Monday, March 05, 2012
12:39 PM

CP

If we combine both charge-conjugation and parity reversal, then it looks like we might be getting something that is a good symmetry of the SM:

$$\dot{\pi}^+ \longrightarrow \overset{\xleftarrow{\text{left}}}{\mu^+} + \overset{\xrightarrow{\text{left}}}{\nu_\mu}$$

$$P \quad \dot{\pi}^+ \longrightarrow \overset{\xrightarrow{\text{right}}}{\mu^+} + \overset{\xleftarrow{\text{right}}}{\nu_\mu} \quad \times$$

$$C \quad \dot{\pi}^- \longrightarrow \overset{\xleftarrow{\text{left}}}{\mu^-} + \overset{\xrightarrow{\text{left}}}{\bar{\nu}_\mu} \quad \times$$

$$CP \quad \dot{\pi}^- \longrightarrow \overset{\xrightarrow{\text{right}}}{\mu^-} + \overset{\xleftarrow{\text{right}}}{\bar{\nu}_\mu} \quad \checkmark$$

So yeah, it looks like CP is good... well, uhm...

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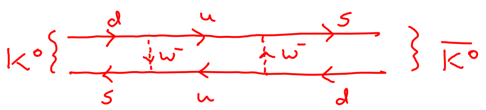
Back to those pesky kaons!

Consider a neutral kaon $K^0 = d\bar{s}$ happily wandering along:



Clearly by this weak interaction a K^0 can become a $\overline{K^0}$ and vice-versa! (Note this won't work w/ $K^\pm$)

But... $K^0 \neq \overline{K^0}$!! It is not its own antiparticle.

Well that's neat but why is it important?

K^0 is a pseudo-scalar so $PK^0 = -K^0$ and $P\overline{K^0} = -\overline{K^0}$ (recall same because bosons)
also $CK^0 = \overline{K^0}$ and $C\overline{K^0} = K^0$
then $CPK^0 = -\overline{K^0}$ and $CP\overline{K^0} = -K^0$

To form CP eigenstates we can combine K^0 and $\overline{K^0}$ w/ $l=0, s=0$: $K_1 = \frac{1}{\sqrt{2}}(K^0 - \overline{K^0})$ $CP = +1$
$K_2 = \frac{1}{\sqrt{2}}(K^0 + \overline{K^0})$ $CP = -1$

So if CP is good, then it should be conserved in decays.

Consider: $K_1 \to 2\pi$ $(\pi^0 + \pi^0$ or $\pi^+ + \pi^-)$ $\quad CP = \overbrace{+1 \cdot +1}^{C} \cdot \overbrace{-1 \cdot -1}^{P} = +1$

$K_2 \to 3\pi$ $(\pi^0 + \pi^0 + \pi^0$ or $\pi^0 + \pi^+ + \pi^-)$ $\quad CP = \underbrace{+1 \cdot +1 \cdot +1}_{C} \cdot \underbrace{-1 \cdot -1 \cdot -1}_{P} = -1$

To check if CP is good we could make K_1 (or K_2) and see if it decays into the wrong # of π's.

Not so easy!! We make K's via strong interactions which produce $K^0 = \frac{1}{\sqrt{2}}(K_1 + K_2)$
and $\overline{K^0} = \frac{1}{\sqrt{2}}(K_1 - K_2)$

So when you "make" a K, it could then decay into 2 or 3 π's still conserving CP.

To look for CP violation you make a bunch of K's (K^0 or $\overline{K^0}$) and then let them travel down some path. The important point is that the 2π mode is energetically favorable over the 3π mode, so with time (or far enough down the beam) all of the K_1 component will have decayed out leaving a pure sample of K_1 (some would have been lost as well).

At this point in the beam, we should only see 3π decay events.

Guess what!? You still see a small # of 2π events.

$\Downarrow$

$\boxed{\text{CP is violated (slightly) in the SM!}}$

This was a huge surprise, and much harder to incorporate into the theory than the "maximal" violation of parity.

In fact this observation was made before the 3rd generation of quarks had been found.
This was theoretically answered by Kobayashi + Maskawa as a means of setting

They were theoretically proposed by Kobayashi + Moskawa as a means of getting some CP-violation into the SM through the 3x3 CKM matrix. Later exp. found.

CP-violation is actually useful as one of the Sahkarov conditions (w/ non-thermal equ., and Baryon # violation) which are the key ingredients in dynamically generating the matter/antimatter asymmetry seen today.

Tuesday, March 06, 2012
6:39 AM

CPT

So you might be wondering if any of these discrete symmetries are "good" in the SM.

To be fair: P (and C) are good in strong and EM. Awful in weak.
CP is only slightly violated.

So in many cases these are still useful.

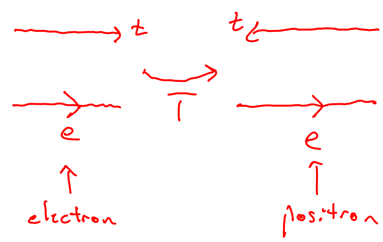
But, CPT is actually an exact symmetry of the SM (or any relativistic QFT).

To see rigorously why requires full blown QFT, but I can give you a heuristic argument w/ the same spirit.

Recall that P is a reflection in x,y,z or a reflection in x and R180 in y-z.
That is P reverses 1 or 3 coordinates. So a rotationally invariant theory need not be P-invariant.

In 4D we have Lorentz invariance. P reflects x,y,z and T reflects t.
But now we are reflecting an even # of coordinates which could actually correspond to a "generalized 4D rotation."

The only subtlety is in reversing t. Consider:



But if we combine PT w/ C (which interchanges particles & antiparticles) then we get a transformation which really is just a Lorentz transformation on our system.

So CPT must be an exact symmetry of a Lorentz invariant theory (like the SM).

To test this we need only compare the lifetimes of particles & antiparticles and to date all are identical.

What about T? T invariance implies identical rates for inverse processes (even decays).
This of course is ridiculously hard to test.
However we know CPT is good and CP is violated, so T is violated in the SM as well.