSTATES OF COLOUR FORCE

$$C|u\rangle = c_u|u\rangle$$

THESE CANNOT BE THE EIGENSTATES THAT WEAK INTERACTION SEES → IT DOES NOT CONSERVE QUARK FLAVOUR

EIGENSTATES OF WEAK INTERACTION ARE A MIXTURE OF DEFINITE FLAVOUR STATES

→ THIS IS WHY WEAK INTERACTION CAN INDUCE TRANSITIONS BETWEEN STATES OF DEFINITE FLAVOUR

$$\begin{pmatrix} u \\ d \end{pmatrix}$$

COLOUR EIGENSTATE
= MASS EIGENSTATE

$$\begin{pmatrix} u \\ d\cos\theta_C + s\sin\theta_C \end{pmatrix}$$

WEAK EIGENSTATES

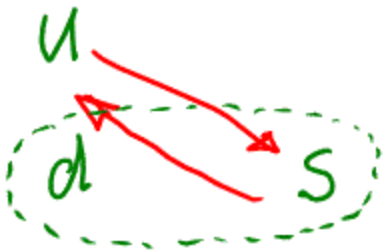
$d \to u\ \alpha\ \cos^2\theta_C$
$s \to u\ \alpha\ \sin^2\theta_C$

$$\begin{pmatrix} d \\ s \end{pmatrix}_{WEAK} = \begin{pmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{pmatrix} \begin{pmatrix} d \\ s \end{pmatrix}_{COLOUR}$$

CABIBBO ANGLE

MAINLY WEAK INTERACTION INDUCES

d & s BEING MIXED — CAN INDUCE



MODIFIES UNIVERSAL FERMION WEAK COUPLING

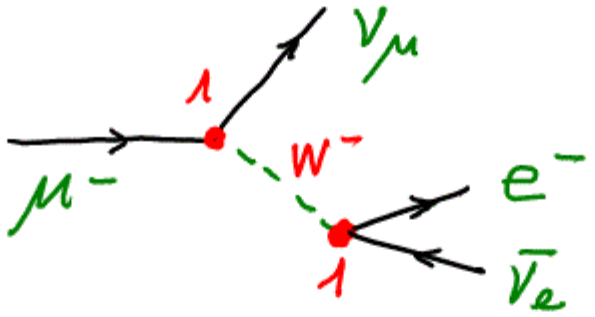
→ MEASUREMENTS CONSISTET WITH

UNIVERSAL CABBIBO ANGLE

θ_c

STRENGTH

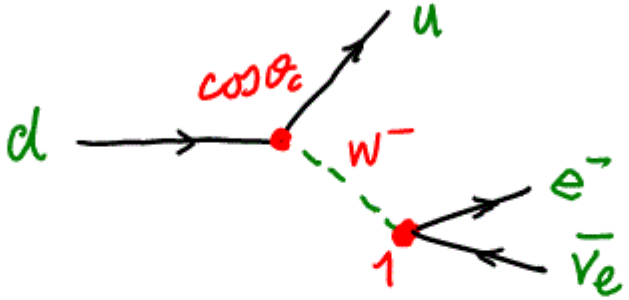
$\mu^- \to \nu_\mu e^- \bar{\nu}_e$



$1 \times G_F^2$

$d \to u e^- \bar{\nu}_e$

$(n \to p e^- \nu)$

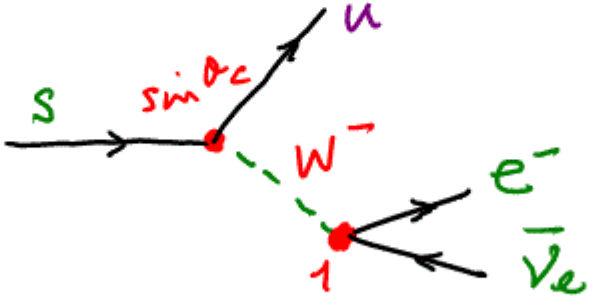


~ 0.95

$(\cos^2\theta_c)$

$S \to u e^- \bar{\nu}_e$

$\left(\Lambda \to p e^- \nu \right.$
$\left. Br \sim 10^{-3}\right)$

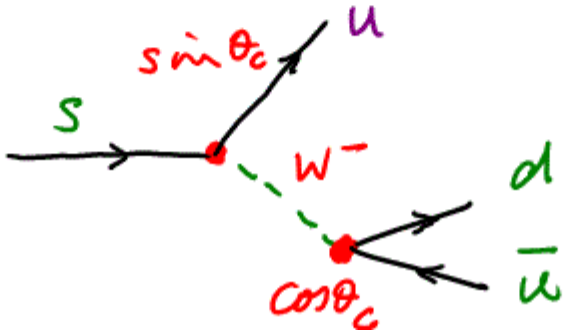


~ 0.05

$(\sin^2\theta_c)$

$S \to u d \bar{u}$

$(\Lambda \to p \pi^-)$

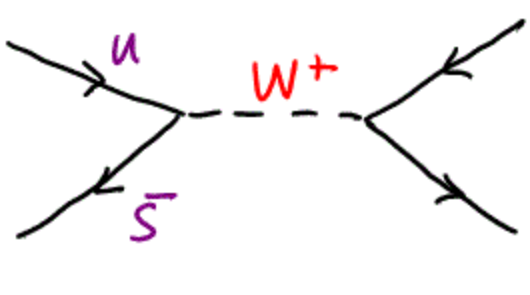


~ 0.09

$(\sin\theta_c \cos\theta_c)$

Z^0 DOES NOT INDUCE DECAYS — WHY?

$K^+ \to \mu^+ \nu_\mu$



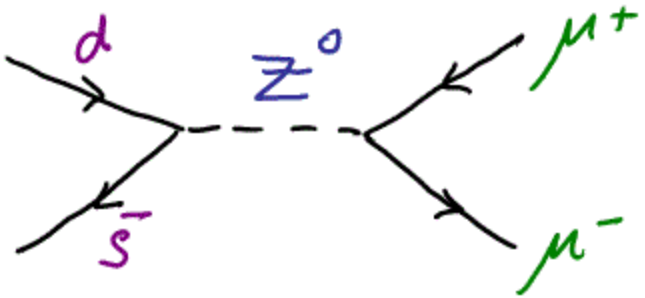
PARITY VIOLATION

$$\text{AMP} \sim \frac{G}{\sqrt{2}} \cdot \sin\theta_c \cdot f_K \, m_\mu \, \bar{\nu} \gamma_5 \mu$$

$$\text{DECAY} \quad \Gamma \sim \frac{G^2}{8\pi} \sin^2\theta_c \, f_K^2 \, m_K \, m_\mu^2 \left(1 - m_\mu^2/m_K^2\right)$$

AGREES WITH EXPERIMENT $\tau \sim 10^{-8}$ s, BR $\sim 64\%$

$K_L^0 \to \mu^+\mu^-$



SHOULD BE ABOUT SAME Γ AS THE W^- DIAGRAM

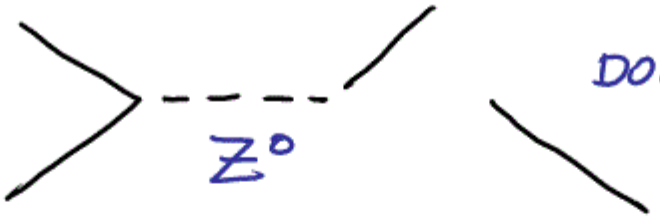
BUT EXPERIMENTALLY $\tau_{K_L} = 5 \times 10^{-8}$ s

BR $= 9.5 \times 10^{-9}$

NO FLAVOUR CHANGING NEUTRAL CURRENTS

NO FIRST ORDER FLAVOUR CHANGING NEUTRAL CURRENT

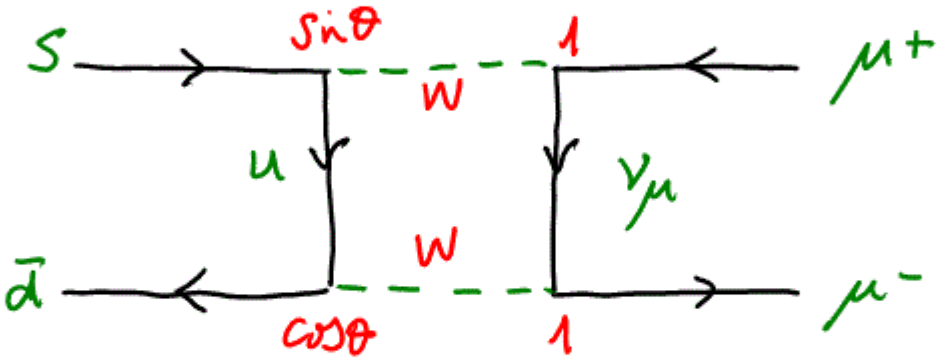
$K^0_L \to \mu^+\mu^-$



DOES NOT EXIST

BUT $W^\pm$ CAN INDUCE AT HIGHER ORDER

K^0_L

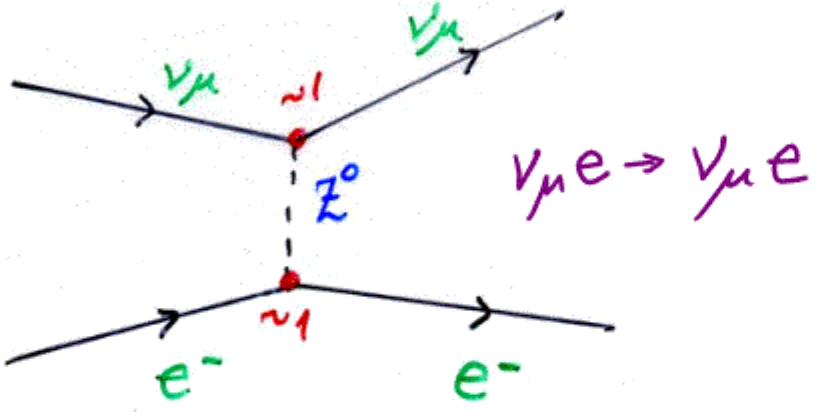


$$\frac{\Gamma(K^0_L \to \mu\mu)}{\Gamma(K^+ \to \mu\nu)} \approx \left(\frac{3\sqrt{2}\alpha}{\pi}\right)^2 \longrightarrow BR(K^0_L \to \mu^+\mu^-) \approx 3 \times 10^{-4}$$

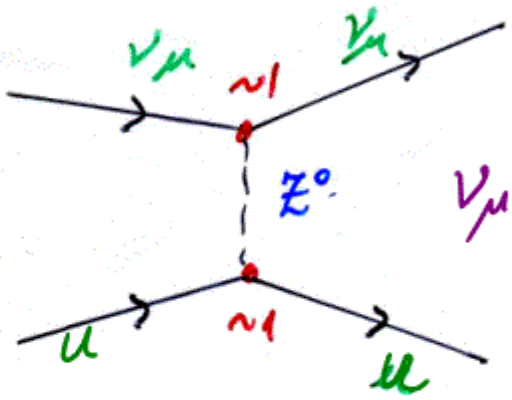
Cf EXPERIMENT $BR \sim 10^{-9}$ { SOME SUPPRESSION MECHANISM IS AT WORK HERE

BUT NEUTRAL CURRENTS DO EXIST.

THE FOLLOWING ν INTERACTIONS OBSERVED WITH EXPECTED WEAK COUPLING STRENGTH



$\nu_\mu e \to \nu_\mu e$



$\nu_\mu p \to \nu_\mu p$

NOTICE THAT THESE INTERACTIONS DO NOT CHANGE QUARK FLAVOUR FROM INITIAL TO FINAL STATE

WHY DOES Z^0 NOT INDUCE

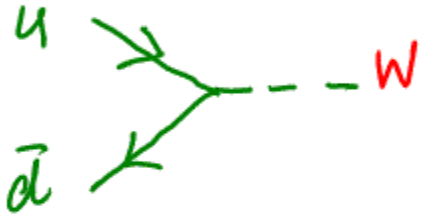
$$K_L^0 \to \mu^+\mu^-$$

$S = -1$ $\qquad$ $S = 0$ ← FLAVOUR CHANGE

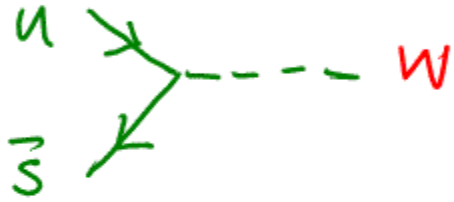
FROM

WE CAN WRITE THE TRANSITION AMPLITUDES

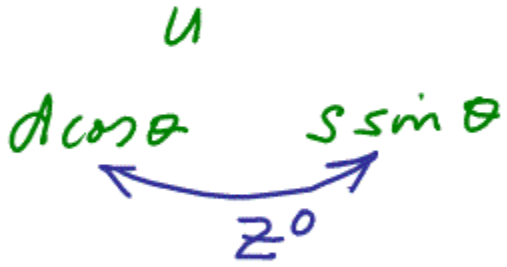
$\sim u\bar{d}\cos\theta$

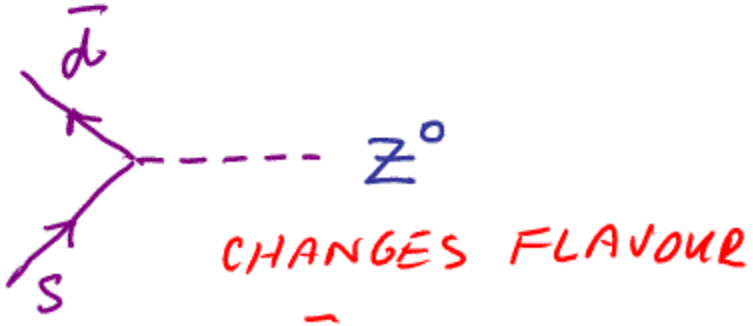


$u\bar{s}\sin\theta$



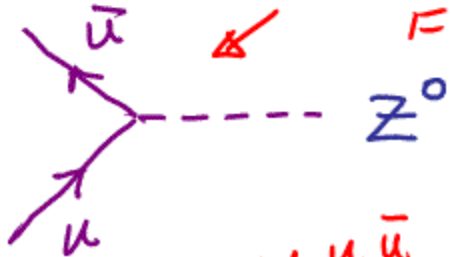
BUT ALSO HAVE





$\sim s\bar{d}\cos\theta\sin\theta$

CONSERVES FLAVOUR

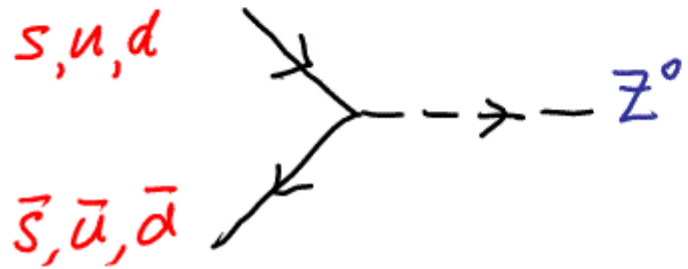


$\sim u\bar{u}$

$$\begin{pmatrix} u \\ d\cos\theta & s\sin\theta \end{pmatrix}$$

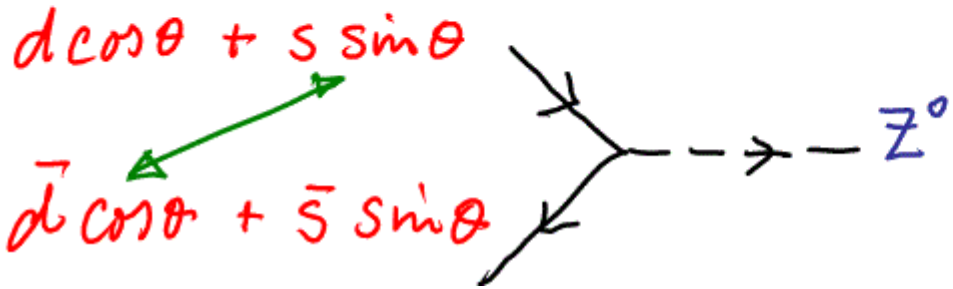
EXPAND OUT ALL POSSIBLE TRANSITIONS FOR Z^0

$$u\bar{u} + d\bar{d}\cos^2\theta + s\bar{s}\sin^2\theta$$



FLAVOUR CONSERVING
OBSERVED IN ν SCATTERING

$$s\bar{d}\sin\theta\cos\theta + \bar{d}s\sin\theta\cos\theta$$



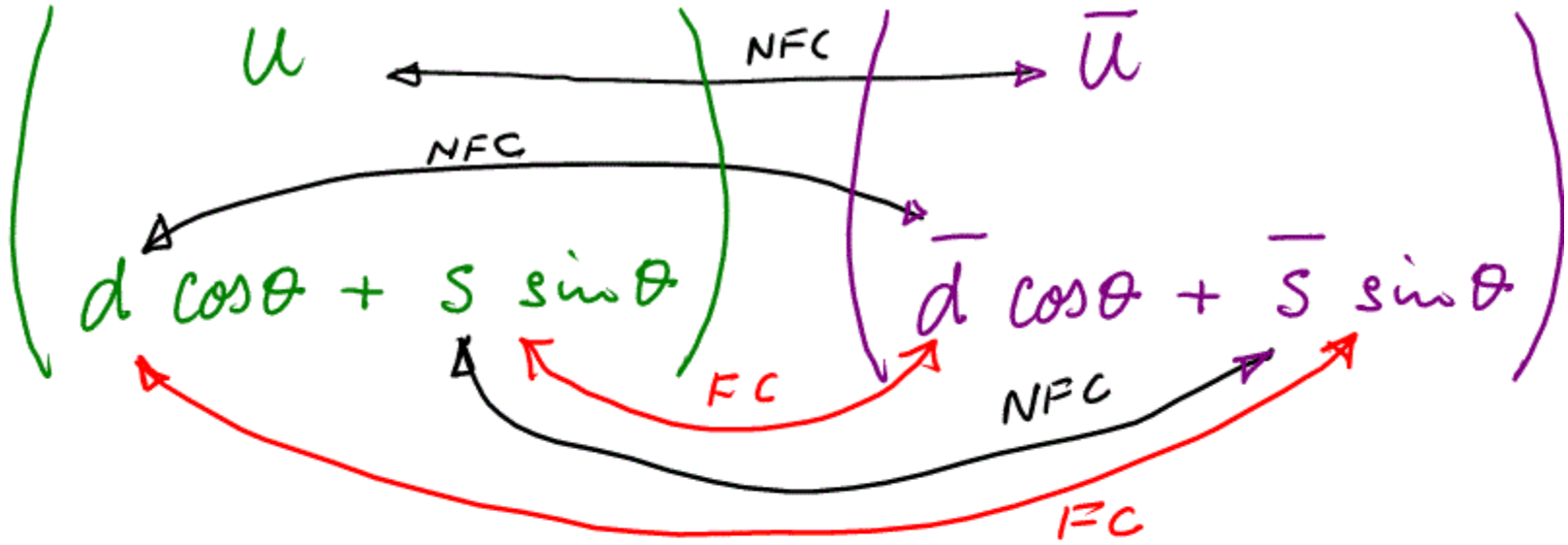
FLAVOUR CHANGING
NOT OBSERVED IN DECAY

ABSENCE OF Z^0 DECAYS LED GLASHOW, ILIOPOULOS & MAIANI TO MAKE THE FOLLOWING PREDICTION BEFORE C-QUARK DISCOVERY

$$\begin{pmatrix} u \\ d \end{pmatrix} \quad \begin{pmatrix} c \\ s \end{pmatrix} \rightarrow \text{COLOUR EIGENSTATES}$$

$$\begin{pmatrix} u \\ d\cos\theta + s\sin\theta \end{pmatrix} \quad \begin{pmatrix} c \\ s\cos\theta - d\sin\theta \end{pmatrix}$$

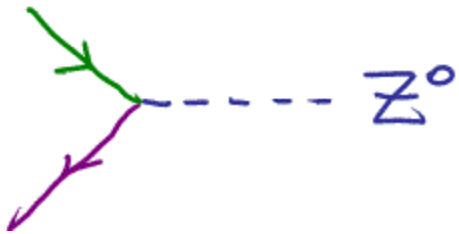
AS THE WEAK EIGENSTATES



$$\begin{pmatrix} c \\ s\cos\theta - d\sin\theta \end{pmatrix} \quad \begin{pmatrix} \bar{c} \\ \bar{s}\cos\theta - \bar{d}\sin\theta \end{pmatrix}$$

NFC = NO FLAVOUR CHANGE

FC = FLAVOUR CHANGE



WRITE OUT TRANSITION AMPLITUDES

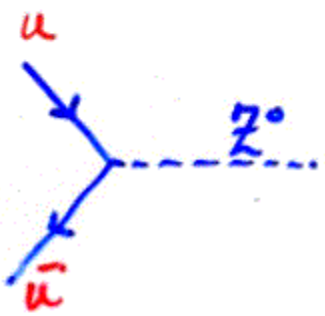
$$u\bar{u} + c\bar{c} + (\bar{d}d + s\bar{s})\cos^2\theta + (s\bar{s} + d\bar{d})\sin^2\theta$$

→ CONSERVES FLAVOUR

$$+$$

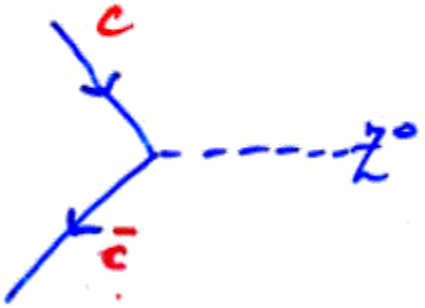
$$(s\bar{d} + \bar{s}d - \bar{s}d - s\bar{d})\cos\theta\sin\theta$$

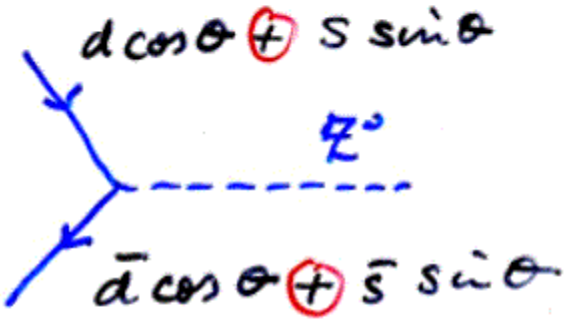
→ FLAVOUR CHANGING PART VANISHES



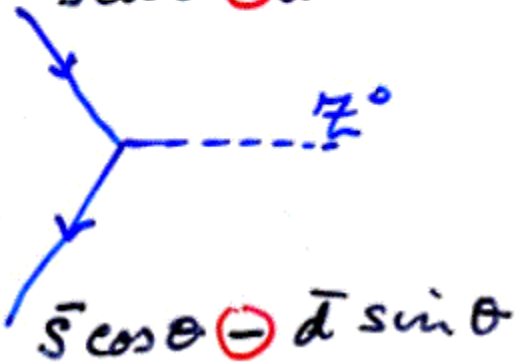
THESE CANNOT MEDIATE DECAYS

$m_u = m_{\bar{u}}$ $m_c = m_{\bar{c}}$



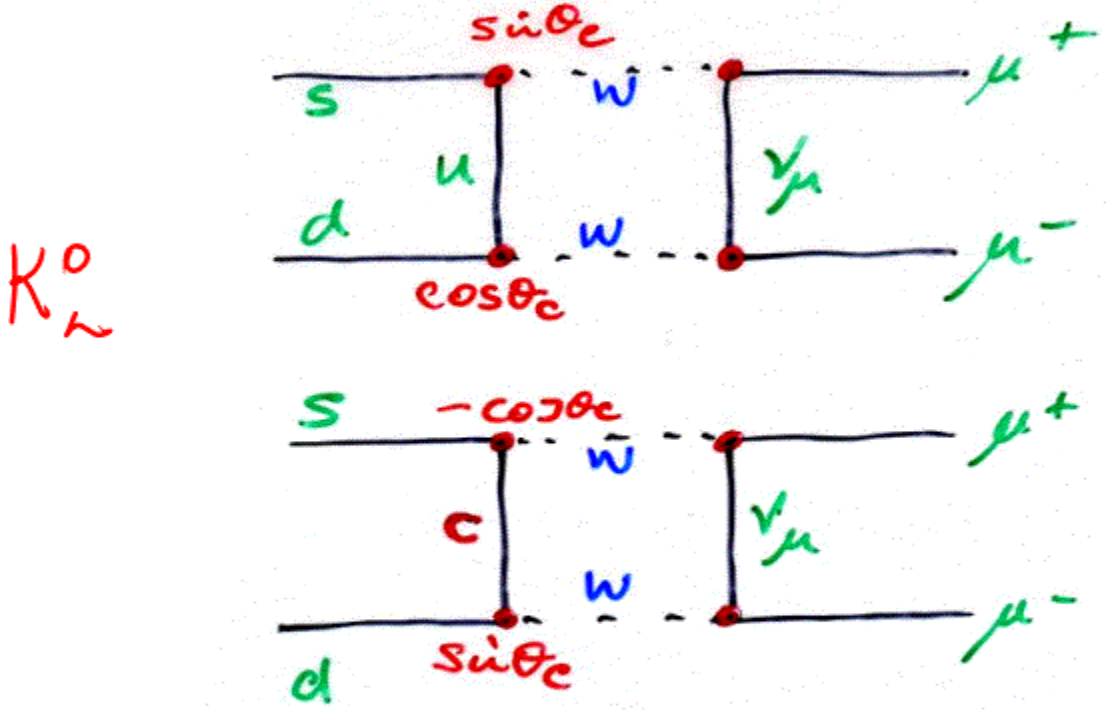


CANCELLATIONS



GIM MECHANISM PREDICTED m_{CHARM}

FOR $K_L^0 \to \mu^+\mu^-$ NOW HAVE TWO 2ND ORDER DIAGRAMS



$$BR(K_L \to \mu\mu) \sim 7 \times 10^{-5} \frac{m_c^2 - m_u^2}{m_W^2} \ln \frac{m_W^2}{m_u^2}$$

PREDICTED $\to$ $m_c \approx 1.5 \frac{GeV}{c^2}$ ✓

GENERALLY TRUE THAT THESE BOX DIAGRAMS ARE DOMINATED BY HEAVIEST QUARK THAT CAN CONTRIBUTE TO THE INTERAL LOOP

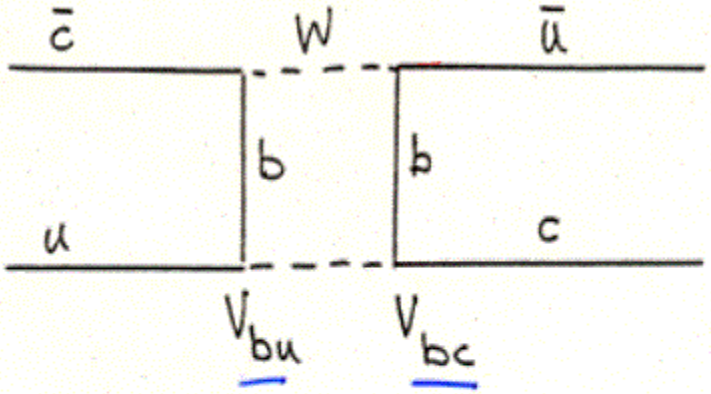
$m_c \rightarrow$ K DECAYS

$m_t \rightarrow B^0 \bar{B}^0$ MIXING

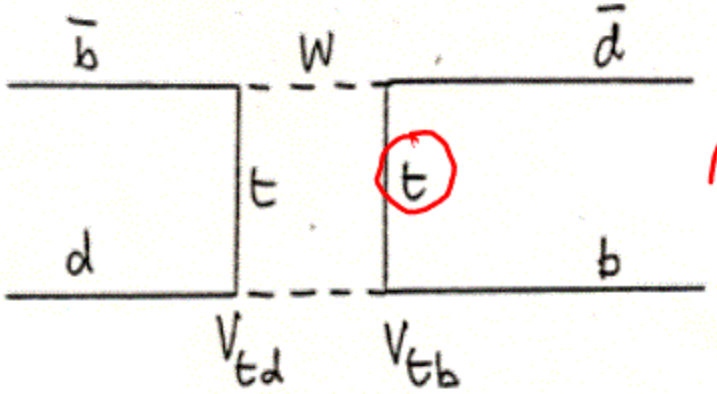
$m_H \rightarrow$ RADIATIVE CORRECTIONS

RARE DECAYS CAN ACCESS HIGHER MASS SCALES THAN DIRECT PRODUCTION AT ACCELERATORS

$D^0 \; \bar{D}^0$



$B_d^0 \; \bar{B}_d^0$



$m_t > 150 \frac{GeV}{c^2}$

$e^+e^- \to b\bar{b}$ @ 10 GeV

$B_s^0 \; \bar{B}_s^0$