Preflight #5

We discussed in class processes mediated by the weak force where Strangeness changes, e.g. \( \bar{K}^0(d\bar{s}) \to \Pi^+(d\bar{u})e^-\bar{\nu}_e \). We understood this process as a transition from a \( s \)-quark to an \( u \)-quark by emitting a \( W^- \): \( s \to u + W^- \), where \( W^\pm \) is the charged mediator of the weak force. The corresponding charged weak current is described by the quark isospin doublet

\[
\begin{pmatrix}
  u \\
  d'
\end{pmatrix}
\]

so that the weak current reads (\( \gamma_\mu \) and \( \gamma_5 \) are \( 4 \times 4 \) matrices; their exact form is not important for this discussion)

\[
\bar{u}\gamma_\mu(1 - \gamma_5)d'
\]

With \( d' = d \cos \theta_C + s \sin \theta_C \) one finds

\[
\bar{u}\gamma_\mu(1 - \gamma_5)d \cos \theta_C + \bar{u}\gamma_\mu(1 - \gamma_5)s \sin \theta_C
\]

In this way you can have \( u \leftrightarrow d \) and \( u \leftrightarrow s \) transitions. Consider now weak processes, where the charge of the quark does not change, e.g. \( u \leftrightarrow u \) transitions.

These processes take place via a neutral weak force mediator, the \( Z^0 \) boson, and the corresponding neutral weak current reads (\( v, a \) are real numbers)

\[
\bar{u}\gamma_\mu(v - a\gamma_5)u + \bar{d}\gamma_\mu(v - a\gamma_5)d'
\]

with \( d' = d \cos \theta_C + s \sin \theta_C \).

(a) Under these assumptions can the decay \( K^- (s\bar{u}) \to \Pi^- (d\bar{u})e^+e^- \) happen?
(b) What if I tell you that this decay has not been observed?

What will happen, if you assume the existence of a forth quark, \( c \), so that there is a second quark doublet

\[
\begin{pmatrix}
  c \\
  s'
\end{pmatrix}
\]

with \( s' = -d \sin \theta_C + s \cos \theta_C \). It is an exact copy of the \( (u,d') \) doublet but the \( c, s \) quarks are heavier than the \( u, d \) quarks. How does the neutral weak current change? Can you now explain why this decay has not been observed?